Comments by Bill Gray on the *Nature* paper titled "Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation" (Shakun, *et al*. 2012)

(Prepared for Don Easterbrook and Joe D'Aleo)

Summary. This paper has many physical flaws and should not have been published.

There is no way one could truthfully say that if CO_2 increased at a faster rate than global temperature during the retreat of the last ice-age that these increases in CO_2 were the primary driving components that lead to the ice-age's demise.

For instance, let's look at this assumption from the current global energy budget point-of-view (Figure 1). Note that there are about 342 Wm^{-2} average solar energy impingement on the globe and 235 OLR Wm^{-2} plus 107 (albedo) = 342 Wm^{-2} units of balancing energy going back to space.

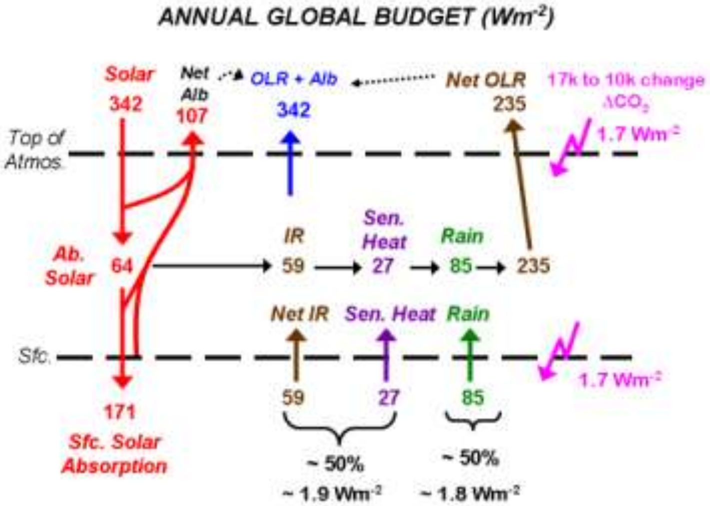

Figure 1. Vertical cross-section of the current annual global energy budget as determined from a combination of ISCCP and NCEP reanalysis data over the period of 1984-2004. Note on the right, how small is the ΔCO_2 induced increase OLR (or IR) blockage that has occurred between 17k years and 10k years and how relatively small is this blockage of 1.7 Wm^{-2}. 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.

The main deglaciation changes from Figure 3 of the Shakun, *et al.* paper took place from 17k to 10k years ago when CO_2 went from 190 to 260 ppmv. Using natural logarithms of this increase I calculate a change of ΔCO_2 forcing of 1.7 Wm^{-2} over this 7k year period. Compare this 1.7 Wm^{-2} change to the current global average energy budget and you see how very small the 1.7 Wm^{-2} is compared to the other terms. Any slight percentage changes in these other terms could overwhelm the ΔCO_2 change of 1.7 Wm^{-2}.

The main problem with all the warmers is that they assume that they can keep all these other much larger energy terms constant over long periods and that the only changes that matter to climate change are the very small amounts of CO_2. Small percentage changes of any of the other much larger components can cause these small changes in CO_2 to be in the noise level. How could these warmers be so terribly naïve to only see ΔCO_2 as the primary climate forcer?

There are other effects going on. For instance, as the ice melts and the snow retreats over this 7k year period the albedo could easily go down 2-3 Wm^{-2}. But more importantly, as the ice melts and fresh water flows into the North Atlantic the salinity and density of the North Atlantic upper ocean water will be substantially lowered and the Atlantic thermohaline circulation (THC) become significantly weakened or shut down entirely. This means that there will be less cold water upwelling in the tropical and South Pacific and tropical Indian Oceans. This causes a slow but steady warming of the global oceans and more CO_2 to be released from the oceans to the atmosphere. These are natural atmospheric CO_2 increases. The opposite happens as ice ages develop. Large amounts of fresh water is deposited over the continents. This causes the upper ocean of the Atlantic to have more evaporation than precipitation. Salinity of the North Atlantic goes up and the Atlantic THC (or global Meridional Overturning Circulation – MOC) becomes stronger. We then have more cold water upwelling in the tropical Pacific and tropical Indian oceans. The oceans cool and thus take up more CO_2 and the atmospheric CO_2 amounts go down. I have also found from NCEP reanalysis data that during multi-decadal periods when the THC is strong there is more global evaporation-rainfall than when the THC is weak.

