# EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2013

We continue to foresee a very active 2013 Atlantic hurricane season. The tropical Atlantic remains very warm, and we do not anticipate development of a significant El Niño. Given the above-average forecast, we are calling for an above-average probability of United States and Caribbean major hurricane landfall.

(as of 3 June 2013)

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

This forecast as well as past forecasts and verifications are available via the World Wide Web at http://hurricane.atmos.colostate.edu/Forecasts

Kate Jeracki, Colorado State University Media Representative, (970-491-2658 or Kate.Jeracki@colostate.edu) is available to answer various questions about this forecast

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2013

| Forecast Parameter and 1981-2010 Median (in parentheses) | Issue Date 10 April 2013 | Issue Date 3 June 2013 |
|---|---|---|
| Named Storms (NS) (12.0) | 18 | 18 |
| Named Storm Days (NSD) (60.1) | 95 | 95 |
| Hurricanes (H) (6.5) | 9 | 9 |
| Hurricane Days (HD) (21.3) | 40 | 40 |
| Major Hurricanes (MH) (2.0) | 4 | 4 |
| Major Hurricane Days (MHD) (3.9) | 9 | 9 |
| Accumulated Cyclone Energy (ACE) (92) | 165 | 165 |
| Net Tropical Cyclone Activity (NTC) (103%) | 175 | 175 |

PROBABILITIES FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE LANDFALL ON EACH OF THE FOLLOWING COASTAL AREAS:

1) Entire U.S. coastline - 72% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 48% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 47% (average for last century is 30%)

PROBABILITY FOR AT LEAST ONE MAJOR (CATEGORY 3-4-5) HURRICANE TRACKING INTO THE CARIBBEAN (10-20°N, 60-88°W)

1) 61% (average for last century is 42%)

2013 STATE IMPACT PROBABILITIES (NUMBERS IN PARENTHESES ARE LONG-PERIOD AVERAGES)

| State | Hurricane | Major Hurricane |
|---|---|---|
| Texas | 50% (33%) | 20% (12%) |
| Louisiana | 47% (30%) | 20% (12%) |
| Mississippi | 18% (11%) | 8% (4%) |
| Alabama | 26% (16%) | 4% (3%) |
| Florida | 71% (51%) | 34% (21%) |
| Georgia | 19% (11%) | 2% (1%) |
| South Carolina | 28% (17%) | 7% (4%) |
| North Carolina | 44% (28%) | 13% (8%) |
| Virginia | 11% (6%) | 1% (1%) |
| Maryland | 2% (1%) | <1% (<1%) |
| Delaware | 2% (1%) | <1% (<1%) |
| New Jersey | 2% (1%) | <1% (<1%) |
| New York | 13% (8%) | 6% (3%) |
| Connecticut | 12% (7%) | 3% (2%) |
| Rhode Island | 10% (6%) | 4% (3%) |
| Massachusetts | 12% (7%) | 3% (2%) |
| New Hampshire | 2% (1%) | <1% (<1%) |
| Maine | 7% (4%) | <1% (<1%) |
| Whole US | 96% (84%) | 72% (52%) |

**Please also visit the Landfalling Probability Webpage at http://www.e-transit.org/hurricane for landfall probabilities for 11 U.S. coastal regions and 205 coastal and near-coastal counties from Brownsville, Texas to Eastport, Maine. In addition, we now include probabilities of named storms, hurricanes and major hurricanes tracking within 50 and 100 miles of various islands and landmasses in the Caribbean and Central America. We suggest that all coastal residents visit the Landfall Probability Webpage for their individual probabilities. We also urge coastal residents to fully prepare for all hurricane seasons, regardless of what our seasonal forecast may be.**

# ABSTRACT

Information obtained through May 2013 indicates that the 2013 Atlantic hurricane season will have more activity than the median 1981-2010 season. We estimate that 2013 will have about 9 hurricanes (median is 6.5), 18 named storms (median is 12.0), 95 named storm days (median is 60.1), 40 hurricane days (median is 21.3), 4 major (Category 3-4-5) hurricanes (median is 2.0) and 9 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be about 140 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2013 to be approximately 175 percent of the long-term average. This forecast is the same as the forecast that we issued in early April.

**This forecast is based on a new extended-range early June statistical prediction scheme that was developed utilizing 29 years of past data. Analog predictors are also utilized. We anticipate an above-average Atlantic basin hurricane season due to the combination of an anomalously warm tropical Atlantic and a relatively low likelihood of El Niño. Coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them, and they need to prepare the same for every season, regardless of how much activity is predicted.**

# Why issue extended-range forecasts for seasonal hurricane activity?

We are frequently asked this question. Our answer is that it is possible to say something about the probability of the coming year's hurricane activity which is superior to climatology. The Atlantic basin has the largest year-to-year variability of any of the global tropical cyclone basins. People are curious to know how active the upcoming season is likely to be, particularly if you can show hindcast skill improvement over climatology for many past years.

Everyone should realize that it is impossible to precisely predict this season's hurricane activity in early June. There is, however, much curiosity as to how global ocean and atmosphere features are presently arranged as regards to the probability of an active or inactive hurricane season for the coming year. Our new early June statistical forecast methodology shows strong evidence over 29 past years that improvement over climatology can be attained. **We would never issue a seasonal hurricane forecast unless we had a statistical model developed over a long period which showed significant hindcast skill over climatology.**

We issue these forecasts to satisfy the curiosity of the general public and to bring attention to the hurricane problem. There is a general interest in knowing what the odds are for an active or inactive season. One must remember that our forecasts are based on the premise that those global oceanic and atmospheric conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about similar trends in future seasons. This is not always true for individual seasons. It is also important that the reader appreciate that these seasonal forecasts are based on statistical schemes which, owing to their intrinsically probabilistic nature, will fail in some years. Moreover, these forecasts do not specifically predict where within the Atlantic basin these storms will strike. The probability of landfall for any one location along the coast is very low and reflects the fact that, in any one season, most U.S. coastal areas will not feel the effects of a hurricane no matter how active the individual season is.

## Acknowledgment

This year's forecasts are funded by private and personal 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 also thank Bill Thorson for his long-period 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.

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 30th 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. This year's June forecast is based on a statistical methodology derived from 29 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 3-4 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 should show significant hindcast skill before it is used in real-time forecasts.

# 2 June Forecast Methodology

## 2.1 New June Statistical Forecast Scheme

We have developed a new June statistical forecast model which we are using for the third time this year. This model has been built over the period from 1982-2010 to incorporate the most recent and reliable data that is available. It utilizes a total of four predictors. The new Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) has been completed from 1979-2009, while the NOAA Optimum Interpolation (OI) SST

(Reynolds et al. 2002) is available from 1982-present. This new 1 June TC forecast model shows significant skill in predicting levels of Net Tropical Cyclone (NTC) activity over the 31-year period from 1982-2012. This hindcast model correlates with NTC at 0.82 when all years are included in the model, while a drop-one cross-validation (jackknife) analysis yields a correlation with NTC of 0.74.

Table 1 displays cross-validated NTC hindcasts from 1982-2010, along with real-time forecasts for 2011-2012 using this new statistical scheme, while Figure 1 displays observations versus cross-validated NTC hindcasts. We have correctly predicted above- or below-average seasons in 26 out of 31 hindcast years (84%). Our predictions have had a smaller error than climatology in 24 out of 31 years (77%). Our average hindcast error is 33 NTC units, compared with 54 NTC units for climatology.

Figure 2 displays the locations of each of our predictors, while Table 2 displays the individual linear correlations between each predictor and NTC over the 1982-2010 hindcast period. All predictors correlate significantly at the 95% level using a two-tailed Student's t-test and assuming that each year represents an individual degree of freedom. The reader will note that we are incorporating a dynamical SST forecast from the European Centre for Medium-Range Weather Forecasts (ECMWF). Hindcast data provided by Frederic Vitart indicates that the ECMWF model has significant forecast skill for SSTs across the various Nino regions for September from a 1 May forecast date. We utilize the ECMWF ensemble mean prediction for the following September Nino 3 SSTs. Hindcast data from 1982-2010 show that the ECMWF forecast system 3 from 1 May correlates with observed September Nino 3 SSTs at 0.81. ECMWF has recently upgraded to system 4, which we assume has similar (if not improved) ENSO skill to system 3. Table 3 displays the 2013 observed values for each of the four predictors in the new statistical forecast scheme. Three out of the four predictors are calling for above-average Atlantic hurricane activity in 2013. Table 4 displays the statistical model output for the combination of the four predictors for the 2013 Atlantic hurricane season.

Table 1: Observed versus early June cross-validated hindcast NTC for 1982-2010 and real-time forecast for 2011-2012 using our new forecast scheme. Average errors for cross-validated hindcast NTC and climatological NTC predictions are given without respect to sign. Red bold-faced years in the "Hindcast NTC" column are years that we did not go the right way, while red bold-faced years in the "Hindcast improvement over Climatology" column are years that we did not beat climatology. The hindcast went the right way with regards to an above- or below-average season in 26 out of 31 years (84%), while hindcast improvement over climatology occurred in 24 out of 31 years (77%).

| Year | Observed NTC | Hindcast NTC | Observed minus Hindcast | Observed minus Climatology | Hindcast improvement over Climatology |
|---|---|---|---|---|---|
| 1982 | 38 | 52 | -14 | -65 | 51 |
| 1983 | 31 | 40 | -9 | -72 | 63 |
| 1984 | 80 | 101 | -21 | -23 | 2 |
| 1985 | 106 | **88** | 18 | 3 | **-15** |
| 1986 | 37 | 69 | -33 | -66 | 34 |
| 1987 | 46 | 55 | -9 | -57 | 48 |
| 1988 | 117 | 144 | -27 | 14 | **-13** |
| 1989 | 130 | 149 | -19 | 27 | 7 |
| 1990 | 100 | **158** | -58 | -3 | **-55** |
| 1991 | 58 | 45 | 13 | -45 | 33 |
| 1992 | 67 | 62 | 5 | -36 | 31 |
| 1993 | 52 | 45 | 7 | -51 | 44 |
| 1994 | 35 | 50 | -14 | -68 | 53 |
| 1995 | 222 | 231 | -9 | 119 | 110 |
| 1996 | 192 | 164 | 28 | 89 | 61 |
| 1997 | 54 | **141** | -88 | -49 | **-39** |
| 1998 | 169 | 153 | 16 | 66 | 50 |
| 1999 | 182 | 144 | 38 | 79 | 41 |
| 2000 | 134 | 107 | 26 | 31 | 4 |
| 2001 | 135 | 155 | -20 | 32 | 12 |
| 2002 | 83 | 40 | 43 | -20 | **-23** |
| 2003 | 175 | 147 | 28 | 72 | 44 |
| 2004 | 232 | 130 | 101 | 129 | 27 |
| 2005 | 279 | 153 | 127 | 176 | 50 |
| 2006 | 85 | **161** | -76 | -18 | **-58** |
| 2007 | 99 | **171** | -72 | -4 | **-68** |
| 2008 | 162 | 179 | -17 | 59 | 42 |
| 2009 | 69 | 72 | -3 | -34 | 31 |
| 2010 | 196 | 229 | -33 | 93 | 60 |
| 2011 | 145 | 176 | -31 | -42 | 11 |
| 2012 | 131 | 119 | 12 | -28 | 16 |
| **Average** | **117** | **120** | **\|33\|** | **\|54\|** | **+21** |

