EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2012

We foresee slightly below-average activity for the 2012 Atlantic hurricane season. We have increased our forecast slightly from early April, due to large amounts of uncertainty in both the phase of ENSO as well as in Atlantic basin conditions. We anticipate a slightly below-average probability of United States and Caribbean major hurricane landfall.

(as of 1 June 2012)

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

Emily Wilmsen, Colorado State University Media Representative, (970-491-6432) is available to answer various questions about this forecast

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ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2012

Forecast Parameter and 1981-2010 Median (in parentheses)	Issue Date 4 April 2012	Issue Date 1 June 2012
Named Storms (NS) (12.0)	10	13*
Named Storm Days (NSD) (60.1)	40	50
Hurricanes (H) (6.5)	4	5
Hurricane Days (HD) (21.3)	16	18
Major Hurricanes (MH) (2.0)	2	2
Major Hurricane Days (MHD) (3.9)	3	4
Accumulated Cyclone Energy (ACE) (92)	70	80
Net Tropical Cyclone Activity (NTC) (103%)	75	90

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

1) Entire U.S. coastline - 48% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida - 28% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville - 28% (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) 39% (average for last century is 42%)

Special Note

*Our early June forecast includes Tropical Storms Alberto and Beryl which formed prior to 1 June. Our prediction for the remainder of the season is for eleven additional post-1 June named storms.

Pre-1 June activity has very little bearing on the rest of the hurricane season. The only two seasons on record with two named storms prior to 1 June were 1887 and 1908. While 1887 was a very active season, 1908 had average levels of activity. The last season with a U.S. landfall prior to 1 June was 1976, which was a relatively quiet season.

All landfall probabilities are for TCs developing after 1 June.

2012 STATE IMPACT PROBABILITIES (NUMBERS IN PARENTHESES ARE LONG-PERIOD AVERAGES)

State	Hurricane	Major Hurricane
Texas	30% (33%)	11% (12%)
Louisiana	28% (30%)	11% (12%)
Mississippi	10% (11%)	4% (4%)
Alabama	14% (16%)	2% (3%)
Florida	47% (51%)	19% (21%)
Georgia	10% (11%)	1% (1%)
South Carolina	16% (17%)	3% (4%)
North Carolina	26% (28%)	7% (8%)
Virginia	6% (6%)	1% (1%)
Maryland	1% (1%)	<1% (<1%)
Delaware	1% (1%)	<1% (<1%)
New Jersey	1% (1%)	<1% (<1%)
New York	7% (8%)	3% (3%)
Connecticut	6% (7%)	2% (2%)
Rhode Island	5% (6%)	2% (3%)
Massachusetts	6% (7%)	2% (2%)
New Hampshire	1% (1%)	<1% (<1%)
Maine	3% (4%)	<1% (<1%)
Whole US	64% (68%)	48% (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 2012 indicates that the 2012 Atlantic hurricane season will have slightly less activity than the average 1950-2000 season. We estimate that 2012 will have about 5 hurricanes (average is 5.9), 13 named storms (average is 9.6), 50 named storm days (average is 49.1), 18 hurricane days (average is 24.5), 2 major (Category 3-4-5) hurricanes (average is 2.3) and 4 major hurricane days (average is 5.0). The probability of U.S. major hurricane landfall is estimated to be about 90 percent of the long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2012 to be approximately 90 percent of the long-term average. We have increased our numbers slightly from our early April forecast, due largely to our uncertainty as to whether an El Niño will develop later this summer and to marginal Atlantic basin conditions. A brief update on El Niño conditions may be issued prior to the next forecast update on August 3 if conditions warrant.

This forecast is based on a new extended-range early June statistical prediction scheme that utilizes 29 years of past data. Analog predictors are also utilized. Overall, conditions are expected to lead to a slightly below-average hurricane season.

Why issue extended-range forecasts for seasonal hurricane activity?

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

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

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

Acknowledgment

This year's forecasts are funded by private and personal funds. We thank the GeoGraphics Laboratory at Bridgewater State College (MA) for their assistance in developing the United States Landfalling Hurricane Probability Webpage (available online at http://www.e-transit.org/hurricane).

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

DEFINITIONS AND ACRONYMS

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

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

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

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

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

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

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 10-20°N, 20-70°W.

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

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

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

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

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

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

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

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

Sea Surface Temperature – SST

Sea Surface Temperature Anomaly – SSTA

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

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

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

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

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

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

1 Introduction

This is the 29th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. This year's June forecast is based on a statistical methodology derived from 29 years of past data. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic basin TC activity and landfall probability. We believe that seasonal forecasts must be based on methods that show significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided that the atmosphere continues to behave in the future as it has in the past.

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

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 3-4 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

2 June Forecast Methodology

2.1 New June Statistical Forecast Scheme

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

(Reynolds et al. 2002) is available from 1982-present. The CFSR will begin to be updated in real-time shortly, but for the time being, we utilize the NCEP/NCAR Reanalysis for 2010-2012 values. This new 1 June TC forecast model shows significant skill in predicting levels of Net Tropical Cyclone (NTC) activity over the 29-year period from 1982-2011. This hindcast model correlates with NTC at 0.82 when all years are included in the model, while a drop-one cross-validation (jackknife) analysis yields a correlation with NTC of 0.74.

Table 1 displays cross-validated NTC hindcasts for 1982-2011 using this new statistical scheme, while Figure 1 displays observations versus cross-validated NTC hindcasts. We have correctly predicted above- or below-average seasons in 25 out of 30 hindcast years (83%). Our predictions have had a smaller error than climatology in 23 out of 30 years (77%). Our average hindcast error is 34 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 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 2012 observed values for each of the four predictors in the new statistical forecast scheme. The two predictors in the Atlantic basin (Predictors 1 and 4) are slightly favorable for an active season, while the two predictors in the Pacific basin (Predictors 2 and 3) are unfavorable. Table 4 displays the statistical model output for the combination of the four predictors for the 2012 Atlantic hurricane season.

Table 1: Observed versus early June cross-validated hindcast NTC for 1982-2010 and the real-time forecast for 2011 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 25 out of 30 years (83%), while hindcast improvement over climatology occurred in 23 out of 30 years (77%).

Year	Observed NTC	Hindcast NTC	Observed minus Hindcast	Observed minus Climatology	Hindcast improvement over Climatology
1982	38	52	-14	-65	51
1983	31	40	-9	-72	63
1984	80	101	-21	-23	2
1985	106	**88**	18	3	**-15**
1986	37	69	-33	-66	34
1987	46	55	-9	-57	48
1988	117	144	-27	14	**-13**
1989	130	149	-19	27	7
1990	100	**158**	-58	-3	**-55**
1991	58	45	13	-45	33
1992	67	62	5	-36	31
1993	52	45	7	-51	44
1994	35	50	-14	-68	53
1995	222	231	-9	119	110
1996	192	164	28	89	61
1997	54	**141**	-88	-49	**-39**
1998	169	153	16	66	50
1999	182	144	38	79	41
2000	134	107	26	31	4
2001	135	155	-20	32	12
2002	83	40	43	-20	**-23**
2003	175	147	28	72	44
2004	232	130	101	129	27
2005	279	153	127	176	50
2006	85	**161**	-76	-18	**-58**
2007	99	**171**	-72	-4	**-68**
2008	162	179	-17	59	42
2009	69	72	-3	-34	31
2010	196	229	-33	93	60
2011	145	176	-31	-42	11
Average	**116**	**116**	**|34|**	**|55|**	**+21**

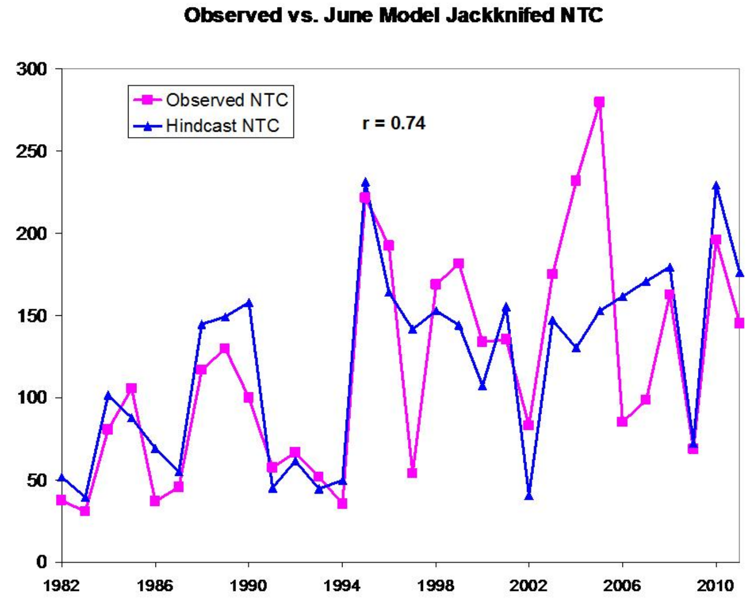

Observed vs. June Model Jackknifed NTC

Figure 1: Observed versus early June jackknifed hindcast values of NTC for 1982-2011. The hindcast model explains 55% of the variance from climatology.

New June Forecast Predictors

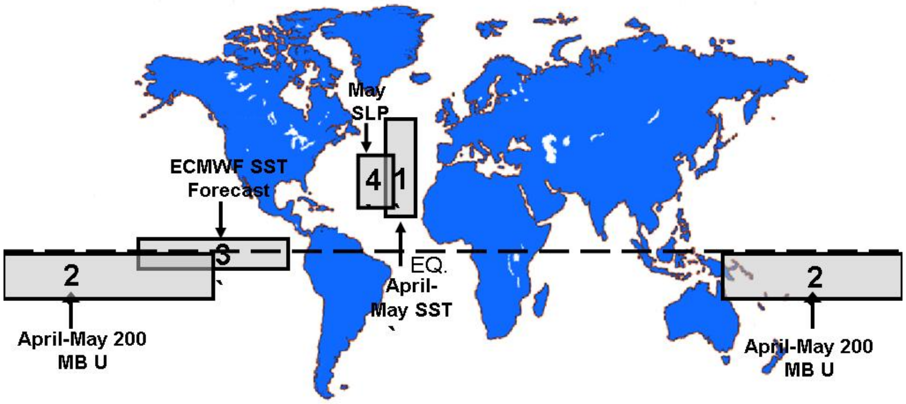


Figure 2: Location of predictors for our early June extended-range statistical prediction for the 2012 hurricane season. Predictor 2 spans both sides of the International Date Line.