In analyzing the Atlantic THC over the last 150 years, I also find that global temperatures rise when the THC is weak and cool when the THC is strong. Strong THC leads to higher North Atlantic SSTs and more frequent N. Atlantic blocking and associated more variable West European temperature and precipitation – like in Little Ice Age. By contrast, when the THC is weak there is less blocking action, stronger mid-latitude westerlies, and less variable weather over Europe like in the MWP. Figure 2 illustrates these two contrasting THC circulation patterns. The strong vs. weak multi-decadal THC changes in terms of global mean energy forcing can be, from my calculations be as much as 5-8 Wm^{-2} in global energy forcing.

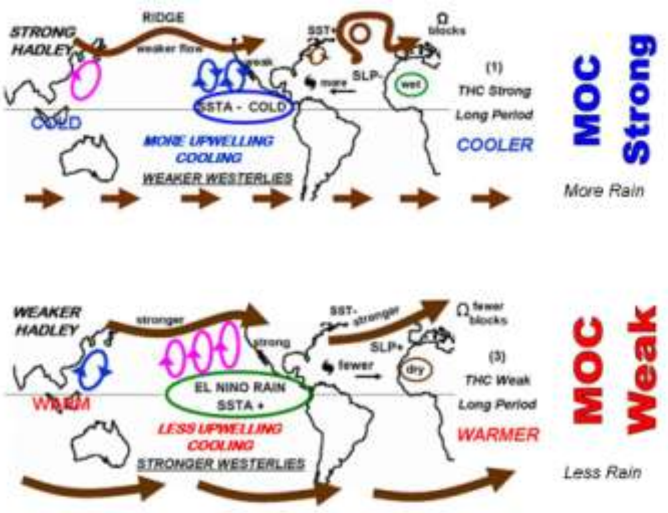

Figure 2. The top diagram shows the typical global wind patterns when the MOC has been strong for a long period and cold water upwelling in the Southern Hemisphere has been greater than the long period average. This leads to global temperatures becoming gradually cooler than average and more global rainfall (top diagram). The bottom diagram shows the typical global wind patterns when the MOC have been weaker than average for a long period and there has been reduced cold water upwelling in the Southern Hemisphere. The globe becomes gradually warmer during these periods and global rainfall is reduced. The top diagram shows characteristics of the conditions which existed during the modest global cooling period between the mid-1940s and the mid-1970s. The bottom diagram is characteristic of the conditions during the warming period of the mid-1970s to around 2000.

The Shakun, *et al.* paper's Figure 3 shows a June 21 at 65°N percentage solar isolation increase from 17k to 10k years of 5 percent or approximately 45-50 Wm^{-2} – giving a summer mean of about 30-35 Wm^{-2} at these higher latitudes just at the time when ice melting can occur.

So we can compare the mean increased energy forcing of an increase in CO_2 – between 17k years and 10k years of about 1.7 Wm^{-2} with:

1. This high latitude summer only solar increase of about 30-35 Wm^{-2} during this 7k year deglaciation occurs just at the time necessary to enhance ice melting. No such summer peak of the weaker ΔCO_2 change of 1.7 Wm^{-2} occurs.
2. Ocean THC (or MOC) slow-down global warming of approximately half of the ΔMOC of 5-8 Wm^{-2} forcing during this 7k year difference period.
3. Likely global albedo decreases over this period ~ 2-3 Wm^{-2}.

It is the combined influence of these latter three influences (almost 10 times greater than the citied increased CO_2 influence of about 1.7 Wm^{-2}) which likely acted to bring about this 7k year period of deglaciation.

During this 7k year period the global sea level rose 65 m. Assuming the ocean is 2/3 of the globe and that ice melting occurs only during the 6-month summer period, then the mean enhanced energy forcing for extra ice melting that we would expect for each half year summer period would be: 2(6500 cm)(80 cal/gm)/3(7000 years)(183 days) = 0.27 cal/cm^2d = 0.14 Wm^{-2}.

We thus have an excess average warming imbalance over each 6-month melting period for 7000 year of only about 0.14 Wm^{-2}. This is sufficient to cause enough melting (80 cal/gm) so as to produce a sea level rise of 65 m. This global energy excess of only 0.14 Wm^{-2} is much smaller than any of the above changes of energy forcing mechanisms and is an illustration that even in strong warming periods of deglaciation that the global climate system quickly and efficiently balances any excess or deficient energy forcing through the powerful Stefan-Boltzmann equation ($E = \sigma T^4$). In both glaciating and deglaciation periods the global net average energy excess or deficit is quite small.

