Why the Atlantic was surprisingly quiet in 2013

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ABSTRACT

This paper discusses the causes of the unusual dearth of Atlantic hurricane activity in 2013. Most groups issuing seasonal forecasts called for an active season in 2013 and significantly busted their predictions.

We believe that the primary cause of the lack of 2013 hurricane activity was the unexpectedly large decrease in the strength of the Atlantic Ocean Thermohaline Circulation (THC) between the winter (January-March) and the spring (April-June) period. Our THC proxy discussed below shows that the winter to spring weakening of the THC was stronger than any previous year in our data records.

The reduction in our THC proxy was likely due to a temporary lowering of North Atlantic Ocean salinity content and a resulting decrease in North Atlantic Deep Water Formation (NADWF). This brought about a strengthening of the Atlantic sub-tropical oceanic and atmospheric gyre circulations. This increased the strength of southward advection of cold air and water in the eastern Atlantic. Cold advection, acting over several months, brought about a significant cooling within and to the north of the Atlantic's hurricane Main Development Region, (MDR – 10-20°N; 60°W-20°W). These spring-induced tropical Atlantic changes lingered through the summer-early fall, and modified large-scale conditions such as vertical wind shear, mid-level moisture, atmospheric stability, that acted together to generate an environment that was unfavorable for hurricane development in the MDR. As a consequence, the 2013 season experienced only two weak Category 1 hurricanes. Changes in strength of the THC primarily impact frequency of major hurricanes. Signals for tropical storms are much weaker.

This paper offers a discussion of the physical causes of the unusual dearth of Atlantic hurricane activity in 2013. Most seasonal forecasts called for a very active season in 2013, and we were surprised by the reduced lack of activity that occurred compared with expectations.

After several months of studying the 2013 hurricane season, we have come to the conclusion that the primary cause of the lack of 2013 hurricane activity was the large and unexpected decrease in the strength of the THC (Figure 1) between the winter (January-March) and the spring (April-June) of 2013. This large spring decrease in the THC was larger than in any prior year in the NCEP/NCAR reanalysis data going back to 1950. Our earlier studies had primarily focused on the multi-decadal THC changes as portrayed in Figure 2. THC changes were previously known to greatly influence major hurricane activity as shown in Figure 3. The 2013 season shows that in some years THC changes can play a dominant role on the seasonal time-scale.

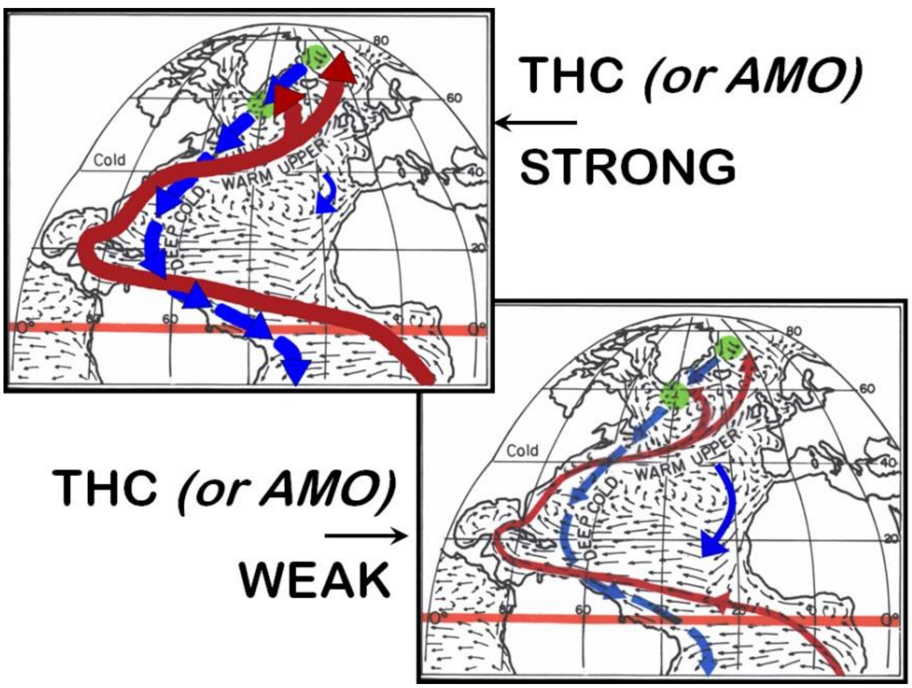

Figure 1. Illustration of strong (top) and weak (bottom) phases of the THC or Atlantic Multi-decadal Oscillation (AMO).

