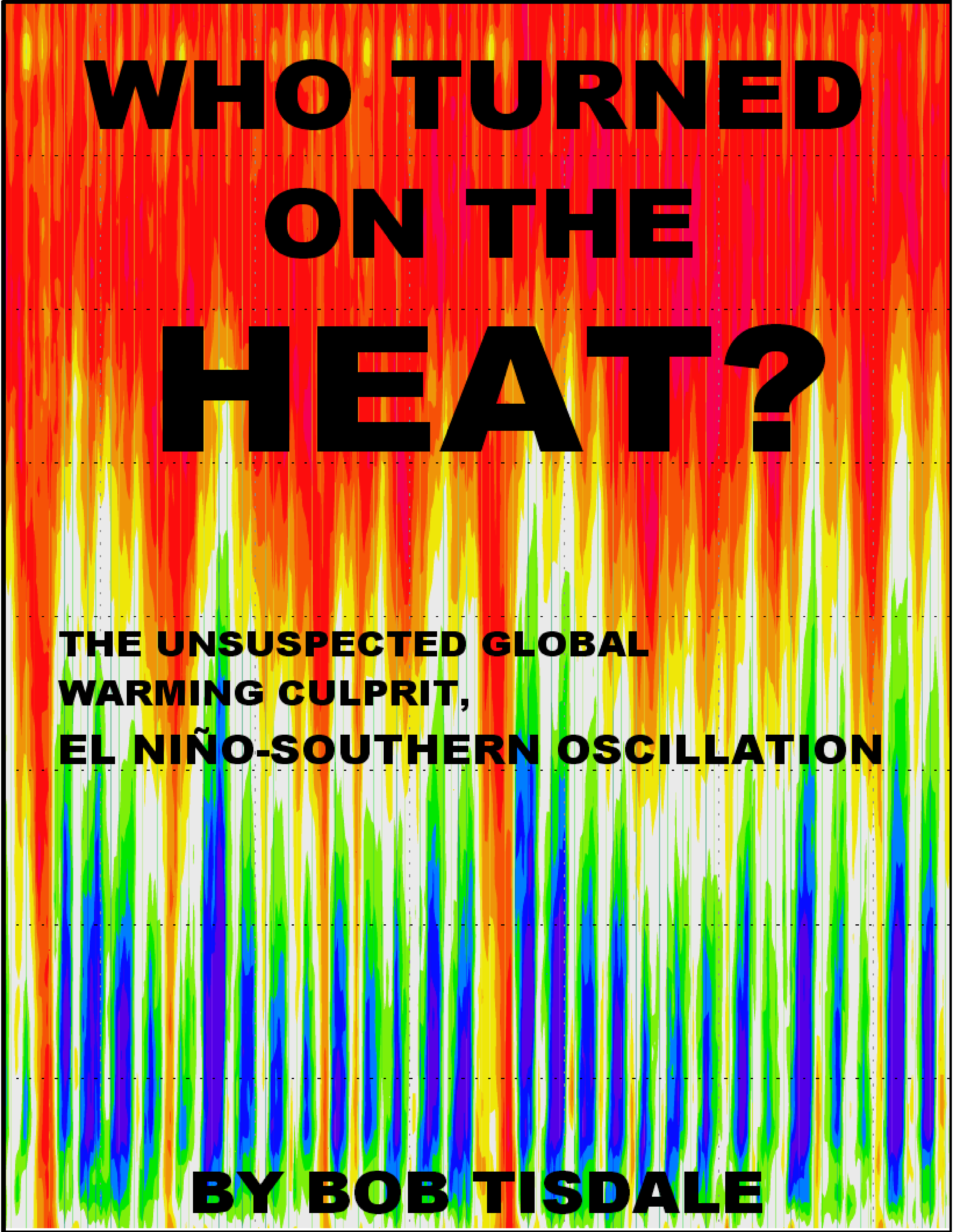

WHO TURNED ON THE HEAT?

THE UNSUSPECTED GLOBAL WARMING CULPRIT, EL NIÑO-SOUTHERN OSCILLATION

BY BOB TISDALE

Who Turned on the Heat?

The Unsuspected Global Warming Culprit -- El Niño-Southern Oscillation

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The cover art was created at the KNMI Climate Explorer. It is a Hovmöller diagram of the sea surface temperatures for the equatorial Pacific (120E-80W) from November 1981 to June 2012. Refer to **ABOUT THE COVER** for more information. The illustration looks awfully warm, because it includes the longitudes of the Pacific Warm Pool. However, sea surface temperature anomalies for the equatorial Pacific (5S-5N, 120E-80W) have cooled at a rate of -0.047 Deg C per decade for the period of November 1981 to June 2012, which is the time span of that satellite-based dataset.

IMPORTANT NOTE: This ebook was written in 2012. Because websites are constantly being updated, hyperlinks may no longer be operational. Sorry.

THE SECTIONS AND CHAPTERS IN THE TABLE OF CONTENTS ARE LINKED TO THEIR CONTENT. IF YOU SEE A SUBJECT THAT INTERESTS YOU IN THE TABLE OF CONTENTS, CLICK ON IT.

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INTRODUCTION

The title asks the question, *Who Turned on the Heat?* It is asked in disbelief, with the emphasis on "Who". The subtitle, *The Unsuspected Global Warming Culprit, El Niño-Southern Oscillation,* identifies the real perpetrator, which is not the one being marketed by the Intergovernmental Panel on Climate Change. There's no evidence in the sea surface temperature records that increased carbon dioxide emissions are responsible for the warming over the past three decades. This will become crystal clear as you read this book.

Speaking of disbelief: You're probably saying to yourself, *Oh great, another theory about global warming*. You may also be wondering how a weather phenomenon that includes oscillation in its name could cause global warming. If you're really being critical, you're likely thinking (incorrectly) *El Niño and La Niña events are opposites—they oppose and cancel each other.*

Wonder and be critical no longer. Everything presented in this book is supported by data. The sea surface temperature records, if you're not aware, contradict the hypothesis of anthropogenic global warming as presented by climate models. If the data does not agree with the hypothesis, the hypothesis is flawed.

Also, the use of the word "oscillation" in "El Niño-Southern Oscillation" is a matter of convenience—nothing more. The Southern Oscillation was discovered decades before it was found to be related to El Niño and La Niña events, which are not repetitive in time, so they are not parts of a true oscillation. While there are portions of El Niño and La Niña processes that behave as cycles, those cycles break down, and an El Niño or a La Niña can evolve as an independent event. Further, El Niño and La Niña are not opposites. That's also very obvious in the sea surface temperature records. La Niña is an exaggeration of the normal state of the tropical Pacific, while an El Niño is the anomalous phase. That's why many researchers believe there are only two states of the tropical Pacific: El Niño and "other". Also, over the last 30 years it's rare when a La Niña has been as strong as the El Niño that preceded it. How then could a La Niña counteract an El Niño? Of course, the temperature records also show a multidecadal period when La Niña were as strong as El Niño, and it's no coincidence that global surface temperature did not warm during it.

El Niño events cause catastrophic events around the globe. At the bottom of page 5 of the World Meteorological Organization (WMO) document **The 1997/98 El Niño Event in Brief** is a small table, replicated below. They're grim statistics about the 1997/98 El Niño, citing the U.S. NOAA Office of Global Programs:

"The Global Assessment"

Direct loss	US$34 billion
Mortality	24 thousand
Morbidity	533 thousand
Displaced persons	6 million
Affected persons	111 million
Land affected	56 million acres

Curiously, two terms are absent from that 1999 WMO document: "global warming" and "climate change". However, they do include a subheading on page 2 that reads "A recurring pattern of climate extremes", which is an excellent representation of the global weather responses to El Niño and La Niña.

Further, a very strong El Niño like the one in 1997/98 is capable of temporarily raising global surface temperatures more than 0.4 deg C (about 0.7 deg F) over a 12-month period, and for some reason, many climate scientists claim such an event has no long-term aftereffects. This means those scientists have failed to account for the warm water that is redistributed after a strong El Niño and for the effects those leftover warm waters have on global climate. Those aftereffects are blatantly obvious once you know they exist.

An El Niño and his sibling La Niña can cause flooding in some parts of the world, droughts in others—blizzards in some areas, record low snowfalls elsewhere. The strong storms they produce erode coastlines. They can suppress the development of tropical cyclones (hurricanes) in some parts of the globe and enhance the conditions for their development in others. It should go without saying that they cause heat waves and cold spells depending on the season and location. These causes and effects have been known for decades. Recently, however, a few headline-seizing climate scientists, with the help of mainstream media and blogs, have now redirected the blame for those weather events to carbon dioxide and other greenhouse gases.

Specialized weather models, those used to predict whether the next event will be an El Niño or a La Niña, still can't forecast the upcoming phase more than a few months in advance, yet they've been trying for decades. By the time the models get the phase right, precursors of the El Niño or La Niña have happened and the event is underway. The lack of a reasonable prediction time is really not the forecasters' fault. Mother Nature has created a "springtime prediction barrier", which limits the forecasting range of the models used to predict El Niño and La Niña events.

At the other end of the spectrum, there are the climate models used by the Intergovernmental Panel on Climate Change (IPCC). Those models are not able to simulate the coupled ocean-atmosphere processes associated with El Niño and La Niña events. Needless to say, if El Niño and La Niña events had long-term effects on global surface temperatures, those impacts would not be simulated by the IPCC's climate models. As this book will plainly show, El Niño and La Niña events, when they're large enough, can and do have long-lasting effects on global surface temperatures.

Uh-oh. I've mentioned a political entity twice. Now some people will think this book was motivated by politics. They're wrong. Only political people believe the global warming debate is centered on partisan politics. They understand what drives them and think others are focused the same way. Me? I am not a political person, far from it. My motives are simple. They are to educate readers about the processes driving El Niño and La Niña events, to present the plainly evident long-term reverberations of those events, and to correct the misunderstandings about the processes that cause those long-lasting effects—misunderstandings manufactured and sustained by those who misrepresent the causes of global warming.

Also, I'm simply using IPCC to represent the group of activist climate scientists who have been very successful at convincing a very gullible public that anthropogenic greenhouse gases, primarily carbon dioxide, are the primary cause of global warming, when they clearly are not. IPCC is much easier to write.

The IPCC uses climate model simulations of global surface temperatures with and without radiative forcings from manmade greenhouse gases to show that the warming of global surface temperatures for the past three decades could only be simulated by the models that included anthropogenic greenhouse gases. For the IPCC, this provided irrefutable proof that greenhouse gases were responsible for the warming. To the general public, however, it suggested another possibility. If climate models without radiative forcings from greenhouse gas couldn't simulate the warming, then those assumption-based climate models might be seriously flawed. This book, using the outputs of the climate models used by the IPCC, confirms that they are in fact flawed. Climate models show no skill whatsoever at being able to simulate the ocean processes that produced the warming of global sea surface temperatures for the past 3 decades.

Maybe the IPCC should examine the sea surface temperature records for the past 30 years. Why? They do not agree with the IPCC's conclusions. Satellite-based sea surface temperature records show El Niño and La Niña are responsible for most of the warming of global sea surface temperatures over the past 3 decades. That fact shows up plain as day in sea surface temperature records. It's tough to miss. It really is. Maybe the IPCC has overlooked it intentionally.

Who Turned on the Heat? includes detailed introductions to El Niño and La Niña and how those phases interact with temperatures globally and regionally. Therefore, even if the processes of El Niño and La Niña are new to you, the background information allows you to confirm what's described and illustrated by the data herein.

Who Turned on the Heat? uses observations-based data, not climate models, to illustrate where and how ENSO is capable of raising global sea surface temperatures over periods of 10, 20, 30 years and more. Because land surface air temperatures are basically along for the ride, mimicking the variations in sea surface temperatures, ENSO can be said to be responsible for most of the warming of global land plus sea surface temperatures for the past three decades as well.

El Niño and La Niña events are often described as the "unusual" warming (El Niño) and cooling (La Niña) of the surface of the eastern tropical Pacific Ocean. They happen every couple of years, so there's really nothing unusual about them. In fact, based on the NOAA's **Oceanic NINO Index (ONI)**, official El Niño and La Niña months occurred about 55% of the time since 1950. Also, scientists who study historical changes in climate (paleoclimatologists) have presented evidence that El Niño and La Niña events were occurring 3 to 5 million years ago. See **Watanabe et al (2011)**. In other words, not only do El Niño and La Niña events occur often, they've been around a long, long time.

El Niño and La Niña are siblings, Mother Natures' mischievous but mighty children. Contrary to popular beliefs, they do not counteract one another. This is also plainly evident in sea surface temperature data. Further, El Niño is usually more powerful than his sister. On the other hand, La Niña can endure for as long as three years, while the stronger El Niño normally lasts for less than one year. Look out, though, when they both decide to test themselves as strong events in sequence, wrestling with global surface temperatures as a tag team. Together they can cause global surface temperatures to shift upwards for a decade, until they act together again as a team and cause another persistent change in surface temperatures around the globe. This happens because of some not-so-subtle differences between La Niña and El Niño phases, a fact that is very apparent once you understand those phases.

To simplify the discussion, *Who Turned on the Heat?* uses the standard acronym ENSO when talking about the process as a whole. ENSO stands for El Niño-Southern Oscillation: El Niño representing the ocean portion of the coupled ocean-atmosphere process, and Southern Oscillation representing the atmospheric side. When discussing the warming events, we'll use El Niño and, likewise, we'll use La Niña when discussing what are often described as the cooling events. However, La Niña is much more than a cooling event as you shall discover. Other than ENSO, very few acronyms are used in the text to make it easy to read and understand.

ENSO is misunderstood, modeled poorly, and misrepresented. Some climate scientists and statisticians present ENSO in ways that mislead those who study global climate change—and mislead those who make policy decisions based on those scientific studies. Example: those scientists and statisticians would like you to believe an ENSO index represents the process of ENSO and all of its aftereffects. The reality: Using an ENSO index in that way is like trying to do a play-by-play analysis of a soccer game from the overhead view of one goal. Those climate scientists and statisticians, claiming that ENSO only creates noise in the global temperature record, use that ENSO index in their simplistic attempts to remove the effects of so-called ENSO noise from the global surface temperature data. They then proclaim the remaining global warming is caused by anthropogenic greenhouse gases. Their misguided efforts are, to put it in simple words, nonsense.

Climate models used by the Intergovernmental Panel on Climate Change (IPCC) cannot match the sea surface temperature records that show how often and how strongly ENSO events have occurred since 1900. Climate models can't even simulate the ENSO events since the start of the recent warming period in the mid-1970s. However, the models need to be able to mimic the historical instrument-based ENSO records. In fact it's critical that they do, and it's easy to understand why. The strength of ENSO phases, along with how often they happen and how long they persist, determine how much heat is released by the tropical Pacific into the atmosphere and how much warm water is transported by ocean currents from the tropics toward the poles. During a multidecadal period when El Niño events dominate (a period when El Niño events are stronger, when they occur more often and when they last longer than La Niña events), more heat than normal is released from the tropical Pacific and more warm water than normal is transported by ocean currents toward the poles—with that warm water releasing heat to the atmosphere along the way. As a result, global sea surface and land surface temperatures warm during multidecadal periods when El Niño events dominate. They have to. There's no way they cannot warm. Conversely, global temperatures cool during multidecadal periods when La Niña events are stronger, last longer and occur more often than El Niño events. That makes sense too because the tropical Pacific is releasing less heat and redistributing less warm water than normal then.

The IPCC's climate models are allegedly used to determine the causes of the past warming and cooling of global surface temperatures, and they are employed to project global surface temperatures into the future based on a number of assumptions. Here's a simple but realistic way to look at the climate models: Climate models show how surface temperatures would warm IF they were warmed by manmade greenhouse gases. The truth is, the Earth's oceans do not respond to manmade greenhouse gases as the modelers have assumed. The sea surface temperature records show the global oceans couldn't care less about a little back radiation from anthropogenic greenhouse gases. While global sea surface temperatures have definitely warmed over the past 3 decades, there is no indication that additional infrared radiation from increased concentrations of carbon dioxide caused the warming.

For example: the climate models simulate all ocean basins warming at basically the same rate. To contradict that, the sea surface temperature data shows:

1. 33% of the surface area of the global oceans, an area that occupies more than half of the largest ocean basin, hasn't warmed in 30 years. Naturally created warm waters from below the surface of the western tropical Pacific slosh into this area during an El Niño, and they slosh back out when it's over. On the other hand,
2. 53% of the surface area of the global oceans warms only during major El Niño events and does not cool proportionately during the La Niña events that follow them. The lack of cooling during the La Niña is attributable to the warm waters left over from the major El Niño. When the warm water sloshes back out of the ocean basin (1.) above, it has to go somewhere, and it winds up in this large part of the global oceans. And,
3. An ocean basin that represents about 14% of the surface area of the global oceans has an additional mode of natural variability that has caused it to warm significantly more than the other ocean basins over the past 30 years, but it's "cycle" is close to reaching its peak, if it hasn't already attained that peak, and it will soon begin to warm less than the other ocean basins, if not cool. Paleoclimatological data shows this basin has warmed and cooled in this fashion for thousands of years.

Climate modelers missed (or purposely suppressed in the models) a very basic reality. ENSO is a variable source of naturally created and released thermal energy, and because their climate models can't simulate it, the scientists who rely on those models cannot determine if past long-term warming and cooling of global surface temperatures are actually the results of manmade greenhouse gases. That fact will become very obvious to you while reading this book.

Examples of climate model problems: Most of the climate models used by the IPCC in their 2007 4th Assessment Report (AR4), in addition to the failings already discussed, have multiple flaws with how they simulate the natural processes taking place in the tropical Pacific. They have difficulties simulating precipitation, cloud cover, downward shortwave radiation, trade wind speeds and location, etc., which are all interrelated and associated with El Niño-Southern Oscillation. Climate models tend to make La Niña events as strong as El Niño events, while in the real world, starting in the late 1970s, El Niño events have tended to be stronger than La Niña events. Recently, though, they've been working their way back to a regime when El Niño and La Niña are more equally weighted. It is well known that El Niño and La Niña events are tied to the seasonal cycle with both phases peaking around December, but this is not the case in all climate models. These problems and others are discussed and documented in numerous scientific studies, and those problems are presented within these pages. Hopefully, if I've done my job, by the time you reach that chapter, you will have a sufficient background in El Niño-Southern Oscillation to understand why those are major problems in climate models.

Who Turned on the Heat? relies on observational data (satellite-based sea surface temperature records primarily) for the discussions of El Niño and La Niña events and for the presentations of their long-term impacts on global surface temperatures. More to the point, this book presents data in very simple and logical ways that allow the data to show you how and why it has warmed. This cannot be done by looking at data on a global basis. It has to be broken down into logical subsets. I've limited that breakdown to four regions.

The data is presented in graphs. Many people have little need to study graphs as part of their daily routine, so they may have a little difficulty interpreting them. For those readers, I've included easy-to-read, entry-level discussions about the types of graphs presented in this book, how linear trend lines are calculated and why they're important.

Very basic, non-technical terms are used in *Who Turned on the Heat?* to introduce and explain the coupled ocean-atmosphere processes that are part of ENSO events. Don't let the phrase "coupled ocean-atmosphere processes" scare you. Those events may appear complex at first due to the number of variables and due to the interactions between those variables, but in reality the processes that drive El Niño and La Niña events are relatively easy to understand. You may need to study the discussions in Sections 1 and 3 a couple of times, that's to be expected, but eventually it will all fall into place. That little light above your head will click on, you'll snap your fingers and say, *Now I get it*! Of course, I'm available to answer questions at my blog **Climate Observations** if something just won't click.

Some of you have searched through the hundreds of web pages that describe ENSO and you're still having trouble understanding it. There's nothing unusual about that. The descriptions at some websites are vague and under illustrated; at others, the descriptions are overly complex and under illustrated. This book details the processes of ENSO with fundamental descriptions and illustrations, taking the key features of many presentations around the web and merging them. One thing for certain about this book: it is well illustrated.

The biggest problem with most descriptions of ENSO is their use of the word opposite when discussing El Niño and La Niña. They are not opposites. They may have opposing effects on weather in certain parts of the globe, but in others their effects are cumulative. *Who Turned on the Heat?* presents the multiyear aftereffects of specific ENSO events that are clearly visible in the instrument-based records.

Who Turned on the Heat? presents data to confirm that El Niño and La Niña events are natural processes, that they are phenomena Mother Nature has devised to vary the rate at which naturally stored thermal energy (in the form of warm water) is released by, and renewed in, the tropical Pacific Ocean. Very simply, after reading this book, you'll understand why global surface temperatures warm during multidecadal periods when El Niño events are stronger, last longer, and occur more often than La Niña events and why the opposite occurs when La Niña events dominate.

We'll compare satellite-based sea surface temperature data for the past 30 years to the outputs of the climate models used by the IPCC for their 4th Assessment Report. You'll quickly understand that climate models have no skill at being able to simulate the observed warming of sea surface temperatures. No skill at all.

Why is that important?

1. Surface temperatures are the metric most often used to describe global warming (that makes sense because we live on the surface),
2. Sea surface temperatures are the metric used for the surface temperatures of the global oceans,
3. The oceans cover about 70% of the surface of our planet Earth,
4. Land surface air temperatures (representing the other 30%) mimic and exaggerate the changes in sea surface temperature, so,
5. If the climate models show no skill at being able to reproduce the sea surface temperature records of the past 30 years, both globally and on an ocean-basin basis, there is no reason to believe the models have any use as a tool to project future climate globally or regionally. No reason whatsoever to believe them.

Proponents of anthropogenic global warming, after reading one of my blog posts that discuss and illustrate the long-term effects of ENSO, often try to redirect the discussion to a dataset called ocean heat content, claiming that Mother Nature can't explain the warming of the global oceans below the surface layers. They're wrong, of course. The warming of the global oceans can be explained by natural variables. One simply has to divide the global oceans into logical subsets in order to show it. This and other failed arguments by proponents of manmade global warming are presented in *Who Turned on the Heat?*

There have always been problems with the hypothesis of anthropogenic global warming and there still are. A big problem with it: how can downward longwave radiation (infrared radiation associated with greenhouse gases) have any impact on the surface and subsurface temperatures of the global oceans when infrared radiation can only penetrate the top few millimeters of ocean surface? For those readers not familiar with metric measurements, 2 millimeters is less than 3/16 inch. This book shows that greenhouse gases do not have a measureable impact the surface and subsurface temperatures of the oceans. This implies that the infrared radiation from manmade greenhouse gases only adds to the evaporation at the ocean surface, as many oceanographers and physicists have stated all along. Manmade greenhouse gases may impact land surface temperatures, but they should now appear far down on the list of contributors to the warming there.

A few of the chapters from my first book have been rewritten and expanded in the Preliminary Discussions (Section 2) of this book. However, the vast majority of the discussions in this book are new. I've provided more detail on the transitions between ENSO-neutral, El Niño, and La Niña phases. I've presented why and where global sea surface temperatures should decline during a multidecadal period when La Niña dominates the ENSO record, something we haven't seen during the satellite era. Many of the topics covered in these pages have never been discussed in my blog posts.

I've added notes to most illustrations to highlight what's important, with hope of reducing the amount of time you, the reader, need to study them. Some of you will likely skim through the illustrations the first time through, just to get a feel for the subject matter. Hopefully, you'll then go back and read the rest of the book.

This book relies on data from satellites that measure sea level, precipitation, cloud cover, sea surface temperature, temperatures of the atmosphere at a given altitude, etc. We use the 1997/98 El Niño and the three-year La Niña event that followed it for many of the discussions. That El Niño was the strongest event the 20th Century, strong enough to overcome the normal weather noise that hinders the study of lesser events. In this book, I've also illustrated and discussed how minor El Niño events are not the same as the major events.

Who Turned on the Heat? as mentioned above, is well illustrated. In includes more than 380 graphs, color-coded maps, and annotated illustrations (cartoon-like depictions) of the process of ENSO. If you're wondering why the pdf edition of this e-book is about 22MB, it's all of those color illustrations. They are intended to help readers understand how ENSO functions and how it is responsible for the warming of global sea surface temperatures over the satellite era—the last 30 years. There are more than 300 hyperlinks to scientific papers; meteorological-, oceanographic- and climate science-related websites; blog posts; animations; etc., to support and further document ENSO.

One last group of notes: I only present quick looks at the history of ENSO research in this book. There are no equations provided in it. There are no pictures of **Gilbert Walker** or **Jacob Bjerknes** who, among others, helped form our current understanding of ENSO. If you're looking for equations and a detailed history of ENSO research, this is not the book for you. This is basically a show-and-tell book that describes and illustrates the many facets and aftereffects of the ENSO process using publicly available data. I've attempted to make this as easy to understand as possible, but it is a somewhat complex subject. For those looking for more in-depth discussions, I have also covered a multitude of ENSO details—beyond the basics. Please read the table of contents.

If you're a graduate student or a research scientist looking for an e-book that includes detailed theoretical discussions of the physics of ENSO processes with equations, you'll want to look elsewhere. On the other hand, if you're interested in a detailed, easy-to-read and well-illustrated overview of ENSO, then *Who Turned on the Heat?* should satisfy your needs. *Who Turned on the Heat?* should help you understand the natural processes that can and do explain the vast majority of the warming of global sea surface temperatures over the past 3 decades.

Let's jump right into it with a description of the ENSO process with annotated (cartoon-like) illustrations.

Section 1 - A Description of El Niño and La Niña Events Using Annotated Illustrations

1.1 Preliminary Discussion of the ENSO Annotated Illustrations

Most introductions to the El Niño-Southern Oscillation (ENSO) on the web include boiler-plate descriptions and three illustrations: one each for El Niño, La Niña and ENSO-neutral phases. The reader has to jockey back and forth, scrolling up and down, to read the text and compare it to the illustrations. Unfortunately, much of what's discussed in the text of those ENSO introductions isn't shown in the graphics. To overcome that, I've prepared a 29-cell series of annotated (cartoon-like) illustrations that first introduce readers to background information about the Pacific Ocean. There are also introductions to trade winds and ocean currents, both of which have important roles in ENSO. With multiple cartoon-like illustrations for each phase and the transitions between them, the reader is taken through a complete cycle of ENSO phases: ENSO neutral to El Niño, back to ENSO neutral, on to La Niña, and then back to ENSO neutral. At each phase, the interaction between sea surface temperatures across the tropical Pacific, trade winds, sea surface height, precipitation and subsurface ocean temperatures are illustrated and discussed. Also presented are the differences between El Niño and La Niña events and the reasons why global surface temperatures vary in response to ENSO events.

To reinforce and confirm what's presented in this section, Section 3 includes more-detailed, data-reinforced descriptions and illustrations.

NOTE: If parts of the illustrations look "fuzzy" to you, just zoom in. They're clear on my ancient desktop and new laptop at 100% and even clearer at 125% magnification.

1.2 The ENSO Annotated Illustrations

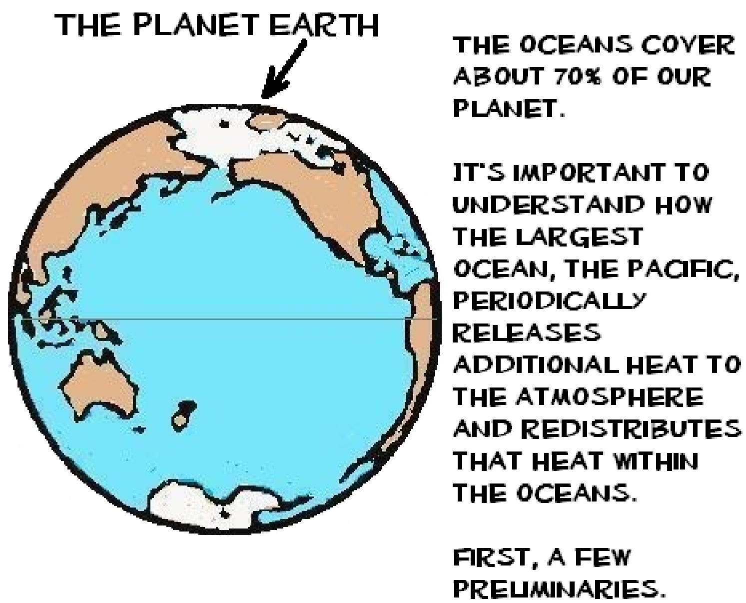

Figure 1-1 Bob Tisdale

HHH

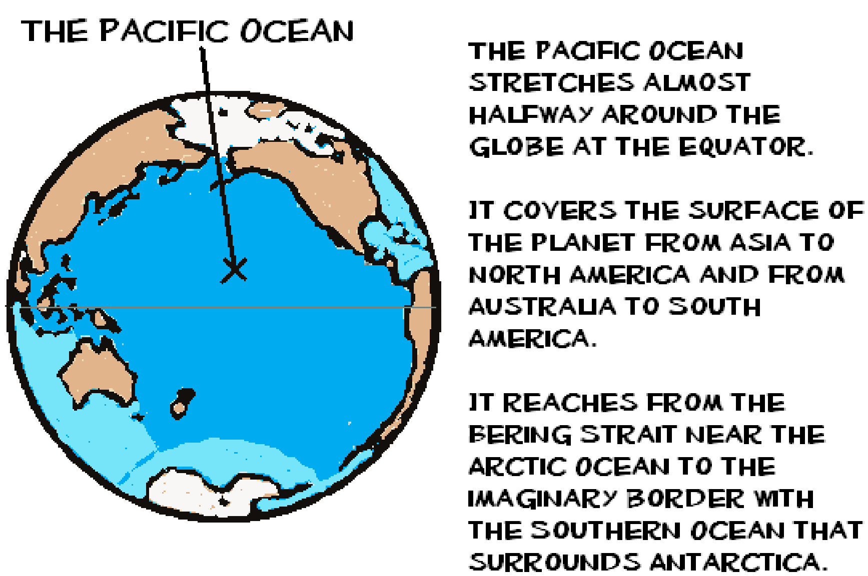

Figure 1-2 Bob Tisdale

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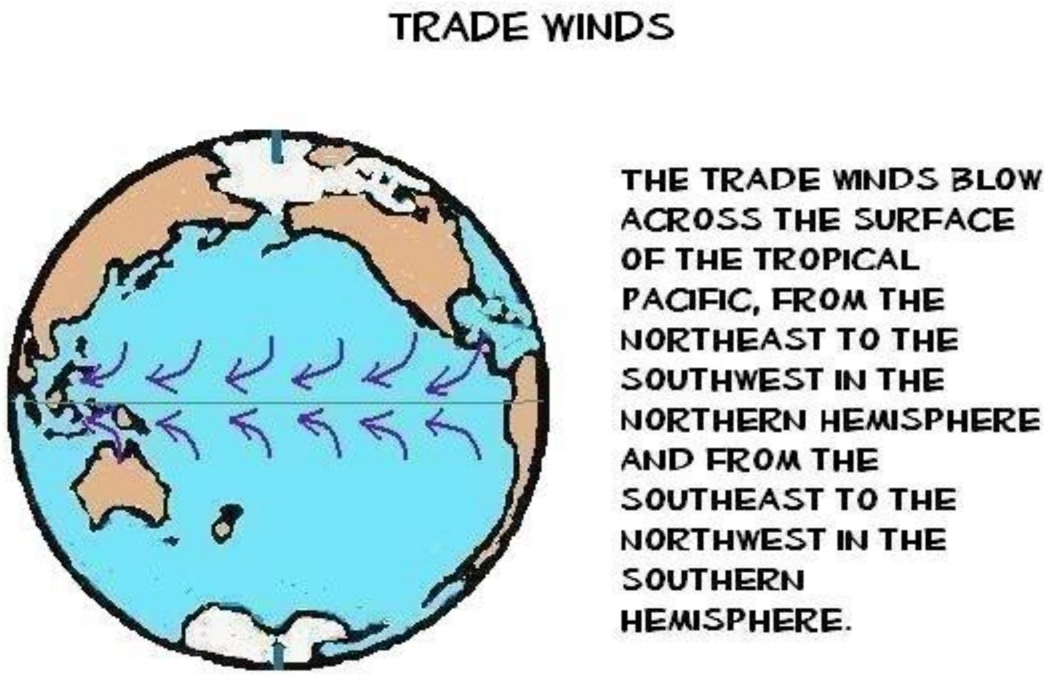

Figure 1-3 Bob Tisdale

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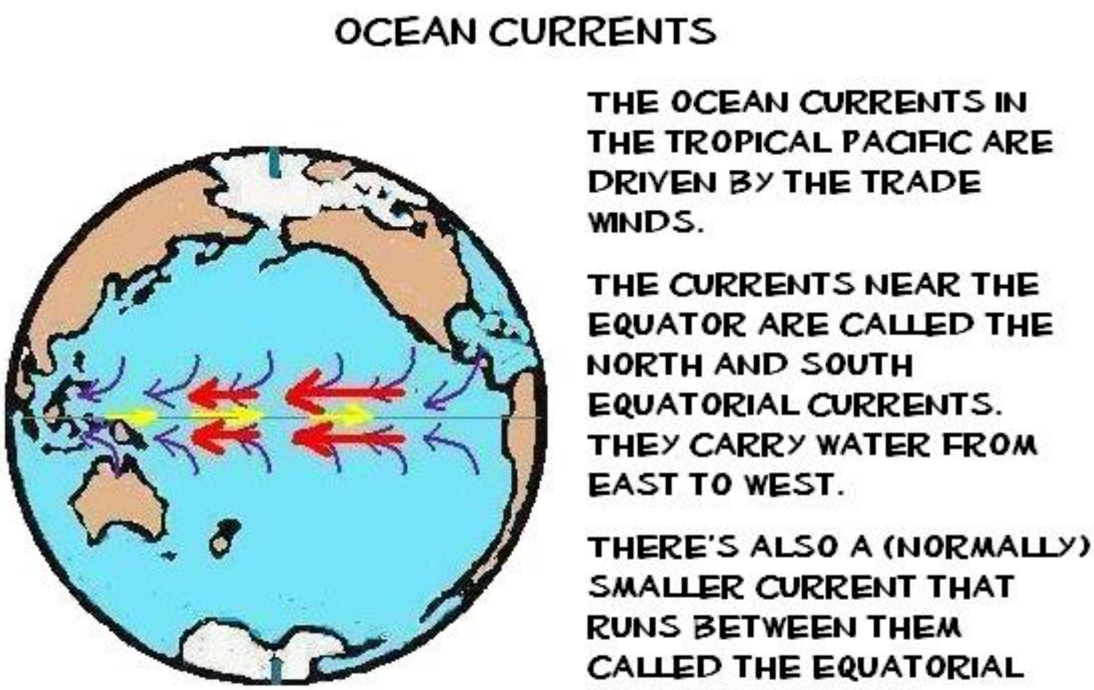

Figure 1-4 Bob Tisdale

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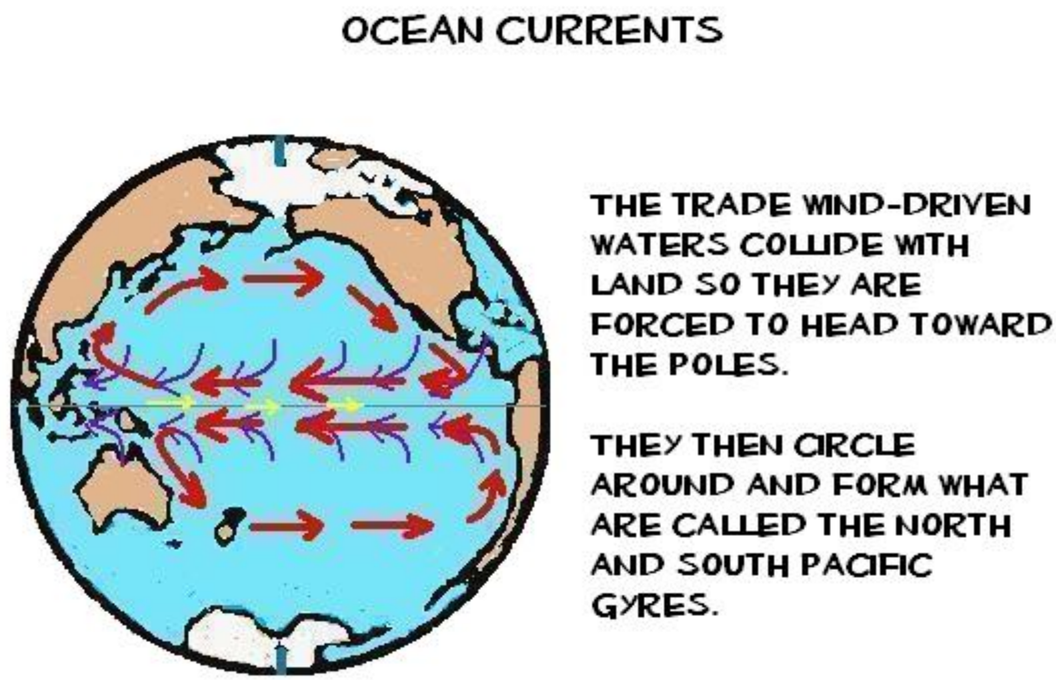

Figure 1-5 Bob Tisdale

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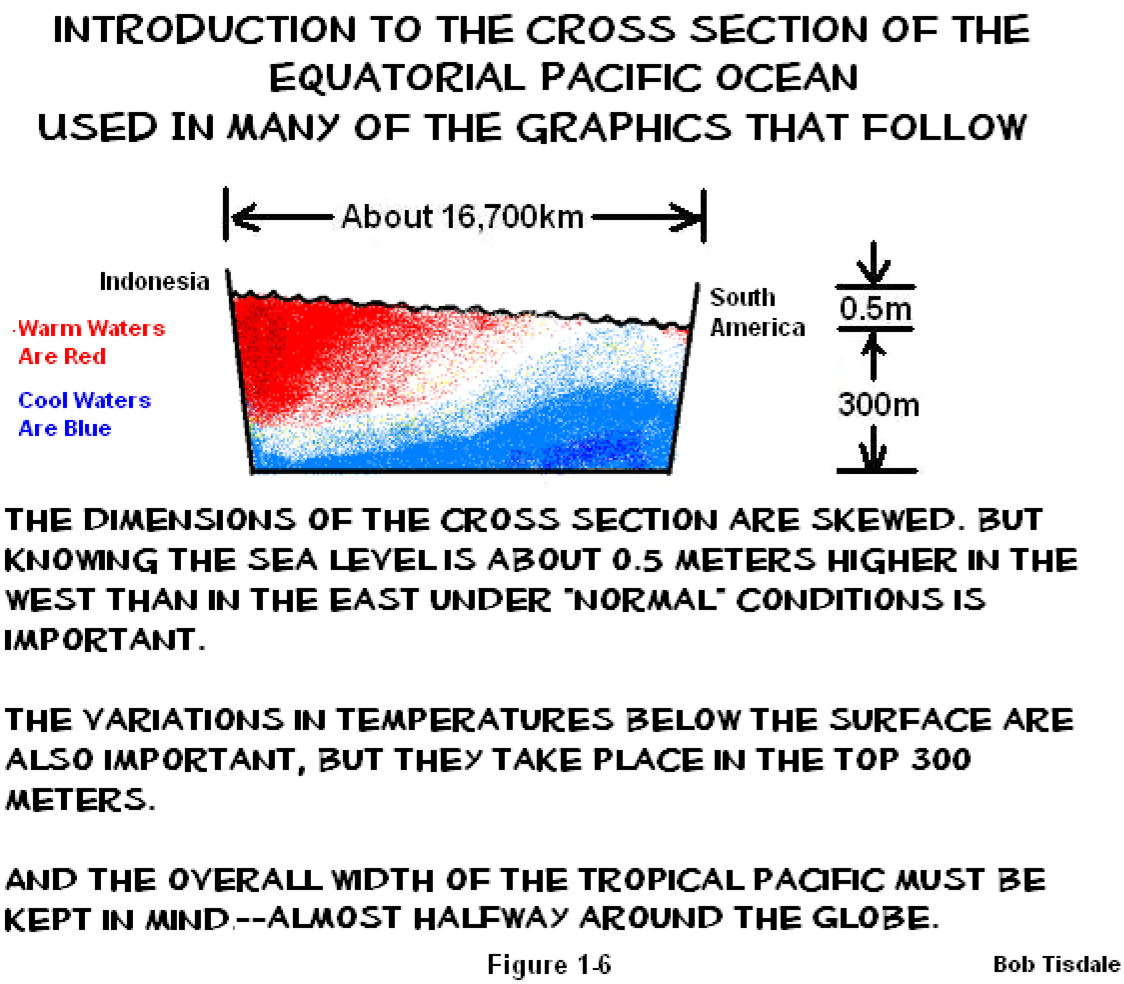

Figure 1-6

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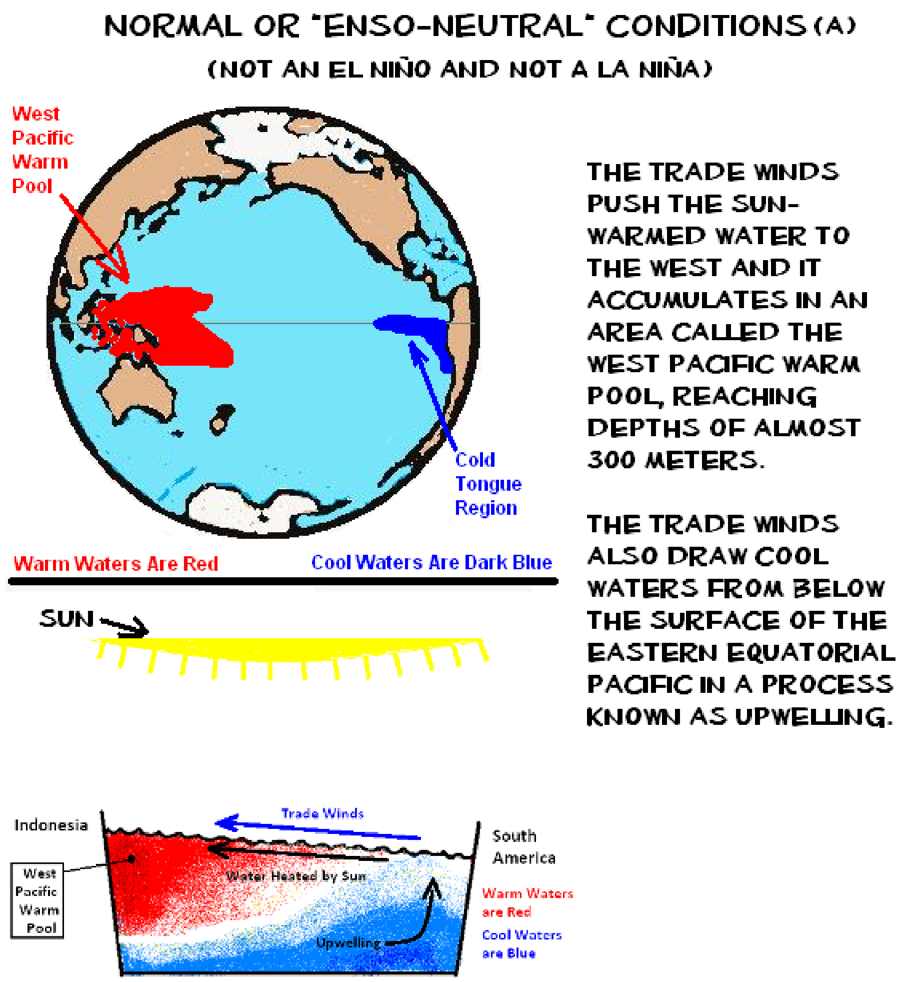

Figure 1-7 Bob Tisdale

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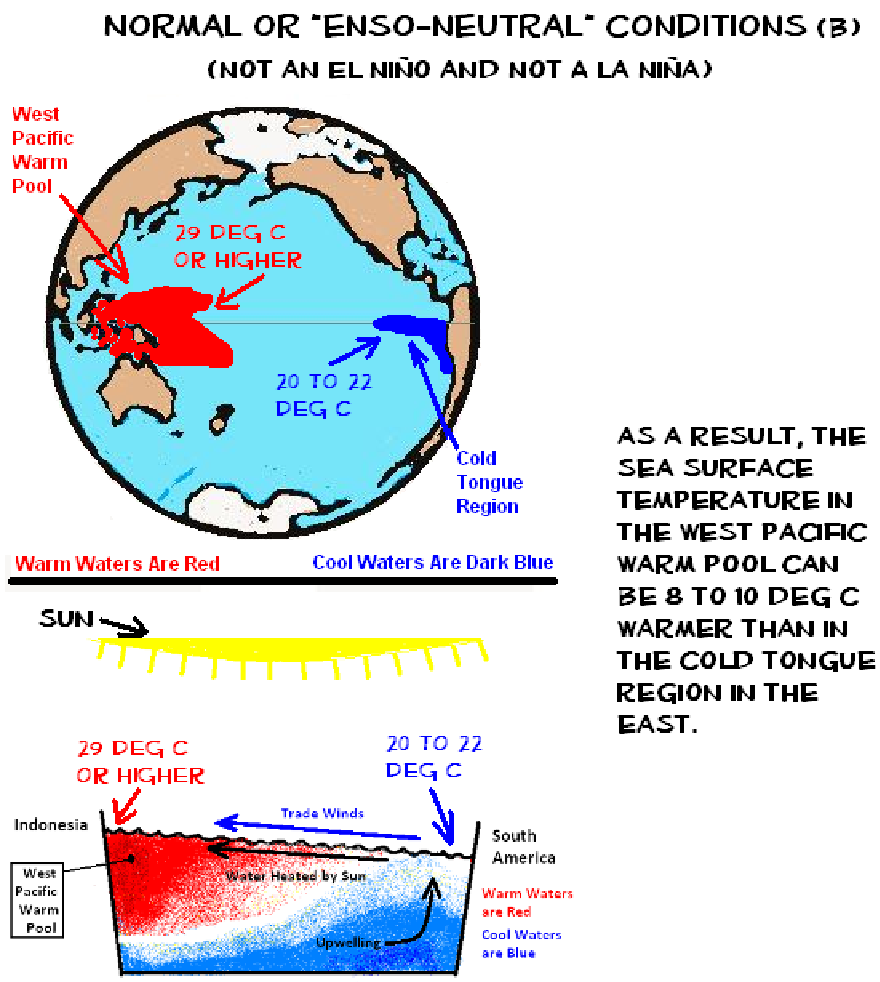

Figure 1-8

Bob Tisdale

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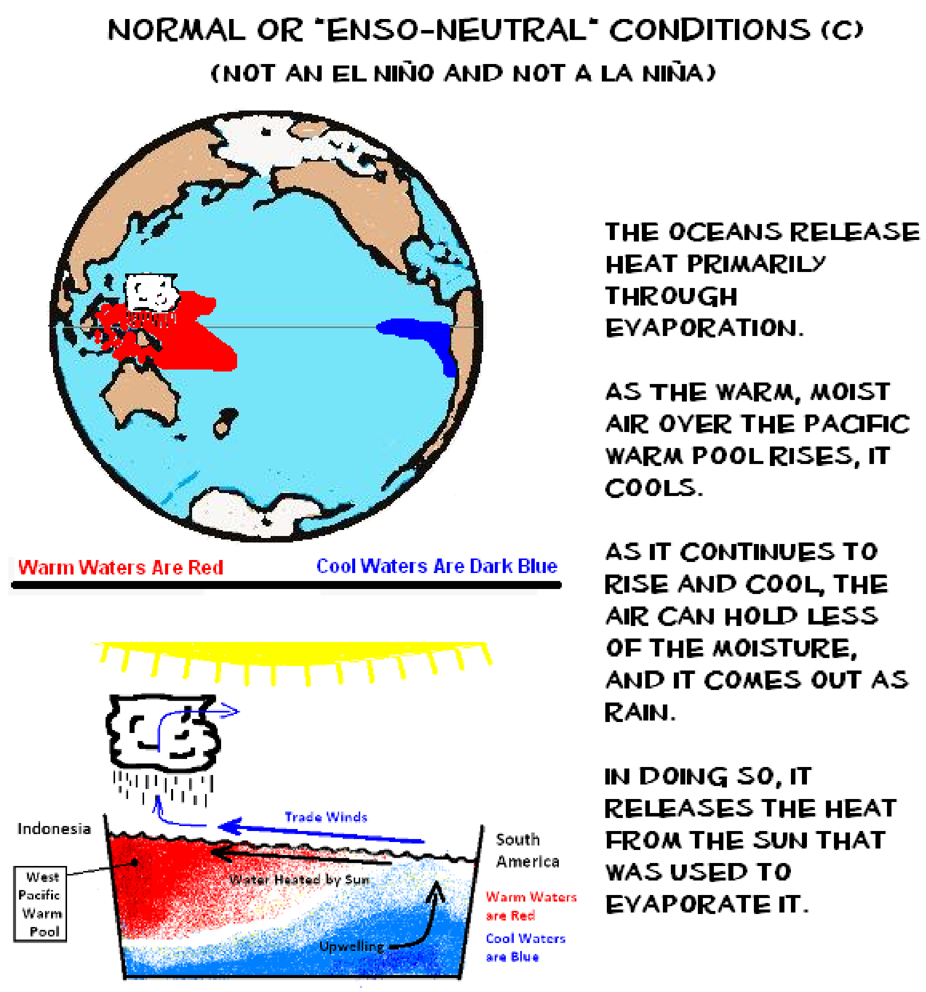

Figure 1-9

Bob Tisdale

HHH

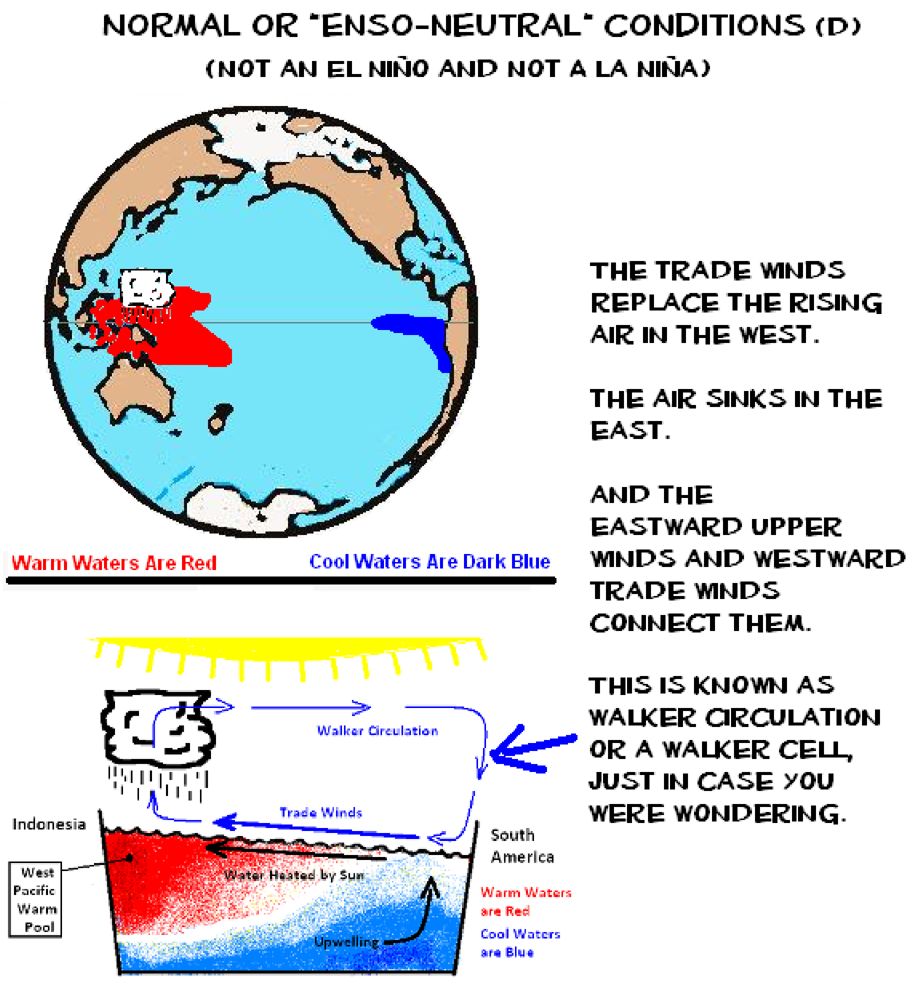

Figure 1-10 Bob Tisdale

HHH

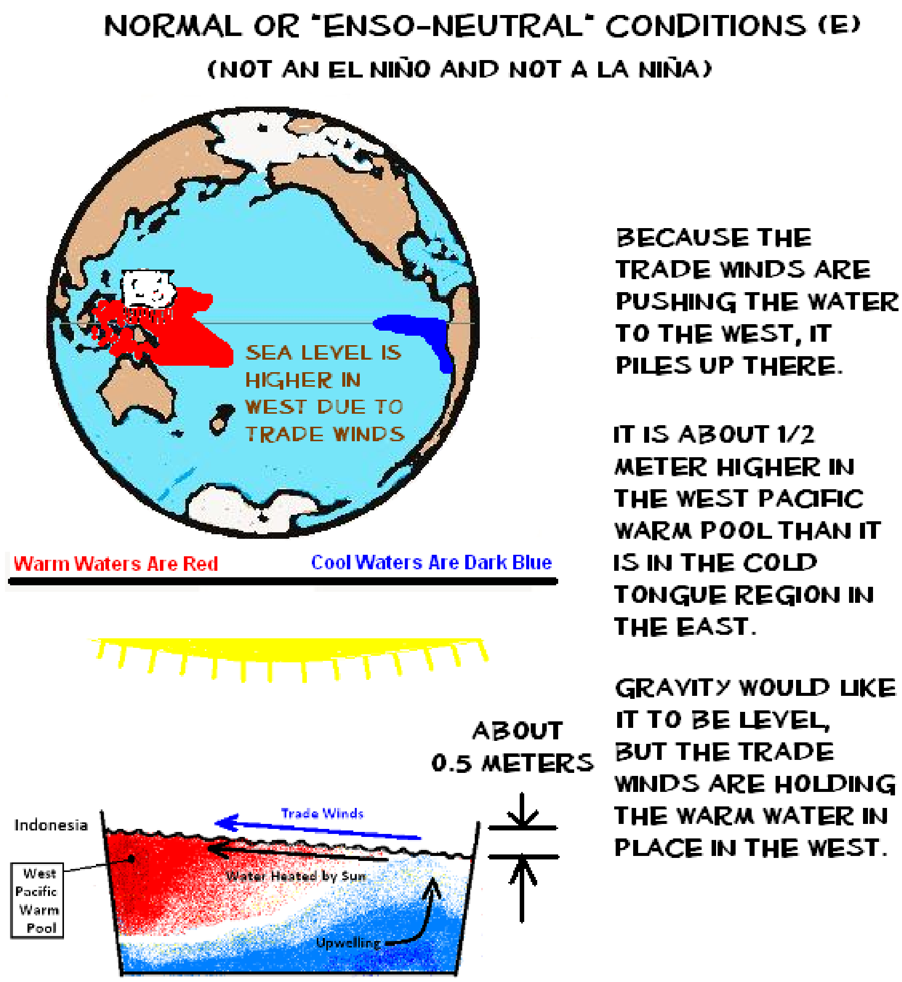

Figure 1-11 Bob Tisdale

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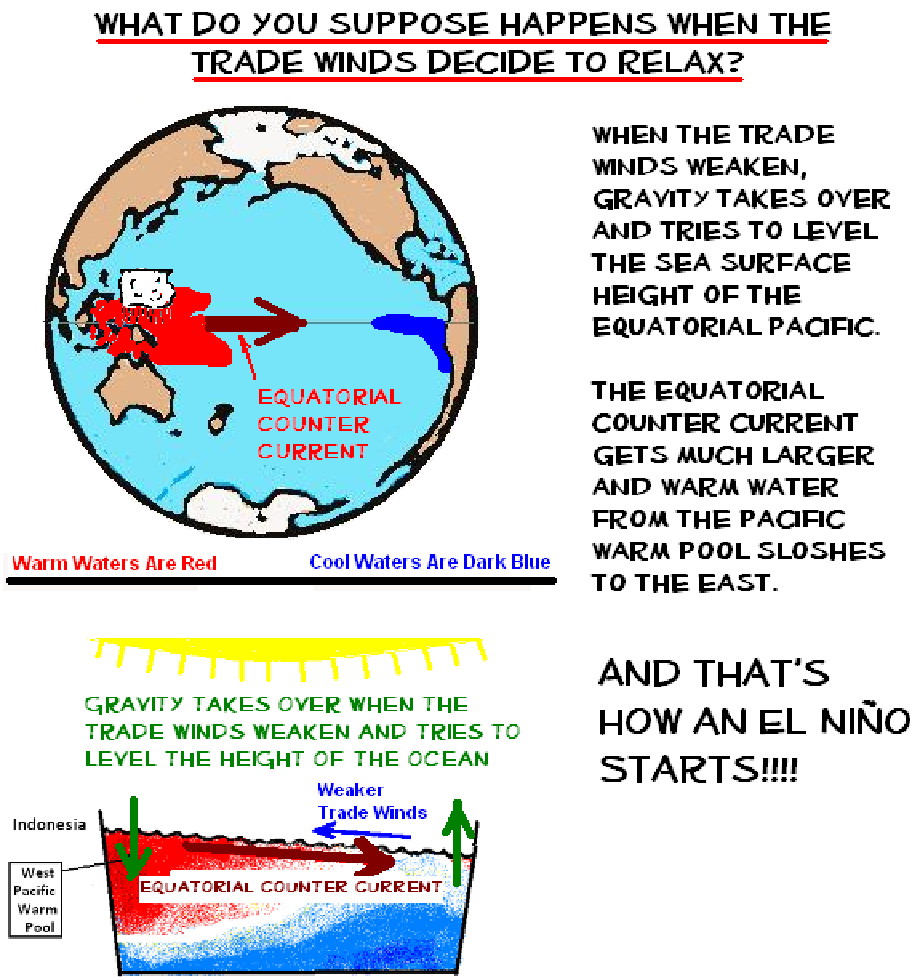

Figure 1-12 Bob Tisdale

Now's a good time to take a quick break from the cartoon-like illustrations. We'll go into more detail in Section 3 about the interrelated processes taking place before an El Niño, but it's important now to reinforce what's been discussed so far. I'll reword the presentation a little with hope that it will help make things click for you.

The trade winds are an important part of our discussion of ENSO-neutral, or "normal", conditions in the tropical Pacific. They blow from east to west across the surface and cause the surface waters to also travel from east to west. That makes sense. If you blow on a liquid long and hard enough, the surface of the liquid will move it the direction you're blowing.

The trade winds also blow clouds toward the west. That's not hard to imagine, either. This allows that wonderfully strong tropical sun to beat down on the surface of the tropical Pacific and to reach into the subsurface waters to depths of 100 meters. Though most of that sunlight is absorbed nearer the surface, in the top 10 meters (roughly 33 feet) or so, it does reach farther. All of Mother Nature's glorious sunlight warms the tropical Pacific waters as they travel west.

The trade winds push the waters up against the land masses of Indonesia and Australia. This causes the warm water to, in effect, pile up in the western tropical Pacific, in an area called the west Pacific Warm Pool. The trade winds driving the westward movement of surface waters also draw cool waters from below the surface of the eastern equatorial Pacific, in a process called upwelling. That upwelled water provides a continuous source of cool water at a relatively constant temperature that's then warmed by the sun as it travels west. The water is, therefore, cooler in the eastern equatorial Pacific, in an area called the Cold Tongue Region, than it is in the west Pacific Warm Pool. Remember, the tropical Pacific stretches almost halfway around the globe, so that nice cool supply of water in the east travels a long way under the tropical sun before it reaches the warm pool in the west.

The trade winds cause the temperature difference between the east and west portions of the tropical Pacific. Now, here's the interesting part. The temperature difference between the eastern and western tropical Pacific causes the trade winds to blow. That's right. The temperature gradient of the tropical Pacific sea surface temperatures and the trade winds interact with one another in a positive feedback loop called Bjerknes feedback.

Why does that happen?

There nothing mysterious going on. The warmest water is in the western tropical Pacific. We've discussed that, and we'll confirm it in Section 3. The warm water there heats the air above it, and that relatively hot air rises. All of that rising hot air has to be replaced by other air, and it's the trade winds out of the east that supply the necessary make-up air. Because the tropical Pacific is cooler in the east, the air sinks there, and eastward-blowing upper winds complete the circuit. Overall, the warm air rises in the west; it cools as it's carried east by the upper winds; then it sinks in the eastern tropical Pacific, where it heads back to the west as the trade winds. That circuit is called a Walker cell. The trade winds continuously push cool water from the east to the west, sunlight warms the water as it travels west, and when that warm water reaches the west Pacific Warm Pool, it supplies the heat necessary to maintain the updraft, which, in turn, causes to trade winds to blow. The briefest way to explain it: the trade winds and the sea surface temperatures are coupled, meaning they interact with one another.

With all of that warm water being piled up in the western tropical Pacific, and with all of the cool water being drawn from the eastern equatorial Pacific, the surface of the water—the sea level—in the west Pacific Warm Pool is about 0.5 meters (approximately 1.5 feet) higher in elevation than it is in Cold Tongue Region in the east.

Everything's in tune, running in its normal state. The temperature difference between the east and west keeps the trade winds blowing—and—the trade winds maintain the temperature difference between east and west—and—the trade winds keep the warm water in the west Pacific Warm Pool at a higher elevation than it is in the eastern equatorial Pacific.

We can't forget about gravity. It's always there, our constant companion. Gravity would like the sea surface height in the west to equal the height in the east. It likes level playing fields. It's working against the trade winds, and the trade winds are piling up the warm water against gravity. Still, everything is in relatively constant state of balance, with little gives and takes here and there.

Then some weather event—and that's precisely what it is, a weather event or group of weather events—causes the trade winds to relax. That means the coupled ocean-atmosphere processes taking place in the tropical Pacific are no longer in balance. Sometimes, the weakened trade winds aren't strong enough to hold the warm water in place in the west Pacific Warm Pool against gravity, so gravity takes over and all of that lovely warm water that was piled in the west Pacific Warm Pool suddenly sloshes to the east. That's how an El Niño starts.

I'm now going discuss parts of the process that haven't been shown in the illustrations yet.

The Pacific Ocean is awfully wide at the equator, so it takes a while, about 2 months, for the warm water to slosh to the east as far as the coast of South America.

Let's put things into perspective. The west Pacific Warm Pool holds a massive amount of warm water. It varies in size. When it's large, the west Pacific Warm Pool can cover a surface area of about 19 million square kilometers (7.3 million square miles) but it averages about 12 million square kilometers (4.6 million square miles). Numbers that large are hard to embrace, so, when the west Pacific Warm Pool is larger than normal, think of an area the size of Russia or a little less than twice the size of the United States. Refer to the Mehta and Mehta (2004) presentation **Natural decadal-multidecadal variability of the Indo-Pacific Warm Pool and its impacts on global climate**. Also imagine the warm water reaches depths of 300 meters (about 1000 feet). Sometimes, during a very strong El Niño, most of that water from the west Pacific Warm Pool will be transported east and much of it will spread across the surface of the central and eastern tropical Pacific. Now remember that the Pacific stretches almost halfway around the globe at the equator. An El Niño dwarfs all other weather-related events. How big are they? Sometimes it takes a pair of tropical cyclones just to trigger an El Niño. Yes, tropical cyclones as in hurricanes.

Let's return to the ENSO-neutral phase for a second. A weather event—for example, a couple of tropical cyclones or a pair of them that straddle the equator—a weather event that's teeny by comparison, has caused the Pacific trade winds to relax, which in turn has unleashed a monstrously large phenomenon that is capable of raising global temperatures 0.4 degrees C in less than a year. In turn, there are heat waves and cold spells. Floods will strike some parts of the globe. Drought conditions form in others. Snowfall will pile to record heights in some areas, and in others it will decrease. These effects were studied and documented decades ago, and they're still being studied, for example, to account for differences between Central Pacific and the more powerful East Pacific El Niño events.

Of course, some publicity seeking climate scientists continue to (very unwisely) blame carbon dioxide for the heat waves and cold spells, flooding and drought, blizzards and low snowfall, creating further disbelief in climate science. They have only themselves to blame for their loss of credibility. I digress.

An El Niño is one of Mother Nature's ways of reminding us who's in charge.

Back to the cartoon-like illustrations.

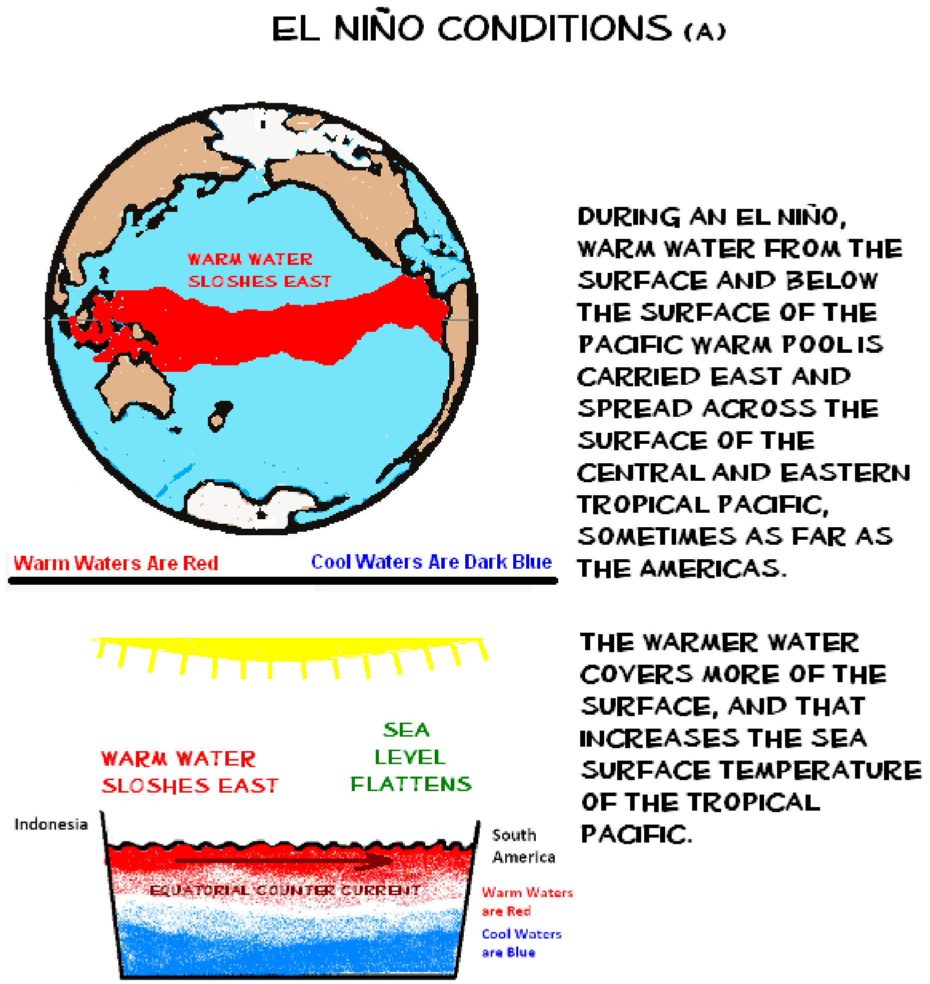

Figure 1-13 Bob Tisdale

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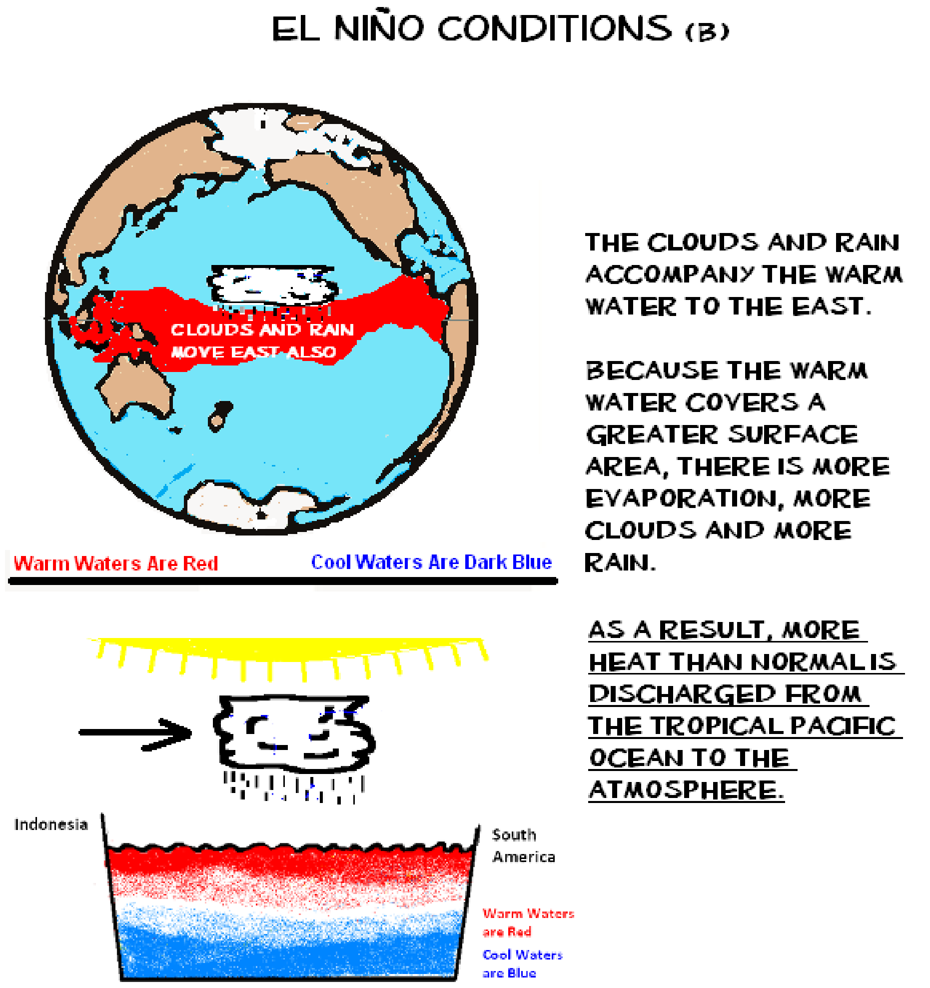

Figure 1-14

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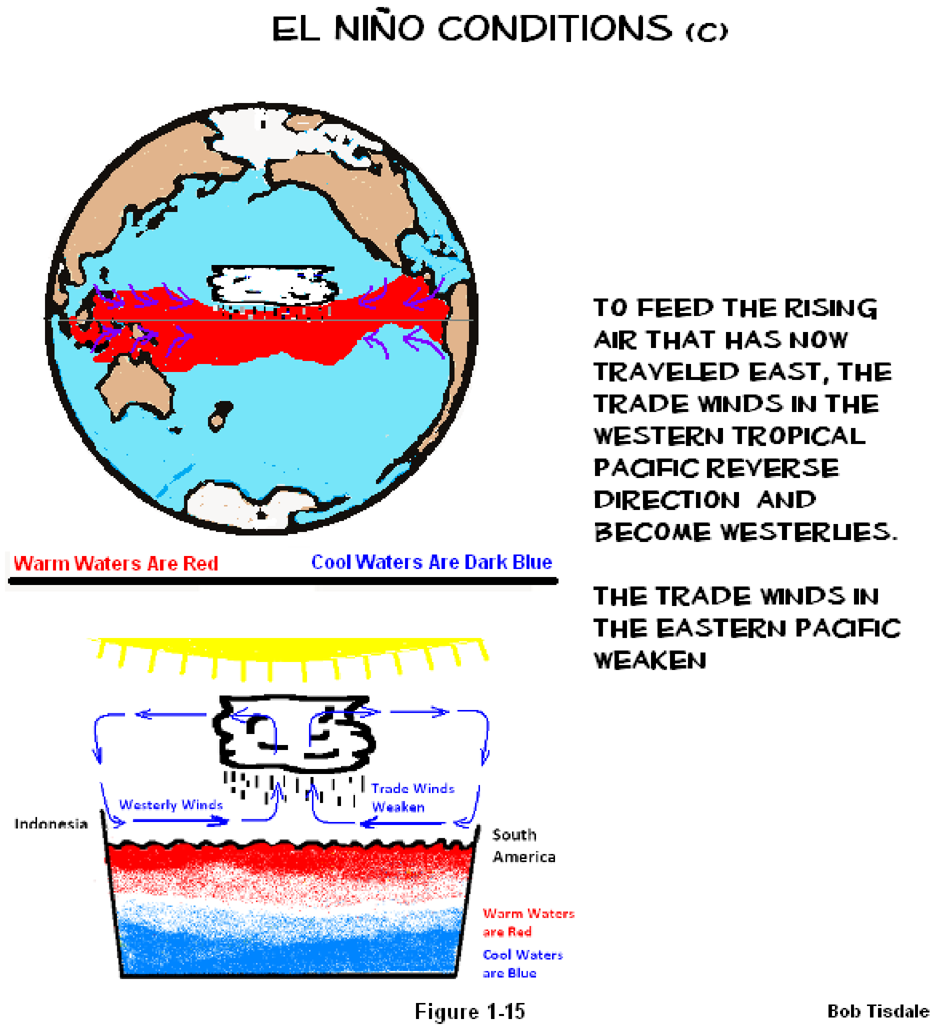

Figure 1-15

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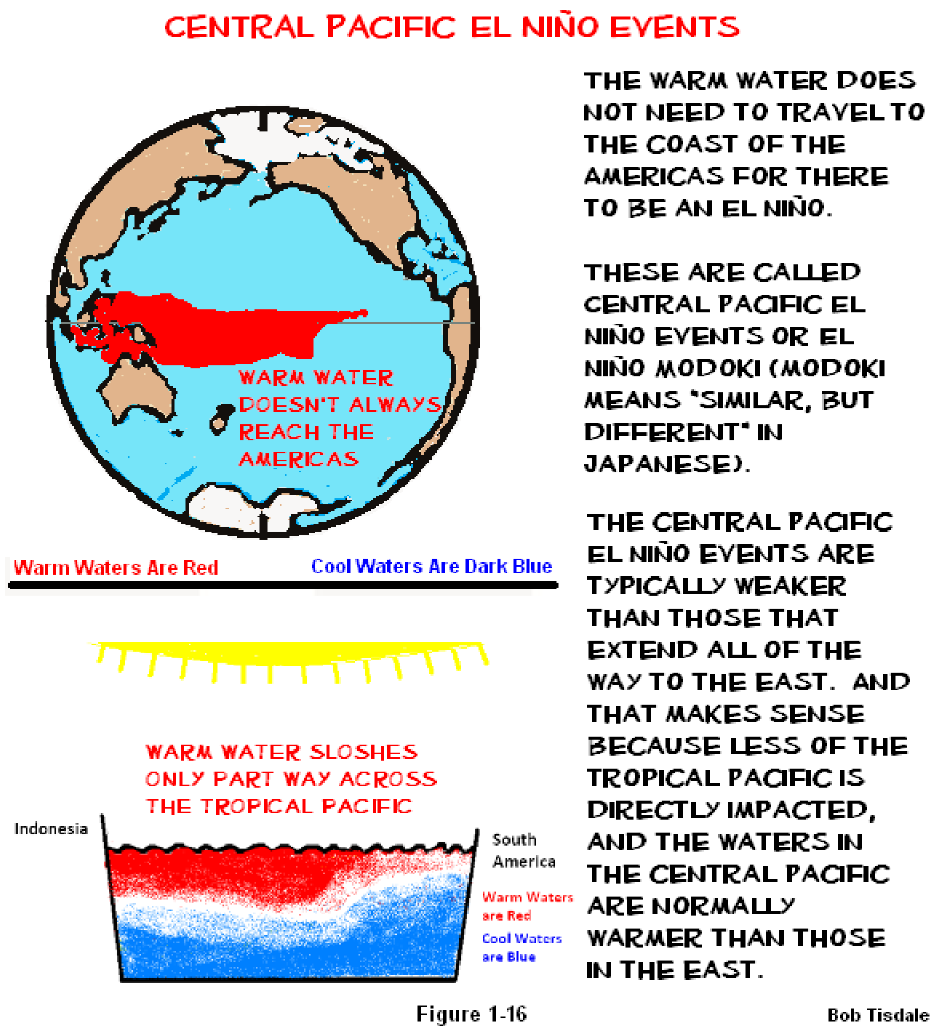

Figure 1-16

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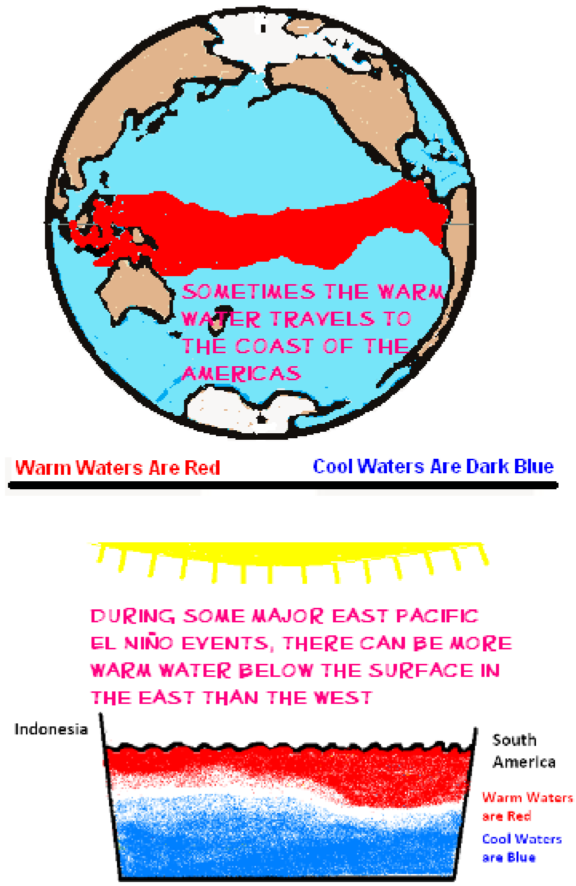
EAST PACIFIC EL NIÑO EVENTS



DURING EAST PACIFIC EL NIÑO EVENTS, THE WARM WATER REACHES THE COASTS OF THE AMERICAS.

EAST PACIFIC EL NIÑO EVENTS ARE TYPICALLY STRONGER THAN CENTRAL PACIFIC EL NIÑO—SO STRONG, THEY CAN RAISE EASTERN PACIFIC SEA SURFACE TEMPERATURES AS MUCH AS 5 DEG C (9 DEG F) IN SOME PLACES.

DURING A VERY STRONG EL NIÑO, THERE CAN BE MORE WARM WATER BELOW THE SURFACE IN THE EASTERN PACIFIC THAN IN THE WEST.

Figure 1-17 Bob Tisdale

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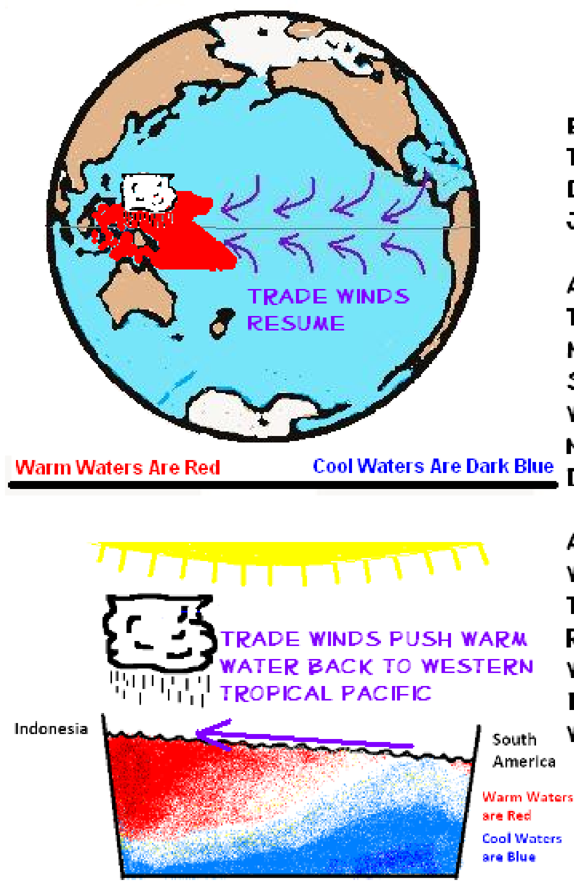
TRANSITION FROM EL NIÑO TO ENSO-NEUTRAL (A)



EL NIÑO EVENTS TYPICALLY PEAK IN DECEMBER AND JANUARY.

AS THE TROPICAL PACIFIC TRANSITIONS FROM EL NIÑO TO ENSO-NEUTRAL STATES, THE TRADE WINDS RESUME THEIR NORMAL EAST TO WEST DIRECTION.

ANY WARM SURFACE WATERS LEFT OVER FROM THE EL NIÑO ARE RETURNED TO THE WESTERN TROPICAL PACIFIC BY THE TRADE WINDS.

Figure 1-18 Bob Tisdale

HHH

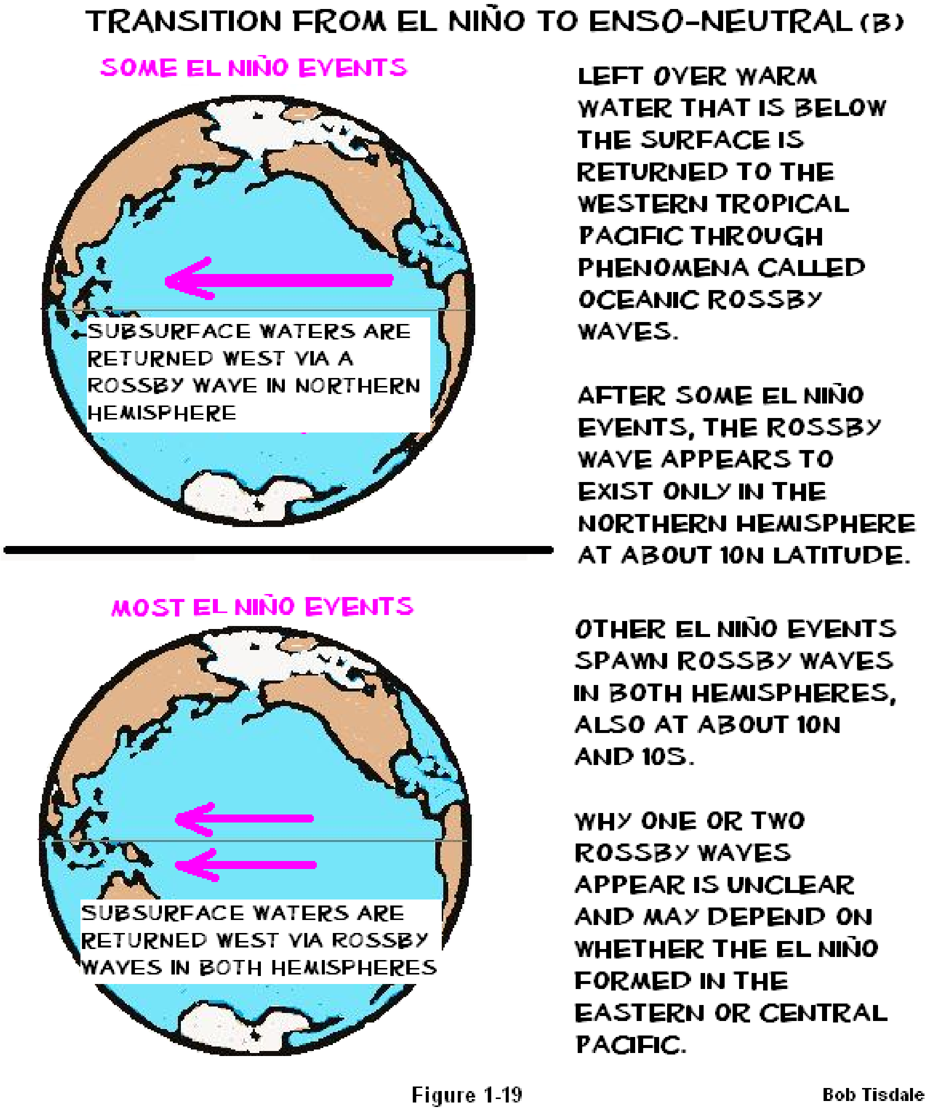


Figure 1-19

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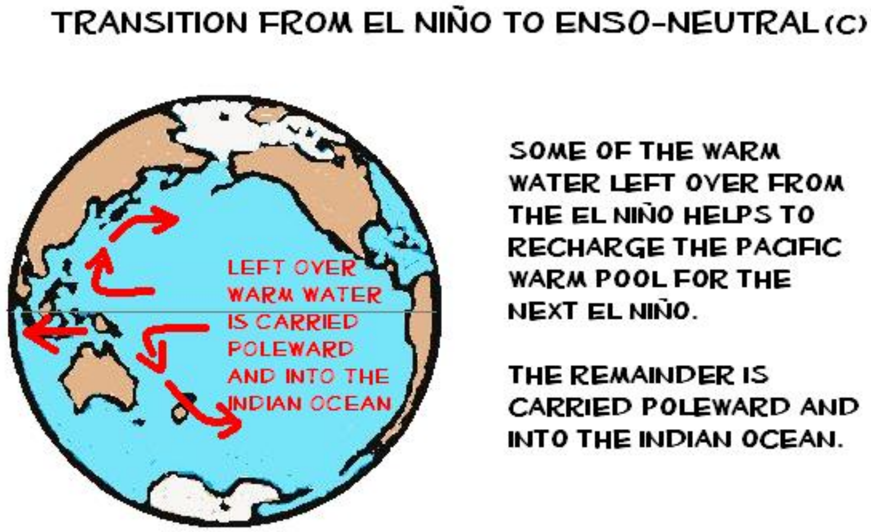

Figure 1-20 Bob Tisdale

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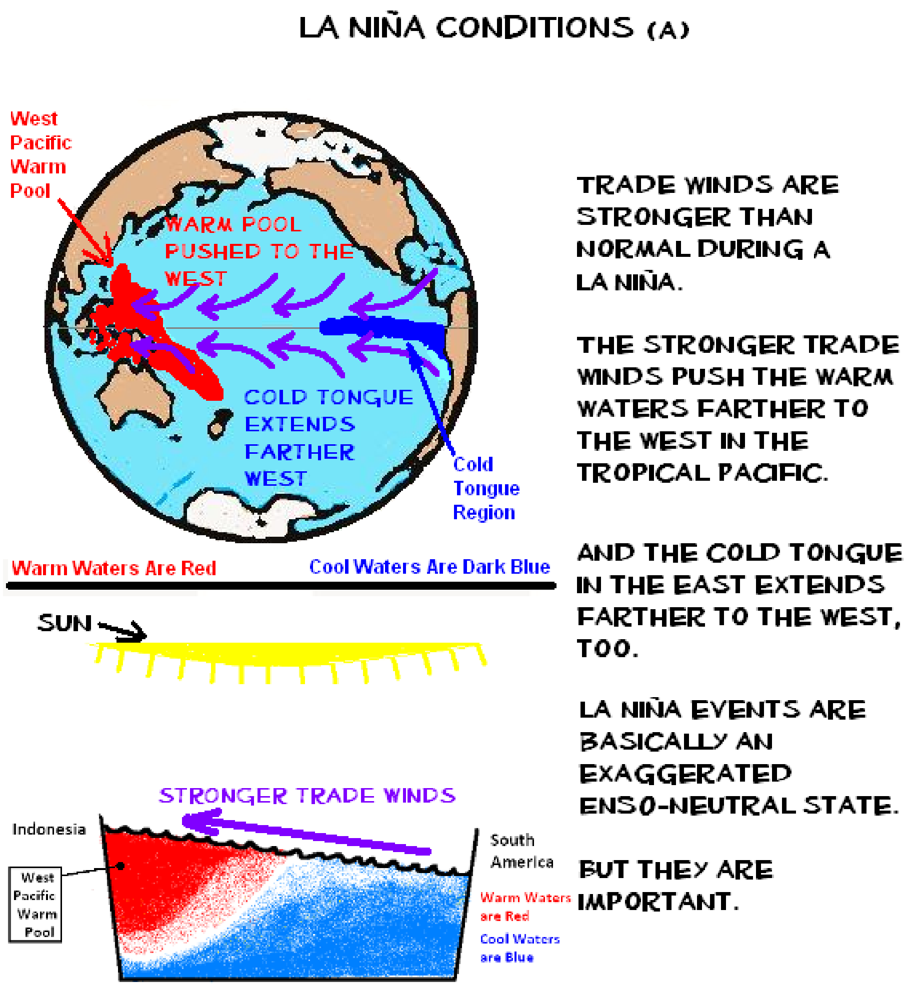

Figure 1-21 Bob Tisdale

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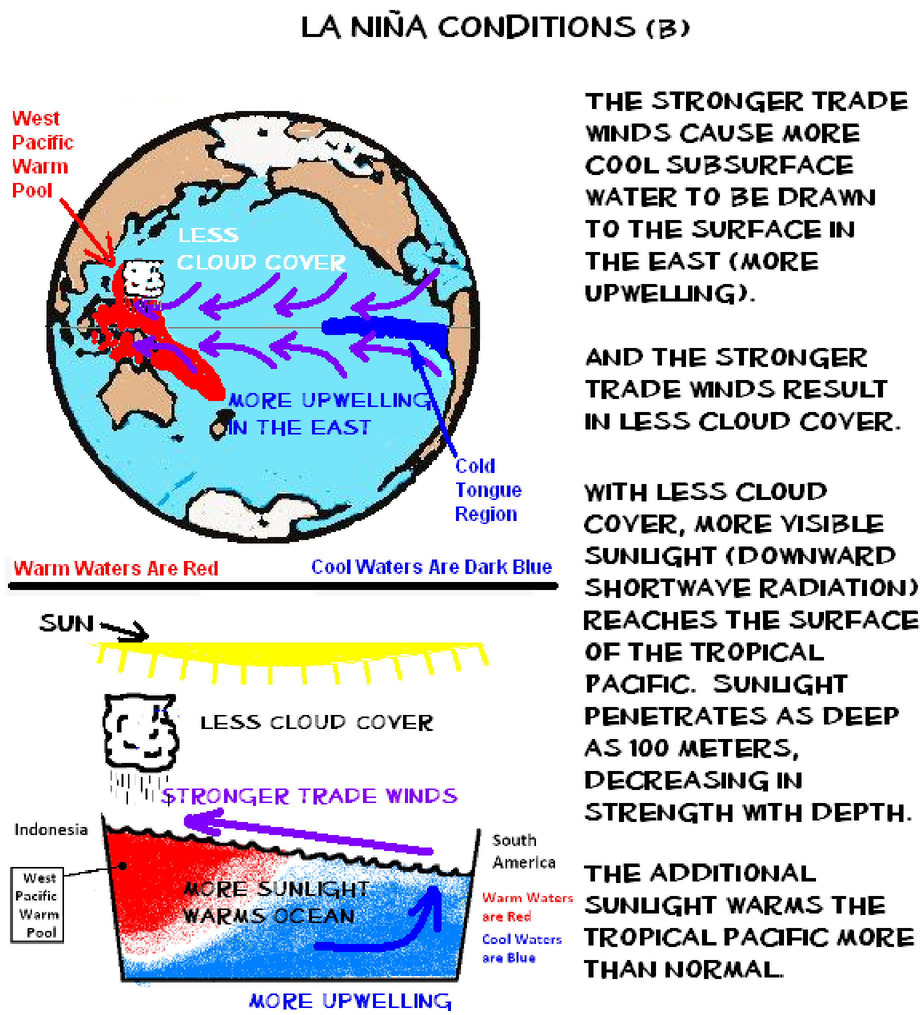

Figure 1-22 Bob Tisdale

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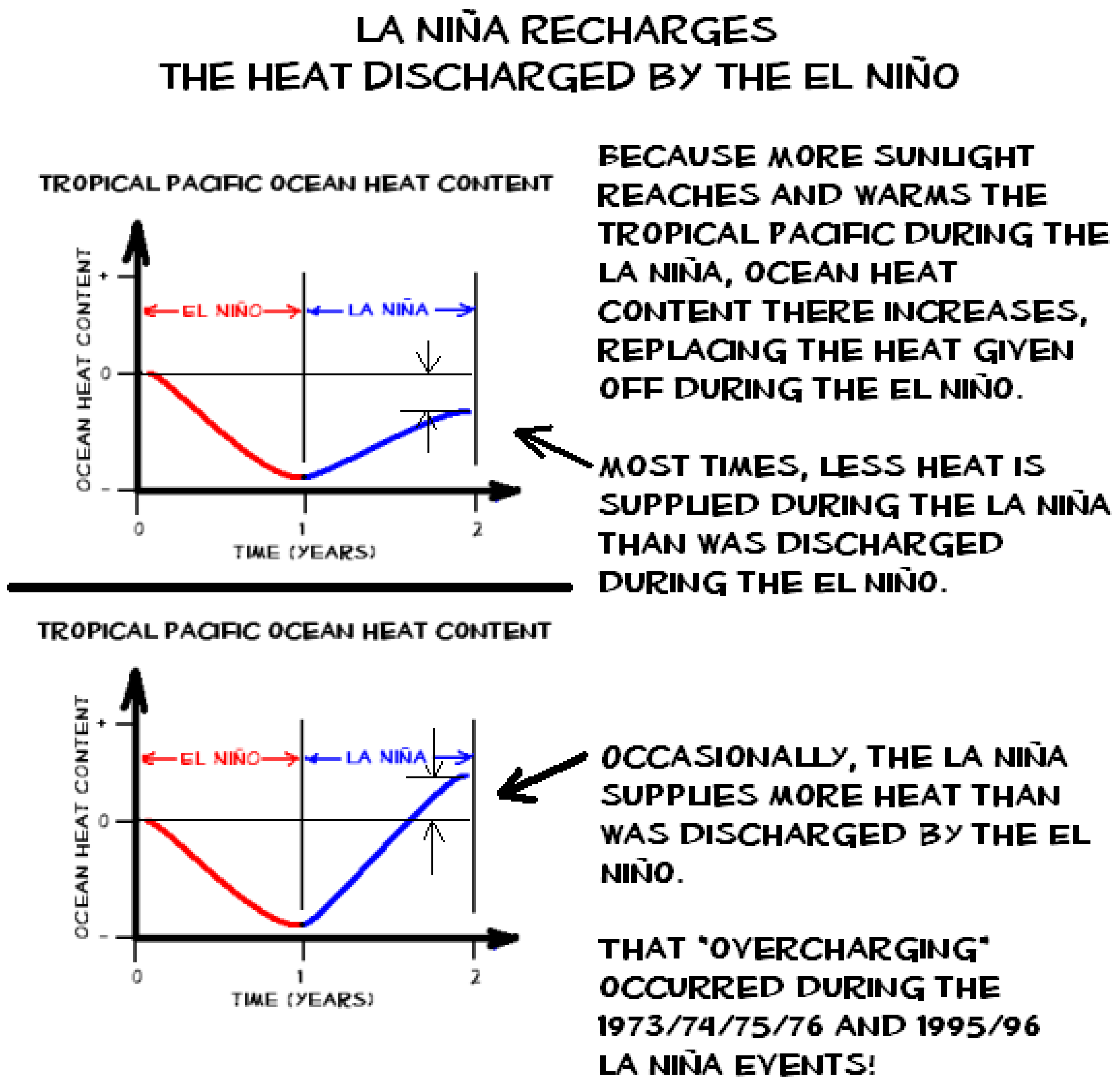

Figure 1-23 Bob Tisdale

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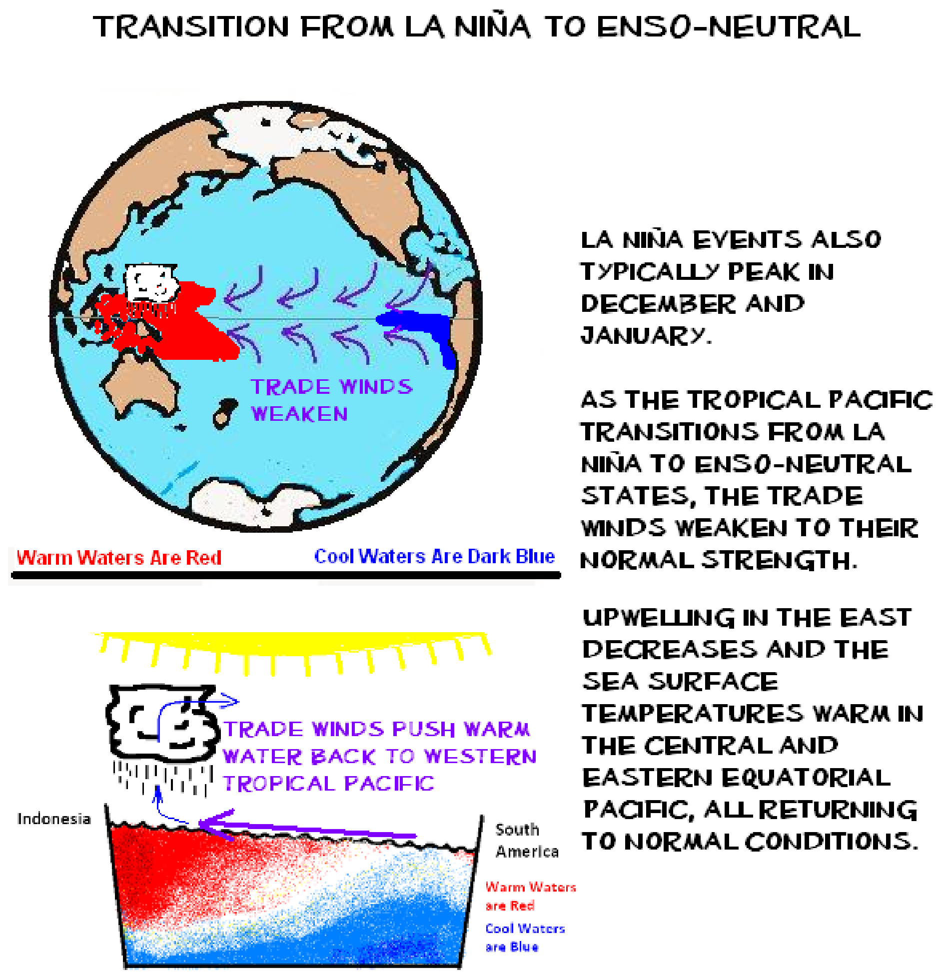

Figure 1-24 Bob Tisdale

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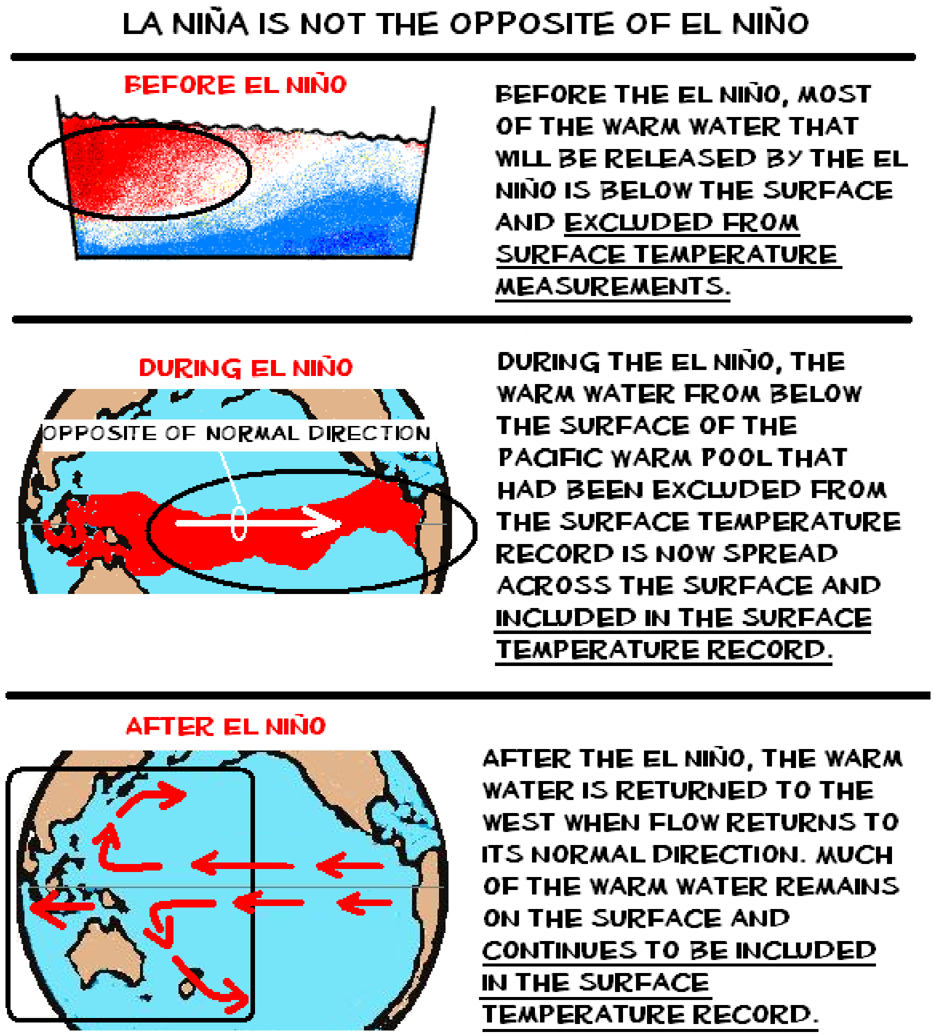

Figure 1-25 Bob Tisdale

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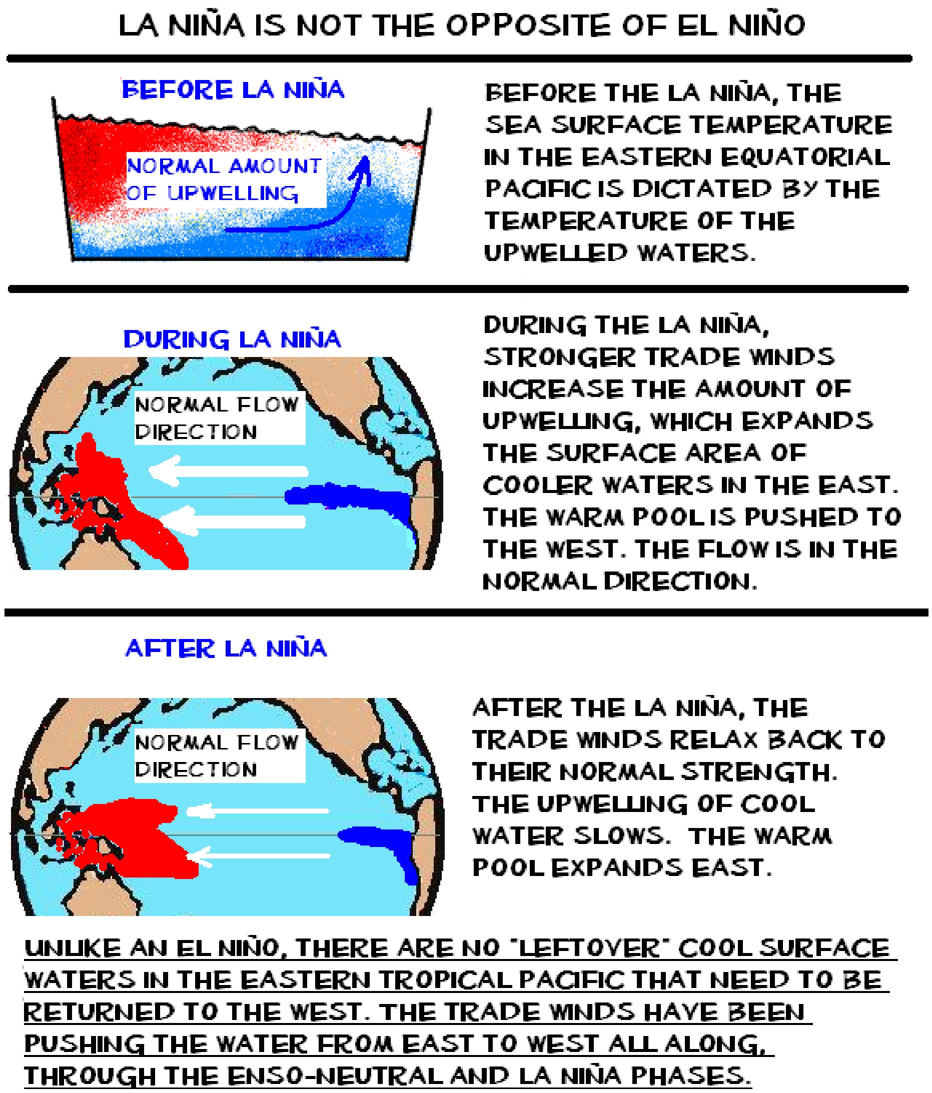

Figure 1-26

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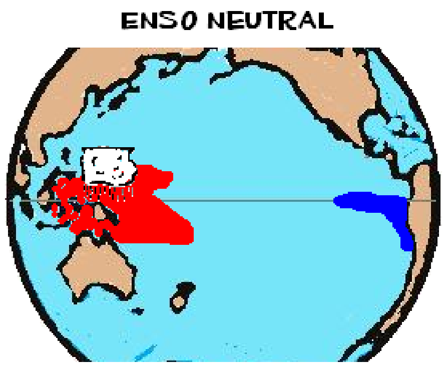
WHY GLOBAL SURFACE TEMPERATURES WARM DURING AN EL NIÑO (A)



AN EL NIÑO RELEASES HEAT INTO THE ATMOSPHERE. BUT THAT IS NOT WHY GLOBAL SURFACE TEMPERATURES WARM IN RESPONSE TO THE EL NIÑO.

BECAUSE THE PACIFIC WARM POOL IS SO WARM, A LOT OF MOISTURE IS PUMPED INTO THE ATMOSPHERE THERE.

BECAUSE THE PACIFIC WARM POOL IS ALSO SO LARGE, IT IS ONE OF THE DRIVING FORCES OF GLOBAL CLIMATE.

Figure 1-27 Bob Tisdale

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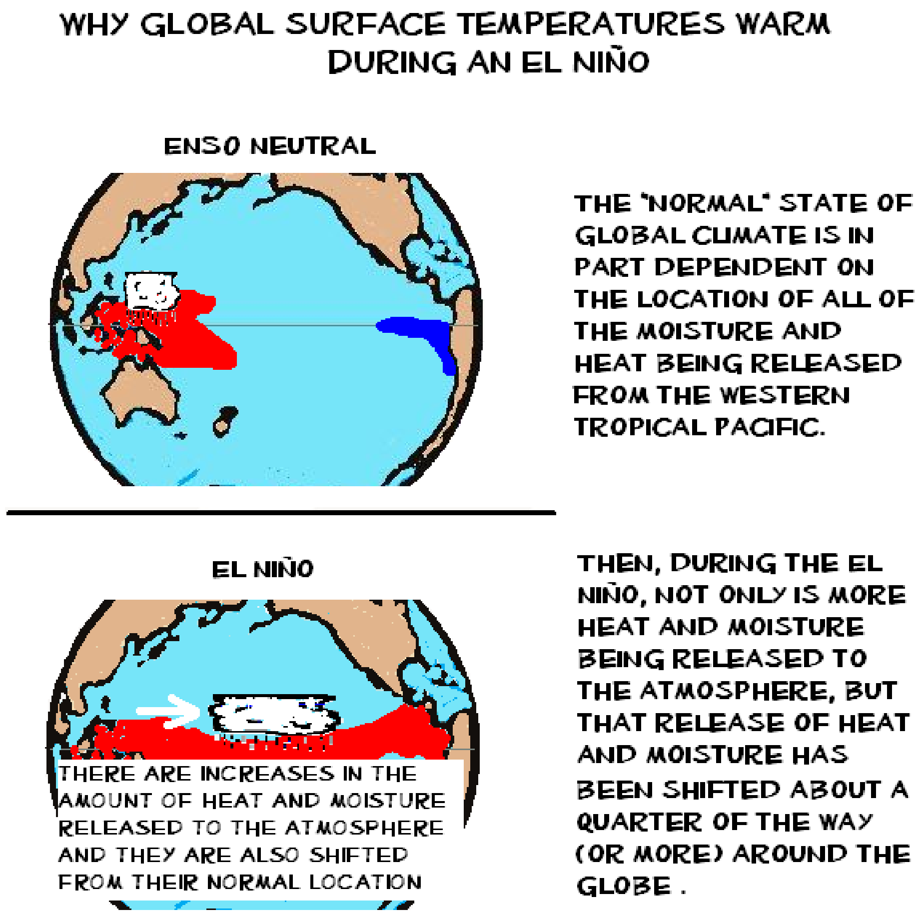

Figure 1-28 Bob Tisdale

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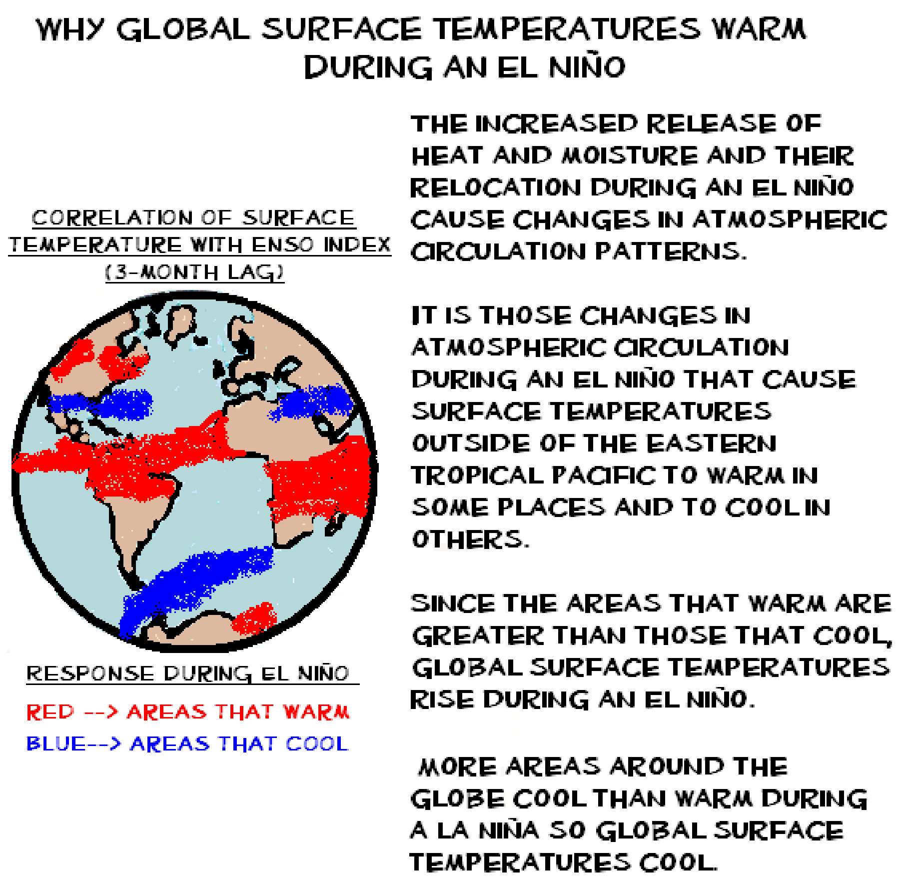

Figure 1-29 Bob Tisdale

1.3 Recap of Section 1

Trade winds cause the sea surface temperature and height in the western tropical Pacific to be greater than they are in the east. El Niño events are started by the weakening of the trade winds. The weaker trade winds can no longer hold the warm water in place in the west Pacific Warm Pool, and this allows gravity to carry the warm water east, raising sea surface temperatures in the central and eastern equatorial Pacific.

El Niño events are the abnormal phase of ENSO. The Equatorial Countercurrent strengthens and carries a large volume of warm water from west to east, and that increased volume from west to east opposes the normal east-to-west flow during ENSO-neutral and La Niña phases. The winds also change directions during an El Niño, with trade winds becoming westerlies in the western tropical Pacific. On the other hand, during ENSO-neutral and La Niña phases, the trade winds are blowing in their normal east-to-west direction.

La Niña events are easy to describe. They are exaggerations on the ENSO neutral phase. However, La Niña events play the important role of replenishing the heat given off by the El Niño that precedes it, and sometimes a La Niña can create more warm water than was released by the El Niño.

Warm water that has traveled east during the El Niño and that is not "exhausted" by the El Niño does not remain in the eastern tropical Pacific. It is returned to the West Pacific and Indian Oceans, where much of it remains on the surface. Before the El Niño, most of that warm water is below the surface of the west Pacific Warm Pool and excluded from the surface temperature record. Then, after the El Niño, part of what remains of that warm water is now on the surface of the West Pacific and East Indian Oceans. The opposite does not occur during the La Niña phase. The result: strong El Niño events can raise global sea surface temperatures for extended periods of time. This will be discussed in detail in Section 5.

Section 2 – A Few Preliminary Discussions

This section covers a few introductory topics. First, we'll discuss the misunderstandings about the use of cycle and oscillation when describing El Niño and La Niña processes as a whole.

For those who don't read graphs as part of their daily routine, we'll provide an overview of the graphs used in this book. They are time-series graphs, comparison graphs, zonal-mean graphs and Meridional-mean graphs. Don't let the names of those last two scare you; they're easy to understand. Climate scientists use funky adjectives when discussing things relating to latitudes and longitudes.

We'll discuss how linear trends are calculated and what they mean. Because this book is about El Niño and La Niña events, there is a discussion about how those events present themselves in the graphs.

We'll illustrate why we use anomalies instead of the "raw" absolute data. In the book, there are a few graphs of climate model outputs so we'll discuss why we're looking at the average of all of the computer model runs that were prepared by modeling groups for the IPCC's Assessment Reports. Also, because the majority of this book deals with satellite-based sea surface temperature data, we'll discuss why we're using it and not the other datasets that rely only on temperature measurements from buoys and ships.

2.1 Do the Words "Oscillation" and "Cycle" in the names "El Niño-Southern Oscillation" and "ENSO Cycle" Cause Misunderstandings?

The words oscillation and cycle are used to describe the processes of El Niño and La Niña events as a single phenomenon. The commonly used term ENSO stands for El Niño-Southern Oscillation. The seemingly redundant term ENSO Cycle (El Niño-Southern Oscillation Cycle) is also used often. Many persons assume because cycle and oscillation are used to describe El Niño and La Niña that the two states oppose and offset one another, that a La Niña will counteract an El Niño. Bad assumptions. They definitely do not work that way.

The most obvious difference between the two states, which we discuss in Sections 1 and 3, is, El Niño events randomly release vast amounts of warm water from below the surface of the west Pacific Warm Pool and spread it across the central and eastern equatorial Pacific, but the reverse does not occur during La Niña events.

Are El Niño and La Niña events cyclical or oscillatory? Some parts are, and some parts aren't. We'll discuss this further in Chapter 4.17 **ENSO – A Cycle or Series of Events?**

AN OVERVIEW OF THE TERMS EL NIÑO-SOUTHERN OSCILLATION AND ENSO CYCLE

El Niño-Southern Oscillation is the combination of two names. The term is said to have been coined by Rasmussen and Carpenter in their (1982) paper **Variations in Tropical Sea Surface Temperature and Surface Wind Fields Associated with the Southern Oscillation/El Niño**. Let's see what Rasmussen and Carpenter have to say about the individual components. Their Introduction begins with the term El Niño:

> *The interannual variability of sea surface temperature (SST) along the Peru-Ecuador coast is dominated by the El Niño phenomenon. The name El Niño was originally applied to a weak warm coastal current which annually runs southward along the coast of Ecuador around the Christmas season (Wyrtki 1975). In scientific usage, the term has now become more narrowly associated with the extreme warmings which occur every few years (Wyrtki 1979a), and which result in catastrophic effects on the ecological system of the region. In more recent years, Ramage (1975), Weare et al. (1976), and others have used the term to encompass the larger-scale features of the warming event; i.e., the upwelling area along both the equator and the South American coast.*

A few paragraphs later, Rasmussen and Carpenter describe the Southern Oscillation after discussing some initial findings from as far back as 1897:

> *It remained, however, for Sir Gilbert Walker, in a classical series of papers (Walker, 1923, 1924, 1928; Walker and Bliss, 1930, 1932, 1937) to name the SO [Southern Oscillation] and describe the salient features of the surface pressure, temperature and precipitation fluctuations.*

The full title of the first Walker paper is WALKER, G. T. (1923). Correlation in seasonal variations of weather. VIII. A preliminary study of world-weather. Memoirs of the Indian Meteorological Department 24(Part 4) 75–131.

These papers by Walker were not discussions of El Niño, however. The link between El Niño and the Southern Oscillation wasn't established until the 1960s. Therefore, the word oscillation in Southern Oscillation does not apply to El Niño and La Niña events or their processes. It only applies to the impacts of El Niño and La Niña on the sea level pressures in Tahiti and Darwin, Australia.

The sequence of papers and the advancement in ENSO research is further described in Rasmussen and Carpenter (1982).

Then there's the term "ENSO Cycle". The NOAA Climate Prediction Center (CPC) and many others, including me, use the phrase to describe El Niño and La Niña events and the variations from one state to the other. Refer to the CPC's wonderful series of ENSO-related web pages **ENSO Cycle** that we'll use for further discussions in **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation.**

DEFINITIONS OF OSCILLATION AND CYCLE

The Wikipedia definition of **Oscillation** begins:

> **Oscillation** is the repetitive variation, typically in **time**, of some measure about a central value (often a point of **equilibrium**) or between two or more different states.

El Niño and La Niña events do not repeat in time, there are very few things that are repetitive in ENSO, so by this definition, ENSO isn't a true oscillation. In fact, Wikipedia writes in their initial description of **El Niño-Southern Oscillation**.

> "**El Niño/La Niña-Southern Oscillation**, or **ENSO**, is a **quasiperiodic climate pattern** that occurs across the tropical **Pacific Ocean** roughly every five years."

Oscillation is much easier to write than “quasiperiodic climate pattern”. To add confusion, “pattern” has multiple meanings. It could be used as “pattern in time”, or to describe a “spatial pattern”, as in the warming or cooling of the central and eastern equatorial Pacific.

Webster has a number of definitions for the word cycle. The one that fits ENSO best is:

> *1: a recurring series of events: as…*
>
> > *c* **:** *a series of ecological stages through which a substance tends to pass and which usually but not always leads back to the starting point <the cycle of nitrogen in the living world>*

Because an El Niño event does not always lead to a La Niña event and because La Niña events can be followed by another independent La Niña event, this definition of cycle under “c” is applicable to ENSO.

The term Southern Oscillation is used to represent the effects of El Niño and La Niña on the sea level pressure of the off-equatorial South Pacific. We’ll discuss it further in **Chapter 4.3 ENSO Indices.** Also discussed in that chapter, there’s another widely used ENSO index. It represents the effects of El Niño and La Niña events on the sea surface temperature anomalies of the equatorial Pacific region called NINO3.4, which is bounded by the coordinates of 5S-5N, 170W-120W. The Southern Oscillation Index and NINO3.4 sea surface temperature anomalies do NOT represent the process of ENSO. They are used only to indicate the frequency, strength and duration of El Niño and La Niña events. They indicate nothing more. They do not represent the process of ENSO, only its effect on the variable being measured for the index.

RECAP

El Niño-Southern Oscillation and ENSO Cycle are convenient phrases used to describe El Niño and La Niña. El Niño and La Niña events are not repetitive in time so they are not true oscillations. If it’s understood that an ENSO cycle may not lead to another series of El Niño and La Niña events nor even lead to the opposite phase, then cycle is applicable.

It’s a lot easier to write El Niño-Southern Oscillation than it is to write El Niño-La Niña/Sea Level Pressure Difference Between Darwin and Tahiti Quasiperiodic Climate Pattern.

2.2 The Types of Graphs Presented

The type of graph used most often in this book is a **time-series graph**. Time in months or years is measured in the horizontal axis (x-axis). The variable being presented is shown on the vertical axis (y-axis). An example is illustrated in Figure 2-1. It shows global sea surface temperature anomalies for the period of November 1981 to April 2012. November 1981 is the start month for this satellite-based dataset, and I prepared the graph in May 2012, so the data ends in April 2012. The period being presented is shown in the last line of the title block, which is at the top of the graph. The rest of the title block gives an overview of the data. "Reynolds OI.v2" in parentheses is the name of the dataset. The units of the horizontal axis are years. The units of the vertical axis, degrees C, are displayed. My apologies to those more familiar with the Fahrenheit scale, but the scientific community uses Celsius.

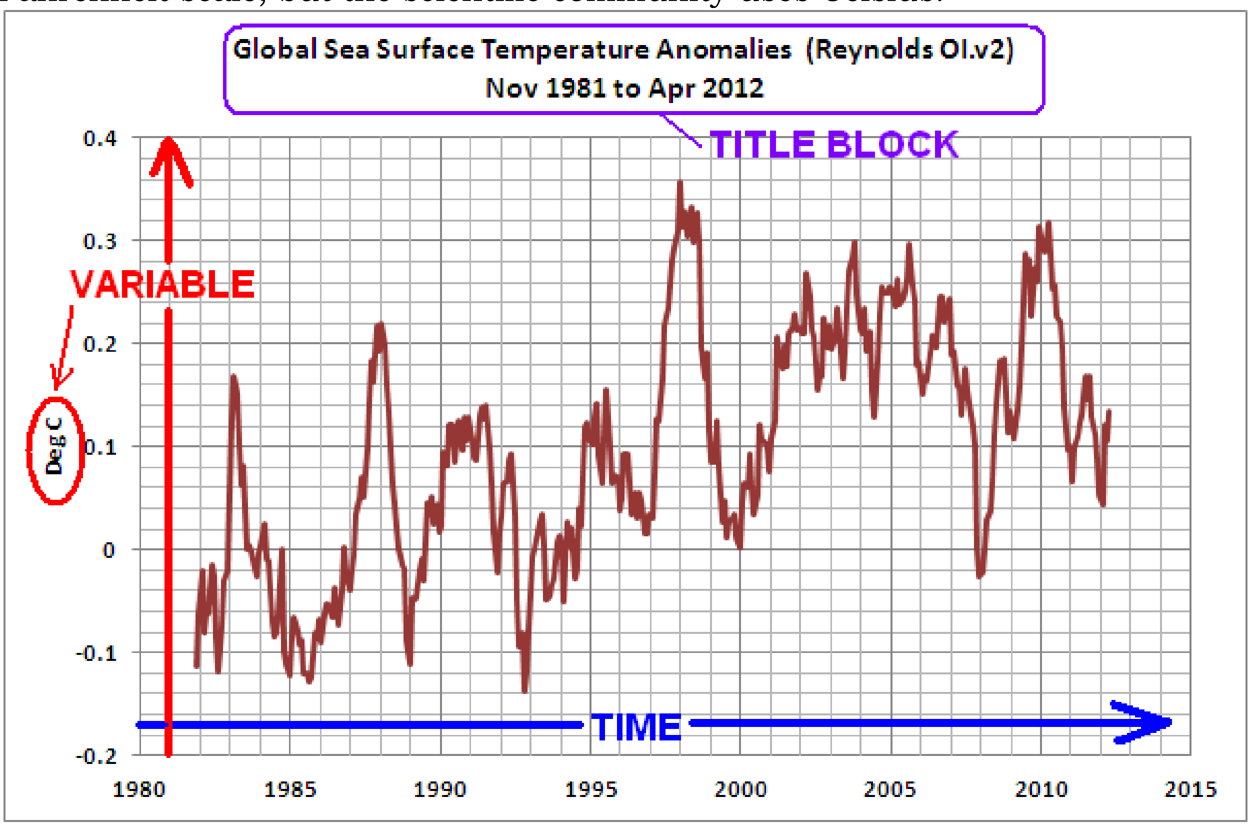

Figure 2-1 Bob Tisdale

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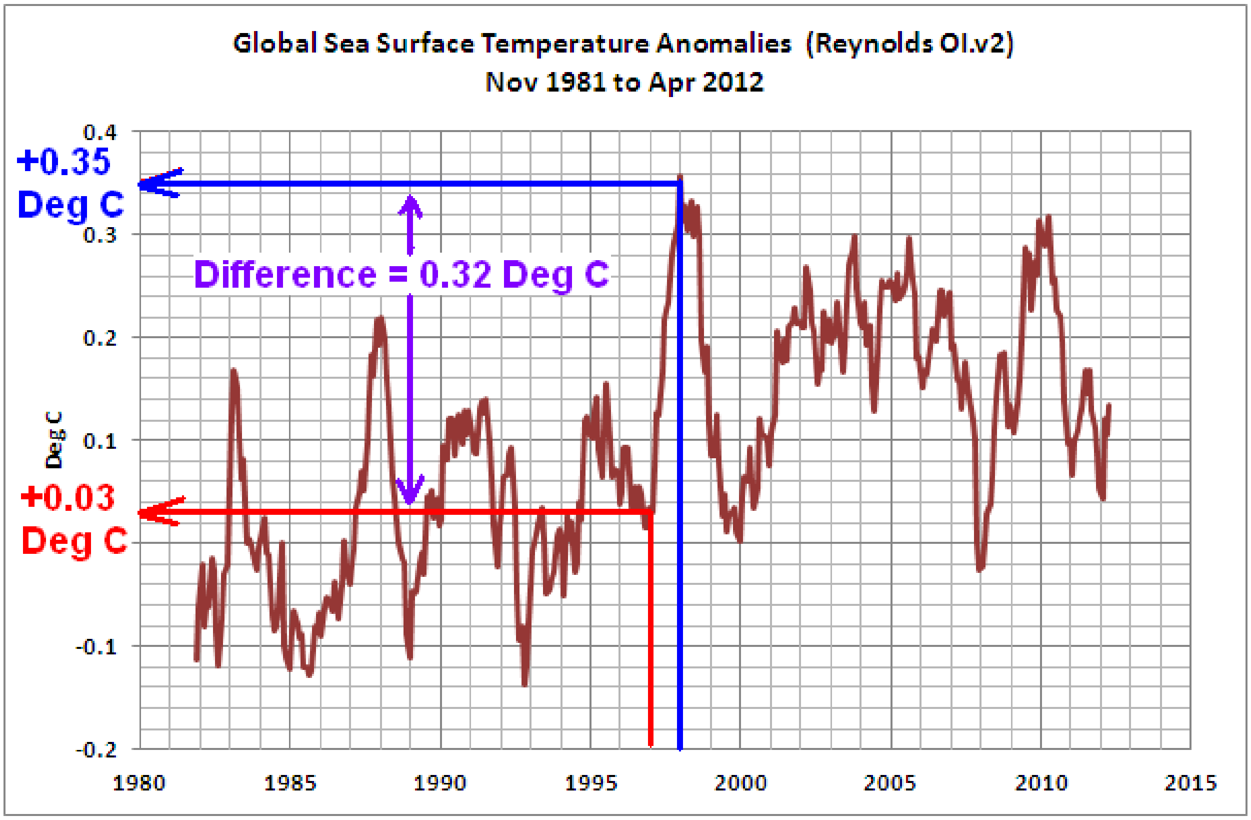

Figure 2-2

Bob Tisdale

As shown in Figure 2-2, global sea surface temperature anomalies temporarily warmed from +0.03 deg C to +0.35 deg C. In other words, the sea surface temperature anomalies for the entire globe, or about 360 million square kilometers of ocean, warmed temporarily about 0.32 deg C, or about 0.58 deg F, over a one-year period. That massive amount of warming occurred in response to the 1997/98 El Niño. Roughly half of that warming occurred in the eastern tropical Pacific. The other half of the warming occurred as responses to the changes in atmospheric circulation caused by the El Niño on sea surface temperatures throughout the rest of the global oceans. We'll discuss how that warming occurs a few times later in this book.

We'll also be showing more than one variable on a graph, and these are called **comparison graphs**. Most of the comparison graphs are time-series graphs with more than one variable. Sometimes we use comparison graphs to show that the variations with time in one dataset are much greater than the other, as shown in Figure 2-3. Or, more often, we'll multiply one of the datasets by a scaling factor that allows for easier visual comparison. For example, in Figure 2-4, the variations in the two datasets mimic one another. There are other reasons for the comparisons. We'll use them to illustrate the relationships between variables such as the sea surface temperature of the eastern equatorial Pacific and trade winds, ocean heat content, downward shortwave radiation (visible light), sea level, etc., so that we can confirm our understanding of the processes of ENSO. We'll also illustrate how major portions of the global oceans respond to El Niño and La Niña events.

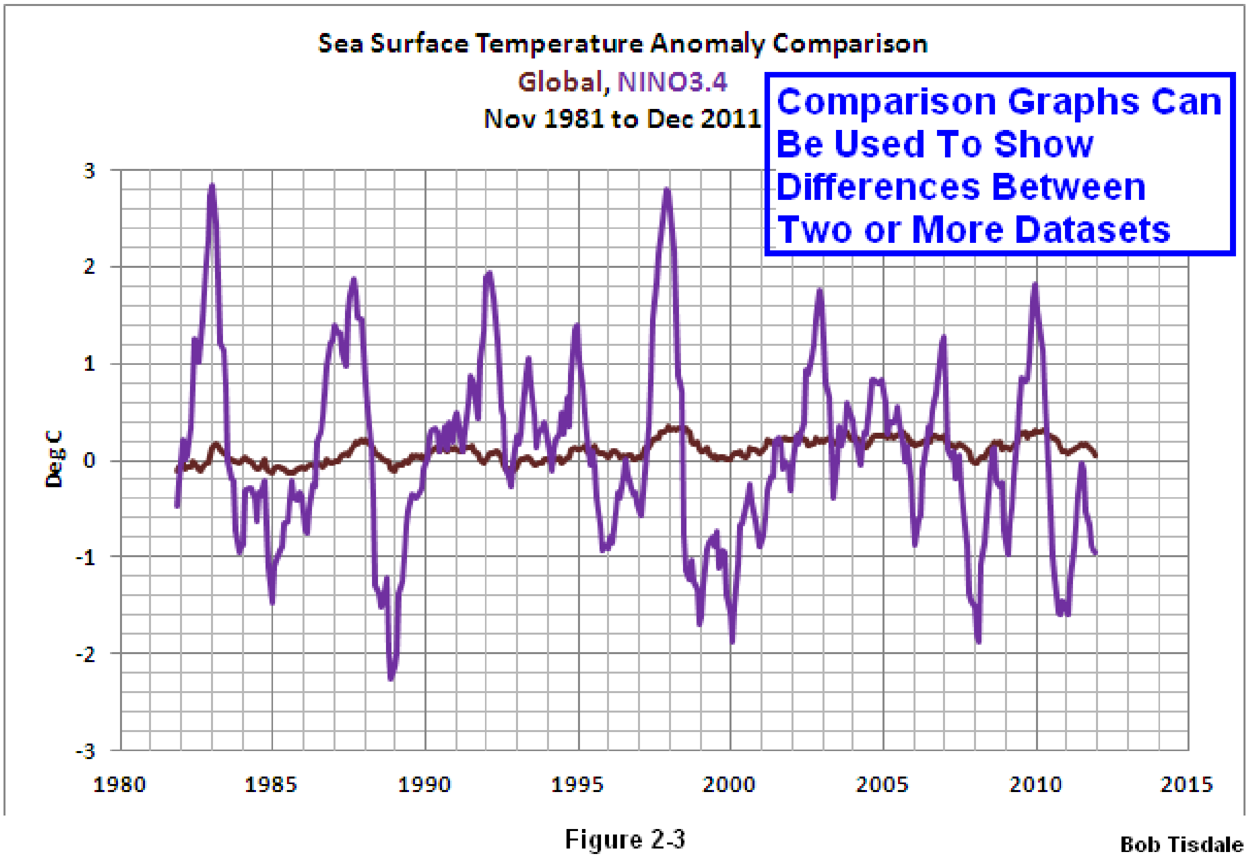

Figure 2-3

The title block in Figure 2-4 notes that the NINO3.4 sea surface temperature anomalies have been scaled. The scaling factor of 0.2 is shown in parentheses in the title block. There's nothing magical about scaling. Every data point was simply multiplied by 0.2 in that example, and that's quick and easy to do in a spreadsheet. The variations in the scaled dataset are proportional to the original data because all of the data were multiplied by a common factor. The scaling is a simple technique that's used to help with visual comparisons. What it also implies is, in this example, that the year-to-year variations in NINO3.4 sea surface temperature anomalies are about 5 times greater than the East Pacific data. The reciprocal of 0.2 is 5.0.

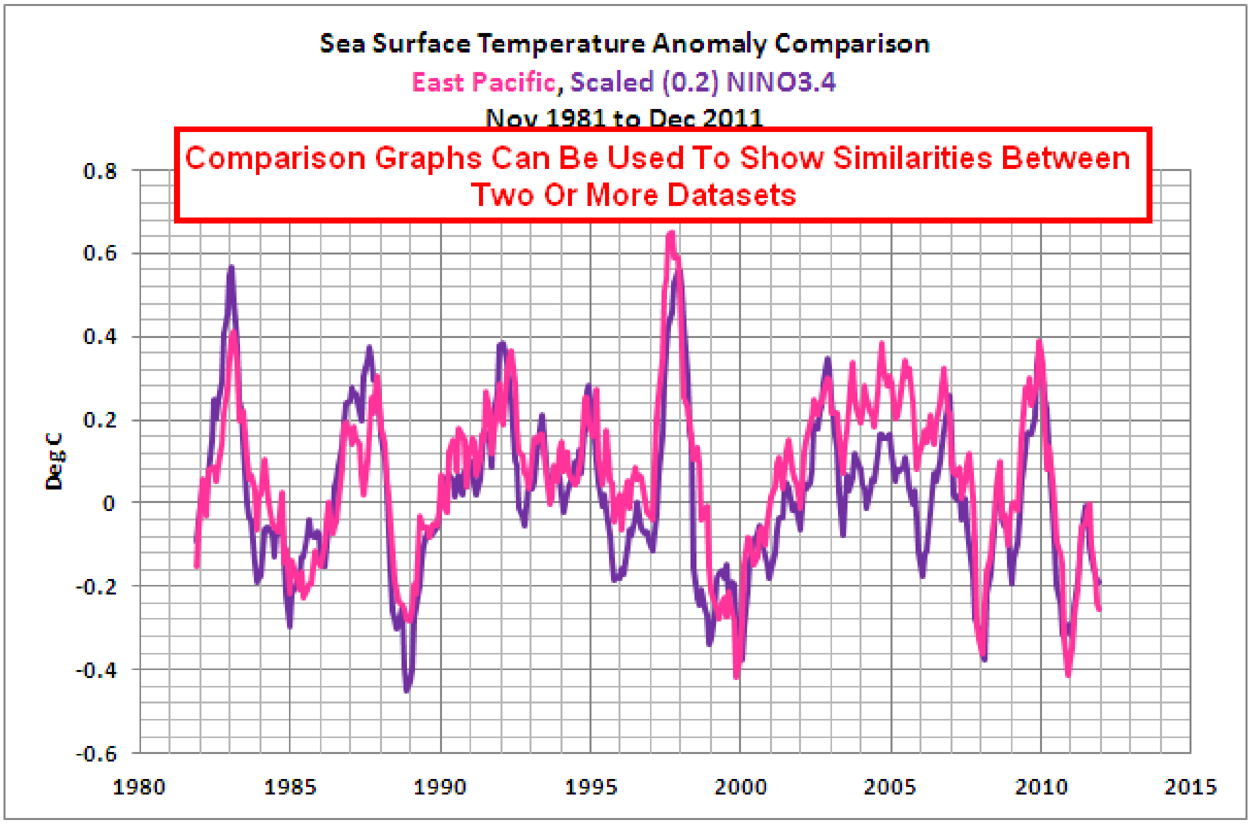

Figure 2-4

Bob Tisdale

Don't worry. I'll explain in Chapter 2.4 where the NINO3.4 region is and why it's important in discussions of ENSO. As you will see, sometimes we'll use the ENSO index in a comparison graph to illustrate the timing of ENSO events so that we can examine the response of the other variable.

Zonal-mean graphs present the value of a given variable at specified latitudes. "Zonal-mean" means latitude average. For the zonal-mean graphs in this book, the variable is shown in the vertical axis, and in Figure 2-5 the variable is sea surface temperature, with the units in deg C. The x-axis is latitude. Figure 2-5, as noted in the title block, is showing the average sea surface temperatures of the Pacific Ocean for the period of November 1981 to April 2012 in 5-degree latitude increments.

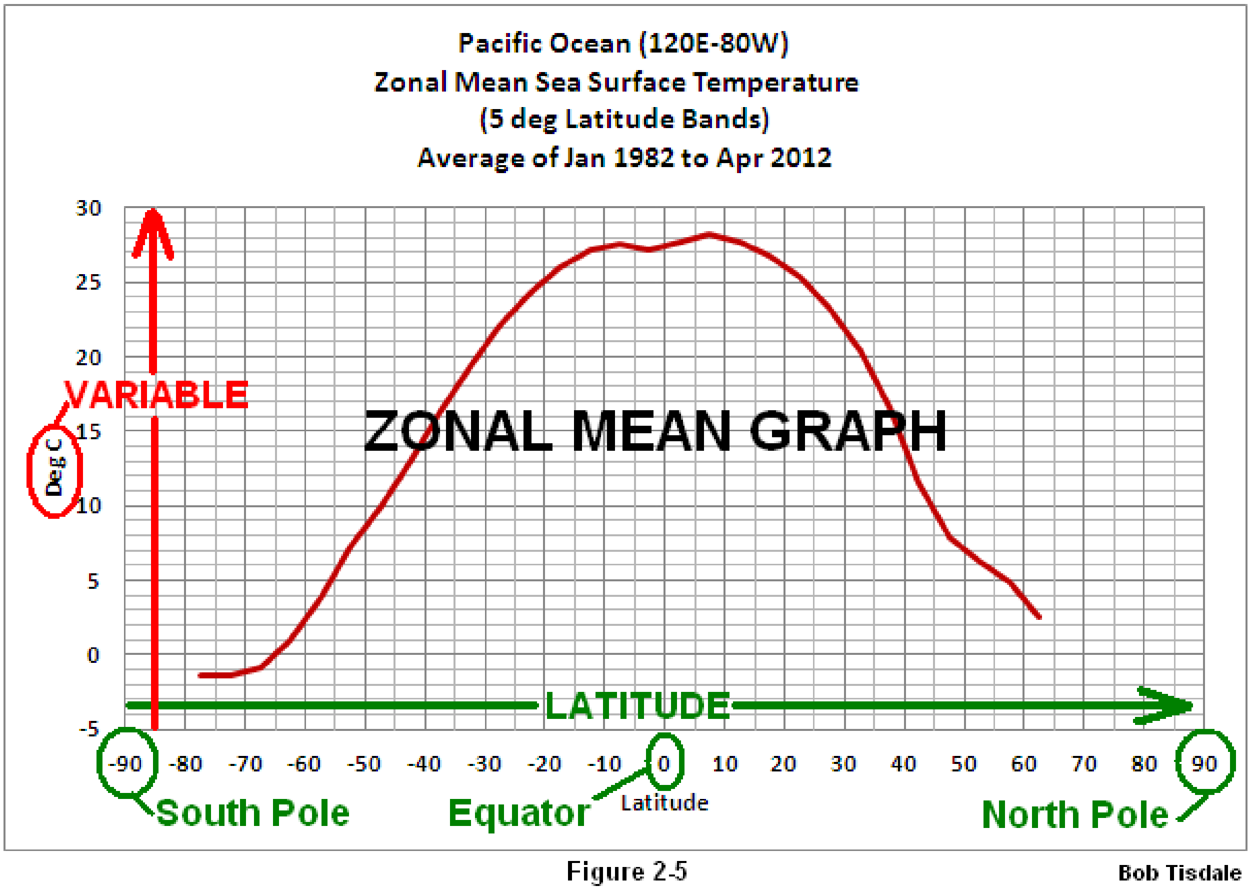

Figure 2-5

I prepared Figure 2-6 to help illustrate what a zonal-mean graph represents. The graph shows the average zonal-mean sea surface temperature for the year 2011; that is, it's the average of the monthly data from January to December, 2011. Below it is the corresponding sea surface temperature map. The graph starts at left with the annual average sea surface temperatures below zero in the Southern Ocean, south of the Pacific and north of Antarctica. It ends at the latitude band of 60N-65N, and that's where the Bering Strait is located. The average sea surface temperatures there for 2011 are approximately 2.5 deg C. Near the equator the sea surface temperatures are much warmer, with the highest sea surface temperatures being a little more than 28 deg C at the latitude band of 5N-10N.

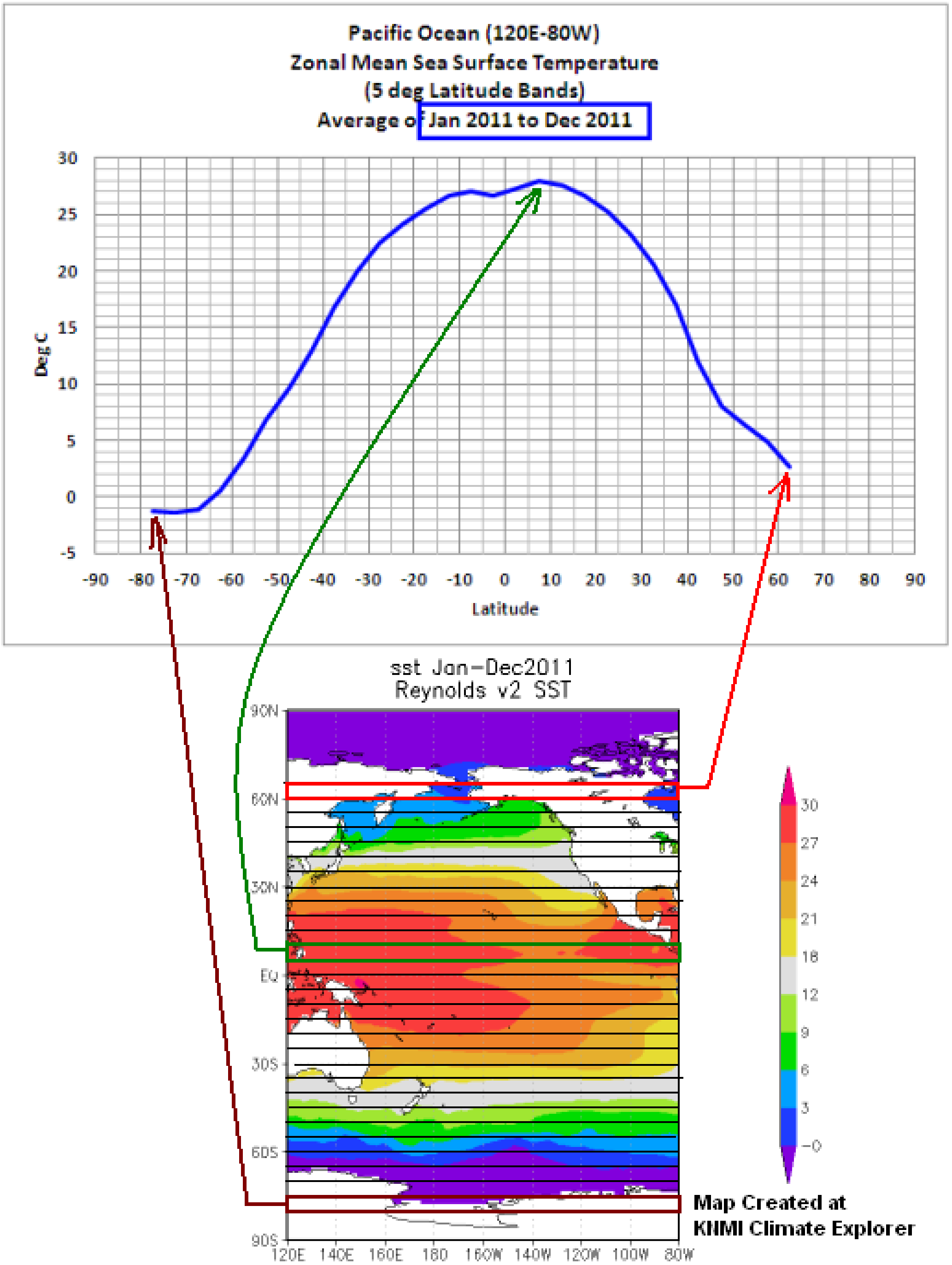

Figure 2-6 Bob Tisdale

In Figure 2-6, I've included horizontal lines in increments of 5-degrees latitude. To create the zonal-mean graph, the sea surface temperature data for each of those segments was downloaded, using the longitudes of 120E-80W for all of them. That is, the data point at 82.5 S on the graph represents the average sea surface temperature (January to December 2011) for the slice with the coordinates of 85S-80S, 120E-80W. The next data point at 77.5S shows the average sea surface temperature for 80S-75S, 120E-80W. The process is repeated in 5 degree increments moving northward until the last point on the graph to the right at 62.5N shows the average sea surface temperature for 60N-65N, 120E-80W.

We'll also be illustrating more than one variable on the zonal-mean graphs, so they will also fit into the comparison graph category.

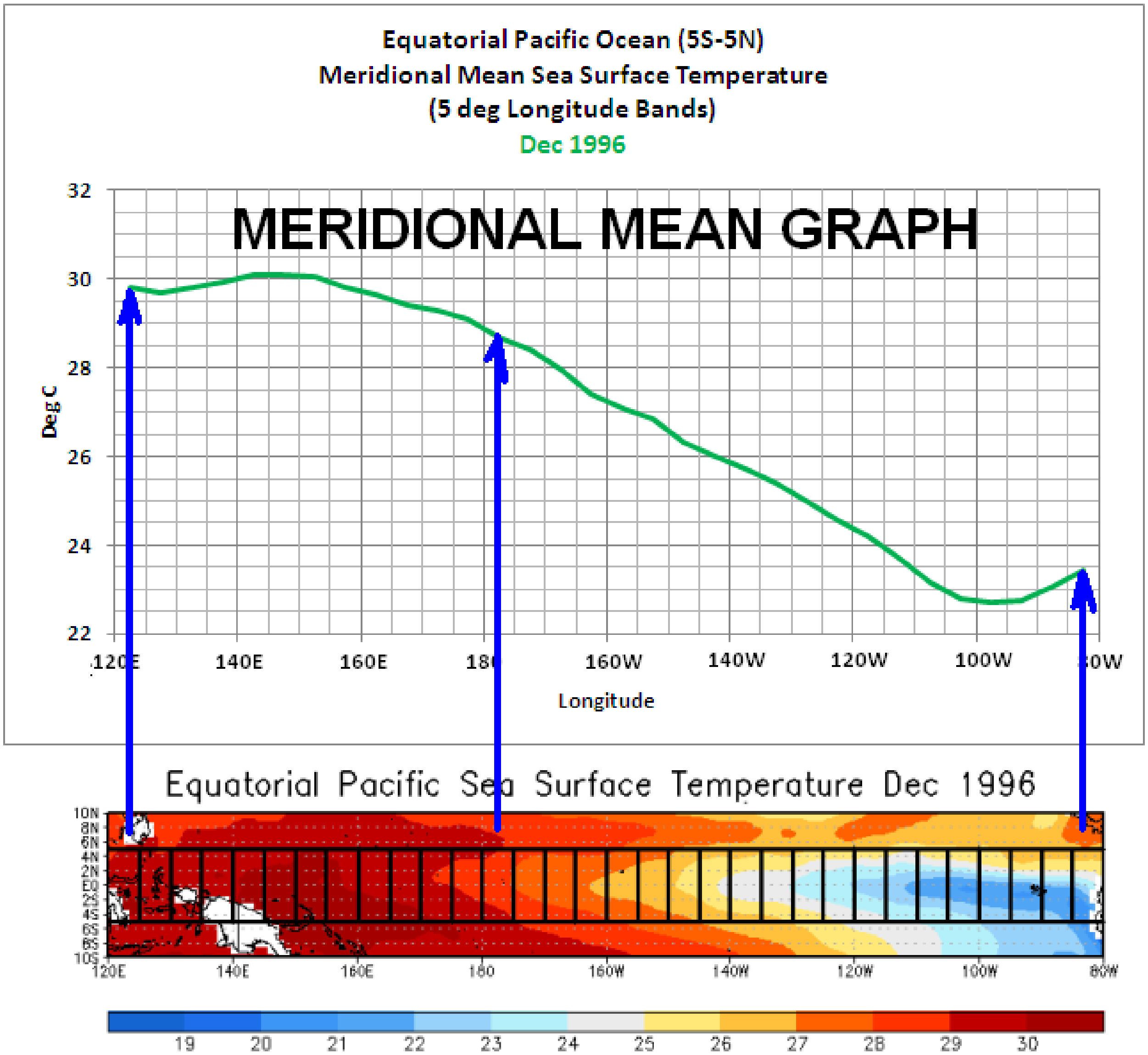

Figure 2-7 Bob Tisdale

Meridional-mean graphs are similar to the zonal-mean graphs, but instead of looking at temperatures on a latitudinal basis, we're looking at them on a longitudinal basis. I'll be using the meridional-mean graphs primarily to show the sea surface temperatures from west to east across the equatorial Pacific, in 5-degree-longitude increments. An example is shown in Figure 2-7, along with the corresponding sea surface temperature map. The vertical axis (y-axis) is once again temperature in degrees C, but in this case the horizontal axis (x-axis) is longitude, starting with 120E to the left (west) and ending with 80W to the right (east). The graph is displaying the average sea surface temperatures for each of the longitude bands across the equator (5S-5N) from Indonesia to the South American coast.

2.3 Linear Trends

The linear trends presented in the book represent the rate at which the variable is changing with time. They are a calculated by the spreadsheet (EXCEL) using a statistical model that's part of the standard software package.

For example, let's look again at a time-series graph of global sea surface temperature anomalies. Refer to Figure 2-8. Some years global sea surface temperature anomalies warmed rapidly and in others they cooled. There's lots of variability from one year to the next. Overall we can see that the global sea surface temperatures have warmed, but we don't really know how fast they are warming. The annual variations are so great that we can't use the two end points in November 1981 and April 2012.

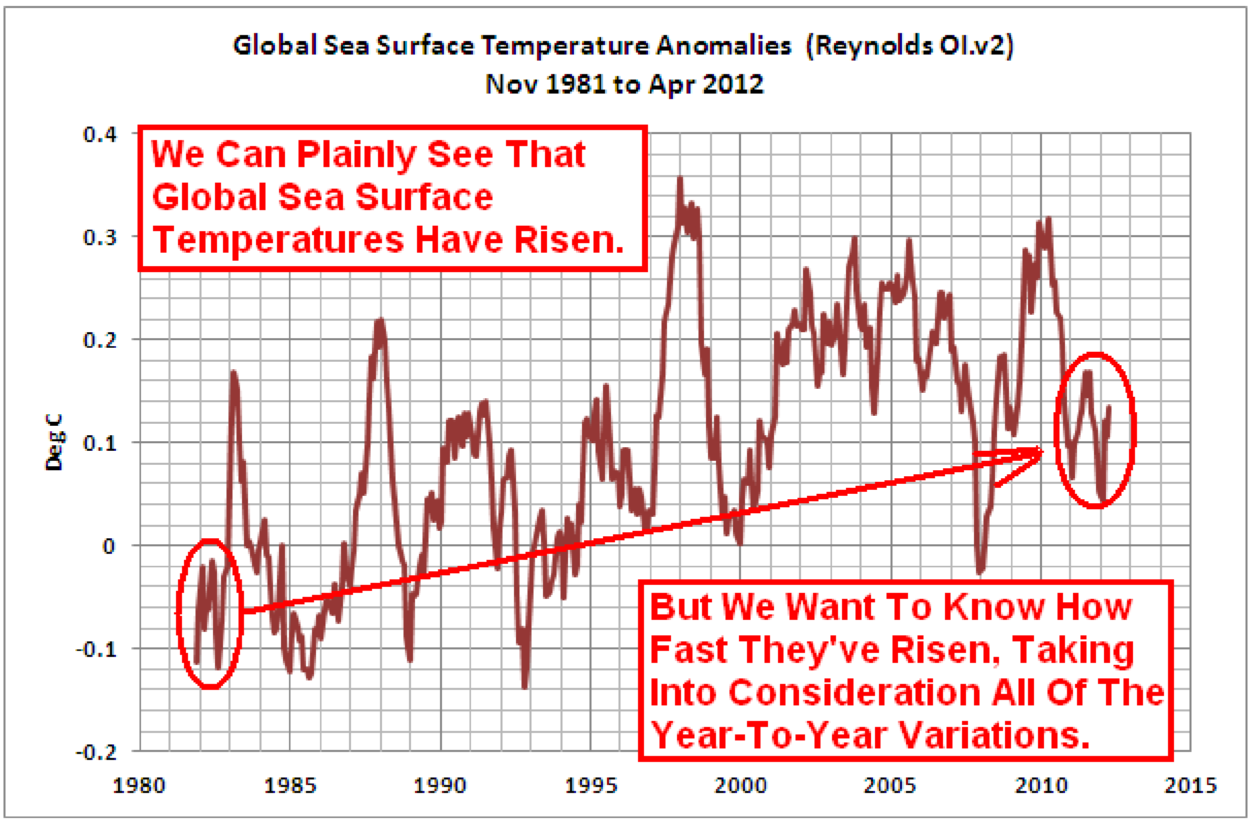

Figure 2-8 Bob Tisdale

Taking all of those variations into account, the linear trend for our example represents the calculated rate at which the global sea surface temperatures warmed during the specific period. Figure 2-9 shows the global sea surface temperature anomalies from November 1981 to April 2012 along with the linear trend line. The linear trend line confirms that the global sea surface temperatures have, in fact, warmed since November 1981. We know this because the linear trend is higher at the end than it is at the beginning. (Note: The spreadsheet added the linear trend line to the graph. It's not something I added.) The spreadsheet also calculated the rate at which the global sea surface temperature anomalies have warmed. That's listed in the upper left-hand corner of the graph. As shown, the spreadsheet program has determined that the global sea surface temperature anomalies have warmed at a rate of 0.084 deg C per decade. The linear trend can also confirm for us that a major portion of the global oceans, the East Pacific Ocean from pole to pole for example, have warmed very little in 30 years. See Figure 2-10. There's a very simple reason for that and we'll confirm the reason later in the book.

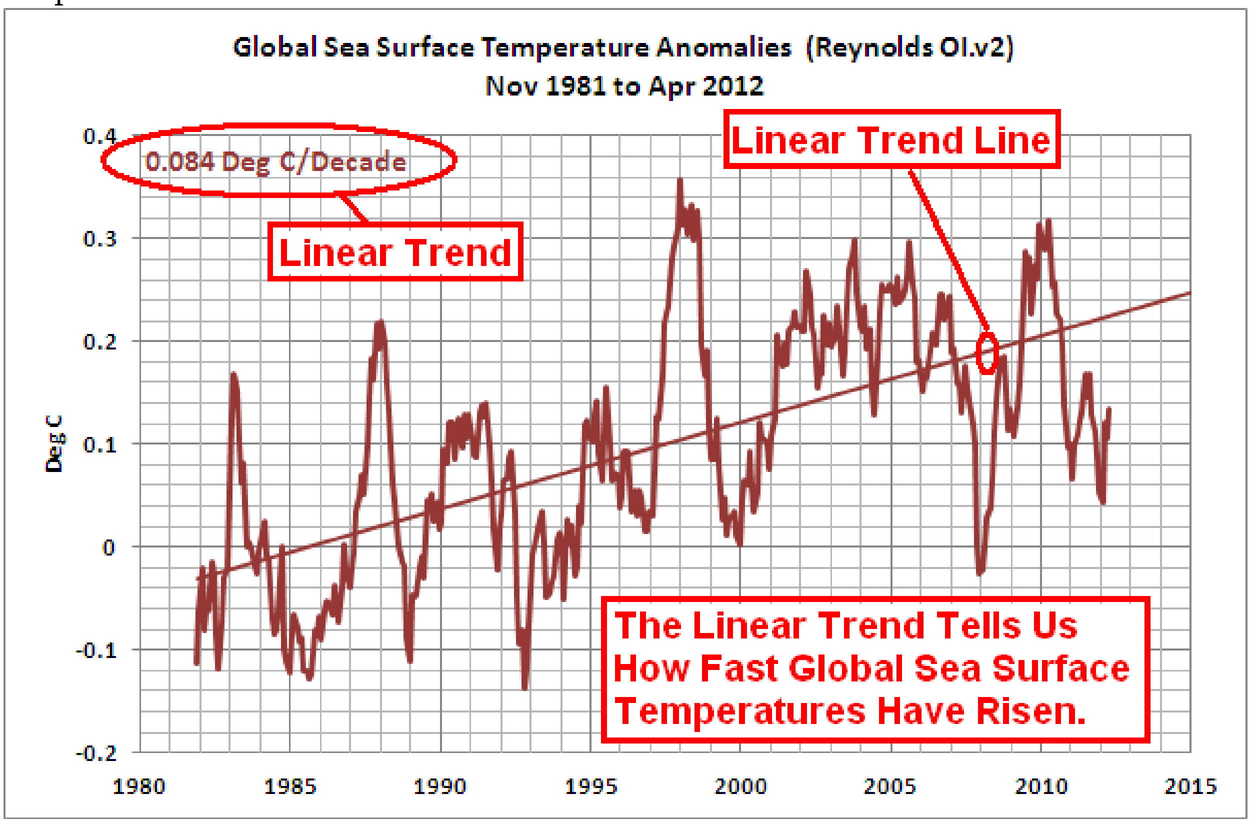

Figure 2-9 Bob Tisdale

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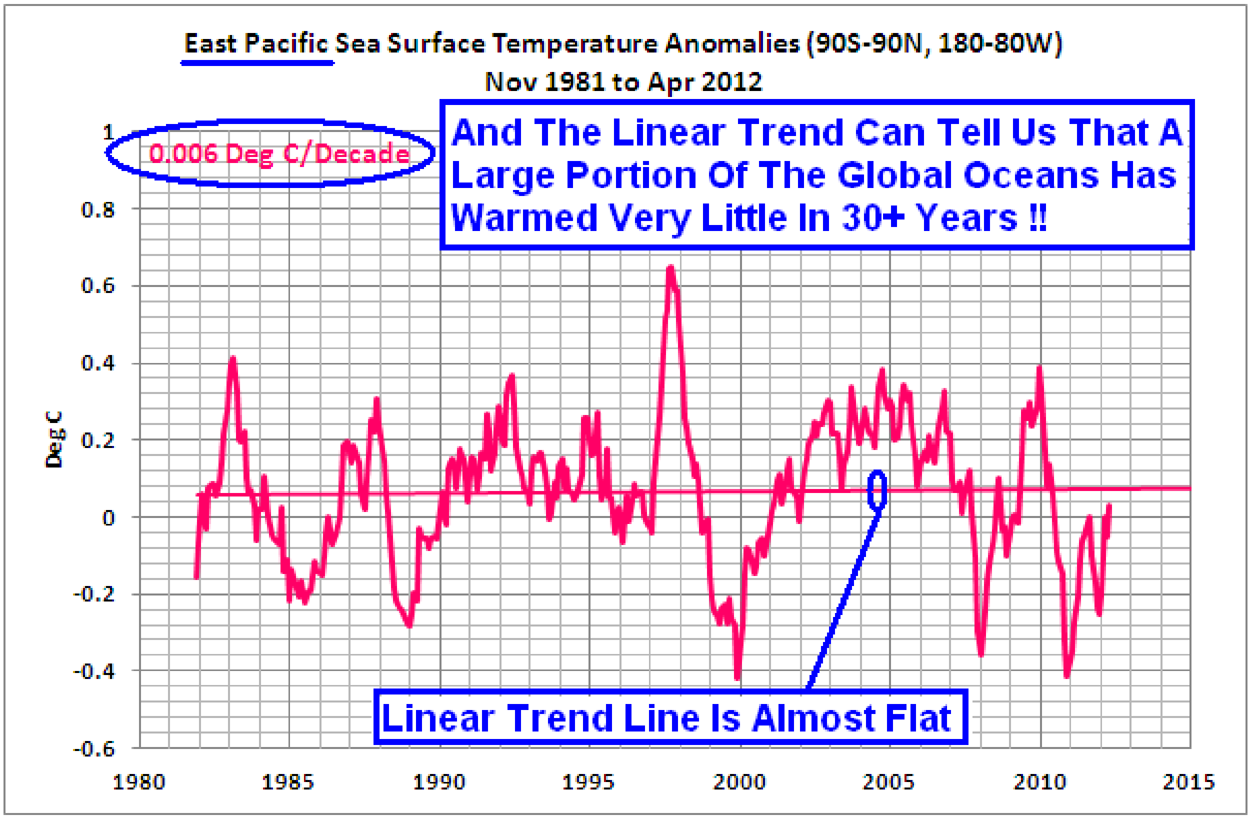

Figure 2-10

Bob Tisdale

2.4 How El Niño and La Niña Events Present Themselves in the Sea Surface Temperature Record

As discussed in Section 1, El Niño events cause warm water from the Pacific Warm Pool to slosh eastward across the surface of the central and eastern equatorial Pacific, and that causes the sea surface temperatures to warm there during an El Niño. On the other hand, during a La Niña, sea surface temperatures in the eastern and central equatorial Pacific cool because more cool water than normal is being upwelled from below the surface there. Therefore, one of the most commonly used references (or indices) for the timing, strength, and duration of El Niño and La Niña events is the sea surface temperature anomalies for an area of the central and eastern equatorial Pacific called the NINO3.4 region. The location and coordinates are shown in Figure 2-11. In the 1990s and early 2000s, scientists were studying which area of the eastern equatorial Pacific had sea surface temperatures that aligned best with the effects of El Niño and La Niña events on global surface temperatures. They decided on the latitudes of 5S and 5N and the longitudes of 170W and 120W for the region. They called it the NINO3.4 region. Trenberth (1997) **The Definition of El Niño** provides a reasonably easy-to-understand discussion of why the NINO3.4 region was selected. No El Niño and La Niña index, more commonly referred to as an ENSO index, can be used to determine all of the effects those events have on global surface temperatures. We'll discuss that later in the book, but the NINO3.4 sea surface temperature anomalies are a frequently used index.

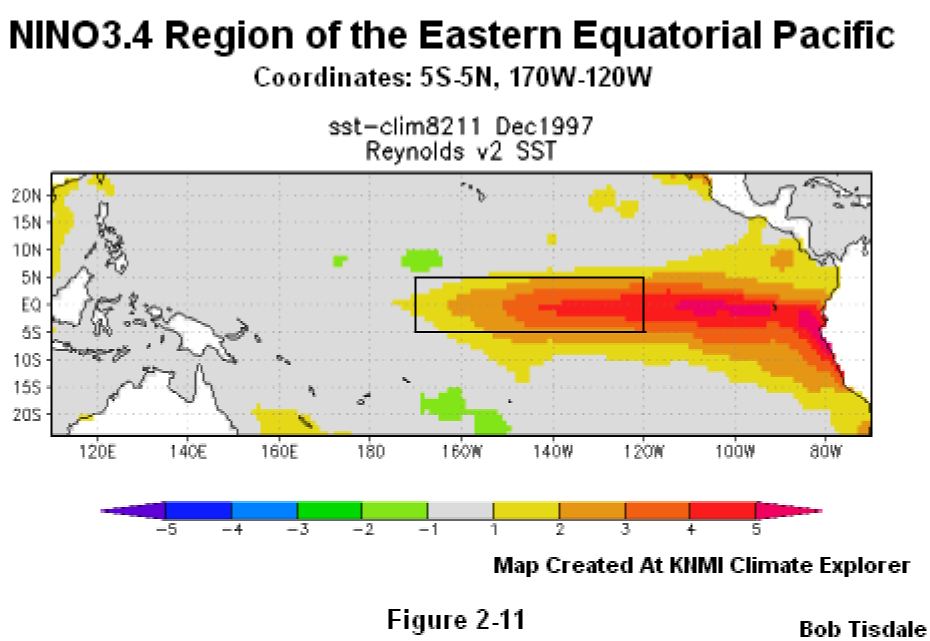

Figure 2-11

The time-series graph in Figure 2-12 shows the sea surface temperature anomalies for the NINO3.4 region, from November 1981 (which is the start of that satellite-based dataset) to April 2012. The horizontal red and blue lines indicate the thresholds of El Niño (+0.5 deg C) and La Niña (-0.5 deg C) conditions. ENSO-neutral (jokingly referred to as La Nada) conditions are said to exist between them. When NINO3.4 sea surface temperature anomalies are warmer than or equal to +0.5 deg C for a specified time period, the **National Oceanic and Atmospheric Administration** (NOAA) considers the El Niño to be an "official" El Niño event, and when NINO3.4 sea surface temperature anomalies are cooler than or equal to -0.5 deg C and remain there long enough, it's an "official" La Niña event.

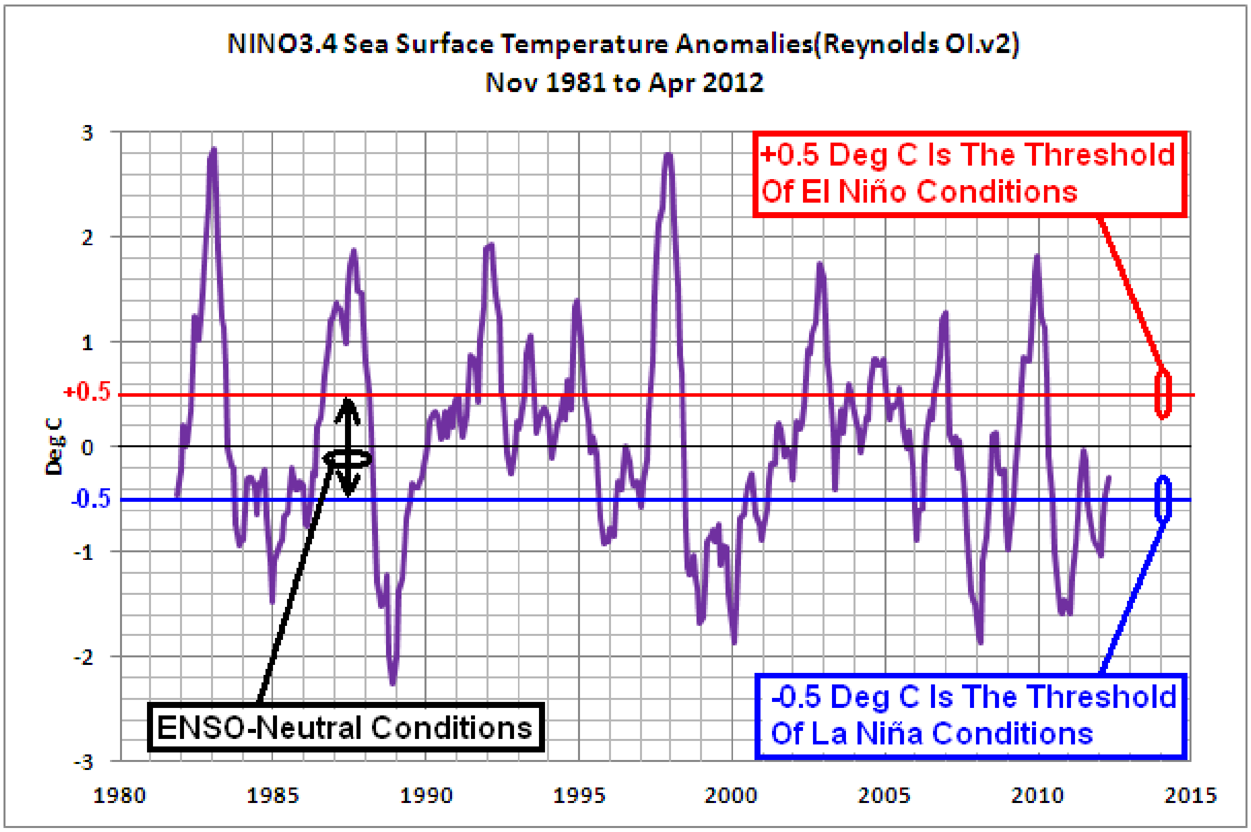

Figure 2-12 Bob Tisdale

A couple of things to point out: El Niño events can be significantly stronger than La Niña events. During the satellite era, the 1982/1983 and 1997/98 El Niño events both created monthly sea surface temperature anomalies approaching 3.0 deg C in the NINO3.4 region. On the other hand, since the start of this dataset, there was only one La Niña (1988/89) that produced NINO3.4 sea surface temperature anomalies cooler than -2.0 deg C. That La Niña followed the only El Niño event to last for 2 years. Also notice how every El Niño event is not followed by a La Niña event. Likewise, every La Niña event does not spawn an El Niño. There can be back-to-back La Niña events, known as double-dip La Niña. All of those odd variations contradict the thoughts that

ENSO is an oscillation or cycle.

Figure 2-13 is a graph of Global sea surface temperature anomalies. The major upward spikes are caused by El Niño events, and most of the major downward spikes are caused by La Niña events. The dip and rebound starting in 1991 was caused by the eruption of Mount Pinatubo in the Philippines. If you were to scroll back up to Figure 2-12, you'll note that that the 1982/83 El Niño is comparable in size to the one that took place in 1997/98 based on the NINO3.4 data. Now note in Figure 2-13 how the global sea surface temperature response to the 1982/83 event is less than the 1997/98 El Niño. The warming spike in 1982/83 looks sickly compared to the 1997/98 El Niño. There's a good reason for that. Outside of the tropical Pacific, the response of global sea surface temperatures to the 1982/83 El Niño was counteracted by the 1982 volcanic eruption of El Chichon in Mexico. The El Niño and La Niña events, as well as the timing of the effects of the two major volcanic eruptions, are shown in the (very busy) Figure 2-14.

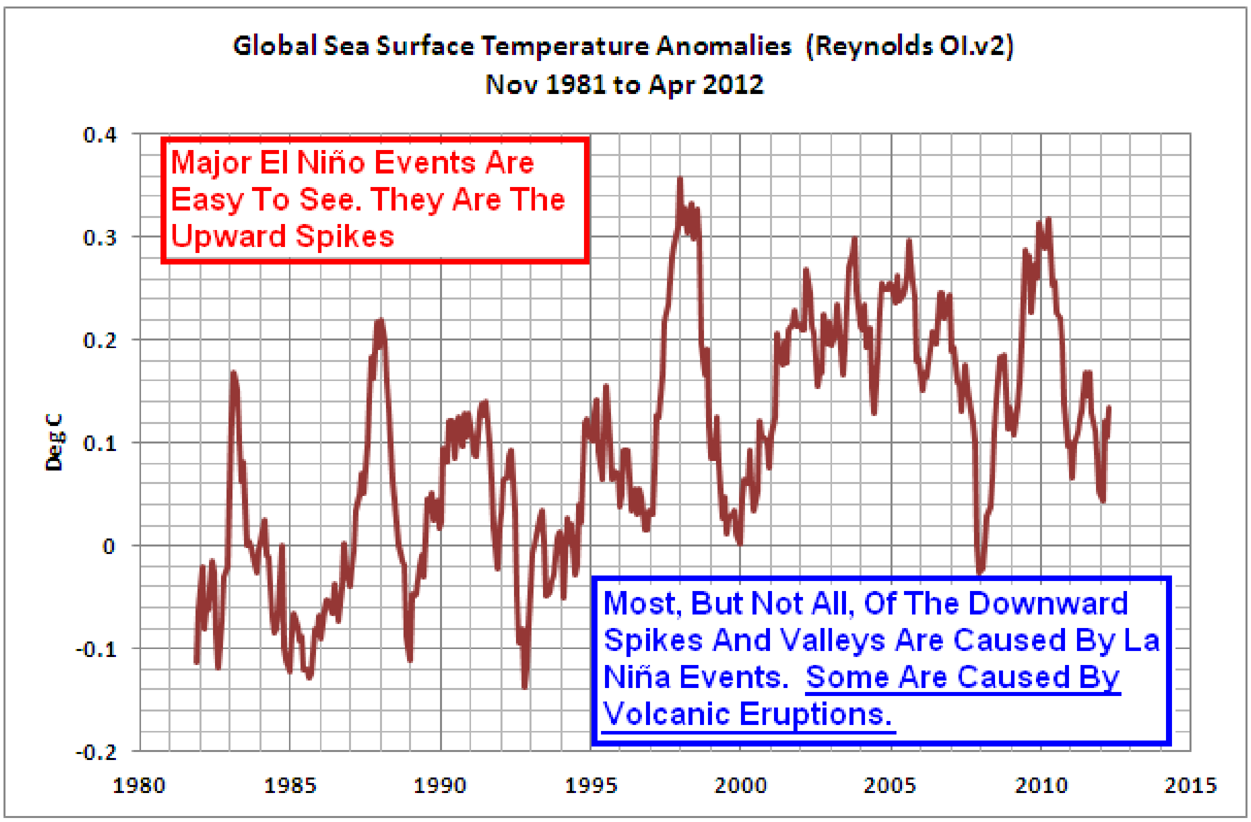

Figure 2-13

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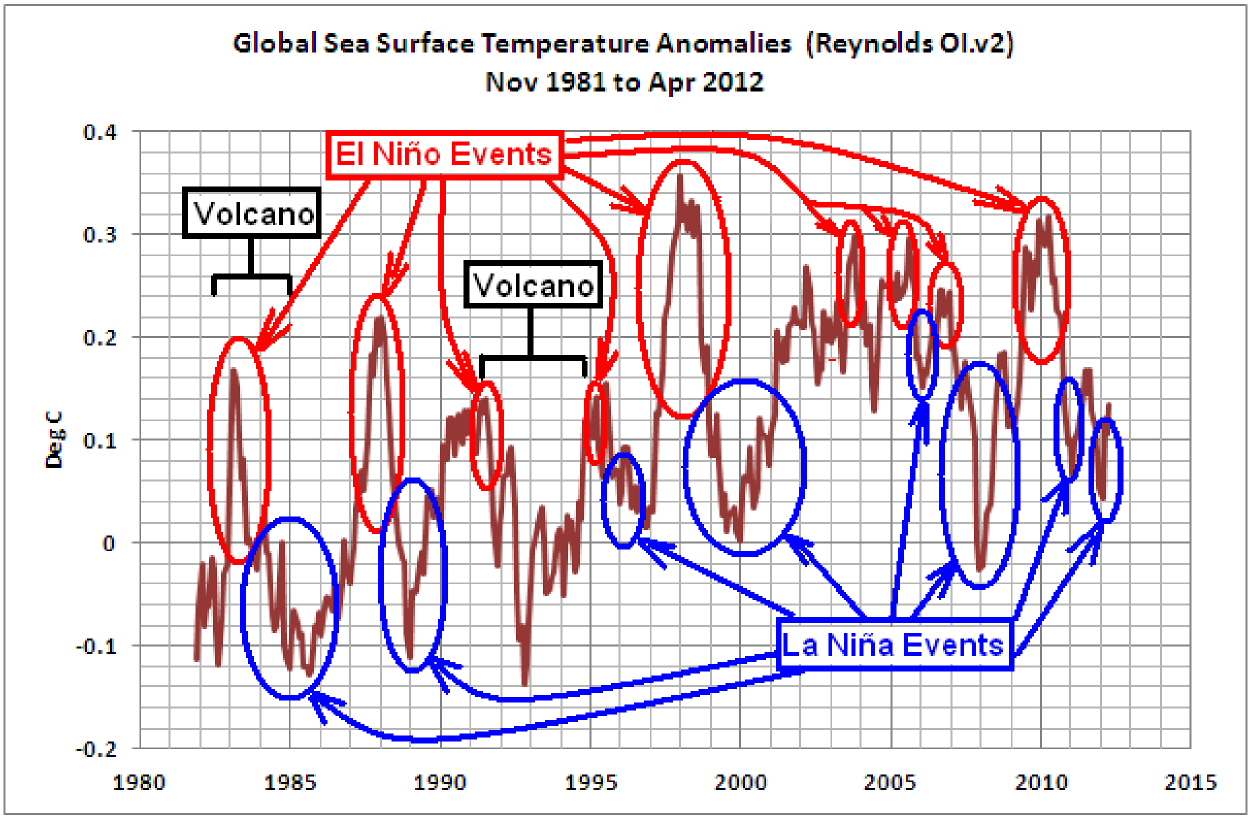

Figure 2-14

Bob Tisdale

We discussed linear trends in Chapter 2.3. Let's take a look at the linear trend of the NINO3.4 sea surface temperature anomalies, Figure 2-15. The trend is clearly negative, meaning the sea surface temperatures of the central/eastern equatorial Pacific have cooled since November 1981. The results, of course, are skewed a little by the data starting during a major El Niño and then ending with a La Niña.

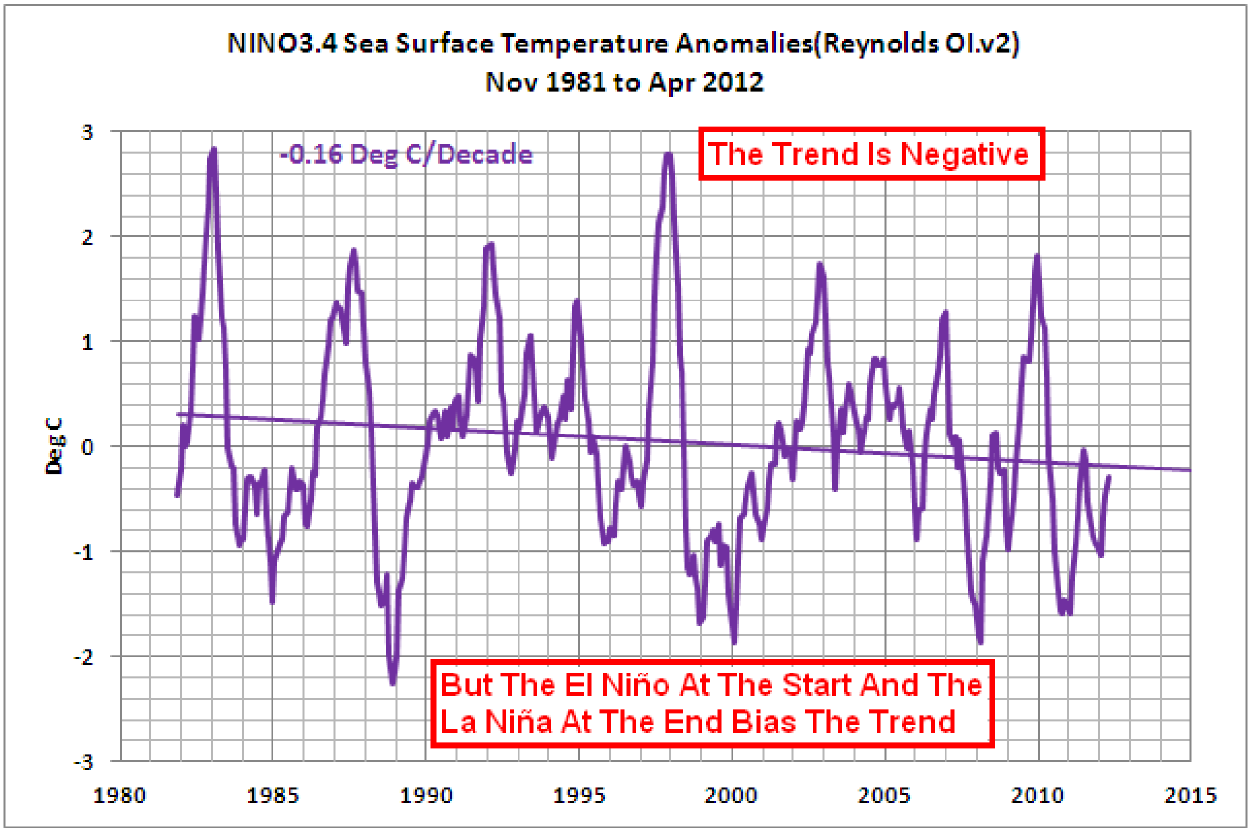

Figure 2-15 Bob Tisdale

To show how flat the trend line is for that dataset, for illustrative purposes only, we can splice the 1982/83 El Niño onto the end, so that we start and end with the same major El Niño event. See Figure 2-16. The modified NINO3.4 data show that NINO3.4 sea surface temperature anomalies have not warmed in 30 years. We'll discuss the reason for this and its implications later in the book.

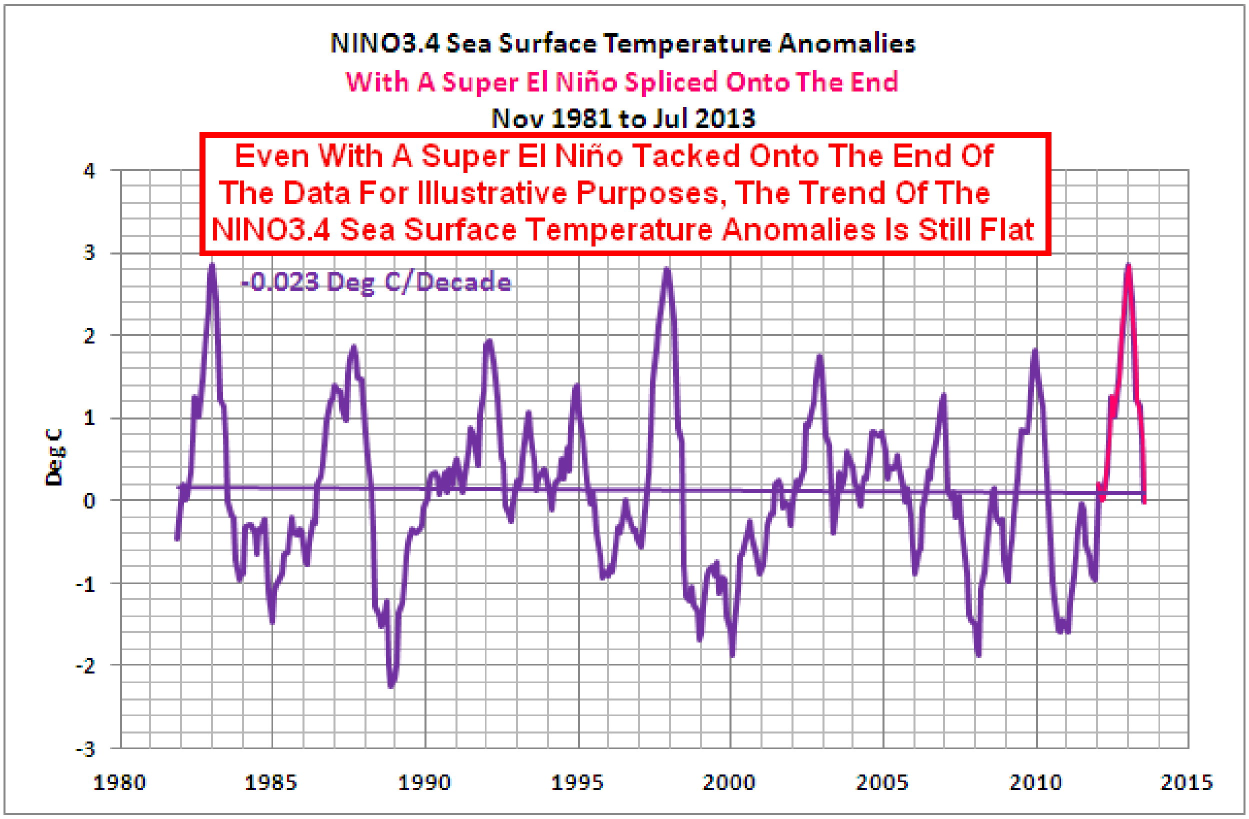

Figure 2-16

Bob Tisdale

2.5 Our Primary ENSO Index is NINO3.4 Sea Surface Temperature Anomalies

The sea surface temperature anomalies of the NINO3.4 region (known as NINO3.4 sea surface temperature anomalies) will be used as our primary reference for the timing, strength and duration of El Niño and La Niña events. Refer again to Figures 2-12, 2-15 and 2-16 above. Somewhere along the line at my blog, I began using purple, a regal color, for NINO3.4 sea surface temperature anomalies, and I've been using it ever since.

Because the variations in the NINO3.4 sea surface temperature anomalies are much greater than many of the other datasets it will be compared to, the NINO3.4 sea surface temperature anomalies will be scaled (multiplied by a factor) to better align the variations of the two datasets. There are some datasets like ocean heat content for the tropical Pacific that cool during an El Niño and warm during a La Niña, which is the opposite of how the NINO3.4 sea surface temperature anomalies react. We can still compare the two datasets, but in those instances I'll invert the NINO3.4 sea surface temperature anomalies by multiplying them by a negative scaling factor. It's another simple way to help display the relationships between variables.

2.6 How ENSO Events Are Presented in the Text

As you may have noticed, when I discuss an El Niño event, I include the start and end years, like 2009/10, or if it was a multiyear ENSO event, I include all years, like the 1986/87/88 El Niño. Other people use one year to describe an El Niño, like 1998. That was the decay year of that El Niño but it was also the evolution year of the 1998/99/00/01 La Niña, so using a single year to describe an ENSO event can be confusing. We'll avoid that confusion.

2.7 On the Use of Anomalies

Surface temperature and the other datasets in this book are presented as anomalies, not as absolute values. To show why we're using anomalies, let's take a look at global sea surface temperatures in absolute form. Figure 2-17 shows monthly global surface temperatures (not anomalies) from November 1981 to November 2011. As you can see, there are wide seasonal swings in global surface temperature every year. When looking at absolute surface temperatures, it's difficult at best to compare the changes in global sea surface temperatures from one year to the next because the annual cycle is so great.

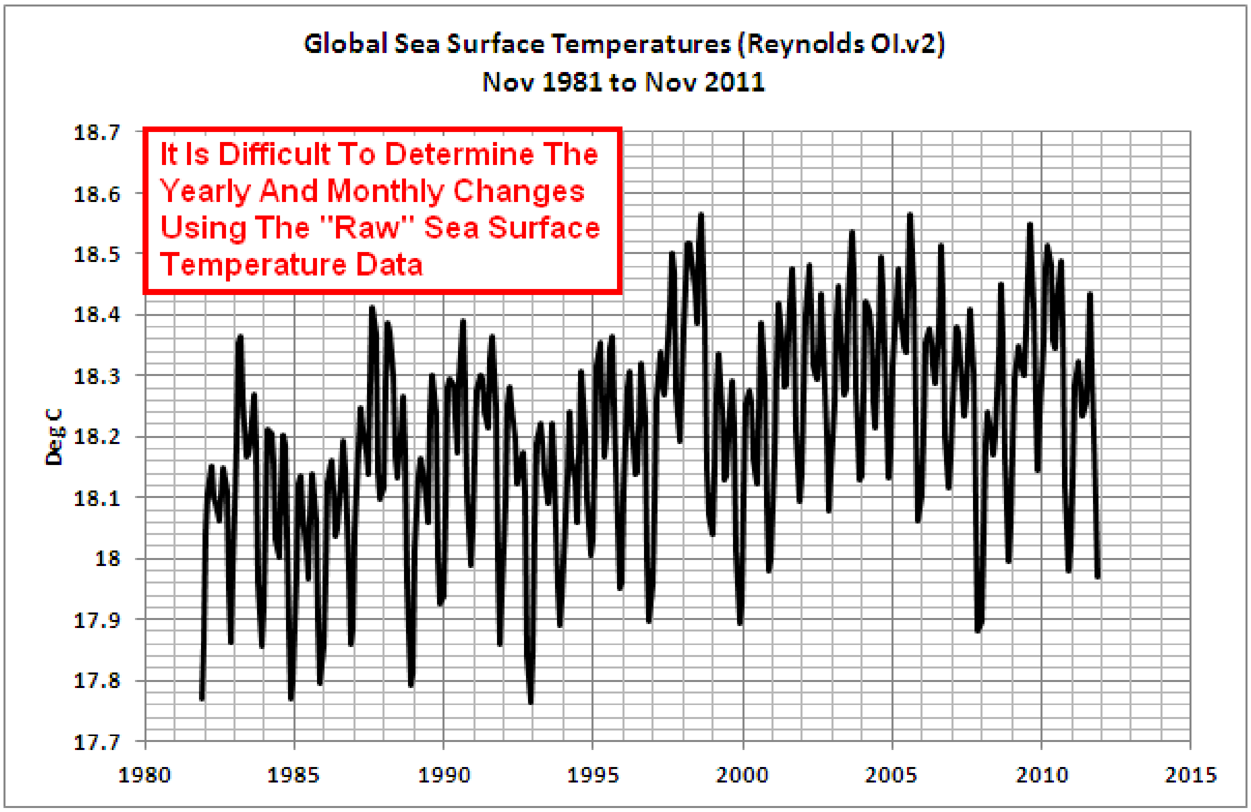

Figure 2-17 Bob Tisdale

Imagine trying to compare the surface temperatures of the Northern and Southern Hemispheres. Refer to Figure 2-18. The seasonal signals in the data from the two hemispheres oppose each other. When the Northern Hemisphere is warming as winter changes to summer, the Southern Hemisphere is cooling because it's going from summer to winter at the same time. Those two datasets are 180 degrees out of phase. The Northern Hemisphere sea surface temperature data is also significantly warmer than the waters of the Southern Hemisphere.

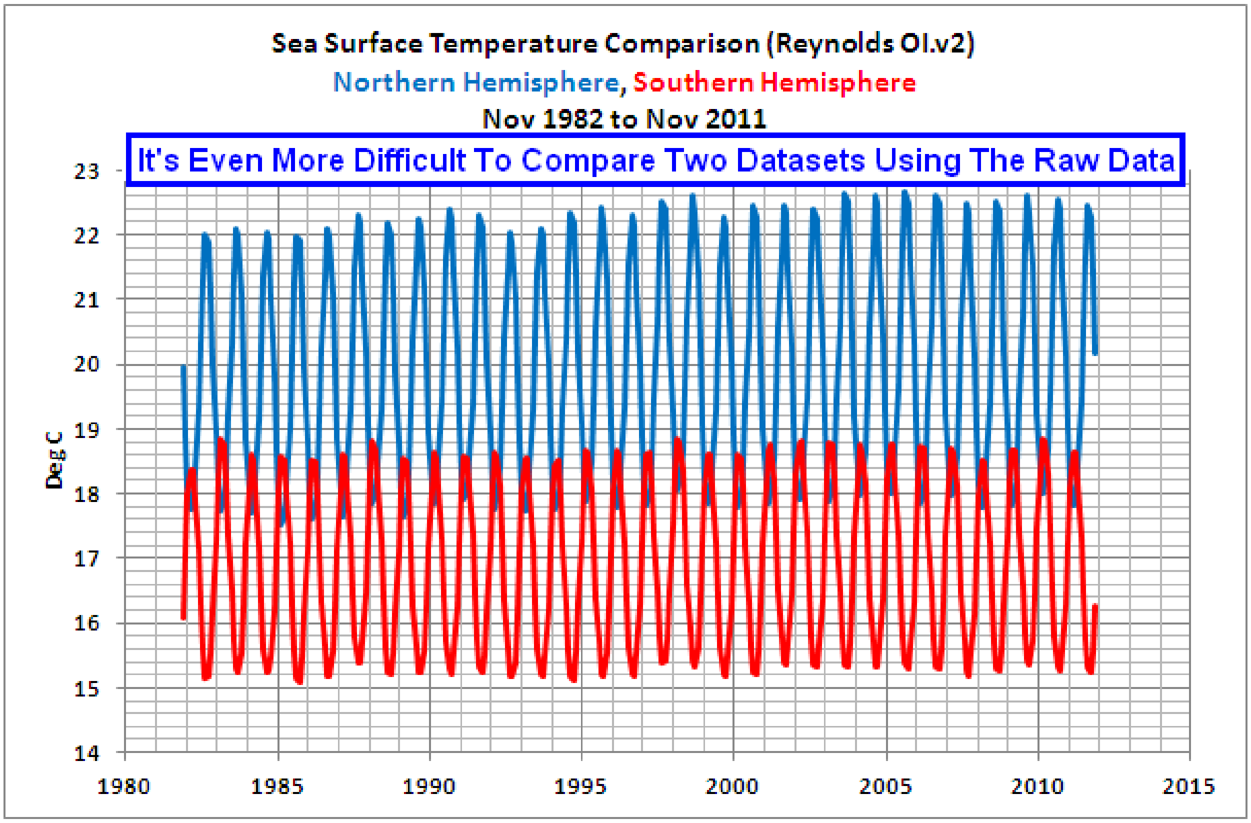

Figure 2-18

Bob Tisdale

After converting those two datasets to anomalies, Figure 2-19, they are much easier to compare. The Northern Hemisphere data definitely warmed more than the Southern Hemisphere. That was very difficult to see with the “raw” data.

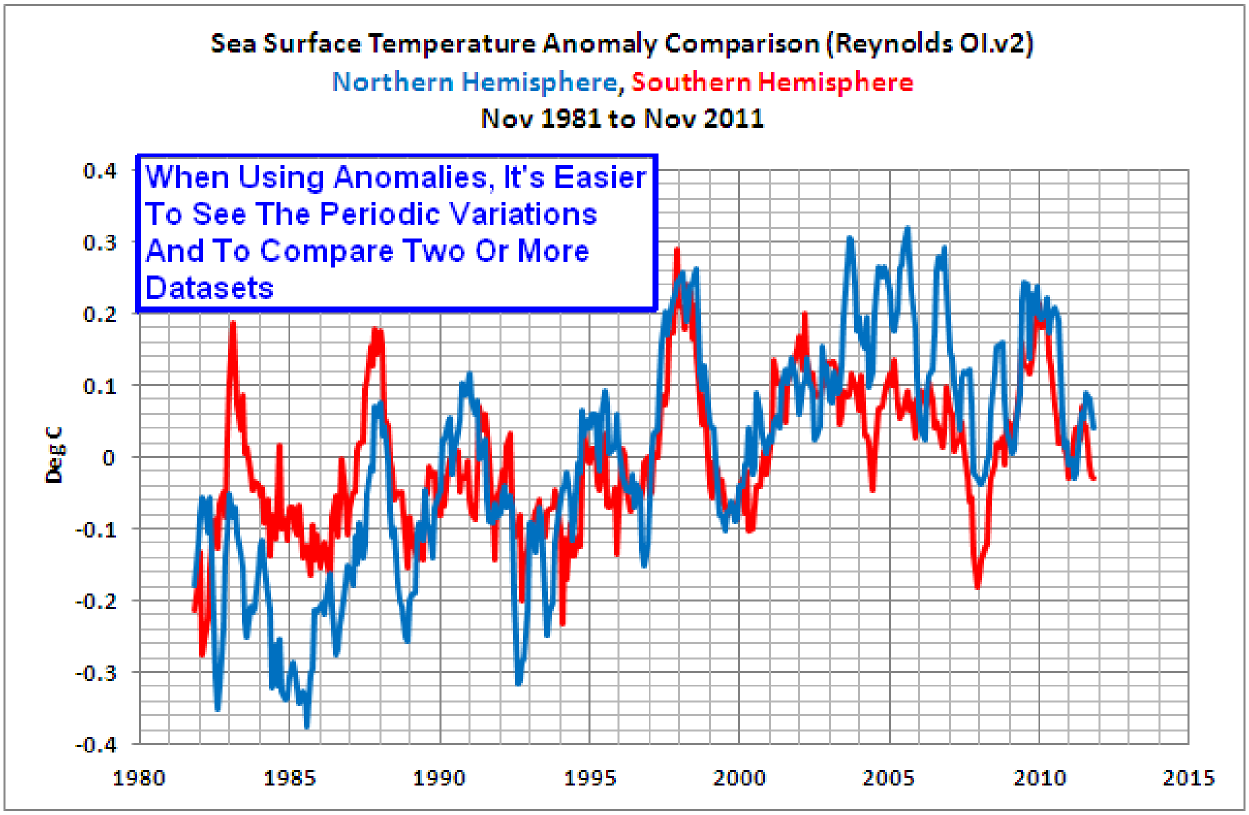

Figure 2-19 Bob Tisdale

2.8 Converting Monthly Absolute Data to Anomalies

To convert the absolute surface temperatures shown in Figure 2-18 to anomalies presented in Figure 2-19, first a reference period must be chosen. The reference period is often referred to as the "base years" for the anomalies. For this example, we'll use 1982 to 2011. The sea surface temperatures for all the Januaries from 1982 to 2011 are averaged. Same thing for the Februaries and so on through Decembers; they are averaged separately for the respective months. To determine the January 1982 sea surface temperature anomaly, the average January sea surface temperature is subtracted from the observed January 1982 temperature. Because the January 1982 surface temperature is below the average temperature of the base years, the anomaly is a negative value. If it had been higher, the anomaly would have been positive. The process continues as February 1982 is compared to the average temperature for Februaries, and so on through November 2011. It's easy to create a spreadsheet to do that, but, thankfully, data source websites like the **KNMI Climate Explorer** and **NOAA NOMADS** do all of those calculations for you, so you can save a few steps. Nonetheless, that's how they're determined and what they represent.

Let's switch to the NINO3.4 region for the example in Figure 2-20. The base year sea surface temperature anomalies show an annual cycle. The average maximum sea surface temperature for that region during the base period of 1971 to 2000 was in May and the minimum was in December. Also shown are the actual sea surface temperatures (absolute, not anomalies) for the period of January 1995 to January 2005. NINO3.4 sea surface temperatures warmed well above the seasonal "normals" during the 1997/98 El Niño. As discussed above, anomalies are determined by subtracting the base period values from the actual sea surface temperatures. The differences, the sea surface temperature anomalies for the NINO3.4 region, are shown in Figure 2-21.

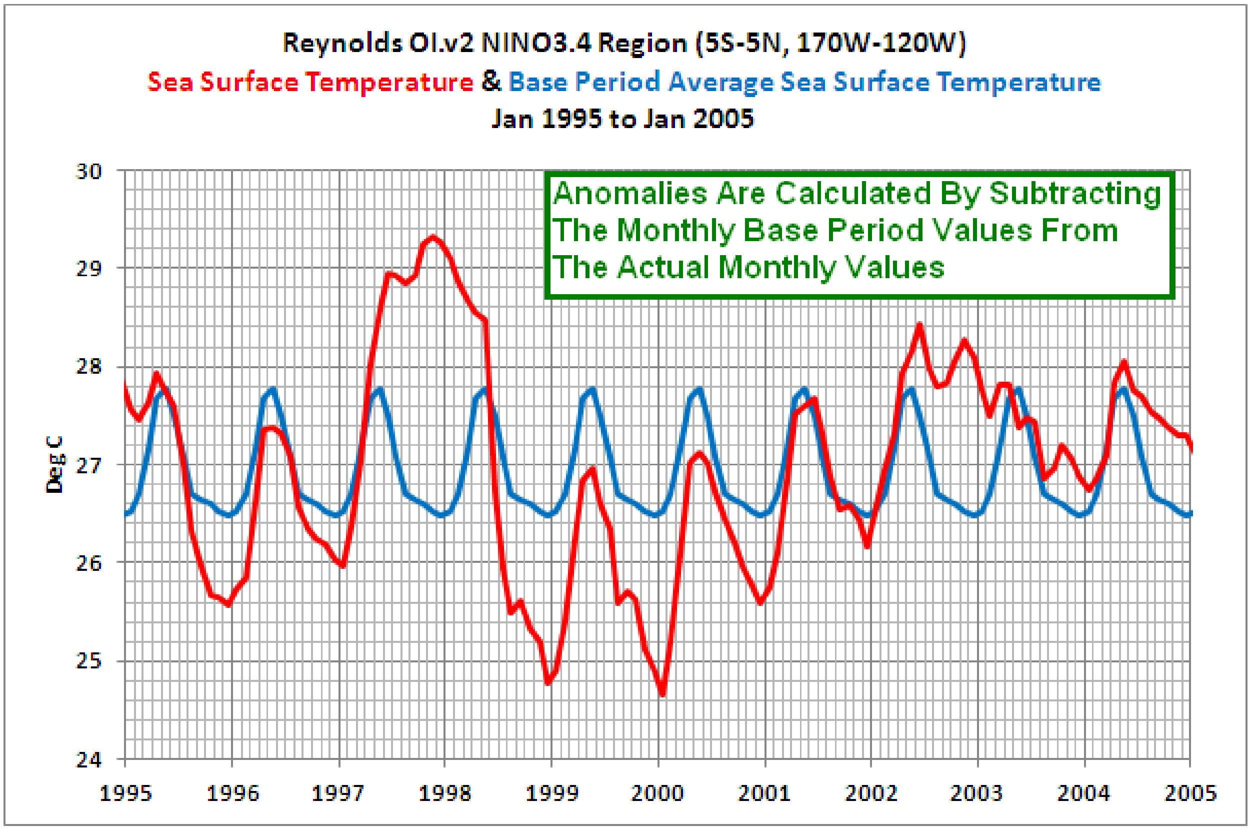

Figure 2-20 Bob Tisdale

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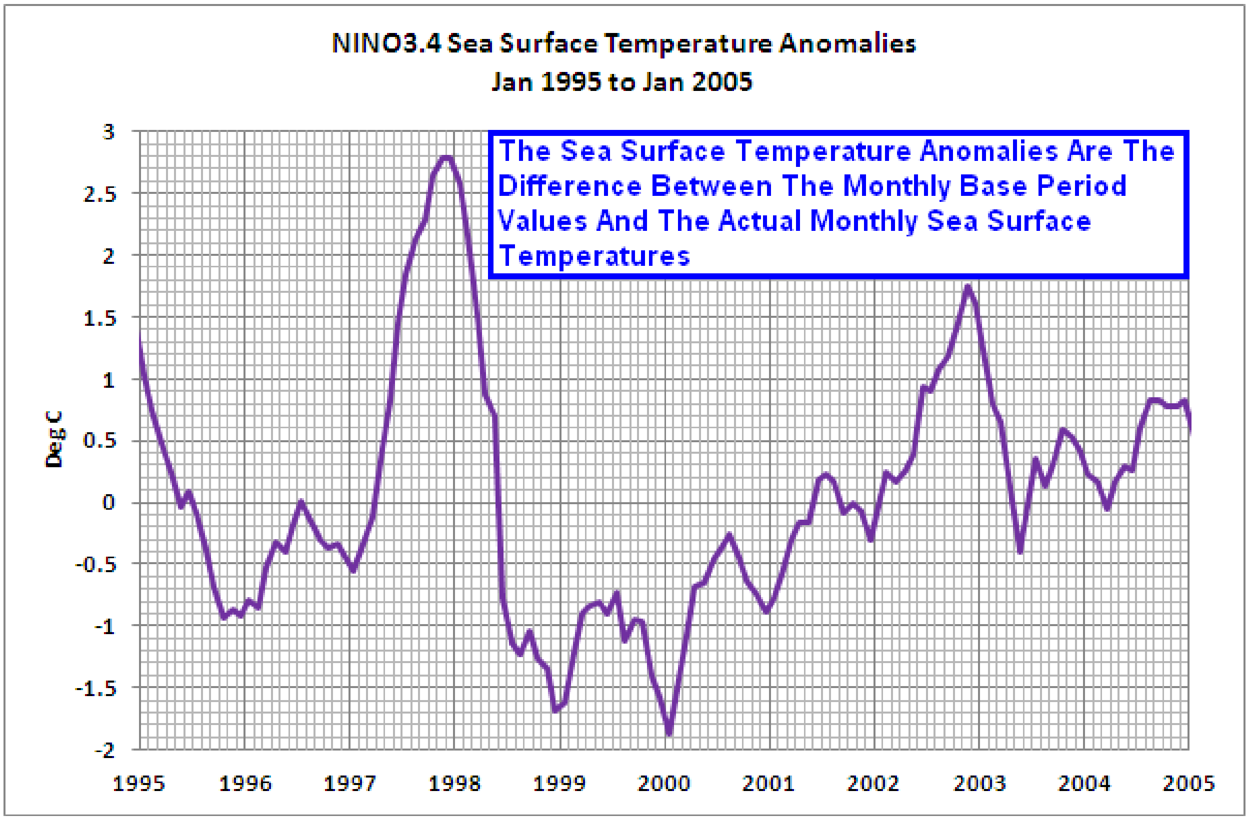

Figure 2-21 Bob Tisdale

Please don't assume the annual cycle in the base period temperatures around the globe are similar to that of the NINO3.4 region. Due to seasonal variations, Northern and Southern Hemisphere cycles oppose each other, as shown in Figure 2-22. The seasonal cycle in base period temperatures for different parts of tropical Pacific can be quite different. The cycles in base year temperatures for the Pacific Warm Pool (20S-20N, 120E-165E) and the NINO3.4 region (5S-5N, 170W-120W) are shown in Figure 2-23, as an example.

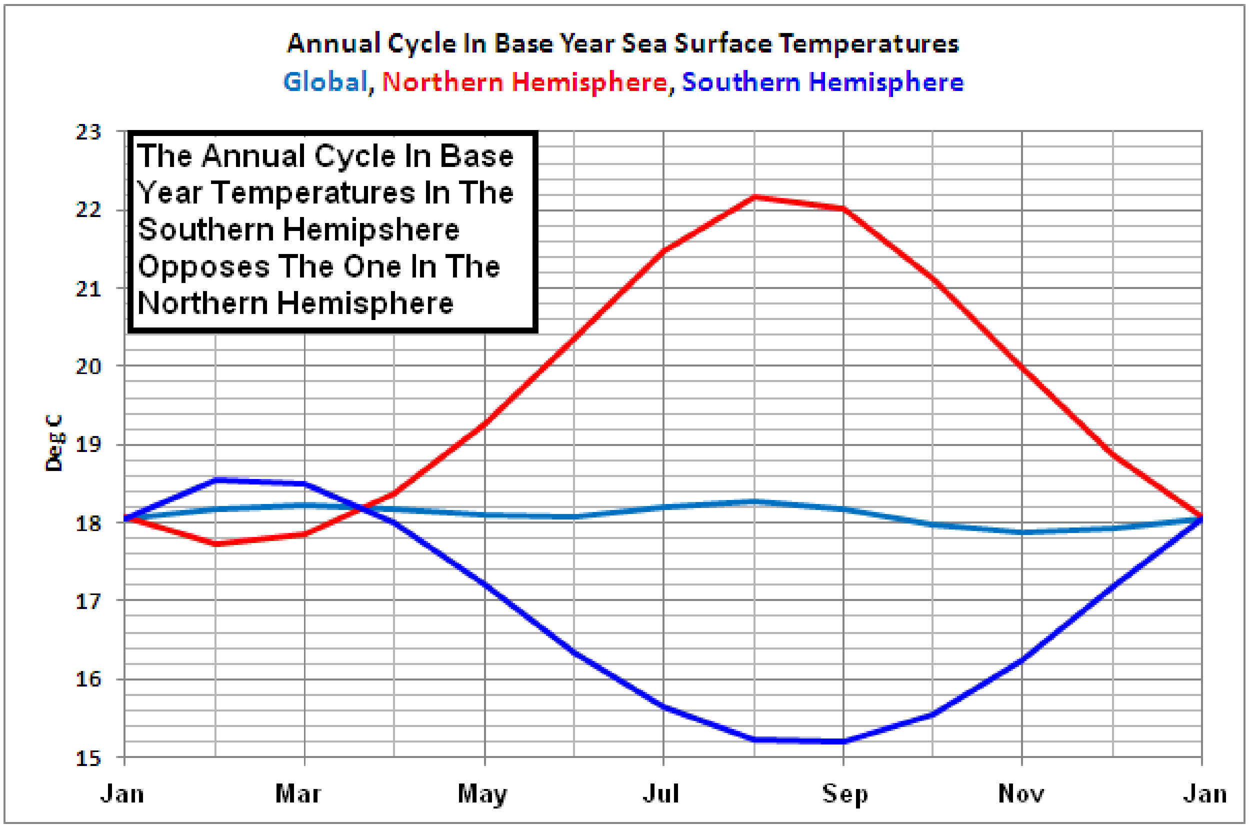

Figure 2-22

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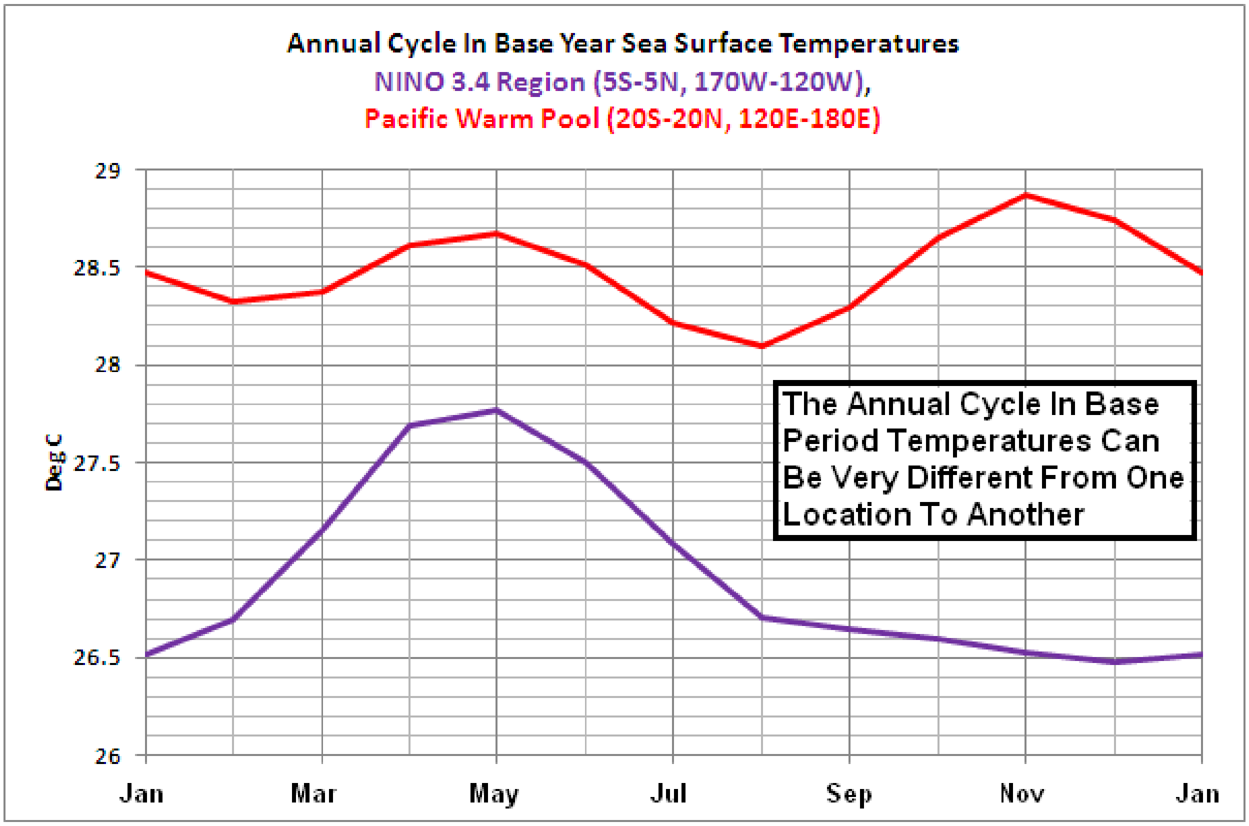


Figure 2-23

Bob Tisdale

2.9 Using the Model Mean of the IPCC's Climate Models

We'll be comparing in a few instances the satellite-based sea surface temperature anomalies and the computer simulations of it. Those computer simulations are based on the climate models used by the IPCC in their 4th Assessment Report (AR4). I've also included the outputs of the climate models that have been prepared for the IPCC's upcoming 5th Assessment Report (AR5) in some chapters. The outputs of those computer simulations are also available through the KNMI Climate Explorer. The model mean is presented, and by model mean, we're referring to the multi-model ensemble mean (the average of all of the simulations by all of the climate models) that are being forced by natural and anthropogenic (manmade) factors. However, we will not be including all of those individual ensemble members that the IPCC normally presents in its comparison graphs. A reproduction of one is shown as an example in Figure 2-24, with the individual ensemble members shown as yellow curves.

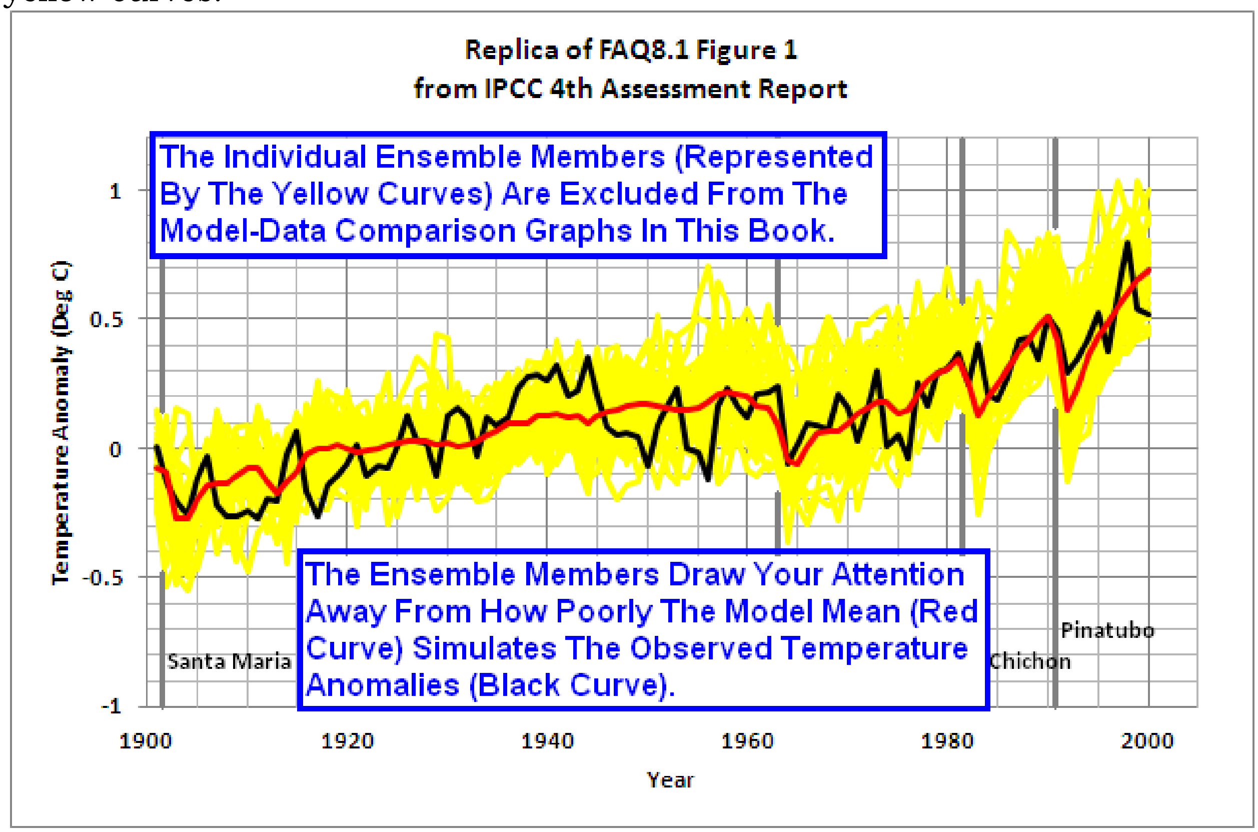


Figure 2-24 Bob Tisdale

Why are we using the model mean and not the individual simulations (ensemble members)?

First we have to determine why climate scientists use more than one model run when they simulate global climate.

The **National Center for Atmospheric Research (NCAR)**'s **Geographic Information Systems (GIS) Climate Change Scenarios** webpage has a relatively easy-to-read description. This quote appears on their **Frequently Asked Questions webpage** (my boldface):

> *Climate models are an imperfect representation of the earth's climate system and climate modelers employ a technique called ensembling to capture the range of possible climate states. A climate model run ensemble consists of two or more climate model runs made with the exact same climate model, using the exact same boundary forcings, where the only difference between the runs is the initial conditions. An individual simulation within a climate model run ensemble is referred to as an ensemble member. The different initial conditions result in different simulations for each of the ensemble members due to the nonlinearity of the climate model system. Essentially, the earth's climate can be considered to be a special ensemble that consists of only one member.* ***Averaging over a multi-member ensemble of model climate runs gives a measure of the average model response to the forcings imposed on the model.*** *Unless you are interested in a particular ensemble member where the initial conditions make a difference in your work, averaging of several ensemble members will give you best representation of a scenario.*

Let me try to put that in non-technical terms: Climate models simulations do not duplicate how Earth's climate actually works. Because of this, the climate modelers use multiple computer runs, and the collection of those model runs is called an ensemble, with the individual model members called ensemble members. The climate scientists/modelers believe, if they perform multiple simulations with the same inputs and then average the outputs, the average will provide a good measure of how the Earth's climate in the models responds to the forcings that serve as inputs to the models. It makes sense, except for the fact that the models show no skill at being able to simulate global or regional climate, but that's another story—which we will discuss and illustrate later.

Now, we'll refer to a Climate Scientist's description of why the model mean has value for our discussion and why the individual ensemble members do not. The following is the best description I can find on the internet. A quick introduction is due at this point: Dr. Gavin Schmidt is a climatologist and climate modeler at the NASA Goddard Institute for Space Studies—GISS. He is also one of the regular contributors at the website **Real Climate**. As they say in their header, "RealClimate, Climate science from climate scientists." There are a good number of other well-respected climate scientists who serve as contributors to that blog.

On the thread of the RealClimate post **Decadal predictions,** a visitor asked the very basic question, "If a single simulation is not a good predictor of reality how can the average of many simulations, each of which is a poor predictor of reality, be a better predictor, or indeed claim to have any residual of reality?"

Gavin Schmidt replied:

> *Any single realisation can be thought of as being made up of two components – a forced signal and a random realisation of the internal variability ('noise'). By definition the random component will [be] uncorrelated across different realisations and when you average together many examples you get the forced component (i.e. the ensemble mean).*

Gavin Schmidt used "noise", where the earlier NCAR description discussed variations of the individual ensemble members "due to the nonlinearity of the climate model system". Noise is much quicker to write. He also used "realisation" in place of "ensemble member".

Note also, when Gavin Schmidt is discussing "*random realisation of the internal variability ('noise')*", he's not discussing the internal variability of the real world; he's discussing the internal variability of the models, which may not have any relationship to the real world. Keep in mind, as described earlier, "*Climate models are an imperfect representation of the earth's climate system.*"

To paraphrase Gavin Schmidt's comment, the individual ensemble members are unnecessary information. The model mean, which is the average of the ensemble members, represents the "forced component" of the anthropogenic and natural factors that serve as inputs to the climate models.

In other words, the model mean is the IPCC's best-guess estimate of the modeled response to the natural and anthropogenic forcings.

It's an important point, and we need to make sure it's understandable, so let's reword that. With the model mean, the IPCC presented what they believe to be the best estimate of how the 20th Century global surface temperatures warmed that's available from the models, and that model-based estimate was produced by their best estimate of the natural and anthropogenic factors (forcings) that served as inputs.

The model mean portrays how the IPCC believes climate should respond (projection), or should have responded (hindcast), to the natural and manmade factors they used as inputs to the climate models.

There are two grand assumptions, therefore. The first assumption is that the climate models provide an accurate representation of Earth's climate, but they've already noted that they are not. The second assumption is that the forcings used as inputs are accurate representations of the factors that influence climate on Earth. Keep those assumptions in mind.

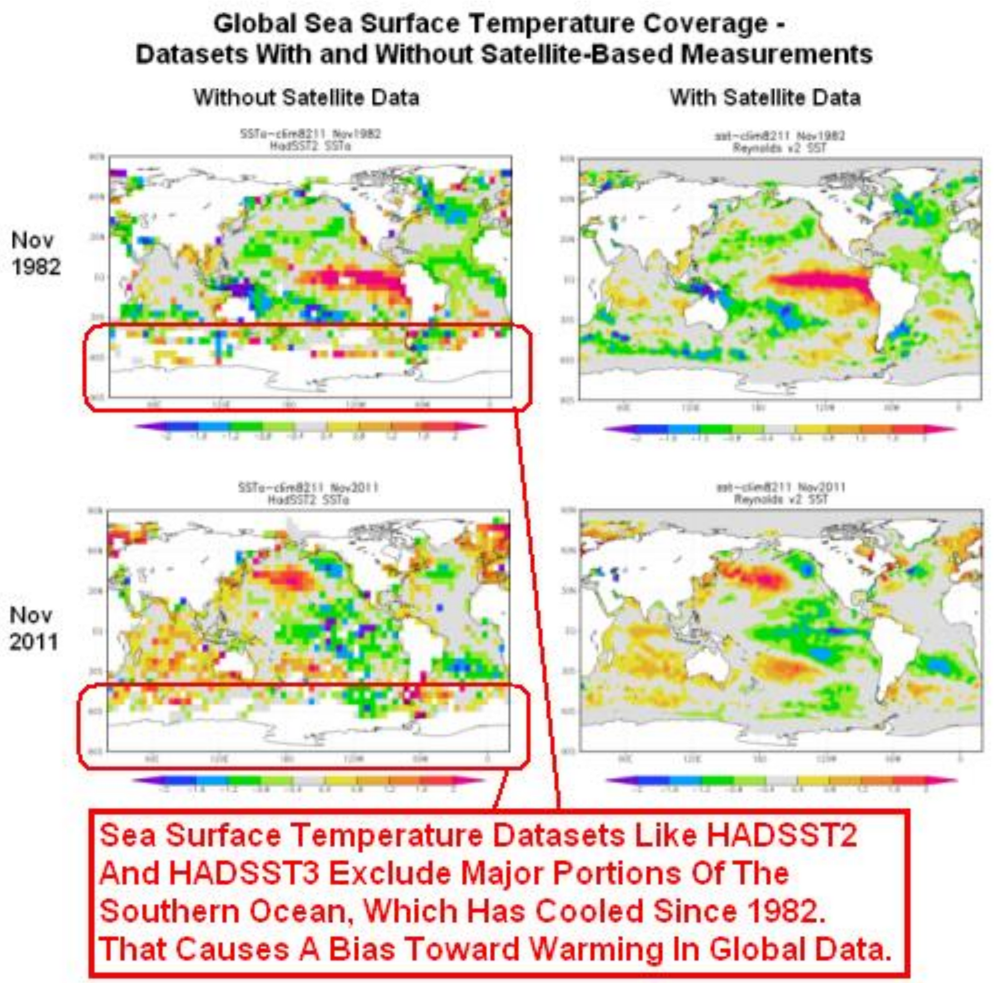
2.10 Why We'll Be Using Satellite-Based Sea Surface Temperature Data

The surface of the Earth is covered mostly by water, not earth. Whoever named our planet must have had a limited view of it. Oceans, lakes, rivers, and streams make up about 70% of its surface. Therefore, the measured surface temperatures of the global oceans are important and understanding how they responded, if at all, to anthropogenic greenhouse gases is equally important.