CO_2 changes have very little influence on global temperature changes and most certainly are not the dominant factor in deglaciation.

This paper should not have been accepted for publication. Apparently no experienced meteorologists or geologists reviewed it. I have never heard of any of the nine listed authors. They obviously are warmers who are out to show that CO_2 increases can strongly influence climate changes even as extreme as deglaciation. The trouble is that this type of paper sells well and most people that have not been down in the meteorological or geological trenches for an extended period.

The following figures give an illustration of my ideas on how the primary driver for climate change on sub-orbital time scales are variations in the deep-ocean circulation on both multi-decadal and multi-century time scales. The deep ocean circulation changes are a result of natural varying upper-ocean salinity.

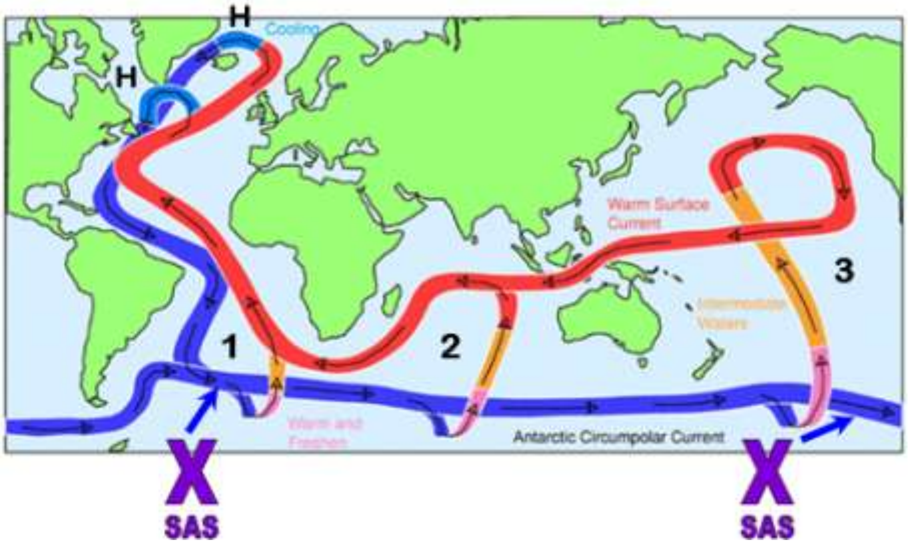

Figure 3. Idealized portrayal of the deep water Global Ocean Conveyor Belt (often referred to as the MOC) showing the typical locations in the Southern Hemisphere where upwelling occurs into the upper ocean thermocline and mixed layer (areas 1, 2, and 3) that is required to balance THC subsidence (H areas). Surrounding Antarctic Subsidence (SAS) is shown by X's. The MOC = (THC + SAS). Estimates are that the mass of the North Atlantic deep water subsidence is about twice the mass as the ocean subsidence around Antarctica. Figure adapted from John Marshall, of MIT.

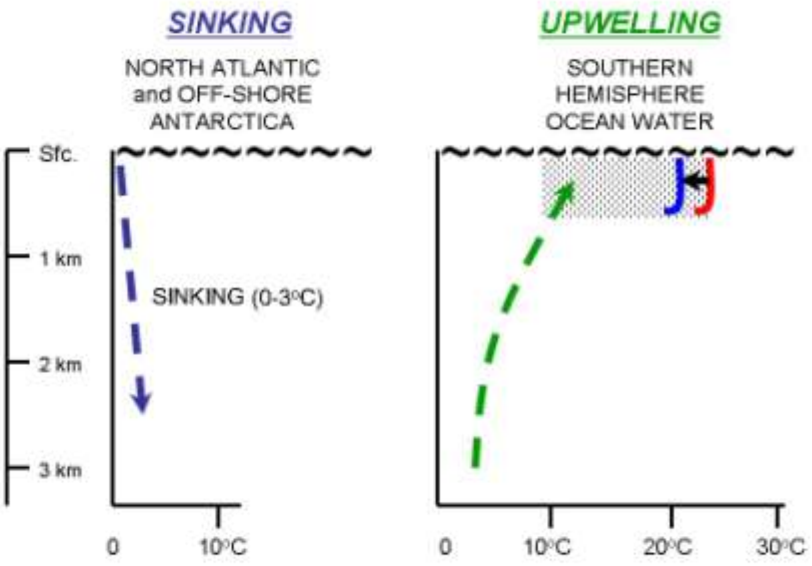

Figure 4. Illustratation of how cold water subsidence in polar regions and compensating upwelling in the Southern Hemisphere tropics could lead to upper ocean cooling.