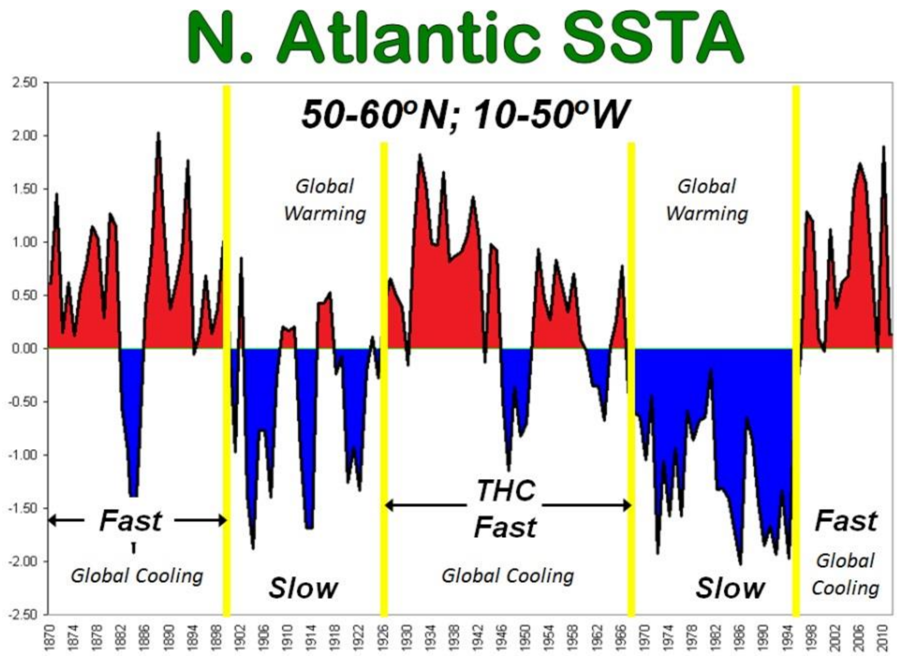

Figure 2. Long-period portrayal (1870-2013) of North Atlantic sea surface temperature anomalies (SSTA) from 50-60°N, 50-10°W. The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average. 84 major hurricanes formed when the THC was strong compared with 27 when the THC was weak.

This unexpected April through June weakening of our THC proxy was potentially due to a strong temporary lowering of North Atlantic Ocean salinity content and a resulting decrease in higher latitude NADWF. Changes in salinity dominate over ocean temperature in determining ocean density at temperatures near or just above freezing. Much of the ocean water that would have normally sunk to deep ocean levels in the far North Atlantic during the spring of 2013 remained farther south at higher levels in the ocean. More water was thus forced into the eastern mid-latitude Atlantic. This brought about an increase in the strength of the North Atlantic subtropical anticyclone and a consequent increase in the East Atlantic's southward ocean and lower-level wind flow. The persistence of these conditions during the three-month period significantly cooled sea surface temperatures (SSTS) in the eastern subtropical Atlantic. These cooler SSTs were then advected into the lower latitude tropical Atlantic.

This springtime advection acted to enhance the south-to-north temperature gradient and enhanced the tropospheric vertical wind shear within and around the MDR. Changes included small enhancements of both trade winds and upper tropospheric westerly winds. This effect also acted to slightly raise the MDR's sea level pressure (SLP) and reduce SSTs. These spring-induced changes around the MDR lingered through the summer when the solar induced tropical to mid-latitude energy differences are very weak. These changes acted to reduce intense hurricane activity.

Large-scale parameters during August-October (trade wind strength, upper-tropospheric westerly wind strength, tropospheric vertical wind shear, SST, SLP, etc.) in the Main Development Region (MDR) which largely specify seasonal major hurricane variability have been found to be strongly correlated with the strength of the THC in the prior April through June and May through July periods. We did not expect that these early spring conditions could play such a dominant role in the later August through October period. This finding will be incorporated in future forecasts.

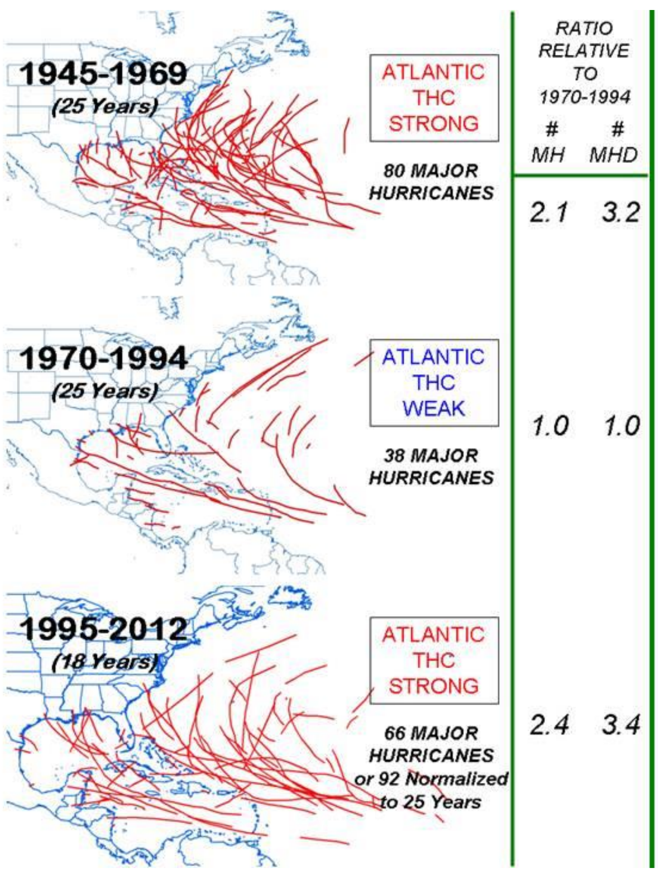

Figure 3. Major hurricane (MH) (Cat 3-4-5) tracks during strong (1945-1969 and 1995-2012) versus weak (1970-1994) THC periods. The ratio of the average of number of MHs and major hurricane days (MHD) to the normalized activity of 1970-1994 is given on the right.

