EXTENDED-RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND LANDFALL STRIKE PROBABILITY FOR 2010

We foresee a very active hurricane season in 2010. We have increased our forecast from early April, due to a combination of a transition from El Niño to currently-observed neutral conditions and the continuation of unusually warm tropical Atlantic sea surface temperatures. We anticipate a well above-average probability of United States and Caribbean major hurricane landfall. All factors are lining up for a very active 2010 hurricane season.

(as of 2 June 2010)

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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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 very curious to know how active the upcoming hurricane 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 based on similar conditions in past years. Our early June statistical forecast methodology shows strong evidence over 58 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 an 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. However, all coastal residents should prepare for an active hurricane season every year. Landfalling tropical cyclones can devastate communities in inactive or active seasons. It only takes one landfalling system to make this a very active season for you.

ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2010

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Issue Date 9 December 2009	Issue Date 7 April 2010	Issue Date 2 June 2010
Named Storms (NS) (9.6)	11-16	15	18
Named Storm Days (NSD) (49.1)	51-75	75	90
Hurricanes (H) (5.9)	6-8	8	10
Hurricane Days (HD) (24.5)	24-39	35	40
Major Hurricanes (MH) (2.3)	3-5	4	5
Major Hurricane Days (MHD) (5.0)	6-12	10	13
Accumulated Cyclone Energy (ACE) (96.1)	100-162	150	185
Net Tropical Cyclone Activity (NTC) (100%)	108-172	160	195

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

1) Entire U.S. coastline - 76% (average for last century is 52%)
2) U.S. East Coast Including Peninsula Florida - 51% (average for last century is 31%)
3) Gulf Coast from the Florida Panhandle westward to Brownsville - 50% (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) 65% (average for last century is 42%)

ABSTRACT

Information obtained through May 2010 indicates that the 2010 Atlantic hurricane season will be much more active than the average 1950-2000 season. We estimate that 2010 will have about 10 hurricanes (average is 5.9), 18 named storms (average is 9.6), 90 named storm days (average is 49.1), 40 hurricane days (average is 24.5), 5 major (Category 3-4-5) hurricanes (average is 2.3) and 13 major hurricane days (average is 5.0). The probability of U.S. major hurricane landfall and Caribbean major hurricane activity is estimated to be well above its long-period average. We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2010 to be approximately 195 percent of the long-term average. We have increased our seasonal forecast from early April.

This forecast is based on an extended-range early June statistical prediction scheme that utilizes 58 years of past data. Analog predictors are also utilized. The influence of El Niño conditions is implicit in these predictor fields, and therefore we do not utilize a specific ENSO forecast as a predictor.

We expect that the current trend from El Niño to neutral conditions will persist and that weak La Niña conditions will develop by the most active portion of this year's hurricane season (August-October). The expected trend towards weak La Niña conditions should lead to reduced levels of vertical wind shear compared with what was witnessed in 2009. Another reason for our forecast increase is due to the persistence of anomalously warm sea surface temperatures in both the tropical and North Atlantic. Current SST anomalies are running at near-record warm levels. These very warm waters are associated with dynamic and thermodynamic factors that are very conducive for an active Atlantic hurricane season. Another factor in our forecast increase is the weaker-than-normal Azores High that prevailed during April-May. Weaker high pressure typically results in weaker trade winds that are commonly associated with more active hurricane seasons. Another important factor is that we are in the midst of a multi-decadal era of more major hurricane activity. Major hurricanes cause 80-85 percent of normalized hurricane damage.

We are also debuting a hurricane forecast for activity in the Caribbean Basin. This forecast is based on a statistical prediction scheme that utilizes 60 years of past data. This model is predicting a very active season for the Caribbean.

How will the Gulf oil spill impact a hurricane?

We do not anticipate that the oil spill will have any noticeable impact on tropical cyclone intensity or frequency. The strong winds of a tropical storm or hurricane should sufficiently mix the oil and water that there should be no noticeable alterations in broad-scale evaporation and sensible and latent heat flux.

What impact will a hurricane have on the Gulf oil spill?

This depends on the storm's track in relation to the oil spill. If the storm tracks to the west of the oil, there is the potential that the counter-clockwise circulation of the hurricane could drive some of the oil further towards the U.S. Gulf Coast. Alternatively, a storm tracking to the east of the oil could push the oil further offshore. But, little is understood about the interaction of tropical cyclones and oil.

Notice of Author Changes

By William Gray

The order of the authorship of these forecasts was reversed in 2006 from Gray and Klotzbach to Klotzbach and Gray. After 22 years (1984-2005) of making these forecasts, it was appropriate that I step back and have Phil Klotzbach assume the primary responsibility for our project's seasonal forecasts. Phil has been a member of my research project for the last ten years and was second author on these forecasts from 2001-2005. I have greatly profited and enjoyed our close personal and working relationship.

Phil is now devoting much more time to the improvement of these forecasts than I am. I am now giving more of my efforts to the global warming issue and in synthesizing my projects' many years of hurricane and typhoon studies.

Phil Klotzbach is an outstanding young scientist with a superb academic record. I have been amazed at how far he has come in his knowledge of hurricane prediction since joining my project in 2000. I foresee an outstanding future for him in the hurricane field. He is currently developing new seasonal and two-week forecast innovations that are improving our forecasts. The success of the last two years of seasonal forecasts is an example. Phil was awarded his Ph.D. degree in 2007. He is currently spending most of his time working towards better understanding and improving these Atlantic basin hurricane forecasts.

Acknowledgment

We are grateful to the National Science Foundation (NSF) for providing partial support for the research necessary to make these forecasts. We also 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 project members and now colleagues Chris Landsea, John Knaff and Eric Blake. We also thank Professors Paul Mielke and Ken Berry of Colorado State University for much statistical analysis and advice over many years. We also 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.

Atlantic Multi-Decadal Oscillation (AMO) – A mode of natural variability that occurs in the North Atlantic Ocean and evidencing itself in fluctuations in both sea surface temperature and sea level pressure fields. The AMO is likely related to fluctuations in the strength of the 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 approximately 40-50 days.

Main Development Region (MDR) – An area in the tropical Atlantic where a majority of major hurricanes form, defined 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 Scale – A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane; whereas, five is the most intense hurricane.

Southern Oscillation Index (SOI) – A normalized measure of the surface pressure difference between Tahiti and Darwin.

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.

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 (18 ms^{-1} or 34 knots) and 73 (32 ms^{-1} or 63 knots) miles per hour.

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 27th year in which the CSU Tropical Meteorology Project has made forecasts of the upcoming season's Atlantic basin hurricane activity. Our research team has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill exceeding climatology. These forecasts are based on a statistical methodology derived from 58 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 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 that portion of the variance of seasonal hurricane activity that is not associated with the other forecast variables. It is possible for an important hurricane forecast parameter to show little direct relationship to a predictand by itself but to have an important influence when included with a set of 2-3 other predictors.

A direct correlation of a forecast parameter may not be the best measure of the importance of this predictor to the skill of a 2-3 parameter forecast model. This is the nature of the seasonal or climate forecast problem where one is dealing with a very complicated atmospheric-oceanic system that is highly non-linear. There is a maze of changing physical linkages between the many variables. These linkages can undergo unknown changes from weekly to decadal time scales. It is impossible to understand how all these processes interact with each other. No one can completely understand the full complexity of the atmosphere-ocean system. But, it is still possible to develop a reliable statistical forecast scheme which incorporates a number of the climate system's non-linear interactions. Any seasonal or climate forecast scheme should show significant hindcast skill before it is used in real-time forecasts.

2 June Forecast Methodology

We developed a new June forecast scheme which was used for the first time in 2008. This scheme worked out quite well in predicting a very active season in 2008. It predicted approximately average activity in 2009 (an over-forecast). Complete details on the earlier June forecast schemes used from 1995-2007 are available in our June 2008 forecast (Klotzbach and Gray 2008).

2.1 Current June Statistical Forecast Scheme

We have found that using two spring predictors and our early April hindcast, we can obtain early June hindcasts that show considerable skill over the period from 1950-2007. This new forecast model also provided a very accurate prediction for the 2008 hurricane season.

This new scheme was created by evaluating the two spring predictors using least-squared regression along with our early April NTC forecast. The adjusted June NTC forecast was calculated using the following equation.

