Public Information Misconceptions Associated With Seasonal Hurricane Prediction

by

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1. INTRODUCTION

There are some misconceptions among the Eastern US coastal populations concerning some aspects of the Atlantic basin hurricane activity. This paper discusses two of these topics of potential misunderstandings.

a. Will global warming make hurricanes more frequent and intense?
b. What is the nature of large multi-decadal variability in Atlantic major hurricanes?

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Southeast landfalling hurricanes of 2004 – Charley, Frances, Ivan and Jeanne, raised questions about the possible role that global warming played in those two unusually destructive seasons. There was a media frenzy during and following the 2005 season. A number of researchers have tried to link the rising CO_2 levels with SST increases during the late 20th century and say that this has brought on higher levels of hurricane intensity.

The speculation that hurricane intensity has increased in partial response to human activity has been given much media attention and has been supported by the recent IPCC-IV report. Many in the general public also believe that humans have had a role in making these storms more frequent and intense. But observational data from around the globe does not support such an assessment.

Because there has been such a large increase in Atlantic basin major hurricane activity since 1995 in comparison with the very inactive prior 16-year period of 1979-1994 (Figure 1) as well as the prior quarter-century period of 1970-1994 – it has been tempting for many who do not have a strong background of hurricane information to jump on this recent increase in major hurricane activity as strong evidence of a human influence on these systems. It should be noted, however, that the last 16-year active major hurricane period of 1995-2010 has, however, not been more active than the earlier 16-year period of 1949-1964 when the Atlantic Ocean circulation conditions were similar to what has been observed over the last 16 years. These earlier active conditions occurred even though atmospheric CO_2 amounts were lower during the earlier period.

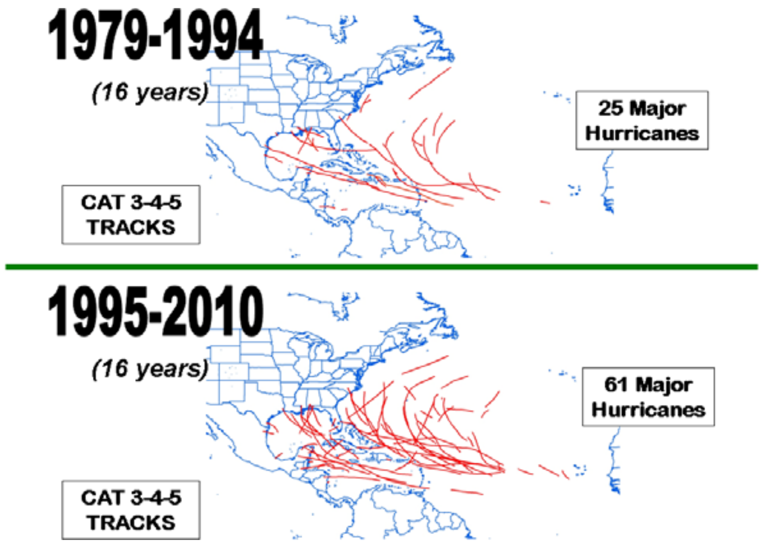

Figure 1: The tracks of major (Category 3-4-5) hurricanes during the 16-year period of 1995-2010 when the Atlantic thermohaline circulation (THC) was strong versus the prior 16-year period of 1979-1994 when the THC was weak. Note that there were approximately 2.5 times as many major hurricanes when the THC was strong as when it was weak.

Table 1 shows how large Atlantic basin hurricane variations are between strong and weak THC periods. Note especially how large the ratio is for major hurricane days (3.7) during strong vs. weak THC periods. Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) and Pielke et al. (2008) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction even though these major hurricanes make up only 20-25 percent of named storms.

Table 1: Comparison of annual Atlantic basin hurricane activity in two 16-year periods when the Atlantic Ocean THC was strong versus an intermediate period (1970-1994) when the THC was weak.