In the spring (April-June) of 2013 a significant reduction in the strength of the THC occurred as evidenced by a:

1) Reduction of springtime cyclonic action and rainfall across the middle latitude North Atlantic.
2) Increased high pressure over the mid-latitude Atlantic and a large strengthening of the subtropical Atlantic gyre
3) An associated change in parameters in the Atlantic MDR which are typically associated with a weak THC. These observed changes occurred during the spring but then tended to carry over to the late summer-early fall period. These included:
    a. slightly stronger low-level trade winds
    b. slightly stronger upper-tropospheric zonal winds and greater tropospheric vertical wind shear
    c. slightly higher sea level pressure along the central Atlantic's inter-tropical convergence zone (ITCZ) and less low-level mass wind convergence and rainfall in the ITCZ
    d. Reduced middle-tropospheric moisture in the MDR due to lesser amounts of deep cumulus convective activity, more upper-level subsidence, and suppressed horizontal moisture advection into the MDR from surrounding higher moisture areas. Such reduced middle-tropospheric conditions acted to inhibit deep cumulonimbus (Cb) convection and meso-scale cloud cluster formation through dryer air entrainment into deep penetrating clouds.

Figure 4 shows the Atlantic SLP anomaly (SLPA) during winter (Jan-Mar) and spring (Apr-Jun) of 2013. Subtropical Atlantic SLPAs rose over 6-7 mb. These were the largest winter to spring SLPA anomaly changes in our data set going back to 1950. During the winter of 2012/2013 the Atlantic had above average mid-latitude cyclone activity, and in the spring of 2013 there was a changeover to strong high pressure and above average anticyclonic activity. However, as Figure 5 demonstrates, the pressure and SST patterns reverted back to conditions more like the winter of 2012/2013 by August-October 2013.