The measured **surface** temperature of the oceans is known as Sea Surface Temperature. Scientists use the initials SST in papers and reports, but we'll avoid as many acronyms as we can to make this book easy to read and understand.

Sea surface temperature data has many advantages over land surface data. The first is the coverage of the sampling. Satellites have been used to measure sea surface temperatures since the early 1980s, and since they were introduced, they have sampled the sea surface temperatures in all of the ocean basins, including the Arctic Ocean and the Southern Ocean that surrounds Antarctica. Before the satellite-era, scientists had to rely on sea surface temperature measurements from ships and strategically placed buoys. Unfortunately, the buoys and ship measurements did not cover all of the global oceans.

There are still some sea surface temperature datasets that do not use satellite data; they continue to rely only on the readings from buoys and ships. Figure 2-25 provides maps that compare the coverage of the Hadley Centre's HADSST2 data (left-hand maps), which does not use satellite data, to the satellite-based dataset (right-hand maps) from NOAA known as Reynolds Optimum Interpolation Sea Surface Temperature, version 2 (OI.v2). Areas without sea surface temperature data are shown in white. The top cells are for the month of November 1982 and the bottom cells are for November 2011. As shown in the HADSST2 maps, there are vast portions of the global oceans without buoy- and ship-based data even to this day, especially south of 60 degrees south latitude. The sea surface temperature for that portion of the global oceans is very important to include. Why? Since 1982, the sea surface temperature anomalies of the Southern Ocean have cooled. Incomplete datasets like HADSST2 and its recently released replacement HADSST3 do not fully sample the portion of the global oceans that is cooling.



Maps Created At KNMI Climate Explorer

Figure 2-25

Bob Tisdale

You might wonder why scientists would not add satellite-based sea surface temperature measurements to their datasets. Some have. The Hadley Centre also produces a long-term sea surface temperature dataset called HADISST, which includes satellite data starting in the 1980s. Then again, the UK Met Office chooses not to use that sea surface temperature data in their HadCRUT3 global land-plus-sea surface temperature dataset. Instead they use their HADSST2 dataset in HadCRUT3. Figure 2-26 is a comparison graph of the two current Hadley Centre sea surface temperature datasets: the HADISST dataset, which includes satellite-based data, and their HADSST2 data that excludes it. The data are for the global oceans and they cover the period from January 1982 to March 2012. It shows that the Hadley Centre's sea surface temperature anomaly dataset without satellite-based data has a linear trend that's 75% higher than their dataset with satellite-based data. One might assume the underlying reason the Met Office uses the sea surface temperature data that's not satellite based in its global land-plus-sea surface temperature dataset is because it shows more warming than the satellite-based sea surface temperature data.

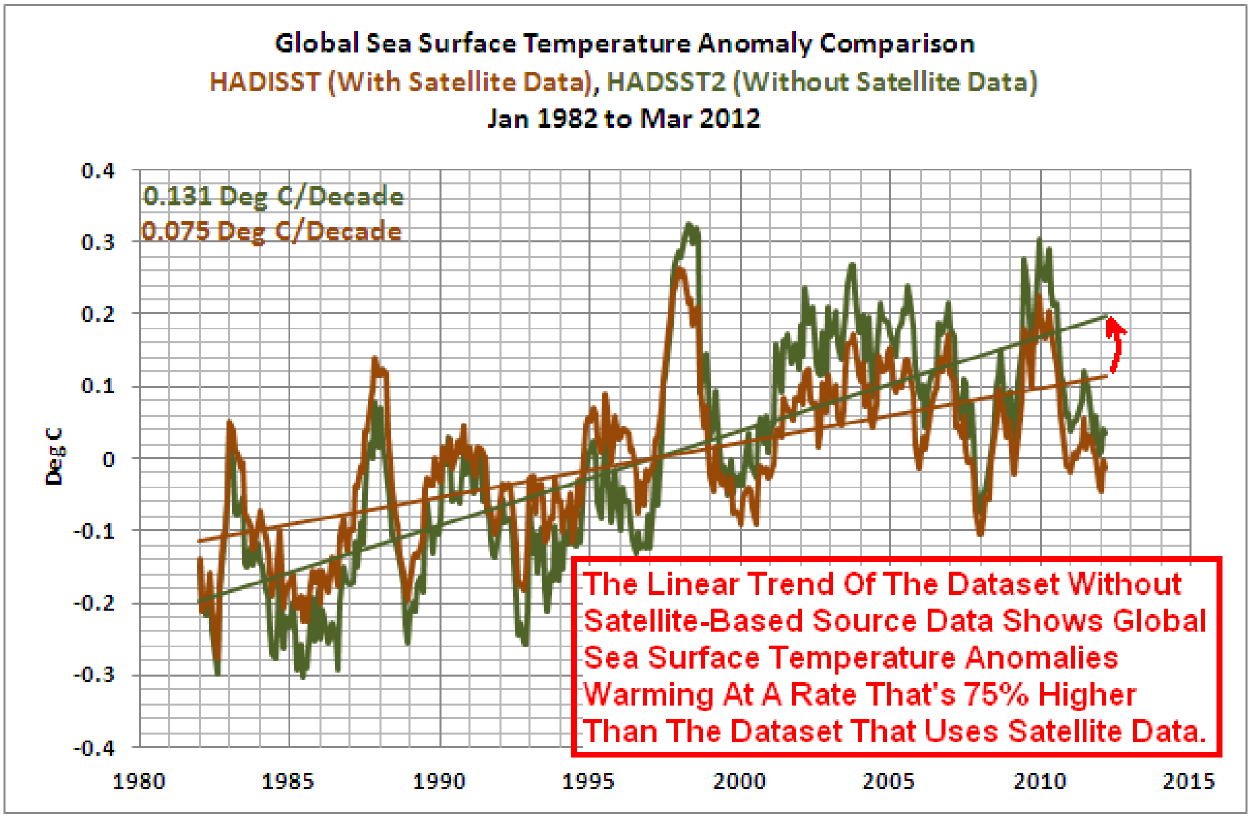


Figure 2-26 Bob Tisdale

In addition to under-sampling a region of the global oceans where it's cooling, there's another reason why the HADSST2 data has such a remarkably higher warming trend. The Hadley Centre changed suppliers of source sea surface temperature data in 1998, and they apparently did not account for the differences in the two source datasets. The HADSST2 data acquired an upward bias after 1998 of about 0.12 deg C, when compared to their HADISST data. Refer to the graph **here** from the blog post **here**.

In short, the significant warming biases in the HADSST2 data and the fact that it's spatially incomplete prevent us from using it as the primary sea surface temperature dataset in this book.

The National Climatic Data Center (NCDC) of NOAA also had (past tense, because it no longer exists) a long-term sea surface temperature dataset called ERSST.v3. It included satellite-based data for the period starting in 1982, but "users" felt the satellite data included a bias that reduced the warming. The NCDC then reissued the dataset without the satellite-based data and called it ERSST.v3b. The explanation for the change is presented on the NOAA/NCDC webpage **here**. There they write (my boldface):

> *In the ERSST version 3 on this web page we have removed satellite data from ERSST and the merged product. The addition of satellite data caused problems for many of our users. Although, the satellite data were corrected with respect to the in situ data as described in reprint, there was a residual cold bias that remained as shown in Figure 4 there.* ***The bias was strongest in the middle and high latitude Southern Hemisphere where in situ data are sparse. The residual bias led to a modest decrease in the global warming trend and modified global annual temperature rankings.***

The "reprint" discussed in the quote is the 2008 Smith et al paper **Improvements to NOAA's Historical Merged Land-Ocean Surface Temperature Analysis (1880-2006).** See their Figure 4.

In the above quote, the NCDC acknowledged that satellite-based sea surface temperature data is corrected for satellite-caused biases. However, they then explained that there is another bias in parts of the globe where there is poor sampling from ships and buoys. Satellite-based sea surface temperature data include measured temperatures where there's poor sampling from buoys and ships. It would, therefore, seem as though the methods used by the NCDC to infill the missing data actually cause a warm bias in the dataset that doesn't use the satellite data. In other words, it seems as though the NCDC's logic is backwards.

The Global sea surface temperature anomalies from 1982 to 2007 for the satellite-based ERSST.v3 and its successor, ERSST.v3b, without the satellite data, are compared in Figure 2-27. The data in the graph ends in 2007 because the ERSST.v3 data was introduced and made obsolete a few short months later in 2008, so a full year of data does not exist after 2007. The trends are reasonably close, hence the NCDC's comment that the "bias led to a modest decrease in the global warming trend". Nevertheless, the real concern apparently was, based on the quote above, which year had the highest temperature. With the satellite-based data, 1998 is the winner by a miniscule 0.01 deg C over 2003, but with the satellite data removed, 2003 is ranked highest because it was 0.002 deg C warmer than 1997. This agrees with the quote from above, "***The residual bias led to a modest decrease in the global warming trend and modified global annual temperature rankings."*** In other words, they removed the satellite-based data so they could say global warming continued between 1997 and 2003 because 2003 was warmer than 1997—by 0.002 deg C.

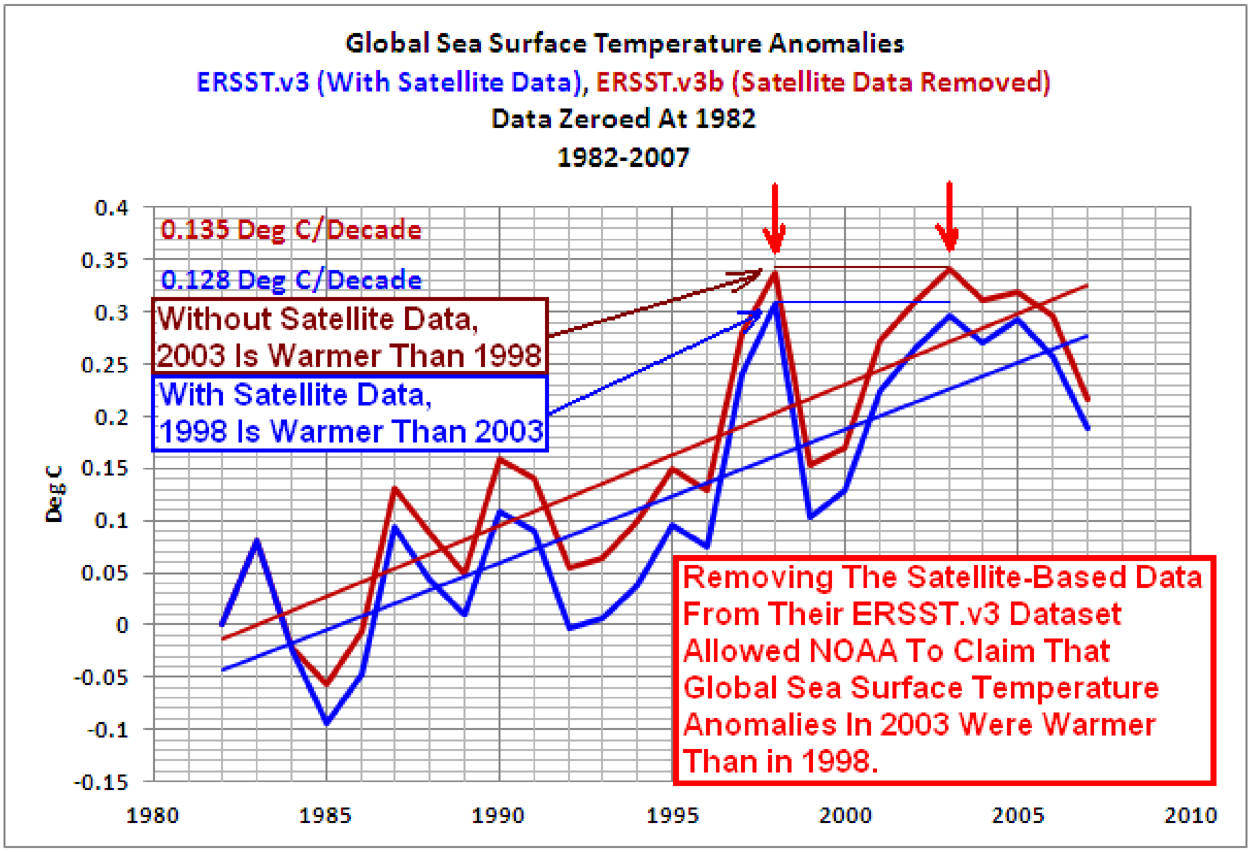


Figure 2-27

That's quite remarkable when you think about it. A group of scientists worked hard to create the best long-term sea surface temperature dataset possible by including satellite-based data, but an unidentified group of "users" felt which year was ranked warmest was more important, so the data was changed to accommodate them. The curious thing: the primary "user" of the NOAA/NCDC ERSST.v3b data is NOAA/NCDC itself. They use it in their global land plus sea surface temperature dataset.

By removing the satellite-based data from their temperature dataset, the NCDC has created another problem for itself. The original ERSST.v3 data was based on the Smith et al (2008) paper **Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880-2006).** That paper presented a long-term sea surface temperature dataset that included satellite-based data. In fact, most of that paper was about the satellite data. The NCDC removed the satellite data, and now they no longer have a peer-reviewed paper to support the revised dataset. For many users, peer review is a necessity.

Like the HADSST2 data, the ERSST.v3b sea surface temperature dataset only relies on measurements from ships and buoys. In addition, NOAA adds another feature to its ERSST.v3b data that is not used by the Hadley Centre for its HADSST2 or HADSST3 datasets. Using statistical techniques, NOAA enters data in the grids where there are no measurements, making the ERSST.v3b dataset spatially complete. While it helps to provide data in the areas where there are no readings from buoys and ships, it is basically "make believe" data. The bottom line, Figure 2-28, is that the ERSST.v3b data (without satellite data) shows global sea surface temperature anomalies warming at a rate that's about 18% faster than their satellite-based Reynolds OI.v2 sea surface temperature data.

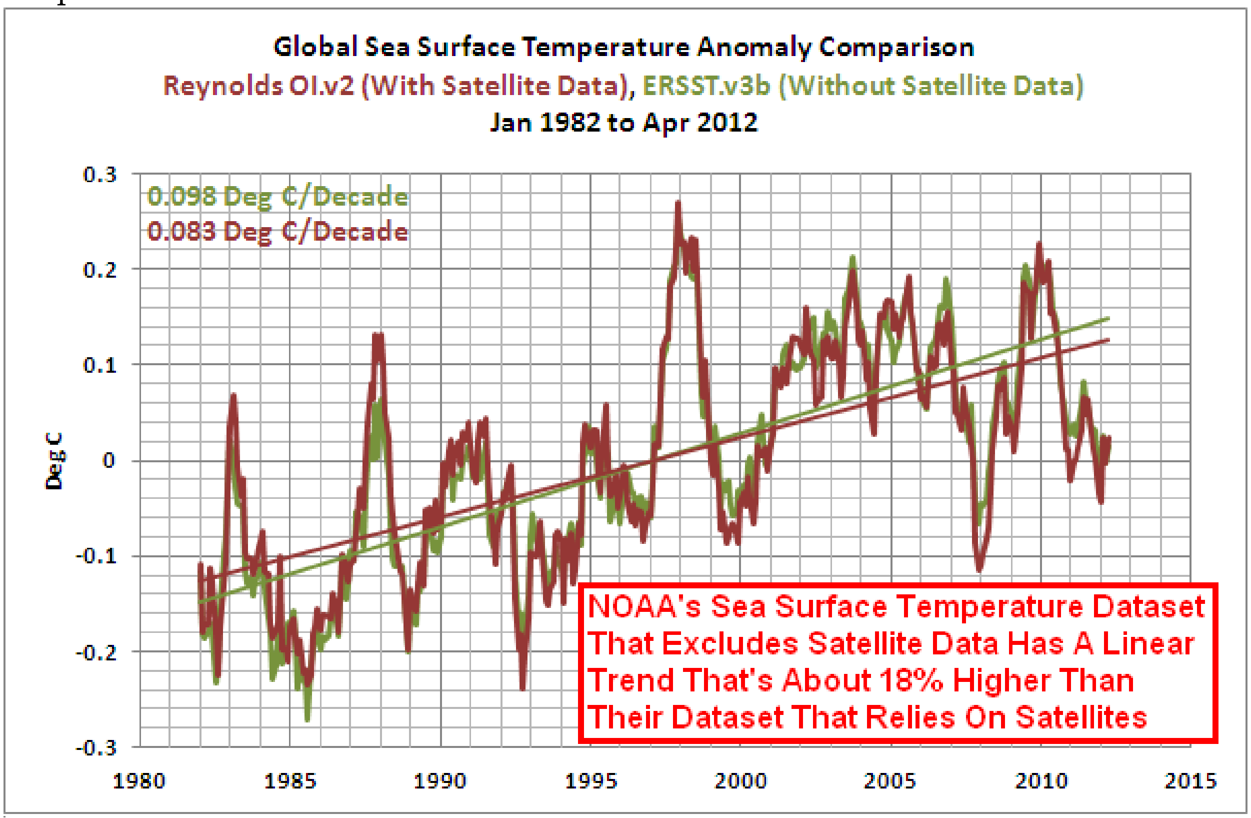


Figure 2-28 Bob Tisdale

I'm going to change topics slightly to confirm something else. This book concentrates on sea surface sea surface temperature data, not land surface temperature data and not land-plus-sea surface temperature data. We will in a few chapters refer to land-plus-sea surface temperature data, but it's not the primary dataset used in this book.

A recent study has shown that variations in land surface temperatures generally follow and respond to the changes in sea surface temperature. Compo and Sardeshmukh presented a paper about this subject in 2009: **Oceanic influences on recent continental warming**. The abstract reads:

> *Evidence is presented that the recent worldwide land warming has occurred largely in response to a worldwide warming of the oceans rather than as a direct response to increasing greenhouse gases (GHGs) over land. Atmospheric model simulations of the last half-century with*

> *prescribed observed ocean temperature changes, but without prescribed GHG changes, account for most of the land warming. The oceanic influence has occurred through hydrodynamic-radiative teleconnections, primarily by moistening and warming the air over land and increasing the downward longwave radiation at the surface. The oceans may themselves have warmed from a combination of natural and anthropogenic influences.*

That reinforces what I had written in the Introduction: Land surface temperatures (representing the other 30%) mimic and exaggerate the changes in sea surface temperature…

Back to our discussions of why we're using satellite-based sea surface temperature data:

Another reason we'll be looking at satellite-era sea surface temperature data: the effects being illustrated are very easy to see in that dataset. That is very important.

Truth. It is the last reason for using this satellite-based sea surface temperature dataset: Two scientists who were responsible for creating the NCDC's long-term sea surface temperature datasets, Smith and Reynolds, wrote the following in a 2004 paper **Improved Extended Reconstruction of SST (1854-1997)**. It is about the Reynolds OI.v2 data we'll be using as the primary source of data for this book:

> *Although the NOAA OI analysis contains some noise due to its use of different data types and bias corrections for satellite data, it is dominated by satellite data and gives a good estimate of the truth.*

The truth is a good thing.

RECAP

In summary, sea surface temperature datasets that exclude satellite-based data are spatially incomplete or are based on spatially incomplete sampling. Because the areas where the measurements are incomplete are also regions of the global oceans that are cooling, those datasets have a warm bias. Satellite-based sea surface temperature data is spatially complete and as such captures the portions of the global oceans that have been cooling for the past 30 years. We're presenting the Reynolds OI.v2 data as our primary sea surface temperature data source in this book because it is said to be the closest of the datasets to the truth.

2.11 Data Smoothing and Detrending

In some of the datasets, there are lots of month-to-month variations. For example, let's take a look at the land-plus-sea surface temperature anomalies for the mid-latitudes of the Northern Hemisphere (20N-65N). We'll be looking at this dataset later in the book. It's north of the tropics, but south of the Arctic, and covers about 28% of the surface of the planet. It is a subset of the GISS Land-Ocean Temperature Index (LOTI). As you can see in Figure 2-29, the monthly variations can be quite large. Some of the wiggles are responses to ENSO events; others are not. It's tough to tell what's going on with all of that (what some people would call) noise.

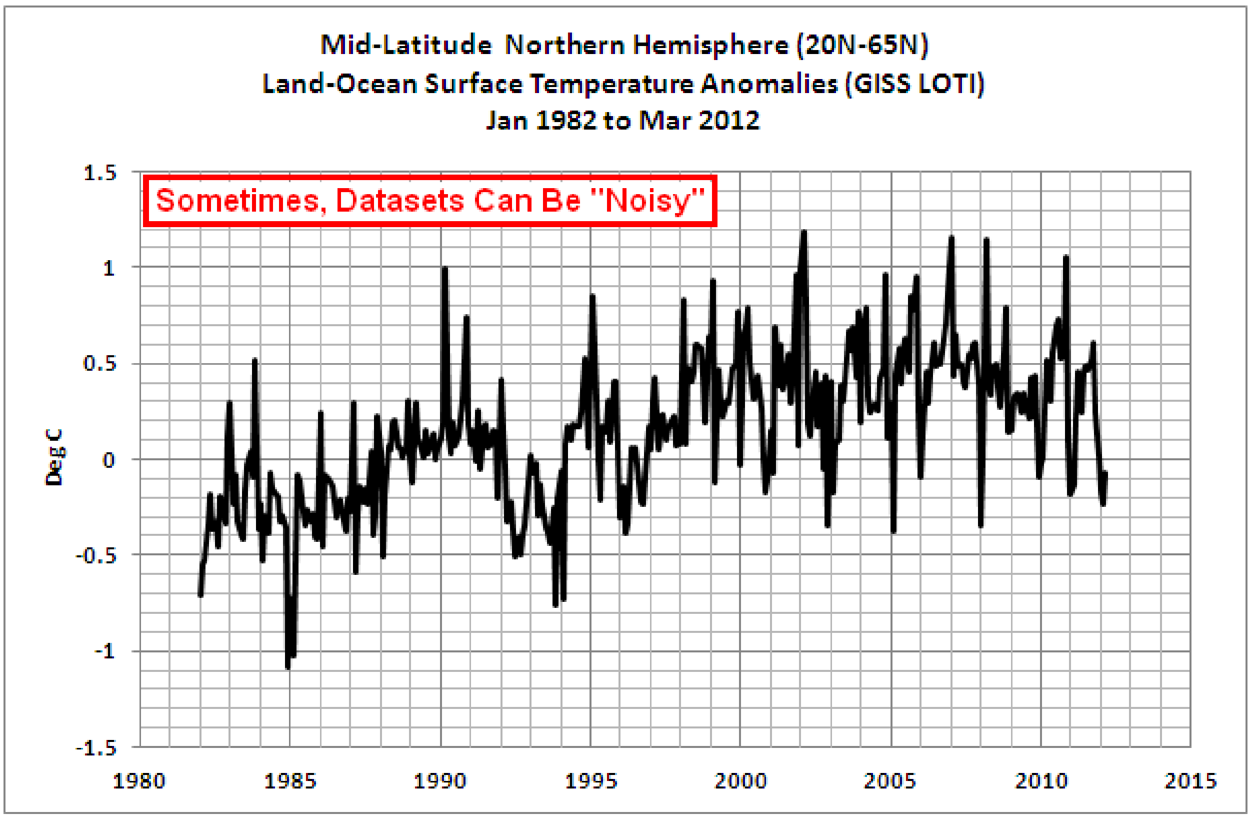


Figure 2-29 Bob Tisdale

In those instances, we'll smooth the data with a 13-month running-average filter. This drastically reduces any weather noise and minimizes the seasonal component in the data. See Figure 2-30. To create that filter, each data point in the curve represents a 13-month average centered on the 7th month. In other words, the first data point is at July 1982 and it represents the average surface temperature anomalies from January 1981 to January 1982, the next data point is in August 1982 and it shows the average for the period of February 1981 to February 1982, and so on, until the final data point in September 2011 for the 13-month period of March 2011 to March 2012.

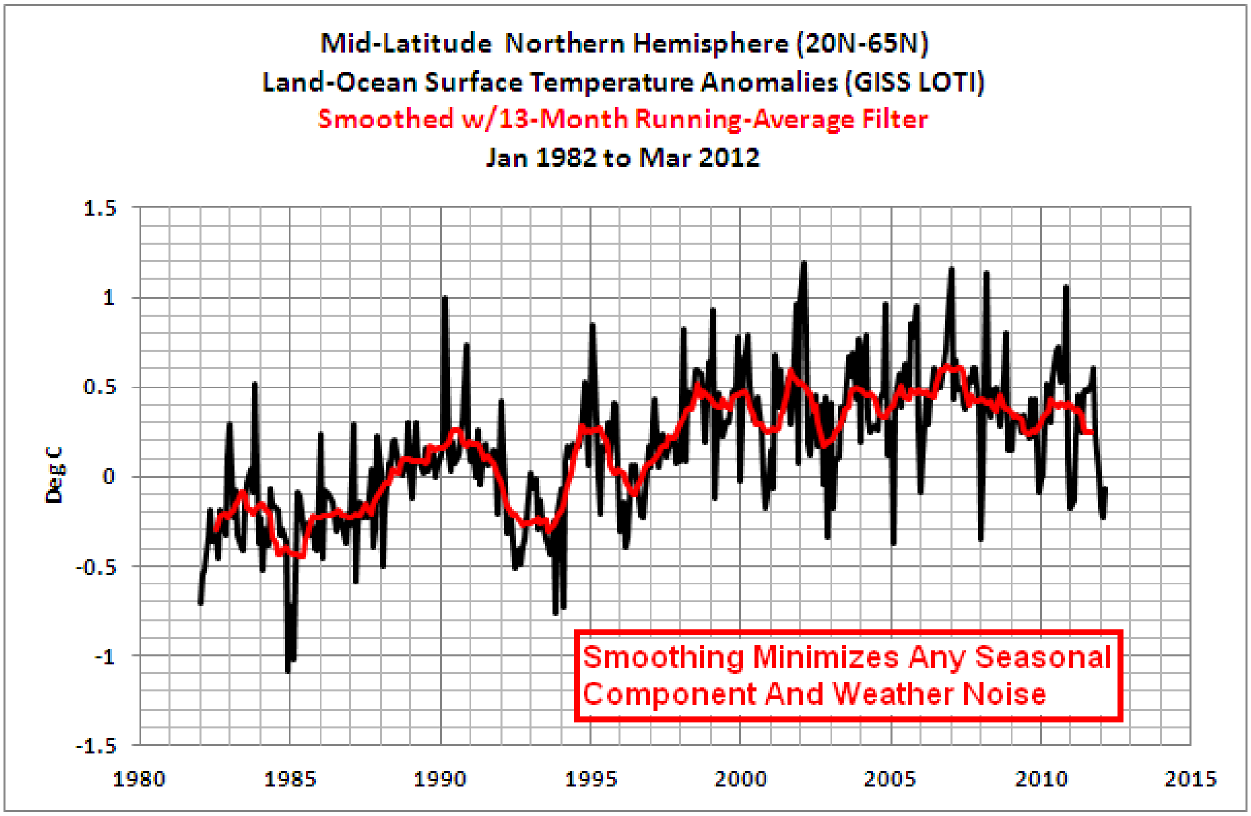


Figure 2-30

Bob Tisdale

We won't be presenting the "raw" data in those graphs of the smoothed data, but the filtering will be noted in the title block of the graph. See Figure 2-31 as an example.

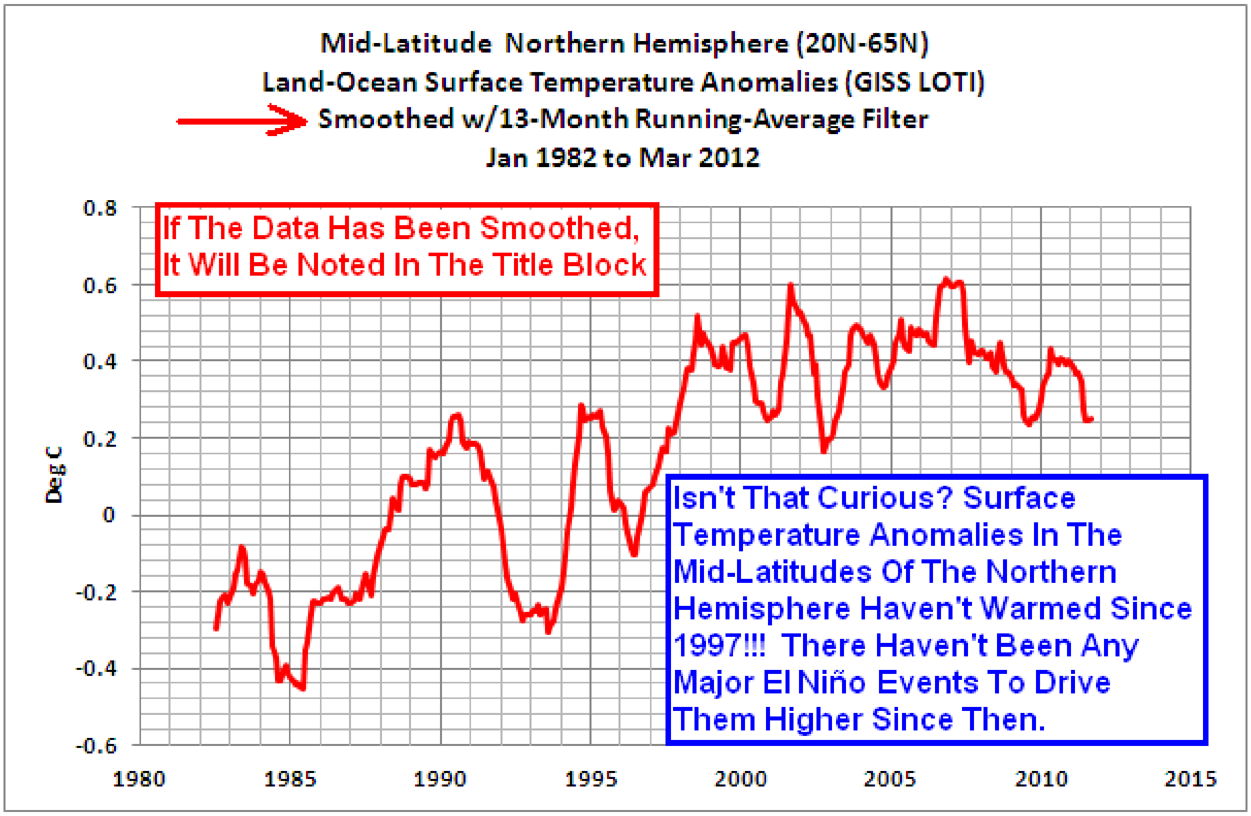


Figure 2-31

Bob Tisdale

The smoothing, as you can see, helped to show that surface temperatures haven't warmed in the mid-latitudes of the Northern Hemisphere since 1997. Why? We'll discuss that in detail in **Section 5 – The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies.**

There are a few instances in this book that we'll be looking at long-term sea surface temperature data, starting in 1900. In some of them, we'll smooth the data with 121-month running-average filters to bring out the decadal variations. For example, NOAA uses a 121-month filter for their Atlantic Multidecadal Oscillation data.

The reference to the Atlantic Multidecadal Oscillation is a good way to introduce detrending. First, a quick introduction: The Atlantic Multidecadal Oscillation, or AMO, is a natural mode of climate variability that occurs in the North Atlantic Ocean. It will be presented and discussed in more detail in Chapter 2.13 and in Section 5. The Atlantic Multidecadal Oscillation was first identified in the mid-1990s. As Wikipedia notes on its **Atlantic Multidecadal Oscillation webpage**:

> *The AMO signal is usually defined from the patterns of SST [Sea Surface Temperature] variability in the North Atlantic once any linear trend has been removed.*

The easiest way to explain that sentence is to first show you a graph of the sea surface temperature anomalies of the North Atlantic since 1900, along with the linear trend of the data, Figure 2-32. As shown, North Atlantic sea surface temperature anomalies have warmed at a rate of 0.053 deg C per decade since 1900 based on the linear trend. In addition to the overall warming, there is an additional long-term variation that caused North Atlantic sea surface temperatures to warm much faster than the long-term trend from 1900 to the late 1930s. Then, the sea surface temperature anomalies were relatively flat (not warming or cooling other than the yearly variations) until the early 1960s. Sea surface temperatures cooled quite rapidly from the early 1960s until the mid-1970s. They've then warmed since the mid-1970s. The length of the cycle since 1900 appears to be near 60 years. Paleoclimatological studies have shown the cycle varies in length and that its time span can range between 50 and 80 years.

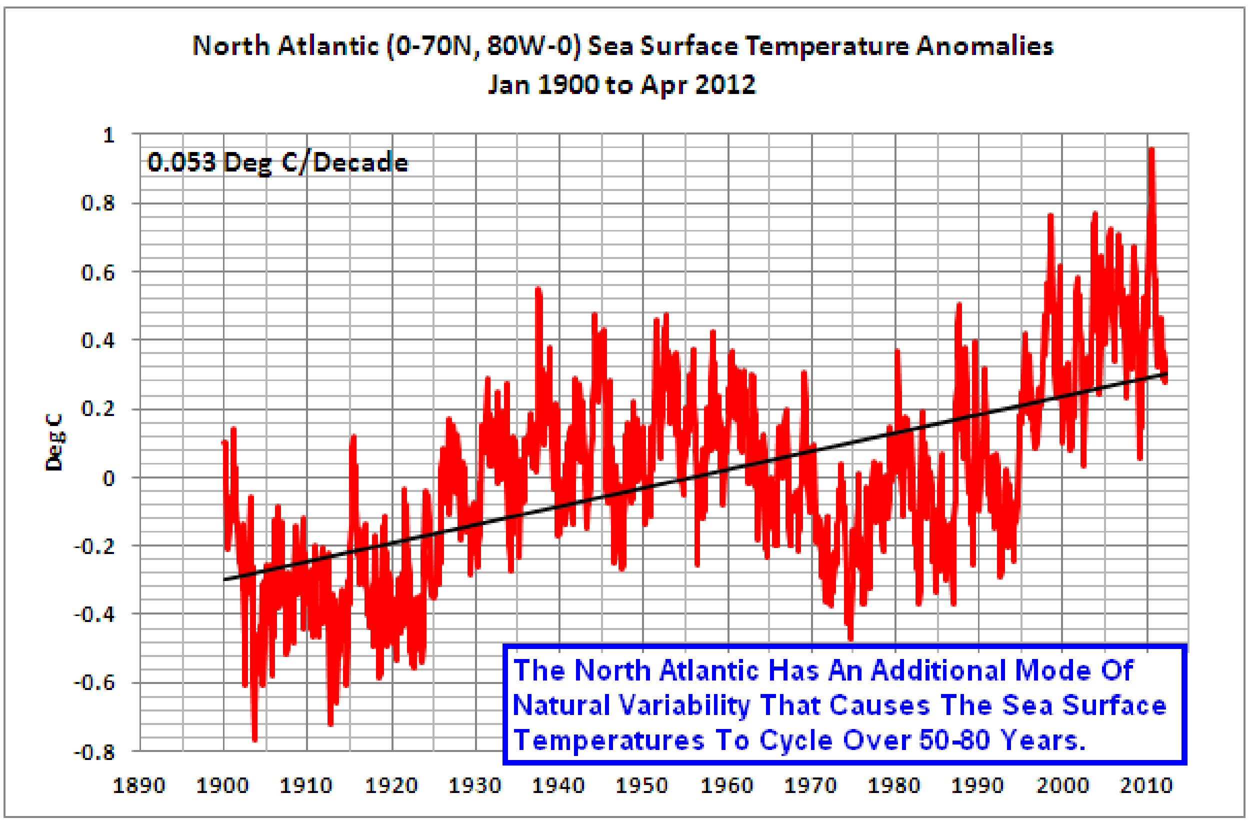


Figure 2-32 Bob Tisdale

To remove the linear trend from the data, also known as detrending, the monthly values of the linear trend line are determined. Then those values are subtracted from, in this example, the North Atlantic sea surface temperature anomalies. See Figure 2-33. The black line at zero degrees C is the actual linear trend of the detrended data. It is flat. The detrended North Atlantic sea surface temperature anomalies no longer have a trend.

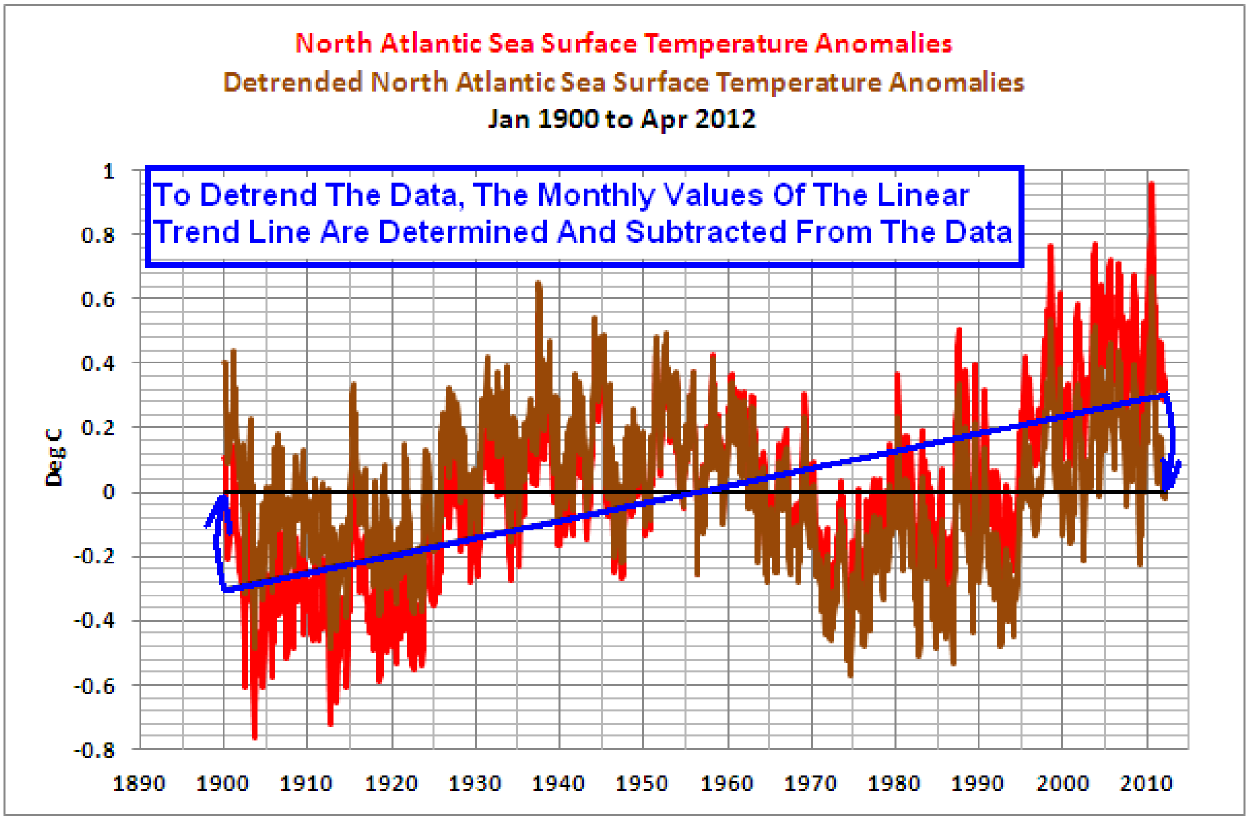


Figure 2-33 Bob Tisdale

NOAA calls the detrended North Atlantic sea surface temperature anomaly data the **Atlantic Multidecadal Oscillation (AMO) Index**. As shown, the monthly variations in the data in Figure 2-33 are quite strong. As a result, NOAA uses a 121-month running-average filter to show the underlying multidecadal variations. I've smoothed the data with a 121-month filter in Figure 2-34. The first warming period in the detrended data peaks in the early 1940s then cools slowly until the late 1950s. From the late 1950s until the mid-1970s, the detrended North Atlantic sea surface temperature anomalies cooled rapidly. Then they warmed, slowly until the late 1980s and then much more quickly through the end of the data. If history were to repeat itself, the multidecadal cycle in the detrended North Atlantic sea surface temperature anomalies should peak in the not-too-distant future.

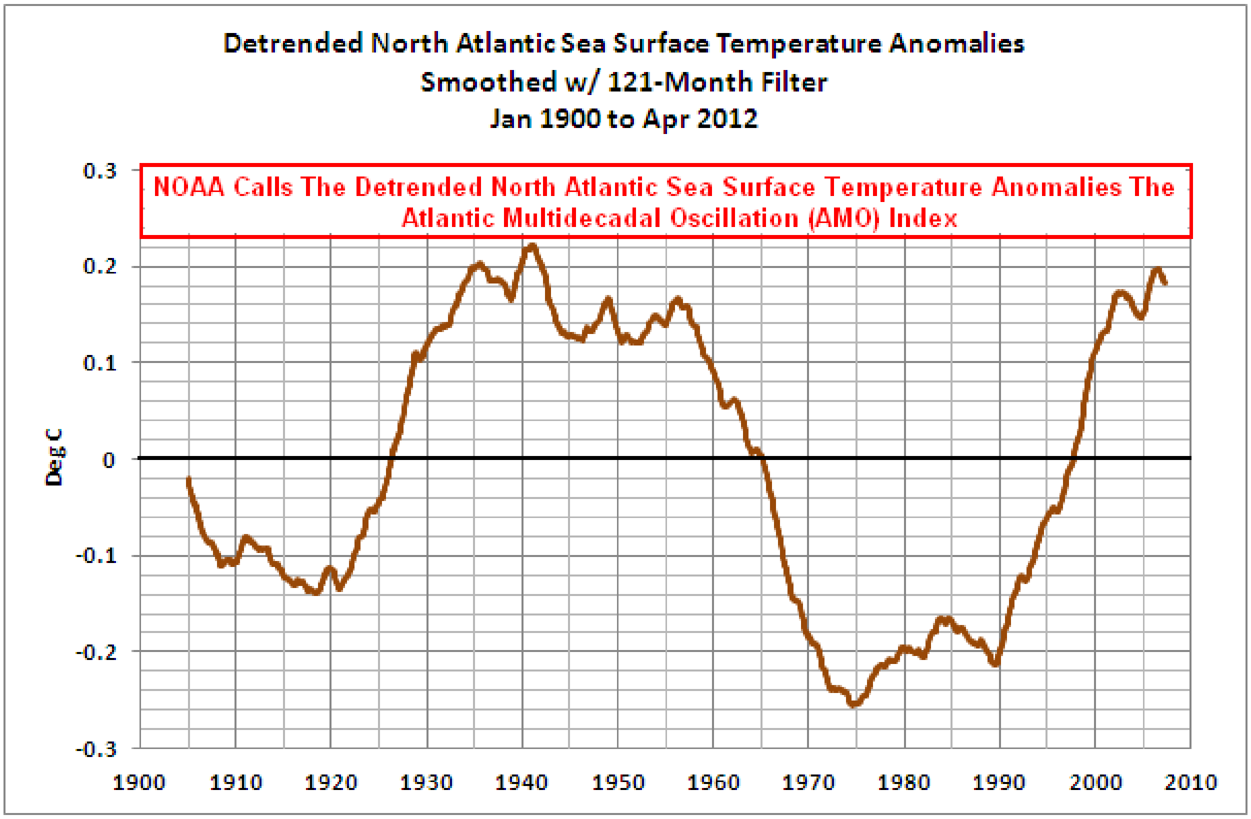


Figure 2-34 Bob Tisdale

RECAP

Occasionally, data will smoothed in this book to reduce the additional monthly variations (short wiggles). In those cases we'll use a 13-month running-average filter. A 121-month running-average filter is used to more clearly illustrate the longer-term variations (longer wiggles). Also, a few times in this book, data will be detrended. This is done by determining the monthly values of the linear trend line for a dataset and then subtracting those linear trend values from the actual data.

2.12 The IPCC Says Only Climate Models Forced by Manmade Greenhouse Gases can Explain the Recent Warming

This is a combination of similar discussions in the Introduction and Chapter 1.1 of my first book ***If the IPCC was Selling Global Warming as a Product, Would the FTC Stop Their Deceptive Ads?*** It is intended to show why the IPCC believes that only greenhouse gases can explain the warming of global surface temperatures over the past 30 years. We'll illustrate and discuss why this belief is fatally flawed in Section 5.

There is also a discussion of the difference in the effects on ocean temperatures of downward longwave radiation (infrared radiation) associated greenhouse gases and of downward shortwave radiation (visible light) associated with the sun.

Figure 2-35 is a replica of the IPCC's Figure 9.5 from Chapter 9 of their 4th Assessment Report (AR4). There are a few differences between the original and the replica, but they do not impact this discussion. If you'd prefer to look at the original while it's being discussed, a link to it is **here**.

Chapter 9 of the IPCC's AR4 is titled "Understanding and Attributing Climate Change", and the heading of the section that includes their Figure 9.5 is "Simulations of the 20th Century". In their Figure 9.5, the IPCC tries to show how well climate models perform when manmade greenhouse gases and other anthropogenic factors are used as inputs to the models. Climate scientists call those model inputs forcings. The second graph is included to show how poorly the models perform when they are driven only by natural forcings, which are data that represents the aerosols emitted by explosive volcanic eruptions and data that represents the variations in the output of the sun.

Their top graph in Figure 2-35 seems to demonstrate that climate models do a fantastic job of simulating surface temperatures over the 20th Century.

The black curve represents global surface temperature anomalies. It's based on millions of land and sea surface temperature measurements since 1901, and, of course, thermometers in multiple forms were used to measure those temperatures around the globe.

The noisy yellow curves in the graph are the dozens of individual outputs of the global temperature simulations from 12 different climate models. That's a lot of conjecture-based number crunching from gazillion-dollar super computers. The more-subdued red curve is the average of those individual model simulations. Climate scientists call that average the multi-model ensemble mean. We'll refer to it as the model mean in this book. The x-axis (horizontal base line) is formatted as time in years. The y-axis (vertical line to the left of the graph) is formatted as temperature in degrees Celsius. The data in the graph is presented on an annual average basis.

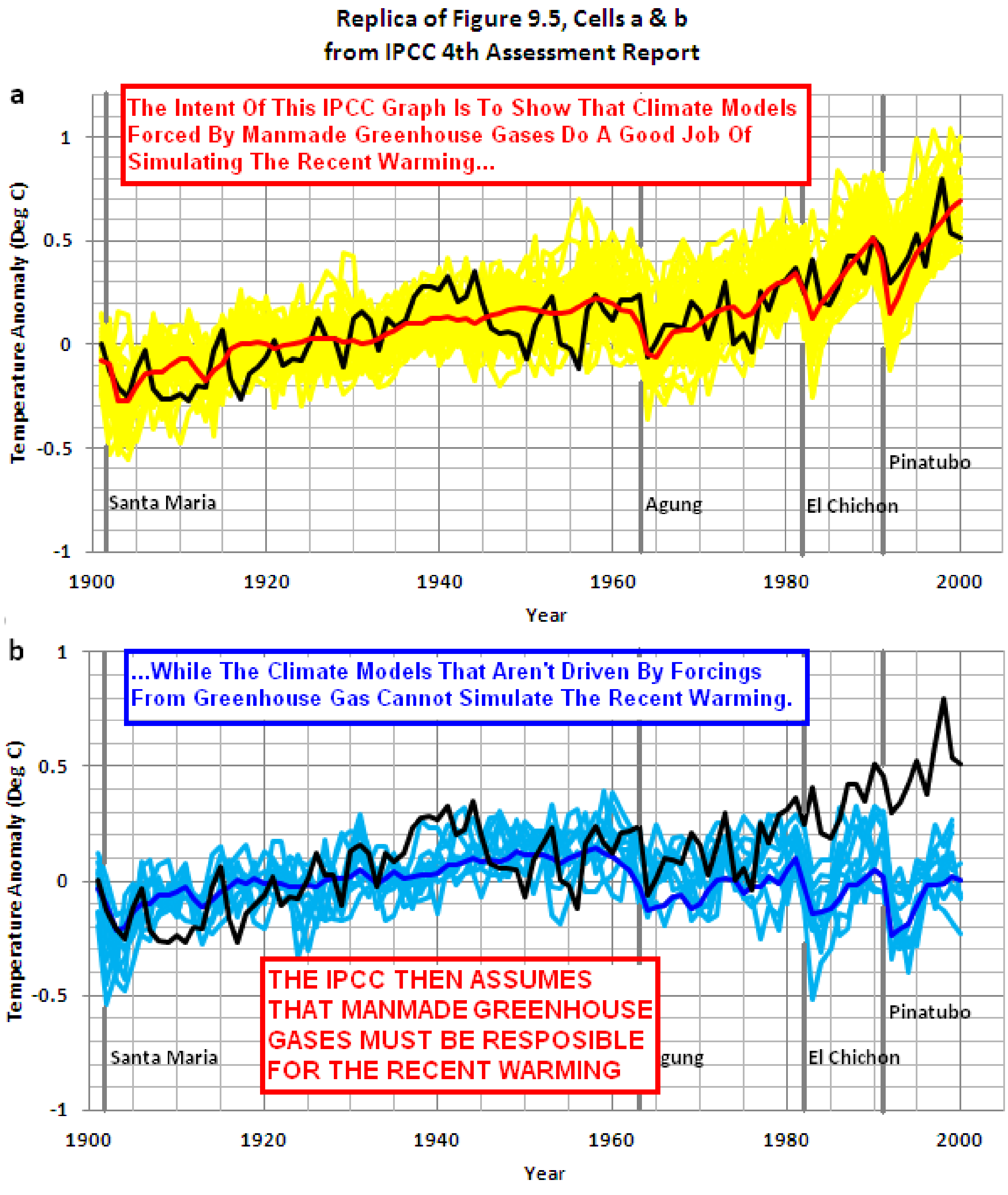


Figure 2-35

Figure 2-35 also includes grey vertical lines to mark the years of the explosive volcanic eruptions of Santa Maria in Guatemala (1902), Mount Agung in Bali (1963), El Chichon in Mexico (1982), and Mount Pinatubo in the Philippines (1991). Explosive volcanic eruptions can send sun-blocking aerosols up into the stratosphere. The resulting decrease in sunlight reaching the Earth causes global surface temperatures to cool temporarily. The IPCC must be proud that the climate models can reproduce those volcano-caused dips and rebounds in temperature. (More on this later in this chapter.)

Now let's take a look at the lower graph in Figure 2-35. The lighter blue curves in cell b represent the individual model simulations of global surface temperature for the 20th Century, with natural forcings only. Again, that means they used as inputs to the models only the data that represents aerosols emitted by explosive volcanic eruptions and the data that represents the variations in the output of the sun. Fewer modeling groups submitted their models without anthropogenic forcings to the archive used by the IPCC, so there are less simulations than in cell a. The dark blue line represents the average of the individual simulations with only natural forcings. Like the top graph, the IPCC also included vertical lines to mark the time of the major volcanic eruptions. The responses of the models and measured global surface temperatures to those eruptions can be seen in the dips and rebounds that followed them.

The IPCC's Figure 9.5 draws your attention to the differences between the two types of model simulations. One is presented as good; the other is bad. The "good" models with anthropogenic forcings, including manmade carbon dioxide, are able to simulate the warming since the 1970s while the "bad" models that only include natural forcings can't. That's the point of those two graphs. The IPCC's assumption is, if the "bad" models that include only natural forcings can't simulate the warming of the late 20th Century, and if the "good" models with anthropogenic forcings can simulate it, then anthropogenic forcings must be the cause of the warming of global surface temperatures since 1976.

The IPCC carried that flawed assumption to their **Summary for Policymakers** and presented it there. The fourth bullet-point paragraph under the heading of "Understanding And Attributing Climate Change" (page 10) reads [my bold face]:

> *It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM.4).* ***The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing.*** *The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR. {3.2, 9.4}*

Most persons only read the Summary for Policymakers, so the IPCC's assumption about climate models and anthropogenic forcings is right there, front and center, for those persons to grasp and hold tight.

But the Models Do a Good Job of Simulating the Dip and Rebound from Volcanic Eruptions

As shown, the model mean in both cells of Figure 2-35 capture the temporary cooling in surface temperatures caused by the explosive volcanic eruptions. This similarity also shows up in other model-observation comparison graphs.

Let's consider only sea surface temperature data for the rest of this discussion. The sea surface temperatures in the models and observations cool as one would expect from the sun-blocking aerosols emitted by explosive volcanic eruptions. Then, as the volcanic aerosols dissipate with time, the model mean and the observed sea surface temperatures both warm back up. Some readers may believe that's an indication the models have bases in reality. Maybe that's why the IPCC highlighted the timing of the volcanic eruptions in their Figure 9.5.

The hypothesis of anthropogenic global warming relies on the infrared radiation from manmade greenhouse gases. Keep in mind, though, infrared radiation only penetrates the top few millimeters of the ocean surface. That's many orders of magnitude less than how far sunlight penetrates the oceans. Volcanic aerosols reduce the amount of sunlight reaching the ocean surface. Sunlight is downward shortwave radiation, and the anthropogenic global warming hypothesis is not based on it. Downward shortwave radiation penetrates the oceans to depths of about 100 meters. That's one hundred meters for sunlight versus a few millimeters for infrared radiation caused by greenhouse gases.

In short, the dips and rebounds in the models associated with volcanic eruptions do not mean the models have skill at simulating warming associated with greenhouses gases. The volcano-induced dips and rebounds are caused by a drop in visible sunlight, while the hypothesis of manmade global warming is not based on sunlight. It's based on downward longwave radiation from greenhouse gases which has little to no impact on the global oceans. We'll confirm that later in this book.

There are many oceanographers and physicists who believe that the additional infrared radiation from manmade greenhouse gases only increases evaporation at the ocean surface. In fact, as illustrated and discussed in Section 5, even though global sea surface temperatures have warmed over the past 30 years, there is no indication that anthropogenic greenhouse gases were responsible for any of that warming.

RECAP

This chapter was intended to show the basic premise behind the IPCC's belief that only anthropogenic greenhouse gases can explain the surface temperature warming of the past 30 years.

The IPCC models did a reasonable job of simulating the short-term effects of the loss in downward shortwave radiation (visible sunlight) due to the aerosols emitted by explosive volcanic eruptions, but the hypothesis of anthropogenic global warming is not based on downward shortwave radiation. The hypothesis of manmade global warming is based on longwave radiation and the models have no apparent skill at simulating what has caused sea surface temperatures to warm over the past 30 years, as will be discussed and shown later in this book.

Note: As described, sunlight can reach far onto the oceans to warm them, but the oceans can only release heat at the surface, and they do this primarily through evaporation. Because the oceans are warmed to depth but can only release heat at the surface, they have their own greenhouse-like effect.

In closing, the IPCC used the divergence between the "good" climate models with anthropogenic forcings and the "bad" climate models without them to show that only "good" models forced by greenhouse gases could explain the recent warming.

It's not a bad marketing tactic—until someone comes along and shows that the recent warming can be explained without greenhouse gases. That's exactly what's presented later in this book. With that in mind, the IPCC's tactic of using climate models to support the hypothesis of manmade global warming backfired on them for two reasons: First, it shows their models can't replicate the past and, therefore, have little value as forecasting/projection tools. Second, it destroys their hypothesis of anthropogenic global warming and their contention that manmade greenhouse gases were responsible for the majority of the warming.

The terrible downside to all this is that it causes the public to lose even more faith in science as a whole. What happens in the future when there really is a problem? The public will shy away from science, assuming, based on past history, the boy is only crying wolf—again. It's a shame.

2.13 The Additional Mode of Natural Variability in the North Atlantic Sea Surface Temperatures—Introduction to the Atlantic Multidecadal Oscillation

This discussion appeared in my first book. It appears here because the Atlantic Multidecadal Oscillation has contributed to the warming of global sea surface temperatures over the past 30 years. It serves as a reference for the detailed presentation of the warming of the North Atlantic Ocean in Chapter 5.6 **The Additional Warming of the North Atlantic Sea Surface Temperatures are Caused by Another Mode of Natural Variability**.

The NOAA Earth Science Research Laboratory (ESRL) uses the coordinates of 0-70N, 80W-0 for the North Atlantic sea surface temperature anomaly data at their **Atlantic Multidecadal Oscillation webpage**, so we'll use those coordinates for the discussion in this chapter.

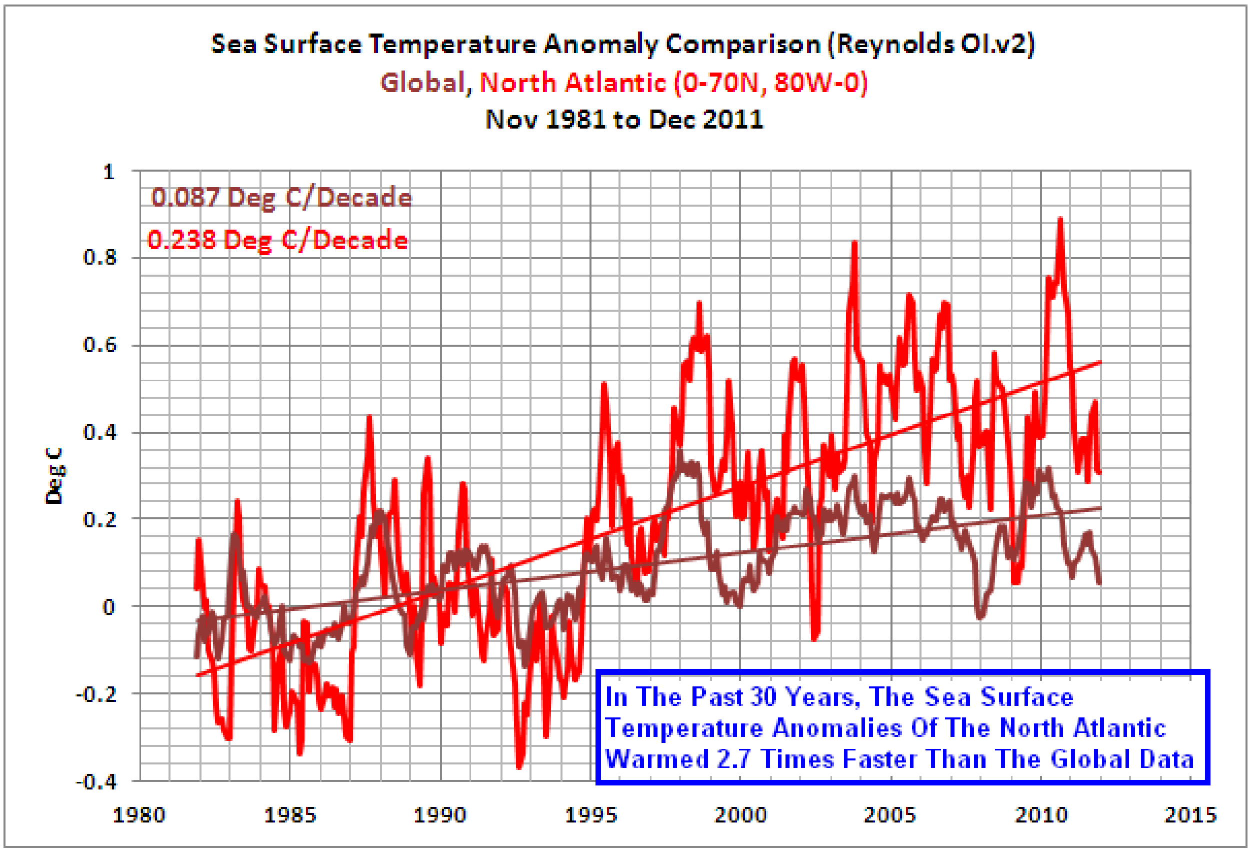


Figure 2-36 Bob Tisdale

Figure 2-36 compares North Atlantic sea surface temperature anomalies to those of the global oceans. It covers the last 30 years. The North Atlantic sea surface temperature anomalies are a noisy dataset. The 1986/87/88, 1997/98, and 2009/10 El Niño events show up well in the global data, but the response of the North Atlantic to those events is much greater. The 1994/95 El Niño can also be seen in the North Atlantic sea surface temperature data. Also notice the extra annual component in the North Atlantic data. We're looking at sea surface temperature anomalies and they still hold onto a portion of the seasonal cycle. Then again, what really stands out is how fast the North Atlantic has warmed. The North Atlantic sea surface temperature anomalies warmed at a rate that's 2.7 times greater than the global oceans.

A few questions come to mind: why has the North Atlantic warmed so much faster? Will it continue to warm at that excessive rate?

If we look at Global and North Atlantic sea surface temperature anomalies extended back in time to 1900, those questions will be easier to answer. We'll need to switch sea surface temperature datasets to do this. We'll use the Hadley Centre's HADISST dataset. It uses satellite-based data from 1982 to present, and for the period before 1982, the Hadley Centre has filled in the grids where there weren't any measurements. The infilling makes it easier to use, because there is data in every grid for every month. We'll present the Global and North Atlantic sea surface temperature anomalies on an annual basis in Figures 2-37 and 2-38 to reduce the noise.

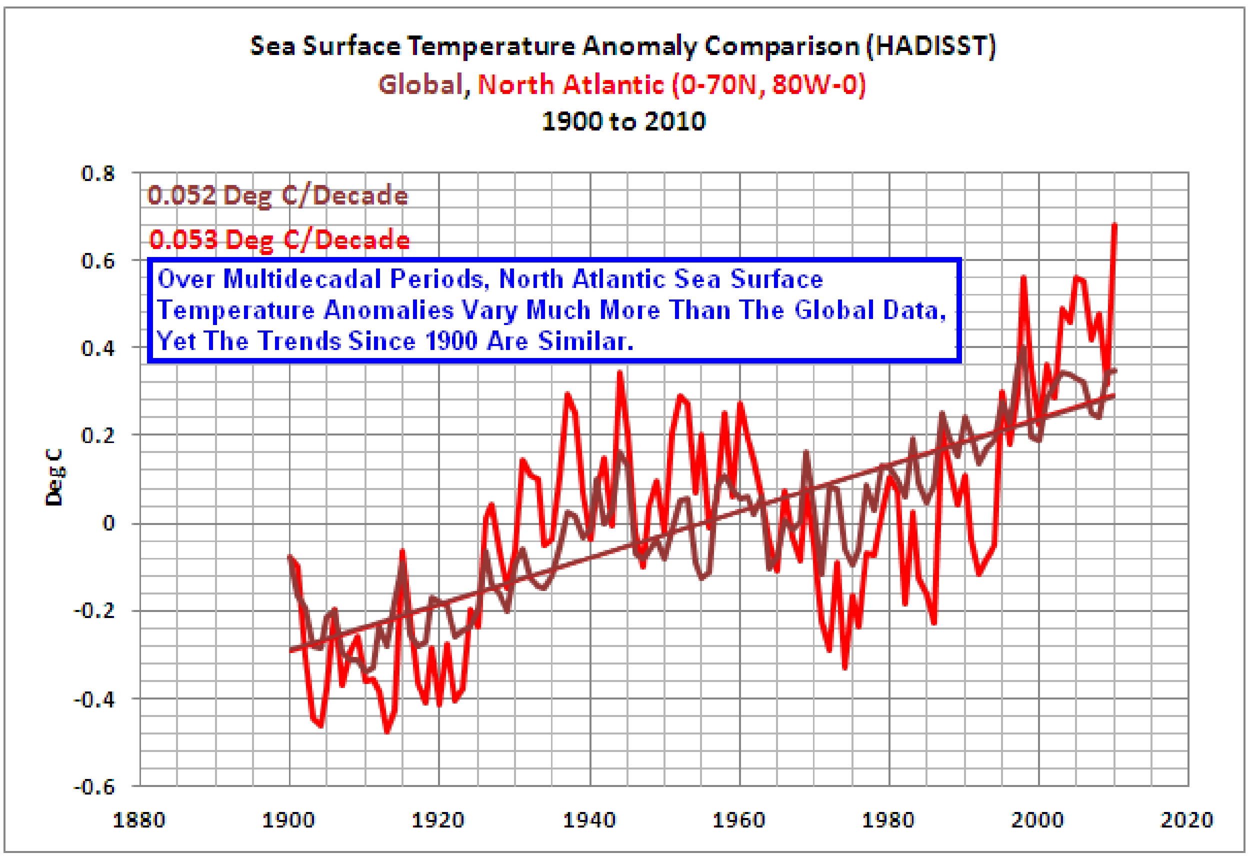


Figure 2-37

The North Atlantic and Global sea surface temperature anomalies from 1900 to 2010 are compared in Figure 2-37. Not only are the yearly variations in the

North Atlantic data much greater than the Global data, but the long-term rates at which the North Atlantic varies are also much greater. For example, during the early warming period, the North Atlantic warmed much faster than the Global oceans, and during the mid-20th Century "flat temperature" period of the global data, the North Atlantic sea surface temperatures cooled significantly. We don't need a linear trend line to help us see that drop.

One way to illustrate the additional multidecadal variations in the North Atlantic sea surface temperatures is to subtract the Global data from the North Atlantic data. See Figure 2-38. This method was proposed in the Trenberth and Shea (2006) paper "**Atlantic hurricanes and natural variability in 2005**". They subtracted the global sea surface temperature data without the polar oceans (60S-60N) from the North Atlantic data. In the example shown in Figure 5-3, the polar oceans are included.

NOTE: Ideally, we'd first remove the North Atlantic sea surface temperature data from the Global data before subtracting the Global data from the North Atlantic. That way we're subtracting the sea surface temperature anomalies of the rest of the global oceans from the North Atlantic. That provides a true indication of the additional variations in the North Atlantic sea surface temperatures that are above and beyond the other global oceans, but that is a refinement that's not really necessary for this discussion.

The additional multidecadal variations in the North Atlantic sea surface temperatures are plain to see Figure 2-38. The data in that graph has also been smoothed with an 11-year running-average filter to minimize the noise. The NOAA ESRL uses the same filter to smooth its annual Atlantic Multidecadal Oscillation data. I've also highlighted the satellite era of sea surface temperature data to show that the multidecadal variations in the North Atlantic have been in the warming mode over the past 30 years.

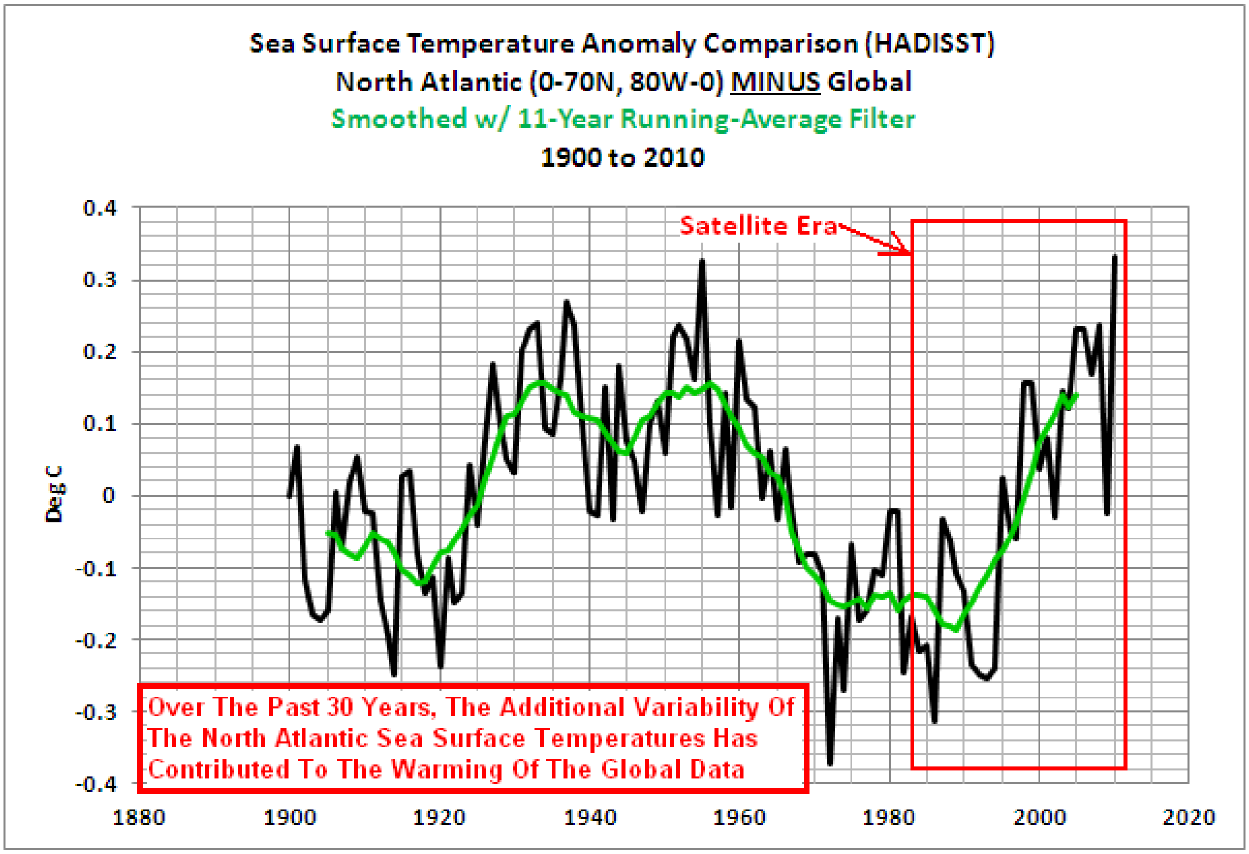


Figure 2-38 Bob Tisdale

The ESRL Atlantic Multidecadal Oscillation webpage is linked **here**. They refer to the **Wikipedia definition of the Atlantic Multidecadal Oscillation**. Wikipedia writes:

> "The Atlantic multidecadal oscillation (AMO) was identified by Schlesinger and Ramankutty in 1994. The AMO signal is usually defined from the patterns of SST variability in the North Atlantic once any linear trend has been removed. This detrending is intended to remove the influence of greenhouse gas-induced global warming from the analysis. However, if the global warming signal is significantly non-linear in time (i.e. not just a smooth increase), variations in the forced signal will leak into the AMO definition. Consequently, correlations with the AMO index may alias effects of global warming."

As discussed in an earlier chapter, detrending is a simple process that is illustrated in Figure 2-39. As Wikipedia notes, the detrending is "intended to remove the influence of greenhouse gas-induced global warming from the analysis."

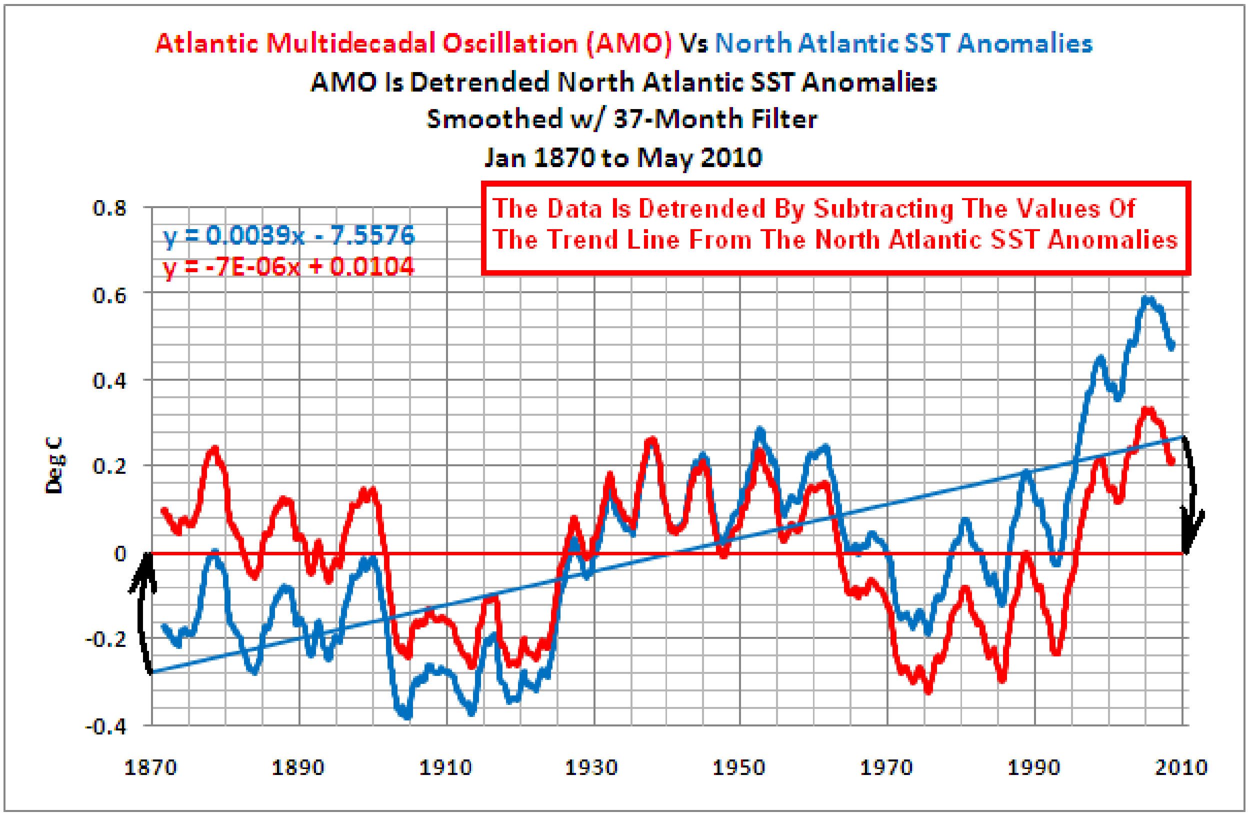


Figure 2-39

Bob Tisdale

We know that the "global warming signal is significantly non-linear in time". There's no doubt about that. We can see this in Figure 2-40 when we compare the Global sea surface temperatures to the linear trend. For some multidecadal periods, the Global sea surface temperatures are below the trend line, and for others they are above it.

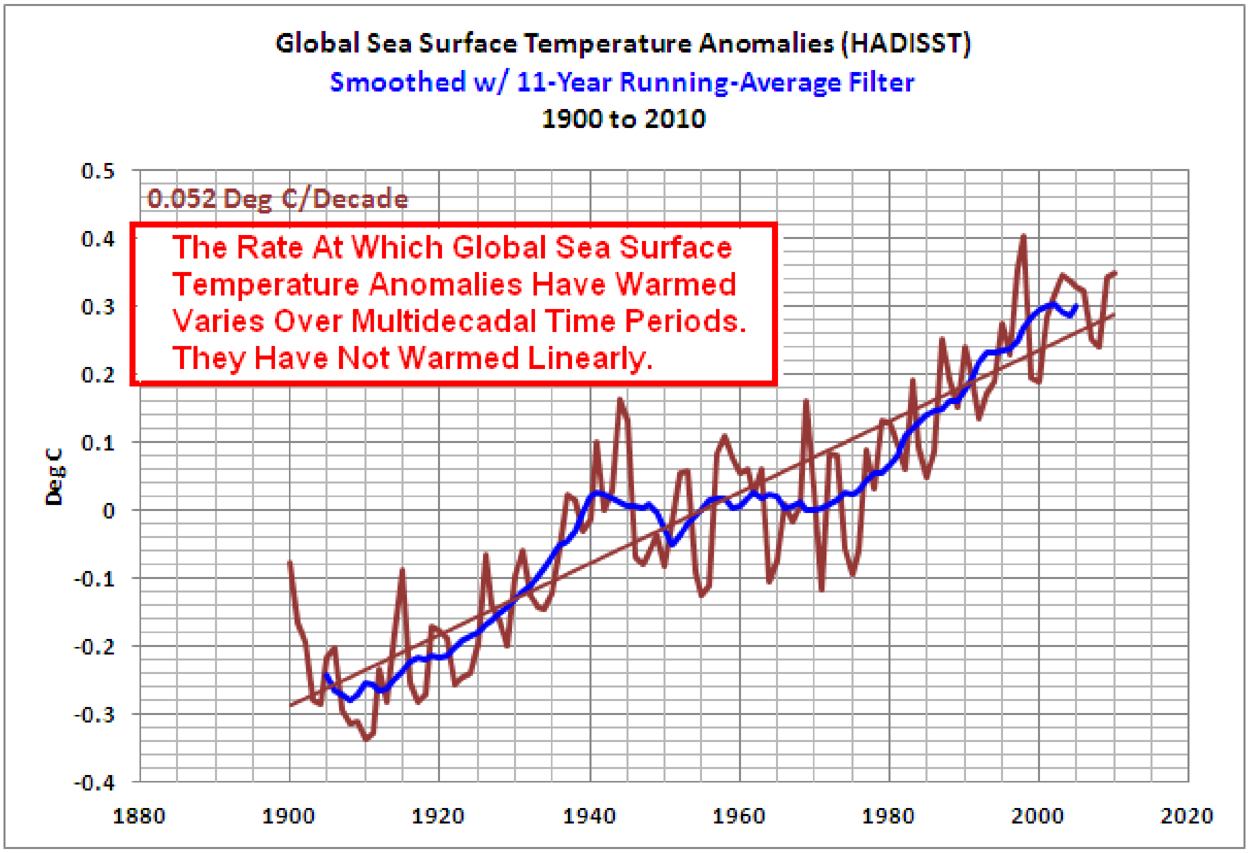


Figure 2-40

The Atlantic Multidecadal Oscillation data from the NOAA ESRL is one of the datasets that uses detrended North Atlantic sea surface temperature anomalies. Let's compare it to the difference between the North Atlantic and Global sea surface temperatures (North Atlantic MINUS Global). Then we can see if the non-linearity of the global warming signal really has a major impact on the portrayal of the Atlantic Multidecadal Oscillation. I borrowed Figure 2-41 from **a post at my blog**. It uses monthly data and the data have been smoothed with 121-month running-average filters. Both datasets show multidecadal variations. The timings of the variations are different and so is the magnitude of the variations. Therefore, the Wikipedia definition is true in those respects.

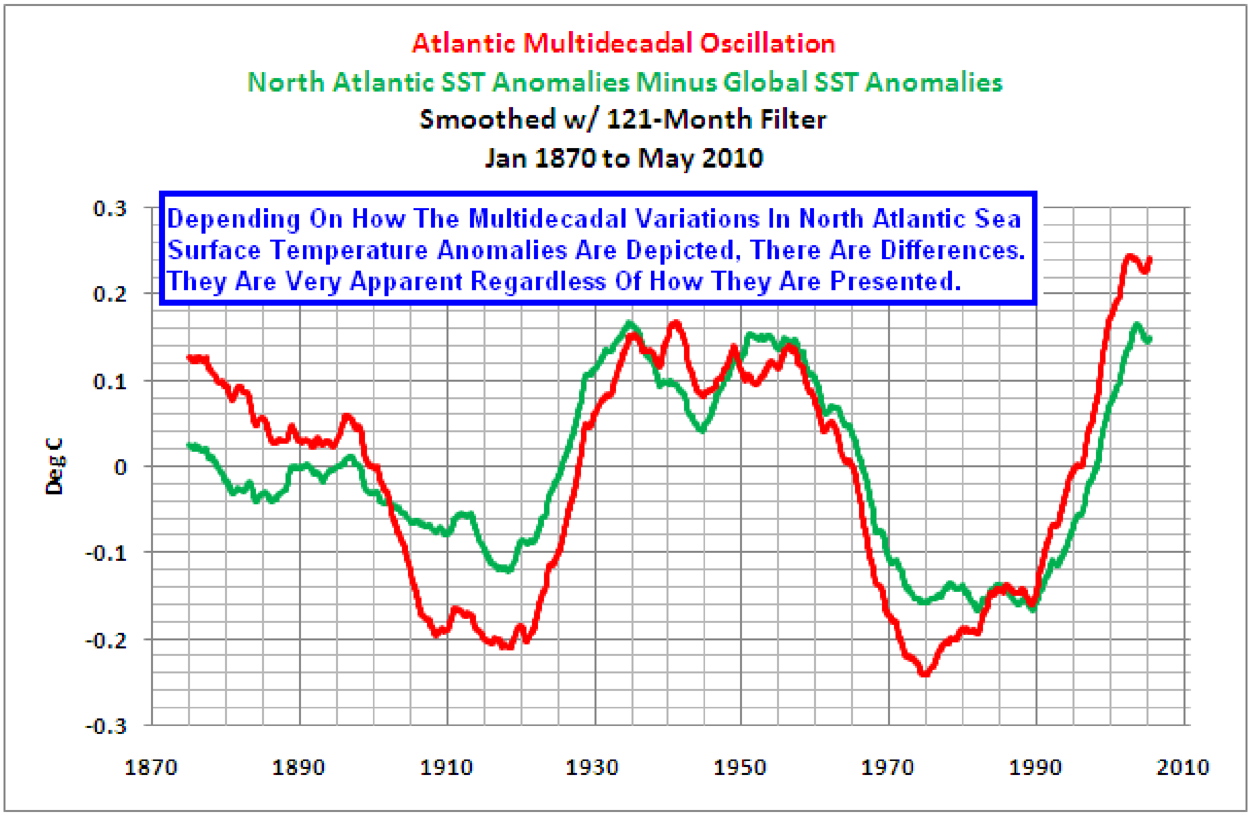


Figure 2-41 Bob Tisdale

Either way, though, the multidecadal variations in the North Atlantic sea surface temperatures are easy to see.

Of course, the Wikipedia webpage makes some monumental assumptions about the cause of the warming of North Atlantic and Global sea surface temperatures. They include the following two phrases in their definition: "influence of greenhouse gas-induced global warming", and "variations in the forced signal will leak into the AMO definition."

We'll illustrate in a number of Sections of this book that there is little evidence that greenhouse gases have had any influence on the rates at which global sea surface temperatures varied over the past 30 years. Therefore, the assumptions made by Wikipedia are not supported by sea surface temperature data.

We discussed in Chapter 2.9 that the weblog RealClimate is a website run by climate scientists. They have a glossary webpage dedicated to the **Atlantic Multidecadal Oscillation**. It reads:

> "A multidecadal (50-80 year timescale) pattern of North Atlantic ocean-atmosphere variability whose existence has been argued for based on statistical analyses of observational and proxy climate data, and coupled

> Atmosphere-Ocean General Circulation Model ("AOGCM") simulations. This pattern is believed to describe some of the observed early 20th century (1920s-1930s) high-latitude Northern Hemisphere warming and some, but not all, of the high-latitude warming observed in the late 20th century. The term was introduced in a summary by Kerr (2000) of a study by Delworth and Mann (2000)."

That quote from RealClimate confirms that it takes 5 to 8 decades for the Atlantic Multidecadal Oscillation to run through a complete "cycle". It also notes that the additional variability of the North Atlantic "is believed to describe…some, but not all, of the high-latitude warming observed in the late 20th century." In other words, the Atlantic Multidecadal Oscillation is responsible for some but not all of the warming in the North Atlantic sea surface temperatures during the last 30 years.

There's also paleoclimatological evidence that the Atlantic Multidecadal Oscillation has existed for hundreds if not thousands of years. I presented the data associated with Gray et al (2004) **A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D.** in the blog post **Atlantic Multidecadal Oscillation Index Reconstruction**. More recently there's the paper Chylek et al (2012) **Greenland ice core evidence for spatial and temporal variability of the Atlantic Multidecadal Oscillation**. Chylek et al (2012) is hidden behind a paywall, but one of its conclusions has been quoted often around the blogosphere:

> *The observed intermittency of these modes over the last 4000 years supports the view that these are internal ocean-atmosphere modes, with little or no external forcing.*

RECAP

The Atlantic Multidecadal Oscillation is a mode of natural variability that impacts the sea surface temperature of the North Atlantic. When the sea surface temperatures of the North Atlantic are rising faster than global sea surface temperatures, as they have for the past few decades, the Atlantic Multidecadal Oscillation is contributing to the warming of the global oceans. Conversely, when the sea surface temperatures of the North Atlantic are rising slower than global sea surface temperatures, or when they're cooling, the Atlantic Multidecadal Oscillation is suppressing the warming of the global oceans. This will happen in the not-too-distant future, if it hasn't begun to do so already.

2.14 The Two Primary Data Sources

The primary sea surface temperature dataset used in this book is the **NOAA satellite-based Optimum Interpolation sea surface temperature data, version 2** (Reynolds OI.v2). Reynolds OI.v2 data on a monthly time series basis are available through the **NOAA NOMADS website**. It spans the last 30 years, starting in November 1981, and provides complete coverage of the global oceans and seas.

Additional data—land plus sea surface temperature, lower troposphere temperature, cloud cover, precipitation, longer-term HADISST sea surface temperature, Ocean Heat Content, etc.—are available through the **Royal Netherlands Meteorological Institute (KNMI) Climate Explorer**.

The NOAA NOMADS and the KNMI Climate Explorer websites are open to the public and are very easy to use. They are great resources.

2.15 Recap of Section 2

We'll be using four types of graphs in this book: times-series graphs, comparison graphs, zonal-mean graphs and meridional-mean graphs. Time-series graphs show how a variable changes with time. The comparison graphs will primarily be time-series graphs with more than one variable, allowing readers to witness how different variables change with time, and to see how some parts of the global oceans respond to ENSO events. There will be a few comparisons in the book using zonal-mean graphs, which show the values of variables in latitude bands. Meridional-mean graphs will be used to show the variables in longitude bands.

Linear trends are calculated from all of the data during a time period, and they represent the rate that a variable is changing with time.

One of the most commonly used references for the frequency, magnitude, and duration of El Niño and La Niña events is the sea surface temperature of an area in the east-central equatorial Pacific. The area is known as the NINO3.4 region and it is bounded by the coordinates of 5S-5N, 170W-120W.

Sea surface temperature anomalies and the anomalies of other variables are presented instead of "raw" data. Most "raw" climate data include a seasonal component with large variations. Most of these additional seasonal variations are removed when presenting data as anomalies, making it easier to see how a variable changes with time.

We will be presenting and discussing the outputs of climate models a few times. The climate model output we'll be using is the average of the multiple simulations from the multiple models that the IPCC used for its 4th and 5th Assessment Reports. That average is known as the multi-model ensemble mean, or model mean for short. That model mean represents the best estimate of how the climate models foresee a variable should be changing with time, assuming the changes in the variable were dictated by greenhouse gases and other manmade forcings. As we'll see later in this book, it's an erroneous assumption.

NINO3.4 sea surface temperature anomalies are the primary ENSO Index used in this book. It's used to note the timing, magnitude and duration of El Niño and La Niña events.

We'll be using satellite-based sea surface temperature data because the satellites measure the surface temperatures of the global oceans more completely than the datasets that rely only on temperature measurements from ships and buoys.

With “noisy” data, we’ll be smoothing the data with a simple running-average filter. Occasionally, we’ll also detrend the data.

Based on the performance of models driven with and without anthropogenic forcings, the IPCC represents that only manmade greenhouse gases could be responsible for the warming over the past 30 years. This book illustrates that the models are wrong. The satellite-based sea surface temperature records indicate that ENSO is responsible for the vast majority of the warming, with the Atlantic Multidecadal Oscillation contributing during the past 3 decades.

Another natural mode of sea surface temperature variation has impacted global surface temperatures over the past 30 years, and will be discussed later in this book. It is known as the Atlantic Multidecadal Oscillation or AMO. It can contribute to or suppress the warming of the global oceans associated with ENSO.

Section 3 - A More-Detailed Discussion of ENSO Processes

The cartoon-like annotated illustrations in Section 1 provided an overview of the processes of ENSO. The discussions in this section go into much more detail and use data to support them.

We'll keep the same order in this section, starting again with the trade winds and ocean currents, and then continuing on into the discussion of the ENSO process with the ENSO-neutral phase.

3.1 A Quick Look at the Size of the Pacific Ocean

Statistics never seem to do the Pacific Ocean justice. It covers about 32% of the surface of the Earth. That means the Pacific Ocean is larger than the combined surface areas of the continents. It stretches almost halfway around the globe at the equator. Superlatives like enormous, colossal and monumental don't seem large enough. As they say, seeing is believing. Try this. Open Google Earth on your computer and enter 0, -160, for the coordinates of 0 and 160W. After you hit enter, Google Earth will zoom in on a barren part of the Pacific Ocean floor. Back out until you get a complete image of the Globe. It should look similar to Figure 3-1.

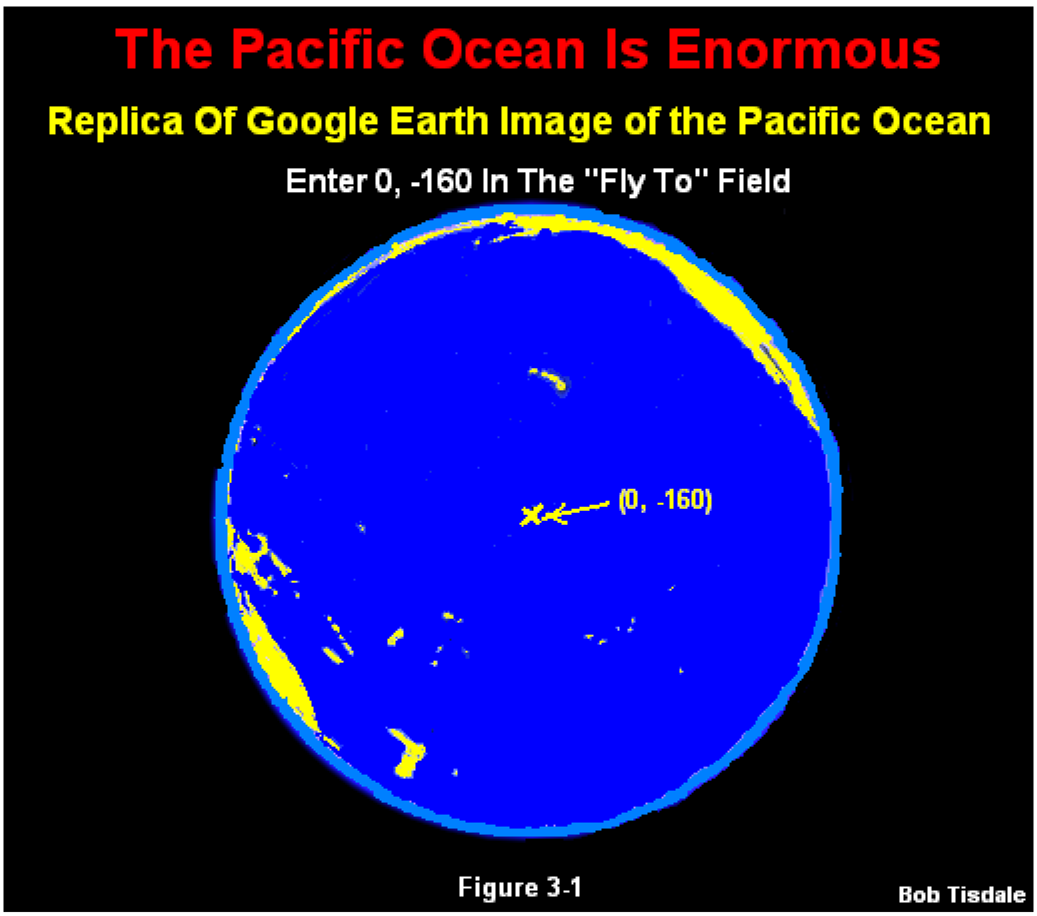


Figure 3-1

You'll see very little land. The North American coast is off to the north and northeast. New Zealand and part of Australia can be seen to the southwest. To the west is Indonesia. The coast of Asia makes a very limited appearance in the northwest. Other than islands, the rest is ocean, Pacific Ocean. If you'd like to see even less land, try the coordinates of -23, -135, or 24S, 135W, which will take you just northwest of the island of Mangareva. Now back out again until you can see the whole globe. There's even less land visible. It should make you wonder why this planet is called Earth. Apparently, someone with very limited knowledge of this planet named it.

Why are we spending so much time looking at the size of the Pacific Ocean? During discussions of ENSO, the size of the Pacific Ocean has to be kept in mind. It's tremendous. El Niño and La Niña events take place there, and, after explosive volcanic eruptions, they are the natural phenomena that have the greatest effects on global surface temperatures and weather.

3.2 Pacific Trade Winds and Ocean Currents

Trade winds are the prevailing surface winds in the tropics. They're called easterlies because they blow primarily from east to west. In the Northern Hemisphere, the trade winds travel from the northeast to the southwest, and they travel from southeast to northwest in the Southern Hemisphere.

The trade winds blow because the surface temperature is warmer near the equator than it is at higher latitudes. Refer to Figure 3-2 for the annual 2011 zonal-mean sea surface temperatures for the Pacific Ocean.

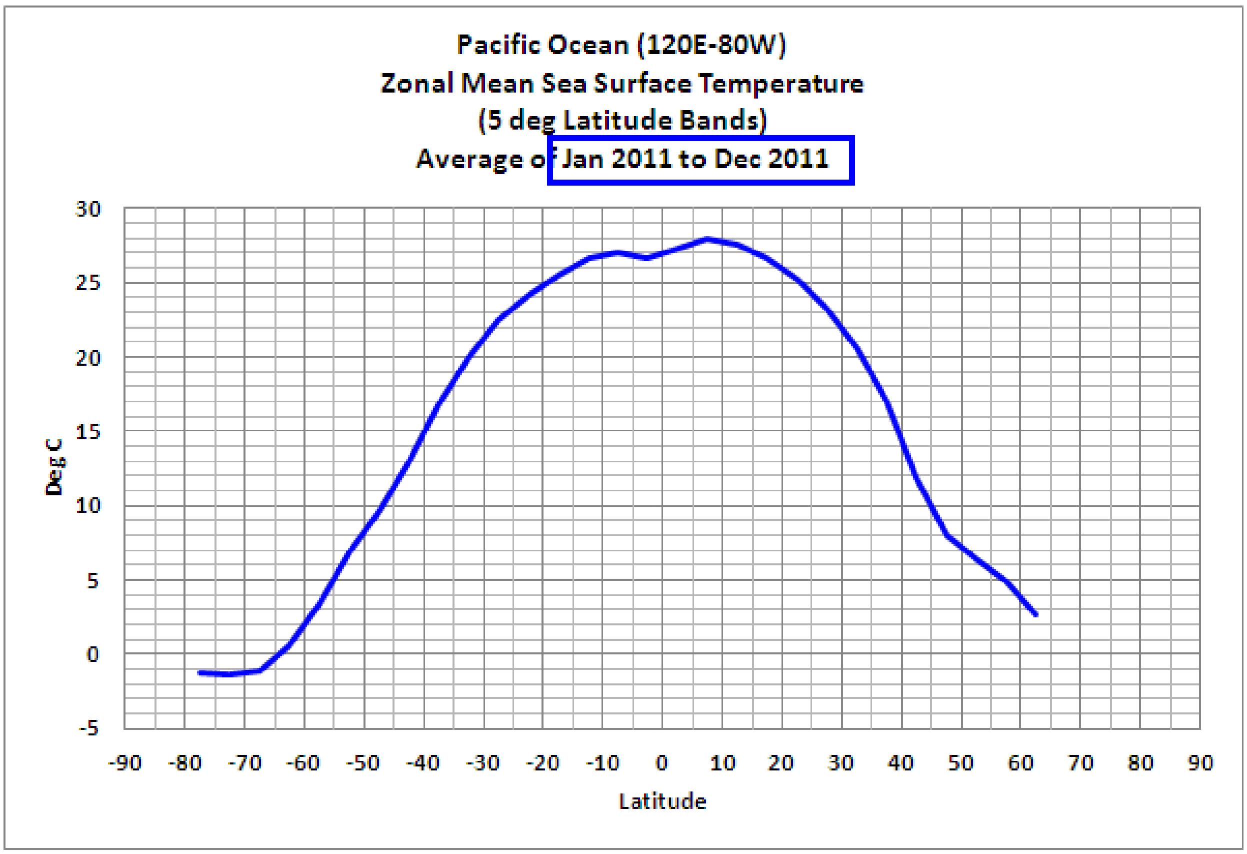


Figure 3-2 Bob Tisdale

Warm, moist air rises near the equator. This upward motion draws replacement surface air from the north in the Northern Hemisphere and from the south in the Southern Hemisphere. In other words, the air at the surface is being drawn toward the equator due to the updraft there. In turn, the equatorward surface winds need to be replaced, and that cool, dry air is drawn down from higher altitudes at about 30N and 30S. Upper winds traveling poleward from the equator complete the circuit. That circuit is called a Hadley Cell. See Figure 3-3. Because the Earth is rotating, the equatorward surface winds are deflected toward the west by the Coriolis force.

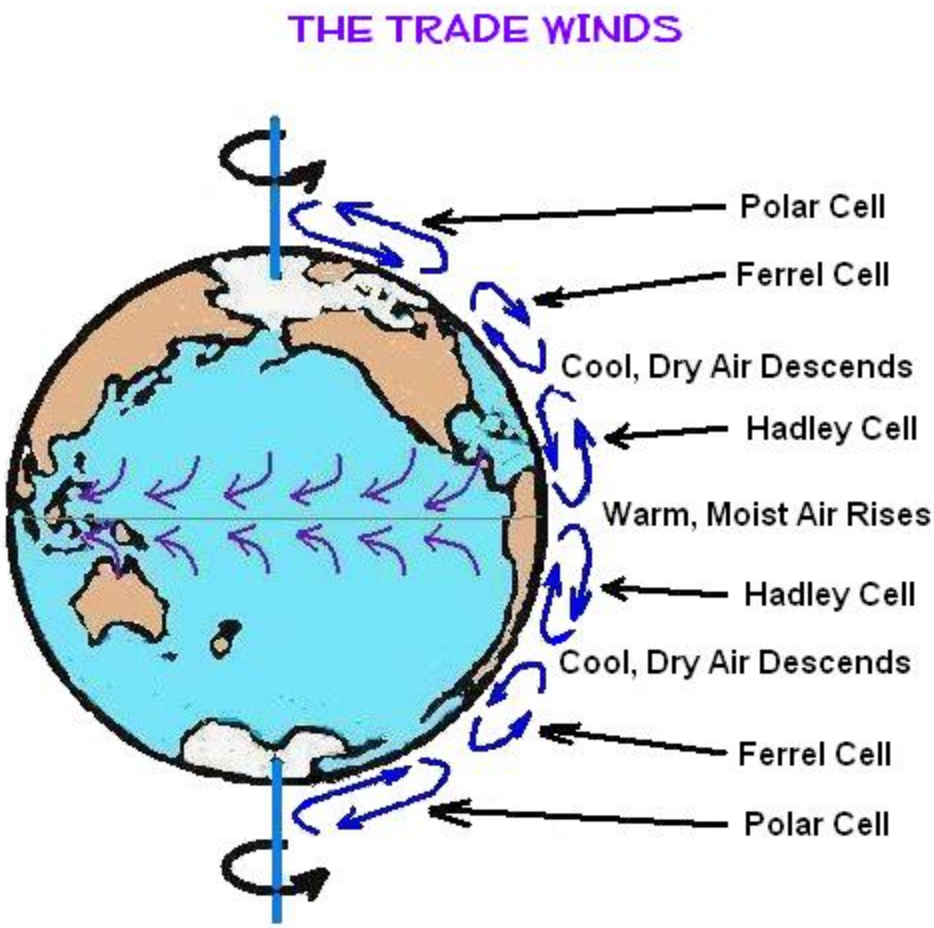


Figure 3-3 Bob Tisdale

We can explain the Hadley Circulation another way, if you prefer. We'll start again near the equator where warm, moist air rises. It travels poleward at an altitude of 10 to 15 kilometers (32,800 to 45,800 feet) losing heat and moisture along the way. The cooler, dryer air then drops back toward the surface in the subtropics at about 30N and 30S. The surface winds then complete the circulation pattern. If the Earth was not rotating, the tropical surface winds would be out of the north in the Northern Hemisphere and out of the south in the Southern Hemisphere. Because the Earth is rotating, however, the tropical surface winds—the trade winds—are deflected toward the west.

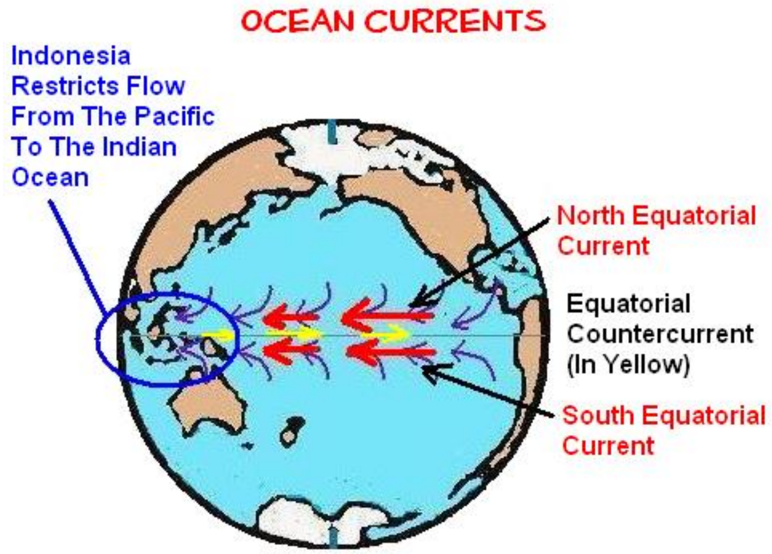


Figure 3-4

The prevailing tropical winds are, therefore, from east to west. They blow across the surface of the tropical Pacific Ocean, dragging the surface waters along with them. There are two surface currents as a result, traveling from east to west, one per hemisphere. They are logically called the North and South Pacific Equatorial Currents. There is a smaller surface current flowing between them that returns some of the water back to the east and it's called the Equatorial Countercurrent. See Figure 3-4.

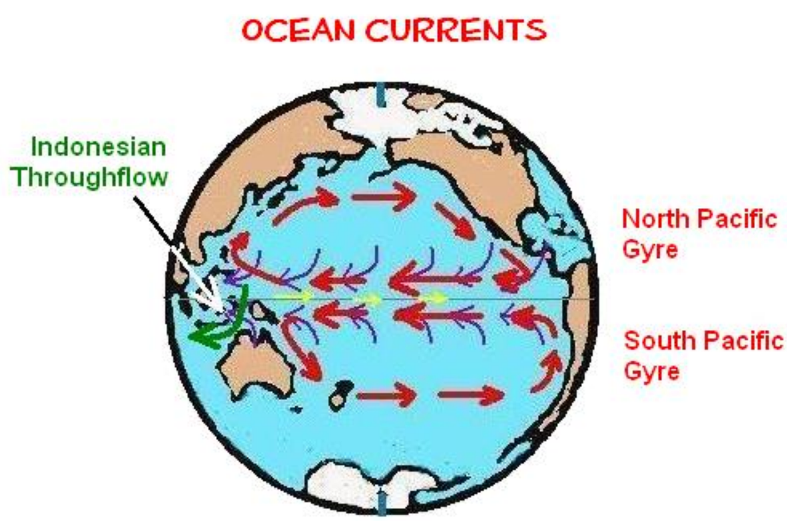


Figure 3-5

The Equatorial Currents carry the waters across the tropical Pacific. Then they encounter Indonesia, which restricts continued flow to the west. Some of the water is carried through all of the islands to the Indian Ocean by a surface current called the Indonesian Throughflow. As noted above, a little of the water is carried east by the Equatorial Countercurrent. The rest of the water is carried poleward. The overall systems of rotating ocean currents in the Northern and Southern Hemispheres are known as gyres. Gyres exist in all ocean basins. The ones in Figure 3-5 are called the North Pacific Gyre and the South Pacific Gyre.

The NASA Ocean Motion website is a great resource for entry-level discussions of ocean currents. Refer to their **Home** and **Wind Driven Surface Currents: Equatorial Currents Background** web pages. Take a tour; there's lots of interesting information there.

3.3 Putting the Equatorial Pacific Cross Sections in Perspective

The next discussion is about part of the illustrations used in the following chapters about ENSO. We need to put their equatorial Pacific cross sections into perspective. See Figure 3-6. It's an incomplete illustration from a "normal" or "ENSO Neutral" period, meaning a period without an El Niño or La Niña event. During an ENSO-neutral period, the waters in the western tropical Pacific near Indonesia are about ½ meter higher in elevation than the waters in the eastern tropical Pacific near South America. That difference in elevation plays a role in an El Niño event, so it needs to be illustrated. The areas where warm and cool waters exist below the surface of the equatorial Pacific also need to be shown. Unfortunately, the variations we're trying to illustrate take place in the top 300 meters, and that creates a conflict when trying to show the ½ meter elevation and the 300 meter depth on the same illustration. Then there's the width of the Pacific Ocean at the equator. It's more than 16,000 km wide. Its massive dimension plays a role, too. In short, the dimensions in the cross sections are skewed, but there are reasons to show them on the same illustration.

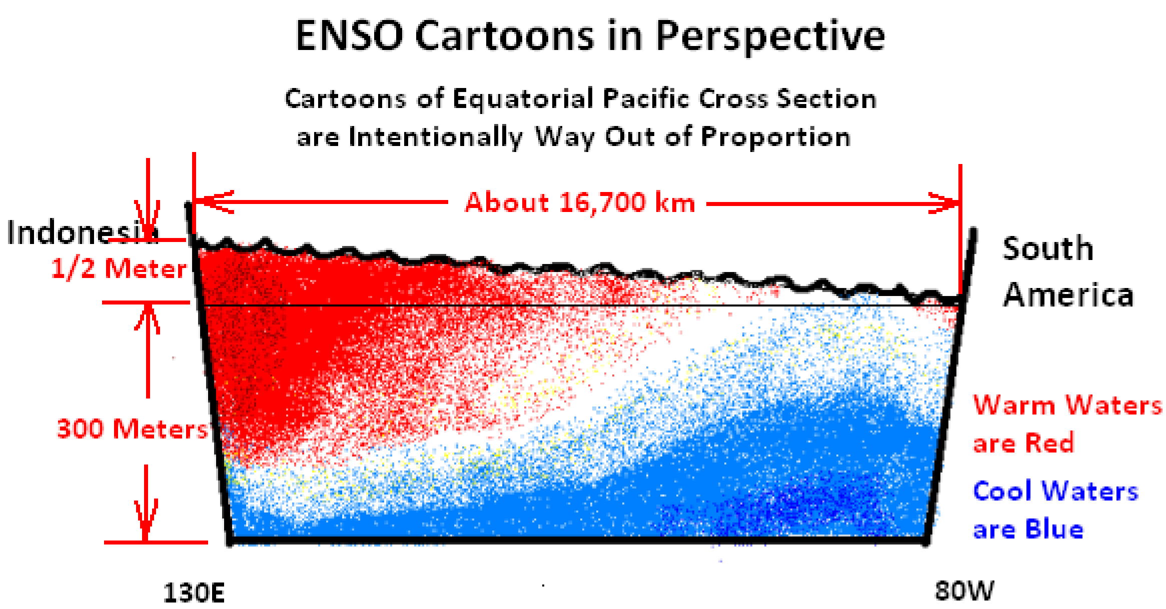


Figure 3-6

There are dozens of illustrations on the internet that show similar cross sections of the equatorial Pacific. Some are in two dimensions, others in three. Other than the illustrations in my first book, I do not recall ever seeing one that includes the sun. The sun plays a major role in the process of ENSO, so I've included a bright yellow object in the top part of the equatorial Pacific cross-sections that follow—simply as a reminder.

3.4 The ENSO-Neutral State of the Tropical Pacific

Let's start with the "normal" or ENSO-neutral state of the tropical Pacific. Refer to the illustration in Figure 3-7. As discussed earlier, this is the state of the tropical Pacific between El Niño and La Niña events.

The trade winds drive the tropical Pacific surface currents from east to west. The sun is strong in the tropics so it warms the water as it is carried westward by the ocean currents.

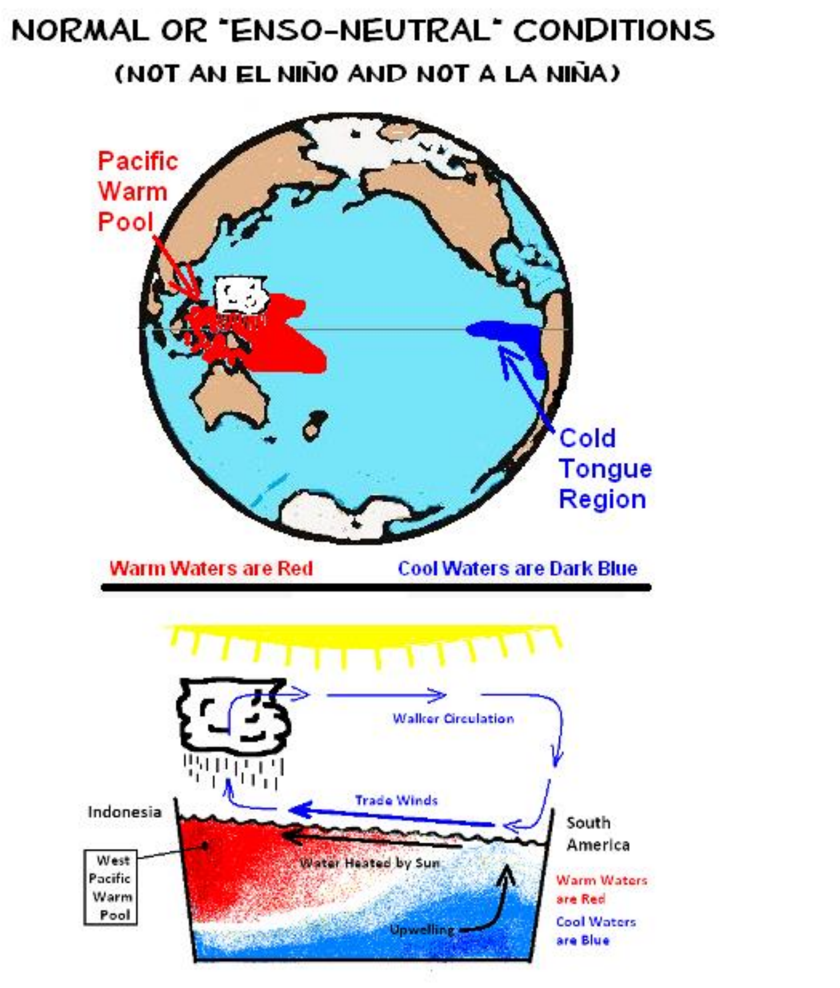


Figure 3-7

The warming water travels far across the tropical Pacific Ocean, and then it runs into Indonesia. The wind-driven water has to go somewhere. Some of the warm water is carried north and south by the **Western Boundary Currents** of the North and South Pacific gyres shown in Figure 3-5. Some of the warm water is carried into the Indian Ocean by a current called the **Indonesian Throughflow**. A little of the water is circulated back toward the east by the Equatorial Countercurrent, and some of the warm water accumulates in an area of the western tropical Pacific called the west Pacific Warm Pool. (It's known by a few other names, one of which is the Indo-Pacific Warm Pool, because it extends into the Indian Ocean.) That accumulating warm water can reach depths of 300 meters. We're interested in that pool of warm water as part of the preliminary ENSO discussion, because it supplies the "fuel" for an El Niño event.

Back towards South America, cool subsurface water is drawn to the surface along the equator in a process called upwelling.

With all of that water being pushed to the west, warming, and then accumulating in the west Pacific Warm Pool, the surface of ocean in the western tropical Pacific near Indonesia is about ½ meter higher than it is in the eastern tropical Pacific near South America. It's quite a balancing act: all of that warm water is being held in place by the trade winds.

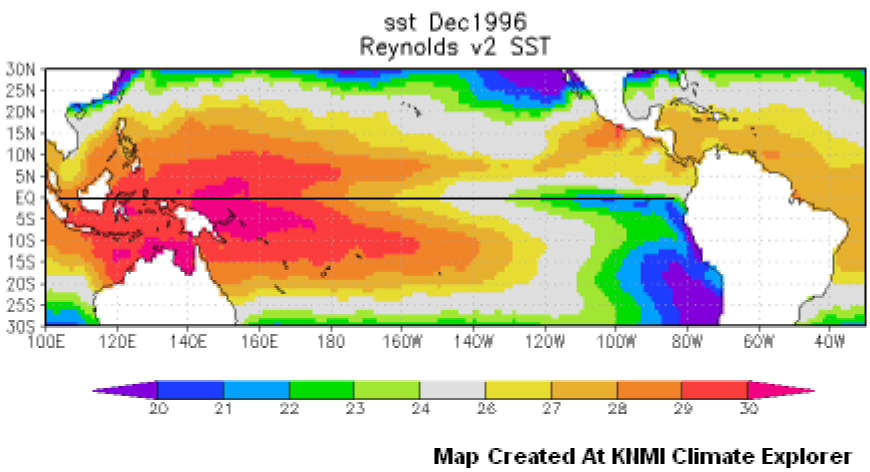


Figure 3-8 Bob Tisdale

The sea surface temperature map (not anomalies) in Figure 3-8 shows the west Pacific Warm Pool. It also illustrates the difference in the surface temperature between the east and west portions of the equatorial Pacific. The map presents the sea surface temperatures in December 1996, when the tropical Pacific was in an ENSO-neutral state. I've highlighted the equator with a thin black line. Let's assume for discussion that the dimensions of the west Pacific Warm Pool are defined by those areas with sea surface temperatures of 29 deg C and higher, or the dark orange and hot pink locations. (For those who are more familiar with the Fahrenheit scale, that's about 84 deg F.) That's an extremely large area of warm water that serves as the fuel for an El Niño. It is also 300 meters (almost 1,000 feet) deep in some locations. Also, notice the surface temperatures in the east along the equator. They're in the range of 20 to 22 deg C, but in the west they're in excess of 30 deg C in places. That's an 8 to 10 deg C temperature difference. As a reminder, the temperature difference is caused by the trade winds, the sun, and by the upwelling of cool subsurface waters in the east.

The map of tropical Pacific sea surface temperatures in Figure 3-8 is for the month of December 1996. That's one year before the peak of the 1997/98 El Niño, which was the strongest El Niño of the 20th Century. December 1996 is also 2 years before the seasonal peak of the 1998/99 portion of the 1998/99/00/01 La Niña event. We'll be using that December 1996 map as a reference for upcoming comparisons with the sea surface temperatures during those ENSO events.

The map in Figure 3-8 is useful because it confirms and clarifies the cartoon-like image in Figure 3-7. We can also illustrate the change in sea surface temperature from west to east along the equator (5S-5N) using a meridional-mean graph, Figure 3-9. It also is for December 1996, a year before the peak of the 1997/98 El Niño. It reinforces our understanding that the sea surface temperatures are much greater in the western equatorial Pacific than in the eastern portion during an ENSO-neutral month.

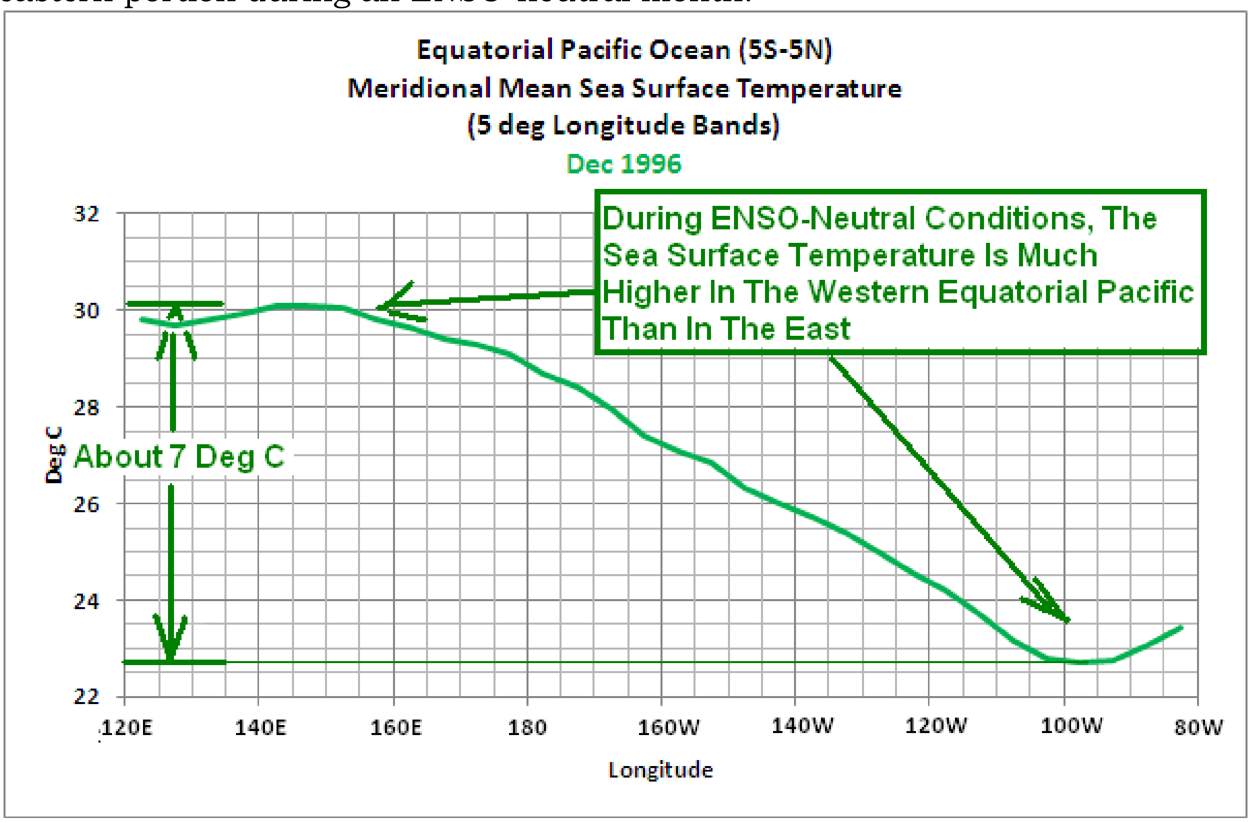


Figure 3-9 Bob Tisdale

Clouds with rain are shown over the western tropical Pacific in Figure 3-7. There are blue arrows noting the atmospheric circulation. Let's discuss the atmospheric circulation first.

The trade winds cause the difference in sea surface temperature between the eastern and western tropical Pacific because the trade winds push the warm water to the west and cause the upwelling of cooler waters in the east. Then again, the temperature difference between the east and west portions of the tropical Pacific also causes the trade winds to blow. This happens because the warmer water in the west heats the air above it and warm air tends to rise. That rising air has to be replaced by other air and the trade winds supply that air. Because the tropical Pacific sea surface temperatures affect the trade winds and the trade winds affect the sea surface temperatures, the oceans and the atmosphere are interrelated. Sea surface temperatures and the atmosphere are constantly communicating. You'll often see the word "coupled" used to describe the interdependence of trade winds and sea surface temperature. In fact, you'll often see ENSO called a coupled ocean-atmosphere process. By reinforcing one another, the coupled trade winds and temperature gradient from west to east provide positive feedback, known as Bjerknes feedback. The positive feedback is one of the key features of ENSO dynamics.

Bill Kessler of the NOAA **Pacific Marine Environmental Laboratory** provides a more detailed description of the chicken-and-egg relationship between the trade winds and the tropical Pacific sea surface temperature at his ENSO FAQ webpage **here**. It is worth reading.

Now for the clouds and rain in the cartoon-like illustration: The oceans release heat primarily through evaporation. Logically, most of the evaporation takes place where the water is warmest—in the western tropical Pacific. That moist air rises, it cools as it rises, and that causes it to condense and form clouds. There's a more detailed discussion of this process at the WeatherQuestions webpage **How do Clouds Form?**

Further to this, Bill Kessler of NOAA writes in his FAQ webpage:

> *Note that the rising air over the western Pacific is associated with rainfall (see the figure of rainfall and winds just above). When air rises it cools, and can hold less evaporated water. The water comes out as rain. But in returning to a liquid state, it releases the heat that was used to evaporate it from the ocean surface (heat that came from the sun), and this middle atmosphere heating amplifies the rising motion. This is a principal mechanism for heat from the sun to warm the atmosphere (the atmosphere by itself is relatively transparent to solar radiation).*

Walker circulation (or Walker cell) is the name for the tropical air circulation pattern illustrated in Figure 3-7, where it rises in the west, sinks in the east, and is connected by the westward trade winds at the surface and the eastward upper winds.

Now the reason for the sun in Figure 3-7: It's there to remind us that the sun heats the ocean. Sunlight (downward shortwave radiation) not only warms the surface, but it also reaches deep into the oceans. Most of the sunlight is absorbed in the top 10 meters of the ocean, but it does reach depths of 100 meters. Cloud cover limits the amount of sunlight reaching and warming the ocean, and cloud cover is impacted by the strength of the trade winds. Strong trade winds reduce cloud cover by pushing the clouds farther to the west; this allows more sunlight to shine down and warm the tropical Pacific. With weaker trade winds, there is more sun-blocking cloud cover and less sunlight warming the tropical Pacific Ocean.

There is another very well-known aspect of ENSO, and it relates to the surface pressure of the air in the eastern and western tropical Pacific. The difference in surface air pressure is measured and serves as an ENSO index called the Southern Oscillation Index. We'll discuss this later. We've got enough variables to be concerned with right at the moment without adding sea level pressure.

RECAP

So far we've briefly discussed the interrelationships between sea surface temperatures, trade winds, subsurface ocean temperatures, precipitation, clouds, and the amount of sunlight (downward shortwave radiation) reaching the ocean. All of those variables are interrelated. In other words, they are coupled. If someone were to start a description of ENSO with the sentence, "ENSO is a coupled ocean-atmosphere process", you would now have a basic idea of the roles played by the ocean and atmosphere—along with the sun. Those roles should become clearer with the discussions of El Niño and La Niña events.

3.5 The Transition from ENSO-Neutral to El Niño

While the tropical Pacific is in the ENSO-neutral phase, the trade winds push the warm water to the west so that sea level there is higher than it is in the east. The sea level would like to be the same height because of gravity, but the trade winds are holding all of that warm water in place. The trade winds are being reinforced by the warmer sea surface temperatures in the western tropical Pacific. Similarly, the warmer waters in the western tropical Pacific are being reinforced by the trade winds. They are providing positive feedback to one another (Bjerknes feedback). With the positive feedback, the tropical Pacific would tend to stay in the ENSO-neutral mode. Something has to force things to change.

The trade winds in the western Pacific are, like all winds, quite variable. They strengthen and weaken with changes in weather. The size and shape of the Pacific Warm Pool varies in response. However, under "normal" conditions, the trade winds continue to hold the warm water in the western tropical Pacific.

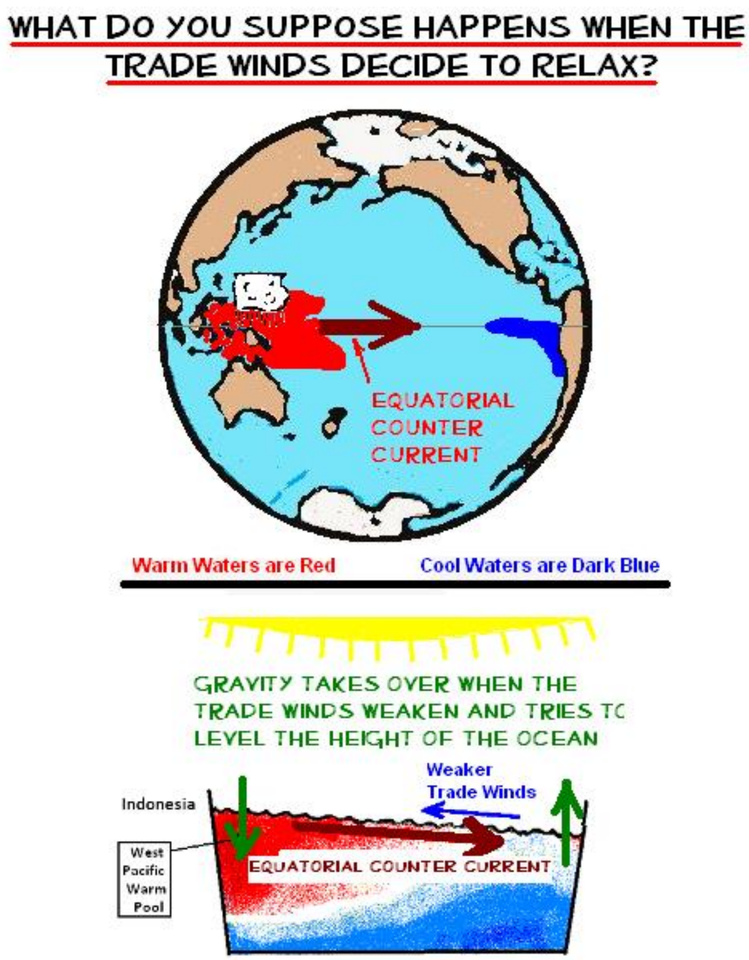


Figure 3-10 Bob Tisdale

Suppose the trade winds were to weaken to the point, and weaken long enough, that they could no longer hold the warm water in place in the west Pacific Warm Pool. The water would slosh to the east.

That's how an El Niño event starts. Figure 3-10 shows the ENSO-neutral conditions changing to El Niño.

As shown in Figure 3-10, the Equatorial Countercurrent in the Pacific carries the warm water eastward. Normally, it's a relatively small current compared to the North and South Equatorial Currents, but during an El Niño, the Pacific Equatorial Countercurrent becomes much larger. See Figure 3-11.

Figure 3-11 presents maps that show the direction of the currents in the central portion of the tropical Pacific. The eastward-flowing Equatorial Countercurrent is shown in dark blue. The westward-flowing North and South Equatorial Currents are shown in the off-color green. The top map shows the relatively small Equatorial Countercurrent in December 1996, which was an ENSO-neutral month. The bottom map shows that it's much larger near the peak of the 1997/98 El Niño in December 1997. The maps are available through the **NASA Ocean Motion** website, at their **OSCAR** webpage.

A couple of years ago, I used those maps of the tropical Pacific Ocean currents to create a series of animations that I presented on YouTube. The animations capture the strengthening of the Equatorial Countercurrent during the transition from ENSO-neutral phase to the 1997/98 El Niño phase and its subsequent weakening as the El Niño event transitions back toward ENSO-neutral. Because there are multiple animations showing different portions of the tropical Pacific, I'll refer you to the post **Equatorial Currents Before, During, and After The 1997/98 El Niño**.

HHH

A NOTE ABOUT THE LINKS TO THE ANIMATIONS

If you're reading the .pdf and Kindle-for-PC editions of this book, the links should work and the animations should open in a separate window. If you're reading the Kindle version on a Kindle Reader, as far as I know, the links will not operate, so you'll have to switch to your computer and visit my blog to view the animations. Input the title of the post **Animations Discussed in "Who Turned on the Heat?"** into your search engine. There you'll find the same introductions to the animations along with links.

HHH

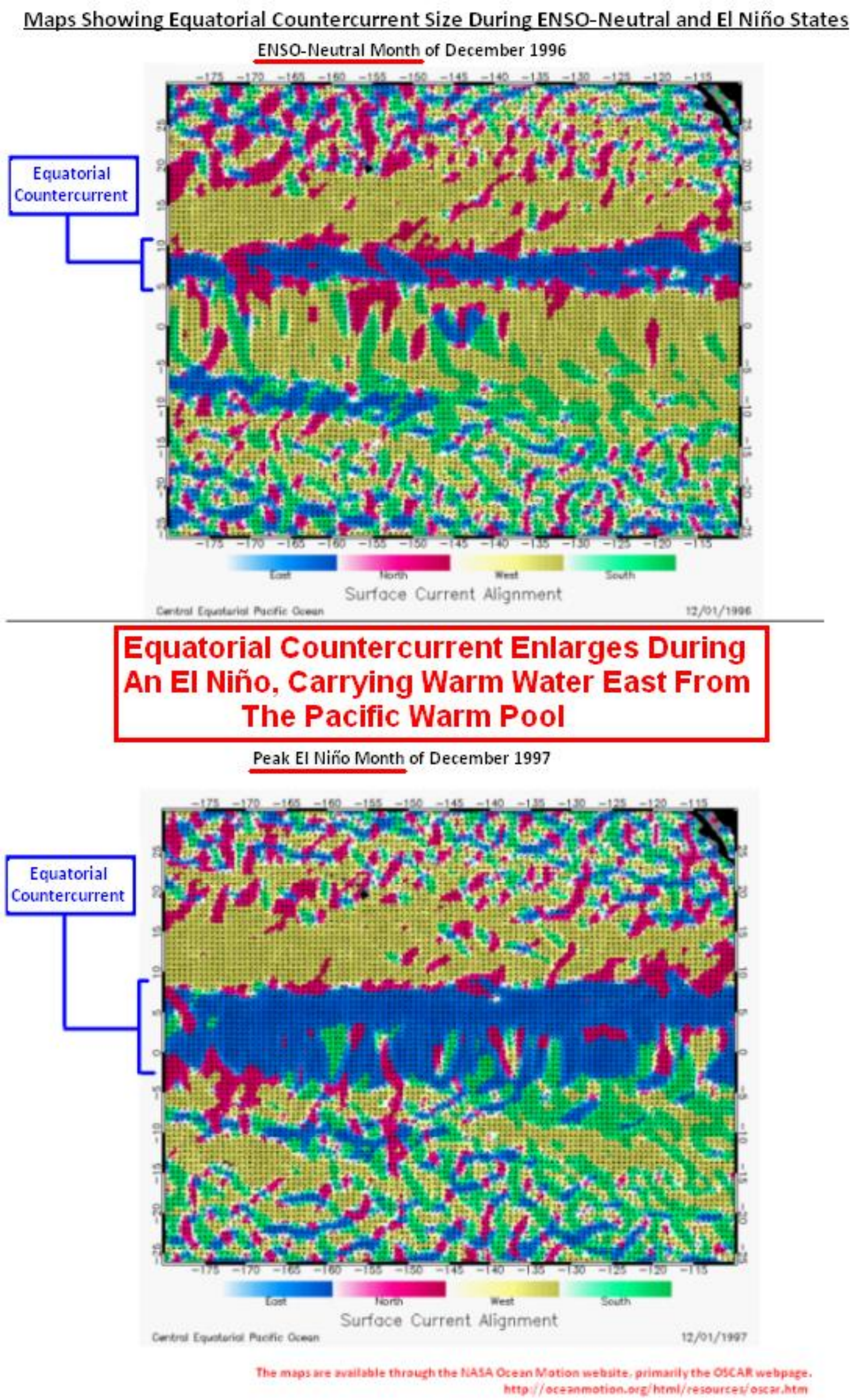


Figure 3-11 Bob Tisdale

Figure 3-12 compares two ENSO-related variables: western equatorial Pacific trade wind strength and NINO3.4 sea surface temperature anomalies, our ENSO index. The NINO3.4 sea surface temperature anomalies have been scaled and inverted (multiplied by a scaling factor of -2.0) so that the variations in both datasets are in the same direction. That is, the El Niño events are now the large downward spikes. The western equatorial Pacific trade wind data is from the NOAA/Climate Prediction Center **Monthly Atmospheric & SST Indices webpage**. There it's identified as "850 mb Trade Wind Index (135°East-180°West) 5°North-5°South West Pacific". The Trade Wind Index data presented in the graph are the anomalies, which are the second group **here**. As illustrated, the El Niño events are preceded by significant drops in western equatorial Pacific trade wind strength.

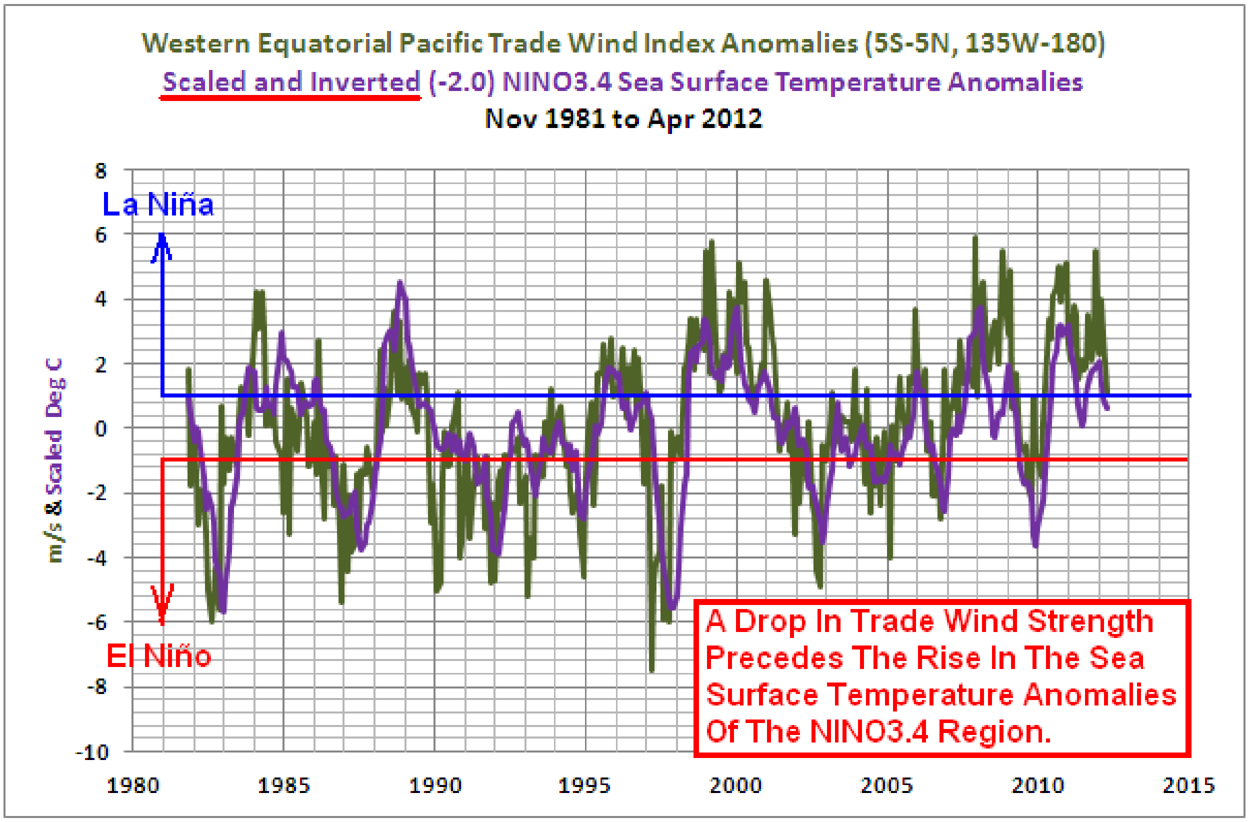


Figure 3-12

Bob Tisdale

RECAP

In Figure 3-11, we confirmed that the Equatorial Countercurrent enlarges during an El Niño, carrying the warm water from the Pacific Warm Pool eastward. The dark green curve of the trade wind anomalies leads the sea surface temperature in Figure 3-12. This confirms that a weakening of the trade winds in the western tropical Pacific happens a number of months before the NINO3.4 sea surface temperature anomalies register the El Niño event. In other words, it takes a couple of months after the weakening of the west Pacific trade winds for the enlarged Equatorial Countercurrent to carry the warm water east so that it warms the sea surface temperatures of the NINO3.4 region.

We'll expand on this discussion, introducing a phenomenon called a Kelvin wave, in **Chapter 4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves.**

3.6 El Niño Phase

During an El Niño, warm water that was once below the surface of the Pacific Warm Pool is spread across the surface of the central and eastern tropical Pacific. The warm water now covers a much larger surface area. Refer to the maps in Figure 3-13. Those maps show the sea surface temperatures (not anomalies) during the ENSO-neutral month of December 1996 (top map) and the sea surface temperatures in December 1997, at the peak of the 1997/98 El Niño (bottom map). The dark orange color indicates water temperatures from 29 to 30 deg C. That warm water extends much farther to the east during the El Niño. Note also how the cold tongue in the east along the equator disappeared then, too.

Sea Surface Temperature during ENSO-Neutral and El Niño Months

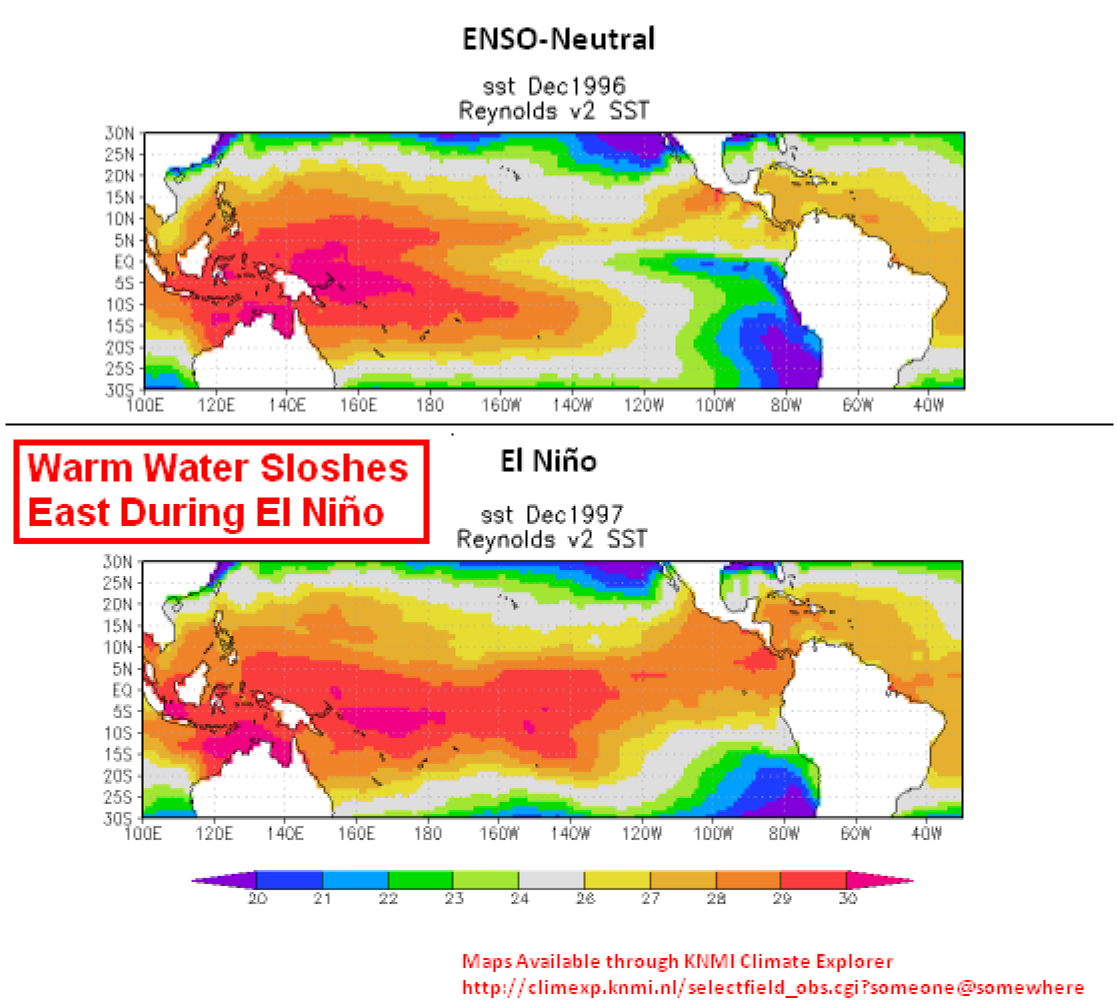


Figure 3-13 Bob Tisdale

We can illustrate the change in sea surface temperatures across the equatorial Pacific using a meridional-mean graph. Figure 3-14 compares the equatorial sea surface temperatures (5S-5N) in 5 degree longitude bands for the months of December 1996 (ENSO-neutral month) and December 1997 (peak of 1997/98 El Niño). In December 1996, the warmest sea surface temperatures were in the western equatorial Pacific, but during that El Niño (December 1997), the warmest water is in the central equatorial Pacific. Notice also how the greatest change in temperature over those 12 months took place in the eastern equatorial Pacific. That doesn't happen during every El Niño event. We'll discuss that further in **Chapter 4.2 Central Pacific versus East Pacific El Niño Events**.

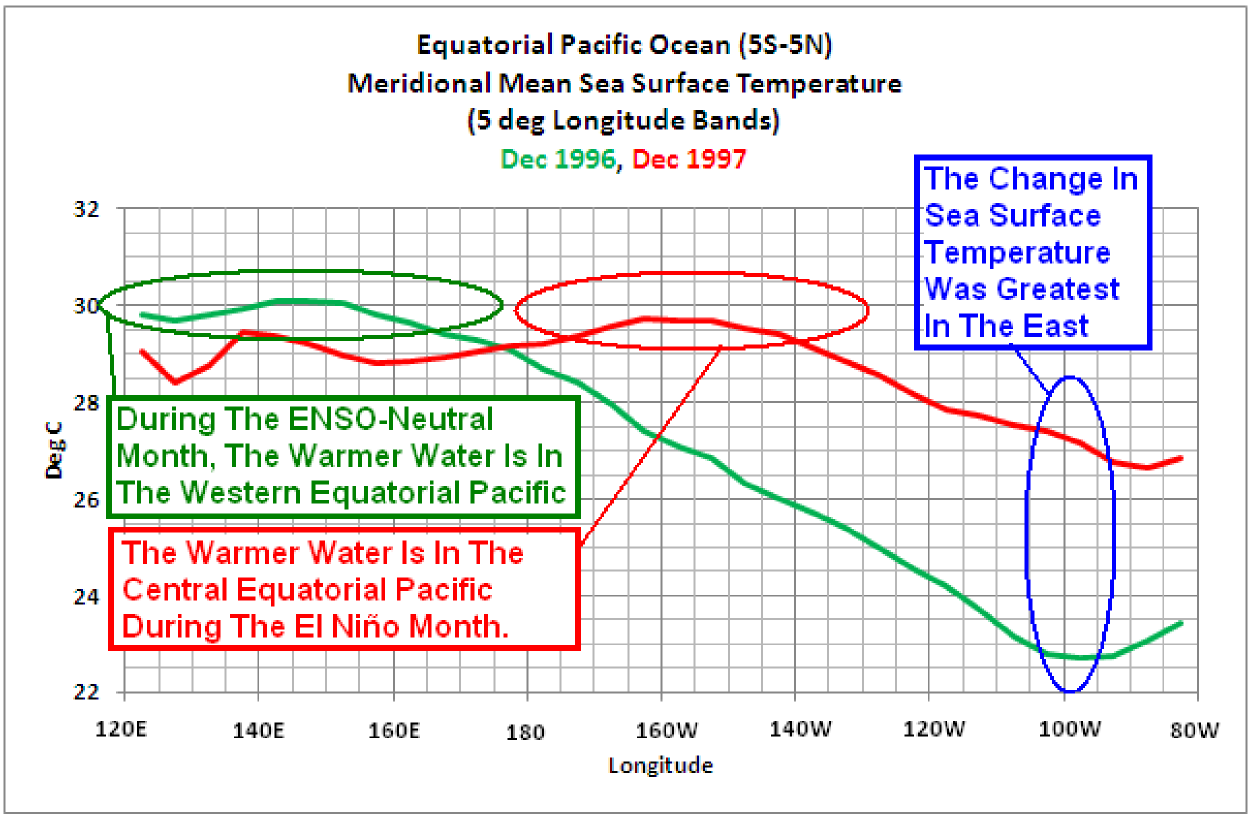


Figure 3-14

Bob Tisdale

We can also show that the sea surface temperatures warmed more in the eastern equatorial Pacific than they cooled in the west using a graph of sea surface temperature anomalies on a meridional-mean basis. See Figure 3-15. This implies that the surface waters in the western equatorial Pacific were responsible for only a small part of the warming of sea surface temperature anomalies in the east. The warm water had to come from somewhere, and if it wasn't all supplied from the surface of the western tropical Pacific, it must have come from below the surface of the west Pacific Warm Pool. Let's confirm that.

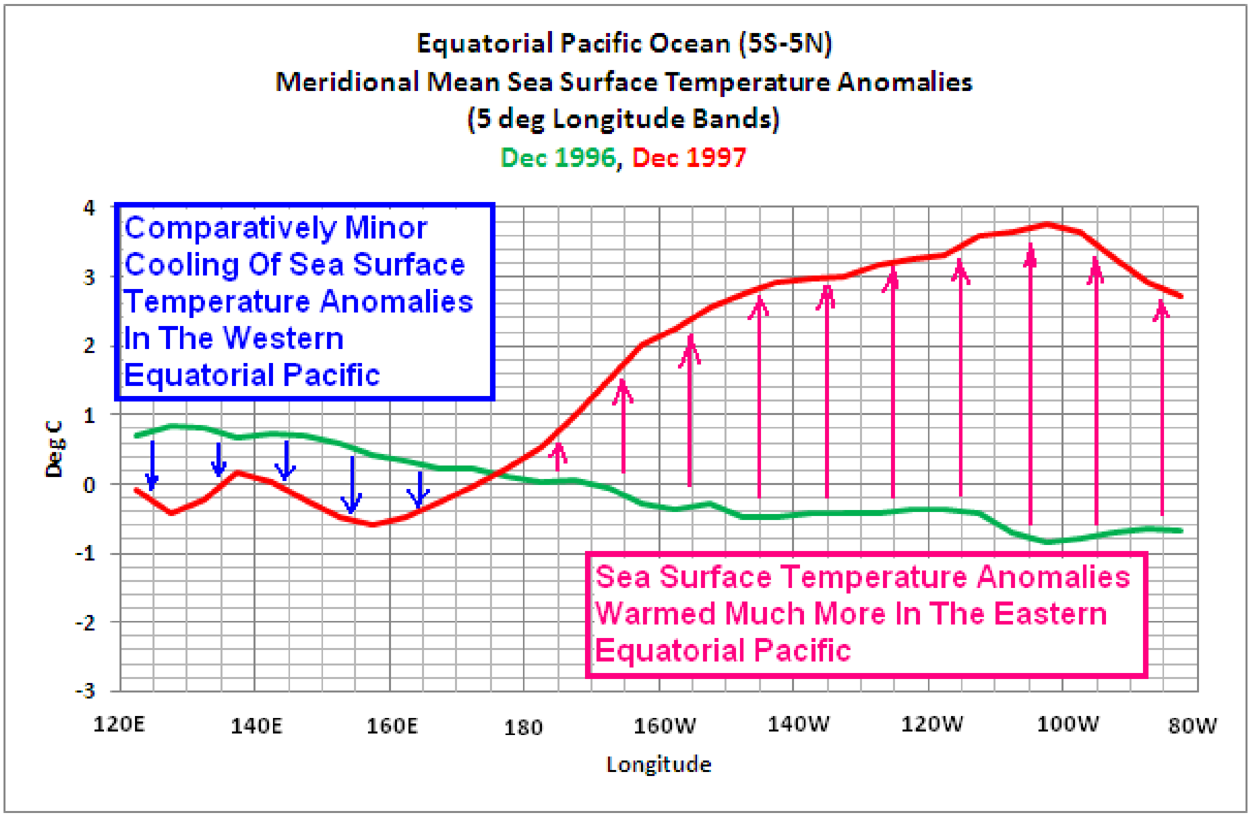


Figure 3-15 Bob Tisdale

Sea level anomalies represent, in part, the temperature of the column of water from the surface to the floor of the ocean. Figure 3-16 compares December 1996 (ENSO-neutral) and December 1997 (peak of the 1997/98 El Niño) sea level anomalies for the equatorial Pacific on a meridional-mean basis. As shown, the decrease in western equatorial sea level is comparable to the rise in sea level in the east. Because we've already established that the warm water in the east didn't all come from the surface in the west, the change in sea level strongly suggests that the warm water that supplies the El Niño comes from the surface AND below the surface of the west Pacific Warm Pool. Also note how much sea level anomalies changed along the eastern equatorial Pacific between Decembers 1996 and 1997. At 85W longitude, the change was about 39 cm or 15 inches. A colossal volume of warm water changed location during the 1997/98 El Niño.

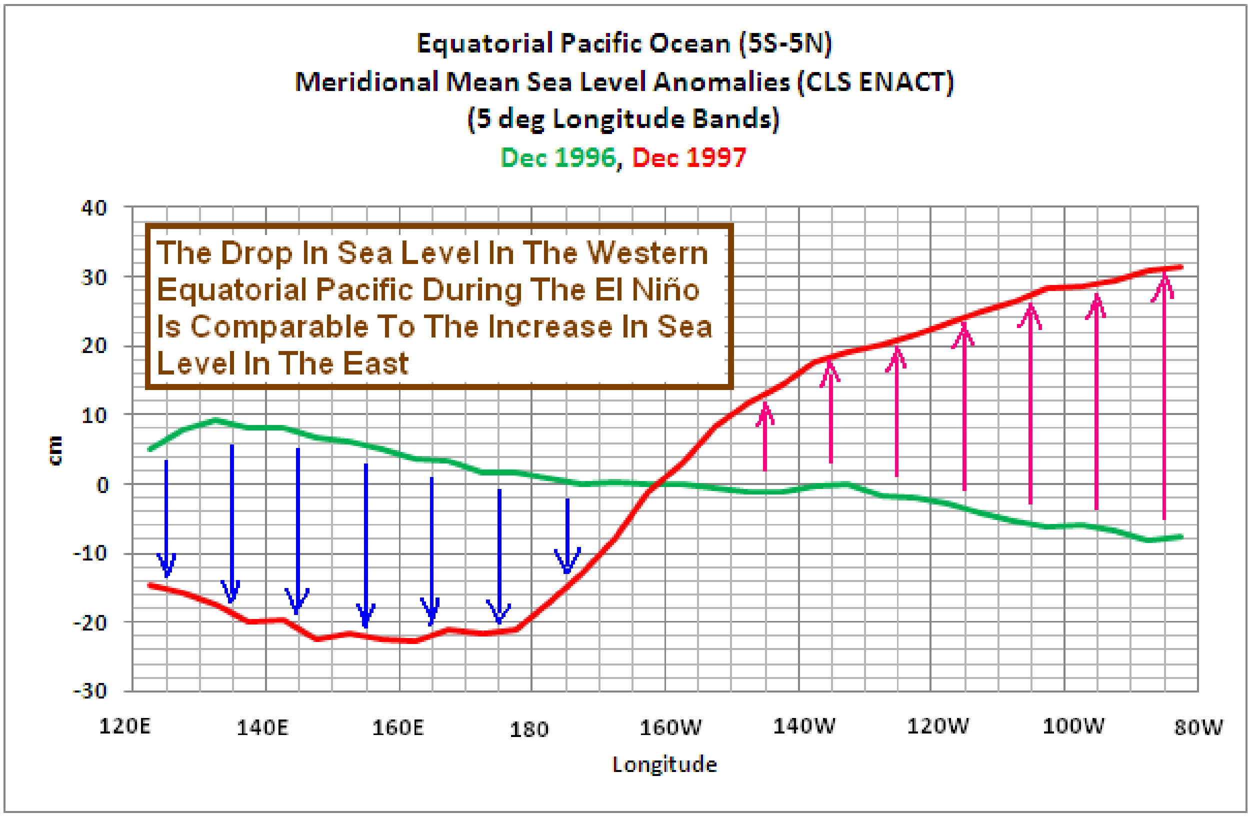


Figure 3-16

Bob Tisdale

The sea level anomaly maps in Figure 3-17 help to show the effect of the 1997/98 El Niño had on the amount of warm water in the Pacific Warm Pool. Prior to the El Niño in December 1996, the sea level anomalies were slightly elevated north of Australia and along the South Pacific Convergence Zone (SPCZ) that extends to the southeast from the Pacific Warm Pool. Then, a year later, the Pacific Warm Pool anomalies dropped significantly, because the warm water was carried to the east, where it raised sea level anomalies. The maps also show that much more than the equatorial Pacific can be directly impacted by an El Niño.

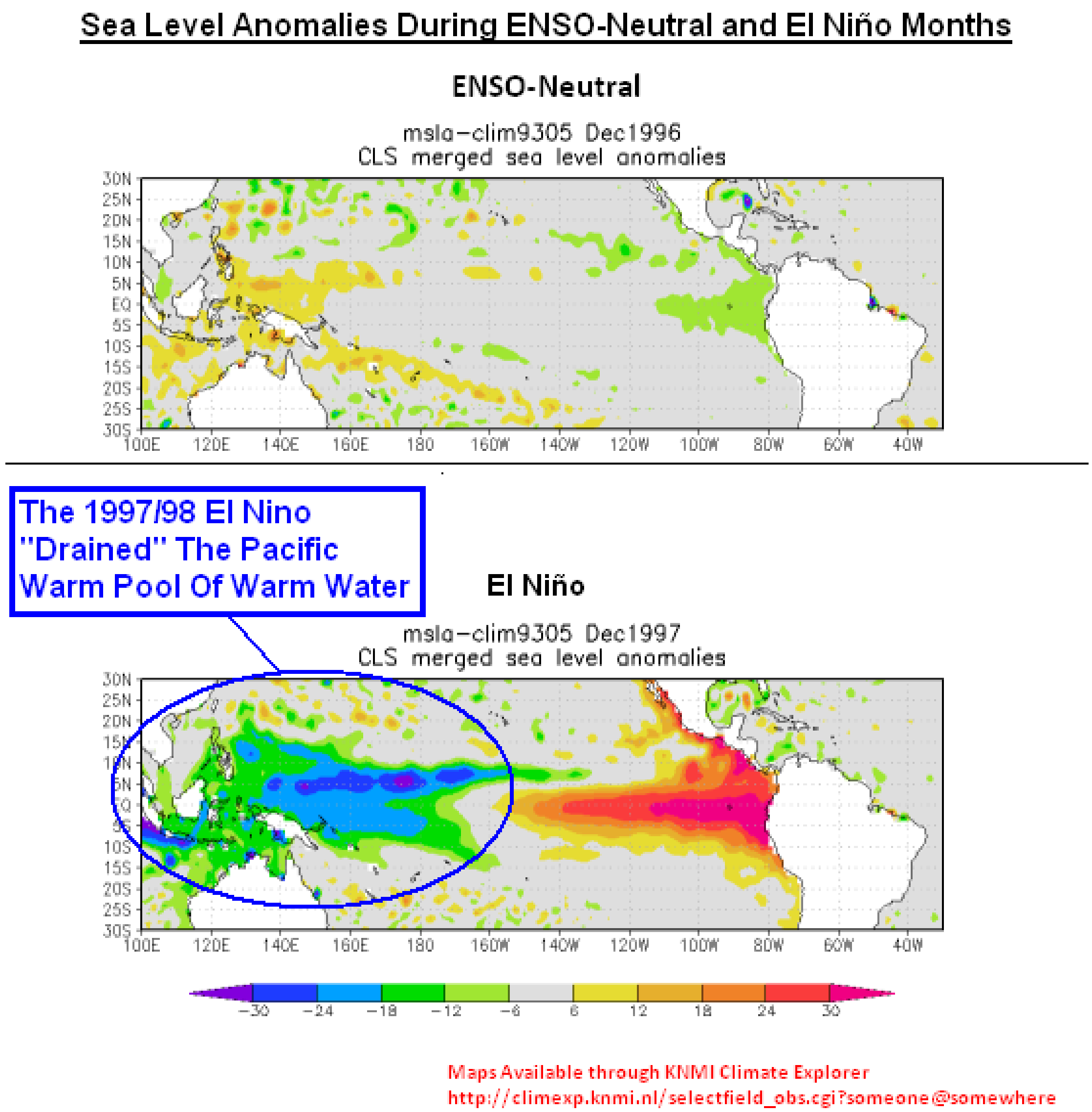


Figure 3-17 Bob Tisdale

As the warm water sloshes to the east during the El Niño, the evaporation, the cloud cover, and the precipitation accompany it. Refer to Figure 3-18. The warm air is still rising, but it's doing it much farther to the east than it was under "normal" conditions. Westerly winds from the western tropical Pacific feed the rising air, again with the positive feedback. Because the temperature difference between the east and west parts of the tropical Pacific has decreased during the El Niño, the trade winds in the east weaken.

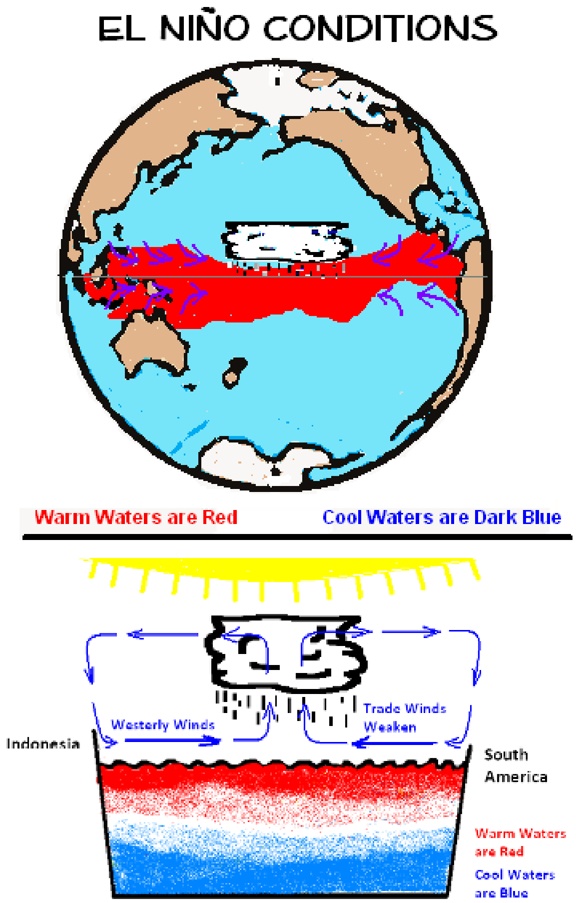


Figure 3-18

Bob Tisdale

RECAP

The El Niño phase is the truly unusual or anomalous state of the tropical Pacific. Trade winds weaken and reverse to become westerly winds. The warm water from the west Pacific Warm Pool travels east and spreads across the surface, sometimes as far as the coast of the Americas. We confirmed the warm water that fuels the El Niño comes primarily from below the surface of the west Pacific Warm Pool.

The evaporation, cloud cover, and rain accompany the warm water to the east. As we'll discuss in an upcoming chapter, the relocation of those processes from the Pacific Warm Pool to the central and eastern tropical Pacific upsets atmospheric circulation patterns globally. Let's continue on with the ENSO processes before we discuss that.

3.7 The Transition from El Niño to ENSO Neutral

El Niño events peak in December and this appears to be related to the seasonal cycle of sea surface temperatures in the western Pacific. This is discussed further in **Chapter 4.7 ENSO Events Run in Synch with the Annual Seasonal Cycle**.

That aside, there are a number of reasons why an El Niño ends. Two are presented now. There is a third reason, and it addresses the tendency for the tropical Pacific to want to stay in El Niño mode due to the positive feedback between sea surface temperatures and the reversed (westerly) trade winds. We'll discuss that reason in **Chapter 4.9 - An Introduction to the Delayed Oscillator Mechanism**. Two of the other reasons an El Niño ends include:

1. There is limited supply of warm water in the Pacific Warm Pool available for an El Niño.

2. The El Niño event is releasing heat from the central and eastern equatorial Pacific:

A. The warmer-than-normal waters in the central and eastern tropical Pacific release heat to the atmosphere, primarily through evaporation.

B. The warm waters at the equator "drain" north and south along the coasts of the Americas, assuming the warm waters made it that far to the east. Back toward the central equatorial Pacific, the warm waters also "drain" poleward to the interiors of the North and South Pacific. As the warm waters at the surface of the equator drain away, more of the cooler subsurface waters there are exposed. Logically, the sea surface temperatures along the equator then cool. The cooler sea surface temperatures allow the westerlies to subside and the trade winds to restore their normal pattern.

The El Niño does not exhaust all of the warm water that had been carried east. The "leftover" warm water on the surface is swept back to the western tropical Pacific by the restored trade winds. See the two left-hand cells in Figure 3-19. No ENSO indices account for the effects of the warm leftover surface water that's returned to the West Pacific after an El Niño.

There's also leftover warm water below the surface. The ever-resourceful Mother Nature created a way to return those leftover warm subsurface waters back to the western tropical Pacific. They are phenomena called oceanic Rossby waves. As noted in the two right-hand cells in Figure 3-19, sometimes a Rossby wave appears to form only in the Northern Hemisphere at approximately 10N. After those El Niño events, the single Rossby wave carries the warm water back to the northwestern tropical Pacific. Sometimes Rossby waves form in both hemispheres at approximately 10S and 10N, so that the warm water is returned to the western tropical Pacific north and south of the equator.

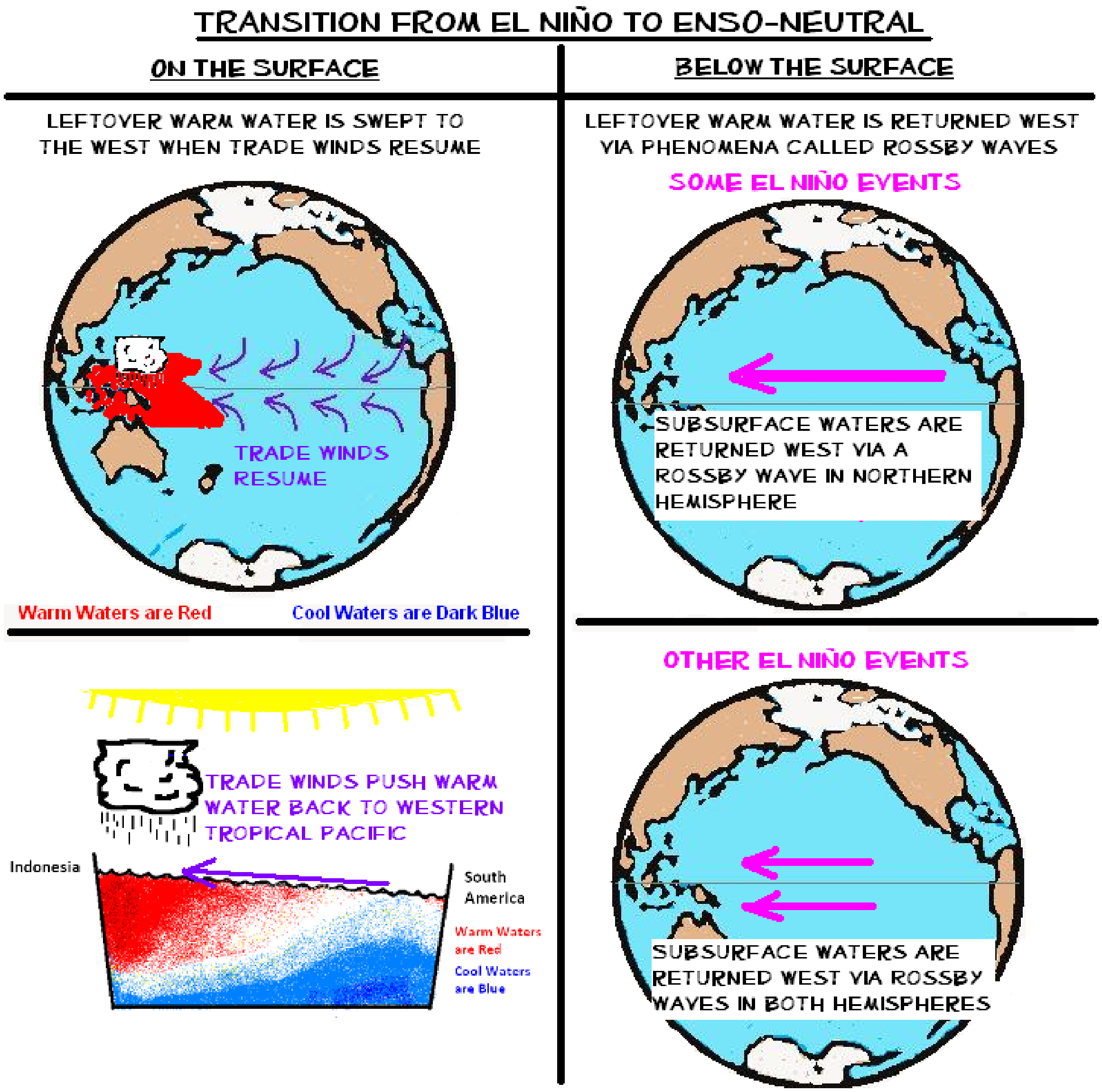


Figure 3-19

We'll discuss what appears to be the reason for one or two Rossby waves in **Chapter 4.9 - An Introduction to the Delayed Oscillator Mechanism**.

Let's take a look at a Rossby wave. The 1997/98 El Niño was an East Pacific event. Warm waters travelled east near the equator and slammed up against the coasts of the Americas. The trade winds reversed and temporarily held the warm water against the American coasts. After the peak of the El Niño, a slow-moving oceanic Rossby wave formed in the northeast tropical Pacific, west of the Central American coast, at about 5N-10N. The Rossby wave is clearly visible in ocean heat content anomaly animations, and better still in sea level residual animations from the Jet Propulsion Laboratory (JPL).

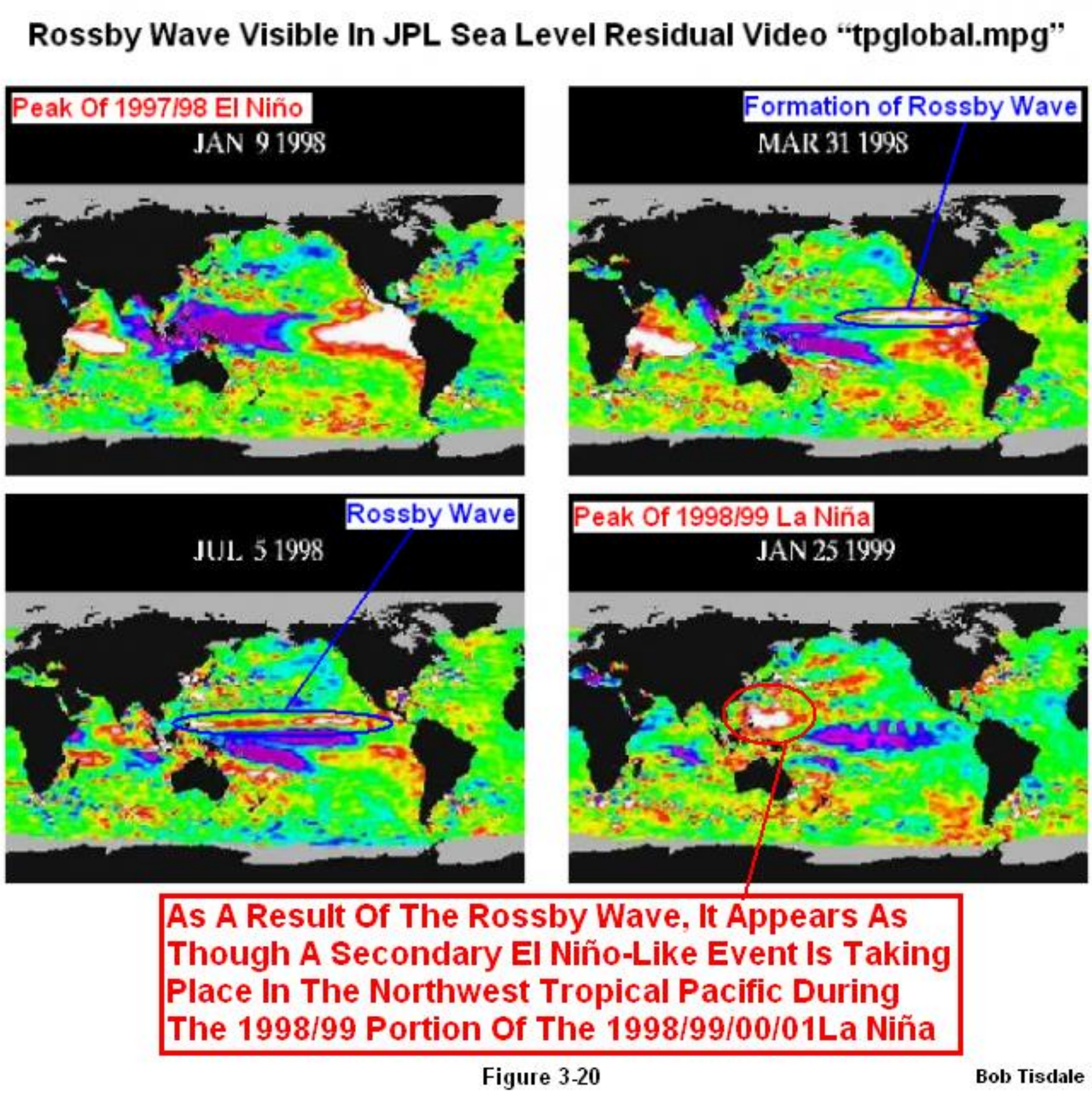


Figure 3-20

In Figure 3-20, I've highlighted the Rossby wave in screen captures from a JPL video. The upper right-hand cell shows the formation of the Rossby wave and the lower left-hand cell captures the Rossby wave travelling from east to west at approximately 5N-10N. It is carrying leftover warm water back to the western Pacific during the transition from the 1997/98 El Niño to the La Niña that followed. It's important to note that warm water is not visible in the surface temperature records. Last, in the lower right hand cell of Figure 3-20, notice what happens to the sea level residuals in the western Pacific after the Rossby wave reaches there. It's like another El Niño, but in the western tropical Pacific at about 10N.

There are no ENSO indices that capture the effects of Rossby waves.

The Rossby wave can be seen in the first 10 to 15 seconds of the YouTube video titled **Impact of the 1998 through 2001 La Niña on Sea Level Residuals**. It is a cropped version of the Jet Propulsion Laboratory animation "tpglobal.mpeg", which used to be available through the **JPL Ocean Surface Topography from Space** website. Unfortunately, JPL has since removed it from their **Video Gallery**. The slow-moving Rossby wave can also be seen in **Animation 3-1**. It is a gif animation created from screen captures from the JPL animation discussed above. In the Animation 3-1, I've limited the period to 1998.

If you allow the YouTube video to play through, you will note that there are no comparably sized Rossby waves carrying cool waters back to the western tropical Pacific at 5N-10N after the 1998/99/00/01 La Niña.

To confirm this basic difference between El Niño and La Niña events, refer to the **full YouTube version of the JPL animation "tpglobal.mpeg"**, which runs from 1992 to 2002. There are also no comparably-sized Rossby waves carrying cool waters back to the western tropical Pacific at 5N-10N or at 10S-5S after any La Niña event. This is further illustrated in **Chapter 4.9 - An Introduction to the Delayed Oscillator Mechanism**.

A number of sea level residual animations from JPL are still available. One captures the Rossby wave after the 1997/98 El Niño. Refer to their **SSH and SST – Global** video that compares sea surface height and sea surface temperature. It runs from 1996 to 1999 and plays at relatively slow speed. The sea level residuals are the top maps, and the sea surface temperature maps are on the bottom.

As discussed, surface and subsurface warm waters that are left over from the El Niño are carried back to the western tropical Pacific. Some of that leftover warm water helps to recharge the Pacific Warm Pool for the next El Niño, some of the leftover warm water is carried into the eastern Indian Ocean by a current called the Indonesian Throughflow, and some of the warm water is carried toward the poles. See Figure 3-21.

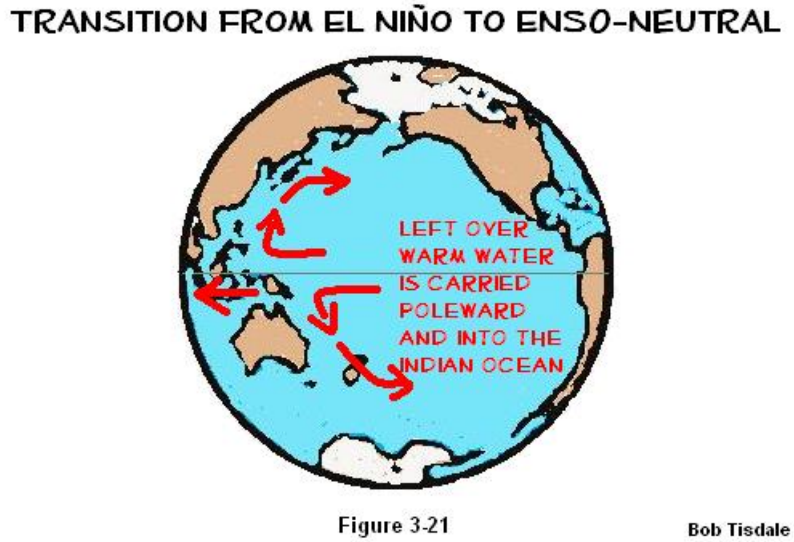


Figure 3-21

RECAP

The transition from El Niño to ENSO-neutral starts after the El Niño has reached its seasonal peak, usually in December. When tropical Pacific sea surface temperatures have cooled sufficiently, the westerlies subside and the trade winds return and strengthen toward normal. Any leftover warm surface waters are swept back to the western tropical Pacific. Any leftover warm subsurface waters are returned to the western tropical Pacific via phenomena called Rossby waves. The returned warm waters left over from the El Niño help to recharge the Pacific Warm Pool for the next El Niño, and those leftover warm waters are carried poleward in the western Pacific Ocean and carried into the Indian Ocean, where they warm the surface and subsurface waters of those oceans.

I've searched for years, but I've never found a scientific study that attempts to estimate how much warm water remains after El Niño events. One might then conclude that the impact of the leftover warm water on global surface temperatures has also not been estimated, but as we will see later in this book, the aftereffects of that leftover warm water are easy to see—remarkably easy to see. In fact, you can't miss those aftereffects once you know they're there.

3.8 La Niña Phase

Many researchers believe there are two ENSO phases: El Niño and other. Why? In many respects, but not all, the La Niña phase is simply an exaggerated ENSO-neutral state. See the cartoon-like illustration in Figure 3-22. As you've noted, I've jumped from ENSO-neutral to La Niña without a chapter on the transition between the phases. The reason for that: there's little difference between the two phases. One of the factors that establishes the interaction between the trade winds and the tropical Pacific sea surface temperatures overshoots its "normal" level, and the trade winds become stronger than normal, which lowers the sea surface temperature in the east.

Notice, however, I did NOT say La Niña was the opposite of an El Niño, because it is not.

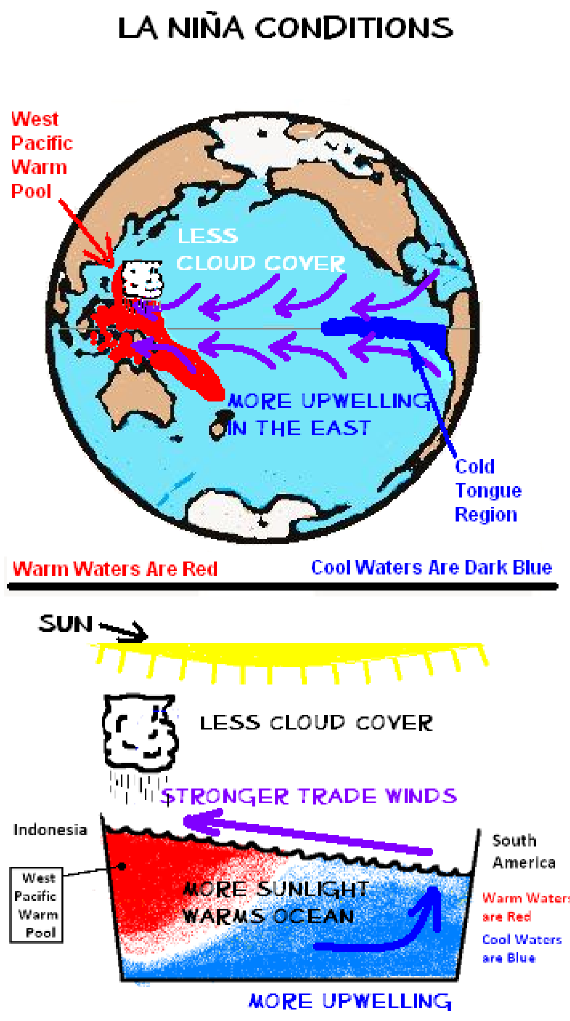


Figure 3-22

During a La Niña, the trade winds become stronger than they are normally, and that causes more water than normal to be pushed to the west. In turn, more cool water is drawn up (upwelled) from below the surface in the eastern tropical Pacific. The sea surface temperature anomalies there drop below normal. The stronger trade winds push the clouds farther to the west, so there is less cloud cover. With less cloud cover, more sunlight reaches the surface of the tropical Pacific to warm the water. (A reminder: sunlight reaches and warms the oceans to depths of 100 meters, but more of the warming takes place nearer the surface.) The sea surface temperature in the west Pacific warms more than normal and the warmer-than-normal water "piles up" in the Pacific Warm Pool, recharging it for the next El Niño.

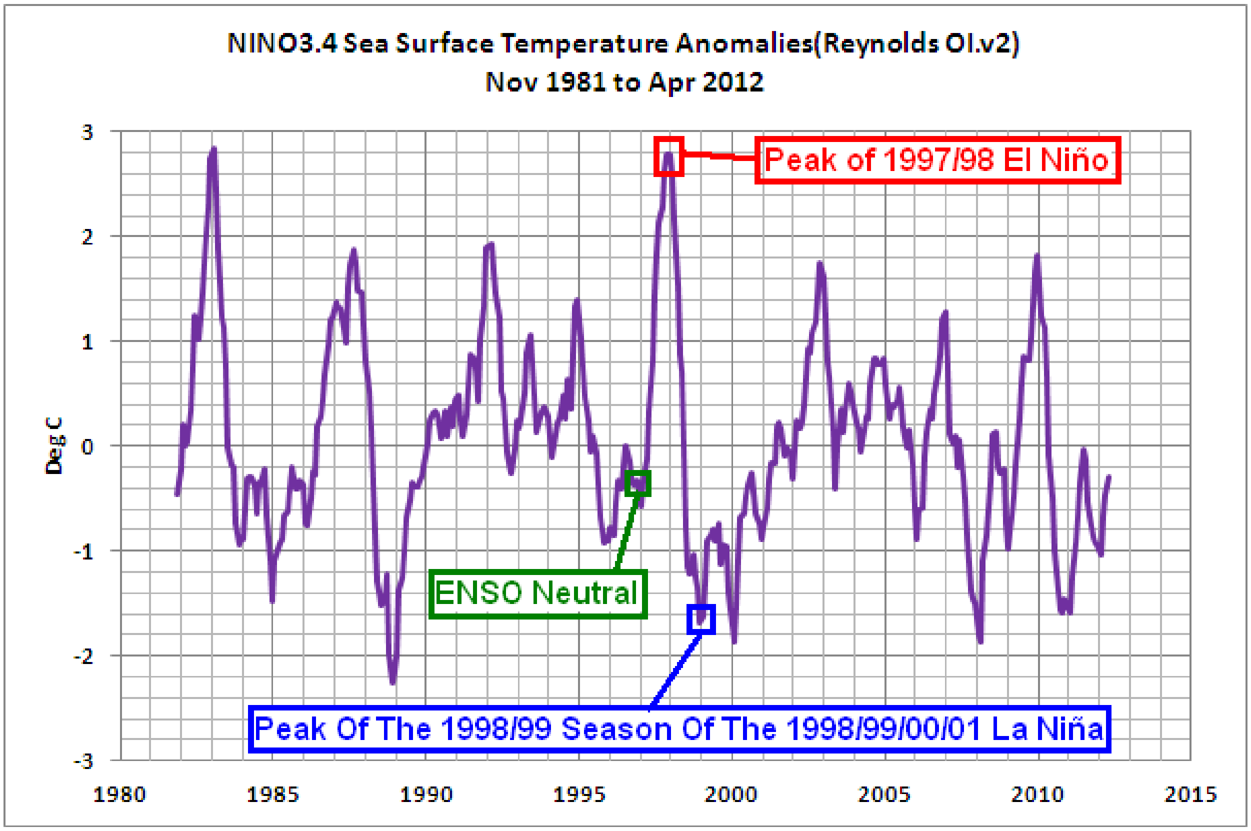


Figure 3-23 Bob Tisdale

Let's take a look at our ENSO Index, the sea surface temperature anomalies for the NINO3.4 region, Figure 3-23. We haven't looked at them for a while. Again, we're using the ENSO Index to show when ENSO events occur, how strong they are and how long they last. In earlier chapters, we've looked at maps and graphs of sea surface temperatures and sea level for the Decembers of 1996 and 1997, so that we could look at the differences between El Niño and ENSO-neutral conditions. We'll use the maps and graphs again in this chapter to show the differences between ENSO-neutral, El Niño, and La Niña conditions. Highlighted in red in Figure 3-23 is the peak of the 1997/98 El Niño. It was the strongest one-season El Niño event of the 20th Century. The blue box shows the peak of the 1998/99 portion of the three-year 1998/99/00/01 La Niña that followed that "Super" 1997/98 El Niño. Last, the small green box shows where December 1996 fits on the ENSO Index. We're using December 1996 as a reference for a number of reasons. While the NINO3.4 sea surface temperature anomalies aren't zero in December 1996, they are within ENSO-neutral range. Another reason to use December 1996 is because the typical El Niño and La Niña event peaks in December. The last reason to use December 1996 is it gives us three back-to-back-to-back Decembers in sequence, so that we're looking at conditions before, during and after a very strong El Niño event. From December 1996 to December 1997, NINO3.4 sea surface temperature anomalies warmed more than 3 deg C. They then cooled more than 4.4 deg C from December 1997 to December 1998. However, the December 1998 negative NINO3.4 sea surface temperature anomalies never came close to matching the positive value reached in 1997.

Note: IF—big if—La Niña events were the opposite of El Niño events, the 1998/99 portion of that multiyear La Niña could not have counteracted the warming caused by the 1997/98 El Niño. Then again, the two phases are not opposites, so we would not expect a La Niña event to counteract an El Niño.

The response of global surface temperatures to La Niña events is assumed by many to be similar to those of El Niño events, but in the opposite direction. That is, areas that typically warm during an El Niño are thought to cool during a La Niña. Likewise, areas that cool during an El Niño are thought to warm during a La Niña. We'll discuss this is more detail later in **Chapter 4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific**. Again, even if all the effects opposed one another, the remote effects of a La Niña that's not as strong as an El Niño cannot counteract the effects of the El Niño. There are, therefore, warming residuals leftover after the El Niño and La Niña.

Figure 3-24 shows two maps of tropical Pacific sea surface temperatures (not anomalies). It is similar to Figure 3-13, but in these maps we're comparing sea surface temperatures for an ENSO-neutral month (December 1996) to a La Niña month (December 1998). During the La Niña, the trade winds are stronger than normal. This causes more cool subsurface waters to be upwelled. In turn, the "cold tongue" along the eastern equator extends farther to the west. Notice also how the warm pool in the western tropical Pacific appears smaller in the La Niña month than it did in ENSO-neutral month. Part of the apparent decrease in size is caused by the trade winds pushing the warm water farther to the west. The other reason for the decrease in size is there was the monstrously large 1997/98 El Niño between the two months, and it released vast amounts of heat into the atmosphere.

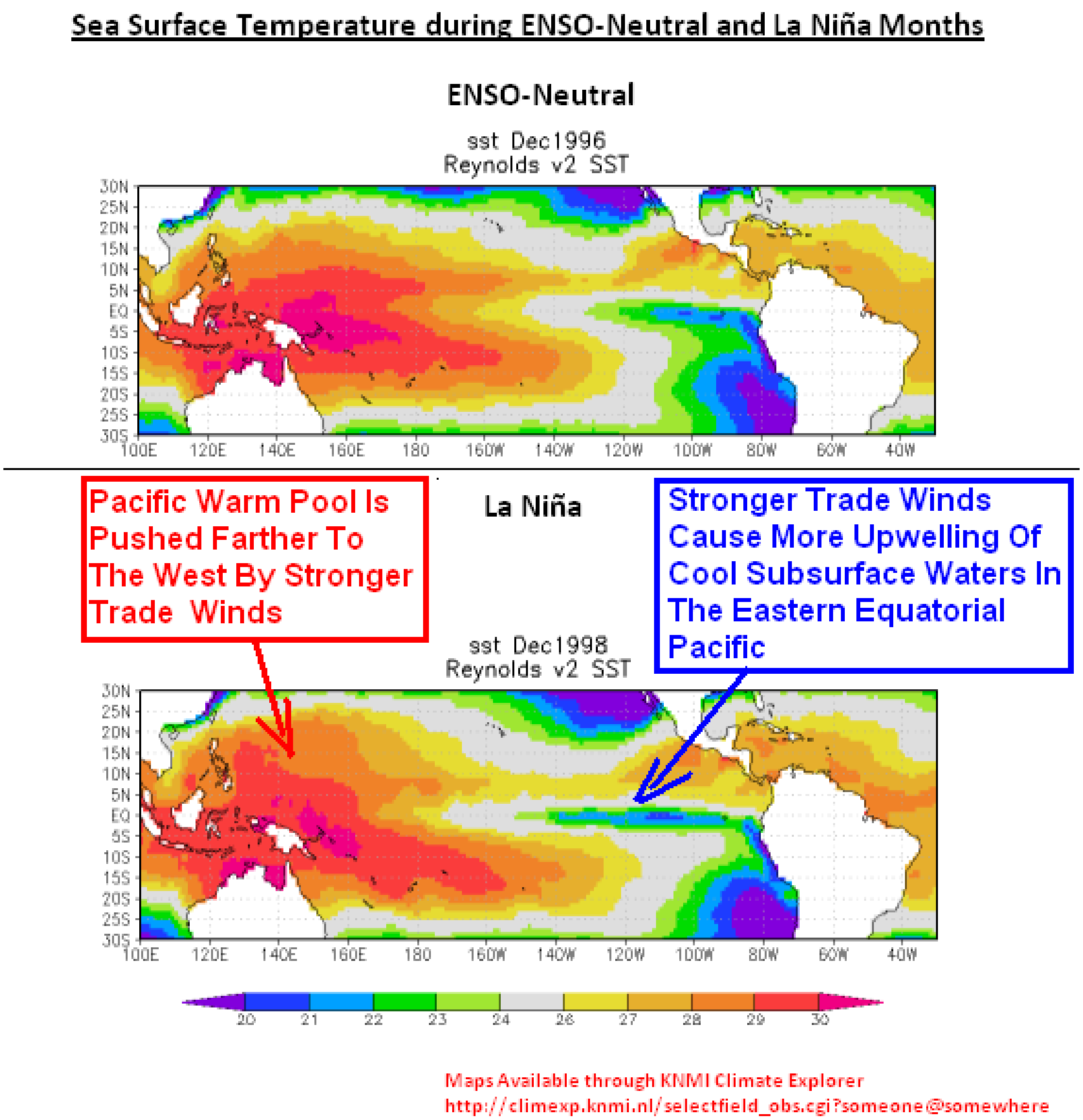


Figure 3-24 Bob Tisdale

Figure 3-25 shows the meridional-mean sea surface temperatures across the equatorial Pacific (5S-5N) during the Decembers of 1996 (ENSO-neutral), 1997 (peak of the 1997/98 El Niño) and 1998 (the peak of the 1998/99 part of the 1998/99/00/01 La Niña). The meridional-mean sea surface temperature plot shows temperatures along the equator (5S-5N) in the Pacific in 5-degree longitude increments. In other words, we're looking at the sea surface temperatures for the equatorial Pacific from west to east. As illustrated, the sea surface temperatures at the peak of the 1998/99 La Niña (blue curve) have a steep temperature gradient from west to east that's similar to the ENSO-neutral conditions (green curve). The sea surface temperatures across the equatorial Pacific during the El Niño (red curve) are abnormal.

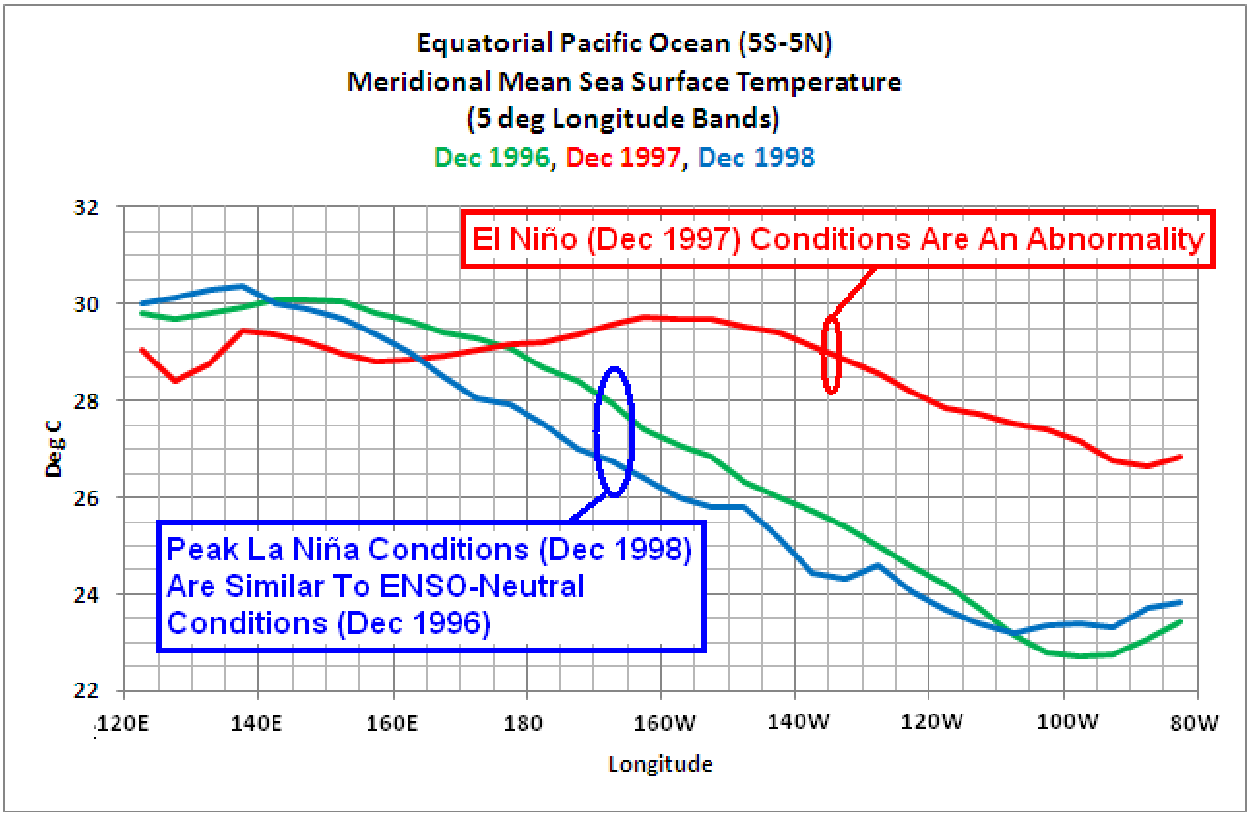


Figure 3-25 Bob Tisdale

If you were to scroll up to the ENSO Index in Figure 3-23, you can see that the NINO3.4 sea surface temperature anomalies during the 1997/98 El Niño reached about +2.8 degrees C, while at the peak of the 1998/99 portion of the three-year La Niña event, the sea surface temperature anomalies there only reached -1.7 degrees C. That's still a relatively strong La Niña, but it paled by comparison to the El Niño that came before it. To reinforce that, let's take a look at the sea surface temperature anomalies for the three Decembers again, using the meridional-mean plot. See Figure 3-26. Across the eastern equatorial Pacific, the difference between the El Niño and the ENSO-neutral conditions are much greater than the difference between the La Niña and ENSO-neutral sea surface temperature anomalies. Note also where along the equatorial Pacific the greatest differences occurred. For the El Niño, the greatest differences with the ENSO-neutral phase were toward the eastern equatorial Pacific, while during the La Niña the greatest differences occurred more toward the central equatorial Pacific. In other words, the locations where the sea surface temperature anomalies along the equatorial Pacific cooled during that La Niña were not the same places where they warmed during the El Niño that preceded it.

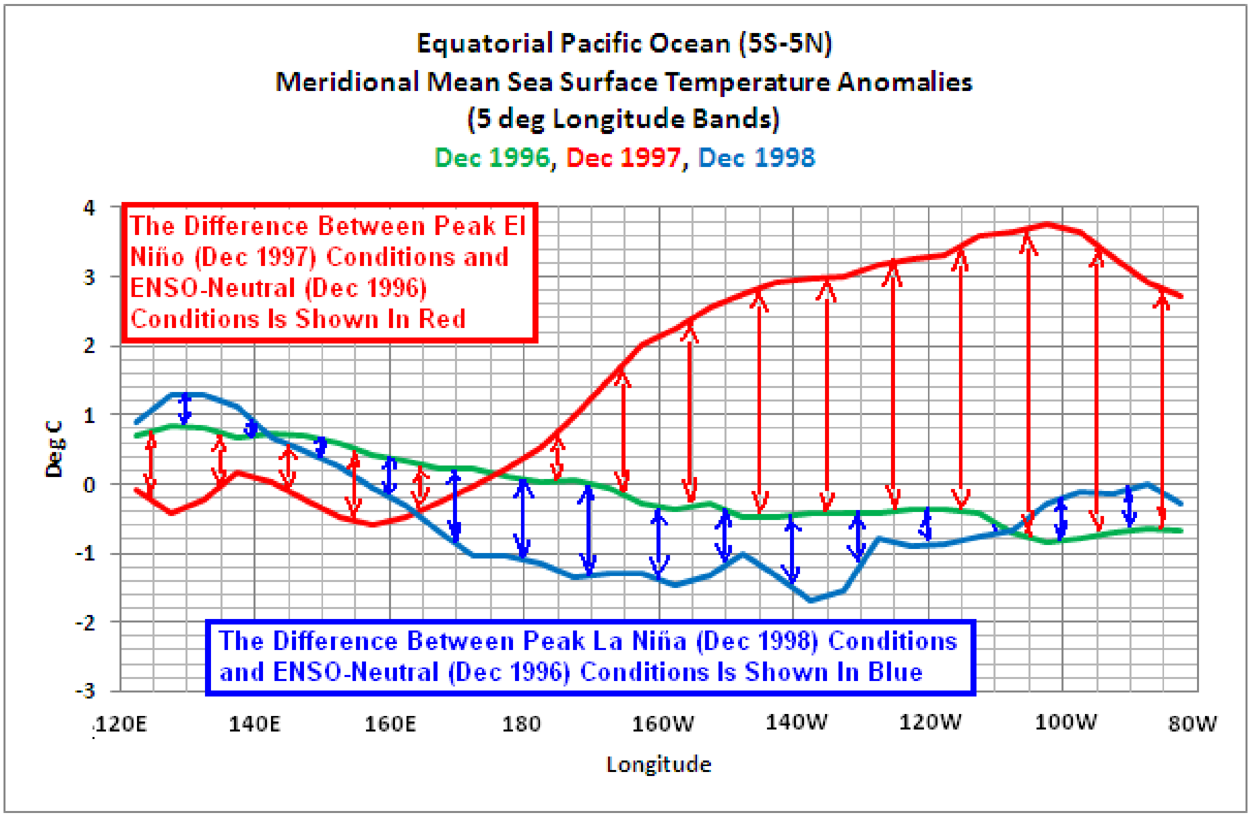


Figure 3-26 Bob Tisdale

Figure 3-27 shows the equatorial Pacific **sea level** anomalies on a meridional-mean basis, for the same ENSO-neutral, El Niño and La Niña Decembers. Note how the sea level declines across the equatorial Pacific, from east to west, during the La Niña. A La Niña exposes cooler subsurface waters in central and eastern equatorial Pacific due to the stronger trade winds. Keep in mind that sea level anomalies also represent, in part, the temperature of the column of water from the surface to the ocean floor.

Also note the difference between the El Niño and La Niña. During the La Niña, sea level is depressed across almost the entire equatorial Pacific, but during the El Niño, sea level drops in the west and increases in the east as warm water is relocated from the west to the east.

How many ways can we show that La Niña events are not the opposite of El Niño events? Physically, they are different processes. The two variables shown in this chapter, equatorial sea surface temperature and sea level, show little in the way of opposing responses.

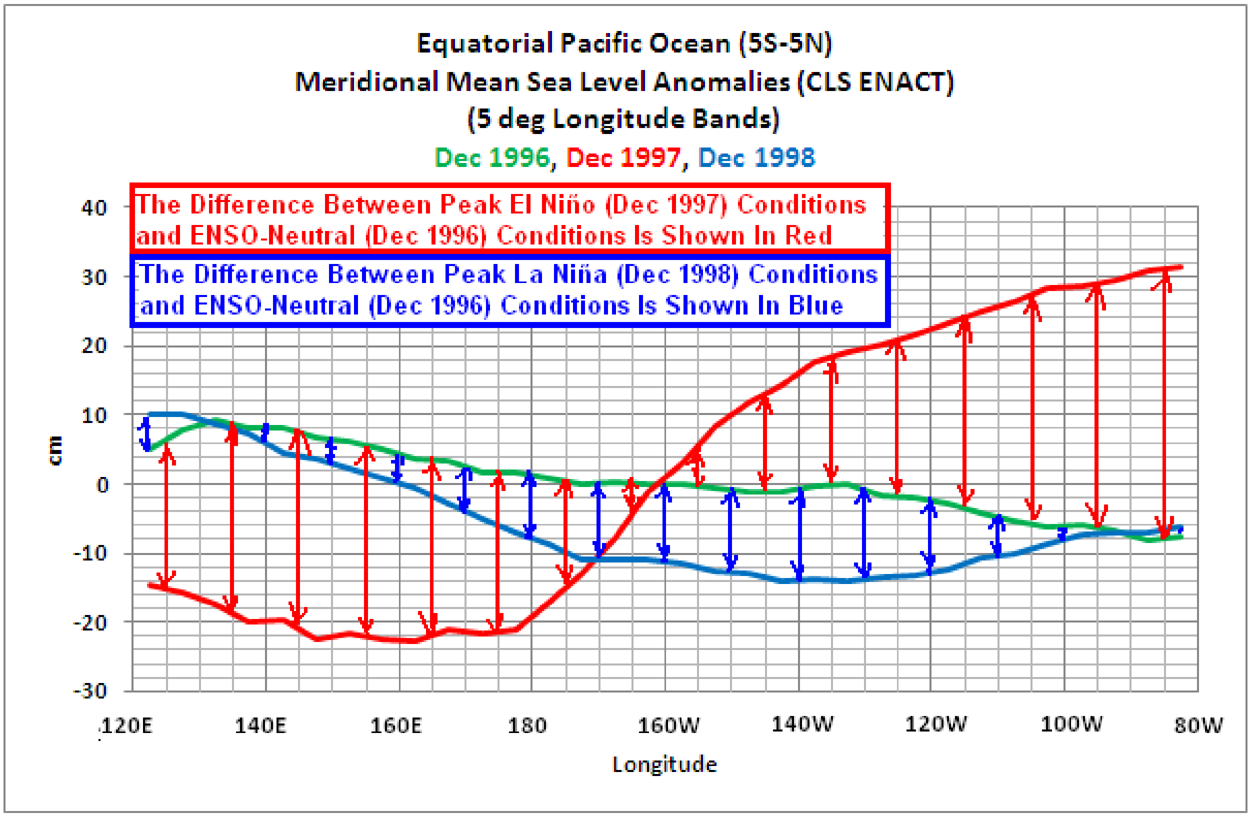


Figure 3-27 Bob Tisdale

RECAP

A La Niña is basically an exaggerated ENSO-neutral state. Trade winds are stronger during a La Niña. The stronger trade winds cause more upwelling of cool subsurface waters in the eastern equatorial Pacific and the stronger trade winds also push the warm waters in the Pacific Warm Pool farther to the west. Also as a result of the stronger trade winds, cloud cover decreases and this allows more sunlight to warm the tropical Pacific. That additional sunlight recharges the heat that was discharged during the El Niño. We'll confirm that in the Chapter 3-10.

3.9 The Transition from La Niña to ENSO Neutral

We're going to postpone the discussion of the transition from La Niña to ENSO-neutral conditions. That phase also includes the return of cooler-than-normal subsurface waters (not surface waters) to the west by Rossby waves, similar to the return of warmer-than-normal subsurface waters after an El Niño. The Rossby waves following a La Niña are much smaller than those that follow a strong El Niño. We'll discuss it in **Chapter 4.9 An Introduction to the Delayed Oscillator Theory**. It also requires us to discuss equatorial Kelvin waves. Those are presented in **Chapter 4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves**.

3.10 The Recharge of Ocean Heat during the La Niña

Let's discuss the recharging of the West Pacific Warm pool that takes place during a La Niña—a La Niña that follows an El Niño. We can show the discharge and recharge with a dataset called Ocean Heat Content, or OHC. The Ocean Heat Content data to be discussed uses ocean temperature measurements to depths of 700 meters. That dataset also uses salinity readings because the "saltiness" of the ocean water also varies and that affects how much heat energy is stored by the water. Using Ocean Heat Content data, we can confirm that an El Niño releases heat from the tropical Pacific, and that a La Niña event recharges it. First, the simple depiction:

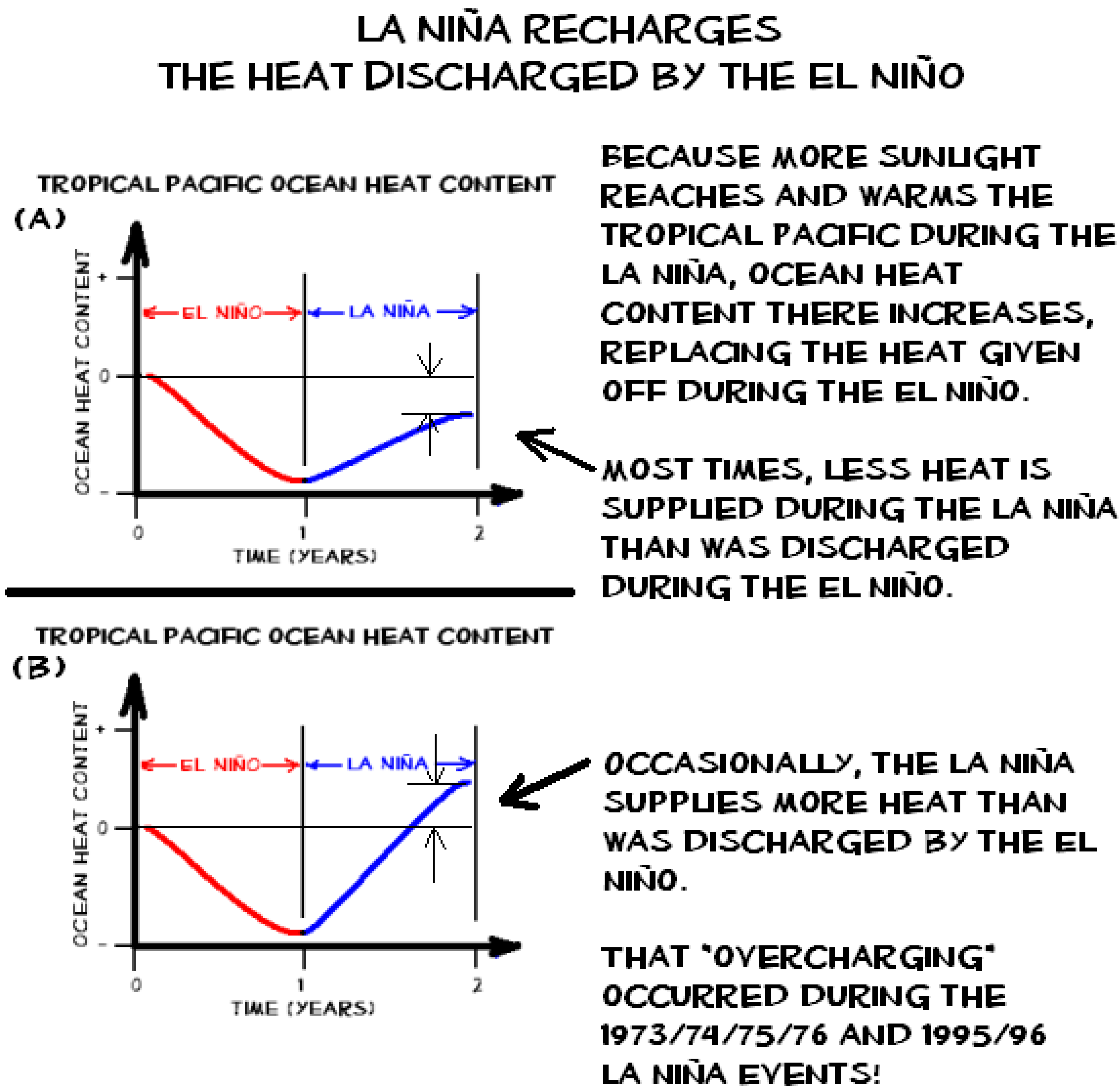


Figure 3-28 Bob Tisdale

In Section 1, we used two simple graphs to show what happens when the stronger-than-normal trade winds decrease cloud cover during a La Niña. See Figure 3-28. In both the top and bottom cells, tropical Pacific Ocean Heat Content drops during the El Niño, shown in red. The top cell (A) also shows that the La Niña replaces some of the heat that was released during the El Niño before it. That's what happens most often. Occasionally, as shown in the bottom cell (B), there's an unusual La Niña event that not only replaces the heat that was released during the El Niño, but it also supplies additional heat. In effect, those unusual La Niña events overcharge the tropical Pacific for the next El Niño event or events. That overcharging is what happened during the 1973/74/75/76 and 1995/96 La Niña events.

The **Ocean Heat Content (OHC) data** used in this chapter is from the NOAA **National Oceanographic Data Center** (NODC). The most recent version of it is based on the Levitus et al (2012) paper **World Ocean Heat Content and Thermosteric Sea Level change (0-2000 m), 1955-2010**. The NODC Ocean Heat Content data is available in two depths: 0-700 meters and 0-2000 meters. We're using the data for the depths of 0-700 meters because the vast majority of the changes in tropical Pacific Ocean Heat Content occur in the top 300 meters. Keep in mind, Ocean Heat Content data represents, in part, the ocean temperatures to depths of 700 meters.

ENSO events peak in Northern Hemisphere winters and we've been using maps of Decembers in earlier illustrations. For the next illustration, we'll use Januarys for a change of pace. Figure 3-29 contains four maps that show the Ocean Heat Content anomalies in the western tropical Pacific (west Pacific Warm Pool).

1. Upper left-hand corner: January 1995 (the peak of the 1994/95 El Niño),

2. Upper right-hand corner: January 1996 (the peak of the 1995/96 La Niña),

3. Lower left-hand corner: January 1997 (ENSO-neutral just before the start of the 1997/98 El Niño), and

4. Lower right-hand corner: January 1998 (the peak of the 1997/98 El Niño).

As discussed earlier, warm water from the surface and below the surface of the Pacific Warm Pool sloshes east during an El Niño. This causes the Ocean Heat Content in the western Tropical Pacific to cool during the El Niño events shown in the upper left-hand and lower right-hand maps.

During the transition from El Niño to La Niña (and during the La Niña itself) some of the "leftover" warm water that was spread across the surface by the El Niño is now pushed back to the west by the trade winds, which resume their normal east-to-west direction and also strengthen during the La Niña. Also during the transition, a Rossby wave or a pair of Rossby waves return(s) leftover subsurface waters to the west and some of that helps to recharge the Pacific Warm Pool. The strengthening of the trade winds during the La Niña also reduces tropical Pacific cloud cover. The reduced cloud cover allows more Downward Shortwave Radiation (visible sunlight) to warm the tropical Pacific to depths of 100 meters. The trade wind-driven ocean currents in the tropical Pacific carry this warm water to the west where part of it “accumulates” in the Pacific Warm Pool. Refer to the upper right-hand map. In this way, the warm waters in the western tropical Pacific are recharged by the La Niña for the next El Niño event. Last, the map in the lower left-hand corner of Figure 6-14 shows the positive ocean heat content anomalies in the western tropical Pacific, just before the 1997/98 El Niño of the Century.

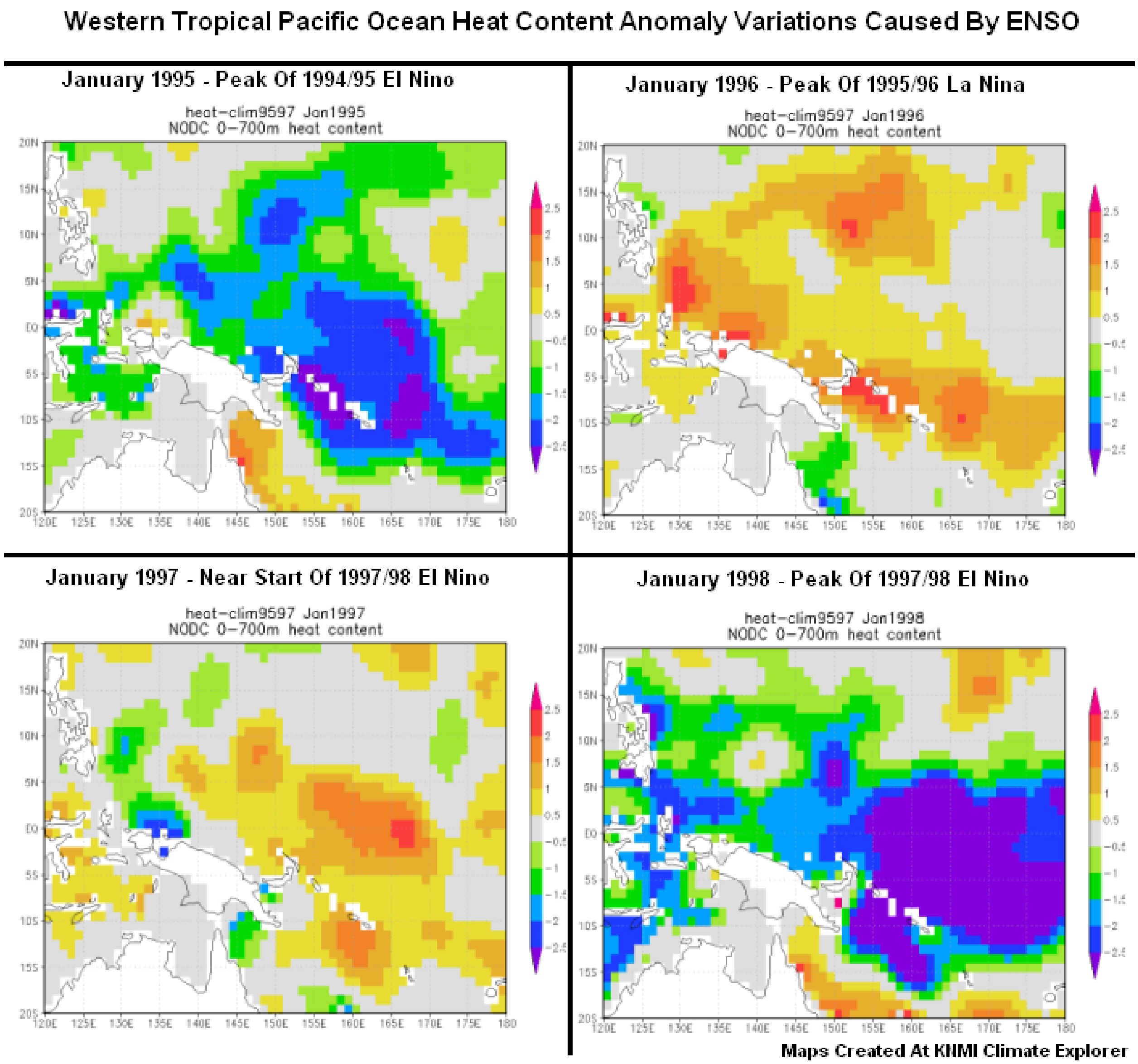


Figure 3-29

Bob Tisdale

The variations in the Ocean Heat Content anomalies of the Pacific Warm Pool are closely related to variations in NINO3.4 sea surface temperature anomalies, our ENSO index. It's an inverse relationship, meaning when one cools the other warms and vice versa. Figure 3-30 illustrates how closely they are related. It's a time-series graph that starts in 1995 to capture the events leading up to the very strong 1997/98 El Niño. It compares the Ocean Heat Content in the western tropical Pacific (in Gigajoules per square meter) to inverted NINO3.4 sea surface temperature anomalies (in degrees C). The coordinates used for the Western Tropical Pacific ocean heat content data are 20S-20N, 120E-180, so it's a big area. The NINO3.4 data was inverted by multiplying it by -1.0. When the NINO3.4 sea surface temperature anomalies warm in response to an El Niño, the Ocean Heat Content anomalies of the Western Tropical Pacific cool because it is supplying the warm water that fuels the El Niño. Similarly, when NINO3.4 sea surface temperature anomalies cool in response to a La Niña, the Western Tropical Pacific Ocean Heat Content warms, because some of the leftover warm water is returned there and because an increase in Downward Shortwave Radiation (visible sunlight) warms the tropical Pacific to depths of 100 meters and that water is carried west to the Pacific Warm Pool.

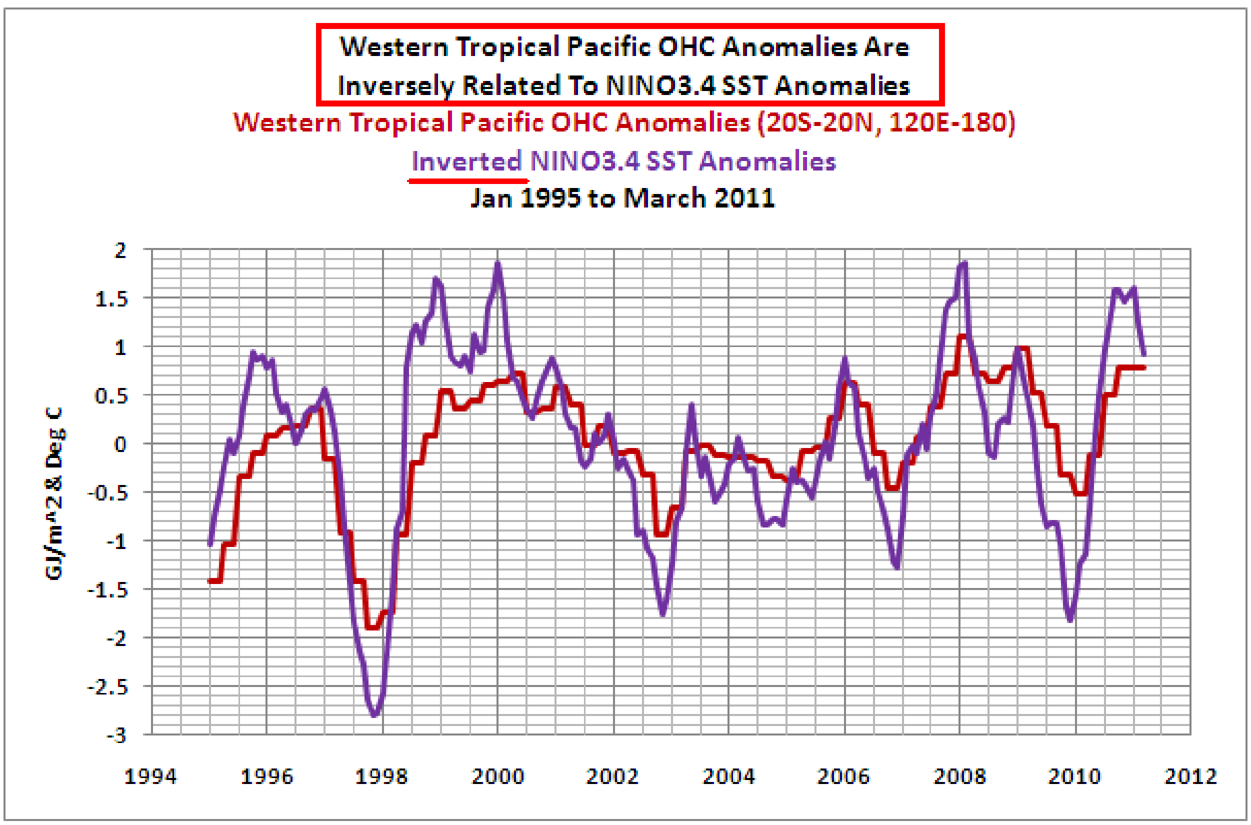


Figure 3-30

We're going to take a look at that relationship travelling further back in time, but in order to do so, we'll have to expand the Ocean Heat Content data to cover the entire tropical Pacific. Buoys used to monitor ENSO were installed gradually from the mid-1980s to the mid-1990s. Before then, sampling of subsurface temperatures was poor.

Figure 3-30a

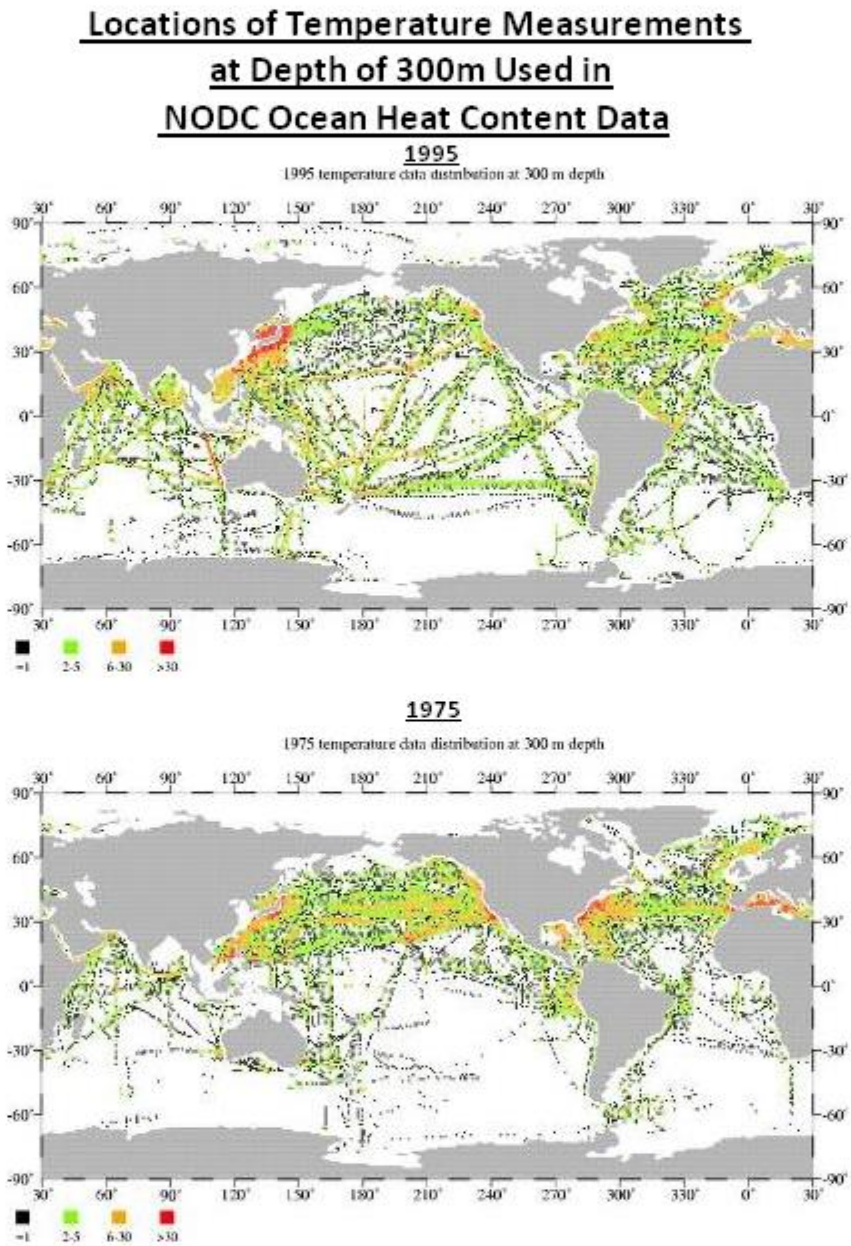


Figure 3-31a

Bob Tisdale

With all climate-related datasets (temperature, precipitation, cloud cover, etc.) you have to keep in mind that there are fewer and fewer measurements the further back in time you go. To make matters worse, the spatial coverage of samples and the timing of those samples are different for each dataset. Some of the surface temperature datasets start in the 1850s, but there are very few areas with temperature measurements in 1850. Ocean Heat Content starts in

1955 due to the very limited number of temperature measurements at depth at that time. Understand that the Ocean Heat Content dataset is based on temperature readings at depths from zero to 700 meters (and for those of you more familiar with measurements in feet, 700 meters is about 2,300 feet). Ships don't normally sample temperatures to those depths. Those measurements are taken during research voyages.