Adjusted June NTC = 0.4 * (Preliminary June NTC Hindcast) + 0.6 * (Final April NTC Hindcast).

In rapid changeover years from El Niño to La Niña or from La Niña to El Niño, our early April statistical forecast will likely either over-estimate or under-estimate activity. However, by early June of transition ENSO years, the atmosphere/ocean system has often begun its transition to the new ENSO phase, and therefore our April/May predictors for our early June forecast should provide us with more reliable information about the activity likely to occur for the upcoming season than our early April forecast.

By definition, least-squared regression tends to be conservative, and therefore, predicting large outlier events can be quite challenging. In order to help adjust for this challenge, the hindcasts from the linear regression model were adjusted to the final hindcast in the following manner.

The standardized value of each hindcast was calculated. These hindcasts were then adjusted to the final hindcast by multiplying by the standard deviation of the observations. Since the standard deviation of the observations is considerably larger than the standard deviation of the hindcasts, this aids in the forecast of outlying events. Any hindcasts that resulted in an NTC forecast of less than 30 NTC units were adjusted to 30 NTC units, since no season has had an NTC of lower than 30 units since 1950.

As mentioned before, our new statistical scheme shows enhanced levels of hindcast skill, explaining 61 percent of the variance from 1950-2007 and 83 percent of the variance from 1995-2007. We believe that we have solid physical links between these predictors and the upcoming Atlantic basin hurricane season.

Table 1 displays our early June hindcasts for 1950-2007 using the new statistical scheme, while Figure 1 displays observations versus NTC hindcasts. Our early June hindcasts have correctly predicted above- or below-average seasons in 42 out of 58 hindcast years (72%). These hindcasts have had a smaller error than climatology in 31 out of 58 years (53%). Our average hindcast error is 31 NTC units, compared with 46 NTC units for climatology. This scheme also shows considerable stability when broken in half, explaining 54 percent of the variance from 1950-1978 and 70 percent of the variance from 1979-2007. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2007 versus the inactive hurricane period from 1970-1994 (Table 2). Note how small the errors are for multi-decadal prediction.

The forecast scheme has shown excellent skill from 1980-2009. The average forecast error using a climatological forecast of 100 NTC units over this period was 52 units, while the average hindcast error using our June statistical forecast was only 27 units (about half as much).

Figure 2 displays the locations of the two 1 June (using April-May data) predictors used in this scheme in map form. Please refer to Figure 2 of our early April forecast for locations of predictors used in our early April prediction scheme. Table 3 lists the three (two new spring predictors and our early April prediction) predictors that are utilized for this year's June forecast. A more extensive discussion of current conditions in the Pacific and Atlantic basins is provided in Sections 6 and 7, respectively.

Table 1: Observed versus hindcast NTC for 1950-2007 using the current June scheme. Average errors for hindcast NTC and climatological NTC predictions are given without respect to sign. Red bold-faced years in the "Hindcast NTC" column (2) are years that we did not go the right way, while red bold-faced years in the "Hindcast improvement over Climatology" column (5) are years that we did not beat climatology. The hindcast went the right way with regards to an above- or below-average season in 42 out of 58 years (72%), while hindcast improvement over climatology occurred in 31 out of 58 years (53%). The real-time forecasts for 2008 and 2009 are also listed.

Year	(1) Observed NTC	(2) Hindcast NTC	(3) Observed minus Hindcast	(4) Observed minus Climatology	(5) Hindcast improvement over Climatology
1950	247	212	35	147	112
1951	148	114	34	48	14
1952	103	177	-74	3	**-71**
1953	127	186	-59	27	**-33**
1954	127	126	1	27	26
1955	207	181	26	107	81
1956	68	**123**	-55	-32	**-23**
1957	86	**119**	-33	-14	**-19**
1958	144	166	-21	44	23
1959	96	**108**	-12	-4	**-8**
1960	93	**139**	-46	-7	**-39**
1961	230	214	16	130	114
1962	41	**126**	-85	-59	**-26**
1963	116	**75**	41	16	**-25**
1964	184	171	13	84	71
1965	86	**149**	-63	-14	**-49**
1966	140	136	4	40	36
1967	102	**99**	3	2	**-1**
1968	47	53	-6	-53	47
1969	182	145	37	82	45
1970	64	86	-21	-36	14
1971	91	52	40	-9	**-31**
1972	35	30	5	-65	59
1973	53	**101**	-49	-47	**-1**
1974	83	30	53	-17	**-36**
1975	92	71	20	-8	**-12**
1976	86	33	53	-14	**-39**
1977	47	38	9	-53	43
1978	82	30	52	-18	**-35**
1979	97	30	67	-3	**-63**
1980	130	**89**	42	30	**-11**
1981	113	**95**	18	13	**-5**
1982	38	35	2	-62	60
1983	31	34	-3	-69	66
1984	80	**131**	-51	-20	**-31**
1985	106	126	-20	6	**-14**
1986	37	30	7	-63	56
1987	46	**103**	-58	-54	**-3**
1988	117	**96**	21	17	**-4**
1989	130	159	-30	30	0
1990	100	116	-15	0	**-15**
1991	58	30	28	-42	15
1992	67	34	33	-33	0
1993	52	**102**	-50	-48	**-2**
1994	35	53	-17	-65	47
1995	222	209	13	122	109
1996	192	176	16	92	76
1997	54	59	-5	-46	41
1998	169	194	-25	69	44
1999	182	197	-16	82	66
2000	134	181	-47	34	**-14**
2001	135	124	12	35	24
2002	83	86	-2	-17	14
2003	175	143	32	75	43
2004	232	173	59	132	73
2005	279	204	76	179	104
2006	85	**137**	-52	-15	**-37**
2007	99	100	-2	-1	**0**
Average	**112**	**113**	**31**	**46**	**+15**
2008	**162**	**181**	**-19**	**62**	**+41**
2009	**69**	**108**	**-39**	**-31**	**-8**

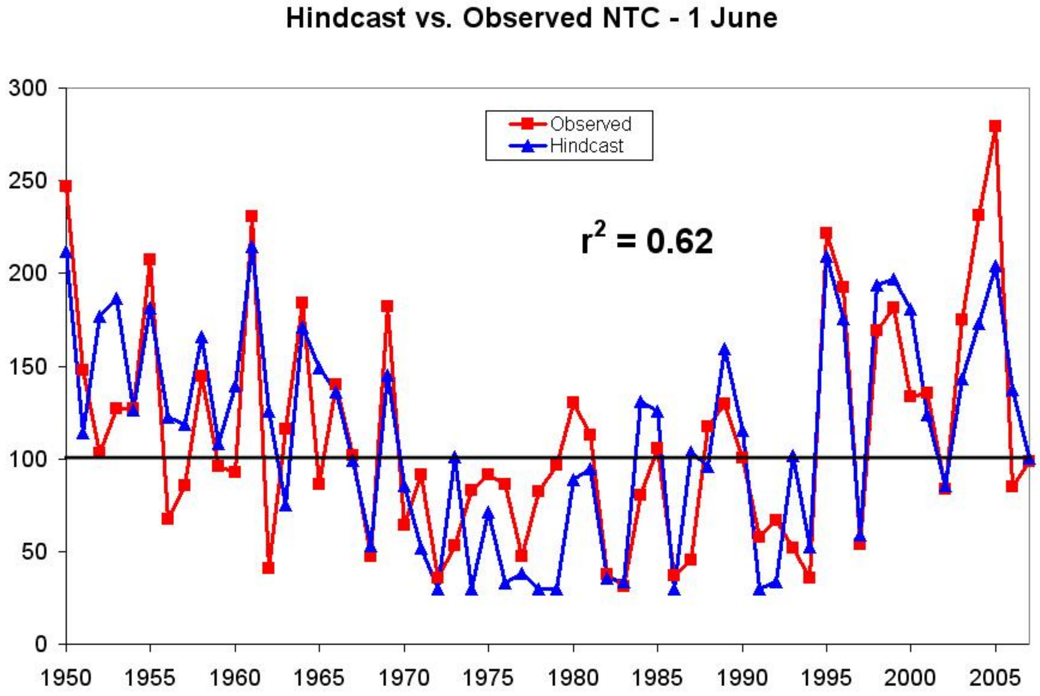


Figure 1: Observed versus hindcast values of NTC for 1950-2007.