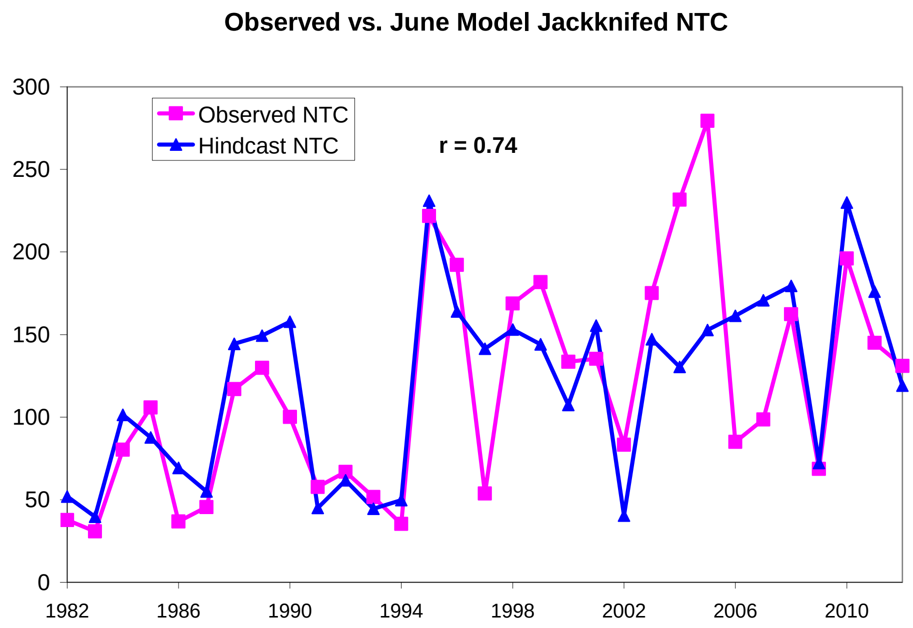


Figure 1: Observed versus early June jackknifed hindcast values of NTC for 1982-2012. The hindcast model explains 55% of the variance from climatology.

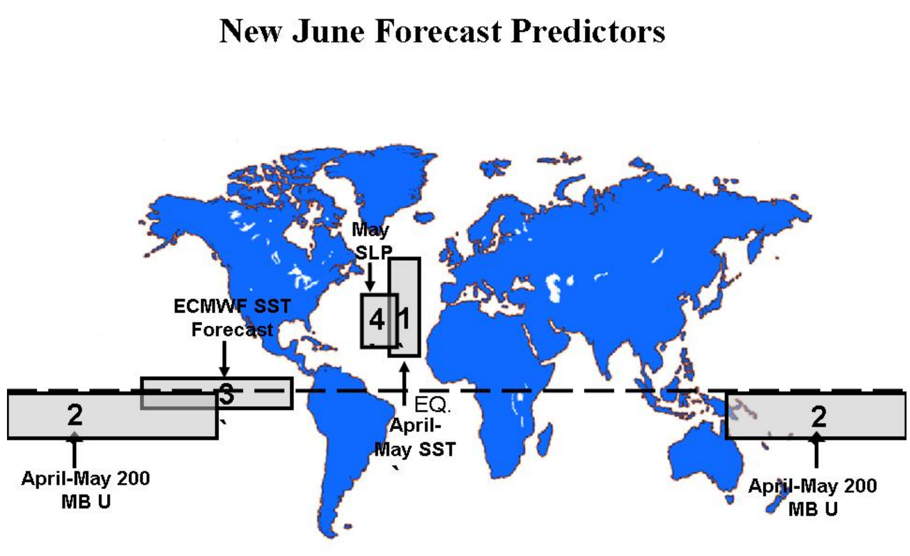


Figure 2: Location of predictors for our early June extended-range statistical prediction for the 2013 hurricane season. Predictor 2 spans both sides of the International Date Line.

Table 2: Linear correlation between each 1 June predictor and NTC over the 1982-2010 hindcast period. For more NTC activity, the sign of predictors 1 and 2 should be positive, while the sign of predictors 3 and 4 should be negative.

| Predictor | Correlation w/ NTC |
|---|---|
| 1) April-May SST (15-55°N, 15-35°W) (+) | 0.61 |
| 2) April-May 200 MB U (0-15°S, 150°E-120°W) (+) | 0.65 |
| 3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-) | -0.47 |
| 4) May SLP (20-40°N, 30-50°W) (-) | -0.44 |

Table 3: Listing of 1 June 2013 predictors for the 2013 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity.

| Predictor | 2013 Forecast Value |
|---|---|
| 1) April-May SST (15-55°N, 15-35°W) (+) | +0.7 SD |
| 2) April-May 200 MB U (0-15°S, 150°E-120°W) (+) | +0.6 SD |
| 3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-) | -0.2 SD |
| 4) May SLP (20-40°N, 30-50°W) (-) | +0.4 SD |

Table 4: Statistical model output for the 2013 Atlantic hurricane season.

| Forecast Parameter and 1981-2010 Median (in parentheses) | Statistical Forecast |
|---|---|
| Named Storms (12.0) | 12.7 |
| Named Storm Days (60.1) | 67.0 |
| Hurricanes (6.5) | 7.5 |
| Hurricane Days (21.3) | 32.1 |
| Major Hurricanes (2.0) | 3.7 |
| Major Hurricane Days (3.9) | 9.2 |
| Accumulated Cyclone Energy Index (92) | 134 |
| Net Tropical Cyclone Activity (103%) | 144 |

### 2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the predictors for our early June statistical forecast are now discussed. It should be noted that all predictors correlate with physical features during August through October that are known to be favorable for elevated levels of hurricane activity. All of these factors are generally related to August-October vertical wind shear in the Atlantic Main Development Region (MDR) from 10-20°N, 20-70°W as shown in Figure 3.

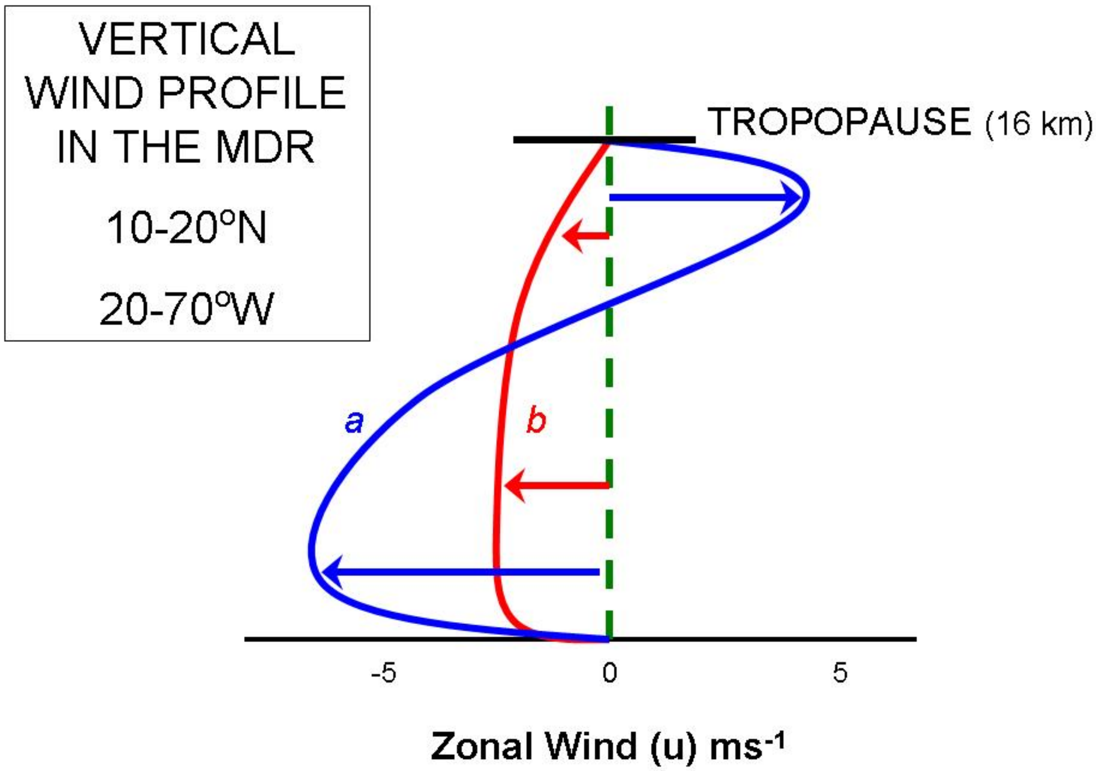


Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of tropospheric vertical wind shear.

For each of these predictors, we display a four-panel figure showing linear correlations between values of each predictor and August-October values of sea surface temperature (SST), sea level pressure, 200 mb zonal wind, and 850 mb zonal wind, respectively. In general, higher values of SSTs, lower values of SLPA, anomalous westerlies at 850 mb and anomalous easterlies at 200 mb are associated with active Atlantic basin hurricane seasons. SST correlations are displayed using the NOAA Optimum Interpolation (OI) SST, while SLP, 850 mb, and 200 mb zonal wind correlations are displayed using the Climate Forecast System Reanalysis (CFSR).