Figures 3-31 a (above) and b (below) show the locations and quantities (color coded) of temperature measurements used by the NODC for its Ocean Heat Content data. There are three years shown. The Ocean Heat Content data is furnished in quarters, but the maps at the NODC's webpage (**here**) are also available showing all of the measurement locations for a given year. Also, they provide maps of the locations at different depths. The maps in Figure 3-31 a (above) and b (below) show the locations of temperature measurements at 300 meters for 1995, 1975 and 1955, which is the start year of the dataset.

Figure 3-30b

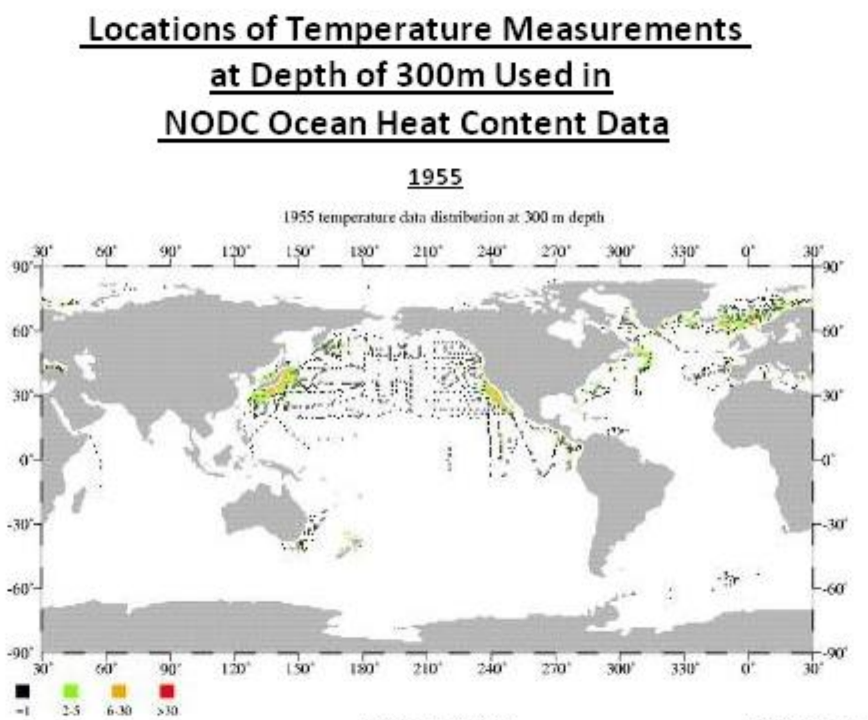


Figure 3-31b Bob Tisdale

The data from areas where there are very few measurements have to be taken with a grain of salt. As is very obvious, the Ocean Heat Content data is based primarily on a few samples in the Northern Hemisphere in 1955. The western and eastern tropical Pacific have measurements in some areas in 1975, but very few toward the central tropical Pacific. With that in mind, sometimes it helps to increase the size of the area being studied when you go back in time. At least you can get a feel for when and why major changes happen. Therefore, instead of looking at only the western tropical Pacific in the next graph, we'll expand it to the entire tropical Pacific to see how El Niño and La Niña events impact it. We'll also illustrate the data beginning in 1955, which is the start year for that Ocean Heat Content dataset.

Figure 3-32 is a time-series graph of the tropical Pacific Ocean Heat Content anomalies (24S-24N, 120E-80W) from 1955 to present. I've also included scaled (0.2) NINO3.4 sea surface temperature anomalies as a reference. The NINO3.4 data was also inverted to align its variations with those of the tropical Pacific Ocean Heat Content data. Both datasets have been smoothed with 13-month running average filters to reduce the noise. I've also highlighted three La Niña events with fine-lined red boxes. The first is the 1973/74/75/76 La Niña, which was obviously a multiyear ENSO event. In addition to lasting about three years, it was also a relatively strong La Niña. Notice how the tropical Pacific Ocean Heat Content anomalies (green curve) were at a level of approximately -0.13 GJ/m^2 (Gigajoules per square meter) during the late sixties and early 1970s. Then the 1972/73 El Niño caused the Ocean Heat Content data for the tropical Pacific to drop. The 1973/74/75/76 La Niña kicked in, and over that 3-year period, the tropical Pacific Ocean Heat Content data warmed to a new level that was at least 0.1 GJ/m^2 higher than in the late 1960s and early 1970s.

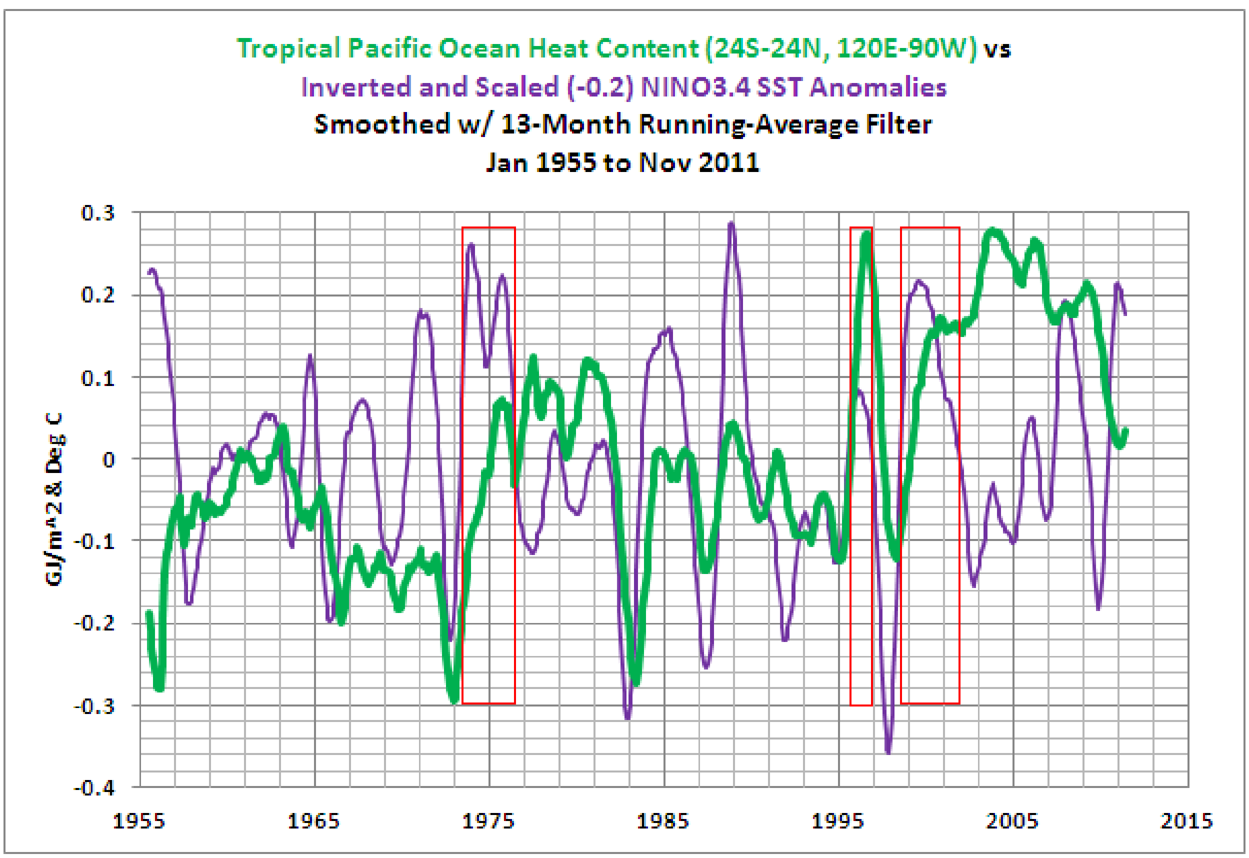


Figure 3-32 Bob Tisdale

The next major variation in tropical Pacific Ocean Heat Content is the dip and rebound that occurs in response to the 1982/83 El Niño and the 1983/84/85 La Niña that followed it. That La Niña did not recharge all of the heat released by the El Niño before it, according to the data. The 1986/87/88 El Niño is next, and the La Niña in 1988/89 created slightly more heat or warm water than was released by the El Niño preceding it. Something else to notice: the tropical Pacific Ocean Heat Content has declined quite significantly over the period from the early 1980s to 1995. It, therefore, appears that the 1973/74/75/76 La Niña provided the initial warm water for the two significant El Niño events of 1982/83 and 1986/87/88. The La Niña events that followed those El Niño events recharged part or all of the heat discharged, but overall, the initial charge of warm water was provided by the multiyear La Niña in the mid-1970s.

Then came the 1995/96 La Niña, which is highlighted. It wasn't particularly strong; in fact, it was toward the weak side for a La Niña according to the NINO3.4 data. Nevertheless, the warm water that fueled the monstrous 1997/98 El Niño was created during it. We'll return to that La Niña in a moment. The discharge of heat by the 1997/98 El Niño is easy to see with the sharp drop in the ocean heat content data. Then the 1998/99/00/01 La Niña (also highlighted) recharged most of it.

Why did the tropical Pacific Ocean Heat Content continue to warm after the two multiyear La Niña events?

A likely, but speculative, answer is that some of the warm water created during those multiyear La Niña events was carried out of the tropical Pacific by surface and subsurface ocean currents. Then the warm water returned to the tropical Pacific over the next few years. Again, it's a logical answer, but it is speculation on my part. There may be papers that describe the reason, but I have not found them—yet.

Now the 1995/96 La Niña: It was a relatively weak La Niña based on NINO3.4 sea surface temperature anomalies. Of course, that raises the question: what was so special about it that caused that La Niña to create all of that warm water that fueled the 1997/98 El Niño?

There is a scientific paper that explains it. It is McPhaden (1999) **Genesis and Evolution of the 1997-98 El Niño**. McPhaden writes (my boldface):

> *For at least a year before the onset of the 1997–98 El Niño, there was a buildup of heat content in the western equatorial Pacific due to* ***stronger than normal trade winds*** *associated with a weak La Niña in 1995–96.*

Stronger than normal trade winds makes sense, with what we know of the ENSO process. That weak 1995/96 La Niña caused a major warming of tropical

Pacific Ocean Heat Content, and all of that warm water served as the fuel for the 1997/98 El Niño. The 1998/99/00/01 La Niña then recharged part of the heat released, and tropical Pacific OHC has been fluctuating at its new elevated level since then—until recently.

A side discussion: While NINO3.4 sea surface temperatures during the 1995/96 La Niña were not remarkably cool, other portions of the ENSO process in other places were impressive, according to McPhaden (1999). This is a clear indication that our ENSO index (NINO3.4 sea surface temperature anomalies) is not able to capture all of the factors that relate to ENSO. No ENSO Index can. An ENSO index simply captures the influence of ENSO on the variable or variables being measured for the ENSO index. As I noted in the Introduction, relying on an ENSO index as a proxy for all of the interrelated effects of ENSO is like trying to do a play-by-play of a soccer game from a TV overhead camera shot of only one goal. You just can't do it.

The cloud amount and downward shortwave radiation (visible light) aspect of the recharge mode is discussed in the Pavlakis et al (2008) paper **ENSO Surface Shortwave Radiation Forcing over the Tropical Pacific**. Basically, Pavlakis et al used satellite-based cloud amount data, aerosols data, and data from computer-aided reanalysis of other climate variables as inputs to a specific computer model. From them, they simulated the relationship between ENSO and downward shortwave radiation (visible sunlight, not longwave radiation) over the tropical Pacific. They studied a number of areas there. In one area in the central equatorial Pacific, there was a very close but inverse relationship between NINO3.4 sea surface temperature anomalies and downward shortwave radiation. During El Niño events, downward shortwave radiation could drop as much as 40 watts per square meters. That's what we would expect with the clouds accompanying the warm water east during the El Niño and blocking sunlight from reaching the ocean. (That's also when the tropical Pacific is releasing vast amounts of heat through evaporation and causing the clouds to form.) They also found that downward shortwave radiation could increase as much as 40 watts per square meter during a La Niña. That should be expected from stronger trade winds reducing the cloud amount. Refer to the Pavlakis et al (2008) Figure 6 (not shown). That's a total change of 80 watts per square meter from the low point during an El Niño to the high point during a La Niña. That swing of 80 watts per square meter indicates there can be a lot of energy from the sun entering the tropical Pacific to depths of 100 meters.

Figure 3-33 shows the relationship between NINO3.4 SST anomalies and the Total Cloud Amount anomalies for the two regions presented in the Pavlakis et al Figure 6. Those regions are the NINO3.4 region (5S-5N, 170W-120W) and a region just west of there (7S-5N, 160W-160E). The Total Cloud Amount anomalies are presented as a decimal. In other words, the Total Cloud amount anomalies for the NINO3.4 region (blue curve) rose about 35% from mid-1996 to late 1997. Unfortunately, the **ISCCP** Cloud Amount data is only available at the KNMI Climate Explorer for the period of July 1983 to June 2006.

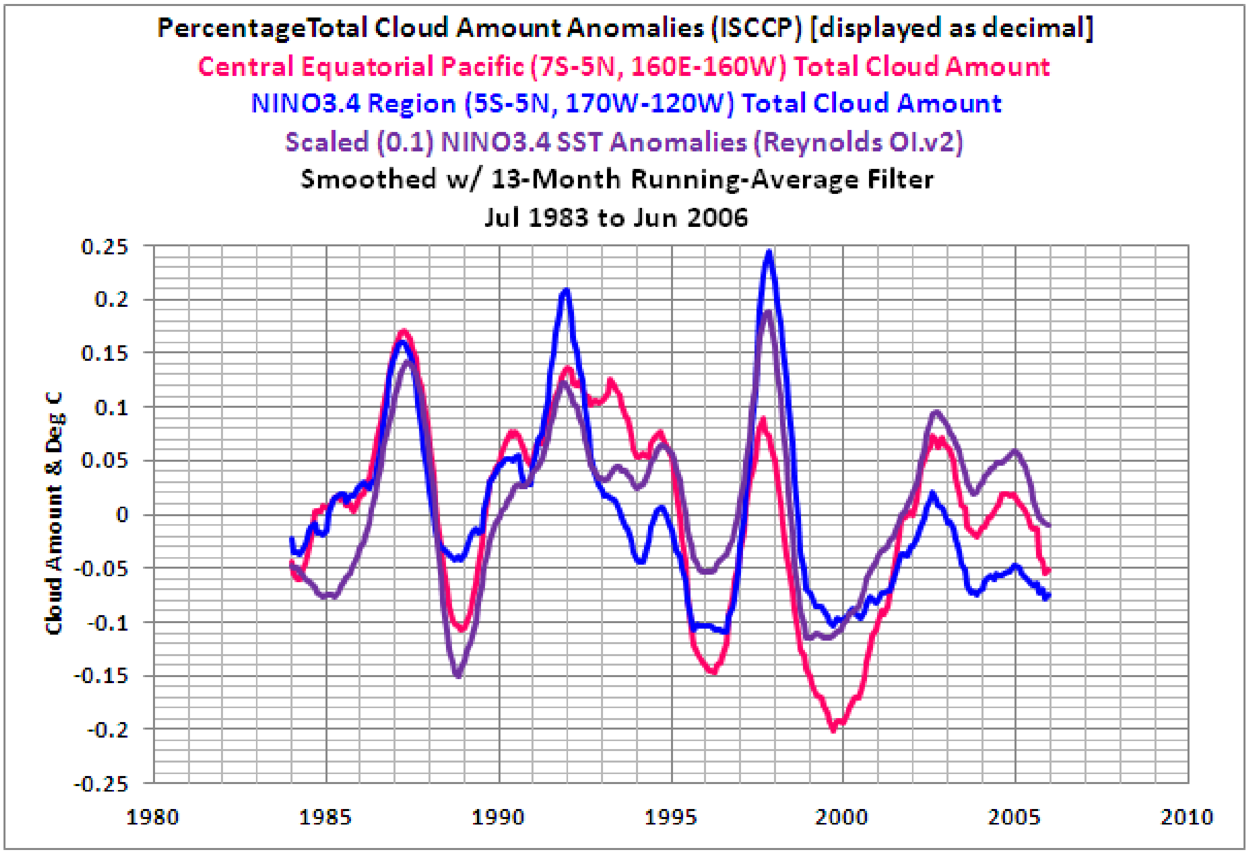


Figure 3-33 Bob Tisdale

Note: Like many datasets, there are factors about the ISCCP cloud amount data that have to be considered by researchers. One of them is the influence of volcanic aerosols. This skews the results in 1991 and for a few years afterwards. If we were doing scientific research, it would be a consideration, but we're just using data to confirm our understanding of the many interrelationships.

What is clearly shown in Figure 3-33, however, is Total Cloud Amount over the central equatorial Pacific does increase during El Niño events and it does decrease during La Niña events.

A good graph to end this chapter with: We've discussed and illustrated the effects of the 1995/96 La Niña on tropical Pacific Ocean Heat Content and that the massive increase in Ocean Heat Content provided the fuel for the 1997/98 super El Niño. Refer to the discussion of Figure 3-32. As you'll recall, McPhaden (1999) identified abnormally strong trade winds in the western tropical Pacific as the culprit for the buildup of warm water. Figure 3-34 shows the downward shortwave radiation anomalies for a reasonably large portion of the western tropical Pacific (20S-20N, 135E-175E), and in that graph, I've inverted and scaled our ENSO index (NINO3.4 sea surface temperature anomalies) as a reference for timing and magnitude of El Niño and La Niña events. Keep in mind, the ENSO index has been inverted, so the La Niña events are the upward spikes, and vice versa for El Niño. The variations in the downward shortwave radiation for this portion of the western tropical Pacific mimic the inverted ENSO index. The two datasets do diverge at times, it's not a perfect match, but for the most part, downward shortwave radiation for that portion of the western tropical Pacific varies inversely with NINO3.4 sea surface temperature anomalies. That makes sense. During a La Niña, the stronger trade winds reduce cloud cover and the result is an increase in sunlight available to warm the tropical Pacific. Notice the way the downward shortwave radiation rises an extraordinary amount during the 1995/96 La Niña and then remains elevated until 2001, during the decay of that 3-year 1998/99/00/01 La Niña event. One would have expected the drop in downward shortwave radiation during the 1997/98 El Niño to have been more significant.

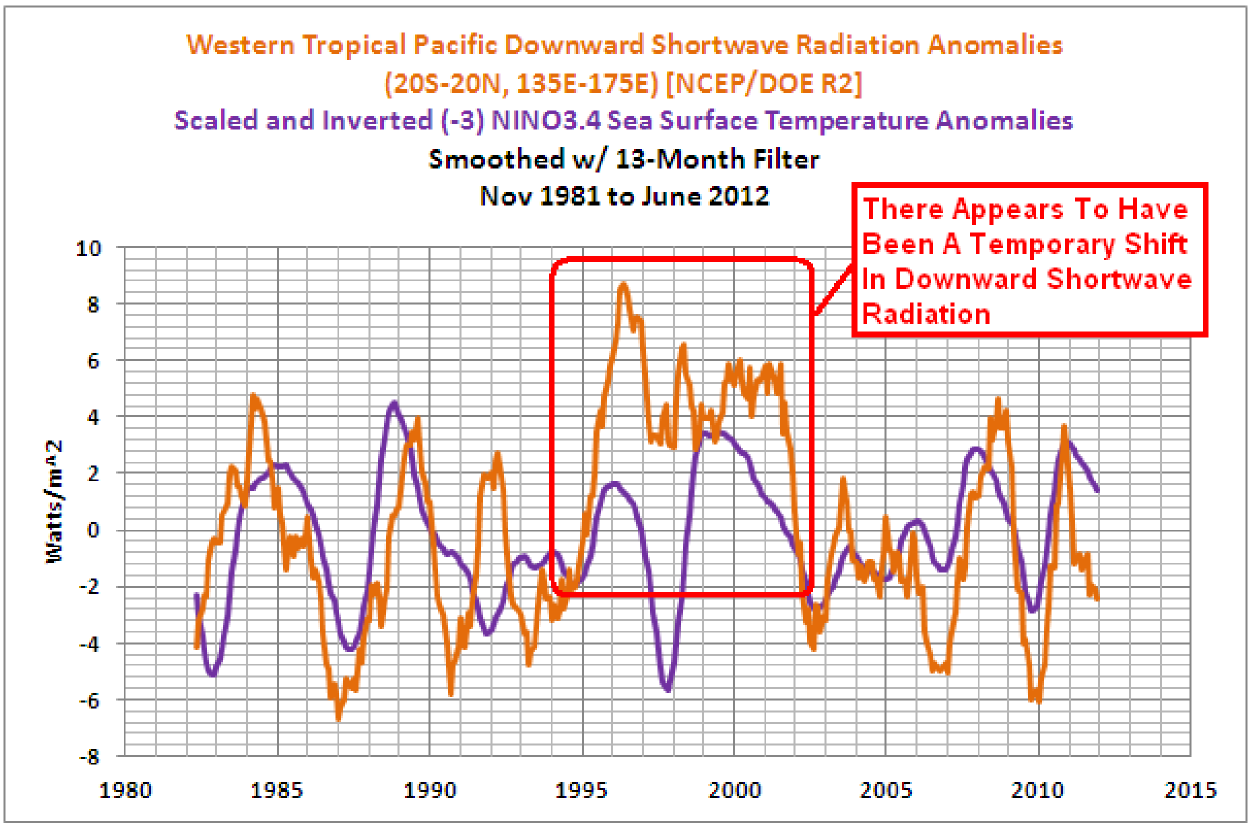


Figure 3-34 Bob Tisdale

RECAP

In summary, using Ocean Heat Content data, we've seen that El Niño events discharge heat from the tropical Pacific and La Niña events recharge it. We've also seen that a La Niña event can "overcharge" the heat available for the next

El Niño, inasmuch as the relatively weak 1995/96 La Niña supplied the warm water for the 1997/98 El Niño, which was the largest El Niño in the 20th Century. Also discussed was the inverse relationship between our ENSO index (NINO3.4 sea surface temperature anomalies) and the amount of visible sunlight reaching the tropical Pacific. We've also illustrated the relationship between our ENSO index and Total Cloud Amount.

We've also seen that an ENSO index, NINO3.4 sea surface temperature anomalies for example, does not capture all of the subtleties of the process of ENSO. Sometimes one or more of the other variables can be out of synch with an ENSO index. For instance, during the 1995/96 La Niña, unusually strong trade winds in the western tropical Pacific allowed more heat than normal to be recharged, providing the fuel for the super El Niño of 1997/98.

3.11 Recap of Section 3

In Section 3, we discussed the processes of ENSO, starting with the ENSO-neutral phase and working through El Niño and La Niña phases.

ENSO is a coupled ocean-atmosphere process in the tropical Pacific that periodically discharges heat to the atmosphere during an El Niño. The phrase "coupled ocean-atmosphere process" refers to the fact that many ocean and atmospheric variables in the tropical Pacific interact with one another. In other words, the ocean and atmosphere are constantly communicating. For that reason, a good number of tropical Pacific variables are impacted directly by ENSO, including sea surface temperature, sea level, ocean currents, ocean heat content, cloud amount, precipitation, the strength and direction of the trade winds, etc. We have confirmed the effects of ENSO on many of those variables in this section. Also, because cloud amount for the tropical Pacific impacts downward shortwave radiation (visible light) there, we've presented and discussed that relationship as well, referring to one of the only scientific studies that discusses the relationship.

In addition to releasing heat into the atmosphere, an El Niño can release a vast amount of naturally created warm water from below the surface of the west Pacific Warm Pool and allow it to be redistributed throughout the nearby ocean basins at the end of the event.

La Niña is not the opposite of El Niño, far from it. La Niña is simply an exaggerated ENSO-neutral state. However, La Niña plays an important role in the ENSO process. La Niña events recharge part of the warm water that was released during the El Niño. Typically, they only recharge part of it. They accomplish this through an increase in downward shortwave radiation (visible sunlight) that is caused by a decrease in tropical Pacific cloud amount, which is caused by the stronger trade winds of a La Niña. Sometimes La Niña events "overcharge" the tropical Pacific, inasmuch as they recharge more ocean heat in the tropical Pacific than was discharged during the El Niño that came before it. That was the case during the 1973/74/75/76 La Niña. Tropical Pacific Ocean Heat Content warmed significantly during the 1973/74/75/76 La Niña, and that provided the initial "fuel" for the 1982/83 Super El Niño and the multi-year 1986/87/88 El Niño, both of which were exceptionally strong El Niño. The La Niña events that followed those El Niño only recharged a portion of the heat discharged by them. Tropical Pacific Ocean Heat Content declined until 1995. Then the 1995/96 La Niña event "overcharged" the Tropical Pacific Ocean Heat Content again and that provided the fuel for the 1997/98 "El Niño of the Century".

FURTHER READING:

There are a multitude of websites that provide introductory (and more detailed) discussions of ENSO. It would be impractical for me to attempt to link them all. The following are a few that I found very helpful when I began studying ENSO. The first is a FAQ webpage by Bill Kessler of NOAA's **Pacific Marine Environmental Laboratory** titled **Frequently-(well, at least once)-asked-questions about El Niño**. It was after reading his description of ENSO for the umpteenth time that I finally had one of those forehead-slapping, now-I-get-it moments.

Texas A&M University has a couple of excellent online books by Robert R Stewart. The first is titled **Our Ocean Planet - Oceanography in the 21st Century - A New Oceanography Book for College Students**. ENSO is introduced in the chapter **El Niño and Tropical Heat**. Refer also to the six-parts of **Chapter 14** of Robert R Stewart's other online textbook **Introduction to Physical Oceanography**.

McPhaden et al (2006), **ENSO as an Integrating Concept in Earth Science**, provides a good general overview of ENSO.

Section 4 – Additional ENSO Discussions

This section presents numerous discussions about the processes of ENSO. In this introduction, I've presented their overviews by chapter because there are so many of them.

4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific

Outside of the tropical Pacific, ENSO impacts surface temperatures around the globe by altering normal atmospheric circulation patterns, not through the exchange of heat.

4.2 Central Pacific versus East Pacific El Niño Events

The direct effects of some El Niño events extend all of the way to the west coast of South America. These are called East Pacific El Niño events. While other El Niño events, called Central Pacific El Niño or El Niño Modoki, are focused more toward the central equatorial Pacific. East Pacific El Niño events are typically stronger and have different effects on global surface temperatures than Central Pacific events.

4.3 ENSO Indices

NINO3.4 sea surface temperature anomalies are used in this book as a reference for the frequency, magnitude and duration of ENSO events. There are other ENSO Indices. The sea surface temperature anomalies for the NINO1+2, NINO3 and NINO4 regions are often presented. The Southern Oscillation Index (SOI) uses the sea level pressure difference between Tahiti and Darwin, Australia as an ENSO indicator. There is the Multivariate ENSO Index (MEI) which utilizes many variables, as its name suggests. There is also the NOAA Oceanic NINO Index (ONI), which NOAA uses to represent the "official" El Niño and La Niña events. They all capture the frequency, magnitude and duration of El Niño and La Niña events by measuring the effects of ENSO on one or more variables. None of those indices, however, can capture all of the processes of ENSO and how those processes impact global surface temperatures.

4.4 ENSO Indices Also Fail to Capture the Relative Strengths of ENSO Events

NINO3.4 sea surface temperature anomalies during the 1982/83 El Niño reached a peak that was about the same as the 1997/98 El Niño. As a result, it's often said that the 1982/83 El Niño was comparable in strength to the 1997/98 El Niño. The 1982/83 El Niño lasted one month longer than the 1997/98 event, but the sea surface temperatures warmed more across the entire equatorial Pacific during the 1997/98 El Niño. So which was stronger?

What about the 1986/87/88 El Niño? Sea surface temperature anomalies remained in El Niño conditions for 18 months during that ENSO event. Was it the strongest El Niño during the last 30 years if we factor in the duration?

4.5 The Repeating Sequence of Primary and Secondary El Niño Events

Starting in 1971, major East Pacific El Niño events were followed by a series of smaller El Niño events, most of them Central Pacific El Niño events. Will that sequence continue or has it already been broken?

4.6 A Look at How a Few More Tropical Pacific Variables Respond to ENSO

This section illustrates the responses to ENSO of precipitation and lower troposphere temperatures in the eastern tropical Pacific. It confirms the interaction of ENSO with a few more variables.

4.7 ENSO Events Run in Synch with the Annual Seasonal Cycle

El Niño and La Niña events normally peak in December. The timing of the normal seasonal cycle in the eastern equatorial Pacific takes on the timing of the western equatorial Pacific during an El Niño. During a La Niña, the timing is similar to the normal seasonal variations in the eastern equatorial Pacific but the variations in temperature are simply exaggerated. Refer also to the introductory discussion of the delayed oscillator theory in Chapter 4.9.

4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves

The subsurface temperatures along the equatorial Pacific have been portrayed in the cartoon-like annotated illustrations of ENSO. This section confirms those depictions. The subsurface temperature **anomalies** there reveal another phenomenon called a Kelvin wave. We'll discuss the impacts of Kelvin waves on ENSO.

4.9 - An Introduction to the Delayed Oscillator Mechanism

To introduce the reader to the delayed oscillator mechanism, the interaction between Kelvin and Rossby waves are discussed. The delayed oscillator mechanism is another fundamental part of the ENSO process. It presents how the warm (downwelling) Kelvin wave that carries the warm water east at the start of an El Niño event also creates slow-moving cool (upwelling) Rossby waves traveling in the opposite direction, from east to west. Those Rossby waves reflect off the landmasses in the western tropical Pacific and then travel east along the equator as a cool (upwelling) Kelvin wave, which causes the end of the El Niño.

4.10 ENSO Versus the Pacific Decadal Oscillation (PDO)

Many persons (climate change bloggers) misunderstand the Pacific Decadal Oscillation and its relationships with global surface temperatures and with ENSO. This chapter discusses and illustrates how the Pacific Decadal Oscillation index does not represent the sea surface temperature anomalies of the North Pacific; in fact, the Pacific Decadal Oscillation index is inversely related to North Pacific sea surface temperature anomalies. The Pacific Decadal Oscillation is an aftereffect of ENSO, with the additional multidecadal variability of the Pacific Decadal Oscillation data being caused by changes in sea level pressure.

4.11 There is a Multidecadal Component to ENSO

Using a 121-month running-average filter of NINO3.4 sea surface temperature anomalies and period-averages of the same data, this chapter discusses and illustrates the underlying multidecadal variability associated with ENSO.

4.12 ENSO Monitoring

In this chapter, we discuss the ENSO updates available from Australia's Bureau of Meteorology (BOM) and NOAA, and the NOAA/PMEL Tropical Ocean Atmosphere (TAO) project, which is the source of much of the atmospheric and ocean (surface and subsurface) data for those reports.

4.13 An Introduction to the Indian Ocean Dipole and How It's Impacted by ENSO

The Indian Ocean Dipole (IOD) and its Dipole Mode Index (DMI) are mentioned in many ENSO papers and, specifically, in the Australian Bureau of Meteorology ENSO updates. This chapter introduces readers to the Indian Ocean Dipole (IOD) and Dipole Mode Index (DMI) and discusses how they are impacted by ENSO.

4.14 Impacts of ENSO Events on Regional Temperature and Precipitation

So far, we've briefly mentioned that, during ENSO events, surface temperatures away from eastern tropical Pacific vary in response to changes in atmospheric circulation. This chapter provides an introduction to the changes in atmospheric circulation that cause those surface temperature variations in areas remote to the eastern tropical Pacific.

4.15 Further Discussion on What Initiates an El Niño Event

An El Niño starts when the trade winds relax sufficiently and long enough so that the warm water in the west Pacific Warm Pool sloshes east. This chapter discusses the many factors that are known to cause the trade winds to relax.

4.16 Weak, Moderate and Strong ENSO Event Thresholds

This chapter presents what NOAA considers to be the thresholds for weak, moderate and strong El Niño and La Niña events.

4.17 ENSO – A Cycle or Series of Events?

The answer to the question: a combination of the two.

4.18 ENSO Influence on Tropical Cyclones

El Niño events influence the formation of tropical cyclones—known as hurricanes in the North Atlantic—and elsewhere around the globe.

I’ve included summaries for the individual chapters at their ends, so there will be no general recap of Section 4. Also note: there were a few chapters that were only a page or two long. I didn’t bother with summaries for them.

4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific

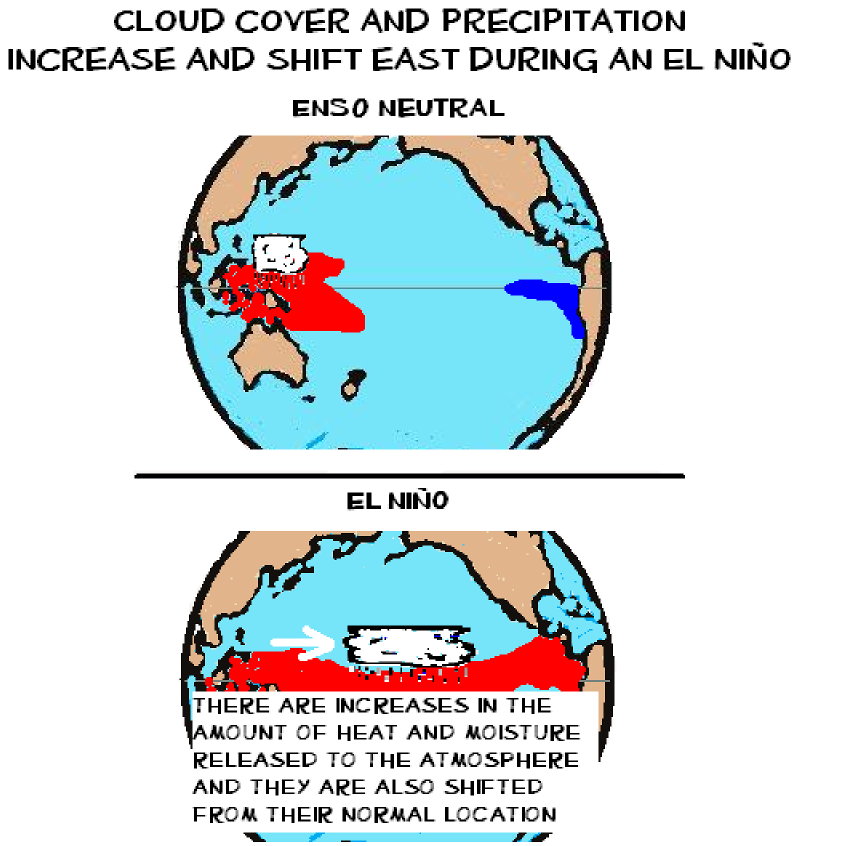


Figure 4-1

Figure 4-1 shows that cloud cover and precipitation increase during an El Niño. More warm water than normal covers the tropical Pacific, and it is located farther to the east than normal. The clouds and precipitation accompany that warm water to the east. Because there's more warm water covering the surface, there's more evaporation, cloud cover and precipitation.

To confirm that in Section 3, I provided maps that show tropical Pacific sea surface temperatures during the ENSO-neutral December before the 1997/98 El Niño (December 1996) and the December at the peak of the 1997/98 El Niño (December 1997). I'll provide it again here as Figure 4-2. To confirm the precipitation aspect, Figure 4-3 includes maps that show precipitation in mm per day for the same two months. The dataset is the satellite-based NOAA **CAMS-OPI** precipitation data, where CAMS-OPI stands for Climate Anomaly Monitoring System (CAMS)-Outgoing Longwave Radiation (OLR) Precipitation Index (OPI).

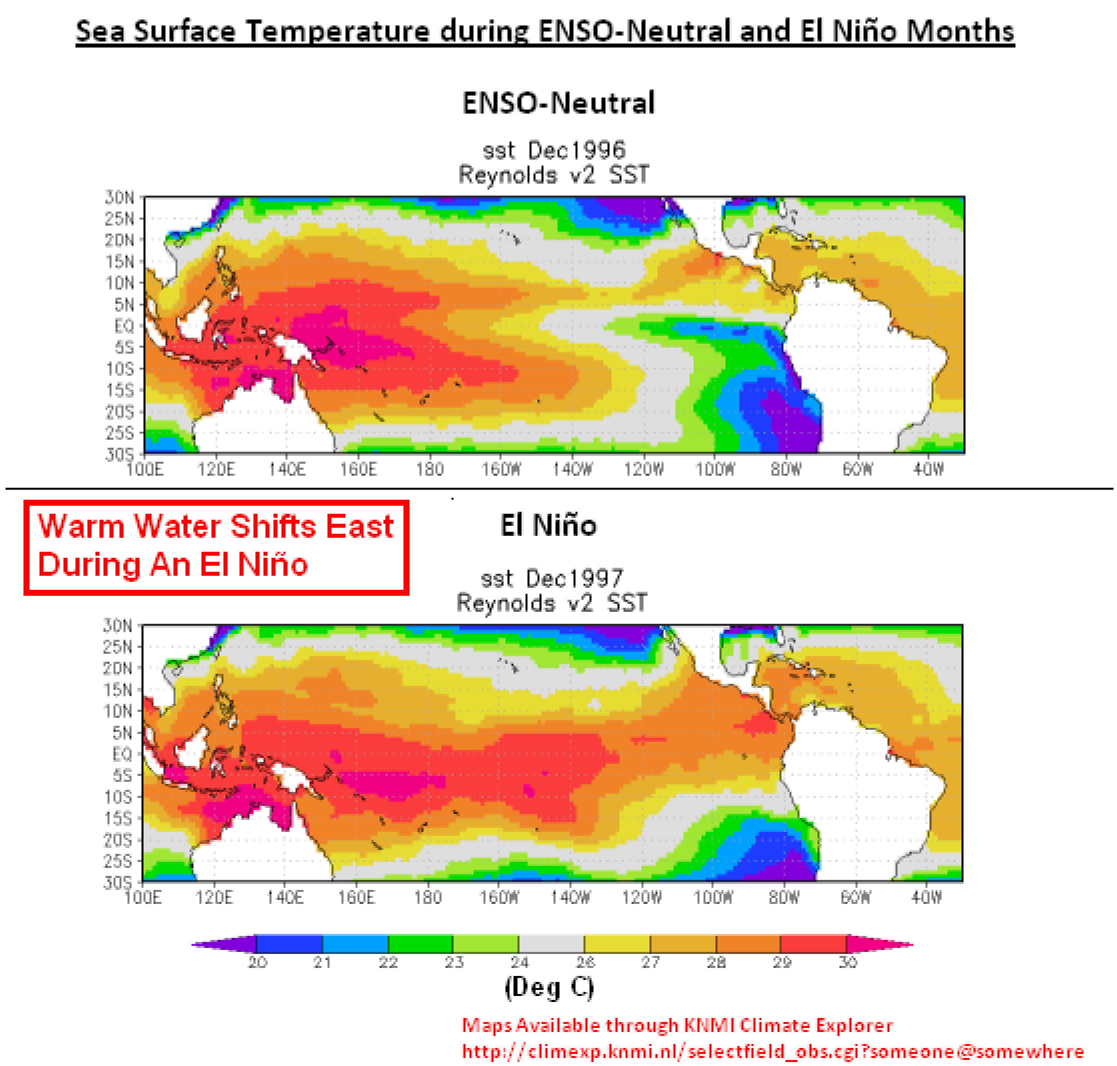


Figure 4-2 **Bob Tisdale**

HHH

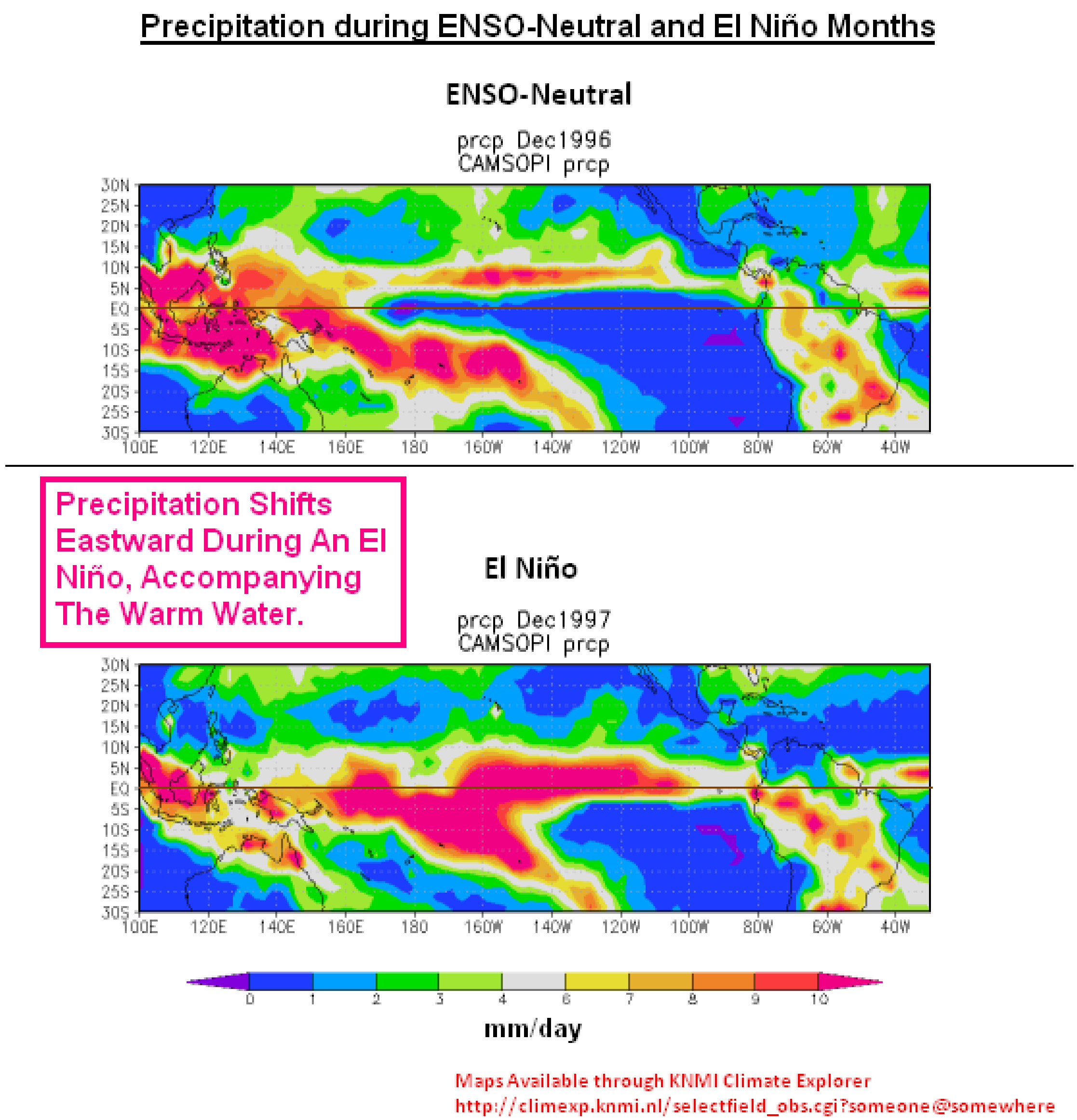


Figure 4-3 Bob Tisdale

Now, hopefully, you're wondering how a shift in the location of the precipitation in the tropical Pacific raises global surface temperatures. First an overview:

The sea surface temperatures in the western tropical Pacific (the Pacific Warm Pool) are among the warmest on Earth. As a result, a lot of moisture is pumped into the atmosphere there, day after day, week after week, month after month… Because the water in the Pacific Warm Pool is so warm, and because the area of the Pacific Warm Pool is so large, the western tropical Pacific is one of the driving forces of global climate.

During ENSO-neutral months, the warm surface water is "contained" in an area called the west Pacific Warm Pool. Atmospheric circulation patterns (jet streams and the like) are in synch with the warm water, evaporation, clouds and rain being at that location. Then there's an El Niño event, and the warm water sloshes eastward in the tropical Pacific. Keep in mind the tropical Pacific covers a long distance from east to west, almost half way around the globe. On maps, like those in Figures 4-2 and 4-3, it never looks very big, but it's huge.

The moisture being pumped into the atmosphere from the surface of the tropical Pacific increases because more of the tropical Pacific surface is covered with the warmer water. The evaporation, the clouds, and the rain all shift east those thousands of kilometers during an El Niño, too. The result: storm tracks, jet streams, winds, surface pressures, and surface temperatures change around the globe.

Rainfall in some locations increases, and in others, it decreases. Meteorologists like your local TV weather person consider the state of the tropical Pacific Ocean (El Niño, or ENSO-Neutral, or La Niña) when making their long-range forecasts.

During an El Niño, some parts of the globe warm in response to those changes in atmospheric circulation, and other parts cool. The warming around the globe is greater than the cooling, so global surface temperatures warm in response to an El Niño. Typically, that additional warming of the areas outside of the tropical Pacific represents about half of the total warming associated with an El Niño, if you're looking for a rough idea.

We can show the areas around the globe that warm or cool during an El Niño event using a correlation tool at the KNMI Climate Explorer. (The KNMI Climate Explorer is a wonderful website if you're interested in doing your own climate research.) See the map in Figure 4-4. The areas that warm (cool) during an El Niño (La Niña) at the same time as NINO3.4 sea surface temperature anomalies (with a zero-month lag) are shown in yellow, orange and red, with the colors showing how well they agree. Conversely, the areas that cool (warm) during an El Niño (La Niña) when NINO3.4 sea surface temperature anomalies warm (cool) are shown in greens and blues. Reynolds OI.v2 sea surface temperature anomalies for the NINO3.4 region (5S-5N, 170W-120W) were used to represent the timing and strengths of the ENSO events, and **GISS Land-Ocean Temperature Index (LOTI) data** was used to show the response of global surface temperatures to those events. The period is 1982 to 2010.

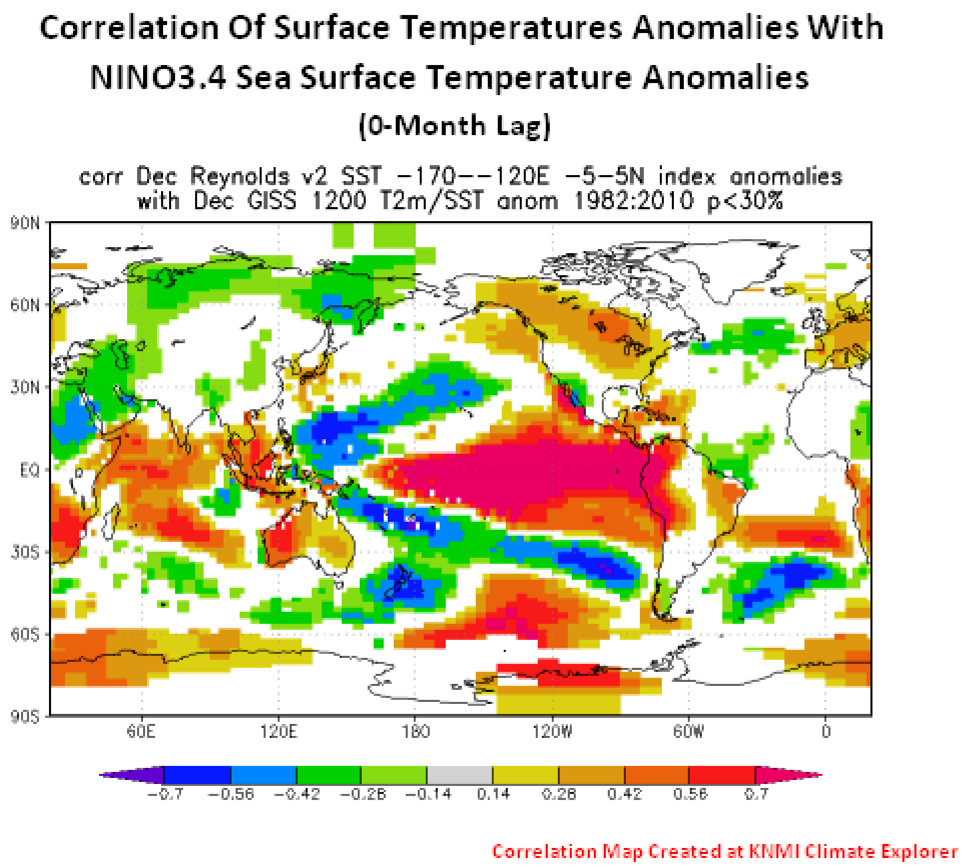


Figure 4-4

We've established, as the El Niño event is taking place, there are changes in atmospheric circulation. We'll discuss those changes in atmospheric circulation in more detail in a later chapter. Consider now that it takes months for those changes in atmospheric circulation to impact the surface temperatures in different parts of the globe. As an example, note how the El Niño has very little effect on the North Atlantic sea surface temperatures in Figure 4-4. A couple of areas cool during an El Niño while a portion of the western tropical Atlantic warms. That correlation map is set for a 0-month lag. If we plot the correlation map again, this time using a 3-month lag, Figure 4-5, the tropical North Atlantic now shows considerable warming in response to an El Niño.

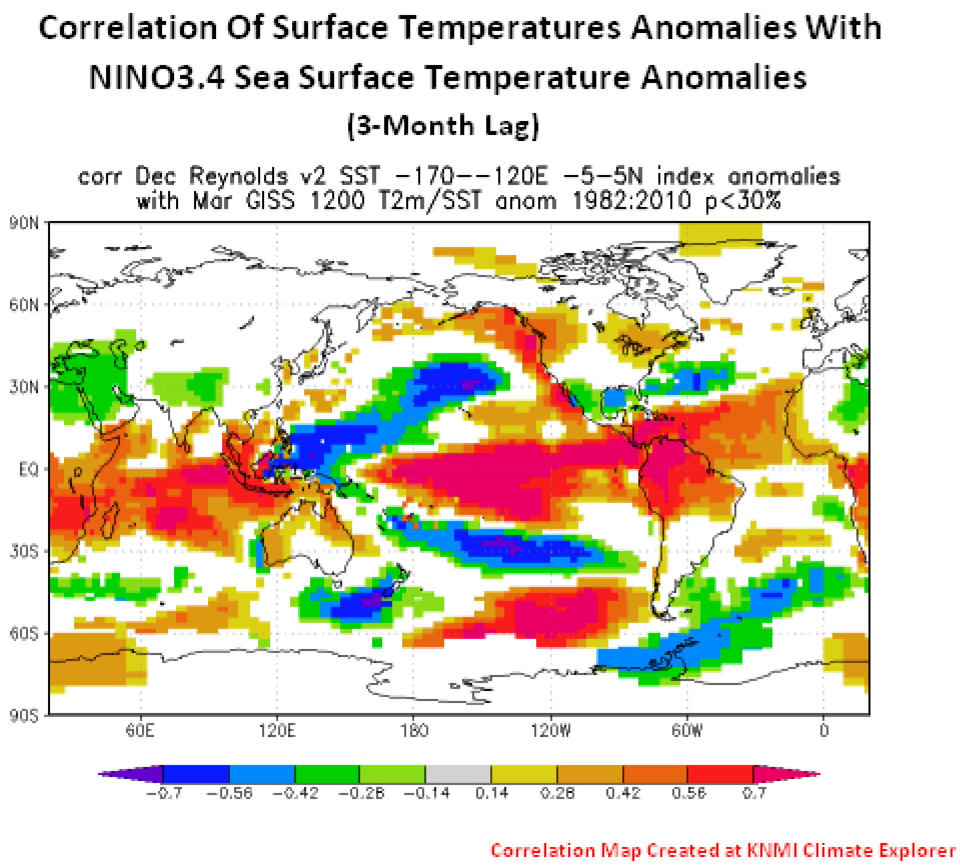


Figure 4-5 Bob Tisdale

A Note about Correlation: Just because the surface temperature anomalies in one part of the globe correlate well with the NINO3.4 sea surface temperature anomalies, it does not mean that the surface temperature anomalies in the remote location are varying the same amount as the NINO3.4 sea surface temperature anomalies. It only means the timing and the relative magnitudes of the variations are similar. For example, the two curves in Figure 4-6 correlate perfectly. They have a correlation coefficient of 1.0. The timings of the variations are the same, but the sizes of the variations in the green curve are not the same as the purple curve. They are proportional, but they are not the same magnitude.

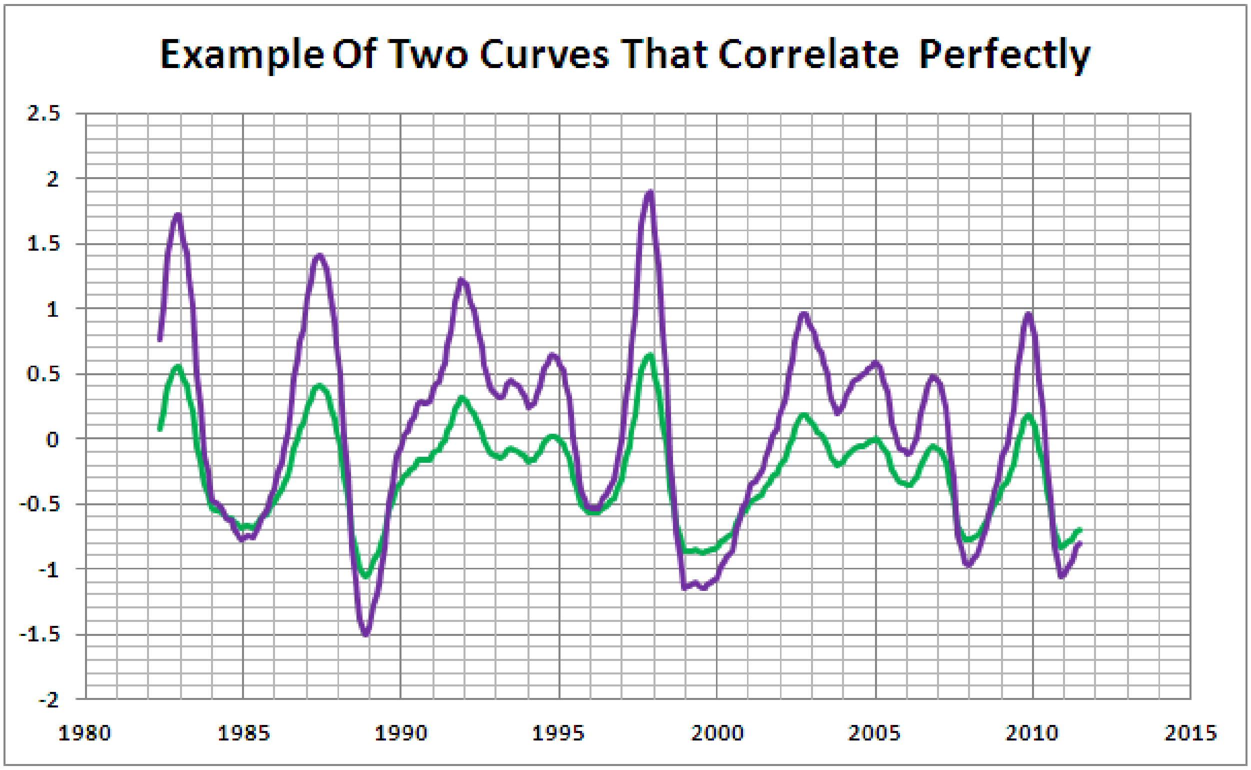


Figure 4-6 Bob Tisdale

Another Note About Correlation: Poor correlation does not mean that sea surface temperatures in a given location aren't impacted by ENSO; it simply means the variations there were not consistent with the variations in NINO3.4 sea surface temperature anomalies. If an area warmed in response to El Niño events AND to the La Niña events that follow them, that area would correlate poorly with the ENSO index.

Back to the discussion of El Niño events: surface temperatures outside of the eastern tropical Pacific warm in most areas due to the changes in atmospheric circulation, not because the heat released into the air is now warming the surfaces of the other areas. For example, when surface temperatures outside of the tropical Pacific warm and cool in response to an El Niño, and when there isn't a direct transfer of heat, climate scientists say the one area is teleconnected to the other area. It's an odd word that brings to mind images of the temperature in one part of the globe picking up the phone and calling the temperature in another part to tell it to change. That aside, teleconnections are well studied and well documented. If you were to enter teleconnection as a search item in **Google Scholar**, there are over 13,000 returns.

An example of a teleconnection: Figure 4-7 is a graph that compares North Atlantic and NINO3.4 sea surface temperature anomalies. The data have been smoothed. We can see the response of the North Atlantic sea surface temperature anomalies to the 1986/87/88, 1997/98, and 2009/10 El Niño events. The North Atlantic sea surface temperatures warm a couple of months after the NINO3.4 data warms. (Notice that the NINO3.4 sea surface temperature anomalies have been multiplied by 0.5 to scale them for the graph. That's another indication that the temperatures in the North Atlantic are not varying as much as they are in the eastern tropical Pacific.)

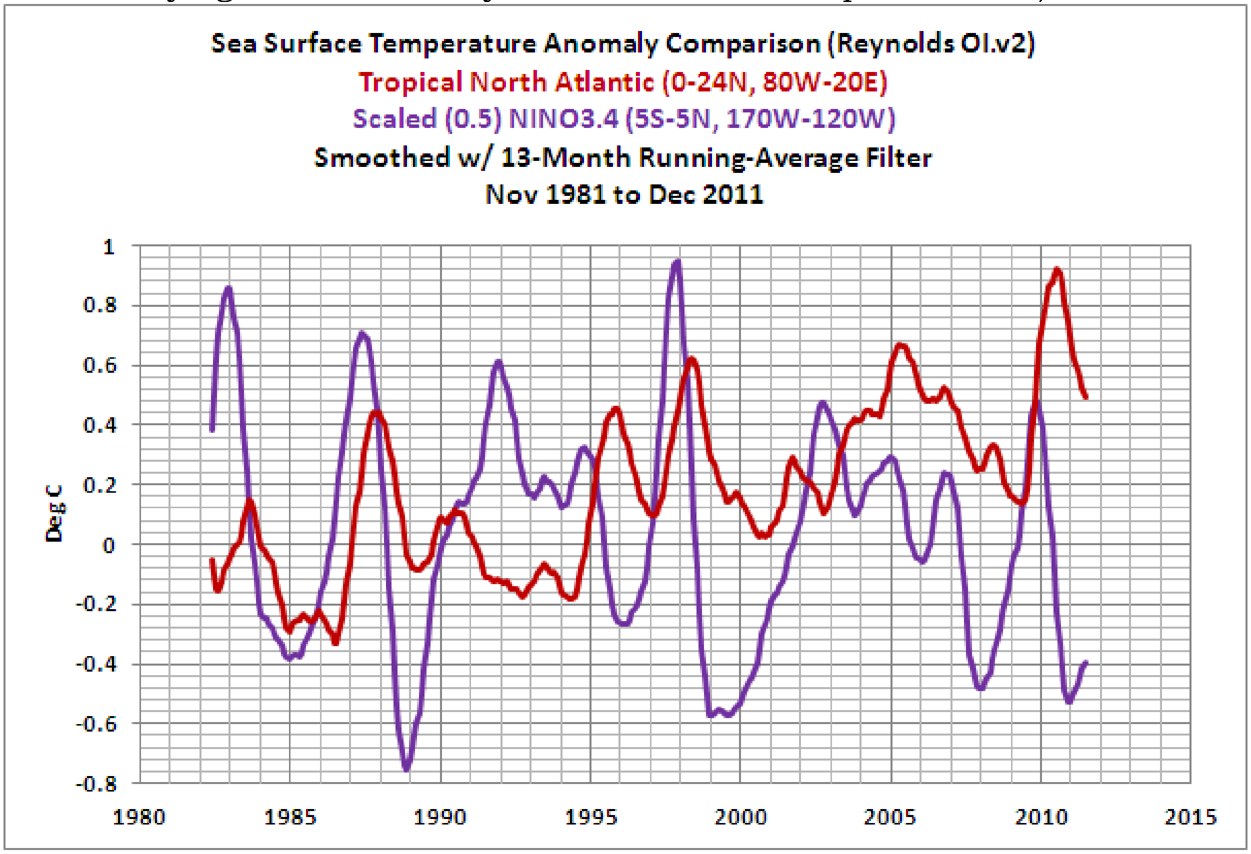


Figure 4-7

Bob Tisdale

Now consider that there's a great big landmass between the eastern tropical Pacific and the tropical North Atlantic. It's Central America and the northernmost part of South America. Even with that chunk of land between them, the tropical North Atlantic warms a few months after the tropical Pacific during an El Niño. The warm El Niño water in the Pacific doesn't slosh across Central America to warm the North Atlantic, and the warm water doesn't circumnavigate South America in a few months to do it either. Still, the tropical North Atlantic warms a few months later. How does that happen? Nope, the Panama Canal can't explain it.

Those two oceans might be separated by the land mass of Central America, but the atmosphere above them is not. We already know how and why the trade winds weaken in the eastern tropical Pacific during an El Niño. Those changes in atmospheric circulation in the Pacific, in turn, cause the trade winds in the tropical North Atlantic to weaken, too. The slower trade winds blowing across the surface of the tropical North Atlantic Ocean don't cool the surface waters as much as they normally would; there's less evaporation with the slower trade winds; so the sea surface temperatures warm in the tropical North Atlantic. That's only part of the explanation. With trade winds in the North Atlantic at their normal strength, cool waters from below the surface are pulled up to the surface there. In other words, where upwelling occurs, it is occurring at its normal rates when the trade winds are at their normal strengths. When the trade winds weaken during an El Niño, there is less cool water being pulled up to the surface, so the tropical North Atlantic warms as a result of that weakening process also. Refer to Wang (2005) **ENSO, Atlantic Climate Variability, And The Walker And Hadley Circulation** for a more detailed discussion.

That's the basic explanation of the teleconnection between the sea surface temperatures in eastern tropical Pacific and the sea surface temperatures of the tropical North Atlantic.

There are further discussions in **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation.** We're not done yet with this subject.

RECAP

An El Niño event is a coupled ocean-atmosphere process that discharges heat from the tropical Pacific Ocean to the atmosphere. The phrase "coupled ocean-atmosphere process" refers to the fact that many ocean and atmospheric variables in the tropical Pacific interact with one another. The variables impacted directly by an El Niño event include sea surface temperature, sea level, ocean currents, ocean heat content, depth-averaged temperature, warm water volume, sea level pressure, cloud amount, precipitation, the strength and direction of the trade winds, etc. Because the El Niño changes the cloud amount in the tropical Pacific, this impacts the amount of sunlight (downward shortwave radiation) reaching and warming the oceans there.

During an El Niño, warm water from the west Pacific Warm Pool can travel thousands of miles to the east across the equatorial Pacific. Keep in mind that the equatorial Pacific stretches almost halfway around the globe. The cloud cover and precipitation accompany that warm water, and their relocation causes changes in atmospheric circulation patterns worldwide. In turn, this causes temperatures outside of the eastern tropical Pacific to vary, some warming, some cooling, but in total, the areas that warm exceed those that cool and global surface temperatures increase in response to an El Niño. This is discussed further in **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation**.

4.2 Central Pacific versus East Pacific El Niño Events

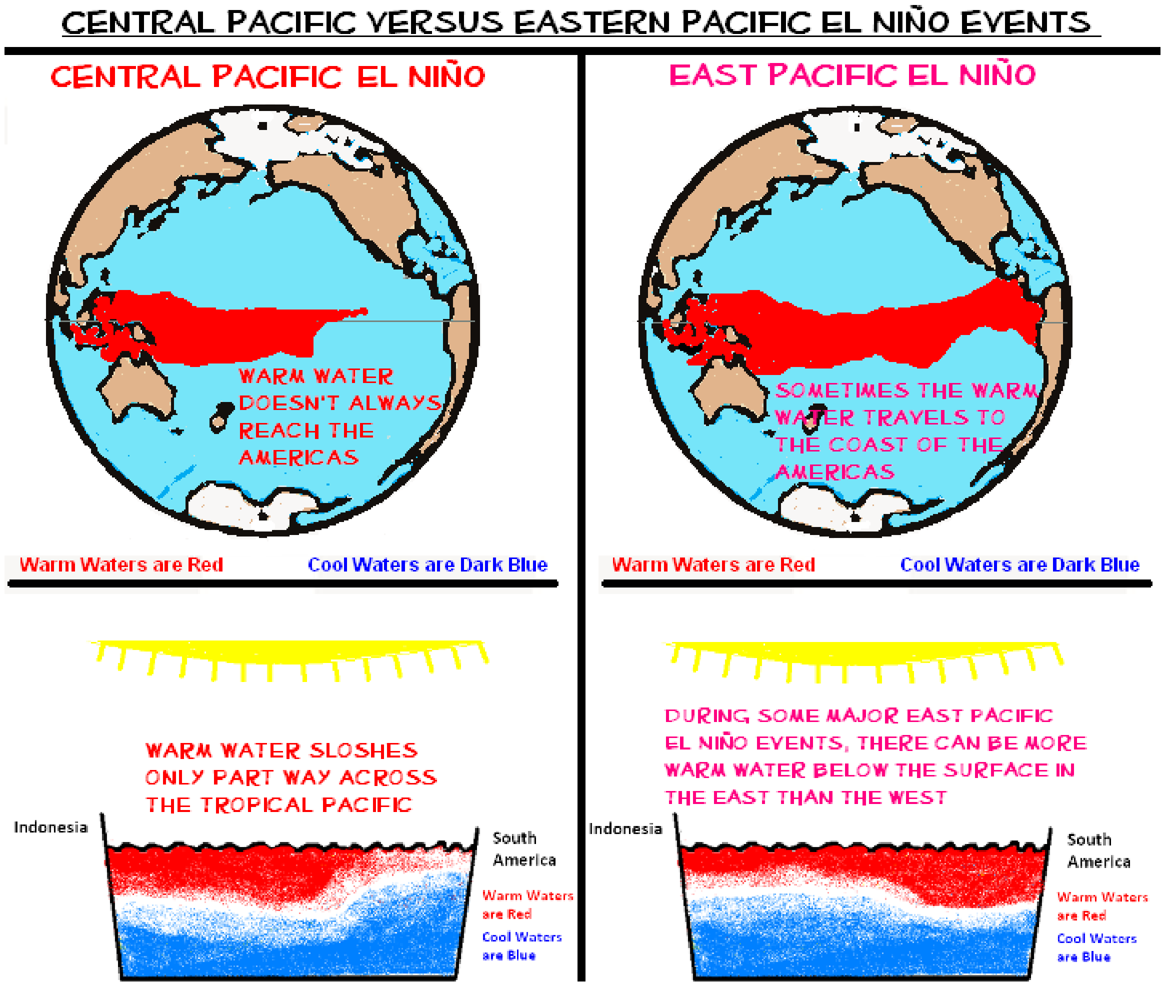


Figure 4-8

There has been considerable research in recent years into the causes and effects of different types of El Niño events based on their locations. Some El Niño events remain more towards the center of the tropical Pacific, while others impact the central and eastern regions. In some scientific papers, East Pacific El Niño events are referred to as Canonical, and Central Pacific El Niño events are called Non-Canonical. In other papers, East Pacific events can be called Cold-Tongue El Niño, while Central Pacific events are called Warm-Pool El Niño, which sounds a little confusing. We'll stick with Eastern and Central to avoid confusion. Central Pacific El Niño can also be called El Niño Modoki. More on that in a moment.

Let's take a look at the sea surface temperatures of the equatorial Pacific, using meridional-mean graphs, to show the difference between Central and East Pacific El Niño. We'll use the Decembers during each of the El Niño years since 1982 (because El Niño events typically peak in December). First, the Central

Pacific El Niño events are shown in Figure 4-9. The greatest sea surface temperature anomalies occur between the dateline and 160W. Then the anomalies grow much less warm toward the east.

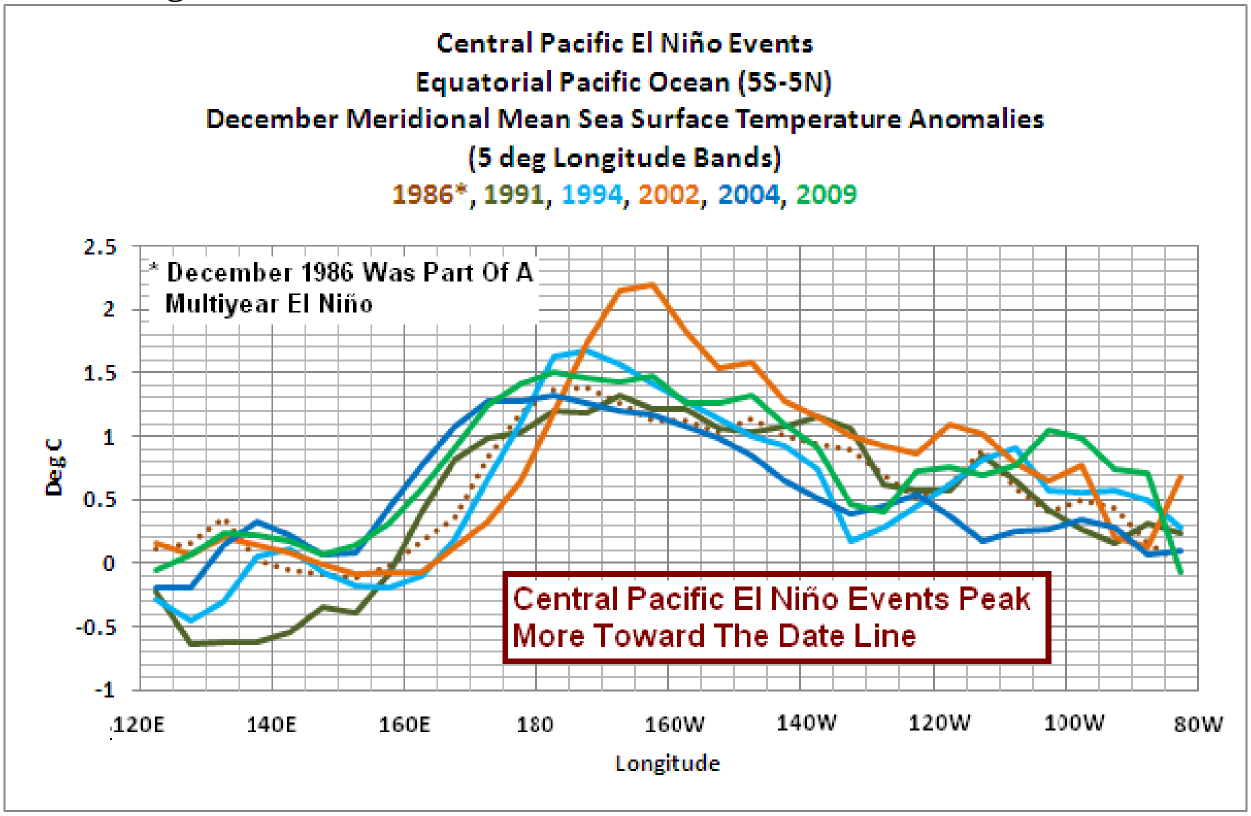


Figure 4-9

Bob Tisdale

Then there are the Eastern Pacific El Niño events, Figure 4-10. Their peak December sea surface temperature anomalies can be very high in the eastern equatorial Pacific.

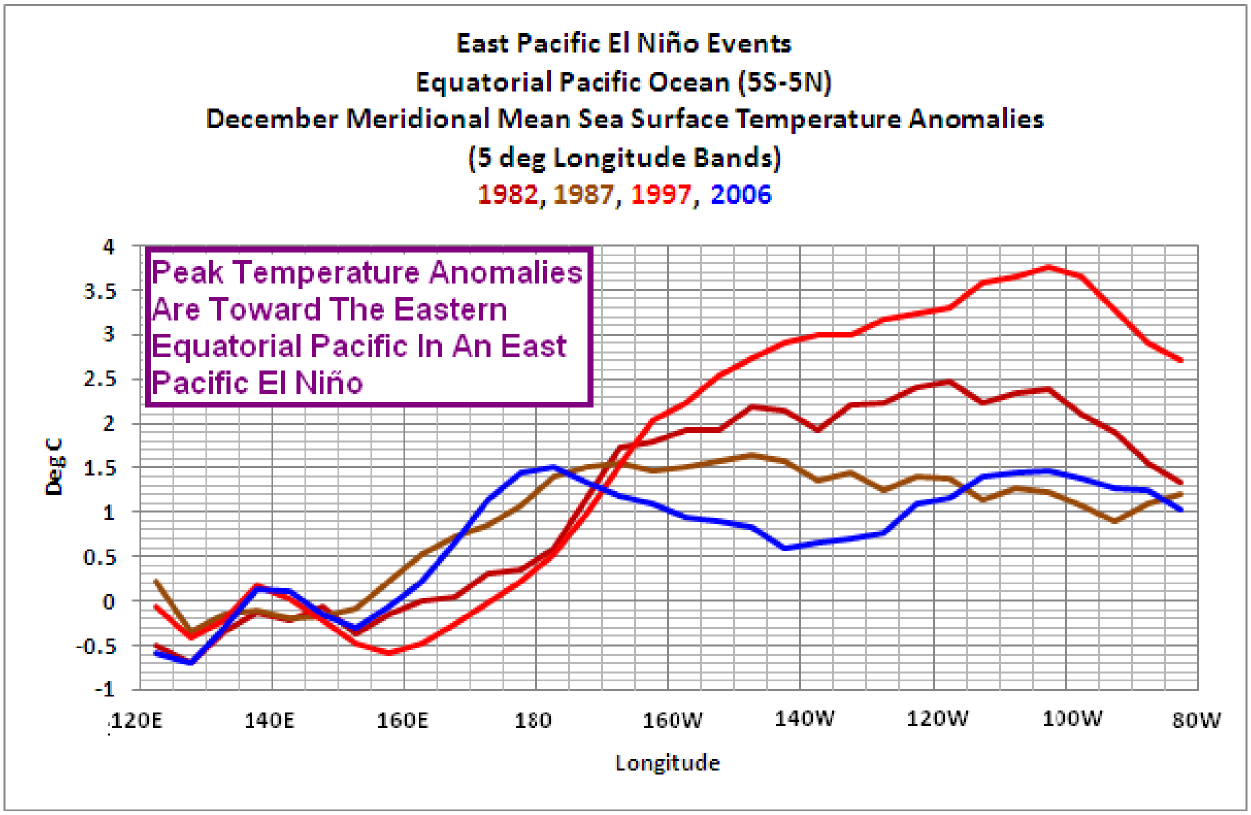


Figure 4-10 Bob Tisdale

Also, if we compare the East Pacific and Central Pacific El Niño events, Figure 4-11, we can see that the East Pacific El Niño events are typically stronger than the Central Pacific events.

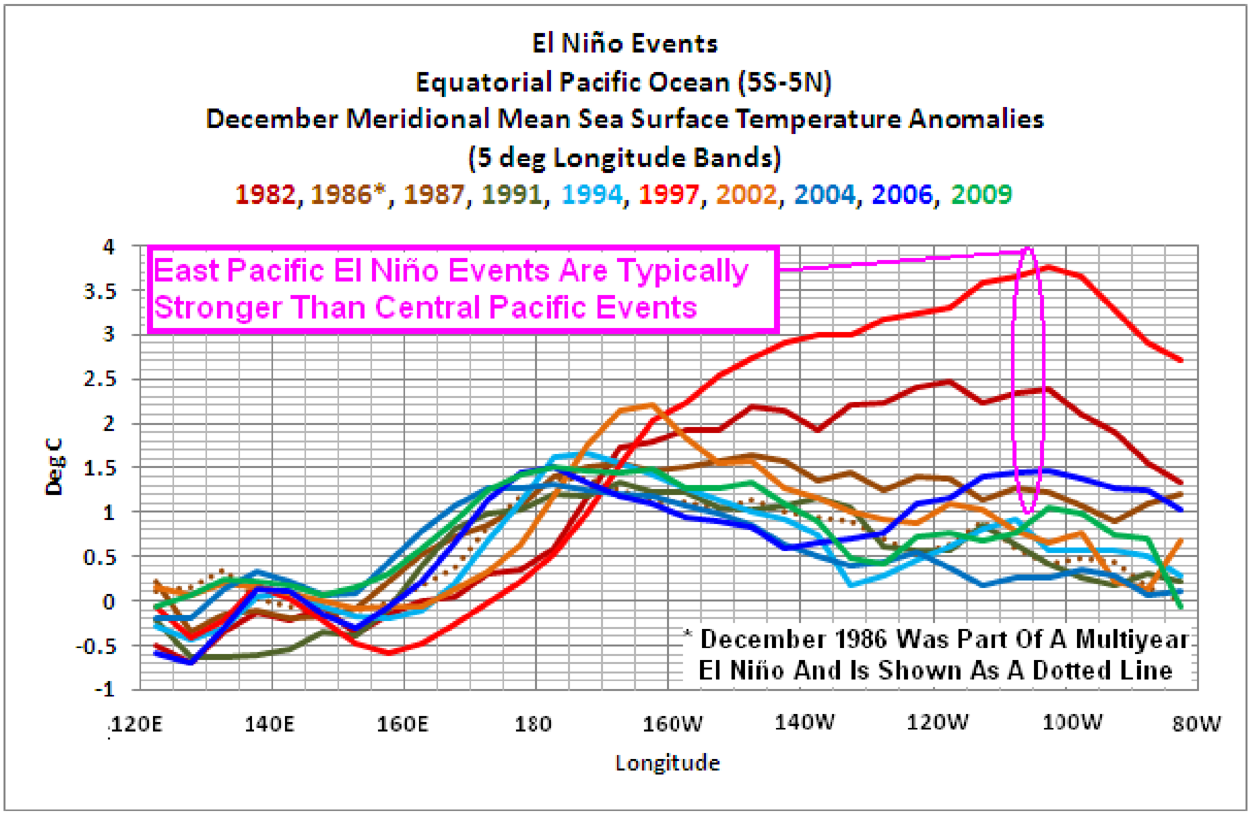


Figure 4-11 Bob Tisdale

Note: The 1986/87/88 was a multiyear El Niño event. Note how it was a Central Pacific El Niño in December 1986, but an East Pacific El Niño in December 1987. Keep that in mind for the discussion of Kelvin waves in an upcoming chapter.

Some studies indicate an increased frequency of Central Pacific El Niño events due to global warming, and others show the frequency of the Central Pacific El Niño events varies with time and that we are simply in the part of the cycle with more Central Pacific El Niño events. As one would expect, the papers that seem to get the interest of the press are the ones that tie a change in the location of ENSO events to anthropogenic global warming. That's happened a couple of times since 2009. Here's what the data says.

A recent study, Ashok et al (2007), **El Niño Modoki and its Possible Teleconnection**, presented a new sea surface temperature anomaly-based index to indicate when Central Pacific El Niño events have occurred. It is called the El Niño Modoki Index. Modoki is Japanese for "a similar but different thing". We can calculate the El Niño Modoki Index using the same method as Ashok et al (2007) with data from the long-term sea surface temperature dataset HADISST. That way we can see if there had been El Niño Modoki events earlier in the 20th Century. The resulting graph, Figure 4-12, reveals that El Niño Modoki events have occurred regularly since 1900. Figure 4-12 is from my 2009 blog post **There Is Nothing New About The El Niño Modoki**. El Niño Modoki events are those El Niño events that take place when the El Niño Modoki Index is above the red line highlighted at 0.7.

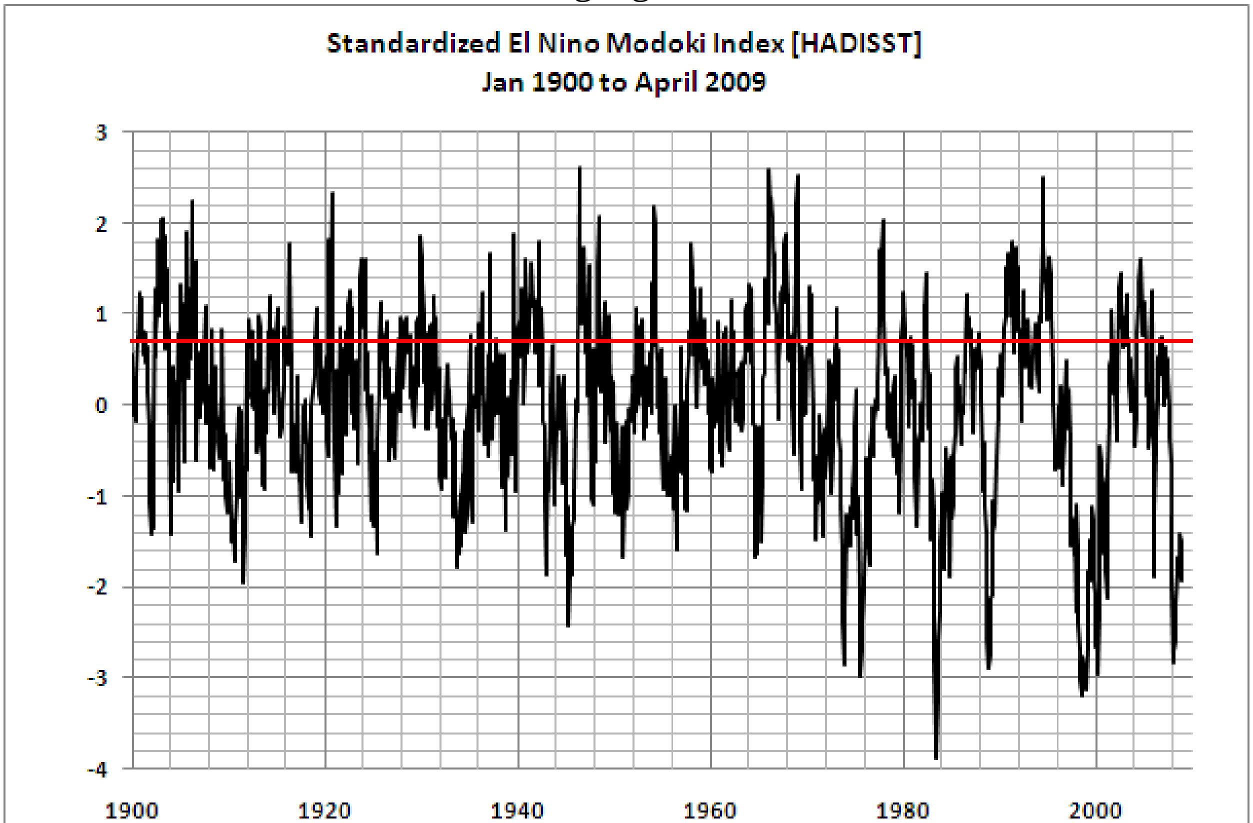


Figure 4-12

About a year later, I compared the El Niño Modoki Index to NINO3.4 sea surface temperature anomalies from 1900 to present. The comparisons were broken down into 4 periods because the El Niño Modoki Index is noisy. If you're interested, refer to the post **here**.

Global surface temperatures will respond differently to the two different types of El Niño events. The East Pacific El Niño events are typically stronger and they are closer to the landmasses of the Americas than the Central Pacific events. Because the evaporation, clouds and precipitation have traveled farther east during the East Pacific El Niño, atmospheric circulation patterns are disturbed more than they are with Central Pacific El Niño events. We can show these differences by first correlating our standard ENSO Index (NINO3.4 Sea Surface Temperature Anomalies) to global surface temperature anomalies and then creating the correlation maps again using the El Niño Modoki Index in place of the NINO3.4 data. The correlation analysis keys off the major events, which were East Pacific events with the NINO3.4 data. While the El Niño Modoki Index captures the Central Pacific ENSO events. Figure 4-13 compares the correlation maps of Central Pacific and East Pacific El Niño events with a zero lag. Different portions of the continents and oceans warm during the East Pacific and Central Pacific El Niño events, with stronger correlations during the East Pacific El Niño events. The same holds true with correlation maps when global surface temperatures are lagged 3 months to account for the slow response times of the temperatures around the globe. See Figure 4-14.

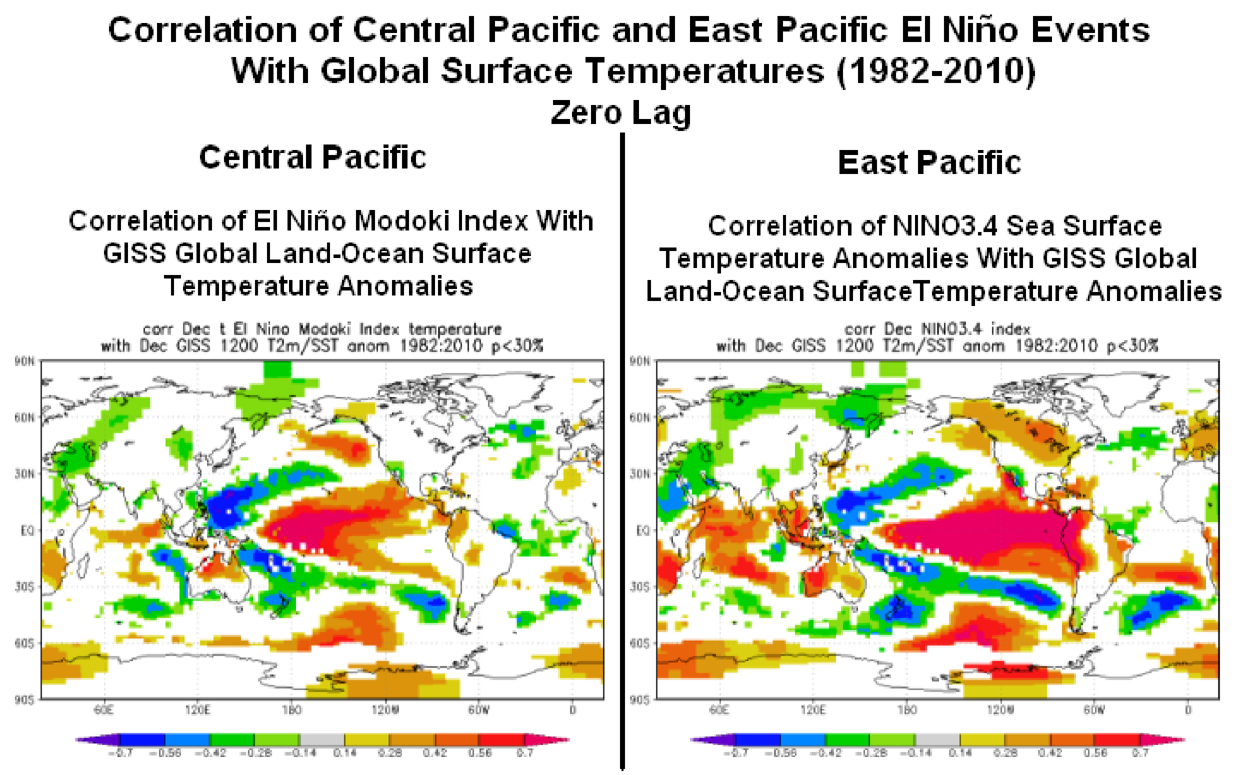


Figure 4-13

Bob Tisdale

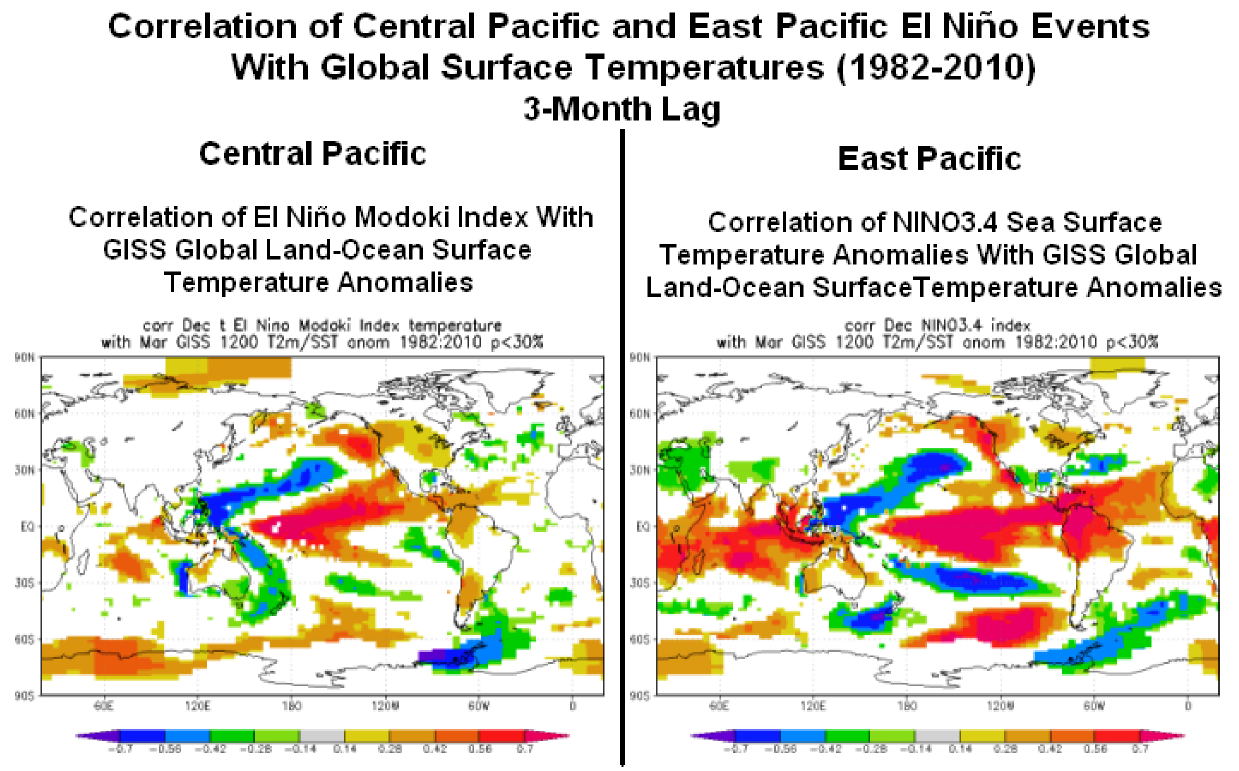


Figure 4-14

Bob Tisdale

RECAP

Not all El Niño events impact the entire eastern tropical Pacific. In fact, since 1982, only four of the ten El Niño Decembers would be considered parts of East Pacific El Niño events. The rest were Central Pacific El Niño events, when sea surface temperatures peak more toward the dateline along the equatorial Pacific. East Pacific El Niño events are typically stronger than Central Pacific events. As one might expect, global surface temperatures respond differently to the two types of El Niño events.

4.3 ENSO Indices

El Niño-Southern Oscillation (ENSO) indices are used to show the frequency (how often they occur), the magnitude (the strength), and the duration (the length in time) of El Niño and La Niña events. So far we've been using a sea surface temperature-based index, the sea surface temperature anomalies of the NINO3.4 region of the equatorial Pacific.

The Southern Oscillation Index, or SOI, is a way to portray the atmospheric component of El Niño and La Niña events. It represents the difference in Sea Level Pressure between Darwin, Australia and the South Pacific island of Tahiti. The term Southern Oscillation was coined by Sir Gilbert Walker in the 1920s. Yes, that's the same Walker as in "Walker Circulation" or "Walker cells". He was the first researcher to note that the surface air pressures in Tahiti and Darwin, Australia opposed one another; that is, when sea level pressure in Tahiti was high, the sea level pressure in Darwin was normally low, and vice versa.

Let's discuss the trade winds again for a moment. The trade winds are blowing from east to west when the surface air pressure in the east (Tahiti) is higher than in the west (Darwin). See Figure 4-15. When the pressure difference between Tahiti and Darwin grows, the trade winds are stronger, and that's an indication of a La Niña event.

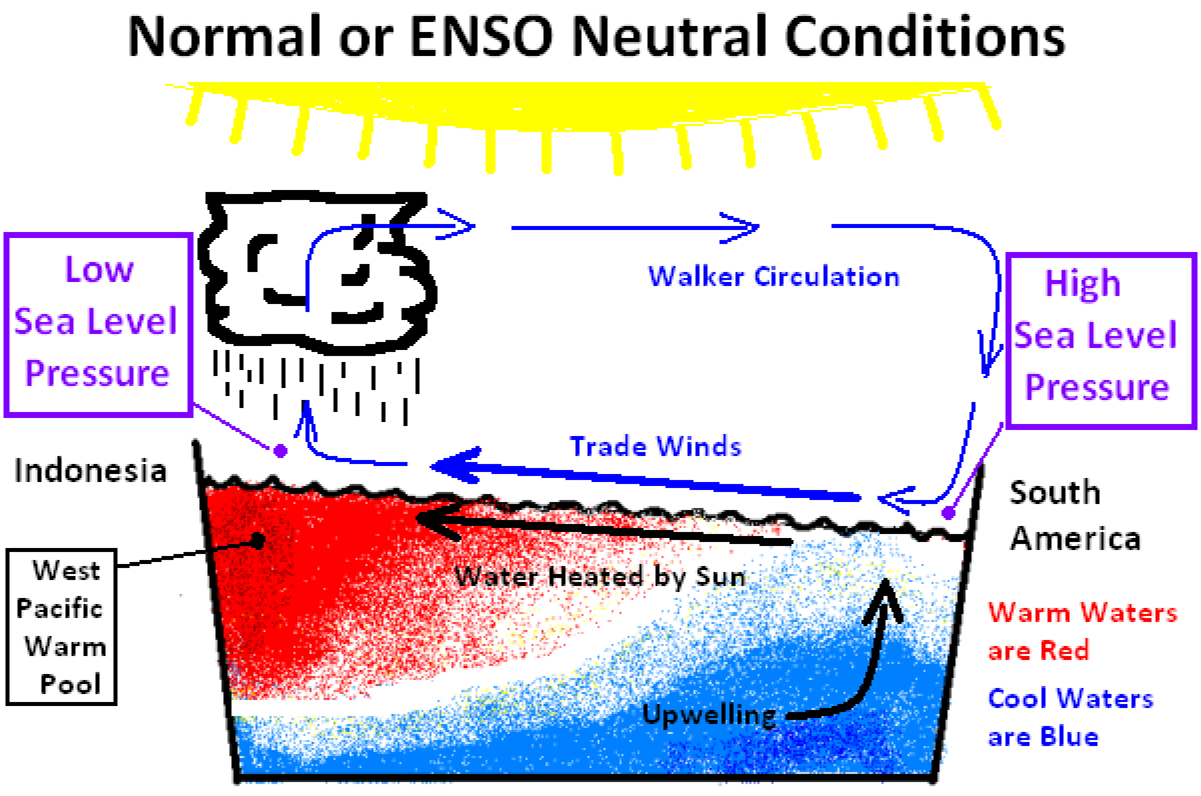


Figure 4-15 Bob Tisdale

The Australian Bureau of Meteorology (BOM) is one of the suppliers of Southern Oscillation Index data. They use a traditional method of presentation, which they explain **here**. Basically—maybe not so basically—the data is calculated by subtracting the sea level pressure in Darwin from the sea level pressure in Tahiti. Then they determine the anomalies using the method described in Chapter 2.8. Here's where the not-so-basically part comes in. The anomalies for that month are divided by the standard deviation, to standardize or normalize the data. After that, they multiply the data by 10. Whew! For those interested, there's a somewhat-simple-to-understand explanation of standard deviation **here**.

Now that that's out of the way, let's compare the Southern Oscillation index data to the NINO3.4 sea surface temperature anomalies we've been using as an ENSO index. See Figure 4-16. Because the Southern Oscillation index data is multiplied by 10 as part of its calculation, we'll need to scale the NINO3.4 sea surface temperature anomalies. A factor of 10 works. The Southern Oscillation index data is noisy, so the two datasets were smoothed with 13-month running-average filters. It's very easy to see the inverse relationship between the two datasets. Equatorial Pacific sea surface temperature warm and cool during the evolution and decay of an El Niño, and Southern Oscillation index data dips and rebounds. The opposite holds true during a La Niña. There are some minor differences. For example, the Southern Oscillation index data shows the 1982/83 El Niño was stronger than the one in 1997/98, while the NINO3.4 sea surface temperature anomalies show them the other way around. Notice also, there doesn't appear to be a La Niña event after the 1982/83 El Niño using the Southern Oscillation index, but one is present in the NINO3.4 data. Other than those and some others minor differences, the two datasets do mimic one another, but inversely.

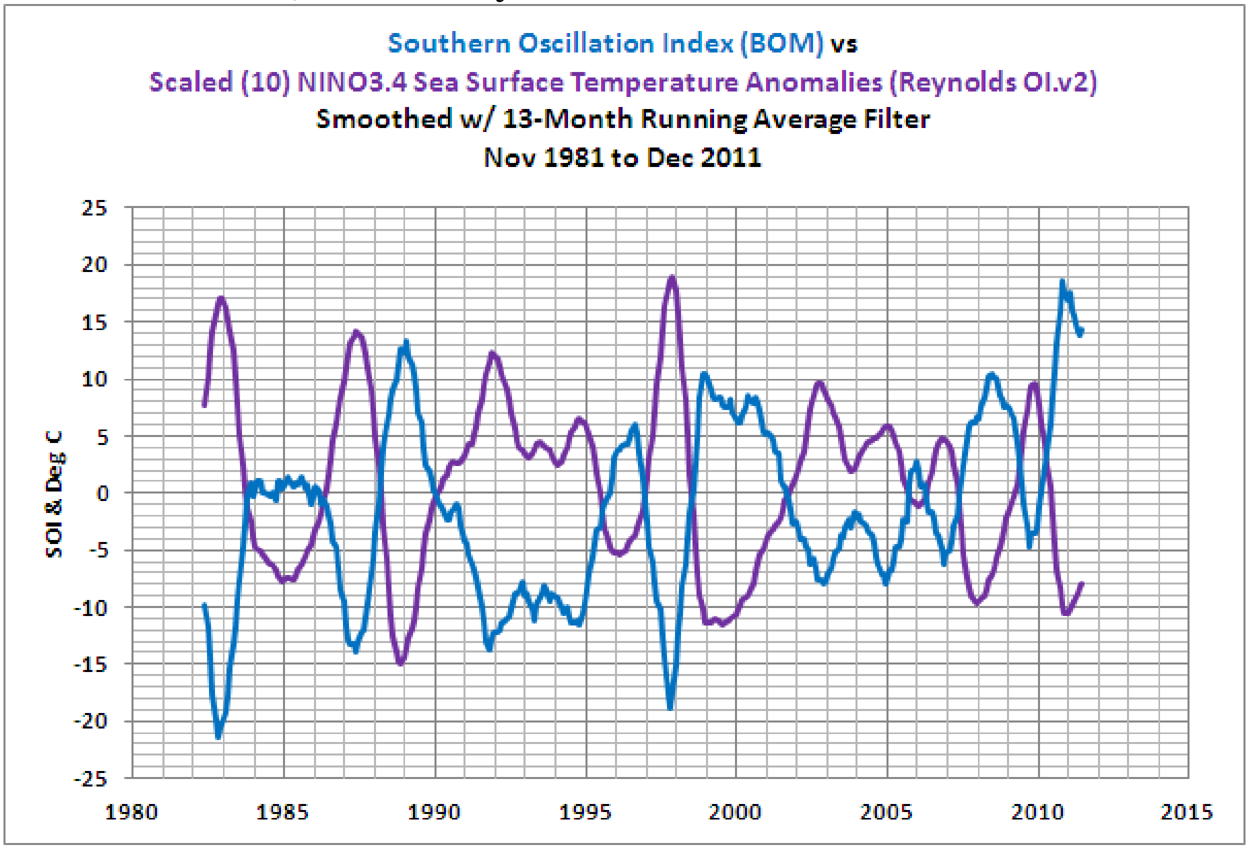


Figure 4-16 Bob Tisdale

According to the BOM, La Niña events are sustained positive Southern Oscillation Index values in excess of +8 and El Niño events are sustained negative values in excess of -8. In that discussion at the BOM website, however, the Southern Oscillation Index data is being presented as a 30-day running average, so you can't apply those values to Figure 4-16, which has been smoothed with a 13-month running-average filter.

MORE ENSO INDICES

Figure 4-17 is a map that shows the locations of three commonly used NINO regions: NINO1+2 (10S-0, 90W-80W), NINO3 (5S-5N, 150W-90W), NINO4 (5S-5N, 160E-150W), and the most commonly used NINO3.4 (5S-5N, 170W-120W), which we're using as our primary ENSO index in this book.

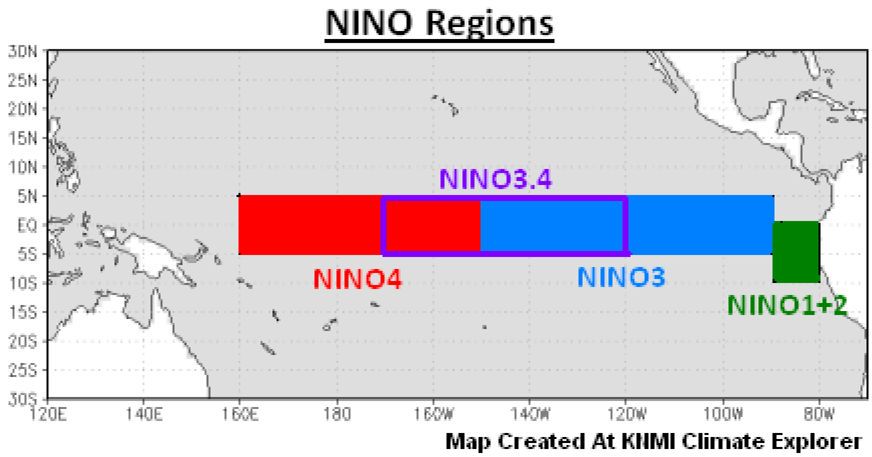


Figure 4-17 Bob Tisdale

The sea surface temperature anomalies for those regions are compared in Figure 4-18. The NINO1+2 data is very noisy between major El Niño events, so I've smoothed all data with13-month running-average filters. The two standouts in that graph are the NINO4 and the NINO1+2 data. The NINO4 sea surface temperature anomalies (red) do not vary as greatly as the other regions during the major El Niño events. This indicates that the major variations during those events are taking place to the east of the NINO4 region. On the other hand, the NINO4 sea surface temperature anomalies can be higher than the others during lesser El Niño events, meaning more of the El Niño event is taking place there than in the east. The NINO1+2 region far to the east had the greatest anomalies in sea surface temperature during the 1982/83 and 1997/98 El Niño events. That indicates that much of the direct effects of those El Niño events reached that far to the east. In other words, the warm water sloshed all the way to the NINO1+2 region. Also notice how the NINO1+2 sea surface temperature anomalies were negative from 2003 to 2006 when those in the NINO4 region were well into the minor El Niño range.

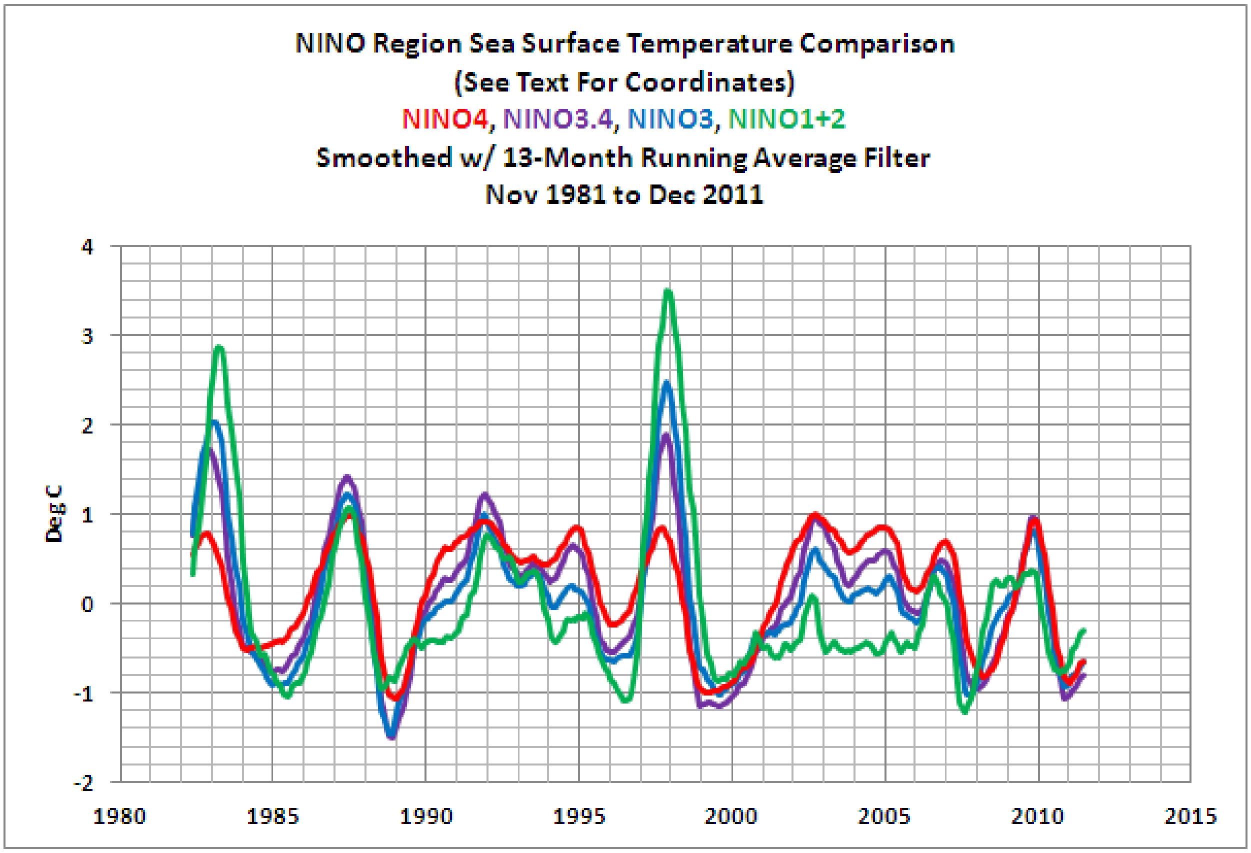


Figure 4-18 Bob Tisdale

Those differences have led to recent research into Central Pacific versus Eastern Pacific El Niño events, which we discussed in Chapter 4.2.

In addition to those ENSO indices, there are a few more. They include the Cold Tongue Index (CTI), and the Oceanic NINO Index (ONI), which is NOAA's official ENSO index. Then there is the Multivariate ENSO Index (MEI) that uses multiple factors to determine the strength and timing of El Niño and La Niña events.

Figure 4-19 shows the locations of the Cold Tongue Index and the NINO3.4 region. They both cover portions of the eastern equatorial Pacific. The NINO3.4 sea surface temperature anomalies are the measured average sea surface temperature anomalies for the area bordered by the coordinates of 5S-5N, 170W-120W. The Cold Tongue Index (CTI) represents the average measured sea surface temperature anomalies for the area bordered by the coordinates of 6S-6N, 180-90W. The Oceanic NINO Index (ONI) is simply NINO3.4 sea surface temperature anomaly data that has been smoothed with a 3-month running average filter. (More on the ONI data in a moment.) During an El Niño event, warm surface and subsurface waters from the Pacific Warm Pool slosh east and the sea surface temperatures warm along the central and sometimes eastern equatorial Pacific. During a La Niña event, tropical Pacific trade winds are stronger than normal and this exposes the cooler subsurface waters in the eastern equatorial Pacific, so the sea surface temperatures cool in those regions.

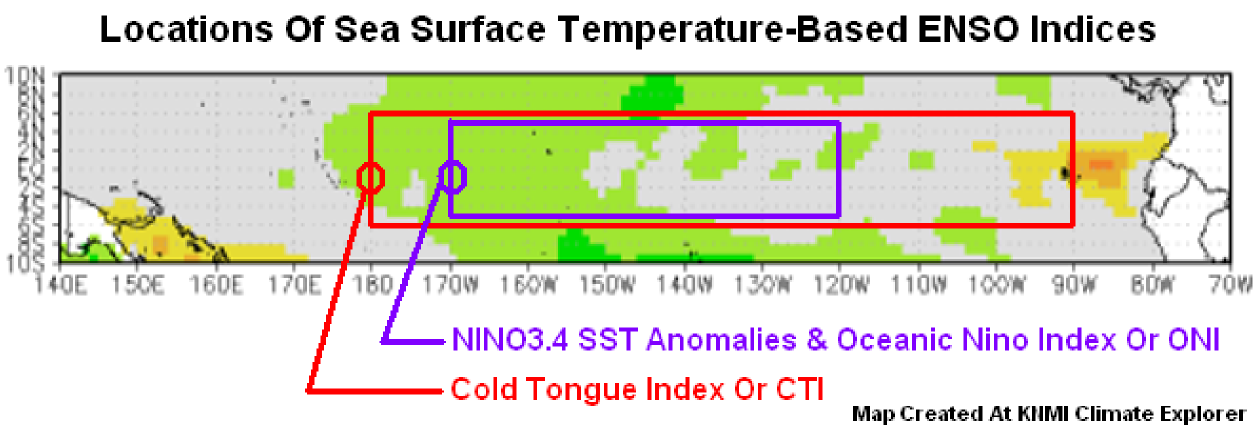


Figure 4-19

Bob Tisdale

The variations in sea surface temperature anomalies are very similar in a comparison graph of NINO3.4, Cold Tongue Index (CTI) and Oceanic Niño Index (ONI) sea surface temperature anomalies. See Figure 4-20. (The sea surface temperature dataset used in this comparison are the satellite-based Reynolds OI.v2 sea surface temperature data, even the ONI data.) Because the Oceanic Nino Index data are NINO3.4 sea surface temperature anomalies that have been smoothed with a 3-month running-average filter, it is only common sense that it should agree with the un-smoothed NINO3.4 data. (Refer to the discussion that follows about the Oceanic NINO Index. NOAA recently changed how it's calculated.)

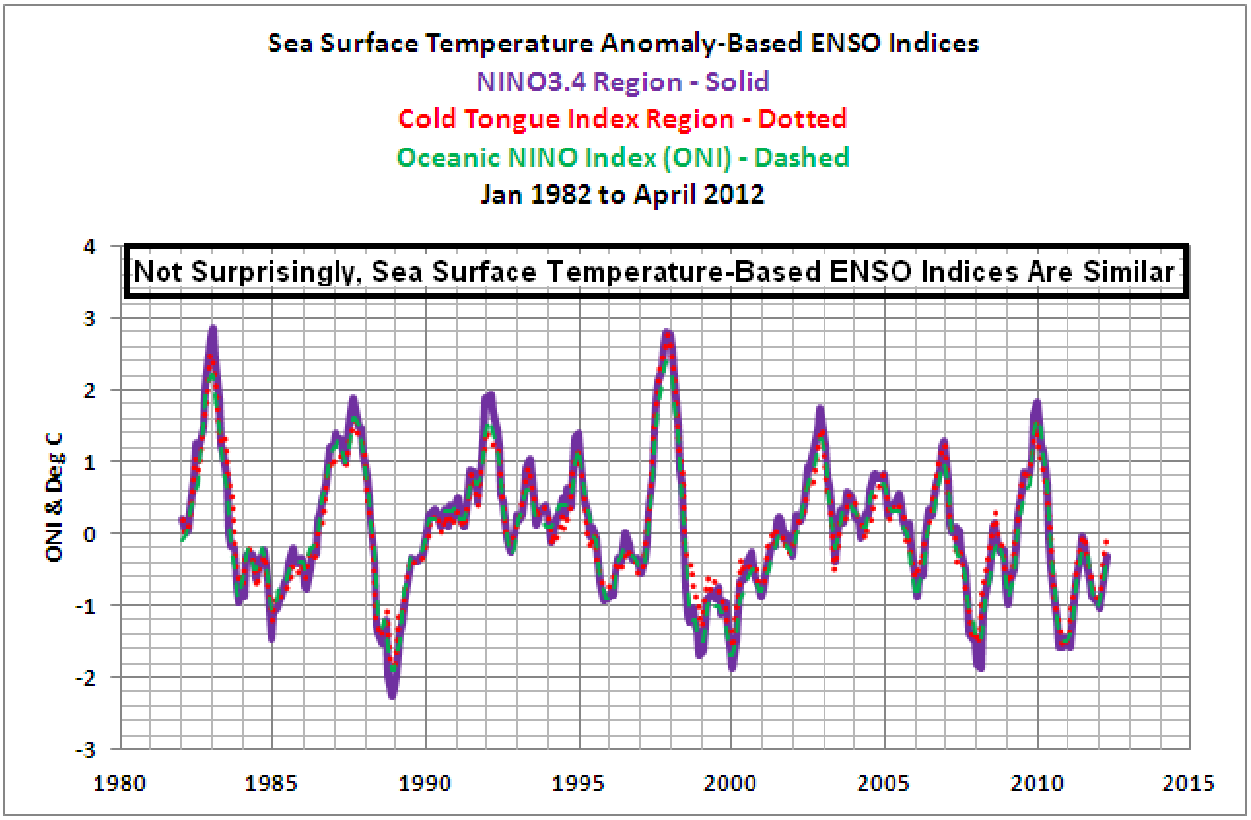


Figure 4-20 Bob Tisdale

When the sea surface temperatures of the NINO index regions warm above a threshold for a period of time, it qualifies as an official El Niño and when they cool to levels below a threshold and remain there long enough, the La Niña is considered an official event. According to the NOAA definition, an "official" El Niño event occurs when the Oceanic Niño Index sea surface temperature anomalies exceed +0.5 for 5 straight months. Likewise, for the cooling of sea surface temperature anomalies in the eastern equatorial Pacific to be considered an "official" La Niña, the Oceanic Niño Index sea surface temperature anomalies must remain lower than -0.5 deg C for 5 straight months. Because the Oceanic Niño Index is a 3-month average of NINO3.4 sea surface temperature anomalies, NOAA normally describes the threshold as 5 straight "seasons", where, for example, Nov-Dec-Jan and Dec-Jan-Feb are considered two consecutive "seasons". Refer to NOAA's Oceanic Niño Index **Warm and Cold Events By Season** webpage.

NOAA's Climate Prediction Center (CPC) recently modified their **Oceanic NINO Index (ONI)**. Refer to their **Description of Changes to Oceanic NINO Index** webpage for a complete description. There they note in the opening paragraph:

> *Due to a significant warming trend in the Niño-3.4 region since 1950, El Niño and La Niña episodes that are defined by a single fixed 30-year base*

> *period (e.g. 1971-2000) are increasingly incorporating longer-term trends that do not reflect interannual ENSO variability. In order to remove this warming trend, CPC is adopting a new strategy to update the base period.*

NOAA does not attribute the claimed "significant warming trend" to anthropogenic greenhouse gases, but anytime that phrase is used it implies manmade warming to many persons. Unfortunately, what NOAA has actually done with their changes is minimize the impact of the 1976 Pacific Climate Shift on NINO3.4 sea surface temperature anomalies. I cannot fathom why they would do that when the 1976 Climate Shift is the subject of numerous scientific studies. Google scholar has **176 returns for "1976 climate shift"**, in quotes. It is an accepted, well-documented phenomenon.

The Oceanic NINO Index is based on the NOAA ERSST.v3b sea surface temperature dataset. Yup, that's the dataset that NOAA introduced in 2008 with bias-corrected satellite data and then quickly modified, **removing the satellite-based data**, when "users" at NOAA discovered that the satellite data made global sea surface temperatures in 1998 warmer than 2003 by a couple hundredths of a deg C. Refer to the discussion of Figure 2-23 in Chapter 2.8.

Figure 4-21 illustrates the ERSST.v3b-based NINO3.4 sea surface temperature anomalies, on which the Oceanic NINO Index data is based. The data does in fact have a positive linear trend of slightly less than 0.06 Deg C per decade. Note that I've highlighted 1976 to point out the Climate Shift.

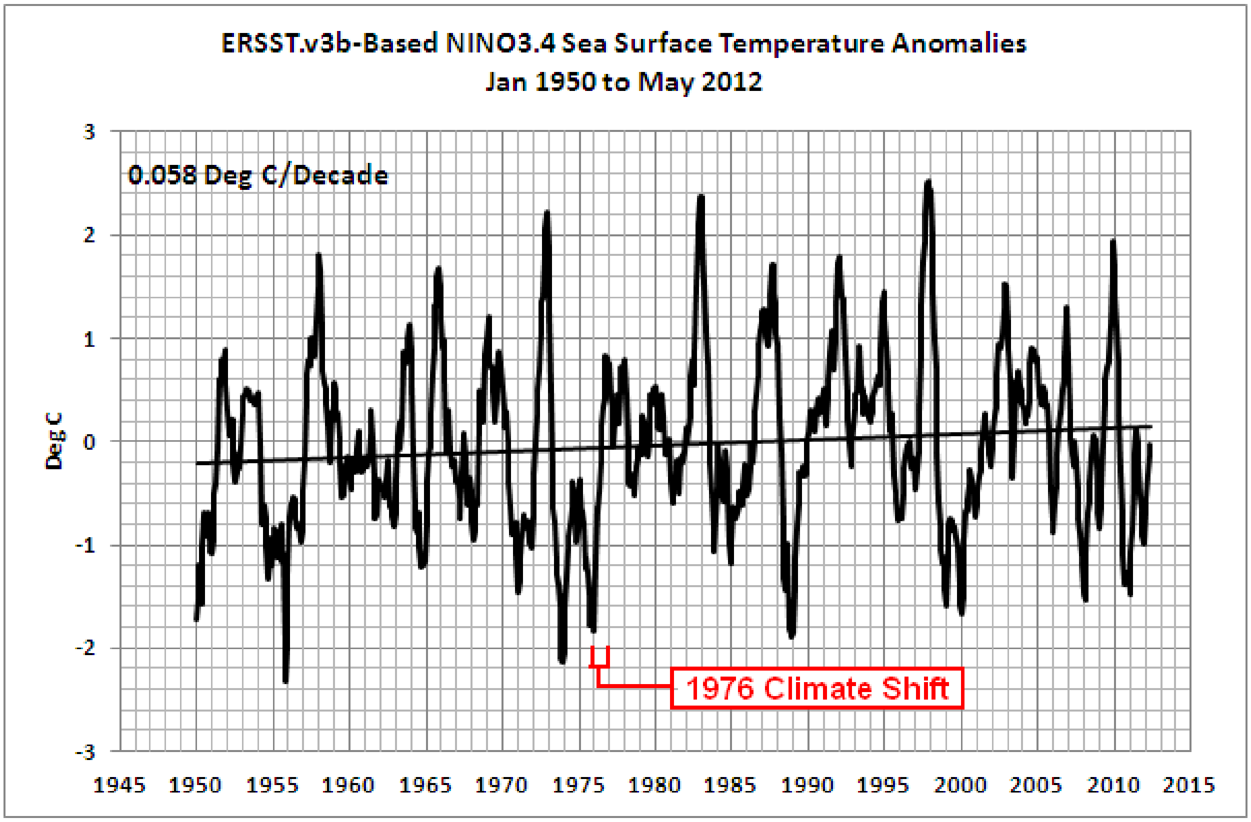


Figure 4-21

Bob Tisdale

Let's look at the data before and after the climate shift. The ERSST.v3b-based period-average sea surface temperature anomalies for the NINO3.4 region from January 1950 to December 1975 and from January 1977 to May 2012 are shown in Figure 4-22. The average sea surface temperature anomalies after the 1976 Pacific Climate Shift are about 0.3 deg C higher than they were before it. By the way, that shift impacted the entire Eastern Pacific Ocean, not just the eastern equatorial Pacific.

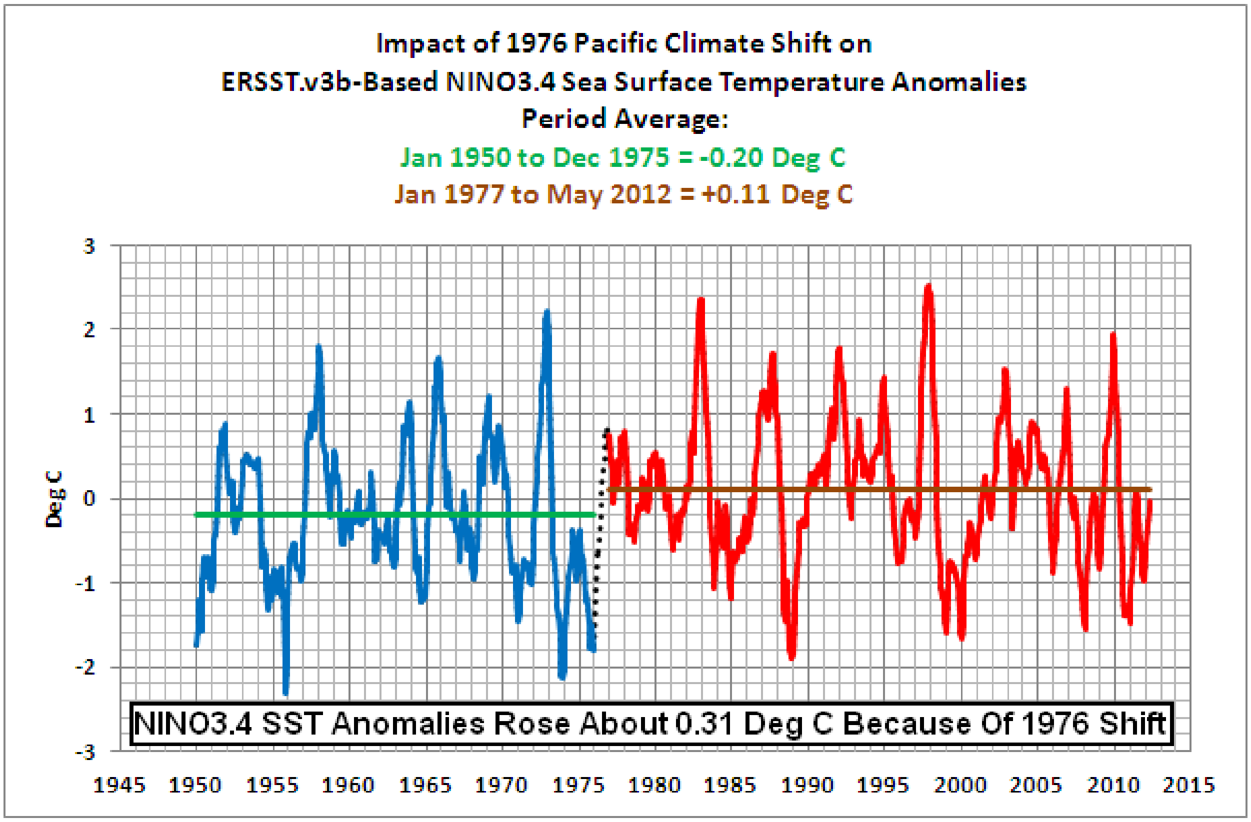


Figure 4-22

Bob Tisdale

Of course, the linear trends before and after the climate shift are negative, Figure 4-23, and that implies the climate shift is responsible for the vast majority of the overall positive linear trend.

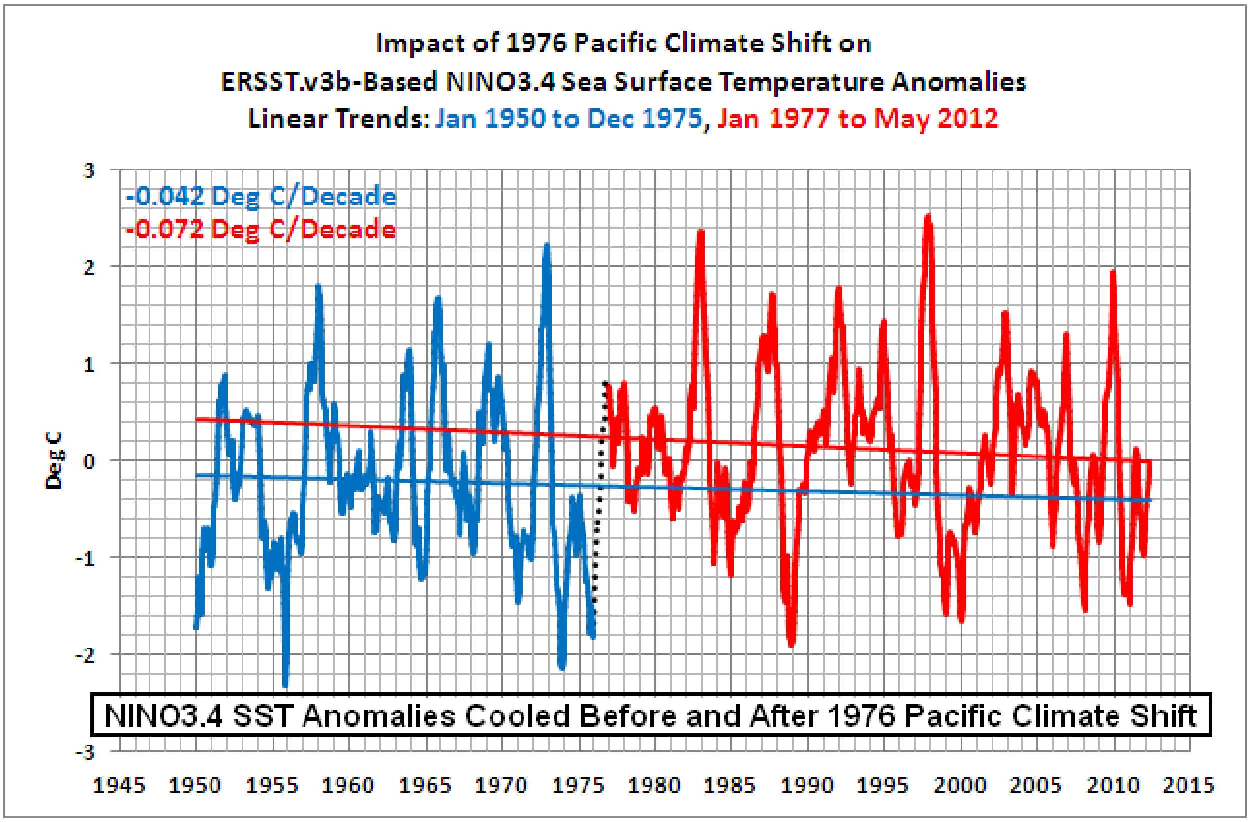


Figure 4-23

Bob Tisdale

To "correct" the "significant warming trend" caused primarily by the 1976 climate shift in the sea surface temperatures of the NINO3.4 region, NOAA no longer uses a single set of base years (1971-2000) for the anomalies in their Oceanic NINO index. They now use a series of shifting base years. They explain:

> *ONI values during 1950-1955 will be based on the 1936-1965 base period, ONI values during 1956-1960 will be based on the 1941-1970 base period, and so on and so forth.*

The result: NOAA has eliminated the positive trend in what used to be sea surface temperature anomalies of the NINO3.4 region. See Figure 4-24. One can't even call them sea surface temperature anomalies anymore with the sliding base years. For now, we'll treat them as anomalies.

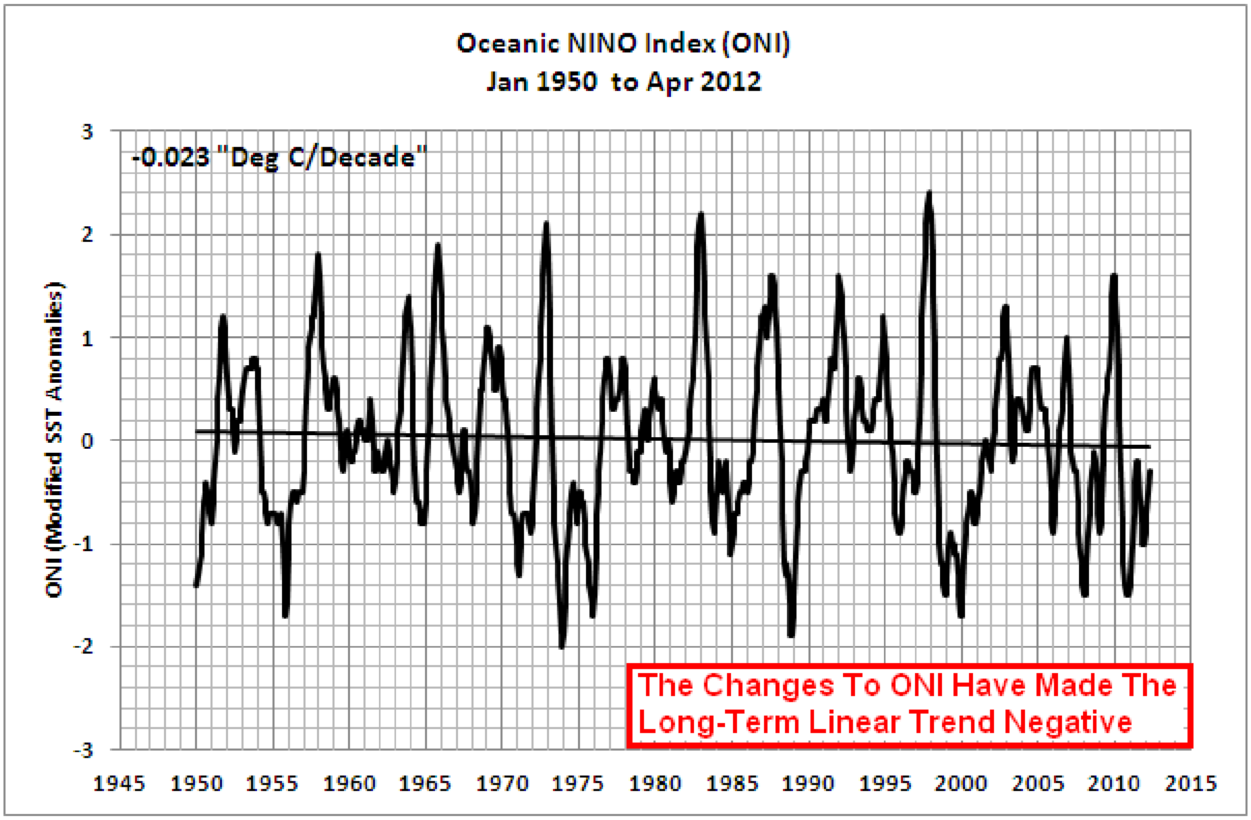


Figure 4-24 Bob Tisdale

With the changes, NOAA has minimized the difference in the period-average NINO3.4 sea surface temperature "anomalies" before and after the 1976 shift. Based on the "raw" ERSST.v3b data, the climate shift caused NINO3.4 sea surface temperature anomalies to shift up 0.3 deg C, but the "corrections" dropped the shift to about 0.04 deg C, as shown in Figure 2-25.

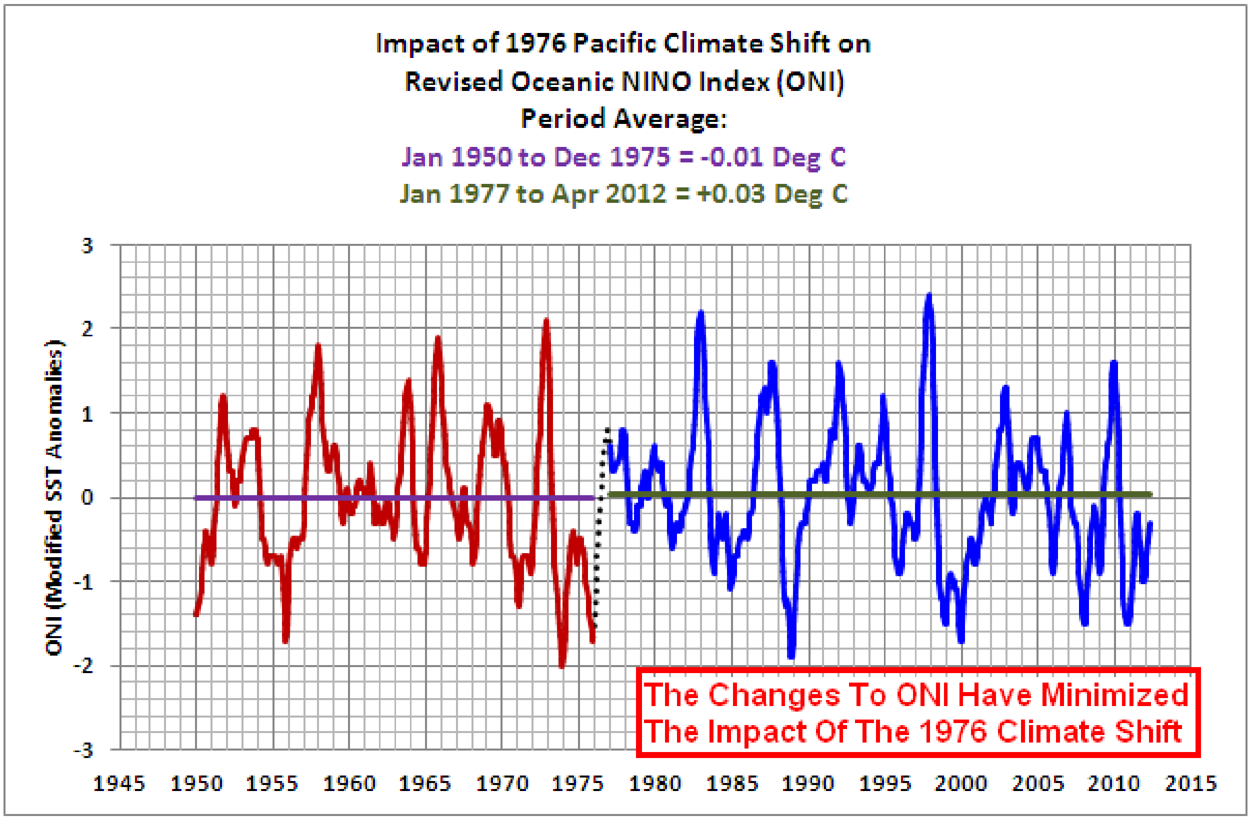


Figure 4-25

Bob Tisdale

The last impact on that ENSO index: the changes to the way NOAA calculates sea surface temperature anomalies for the Oceanic NINO Index has resulted in more severe negative trends before and after the climate shift. See Figure 4-26.

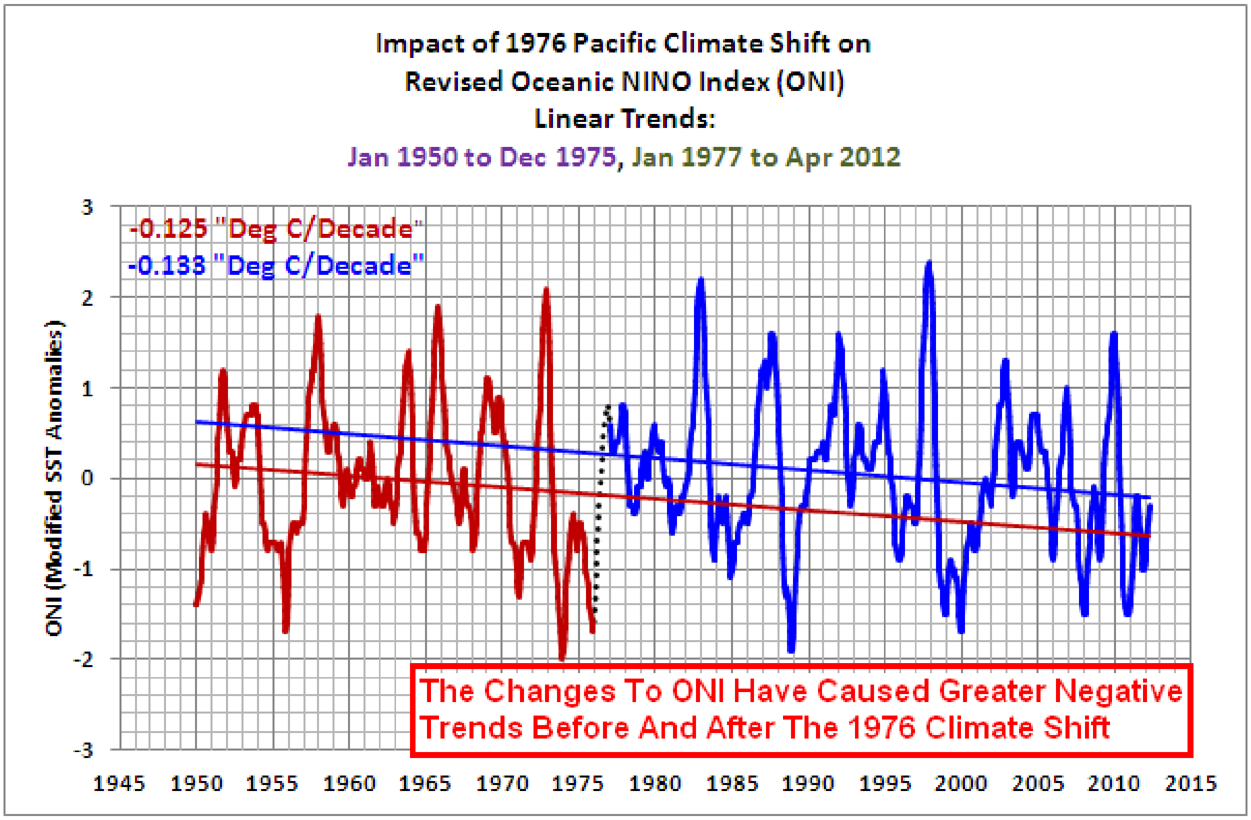


Figure 4-26 Bob Tisdale

I won't speculate about why NOAA would want to minimize the effect of the 1976 Pacific Climate Shift. Consider this though: There are scientific studies where the authors remove the linear effects of ENSO by scaling and subtracting an ENSO index from global surface temperatures. The authors then erroneously claim the remaining trend in global surface temperatures is the result of anthropogenic global warming. This faulty method of determining the effects of ENSO on global surface temperature is discussed further in **Chapter 7.5 Myth - ENSO Only Adds Noise to the Instrument Temperature Record and We Can Determine its Effects through Linear Regression Analysis, Then Remove Those Effects, Leaving the Anthropogenic Global Warming Signal.** Now, because NOAA has flattened the Oceanic NINO index trend, if someone were to use it in one of those misleading scientific studies, the remaining trend in global surface temperature residuals would be a little bit higher than if they had used a sea surface temperature anomaly-based ENSO index.

In summary, because the Oceanic NINO index no longer represents the sea surface temperature anomalies of the NINO3.4 region using a single base period, **and** because NOAA has minimized the impact of the 1976 Pacific Climate Shift as a result of the changes to ONI, **and** because that climate shift exists in all sea surface temperature datasets, I, personally, would not use Oceanic NINO index as an ENSO index. Then again, I don't believe NOAA cares if I use their Oceanic NINO index. On to better things:

There is another ENSO index called the Multivariate ENSO Index (MEI). It is based in part on the sea surface temperature anomalies of the NINO3 region of the eastern equatorial Pacific. The NINO3 region is bordered by the coordinates of 5S-5N, 150W-90W, so it's east of and overlaps with the NINO3.4 region. Refer again to Figure 6-21. In addition, there are a number of other observations from the tropical Pacific that contribute to the Multivariate ENSO Index. These additional variables include sea-level pressure, zonal and meridional components of surface wind, surface air temperature, and total cloudiness fraction of the sky. (Zonal winds are those traveling in east and west directions, and Meridional winds are those traveling north and south.) For more detail, refer to the **Multivariate ENSO Index homepage**. Because it is not based on sea surface temperature, when discussing the Multivariate ENSO Index, you would never refer to sea surface temperatures; you would simply note that the Multivariate ENSO Index was at a specific value. The Multivariate ENSO Index is also presented in standardized form; that is, as discussed earlier, the data is divided by its standard deviation. Even with all of these additional modifications, the variations in the Multivariate ENSO Index data are very similar to those of the NINO3.4 sea surface temperature anomalies as illustrated in Figure 4-27.

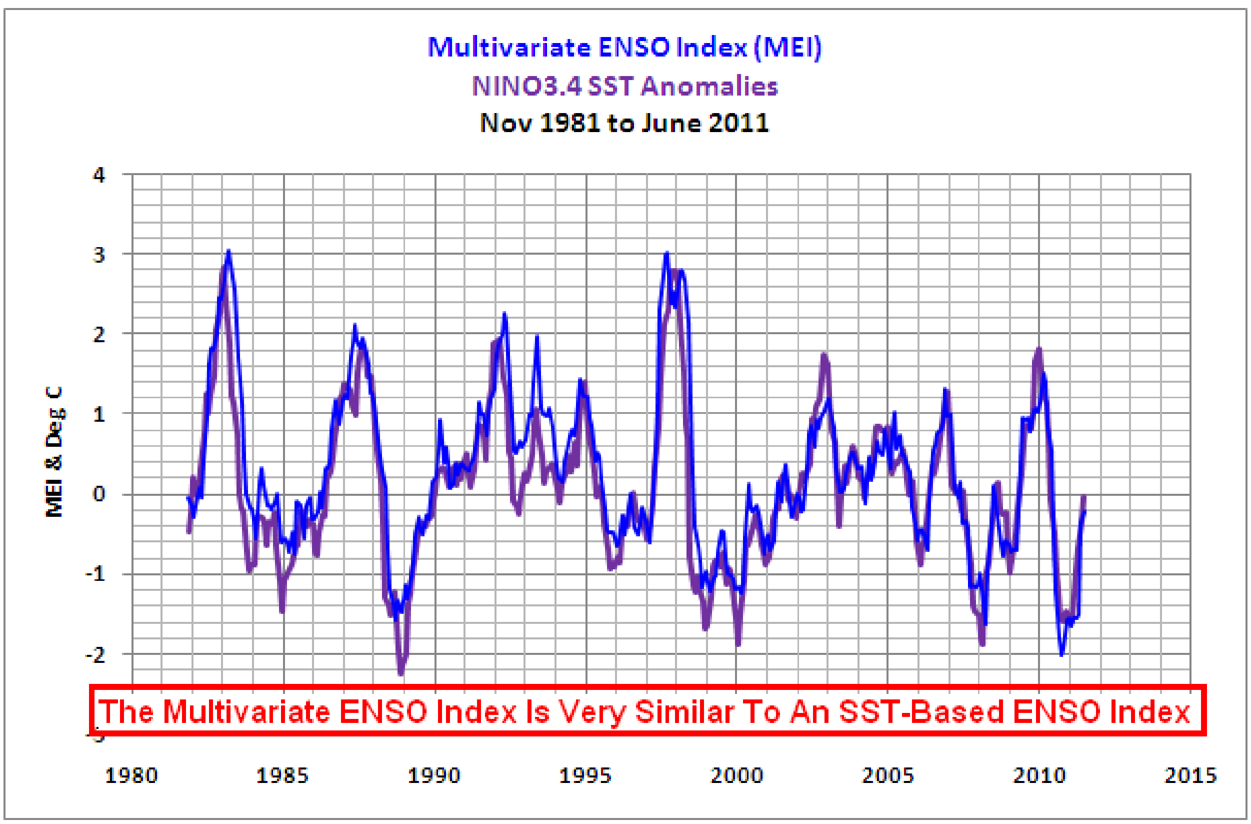


Figure 4-27

RECAP

As discussed, there are a number of ENSO indices. They all represent the timing and strength of El Niño and La Niña events.

Not one of those ENSO indices can represent all of the effects ENSO has on global surface temperature. Not one. No ENSO index captures the additional strength of the trade winds in the western tropical Pacific that resulted in the build-up of the warm water that fueled the 1997/98 El Niño. No ENSO index can be used to account for the leftover warm surface waters that are carried back to the western Pacific after an El Niño. No ENSO index captures the impact of the Rossby waves that carry warm subsurface waters back to the western Pacific or the disparity between the Rossby waves that follow El Niño and La Niña events.

Nevertheless, there are climate scientists and statisticians who misuse an ENSO index when they attempt to remove ENSO from the global surface temperature record and then nonsensically claim the warming trend in the remainder is caused by anthropogenic greenhouse gases. There's a detailed discussion of those misleading climate studies in **Chapter 7.5 Myth - ENSO Only Adds Noise to the Instrument Temperature Record and We Can Determine its Effects through Linear Regression Analysis, Then Remove Those Effects, Leaving the Anthropogenic Global Warming Signal.**

4.4 ENSO Indices Also Fail to Capture the Relative Strengths of ENSO Events

The recap of the last chapter included the note: "Not one of those ENSO indices can represent all of the effects ENSO has on global surface temperature. Not one." In this chapter, we'll also show that ENSO indices don't really capture the strengths of ENSO events.

Two examples:

As discussed in the preceding chapter, the sea surface temperature anomalies for the NINO3.4 region are a standard ENSO index. We've been using, and will continue to use, satellite-based (Reynolds OI.v2) NINO3.4 sea surface temperature anomalies as our ENSO index. As shown in Figure 4-28, the 1982/83 El Niño peaked at about the same level as the 1997/98 El Niño. Does that mean the two were similar in strength? The Southern Oscillation Index shows the 1982/83 El Niño had a lower SOI value than the 1997/98 El Niño. See Figure 4-29. Does that mean the 1982/83 El Niño was stronger?

In reality, it depends on your definition of the strength of an El Niño event. What about the 1986/87/88 El Niño? It lasted for more than 1.5 years. If we look only at peak values, then we're not considering the duration of the El Niño event.

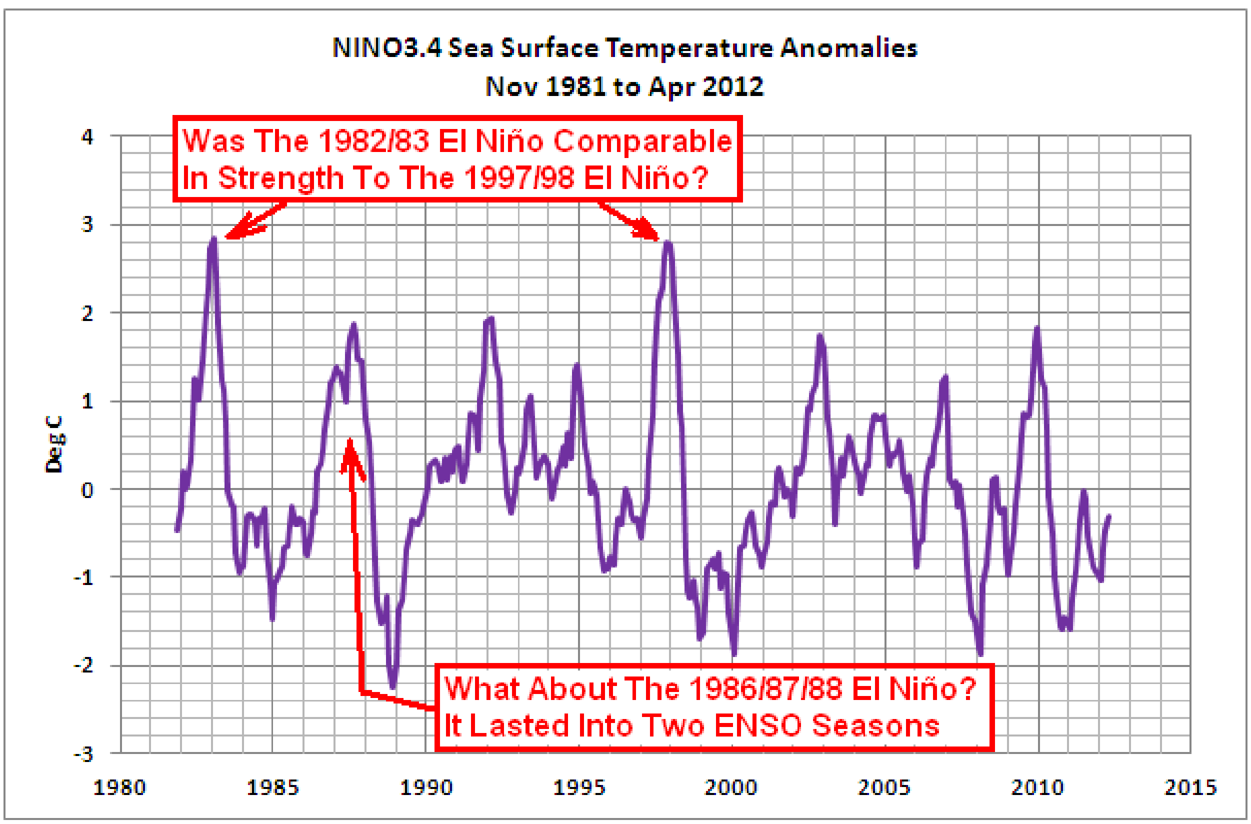


Figure 4-28

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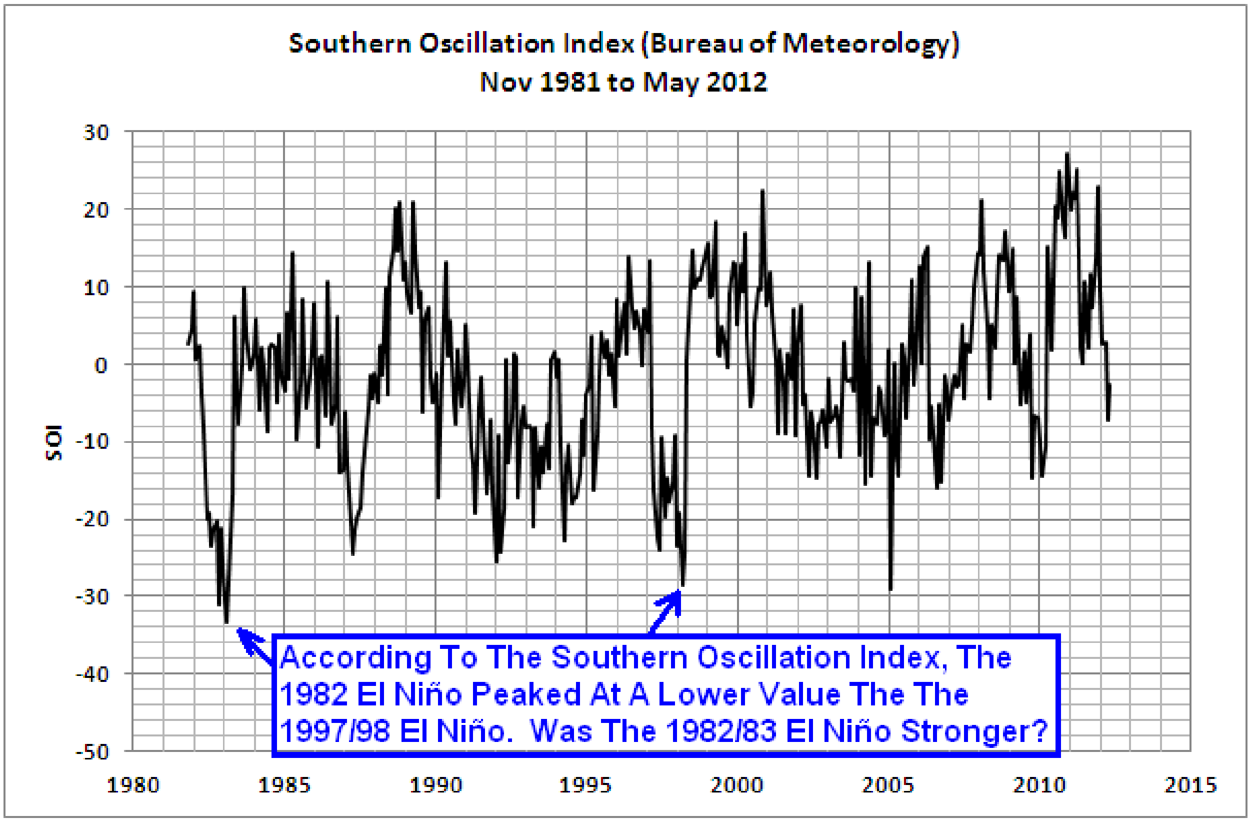

Figure 4-29

Let's stick with sea surface temperature, because this book is about the effect of ENSO on global surface temperatures—sea surface temperatures in particular. Let's look again at the average sea surface temperature anomalies for the durations of all of El Niño events since 1981, Figure 4-30. In Chapter 4.2, we used a similar graph in our discussion of East Pacific and Central Pacific El Niño events. There we used the December sea surface temperature anomalies, but that only captured the temperature anomalies near the peak of the El Niño events. In Figure 4-30, were using the average sea surface temperature anomalies for every month the NINO3.4 sea surface temperature anomalies were greater than 0.5 deg C. For example, the NINO3.4 sea surface temperature anomalies were warmer than 0.5 deg C for the months of May 1982 to June 1983, so we're illustrating the average of the meridional-mean sea surface temperature anomalies during those months for the 1982/83 El Niño. Because the NINO3.4 sea surface temperature anomalies were only above the 0.5 deg C threshold for five months (October 1994 to February 1995) during the 1994/95 El Niño, we're using the meridional-mean sea surface temperature anomalies for only those months. This way we're capturing the average equatorial Pacific sea surface temperature anomalies in those longitude bands during the entire term of each El Niño event.

The dashed lines in Figure 4-30 for the 1983/83 El Niño indicate a volcanic eruption occurred at the same time. The dotted lines are intended to remind us that the 2002/02 and 2004/05 El Niño events were not followed by La Niña events. Dotted and dashed lines for the 1991/92 El Niño indicate a volcano occurred around the same time and there was no La Niña afterwards. Those El Niño events are highlighted simply as references for future discussions.

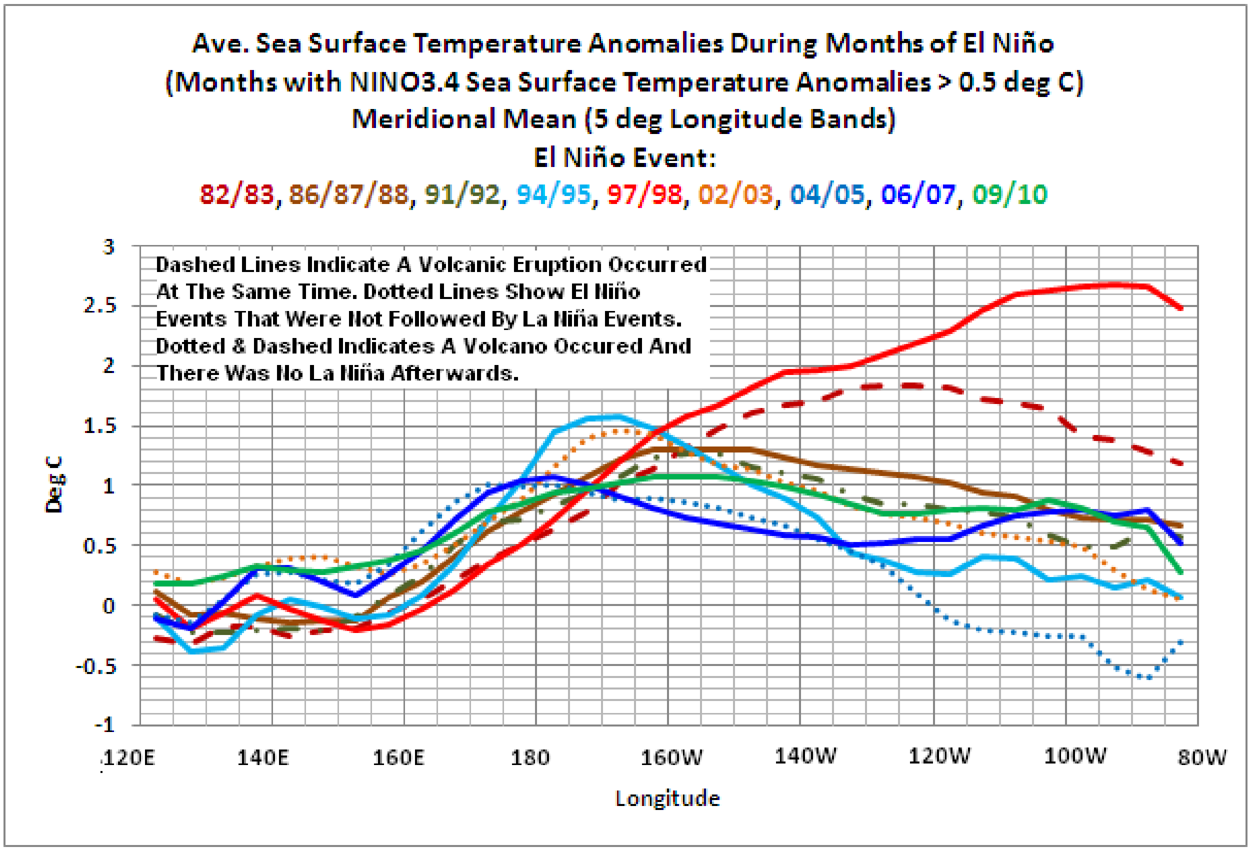

Figure 4-30

Bob Tisdale

As shown in Figure 4-30, while the 1982/83 and 1997/98 El Niño events were by far the strongest events over the past 30 years, the average sea surface temperature anomalies for the duration of the 1997/98 El Niño exceeded those of the 1982/83 El Niño. Notice also how the 1994/95 El Niño (light blue curve) had the highest average sea surface temperature anomalies for its duration between the longitudes of 180 and 160W, but the 1994/95 El Niño only lasted for 5 months according to the NINO3.4 sea surface temperature anomalies. On the other hand, the NINO3.4 sea surface temperature anomalies were above 0.5 deg C for 18 months during the 1986/87/88 El Niño. Therefore, we need to account for the duration of the El Niño events (how long they lasted in time) in our comparison.

To include the duration of the El Niño, we'll simply multiply the average sea surface temperature anomalies while the El Niño events were taking place by the number of months the NINO3.4 sea surface temperature anomalies were above 0.5 deg C for each El Niño. Also, we'll divide the duration in months by 12 to keep the scale within reason on the meridional-mean graph. El Niño "Power" seems to be an appropriate name for the results. We'll use the dotted and dashed lines as we did in the preceding graph. The results are shown in Figure 4-31.

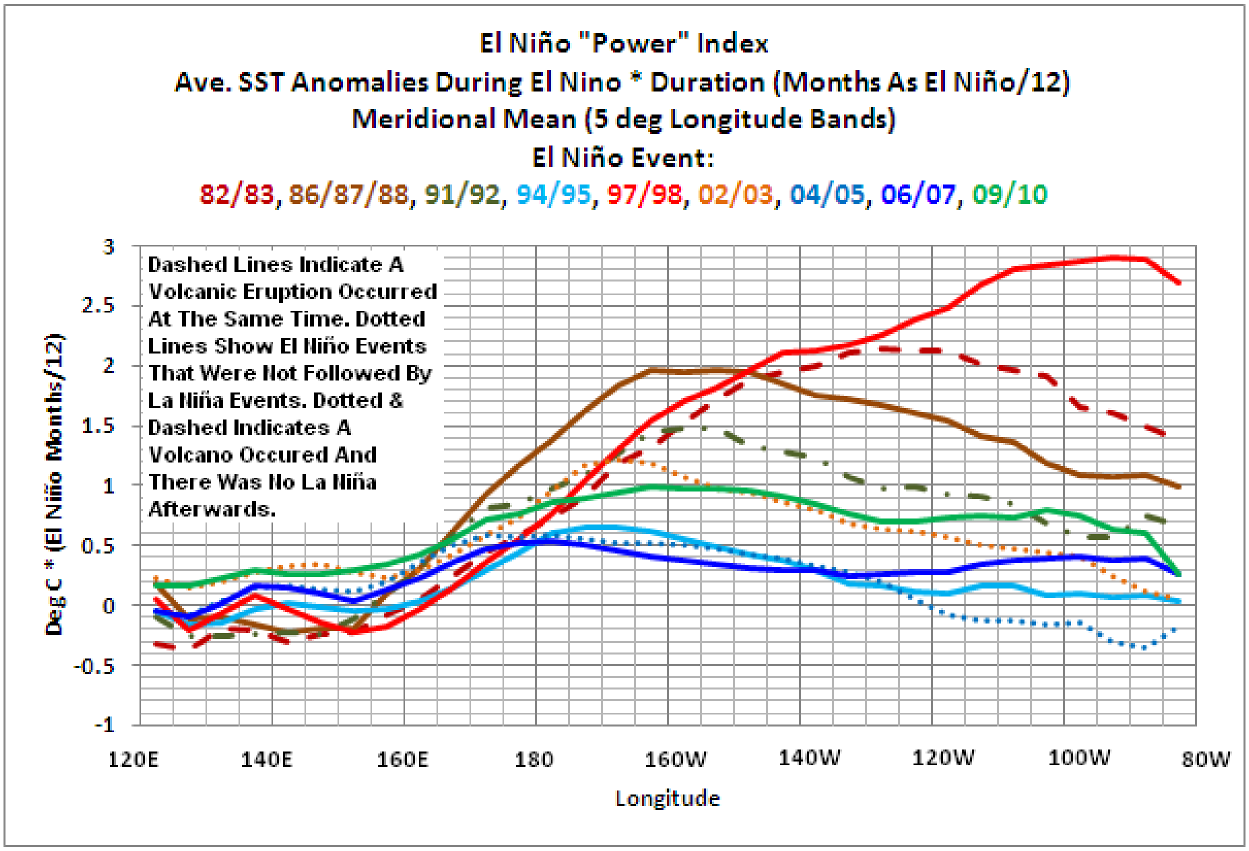

Figure 4-31 Bob Tisdale

The three most powerful events based on these factors are the 1997/98, 1982/83 and 1986/87/88 El Niño events, with the 1982/83 El Niño having to combat the volcanic eruption of El Chichon. The 1991/92, 2002/03 and 2009/10 El Niño events were the mid-range El Niño events in terms of "Power", but 1991/92 and 2002/03 El Niño events were not followed by a La Niña and the 1991/92 El Niño fought against the eruption of Mount Pinatubo in 1991. The 1994/95, 2004/05 and 2006/07 El Niño events are the also-rans, with the 2004/05 El Niño not followed by a La Niña.

Let's carry this analysis farther. We can see that El Niño events directly impact the sea surface temperatures of the entire equatorial Pacific from 120E to 80W. For each El Niño event, we'll take the average sea surface temperature anomalies for the entire equatorial Pacific (5S-5N, 120E-80W) for the months when the NINO3.4 sea surface temperature anomalies were greater than 0.5 deg C, and we'll multiply it by the number of months the NINO3.4 sea surface temperature anomalies were above 0.5 deg C. We'll call the results the "El Niño Power" index. Table 1 shows the factors (average sea surface temperature anomalies and duration) and the results (the "El Niño Power"). I've also placed them in order of power in Table 2. Also listed are whether a volcanic eruption occurred near the same time and if a La Niña followed the El Niño. They will impact how you view El Niño events in later discussions.

Table 4-1

El Niño "Power" Index Factors			
Season	Ave. SST Anomaly* (Deg C)	Duration** (Months)	Power***
1982/83	0.89	14	1.03
1986/87/88	0.69	18	1.04
1991/92	0.58	14	0.68
1994/95	0.48	5	0.20
1997/98	1.26	13	1.36
2002/03	0.67	10	0.56
2004/05	0.32	7	0.19
2006/07	0.57	6	0.29
2009/10	0.69	11	0.63

* Average Sea Surface Temperature Anomalies for the Equatorial Pacific (5S-5N, 120E-80W) While NINO3.4 Sea Surface Temperature Anomalies are Greater than 0.5 deg C.

** The Duration of the El Niño Event in Months for the Period when NINO3.4 Sea Surface Temperature Anomalies are Greater than 0.5 deg C.

*** The Power is the Product of the Multplication of the Average Sea Surface Temperature Anomalies and the Duration in Months Divided by 12.

Table 4-1 Bob Tisdale

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Table 4-2

El Niño Power Index				
Rank	Season	Power	Volcano	Trailing La Niña
1	1997/98	1.36	No	Yes
2	1986/87/88	1.04	No	Yes
3	1982/83	1.03	Yes	Yes
4	1991/92	0.68	Yes	No
5	2009/10	0.63	No	Yes
6	2002/03	0.56	No	No
7	2006/07	0.29	No	Yes
8	1994/95	0.20	No	Yes
9	2004/05	0.19	No	No

Refer to Table 4-1 for Factors that Contribute to El Niño Power Index

Table 4-2 Bob Tisdale

Let's run through the same process for La Niña events. In Figure 4-32, we're illustrating the average equatorial sea surface temperature anomalies during the months of the La Niña events. We're defining the months of the La Niña as those when NINO3.4 sea surface temperature anomalies are cooler than -0.5 deg C. The dashed curves indicate an explosive volcanic eruption occurred within a few years before the La Niña and the dotted curves indicate a La Niña event that's not following an El Niño event.

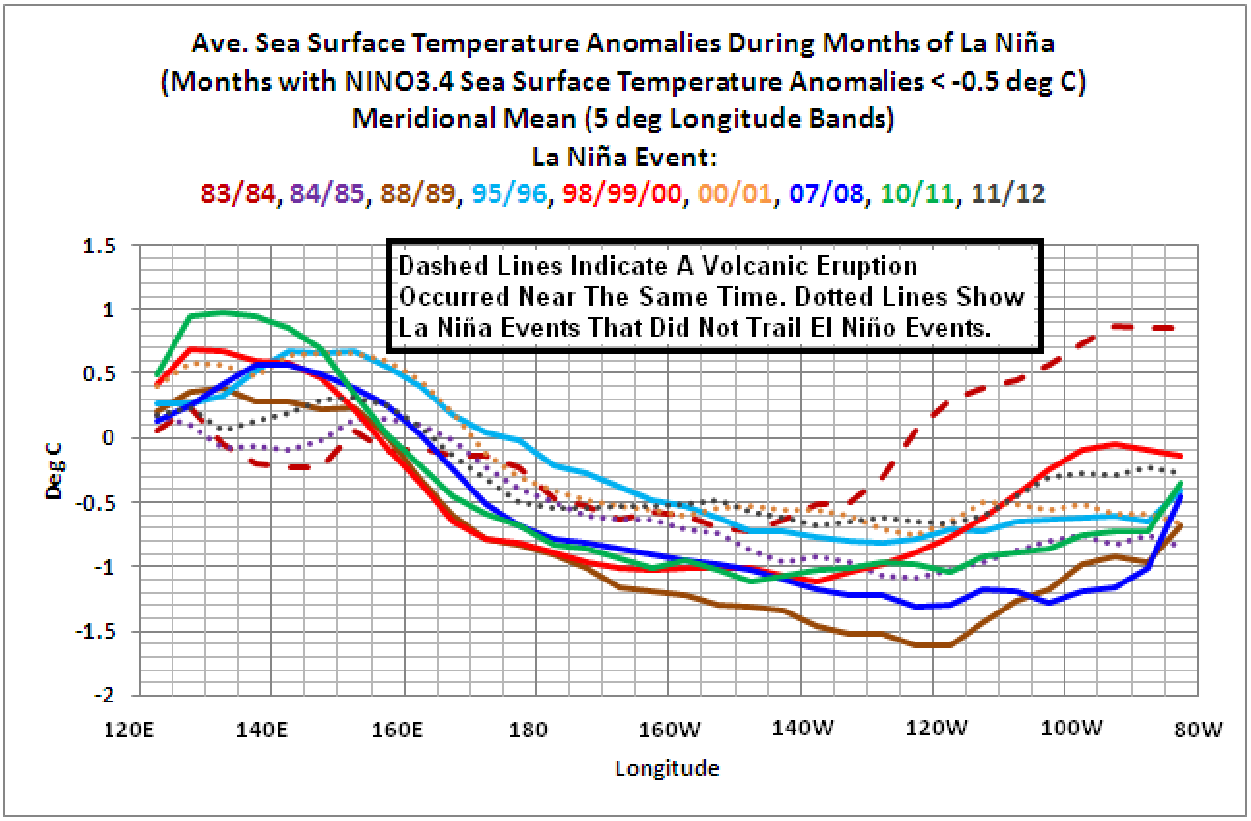

Figure 4-32 Bob Tisdale

I usually describe the 1998/99/00 and the 2000/01 La Niña events as one long La Niña. The reason: while the NINO3.4 sea surface temperature anomalies did warm above the -0.5 deg C threshold of a La Niña in 2000, during the late spring and the summer, the warming appears to have been related to the seasonal cycle. The following winter, La Niña conditions returned. However, in this example, because I'm following a more rigid definition of El Niño and La Niña, I separated the 1998/99/00 and the 2000/01 La Niña events. The same holds true for the 1983/84 and 1984/85 La Niña. The separation of those two events also highlights the weakness of the 1983/84 La Niña, and how warm the sea surface temperatures remained in the east. I haven't found a scientific paper that attempts to explain that very weak portion of that multiyear La Niña. Its weakness raises two questions: First, could the March 1982 eruption of Mexico's El Chichon have upset the processes that take place during the normal transition from the 1982/83 El Niño to the 1983/84 La Niña? Second, did the aerosols emitted from El Chichon influence the satellite sea surface temperature measurements?

The effect of volcanic aerosols on satellite-based sea surface temperature data was determined for the 1991 Mount Pinatubo eruption. Refer to the Reynolds (1992) paper **Impact of Mount Pinatubo Aerosols on Satellite-derived Sea Surface Temperatures**. Based on his findings, volcanic aerosol corrections were made to the satellite-based Reynolds sea surface temperature data. On the other hand, keep in mind, data corrections are attempts to remedy known problems. It doesn't necessarily mean the corrections cured the problems fully.

Figure 4-33 shows the La Niña "Power", which was determined by multiplying the average sea surface temperature anomalies during the La Niña by the number of months of the La Niña, where La Niña conditions are defined as NINO3.4 sea surface temperature anomalies cooler than -0.5 deg C. The dotted and dashed curves indicate La Niña events that did not immediately follow El Niño events, and a La Niña event that occurred within a few years of a major volcanic eruption, respectively.

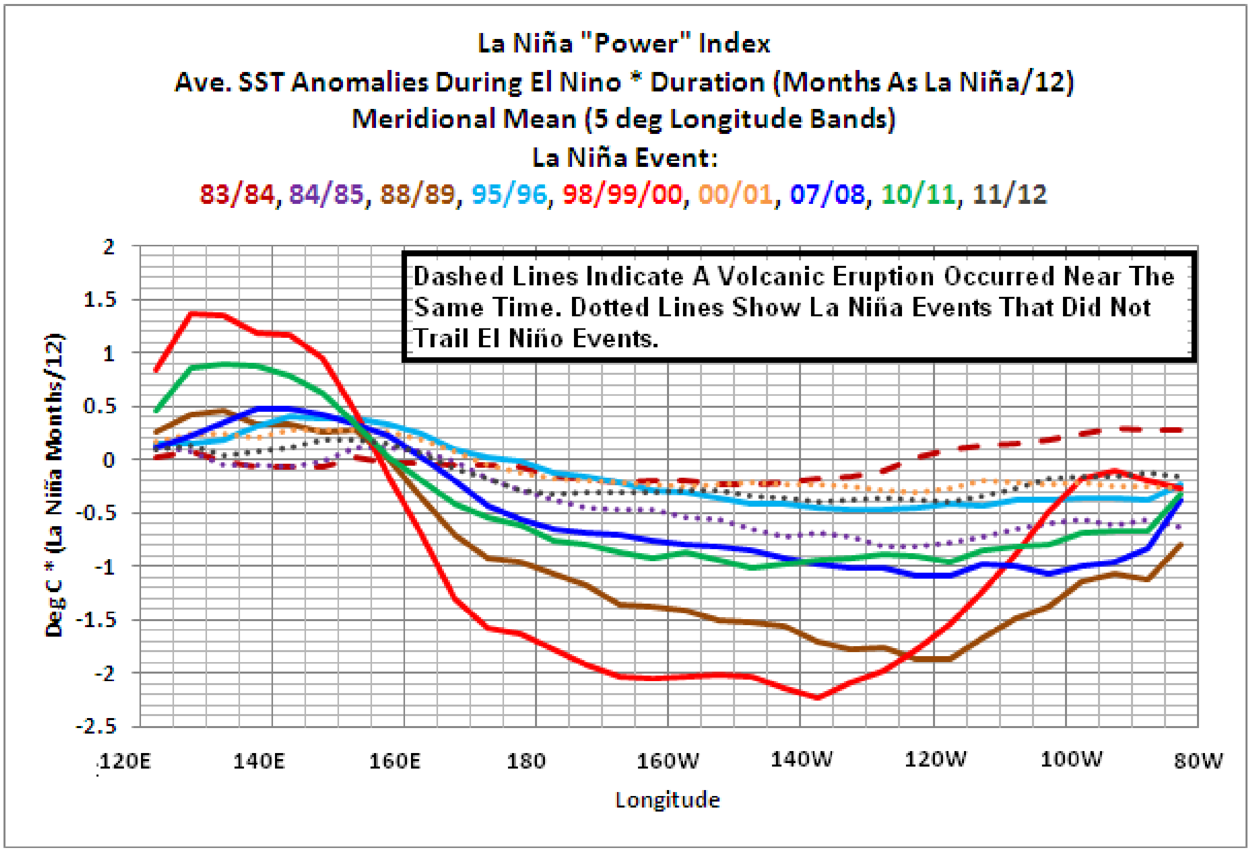

Figure 4-33 Bob Tisdale

The multiyear La Niña of 1998/99/00 had the most powerful effect on the central portion of the equatorial Pacific, but that will be offset by the higher values in the west. The La Niña of 1988/89, ten years earlier, may rival the 1998/99/00 La Niña when we consider the entire basin. Note how the three La Niña events that did not immediately follow El Niño events are among the weaker La Niña and how the more powerful La Niña events of 1988/89 and 1998/99/99 followed the more powerful 1986/87/88 and 1997/98 El Niño.

Which La Niña event was the most powerful? Based on the criteria we've used in this chapter, Table 3 shows the contributing factors and the "Power" factors for each La Niña event in the order they occurred and Table 4 lists the La Niña events according to "Power" ranking. The two most powerful La Niña were the 1988/89 and 1998/99/00 La Niña events, beating the other La Niña by a good margin.

Table 4-3

La Niña "Power" Index Factors			
Season	Ave. SST Anomaly* (Deg C)	Duration** (Months)	Power***
1983/84	-0.07	4	-0.02
1984/85	-0.53	9	-0.39
1988/89	-0.78	14	-0.91
1995/96	-0.24	7	-0.14
1998/99/00	-0.42	24	-0.85
2000/01	-0.21	5	-0.09
2007/08	-0.61	10	-0.51
2010/11	-0.46	11	-0.42
2011/12	-0.29	7	-0.17

* Average Sea Surface Temperature Anomalies for the Equatorial Pacific (5S-5N, 120E-80W) While NINO3.4 Sea Surface Temperature Anomalies are Less Than 0.5 Deg C.

** The Duration of the La Niña Event in Months for the Period when NINO3.4 Sea Surface Temperature Anomalies are Less Than 0.5 Deg C.

*** The Power is the Product of the Multplication of the Average Sea Surface Temperature Anomalies and the Duration in Months Divided by 12.

Table 4-3 Bob Tisdale

HHH

Table 4-4

La Niña Power Index				
Rank	Season	Power	Volcano	Follows El Niño
1	1988/89	-0.91	No	Yes
2	1998/99/00	-0.85	No	Yes
3	2007/08	-0.51	No	Yes
4	2010/11	-0.42	No	Yes
5	1984/85	-0.39	No	No
6	2011/12	-0.17	No	No
7	1995/96	-0.14	No	Yes
8	2000/01	-0.09	No	No
9	1983/84	-0.02	Yes	Yes

Refer to Table 4-3 for Factors that Contribute to La Niña Power Index

Table 4-4 Bob Tisdale

RECAP

ENSO indices can give the wrong impressions about the strengths of El Niño and La Niña events. The eye is drawn to the peaks in a time series graph. We've presented a way (and I'm sure there are many other ways) to show the relative strengths of El Niño and La Niña events. It considers the average sea surface temperature anomalies for the entire equatorial Pacific during the ENSO event and the duration of the ENSO event. Using this method, the 1997/98 El Niño was by far the most powerful El Niño event of the past 30 years, about 30% more powerful than the 1982/83 and 1986/87/88 El Niño events, which were effectively tied for second. The two most powerful La Niña events were the 1988/89 and 1998/99/00 events. Note how both of those La Niña events were led by two of the three most powerful El Niño events.

The second reason we went through this process was to confirm the strengths of the 1986/87/88 and 1997/98 El Niño events and the 1988/89 and 1998/99/00 La Niña events. By far they were the most powerful ENSO events that were not impacted by global temperature-altering volcanic eruptions. We'll be discussing these ENSO events in an upcoming section.

NOTE: I am not proposing these "power" indices as replacements for the traditional ENSO indices. They were provided for illustrative purposes only.

4.5 The Repeating Sequence of Primary and Secondary El Niño Events

In this chapter, we'll look at the similarities in the series of El Niño and La Niña events over three ten-year periods. The periods start with a major El Niño, transition to a multiyear or a strong La Niña, which is then followed by a series of lesser El Niño events. Figure 4-34 highlights the three periods on a time-series graph of NINO3.4 sea surface temperature anomalies. We've had to change sea surface temperature datasets for this discussion. Here we're using the Hadley Centre's HADISST data, which is satellite-based from 1982 to present.

The series of decade-long "cycles" began with the 1972/73 El Niño. The second primary El Niño occurred in 1986/87/88, and the third one was the 1997/98 El Niño. A fourth primary El Niño may be the 2009/10 El Niño, but time will tell. The 1982/83 El Niño is the odd event. Why? The only difference between it and the other major El Niño events is that a major volcanic eruption (El Chichon) occurred at the same time as the 1982/83 El Niño. Could it have somehow changed the "cycle" of primary and secondary events?

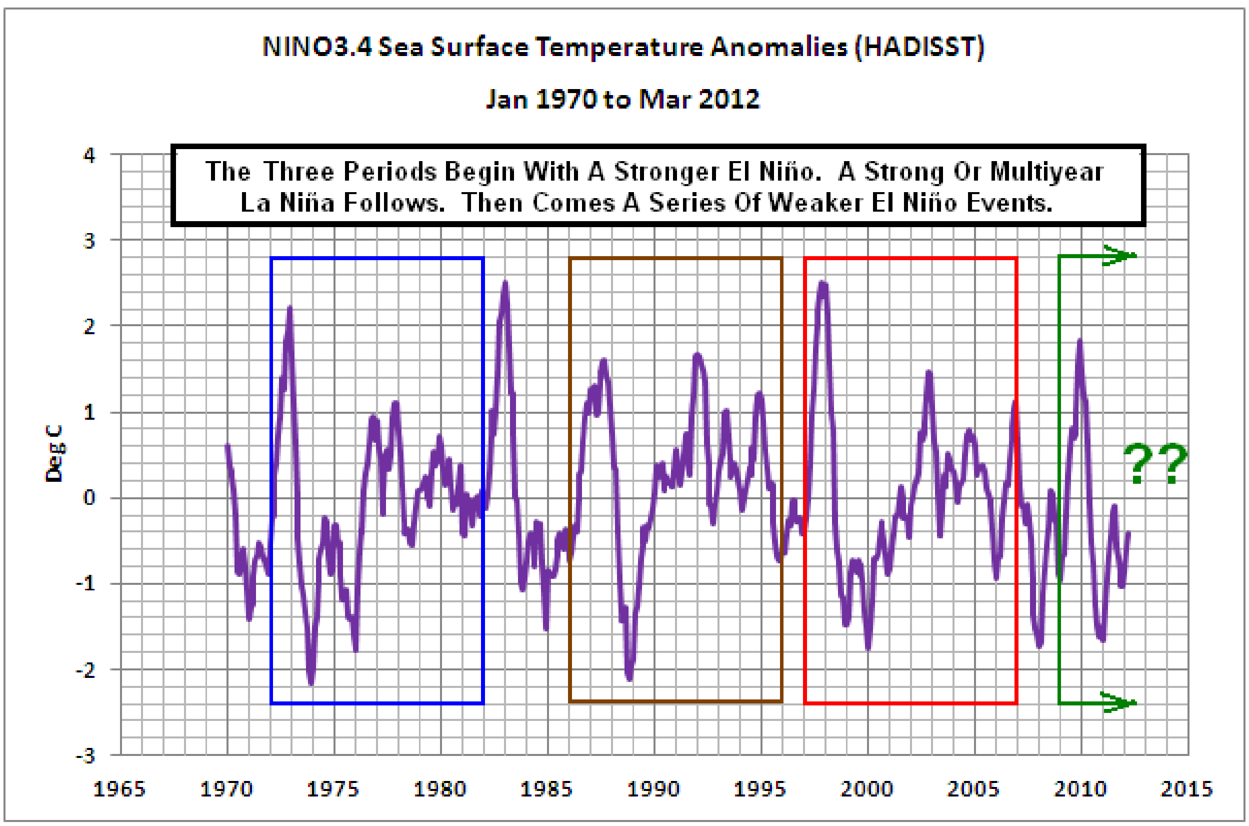

Figure 4-34 Bob Tisdale

Let's take a look at how similar the NINO3.4 sea surface temperature anomalies are during those three periods. I've also included the period that starts with the 2009/10 El Niño. The time-series graphs in Figures 4-35, 4-36 and 4-37 each have four color-coded time periods. The blue period begins in January 1972 and starts with the primary 1972/73 El Niño. The brown period starts in January 1986 to capture the primary 1986/87/88 El Niño. The red period includes the 1997/98 El Niño as the primary event and starts in January 1997. The last time period starts in January 2009 and its primary event is the 2009/10 El Niño.

Figure 4-35 is the raw NINO3.4 sea surface temperature anomalies. What stands out most in it is the additional year of the 1986/87/88 El Niño. Also note the severity of the 1973/74/75/76 La Niña.

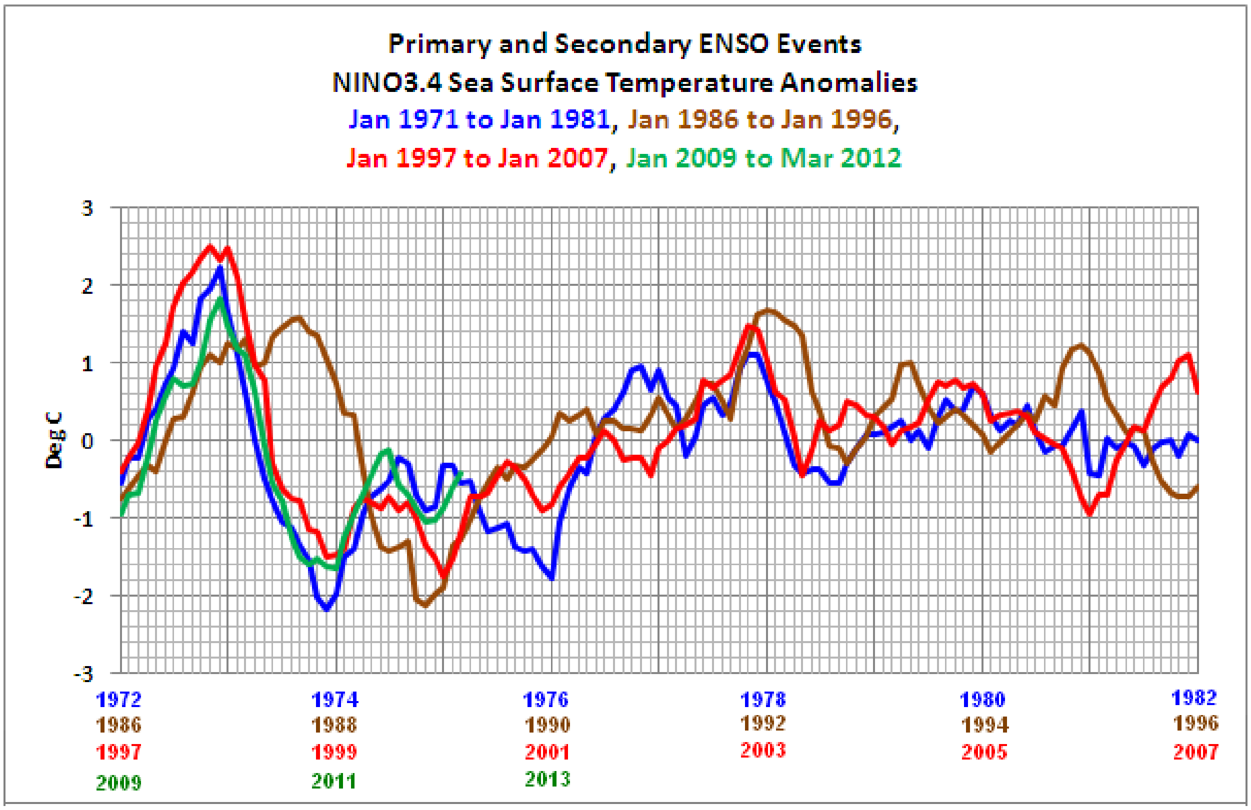

Figure 4-35

The curves are remarkably similar, but they do run slightly out of phase. Curiously, all three periods have secondary El Niño events five years after the primary events, four years after the second phase of the 1986/87/88 El Niño. Those 1977/78, 1991/92 and 2002/03 El Niño events are also the peak of the secondary curves.

At first glance, the green curve that starts with the 2009/10 El Niño seems to fit. If there is moderate El Niño during the 2012/13 season (and it looks like there's going to be one), it would then seem as though the "cycle" would be broken; that is, it would not to fit into the earlier decade-long primary and secondary "cycle". Time will tell. It could be that we've entered a new era of shorter "cycles" that begin with a moderate El Niño event and are then followed by two separate back-to-back La Niña events. Then the 2006/07 El Niño and its trailing La Niña events would fit with the 2009/10 El Niño and the two La Niña events that followed it.

The data have been smoothed with 13-month running-average filters in Figure 4-36 to reduce the seasonal noise and smoothed with a 25-month filter in Figure 4-37 in an effort to further reduce the year-to-year variations. As I noted above, the three curves are remarkably similar.

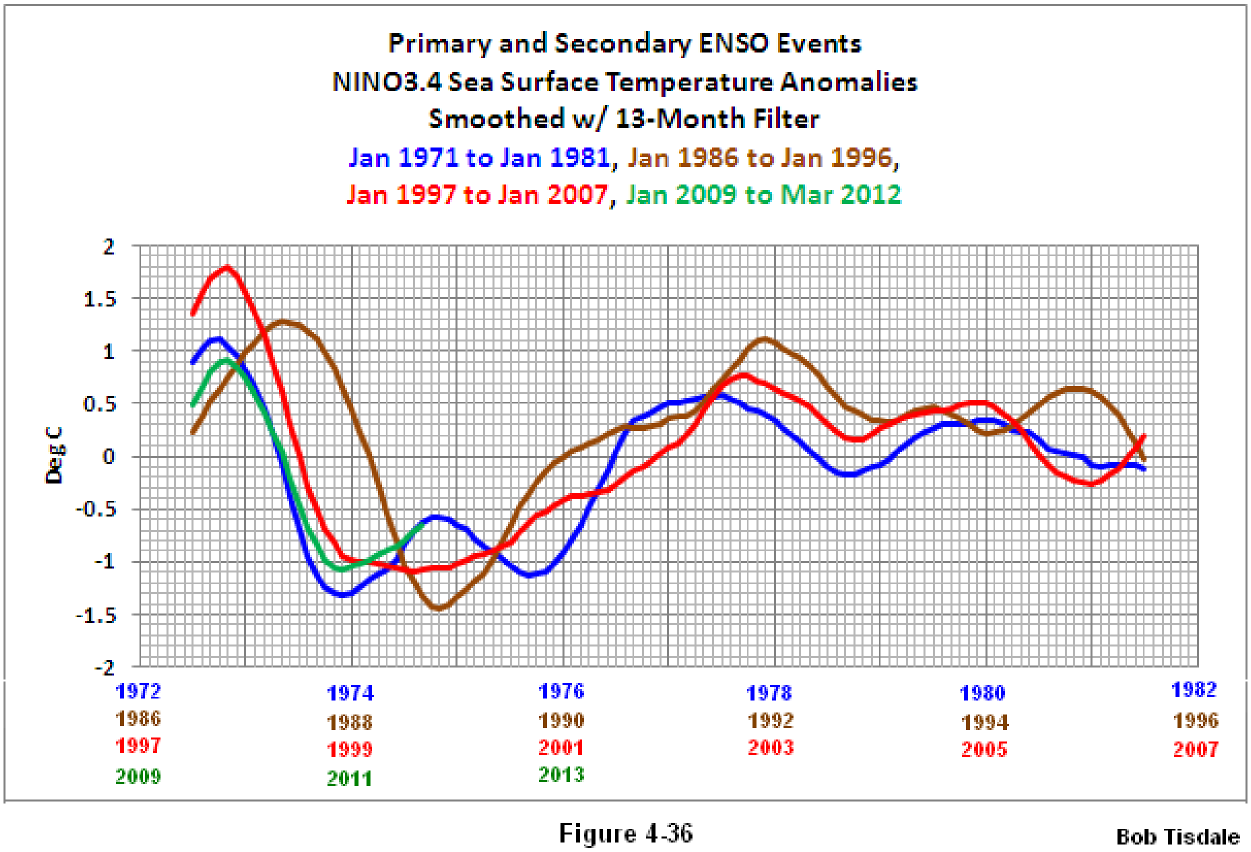

Figure 4-36

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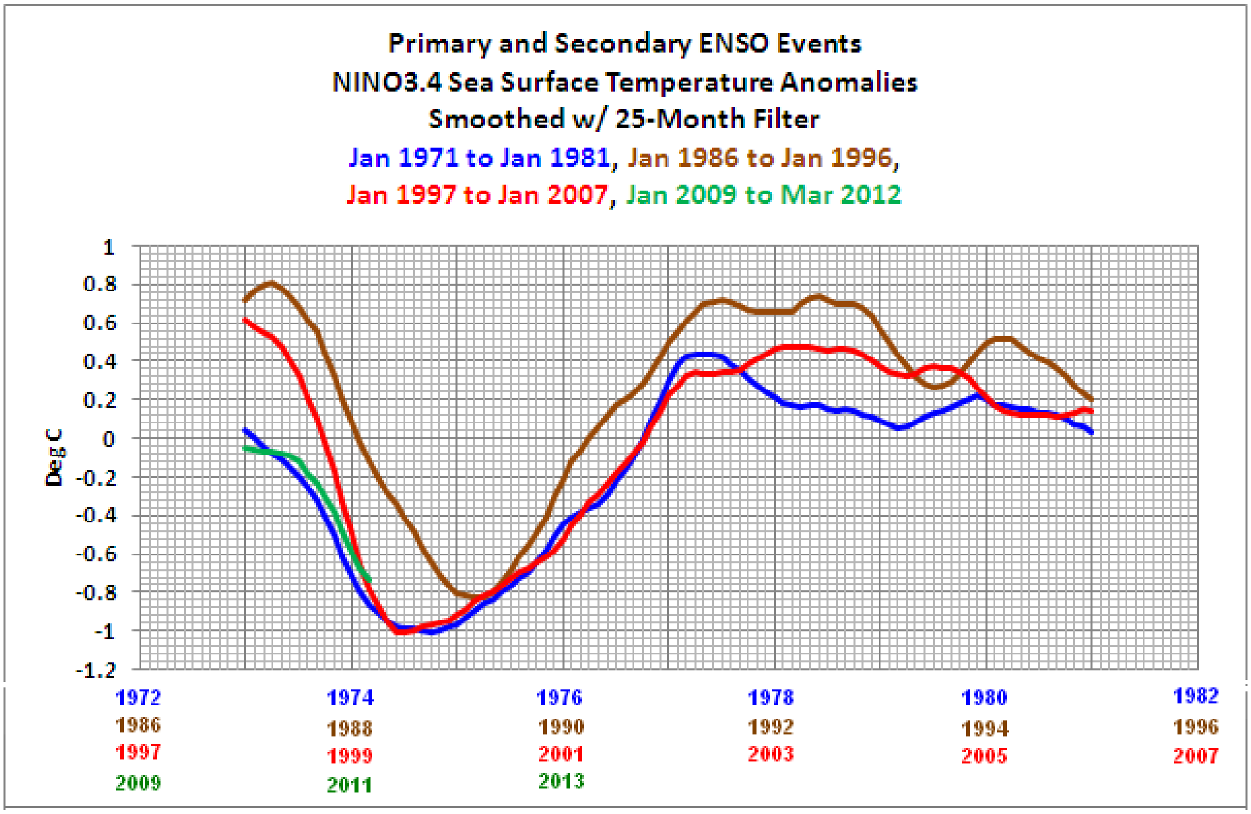


Figure 4-37 Bob Tisdale

RECAP

ENSO appears to have gone through an era when primary major El Niño events were followed by La Niña, then a series of lesser secondary El Niño but with no La Niña separating secondary El Niño. The three primary El Niño took place in 1972/72, 1986/87/88, and 1997/98. The 2009/10 El Niño appeared at first as though it would serve as the 4th primary El Niño, but we may have entered a new era of weaker El Niño followed by back-to-back La Niña. Time will tell.

4.6 A Look at How a Few More Tropical Pacific Variables Respond to ENSO

So far in this book we've compared an ENSO index to a number of variables in the tropical Pacific. Let's take a quick look at a few more variables. This will reinforce the earlier descriptions of the process of ENSO. The two datasets are satellite-based.

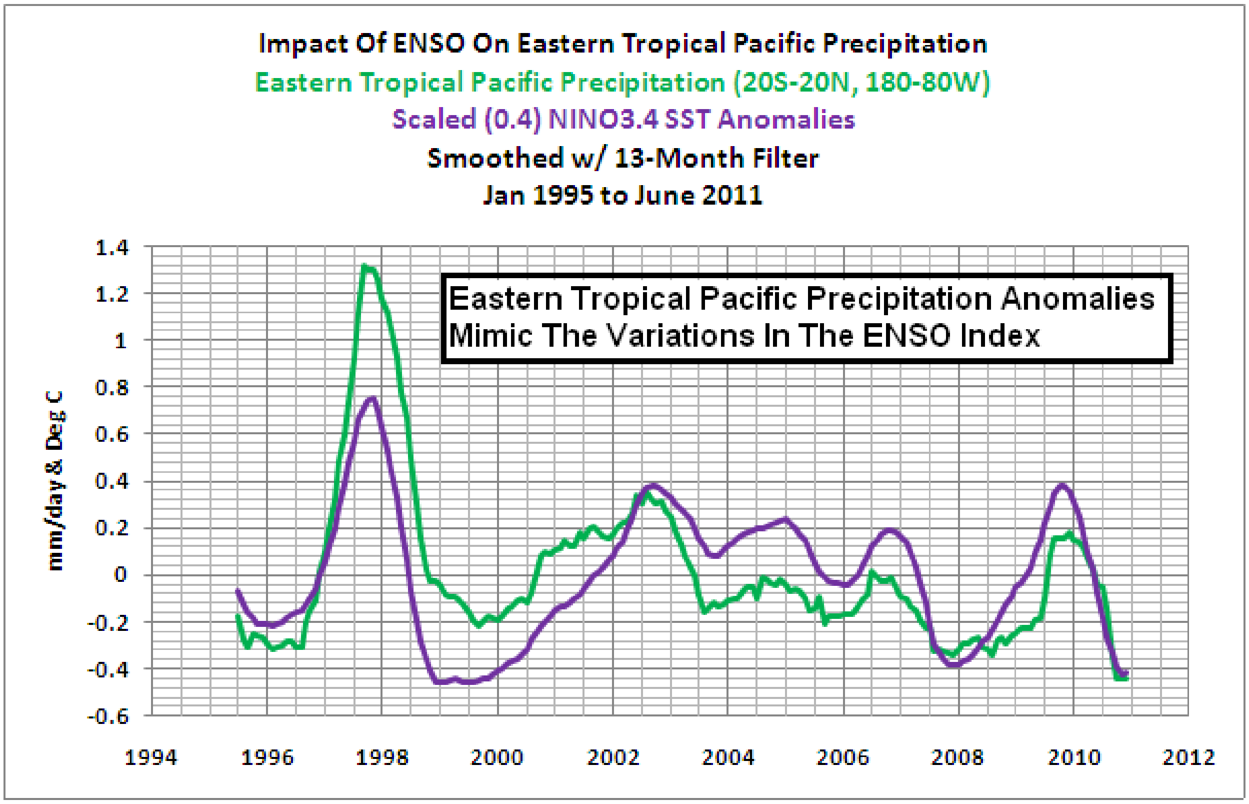


Figure 4-38 Bob Tisdale

The first is shown in Figure 4-38. In that graph we compare the ENSO index (NINO3.4 sea surface temperature anomalies) to the satellite-based precipitation anomalies for the Eastern Tropical Pacific (20S-20N, 180-80W)—from the dateline east. That precipitation data is from **Climate Anomaly Monitoring System (CAMS) – OLR Precipitation Index (OPI)**. The CAMS-OPI precipitation data is yet another dataset available through the KNMI Climate Explorer. The precipitation data in Figure 4-38 is presented as millimeters per day (mm/day) anomalies. Note that the NINO3.4 sea surface temperature anomalies have been scaled (multiplied by a factor of 0.4) for this illustration, and that both datasets were smoothed with 13-month running average filters because of the noise in the precipitation data. As shown, Eastern Tropical Pacific precipitation (from the dateline east) rises and falls with the ENSO index, and during the 1997/98 East Pacific El Niño, the Eastern Tropical Pacific precipitation increased a much greater amount than it did during the lesser Central Pacific El Niño events.

The general agreement between the two curves in Figure 4-38 confirms the earlier discussions of the ENSO process. Convection, cloud cover and precipitation accompany the warm water to the east during an El Niño. This raises Eastern Tropical Pacific precipitation. During a La Niña, the stronger-than-normal trade winds push the convection, cloud cover and precipitation farther to the west, so Eastern Tropical Pacific precipitation decreases.

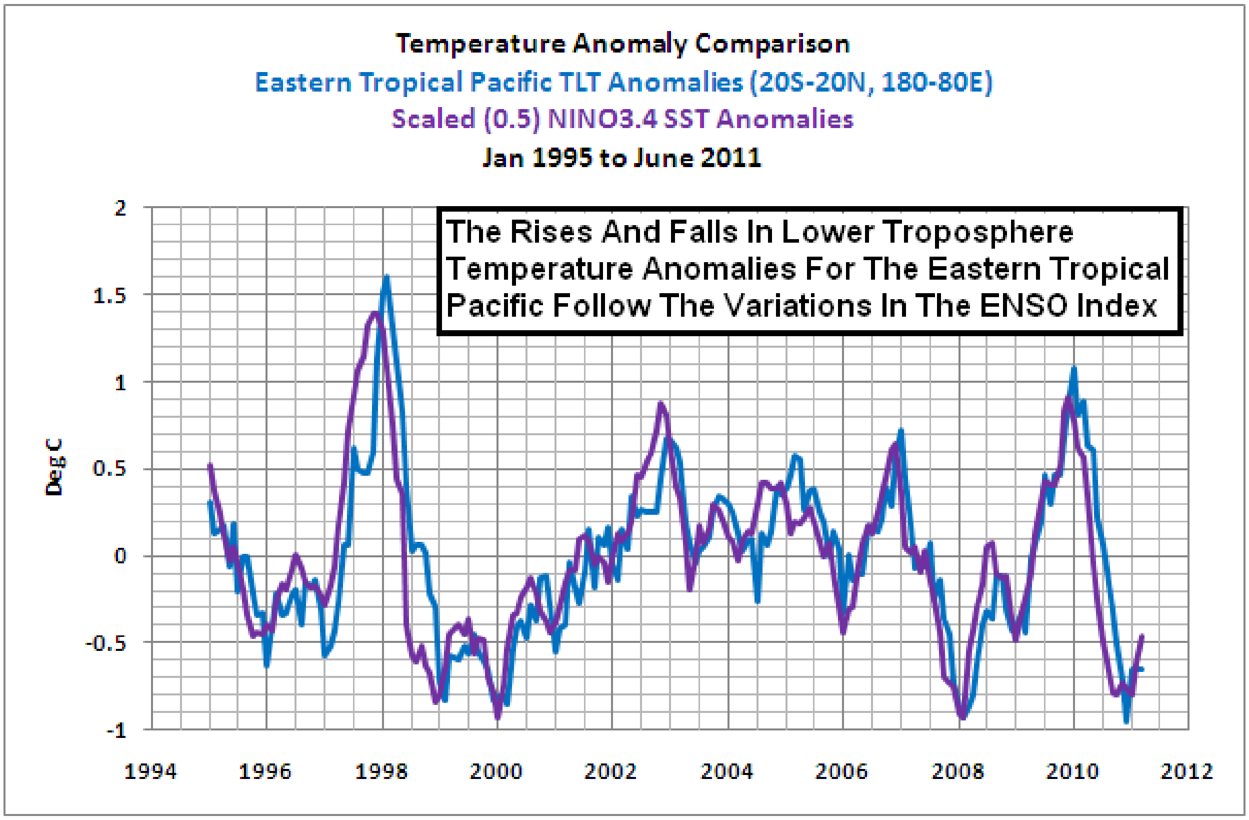


Figure 4-39

Bob Tisdale

As discussed in Sections 1 and 3, the Eastern Tropical Pacific Ocean releases heat during an El Niño, and this occurs primarily through evaporation. As the moisture-laden air rises, it cools, and as it cools, it can hold less moisture. The result is rain. When the moisture in the air returns to a liquid state, it releases the heat from the sun that was used to evaporate it. This warms the atmosphere. We can illustrate the aftereffect of this process by comparing the ENSO index (scaled by a factor of 0.5) and the satellite-based Lower Troposphere Temperature (TLT) anomalies for the eastern Tropical Pacific. See Figure 4-39. Lower Troposphere Temperature (TLT) anomalies are measured at about 3,000 meters above sea level. The Lower Troposphere Temperature anomaly data is the product of the National Space Science & Technology Center (**NSSTC**) at the University of Alabama at Huntsville (UAH). It's available through the KNMI Climate Explorer, or from UAH in specific subsets **here**. As shown in Figure 4-39, this is yet another dataset that shows the closely linked relationship between ENSO and Eastern Tropical Pacific Temperatures.

The heat released in the eastern tropical Pacific travels eastward and toward the poles. This is very visible in .gif animations available through links in Section 6.

RECAP

Eastern tropical Pacific precipitation and Lower Troposphere Temperature anomalies both mimic the variations in the NINO3.4 sea surface temperature anomalies. That is, when the NINO3.4 data warms during an El Niño, eastern tropical Pacific precipitation increases and vice versa during a La Niña. Similarly, when east/central equatorial Pacific sea surface temperatures warm during an El Niño, Lower Troposphere Temperature anomalies in the eastern tropical Pacific warm in response, and vice versa during a La Niña.

4.7 ENSO Events Run in Synch with the Annual Seasonal Cycle

We'll discuss and present what is called the "phase locking" of ENSO events to the seasonal cycle in this chapter.

The sea surface temperature **anomalies** of the NINO3.4 region are warmest in December during a typical El Niño and coolest in December during a typical La Niña. That is, El Niño and La Niña events normally peak in December.

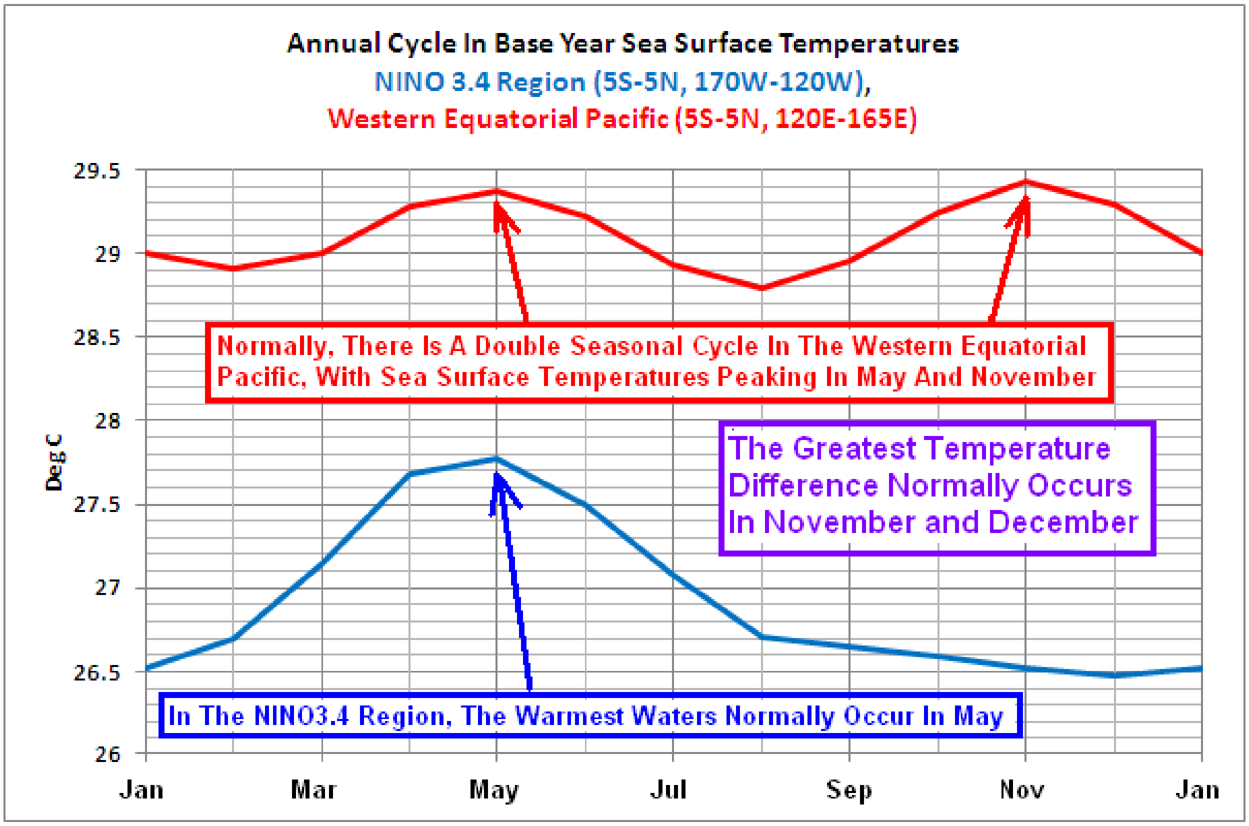


Figure 4-40 Bob Tisdale

Let's look at the normal annual cycle in sea surface temperatures (not anomalies) of the NINO3.4 region (5S-5N, 170W-120E) and the Western Equatorial Pacific (5S-5N, 120E-165E). See Figure 4-40. You'll notice in the title block that the graph shows the cycle in the "base year" temperatures that are used to determine anomalies. As you'll recall, that base period data is the average of 30 years of sea surface temperatures for a specific region. NOAA uses the base period of 1971 to 2000. Basically, those two curves show the average annual cycles in sea surface temperatures for those two regions for that 30-year time period. In the NINO3.4 region, the annual cycle for the average year peaks in May and the lowest temperature normally appears in December. The Western Equatorial Pacific, on the other hand, has a double cycle annually, with the warmest waters appearing there in May and

November, with November winning by a nose. The sea surface temperature minimums for the Western Equatorial Pacific occur in February and August. The greatest difference between the two curves occurs in November and December.

Let's recall our ENSO basics. During an El Niño, the NINO3.4 region is being fed warm water from the west Pacific Warm Pool; that is, the Equatorial Counter Current strengthens and carries warm water eastward. As a result, the normal annual sea surface temperature cycle in the NINO3.4 region is now being influenced by the annual cycle of the sea surface temperatures in the West Pacific Warm Pool. This is easily seen in Figure 4-41. It compares NINO3.4 sea surface temperatures (not anomalies) for the period of January1995 to January 2005 and also the series of base year cycles in the sea surface temperatures for the Western Equatorial Pacific (5S-5N, 120E-165E) and the NINO3.4 region. Also note that the La Niña events reach their lowest temperatures in December-January, which is another example of how a La Niña event is simply an exaggeration of an ENSO-neutral (average) phase.

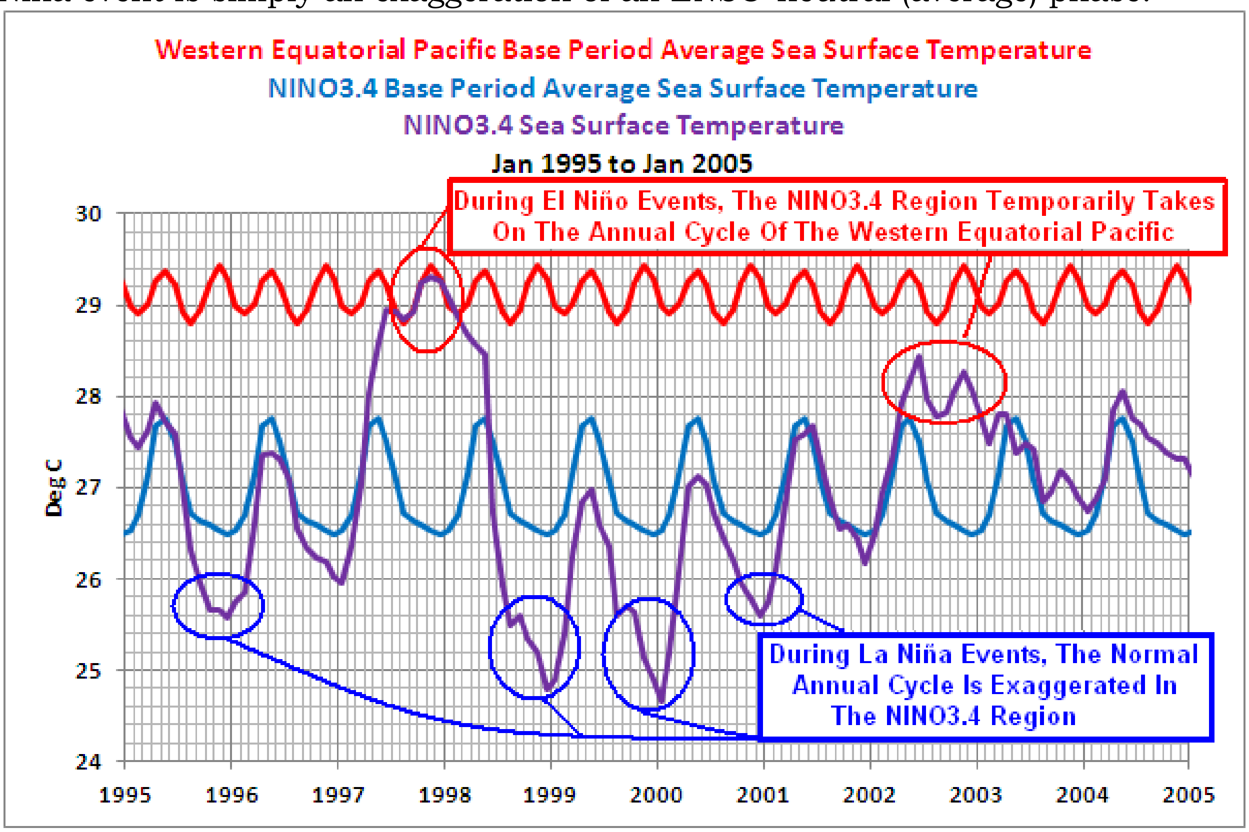


Figure 4-41 Bob Tisdale

Let's carry that discussion farther. In the 2008 paper **Seasonal Cycle–El Niño Relationship: Validation of Hypotheses**, Xiao and Mechoso presented three hypotheses, two of which they confirmed with climate models. Let's discuss those two. The first hypothesis they confirmed was:

> *The seasonal warming of the cold tongue in the early part of the calendar year (January–April) favors the initial growth of an event.*

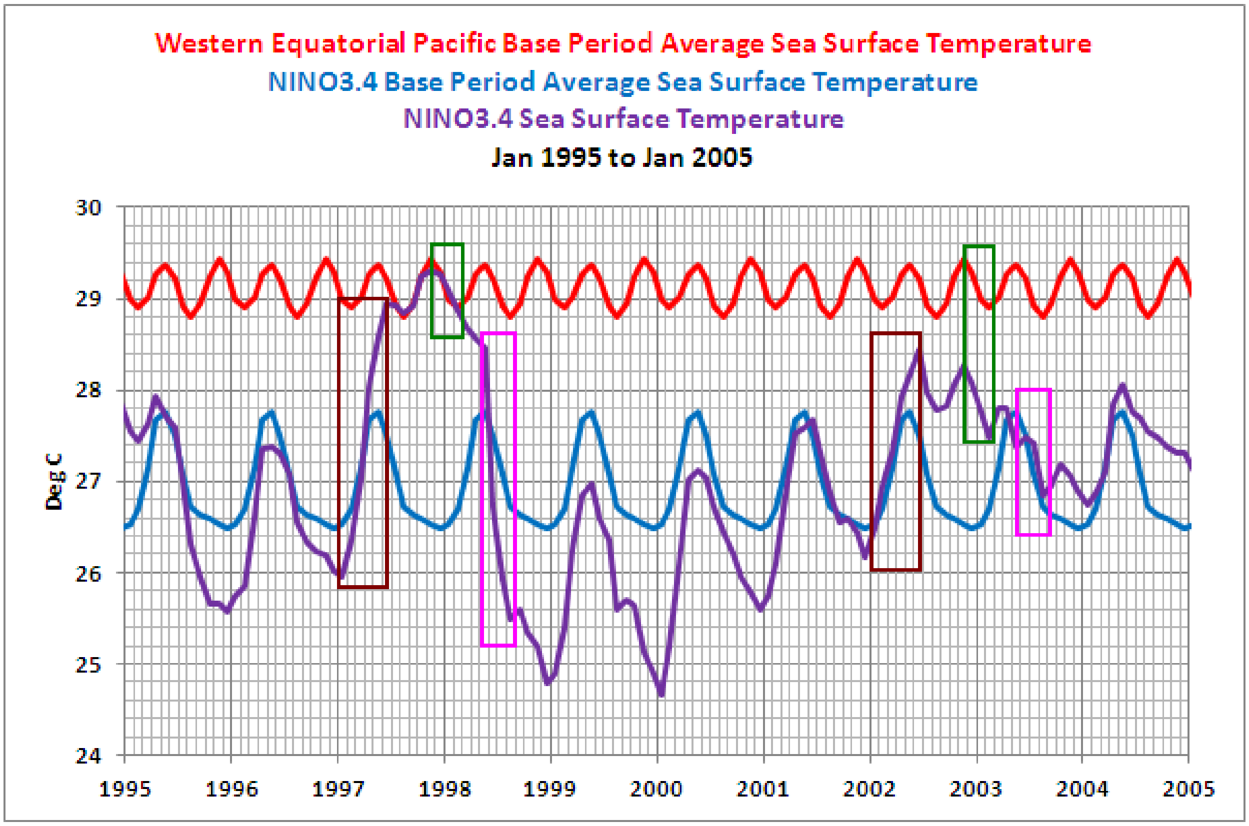
The NINO3.4 region captures the western portion of the cold tongue, so the annual cycle in NINO3.4 sea surface temperatures shown in Figure 4.40 above confirms the seasonal warming of the cold tongue region in the early part of the year.

Xiao and Mechoso (2008) also discussed their third hypothesis, which is:

> *The warm surface waters returning in the western basin from the Northern to the Southern Hemisphere toward the end of the calendar year (November– January) favor the demise of ongoing El Niño events.*

The sun passes over the equator twice during the year, at the March and September equinoxes. As shown above in Figure 4-40, the sea surface temperatures in the western equatorial Pacific reach their maximums a few months later in May and November. The warm water is basically following the sun, with a lag, as it progresses between hemispheres. As Xiao and Mechoso (2008) describe, and to put it into terms of the data we've presented, the El Niño ebbs as the warm water passes from the western equatorial Pacific into the Southern Hemisphere.

Figure 4-42 presents the same data as Figure 4-41. The two graphs are the same, but the notes are different. I've highlighted the evolutions of the 1997/98 and 2002/03 El Niño events in maroon in Figure 4-42 to show that the El Niño events do grow during the normal seasonal upswing in NINO3.4 sea surface temperatures. I've also highlighted in green the initial decreases in sea surface temperatures that correspond to the decrease in Western Equatorial Pacific sea surface temperatures. Additionally, I've repeated those highlighted periods in Figure 4-43 for the period of January 2004 to May 2012 to show the evolutions and decays of the 2004/05, 2006/07 and 2009/10 El Niño events. In both illustrations, I've also highlighted in pink the secondary, but major, decays in the sea surface temperatures that align with the normal seasonal portion of the major drop in annual average NINO3.4 sea surface temperatures.



According To Xiao & Mechoso (2008):

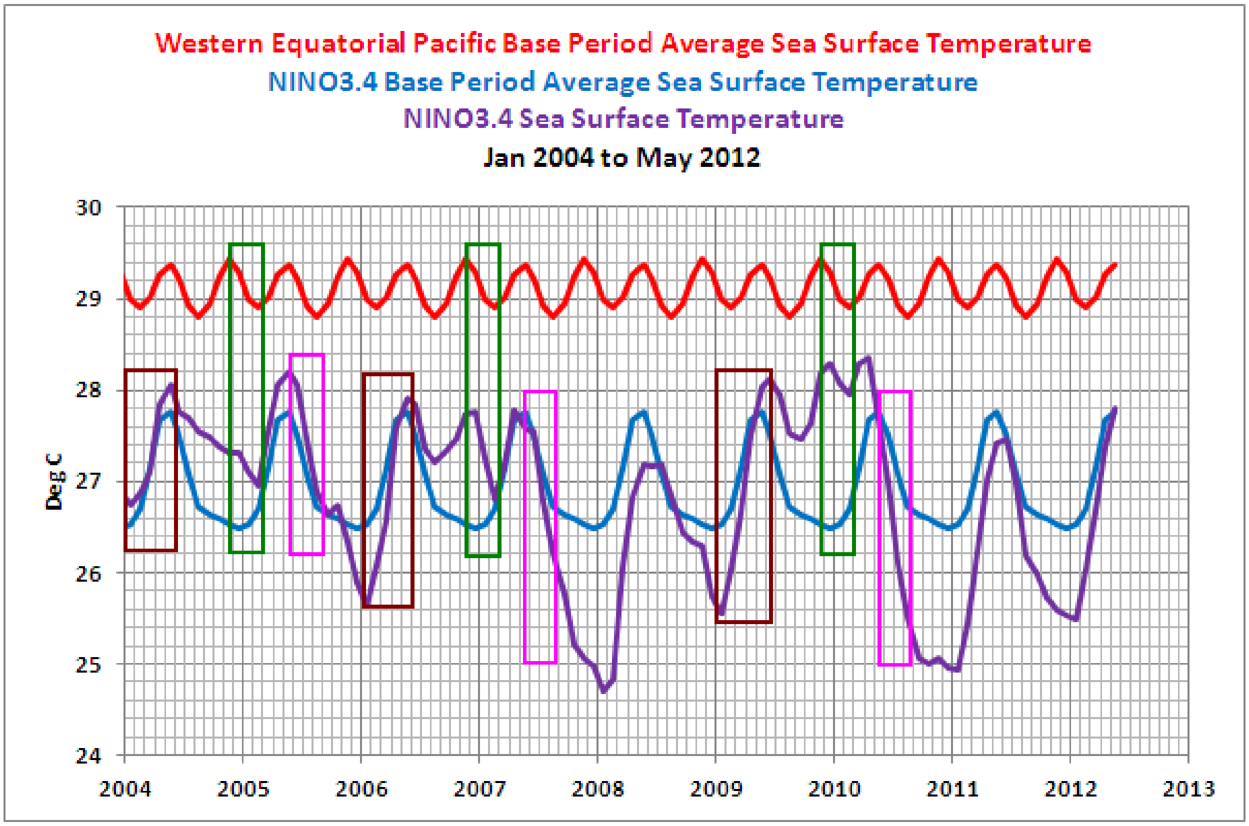
1. Seasonal Warming Of The Cold Tongue Region Favors Initial El Niño Growth.
2. The Warm Water Returning From The Northern To The Southern Hemisphere Favors The Demise Of The El Niño.

Additionally:

The Secondary Decay Aligns With The Seasonal Cooling Of The NINO3.4 Region.

Figure 4-42 Bob Tisdale

HHH



According To Xiao & Mechoso (2008):

1. Seasonal Warming Of The Cold Tongue Region Favors Initial El Niño Growth.
2. The Warm Water Returning From The Northern To The Southern Hemisphere Favors The Demise Of The El Niño.

Additionally:

The Secondary Decay Aligns With The Seasonal Cooling Of The NINO3.4 Region.

Figure 4-43 Bob Tisdale

RECAP

El Niño events, using NINO3.4 sea surface temperatures (not anomalies) are in phase with the seasonal cycle in the eastern tropical Pacific, the cold tongue region, for the evolution and secondary decay portions of the events. The seasonal peak and decay of the El Niño are in phase with the late year cycle in the western equatorial Pacific. La Niña events appear to simply exaggerate the normal seasonal cycle in the eastern tropical Pacific.

The delayed oscillator mechanism of ENSO, Chapter 4.9, must also be considered when discussing the end of ENSO events.

4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves

A basic understanding of the processes taking place below the surface of the tropical Pacific is also important. The subsurface temperatures along the equatorial Pacific have been portrayed in the cartoon-like ENSO illustrations. All of the cross sections of the equatorial Pacific sea surface temperatures so far have been very basic. See the examples in Figure 4-44. There were no temperature scales. Warmer waters were shown in red and cooler waters in blue. The intent of those simple illustrations was to reinforce the fact that warm waters from the surface and below the surface of the western Pacific Warm Pool slosh east during an El Niño. This chapter will first confirm that the annotated illustrations provided reasonable depictions. Then we'll discuss the subsurface temperature **anomalies** along the equatorial Pacific, which will lead us to an introduction to Kelvin waves.

