EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2015

We continue to foresee a well below-average 2015 Atlantic hurricane season. A strong El Niño event now appears likely. Conditions in the tropical Atlantic remain unfavorable for hurricane formation. We continue to call for a below-average probability of United States and Caribbean major hurricane landfall.

(as of 1 June 2015)

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) is available to answer various questions about this verification.

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2015

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 9 April 2015	Issue Date 1 June 2015
Named Storms (NS) (12.0)	7	8*
Named Storm Days (NSD) (60.1)	30	30
Hurricanes (H) (6.5)	3	3
Hurricane Days (HD) (21.3)	10	10
Major Hurricanes (MH) (2.0)	1	1
Major Hurricane Days (MHD) (3.9)	0.5	0.5
Accumulated Cyclone Energy (ACE) (92)	40	40
Net Tropical Cyclone Activity (NTC) (103%)	45	45

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

1) Entire U.S. coastline - 28% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 15% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 15% (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) 22% (average for last century is 42%)

*The forecast has been increased from 7 to 8 named storms due to the formation of Tropical Storm Ana in May.

2015 STATE IMPACT PROBABILITIES (NUMBERS IN PARENTHESES ARE LONG-PERIOD AVERAGES)

State	Hurricane	Major Hurricane
Texas	16% (33%)	5% (12%)
Louisiana	15% (30%)	5% (12%)
Mississippi	5% (11%)	2% (4%)
Alabama	7% (16%)	1% (3%)
Florida	27% (51%)	10% (21%)
Georgia	5% (11%)	1% (1%)
South Carolina	8% (17%)	2% (4%)
North Carolina	14% (28%)	3% (8%)
Virginia	3% (6%)	<1% (1%)
Maryland	1% (1%)	<1% (<1%)
Delaware	1% (1%)	<1% (<1%)
New Jersey	1% (1%)	<1% (<1%)
New York	3% (8%)	1% (3%)
Connecticut	3% (7%)	1% (2%)
Rhode Island	3% (6%)	1% (3%)
Massachusetts	3% (7%)	1% (2%)
New Hampshire	1% (1%)	<1% (<1%)
Maine	2% (4%)	<1% (<1%)
Whole US	**57% (84%)**	**28% (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 2015 indicates that the 2015 Atlantic hurricane season will likely have much less activity than the median 1981-2010 season. We estimate that 2015 will have only 3 hurricanes (median is 6.5), 8 named storms (median is 12.0), 30 named storm days (median is 60.1), 10 hurricane days (median is 21.3), 1 major (Category 3-4-5) hurricane (median is 2.0) and 0.5 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be about 55 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2015 to be approximately 45 percent of their long-term averages.

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 a well below-average Atlantic basin hurricane season due to the combination of a high likelihood of a strong El Niño event and unfavorable hurricane formation conditions in the tropical Atlantic. 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.

Special Note from Bill Gray

I began making seasonal Atlantic hurricane forecasts from Colorado State University (CSU) in 1984 and have been involved with all of the seasonal forecasts over the past 31 years. Phil Klotzbach joined my research project as a graduate student in 2000. He had an outstanding academic undergraduate record and a great desire to study hurricanes. He was a talented graduate student. He received both his M.S. (2002) and Ph. D. (2007) degrees on climate-hurricane related topics.

Phil has shown outstanding growth in his knowledge and prowess as a hurricane researcher and forecaster over the last 15 years. He continues to work full-time at improving our understanding of the global climate-hurricane relationship and in the development of new and more skillful forecast products.

Klotzbach became lead author on the CSU forecasts in 2006 and in recent years has expended most of his efforts in researching and writing up these forecasts and their post-season evaluation. We still talk nearly every day on climate-hurricane matters, and no forecast has been released without my detailed comments. Phil has been making all the final forecast decisions in recent years. He has, nevertheless, appointed me to serve in the important role of taking the blame for any and all forecast busts with all credit for successful forecasts going to him. I have fully embraced this special arrangement!

Although I still come to my office every working day and remain quite active, I am now devoting more of my research efforts to the climate change and global warming issue. For this reason I will be discontinuing my formal association with these seasonal hurricane forecasts at the end of this year. But I will remain as a special personal advisor to Phil in all of his future CSU hurricane forecasts as long as I am able.

I am happy at the progress in climate-hurricane relationship studies that have been made by my research project (including former graduate students Chris Landsea, John Knaff, Eric Blake and Todd Kimberlain) and by other non-CSU groups since I began issuing these forecasts in 1984. At that time we had no objective way of determining how active the upcoming hurricane season was likely to be. But we do now!

Age, technology change, and my growing new interests in the climate change debate dictate that I discontinue my formal involvement with these Atlantic basin seasonal hurricane forecasts after this year (my 32nd). I expect and hope that Phil Klotzbach will carry these CSU seasonal hurricane forecasts forward for many years into the future with his ever improving hurricane-climate understanding and continuous forecast skill improvement. There is no one (in my view) better able to do this than Phil. I will assist him in the coming years as much as I can.

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 significant improvement over climatology can be attained. We would never issue a seasonal hurricane forecast unless we had a statistical model developed over a long hindcast period which showed significant 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.

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

We are grateful for support from Interstate Restoration, Ironshore Insurance and Macquarie Group that partially support the release of these predictions. We acknowledge a grant from the G. Unger Vetlesen Foundation for additional financial support. We thank the GeoGraphics Laboratory at Bridgewater State University (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

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

DEFINITIONS AND ACRONYMS

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

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the oceanic thermohaline circulation. Although several definitions of the AMO are currently used in the literature, we define the AMO based on North Atlantic sea surface temperatures from 50-60°N, 50-10°W and sea level pressure from 0-50°N, 70-10°W.

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

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

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

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

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

Madden Julian Oscillation (MJO) – A globally propagating mode of tropical atmospheric intra-seasonal variability. The wave tends to propagate eastward at approximately 5 ms^{-1}, circling the globe in roughly 30-60 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, 75-20°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.

Proxy – An approximation or a substitution for a physical process that cannot be directly measured.

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, 57.5-15°W.

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

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

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

1 Introduction

This is the 32nd year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. 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 June Statistical Forecast Scheme

Our current June statistical forecast 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-present, 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 32-year period from 1982-2014. This hindcast model correlates with NTC at 0.79 when all years are included in the model, while a drop-one cross-validation (jackknife) analysis yields a correlation with NTC of 0.71.

Table 1 displays cross-validated NTC hindcasts from 1982-2010, along with real-time forecasts for 2011-2014 using the current statistical scheme, while Figure 1 displays observations versus cross-validated NTC hindcasts/forecasts. We have correctly predicted above- or below-average seasons in 27 out of 33 hindcast years (82%). Our predictions have had a smaller error than climatology in 25 out of 33 years (76%). Our average hindcast error is 34 NTC units, compared with 53 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 2015 observed values for each of the four predictors in the new statistical forecast scheme. All four predictors are calling for a below-average season this year. Table 4 displays the statistical model output for the combination of the four predictors for the 2015 Atlantic hurricane season.

Table 1: Observed versus early June cross-validated hindcast NTC for 1982-2010 and real-time forecast NTC for 2011-2014 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 27 out of 33 years (82%), while hindcast improvement over climatology occurred in 25 out of 33 years (76%).

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
2013	47	**140**	-93	-53	**-40**
2014	82	85	-3	-21	18
Average	**115**	**121**	**|34|**	**|53|**	**+19**

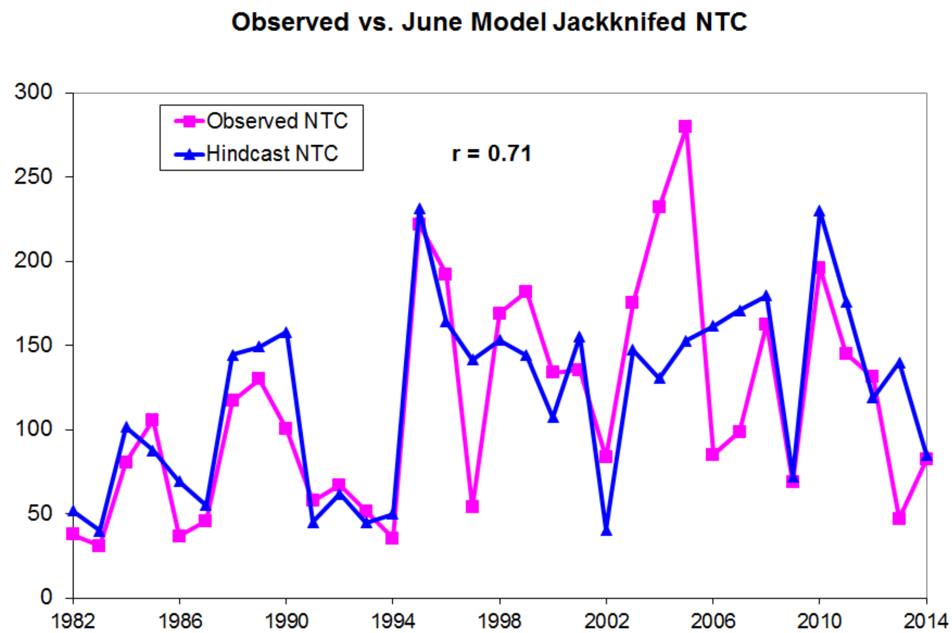

Figure 1: Observed versus early June jackknifed hindcast values of NTC for 1982-2014. The hindcast model explains approximately 50% of the variance from climatology.

