QUALITATIVE DISCUSSION OF ATLANTIC BASIN SEASONAL HURRICANE ACTIVITY FOR 2015

We discontinued our early December quantitative hurricane forecast in 2012 and are now giving a more qualitative discussion of the factors which will determine next year's Atlantic basin hurricane activity. One of the big uncertainties for the 2015 Atlantic basin hurricane season is if the currently developing weak El Niño will persist through next summer.

Our first quantitative forecast for 2015 will be issued on Thursday, April 9.

(as of 11 December 2014)

By Philip J. Klotzbach[1] and William M. Gray[2]

This discussion as well as past forecasts and verifications are available online at http://hurricane.atmos.colostate.edu

Kortny Rolston, Colorado State University Media Representative, (970-491-5349) is available to answer various questions about this verification.

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ABSTRACT

We are providing a qualitative discussion of features likely to impact the 2015 Atlantic basin hurricane season rather than a specific numbers forecast. This outlook for 2015 will give our assessment of the probability of four potential scenarios for Net Tropical Cyclone (NTC) activity.

We have developed a new way of assessing next year's activity in terms of two primary physical parameters:

1. the strength of the Atlantic thermohaline circulation (THC)
2. the phase of ENSO

We believe that we are still in an active era for Atlantic basin tropical cyclones since 1995 (despite the quiet seasons that occurred in 2013-2014), and we expect that typical conditions associated with a positive Atlantic Multi-Decadal Oscillation (AMO) and strong thermohaline circulation (THC) will return in 2015. One of the big challenges for 2015 is whether or not the currently developing weak El Niño will persist through the 2015 hurricane season. While we saw a significant weakening of the Atlantic Multidecadal Oscillation (AMO) and thermohaline circulation (THC) during the spring of 2014, North Atlantic SST and sea level pressure patterns have since rebounded to conditions characteristic of an active era. We anticipate that the 2015 Atlantic basin hurricane season will be primarily determined by the strength of the THC/AMO and by the state of ENSO.

For the 2015 hurricane season, we anticipate four possible scenarios with the probability of each as indicated on the next page:

1. THC circulation becomes unusually strong in 2015 and no El Niño event occurs (resulting in a seasonal average net tropical cyclone (NTC) activity of ~ 180) – **10% chance**.

2. THC continues in the above-average condition it has been in since 1995 and no El Niño develops (NTC ~ 140) – **40% chance**.

3. THC continues in above-average condition it has been in since 1995 with the development of a significant El Niño (NTC ~ 75) – **40% chance**.

4. THC becomes weaker and there is the development of a significant El Niño (NTC ~ 40) – **10% chance**.

Typically, seasons with the above-listed NTC values have TC activity as follows:

180 NTC – 14-17 named storms, 9-11 hurricanes, 4-5 major hurricanes
140 NTC – 12-15 named storms, 7-9 hurricanes, 3-4 major hurricanes
75 NTC – 8-11 named storms, 3-5 hurricanes, 1-2 major hurricanes
40 NTC – 5-7 named storms, 2-3 hurricanes, 0-1 major hurricane

Acknowledgment

We are grateful for support from Interstate Restoration, Ironshore Insurance and Macquarie Group that partially support the release of these predictions. The remainder of this year's forecasts are provided by private funds. We thank the GeoGraphics Laboratory at Bridgewater State University (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

The second author gratefully acknowledges the valuable input to his CSU seasonal forecast research project over many years by former graduate students and now colleagues Chris Landsea, John Knaff and Eric Blake. We also thank Professors Paul Mielke and Ken Berry of Colorado State University for statistical analysis and guidance over many years. We thank Bill Thorson for technical advice and assistance.

DEFINITIONS AND ACRONYMS

Accumulated Cyclone Energy (ACE) - A measure of a named storm's potential for wind and storm surge destruction defined as the sum of the square of a named storm's maximum wind speed (in 10^4 $knots^2$) for each 6-hour period of its existence. The 1950-2000 average value of this parameter is 96 for the Atlantic basin.

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the oceanic thermohaline circulation. Although several definitions of the AMO are currently used in the literature, we define the AMO based on North Atlantic sea surface temperatures from 20-70°N, 40-10°W and sea level pressure from 15-50°N, 60-10°W.

Atlantic Basin – The area including the entire North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico.

El Niño – A 12-18 month period during which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Niño events occur irregularly, about once every 3-7 years on average.

Hurricane (H) - A tropical cyclone with sustained low-level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day (HD) - A measure of hurricane activity, one unit of which occurs as four 6-hour periods during which a tropical cyclone is observed or is estimated to have hurricane-force winds.

Indian Ocean Dipole (IOD) - An irregular oscillation of sea surface temperatures between the western and eastern tropical Indian Ocean. A positive phase of the IOD occurs when the western Indian Ocean is anomalously warm compared with the eastern Indian Ocean.

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in roughly 40-50 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, which we define as 7.5-22.5°N, 20-75°W.

Major Hurricane (MH) - A hurricane which reaches a sustained low-level wind of at least 111 mph (96 knots or 50 ms^{-1}) at some point in its lifetime. This constitutes a category 3 or higher on the Saffir/Simpson scale.