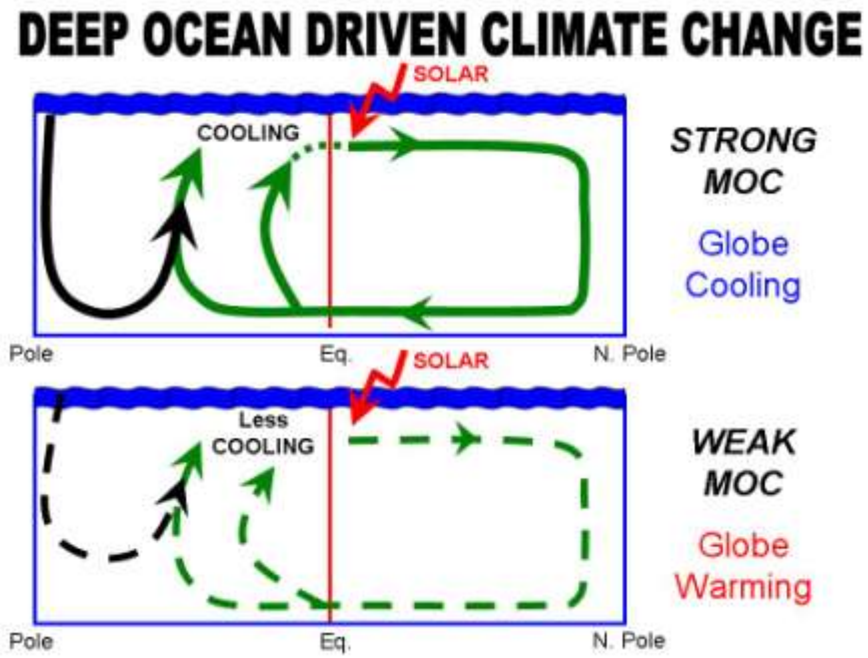

Figure 5. Idealized North-South graphical illustration of a strong (top) and weak (bottom) MOC. It is hypothesized that these differences in MOC strength are caused by salinity variations.

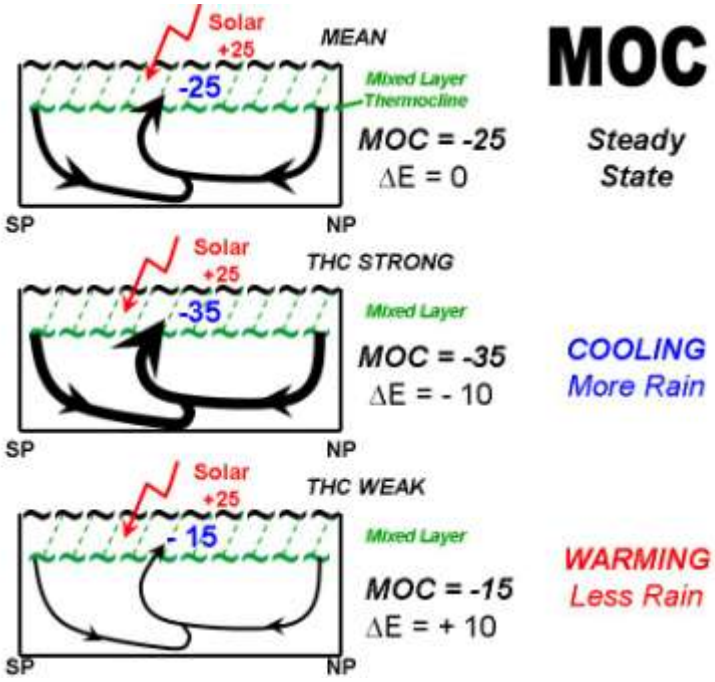

Figure 6. Hypothesized global MOC induced upper ocean energy budget for steady (top), cooling (middle) and warming (bottom) global conditions. Observations indicate that the globe has somewhat more rainfall when the MOC is strong than when it is weak. MOC units in Sverdrups (10^{12} gm/s). ΔE gives upper ocean energy changes. There is theoretical and observational evidence that north and south polar subsidence is related to each other over longer multi-decadal time periods.

