New Paper Tries to Explain Disparities in Deep Ocean Warming Between Two Basins

PREFACE

I comment frankly about the NODC ocean heat content data a number of times in this post. Please do not take those remarks as criticisms about the efforts of the NODC to assemble that data. The following quote includes links to maps of the locations of subsurface ocean temperature measurements at three depths. As you'll note, the NODC had little source data to work with prior to the introduction of the ARGO floats.

I first presented these maps in the March 2013 post Is Ocean Heat Content Data All It's Stacked Up to Be? That post provides a very detailed overview of the problems with ocean heat content data. The following is the discussion of the animations from that earlier post (with typos removed). This post focuses on the data for the depths of 0-700 meters, so the first two animations are relevant:

The animations are for the depths of 250, 500 and 1500 meters. Each black dot on a map represents one (1) temperature measurement at that depth for a 3-month period. There is also a scale on the maps that explains the number of readings associated with the green, orange, and red dots. Readings at 250 meters and 500 meters, and other depths, are used in the NODC's data for the depths of 0-700 meters. As you'll note, global coverage improves with time until the 1990s, but then it worsens until the ARGO floats are released in the early 2000s. You'll also note that the sampling is better at the 250 meter level than at 500 meters. It's much, much worse at 1500 meters.

The files are large, so they may take a few moments to download.

Temperature sample maps at 250 meters (11MB).

Temperature sample maps at 500 meters (9MB).

The NODC recently published a version of their ocean heat content data for the depths of 0-2000 meters. Unfortunately, as you will see, there is little observational data at depths of 1500 meters.

Temperature sample maps at 1500 meters (6MB).

There is so very little observational data at depths greater than 700 meters that the NODC elected not to present the data in 3-month blocks. They used 5-YEAR windows, in one year steps, what they refer to as pentads. That is, for example, a temperature measurement in 1959 will be used for the pentads of 1955-1959, 1956-1960, 1957-1961, 1958-1962 and 1959-1963.

[End of quote from earlier post.]

INTRODUCTION

For the past few years, there have been numerous papers that have claimed at least part of the heat missing from the deep oceans, curiously occurring in parallel with the slowdown in global surface warming, has been hiding in the Pacific Ocean, the result of a recent flurry of strong La Niña events. Back in 2013, we illustrated and discussed how the NODC's vertically averaged temperature data to 2000 meters showed the North Atlantic and the Pacific Ocean as a whole had not warmed to depths of 2000 meters since 2003, and that all of the ocean warming was taking place in the South Atlantic and Indian Oceans. See the post [If Manmade Greenhouse Gases Are Responsible for the Warming of the Global Oceans…](#) We updated the primary graph in January 2015, Figure 1, and discussed this problem once again in the post [NODC Data Continue to Indicate the Deep Oceans are Warming in Some Basins But Not Others](#). The data for Figure 1 are found at the NODC webpage [here](#).

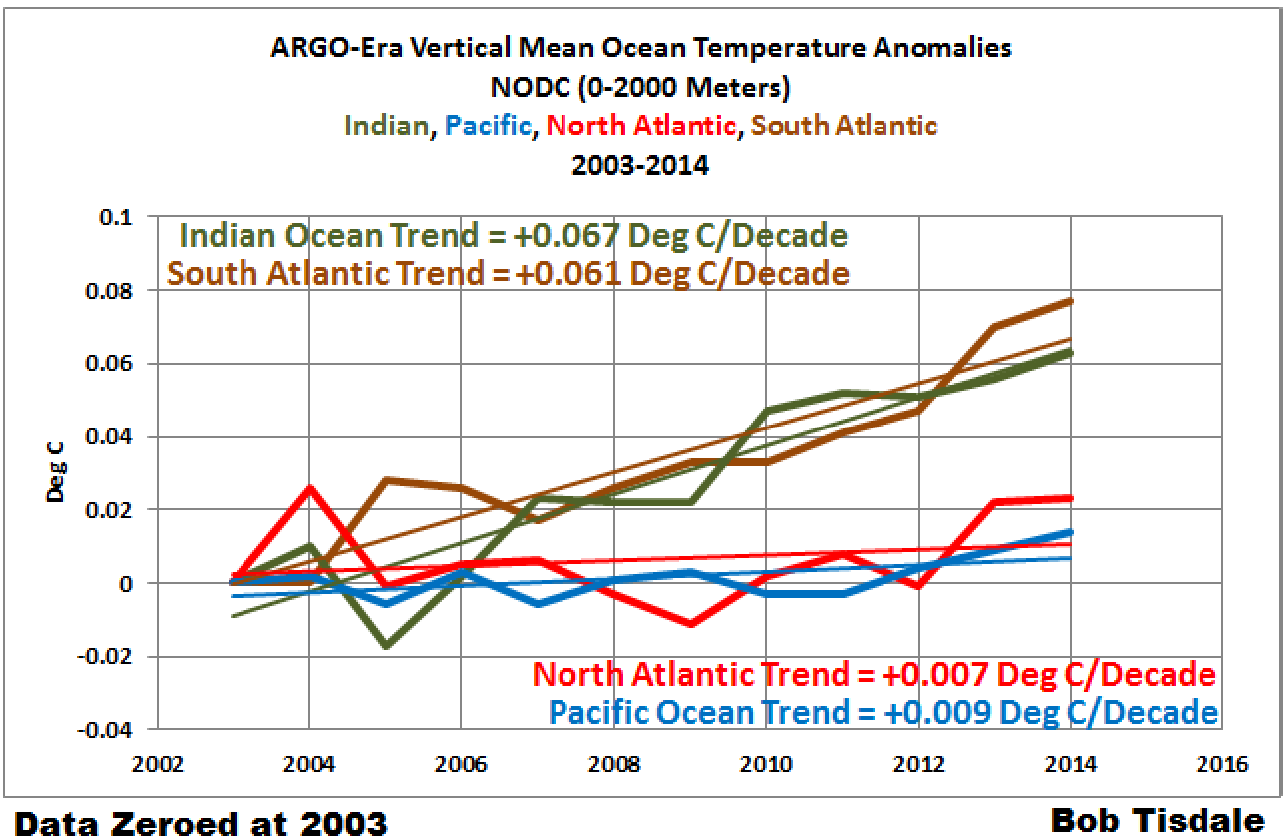

Figure 1

We used vertically averaged temperature anomalies, as opposed to ocean heat content data, to show how small the warming is in terms that most people can relate to.

Now the climate science community is attempting to explain the disparity in the warming of two of the ocean basins, with the paper Lee et al. (2015) Pacific origin of the abrupt increase in Indian Ocean heat content during the warming hiatus [paywalled]. The paper also does not address the difference in warming rates of the North and South Atlantic.

There are a number of curious aspects to the new Lee at al. paper. But first, let's clarify that…

LEE ET AL. (2015) IS NOT ABOUT THE MISSING OCEAN HEAT

Lee et al. (2015) has gotten some recent press. One example is Heat is Piling Up in the Depths of the Indian Ocean at ClimateCentral. It includes a couple of statements from the lead author…and from other scientists who were not part of the paper. Another example was quoted at WattsUpWithThat, with the title Uh, oh: Looks like Lewandowsky and Oreskes will be going after the AGU now for admitting the 'hiatus' exists. It is from the EOS.org article Tracking the Missing Heat from the Global Warming Hiatus. Under the heading of "**Can the Indian Ocean House All of This Hidden Heat?", the EOS.org** article reminds readers of the problem of the "missing heat", which was not addressed by Lee et al. That section ends with this quote from Ka Kit Tung of the University of Washington:

> *"It [Lee et al.] is not a budget calculation," he explained. "There is a difference between finding some warming in the Indian Ocean and justifying the proposition that the amount of heat storage explains what is needed to account for the global hiatus. [We] not only calculated the heat storage in the Indian Ocean in the upper 700 meters but…calculated it down to 1500 meters and showed that it was not enough."*

The heat missing from the oceans, and the growing difference between modeled and observed global surface temperatures, both strongly suggest that the climate models used by the IPCC are way too sensitive to manmade greenhouse gases like carbon dioxide. (The model-data graph linked above is from the most-recent surface temperature update here.)

INITIAL COMMENTS ON LEE ET AL. (2015)

The illustrations for Lee et al. are here and the Supplementary Information is here. You'll note in the Supplementary info (See their Figure S1 here.) that Lee et al. are using the latitude of 34S as the southern border of the Indian and Pacific Oceans, not 60S as is more-often used. The lack of source data south of 34S before the ARGO era might be the reason…yet, curiously, they present a model-data comparison for the Southern Ocean in their Supplementary material even though there is little to no source data for ocean heat content data south of 34S before the early 2000s.

The abstract of Lee et al. (2015) reads (my boldface):

> *Global mean surface warming has stalled since the end of the twentieth century*[1, 2]*, but the net radiation imbalance at the top of the atmosphere continues to suggest an increasingly warming planet. This apparent contradiction has been reconciled by an anomalous heat flux into the ocean*[3, 4, 5, 6, 7, 8]*, induced by a shift towards a La Niña-like state with cold sea surface temperatures in the eastern tropical Pacific over the past decade or so.* ***A significant portion of the heat missing from the atmosphere is therefore expected to be stored in the Pacific Ocean. However,*** **in situ** ***hydrographic records indicate that Pacific Ocean heat content has been decreasing***[9]***.*** *Here, we analyse observations along with simulations from a global ocean–sea ice model to track the pathway of heat.* ***We find that the enhanced heat uptake by the Pacific Ocean has been compensated by an increased heat transport from the Pacific Ocean to the Indian Ocean, carried by the Indonesian throughflow.*** *As a result, Indian Ocean heat content has increased abruptly, which accounts for more than 70% of the global ocean heat gain in the upper 700 m during the past decade. We conclude that the Indian Ocean has become increasingly important in modulating global climate variability.*

Lee et al. (2015) confirmed our previous posts in which we noted that the ocean heat content data contradicted the assumption that the missing heat was hiding in the Pacific.

Lee et al. (2015) addressed the warming of the top 700 meters of the Pacific and Indian Oceans, using the NODC ocean heat content data. That is, they did not use the 0-2000 meter data. Curiously, the CO_2 obsessed haven't complained about this breach of alarmist etiquette. Lee et al. explained in their Supplementary Information (my boldface):

> *For the ocean heat content changes* ***below 700 m, there is no reliable in-situ global deep ocean data before the Argo observations*** *whose spatial coverage over the global ocean reached a mature state only around 2004-2005. Since there is no reliable global deep ocean observation data for the study period (1971-2012), the ocean heat content changes below 700 m were not explored in this study.*

How refreshing. We're seeing some realism from the climate science community. But they're assuming the pre-ARGO in-situ data above 700 meters are reliable. That's a big assumption.

Figure 2 is the same format as Figure 1, but in Figure 2, we're using the data for the depths of 0-700 meters. The data for Figure 2 are also found at the NODC webpage here. You'll note that the disparity between the ocean basins still exists. For the depths of 0-700 meters, the North Atlantic even shows a slight cooling. This cooling in the North Atlantic was not addressed by Lee et al.