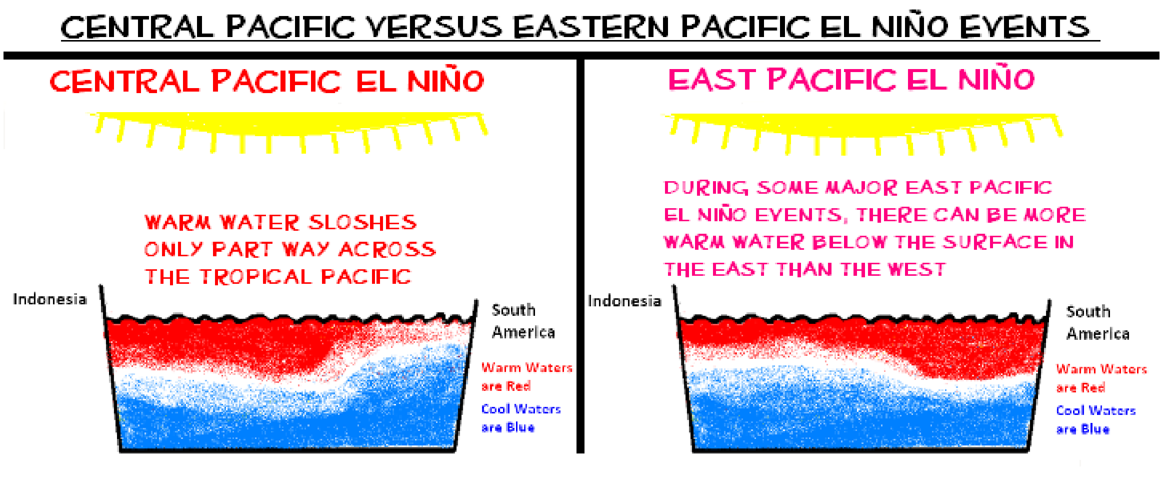


Figure 4-44

We'll be using cross sections of subsurface temperatures and temperature anomalies along the equatorial Pacific for this chapter. The color-coded illustrations are available at the **European Centre for Medium-Range Weather Forecasts** (ECMWF) website, from their webpage **Monthly equatorial sections from the S3 ocean re-analysis**. The illustrations from ECMWF also include the cross sections of the Indian and Atlantic Oceans. I've removed those additional ocean basins from the following illustrations so that we can concentrate on the equatorial Pacific.

A white band is shown in the illustrations. It depicts the contour line (isotherm) at 20 deg C, which typically represents the thermocline in the tropical Pacific. The thermocline separates the warmer mixed layer of the equatorial Pacific from the calmer, cooler deep water below it. The mixing in the mixed layer is caused by surface waves and ocean currents.

Keep in mind the dimensions are skewed in the cross sections. The vertical height is 300 meters, and the horizontal distance is about 16,700 kilometers.

Figure 4-45, in the left-hand cell, shows the cross section of equatorial Pacific subsurface temperatures for December 2004. That was the peak of the Central Pacific El Niño of 2004/05. The right-hand cell represents the temperatures in December 1997, which was at the peak of the 1997/98 East Pacific El Niño. During the Central Pacific El Niño, the waters at 29 deg C and warmer have only traveled eastward part way across the equatorial Pacific. During the 1997/98 El Niño, on the other hand, the warmer water has traveled eastward to the coast of South America. In fact, there is more warm water in the east than in the west during the 1997/98 El Niño.

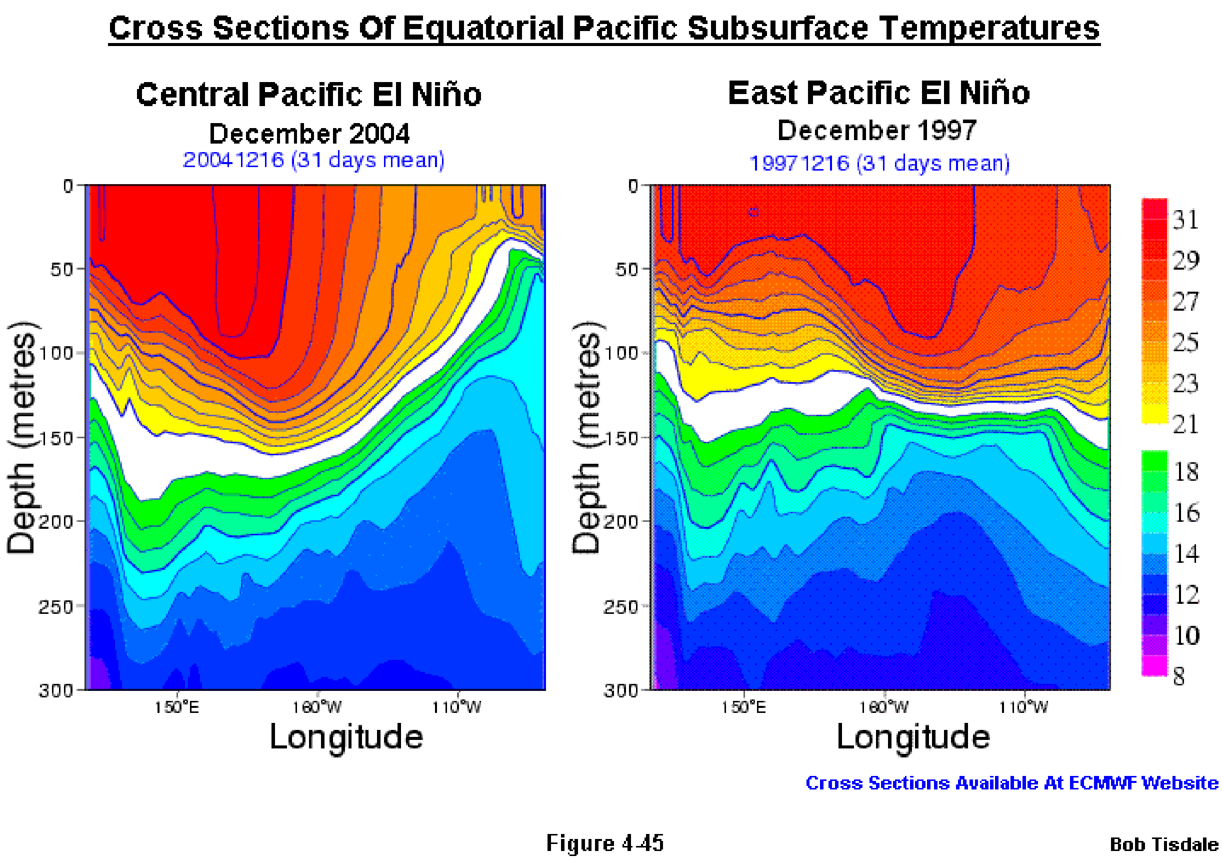


Figure 4-45

In Figure 4-46, the subsurface temperatures for the ENSO-neutral month of December 1996 are compared to the very strong East Pacific El Niño month of December 1997. During the ENSO-neutral month on the left, the trade wind-driven currents are causing the warm surface waters to “pile up” in the western equatorial Pacific. By December 1997 on the right, the trade winds have relaxed and become westerlies, and the warm water has sloshed eastward. Based on the depth of the isotherm at 20 deg C, shown in white, the Kelvin wave can impact the top 150 meters or so of the equatorial Pacific.

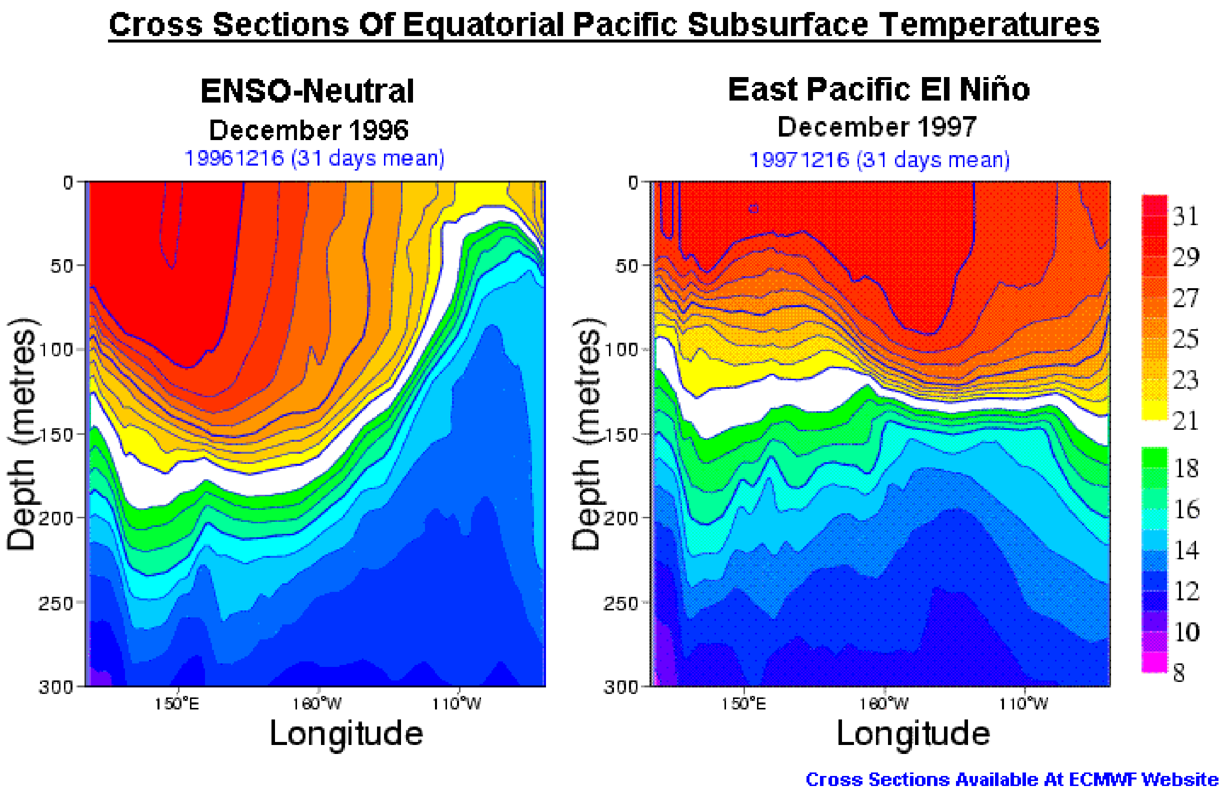


Figure 4-46

Bob Tisdale

ENSO-neutral (December 2006) and La Niña (December 2008) cross sections of equatorial Pacific subsurface temperatures are shown in Figure 4-47. The warmer waters are pushed farther to the west during the La Niña by the stronger-than-normal trade winds, and the strengthened La Niña trade winds are causing more cool water than normal to be upwelled in the east. Notice also how there is less warm water in the west in December 1998 than there was in December 1996, before the El Niño. Remember that the El Niño released a tremendous amount of heat into the atmosphere through evaporation and the leftover subsurface warm water was returned to the west via a Rossby wave at about 10N, so only part of what was returned would appear along the equator by December 1998. The rest was carried northward away from the equator and into the eastern tropical Indian Ocean.

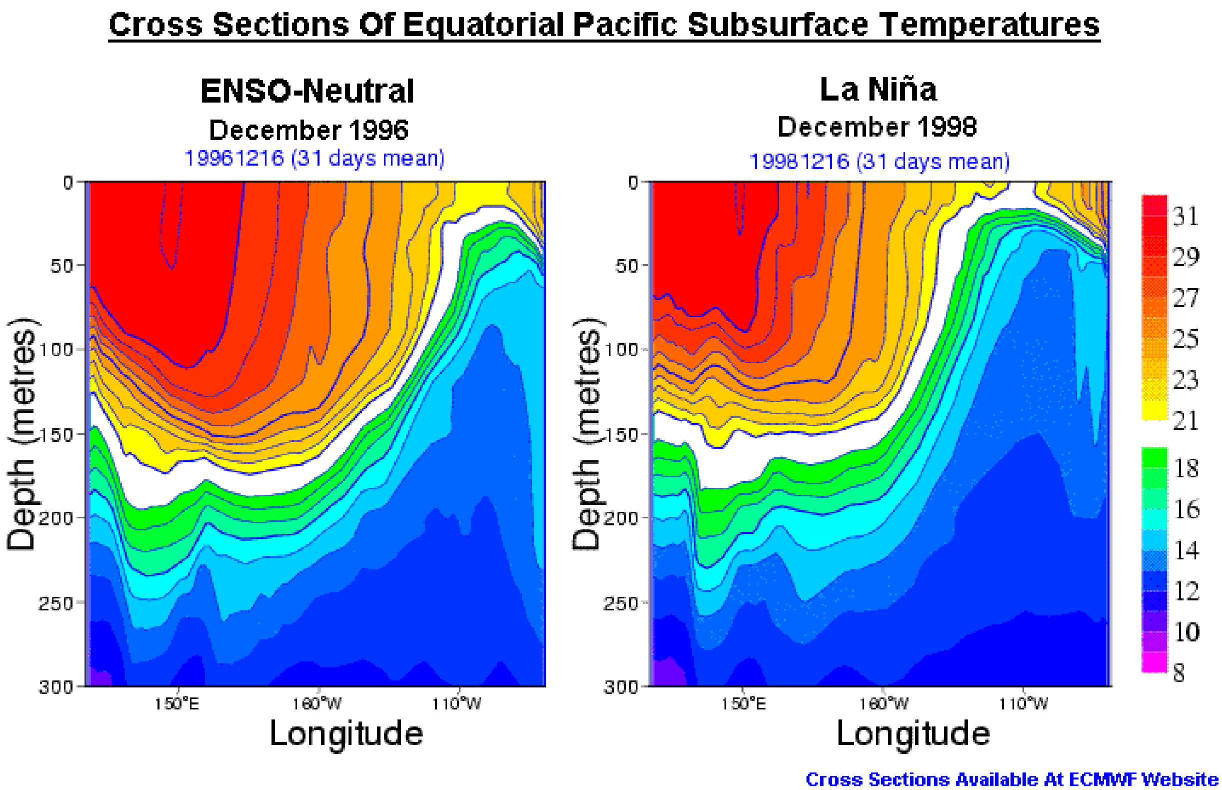


Figure 4-47

Bob Tisdale

Now let’s take a look at the subsurface temperature **anomalies** at depth along the equator. We’ll begin with the comparison of the Central Pacific (December 2004) and East Pacific (December 1997) El Niño events, Figure 4-48. The equatorial subsurface temperature anomalies are much greater in the east during an East Pacific El Niño. That stands to reason, because the normal (or average) subsurface temperature (not anomaly) is much cooler there, about 14 to 16 deg C. Then, during the El Niño, that cooler water is replaced by the warm water from the Pacific Warm Pool that’s about 27 to 28 deg C. The big white pocket indicates that the subsurface temperature anomalies have warmed above the 9.5 deg C top end of the scale.

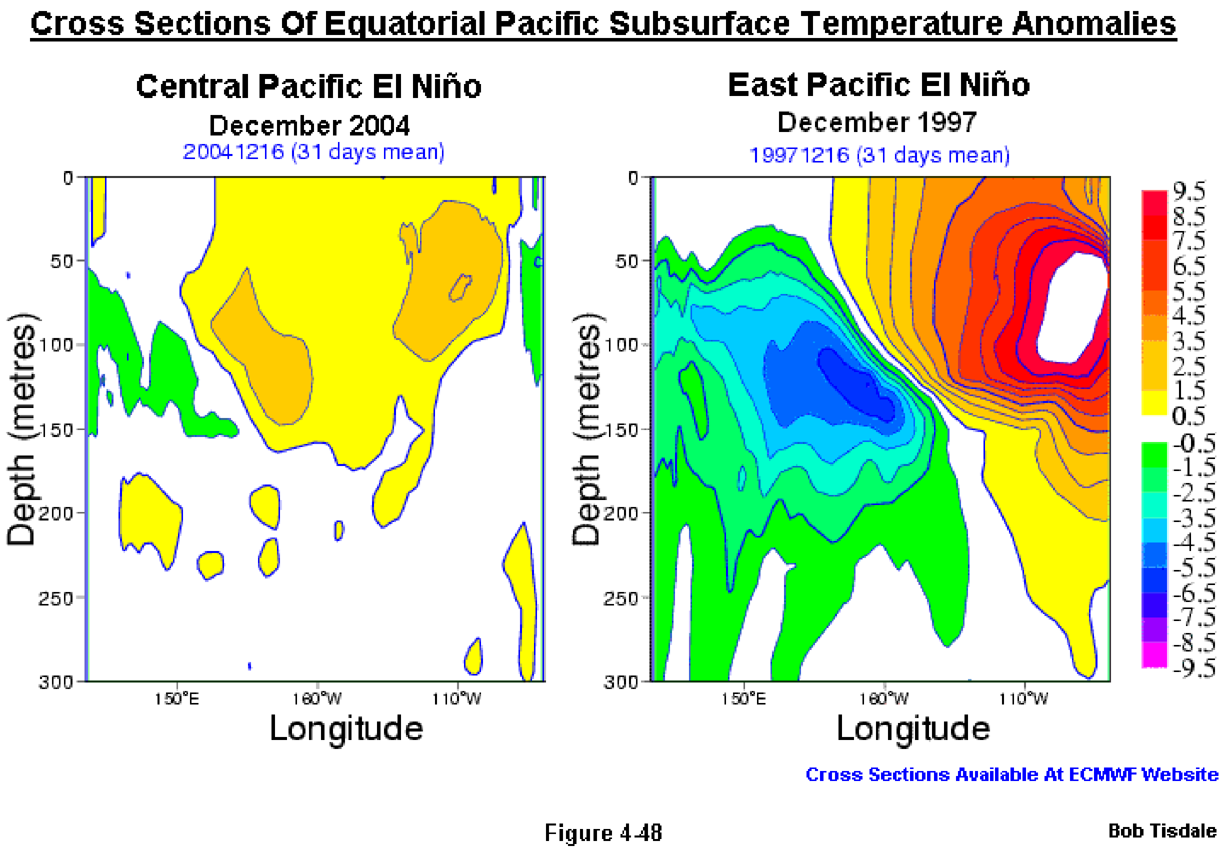


Figure 4-48

Figure 4-49 compares subsurface temperature anomalies along the equatorial Pacific for the ENSO-neutral December (1996) and the East Pacific El Niño December (1997). As you'll recall, the NINO3.4 sea surface temperature anomalies are below zero in December 1996, but they had not reached La Niña levels. That explains why the subsurface temperature anomalies are slightly less than normal toward the east in the ENSO-neutral cross section. Note the warmer-than-normal temperature anomalies at depth in the west before the El Niño. That additional warm water supplied some of the extra "fuel" for the 1997/98 Super El Niño. Keep in mind, the warm water from the Pacific Warm Pool that supplies an El Niño does not only come from along the equator; the warm water is taken from a large area. During the El Niño in the right-hand cell, in addition to the elevated subsurface temperature anomalies in the east, note also how the anomalies are depressed toward the west. Refer back to Figure 4-44. That means the volume of warm water that had traveled to the east during the 1997/98 El Niño was so great that cooler waters from depths were drawn toward the surface.

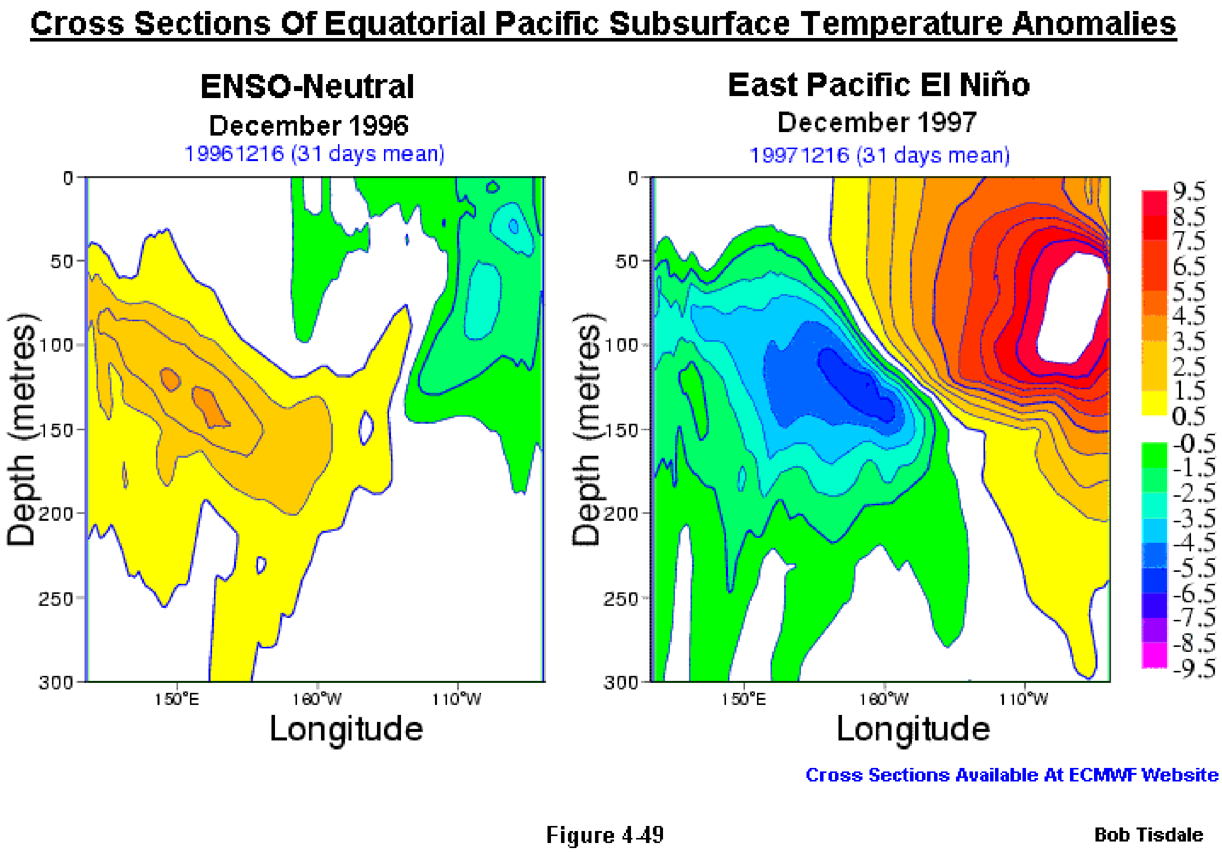


Figure 4-49

The last of the subsurface temperature anomaly comparisons, Figure 4-50, shows the conditions during ENSO-neutral December (1996) and the La Niña December (1998) two years later. The subsurface temperature anomalies in the west have decreased from December 1996 to December 1998 because the El Niño released a massive amount of heat, and because the warm water that was left over from the El Niño was carried back to the west by the Rossby wave, but away from the equator at 10N. By December 1998, the stronger-than-normal trade winds have reduced cloud cover, and the additional sunlight has begun to recharge the supply of warm water in the Pacific Warm Pool, but it hasn't replenished it fully. The cooler-than-normal subsurface temperature anomalies in the east are also caused by the trade winds drawing more of the cooler water toward the surface.

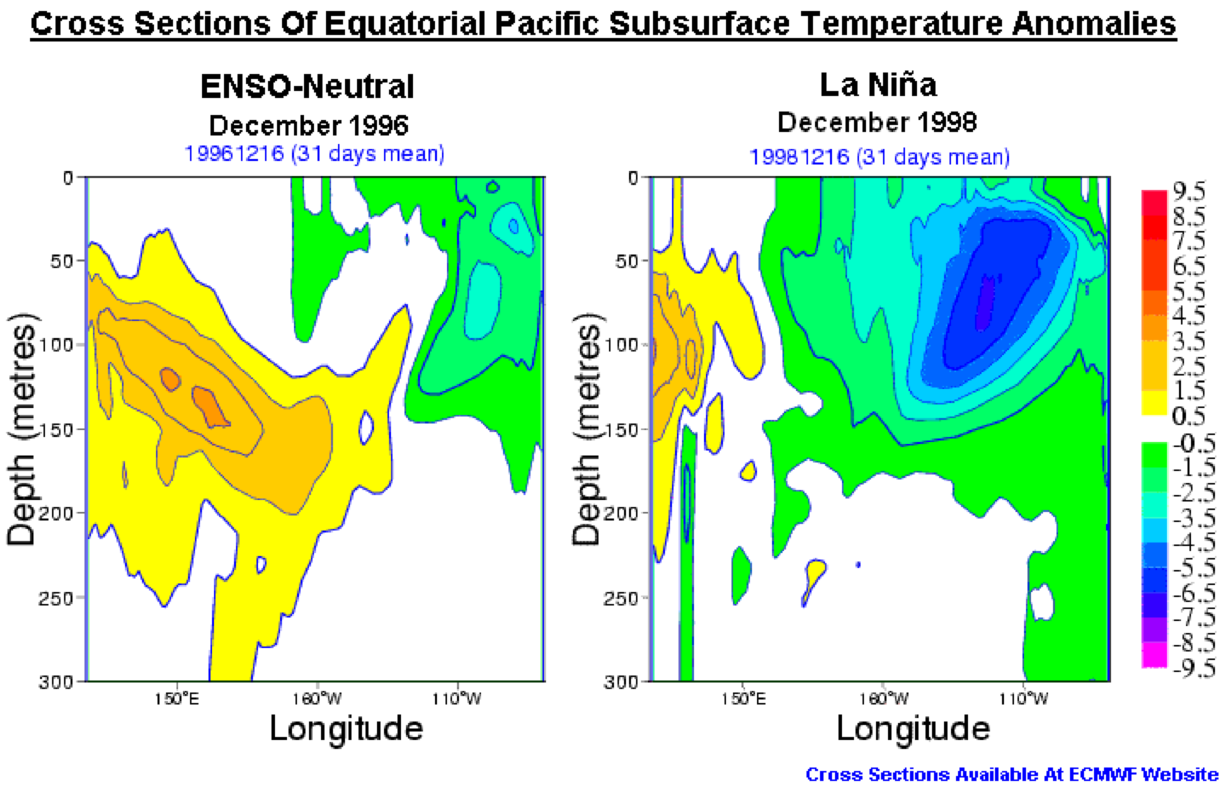
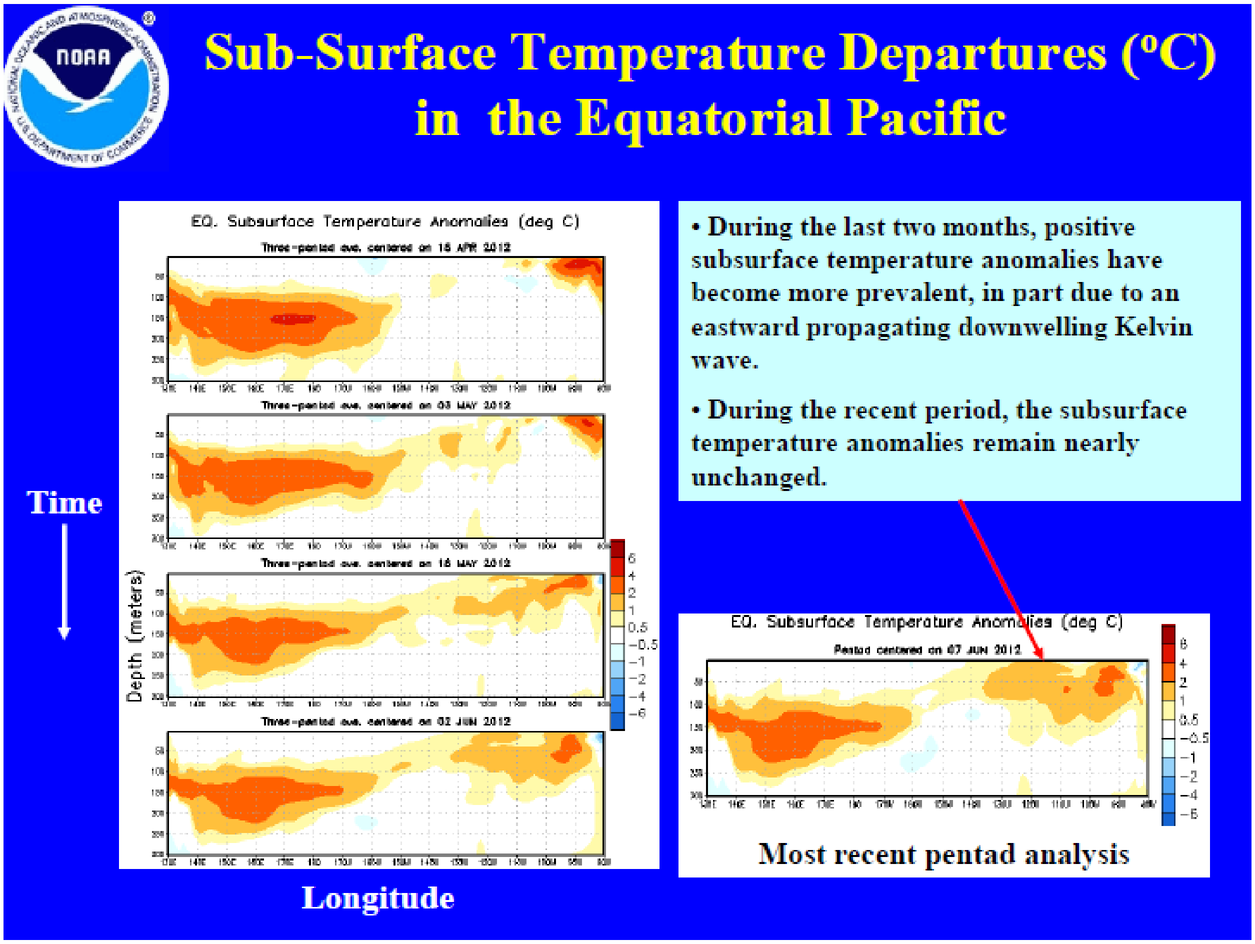


Figure 4-50 Bob Tisdale

NOAA presents subsurface temperature anomalies for the equatorial Pacific in their weekly report titled "ENSO Cycle: Recent Evolution, Current Status and Predictions". The weekly ENSO report is available in **pdf** and **PowerPoint** formats from the NOAA/Climate Prediction Center (CPC) **El Niño/Southern Oscillation (ENSO) Diagnostic Discussion** webpage, under the heading of Weekly ENSO Update. An example of the NOAA presentation of subsurface equatorial Pacific temperature anomalies from the June 11, 2012 report is shown in Figure 4-51.

Sample NOAA Discussion of Equatorial Pacific Subsurface Temperature Anomalies from Their Weekly ENSO Report



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

Figure 4-51

Bob Tisdale

There's one cross section at the bottom of the right-hand side of the NOAA illustration in Figure 4-51. It presents the subsurface temperature anomalies of the equatorial Pacific in degrees C, for the "most recent pentad", where a pentad is a 5-day period. There are four cross sectional views of subsurface temperature anomalies along the left-hand side, in sequence from top to bottom. Each presents the average subsurface temperature anomalies for three pentads, or fifteen days, and the dates listed are the 8th day midpoints. From the top to bottom, they are centered on April 16th, May 3rd, May 18th, and June 2nd. Looking at the cross sections in sequence should lead you to believe that a portion of the warm subsurface temperature anomalies have shifted east over the last four 15-day periods. That's precisely what happened.

The text at the top of the right-hand side in Figure 4-51 reads:

> During the last two months, positive subsurface temperature anomalies have become more prevalent, in part due to an eastward propagating downwelling Kelvin wave.

NOAA is discussing an (oceanic) equatorial Kelvin wave. An equatorial Kelvin wave is a phenomenon that carries warm or cool water from west to east along the equator. They typically move at about 2.8 meters per second (about 6.3 miles per hour) and can travel the distance between New Guinea in the west and South America in the east in about two months. They come in two flavors downwelling and upwelling Kelvin waves. Kelvin waves that carry warmer-than-normal waters eastward are called downwelling because they push down the cooler waters in the east, away from the surface. Conversely, Kelvin waves carrying cooler-than-normal waters to the east are called upwelling Kelvin waves because they draw the cool waters in the east upward, toward the surface. I know, I know, it would have been easier to understand if the scientists had called them warm and cool Kelvin waves. To help with the discussion, I'll call them warm and cool and place the downwelling and upwelling in parentheses.

I've prepared a couple of animations to help illustrate the Kelvin waves and the difference between the warm (downwelling) and cool (upwelling) varieties. First, Animation 4-1 shows the impact of the warm (downwelling) and cool (upwelling) Kelvin waves on cross sections of subsurface temperatures and temperature anomalies. I've used the cross sections from the **European Centre for Medium-Range Weather Forecasts** (ECMWF) website that were used in Figures 4-45 through 4-50 above, but in the animations, I have not deleted the Indian and Atlantic Oceans. As a result, you'll have to concentrate on the center section. Each cell in Animation 4-1 includes the monthly subsurface temperature anomalies on top and the monthly subsurface temperatures (not anomalies) on the bottom. See Figure 4-52 for a sample cell. Animation 4-1 runs from December 1996 to December 2001 to capture the evolutions and decays of the 1997/98 El Niño and the 1998/99/00/01 La Niña. I've also noted when the animation starts (in red), because it repeats automatically.

Sample Cell From Animation 4-1

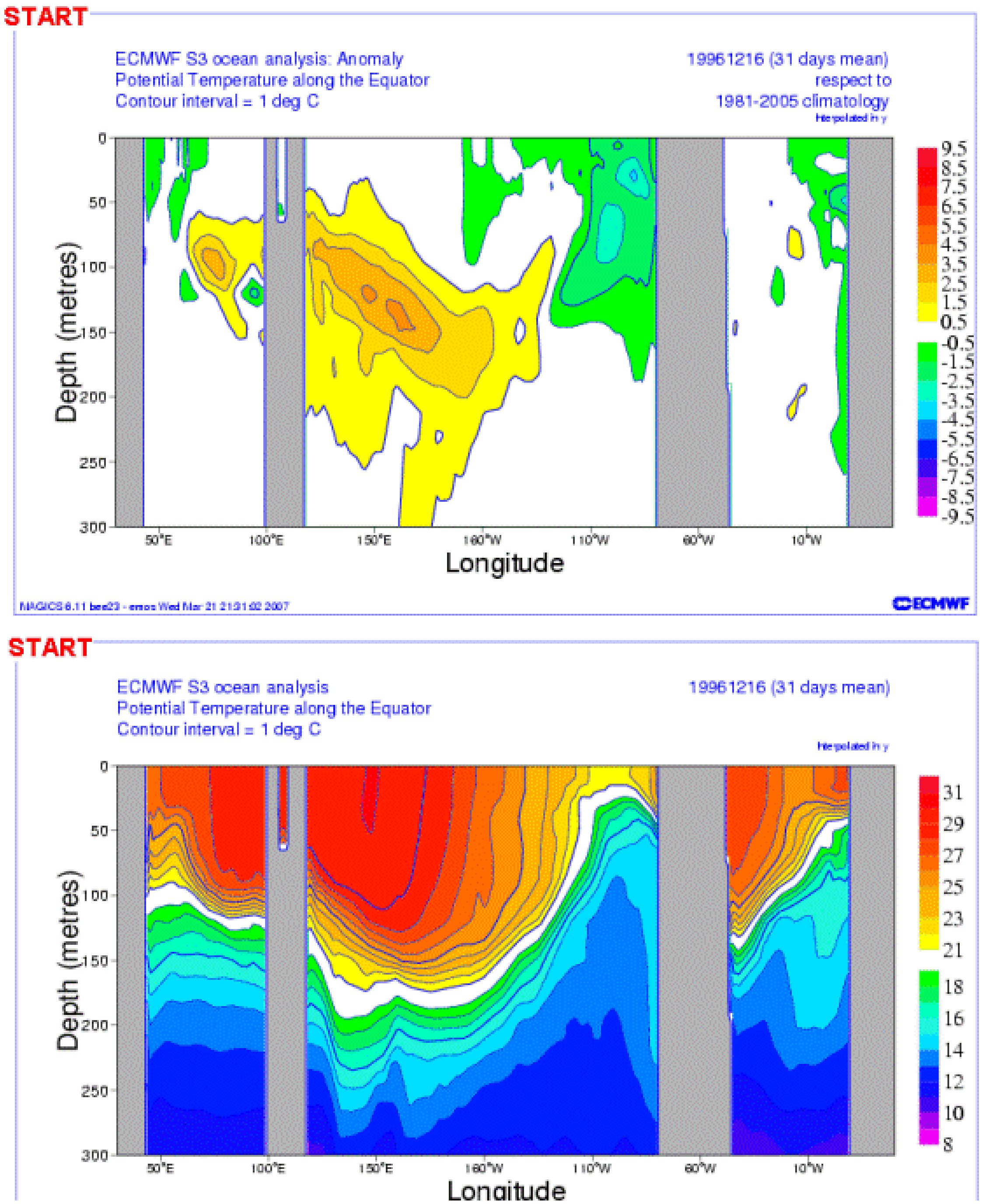


Figure 4-52 **Bob Tisdale**

Animation 4-1 is the full-sized version. The warm (downwelling) Kelvin wave takes place during 1997 when the warm anomalies, shown with contours of yellows and oranges, shift east. Afterwards, the cool (upwelling) Kelvin wave can be seen in 1998 when the cooler subsurface waters, shown in blues and greens, travel east. The animation continues through December 2001 to capture the rest of the 1998/99/00/01 La Niña. Note how the warm anomalies in the west continue to increase over the term of the La Niña. As a reminder, that recharging is caused by the increase in visible sunlight that's allowed to warm the ocean, which is caused by the stronger-than-normal La Niña trade winds reducing cloud cover. (You might find your eyes drawn to the upper, anomaly portion of the animation. The lower animation is very revealing near the beginning, during the El Niño and the evolution of the La Niña.)

Just in case your browser does not automatically reduce the size of the animation after downloading, I've prepared a **Half-Sized Version of Animation 4-1** so that top and bottom parts cells will be visible on your screen. Unfortunately, much of the clarity was lost when the images were reduced in size.

HHH

A REMINDER ABOUT THE LINKS TO THE ANIMATIONS

If you're reading the .pdf and Kindle-for-PC editions of this book, the links should work and the animations should open in a separate window. If you're reading the Kindle version on a Kindle Reader, as far as I know, the links will not operate, so you'll have to switch to your computer and visit my blog to view the animations. Input the title of the post **Animations for "Who Turned on the Heat?"** into your search engine. There you'll find the same introductions to the animations, along with links.

HHH

Animation 4-2 is another .gif animation and it presents satellite-based maps of the sea level anomalies for the global oceans. Like **Animation 3-1**, it was created from screen captures taken from the JPL animation "tpglobal.mpeg". Refer also to the complete JPL animation "tpglobal.mpeg" available on YouTube as **full YouTube version of the JPL animation "tpglobal.mpeg"**. Animation 4-2 starts in mid-December 1996 to capture the first of two warm (downwelling) Kelvin waves. The weaker first Kelvin wave starts at the end of December 1996 and reaches the coast of South America by February 1997. Apparently, it wasn't strong enough to kick off the El Niño. A month later in March 1997, however, the second, much-stronger warm (downwelling) Kelvin waves begins, and it initiates the colossal 1997/98 El Niño.

So far you've seen warm (downwelling) Kelvin waves from the side and top. The cool (upwelling) Kelvin waves are a little more difficult to show. Let's look at **Animation 3-1** again, concentrating on the western tropical Pacific at its start. Sea levels in the western equatorial Pacific are extremely low at the time. Part of the drop in sea level anomalies at that time is caused by the westerly winds pushing the warm water to the east, and part is caused by the lower temperatures there. Those factors have dropped sea level anomalies to heights lower than the minimum contour value on the color-coded anomaly scale. As a result, any additional variations are lost. Unfortunately, that's what we're looking for: the additional variation that shows the formation of the cool (upwelling) Kelvin wave.

Using another sea level dataset (**AVISO CLS** sea level anomaly data) and the map-making feature at the KNMI Climate Explorer, I've captured the cool (upwelling) Kevin wave that ended the 1997/98 El Niño and initiated the La Niña of 1998/99/00/01. See **Animation 4-3**. As you'll note, the contour levels for the maps are large and they're also heavily weighted toward the positive anomalies, which suppresses the positive anomalies. This allows us to concentrate on the negative anomalies. The animation shows maps of monthly sea level anomalies from January 1997 to December 1998. The cool (upwelling) Kelvin wave appears to start in February 1998. It then travels eastward, with the negative anomalies appearing to decrease before arriving at the coast of South America.

One more view of the subsurface temperature anomalies: This time we'll be looking at another set of cross sections, but this time the cross sections run from south to north in the Pacific. These cross sections are available, once again, from the **ECMWF** website.

Figure 4-53 shows the subsurface temperature anomalies at 140W longitude, from 40S to 40N. The top cell is for the month of December 1996, a year before the peak of the 1997/98 El Niño. The middle cell is for December 1997 at the peak of that event. Last, the bottom cell captures the December 1998 peak of the initial phase of the La Niña that followed. There should be no surprise that the temperature anomalies at the equator are positive during the El Niño and negative during the La Niña. The intent of Figure 4-53 is to confirm that those anomalies are strongest at depths far below the sea surface.

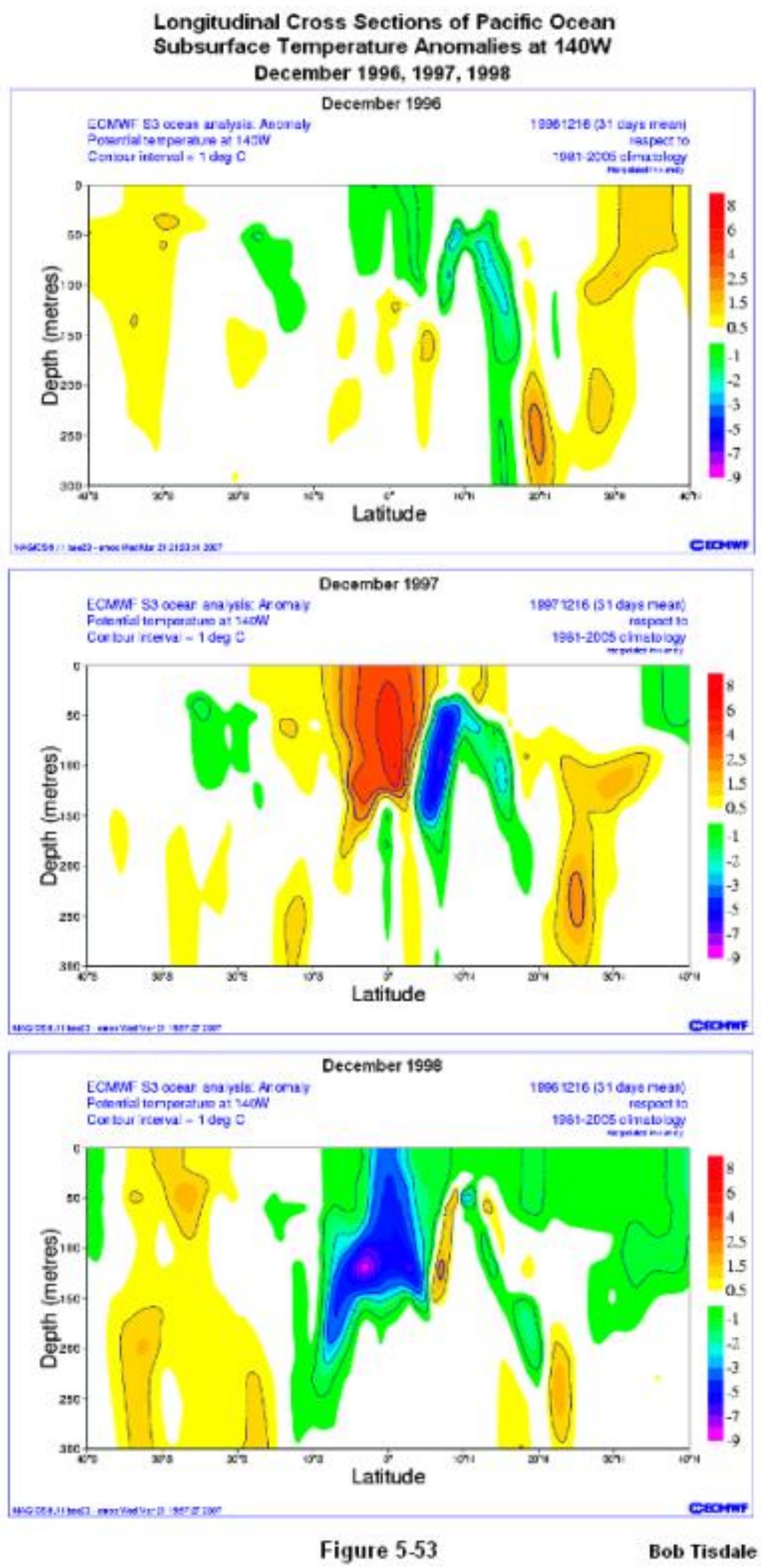


Figure 5-53

RECAP

There is a lot taking place below the surface of the equatorial Pacific during an ENSO event. Kelvin waves carry warm or cool waters eastward. They can travel the width of the Pacific at the equator, from New Guinea to South America, in about 2 months. Based on the variations in the isotherm at 20 deg C, the eastward propagating Kelvin waves can extend to depths of about 150 meters. The warm Kelvin waves are often described as downwelling, and cool Kelvin waves are, conversely, called upwelling. The terms upwelling and downwelling are based on how they impact the level of cool waters in the eastern equatorial Pacific. That is, downwelling (warm) Kelvin waves push down at the cooler waters, and upwelling (cool) Kelvin waves draw the cooler waters up toward the surface.

This discussion provides a good lead in to the delayed oscillator mechanism.

4.9 An Introduction to the Delayed Oscillator Mechanism

In Chapter 4.7, we discussed how an El Niño typically peaks in December and showed that the December maximum in sea surface temperature anomalies of the NINO3.4 region (our ENSO index) during an El Niño aligned with the seasonal cycles in the sea surface temperatures (not anomalies) of the western equatorial Pacific. We discussed how the NINO3.4 sea surface temperatures were temporarily taking on the annual cycle of the sea surface temperatures of the western equatorial Pacific because the trade winds had reversed in the western tropical Pacific and were now feeding warm water from the west Pacific Warm Pool toward the east.

In addition, in Chapter 3.6, we discussed two of the reasons an El Niño event would eventually end: the tropical Pacific is releasing heat and there's only so much warm water available from the Pacific Warm Pool for an El Niño. Then again, we also mentioned that the tropical Pacific would want to stay in El Niño phase due to the positive feedback from sea surface temperatures and the westerlies in the western tropical Pacific. In other words, there has to be something to interrupt the positive feedback, which then allows the El Niño to return to ENSO-neutral or La Niña phase.

The mechanism Mother Nature devised to end an ENSO event is made up of a pair of cool (upwelling) Rossby waves (travelling to the west) that are formed by the warm (downwelling) Kelvin wave as it carries the warm water to the east at the start of an El Niño. The components of the delayed-oscillator theory are shown in the three annotated illustrations of Figure 4-54. The presentation is very simple, with hope of presenting the very basic parts of the delayed-oscillator theory.

At the top of Figure 4-54, cell A shows an eastward-moving warm (downwelling) Kelvin wave on the equator. Kelvin waves, as discussed earlier, typically travel at about 2.8 meters per second (about 6.3 miles per hour) and can trek between New Guinea and South America along the equator in a little more than two months. Also shown are two slower-moving, cool (upwelling) Kelvin waves traveling to the west off the equator. Those Rossby waves don't speed across the Pacific as fast as a Kelvin wave. They take a leisurely stroll toward the west at about one-third as fast as the Kelvin waves, so it takes them about 6-7 months to cross the Pacific at about 5N-10N and 10S-5S. The Rossby waves are created by the mass deficit left by the eastbound Kelvin wave. They then plod westward.

At the same time, the warm (downwelling) Kelvin wave zips eastward and the El Niño event starts. The trade winds reverse in the western Pacific, becoming westerlies, and drive more warm water to the east. The westerlies and the sea surface temperature gradient, now cooler in the west than in the central

Pacific, reinforce one another, supplying positive feedback. Therefore, the El Niño conditions need something to interrupt the feedback and allow the tropical Pacific to return to ENSO-normal conditions…or to swing past and become a La Niña.

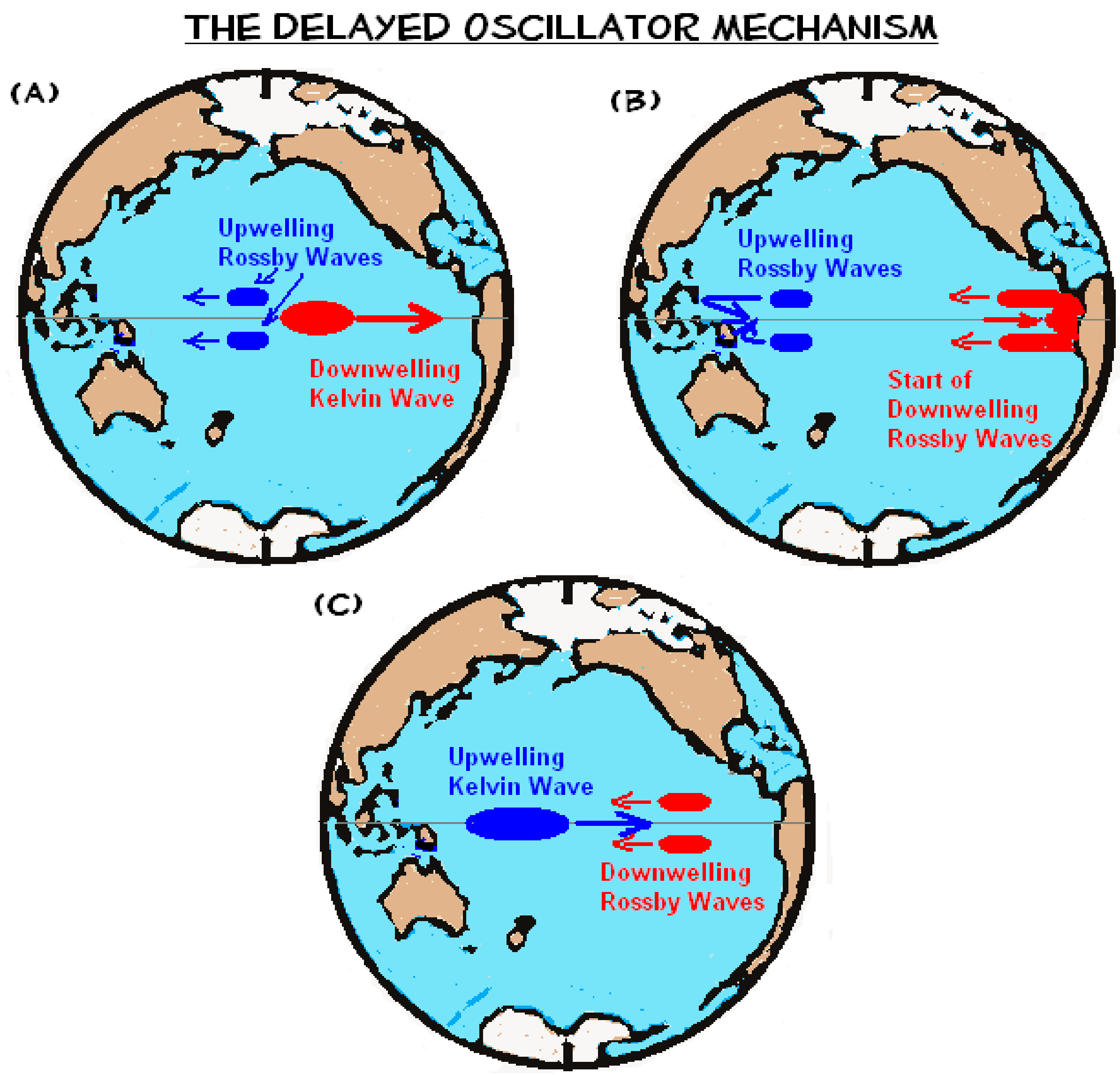


Figure 4-54 Bob Tisdale

By cell B, a couple of months have passed and the warm (downwelling) Kelvin wave has reflected off the coastline of the Americas and is becoming two slow-moving, warm (downwelling) Rossby waves. The westbound cool (upwelling) Rossby waves are approaching the coastlines of Indonesia, New Guinea and Australia. They will be reflected, in part, back toward the equator. There they form a cool (upwelling) Kelvin wave that travels east and creates the imbalance necessary to end the El Niño, cell C. At the same time, the two slow-moving, warm (downwelling) Rossby waves are plodding along, traveling to the west.

The **International Research Institute for Climate and Society** (IRI) website has a relatively easy-to-understand, but a much-more-detailed, discussion of the delayed oscillator theory. See their **Advanced ENSO Theory: The Delayed Oscillator** webpage. They present the warm (downwelling) Kelvin wave reflecting off the coasts of the Americas and creating two warm (downwelling) Rossby waves. See their Figures 6 and 7 on their **Evolution of Kelvin and Rossby Waves** webpage. Showing the Rossby waves in both hemispheres is typical of other presentations of the delayed oscillator mechanism.

Let's refer again to **Animation 3-1** and to the screen caps of the Rossby wave after the 1997/98 El Niño taken from the JPL sea level animation, shown again as Figure 4-55. There's only one Rossby wave visible, and it's in the northern hemisphere.

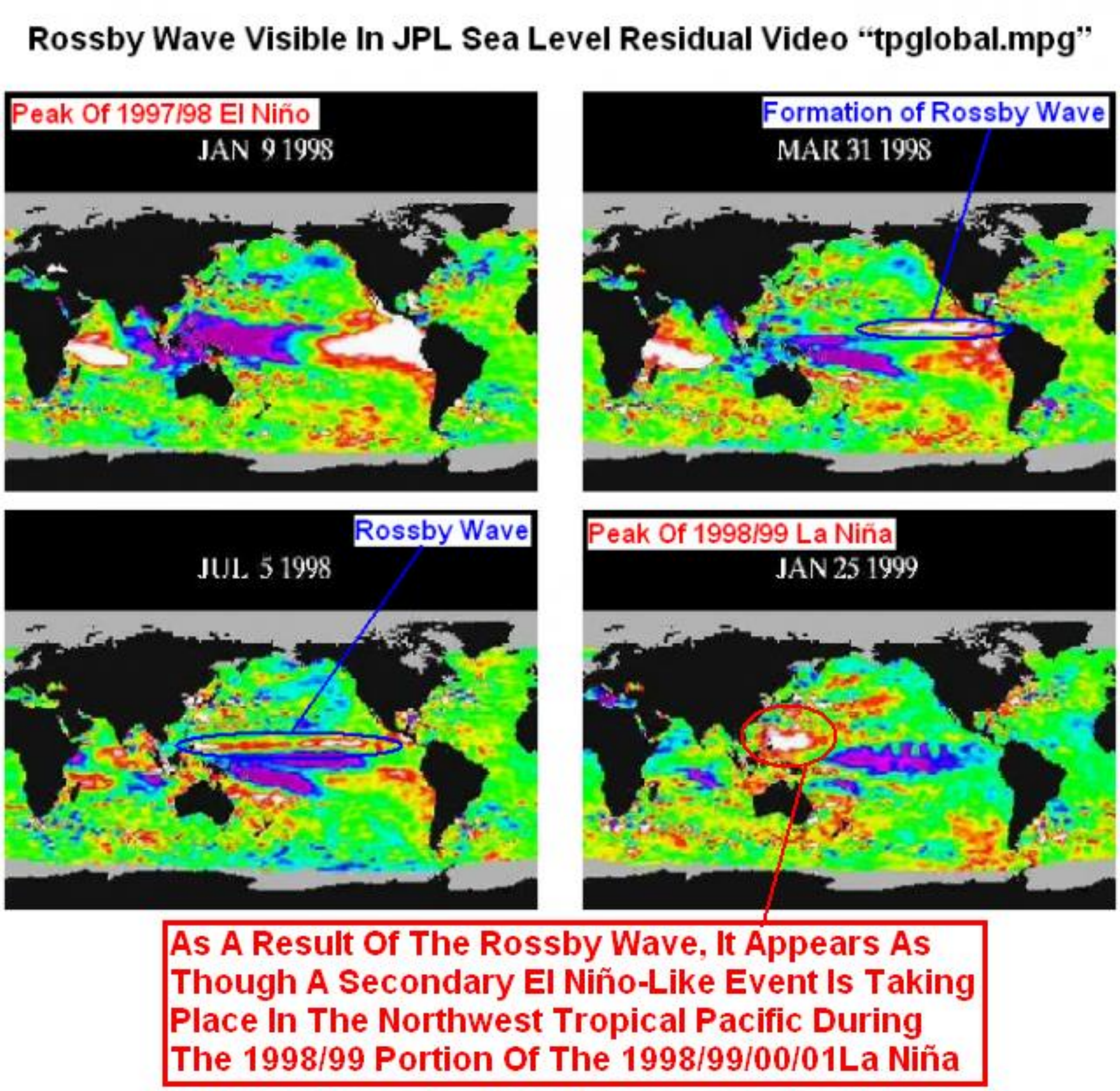


Figure 4-55

Those images might make one believe that two Rossby waves don't form after a Kelvin wave reflects off the coasts of the Americas. However, the 1997/98 El Niño is the exception. It was so large it changed the rules, or possibly, a Rossby wave existed in the Southern Hemisphere, but it's hidden by the other aftereffects of that El Niño. Let's consider the 1997/98 El Niño event again. It was strongest in the far eastern tropical Pacific. The coastline of South America near the equator runs somewhat diagonally from the southwest to the northeast as you head north. It seems only logical that most of the warm water that traveled to the coast as part of that El Niño would be deflected northward. Nevertheless, the 1997/98 El Niño still should have created a downwelling (warm) Rossby wave in the Southern Hemisphere because some of the warm water was deflected there.

To illustrate the Rossby waves after each ENSO event since 1992, let's switch to sea level anomaly maps from the **AVISO** website. They are another supplier of sea level anomaly data. The maps presented in Figures 4-56 through 4-69 are from their **AVISO Altimetry – ENSO Maps webpage**. They present sea level anomaly data with the annual cycle removed.

The sea level anomaly maps in Figures 4-56 through 4-61 capture the apparent effects on sea level anomalies of the downwelling (warm) Rossby waves that formed after the El Niño events of 1994/95, 1997/98, 2002/03, 2004/05, 2006/07 and 2009/10. You'll note that March, April and May maps were used. I selected the month during the El Niño decay phase that provided what I felt was the best depiction of the Rossby waves. None were as well-defined as the Rossby wave that formed after the 1997/98 El Niño. As you'll note, with the exception of the 1997/98 El Niño, all of the El Niño events spawned warm (downwelling) Rossby waves in both hemispheres at approximately 10-5S and 5-10N.

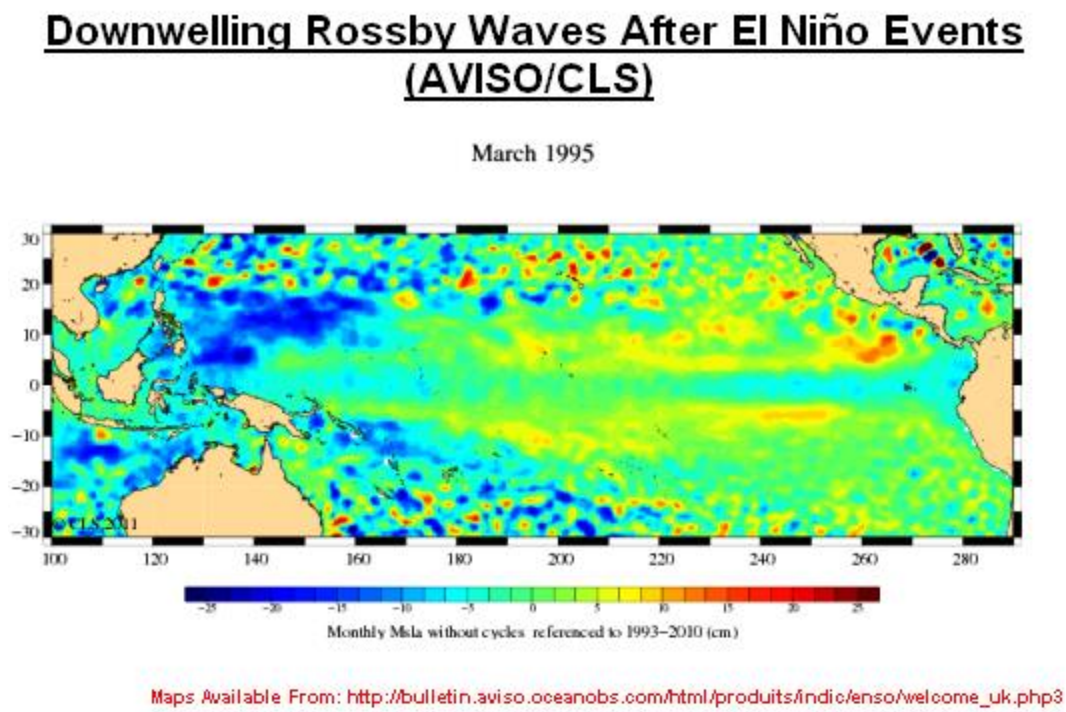
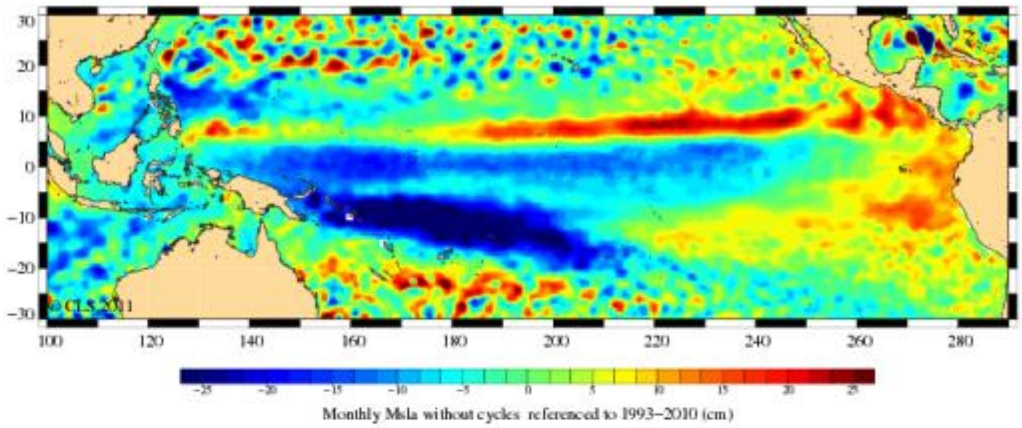


Figure 4-56

HHH

Downwelling Rossby Waves After El Niño Events (AVISO/CLS)

May 1998



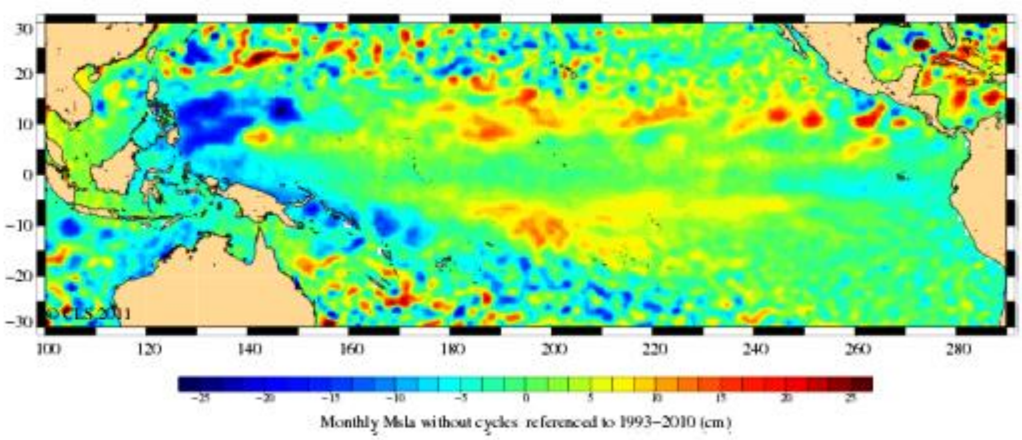
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-57 Bob Tisdale

HHH

Downwelling Rossby Waves After El Niño Events (AVISO/CLS)

March 2003



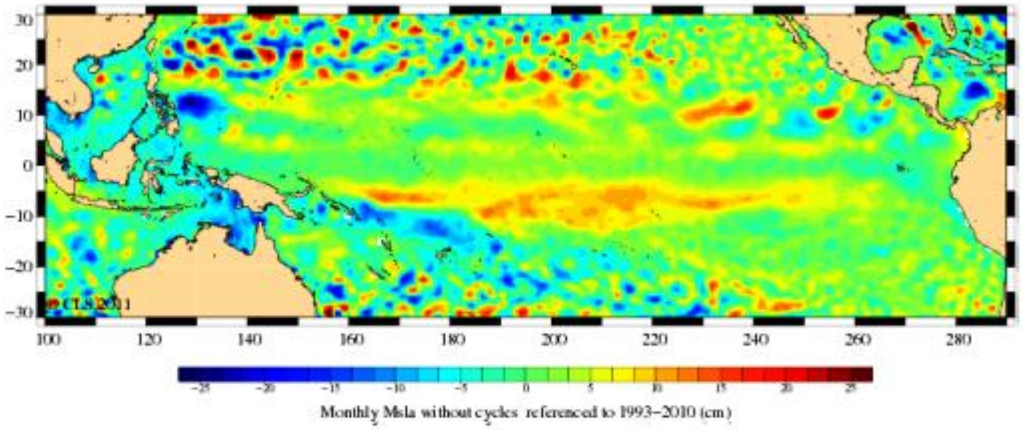
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-58 Bob Tisdale

HHH

Downwelling Rossby Waves After El Niño Events (AVISO/CLS)

May 2005



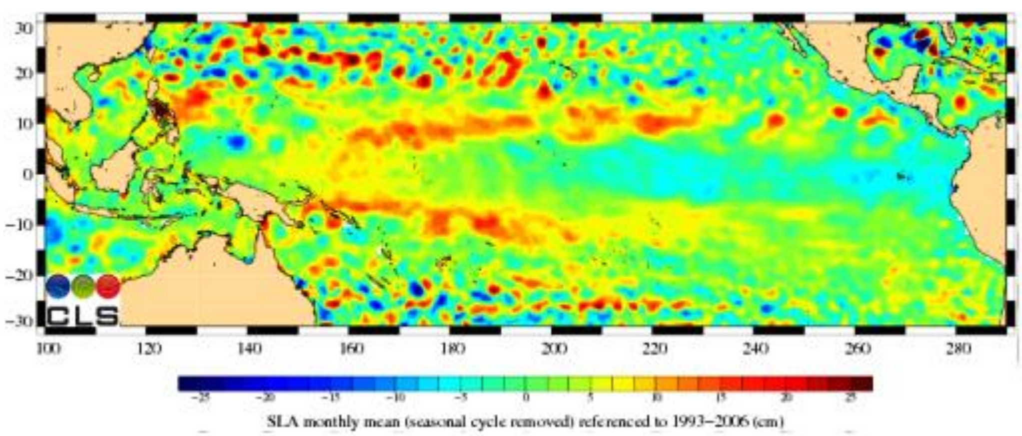
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-59 Bob Tisdale

HHH

Downwelling Rossby Waves After El Niño Events (AVISO/CLS)

April 2007

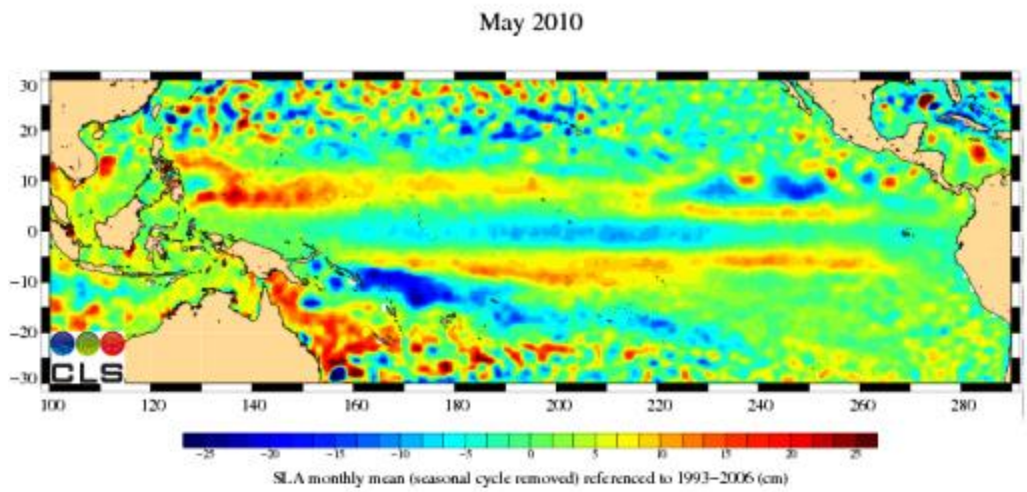


Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-60 Bob Tisdale

HHH

Downwelling Rossby Waves After El Niño Events (AVISO/CLS)



Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

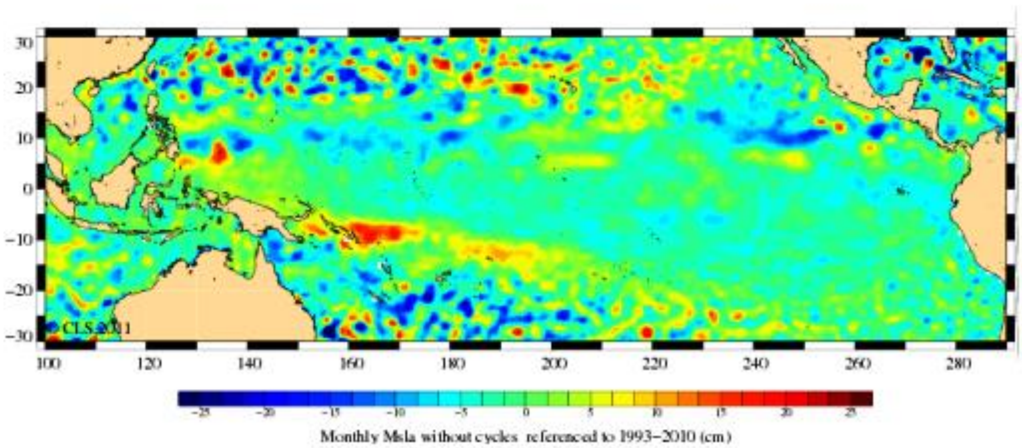
Figure 4-61 **Bob Tisdale**

Notice also how in May 2005 (Figure 4-59) the Rossby wave in the southern hemisphere very clearly was much stronger than the Rossby wave in the Northern Hemisphere. I don't have an answer for you as to why that happens.

Yes, upwelling (cool) Rossby waves are visible after La Niña events. They are not as clear as their counterparts that form after El Niño events, but that should be expected because El Niño events have been much stronger than La Niña events during the satellite era of sea level anomaly data. In fact, it's very difficult to find the upwelling (cool) Rossby waves after the 1994/95 La Niña shown in Figure 4-62. In addition to the aftereffects of that La Niña, Figures 4-63 through 4-69 capture the upwelling Rossby waves after the La Niña events of 1998/99, 1999/00, 2000/01, 2005/06, 2007/08, 2010/11 and 2011/12.

Upwelling Rossby Waves After La Niña Events (AVISO/CLS)

April 1996



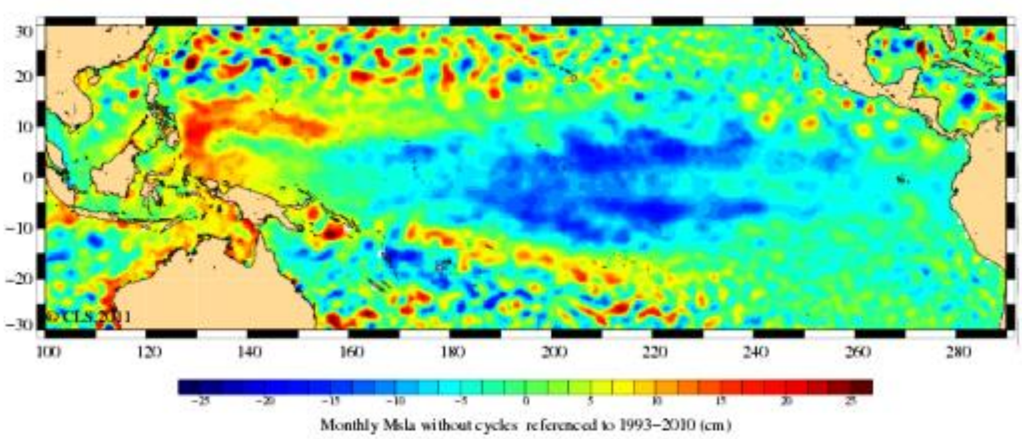
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-62 Bob Tisdale

HHH

Upwelling Rossby Waves After La Niña Events (AVISO/CLS)

April 1999



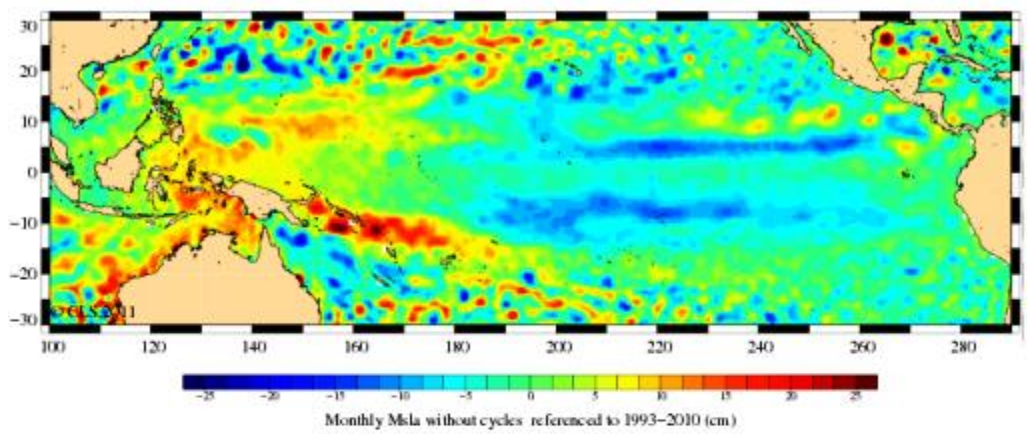
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-63 Bob Tisdale

HHH

Upwelling Rossby Waves After La Niña Events (AVISO/CLS)

May 2000



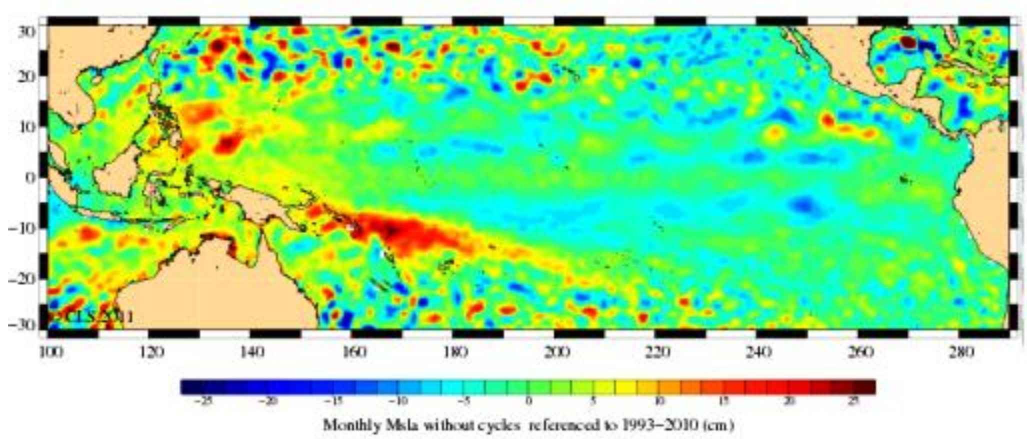
Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-64 Bob Tisdale

HHH

Upwelling Rossby Waves After La Niña Events (AVISO/CLS)

April 2001



Maps Available From: http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3

Figure 4-65 Bob Tisdale

HHH

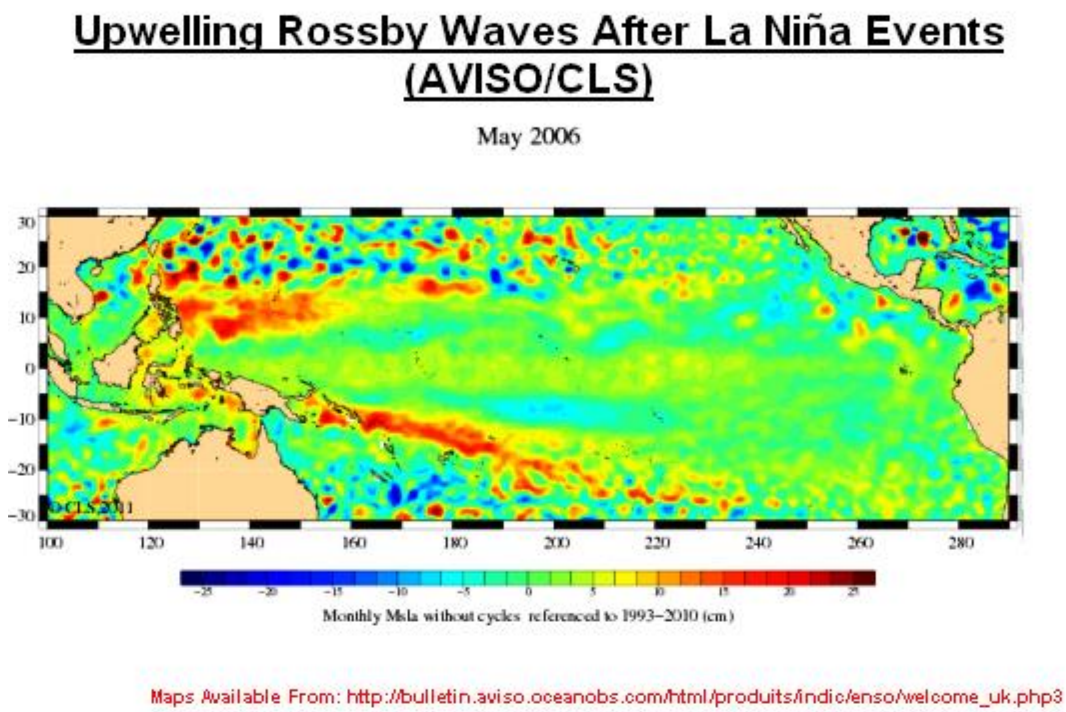


Figure 4-66 Bob Tisdale

HHH

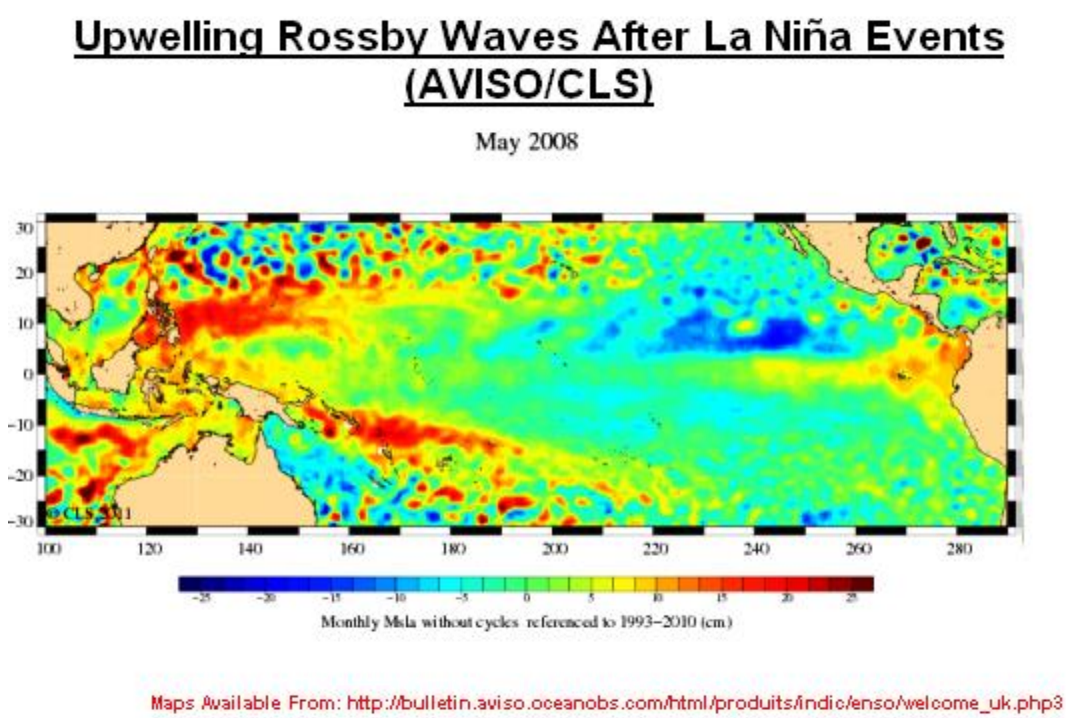


Figure 4-67 Bob Tisdale

HHH

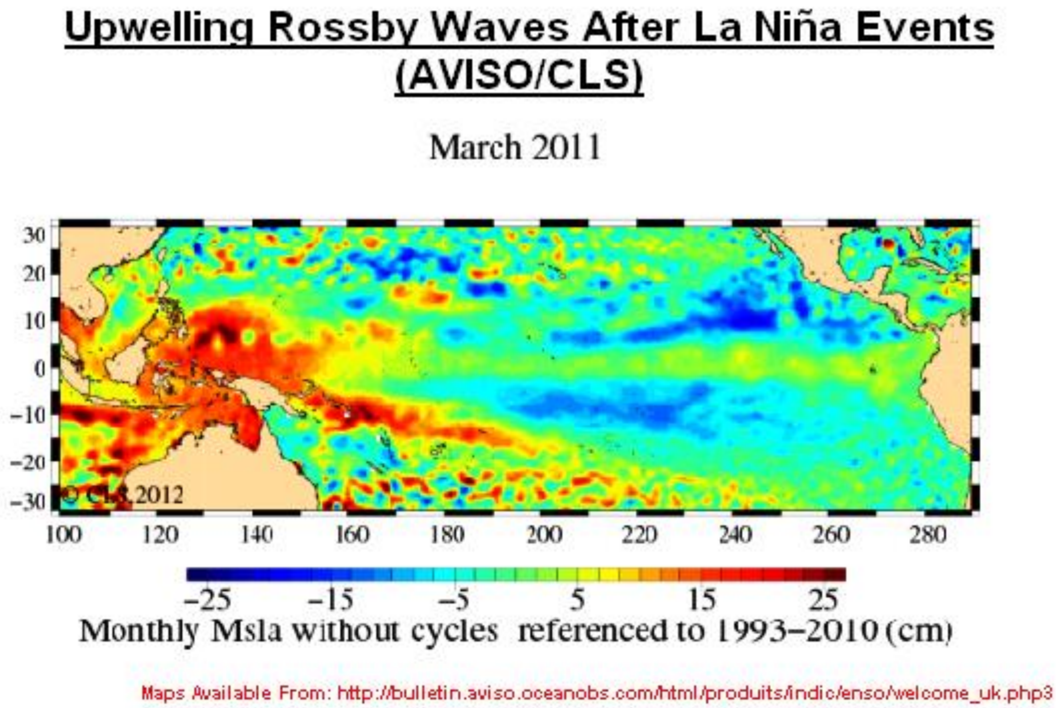


Figure 4-68 Bob Tisdale

HHH

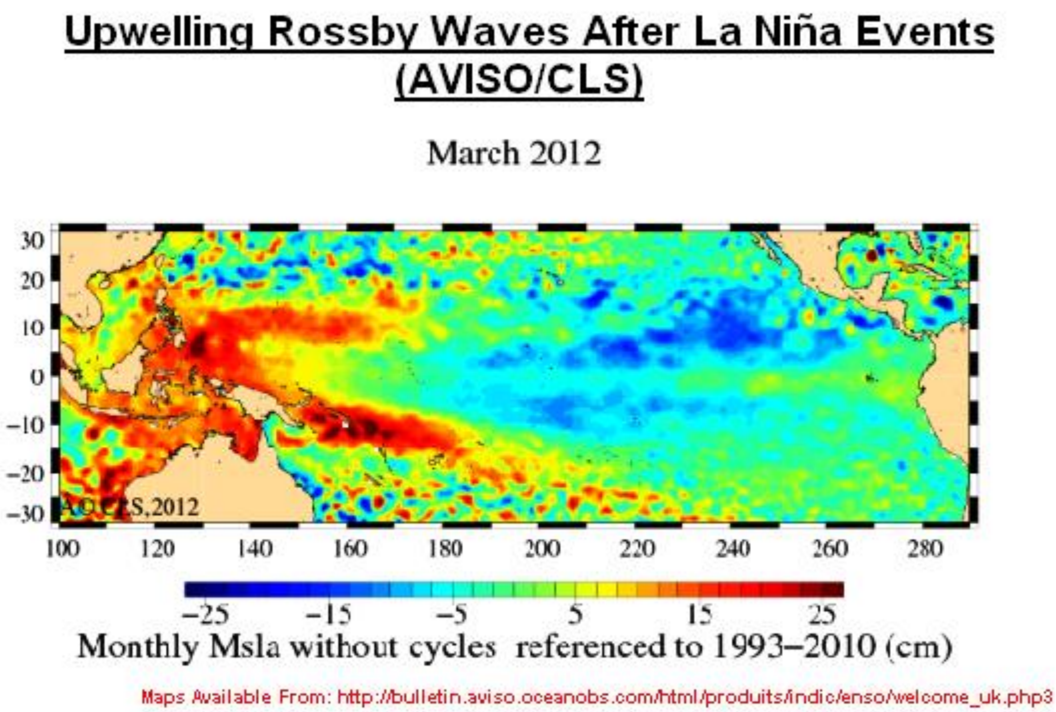


Figure 4-69 Bob Tisdale

For those who like animations, I've linked gif animations of the AVISO/CLS monthly tropical Pacific sea level anomaly maps, so that you can watch the interplay between Kelvin and Rossby waves. Unfortunately, AVISO/CLS changed their maps slightly after November 2010, so I've had to divide the animations into two periods. **Animation 4-4** shows the maps from November 1992 to November 2010, and **Animation 4-5** presents the monthly sea level anomaly maps from December 2010 through May 2012.

One thing that hasn't been mentioned yet: These oceanic Rossby waves that return warm or cool water from the eastern tropical Pacific are taking place primarily below the surface. This is why they're being presented with sea level maps. A couple of years ago I prepared an animation that placed the AVISO/CLS sea level anomaly maps side-by-side with sea surface temperature anomaly maps that are also available from that web page. I've presented it here as **Animation 4-6**. I have found little evidence of those Rossby waves in the sea surface temperature data, but they are easily visible in the sea level anomaly maps.

You should come to at least one conclusion from this chapter: the amount of water returned to the western Pacific by the Rossby wave after the 1997/98 El Niño was well above the volume returned by any other Rossby wave or pair of Rossby waves before or after it. The 1997/98 El Niño was monumental in its size and its aftereffects.

RECAP

The trade winds (or westerlies during an El Niño) and the gradient in sea surface temperatures between the eastern and western tropical Pacific reinforce one another. This positive feedback would tend to keep the tropical Pacific in whatever ENSO phase it happened to be in. Therefore, there has to be a mechanism that interrupts the positive feedback. That mechanism is described by the delayed oscillator theory.

An ENSO event starts with a Kelvin wave crossing the equatorial Pacific from west to east along the equator. Rossby waves of the opposite sign are created by the Kelvin wave and they travel from east to west. After reflecting off the western boundaries of the western Pacific, the Rossby waves form into a Kelvin wave, still the opposite sign from the initial Kelvin wave. The new opposing Kelvin wave travels east and interrupts the positive feedback created by original ENSO event. This allows the tropical Pacific to enter into a new phase.

The delayed-oscillator theory implies that ENSO is a cycle, where the preceding event initiates the next phase and where the event itself creates the mechanism that causes the event to end. The delayed oscillator theory works in many cases, but not in all. There can be back-to-back El Niño events, back-to-back La Niña events, multiyear El Niño and multiyear La Niña events. All of those indicate that ENSO is a series of independent events. This is discussed further in chapter 4.17 **ENSO – A Cycle or Series of Events?**

A CLOSING NOTE TO THIS CHAPTER

In addition to the delayed oscillator theory, there are a number of other theories about the formation and evolution of ENSO. These include the linear stochastic theory, the recharge/discharge theory [but they are not using discharge and recharge as I have in this book], the advective-reflective oscillator theory and the unified oscillator theory. These other theories will not be presented in this book, but there are numerous studies available online for those interested in carrying their research farther.

4.10 ENSO Versus the Pacific Decadal Oscillation (PDO)

If you've been using the internet to study climate change and global warming, it's likely you've run across a comment that's something to the effect of "when Pacific Decadal Oscillation data is positive, global surface temperatures warm, and when Pacific Decadal Oscillation data is negative, global surface temperatures cool." See Figure 4-70. They then assume the Pacific Decadal Oscillation is driving global surface temperatures. Bad assumption—for a couple of reasons. First, there's no mechanism through which the Pacific Decadal Oscillation could drive global surface temperatures. The second reason reinforces the first. That second reason is, the Pacific Decadal Oscillation data is inversely related to the sea surface temperature of the North Pacific over decadal time periods. In other words, when the Pacific Decadal Oscillation data is rising, the sea surface temperatures of the North Pacific (where the Pacific Decadal Oscillation data are derived) are cooling, and vice versa.

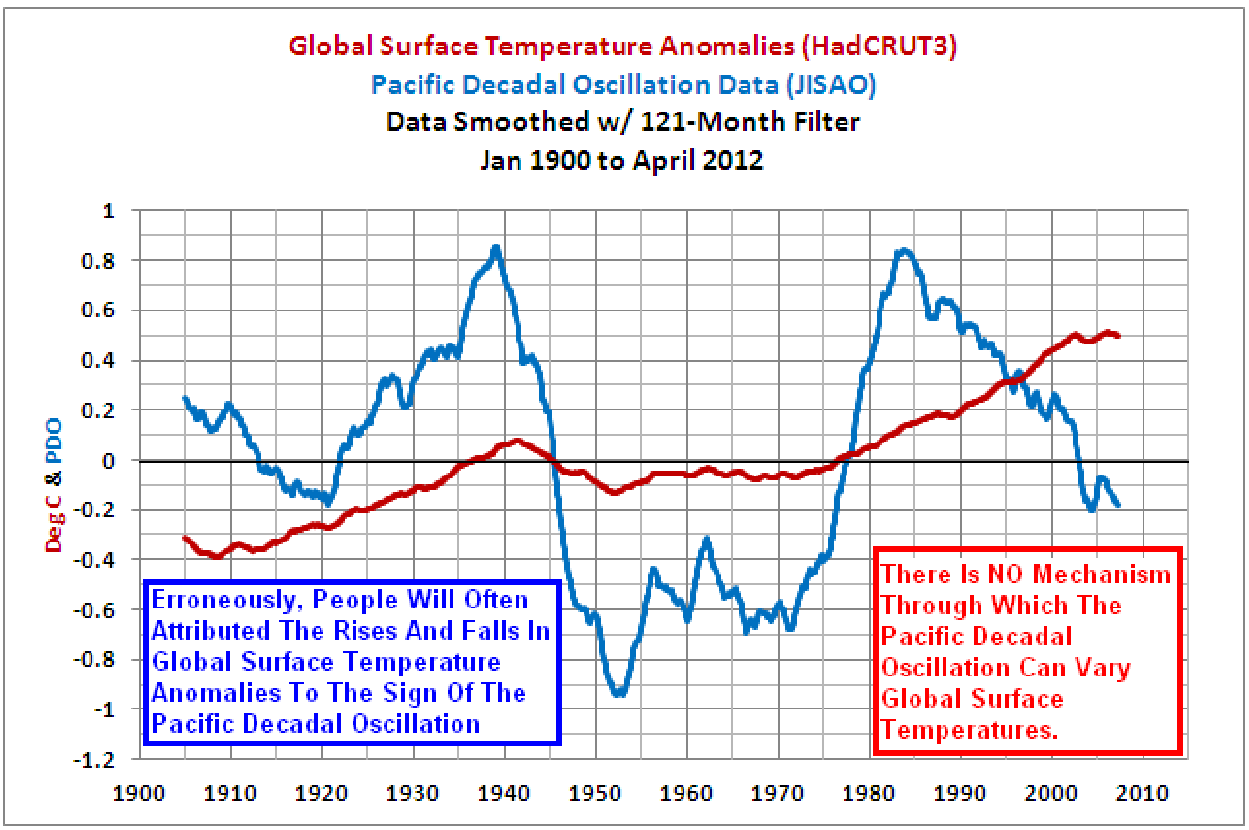


Figure 4-70 Bob Tisdale

Additionally, you may have seen someone else noting something like, "when the Pacific Decadal Oscillation data is positive, there tends to be more and stronger El Niño events, and when the Pacific Decadal Oscillation data is negative, the La Niña events tend to be stronger and occur more often." Refer to Figure 4-71. They then assume the Pacific Decadal Oscillation drives ENSO. That's another bad assumption. The assumption that the Pacific Decadal Oscillation drives ENSO has cause and effect backwards.

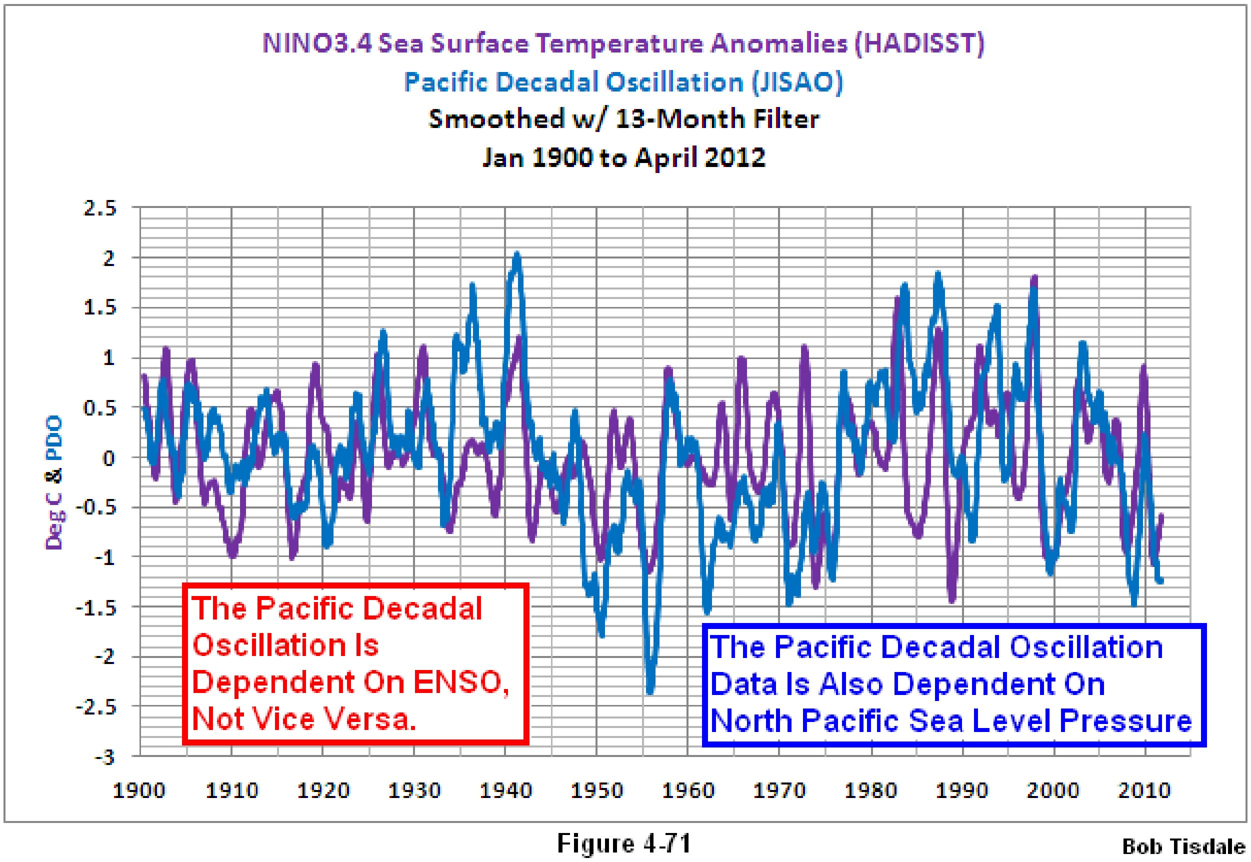


Figure 4-71

As you'll note above, the Pacific Decadal Oscillation data and the NINO3.4 sea surface temperature anomalies (our ENSO index, but this long-term version is based on HADISST data) have similarly timed yearly variations. Then again, the Pacific Decadal Oscillation data also has some additional long-term variability. The additional variations in the Pacific Decadal Oscillation data are caused by changes in sea level pressure, which also impacts that dataset. Refer to the blog post **Is The Difference Between NINO3.4 SST Anomalies And The PDO A Function Of Sea Level Pressure?** Refer also to the discussion of Figure 3 in Di Lorenzo and Schneider **An overview of Pacific Climate Variability**. They also present another mode of variability in the North Pacific called the North Pacific Gyre Oscillation and its relationship to Central Pacific El Niño events. The North Pacific Gyre Oscillation (NPGO) is the second dominant mode of sea surface height variations, but it's beyond this discussion.

Let's take a look at what the Pacific Decadal Oscillation data does and does not represent. I'm going to borrow some illustrations from my blog posts on the Pacific Decadal Oscillation. I'll even borrow some of the text.

WHAT THE JISAO PACIFIC DECADAL OSCILLATION WEBPAGE SAYS

Someone new to discussions of climate and weather who is looking for information about the Pacific Decadal Oscillation would find a link the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) **Pacific Decadal Oscillation webpage**. (JISAO "is a Cooperative Institute between the **National Oceanic and Atmospheric Administration** and the **University of Washington**…") The JISAO Pacific Decadal Oscillation webpage introduces the Pacific Decadal Oscillation as:

> *The 'Pacific Decadal Oscillation' (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time.*

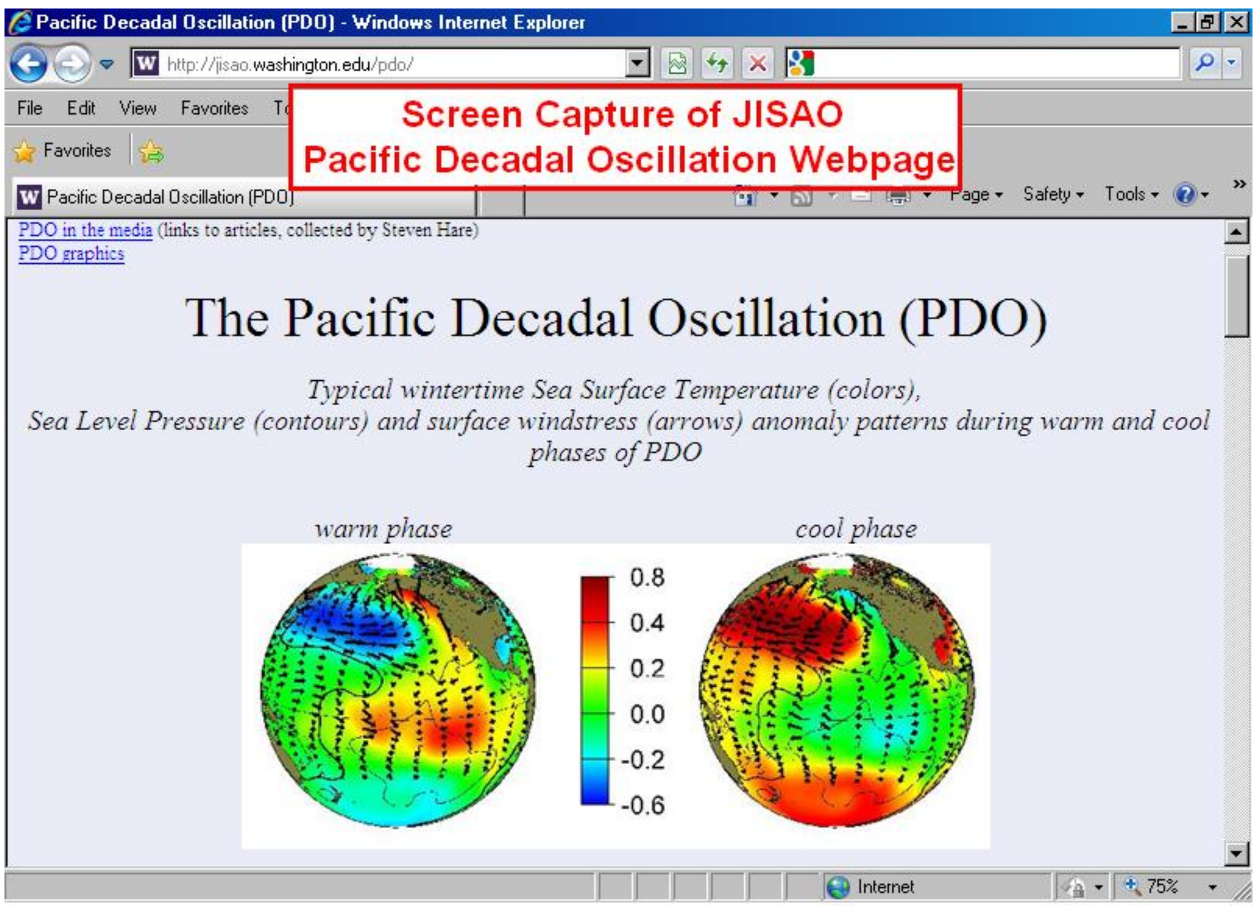


Figure 4-72

Bob Tisdale

Figure 4-72 is a screen capture of the first illustration on the JISAO Pacific Decadal Oscillation webpage. It is described as:

> *Typical wintertime Sea Surface Temperature (colors), Sea Level Pressure (contours) and surface windstress (arrows) anomaly patterns during warm and cool phases of Pacific Decadal Oscillation.*

The Sea Level Pressure and windstress representations make the maps busy, but they provide a lot of information.

If you were to follow the **PDO Index Monthly Values** link at the top of the JISAO Pacific Decadal Oscillation webpage, you'd discover the following description of how the Pacific Decadal Oscillation is calculated:

> *Updated standardized values for the Pacific Decadal Oscillation index, derived as the leading PC [Principle Component] of monthly SST anomalies in the North Pacific Ocean, poleward of 20N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data.*

In short, the Pacific Decadal Oscillation data is a statistically created dataset. The question that comes to mind: does the Pacific Decadal Oscillation bear any relationship to the actual sea surface temperature anomalies of the North Pacific?

LET'S LOOK CLOSER AT THOSE DESCRIPTIONS

In the first quote above, the "long-lived El Niño-like pattern of Pacific climate variability" does NOT mean that the North Pacific (north of 20N) has a separate El Niño-like event.

It does mean a typical El Niño event creates a SPATIAL PATTERN in the North Pacific where it is warmer in the east than it is in the central and western portions, and a typical La Niña event will create the opposite pattern, cooler in the east than it is toward the center and west of the North Pacific. These can be seen in the two maps of the North Pacific sea surface temperature anomalies in Figure 4-73. The top map presents the average sea surface temperature anomalies during the 11-month period of May 1997 to March 1998. It captures the development and decay of the 1997/98 El Niño event. Again, during an El Niño, the PATTERN in the North Pacific typically has warmer sea surface temperature anomalies in the east and cooler sea surface temperature anomalies in the central and western portions. (There are a number of interacting ocean-atmosphere processes that cause the pattern, and we'll discuss those later.) The opposite holds true during the typical La Niña event. This can be seen in the lower map of sea surface temperature anomalies. That map presents the average sea surface temperature anomalies during the 11-month period from March 1998 to January 1999, and it captures the development stage of the 1998/99/00/01 La Niña.

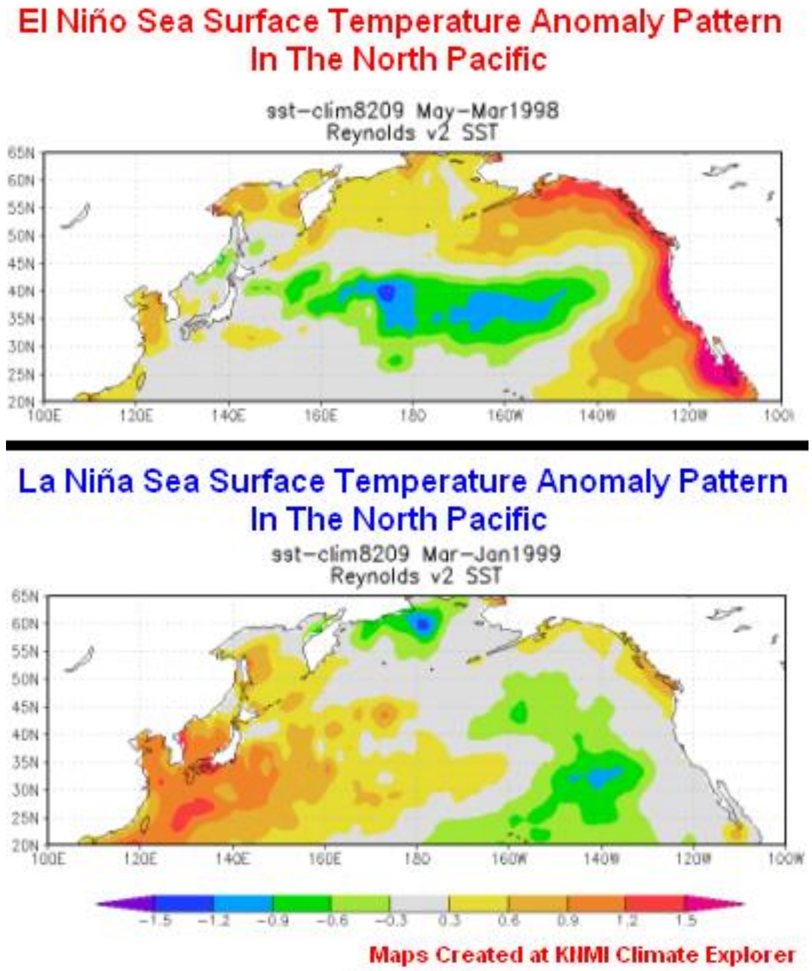


Figure 4-73 Bob Tisdale

As you may have noticed, the maps in Figure 4-73 include only the North Pacific north of 20N. The definition of the Pacific Decadal Oscillation states that the Pacific Decadal Oscillation is “derived as the leading PC [Principle Component] of monthly SST anomalies in the North Pacific Ocean, poleward of 20N.” Nothing more. Unfortunately, many people see the illustration on the JISAO webpage (Figure 4-72) and wrongly assume the Pacific Decadal Oscillation data is determined from the entire Pacific Ocean.

JISAO is simply illustrating the El Niño-like spatial pattern, and to do that, they need to include the tropical Pacific where ENSO events take place. In Figure 4-73, I’ve marked up the JISAO maps to show where the Pacific Decadal Oscillation data is derived from and where the Pacific Decadal Oscillation takes place.

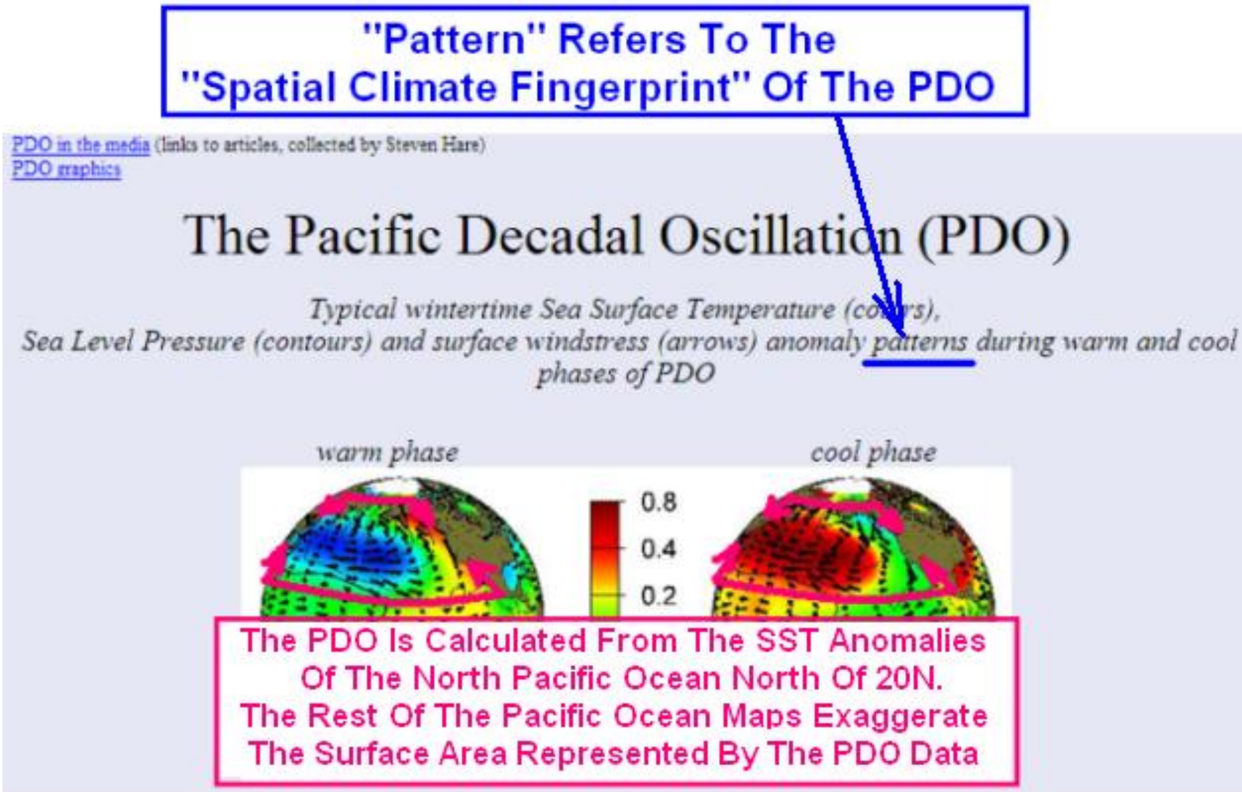


Figure 4-74

Bob Tisdale

Let's look at the JISAO introduction to the Pacific Decadal Oscillation again in a slightly different way. The "long-lived El Niño-like pattern of Pacific climate variability," means that the spatial pattern of sea surface temperature anomalies that is normally associated with El Niño and La Niña events lasts longer than those El Niño and La Niña events. This could mean that another variable or process is creating a similar pattern or causing the ENSO-related pattern to persist. We've already introduced what's causing the difference between the ENSO and Pacific Decadal Oscillation, and it's the sea level pressure of the North Pacific.

Nate Mantua of JISAO provides a slightly different description of the Pacific Decadal Oscillation in his (1999) paper **The Pacific Decadal Oscillation and Climate Forecasting for North America**. It adds an important aspect. He writes:

> *The SST pattern highlights the strong tendency for temperatures in the central North Pacific to be anomalously cool when SSTs along the coast of North America are unusually warm, and vice-versa (Graham 1994, Miller et al 1995, Zhang et al 1997, Mantua et al 1997).*

"Strong tendency" is a great choice of words, because it implies that the Pacific Decadal Oscillation pattern is not the only spatial pattern of sea surface temperature anomalies that appears in the North Pacific, which is very true. Written another way to reinforce the point, the North Pacific sea surface temperature anomalies will most often have that spatial pattern. The Pacific Decadal Oscillation pattern is also said to be the "dominant pattern".

HOW DO RESEARCHERS DETERMINE WHICH PATTERN REPRESENTS THE PACIFIC DECADAL OSCILLATION?

Researchers use a method of statistical analysis called **empirical orthogonal function (EOF) analysis** to determine the pattern that represents the Pacific Decadal Oscillation. Wikipedia describes EOF analysis as:

> *a decomposition of a signal or data set in terms of orthogonal basis functions which are determined from the data. It is the same as performing a principal components analysis on the data, except that the EOF method finds both time series and spatial patterns.*

Further discussions of this are well beyond the scope of this book.

GLOBAL SEA SURFACE TEMPERATURE ANOMALIES ARE REMOVED FROM THE PACIFIC DECADAL OSCILLATION

The JISAO description of the Pacific Decadal Oscillation data also includes the following sentence:

> *The monthly mean global average SST anomalies are removed to separate this pattern of variability from any 'global warming' signal that may be present in the data.*

Let's clarify why and how they do that. The Pacific Decadal Oscillation was first calculated in Zhang et al (1997) **ENSO-like Interdecadal Variability: 1900–93**. In that paper, the Pacific Decadal Oscillation was identified as "NP". Zhang et al explain why they remove the global average sea surface temperature anomalies on page 8, under the heading of "Analysis for the period 1900-93." They write:

> *When Parker and Folland (1991) performed conventional EOF/PC analysis on the global SST field based on the longer period of record 1900–90, their leading mode was dominated by the upward trend in global mean SST prior to the 1940s. The mathematical constraint that subsequent PCs be orthogonal to this 'global warming mode' seems physically unrealistic.*

Based on their findings, and to isolate the pattern of variability from the changes in global sea surface temperature anomalies, Zhang et al subtracted the Global sea surface temperature anomalies from the sea surface temperature anomalies of every grid (5 deg latitude by 5 deg longitude) in the global sea surface temperature dataset. Then they performed the EOF/PC analysis on what was left, what they called the residuals.

As I noted earlier, the Pacific Decadal Oscillation data is a statistically created dataset. Then again, there's one more statistical device yet to be discussed.

PACIFIC DECADAL OSCILLATION INDEX DATA

Figure 4-75 is a time-series graph of the JISOA Pacific Decadal Oscillation Index data. In its "raw" form, it is a noisy dataset.

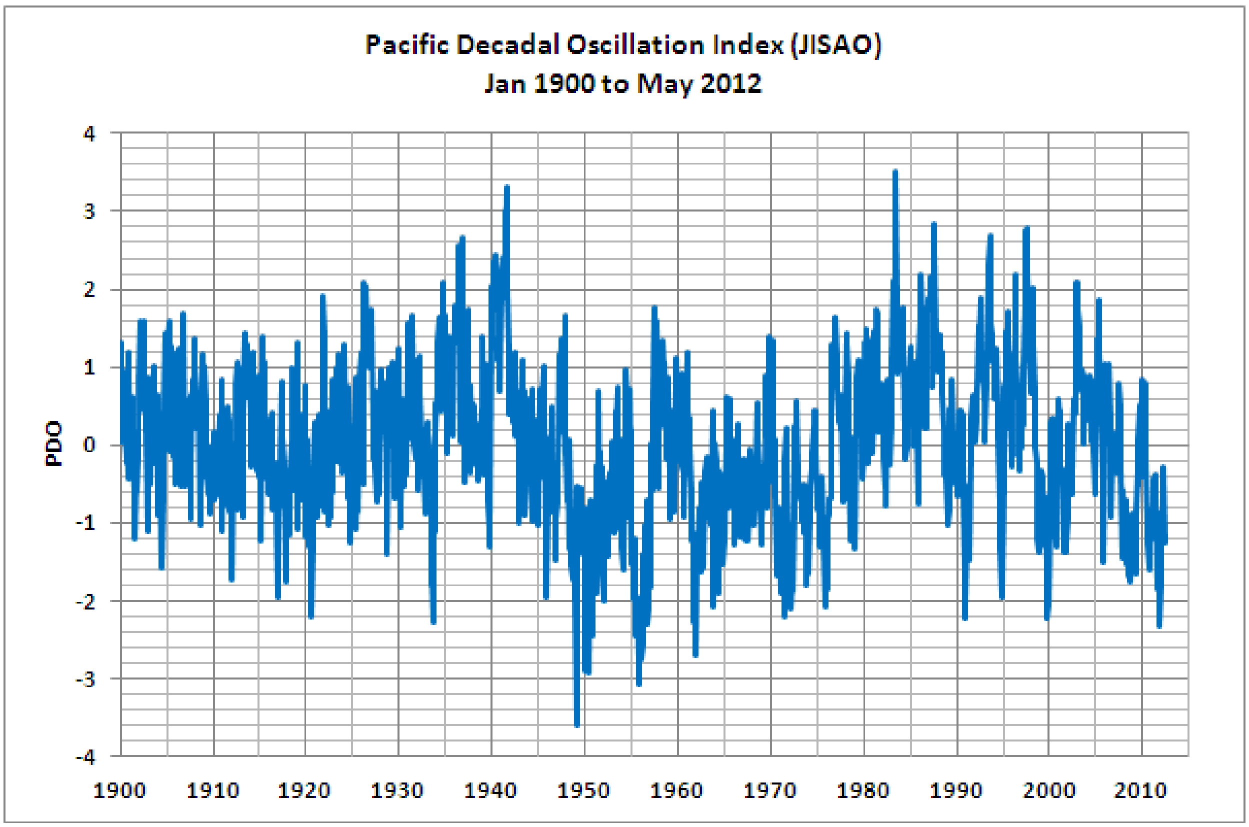


Figure 4-75 Bob Tisdale

In Figure 4-76, the Pacific Decadal Oscillation data has been smoothed with a 13-month running-average filter to reduce the noise.

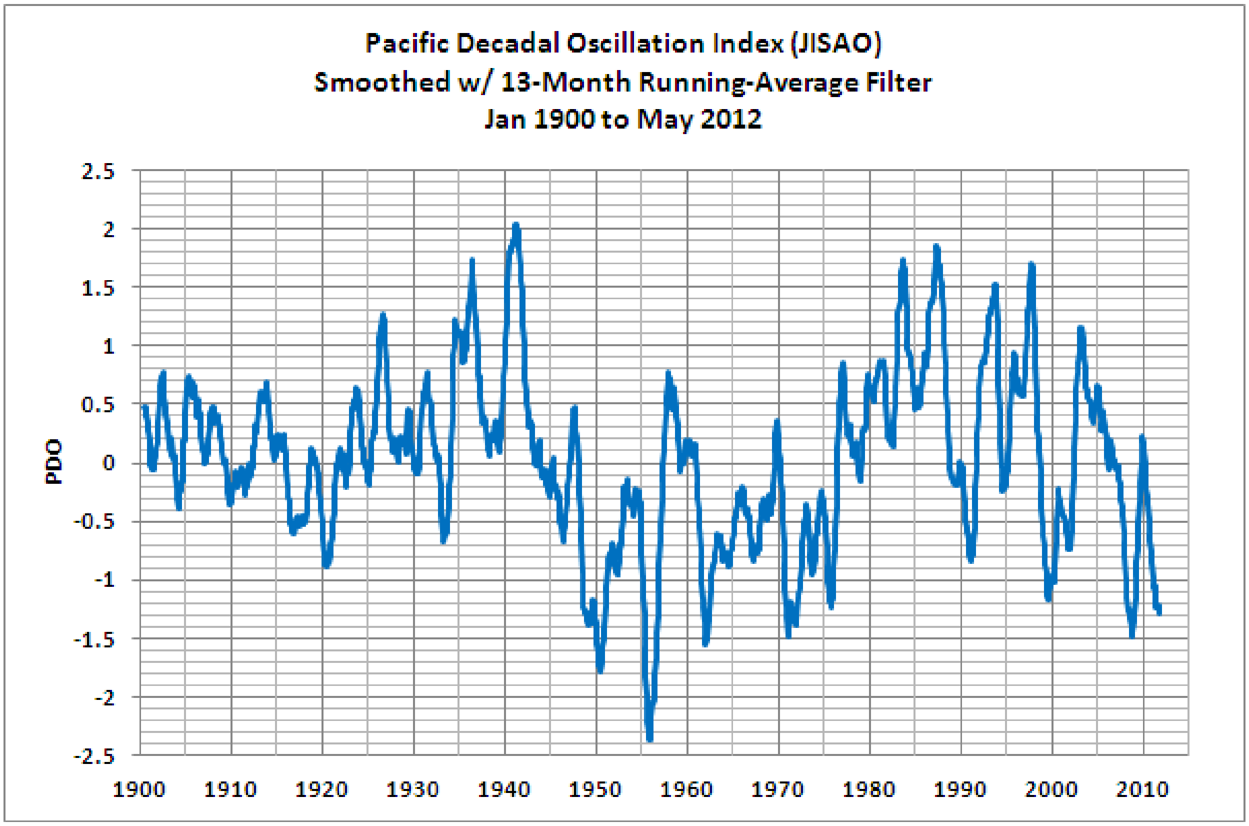


Figure 4-76 Bob Tisdale

As you'll note, there are no units. The vertical axis (y-axis) is not identified as deg C. I've listed the units as PDO. There's good reason for that. The units aren't degrees C. Let's look again at the description of the PDO data (my boldface):

> *Updated **standardized values** for the Pacific Decadal Oscillation index, derived as the leading PC [Principle Component] of monthly SST anomalies in the North Pacific Ocean, poleward of 20N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data.*

Standardization is a statistical tool that is often used when comparing a couple of datasets that have different magnitudes of variability. To standardize or normalize the data, the monthly values are divided by the standard deviation of the data for the term of that dataset. For those interested, there a reasonably easy explanation of standard deviation **here**. EXCEL spreadsheet software will determine the standard deviation of a dataset. It's the EXCEL statistical function identified at "STDEV".

Let's look at an example of the impact of standardization on the PDO. Figure 4-76 compares standardized and not-standardized versions of the 1st Principal Component of detrended North Pacific sea surface temperature anomalies

(20N-65N, 100E-100W) that I created at the KNMI Climate Explorer, using HADSST2 and the current version of the Reynolds data (OI.v2) instead of the obsolete datasets that exist in the JISAO Pacific Decadal Oscillation data. The datasets are similar enough that it makes little difference in this example. As you can see, the monthly variations in the standardized version, which is created similarly to the Pacific Decadal Oscillation data, dwarfs the "raw" data that hasn't been standardized. The standard deviation of the "raw" data is 0.173, and dividing the "raw" data by 0.173 is the same as multiplying it by 5.77. In other words, the standardizing has increased the perceived value of the Pacific Decadal Oscillation index. This is likely the reason why those websites promote the Pacific Decadal Oscillation as a factor that is capable of warming and cooling global surface temperatures. Those promoting it simply don't understand how that dataset is created.

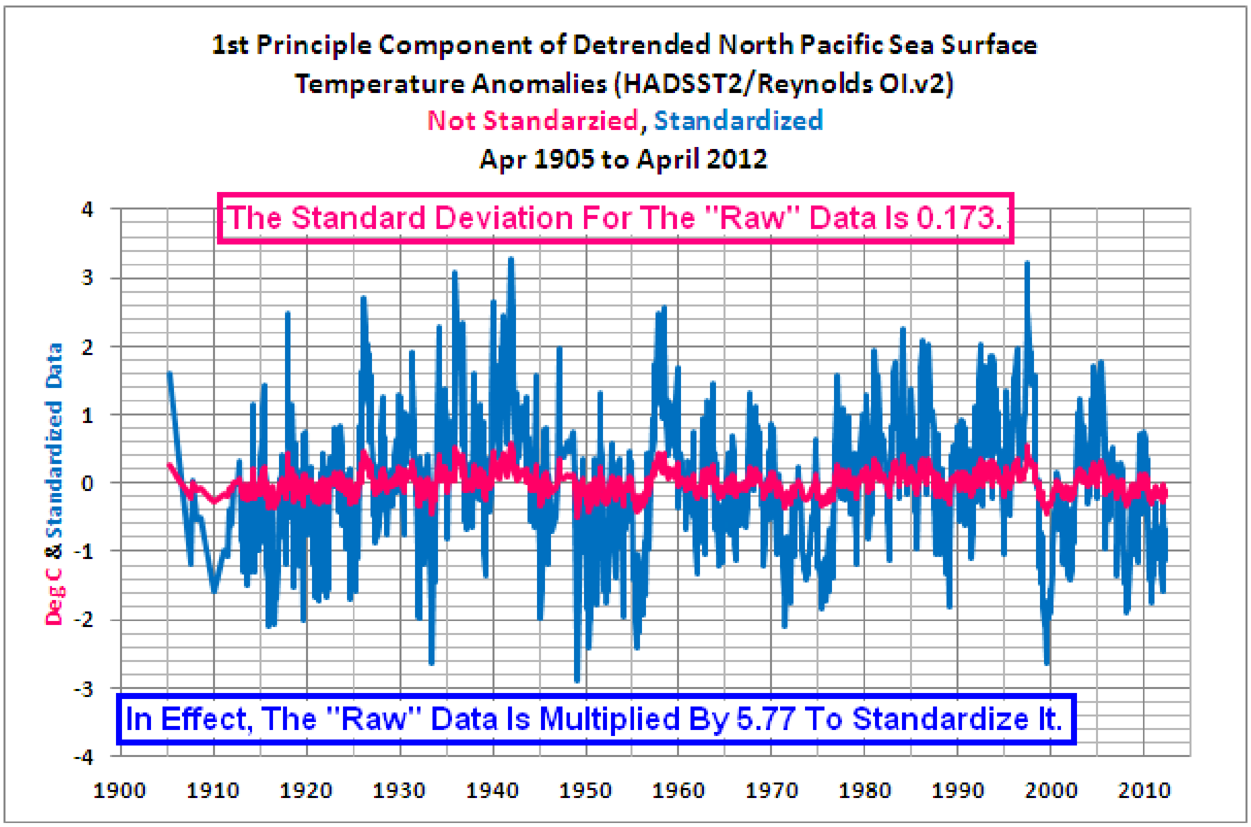


Figure 4-77 Bob Tisdale

Looking back at Figure 4-71, which compared the long-term Pacific Decadal Oscillation data to the NINO3.4 sea surface temperature anomalies, one can understand why some bloggers might believe the Pacific Decadal Oscillation was capable of raising and global surface temperatures, especially if they looked at the maps shown at the JISAO PDO webpage (Figure 4-72) and had the mistaken belief that the Pacific Decadal Oscillation data represented the entire Pacific Ocean. It's understandable. However, the image one needs to keep in their mind is the relative magnitudes of the variations in NINO3.4 sea surface temperature anomalies and the non-standardized data that's created similarly to the Pacific Decadal Oscillation index, Figure 4-78. The variations in the sea surface temperature of the NINO3.4 region dwarf the not-standardized PDO data.

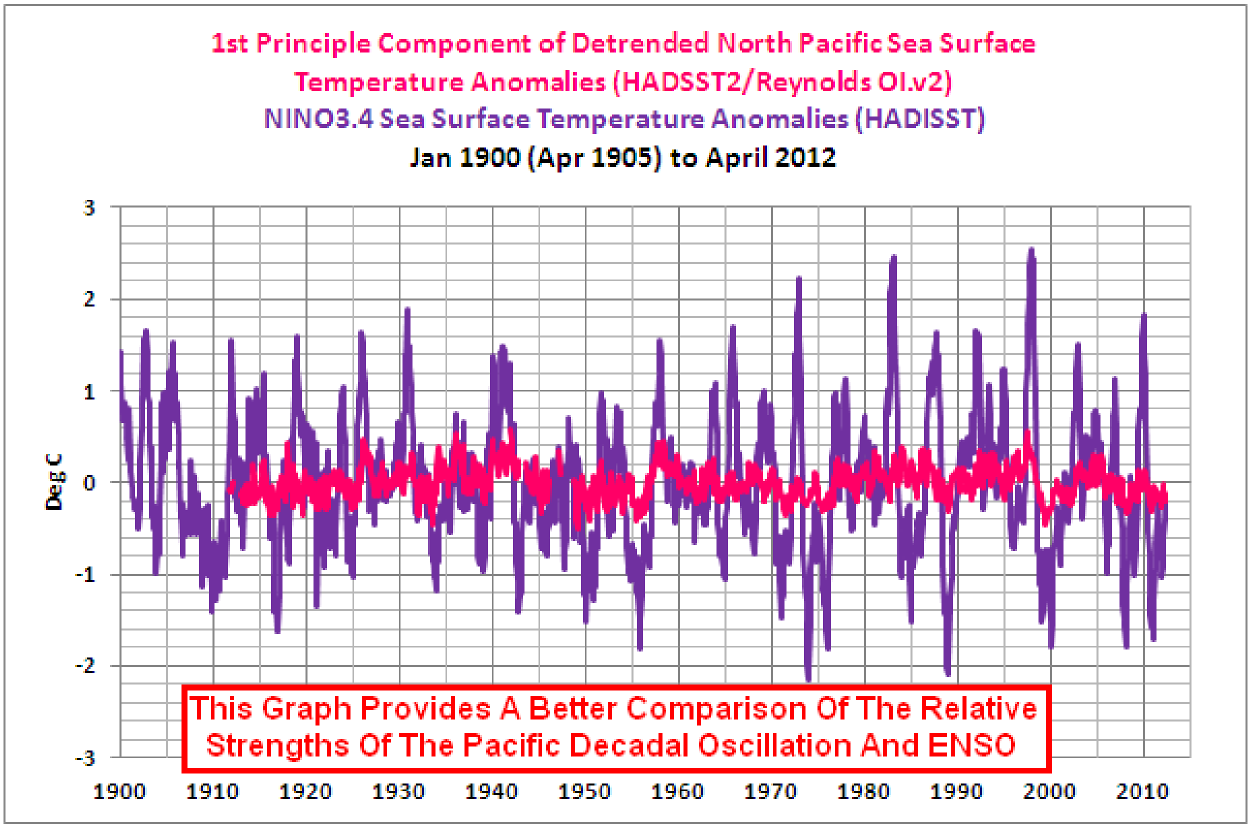


Figure 4-78 Bob Tisdale

Even that's misleading, because the ENSO index in Figure 4-78 represents the sea surface temperature anomalies of a section of the equatorial Pacific but...

THE PACIFIC DECADAL OSCILLATION INDEX DOES NOT REPRESENT THE SEA SURFACE TEMPERATURE ANOMALIES OF THE NORTH PACIFIC

Figure 4-79 illustrates the sea surface temperature anomalies for the area of the North Pacific north of 20N. I've used the same coordinates as the Pacific Decadal Oscillation Index (20N-65N, 100E-100W). In this example, I'm using the Hadley Centre's HADISST data, which has been infilled by the data supplier and is, therefore, easier to use than their HADSST2 data, which has large gaps in the data during the early- and mid-20th Century. As shown, North Pacific sea surface temperature anomalies since 1900 warmed from the early-1900s to the mid-1950s, cooled from the mid-1950s to the late-1970s, and then warmed until about 2004. There is a definitely a multidecadal component to the variations in the North Pacific sea surface temperature anomalies. It also appears they may have taken another downturn and have been cooling since 2004.

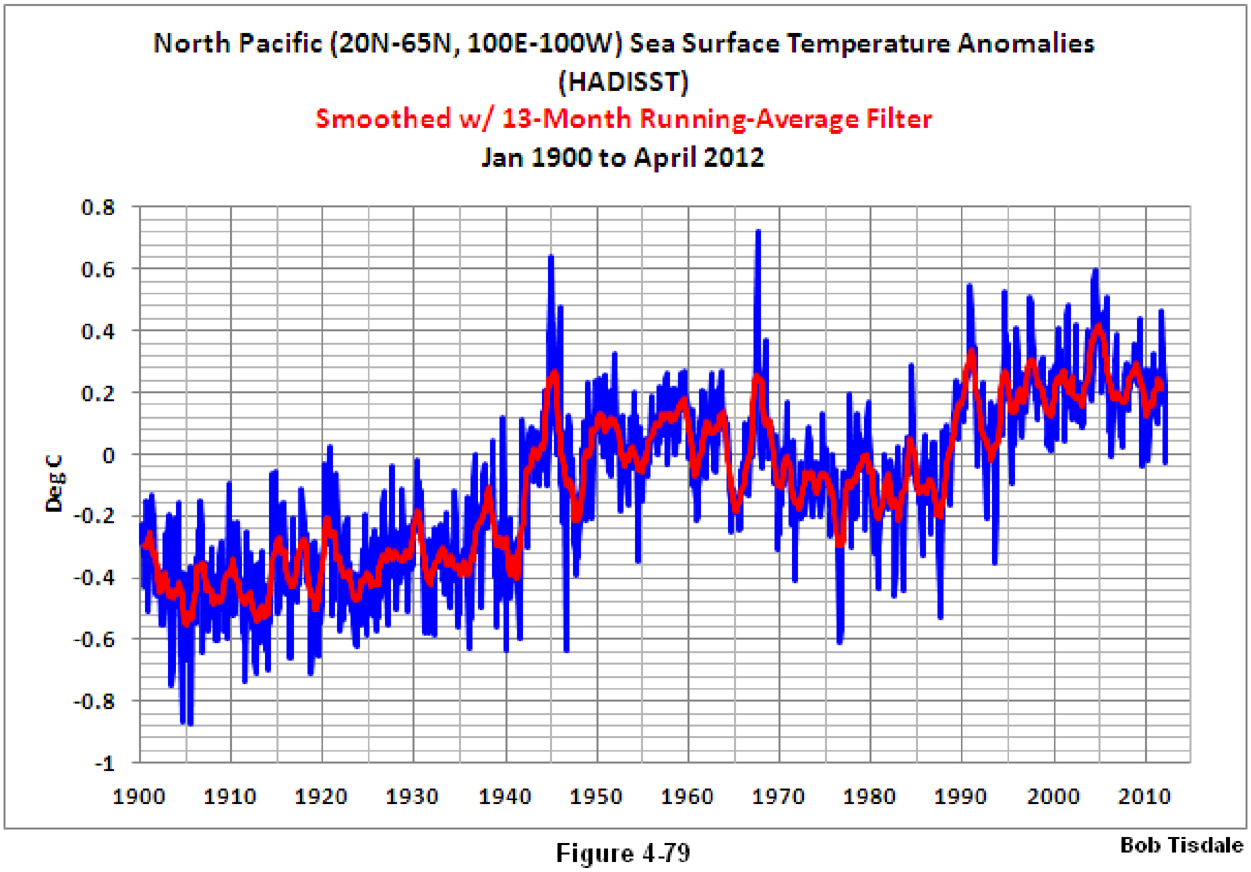


Figure 4-79

As noted at the beginning of this chapter, the Pacific Decadal Oscillation Index does not represent the sea surface temperature anomalies of the North Pacific. That fact is pretty obvious from the above graph, but let's confirm it. Figure 4-80 compares the North Pacific sea surface temperature anomalies (20N-65N, 100E-100W) to the Pacific Decadal Oscillation Index. I've smoothed both with 13-month running-average filters. There are no similarities between the two datasets. None. On the other hand, notice how, at times, the North Pacific sea surface temperature data appear as though they may be warming when the Pacific Decadal Oscillation data are falling and vice versa.

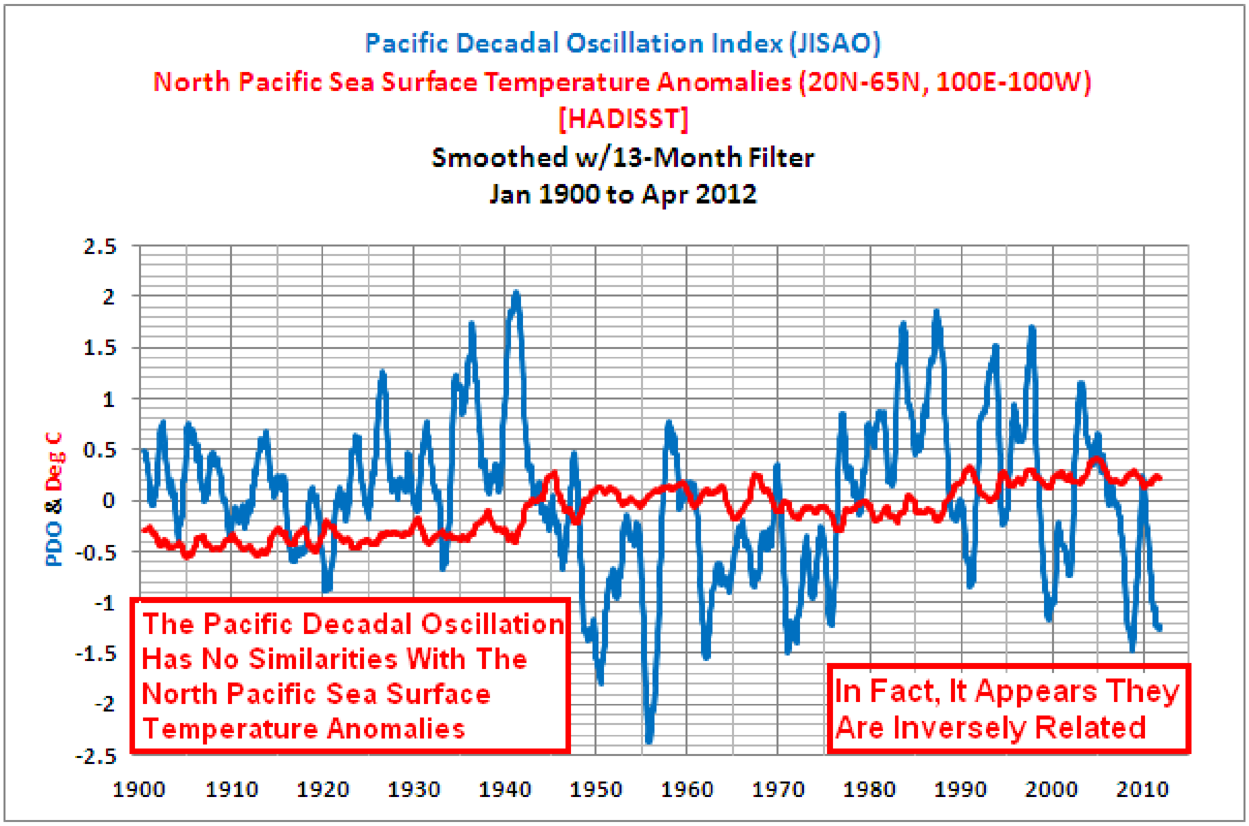


Figure 4-80

Bob Tisdale

Let's see if that's correct. We know that one of the steps in calculating the Pacific Decadal Oscillation Index is subtracting the global sea surface temperatures from every 5 by 5 degree latitude and longitude grid in the North Pacific. We'll take a shortcut for our example and simply subtract the global data from the North Pacific sea surface temperature anomalies. Because the Pacific Decadal Oscillation Index data has been standardized, we'll multiply it by 0.173, which was the standard deviation of the data presented in Figures 4-77 and 4-78. Because we think the two datasets may be inversely related, we'll have to invert the Pacific Decadal Oscillation Index data, and to do that, we'll make the sign of the scaling factor negative, using -0.173. The last thing we'll do is smooth both datasets with 121-month running-average filters, to bring out the underlying decadal variations. See Figure 4-81. The similarities are striking, especially when we consider they were derived from two different sea surface temperature datasets. Therefore, the Pacific Decadal Oscillation Index is inversely related to the sea surface temperatures of the North Pacific sea surface temperatures. That would make it impossible for the Pacific Decadal Oscillation to drive the warming and cooling of global surface temperatures.

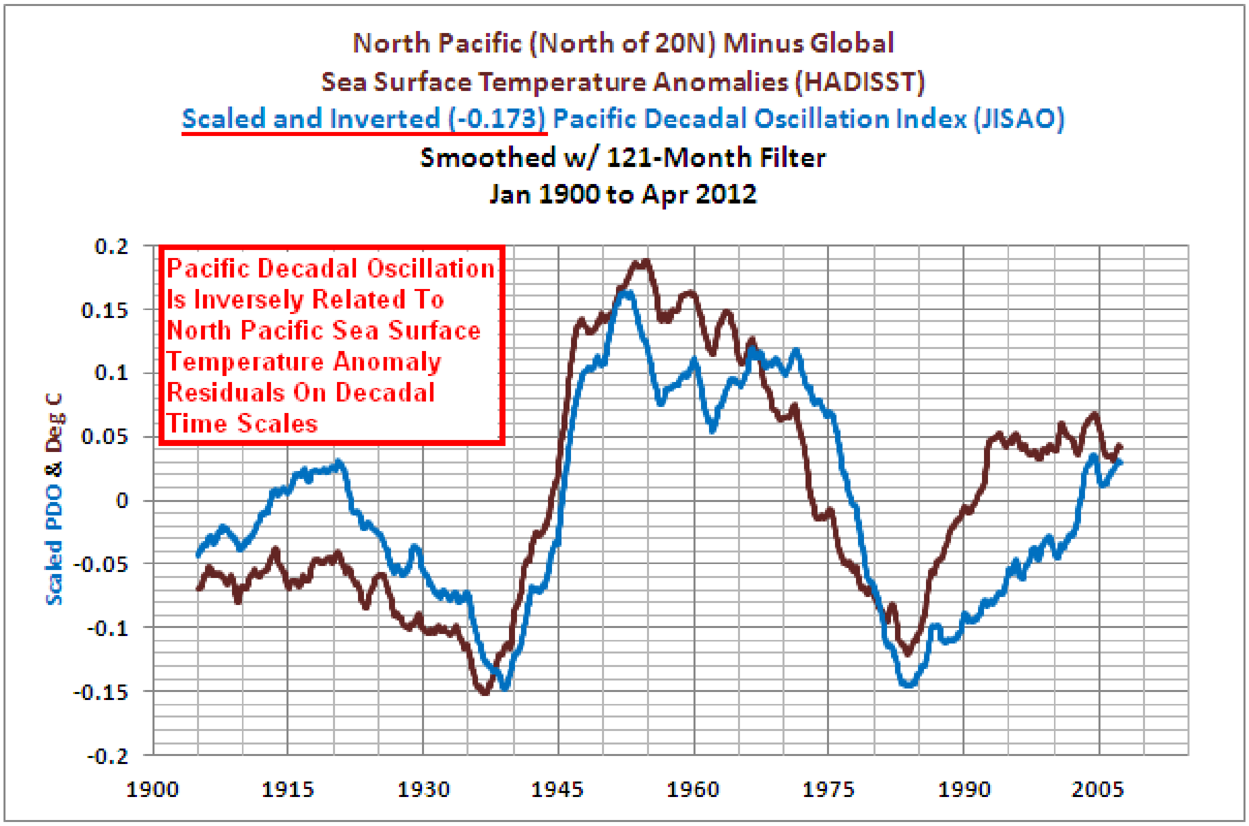


Figure 4-81

THE PACIFIC DECADAL OSCILLATION DOES NOT DRIVE ENSO

There are posts and comments around the blogosphere that state something to the effect of "when the Pacific Decadal Oscillation is positive, El Niño events are more frequent, and when the Pacific Decadal Oscillation is negative, there are more La Niña events." The authors of those comments have cause and effect reversed. Keep in mind, the Pacific Decadal Oscillation represents the El Niño-like spatial pattern of the sea surface temperature anomalies in the North Pacific north of 20N. During periods when the frequency and amplitude of El Niño events outweigh those of La Niña events, the positive Pacific Decadal Oscillation pattern (warmer in the east and cooler in the central and west) will tend to appear more frequently and the Pacific Decadal Oscillation will be positive. The reverse occurs when the frequency and amplitude of La Niña events outweigh those of El Niño events.

The Pacific Decadal Oscillation also lags ENSO, so it would be difficult for the Pacific Decadal Oscillation to initiate the variations in ENSO. Zhang et al refer to the Pacific Decadal Oscillation as "NP". For an ENSO index, they used the Cold Tongue Index (CT) in place of NINO3.4 sea surface temperature anomalies. As you'll recall from **Chapter 4.3 ENSO Indices**, the Cold Tongue Index represents the sea surface temperature anomalies of the eastern equatorial region that was slightly different than the NINO3.4 region and you'll remember that they were very similar. In Figure 7 of Zhang et al, shown here as Figure 4-82, they illustrate the cross-correlation functions between the Cold Tongue and the other time series they examined. Note how in the bottom right-hand cell NP (Pacific Decadal Oscillation) lags (CT) ENSO by approximately 3 months.

Figure 7 From Zhang et al (1997)

(The Graphs Have Been Rearranged To A Side-By-Side Format)

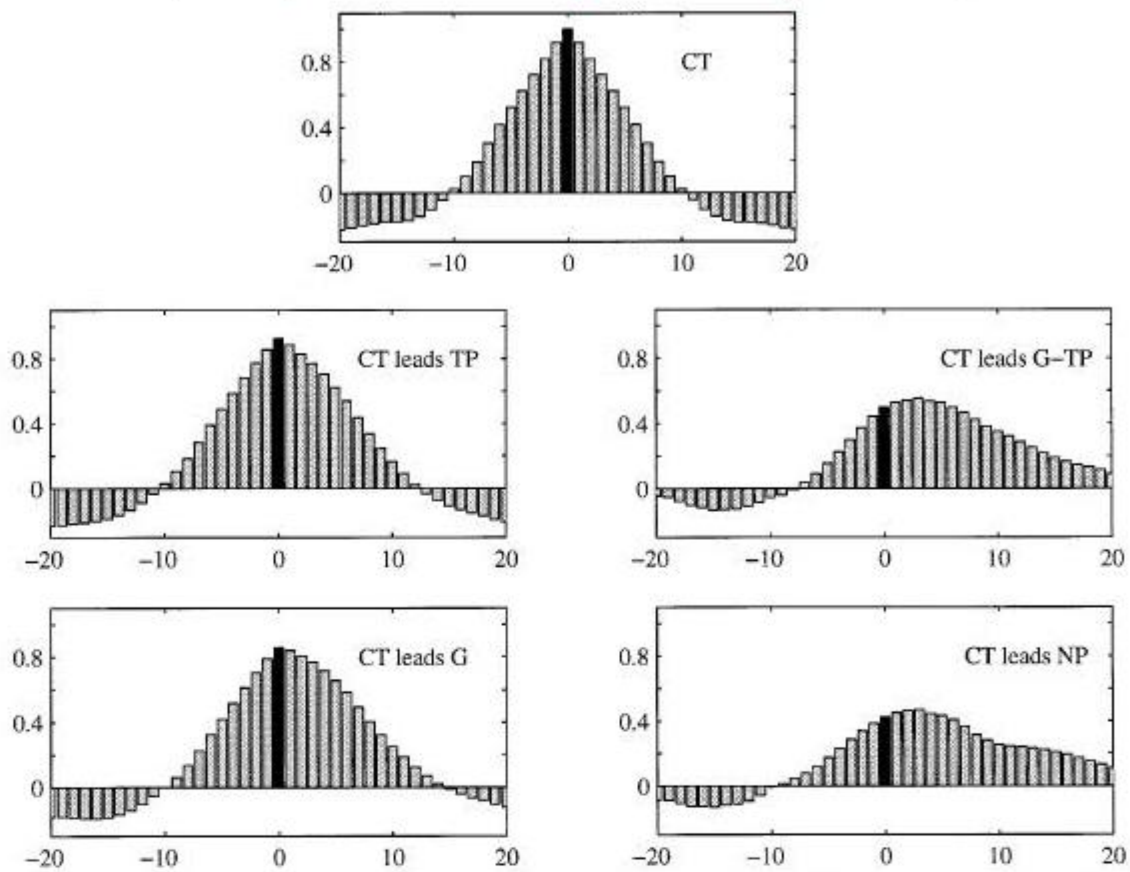


FIG. 7. Cross-correlation functions between the cold tongue index and the time series in Fig. 5, based on unfiltered data. The x axis represents the lag in months, where positive values indicate that CT is leading the other time series.

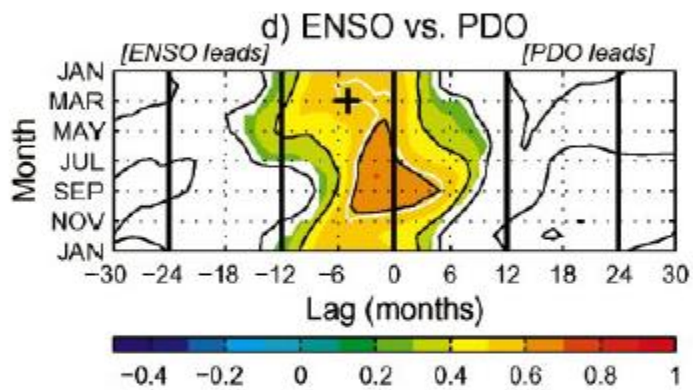
Figure 4-82

Bob Tisdale

Confirmation of the lag: In **ENSO-Forced Variability of the Pacific Decadal Oscillation**, Newman et al (2004) also found that the Pacific Decadal Oscillation lags ENSO. Figure 4-83 is cell d of Figure 1 from Newman et al. They describe it in the text as:

ENSO also leads the Pacific Decadal Oscillation index by a few months throughout the year (Fig. 1d), most notably in winter and summer. Simultaneous correlation is lowest in November– March, consistent with Mantua et al. (1997). The lag of maximum correlation ranges from two months in summer (r ~ 0.7) to as much as five months by late winter (r ~ 0.6). During winter and spring, ENSO leads the Pacific Decadal Oscillation for well over a year, consistent with reemergence of prior ENSO-forced Pacific Decadal Oscillation anomalies. Summer Pacific Decadal Oscillation appears to lead ENSO the following winter, but this could be an artifact of the strong persistence of ENSO from summer to winter (r = 0.8), combined with ENSO forcing of the Pacific Decadal Oscillation in both summer and winter. Note also that for intervals less than 1yr the lag autocorrelation of the Pacific Decadal Oscillation is low when the lag autocorrelation of ENSO (not shown) is also low, through the so-called spring persistence barrier (Torrence and Webster 1998).

Figure 1d From Newman et al (2003)



Annual cycle of cross correlation between ENSO and the PDO. The PDO leads ENSO for positive lags; ENSO leads the PDO for negative lags. The month ordinate refers to the PDO; e.g., the cross represents correlation between Mar PDO and Oct (lag −5) ENSO. The thin white line is the 0.58 contour. Correlations are for the period 1950–2001, and contour (fill) interval is 0.2 (0.1). Only values that are at least 90% significant are shaded.

Figure 4-83 **Bob Tisdale**

IMPORTANT NOTE: This does not mean that the sea surface temperatures of the North Pacific cannot or does not influence the frequency, magnitude and duration of ENSO events. The North Pacific gyre circulates waters from the eastern North Pacific equatorward.

THERE ARE OTHER USES OF THE TERM PACIFIC DECADAL OSCILLATION

Many times bloggers, climate scientists and meteorologists will use the term Pacific Decadal Oscillation (PDO) when they're referring to the decadal and multidecadal variations in the sea surface temperature anomalies of the Pacific as a whole. Unfortunately, this practice is becoming common place. This use of Pacific Decadal Oscillation is very confusing to those who are new to the term, who would then check references on the internet and discover the original definition. It's also confusing to those who understand the original definition and can lead to drawn out debates when the non-classical use of Pacific Decadal Oscillation is used by one of the parties.

Pacific Decadal Variability is a term that's used by a few people to avoid that confusion. Hopefully, more people will start to use it.

RECAP

The Pacific Decadal Oscillation Index is a statistically created dataset. It does not represent the sea surface temperature of the North Pacific, where it is derived. It basically represents the spatial pattern of the sea surface temperature anomalies in the North Pacific, north of 20N. There is no mechanism through which the Pacific Decadal Oscillation could raise and lower global temperatures. The Pacific Decadal Oscillation does not drive ENSO. In fact, the Pacific Decadal Oscillation lags ENSO so it would be difficult for the PDO to do so. The Pacific Decadal Oscillation Index data is also inversely related to the sea surface temperatures of the North Pacific, which makes it even more difficult for it to contribute to the multidecadal variations in global temperatures.

Please don't assume this chapter is an attempt to downplay the importance of the Pacific Decadal Oscillation Index. It is useful. The Pacific Decadal Oscillation Index is used by meteorologists for weather predictions. The early papers about the Pacific Decadal Oscillation discussed its impact on salmon production, so it is also useful in those endeavors. However, the Pacific Decadal Oscillation Index cannot be used to explain epochs of global warming or cooling because the Pacific Decadal Oscillation Index does not represent a process through which the North Pacific could raise or lower global temperatures.

4.11 There is a Multidecadal Component to ENSO

I'm sure one of the reasons people like the look of the Pacific Decadal Oscillation Index graphs is there appears to be clearly defined "warm" and "cool" periods that last for a couple of decades. They see the possibility that the Pacific Ocean releases more heat than normal during some multidecadal periods and releases less heat during others—and then see that global temperatures warm when the Pacific Decadal Oscillation is in a warm mode and cools in the cool mode. Unfortunately, because the Pacific Decadal Oscillation does not represent the sea surface temperature of the North Pacific, there's really no mechanism for it to raise and lower global temperatures.

On the other hand, ENSO does have that capacity. When we look at a graph of "raw" NINO3.4 sea surface temperature anomalies (our ENSO index) since 1900, Figure 4-84, the data appears noisy. Each of the upward spikes indicates an El Niño event and the downward ones are La Niña events. Because we're looking at over 110 years of data, there are lots of upward and downward spikes. The warm and cool epochs aren't clear, if they exist.

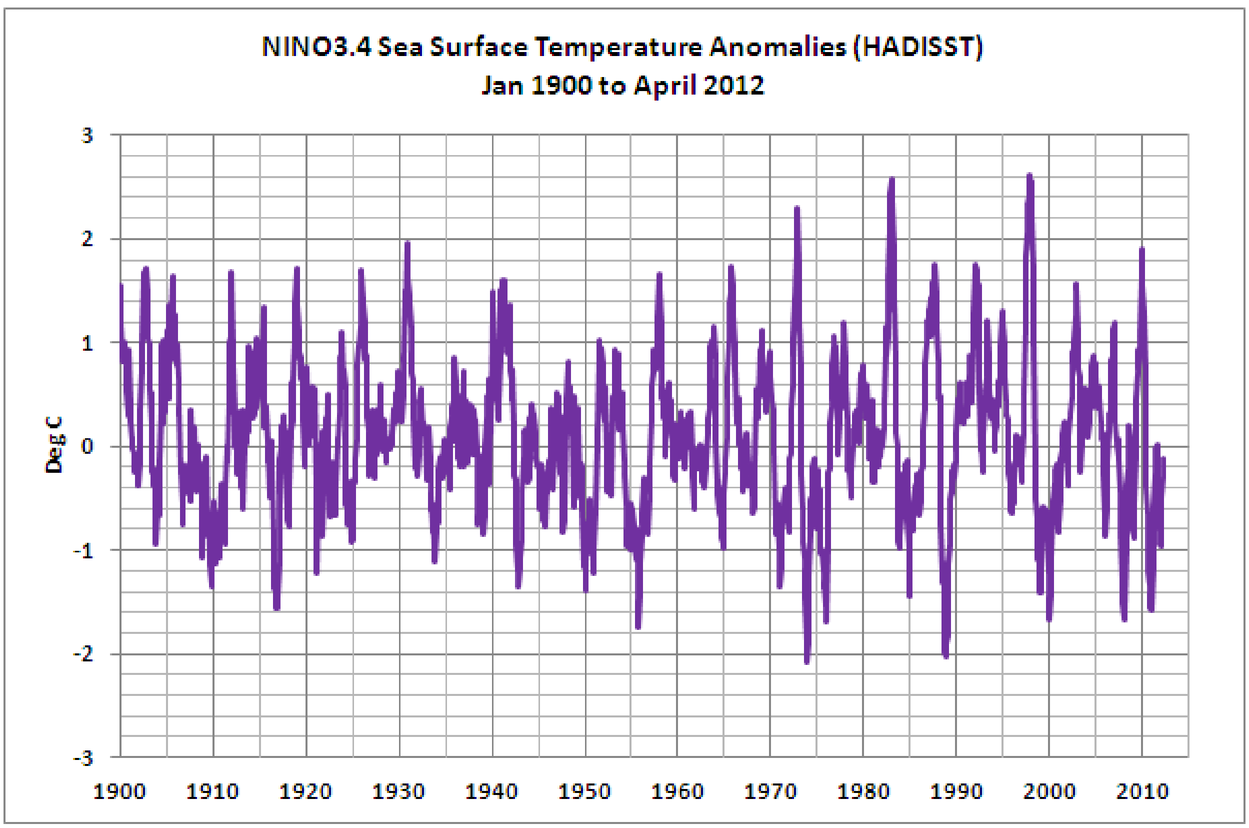


Figure 4-84

Bob Tisdale

If we smooth the data with a 121-month filter (the same filter that NOAA uses for their Atlantic Multidecadal Oscillation data), Figure 4-85, we discover there is multidecadal variability to ENSO, and it can be seen in the equatorial Pacific sea surface temperature data. The NINO3.4 sea surface temperature anomaly data show El Niño events dominated from the mid-1910s to the mid-1940s and from the mid-1970s to present. Between the mid-1940s and the mid-1970s, the NINO3.4 sea surface temperature anomalies cycled from La Niña dominance to El Niño, then back to La Niña again. For the mid-20th century period, it appears La Niña may have dominated.

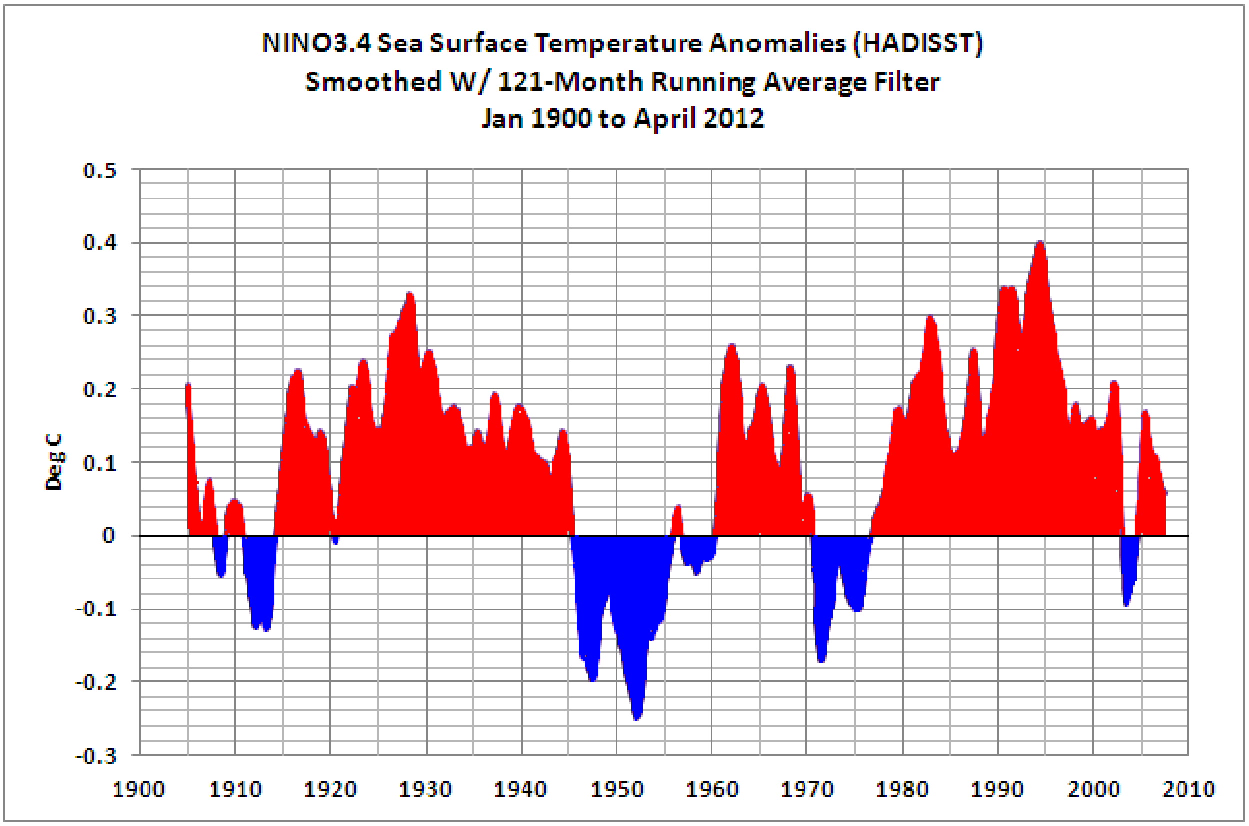


Figure 4-85

Bob Tisdale

The way to confirm which mode dominated the period from the mid-1940s to the mid-1970s is to average the NINO3.4 sea surface temperature anomalies. While we're at it, we might as well average the data over the two periods when El Niño events dominated. In Figure 4-87, using monthly data, I've divided the data into periods based on what appear to be the dividing years of El Niño- and La Niña-dominated eras. The periods are shown in the title block. The period average NINO3.4 sea surface temperature anomalies were below zero (-0.07 deg C) for the period of January 1942 to December 1975, so La Niña events did actually dominate then. During the El Niño-dominated periods before and after, the average NINO3.4 sea surface temperature anomalies were well above zero. That makes sense.

RECAP

There have been multidecadal periods since 1900 when El Niño events dominated. These occurred from the early-1900s to the early-1940s and from the mid-1970s to present. They were separated by a period from the early-1940s to the mid-1970s, when La Niña events were slightly more prevalent than El Niño events.

These periods align with the multidecadal periods when global surface temperatures warmed and cooled since the early 1900s. Further, ENSO does have the capability of warming and cooling global surface temperatures, while the Pacific Decadal Oscillation does not.

4.12 ENSO Monitoring

NOAA and Australia's Bureau of Meteorology (BOM) produce periodic ENSO status bulletins. The Weekly NOAA ENSO updates are available in **pdf** and **PowerPoint** formats. NOAA also produces a **monthly El Niño/Southern Oscillation (ENSO) Diagnostic Discussion** that is available in html, pdf and MS Word formats, in Spanish and English. An **Archive** of NOAA's diagnostic discussions since 2001 is also available. The World Meteorological Organization (WMO) also produces a relatively short monthly **El Niño/La Niña Update**.

THE BOM ENSO WRAP-UP

The BOM presents an **ENSO Wrap-up** every other week. A screen capture of the webpage is shown in Figure 4-87. I've highlighted the seven tabs that appear on it. The first (default) tab is marked "Sea Surface". There, there are discussions and recent maps of tropical Pacific sea surface temperatures and temperature anomalies. There are also links under that tab to monthly and weekly graphs of NINO3, NINO3.4 and NINO4 sea surface temperature anomalies.

Screen Capture of BOM's "ENSO Wrap-up" Webpage

http://www.bom.gov.au/climate/enso/

Figure 4-87

Bob Tisdale

The "Sea sub-surface" tab reveals a discussion and recent illustrations of the equatorial Pacific cross sections of subsurface temperatures and temperature anomalies. They are similar to the cross sections we discussed and showed in Figures 4-45 through 4-50.

The “SOI” tab presents a graph of the Southern Oscillation Index for the last two and a half years. They present the data using a 30-day running-average, where the current value represents the average of the last 30 days. Keep in mind, the Southern Oscillation Index is inversely related to equatorial Pacific sea surface temperature anomaly-based indices. That is, with the Southern Oscillation Index, La Niña events are sustained positive values in excess of +8 and El Niño events are sustained negative values in excess of -8.

The “Trade Wind” tab at the BOM ENSO wrap-up webpage presents maps of tropical Pacific sea surface temperature and temperature anomalies with wind directions and strengths and their anomalies overlaid on them. Those maps from the BOM represent the data for the last 5 days. Those maps are also available from the NOAA Tropical Ocean-Atmosphere (TAO) project website, which we’ll discuss later in this chapter. The maps presented on the BOM website are similar to the full-sized monthly maps linked **here** at the TAO project website.

“Cloudiness” is the next tab. BOM presents Outgoing Longwave Radiation (infrared radiation) as a proxy for cloudiness, using the acronym OLR. They use the coordinates of 7.5S-7.5N, 170E-170W for equatorial Pacific Outgoing Longwave Radiation data at the dateline. As BOM notes:

> *Positive values of OLR indicates less cloud than usual, while negative values indicate more cloud.*

And:

> *Cloudiness along the equator, near the Date Line, is an important indicator of ENSO conditions. It typically increases (negative OLR anomalies) near and to the east of the Date Line during an El Niño event and decreases (positive OLR anomalies) during a La Niña event.*

The BOM description fits with our discussions of ENSO. As the warm water sloshes east during an El Niño, the convection, cloud cover and precipitation accompany it. Outgoing Longwave Radiation decreases at that time. Conversely, during a La Niña, trade winds increase, reducing cloud cover. This increases the Outgoing Longwave Radiation along the equator at the dateline.

NOAA’s Interpolated Outgoing Longwave Radiation dataset is available through the KNMI Climate Explorer. Using the same coordinates as the BOM (7.5S-7.5N, 170E-170W), we can compare the equatorial Pacific Outgoing Longwave Radiation at the dateline to our ENSO index, which are NINO3.4 sea surface temperature anomalies. Because the Outgoing Longwave Radiation data runs continuously from 1979, we’ll use the HADISST version of the NINO3.4 data. See Figure 4-88. The Outgoing Longwave Radiation is noisy, but not overly so. It’s very clear that the two datasets are inversely related. Outgoing Longwave

Radiation along the equator, at the dateline, increases when NINO3.4 sea surface temperature anomalies cool, indicating a La Niña, and during an El Niño, as the NINO3.4 sea surface temperature anomalies warm, the Outgoing Longwave Radiation decreases.

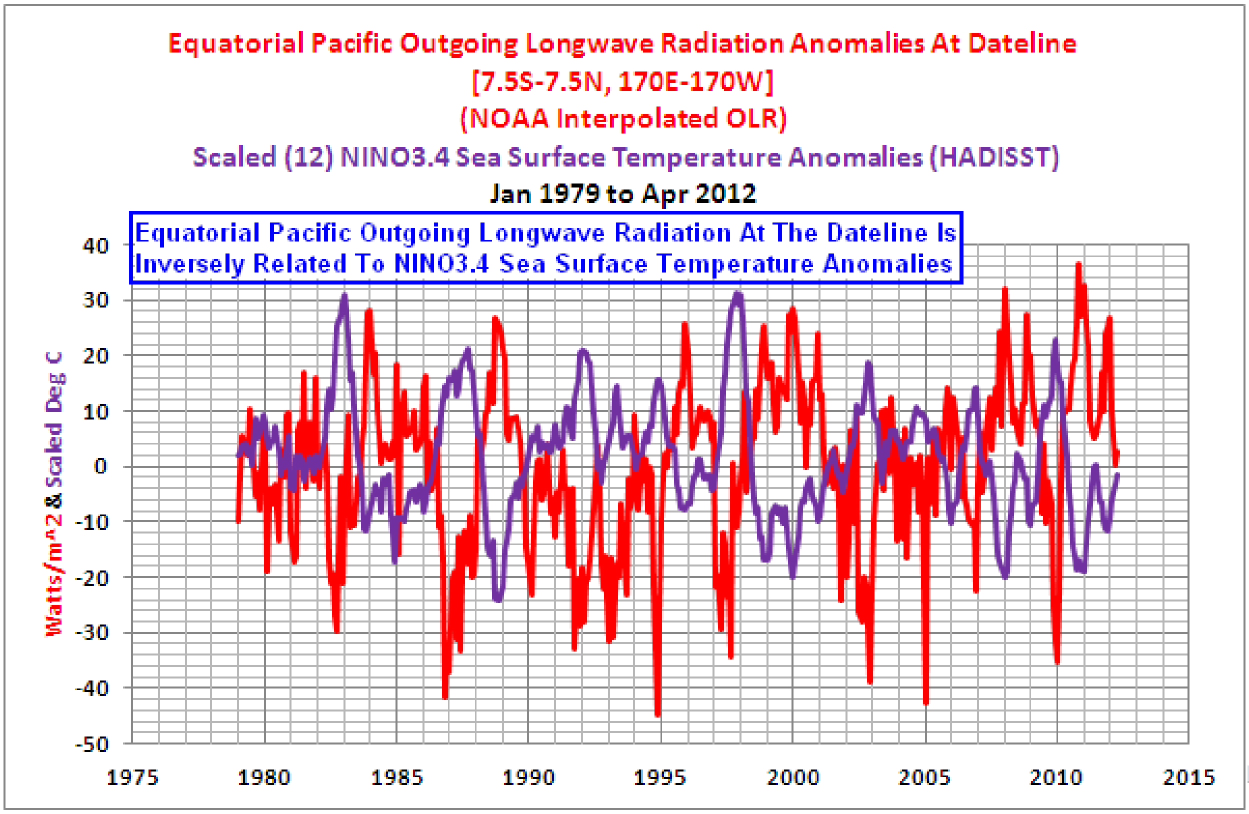


Figure 4-88 Bob Tisdale

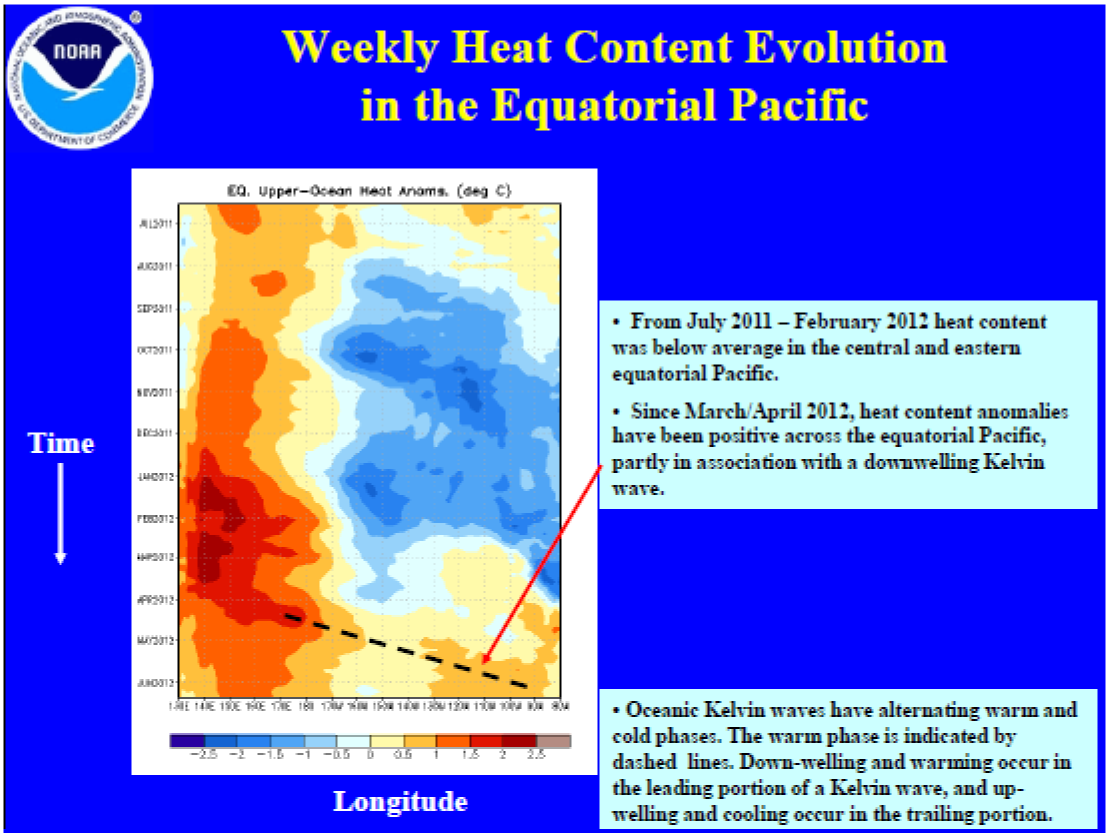
Moving on to the next tab, "Climate Models", on the "ENSO Wrap-up", the BOM presents the ENSO forecasts from seven models: BOM's **POAMA**, NCEP's **CFS**, NASA Goddard GMAO's **GEOS-5**, ECMWF's **System 4**, Japan Met Agency's **JMA/MRI-CGCM**, UK Met Office's **GloSea**, and MeteoFrance's **ARPEGE**. (Some of the links will bring you to the modeling agency's website, others to the BOM website.) On their "Climate Models" webpage, BOM is presenting the average of the forecasts from each agency, and the average of those averages.

The final tab is marked "IOD", which stands for the Indian Ocean Dipole. It is a coupled ocean-atmosphere phenomenon along the equator of the Indian Ocean, not the Pacific. The Indian Ocean Dipole has been found to be independent of ENSO. The Indian Ocean Dipole impacts rainfall patterns in Australia. BOM provides further presentations of the **effects of the positive Indian Ocean Dipole years** on Australian precipitation during El Niño and La Niña events and the **effects of negative Indian Ocean Dipole years** during those ENSO modes.

We'll discuss the Indian Ocean Dipole in Chapter 4.13.

NOAA'S WEEKLY ENSO UPDATES

Sample Hovmöller Diagram From NOAA ENSO Update



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

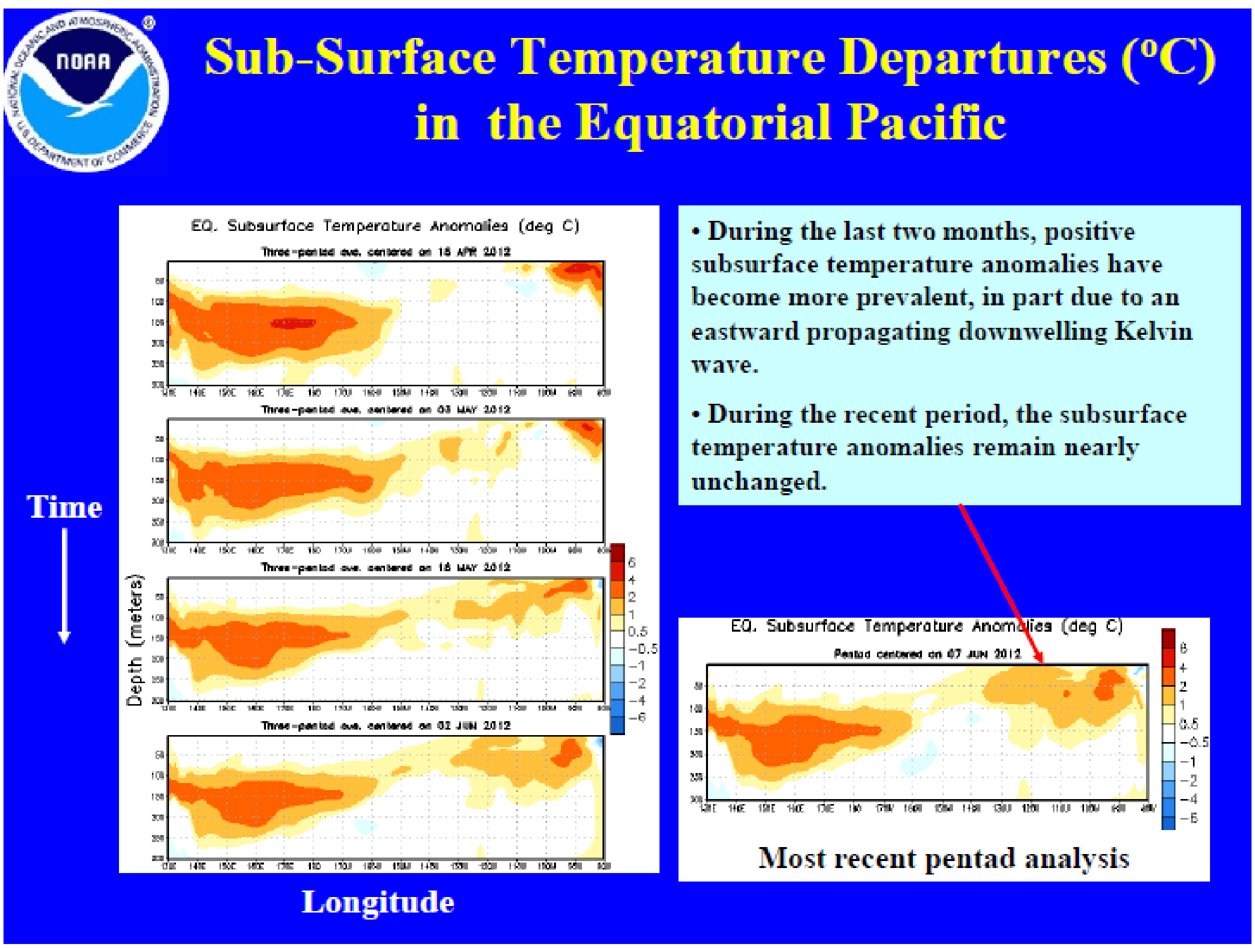
Figure 4-89 Bob Tisdale

As noted earlier, NOAA's weekly ENSO updates are available in **pdf** and **PowerPoint** formats, and they're produced on Mondays. The NOAA updates are 30-page documents. They include presentations and discussions of equatorial Pacific, tropical Pacific and global sea surface temperature anomalies. There are numerous presentations and discussions of the equatorial Pacific subsurface temperature anomalies similar to those presented in Chapter 4.8. Like the BOM update, they present Outgoing Longwave Radiation and Wind Anomalies. They also include Pacific and North American atmospheric circulation maps (that likely elude most visitors to their website and would require a separate book just to explain them.) There are North American temperature and precipitation anomaly illustrations. NOAA presents the Oceanic NINO Index (ONI), which we discussed in Chapter 4.3. Towards the end, NOAA includes a number of ENSO forecasts from different models.

NOAA includes Hovmöller diagrams a couple of times in their weekly ENSO updates. A sample is provided above in Figure 4-89. If you're not used to them, you may glance at the Hovmöller diagrams and think NOAA is presenting something that's difficult to understand. Actually, they're as easy to understand as time-series graphs, and they are a wonderful way to present data. Let's discuss how to read the Hovmöller diagrams.

Note: The title block for the entire slide and the discussion in Figure 4-89 refers to "Heat Content", but it's not heat content in terms of Joules. The units are deg C, so it's an illustration of average subsurface temperature anomalies.

Sample NOAA Discussion of Equatorial Pacific Subsurface Temperature Anomalies from Their Weekly ENSO Report



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

Figure 4-90

Bob Tisdale

Back in Chapter 4.3, we discussed the cross sections of subsurface temperatures and temperature anomalies across the equatorial Pacific for the top 300 meters. We also discussed another of the NOAA illustrations, which I have provided again as Figure 4-90. The left-hand side shows a series of cross sections, in sequence from top to bottom. Each presents the average subsurface temperature anomalies for fifteen days, and the dates listed are the 8th day midpoints. Again, looking at the cross sections in sequence, a portion of the warm subsurface temperature anomalies have shifted east over those four 15-day periods.

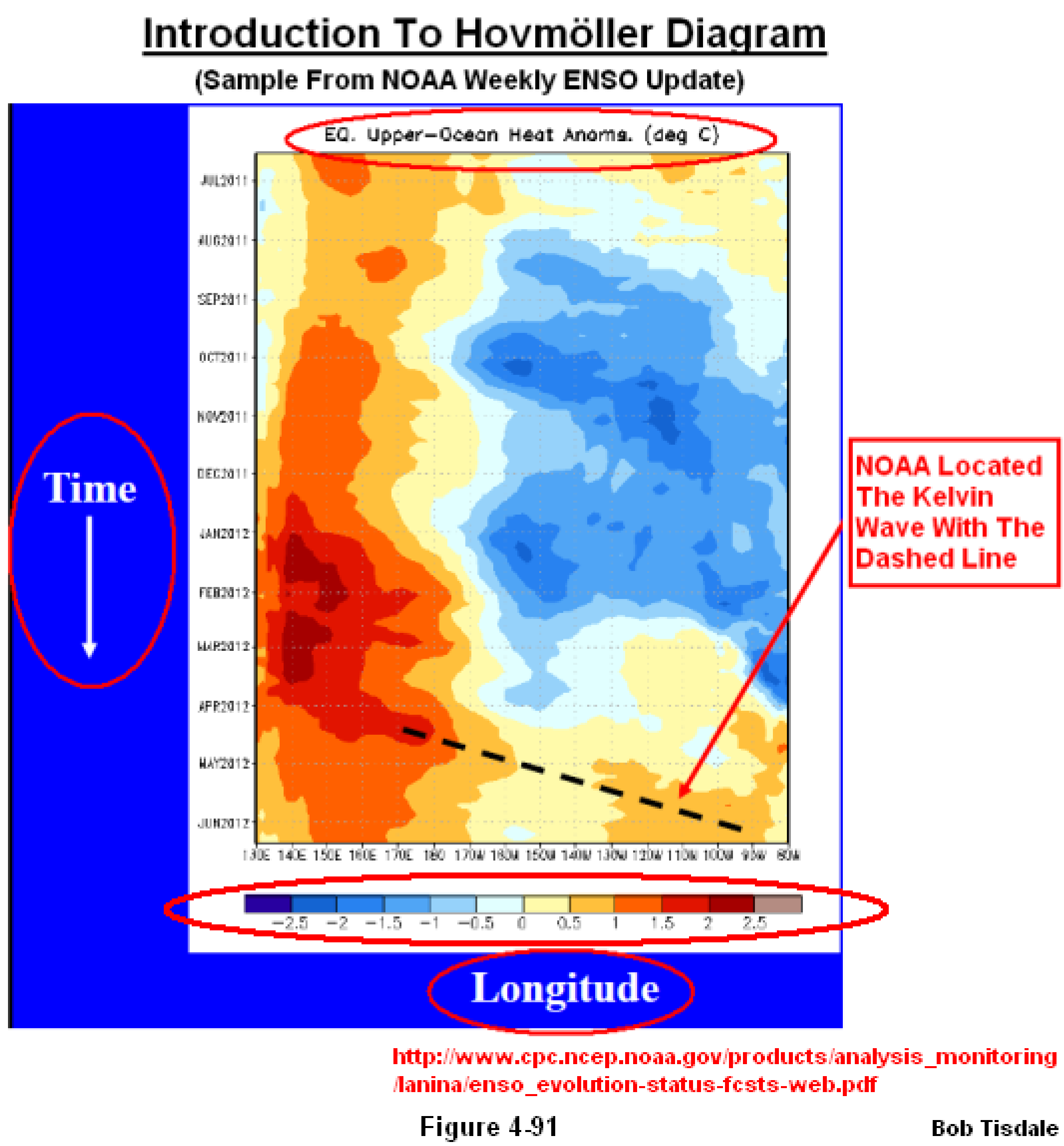


Figure 4-91

Back to the Hovmöller diagram. I've isolated the Hovmöller diagram in Figure 4-91 and added a note. The small title block at the top reads "Eq. Upper-Ocean Heat Anoms. (deg C)." It should represent the average subsurface temperature anomalies along the equator in deg C, for the depths of 0-300 meters, though they don't state it. Longitude is the horizontal axis. It runs from 130E to the left (near Indonesia) to 80W to the right (near South America). The vertical axis is time, and it runs from the top (mid-June 2011) to the bottom (mid-June 2012). The temperature scale runs from purple and lightening shades of blue for negative (cool) temperature anomalies to yellow, orange, darkening shades of red and a tan for positive (warm) temperature anomalies. In short, for much of the scale, reds are warmer-than-normal temperature anomalies and blues are cooler-than-normal temperature anomalies.

Over the past year (top to bottom), the average subsurface temperature anomalies from 0 to 300 meters along the equator ran from ENSO-neutral conditions to La Niña conditions and back to ENSO-neutral conditions. Over that period, toward the west (left), equatorial subsurface temperature anomalies warmed, peaking in January to March, and then cooled. Toward the east (right), over that period, subsurface temperature anomalies cooled, peaking in December and January, and then warmed. NOAA used a dashed black line to identify a downwelling (warm) Kelvin wave traveling from west to east and taking about two months to cross the Pacific at the equator.

TROPICAL ATMOSPHERE-OCEAN (TAO) PROJECT

Much of the data for the BOM and NOAA ENSO updates are supplied by the **Tropical Atmosphere-Ocean (TAO) Project**, which is maintained by NOAA's **Pacific Marine Environmental Laboratory (PMEL)**. The TAO Project employs an array of moored buoys with **sensors** for measuring ocean and atmosphere variables. On the atmospheric side, these included air temperature, humidity, wind speed and direction, downward shortwave radiation, downward longwave radiation, barometric pressure and rainfall. They're like weather stations out in the tropical Pacific, bobbing around on buoys anchored to the ocean floor. The buoys also include instruments for measuring surface and subsurface ocean conditions such as temperature, salinity, water pressure and current profiles. In 1999, the **Japan Agency for Marine-Earth Science and Technology (JAMSTEC)** started to maintain the buoys in the western tropical Pacific and over time has installed Triangle Trans-Ocean Buoy Network (TRITON) buoys at those locations. Figure 4-92 illustrates the locations of the TAO/TRITON buoys.

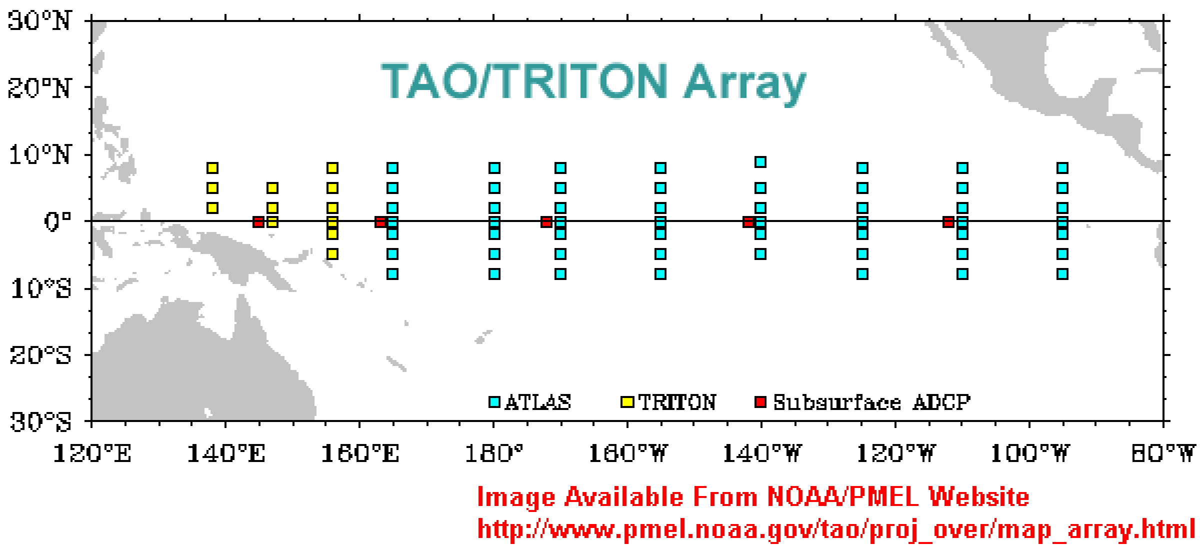


Figure 4-92

The NOAA PMEL website includes an **animated slide show** that provides a simple, easy-to-understand overview of the TOA project.

RECAP

Australia's Bureau of Meteorology (BOM) and NOAA produce periodic status updates on the variables associated with the ENSO process. Much of the data is provided by the NOAA/PMEL Tropical Ocean Atmosphere (TAO) project, which obtains atmospheric and ocean (surface and subsurface) conditions from an array of moored buoys in the tropical Pacific.

4.13 An Introduction to the Indian Ocean Dipole and How It's Impacted by ENSO

As noted in Chapter 4.12, Australia's Bureau of Meteorology (BOM) includes a discussion of the Indian Ocean Dipole (IOD) in its ENSO update web pages, because the Indian Ocean Dipole can impact the effects of ENSO events on Australia.

Indian Ocean Dipole is a coupled ocean-atmosphere phenomenon along the equator of the Indian Ocean. It has been found to be independent of ENSO. Refer to the abstract of Saji et al (1999), **A dipole mode in the tropical Indian Ocean**.

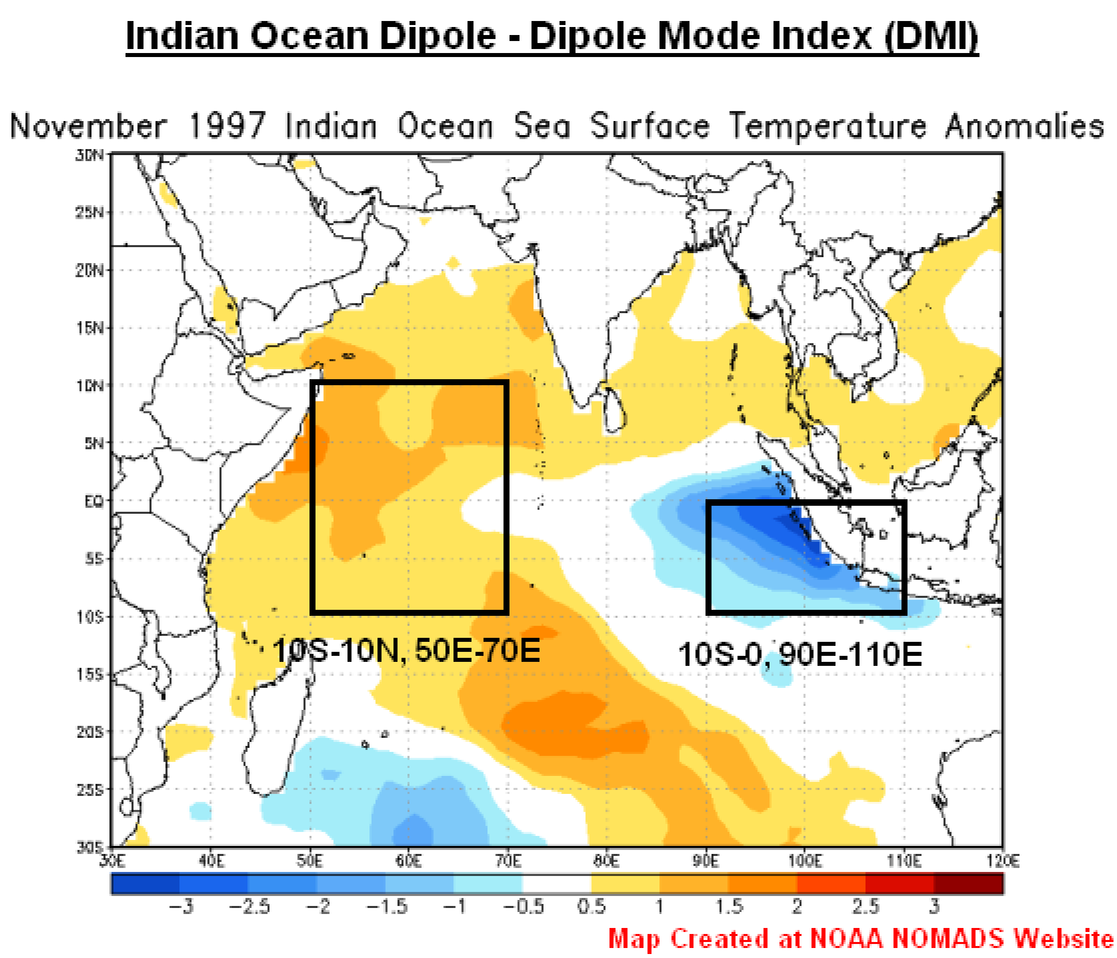


Figure 4-93 Bob Tisdale

The Indian Ocean Dipole is normally presented with a dataset called the Dipole Mode Index (DMI). The Dipole Mode Index is calculated as the sea surface temperature anomaly difference between western (10S-10N, 50E-70E) and eastern (10S-0, 90E-110E) portions of the tropical Indian Ocean, with the eastern data subtracted from the western. Refer to the map in Figure 4-93.

A time-series graph of the Dipole Mode Index is presented in Figure 4-94. There is a major spike in 1997/98 that appears related to the 1997/98 El Niño, but the other two major El Niño events in1982/83 and 1986/87/88 appear to have had little impact on the Dipole Mode Index. Then again, the Dipole Mode Index seems to have exaggerated responses to the moderate El Niño events of 1994/95 and 2006/07.

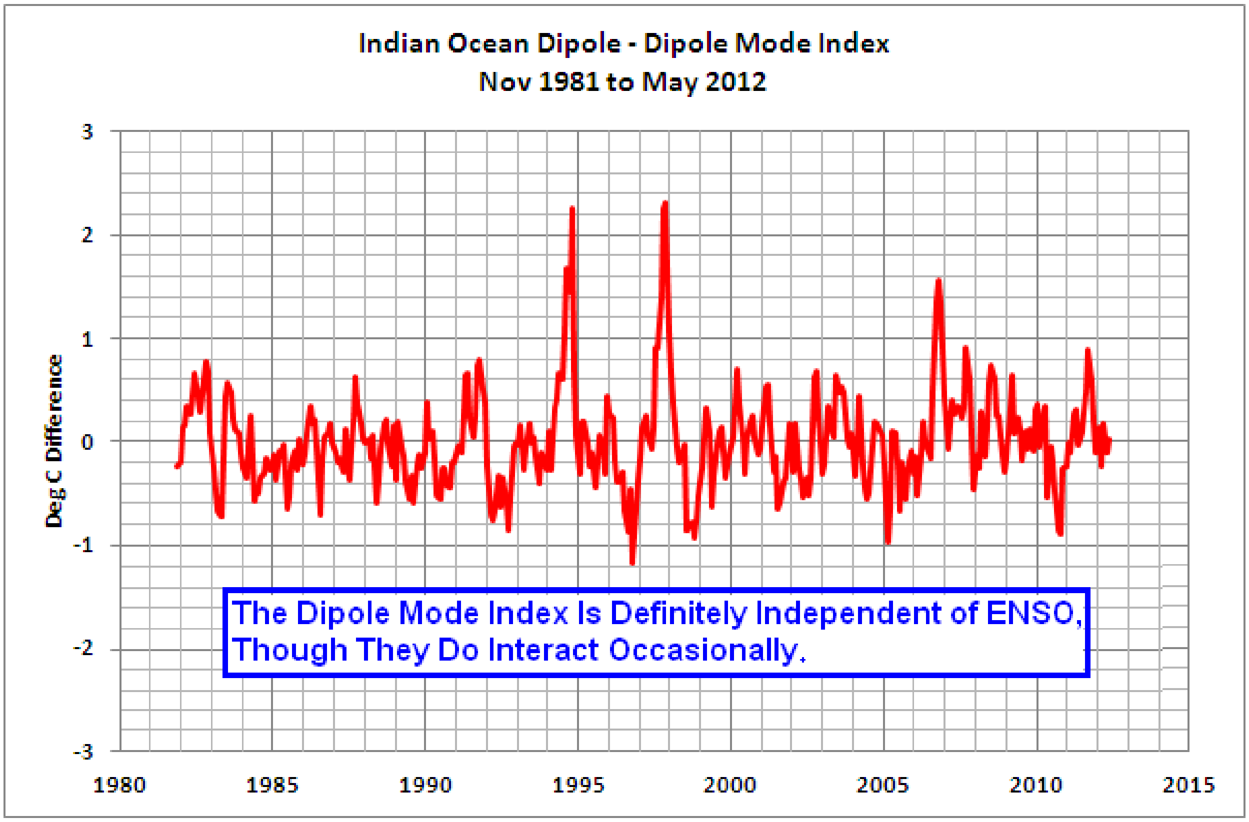


Figure 4-94 Bob Tisdale

Let’s confirm the timing of the major spikes in the Dipole Mode Index by comparing it to our ENSO index, Figure 4-95. You’ll note that the NINO3.4 sea surface temperature anomalies have not been scaled in this graph. That does not mean, however, that the sea surface temperature anomalies in the regions that make up the Dipole Mode Index are varying as much as the NINO3.4 data. The NINO3.4 data are the “raw” sea surface temperature anomalies for the NINO3.4 region, while the Dipole Mode Index portrays the temperature difference between two regions. If the sea surface temperature anomalies in the eastern Dipole Mode Region are dropping when they’re rising in the western region, the Dipole Mode Index would reflect the difference between the rise and fall. On the other hand, they would offset one another if they warmed and cooled in unison.

During the 1994/95 and 2006/07 El Niño events, the rises and falls in the Dipole Mode Index shown in Figure 4-95 came before the rises and falls in the NINO3.4 sea surface temperature anomalies. On the other hand, for the 1997/98 El Niño, the rise in the NINO3.4 data led the Dipole Mode Index, while during the decay of that event, the NINO3.4 data followed the Dipole Mode Index. Note also how the Dipole Mode Index responds to some La Niña events, but not others.

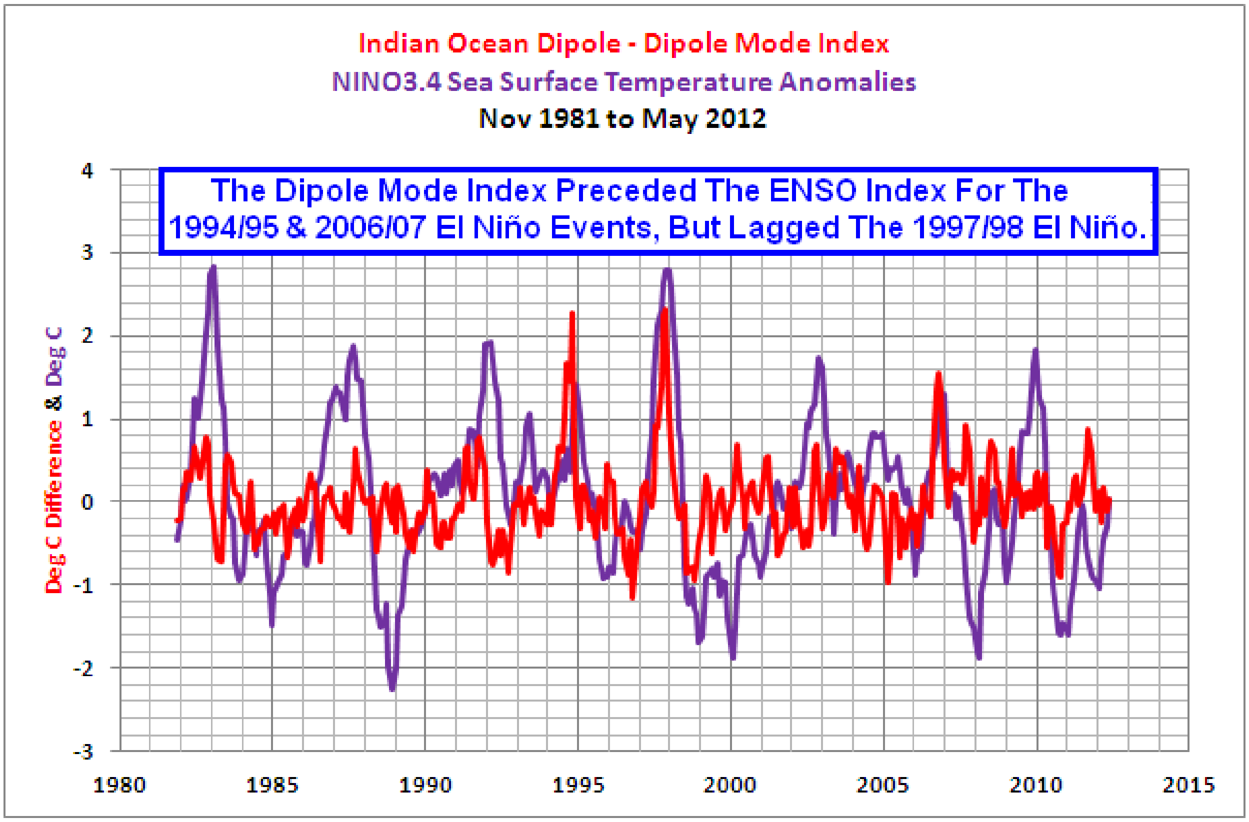


Figure 4-95 Bob Tisdale

Comparing the ENSO index to the sea surface temperature anomalies of the eastern and western regions of the Dipole Mode Index helps to illustrate the causes for the spikes, and they also present a few curiosities. Figure 4-96 shows the sea surface temperature anomalies for the Western Region of the Dipole Mode Index compared to scaled (0.4) NINO3.4 sea surface temperature anomalies. Both datasets were smoothed with 13-month running-average filters. That region represents a good portion of the western tropical Indian Ocean. The western Dipole region appears to respond proportionately to most El Niño events, with a few exceptions. The response to the 1991/92 El Niño appears to have been suppressed by the 1991 eruption of Mount Pinatubo, just as the response to the 1982/83 El Niño was impacted by the 1982 eruption of El Chichon. Notice also how the sea surface temperature anomalies of the western Dipole Mode Index Region fail to cool fully in response to the1988/89 and 1998/99/00/01 La Niña events, but they cool in response to other La Niña. The 1988/89 and 1998/99/00/01 La Niña events followed the two strongest El Niño events that weren't countered by volcanic eruptions. This is one of the examples of how sea surface temperatures (in areas remote to the eastern equatorial Pacific) respond in an unusual way to major El Niño events; they don't react to the trailing La Niña. We'll discuss the reason for that in Section 5.

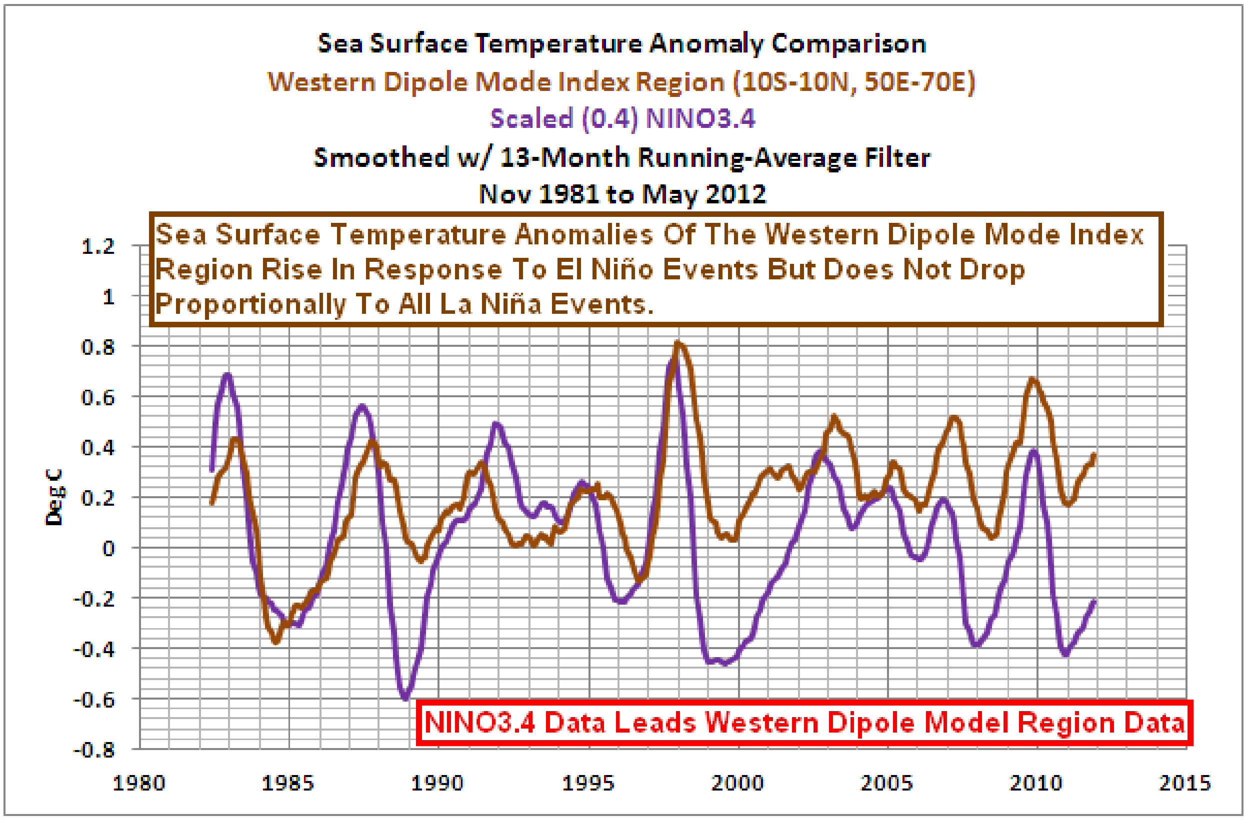


Figure 4-96

Bob Tisdale

However, that wouldn't explain the strong spikes in the Dipole Mode Index during the 1994/95, 1997/98 and 2006/07 El Niño events. There has to be something unusual about how the sea surface temperature anomalies of the eastern Dipole Mode Index region respond to ENSO events. Referring to the comparison graph in Figure 4-97, there is unusual behavior. The eastern Dipole region data can run in and out of synch with the ENSO index. Let's discuss what appears unusual. The sea surface temperature anomalies of the eastern dipole region do not cool during the 1988/89 La Niña. They cool a disproportionately large amount in advance of the 1994/95 El Niño. The eastern Dipole region anomalies cool initially in response to the 1997/98 El Niño but then turn around and warm with about a 6-month lag. Once again, they do not cool fully in response to the La Niña event of 1998/99/00/01, but warm in response to the rebound in the ENSO index as that La Niña event comes to an end. Then, there's the last bit of unusual behavior: the failure of the sea surface temperature anomalies of the eastern Dipole region to respond to the 2006/07 El Niño. The "proper" responses to the 2004/05 and 2009/10 El Niño events almost appear unusual, because everything else is so odd.

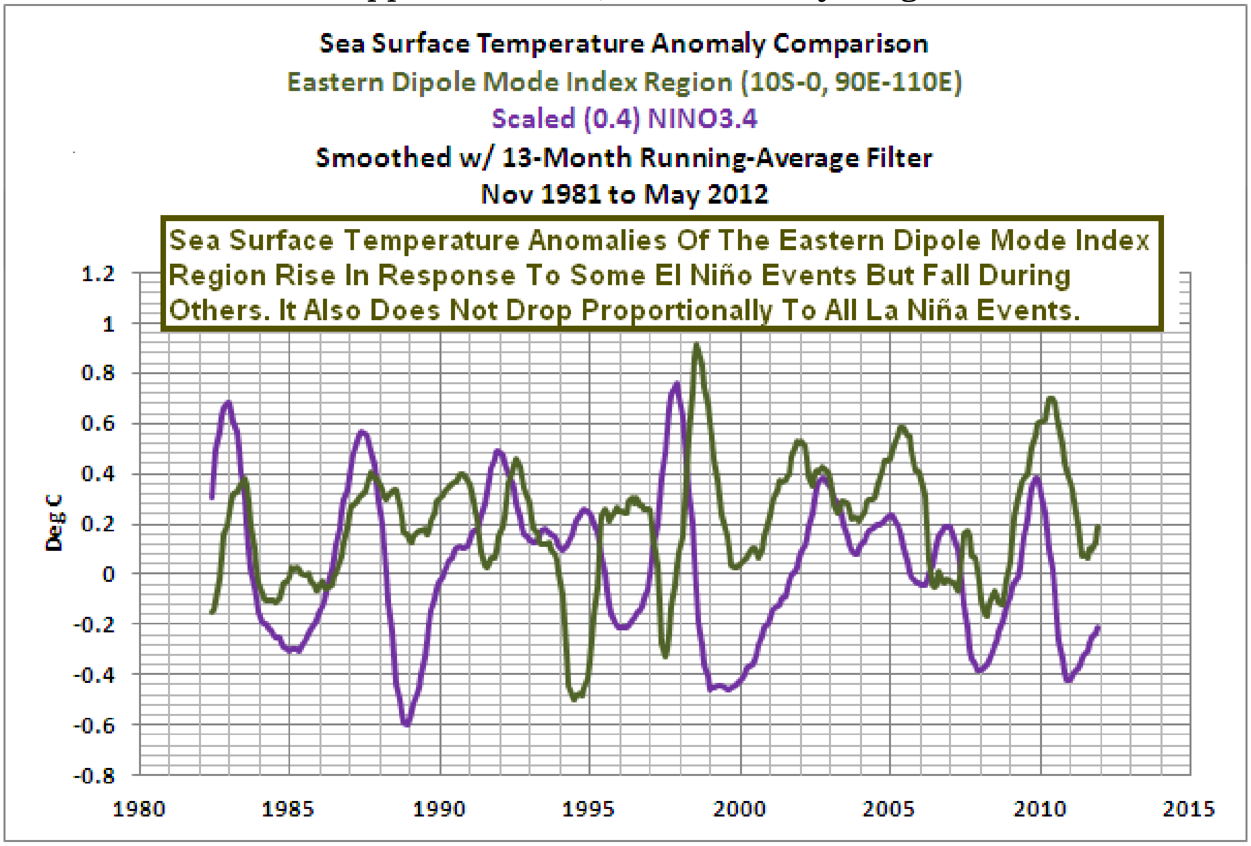


Figure 4-97 Bob Tisdale

RECAP

The Indian Ocean Dipole is a coupled ocean-atmosphere phenomenon that makes its presence known in the sea surface temperature anomalies of the tropical Indian Ocean. The Dipole Mode Index is used to represent the Indian Ocean Dipole. It is determined by subtracting the sea surface temperatures of the eastern tropical Indian Ocean from those in the western portion of the tropical Indian Ocean.

The sea surface temperatures of the regions used in the Dipole Mode Index are not varying as much as those in the NINO3.4 region. Because the Dipole Mode Index represents a temperature anomaly difference, the major spikes in it are caused by the sea surface temperatures in the eastern region cooling while the western region sea surface temperature anomalies are warming.

The eastern region has the more unusual behavior; it can run in and out of synch with the ENSO index.

The sea surface temperature anomalies of both regions failed to respond fully to the La Niña events that followed the major El Niño events of 1986/87/88 and 1997/98.

As noted in Chapter 4-12, the BOM provides presentations of the **effects of the positive Indian Ocean Dipole years** on Australian precipitation during El Niño and La Niña events and the **effects of negative Indian Ocean Dipole years** during those ENSO modes.

4.14 Impacts of ENSO Events on Regional Temperature and Precipitation

A number of times we've discussed that surface temperatures outside of the eastern tropical Pacific varied due to changes in atmospheric circulation caused by the ENSO events. In this chapter, we'll provide an overview of those **typical** ENSO-caused changes in atmospheric circulation, with links to more-detailed discussions. Keep in mind, typical does not mean they respond the same to all ENSO events.

The impact of ENSO events on regional temperature and precipitation (weather) has been studied for decades. Some of the early papers that investigated the relationship include:
Berlage (1976) *Southern Oscillation and World Weather*,

Newell and Weare (1976) **Factors Governing Tropospheric Mean Temperature**,

Angell (1981) **Comparison of Variations in Atmospheric Quantities with Sea Surface Temperature Variations in the Equatorial Eastern Pacific**,

Pan and Oort (1983) **Global Climate Variations Connected with Sea Surface Temperature Anomalies in the Eastern Equatorial Pacific Ocean for the 1958–73 Period**.

There are a number of websites and scientific papers that discuss the regional impacts of ENSO events. We'll discuss two of them. The first is the **NOAA Climate Prediction Center (CPC)** webpage titled **The ENSO Cycle**. It is a wonderful resource, with links to basic discussions and illustrations of ENSO. Please take the time to read them. They reinforce what has been presented in Sections 1 and 3. That webpage also links to discussions that are more detailed, especially about atmospheric circulation, something we've glanced over so far, and that we'll discuss in this chapter. Keep in mind, these are basic discussions. I'm using the ENSO illustrations from the NOAA web pages as references. Those illustrations are based on scientific papers from the 1980s and early 1990s—oldies but goodies. I've provided links to those papers at the end of the chapter. There have been dozens, if not hundreds, of papers written on these subjects since then, providing more detailed discussions, detailing differences between events, and the like. Again, this chapter is intended simply as an overview.

Back to the NOAA webpage "The ENSO Cycle":

Don't overlook the first link at the top of it, **Climate variability**. Figure 4-98 is a screen capture of the four photos at the top of that page. They show a thunderstorm, strong waves eroding a beach, a wildfire, and a pickup truck partly submerged by a flood.

I call your attention to this webpage for two reasons. First, a synonym for "variability" is change. NOAA/CPC used the word change once in that webpage, and carefully avoided the use of the phrase "climate change". There could be any number of reasons why the CPC used variation and other synonyms for "change", so I won't speculate about them.

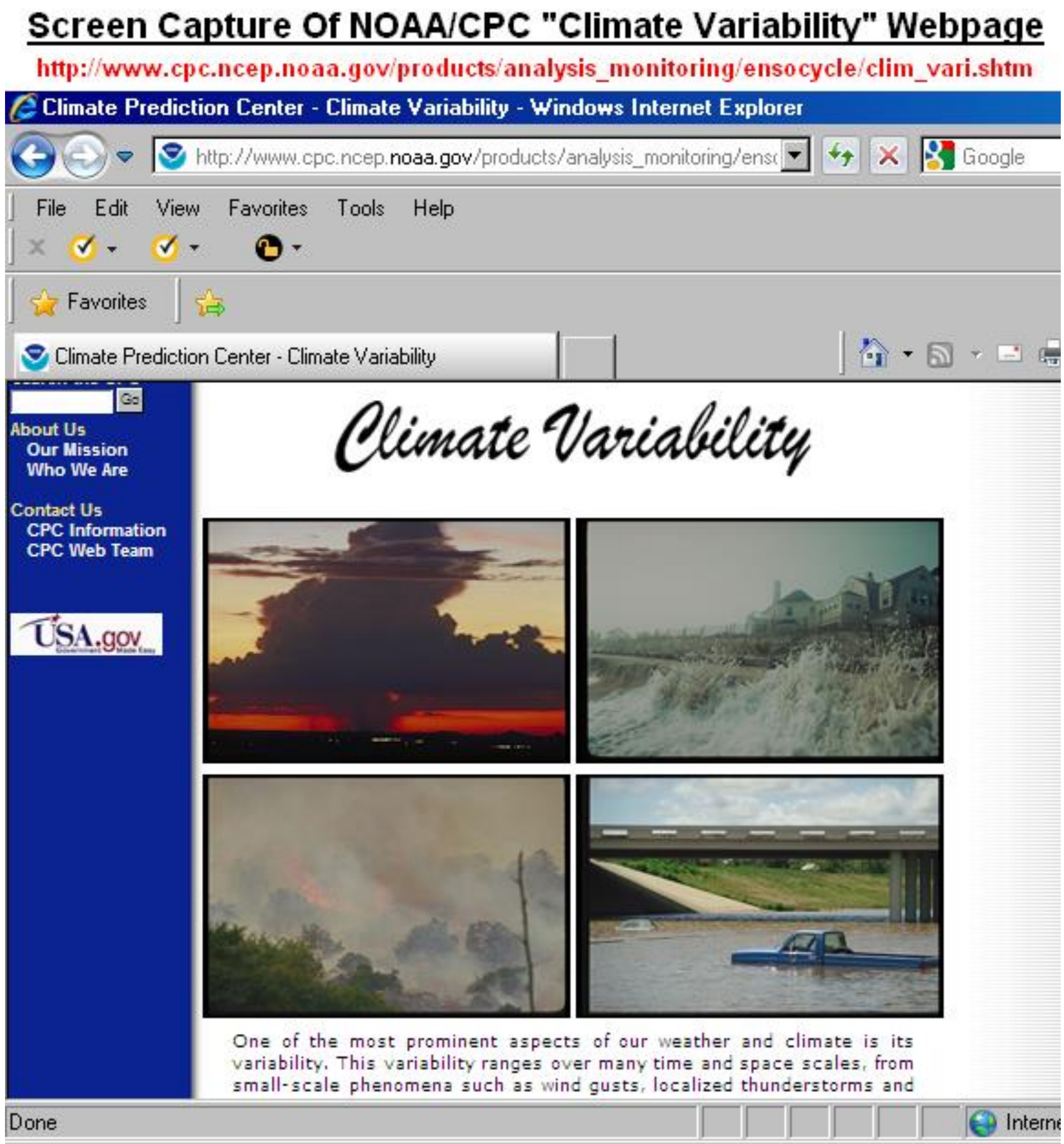


Figure 4-98 Bob Tisdale

In recent years, we've seen similar photographs used repeatedly by climate change alarmists as misleading "proof" of anthropogenic climate change, yet the images in Figure 4-98 weren't used in a discussion of manmade global warming. They were included in a discussion of ENSO. NOAA/CPC provides an excellent overview of natural climate variability/change on that webpage. They conclude with (my boldface):

> *In general, the longer time-scale phenomena are often associated with changes in the atmospheric circulation that encompass areas far larger than a particular affected region. At times, these persistent circulation features occur simultaneously over vast, and seemingly unrelated, parts of the hemisphere, or even the globe, and result in abnormal weather, temperature and rainfall patterns throughout the world. During the past several decades, scientists have discovered that important aspects of this interannual variability in global weather patterns are linked to a global-scale,* ***naturally occurring*** *phenomenon known as the El Niño/ Southern Oscillation (ENSO) cycle. The terms El Niño and La Niña represent opposite extremes of the ENSO cycle.*

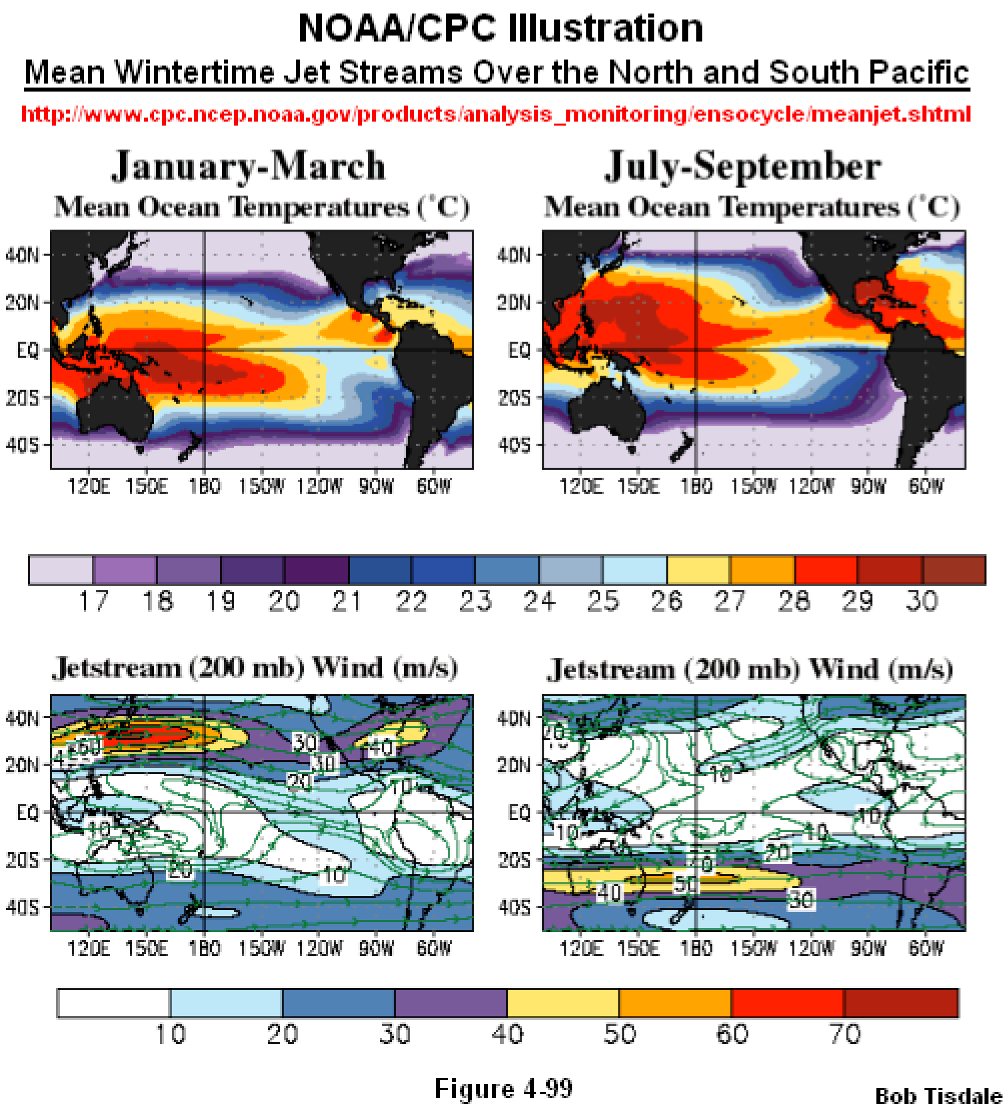


Figure 4-99

The next webpage linked in CPC's ENSO discussion is **Mean ocean surface temperatures**, but we've already discussed that a number of times, so we'll skip ahead to the discussion of the "normal" state of atmospheric circulation linked to **Mean wintertime jet streams over the North Pacific and South Pacific**. Figure 4-99 shows the NOAA/CPC maps titled "Mean Wintertime Jet Streams Over the North and South Pacific." The size of the area presented in the maps is the first thing to acknowledge. The maps reach from 50S-50N, which stretches about 78% of the distance from pole-to-pole, and they stretch about 60% of the way around the globe, from 100E to 40W, so in total, the areas shown in the maps represent about 48% of the surface of the globe. That's a chunk. The upper maps show sea surface temperatures, not anomalies. Their color-coded scale runs from less than 17 deg C to greater than 30 deg C. The lower maps present jet stream wind speed and direction in meters/second (m/s) at 200mb (about 39,000 feet). In other words, those definitely are NOT surface winds. Their color-coded scale runs from less than 10m/s to more than 70m/s (about 157 MPH). The two left-hand maps are the average conditions for winters in the Northern Hemisphere, and those on the right side are the average conditions for Southern Hemisphere winters. NOAA/CPC has added horizontal lines at the equator and vertical ones at the dateline.