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 2012 predictors for the 2012 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity.

Predictor	2012 Forecast Value
1) April-May SST (15-55°N, 15-35°W) (+)	+0.2 SD
2) April-May 200 MB U (0-15°S, 150°E-120°W) (+)	-0.4 SD
3) ECMWF 1 May SST Forecast for September Nino 3 (5°S-5°N, 90-150°W) (-)	+0.9 SD
4) May SLP (20-40°N, 30-50°W) (-)	-0.7 SD

Table 4: Statistical model output for the 2012 Atlantic hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Forecast
Named Storms (12.0)	10.4
Named Storm Days (60.1)	50.3
Hurricanes (6.5)	5.8
Hurricane Days (21.3)	22.2
Major Hurricanes (2.0)	2.4
Major Hurricane Days (3.9)	5.4
Accumulated Cyclone Energy Index (92)	92
Net Tropical Cyclone Activity (103%)	101

2.2 Physical Associations among Predictors Listed in Table 2

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

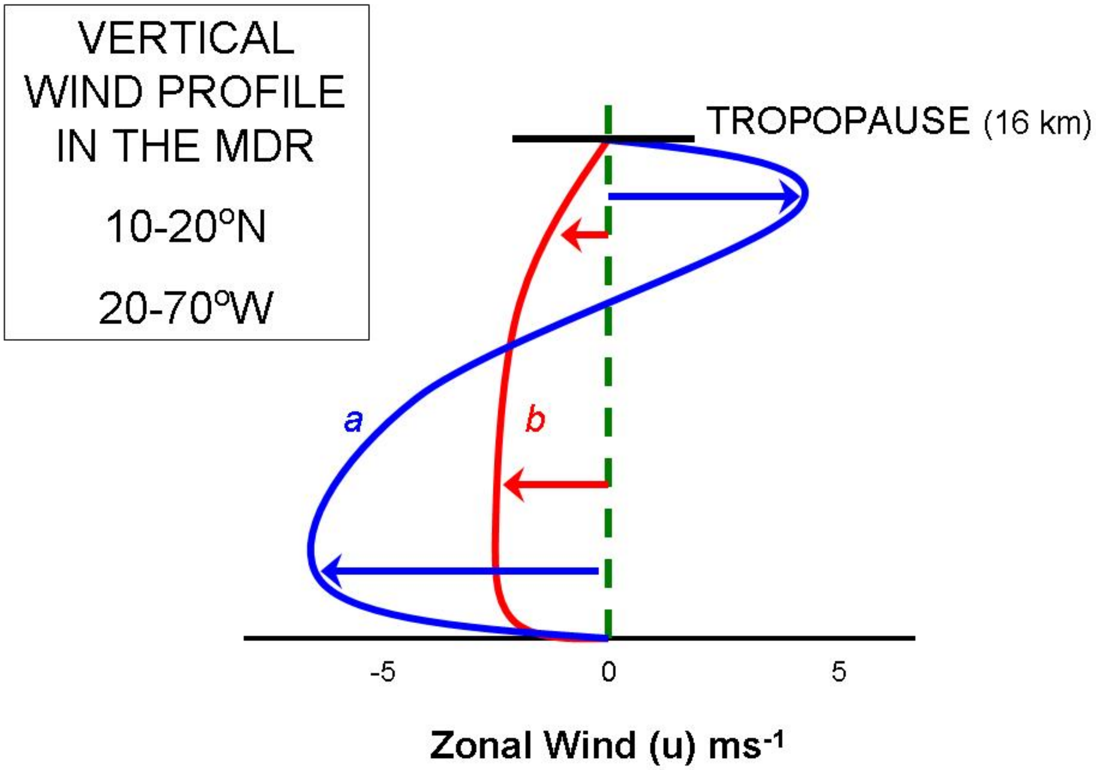


Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of tropospheric vertical wind shear.

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

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

(15-55°N, 15-35°W)

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

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 feed back to promote the development or sustenance of warm anomalies in the tropical Atlantic. These warm anomalies tend to persist throughout the peak months of the hurricane season (Figure 7). Also, upper-level easterly anomalies in the Caribbean are associated with low values of this predictor.

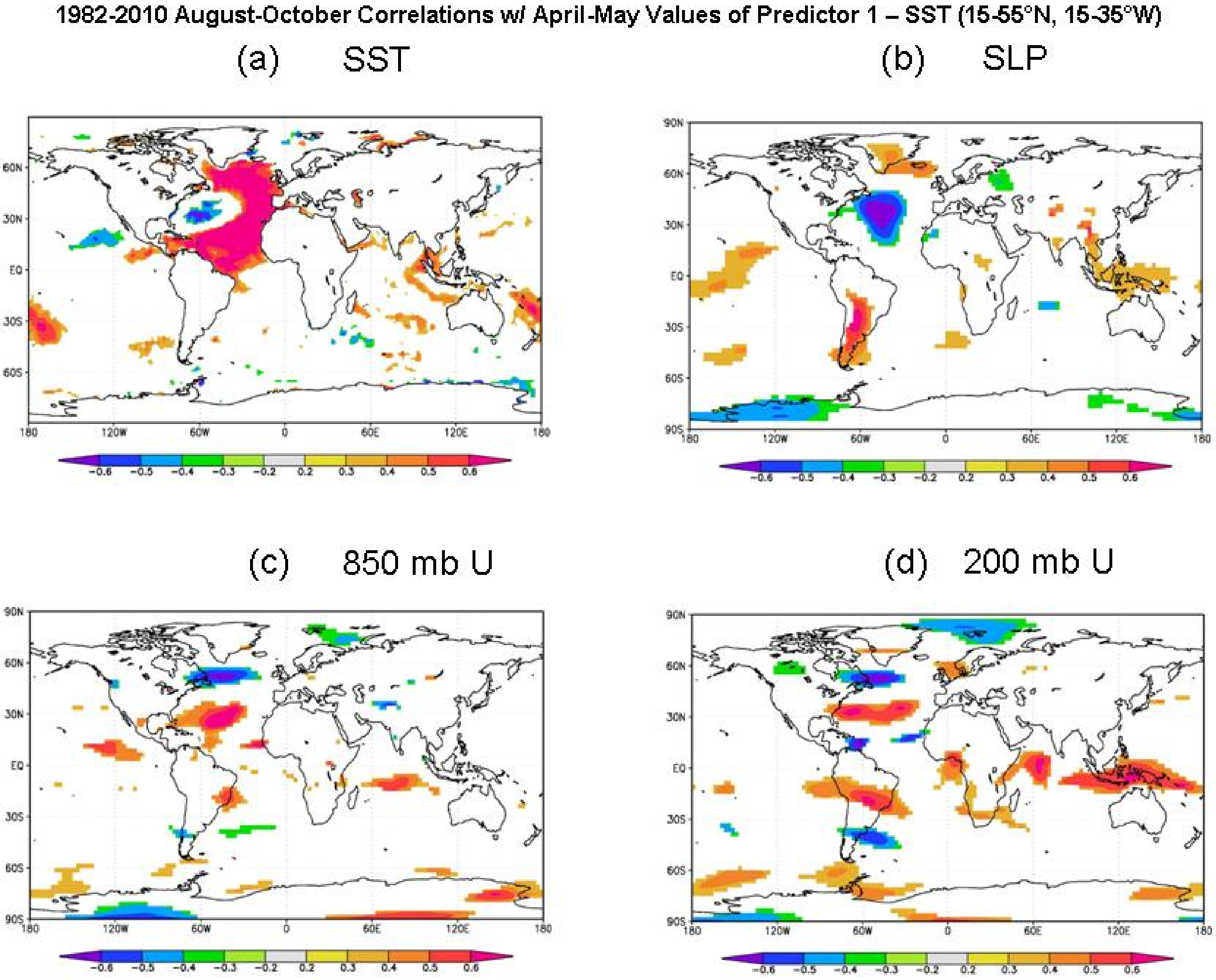
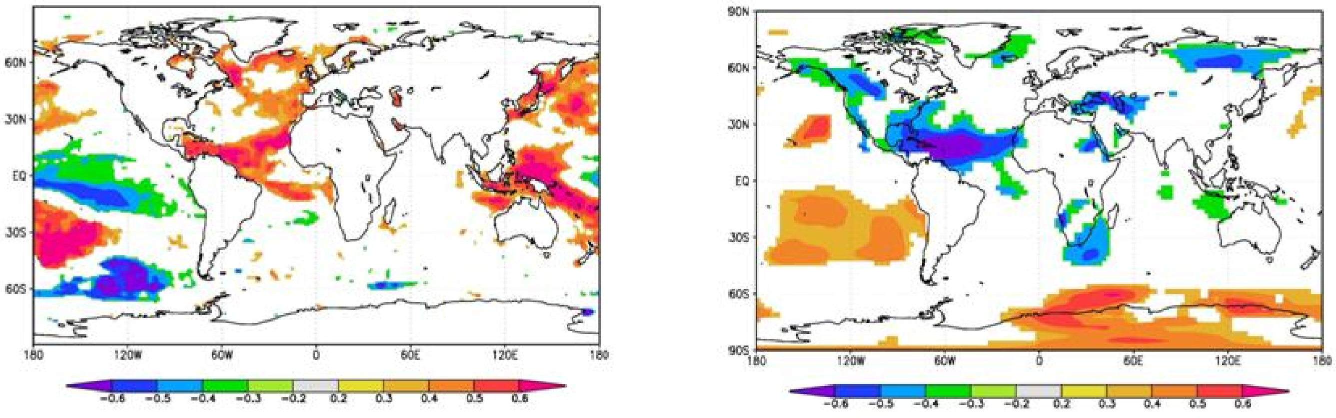


Figure 4: Linear correlations between April-May SST in the eastern Atlantic (Predictor 1) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following August-October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

1982-2010 August-October Correlations w/ April-May Values of Predictor 2 – 200 mb U (0-15°S, 150°E-120°W)