Global Oceans

MOC = THC + SAS

Meridional	Atlantic	Surrounding
Overturning	Thermohaline	Antarctic
Circulation	Circulation	Subsidence

Figure 7. The MOC is thought to be a combination of the THC and SAS.

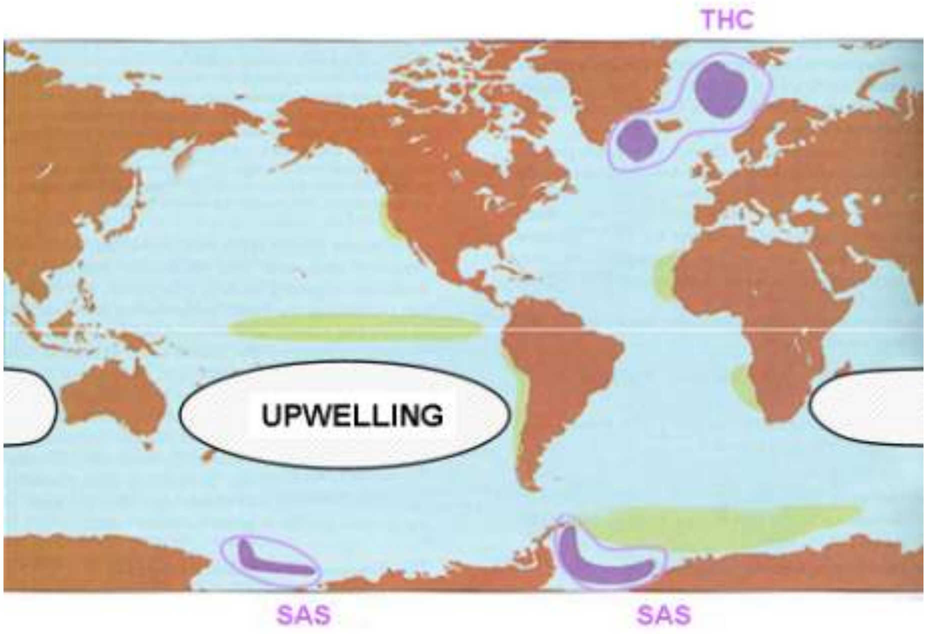

Figure 8. Areas of THC and SAS deep water formation (purple) and typical areas of corresponding upwelling (white).

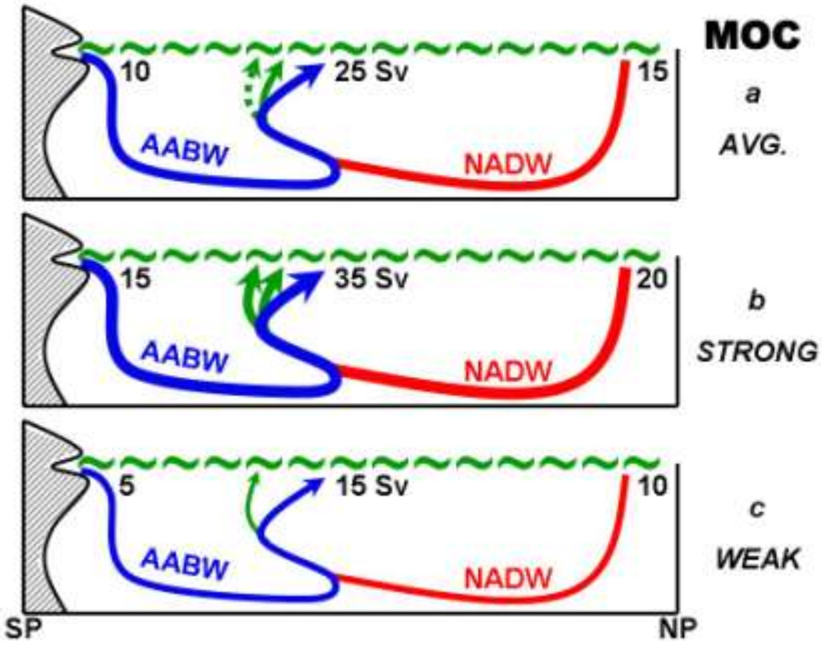

Figure 9. Idealized portrayal of the typical strength of the THC characterized by North Atlantic Deep Water formation (NADW) and Antarctica bottom water (AABW) in Sverdrups. The top diagram is for average conditions, the center is for strong MOC conditions and the bottom is for weak MOC conditions. It has been diagnosed that NADW (or THC) is typically about 1½ to 2 times stronger than AABW (or SAS). And there is evidence that on long time scales they tend to be of similar sign.