The illustrations show that the jet stream winds are "normally" strongest in the both hemispheres during their respective winters. ("Normal" in this discussion will imply ENSO-neutral conditions in the tropical Pacific.) That is, the jet stream winds in the Southern Hemisphere are "normally" strongest in July to September, which is winter in the Southern Hemisphere, and the jet stream winds in the Northern Hemisphere are "normally" strongest during the months of January to March, which is wintertime there. As you'll note, the location of the strongest jet stream winds and how far they extend east of the dateline are related to the "normal" sea surface temperature patterns.

We've all heard and seen the local TV weather person pointing to a regional map and saying that the jet stream for the next "n" days will be out of the "X & Y" direction, and this will bring "w" type of weather to your area. So, during wintertime in both hemispheres, the "normal" sea surface temperature patterns shown in Figure 4-99 determine the "normal" location, strength and extent of the jet stream winds, which in turn, control the "normal" winter storm tracks and weather patterns in both hemispheres.

ENSO events change those "normal" tropical Pacific sea surface temperature patterns, which determine the jet stream wind positions and strengths, which determine storm tracks and weather patterns, which determine what parts of the globe are warmer or cooler and wetter or dryer.

EL NIÑO CONDITIONS

Let's take a look at the jet stream wind maps for the 1997/98 super El Niño that NOAA/CPC provides in their webpage **El Niño-related changes in atmospheric circulation in the subtropics and middle latitudes**. They are the four maps to the right of the heavy black line in Figure 4-100. That webpage is still part of the NOAA/CPC "The ENSO Cycle" discussion. The link is under the heading of "El Niño". The outlines of the continental landmasses in those four maps to the right are shown in a very light green, but they're there. As you can see, I've taken the "normal" or base period jet stream wind maps for January to March and for July to September from Figure 4-99 and placed them to the left of NOAA's illustration as visual references. The explanation is much easier with those reference maps on the same page.

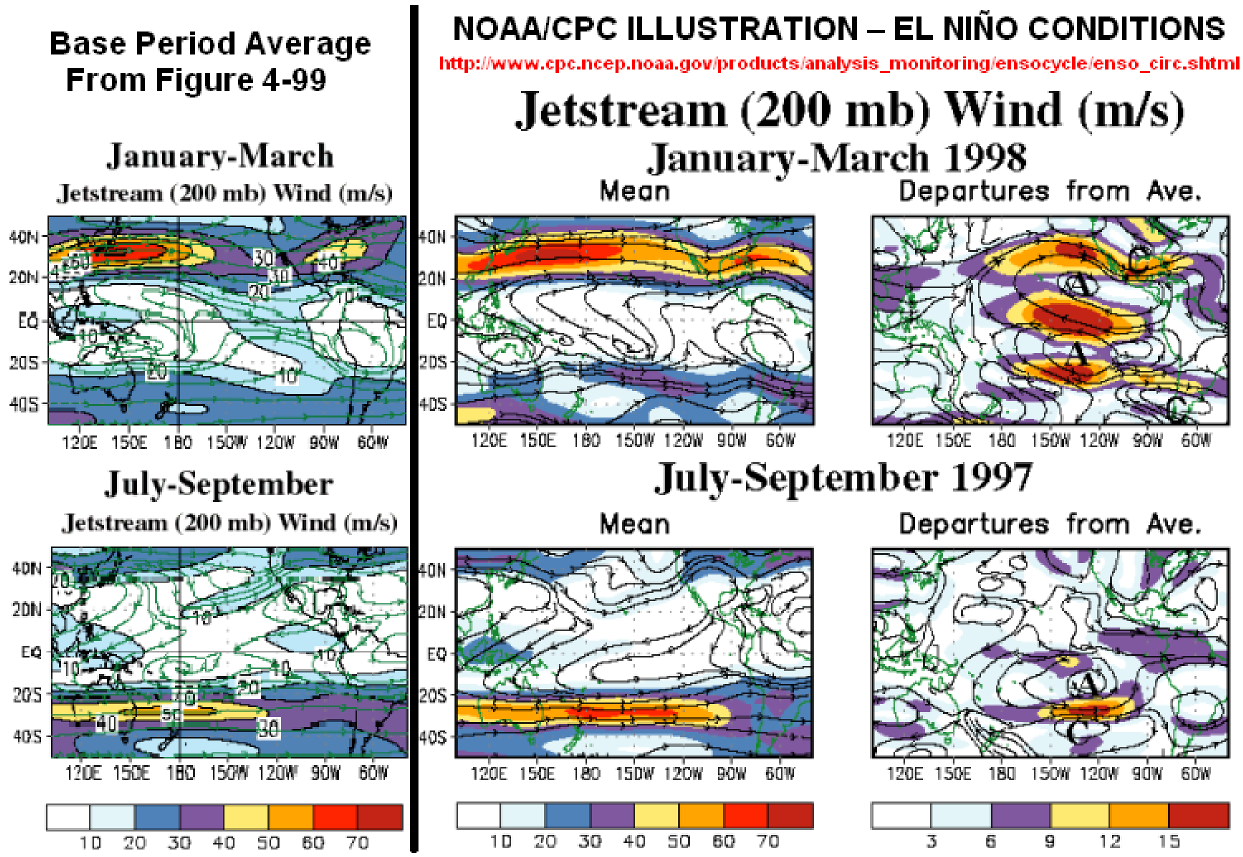


Figure 4-100

Bob Tisdale

The top center map in Figure 4-100 shows the average upper-level wind strengths and directions for the months of January to March 1998, which represents the Northern Hemisphere winter immediately after the peak of the 1997/98 El Niño. If you were to compare it to the top left-hand map, you'd note that the jet stream winds in the Northern Hemisphere grew much stronger than "normal" to the east of the dateline during the months of January to March 1998, and it also caused the jet stream winds to dip closer toward the equator in the eastern Pacific. The 1997/98 El Niño caused those changes in atmospheric circulation. How? Basically, the warm water from Pacific Warm Pool sloshed east during the El Niño, and the winter jet stream winds in the Northern Hemisphere are now responding to the new location of all of that warm water. The departure-from-average map, top right, illustrates the difference between the "normal" conditions (top left-hand map) and the January to March 1998 El Niño-related conditions (top center map). The departure map includes the capital letters "A" and "C". The "A" stands for anticyclonic circulation, and the "C" stands for cyclonic circulation.

Note: While reading the NOAA/CDC discussion, if you're familiar with terms used by your weather person, it may help you to know that anticyclonic circulation ("A") in the "departure from average" maps is associated with a large-scale **high pressure** cell, and, conversely, the cyclonic circulation ("C") is associated with a large-scale **low pressure** cell. The circulation of winds around an anticyclonic (high pressure cell) is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. On the other hand, the circulation of winds around a cyclonic cell (low pressure cell) is counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

The lower center cell in Figure 4-100 shows the average jet stream wind speed and directions in meters/second for the months of July to September 1997. This is during the evolution of the 1997/98 super El Niño. By that time, the NINO3.4 sea surface temperature anomalies were well into the range of a strong El Niño event. NINO3.4 sea surface temperature anomalies were about 1.8 deg C in July 1997 and warmed to 2.3 deg C by September 1997. As you'll remember, the threshold for "official" El Niño conditions is considered to be 0.5 deg C.

During the "normal" Southern Hemisphere winter months, the lower left-hand cell of Figure 4-100, the jet stream winds have a maximum speed in the range of 50-60 m/s (orange), extending from about 140E to 160W, at a latitude of about 30S. Also notice how the contour line for the 40-50 m/s range (yellow) extends east at that latitude to about 125W. On the other hand, during the Southern Hemisphere winter months (July-September) of 1997, the jet stream wind speeds have increased drastically and the higher speeds are extending much farther into the eastern South Pacific. Referring to the "departure from normal" in the lower right-hand corner, the jet stream has also been shifted toward the equator in the eastern South Pacific.

The increased speeds and equatorward shifts in the winter jet stream winds in both hemispheres alter storm tracks and weather patterns, which in turn determine where precipitation increases or decreases and where it's warmer or cooler than normal.

Figure 4-101 shows the **El Niño-related global temperature and rainfall patterns** presented by NOAA/CPC as part of their "The ENSO Cycle" discussion.

The El Niño-related temperature and precipitation patterns in the tropical Pacific agree with our past discussions of the ENSO process. During an El Niño, warm water from the western Pacific Warm Pool sloshes east, and the convection, cloud cover and precipitation accompany it. The central and eastern tropical Pacific become warmer and wetter, and the western tropical Pacific becomes much dryer, but not cooler. Sea surface temperatures in the western tropical Pacific do not cool appreciably during the evolution of the El Niño, and, eventually, the changes in atmospheric circulation that cause the surface temperatures to vary work their way eastward around the globe and warm the western tropical Pacific and eastern Indian Ocean.

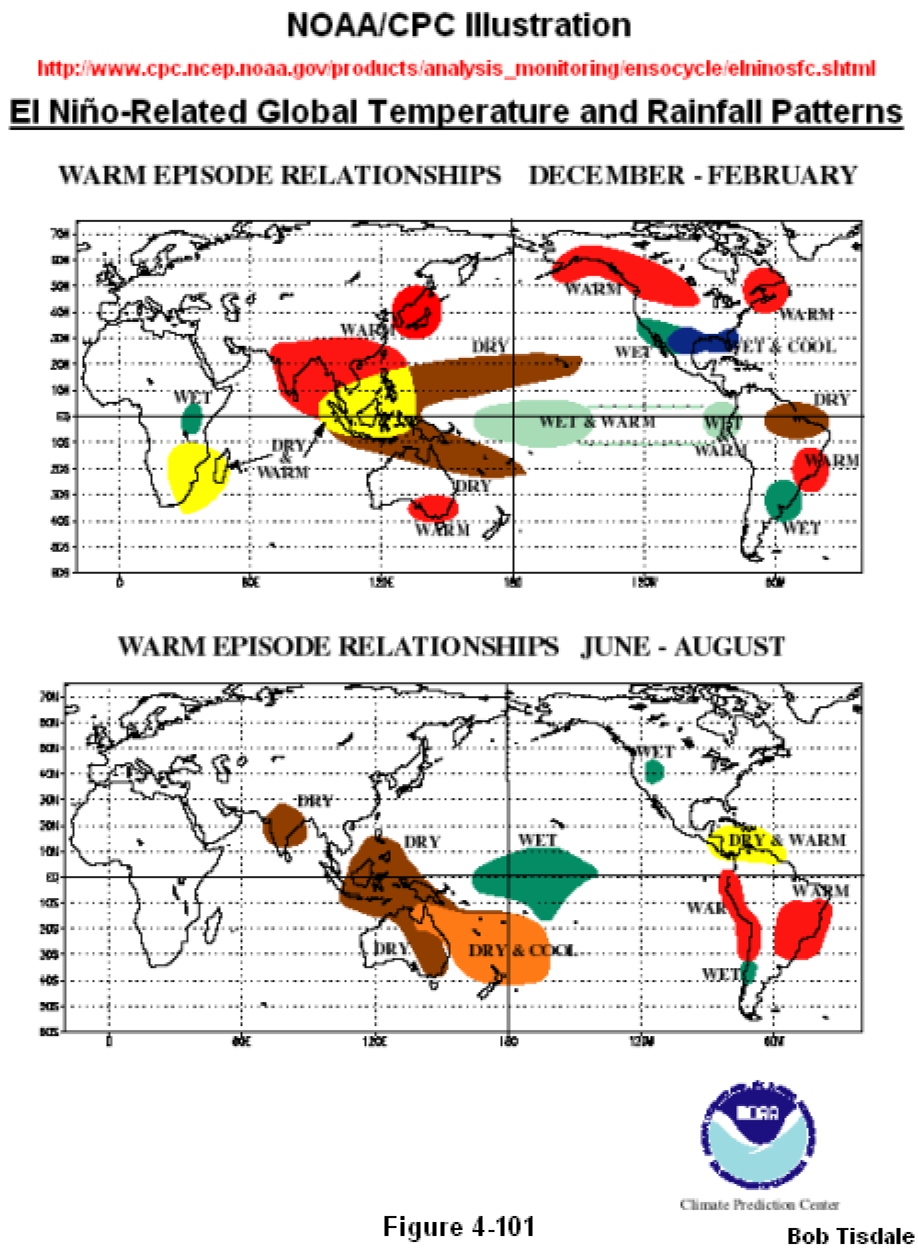


Figure 4-101

The NOAA/CPC description of the global temperature and rainfall patterns during typical El Niño events are not technical, so I'll quote them:

> *In the Tropics, El Niño episodes are associated with increased rainfall across the east-central and eastern Pacific and with drier than normal conditions over northern Australia, Indonesia and the Philippines. Elsewhere, wetter than normal conditions tend to be observed 1) during December-February (DJF) along coastal Ecuador, northwestern Peru, southern Brazil, central Argentina, and equatorial eastern Africa, and 2)*

during June-August (JJA) in the intermountain regions of the United States and over central Chile. Drier than normal conditions generally observed over northern South America, Central America and southern Africa during DJF, and over eastern Australia during JJA. El Niño episodes also contribute to large-scale temperature departures throughout the world, with most of the affected regions experiencing abnormally warm conditions during December-February. Some of the most prominent temperature departures include: 1) warmer than normal conditions during December-February across southeastern Asia, southeastern Africa, Japan, southern Alaska and western/central Canada, southeastern Brazil and southeastern Australia; 2) warmer than normal conditions during June-August along the west coast of South America and across southeastern Brazil; and 3) cooler than normal conditions during December-February along the Gulf coast of the United States.

LA NIÑA CONDITIONS

La Niña is not the opposite of El Niño so there needs to be a separate discussion of how La Niña events impact atmospheric circulation. The jet stream maps for the 1988/89 La Niña that NOAA/CPC provides in their webpage **La Niña-related changes in atmospheric circulation in the subtropics** are shown to the right of the thick black line in Figure 4-102.

One has to assume NOAA/CPC selected the 1988/89 La Niña because it was the strongest single-season La Niña in recent decades. The 1987/88 portion of the 1986/87/88 El Niño peaked earlier than normal in August 1987, so there was an early transition to the 1988/89 La Niña. By July 1988, NINO3.4 sea surface temperature anomalies were at -1.54 deg C, just into strong La Niña event range. They warmed a little through September, before cooling to their seasonal low of -2.25 deg C in November 1988.

To the left of the black line in Figure 4-102, I've also included the base period "normal" maps from Figure 4-99 as a reference. Immediately, the "departure from normal" maps on the right stand out. They appear to be the opposite sign of the departure maps in Figure 4-100. That is, note how, by comparing the normal to the La Niña winter maps in the Northern Hemisphere, that the stronger jet stream winds have moved to the west during the La Niña. The jet stream winds east of the date line have weakened, yet the departure map to the right shows the difference to be the same sign as the departure map in Figure 4-100 when there was an increase in jet stream wind strength east of the dateline. That is, NOAA did not present positive and negative anomalies in those departure maps. Keep that in mind when looking at the departure maps.

We've just discussed the effect of the La Niña event on the jet stream winds in the Northern Hemisphere during its winter months. The overall shift to the west from the "normal" conditions occurred because the stronger trade winds (at the surface) have pushed the warm water in the west Pacific Warm Pool farther to the west, so the convection, cloud cover and precipitation have accompanied that warm water and shifted west also.

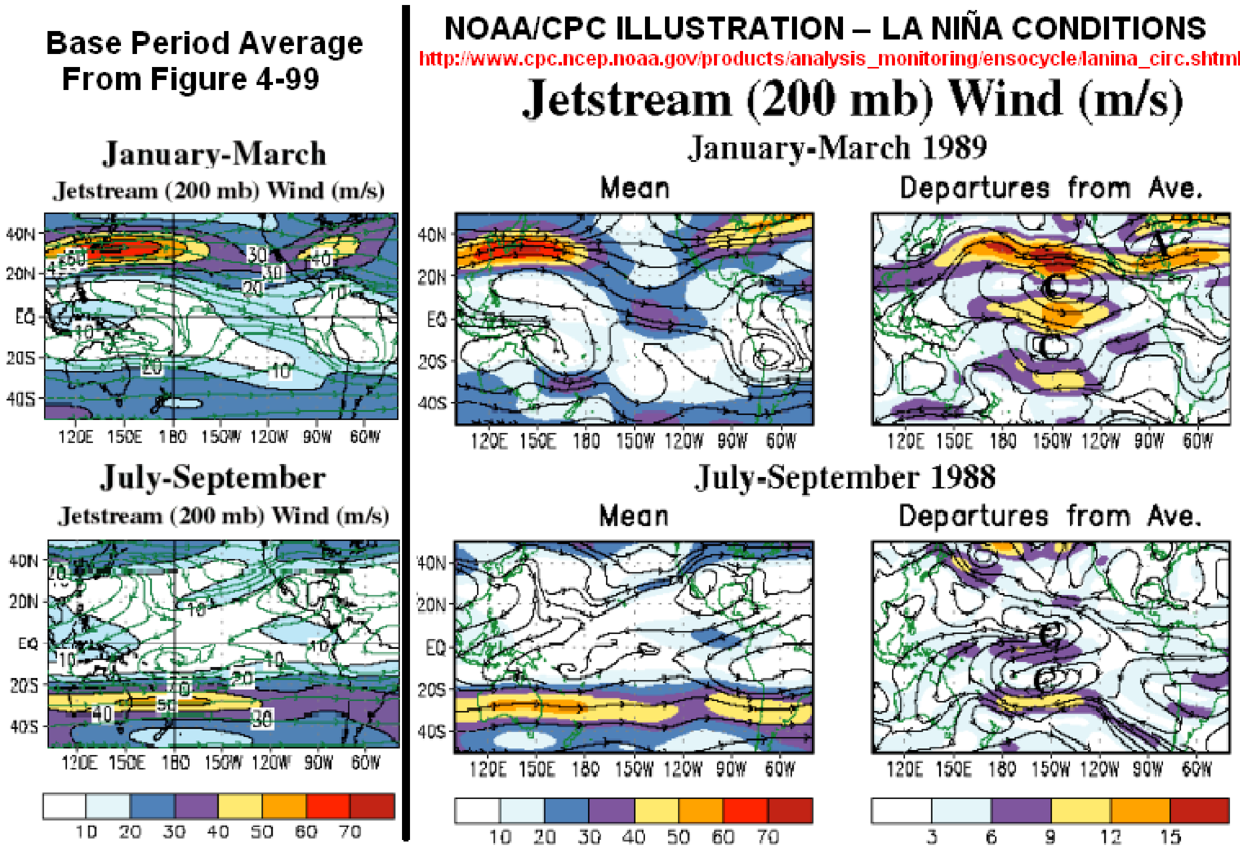


Figure 4-102 Bob Tisdale

The same thing happens in the Southern Hemisphere, the lower maps, during its winter months of July to September. The stronger jet stream winds also moved to the west of the dateline. Then, well to the east of the dateline, notice how the La Niña maps for both hemispheres also show strong jet stream winds east of about 95W. They are stronger than they appear in the "normal" conditions. (NOTE again: the departure maps show the strengthening with the same sign as a weakening. Those departure maps could be very confusing to someone used to anomaly maps, where departures of opposite signs have different colors.) Another thing to note is where the winter jet stream winds are being drawn toward the equator during the La Niña. The troughs are appearing farther west than during "normal" conditions. During El Niño events, the troughs were occurring to the east of "normal".

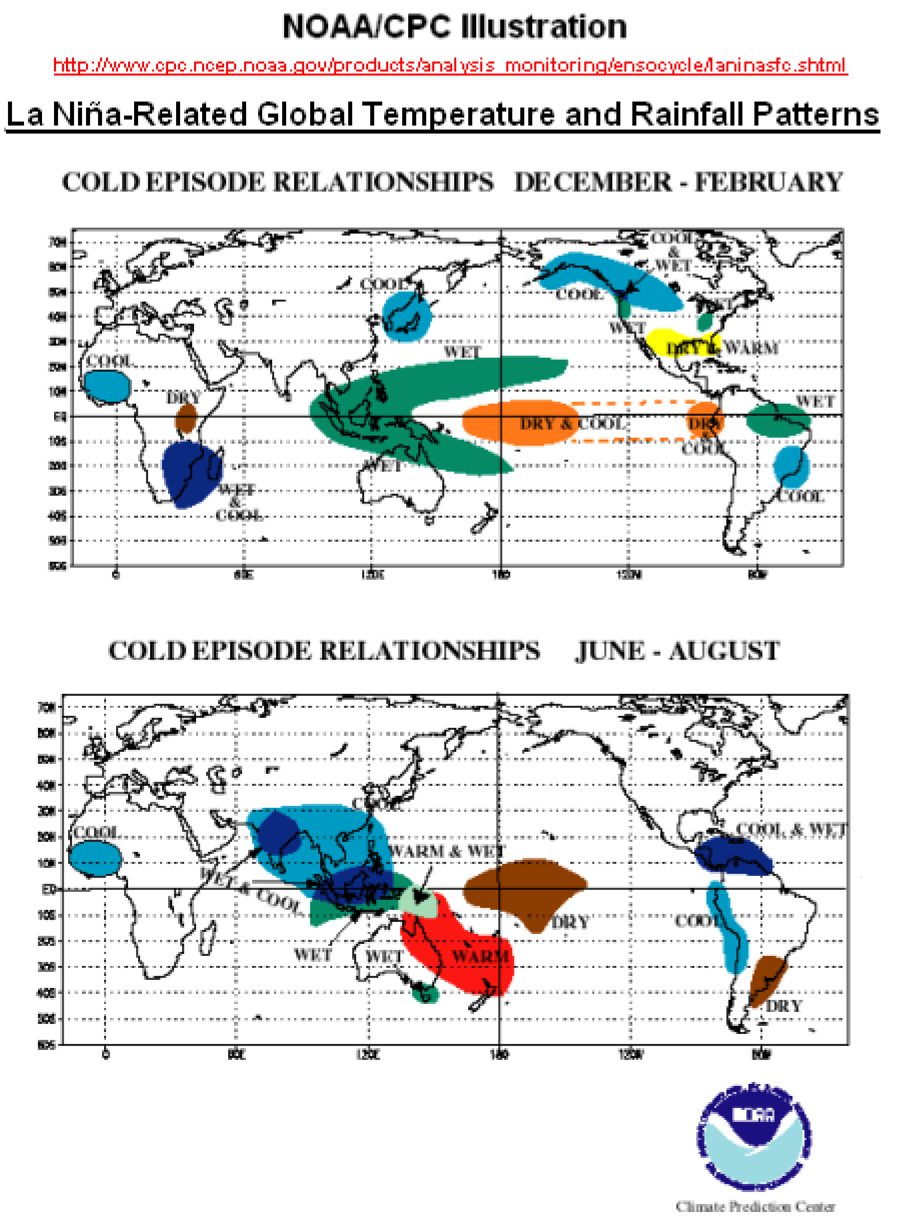


Figure 4-103

Bob Tisdale

Figure 4-103 shows the **La Niña-related global temperature and rainfall patterns** maps presented by NOAA/CPC under the heading of La Niña. In the tropical Pacific, the La Niña-related temperature and precipitation maps confirm our past discussions. The trade winds (surface winds) increase in strength during the La Niña, pushing the warm water and cloud cover farther to the west than during ENSO-neutral conditions. The stronger trade winds also cause more upwelling along the equator in the eastern equatorial Pacific, drawing more cool subsurface water to the surface than normal. Therefore, cooler and dryer conditions occur over the eastern tropical Pacific, and wetter conditions occur in the western tropical Pacific.

I'll once again quote the NOAA/CPC discussions of these typical temperature and rainfall pattern maps, because they are not technical:

> *During La Niña episodes rainfall is enhanced across the western equatorial Pacific, Indonesia and the Philippines and is nearly absent across the eastern equatorial Pacific. Elsewhere, wetter than normal conditions tend to be observed during December-February (DJF) over northern South America and southern Africa, and during June-August (JJA) over southeastern Australia. Drier than normal conditions are generally observed along coastal Ecuador, northwestern Peru and equatorial eastern Africa during DJF, and over southern Brazil and central Argentina during JJA.*
>
> *La Niña episodes also contribute to large-scale temperature departures throughout the world, with most of the affected regions experiencing abnormally cool conditions. Some of the most prominent temperature departures include: 1) below-normal temperatures during December-February over southeastern Africa, Japan, southern Alaska and western/central Canada, and southeastern Brazil; 2) cooler than normal conditions during June-August across India and southeastern Asia, along the west coast of South America, across the Gulf of Guinea region, and across northern South America and portions of central America; and 3) warmer than normal conditions during December-February along the Gulf coast of the United States.*

ANOTHER NOAA PRESENTATION

There are numerous NOAA web pages dedicated to ENSO. Some are entry level, which is always a good place to start. The following is included in the NOAA **National Weather Service** (NWS) discussion of **Tropical Weather**. It's part of the NOAA/NWS **Jet stream - Online School for Weather** website. The specific page I'll be quoting is their discussion of the **Weather Impacts of ENSO**.

This NOAA webpage is being discussed to clarify something: the presentations so far about the effects of ENSO on global temperatures and precipitation are generalities. That is, the maps portray "typical" effects of ENSO. Every El Niño and La Niña event is subtly different in strength, timing, location, etc., and because there are other factors that govern weather in a specific region, there will be differences in the effects from one ENSO event to the next.

Figure 4-104 is a screen capture of NOAA/NWS webpage "Weather Impacts of ENSO". It includes an image of the globe with typical Northern Hemisphere jet stream locations for El Niño and La Niña events. I've highlighted in red a dialogue box that appears if you place your cursor over the globe. It reads:

Typical average position of the jet stream during El Niño and La Niña.

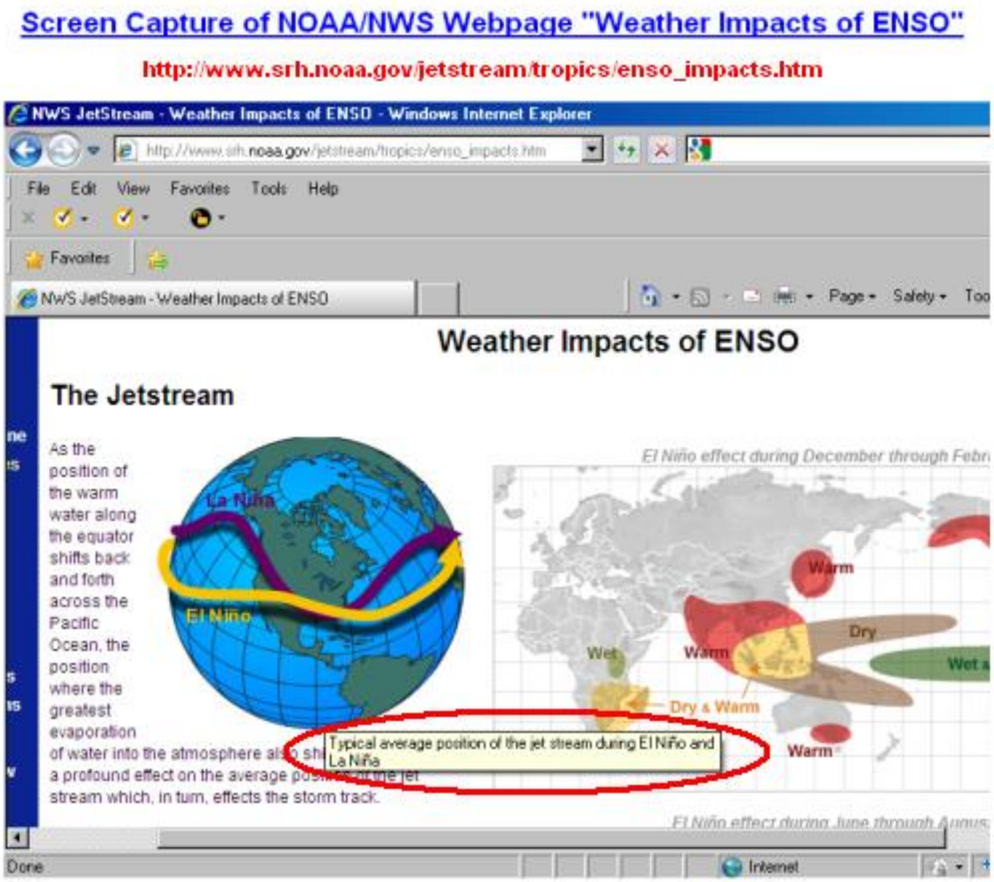


Figure 4-104 **Bob Tisdale**

The "typical" and "average" appear redundant, but I interpret that to mean the average position of the jet stream during typical/normal/average El Niño and La Niña events. NOAA/NWS reinforces that in their discussion. It reads:

> *As the position of the warm water along the equator shifts back and forth across the Pacific Ocean, the position where the greatest evaporation of water into the atmosphere also shifts with it. This has a profound effect on the average position of the jet stream which, in turn, effects the storm track.*
>
> *During El Niño (warm phase of ENSO), the jet stream's position shows a dip in the Eastern Pacific. The stronger the El Niño, the farther east in the Eastern Pacific the dip in the jet stream occurs. Conversely, during La Niña's, this dip in the jet stream shifts west of its normal position toward the Central Pacific.*

The position of this dip in the jet stream, called a trough, can have a huge effect on the type of weather experienced in North America.

During the warm episode of ENSO (El Niño) the eastern shift in the trough typically sends the storm track, with huge amounts of tropical moisture, into California, south of its normal position of the Pacific Northwest.

Very strong El Niños will cause the trough to shift further south with the average storm track position moving into Southern California.

During these times, rainfall in California can be significantly above normal, leading to numerous occurrences of flash flood and debris flows. With the storm track shifted south, the Pacific Northwest becomes drier and drier as the tropical moisture is shunted south of the region.

The maps (right) show the regions where the greatest impacts due to the shift in the jet stream as a result of ENSO. The highlighted areas indicate significant changes from normal weather occur. The the [sic] magnitude of the change from normal is dependent upon the strength of the El Niño or La Niña.

The maps referred to are similar to those presented in Figures 4-101 and 4-103.

Recent research has also shown that the changes in regional temperature and rainfall also depend on whether the ENSO event is an East Pacific or Central Pacific variety. Refer back to the discussion of Figures 4-13 and 4-14 in Chapter 4.2 **Central Pacific versus East Pacific El Niño Events**. Also consider this: because a La Niña event is normally not as strong as the El Niño before it, one should not expect a La Niña event to counteract the effects of the El Niño. The fact that a La Niña event is not the opposite of an El Niño can also impact regional weather effects of ENSO.

STUDIES THAT SERVED AS SOURCES FOR THE NOAA MAPS

The scientific studies that serve as the basis for the NOAA temperature and rainfall maps are listed at the bottoms of the NOAA/CPC web pages titled **Warm (El Niño/Southern Oscillation - ENSO) Episodes in the Tropical Pacific** and **Cold (La Niña) Episodes in the Tropical Pacific**. The papers listed include:

Ropelewski and Halpert (1987): **Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation (ENSO).**

Ropelewski and Halpert (1989): **Precipitation Patterns Associated with the High Index Phase of the Southern Oscillation**

Halpert and Ropelewski (1992): **Temperature Patterns Associated with the Southern Oscillation**

The two other references listed by NOAA/CPC provide general discussions of ENSO events and upper level circulation patterns:

Arkin (1982): **The relationship between interannual variability in the 200 mb tropical wind field and the Southern Oscillation**

Rasmusson and Carpenter (1982): **Variations in tropical Pacific sea surface temperatures and surface wind fields associated with Southern Oscillation/El Nino**

ADDITIONAL REFERENCES

Trenberth et al (2002) **Evolution of El Niño–Southern Oscillation and global atmospheric surface temperatures** provides very detailed discussions of the impacts of ENSO on regional weather. They note in their conclusions, however, that the analysis methods used in their study would emphasize strong events.

Because East Pacific events are typically the strong events, Trenberth et al (2002) might be considered a paper that deals primarily with East Pacific ENSO events. For those interested in the effects of Central Pacific ENSO events on temperature and precipitation, consider Ashok et al (2007) **El Niño Modoki and its possible teleconnection**.

The Royal Netherlands Meteorological Institute (KNMI) provides a breakdown of the effects of ENSO on temperature and precipitation, but KNMI provides it for all four seasons. See their **Effects of El Niño on world weather** webpage.

MONTHLY MAPS THAT ALSO SHOW IMPACTS ON EUROPE AND CENTRAL ASIA

For those looking for monthly maps of typical weather responses to El Niño and La Niña, the NOAA Earth Systems Research Laboratory (ESRL) has a webpage with links to **ENSO's effect on climate by month**. The September to December maps are for the evolution and peak of El Niño and La Niña, and the January to June maps run from the peak through the decay months. They capture the impacts on Europe and Central Asia better than other presentations.

Note how the headers of the maps are identified at the top of the web pages. For El Niño, they read "Composite El Niño 1965, 72, 82, 86, 91", and for La Niña, they read "Composite La Niña 1964, 70, 71, 73, 75, 88". One has to assume with composite, they're referring to the typical or essential responses to those ENSO events as a group. This would indicate that there were differences in the responses to the ENSO events and what is shown is the typical response. It also indicates the response will be different if the event is unusual.

RECAP

In areas remote to the tropical Pacific, El Niño and La Niña events alter normal temperature and precipitation patterns through changes in global atmospheric circulation. The keys to these changes in atmospheric circulation are the variations in the jet streams in both hemispheres caused by the El Niño and La Niña events, which, in turn, alter normal storm tracks and weather patterns.

4.15 Further Discussion on What Initiates an ENSO Event

When Anthony Watts cross posts one of my blog posts about ENSO at his widely read blog **WattsUpWithThat**, a question that's often asked is "What initiates an El Niño?" My reply is typically something to the effect of: An El Niño event is initiated by a weakening of the tropical Pacific trade winds. This allows the warm water that had been held in place in the west Pacific Warm Pool to slosh east.

Sometimes there's the follow-up question "What causes the trade winds to relax?" My usual reply is: There are a number of causes and they vary.

This doesn't satisfy some people who are looking for a single definite answer, but, unfortunately, it's true. There are numerous scientific papers that discuss this fact. In this chapter, we'll present relatively simple descriptions of the many factors that cause the relaxing of the trade winds.

A phenomenon known as a Westerly Wind Burst (WWB), also known as a Westerly Wind Event (WWE), accompanies the relaxed trade winds. If you wanted to investigate this further, those would be the phrases to use in your searches. There are multiple causes of Westerly Wind Bursts, including:

1. Cross-equatorial tropical cyclones in the western tropical Pacific. This refers to a time when one tropical cyclone exists north of the equator in the western tropical Pacific, while, at the same time, another tropical cyclone exists there but south of the equator. The tropical cyclone winds in the Northern Hemisphere rotate counterclockwise and in the Southern Hemisphere they're clockwise. Between them, the winds would be traveling from east to west. These are discussed in Keen (1982) **The Role of Cross-Equatorial Tropical Cyclone Pairs in the Southern Oscillation**.

2. A single cyclone and series of cyclones in the western tropical Pacific. These are discussed in Hartten (1996) **Synoptic settings of westerly wind bursts**.

3. Cold surges from mid-latitudes, discussed in Harrison (1984) **The appearance of sustained equatorial surface westerlies during the 1982 pacific warm event**

4. Convective cloud clusters associated with the Madden–Julian oscillation (MJO). Refer to Zhang (1995) **Atmospheric Intraseasonal Variability at the Surface in the Tropical Western Pacific Ocean**.

As noted earlier, there are a plethora of other papers that discuss these factors. There is a good overall discussion in Vecchi and Harrison (2000) **Tropical**

Pacific Sea Surface Temperature Anomalies, El Niño, and Equatorial Westerly Wind Events.

Then, after you've digested all of the factors that can trigger El Niño events, there's a study that could shift your understanding once again. The paper is Yu et al (2003) **Case analysis of a role of ENSO in regulating the generation of westerly wind bursts in the Western Equatorial Pacific**. Yup, you read that title correctly. Yu et al (2003) found that ENSO can create favorable background conditions for westerly wind bursts. In other words, ENSO has the built-in ability to trigger itself.

RECAP

El Niño events are initiated by the relaxation of the trade winds associated with a single or a series of Westerly Wind Bursts in the western tropical Pacific. The causes of Westerly Wind Bursts are tropical cyclones (individual, multiple, and cross equatorial), cold surges from the mid-latitudes, and convection associated with the Madden–Julian oscillation (MJO), or a combination of them. To complicate things, there are indications that ENSO can create the background conditions that promote Westerly Wind Bursts.

4.16 Weak, Moderate and Strong ENSO Event Thresholds

The more you study El Niño and La Niña events or discuss them on blogs, the more you'll come across the classifications of weak, moderate and strong events. It's often difficult to find a source that specifies the ranges associated with them. A member of NOAA has classified them in presentation called **El Niño Talking Points**, which appears to have been given in Southern California. On page 34, you'll find, during a discussion of La Niña events:

> *Weak is Niño Oscillation Index between -0.5 and -0.9. Moderate between -1.0 and -1.4. Strong is greater than -1.4.*

There's a similar breakdown on page 35 for El Niño events. The El "Niño Oscillation Index" referred to in the presentation is NOAA's Oceanic NINO Index (ONI), which is discussed in Chapter 4.3 **ENSO Indices**. As you'll recall, it is a NINO3.4 sea surface temperature-based index with a varying base period for anomalies that has been smoothed with a 3-month running-average filter.

RECAP

NOAA provides a breakdown of the strength of ENSO events. Because it is provided with only one decimal place, the ranges could be rewritten as:

Strong El Niño = NINO3.4 Sea Surface Temperature anomalies warmer than or equal to 1.5 deg C.

Moderate El Niño = NINO3.4 Sea Surface Temperature anomalies between or equal to 1.0 to 1.4 deg C.

Weak El Niño = NINO3.4 Sea Surface Temperature anomalies between or equal to 0.5 to 0.9 deg C.

Weak La Niña = NINO3.4 Sea Surface Temperature anomalies between or equal to -0.5 to -0.9 deg C.

Moderate La Niña = NINO3.4 Sea Surface Temperature anomalies between or equal to -1.0 to -1.4 deg C.

Strong La Niña = NINO3.4 Sea Surface Temperature anomalies cooler than or equal to -1.5 deg C.

4.17 ENSO – A Cycle or Series of Events?

If you were to Google ENSO and cycle, you'd get over 700,000 results. Limit your search to Google Scholar and there are more than 39,000 results. Place "ENSO cycle" in quotes and there's almost 5,800. One of the reasons: ENSO stands for El Niño-Southern Oscillation and oscillation implies cyclical behavior. Another reason: the delayed oscillator theory suggests that one phase leads to the next, and that sure sounds like a cycle. However, is ENSO really a cycle?

The need to treat ENSO as a cycle arises from the attempts to model ENSO with computers. Mother Nature, however, apparently isn't concerned about our ability to model it. While parts of ENSO act as a cycle, the evolution of an El Niño event requires a basically random event to initiate it. Therefore, to answer the title question of this chapter, ENSO is a combination of the two.

Kessler (2002) **Is ENSO a cycle or a series of events?** discusses how observational data suggest that El Niño events are event-like disturbances, while other phases display the behavior of a cycle. The abstract reads:

> *After early ideas that saw El Niños as isolated events, the advent of coupled models brought the conception of ENSO as a cycle in which each phase led to the next in a self-sustained oscillation. Twenty-two years of observations that represent the El Niño and La Niña peaks (east Pacific SST) and the memory of the system (zonal-mean warm water volume) suggest a distinct break in the cycle, in which the coupled system is able to remain in a weak La Niña state for up to two years, so that memory of previous influences would be lost. Similarly, while the amplitude of anomalies persists from the onset of a warm event through its termination, there is no such persistence across the La Niña break. These observations suggest that El Niños are in fact event-like disturbances to a stable basic state, requiring an initiating impulse not contained in the dynamics of the cycle itself.*

When studying this subject and looking for additional papers, it is important to isolate discussions of models and the efforts being taken to improve them. Models are not reality. They are attempts to simulate Mother Nature with computers. The discussion of whether ENSO is a cycle or a series of events is an observations-based discussion. Some of the model-based papers do include discussions of observations, but you have to make sure you're basing your understandings of ENSO on the observations and not the models in those papers. That pretty much holds true for all climate and climate change papers.

4.18 ENSO Influence on Tropical Cyclones (Hurricanes)

In this chapter, we'll discuss how and where tropical cyclones are impacted by ENSO events.

Most people interested in Atlantic hurricanes have heard of Dr. William Gray, Professor of Atmospheric Science at Colorado State University. He and his team have been forecasting Atlantic hurricanes since 1984. That's the same year Dr. Gray published a 2-part study that discussed ENSO as one of the significant factors that influence tropical cyclone development. Refer to Gray (1984) **Atlantic Seasonal Hurricane Frequency. Part I: El Niño and 30 mb Quasi-Biennial Oscillation Influences** and **Atlantic Seasonal Hurricane Frequency. Part II: Forecasting its Variability**. Dr. Gray noted in the abstract of Part I (my boldface):

> *El Niño events are shown to be related to an anomalous increase in upper tropospheric westerly winds over the Caribbean basin and the equatorial Atlantic. Such* ***anomalous westerly winds inhibit tropical cyclone activity by increasing tropospheric vertical wind shear*** *and giving rise to a regional upper-level environment which is less anticyclonic and consequently less conductive to cyclone development and maintenance.*

Basically, El Niño events create a phenomenon called vertical wind shear in areas where hurricanes develop. That leads back to an earlier paper by Dr. Gray. In 1968, he described the role of wind shear on tropical storms in **Global View of the Origin of Tropical Disturbances and Storms**. There he writes:

> *In the SW Atlantic and central Pacific, where tropical storms do not occur, the observed climatological tropospheric* ***wind shear*** *is large (i.e., 20-40 kt). This is believed to be the major inhibitor to development in these areas.*

What's wind shear? Wind shear is a change in wind speed or direction across a straight line. There are horizontal and vertical components to wind shear. Microbursts or strong downdrafts, concerns of airplane pilots, are associated with horizontal wind shear. We're not interested in that, though. It's vertical wind shear that impacts tropical cyclone formation and their demise. When there are large differences in the wind speeds at high and low levels in the troposphere, vertical wind shear is high. Refer to Figure 4-105. Conversely, if there's little difference in speed between high and low level winds, vertical wind shear is low.

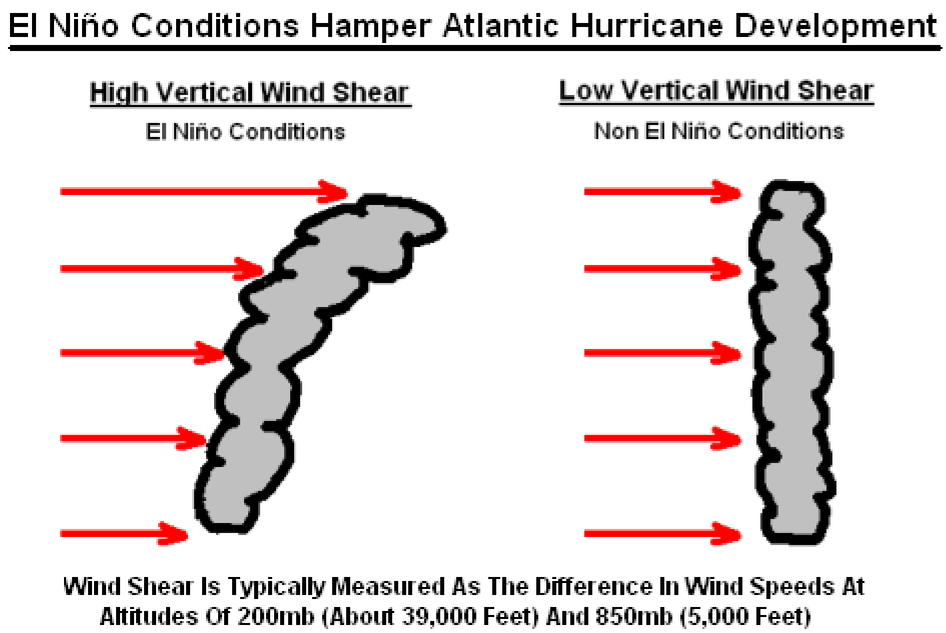


Figure 4-105

The recipe for a tropical cyclone has three primary ingredients. The first is warm water—waters in excess of 26 deg C. Because the tropical storm feeds off the warm water, it cools the sea surface, so the warm water has to reach depths of about 60 meters in order to support the development of the tropical cyclone. The second ingredient is moisture and lots of it. The moisture has to cover a large area and be thick, normally extending from the sea surface to altitudes to 20,000 feet (about 465mb). The third ingredient is relatively light winds. That's where an El Niño spoils the recipe.

An El Niño event in the tropical Pacific causes stronger-than-normal high level westerly winds in the Main Development Region of the tropical North Atlantic, and those strong high level winds can cause wind shear.

As we've discussed, El Niño events impact climate conditions around the globe. Therefore, in addition to affecting the development of tropical cyclones in the North Atlantic, ENSO events impact their formation in the east and west Pacific and in the eastern Indian Ocean as well. Table 4-5 is a screen capture of a table from the NOAA **Weather Impacts of ENSO** webpage. It shows the changes in the number and intensity of tropical cyclones worldwide. As illustrated, those El Niño-caused changes vary greatly from region to region. In regions where there are increases in tropical cyclone strength and number, like the eastern North Pacific, wind shear is reduced during El Niño events.

Note: In the Table 4-5, the Western Australian region is actually in the eastern portion of the South Indian Ocean. It's isolate from the other Indian Ocean regions because there are some minor changes in the Western Australian region during El Niño years, while in the two other Indian Ocean regions, there's no change in the number and intensity of tropical cyclones.

Number And Intensity Of Tropical Cyclones Around The World Due To The Effects Of El Niño

(Screen Capture From NOAA "Weather Impacts of ENSO" Webpage)
http://www.srh.noaa.gov/jetstream/tropics/enso_impacts.htm

From Australia Bureau of Meteorology

Region		El Niño Years		Non-El Niño Years	
		Number of Storms	Intensity	Number of Storms	Intensity
North Atlantic		Large Decrease	Small Decrease	Small Increase	Small Increase
Eastern North Pacific		Slight Increase	Increase	Slight Decrease	Decrease
Western North Pacific	Eastern half	Increase	No Change	Decrease	No Change
	Western half	Decrease	No Change	Increase	No Change
Indian Ocean (North / South)		No Change	No Change	No Change	No Change
Australian Region	Western	Slight Decrease	No Change	Slight Increas	No Change
	Central and East	Decrease	Slight Decrease	Increase	Slight Increase
South / Central Pacific (>160°E)		Increase	Increase	Decrease	Slight Decrease

Table 4-5 Bob Tisdale

Two recent studies present how the East Pacific and Central Pacific El Niño events have different impacts on tropical cyclones in the Atlantic and in the North Pacific. Refer to Kim et al (2009) **Impact of Shifting Patterns of Pacific Ocean Warming on North Atlantic Tropical Cyclones** and Kim et al (2011) **Modulation of North Pacific Tropical Cyclone Activity by Three Phases of ENSO**.

RECAP

El Niño conditions in the equatorial Pacific impacts the development of tropical cyclones throughout the world. El Niño events alter normal wind shear. Increased wind shear limits cyclone development, and decreased wind shear supports it.

Section 5 – The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies

We'll start with a discussion and presentation of the very obvious long-term impacts of certain ENSO events on the global sea surface temperature anomalies. As many of you understand, global data hides the differing effects ENSO has on various parts of the global oceans. To isolate them, we'll divide the global oceans into logical subsets and present them in a logical order.

There are three distinct ENSO-related signals in the satellite-era sea surface temperature record and they make their presence known in those three subsets: The ENSO "Cycle" of the East Pacific, The Staggered Saw-Tooth Pattern of the East Indian and West Pacific Oceans, which extends out to the larger subset of the South Atlantic-Indian-West Pacific Oceans, and the third signal, which is the staggered saw-tooth pattern on a positive trend in the North Atlantic. These three ENSO-related signals exist because the global oceans respond differently to large El Niño events that are followed by La Niña events than they do to lesser El Niño and La Niña events.

Next, we'll present and discuss the impacts of those same ENSO events on Lower Troposphere Temperature anomalies. Temperatures of the troposphere and stratosphere are measured by satellites, and the Lower Troposphere Temperature is measured at an altitude of about 3000 meters. The Lower Troposphere Temperature anomalies for the mid-to-high latitudes of the Northern Hemisphere clearly portray a saw-tooth pattern. Then we'll move on to the very obvious impacts of those specific ENSO events on global land-plus-sea surface temperature anomalies. We'll illustrate and discuss the processes that cause the saw-tooth patterns in surface and lower troposphere temperatures of the mid-to-high latitudes in the Northern Hemisphere.

Let's start with the portion of the global oceans where the impacts of ENSO are as one would expect. That is, during an El Niño event, sea surface temperatures warm and during a La Niña, the sea surface temperatures cool proportionately. Proportionately is the key word.

5.1 No Surprise - East Pacific Sea Surface Temperature Anomalies Mimic ENSO, But Where's The Anthropogenic Global Warming Signal?

The East Pacific Ocean (90S-90N, 180-80W) responds to ENSO as one would expect. It warms during the evolution of an El Niño, cools during the decay of the El Niño, cools more during the evolution of the La Niña, and then warms during the La Niña decay. In other words, time-series graphs of the East Pacific Ocean present a pattern in time that mimics the "ENSO cycle".

The East Pacific Ocean serves only as a temporary home for the warm water released by an El Niño. Warm water from the surface and below the surface of the west Pacific Warm Pool sloshes east and enters the tropical East Pacific Ocean. Slow moving Rossby waves and the renewed trade winds return the warm water back to the West Pacific when an El Niño is finished. The East Pacific Ocean is also only a temporary home of the additional cool waters drawn from below the surface of the eastern equatorial Pacific by a La Niña. During a La Niña, the stronger trade winds cause more cool water than normal to be upwelled in the eastern tropical Pacific, and the stronger ocean currents carry that cool water westward under a cloud-reduced sky, warming it on its way to the West Pacific. One might think, because the East Pacific Ocean is simply a temporary home for the warm and cool waters, then any anthropogenic global warming signal should be very apparent there.

On the contrary, there's no evidence of an anthropogenic global warming signal in the East Pacific Ocean. None. Nada. Zip. Zilch.

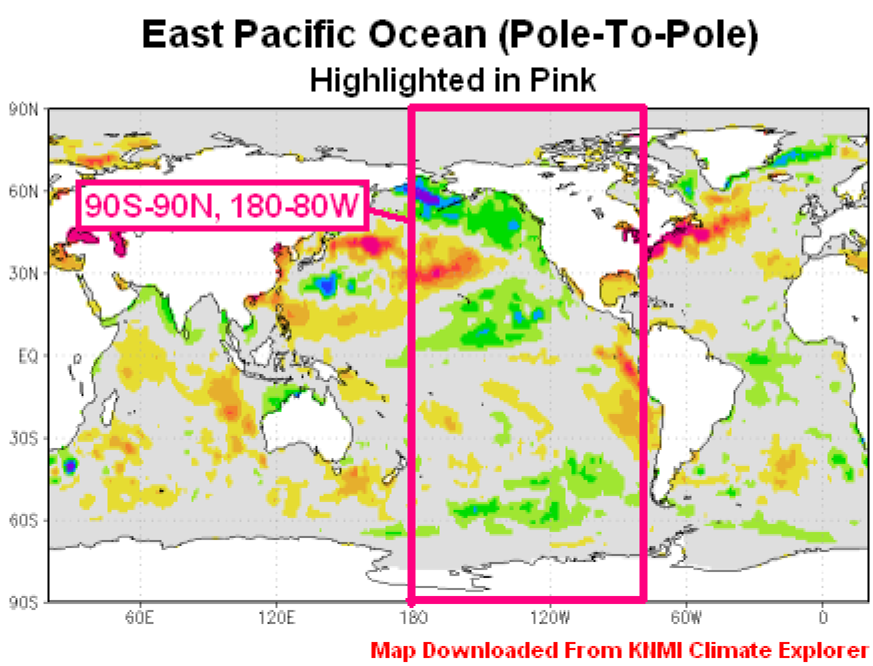


Figure 5-1

Figure 5-1 shows the area of the global oceans we'll use when discussing the East Pacific sea surface temperature. It captures the data from pole to pole, and also includes parts of the Arctic Ocean, Gulf of Mexico, Caribbean Sea, and Southern Ocean, which has no physical boundary with other ocean basins. The separation at 80W is basically a convenience, because the data is readily available using global coordinates. This also makes it easier for readers to duplicate the results if there are any questions. Also, the ENSO signal is so strong in the eastern Tropical Pacific that the additional small portions of the other basins have little impact on the results of this discussion.

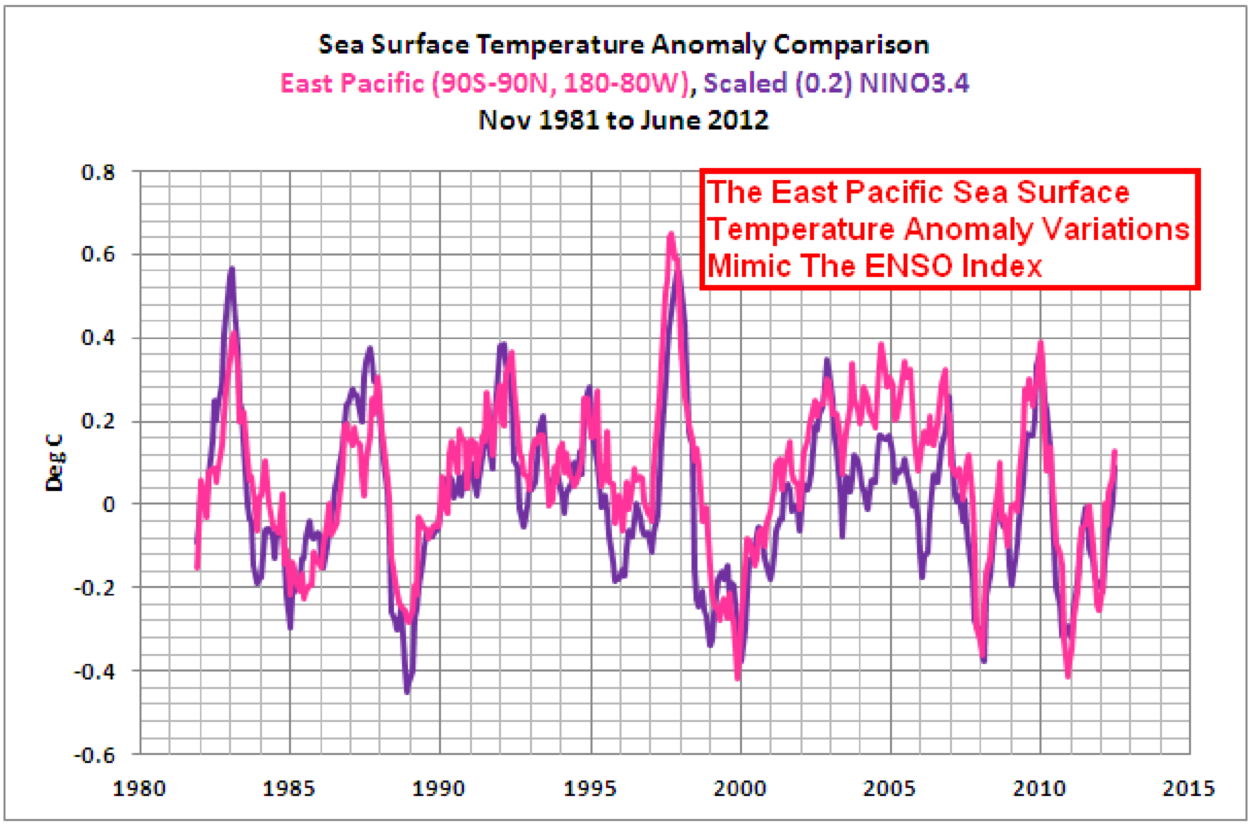


Figure 5-2

Bob Tisdale

Another thing to keep in mind: the East Pacific data represents about 33% of the surface area of the global oceans. This is not a small region.

As noted in the title of this chapter, the variations in the sea surface temperatures of the East Pacific Ocean mimic the variations of ENSO. This is plainly illustrated in the comparison graph of scaled sea surface temperature anomalies of the NINO3.4 region and of the East Pacific Ocean, from pole to pole. See Figure 5-2. The two datasets wander away slightly from one another occasionally, but all-in-all, the East Pacific data is responding to the massive variations in the tropical portion. Note the scaling factor of 0.2 used for the ENSO index. The sea surface temperature anomalies of the NINO3.4 region are varying at a rate that's about five times greater than the overall East Pacific, so the changes in the sea surface temperatures along the equator make up a good part of the East Pacific's variability.

I've removed the scaled ENSO index data in the Figure 5-3 and had EXCEL determine the linear trend of the East Pacific sea surface temperature anomalies since the start of the satellite-based data; that is, for the past 30 years. The sea surface temperature anomalies of the East Pacific Ocean, from pole to pole, have not warmed in that time. A trend of 0.006 deg C per decade is basically flat. That's 6 thousandths of a deg C per decade, or based on the linear trend, they've warmed 1.8 one-hundredths of a deg C over the past 30 years. It's foolish to think in terms that small when dealing with a body of water that's about 120 million square kilometers or about 46 million square miles. To put that in perspective, the land surface area of the Earth is about 149 million square kilometers.

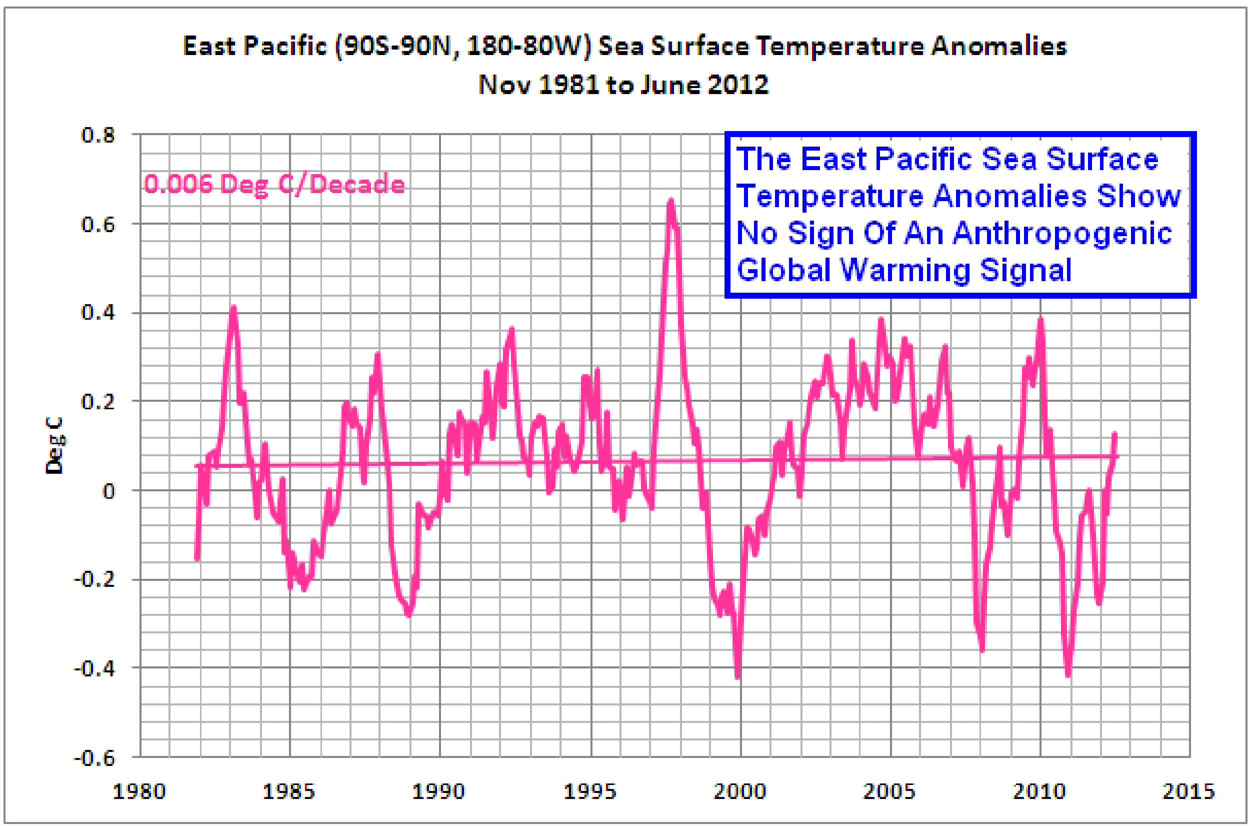


Figure 5-3 Bob Tisdale

Then there are the climate models used by the IPCC in their 4th Assessment Report published in 2007, and the "new-and-improved" climate models prepared for the upcoming 5th Assessment Report due out in 2013. Their simulations show that, according the hypothesis of anthropogenic global warming, East Pacific sea surface temperature anomalies should have warmed at a rate of about 0.14 to 0.15 deg C per decade. See Figure 5-4. The models show it should have warmed, but the satellite-based sea surface temperature data show the warming there has been negligible.

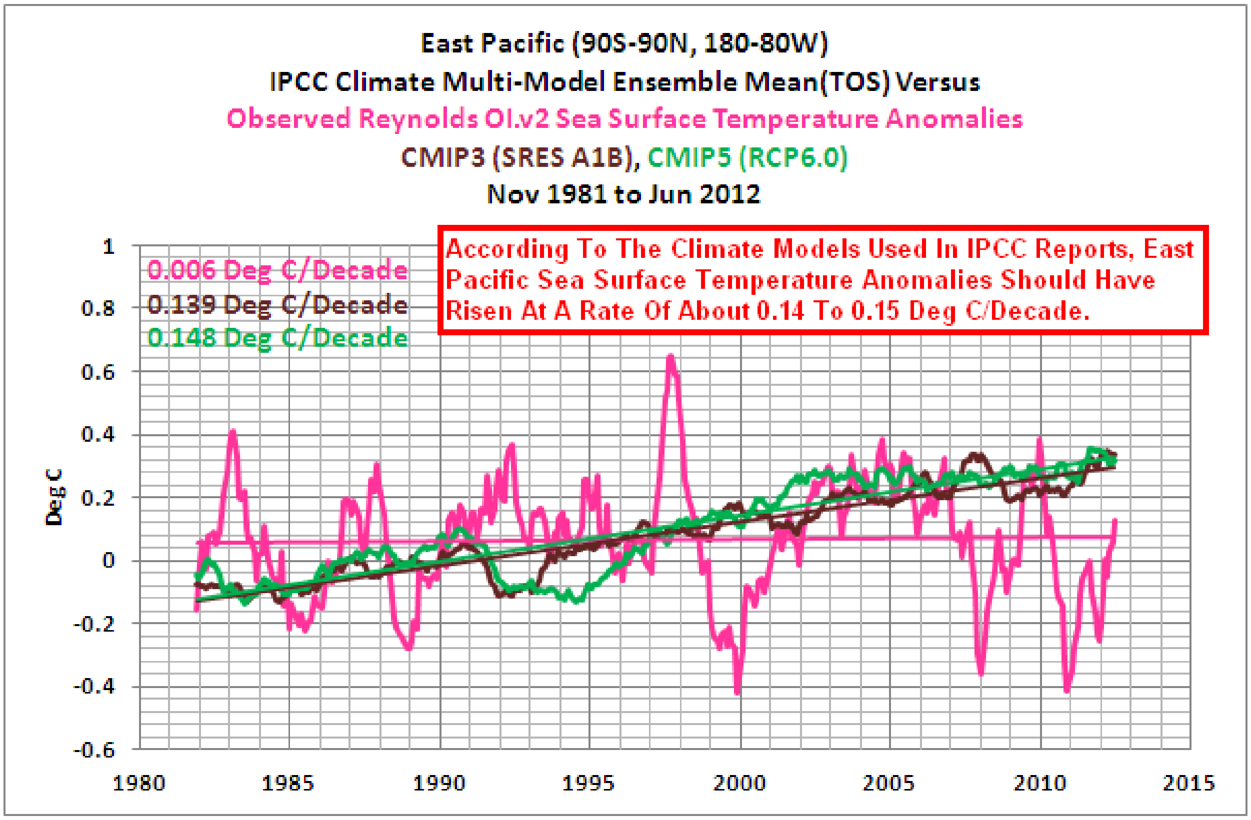


Figure 5-4

Bob Tisdale

The most obvious differences between the model curves (green and brown) and the instrument-based sea surface temperature observations (pink curve) are the year-to-year variations in the observations. The upward spikes in the observations are caused by El Niño events and most of the downward spikes are caused by La Niña events. Why don't the model-mean curves show the upward and downward spikes from the El Niño and La Niña events?

Keep in mind the multi-model mean represents the average of dozens of individual climate model simulations. Refer to our discussion of climate models in **Chapter 2.9 Using the Model Mean of the IPCC's Climate Models**. Some of those climate models try to produce El Niño and La Niña events, but they don't do it well. In fact, there are many scientific studies that discuss how poorly the models simulate them. None of the models can simulate the strengths and timing of the El Niño and La Niña events as they actually happened during the 20th Century. Additionally, because each model creates the El Niño and La Niña events at random times and strengths, and because each ensemble member is different, averaging dozens of simulations minimizes any upwards and downward spikes. In other words, the averaging used to create the model mean smooth out the spikes in the data.

Regardless, 33% of the global oceans, a major portion, has not warmed in 30 years, but the models are saying, if greenhouse gases were the reason the oceans warmed, the East Pacific would have warmed about 0.42 to 0.45 deg C.

WHAT ARE CMIP3, CMIP5, SRES A1B, AND RCP6.0?

I've used a few new acronyms in Figure 5-4: CMIP3, CMIP5, SRES A1B, and RCP6.0.

The Lawrence-Livermore National Laboratory (**LLNL**) Program for Climate Model Diagnosis and Intercomparison (**PCMDI**) maintains archives of climate models used in the IPCC's assessment reports. These archives are known as Coupled Model Intercomparison Project (CMIP). The 3rd phase archive (**CMIP3**) served as the source of climate models for the IPCC's 4th Assessment Report (AR4), and the 5th phase archive (**CMIP5**) is the source of models for the IPCC's upcoming 5th Assessment Report (AR5).

SRES A1B, and RCP6.0 represent forcing scenarios used as inputs to the climate models. Refer to the **Summary for Policymakers of Working Group 1** of the Intergovernmental Panel on Climate Change's (IPCC's) 4th Assessment Report (AR4). It shows hindcasts and projections of global surface temperatures for a number of scenarios. The scenarios are explained on page 18 of the linked Summary for Policymakers. Scenario A1B is commonly referenced. In fact, that is the only scenario provided as merged hindcast-projection data (the first 3 fields) at the **Monthly CMIP3+ scenario runs** webpage at the KNMI Climate Explorer. For the upcoming 5th Assessment Report, the IPCC has changed forcing scenarios.

IPCC will be presenting four new scenarios in AR5, and those scenarios are called Representative Concentration Pathways or RCPs. The World Meteorological Organization (WMO) writes on the **Emissions Scenario** webpage:

> *The Representative Concentration Pathways (RCP) are based on selected scenarios from four modelling teams/models working on integrated assessment modelling, climate modelling, and modelling and analysis of impacts. The RCPs are not new, fully integrated scenarios (i.e., they are not a complete package of socioeconomic, emissions, and climate projections). They are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modelling. Conceptually, the process begins with pathways of radiative forcing, not detailed socioeconomic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result*

from a diverse range of socioeconomic and technological development scenarios. Four RCPs were selected, defined and named according to their total radiative forcing in 2100 (see table below). Climate modellers will conduct new climate model experiments using the time series of emissions and concentrations associated with the four RCPs, as part of the preparatory phase for the development of new scenarios for the IPCC's Fifth Assessment Report (expected to be completed in 2014) and beyond.

Table 1.1: Overview of Representative Concentration Pathways (RCPs)

RCP 8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.
RCP 6	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100
RCP 4.5	Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100
RCP 3-PD2	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline

NOTE: RCP 3-PD2 is listed as "RCP 2.6" at the KNMI Climate Explorer **Monthly CMIP5 scenario runs** webpage.

Further information about the individual RCPs can be found at the International Institute for Applied Systems Analysis (IIASA) webpage **here**.

RCP 6.0 projects about the same warming of surface temperature as SRES A1B, and if memory serves, the SRES A1B forcing in 2100 was about 6.05 watts/m^2, and that's comparable to RCP 6.0.

RECAP

The direct effects of El Niño and La Niña events dominate the yearly variations in the sea surface temperatures of the East Pacific Ocean, from pole to pole. Therefore, the sea surface temperature anomalies of the East Pacific Ocean mimic those of the NINO3.4 region. In other words, sea surface temperatures for the East Pacific respond to ENSO as one would expect. During an El Niño event, East Pacific sea surface temperature anomalies warm, and sea surface temperatures there cool proportionately during La Niña events.

Climate models used by the IPCC indicate the sea surface temperatures of the East Pacific Ocean from pole to pole should have warmed about 0.42 to 0.45 deg C over the past 30 years, but satellite-based observations show they have not warmed at all during that period. In other words, there is no evidence that the sea surface temperatures of 33% of the surface area of the global oceans have been impacted by the increase in anthropogenic greenhouse gases. No evidence at all.

This chapter confirms what was noted in the introduction:

Climate models show how surface temperatures would warm IF they were warmed by manmade greenhouse gases. The truth is, the Earth's oceans do not respond to manmade greenhouse gases as the modelers have assumed. The sea surface temperature records show the global oceans couldn't care less about a little back radiation from anthropogenic greenhouse gases. While global sea surface temperatures have definitely warmed over the past 3 decades, there is no indication that additional infrared radiation from increased concentrations of carbon dioxide caused the warming.

5.2 But Global Sea Surface Temperature Anomalies Have Warmed During the Satellite Era

We've just seen and discussed that the sea surface temperatures for a major portion (33%) of the global oceans have not warmed in 30 years. This contradicts the hypothesis of anthropogenic global warming. The models show the East Pacific Ocean should have warmed 0.42 to 0.45 deg C during the satellite era, but they haven't warmed at all.

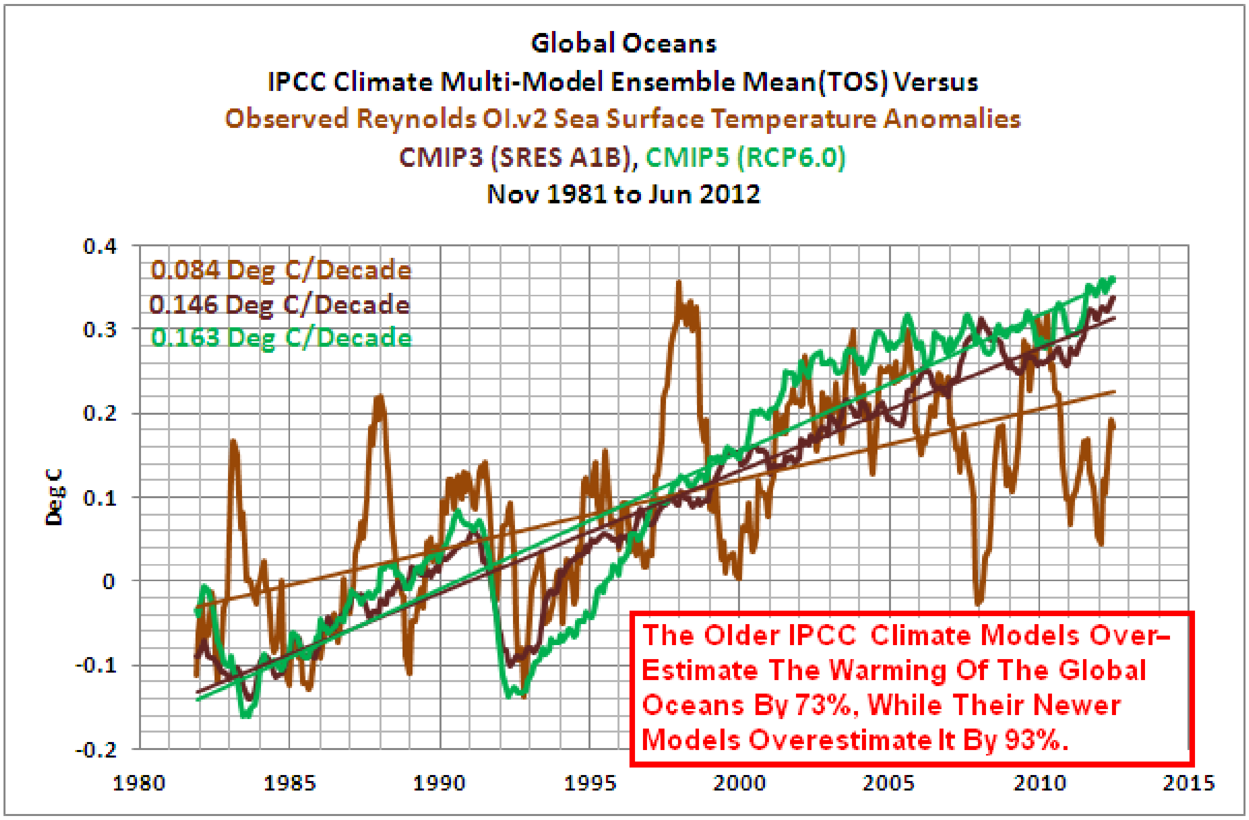


Figure 5-5

Bob Tisdale

On the other hand, if we look at the global sea surface temperature record for the past 30 years, Figure 5-5, we can see that they have warmed. The IPCC's climate models indicate sea surface temperatures globally should have warmed and they have. Note, however, based on the linear trends the older climate models have overestimated the warming by 73% and the newer models used in the upcoming IPCC AR5 have overshot the mark by 94%. In simple words, the IPCC's models have gone from terrible to worse-than-that. The recent models estimate a warming rate for the global oceans that's almost twice the actual warming. Basically, the sea surface temperatures of the global oceans are not responding to the increase in manmade greenhouse gases as the climate models say they should have. Not a good sign for any projections of future climate the IPCC may make.

If the East Pacific data haven't warmed, but global sea surface temperatures have, then the rest-of-the-world (Atlantic-Indian-West Pacific) sea surface temperatures should be more in line with the climate models, and that's what happened. As shown in Figure 5-6, the models do a much better job of simulating the warming trend of the Atlantic-Indian-West Pacific sea surface temperatures. Then again, that's fundamentally luck. The climate models are driven by anthropogenic forcings, but the sea surface temperature record shows the warming of the Atlantic-Indian-West Pacific Oceans is caused by natural processes, not anthropogenic forcings.

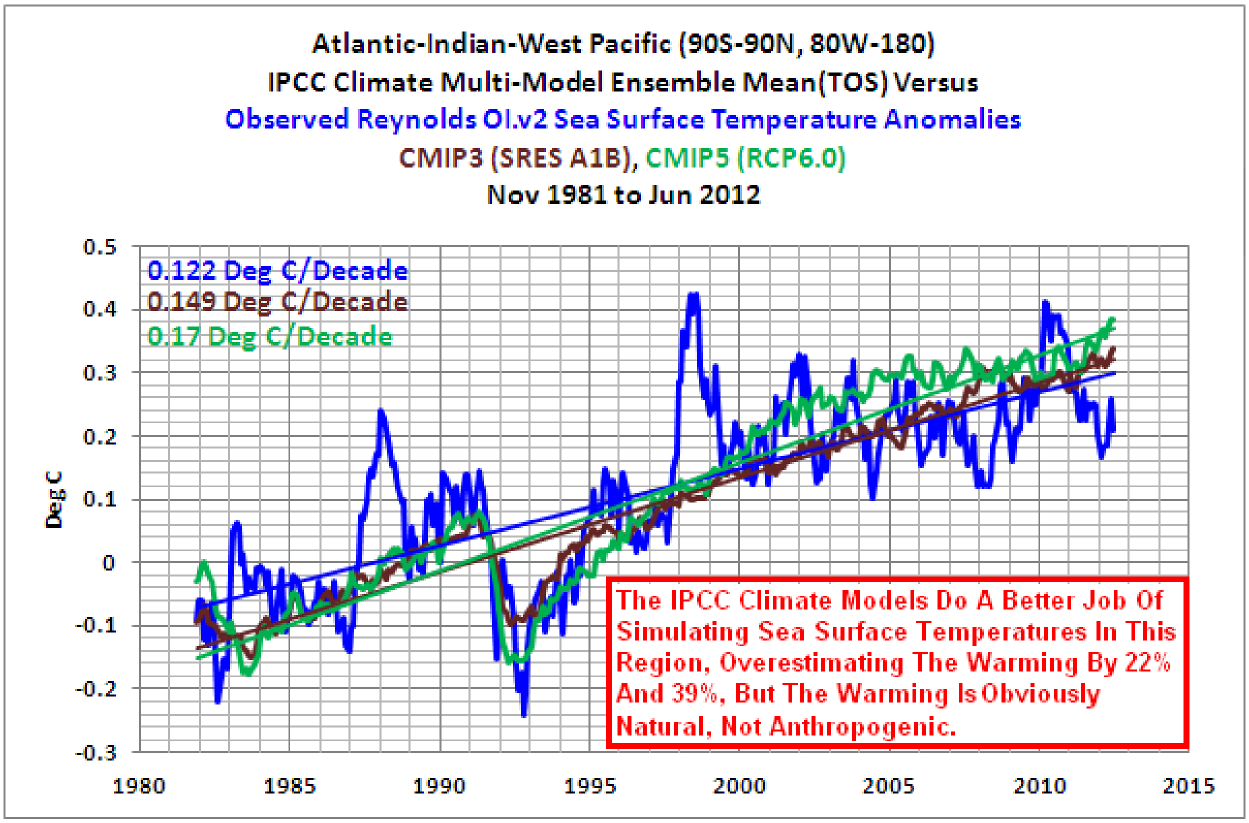


Figure 5-6 Bob Tisdale

RECAP

The fact that the sea surface temperatures of the East Pacific have not warmed in 30 years, while the global data shows warming, does not indicate there is an anthropogenic global warming signal in the global data. As we shall see, there is no evidence of any anthropogenic warming of global sea surface temperatures.

Also, the use of a global temperature metric is misleading in a discussion of anthropogenic global warming. It sounds odd, but it's true. The global data hides the true cause or causes of the warming.

5.3 Where and Why Sea Surface Temperatures Can Warm in Response to Certain El Niño AND La Niña Events

This chapter is basically a "lead-in" to the discussion of the time-series graph of the East Indian and West Pacific sea surface temperatures in the next chapter.

In Sections 1 and 3, we discussed how El Niño and La Niña events are different. There were also brief mentions of their differences in Section 4. Let's take another look as a refresher.

La Niña is basically an exaggerated ENSO-neutral state. The trade winds are blowing in the normal east-to-west direction during a La Niña, and the stronger trade winds are causing additional upwelling of cool subsurface waters in the central equatorial Pacific. That cool water travels to the west just as it normally does during the ENSO-neutral phase.

On the other hand, El Niño is the atypical phase. Warm water from the surface and from below the surface of the west Pacific Warm Pool is carried eastward by an engorged Pacific Equatorial Counter Current. Most of the warm water for the El Niño comes from below the surface of the Pacific Warm Pool. Before the El Niño, that warm subsurface water wasn't included in the global surface temperature record, but during the El Niño, it is included. See Figure 5-7. After the El Niño, all of the leftover warm water that's on the surface doesn't magically disappear. It has to go somewhere. The trade winds and ocean currents transport it back to the western Pacific Ocean, where it is carried poleward by the western boundary currents and carried westward into the Indian Ocean.

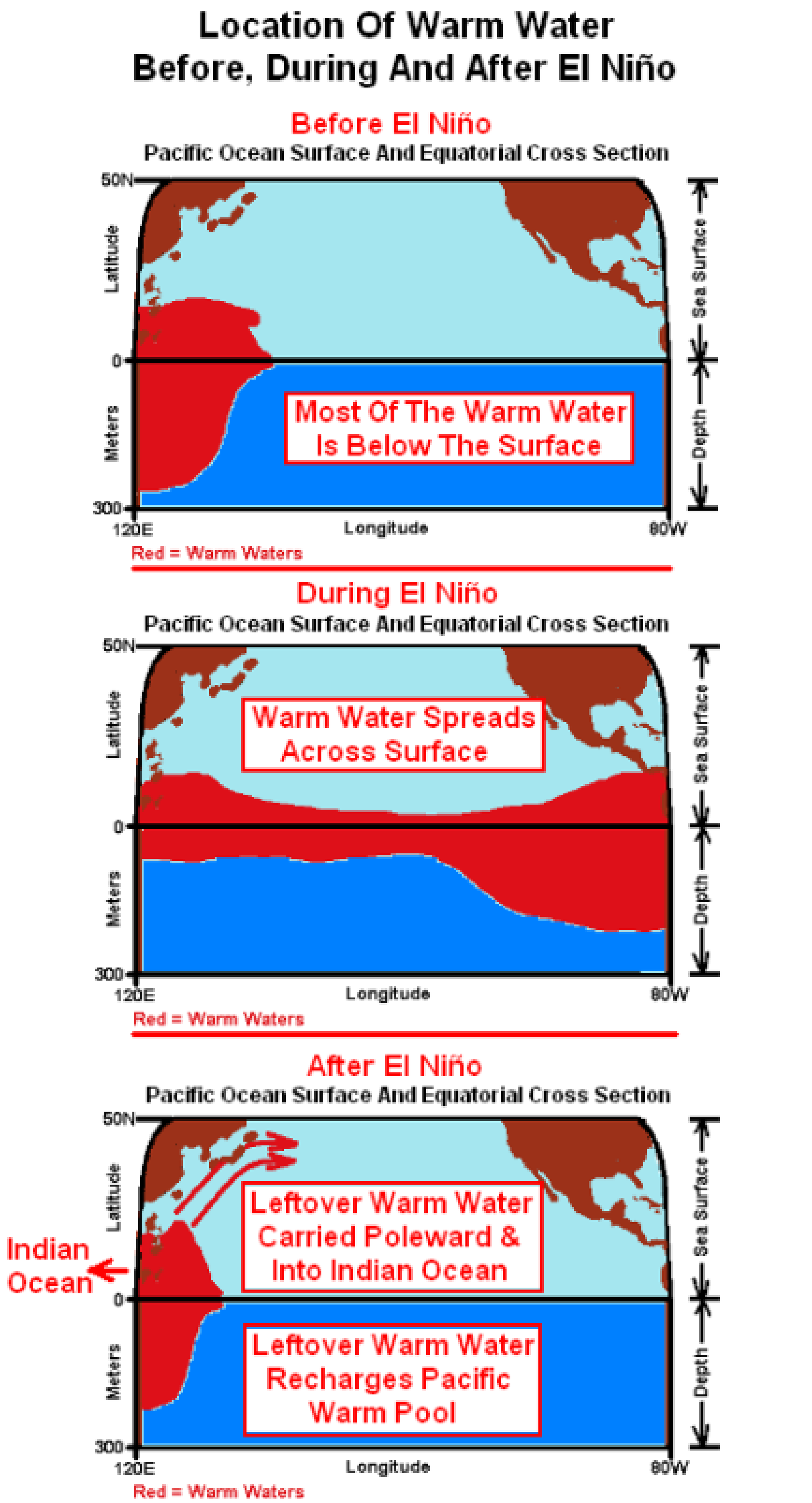

Location Of Warm Water
Before, During And After El Niño
Before El Niño
Pacific Ocean Surface And Equatorial Cross Section
50N
Latitude
0
Meters
300
120E
Longitude
80W
Sea Surface
Depth
Most Of The Warm Water
Is Below The Surface
Red = Warm Waters
During El Niño
Pacific Ocean Surface And Equatorial Cross Section
Warm Water Spreads
Across Surface
Red = Warm Waters
After El Niño
Pacific Ocean Surface And Equatorial Cross Section
Indian
Ocean
Leftover Warm Water
Carried Poleward &
Into Indian Ocean
Leftover Warm Water
Recharges Pacific
Warm Pool
Red = Warm Waters
Bob Tisdale

Figure 5-7

We can actually see the aftereffects of this leftover warm water on the East Indian and Pacific Oceans by looking at sea surface temperature maps before, during and after the 1997/98 El Niño. Figure 5-8 presents a series of sea surface temperature anomaly maps. The maps represent 12-month average sea surface temperature anomalies. The 12-month averages were used to minimize any seasonal components and weather noise. I've highlighted the dateline and 80W longitude to isolate two parts of the sea surface temperature anomaly maps. The East Indian-West Pacific portion discussed in the following is captured by the longitudes of 80E-180, while the East Pacific, which we've already discussed, is captured by the longitudes of 180-80W. Cell A in the upper left-hand corner presents the average sea surface temperatures for the East Indian and Pacific Oceans from June 1996 to July 1997. It serves as our "before" reference. The 1997/98 sea surface temperature anomalies in the upper-right hand map (Cell B) reflect the impact of that enormous El Niño. Sea surface temperature anomalies are very high in the eastern tropical Pacific, and they indicate the direct impact of the El Niño. Elevated anomalies exist along the west coasts of the Americas. In the East Indian and West Pacific Oceans, the sea surface temperatures have warmed in part in response to the changes in atmospheric circulation that have worked their way eastward around the globe.

Cell C shows the average sea surface temperature anomalies for the 12-month period a year after the 1997/98 El Niño. Whenever I see that map I'm reminded of the old-wives' tale that says global surface temperatures cool during La Niña events. There are many climate scientists still telling that fictional story about ENSO. Sea surface temperature anomalies in the East Indian and West Pacific Oceans warm during a La Niña that follows an El Niño (especially a large East Pacific El Niño event) for a number of reasons: First, the El Niño caused changes in atmospheric circulation, and they worked their way around the globe and have warmed the East Indian and West Pacific Oceans. Second, the warm surface waters that are left over from the El Niño have been swept back to the East Indian and West Pacific Oceans by the return of the trade winds. Third, a slow-moving Rossby wave carried a vast amount of subsurface warm water back to the West Pacific, where it rises to the surface due to subsurface currents and gravity (the warmer water is lighter than cooler water). Fourth, the La Niña helps to maintain the elevated sea surface temperatures in the East Indian and West Pacific Oceans, through the increased visible sunlight (downward shortwave radiation), caused by the stronger trade winds and associated reduction in cloud cover, which provides additional warm surface waters. Even two years after the 1997/98 El Niño, Cell D, sea surface temperatures remain elevated in the East Indian and West Pacific Oceans. Granted, the sea surface temperatures in the tropical East Indian and West Pacific Oceans have decreased by the second year, but the sea surface temperature anomalies east of Japan, along the Kuroshio-Oyashio Extension (KOE), are still very high, still releasing heat into the atmosphere. In fact, it almost appears as though a secondary El Niño is taking place east of Japan—two years after the original El Niño.

We'll confirm the response of the East Indian and West Pacific Oceans in the next chapter using time-series graphs. A few comments first:

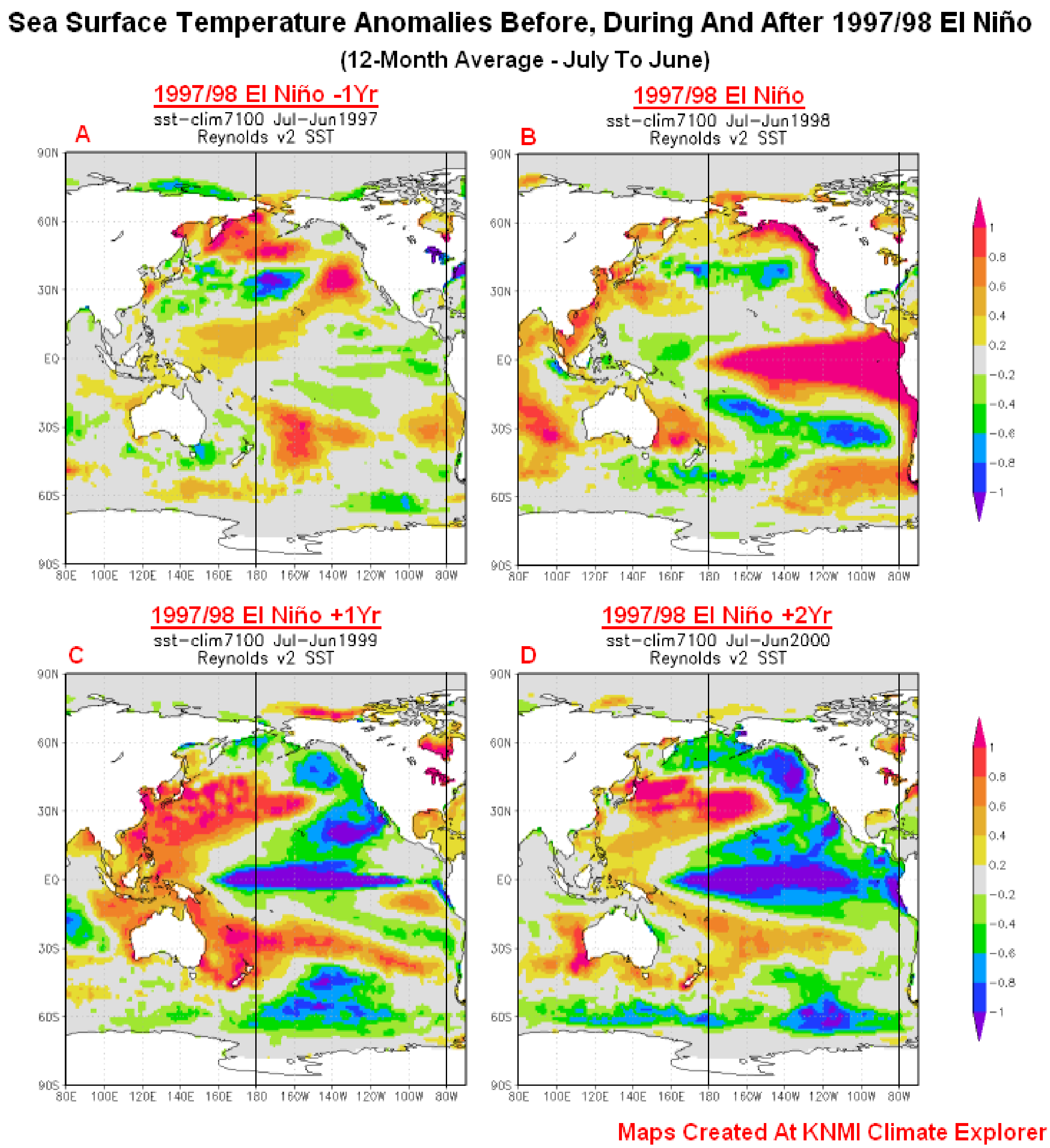


Figure 5-8

Bob Tisdale

BUT THE OCEANS SHOWED WARM AREAS BEFORE THE 1997/98 EL NIÑO!

Looking at Cell A above, you might be concerned that it shows areas that are warm even before the 1997/98 El Niño. That's very true. There are warm areas. Those are parts of year-to-year spatial patterns of sea surface temperature anomalies. Some areas are cooler than normal, while others are warmer. However, we've already discussed the East Pacific data, which is the dataset between the dateline and 80W, and it displayed two things: First, it varies proportionately with our ENSO index. Second, it hasn't warmed in 30 years. We can put the East Pacific data off to the side for a while, but we can't forget about it.

Also, I highlighted the dateline to allow you to focus on the data to the west of it. That portion of the maps represents the East Indian-West Pacific Oceans. Notice how much the East Indian-West Pacific warmed between Cells A and C, yet we're told global temperatures cool during a La Niña. The East Indian-West Pacific dataset warmed in response to the El Niño, but did not cool proportionately to the La Niña. The sea surface temperatures there are still elevated two years after the 1997/98 El Niño, as shown in Cell D. We'll confirm that in the next chapter.

BUT AREN'T THERE SIMILARITIES BETWEEN EL NIÑO AND LA NIÑA PROCESSES?

When we looked at Figure 5-8, we discussed a number of the processes that caused the East Indian-West Pacific data to warm during the La Niña. You're likely thinking that many of the things happen in reverse during a La Niña. To counter that thought, as we've discussed many times, the similarities between El Niño and La Niña do not mean they're opposites.

Consider this: the discussion so far in this chapter has been about an El Niño (1997/98) that's followed by a La Niña (1998/99/00/01). Basically, we're looking at the combined effects of a strong (East Pacific) El Niño that's followed by a strong (Central Pacific) La Niña. During the last 30 years, the two largest La Niña events (which by no small coincidence followed the two strongest El Niño events) were the 1988/89 and 1998/99/00/01 La Niña events. Those La Niña were not followed immediately by El Niño. The 1991/92 El Niño was the first El Niño after the 1988/89 La Niña. It developed two years after the demise of the 1988/89 La Niña. Further to this, the El Niño that followed the 1998/99/00/01 La Niña waited until 2002/03. More than a year had passed before it developed. As you'll recall, delays like that are what altered the thoughts that ENSO is a true cycle, as represented by the delayed oscillator theory. This was discussed in Chapter 4.17 **ENSO – A Cycle or Series of Events?**

In **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation,** we've discussed that the effects of La Niña events on surface temperatures and precipitation are similar but the opposite sign of El Niño events, and how they're both caused by changes in atmospheric circulation patterns. As you'll remember, NOAA also noted how stronger ENSO events have greater impacts on regional temperatures and precipitation. On their **Weather Impacts of ENSO** webpage, NOAA writes:

> *The the [sic] magnitude of the change from normal is dependent upon the strength of the El Niño or La Niña.*

Rarely are La Niña events as strong as El Niño events, so a La Niña would not counteract the effects of the stronger El Niño, meaning there would be warming residuals left after the El Niño and La Niña events had occurred.

Granted, there are slow-moving off-equatorial Rossby waves associated with both El Niño and La Niña events, but the Rossby waves that are part of La Niña events are rarely if ever as strong as those associated with El Niño events. In fact, if you'll recall, it was difficult to see some of the off-equatorial Rossby waves that occurred after the La Niña events shown in Chapter 4.9 **An Introduction to the Delayed Oscillator Mechanism**. Refer back to the sea level anomaly maps in Figures 4-62 through 4-69, and then compare them to the post-El Niño Rossby waves shown in Figures 4-56 through 4-61.

Last, and very important, there are no leftover cool surface waters in the East Pacific after a La Niña event, because the trade winds have been pushing the cool waters from east to west throughout the La Niña. Remember, the La Niña phase is only an exaggerated ENSO-neutral phase. But there can be a tremendous amount of leftover warm water in the Eastern Tropical Pacific after an El Niño, and it has to go somewhere afterwards. That somewhere is the West Pacific and East Indian Oceans. Wait till you see what it can do.

RECAP

In summary, we illustrated and discussed in this chapter how La Niña events are not the opposite of El Niño events. As a result, the East Indian and West Pacific Oceans can and do warm in response to an El Niño and a La Niña event, when a La Niña event follows a very strong El Niño event. Before an El Niño event, most of the warm water that will serve as the fuel for the El Niño is below the surface of the West Pacific Warm Pool and excluded from the surface temperature record. During the El Niño event, the warm water is now on the surface and included in the calculation of global surface temperatures. After the El Niño, the leftover warm water remains in the calculation of global surface temperatures and it can be found in the surface temperature record of East Indian and West Pacific Oceans. Every time there is a major El Niño event, the sea surface temperature anomalies of the East Indian and West

Pacific Oceans take an upward step. However, it's not a true step, as we will see, because that warm leftover water is also redistributed within the oceans and the leftover warm water releases heat to the atmosphere, so sea surface temperatures there cool with time.

The leftover warm water makes its presence known best in the time-series graphs of the East Indian and West Pacific Oceans. The sea surface temperatures there warm in response to the evolution of the El Niño, but do not cool in response to the decay phase of the El Niño and they cool very little during the evolution phase of the La Niña.

5.4 The Obvious ENSO-Caused Upward Shifts in the Sea Surface Temperature Anomalies of the East Indian and West Pacific Oceans

In this chapter, we'll use time-series graphs to show that the effects of La Niña events on global surface temperatures are not the opposite of El Niño events, and that the warm water left over from a major El Niño event played a big role in the warming of the global oceans during the past 30 years.

A time-series graph of the sea surface temperature anomalies of the East Indian and West Pacific Oceans portrays a pattern in time that resembles a saw tooth. That is, it warms quickly in a lagged response to the evolution of the El Niño and cools very little during the decay of the El Niño and during the evolution of the La Niña that follows. This happens because the leftover warm water from the El Niño has returned to the West Pacific and East Indian Oceans. The sea surface temperatures then decay over a number of years, varying in response to the lesser ENSO events, until the next major El Niño, when they warm again. It's logical to say that the sea surface temperatures shift upwards, but clearly the shifts are not pure step changes. The actually portray themselves as a staggered saw-tooth pattern.

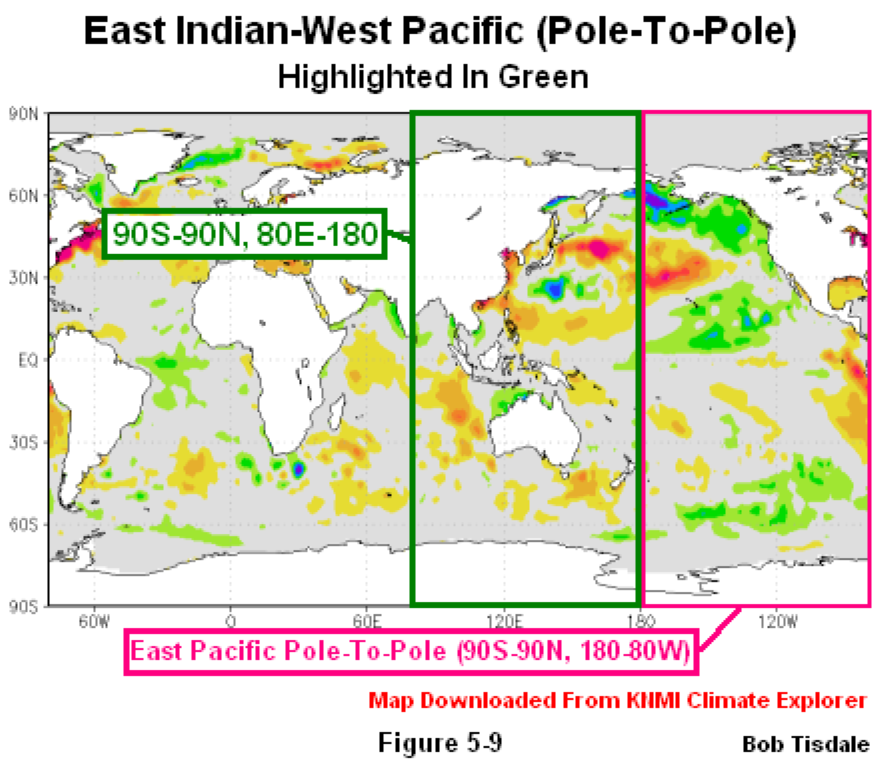


Figure 5-9

For the data used in our illustrations and discussions in this chapter, we'll use the coordinates of 90S-90N, 80E-180 for the East Indian and West Pacific sea surface temperature anomalies. See Figure 5-9. The dataset extends from the Southern Ocean north of Antarctica to the Arctic Ocean and from the Sri Lanka to the dateline. While East Indian-West Pacific dataset stretches the same 80 degrees longitude as the East Pacific, it covers a smaller portion of the global oceans because it includes more land mass.

The sea surface temperature anomalies for the East Indian-West Pacific oceans have warmed significantly over the 30-year term, as shown in Figure 5-10. The linear trend shows it has warmed at a rate of about 0.123 deg C per decade. Or in total, based on the linear trend line, the East Indian-West Pacific sea surface temperature anomalies have warmed about 0.37 deg C. Notice, however, there's something very interesting about the sea surface temperature data for the East Indian-West Pacific subset. It appears to warm in steps. In1987, it warms. Then, with the exception of the dip and rebound associated with the eruption of Mount Pinatubo in 1991, East Indian-West Pacific sea surface temperature anomalies appear to remain at about the same temperature anomaly for close to a decade. Later, in late 1997, early1998, it shifts upward once again. The East Indian-West Pacific data has varied since then, but all in all, it hasn't really warmed since the upward shift in 1997/98.

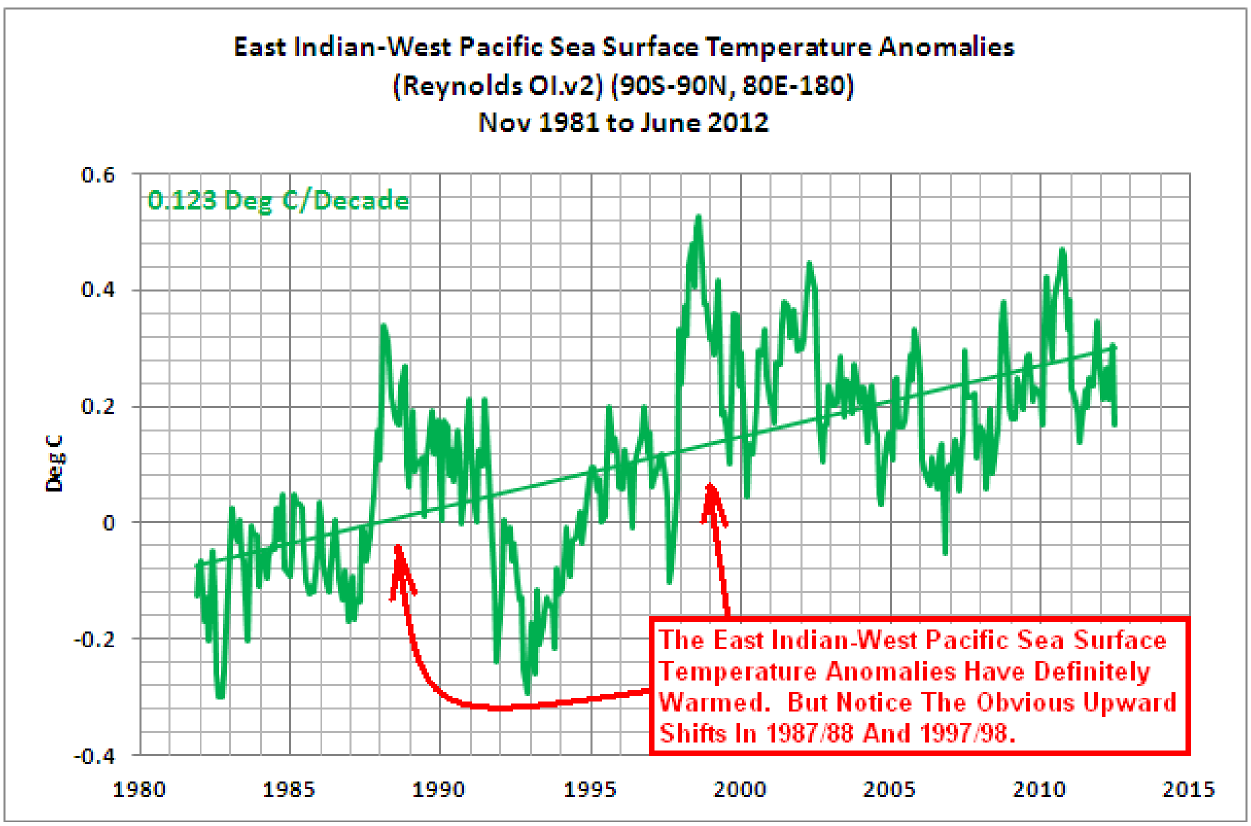


Figure 5-10 Bob Tisdale

We know that the two strongest El Niño events, the effects of which were not counteracted by volcanic eruptions, occurred in 1986/87/88 and in 1997/98. Just in case you've been skipping around and haven't read the numerous earlier discussions, Figure 5-11 shows the timing of those two El Niño events, using scaled NINO3.4 sea surface temperature anomalies, and the timing of the delayed response of the East Indian-West Pacific sea surface temperature anomalies.

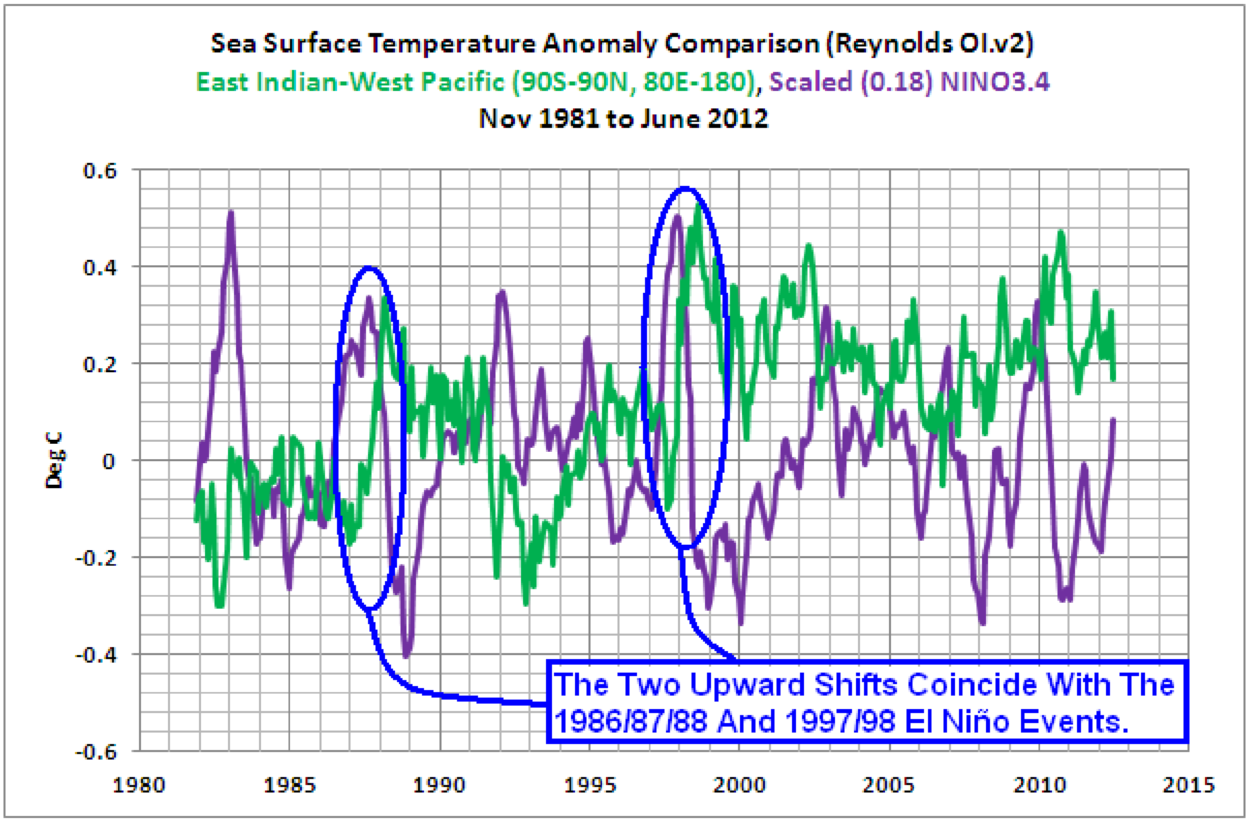


Figure 5-11 Bob Tisdale

I first presented these upward shifts in the sea surface temperature anomalies of the East Indian-West Pacific oceans in a two-part blog post back in January 2009, more than 3 years ago. See the posts titled **Can El Niño Events Explain All of the Global Warming Since 1976? – Part 1** and **Part 2**. They were also cross posted at WattsUpWithThat, so there are lots of comments on the threads **here** and **here**. For those early presentations, I excluded the polar oceans, limiting the data to the latitudes of 60S-65N, because I was using the now-obsolete buoy- and ship-based NOAA ERSST.v2 sea surface temperature data, and as described and illustrated in Chapter 2.10, because they did not include satellite-based data in that dataset, there was very little observational data in the polar oceans. I have since switched to NOAA's satellite-based Reynolds OI.v2 data.

Over those three years I have researched ENSO and refined the discussion and the presentations. The best way (my favorite way) I've found to illustrate those upward shifts is to isolate the months when the major El Niño events were taking place. For this, we'll use the "official" NOAA El Niño months from their **original Oceanic NINO Index (ONI) webpage**. We'll also shift them 6 months to accommodate the time lag between the response of the NINO3.4 region to the response of the East Indian-West Pacific sea surface temperature anomalies. To make things easier to see, we'll present the sea surface temperatures between the El Niño events using different colors, and use a flat line to show the average sea surface temperature anomalies for the East Indian-West Pacific data during the periods between the major El Niño events. See Figure 5-12. The data before and during the 1982/83 El Niño are excluded, as are the East Indian-West Pacific sea surface temperature anomalies during the 1986/87/88 and 1997/98 El Niño events. In 2009, as the 2009/10 El Niño was developing, I decided to isolate that El Niño as well. Now, because there's been such a small upward shift after the last El Niño event, it doesn't seem to be needed, but I've left it to maintain consistency with past presentations.

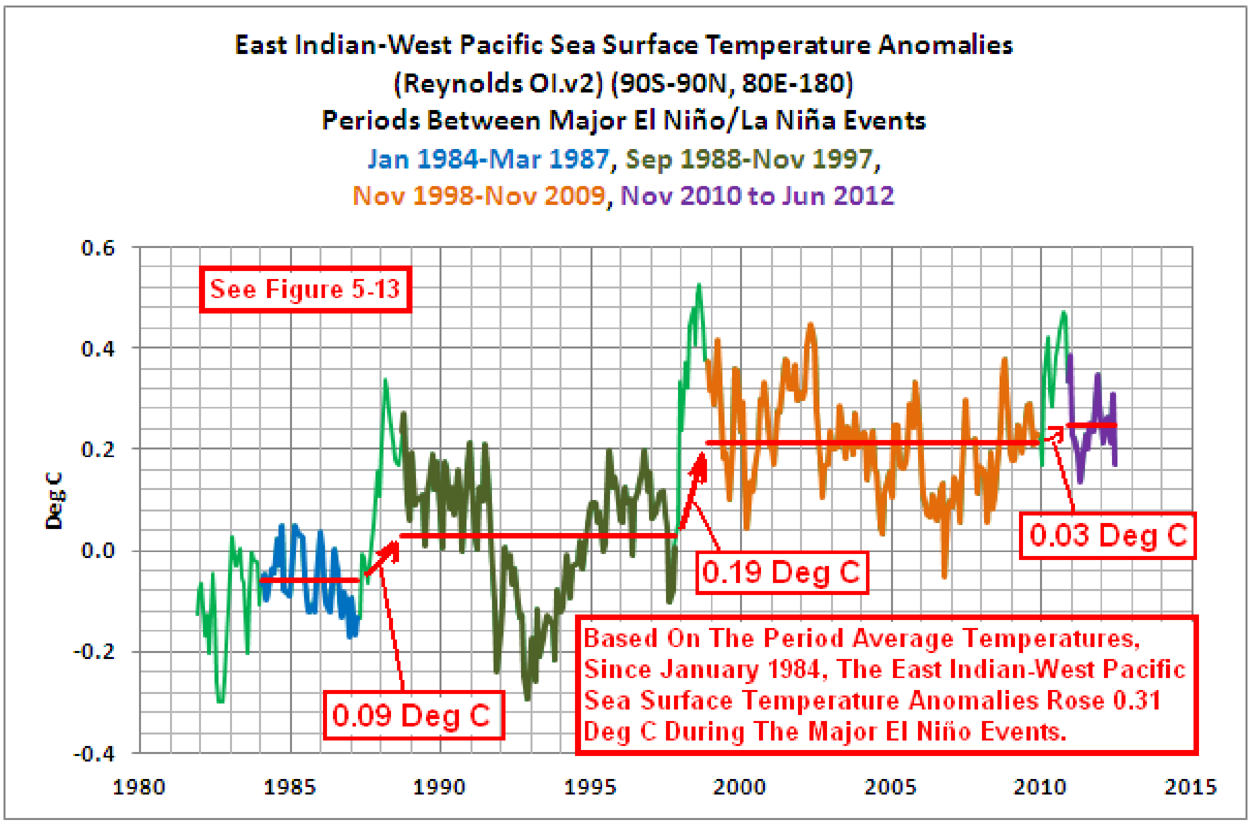


Figure 5-12

The red horizontal lines show the average East Indian-West Pacific sea surface temperature anomalies between the major El Niño events. I've also shown how much the average sea surface temperature anomalies warmed during the El Niño events, based on the period averages before and after them. In other words, from January 1984 to June 2012, the sea surface temperature anomalies of the East Indian-West Pacific Oceans warmed a total of 0.31 deg C, but only during the 1986/87/88, 1997/98 and 2009/10 El Niño events. Here's something that will come as no surprise: based on the linear trend for that period (January 1984 to June 2012) the sea surface temperature anomalies warmed 0.33 deg C, just a little bit more than occurred during those upward shifts during the El Niño events. See Figure 5-13. In other words, about 94% the total warming of sea surface temperature anomalies of the East Indian-West Pacific from January 1984 to June 2012 occurred only during those three El Niño events. Or put yet another way, without the upward shifts that occurred in response to those El Niño events, the sea surface temperatures for the East Indian-West Pacific Oceans would show very little warming.

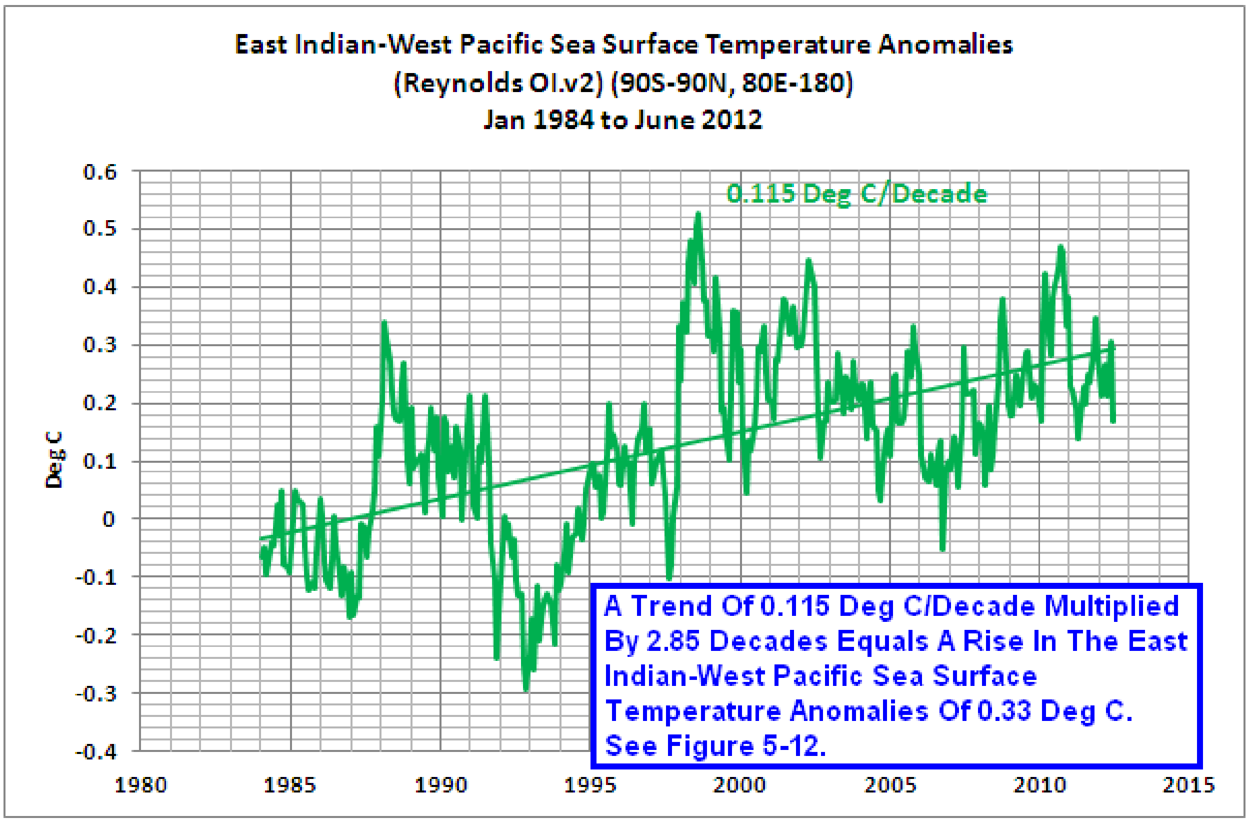


Figure 5-13 Bob Tisdale

This discussion confirms, with data, the effects of strong El Niño events that are followed by La Niña events. Refer back to the Chapter 5.3 **Where and Why Sea Surface Temperatures Can Warm in Response to Certain El Niño AND La Niña Events** for detailed explanations of those processes.

In my blog posts, based on questions I've received in earlier blog posts, I try to anticipate other questions you might have. Someone is bound to ask about the actual linear trends for the periods between the 1986/87/88 and 1997/98 El Niño events and between the 1997/98 and 2009/10 El Niño events. They might think the horizontal red lines that represent the average temperatures for those periods were misleading. That is, the horizontal lines might be fooling the readers into thinking that the temperature trends during those periods are flat, when they're not. Those readers would be correct—the temperature trends are not flat between the major El Niño events. Based on the linear trends, the East Indian-West Pacific sea surface temperature anomalies actually cooled between them, as shown in Figure 5-14.

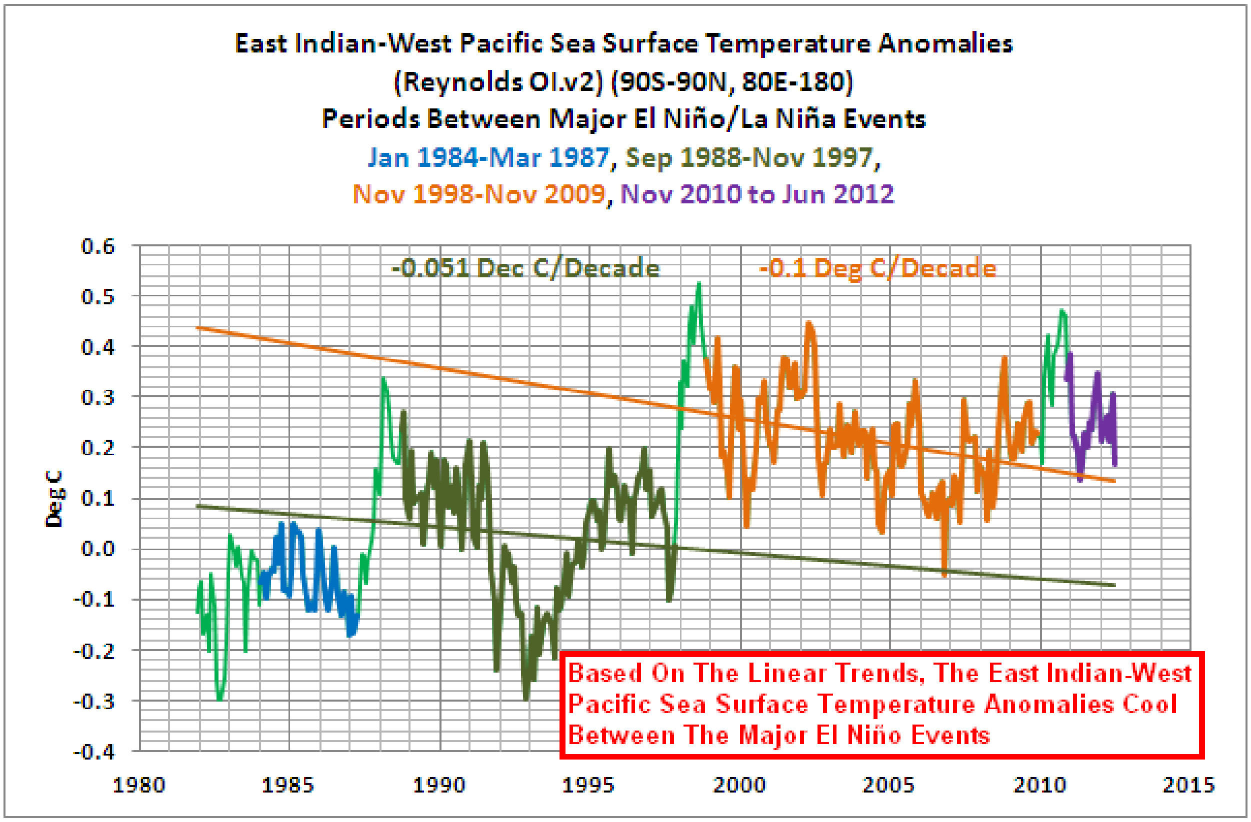


Figure 5-14

Bob Tisdale

In other words, the sea surface temperature anomalies of the East Indian-West Pacific oceans are another dataset that provides no evidence of anthropogenic global warming.

Let's stop and look back for a moment. That's two portions of the global oceans that show no evidence of anthropogenic global warming for the past 30 years. Additionally, those two portions represent more than half of the surface area of the global oceans. Remember, this is a period when the IPCC, based on their models, say **only** greenhouse gases could have caused global surface temperatures to warm. Unfortunately for the models, the data contradicts them. That is, as we've seen, the sea surface temperatures of one of the subsets, the East Pacific Ocean from pole to pole, have not warmed in 30 years, and the other, the East Indian-West Pacific from pole to pole, only warms during, and in response to, El Niño events, and between those El Niño events, the sea surface temperatures there actually cool.

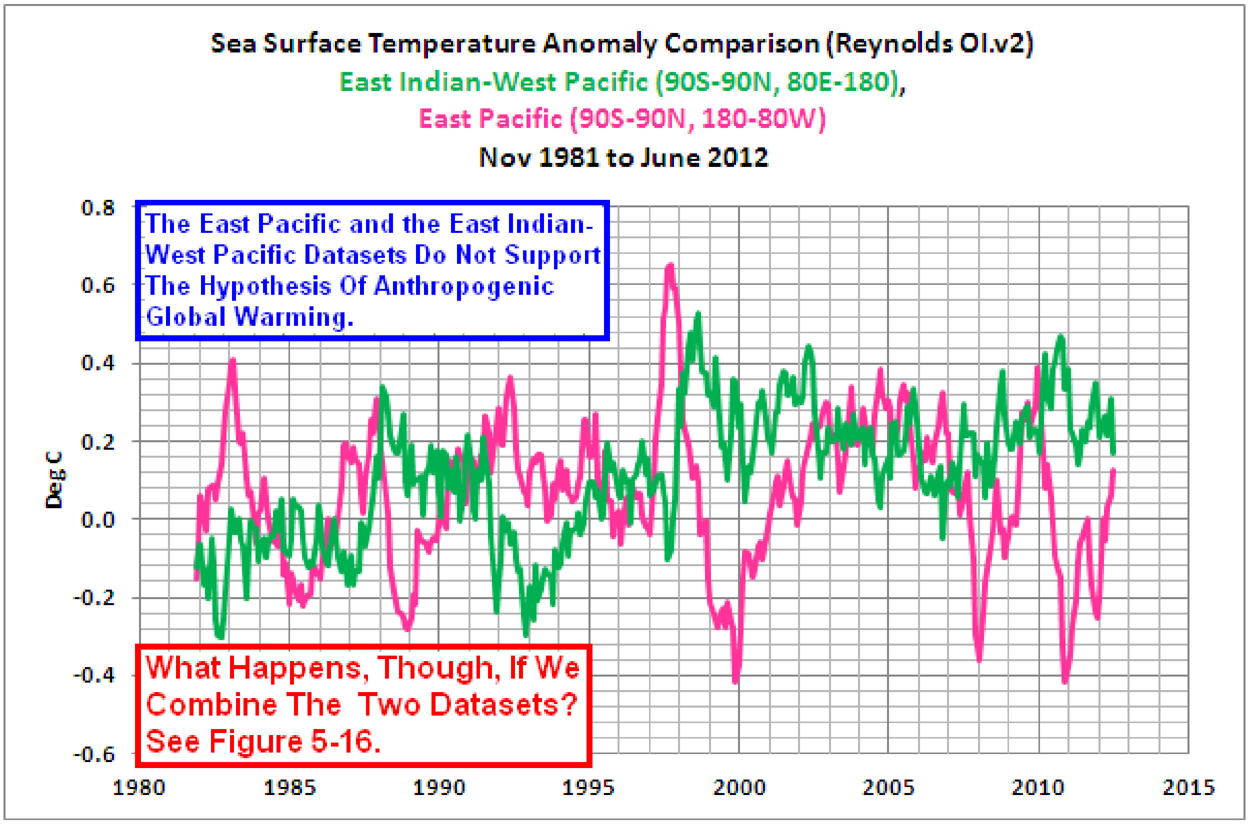


Figure 5-15

Let's compare the sea surface temperature anomalies of those two regions in one graph. See Figure 5-15. The two upward shifts in the sea surface temperature anomalies of the East Indian-West Pacific lag the responses of the East Pacific to the 1986/87/88 and 1997/98 El Niño events. That makes sense because it takes a number of months for the changes in atmospheric circulation caused by the El Niño to work their way eastward around the globe. The sea surface temperature data of the East Indian-West Pacific might cool a little during evolution of those El Niño events, but those short-term periods of cooling in the East Pacific are definitely outweighed by the warming that follow. This supports our understanding that most of the warm water for the El Niño in the East Pacific comes from below the surface of the west Pacific Warm Pool. Then, because the El Niño doesn't "consume" all of the warm water that had shifted east, the East Indian-West Pacific data warms and remains at the elevated temperatures during the subsequent La Niña events. This is caused by the leftover warm water being sent back to the West Pacific and into the East Indian Ocean, and, second, by the La Niña events themselves in the Pacific, which are helping to maintain the elevated sea surface temperatures in the East Indian-West Pacific. While that's occurring, there are subsurface processes taking place: the warm waters that had been returned to the west by the downwelling (warm) Rossby waves, are rising to the surface (warmer water is lighter than cooler water so gravity causes it to rise to the surface). This contributes to the sea surface temperature warming of the East Indian and

West Pacific Oceans after the El Niño. We can also see the delayed impact of the La Niña-caused changes in atmospheric circulation on the sea surface temperatures of the East Indian-West Pacific data. It dips from 1998 to 2000 and then rebounds until 2002, after which time there's a sharp, but relatively small, drop in temperatures. The East Indian-West Pacific data responds precisely as we would expect to major El Niño events. Conclusion: both datasets shown in Figure 5-15 do not support the hypothesis of anthropogenic global warming.

What do you suppose happens if we combine the two datasets, so that we're looking at the sea surface temperature anomalies of the East Indian and Pacific Oceans from pole to pole? That is, we're discussing combining the two datasets highlighted in green and pink in the map back in Figure 5-9. We'll compare that combined dataset to global surface temperatures to illustrate the effect. See Figure 5-16. If we didn't know better, we might think the East Indian and Pacific sea surface temperature anomalies support the hypothesis of anthropogenic global warming. Individually, the East Pacific and East Indian-West Pacific data don't support manmade global warming. Combined, they APPEAR to support it.

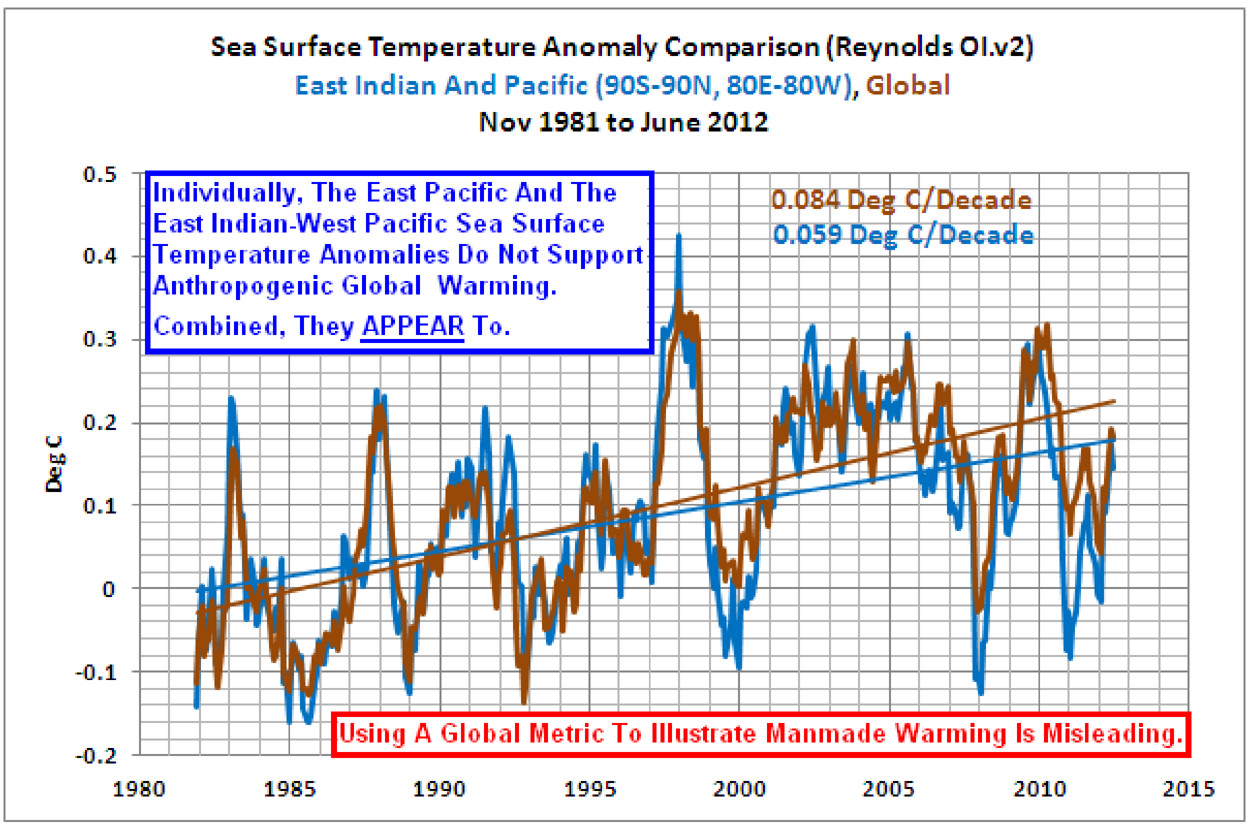


Figure 5-16

Bob Tisdale

Years ago, when I first started examining subsets of global surface temperature data (individual ocean basins or continental landmasses) at different latitudes and longitudes, something became more and more obvious to me. Using a global surface temperature dataset to show proof of manmade carbon dioxide-caused warming was misleading. If subsets of the global oceans do not support the hypothesis of anthropogenic warming, the global data does not support it.

RECAP

Using time-series graphs we illustrated and discussed how the effects of La Niña events on global surface temperatures are not the opposite of El Niño events. The effects of El Niño and La Niña events can actually be cumulative. More to the point, the satellite-based sea surface temperature data contradict the assumption that the effects on global surface temperatures of a La Niña event oppose the impacts of an El Niño event.

The warm water left over from a major El Niño event has played a big role in the warming of the global oceans during the past 30 years.

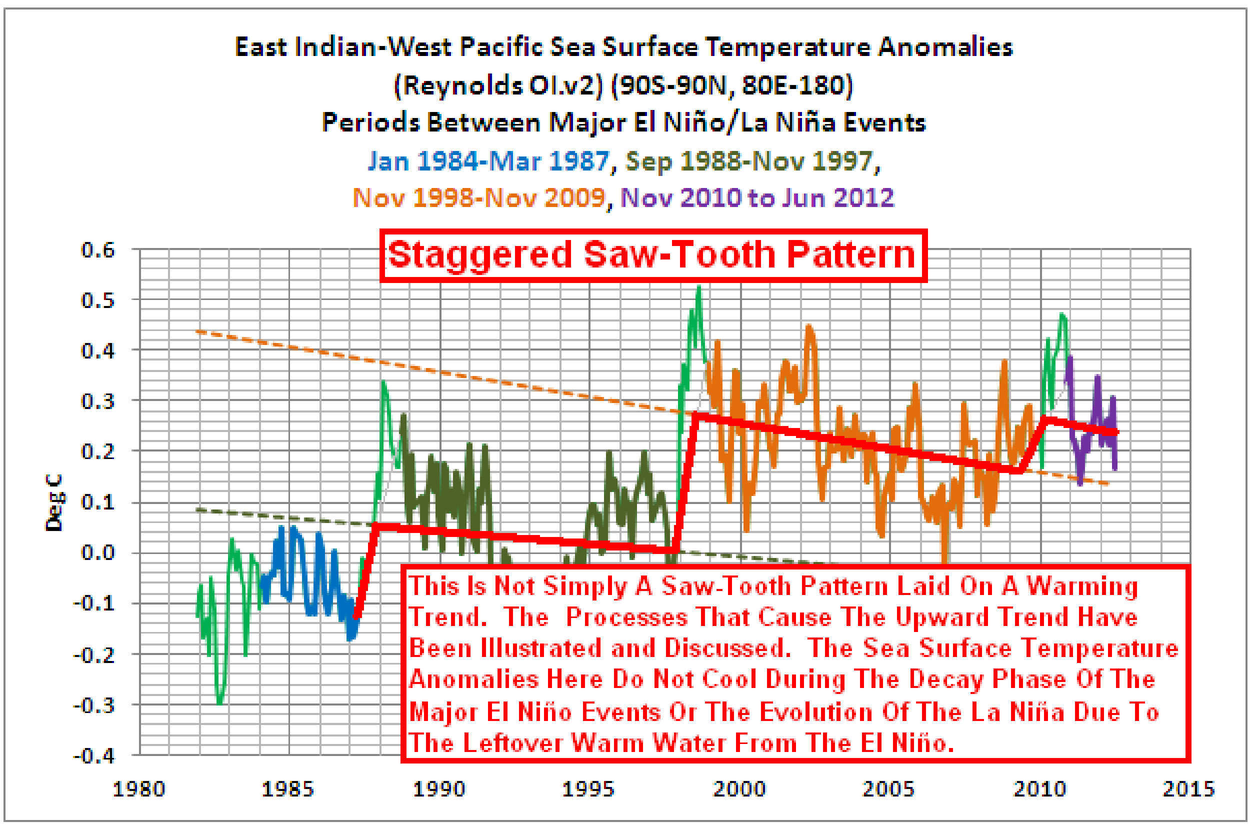


Figure 5-17 Bob Tisdale

Globally, sea surface temperatures have warmed. There's no doubt about that, but so far we've seen no evidence of a manmade warming signal in either of the two subsets we've looked at. If you're hoping it will show itself as we expand our view of the sea surface temperature data for the past 30 years, be prepared to be disappointed.

I mentioned at the start of this chapter that the time-series graph of the East Indian-West Pacific Oceans portrayed a pattern in time that resembled a staggered saw-tooth. So not to take away from the other portions of the discussion, I've waited until the recap to illustrate that staggered saw-tooth effect. See Figure 5-17.

As noted in Figure 5-17, the staggered saw-tooth pattern is NOT simply a saw-tooth pattern laid over a positive linear trend. We've discussed and illustrated the processes that cause these modified upward steps. The warm water that's left over from the major El Niño events prevent the sea surface temperatures from responding fully to (cooling during) the decay phase of the El Niño and the evolution phase of the La Niña that follows. That is, sea surface temperatures for the East Indian-West Pacific oceans do not respond proportionately (linearly) to El Niño and La Niña events. Additionally, the additional trade wind strength and increased downward shortwave radiation associated with the La Niña help to maintain the elevated sea surface temperatures in the East Indian and West Pacific Oceans—until the next major El Niño, when the process started all over again.

5.5 The ENSO-Caused Upward Shifts Still Exist if We Add the South Atlantic and West Indian Sea Surface Temperature Data to the East Indian and West Pacific

In this chapter, we'll add the South Atlantic and West Indian sea surface temperature anomaly data to the East Indian and West Pacific data. The intent is to show that there are few changes by expanding the area of the data. The upward steps (staggered saw-tooth patterns) still exist, and the sea surface temperature anomalies still cool between the major El Niño events. In other words, for this larger dataset that excludes only the North Atlantic and East Pacific Oceans, there is still no evidence of manmade global warming.

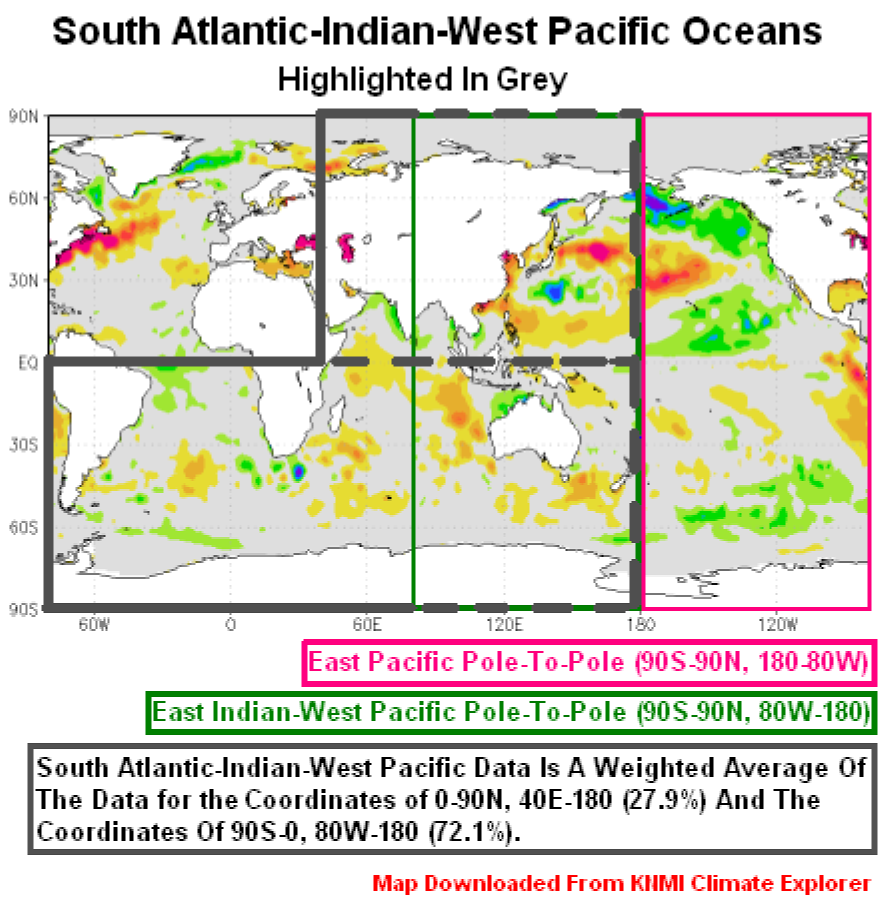


Figure 5-18 Bob Tisdale

The area highlighted in grey in Figure 5-18 illustrates the South Atlantic-Indian-West Pacific subset. Because the NOAA NOMADS website (the source of the data) requires coordinates as inputs to retrieve sea surface temperature data, the data has to be downloaded for two regions and then combined. (Or I could have downloaded the data for the larger area and for the North Atlantic and then subtracted the North Atlantic data.) For this discussion, I separated the data at the equator and then merged the two using a weighted average of the data for the coordinates of 0-90N, 40E-180 to capture the North Indian and western North Pacific (27.9%) and the data for the coordinates of 90S-0, 80W-180 for the South Atlantic, South Indian and western South Pacific (72.1%). The areas also include data for the Arctic and Southern Oceans. The data used in this chapter is isolated from the East Pacific data, because the East Pacific data mimics our ENSO index and has not warmed, and it's isolated it from the North Atlantic, because the North Atlantic has another mode of natural variability, which we'll discuss separately.

As you can see, the South Atlantic-Indian-West Pacific dataset covers a very large area. This dataset represent more than half of the surface area of the global oceans, about 53.5%. If you'd like raw numbers, assuming the global oceans occupy about 361 million square kilometers of global surface area, the South Atlantic-Indian-West Pacific data covers about 193 million square kilometers (75 million square miles). It covers about 30% more of the globe than all of the continental landmasses combined. While South Atlantic-Indian-West Pacific data does have a significant warming rate (0.093 deg C per decade), it clearly warms in ENSO-caused steps just like the East Indian-West Pacific Oceans, and that makes sense, because the East Indian-West Pacific data is part of the South Atlantic-Indian-West Pacific data. See Figure 5-19.

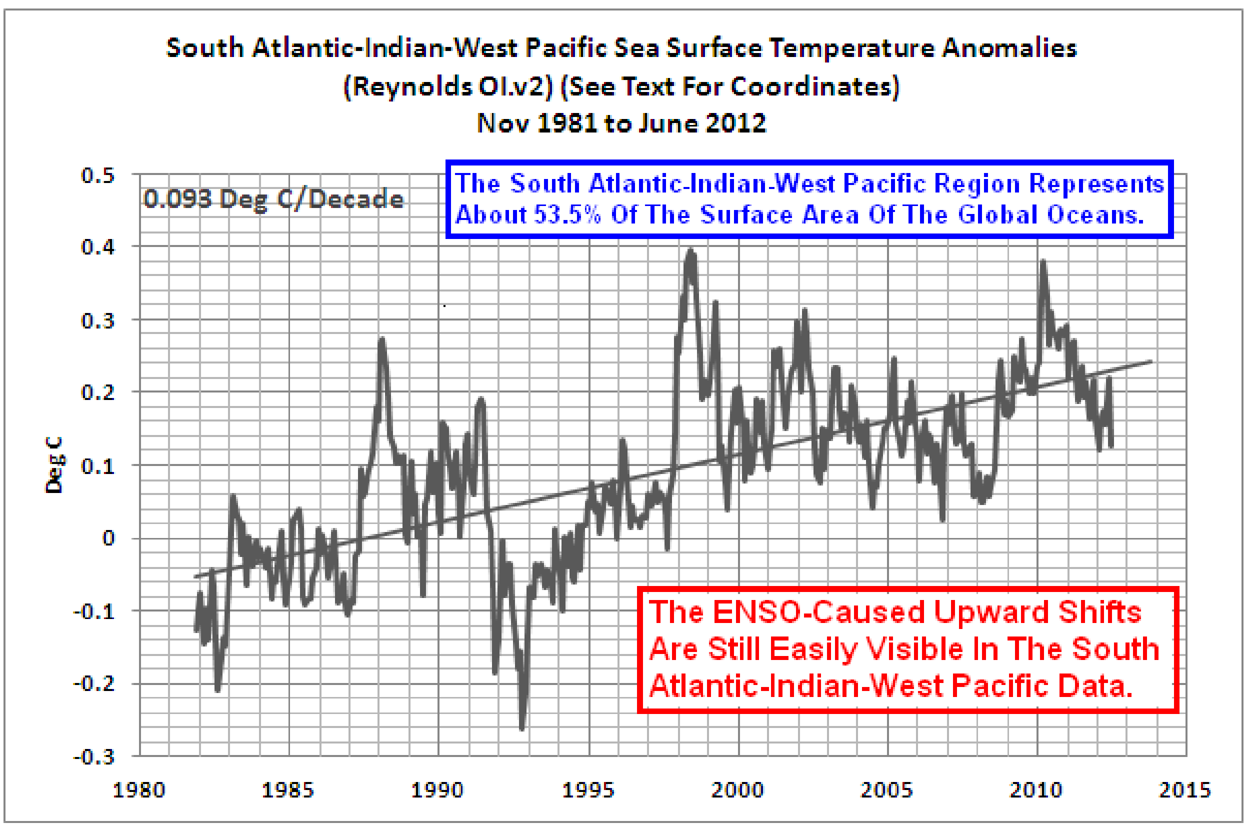


Figure 5-19

Bob Tisdale

Let's compare the East Indian-West Pacific data to this expanded South Atlantic-Indian-West Pacific data. See Figure 5-20. The East Indian-West

Pacific data has more variability than the sea surface temperature anomalies of the South Atlantic-Indian-West Pacific. That makes sense. Not surprisingly, the two datasets correlate quite well, with a correlation coefficient of 0.92. Therefore, we can say that the larger dataset (the South Atlantic-Indian-West Pacific data) mimics the ENSO-caused variations of the East Indian-West Pacific. The South Atlantic-Indian-West Pacific sea surface temperature anomalies have a lower trend, have warmed less than the East Indian-West Pacific dataset, so the additional data (South Atlantic and West Indian) has not added to the warming. Basically, the South Atlantic and West Indian Oceans are tagging along with the East Indian and West Pacific Oceans, suppressing the variations slightly.

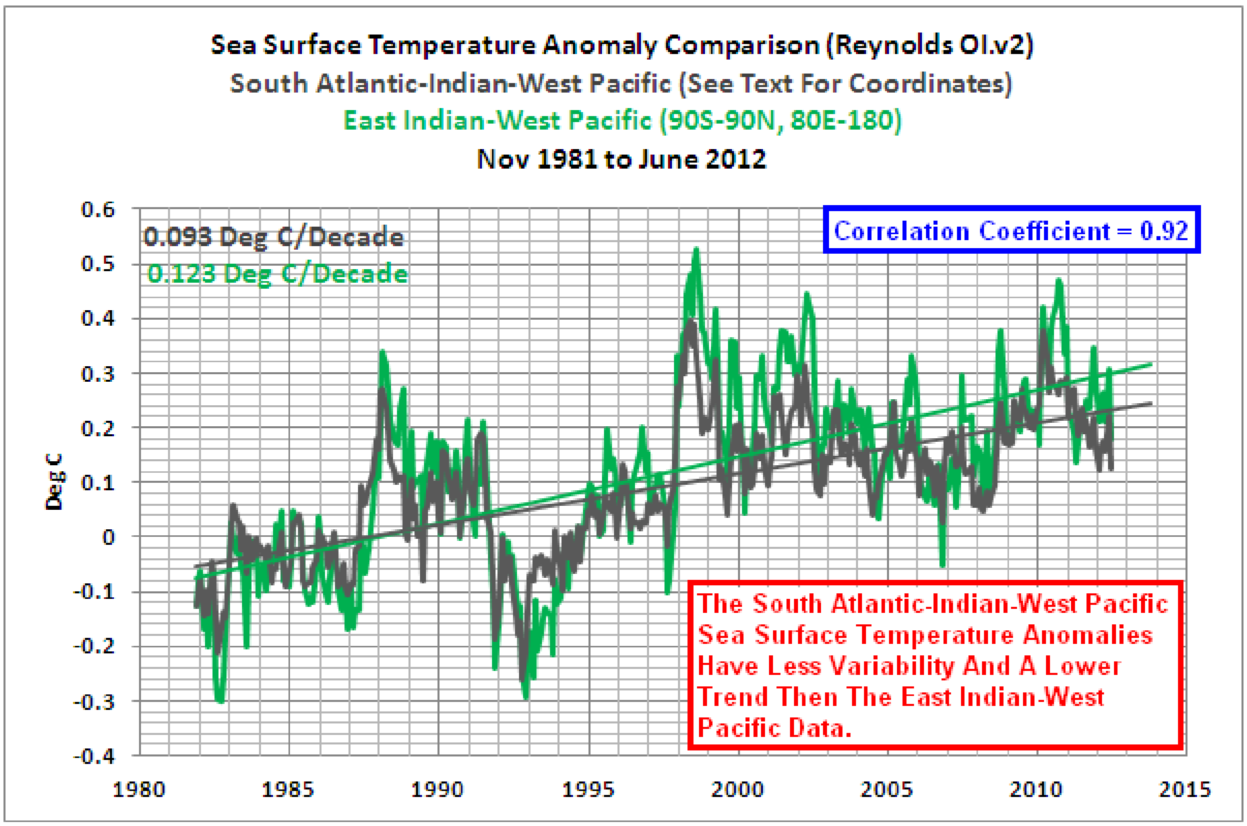


Figure 5-20

Bob Tisdale

If we include the average sea surface temperature anomalies between the major El Niño events, the red horizontal lines in Figure 5-21, we can highlight how the sea surface temperatures of the South Atlantic-Indian-West Pacific don't appear to warm between those El Niño, or in other words, we can show that the only time the South Atlantic-Indian-West Pacific data warmed was during the El Niño events. Based on the average sea surface temperatures between the major El Niño events, the 1986/87/88, the 1997/98 and the 2009/10 El Niño events warmed 53.5% of the surface area of the global oceans since January 1984 a total of 0.24 deg C.

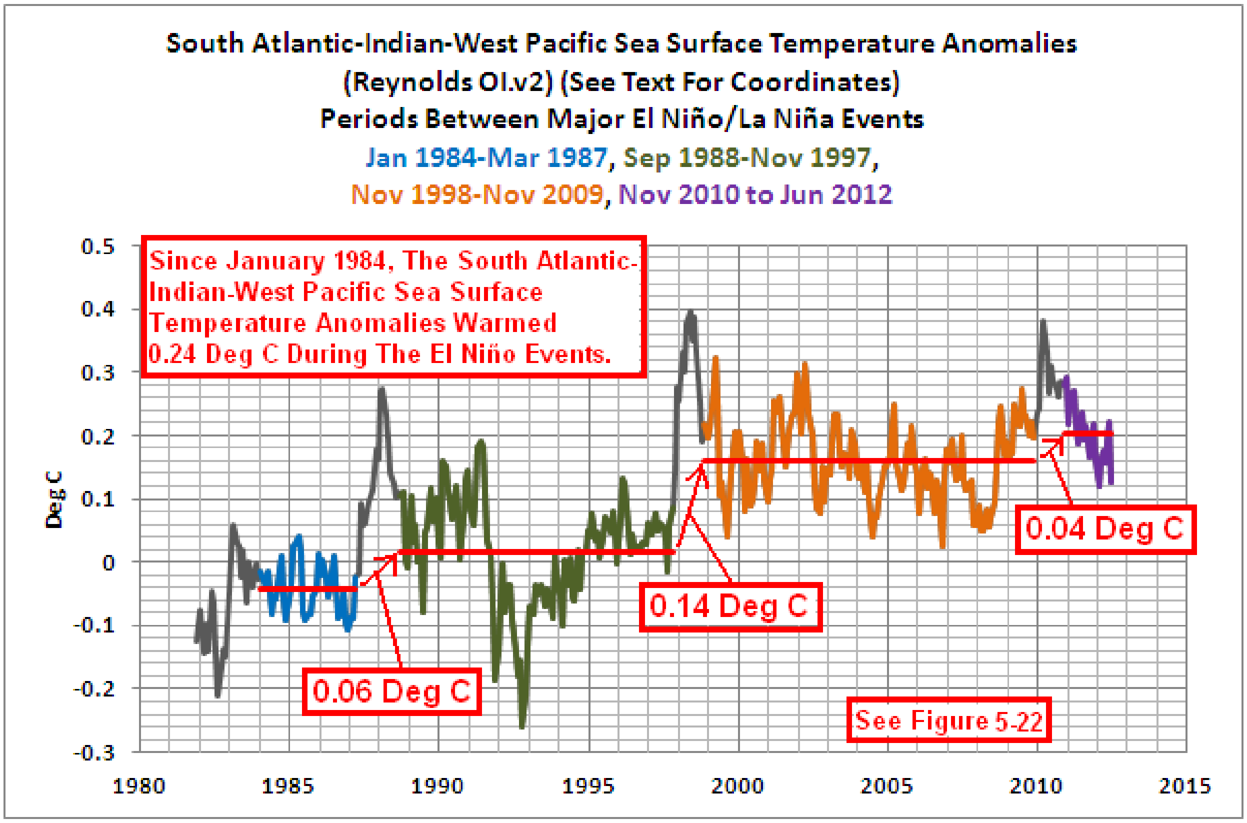


Figure 5-21

Based on the linear trend of the South Atlantic-Indian-West Pacific sea surface temperature anomalies since January 1984, Figure 5-22, that dataset has warmed at a rate of 0.089 deg C per decade, or based on the linear trend, it warmed about 0.25 deg C. In other words, the vast majority of the warming took place during the El Niño events.

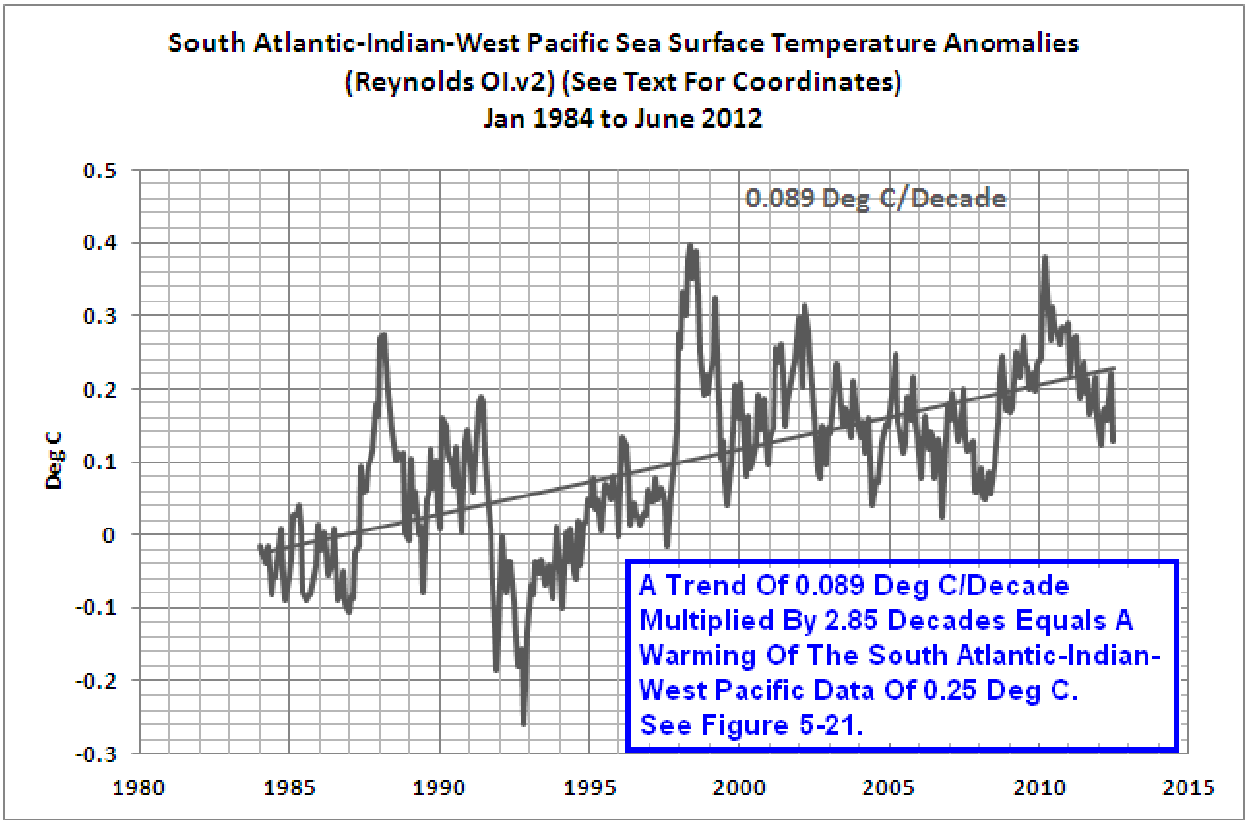


Figure 5-22

Bob Tisdale

Of course, because variations in the sea surface temperatures of the South Atlantic-Indian-West Pacific were so similar to the ENSO-caused variations in the East Indian-West Pacific data, we would expect the larger area (South Atlantic-Indian-West Pacific data) to cool between the major El Niño events. That's precisely what happens, as shown in Figure 5-23.

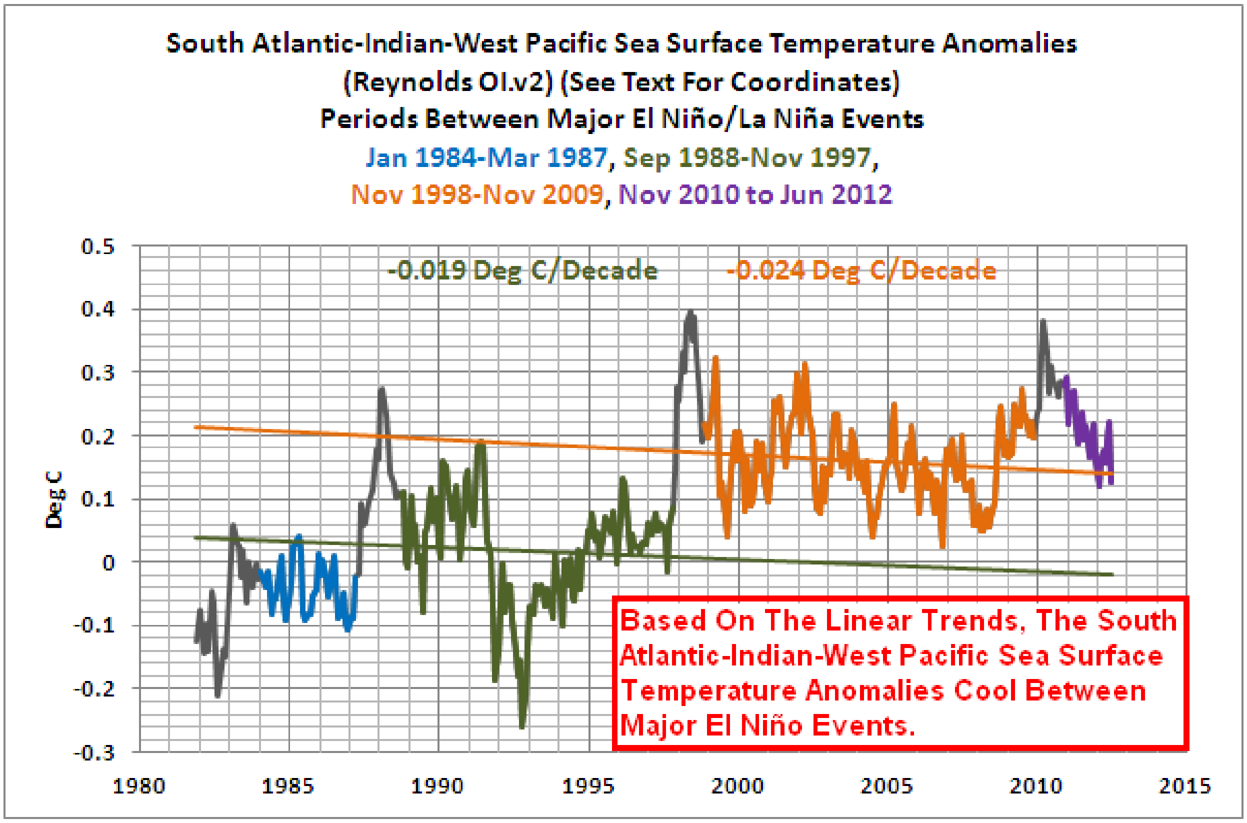


Figure 5-23 Bob Tisdale

RECAP

The South Atlantic-Indian-West Pacific sea surface temperature subset excludes the East Pacific and the North Atlantic Oceans. It represents about 53.5% of the surface area of the global oceans. That very large dataset mimics the ENSO-induced long-term warming of the East Indian-West Pacific data. Both datasets only warm during the major El Niño events, and they do not cool proportionately to the trailing La Niña events, but over the decade-long periods between the major El Niño events, they cool.

In other words, we have examined the sea surface temperature anomaly data of the East Pacific Ocean, and it shows no warming (Chapter 5.1). We've also examined in this chapter the South Atlantic-Indian-West Pacific sea surface temperature anomaly data, and while it has definitely warmed, the warming only happened during, and was caused by, major El Niño events. Therefore, there is also no evidence of anthropogenic global warming in that dataset.

So far, we've examined the sea surface temperature data for about 86% of the global oceans, and we haven't found any evidence of manmade global warming. All we have left is the North Atlantic.

5.6 The Additional Warming of the North Atlantic Sea Surface Temperatures is Caused by the Atlantic Multidecadal Oscillation AND Additional ENSO-Impacted Processes

We discussed the Atlantic Multidecadal Oscillation in **Chapter 2.13 The Additional Mode of Natural Variability in the North Atlantic Sea Surface Temperatures—Introduction to the Atlantic Multidecadal Oscillation.** Please refer to that overview of the Atlantic Multidecadal Oscillation. It is responsible for much of the additional warming of the North Atlantic during the past 30 years. See Figure 5-24. The warming trend of the "North Atlantic Plus" data is 4.3 times higher than the rest of the oceans, shown as the dataset identified as "Global Without 'North Atlantic Plus'".

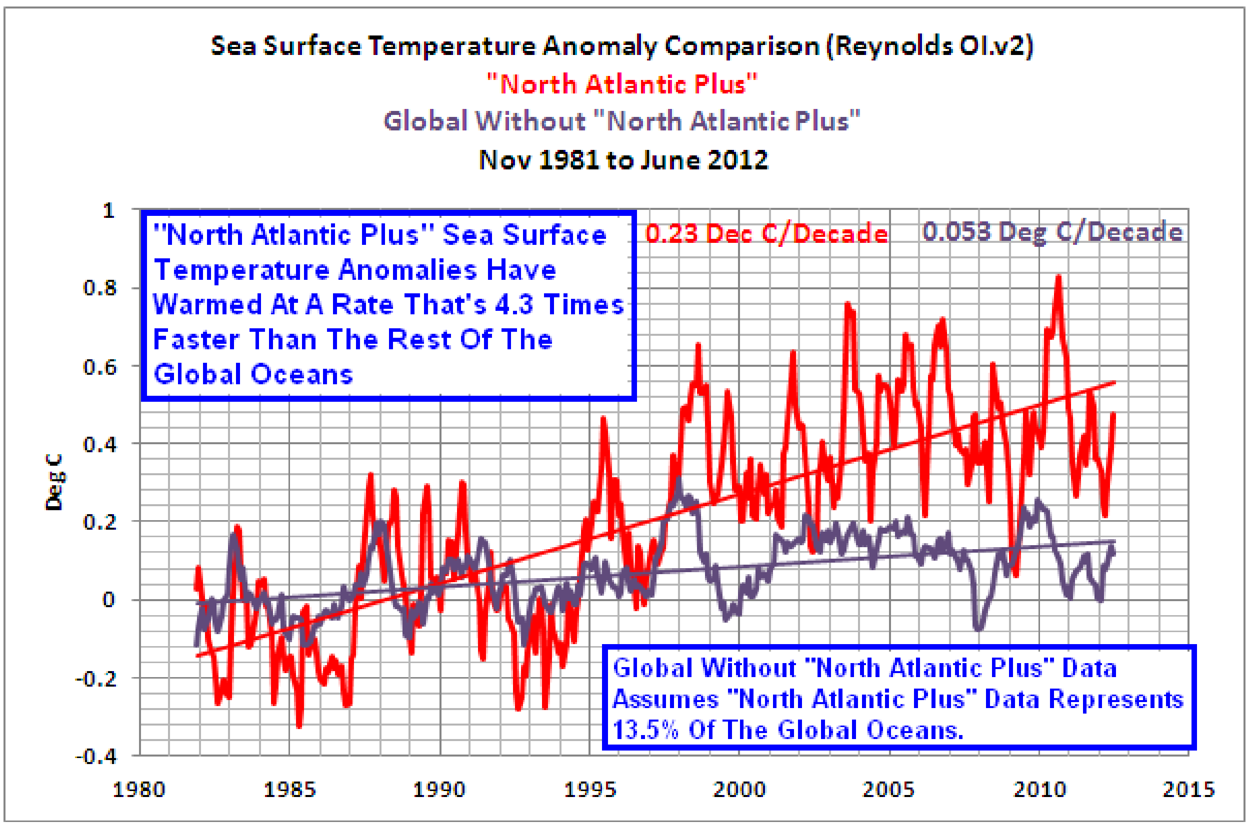


Figure 5-24 Bob Tisdale

Ideally, the Atlantic Multidecadal Oscillation would be presented as the difference between sea surface temperature anomalies of the North Atlantic and the Global data without the North Atlantic. It would then account for the additional 0.177 deg C per decade trend in "North Atlantic Plus" data. In other words, this would then show the additional variability of the North Atlantic above the variations of the rest of the global oceans.

AN IMPORTANT POINT

In **Chapter 2.13 The Additional Mode of Natural Variability in the North Atlantic Sea Surface Temperatures—Introduction to the Atlantic Multidecadal Oscillation**, we referred to NOAA ESRL webpage and noted that they refer to the **Wikipedia definition of the Atlantic Multidecadal Oscillation**. Wikipedia writes (my boldface):

> "The Atlantic multidecadal oscillation (AMO) was identified by Schlesinger and Ramankutty in 1994. The AMO signal is usually defined from the patterns of SST variability in the North Atlantic once any linear trend has been removed. **This detrending is intended to remove the influence of greenhouse gas-induced global warming from the analysis.** However, if the global warming signal is significantly non-linear in time (i.e. not just a smooth increase), variations in the forced signal will leak into the AMO definition. Consequently, correlations with the AMO index may alias effects of global warming."

We have found no evidence of "greenhouse gas-induced global warming" in the East Pacific or the South Atlantic-Indian-West Pacific sea surface temperature data. This is why I refer to the Atlantic Multidecadal Oscillation as the **additional** mode of natural variability in the North Atlantic sea surface temperature data.

A NOTE ABOUT THE COORDINATES USED FOR THE NORTH ATLANTIC

Some readers become concerned when I use coordinates for an ocean basin that encompasses an area that's larger or smaller than they're accustomed to seeing. The NOAA ESRL uses the coordinates of 0-70N, 80W-0 for its version of the Atlantic Multidecadal Oscillation data. As we can see in the map in Figure 5-25, those coordinates capture most of the North Atlantic, but not all of it. If they were to shift the eastern boundary to the east, then they're including more of the Mediterranean Sea, or if they were to shift the north boundary toward the pole, then they have included more of the Arctic Ocean. Depending on the research paper, the coordinates for the North Atlantic sea surface can be quite different than those outlined in blue. The authors of the scientific papers will describe why they selected specific coordinates for the North Atlantic. We're going to expand them so that we can capture the rest of the global oceans that are not included in the East Pacific and the South Atlantic-Indian-West Pacific subsets we've already presented. We're going to expand the coordinates for the North Atlantic to the east and north. That way we've covered the global oceans completely.

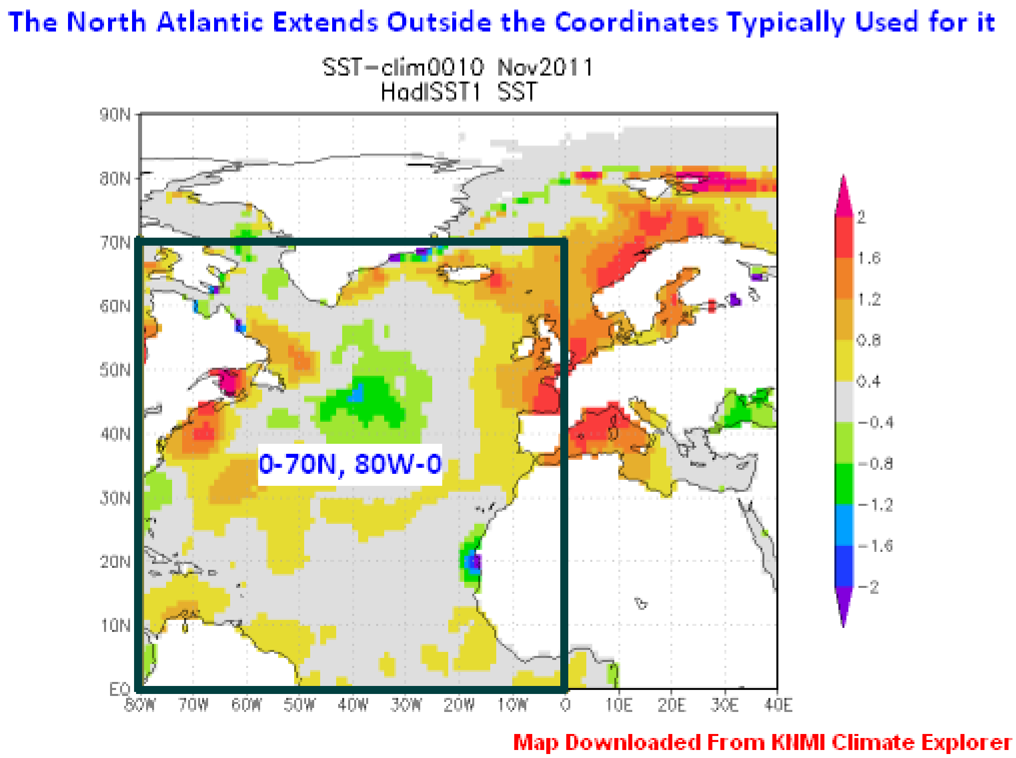


Figure 5-25

The sea surface temperatures of the waters included in that entire map (0-90N, 80W-40E) in Figure 5-25 have the same basic variability as the smaller area (0-70N, 80W-0), in the short term and in the long term. That is, adding the Mediterranean Sea data, the Black Sea data and part of the Arctic Ocean data to the North Atlantic data has very little influence on it. This can be seen in the sea surface temperature comparison graphs of the North Atlantic (0-70N, 80W-0) and the "North Atlantic Plus" data (0-90N, 80W-40E). Refer to Figures 5-26 and 5-27.

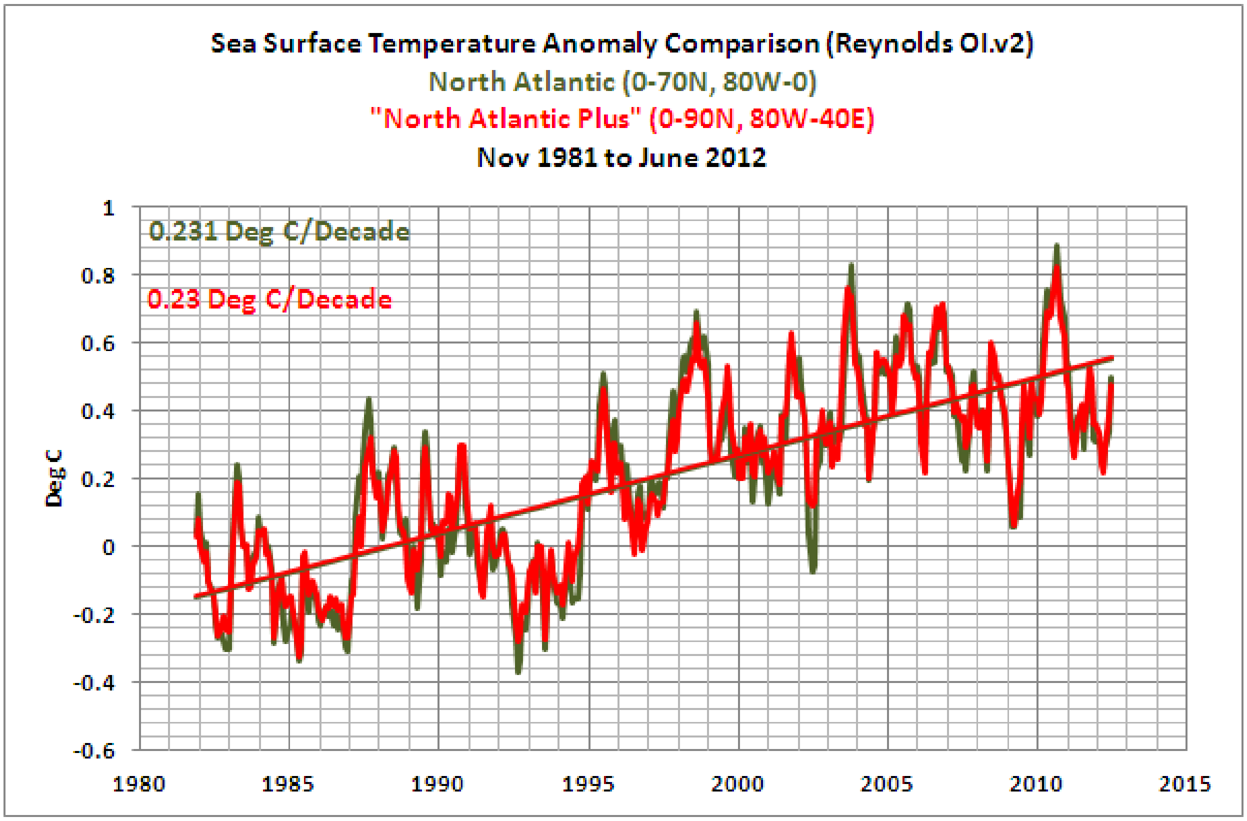


Figure 5-26

Bob Tisdale

HHH

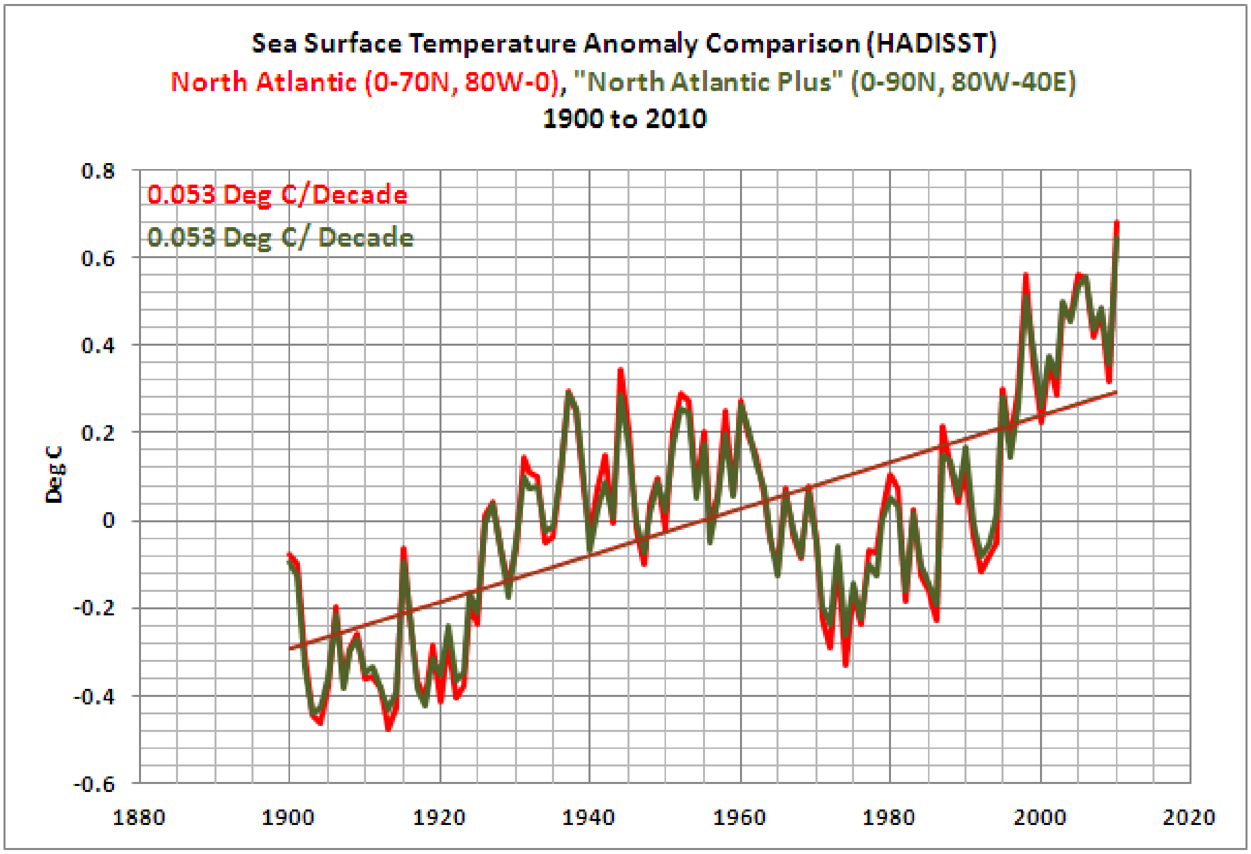


Figure 5-27 Bob Tisdale

BACK TO THE DISCUSSION OF THE NORTH ATLANTIC SEA SURFACE TEMPERATURE ANOMALIES AND ENSO

The linear trend for the North Atlantic sea surface temperature anomalies is extremely high. See Figures 5-24 and 5-26. This happens in part because we've been on the upswing of the Atlantic Multidecadal Oscillation since the mid-1970s. Logically, we would expect the periods between major El Niño events to show significant warming, too. That's precisely what the sea surface temperature anomaly data for the "North Atlantic Plus" region shows if we isolate and remove the monthly data associated with the 1982/83, 1986/87/88, 1997/98 and 2009/10 El Niño events, using the 6-month lag we've used for the other subsets. Refer to Figure 5-28. Note also that the "North Atlantic Plus" trend between the 1997/98 and 2009/10 El Niño events is less than the trend between the 1986/87/88 and 1997/98 El Niño events. Significantly less. Is the Atlantic Multidecadal Oscillation nearing its peak for this upward part of the cycle? Has it already peaked? Or is the difference in the warming trends caused by the impact of the Mount Pinatubo eruption on the earlier data? If it wasn't for the response to the 2009/10 El Niño, the "North Atlantic Plus" data would appear to have peaked around 2005, seven years ago. Nevertheless, it's still too early to tell.

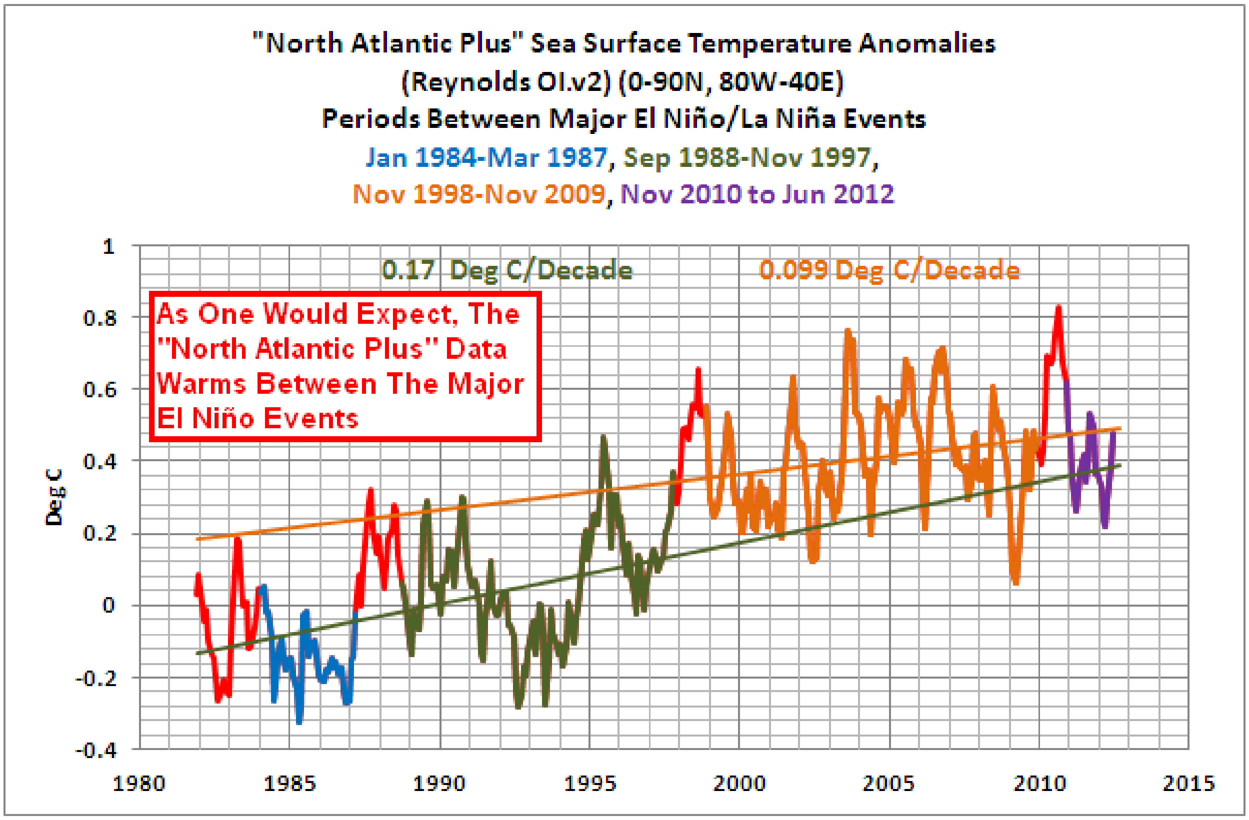


Figure 5-28

Bob Tisdale

Because the trend line of the later period (November 1998 to November 2009) is located above the trend line for the period of September 1988 to November 1997 it may appear that there are upward shifts in the North Atlantic Plus data. That would happen if the "North Atlantic Plus" data does not respond fully to the La Niña events that follow the major El Niño events.

There's a way to check to see if the "North Atlantic Plus" data does or does not respond fully to the La Niña events that follow the major El Niño events. We'll detrend the "North Atlantic Plus" data. Refer to Chapter **2.11 Data Smoothing and Detrending.** The detrended "North Atlantic Plus" sea surface temperature should mimic the variations in our ENSO index if the North Atlantic responds the same to La Niña events as it does to El Niño events.

FIRST AN EXAMPLE OF A DATASET THAT DOESN'T RESPOND PROPORTIONATELY TO LA NIÑA

As an example of a dataset that doesn't mimic the cooling during certain La Niña events, let's detrend East Indian-West Pacific sea surface temperature anomalies. We know the East Indian-West Pacific data doesn't cool completely during specific La Niña events due to the warm water that's left over from the major El Niño events. To illustrate this, we'll compare the detrended East

Indian-West Pacific data to scaled and lagged NINO3.4 sea surface temperature anomalies. To scale the NINO3.4 sea surface temperature anomalies, they were multiplied by a factor of 0.15. The NINO3.4 sea surface temperature anomalies were also shifted back 6-months to better align the responses of both datasets to ENSO. See Figure 5-29. I've crosshatched four periods when the two curves separate (diverge) from one another. The divergences caused by the explosive volcanic eruptions of El Chichon in 1982 and Mount Pinatubo in 1991 are crosshatched in blue. Similarly, the two divergences after the 1986/87/88 and 1997/98 El Niño events have brown crosshatches.

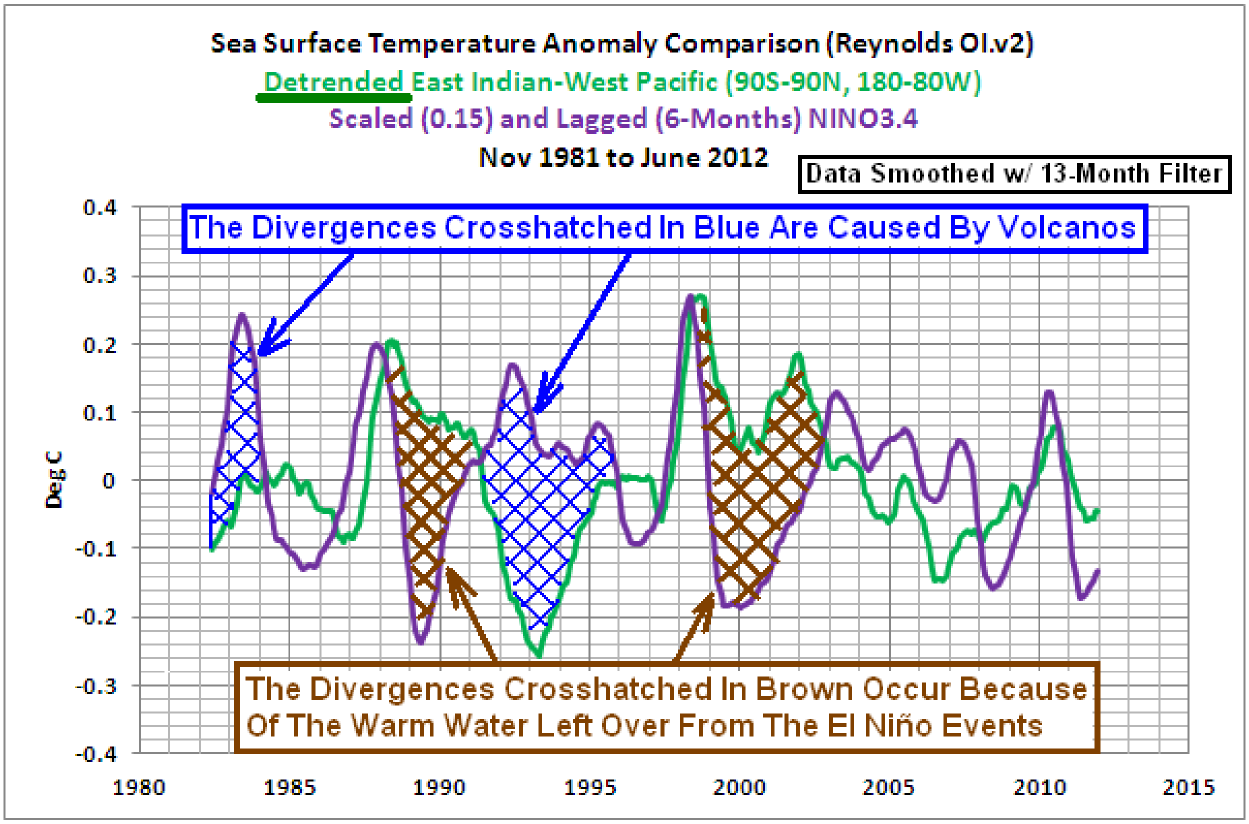


Figure 5-29 Bob Tisdale

We have discussed in great detail how warm water left over from the El Niño event is the cause for the upward shifts in the East Indian-West Pacific sea surface temperature anomalies. The leftover warm water prevents the East Indian-West Pacific data from cooling fully in response to the changes in atmospheric circulation caused by the La Niña events that follow the major 1986/87/88 and 1997/98 El Niño events. This shows itself as the divergences (crosshatched in brown) between the ENSO index and the detrended East Indian-West Pacific data in Figure 5-29.

Because the East Indian-West Pacific data can't cool completely in response to those La Niña events, it acquires a positive long-term linear trend. In other words, it warms over the long-term. Let's phrase that another way: the East Indian-West Pacific sea surface temperature anomalies acquire a long-term trend because the warm water that's left over from the El Niño prevents the East Indian-West Pacific data from cooling linearly (proportionately) to the La Niña.

THE DETRENDED NORTH ATLANTIC DATA SHOWS A SIMILAR RESPONSE TO LA NIÑA

As a result, we know why that happens in the East Indian-West Pacific data. We also know that the "North Atlantic Plus" region is physically isolated by the Americas from the warm waters associated directly with the El Niño events. We discussed in Chapter 4.1 how the tropical North Atlantic is teleconnected to the tropical Pacific, but the tropical North Atlantic should also cool in response to a La Niña event. Why then does the detrended "North Atlantic Plus" data also diverge from the NINO3.4 data after the strong 1986/87/88 and 1997/98 El Niño events. See Figure 5-30. What processes in the North Atlantic keep its sea surface temperature anomalies from responding fully to those La Niña events?

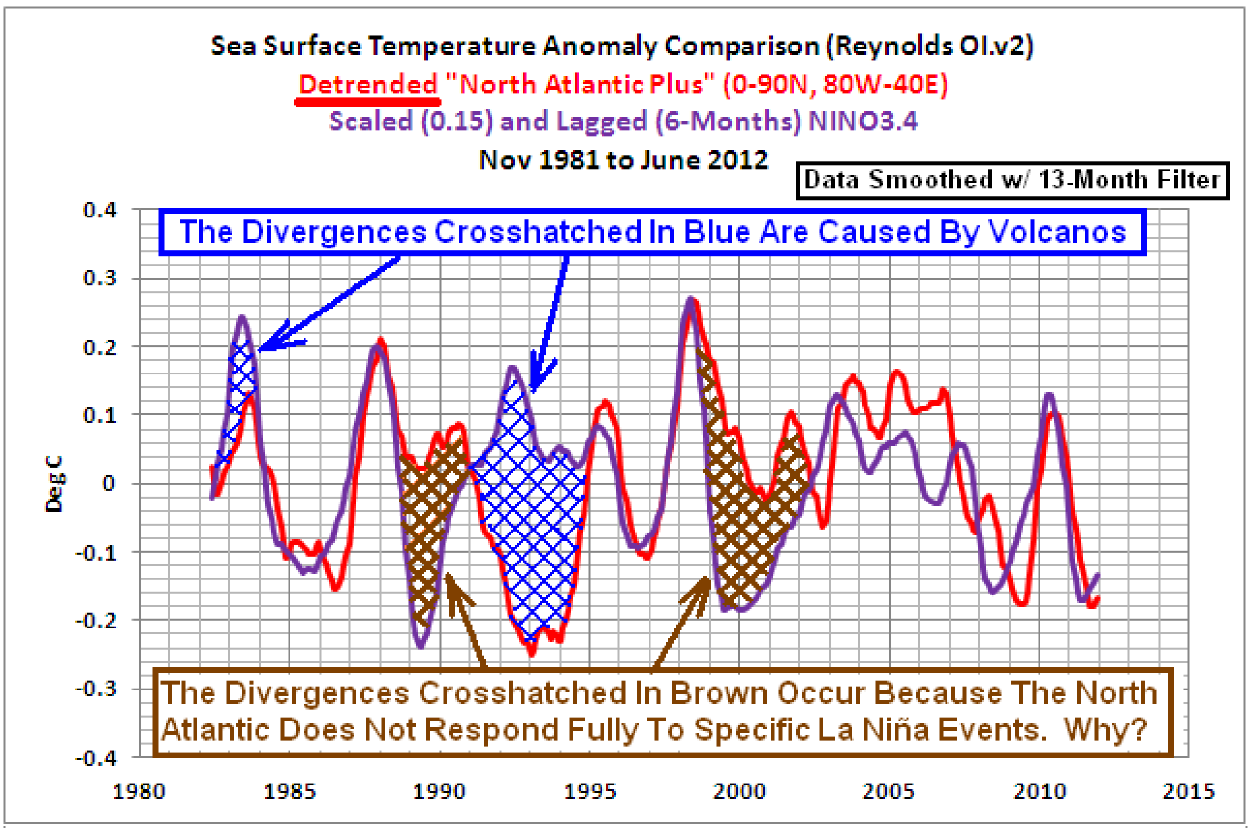


Figure 5-30 Bob Tisdale

I don't have a definite answer. I also have found no scientific studies that address this question. Is it caused by the lag time of the seasonal melting of sea ice in the Arctic Ocean in response to the El Niño? Is it caused by the lag time of the Atlantic Meridional Overturning Circulation in its return to normal strength after an El Niño? Is it caused by the lagged impact of ENSO on Saharan dust that migrates across the North Atlantic? Is it caused by a teleconnection to an area in the North Pacific (the Kuroshio-Oyashio Extension) that warms during a La Niña?

This additional warming of the North Atlantic resulting from its failure to respond fully to La Niña events might typically be explained as the additional variability of the Atlantic Multidecadal Oscillation. However, it is clearly ENSO-related.

RECAP

The mode of natural variability called the Atlantic Multidecadal Oscillation accounts for the additional warming of the North Atlantic sea surface temperature anomalies—those above and beyond the natural warming of the rest of the global oceans caused by ENSO. In addition, as we've seen, the North Atlantic also has warming surges in sea surface temperature anomalies that are caused by its failure to respond fully to the La Niña events that follow major El Niño events.

It looks like natural variables can explain all of the warming of global sea surface temperature anomalies for the past 30 years. ENSO accounts for most of the warming, and the Atlantic Multidecadal Oscillation explains the additional warming of the North Atlantic sea surface temperature data.

How well do the IPCC's climate models simulate that warming? And how do they apparently and incorrectly drive sea surface temperatures? That's discussed in the next two chapters.

5.7 The IPCC's Climate Models do a Terrible Job of Simulating East Pacific, "North Atlantic Plus", and South Atlantic-Indian-West Pacific Sea Surface Temperatures

We'll need to look at the observed warming trends before we examine the trends of the climate model simulations to see how well they perform. Figure 5-31 compares the observed sea surface temperature anomalies and linear trends of the East Pacific, the "North Atlantic Plus" and the South Atlantic-Indian-West Pacific datasets. It's a very noisy graph visually, but it's only being presented for a comparison of the linear trends. The East Pacific hasn't warmed for the past 30 years. It's simply a temporary home for the warm water released by El Niño events. The warm water from beneath the Pacific Warm Pool sloshes into the East Pacific, releases heat, changes atmospheric circulation patterns globally, and it sloshes back out. The South Atlantic-Indian-West Pacific sea surface temperature anomalies have warmed because they receive the warm water left over from the El Niño events, warm water that's created naturally by the sun during La Niña events. And the "North Atlantic Plus" data has the highest rate of warming, because it is impacted by the additional mode of natural variability called the Atlantic Multidecadal Oscillation. Then again, that should eventually peak, if it hasn't already, and the "North Atlantic Plus" data will start to warm less than the rest of the global oceans.

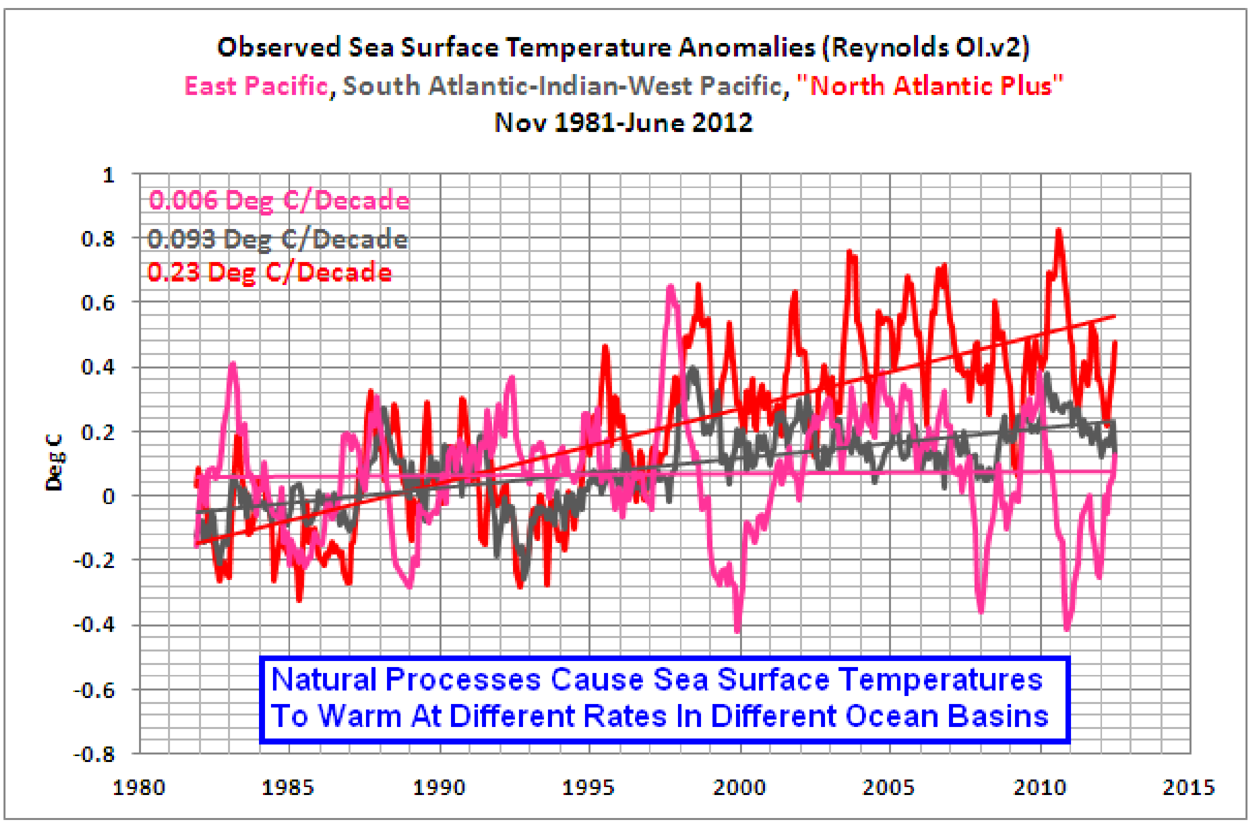


Figure 5-31 Bob Tisdale

We haven't discussed the IPCC's climate models for a while. As a reminder, climate modeling organizations submit their efforts to an archive for use by the IPCC in their reports. The CMIP3 archive contains the models used by the IPCC for their 4th Assessment Report (AR4), and CMIP5 is the archive for the upcoming 5th Assessment Report (AR5). The data for both archives are available through the KNMI Climate Explorer, which, as I've written before, is a wonderful tool, especially for independent researchers. In addition to the individual models and their ensemble members, KNMI also presents the multi-model ensemble mean (the average) of all of the simulations for a specific forcing, which makes investigations such as this even easier.

Figure 5-32 illustrates the simulations of sea surface temperature anomalies and linear trends for the East Pacific, the "North Atlantic Plus" and the South Atlantic-Indian-West Pacific datasets, and they're based on the models used in the IPCC's AR4. They are a merger of the often-cited SRES A1B (projection) and 20C3M (hindcast of the 20th Century). Again, we expect the year-to-year variations of the model mean to be less than the observations, because the timing of the ENSO events differ with each model simulation and we're presenting the average of those individual model simulations with the multi-model ensemble mean.

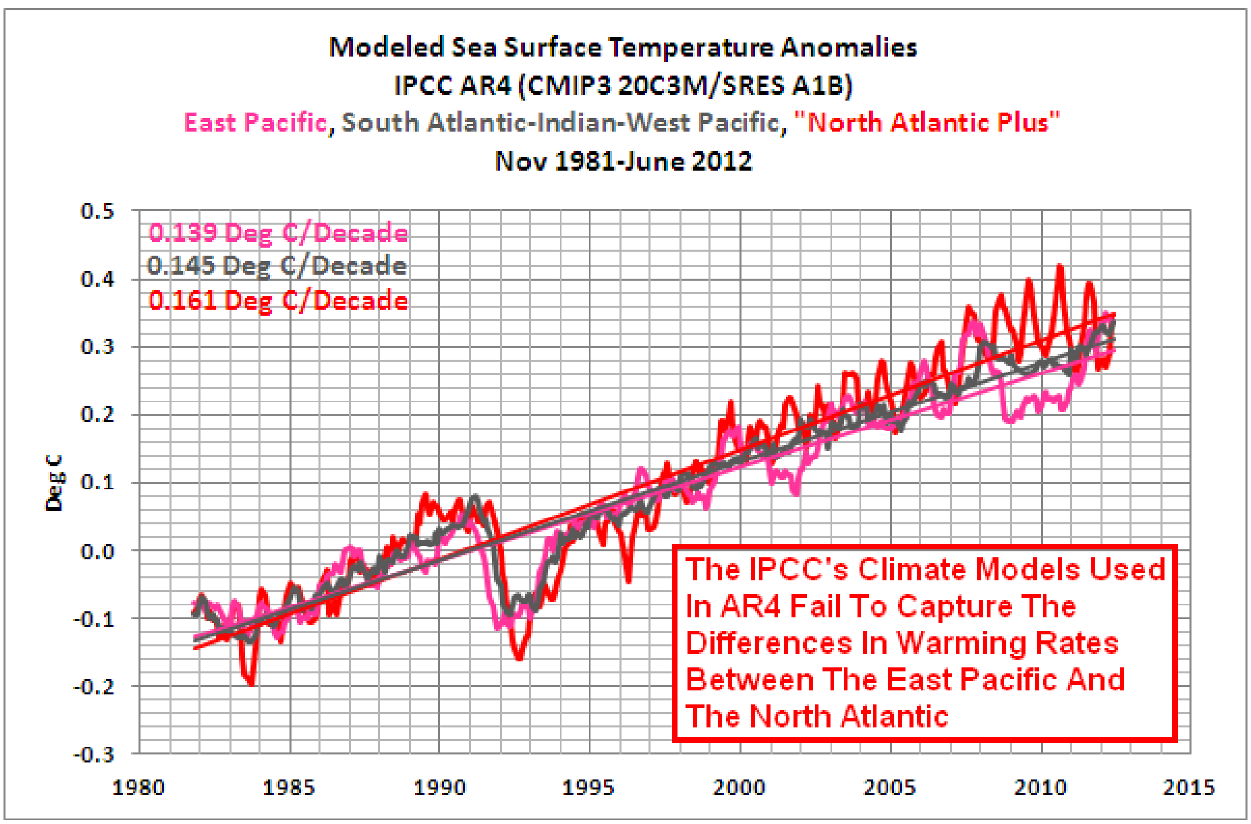


Figure 5-32

Bob Tisdale

Notice how the linear trends are all very similar. The "North Atlantic Plus" trend isn't 2.5 times higher than the South Atlantic-Indian-West Pacific dataset, but that is also expected because the models are not initialized to produce the multidecadal variations of the North Atlantic. Some might think the reason they aren't initialized to do so is because they cannot simulate those multidecadal variations. I've presented the multidecadal trends of the individual models on a global basis in a blog post and many of the models do not produce multidecadal variations. See Animation 1 in the post **Tamino Misses The Point And Attempts To Distract His Readers.**

The very obvious flaw in Figure 5-32 is the modeled warming trend in the sea surface temperatures of the East Pacific. Makes one wonder how the models simulate ENSO, other than poorly.

The CMIP5-archived models that have been prepared for the upcoming IPCC AR5 still show that major flaw. See Figure 5-33.

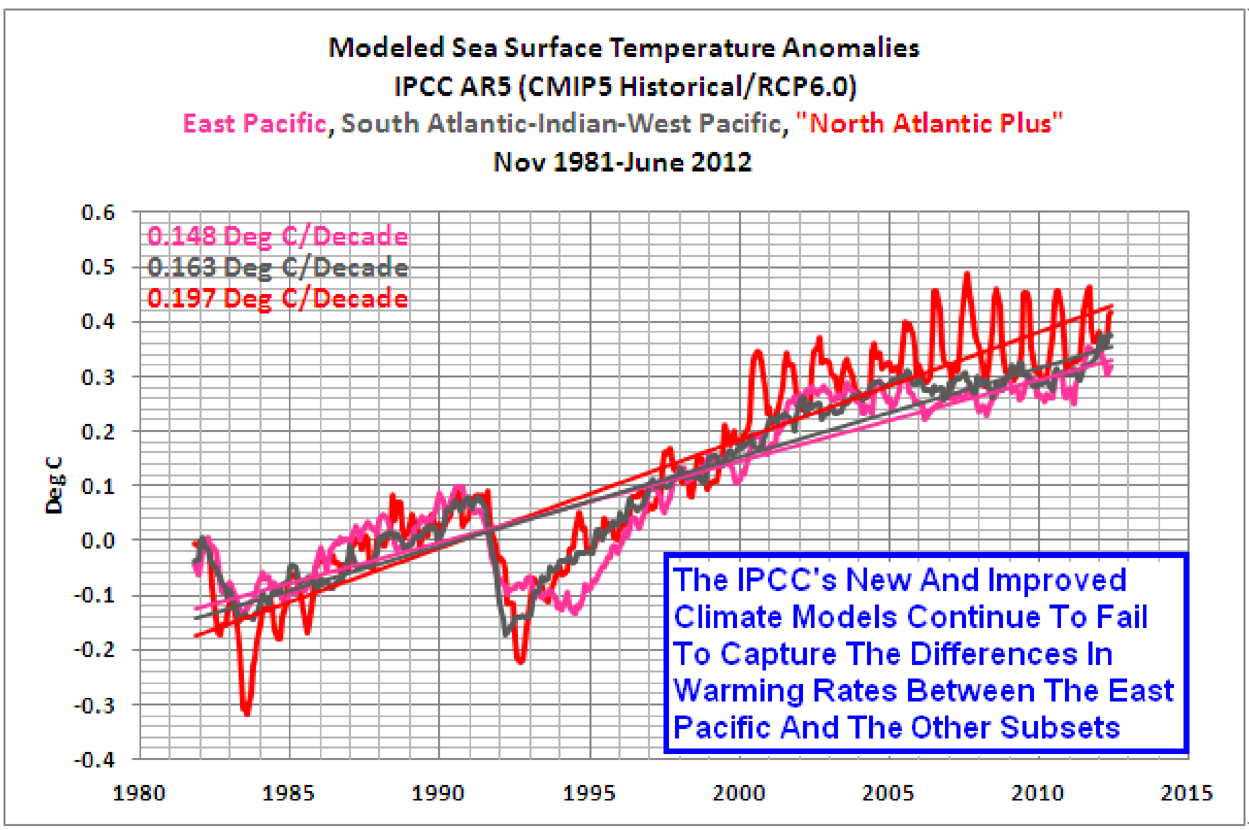


Figure 5-33 Bob Tisdale

The multi-model mean of the CMIP3 (AR4) and CMIP5 (AR5) climate model simulations are compared to the observed sea surface temperatures of our three subsets in Figures 5-34, 5-35 and 5-36. They will help clarify and reinforce the differences. The models are forced with input data that represent greenhouse gases and other natural and anthropogenic forcings. According to the models, the East Pacific Ocean should have warmed 0.42 to 0.44 deg C over the past 30 years, Figure 5-34, but it hasn't warmed. Some people try to rationalize that by reminding themselves that the IPCC says temperature changes will vary regionally and that some areas may not warm. Two points to consider: First, the East Pacific isn't a small region. It represents 33% of the surface area of the global oceans. Second, the reason the East Pacific sea surface temperatures haven't warmed for 30 years is process related, and the process is called ENSO. The East Pacific is only the temporary home of the warm water released from below the surface of the west Pacific Warm Pool by an El Niño event. That warm water has no apparent long-term impact on the surface temperatures of the East Pacific Ocean.

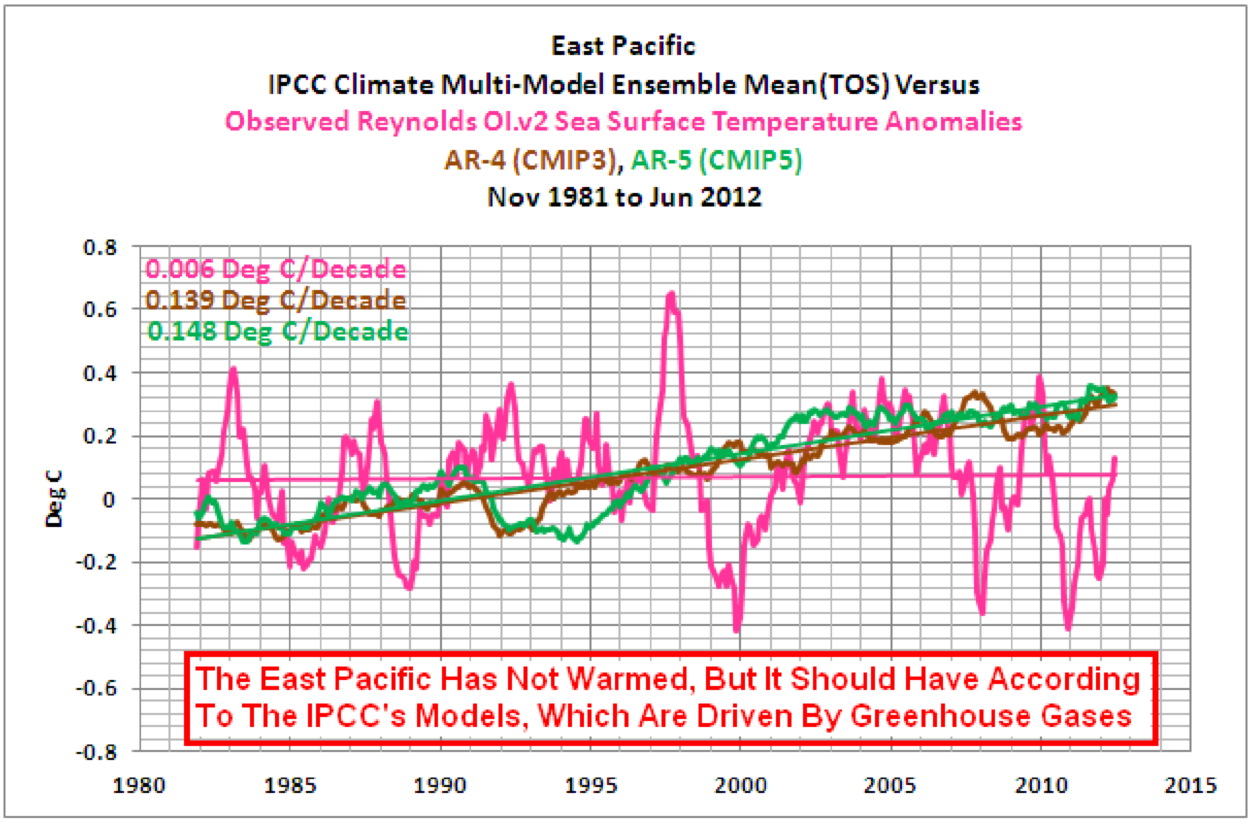


Figure 5-34 Bob Tisdale

On the other hand, the warm water released by El Niño events does have a long-term effect on the sea surface temperatures of the South Atlantic-Indian-West Pacific oceans. The impacts of strong El Niño events, the upward surges in temperature, are very difficult to miss once you know they exist and understand the reasons for them. Those ENSO-related rises in sea surface temperature have caused the South Atlantic-Indian-West Pacific subset to warm. In fact, we've shown that the majority of the warming occurred during the 1986/87/88, the 1997/98 and the 2009/10 El Niño events. Regardless, according to the models, the sea surface temperatures should have warmed at greater rates, about 56% to 75% faster. (Good thing those El Niño events weren't stronger. Then the models might have looked better.)

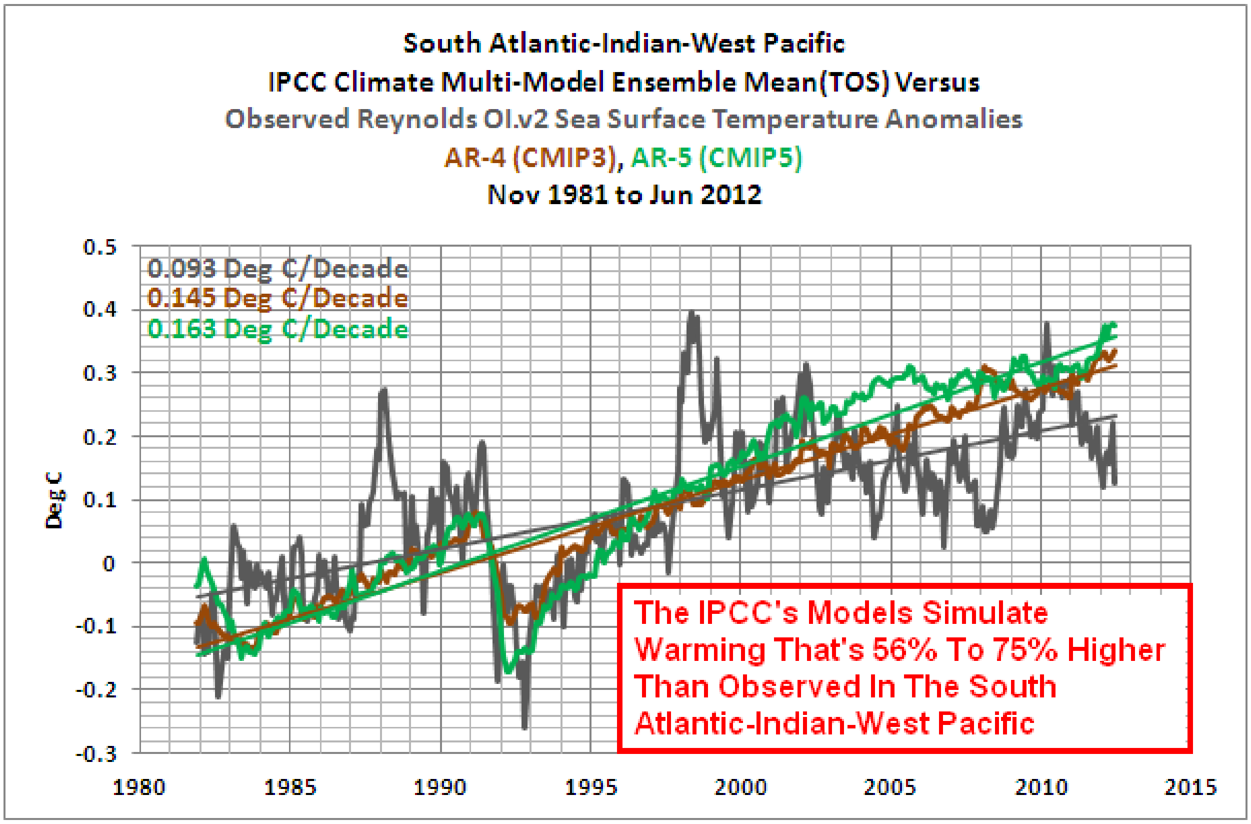


Figure 5-35

That leaves the "North Atlantic Plus" data, Figure 5-36. This is the only subset where the models underestimated the warming, and the reason for that is known. Since the mid-1970s, the North Atlantic sea surface temperatures have been warming faster than the global oceans because of the Atlantic Multidecadal Oscillation. Eventually, the warming of North Atlantic sea surface temperature anomalies will slow, or reverse and wind up cooling, as they have for hundreds if not thousands of years. The models will then overestimate the warming during that multidecadal period. Please refer to Chylek et al (2012) **Greenland ice core evidence for spatial and temporal variability of the Atlantic Multidecadal Oscillation**, and Gray et al (2004) **A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D.** Those papers were referenced in **Chapter 2.13 The Additional Mode of Natural Variability in the North Atlantic Sea Surface Temperatures—Introduction to the Atlantic Multidecadal Oscillation.** One of the often-quoted conclusions of Chylek et al (2012) reads:

The observed intermittency of these modes over the last 4000 years supports the view that these are internal ocean-atmosphere modes, with little or no external forcing.

Without the help of the additional natural warming of the North Atlantic, the climate models would overestimate the warming of the global sea surface temperatures by an even larger amount.

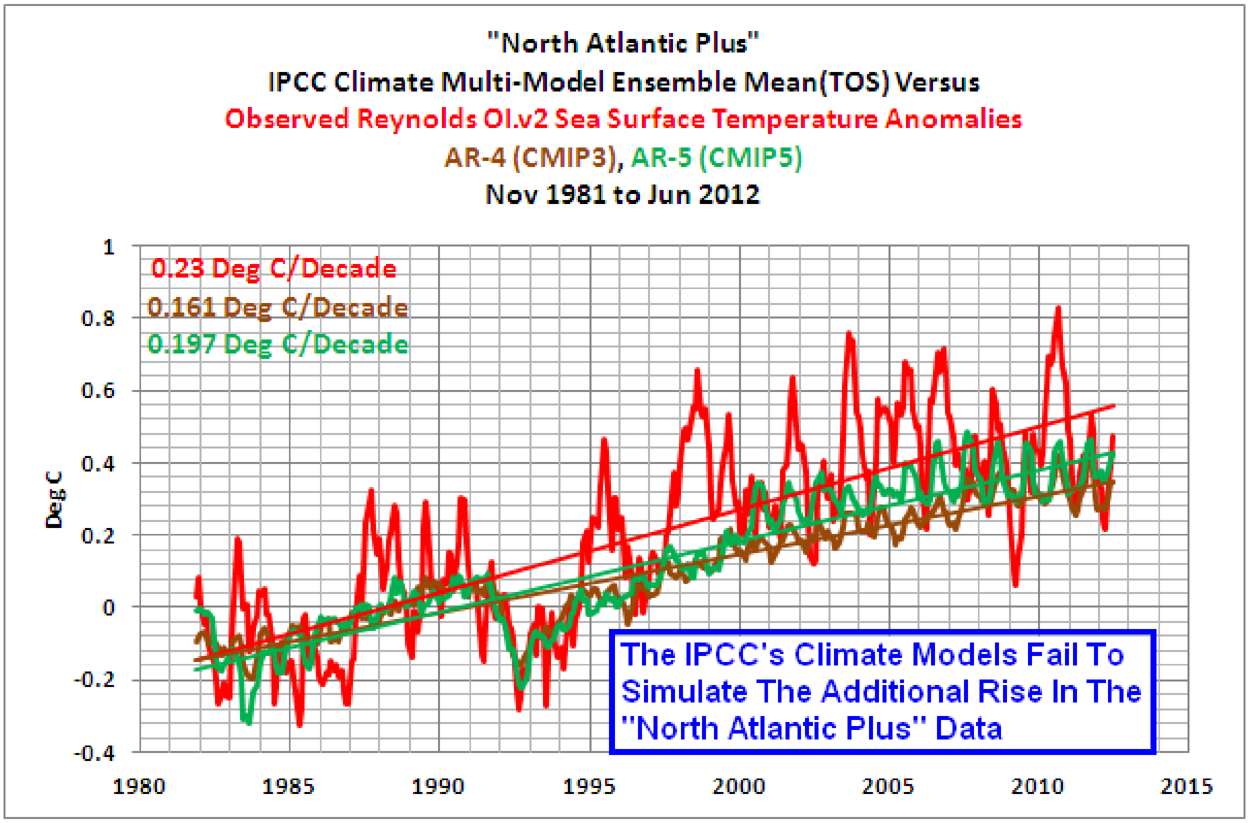


Figure 5-36 Bob Tisdale

THE BEST EXAMPLE OF CLIMATE MODEL FAILURE IS...

One last model-data comparison: Figure 5-37 is a graph that compares the observed and climate model-simulated linear trends of Pacific Ocean on a zonal-mean basis for the past 30 years. The vertical axis shows the warming rates in deg C per decade and the horizontal axis is latitude. The trends were analyzed in 5-degree latitude bands from the Southern Ocean near Antarctica (on the left) through the Bering Strait near the Arctic Ocean (on the right). The equator is at zero latitude. As shown, the equatorial Pacific from 10S to 10N has cooled over the past 30 years. The warm water released by El Niño events from below the surface of the west Pacific Warm Pool has caused no long-term warming there. Note the latitudes at which the Pacific has warmed the most in the observations. As we have described many times in this book, after the leftover warm water returns to the West Pacific, it is carried poleward by the western boundary currents, to the extensions of the western boundary currents in both hemispheres of the Pacific. This is why the mid-latitudes have warmed.

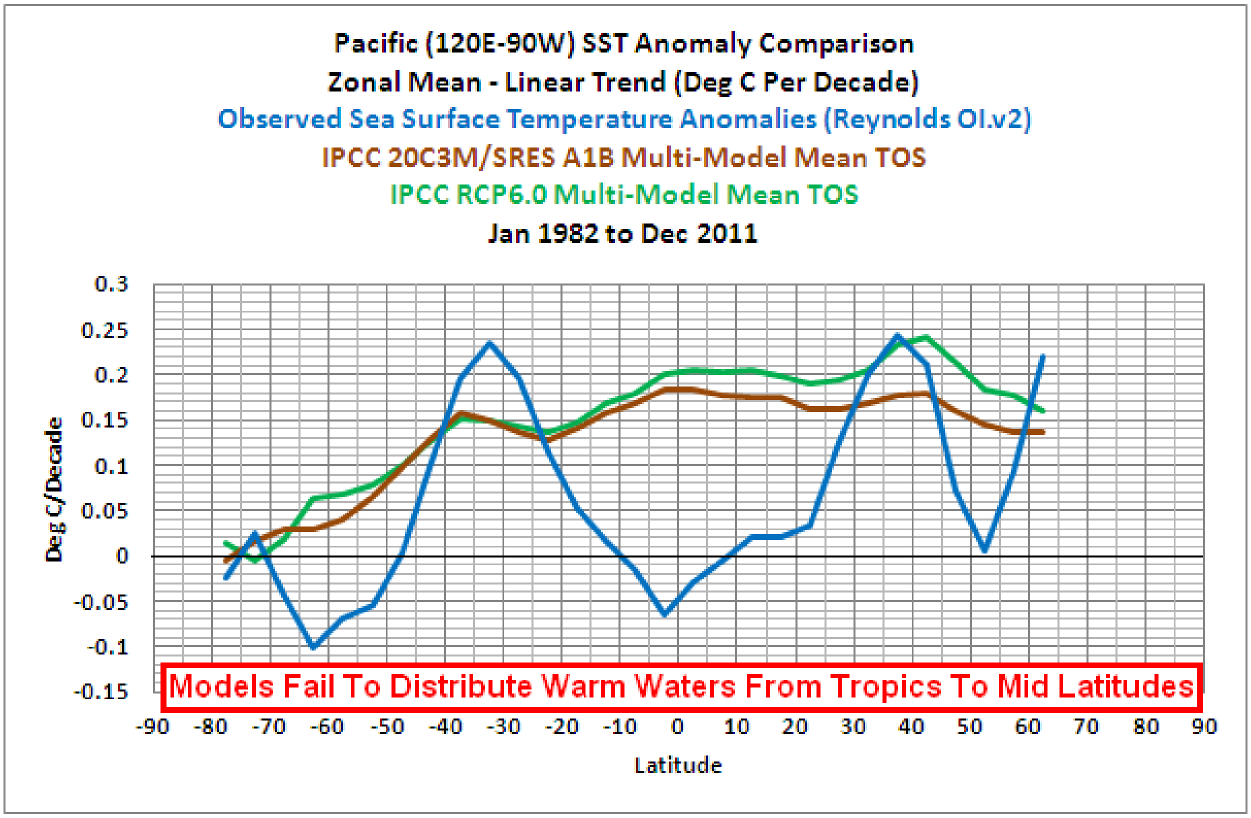


Figure 5-37 Bob Tisdale

Also shown are the warming trends as simulated by the IPCC's models. They show no evidence of the very basic sea surface temperature patterns that one would associate with ENSO. The highest trends of the CMIP3 (AR4) models are in the tropics. Curiously, that's no longer the case for the CMIP5 models that have been prepared for the IPCC's upcoming AR5. While the CMIP5 models agree with the earlier models in the Southern Hemisphere, they diverge from them in the mid-latitudes of the Northern Hemisphere, showing additional warming there. Regardless, the CMIP5 models also fail to capture the latitudinal patterns of warming and cooling in the Pacific.

