EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2014

We anticipate that the 2014 Atlantic basin hurricane season will have below-average activity compared with the 1981-2010 climatology. It appears quite likely that an El Niño of at least moderate strength will develop this summer and fall. In addition, the tropical Atlantic has anomalously cooled over the past few months. We anticipate a below-average probability for major hurricanes making landfall along the United States coastline and in the Caribbean. Despite the quiet forecast, coastal residents are reminded that it only takes one hurricane making landfall to make it an active season for them. They are reminded to prepare the same for every season, regardless of how much or how little activity is predicted.

(as of 10 April 2014)

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

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

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2014

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 10 April 2014
Named Storms (NS) (12.0)	9
Named Storm Days (NSD) (60.1)	35
Hurricanes (H) (6.5)	3
Hurricane Days (HD) (21.3)	12
Major Hurricanes (MH) (2.0)	1
Major Hurricane Days (MHD) (3.9)	2
Accumulated Cyclone Energy (ACE) (92)	55
Net Tropical Cyclone Activity (NTC) (103%)	60

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

1) Entire U.S. coastline - 35% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 20% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 19% (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) 28% (average for last century is 42%)

ABSTRACT

Information obtained through March 2014 indicates that the 2014 Atlantic hurricane season will likely have less activity than the median 1981-2010 season. We estimate that 2014 will have only 3 hurricanes (median is 6.5), 9 named storms (median is 12.0), 35 named storm days (median is 60.1), 12 hurricane days (median is 21.3), 1 major (Category 3-4-5) hurricanes (median is 2.0) and 2 major hurricane days (median is 3.9). The probability of U.S. major hurricane landfall is estimated to be about 65 percent of the long-period average. We expect Atlantic basin Accumulated Cyclone Energy (ACE) and Net Tropical Cyclone (NTC) activity in 2014 to be approximately 60 percent of their long-term averages.

This forecast is based on a new extended-range early April statistical prediction scheme that was developed utilizing 29 years of past data. Analog predictors are also utilized. We anticipate a below-average Atlantic basin hurricane season due to the combination of a relatively high likelihood of at least a moderate El Niño and a relatively cool 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.

Why was the 2013 Atlantic hurricane seasonal forecast such a large bust?

We have spent a significant amount of time researching this question over the past few months. It appears that the primary reason was the most significant spring weakening observed since 1950 of the Atlantic thermohaline circulation (THC). A brief discussion is available here.

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 April. 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 April 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. When outlying events occur, such as the massive weakening of the THC in the spring of 2013, our statistical model is unable to correctly predict activity.

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 and Ironshore Insurance that partially support the release of these predictions. The remainder of this year's forecasts are provided by 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 thank Bill Thorson for technical advice and assistance.

DEFINITIONS AND ACRONYMS

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

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

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

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

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

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

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.

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, 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 31st year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's April 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. When dramatic changes occur that are not in the observational record, such as occurred during the spring of 2013, these forecast models may fail.

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 April Forecast Methodology

2.1 New April Statistical Forecast Scheme

We have developed a new April statistical forecast model which we are using for the fourth 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-present, while the NOAA Optimum Interpolation (OI) SST (Reynolds et al. 2002) is available from 1982-present. This new model shows significant skill in predicting levels of Net Tropical Cyclone (NTC) activity over the 1982-2010 developmental period. 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 1950-2000 climatological average. The model correlates with NTC at 0.57 from 1982-2013 when a drop-one cross-validation (jackknife) analysis is conducted. A cross-validation approach provides a more realistic view of skill the model is expected to have in future years.

Table 1 displays cross-validated NTC hindcasts for 1982-2010 along with real-time forecast values for 2011-2013 using the new statistical scheme, while Figure 1 displays observations versus cross-validated NTC hindcasts. The large forecast bust of our early April prediction that occurred in 2013 was due to massive changes in the tropical and subtropical Atlantic that occurred after the issuance of this forecast.

We have correctly predicted by early April above- or below-average seasons in 22 out of 32 hindcast years (69%). Our predictions have had a smaller error than climatology in 19 out of 32 years (59%). Our average hindcast error is 44 NTC units, compared with 55 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 90% 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 system 3 has significant forecast skill for SSTs across the various Nino regions for September from a 1 March forecast date. We utilize the ECMWF ensemble mean prediction for September Nino 3 SSTs. The ECMWF has recently upgraded to system 4. Hindcast data from this new model is not available yet, but it is assumed that the model has improved skill to system 3. Hindcast data from 1982-2010 show that the ECMWF forecast from system 3 from a 1 March issue date correlates with observed September Nino 3 SSTs at 0.63. Table 3 displays the 2014 observed values for each of the four predictors in the new statistical forecast scheme. Table 4 displays the statistical model output for the 2014 hurricane season.

Table 1: Observed versus early April cross-validated hindcast NTC for 1982-2010 using our new forecast scheme as well as the statistical model's real-time output for 2011-2013. 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 22 out of 32 years (69%), while hindcast improvement over climatology occurred in 19 out of 32 years (59%). The hindcast has improved upon climatology in all but seven years since 1993.

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1982	38	**101**	-63	-62	**-1**
1983	31	20	11	-69	58
1984	80	**163**	-82	-20	**-63**
1985	106	**60**	45	6	**-40**
1986	37	32	5	-63	58
1987	46	71	-25	-54	29
1988	117	134	-17	17	0
1989	130	**96**	34	30	**-4**
1990	100	91	9	0	**-9**
1991	58	97	-39	-42	3
1992	67	20	47	-33	**-14**
1993	52	60	-8	-48	40
1994	35	71	-35	-65	29
1995	222	158	64	122	58
1996	192	189	3	92	89
1997	54	91	-38	-46	9
1998	169	166	3	69	66
1999	182	121	60	82	21
2000	134	154	-21	34	13
2001	135	113	22	35	13
2002	83	**136**	-53	-17	**-36**
2003	175	139	36	75	39
2004	232	**89**	142	132	**-11**
2005	279	185	94	179	85
2006	85	**139**	-54	-15	**-39**
2007	99	**135**	-36	-1	**-35**
2008	162	201	-39	62	24
2009	69	78	-9	-31	22
2010	195	235	-40	95	55
2011	145	200	-55	45	**-10**
2012	131	**52**	79	31	**-46**
2013	47	**200**	-153	-53	**-100**
Average	**115**	**119**	**44**	**55**	**+11**

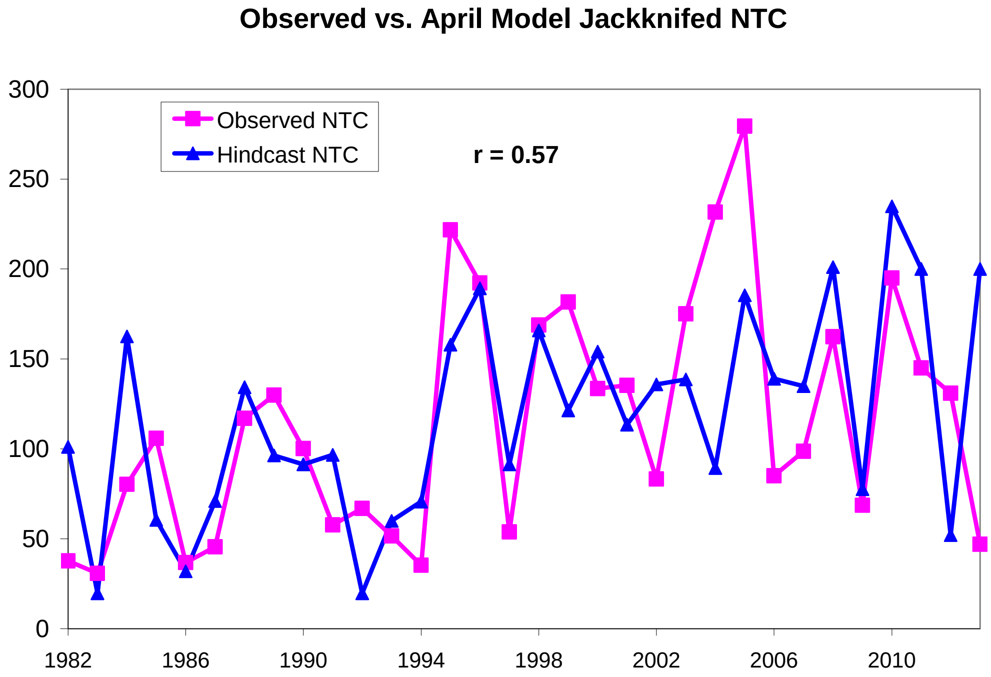


Figure 1: Observed versus early April jackknifed hindcast values of NTC for 1982-2010 along with real-time forecast values for 2011-2013.