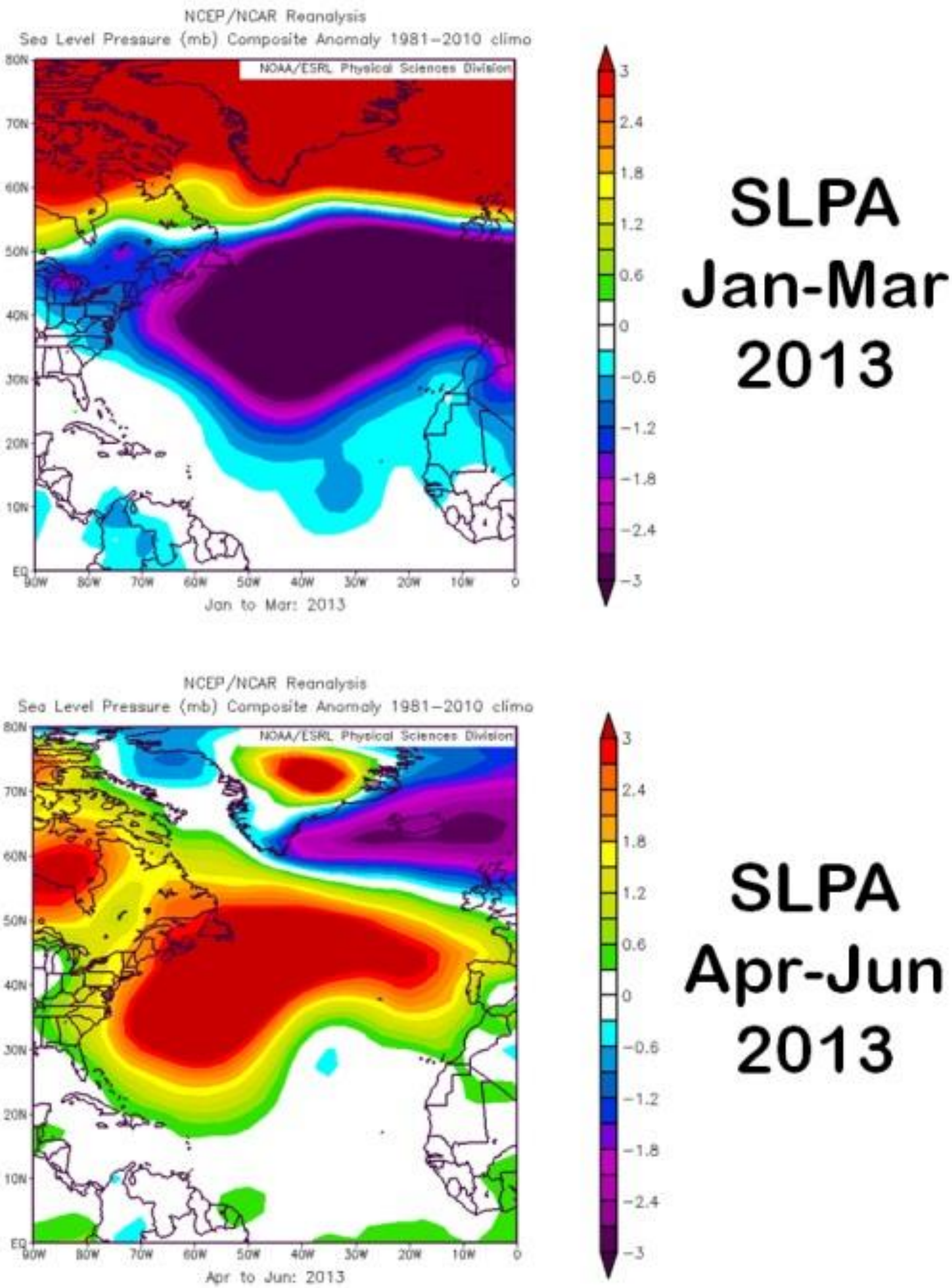

Figure 4. Comparison of sea level pressure anomalies for January-March and April-June 2013.

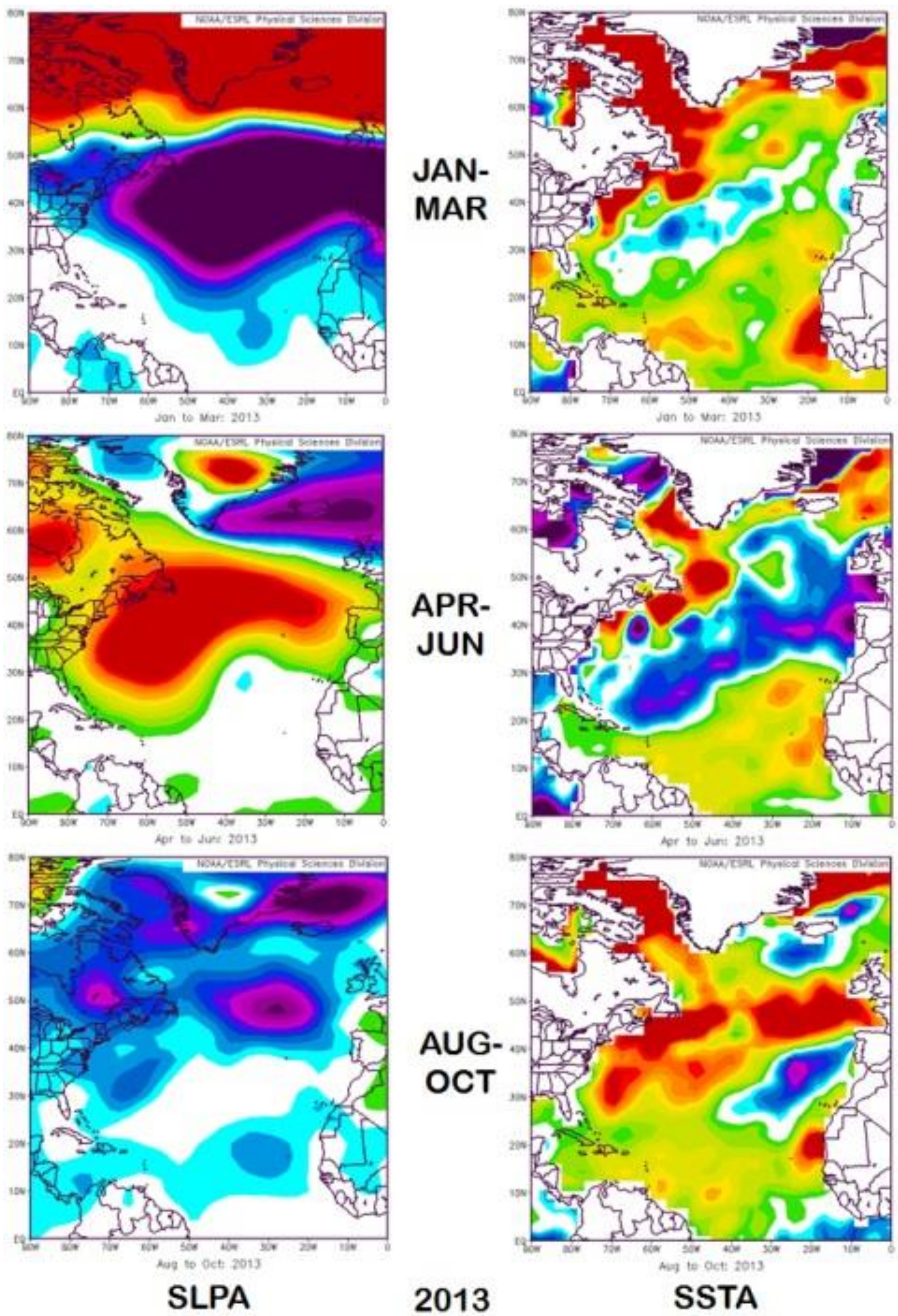

Figure 5. Three month anomalies during 2013.

Figure 6-8 portray 2013 April-June SLPA, SSTA, and low-level wind anomalies and anomaly differences from 2013 for 10 strong THC years (Accumulated Cyclone Energy (ACE) average 205) and 10 weak THC years (average ACE 57) since 1950. Note the lower mid-latitude Atlantic pressures, low-level cyclonic wind anomalies, and warmer East Atlantic SSTAs during strong vs. weak THC springs. These springtime differences established conditions that drove three times greater amounts of major hurricane activity in the following months for strong vs. weak THC years.

