3B.8 WILL INCREASES IN CO_2 AMOUNTS DURING THIS CENTURY LEAD TO SIGNIFICANT CHANGES IN GLOBAL TROPICAL CYCLONE ACTIVITY?

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THE MAIN MISCONCEPTION OF THE GLOBAL WARMERS IS TO ASSUME THAT ALL THE OTHER MUCH LARGER ENERGY TERMS OF THE CLIMATE SYSTEM REMAIN CONSTANT OVER LONG PERIODS AND THAT THE ONLY CHANGES THAT MATTER IN CLIMATE ALTERATION ARE THE SMALL MAGNITUDE VARIATIONS IN CO_2.

HOW COULD THE WARMERS BE SO NAÏVE AS TO BELIEVE THAT CHANGES IN ΔCO_2 CAN BE THE PRIMARY CLIMATE FORCER?

Abstract

Increases in CO_2 and other greenhouse gases will not be able to bring about significant climate disruption or significantly alter global tropical cyclone activity. Any influences of rising levels of CO_2 will be well buried in the tropical circulation noise level and will likely never be able to be isolated. Variation in the global deep ocean circulation patterns are the most important physical component in tropical cyclone variability and intensity change. The fundamental problem with the Anthropogenic Global Warming (AGW) theory is the false treatment of the global hydrologic cycle. The water vapor, cloud, and condensation-evaporation assumptions within the conventional AGW theory and within the AGW global general circulation (GCM) model simulations are incorrectly assumed and designed to block too much short wave (albedo) and infrared (IR) radiation to space. This results in a large artificial warming that is not realistic.

The global warming of about 0.7°C that has been experienced over the last 150 years and the multi-decadal up-and-down global temperature changes of 0.3-0.4°C that have been observed over this period is hypothesized to be driven by deep global ocean circulation changes due to global scale upper ocean salinity variations.

1. BACKGROUND DISCUSSION

Although rises in CO_2 gases act to block the normal long wave infrared (IR) radiation to space, this blockage is small – about 3.7 Wm^{-2} of IR energy interception for a doubling of CO_2 (Fig. 1). Since the mid-19th century, CO_2 IR blockage has increased by ~ 1.4 Wm^{-2} or 0.6 of 1 percent of the continuous average IR flux to space of 235 Wm^{-2}. The continuous balancing in-and-out net global average radiation flux is, by contrast, about 342 Wm_2, almost 100 times larger than will be the amount of radiation blockage due to a CO_2 doubling. A doubling of CO_2 gas requires a warming of the globe of ~1°C to enhance outward IR flux by 3.7 Wm^{-2} to just be enough to balance the blockage of IR flux to space for a doubling of CO_2.

But this pure IR energy blocking by CO_2 versus compensating temperature rise for radiation equilibrium is unrealistic for the long-period and slow CO_2 rises that are observed. Only half of the blockage of 3.7 Wm^{-2} should be expected to go into temperature rise. The other half (~1.85 Wm^{-2}) of the blocked IR energy to space will be utilized for extra surface evaporation in a similar way as the earth's surface energy budget compensates to balance its total incoming solar energy absorption of 171 Wm^{-2}. Note that the globe's surface solar absorption of 171 Wm^{-2} is balanced about half by evaporation (85 Wm^{-2}) and the other half (86 Wm^{-2}) by net upward IR (59 Wm^{-2}) flux plus surface to air sensible heat transfer (27 Wm^{-2}). Assuming that the imposed extra CO_2 doubling of imposed IR energy of 3.7 Wm^{-2} is taken-up by the earth's surface as the solar absorption is taken-up and balanced by an equal surface to air opposite flux we should expect a warming of only ~ 0.5°C for a doubling of the CO_2. The 1°C assumption of warming assumes that the energy balance is made with no surface evaporation. But the global energy budgets show that about half the globe's surface absorption is accounted for by evaporation (see Figs. 1 and 2). These two figures show how equally the surface solar energy absorption (171 Wm^{-2}) is balanced by a near equal division between temperature rise (enhancing IR and sensible heat loss) and energy loss from surface evaporation. We should assume that the imposed downward IR energy gain due to a doubling of CO_2 will similarly be divided in this same approximate ratio. This will cause an enhancement of the strength of the hydrologic cycle by about 2 percent (or 1.85 Wm^{-2} of extra evaporation over the ~ 85 Wm^{-2} energy equivalent evaporation).

<u>Variations of Radiation is only part of the Climate Change Physics.</u> Internal mechanisms of evaporation-condensation also play a major role in climate change. Note in Figure 8 that half the balancing of the earth's surface absorption of solar radiation (85 Wm-2) is due to surface evaporation. And immediate evaporation is determined primarily by the Bulk Formula as illustrated in Figure 11 that depends primarily on surface wind speed, sea minus air temperature difference, and surface air relative humidity.

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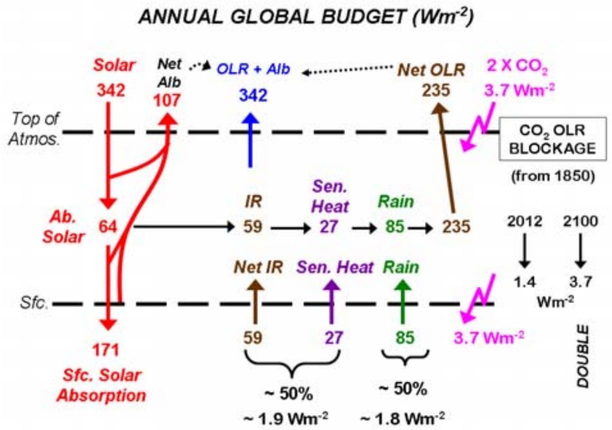


Figure 1. Vertical cross-section of the annual global energy budget as determined from a combination of ISCCP and NCEP reanalysis data over the period of 1984-2004. Note on the right, how small is the OLR (or IR) blockage that has occurred up to now due to CO_2 increases (~ 1.4 Wm^{-2}) and how relatively small is the blockage of 3.7 Wm^{-2} that is estimated to occur when a doubling of CO_2 occurs by the end of this century. Compare these small CO_2 induced IR changes in Wm^{-2} to the global average solar impingement of 342 Wm^{-2} of incoming energy, 235 Wm^{-2} of outgoing OLR, 107 Wm^{-2} of outgoing albedo flux, and 171 Wm^{-2} of surface solar absorption.

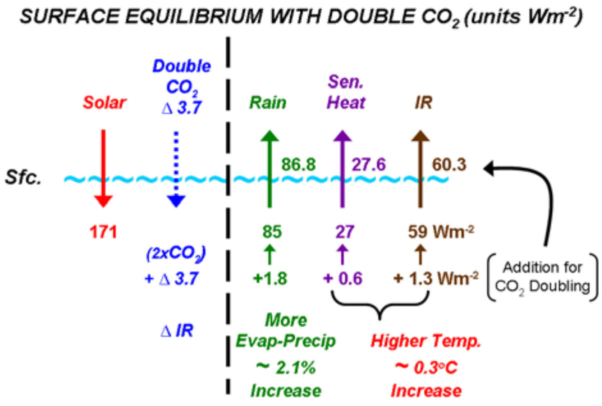
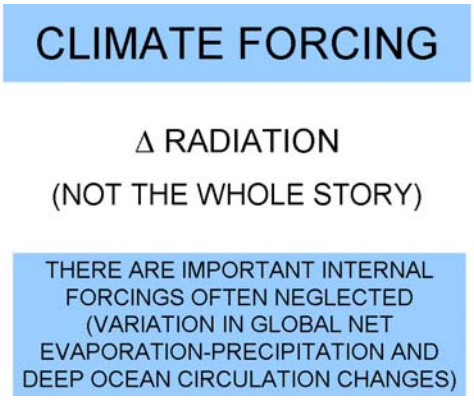


Figure 2. Estimated change at the surface of global mean rainfall (2.1% increase) and global mean temperature (~ 0.3°C) when, and if, equilibrium energy balance were even established for a doubling of CO_2 (and a blockage of IR energy to space of 3.7 Wm^{-2}).



CLIMATE FORCING

Δ RADIATION

(NOT THE WHOLE STORY)

THERE ARE IMPORTANT INTERNAL FORCINGS OFTEN NEGLECTED (VARIATION IN GLOBAL NET EVAPORATION-PRECIPITATION AND DEEP OCEAN CIRCULATION CHANGES)

Figure 3. Because CO_2's influence to block IR to space makes most analyzers to think only of radiation as a cause of climate change. But internal evaporation-condensation and ocean circulation changes are also important.