Table 2: Hindcast versus observed average NTC for active vs. inactive multi-decadal periods.

Years	***Average Hindcast NTC***	***Average Observed NTC***
1950-1969 (Active)	141	129
1970-1994 (Inactive)	69	75
1995-2007 (Active)	153	157

New June Forecast Predictors

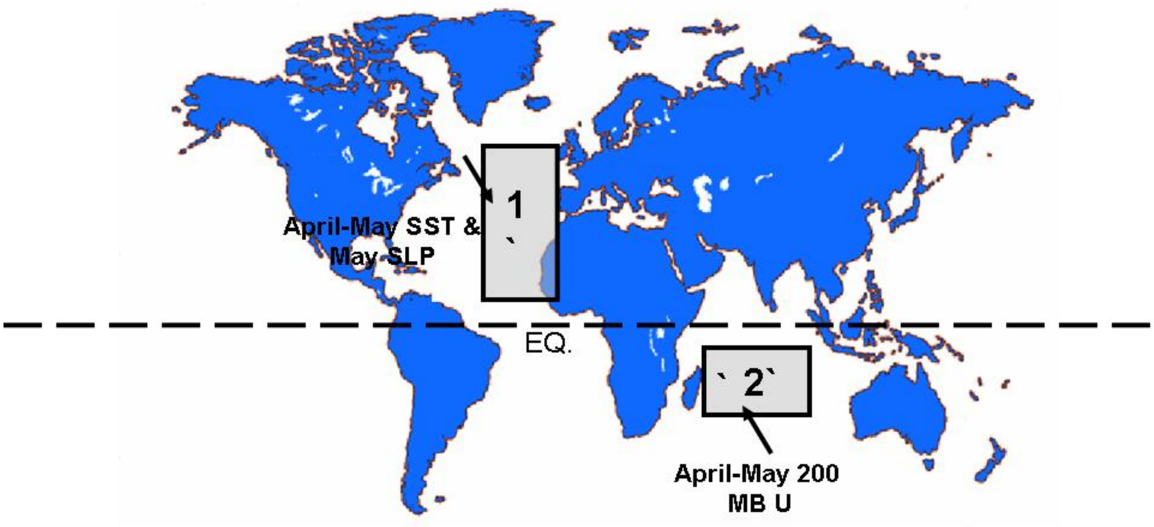


Figure 2: Location of spring predictors for our June extended-range statistical prediction for the 2010 hurricane season.

Table 3: Listing of 1 June 2010 predictors using the June statistical model for the 2010 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2010 Forecast Values
1) Subtropical Atlantic Index (+): April-May SST (20-50°N, 15-30°W) (+) & May SLP (10-35°N, 10-40°W) (-)	+1.6 SD
2) April-May 200 MB U (5-25°S, 50-90°E) (-)	+0.9 SD
3) Early April Hindcast (+)	102 NTC

There is also extended-range forecast skill from 1 June for United States hurricane landfall probabilities. In the 15 out of 58 years where our current hindcast scheme forecast NTC values that were above 150, we had more than twice as many hurricane (41 versus 20) landfalls and more than three times as many major hurricane (17 versus 5) landfalls along the U.S. coastline when compared with the 15 out of 58 years where our hindcast scheme gave NTC values that were below 60. For the Florida Peninsula and the U.S. East Coast, the ratio between NTC hindcast values greater than 150 and below 60 were 25 to 9 for hurricanes and 9 to 1 for major hurricanes – a remarkable difference.

2.2 Physical Associations among Predictors Listed in Table 3

The locations and brief descriptions of the two spring predictors for our early June statistical forecast are now discussed. It should be noted that both forecast parameters correlate significantly with seasonal physical features that are known to be favorable for elevated levels of hurricane activity. These factors are primarily 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.

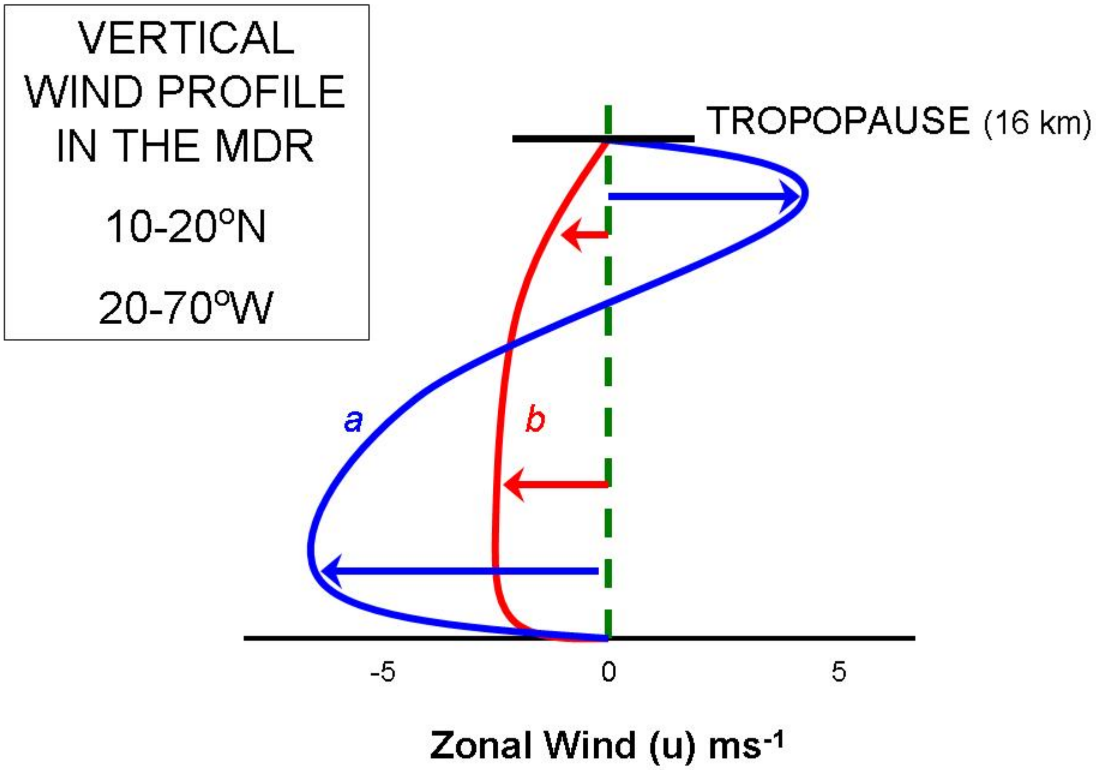


Figure 3: Vertical wind profile typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.

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, sea level pressure, 200 mb zonal wind, and 925 mb zonal wind, respectively. In general, higher values of SSTA, lower values of SLPA, anomalous westerlies at 925 mb and anomalous easterlies at 200 mb are associated with active Atlantic basin hurricane seasons.

For more information about the predictors utilized in our early April statistical forecast (used as 60% of our early June forecast), please refer to our early April 2010 forecast:

http://tropical.atmos.colostate.edu/Forecasts/2010/april2010/apr2010.pdf

1. Subtropical Atlantic Index (+): April-May SST (20-50°N, 15-30°W) (+) & May SLP (10-35°N, 10-40°W) (-)

A combination of above-normal sea surface temperatures (SSTs) in the eastern subtropical Atlantic and lower-than-normal sea level pressures in the subtropical Atlantic are associated with a weakened Azores high and reduced trade wind strength during the late spring (Knaff 1997). This combined index in April-May is strongly correlated with weaker trade 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 surface latent and sensible heat fluxes, respectively. Stronger-than-normal values of this index correlate quite well (~0.5) with active Atlantic basin tropical cyclone seasons.