(a) SST (b) SLP



(c) 850 mb U (d) 200 mb U

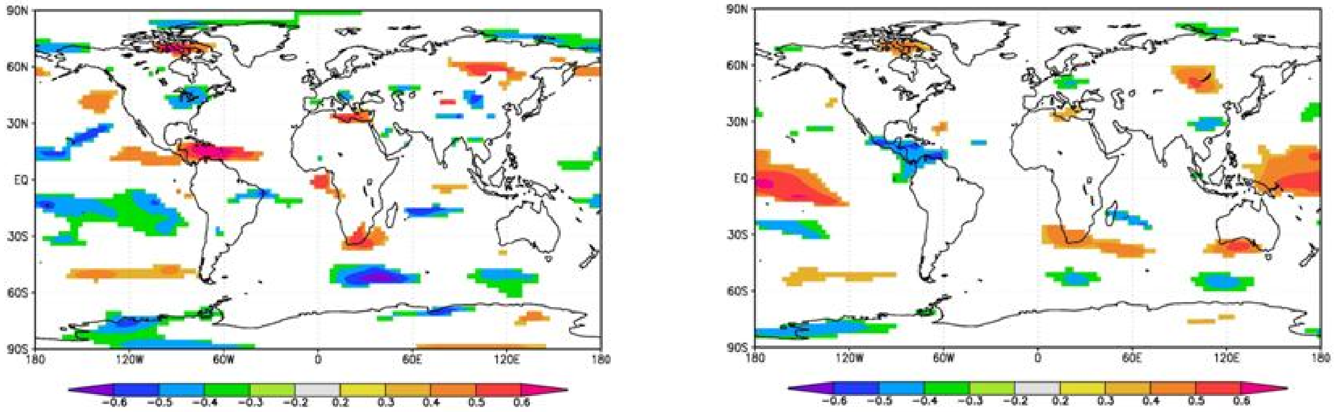


Figure 5: Linear correlations between April-May 200-mb zonal winds in the south-central tropical Pacific (Predictor 2) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c)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

1982-2010 August-October Correlations w/ May Values of Predictor 3 – ECMWF September Nino 3 Forecast

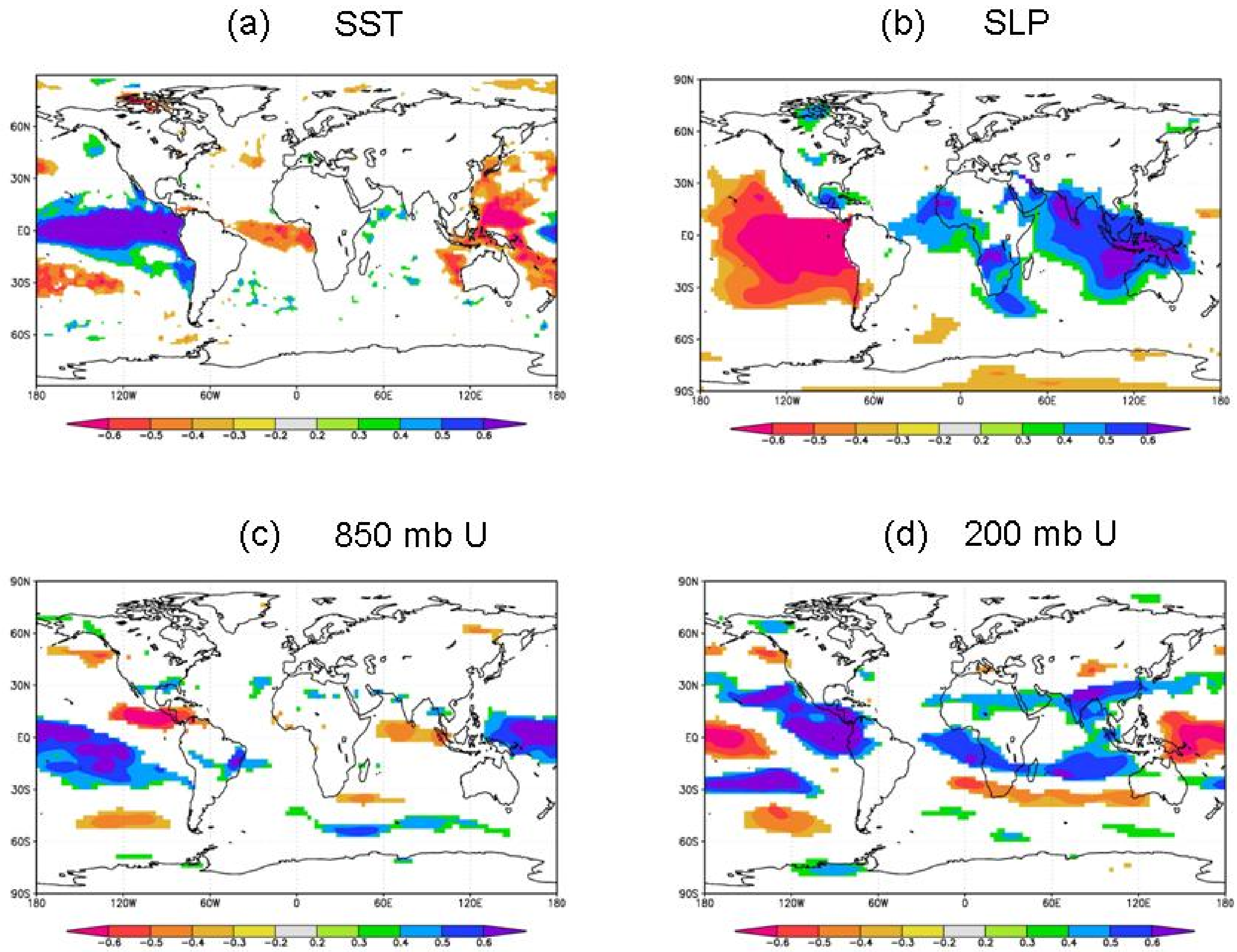


Figure 6: Linear correlations between a 1 May ECMWF SST forecast for September Nino 3 (Predictor 3) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following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

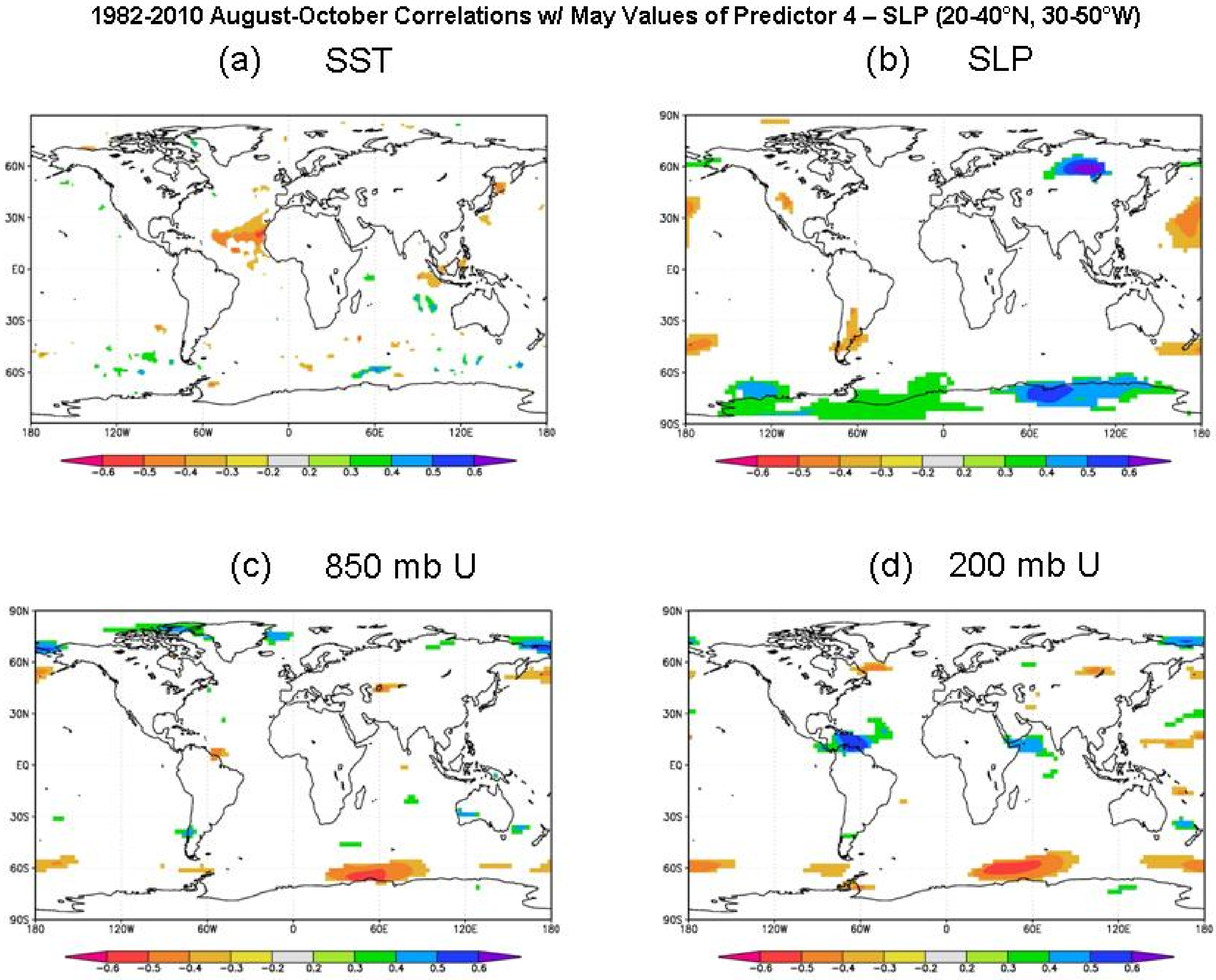


Figure 7: Linear correlations between May sea level pressure in the central Atlantic (Predictor 4) and the following August-October sea surface temperature (panel a), the following August-October sea level pressure (panel b), the following August-October 850 mb zonal wind (panel c) and the following 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 2012 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments.

Parameter	Hindcast Error (SD)	2012 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	3.7	13	9.3 – 16.7
Named Storm Days (NSD)	21.1	50	28.9 – 71.1
Hurricanes (H)	2.1	5	2.9 – 7.1
Hurricane Days (HD)	10.2	18	7.8 – 28.2
Major Hurricanes (MH)	1.6	2	0.4 –3.6
Major Hurricane Days (MHD)	5.3	4	0 – 9.3
Accumulated Cyclone Energy (ACE)	48	80	32 – 128
Net Tropical Cyclone (NTC) Activity	48	90	42 – 138

4 Analog-Based Predictors for 2012 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are similar to 2012. These years also provide useful clues as to likely trends in activity that the forthcoming 2012 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 2012 conditions as well as expected August-October conditions. Table 6 lists our analog selections. We searched for years that were generally characterized by neutral ENSO conditions in April-May and average tropical Atlantic and far North Atlantic SSTs during April-May followed by August-October periods that were generally characterized by weak El Niño conditions and average tropical Atlantic SST conditions.