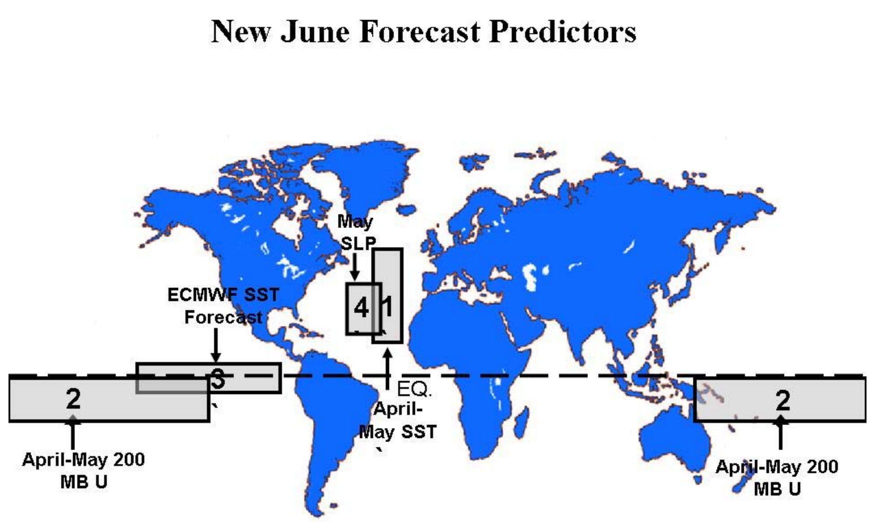

Figure 2: Location of predictors for our early June extended-range statistical prediction for the 2015 hurricane season. Predictor 2 spans both sides of the International Date Line.

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 2015 predictors for the 2015 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity. All predictors are detrimental for hurricane formation this year.

Predictor	**2015 Forecast Value**
1) April-May SST (15-55°N, 15-35°W) (+)	-1.3 SD
2) April-May 200 MB U (0-15°S, 150°E-120°W) (+)	-0.3 SD
3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	+2.1 SD
4) May SLP (20-40°N, 30-50°W) (-)	+0.3 SD

Table 4: Statistical model output for the 2015 Atlantic hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast
Named Storms (12.0)	6.7
Named Storm Days (60.1)	23.3
Hurricanes (6.5)	3.1
Hurricane Days (21.3)	6.2
Major Hurricanes (2.0)	0.3
Major Hurricane Days (3.9)	0.0
Accumulated Cyclone Energy Index (92)	19
Net Tropical Cyclone Activity (103%)	32

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. 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.

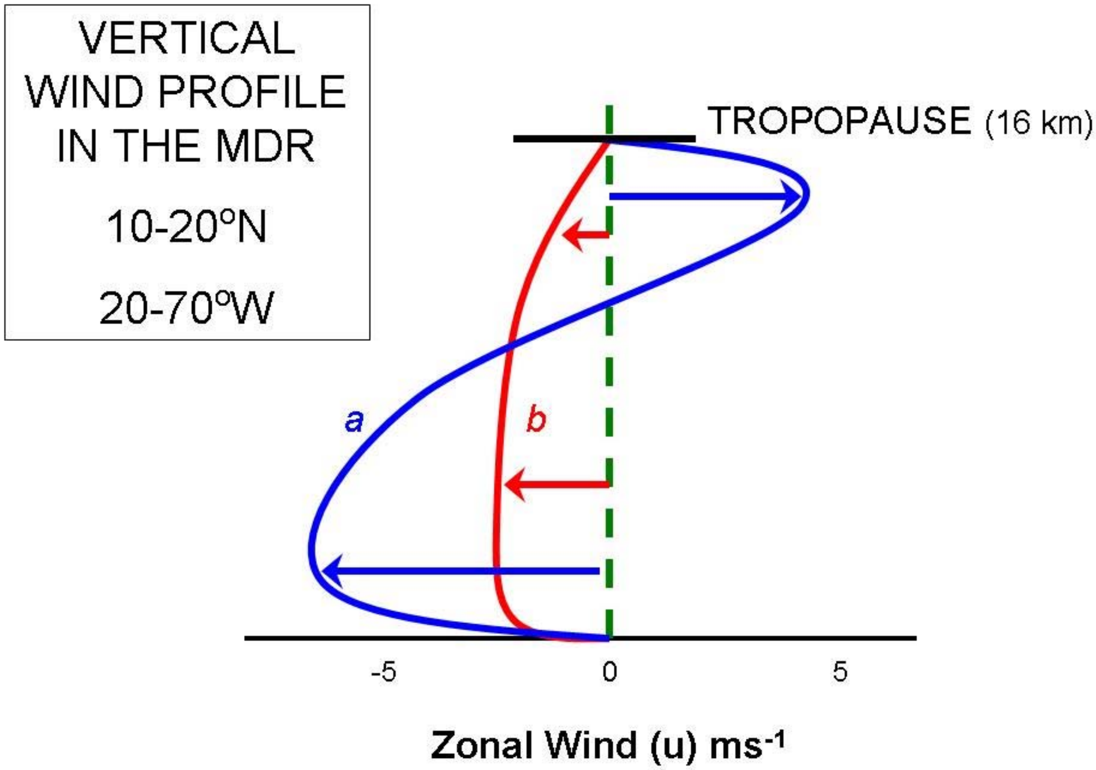

Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of tropospheric vertical wind shear.

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.

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

(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.

Predictor 3. ECMWF 1 May SST Forecast for September Nino 3 (-)

(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).

Predictor 4. May SLP in the central Atlantic (-)

(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 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.