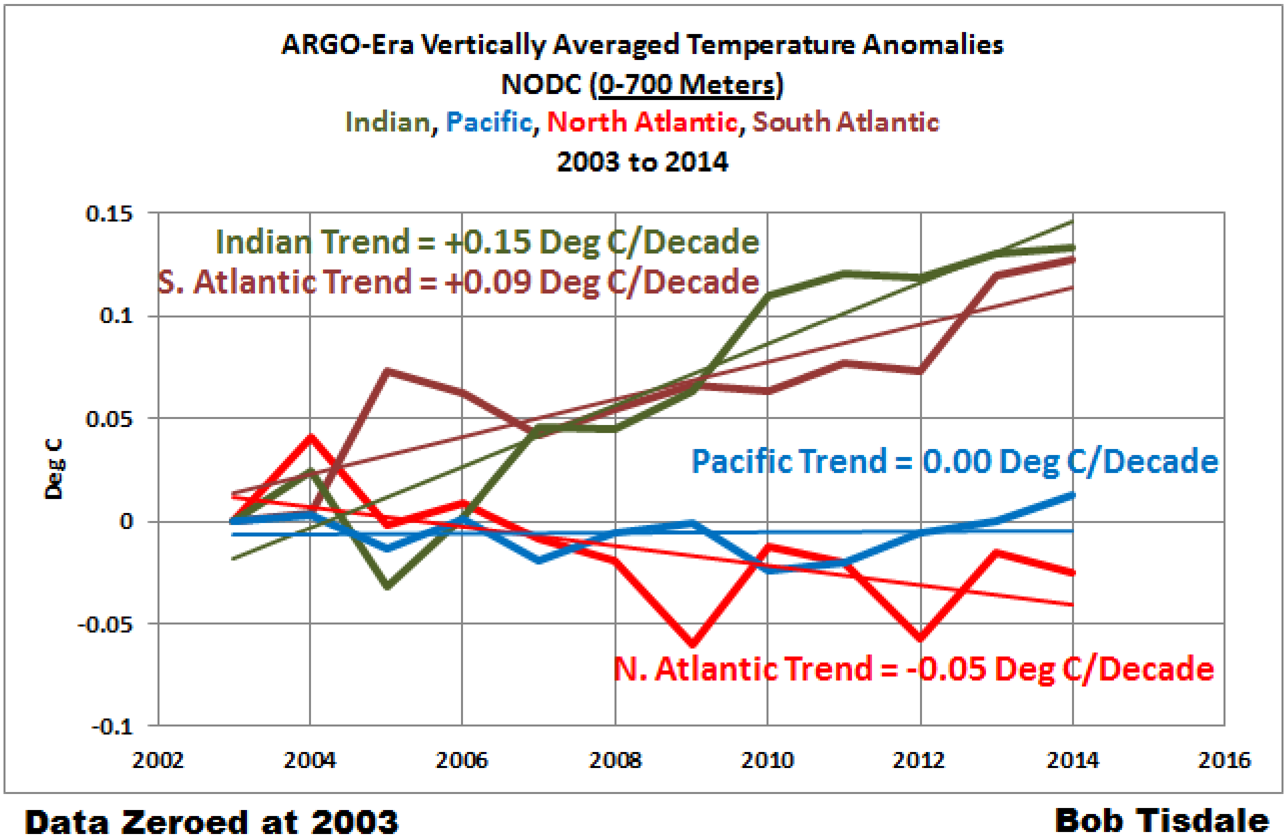

Figure 2

The NODC does not present data separately for the Southern Ocean like Lee et al., so it is likely that the Southern Ocean data are included in the data for the South Atlantic, Indian and Pacific Oceans. That is, Figure 2 includes more of the Pacific and Indian Oceans than were evaluated by Lee et al. (2015).

Lee et al. evaluated ocean heat content from the NODC to depths of 700 meters for two periods that are separated by a few years: 1971-2000 and 2003-2012. This exclusion of data from 2001 and 2002 should also have been disapproved by the CO2 obsessed. Lee et al. explain in the next paragraph in the Supplementary Material (my boldface):

> *It should be also noted that the OHC700 derived from WOA13 increased sharply during 2001- 2003 in all ocean basins including the Atlantic and Southern Oceans (Figs. 1 and S2).* ***Previous studies have suggested that the changes in the historical observation network from a ship-based system to Argo floats introduced an artificial jump in OHC700 during the initiation of the***

> ***global Argo array (2001-2003)****[2,3,4]. Therefore, the OHC700 changes derived from WOA13 during 2001- 2003 were not used in this study.*

The first referenced paper is Cheng and Zhu (2014) Artifacts in variations of ocean heat content induced by the observation system changes. Its abstract reads (my boldface):

> *The heat content of the upper ocean is a key climate indicator, contributing to a substantial portion of the global sea level rise. Recent ocean heat content (OHC) calculations have shown a dramatic shift during the period 2001–2003, which is nearly coincident with a major transition in the ocean observation network from a ship-based system to Argo floats.* ***Here we demonstrate that the changes in the spatial sampling of the historical observation network introduced an artificial jump during the initiation of the global Argo array (2001–2003). The start of the Argo program is responsible for such a shift.*** *Considering the sampling bias, new methods to assess long-term trends in the OHC (0–700 m) are proposed that suggest the presence of a continuous upper ocean warming (0.36 ± 0.08 W m^{-2}) since 1966.*

That's something else to keep in mind about the NODC ocean heat content data. Skeptics have been noting that obvious shift—and the reason for it—for years. I'll be presenting a post about Cheng and Zhu (2014) in a few days.

Those things aside, back to the findings of Lee et al.

Basically, Lee et al. (2015) used a climate model specially programmed for the paper to show that warm waters from the Pacific Ocean had been relocated to the Indian Ocean by way of the ocean current that transports waters from the tropical Pacific to the tropical Indian Ocean—a current called the Indonesian Throughflow. (In other words, Lee et al. did not evaluate the output of a model from the CMIP5 archive, which was used by the IPCC for attribution studies and projections of future climate. They used a model that was specially programmed for this study. It's commonly done, but I wanted readers to understand that point.)

For the location of the Indonesian Throughflow, see my Figure 3, which is from the ClimateCentral post. Oddly, ClimateCentral attribute that illustration to Lee et al (2015), but that illustration does not appear in the paper or supplementary information. Nice illustration, though. Note that it appears to include color scales for sea surface temperatures, not sea surface temperature anomalies...just in case you're wondering why everything looks so warm in the tropics.

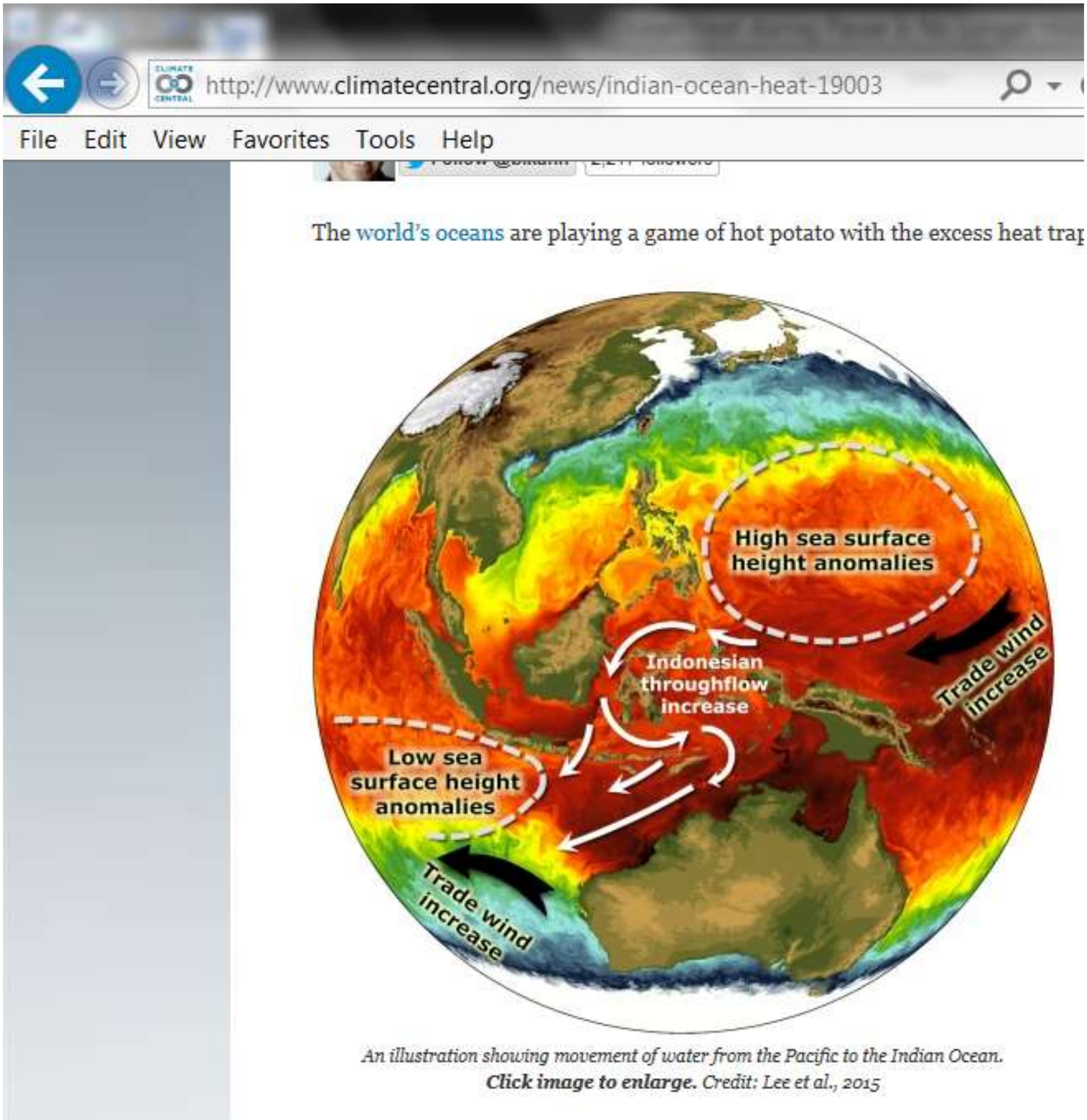

Figure 3

MODEL FORCINGS

Under the heading of Methods, Lee et al. begin (their boldface):

> ***Model****. The global ocean-sea ice coupled model of the NCAR Community Earth System Model version 1 (CESM1; ref. 27) forced with the bias-corrected*

> *twentieth century reanalysis (20CR) surface flux variables[14] (see Supplementary Information 3) is used as the primary tool in this study.*

A reanalysis is a computer model that is forced with observations-based data. But there are few to no long-term observations of surface flux metrics for the oceans such as surface downward shortwave radiation (sunlight) and surface downward longwave (infrared) radiation. Those are computed.

In other words, Lee et al. used the output of one climate model to force a second climate model.

NOTHING MAGICAL ABOUT THE MIGRATION OF WATER ALONG THE INDONESIAN THROUGHFLOW

A primary finding of Lee et al. was:

> *We find that the enhanced heat uptake by the Pacific Ocean has been compensated by an increased heat transport from the Pacific Ocean to the Indian Ocean, carried by the Indonesian throughflow.*

We had discussed this likely explanation for the warming of the Indian Ocean and the absence of warming in the Pacific basin in the March 2013 post Is Ocean Heat Content Data All It's Stacked Up to Be? I even provided animations so that you could watch the process at work. After showing the disparity between the Indian Ocean warming and the lack of warming in the Atlantic and Pacific Oceans to depths of 700 meters, I wrote in that earlier post (Figure number updated for this post).

Why is the Indian Ocean warming during the ARGO era? [Figure 4] compares ocean heat content data for the Indian Ocean (90S-90N, 20E-120E) to scaled sea surface temperature anomalies for the NINO3.4 region of the equatorial Pacific. Both datasets have been smoothed with 12-month running average filters. The NINO3.4 data is a commonly used index for the timing, strength and duration of El Niño and La Niña events. The ocean heat content for the Indian Ocean warms in response to El Niño events, but it obviously does not cool proportionally during strong La Niñas.

Why?

It's simply yet another example of what I've been noting for a number of years: La Niñas are not the opposite of El Niños.