There were four hurricane seasons since 1949 with characteristics most similar to those listed. These four years are 1953, 1968, 2001, and 2009. We anticipate that the 2012 hurricane season will have activity in line with what was experienced in the average of these four years.

Table 6: Best analog years for 2012 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1953	14	64.50	6	18.00	4	6.75	104	127
1968	8	33.75	5	11.75	0	0.00	45	47
2001	15	68.75	9	25.50	4	4.25	110	135
2009	9	30.00	3	12.00	2	3.50	53	69
Average	11.5	49.3	5.8	16.8	2.5	3.6	78	95
2012 Forecast	**13**	**50**	**5**	**18**	**2**	**4**	**80**	**90**

5 ENSO

The weak-to-moderate La Niña conditions of December 2011 - February 2012 diminished rapidly during the late winter into the early spring. According to the Climate Prediction Center (CPC), SST anomalies in the central and eastern tropical Pacific have now warmed to the point where ENSO is in its neutral state. One of the big uncertainties with this forecast is whether or not we will see a significant El Niño develop by the peak of this year's Atlantic basin hurricane season. Upper-ocean heat content anomalies in the eastern and central Pacific (0-300 meters) became positive in early April and have continued to trend upwards since that time (Figure 8).

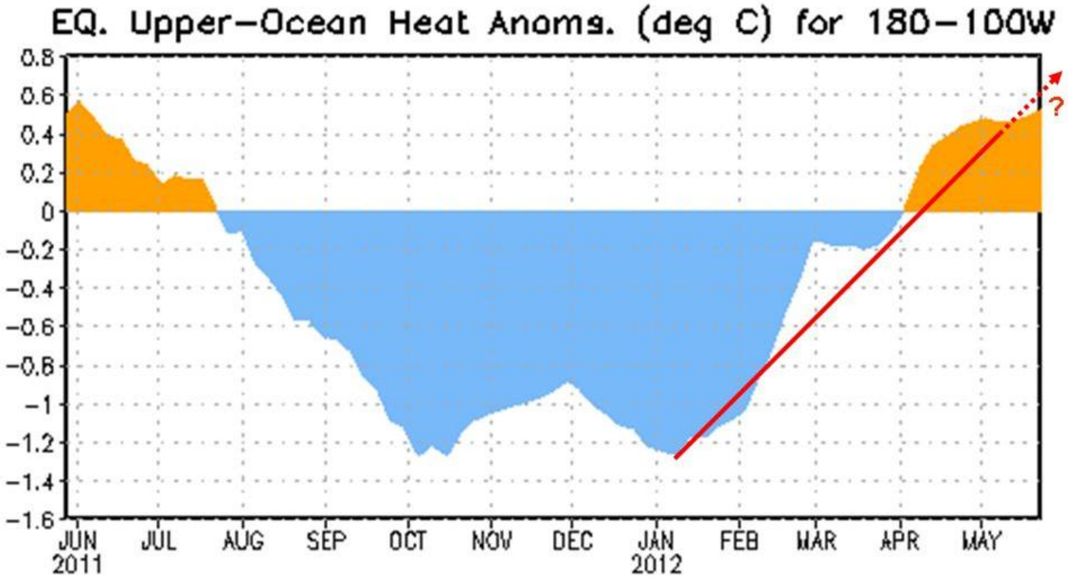


Figure 8: Central and eastern tropical Pacific upper ocean (0-300 meters) heat content anomalies over the past year. Upper ocean heat content anomalies have trended steadily upwards since January.

Currently, SSTs anomalies are slightly above average for most of the tropical central Pacific, with well above-average SST anomalies recently observed in the Nino 1+2 region of the tropical eastern Pacific. Table 7 displays March and May SST anomalies for the four Nino regions. All of the Nino regions have experienced considerable anomalous warming over the past two months. The big question is how much additional anomalous warming will take place during the next several months.

Table 7: March and May 2012 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	0.3	1.2	+0.9
Nino 3	-0.2	0.1	+0.3
Nino 3.4	-0.6	0.0	+0.6
Nino 4	-0.7	-0.2	+0.5

There is considerable uncertainty as to what is going to happen with the current neutral ENSO event. The spring months are known for their ENSO predictability barrier. While we are nearing the end of this predictability barrier, considerable changes with ENSO often take place between June and September. Both statistical and dynamical models show improved skill by the end of May for the August-October period when compared with their skill at the end of March. However, there remains a very wide spread in both the statistical and dynamical model guidance for the August-October period (Figure 9).

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 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. For reference, the correlation skill of a 1 March forecast from the ECMWF model was 0.71, indicating that approximately 15% additional variance can be explained by shortening the lead time of the forecast from 1 March to 1 May. The average of the various ECMWF ensemble members is calling for a September Nino 3.4 SST anomaly of approximately +0.6°C, with a large spread between ensemble members. If a weak El Niño were to develop this year, its impacts on Atlantic basin TC activity may be somewhat more significant than if conditions in the tropical Atlantic were as warm as they had been over the past couple of years. The tropical Atlantic has cooled significantly from the warm anomalies observed in 2010-2011 (discussed in detail in the next section). About 2/3 of ensemble members from the 1 May ECMWF prediction call for an El Niño (SSTA > 0.5°C) to develop by September (Figure 10).

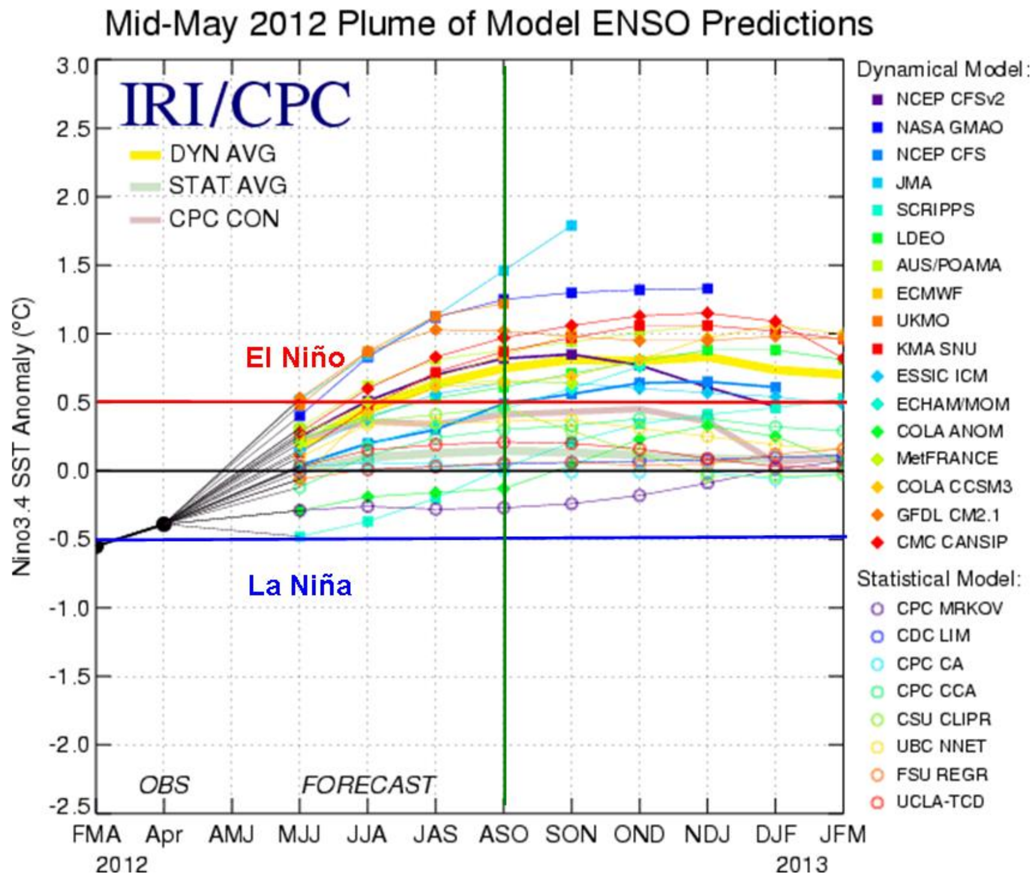


Figure 9: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). There is a very wide spread in the model guidance for the August-October period, with approximately half of the models calling for El Niño conditions and the rest calling for neutral conditions.

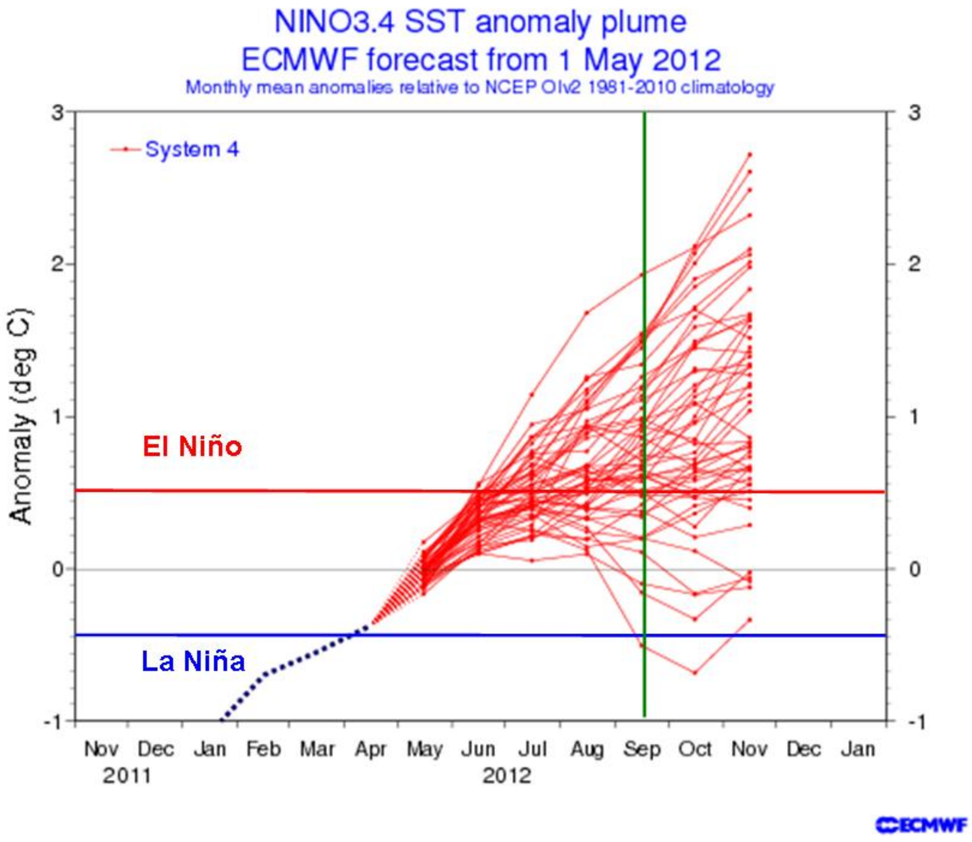


Figure 10: ECMWF ensemble model forecast for the Nino 3.4 region.