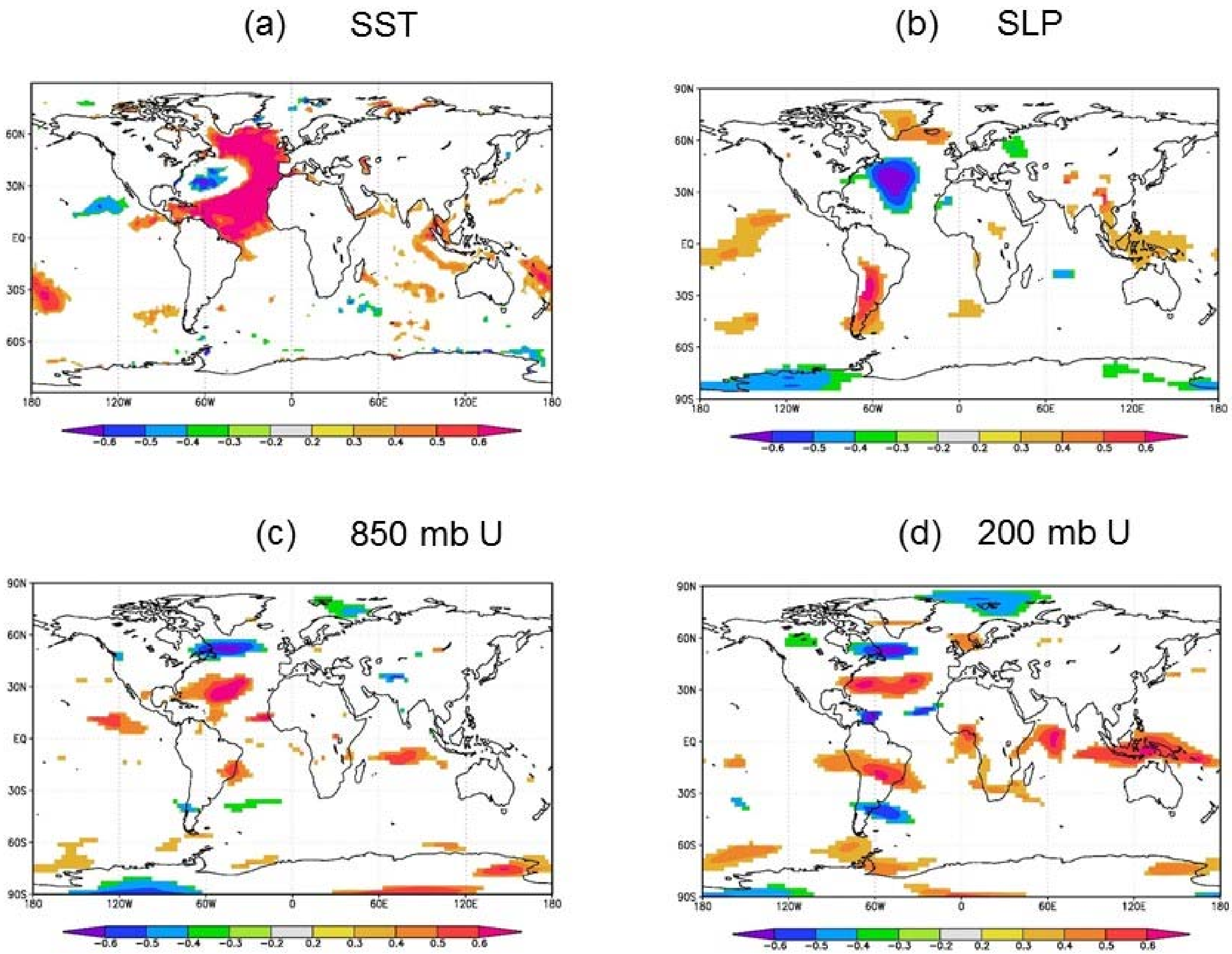

Figure 4: Linear correlations between April-May SST in the eastern Atlantic (Predictor 1) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October 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.

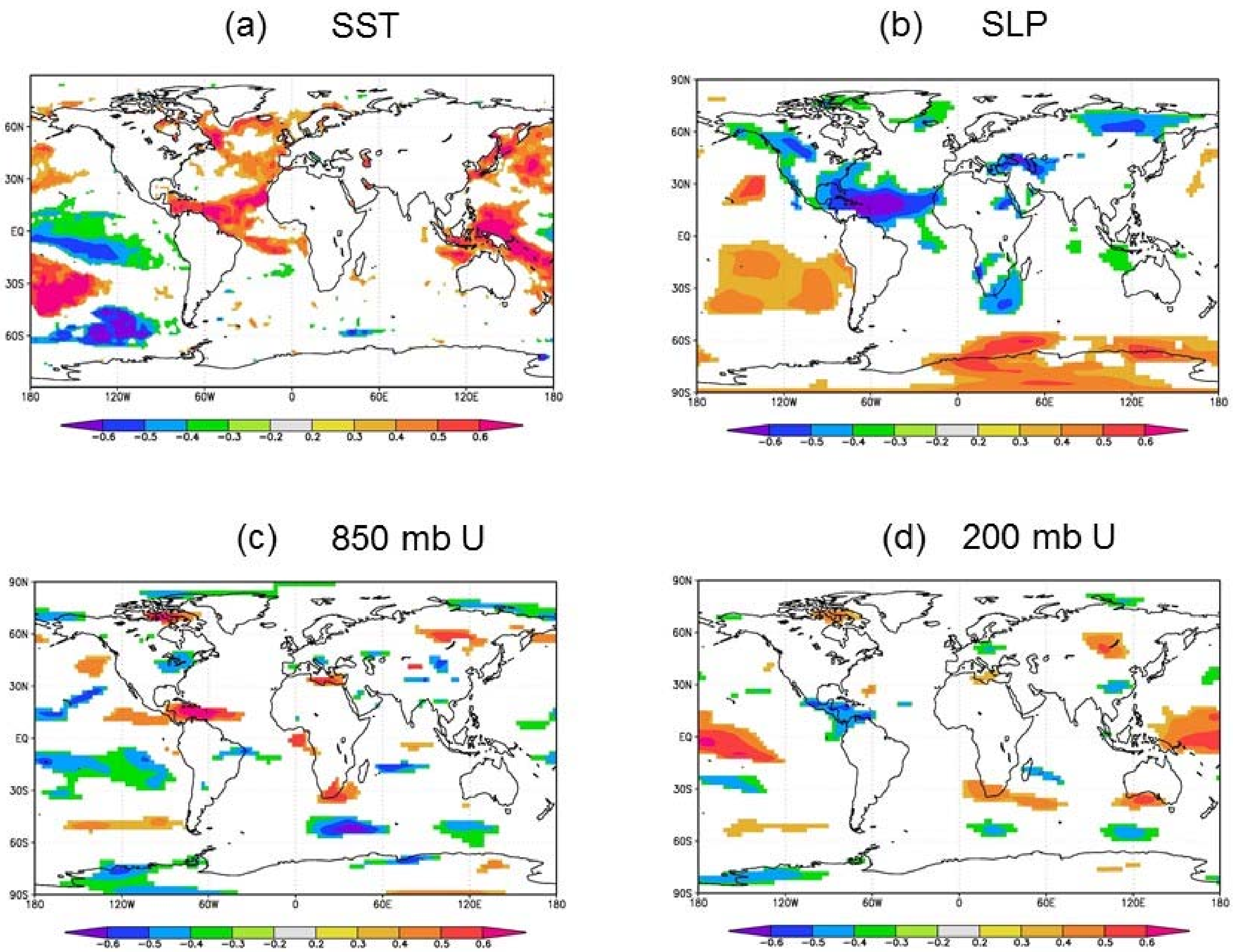

Figure 5: Linear correlations between April-May 200-mb zonal winds in the south-central tropical Pacific (Predictor 2) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) 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.

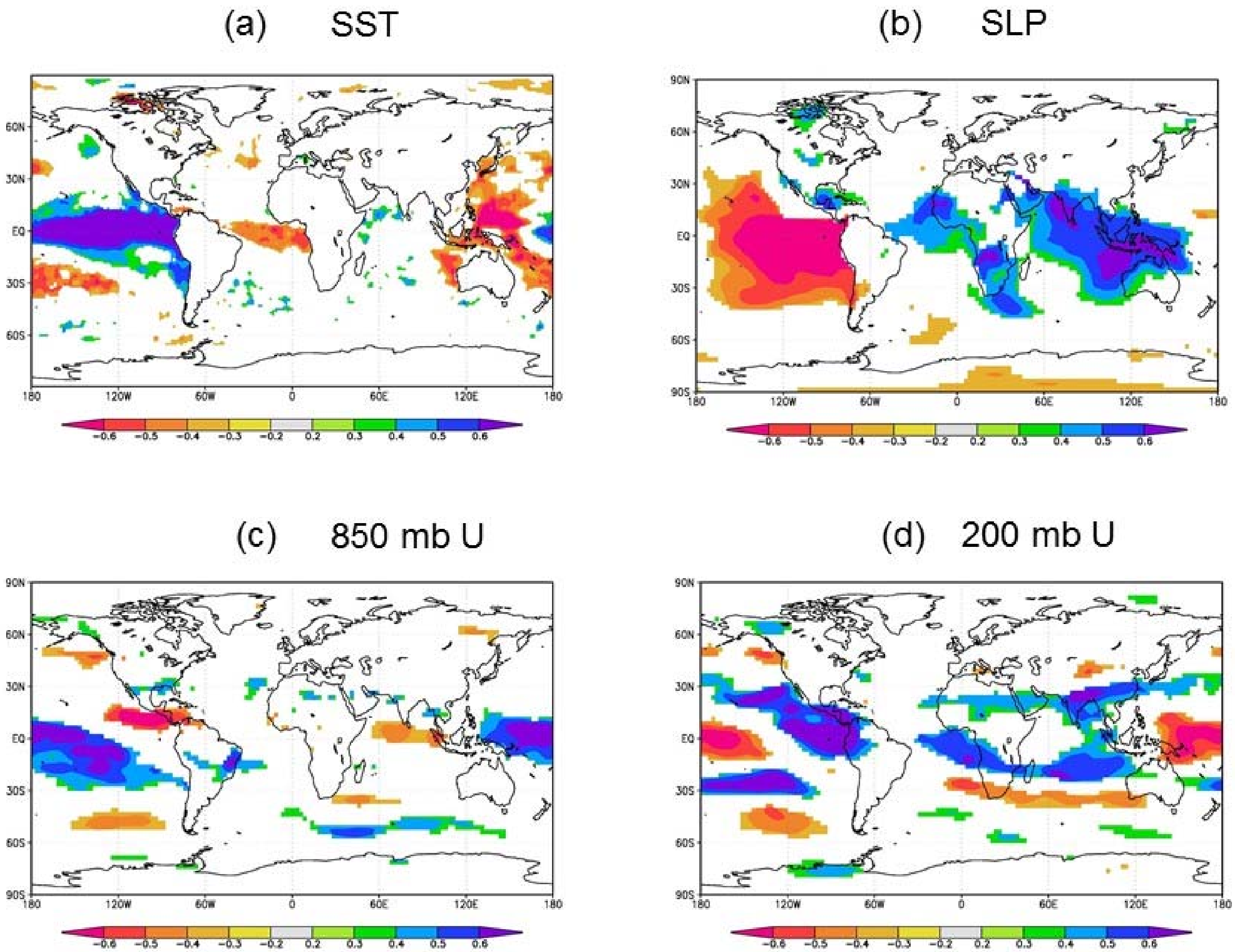

Figure 6: Linear correlations between a 1 May ECMWF SST forecast for September Nino 3 (Predictor 3) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following 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.