Major Hurricane Day (MHD) - Four 6-hour periods during which a hurricane has an intensity of Saffir/Simpson category 3 or higher.

Multivariate ENSO Index (MEI) – An index defining ENSO that takes into account tropical Pacific sea surface temperatures, sea level pressures, zonal and meridional winds and cloudiness.

Named Storm (NS) - A hurricane, a tropical storm or a sub-tropical storm.

Named Storm Day (NSD) - As in HD but for four 6-hour periods during which a tropical or sub-tropical cyclone is observed (or is estimated) to have attained tropical storm-force winds.

Net Tropical Cyclone (NTC) Activity –Average seasonal percentage mean of NS, NSD, H, HD, MH, MHD. Gives overall indication of Atlantic basin seasonal hurricane activity. The 1950-2000 average value of this parameter is 100.

Saffir/Simpson Hurricane Wind Scale – A measurement scale ranging from 1 to 5 of hurricane wind intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin. Low values typically indicate El Niño conditions.

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

Thermohaline Circulation (THC) – A large-scale circulation in the Atlantic Ocean that is driven by fluctuations in salinity and temperature. When the THC is stronger than normal, the AMO tends to be in its warm (or positive) phase, and more Atlantic hurricanes typically form.

Tropical Cyclone (TC) - A large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels; including hurricanes, tropical storms and other weaker rotating vortices.

Tropical North Atlantic (TNA) index – A measure of sea surface temperatures in the area from 5.5-23.5°N, 15-57.5°W.

Tropical Storm (TS) - A tropical cyclone with maximum sustained winds between 39 mph (18 ms^{-1} or 34 knots) and 73 mph (32 ms^{-1} or 63 knots).

Vertical Wind Shear – The difference in horizontal wind between 200 mb (approximately 40000 feet or 12 km) and 850 mb (approximately 5000 feet or 1.6 km).

1 knot = 1.15 miles per hour = 0.515 meters per second

1 Introduction

This is the 32nd year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. These forecasts are based on a statistical methodology derived from 30-60 years of past data. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin TC activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

The best predictors do not necessarily have the best individual correlations with hurricane activity. The best forecast parameters are those that explain the portion of the variance of seasonal hurricane activity that is not associated with the other forecast variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 2-3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 2-3 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme must show significant hindcast skill before it is used in real-time forecasts.

2 Previous Extended-Range Early December Statistical Forecasts

Our seasonal hurricane forecast schemes issued in early June and early August have shown significant real-time skill since they began being issued in 1984. Our early April forecasts have also begun to show significant forecast skill in recent years. Our early December forecasts did not show skill in real-time forecast mode from 1992-2011, and we suspended them beginning in 2012. See Klotzbach and Gray (2011) for a full discussion of the lack of skill of real-time predictions from early December

Over the next few pages, we discuss two large-scale physical features which we know are fundamental for how active the 2015 Atlantic hurricane season is likely to be.

3 The Atlantic Ocean Thermohaline Circulation (THC) and the Strength of the Atlantic Gyre on Atlantic Hurricane Activity

The longer-period SST changes which the Atlantic Ocean experiences are due primarily to variations in the strength of the southwest to northeast upper branch of the THC in the high latitude Atlantic. The THC (which is observed and modeled to vary considerably in strength on multi-decadal timescales) 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 deep water then moves southward 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. The strong association between North Atlantic SSTA and North Atlantic salinity is shown in Figure 1. High salinity implies higher rates of NADWF. When the salinity rates are lower, less NADWF formation occurs. During these periods, the water tends to recirculate and increase the ocean's clockwise circulating gyre motion.

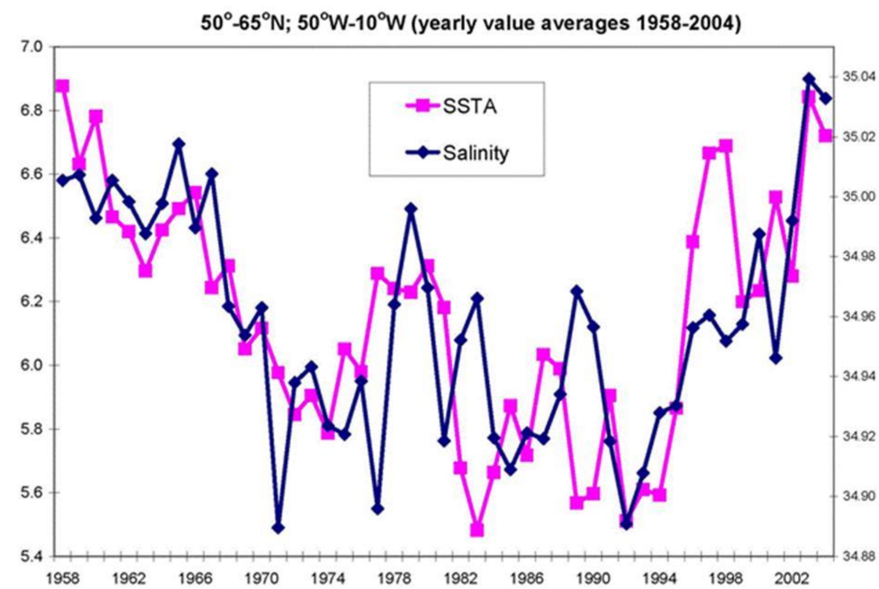

Figure 1: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

Through a progression of associations the strength of the NADWF and inverse strength of the Atlantic gyre 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 – 7.5-22.5°N; 20-75°W).

