**QUALITATIVE DISCUSSION OF ATLANTIC BASIN SEASONAL HURRICANE ACTIVITY FOR 2014**

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 2014 Atlantic basin hurricane season is whether or not El Niño will develop.

Our first quantitative forecast for 2014 may be issued on Thursday, April 10 if additional funding is forthcoming.

(as of 10 December 2013)

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.

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Email: amie@atmos.colostate.edu

[1] Research Scientist
[2] Professor Emeritus of Atmospheric Science

**ABSTRACT**

We are providing a qualitative discussion of features likely to impact the 2014 Atlantic basin hurricane season rather than a specific numbers forecast. This outlook for 2014 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 have been in an active era for Atlantic basin tropical cyclones since 1995 (despite the quiet season that occurred in 2013), and we expect that typical conditions associated with a positive Atlantic Multi-Decadal Oscillation (AMO) and strong thermohaline circulation (THC) will continue. One of the big challenges for 2014 is whether or not El Niño will develop for the 2014 hurricane season. Since El Niño has not occurred since 2009, the odds of an El Niño this year are fairly high. In addition, many of the global models are hinting at the possibility of El Niño developing next year. While we saw a significant weakening of the Atlantic Multidecadal Oscillation (AMO) and thermohaline circulation (THC) during the summer of 2013, North Atlantic SST and sea level pressure patterns have since rebounded to conditions characteristic of an active era. We anticipate that the 2014 Atlantic basin hurricane season will be primarily determined by the strength of the THC/AMO and by the state of ENSO.

For the 2014 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 2014 and no El Niño event occurs (resulting in a seasonal average net tropical cyclone (NTC) activity of ~ 180) – **15% chance**.

2. THC continues in the above-average condition it has been in since 1995 and no El Niño develops (NTC ~ 140) – **35% 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 hurricanes


## Acknowledgment

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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 much statistical analysis and advice 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 50-60°N, 10-50°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.

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.

Oceanic Nino Index (ONI) – Three-month running mean of SST in the Nino 3.4 region (5°N-5°S, 120°-170°W).

Saffir/Simpson Scale – A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge 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

# NOTICE OF FORECAST SUSPENSION

The Tropical Meteorology Project has been issuing forecasts for the past thirty years. These predictions have served as a valuable information tool for insurance interests, emergency managers and coastal residents alike. While these forecasts were largely developed utilizing funding from various government agencies, recent attempts at obtaining continued grant funding have been unsuccessful. Funding from several insurance companies enabled the continuation of these forecasts in recent years. However, the forecast team has recently lost some of its financial support from industry. Consequently, new sources of revenue are required to keep the forecast going. Interested parties are invited to contact Phil Klotzbach directly via email at philk@atmos.colostate.edu for additional discussion of potential sponsorship opportunities.

The Tropical Meteorology Project will suspend issuing seasonal forecasts beginning in April 2014, unless additional funding for the forecasts is forthcoming. The CSU forecast team is currently seeking partnerships with the private sector in order to continue these predictions. Please see the sponsorship brochure if you are interested in supporting the forecast team.

# 1 Introduction

This is the 31st 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

Despite the significant forecast bust that occurred in 2013, 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 last year. 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 2014 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. The ocean water that does not sink in weaker periods of the NADWF tends to recirculate and increase the ocean's clockwise circulating gyre motion.

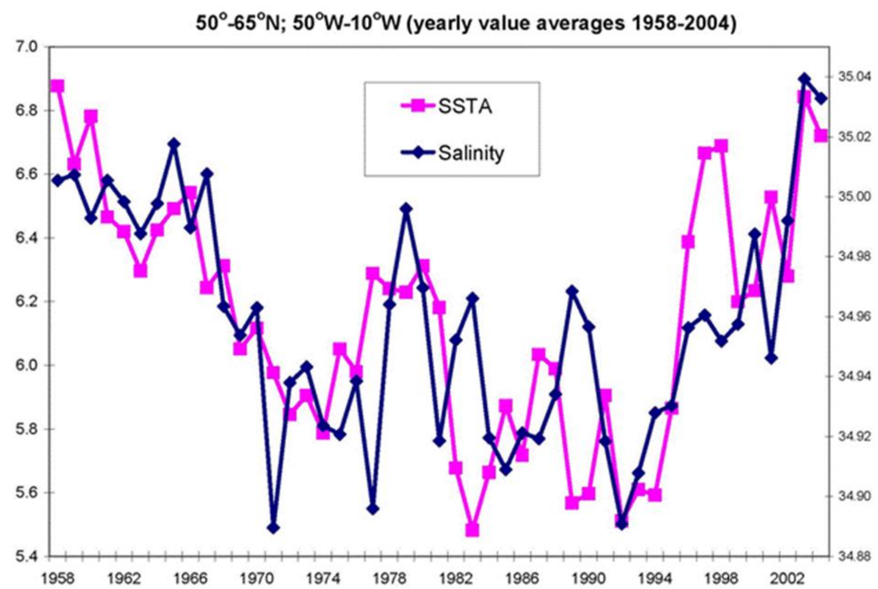


Figure 1: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

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 <u>M</u>ain <u>D</u>evelopment <u>R</u>egion (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.