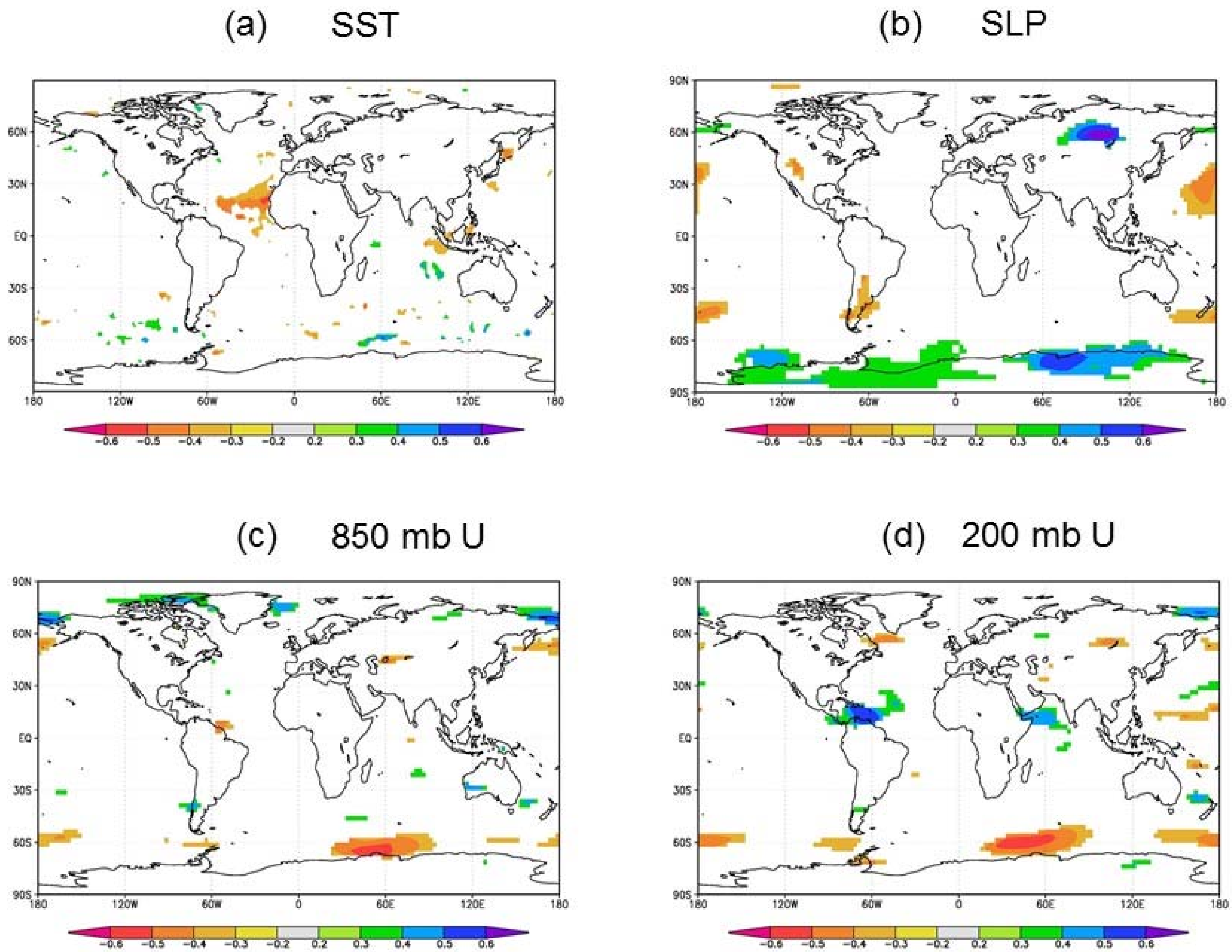

Figure 7: Linear correlations between May sea level pressure in the central Atlantic (Predictor 4) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following 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 2015 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2015 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	3.7	8	4.3 – 11.7
Named Storm Days (NSD)	21.1	30	8.9 – 51.1
Hurricanes (H)	2.1	3	0.9 – 5.1
Hurricane Days (HD)	10.2	10	0.0 – 20.2
Major Hurricanes (MH)	1.6	1	0.0 – 2.6
Major Hurricane Days (MHD)	5.3	0.5	0.0 – 5.8
Accumulated Cyclone Energy (ACE)	48	40	0 – 88
Net Tropical Cyclone (NTC) Activity	48	45	0 – 93

4 Analog-Based Predictors for 2015 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2015. These years also provide useful clues as to likely trends in activity that the forthcoming 2015 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 2015 conditions. Table 6 lists our analog selections.

We select prior hurricane seasons since 1950 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that were characterized by moderate to strong El Niño conditions and generally cool conditions in the tropical Atlantic during the upcoming hurricane season.

There were six hurricane seasons since 1950 with characteristics most similar to what we expect to see in August-October of 2015. We anticipate that the 2015 hurricane season will have slightly less activity than the average of our six analog years, given the significant impact that a moderate to strong El Niño has on Atlantic hurricane activity. We believe that this season should experience well below-average activity.

Table 6: Best analog years for 2015 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1957	8	38.00	3	21.00	2	6.50	84	86
1965	6	39.50	4	27.25	1	7.50	84	86
1972	7	30.75	3	6.25	0	0.00	36	35
1982	6	18.50	2	5.75	1	1.25	32	38
1987	7	37.25	3	5.00	1	0.50	34	46
1997	8	30.00	3	9.50	1	2.25	41	54
Average	7.0	32.3	3.0	12.5	1.0	3.0	52	57
2015 Forecast	**8**	**30**	**3**	**10**	**1**	**0.5**	**40**	**45**

5 ENSO

Warm neutral ENSO conditions were present during the winter of 2014/2015. Upper ocean heat content (top 300 meters) anomalies dropped to near-normal levels during January and have since rapidly increased and are now over 1°C in the eastern and central tropical Pacific (Figure 8). These upper-ocean heat content anomalies have stabilized, although at elevated levels in recent weeks. Upper-ocean heat content anomalies for April/May 2015 were the second warmest on record (since records began in 1979), trailing only 1997, which was the strongest El Niño event of the 20th century.

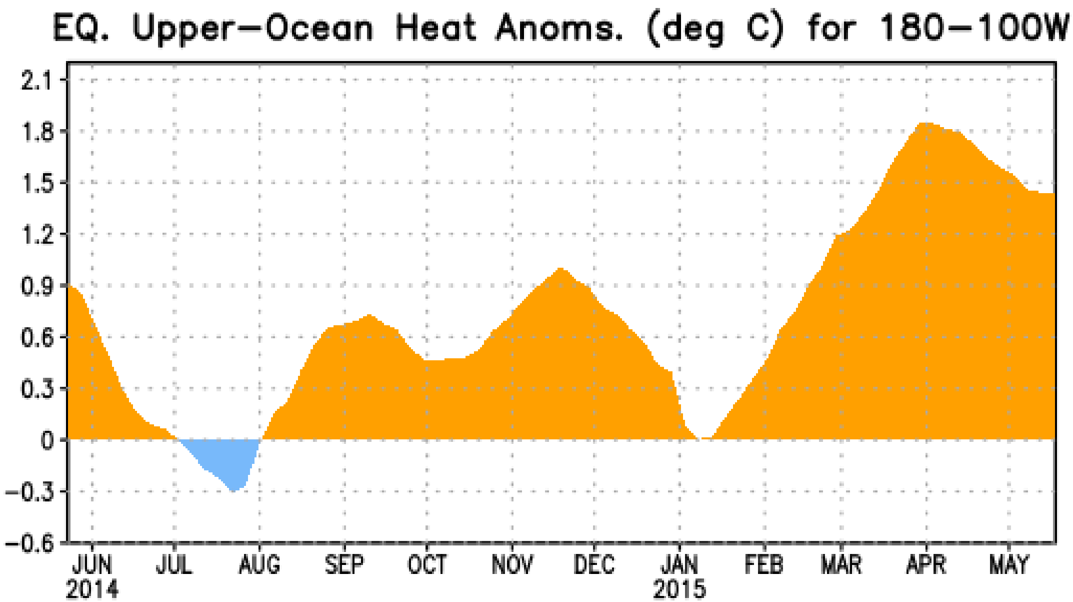

Figure 8: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Anomalies dropped during the early portion of the winter, rapidly increased into early April and have since stabilized at well above-average levels.