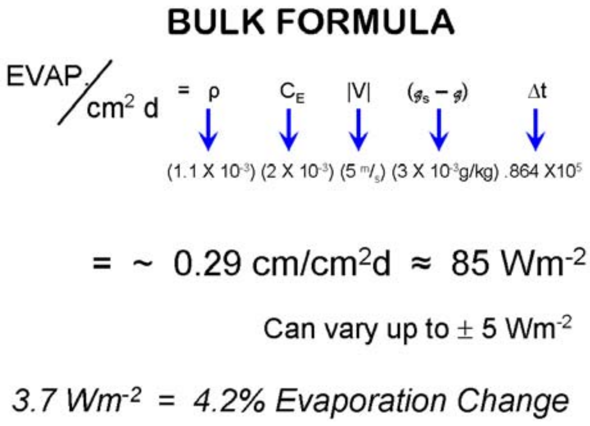


Figure 4. Illustration of the breakdown of terms in the Bulk Formula and their typical global average necessary to give an evaporation rate of a little under 0.3 gm/cm^2 per day. A doubling of CO_2 would bring about a blockage of 3.7 Wm^{-2} which is equivalent to variation of average global evaporation of about 4.2 percent.

2. BRIEF SUMMARY OF REASONS NOT TO BELIEVE A HUMAN INFLUENCE ON TROPICAL CYCLONES (TCs) – IN CONTRADICTION TO THE IPCC-AR4 REPORT

This section briefly discusses:

a. Last 20-year downward trend in global TC activity.
b. CO_2's extremely small relative energy influence.
c. Lack of SST vs. TC activity correlation.
d. Atlantic Ocean thermohaline circulation (THC) influence on Atlantic SST variations.

Last 20-Year Downward Trend in Global TC Activity. Although global surface temperatures appear to have increased during the 20th century by about 0.65°C or 1°F, there is no reliable data to indicate that increases in TC frequency or intensity changes occurred in any of the globe's TC basins. Global Accumulated Cyclone Energy (ACE) shows significant year-to-year and decadal variability over the past 40 years (when global TC data is deemed reasonably reliable) but no period-long increasing trend. In fact, global TC activity has shown (red line) a distinct decrease over the last 20 years when CO_2 amounts were increasing (Figure 5). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005 when tropical SSTs and CO_2 amounts were rising (Figure 6).

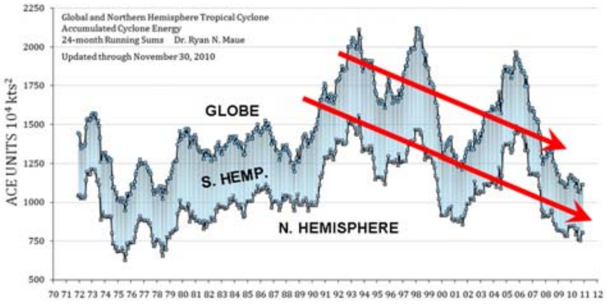


Figure 5. Northern Hemisphere, Southern Hemisphere, and Global Accumulated Cyclone Energy (ACE) over the period from 1971-2010. Figure has been adapted from R. Maue (2011) at the Naval Research Lab., Monterey, CA.

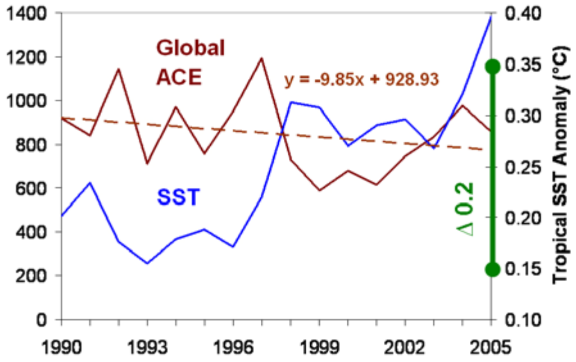


Figure 6. Global ACE values for 1990-2005 (brown line). A linear trend has been fitted to global ACE. Five-year running mean tropical NCEP Reanalysis SST anomalies (23.5°N-23.5°S, all longitudes) blue line. The base period for tropical SSTs is 1951-1980. Figure adapted from Klotzbach, 2006.

CO_2's Extremely Small Relative Energy Influence. The energy change that will be brought about by rising levels of CO_2 have been and will be for many decades far too small to cause a detectable influence on TCs. Figure 7 shows a vertical cross-section of the annual energy budget for the tropics (30°N-30°S; 0-360°). Note how large the surface, troposphere, and top of the atmosphere energy flux components are in comparison with the reduced infrared (IR) flux to space of 3.7 Wm^{-2} for a doubling of CO_2 that is expected to occur by the end of the 21st century. We are now about one-third of the way (~ 1.4 Wm^{-2}) to a doubling of CO_2 from the background state of the mid-19th century. Any potential CO_2 influence on TCs will be too miniscule to be isolated, and we do not know if once an influence is ever able to be detected whether it will have a positive or a negative effect on TC intensity and/or frequency.

Lack of SST vs. TC Activity Correlation. These two parameters are only slightly related in all global TC basins besides the Atlantic (Figure 8). Long-period SST increases should not be expected to bring about significant global lapse-rate buoyancy increases or enhanced deep cumulonimbus (Cb) convection. If global surface temperature and surface moisture changes on a climate time scale do occur, so too will upper-level temperature and moisture conditions change in a way so as to maintain global rainfall and energy budgets near their long-period average. With global warming or cooling of but a degree or so it is to be expected that average global lapse-rates and TC activity will not appreciably change.

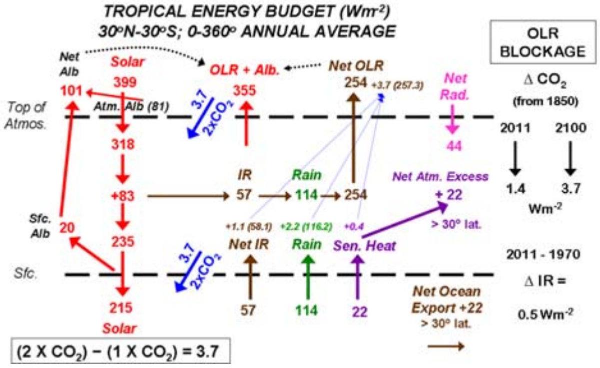


***Figure 7** – Vertical cross-section of the annual tropical energy budget as determined from a combination of International Satellite Cloud Climatology Project (ISCCP) and National Center for Environmental Prediction (NCEP) Reanalysis data over the period of 1984-2004. Abbreviations are IR for longwave infrared radiation, OLR for outgoing longwave radiation and Alb for albedo. The tropics receive an excess of about 44 Wm^{-2} which is exported to latitudes poleward of 30°. Estimates are that about half (22 Wm^{-2}) 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 (~ 1.4 Wm^{-2}) and how relatively small is the blockage of 3.7 Wm^{-2} units of energy (left side in blue) in comparison to the much larger other energy terms. The recent CO_2 buildup (1970 to 2011 – lower right) is too small (~0.5 Wm^{-2}) to have had any type of a known detectable influence on TCs.*

	Yearly Mean ACE	ACE vs. SST Correlation
Northeast Pacific SST (10-15°N)	134	0.01
Northwest Pacific SST (10-15°N)	310	-0.30
S. Hemisphere SST (10-15°S; 50°E-135°W)	205	0.23
Globe SST (20°N-20°S)	769	-0.08

Figure 8 *– Correlation of yearly accumulated cyclone energy (ACE) with late summer-early fall sea surface temperature (SST) in three large non-Atlantic TC basins. (ACE data from R. Maue, 2011)*

ATLANTIC OCEAN THERMOHALINE CIRCULATION (THC) INFLUENCE ON ATLANTIC SST VARIATIONS. The Atlantic Ocean undergoes significant multi-decadal variability in SST due to the strong multi-decadal variability of the Atlantic Thermohaline Circulation (THC) (Figure 9). Changes in this oceanic THC are driven by naturally occurring Atlantic salinity variations which cause multi-decadal variations in Atlantic SST, surface pressure, upper level winds, middle-level moisture, and other climate fields which are associated with TC activity. CO_2 or other radiation changes play little or no role in such oceanic circulation alterations. Figure 10 and 11 illustrate how well related are the frequency of multi-decadal variations of Atlantic major (Cat 3-4-5) hurricane activity and North Atlantic SST. Note in Figure 11 how large the multi-decadal variations in Atlantic major hurricane activity have been over the last century.