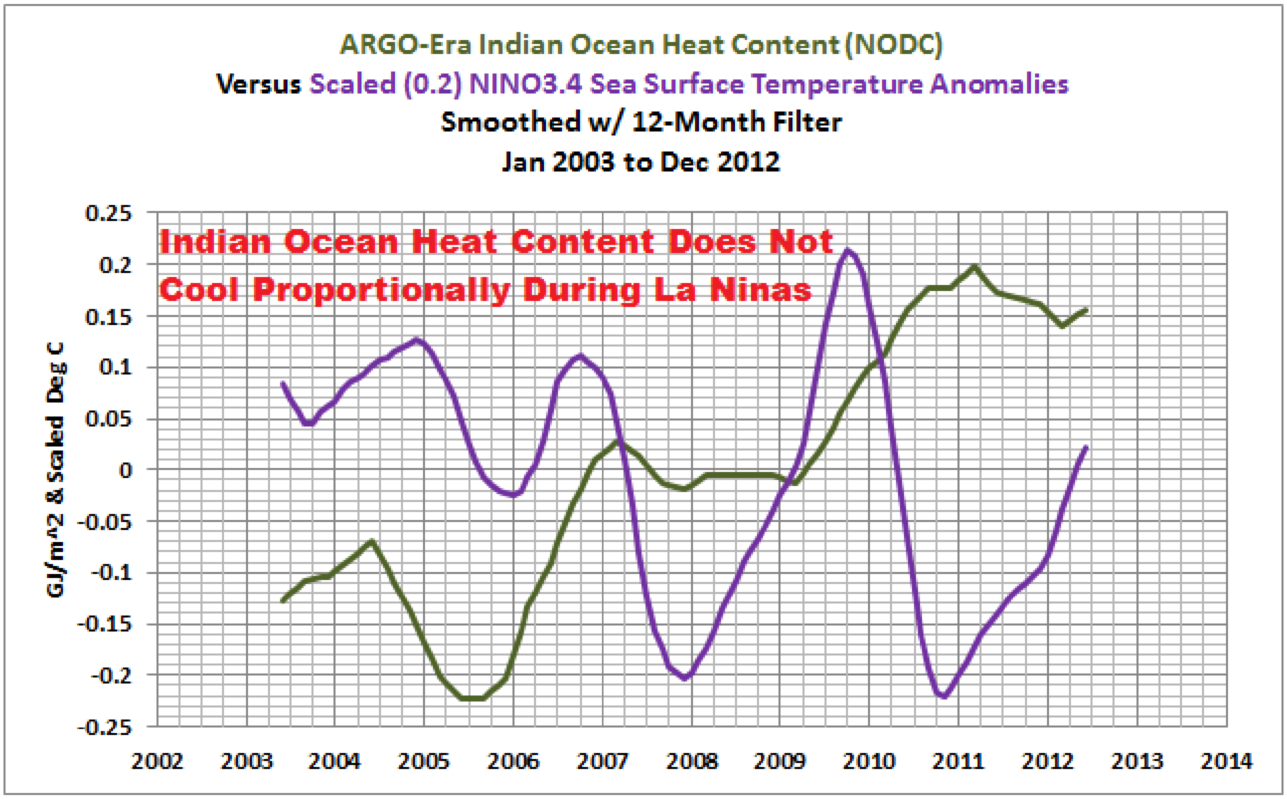

Figure 4

In the following animations, you can watch warm water that's left over from the El Niños being passed from the tropical Pacific into the Indian Ocean during the trailing La Niñas by the current called the Indonesian Throughflow. That leftover warm water counteracts any cooling that would result during the trailing La Niñas due to changes in atmospheric circulation.

Animation 1 presents maps of the NODC ocean heat content data for the ARGO-era, using 12-month averages. The first cells are the average ocean heat content from January to December 2003. These are followed by cells that show the period of February 2003 to January 2004, then March 2003 to February 2004 and so on, until the final cell that captures the average ocean heat content from January to December 2012. The 12-month averages reduce the visual noise and any seasonal component in the data. It's like smoothing data with a 12-month filter in a time-series graph. (You may have to click-start the animation.)

Animation 1

Due to the resolution of the ocean heat content data, you might be having trouble catching the processes that cause the leftover warm water from 2006/07 and 2009/10 El Niños to be carried into the Indian Ocean. Animation 2 is a gif animation of sea level *maps for the tropical Pacific from the [AVISO altimetry website](). The maps also capture the easternmost portion of the tropical Indian Ocean. I've started the animation in January 2003 to agree with the discussion of ARGO-era ocean heat content data. So there are a couple of minor El Niños before the 2006/07 El Niño. At the end of the 2006/07 El Niño, a (cool) downwelling Kelvin wave splits the elevated (warm) sea level anomalies along the equator. The residual warm waters are carried west by Rossby waves to Indonesia, and the stronger-than-normal trade winds in the Pacific during the trailing La Niña help to force the residual warm water past Indonesia into the eastern Indian Ocean. In addition to the Indonesian Throughflow, warm water from the southern tropical Pacific also migrates west into the eastern Indian Ocean through the Torres Strait, between Australia and New Guinea. The same thing happens after the 2009/10 El Niño. (My apologies for the shift in the animation in 2011. Aviso changed the format of the maps.)*

Animation 2

[End of quote from earlier post.]

Lee et al. (2015) confirmed that the warm water from the tropical Pacific migrates to the tropical Indian Ocean. But…

LEE ET AL. (2015) OVERLOOKED A FUNDAMENTAL REALITY

Lee et al. (2015) noted the transport of waters from the tropical Pacific to the Indian Ocean was associated with El Niño and La Niña events (where ITF is Indonesian Throughflow):

It has been shown that the ITF volume transport is mainly dominated by interannual variability associated with El Niño/Southern Oscillation (ENSO; refs 18,19). Indeed, in the control experiment, the reduced ITF volume transport during 1997-1998 coincides with the 1997-1998 El Niño. Conversely, the large increase in the ITF volume transport during 2006-2008 coincides with the three near consecutive La Niña events, namely the 2005-2006, 2007-2008 and 2008-2009 events, which contributed significantly to the recent La Niña-like state in the Pacific Ocean. Observational evidence is consistent with the reduced ITF during the 1997-1998 El Niño and the increased ITF during the series of La Niña events from 2006 to 2008. Therefore, it is logical to conclude that a series of long-lasting La Niña events without strong and intervening El Niño events has led to the increased ITF heat transport in the 2000s.

But as we illustrated and showed in the animations earlier, the warm water that migrated into the Indian Ocean was basically the leftovers from El Niño events in the tropical Pacific, supplemented by any additional warm water created during the La Niñas.

Lee et al.'s controlled experiment (climate model) showed increased flow through the Indonesian Throughflow during the 2007/08 and 2008/09 La Niñas. This is basically the explanation for why the ocean heat content of the Indian Ocean did not cool proportionally during those La Niñas. Note, however, in Figure 3 that the ocean heat content of the Indian Ocean did drop during the 2005/06 La Niña, which seems to contradict Lee et al.'s model. The Lee et al. model also did not appear to respond to the 1998-01 La Niña, while the data indicate the warming of the Indian Ocean actually began then, after a drop a few years earlier.

Not surprisingly, there is no mention in Lee et al. (2015) that the warm water for El Niños is furnished by sunlight, not manmade greenhouse gases, during La Niña events. In other words, they likely failed to properly account for the downward shortwave radiation reaching into and warming the tropical Pacific during La Niñas.

In numerous posts over the years, we've presented the following quote from Trenberth et al. (2002) Evolution of El Niño-Southern Oscillation and global atmospheric surface temperatures (my boldface):

> *The negative feedback between SST and surface fluxes can be interpreted as showing the importance of the discharge of heat during El Niño events and of the recharge of heat during La Niña events. Relatively clear skies in the central and eastern tropical Pacific allow* **solar radiation to enter the ocean***, apparently offsetting the below normal SSTs, but the heat is carried away by Ekman drift, ocean currents, and adjustments through ocean Rossby and Kelvin waves, and the heat is stored in the western Pacific tropics. This is not simply a rearrangement of the ocean heat, but also a restoration of heat in the ocean.*

That paragraph is the basis for my constant description of ENSO as a chaotic, naturally occurring, sunlight-fueled, recharge-discharge oscillator, where El Niño events act as the discharge phase and La Niña events act as the recharge and redistribution phase.

Trenberth and Fasullo (2009) Tracking Earth's Energy: From El Niño to Global Warming confirmed the cause of the increased sunlight, and the role it plays, in the tropical Pacific during La Niña events:

> *Typically prior to an El Niño, in La Niña conditions, the cold sea waters in the central and eastern tropical Pacific create high atmospheric pressure and clear skies,* **with plentiful sunshine heating the ocean waters***. The ocean currents redistribute the ocean heat which builds up in the tropical western Pacific Warm Pool until an El Niño provides relief (Trenberth et al. 2002).*

In the post Open Letter to the Royal Meteorological Society Regarding Dr. Trenberth's Article "Has Global Warming Stalled?", we confirmed that sunlight provides the warm water that serves as fuel for El Niños. It can't be downward longwave (infrared) radiation, because infrared radiation decreases during La Niña events, when the ocean heat in the tropical Pacific is replenished. We'll expand on this discussion in a few moments.

For a further introductory discussion on the natural warming of the global oceans (at the surface and to depth), see the illustrated essay [The Manmade Global Warming Challenge] (42MB pdf).

In Trenberth and Fasullo (2009) [Tracking Earth's Energy: From El Niño to Global Warming], the authors also describe additional sunlight-based warmings associated with El Niño events outside of the tropical Pacific (my boldface) :

> *But a major challenge is to be able to track the energy associated with such variations more thoroughly: Where did the heat for the 2009–2010 El Niño actually come from? Where did the heat suddenly disappear to during the La Niña? Past experience (Trenberth et al. 2002) suggests that global surface temperature rises at the end of and lagging El Niño, as heat comes out of the Pacific Ocean mainly in the form of moisture that is evaporated and which subsequently rains out, releasing the latent energy. Meanwhile, **maximum warming of the Indian and Atlantic Oceans occurs about 5 months after the El Niño owing to sunny skies and lighter winds (less evaporative cooling), while the convective action is in the Pacific**.*

Strong blasts of sunlight over the Indian Ocean during El Niños, and strong blasts of sunlight over the tropical Pacific during La Niñas, both contributed to the warming of the Indian Ocean, if we merge the Lee et al. (2015) and the Trenberth and Fasullo (2009) discussions:

- The Indian Ocean warms first during El Niños in response to El Niño-caused increase in sunlight there (Trenberth and Fasullo (2009)).
- The Indian Ocean is prevented from cooling during the trailing La Niñas because sunlight-created warm waters are being transported from the tropical Pacific to the tropical Indian Ocean by the Indonesian Throughflow (Lee et al. (2015)).

By the way, that's two papers by Trenberth that state very clearly that temporary blasts of sunlight associated with ENSO cause the tropical Pacific, the Atlantic Ocean and the Indian Ocean to warm to depth.

HOW LEE ET AL. (2015) LIKELY FOOLED THEMSELVES WITH THEIR MODELING EFFORTS

This discussion relates to the models presented by Lee et al., and to their data presentation, not necessarily their conclusion that warm water migrates from the Pacific to Indian Oceans through the Indonesian Throughflow.

Lee et al. (2015) presented their model-data comparison of ocean heat content (0-700 meters) globally (top) and for the Indian (middle) and the Pacific (bottom) in their Figure 1. I've included it here as my Figure 5. The time-series graphs are on the left (cells a-c) and the heat budgets are on the right (cells d-f). About the global model-data comparison, Lee et al. wrote:

> *The results from these ensemble experiments can be summarized as two sets of global OHC700 time series (Fig. 1a). The simulated global OHC700 from the control experiment follows the time variability of in situ observations since the 1950s (ref. 9) reasonably well.*

Lee et al. did not make that same claim for their modeling (control experiment) of the Pacific and Indian Oceans…and for good reasons.

Figure 1 from Lee et al. (2015)