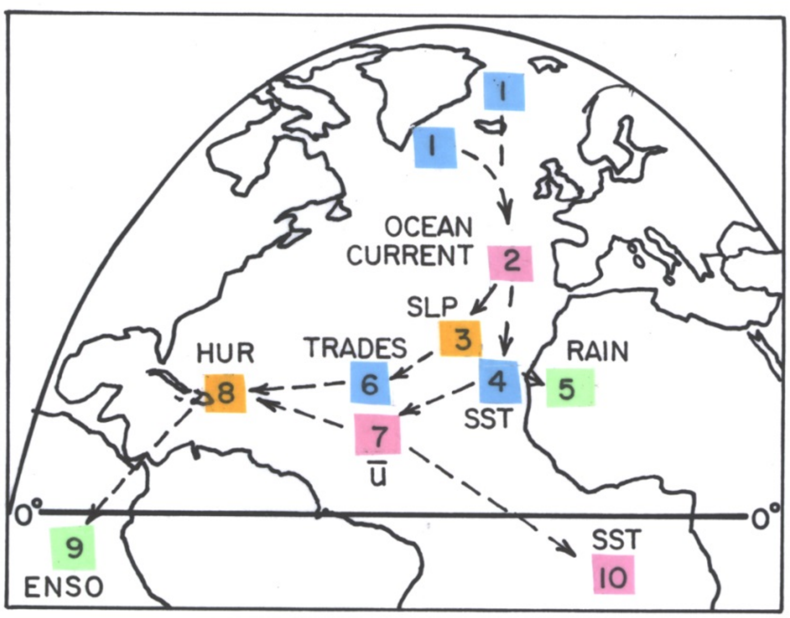


Figure 2: Idealized analysis of how changes in North Atlantic SST and salinity (area 1) lead to progressive ocean current, wind, pressure, SST, vertical shear and rain changes as portrayed in nine areas. It is this complete package of Atlantic/eastern Pacific ocean/atmosphere parameter changes on multi-decadal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

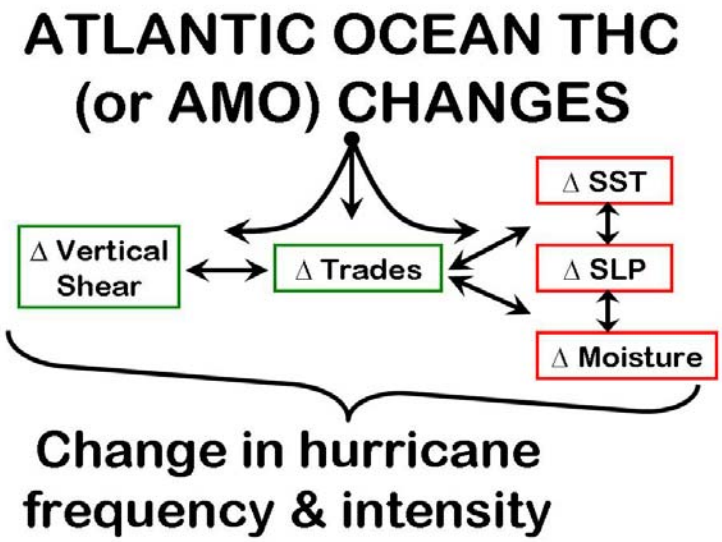


Figure 3: Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic's MDR between 7.5-22.5°N; 20-75°W. Vertical shear, trade-wind strength, and SST are the key parameters which respond to the THC changes. Favorable SLPA and mid-level moisture changes 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 (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. We believe this played a major role in the much weaker than predicted 2013 hurricane season that occurred this year. Other examples of 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 (1950-69) and 1988 (ACE 103) and 1989 (ACE 135) during a negative multi-decadal phase of the THC (1970-94).

### 3.1 Rapid Changes in the THC and Atlantic Gyre in 2013

The THC (or AMO) was quite strong during the first three months of 2013 according to our inverse proxy signal of the pressure gyre strength. The THC then weakened and the gyre strength dramatically increased during the spring (Figure 4 and 5). Values in May/June were the lowest observed in the Atlantic basin since 1950. However, these values soon rebounded and were back above normal by July. Despite the rapid re-strengthening of the THC during the summer of 2013, it appears that the lagged impact of the sudden and strong weakening during the spring months carried over into the late summer period and was primarily responsible for the much weaker amount of hurricane activity than we had anticipated for 2013.

**Reasons for the 2013 hurricane season being so weak?** The majority of Atlantic basin hurricane seasons with the least amount of activity occur in El Nino years. The average amount of hurricane activity as expressed by ACE in 12 (or 20%) of the last 64 years in which moderate or strong El Ninos have occurred was only 50. The average ACE of the other 48 (or 80% of years since 1950) years in which El Nino activity was not present was 120 or 240 percent greater.