The strong 2013 anomalous anticyclonic high pressure system during the spring was a good proxy for a weak THC. By contrast, when the THC in the springtime is strong, there is a reverse of the above inhibiting factors – low pressure and cyclonic flow occur and Atlantic hurricane activity in the following August through October period is, by contrast, enhanced. Figures 9-12 display idealized figures demonstrating flow patterns associated with strong and weak THC periods during the April-October period.

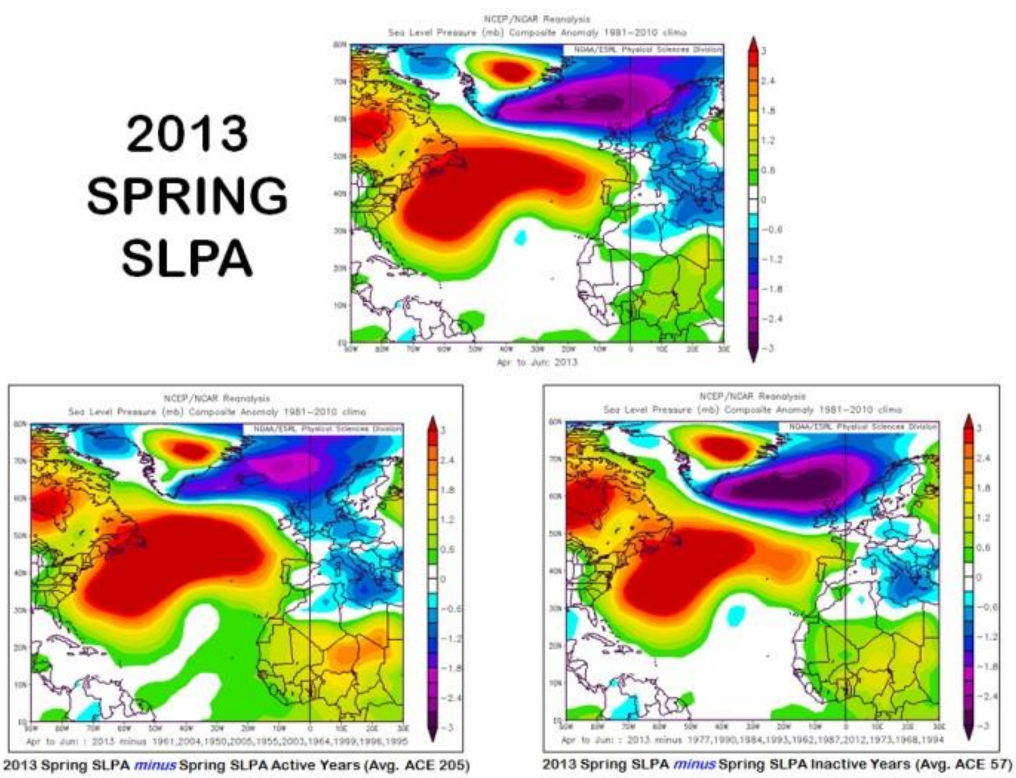

Figure 6. SLPA for April-June 2013 (top diagram) and differences of this 2013 SLPA pattern with the average of the 10 most active hurricane seasons (lower left diagram) and the 10 most inactive hurricane seasons (lower right diagram).

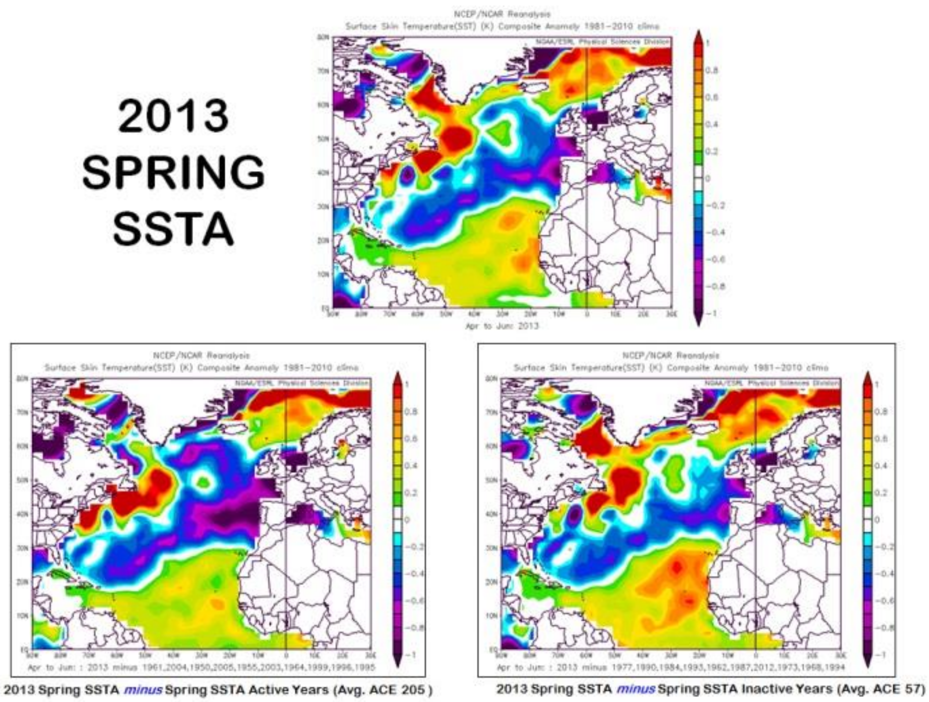

Figure 7. As in Figure 6 but showing April-June 2013 SSTA (top) and 2013 SSTA values minus 10 high vs. 10 low hurricane periods.