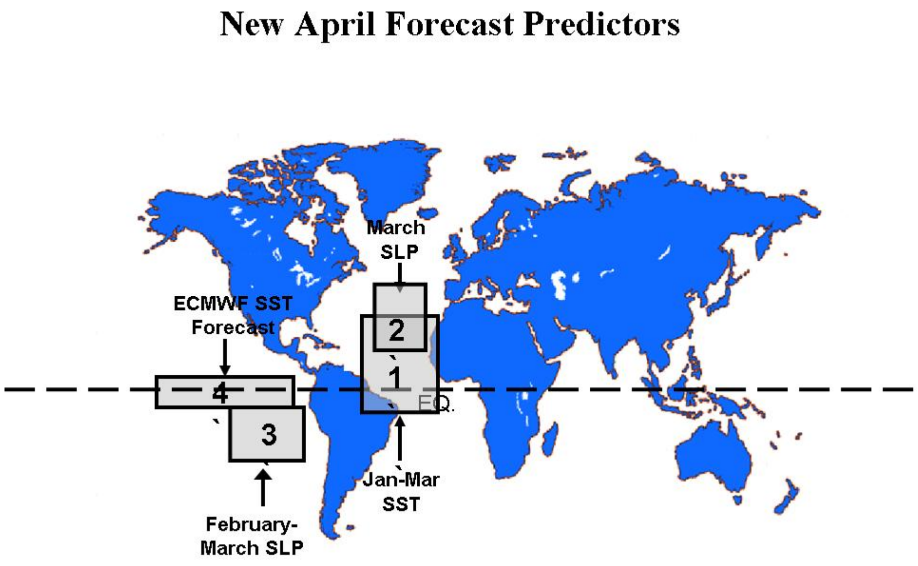


Figure 2: Location of predictors for our early April extended-range statistical prediction for the 2014 hurricane season.

Table 2: Linear correlation between each 1 April predictor and NTC over the 1982-2010 hindcast period.

Predictor	Correlation w/ NTC
1) January-March Atlantic SST (5°S-35°N, 10-40°W) (+)	0.60
2) March SLP (20-40°N, 20-35°W) (-)	-0.49
3) February-March SLP (5-20°S, 85-120°W) (+)	0.34
4) ECMWF 1 March SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	-0.40

Table 3: Listing of 1 April 2014 predictors for the 2014 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity.

Predictor	2014 Forecast Value	Impact on 2014 TC Activity
1) Jan-Mar Atlantic SST (5°S-35°N, 10-40°W) (+)	-1.0 SD	Decrease
2) Mar SLP (20-40°N, 20-35°W) (-)	+0.9 SD	Decrease
3) Feb-Mar SLP (5-20°S, 85-120°W) (+)	+0.7 SD	Increase
4) ECMWF 1 Mar SST Forecast for Sep Nino 3 (5°S-5°N, 90-150°W) (-)	+1.4 SD	Decrease

Table 4: Statistical model output for the 2014 Atlantic hurricane season, along with the final adjusted forecast.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast	Final Forecast
Named Storms (12.0)	8.4	9
Named Storm Days (60.1)	35.8	35
Hurricanes (6.5)	4.3	3
Hurricane Days (21.3)	13.6	12
Major Hurricanes (2.0)	1.3	1
Major Hurricane Days (3.9)	2.1	2
Accumulated Cyclone Energy Index (92)	56	55
Net Tropical Cyclone Activity (103%)	64	60

2.2 Physical Associations among Predictors Listed in Table 2

The locations and brief descriptions of the predictors for our early April 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. These factors are all 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.

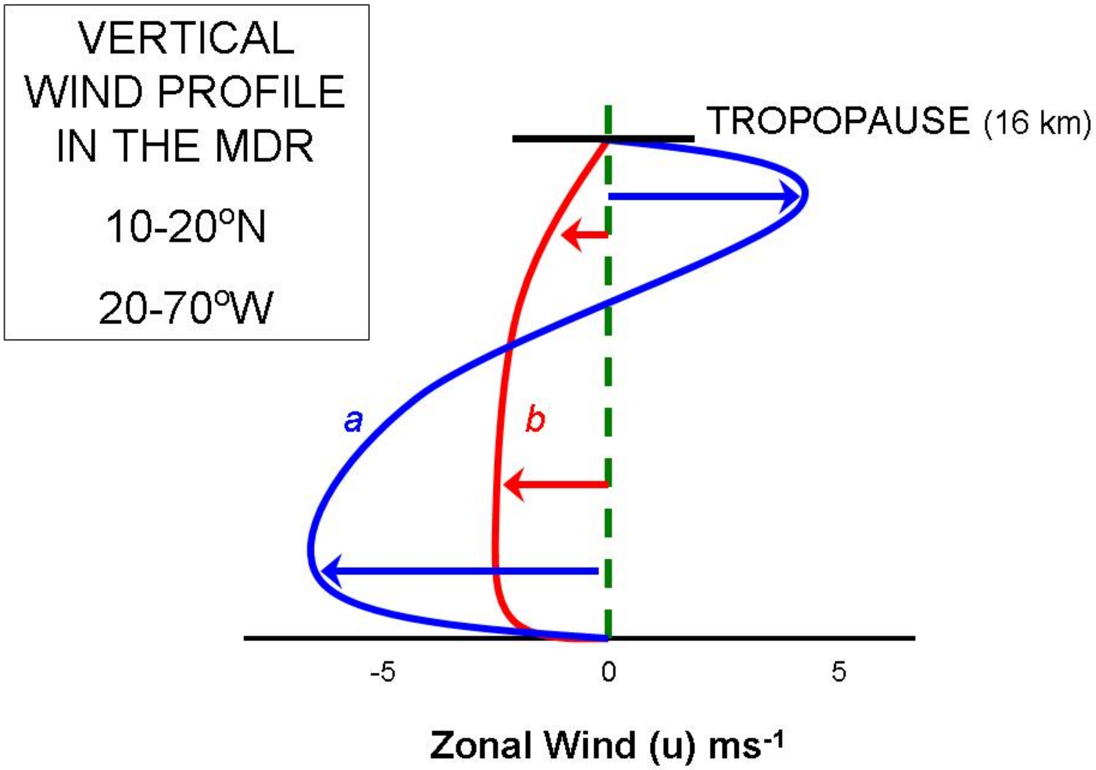


Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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 (SLP), 200 mb zonal wind, and 850 mb zonal wind, respectively. In general, higher values of SSTs, lower values of SLP, 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, SLP and 850 mb zonal wind correlations are displayed using the Climate Forecast System Reanalysis (CFSR), while 200 mb zonal wind correlations are displayed using the NCEP/NCAR Reanalysis, as there are questions about the quality of the upper-level wind reanalysis in the CFSR.