The 2013 Atlantic hurricane season had an ACE value of only 33. This low hurricane season is only rivaled for low activity since 1950 during non-El Nino years by 1962 (ACE = 36), 1968 (ACE = 45), 1977 (ACE = 25), 1993 (ACE = 39), and 1994 (ACE = 32).

We attribute a sizable portion of the reduction in the 2013 hurricane activity to the unusual springtime (April through June) weakening of the THC/AMO and the associated large increase in strength of the Atlantic gyre. We failed to realize the importance of this first half of the year reduction in the strength of the THC and increase in strength of the subtropical gyre. Part of our failure was due to the rapid reversal in strength of the THC (and gyre) in July that has continued to the present. We will use this 2013 experience to more carefully monitor the smaller-scale changes of the THC in the future.

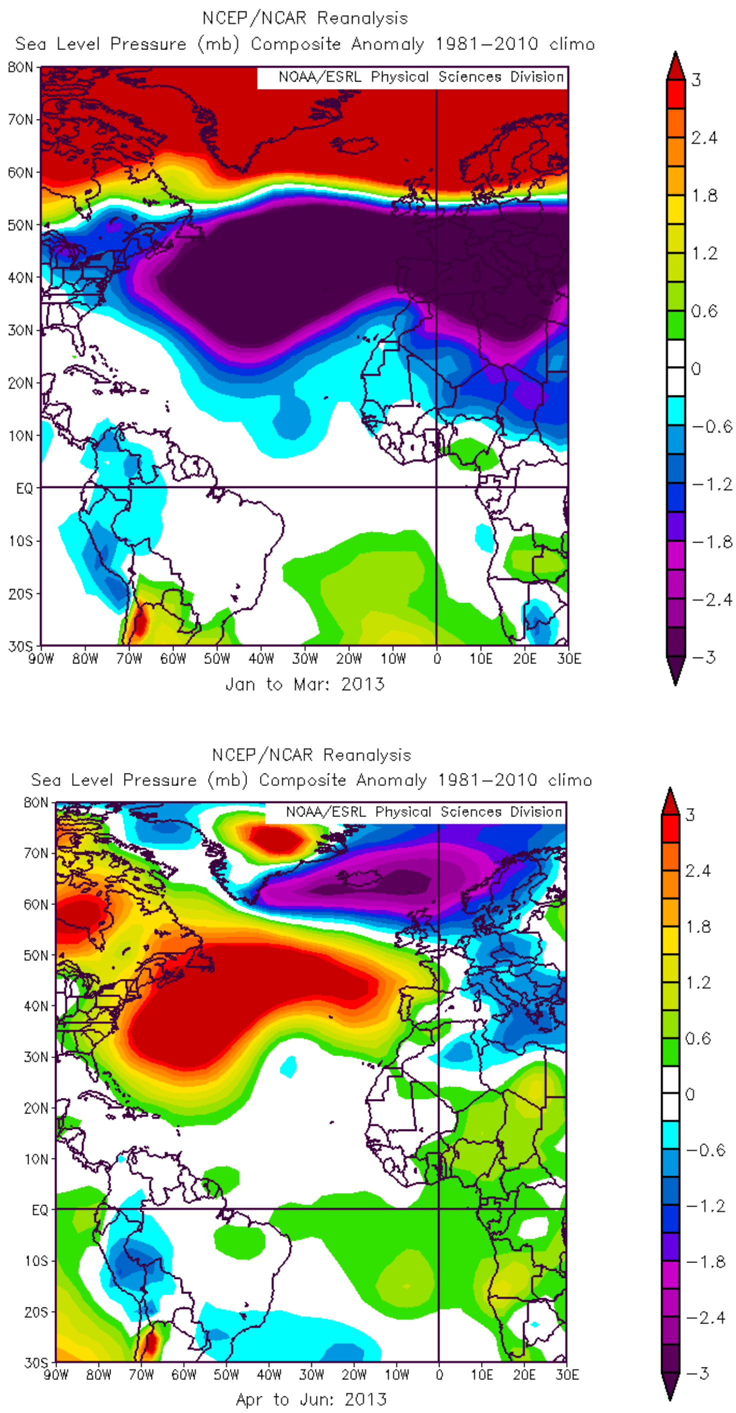


Figure 4: Illustration of large 2013 sea level pressure anomaly increase between Jan-Mar (top) and April-June (bottom). Units are in mb.