Predictor 1. April-May SST in the Eastern Atlantic (+)

(15-55°N, 15-35°W)

Warmer-than-normal SSTs in the eastern Atlantic during the April-May period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SST anomalies in April-May are correlated with weaker trade winds and weaker upper tropospheric westerly winds, lower-than-normal sea level pressures and above-normal SSTs in the tropical Atlantic during the following August-October period (Figure 4). All three of these August-October features are commonly associated with active Atlantic basin hurricane seasons, through reductions in vertical wind shear, increased vertical instability and increased mid-tropospheric moisture, respectively. Predictor 1 correlates quite strongly (~0.6) with NTC. Predictor 1 also strongly correlates (r = 0.65) with August-October values of the Atlantic Meridional Mode (AMM) (Kossin and Vimont 2007) over the period from 1982-2010. The AMM has been shown to impact Atlantic hurricane activity through alterations in the position and intensity of the Atlantic Inter-Tropical Convergence Zone (ITCZ). Changes in the Atlantic ITCZ bring about changes in tropical Atlantic vertical and horizontal wind shear patterns and in tropical Atlantic SST patterns.

<u>Predictor 2. April-May 200-mb zonal winds in the south-central Tropical Pacific (+)</u>

(0-15°S, 150°E-120°W)

Anomalous upper-level westerly zonal winds in the south-central tropical Pacific are typically associated with ongoing La Niña conditions and a strong Walker Circulation. The spring months are the climatologically favored time for ENSO events to transition from one phase to another (e.g., El Niño to La Niña or vice versa). If the atmosphere is strongly locked into the La Niña phase as evidenced by anomalously strong upper-level westerly winds, the odds of transitioning to an El Niño are reduced. Figure 5 shows that positive values of this predictor are also associated with favorable hurricane formation conditions in the tropical Atlantic, including above-average SSTs and below-average SLPs and zonal wind shear.

<u>Predictor 3. ECMWF 1 May SST Forecast for September Nino 3 (-)</u>

(5°S -5°N, 90-150°W)

The ECMWF seasonal forecast system 3 has shown skill at being able to forecast SST anomalies associated with ENSO several months into the future (Stockdale et al. 2011). ECMWF has recently upgraded their seasonal forecast model to system 4. ENSO has been documented in many studies to be one of the primary factors associated with interannual fluctuations in Atlantic basin and U.S. landfalling hurricane activity (Gray 1984, Goldenberg and Shapiro 1996, Bove et al. 1998, Klotzbach 2011), primarily through alterations in vertical wind shear patterns. The ensemble-averaged ENSO forecast for September values of the Nino 3 region from a 1 May issue date correlates with observations at 0.81. When the ECMWF model predicts cool SST anomalies for September, it strongly correlates with observed cool anomalies throughout the tropical Pacific associated with La Niña conditions, as well as reduced vertical wind shear, especially across the Caribbean (Figure 6).

<u>Predictor 4. May SLP in the central Atlantic (-)</u>

(20-40°N, 30-50°W)

Low pressure during the month of May in the central Atlantic is associated with reduced trade wind strength across the tropical Atlantic. This reduced trade wind strength promotes reduced upwelling, mixing and enhances ocean current flow from the south, all of which feed back to promote the development or sustenance of warm anomalies in the tropical Atlantic. These warm anomalies tend to persist throughout the peak months of the hurricane season (Figure 7). Also, upper-level easterly anomalies in the Caribbean are associated with low values of this predictor.

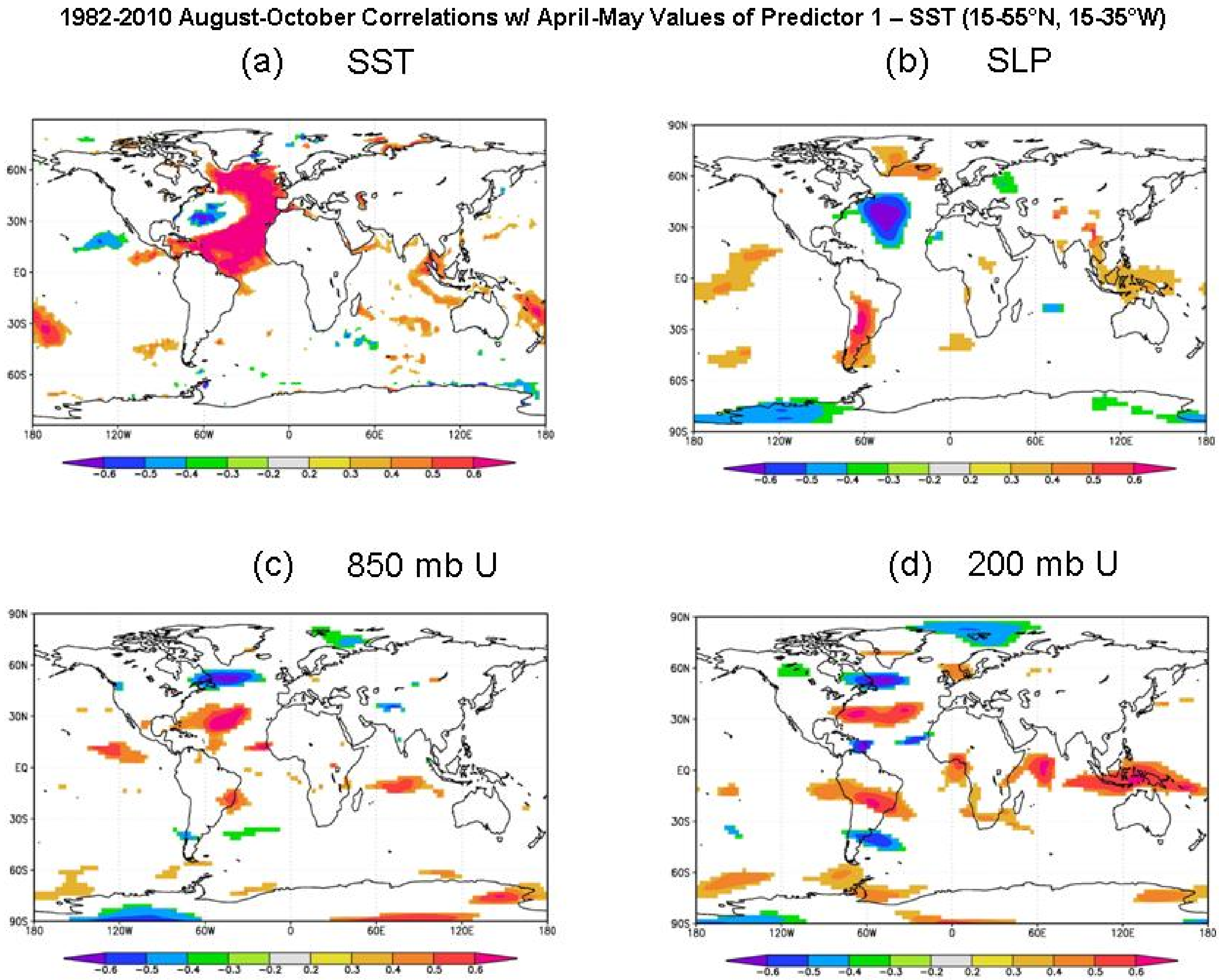


Figure 4: Linear correlations between April-May SST in the eastern Atlantic (Predictor 1) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). All four of these parameter deviations in the tropical Atlantic are known to be favorable for enhanced hurricane activity.

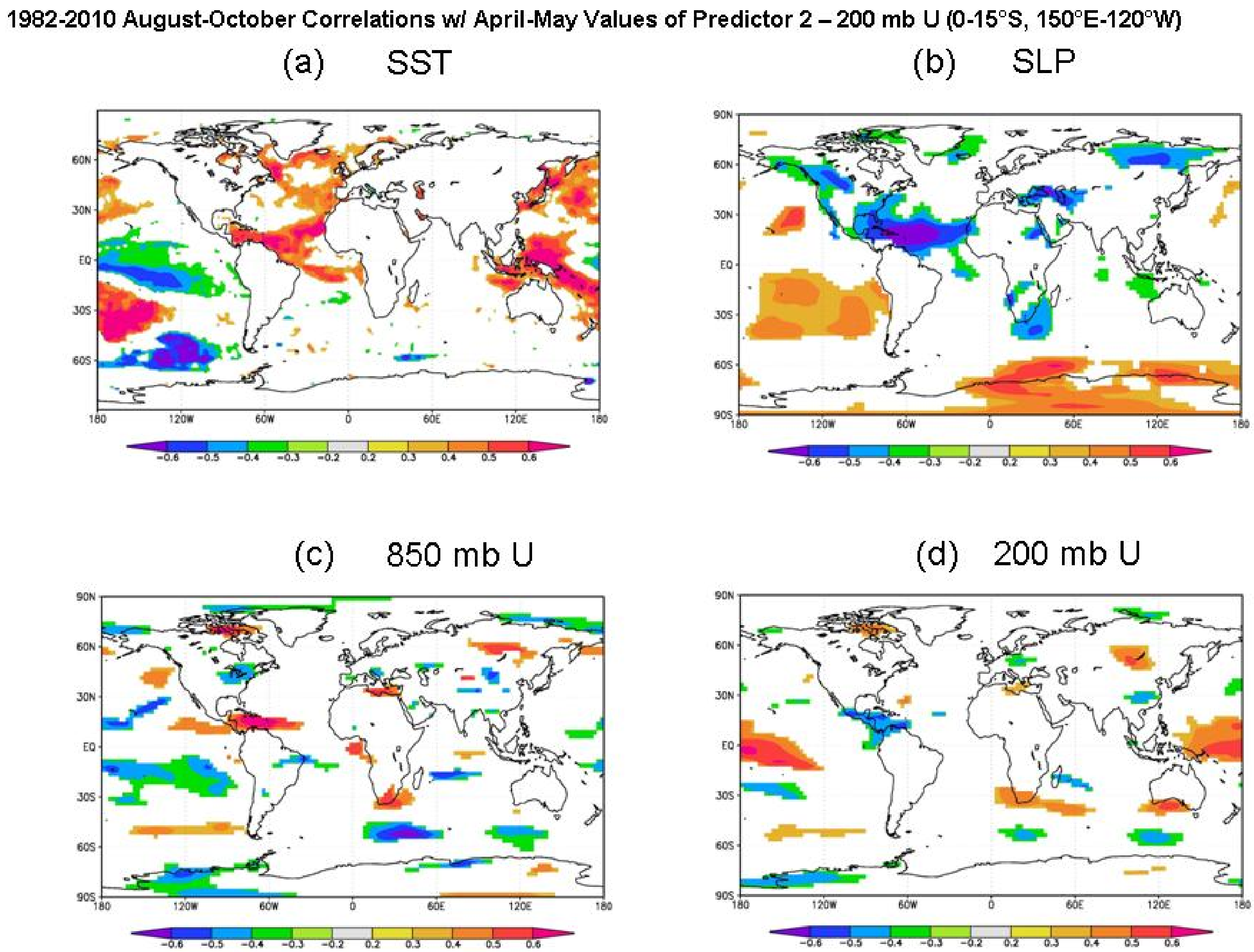


Figure 5: Linear correlations between April-May 200-mb zonal winds in the south-central tropical Pacific (Predictor 2) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). All of these parameter deviations over the tropical Atlantic and tropical Pacific tend to be associated with active hurricane seasons.