RECAP

The climate models used by the IPCC in the 4th Assessment Report, and being used to for their upcoming 5th Assessment Report, show no skill at being able to simulate the rates at which global oceans have warmed over the past 30 years. Why anyone would have any confidence in model projections of future climate is a mystery to me.

I ask the following two-part question in my monthly sea surface temperature updates:

Since 1982, what anthropogenic global warming-related processes would overlook the Sea Surface Temperatures of 33% of the global oceans (the East Pacific), and what anthropogenic processes would have an impact on the other 67% (the Atlantic-Indian-West Pacific) but only during the months of the significant El Niño events of 1986/87/88, 1997/98, and 2009/10?

It's a question the IPCC cannot answer.

They definitely can't use their climate models to answer the question.

Here's a question that serves as the title to one of the chapters from my first book: Do Satellite-Era Sea Surface Temperature Records Confirm the Hypothesis of Anthropogenic Global Warming?

The answer is no. The satellite-era sea surface temperature data contradict the hypothesis of anthropogenic global warming.

5.8 Scientific Studies of the IPCC's Climate Models Reveal How Poorly the Models Simulate ENSO Processes

The model-data comparisons in Chapter 5.7 highlight the differences between how Mother Nature warms sea surface temperatures and how the IPCC's climate models show them warming according to the hypothesis of anthropogenic global warming. Of course, in the case of the models, the grand and faulty assumption is that sea surface temperatures are warmed by the anthropogenic forcings. In this chapter, we'll present the findings of scientific papers that describe the ENSO-related climate model deficiencies. You can replace deficiencies with failures or failings in the last sentence if you like.

One paper will serve as the primary focus of this chapter and it is Guilyardi et al (2009) **Understanding El Niño in Ocean-Atmosphere General Circulation Models: progress and challenges**. It provides a detailed overview of the model problems and how those problems impact the modeled portrayal of ENSO, with a virtual smorgasbord of climate model and ENSO references, citing more than 120 other papers. If one of the deficiencies sparks your interest, scroll down to the list of references and you'll be able to find more detail. I'll reword or explain their findings and provide links to definitions of terms we haven't used in this book, so that Guilyardi et al will be easier to understand.

THE "NORMAL" STATE AND ANNUAL CYCLE OF THE TROPICAL PACIFIC

Under the sidebar heading of "Tropical Pacific mean state and annual cycle performance in CGCMs", page 326 (2 of 16), Guilyardi et al introduce problems with zonal wind stress, meridional extent of wind variability, the "double Intertropical Convergence Zone (ITCZ)", thermocline depth and slope at the equator, and problems with the portrayal of the cold tongue in the eastern equatorial Pacific.

Wind stress is the horizontal force of the wind on the sea surface. Refer to the University California, San Diego (UCSD) discussion of **Wind Stress**. Zonal winds are those traveling from east to west and from west to east. Because the topic is the mean state and annual cycle of the Tropical Pacific, they're discussing the horizontal force of the trade winds (east to west) on the ocean surface. Guilyardi et al (2009) note:

> *…most models simulate a mean zonal equatorial wind stress that is too strong and that has an annual amplitude that is also too strong (Fig. 1; see also Guilyardi 2006; Lin 2007a). This has profound effects on ENSO behavior in that it limits the regimes in which interannual anomalies can develop.*

With meridional extent of wind variability, they're discussing how close to the equator the variations in wind are taking place. Guilyardi et al write:

> *Similarly, the meridional extent of the wind variability, of importance for ENSO phase change, is too confined near the equator (Zelle et al. 2005; Capotondi et al. 2006; Capotondi 2008).*

Wikipedia defines the **[Intertropical Convergence Zone (ITCZ)]** as:

> *…the area encircling the earth near the equator where winds originating in the northern and southern hemispheres come together…The ITCZ appears as a band of clouds, usually thunderstorms, that circle the globe near the equator.*

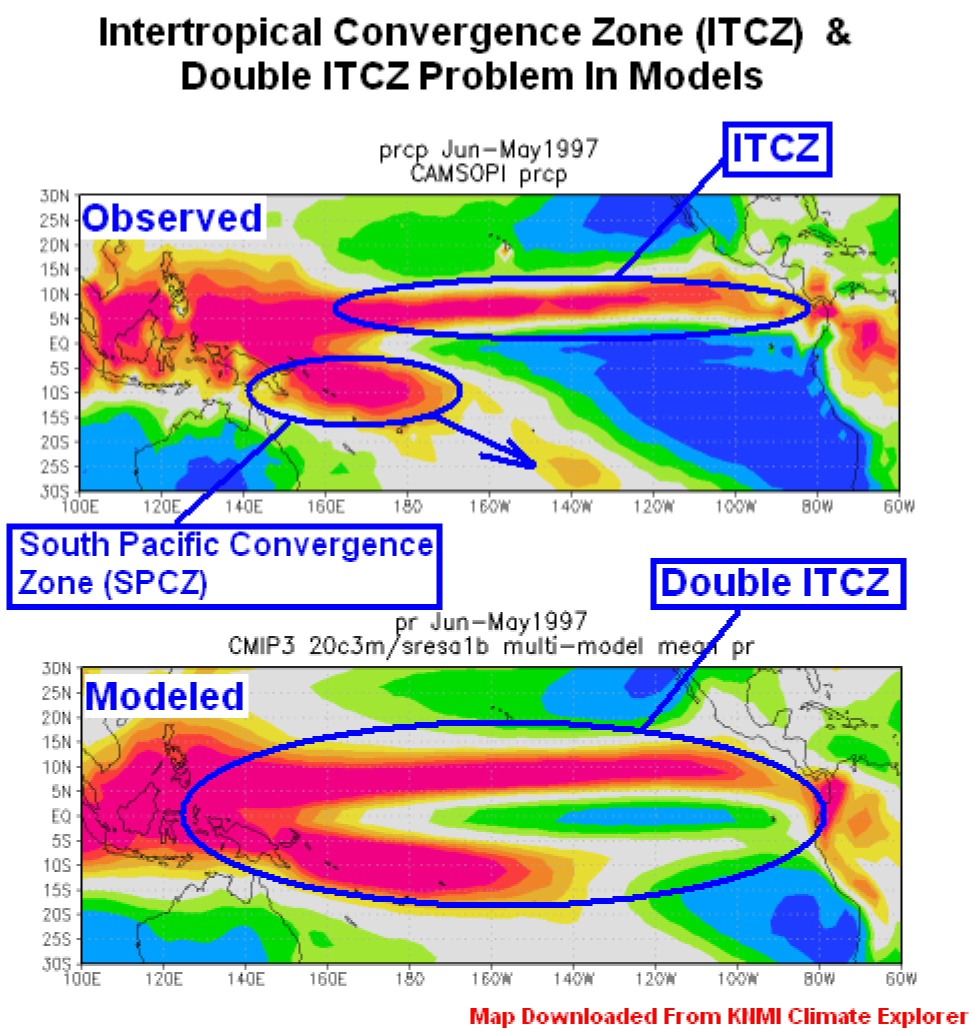


Figure 5-38 Bob Tisdale

We can illustrate the Intertropical Convergence Zone in the Pacific with a map of precipitation data. See the top cell of Figure 5-38. I've used July 1996 to

June 1997 as an example of a typical ENSO-neutral year. The Intertropical Convergence Zone does change position over the course of the normal year, following the warmest water as it chases the sun, but in the Pacific, its average position is north of the equator—north of the cold tongue region at about 5N-10N. The South Pacific Convergence Zone (SPCZ) is also highlighted in the top cell. Typically, it extends from the west Pacific Warm Pool toward the southeast. In the climate models (CMIP3), as shown in the bottom cell, the South Pacific Convergence Zone does not extend to the southeast, but "hugs" the equator at about 10S-5S, extending to the east. That's what's called the Double Intertropical Convergence Zone problem. It has to be noted that a Double Intertropical Convergence Zone can exist in nature, but it is not the normal background state, as depicted in the models.

About the Double Intertropical Convergence Zone (ITCZ) problem, Guilyardi et al (2009) write:

> *The "double Intertropical Convergence Zone (ITCZ)" problem, in which a symmetrization of the circulation across the equator leads to a spurious Southern Hemisphere ITCZ and is associated with excessive precipitation over much of the tropics, remains a major source of model error in simulating the annual cycle in the tropics (Lin 2007a), and it can ultimately impact the fidelity of the simulated El Niño (Guilyardi et al. 2003; Sun et al. 2009).*

As discussed in **Chapter 4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves**, the thermocline is the boundary between the warm mixed layer and the cool waters below. Typically this is presented as the contour line (isotherm) at 20 deg C. In the normal state of the equatorial Pacific, there's the pocket of warm water in the west and there's upwelling of cool water in the east, so the thermocline slopes upward toward the surface from west to east. In some respects, the depth and slope of the thermocline relate to the amount of warm water available for El Niño events. Guilyardi et al (2009) note the problems with how the climate models present the thermocline:

> *Similarly, there are still large differences in how the models reproduce the mean state of the tropical ocean, including the mean thermocline depth and slope along the equator (Fig. 2) and the structure of the equatorial currents (Brown and Fedorov 2008).*

Based on the abstract of Brown and Fedorov (2008) **Mean energy balance in the tropical Pacific Ocean**, they're discussing the South Equatorial Current and the Equatorial Counter Current, which we illustrated and discussed in Sections 1 and 3.

Next on the Guilyardi et al (2009) list of problems with the normal state in the models is the modeled temperatures of the cold tongue region. Figure 5-39 presents an example of the observed tropical Pacific sea surface temperature gradients in the top cell, using the ENSO-neutral year of July 1996 to June 1997. I've highlighted the cold tongue region. The bottom cell shows a sample of the model mean sea surface temperature gradients (CMIP3), with the cold tongue region highlighted. Guilyardi et al (2009) note:

> *Along the equator in the Pacific, the models have difficulty capturing the correct intensity and spatial structure of the East Pacific cold tongue. Often, the simulated cold tongue is too equatorially confined, extends too far to the west and is too cold (see Fig. 4 of Reichler and Kim 2008).*

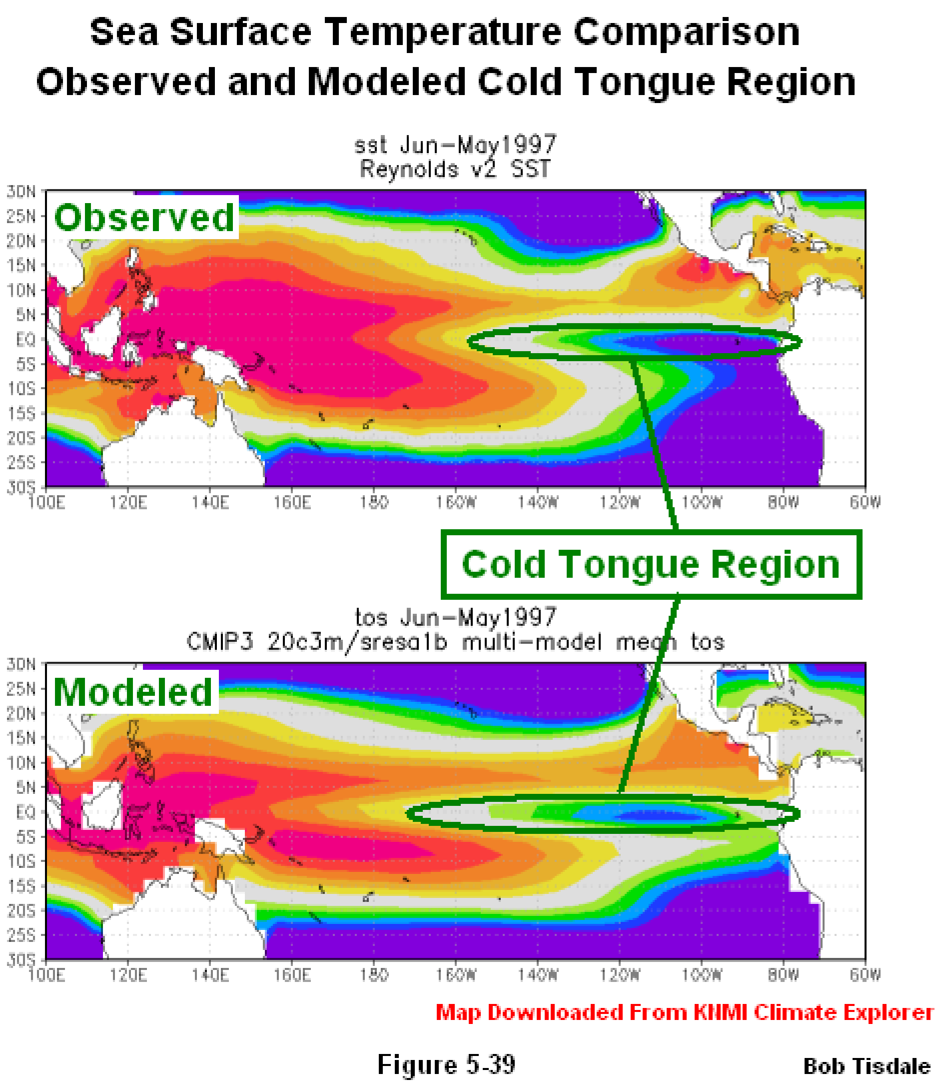


Figure 5-39

To sum up the problems with the mean state and annual cycle, Guilyardi et al (2009) write (my boldface):

> *These recurrent biases, already present in CMIP1 15 yr ago, arise from numerous factors including overly strong trade winds, leading to increased cooling via oceanic upwelling, mixing, and latent heat flux to the atmosphere; a diffuse thermocline structure, leading to improper sensitivity of SST to anomalous upwelling and vertical mixing;* ***insufficient surface and penetrating solar radiation****, and weak ocean vertical mixing in the subtropics, leading to subsurface temperature errors along the equator; and weak tropical instability waves, resulting in too little meridional spreading of SST anomalies during cold events (Meehl et al. 2001; Luo et al. 2005; Wittenberg et al. 2006; Lin 2007a).*

If the downward shortwave radiation is too low in the normal state, is it also too low during the La Niña phase when it serves to recharge the heat (warm water) released by the El Niño? If so, in some respects this may be the greatest failing of the models. How then do they recharge the heat released by the El Niño and recharge the warm water that was redistributed by ENSO from the tropics to the poles? Based on the zonal-mean graph, Figure 5-37, at the end of Chapter 5.7, the models do not distribute warm water from the tropics to the poles!

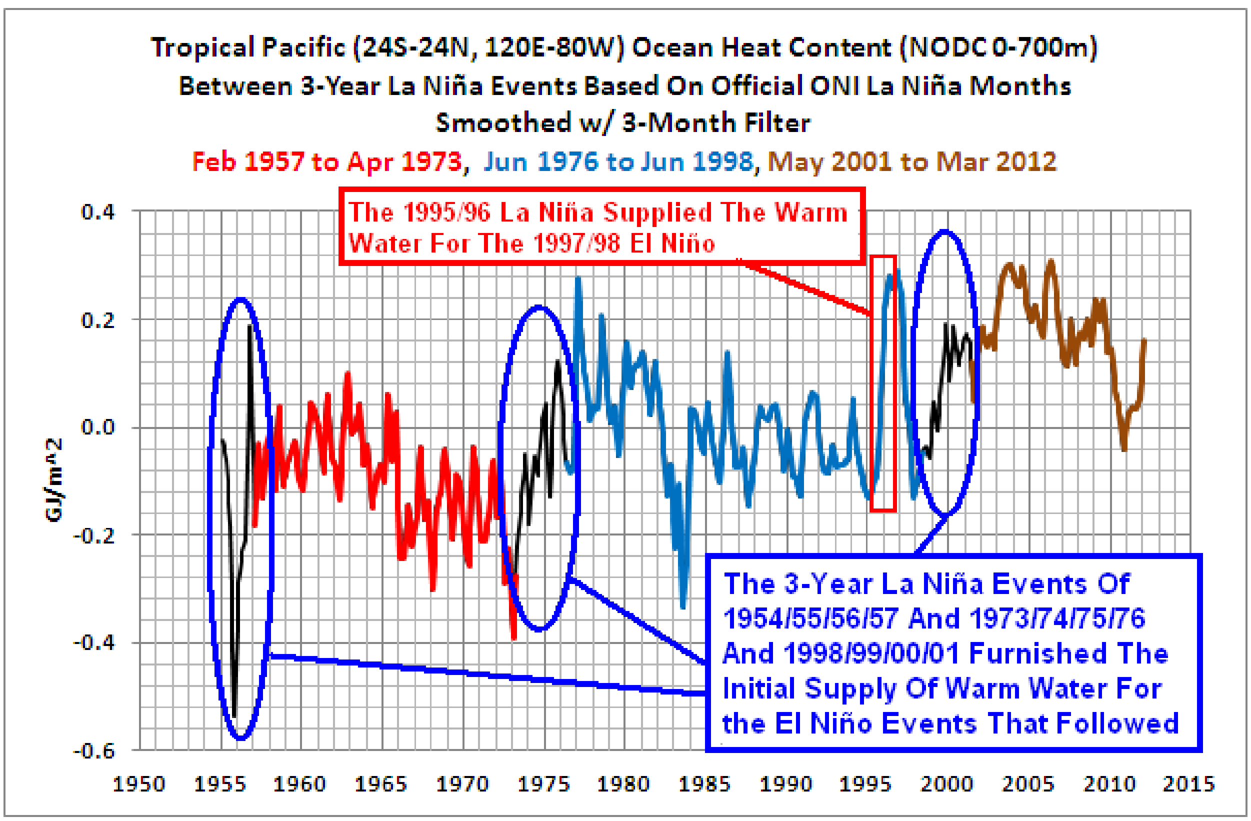


Figure 5-40

"Insufficient surface and penetrating solar radiation" also brings to mind another question. Do models, like Mother Nature, create 3-year-long La Niña events? These multiyear La Niña events have occurred every couple of decades since the 1950s, and they furnish the initial supply of warm water for El Niño events. The shorter La Niña events that follow El Niño events replenish part of the warm water discharged by the El Niño. Refer to Figure 5-40. It's a time-series graph of Tropical Pacific (24S-24N, 120E-80W) Ocean Heat Content from 1955 to present. In it, I've isolated the data for the periods between the 3-year La Niña events of 1954/55/56/57 (starting in 1955) and 1973/74/75/76 and 1998/99/00/01. The NOAA Oceanic NINO Index data (original version) serves as the source of the "official" La Niña months. As shown, it's the 3-year La Niña events that raise Tropical Pacific Ocean Heat Content, supplying the initial warm waters that feed El Niño events for periods of up to about 2 decades, with the La Niña events that follow El Niño events recharging part of the heat discharged by the El Niño. Of course, as discussed in **Chapter 3.10 The Recharge of Ocean Heat during the La Niña**, the relatively weak 1995/96 La Niña supplied the warm water for the super 1997/98 El Niño, so the 1998/99/00/01 La Niña also served to replenish the warm water released by that monstrous El Niño.

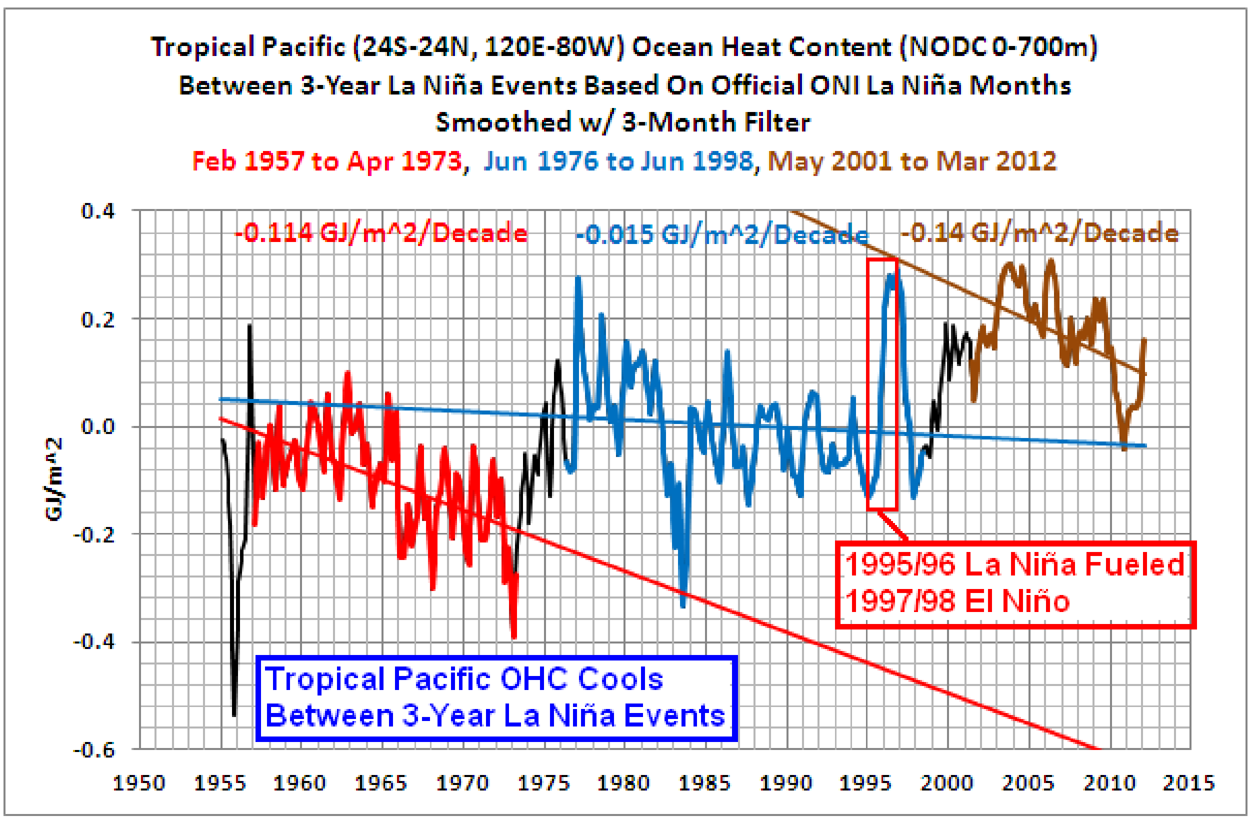


Figure 5-41 Bob Tisdale

The continued rise in Tropical Pacific Ocean Heat Content for a few years after the 3-year La Niña events may be caused by the warm water returning to the tropics through shallow overturning circulation. Regardless, the linear trends in Tropical Pacific Ocean Heat Content between the 3-year La Niña events are negative. See Figure 5-41. In other words, for the depths of 0-700 meters, the Tropical Pacific Ocean cools between the multiyear La Niña events of 1954/55/56/57 and 1973/74/75/76 and 1998/99/00/01, and they cooled after the last of the 3-year La Niña. We'll discuss this further in **Chapter 5.9 A Look at the Long-Term Impacts of ENSO and Other Natural Variables on Ocean Heat Content Data**.

Back to Guilyardi et al (2009): They continue:

> *There are also errors in the tropical Pacific seasonal cycle, both in SST and wind: many models exhibit an overly strong seasonal cycle in the east Pacific (Fig. 1) and/or a spurious semiannual cycle, possibly tied to the lack of sufficient meridional asymmetry in the background state (Li and Philander 1996; Guilyardi 2006; Timmermann et al. 2007) and/or errors in the water vapor feedbacks (Wu et al. 2008).*

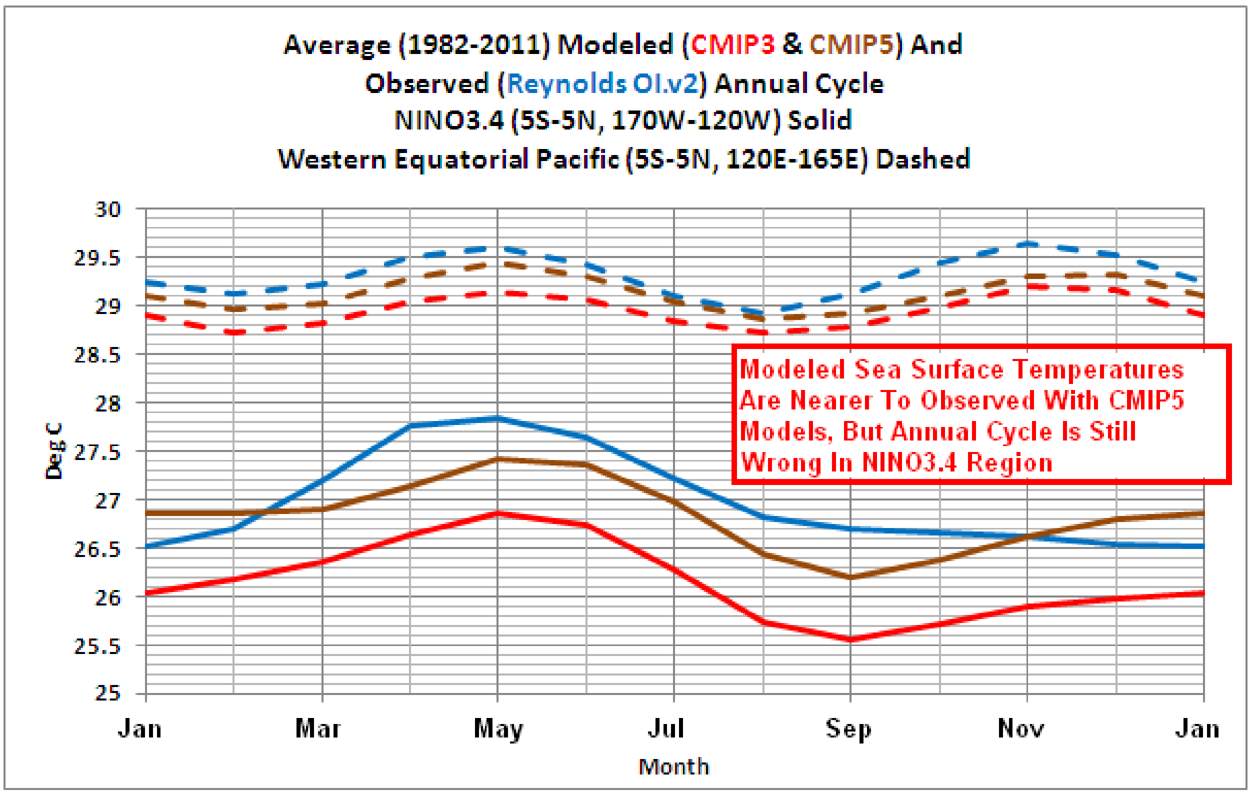


Figure 5-42 Bob Tisdale

Figure 5-42 shows the observed and modeled seasonal cycles for the NINO3.4 region (5S-5N, 170W-120W) and the Western Equatorial Pacific (5S-5N, 120E-165E). They represent the average monthly sea surface temperatures for the period of 1982 to 2011. The model data is the multi-model ensemble mean of the simulations in the CMIP3 (IPCC AR4) and CMIP5 (upcoming AR5) archives. Guilyardi et al (2009) discussed problems with individual models but the multi-model mean show the models seem to capture the seasonal cycle in the Western Equatorial Pacific reasonably well. The second peak in the observations arrives in November, but in the models it appears in December. That's minor compared to the problems in the eastern Pacific. The western equatorial Pacific sea surface temperature of CMIP5 models are nearer to the observations than the CMIP3 models, so there's been a minor improvement. For the NINO3.4 region, on the other hand, the models reach their lowest values in September, while the observations reach their minimum seasonal temperatures in November and December. The skewed modeled seasonal cycle in the eastern equatorial Pacific (NINO3.4 region used as an example) would make it difficult for them to capture the seasonal cycle of El Niño and La Niña events.

So far, we've only discussed the problems with model simulations of the "normal" state. It's not going to get better when we look at the…

MODELED SIMULATIONS OF EL NIÑO & LA NIÑA EVENTS

Guilyardi et al (2009) begin their discussion of the problems with the modeled ENSO events under the heading of "Current Model Performance". In the last paragraph of regular (not sidebar) text on page 327 (3 of 16), they write:

> *Coupled GCMs produce a variety of El Niño variability time scales (Fig. 3): model spectra range from very regular near-biennial oscillations to spectra that are close to the observed 2–7 yr.*

The "very regular near-biennial oscillations" sounds like those models create an El Niño every other year with a La Niña between them, as though they have an uninterrupted delayed-oscillator simply sloshing waters back and forth. Guilyardi et al (2009) continue (my boldface):

> *The observed seasonal phase locking—El Niño and La Niña anomalies tend to peak in boreal winter and are weakest in boreal spring—is often not captured by models, which either show little seasonal modulation or a phase locking to the wrong part of the annual cycle, although some models do show some tendency to have ENSO peaking in boreal winter (not shown).* ***All of these biases combine to generate errors in ENSO amplitude, period, irregularity, skewness, or spatial patterns (Fig. 4)****.*

We discussed "period", how often ENSO events occur. I'll assume that irregularity refers to the fact that El Niño events occur at 2 to 7-year intervals, which they've also mentioned. They've illustrated some of the differences in between observed and modeled spatial patterns in their Figure 4, but we'll return to that. Let's see what Guilyardi et al (2009) have to say about amplitude and skewness. Amplitude refers to the strengths of the El Niño and La Niña events. They write:

> *Even though CGCMs have common biases, they still exhibit a diversity of El Niño behavior that is well beyond the observed diversity of events. For instance, the modeled amplitude of El Niño ranges from less than half to more than double the observed amplitude (van Oldenborgh et al. 2005; AchutaRao and Sperber 2006; Guilyardi 2006; Fig. 5).*

For a model to create El Niño events that are stronger than those observed, the normal temperature gradient between the west Pacific Warm Pool and the Cold Tongue Region has to be larger than observed. They've already discussed how that's the case in many models.

By skewness, Guilyardi et al (2009) are referring to the fact that El Niño events have tended to be stronger than La Niña events since 1900 and since the Pacific climate shift of 1976/77. They note:

> *Unlike observations, most GCMs exhibit a linear ENSO, with SST skewness near zero in the tropical Pacific (Hannachi et al. 2001; van Oldenborgh et al. 2005). This could conceivably render them less sensitive than the real world to changes in climate, even though other studies attribute the positive skewness of ENSO to sources other than nonlinearity such as the superposition of ENSO, decadal variations, or global warming trends (Lau and Weng 1999).*

The "linear ENSO" problem exhibited by the models, with modeled El Niño and La Niña having the same strengths, frequencies and durations, is a major flaw. It would neutralize ENSO; that is, in the models, La Niña and El Niño events would balance out against one another. ENSO then becomes a nonentity, nothing more than a source of noise in the modeled temperature record. Not surprisingly, that is exactly how many climate scientists portray ENSO—incorrectly, misleadingly. Some readers may believe the "linear ENSO" problem in models is intentional, that it's the way the modelers neutralize ENSO, so that ENSO can't contribute to the long-term warming. That is, some readers may think the modelers discovered the oceans will warm **without** anthropogenic forcings if ENSO is skewed toward El Niño, and because that undermines their preconceived notions about manmade global warming, the modelers "fix" ENSO so that it can't become skewed one way or the other. Who knows? Those thoughts might have merit. Two things are certain: the global oceans do warm when ENSO is skewed toward El Niño, and the reason they warm is **because** ENSO is skewed toward El Niño.

The instrument temperature record shows that El Niño events dominate some multidecadal periods, and that La Niña events dominate others. That is, during some multidecadal periods, the frequency, magnitude and duration of El Niño events outweigh those of La Niña events, and during other multidecadal periods, the reverse occurs, with the frequency, magnitude and duration of La Niña events outweighing those of El Niño events. We can show this very simply using the period average sea surface temperatures of the NINO3.4 region since 1917, and to make it easier to visualize we'll use annual not monthly data. See Figure 5-43. The data was divided into the three periods of 1917 to 1944, 1944 to 1976, and 1976 to 2011. The average NINO3.4 sea surface temperature anomalies for the periods ending in 1944 and starting in 1976 were positive, well in excess of zero. El Niño events dominated those periods. On the other hand, during the period of 1944 to 1976, the average NINO3.4 sea surface temperature anomalies were slightly less than zero. La Niña events dominated that period, but it wasn't by a significant amount.

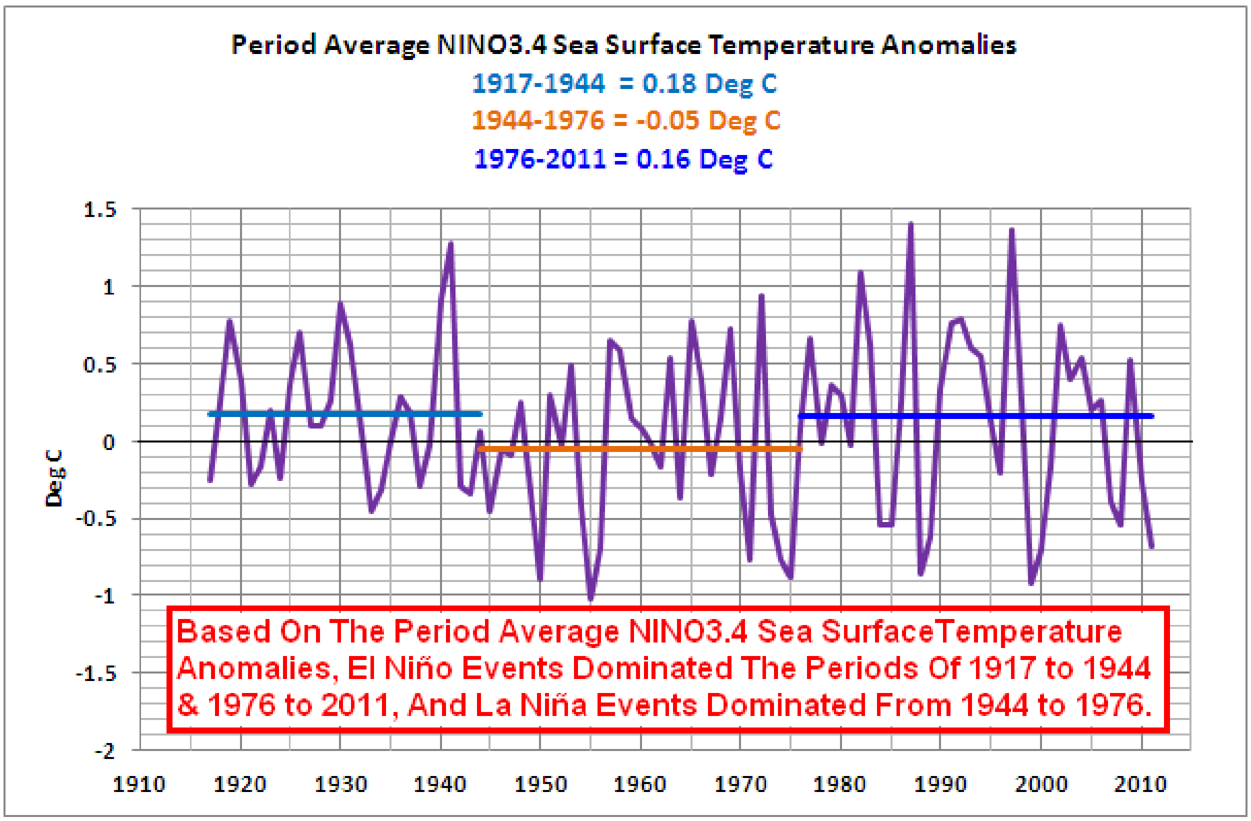


Figure 5-43 Bob Tisdale

You may be wondering why I selected those periods. 1917 is the start year of the warming period in the early 20th Century, the years 1944 to 1976 capture mid-century cooling period, the recent warming period started in 1976. Let me repeat two statements I made in the Introduction.

First: El Niño and La Niña events are phenomena Mother Nature has devised to vary the rate at which naturally stored thermal energy (in the form of warm water) is released by, and renewed in, the tropical Pacific Ocean.

That statement is supported by what's been presented in this book.

Second: The strength of ENSO phases, along with how often they happen and how long they persist, determine how much heat is released by the tropical Pacific into the atmosphere and how much warm water is transported by ocean currents from the tropics toward the poles. During a multidecadal period when El Niño events dominate (a period when El Niño events are stronger, when they occur more often and when they last longer than La Niña events), more heat than normal is released from the tropical Pacific and more warm water than normal is transported by ocean currents toward the poles—with that warm water releasing heat to the atmosphere along the way. As a result, global sea surface and land surface temperatures warm during multidecadal periods when El Niño events dominate. They have to. There's no way they cannot warm. Conversely, global temperatures cool during multidecadal periods when La Niña events are stronger, last longer and occur more often than El Niño events. That makes sense too because the tropical Pacific is releasing less heat and redistributing less warm water than normal then.

Figure 5-44 confirms the second statement. I've added GISS Global Land-Ocean Temperature Index data to graph of period average NINO3.4 sea surface temperature anomalies, and I've divided it into the corresponding periods.

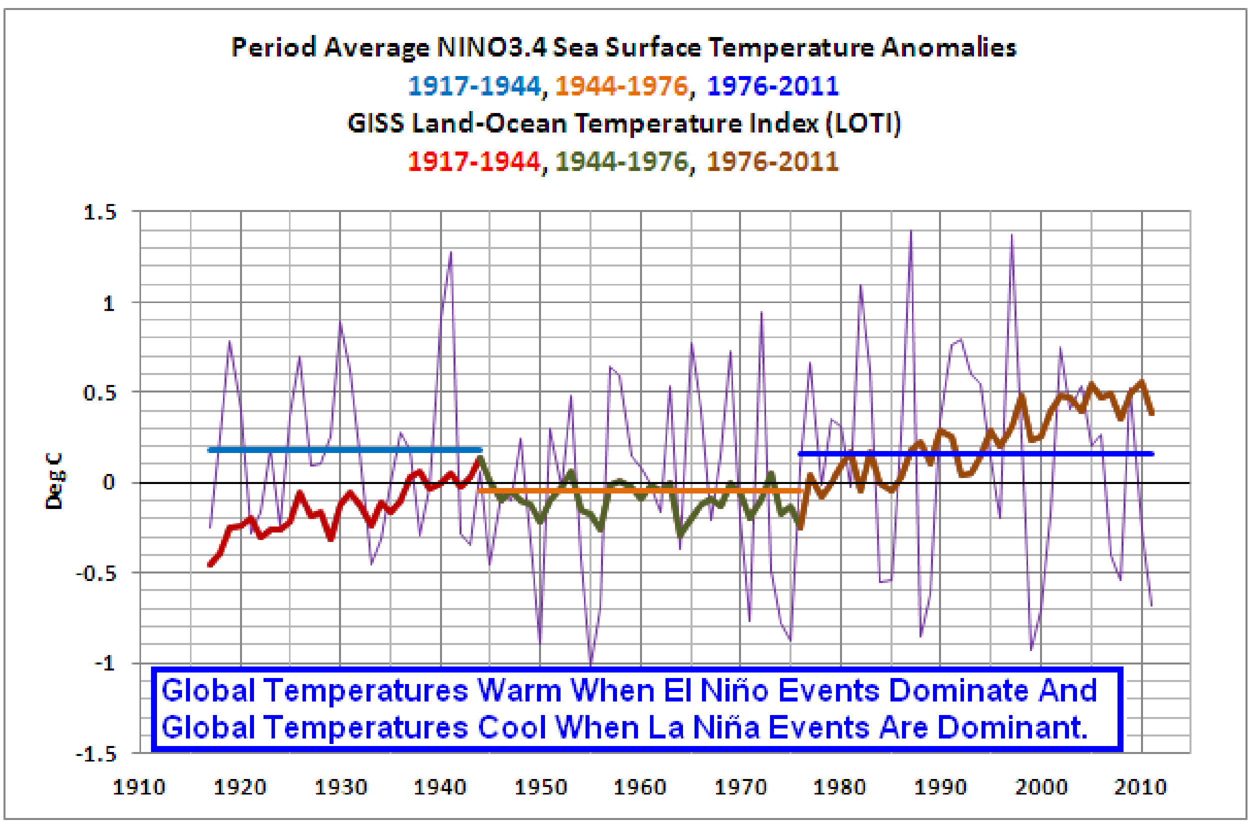


Figure 5-44 Bob Tisdale

For those wondering about the linear trends in the global temperature anomalies for the three periods, I've included Figure 5-45. The trend lines make the graph a bit busy. The two warming periods have remarkably similar warming rates (linear trends), especially when you consider how little source data exists in the early warming period and when you consider that greenhouse gases have been rising at an exponential rate. Also, the rate at which global surface temperatures cooled during the mid-20th Century period is comparatively small compared to the two warming rates, as one would expect.

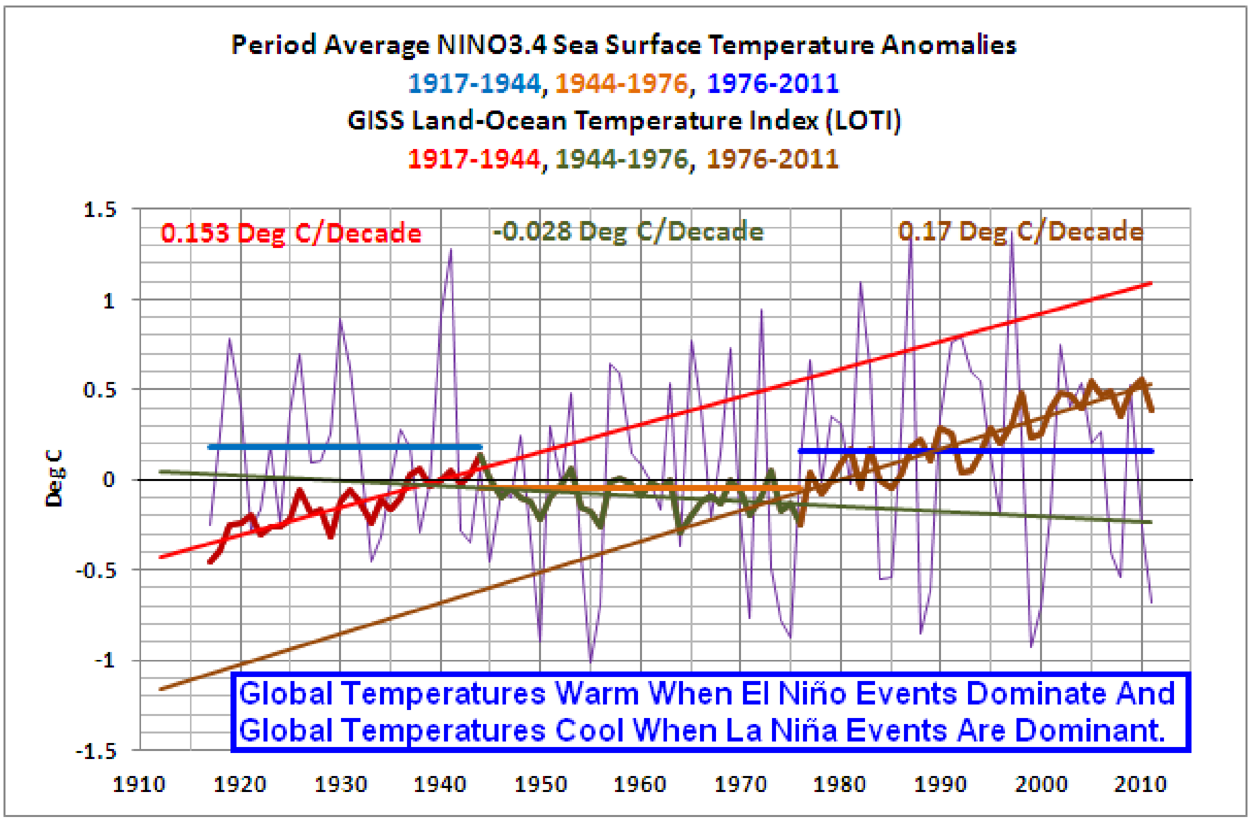


Figure 5-45 Bob Tisdale

RECAP

There are a multitude of problems with how climate models depict ENSO. Guilyardi et al (2009) did not discuss Central Pacific and Eastern Pacific El Niño events, and how some El Niño events develop from west to east while others develop from east to west, though they did mention spatial patterns as a whole. The problem with how they simulate downward shortwave radiation is significant. To me, the linear ENSO problem is the biggest problem because it neutralizes ENSO.

I'll close this chapter with one more quote from Guilyardi et al (2008)[my boldface]:

> ***Because ENSO is the dominant mode of climate variability at interannual time scales, the lack of consistency in the model predictions of the response of ENSO to global warming currently limits our confidence in using these predictions to address adaptive societal concerns, such as regional impacts or extremes (Joseph and Nigam 2006; Power et al. 2006).***

That's a very strong statement from a group of well-respected climate scientists.

5.9 A Look at the Long-Term Impacts of ENSO and Other Natural Variables on Ocean Heat Content Data

As mentioned earlier, Anthony Watts cross posts at WattsUpWithThat many of my blog posts about the long-term effects of ENSO. While guest posts at WattsUpWithThat are generally written by authors who are skeptical of anthropogenic global warming, there are many frequent visitors who comment there who are proponents of it. The mix of views ensures abundant discussions and arguments. Those who read the comments on the threads of my ENSO-related posts at WattsUpWithThat will note the regularity with which the proponents of anthropogenic global warming try to shift topics of discussion from sea surface temperature to ocean heat content. It's a diversion or redirection tactic. Some might even call it misdirection. It's almost as though they acknowledge that ENSO does explain much of the warming of sea surface temperatures over the past 30 years, so they try to redirect the discussion by changing datasets to ocean heat content, saying the ENSO can't explain that warming. Many times, they'll link a graph of global ocean heat content, similar to the one in Figure 5-46.

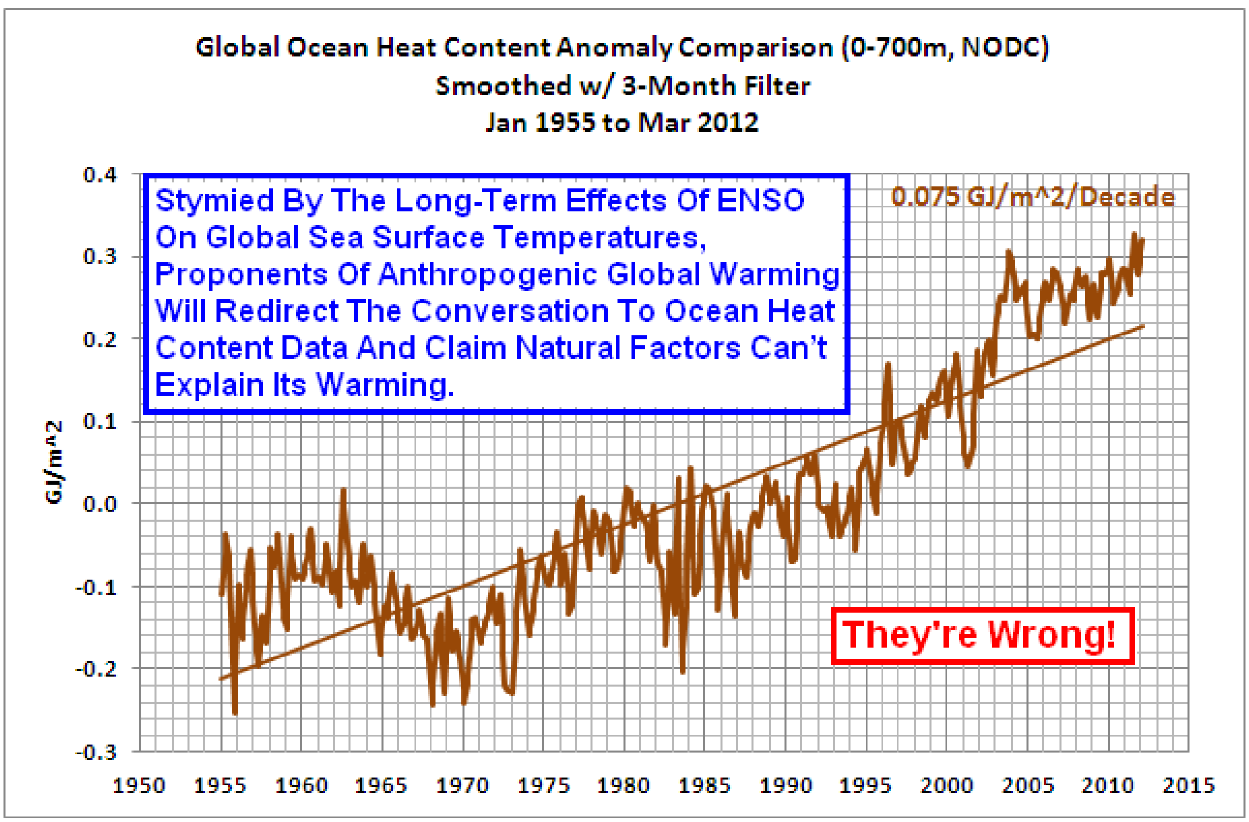


Figure 5-46 Bob Tisdale

The Ocean Heat Content data that we've used in this book, as you'll recall, represents, in part, the ocean temperatures to depths of 700 meters (about 2300 feet), with the other portion being the salinity of the water. The global warming proponents are wrong about ENSO not having a long-term effect on ocean heat content, of course, and I have to point this out to them every time they attempt to redirect the discussion. All one needs to do is divide the global oceans into logical subsets to see the impacts of natural variables on ocean heat content data. In other words, as we've mentioned before, the use of a global metric can be misleading.

To illustrate the impacts of ENSO and other natural factors on Ocean Heat Content data we'll divide the global oceans into 5 subsets. Refer to the top cell in Figure 5-47. It's a map of the subsurface temperature measurement locations of the data the NODC used to create its ocean heat content dataset. The map shows the measurement locations at the depth of 700 meters for the year 2000. We'll exclude the data from the Southern Hemisphere south of the tropics in this chapter because there is so little source data. The lack of source data south of the tropics is confirmed in the lower map in Figure 5-47. It is a similar map available from the NODC ocean heat content website, and it captures subsurface temperature measurement locations at the depth of 700 meters for the year 1975. There are fewer measurements as we go back further in time. Granted, there are more measurements at depths shallower than 500 meters. I simply wanted to show you how poorly sampled the oceans were at the maximum depth of that data. It does not improve at depths greater than 700 meters.

There will be readers who will be concerned that we won't be discussing a major portion of the global oceans, but there's so little source data it would be wasted time. To try to relieve some of those concerns, though, we can compare the global ocean heat content anomalies (0-700 meters) to the data for the oceans north of 24S. See Figure 5-48. The ocean heat content data that we'll be examining in this chapter has a slightly higher linear trend than the complete global dataset. In other words, the additional data south of 24S, which is based on very few source measurements, only suppresses the long-term trend. Based on the limited source data, the oceans south of 24S have warmed at a slower pace than the oceans north of 24N.

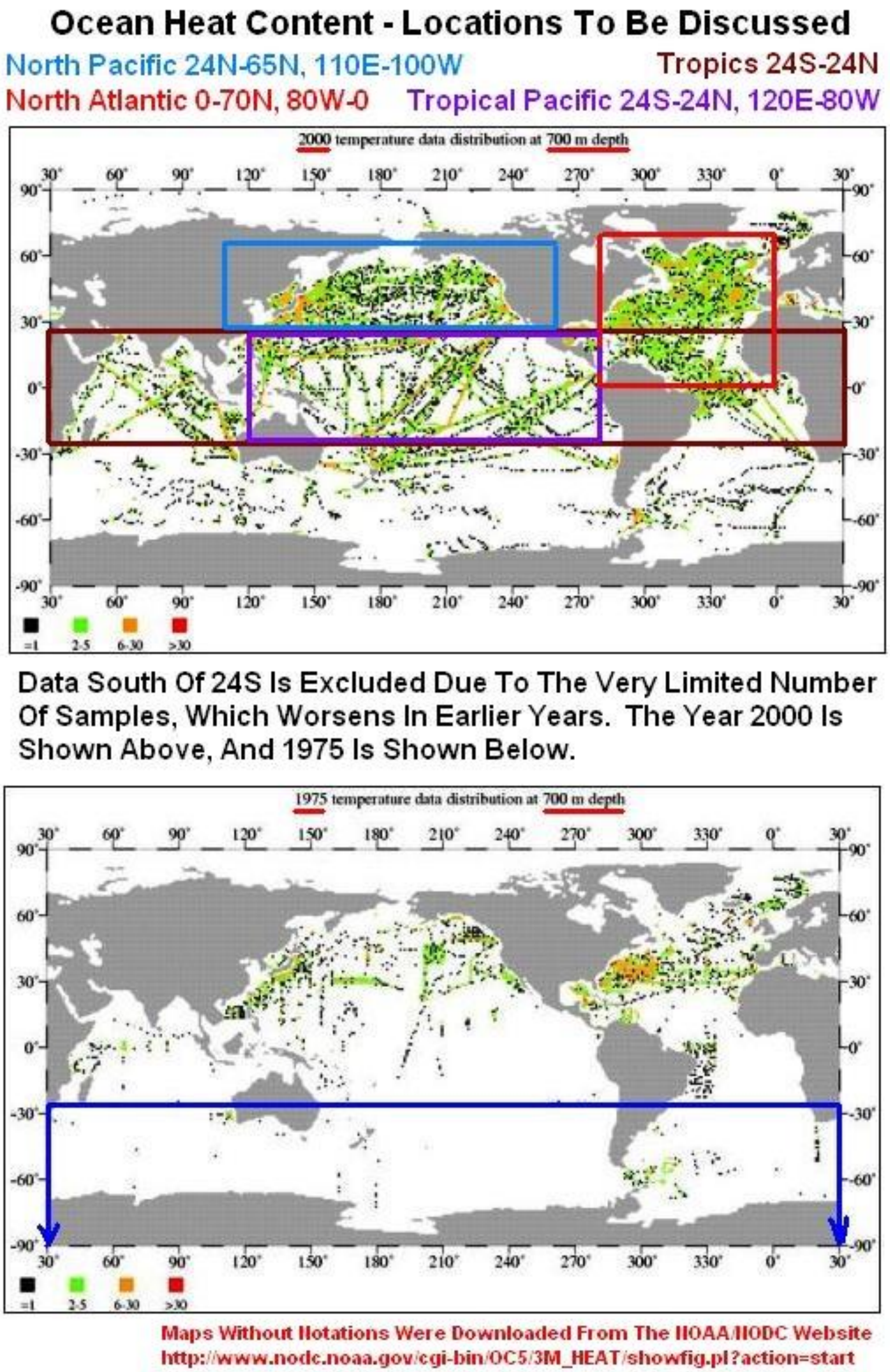


Figure 5-47

Bob Tisdale

HHH

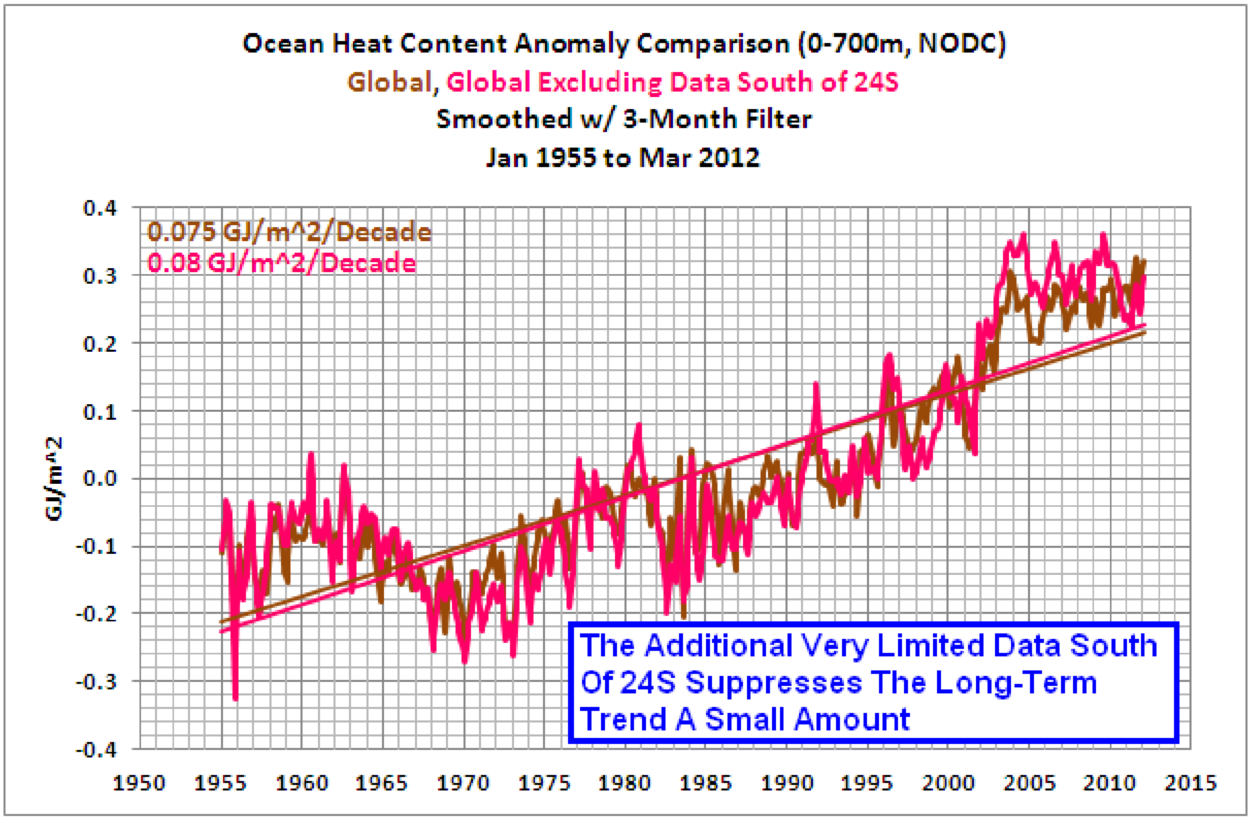


Figure 5-48 Bob Tisdale

Let's first examine the ocean heat content anomalies for the areas where ENSO explains a major portion of the warming of the oceans: the tropical Pacific and the tropics. For the discussion of each subset, we'll first compare that data to global ocean heat content anomalies.

A quick note about the 3-month smoothing: The NODC furnishes its ocean heat content data for the depths of 0-700 meters on a quarterly basis. The KNMI Climate Explorer presents the NODC's data in monthly form, assigning the quarterly values to the 3 months that make up the quarter. While the monthly presentation allows us to compare the ocean heat content to other variables more easily, it creates a distracting box-like effect so I've smoothed the NODC's data with a 3-month running-average filter.

MULTIYEAR LA NIÑA EVENTS EXPLAIN MOST OF THE OCEAN HEAT CONTENT WARMING IN THE TROPICAL PACIFIC SINCE 1955

Figure 5-49 compares the Tropical Pacific ocean heat content anomalies to the global data. The long-term trend for the Tropical Pacific shows that it is warming at a slower pace than the global data. The global data also appears to mimic the variations in the Tropical Pacific ocean heat content anomalies. That should be expected because the Tropical Pacific is directly impacted by ENSO.

As noted earlier, the monumental rise in 1995/96 was caused by the 1995/96 La Niña event. The drop after that rise was caused by the 1997/98 El Niño.

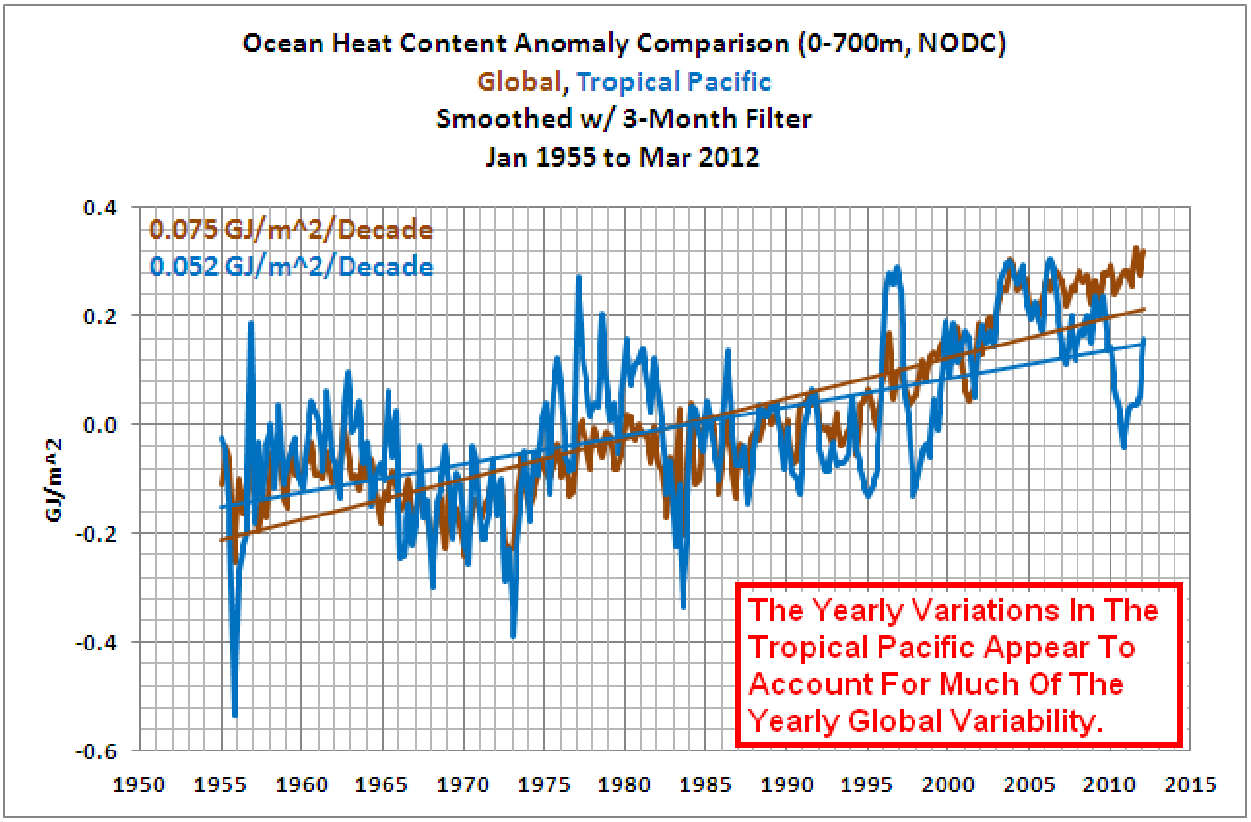


Figure 5-49 Bob Tisdale

We discussed in **Chapter 3.10 The Recharge of Ocean Heat during the La Niña** how the 1976/77 to the 1994/95 El Niño events fed from the warm water that was initially created during the 1973/74/75/76 La Niña, and that the La Niña events that followed El Niño recharged part of the ocean heat content released by the El Niño events. The same thing has basically taken place since the end of the 1998/99/00/01 La Niña. The El Niño events since then have fed off the warm water created during the multiyear La Niña, with the other La Niña replenishing part of the warm water released by the El Niño events.

The 1995/96 La Niña was the anomaly, having created the warm water for the 1997/98 El Niño. The multiyear 1998/99/00/01 La Niña that followed it recharged much of that warm water released by that super El Niño.

We've forgotten to discuss the other multiyear La Niña event, the one in the early 1950s. According to the **Oceanic NINO Index**, there was a 3-year La Niña event that lasted from April 1954 to January 1957, and it would logically explain the rise in the ocean heat content for the Tropical Pacific that occurs at the beginning of the data.

Keep in mind, there is very little source data at the beginning of the NODC ocean heat content data, so you have to look at the year-to-year variations, like the anomalous looking spikes, with good deal of suspicion. However, we can get an idea whether the data supports our understanding of how ENSO impacts the ocean heat content data if we look at it in multiyear blocks. With that in mind, let's remove the ocean heat content data for the Tropical Pacific that coincides with the "official" months of the 3-year La Niña events, using the older version of the Oceanic NINO index. If the ONI data temporarily rises above the threshold of the La Niña before returning to La Niña values, we'll assume it to be a continuous La Niña. That would leave us with the Tropical Pacific ocean heat content data between the 3-year La Niña events—or after it in the case of the last multiyear La Niña. As we have in the past, we'll determine the linear trends for those periods. Refer to Figure 5-50.

(If it looks familiar, it's the same graph as Figure 5-41. There was no reason for me to ask readers to scroll back to it.) As we can plainly see, between the 3-year La Niña events, Tropical Pacific ocean heat content cools. Because the tropical Pacific cools during those multidecadal periods between the multiyear La Niña, and because the ocean heat content there warms during the multiyear La Niña events, and because the long term data shows a significant warming trend, then one might assume that the multiyear La Niña events are responsible for most of the long-term warming of the Tropical Pacific Ocean.

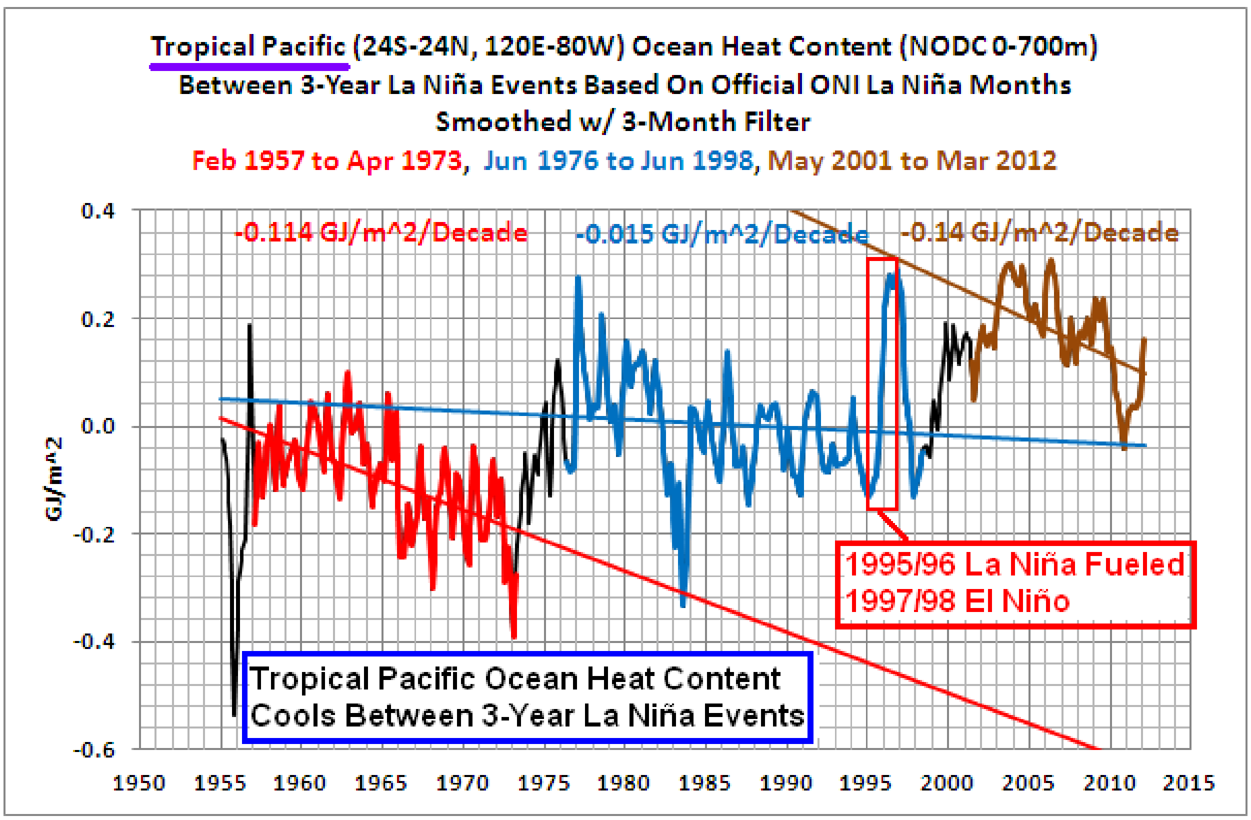


Figure 5-50

Bob Tisdale

The sudden rise in 1995/96 that was caused by the 1995/96 La Niña skews the data for the period of June 1976 to June 1998, so, for the sake of discussion, let's shorten that period, ending it at the start of the 1995/96 La Niña. Refer to Figure 5-51. As shown, the cooling trend of the middle period between the 1973/74/75/76 and the 1995/96 La Niña events now falls better in line with the cooling that took place during the other two multidecadal/multiyear periods. All in all, while there is a long-term warming of the Tropical Pacific ocean heat content, as shown in Figure 5-49, the vast majority of that warming is the natural response to the 3-year La Niña events and the anomalous 1995/96 La Niña event. In other words, ENSO is responsible for the warming and there's no evidence that greenhouse gases had any measurable impact on tropical Pacific Ocean Heat Content anomalies since 1955.

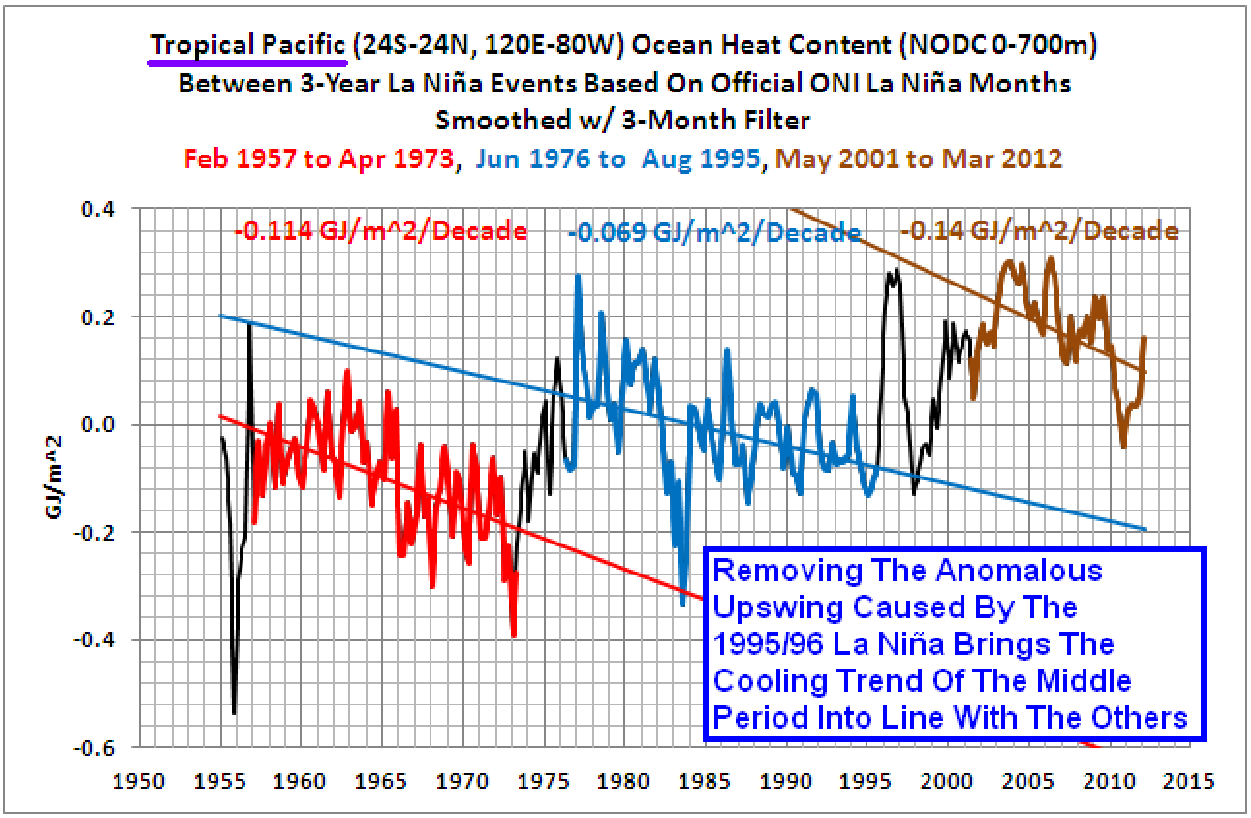


Figure 5-51 Bob Tisdale

Let's expand our discussion to the ocean heat content data for the tropical oceans, highlighted in maroon in Figure 5-47.

MOST OF THE OCEAN HEAT CONTENT WARMING OF THE TROPICAL OCEANS SINCE 1955 IS ALSO EXPLAINED BY MULTIYEAR LA NIÑA EVENTS

The tropical oceans (24S-24N) cover about 42% of the surface area of the global oceans. That's a big chunk. Figure 5-52 compares the NODC's tropical and global ocean heat content anomalies for the depths of 0-700 meters. The two datasets are so similar at the beginning that it makes one question the reliability of the data before the late-1970s. As shown in later decades, the two datasets can and should be significantly different at times. The other thing that stands out is how flat the tropical ocean heat content data is from the mid-1970s to the late 1990s. It shows little warming, maybe even cooling, during that period. Tropical ocean heat content anomalies also peaked in 2004 and have cooled since then.

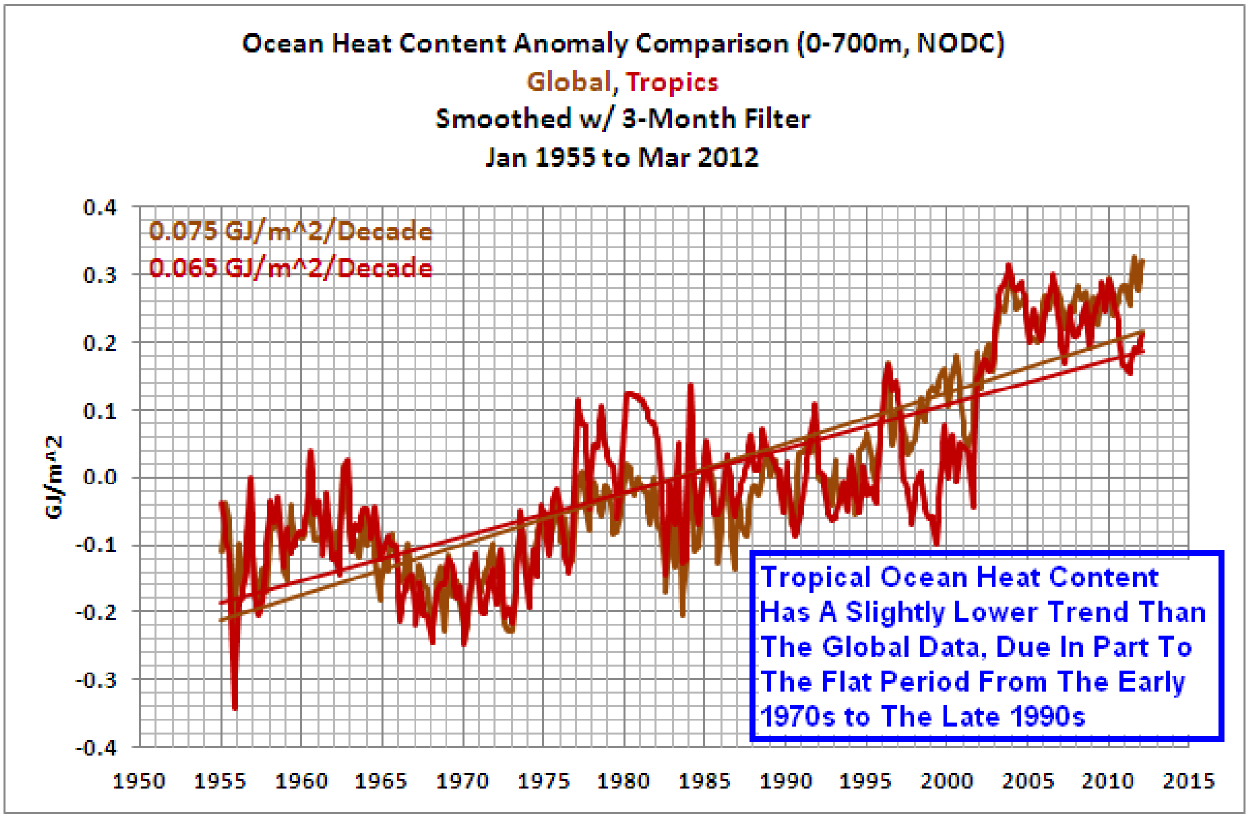


Figure 5-52 Bob Tisdale

Let's isolate the tropical data between the 3-year La Niña events to see whether we get results that are similar to the tropical Pacific. We'll lag the La Niña periods by 9 months to account for the time delay between ENSO and the ocean heat content response in the rest of the tropical oceans. See Figure 5-53. The 9-month lag on the La Niña months captures the start and end points of the warming in the mid-1970s, and it also appears to capture the warming that took place in response to the 1998/99/00/01 La Niña. The additional rise in 2003 looks odd. That upward shift occurs at the time when ARGO floats were being deployed and global coverage of temperature measurements at depth increased greatly. The NODC made corrections a couple of years ago (2010) that reduced that upward shift. Maybe they need to make a few more adjustments. Nevertheless, Tropical Ocean Heat Content anomalies have cooled since December 2001—for more than a decade. The cooling rate (based on the linear trend) during that period is comparable to the cooling rate from March 1977 to March 1999, but we could lower the trend during the middle two decades by isolating the 1995/96 La Niña as well. There's no real reason to do that because the obvious effect has been illustrated: Tropical Ocean Heat Content cools between 3-year La Niña events, as one would expect, and rises primarily during the 3-year La Niña events. Because we understand the processes that take place, we might conclude that ENSO was responsible for the rise in Tropical Ocean Heat Content since 1955.

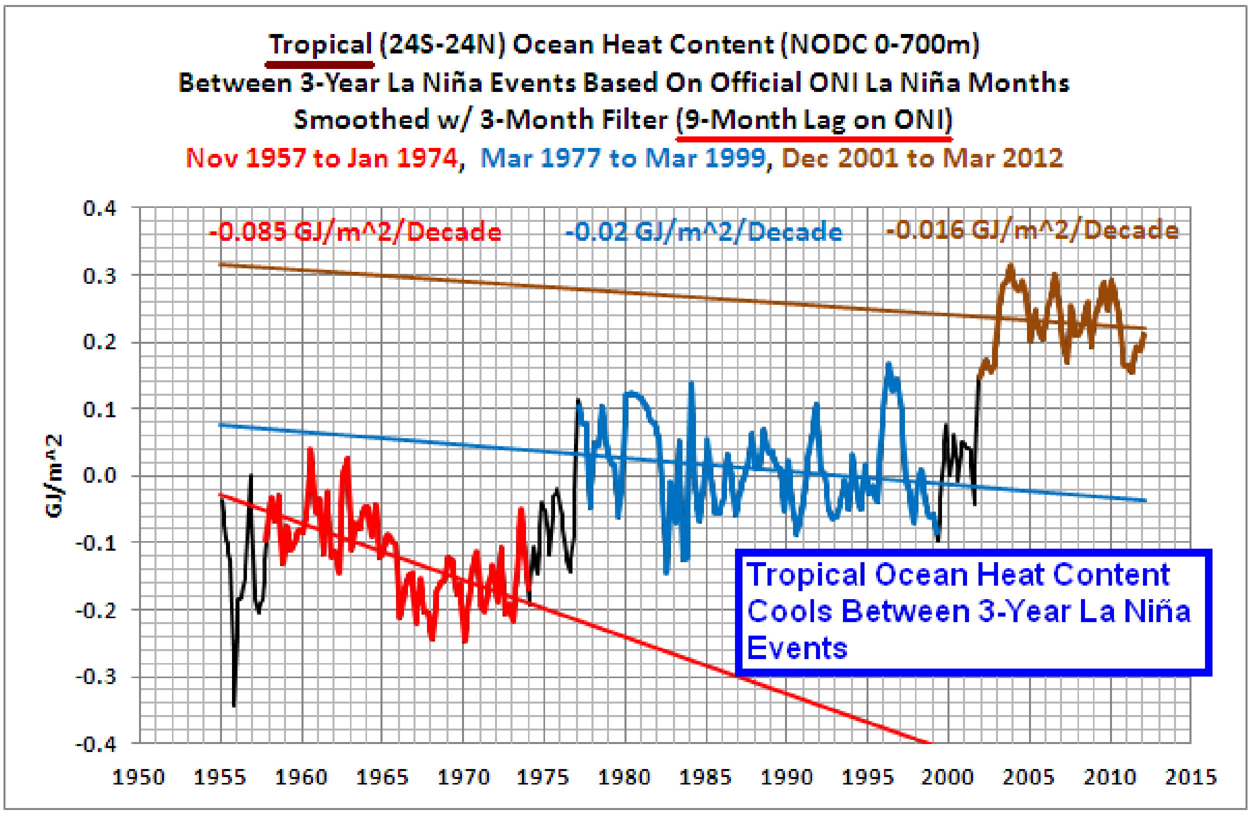


Figure 5-53

Bob Tisdale

IF GREENHOUSES GASES WARM THE OCEANS WHY DID THE NORTH PACIFIC OCEAN HEAT CONTENT COOL UNTIL THE LATE 1980s?

In this portion of the discussion of Ocean Heat Content anomalies for the depths of 0-700 meters, we're going to examine the data for the North Pacific north of 24N. We'll call it the North Pacific to simplify the discussion. This subset displays a pattern in time that is not consistent with the assumption that downward longwave (infrared) radiation from greenhouse gases is responsible for the warming of the global oceans. Unlike the tropical Pacific and tropics, the North Pacific data does not display the logical warming during multiyear La Niña events followed by multidecadal cooling, but it does contradict what we've been led to believe about the warming of the global oceans.

Figure 5-54 compares North Pacific (north of 20N) and global Ocean Heat Content anomalies since the start of the NODC's dataset in 1955. The North Pacific Ocean Heat Content data has a slightly lower trend than the global data. The reason: the North Pacific subset cooled from the early 1960s until the late 1980s. It's really tough to miss that drop in Ocean Heat Content.

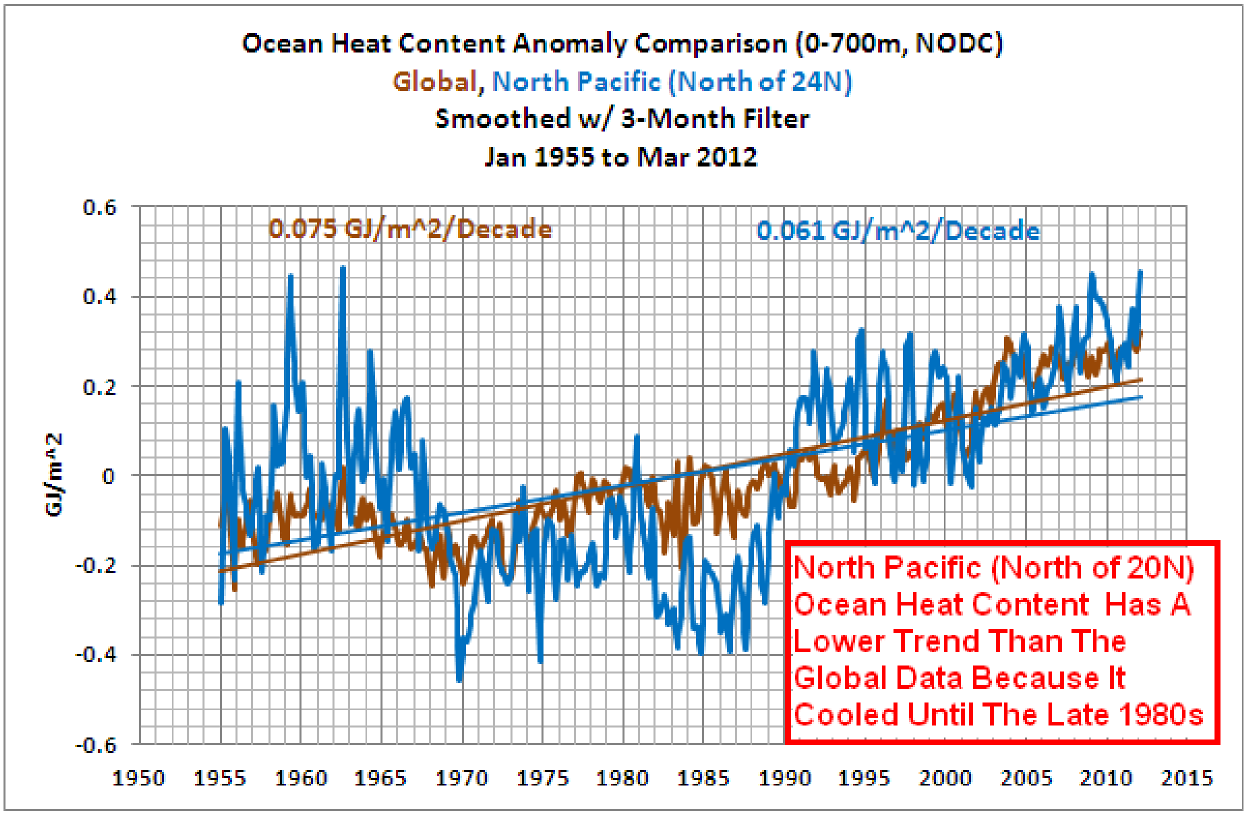


Figure 5-54

Bob Tisdale

If we examine the data more closely, Figure 5-55, we can see two very obvious things. Referring to the linear trend line from January 1955 to December 1988, it's very obvious the North Pacific Ocean Heat Content anomalies cooled over that period. The cooling was significant. I've also highlighted a 2-year period to show the vast majority of the long-term warming occurred during those 2 years.

I have found no scientific papers that discuss that very obvious long-term cooling and then sudden warming. I did, however, illustrate and discuss them in a blog post. The sudden warming was likely caused by a shift in North Pacific sea level pressure. Refer to the post **North Pacific Ocean Heat Content Shift In The Late 1980s**. We'll discuss how sea level pressure can impact ocean heat content during the discussion of the North Atlantic Ocean Heat Content that follows, but…

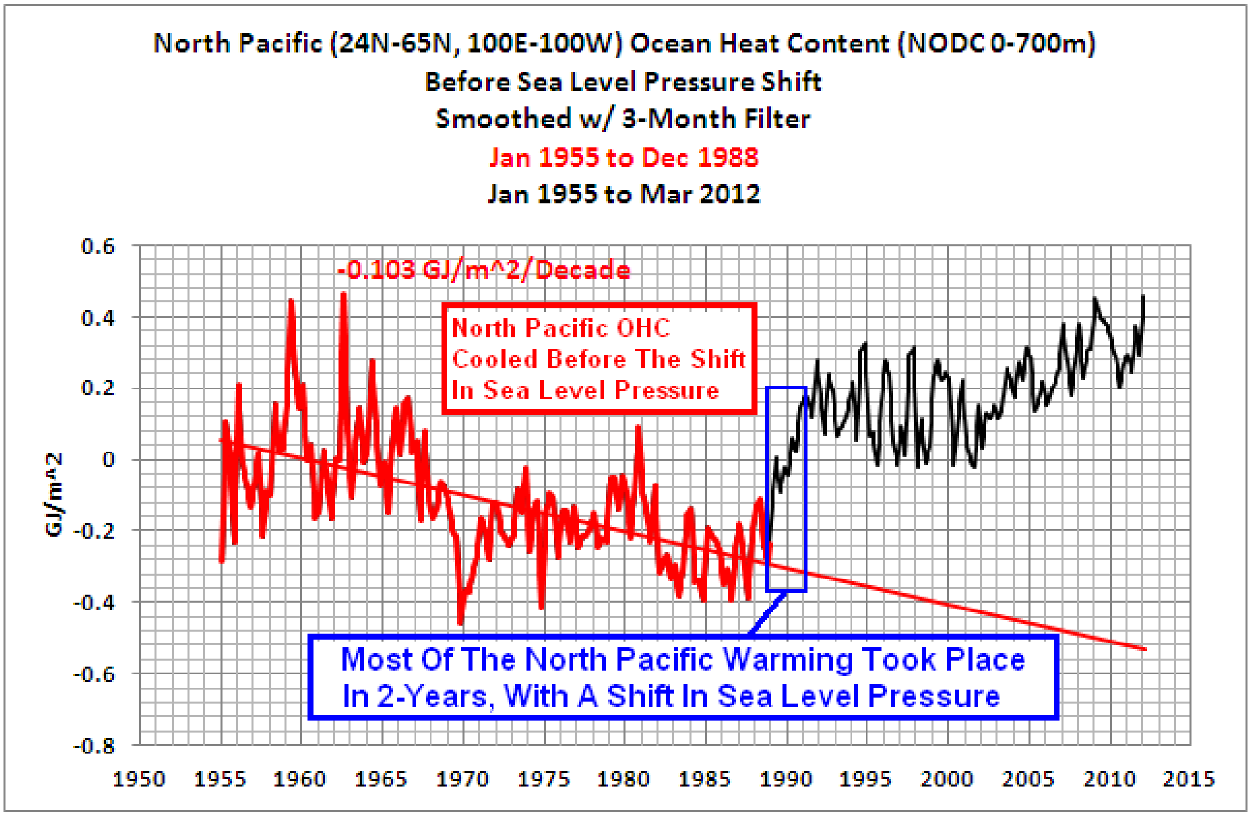


Figure 5-55 Bob Tisdale

For the sake of discussion, what do you suppose would happen to the long-term (1955 to 2012) trend if that sudden shift in the North Pacific data had not happened? The difference between the readings in December 1988 and January 2001 is 0.399 GJ/m2, so let's subtract that value from monthly data for the period of January 2001 to March 2012. We'll use the December 1988 reading to fill in the blank 2 years. That way we eliminate the effect of that 2-year shift on the North Pacific data. As shown in Figure 5-56, if that change in sea level pressure had not happened, which, in turn, caused the North Pacific Ocean Heat Content to warm sharply over a 2-year period, North Pacific Ocean Heat Content would actually have cooled from 1955 to 2012.

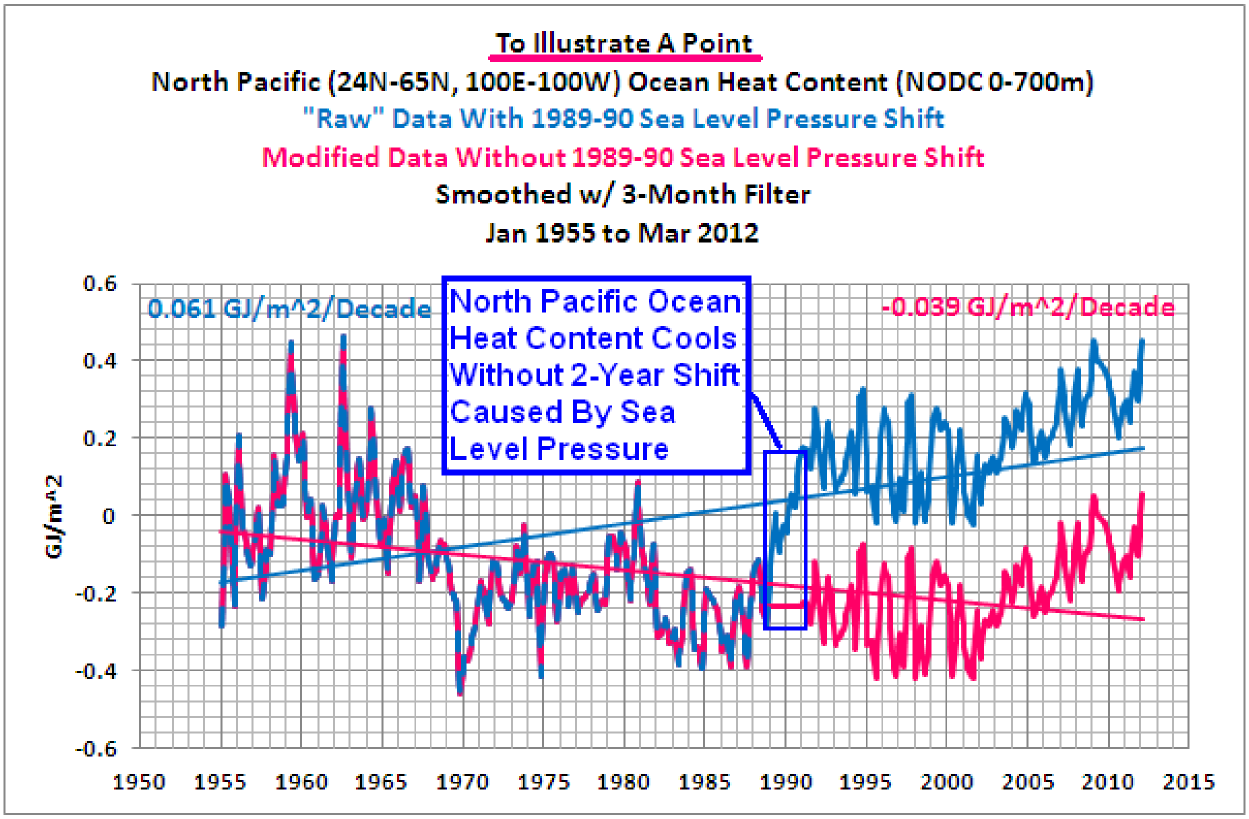


Figure 5-56 Bob Tisdale

It's amazing what people miss by looking at global datasets.

So far we have found no hard evidence that anthropogenic greenhouse gases have caused any of the warming of the tropical oceans or the North Pacific to depths of 700 meters. That is, while the Ocean Heat Content data for the tropical Pacific, the tropics, and the North Pacific subsets have all shown warming since 1955, all of that warming can be explained by natural variables.

Don't forget: so far, the long-term warming trends of all of our Ocean Heat Content subsets have been less than the global data. We've already illustrated that the additional Ocean Heat Content warming is not coming from the very sparse data south of 24S. That leaves the North Atlantic as the source of the additional warming. That sounds surprisingly similar to sea surface temperature data, which is impacted of another natural phenomenon.

NORTH ATLANTIC OCEAN HEAT CONTENT WARMING CAN ALSO BE EXPLAINED WITH NATURAL VARIABLES

North Atlantic Ocean Heat Content anomalies display a much higher linear trend than the Global dataset. As shown in Figure 5-57, North Atlantic Ocean Heat Content anomalies warmed at a rate that's more than 2.5 times faster than the global data.

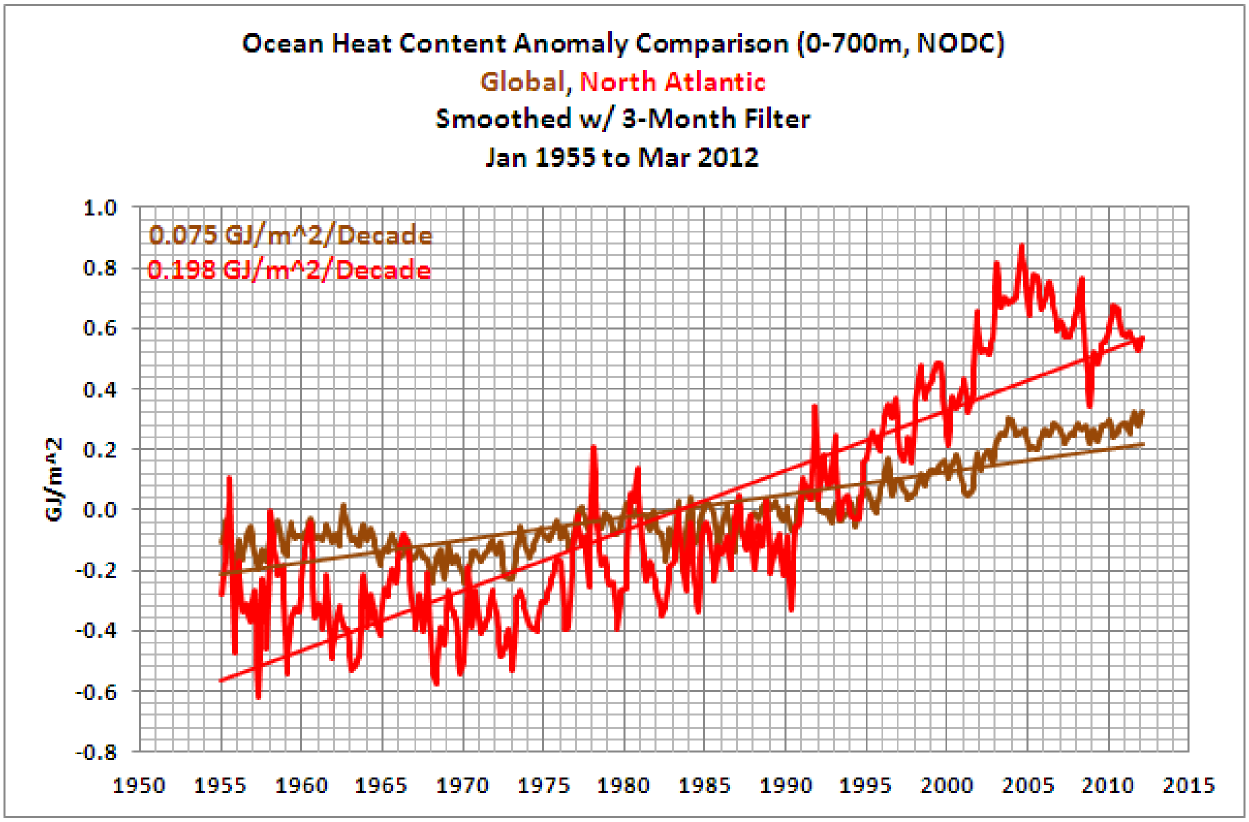


Figure 5-57

Bob Tisdale

There is a study that provides an explanation for that additional warming. See Lozier et al (2008) **The Spatial Pattern and Mechanisms of Heat-Content Change in the North Atlantic**.

First, a quick introduction to one of the terms used in the following quotes: The **North Atlantic Oscillation** is an atmospheric climate phenomenon in the North Atlantic. Like the Southern Oscillation Index described in **Chapter 4.3 ENSO Indices**, the North Atlantic Oscillation is expressed as the sea level pressure difference between two points. The sea level pressures in Iceland, at the weather stations in Stykkisholmur or Reykjavik, can be used to calculate North Atlantic Oscillation Indices. Which Iceland location they elect to use as the high-latitude sea level pressure reference depends on the dataset supplier. The other point captures the sea level pressure at the mid-latitudes of the North Atlantic, and there are a number of locations that have been used for it: Lisbon, Portugal; Ponta Delgada, Azores; and Gibraltar. The North Atlantic Oscillation Index is primarily used for weather prediction. The direction and strength of the westerly winds in the North Atlantic are impacted by the sea level pressures in Iceland and the mid-latitudes of the North Atlantic, which, in turn, impact weather patterns in Europe and the East Coast of North America. If you live in those locations, you'll often hear your weather person referring to the North Atlantic Oscillation. As will be discussed, winds in the North Atlantic can also impact Ocean Heat Content.

I'll present two quotes from the Lozier et al (2008) paper. I'll follow them with quotes from the press release that describes in layman terms how the North Atlantic Oscillation impacts the Ocean Heat Content of the North Atlantic. Back to Lozier et al (2008):

The abstract reads:

> *The total heat gained by the North Atlantic Ocean over the past 50 years is equivalent to a basinwide increase in the flux of heat across the ocean surface of 0.4 ± 0.05 watts per square meter. We show, however, that this basin has not warmed uniformly: Although the tropics and subtropics have warmed, the subpolar ocean has cooled. These regional differences require local surface heat flux changes (±4 watts per square meter) much larger than the basinwide average. Model investigations show that these regional differences can be explained by large-scale, decadal variability in wind and buoyancy forcing as measured by the North Atlantic Oscillation index. Whether the overall heat gain is due to anthropogenic warming is difficult to confirm because strong natural variability in this ocean basin is potentially masking such input at the present time.*

In the paper, Lozier et al (2008) note, using NAO for North Atlantic Oscillation:

> *A comparison of the zonally integrated heat-content changes as a function of latitude (Fig. 4B) confirms that the NAO difference can largely account for the observed gyre specific heat-content changes over the past 50 years, although there are some notable differences in the latitudinal band from 35° to 45°N. Thus, we suggest that the large-scale, decadal changes in wind and buoyancy forcing associated with the NAO is primarily responsible for the ocean heat-content changes in the North Atlantic over the past 50 years.*

Based on the wording of the two quotes, the paper appears to indicate that Lozier et al (2008) are describing the entire warming of ocean heat content in the North Atlantic. In other words, it seems that Lozier et al (2008) are not stating that the North Atlantic Oscillation is primarily responsible for the additional ocean heat-content changes in the North Atlantic, above and beyond the rest of the world, over the past 50 years; they're saying it's primarily responsible for <u>all</u> of the variability. The press release for the paper, on the other hand, leads you to believe the North Atlantic Oscillation is responsible for the North Atlantic warming above and beyond the global warming.

The Duke University press release for the paper is titled **North Atlantic Warming Tied to Natural Variability**. Though the other ocean basins weren't studied by Lozier et al, the subtitle of the press release includes the obligatory reference to an assumed manmade warming in other basins: “But global warming may be at play elsewhere in the world's oceans, scientists surmise”. To contradict that, we’ve found no evidence of an anthropogenic component in the warming of the other ocean basins.

The press release reads with respect to the North Atlantic Oscillation (NAO):

> *Winds that power the NAO are driven by atmospheric pressure differences between areas around Iceland and the Azores. "The winds have a tremendous impact on the underlying ocean," said Susan Lozier, a professor of physical oceanography at Duke's Nicholas School of the Environment and Earth Sciences who is the study's first author.*

Further to this, they write:

> *Her group's analysis showed that water in the sub-polar ocean—roughly between 45 degrees North latitude and the Arctic Circle—became cooler as the water directly exchanged heat with the air above it.*
>
> *By contrast, NAO-driven winds served to "pile up" sun-warmed waters in parts of the subtropical and tropical North Atlantic south of 45 degrees, Lozier said. That retained and distributed heat at the surface while pushing underlying cooler water further down.*
>
> *The group's computer model predicted warmer sea surfaces in the tropics and subtropics and colder readings within the sub-polar zone whenever the NAO is in an elevated state of activity. Such a high NAO has been the case during the years 1980 to 2000, the scientists reported.*
>
> *"We suggest that the large-scale, decadal changes...associated with the NAO are primarily responsible for the ocean heat content changes in the North Atlantic over the past 50 years," the authors concluded.*

As expected, the press release, towards the end, redirects the discussion back to anthropogenic global warming:

> *However, the researchers also noted that this study should not be viewed in isolation. Given reported heat content gains in other oceans basins, and rising air temperatures, the authors surmised that other parts of the world's ocean systems may have taken up the excess heat produced by global warming.*
>
> *"But in the North Atlantic, any anthropogenic (human-caused) warming would presently be masked by such strong natural variability," they wrote.*

Another resource for the warming of North Atlantic Ocean Heat Content is the 2005 Polyakov et al paper **Multidecadal Variability of North Atlantic Temperature and Salinity during the Twentieth Century**. It is a detailed discussion of the natural multidecadal variations in temperature and salinity (the components of ocean heat content data) for depths of 0-3000 meters. If you'll scroll back up to Figure 5-57, it appears North Atlantic ocean heat content peaked in 2005, because it has been cooling very rapidly ever since.

We know the Ocean Heat Content warming for the rest of the global oceans we've examined can be shown to result from natural factors. One would then think there should be no reason the North Atlantic warming isn't also natural—especially with the results of Lozier et al (2008).

GENERAL OCEAN HEAT CONTENT DATA DISCUSSION

There will likely be some attempts to undermine the discussion in this chapter because it only presents Ocean Heat Content data for the depths of 0-700 meters. The NODC recently released data for the depths of 0-2000 meters, so there are people who think it would be a better dataset to use because it reaches deeper.

First, I have presented the NODC's Ocean Heat Content data for 0-700 meters because it is available through the KNMI Climate Explorer in an easy-to-use format. That way readers could verify the results with little effort. Second, the NODC's dataset has been adjusted, modified and tweaked for every imaginable sensor problem climate scientists could come up with (with many people thinking the adjustments were made so that the data would align with climate model simulations). Third, if the NODC Ocean Heat Content data was available for 0-2000 meters without the 5-year smoothing, and if it was available through the KNMI Climate Explorer, I would be happy to use it. Why? The results of this chapter should be very similar using the data for the depths of 0-2000 meters. I'll explain:

Due to the massive heat capacity of the global oceans, there is increasing interest in using Ocean Heat Content data as a metric to express global warming. The simple reasons: The global data presented in this chapter shows a strong warming—and proponents of anthropogenic global warming assume, incorrectly, that the warming can't be explained by natural factors.

As we illustrated and discussed in **Chapter 3.10 The Recharge of Ocean Heat during the La Niña**, there were very few temperature and saline measurements at depth prior to the deployment of ARGO floats, which began to provide reasonable coverage of the global oceans starting in 2003/04. The measurements from the new ARGO floats presented researchers with a problem. They showed the global oceans were cooling, not warming as projected by the anthropogenic global warming hypothesis. The researchers then determined there had to be a problem with the ARGO floats and they made corrections to the data. Still, even with the adjustments, the Ocean Heat Content data for the depths of 0-700 meters are not warming as fast as projected by climate models. This can be seen in the ocean heat content model-data comparisons at RealClimate—which were also recently corrected, causing the model simulations to diverge from the observations-based data even more. Refer to my blog post **Corrections to the RealClimate Presentation of Modeled Global Ocean Heat Content**. It also provides the background to a comparison graph, Figure 5-58, of modeled and observed global ocean heat content that I've present in my updates of Ocean Heat Content data in recent years. See the recent update **here**.

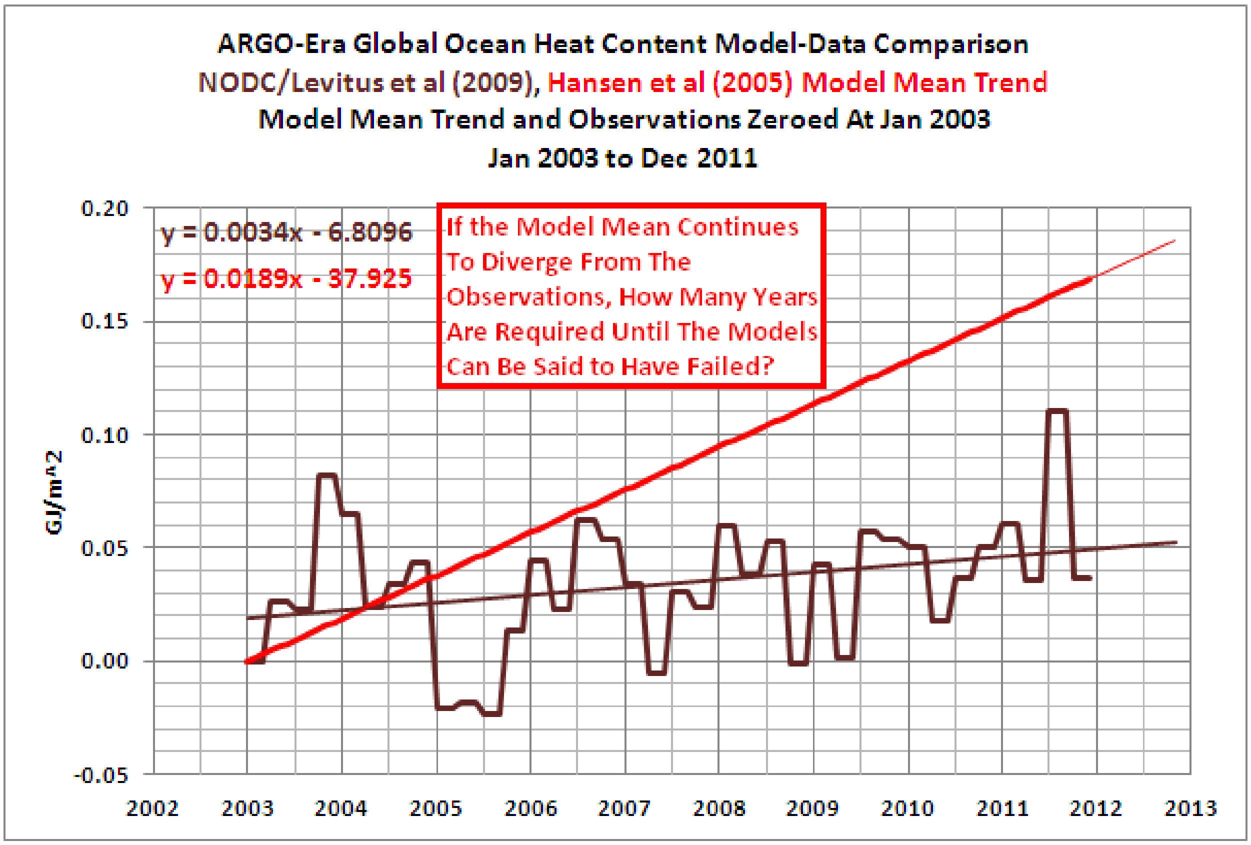


Figure 5-58

Bob Tisdale

As noted above, the supplier of the Ocean Heat Content data that I've presented so far in this book, and that is used as a reference in many scientific studies (and the RealClimate blog posts), is from the NOAA **National Oceanographic Data Center** (NODC). They recently released a new Ocean Heat Content dataset to depths of 2000 meters. The NODC presented the new dataset in the Levitus et al (2012) paper **World Ocean Heat Content and Thermosteric Sea Level change (0-2000 m).** While the data for 0-700 meters has flattened since 2003, the NODC's data for 0-2000 meters continues to show warming, primarily in the northern North Atlantic and the Southern

Ocean surrounding Antarctica. Some might think the NODC prepared that dataset solely to combat the problems posed by the flattening of the 0-700 meter data. The problem with the dataset: the measurements prior to the ARGO era are so sparse below 700 meters that the new dataset for depths to 2000 meters is furnished as a 5-year average.

Earlier in 2012, KNMI added the UK Met Office Ocean Heat Content dataset called EN3 to the Climate Explorer. (It remained on the Climate Explorer for a short time, but we'll return to that.) The UKMO EN3 ocean heat content data had not received any of the recent adjustments to the source data. It was a dataset I was very interested in examining. Prior to the ARGO era, the UKMO EN3 data included an earlier (2005) version the NODC ocean heat content data. It was the version with the hump in the 1970s and 80s. See Figure 5-59. The ARGO-era data in the UKMO EN3 dataset had not been modified, so it still showed the global oceans cooling from about 2004. Also note, after 2004, how small the difference is between the corrected NODC data and the uncorrected KNMO EN3 data. Still, the climate science community was concerned about the cooling. (There are many people who believe the corrections are unwarranted.)

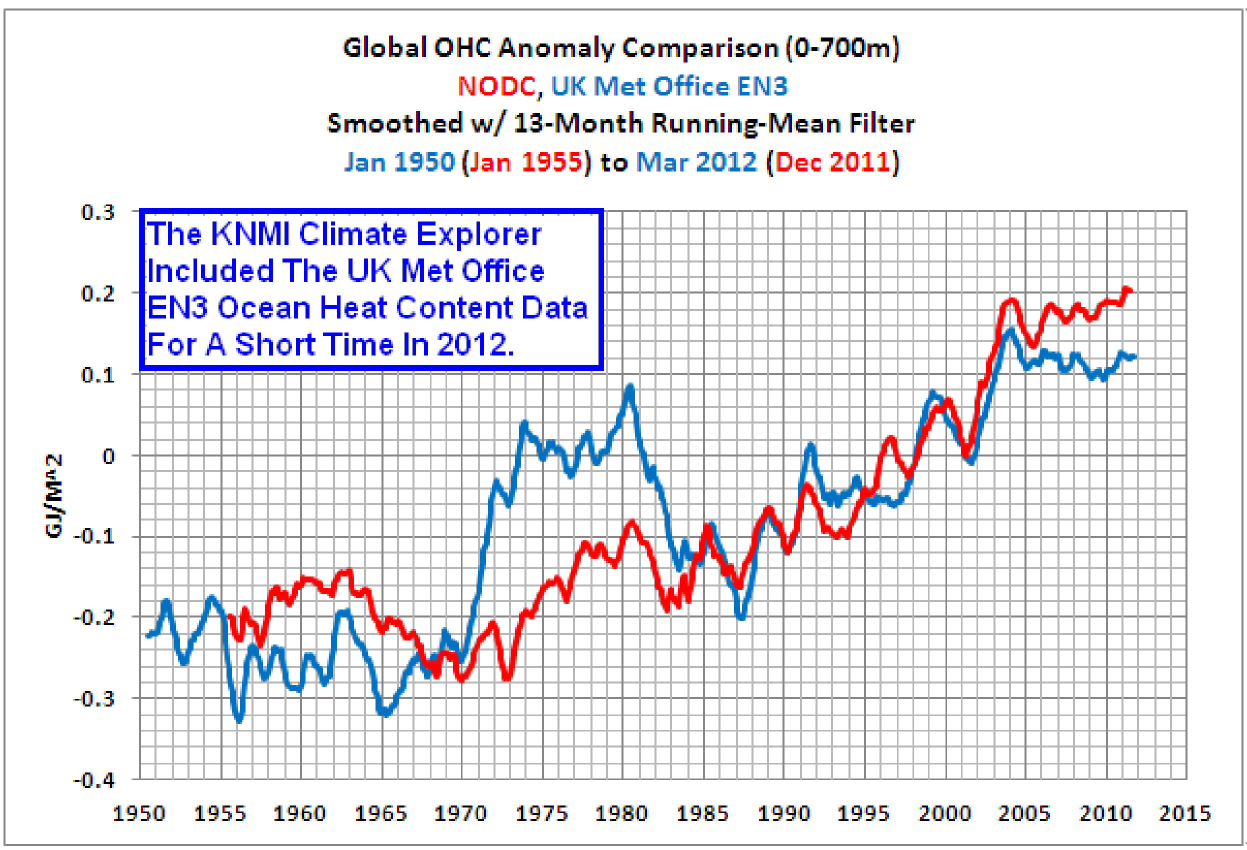


Figure 5-59

The UKMO EN3 dataset also included ocean heat content anomaly data for depths of 0-2000 meters. The global UKMO EN3 data for the depths of 0-700 and 0-2000 meters are shown in Figure 5-60. The first thing to note: The UKMO EN3 data for 0-2000 meters has not been smoothed with a 5-year filter. It, like the shallower dataset, is available on a monthly basis. The 0-2000 meter data has a 35% higher linear trend, but its measurements reach 2.86 times deeper. In other words, the vast majority of the heating takes place in the top 700 meters, and that fact had been acknowledged in papers a number of years ago. The datasets for the two depths also correlate very well. Their correlation coefficient is 0.98. This means the variations in the 0-2000 meter data are extremely similar to those for the shallower depths of 0-700 meters. It is likely then that the discussions in this chapter wouldn't change if we were to use 0-2000 meter data, assuming it wasn't smoothed with a 5-year filter. I know what you're thinking: the trends between La Niña events may not be negative if we were to use the 0-2000 meter data. In reply, it would make no difference to the discussion of the tropical data. Why?

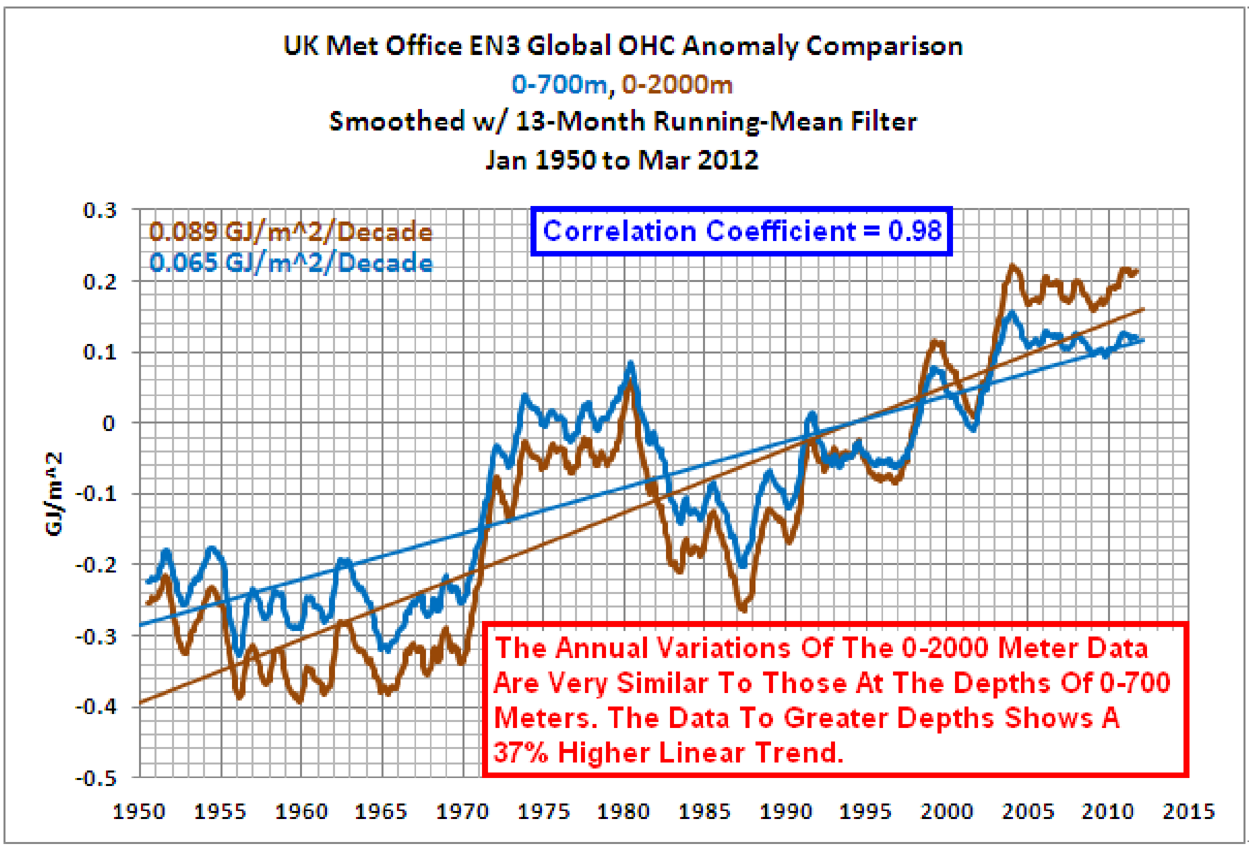


Figure 5-60 Bob Tisdale

It's well known that the majority of the variations in tropical ocean heat content take place in the upper 300 meters. In fact, we showed that using cross sections of the equatorial Pacific subsurface temperatures and temperature anomalies in **Chapter 4.8 Subsurface Temperature and Temperature Anomaly Variations in the Equatorial Pacific And an Introduction to Kelvin Waves**. As you'll recall, those cross sections showed the variations taking place at depths from about 0-150 meters. If you're still concerned the tropical Pacific Ocean Heat Content data for 0-700 meters might be different than the data for 0-2000 meters, refer to Figure 5-61.

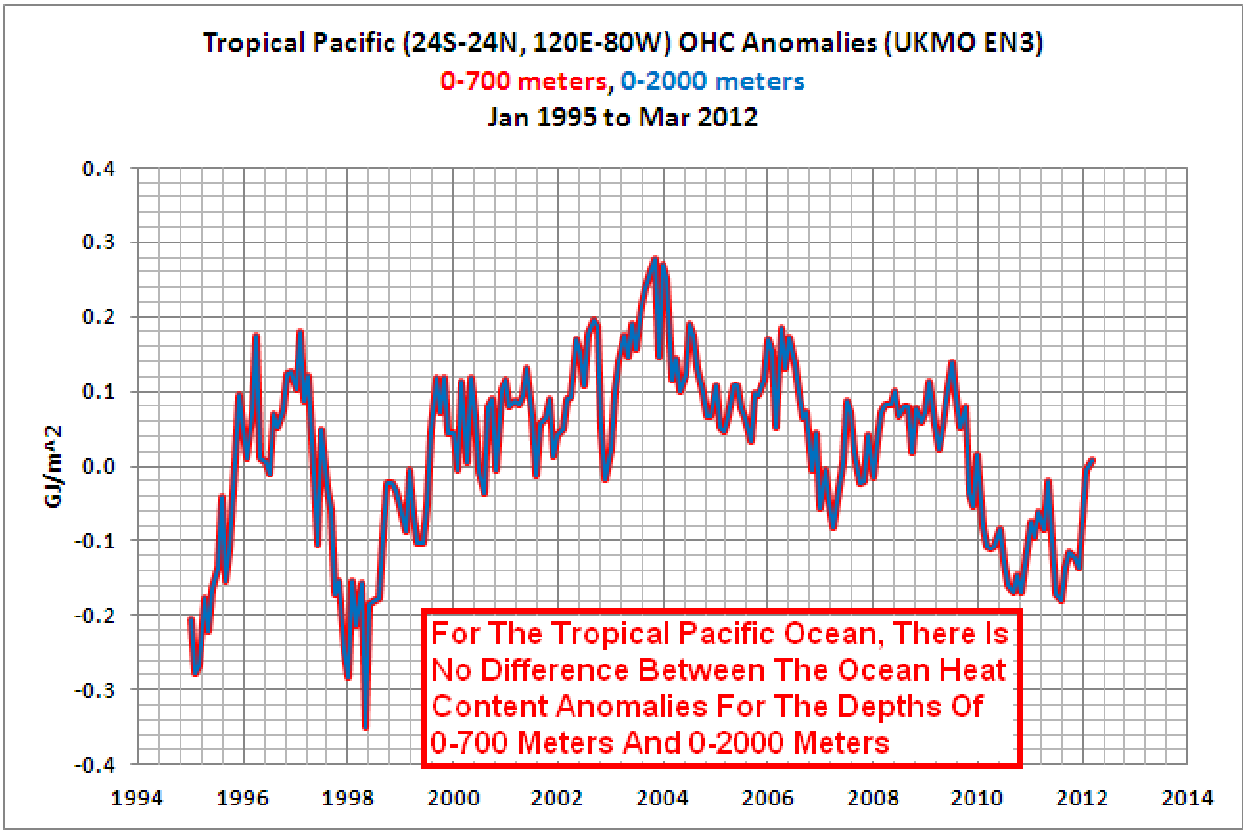


Figure 5-61 Bob Tisdale

Ocean Heat Content data for the Tropical Pacific at depths of 0-700m and 0-2000m are identical. Makes one wonder why the NODC chose to smooth the 0-2000 meter data with a 5-year filter, when in the tropics, there should be no difference between it and the 0-700 meter data.

The differences between the 0-700 meter and 0-2000 meter datasets must then come from latitudes poleward of the tropics. This would slow the rate at which the North Pacific (north of 24N) data cooled until the late 1980s. Unfortunately, I did not download the UKMO EN3 (0-2000m) data for those latitudes of the North Pacific dataset before it was removed from the KNMI Climate Explorer. (I did, however, download the UKMO EN3 data for the depths of 0-700m for the entire North Pacific, and they will be presented in a moment.) Regardless, we've shown the warming of the North Pacific for the depths of 0-700 meters occurred during a 2-year span, not what we would expect from anthropogenic global warming. This would lead us to believe the warming of the top 700 meters there was natural. Greenhouse gases can't bypass the upper 700 meters to warm the oceans below, so the argument that I haven't used the 0-2000 meter dataset has a major problem.

THE SHORT HISTORY OF THE UKMO EN3 DATA AT THE KNMI CLIMATE EXPLORER

During my initial investigations of the UKMO EN3 dataset, I had downloaded the data for both 700 meter and 2000 meter depths of the tropical Pacific. That was fortunate because it allowed be to provide the comparison shown above. Unfortunately, the UKMO EN3 ocean heat content data was removed from the KNMI Climate Explorer shortly after it appeared. Why was it deleted? I presented one ARGO-era graph using the UKMO EN3 data in a blog post (**here**). Two days later that dataset was removed from the KNMI Climate Explorer. Refer to the post **UKMO EN3 Ocean Heat Content Anomaly Data Disappeared From The KNMI Climate Explorer As Suddenly As It Appeared**. The sequence of events runs like this: The day after I published the first post and it was cross posted at WattsUpWithThat, according to the stats data from my blog, I had visitors to my website from NOAA, the UK Met Office and KNMI over the course of a few hours. One would guess that NOAA and the UK Met Office requested that KNMI remove the dataset with all of that unadjusted data and KNMI complied.

There are many people who believe the corrections to the ocean heat content data over the past few years were made to align it with climate model outputs. That is, they think the 1970s to early 1980s hump in the older Ocean Heat Content data was eliminated because the models could not reproduce it. They also believe the ARGO-era data was adjusted to give it a warming trend, because the models showed it should be warming.

Researchers definitely started scrutinizing the data because the models couldn't reproduce the decadal variations in the data. However, for the ARGO era, there was also satellite-based sea level data that indicated the oceans should be warming. Then came the recent research results that surprised many climate scientists. It showed pumping ground water to the surface had made a major contribution (about 40%) to the rise in sea level—results that have the potential to skew the interpretation of satellite-based sea level data. Where does that leave us? If we look at the UKMO EN3 and NODC data for the extratropical (20N-65N) North Pacific for the depths of 0-700m, Figure 5-62 above, the 1970s-80s hump definitely looks out of place, but so do the corrections. Also, the UKMO EN3 data shows a gradual cooling since 1992, while the adjusted NODC data diverges awkwardly from it during the ARGO era.

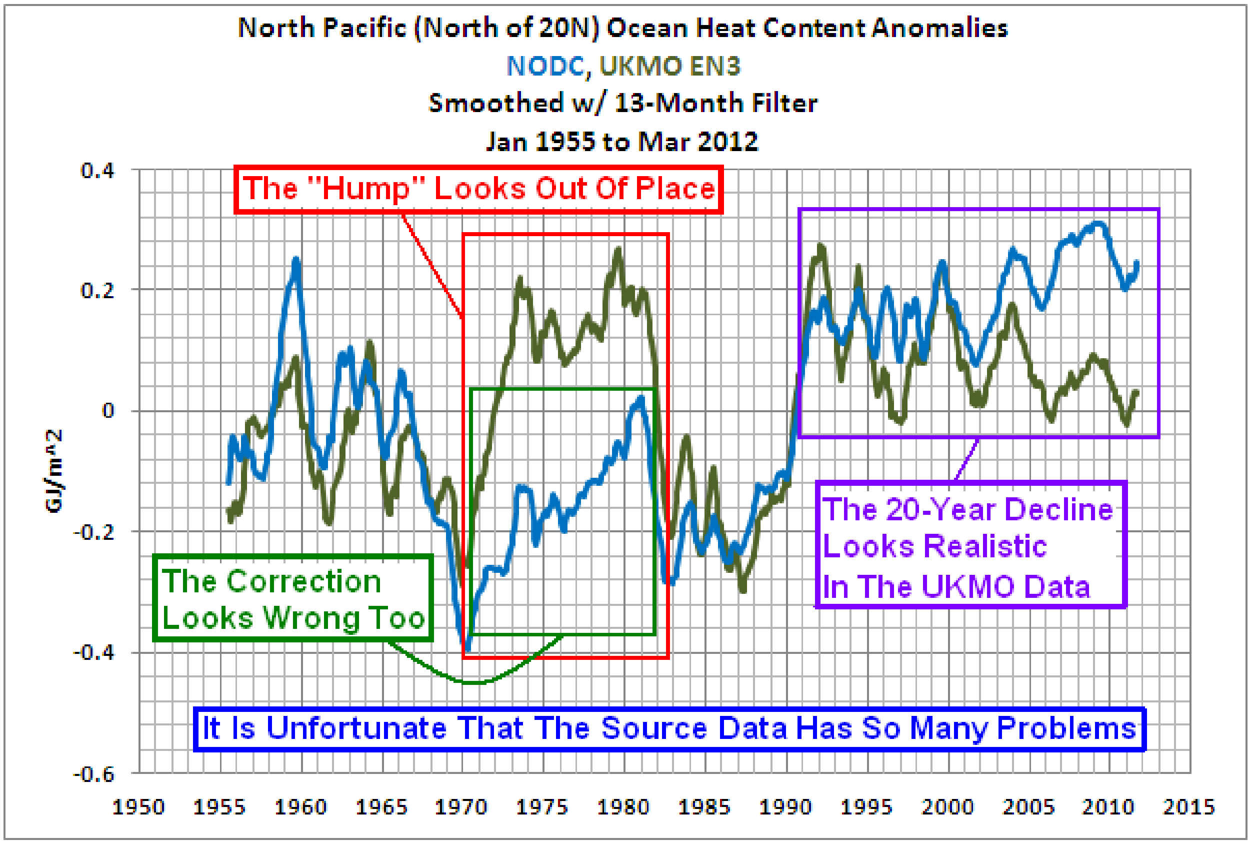


Figure 5-62

As noted on the illustration, it is unfortunate that the sensors used to measure temperature at depth have had so many problems—and it's also very unfortunate that that the data is so sparse in early years, especially at depth. The best we can do with the ocean heat content data is examine multiyear and multidecadal changes and hope all of the adjustments have created a dataset that's at least in the right ballpark.

RECAP

Even with all of the problems with the source data for the ocean heat content data, and even with all of the corrections made to them, the warming of the global oceans can be explained as responses to natural variables. The tropical Pacific, and the tropical oceans as a whole, warmed only during the 3-year La Niña events and the anomalous 1995/96 La Niña event. Between those La Niña, and after the most recent 3-year La Niña, the tropics cooled. The ocean heat content data for the North Pacific north of 24N cooled from 1955 to the late 1980s and then suddenly shifted upwards in 2 years. The shift likely resulted from a change in sea level pressure. Without that shift, the North Pacific Ocean for depths of 0-700 meters would have cooled since 1955. Last, a number of climate studies have shown the additional warming of the North Atlantic is natural and part of a multidecadal mode of natural variability. That leaves the data south of 24S. Because we've shown that the warming of the rest of the oceans is likely natural, it's unlikely the warming there was anthropogenic.

5.10 Examples of the Obvious Long-Term Impacts of ENSO on Lower Troposphere and Land-Plus-Sea Surface Temperature Anomalies

Satellites are used to determine temperatures at different heights in the atmosphere. The normally used dataset for global temperatures represents the temperatures at an altitude of about 3000 meters, and it's called Lower Troposphere Temperature or TLT. There are two suppliers of satellite-based atmospheric temperature data: Remote Sensing System (RSS) and the University of Alabama at Huntsville (UAH). There are minor differences between the Lower Troposphere Temperature anomaly data from the two suppliers. The scientists producing them both argue in favor of their datasets. Proponents of anthropogenic global warming prefer the RSS data because the scientists who created the UAH dataset are skeptics of anthropogenic global warming. To eliminate that possible objection to what's presented in this chapter, we'll use the RSS Lower Troposphere Temperature anomaly data.

We'll also be looking at land-plus-sea surface temperature data in this chapter, using the GISS Land-Plus-Ocean Temperature Index dataset, also known as LOTI. GISS uses Reynolds OI.v2 sea surface temperature data since December 1981, and we've been using that sea surface temperature dataset throughout this book. For the air temperature over land surfaces, GISS uses a 1200km smoothing technique to approximate land surface air temperatures in areas where there aren't measurements. That technique provides results that are similar to the more complex method of infilling used by the NOAA/NCDC. Of course, they use basically the same source data, so the results should be similar.

To show the blatantly obvious long-term impacts of ENSO on Lower Troposphere and Land-Plus-Sea Surface Temperature data, we'll use the Northern Hemisphere band of 20N to 65N latitude. It has a relatively high ratio of land versus ocean surface, with land covering about 53% of the surface area. Most of North America, Europe, Asia, and a portion of northern Africa are included within those latitudes. We're excluding the Arctic for a number of reasons. The temperatures there are strongly influenced by changes in atmospheric pressure, which can lead to variations that also have to be explained. The Arctic temperature data is also impacted by a phenomenon called polar amplification, which skews the data. Also, for all intents and purposes, GISS deletes sea surface temperature data in areas of seasonal sea ice in both polar oceans. They then replace it with land surface temperature data, which will exaggerate the long-term warming there because land surface temperatures vary much more than sea surface temperatures. I discussed the impact of this in two blog posts. Refer to **GISS Deletes Arctic And Southern Ocean Sea Surface Temperature Data** and **The Impact of GISS Replacing Sea Surface Temperature Data With Land Surface Temperature Data**.

The last but not least reason we'll be looking at the temperature data for those latitudes: the blatantly obvious long-term impacts of ENSO on Lower Troposphere and Land-Plus-Sea Surface Temperature data present themselves extremely well at those latitudes. As they say, seeing is believing.

The GISS Land-Ocean Temperature Index and RSS Lower Troposphere Temperature anomalies are shown in Figure 5-63. They both have relatively high trends due to the amount of land surface at those latitudes.

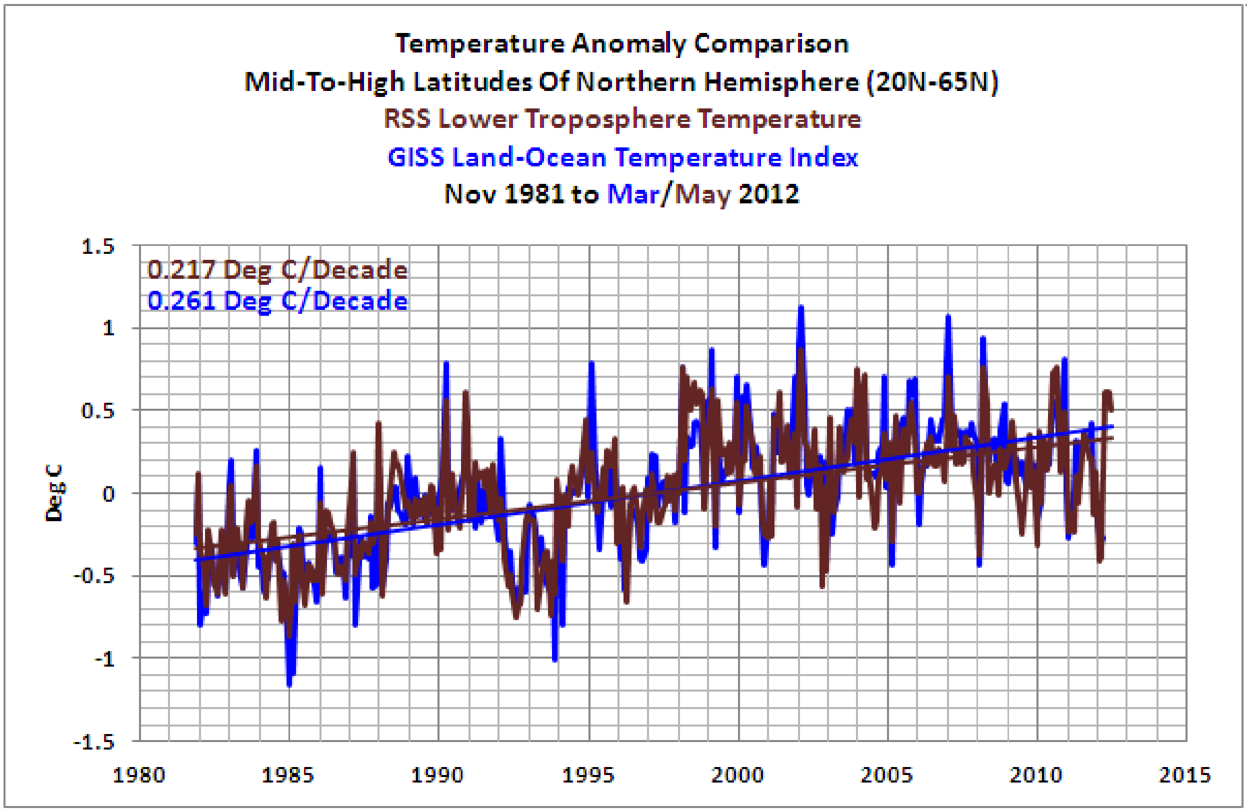


Figure 5-63 Bob Tisdale

LOWER TROPOSPHERE TEMPERARURE ANOMALIES OF THE MID-TO-HIGH LATITUDES OF THE NORTHERN HEMISPHERE

Figure 5-64 is a time-latitude plot (Hovmöller) of Global Lower Troposphere Temperature anomalies prepared by **Remote Sensing Systems**. It is available at their website toward the bottom of their **Description of MSU and AMSU Data Products** webpage. The temperature anomalies are color-coded. See the scale below the Hovmöller. The horizontal axis (x-axis) is time, running from the start of the dataset in January 1979 and ending in June 2012. The vertical axis (y-axis) is latitude, with the North Pole at the top and the South Pole at the bottom. I've also highlighted the latitudes of 20N-65N with thin black lines.

Also, I've highlighted in purple the 1986/87/88, 1997/98, and 2009/10 El Niño events. As you'll recall, the tropical Pacific releases more heat than normal during an El Niño, primarily through evaporation. The warm, moist air rises, cooling as it rises. When it condenses, it releases heat. That's the reason for the warm temperature anomalies in the tropics at 3000 feet during the El Niño events. The La Niña events following them can be seen to the right of the highlighted El Niño, as can the lesser (secondary) El Niño events between them the major events. The 1982/83 El Niño should have shown warming comparable to the 1997/98 El Niño, but it was counteracted by the eruption of El Chichon.

Time-Latitude Plot
Global RSS Lower Troposphere Temperature Anomalies

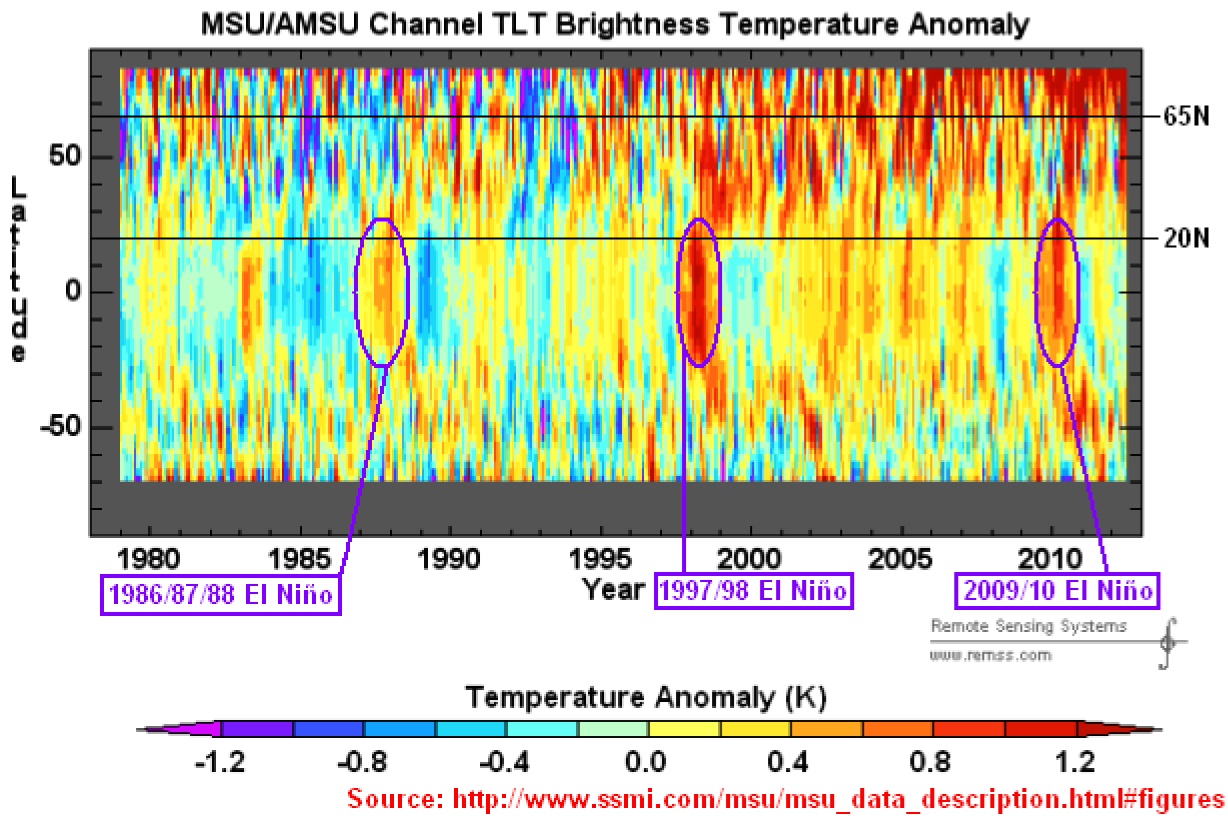


Figure 5-64 Bob Tisdale

Let's focus on the 1997/98 El Niño, the strongest of the strong events. Right after the peak warming of the tropics in early 1998 the mid-to-high latitudes warm (20N-65N, between the two thin black lines). They stay warm during the La Niña. Again, this contradicts the assumption that the globe cools proportionately during La Niña events. The lesser El Niño events in 2002/03, 2004/05 and 2006/07 then maintain the elevated temperatures. The same thing happens again with the 2009/10 El Niño. It helps to maintain the Lower

Troposphere Temperature anomalies at their elevated levels. Moving back in time to the 1986/87/88 El Niño, the same thing may have happened, but it's difficult to tell with the color coding and the amount of warming.

We can check that with a time-series graph of the data for those latitudes, which we'll call the Extratropics of the Northern Hemisphere to simply things. See Figure 5-64. As you'll note, I've prepared the graph similar to those used in the earlier discussion of the sea surface temperatures. I've isolated the period between the 1986/87/88 and 1997/97 El Niño events. In Figure 5-64, the 2009/10 El Niño had a limited impact on the Lower Troposphere Temperature anomalies for the Extratropical Northern Hemisphere, so I did not bother to isolate it or the data after it. The trend between the 1986/87/88 and 1997/98 El Niño events is flat, and that dataset has been cooling slightly since the 1997/98 El Niño. It definitely hasn't been warming at the 0.217 Deg C per decade pace shown by the long-term data (Figure 5-63).

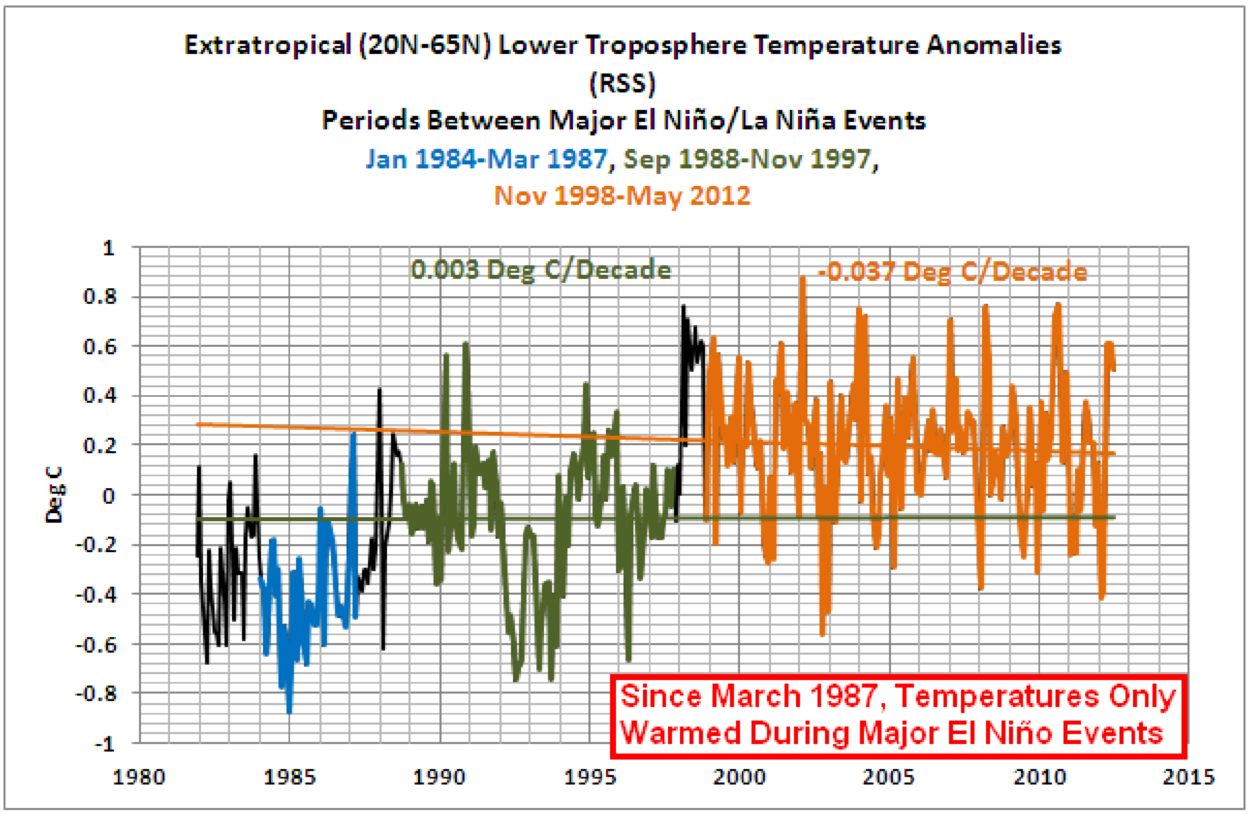


Figure 5-65 Bob Tisdale

Using the period-average temperatures in Figure 5-66, we can show that the Lower Troposphere Temperature anomalies for the Northern Hemisphere latitudes of 20N-65N warmed about 0.59 deg C during the two El Niño events, which is how we would expect Lower Troposphere Temperatures to respond to El Niño events. The response to La Niña events is missing. Why don't the temperature anomalies cool during the La Niña events that follow the major El

Niño? We'll discuss that in the **Chapter 5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events.**

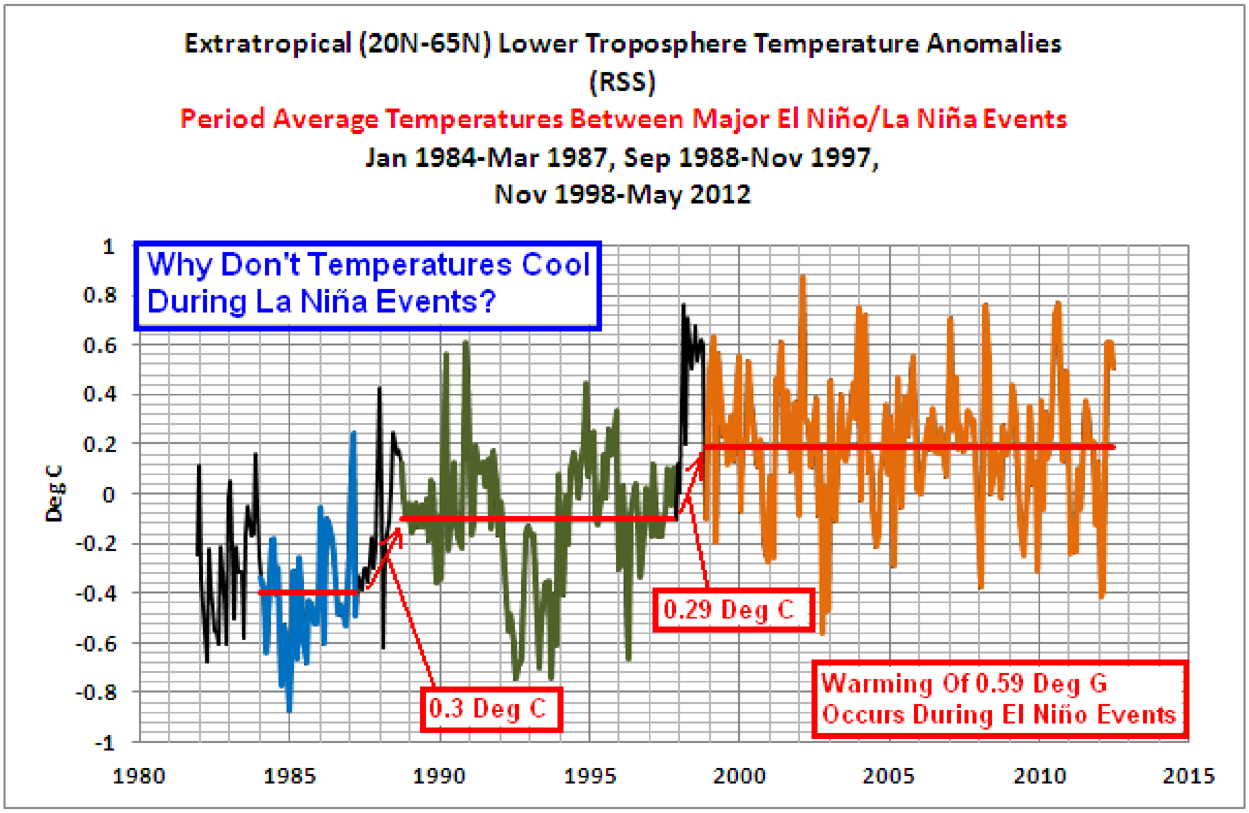


Figure 5-66 Bob Tisdale

LAND-PLUS-SEA SURFACE TEMPERARURE ANOMALIES OF THE MID-TO-HIGH LATITUDES OF THE NORTHERN HEMISPHERE

It should come as no surprise that I'm going to present exactly the same thing using the GISS Land-Ocean Temperature Index data for the 20N-65N latitude band of the Northern Hemisphere. See Figures 5-67 and 5-68.

A quick note: The dataset is called the Land-Ocean Temperature Index. It is made up of sea surface temperature data and land **air** temperature data. I just wanted to make sure you weren't thinking this dataset represented the surface temperature of the continental landmasses.

Extratropical Northern Hemisphere Surface Temperature anomalies cooled between the El Niño events of 1986/87/88 and 1997/98, and they cooled after the 1997/98 El Niño. See Figure 5-67. The trends during those periods are negative even though the long-term trends are positive. If the long-term trend shows warming, but the trends between and after the major El Niño events show cooling, then one might conclude the warming takes place during, and was caused by, the El Niño events. Then, using the period-average surface temperatures between and after the major El Niño events, Figure 5-68, we can see that the GISS land-plus-sea surface temperature data for these latitudes warmed about 0.69 deg C during the 1986/87/88 and 1997/98 El Niño events.

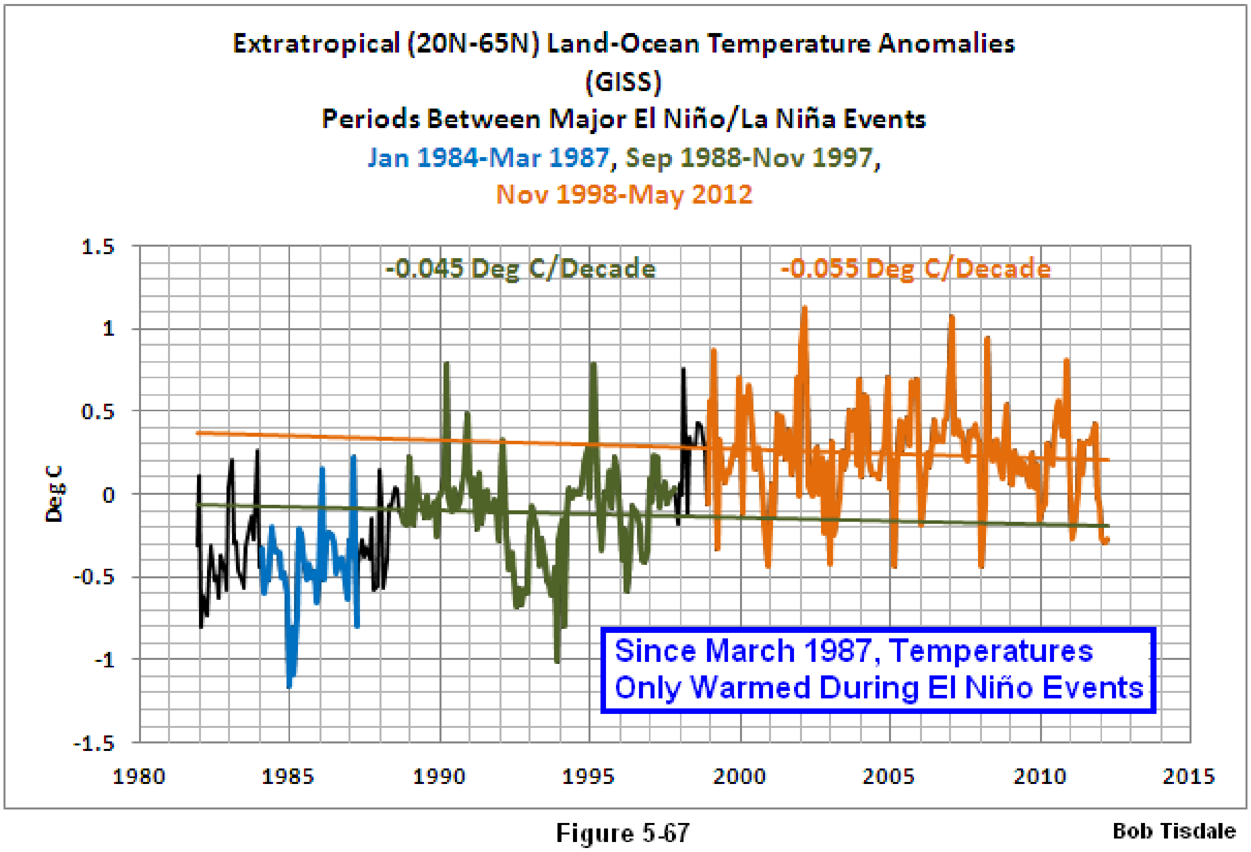


Figure 5-67

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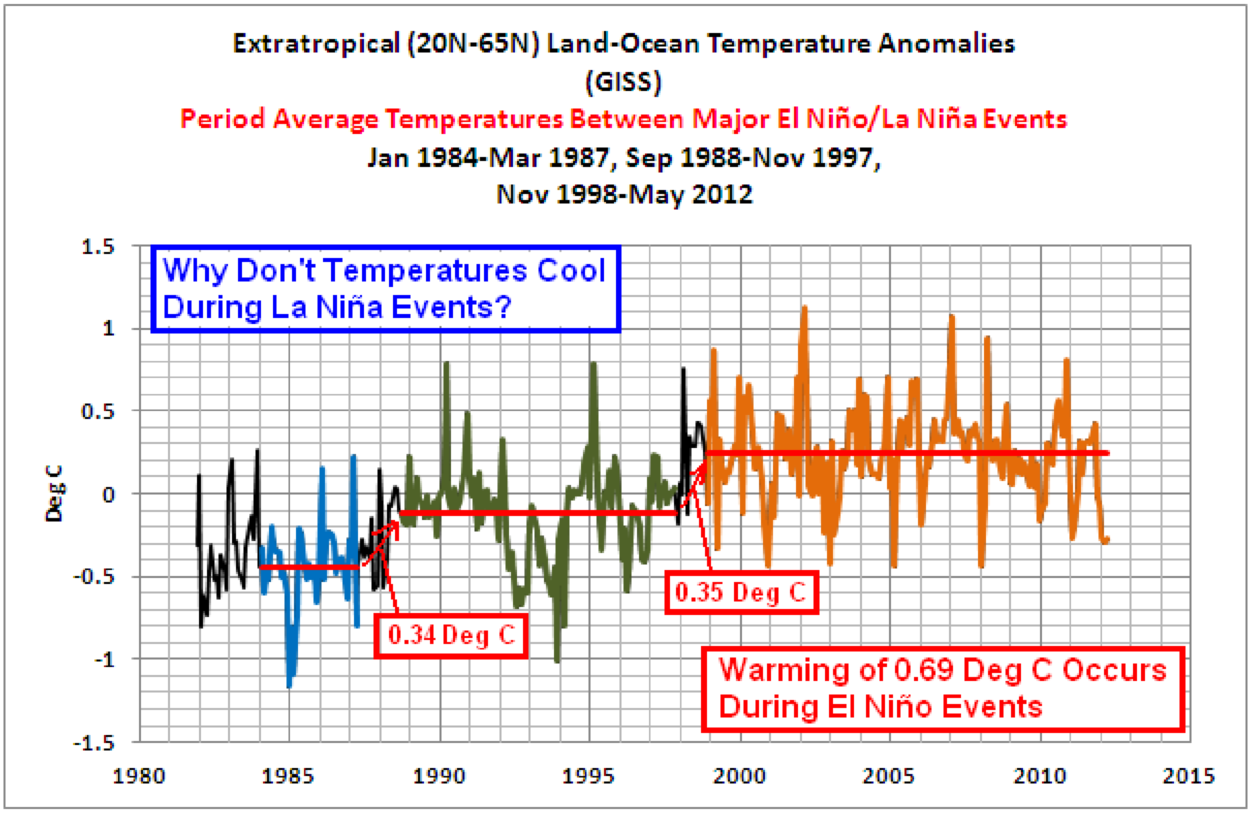

Figure 5-68

Bob Tisdale

SMOOTHING THE DATA HELPS THE VISUALIZATION

The two datasets shown in the graphs above are noisy. Let's smooth them with 13-month running-average filters and compare them to scaled (0.3) NINO3.4 sea surface temperature anomalies, our ENSO index. See Figure 5-69. The two Extratropical Northern Hemisphere temperature datasets very clearly warm in response to the El Niño events of 1986/87/88 and 1997/98, but they do not cool proportionately (if at all) in response to the La Niña events of 1988/89 and 1998/99/00/01.

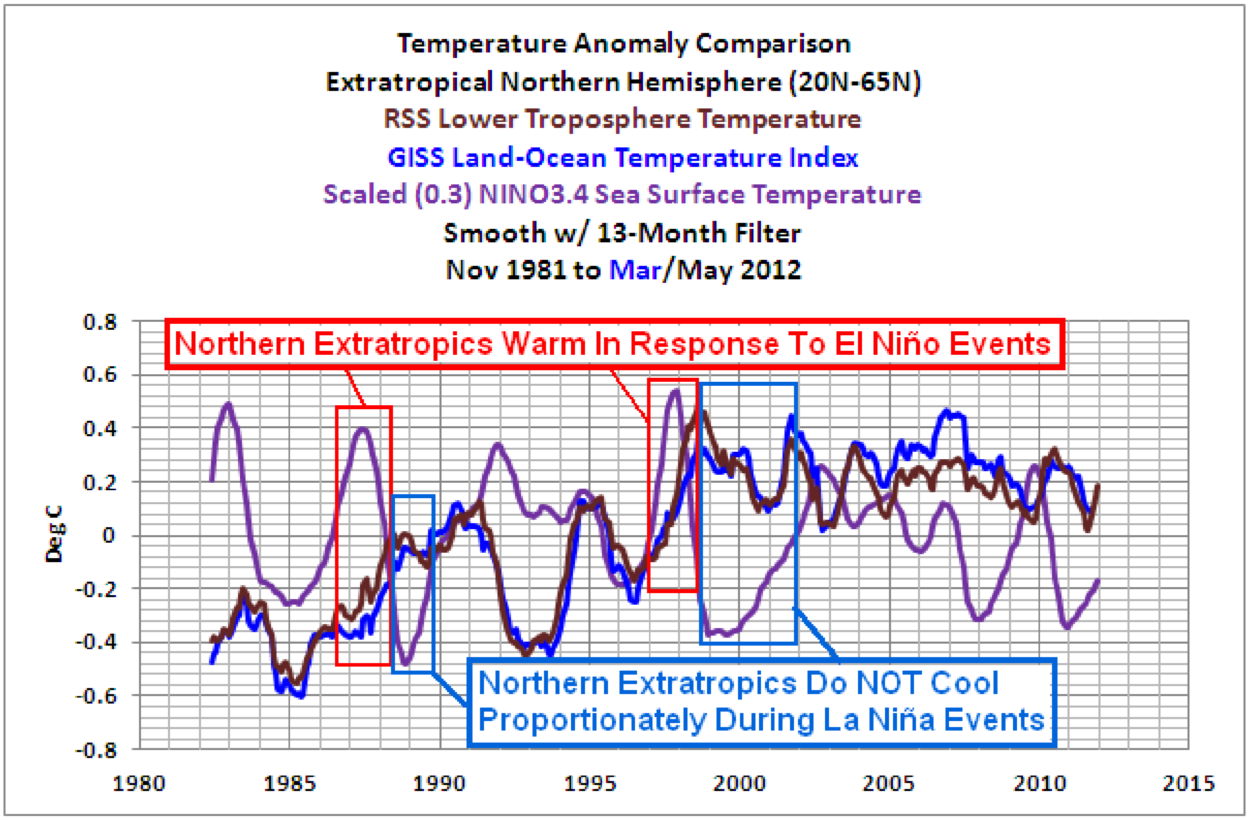

Figure 5-69

Bob Tisdale

DETRENDED

Proponents of anthropogenic global warming are skeptical of these ENSO-caused shifts in surface temperatures. When I present graphs similar to Figure 5-69 above, they will often attempt to argue that the surface temperature or lower troposphere temperature data is responding to the La Niña event, but the anthropogenic warming trend somehow disguises that response. They try the argument, but it's nonsense.

The easiest way to show the very clear failure of that argument is to detrend the data. If the detrended temperature datasets mimic the variations in the ENSO index during the La Niña, then the trend is hiding the response of the dataset to La Niña events. If the dataset does not respond fully to the La Niña, then it's the failure of the temperature dataset to respond to the La Niña that's causing the trend.

Figures 5-70 compares scaled and lagged NINO3.4 sea surface temperature anomalies to detrended Lower Troposphere Temperature anomalies. Scaled and lagged NINO3.4 data is compared to GISS Land-Ocean Temperature anomalies for the Northern Hemisphere extratropical latitudes of 20N-65N in Figure 5-71. Refer to the title blocks for the scaling factors and the number of months the NINO3.4 data was lagged to account for the time delay in the responses. I've used crosshatching to highlight the major areas where the detrended data diverge from the ENSO index. The departures with green cross hatches are caused by volcanic eruptions, and the divergences with the red crosshatches are caused by failure of the extratropical temperatures to respond to the La Niña event. Surface and lower troposphere temperatures clearly do not respond the same to La Niña events as they do to El Niño events.

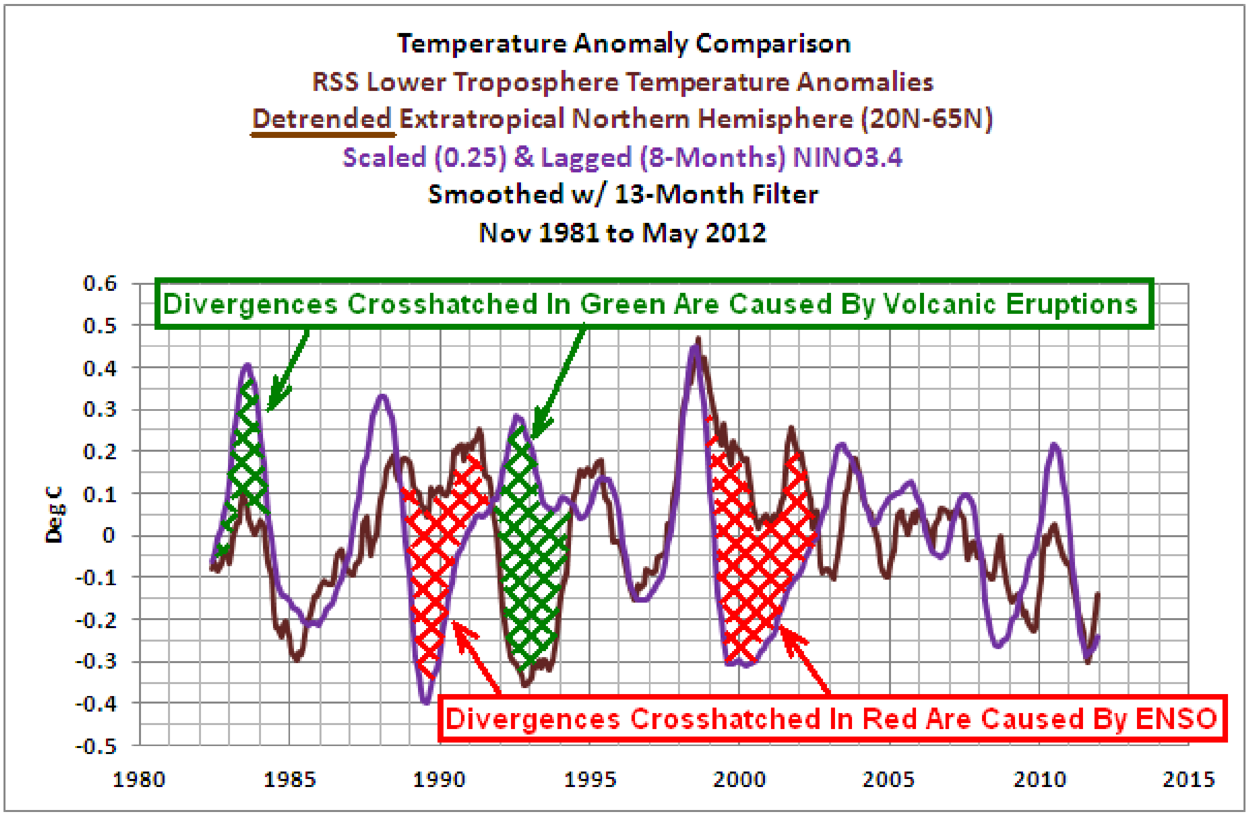

Figure 5-70 Bob Tisdale

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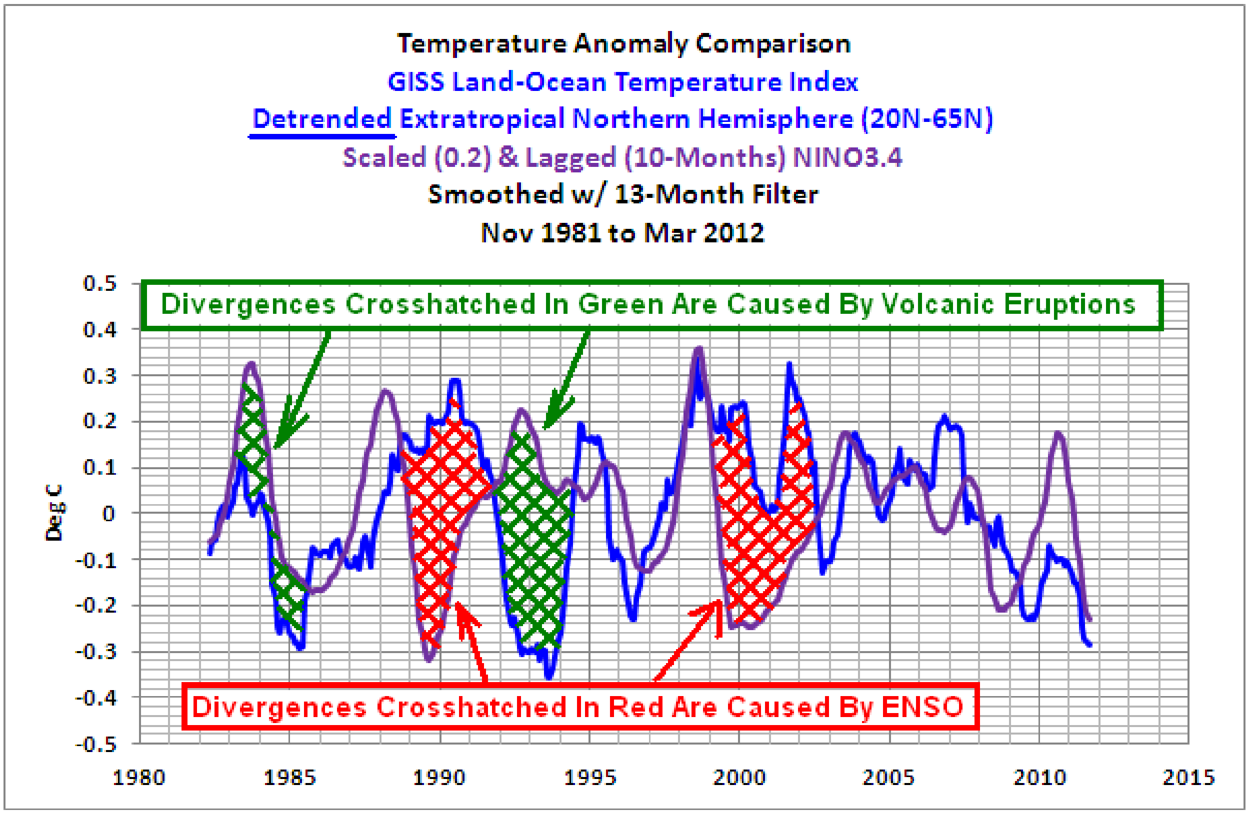

Figure 5-71 Bob Tisdale

RECAP

This chapter presented the RSS Lower Troposphere Temperature and GISS Land-Ocean Temperature Index data for the Northern Hemisphere extratropical latitudes of 20N-65N. Surface and lower troposphere temperature anomalies there warmed as one would expect during the 1986/87/88 El Niño event. That makes perfect sense. But…

For decades, we've been told that the response of global surface temperatures to La Niña events is the opposite of El Niño events. As very clear examples of how data contradicts that myth, they did not cool proportionately during the 1988/89 La Niña, but remained at the elevated level. They then cooled slowly for almost a decade, even with the lesser El Niño events helping to maintain the elevated temperatures, until the next major El Niño event in 1997/98. That El Niño event drove extratropical temperatures higher, but again they did not cool during the 1998/99/00/01 La Niña, and they have not warmed since the 1997/98 El Niño. But they have cooled slightly even though the lesser El Niño events have been trying to maintain the elevated temperatures.

The next question: Why don't the Northern Hemisphere surface temperatures for those latitudes cool during the La Niña events that follow the major El Niño events? We had the same question during our discussion of North Atlantic sea surface temperature anomalies.

That's a good introduction for the next chapter.

5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events

The warming of the East Indian and West Pacific Oceans (or their failure to cool) during the La Niña events that follow major El Niño events is a function of the warm water that's left over from the El Niño portion of the ENSO process. Curiously, the lower troposphere and land-plus-sea surface temperature anomalies for the mid-to-high latitudes (20N-65N) of Northern Hemisphere also don't cool during those La Niña events. Likewise, the same thing happens with the sea surface temperature anomalies of the North Atlantic.

The leftover warm water from the El Niño events could impact those other datasets. It would make sense with the land-plus-sea surface temperatures of the Northern Hemisphere. Any leftover warm water that is transported poleward into the North Pacific would be included in the land-plus-sea surface temperatures of the mid-to-high latitudes. Also, the lower troposphere temperature anomalies at those latitudes are impacted by the surface temperatures. However, the North Atlantic is separated from the North Pacific by North and Central America, so the North Atlantic would need to be teleconnected to the North Pacific.

Let's see what we can see.

Figure 5-72

In **Chapter 3.7 The Transition from El Niño to ENSO Neutral,** we discussed how the warm water that was left over from an El Niño was carried west, and then carried to the mid-latitudes by the Western Boundary Currents. Refer to Figure 5-72. The leftover warm waters have very strong impacts on the sea surface temperature anomalies of the extensions of those Western Boundary

Currents. For this discussion, we'll use the coordinates of 30N-45N, 150E-150W for the Kuroshio-Oyashio Extension in the west-central portion of the North Pacific and the coordinates of 35S-20S, 160E-150W for the South Pacific Convergence Zone Extension in the west-central portion of the South Pacific. See Figure 5-73.

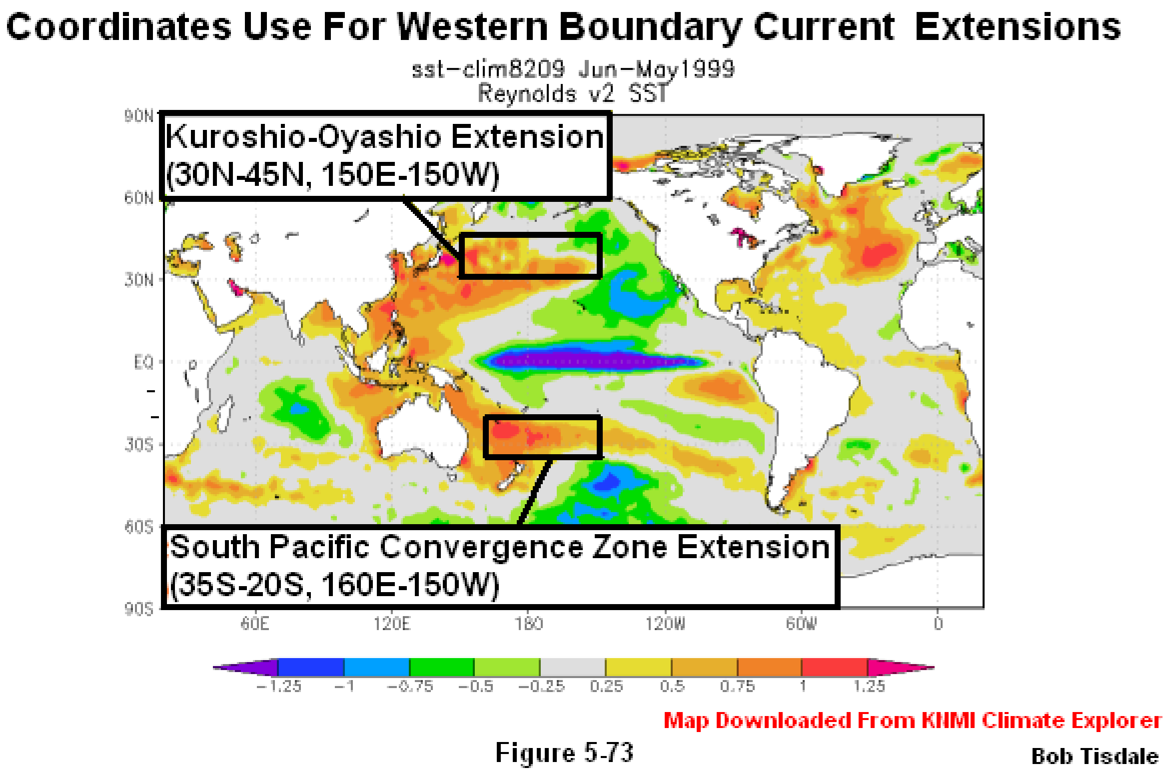

Figure 5-73

So far we've used very few acronyms. The names "Kuroshio-Oyashio Extension" and "South Pacific Convergence Zone Extension" are so long they would consume much of the space available on the graphs for notes. I've had to use KOE and SPCZ Extension for those notes, but I've used their full names in the book text.

We discussed how ENSO processes cause long-term warming of the East Indian-West Pacific sea surface temperatures in **Chapter 5.4 The Obvious ENSO-Caused Upward Shifts in the Sea Surface Temperature Anomalies of the East Indian and West Pacific Oceans.** Let's take a look at the magnitude and timing of the two strongest, secondary ENSO-related signals that take place in the mid-latitudes of the North and South Pacific. First, the stronger of the two, the…

SEA SURFACE TEMPERATURE VARIATIONS OF THE KUROSHIO-OYASHIO EXTENSION

The sea surface temperature anomalies of the Kuroshio-Oyashio Extension (KOE) are compared to those of the East Indian-West Pacific Oceans in Figure 5-74. The long-term trend (warming rate) of the Kuroshio-Oyashio Extension is about 2.5 times greater than the East Indian-West Pacific dataset. The ENSO-related short-term variations are also much greater, on the order of about 3 times greater. Notice the size of the upward shifts in 1988 and 1998.

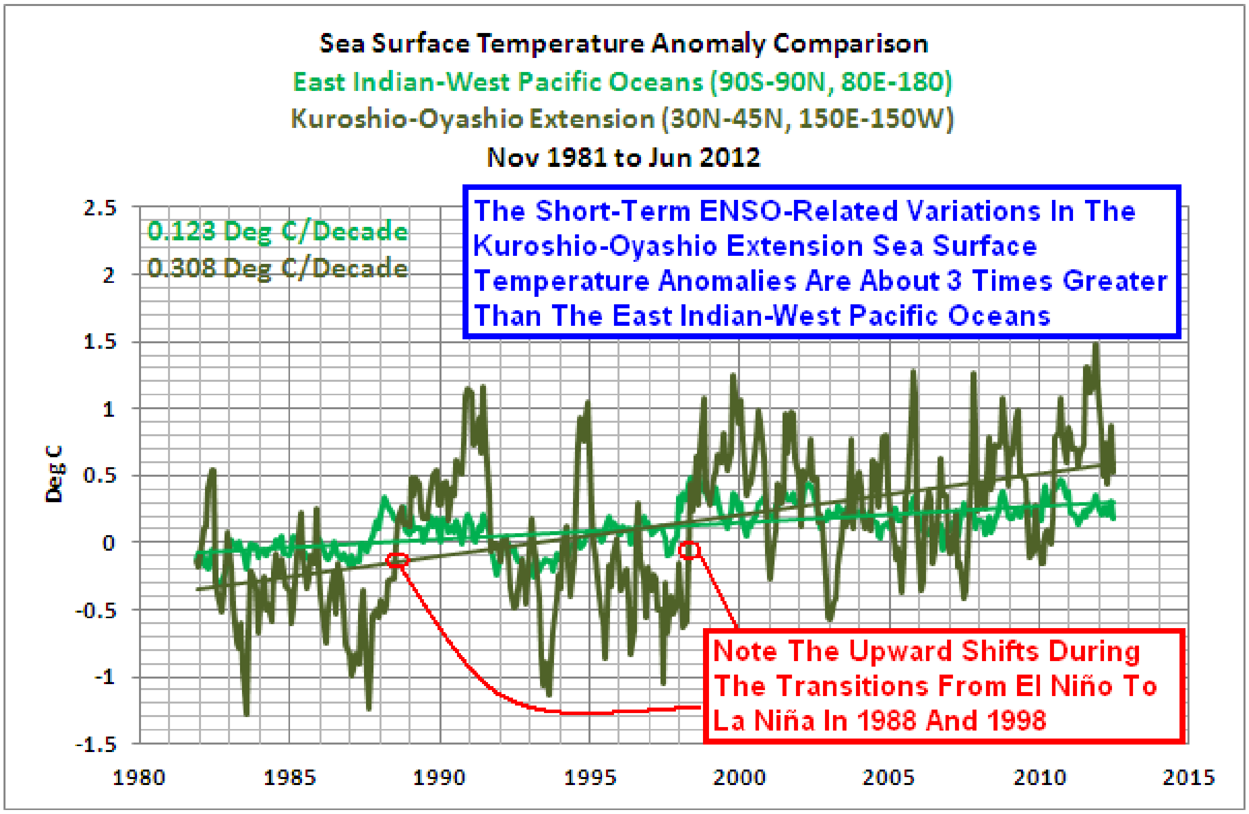

Figure 5-74 Bob Tisdale

Those shifts in the sea surface temperature anomalies of the Kuroshio-Oyashio Extension occur toward the end of the El Niño events or at the start of the subsequent La Niña. We can see this in the comparison of NINO3.4 and Kuroshio-Oyashio Extension sea surface temperature anomalies in Figure 5-75. Note the magnitude of the variations in the sea surface temperature anomalies of the Kuroshio-Oyashio Extension. As a reference, the standard deviation for the NINO3.4 sea surface temperature anomalies is about 0.96 deg C, while the standard deviation for the sea surface temperature anomalies of the Kuroshio-Oyashio Extension is about 0.56 deg C—more than half the standard deviation of the NINO3.4 data. One would think that the warm leftover water from the El Niño, with its arrival at the Kuroshio-Oyashio Extension, should be capable of offsetting some of the effects of the La Niña event in the tropics. When you think about it, that's all it has to do. It has to keep the other datasets from cooling during the La Niña. And it looks like it does that, as you shall see.

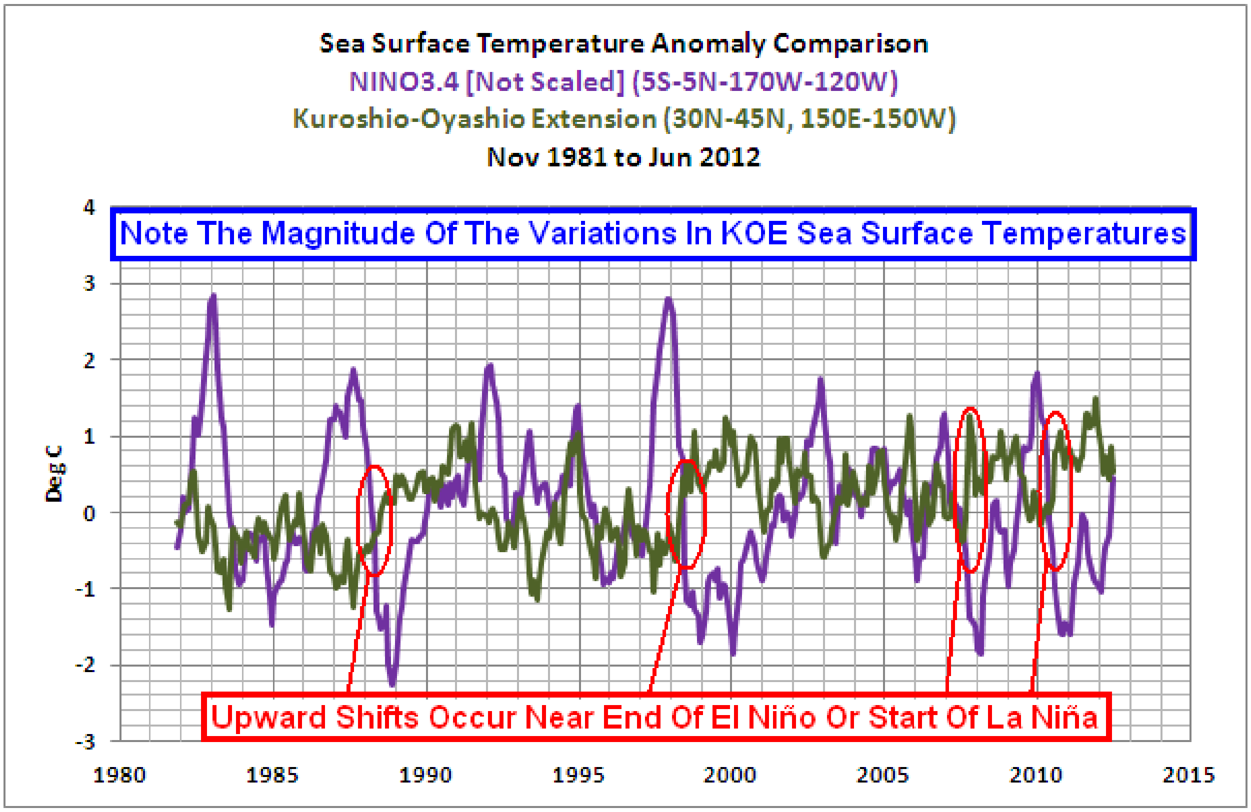

Figure 5-75

As a reminder, much of the warm water being spun up into the Kuroshio-Oyashio Extension after an El Niño originated from the West Pacific Warm Pool. Moving back in time, the warm water there was created during a La Niña event that preceded the release of that warm water during an El Niño event. That is, a La Niña “a” created the warm water that’s stored in the Pacific Warm Pool, it’s then released by El Niño “b”, and after El Niño “b”, during the second La Niña “c”, some of that warm water is returned to the western Pacific and makes its way into the Kuroshio-Oyashio Extension.

The Kuroshio-Oyashio Extension cools slightly during the evolution of the El Niño event. In the western Pacific, the trade winds become westerlies during the El Niño, and less warm water is being circulated poleward. On the other hand, the total warming of Kuroshio-Oyashio Extension sea surface temperature anomalies in response to an El Niño and La Niña can be quite large.

That warming can at times be comparable to the peak cooling in NINO3.4 sea surface temperature anomalies during the La Niña events. These responses in sea surface temperatures are easier to see if we smooth the NINO3.4 and Kuroshio-Oyashio Extension sea surface temperature data with 13-month running-average filters, Figure 5-76. Notice how the smoothed Kuroshio-

Oyashio Extension sea surface temperature data warmed about 1.1 deg C in response to the 1986/87/88 El Niño, while the NINO3.4 data peaked at -1.5 deg C during the 1988/89 La Niña. A decade later, while the smoothed NINO3.4 data reaches a little more than -1.1 deg C during the peak of the 1998/99/00/01 La Niña, the Kuroshio-Oyashio Extension data warms about 1.2 deg C. That's a very significant secondary ENSO-related warming signal in the mid-latitudes of the North Pacific. Keep in mind, 1.0 deg C is threshold of a moderate-strength El Niño. Also recall that it's not accounted for by any ENSO index.

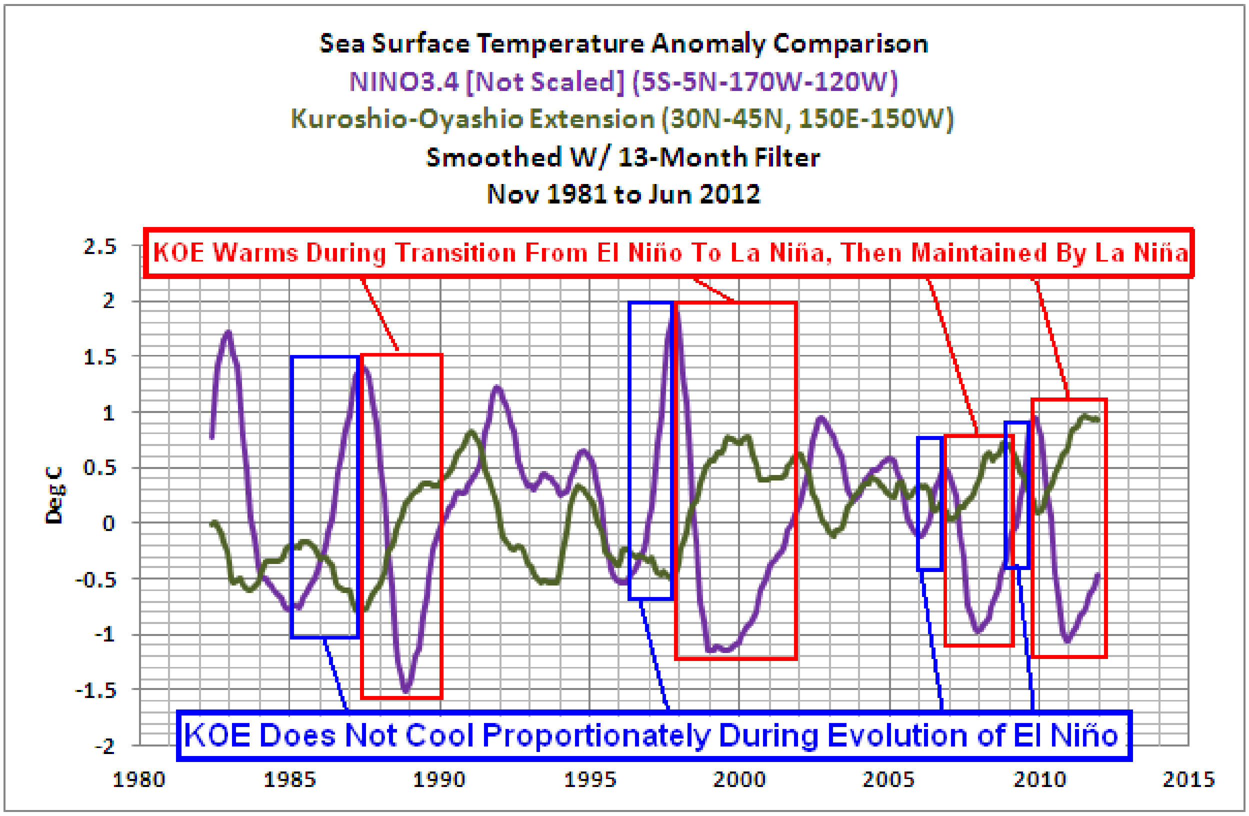

Figure 5-76 Bob Tisdale

The smoothing also provides a different perspective. With it, the Kuroshio-Oyashio Extension sea surface temperature anomalies appear to warm during the transition from El Niño to La Niña, and that the La Niña events help to maintain the elevated sea surface temperatures there. Even the La Niña event of 2007/08, which followed the 2006/07 El Niño, appears to have created an upward surge in Kuroshio-Oyashio Extension sea surface temperature anomalies. This wasn't readily apparent with the East Indian-West Pacific data.

In our discussions of the East Indian-West Pacific dataset and the South Atlantic-Indian-West Pacific dataset, we've illustrated the sea surface temperatures between the major El Niño events, and shown that sea surface temperatures cooled between them. We've also presented the RSS lower troposphere temperature and GISS Land-Ocean Temperature Index anomalies the same way in the last chapter. Some readers would think I was trying to hide something if I didn't show the Kuroshio-Oyashio Extension sea surface temperature anomalies the same way.

Of course, that extra response of the Kuroshio-Oyashio Extension data to the 2006/07 El Niño and 2007/08 La Niña will have an impact on the rate at which that dataset cools between the 1997/98 and 2009/10 El Niño events. We can see that impact in Figure 5-77. The sea surface temperature anomalies of the Kuroshio-Oyashio Extension between the 1997/98 and 2009/10 El Niño events do cool, but it's nowhere near the rate they cooled between the 1986/87/88 and 1997/89 El Niño.

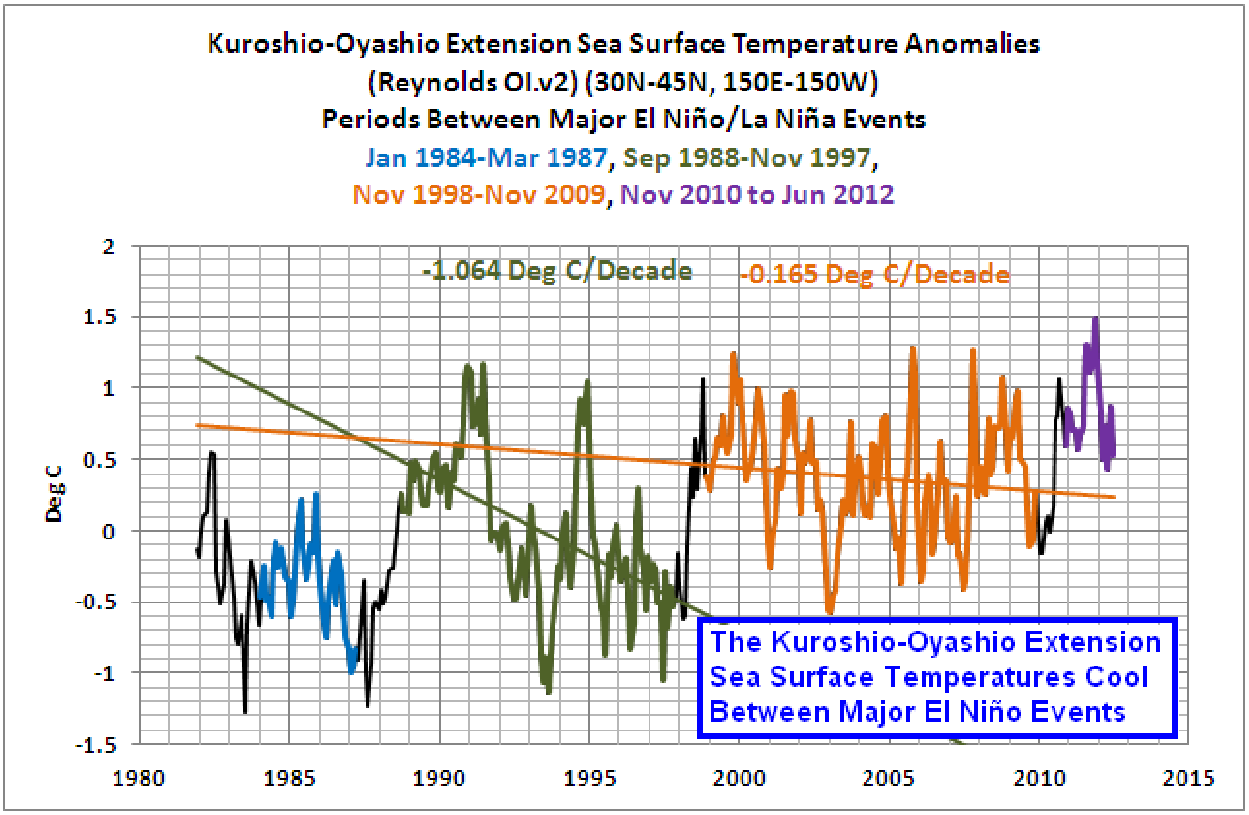

Figure 5-77

For those wondering how quickly the Kuroshio-Oyashio Extension data cools between the 1997/98 El Niño and the 2006/07 El Niño, refer to Figure 5-78. During that shortened period, the sea surface temperatures there cooled at a rate that was a little more than half that of the earlier period. There could be any number of reasons for the differences in the rates of cooling, including differences in sea level pressures and their effects on the distribution of warm water from the tropics to the Kuroshio-Oyashio Extension, or additional warm subsurface waters in the Kuroshio-Oyashio Extension after the 1997/98 El Niño. The 1997/98 El Niño was stronger than the 1986/87/88 El Niño. The amount of warm water returned to the western tropical Pacific via a downwelling (warm) Rossby wave and then circulated north to the Kuroshio-Oyashio Extension should have been greater after the 1997/98 El Niño. Unfortunately, the subsurface temperature measurements in the mid-to-late1980s were so sparse there is no reasonable way to show the differences. Hopefully, now that there are all of those ARGO floats bobbing around the global oceans scientists can better track the warm subsurface waters that are left over from an El Niño event.

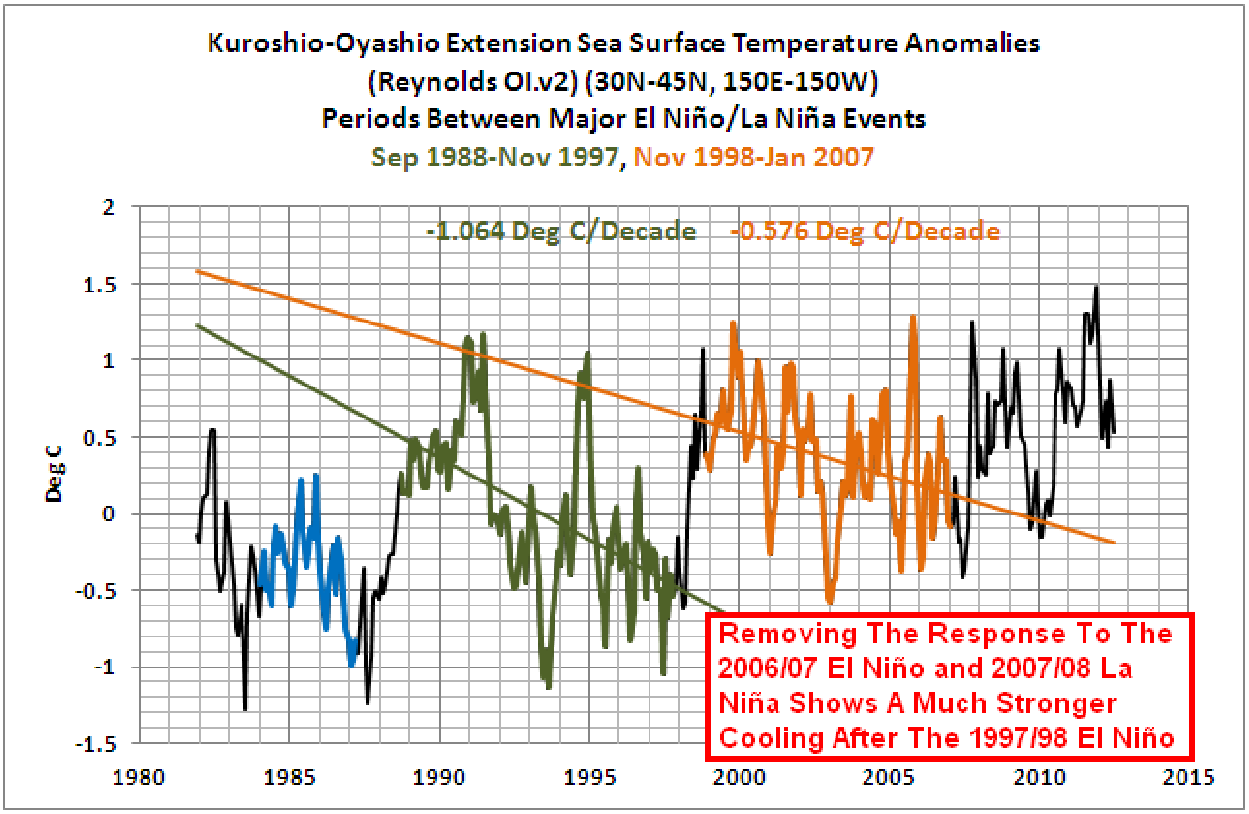

Figure 5-78 Bob Tisdale

To maintain the same format as our earlier discussions, Figure 5-79 shows the period-average sea surface temperature anomalies of the Kuroshio-Oyashio Extension between the major El Niño events. Again, because the Kuroshio-Oyashio Extension warms significantly in response to the major El Niño events, and because the Kuroshio-Oyashio Extension data cools slowly over the decade periods between the major El Niño events, and because the Kuroshio-Oyashio Extension sea surface temperature anomalies show a long-term warming trend, then it's likely the long-term warming was caused by the major El Niño events. We've discussed the processes that cause the temporary upward shifts, and in Section 6 there are discussions of and links to animations of sea surface temperature anomalies, so you can watch the Kuroshio-Oyashio Extension warm in response to ENSO, along with the rest of the East Indian-West Pacific data.

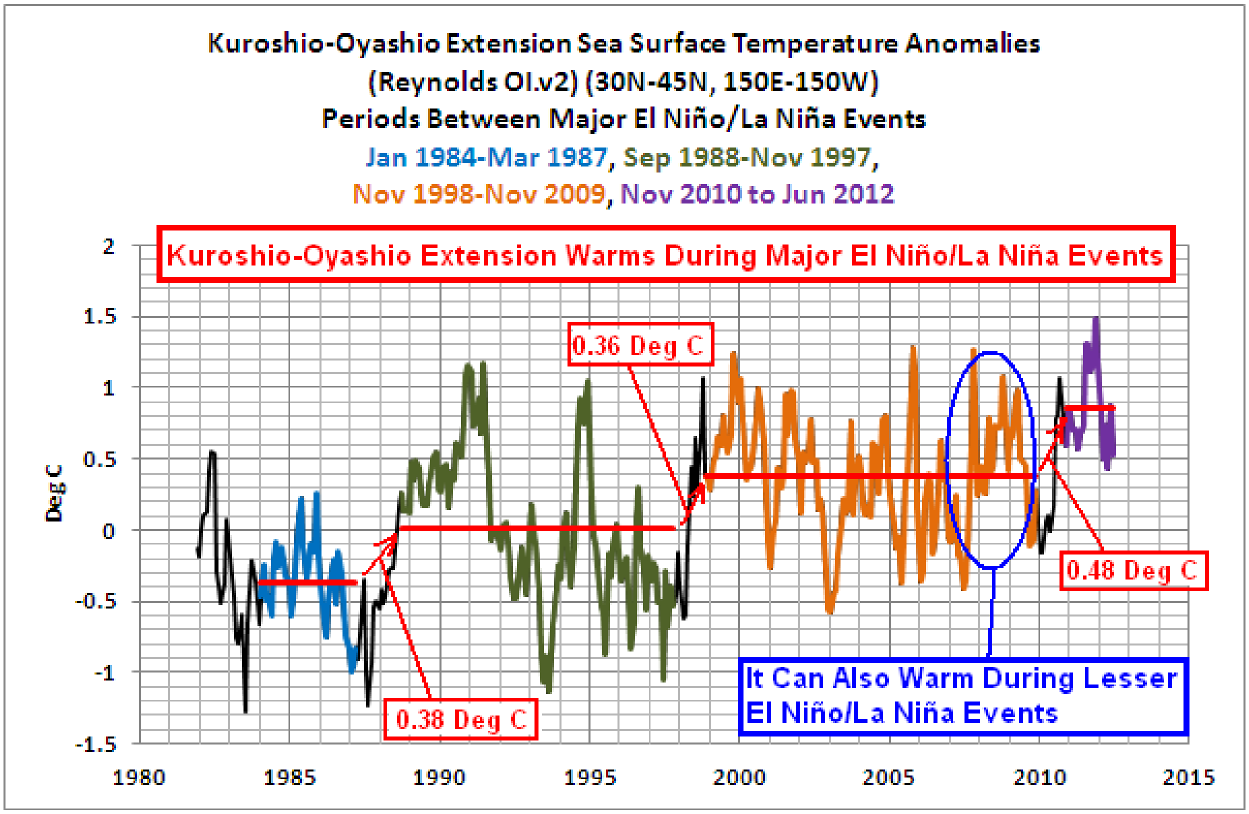

Figure 5-79 Bob Tisdale

REVISITING THE TEMPERATURE ANOMALIES OF THE MID-TO-HIGH LATITUDES OF THE NORTHERN HEMISPHERE

Figure 5-80 compares the sea surface temperature anomaly data for the Kuroshio-Oyashio Extension to the GISS Land-Ocean Temperature Index and to the RSS Lower Troposphere Temperature anomalies for the extratropical Northern Hemisphere (20N-65N). The sea surface temperature variability of the Kuroshio-Oyashio Extension is much greater than that of the other two datasets. That makes sense, because the Kuroshio-Oyashio Extension is bearing the direct impacts of the warm leftover water from ENSO. Also, the Kuroshio-Oyashio data is a small part of the GISS Land-Ocean Temperature Index data and the RSS Lower Troposphere Temperature anomalies are seeing the indirect effects. However, the timings of the major variations appear to coincide only part of the time.

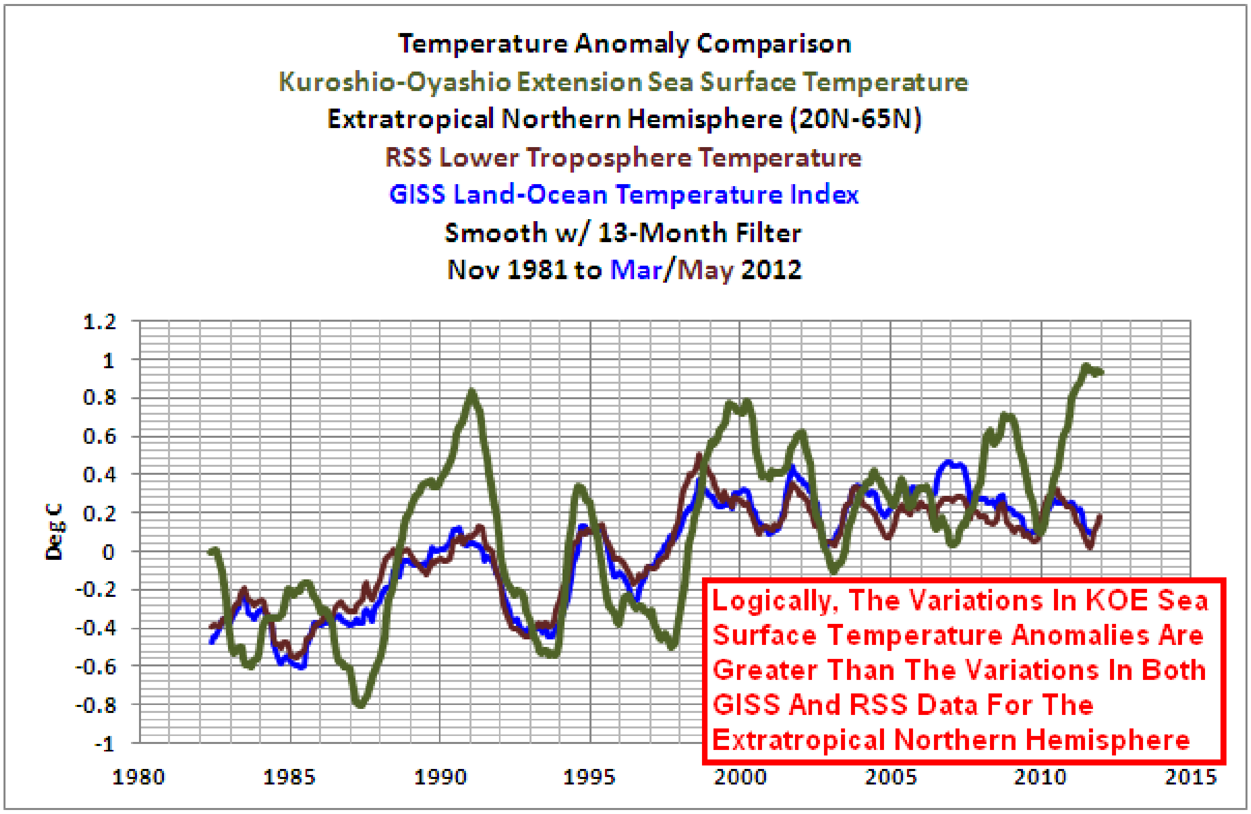

Figure 5-80

Let's add scaled NINO3.4 sea surface temperature anomalies to that comparison so that we can confirm the timing of ENSO events. See Figure 5-81. I've highlighted the periods of the major El Niño events in red and the subsequent La Niña events in blue. The La Niña periods are, of course, when the Kuroshio-Oyashio Extension warms with the leftover warm water from the El Niño events. It appears the GISS and RSS temperature datasets for the mid-to-high latitudes of the Northern Hemisphere warm first in response to the major El Niño events. Those effects are well studied. Then, it looks like the Kuroshio-Oyashio Extension helps to maintain the GISS and RSS temperature data for those latitudes at elevated levels during the La Niña events. The cooling that took place in the GISS and RSS datasets after the warming response to the 2009/10 El Niño doesn't seem to agree with aftereffects of the other two much-stronger El Niño events.

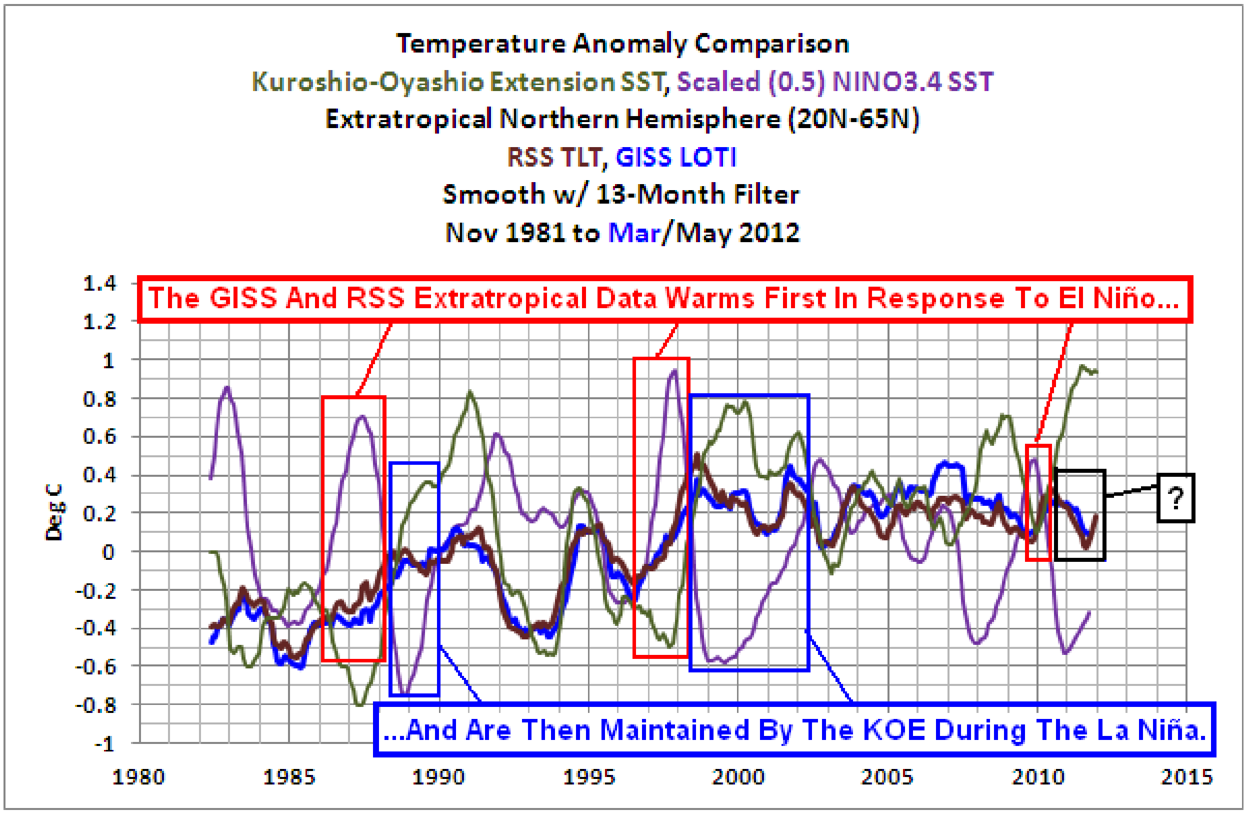

Figure 5-81

Bob Tisdale

Figure 5-81 is very busy. To some it may look like a plate of colored spaghetti. Just in case you're having trouble seeing the relationships described in the preceding paragraph, I'll present the results of one of my blog posts, one from January 2011. That post is **Can Most Of The Rise In The Satellite-Era Surface Temperatures Be Explained Without Anthropogenic Greenhouse Gases?** In it, I removed the linear effects of ENSO and volcanic eruptions from the GISS Land-Ocean Temperature Index (LOTI) data for a similar extratropical Northern Hemisphere latitude band. (I used 20N-60N in that post, where I've illustrated 20N-65N in this chapter. The additional 5 deg latitude would have little impact on the results here. Refer to the comparison graph in the Recap of this chapter.) Then I compared the ENSO- and volcano-adjusted GISS Land-Ocean Temperature Index data for those latitudes to scaled Kuroshio-Oyashio Extension sea surface temperature anomalies. The intent was to see whether the secondary effects of ENSO could explain the warming in the extratropical northern hemisphere GISS data. Figure 5-82 is Figure 13 from that post. (I've added a comment to the graph). The variations in the ENSO- and volcano-adjusted extratropical GISS Northern Hemisphere Land-Ocean Temperature Index data agree remarkably well with the scaled Kuroshio-Oyashio Extension sea surface temperature anomalies. The exception is the anomalous spike in the Kuroshio-Oyashio Extension sea surface temperature data that's highlighted in blue. The comparison graph indicates there is a strong possibility the secondary effects of ENSO can be used to explain the long-term warming of the GISS land-plus sea surface temperatures of the extratropical Northern Hemisphere.

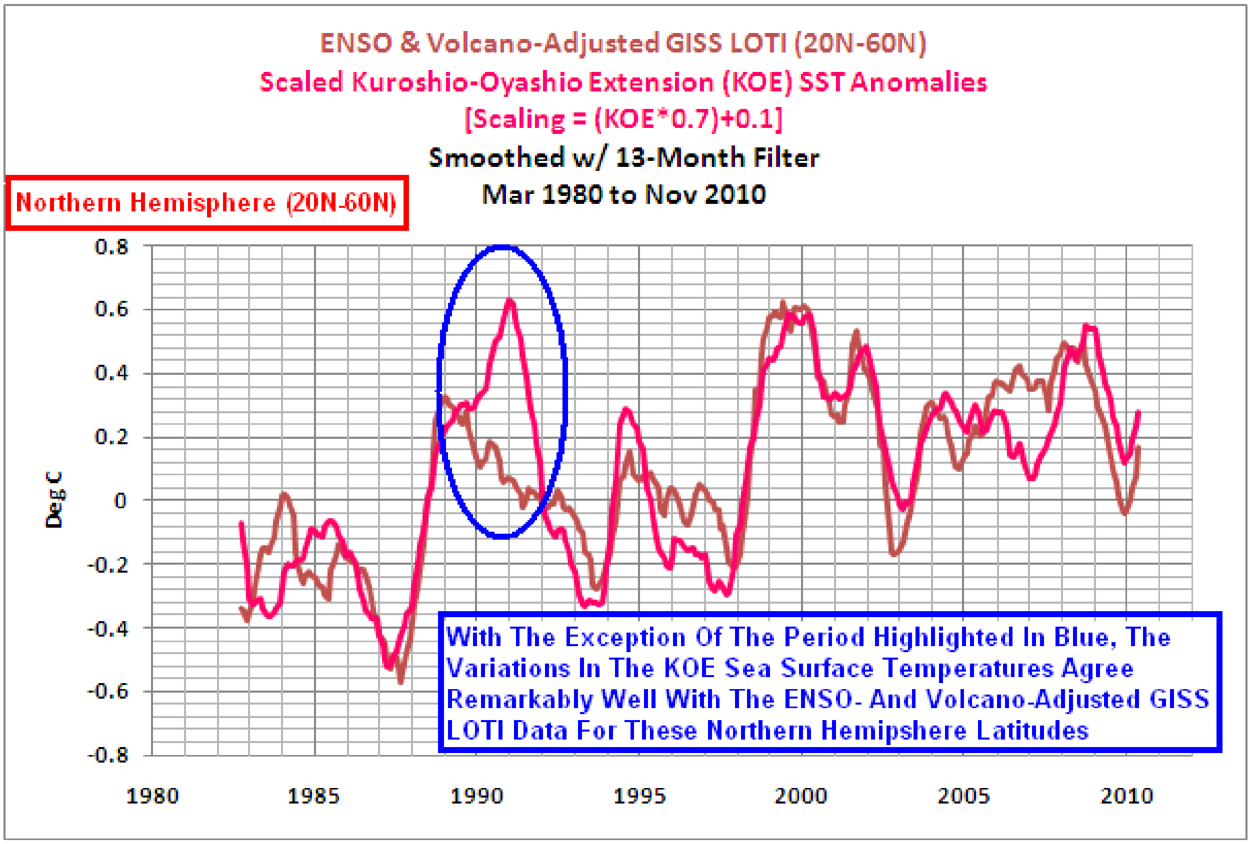

Figure 5-82 Bob Tisdale

We've discussed ENSO-caused changes in atmospheric circulation and how land and sea surface temperatures outside of the tropical Pacific warm or cool in response. Refer to **Chapter 4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific** and **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation**. We've also presented maps that show the correlation of NINO3.4 sea surface temperatures with global surface temperature data. They showed where the variations in surface temperature around the globe agreed with the frequency, magnitude and duration of the ENSO events as portrayed by NINO3.4 data. As you'll recall, areas that were highly correlated with the NINO3.4 data did not mean they were warming and cooling as much, just that the variations in the two curves were similar. Areas that were negatively correlated with the NINO3.4 data cooled when NINO3.4 sea surface temperatures warmed and vice versa. Poor correlation does not mean that sea surface temperatures in a given location aren't impacted by ENSO; it simply means the variations there were not proportional to and consistent with the variations in NINO3.4 sea surface temperature anomalies.

Figure 5-83 presents two correlation maps of Northern Hemisphere temperature anomalies with NINO3.4 sea surface temperatures for the period of 1982 to 2011. The top is for GISS Land-Ocean Temperature Index data and the bottom is for RSS Lower Troposphere Temperature anomalies. (I've highlighted the general location of the Himalayas because they rise above the 3000 meter altitude of the dataset and there's no Lower Troposphere Temperature data there.) Then take a look at the maps for the two datasets correlated with Kuroshio-Oyashio Extension sea surface temperature anomalies, Figure 5-84. Which dataset appears to have the greater impact on Northern Hemisphere temperatures, the sea surface temperatures anomalies of the NINO3.4 region or the Kuroshio-Oyashio Extension?

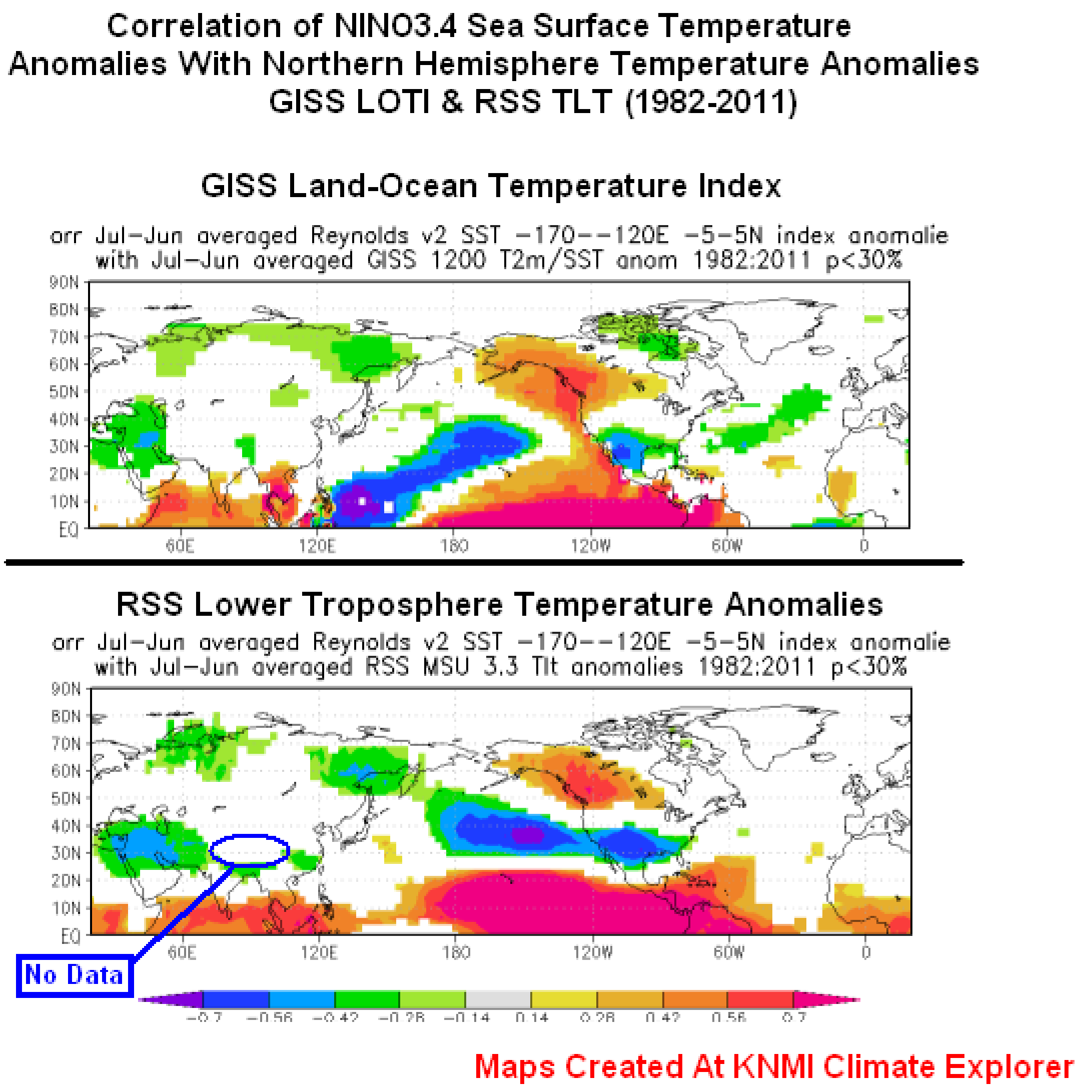

Figure 5-83

Bob Tisdale

HHH

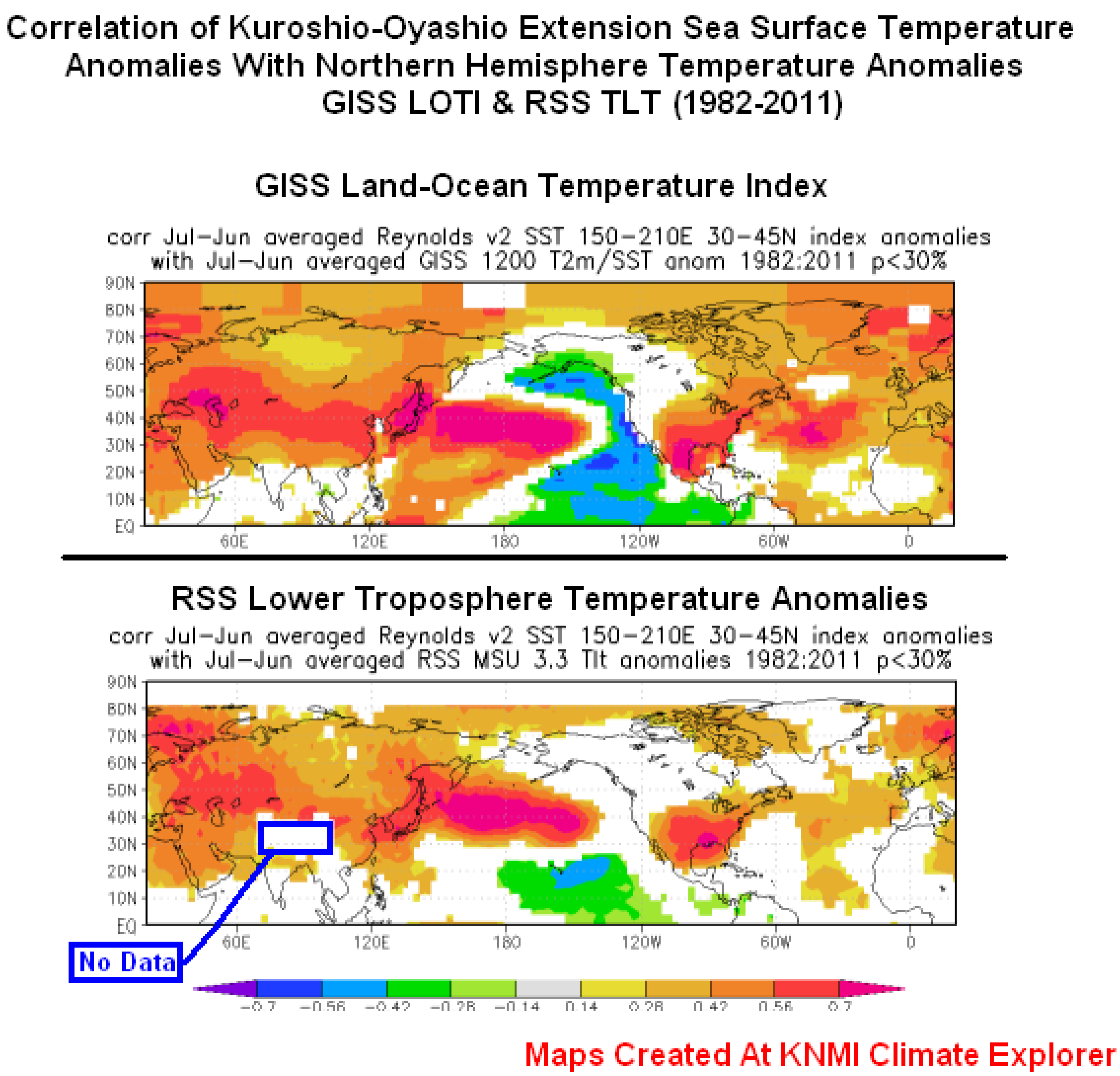

Figure 5-84 Bob Tisdale

The ENSO-caused variations in Kuroshio-Oyashio sea surface temperature anomalies, based on the correlation maps, appear to have a greater impact than NINO3.4 data on Northern Hemisphere temperature anomalies. Still, I have not been able to find any scientific studies that present the impacts of Kuroshio-Oyashio Extension sea surface temperatures on Northern Hemisphere surface or lower troposphere temperatures. If you're looking for an idea for your doctoral thesis or a scientific paper, there's one.