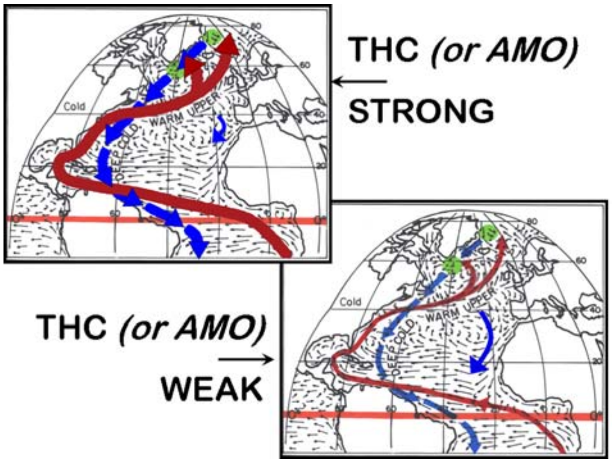


Figure 9. Illustration of strong (top) and weak (bottom) phases of the Atlantic Thermohaline Circulation (THC) or the Atlantic Multidecadal Oscillation (AMO) as it is sometimes called.

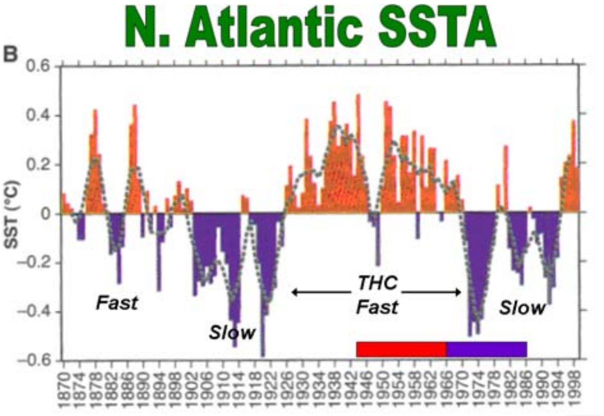


Figure 10. Long-period portrayal (1870-2006) of North Atlantic sea surface temperature anomalies (SSTA) from a multi-century mean upward sloping curve. The red (warm) periods are when the THC is stronger than average and the blue periods are when the THC is weaker than average. (50-65°N; 10-50°W).

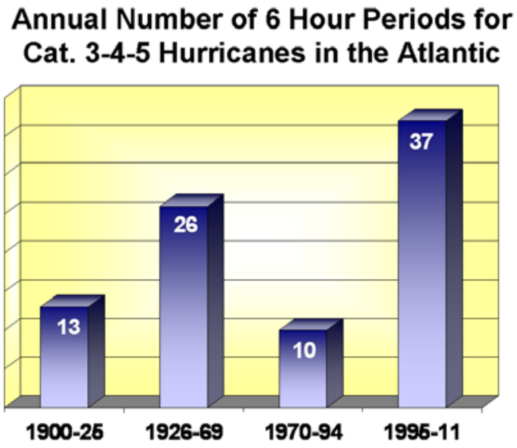


Figure 11. Multi-decadal comparison of the average number of Atlantic basin annual 6-hour reports of major (Cat. 3-4-5) hurricane activity. The two earlier periods may be somewhat of an underestimate.

3. CLIMATOLOGICAL CONSIDERATIONS

I have previously shown that the climatological aspects of the seasonal frequency of tropical cyclone formation at any global location are closely related to the product of six seasonally averaged parameters (Gray 1975, 1979). They are:

1. the Coriolis parameter (f)
2. low-level relative vorticity (ζ_r)
3. inverse of the tropospheric vertical wind shear ($1/S_z$)
4. ocean thermal energy, manifested as ocean temperatures greater than 26°C to a depth of 60 meters [E]

5. the difference in equivalent potential temperature between the surface and 500 mb ($\Delta\theta_e$).
6. relative humidity in the mid-troposphere (RH) – 700 mb and 500 mb.

The product of parameters 1, 2, and 3 specifies a dynamic potential ($f\ \zeta_r/S_z$), while the product of parameters 4, 5 and 6 yields a thermal potential ($E\ \Delta\theta_e$ RH). Multiplying both dynamic and thermal potentials together specifies a "seasonal genesis parameter" which provides a very good estimate of the long-term frequency of occurrence of tropical cyclones at all global locations for each season of the year.

The seasonal genesis parameter may also be thought of in the form of:

Seasonal Genesis Parameter = (Dynamic Potential) X (Thermal Potential)

where

Dynamic Potential = $(f)\ (\zeta_r + 5)\ [1 / (S_z + 3)]$

Thermal Potential = $(E)\ (\delta\ \theta_e / \delta p + 5)$ (RH Parameter)

where the values 5 and 3 are empirical scaling factors.

It is remarkable that the frequency of a phenomenon as variable as tropical cyclones should have such a close association with the long-term climatology of seasonally averaged parameters. This association is an indication of how tropical cyclones are, to a high degree, a consequence of the large-scale climatological conditions existing in each formation region.

Note that this genesis parameter has no explicit reference to SST. This implies that SST, by itself, is not a primary determiner of TC frequency. It is much more important that deep warm ocean water greater than 26°C extends downward to 50-100 m depth, so that cool-dry downdrafts into the PBL can be more readily 'recharged' to warmer and moister air. See Figures 12 and 13 for illustrations of how deep warm water can extend in various tropical regions.

Confusing Local and Climate Time Scales. A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo a degree of 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 SST causes the hurricane's inner-core PBL temperature and moisture content to rise. While these low-level changes are occurring, upper tropospheric conditions are typically not being altered. These rapidly occurring lower- to upper-level potential buoyancy increases can cause the inner-core hurricane lapse-rates to increase and likely produce more inner-core deep Cb convection. This can cause an increase in the hurricane's intensity. Such observations and the clear association of the most intense individual typhoons and hurricanes with the highest SSTs has led many observers to directly correlate SST with hurricane intensity on longer-period climate scales. This is valid reasoning for local and day-to-day hurricane intensity changes that are associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in a climatologically altered tropical ocean environment where upper tropospheric temperature and moisture conditions have had time to become adjusted to a warmer or cooler and moister or dryer PBL. Such balancing upper and lower tropospheric mutual adjustments inhibit lapse-rate alteration. We should not expect that the frequency and/or intensity of Cat. 4-5 hurricanes will necessarily change if the globe should become somewhat warmer or somewhat cooler.

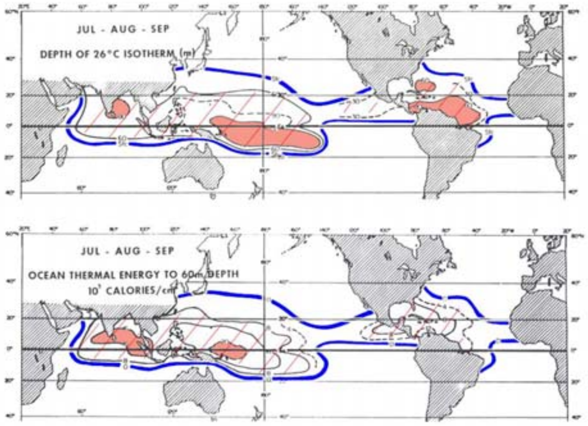


Figure 12. July through September climatology of the depth of 26°C water in meters (top) and the net ocean thermal energy above 60 m depth in units of 1000 cal/cm2 (bottom) – Gray (1979).

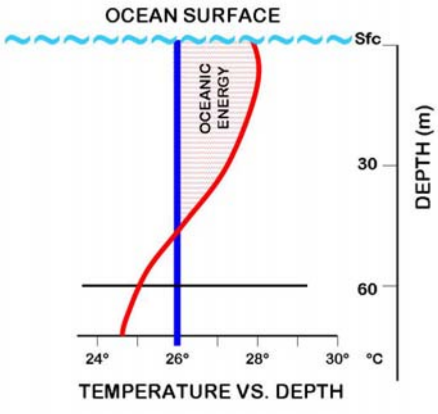


Figure 13. Cross section view of the typical ocean temperature decrease with depth and how the ocean thermal energy is defined (the area to the right of the 26°C isotherm to a depth of 60 m) – (Gray 1979).