Currently, SSTs are running well above 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 tropical Pacific has warmed during the two-month period, with the warming being most dramatic in the eastern part of the basin. SST anomalies in the Nino 1+2 region are currently warmer than at any time since early June 1998.

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	+2.3	+2.2
Nino 3	+0.2	+1.2	+1.0
Nino 3.4	+0.6	+1.1	+0.5
Nino 4	+1.1	+1.2	+0.1

While we also believed that a moderate to strong El Niño event was possible in 2014, this year's event is much farther along than last year. Table 8 displays May SST anomalies for 2015 and 2014 for the various Nino regions. Current-year values are much higher than they were last year at this time.

Table 8: May 2014 and May 2015 SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. May 2015 minus May 2014 SST anomaly differences are also provided.

Region	May 2014 SST Anomaly (°C)	May 2015 SST Anomaly (°C)	May 2015 – May 2014 SST Anomaly (°C)
Nino 1+2	+1.3	+2.3	+1.0
Nino 3	+0.6	+1.2	+0.6
Nino 3.4	+0.5	+1.1	+0.6
Nino 4	+0.8	+1.2	+0.4

There is still considerable uncertainty as to what the magnitude of this year's El Niño is going to be. The spring months are known for their ENSO predictability barrier. While we are nearing the end of this predictability barrier, considerable changes in ENSO often take place in June and July. 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. These models show even better skill by the end of June and July. All of the dynamical and most of the statistical models are calling for a moderate to strong El Niño event in 2015 (Figure 9).

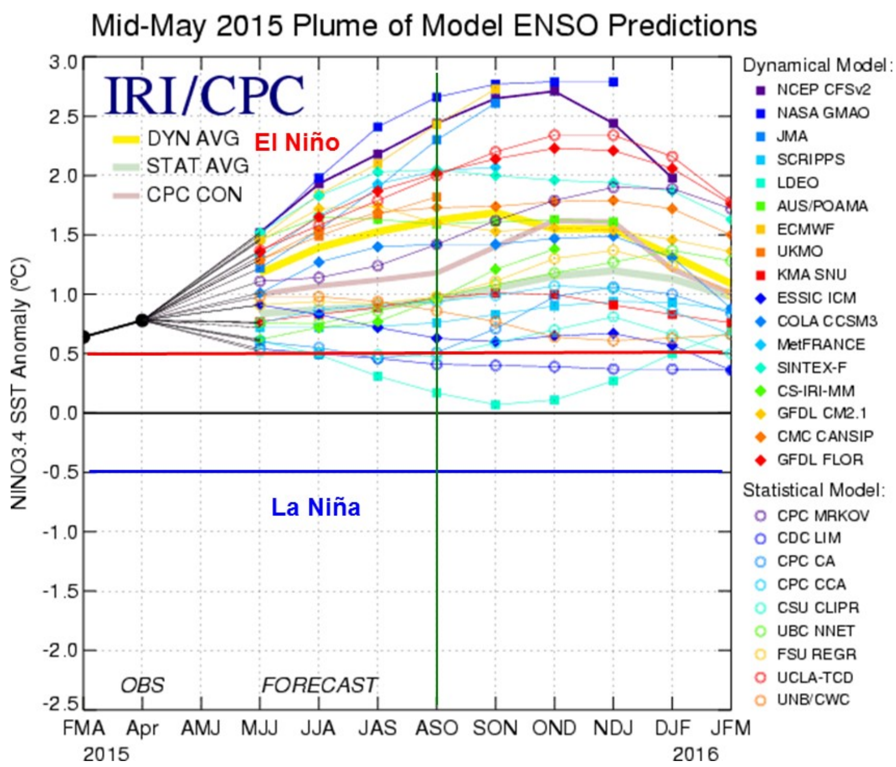

Figure 9: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). Most models call for a moderate to strong El Niño over the next several months.

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 2.4°C. Also plotted in the figure below are the five strongest ENSO events during the peak months of the Atlantic hurricane season from August-October. Note that approximately 60% of the ensemble members are calling for an event stronger than 1997 by September. 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).

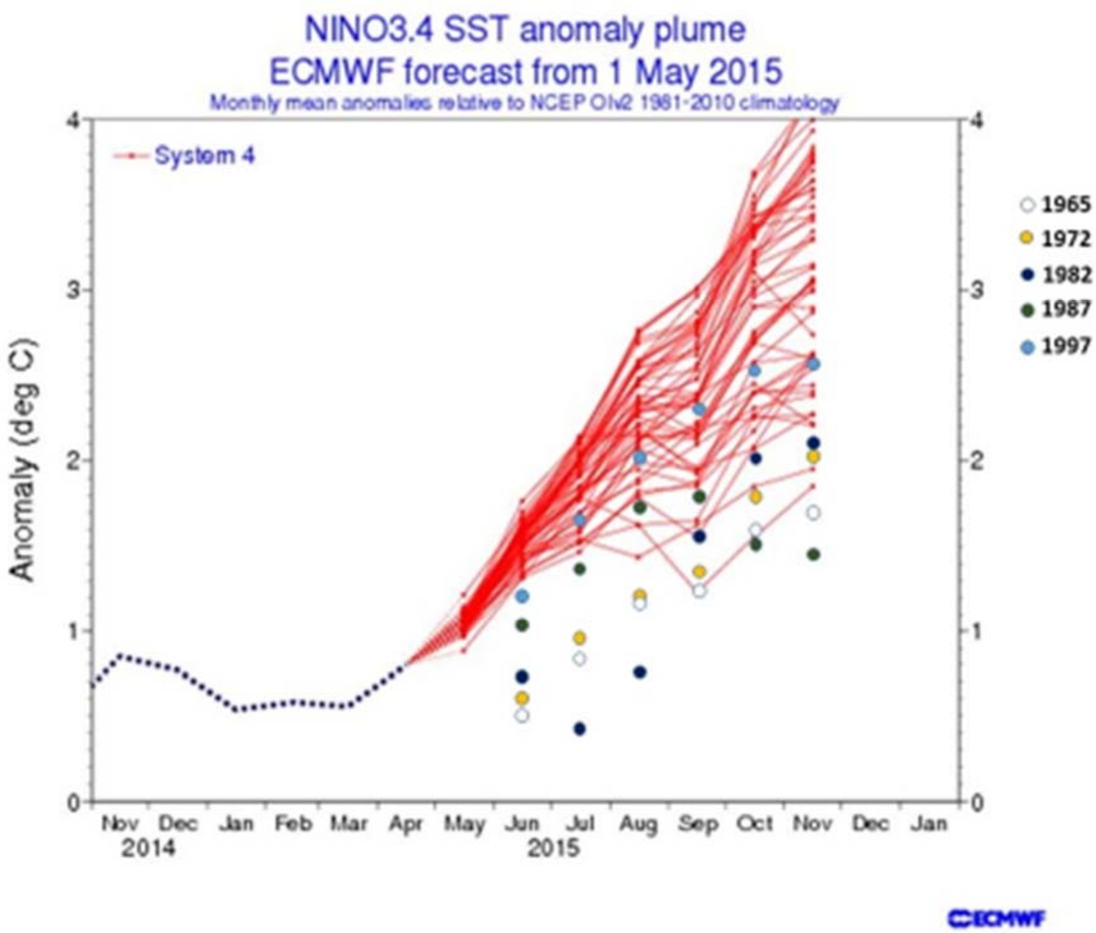

Figure 10: ECMWF ensemble model forecast for the Nino 3.4 region.