	THC (or AMO)	SST (10-15°N; 70-40°W)	Avg. CO_2 ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
1949-1964 (16 years)	**Strong**	**27.93**	**319**	**10.1**	**54.1**	**6.5**	**29.9**	**3.8**	**9.5**	**121**	**133**
1970-1994 (25 years)	**Weak**	**27.60**	**345**	**9.3**	**41.9**	**5.0**	**16.0**	**1.5**	**2.5**	**68**	**75**
1995-2010 (16 years)	**Strong**	**28.02**	**373**	**14.6**	**74.1**	**7.8**	**32.0**	**3.8**	**9.4**	**140**	**153**
Per Year Ratio Strong/Weak THC		**0.35°C**	**~ 0**	**1.3**	**1.5**	**1.4**	**1.9**	**2.5**	**3.7**	**1.9**	**1.9**

Although global surface temperatures increased during the late 20th century, there is no reliable data to indicate increased hurricane frequency or intensity in any of the globe's other tropical cyclone basins since 1979. Global Accumulated Cyclone Energy (ACE) from Ryan Maue shows significant year-to-year and decadal variability over the past thirty years but no increasing trend (Figure 2). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005.

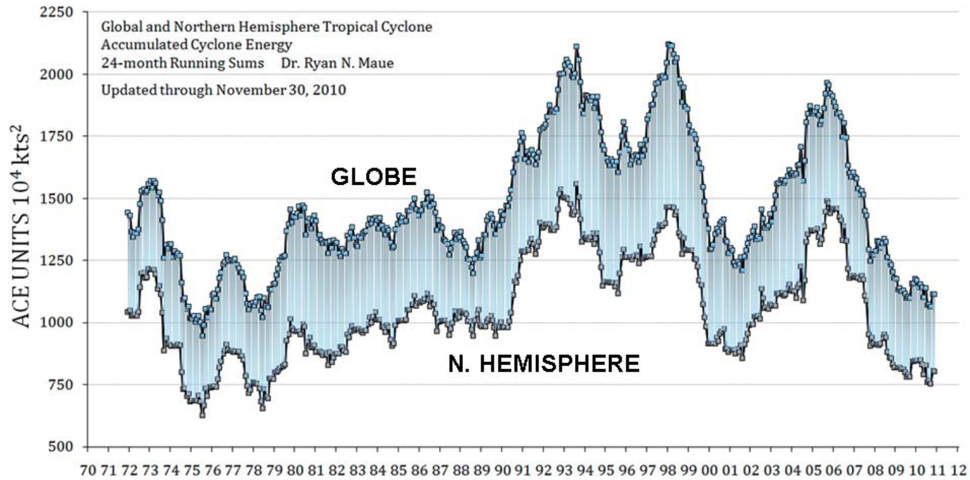

Figure 2: Northern Hemisphere and global Accumulated Cyclone Energy (ACE) over the period from 1970-November 2010. Figure has been adapted from Ryan Maue, Center for Ocean-Atmospheric Prediction Studies, Florida State University.

Causes of the Upswing in Atlantic Basin Major Hurricane Activity since 1995. The Atlantic Ocean has a strong multi-decadal signal in its hurricane activity which is likely due to multi-decadal variations in the strength of the THC (Figure 3). The oceanic and atmospheric response to the THC is often referred to as the Atlantic Multi-decadal Oscillation (AMO). We use the THC and AMO interchangeably throughout the remainder of this discussion. The strength of the THC can never be directly measured, but it can be diagnosed, as we have done, from the magnitude of the sea surface temperature anomaly (SSTA) in the North Atlantic (Figure 4) combined with the sea level pressure anomaly (SLPA) in the Atlantic between the latitudes of the equator and 50°N (Klotzbach and Gray 2008).

The THC (or AMO) is strong when there is an above-average poleward advection of warm low-latitude waters to the high latitudes of the North Atlantic. This water can then sink to deep levels when it reaches the far North Atlantic in a process known as North Atlantic Deep Water Formation (NADWF). The water then moves southward at deep levels in the ocean. The amount of North Atlantic water that sinks is proportional to the water's density which is determined by its salinity content as well as its temperature. Salty water is denser than fresh water especially at water temperatures near freezing. There is a strong association between North Atlantic SSTA and North Atlantic salinity as calculated from the Simple Ocean Data Assimilation (SODA) reanalysis (Figure 5). High salinity implies higher rates of NADWF (or subsidence) and thus a stronger flow of upper level warm water from lower latitudes as replacement. See the papers by Gray et al. (1996), Goldenberg et al. (2001), and Grossman and Klotzbach (2009) for more discussion.