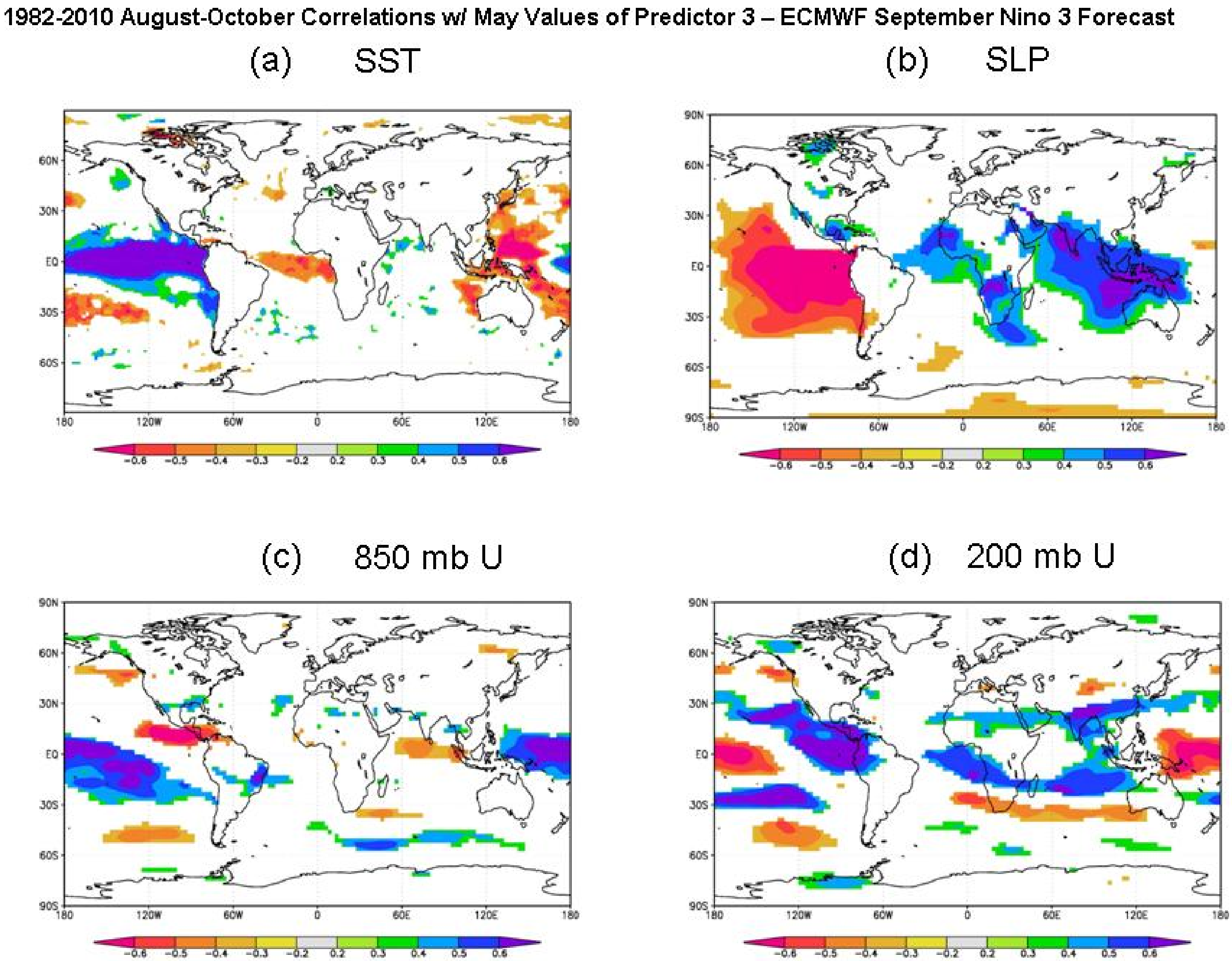


Figure 6: Linear correlations between a 1 May ECMWF SST forecast for September Nino 3 (Predictor 3) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). The predictor correlates very strongly with ENSO as well as vertical shear in the Caribbean. The correlation scale has been flipped to allow for easy comparison of correlations for all four predictors.

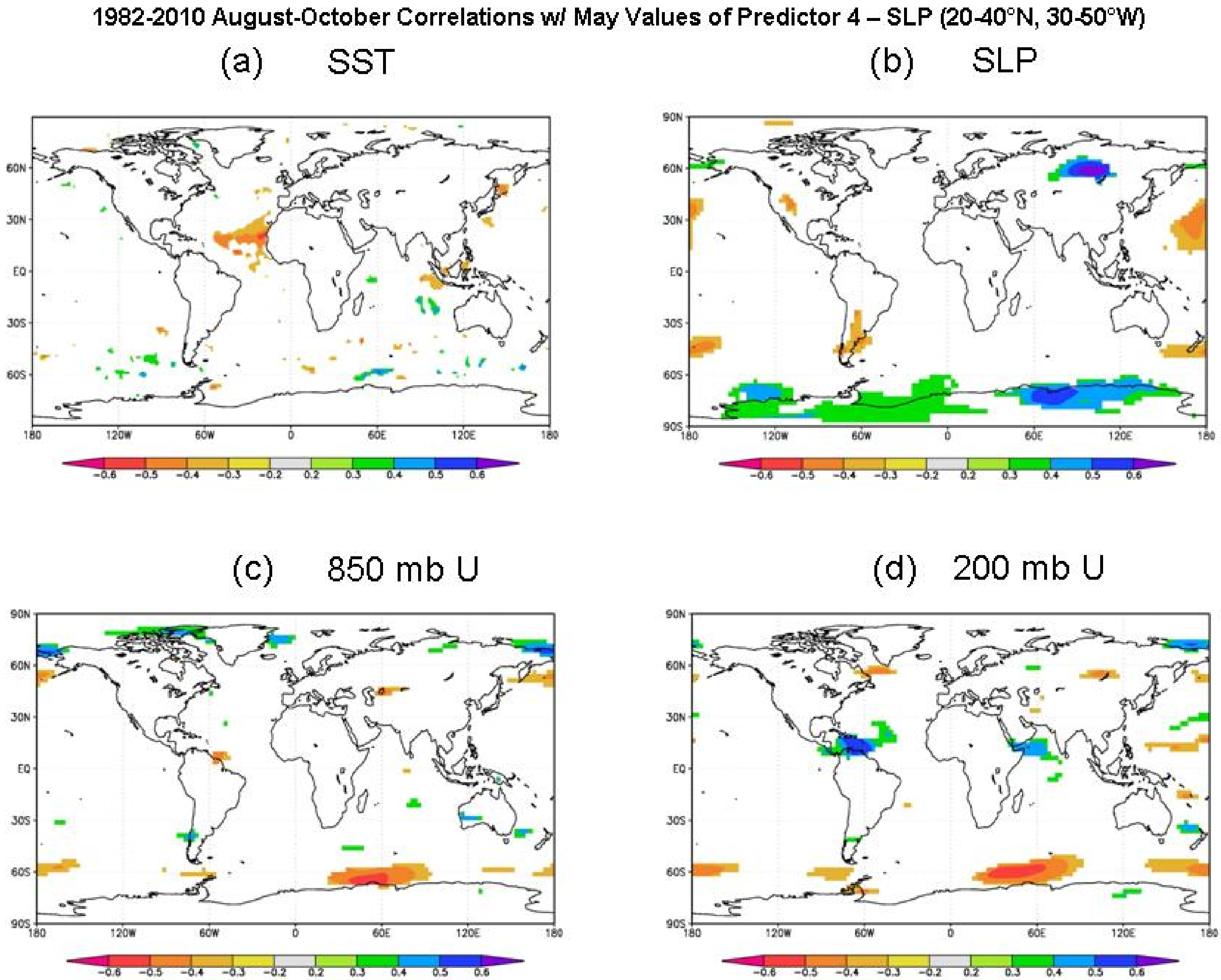


Figure 7: Linear correlations between May sea level pressure in the central Atlantic (Predictor 4) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 200 mb zonal wind (panel d). The correlation scale has been flipped to allow for easy comparison of correlations for all four predictors.

# 3 Forecast Uncertainty

One of the questions that we are asked regarding our seasonal hurricane predictions is the degree of uncertainty that is involved. Our predictions are our best estimate, but there is with all forecasts an uncertainty as to how well they will verify.

Table 5 provides our early June forecasts, with error bars based on one standard deviation of the 1982-2010 cross-validated hindcast error. We typically expect to see 2/3 of our forecasts verify within one standard deviation of observed values, with 95% of forecasts verifying within two standard deviations of observed values.