Predictor 1. January-March SST in the Tropical and Subtropical Eastern Atlantic (+)

(5°S-35°N, 10-40°W)

Warmer-than-normal SSTs in the tropical and subtropical Atlantic during the January-March time period are associated with a weaker-than-normal subtropical high and reduced trade wind strength during the boreal spring (Knaff 1997). Positive SSTs in January-March 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. March SLP in the Subtropical Atlantic (-)

(20-40°N, 20-35°W)

Our April statistical scheme in the late 1990s used a similar predictor when evaluating the strength of the March Atlantic sub-tropical ridge (Azores High). If the pressure in this area is higher than normal, it correlates strongly with increased Atlantic trade winds. These stronger trades enhance ocean mixing and upwelling, driving cooler tropical Atlantic SSTs. These cooler SSTs are associated with higher-than-normal sea level pressures which can create a self-enhancing feedback that relates to higher pressure, stronger trades and cooler SSTs during the hurricane season (Figure 5) (Knaff 1998). All three of these factors are associated with inactive hurricane seasons.

Predictor 3. February-March SLP in the southeastern tropical Pacific (+)

(5-20°S, 85-120°W)

High pressure in the southeastern tropical Pacific during the months of February-March correlates strongly with a positive Southern Oscillation Index and strong trades blowing across the eastern tropical Pacific. Strong trade winds help prevent eastward propagating Kelvin waves from transporting warmth from the western Pacific warm pool region and triggering El Niño conditions. During the August-October period, positive values of this predictor are associated with weaker trades, lower sea level pressures, and relatively cool SST anomalies in the eastern Pacific (typical of La Niña conditions) (Figure 6). The combination of these features is typically associated with more active hurricane seasons.

Predictor 4. ECMWF 1 March SST Forecast for September Nino 3 (-)

(5°S -5°N, 90-150°W)

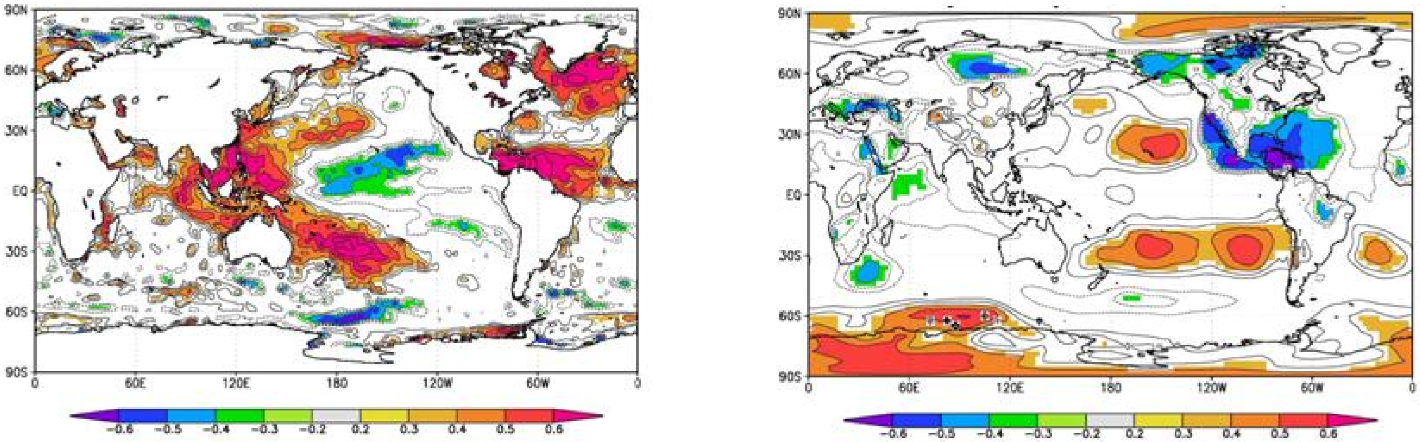
The ECMWF seasonal forecast system 3 has shown skill at being able to predict SST anomalies associated with ENSO several months into the future (Stockdale et al. 2011). ECMWF has recently upgraded their seasonal forecast system to system 4. ENSO has been documented in many studies to be one of the primary 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 March forecast date correlates with observations at 0.63, which is impressive considering that this forecast goes through the springtime predictability barrier, where fluctuations in ENSO lead to greatly reduced forecast skill. 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 7).

August-October Correlations w/ Predictor 1

(a) SST

(b) SLP



(c) 850 mb U

(d) 200 mb U

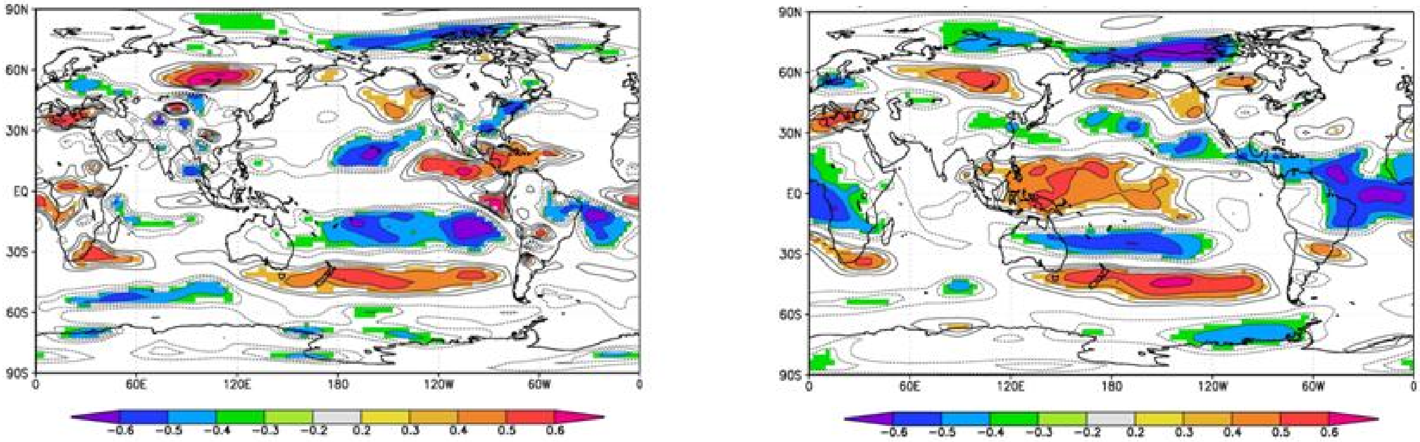


Figure 4: Linear correlations between January-March SST in the tropical and subtropical Atlantic (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d).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