Changes of SST in the MDR are a consequence of a combination of the THC's influences on a variety of other parameters in the MDR (Figure 2). 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 2 to bring about more or less favorable parameters in the MDR for TC formation and intensification. This figure illustrates how the changing rate of southward advection of cold 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 and especially major hurricane activity follow (8). It is also found that in periods with a strong THC, El Niño frequency and intensity is typically reduced (9) and tropical South Atlantic SSTs are decreased (10).

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 3). The simple argument of increasing or decreasing SST alone, without other important parameter changes is not typical of what we observe with TC activity variation in this region.

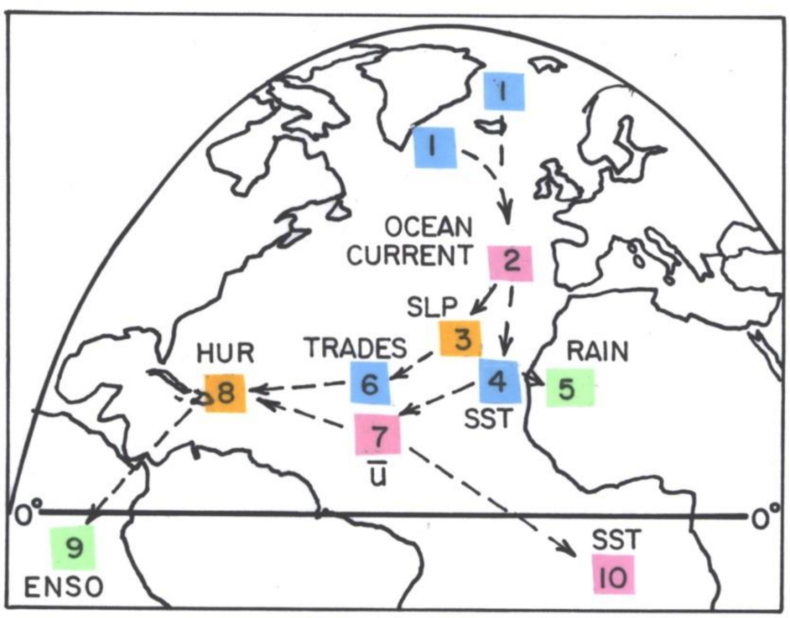

Figure 2: Idealized analysis of how changes in North Atlantic SST and salinity (area 1) lead to progressive ocean current, wind, pressure, SST, vertical shear and rain changes as portrayed in nine areas. It is this complete package of Atlantic/eastern Pacific ocean/atmosphere parameter changes on multi-decadal time scales which cause large changes in Atlantic major hurricanes on this time scale.

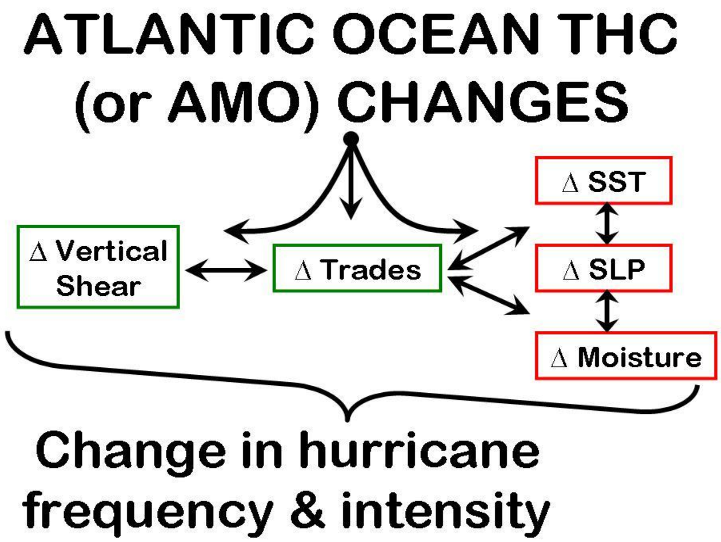

Figure 3: Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic's MDR between 7.5-22.5°N; 75-20°W. Vertical shear, trade-wind strength, and SST are the key parameters which respond to the THC changes. Favorable SLPA and mid-level moisture changes 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.

One of the primary physical drivers for active versus inactive Atlantic basin hurricane seasons is the strength of the THC or AMO (Gray et al. 1996, Goldenberg et al. 2001, Klotzbach and Gray 2008). A positive phase of the AMO (or strong phase of the THC) typically leads to 3-5 times more major Atlantic basin hurricane activity than does a negative phase. The typical period of the THC is about 60 years, with the period length varying between as short as 40-50 years and as long as 70-80 years. This means that we typically have 25-35 years of above-average Atlantic basin major TC activity and similar length periods with considerably reduced amounts of major TC activity.