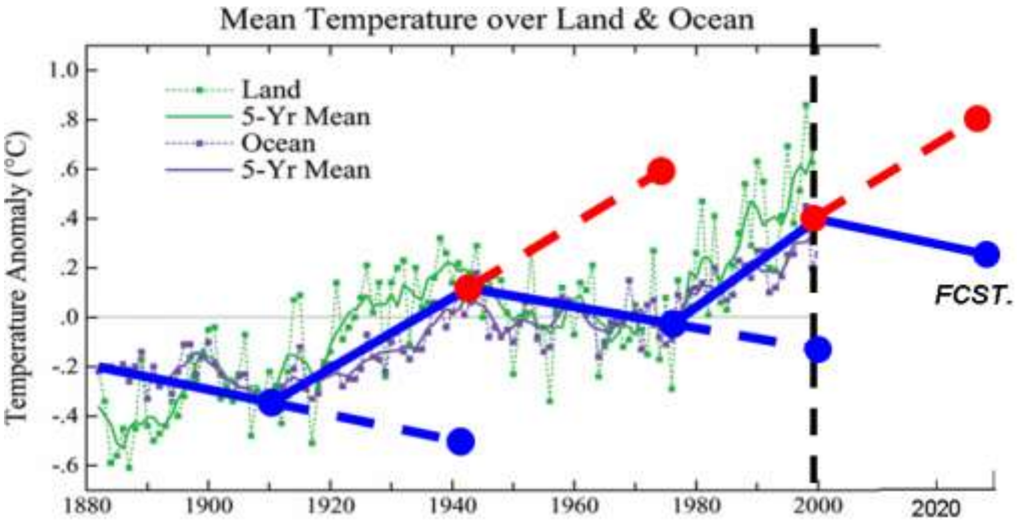

Figure 10. Illustration of how much error one would have made by extrapolating a cooling or warming curve beyond 30-35 years. The recent 1975-2000 warming trend did not continue. We have seen weak global cooling since 2001. I estimate global temperature by 2030 will be somewhat below the value of today's global temperature.

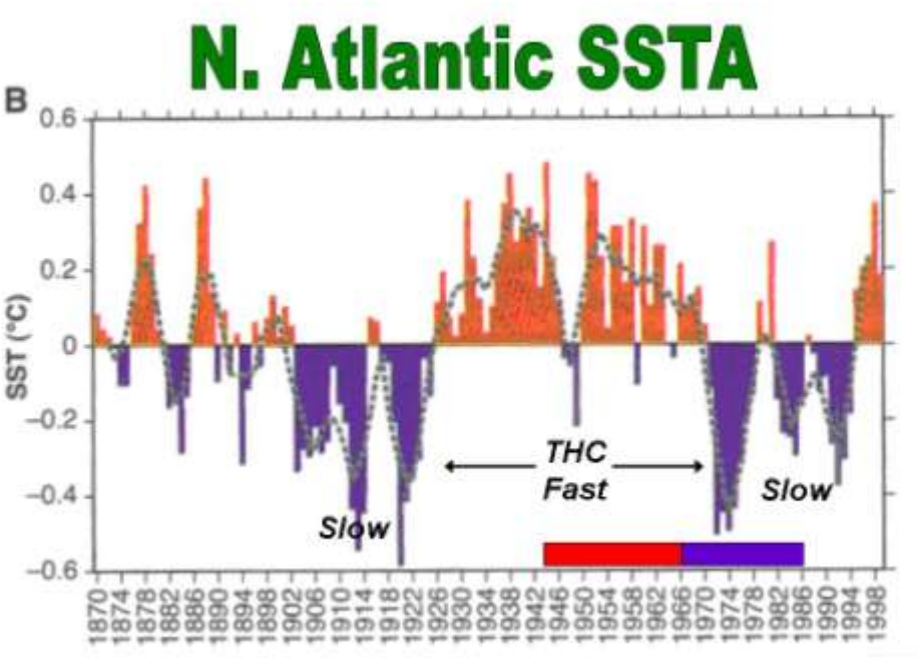

Figure 11. North Atlantic (50-65^{o}N; 50-20^{o}W) sea surface temperature anomalies (SSTA) from 1870-2000. Warmer temperature anomalies correspond to stronger than average THC conditions, and colder SST anomalies correspond to weaker than average THC conditions.