Most of these papers hypothesize a climatologically direct linkage between rising SST values and rising levels of TC activity. This is not a valid assumption on a climate change time scale.

Evidence of Little SST-TC Association On Seasonal Time Scales. The physics of those proposing a direct physical link between rising levels of CO_2 and TC activity is given in Figure 14. This is a plausible physical argument over a short period. But on the climate time-scale the assumed linkage between steps 3 to 6 is not valid.

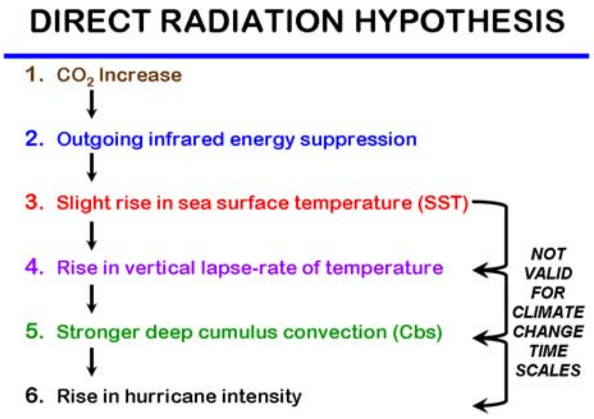


Figure 14. Physical reasoning of those who believe that increases in CO_2 should make hurricanes more intense and more frequent (left arrows). The problem is the assumed direct linkage between steps 3 to 6, which are not valid and climate scale time changes.

Figure 15 shows the year-by-year variation of late summer SSTs in the primary TC formation area in the NW Pacific with yearly variations of Accumulated Cyclone Energy (ACE). Note the lack of a clear association. Similar figures have been constructed for the other global storm basins. Table ? shows the correlation of seasonal ACE with late summer-early fall SSTs in 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 TC basins. It is obvious that other physical processes besides SST changes are responsible for differences in net seasonal TC activity. There is an association of warmer SSTs in the Atlantic Ocean. More intense TCs form in the main development area (10°N-20°N; 60°W-20°W) when SSTs are higher. But this (as is discussed in section 13) is due primarily to changes in other large-scale factors (vertical shear, trade-wind strength, moisture) which themselves and the SSTs are driven by fluctuations in the strength of the THC.

TC Associations with Distant SST Patterns. There are SST patterns removed from the various TC basins which, nevertheless, are known to be associated with alterations in TC activity at distant locations. For instance, Atlantic seasonal TC activity is typically enhanced or typically reduced when positive or negative SST anomalies are present in the far North Atlantic (50-65°N; 10-50°W). These Atlantic SST patterns are associated with the changing strength of the Atlantic Thermohaline Circulation (THC) or the Atlantic Multi-decadal Oscillation (AMO).

Northwest Pacific typhoons are known to typically form further eastward and have longer tracks during El Nino years. It is well known that tropical Atlantic basin hurricane activity is strongly suppressed in El Nino years when eastern equatorial Pacific SSTs become abnormally warm.

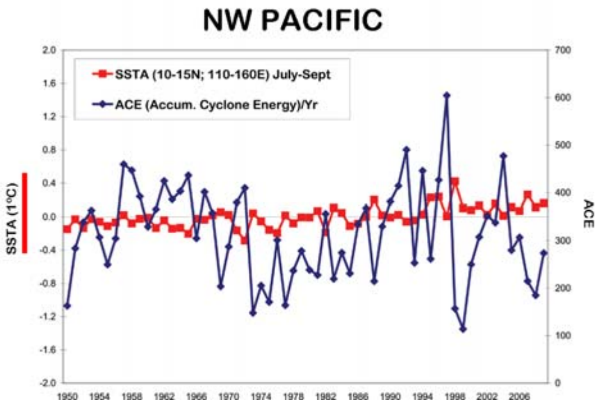


Figure 15. Late summer SST (red) in the primary NW Pacific TC formation vs. NW Pacific seasonal Accumulated Cyclone Energy (ACE) – in blue. Note the lack of an association. (ACE data from R. Maue)

Table 1 – Correlation of yearly ACE with late summer-early fall SST in three non-Atlantic TC basins over the last 30 years. ACE is the sum of the squares of each named TC's maximum wind (V_{max}) at each 6-hour period for an entire season. ACE data from R. Maue.

	Yearly Mean ACE	ACE vs. SST Correlation
Northeast Pacific SST (10-15°N)	134	0.01
Northwest Pacific SST (10-15°N)	310	-0.30
S. Hemisphere SST (10-15°S; 50°E-135°W)	205	0.23
Globe SST (20°N-20°S)	769	-0.08

These differing regional SST patterns are at locations which are removed from where the individual cyclones form. Their influence on hurricane enhancement or suppression is usually not related to changing lapse-rate buoyancy or SSTs at the locations of the TCs. Rather, these distant SST patterns are more associated with changes of other known and required features for TC formation and intensity change – such favorable features as reduced tropospheric vertical wind shear, stronger positive low level vorticity, more rainfall, lower surface pressure, higher middle-level moisture, etc. This has also been discussed by Vecchi and Soden (2007).

DISCUSSION. Observations show that upper tropospheric horizontal gradients of θ_e over the TC basins show substantially less variability than do horizontal θ_e gradients within the PBL. Pockets of higher or lower PBL temperature and moisture lead to local areas of higher or lower lapse-rate buoyancy and thus varying degrees of potential Cb convection strength.

We usually observe higher intensity hurricanes in oceanic areas of higher SST. These observations should not be used to exaggerate the importance of SST as a primary distinguisher for TC frequency and intensity for long-period climatologically altered environments where upper and lower temperature conditions have had time for adjustment. Also, when higher SSTs are present during active TC periods, other required TC formation and intensity parameter conditions are typically also present (vertical shear, low-level vorticity, middle-level moisture, etc.) and play as large or larger role than the differing SST values.

SUMMARY. This discussion goes opposite to what so many scientists currently assume to be a direct association between SST increases, cumulus potential lapse-rate buoyancy, and hurricane activity. Their thinking is valid in individual cyclone cases but not valid on the longer period climate time scales where the entire global system has had time to become in balance to a new circulation state. The change of tropical SSTs over the entire tropics and globe during long time periods of decades to a century should not be assumed to automatically bring about any systematic increases or decreases in TC intensity or frequency.

4. GLOBAL RAINFALL'S STIMULATION OF RADIATION ENERGY TO SPACE (IMPLICATIONS FOR CLIMATE PREDICTION AND GLOBAL ARMING)

THE CONCENTRATED NATURE OF GLOBAL RAINFALL. Precipitation is a fundamental component of the global and the tropical energy budgets. Global energy budget requirements dictate that every day slightly less than 0.3 cm of global average precipitation occurs (or about 1 m/yr). Of this, about 0.4 cm/d average precipitation must occur within the tropics (30^oN-30^oS) and about 0.2 cm/d average precipitation occurs in the middle-latitude and polar regions (> 30^o latitude).

Most global precipitation (approximately two-thirds) occurs in concentrated Cb and/or towering cumulus convective clouds. If we assume that the average deep cumulus cloud produces rainfall at a modest average rate of 1 cm/hour, then all these convective clouds, at any one time, would cover only about one percent of the globe's surface. All of the upward mass flux associated with these concentrated deep convective clouds which extend into the upper-half of the troposphere must be balanced by a return flow mass sinking over the remaining 99 percent of the globe. This return flow subsidence originates from higher and colder levels where the air holds little water vapor. As this dry air descends and spreads out at lower levels, it brings its low moisture content air with it. The typical low relative humidities (RH) of the globe's upper and middle tropospheric air (~20-50 percent) attests to the importance of this broad-scale subsidence drying in response to the globe's rainfall.

Most of the globe's 'daily average' rainfall is concentrated in selective areas covering no more than 4-6 percent of the globe's surface where about 3 cm/day (or 1.2 inches/day) of rainfall occurs. It is from such organized meso-scale rain areas of the warmer portions of the oceanic tropics that TCs form (Figure 16).