A strong westerly wind burst occurred near the International Date Line during late March and early April. This westerly wind burst triggered an eastward-propagating Kelvin wave that helped to warm the central and eastern tropical Pacific. However, since that time, the trade winds have remained strong, and the warming has waned (Figure 11). It appears to us that another westerly wind burst is going to be required to move from neutral to El Niño conditions. These westerly wind bursts are often triggered by Madden-Julian Oscillation (MJO) events or other equatorial wave activity. Over the past several weeks, the MJO has been relatively weak. Current model projections indicate continued weak MJO conditions for the next couple of weeks, which adds much uncertainty as to the fate of ENSO for the peak of this year's hurricane season.

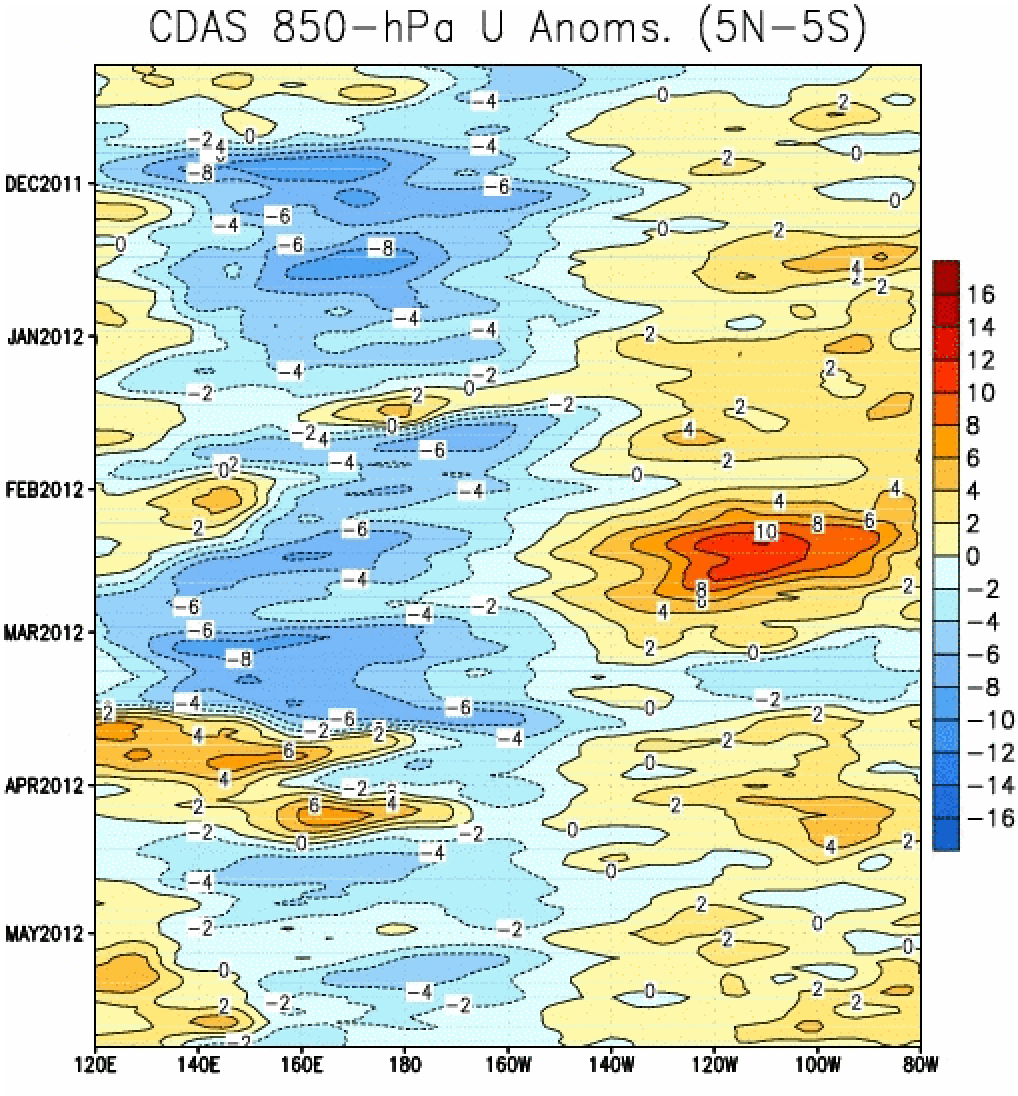


Figure 11: Anomalous low-level wind flow across the tropical Pacific over the past few months. Note the anomalous low-level westerlies near the International Date Line in late March/early April which triggered a Kelvin wave that caused some warming in the tropical Pacific. Also note the persistence of anomalous easterlies near the International Date Line since that time.

At this point, our best estimate is that we will have a weak El Niño develop by the peak of this year's hurricane season in September. However, as discussed in this section, there is considerable uncertainty in this outlook. There remains a need to closely monitor these conditions over the next few months.

6 Current Atlantic Basin Conditions

As was seen with ENSO, mixed signals also exist in the tropical Atlantic. SSTs in the tropical Atlantic are currently at near-average levels (Figure 12). While the anomalously strong North Atlantic Oscillation (NAO) that triggered so much cooling last winter has returned to near-average levels over the past couple of months, the Atlantic is much cooler this year than it was last year at this time, especially in the eastern Atlantic (Figure 13). Overall, the Atlantic is experiencing more marginal conditions this year than in many previous years during the active era that has been experienced since 1995.

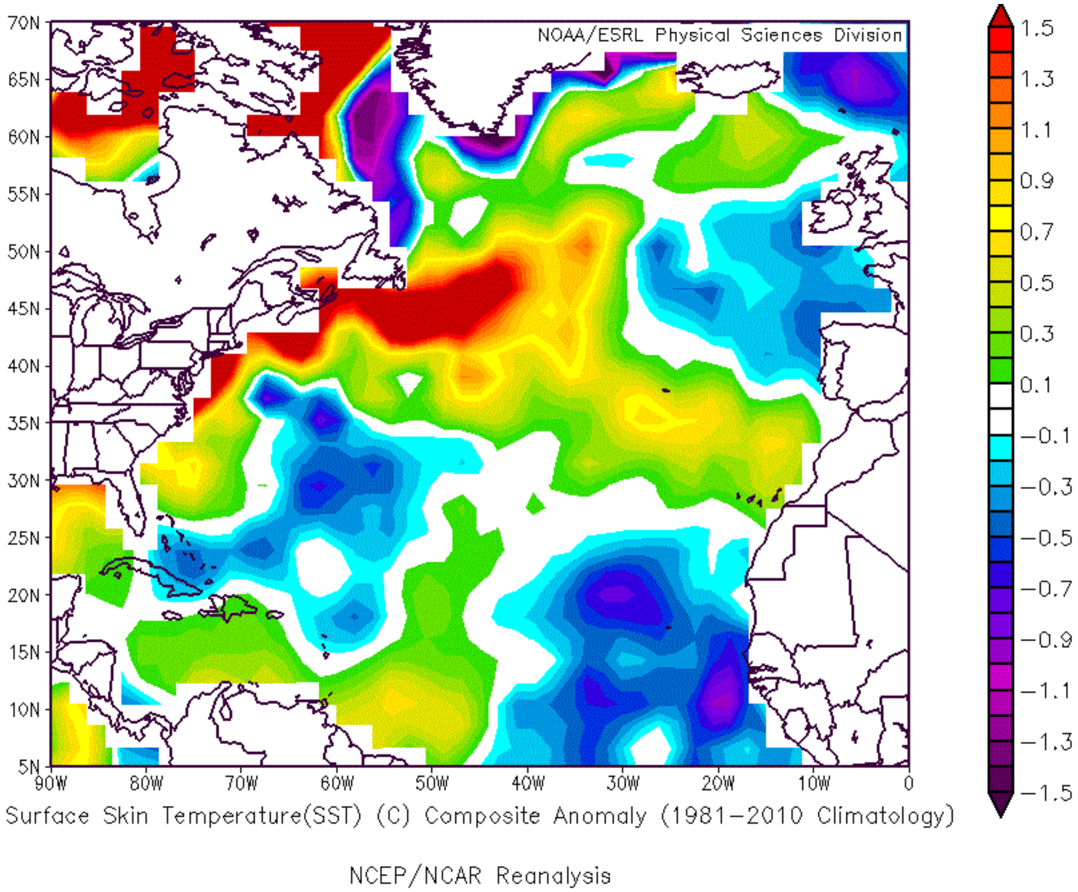


Figure 12: May 2012 SST anomaly pattern across the Atlantic Ocean.