The sea surface temperature anomalies of the Kuroshio-Oyashio Extension contain a very strong ENSO-related signal:
--an ENSO-related signal that's more than half the strength of NINO3.4 sea surface temperature data,
--an ENSO-related signal that occurs at mid-latitudes,

--an ENSO-related signal that could offset much of the La Niña impacts on the northern hemisphere, and
--an ENSO-related signal that correlates poorly with an ENSO index because it can and does warm in collective responses to major El Niño and La Niña events.

The strong ENSO-caused variations in Kuroshio-Oyashio Extension sea surface temperature should impact the Northern Hemisphere jet streams, surface temperatures and precipitation; that is, the Kuroshio-Oyashio Extension sea surface temperatures should have teleconnections throughout the Northern Hemisphere.

For example, note the correlation of North Atlantic sea surface temperatures with the Kuroshio-Oyashio Extension data. Is this a secondary ENSO-related warming of the North Atlantic? Is it independent of the Kuroshio-Oyashio Extension? How does it impact our understanding of the Atlantic Multidecadal Oscillation?

THE IMPACT OF THE SOUTH PACIFIC CONVERGENCE ZONE EXTENSION

Warm waters that are left over from El Niño events also gather in one location in the Southern Hemisphere. For the sake of discussion, we'll call that area the South Pacific Convergence Zone Extension and give it the coordinates of 35S-20S, 160E-150W. The long-term warming trend of the South Pacific Convergence Zone Extension is about 87% of the trend for the Kuroshio-Oyashio Extension. See Figure 5-85.

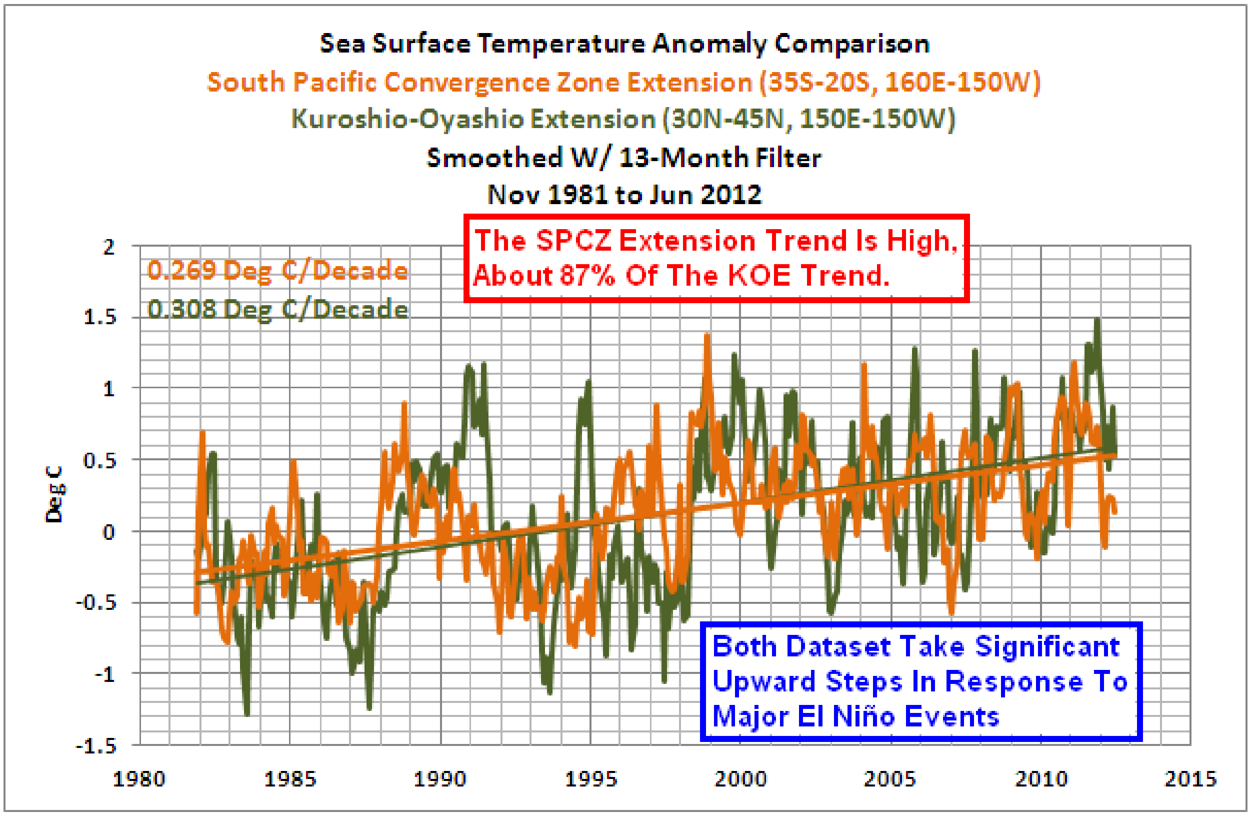

Figure 5-85

For those interested, the standard deviation of the sea surface temperature anomalies for the South Pacific Convergence Zone Extension is about 0.44 deg C, while the standard deviations of NINO3.4 and Kuroshio-Oyashio Extension data are 0.96 deg C and 0.56 deg C, respectively. In other words, the variations in the South Pacific Convergence zone are about 46% as strong as those of our ENSO index.

Like the Kuroshio-Oyashio Extension, the sea surface temperature anomalies of the South Pacific Convergence Zone Extension warm significantly during the El Niño decay and La Niña phases, but that warming is not offset by the cooling during the El Niño evolution. Refer to Figure 5-86. This is a function of the leftover warm water from El Niño events.

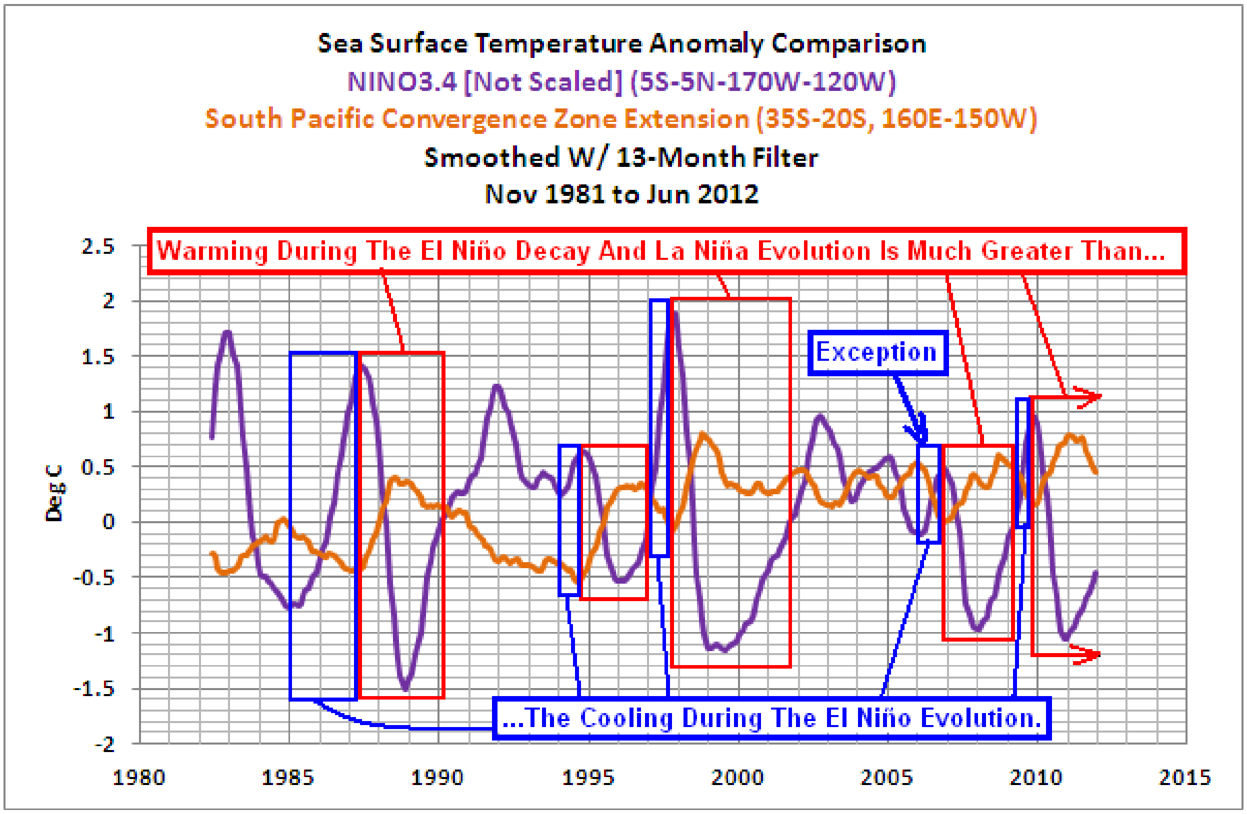

Figure 5-86 Bob Tisdale

Figure 5-87 compares the sea surface temperature anomalies of the South Pacific Convergence Zone Extension and Kuroshio-Oyashio Extension again, but this time we're smoothing the data with 13-month running-average filters. With the smoothing, more differences between the two datasets are visible. The South Pacific Convergence Zone Extension data does not have that curious early 1990s spike, and the two datasets are out of sync during the mid-1990s. The South Pacific Convergence Zone Extension data cools slightly during the evolution of the 1994/95 El Niño, then warms drastically during the 1995/96 La Niña. On the other hand, the Kuroshio-Oyashio Extension data appears to warm during the 1994/95 El Niño, but that also could be a rebound from the dip caused by the eruption of Mount Pinatubo. Also, the Kuroshio-Oyashio Extension sea surface temperatures don't warm during the 1995/96 La Niña as one would expect. Other than those differences, the two datasets do share many similar responses to ENSO.

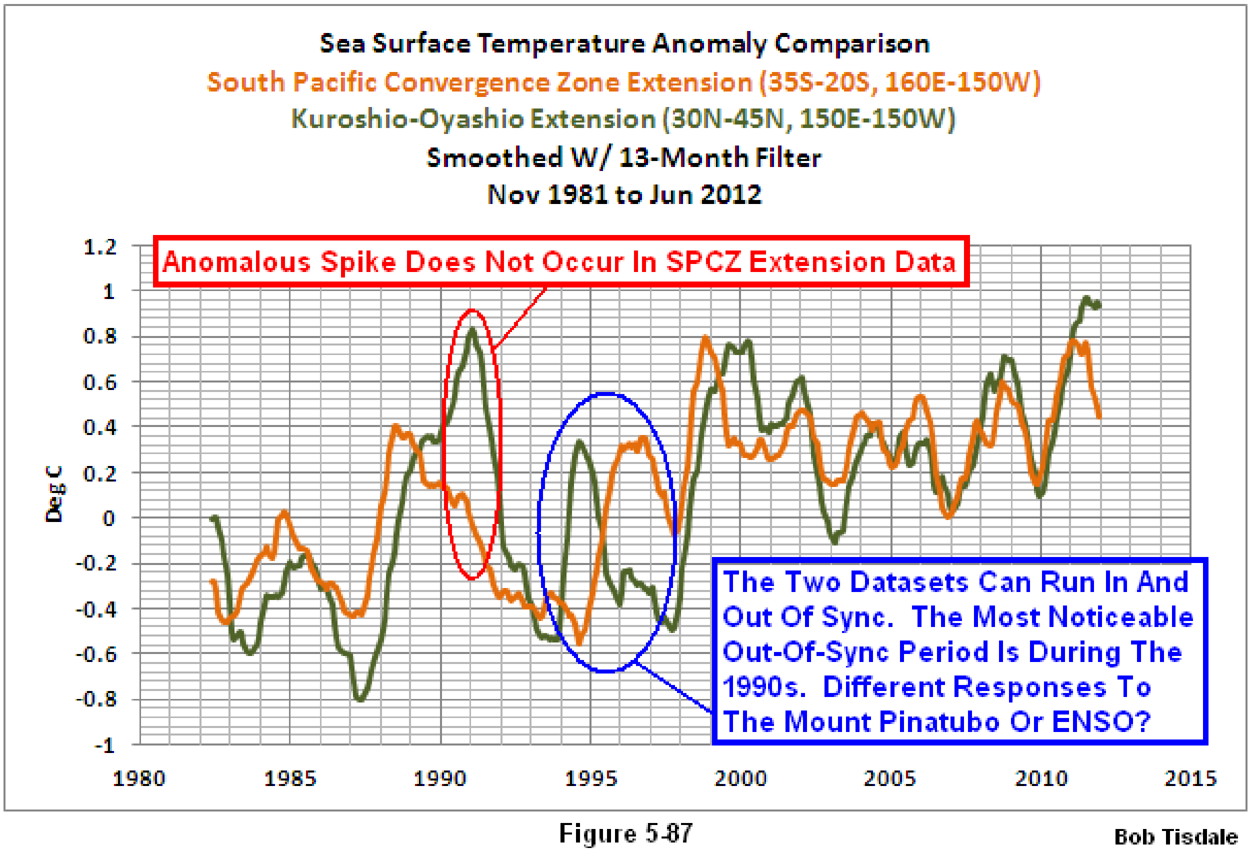

Figure 5-87

The most obvious similarities are the major upward shifts in response to the leftover warm water from the strong El Niño events. The ENSO-caused shifts will allow us to once again show how quickly the sea surface temperature anomalies for the South Pacific Convergence Zone Extension cool between the major El Niño events, Figure 5-88. Both periods show late upsurges due to lesser El Niño and La Niña events. During the period between the 1986/87/88 and 1997/98 El Niño events, there's the upsurge caused by the 1994/95 El Niño and 1995/95 La Niña. Similarly, the upward surge in response the 2006/07 El Niño and 2007/08 La Niña comes near the end of the period between the 1997/98 and 2009/10 El Niño events. Even with those late upsurges, sea surface temperatures for the South Pacific Convergence Zone Extension cool considerably between the major El Niño events.

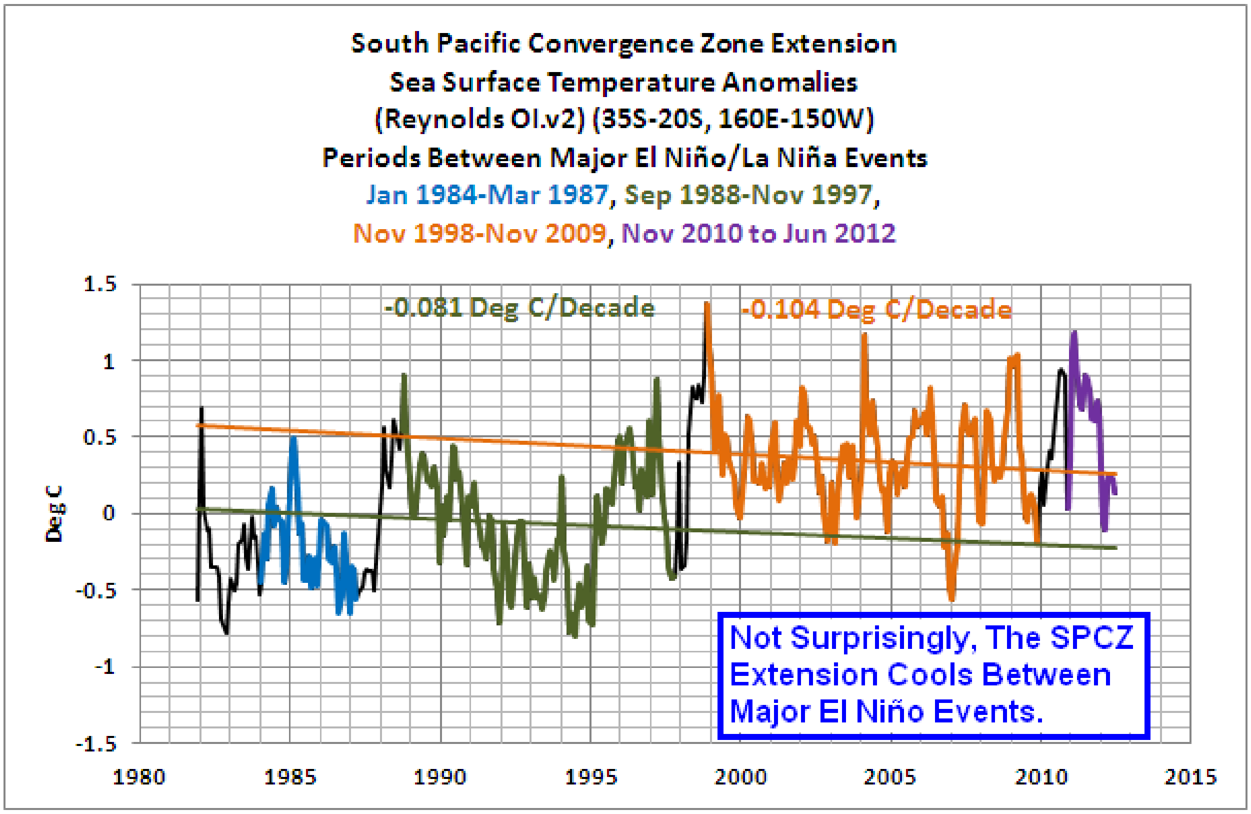

Figure 5-88 Bob Tisdale

A NOTE TO READERS: Some of you may find my repeated use of similar graphs to be unnecessary, especially these graphs that show the trends and period-average temperatures between major El Niño events. They are, however, necessary for other readers who would think I was attempting to hide something by not including them. That has happened in blog posts, and then I have to provide the graphs in the comment thread or in an update to the blog post.

Back to the discussion of the South Pacific Convergence Zone Extension:

The period-average sea surface temperature anomalies for the South Pacific Convergence Zone Extension can, like the other datasets, be used to show the magnitude of the upward shifts caused by the major El Niño events. As I've noted many times before for other datasets, because the South Pacific Convergence Zone Extension data cools between the major El Niño events, and because the warming only occurs during the El Niño events, and because the data shows a long-term warming trend, then the long-term warming has be caused by the major El Niño events.

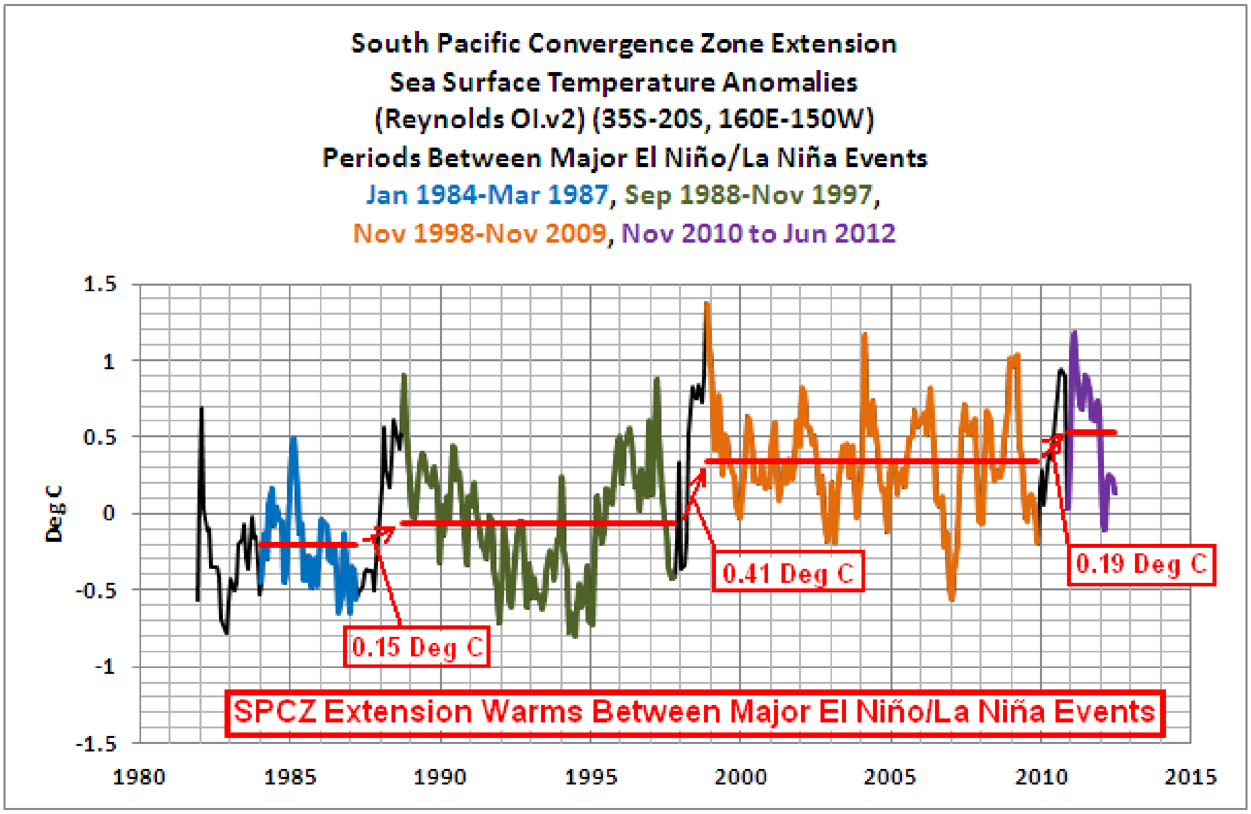

Figure 5-89

Bob Tisdale

I've borrowed Figure 5-90 from the post we discussed earlier: **Can Most Of The Rise In The Satellite-Era Surface Temperatures Be Explained Without Anthropogenic Greenhouse Gases?** It is Figure 22 in that post. GISS Land+Ocean Temperature Index data for a major portion of the globe was adjusted for the linear effects of ENSO and volcanic aerosols, then compared to the ENSO-related South Pacific Convergence Zone Extension sea surface temperature data, to see whether the secondary effects of ENSO could explain the warming of land-plus-sea surface temperatures for that major portion of the globe.

The ENSO- and volcano-adjusted GISS Land-Ocean Temperature Index data in Figure 5-90 is for the latitudes of 60S to 20N. It captures the tropics and the mid-to-high latitudes of the Southern Hemisphere (without the polar data). It's compared to the scaled sea surface temperature anomalies of the South Pacific Convergence Zone Extension. The two datasets are remarkably similar, indicating once again that the secondary effects of ENSO can likely be used to explain the long-term warming of the land-plus-sea surface temperatures of the Southern Hemisphere and Tropics.

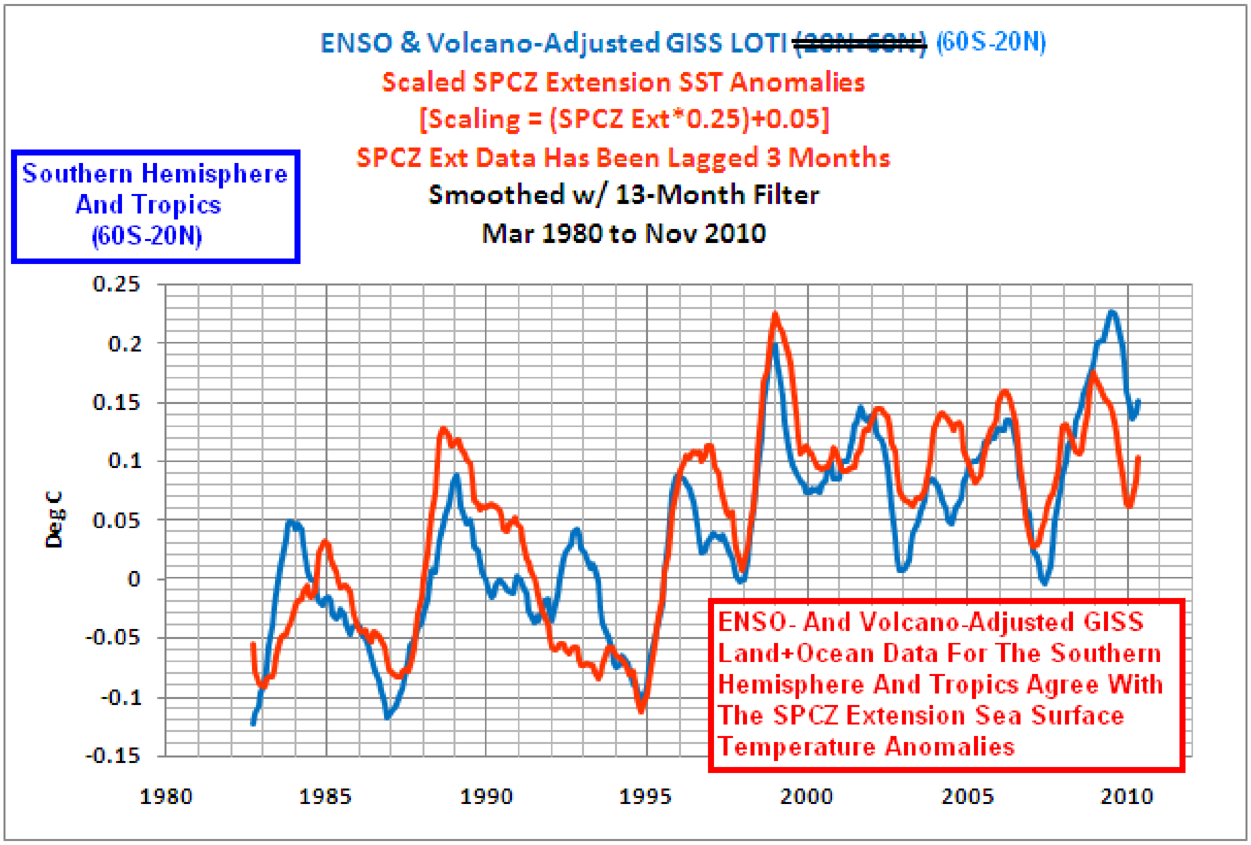

Figure 5-90

Bob Tisdale

Figure 5-91 includes two correlation maps. They are provided simply as references. The top map shows the correlation of NINO3.4 sea surface temperature anomalies with GISS Land-Ocean Temperature Index data for the Southern Hemisphere and Tropics (90S-20N). The bottom map shows the correlation of the sea surface temperature anomalies for the South Pacific Convergence Zone with the GISS land-plus-sea surface temperature data. The patterns are similar but of the opposite sign in some locations, but quite different in others, especially the tropical North Atlantic. Figure 5-92 provides the same maps using RSS Lower Troposphere Temperature Anomalies.

Curiously, the North Atlantic sea surface temperature anomalies seem to correlate with the South Pacific Convergence Zone Extension data. Keep in mind, though, the major variations in the South Pacific Convergence Zone Extension and the Kuroshio-Oyashio Extension data are very similar, especially during the major upward shifts, which are key variations in the correlation analyses because they are so large. The tropical North Atlantic is likely responding to the Kuroshio-Oyashio Extension, not the South Pacific Convergence Zone.

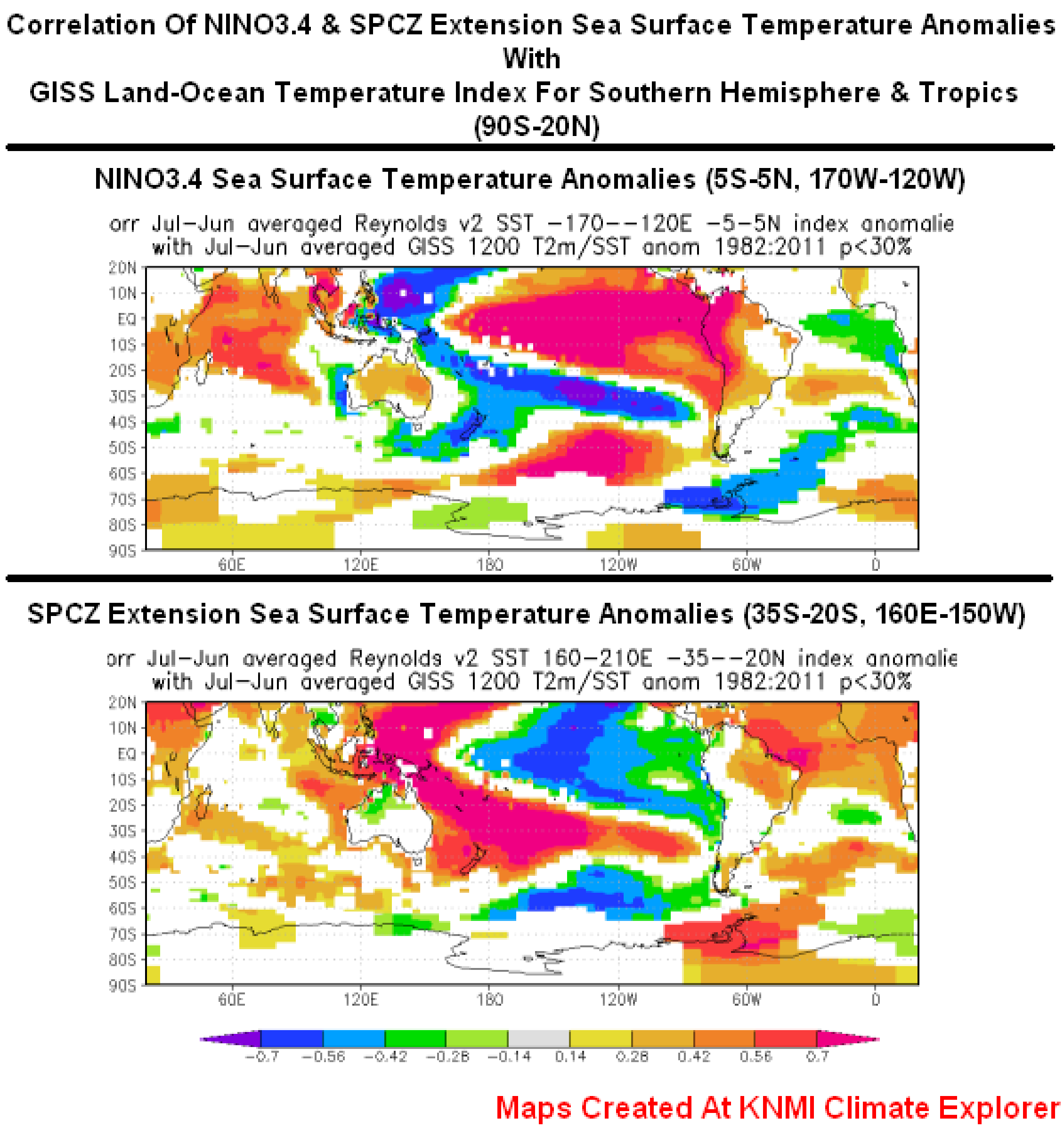

Figure 5-91 Bob Tisdale

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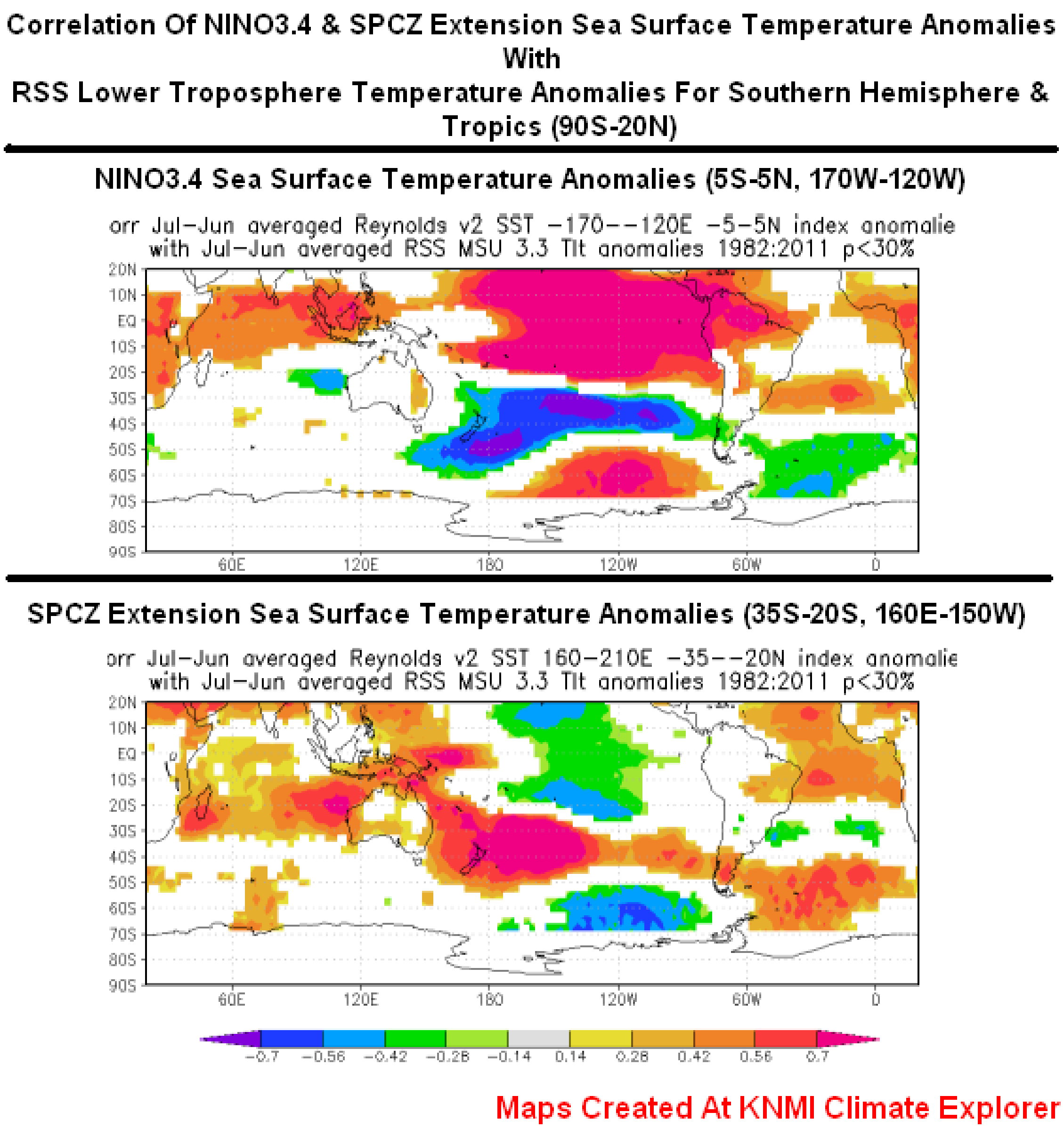

Figure 5-92 Bob Tisdale

RECAP

During the transition from El Niño to ENSO-neutral conditions, NINO3.4 sea surface temperatures cool to zero. This indicates the end of the El Niño in the central and eastern equatorial Pacific. That is, the ENSO index returning to zero only shows that the warm water released from below the surface of the west Pacific Warm Pool by the El Niño is no longer impacting the sea surface temperatures of the NINO3.4 region in the central and eastern equatorial Pacific. It does not mean the warm water that's left over from the El Niño is not directly impacting sea surface temperatures in other parts of the globe. It also does not mean that leftover warm water is not indirectly impacting sea surface and land surface temperatures elsewhere. The warm water is simply gone from the NINO3.4 region.

In this chapter, we've shown that much of the warming of global land-plus-sea surface temperatures and lower troposphere temperatures over the past 30 years can be explained by ENSO. One simply has to follow the warm leftover water to determine the secondary effects of ENSO.

The leftover warm water finds its way to the western boundary current extensions of the North and South Pacific, and those areas are called the Kuroshio-Oyashio Extension and the South Pacific Convergence Zone extension. We've shown in this chapter how the secondary ENSO-related warming of the sea surface temperatures of those regions could be used to explain the vast majority of the global warming over the past 30 years in the land-plus-sea surface temperature and lower troposphere temperature anomaly datasets.

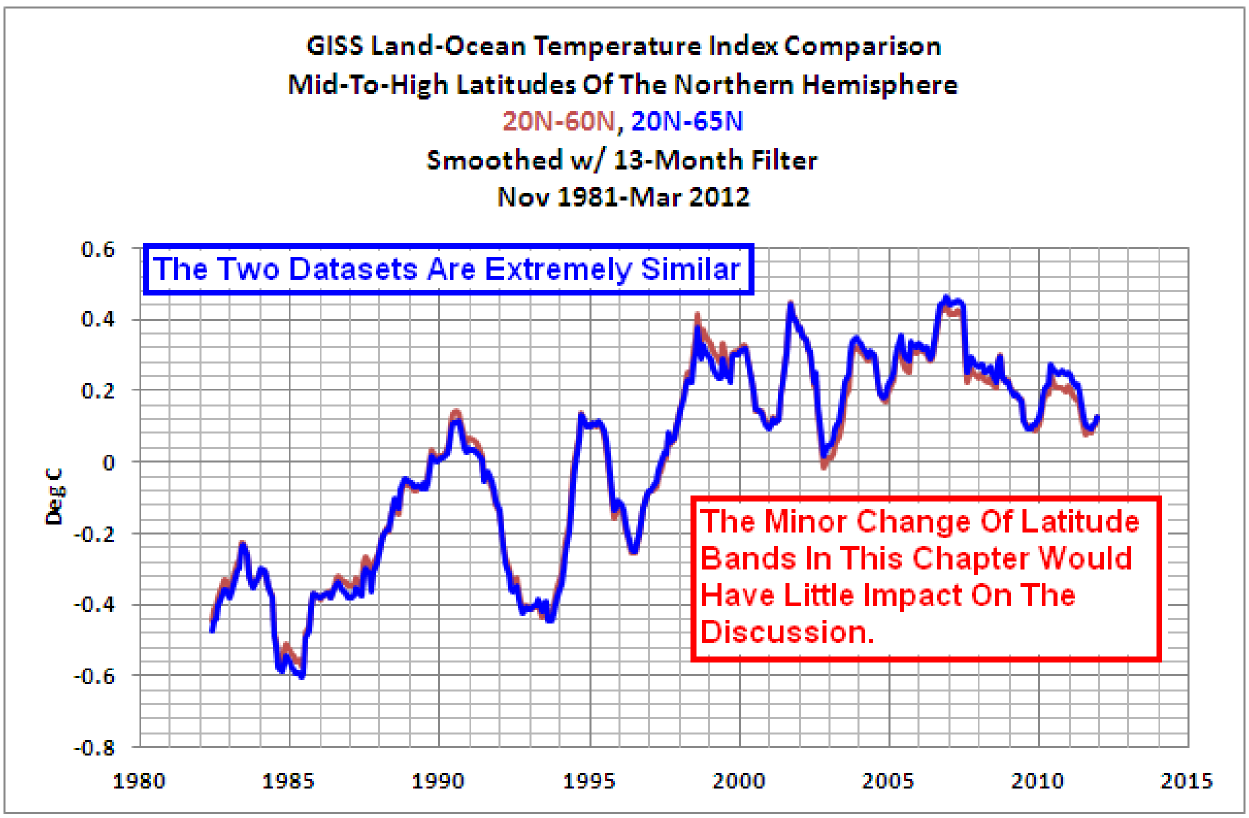

Figure 5-93 Bob Tisdale

I made a comment in this chapter that some readers may want me to confirm. I used the latitudes of 20N to 65N in the discussion of land-plus-sea surface and lower troposphere temperature anomalies, and then referred to a blog post that used the latitudes of 20N-60N. I noted that the change in latitudes would have little impact on the discussion. Figure 5-93 compares the GISS Land-

Ocean Temperature Index data for those two latitude bands. The differences are so small they would have little impact on the discussions in this chapter.

The same thing holds true for Lower Troposphere Temperature anomalies. There are a number of comparison graphs that include GISS Land-Ocean Temperature Index and RSS Lower Troposphere Temperature anomalies for the different latitude bands. The two datasets are so similar I could have used ENSO- and volcano-adjusted RSS Lower Troposphere Temperature anomalies in place of the GISS data in Figures 5-82 and 5-90 and showed similar results.

A closing note to this chapter: In the post **Can Most Of The Rise In The Satellite-Era Surface Temperatures Be Explained Without Anthropogenic Greenhouse Gases?**, which was referred to a couple of times in this chapter, we determined that about 85% of the global warming signal over the past 30 years could be accounted for with natural variables, primarily ENSO and the secondary effects of ENSO. Keep that percentage in mind. It'll come up again.

Section 6 – Discussions of and Links to ENSO-Related Animations – Two Chapters Repeated from My First Book

The two chapters in this section appeared in my first book ***If the IPCC was Selling Manmade Global Warming as a Product, Would the FTC Stop their deceptive Ads?*** Chapter 6.1 in this book was part of **Chapter 6-10 – Large Parts of the Global Oceans Warm in Response to El Niño AND La Niña Events** and Chapter 6.2 is **Chapter 6-11 – More ENSO Animations** from the first book. There are links to the animations discussed in the following chapters. The animations can also be found in the two-part blog post **1997/98 El Niño through 1998/99/00/01 La Niña Animations Part 1** and **Part 2**.

I've changed the Figure numbering and altered some of the wording. I've also added subheadings in boldface to Chapter 6.2.

6.1 Introduction to the Animation Illustrating the Warming of the East Indian-West Pacific Sea Surface Temperatures in Response to the 1997/98 El Niño AND the 1998/99/00/01 La Niña

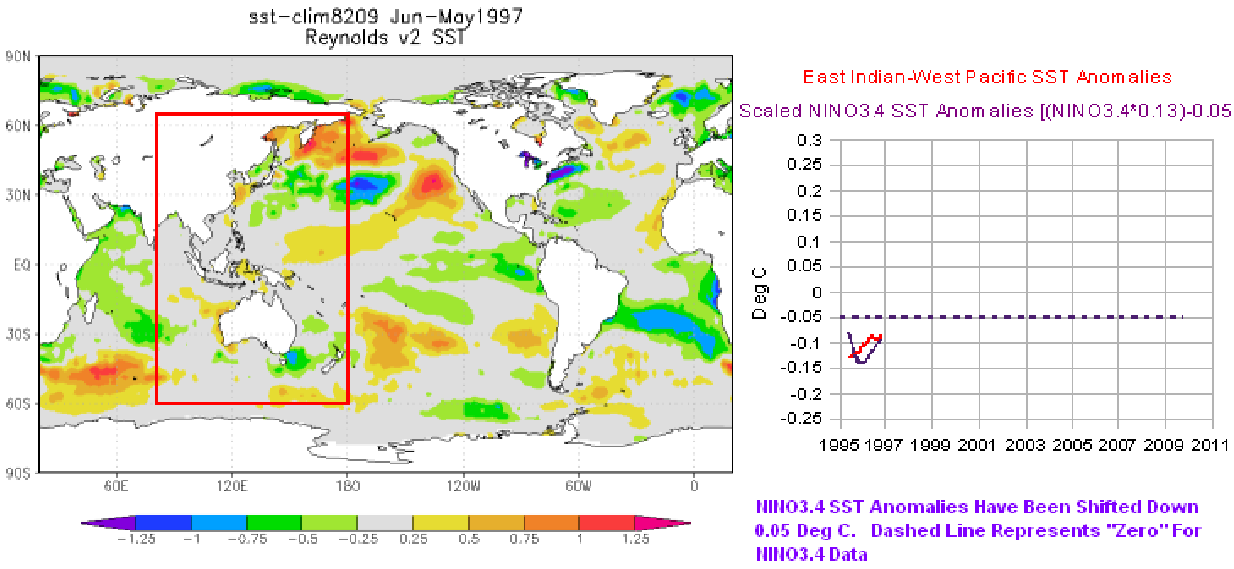

Figure 6-1

Figure 6-1 is one of the cells from the animation linked at the end of this chapter. The animation illustrates the variations in global sea surface temperature anomalies before, during and after the 1997/98 El Niño and continues through the 1998/99/00/01 La Niña. The East Indian and West Pacific Oceans (60S-65N, 80E-180) are initially highlighted with a red box. The maps were created at the KNMI Climate Explorer, using Reynolds OI.v2 satellite-based sea surface temperature data. The animation also includes a graph that compares East Indian-West Pacific Ocean sea surface temperature anomalies and scaled NINO3.4 sea surface temperature anomalies. The NINO3.4 data (our ENSO index) has been scaled by a factor of 0.13 and it has also been shifted down 0.05 deg C to better align the two datasets at the beginning of the animation. The base years for anomalies are 1982 to 2009. The data in the graph has been smoothed with a 12-month running-average filter to reduce the noise and minimize any seasonal component in the East Indian-West Pacific data. The 12-month data filter also aligns it with the map, because each map represents a 12-month average of sea surface temperature anomalies. Using the 12-month averages in the maps has the same effect as smoothing data in a graph: it reduces the weather noise and reduces any seasonal component. In the animation, the June 1996 to May 1997 map is followed by a map that shows the average for the next 12-month period, July 1996 to June 1997. The animation continues on in sequence until the final map that shows the average sea surface temperature anomalies for the period of August 2001 to July 2002. The animation can also be found in the blog post **1997/98 El Niño through 1998/99/00/01 La Niña Animations Part 1**. There it's listed as Animation1.

The animation starts toward the end of the 1995/96 La Niña. Sea surface temperature anomalies in the eastern tropical Pacific are still showing some remnants of that La Niña. There are a couple of warm and cool spots in the North Pacific, with the coolest spot just east of the boundary of the East Indian-West Pacific data. The area east of Japan out to that cool spot is called the Kuroshio-Oyashio Extension or KOE.

Figure 6-2 illustrates the map and graph six months later. It shows the average sea surface temperature anomalies for the period of December 1996 to November 1997. The El Niño is underway but nowhere near its peak, and the East Indian-West Pacific sea surface data have cooled a little in response. However, that's a far as they will cool.

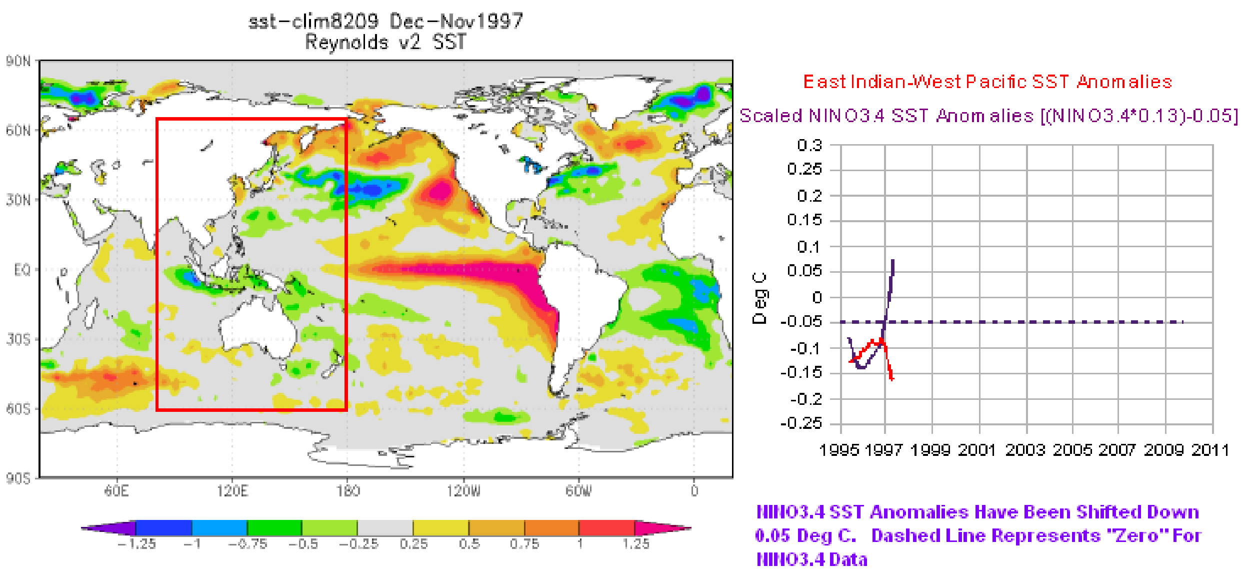

Figure 6-2

Bob Tisdale

Six months after that the El Niño reaches its peak. See Figure 6-3. By that time, the El Niño-caused changes in atmospheric circulation have worked their way around the globe and have begun to warm the East Indian-West Pacific Oceans.

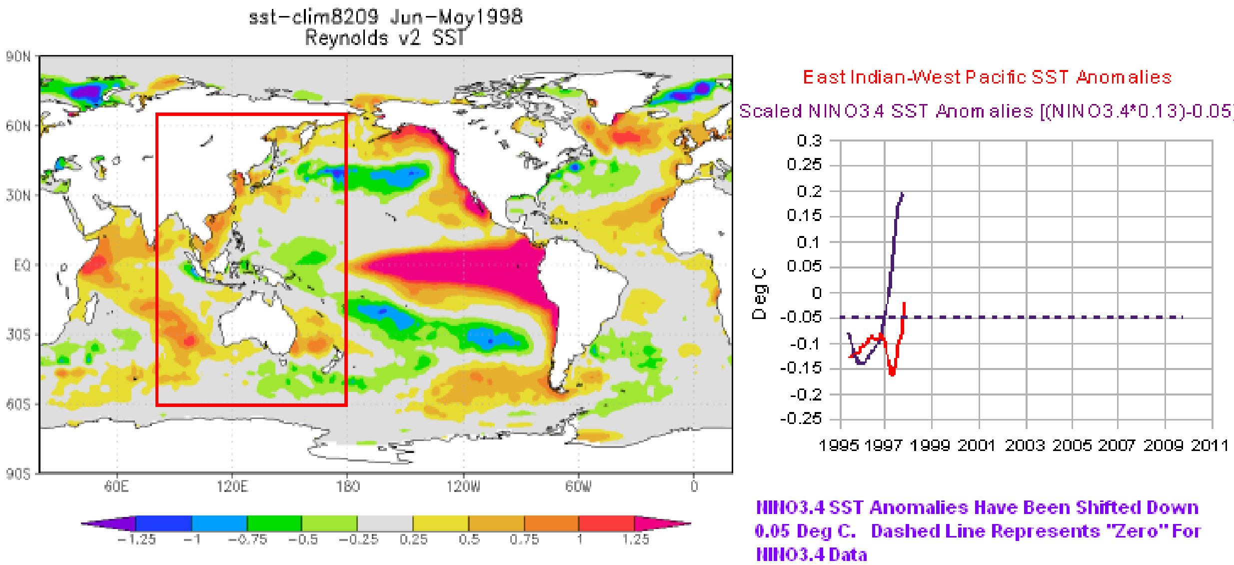

Figure 6-3

Bob Tisdale

In eight more months, Figure 6-4, the East Indian-West Pacific sea surface temperature anomalies have reached their peak in response to the 1997/98 El Niño. By that time, the La Niña is already underway. That means some of the warm surface waters from the eastern Pacific have been returned to the west, the Rossby wave has arrived in the western Pacific, cloud cover over the tropical Pacific has decreased and the trade winds are pushing the La Niña-created sun-warmed water into the West Pacific. All four of the factors contributed to the peak warming of the East Indian-West Pacific data.

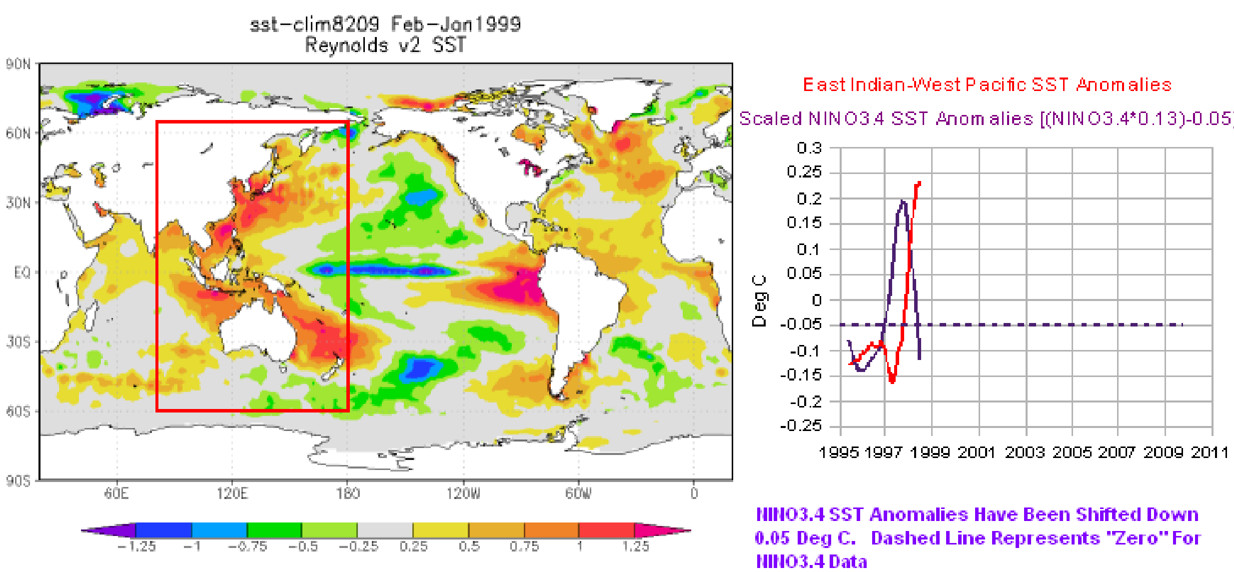

Figure 6-4

Bob Tisdale

The NINO3.4 sea surface temperature anomalies reach their low point for the 1998/99 portion of the multiyear La Niña in another six months. See Figure 6-

5. Notice how the East Indian-West Pacific sea surface temperature data begins to respond to the La Niña-caused changes in atmospheric circulation that have worked their way eastward around the globe from the central equatorial Pacific. That decrease is being opposed by the La Niña pushing the extra sun-warmed waters into the western Pacific.

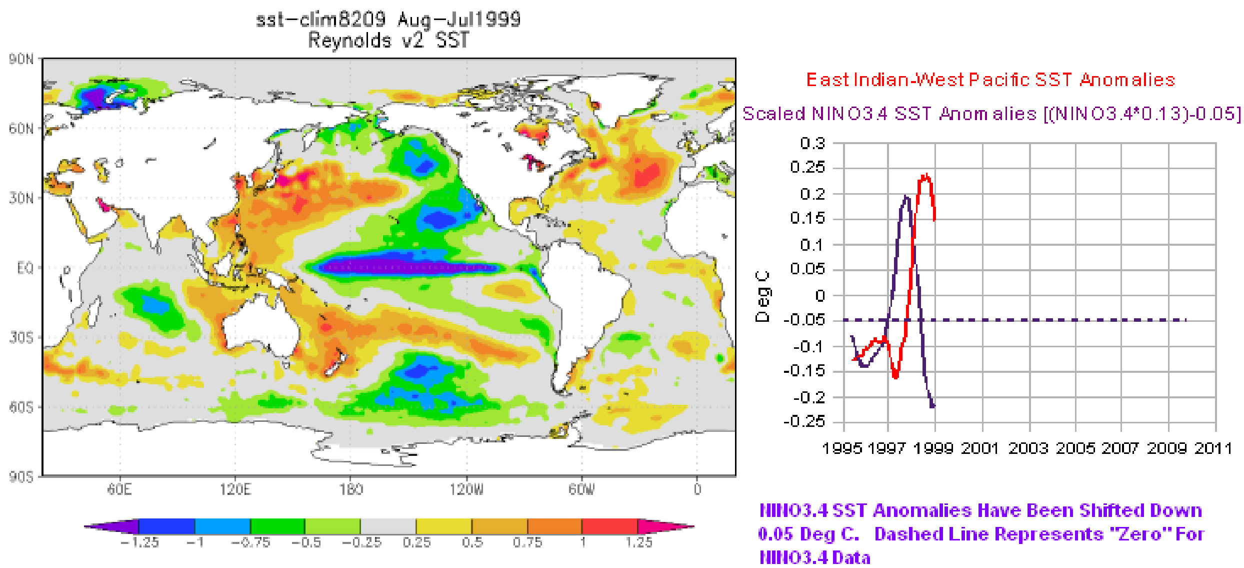

Figure 6-5

Bob Tisdale

A year passes. Refer Figure 6-6. NINO3.4 sea surface temperatures haven't changed much, they are still cool, and in that time, the East Indian-West Pacific data have reached their low point for the 1998/99/00/01 La Niña. Notice, however, how the warm water has gathered in the area east of Japan called the Kuroshio-Oyashio extension or KOE. That area is providing a secondary release of heat, during the La Niña, more than two years after the peak of the 1997/98 El Niño. Whether or not there is still any residual warm water leftover from the El Niño at that point would be difficult to determine. Nonetheless, that secondary release of heat in the Kuroshio-Oyashio extension was initiated by the 1997/98 El Niño.

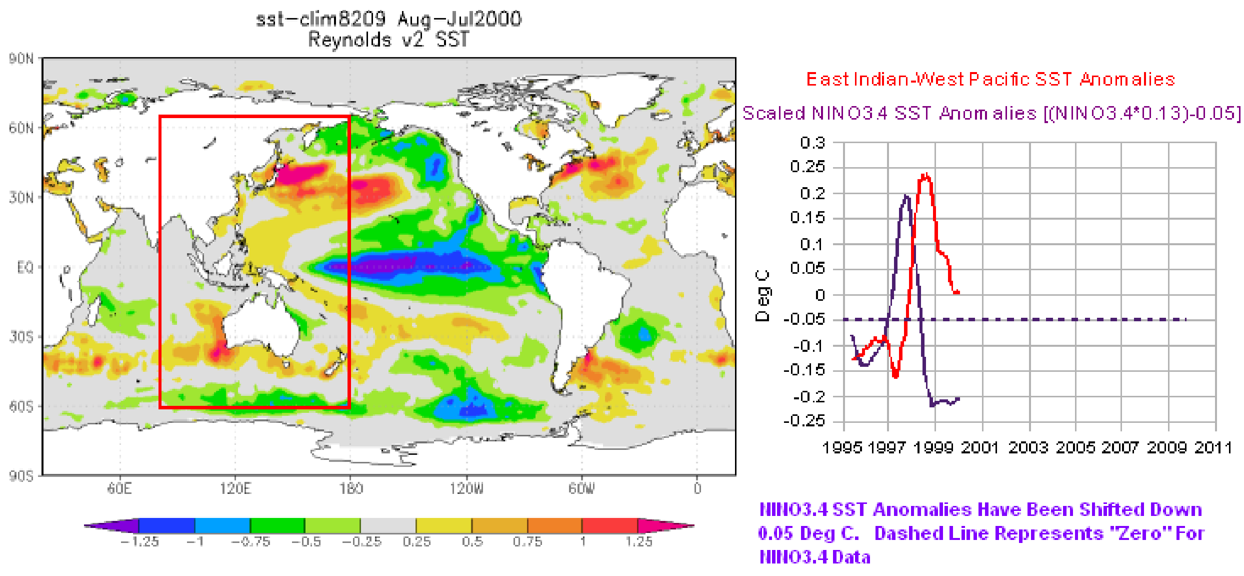

Figure 6-6

The last cell from the animation to be discussed, Figure 6-7, is for the period of November 2000 to October 2001. NINO3.4 sea surface temperature anomalies have returned to approximately the same value they were at in the first cell, Figure 6-1. However, the East Indian-West Pacific sea surface temperature anomalies are now almost 0.2 deg C warmer. They warmed in response to the 1997/98 El Niño **AND** the 1998/99/00/01 La Niña.

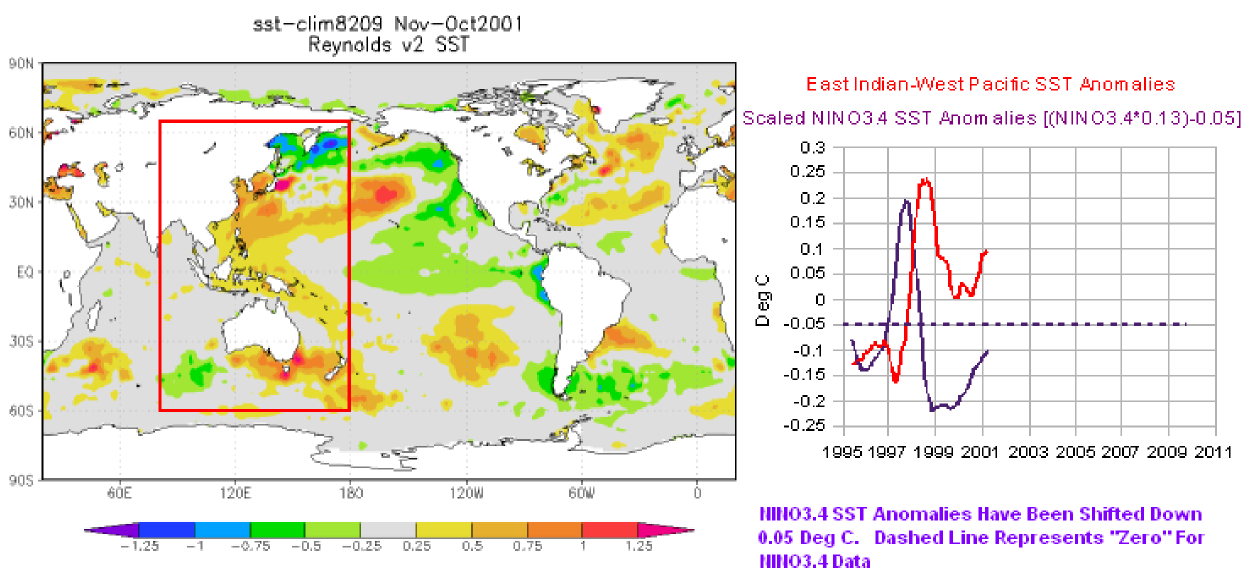

Figure 6-7

Animation 6-1 shows the impact of the 1997/98 El Niño and the 1998/99/00/01 La Niña on the sea surface temperature anomalies of the East Indian and West Pacific Oceans. The East Indian-West Pacific sea surface temperature anomaly data in the graph are for the coordinates of 60S-65N, 80E-180. As a reminder, as illustrated in Figure 5-20, the East Indian-West Pacific data is the primary source of the variations in the South Atlantic-Indian-West Pacific data. This was discussed in **Chapter 5.5 The ENSO-Caused Upward Shifts Still Exist if We Add the South Atlantic and West Indian Sea Surface Temperature Data to the East Indian and West Pacific**, and as you'll recall, the South Atlantic-Indian-West Pacific dataset represents more than half of the surface area of the global oceans.

6.2 – More ENSO Animations

The animations in this chapter are intended to help the reader visualize the interaction between tropical Pacific sea surface temperature anomalies and a number of other variables. They can also be found in the two-part blog post **1997/98 El Niño through 1998/99/00/01 La Niña Animations Part 1** and **Part 2**.

Each of the first five animations linked in this chapter use Animation 6-1 as its base. They have the same sea surface temperature maps and graphs. The animations present all of the data the same way, with cells representing 12-month averages, and they cover the same period of June 1996-May 1997 through August 2001-July 2002. For these animations, however, a second set of animated maps are added below the sea surface temperature maps and those new sets present:

Animation 6-2: Total cloud amount anomalies
Animation 6-3: Precipitation anomalies
Animation 6-4: Sea level anomalies
Animation 6-5: Pacific Ocean sea surface temperatures (not anomalies)
Animation 6-6: Lower troposphere temperature (TLT) anomalies

The base years for anomalies for the sea surface temperature data are 1982 to 2009. That was the full term of the data when I created these animations. The base years for the secondary datasets will be different, because they also use the full term for those datasets as they were available at the KNMI Climate Explorer.

There are two additional animations. They show the impacts of ENSO on the North Atlantic sea surface temperature anomalies. The sea surface temperature anomaly maps in Animation 6-7 are the same as Animation 6-1, but the graph includes North Atlantic sea surface temperature anomaly data, for the coordinates of 0-70N, 80W-0. Animation 6-8 presents only maps of the North Atlantic, with the infilling graph to mark the timing of the El Niño and La Niña events.

Animation 6-2: Total Cloud Amount Anomalies

Figure 6-8 shows a cell from Animation 6-2, which compares sea surface temperature anomalies to total cloud amount anomalies. The total cloud amount anomalies are based on the **ISCCP** Cloud Amount data. ISCCP stands for International Satellite Cloud Climatology Project. Note the inverted funnel shape over the Indian Ocean in the cloud amount data (lower map). That's from a satellite blind spot in early years that impacts the anomalies. Because our focal point is the tropical Pacific, that problem in the Indian Ocean data is not a concern. To view the animation, click **here**.

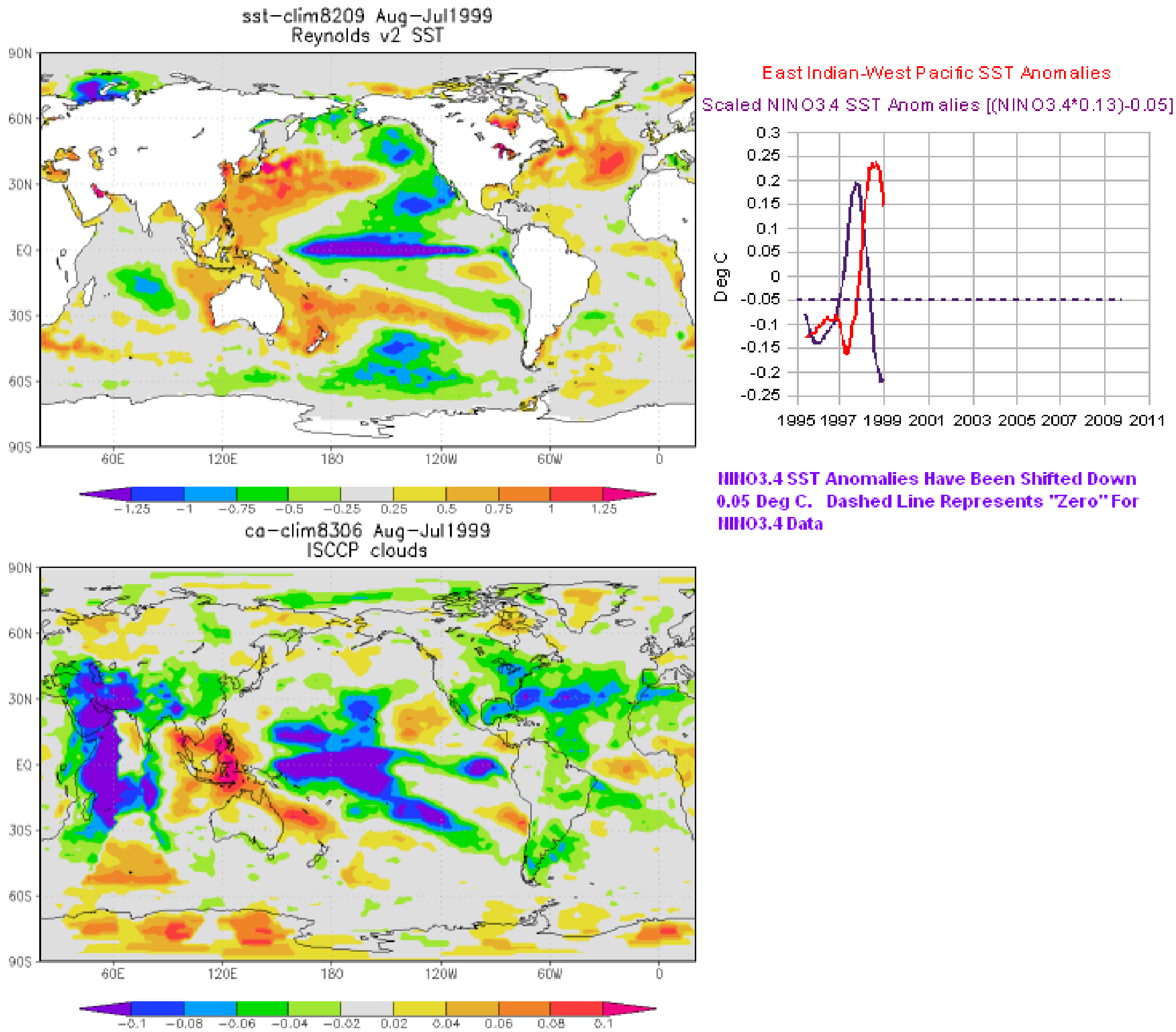

Figure 6-8

HHH

Animation 6-3: Precipitation anomalies

Animation 6-3 presents sea surface temperature anomalies with **Climate Anomaly Monitoring System (CAMS) – OLR Precipitation Index (OPI)** (CAMS-OPI) precipitation anomalies. Figure 6-9 is a sample cell. To view the animation, click **here**.

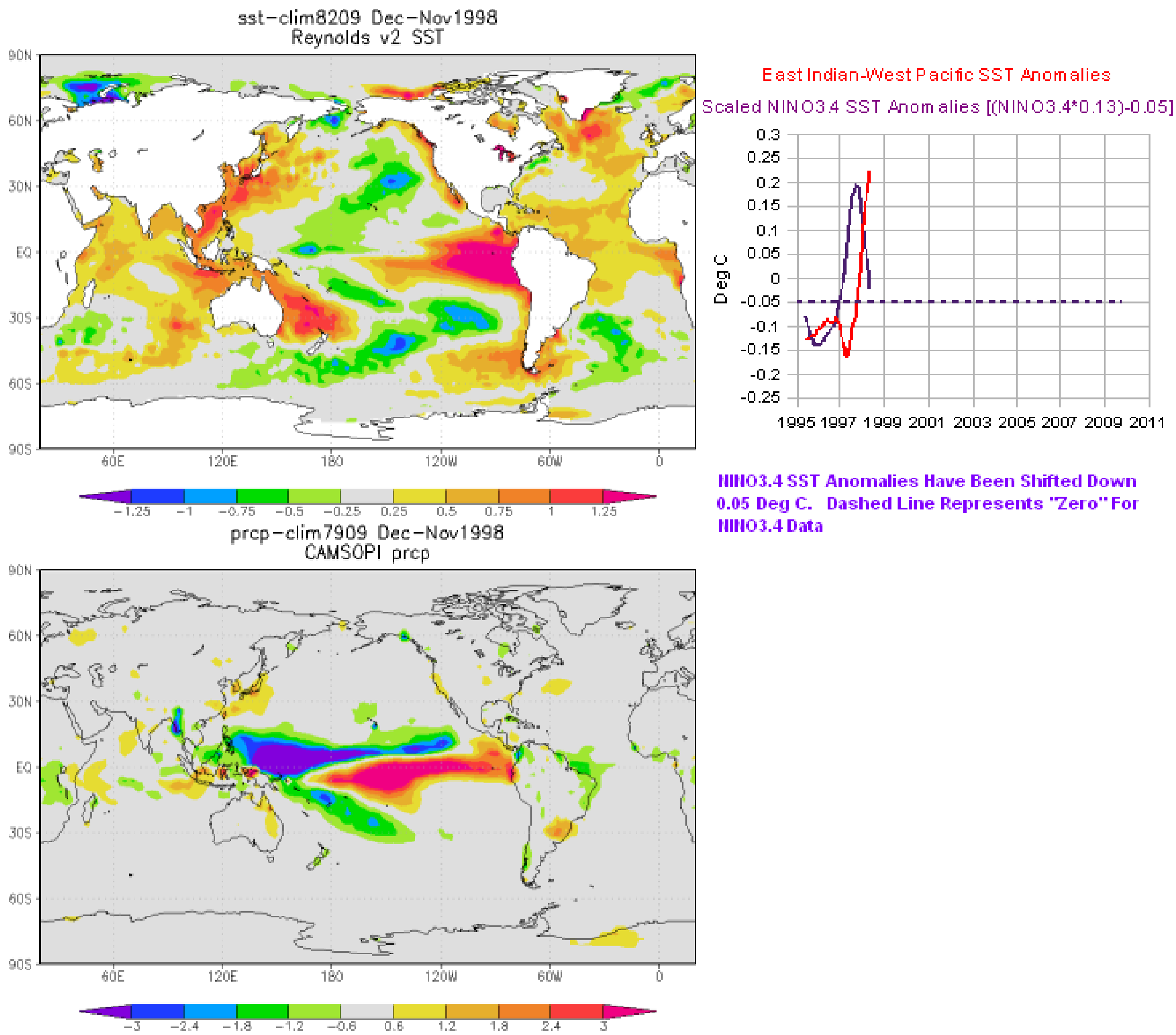

Figure 6-9

Bob Tisdale

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Animation 6-4: Sea level anomalies

Figure 6-10 is a sample cell from Animation 6-4 which compares Reynolds OI.v2 sea surface temperature anomalies to an early version of the **AVISO CLS** sea level anomaly data. Note that the sea level anomaly map in Figure 6-10 captures the formation of the warm (downwelling) Rossby wave at the end of the 1997/98 El Niño. Click **here** to view Animation 6-4.

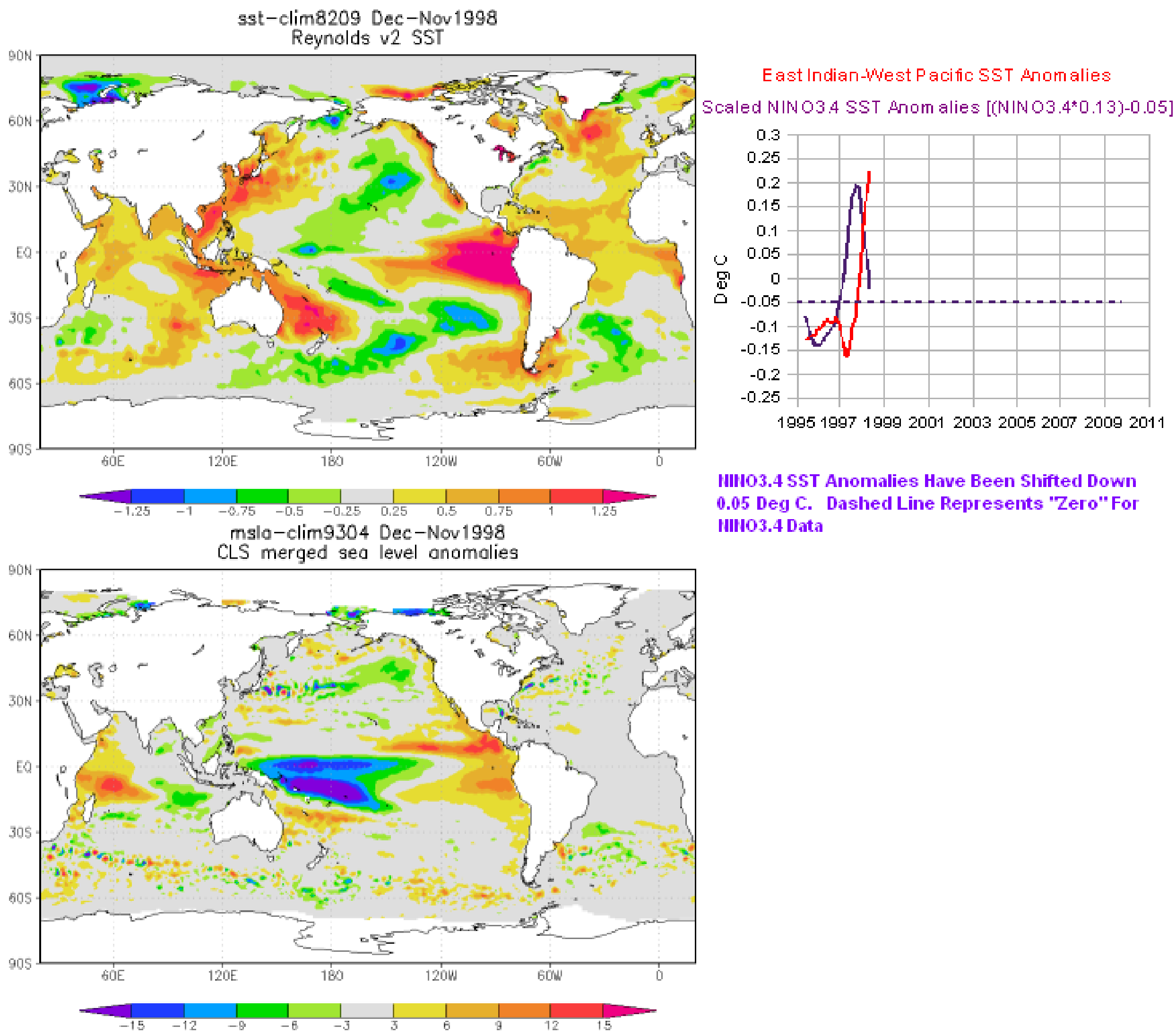

Figure 6-10

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Animation 6-5: Pacific Ocean sea surface temperatures (not anomalies)

Sea surface temperature anomalies are compared to Pacific Ocean sea surface temperatures (not anomalies) in Animation 6-5. Figure 6-11 is a sample cell. To view the animation, click **here**.

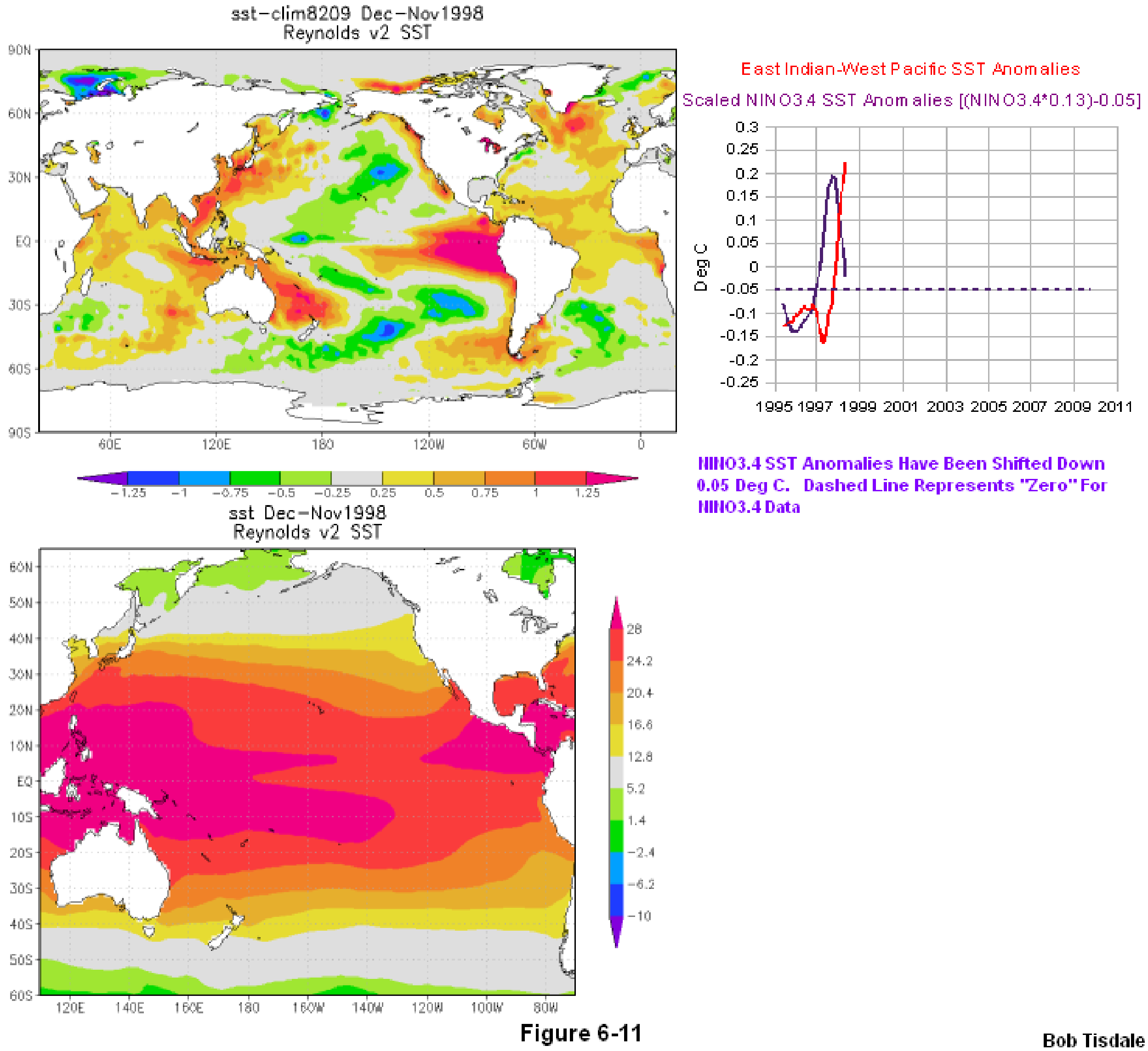

Figure 6-11

HHH

Animation 6-6: Lower troposphere temperature (TLT) anomalies

Figure 6-12 is a sample cell from the last of the comparison animations. Animation 6-6 presents sea surface temperature anomalies versus Remote Sensing Systems (**RSS**) lower troposphere temperature (TLT) anomalies. It's one of my favorite animations. Note how long it takes for the lower troposphere temperature anomalies in the eastern tropical to respond to the warming of the sea surface temperature anomalies and how different the spatial patterns are. Click **here** to view animation 6-6.

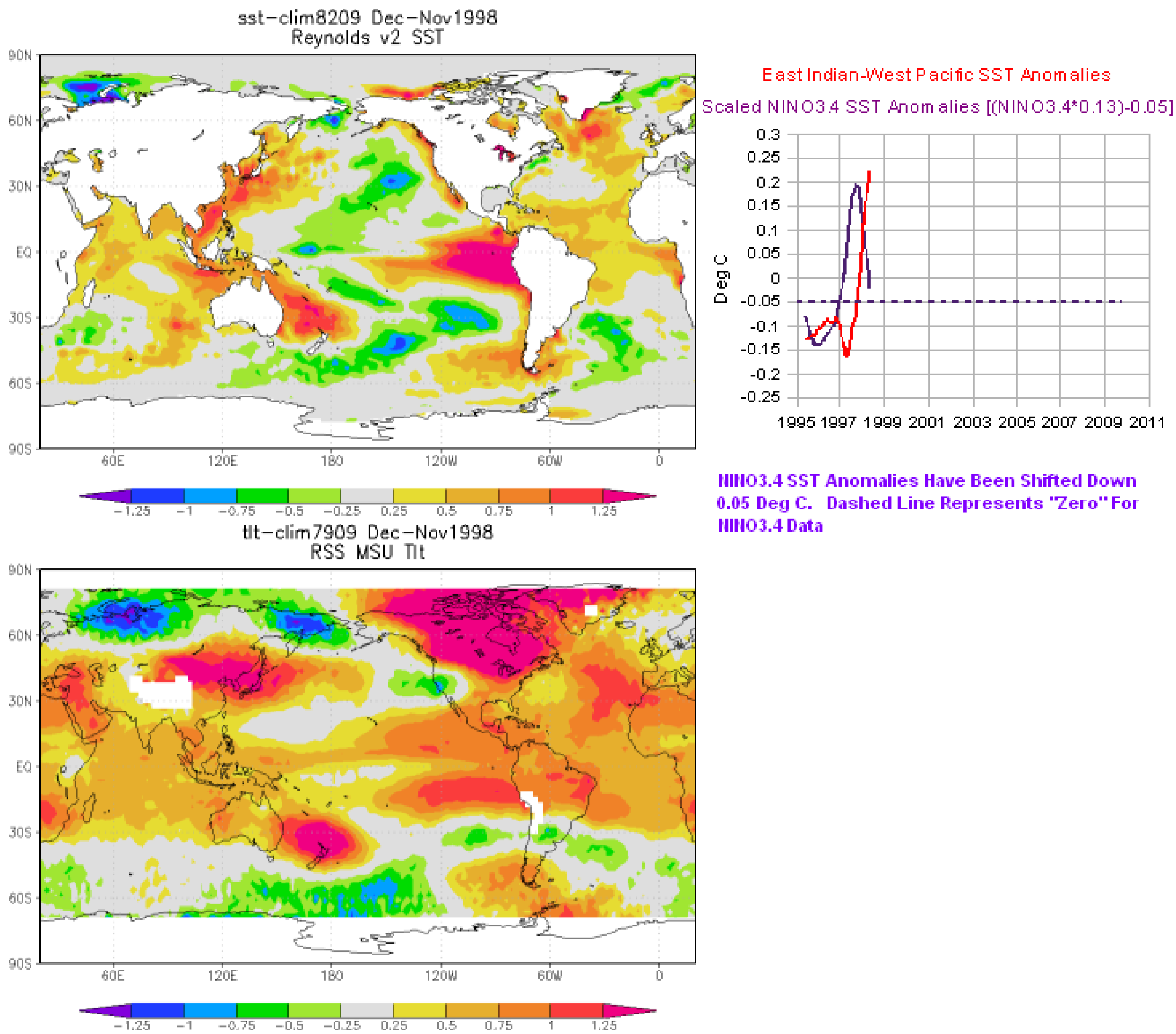

Figure 6-12

Bob Tisdale

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Animation 6-7: Global with North Atlantic Graph

The first of the North Atlantic sea surface temperature animations is Animation 6-7. A sample cell is shown in Figure 6-13. With the exception of the graph and the opening few cells which highlight the location of the North Atlantic data, the maps are the same as Animation 6-1. **The graph is different**. It includes North Atlantic sea surface temperature anomaly data for the coordinates of 0-70N, 80W-0. To view the animation, click **here**.

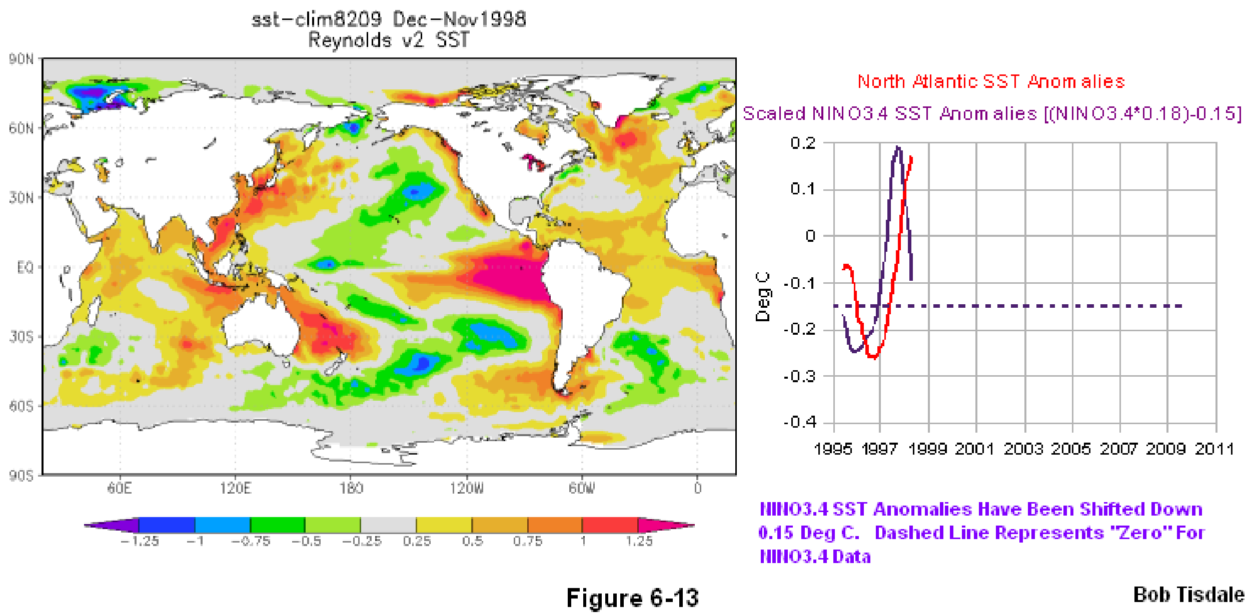

Figure 6-13

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Animation 6-8: North Atlantic and Corresponding Graph

Animation 6-8 presents only maps of the North Atlantic. See the sample cell in Figure 6-14. Click **here** to view Animation 6-8.

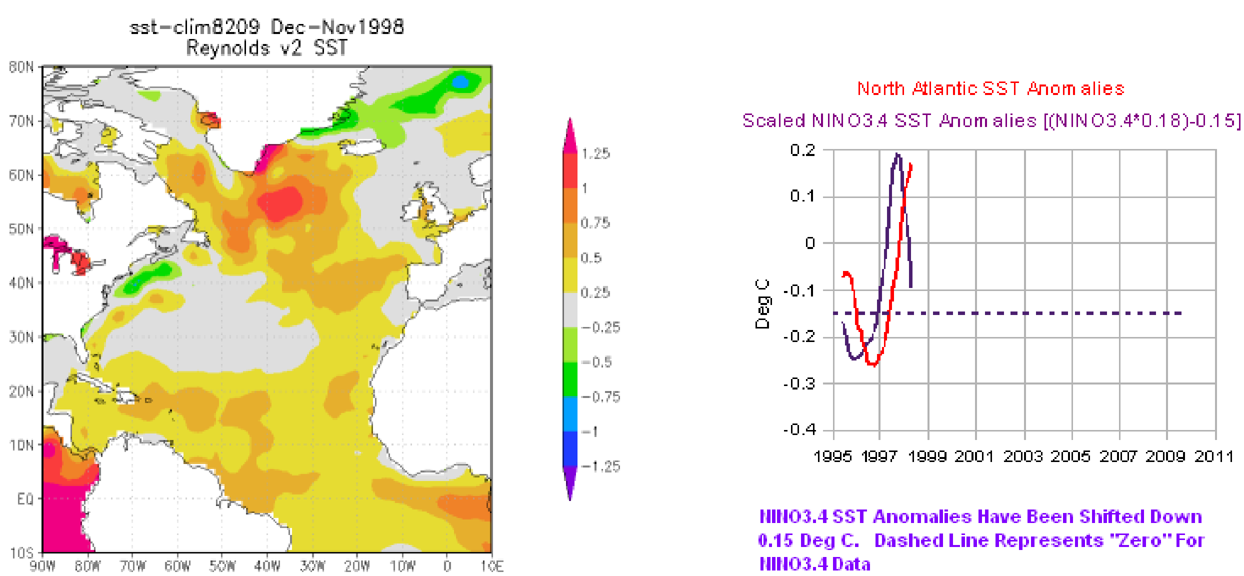

Figure 6-14

Section 7 –Common ENSO-Related Myths and Failed Arguments Against ENSO as the Primary Contributor To Global Warming

The following is a list of the chapter titles in this section. They are ENSO myths and failed arguments that have been presented by proponents of anthropogenic global warming to dispute the long-term effects of major ENSO events. As you'll note, some of the arguments appear very similar, but my responses to them will be different.

7.13 Old Failed Argument – But the Arctic Sea Ice is Melting. Isn't that Proof of Anthropogenic Global Warming? (Typical Example of the Debate Tactic Called Redirection)

7.1 Myth - ENSO Has No Trend and Cannot Contribute to Long-Term Warming

We've discussed and illustrated in Section 5 of this book how ENSO has been responsible for the warming of global sea surface temperatures over the past 30 years. In fact, the intent of this book was to provide the reader with a strong enough background in ENSO to understand why this myth is wrong. Regardless, let's examine this myth a little closer and see what else we can learn from it.

The "ENSO has No Trend" part of this myth depends on the dataset. That is, since 1900, some sea surface temperature-based ENSO indices show long-term trends, warming and cooling; another is flat. Let's look at NINO3.4 sea surface temperature anomalies using a number of different datasets. We'll start with ERSST.v3b and Kaplan, both from NOAA, and HADISST from the Hadley Centre. Refer to Figure 7-1. NINO3.4 sea surface temperature anomalies for the ERSST.v3b, Kaplan, and HADISST datasets are available through the KNMI Climate Explorer Monthly Climate Indices webpage. The ERSST.v3b version of NINO3.4 sea surface temperatures has a significant warming trend, while the Kaplan version of NINO3.4 data shows significant cooling. The HADISST-based NINO3.4 data since 1900 has a slightly negative trend, but it's basically flat.

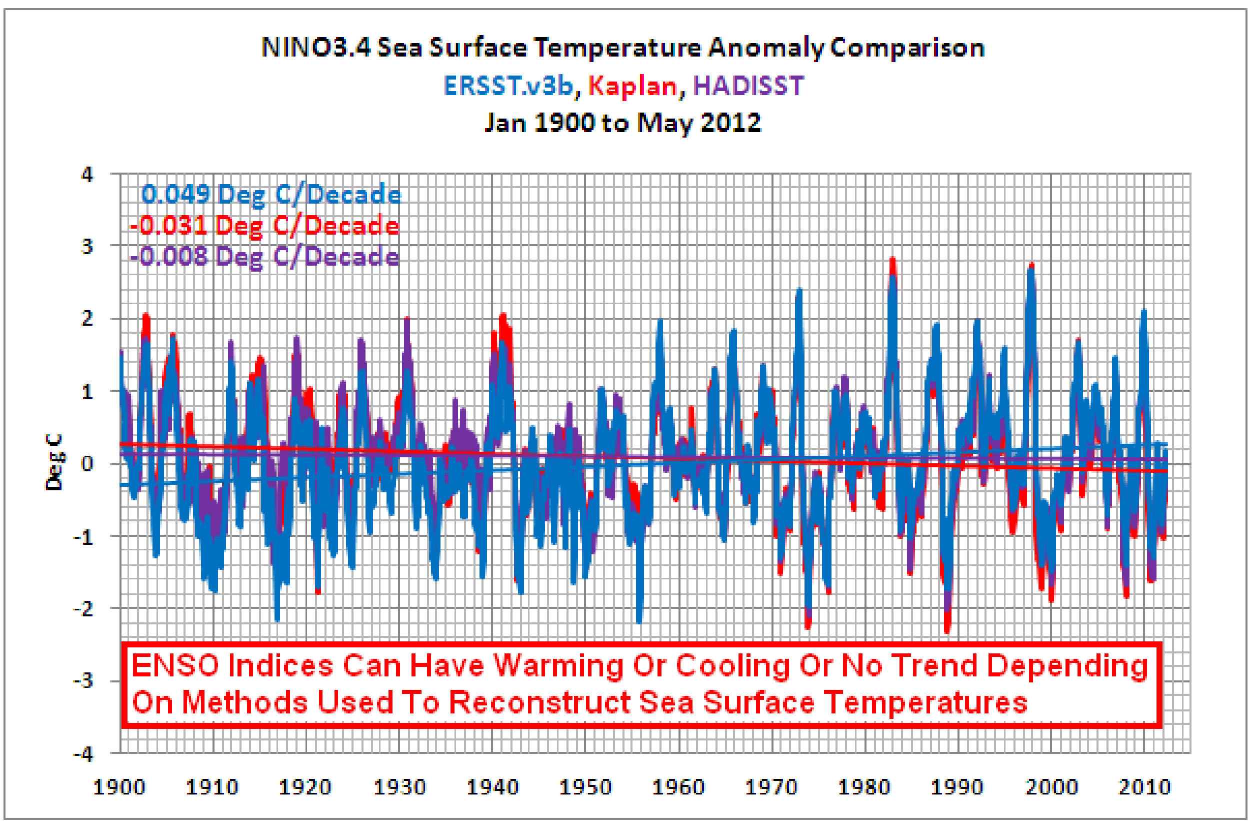

Figure 7-1

Bob Tisdale

Figure 7-2 presents the average of the ERSST.v3b, HADISST and Kaplan versions of NINO3.4 sea surface temperature anomalies. The linear trend of 0.003 deg C per decade is basically flat.

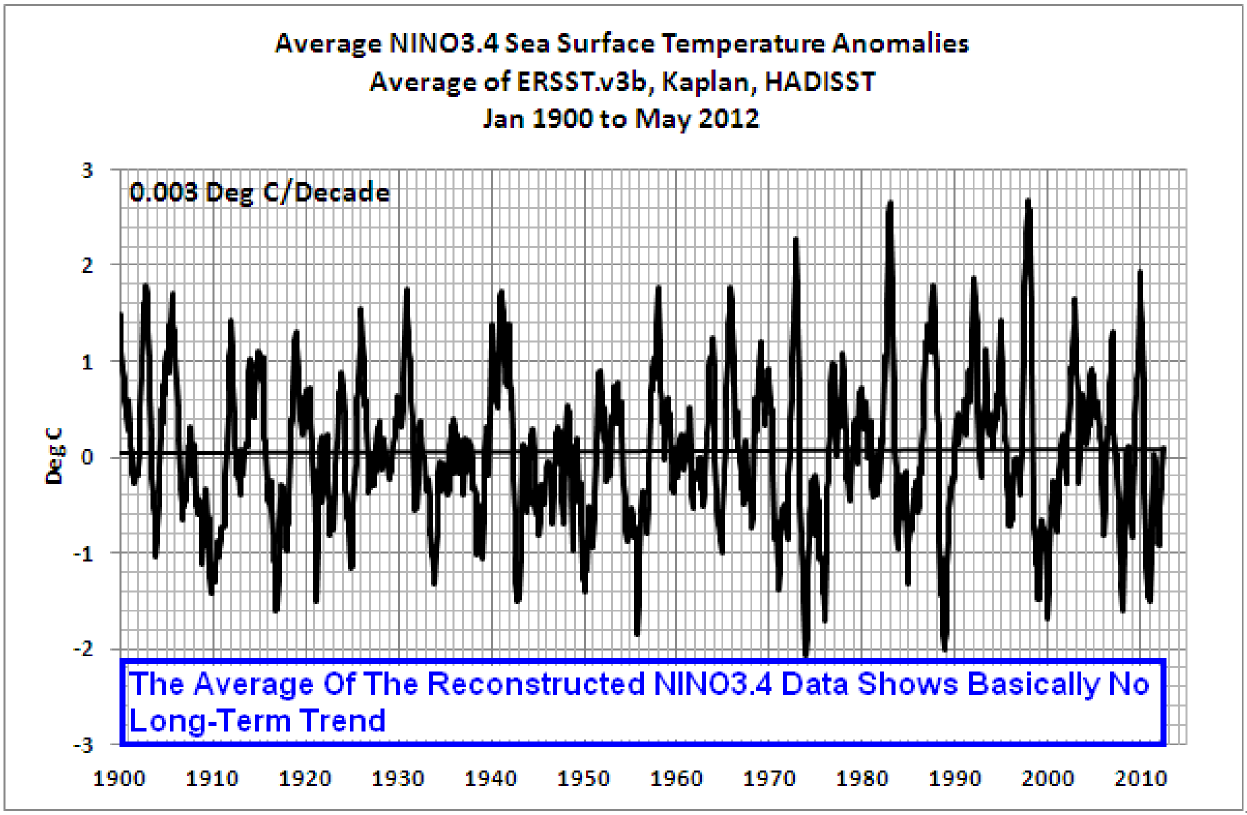

Figure 7-2

Bob Tisdale

HADSST2 and HADSST3 are also available at the Climate Explorer, but their data for the NINO3.4 region are so sparse at times that there are large gaps, with many missing months. Fortunately, a recent climate paper presented an ENSO index based on HADSST2 sea surface temperature anomalies. The paper was Thompson et al (2009) **Identifying signatures of natural climate variability in time series of global-mean surface temperature: Methodology and Insights.** We'll discuss this paper again in another myth. Thompson et al (2009) were kind enough to provide data along with their paper. The instructions for use and links to the data are **here.** Thompson et al (2009) used the sea surface temperature anomalies for Cold Tongue Index region instead of the more commonly used NINO3.4 region. There are very slight differences between the two datasets. Thompson et al also scaled the data so that they could subtract it from global surface temperatures. We'll standardize it so the dataset doesn't look so odd, Figure 7-3. The trend clearly shows cooling. That's even steeper than the cooling trend in the Kaplan NINO3.4 data.

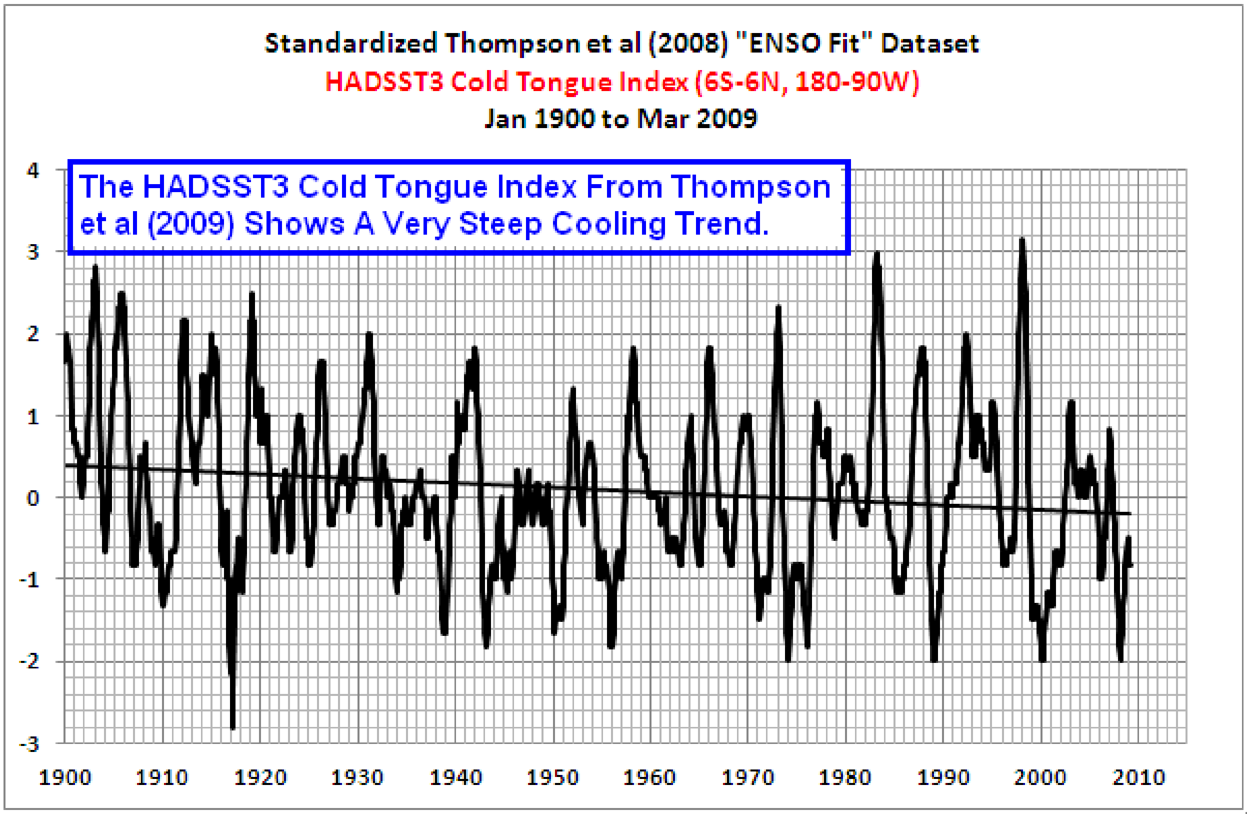

Figure 7-3

In summary, sea surface temperature anomaly-based ENSO indices do have trends. The trend depends on the dataset. Most show a cooling trend over the 20th century and on into current times.

That's not the primary fault with that myth. What defies logic with that fairytale is the idea that a variable source of heat with a flat long-term linear trend cannot raise or lower temperatures over periods of time.

For example, let's say a hospital recently built a new multistory wing. The engineering department has received complaints about the temperature in a storeroom. Rarely does anyone enter the storeroom, but when they do, the temperature there can be very cool or very warm, or sometimes it's just right. The storeroom is in the center of the building. It's surrounded by occupied spaces and there are occupied floors above and below it. The temperatures in all of the spaces surrounding the storeroom are controlled by thermostats to maintain temperatures at 21 deg C (70 deg F). The lights in the storeroom are controlled by an occupancy sensor and there is no equipment in that space causing a heat load. Basically, the storeroom has no heat gains or losses when it's unoccupied. To save on construction costs, hospital administrators elected not to install a thermostat in the storeroom with a separate supply of heating and cooling. The heating and air conditioning system does, however, serve the storeroom, providing a minimum amount of conditioned air for ventilation. The air conditioned or heated supply air comes from a duct that's controlled by a thermostat in an adjacent office space, which is unfortunately an exterior zone, with heat losses and heat gains and varying occupancy. The head of the engineering department sends a new hire to the storeroom with a couple of temperature sensors and digital recorder.

After a period of time, the new hire stops by the boiler room to consult with the crusty old boiler room foreman. The new hire explains his findings to foreman. The temperature of the storeroom does vary, and he provides a graph that shows the temperature there initially warmed, then cooled slightly, and then warmed again. See Figure 7-4.

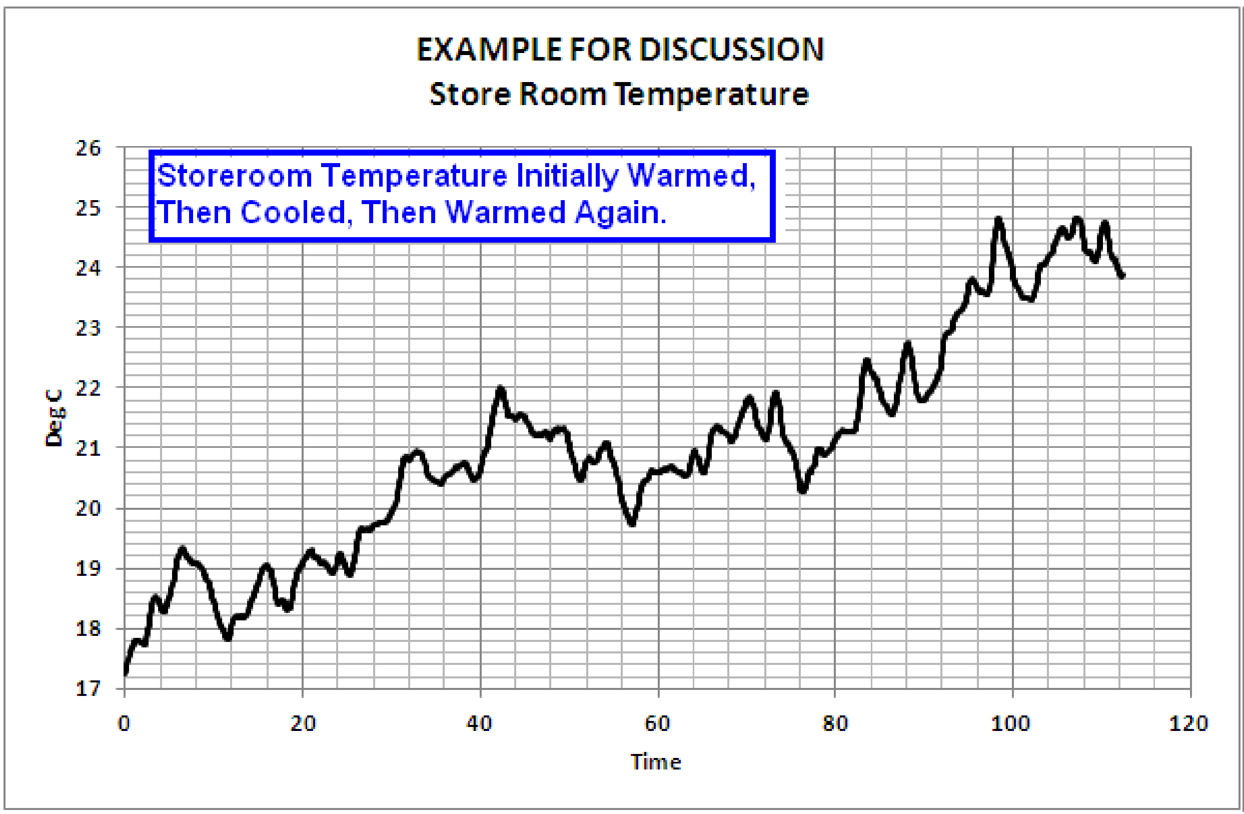

Figure 7-4 Bob Tisdale

The new hire is baffled, though. The graph of the temperature of the air being supplied to the space, Figure 7-5, shows lots of variability. If he compares the supply air and space temperature, the new hire can see that the temperature of the air being supplied to the space has a strong short-term effect on space temperature. When there's a short-term supply of warm air, the space temperature warms and, conversely, when there's a short-term supply of cool air, the space temperature cools. What baffles the new hire is that space temperatures obviously warmed over the long-term, but the supply air temperature shows no trend. In fact, it shows a slight cooling trend.

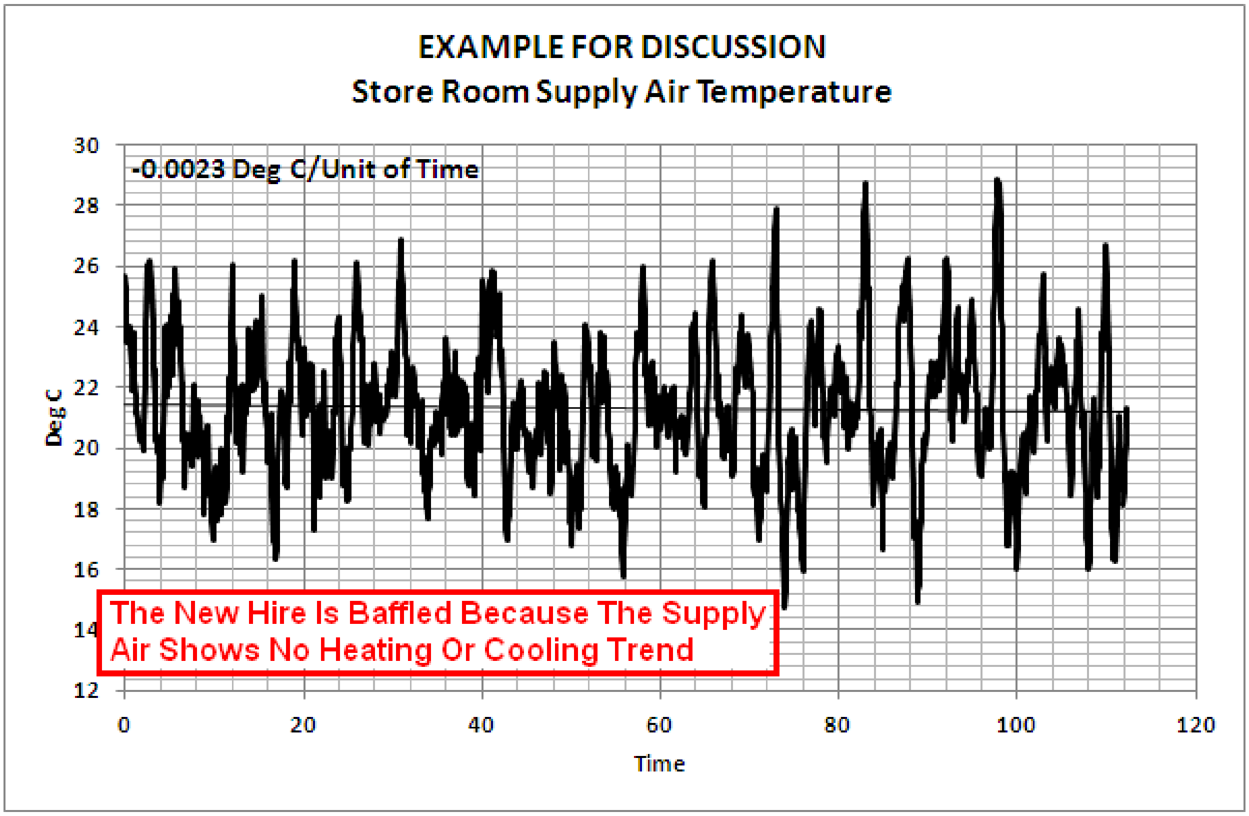

Figure 7-5

Bob Tisdale

The boiler room foreman suggests the new hire determine the average temperatures of the supply air entering the space during the early and late warming periods and determine the average supply air temperature for the relatively flat temperature period between them. The new hire returns with a revised graph that shows the average supply air temperatures were in heating mode during the two warming periods and in cooling mode, just slightly, during the period between them. All of the variability had hidden the obvious from him when he looked at the data for the first time. The new hire states the supply air was an uncontrolled supply of variable heating and cooling, and it was causing the space temperatures to warm and cool. The foreman and the new hire go into a more detailed discussion to clarify the reasons for the warming and cooling before the new hire reports back to the head of engineering.

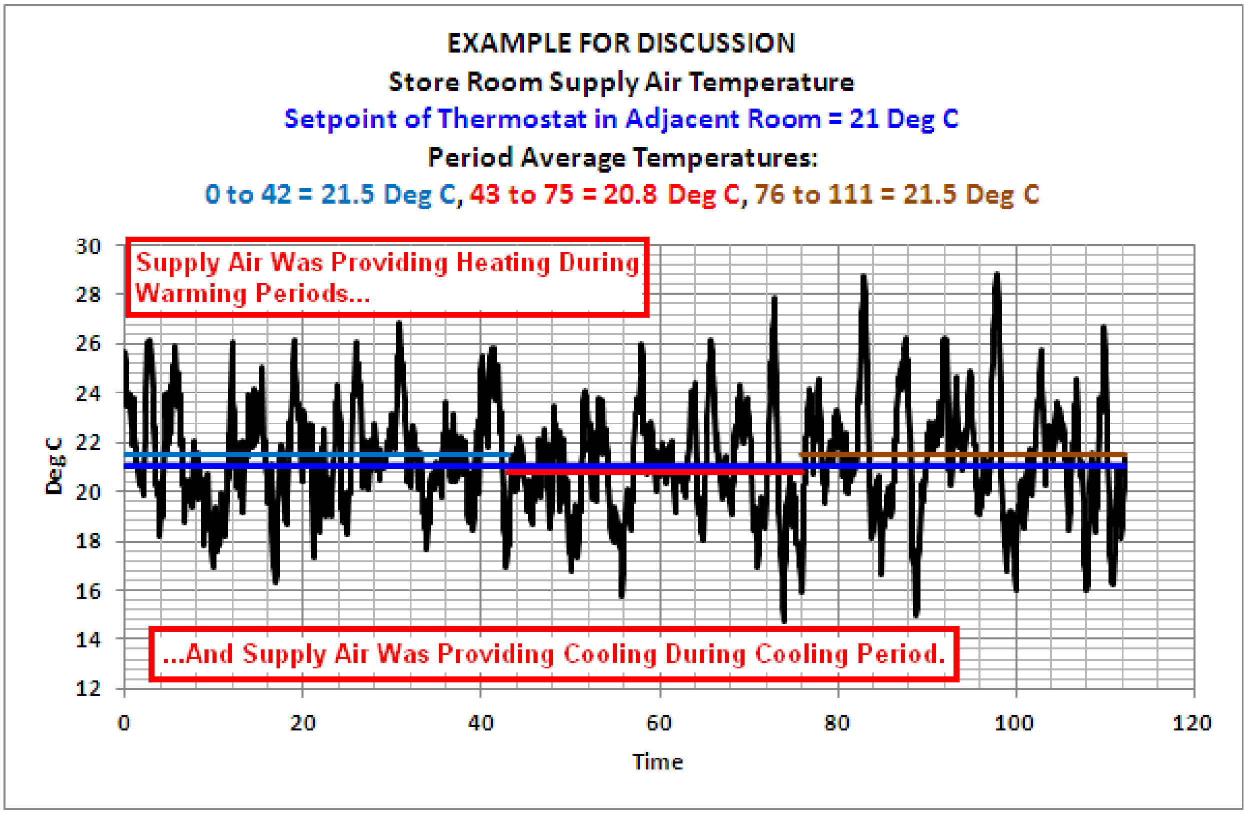

Figure 7-6

If you hadn't noticed, I used scaled and ranged NINO3.4 sea surface temperature anomalies since 1900 to create the supply air temperature data in Figures 7.5 and 7.6, and the space temperature in Figure 7-4 bears a striking resemblance to global surface temperatures since 1900 as well. I'm sure some readers will think it was a poor example and that there are better examples I could have used in the discussion above, but let's look at the bottom line.

Isn't that all ENSO is? Isn't ENSO simply a natural, uncontrolled, variable source of heat to the global oceans and atmosphere? Global Land Plus Sea surface temperatures warmed from 1917 to 1944 and warmed again from 1976 to present, and they cooled slightly from 1944 to 1976. Using period-average NINO3.4 sea surface temperatures, we can see that El Niño events dominated the global warming periods, and La Niña events dominated the period between them when global temperatures cooled.

We've discussed this in **Chapter 5.8 Scientific Studies of the IPCC's Climate Models Reveal How Poorly the Models Simulate ENSO Processes**. Let's repeat that discussion.

The strength of ENSO phases, along with how often they happen and how long they persist, determine how much heat is released by the tropical Pacific into the atmosphere and how much warm water is transported by ocean currents from the tropics to the poles. During a multidecadal period when El Niño events dominate (a period when El Niño events are stronger, when they occur more often and when they last longer than La Niña events), more heat than normal is released from the tropical Pacific and more warm water than normal is transported by ocean currents toward the poles—with that warm water releasing heat to the atmosphere along the way. As a result, global sea surface and land surface temperatures warm during multidecadal periods when El Niño events dominate. See Figure 7-7. Similarly, global temperatures cool during multidecadal periods when La Niña events are stronger, last longer and occur more often than El Niño events.

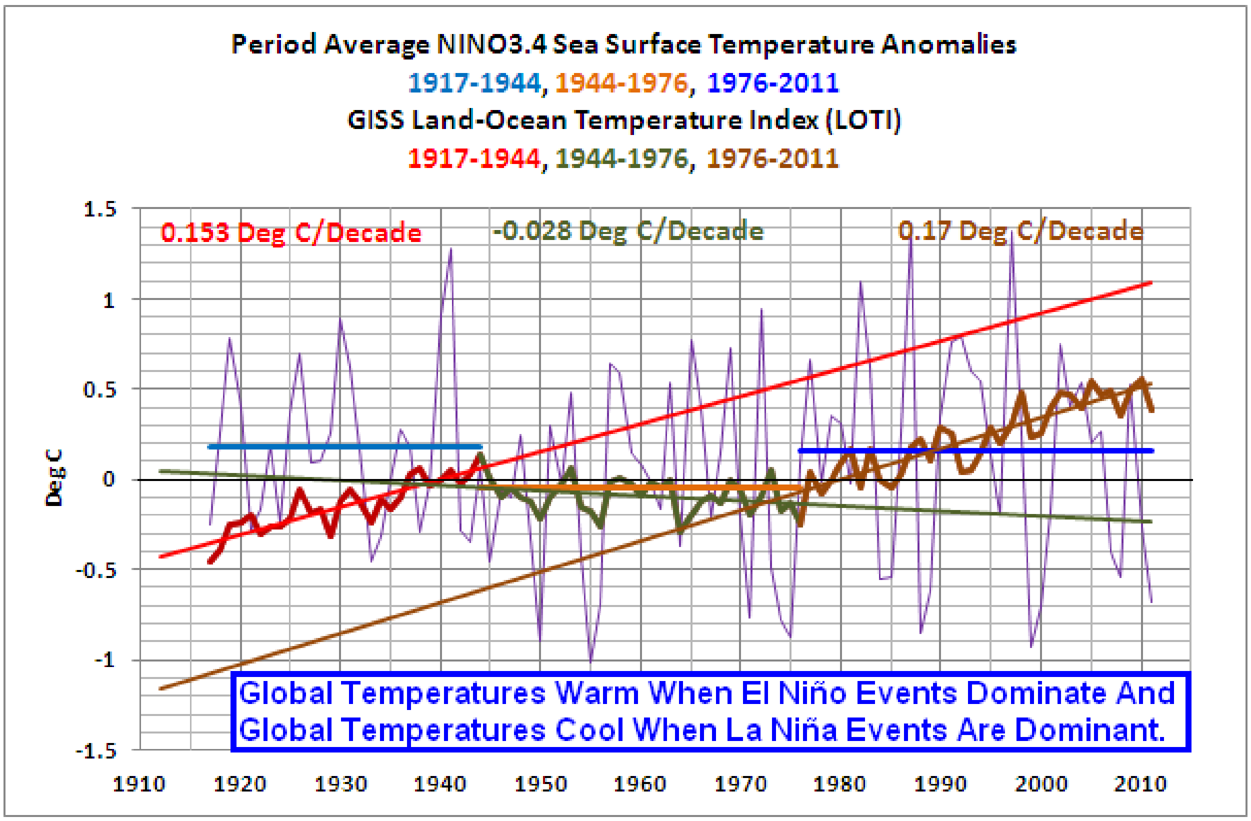

Figure 5-7

Bob Tisdale

The myth "ENSO Has No Trend and Cannot Contribute to Long-Term Warming" is flawed in a number of ways.

7.2 Myth - The Effects of La Niña Events on Global Surface Temperatures Oppose those of El Niño Events

The myth that “the Effects of La Niña Events on Global Surface Temperatures Oppose those of El Niño Events” sounds logical if you don’t understand ENSO.

We discussed and illustrated the errors in this myth in **Section 5 – The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies.**

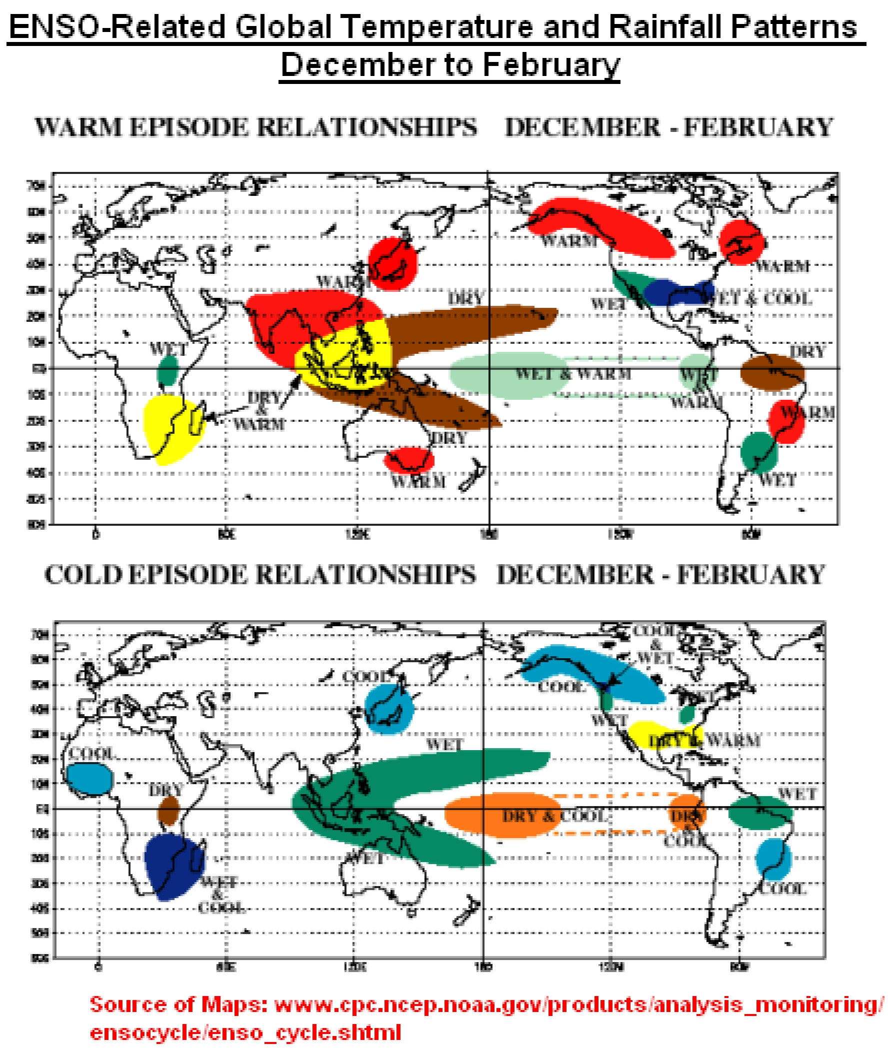

Figure 7-8 Bob Tisdale

My guess is this myth was started by someone who misunderstood the maps NOAA provides that show the impacts of ENSO events on global surface temperature and precipitation. In Figure 7-8 and 7-9, to help show how "typical" El Niño and La Niña temperature and rainfall patterns oppose one another, I've rearranged the maps NOAA provides in its **El Niño-related global temperature and rainfall patterns** and its **La Niña-related global temperature and rainfall patterns** web pages.

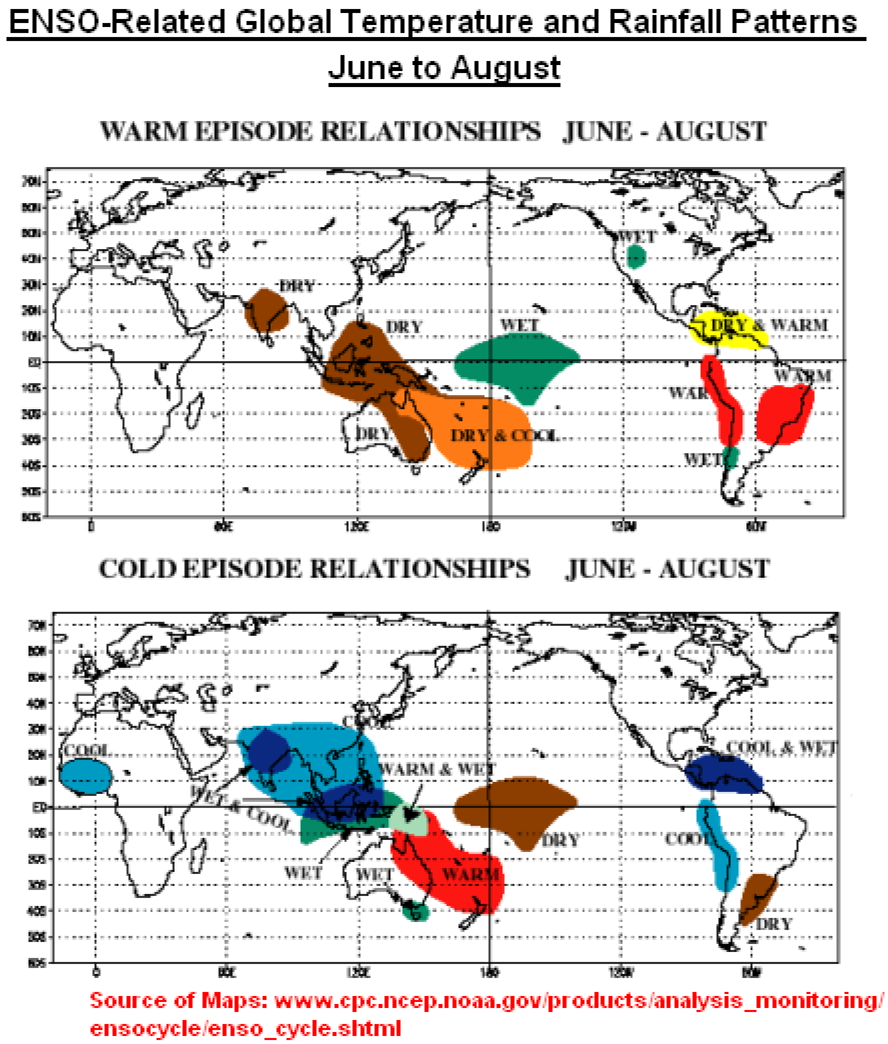

Figure 7-9 Bob Tisdale

Toward the end of **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation**, I presented the studies that NOAA list as the sources of their maps. They include:

Ropelewski and Halpert (1987): **Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation (ENSO)**.

Ropelewski and Halpert (1989): **Precipitation Patterns Associated with the High Index Phase of the Southern Oscillation**

Halpert and Ropelewski (1992): **Temperature Patterns Associated with the Southern Oscillation**

The studies were investigations into the effects of "typical" ENSO events on global precipitation and temperature patterns. Basically, they were intended as weather forecasting aids. They are not studies of how El Niño and La Niña events are different. They are not studies of ENSO processes. The authors were searching for similarities in the patterns, not dissimilarities, to help them make weather forecasts. The authors are not stating that other locations can't warm or cool during ENSO events, and they definitely were not looking for regions where El Niño and La Niña events can both cause warming.

RECAP

Section 5 – The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies illustrated quite explicitly that the effects of La Niña events on global sea surface temperatures do not oppose El Niño events. Parts of the global oceans warm in response major El Niño events, but then fail to cool during the trailing La Niña. These areas include the "North Atlantic Plus" dataset, which represents about 14% of the surface area of the global oceans, and the South Atlantic-Indian-West Pacific dataset, which represents about 53% of the surface area of the global oceans. That is, the sea surface data for 67% of the global oceans contradict this myth.

7.3 A New Myth - ENSO Balances Out to Zero over the Long Term

A new myth about ENSO recently appeared in posts at the website **SkepticalScience**. This year one author there has been writing something to the effect of, El Niño and La Niña events balance out to zero over the long term. That's nonsense, plain and simple nonsense. There are a number of ways to show the errors with this myth. The best way is to create a running total of NINO3.4 sea surface temperature anomalies.

Wikipedia provides an easy-to-understand explanation of a **Running Total**:

> *A **running total** is the summation of a sequence of numbers which is updated each time a new number is added to the sequence, simply by adding the value of the new number to the running total. Another term for it is partial sum.*
>
> *The purposes of a running total are twofold. First, it allows the total to be stated at any point in time without having to sum the entire sequence each time. Second, it can save having to record the sequence itself, if the particular numbers are not individually important.*

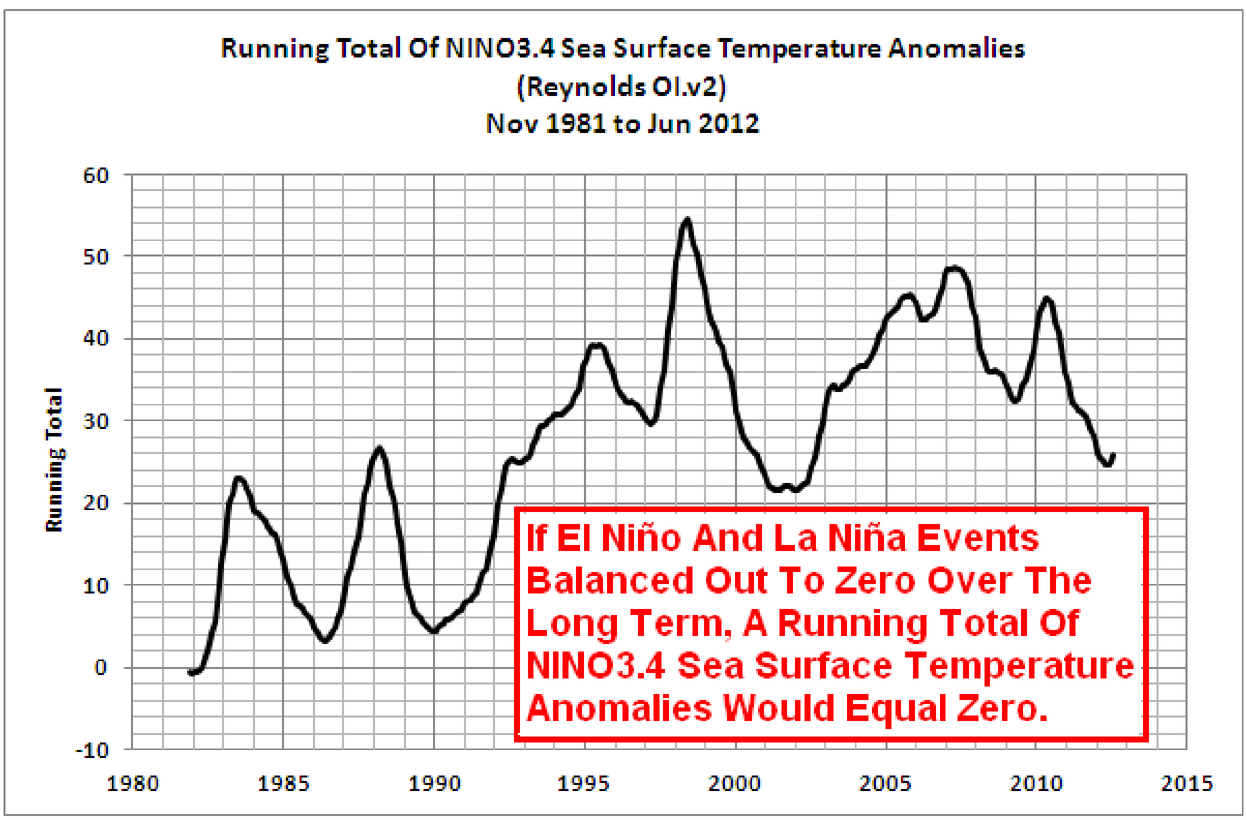

Figure 7-10

Bob Tisdale

If, over the long term, El Niño and La Niña events balanced out to zero, then a running total of NINO3.4 sea surface temperature anomalies would equal zero. Does it? Refer to Figure 7-10.

El Niño and La Niña events obviously have NOT balanced out to zero over the past 30+ years. That curve of the running total of NINO3.4 data looks surprisingly similar to the global sea surface temperature anomaly curve. It's really difficult to miss the very obvious increase.

I've actually had someone reply in a blog comment that 30 years was not long enough. I then provided a running total of NINO3.4 sea surface temperature anomalies starting in 1900. That early start year is pushing the boundaries when it comes to equatorial sea surface temperature data. The Panama Canal opened in 1914, and before then, equatorial Pacific sea surface temperature data becomes increasingly sparse.

The base years for anomalies would also impact the running total, especially one that long, so we need to pick some. Trenberth (1997) **The Definition of El Niño** stated that 1950 to 1979 was the best base period for NINO3.4 sea surface temperature anomalies. Trenberth writes:

> *Figure 1 shows the five month running mean SST time series for the Niño 3 and 3.4 regions relative to a base period climatology of 1950-1979 given in Table 1. The base period can make a difference. This standard 30 year base period is chosen as it is representative of the record this century, whereas the period after 1979 has been biased warm and dominated by El Niño events (Trenberth and Hoar 1996a). Mean temperatures are higher in the Niño 3.4 region than in Niño 3 and its proximity to the Pacific warm pool and main centers of convection is the reason for the physical importance of Niño 3.4.*

We'll use 1950 to 1979 as the base period for anomalies for our NINO3.4 sea surface temperature anomalies.

Figure 7-11 is the running total of HADISST NINO3.4 sea surface temperature anomalies, starting in January 1900 and ending in May 2012. It does not return to zero. However, it really looks like the global temperature anomaly curve.

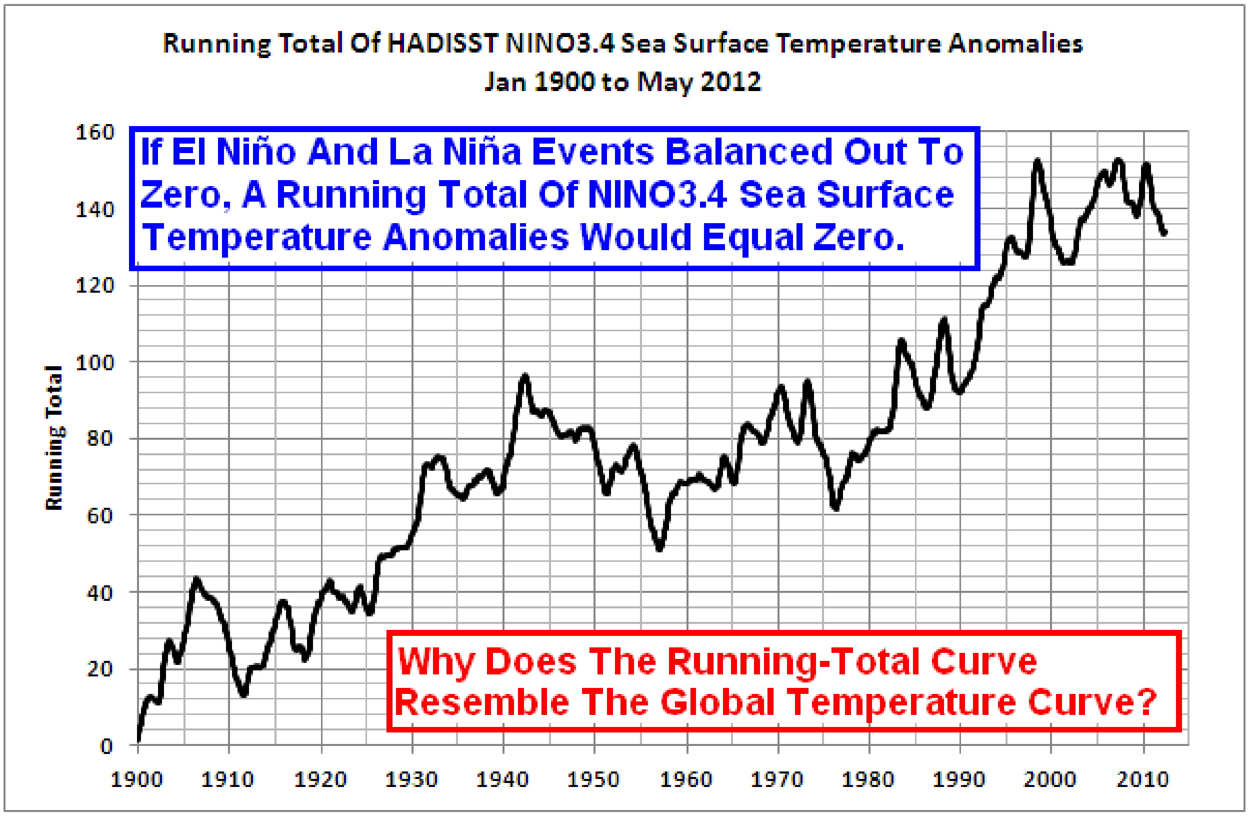

Figure 7-11

Bob Tisdale

The similarity between the curve of the running total of HADISST-based NINO3.4 sea surface temperature anomalies and a global temperature anomaly curve is remarkable. Unfortunately, it only works with HADISST-based NINO3.4 data. A running total of NINO3.4 data based on the ERSST.v3b or Kaplan datasets bears no similarities to the global temperature curve. Also, it only works with the base years of 1950-1979. That is, if you were to shift the base years so that they were weighted more toward El Niño events, like the period of 1971 to 2000, you'd wind up with a long-term running-mean curve that looks completely different. That makes the curve illustrated in Figure 7-11 a curiosity. Nothing more—just a curiosity, because I can't justify the use of the base years of 1950-1979. It should definitely make you think, though.

That running total was one of the things that sparked my interest in ENSO. I discovered that curious running-total effect in April 2008, and presented it in a post titled **Is There A Cumulative ENSO Climate Forcing?** (ENSO isn't a forcing, but that's neither here nor there.) If you were to include the effects of volcanic aerosols and solar variability, the fit becomes even better. I presented that in a post titled **Reproducing Global Temperature Anomalies With Natural Variables**.

Regardless, ENSO has been skewed toward El Niño in recent decades. It has been skewed toward La Niña as well—the period from the 1940s to the mid-

1970s for example. This is well known. We've shown the "skewness" in the preceding chapter using period average sea surface temperatures for the NINO3.4 region.

The myth that "El Niño and La Niña events balance out to zero over the long term" is simply another very obvious attempt to neutralize El Niño and La Niña. It's a comical attempt that failed.

7.4 Myth - El Niño Events Dominated the Recent Warming Period Because of Greenhouse Gases

A number of climate studies have attempted to show that the recent spell of strong El Niño events was caused by anthropogenic greenhouse gases. Similarly, some have tried to show that climate forcings like greenhouse gases and anthropogenic aerosols are what dictates whether El Niño or La Niña events dominate. As far as I know, none have been successful at confirming the speculations of the authors. Their major obstacle: they attempt to use climate models to show how climate forcings impact ENSO, but climate models simulate ENSO so poorly they have no basis for any claims.

To put it another way, they are topics that receive a lot of conjecture—climate model-based conjecture.

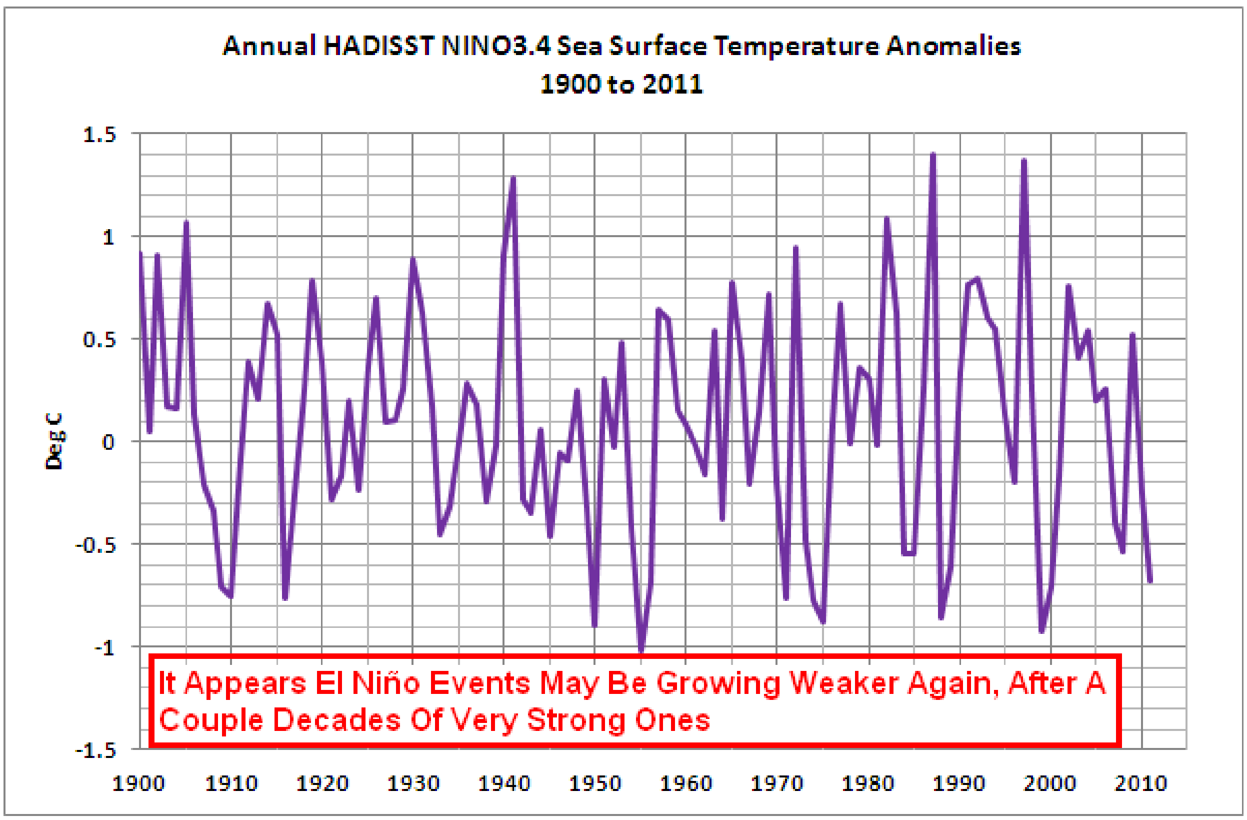

Figure 7-12

Bob Tisdale

A big problem for that myth: There hasn't been a super El Niño since 1997/98. It's rapidly approaching 15 years since the last one. It appears El Niño events are weakening, returning to strengths seen in the 1950s and 1960s. This is easiest to show with annual NINO3.4 sea surface temperature anomalies, Figure 7-12. It's not as noisy as the monthly NINO3.4 data. The annual NINO3.4 data also presents the 1986/87/88 El Niño as a very strong El Niño, which it was, though we've shown that it was not stronger than the 1997/98 El

Niño. Refer to **Chapter 4.4 ENSO Indices Also Fail to Capture the Relative Strengths of ENSO Events**.

The recent weakening of El Niño events, or better said, the recent transition to a period when El Niño and La Niña events are growing more equal in strength and frequency, can be seen if we smooth the annual NINO3.4 data with an 11-year running-average filter, Figure 7-13. This is basically the same filter used by the NOAA/ESRL for its Atlantic Multidecadal Oscillation Index data. There are very obvious low-frequency decadal and multidecadal variations.

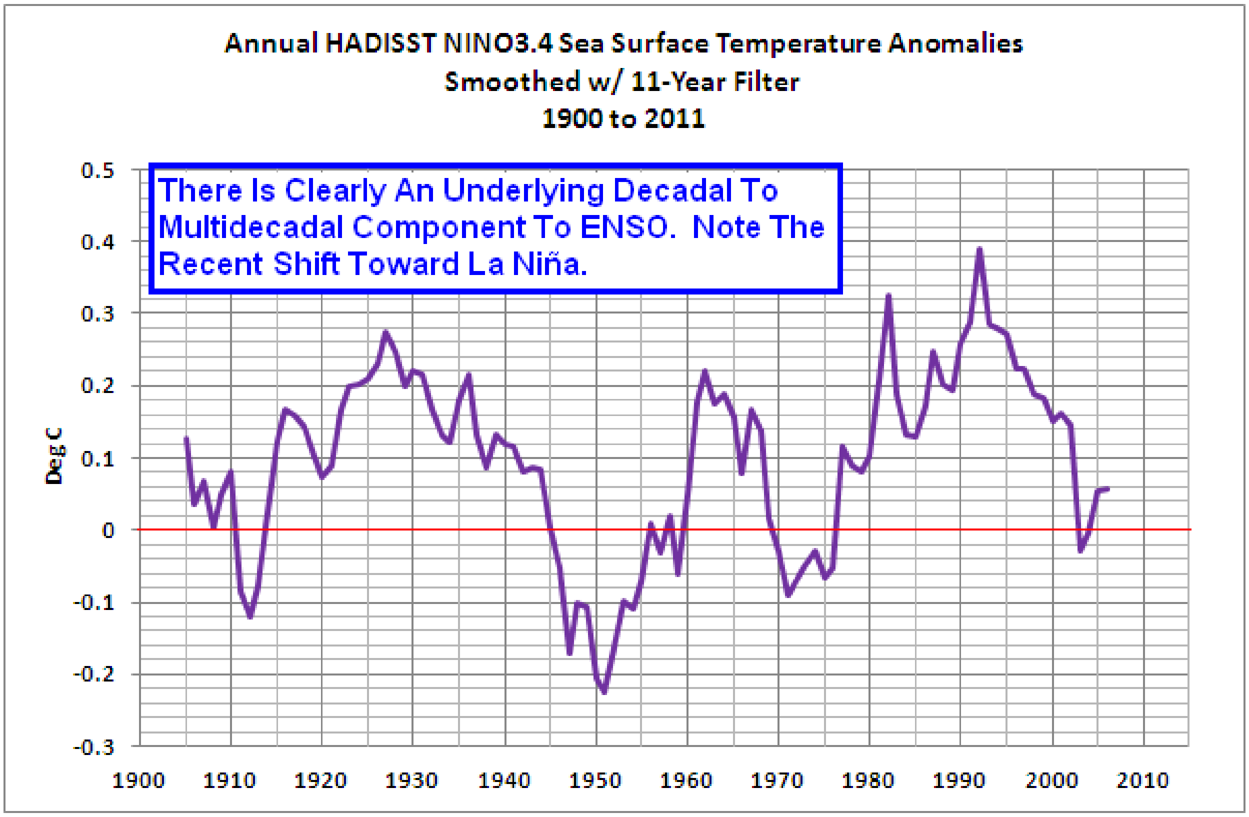

Figure 7-13 Bob Tisdale

The myth "El Niño Events Dominated the Recent Warming Period Because of Greenhouse Gases" does not stand closer scrutiny: Anthropogenic greenhouse gas emissions continue to rise, yet ENSO has shifted back toward a period when El Niño and La Niña events are more equal in terms of frequency and strength.

7.5 Myth - ENSO Only Adds Noise to the Instrument Temperature Record and We Can Determine its Effects through Linear Regression Analysis, Then Remove Those Effects, Leaving the Anthropogenic Global Warming Signal

The relationship between ENSO events and global surface temperatures is known. During an El Niño event, some places around the globe warm in response and other places cool. The warming exceeds the cooling, so global temperatures, as a whole, warm in response to an El Niño event. On the other hand, during a La Niña event, the cooling around the globe exceeds the warming and, as a whole, global temperatures cool in response to a La Niña event. Early work on the relationship between ENSO and weather (temperature and precipitation) around the globe, as noted earlier in the book, include Berlage (1976) *Southern Oscillation and World Weather*, Newell and Weare (1976) **Factors Governing Tropospheric Mean Temperature**, Angell (1981) **Comparison of Variations in Atmospheric Quantities with Sea Surface Temperature Variations in the Equatorial Eastern Pacific**, Pan and Oort (1983) **Global Climate Variations Connected with Sea Surface Temperature Anomalies in the Eastern Equatorial Pacific Ocean for the 1958–73 Period**.

Somewhere along the line, possibly Jones in the 1989 book *The influence of ENSO on global temperatures* [not available online], a study used a statistical tool such as correlation or regression analysis to determine the linear relationship between an ENSO index and global temperature. With that factor and an appropriate time lag between the ENSO index and global surface temperatures, they then crossed a hurdle. They subtracted the scaled ENSO index from the global temperature data and claimed the difference was caused by manmade greenhouse gases.

That is, with a statistical tool, they used an ENSO index and global surface temperatures to determine how much global surface temperatures warmed and cooled in response to the ENSO signal represented by the ENSO index. They also determine the time lag between the change in the ENSO index and the response in global surface temperatures. For example, let's say a study determined that global surface temperatures varied 0.18 deg C for every 1.0 deg change in the ENSO index and that global surface temperatures lagged the ENSO index by 3 months. Further, let's say the study also included a dataset called Aerosol Optical Depth (AOD) to account for the sun-shading effects of volcanic aerosols spewed into the stratosphere by explosive volcanic eruptions. ENSO and volcanic aerosols are the two primary causes of the year-to-year wiggles in the global surface temperature record. Like before, also for the example, we'll exclude polar data, so we'll only examine the GISS Land-Ocean Temperature Index data from 65S-65N.

As a reminder, the Arctic temperature data is also impacted by a phenomenon called polar amplification, which skews the data. As also noted before, GISS, for all intents and purposes, deletes sea surface temperature data in areas of seasonal sea ice in both polar oceans. They then replace it with land surface temperature data, which will exaggerate the long-term warming there because land surface temperatures vary much more than sea surface temperatures. There's no need to include those biases in our discussion.

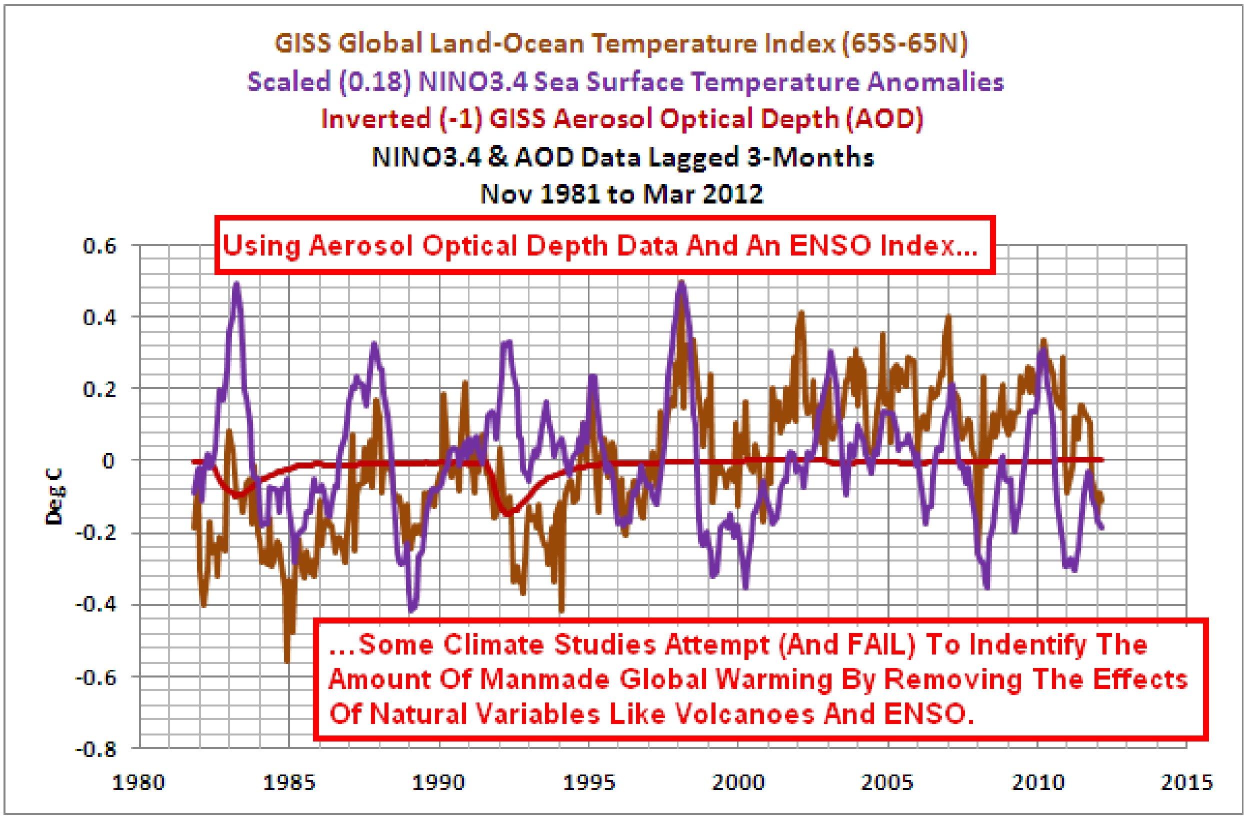

Figure 7-14

Bob Tisdale

The three datasets are shown in Figure 7-14. Note that I haven't scaled the volcanic aerosol data, and that it shows a dip of about 0.15 deg C in 1991 in response to the eruption of Mount Pinatubo. Climate studies have estimated the impact of Mount Pinatubo to have been in the range of 0.2 to 0.5 deg C. I'll show you what they missed—later.

The climate studies that attempt to remove the impacts of ENSO and the volcanic eruptions, very simply, then subtract the scaled and lagged ENSO index and Aerosol Optical Depth data from the global surface temperature data and assume the warming shown is caused by anthropogenic greenhouse gases. See Figure 7-15. It's nonsense, but there are a good number of studies that attempt to show this. Why is it nonsense?

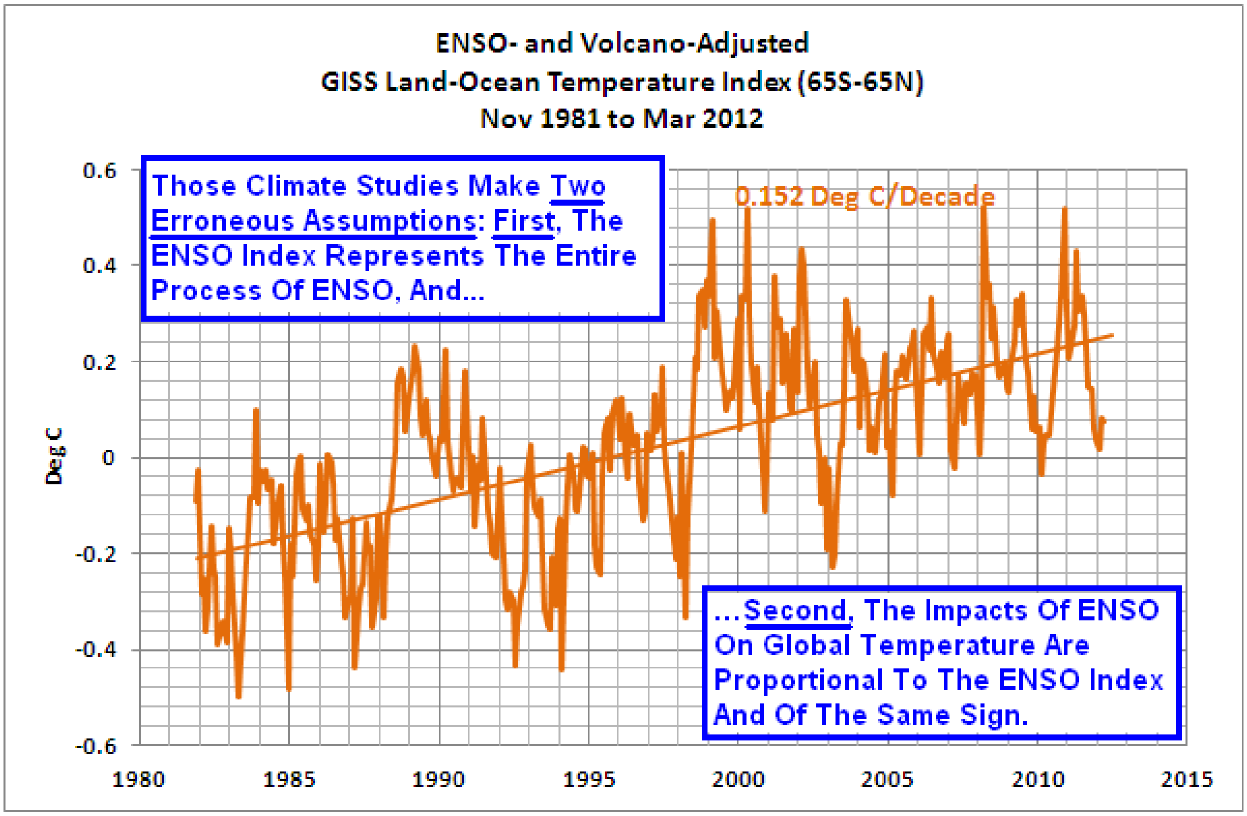

Figure 7-15 Bob Tisdale

There are two very obvious erroneous assumptions made by those studies. First, they assume the ENSO index represents the all of the effects of the entire ENSO process. We know that's not correct. The ENSO index only represents the effects of ENSO on the variable or variables being measured. For NINO3.4 sea surface temperature anomalies, the ENSO index only represents the impacts of El Niño and La Niña on the sea surface temperatures of a small region along the equatorial Pacific. The Southern Oscillation Index only represents the effects of ENSO on the sea level pressures of Tahiti and Darwin, Australia. Those ENSO indices do not account for the effects of the warm surface waters in the tropical Pacific that are left over after an El Niño and they do not account for the warm subsurface waters that are returned to the west Pacific and East Indian Ocean by Rossby waves. The Multivariate ENSO Index, which includes a number of other different variables, also fails to capture these important aspects of ENSO.

The second erroneous assumption—maybe it's actually the second and third erroneous assumptions—is they assume the effects of ENSO on global surface temperature are proportional or linear to the ENSO index and that those effects are all the same sign. We know the effects of ENSO on global sea surface temperatures are NOT proportional to the ENSO index. The sea surface temperatures of the East Indian and West Pacific Ocean warm in response to an El Niño but fail to cool during the trailing La Niña event. Also, we've already shown and discussed a number of times that there are places around the globe that warm in response to an El Niño and some that cool in response to an El Niño, and vice versa for a La Niña. As a reminder, the map in Figure 7-16 presents the correlation of GISS Land-Ocean Temperature Index data with NINO3.4 sea surface temperature anomalies, with a 3-month lag.

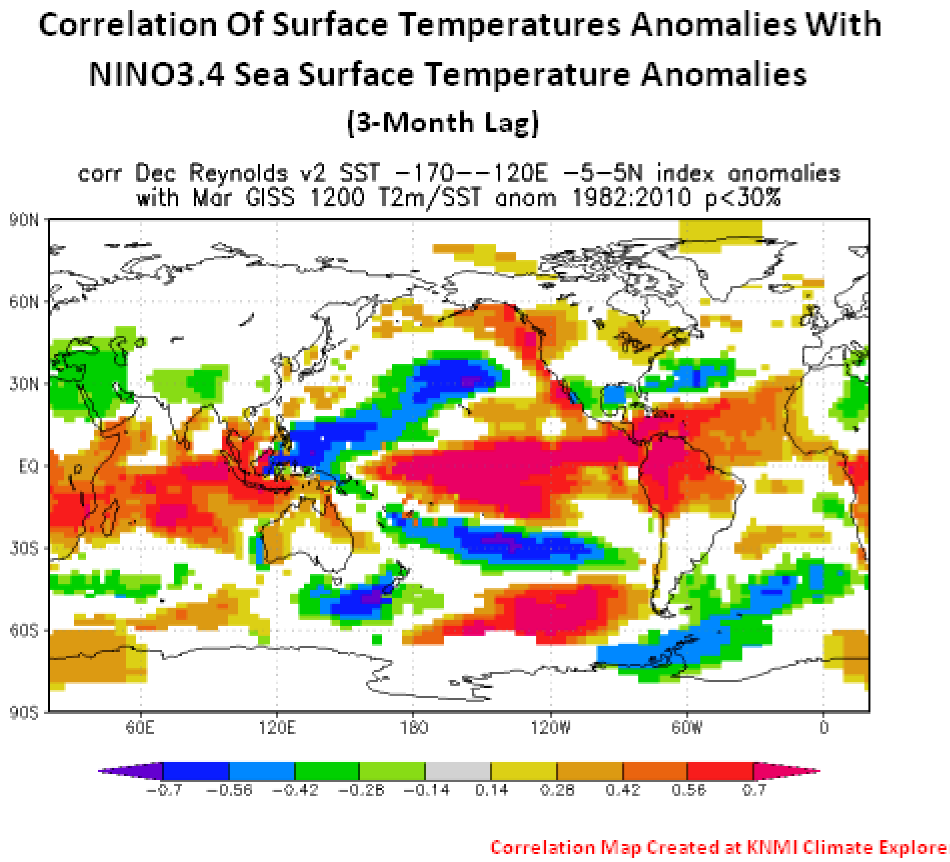

Figure 7-16

Bob Tisdale

Let's smooth the ENSO- and volcano-adjusted GISS Land-Ocean Temperature Index data with a 13-month running-average filter, Figure 7-17, and see what we can see. You may have noticed the upward shifts during the 1986/87/88 and 1997/98 El Niño events in the "raw" (unsmoothed) data (Figure 7-15), but they stand out remarkably well in the smoothed data. The periods before, between, and after the 1986/87/88 and 1997/98 El Niño events (highlighted in blue) still show signs of ENSO-related variations, but they're inversely related to the NINO3.4 data. Stop and think about that for a moment. Considering the different time lags and when and where global surface temperatures are impacted by ENSO at those assorted time lags, it's very logical that there are noticeable ENSO related signals visible that are the opposite sign after you remove the major variations of the same sign. In fact, you should expect to see them.

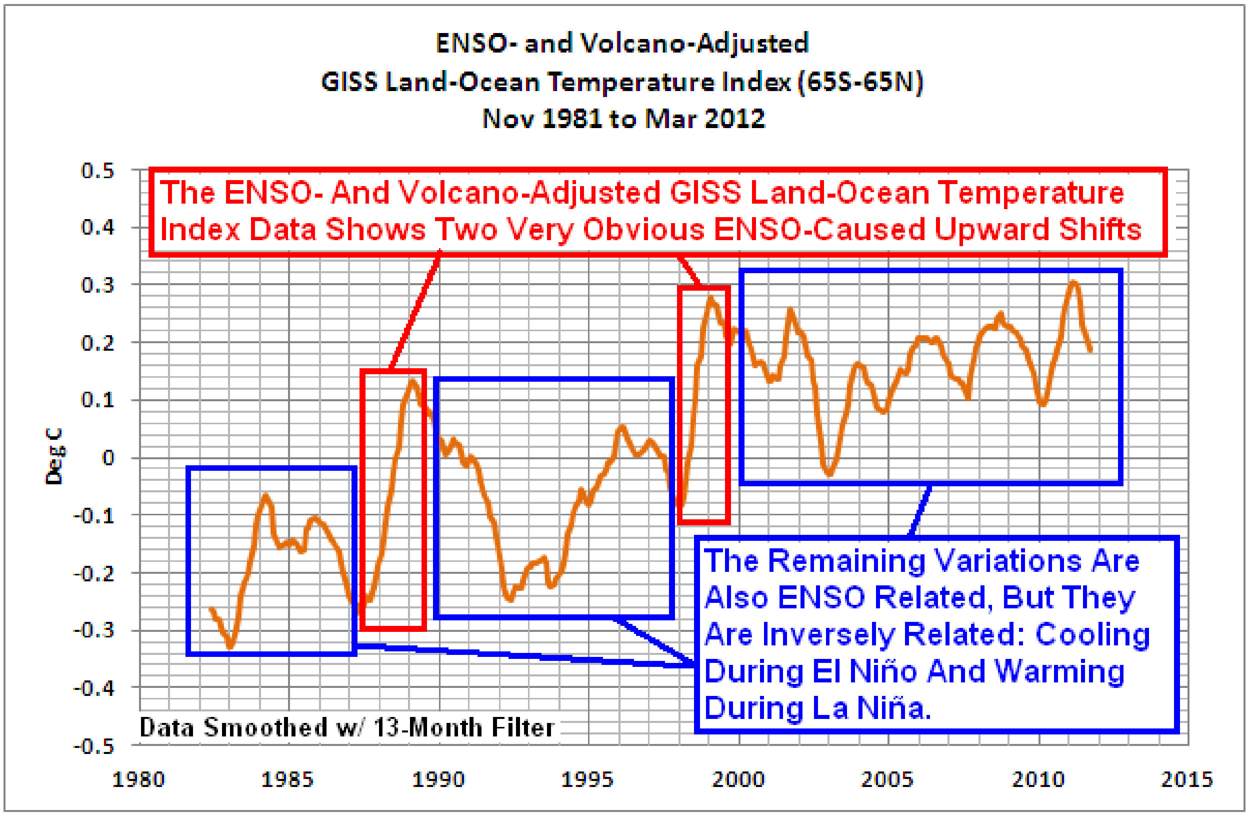

Figure 7-17

Bob Tisdale

We can show the inverse relationship between ENSO and the ENSO- and volcano-adjusted GISS surface temperature data, by scaling and inverting the NINO3.4 sea surface temperature anomalies. In Figures 7-18, 7-19 and 7-20, the NINO3.4 data was scaled by a factor of 0.12, which is less than the scaling factor we used when we originally adjusted the data; then we used a scaling factor of 0.18. The NINO3.4 data in the three upcoming figures has not been lagged. This helps to show the timing of the upward shifts, which occur during the transitions from El Niño to La Niña. The upward shifts trail the NINO3.4 data by a couple of months. The lagged relationship between the inverted NINO3.4 data and the adjusted GISS Land-Ocean temperature stands out best in Figure 7-20, but it can also be seen in Figure 7-19, for the period between the 1986/87/88 and 1997/98 El Niño. You're probably asking yourself why I'm using three graphs of the same two datasets. In Figure 7-18, I've offset the NINO3.4 data by -0.15 deg C, to show how well the adjusted GISS data and the inverted and scaled NINO3.4 data agree before the 1986/87/88 El Niño. The NINO3.4 data is offset -0.05 deg C in Figure 7-19 to show how well the two datasets agree between the 1986/87/88 and 1997/98 El Niño events. Then, in Figure 7-20, the inverted and scaled NINO3.4 sea surface temperature anomalies were offset +0.15 deg C to show how well that inverted NINO3.4 data now agrees with the ENSO- and volcano-adjusted GISS Land-Ocean Temperature Index data after the 1997/98 El Niño. The changes in the offsets provide a very rough approximation of the shifts in surface temperatures caused by the 1986/87/88 and 1997/98 El Niño events.

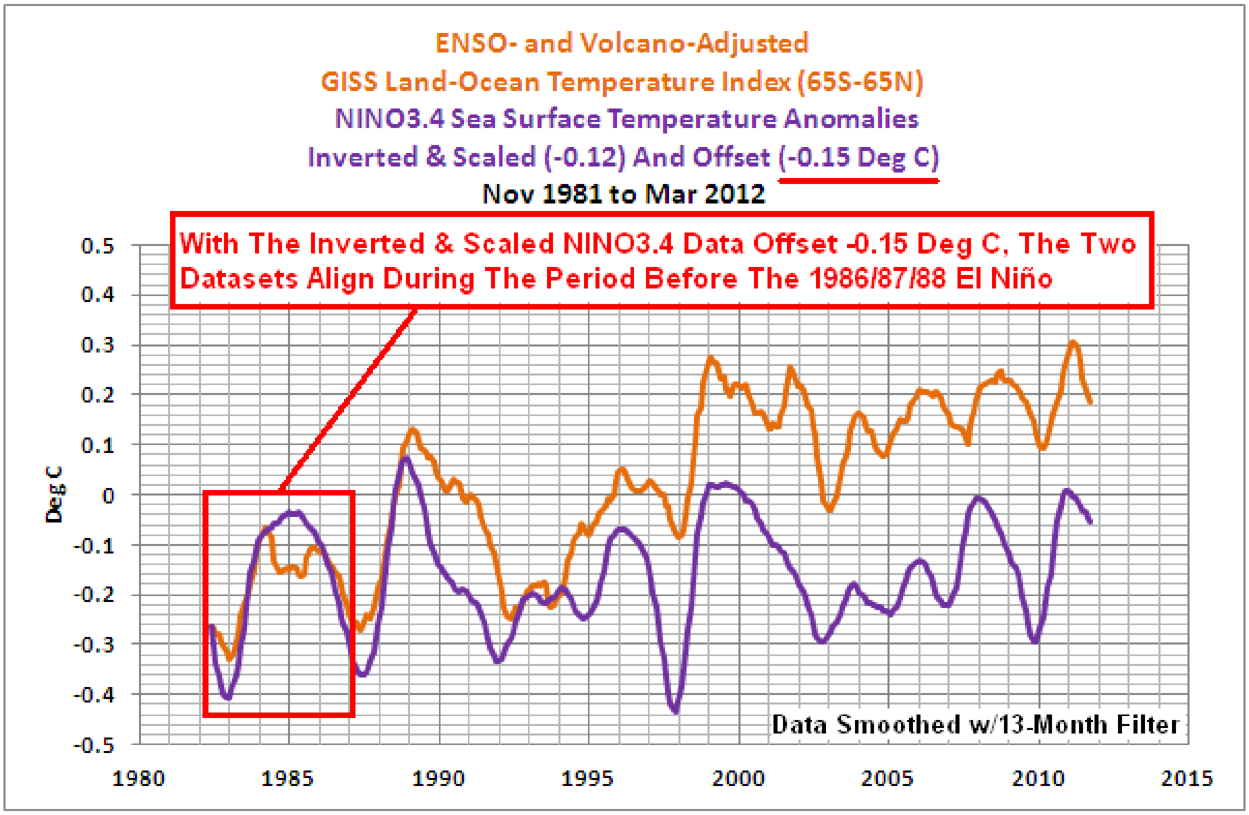

Figure 7-18 Bob Tisdale

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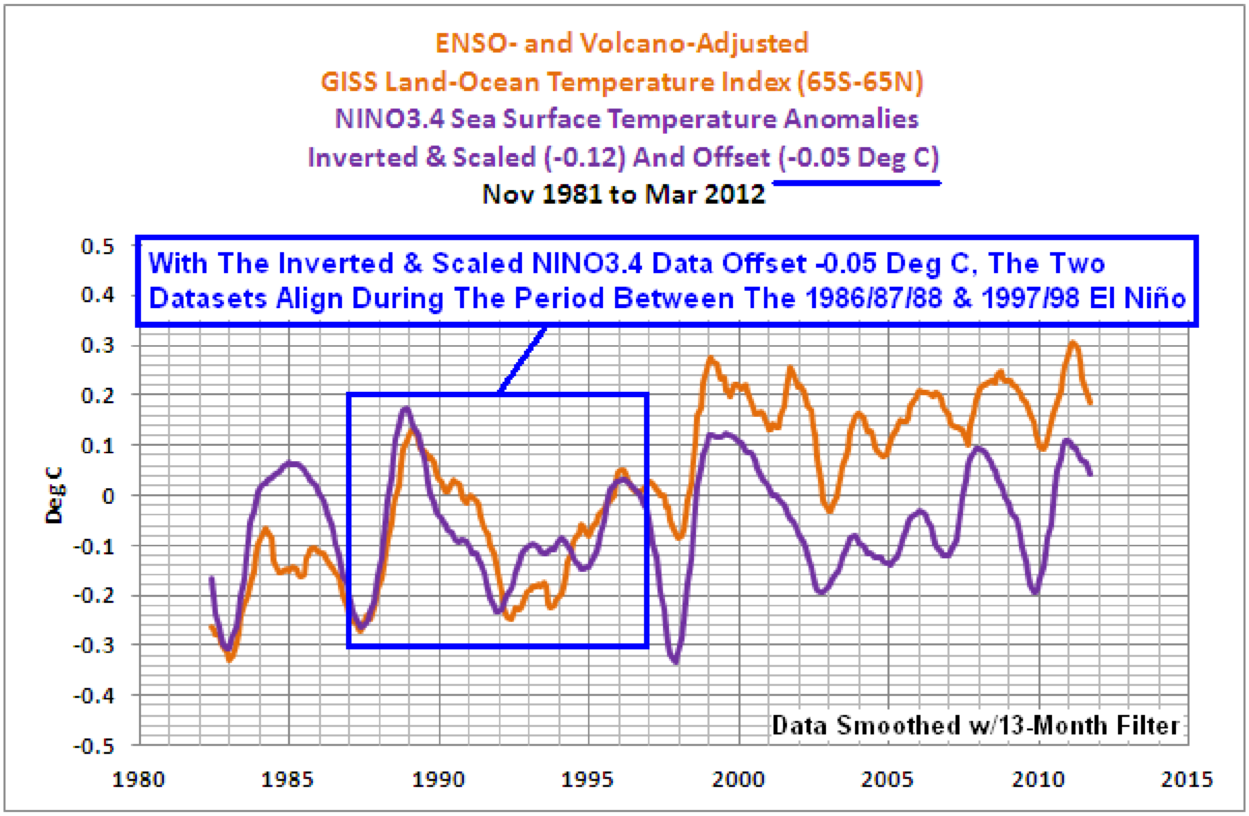

Figure 7-19 Bob Tisdale

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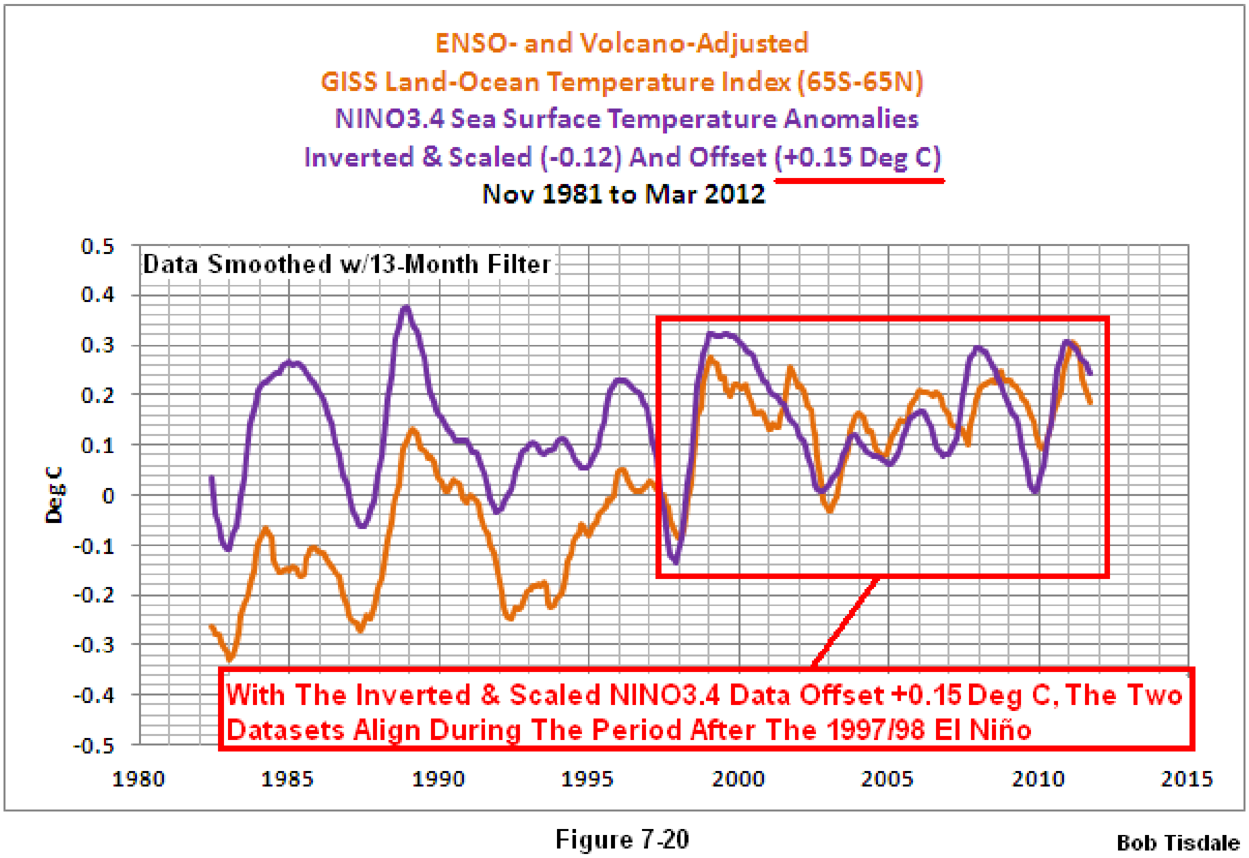

Figure 7-20

It all makes sense, and there was no need to rely on greenhouse gases to explain the warming of land plus sea surface temperatures from November 1981 to March 2012, for the latitudes of 65S-65N. If you're not aware, the latitudes of 65S-65N cover about 90% of the planet, and the GISS data north of 65N and south of 65S has been modified by their deletion of sea surface temperature data and replacing it with land surface temperature data.

Recall that in Figure 5-14 we assumed the eruption of Mount Pinatubo only cooled global surface temperatures by about 0.15 deg C. We also noted that climate studies determined that global surface temperatures cooled 0.2 to 0.5 deg C in response to the volcano. Some of those studies removed the linear effects of ENSO to determine the response of global temperatures to Mount Pinatubo. They assumed incorrectly that the response of global surface temperatures to ENSO were all the same sign. They didn't bother to consider the fact that there are areas around the globe that cool in response to El Niño and warm in response to La Niña AND that these inverse effects may be strongest at a different time lag. Now, if you would, please scroll back up to Figure 7-19. Note how well the scaled and inverted NINO3.4 data agrees with the ENSO- and volcano-adjusted GISS Land-Ocean Temperature Index data at the time of the Mount Pinatubo eruption. The adjusted GISS land plus sea surface temperature data is cooling in response to the string of El Niño events from 1991 to 1995. The studies appear to have overestimated the response of global surface temperatures to the eruption of Mount Pinatubo, because they failed to notice that the ENSO-adjusted surface temperatures (which were adjusted for surface temperature response to ENSO with the same sign) were cooling in response to the El Niño events.

Let's look at the climate model hindcasts for the period of 1999 to 2000 that were and will be used by the IPCC in the 4th and 5th Assessment Reports, Figure 7-21. The data has been detrended to approximately "zero" before and after the responses to the 1991 eruption of Mount Pinatubo. I've also presented the Aerosol Optical Depth data required to account for the actual dip and rebound caused by it. The multi-model ensemble mean of the climate models prepared for the IPCC's upcoming 5th Assessment Report more than doubles the response needed to explain the dip and rebound.

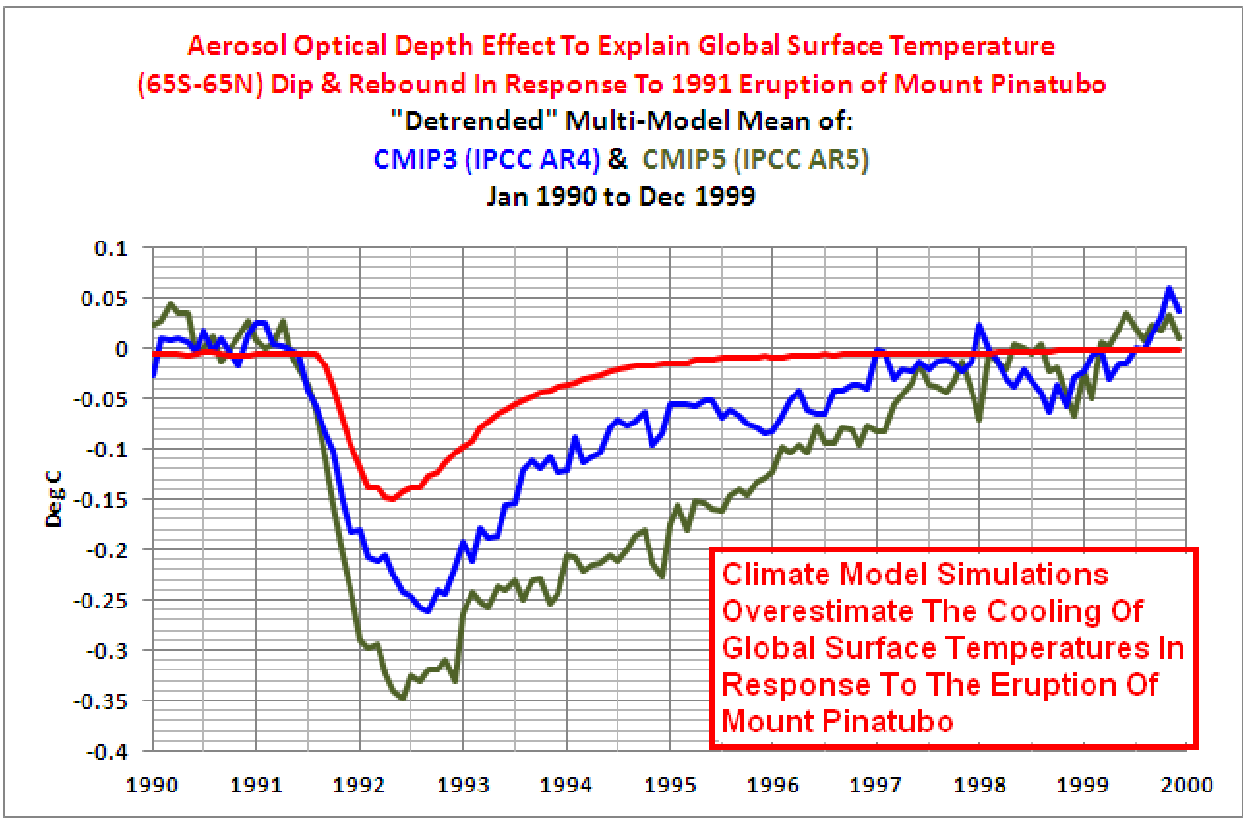

Figure 7-21

Bob Tisdale

RECAP

In summary, ENSO is a coupled ocean-atmosphere process and its effects on Global Surface Temperatures are not represented by an ENSO index. ENSO indices cannot account for the impacts of the warm water released by an El Niño event, returned to the West Pacific and redistributed from there. Therefore, any scientific papers that attempt to determine manmade global warming by removing the linear effects of ENSO with a scaled and lagged ENSO index and subtracting it from global surface temperatures are fatally flawed. Papers that make this error-filled, misleading effort include:

Foster and Rahmstorf (2011) **Global Temperature Evolution 1979–2010**

Fyfe et al (2010) **Comparing variability and trends in observed and modelled global-mean surface temperature**

Lean and Rind (2009) **How Will Earth's Surface Temperature Change in Future Decades?**

Lean and Rind (2008) **How Natural and Anthropogenic Influences Alter Global and Regional Surface Temperatures: 1889 to 2006**

Fawcett (2008) **Has the world cooled since 1998?**

Santer et al (2001) **Accounting for the effects of volcanoes and ENSO in comparisons of modeled and observed temperature trends**

Thompson et al (2008) **Identifying signatures of natural climate variability in time series of global-mean surface temperature: Methodology and Insights**

Trenberth et al (2002) **Evolution of El Niño–Southern Oscillation and global atmospheric surface temperatures**

Wigley, T. M. L. (2000) **ENSO, volcanoes, and record-breaking temperatures**

A COUPLE OF FINAL NOTES FOR THIS CHAPTER

Trenberth et al (2002) is a widely cited paper about ENSO. I've used it as a reference in this book. Only a very small portion of that paper makes the error discussed in this chapter. Trenberth et al also provide a disclaimer in the second paragraph of their Conclusions, (their paragraph 52, my boldface):

> *The main tool used in this study is correlation and regression analysis that, through least squares fitting, tends to emphasize the larger events. This seems appropriate as it is in those events that the signal is clearly larger than the noise. Moreover, the method properly weights each event (unlike many composite analyses).* ***Although it is possible to use regression to eliminate the linear portion of the global mean temperature signal associated with ENSO, the processes that contribute regionally to the global mean differ considerably, and the linear approach likely leaves an ENSO residual.***

The ENSO "residuals" are a significant contributor to the warming of Global sea surface temperatures during the satellite era, as we've shown throughout this book.

A more recent paper, Compo and Sardeshmukh (2010) **Removing ENSO-Related Variations from the Climate Record**, seems to be a very important step in the right direction. They write (my boldface):

> *An important question in assessing twentieth-century climate is to what extent have ENSO-related variations contributed to the observed trends. Isolating such contributions is challenging for several reasons, including ambiguities arising from how ENSO is defined.* ***In particular, defining ENSO in terms of a single index and ENSO-related variations in terms of regressions on that index, as done in many previous studies, can lead to wrong conclusions. This paper argues that ENSO is best viewed not as a number but as an evolving dynamical process for this purpose.***

Note: While Compo and Sardeshmukh made a step in the right direction, they missed a very important aspect of ENSO. They overlooked the significance of the huge volume of warm water that is left over after certain El Niño events, and they failed to account for its contribution to the warming of global Sea Surface Temperature anomalies since about 1975/76.

7.6 Failed Argument - Correlation is Not Causation. The Upward Steps May Occur at the Same Time as the Major El Niño Events But That Doesn't Mean Those El Niño Events Caused the Upward Steps

As noted very early in this book, I have been presenting the very obvious long-term effects of ENSO for more than 3 years. I find it surprising that the some people will attempt this tactic, claiming that the upward shifts occurring at the same time as the El Niño events does not mean the El Niño events caused the upward shifts.

The processes that cause global temperatures to warm in response to El Niño events have been studied for decades. They are known. They have been discussed in this book. I've also provided links in earlier chapters to those studies for those who want to examine the causes more closely. Further, I've provided links to animations so readers could watch how global surface temperatures responded to the monumental El Niño event of 1997/98. I've presented those animations using maps that represent 12-month averages of surface temperatures to minimize the visual effects of weather noise and seasonal components in the anomaly data.

The question is not IF global temperatures warm in response to El Niño events. The upward shifts presented in this book should raise the question: why don't surface temperatures cool proportionately during the La Niña events that follow the major El Niño events? We've answered that question. In a nutshell, after a major El Niño event there is so much warm surface and subsurface water leftover from the El Niño that surface temperatures can't cool fully during the La Niña.

7.7 Failed Argument - Move Along – There's Nothing to See Here – The Surface Temperature Record Always Shows Decadal Periods of Flat or Cooling Temperatures

As many of you are aware, the website **SkepticalScience** is not a run by persons skeptical of manmade global warming. It's run by alarmist proponents of it. They present arguments used by climate skeptics and the reasons the bloggers at SkepticalScience believe the skeptical arguments are wrong. Believe is the key word in that sentence. The authors of their blog posts present the latest climate science paper that supports their views. Regardless of whether you agree with the notion that CO2 is the primary driver of global surface temperatures, one has to admit some of the SkepticalScience data presentations can be very creative.

The good example is their **"Escalator" gif animation**. Please click on the link and watch it. I am not going to waste the time to duplicate it. It presents the Berkeley Earth Surface Temperature (BEST) anomaly data from 1973 to 2010. SkepticalScience then divides the data into independent and sometimes overlapping periods that present flat or negative linear trends. What's unique is how they have formatted their gif animation. It starts with the data and negative linear trend for the period of 1973 to 1983. The next cell in the animation adds the data and cooling trend for the period of 1980 to 1988. They repeat this process, showing how the land surface temperature warms in steps until the final period of 2002 to 2010. While all of those little upwards steps are taking place, the title block reads "How 'Skeptics' View Global Warming". Then they erase all of the short-term linear trend lines and present the long-term warming trend with the title block "How Realists View Global Warming". Personally, I think it's one of their best data presentations to date, even though their argument is flawed. Regardless…

Invariably, whenever Anthony Watts cross posts at WattsUpWithThat one of my blog posts that includes a graph showing the ENSO-caused upward steps, one of the disciples of SkepticalScience will link that graphic. They then argue that the upward steps occur while the CO2-caused warming continues.

Why does their attempt to dispute my findings fail when they link that "Escalator" gif animation? First, they're not presenting sea surface temperature data. They've presented land surface data. Land surface temperature data has much wider variations. Second, curiously, even though they are also proponents of peer-review, they've presented a dataset that's not peer-reviewed. As of this writing, the papers that support the BEST land surface temperature dataset have not been published. Third, I've also divided the global oceans into logical subsets to illustrate the ENSO-caused upward shifts. Unfortunately for the disciples of SkepticalScience, that presents them with a number of things for which they have no explanation. The SkepticalScience disciples cannot explain why the East Pacific Ocean has not warmed in 30 years. They cannot explain why the East Indian-West Pacific subset or the South Atlantic-Indian-West Pacific subset only warm during major El Niño events. They cannot explain why those two subsets don't cool proportionately during the La Niña that trail the major El Niño events. How do I know they can't explain why those things happen? I ask them to explain, and I receive no replies. That's the time they change subjects or they stop arguing and disappear.

In this book, I have presented the reasons why the ocean basins warm naturally. Those reasons have been discussed and illustrated a number of ways throughout it. The processes that cause the upward steps should now be well understood by you the reader. If not, refer again to **Section 5 The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies.**

7.8 Myth - The Warm Water Available for El Niño Events Can Only be Explained by Anthropogenic Greenhouse Gas Forcing

Occasionally, a proponent of anthropogenic global warming will state in a blog comment that the warm water available for El Niño events can only be explained by anthropogenic greenhouse gas forcings. They provide nothing to support the claim. It seems as though the thought suddenly occurs to them as they're reading one of my posts about ENSO and they simply express their belief.

In other words, this argument is presented by someone who has not bothered to examine the instrument temperature record and who has a very limited understanding of the ENSO process, particularly how the warm water that fuels an El Niño is created.

The warm water for an El Niño event is created during the preceding La Niña or during the 3-year La Niña event before it. This was initially presented in the cartoon-like illustrations of **Chapter 1.2 The ENSO Annotated Illustrations**. Refer to Figures 1-22 and 1-23. There are more detailed discussions, with data for confirmation, in **Chapter 3.10 The Recharge of Ocean Heat during the La Niña**, and in the opening portion of **Chapter 5.9 A Look at the Long-Term Impacts of ENSO and Other Natural Variables on Ocean Heat Content Data.**

Basically, during a La Niña event, trade winds are stronger than normal. The stronger trade winds reduce cloud cover, which allows more sunlight than normal to warm the tropical Pacific to depths of 100 meters, with the warming decreasing in intensity with depth. Some of that additional warm water created by the additional sunlight collects in the west Pacific Warm Pool to be used by the next El Niño and some of that warm water is carried poleward in the Pacific and into the eastern tropics of the Indian Ocean.

A subtle twist of this argument by proponents of manmade global warming is, they claim I fail to present the forcings that create the warm water. They obviously haven't read the discussions of La Niña and how downward shortwave radiation (visible sunlight) in the NINO3.4 region can increase as much as 40 watts per square meter above normal during a La Niña. Refer again to **Chapter 3.10 The Recharge of Ocean Heat during the La Niña.**

7.9 Myth - The Frequency and Strength of El Niño and La Niña Events are Dictated by the Pacific Decadal Oscillation

I devoted an entire chapter in Section 4 to the relationship between ENSO and the Pacific Decadal Oscillation. Refer to **Chapter 4.10 ENSO Versus the Pacific Decadal Oscillation (PDO).**

The Recap of that chapter reads (boldface added here):

The Pacific Decadal Oscillation Index is a statistically created dataset. It does not represent the sea surface temperature of the North Pacific, where it is derived. It basically represents the spatial pattern of the sea surface temperature anomalies in the North Pacific, north of 20N. There is no mechanism through which the Pacific Decadal Oscillation could raise and lower global temperatures. **The Pacific Decadal Oscillation does not drive ENSO. In fact, the Pacific Decadal Oscillation lags ENSO so it would be difficult for the PDO to do so. The Pacific Decadal Oscillation Index data is also inversely related to the sea surface temperatures of the North Pacific, which makes it even more difficult for it to contribute to the multidecadal variations in global temperatures.**

Please don't assume this chapter is an attempt to downplay the importance of the Pacific Decadal Oscillation Index. It is useful. The Pacific Decadal Oscillation Index is used by meteorologists for weather predictions. The early papers about the Pacific Decadal Oscillation discussed its impact on salmon production, so it is also useful in those endeavors. However, the Pacific Decadal Oscillation Index cannot be used to explain epochs of global warming or cooling because the Pacific Decadal Oscillation Index does not represent a process through which the North Pacific could raise or lower global temperatures.

7.10 Failed Argument - The East Indian-West Pacific and East Pacific Sea Surface Temperature Datasets are Inversely Related. That Is, There's a Seesaw Effect. One Warms, the Other Cools. They Counteract One Another.

This argument has been tried more than once. It's typically voiced when I present a gif animation that shows the East Pacific warming and cooling in response to ENSO and shows the East Indian-West Pacific sea surface temperatures varying in the opposite direction. See **Animation 7-1**. The argument is, the seesaw effect between the East Pacific and the East Indian-West Pacific datasets—better described as their opposing warming and cooling—causes the two datasets to counteract one another. The argument is intended to downplay the importance of the variation in the sea surface temperatures of the East Indian-West Pacific subset.

The gif animation linked above is Figure 9 from the November 2009 post **More Detail On The Multiyear Aftereffects Of ENSO – Part 2 – La Niña Events Recharge The Heat Released By La Niña Events AND…** The continuation of the title is, *…During Major Traditional ENSO Events, Warm Water Is Redistributed Via Ocean Currents.*

My blog posts are well illustrated, like this book. Many times those reading the post aren't actually reading the text; they're trying to get an overview by skimming through the notes on the illustrations. Those readers noticed the seesaw effect in that animation and spew forth their comment. If they had read the text, or had continued skimming through the illustrations, they would have realized I had answered their concerns a few paragraphs and illustrations later. For example, the following text and illustrations are from that post. I've changed the illustration numbers for the book, and replaced the acronym SST with sea surface temperature:

Figure 7-22 is a comparison of East Pacific sea surface temperature anomalies and the sea surface temperature Anomalies of the East Indian and West Pacific Oceans. I've also included scaled NINO3.4 sea surface temperature anomalies as a reference for timing. The 1986/87/88 and 1997/98 El Niño events and the initial portions of the subsequent La Niña events are highlighted. It is very clear that the two datasets are out of phase.

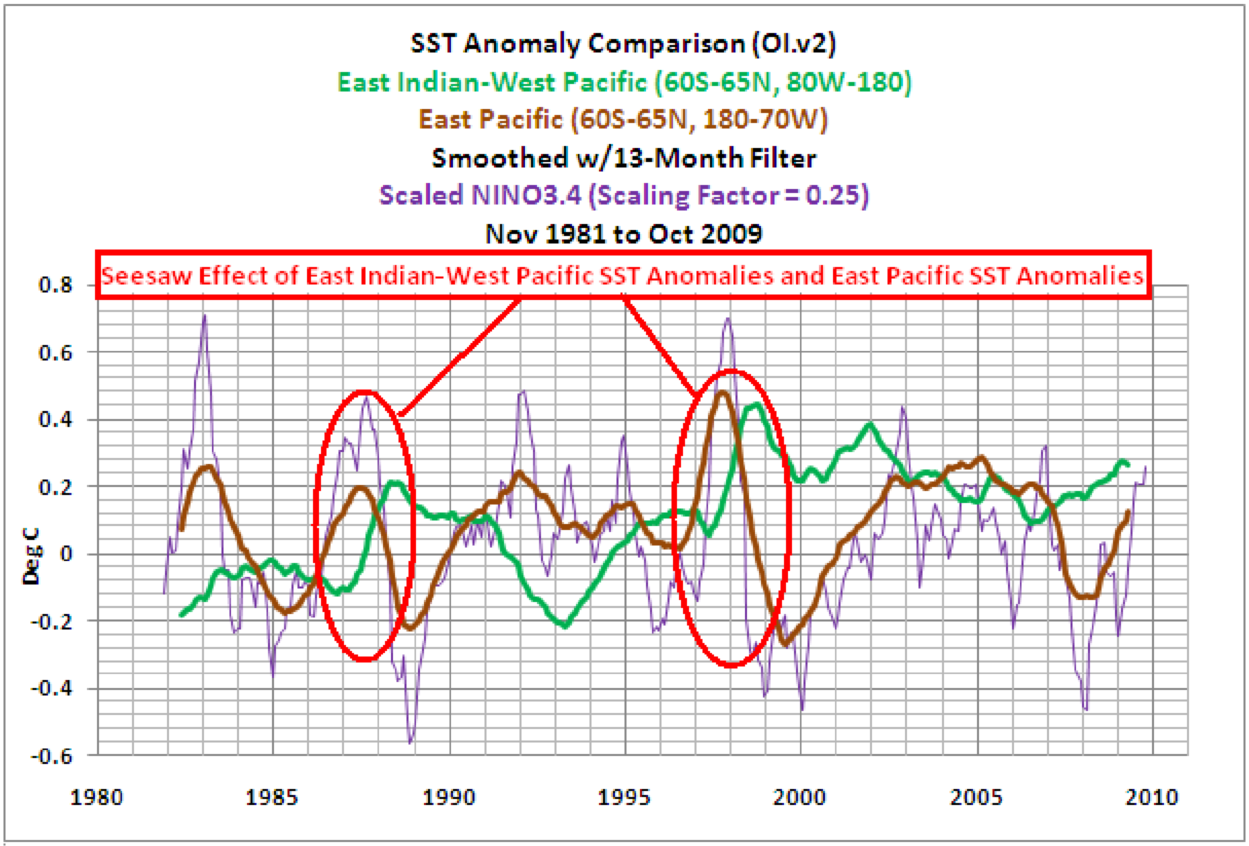

Figure 7-22 Bob Tisdale

Figure 7-23 is the same comparison graph, but in it, I've highlighted a different portion of the data. The response of the East Pacific sea surface temperature anomalies to the major El Niño events of 1986/87/88 and 1997/98 is very visible in that comparison graph. On the other hand, note that the sea surface temperature anomalies of the East Indian and West Pacific cool very little (the area highlighted) while the sea surface temperature anomalies in the East Pacific are rising dramatically. This happens because El Niño events are fueled by subsurface waters from the Western Tropical Pacific, from depths to 300 meters in the Pacific Warm Pool. These subsurface waters are not included in sea surface temperature measurements.

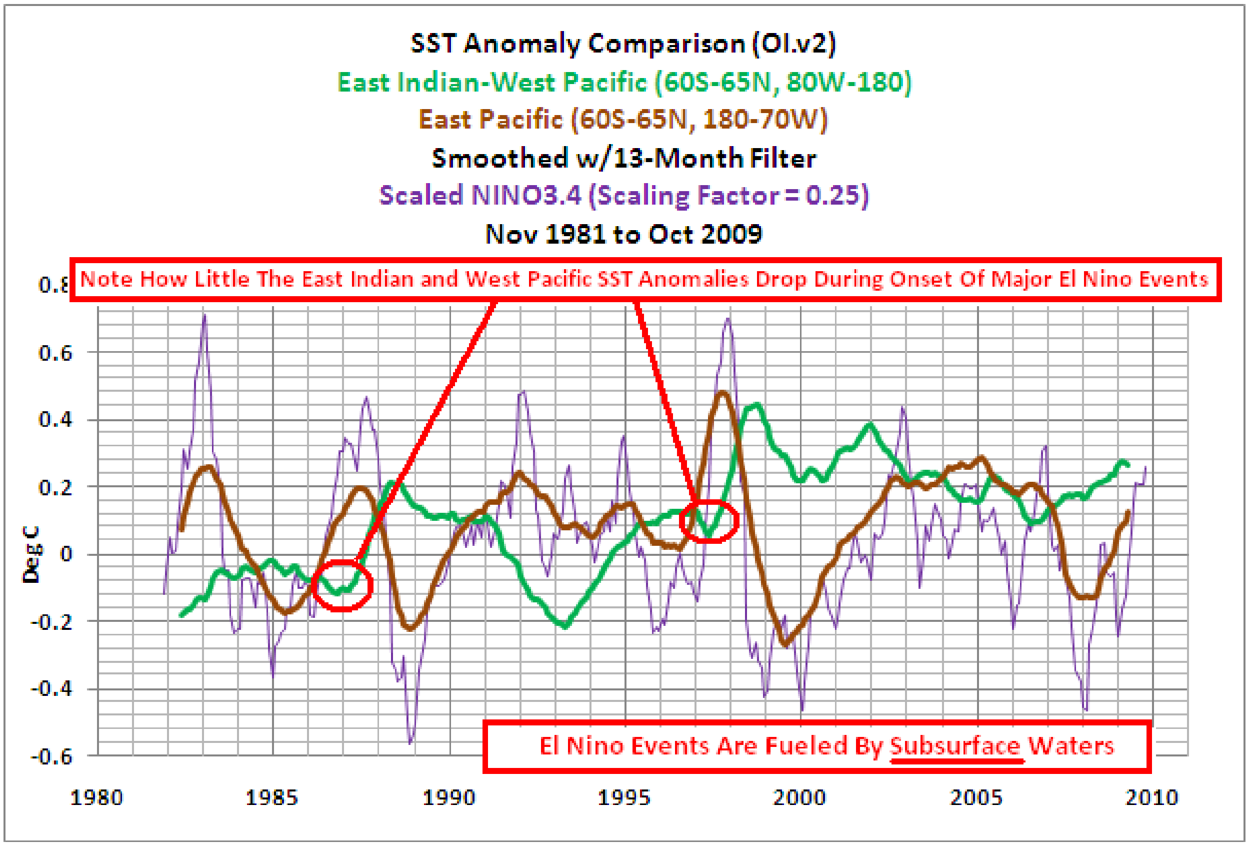

Figure 7-23 Bob Tisdale

In summary, the seesaw effect only occurs during, and is caused by, the transition from El Niño to La Niña, when the warm water that's left over from the El Niño is carried back to the western Pacific and eastern Indian Oceans. The seesaw effect does not occur to the same level during the evolution phase, when the sea surface temperatures of the East Indian-West Pacific data cool very slightly as the East Pacific warms significantly. The reason for this is, the majority of the warm water that fuels an El Niño comes from below the surface of the west Pacific Warm Pool.

RECAP

The seesaw effect basically shows the impact on the East Indian-West Pacific sea surface temperature data of the warm water from the El Niño that's left over when the El Niño has ended in the eastern tropical Pacific. The seesaw effect does not occur during the evolution of the El Niño, because most of the warm water that fuels a major El Niño event comes from below the surface of the west Pacific Warm Pool. It is, therefore, not a true seesaw effect throughout the evolutions and decays of both phases of ENSO.

7.11 Failed Argument - El Niño Events Don't Create Heat

A simple and seemingly powerful argument was tried a couple of years ago. The argument was something to the effect of: El Niño events don't create heat.

In some respects, the statement is correct; in others it's wrong. Let's discuss the tropical Pacific, which is impacted directly by the ENSO event, and then we'll discuss the areas outside of the tropical Pacific that are affected indirectly through teleconnections.

TROPICAL PACIFIC

We know warm water from the surface and below the surface of the west Pacific Warm Pool migrates east during an El Niño event. Therefore, an El Niño has not created any warm water there. It simply relocated it. The ocean heat content of the tropical Pacific drops during an El Niño and that means the El Niño released heat to the atmosphere.

The statement so far is correct. El Niño events do not "add heat" to the tropical Pacific. They redistribute warm water and release heat.

Unfortunately, the term El Niño can have multiple meanings. To some, El Niño is a phase of ENSO; to others, El Niño represents the phenomenon as a whole. If the term El Niño is used as we've been using it throughout this book, as a phase of ENSO, the statement is correct. If El Niño is used as the general name for the ocean portion of ENSO, encompassing both El Niño and La Niña events, then the statement is wrong. Let's recall why it's wrong.

As we've discussed a number of times, the La Niña phase raises Ocean Heat Content of the tropical Pacific through a known process: stronger trade winds yield less cloud cover, which in turn yields more sunlight penetrating and warming the tropical Pacific. As illustrated in **Chapter 5.9 A Look at the Long-Term Impacts of ENSO and Other Natural Variables on Ocean Heat Content Data,** three-year La Niña events create the initial supply of warm water that's then used by the El Niño events that follow for a decade or two, with the shorter La Niña replacing part of the warm water released by the individual El Niño events. That process continues until the next three-year La Niña, or until an unusual La Niña like the 1995/96 La Niña, which supplied the warm water for the monstrous 1997/98 El Niño.

REGIONS OUTSIDE OF THE TROPICAL PACIFIC

Let's assume for this part of the discussion that El Niño is referring to the phase of ENSO and not ENSO as a whole. In that sense, the argument that El

Niño events don't add heat is wrong when we look at regions outside of the tropical Pacific.

During an El Niño, around the globe, some regions warm, while others cool. The areas that warm and the amount they warm outweigh the areas that cool, so global surface temperatures warm during an El Niño. There's no direct transfer of warm water between the tropical Pacific to many of these places, so surface temperatures vary due to changes in atmospheric circulation associated with the El Niño. For example, we discussed how the tropical North Atlantic warms in response to an El Niño in **Chapter 4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific**. During an El Niño, trade winds in the tropical North Atlantic weaken. With the weaker trade winds, there is less evaporation, and there is less upwelling of cool water from below the surface. As a result, surface temperatures warm.

Because the sea surface temperature anomalies in the tropical North Atlantic warms during an El Niño due primarily to a decrease in evaporation, one would expect ocean heat content for the region to warm as well during the El Niño. There's very clear evidence that happens. Refer to Figure 7-24. It compares the ARGO-era ocean heat content anomalies for the tropical North Atlantic to scaled (0.3) and lagged (12-months) NINO3.4 sea surface temperature anomalies. Clearly, there is an ENSO component to the variations in tropical North Atlantic ocean heat content. The North Atlantic ocean heat content clearly responds to ENSO events.

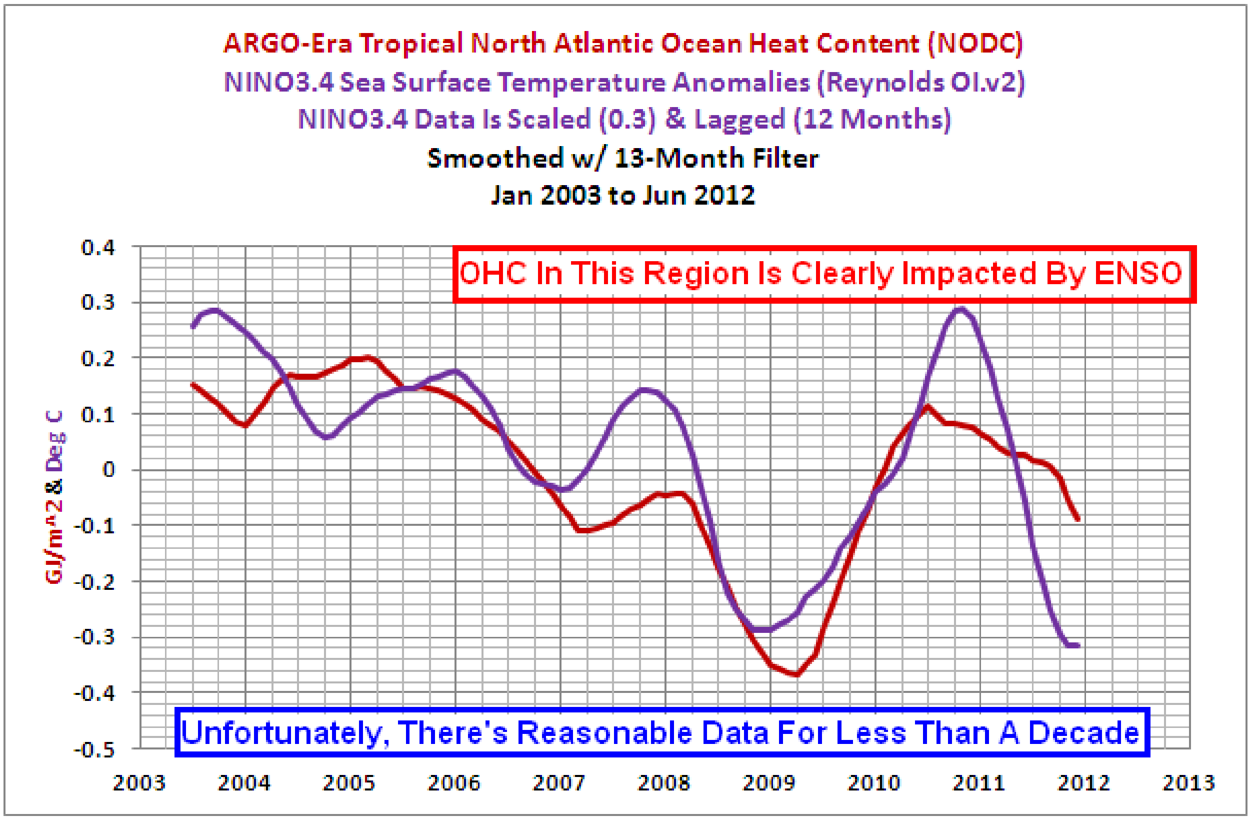

Figure 7-24 Bob Tisdale

As noted on the illustration, it is unfortunate that reasonable ocean heat content data exists for less than a decade. In a few more decades, researchers may be able to have a reasonable idea of how ENSO impacts ocean heat content around the global.

7.12 Failed Argument - Paper "x" Does NOT Support the Theory that ENSO Can Contribute to the Long-Term Warming Trend

Recently, during blog discussions of the long-term impacts of ENSO on global surface temperatures, proponents of anthropogenic global warming have taken a new tack with their arguments. They'll link scientific papers about ENSO and note that the paper does not support my findings that ENSO is a major contributor to the warming of global surface temperatures over the past 30 years. Their intent—to downplay the findings presented in this book—is clear. This tactic seems to be taken by those who have little understanding of ENSO, and this becomes obvious when many of the papers they link have little to do with the topics being discussed on a particular thread. It appears they're using key words in their Google Scholar searches and providing links they think are relevant, without understanding what they're linking.

The bloggers who employ this tactic also fail to understand something very basic. Those who have followed my blog discussions over the past 3 years are fully aware that there are no scientific papers written to date that support my findings about the long-term effects of major ENSO events. In fact, my post from April 2011 is titled **How Can Things So Obvious Be Overlooked By The Climate Science Community?**

I linked an important recent paper in the Recap of **Chapter 7.5 ENSO Only Adds Noise to the Instrument Temperature Record and We Can Determine its Effects through Linear Regression Analysis, Then Remove Those Effects, Leaving the Anthropogenic Global Warming Signal.** Compo and Sardeshmukh (2010) **Removing ENSO-Related Variations from the Climate Record** is a very important step in the right direction.

While there may be no scientific papers that support my findings about the long-term effects of ENSO, all data presented in the book and all of the papers linked support and confirm the general discussions of ENSO. That is, the ENSO processes are as I have described and illustrated, including the upward steps in the East Indian-West Pacific dataset and the larger South Atlantic-Indian-West Pacific dataset. It will take time for the scientific community to acknowledge the long-term impacts of major ENSO events.

7.13 Old Failed Argument – But the Arctic Sea Ice is Melting. Isn't that Proof of Anthropogenic Global Warming? (Typical Example of the Debate Tactic Called Redirection)

Arctic sea ice extent and area are poised to reach new lows for the satellite era in 2012. By the time this book is published they may have reached new lows. Many persons believe this is proof of anthropogenic global warming. I've recently been criticized for not being concerned about the loss of seasonal sea ice.

The reality is, the Arctic sea ice will likely reach new seasonal lows this year, if it hasn't by the time you're reading this. This year's ice loss means the Arctic has warmed since the satellites began measuring sea ice extent and area—and that weather conditions have exacerbated the loss during that time. It does not indicate the cause of warming. The Arctic sea ice loss is simply long-term responses to the warming, regardless of the cause, and the weather conditions.

We've shown and discussed in **Chapter 5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events** that about 85% of the warming of land plus sea surface temperatures between the latitudes of 65S to 65N can be explained by the natural warming of the global oceans. There I had noted:

In the post **Can Most Of The Rise In The Satellite-Era Surface Temperatures Be Explained Without Anthropogenic Greenhouse Gases?**, which was referred to a couple of times in this chapter, we determined that about 85% of the global warming signal over the past 30 years could be accounted for with natural variables, primarily ENSO and the secondary effects of ENSO. Keep that percentage in mind. It'll come up again.

In **Chapter 8.11 Since Climate Models used by the IPCC Don't Simulate ENSO Properly and Don't Account for the Long-term Impacts of ENSO, Can Climate Models be used to Project Future Climate?** we'll confirm that 85%, using climate model simulations. I present the outputs of global climate models that were run with sea surface temperature and sea ice observational data as the only model forcings, and compare them to the outputs of the same global models run with anthropogenic forcings in addition to the sea surface temperature and sea ice observational data. 85% of the warming is explained by the warming of the oceans.

There are differences in the latitudes between those two analyses. One deals only with the latitudes of 65S-65N, while the models covered the globe from pole to pole, yet the results were exactly the same. This implies that on a percentage basis the additional polar data has little impact on the results. The oceans still represent 85% of the warming.

For the Arctic, there's of a phenomenon called polar amplification. The following describes polar amplification and presents how poorly climate models simulate it. It's a reprint of my post **Polar Amplification: Observations versus IPCC Climate Models.** I've removed a portion that describes zonal-mean graphs, because we should be familiar with them by now.

We've illustrated and discussed polar amplification in a few posts in the past. See **here** and **here**. Wikipedia has a **short blurb about it**:

> ***Polar amplification*** *is the greater temperature increases in the Arctic compared to the earth as a whole as a result of the effect of feedbacks and other processes[1] It is not observed in the Antarctic, largely because the Southern Ocean acts as a heat sink and the lack of seasonal snow cover.[2] It is common to see it stated that "Climate models generally predict amplified warming in polar regions", e.g. Doran et al.[3]. However, climate models predict amplified warming for the Arctic but* only modest warming for Antarctica.[2]

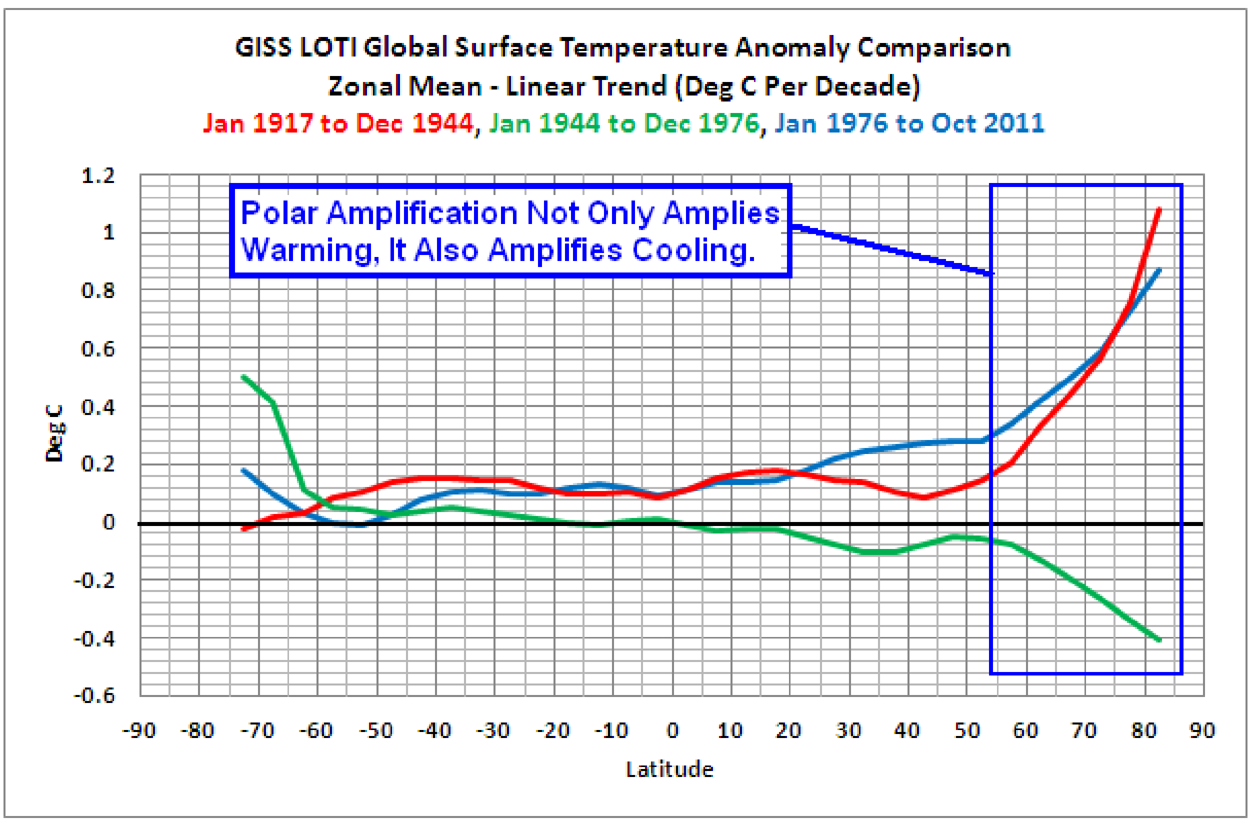

Figure 7-25

Bob Tisdale

Many discussions about polar amplification around the climate-related blogosphere have similar definitions, leading readers to believe polar amplification is a phenomenon that only occurs in a warming world. That's incorrect. If we divide the data since 1917 into its cooling period (1944-1976) and two warming periods (1917-1944 and 1976-2011), and present the surface temperature linear trends on a zonal-mean (latitudinal) basis, Figure 7-25, we can see that polar amplification works both ways. That is, during a period when global temperatures cool, like 1944-1976, there is greater cooling in the Arctic than elsewhere. Note also that, according to the GISS Land-Ocean Temperature Index (LOTI) data, the rate at which the Arctic warmed was higher during the early warming period (1917-1944) than it has been during the current warming period (1976-present).