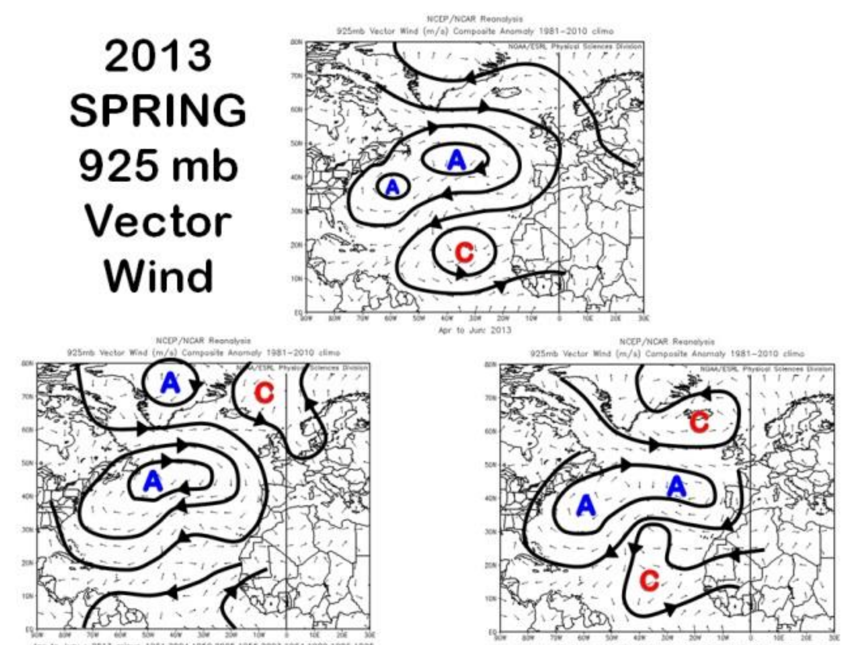

Figure 8. As in Figure 6 but for 925 mb wind anomalies. A represents anticyclonic wind anomalies, while C represents cyclonic wind anomalies.

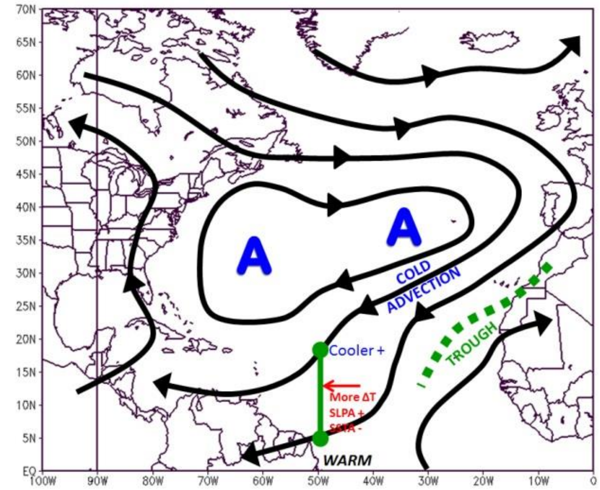

Figure 9. Idealized surface-300 mb mean deviational flow patterns during April through October when the THC in April through June or May through July was significantly weaker than climatology. Note the cooler temperatures near 20°N, 50°W from colder wind and ocean advection from the northeast. This enhances the N-S temperature gradient (in the thick green line area) and leads to increased tropospheric vertical wind shear, stronger trade winds, cooler SSTs and higher SLPs.

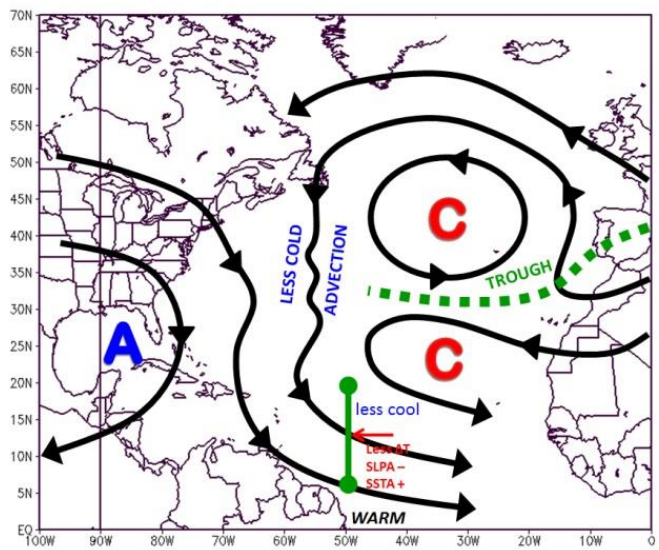

Figure 10. As in Figure 9 but when Atlantic THC conditions are significantly stronger than climatology. This causes a reduced N-S temperature gradient in the MDR, and consequently reduced tropospheric wind shear, lower SLPA and higher SSTA.