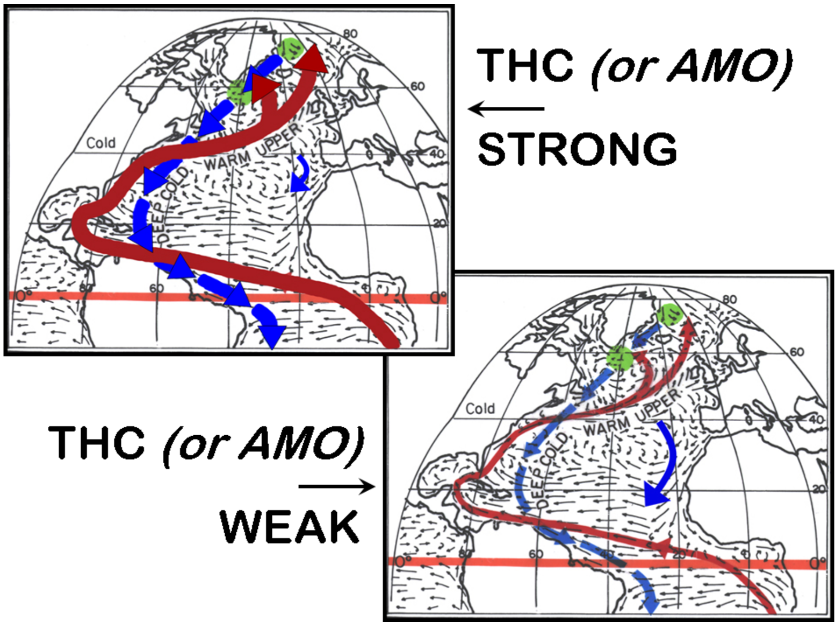

Figure 3: Illustration of strong (top) and weak (bottom) phases of the THC or AMO.

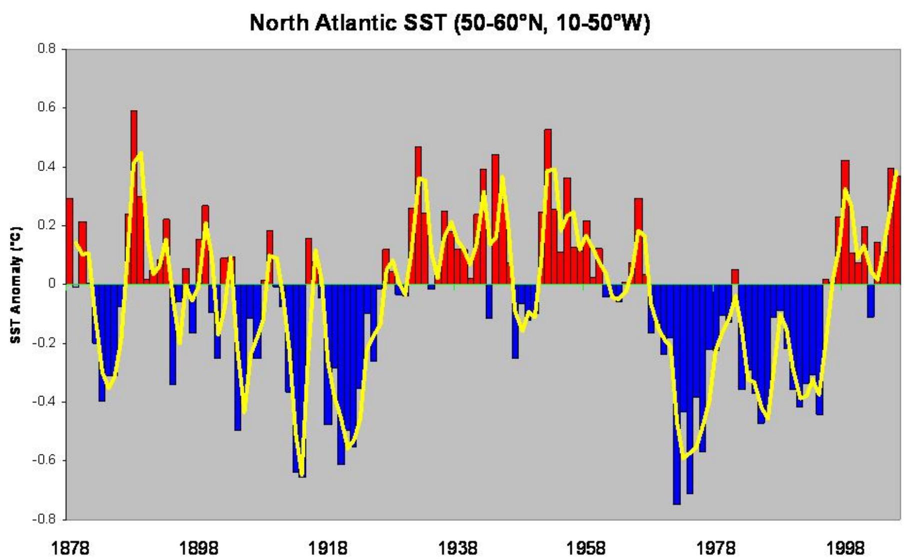

Figure 4: Long-period portrayal (1878-2006) of North Atlantic sea surface temperature anomalies (SSTA). The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average.

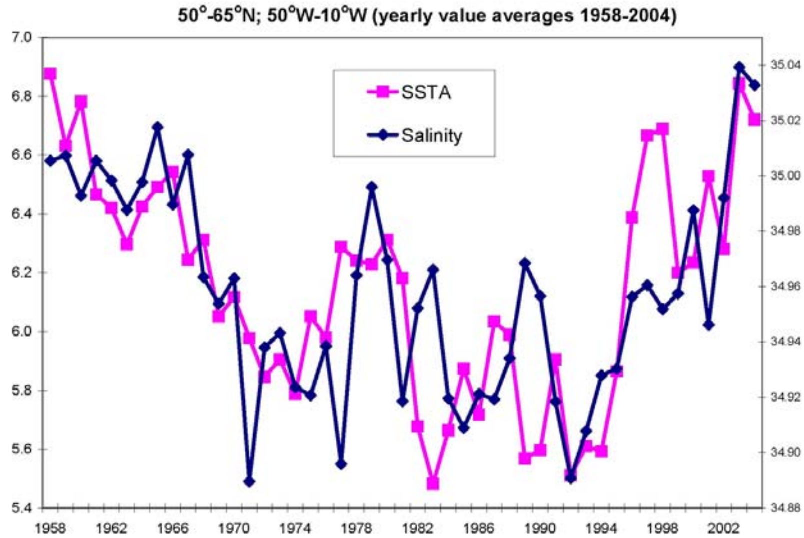

Figure 5: Illustration of the strong association of annually-averaged North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004. Salinity data from SODA as discussed in the text.