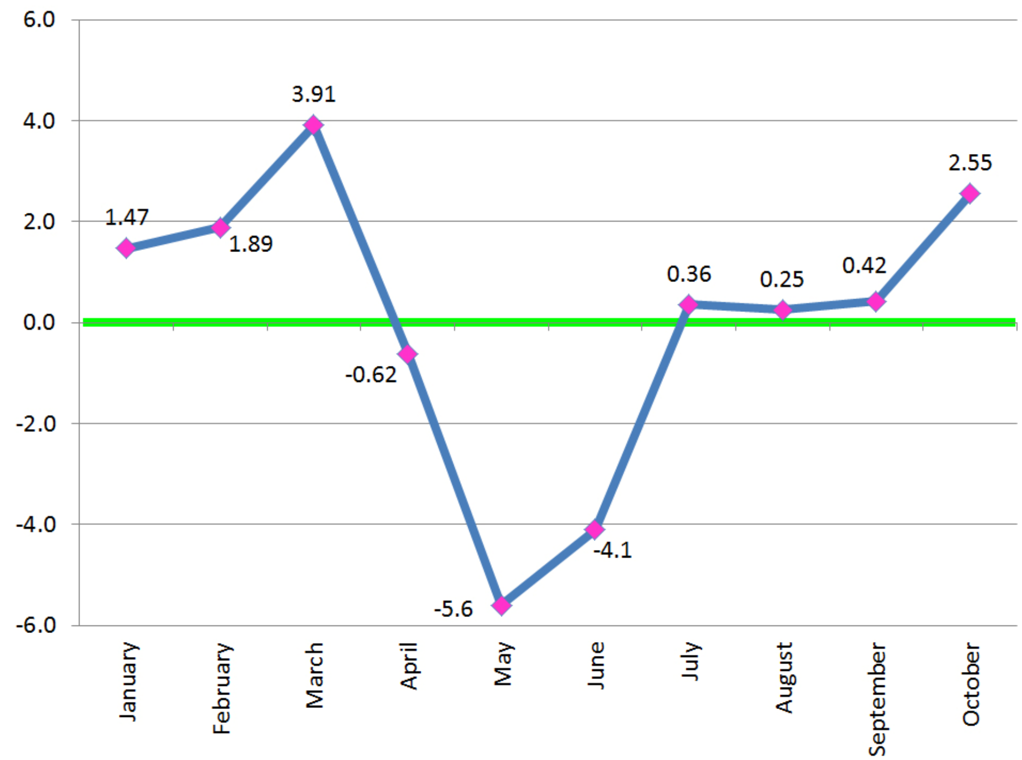


Figure 5: Sum of the standard deviations of the old and new proxies for the THC (or AMO) from January-October 2013. Note the dramatic spring collapse. The combined May-June 2013 value was the lowest of any year since 1950.

**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. The spring of 2013 had one of the strongest Bermuda-Azores gyres on record.

An increasing 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.

Observations show that prior season increasing or decreasing strength of the Atlantic gyre pressure has a direct influence on hurricane frequency and intensity irrespective of the strength of the gyre circulation alone.

The character of the 2013 season was unusual in that there were an average number of tropical storms (13), but only two minimal (Cat. 1) short-lived hurricanes developed. Previous research has taught us of the strong influence of multi-decadal variations of the THC/AMO to the changing number and period of the most intense hurricanes. But we had not analyzed in as much detail the influence of shorter period variations of the THC and subtropical gyre on the influence on yearly hurricane changes.

Our large forecast error in 2013 was primarily due to a gross over-estimate of the number and strength of major hurricanes. We were unprepared for the consequences of such an unusual 2013 winter (Jan-Mar) to spring (April-June) decrease in the strength of the THC/AMO and its associated increase in strength of the high pressure gyre. We estimate THC strength from the proxy signals shown in Figure 6. Our older proxy used the SSTA of the North Atlantic minus the SLPA of the Atlantic south of 50°N. A newer proxy for the THC/AMO uses a combination of the SSTA, SLPA and the surface meridional wind (V) in the eastern sub-tropical Atlantic.

The strength of the Atlantic high pressure gyre (or weakness in the THC/AMO) in the spring period of April to June typically gives a good indication of the amount of intense hurricane activity to follow later in the year.

It is very rare to observe such a large increase in the high pressure of the Atlantic gyre between any winter to spring period as occurred in 2013. This large gyre increase was the largest in our data sets. It is a rare ocean-atmosphere change event that was thus not in our forecast developmental data set up to now – but will be included in future seasonal forecasts.

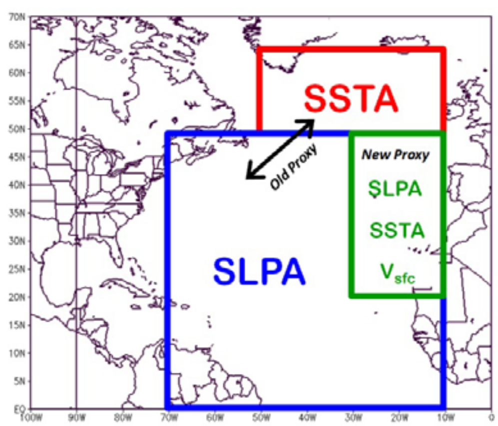


Figure 6: Areas used for our proxies of the strength of the Atlantic THC and the inverse strength of the Atlantic high pressure gyre.