Most tropical rainfall is concentrated in localized meso-scale (250-500 km) areas of groups of deep convective units between broad scattered cloud and clear regions of weak subsidence air. The subsidence areas between rain areas cause the upper and middle tropospheric levels to be strongly sub-saturated. <u>The more rain that occurs in these restrictive rain areas the more upward vertical motion and the more mass balancing subsidence there is (and the lower are the RH values) in the non-rain areas</u>. This keeps the broad upper tropospheric IR radiation emission level from becoming more elevated and cooler as rainfall increases. More rainfall can thus lead to an IR (or OLR) radiative emission level being lowered to a slightly warmer level (due to upper tropospheric water vapor reduction) in the broader subsidence areas. This allows for a higher rate of IR (or OLR) radiation to be emitted (σT^4) to space even though net rainfall rates and net precipitable water amounts over the whole tropics or over the globe may have increased.

The author and his colleague, B. Schwartz, through extensive analysis of NOAA-NCEP reanalysis data and International Satellite Cloud Climatology Project (ISCCP) satellite products find that when tropical and global rainfall rates are increased by a few percent, there is typically a corresponding small increase in net radiation energy to space. Both IR and albedo radiation flux to space become, in combination, typically larger by an amount about equal to the energy required for the enhanced surface evaporation (Gray and Schwartz, 2011).

Our measurements do not agree with the conclusions of the 19 IPCC-AR4 GCM simulations which are all in close agreement in showing a strong positive rainfall-water vapor enhanced warming feedback of 2^oC with their climate simulations of the influence of a doubling of CO_2. These GCM warming scenarios appear to have greatly exaggerated the influence of CO_2 warming by a factor of as much as 5 to 10 due to their assumption that upper-level water vapor will increase as rainfall rates increase – the so called ‘positive water vapor feedback’. Our data analysis does not support this crucial but flawed assumption.

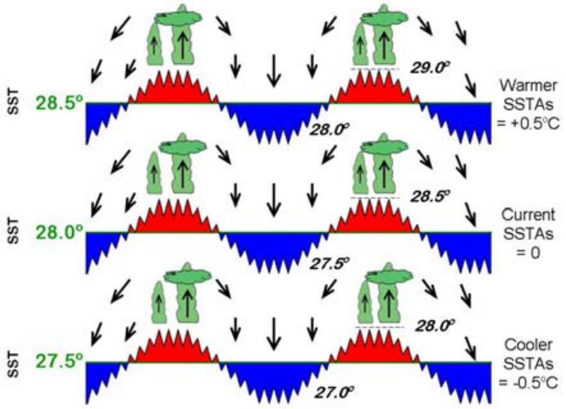


Figure 16. Illustration of how the mean SST climatology of the summertime tropics (30°N-30°S; 0-360°) might rise or fall by 0.5°C from the middle diagram (28°C) but the potential lapse-rates for deep Cb convection in the TC basins (red areas) are not significantly altered. SST changes over the whole tropics are different from local region SST changes. As the global temperature increases or decreases, we should expect all relative warmer and colder areas to increase in unison and vertical lapse-rates in these areas to also increase or decrease in unison. Lapse-rates and rainfall rates should be little affected.

LITTLE POTENTIAL INFLUENCE OF CO_2 ON GLOBAL TC ACTIVITY. Even though CO_2, methane, and other smaller trace gases are designated greenhouse gases (similar to water vapor), they act in very different ways from the atmosphere’s primary greenhouse gas of water vapor. Water vapor continuously rains out of the troposphere at a rate of about 10 percent per day. It totally replaces itself in the atmosphere every 10 days. Water vapor is quite variable by location, altitude, and time of year. The surface evaporation necessary for the troposphere’s rapid water vapor replacement acts as the globe’s primary coolant to balance the earth surface’s large average solar energy absorption of 171 Wm^{-2}.

Figure 2 portrays the globe’s annual energy budget. Note that the earth’s surface absorbs about half (171 of 342 Wm^{-2}) of all the solar energy which impinges upon the earth. The globe’s surface evaporation rate balances about half (85 of 171 Wm^{-2}) of the solar energy which the earth absorbs. The other half (~ 86 Wm^{-2}) is balanced by surface upward IR flux and sensible heat flux to the air above. Energy is lost from the surface through the conversion of liquid water to vapor. It takes 290 Wm^{-2} of solar energy for each gram/cm^2 per day of water which is evaporated.

I hypothesize that when CO_2 amounts double near the end of this century and there becomes a blockage of IR energy to space of 3.7 Wm^{-2}, the global system will adjust to this 3.7 Wm^{-2} IR blockage in about the same relative ratios as it does with the total energy budget today. We would thus see (Figure 3) a global rainfall increase of about 1.8 Wm^{-2} (or 85 to 86.8 Wm^{-2}), a surface enhanced upward IR flux increase of 1.3 Wm^{-2} (or 59 to 60.3 Wm^{-2}) and a surface to air increase of sensible heat upward flux of 0.6 Wm^{-2} (or 27 to 27.6 Wm^{-2}). These changes would cause an increase of global average rainfall of about 2.1% and an increase of global mean surface temperature of about 0.3°C. This warming is only about 10-15 percent as much as the GCMs have been projecting. This amount of warming should not raise alarm.

Although the net water vapor in the troposphere (or precipitable water) may go up a little as rainfall increases, the water vapor content in the upper troposphere is expected to slightly decrease with enhanced global rainfall. The tropics and the globe’s average radiation emission level of IR (or OLR) to space are expected to be somewhat lowered during global rainfall enhancement. This will allow for more IR flux to space. There are also slightly higher amounts of albedo energy loss to space with higher rates of global and/or tropical rainfall.

It is important to separate the atmosphere’s ‘dominant’ and ‘active’ greenhouse gas of water vapor from the more minor and inert greenhouse gases of CO_2, methane, etc. Although the globe’s net precipitable water in the troposphere may rise a bit during periods of enhanced global rainfall, the water vapor in the upper troposphere is observed to slightly decrease and the net radiation energy to space (IR + albedo) increase by small amounts when global and/or tropical rainfall is increased by a few percent. The reverse also occurs. Energy to space typically decreases by a few percent when global and/or tropical rainfall is decreased by a similar percentage.

Figure 17 graphically illustrates how a slight lowering of the IR emission level of 1°C, due to enhanced global rainfall, would lead to about a 3.5 Wm^{-2} enhancement of OLR to space and, all other factors being constant, a small cooling of the troposphere in response. Figure 18 illustrates our concept of the basic difference between the net-radiation to space which occurs when deep precipitation is increased (top diagram) and the opposite concept that the GCMers and most scientists have when global rainfall is increased (bottom diagram). The GCM modelers believe that increased rainfall leads to increases in upper-tropospheric water vapor and that this increased water vapor adds additional blockage of OLR to space. From our extensive analysis of the reanalysis and ISCCP data sets we are finding the opposite.

Unlike the ocean, the atmosphere does not have the capacity to store energy. The atmosphere’s equilibrium state is determined by the amount of energy which is impinged upon it. A high impingement of energy to the atmosphere would require that it adjust to this large energy gain by developing an export mechanism (radiation or water change of state) that rises just enough so as to balance most of this impinged energy gain. The opposite should occur when the atmosphere cools.

We assume that a 3.7 Wm^{-2} blockage of OLR from the doubling of CO_2 would, in time, be able to develop a new equilibrium state for the global system that is only about 0.3^{o}C warmer than before the industrial revolution. This amount of warming would not bring climate degradation.

This analysis would also argue against a significant solar activity influence on global climate and on TC activity. Sun spots, cosmic rays, and other types of solar variability are just too small in magnitude to compare with the influences of a doubling of CO_2. Here I agree with the modelers.

TROPICAL CYCLONE INFLUENCE ON THE GLOBAL RAINFALL BUDGET. Accepting the fact that most (75%) of the globe's rainfall (the other 25% being sensible heat flux) occurs primarily as an up-moist and down-dry warming response to balance the troposphere's radiational cooling, one can ask: to what extent does TC rainfall contribute to the overall global rainfall balance?

Global TC activity is least frequent during April and May when the sensible heat transport from the Eurasian and North American continental land areas is at a yearly maximum and less rainfall is needed to balance tropospheric radiational loss. Surface evaporation and rainfall are reduced during this period. TC activity is at a maximum in August through October when land to air sensible heat transport is reduced, and lapse-rate stability over land is reduced due to the seasonal lag of upper air cooling behind surface land cooling. Overland convective rainfall is reduced in late summer and autumn. More of the global rainfall must then come from organized weather systems such as TCs as a compensation for reduced land lapse-rates and precipitation.