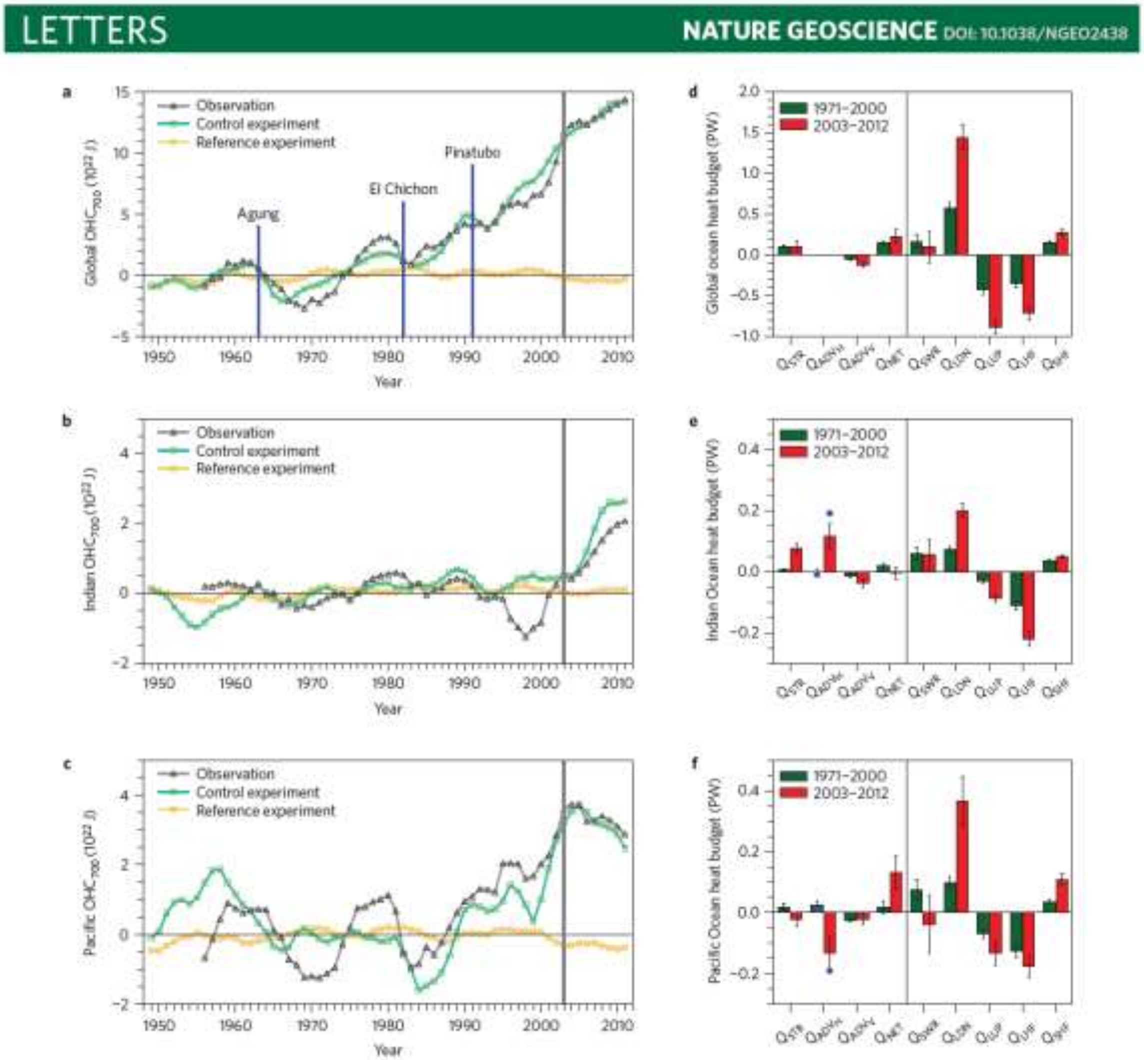

Figure 1 | OHC_{700} and heat budget for the global ocean, and the Indian and Pacific oceans. a–c, Time series of OHC_{700} for the global (**a**), Indian (**b**) and Pacific (**c**) oceans derived from the control and reference experiments and observations[9]. **d–f**, Storage rate (Q_{STR}), horizontal and vertical advections (Q_{ADV_H} and Q_{ADV_V}), net surface heat flux (Q_{NET}), shortwave radiation (Q_{SWR}), downward and upward longwave radiations (Q_{LDN} and Q_{LUP}), and latent and sensible heat fluxes (Q_{LHF} and Q_{SHF}) for the global (**d**), Indian (**e**) and Pacific (**f**) oceans derived from the control experiment relative to the reference experiment are averaged for the 1971–2000 (green bars) and 2003–2012 periods (red bars). The error bars show the 90% confidence levels derived from the six-member ensemble runs. The blue circles in **e**,**f** indicate the values for inter-ocean heat transport via the Indonesian passages.

Figure 5

Let's start with their data presentation, the black curves. The data in cells a through c have obviously been filtered (or smoothed). Yet I have not found any mention of the type of filter used in Lee et al (2015) or their Supplementary information.

Figure 6 compares cell b of Figure 1 for the Indian Ocean from Lee et al. with the annual ocean heat content data for the Indian Ocean, using the coordinates of 34S-

30N, 20E-120E). The annual variations are obviously missing. Both depictions show a slight cooling from 1955 to the mid-to-late 1990s, followed a sudden rise (a rise starts well before the model.) Thus for the Indian Ocean, the smoothing doesn't seem to make much of a difference.

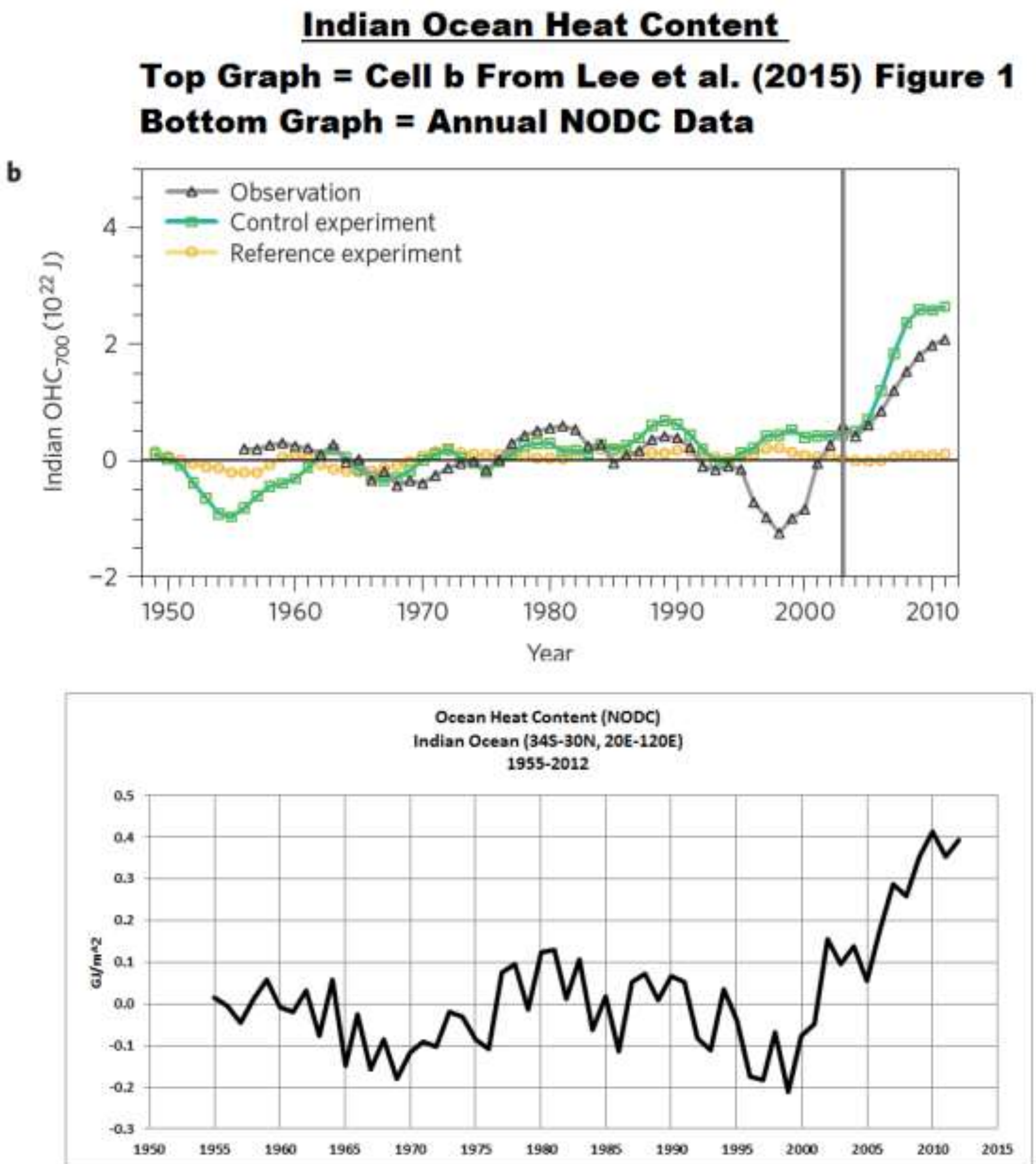

Figure 6

The same cannot be said for the Pacific Ocean (34S-65N, 120E-80W), as shown in Figure 7. Two of the defining features of the ocean heat content data of that Pacific subset were casually removed by Lee et al., the monumental rise in Pacific Ocean heat content from the 1995/96 La Niña and the subsequent drop due to the 1997/98 El Niño. Most of the warming from 1998 to 2001 is actually a recharge from the 1998-01 La Niña, but that would be difficult to observe without the spike from the 1995/96 La Niña serving as reference.

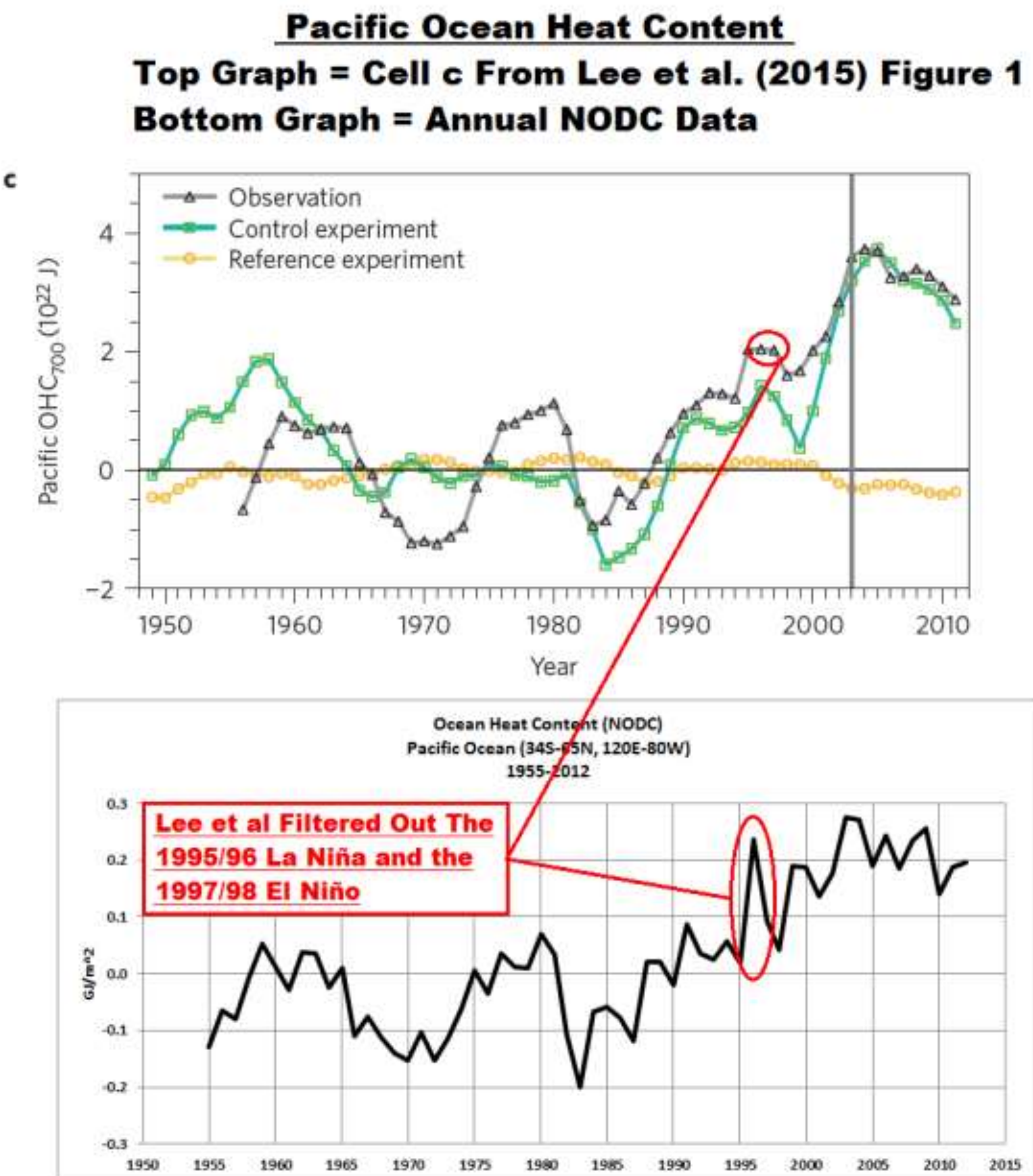

Figure 7

Once again, climate modelers have done away with an inconvenient reality. If the models can't explain it, the modelers change the data (or their presentation of the data) to meet the models.

We'll discuss the 1995/96 La Niña further in a few moments, along with the importance of La Niñas in general.

Next, you'll note that Lee et al. modeled and evaluated the Pacific Ocean (from 34S to 65N) as a whole, as though it warms uniformly as one body of water. Data do not support that assumption.