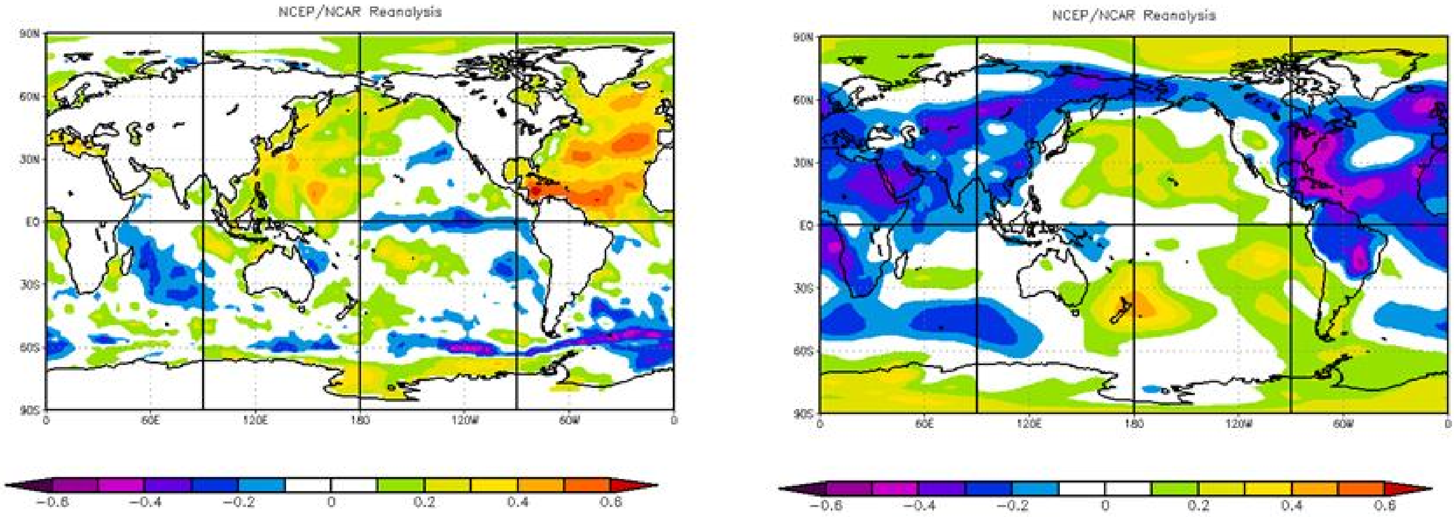
Predictor 2. April-May 200 MB U in the South Indian Ocean (-)

(5-25°S, 50-90°E)

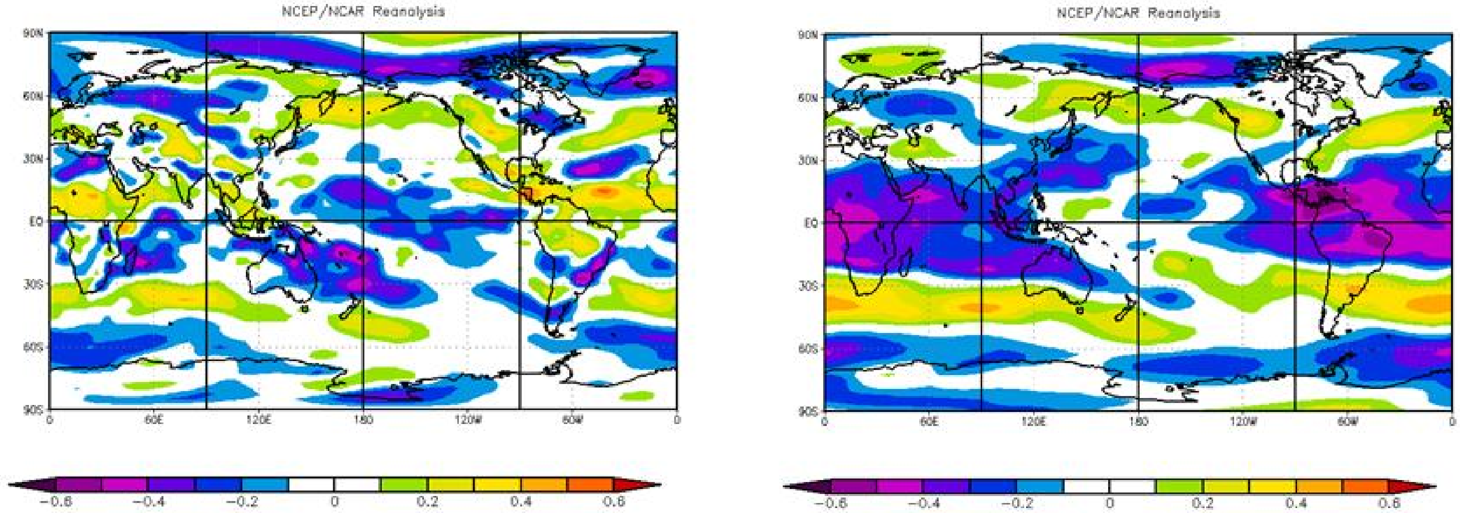
Upper-level easterly wind anomalies in the South Indian Ocean during April-May are associated with anomalously low sea level pressure and anomalous upper-level divergence in the western tropical Pacific and anomalously high sea level pressure and anomalous upper-level convergence in the eastern tropical Pacific. These features are associated with an active Walker Circulation, which is typically observed in cool ENSO years. Figure 5 displays the significant correlations that are achieved between values of this predictor in April-May and August-October sea surface temperatures, sea level pressure and 925 and 200 mb zonal wind anomalies, respectively. Note the anomalous easterly winds that are typically observed at upper levels over the tropical Atlantic and Caribbean in August-October when upper-level easterly wind anomalies exist in the South Indian Ocean in April-May. These anomalous easterlies combined with anomalous westerlies at 925 mb in the tropical Atlantic, reduce vertical wind shear across the tropical Atlantic providing a more favorable environment for tropical cyclone formation and intensification. Predictor values have been trending slightly more positive in this region since the 1950s. We have removed the trend in zonal wind anomalies from our predictor calculations to avoid a potentially non-physical lowering of forecast values, as there is some uncertainty as to the quality of the NCEP/NCAR reanalysis data for upper-level winds in the 1950s.

This predictor is located in an area that has not been considered in our previous early June forecasts. Since this predictor is new, we have gone through extensive testing to make sure that the predictor is valid. The predictor shows considerable stability when evaluated over both the 1950-1989 period and the 1990-2007 period. It correlates with NTC at -0.57 over the period from 1950-1989 and correlates with NTC at -0.60 over the period from 1990-2007. The correlation with NTC over the full time period from 1950-2007 is -0.59 (Figure 6).

When we examined the top 10 years when the predictor had its highest values and compared them with the bottom 10 years when the predictor had its lowest values, considerable differences were evident. In the 10 years when the zonal winds had their largest easterly anomalies, an average of 150 NTC units were observed, compared with an average of only 66 NTC units in the 10 years when the zonal winds had their largest westerly anomalies (Figure 7).