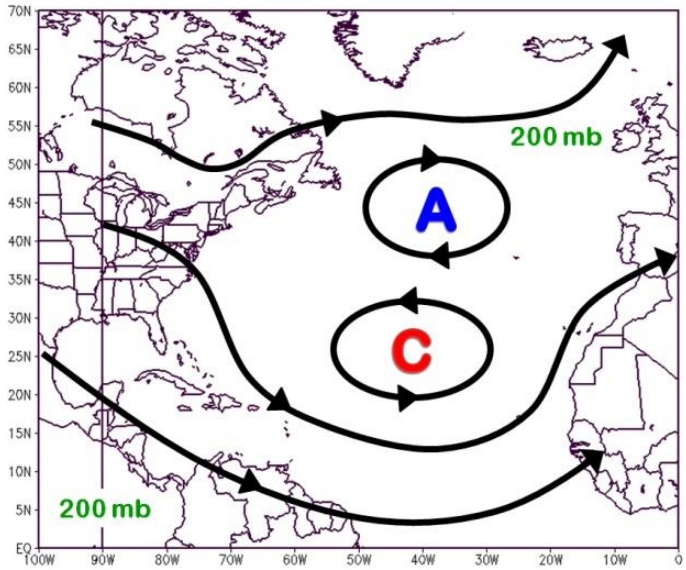

Figure 11. Idealized typical deviational flow pattern at 200 mb (12 km altitude) during April through October when the Atlantic THC is weaker than climatology during the spring. Upper tropospheric winds around the MDR are stronger than average from the west. This causes tropospheric vertical wind shear within and around the MDR to be enhanced and hurricane activity in this area to be suppressed.

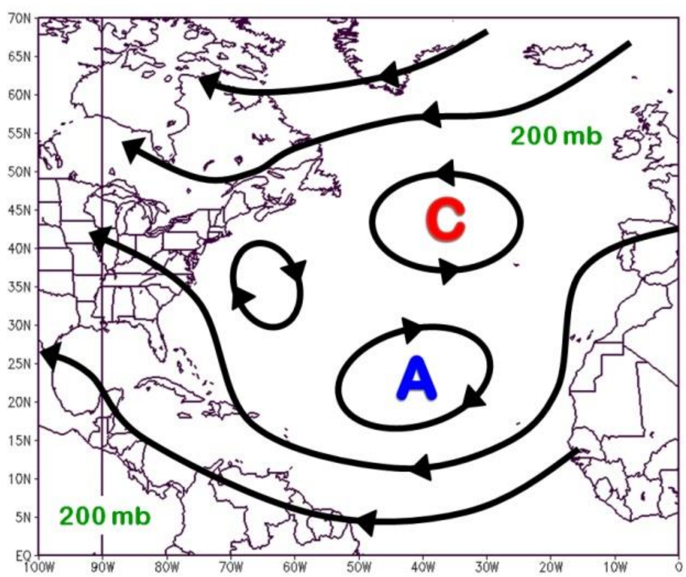

Figure 12. As in Figure 11 but when the Atlantic THC is significantly stronger than climatology. This causes upper tropospheric or 200 mb winds during the August-September period to be stronger than average from the east.

<u>Importance of the Ocean for Long-Period Maintenance of the Tropospheric Circulation</u> The globe's tropospheric winds are frictionally dissipated at a rate of about 10 percent per day. It is necessary that new wind patterns are continuously generated to balance these high rates of dissipation. Water vapor in the troposphere is also rained out at about 10 percent per day.

The Atlantic Ocean's deep circulation patterns play a fundamental role in dictating how individual atmospheric wind patterns (which affect Atlantic hurricane frequency and intensity) are regenerated on these relatively small time-scales. On monthly to seasonal timescales, the ocean drives a high percentage of future changes in wind.

COMBINED EL NINO AND THC INFLUENCES ON ATLANTIC HURRICANES

A large number of the least active Atlantic basin hurricane seasons have occurred during El Nino years. The average Accumulated Cyclone Energy (ACE) of 12 (or 19%) of the last 64 years in which a moderate or strong El Niño have occurred was 50. The ACE of the other 48 (or 81% of years since 1950) non-El Niño years has been 120 or 2.5 times greater than that in the moderate to strong El Niño years.

The 2013 Atlantic hurricane season value of ACE of 36 is only rivaled by the low ACE values in other non-El Niño years since 1950 of 1962 (36), 1968 (45), 1977 (25), 1993 (39), and 1994 (32).

In analyzing why the non-El Niño year of 2013 had such a lack of Atlantic hurricane activity, we now realize that we failed to realize the importance of the strong springtime THC weakening because we had not previously experienced it in our developmental data sets. Also, this massive THC weakening appeared to have reversed itself and recovered to more typical values for the remainder (July-October) of the 2013 hurricane season.