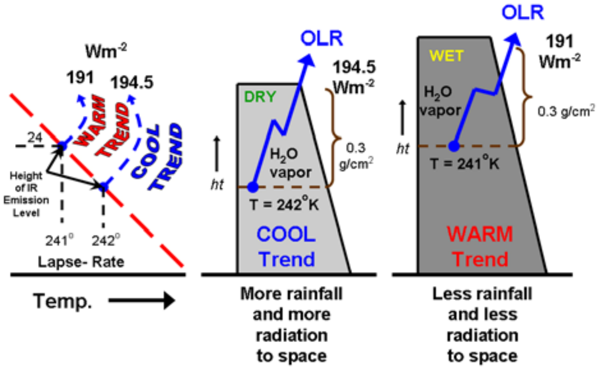


Figure 17. Greatly exaggerated illustration of how lowering of upper-level water vapor (and the IR emission level) from 241°K (right) to 242°K (left) increases OLR by 3.5 Wm^{-2} due to enhanced radiation (σT^4). Deeper and more intense convection, more upper-level mass subsidence, and a lowering of the emission level (left area) is hypothesized to let more OLR to space and lead to a cooling trend. The opposite occurs in the right area. The greater rainfall would also lead to a slightly higher albedo and yet more radiation to space.

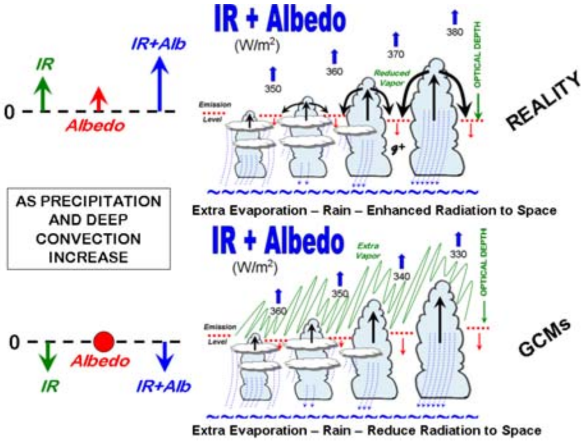


Figure 18. Two contrasting views of the effects of how the continuous intensification of deep cumulus convection would act to alter radiation flux to space. The top diagram emphasizes the increasing extra mass flow return subsidence associated with an ever increasing depth and intensity of cumulus convection. Radiation flux to space increases with enhanced deep convection and rainfall due to a lowering of the upper-level emission level and an increase in albedo. By contrast, the bottom diagram interprets the increase of deep convection (like the GCMs have done) as acting to add moisture to the upper tropospheric levels and cause a decrease of radiation to space. The bottom diagram is not realistic and a primary reason why the GCMs exaggerate CO_2's influence on global warming.

W. Frank (1977) has estimated that the mean precipitation within 6^{o} radius of the average west Pacific tropical cyclone whose central pressure is <980 mb is ~2.3 cm/d. Most TC precipitation occurs within 6^{o} radius. As west Pacific cyclones are typically larger, and produce somewhat more rainfall than those of other regions, it will be assumed that the average global TC (0-6^{o} radius) has a mean precipitation of about two-thirds of this amount, or ~1.5 cm/d. This is five times the amount of global average precipitation.

Assuming that the global average annual precipitation is ~1 m/year, that the average cyclone maintains its rainfall for about one week, and that there are about 75 global named storms per year, one can estimate that TCs account for about 2 percent (1.5 cm/day x 7 days x 75 x ($A_{cyclone}$/100 cm A_{globe}) of the global annual precipitation. During August and September they probably account for about 4-5 percent of the global precipitation while during April and May only about 0.5-1 percent. During especially active 10-20 day periods in August and September, TCs may account for as much as 10-15 percent of the global precipitation and 20-30 percent of northern hemisphere precipitation. Thus, at selective times of the year, the influence of the TC is likely to be a significant component of the day to day maintenance of the global water budget. For the long-term point of view, however, the condensation energy contribution of TCs does not appear to be a primary component of the tropospheric water budget.

If TCs are responsible for about 2 percent of the global annual rainfall (~85 Wm^{-2}) and the doubling of CO_2 will bring about 2 percent additional global TC rainfall, then we can estimate that a doubling of CO_2 would cause global annual TC activity to bring about (.02 x .02) = .0004 or about 1/2500 of the globe's annual rainfall. Doubling of CO_2 will have minimal influence on global TC rainfall. If this argument is valid then we could also conclude that CO_2 doubling to have minimal influence on TC lapse-rates and net global TC activity.

Over the tropical oceans where TCs form, we should expect a higher percent of the blocked IR flux from a doubling of CO_2 to go into enhanced evaporation (perhaps 2.7 Wm^{-2}) with less into IR and sensible heat (perhaps 1.0 Wm^{-2}). This implies that a doubling of CO_2 would cause an increase in SST in the areas where TCs form of only 0.1-0.2°C.

CO_2-INDUCED CHANGES IN TC ACTIVITY. We have no plausible physical reason for believing that global TC frequency or intensity will necessarily change to any significant degree if global SSTs were to rise or be lower by a small amount due to an excess or deficit of external (solar or infrared) energy impinging on the earth. For TC activity and SST changes to be strongly correlated, it would be necessary for other basic requirements for TC intensity and frequency to also be altered.

One would not expect the ocean to air energy fluxes to be much altered if SSTs in the tropical formation regions were somewhat higher or somewhat lower than average. Small global SST increases or reductions of ± 0.5°C over long decadal or century time periods should not have much of an influence on the frequency and/or intensity of global TC activity (Figure ?).

Although the existence of conditionally unstable lapse-rates are required for the presence of Cb convection, such lapse-rate buoyancy is not the only needed component for the maintenance of organized tropical cloud clusters and developed hurricanes. Very similar vertical lapse-rate temperature conditions exist in nearly all pre-cyclone cloud clusters and also in the broad lower latitude party-cloudy and clear regions. It is often the middle-level moisture which most distinguishes the cloud clusters which become TCs from those which do not. Temperature lapse-rate conditions are usually not a significant element in determining the existence and the intensity of Cb convective elements or of the amount of mass which the cloud cluster carries into the upper troposphere. Other factors such as downdraft strength and frequency, outer radius wind surge action, establishment of banded deep convection, etc. can often play more dominant roles.

Evidence from historical and paleo climate records appear to indicate that hurricanes of the Atlantic or typhoons of the Northwest Pacific were not necessarily less intense during the Little Ice Age when tropical SSTs were likely somewhat cooler.

For the development of the most intense hurricanes and typhoons it is necessary that many other features besides SST and conditionally unstable lapse-rate conditions be present. Other factors needed for maximum TC intensity include:

1. Depth of warm water over which the cyclone moves (primary element).
2. The moisture content of the mid-tropospheric air flowing into the disturbance.
3. The degree of horizontal wind blow-through (or ventilation) the cyclone system.
4. Character of the outer rain band structure and its variations.
5. Strength of the cyclone's outer low and middle-level cyclonic circulation and their changes with height and time.
6. Characteristics and strength of the hurricane's upper-level outflow circulation.
7. Speed, and direction of the TC movement.
8. Changing dimensions of the eye-wall cloud and other bands.
9. Slope of the eye-wall cloud.
10. Etc.

One should not assume that small increases in SST or increases in lapse-rates would necessarily act to make variations in these many differing TC features to function in the direction of causing TCs to become more intense or more frequent.

WHY SKILLFUL LONG RANGE CLIMATE AND TROPICAL CYCLONE PREDICTION IS NOT POSSIBLE. Very skillful initial-value GCM forecasts for tropical cyclone climate will likely never be possible. This is due to the overly complex nature of the atmosphere-ocean-land system and the inability of numerical models to realistically represent this full range of this complexity and to integrate such a complex system forward in time for hundreds of thousands of time steps into the future. Skillful short-range prediction of 5-10 days is possible because there tends to be conservatism in the initial momentum-pressure fields which can be extrapolated or advected for short periods into the future. But beyond about 10-15 days, the many multiple unknown and non-linear energy and moisture exchanges within the earth system become dominant. Unexpected and unpredictable turbulent bursts occur that rearrange the large scale circulation patterns (Ramage, 1976). Model results soon decay into chaos. Any imperfect representations of the highly non-linear parameters of the atmosphere-ocean system tend to quickly undergo exponential growth (the so-called butterfly effect) and decay into unrealistic flow states upon a very long integration period.