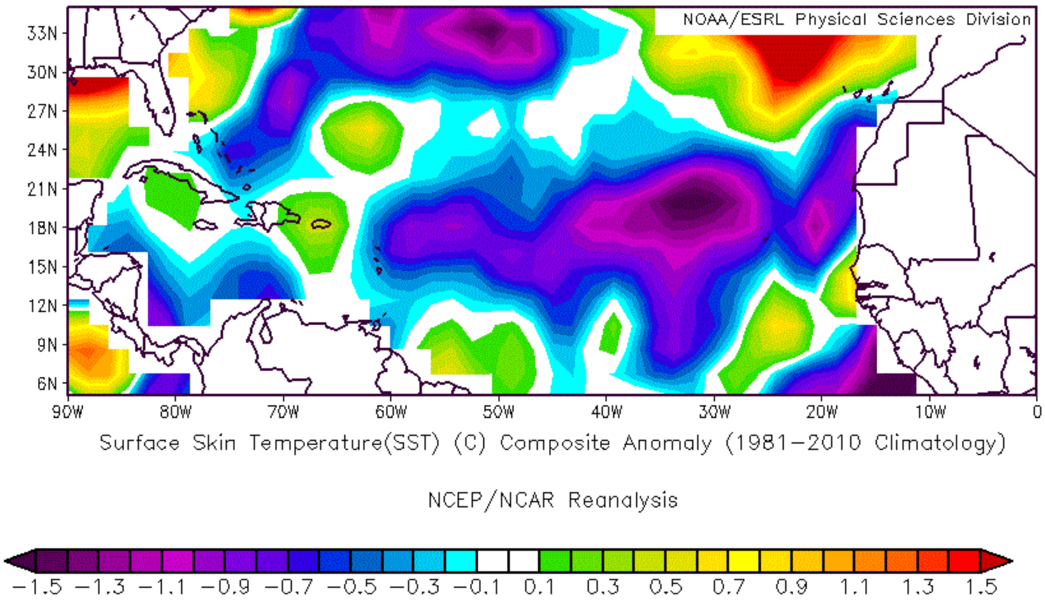


Figure 13: Late May 2012 - late May 2011 SST anomaly difference. Note the significant cooling that has occurred throughout the tropical Atlantic from last year at this time.

7 Adjusted 2012 Forecast

Table 8 shows our final adjusted early June forecast for the 2012 season which is a combination of our statistical scheme, our analog scheme and qualitative adjustments for other factors not explicitly contained in any of these schemes. Both the statistical and the analog scheme call for approximately average activity this year. Overall, we are predicting a slightly below-average season for the Atlantic basin in 2012.

Table 8: Summary of our early June statistical forecast, our analog forecast and our adjusted final forecast for the 2012 hurricane season.

Forecast Parameter and 1981-2010 Median (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (12.0)	10.4	11.5	13*
Named Storm Days (60.1)	50.3	49.3	50
Hurricanes (6.5)	5.8	5.8	5
Hurricane Days (21.3)	22.2	16.8	18
Major Hurricanes (2.0)	2.4	2.5	2
Major Hurricane Days (3.9)	5.4	3.6	4
Accumulated Cyclone Energy Index (92)	92	78	80
Net Tropical Cyclone Activity (103%)	101	95	90

*Includes the two pre-seasonal tropical storms of 2012 - Alberto and Beryl.

8 Landfall Probabilities for 2012

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

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

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

Table 10 lists strike probabilities for the 2012 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 2012 is expected to be slightly below its long-term average of 100, and therefore, landfall probabilities are slightly 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 19% which is slightly lower than the yearly climatological average of 21%.

South Florida is much more prone to being impacted by a hurricane on an individual-year basis compared with northeast Florida. For instance, the probability of Miami-Dade County being impacted by hurricane-force wind gusts this year is 10%. 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 30%, 14%, and 4%, 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 2012. 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)	76% (79%)	64% (68%)	48% (52%)	81% (84%)	95% (97%)
Gulf Coast (Regions 1-4)	55% (59%)	39% (42%)	28% (30%)	56% (60%)	80% (83%)
Florida plus East Coast (Regions 5-11)	47% (50%)	41% (44%)	28% (31%)	56% (61%)	77% (81%)
Caribbean (10-20°N, 60-88°W)	79% (82%)	53% (57%)	39% (42%)	71% (75%)	94% (96%)

9 Have Atmospheric CO_2 Increases Been Responsible for the Recent Large Upswing (since 1995) in Atlantic Basin Major Hurricanes?

A. BACKGROUND

The U.S. landfall of major hurricanes Dennis, Katrina, Rita and Wilma in 2005 and the four Southeast landfalling hurricanes of 2004 – Charley, Frances, Ivan and Jeanne, raised questions about the possible role that global warming played in those two unusually destructive seasons for the U.S. In addition, three hurricanes (Dolly, Gustav and Ike) pummeled the Gulf Coast in 2008 causing considerable devastation. Some researchers have tried to link the rising CO_2 levels with SST increases during the late 20th century and say that this has brought on higher levels of hurricane intensity.

These speculations that hurricane intensity has increased due to CO_2 increases have been given much media attention; however, we believe that they are not valid, given current observational data. The long manuscript by Gray (2011) goes into extensive detail describing why a significant relationship between increased CO_2 and increased Atlantic hurricane activity is not valid.

There has, however, been a large increase in Atlantic basin major hurricane activity in the last seventeen years (since 1995) in comparison with the prior 17-year period of 1978-1994 (Figure 14) as well as the prior quarter-century period of 1970-1994. It has been tempting for many who do not have a strong background of hurricane information to jump on this recent increase in major hurricane activity as strong evidence of a human influence on hurricanes. It should be noted, however, that the last 17-year active major hurricane period of 1995-2011 has not been more active than the earlier 17-year period of 1948-1964 when the Atlantic Ocean circulation conditions were similar to what has been observed during the last 17 years. These earlier active conditions occurred even though atmospheric CO_2 amounts and global SSTs were lower during this earlier period.

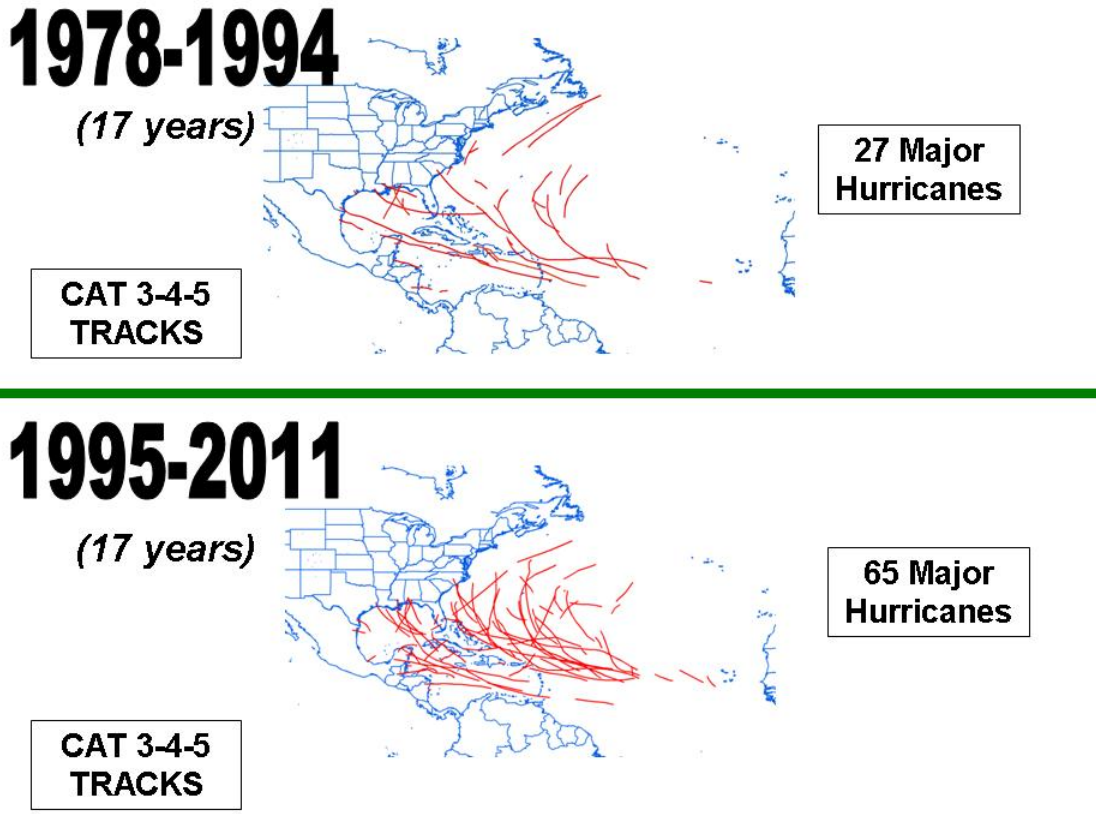


Figure 14: The tracks of major (Category 3-4-5) hurricanes during the 17-year period of 1995-2011 when the THC was strong versus the prior 17-year period of 1978-1994 when the THC was weak. Note that there were approximately 2.5 times as many major hurricanes when the THC was strong as when it was weak.

Table 11 shows how large Atlantic basin hurricane variations can be between strong and weak THC periods. Note especially how large the ratio is for major hurricane days (3.7) during strong vs. weak THC periods. Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) and Pielke et al. (2008) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction. This occurs even though these major hurricanes make up only 20-25 percent of named storms. This would give a general relative potential destructive difference of 3.7 * 4.25 or about 15 to 1.

Although global surface temperatures increased during the late 20th century, there is no reliable data to indicate increased hurricane frequency or intensity in any of the globe's other tropical cyclone basins since 1972. Global Accumulated Cyclone Energy (ACE), 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, shows significant year-to-year and decadal variability over the past forty years but no increasing trend (Figure 15). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005.

Table 11: Comparison of Atlantic annual basin hurricane activity in two 17-year periods when the Atlantic Ocean THC (or AMO) was strong versus an intermediate period (1970-1994) when the THC was weak.