2. WHY CO_2 INCREASES ARE NOT RESPONSIBLE FOR ATLANTIC SST AND HURRICANE ACTIVITY INCREASES

Theoretical considerations do not support a close relationship between SSTs and hurricane intensity. In a global warming world, the atmosphere's upper air temperatures will warm or cool in unison with longer-period SST changes. Vertical lapse rates will thus not be significantly altered in a somewhat warmer tropical oceanic environment. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will significantly change if global or Atlantic Ocean temperatures were to rise by 1-2°C. Without corresponding changes in many other basic features, such as vertical wind shear or mid-level moisture, little or no additional TC activity should occur with SST increases.

Confusing Time Scales of SST Influences. A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo some intensification. This is due to the sudden lapse rate increase which the hurricane's inner core experiences when it passes over warmer water. The warmer SSTs cause the hurricane's lower boundary layer temperature and moisture content to rise. While these low-level changes are occurring, upper tropospheric conditions are often not altered significantly. These rapidly occurring lower- and upper-level temperature differences cause the inner-core hurricane lapse rates to increase and produce more intense inner-core deep cumulus convection. This typically causes a rapid increase in hurricane intensity. Such observations have led many observers to directly associate SST increases with greater hurricane potential intensity. This is valid reasoning for day-to-day hurricane intensity change associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in an overall climatologically warmer (or cooler) tropical oceanic environment where broad-scale global and tropical rainfall conditions are not expected to significantly vary. During long-period climate change, temperature and moisture conditions rise at both lower and upper levels. Lapse rates are little affected (Figure 6).

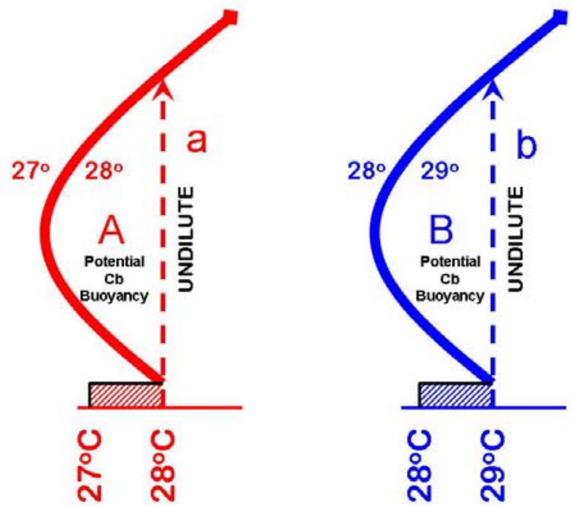

Figure 6: Illustration of how SST increases of 1°C will bring about higher planetary boundary layer (PBL) temperature and moisture increases that will also occur in small amounts throughout the troposphere. The combination of these changes is such that potential buoyancy for cumulonimbus (Cb) development is not significantly altered by increases in SST alone – area b is no larger than area a even though area b has a higher SST.

Any warming-induced increase in boundary layer temperature and moisture will be (to prevent significant global rainfall alteration) largely offset by a similar but weaker change through the deep troposphere up to about 10 km height. Upper-tropospheric changes are weaker than boundary layer changes, but they occur through a much deeper layer. These weaker and deeper compensating increases in upper-level temperature and moisture are necessary to balance out the larger increases in temperature and moisture which occur in the boundary layer. Global and tropical rainfall would be altered significantly only if broad-scale lapse rates were ever altered to an appreciable degree.

Thus, we cannot automatically assume that with warmer global SSTs that we will necessarily have more intense hurricanes due to lapse-rate alterations. We should not expect that the frequency and/or intensity of Category 4-5 hurricanes will necessarily change as a result of changes in global or individual storm basin SSTs. Historical evidence does not support hurricanes being less intense during the late 19th century and the early part of the 20th century when SSTs were slightly lower.