If the climate prediction problem is treated as a boundary-value problem where only the future climate energy forcing components are predicted, different but no less tractable problems arise. For instance, besides the known and impossible to overcome 'butterfly' problems, there are known systematic errors in all the current GCMs. These systematic errors would also make the boundary value treatment of the climate prediction problem unrealistic. For instance:

> 1) The gross errors of the GCMs which are associated with their programmed strong positive water vapor feedback assumption. This causes the GCMs to give far too much global warming to their CO_2 doubling simulations. This is currently a major impediment to any type of realistic global simulation. There is no way a CO_2 doubling by itself could ever bring about the amount of 2-5°C global warming the GCMs have been predicting over the last 20-25 years. Observations show that the assumption of constant relative humidity (RH) in the upper troposphere as global warming occurs is invalid. The Charney Report (1979) assumption that constant RH will accompany temperature increase (accepted by nearly all climate models) is not correct for the upper troposphere. Due to the unique character of the individual units of deep cumulus convection, upper-tropospheric RH in the tropics does not necessarily go up with increased global rainfall or increased upper tropospheric temperature. Measurements show that upper tropospheric RH has been going down since the mid-1970s despite some upper tropospheric global warming. And recent-year ISCCP data has indicated a small enhancement (not reduction) of IR radiation to space of 1-2 Wm^{-2}.
>
> I don't think any of the global modelers fully understand atmospheric moist processes, particularly the effect of deep Cb convection, to the extent that is necessary to be able to develop moist parameterization schemes realistic enough to be able to forecast future climate with any reliability. They are still not able to properly model or parameterize the strong sub-grid scale mass compensating up-moist and down-dry-and-moist processes of the troposphere.
>
> 2) The GCMs also do not include or are not able to properly model the decadal and century scale deep-ocean circulation changes which appear to be driven by ocean salinity variations. This includes the Meridional Overturning Circulation (MOC) of which the Atlantic Thermohaline Circulation (THC) is a fundamental component. These deep ocean circulation patterns have yet to be well understood and will require much study before they can be correctly included in the climate models. Modeling these ocean circulations requires the realistic prediction of variations in surface and deep-ocean salinity variations - a very difficult task which has yet to be satisfactorily incorporated in the GCMs.

If the GCMs are not able to produce a realistic basic future climate, how can we ever expect them to be able to realistically downscale these results to be able to realistically deal with future changes in the global sum of meso-scale events such as tropical cyclone frequency as well as TC intensity changes? There are a growing number of papers showing that downscaling from global model runs to determine regional climate changes does not show reliable skill. This is, of course, to be expected if the GCM from which the downscaling occurs is invalid.

A RECENT TC CLIMATE MODELING PAPER. There has recently been a climate modeling paper projecting future TC activity by T. Knutson and 9 other authors (2010) saying that during the remainder of the 21st century that we should expect to experience fewer global tropical cyclones. However, the TCs which do form will tend to be stronger than the ones in the past due primarily to increases of CO_2. This is an example of pure (and unreliable) climate model speculation. There is absolutely no objective basis for this near century-long forecast of TC activity. Any sensible observer knowing how faulty the GCM global warming predictions of the IPCC-AR4 are should not put any confidence at all in such a down-scaled version of the GCMs from which this near century long TC forecast has been derived.

5. THE OCEAN AS A POWERFUL MODULATOR OF GLOBAL CLIMATE AND ATLANTIC MAJOR HURRICANE ACTIVITY

One of the most unique features of the earth in comparison with other planets is that its surface is covered by almost 70 percent water (with a global average depth of 3.8 km). Having deep oceans covering so much of the globe means that the earth's surface can absorb, store and give out vast quantities of energy which are not directly related to the current in-and-out radiation of the earth and only weakly related to the ocean's SST. The earth's surface and atmospheric temperatures of each hemisphere would warm up many times more in summer and cool down many times more in winter if the globe's percent of ocean surface were substantially less. Global temperature is not regulated by radiation alone. Ocean to air energy flux variations also plays a large role.

The earth's surface is continually absorbing substantially more solar energy than it re-radiates as long-wave energy back to the atmosphere. A high percent (~ 50 percent) of the globe's surface solar energy absorption is expended to evaporative water. The other half of the surface solar radiation energy absorption that is not expended in evaporative water is given to surface IR and sensible energy flux to the atmosphere above or is stored as excess or deficit ocean energy. The middle and high latitude oceans store great quantities of energy in spring and summer and give off very large quantities of this stored energy to the atmosphere in the fall and winter.

CIRCULATION CHANGES RELATED TO THE STRONG VS. WEAK MODES OF THE THC. There are distinct multi-decadal parameter differences in the global atmospheric and global ocean's general circulation during periods when the Atlantic Thermohaline Circulation (THC) is strong versus periods when it is weak. Table 2 illustrates these differences. Figure 19 gives a graphical illustration of these features. We hypothesize that these multi-decadal global circulation changes are primarily a result of naturally occurring multi-decadal changes in the Atlantic Thermohaline Circulation (THC) or the Meridional Overturning Circulation (or MOC) which is largely driven on long time scale ocean salinity variations. One should expect little or no influence to THC changes from variations in solar radiation or from increases in atmospheric CO_2 content.

Knowing these typical multi-decadal parameter variations of Figure 19, it is thus possible to make multi-decadal forecasts of parameters which have been shown to be associated with the THC strong or weak modes. For instance, the author has used historical information of multi-decadal fluctuations in THC strength to issue multi-decadal forecasts of future Atlantic basin hurricane activity and future multi-decadal global temperature change.

The Atlantic THC switched from its long multi-decadal period of being weak (1970-1994) to becoming strong in 1995. It has continued in this strong mode since (1995-2011), and if the future is like the past this strong THC should be expected to continue for another 10-15 years or so. It is then likely that the North Atlantic will have exhausted its current higher than average levels of salinity content and the THC will consequently weaken to below-average strength. When this happens the current higher levels of hurricane conditions which have been experienced since 1995 will switch over to conditions more in line with the lower-levels of activity which was experienced during the quarter century period between 1970-1994, or the period between 1900-1925.

Figure 20 is a quote of a multi-decadal forecast which I issued in 1996 about the expected large future increase in hurricane activity that I expected to occur at that time. See Figure ? to observe how well the increased hurricane portion of this forecast verified. Also, the global cooling part of this forecast appears to have merit in that during the last decade, mean global temperature appears to be entering a weak cooling phase. I anticipate continued weak global cooling over the next decade or two due to the expected continuance of the current strong THC pattern.

Table 2 – Contrast of 6 basic global parameter circulation features (center column) when the Atlantic THC (or MOC) is strong (left column) in comparison with when it is weak (right column).

MULTI-DECADAL PERIODS WHEN THE (THC) IS **STRONG**	GLOBAL PARAMETER	MULTI-DECADAL PERIODS WHEN THE (THC) IS **WEAK**
More rain	Global Rainfall	Less rain
Cooling	Mean Global Temperature Trend	Warming
Less Frequent & Weaker	El Nino Activity	More Frequent & Stronger
Weaker	Atlantic Mid-Latitude Zonal Wind Strength	Stronger
Weaker	Strength of N. Atlantic Subtropical Oceanic Gyre Circulation and Atmospheric High Pressure	Stronger
Higher	Atlantic Hurricane Activity (particularly major hurricane activity)	Lower

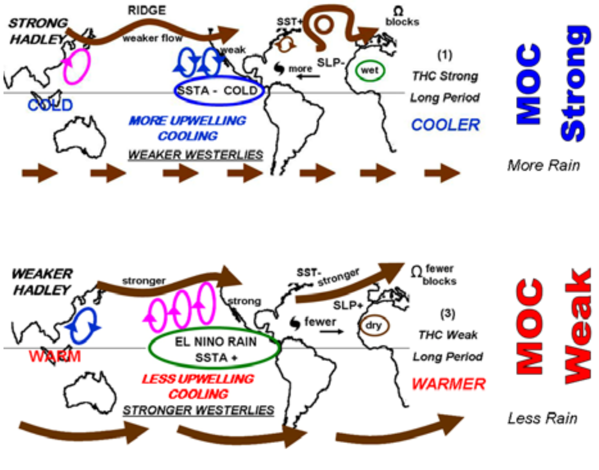
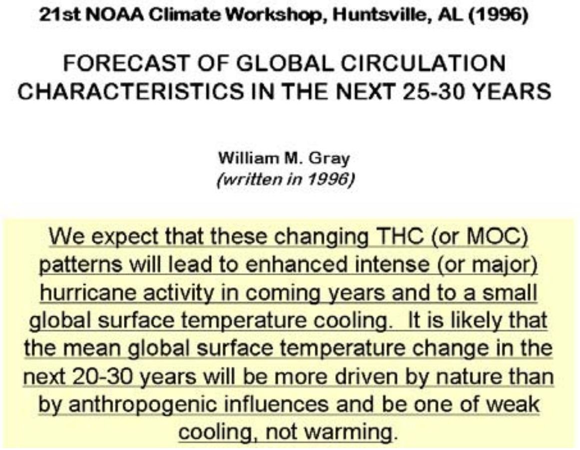


Figure 19. Portrayal of typical global circulation differences between a strong and a weak THC or Meridional Overturning Circulation (MOC). The globe typically undergoes cooling and less rainfall during strong vs. weak phases of the THC or MOC.