We know that there are monumental differences between the tropical Pacific and the extratropical North Pacific in how, when and why they warmed to depth. The variations in the ocean heat content of the tropical Pacific are dominated by ENSO, while, in the extratropical North Pacific, they're impacted primarily by shifts in sea level pressure and associated changes in wind patterns. We've been showing and discussing this for more than 5 years, ever since KNMI added the NODC ocean heat content data (0-700 meters) to their Climate Explorer back in 2009. My first introductory discussion of this topic was the September 2009 post ENSO Dominates NODC Ocean Heat Content (0-700 meters) Data.

So let's breakdown the ocean heat content data for the Pacific into subsets. Normally, we've presented them as the tropical Pacific (24S-24N, 120E-80W) and the extratropical North Pacific (24N-65, 120E-80W). But Lee et al. (2015) used 34S for the southern boundary of the Pacific, so we'll use the coordinates of 34S-24N, 120E-80W and call that subset the "Tropical Pacific Plus". (It makes no difference to the presentation, as you'll see.) And we'll use the normal coordinates for the extratropical North Pacific. For the Indian Ocean, we'll use coordinates of 34S-30N, 20E-120E, with the southernmost latitude once again dictated by Lee et al. The source of the NODC ocean heat content data (0-700m) for this portion of the post is the KNMI Climate Explorer, so the units are gigajoules per square meter (GJ/m^2).

First, let's examine the short-term period of 2003-2012. Figure 8 presents the ocean heat content (anomalies) for the global oceans, the Indian Ocean, the extratropical North Pacific and the Tropical Pacific Plus region. The Indian Ocean, of course, has the highest warming rate. The extratropical North Pacific also shows warming, at a rate that is slightly higher than that of the global oceans. The tropical Pacific Plus subset is the only one of this group that shows cooling. Thus, the extratropical North Pacific is unlikely to be the source of the warm water accumulating in the Indian Ocean…that and the fact that the Indonesian Throughflow connects the tropical Indian Ocean to the tropical Pacific, not the Extratropical North Pacific.

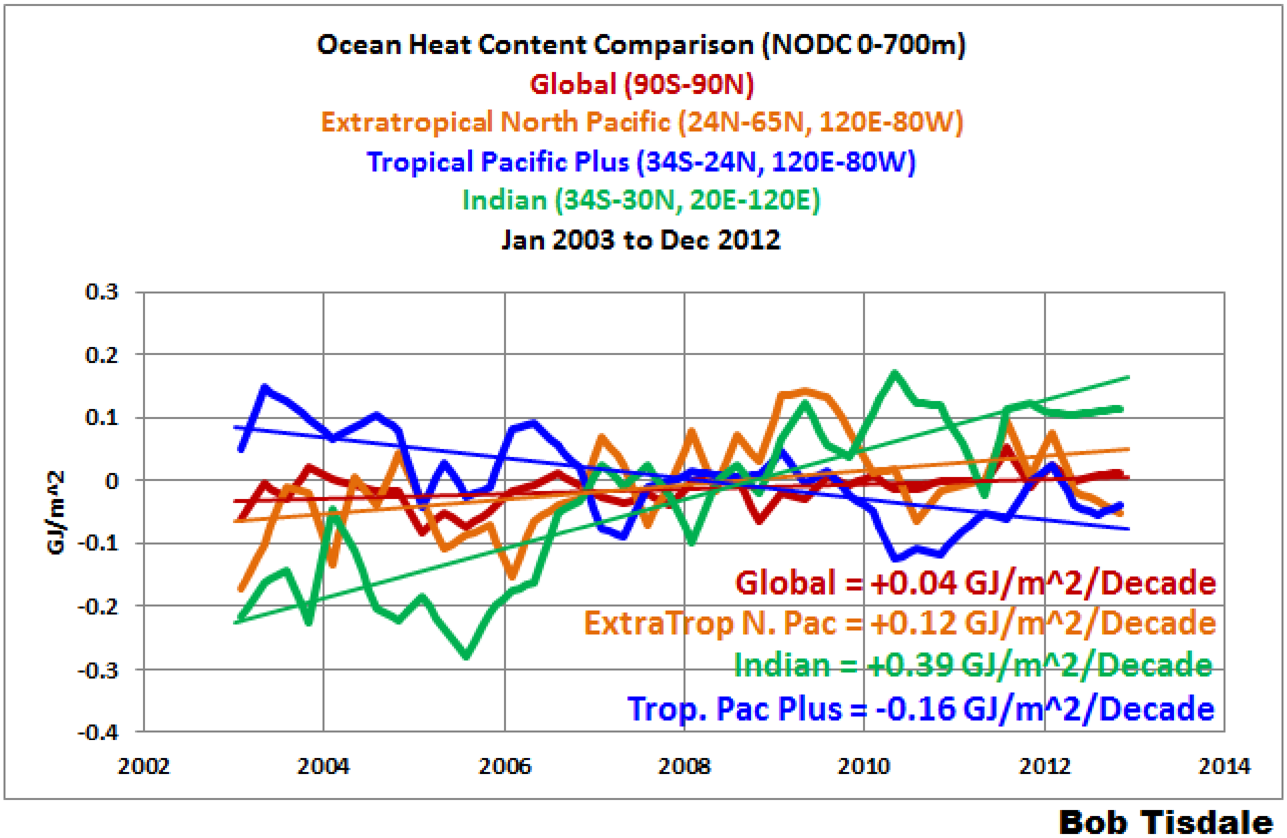

Figure 8

The modeling efforts of Lee et al. (2015), therefore, were likely skewed by their failure to study the tropical Pacific in isolation.

It is well known that the NODC ocean heat content data have been adjusted beyond recognition, even during the ARGO era. The UKMO EN3 ocean heat content data, on the other hand, appear not to have been. The UKMO EN3 data used to be available through the KNMI Climate Explorer but were removed from the Monthly observations webpage soon after I presented them during the ARGO era in a post. See the post UKMO EN3 Ocean Heat Content Anomaly Data Disappeared from the KNMI Climate Explorer As Suddenly as It Appeared. So in anticipation of a request in comments to see the unadjusted ARGO-era data, I’ve replicated Figure 8 with the UKMO EN3 data for the depths of 0-700 meters. See Figure 9.

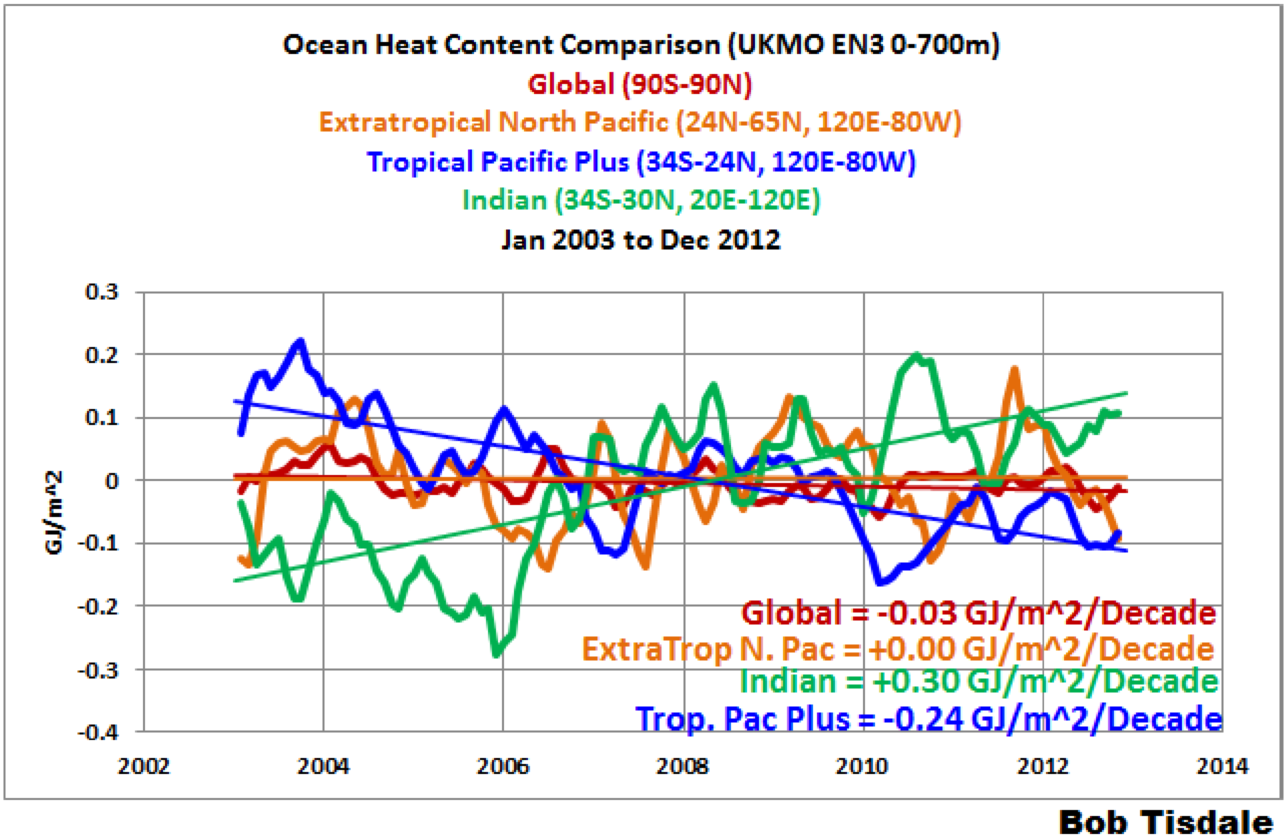

Figure 9

According to the unadjusted ARGO-era ocean heat content data, there had been no warming of the global oceans to depths of 0-700 meters from 2003 to 2012. The extratropical North Pacific shows a very slight warming. And the disparity between the Indian Ocean and tropical Pacific still exists, with the tropical Pacific cooling and the Indian Ocean warming. This confirms the earlier findings that the waters being transported to the Indian Ocean appear to have had little impact on the warming of the extratropical North Pacific.

THE NODC's CORRECTIONS INSERT A CLIMATE SHIFT IN THE INDIAN OCEAN IN 2001 BUT ELIMINATE ANOTHER IN 2006/07

Figure 10 contains two graphs. The top one compares the NODC and UKMO EN3 ocean heat content data (0-700 meters) for the Indian Ocean (34S-30N, 20E-120E), for the period of January 1995 to December 2012. The bottom graph presents the difference between the two depictions of that ocean heat content subset, with the UKMO EN3 data subtracted from the NODC data.