# 4 ENSO

We currently have neutral ENSO conditions in place over the tropical Pacific. Neutral conditions have been present in the tropical Pacific for the past several months.

One of the important questions for the upcoming hurricane season is whether El Niño will develop for the 2014 hurricane season. Table 1 displays years since 1950 with similar September-October MEI values to 2013 (from -0.25 to 0.25 standard deviations of normal). Also displayed are the following year's August-September MEI values. Of the thirteen years with similar MEI values to late 2013, five (38%) experienced El Niño conditions (defined as an August-September MEI greater than 0.5 standard deviations above normal) the following year. In addition, we have now gone since 2009 without an El Niño. Typically, warm ENSO events occur about 3-7 years.

Given this analysis, there is significant uncertainty in exactly what ENSO conditions will look like next year. Most statistical and dynamical forecast models indicate that neutral conditions will persist through the winter (Figure 7), with a significant contingent of the dynamical models hinting at the development of El Niño next spring and summer as evidenced by predictions for the Nino 3.4 region (5°S-5°N, 120°-170°W). The ECMWF model shows a slight skewness towards a warm ENSO event next summer (Figure 8). In general, this model has the highest levels of skill at predicting ENSO events, and consequently, there appears to be some likelihood that an El Niño will develop next year. We will be closely monitoring ENSO conditions over the next few months and will have more to say with our early April update.

Table 1: Years with September-October MEI values between -0.25 and 0.25 standard deviations, and the following year's August-September MEI values. Five of the thirteen years had El Niño develop by the later part of the following summer. The correlation between the September-October MEI and the following year's August-September MEI is near zero.

| Year | September-October MEI | Following Year's August-September MEI |
|---|---|---|
| 1953 | 0.1 | -1.2 |
| 1958 | 0.2 | 0.1 |
| 1959 | -0.1 | -0.5 |
| 1966 | 0.0 | -0.6 |
| 1978 | 0.0 | 0.8 |
| 1980 | 0.2 | 0.2 |
| 1981 | 0.1 | 1.8 |
| 1983 | 0.0 | -0.1 |
| 1984 | 0.0 | -0.5 |
| 1985 | -0.1 | 1.2 |
| 1990 | 0.2 | 0.7 |
| 2005 | -0.2 | 0.8 |
| 2012 | 0.1 | -0.2 |
| | | |
| **Average** | **0.0** | **0.1** |
| | | |
| 2013 | 0.1 | |

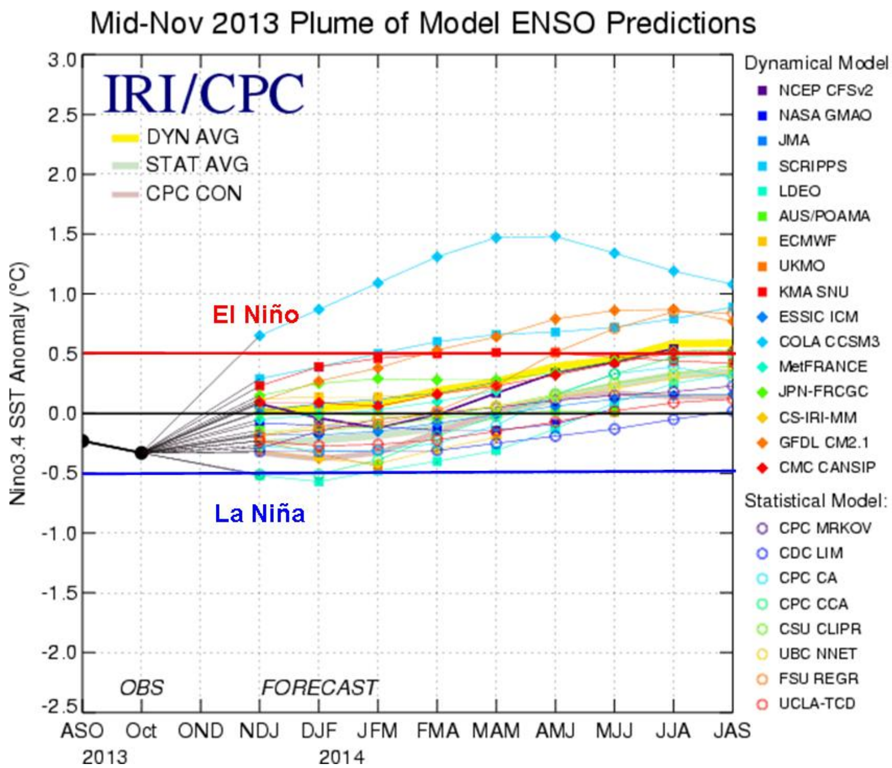


Figure 7: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI).