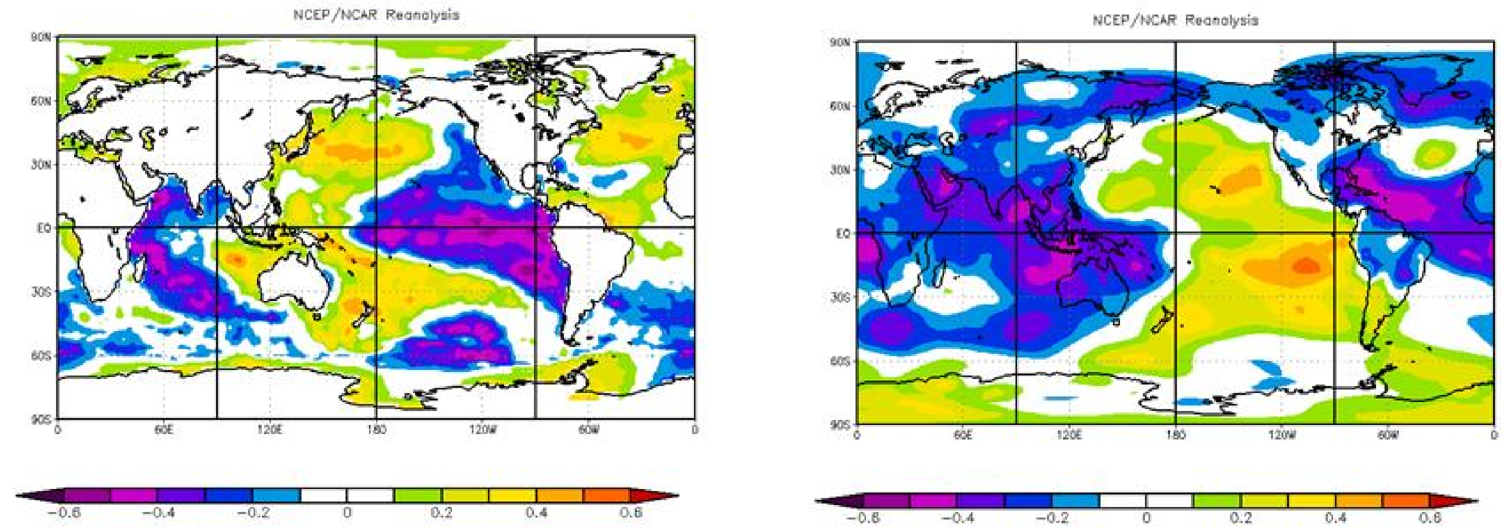

(a) SST

(b) SLP

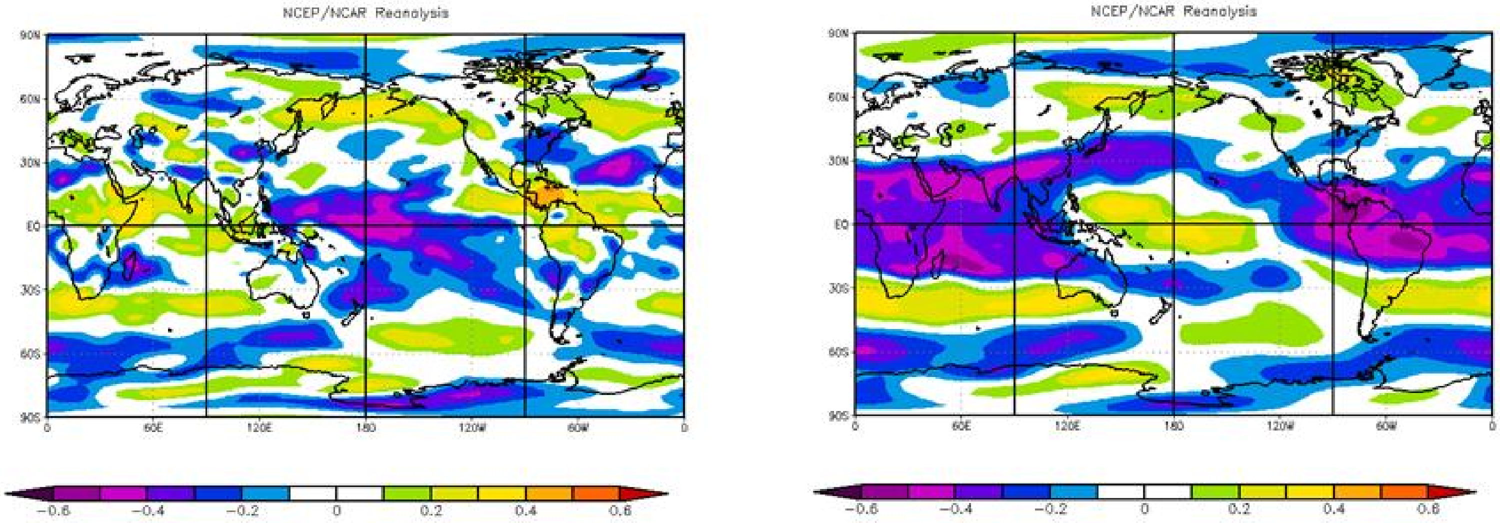

(c) 925 mb U

(d) 200 mb U

Figure 4: Linear correlations between the subtropical Atlantic index (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.


(a) SST

(b) SLP


(c) 925 mb U

(d) 200 mb U

Figure 5: Linear correlations between April-May 200 mb U in the South Indian Ocean (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity. Predictor values have been multiplied by -1 to allow for easy comparison with Figure 4.

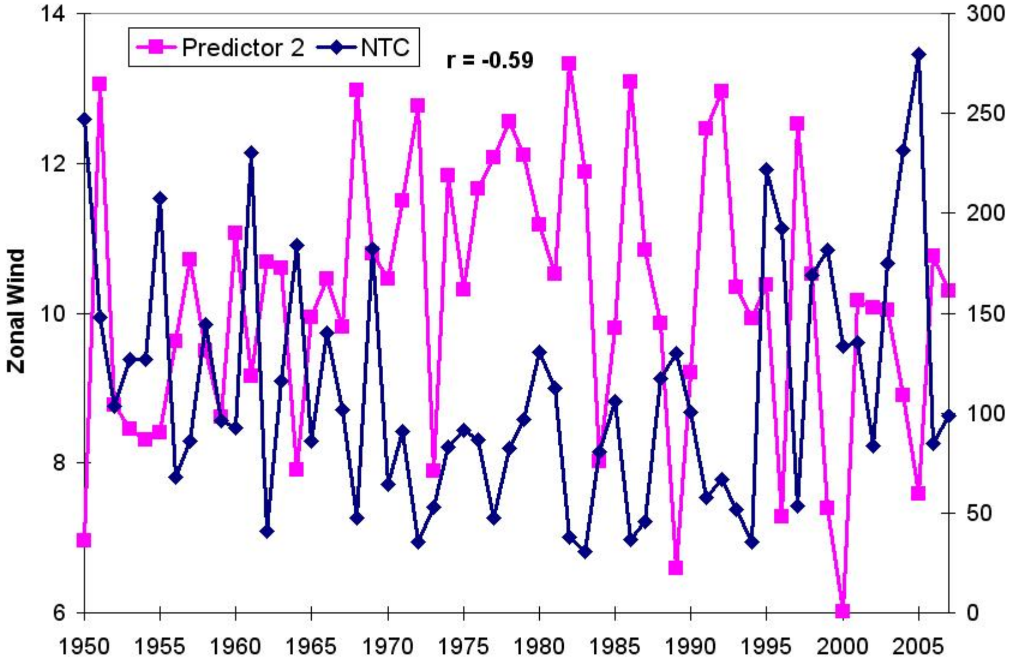


Figure 6: April-May values of Predictor 2 (pink line) and Atlantic basin NTC activity (blue line). Note the strong negative correlation between the two curves.

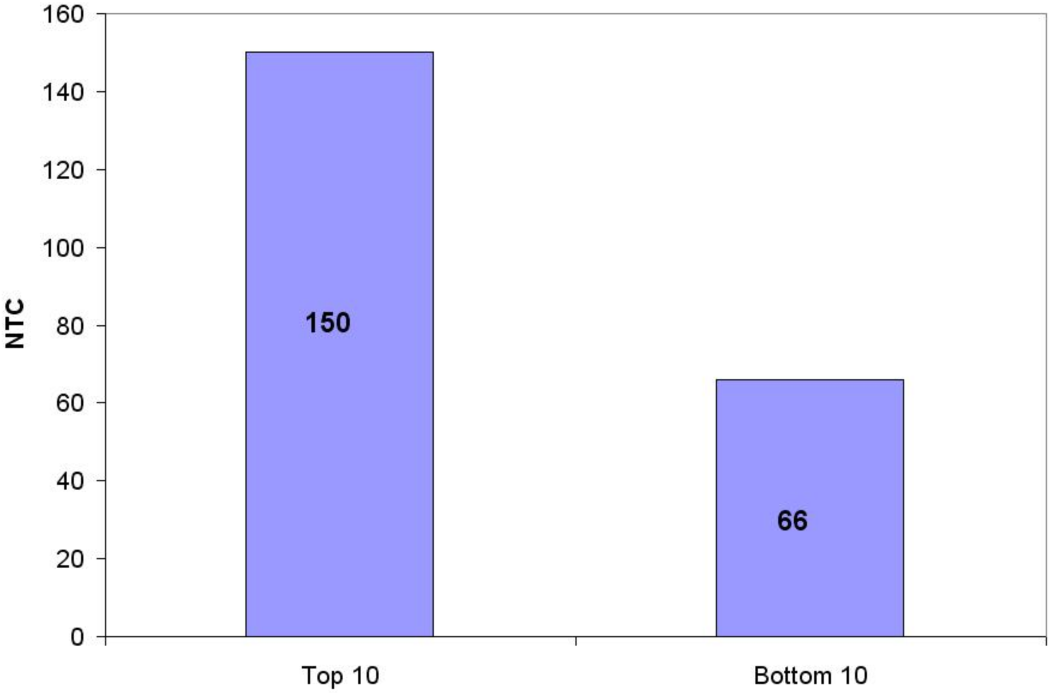


Figure 7: Top 10/bottom 10 NTC ratios for Predictor 2. Note that much larger values of NTC were observed when Predictor 2 had anomalous easterly winds.