Table 5: Model hindcast error and our 2013 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

| Parameter | Hindcast Error (SD) | 2013 Forecast | Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range) |
|---|---|---|---|
| Named Storms (NS) | 3.7 | 18 | 14.3 – 21.7 |
| Named Storm Days (NSD) | 21.1 | 95 | 73.9 – 116.1 |
| Hurricanes (H) | 2.1 | 9 | 6.9 – 11.1 |
| Hurricane Days (HD) | 10.2 | 40 | 29.8 – 50.2 |
| Major Hurricanes (MH) | 1.6 | 4 | 2.4 –5.6 |
| Major Hurricane Days (MHD) | 5.3 | 9 | 3.7 – 14.3 |
| Accumulated Cyclone Energy (ACE) | 48 | 165 | 117 – 213 |
| Net Tropical Cyclone (NTC) Activity | 48 | 175 | 127 – 223 |

## 4 Analog-Based Predictors for 2013 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2013. These years also provide useful clues as to likely trends in activity that the forthcoming 2013 hurricane season may bring. For this early June extended-range forecast, we determine which of the prior years in our database have distinct trends in key environmental conditions which are similar to current April-May 2013 conditions. Table 6 lists our analog selections. We searched for years that were generally characterized by neutral ENSO conditions in April-May and above-average tropical Atlantic and far North Atlantic SSTs during April-May.

There were five hurricane seasons since 1949 with characteristics most similar to those listed. These five years are 1961, 1996, 2005, 2007, and 2011. We anticipate that the 2013 hurricane season will have activity in line with what was experienced in the average of these five years.

Table 6: Best analog years for 2013 with the associated hurricane activity listed for each year.

| Year | NS | NSD | H | HD | MH | MHD | ACE | NTC |
|---|---|---|---|---|---|---|---|---|
| 1961 | 11 | 70.75 | 8 | 47.50 | 7 | 24.50 | 205 | 230 |
| 1996 | 13 | 79.00 | 9 | 45.00 | 6 | 13.00 | 166 | 192 |
| 2005 | 28 | 131.50 | 15 | 49.75 | 7 | 17.50 | 250 | 279 |
| 2007 | 15 | 37.75 | 6 | 12.25 | 2 | 6.00 | 74 | 99 |
| 2011 | 19 | 89.75 | 7 | 26.00 | 4 | 4.50 | 126 | 145 |
| | | | | | | | | |
| Average | 17.2 | 81.8 | 9.0 | 36.1 | 5.2 | 13.1 | 164 | 189 |
| | | | | | | | | |
| **2013 Forecast** | **18** | **95** | **9** | **40** | **4** | **9** | **165** | **175** |

# 5 ENSO

Neutral ENSO conditions were present during the winter of 2012/2013. Upper ocean heat content (top 300 meters) anomalies dropped to slightly below-normal levels during January and early February, returned to near-normal levels during the early spring and have recently dropped slightly in the eastern and central tropical Pacific (Figure 8).

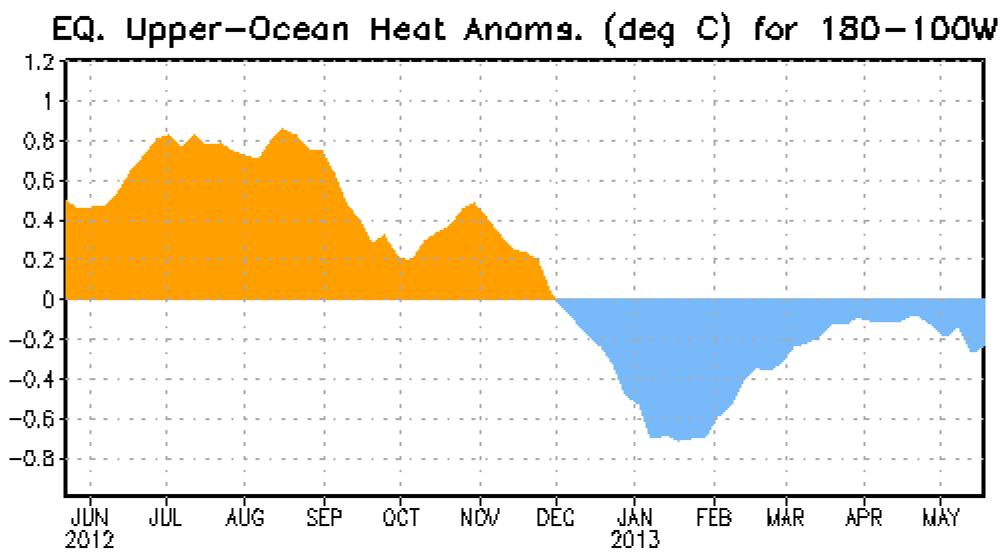


Figure 8: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Anomalies dropped during the early portion of the winter, rebounded to near-average levels in April and have since dropped slightly.

Currently, SSTs are generally within 0.5°C of the average across most of the eastern and central tropical Pacific. Table 7 displays March and May SST anomalies for several of the Nino regions. The eastern tropical Pacific has undergone some cooling over the past two months, while central tropical Pacific SST anomalies have not changed much since March.

Table 7: March and May SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. May-March SST anomaly differences are also provided.

| Region | March SST Anomaly (°C) | May SST Anomaly (°C) | May – March SST Anomaly (°C) |
|---|---|---|---|
| Nino 1+2 | 0.1 | -1.1 | -1.2 |
| Nino 3 | 0.1 | -0.5 | -0.6 |
| Nino 3.4 | -0.2 | -0.2 | 0.0 |
| Nino 4 | -0.2 | -0.1 | +0.1 |

There is still considerable uncertainty as to what is going to happen with the current neutral ENSO. The spring months are known for their ENSO predictability barrier. While we are nearing the end of this predictability barrier, considerable changes with ENSO often take place between June and September. Both statistical and dynamical models show improved skill by the end of May for the August-October period when compared with their skill at the end of March. In addition, none of the dynamical or statistical models call for an El Niño event during the August-October period (Figure 9).

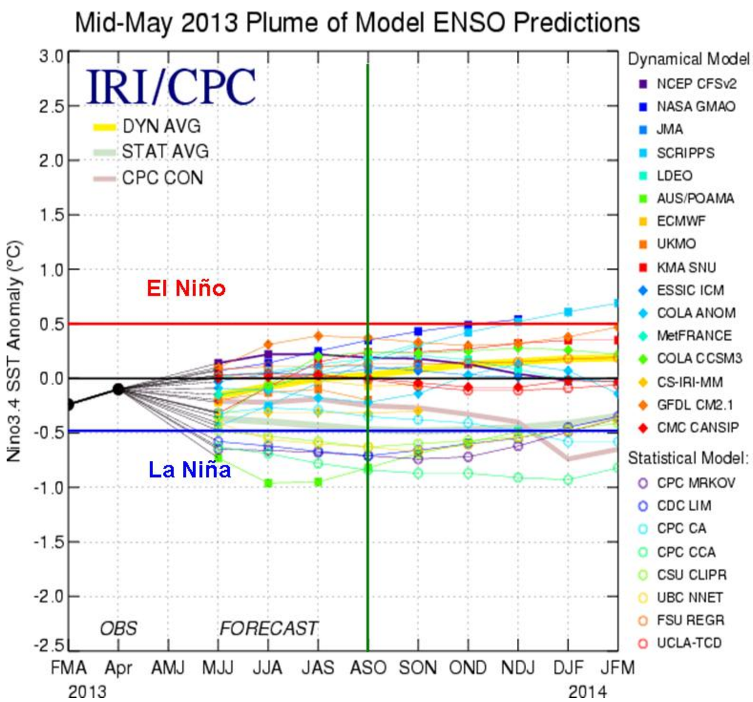


Figure 9: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). Most models call for the continuation of ENSO-neutral conditions for the next few months.

We find that, in general, the European Centre for Medium-Range Weather Forecasts (ECMWF) shows the best prediction skill of the various ENSO models. The correlation skill between a 1 May forecast from the ECMWF model system 3 and the observed September Nino 3.4 anomaly is 0.82, based on hindcasts/forecasts from 1982-2010, explaining approximately 65% of the variance in Nino 3.4 SST. The ECMWF has recently upgraded to system 4, which is likely to have even better skill than the previous version. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately 0.2°C. There is a fairly widespread range in the outcomes predicted by the various ensemble members, which indicates the large degree of uncertainty in future ENSO conditions (Figure 10).

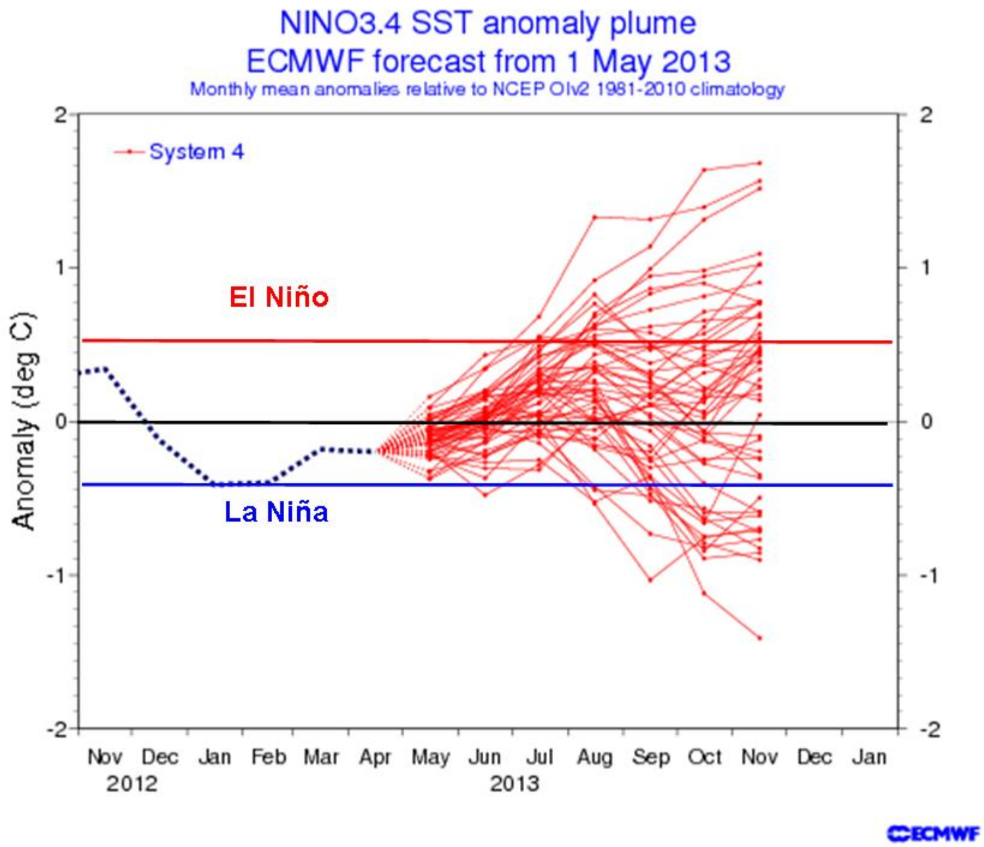


Figure 10: ECMWF ensemble model forecast for the Nino 3.4 region.