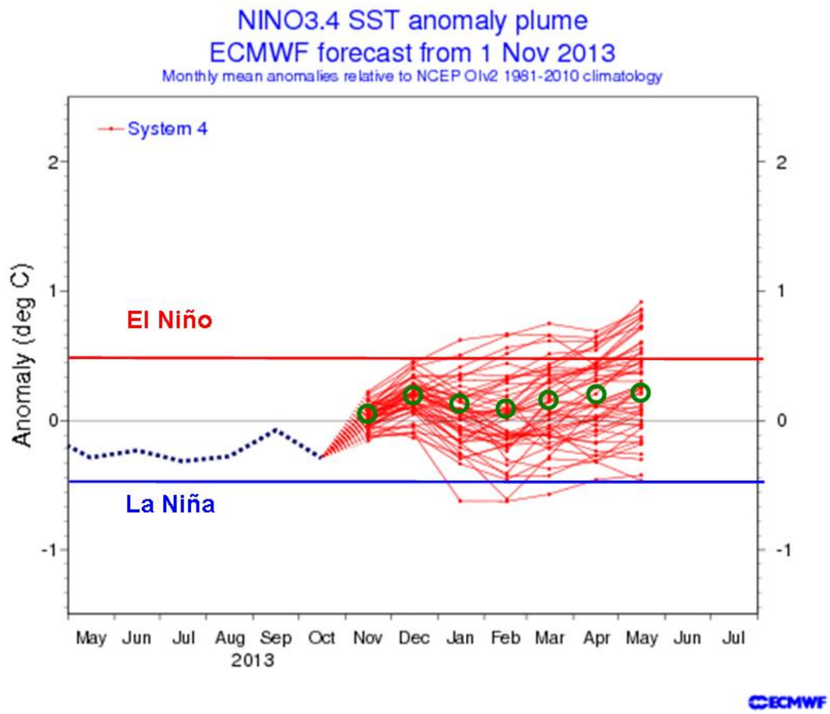


Figure 8: Scatterplot of ECMWF system 4 ensemble members for the Nino 3.4 region. Note that approximately 1/3 of ensemble members are predicting El Niño conditions by May. The green circle indicates the approximate midpoint of ensemble members.

## 5 Qualitative 2014 Hurricane Outlook Summary

Two of the major influences that need to be monitored during the winter of 2013/2014 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 2014 season is likely. However, given our current statistical analysis, it appears that there is a moderate chance (approximately 50%) that El Niño will develop for the 2014 Atlantic basin hurricane season. By early April of next year, we should have a better idea of the likelihood of ENSO developing. 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 2014 Atlantic hurricane season. Table 2 displays the median season experienced during an active phase 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 2: 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 3 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 3: 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 2) unless an El Niño develops. 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 2014 Atlantic hurricane season, but if that were the case, we would expect activity more in line with the median values listed in Table 3.

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. Lastly, we reiterate the outlook discussed in our abstract as our best estimate for the 2014 Atlantic hurricane season:

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1. THC circulation becomes unusually strong in 2014 and no El Niño event occurs (resulting in a seasonal average net tropical cyclone (NTC) activity of ~ 180) – **15% chance**.

2. THC continues in the above-average condition it has been in since 1995 and no El Niño develops (NTC ~ 140) – **35% 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 hurricanes

## 7 Landfall Probabilities for 2014

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 4 lists climatological strike probabilities for the 2014 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 4: 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% |

The second author broke down the United States coastline into eleven regions based upon climatological probabilities of landfall during the 20th century. Figure 9 displays landfalling TCs along the United States coastline from 1900-1999, along with the locations of the eleven landfall regions. The black line between Region 4 and 5 delineates our breakdown between the Gulf Coast and Florida Peninsula and East Coast regions.

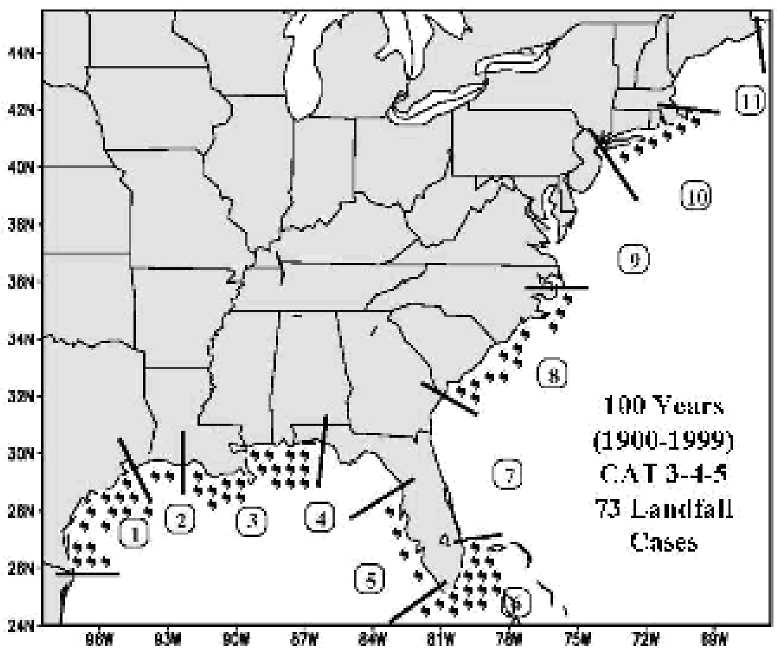


Figure 9: Eleven regions along the United States coastline which were created based upon the frequency of major hurricane landfall during the period from 1900-1999.