Our confidence that a significant El Niño event will develop during this year's hurricane season has remained high since early April. Anomalously strong low-level westerly flow has persisted for the past two months near the International Date Line

(Figure 11), triggering eastward propagating Kelvin waves that have transported warm water from the western Pacific eastward (Figure 12).

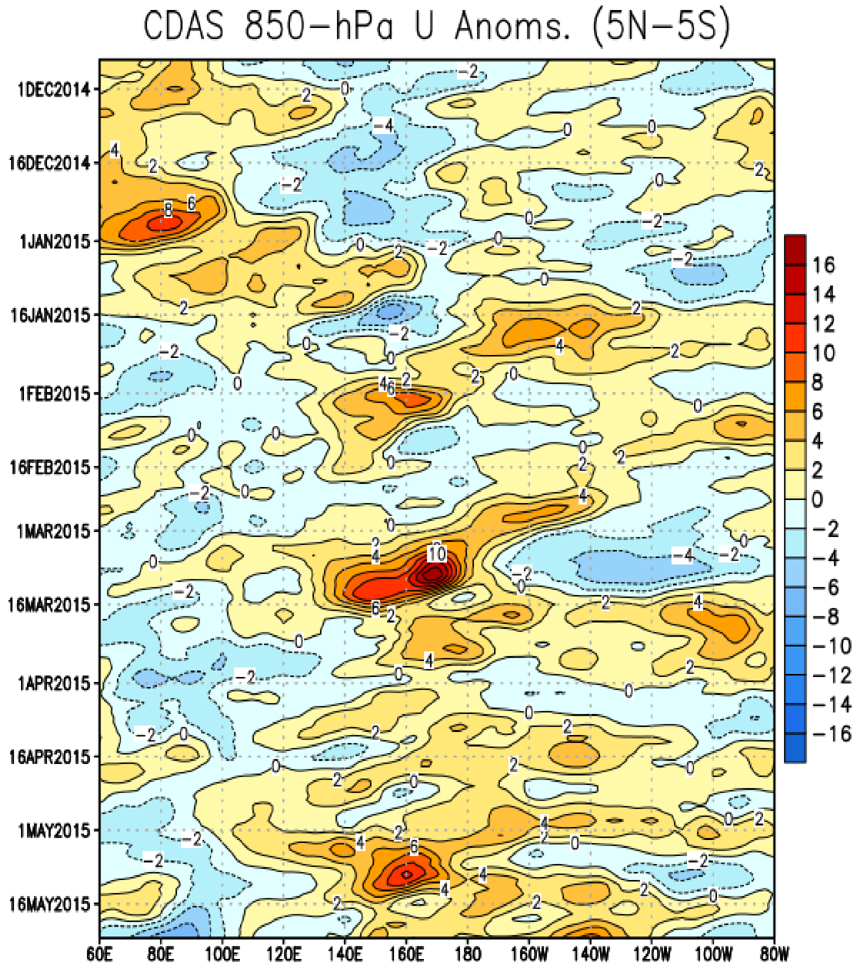

Figure 11: Anomalous low-level winds across the tropical Pacific since late November 2014. Note the persistence of anomalous westerlies near the International Date Line since early March. This anomalously strong westerly wind flow drives eastward-propagating Kelvin waves associated with basinwide warming.

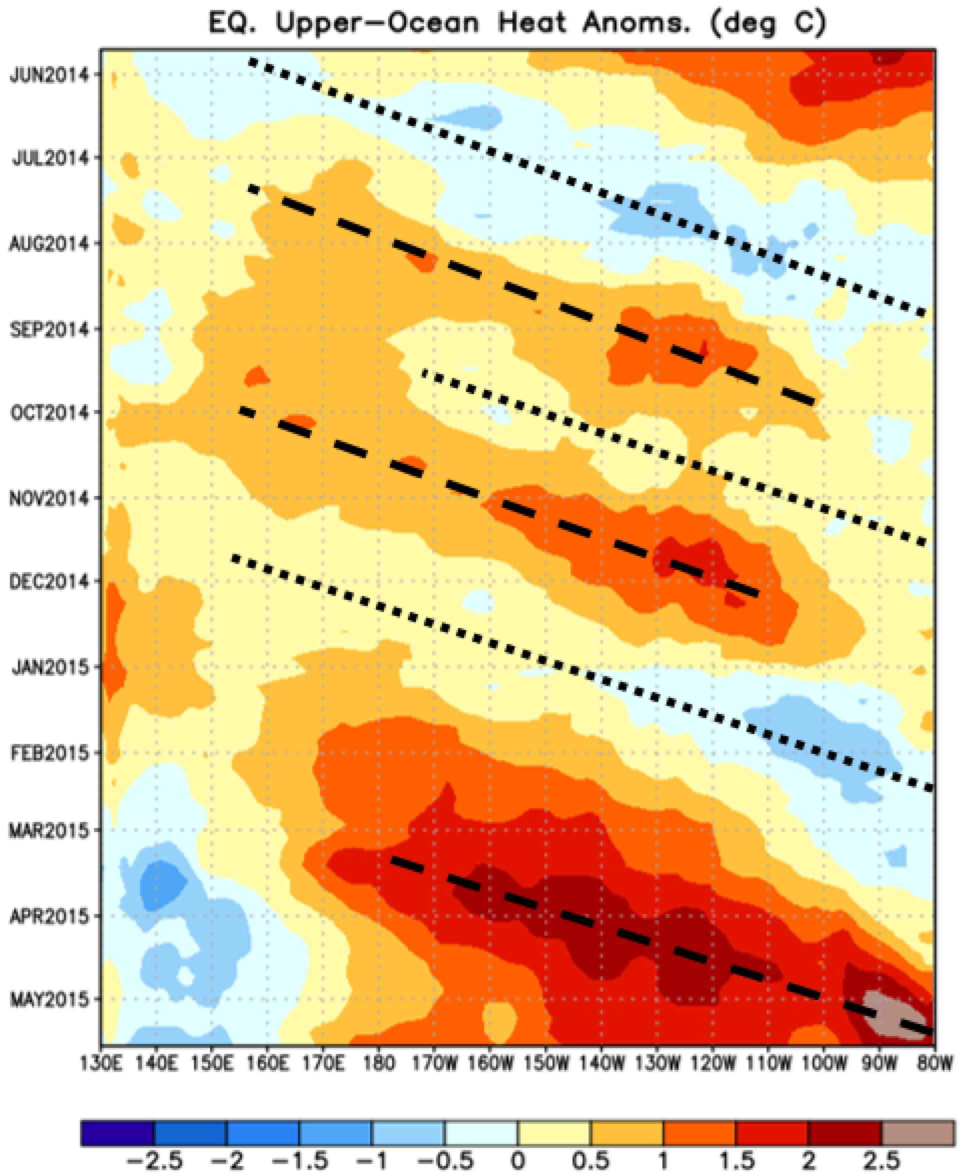

Figure 12: Upper-ocean heat content anomalies across the tropical Pacific. Note the significant warming that has occurred since the latter part of March across the central and eastern Pacific, associated with a strong Kelvin wave propagating across the Pacific basin. Dashed lines represent the warming (downwelling) phase of the Kelvin wave, while the dotted lines represent the cooling (upwelling) phase of the Kelvin wave.

Based on the above information, we are currently anticipating a strong El Niño event that will significantly impact this year's Atlantic hurricane season. There remains a need to closely monitor ENSO conditions over the next few months. Additional discussion of ENSO will be included with the July 1 and August 3 updates.

6 Current Atlantic Basin Conditions

Most of the tropical Atlantic is relatively cold right now (Figure 13). As was the case last year, the overall SST pattern across the Atlantic basin appears to resemble the negative phase of the AMO or weak phase of the THC. A weak phase of the THC is typically associated with quieter Atlantic basin hurricane seasons. There has been a very strong anomalous cooling of the tropical and North Atlantic since last November (Figure 14), which was driven by a much stronger subtropical high in recent months (Figure 15). The circulation around the subtropical high brings anomalous cold air and water advection along its eastern periphery.