CO_2 Influence on Hurricane Activity. We have been performing research with the International Satellite Cloud Climatology Project (ISCCP) and the NOAA National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data sets. We have used this data to make an annual average of the global tropical (30°N-30°S; 0-360°) energy budget (Figure 7) for the years from 1984-2004. Note that the various surface and top of the atmosphere energy fluxes are very large. For the tropical surface, for instance, there are 637 Wm^{-2} units of downward incoming solar and infrared (IR) energy. This downward energy flux is largely balanced by an upward surface energy flux of 615 Wm^{-2} which is due to upward fluxes from IR radiation, evaporated liquid water, and sensible heat. Similar large energy fluxes are present at the top of the atmosphere and within the troposphere.

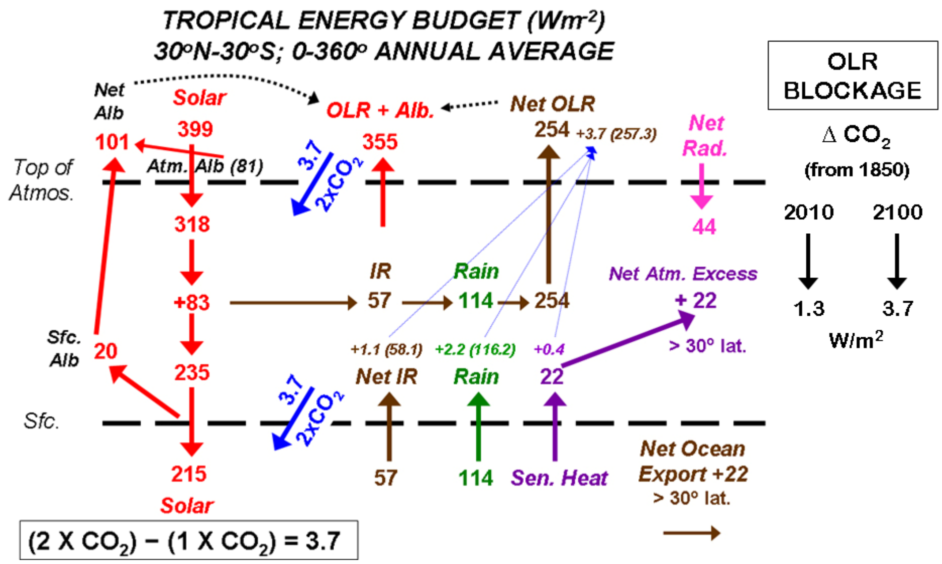

Figure 7: Vertical cross-section of the annual tropical energy budget as determined from a combination of ISCCP and NCEP/NCAR Reanalysis data over the period from 1984-2004. Abbreviations are **IR** for longwave infrared radiation, **Alb** for albedo and **OLR** for outgoing longwave radiation. The tropics receives an excess of about 44 Wm^{-2} radiation energy which is convected and exported as sensible heat to latitudes poleward of 30°. Estimates are about half (22 Wm^{-2}) of this excess is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small an OLR blockage has occurred up to now due to CO_2 increases (~ 1.3 Wm^{-2}) and the blockage of 3.7 Wm^{-2} that will occur from a doubling of CO_2 by the end of this century.

It has been estimated that a doubling of CO_2 (from the pre-industrial period) without any feedback influences would result in a blockage of OLR to space of about 3.7 Wm^{-2}. The currently-measured value of CO_2 in the atmosphere is 385 parts per million by volume (ppmv). If we take the background pre-industrial value of CO_2 to be 285 ppmv, then by theory we should currently be having (from CO_2 increases alone) about (100/285)*3.7 = 1.3 Wm^{-2} less OLR energy flux to space than was occurring in the mid-19th century.