	THC	SST (10-15°N; 70-40°W)	Avg. CO_2 ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
1948-1964 (17 years)	Strong	27.93	319	10.0	54.0	6.5	29.9	3.8	9.4	120	133
1970-1994 (25 years)	Weak	27.60	345	9.3	41.9	5.0	16.0	1.5	2.5	68	75
1995-2011 (17 years)	Strong	28.02	373	14.9	75.5	7.8	31.9	3.8	9.0	140	153
Annual Ratio Strong/Weak THC		Δ 0.35°C	~ 0	1.3	1.5	1.4	1.9	2.5	3.7	1.9	1.9

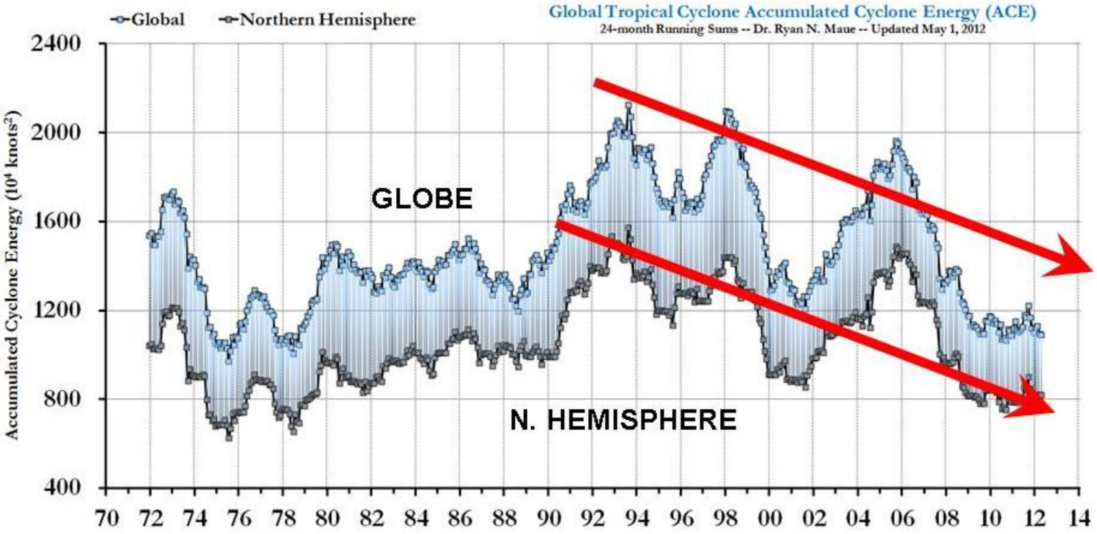


Figure 15: Northern Hemisphere and global Accumulated Cyclone Energy (ACE) over the period from December 1971-April 2012. Figure has been adapted from Ryan Maue.

Causes of the Upswing in Atlantic Major Hurricane Activity since 1995. The Atlantic Ocean has a strong multi-decadal signal in its hurricane activity which is likely due to multi-decadal variations in the strength of the THC (Figure 16). The oceanic and atmospheric response to the THC is often referred to as the Atlantic Multi-decadal Oscillation (AMO). We use the THC and AMO interchangeably throughout the remainder of this discussion. The strength of the THC can never be directly measured, but it can be diagnosed, as we have done, from the magnitude of the SST anomaly (SSTA) in the North Atlantic (Figure 17) combined with the sea level pressure anomaly (SLPA) in the Atlantic between the latitude of the equator and 50°N (Klotzbach and Gray 2008).

The THC (or AMO) is strong when there is an above-average poleward advection of warm low-latitude waters to the high latitudes of the North Atlantic. This water can then sink to deep levels when it reaches the far North Atlantic in a process known as deep water formation. The water then moves southward at deep levels in the ocean. The amount of North Atlantic water that sinks is proportional to the water's density which is determined by its salinity content as well as its temperature. Salty water is denser than fresh water at water temperatures near freezing. There is a strong association between North Atlantic SSTA and North Atlantic salinity (Figure 18). High salinity implies higher rates of North Atlantic deep water formation (or subsidence) and thus a stronger flow of upper level warm water from lower latitudes as replacement. See the papers by Gray et al. (1999), Goldenberg et al. (2001), and Grossmann and Klotzbach (2009) for more discussion.

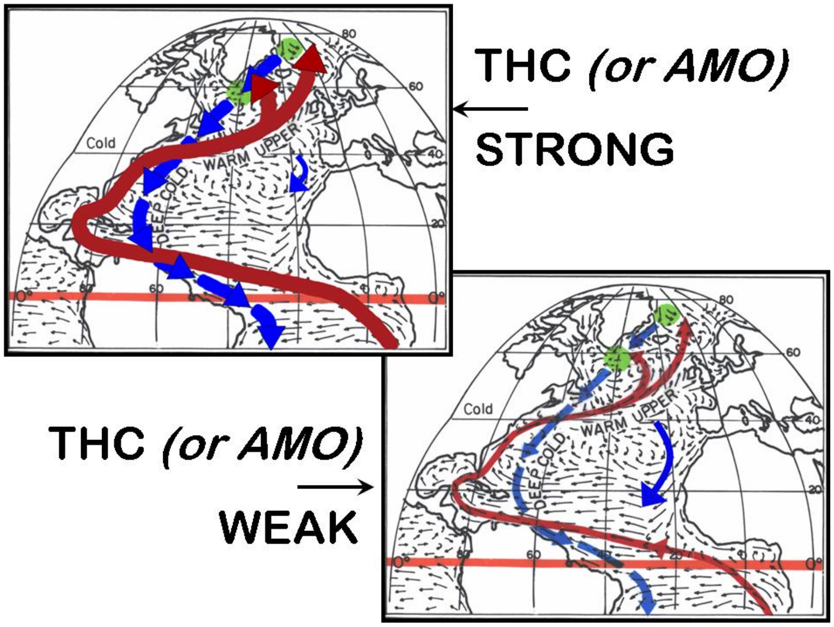


Figure 16: Illustration of strong (top) and weak (bottom) phases of the THC or AMO.

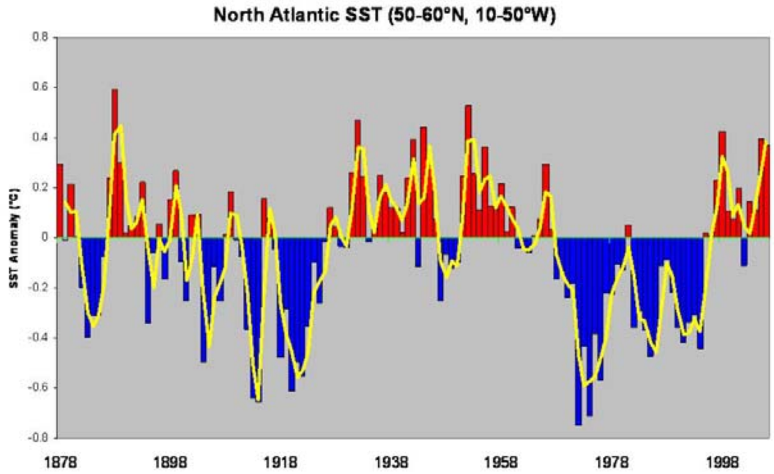


Figure 17: Long-period portrayal (1878-2006) of North Atlantic sea surface temperature anomalies (SSTA). The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average.

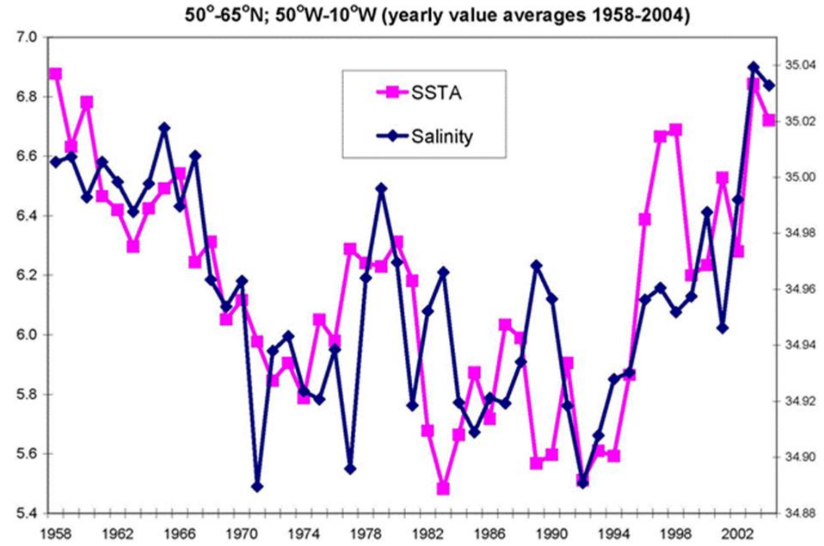


Figure 18: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

B. WHY CO_2 INCREASES ARE NOT RESPONSIBLE FOR ATLANTIC SST AND HURRICANE ACTIVITY INCREASES

Theoretical considerations do not support a close relationship between SSTs and hurricane intensity. In a global warming world, the atmosphere's upper air temperatures will warm or cool in unison with longer-period SST changes. Vertical lapse rates will thus not be significantly altered in a somewhat warmer or somewhat cooler tropical oceanic environment. We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will significantly change if global or Atlantic Ocean temperatures were to rise by 1-2°C. Without corresponding changes in many other basic features, such as vertical wind shear or mid-level moisture, little or no additional TC activity should occur with SST increases.

Confusing Time Scales of SST Influences. A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo some intensification. This is due to the sudden lapse rate increase which the hurricane's inner core experiences when it passes over warmer water. The warmer SSTs cause the hurricane's lower boundary layer temperature and moisture content to rise. While these low-level changes are occurring, upper tropospheric conditions are often not altered significantly. These rapidly occurring lower- and upper-level temperature differences cause the inner-core hurricane lapse rates to increase and produce more intense inner-core deep cumulus convection. This typically causes an increase in hurricane intensity. Such observations have led many observers to directly associate SST increases with greater hurricane potential intensity. This is valid reasoning for day-to-day hurricane intensity change associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in an overall climatologically warmer (or cooler) tropical oceanic environment where broad-scale global and tropical rainfall conditions are not expected to significantly vary. During long-period climate change, temperature and moisture conditions rise at both lower and upper levels. Lapse rates are little affected.

Any warming-induced increase in boundary layer temperature and moisture will be (to prevent significant global rainfall alteration) largely offset by a similar but weaker change through the deep troposphere up to about 10 km height. Upper-tropospheric changes are weaker than boundary layer changes, but they occur through a much deeper layer. These weaker and deeper compensating increases in upper-level temperature and moisture are necessary to balance out the larger increases in temperature and moisture which occur in the boundary layer. Global and tropical rainfall would be altered significantly only if broad-scale lapse rates were ever altered to an appreciable degree.

Thus, we cannot automatically assume that with warmer global SSTs that we will have more intense hurricanes due to lapse-rate alterations. We should not expect that the frequency and/or intensity of major hurricanes will necessarily change as a result of changes in global or individual storm basin SSTs. Historical evidence does not support hurricanes being less intense during the late 19th century and the early part of the 20th century when SSTs were lower than they are today.