Table 5 displays the climatological probability of one or more named storms, hurricanes and major hurricanes making landfall in each of the eleven regions, based upon statistics since the late 19th century.

Table 5: Climatological probability of one or more named storms, hurricanes and major hurricanes making landfall in each of eleven regions.

| Region | Named Storm Probability | Hurricane Probability | Major Hurricane Probability |
|---|---|---|---|
| 1 | 43% | 29% | 13% |
| 2 | 19% | 10% | 3% |
| 3 | 56% | 33% | 17% |
| 4 | 29% | 14% | 2% |
| 5 | 22% | 8% | 5% |
| 6 | 37% | 28% | 14% |
| 7 | 18% | 8% | 2% |
| 8 | 41% | 29% | 9% |
| 9 | 9% | 3% | <1% |
| 10 | 15% | 9% | 4% |
| 11 | 6% | 3% | <1% |

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 6 displays the climatological probabilities for each state along the United States coastline being impacted by a hurricane and major hurricane, respectively.

Table 6: 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. Figure 10 displays the climatological probabilities for all of the counties in Region 1, while Figure 11 displays more in-depth information based on the August 2012 seasonal forecast for Broward County, Florida.

| | A | F | G | I | J | L | M |
|---|---|---|---|---|---|---|---|
| 10-12 | Region/County | Probability of 1 or More Named Storms Making Landfall in the County | 50-Year Probability of a Named Storm Making Landfall in the County | Probability of 1 or More Hurricanes Making Landfall in the County | 50-Year Probability of a Hurricane Making Landfall in the County | Probability of 1 or More Intense Hurricanes Making Landfall in the County | 50-Year Probability of an Intense Hurricane Making Landfall in the County |
| 13 | Cameron | 6.0 | 95.9 | 3.6 | 84.8 | 1.5 | 52.2 |
| 14 | Hidalgo | 6.5 | 97.0 | 4.0 | 87.3 | 1.6 | 55.3 |
| 15 | Willacy | 3.0 | 78.7 | 1.8 | 60.0 | 0.7 | 30.3 |
| 16 | Kenedy | 8.4 | 99.0 | 5.1 | 93.3 | 2.1 | 65.0 |
| 17 | Kleberg | 2.7 | 74.6 | 1.6 | 55.7 | 0.6 | 27.4 |
| 18 | Brooks | 4.4 | 89.9 | 2.6 | 74.2 | 1.1 | 41.2 |
| 19 | Jim Wells | 7.2 | 97.9 | 4.3 | 89.7 | 1.7 | 58.8 |
| 20 | San Patricio | 1.8 | 59.7 | 1.1 | 41.8 | 0.4 | 19.2 |
| 21 | Nueces | 2.7 | 74.6 | 1.6 | 55.7 | 0.6 | 27.4 |
| 22 | Aransas | 5.7 | 95.1 | 3.4 | 83.2 | 1.4 | 50.2 |
| 23 | Calhoun | 4.7 | 91.7 | 2.9 | 77.0 | 1.1 | 43.8 |
| 24 | Matagorda | 9.3 | 99.4 | 5.7 | 95.1 | 2.3 | 69.0 |
| 25 | Refugio | 4.6 | 91.2 | 2.8 | 76.2 | 1.1 | 43.0 |
| 26 | Bee | 2.8 | 75.7 | 1.7 | 56.8 | 0.7 | 28.1 |
| 27 | Goliad | 2.4 | 71.1 | 1.5 | 52.2 | 0.6 | 25.2 |
| 28 | Victoria | 3.4 | 82.9 | 2.0 | 64.9 | 0.8 | 33.7 |
| 29 | Jackson | 3.6 | 84.3 | 2.1 | 66.6 | 0.9 | 35.0 |
| 30 | Wharton | 4.5 | 90.7 | 2.7 | 75.5 | 1.1 | 42.4 |
| 31 | Brazoria | 6.3 | 96.6 | 3.8 | 86.3 | 1.5 | 54.1 |
| 32 | Galveston | 4.3 | 89.4 | 2.6 | 73.6 | 1.0 | 40.6 |
| 33 | Fort Bend | 3.9 | 86.8 | 2.3 | 69.9 | 0.9 | 37.6 |
| 34 | Harris | 4.5 | 90.3 | 2.7 | 74.9 | 1.1 | 41.8 |

Figure 10: Individual county probabilities for Region 1. Probabilities for every county along the United States coastline are listed in a similar fashion on the Landfall Probability Website.