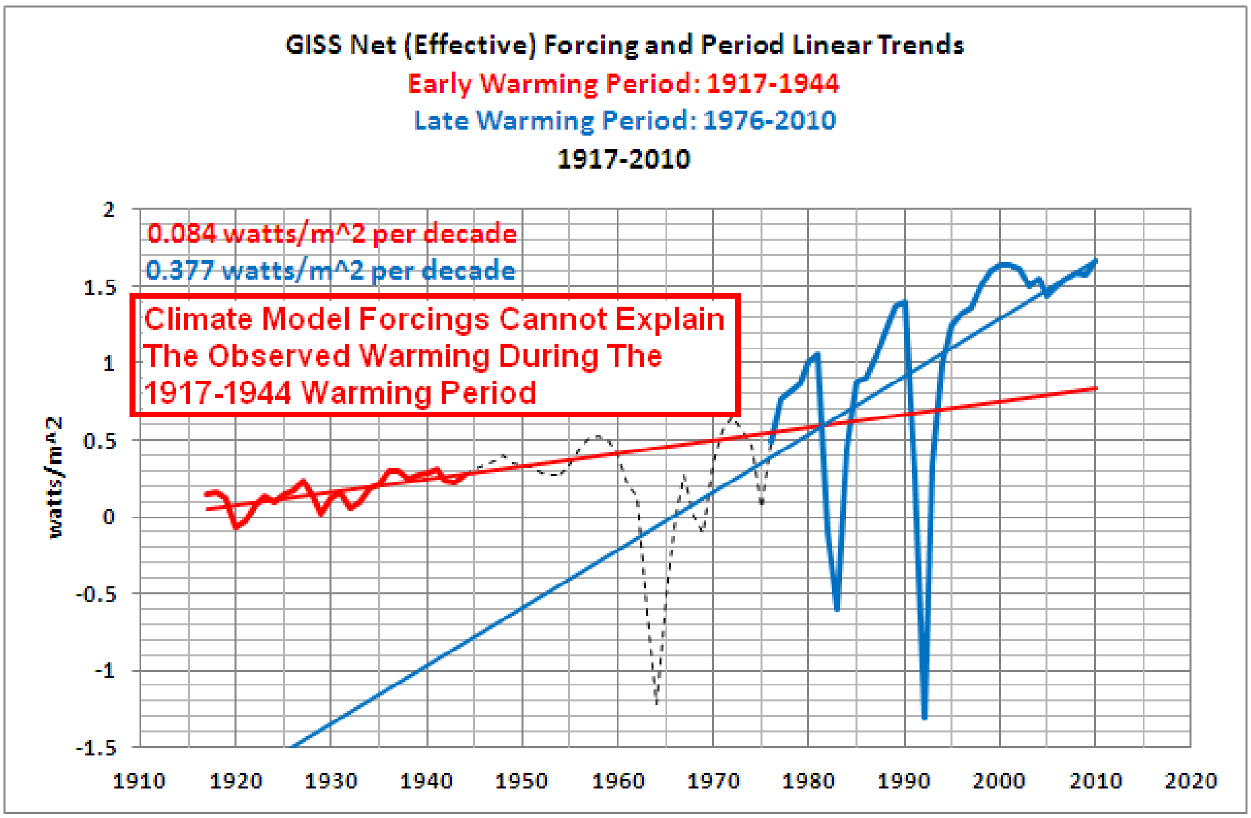

Figure 7-26

Many of you will find it odd that global surface temperatures warmed at such similar rates during the early and late warming periods—especially when we consider that the net effective forcings during the late warming period rose at a rate that's about 4.5 times greater than during the early warming period. See Figure 7-26. The GISS net forcing data is available **here**.

That's one of the ways the surface temperature record contradicts the hypothesis of anthropogenic global warming. According to the net effective forcing data (and the model simulations presented later in this post), the rate at which surface temperatures warmed during the late warming period should much higher than during the early warming period. It's not. The two periods warmed at similar rates. This was discussed in more detail in Section 2 of **my [first] book**. In fact, Figure 7-26 above is an updated version of **Figure 2-17** from the book.

HOW WELL DO THE IPCC's CLIMATE MODELS HINDCAST AND PROJECT POLAR AMPLIFICATION?

One-word answer: poorly. I'll leave it up to readers to come up with a two-word answer.

We'll compare linear trends (deg C/decade) of the GISS Land-Ocean Temperature Index (LOTI) data and the simulations of global surface temperature by the multi-model ensemble mean of the CMIP5-archived coupled climate models that have been prepared for the upcoming 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). I've used the RCP 8.5 scenario hindcast/projection because it was simulated by the most models and because it is similar to most of the other scenarios during these periods. See **Preview of CMIP5/IPCC AR5 Global Surface Temperature Simulations and the HadCRUT4 Dataset**. And again, we'll use the zonal-mean graphs. [Note: The simulations in the CMIP5 archive have been updated with more models since this post was written, and other RCPs may now have more ensemble members. The difference between the RCPs during this period would not alter the results drastically since this was primarily a look at historical climate simulations.]

As shown in Figure 7-27, the models do a good job between the latitudes of 30N to 70N of simulating the rates at which global surface temperatures warmed during the later warming period (1976 to present). They underestimate the warming north of 70N and, for the most part overestimate the warming south of 30S. For example, at the equator, the models are hindcasting/projecting warming that is about 1.6 times higher than the rate that's been observed since 1976 [(0.186 deg C/decade)/(0.113 deg C/decade)].

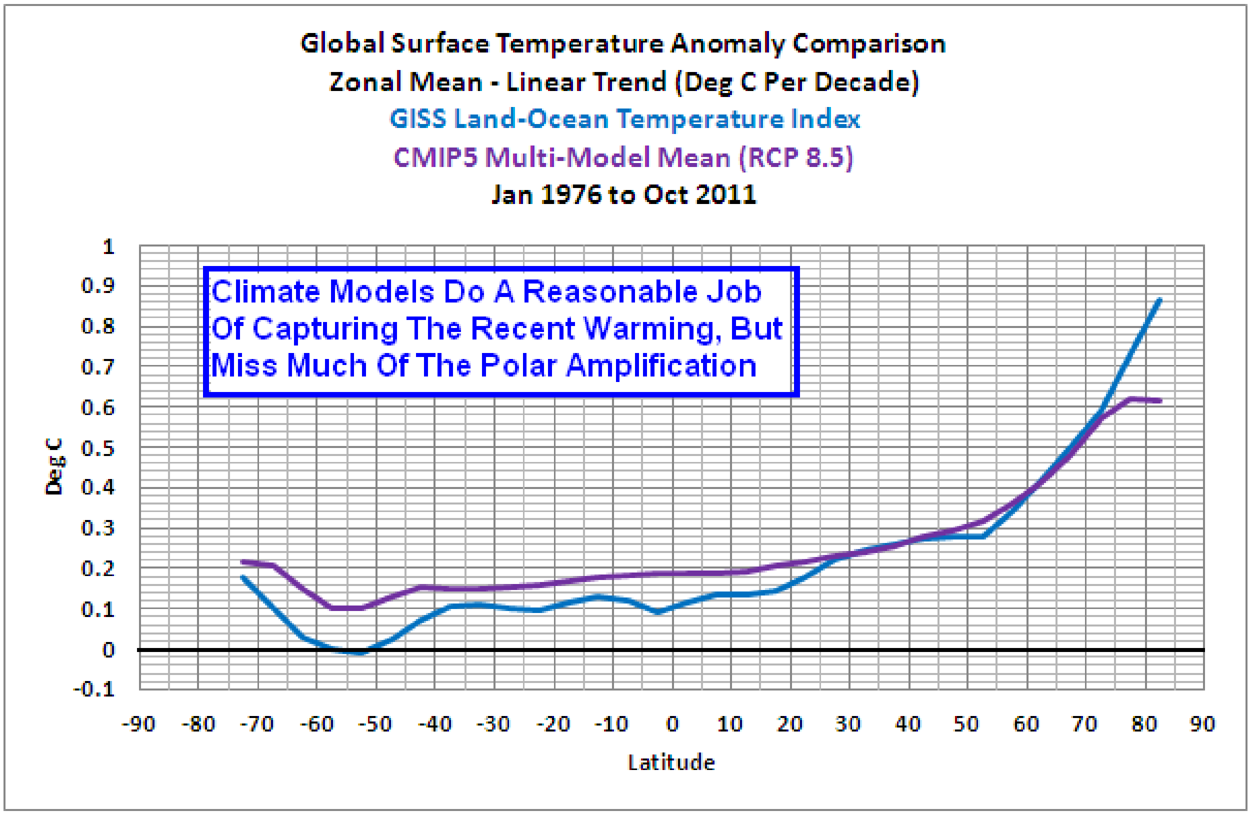

Figure 7-27

Bob Tisdale

During the mid-20th Century "flat temperature" period, Figure 7-28, the models do reasonably good job between the latitudes of 60S-60N, but fail to capture the observed warming of the Southern Ocean and the polar-amplified cooling over the Arctic.

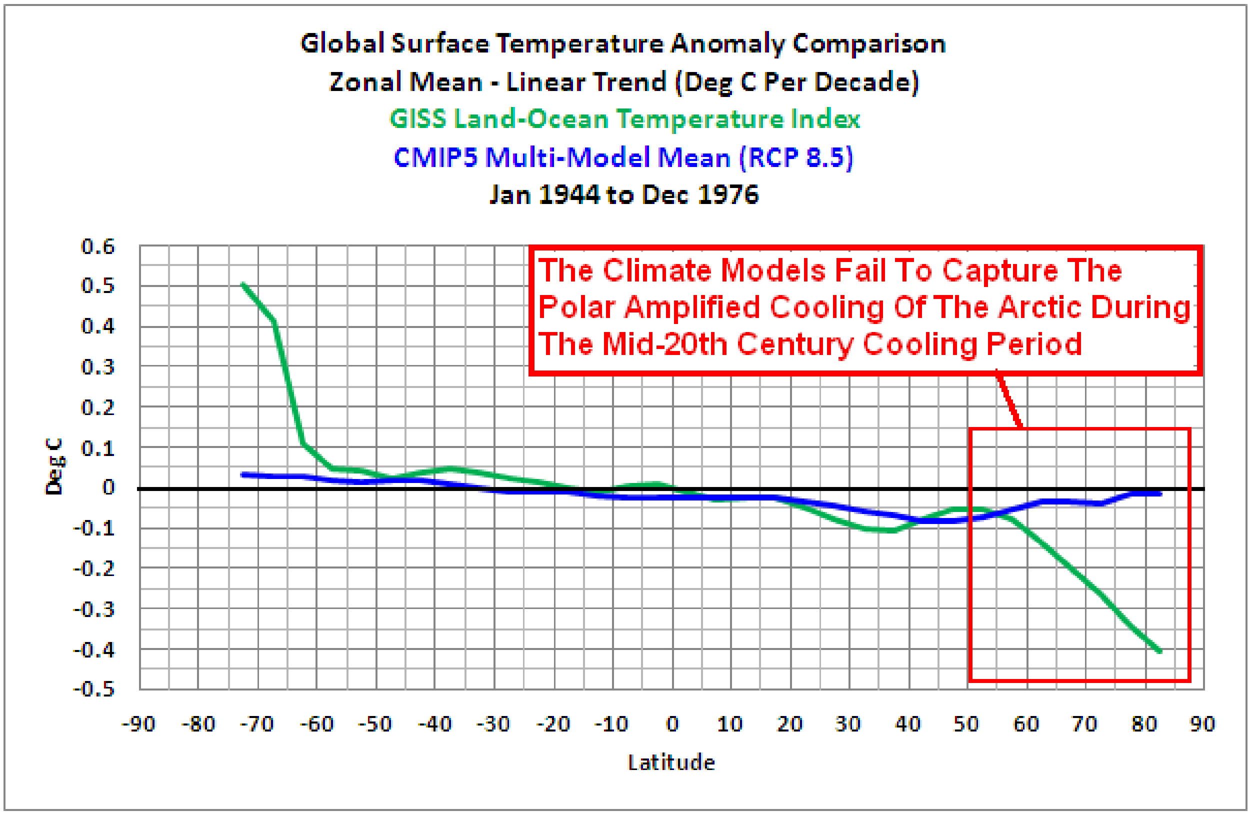

Figure 7-28

Bob Tisdale

And for the early warming period, Figure 7-29, the models are not simulating any polar amplification. They missed the boat during this period too.

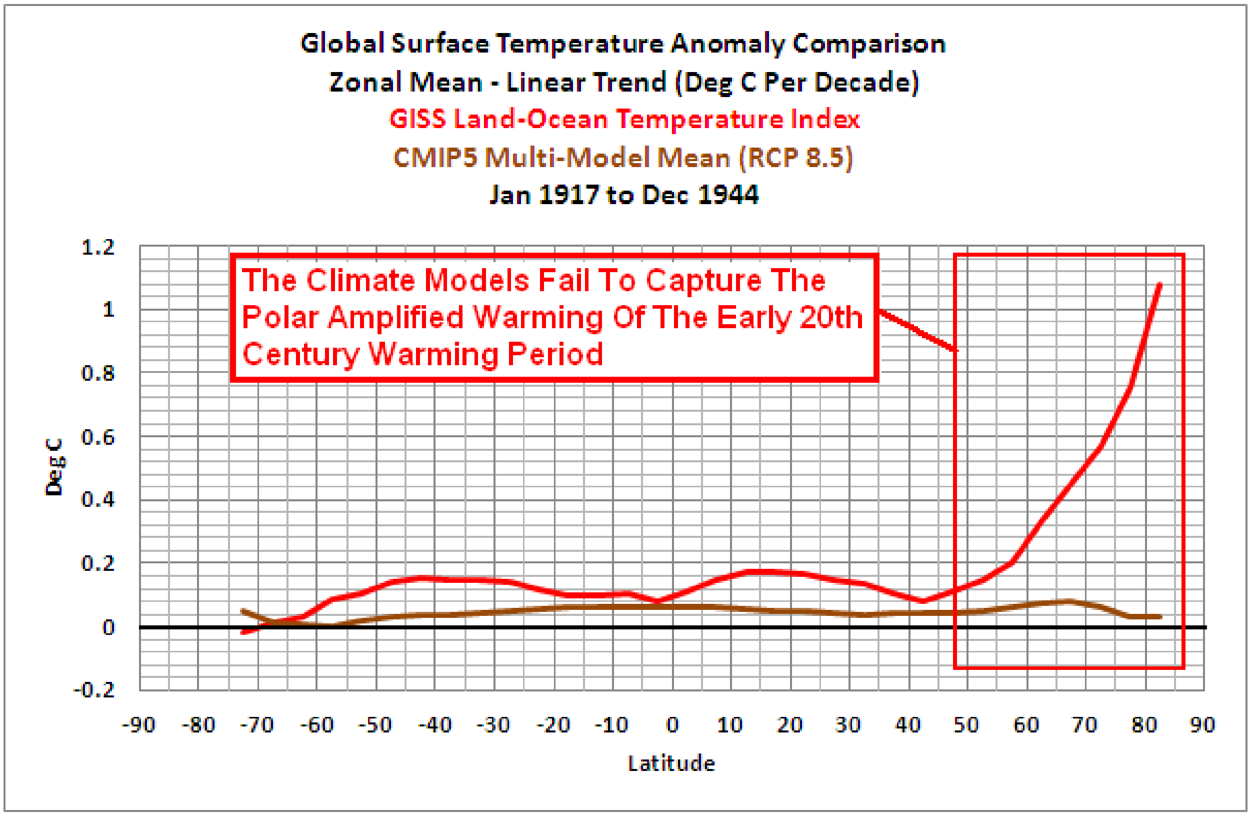

Figure 7-29

Bob Tisdale

And for those interested, Figure 7-30 compares the trends of the simulated warming rates for the three periods on a zonal-mean basis. The brown curve of the early warming period should be similar to the purple curve of the late warming period.

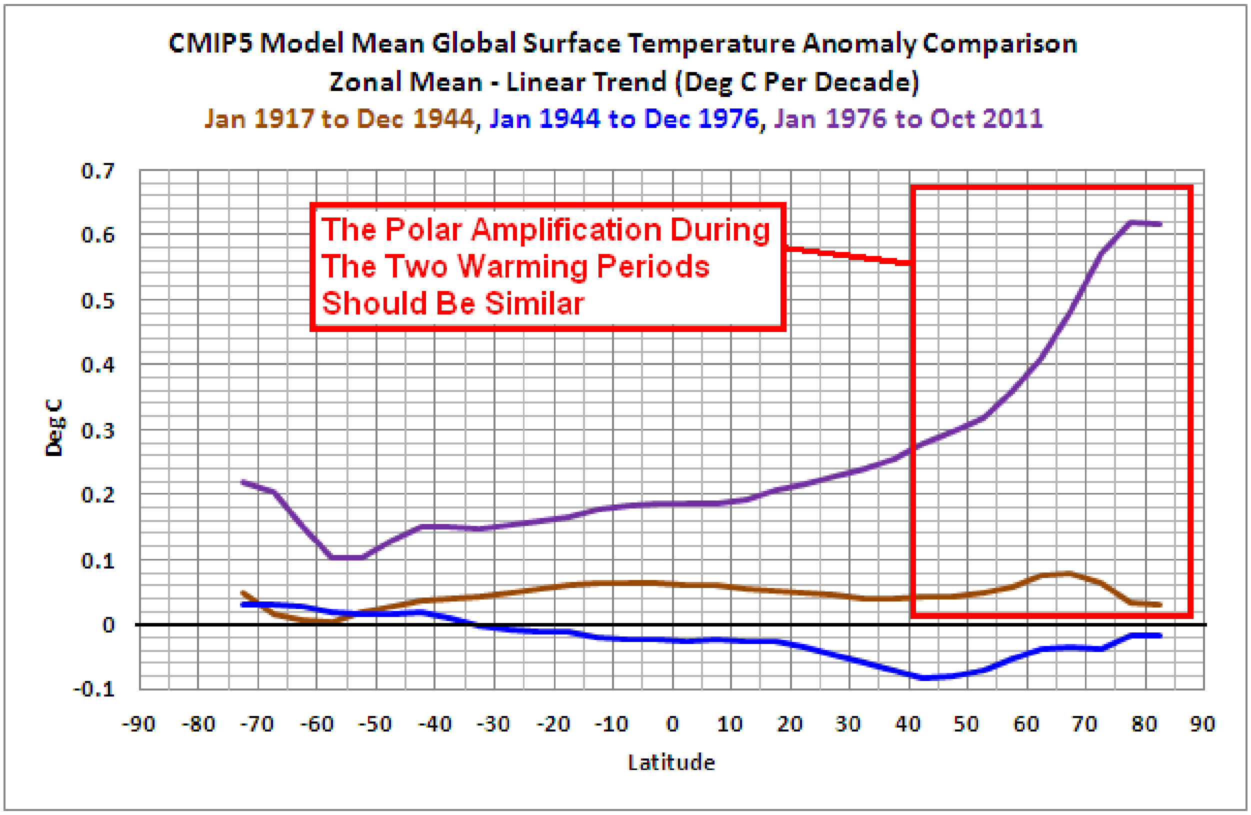

Figure 7-30

Bob Tisdale

CLOSING [TO THE BLOG POST DUPLICATED HERE]

This post was just another way of illustrating that the climate models employed by the IPCC show no skill at being able to simulate the surface temperatures experienced over (nearly) the last century. We've illustrated and discussed these failings numerous ways in past posts. Refer to the other IPCC model-data comparisons at my blog or in my book.

MY FIRST BOOK

As illustrated and discussed in ***If the IPCC was Selling Manmade Global Warming as a Product, Would the FTC Stop their deceptive Ads?***, the IPCC's climate models cannot simulate the rates at which surface temperatures warmed and cooled since 1901 on a global basis, so their failings on a zonal-mean basis as discussed in this post come as no surprise.
Additionally, the IPCC claims that only the rise in anthropogenic greenhouse gases can explain the warming over the past 30 years. Satellite-based sea surface temperature disagrees with the IPCC's claims. Most, if not all, of the warming of global sea surface temperature is shown to be the result of a natural process called the El Niño-Southern Oscillation, or ENSO. This is discussed in detail in my first book, ***If the IPCC was Selling Manmade Global Warming as a Product, Would the FTC Stop their deceptive Ads?***,

which is available in pdf and Kindle editions. A copy of the introduction, table of contents, and closing can be found **here**.

RECAP

One of the factors that impact the loss of seasonal Arctic sea ice is the polar amplified warming of the Northern Hemisphere land plus sea surface temperatures. We've shown that much (about 85%) of the global warming over the past 30 years can be explained as the natural warming of the global oceans. This natural warming is primarily the response of the global oceans to a number of strong ENSO events, and it was compounded by another mode of natural variability called the Atlantic Multidecadal Oscillation. Considering that polar amplification simply exaggerates the warming, or cooling, regardless of cause, we might assume the vast majority of the seasonal sea ice loss that's happened this year is primarily a response to the natural warming of the global oceans as well.

Climate models cannot be relied on as references for polar amplification. The fact the models have done a reasonable job of simulating the recent warming is happenstance. They were not able to simulate the polar amplified warming of the early 20th Century or the polar amplified cooling of the mid-20th Century cooling period.

Section 8 – Q&A

This section presents answers to questions I have been asked about ENSO and about the multiyear aftereffects of the major ENSO events. Some are questions I sought answers for while preparing this book, and some were asked in response to a blog post in which I asked for readers to submit questions to be answered in the book. Refer to the post **Q&A for Who Turned on the Heat?** The following is a list of the chapters:

8.12 Can the Same Upward Steps Caused by Major El Niño events be seen during the Early Warming Period of the 20th Century?

8.13 What is the Springtime Predictability Barrier?

8.14 What are the Differences between the Statistical and Dynamical Models used to Predict the next ENSO Event?

8.15 What is the Pacific Meridional Mode?

8.16 How Far in Advance can the Onset of an El Niño be Predicted?

8.17 Why do ENSO Events have a Greater Impact on the Northern Hemisphere?

8.18 Do Climate Models Simulate Pacific Sea Surface Temperature Trends Better During Multidecadal Periods when ENSO Isn't Skewed Toward El Niño?

8.19 Are there Other Ways to Show that ENSO Causes the Long-Term Trends in Global Sea Surface Temperatures?

8.20 Could the 1997/98 El Niño have been Stronger?

8.21 Is ENSO Only Noise in the Global Surface Temperature Record?

8.1 Since El Niño Events Create an Effect Where Sea Surface Temperatures Appear to Ratchet Upwards, How Can Global Sea Surface Temperatures Flatten or Cool for Multidecadal Periods?

To answer this question, we'll divide the global oceans into the three major subsets we've used in this book: the East Pacific, the "North Atlantic Plus", and the South Atlantic-Indian-West Pacific. The "ratcheting" takes place primarily in the South Atlantic-Indian-West Pacific subset.

The East Pacific sea surface temperature anomalies from pole to pole (90S-90N, 180-80W) have not warmed in 30 years, while the rest of the global oceans have warmed around it.

The sea surface temperature anomalies of the "North Atlantic Plus" dataset (0-90N, 80W-40E) has the additional mode of natural variability known as the Atlantic Multidecadal Oscillation. Since 1870, the North Atlantic Plus data has warmed at rates of about 0.21 to 0.296 deg C per decade and cooled at rates of -0.035 to -0.066 deg C per decade. See Figure 8-1. Note that the trend of the recent warming period is less than the trend of the earlier warming period.

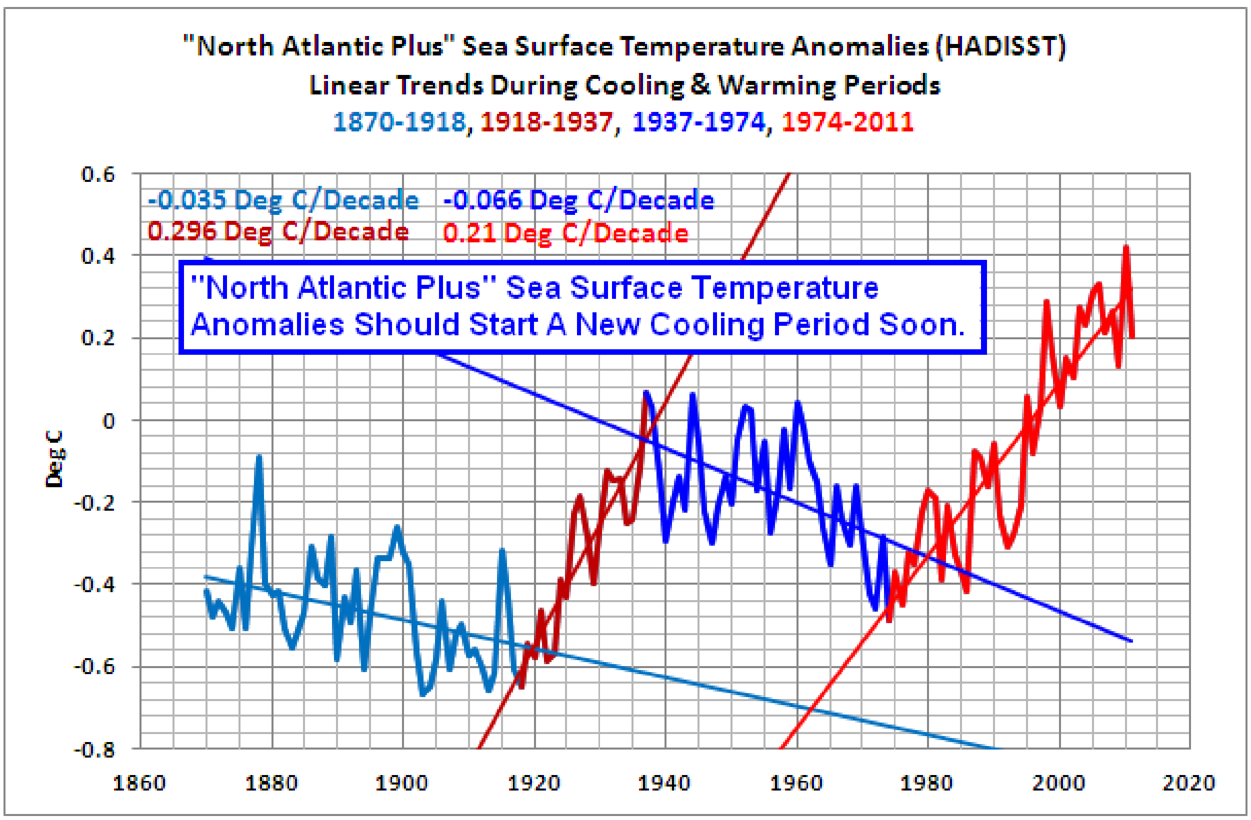

Figure 8-1

Bob Tisdale

We should expect the "North Atlantic Plus" Data to shift to its cooling mode in the not-too-distant future, if it hasn't started already. As you'll note, the "North Atlantic Plus" data could also simply flatten for a decade or more. The trend for the period from 1937 to 1960 is basically flat at +0.005 deg C per decade (trend not illustrated). It's likely the trend of the "North Atlantic Plus" dataset will at least flatten for a few decades sometime in the near future.

That leaves the South Atlantic-Indian-West Pacific dataset to discuss. Refer to Figure 8-2. This dataset cooled slightly between the major El Niño events. In other words, the only time they warmed was during the major El Niño events.

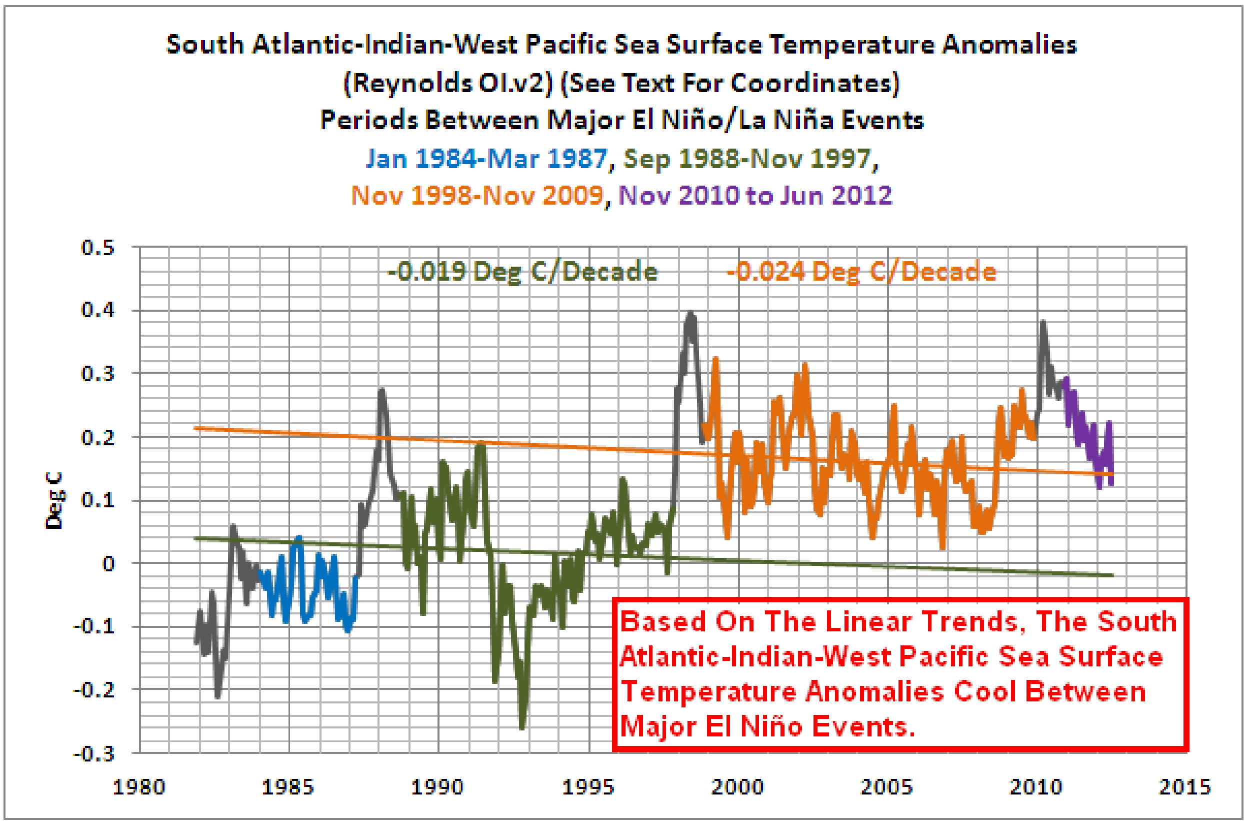

Figure 8-2

Bob Tisdale

Suppose there are no "Super" El Niño Events for a Decade or Two

If there were no major El Niño events for a couple of decades, the primary cause of the warming of the sea surface temperature anomalies of the South Atlantic-Indian-West Pacific would be gone.

Let's assume for the sake of discussion that we've entered a period when there won't be any major El Niño events, and let's assume that it lasts for a decade or two. The 2009/10 El Niño event was considerably weaker than the 1986/87/88 and 1997/98 El Niño events, and because it's only been a few years since that El Niño, it's very difficult to know if an upward shift took place after it. Is there any reason to believe the sea surface temperatures for the South Atlantic-Indian-West Pacific dataset would warm between lesser El Niño events? Unfortunately, the sea surface temperatures for this region aren't providing clean-cut answers yet.

Did the Earlier Pattern in Time of Strong El Niño followed by a Strong or Multiyear La Niña followed by a Series of Weak El Niño End?

We illustrated using NINO3.4 sea surface temperature anomalies how the decade-long periods following the 1972/73, the 1986/87/88 and the 1997/98 El Niño events were remarkably similar; that is, a La Niña event followed the initial (primary) El Niño and then there were a series of minor (secondary) El Niño events. Refer to **Chapter 4.5 The Repeating Sequence of Primary and Secondary El Niño Events.** We also mentioned in that chapter how that sequence appears to have stopped and that we may have entered a new epoch of shorter "cycles" that begin with moderate El Niño events, which are followed by two separate back-to-back La Niña events. As shown in Figure 8-3, there were back-to-back La Niña events in 2010/11 and 2011/12. If the NINO3.4 sea surface temperature anomalies had remained a little cooler during the 2008/09 ENSO season, there would have been "official" back-to-back La Niña events in 2007/08 and 2008/09.

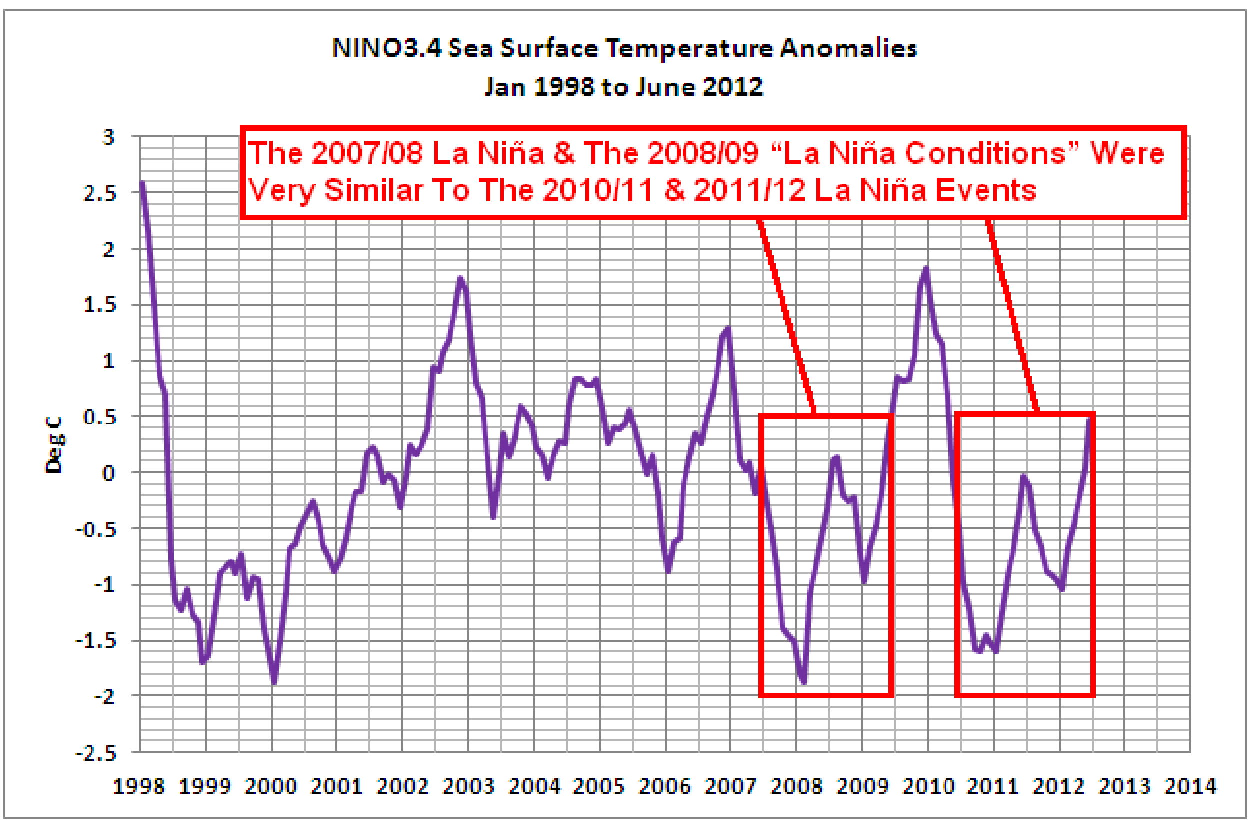

Figure 8-3

Bob Tisdale

Note: Surface temperatures don't care whether a La Niña event was "official." I've simply hesitated to call the earlier (2007/08 and 2008/09) events back-to-back La Niña because someone is bound to refer to the Oceanic NINO Index for the 2008/09 ENSO season and say NOAA didn't list it as an "official" La Niña.

Curiously, during the double-dip La Niña events of 2010/11 and 2011/12, the sea surface temperature anomalies for the South Atlantic-Indian-West Pacific subset cooled, but during the "unofficial" back-to-back La Niña events of 2007/08 and 2008/09, sea surface temperature anomalies there warmed.

If we've entered a new epoch, will sea surface temperatures of the South Atlantic-Indian-West Pacific warm or cool? Time will tell.

RECAP

The question for this chapter was, since El Niño events create an effect where sea surface temperature appear to ratchet upwards, how can global sea surface temperatures flatten or cool for multidecadal periods?

The ratcheting effect took place primarily in the sea surface temperatures of the South Atlantic-Indian-West Pacific dataset. The sea surface temperatures there cooled between major El Niño events, and that means the only time it warmed was during the major El Niño. If we were to enter a period, or have entered a period, when there are no strong El Niño events, the primary cause of warming there would be absent. If the sea surface temperature anomalies of the East Pacific remain flat, and if the North Atlantic Plus dataset switches to multidecadal period of flat or cooling sea surface temperatures, then global surface temperatures should remain flat, or should cool.

Let me point out that there are lots of "ifs" in the last paragraph. Hopefully, in the not-too-distant future we'll be able to witness what takes place.

8.2 If Anthropogenic Greenhouse Gases Don't Warm the Oceans, What Forcing Causes Them to Warm? (The assumption in that question is that radiative forcings are required to cause sea surface temperatures and ocean heat content to warm.)

Some proponents of anthropogenic global warming have become obsessed with radiative forcings from greenhouse gases. In their minds, only radiative forcings from greenhouse gases can cause global temperatures to warm for multidecadal periods. Their fixation is so strong they can't imagine a world in which global surface temperatures vary without anthropogenic radiative forcings.

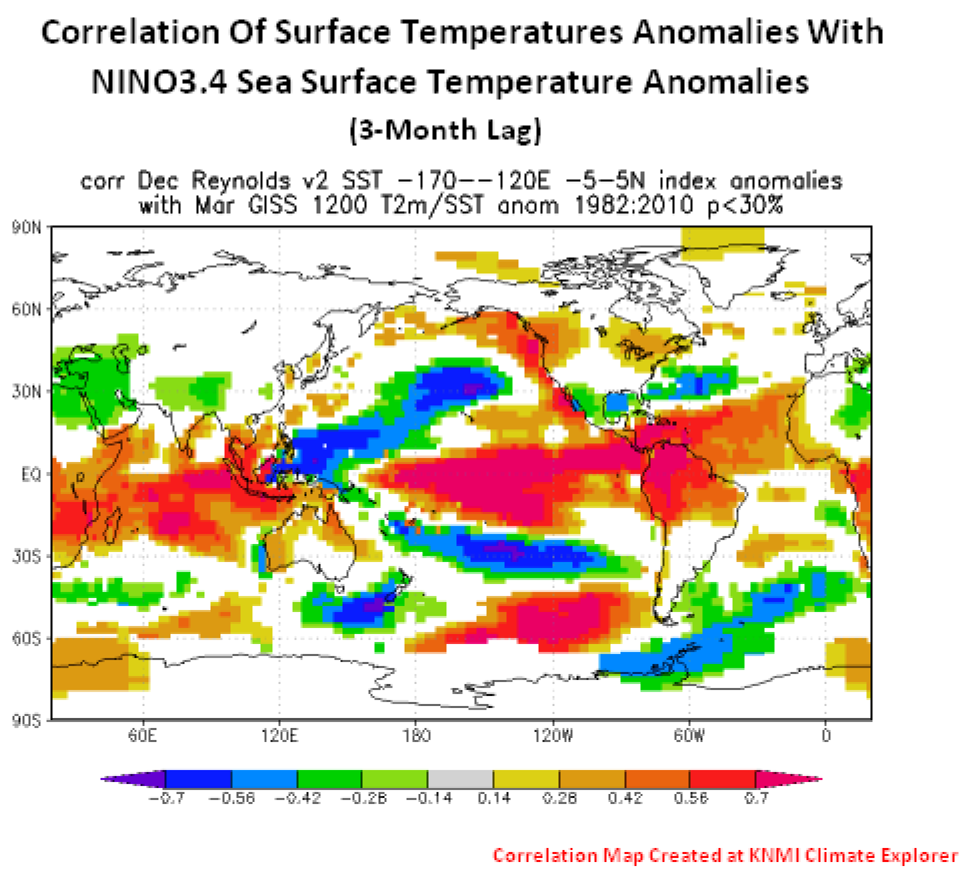

Figure 8.5 Bob Tisdale

Figure 8.5 is the correlation map we've presented a couple of times in this book. It shows the correlation of our ENSO index (NINO3.4 sea surface temperature anomalies) with GISS Land-Ocean Temperature Index data. This is the map with the 3-month lag between the ENSO index and the surface temperatures. During an El Niño event, some regions of the globe warm and others cool. The areas that warm and the amount they warm outweigh the cooling in the other regions and global surface temperatures warm in response. Changes in atmospheric circulation, resulting from ENSO, cause those responses in surface temperatures outside of the eastern tropical Pacific. These processes were documented decades ago and they are understood. We discussed those processes in **Chapter 4.1 How El Niño Events Cause Surface Temperatures to Warm Outside of the Tropical Pacific** and **Chapter 4.14 Impacts of ENSO Events on Regional Temperature and Precipitation.**

How Surface Temperatures Warm Outside of the Tropical Pacific in Response to an El Niño

Let's list the number of ways sea surface temperatures (and ocean heat content) outside of the eastern tropical Pacific can and do warm in response to a major El Niño event.

1. Weaker-than-normal trade winds result in less evaporation, which is the primary source of ocean cooling. The reduced evaporation caused by the weakening of trade winds in the areas outside of the eastern tropical Pacific, therefore, causes sea surface temperatures and ocean heat content to warm in response to an El Niño.

2. Weaker-than-normal trade winds result in less upwelling of cool waters in areas where upwelling normally takes place. The reduced upwelling causes the warming of sea surface temperatures and ocean heat content in response to an El Niño (again in areas remote to the eastern tropical Pacific).

3. After the downwelling (warm) equatorial Kelvin wave associated with the onset of an El Niño reaches the coast of South America, some of it is reflected back as Rossby waves. Part of the equatorial Kelvin wave spreads north and south to high latitudes, along the west coasts of North and South America, as coastal-trapped Kelvin waves. They raise sea surface temperatures along the west coasts of the Americas—as far north as Alaska in response to an El Niño.

4. Due to changes in the location of the jet streams, there are changes in precipitation and cloud cover patterns. A reduction in cloud cover allows more sunlight to penetrate and warm the ocean to depth, increasing sea surface temperatures and ocean heat content in response to an El Niño.

5. Cloud cover accompanies the warm water to the central and eastern tropical Pacific during an El Niño. This obviously reduces the cloud cover in the western tropical Pacific. Less cloud cover, as noted above, allows more sunlight to penetrate and warm the oceans to depth, increasing sea surface temperatures and ocean heat content. This warm water is carried eastward and helps to continue the supply of warm water to the El Niño.

6. During the transition from the El Niño to ENSO-neutral conditions, left over warm surface waters in the eastern Pacific are carried west where they raise the sea surface temperatures and ocean heat content.

7. Also during the transition from the El Niño to ENSO-neutral conditions, left over warm subsurface waters are carried via Rossby waves into the western Pacific and eastern Indian Ocean. This raises the ocean heat content there, and eventually raises sea surface temperatures because gravity causes warm water to rise to the surface.

We've presented seven ways an El Niño event raises sea surface temperatures, and ocean heat content, outside of the eastern tropical Pacific, and not once have we mentioned infrared radiation or greenhouse gases.

What Happens when ENSO is Skewed toward El Niño

All but one of the processes should happen in reverse during a La Niña. The atypical factor is, there are no leftover cool waters in the eastern tropical Pacific after a La Niña because the trade winds have been pushing the cool waters to the west for the duration of the La Niña. For the sake of discussion, let's overlook that factor for a moment and assume that all of the other factors COULD be countered by similar but opposite processes during a La Niña.

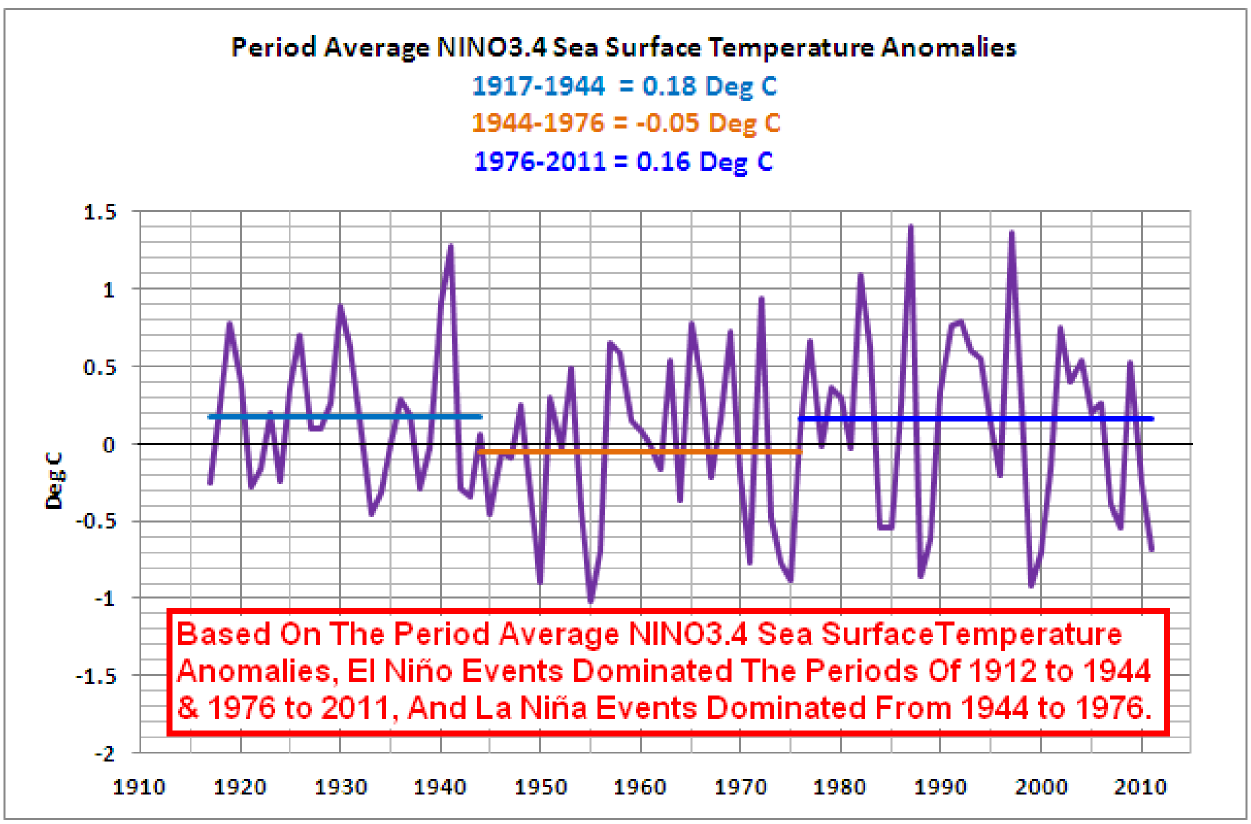

Figure 8-6 Bob Tisdale

In order for the La Niña events to counteract the El Niño events, over the long term, La Niña events would need to be as strong as El Niño events, and they're not. In other words, ENSO would need to act as it is portrayed in the IPCC's climate models, with no bias toward either phase of ENSO, and in the real world ENSO does not act as it does in climate models. During some multidecadal periods, El Niño events dominate and during others, La Niña events dominate. Since 1976, El Niño events have dominated. See Figure 8-6.

We've discussed this next topic a number of times, but I'll reword it and then transition to a discussion of long-term effects. During an El Niño, there are areas around the globe that warm and some areas that cool. The warming in areas remote to the tropical Pacific is greater than the cooling. That is, the warming in the areas that warm is greater than the cooling in the areas that cool. We know this happens because global sea surface temperatures warm in response to the El Niño. Consider now that there are periods of 30 years or longer when everything is skewed toward El Niño conditions. All of the teleconnections, the changes in the jet streams, etc., are all weighted toward their warming (El Niño) mode. Only one thing can happen during those multidecadal periods when El Niño events dominate, and it is, there is a prolonged warming of the areas where sea surface temperatures and ocean heat content warm in response to individual El Niño events. In other words, the processes causing the oceans to warm during El Niño events would become the rule not the exception during a multidecadal period when El Niño events dominated. The oceans are not stagnant; therefore, in response to the prolonged El Niño-weighted conditions, the warm waters created during the long-term warming of those areas are circulated, and this warms the basins as a whole. The opposite occurs during epochs when La Niña events dominate.

RECAP

The question posed in this chapter was, if anthropogenic greenhouse gases don't warm the oceans, what forcing causes them to warm?

As discussed, manmade climate forcings are not required to cause sea surface temperatures and ocean heat content to warm over multidecadal periods. There are numerous processes associated with ENSO that cause sea surface temperatures and ocean heat content to warm in response to El Niño event. During periods when El Niño events dominate ENSO, those processes associated with ENSO are also dominant and sea surface temperatures warm as a result.

8.3 In the East Pacific and West Indian Oceans, Would the Cooling Rates after Major El Niño events be Faster if Anthropogenic Greenhouses Gases Weren't Warming the Oceans?

Figure 8-7 illustrates cooling rates of the East Indian-West Pacific sea surface temperature anomalies between the 1986/87/88 and 1997/98 El Niño events and between the El Niño events of 1997/98 and 2009/10. The question seems appropriate in light of those findings. Would the cooling rates have been any faster if anthropogenic greenhouse gases were not warming the oceans?

It's Not a Realistic Question since There's No Evidence of an Anthropogenic Signal in Sea Surface Temperature Data

Sorry to answer the question with a question, but…is that question valid if we look at that graph another way? The East Indian-West Pacific sea surface temperatures only warmed during those three El Niño events. In other words, there's no evidence that anthropogenic greenhouse gases had any warming effect.

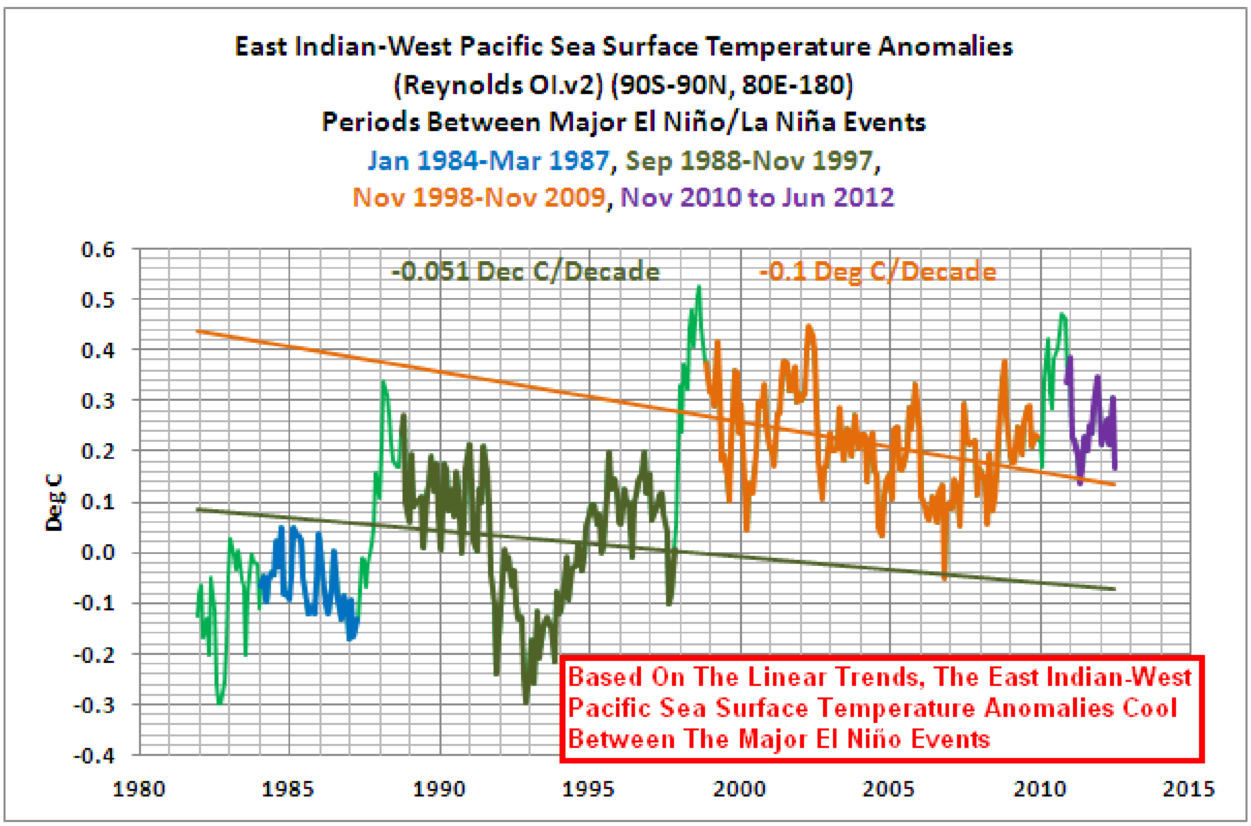

Figure 8-7

Bob Tisdale

The cooling rate of -0.1 deg C per decade between the 1997/98 and 2009/10 El Niño events is a relatively high rate of cooling—especially when we consider that the multi-model mean of the IPCC's climate models show a relatively steady carbon dioxide-driven warming, other than for the dips and rebounds associated with volcanic aerosols.

However, the most powerful argument against any claims that the East Indian-West Pacific would have/could have cooled at a faster rate if they were not warmed by manmade greenhouse gases comes from another subset of the global oceans. Keep in mind, the multi-model mean is the IPCC's best guess at how sea surface temperatures should warm IF they are warmed by manmade greenhouse gases. The sea surface temperature simulations of the IPCC's climate models for the period of Nov 1981 to June 2012 show little difference in the warming rates of the sea surface temperature anomalies for the East Pacific (90S-90N, 180-80W) and the East Indian-West Pacific (90S-90N, 80E-180) oceans. In other words, according to the models, the East Pacific sea surface temperature anomalies over the past 30 years (Figure 8-8) should have warmed at about the same rate as the East Indian-West Pacific subset.

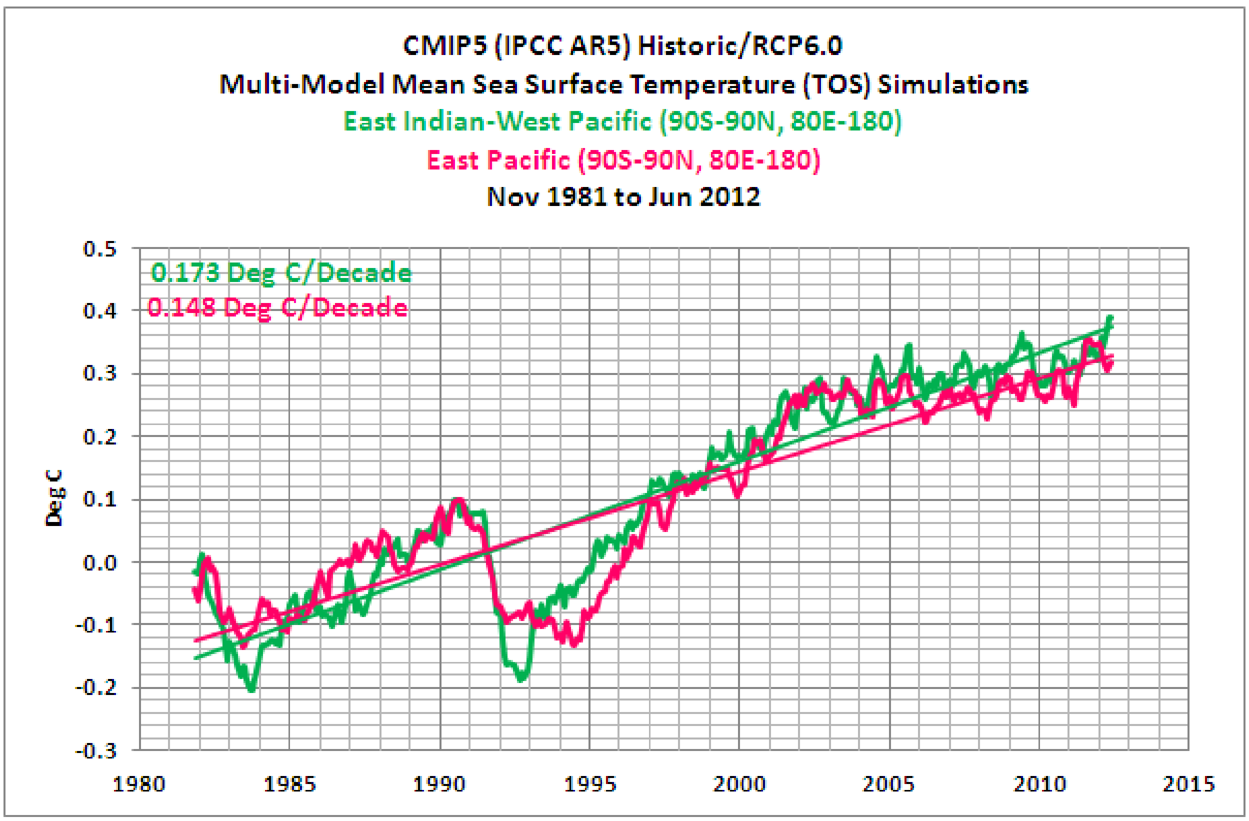

Figure 8-8

Bob Tisdale

However, the sea surface temperature anomalies of the East Pacific Ocean have not warmed in 30+ years.

RECAP

The question asked for this chapter was: in the East Pacific and West Indian Oceans, would the cooling rates after major El Niño events be faster if anthropogenic greenhouses gases weren't warming the oceans?

Because there's no evidence that greenhouse gases were responsible for the warming of the sea surface temperatures anywhere on the planet over the past 30 years, the question has no basis in reality.

8.4 Is There Any Evidence That Downward Longwave (Infrared) Radiation from Anthropogenic Greenhouse Gases Warms the Oceans (Sea Surface Temperature or Ocean Heat Content)?

One of the primary messages of this book is that there is NO EVIDENCE that downward longwave (infrared) radiation from anthropogenic greenhouse gases warms the oceans. No evidence whatsoever. We showed that ENSO was responsible for the warming of sea surface temperatures in most of the ocean basins over the past 30 years, and we discussed how the higher rate of warming in the North Atlantic was a function of an additional mode of natural variability called the Atlantic Multidecadal Oscillation. While our primary metric was sea surface temperature anomalies, we also discussed and illustrated the impacts of ENSO, sea level pressure and the Atlantic Multidecadal Oscillation on Ocean Heat Content data.

There is a one-word answer to the question posed in the title of this chapter, and it is:

Nope.

8.5 Why is using Global Data as a Metric for Global Warming Misleading?

This is an odd-sounding question: Why is using GLOBAL data misleading as a metric for GLOBAL warming? Nevertheless, it's true. Presenting a global temperature dataset can be misleading in a discussion of global warming.

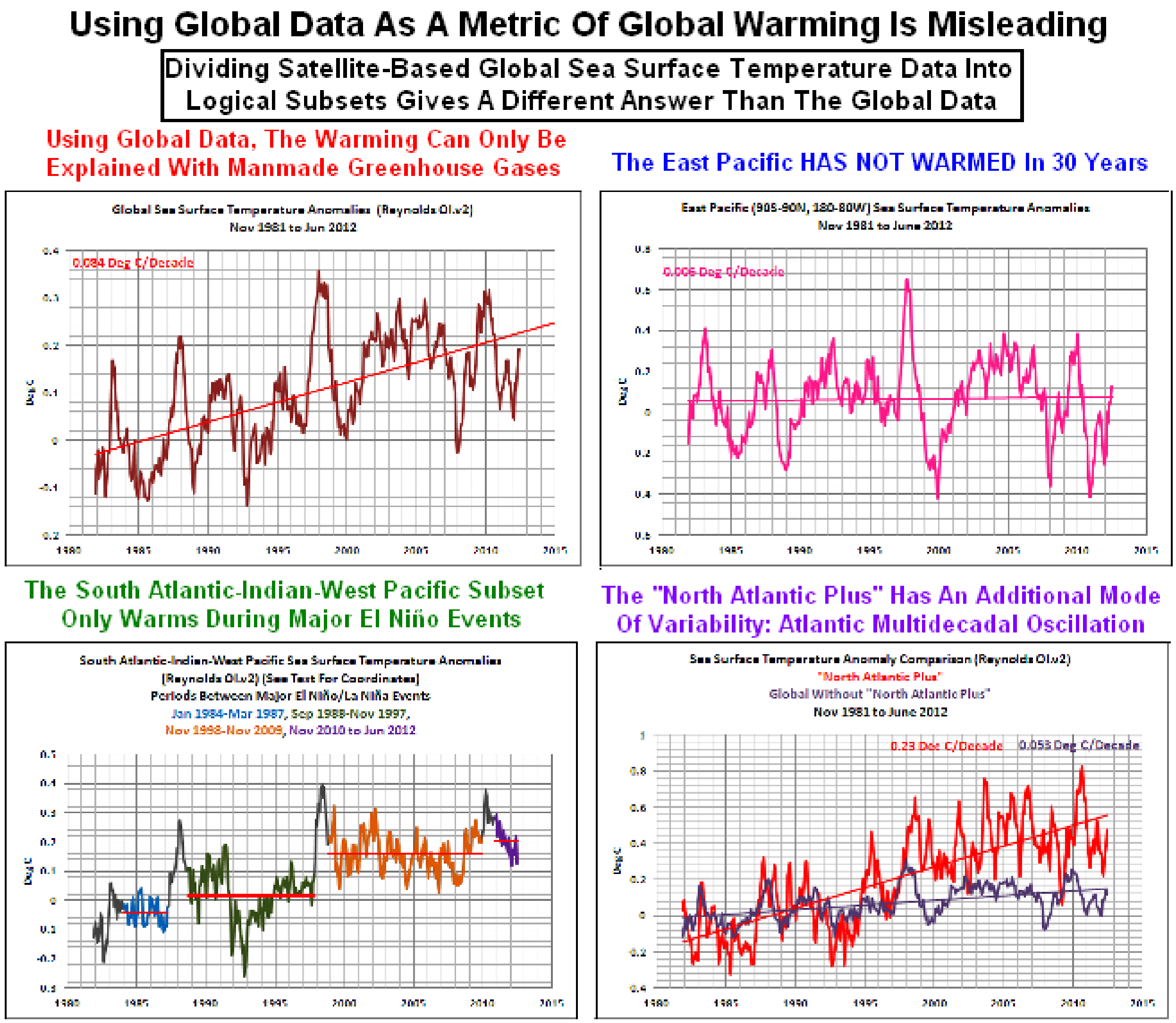

Figure 8-9 Bob Tisdale

The use of global sea surface temperature anomalies and ocean heat content data masks the causes of the warming. Global data gives the misleading impression of a relatively continuous warming over the past 30 years—one peppered with ENSO events and volcanic eruptions—that can only be explained by anthropogenic greenhouses gases. Refer to the upper left-hand cell in Figure

8-9. When divided into logical subsets, however, the warming of satellite-era global sea surface temperature data can be explained with natural factors.

The sea surface temperatures for the East Pacific (upper right-hand cell) haven't warmed in 30 years, despite the continuous rise in anthropogenic greenhouse gases.

The South Atlantic-Indian-West Pacific subset (lower left-hand cell) is dominated by the ENSO-caused warming of the East Indian-West Pacific sea surface temperatures, so it only warms during and in response to major El Niño events.

The "North Atlantic Plus" sea surface temperature anomalies (lower right-hand cell) have warmed at a rate that's considerably faster than the other ocean basins, but it has an additional mode of natural variability called the Atlantic Multidecadal Oscillation. For the past 35-plus years, the Atlantic Multidecadal Oscillation has caused North Atlantic sea surface temperatures to warm faster than the other ocean basins, so it has contributed greatly to the warming of global sea surface temperatures. Eventually, the Atlantic Multidecadal Oscillation will switch modes and then warm at a much slower rate, if not cool, for a multidecadal period. Then, it will act to suppress the warming of global sea surface temperatures.

RECAP

The question for this chapter was, Why is using Global Data as a Metric for Global Warming Misleading?

The brief answer: Global datasets mask the true causes of global warming.

We've illustrated and discussed the actual causes of the warming of sea surface temperature data in **Section 5 The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies.** Also included in that section were discussions of ocean heat content, lower troposphere temperatures and combined land plus sea surface temperatures. Refer to **Chapter 5.9 A Look at the Long-Term Impacts of ENSO and Other Natural Variables on Ocean Heat Content Data** and **Chapter 5.10 Examples of the Obvious Long-Term Impacts of ENSO on Lower Troposphere and Land-plus-sea Surface Temperature Anomalies.** The discussions in Chapter 5.10 are supplemented by **Chapter 5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events.**

8.6 Is the Atlantic Multidecadal Oscillation Impacted by ENSO?

The sea surface temperatures of all ocean basins are directly or indirectly impacted by ENSO. Because the Atlantic Multidecadal Oscillation data is simply detrended long-term sea surface temperature anomalies of the North Atlantic, ENSO impacts it as well.

The Atlantic Multidecadal Oscillation was discussed in **Chapter 2.13 The Additional Mode of Natural Variability in the North Atlantic Sea Surface Temperatures—Introduction to the Atlantic Multidecadal Oscillation** and in **Chapter 5.6 The Additional Warming of the North Atlantic Sea Surface Temperatures is Caused by the Atlantic Multidecadal Oscillation AND Additional ENSO-Impacted Processes.** Please refer to those chapters for further general information about it.

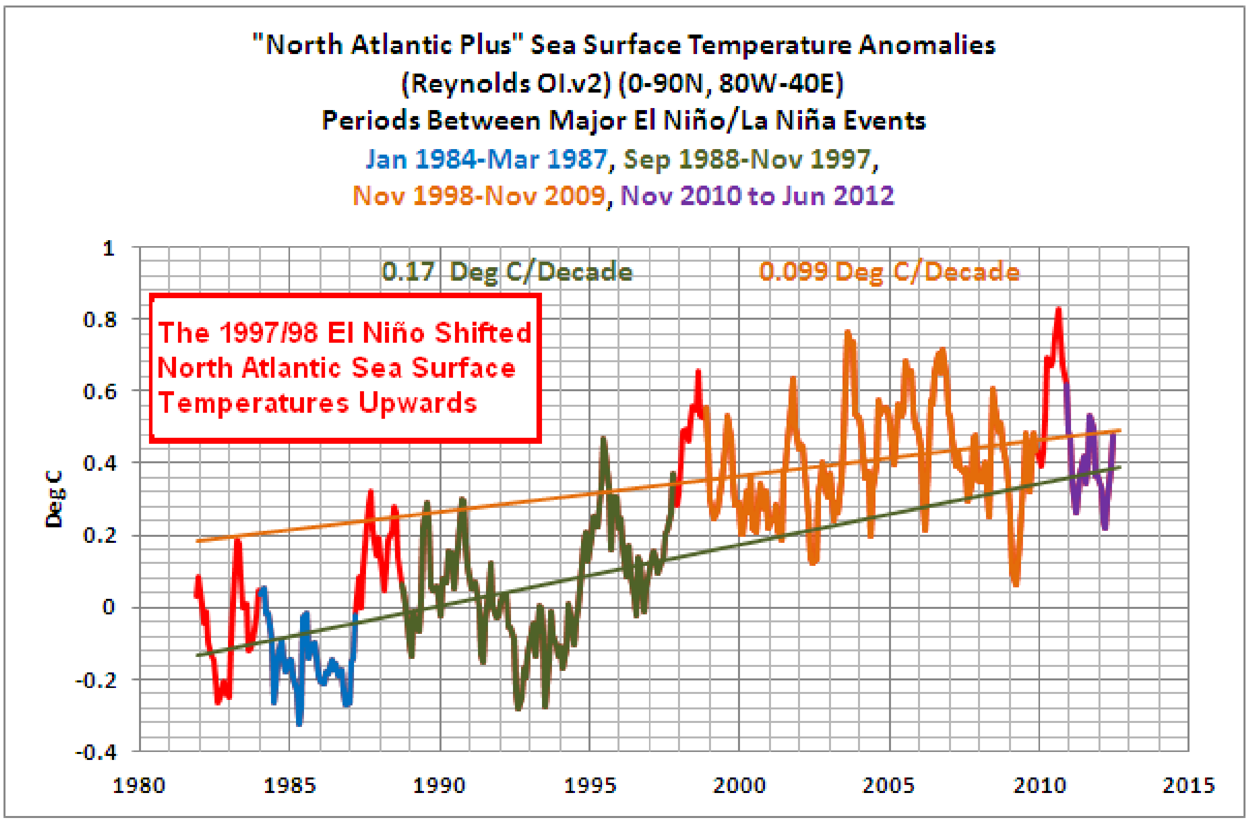

Figure 8-10 Bob Tisdale

As discussed, the Atlantic Multidecadal Oscillation is typically presented as detrended long-term North Atlantic sea surface temperature anomalies. However, for the initial portion of the discussion, we'll leave the North Atlantic data "undetrended". (No. I'm not the first person to use that word.) We can see in Figure 8-10 that the North Atlantic sea surface temperature anomalies warm between the major El Niño events, but notice how the trend line for the period between the 1997/98 and 2009/10 El Niño events is above the trend line for the period between the 1986/87/88 and 1997/98 El Niño events. That is, the 1997/98 El Niño shifted the North Atlantic sea surface temperatures higher.

We discussed why the North Atlantic sea surface temperatures shift upwards: the North Atlantic sea surface temperature anomalies do not respond fully to the La Niña events that follow the 1986/87/88 and 1997/98 El Niño. We showed this by detrending the short-term North Atlantic sea surface temperature and comparing them to the ENSO index. See Figure 8-11.

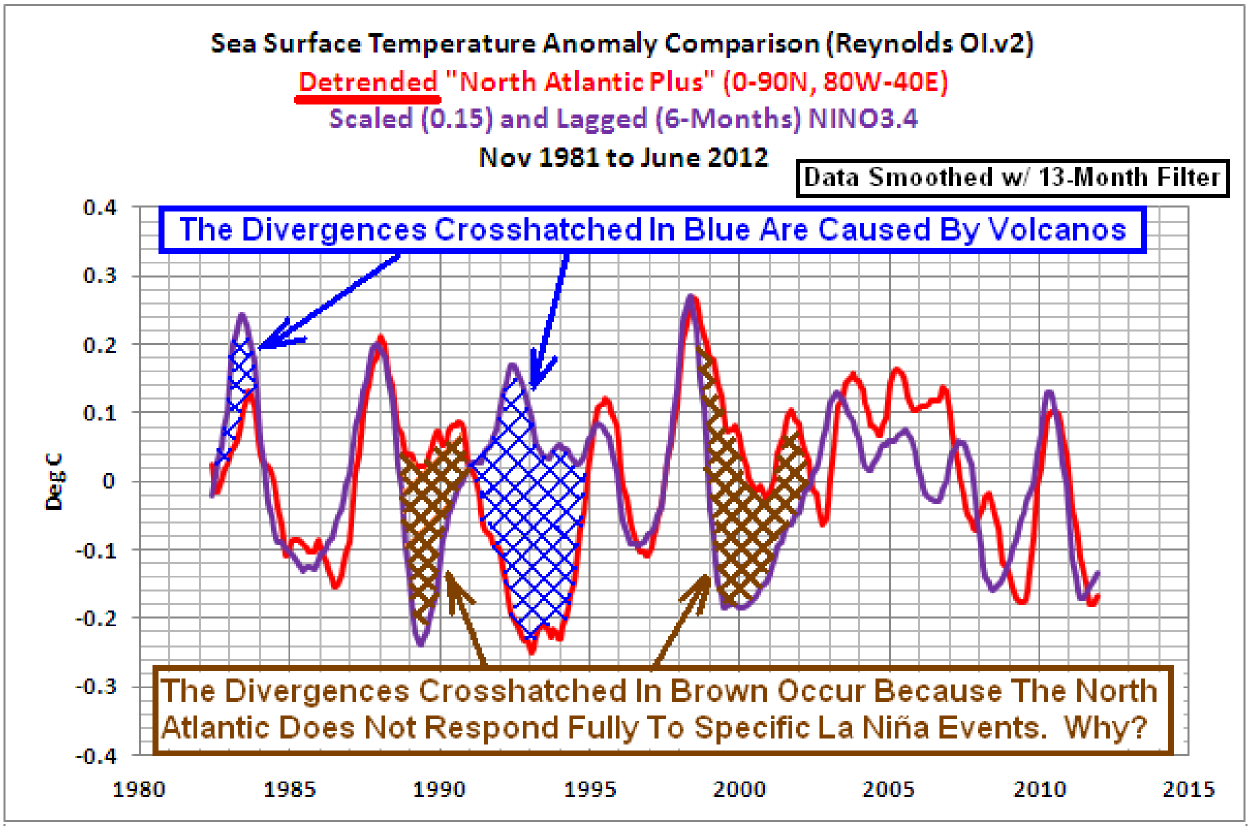

Figure 8-11

Bob Tisdale

Figure 8-12 is a cropped version of Figure 5-84 from **Chapter 5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events.** Figure 8-12 presents only the correlation map of Northern Hemisphere temperature anomalies with Kuroshio-Oyashio Extension sea surface temperatures for the period of 1982 to 2011. We discussed that the significant warmings of the Kuroshio-Oyashio Extension occurred as secondary responses to the 1986/87/88 and 1997/98 El Niño events. Note how a wide area of the North Atlantic is correlated positively with the variations in sea surface temperature anomalies of the Kuroshio-Oyashio Extension. As a reminder, this does not mean that the ENSO-caused warming the sea surface temperatures of the Kuroshio-Oyashio

Extension are in turn causing the warming of the North Atlantic. It also doesn't mean the North Atlantic is warming as much as the Kuroshio-Oyashio Extension. It simply shows that the timings indicate there is a possible interaction. Also recall the strength of that warming signal in the Kuroshio-Oyashio Extension. It's more than half the strength of the NINO3.4 sea surface temperature anomalies, so it's like there a smaller, secondary El Niño event taking place at the mid-latitudes of the North Pacific.

Correlation of Kuroshio-Oyashio Extension Sea Surface Temperature Anomalies With Northern Hemisphere Temperature Anomalies GISS LOTI (1982-2011)

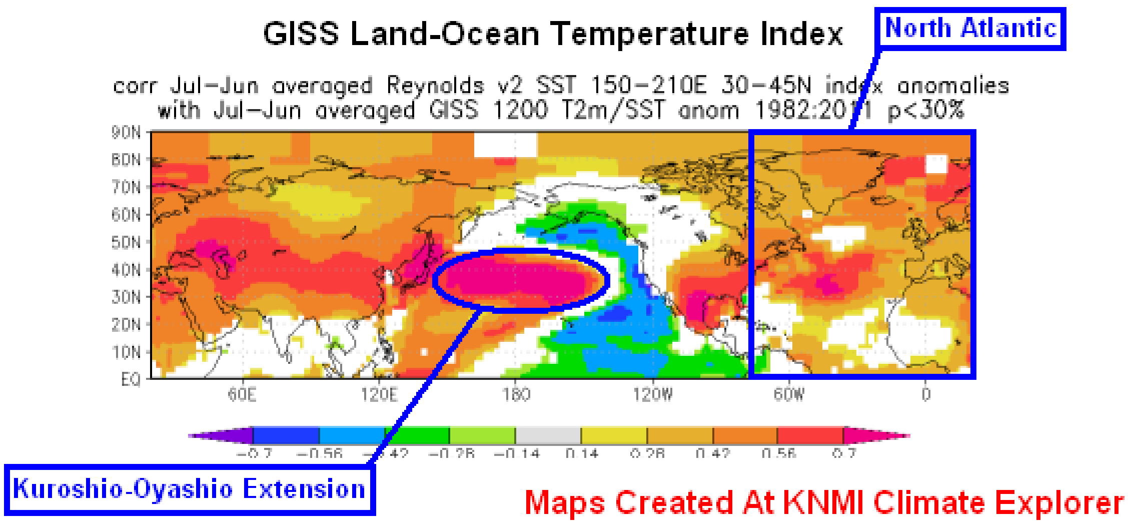

Figure 8-12 Bob Tisdale

Guan and Nigam (2009) discusses the influence of the Pacific on the North Atlantic in **Analysis of Atlantic SST variability factoring inter-basin links and the secular trend: clarified structure of the Atlantic Multidecadal Oscillation**. Referring to their Summary and Closing Remarks, they found (my boldface):

> *Atlantic Multidecadal Oscillation (AMO-Atl): this leading mode is characterized by alternation of warm and cold anomalies centered in the North Atlantic basin, with a cycle of ;70 yr. The mode differs from the conventional AMO (AMO-Tot here; Fig. 5d) in the tropics and subtropics where its footprint is muted because of the exclusion of the Pacific influence. Both the phase and trend of the conventional AMO index are found to be impacted by the Pacific influence (cf. Fig. 5a).* ***The AMO mode (AMO-Atl; Fig. 5b) and the Pacific influence on the Atlantic (AMO-Pac; Fig. 5c) together explain about 75% of the variance represented by the conventional AMO (AMO-Tot), with about 45% coming from the Pacific influence****…*

Much of their earlier paper discussed the influence of the different modes of Pacific sea surface temperature variability on the North Atlantic sea surface temperatures. Refer to Guan and Nigam (2008) **Pacific sea surface temperatures in the twentieth century: An evolution-centric analysis of variability and trend**.

RECAP

The question for this chapter was, Is the Atlantic Multidecadal Oscillation Impacted by ENSO?

ENSO impacts the year-to-year variability of the Atlantic Multidecadal Oscillation. Because the North Atlantic sea surface temperatures (and the Atlantic Multidecadal Oscillation) do not respond fully to the La Niña events that follow the major El Niño events, the major El Niño events create upward shifts in the sea surface temperatures of the North Atlantic.

Guan and Nigam (2009) found that about 45% of the Atlantic Multidecadal Oscillation are responses to the variations in the Pacific.

8.7 Is ENSO Impacted by the Atlantic Multidecadal Oscillation?

There are a number of papers, using different methods, that find influences of the sea surface temperatures of the North Atlantic on ENSO. One recent paper is Wang et al (2010) **Teleconnected influence of North Atlantic sea surface temperature on the El Niño onset**. Their abstract starts:

> *Influence of North Atlantic sea surface temperature (SST) anomalies on tropical Pacific SST anomalies is examined. Both summer and winter North Atlantic SST anomalies are negatively related to central-eastern tropical Pacific SST anomalies in the subsequent months varying from 5 to 13 months. In particular, when the North Atlantic is colder than normal in the summer, an El Niño event is likely to be initiated in the subsequent spring in the tropical Pacific.*

Penland and Matrosova (2006), **Studies of El Niño and Interdecadal Variability in Tropical Sea Surface Temperatures Using a Nonnormal Filter**, is an earlier study. They found an Atlantic sea surface temperature signal that was a precursor to ENSO events, but they found it in the southern tropical Atlantic. Their abstract includes:

> *A signature of El Niño in the south tropical Atlantic leads Niño-3.4 SST anomalies by about 9 months.*

It appears the influence of the Atlantic Multidecadal Oscillation on ENSO may exist, but there does not appear to be a clearly established link.

8.8 What Causes the Multidecadal Component of ENSO?

There are a number of papers that propose causes of the multidecadal component of ENSO. Not too unexpectedly they have different findings. For example:

Flugel et al (2004), **The Role of Stochastic Forcing in Modulating ENSO Predictability**, found that random atmospheric noise created the low-frequency component in their model-based study.

A number of papers found the multidecadal variations were caused by changes in the "background state". These include Wang (1995) **Interdecadal Changes in El Niño Onset in the Last Four Decades**, and Fedorov and Philander (2001) **A Stability Analysis of Tropical Ocean–Atmosphere Interactions: Bridging Measurements and Theory for El Niño**. Fedorov and Philander (2001) described the background state in their abstract:

> *Interactions between the tropical oceans and atmosphere permit a spectrum of natural modes of oscillation whose properties—period, intensity, spatial structure, and direction of propagation—depend on the background climatic state (i.e., the mean state). This mean state can be described by parameters that include the following: the time-averaged intensity (t) of the Pacific trade winds, the mean depth (H) of the thermocline, and the temperature difference across the thermocline (DT).*

Dong et al (2006), **Multidecadal modulation of El Niño–Southern Oscillation (ENSO) variance by Atlantic Ocean sea surface temperatures**, argued the background state was impacted by the Atlantic sea surface temperatures.

Rodgers et al (2004), **Tropical Pacific Decadal Variability and Its Relation to Decadal Modulations of ENSO**, found that the change in the mean state resulted due to the asymmetry between El Niño and La Niña events.

Schopf and Burgman (2006) **A Simple Mechanism for ENSO Residuals and Asymmetry** found an increase in the amplitude of the ENSO skews the low-frequency component toward El Niño—that it was not a change in background state.

Like many other parts of ENSO, the causes of the multidecadal component of ENSO are unclear.

8.9 Does the Reemergence Mechanism Help to Prolong the Aftereffects of ENSO?

This is an introductory discussion of the Reemergence Mechanism. I have not found any papers that present how ENSO would interact with the Reemergence Mechanism. However, it appears the Reemergence Mechanism would come into play when looking at the secondary (aftereffects) of the major ENSO events. Specifically, we often see warm water—released by or created by an El Niño—"pooling" in areas such as the Kuroshio-Oyashio Extension. Coincidentally, that's one of the areas where the Reemergence Mechanism is found to occur.

THE REEMERGENCE MECHANISM

I published a blog post in 2009 about **The Reemergence Mechanism**. The following overview is from that post.

The Reemergence Mechanism

Source: Alexander and Dreser (1995)
"A Mechanism for the Recurrence of Wintertime Midlatitude SST Anomalies"

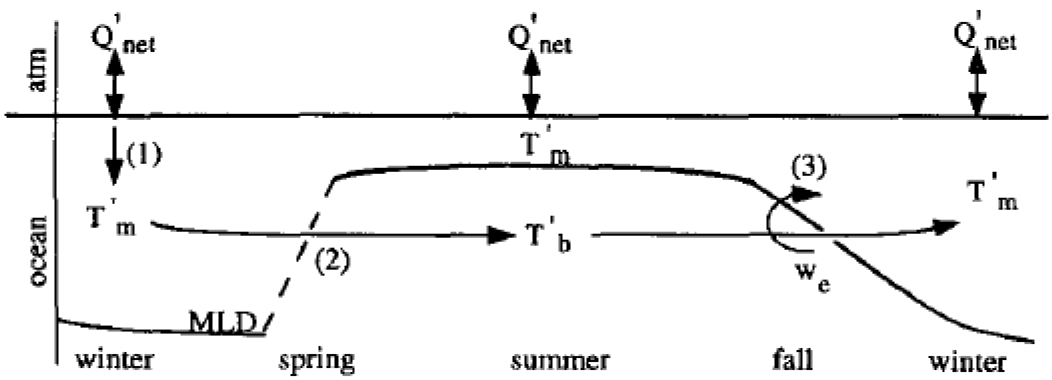

FIG. 1. Schematic diagram of the Namias and Born hypothesis. 1) Anomalous atmospheric forcing (Q'_{net}) in winter creates a temperature anomaly (T'_m) over a deep mixed layer; 2) the temperature anomaly remains beneath the mixed layer (T'_b) when the mixed layer reforms (dashed line) close to the surface in spring; 3) the sub–mixed layer temperature anomaly is entrained (w_e) into the mixed layer in the following fall/winter, influencing the surface temperature.

Source:
http://journals.ametsoc.org/doi/abs/10.1175/1520-0485%281995%29025%3C0122%3AAMFTRO%3E2.0.CO%3B2

Figure 8-13 Bob Tisdale

The following quotes are from the abstract of Alexander and Dreser (1995), **A Mechanism for the Recurrence of Wintertime Midlatitude SST Anomalies**.

In the early 1970s, Namias and Born speculated that ocean temperature anomalies created over the deep mixed layer in winter could be preserved in the summer thermocline and reappear at the surface in the following fall or winter.

The abstract concludes:

These results suggest that vertical mixing processes allow ocean temperature anomalies created over a deep mixed layer in winter to be preserved below the surface in summer and reappear at the surface in the following fall, confirming the Namias–Born hypothesis.

In other words, wintertime sea surface temperature anomalies in certain portions of the global oceans can and do repeat the following falls and winters. Alexander and Dreser (1995) provided a graphic, Figure 8-13, that illustrates and discusses the process of reemergence.

REEMERGENCE OCCURS IN ALL MAJOR OCEAN BASINS

In the paper **'Reemergence' areas of winter sea surface temperature anomalies in the world's oceans**, Hanawa and Sugimoto (2004) illustrated the areas of the global oceans, Figure 8-14 (Hanawa and Sugimoto Figure 1), where they were able to isolate reemergence using multiple sea surface temperature datasets.

Their abstract reads in part:

Using datasets of sea surface temperature (SST), surface heat flux, upper ocean thermal data, and climatological temperature and salinity profiles, we try to detect "reemergence" areas of winter SST anomalies in the world's oceans, and describe characteristics of these areas in terms of mixed layer depth (MLD), annual mean heat flux and properties of waters formed in winter mixed layer. Eventually, seven reemergence areas are found: four in the Northern Hemisphere and three in the southern Hemisphere. All areas have a large seasonal variation of MLD, and are the regions where annual mean heat fluxes are relatively small except for two regions in the Northern Hemisphere…

Reemergence Areas

Source: Hanawa and Sugimoto (2004) 'Reemergence' areas of winter sea surface temperature anomalies in the world's oceans

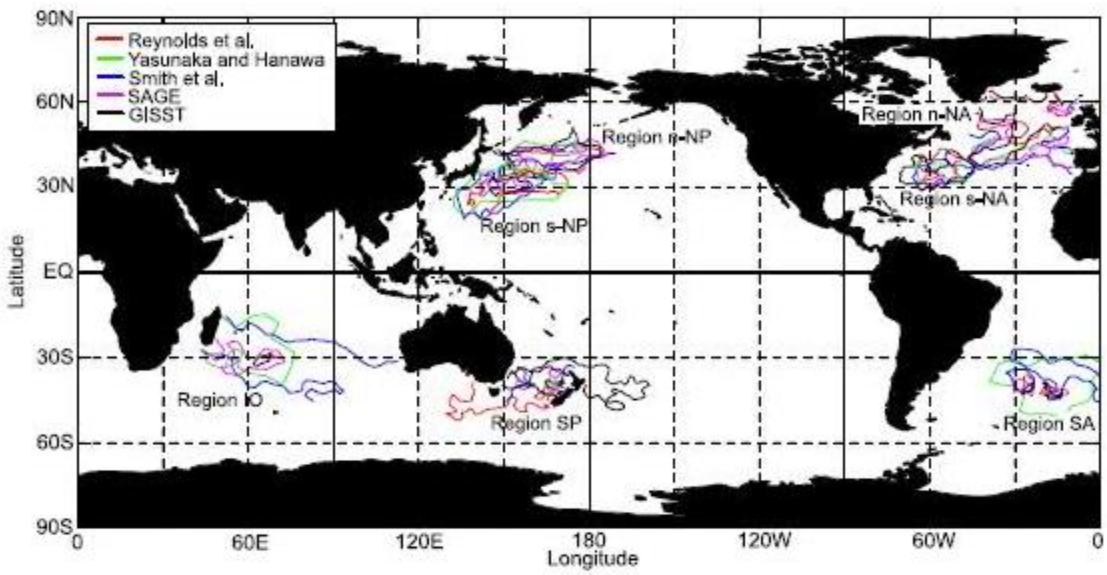

Figure 1. Reemergence areas detected by lag correlation analyses using five SST datasets. Contours denote the areas where the lag correlation coefficients exceed the 99% significance level. See the text on regional names.

Source: http://www.agu.org/pubs/crossref/2004/2004GL019904.shtml

Figure 8-14 **Bob Tisdale**

RECAP

As noted, this was an introductory discussion of the Reemergence Mechanism. The Reemergence Mechanism might possibly help to prolong the ENSO-related sea surface temperature anomalies in certain mid-latitude regions. When ENSO is skewed toward El Niño, the Reemergence Mechanism could help prolong warm anomalies, and vice versa when ENSO is skewed toward La Niña.

8.10 The Whole Process is Very Complex. Is this a Problem for General Circulation Models like the Ones Used by the IPCC? Is it Too Complex even for Powerful Computers?

Coupled climate models used by the IPCC include many complex ocean-atmosphere interactions, and most do attempt to model ENSO now. They get portions of the processes right and other portions wrong. I understand they are improving. Many of the problems the models have simulating ENSO are discussed in the paper Guilyardi et al (2009) **Understanding El Niño in Ocean-Atmosphere General Circulation Models: progress and challenges**, which was used as the primary reference for our discussions of climate models in **Chapter 5.8 Scientific Studies of the IPCC's Climate Models Reveal How Poorly the Models Simulate ENSO Processes**.

The climate models used to study ENSO and those used to hindcast and project climate responses to future forcing scenarios are, more often than not, the same models. Let's discuss them separately.

WHEN USED TO HINDCAST AND PROJECT GLOBAL CLIMATE

As we've seen throughout this book, ENSO is the primary driver of global temperature for annual, decadal and multidecadal periods. It is critical that climate models be able to simulate and reproduce the frequency, magnitude and duration of ENSO events if they are to be considered a useful tool for projecting future climate.

There are major hurdles modelers run into when attempting to simulate the frequency, magnitude and duration of ENSO events. Portions of the process can be explained as a cycle with the delayed oscillator (or other) theory, assuming the models get the proportions of cool and warm waters right and deal properly with the warm surface and subsurface waters left over after an El Niño. However, in nature, ENSO doesn't follow the delayed oscillator theory. There are cyclical components and random ones. The random ones result in abnormalities that can have major impacts on climate for years if not decades.

Example 1: The 1986/87/88 El Niño lasted from one ENSO season through the off season and into to the next ENSO season, and the second season peaked earlier than normal.

Example 2: The 1972/73, 1986/87/88 and 1997/98 El Niño events appear to be the initial events in a sequence of strong El Niño, followed by a strong or multiyear La Niña (a difference there too), which in turn is followed by a series of weak El Niño events. Then again, that sequence appears to have stopped with the 2006/07 El Niño.

There are other random components to ENSO, and they're important.

Example 3: A number of things that are not part of that the delayed oscillator can initiate an El Niño event. They can do it independently or together.

Example 4: There also needs to be warm water in the Pacific Warm Pool to fuel an El Niño. The warm water for the 1997/98 super El Niño was created during the weak 1995/96 La Niña by abnormally high trade winds in the western tropical Pacific. If the freakishly strong trade winds had not reduced cloud cover more than normal and allowed the sun to warm the western tropical Pacific to depth, there would not have been a super El Niño and, in response, surface temperatures would not have been shifted upwards.

The "linear ENSO" problem exhibited by climate models is a significant flaw. The term "linear ENSO" is used to describe how models tend to simulate El Niño and La Niña having the same strengths, frequencies and durations. This was discussed in great detail in **Chapter 5.8 Scientific Studies of the IPCC's Climate Models Reveal How Poorly the Models Simulate ENSO Processes.**

As noted, the "linear ENSO" flaw would tend to make El Niño and La Niña events balance out, to neutralize one another. As a result, ENSO becomes a nonentity in the models, nothing more than a source of noise in the modeled temperature record. That obviously flawed portrayal of ENSO in models should come as no surprise, because that is precisely how many climate scientists portray ENSO—incorrectly, misleadingly—when they attempt to remove the linear effects of ENSO from the surface temperature record and falsely claim the resulting warming trend was caused by anthropogenic greenhouse gases. The errors in that type of analysis was discussed in **Chapter 7.5 ENSO Only Adds Noise to the Instrument Temperature Record and We Can Determine its Effects through Linear Regression Analysis, Then Remove Those Effects, Leaving the Anthropogenic Global Warming Signal**.

WHEN USED TO SIMULATE ENSO

Climate models are used in other roles. They are often used to simulate the aftereffects, precursors and initiators of ENSO. The corresponding papers often include a note to the effect of: *Using a model of medium complexity, we were able simulate the "x" properties of ENSO for the past "y" years*. It stands to reason, if they're reproducing ENSO for the past 30+ years, then ENSO has been skewed toward El Niño. In order to do that, the models must be programmed, parameterized, to recreate the ENSO-related aspects of the instrument temperature record.

That's troubling.

If the modelers are able to simulate ENSO processes as they exist in the temperature records when they're specifically studying ENSO, why then can't they simulate ENSO when they're attempting to reproduce global climate during the 20th Century? To the concerned onlooker, it appears as though modelers neuter ENSO in the 20th Century hindcasts and forecasts of the 21st Century so ENSO can't be a factor that causes global warming, where in the real world ENSO is the driving factor.

RECAP

There are certain aspects of ENSO that make it difficult to reproduce in climate models, and those are the seemingly random factors. The "linear ENSO" problem is a major concern because it neuters ENSO.

Why can modelers simulate ENSO when they're studying ENSO and then lose the ability to simulate it during the 20th Century when they're hindcasting global climate for the IPCC? If the models were skewed toward El Niño, will global temperatures warm without anthropogenic greenhouse forcings? They should.

8.11 Since Climate Models used by the IPCC Don't Simulate ENSO Properly and Don't Account for the Long-term Impacts of ENSO, Can Climate Models be used to Project Future Climate?

We've discussed and illustrated how poorly climate models simulate ENSO. We've also discussed and shown how very poorly they simulate sea surface temperatures over the past 30 years as a result of their failure to model ENSO properly. I also presented how climate models fail to properly simulate 20th Century global surface temperatures in my first book ***If the IPCC was Selling Manmade Global Warming as a Product, Would the FTC Stop their deceptive Ads?*** Refer to the introduction, table of contents, and closing of book **here**.

The question asked by this chapter is relatively easy to answer. Because the climate models used by the IPCC do not simulate ENSO properly, and as a result, do not account for the long-term effects of ENSO on global surface temperatures and climate in general, they are attempting to recreate global climate based on erroneous assumptions. Projecting into the future those erroneous assumptions they've made about the cause of global warming serves no purpose.

In other words, the IPCC has used and continues to use climate models to attribute the warming of the last 30 years to anthropogenic greenhouse gases. That's their primary focus. Unfortunately for the IPCC and all of the contributors, there is little evidence that manmade greenhouse gases have had any impact on surface temperatures over the past three decades. We discussed and illustrated this throughout **Section 5 – The Long-Term Impacts of Major ENSO Events on Global Temperature Anomalies.** Basing their models on falsehoods, and projecting those errors into the future, provides nothing of value.

Let's look again at Compo and Sardeshmukh (2009) **Oceanic influences on recent continental warming**. The first sentence of their abstract reads:

> *Evidence is presented that the recent worldwide land warming has occurred largely in response to a worldwide warming of the oceans rather than as a direct response to increasing greenhouse gases (GHGs) over land.*

Compo and Sardeshmukh (2009) presented maps of the modeled changes in surface temperatures when the models were forced two ways: when the models were forced only by sea surface temperature and sea ice data, and when the models were forced by sea surface temperature, sea ice data and all of the other natural and anthropogenic forcings. Yes, that's right. The climate models referred to by Compo and Sardeshmukh (2009) simulated how the atmosphere, including land surface air temperature, would respond to the variations in sea surface temperature. Unfortunately, Compo and Sardeshmukh (2009) did not present time-series graphs so that we could get an idea of the magnitude of the land surface temperature warming in response to the warming of sea surface temperatures.

Lucky for us, the outputs of models forced by those same parameters are available from the GISS website. Refer to the GISS **ModelE Climate Simulations - Climate Simulations for 1880-2003** webpage, specifically **Table 3**. Those outputs are based on the GISS Model-E coupled general circulation model. They were presented in the Hansen et al (2007) paper **Climate simulations for 1880-2003 with GISS modelE**.

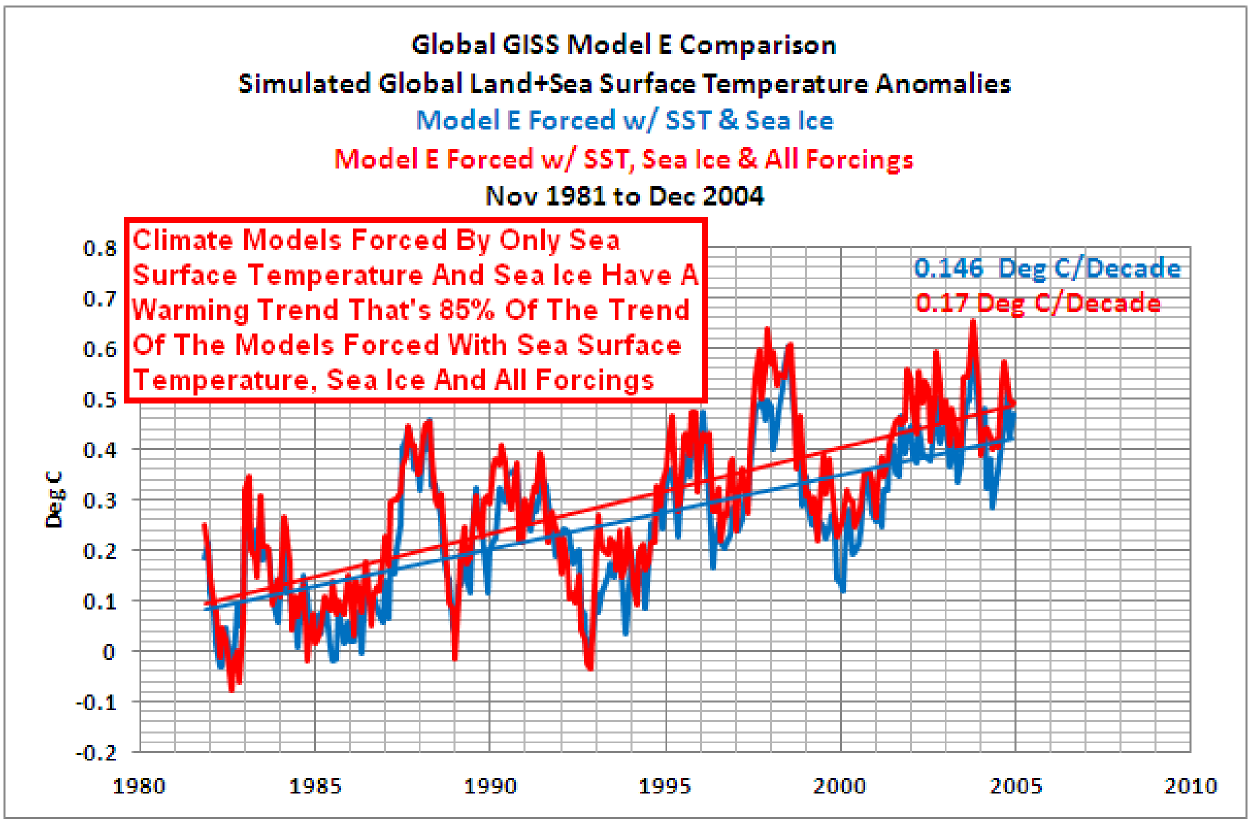

Figure 8-15 Bob Tisdale

Figure 8-15 presents a time-series graph of the ensemble mean of the GISS Model-E simulations of global land plus sea surface temperature anomalies when the models were forced only by sea surface temperature and sea ice data, and the outputs when the models were forced by sea surface temperature, sea ice data **and** anthropogenic forcings. The climate models simulations of global land plus sea surface temperatures when forced only by sea surface temperature and sea ice data have a linear warming trend of +0.146 deg C per decade. On the other hand, when sea surface temperature, sea ice data **and** anthropogenic forcings are used as inputs, land plus sea surface temperatures warmed at a rate of +0.17 deg C per decade. That means that the simulated global surface temperatures of the GISS Model-E when forced only with sea surface temperature and sea ice data have a warming trend that's 85% of the trend of the models that are also forced with all of the other forcings. Because we've shown the warming of sea surface temperatures is natural, that means Mother Nature cannot explain, according to the models, only 15% of the warming that's taken place over the past 30+ years. This, of course, assumes the models are right, and so far that's been the incorrect assumption.

Recall the discussion at the end of **Chapter 5.11 The Apparent Impact of the Warming of the Pacific Western Boundary Current Extensions Following Major El Niño Events.** There I had noted: In the post **Can Most Of The Rise In The Satellite-Era Surface Temperatures Be Explained Without Anthropogenic Greenhouse Gases?**, which was referred to a couple of times in this chapter, we determined that about 85% of the global warming signal over the past 30 years could be accounted for with natural variables, primarily ENSO and the secondary effects of ENSO. Keep that percentage in mind. It'll come up again.

That 15% is a far cry from the assumption or implication that all of the warming over the last 30 years was manmade. That's precisely what the IPCC implied in the **Summary for Policymakers** from their 4th Assessment Report. The fourth bullet-point paragraph under the heading of "Understanding And Attributing Climate Change" (page 10) reads [my bold face]:

> *"It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM.4).* ***The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing.*** *The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR. {3.2, 9.4}"*

The IPCC does temper that assumption in the Summary for Policymakers when they use the vague word "most" in their highlighted statement on page 10:

> *Most of the observed increase in global average temperatures since the mid-20th century is* very likely *due to the observed increase in anthropogenic greenhouse gas concentrations.*

However, the IPCC also makes the inference that all of the warming is manmade. Which do you suppose most people remember?

Compo and Sardeshmukh (2009) was a discussion of the influence of sea surface temperature on land surface temperature. GISS does not provide the model outputs for only land surface temperature through that webpage, but we can get a rough order of magnitude by assuming the oceans represent 70% of the surface of the globe and by subtracting the observed sea surface temperature data from the model outputs. The results are shown in Figure 5-16. Based on the difference in the linear trends, the changes in sea surface temperatures very roughly account for about 73% of the land surface temperature warming.

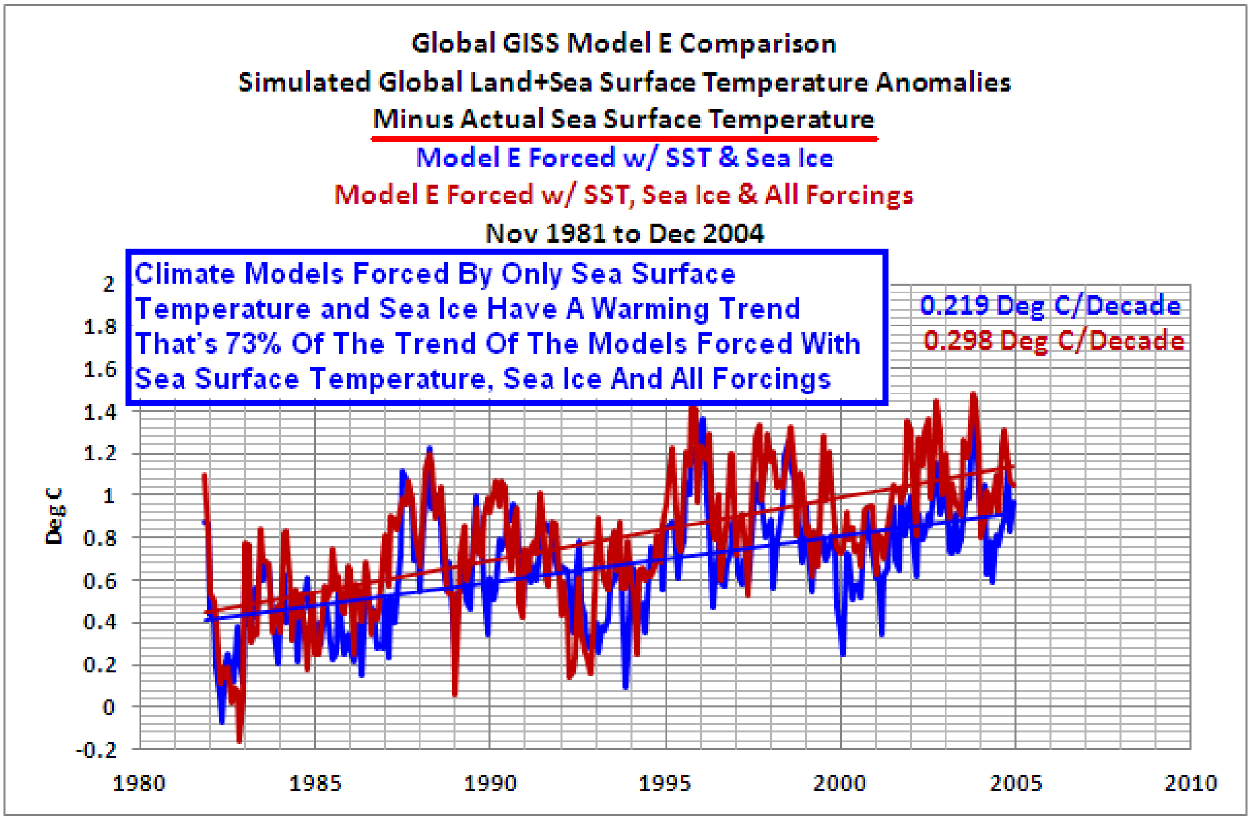

Figure 8-16

Bob Tisdale

While the other 27% is a significant amount, it's still nowhere near the 100% implied by the IPCC. Now consider, there are dozens of papers that contradict the IPCC's statement that "*Most of the observed increase in global average temperatures since the mid-20th century is* very likely *due to the observed increase in anthropogenic greenhouse gas concentrations.*" Those papers show other anthropogenic forcings such as land use changes, heat island effect, black carbon, and the like have all made major contributions to global warming, with many papers claiming as much as 50% of the warming from the specific forcing. In other words, the studies of land use change say as much as 50% of the land surface temperature warming can be attributed to it, the studies of black carbon say about 50% could be attributed to it, etc. With all of those factors contributing 50%, there's not a lot of room left for anthropogenic greenhouse gases.

WHAT ABOUT MULTIDECADAL VARIABILITY?

The climate models used by the IPCC in their 4th Assessment Report were not initialized to reproduce the known multidecadal variability of ocean processes. In fact, many of the models can't reproduce the multidecadal variations of the North Atlantic and North Pacific sea surface temperatures. Recall Kevin Trenberth's 2007 comments at the Nature.com blog titled **Predictions of climate**:

> *None of the models used by IPCC are initialized to the observed state and none of the climate states in the models correspond even remotely to the current observed climate. In particular, the state of the oceans, sea ice, and soil moisture has no relationship to the observed state at any recent time in any of the IPCC models. There is neither an El Niño sequence nor any Pacific Decadal Oscillation that replicates the recent past; yet these are critical modes of variability that affect Pacific rim countries and beyond. The Atlantic Multidecadal Oscillation, that may depend on the thermohaline circulation and thus ocean currents in the Atlantic, is not set up to match today's state, but it is a critical component of the Atlantic hurricanes and it undoubtedly affects forecasts for the next decade from Brazil to Europe. Moreover, the starting climate state in several of the models may depart significantly from the real climate owing to model errors.*

All of these factors contribute to the long-term variability of global surface temperatures, yet the IPCC elected not to simulate them. Is it because many of the models cannot reproduce the multidecadal variability? Most of the models archived in CMIP3 show no evidence of being able produce multidecadal variability that comes close to observations. Or is it because multidecadal variability would decrease the rate at which global surface temperatures warmed and therefore significantly reduced the "alarm factor" of the model projections? That's likely as well.

Looks like I got side-tracked.

RECAP

The question for this chapter was: Since Climate Models used by the IPCC Don't Simulate ENSO Properly and Don't Account for the Long-term Impacts of ENSO, Can Climate Models be used to Project Future Climate?

We've shown and discussed that there is no evidence anthropogenic greenhouse gases have had any impact on sea surface temperatures for the past 30 years. As climate models exist today, basically as a marketing tool for the IPCC, with their reliance on anthropogenic greenhouse gases to reproduce the warming of the global oceans, their projections based on proposed future greenhouse gas scenarios are flawed. They're based on erroneous assumptions—assumptions that are contradicted by the instrument temperature record.

Personally, I am not intimate with the workings of coupled climate models. It would be impossible for me to say whether the current batch of models can be altered so that they're better able to replicate the past, and after the required changes, would be able to better project future climate. However, as is obvious to anyone familiar with climate change research, the anthropogenic greenhouse gas mindset of many of the modelers would have to change if any advancements can be made. I don't see that happening in my lifetime.

8.12 Can the Same Upward Steps Caused by Major El Niño events be seen during the Early Warming Period of the 20th Century?

There are a number of things we have to consider when examining sea surface temperature data before the satellite era. The source data is very sparse and there were major corrections to sea surface temperature data during the first half of the 20th Century.

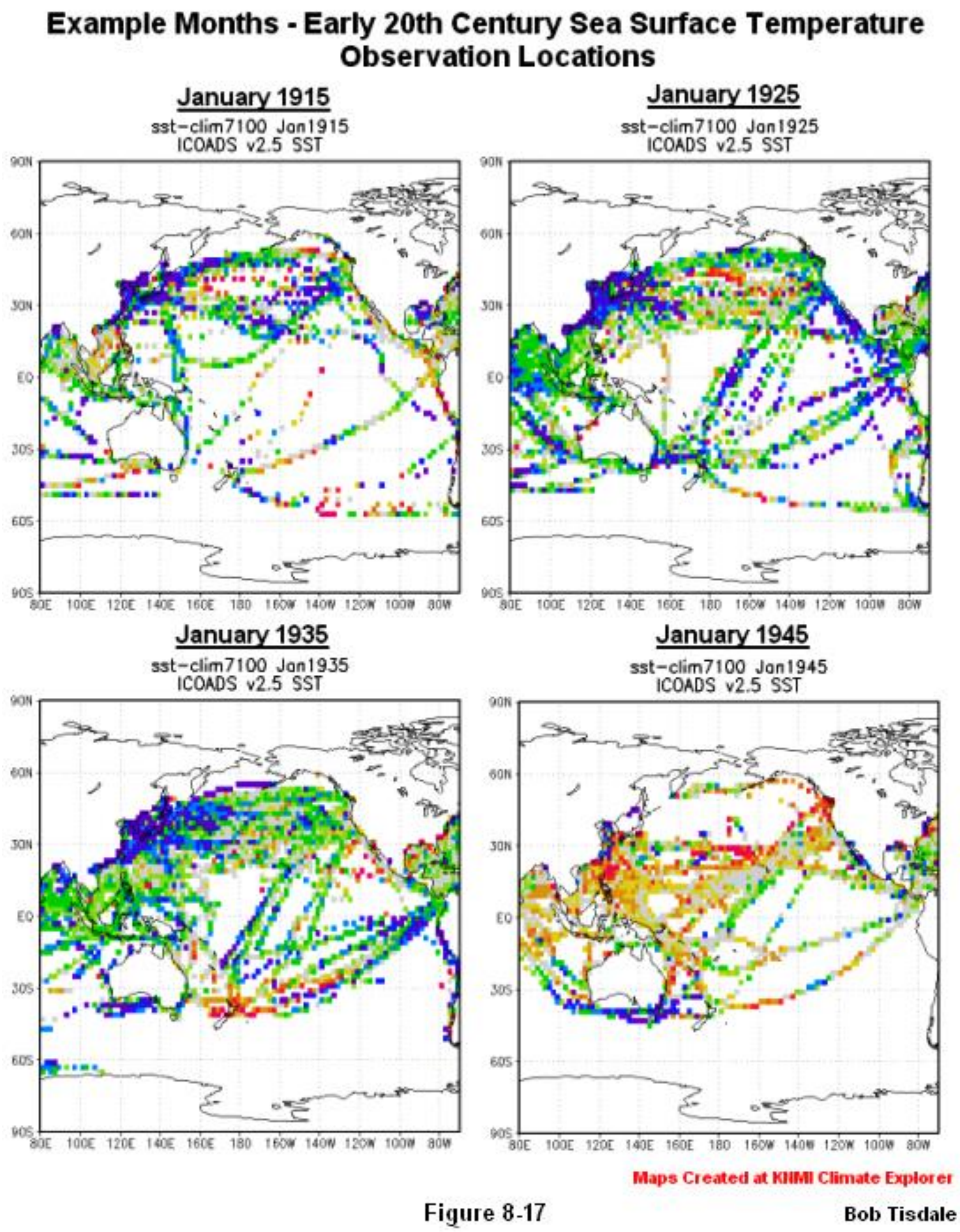

Figure 8-17

Consideration 1: Source Data is Very Sparse before the Satellite Era

Figure 8-17 presents four maps of gridded sea surface temperature anomalies from the ICOADS dataset for the Januarys of 1915, 1925, 1935 and 1945. Grids in white have no data for that month. The maps cover the East Indian and Pacific Oceans, which are oceans impacted directly by the warms waters released by El Niño events. As a reminder, ICOADS provides the source sea surface temperature data for the Hadley Centre and NOAA reconstructions. Prior to the satellite era, there are very few observations in the southeast Pacific and Southern Ocean, and as is very obvious in the maps, there are fewer readings as we reach back in time for data. Keep in mind, many of the grids with data may only have a few measurements for any given month. A sailor tossed a bucket over the side of the ship, hauled the water-filled bucket back on deck and placed a thermometer in the bucket. In fact, you can see the ship tracks in the maps. Now, during the satellite era, there are two satellites making two daily orbits of the globe, sampling the skin temperature of the oceans. There are also fixed buoys in the tropical oceans feeding continuous measurements back through other satellites to research computers. Ship-based observations still exist, but now they're from the temperature measurements of the water entering to cool the ship's engines. Let's not forget the ARGO buoys, which bob to the surface every ten days.

Consideration 2 – There have been Major Corrections to the Source Data before the Satellite Era

In addition to the sparseness of source data, there were also concerns about the early sampling methods and their impacts on measured sea surface temperature. Wooden, canvas, and metal buckets were used, and then there was a transition to ship inlets. Researchers made corrections to the sea surface temperature data, and the most severe changes occurred during the early warming period of the 20th Century. Figure 8-18 compares global sea surface temperature anomalies for the source ICOADS data and the corrected and infilled HADISST reconstruction based on that source data.

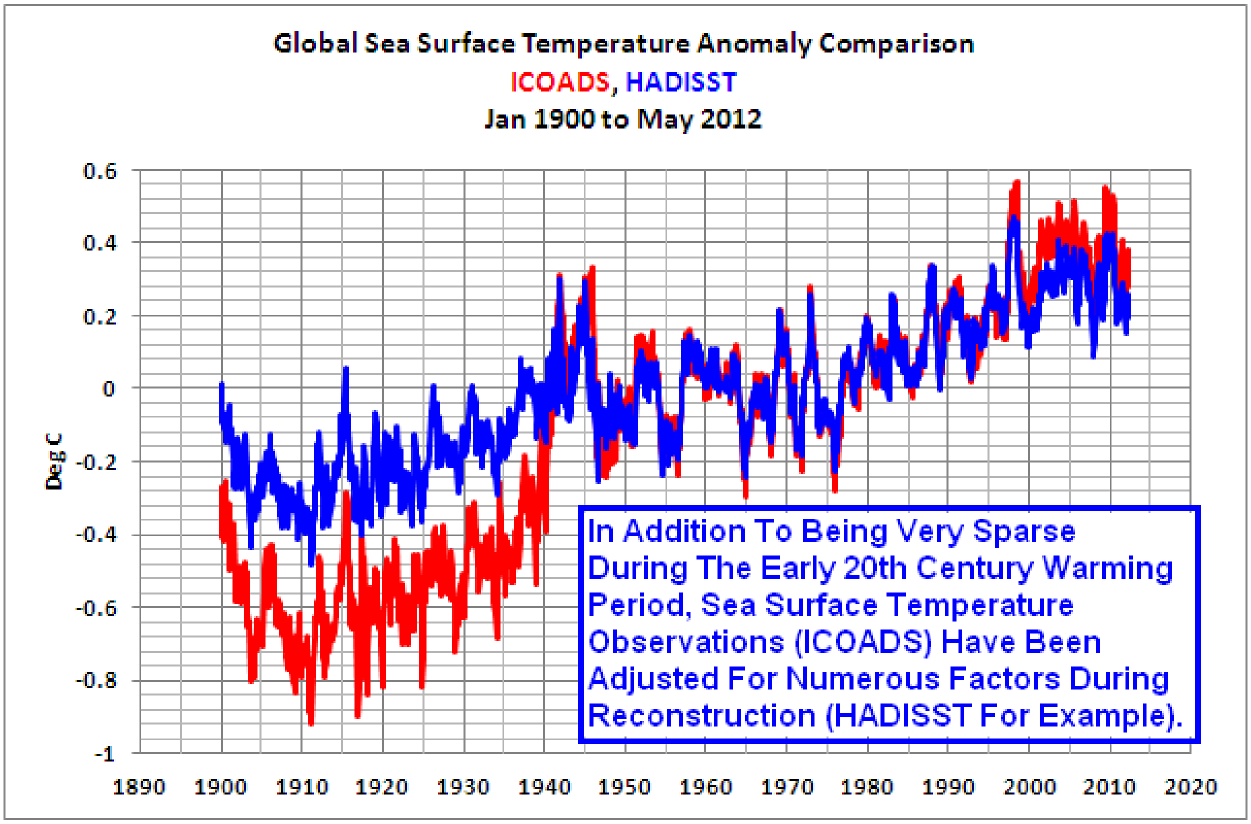

Figure 8-18 Bob Tisdale

Consideration 3 – How Accurate is the Early ENSO Index?

Please scroll back up to the maps showing the sparseness of the measurements, Figure 8-17, and note the very limited the number of measurements along the eastern equatorial Pacific. Our ENSO index, NINO3.4 sea surface temperature anomalies, has the coordinates of 5S-5N, 170W-120W. While it's remarkable that researchers are able to reconstruct sea surface temperatures during that period, the data from small areas like the NINO3.4 region are highly suspect. That's why there seems to be little agreement between the reconstructions of NINO3.4 data, Figure 8-19, in the first half of the 20th Century. The 1918/19/20 El Niño event doesn't appear in the ERSST.v3b data, and there are very few similarities between all reconstructions on La Niña events.

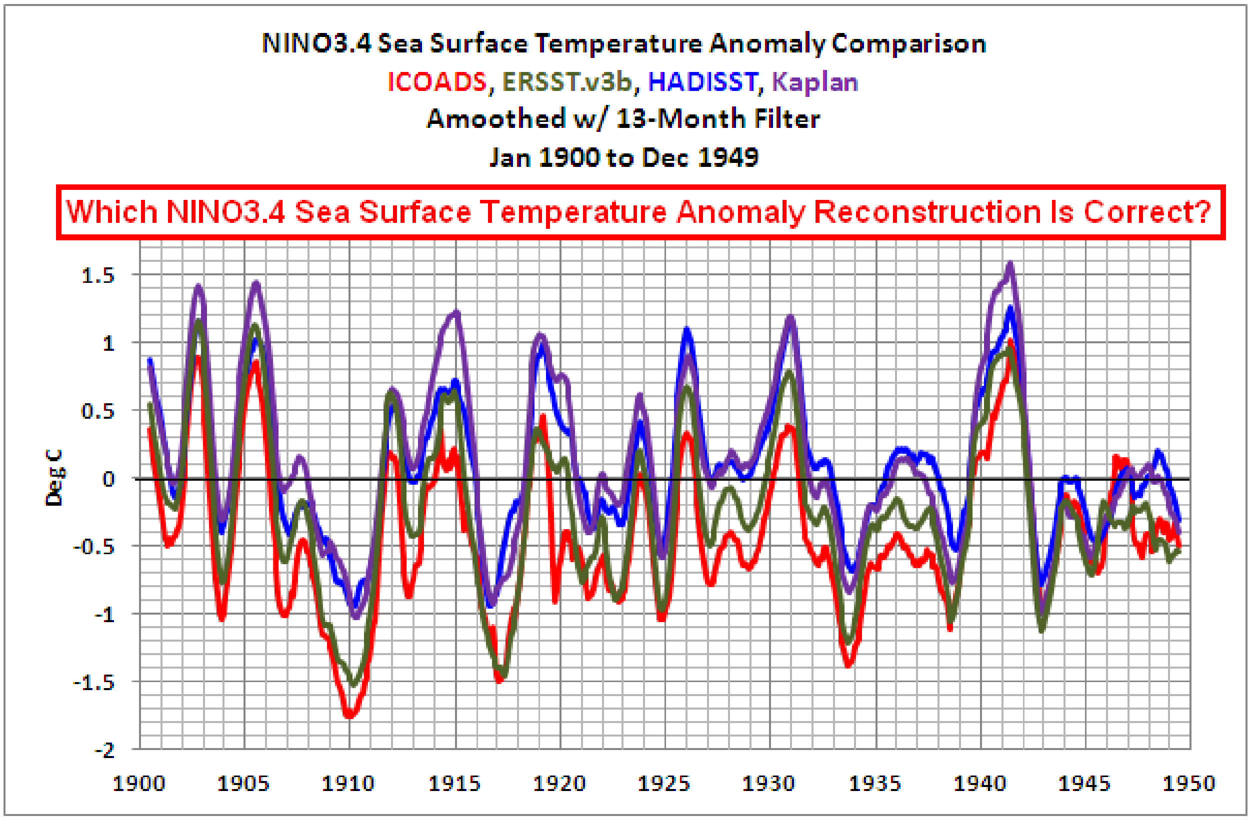

Figure 8-19 Bob Tisdale

Let's Select the Datasets We'll Use to Examine the Earlier Data

A few more things to discuss before we look at the East Indian-West Pacific sea surface temperature data before the satellite era. First, the long-term sea surface temperature dataset that presents the most current understandings of the necessary corrections is the HADSST3 data. This new UKMO/Hadley Centre dataset was introduced with the following two-part paper:

Kennedy et al (2011). Reassessing biases and other uncertainties in sea-surface temperature observations since 1850 part 1: measurement and sampling errors.
And:
Kennedy et al (2011). Reassessing biases and other uncertainties in sea-surface temperature observations since 1850 part 2: biases and homogenisation.

Because it's the latest and greatest, we'll use it for the East Indian-West Pacific sea surface temperature data.

The Giese et al (2009) paper **The 1918/19 El Niño** argued that the 1918/19 portion of the 1918/19/20 El Niño was underestimated in the NINO3.4 sea surface temperature reconstructions, and that it was likely comparable in strength to the 1982/83 and 1997/98 El Niño events. Giese et al (2009) also suggested that the 1912/13 and 1939/40/41/42 El Niño events were also under-rated. Keep that in mind when considering the following. We'll use the Kaplan version of NINO3.4 sea surface temperature anomalies as a reference, because it showed the largest variations in response to those El Niño events, as shown in Figure 8-19 above. We're just using it for timing of El Niño events, so it makes little difference on the results, but it's good to try to use the most appropriate data.

Even with All of those Factors Conspiring Against Us…

Figure 8-20 presents the HADSST3 sea surface temperature anomalies for the East Indian-West Pacific Oceans (90S-90N, 80E-180) from January 1900 to December 2006. The HADSST3 data was originally released as an incomplete dataset. For that reason, the HADSST3 data ends in 2006 at the KNMI Climate Explorer. However, because we've already presented the long-term impacts of the 1997/98 El Niño, the last few years of missing data will not affect this discussion. As shown in Figure 20, it appears there were upward shifts in response to the 1918/19/20 and 1939/40/41/42 El Niño events, in addition to the events of 1986/87/88 and 1997/98. The period between the 1918/19/20 and 1939/40/41/42 El Niño events looks like it might have a positive trend with the upward spike toward the end, but let's take a look.

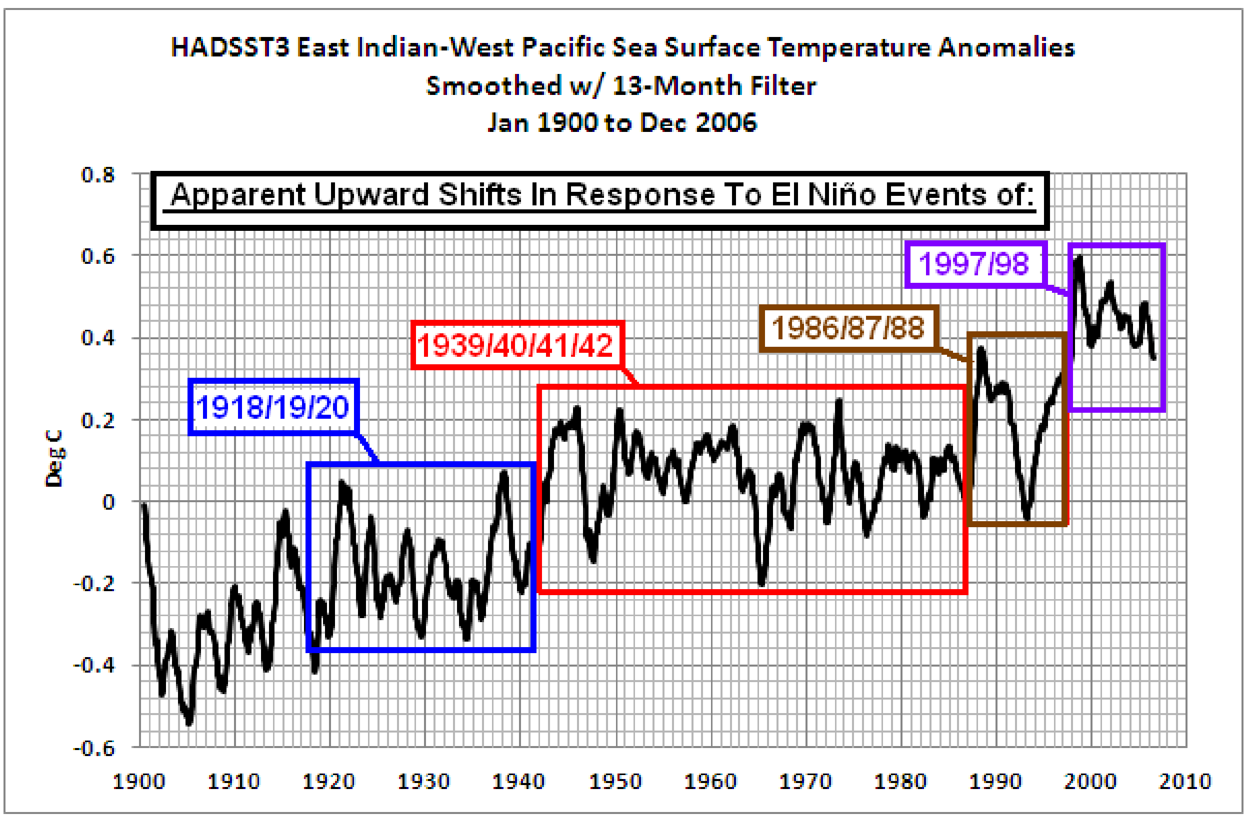

Figure 8-20

Figure 8-21 compares long-term East Indian-West Pacific sea surface temperature anomalies to scaled and inverted NINO3.4 data. I've highlighted the two periods to show that the upward steps occur during the transitions from El Niño to La Niña following the 1918/19/20 and 1939/40/41/42 El Niño events. I'm not going to bother discussing the upward shifts in response to the 1986/87/88 and 1997/98 El Niño events. They were already discussed and illustrated in detail in Chapter 5.4 **The Obvious ENSO-Caused Upward Shifts in the Sea Surface Temperature Anomalies of the East Indian and West Pacific Oceans.**

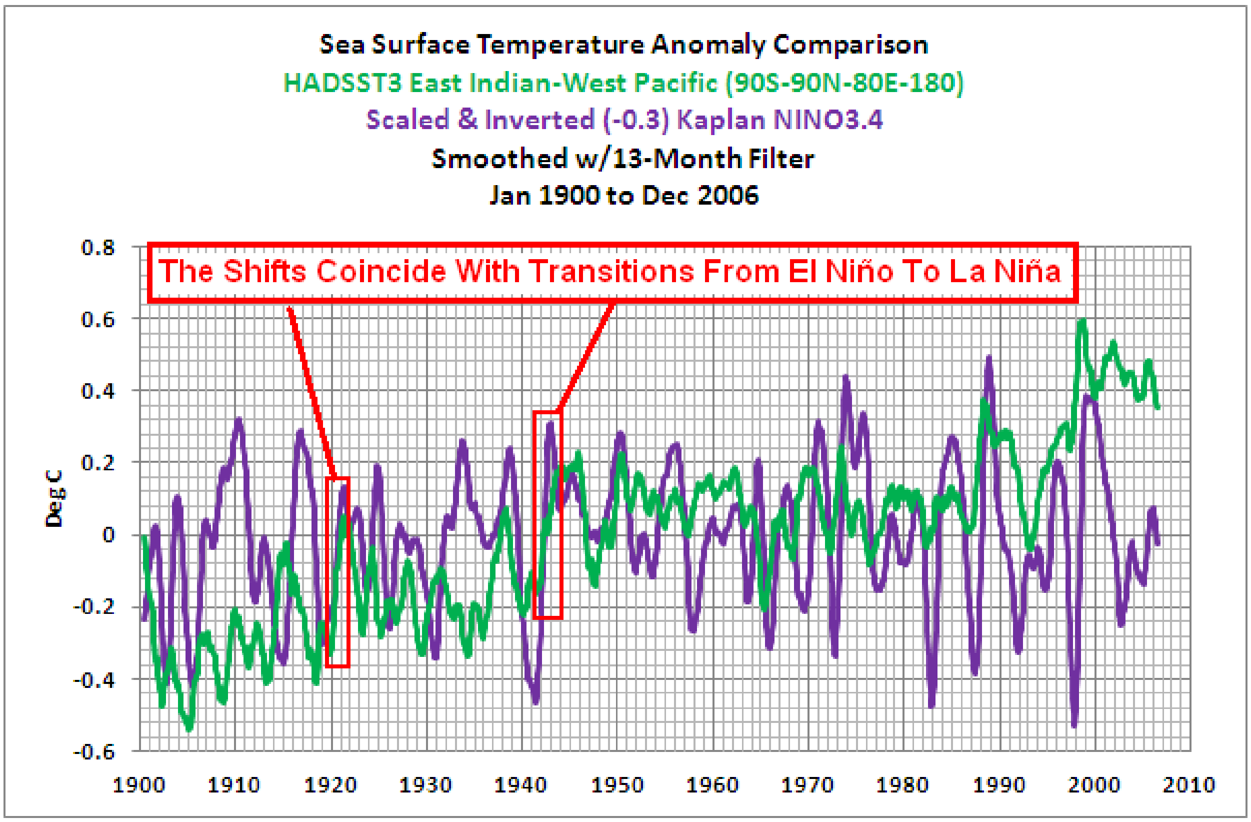

Figure 8-21

Bob Tisdale

In Figures 8-22 and 8-23, I've isolated East Indian-West Pacific data for the periods between the El Niño events of 1918/19/20 and 1939/40/41/42, and between the 1939/40/41/42 and 1986/87/88 El Niño events. Figure 8-22 shows that the East Indian-West Pacific sea surface temperature anomalies actually cooled between those major El Niño. It wasn't a significant cooling, with trends of -0.006 deg C per decade and -0.009 deg C per decade, but, looking at it the other way, they did **not** warm between those multiyear El Niño events.

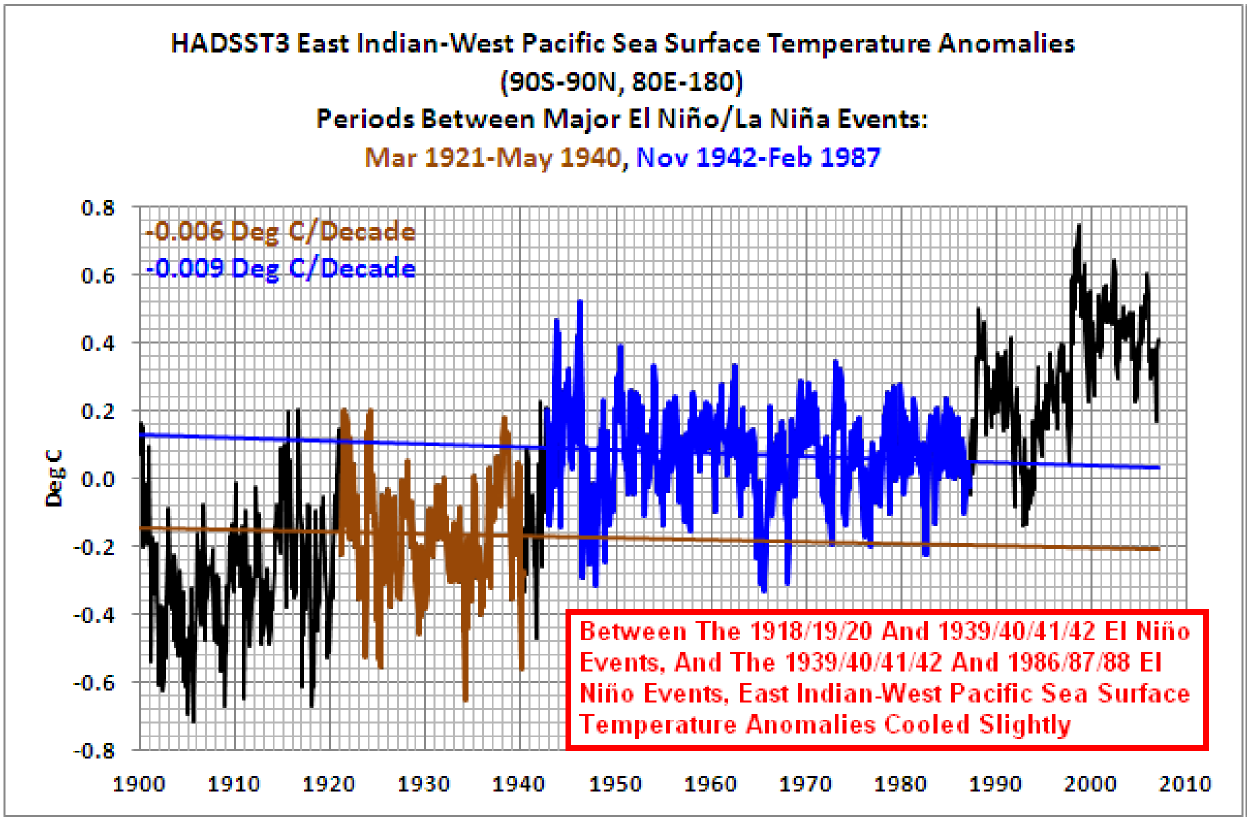

Figure 8-22 Bob Tisdale

The sea surface temperature anomalies for the East Indian-West Pacific dataset have obviously warmed from early 1920s to the mid-1980s, but between the major El Niño events, the sea surface temperature anomalies cool slightly. That means the warming from the early 1920s to the mid-1980s took place during the 1939/40/41/42 El Niño. Using the period-average temperatures between the major El Niño events as a reference, the 1939/40/41/42 El Niño raised East Indian-West Pacific sea surface temperature anomalies 0.23 deg C, and it accounts for all of the warming.

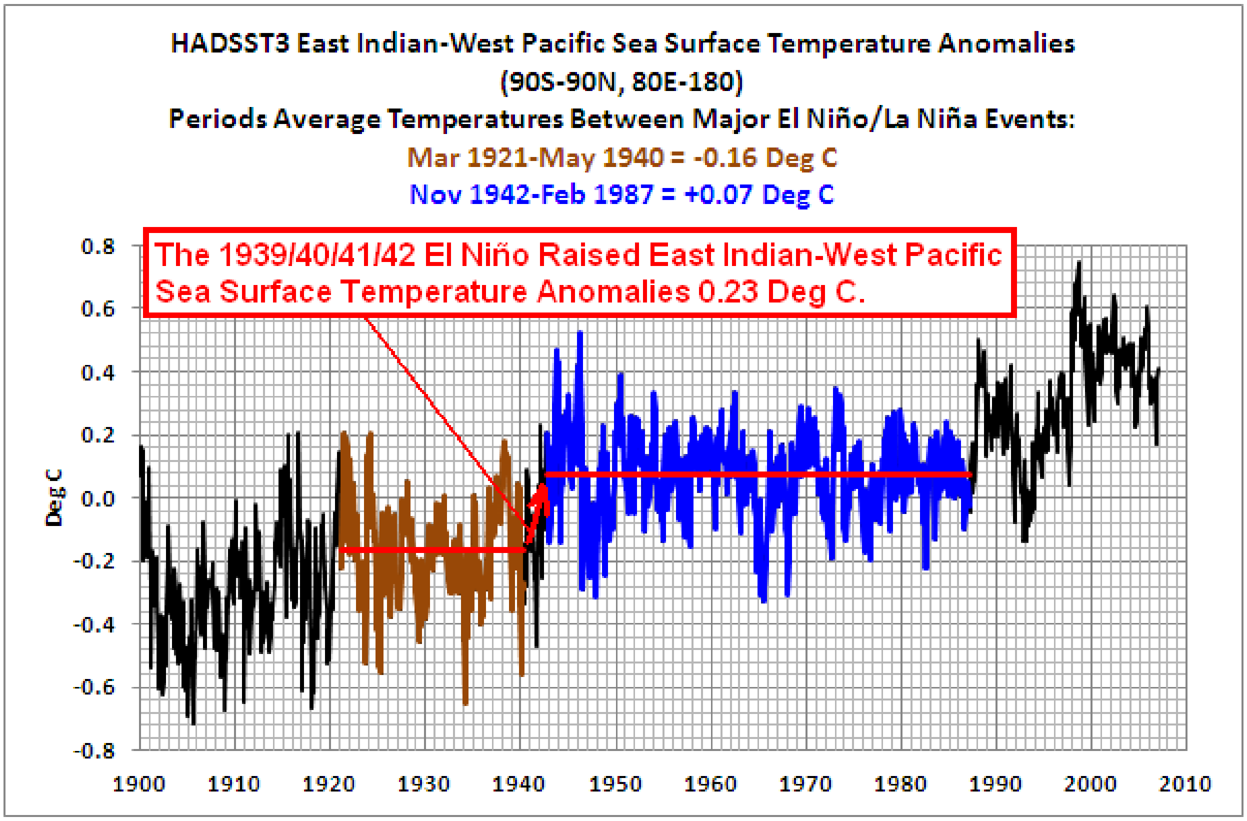

Figure 8-23

Bob Tisdale

When you sit back and think about it, it's quite remarkable that the East Indian-West Pacific sea surface temperature data as far back as the early 1920s confirm our understandings of how sea surface temperatures warm in response to major El Niño events. All things considered, it should come as no surprise that the relationship falls apart before the El Niño event of 1918/19/20. The data simply becomes too sparse to be of any reasonable value. See Figure 8-24. I've included scaled and inverted GISS aerosol optical depth data to represent the timing of volcanic eruptions, just in case you were thinking volcanoes could be the cause of the lack of agreement.

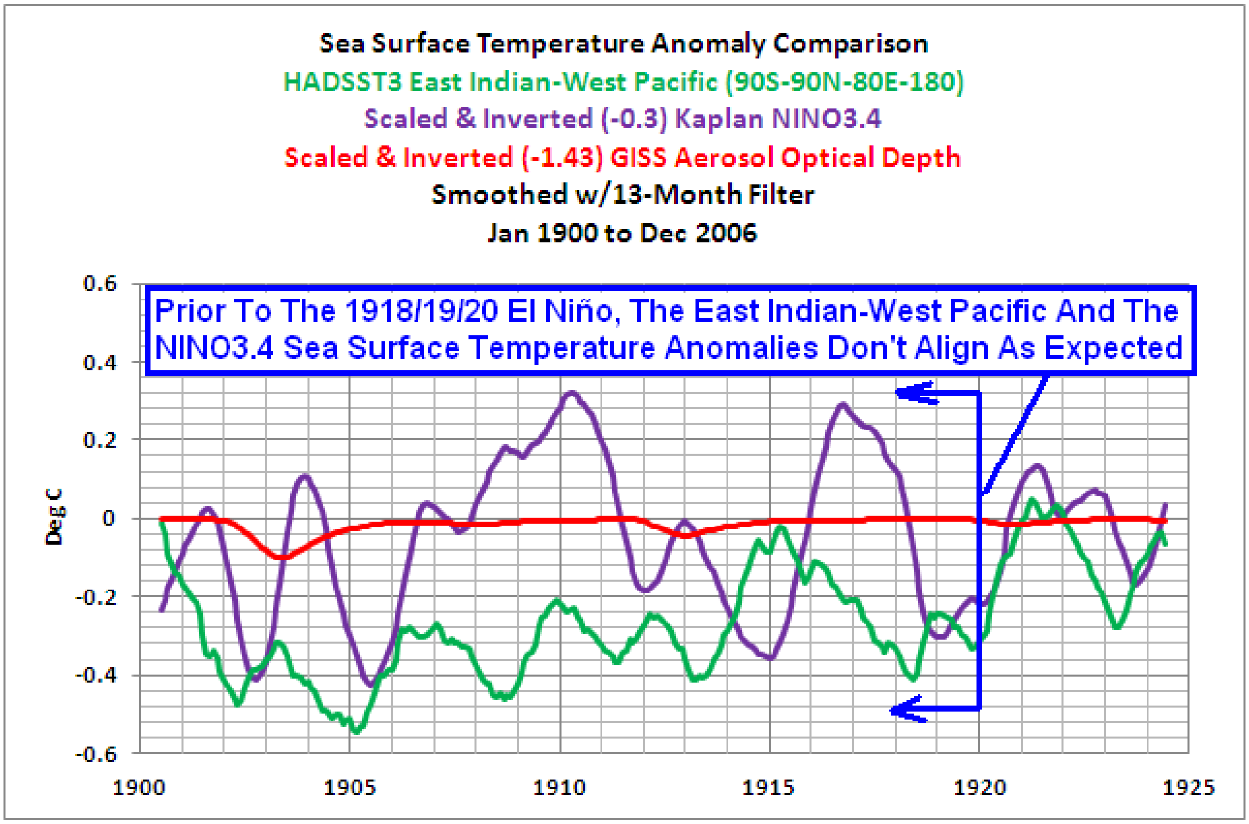

Figure 8-24 Bob Tisdale

RECAP

For this chapter, the question was Can the Same Upward Steps Caused by Major El Niño events be seen during the Early Warming Period of the 20th Century?

The answer is yes, as far back as the early 1920s. Considering how limited the data is before the satellite era and how many corrections have been made to it, I find it amazing that we have been able to show that the major El Niño events of 1918/19/20, 1939/40/41/42, 1986/87/88 and 1997/98 account for all of the warming of the East Pacific-West Indian Oceans (90S-90N, 80E-180) since the early 1920s. I want to thank John Kennedy of the UK Met Office Hadley Centre and the other members of the team who updated the Hadley Centre sea surface temperature data for the HADSST3 data.

8.13 What is the Springtime Predictability Barrier?

The statistical and dynamical models used to forecast the flavor or gender of the next ENSO event encounter difficulties in boreal spring, March to May. They run into what has been termed the "springtime predictability barrier". There is a good overview of the "springtime predictability barrier" in the abstract of Torrence and Webster (1997) **The annual cycle of persistence in the El Niño/Southern Oscillation**. The first two paragraphs of it read:

> *A spring 'predictability barrier' exists in both data and models of the El Niño/Southern Oscillation (ENSO) phenomenon. In statistical analyses this barrier manifests itself as a drop-off in monthly persistence (lagged correlation) while in coupled ocean-atmosphere models it appears as a decrease in forecast skill.*
>
> *The 'persistence barrier' for ENSO indices is investigated using historical sea surface temperature and sea level pressure data. Simple statistical models are used to show that the persistence barrier occurs because the boreal spring is the transition time from one climate state to another, when the 'signal-to-noise' of the system is lowest and the system is most susceptible to perturbations. The strength of the persistence barrier is shown to depend on the degree of phase locking of the ENSO to the annual cycle.*

References to the "springtime predictability barrier" can be found in papers from the early 1990s, and the barrier still exists for forecasters. Mother Nature apparently still has some tricks up her sleeves.

8.14 What are the Differences between the Statistical and Dynamical Models used to Predict the next ENSO Event?

This is a discussion of the models used to predict whether the next ENSO event will be an El Niño or a La Niña and the strength of the event. This is not a discussion of coupled climate models used to hindcast past climate or project it into the future.

There are two types of models used to forecast ENSO: dynamical and statistical. The dynamical models are coupled ocean-atmosphere models. Current atmospheric and ocean conditions are input to the dynamical models and the program forecasts the expected conditions up to six months in advance. A statistical model, on the other hand, uses the existing ocean and atmospheric conditions, and compares them to a long history of observations to make predictions.

The International Research Institute for Climate and Society webpage titled **Predicting ENSO** has more detailed discussions, including the strengths and weaknesses of both types of models.

8.15 What is the Pacific Meridional Mode?

The Pacific Meridional Mode is the dominant statistical mode of sea surface temperatures and surface winds in the eastern tropical Pacific. It is derived from a statistical analysis method called Maximum Covariance Analysis. The Institute for Atmospheric and Climate Science (IACETH), which is part of the Department of Environmental Sciences (**D-USYS**) of the Swiss Federal Institute of Technology Zurich (**ETH Zurich**) provides a basic and reasonably easy-to-understand overview of this method of analysis. That description is on page 2 of what appear to be slides from a lecture titled **Maximum Covariance Analysis**. There they write:

> ***• Purpose***
> *Find patterns in 2 datasets which are highly correlated (i.e. are frequently met simultaneously). E.g. patterns of SST that go along with patterns of SLP.*
>
> ***• Applications***
> *Study the coupling between parameters to understand physical mechanisms of climate variations. E.g. how do SST and SLP mutually influence each other?*
> *Statistical downscaling. (Translate GCM derived climate change scenarios to the local/regional scale.)*
> *Reconstruction / Forecasting*

The Pacific Meridional Mode evolves in the Intertropical Convergence Zone and Cold Tongue region of the eastern tropical Pacific, and is said to be independent of ENSO. Variations in the Pacific Meridional Mode tend to lead ENSO by 2 to 4 seasons (not months). Based on this, it was believed that the Pacific Meridional Mode could help overcome the Springtime Predictability Barrier. Refer to Chang et al (2007) **Pacific meridional mode and El Niño-Southern Oscillation**. The abstract reads:

> *We present intriguing evidence that the majority of El Niño events over the past four decades are preceded by a distinctive sea-surface warming and southwesterly wind anomaly in the vicinity of the Intertropical Convergence Zone (ITCZ) during the boreal spring. This phenomenon, known as the Meridional Mode (MM), is shown to be intrinsic to the thermodynamic coupling between the atmosphere and ocean. The MM effectively acts as a conduit through which the extratropical atmosphere influences ENSO. Modeling results further suggest that the MM plays a vital role in the seasonal phase-locking behavior of ENSO. The findings provide a new perspective for understanding the important role of thermodynamic ocean-atmosphere feedback in ENSO and may have*

> *profound implications for ENSO prediction, particularly the unresolved issue of the spring predictability barrier.*

The last paragraph in the Summary and Discussion of Chang et al (2007) clarifies those hopes related to the Springtime Predictability Barrier:

> *Given that the MM activity peaks during the boreal spring, and potentially affects the onset of ENSO and its seasonal phase-locking behavior, one may conjecture that improving model skills in simulating and predicting the MM may lead to improved skill in forecasting ENSO, and ultimately eliminate the spring predictability barrier [Latif et al., 1998]. If this conjecture is proven true, then a better understanding of thermodynamic feedbacks and the interaction between the tropics and extratropics in the climate system should be considered as a high priority in future climate modeling studies.*

RECAP

The question for this chapter: What is the Pacific Meridional Mode?

Based on the statistical analysis method called Maximum Covariance Analysis, the Pacific Meridional Mode is the dominant statistical mode of sea surface temperatures and surface winds in the Intertropical Convergence Zone and Cold Tongue region of the eastern tropical Pacific. The Pacific Meridional Mode is said to be independent of ENSO. The last page of the 2004 presentation by Vimont and Chang, **The Pacific Meridional Mode: Diagnostics and Impacts** notes that that the Pacific Meridional Mode leads ENSO by 2 to 4 seasons.

8.16 How Far in Advance can the Onset of an El Niño be Predicted?

At present, it appears the Springtime Predictability Barrier is still hampering ENSO prediction models, both statistical and dynamical. By the end of spring, the Kelvin wave that serves as a preliminary part of the ENSO event may have already occurred. The models are then forecasting an event that's underway in those cases.

Every couple of years, researchers find another "precursor of ENSO" with hope of using it to break that predictability barrier. For example, Ramesh and Murtugudde (2012), **All flavours of El Niño have similar early subsurface origins** found that subsurface equatorial Pacific temperature processes begin during the summer and autumn of the year (up to 18 months) before the ENSO event. Their abstract reads:

> *The El Niño/Southern Oscillation phenomenon, characterized by anomalous sea surface temperatures and winds in the tropical Pacific, affects climate across the globe[1]. El Niños occur every 2–7 years, whereas the El Niño/Southern Oscillation itself varies on decadal timescales in frequency and amplitude, with a different spatial pattern of surface anomalies[2] each time the tropical Pacific undergoes a regime shift. Recent work has shown that Bjerknes feedback[3, 4] (coupling of the atmosphere and the ocean through changes in equatorial winds driven by changes in sea surface temperature owing to suppression of equatorial upwelling in the east Pacific) is not necessary[5] for the development of an El Niño. Thus it is unclear what remains constant through regimes and is crucial for producing the anomalies recognized as El Niño. Here we show that the subsurface process of discharging warm waters always begins in the boreal summer/autumn of the year before the event (up to 18 months before the peak) independent of regimes, identifying the discharge process as fundamental to the El Niño onset. It is therefore imperative that models capture this process accurately to further our theoretical understanding, improve forecasts and predict how the El Niño/Southern Oscillation may respond to climate change*

Only time will tell if this find will be able to overcome the Springtime Predictability Barrier.

8.17 Why do ENSO Events Appear to have a Greater Impact on the Northern Hemisphere Surface Temperatures?

The primary reasons why ENSO events appear to have a greater impact on the Northern Hemisphere relate to the fact that the Northern Hemisphere has about twice as much land surface as the Southern Hemisphere and the variations in land surface temperature are much greater than sea surface temperatures.

Land covers about 40% of the surface of the Northern Hemisphere, Figure 8-25, while in the Southern Hemisphere, land only cover about 20%.

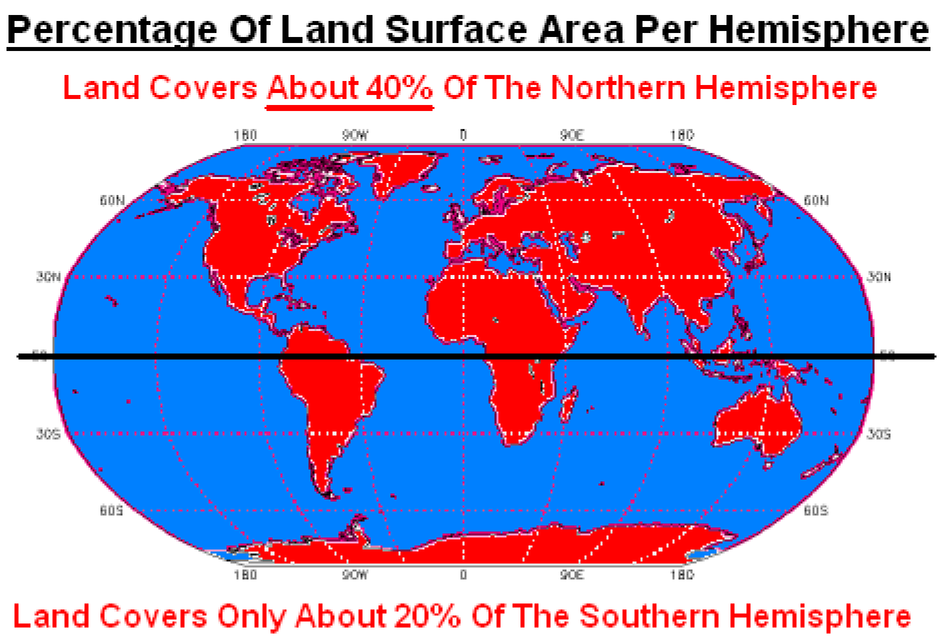

Figure 8-25 Bob Tisdale

Land surface temperature would be better written as land surface **air** temperature. It is, in reality, the temperature of the air measured at approximate 2 meters from the land surface. On the other hand, sea surface temperature is, as the name implies, the water temperature, close to the surface, of the oceans, seas and major lakes. Water has much more mass than air. Water is slower to warm and cool, or it absorbs and releases heat more slowly, because it has "thermal inertia".

The slower and lesser response of sea surface temperature data can be seen in comparison graphs of sea surface and land surface air temperatures (not anomalies) for both hemispheres. See Figure 8-26. The Northern Hemisphere data is in the top graph and the Southern Hemisphere is shown in the bottom one. For example, the Northern Hemisphere land surface temperatures typically cycle seasonally from below 0 deg C to more than 20 deg C during a year, while sea surface temperatures vary from about 18 to 22 deg C annually. The seasonal cycle in sea surface temperature also lags land surface air temperatures by about 3 months, though that's not easily seen in those two graphs. We can also see the difference in the variability by comparing detrended sea surface and land surface (air) temperature anomalies for both hemispheres, Figure 8-27. ENSO and volcanic aerosols have a much larger impact on land surface temperatures than sea surface temperatures.

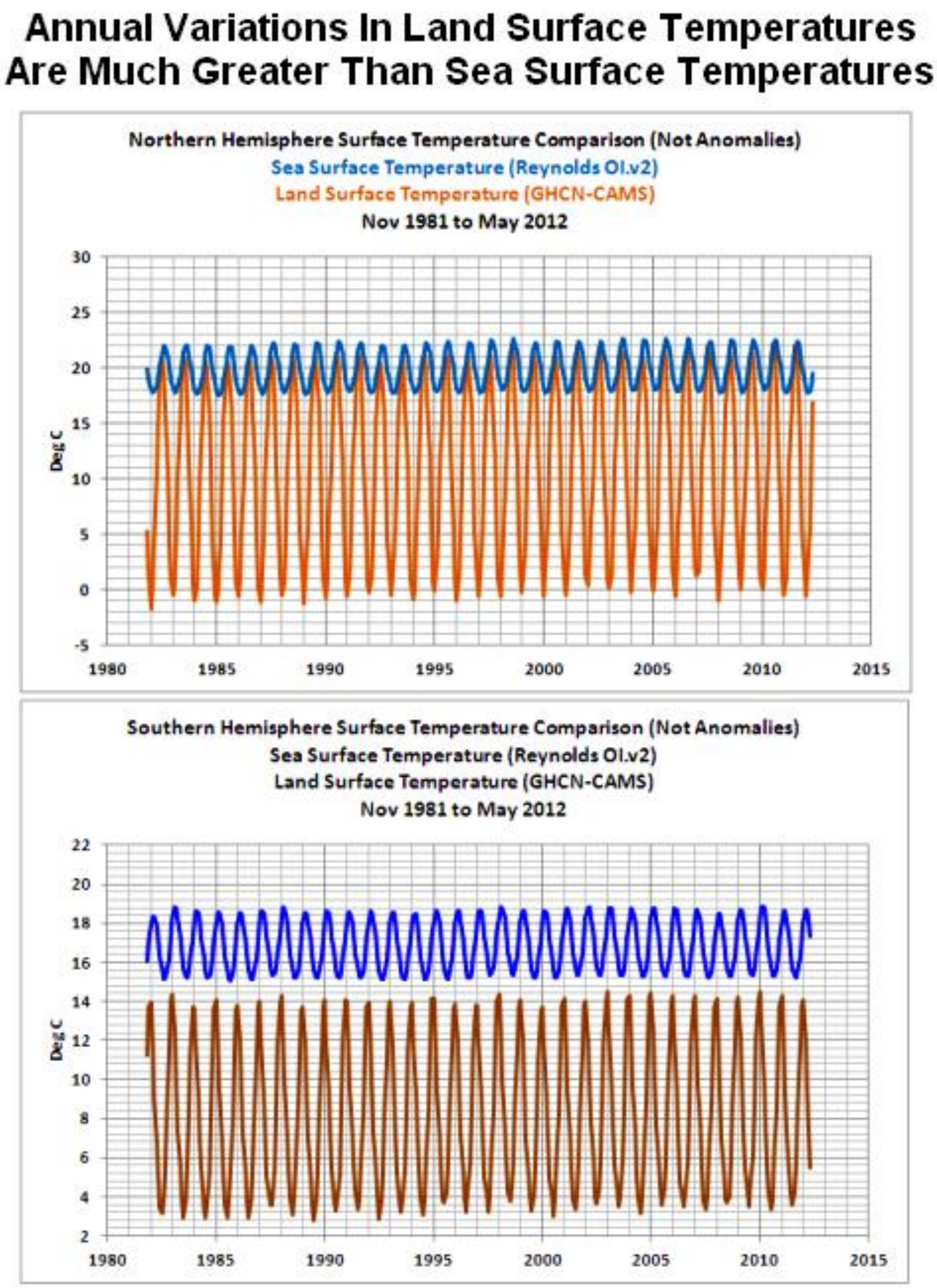

Figure 8-26

HHH

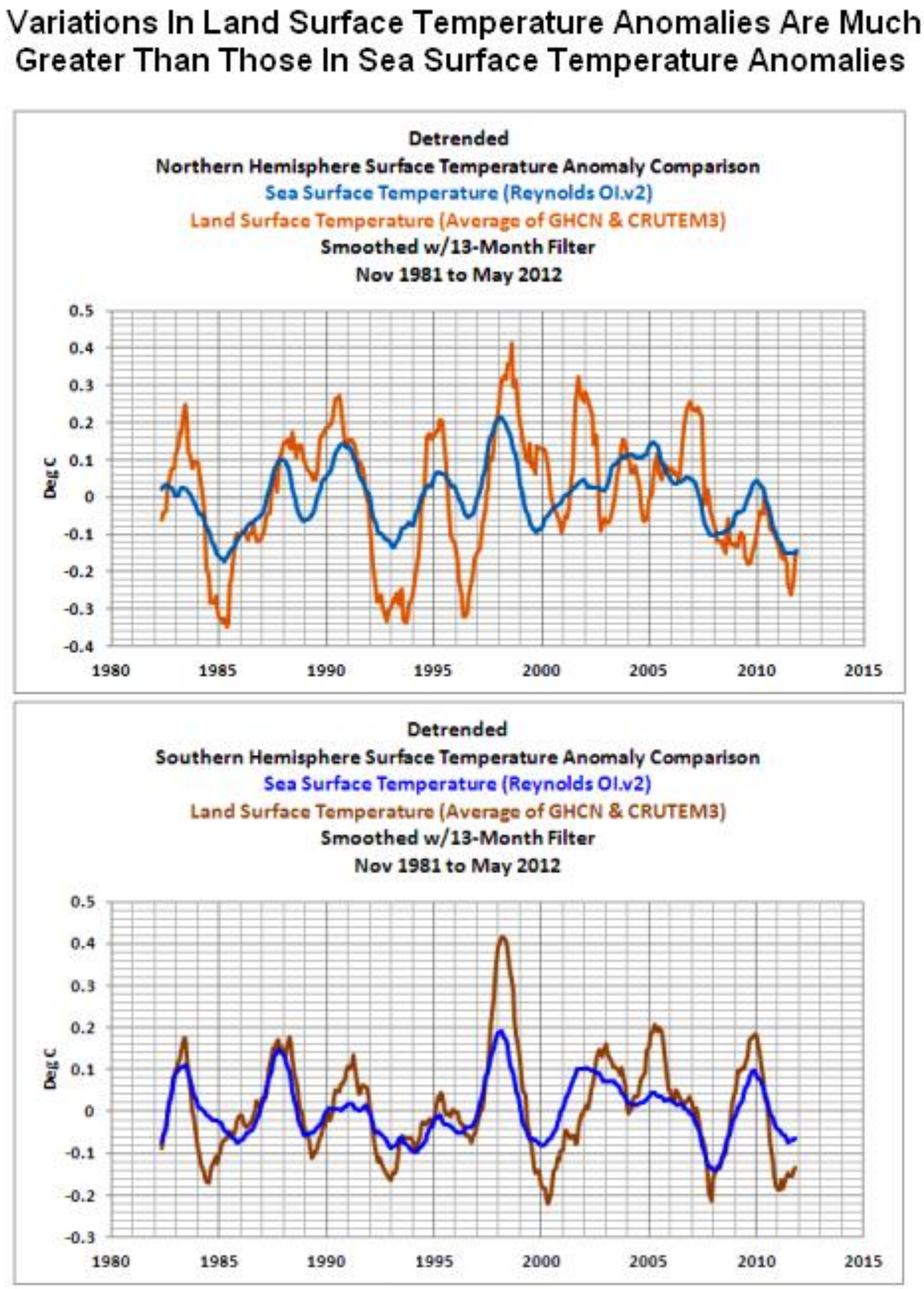

Figure 8-27

In the bottom cell of Figure 8-27, note how the detrended land surface temperatures responded much more than sea surface temperatures to the 1997/98 El Niño, but then they respond similarly to other ENSO events like the 1986/87/88 El Niño. I have found no scientific papers that explain this.

Figure 8-28 shows the detrended land surface temperature anomaly data for both hemispheres. The Northern Hemisphere variations are much greater than those of the Southern Hemisphere.

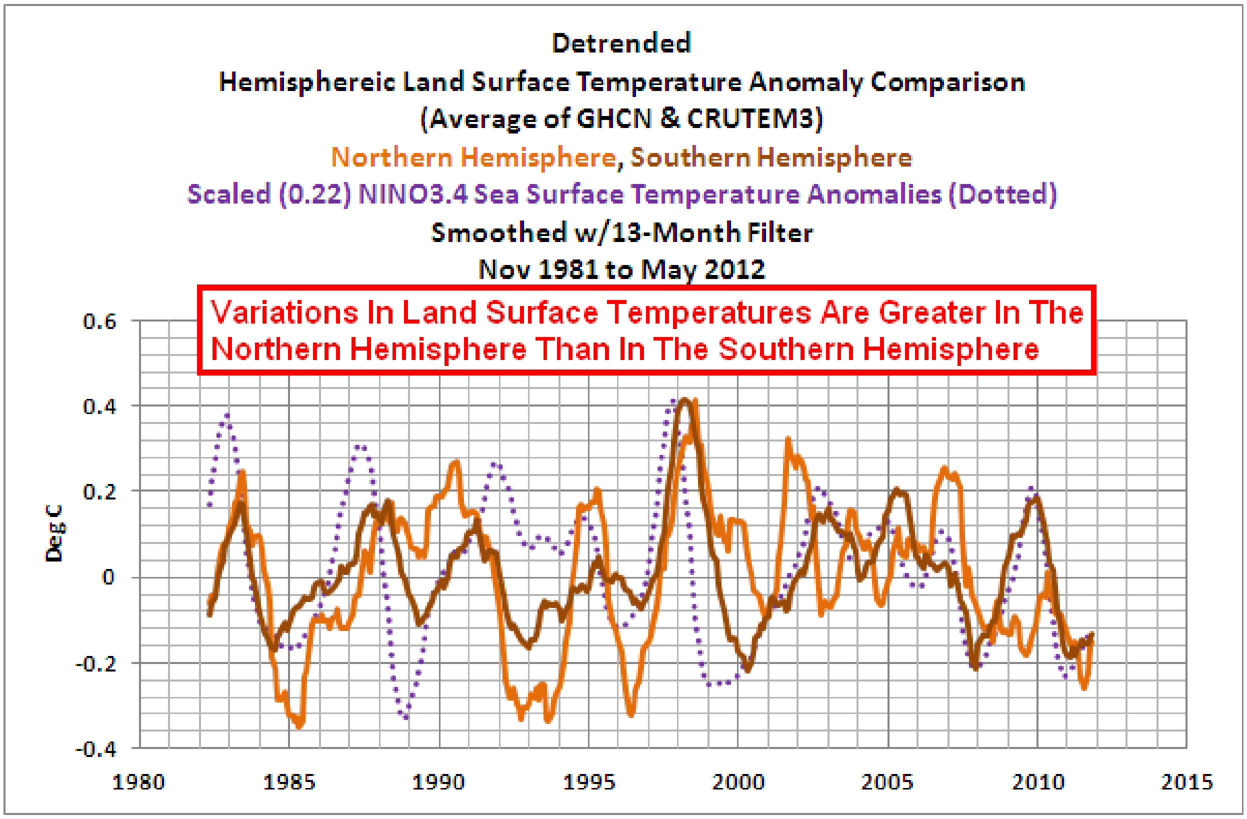

Figure 8-28 Bob Tisdale

Much of that additional variability in the detrended Northern Hemisphere land surface temperature data results from the Arctic Oscillation. See Figure 8-29, which compares detrended Northern Hemisphere land surface temperature anomalies to scaled NINO3.4 sea surface temperature anomalies and scaled Arctic Oscillation data. One can see the influences of ENSO and the Arctic Oscillation on the detrended Northern Hemisphere data. Wikipedia defines the Arctic Oscillation as:

> *The **Arctic oscillation** (**AO**) or **Northern Annular Mode**/**Northern Hemisphere Annular Mode** (**NAM**) is an index (which varies over time with no particular periodicity) of the dominant pattern of non-seasonal sea-level pressure variations north of 20N latitude, and it is characterized by pressure anomalies of one sign in the Arctic with the opposite anomalies centered about 37–45N…*

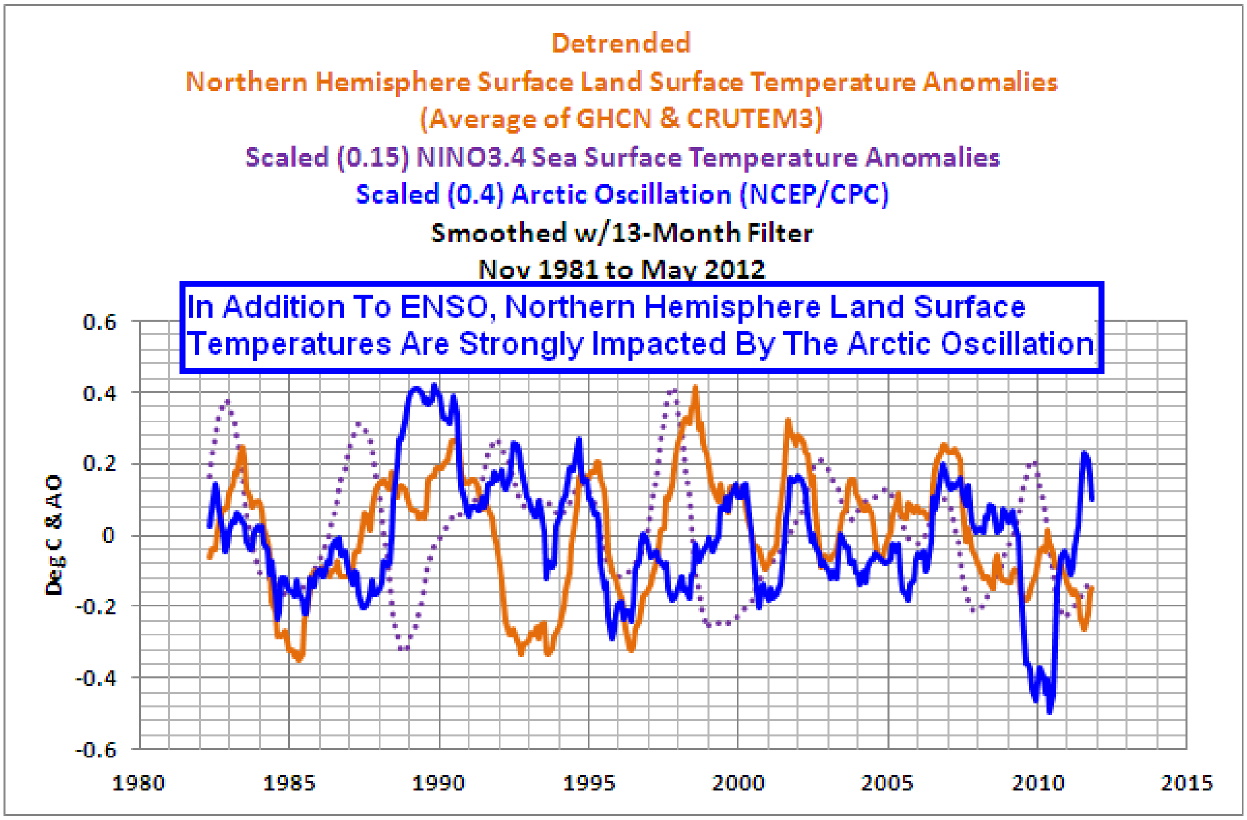

Figure 8-29 Bob Tisdale

RECAP

This chapter's question was, Why do ENSO Events Appear to have a Greater Impact on the Northern Hemisphere Surface Temperatures?

ENSO events appear to have a greater impact on the Northern Hemisphere because the Northern Hemisphere has about twice as much land surface as the Southern Hemisphere and because the responses of land surface air temperature to any influence are much greater than the responses of sea surface temperatures. Because there is more land surface in the Northern Hemisphere, there is less ocean to reduce (or inhibit) the response of surface temperatures there to ENSO. As discussed, the Northern Hemisphere land surface temperature anomalies are also strongly affected by a mode of sea level variability known as the Arctic Oscillation.

8.18 Do Climate Models Simulate Pacific Sea Surface Temperature Trends Better During Multidecadal Periods when ENSO Isn't Skewed Toward El Niño?

This question came up in a discussion of a graph of the Pacific sea surface temperature anomaly trends on a zonal-mean basis, one in which the observed trends were compared to the model mean of the models used by the IPCC in their 4th and upcoming 5th Assessment Reports. Refer to the example in Figure 8-30. That graph was presented as Figure 5-37 in **Chapter 5.7 The IPCC's Climate Models do a Terrible Job of Simulating East Pacific, "North Atlantic Plus", and South Atlantic-Indian-West Pacific Sea Surface Temperatures**.

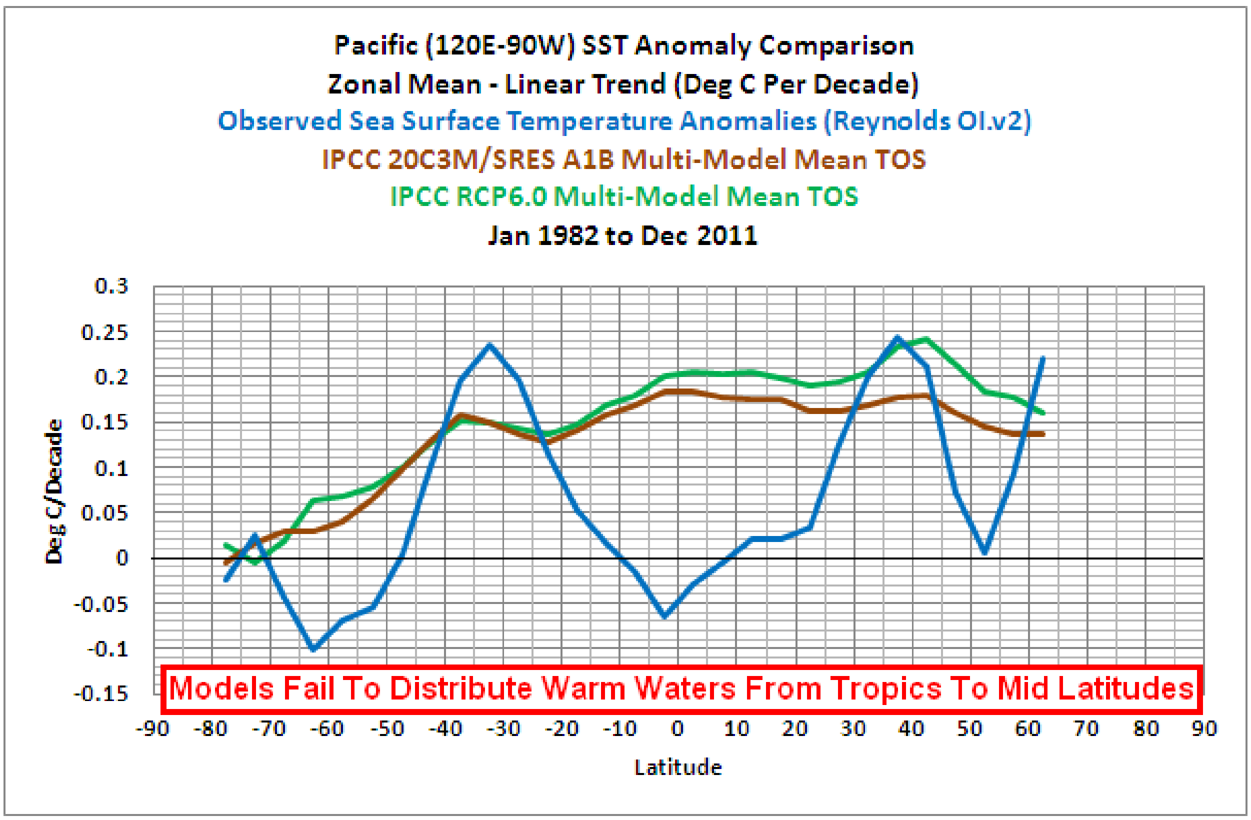

Figure 8-30 Bob Tisdale

So far in this book, we presented that graph using the satellite-based Reynolds OI.v2 data, which covers the period of November 1981 to present. Let's switch to the Met Office/Hadley Centre's HADISST sea surface temperature dataset so that we can look further back in time. HADISST includes satellite-based sea surface temperature data starting in the early 1980s, and prior to then, it relies on in situ measurements from buoys and ship inlets. Ocean grids with missing data are infilled using statistical methods in HADISST.

If you're wondering why we haven't been using HADISST data for the satellite era instead of Reynolds OI.v2 data, there are a couple of reasons. First, the Reynolds OI.v2 data is updated every month very quickly. In fact, the NOAA NOMADS website provides preliminary data for a month based on less than a full month of data. It provides previews of the upcoming monthly data for researchers. On the other hand, HADISST is usually updated a month later, meaning, for example, the Hadley Centre will furnish their July data in September. Second, the HADISST satellite-era data does not receive the same bias corrections as the Reynolds OI.v2 data, and I don't want that as a complaint about what's presented in this book. HADISST is a great long-term sea surface temperature reconstruction dataset. Like the ERSST.v3b reconstruction, HADISST also uses statistical methods to infill missing data from grids where there are no observations. Many researchers prefer the HADISST dataset, because, after the researchers use those statistical methods to infill the areas with missing data, they reinsert the observational data, where with the ERSST.v3b data, the source data is not reinserted. To get what they believe to be the best of the satellite-era and long-term data, some researchers will splice the Reynolds OI.v2 sea surface temperature anomalies to the HADISST data in 1982.

Back to the discussion of climate models:

We'll compare those observations to the multi-model mean of the sea surface temperature anomalies for the Pacific Ocean from the CMIP3 climate models simulations used by the IPCC for their 4th Assessment Report.

Figure 8-31 compares the Pacific Ocean sea surface temperature anomaly trends from January1976 to April 2012 on a zonal-means basis. This captures the full period after the 1976 Pacific climate shift. As you'll recall from prior discussions, it was a period when El Niño events became much stronger and ENSO was heavily skewed toward El Niño. The models during this period show the tropics warming at a high rate. On the other hand, the observations show the equatorial Pacific actually cooled and that observed warming occurred at the mid-latitudes of both hemispheres in the Pacific. In the real world, upwelling keeps the equatorial sea surface temperature anomalies relatively constant, and ENSO distributes sun-warmed water from the tropics to the mid-latitudes. The models show no evidence of this. The modelers have to warm the tropics at a reasonably high rate in their failed attempt to simulate the warming of Pacific during this period.

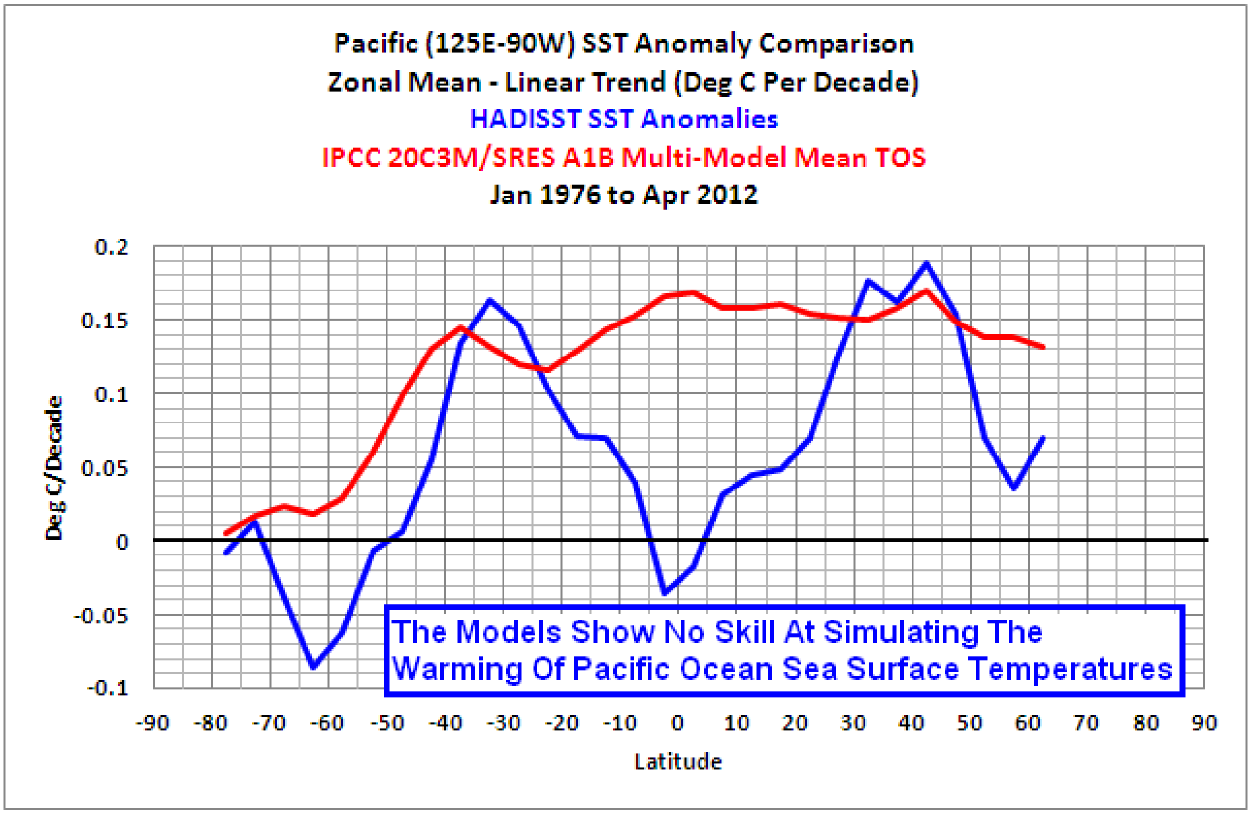

Figure 8-31

Bob Tisdale

As you'll recall, using annual NINO3.4 sea surface temperature anomalies, Figure 8-32, we showed that El Niño events dominated the period of 1976 to 2011, and La Niña events dominated, ever so slightly, the period from 1944 to 1976.

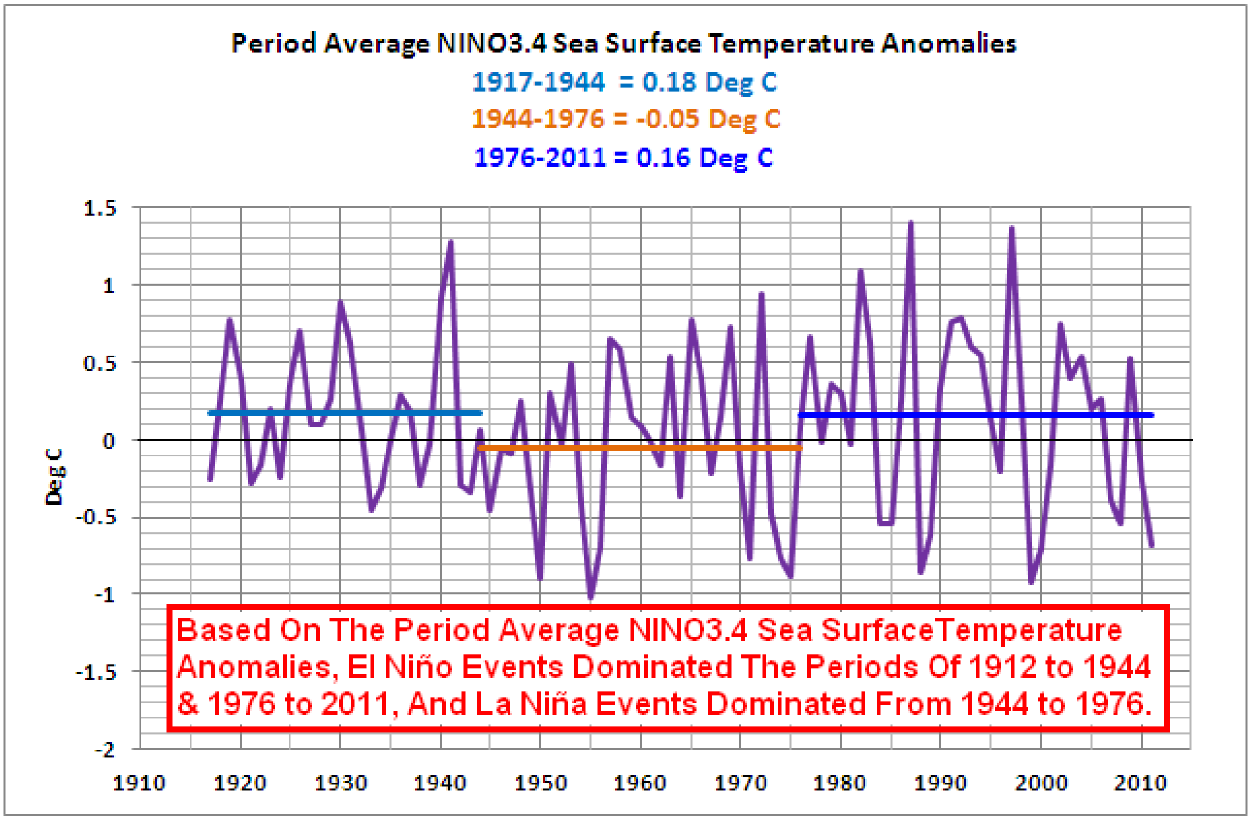

Figure 8-32 Bob Tisdale

The observed HADISST-based zonal-mean trends for the period of January 1944 to December 1975 are compared to the trends from January 1976 to April 2012 in Figure 8-33. The equatorial Pacific shows no evidence of warming in either period. In the mid-latitudes of the Southern Hemisphere during the earlier period, sea surface temperatures warmed at a significantly lower rate, and in the Northern Hemisphere, the mid-latitudes cooled. La Niña events slightly dominated the period of 1944 to 1975, which means that less warm water than normal was distributed from the tropics to the mid-latitudes, and that's precisely what the trends show.

In other words, as I wrote in the Introduction: The strength of ENSO phases, along with how often they happen and how long they persist, determine how much heat is released by the tropical Pacific into the atmosphere and how much warm water is transported by ocean currents from the tropics toward the poles. During a multidecadal period when El Niño events dominate (a period when El Niño events are stronger, when they occur more often and when they last longer than La Niña events), more heat than normal is released from the tropical Pacific and more warm water than normal is transported by ocean currents toward the poles—with that warm water releasing heat to the atmosphere along the way. As a result, global sea surface and land surface temperatures warm during multidecadal periods when El Niño events dominate. They have to. There's no way they cannot warm. Conversely, global temperatures cool during multidecadal periods when La Niña events are stronger, last longer and occur more often than El Niño events. That makes sense too because the tropical Pacific is releasing less heat and redistributing less warm water than normal then.

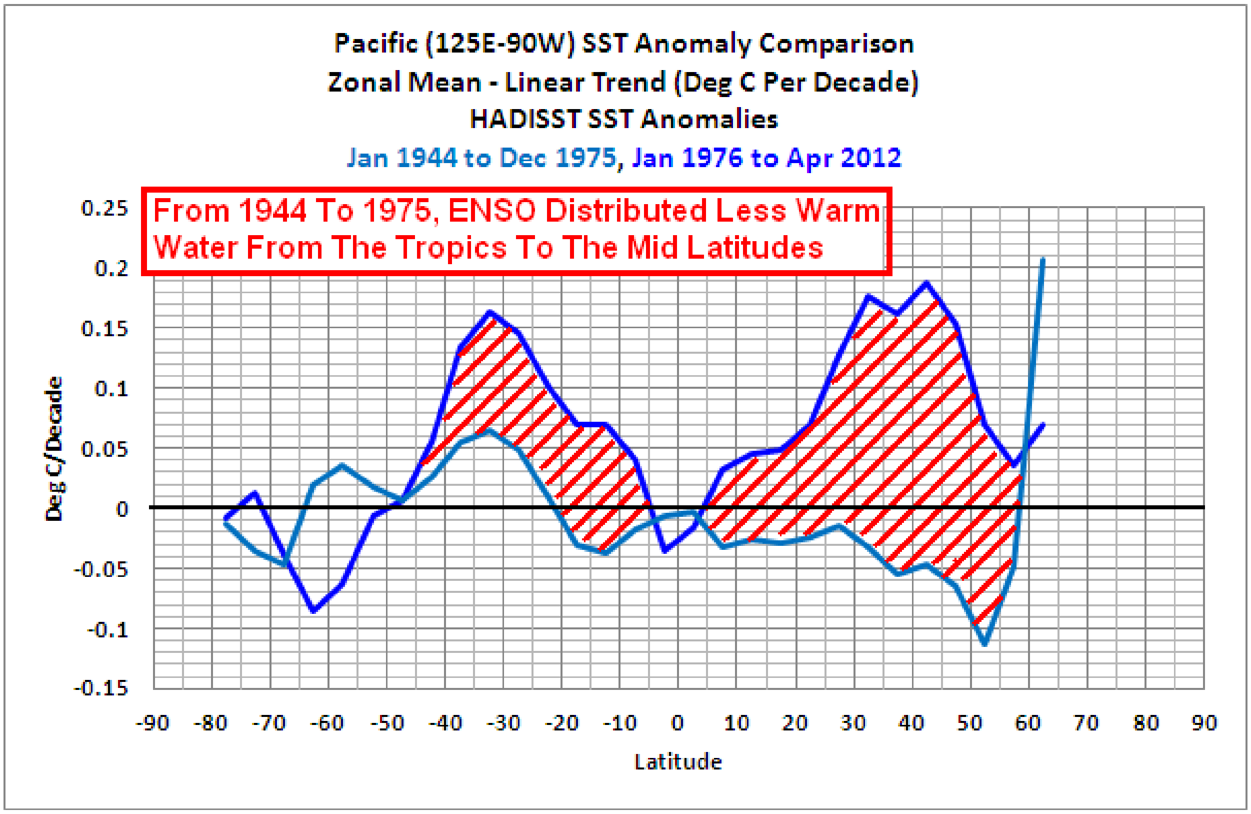

Figure 8-32 Bob Tisdale

A note of caution: There is very little source data in the Southern Ocean before the satellite era. The same holds true for the southeast South Pacific, south of the tropics. Those areas weren't parts of the normal shipping lanes. While the Hadley Centre has done a fantastic job of infilling missing data, it is "make believe" data. Keep that in mind when looking at the observed Southern Hemisphere trends, especially during the period of 1944 to 1975.

Figure 8-33 compares the observed and model-simulated trends of the Pacific Ocean on a zonal-mean basis for the period of January 1944 to December 1975. The climate models appear to perform better during this period, but looks can be deceiving. The models still show warming for the equatorial Pacific. Granted, it's less than the warming that occurred from 1976 to 2011, but it's still a nonexistent warming. The models also miss the cooling that took place from 1944 to 1975 from about 20S to almost 60N.

I've also added a highlight and note about the odd-looking observed warming from about 55N to 65N. That data covers a relatively small area of the North

Pacific. According to the data, that warming occurred right along the Russian coast from the Sea of Okhotsk to the Bering Sea. One has to wonder how much actual data is present there. Regardless, the models should not be expected to capture it. However, they should be expected to capture the ENSO-related trends, or lack thereof, at lower latitudes.

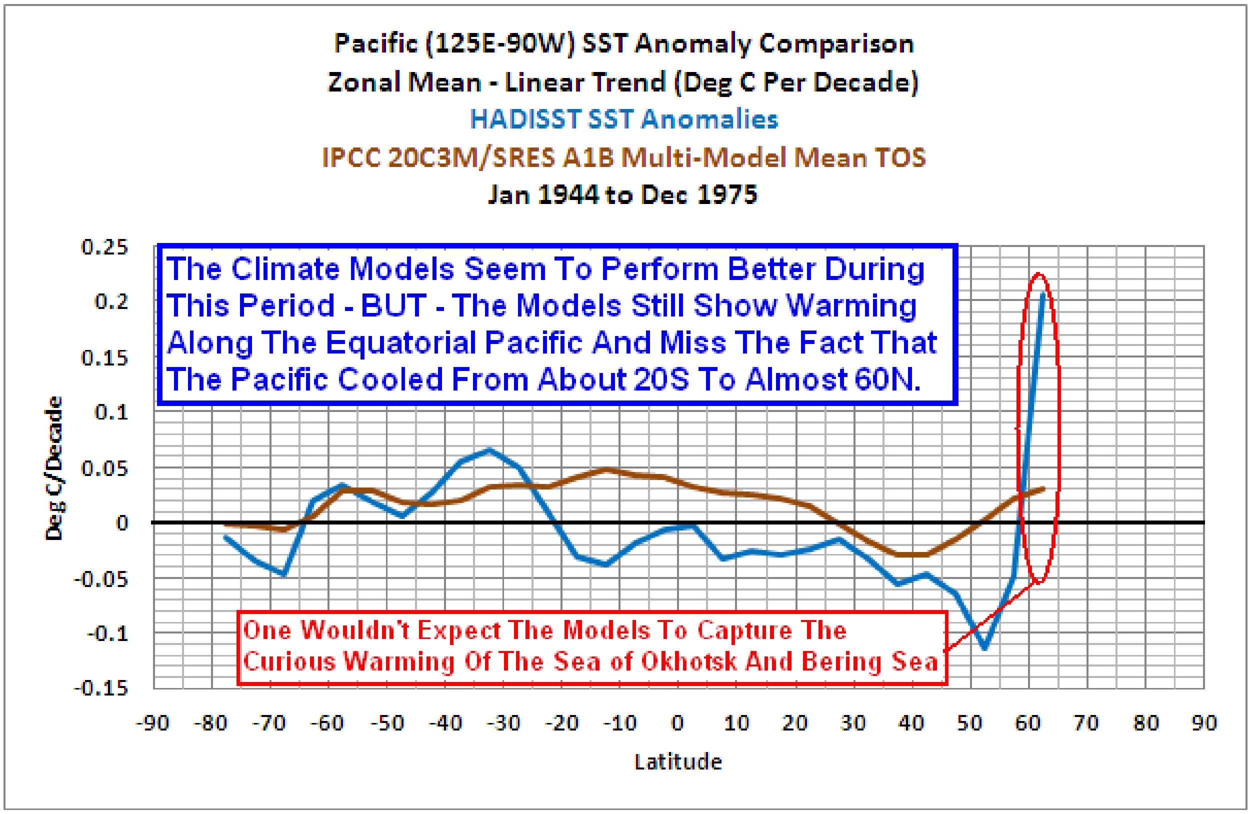

Figure 8-34 Bob Tisdale

The last graph for this discussion, Figure 8-35, compares the modeled trends for the early cooling period (January 1944 to December 1975) and the later warming period) January 1976 to April 2012. For both periods, the Pacific Ocean sea surface temperatures warm north of the Southern Ocean surrounding Antarctica. In the earlier period, sea surface temperatures cool at the mid-latitudes of the North Pacific. The warming during the latter period is greater and highest at the mid-latitudes of the North Pacific. During the latter period, the models fail to capture the additional distribution of warm water from the tropics to mid-latitudes associated with ENSO being skewed toward El Niño, and during the earlier period, they fail to capture the reduction in the distribution of warm water from the tropics that's associated with ENSO being slightly skewed to La Niña. In other words, the models show no skill at being able to simulate the warming and cooling that took place during the two multidecadal periods.

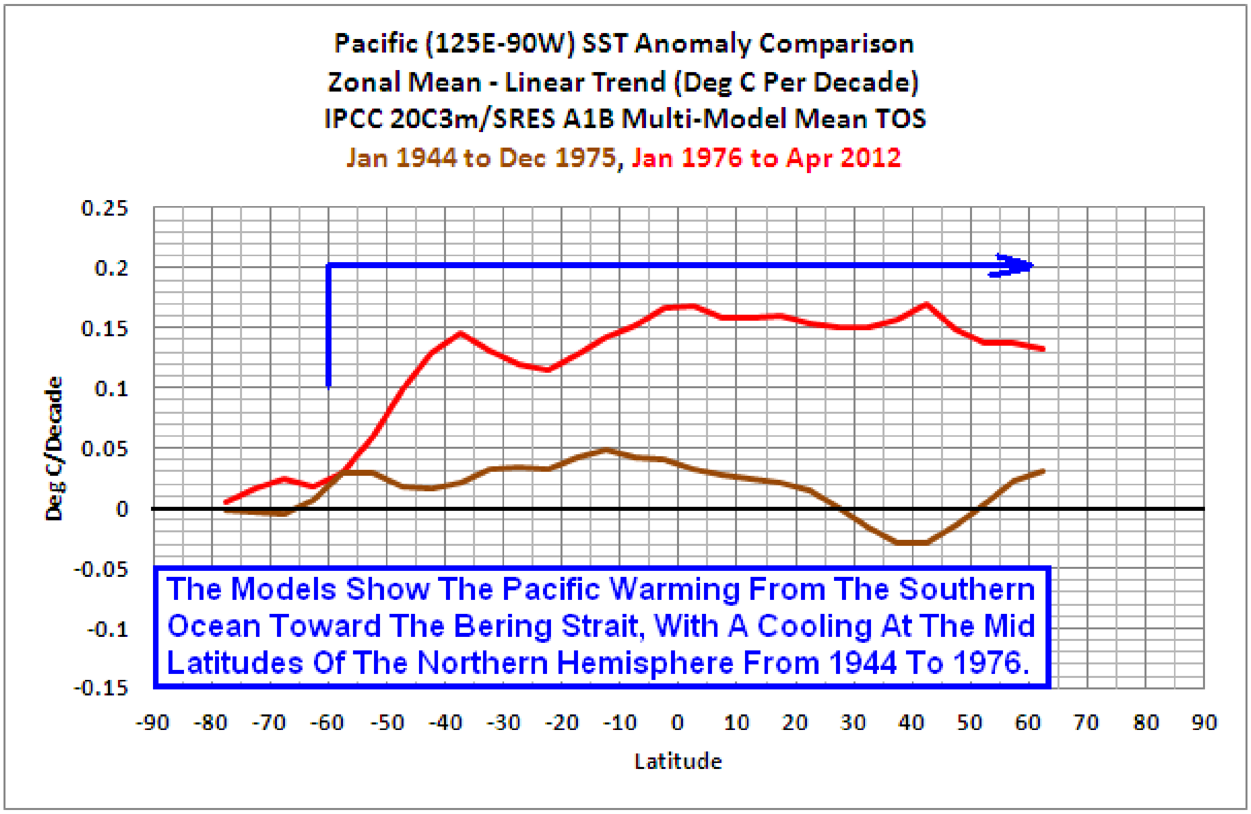

Figure 8-35 Bob Tisdale

RECAP

Do Climate Models Simulate Pacific Sea Surface Temperature Trends Better During Multidecadal Periods when ENSO Isn't Skewed Toward El Niño? was the question for this chapter.

The models appear to better simulate the zonal-mean trends for the Pacific Ocean sea surface temperatures for the period of 1944 to 1975, which is when ENSO was slightly skewed toward La Niña. Better is relative, though. The models did such a poor job of simulating how the Pacific Ocean warmed during the period of 1976 to 2012 that anything would be an improvement.

It's impossible to say whether the models performed better as a result of a lack of ENSO "skewness" during the period of 1944 to 1975. We haven't determined whether the models were "ENSO linear" or skewed toward El Niño or La Niña during either period. We simply know how Mother Nature skewed ENSO during those two periods.

A closing thought for you: What do you think would happen if we fixed all model forcings at a given level and changed the ENSO-related parameters in all of the IPCC's climate models so that they were skewed slightly toward La Niña from 1944 to 1975 and skewed more heavily toward El Niño during the recent warming period? Would the model simulations of the oceans drift toward cooling during period when ENSO was slightly skewed toward La Niña and would the simulated oceans drift more heavily toward warming during the period when ENSO was skewed toward El Niño? They should. If not, then the modelers need to change how they model ENSO.

I used the word drift in the above question for a reason. Coupled ocean-atmosphere climate models can and do drift toward warming without any change in forcing. That was one of the problems with the models when they first began coupling ocean and atmospheric models. Modelers cured the drift by changing parameters in the models. Just food for thought.

8.19 Are there Other Ways to Show that ENSO Causes the Long-Term Trends in Global Sea Surface Temperatures?

In November 2010, I published a post that compared annual NINO3.4 sea surface temperature anomalies that had been smoothed with a 31-year filter to the 31-year changes in global sea surface temperature anomalies based on linear trends. See Figure 8-36. Don't worry. I'll explain the graph in a moment. I've updated it by adding the last two years of data. The blog post was **Multidecadal Changes In Sea Surface Temperature**. It was subtitled **Do Multidecadal Changes In The Strength And Frequency Of El Niño and La Niña Events Cause Global Sea Surface Temperature Anomalies To Rise And Fall Over Multidecadal Periods?**

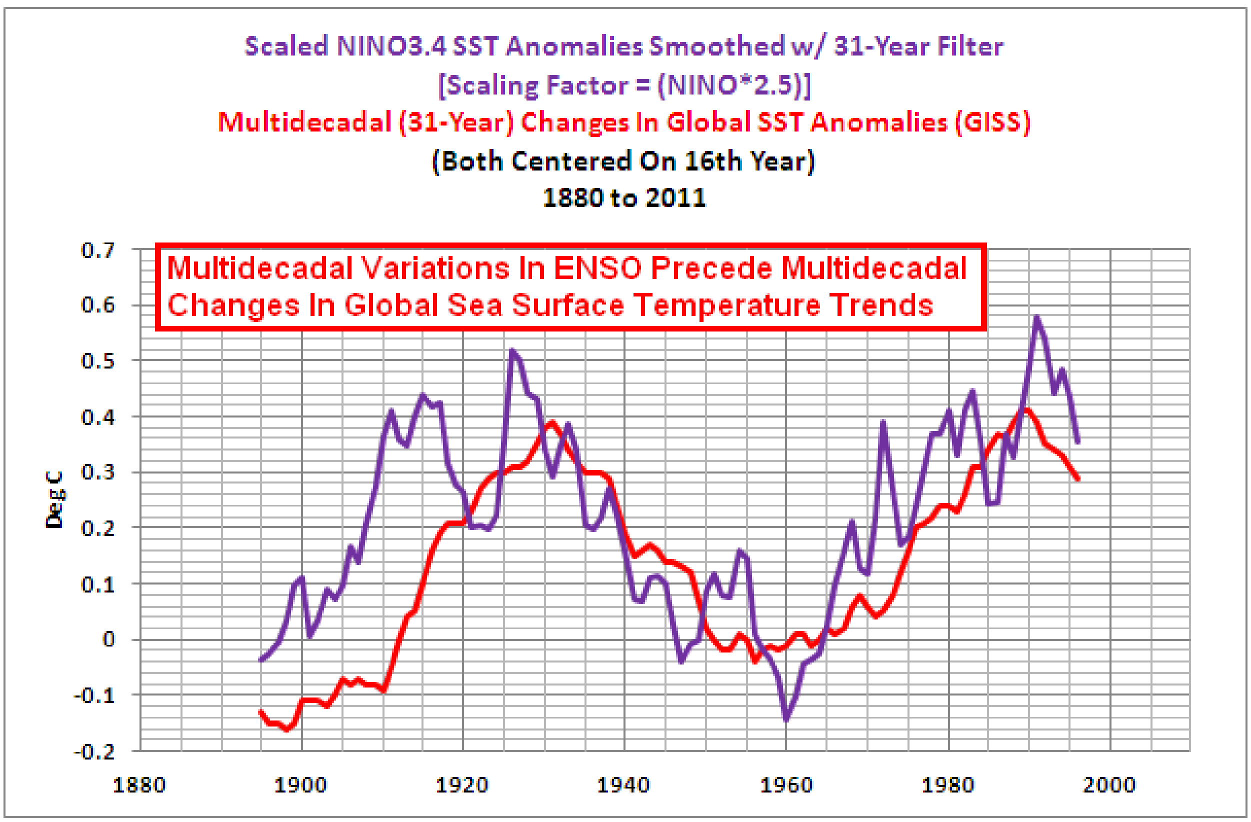

Figure 8-36

The purple curve in Figure 8-36 is annual NINO3.4 sea surface temperature anomalies (our ENSO Index), and it shows that, for example, at its peak in 1926, the frequency and magnitude of the El Niño events from 1911 to 1941 were far greater than the frequency and magnitude of La Niña events. In other words, during the early 1900s ENSO was skewed the most to El Niño conditions in 1926 based on a 31-year average of NINO3.4 sea surface temperature anomalies. The red curve represents the 31-year change in global sea surface temperature anomalies based on linear trends, and it shows, at its peak in 1931 that global sea surface temperature anomalies warmed more from 1916 to 1946 than they did during the other 31-year periods in the early 20th century. Skip ahead a few decades to 1960. Both curves reached a low point about then. At 1960, the purple curve indicates that ENSO was skewed toward La Niña for the period of 1945 to 1975, while at the same time the 31-year trends in global sea surface temperature anomalies showed they cooled most about the same time. Afterwards, the frequency and magnitudes of El Niño events increased and the multidecadal trends in global sea surface temperature anomalies started to rise, eventually reaching their peak around 1990 (the period of 1975 to 2005).

The lag before 1920 looks excessive, but keep in mind that the early source data of sea surface temperature measurements are very sparse. The fact that there are any similarities at all in the curves during those early decades speaks highly about the methods used by the Hadley Centre to infill all of that missing data.

The above graph indicates the 31-year rates (trends) at which global surface temperatures warmed or cooled varied in response to the multidecadal strength of ENSO. Keep in mind, global surface temperatures respond to ENSO, not vice versa.

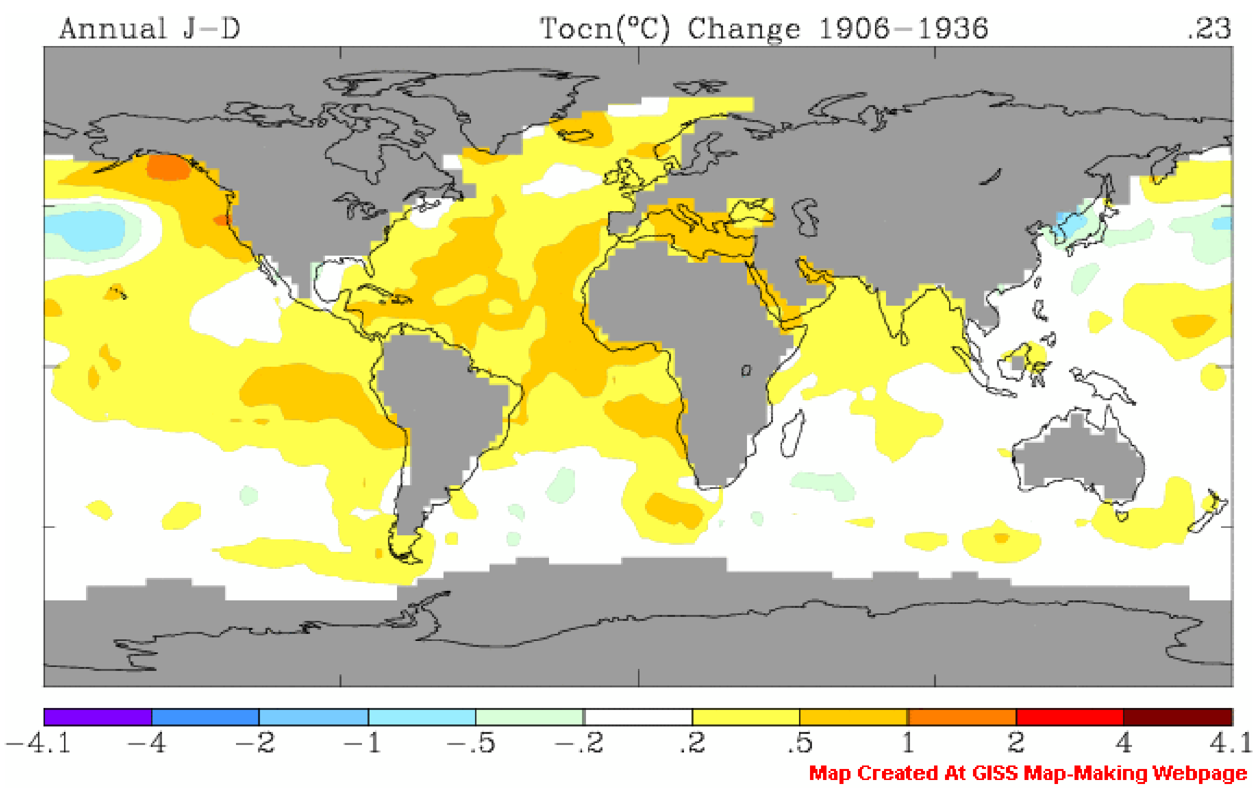

Figure 8-37

Bob Tisdale

I didn't stop the data presentation there. Using the map-making feature at the GISS website, I created maps that showed the 31-year changes in sea surface temperatures (based on local linear trends) and then animated them. I explained in the post:

The Goddard Institute of Space Studies (GISS) **Global Map-Making** webpage allows users to create maps of global sea surface temperature anomalies and maps of the changes in global sea surface temperature anomalies (based on local linear trends) over user-specified time intervals. Figure 8-37 is a sample map of the changes in annual sea surface temperature anomalies for the 31-year period from 1906 to 1936. In the upper right-hand corner is a value that represents the change in annual sea surface temperature anomalies over that time span. GISS describes the value as, "Temperature change of a specified mean period over a specified time interval based on local linear trends." As far as I can tell, these local linear trends are weighted by latitude. I downloaded the GISS maps of the changes in annual global sea surface temperature anomalies, starting with the interval of 1880 to 1910 and ending with the interval of 1979 to 2009, with the intent of animating the maps, but the data they presented was also helpful. I used that data to create the graph shown above in Figure 8-36.

The animation and its implications are explained in detail in the post **Multidecadal Changes In Sea Surface Temperature.** See the YouTube video **Multidecadal Changes In SST Anomalies (Blog Version)**.There is also a longer stand-alone version of the video: **Multidecadal Changes In Sea Surface Temperature Anomalies.wmv**. It runs about 5 minutes longer.

RECAP

The question answered in this chapter was **Are there Other Ways to Show that ENSO Causes the Long-Term Trends in Global Sea Surface Temperatures?**

The answer is yes. This was presented in the post **Multidecadal Changes In Sea Surface Temperature** and in the YouTube videos it contained. The animation of the GISS maps and the data GISS provides with those maps show that the trends in global sea surface temperature are driven by the multidecadal variations in the strengths and magnitudes of El Niño and La Niña events.

The NINO3.4 sea surface temperature data and global sea surface temperature data indicate the multidecadal rates (31-year trends) at which global surface temperatures warmed or cooled varied in response to the multidecadal strength (31-year average) of NINO3.4 sea surface temperature anomalies.

8.20 Could the 1997/98 El Niño have been Stronger?

Figure 8-37 shows the sea surface temperatures of the equatorial Pacific at the peak of the 1997/98 El Niño. As we can see, the eastern equatorial sea surface temperatures were a couple of deg C cooler than the waters back in the west, in the west Pacific Warm Pool. If you'll recall the subsurface temperature and temperature anomalies at that time, a lot of warm water had traveled from west to east during that El Niño. We might assume that the sea surface temperatures in the east could equal the sea surface temperatures in the west Pacific Warm Pool, meaning the 1997/98 El Niño might possibly have been stronger, but there may be physical or time constraints that prevent that from happening. Regardless, it was a strong El Niño, a super El Niño. The only reason I like to see another super El Niño is, there's a lot of ARGO buoys bobbing around out there in the Pacific and we would be able to get a better feel for the redistribution of warm water after an El Niño that size.

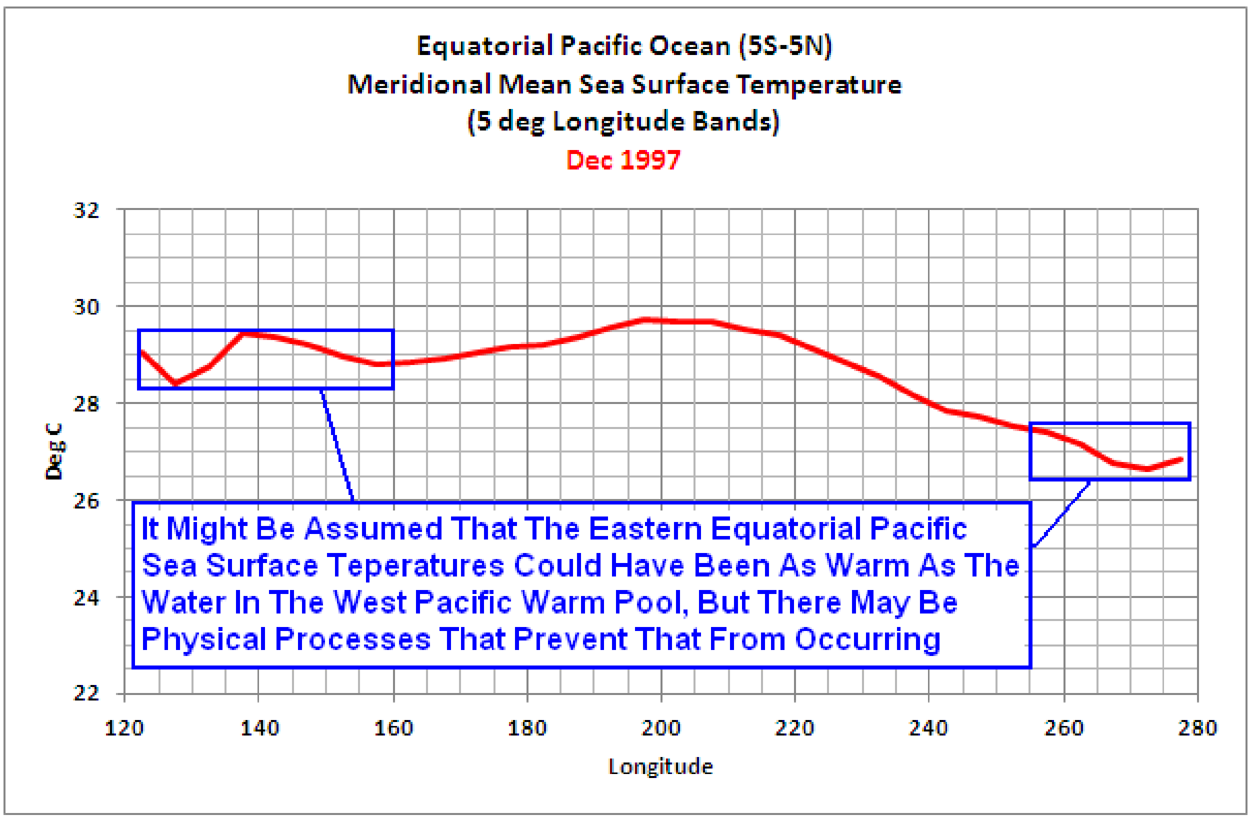

Figure 8-37 Bob Tisdale

ABOUT THE COVER

The cover art is a Hovmöller diagram of the sea surface temperatures (not anomalies) for the Equatorial Pacific (120E-80W) from November 1981 to June 2012. It was created at the KNMI Climate Explorer. The x-axis is longitude. The west Pacific Warm Pool is to the left. The Cold Tongue Region is to the right. The y-axis is time in months from November 1981 (bottom) to June 2012 (top). See illustration below. For the cover, I rotated it 90 degrees clockwise, then tweaked the colors a little, before adding the title, subtitle and name.

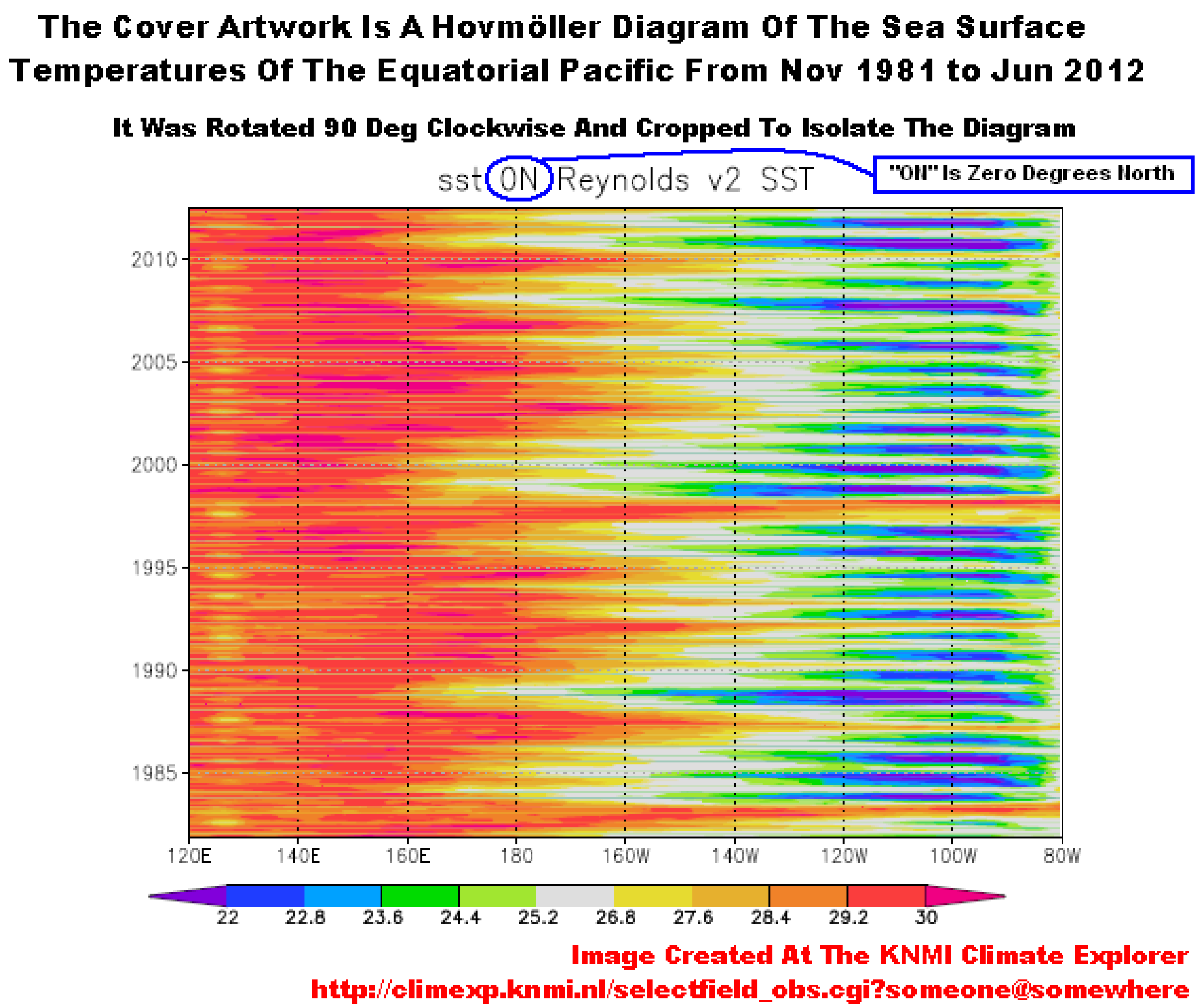

Figure ATC-1

As shown below, sea surface temperature anomalies for the equatorial Pacific (5S-5N, 120E-80W) have cooled at a rate of -0.047

Deg C per decade for the period of November 1981 to June 2012, which is the time span of that satellite-based dataset.

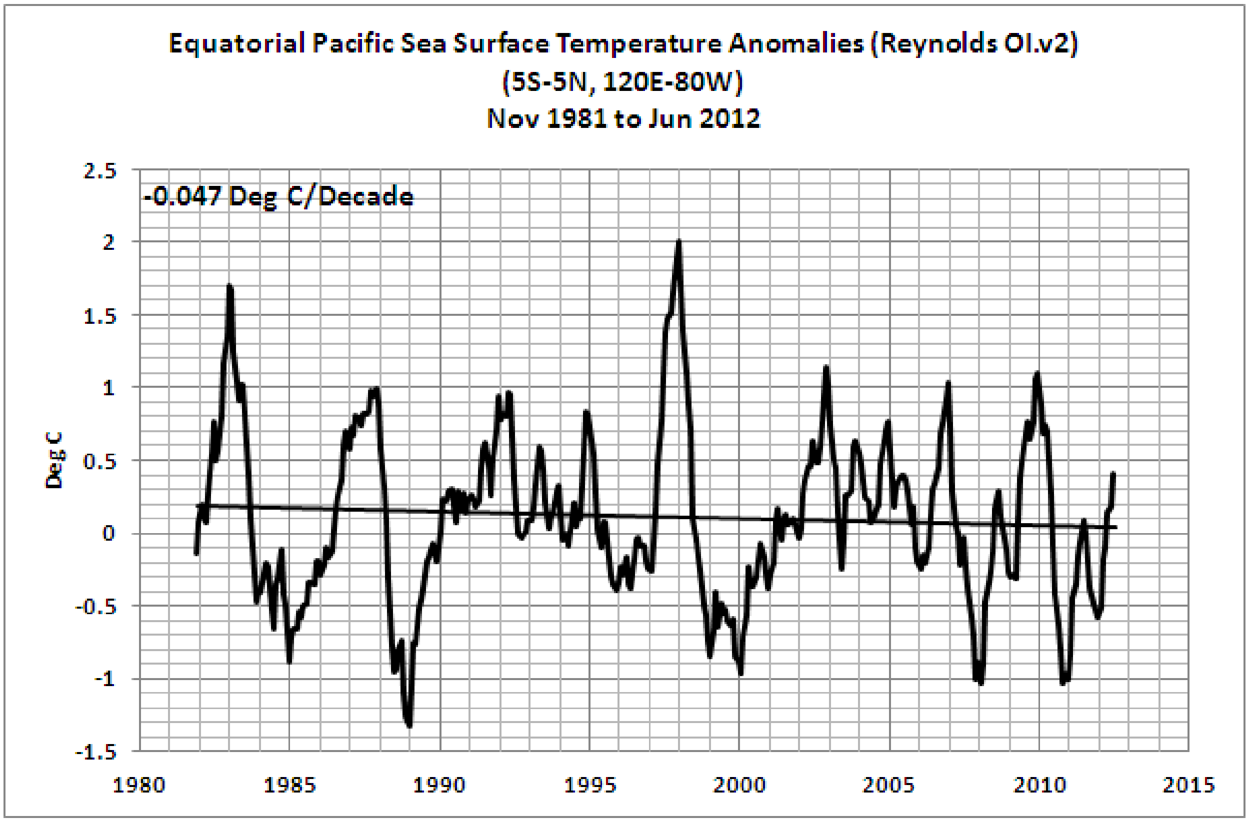

Figure ATC-2 Bob Tisdale

CLOSING

Thanks for buying *Who Turned on the Heat? - The Unsuspected Global Warming Culprit, El Niño-Southern Oscillation*—a book about the phenomenon called the El Niño-Southern Oscillation. *Who Turned on the Heat?* also detailed the contributions of the El Niño-Southern Oscillation to the global warming of the past 30 years, the satellite era of sea surface temperature data. I find the mechanism Mother Nature created to vary the rate at which heat is distributed from the tropics to the poles extremely interesting, and I hope this book ignited your interest as well.

Proponents of anthropogenic global warming, after reading the book from cover to cover, might conclude that I did not disprove the hypothesis of manmade carbon dioxide-driven global warming, and they're correct. I even admitted that within these pages. It's likely anthropogenic greenhouse gases have had an impact on the additional warming of land surface air temperatures that's above and beyond the warming attributable to the natural warming of the global oceans. That additional land surface air temperature warming, however, has also been caused by land-use change, the urban heat island effect, poor surface station siting, overly aggressive corrections to the land surface temperature records, black carbon, aerosols, etc.

However, this book clearly illustrated and described the following:

1. The sea surface temperature and ocean heat content data for the past 30 years show the global oceans have warmed. There is no evidence, however, that the warming was caused by anthropogenic greenhouse gases in part or in whole; that is, the warming can be explained by natural ocean-atmosphere processes, primarily ENSO;

2. The global oceans have not warmed as hindcast and projected by the climate models stored in the CMIP3 and CMIP5 archives, which were used, and are being used, by the IPCC for their 4th and upcoming 5th Assessment Reports; in other words, the models cannot simulate the warming rates or spatial patterns of the warming of the global oceans; and,

3. Based on the preceding two points, the climate models in the CMIP3 and CMIP5 archives, which are used by the IPCC, show no skill; that is, the climate models provide little to no value as tools for projecting future climate change on global and regional levels.

Many thanks to Roger Knights, for his guidance on the title of this book.

Last, thank you again, reader, for your interest in *Who Turned on the Heat? - The Unsuspected Global Warming Culprit, El Niño-Southern Oscillation.* If you have any questions, please ask them on any thread at my blog **Climate Observations**

Sincerely,

Bob Tisdale