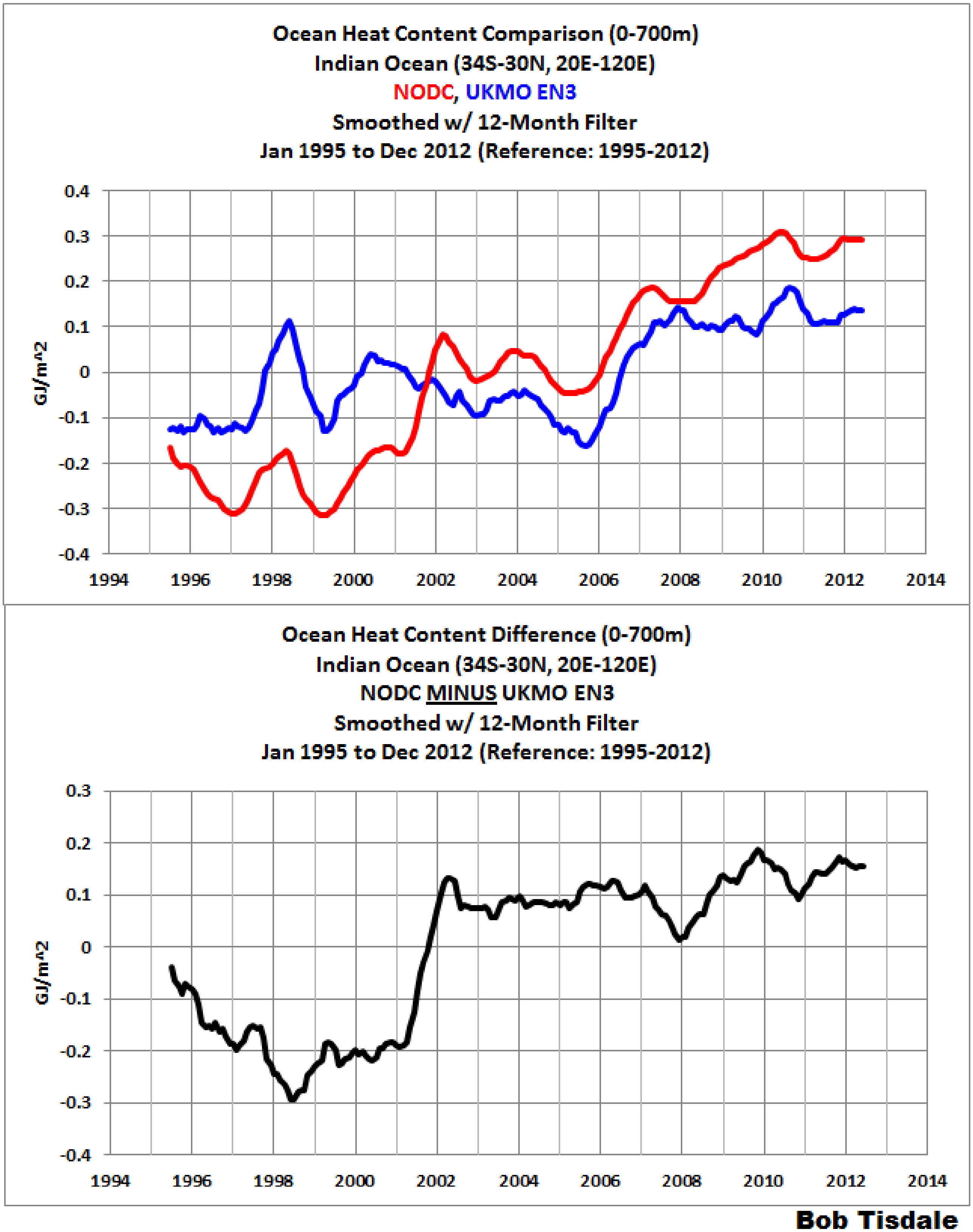
Ocean Heat Content Comparison (0-700m)
Indian Ocean (34S-30N, 20E-120E)
NODC, UKMO EN3
Smoothed w/ 12-Month Filter
Jan 1995 to Dec 2012 (Reference: 1995-2012)
GJ/m^2
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Ocean Heat Content Difference (0-700m)
Indian Ocean (34S-30N, 20E-120E)
NODC MINUS UKMO EN3
Smoothed w/ 12-Month Filter
Jan 1995 to Dec 2012 (Reference: 1995-2012)
GJ/m^2
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Bob Tisdale

Figure 10

Compared to the UKMO EN3 data, the NODC data makes an awkward upward shift in 2001. This allows the NODC data to show a relatively continuous warming from 1999 to 2012. The UKMO EN3 data, on the other hand, show two relatively flat periods, separated by an upward shift in 2006/07.

The Lee at al. models for the Indian Ocean presented in their Figure 1b (my Figure 5) show the warming accelerating after 2003. But the NODC data show the warming there begins in 1999, and the UKMO EN3 data show a shift in 2006/07.

WARMING ATTRIBUTION

Lee et al. (2015) note in the 5th paragraph of the body of the paper, after the abstract:

> *The heat budget indicates that the simulated global OHC700 increase since 1971 was largely driven by an increased downward longwave radiative heat flux, consistent with the thermodynamic effects of increased anthropogenic greenhouse gases in the atmosphere. This flux has accelerated in the most recent decade (that is, 2003-2012) and is damped by both an increased upward longwave radiative heat flux and latent heat flux.*

LEE ET AL. CONTRADICT BASIC UNDERSTANDINGS OF ENSO PROCESSES

Let's examine one of the claims by Lee et al. (2015) once again. With respect to attribution, they stated:

> *These changes in the Indian Ocean are supported by complementary changes in the Pacific Ocean. The net surface heat flux into the Pacific Ocean increased greatly during 2003-2012 (Fig. 1f), consistent with the La Niña-like condition across the Pacific Ocean[6,8].*

See my Figure 5 (above) for their Figure 1f. You'll note the high positive downward longwave radiation flux and negative downward shortwave radiation flux in the bar chart for 2003-2012. So, according to Lee et al., the net surface flux into the Pacific was dominated by the downward longwave radiation during that period (As a reminder, downward longwave radiation is associated with manmade greenhouse gases, and downward shortwave radiation is sunlight.) But we're not interested in the Pacific as a whole. We've already established that the heat uptake in the Indian Ocean had to have come from the tropical Pacific Plus subset, not the extratropical North Pacific.

ENSO dominates the heat uptake and release in the tropical Pacific. During El Niño events, the tropical Pacific releases heat to the atmosphere primarily through evaporation. Due to the increased surface temperatures in the tropical Pacific during El Niños, downward longwave radiation at the surface is higher than normal; but the tropical Pacific is releasing heat at that time. (See Pavlakis et al. 2007 ENSO surface longwave radiation forcing over the tropical Pacific.) Due to the increases in cloud cover over the tropical Pacific during El Niños, downward shortwave radiation (sunlight) at the surface is below normal, which would contribute to the loss of heat from the tropical Pacific. (See Pavlakis et al. 2008 ENSO surface shortwave radiation forcing over the tropical Pacific.)

The reverse occurs during La Niña events. Due to the drop in surface temperatures in the tropical Pacific during La Niñas, downward longwave (infrared) radiation is below normal; but the tropical Pacific is gaining heat at that time. (See the earlier quotes from Trenberth.) And due to the drop in cloud cover, downward shortwave radiation (sunlight) is above normal during La Niñas. Since heat is restored during La Niñas as noted by the Trenberth quotes, the increase in sunlight (downward shortwave radiation at the surface) must be the primary source of energy at those times, not the decrease on infrared radiation (downward longwave radiation).

NOTE: If you were to study the two Pavlakis et al. papers linked above, you'll notice that the ENSO-caused variations in downward longwave and downward shortwave radiation over the tropical Pacific dwarf any increase possible from manmade greenhouse gases. The NOAA Annual Greenhouse Gas Index lists a total increase of about 0.4 watts/m^2 from 2003 to 2012 in downward longwave radiation from manmade greenhouse gases. On the other hand, for parts of the equatorial Pacific, like the NINO3.4 region, sunlight (downward shortwave radiation) can increase temporarily as much as 40 watts/m^2 during a La Niña. In the same region, downward longwave radiation can decrease as much as 20 watts/m^2 during a La Niña.

The other factor to keep in mind is that sunlight (downward shortwave radiation) penetrates the oceans to depths of 100 meters (with most being absorbed nearer the surface in the top 10 meters or so) while downward longwave radiation is absorbed in the top few microns.

In more simple terms, Lee et al. basically discuss the redistribution of ENSO-related warm waters during La Niña events, but they do not properly address its creation.

Let's reinforce this discussion: The commonly used ENSO index of NINO3.4 region sea surface temperature anomalies are presented in Figure 11. The horizontal lines are the average sea surface temperature anomalies for the NINO3.4 region during two identified time periods, not the trends. They show that weak-to-moderate El Niño events dominated the tropical Pacific from 2003 to early 2007. Afterwards, moderate and strong La Niña events dominated from early 2007 to 2012.

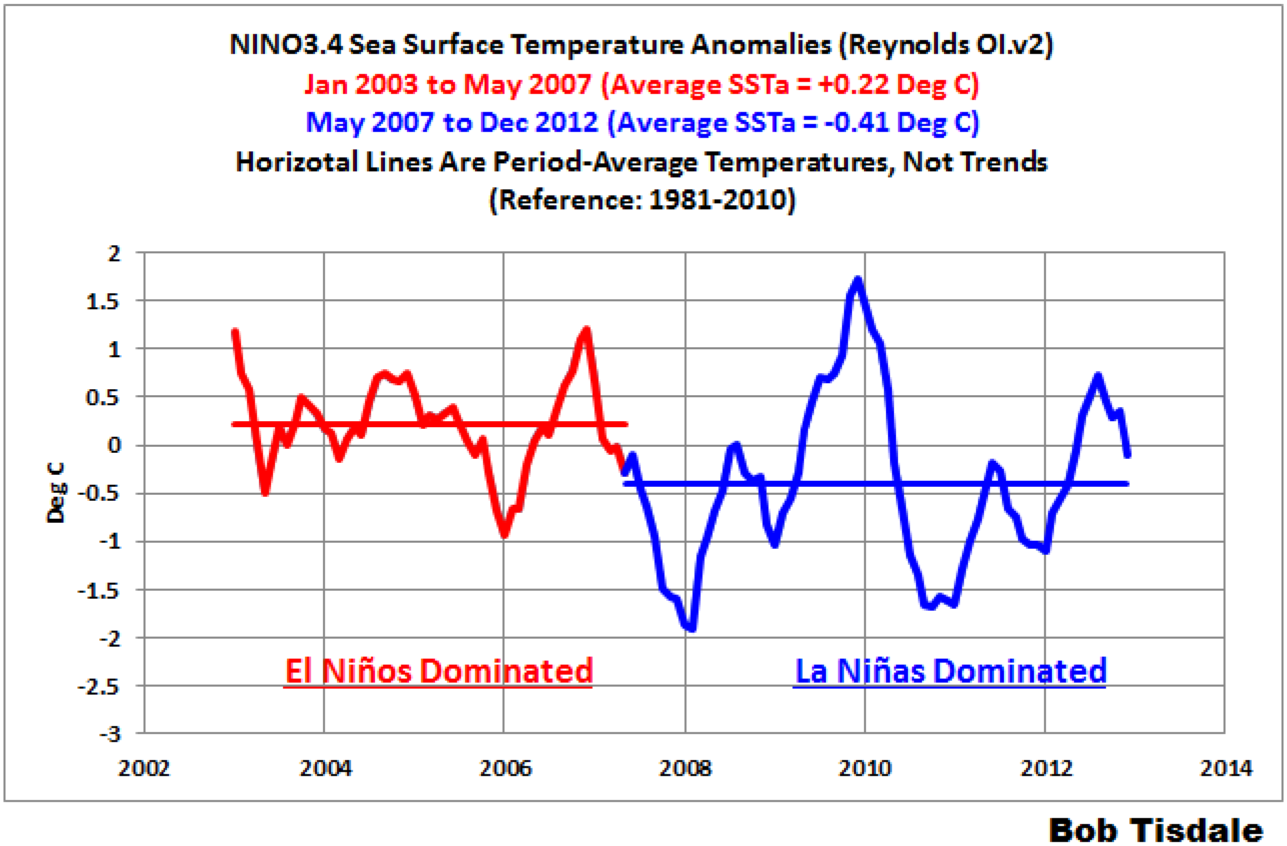

Figure 11

As a result, the tropical Pacific would have gone from a period of above-normal downward longwave radiation at the surface (2003-2007, when the tropical Pacific was releasing heat) to a period of below-normal downward longwave (infrared) radiation (2007-2012, when the tropical Pacific was replenishing and redistributing heat). This strongly suggests that the heat uptake in the tropical Pacific (and, in turn, the Indian Ocean) could not have come from downward longwave radiation during that time, because it would have decreased over the tropical Pacific.

That heat uptake had to have come from an increase in sunlight at the surface, resulting from the transition from a period of below-normal downward shortwave radiation (sunlight) at the surface (2003-2007, when the tropical Pacific was releasing heat) to a period of above-normal downward shortwave radiation (2007-2012, when the tropical Pacific was replenishing and redistributing heat).

That suggests the Lee at al. representations of downward shortwave and downward longwave radiation fluxes are skewed. Maybe that's why they presented the Pacific as a whole, instead of where the warm water is generated by and for ENSO events, which is the tropical Pacific.

Models often differ from theory, though. Climate models used by the IPCC are notorious for not properly simulating even the most basic of ENSO-related processes. See Bellenger et al. (2012) ENSO representation in climate models: from CMIP3 to CMIP5. One of the known problems is that they underutilize sunlight (downward shortwave radiation). See Guilyardi et al (2008) Understanding El Niño in Ocean-Atmosphere General Circulation Models: progress and challenges.

Even reanalyses differ from theory. We've shown in the past and discussed how the NCEP-DOE Reanalysis-2 showed a significant rise in sunlight reaching the surface of the Earth from 1979 to about 2003/04, which was followed by a sudden drop through 2010. Those variations also extended to the equatorial Pacific. We first presented the NCEP-DOE reanalysis of downward shortwave radiation (sunlight) at the surface in the post The Sun Was in My Eyes – Was It More Likely in the Past 3-Plus Decades? The NCEP-DOE Reanalysis-2 outputs of surface downward shortwave and longwave radiation for the equatorial Pacific were presented as Figure 3 in the post Meehl et al (2013) Are Also Looking for Trenberth's Missing Heat.