<u>Proxy Signals for THC.</u> We have previously developed a proxy signal for the Atlantic THC circulation (Diagram **a** in Figure 13). This has been discussed in many of our previous reports. This THC proxy signal has clearly demarked the weak (1970-94) from the strong multi-decadal periods of 1950-69 and 1995-2012. We are now investigating how smaller time-scale THC differences might apply to year-to-year hurricane variability. We have thus expanded our study of the THC proxy signals to be able to better capture the year-to-year variability in the THC as related to hurricanes.

For instance, during the 1970-94 weak THC period, we observed an apparent 2-year break during 1988-1989 when we had three Category 4 hurricanes and two Category 5 hurricane. We thought at that time that the THC may have begun to come out of its weak phase. But this was not the case and for the next five years from 1990-1994 the

THC remained quite weak. We had a strong decrease of tropical cyclone (TC) activity in the 5-year period of 1990-94 when the average ACE was only 34.

It will likely take many future years to sort out all of the physical processes which cause the THC to alternate on a seasonal, yearly, multi-decadal and multi-century time-scale. But regardless of the physical processes involved with such varying THC strength levels, the strong THC-hurricane associations can and should be exploited for improved seasonal prediction. We have learned that very large springtime changes in the THC can have significant repercussions for the remainder of the season, regardless of any perceived rebound in wind/pressure patterns. <u>One always learns more from a busted than a verified forecast.</u>

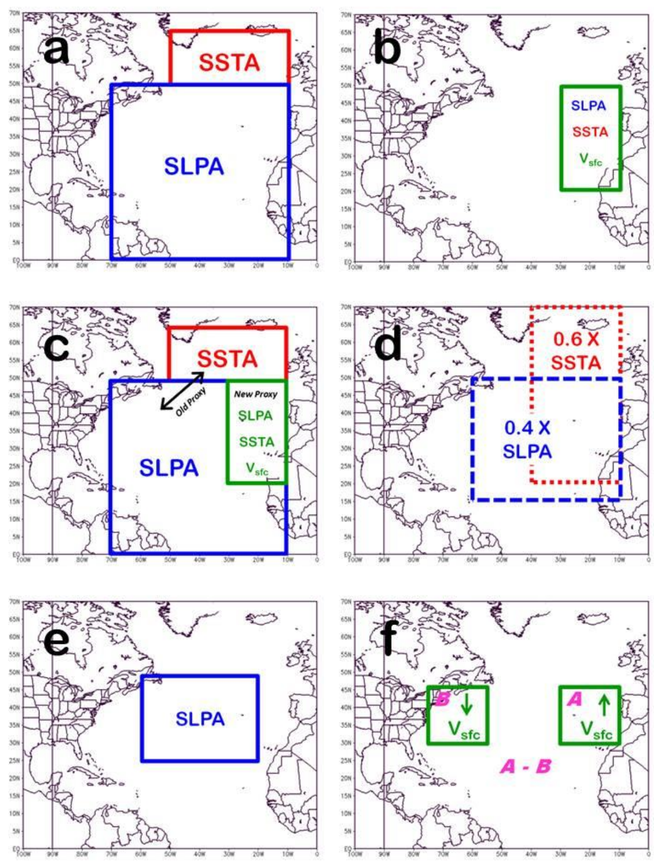

Figure 13. Location of our various proxy signals for the strength of the THC.

<u>New Proxies for THC strength.</u> Although the amount of NADWF cannot be measured, there appears to be a number of reasonable THC proxy measurements for estimating the approximate amount of deep-water formation. All these proxy signals are physically related to the inverse strength of the Atlantic sub-tropical gyre system. The stronger the

THC is – the weaker is the Atlantic gyre. A very strong Atlantic gyre is an indicator of a very weak THC circulation and likely much reduced NADWF.

We have worked extensively with the NCEP/NCAR reanalysis data in recent months to try to relate how April through June Atlantic conditions relate to TC activity. The best April through June proxy for major hurricane activity is found to be proxy **d**.

Table 1 shows how strongly our proxy **d** is related to the most intense TC activity when we stratify this parameter from highest to lowest values. Note how large the ratio differences for major hurricane activity are.

It has been shown that United States landfalling major hurricanes account for about 80-85 percent of all normalized destruction even though they only account for about 20-25 percent of landfalling named storms. The 2013 season had 14 named storms (slightly above average). It was the lack of any intense TC activity in 2013 which was unusual and is the reason we have written this paper. It is fortunate that there exists such a strong springtime precursor signal for major hurricane activity. We will utilize this new information in our future forecasts.

Table 1. April to June highest vs. lowest ratio of Proxy ***d*** *values for later year hurricane activity for the 64-year period of 1950-2013. Proxy* ***d*** *= [0.6*(**SSTA** of 20-70°N; 40-10°W) + 0.4*(**SLPA** of 15-50°N; 60-10°W)]. ACE is accumulated cyclone energy, HDP – hurricane destruction potential, MHD – major hurricane days, and MHDP – major hurricane destruction potential.*

April-June Ratio of Hurricane Activity for Proxy d	***ACE***	***HDP***	***MHD***	***MHDP***
10 highest vs. 10 lowest years	2.42	2.99	7.32	7.15
20 highest vs. 20 lowest years	2.06	2.48	4.42	4.67
32 highest vs. 32 lowest years	1.83	2.14	3.07	3.20

A more in-depth write-up will be forthcoming in the next couple of months.