C. DISCUSSION

We have no plausible physical reasons for believing that Atlantic hurricane frequency or intensity will change significantly if global ocean temperatures were to continue to rise. For instance, in the quarter-century period from 1945-1969 when the globe was undergoing a weak cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, there were only 38 Atlantic major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 20). Atlantic SSTs and hurricane activity do not follow global mean temperature trends.

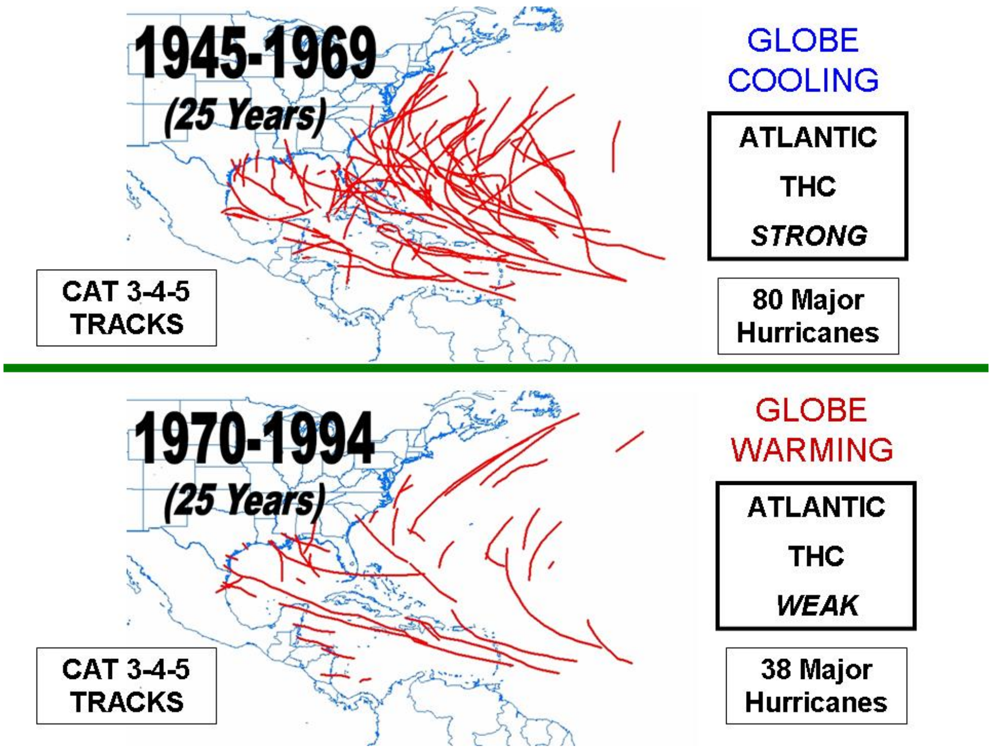


Figure 20: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was less than half as frequent during the latter period despite warmer global temperatures.

The most reliable long-period hurricane records we have are the measurements of US landfalling TCs since 1900 (Table 12). Although global mean ocean and Atlantic SSTs have increased by about 0.4°C between the two 56-year periods (1900-1955 compared with 1956-2011), the frequency of US landfall numbers actually shows a slight downward trend for the later period. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 46-year period of 1920-1965 (24 landfall events) and the 46-year period of 1966-2011 (7 landfall events) has been especially large (Figure 21). For the entire United States coastline, 39 major hurricanes made landfall during the earlier 46-year period (1920-1965) compared with only 26 major hurricanes for the latter 46-year period (1966-2011). This occurred despite the fact that CO_2 averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period.

Table 12: U.S. landfalling tropical cyclones by intensity during two 56-year periods.

YEARS	***Named Storms***	***Hurricanes***	***Major Hurricanes (Cat 3-4-5)***	***Global Temperature Increase***
1900-1955 (56 years)	213	116	45	+0.4°C
1956-2011 (56 years)	182	88	34	

We should not read too much into the four very active hurricane seasons of 2004, 2005, 2008 and 2010. The activity of these years was unusual but well within natural bounds of hurricane variation.

What made the 2004, 2005 and 2008 seasons so destructive was not the high frequency of major hurricanes but the high percentage of hurricanes that were steered over the US coastline. The US hurricane landfall events of these years were primarily a result of the favorable upper-air steering currents present during these years.

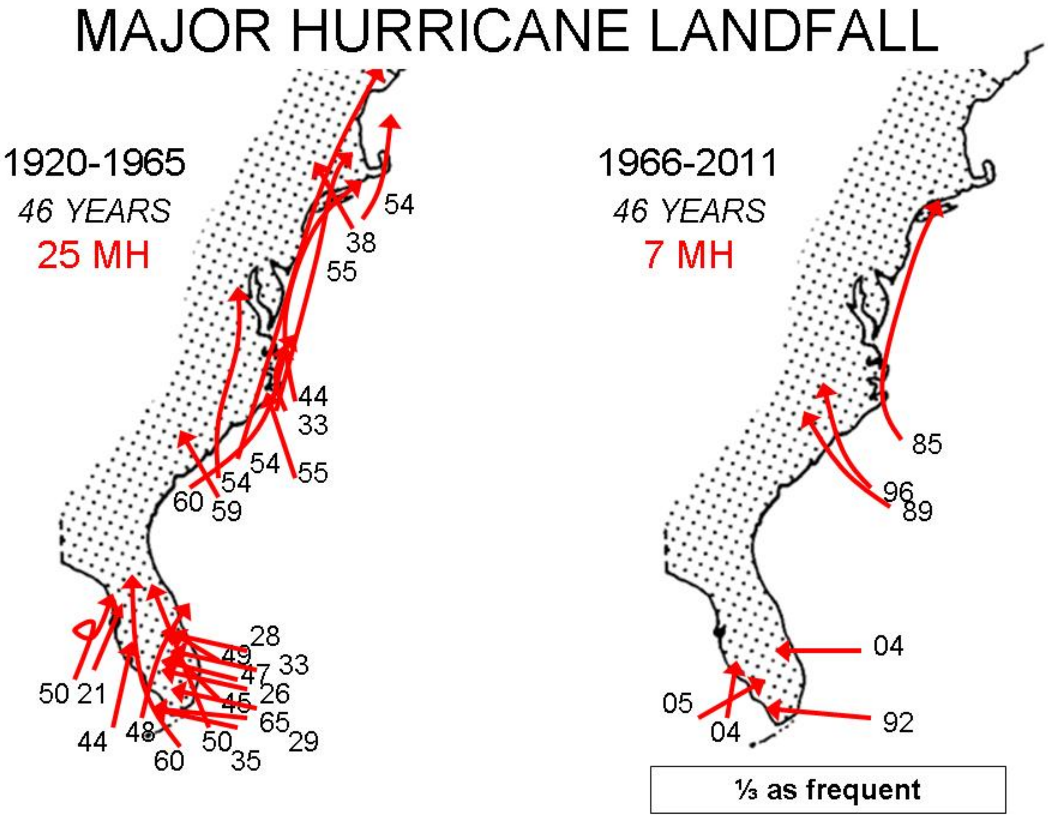


Figure 21: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 46-year period of 1920-1965 versus the most recent 46-year period of 1966-2011.

Although 2005 had a record number of TCs (28 named storms), this should not be taken as an indication of something beyond natural processes. There have been several other years with comparable hurricane activity to 2005. For instance, 1933 had 20 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 20 named storms had tracks west of 60°W where surface observations were more plentiful. If we eliminate all of the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – one more than the number observed in 1933.

Utilizing the National Hurricane Center’s best track database of hurricane records back to 1875, six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also, five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days. Although the 2005 hurricane season was certainly one of the most active on record, it was not as much of an outlier as many have indicated.

We believe that the Atlantic basin remains in an active hurricane cycle associated with a strong THC. This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period like we experienced during the quarter-century periods of 1970-1994 and 1901-1925. Atlantic hurricanes go through multi-decadal cycles. Cycles in Atlantic major hurricanes have been observationally traced back to the mid-19th century. Changes in the THC (or AMO) have been inferred from Greenland paleo ice-core temperature measurements going back thousands of years. These changes are natural and have nothing to do with human activity.

10 Forthcoming Updated Forecasts of 2012 Hurricane Activity

We will be issuing a seasonal update of our 2012 Atlantic basin hurricane forecasts on **Friday, 3 August**. A very short update on El Niño will be issued before 3 August if new data should warrant it.

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 2012 forecasts will be issued in late November 2012. All of these forecasts will be available on the web at: http://hurricane.atmos.colostate.edu/Forecasts.

11 Acknowledgments

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13 Verification of Previous Forecasts

Table 13: Summary verification of the authors' four previous years of seasonal forecasts for Atlantic TC activity between 2008-2011. Verifications of all seasonal forecasts back to 1984 are available here: http://tropical.atmos.colostate.edu/Includes/Documents/Publications/forecast_verifications.xls

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

2009	10 Dec. 2008	Update 9 April	Update 2 June	Update 4 August	Obs.
Hurricanes	7	6	5	4	3
Named Storms	14	12	11	10	9
Hurricane Days	30	25	20	18	12
Named Storm Days	70	55	50	45	30
Major Hurricanes	3	2	2	2	2
Major Hurricane Days	7	5	4	4	3.50
Accumulated Cyclone Energy	125	100	85	80	53
Net Tropical Cyclone Activity	135	105	90	85	69

2010	9 Dec. 2009	Update 7 April	Update 2 June	Update 4 August	Obs.
Hurricanes	6-8	8	10	10	12
Named Storms	11-16	15	18	18	19
Hurricane Days	24-39	35	40	40	38.50
Named Storm Days	51-75	75	90	90	89.50
Major Hurricanes	3-5	4	5	5	5
Major Hurricane Days	6-12	10	13	13	11
Accumulated Cyclone Energy	100-162	150	185	185	165
Net Tropical Cyclone Activity	108-172	160	195	195	196

2011	8 Dec. 2010	Update 6 April	Update 1 June	Update 3 August	Obs.
Hurricanes	9	9	9	9	7
Named Storms	17	16	16	16	19
Hurricane Days	40	35	35	35	26
Named Storm Days	85	80	80	80	89.75
Major Hurricanes	5	5	5	5	4
Major Hurricane Days	10	10	10	10	4.5
Accumulated Cyclone Energy	165	160	160	160	126
Net Tropical Cyclone Activity	180	175	175	175	145

Comment: We are proud of the success of the last four years of our seasonal forecasts. Our forecasts from early April, June and August have shown significant skill over climatology as well as the previous five-year mean.