21st NOAA Climate Workshop, Huntsville, AL (1996)

FORECAST OF GLOBAL CIRCULATION CHARACTERISTICS IN THE NEXT 25-30 YEARS

William M. Gray
(written in 1996)

We expect that these changing THC (or MOC) patterns will lead to enhanced intense (or major) hurricane activity in coming years and to a small global surface temperature cooling. It is likely that the mean global surface temperature change in the next 20-30 years will be more driven by nature than by anthropogenic influences and be one of weak cooling, not warming.

Figure 20. Forecast the author issued in 1996 concerning an anticipated increase in Atlantic basin hurricane activity after the onset of the strong THC in 1995 – and the expected decrease in global temperature in coming decades. This forecast was simply based on the observed change in the strength of the THC (or AMO) and the expected multi-decadal parameter changes which are associated with such THC pattern changes (Table 2). No consideration was given to rising levels of CO_2.

THEORY OF THC (OR AMO) INFLUENCE ON ATLANTIC HURRICANE VARIABILITY. The seasonal hurricane variability in the Atlantic cannot be explained by changes in CO_2-induced radiation. The SST changes which the Atlantic Ocean experiences are due primarily to the variations in the strength of the multi-decadal southwest to northeast North Atlantic upper poleward branch of the THC in the high latitude Atlantic. The THC is strong when there is an above-average poleward advection of warm tropical waters to the high latitudes of the Atlantic. This poleward-moving water can then sink to deep levels if it has high enough salinity content. This sinking process has been termed North Atlantic Deep Water Formation (NADWF). The submerged deep water then moves southward at deep levels in the Atlantic into the Southern Hemisphere. The amount of North Atlantic water that sinks is roughly proportional to the waters' density which at high latitudes, where water temperatures are low, is primarily dependent on salinity content. High salinity implies higher rates of NADWF.

Through a progression of associations the strength of the NADWF is hypothesized to bring about alterations of the tropospheric vertical wind shear, trade wind strength, SSTs, middle-level water vapor, and other conditions in the Atlantic Main Development Region (MDR – 10-20°N; 20-70°W). The favorable changes of SST in the MDR are a consequence of a combination of the ocean's THC influences on a variety of parameters in the Atlantic's MDR (Figure 21). A stronger than average THC causes more ocean sinking in area 1. This in turn reduces the strength of the Atlantic gyre. There is then a change in all of the other conditions shown in Figure 21 to bring about more favorable parameters in the MDR for TC formation and intensification. This figure illustrates how the changing rate of southward advection of colder water in the east Atlantic (2) brings about alterations of SLP (3), SST (4), and rainfall (5). These changes in turn lead to changes in trade wind strength (6) and 200 mb zonal wind (7). Changes in hurricane activity follow. These changing conditions bring about weaker trade winds and reduced evaporation which typically acts to increase SST. It is also found that in periods with a strong THC, El Niño frequency and intensity is typically reduced (9) and Atlantic hurricane activity, particularly major hurricane activity, is enhanced.

The influence of the warmer Atlantic SST is not primarily to enhance lapse rates and Cb convection in the MDR but to act as a net overall positive or negative influence on a combination of parameters that must all change in a positive way to enhance MDR TC activity. These features typically all go together as a package to either enhance or to inhibit TC formation and/or TC intensity change (Figure 22). The simple argument of rising or lowering levels of SST alone, without other important parameter changes is not typical of what we observe with TC activity variation in this region.

Higher rates of NADWF require stronger northward moving west Atlantic replacement water which is typically warmer, and if the stronger poleward flow is to continue, the replacement water must be of higher salinity content and consequently of higher density when such water cools toward freezing. Salinity dominates over water temperature when water temperatures are in the range of 0-7°C above freezing. Figure 23 shows how unique the Atlantic Ocean's salinity contents are at both the surface and at 500 m depth. See the papers by Gray *et al.* (1997); Goldenberg et al. (2001), Grossmann and Klotzbach (2009) and Gray and Klotzbach (2011) for more discussion of this topic.

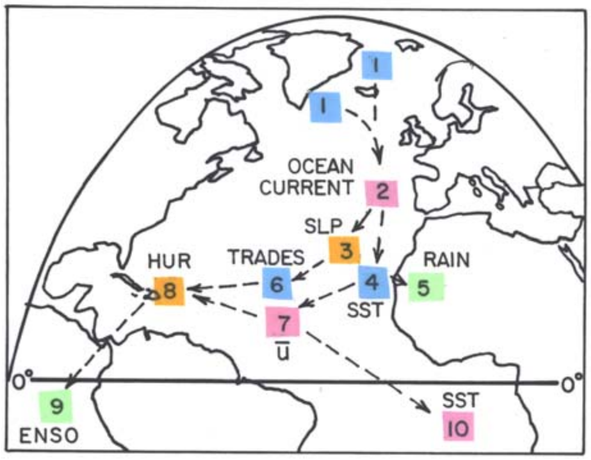


Figure 21. Idealized analysis of how changes in North Atlantic SST and salinity (area 1) lead to progressive wind, pressure, SST, vertical shear or rain changes as portrayed in these 9 areas. It is this complete package of Atlantic/eastern Pacific meteorological parameter changes on a multi-decadal time scale which cause large and unique changes in Atlantic major hurricanes on this time scale.

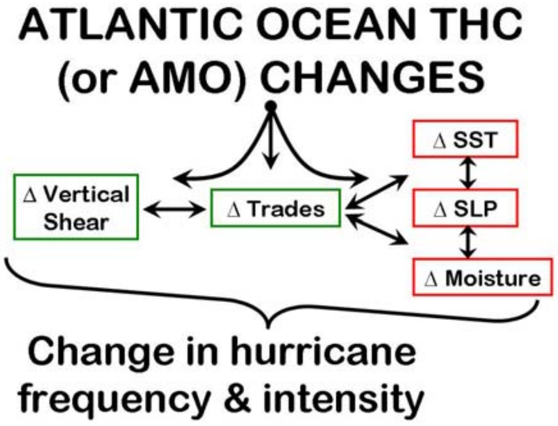


Figure 22. Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic's MDR between 10-20°N; 20-70°W. Vertical shear, trade-wind strength SLP and SST are the key parameters which respond to the THC changes. Favorable SLPA and mid-level moisture changes occur in association with the shear, trade wind, and SST changes. It is the THC's ability to affect a favorable alteration of a combination of these parameters within the MDR which leads to such a strong association between the strength of the THC and major hurricane frequency.

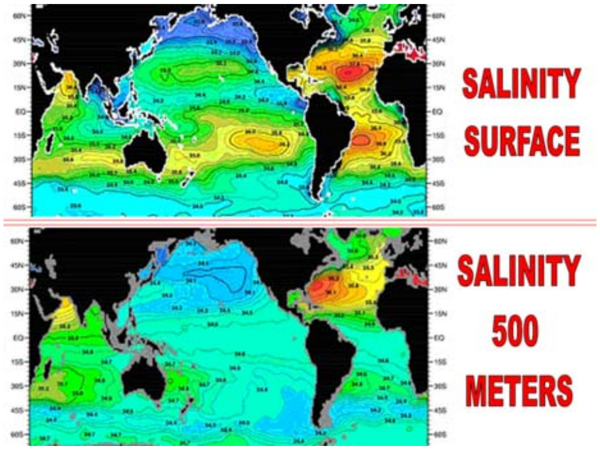


Figure 23. Global surface and 500 meter depth salinity which illustrates how unique the Atlantic is in comparison to the other ocean basins. Higher salinity in the Atlantic is primarily due to its higher evaporation over precipitation.

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