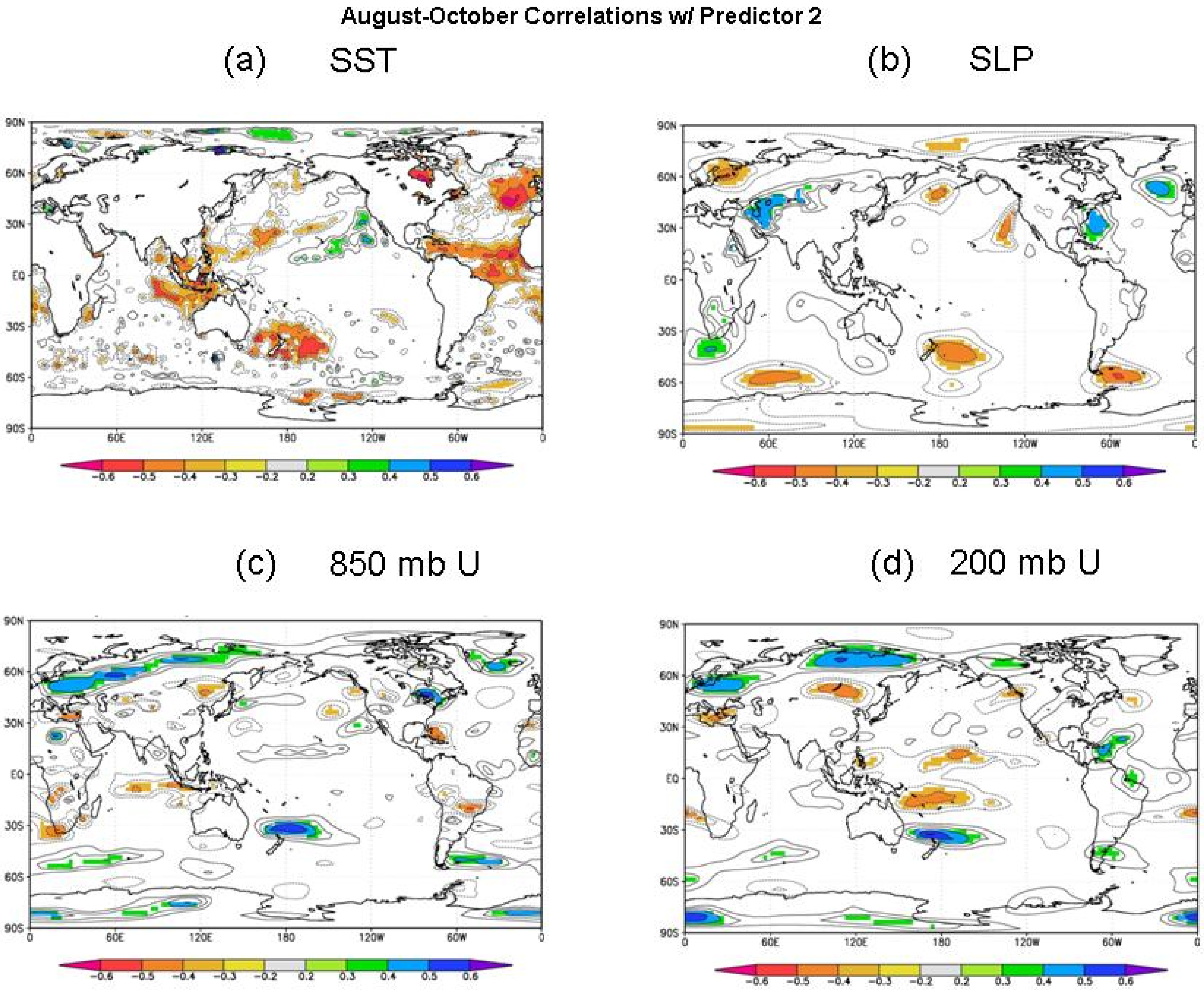


Figure 5: Linear correlations between March SLP in the subtropical Atlantic (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor's primary impact during the hurricane season appears to be with MDR-averaged SST. **The correlation scale has been reversed (sign changed) to allow for easy comparison of correlations for all four predictors.**

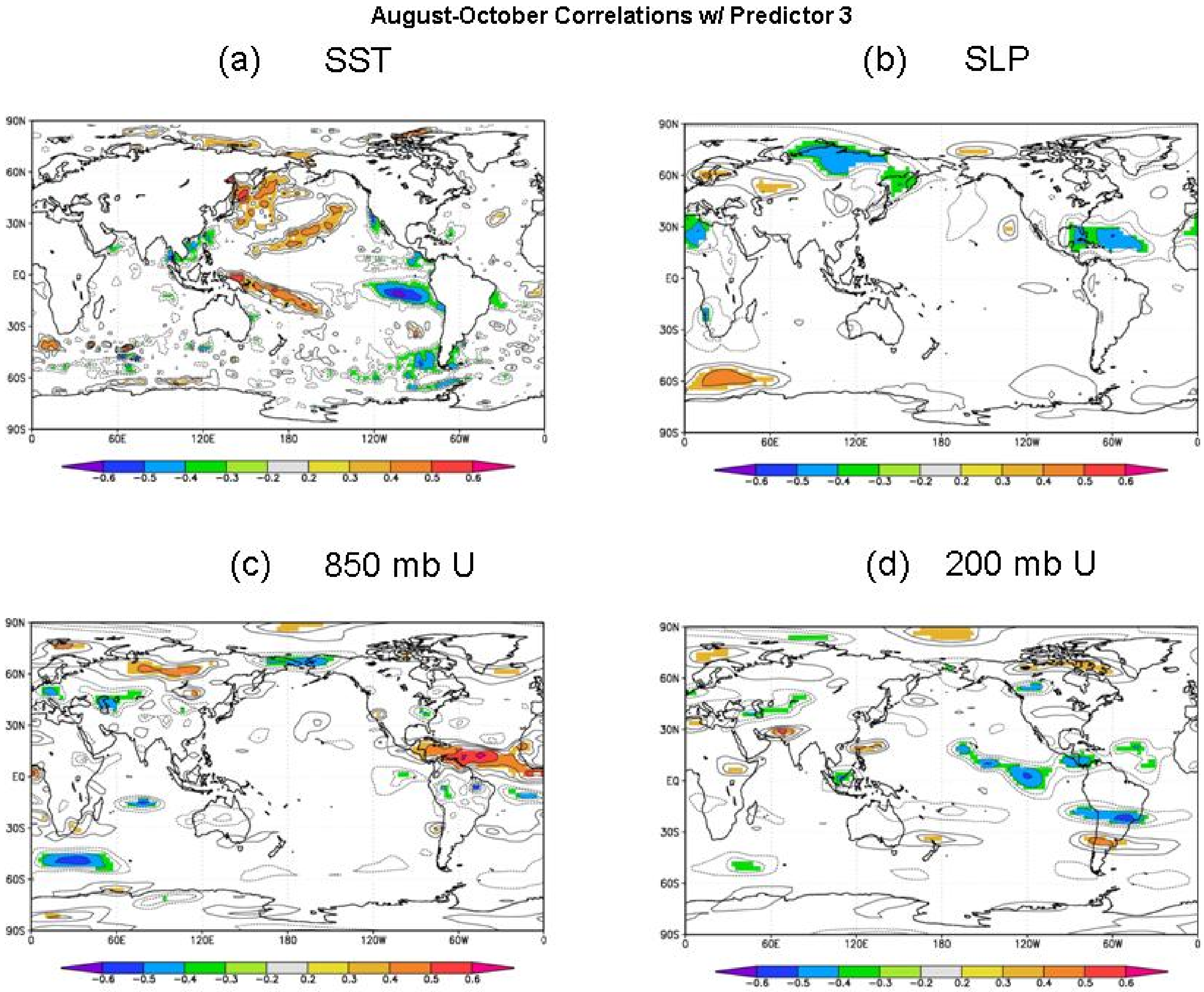


Figure 6: Linear correlations between February-March SLP in the southern tropical Pacific (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor's primary impacts appear to be on sea level pressure and trade wind strength across the tropical Atlantic.