While the THC typically remains in an above-average or in a below-average state for periods of 25-35 years, there can be monthly, seasonal or longer breaks up to a year or two within these decadal periods when the THC (or AMO) conditions of features such as SST, salinity, pressure, wind, and moisture become substantially weaker in positive THC phases or stronger during negative THC phases. We observed a significant weakening of the THC (or AMO) from the winter (January-March) to the spring (April-June) of 2013. The THC was also somewhat weaker than normal in the spring of 2014. We believe this played a major role in the below-normal seasons of 2013 and 2014. Other examples of years where the multi-decadal THC signal was temporarily interrupted were 1962 (ACE 36) and 1968 (ACE 45) during a positive multi-decadal phase of the THC (1926-69) and 1988 (ACE 103) and 1989 (ACE 135) during a negative multi-decadal phase of the THC (1970-94).

General Discussion. There is a strong inverse relationship between the strength of the THC and the strength of the Atlantic gyre (Bermuda-Azores High). This has been well documented in our analysis of various yearly and seasonal gyre and THC proxy variations. Hurricane activity, particularly the most intense hurricane activity, is much more frequent when the Atlantic Bermuda-Azores gyre circulation system is weak and the Atlantic Ocean THC system is strong. Hurricane activity is generally reduced when the reverse conditions occur. Increased gyre strength acts to bring about cooler air (and reduced moisture) and cooler ocean water advection in the eastern half of the Atlantic. This acts to increase the strength of the trade winds and increase the low latitude (5-20°N) south to north tropospheric temperature gradient and the upper tropospheric westerly winds. All of these changes are inhibiting factors for hurricane formation and intensification.

One of the primary reasons why we believe the 2013 Atlantic hurricane season was so quiet was due to a very strong weakening of the THC/AMO during the spring months of that year. The THC was slightly below-average during the spring of 2014 as well. Due to the associated forecast failure with the anomalous THC/AMO changes in 2013, we have created a new index to assess the strength of the THC that is defined as a combination of SST in the region from 20-70°N, 40-10°W and SLP in the region from 15-50°N, 60-10°W (Figure 4). The index is created by weighing the two parameters as follows: 0.6*SST – 0.4*SLP (Figure 5). The THC/AMO is currently about one standard deviation stronger than the 1950-2013 average. This above-average strength of the THC/AMO is one of the reasons why we believe that we currently remain in the active era for Atlantic basin TC activity.

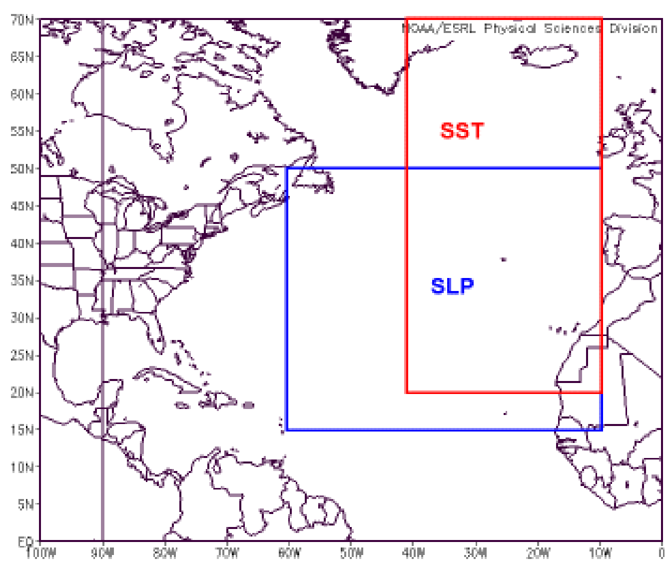

Figure 4: Regions which are utilized for calculation of the new THC/AMO index.