This reduced OLR of 1.3 Wm^{-2} is very small in comparison with most of the other tropical energy budget exchanges. Slight changes in any of these other larger tropical energy budget components could easily negate or reverse this small CO_2-induced OLR blockage. For instance, an upper tropospheric warming of about 1°C with no change in moisture would enhance OLR sufficient that it would balance the reduced OLR influence from a doubling of CO_2. Similarly, if there were a reduction of upper level water vapor such that the long wave radiation emission level to space were lowered about 6 mb (~ 120 m) there would be an enhancement of OLR (with no change of temperature) sufficient to balance the suppression of OLR from a doubling of CO_2. The 1.3 Wm^{-2} reduction in OLR that we have experienced since the mid-19th century (about one-third of the way to a doubling of CO_2) is very small when compared with the overall 399 Wm^{-2} of solar energy impinging on the top of the tropical atmosphere and the mostly compensating 356 Wm^{-2} of OLR and albedo energy going back to space. This 1.3 Wm^{-2} energy gain (0.37% of the net energy returning to space) is much too small to ever allow a determination of its possible influence on TC activity. Any such potential CO_2 influence on TC activity is deeply buried as turbulence within the tropical atmospheres' many other energy components. It is possible that future higher atmospheric CO_2 levels may cause a small influence on global TC activity. But any such potential influence would likely never be able to be detected, given that our current measurement capabilities only allow us to assess TC intensity to within about 5 mph.

3. CONTRAST OF THEORIES OF HURRICANE ACTIVITY CHANGES

Theory of Human-Induced Increases due to Rising CO_2 Levels. Those who think CO_2 increases have and will cause significant increases in hurricane activity believe that the physics of the CO_2-hurricane association is directly related to radiation changes as indicated in Figure 8. They view CO_2 as blocking OLR to space. This acts to warm SSTs and add moisture to the boundary layer just above the ocean surface. These changes cause an increase in lapse rates (the lower levels warm while upper levels do not change much) which lead to more deep cumulonimbus (Cb) convection. More Cb convection leads to a higher percentage of tropical disturbances forming into tropical cyclones and a greater spin-up of the inner-core of those systems which do form.

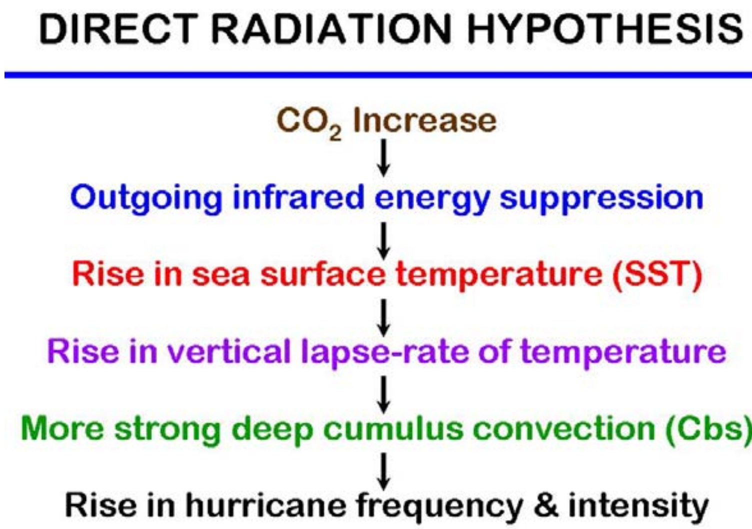

Figure 8: Physical linkage of those who believe that increases in CO_2 are making hurricanes more frequent and/or more intense.

This physical argument is too simplistic. It has no empirical verification in any other global TC basin except for the Atlantic where SST changes are primarily a result of ocean circulation changes. Table 2 shows the correlation of ACE with late summer-early fall SSTs in the Main Development Regions of the Northeast Pacific, the Northwest Pacific and the Southern Hemisphere. Note the low (or even negative) correlations between ACE and SST in each of these three TC basins. It is obvious that other physical processes besides SST are primarily responsible for differences in hurricane activity in these basins.

Table 2: Correlation of ACE with late summer-early fall SSTs in three TC basins from 1980-2009.

	Yearly Mean ACE	**ACE vs. SST Correlation (r)**
Northeast Pacific	134	0.01
Northwest Pacific	310	-0.30
Southern Hemisphere	205	0.23
Globe (SST 20°N-20°S)	769	-0.08

<u>Theory of the THC (or AMO)</u>. We do not view seasonal hurricane variability in the Atlantic as being directly related to changes in CO_2-induced radiation forcing or to SST changes by themselves. For the Atlantic, we view long-period tropical cyclone variability primarily as a result of changes in the strength of the THC (or AMO). We hypothesize that these changes act as shown in Figure 9. THC changes result in alterations of tropospheric vertical wind shear, trade wind strength, and SSTs in the Main Development Region (MDR) of 10-20°N; 20-70°W in the tropical Atlantic. A large component of the SST increase in this area is not a direct result of radiation differences but rather the combination of the effects of reduced southward advection of colder water in the east Atlantic and reduced trade wind strength. Weaker trade winds reduce upwelling and evaporation and typically act to increase SST.