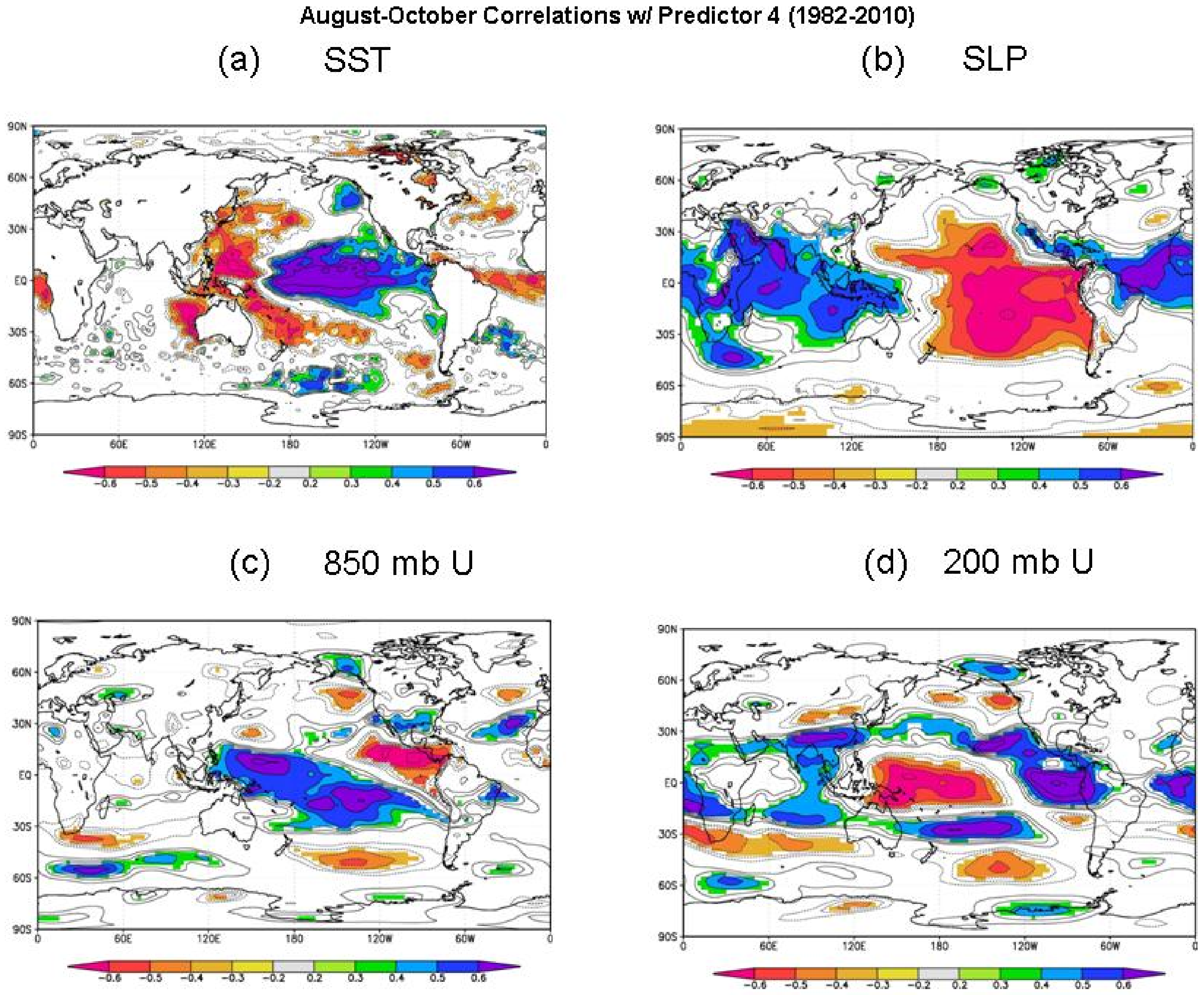


Figure 7: Linear correlations between a 1 March ECMWF SST forecast for September Nino 3 (Predictor 4) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 850 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). The predictor correlates very strongly with ENSO as well as vertical shear in the Caribbean. **The correlation scale has been reversed (sign changed) 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 April forecast, 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. Note the rather large uncertainty ranges at this extended lead time. Large changes can occur during the spring months, such as the massive weakening of the THC that occurred in 2013, and cause significant errors in these early season predictions.

Table 5: Model hindcast error and our 2014 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2014 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	3.4	9	5.6 – 12.4
Named Storm Days (NSD)	21.5	35	13.5 – 56.5
Hurricanes (H)	2.4	3	0.6 – 5.4
Hurricane Days (HD)	12.7	12	0.0 – 24.7
Major Hurricanes (MH)	1.5	1	0 - 2.5
Major Hurricane Days (MHD)	5.5	2	0 - 7.5
Accumulated Cyclone Energy (ACE)	53	55	2 - 108
Net Tropical Cyclone (NTC) Activity	50	60	10 - 110

4 Analog-Based Predictors for 2014 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2014. These years also provide useful clues as to likely trends in activity that the forthcoming 2014 hurricane season may bring. For this early April 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 February-March 2014 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 generally characterized by at least moderate El Niño conditions and neutral to slightly cool conditions in the tropical Atlantic during the upcoming hurricane season. We also selected years that were in positive AMO phases, although there is some question as to whether we are now moving out of the active era.

There were five hurricane seasons since 1950 with characteristics most similar to what we expect to see in August-October of 2014. We anticipate that the 2014 hurricane season will have less activity than the average of our five 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 below-average activity.

Table 6: Best analog years for 2014 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
1963	9	52.00	7	37.25	2	7.00	118	116
1965	6	39.50	4	27.25	1	7.50	84	86
1997	8	30.00	3	9.50	1	2.25	41	54
2002	12	57.00	4	10.75	2	3.00	67	83
Average	8.6	43.3	4.2	21.2	1.6	5.3	79	85
2014 Forecast	**9**	**35**	**3**	**12**	**1**	**2**	**55**	**60**

5 ENSO

Neutral ENSO conditions were present during the winter of 2013/2014. Upper ocean heat content (top 300 meters) anomalies dropped to slightly below-normal levels during January and have since rapidly increased and are now over 1°C in the eastern and central tropical Pacific (Figure 8). Upper-ocean heat content anomalies for March 2014 were the warmest on record (since records began in 1979), and are about 0.4°C warmer than what was measured in 1997, the strongest El Niño event of the 20th century.

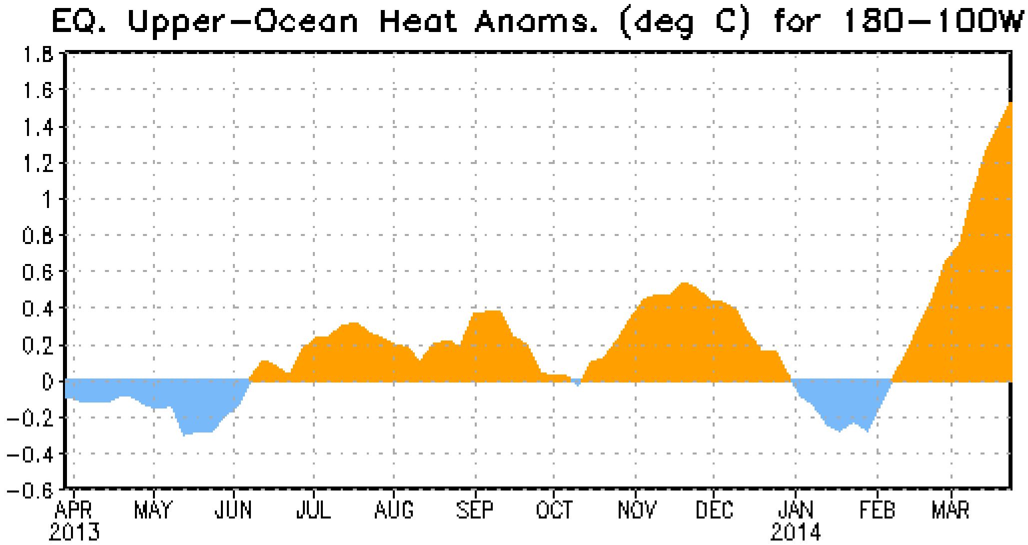


Figure 8: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Anomalies cooled during the early portion of the winter and have since warmed rapidly.

Currently, SSTs are generally within 0.5°C of the average across most of the eastern and central tropical Pacific, although they have recently exceeded 0.5°C in the

Nino 4 region as a downwelling (warming) Kelvin wave approaches the eastern tropical Pacific. Table 7 displays January and March SST anomalies for several Nino regions. We expect to see rapid warming in most of the Nino regions over the next couple of months.

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

Region	January SST Anomaly (°C)	March SST Anomaly (°C)	March – January SST Anomaly (°C)
Nino 1+2	0.3	-0.8	-1.1
Nino 3	-0.4	-0.2	+0.2
Nino 3.4	-0.5	-0.2	+0.3
Nino 4	-0.2	0.5	+0.7

There is considerable uncertainty as to what is going to happen with the current neutral ENSO. The spring months are known for their ENSO predictability barrier. This is when both statistical and dynamical models show their least amount of skill. This is likely due to the fact that from a climatological perspective, trade winds across the Pacific are weakest during the late spring and early summer, and therefore, changes in phase of ENSO are often observed to occur during the April-June period. Several strong westerly wind bursts have occurred across the tropical Pacific (Figure 9) in recent weeks, and these anomalous westerlies drive strong downwelling (warming) Kelvin waves across the tropical Pacific.