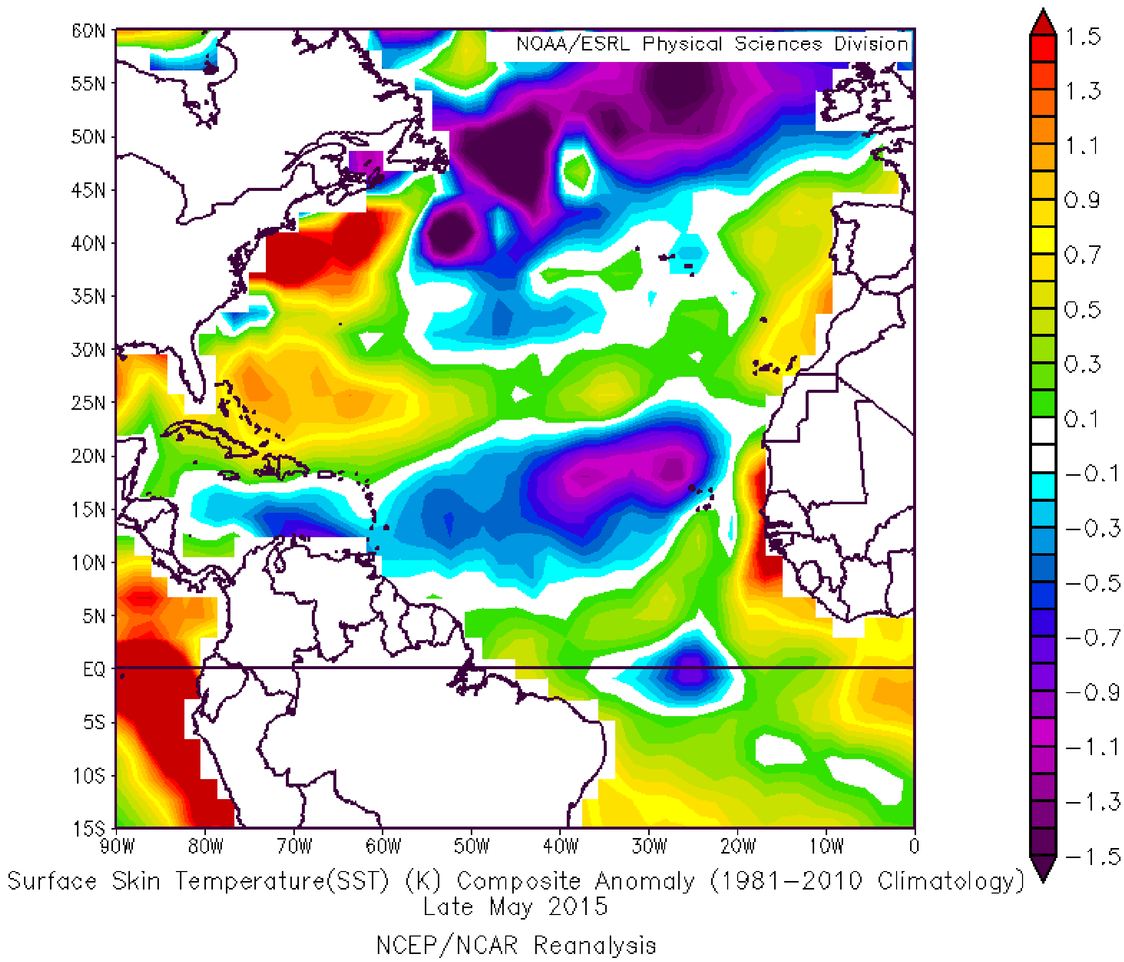

Figure 13: Late May SST anomalies across the Atlantic.

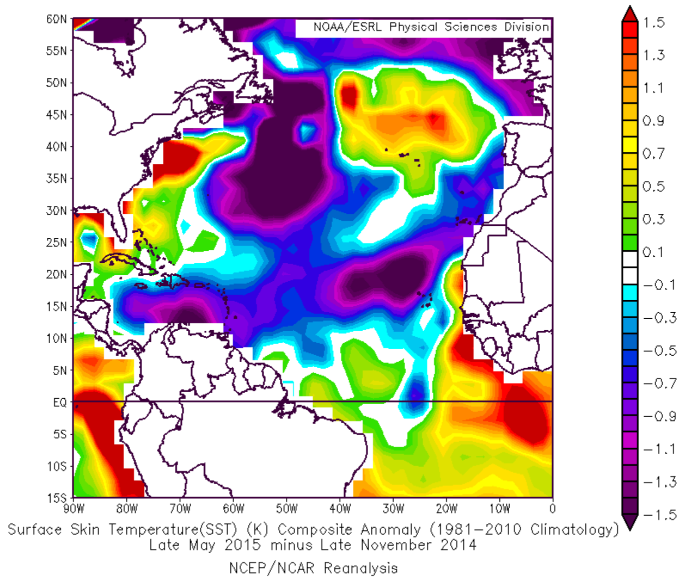

Figure 14: Anomalous SST change from late November 2014 to late May 2015.

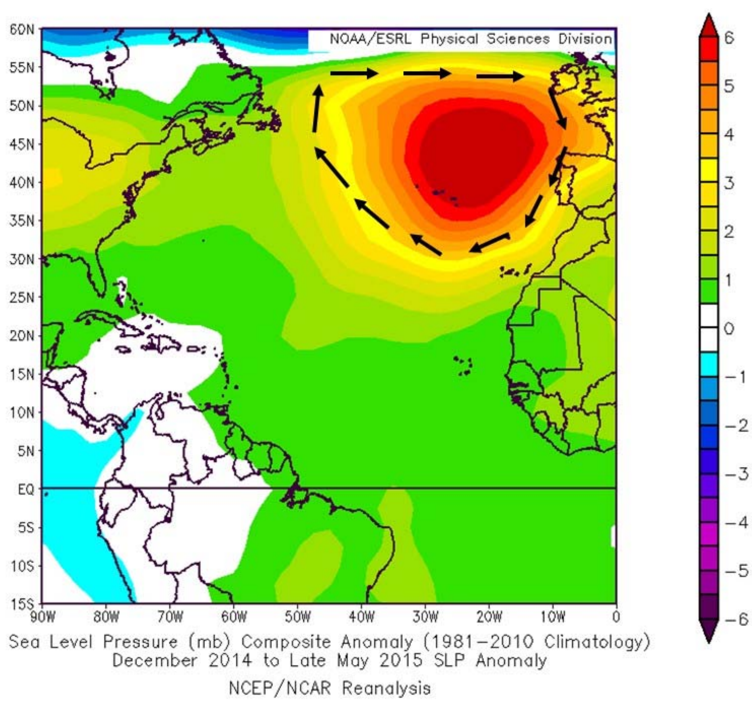

Figure 15: Sea level pressure anomalies from December 2014 to late May 2015. The strong subtropical high that was present across the North Atlantic for most of this period drove strong anomalous cold air and water advection along its eastern periphery (as indicated by the black arrows).

7 Current THC/AMO Strength

One of the big questions that has been asked given the quiet Atlantic hurricane seasons the past two years is if the active era of Atlantic basin storm activity that began in 1995 has come to an end. We currently monitor the strength of the Atlantic Multidecadal Oscillation (AMO) and Atlantic thermohaline circulation (THC) using a combined proxy measure of SST in the region from 50-60°N, 50-10°W and SLP in the region from 0-50°N, 70-10°W (Figure 16). This index was discussed in detail in Klotzbach and Gray (2008).

We currently weigh standardized values of the index by using the following formula: 0.6*SST – 0.4*SLP. Twelve-month running average values of the index are currently at their lowest levels since 1994, when the AMO was in a negative phase.