Our confidence that a significant El Niño event will not develop during this year's hurricane season has grown since early April. Low-level winds near the International Date Line have remained relatively strong out of the east, which helps prevent warming Kelvin waves from propagating eastward across the tropical Pacific (Figure 11). In addition, sea level pressure anomalies have generally been positive across the eastern and central tropical Pacific over the past two months, indicative of a relatively strong Southern Oscillation Index (Figure 12).

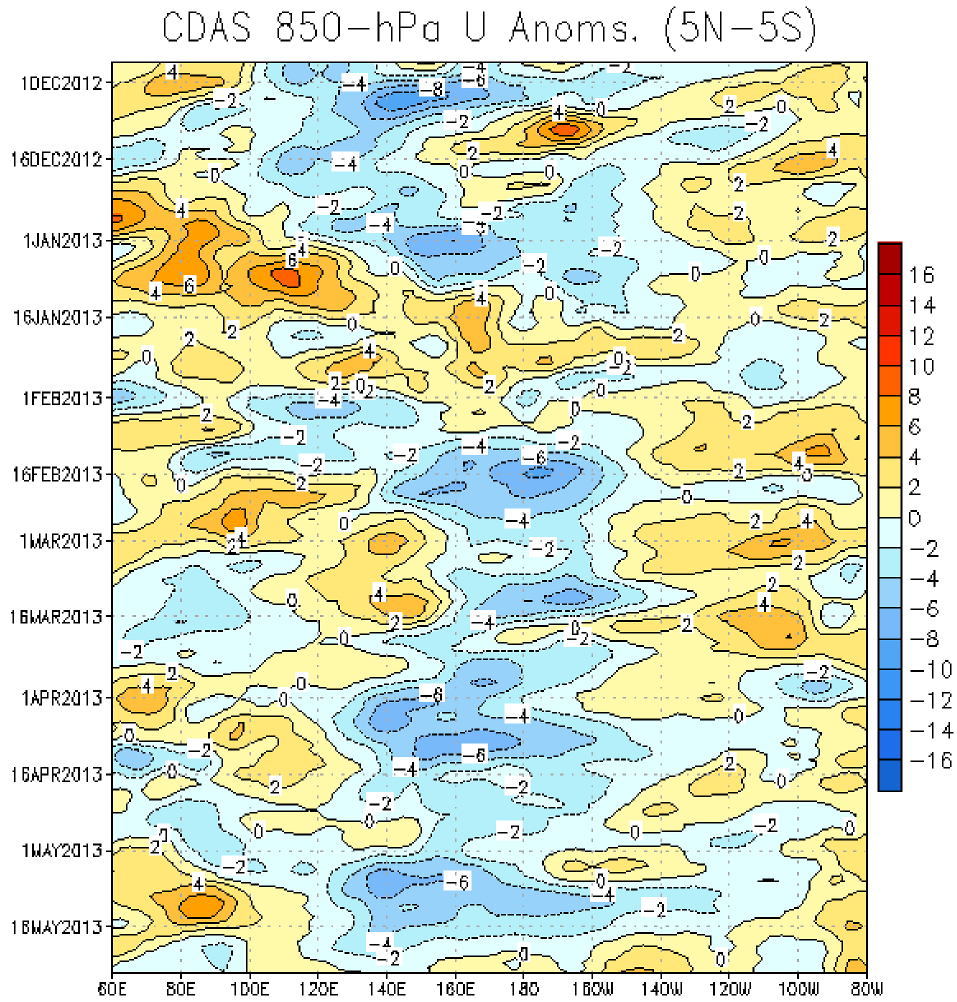


Figure 11: Anomalous low-level winds across the tropical Pacific. Note the anomalous easterly winds that have prevailed near the International Date Line since the middle part of February.

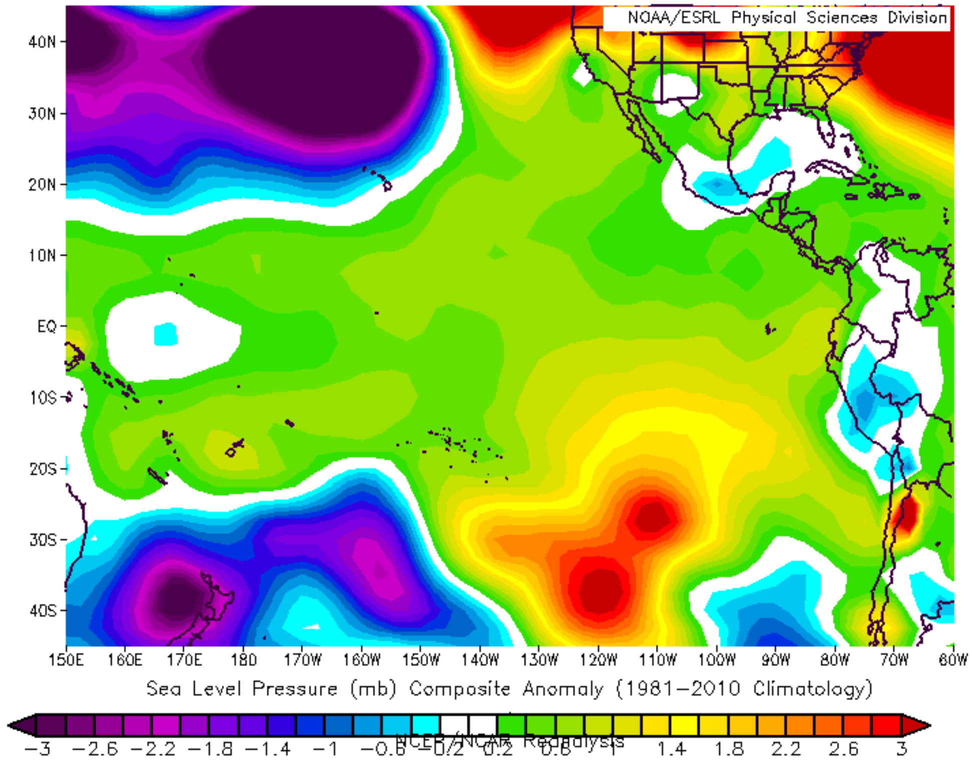


Figure 12: April-May sea level pressure anomalies across the eastern and central Pacific. In general, anomalies have been above average across most of the tropical Pacific.

Based on the above information, our best estimate is that we will likely remain in neutral ENSO conditions for the peak of the Atlantic hurricane season. The buildup of the warm pool in the western tropical Pacific has been relatively weak, and trade winds across the central tropical Pacific have generally been somewhat above-normal over the past few weeks. There remains a need to closely monitor ENSO conditions over the next couple of months. We will have another extensive discussion of ENSO with our final seasonal update on Friday, August 2.

## 6 Current Atlantic Basin Conditions

Significant anomalous warming occurred during the early part of the spring in the tropical Atlantic. SSTs in the western tropical Atlantic are at near-average values, while the eastern tropical Atlantic is now significantly above average (Figure 13). Over the past two months, SSTs have continued to warm in the eastern tropical Atlantic, while they have cooled somewhat in the subtropical Atlantic (Figure 14). Trade winds across the Atlantic tended to be weaker than normal in the eastern part of the basin and stronger than normal in the western part of the basin, which likely led to the anomalous patterns of SST change that were observed over the past two months (Figure 15). In general, correlations between SST anomalies and the Atlantic basin NTC are stronger in the eastern part of the basin (Figure 16), and consequently, the current SST anomaly pattern gives us increased confidence for an active Atlantic hurricane season.

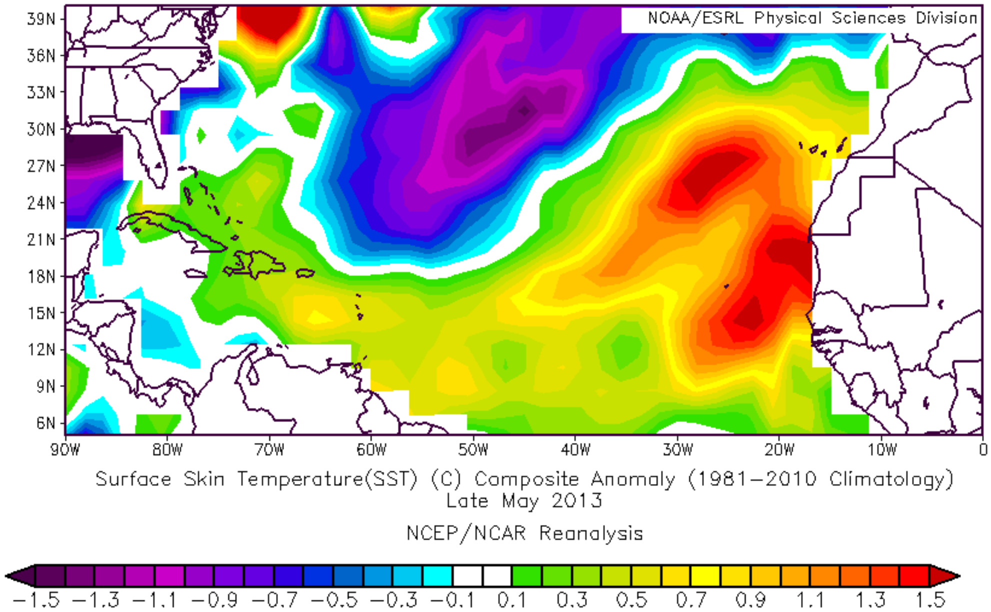


Figure 13: May 2013 SST anomaly pattern across the Atlantic Ocean.