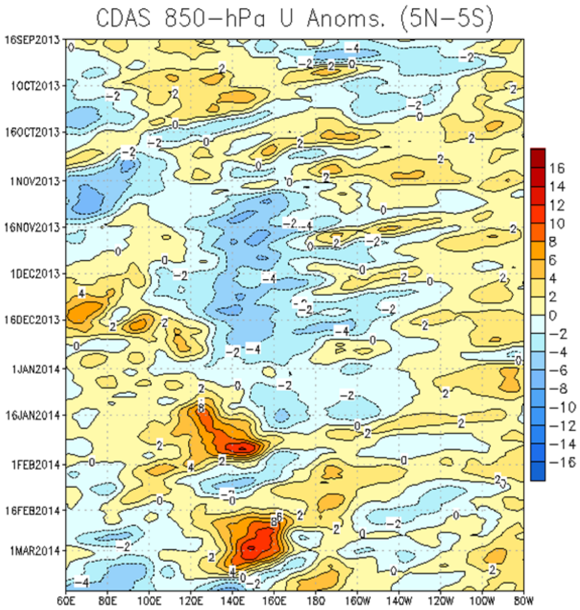


Figure 9: Anomalous 850-mb wind flow in the tropical Pacific. Note the strong anomalous westerly winds that occurred just west of the International Date Line (as evidenced by the dark red colors) in mid-to-late January, late February and during the latter part of March.

The warming effect of these Kelvin waves can be seen in Figure 10. Note the strong warming that has occurred throughout most of the Pacific since the early part of February.

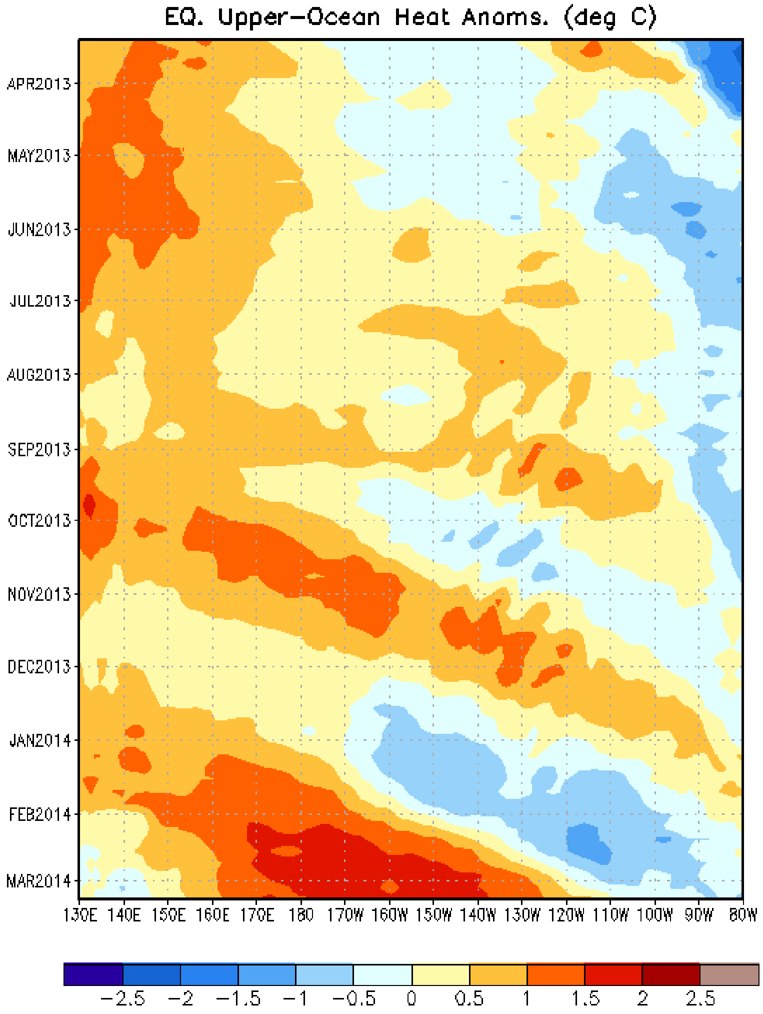


Figure 10: Equatorial upper ocean (0-300 meters) heat content anomalies across the tropical Pacific. Large portions of the central tropical Pacific now have upper ocean heat content anomalies exceeding 1°C.

By August-October, most dynamical and statistical models are calling for weak warm ENSO conditions (Figure 11). 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 March forecast from the ECMWF model system 3 and the observed September Nino 3.4 anomaly is 0.71, based on hindcasts/forecasts from 1982-2010, explaining half of the variance in Nino 3.4 SST. The ECMWF has recently upgraded to system 4, which is likely to have somewhat better skill than the previous version. The hindcast skill from ECMWF is very impressive, considering that the prediction goes through the springtime predictability barrier. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately 1.2°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 12). In general, we put more credence in the ECMWF prediction than in forecasts from the other models, and consequently, we are calling for a stronger El Niño than the median of the forecasts listed in Figure 11.

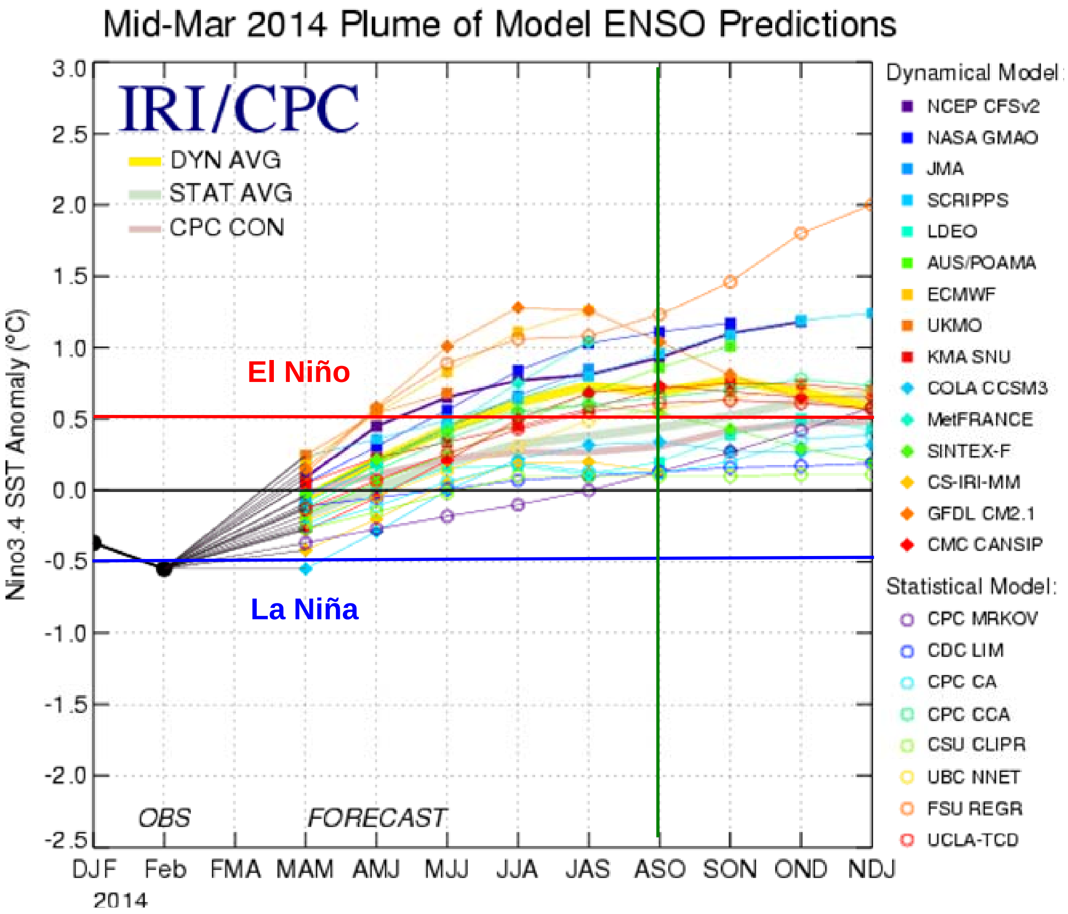


Figure 11: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). Most models call for a transition to warm ENSO conditions in the next few months.