But, the NCEP-DOE Reanalysis-2 is only one of many. Other reanalyses confirm the increase in sunlight reaching the Earth's surface through the early-to-mid 2000s, while others disagree. How much sunlight actually reached into and warmed the oceans during the recent warming period? No one knows. That was one of the problems discussed by Trenberth and Fasullo (2009) Tracking Earth's Energy: From El Niño to Global Warming:

> *But a major challenge is to be able to track the energy associated with such variations more thoroughly: Where did the heat for the 2009–2010 El Niño actually come from? Where did the heat suddenly disappear to during the La Niña?*

That, of course, was a replay of one of Kevin Trenberth's Climategate email to Michael Mann, the follow up to the "travesty" email:

> *Where did the heat go? We know there is a build up of ocean heat prior to El Nino, and a discharge (and sfc T warming) during late stages of El Nino, but is the observing system sufficient to track it?*

One thing is certain: Lee et al. does not specifically address where in the Pacific Ocean the warm waters are being created or the mechanics of how the warm water (that's carried to the Indian Ocean) is generated in the tropical Pacific. Their attempts to force it with downward longwave radiation contradict basic fundamentals of ENSO processes.

THE LONG-TERM NODC OCEAN HEAT CONTENT DATA FOR THE PACIFIC CONFIRM OUR UNDERSTANDING OF ENSO

Now we'll discuss why the 1995/96 La Niña is important.

The replenishment of ocean heat during La Niñas is very obvious in the long-term ocean heat content data for the Tropical Pacific. Again, we normally present this for the coordinates of 24S-24N, 120E-80W, but we'll use the "Tropical Pacific Plus" subset (34S-24N, 120E-80W) because Lee et al. used 34S as their southernmost latitude for the Pacific data.

There are 4 periods highlighted in red in Figure 12. They are the La Niña events that dominated the ocean heat content record for the Tropical Pacific Plus subset. They include the 1954 to 1956 La Niña, the 1973 to 1976 La Niña, the 1995/96 La Niña (which supplied the warm water for the 1997/98 super El Niño) and the 1998 to 2001 La Niña (which replenished the heat released by the 1997/98 El Niño.) You'll note the ocean heat content for the tropical Pacific plus subset effectively shifted upwards in response to the 1995/96 La Niña, aided by the replenishment during the 1998-01 La Niña.

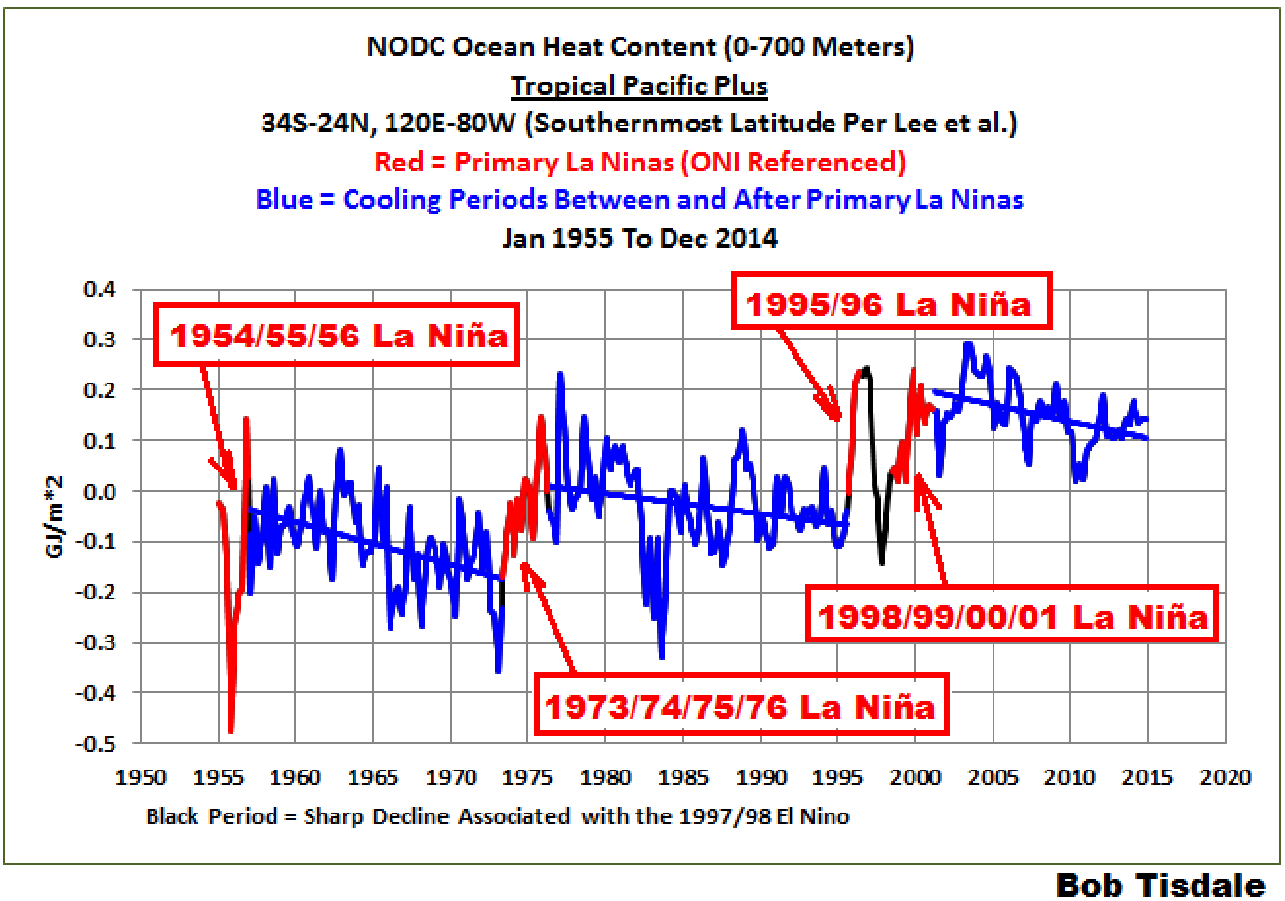

Figure 12

Obviously, the warming of the tropical Pacific Plus subset is dependent on the sunlight-forced warming during La Niñas.

Note: I've used the NOAA Oceanic NINO Index (ONI) as a reference for the "official" timing of La Niña events in that illustration. The original Oceanic NINO Index had the 1954 to 1956 La Niña extending into one month in 1957, making it the 1954-57 La Niña, and there are other minor differences, but they have little impact on the presentation in Figure 12.

Between the 1954 to 56 La Niña and the 1973 to 1976 La Niña, ocean heat content in the Tropical Pacific Plus subset decreased, because the tropical Pacific was releasing and redistributing more heat than it was gaining. Then the 1973 to 1976 La Niña not only replenished the heat lost, but it added to the heat content of the Tropical Pacific Plus subset. The 1973 to 1976 La Niña was followed by another multidecadal period of overall heat loss in the tropical Pacific Plus region, with the 1982/83 El Niño appearing as the sharp drop at that time. The 1995/96 La Niña then added more heat, much more heat, to the tropical Pacific, well above the heat that had been lost and redistributed since the 1973 to 1976 La Niña. And, as noted earlier, the 1998 to 2001 La Niña replenished the heat released by the 1997/98 El Niño.

As a reminder, heat is replenished during La Niñas by temporary drastic increases in the amount of sunlight reaching into and warming the tropical Pacific.

Note the negative trend in the ocean heat content for the Tropical Pacific Plus subset after the 1998 to 2001 La Niña. According to Lee et al., the ocean heat content in the tropical Pacific is declining because the ENSO-related waters are being transported to the Indian Ocean.

But the earlier multidecadal declines in the ocean heat content of the tropical Pacific are comparable to the latest decline.

Should the ocean heat content of the Indian Ocean also have decreased during those cooling episodes in the tropical Pacific?

Unfortunately, the data show just the opposite. From the late 1950s, the data for tropical Pacific plus region and the Indian Ocean mimic one another over decadal time periods…until the 1995/96 La Niña. See the two graphs in Figure 13, which present the two ocean subsets smoothed with 12-month and 61-month filters. That's not too surprising, though, considering how poor the source data are for the NODC ocean heat content data prior to ARGO.

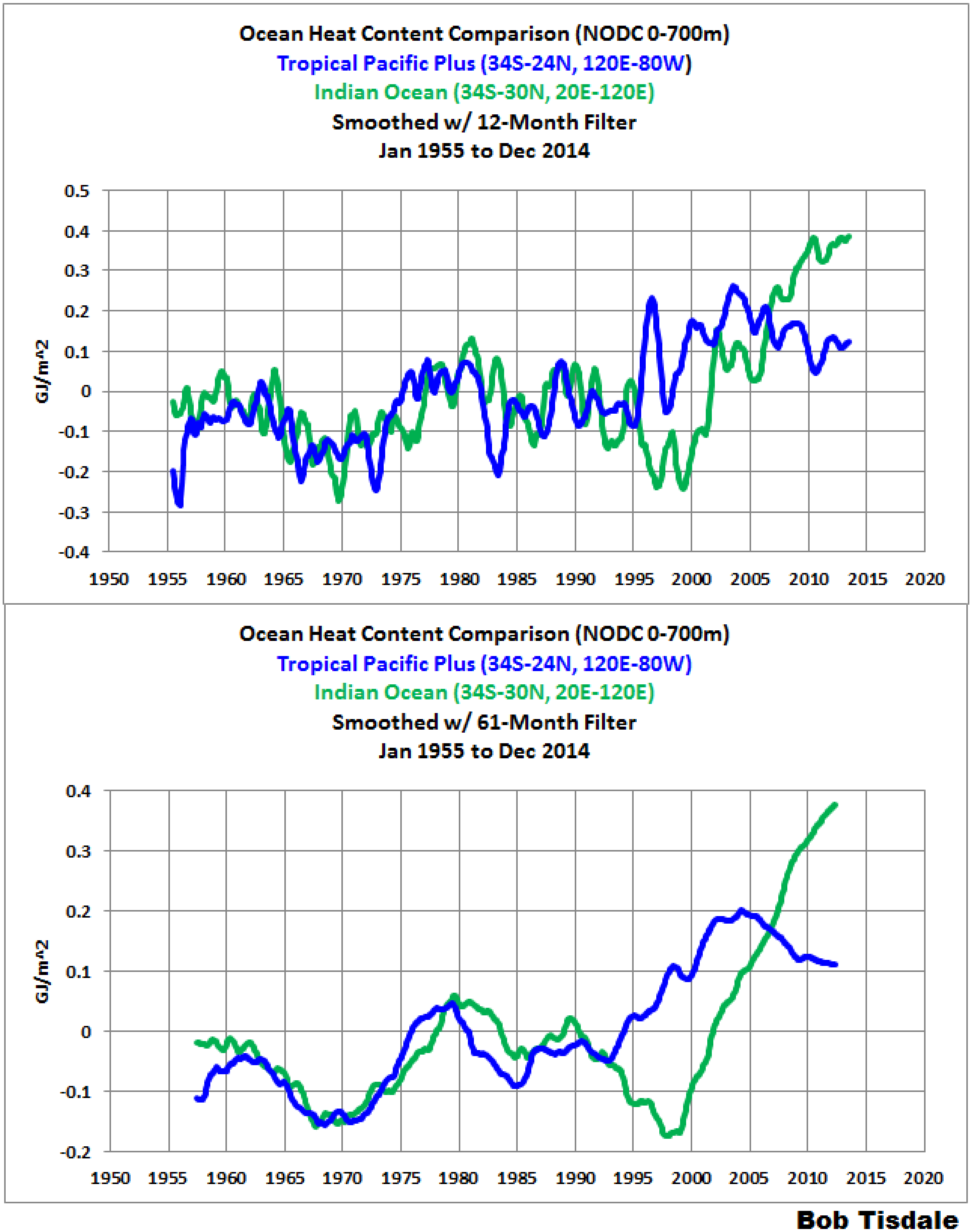
Ocean Heat Content Comparison (NODC 0-700m)
Tropical Pacific Plus (34S-24N, 120E-80W)
Indian Ocean (34S-30N, 20E-120E)
Smoothed w/ 12-Month Filter
Jan 1955 to Dec 2014
GJ/m^2
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Ocean Heat Content Comparison (NODC 0-700m)
Tropical Pacific Plus (34S-24N, 120E-80W)
Indian Ocean (34S-30N, 20E-120E)
Smoothed w/ 61-Month Filter
Jan 1955 to Dec 2014
GJ/m^2
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Bob Tisdale

Figure 13

There could be a number of explanations for the initial mimicry and then divergence of the tropical Pacific and Indian Ocean subsets, including:

- The relationship between the tropical Pacific and the Indian Ocean changed after the 1995/96 La Niña.
- The data are so poor, due to the sparseness of source data, they can't be used for attribution studies.