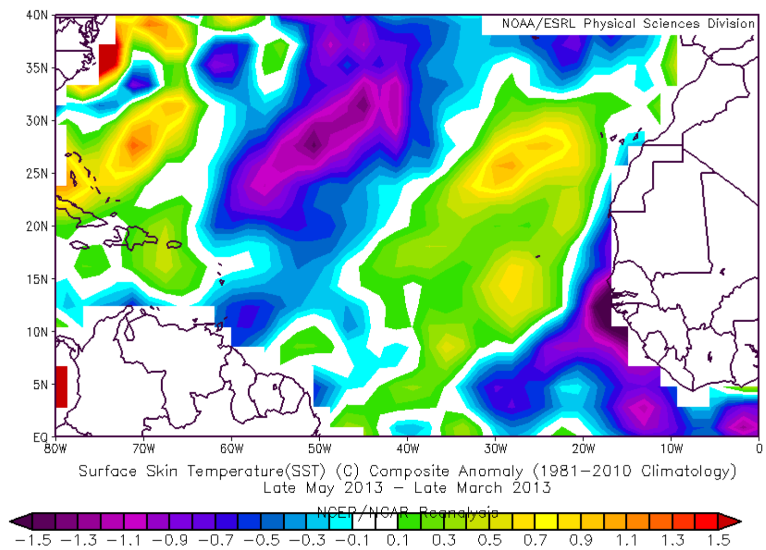


Figure 14: Late May - late March anomalous SST change across the Atlantic.

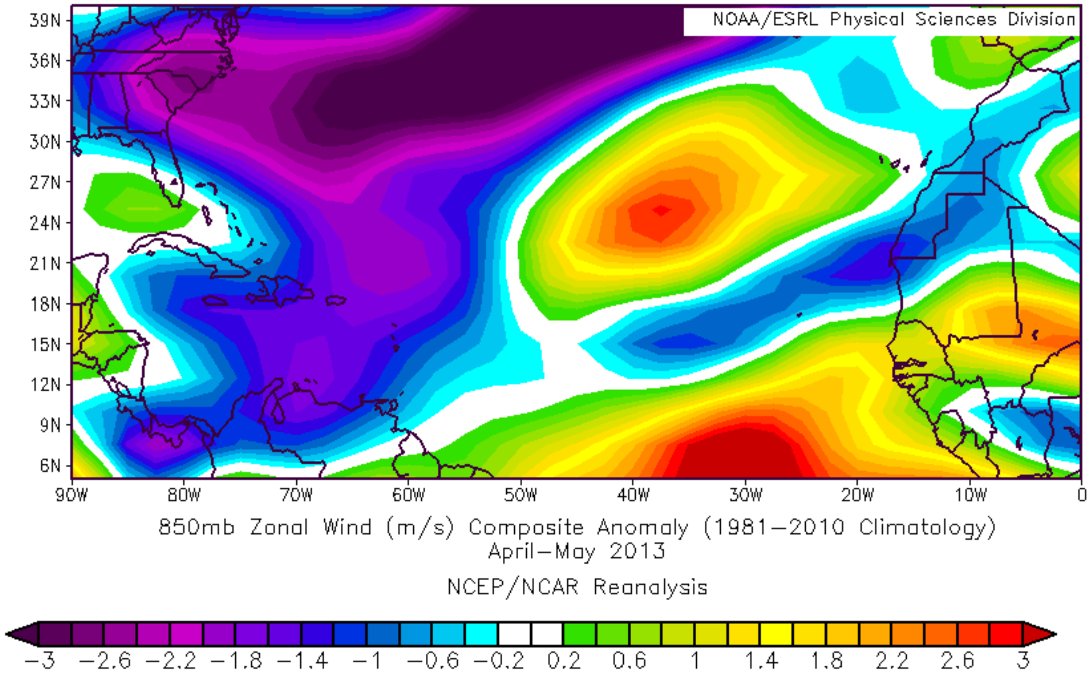


Figure 15: Anomalous trade wind pattern observed across the Atlantic in April-May.

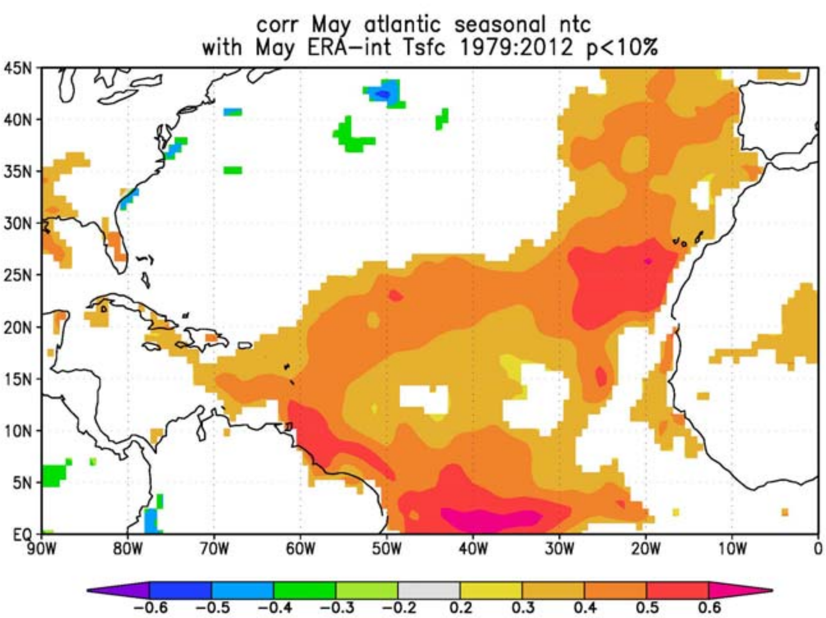


Figure 16: Correlation between May SST as derived from the ERA-Interim Reanalysis and Atlantic basin NTC over the period from 1979-2012.

## 7 Adjusted 2013 Forecast

Table 8 shows our final adjusted early June forecast for the 2013 season which is a combination of our statistical scheme, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. Both the statistical and the analog scheme call for well above-average activity this year. Overall, we are predicting a very active season for the Atlantic basin in 2013.

Table 8: Summary of our early June statistical forecast, our analog forecast and our adjusted final forecast for the 2013 hurricane season.

| Forecast Parameter and 1981-2010 Median (in parentheses) | Statistical Scheme | Analog Scheme | Adjusted Final Forecast |
|---|---|---|---|
| Named Storms (12.0) | 12.7 | 17.2 | 18 |
| Named Storm Days (60.1) | 67.0 | 81.8 | 95 |
| Hurricanes (6.5) | 7.5 | 9.0 | 9 |
| Hurricane Days (21.3) | 32.1 | 36.1 | 40 |
| Major Hurricanes (2.0) | 3.7 | 5.2 | 4 |
| Major Hurricane Days (3.9) | 9.2 | 13.1 | 9 |
| Accumulated Cyclone Energy Index (92) | 134 | 164 | 165 |
| Net Tropical Cyclone Activity (103%) | 144 | 189 | 175 |

## 8 Landfall Probabilities for 2013

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. Whereas individual hurricane landfall events cannot be forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the $20^{th}$ century (1900-1999). Specific landfall probabilities can be given for all tropical cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 9). NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. **Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall.**

Table 9: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term percentage deviation from average. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 MH, and 5 MHD would then be the sum of the following ratios: 10/9.6 = 104, 50/49.1 = 102, 6/5.9 = 102, 25/24.5 = 102, 3/2.3 = 130, 5/5.0 = 100, divided by six, yielding an NTC of 107.

| | 1950-2000 Average | |
|---|---|---|
| 1) | Named Storms (NS) | 9.6 |
| 2) | Named Storm Days (NSD) | 49.1 |
| 3) | Hurricanes (H) | 5.9 |
| 4) | Hurricane Days (HD) | 24.5 |
| 5) | Major Hurricanes (MH) | 2.3 |
| 6) | Major Hurricane Days (MHD) | 5.0 |

Table 10 lists strike probabilities for the 2013 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 now issue probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2013 is expected to be well above its long-term average of 100, and therefore, landfall probabilities are well above their long-term average.

As an example we find that the probability of Florida being hit by a major (Cat 3-4-5) hurricane this year is 34% which is greater than the yearly climatological average of 21%.

South Florida is much more prone to being impacted by a hurricane on an individual-year basis compared with northeast Florida. For instance, the probability of Miami-Dade County being impacted by hurricane-force wind gusts this year is 19%. For Duval County in northeastern coastal Florida, the probability of being impacted by hurricane-force wind gusts is only 5%. However, considering a 50-year period, the probability of Duval County experiencing hurricane-force wind gusts is 75%.

For the island of Puerto Rico, the probability of a named storm, hurricane and major hurricane tracking within 50 miles of the island this year is 50%, 26%, and 8%, respectively.

Table 10: Estimated 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) for 2013. Probabilities of a tropical storm, hurricane and major hurricane tracking into the Caribbean are also provided. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

| Region | TS | Category 1-2 HUR | Category 3-4-5 HUR | All HUR | Named Storms |
|---|---|---|---|---|---|
| Entire U.S. (Regions 1-11) | 94% (79%) | 86% (68%) | 72% (52%) | 96% (84%) | 99% (97%) |
| Gulf Coast (Regions 1-4) | 79% (59%) | 62% (42%) | 47% (30%) | 80% (60%) | 96% (83%) |
| Florida plus East Coast (Regions 5-11) | 71% (50%) | 64% (44%) | 48% (31%) | 81% (61%) | 94% (81%) |
| Caribbean (10-20°N, 60-88°W) | 95% (82%) | 77% (57%) | 61% (42%) | 91% (75%) | 99% (96%) |

# 9 Summary

An analysis of a variety of different atmosphere and ocean measurements (through May) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that 2013 should be a very active hurricane season. The only apparent obstacles to this assessment would be either the formation of a moderate to strong El Niño event or a significant cooling of the tropical Atlantic. At this point, we judge either of these events to be unlikely.

# 10 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. For more information on this topic we refer you to the following four 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, 2012: US hurricane damage - Can rising levels of CO2 be associated with Sandy's massive destruction? *Colorado State University Publication*, 23 pp.

W. M. Gray, and P. J. Klotzbach, 2013: Tropical cyclone forecasting. **National Hurricane Conference,** *New Orleans, Louisiana*, March 28, 2013.

W. M. Gray, and P. J. Klotzbach, 2013: Wind destruction from hurricanes. **Windstorm Insurance Conference,** *Orlando, Florida*, January 30, 2013.