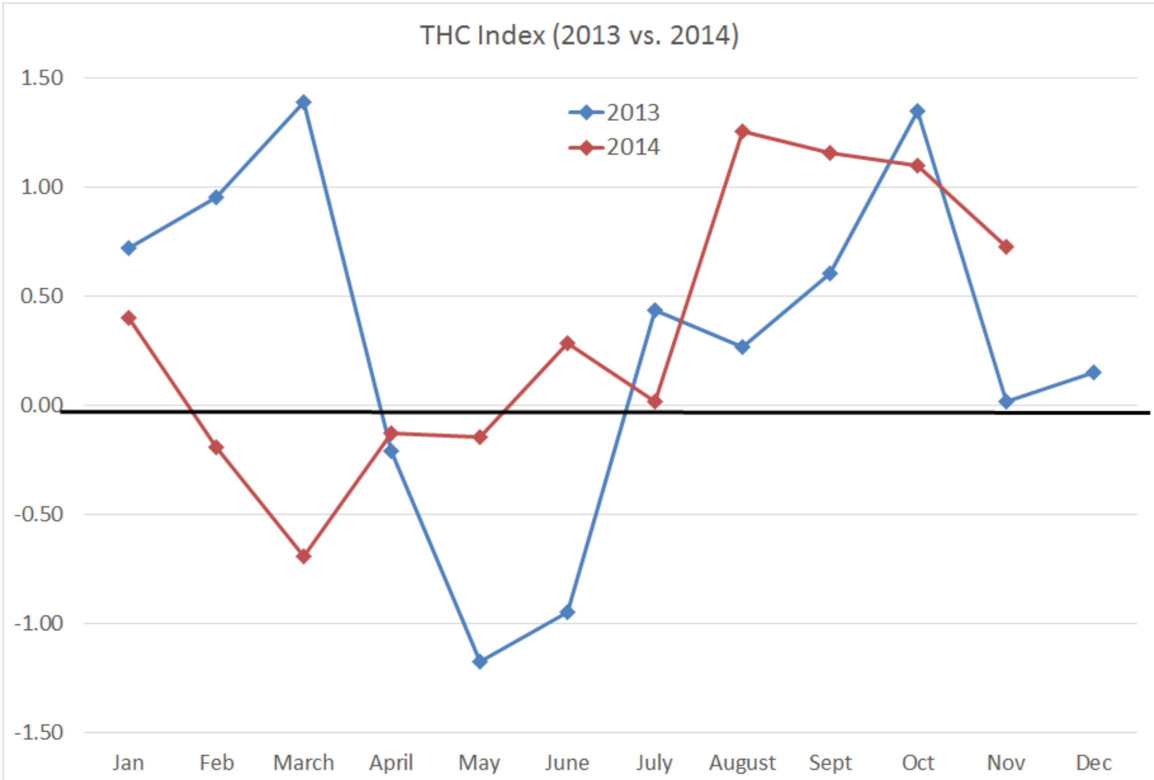

Figure 5: Standardized values of the THC/AMO index by month in 2013 (blue line) and 2014 (red line). Month-to-month changes were much less than 2014. Note that both 2013 and 2014 had THC/AMO values that rebounded significantly to strongly positive during the August-October period. We use THC and AMO interchangeably.

4 ENSO

We are currently in the process of transitioning to a weak El Niño event in the tropical Pacific. At this point, our best estimate is that we will likely see weak El Niño conditions this winter.

One of the important questions for the upcoming hurricane season is to whether the currently developing El Niño is likely to persist through next August-October. There is a significant amount of uncertainty from the various ENSO models for the extended range time period, as evidenced by the spread in the model guidance shown in Figure 6. The average of the numerical model guidance that is available for next July-September calls for borderline warm neutral/weak El Niño conditions next summer. At this point, we think there is an approximately 50% chance that El Niño will play a significant role in impacting next year's hurricane season.

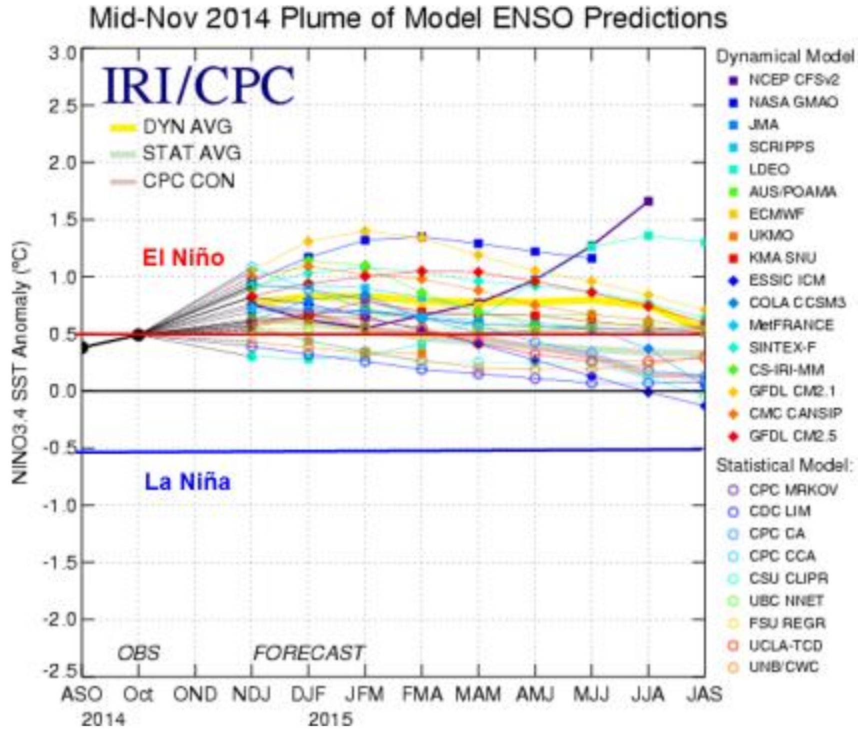

Figure 6: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

5 Qualitative 2015 Hurricane Outlook Summary

Two of the major influences that need to be monitored during the winter of 2014/2015 are the state of ENSO and the strength of the AMO (THC). As mentioned in our discussion, we believe that we remain in an active era for Atlantic basin tropical cyclones, and consequently, if El Niño does not develop, an active 2015 season is likely. However, given our current qualitative analysis and output from various numerical models, it appears that there is a moderate chance (approximately 50%) that El Niño will persist through the 2015 Atlantic basin hurricane season. By early April of next year, we should have a better idea of the likelihood of El Niño persisting. Both dynamical and statistical ENSO forecast models show significantly improved skill for an August-October forecast by early spring.

The following calculations assume that we remain in a strong phase of the THC (positive phase of the AMO) for the 2015 Atlantic hurricane season. Table 1 displays the median season experienced during two active phases of the THC (1950-1969, 1995-2013). Also included are the median active THC years when an El Niño takes place, along with the median for all other years where either neutral or La Niña conditions are present. For this analysis, we define El Niño to be when the August-October Nino 3.4 index is greater than or equal to 0.5°C.