The influence of the warmer Atlantic SST, as previously discussed, is not primarily to enhance lapse rates and Cb convection but rather as a net overall positive influence on lowering the MDR's surface pressure and elevating mean upward tropospheric vertical motion and reducing vertical shear. This causes an increase in tropospheric moisture content.

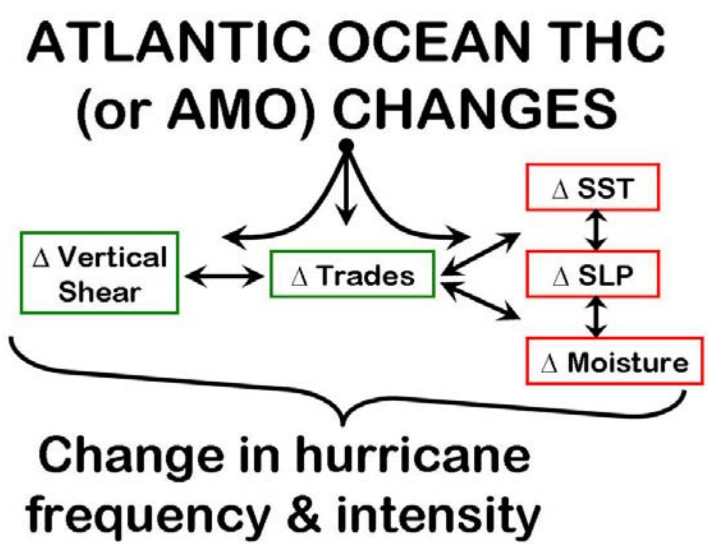

Figure 9: Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic's MDR. Vertical shear, trade-wind strength and SST are the key parameters which respond to THC changes. Favorable SLP and mid-level moisture changes occur in association with the shear, trade wind and SST changes.

4. DISCUSSION

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the SSTs. Vertical lapse rates will not be significantly altered. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures were to continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, there were only 38 Atlantic major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 10). Atlantic SSTs and hurricane activity do not follow global mean temperature trends.

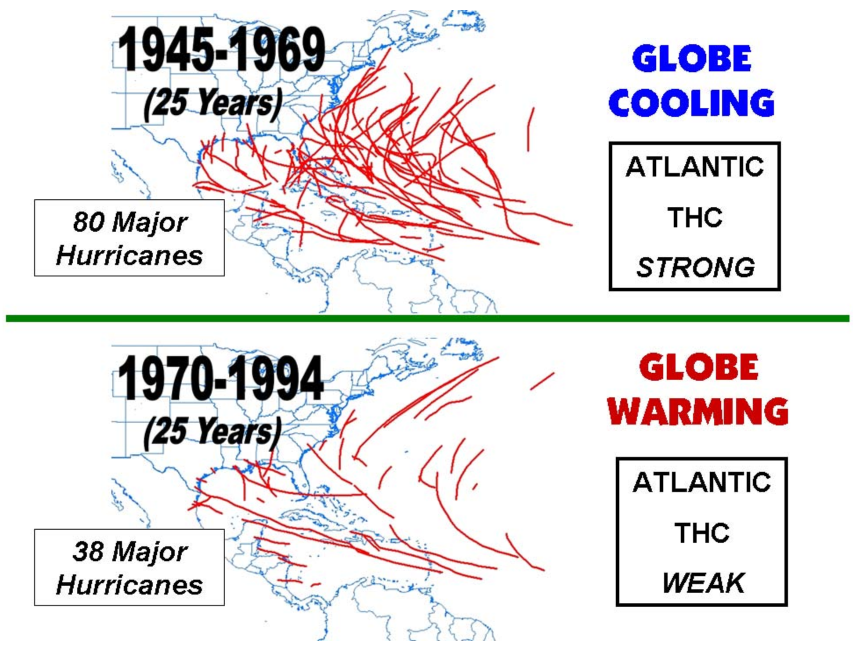

Figure 10: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was only about one-third as frequent during the latter period despite warmer global temperatures.