(I had once thought that the IPCC had made a similar statement to the effect of the ocean heat content data prior to ARGO were so dissimilar among datasets that the data prior to ARGO cannot be used for attribution studies. I can't find that IPCC statement. If you know where to find it, please let me know.)

THE LONG-TERM EXTRATROPICAL NORTH PACIFIC DATA SHOW THAT CHANGES IN WIND PATTERNS THERE CAN CAUSE SUBSTANTIAL WARMING (AND COOLING) SHIFTS IN OCEAN HEAT CONTENT

Figure 14 presents the NODC-based ocean heat content data (0-700m) for the extratropical North Pacific (24-65, 120E-80W). The extratropical North Pacific is often isolated from the tropical North Pacific in studies, (1) because of the massive effects El Niño and La Niña events have in the tropics, and (2) because the climate of the extratropical North Pacific is strongly impacted by other factors. You'll note that I divided the data into 4 time periods:

- 1955 to 1988 – The cooling period before the 1989/90 climate shift
- 1989 to 1990 – The climate shift
- 1991 to 2002 – The cooling period after the 1989/90 climate shift
- 2003 to 2012 – The warming period of the adjusted ARGO data.

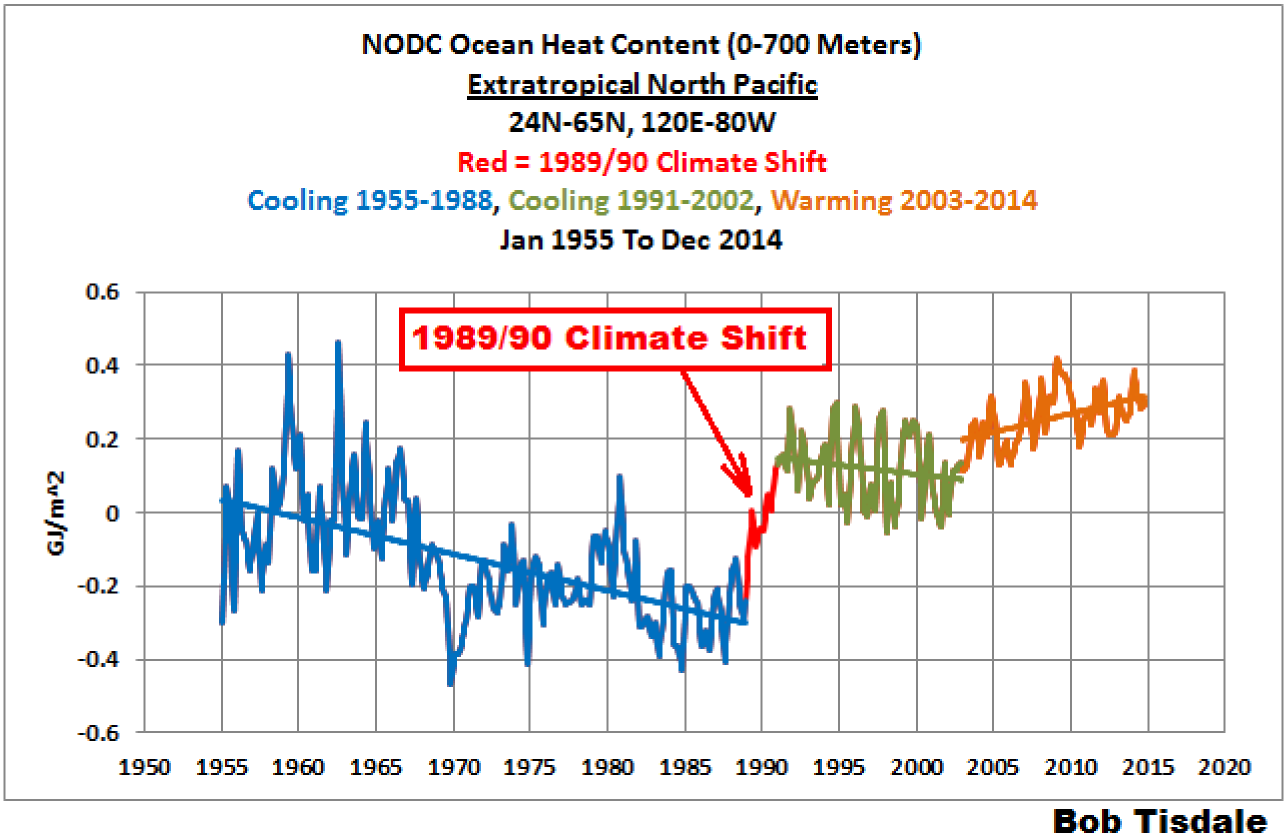

Figure 14

It should be blatantly obvious to all that the long-term warming to depths of 700 meters in the extratropical North Pacific from 1955 to 2012 is dependent on the upward shift in 1989/90. That is, without that upward shift, the extratropical North Pacific to 700 meters would show cooling over the last 55+ years. The cooling from 1955 to 1988 was caused by a downward shift in the late 1960s. Obviously, something other than manmade greenhouse gases dominates the warming (and cooling) of the extratropical North Pacific.

There are no studies that I'm aware of that address those shifts in the ocean heat content of the extratropical North Pacific. But a similar shift in the sea surface temperatures there in the late 1980s is discussed in the 1994 Trenberth and Hurrell paper Decadal atmosphere-ocean variations in the Pacific. See the discussion of their Figure 6. The sudden uptake in ocean heat in the extratropical North Pacific should be the result of a shift in sea level pressures and resulting wind patterns there.

Bottom line for this heading: The long-term warming of the tropical Pacific plus and the extratropical North Pacific to depths of 0-700 meters are primarily dependent on natural factors, not manmade greenhouse gases. By analyzing the extratropical North Pacific and the tropical Pacific as one subset, Lee et al. overlooked those naturally caused warming events. Lee et al. also smoothed the data for the Pacific subset beyond recognition, allowing the models to appear to have properly simulated the warming, when they had not.

CLOSING

Lee et al. (2015) confirmed our past discussions of the disparity in the warming rates of the Indian and Pacific Oceans to depths of 700 meters during the ARGO era (limited by Lee et al. to 2003 to 2012)…and the reason for that disparity: the recent strong La Niña events were forcing ENSO-created warm water from the tropical Pacific to the Indian Ocean along the Indonesian Throughflow. In that effort, Lee et al. presented data and a specially programmed climate model.

Lee et al. (2015) filtered the data to make it appear as though the models were performing reasonably well at simulating ocean heat uptake, but as noted, I have found no description of that filtering.

The warming of the ocean heat content globally during the ARGO era, of course, depends on the adjustments made to the data. In other words, without the adjustments, ocean heat content data globally from 2003-2012 show no warming.

Lee et al., of course, attributed the long-term and short-term warming of the Pacific Ocean (0-700 meters) to downward longwave radiation (from manmade greenhouse gases). Unfortunately for Lee et al., the data, when broken down into tropical Pacific and extratropical North Pacific subsets, indicate that was not the case. This suggests the simulations of ENSO in the tropical Pacific and the simulations of ocean heat uptake related to variations in sea level pressures and wind patterns in the extratropical North Pacific were both flawed in the model used by Lee et al.

Further to attribution, Lee et al. appear to be following the IPCC's failed, model-based assumption that only downward longwave radiation from manmade greenhouse gases are responsible for the warming of the oceans to depth. In Chapter 10 of the IPCC 5th Assessment Report, they used the same misguided (almost childish) argument they use for surface temperatures. Their Cell A from Figure 10.14 is presented as my Figure 15.

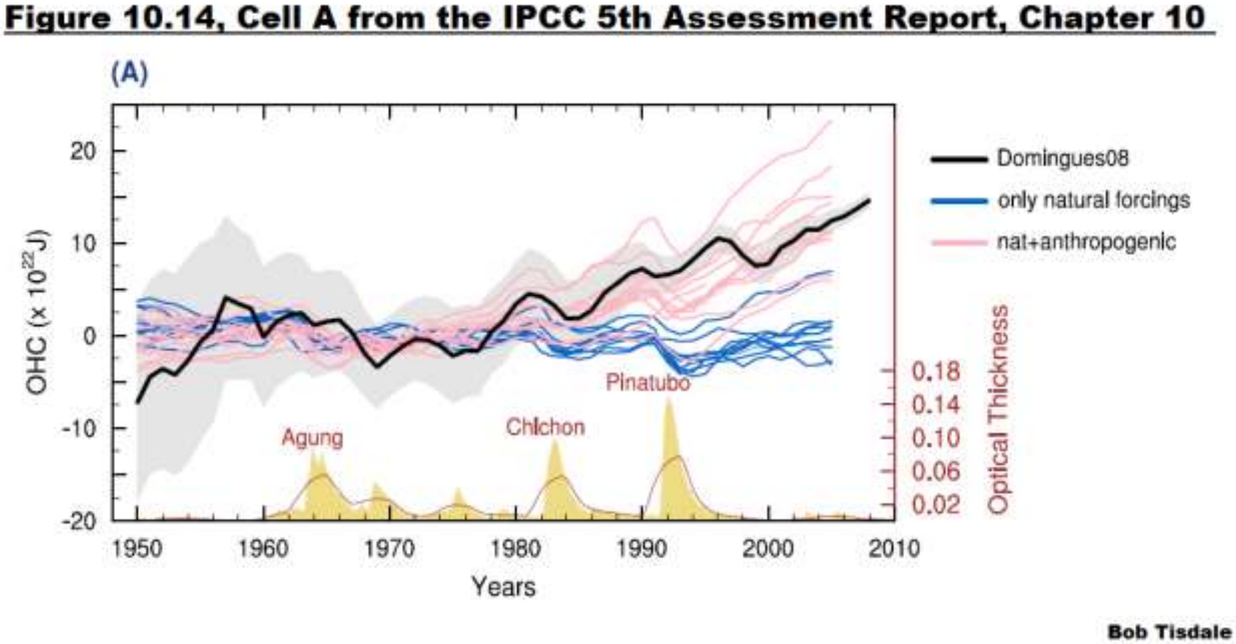

Figure 15

The caption for Cell A reads:

> ***Figure 10.14 |*** *(A) Comparison of observed global ocean heat content for the upper 700 m (updated from Domingues et al. 2008) with simulations from ten CMIP5 models that included only natural forcings ('HistoricalNat' runs shown in blue lines) and simulations that included natural and anthropogenic forcings ('Historical' runs in pink lines). Grey shading shows observational uncertainty. The global mean stratospheric optical depth (Sato et al., 1993) in beige at the bottom indicates the major volcanic eruptions and the brown curve is a 3-year running average of these values.*

The intent of that illustration is blatantly obvious: Climate models that use only natural forcings as inputs do not simulate the warming of the global oceans to depths of 700 meters, while the climate models that also include anthropogenic forcings can produce the warming. Therefore, as the childish logic concludes, only anthropogenic greenhouse gases (primarily from CO_2) could be the cause of ocean warming to depth.

What the IPCC obviously fails to consider is, the climate models they use for attribution studies do not (cannot) properly simulate the naturally occurring ocean-atmosphere processes that can cause the oceans to warm to depth or suppress that warming.

Also relating to the IPCC's climate models, Lee et al. note:

> *It has been shown that the ITF [Indonesian Throughflow] volume transport is mainly dominated by interannual variability associated with El Niño/Southern Oscillation (ENSO; refs 18,19).*

Yet the climate models used by the IPCC for attribution studies and projections of future warming still do not properly simulate ENSO…its basic processes or its aftereffects. In other words, based on the models used by the IPCC for their 5th Assessment Report, the climate science community cannot explain the disparity in warming between the Indian and Pacific Oceans.

LAST NOTE

And as a reminder, I had included the following comment parenthetically in the post: I had once thought that the IPCC had made a similar statement to the effect of the ocean heat content data prior to ARGO were so dissimilar among datasets that the data prior to ARGO cannot be used for attribution studies. I can't find that IPCC statement. If you know where to find it, please let me know.