3 Forecast Uncertainty

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

Table 4 provides our early June forecasts, with error bars (based on one standard deviation of absolute errors) as calculated from hindcasts over the 1990-2007 period, using equations developed over the 1950-1989 period. 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 that even the low value of one standard deviation below our real-time forecast is higher than the climatological average for all forecast parameters.

Table 4: Model hindcast error and our 2010 hurricane forecast. Uncertainty ranges are given in one standard deviation (SD) increments. Climatological average values from 1950-2000 are in parentheses in the right-hand column.

Parameter	Hindcast Error (SD)	2010 Forecast	Uncertainty Range – 1 SD (67% of Forecasts Likely in this Range)
Named Storms (NS)	3.8	18	14.2 – 21.8 (9.6)
Named Storm Days (NSD)	18.3	90	71.7 – 108.3 (49.1)
Hurricanes (H)	2.1	10	7.9 – 12.1 (5.9)
Hurricane Days (HD)	9.0	40	31.0 – 49.0 (24.5)
Major Hurricanes (MH)	1.2	5	3.8 – 6.2 (2.3)
Major Hurricane Days (MHD)	4.5	13	8.5 – 17.5 (5.0)
Accumulated Cyclone Energy (ACE)	39	185	146 – 224 (96.1)
Net Tropical Cyclone (NTC) Activity	37	195	158 – 232 (100)

4 Caribbean Forecast Methodology

We have developed a new forecast for the Caribbean that we are debuting with this early June prediction. Predictors for the Caribbean may be different than those used for the entire Atlantic basin. We intend to explore additional region-specific forecasts in the future, such as forecasts for the Gulf of Mexico or the higher latitude Atlantic.

We define the Caribbean to extend from 10-20°N, 60-88°W. This model attempts to predict seasonal levels of Accumulated Cyclone Energy (ACE) generated in the Caribbean. Through a combination of three predictors discussed in detail below, we can issue a forecast that shows significant levels of hindcast skill. As is done with the overall basinwide forecast, this Caribbean forecast will also be updated in early August.

4.1 Caribbean Statistical Forecast Scheme

We have found that using three spring predictors, we can obtain early June hindcasts that show considerable skill over the sixty-year development period from 1949-2008.

This new scheme was created by evaluating three spring predictors using least-squared regression. By definition, least-squared regression tends to be conservative, and therefore, predicting large outlier events can be quite challenging. In order to help adjust for this challenge, the hindcasts from the linear regression model were adjusted to the final hindcast in the following manner:

The standardized value of each hindcast was calculated. These hindcasts were then adjusted to the final hindcast by multiplying by the standard deviation of the observations. Since the standard deviation of the observations is considerably larger than the standard deviation of the hindcasts, this aids in the forecast of outlying events. Any hindcasts that resulted in a negative ACE prediction were assigned a final ACE value of 0.

Our statistical scheme shows significant hindcast skill, explaining 43% of the variance over the 1949-2008 period. Table 5 displays our early June hindcasts for 1949-2008 using the new statistical scheme, while Figure 8 displays observations versus ACE hindcasts. Our early June hindcasts have correctly predicted above- or below-average seasons in 47 out of 60 hindcast years (78%). These hindcasts have had a smaller error than climatology in 42 out of 60 years (70%). Our average hindcast error is 8.4 ACE units, compared with 12.5 ACE units for climatology. This scheme also shows considerable stability when broken in half, correlating at 0.60 from 1949-1978 and 0.71 from 1979-2008. This new scheme is also well-tuned to the multi-decadal active hurricane periods from 1950-1969 and 1995-2007 versus the inactive hurricane period from 1970-1994 (Table 6). As with our entire Atlantic forecast, the forecast skill for the Caribbean basin since 1980 has been particularly skillful. Forecast improvement over climatology was notably high.

Figure 9 displays the locations of the early June predictors used in this scheme in map form. Table 7 lists the three predictors that are utilized for this year’s June forecast.

The model predicted an ACE of 17 for the Caribbean in 2009, while the observed value of ACE was 4 for the Caribbean in 2009.

Table 5: Observed versus hindcast Caribbean ACE for 1949-2008. Average errors for hindcast ACE and climatological ACE predictions are given without respect to sign. Red bold-faced years in the "Hindcast ACE" column (2) are years that we did not go the right way, while red bold-faced years in the "Hindcast improvement over Climatology" column (5) are years that we did not beat climatology. The hindcast went the right way with regards to an above- or below-average season in 47 out of 60 years (78%), while hindcast improvement over climatology occurred in 42 out of 60 years (70%).

Year	(1) Observed ACE	(2) Hindcast ACE	(3) Observed minus Hindcast	(4) Observed minus Climatology	(5) Hindcast improvement over Climatology
1949	7	8	0	-7	7
1950	16	29	-13	2	**-11**
1951	24	23	1	9	8
1952	8	**23**	-15	-7	**-8**
1953	7	4	3	-8	5
1954	40	20	20	25	5
1955	48	47	1	34	33
1956	5	11	-7	-10	3
1957	0	2	-2	-15	12
1958	9	**21**	-12	-5	**-7**
1959	1	13	-12	-14	1
1960	17	26	-9	2	**-7**
1961	38	35	3	23	20
1962	0	**41**	-41	-15	**-26**
1963	28	33	-4	14	9
1964	21	23	-2	6	4
1965	0	3	-3	-14	11
1966	22	21	2	8	6
1967	27	15	13	13	0
1968	0	8	-8	-14	6
1969	12	**18**	-6	-3	**-4**
1970	4	12	-8	-11	3
1971	19	**0**	19	5	**-15**
1972	0	0	0	-14	14
1973	0	0	0	-14	14
1974	18	**3**	15	4	**-11**
1975	4	0	4	-10	6
1976	1	0	1	-14	13
1977	1	**21**	-20	-14	**-6**
1978	11	14	-2	-3	1
1979	26	**12**	14	11	**-3**
1980	21	17	3	6	3
1981	4	**15**	-12	-11	**-1**
1982	0	0	0	-15	15
1983	0	0	0	-15	15
1984	3	3	0	-11	11
1985	1	0	1	-13	12
1986	1	3	-2	-14	12
1987	6	9	-3	-8	5
1988	42	23	19	27	8
1989	16	19	-2	2	0
1990	8	**22**	-14	-7	**-7**
1991	0	0	0	-15	14
1992	0	0	0	-15	15
1993	4	0	4	-11	7
1994	3	0	3	-12	9
1995	23	23	0	9	8
1996	22	17	5	8	3
1997	3	6	-4	-12	8
1998	44	23	21	30	8
1999	24	37	-12	10	**-3**
2000	13	**29**	-16	-1	**-15**
2001	23	27	-4	9	5
2002	6	8	-2	-8	6
2003	6	**23**	-17	-9	**-9**
2004	51	34	17	36	20
2005	58	39	19	43	25
2006	4	**30**	-25	-10	**-15**
2007	47	25	22	32	11
2008	22	40	-18	7	**-11**
Average	**15**	**16**	**8.4**	**12.5**	**4.1**
2009	4	17	-13	-11	-2