Table 1: Strong or active THC median tropical cyclone values, active THC El Niño tropical cyclone values and all other active THC years.

Forecast Parameter	Active THC (All Years)	Active THC (El Niño)	Active THC (La Niña or Neutral ENSO)
Named Storms (NS)	12.0	10.0	12.5
Named Storm Days (NSD)	64.0	52.8	69.8
Hurricanes (H)	7.0	5.0	7.0
Hurricane Days (HD)	30.5	26.0	32.1
Major Hurricanes (MH)	3.0	2.0	3.5
Major Hurricane Days (MHD)	7.0	6.5	9.1
Accumulated Cyclone Energy (ACE)	121	84	124
Net Tropical Cyclone Activity (NTC)	134	86	142

For comparison, we now provide a similar analysis for the inactive phase of the THC (1970-1994). Table 2 displays the median for all inactive THC years, inactive THC years when an El Niño takes place, and the median for all other years where either neutral or La Niña conditions are present. Note how much lower the statistics are for all three columns, especially for El Niño years. An additional interesting fact is that the median El Niño year in an active THC phase is comparable to a non-El Niño year in an inactive THC phase.

Table 2: The weak or inactive THC median tropical cyclone values, inactive THC El Niño tropical cyclone values and all other inactive THC years.

Forecast Parameter	Inactive THC (All Years)	Inactive THC (El Niño)	Inactive THC (La Niña or Neutral ENSO)
Named Storms (NS)	9.0	7.0	11.0
Named Storm Days (NSD)	40.5	28.8	46.1
Hurricanes (H)	5.0	3.0	5.0
Hurricane Days (HD)	14.3	7.3	19.4
Major Hurricanes (MH)	1.0	1.0	2.0
Major Hurricane Days (MHD)	1.0	0.5	2.9
Accumulated Cyclone Energy (ACE)	68	36	80
Net Tropical Cyclone Activity (NTC)	80	38	87

At this extended lead time when ENSO forecasts have relatively little skill, we would expect to see an active season (in keeping with the median of the right-hand column in Table 1) unless El Niño persists. In that case, we would expect to see activity more in line with the third column of Table 2. At this point, we do not expect the THC to weaken substantially for the 2015 Atlantic hurricane season, but if that were the case, we would expect activity more in line with the median values listed in Table 2.

With our forecast issued in early April, we will also provide landfall probabilities for the United States coastline and the Caribbean. On a statistical basis, more active tropical cyclone seasons tend to have more landfalling hurricanes

7 Climatological Landfall Probabilities for 2015

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline and in the Caribbean. While we are not issuing a quantitative forecast in this early outlook, we can still provide interested readers with the climatological probabilities of landfall for various portions of the United States coastline.

Table 3 lists climatological strike probabilities for the 2015 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also issue probabilities for various islands and landmasses in the Caribbean and in Central America.

Table 3: Climatological probability (expressed in percent) of one or more landfalling tropical storms (TS), category 1-2 hurricanes (HUR), category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, along the Gulf Coast (Regions 1-4), and along the Florida Peninsula and the East Coast (Regions 5-11). Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided.

Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	Named Storms
Entire U.S. (Regions 1-11)	79%	68%	52%	84%	97%
Gulf Coast (Regions 1-4)	59%	42%	30%	60%	83%
Florida plus East Coast (Regions 5-11)	50%	44%	31%	61%	81%
Caribbean (10-20°N, 60-88°W)	82%	57%	42%	75%	96%

More recently, we have also calculated probabilities of each state being impacted by a tropical cyclone, using the impacts database available from the National Hurricane Center. Table 4 displays the climatological probabilities for each state along the United States coastline being impacted by a hurricane and major hurricane, respectively.

Table 4: Climatological probability of each state along the United States coastline being impacted by a hurricane and major hurricane, respectively.

State	Hurricane	Major Hurricane
Texas	33%	12%
Louisiana	30%	12%
Mississippi	11%	4%
Alabama	16%	3%
Florida	51%	21%
Georgia	11%	1%
South Carolina	17%	4%
North Carolina	28%	8%
Virginia	6%	1%
Maryland	1%	<1%
Delaware	1%	<1%
New Jersey	1%	<1%
New York	8%	3%
Connecticut	7%	2%
Rhode Island	6%	3%
Massachusetts	7%	2%
New Hampshire	1%	<1%
Maine	4%	<1%

The Landfall Probability Website (http://www.e-transit.org/hurricane) has additional probability information including county-level probabilities for 205 coastal counties from Brownsville, Texas to Eastport, Maine. These probabilities will be updated on Thursday, April 9 with our first quantitative outlook for 2015.

8 Recent Lack of United States Landfalling Hurricane Activity

The United States has had a remarkable lack of landfalling major hurricane activity since Hurricane Wilma in 2005. None of the 25 major hurricanes that have formed since Wilma have made US landfall. The 20th century climatological average is that 29% of all major hurricanes that form make US landfall as major hurricanes, so assuming that each event is independent and using a binomial distribution, the odds of getting 25 major hurricanes with no US landfalls is approximately 1:5200. In addition, the nine-year period that the US has gone without any major hurricane landfalls exceeds the previous record of eight years set between 1861-1868.