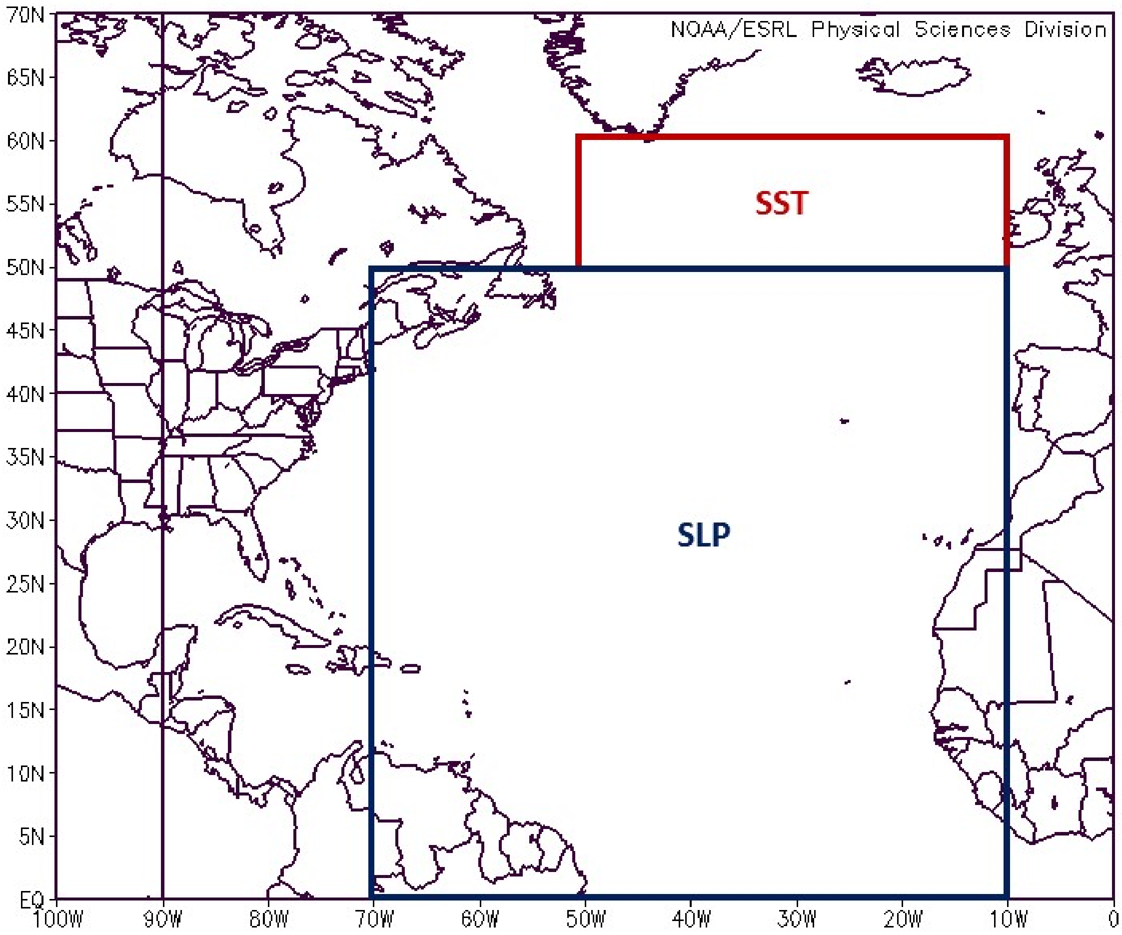

Figure 16: Regions which are utilized for calculations of our THC/AMO index.

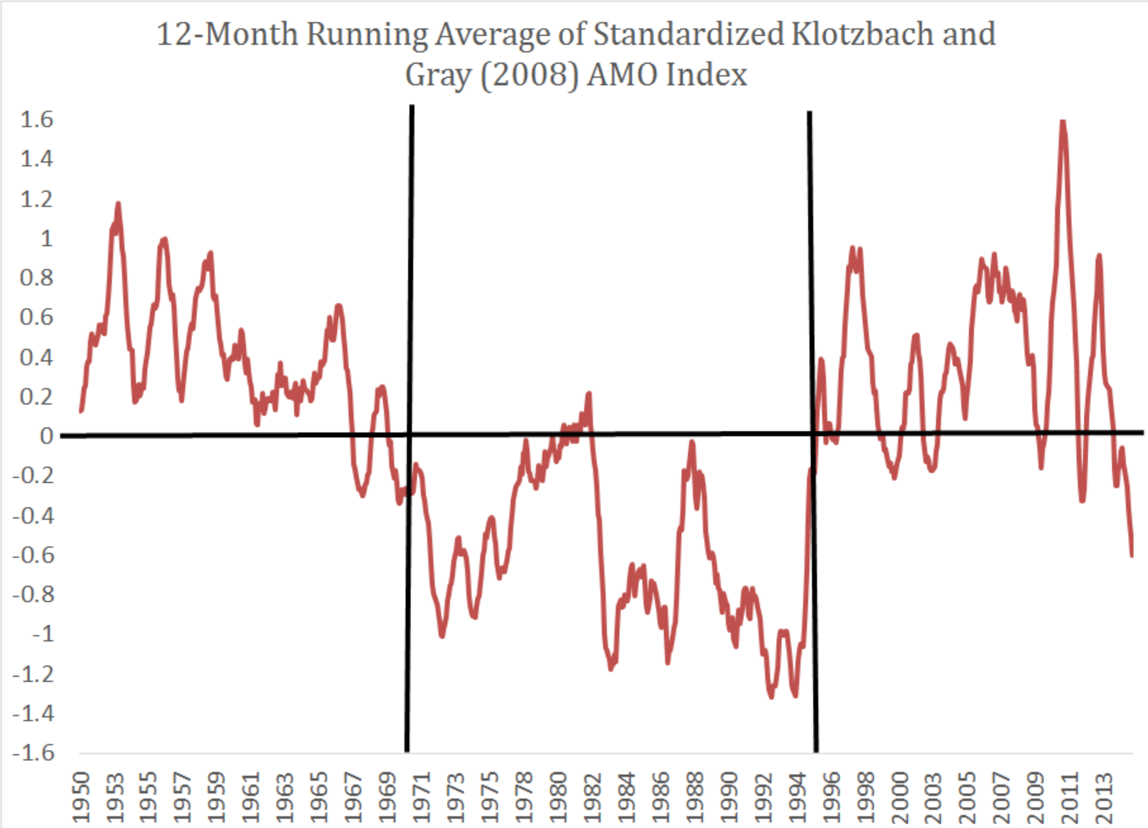

Figure 17: 12-month running average values of our standardized index of the AMO/THC. Current 12-month running average values are at their lowest since 1994.

8 Adjusted 2015 Forecast

Table 9 shows our final adjusted early June forecast for the 2015 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 analog schemes call for well below-average activity. Overall, we are predicting a well below-average season for the Atlantic basin in 2015, due to a combination of an anticipated strong El Niño and unfavorable conditions in the tropical Atlantic.

Table 9: Summary of our early June statistical forecast, our analog forecast and our adjusted final forecast for the 2015 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (12.0)	6.7	7.0	8
Named Storm Days (60.1)	23.3	32.3	30
Hurricanes (6.5)	3.1	3.0	3
Hurricane Days (21.3)	6.2	12.5	10
Major Hurricanes (2.0)	0.3	1.0	1
Major Hurricane Days (3.9)	0.0	3.0	0.5
Accumulated Cyclone Energy Index (92)	19	52	40
Net Tropical Cyclone Activity (103%)	32	57	45

9 Landfall Probabilities for 2015

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline and in the Caribbean. 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 20th 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 10). 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 10: 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 2015 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also now issue probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2015 is expected to be well below its long-term average of 100, and therefore, landfall probabilities are well below 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 10% which is approximately one-half of 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 5%. For Duval County in northeastern coastal Florida, the probability of being impacted by hurricane-force wind gusts is only 1%. 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 16%, 7%, and 2%, 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 2015. 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)	51% (79%)	40% (68%)	28% (52%)	57% (84%)	79% (97%)
Gulf Coast (Regions 1-4)	33% (59%)	22% (42%)	15% (30%)	34% (60%)	55% (83%)
Florida plus East Coast (Regions 5-11)	27% (50%)	23% (44%)	15% (31%)	35% (61%)	52% (81%)
Caribbean (10-20°N, 60-88°W)	54% (82%)	32% (57%)	22% (42%)	46% (75%)	75% (96%)

10 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 2015 should be a well below-average season. A strong El Niño appears likely, and conditions in the tropical Atlantic remain unfavorable for TC formation.

11 Forthcoming Updated Forecasts of 2015 Hurricane Activity

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

12 Acknowledgments

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14 Verification of Previous Forecasts

Table 11: Summary verification of the authors' five previous years of seasonal forecasts for Atlantic TC activity between 2010-2014. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

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	4.50
Accumulated Cyclone Energy	165	160	160	160	126
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	101.25
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

2013	10 April	Update 3 June	Update 2 August	Obs.
Hurricanes	9	9	8	2
Named Storms	18	18	18	14
Hurricane Days	40	40	35	3.75
Named Storm Days	95	95	84.25	42.25
Major Hurricanes	4	4	3	0
Major Hurricane Days	9	9	7	0
Accumulated Cyclone Energy	165	165	142	36
Net Tropical Cyclone Activity	175	175	150	47

2014	10 April	Update 2 June	Update 1 July	Update 31 July	Obs.
Hurricanes	3	4	4	4	6
Named Storms	9	10	10	10	8
Hurricane Days	12	15	15	15	17.75
Named Storm Days	35	40	40	40	35
Major Hurricanes	1	1	1	1	2
Major Hurricane Days	2	3	3	3	3.75
Accumulated Cyclone Energy	55	65	65	65	67
Net Tropical Cyclone Activity	60	70	70	70	82