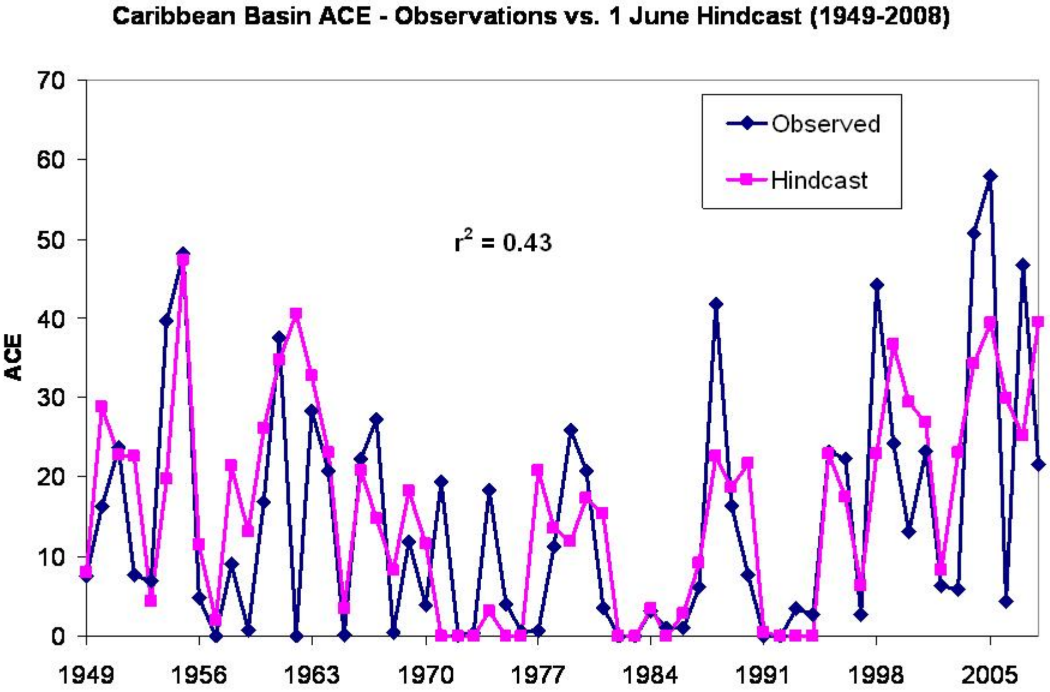


Figure 8: Observed versus hindcast values of Caribbean Basin ACE for 1949-2008.

Table 6: Hindcast versus observed average ACE for active vs. inactive multi-decadal periods. Percentage differences from the climatological average (1949-2008) are in parentheses.

Years	*Average Hindcast ACE*	*Average Observed ACE*
1949-1969 (Active)	20 (133%)	16 (107%)
1970-1994 (Inactive)	7 (47%)	8 (53%)
1995-2008 (Active)	26 (173%)	25 (167%)

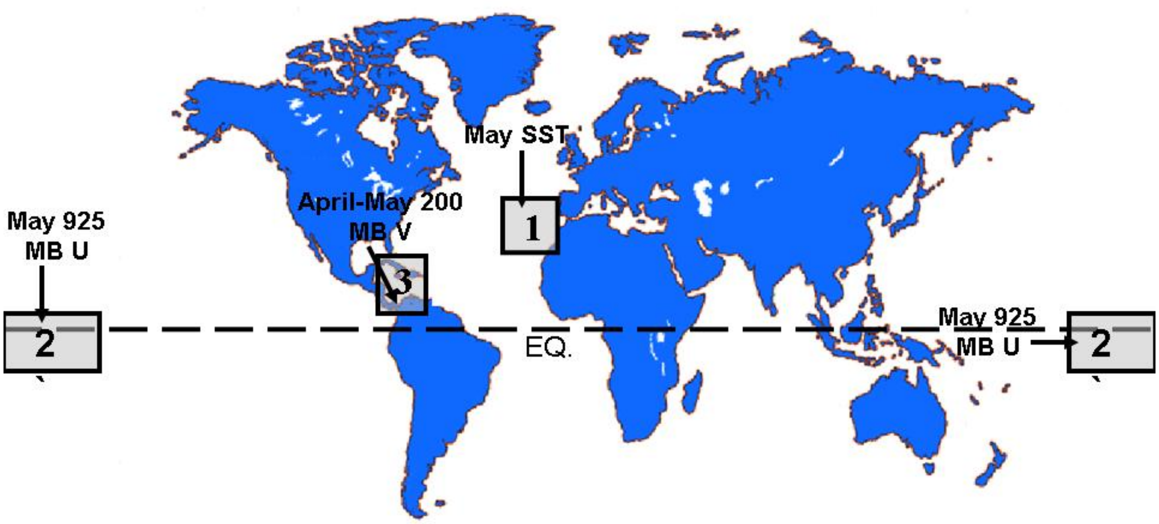

June Caribbean Predictors

Figure 9: Location of spring predictors for our Caribbean statistical prediction for the 2010 hurricane season.

Table 7: Listing of 1 June 2010 Caribbean Basin predictors using the June statistical model for the 2010 hurricane season. A plus (+) means that positive values of the parameter indicate increased hurricane activity during the following year.

Predictor	2010 Forecast Values
1) May SST (15-35°N, 15-30°W) (+)	+2.1 SD
2) May 925 MB U (7.5°S-2.5°N, 160°E-160°W) (-)	-1.8 SD
3) April-May 200 MB V (5-25°N, 60-85°W) (+)	+1.6 SD

The Caribbean model is calling for a very active hurricane season in 2010. Our forecast model is calling for an ACE of 58, which would be the highest recorded since 2005.

4.2 Physical Associations among Predictors Listed in Table 7

The locations and brief descriptions of the three spring predictors for our June Caribbean statistical forecast are now discussed. It should be noted that all three forecast parameters correlate significantly with seasonal physical features that are known to be favorable for elevated levels of hurricane activity. Table 8 and 9 display correlations between each predictor and August-October-averaged sea surface temperature, sea level pressure, 200 mb zonal wind and 925 mb zonal wind in the Main Development Region (MDR) and in the Caribbean, respectively. Since many storms that generate large values of ACE in the Caribbean form in the MDR, one would expect that these predictors would correlate with physical features in both regions. Correlations that are significant at the 95% level using a two-tailed Student's t-test are highlighted in bold-faced type.

Table 8: Correlations between 1 June Caribbean predictors and August-October values of Main Development Region (10-20°N, 20-70°W) sea surface temperature, sea level pressure, 200 mb zonal wind and 925 mb zonal wind.

Predictor	SST	SLP	200 MB U	925 MB U
1) May SST (15-35°N, 15-30°W) (+)	**0.66**	**-0.40**	**-0.36**	**0.37**
2) May 925 MB U (7.5°S-2.5°N, 160°E-160°W) (-)	-0.05	**0.37**	**0.40**	-0.19
3) April-May 200 MB V (5-25°N, 60-85°W) (+)	**0.30**	**-0.37**	**-0.40**	**0.47**

Table 9: Correlations between 1 June Caribbean predictors and August-October values of Caribbean (10-20°N, 60-88°W) sea surface temperature, sea level pressure, 200 mb zonal wind and 925 mb zonal wind.

Predictor	SST	SLP	200 MB U	925 MB U
1) May SST (15-35°N, 15-30°W) (+)	**0.65**	**-0.51**	**-0.49**	**0.42**
2) May 925 MB U (7.5°S-2.5°N, 160°E-160°W) (-)	-0.03	**0.30**	**0.39**	**-0.49**
3) April-May 200 MB V (5-25°N, 60-85°W) (+)	0.25	-0.25	-0.23	**0.34**

As was done with our Atlantic basin forecast, 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, sea level pressure, 200 mb zonal wind, and 925 mb zonal wind, respectively. In general, higher values of SSTA, lower values of SLPA, anomalous westerlies at 925 mb and anomalous easterlies at 200 mb are associated with active Caribbean basin seasons.

1. May SST in the Subtropical Atlantic (+)

(15-35°N, 15-30°W)

Above-normal sea surface temperatures (SSTs) in the eastern subtropical Atlantic are associated with a weakened Azores high and reduced trade wind strength during the late spring (Knaff 1997). This predictor is very strongly positively correlated (0.65 correlation) with Caribbean basin sea surface temperatures during August-October (Figure 10 and Table 9). Lower pressures are typically experienced throughout the Caribbean as well, implying a very favorable thermodynamic environment for tropical cyclone formation and intensification in this area during the climatologically most active portion of the hurricane season. This predictor also correlates favorably with reduced vertical wind shear in the Caribbean as well as above-average SSTs, below-average SLPs and reduced vertical wind shear over the MDR.