One of the big questions is why none of these systems have made US landfall. There is obviously a luck component that has played a significant role, in that several systems were located quite close to the US coast and recurved at the last minute (such as Hurricane Earl in 2010) or were just below major hurricane strength at landfall (such as Hurricane Ike in 2008). Another reason is that unlike 2004 and 2005, when seven of 13 major hurricanes made US landfall, anomalous troughing has tended to dominate the US

East Coast since 2006 (Figure 7). This anomalous troughing has caused westward tracking TCs to gain latitude and recurve before they could encounter the US coastline.

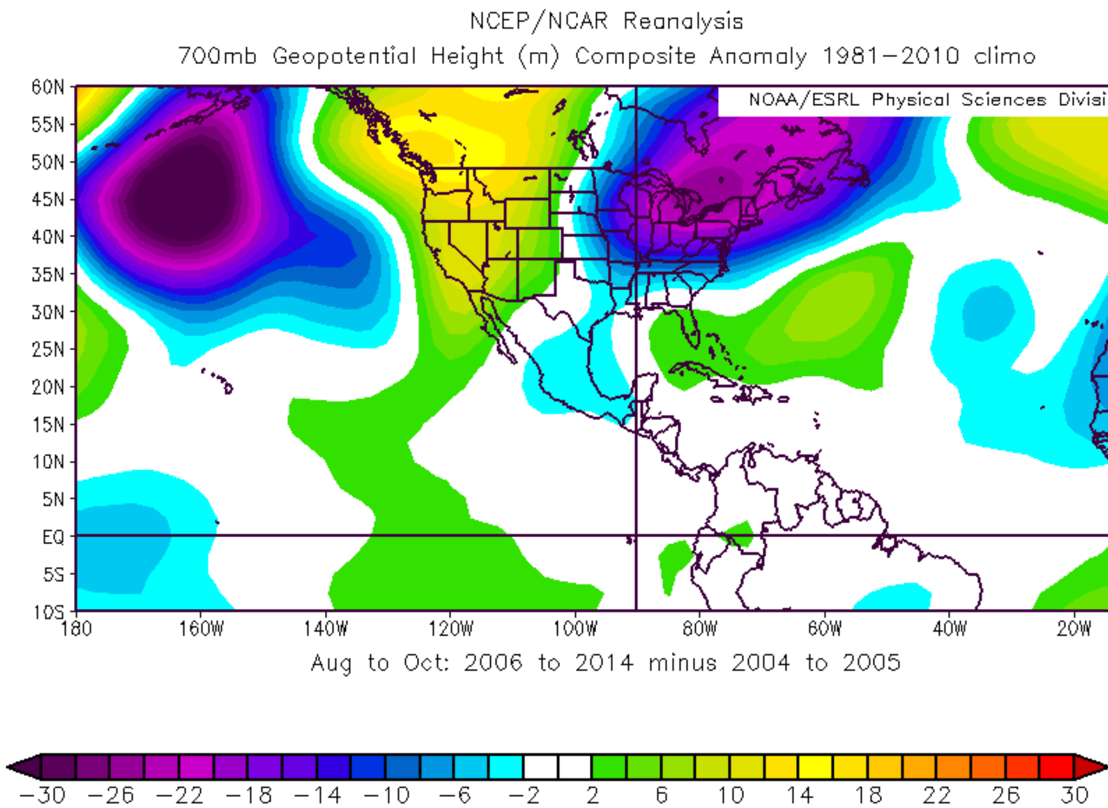

Figure 7: August-October 700-mb heights averaged from 2006-2014 minus August-Occtober 700-mb heights averaged from 2004-2005. Note the anomalous low pressure along the East Coast of the United States.

The state of Florida has also been remarkably lucky to have not been impacted by any hurricanes since Wilma in 2005. The longest period on record that Florida was not hit by a hurricane was the five-year period from 1980-1984 prior to the nine-year period from 2006-2014. In addition, 62 hurricanes have formed in the Atlantic basin since Wilma. The 20th century climatological average is that 9% of all hurricanes that form in the Atlantic basin make Florida landfall, so the odds of getting 62 hurricanes with no Florida landfalls is approximately 1:1200.

There has also been a marked decrease in Florida Peninsula and East Coast major hurricane landfalls over the past 49 years when compared with the previous 49 years. Figure 8 shows the tracks of major hurricane landfalls during the 49-year period from 1966-2014 compared with the previous 49-year period from 1917-1965. There have been less than 30% as many major hurricanes during the more recent period compared with the earlier period.