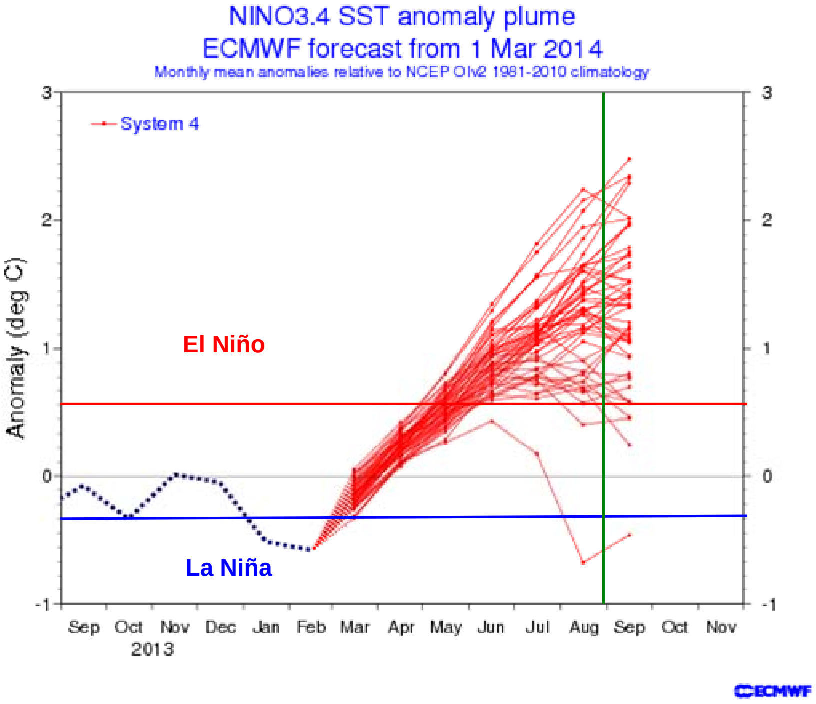


Figure 12: ECMWF ensemble model forecast for the Nino 3.4 region. Almost all members are calling for El Niño conditions next summer.

The Southern Oscillation Index (SOI) has recently been somewhat below normal. The SOI is a normalized pressure differential between Tahiti and Darwin, Australia. When the SOI is positive, it implies strong trade winds across the tropical Pacific and overall, conditions typically associated with La Niña. The current SOI values are indicative of the likely transition to El Niño conditions that may occur. Figure 13 displays the 30-day moving SOI since January 2012. In general, the SOI is close to the lowest values that have been observed since the aborted El Niño attempt during the middle of 2012.

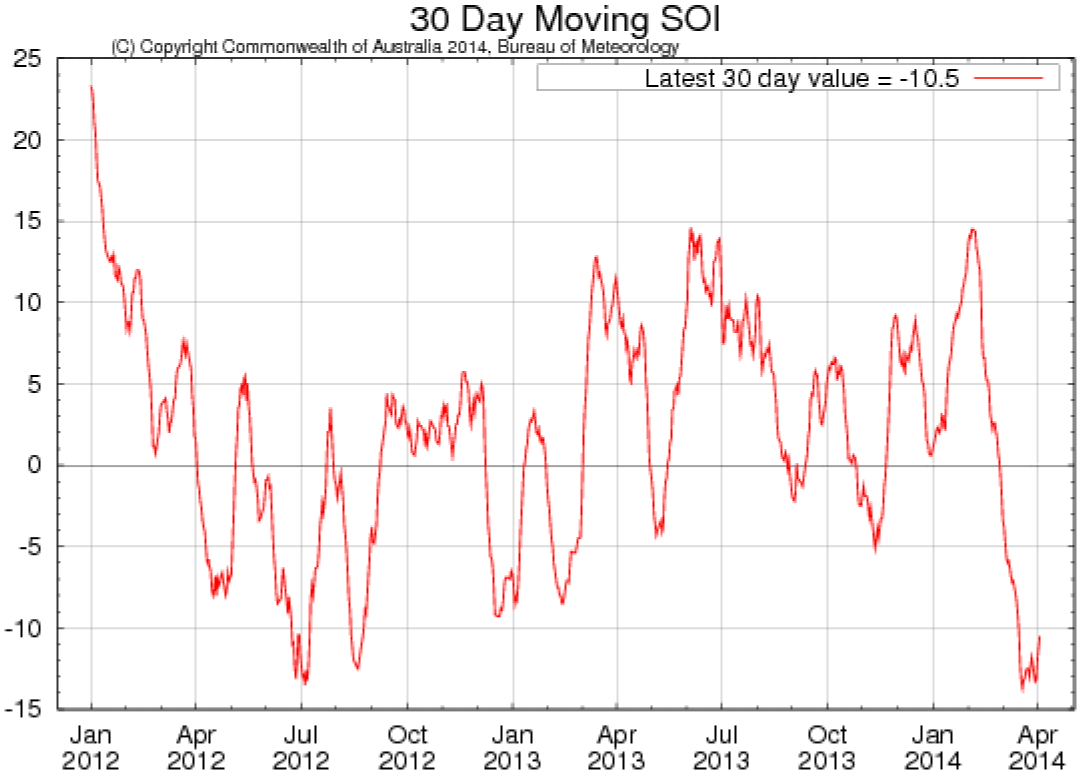


Figure 13: 30-day moving SOI since January 2012. Note how the SOI has recently been at below-average levels, indicating that a rapid transition to El Niño is possible.

Based on the above information, our best estimate is that we will likely transition to warm ENSO conditions for the peak of the Atlantic hurricane season. The buildup of upper ocean heat content in the eastern and central tropical Pacific has been quite dramatic in recent weeks, and trade winds across the central tropical Pacific have generally been somewhat weaker than normal over the past few weeks. There remains a need to closely monitor ENSO conditions over the next few months. We should be more confident about ENSO conditions for the upcoming hurricane season by the time of our next forecast on June 2.

6 Current Atlantic Basin Conditions

Significant anomalous cooling has occurred across the tropical Atlantic during the past two months. SSTs in the western tropical Atlantic are at slightly above-average values, while the eastern tropical and subtropical Atlantic, as well as the North Atlantic are now well below average (Figure 14). Much of this anomalous warming is due to a persistent positive phase of the NAO since late January (Figure 15). A positive phase of the NAO is associated with a strengthened Atlantic subtropical high pressure gyre and anomalously strong trades across the tropical Atlantic. This promotes enhanced mixing as well as upwelling of cold water. Anomalously strong westerly winds in the midlatitudes also promote anomalous ocean currents out of the north, which contributes to general warming SSTs throughout the North Atlantic basin. Figure 16 displays the cooling in SSTs observed in the tropical Atlantic from the latter part of March minus the middle part of January. Figure 17 shows the correlation between SSTs in February and March with the NAO. This figure demonstrates how similar the cooling was in 2014 with what typically is associated with a positive NAO.