Please Select a State: Florida

Please Select a County: Broward

Current State Data (Climatology in Parentheses):

| State Name | Probability of Hurricane Impact | Probability of Major Hurricane Impact |
|---|---|---|
| Florida | 47.3% (51.0%) | 19.1% (21.0%) |

Current Regional Data (Climatology in Parentheses):

| Region Number | Probability of 1 or More Named Storms Making Landfall in the Region | Probability of 1 or More Hurricanes Making Landfall in the Region | Probability of 1 or More Intense Hurricanes Making Landfall in the Region |
|---|---|---|---|
| 6 | 33.8% (36.7%) | 25.5% (27.9%) | 12.6% (13.9%) |

Current County Data (Climatology in Parentheses):

| County Name | Probability of 1 or More Named Storms Making Landfall in the County | Probability of 1 or More Hurricanes Making Landfall in the County | Probability of 1 or More Intense Hurricanes Making Landfall in the County | Probability of Tropical Storm-Force (>= 40 mph) Wind Gusts in the County | Probability of Hurricane-Force (>= 75 mph) Wind Gusts in the County | Probability of Intense Hurricane-Force (>= 115 mph) Wind Gusts in the County |
|---|---|---|---|---|---|---|
| Broward | 3.4% (3.7%) | 2.4% (2.7%) | 1.1% (1.2%) | 30.0% (32.7%) | 10.4% (11.5%) | 4.0% (4.4%) |

50 Year Regional Data:

| Region Number | 50 Year Probability of 1 or More Named Storms Making Landfall in the Region | 50 Year Probability of 1 or More Hurricanes Making Landfall in the Region | 50 Year Probability of 1 or More Intense Hurricanes Making Landfall in the Region |
|---|---|---|---|
| 6 | >99.9% | >99.9% | >99.9% |

50 Year County Data:

| County Name | 50 Year Probability of 1 or More Named Storms Making Landfall in the County | 50 Year Probability of 1 or More Hurricanes Making Landfall in the County | 50 Year Probability of 1 or More Intense Hurricanes Making Landfall in the County | 50 Year Probability of Tropical Storm-Force (>= 40 mph) Wind Gusts in the County | 50 Year Probability of Hurricane-Force (>= 75 mph) Wind Gusts in the County | 50 Year Probability of Intense Hurricane-Force (>= 115 mph) Wind Gusts in the County |
|---|---|---|---|---|---|---|
| Broward | 85.5% | 74.7% | 46.4% | >99.9% | 99.9% | 90.0% |

Figure 11: In-depth county probabilities based on the August 2012 seasonal forecast for Broward County, Florida.

## 8 Have Atmospheric $CO_2$ Increases Been Responsible for the Recent Large Upswing (since 1995) in Atlantic Basin Major Hurricanes and Devastating US Hurricanes of Recent Years?

We strongly believe that the increases in atmospheric $CO_2$ since the start of the $20^{th}$ century have had little or no significant effect on Atlantic basin or global TC activity as extensively discussed in our many previous forecast write-ups and recently in Gray (2011). Global tropical cyclone activity has shown no significant trend over the past thirty years.

We do not believe that Hurricane/Superstorm Sandy, or other destructive tropical cyclones of the past ten years (e.g., Ivan, Katrina, Rita, Wilma, Ike, etc.) are a direct consequence of human-induced global warming. Any impacts of climate change on hurricanes are believed to be quite small and within the noise level. A more complete discussion of Hurricane Sandy and climate change, along with a more in-depth discussion of trends in Atlantic basin TC activity are given in Gray and Klotzbach (2012).

## 9 Forthcoming Updated Forecasts of 2014 Hurricane Activity

Additional funding for our project is required before producing any more seasonal forecasts. Assuming that this funding is forthcoming, we will be issuing seasonal updates of our 2014 Atlantic basin hurricane forecasts on **Thursday April 10**, **Monday 2 June**, **and Friday 1 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 2014 forecasts will be issued in late November 2014. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

## 10 Acknowledgments

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# 12 Verification of Previous Forecasts

Table 7: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2009-2013.

| 2009 | 10 Dec. 2008 | Update 9 April | Update 2 June | Update 4 August | Obs. |
|---|---|---|---|---|---|
| Hurricanes | 7 | 6 | 5 | 4 | 3 |
| Named Storms | 14 | 12 | 11 | 10 | 9 |
| Hurricane Days | 30 | 25 | 20 | 18 | 11.25 |
| Named Storm Days | 70 | 55 | 50 | 45 | 27.25 |
| Major Hurricanes | 3 | 2 | 2 | 2 | 2 |
| Major Hurricane Days | 7 | 5 | 4 | 4 | 3.25 |
| Accumulated Cyclone Energy | 125 | 100 | 85 | 80 | 50 |
| Net Tropical Cyclone Activity | 135 | 105 | 90 | 85 | 66 |

| 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 |