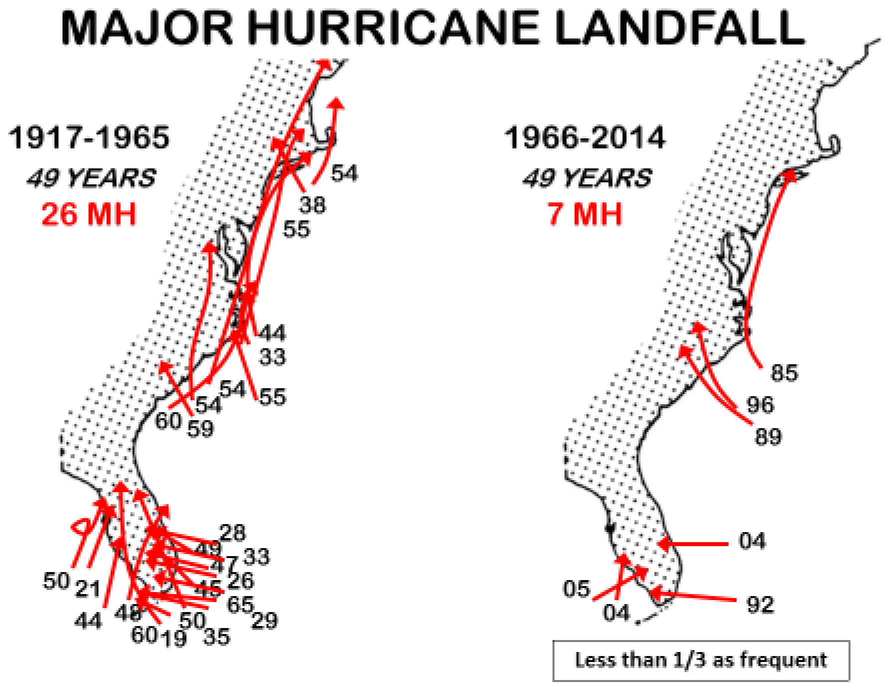

Figure 8: Tracks of major hurricanes making Florida Peninsula/East Coast landfall during the period from 1917-1965 and 1966-2014, respectively.

This luck cannot continue. Climatology will eventually reassert itself with many more US landfalling hurricanes. Coastal residents must realize that hurricanes remain a serious threat and should take preparedness actions before every season.

9 Can Rising Levels of CO_2 be Associated with the Devastation caused by Hurricane Sandy (2012) along with the Increase in Atlantic Hurricane Activity since 1995?

We have extensively discussed this topic in many previous papers which can be found on our Tropical Meteorology website. We do not believe that CO_2 increases have caused any significant increases in Atlantic basin or global tropical cyclone frequency or intensity. For more information on this topic we refer you to the following five references, which can be accessed by clicking on the links below:

Gray, W. M., 2011: Gross errors in the IPCC-AR4 report regarding past and future changes in global tropical cyclone activity. Science and Public Policy Institute, 122 pp.

Gray, W. M., and P. J. Klotzbach, 2011: Have increases in CO_2 contributed to the recent large upswing in Atlantic basin major hurricanes since 1995? Chapter 9 in "Evidence-Based Climate Science", D. Easterbrook, Ed., Elsevier Press, 27 pp.

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10 Forthcoming Updated Forecasts of 2015 Hurricane Activity

We will be issuing seasonal updates of our 2015 Atlantic basin hurricane forecasts on **Thursday April 9**, **Monday 1 June**, **Wednesday 1 July, and Monday 3 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2015 forecasts will be issued in late November 2015. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

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12 Verification of Previous Forecasts

Table 5: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2010-2014.

2010	9 Dec. 2009	Update 7 April	Update 2 June	Update 4 August	Obs.
Hurricanes	6-8	8	10	10	12
Named Storms	11-16	15	18	18	19
Hurricane Days	24-39	35	40	40	37.50
Named Storm Days	51-75	75	90	90	88.25
Major Hurricanes	3-5	4	5	5	5
Major Hurricane Days	6-12	10	13	13	11
Accumulated Cyclone Energy	100-162	150	185	185	163
Net Tropical Cyclone Activity	108-172	160	195	195	195

2011	8 Dec. 2010	Update 6 April	Update 1 June	Update 3 August	Obs.
Hurricanes	9	9	9	9	7
Named Storms	17	16	16	16	19
Hurricane Days	40	35	35	35	25
Named Storm Days	85	80	80	80	90.50
Major Hurricanes	5	5	5	5	3
Major Hurricane Days	10	10	10	10	4.50
Accumulated Cyclone Energy	165	160	160	160	125
Net Tropical Cyclone Activity	180	175	175	175	137

2012	4 April	Update 1 June	Update 3 August	Obs.
Hurricanes	4	5	6	10
Named Storms	10	13	14	19
Hurricane Days	16	18	20	26
Named Storm Days	40	50	52	99.50
Major Hurricanes	2	2	2	1
Major Hurricane Days	3	4	5	0.25
Net Tropical Cyclone Activity	75	90	105	121

2013	10 April	Update 3 June	Update 2 August	Obs.
Hurricanes	9	9	8	2
Named Storms	18	18	18	13
Hurricane Days	40	40	35	3.75
Named Storm Days	95	95	84.25	38.50
Major Hurricanes	4	4	3	0
Major Hurricane Days	9	9	7	0
Accumulated Cyclone Energy	165	165	142	33
Net Tropical Cyclone Activity	175	175	150	44

2014	10 April	Update 2 June	Update 1 July	Update 31 July	Obs.
Hurricanes	3	4	4	4	6
Named Storms	9	10	10	10	8
Hurricane Days	12	15	15	15	17.25
Named Storm Days	35	40	40	40	35
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	2	3	3	3	3.50
Accumulated Cyclone Energy	55	65	65	65	66
Net Tropical Cyclone Activity	60	70	70	70	81