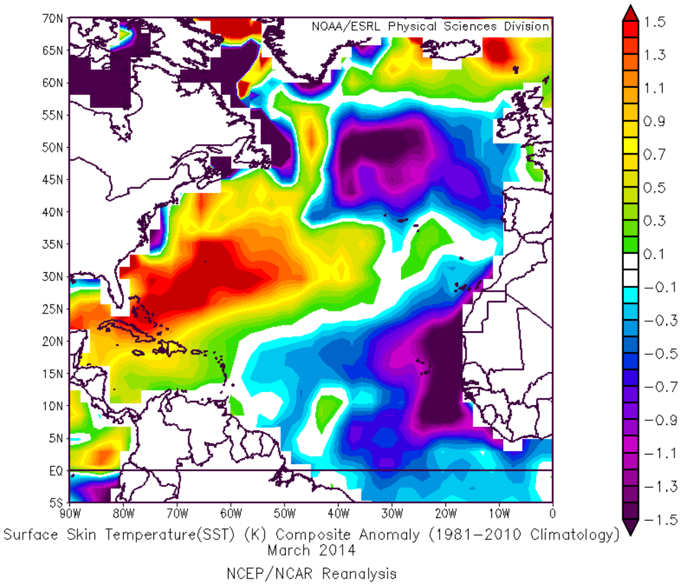


Figure 14: March 2014 SST anomaly pattern across the Atlantic Ocean.

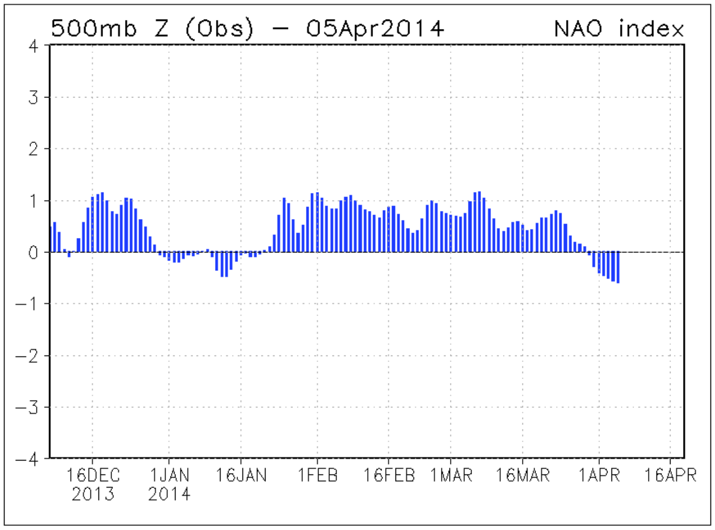


Figure 15: Observed NAO since December 2013. The NAO has generally been positive since the latter part of since January.

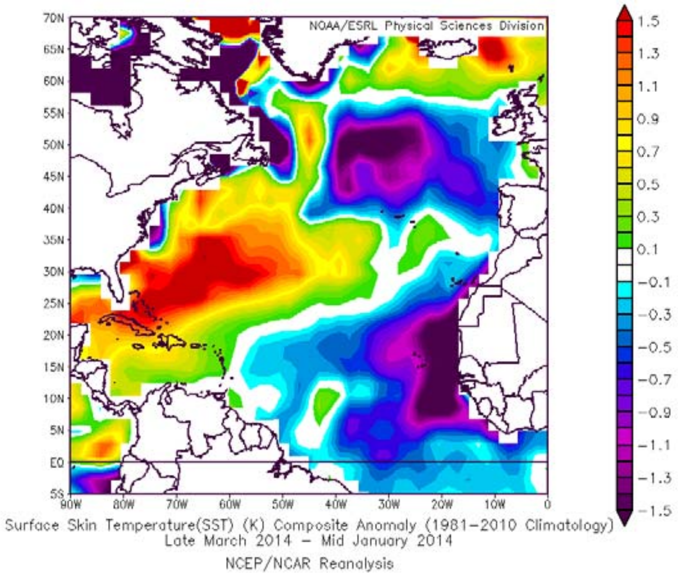


Figure 16: Late March 2014 minus mid January 2014 anomalous SST changes across the Atlantic Ocean. Note the anomalous cooling that has occurred across most of the tropical Atlantic.

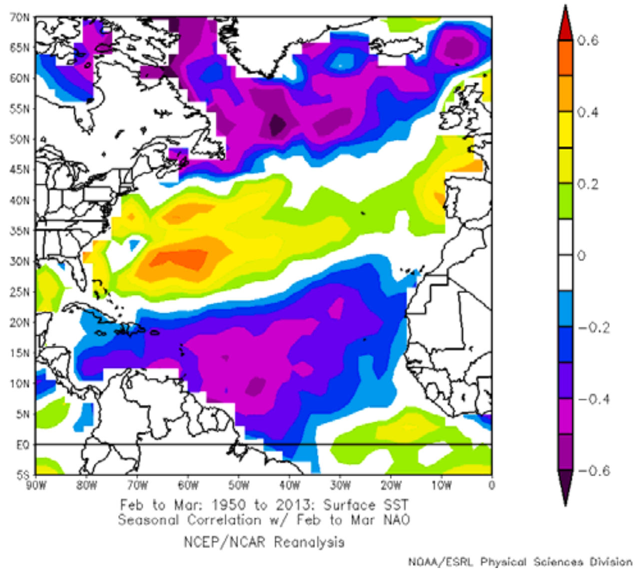


Figure 17: Correlation between February-March SSTs in the tropical Atlantic and the NAO. Note how similar the cooling in 2014 was with what is typically associated with a positive phase of the NAO.

7 Adjusted 2014 Forecast

Table 8 shows our final adjusted early April forecast for the 2014 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. Our analog forecast calls for a slightly below-average season, while the statistical model calls for a quiet season.

Table 8: Summary of our early April statistical forecast, our analog forecast and our adjusted final forecast for the 2014 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (12.0)	8.4	8.6	9
Named Storm Days (60.1)	35.8	43.3	35
Hurricanes (6.5)	4.3	4.2	3
Hurricane Days (21.3)	13.6	21.2	12
Major Hurricanes (2.0)	1.3	1.6	1
Major Hurricane Days (3.9)	2.1	5.3	2
Accumulated Cyclone Energy Index (92)	56	79	55
Net Tropical Cyclone Activity (103%)	64	85	60

8 Landfall Probabilities for 2014

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline and in the Caribbean. Whereas individual hurricane landfall events cannot be accurately 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 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 1950-2000 climatological 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 averages. 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 landfall probabilities for the 2014 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. We also issue probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2014 is expected to be below its long-term average of 100, and therefore, landfall probabilities are below their long-term average.

Please 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. The probability of each U.S. coastal state being impacted by hurricanes and major hurricanes is also included. 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.

As an example we find that the probability of Florida being hit by a major (Cat 3-4-5) hurricane this year is 13% which is below the 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 7%. For Duval County, the probability of being impacted by hurricane-force wind gusts is only 2%. 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 21%, 10%, and 3%, 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 2014. 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)	61% (79%)	49% (68%)	35% (52%)	67% (84%)	87% (97%)
Gulf Coast (Regions 1-4)	41% (59%)	28% (42%)	19% (30%)	42% (60%)	66% (83%)
Florida plus East Coast (Regions 5-11)	34% (50%)	29% (44%)	20% (31%)	43% (61%)	63% (81%)
Caribbean (10-20°N, 60-88°W)	64% (82%)	40% (57%)	28% (42%)	56% (75%)	85% (96%)

9 Summary

An analysis of a variety of different atmosphere and ocean measurements (through March) which are known to have long-period statistical relationships with the upcoming season's Atlantic tropical cyclone activity indicate that 2014 should be a quiet hurricane season. The big question marks with this season's predictions are how strong the El Niño will be if it develops, as well as if tropical and North Atlantic Ocean SSTs remain as cool as they are now.

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 2014 Hurricane Activity

We will be issuing seasonal updates of our 2014 Atlantic basin hurricane forecasts on **Monday 2 June**, **and Thursday 31 July**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2014 forecasts will be issued in late November 2014. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

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

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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 2009-2013. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

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

2013	4 April	Update 1 June	Update 3 August	Obs.
Hurricanes	9	9	8	2
Named Storms	18	18	18	14
Hurricane Days	40	40	35	3.25
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