# 11 Forthcoming Updated Forecasts of 2013 Hurricane Activity

We will be issuing a final seasonal update of our 2013 Atlantic basin hurricane forecasts on **Friday 2 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 2013 forecasts will be issued in late November 2013. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

## 12 Acknowledgments

Besides the individuals named on page 5, there have been a number of other meteorologists that have furnished us with data and given valuable assessments of the current state of global atmospheric and oceanic conditions. These include Brian McNoldy, Art Douglas, Ray Zehr, Mark DeMaria, Todd Kimberlain, Paul Roundy and Amato Evan. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical and data analysis and assistance over a number of years. We have profited over the years from many in-depth discussions with most of the current and past NHC hurricane forecasters. The second author would further like to acknowledge the encouragement he has received for this type of forecasting research application from Neil Frank, Robert Sheets, Robert Burpee, Jerry Jarrell, Max Mayfield, and Bill Read, former directors of the National Hurricane Center (NHC), and the current director, Rick Knabb.

## 13 Citations and Additional Reading


Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N.-C. Lau, and J. D. Scott, 2002: The atmospheric bridge: The influence of ENSO teleconnections on air-sea interaction over the global oceans. *J. Climate*, 15, 2205-2231.

Blake, E. S., 2002: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper No. 719, Colo. State Univ., Ft. Collins, CO, 80 pp.

Blake, E. S. and W. M. Gray, 2004: Prediction of August Atlantic basin hurricane activity. *Wea. Forecasting*, 19, 1044-1060.

Chiang, J. C. H. and D. J. Vimont, 2004: Analogous Pacific and Atlantic meridional modes of tropical atmosphere-ocean variability. *J. Climate*, 17, 4143-4158.

DeMaria, M., J. A. Knaff and B. H. Connell, 2001: A tropical cyclone genesis parameter for the tropical Atlantic. *Wea. Forecasting*, 16, 219-233.

Elsner, J. B., G. S. Lehmiller, and T. B. Kimberlain, 1996: Objective classification of Atlantic hurricanes. *J. Climate*, 9, 2880-2889.

Evan, A. T., J. Dunion, J. A. Foley, A. K. Heidinger, and C. S. Velden, 2006: New evidence for a relationship between Atlantic tropical cyclone activity and African dust outbreaks, *Geophys. Res. Lett*, 33, doi:10.1029/2006GL026408.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and Implications. *Science*, 293, 474-479.

Goldenberg, S. B. and L. J. Shapiro, 1996: Physical mechanisms for the association of El Niño and West African rainfall with Atlantic major hurricane activity. *J. Climate*, 1169-1187.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.*, 112, 1669-1683.

Gray, W. M., 1990: Strong association between West African rainfall and US landfall of intense hurricanes. *Science*, 249, 1251-1256.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6-11 months in advance. *Wea. Forecasting*, 7, 440-455.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1993: Predicting Atlantic basin seasonal tropical cyclone activity by 1 August. *Wea. Forecasting*, 8, 73-86.

Gray, W. M., C. W. Landsea, P. W. Mielke, Jr., and K. J. Berry, 1994a: Predicting Atlantic basin seasonal tropical cyclone activity by 1 June. *Wea. Forecasting*, 9, 103-115.

Gray, W. M., J. D. Sheaffer and C. W. Landsea, 1996: Climate trends associated with multi-decadal variability of intense Atlantic hurricane activity. Chapter 2 in "Hurricanes, Climatic Change and Socioeconomic Impacts: A Current Perspective", H. F. Diaz and R. S. Pulwarty, Eds., Westview Press, 49 pp.

Gray, W. M., 1998: Atlantic ocean influences on multi-decadal variations in El Niño frequency and intensity. Ninth Conference on Interaction of the Sea and Atmosphere, 78th AMS Annual Meeting, 11-16 January, Phoenix, AZ, 5 pp.

Grossmann, I. and P. J. Klotzbach, 2009: A review of North Atlantic modes of natural variability and their driving mechanisms. *J. Geophys. Res.*, 114, D24107, doi:10.1029/2009JD012728.

Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S-L. Shieh, P. Webster, and K. McGuffie, 1998: Tropical cyclones and global climate change: A post-IPCC assessment. *Bull. Amer. Meteor. Soc.*, 79, 19-38.

Klotzbach, P. J., 2002: Forecasting September Atlantic basin tropical cyclone activity at zero and one-month lead times. Dept. of Atmos. Sci. Paper No. 723, Colo. State Univ., Ft. Collins, CO, 91 pp.

Klotzbach, P. J., 2006: Trends in global tropical cyclone activity over the past twenty years (1986-2005). *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL025881.

Klotzbach, P. J., 2007: Revised prediction of seasonal Atlantic basin tropical cyclone activity from 1 August. *Wea. and Forecasting,* 22, 937-949.

Klotzbach, P. J. and W. M. Gray, 2003: Forecasting September Atlantic basin tropical cyclone activity. *Wea. and Forecasting,* 18, 1109-1128.

Klotzbach, P. J. and W. M. Gray, 2004: Updated 6-11 month prediction of Atlantic basin seasonal hurricane activity. *Wea. and Forecasting,* 19, 917-934.

Klotzbach, P. J. and W. M. Gray, 2006: Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc.*, 87, 1325-1333.

Knaff, J. A., 1997: Implications of summertime sea level pressure anomalies. *J. Climate,* 10, 789-804.

Knaff, J. A., 1998: Predicting summertime Caribbean sea level pressure. *Wea. and Forecasting,* 13, 740-752.

Kossin, J. P., and D. J. Vimont, 2007: A more general framework for understanding Atlantic hurricane variability and trends. *Bull. Amer. Meteor. Soc.*, 88, 1767-1781.

Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO, 272 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.,* 121, 1703-1713.

Landsea, C. W., 2007: Counting Atlantic tropical cyclones back to 1900. *EOS,* 88, 197, 202.

Landsea, C. W. and W. M. Gray, 1992: The strong association between Western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate,* 5, 435-453.

Landsea, C. W., W. M. Gray, P. W. Mielke, Jr., and K. J. Berry, 1992: Long-term variations of Western Sahelian monsoon rainfall and intense U.S. landfalling hurricanes. *J. Climate,* 5, 1528-1534.

Landsea, C. W., W. M. Gray, K. J. Berry and P. W. Mielke, Jr., 1996: June to September rainfall in the African Sahel: A seasonal forecast for 1996. 4 pp.

Landsea, C. W., N. Nicholls, W.M. Gray, and L.A. Avila, 1996: Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geo. Res. Letters,* 23, 1697-1700.

Landsea, C. W., R. A. Pielke, Jr., A. M. Mestas-Nunez, and J. A. Knaff, 1999: Atlantic basin hurricanes: Indices of climatic changes. *Climatic Changes,* 42, 89-129.

Landsea, C.W. et al., 2005: Atlantic hurricane database re-analysis project. Available online at http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1996: Artificial skill and validation in meteorological forecasting. *Wea. Forecasting,* 11, 153-169.

Mielke, P. W., K. J. Berry, C. W. Landsea and W. M. Gray, 1997: A single sample estimate of shrinkage in meteorological forecasting. *Wea. Forecasting,* 12, 847-858.

Pielke, Jr. R. A., and C. W. Landsea, 1998: Normalized Atlantic hurricane damage, 1925-1995. *Wea. Forecasting,* 13, 621-631.

Pielke, Jr. R. A., and J. Gratz, C. W. Landsea, D. Collins, and R. Masulin, 2008: Normalized hurricane damage in the United States: 1900-2005. *Nat. Haz. Rev.,* 9, 29-42, doi:10.1061/(ASCE)1527-6988(2008)9:1(29).

Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in tropical sea-surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.,* 110, 354-384.

Seseske, S. A., 2004: Forecasting summer/fall El Niño-Southern Oscillation events at 6-11 month lead times. Dept. of Atmos. Sci. Paper No. 749, Colo. State Univ., Ft. Collins, CO, 104 pp.

Vimont, D. J., and J. P. Kossin, 2007: The Atlantic meridional mode and hurricane activity. *Geophys. Res. Lett.,* 34, L07709, doi:10.1029/2007GL029683.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.,* 132, 1917-1932.

# 14 Verification of Previous Forecasts

Table 11: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2008-2012. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

| 2008 | 7 Dec. 2007 | Update 9 April | Update 3 June | Update 5 August | Obs. |
|---|---|---|---|---|---|
| Hurricanes | 7 | 8 | 8 | 9 | 8 |
| Named Storms | 13 | 15 | 15 | 17 | 16 |
| Hurricane Days | 30 | 40 | 40 | 45 | 30.50 |
| Named Storm Days | 60 | 80 | 80 | 90 | 88.25 |
| Major Hurricanes | 3 | 4 | 4 | 5 | 5 |
| Major Hurricane Days | 6 | 9 | 9 | 11 | 7.50 |
| Accumulated Cyclone Energy | 115 | 150 | 150 | 175 | 146 |
| Net Tropical Cyclone Activity | 125 | 160 | 160 | 190 | 162 |

| 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 | 12 |
| Named Storm Days | 70 | 55 | 50 | 45 | 30 |
| Major Hurricanes | 3 | 2 | 2 | 2 | 2 |
| Major Hurricane Days | 7 | 5 | 4 | 4 | 3.50 |
| Accumulated Cyclone Energy | 125 | 100 | 85 | 80 | 53 |
| Net Tropical Cyclone Activity | 135 | 105 | 90 | 85 | 69 |

| 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 | 38.50 |
| Named Storm Days | 51-75 | 75 | 90 | 90 | 89.50 |
| 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 | 165 |
| Net Tropical Cyclone Activity | 108-172 | 160 | 195 | 195 | 196 |

| 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 | 26 |
| Named Storm Days | 85 | 80 | 80 | 80 | 89.75 |
| Major Hurricanes | 5 | 5 | 5 | 5 | 4 |
| Major Hurricane Days | 10 | 10 | 10 | 10 | 4.5 |
| Net Tropical Cyclone Activity | 180 | 175 | 175 | 175 | 145 |

| 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 | 28.50 |
| Named Storm Days | 40 | 50 | 52 | 101 |
| Major Hurricanes | 2 | 2 | 2 | 2 |
| Major Hurricane Days | 3 | 4 | 5 | 0.50 |
| Accumulated Cyclone Energy | 70 | 80 | 99 | 133 |
| Net Tropical Cyclone Activity | 75 | 90 | 105 | 131 |