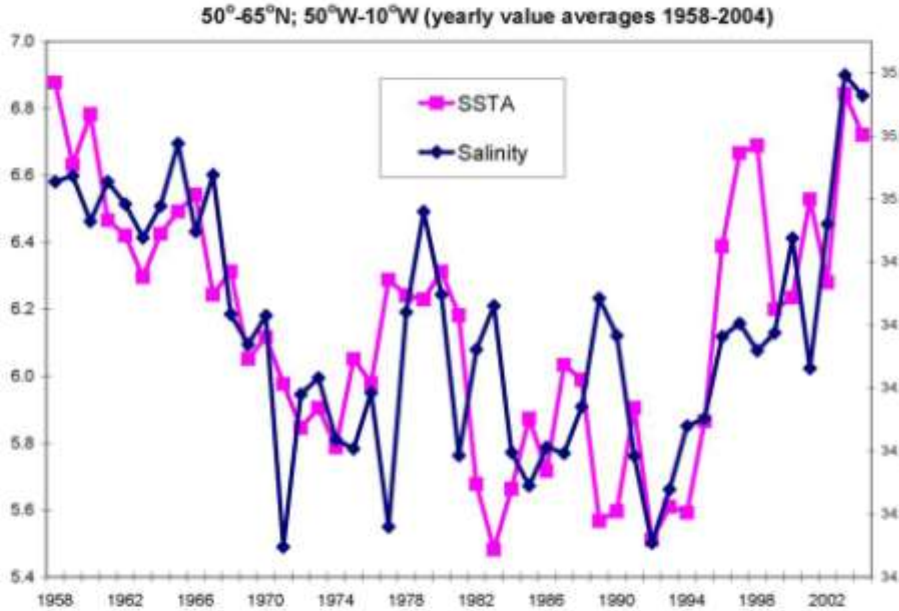

Figure 12. The close association between North Atlantic SSTA and observations of upper ocean salinity.

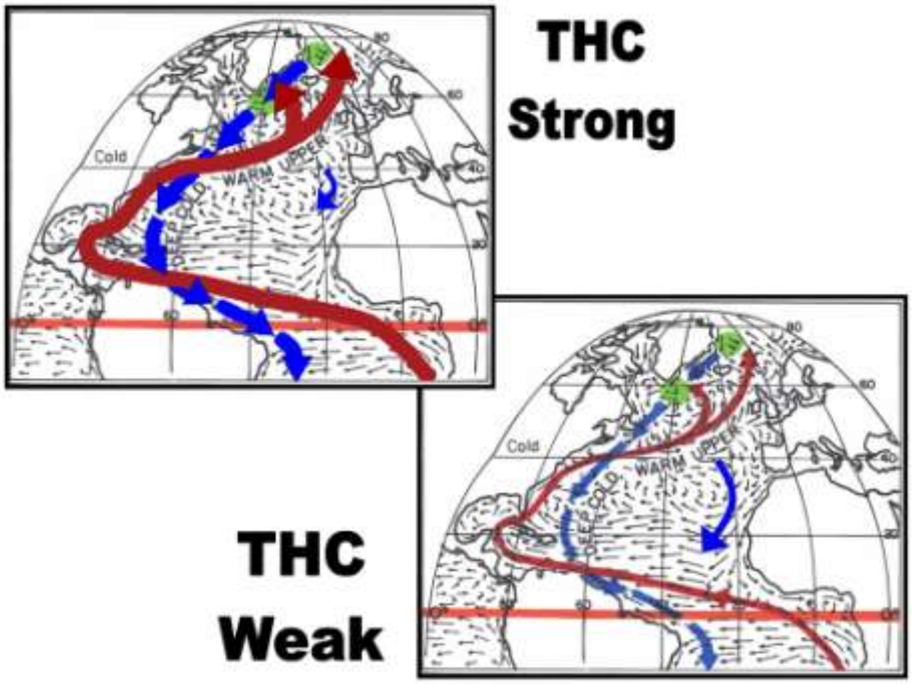

Figure 13. Portrayal of strong and weak THC conditions.