US Landfall Observations. The most reliable long-period hurricane records we have are the measurements of US landfalling TCs since 1900 (Table 3). Although global mean ocean and Atlantic SSTs have increased by about 0.4°C between two 55-year periods (1901-1955 compared with 1956-2010), the frequency of US landfall numbers actually shows a slight downward trend for the latter period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 45-year period of 1921-1965 (24 landfall events) and the 45-year period of 1966-2010 (7 landfall events) was especially large (Figure 11). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 45-year period (1921-1965) compared with only 26 major hurricanes for the latter 45-year period (1966-2010). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period.

Table 3: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Major Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1901-1955 (55 years)	210	115	44	+0.4°C
1956-2010 (55 years)	180	87	34	

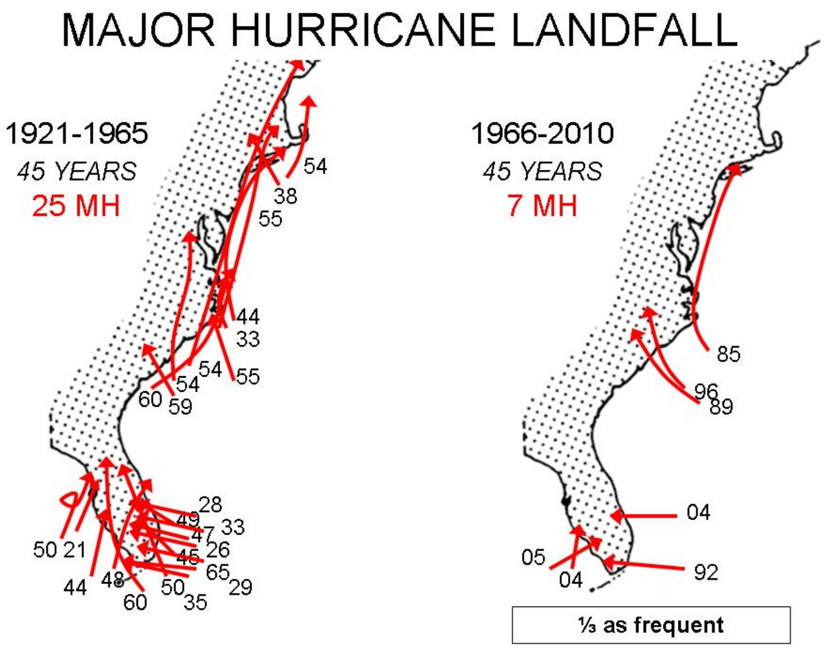

Figure 11: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 45-year period of 1921-1965 versus the most recent 45-year period of 1966-2010.

IPCC-IV's Tropical Cyclone Mis-statements. The author completely disagrees with the large number of papers written around the time of the flurry of landfalling US major hurricanes during 2004-2005. We strongly disagree in how these authors interpreted the hurricane data to imply that rising levels of CO_2 were likely a significant contributing influence to the large amounts of hurricane destruction during those two years.

A number of these papers served as the basis for the IPCC-IV (2007) report concerning tropical cyclones of which one paragraph of the Executive Report (page 239) will be quoted:

> *"<u>Intense tropical cyclone activity has increased since about 1970</u>. …Globally, estimates of the potential destructiveness of hurricanes show a significant upward trend since the mid-1970s, with a trend towards longer lifetimes and greater storm intensity, and such trends are strongly correlated with tropical SST. These relationships have been reinforced by findings of a large increase in numbers and proportion of hurricanes*

reaching categories 4 and 5 globally since 1970 even as total number of cyclones and cyclone days decreased slightly in most basins. The largest increase was in the North Pacific, Indian and southwest Pacific Oceans."

It is unfortunate indeed that, the IPCC-IV report, which shared a Noble Prize for science, would report this information which had already been rebutted by several studies.

8. SUMMARY

It is not possible to directly measure the strength of the THC. We think we can infer its strength from proxy measurements of the North Atlantic SST and salinity anomalies (which are directly related to each other) minus the SLPA over the broad Atlantic (0-50^{o}N; 70^{o}W-10^{o}W). When the THC is strong the Atlantic atmospheric and oceanic sub-tropical gyres are weaker than normal and we have much more Atlantic major hurricane activity. When the Atlantic THC is weaker than average, the gyres are stronger than normal and we encounter less major hurricane activity in the Atlantic.

There is no evidence that Atlantic hurricane activity is significantly impacted by CO_2 increases or by global mean surface temperature changes. This myth should be put to rest. It is the natural variability of the Atlantic's meteorological parameters that we must be most concerned about.

9. REFERENCES

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