Predictor 2. May 925 mb U in the Central Tropical Pacific (-)

(7.5°S-2.5°N, 160°E-160°W)

Enhanced trade wind strength in the central tropical Pacific is typically associated with a La Niña event. Stronger-than-normal trades encourage mixing and upwelling, promoting cooling. In addition, Kelvin wave propagation and associated warm water transport from the western Pacific to the eastern Pacific is inhibited by this stronger easterly flow. Consequently, strong correlations exist between values of this predictor and Nino 3.4 values. The correlation between this predictor and the May Nino 3.4 value is 0.60, the correlation between this predictor and the June-July Nino 3.4 values is 0.64, and the correlation between this predictor and the August-October Nino 3.4 value is 0.55. ENSO is a critical player in Caribbean tropical cyclone activity, as alterations in vertical shear caused by ENSO are more significant here than in any other part of the Atlantic basin (Klotzbach 2010, manuscript submitted to *J. Climate*). There is a significant negative correlation (-0.49) between this predictor and trade wind strength during August-October and a significant positive correlation (0.39) between this predictor and 200 mb wind strength during August-October over the Caribbean, indicating the considerable influence that this predictor has on the vertical shear values experienced over the Caribbean (Figure 11 and Table 9).

Predictor 3. April-May 200 MB V in the Southwest Atlantic (+)

(5-25°N, 60-85°W)

Anomalous southerly flow in the southwest Atlantic Ocean is associated with an anomalous upper-level trough and surface high pressure over South America, consequently driving strong trades over the tropical eastern Pacific and promoting La Niña conditions. Also, southerly flow at upper levels in the Caribbean is indicative of an upper-level anticyclone to the east. This upper-level anticyclone imparts anomalous easterly upper-level flow, weakening the climatological upper-level westerlies and thereby weakening vertical shear over both the tropical Atlantic as well as the Caribbean. It appears that this predictor's impacts are more strongly related to conditions over the MDR as opposed to the Caribbean, as its correlations are statistically significant with SST, SLP, 200 MB U and 925 MB U over the MDR (Figure 12 and Table 8), while displaying only a significant correlation with 925 MB U over the Caribbean (Figure 12 and Table 9).

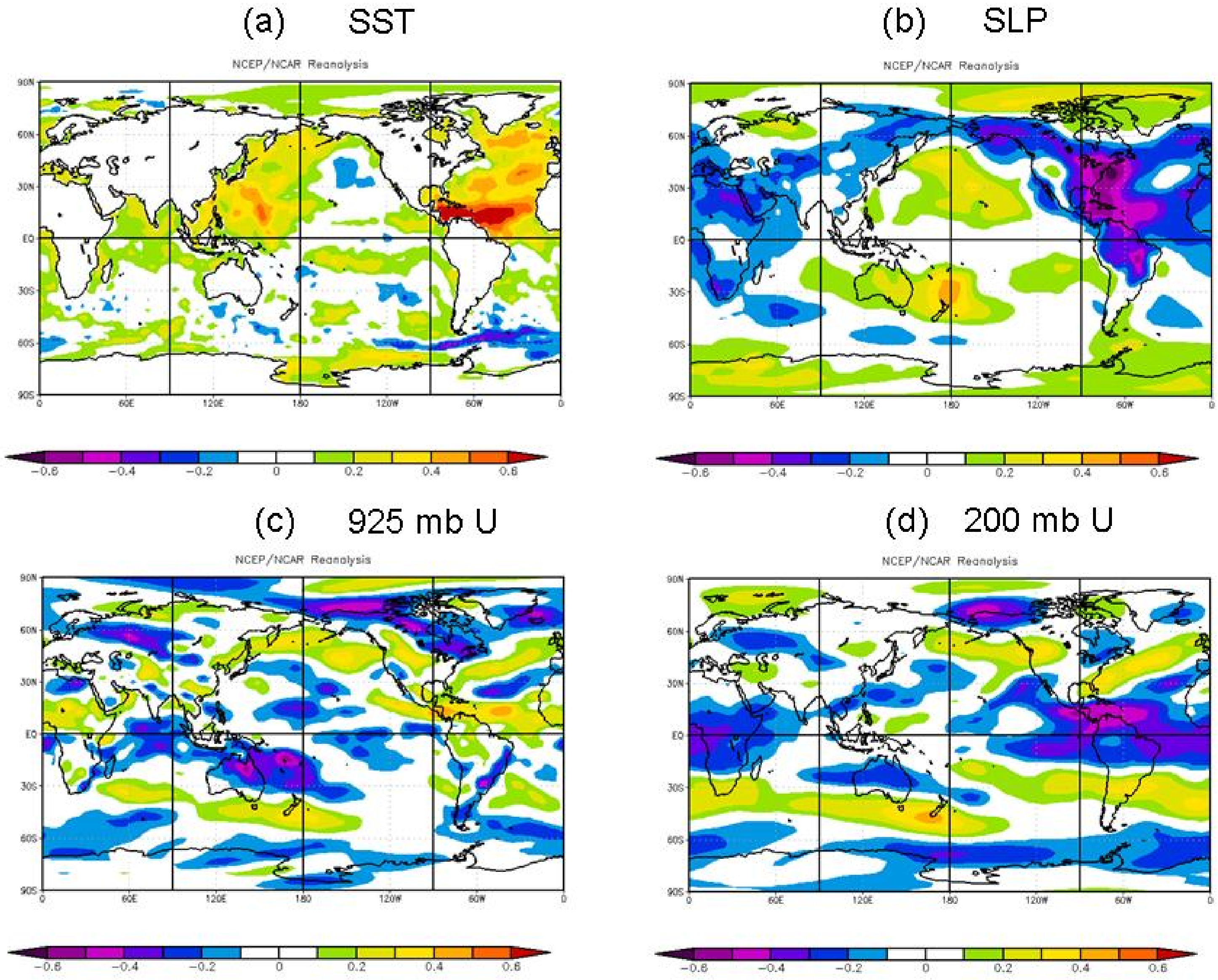
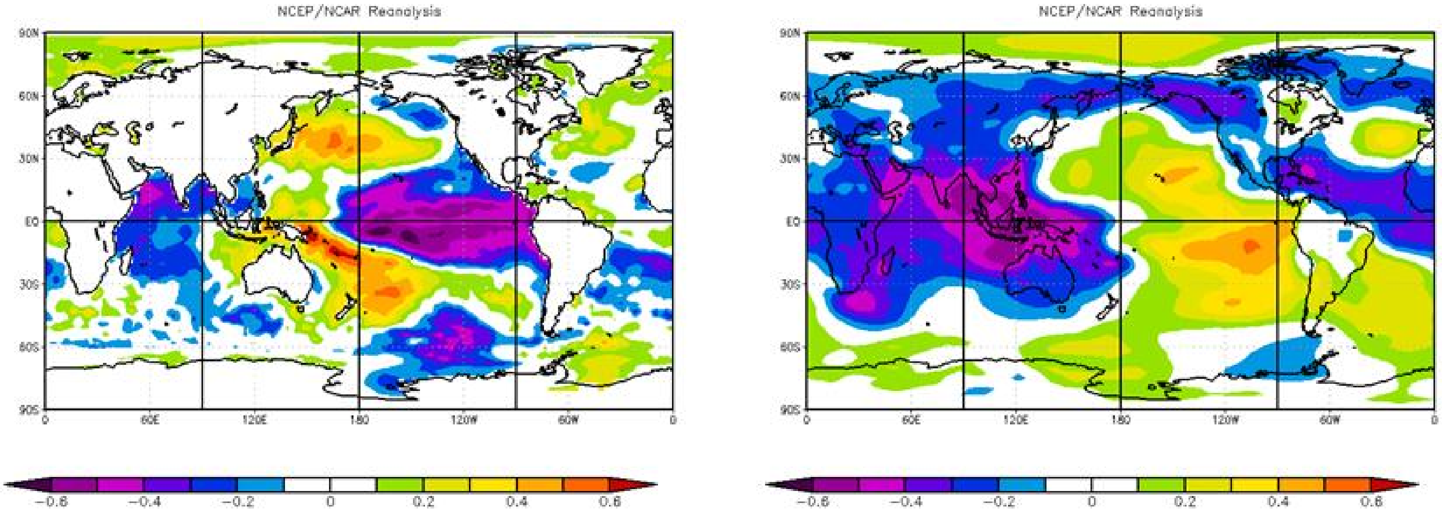


Figure 10: Linear correlations between subtropical Atlantic SST (Predictor 1) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

(a) SST (b) SLP



(c) 925 mb U (d) 200 mb U

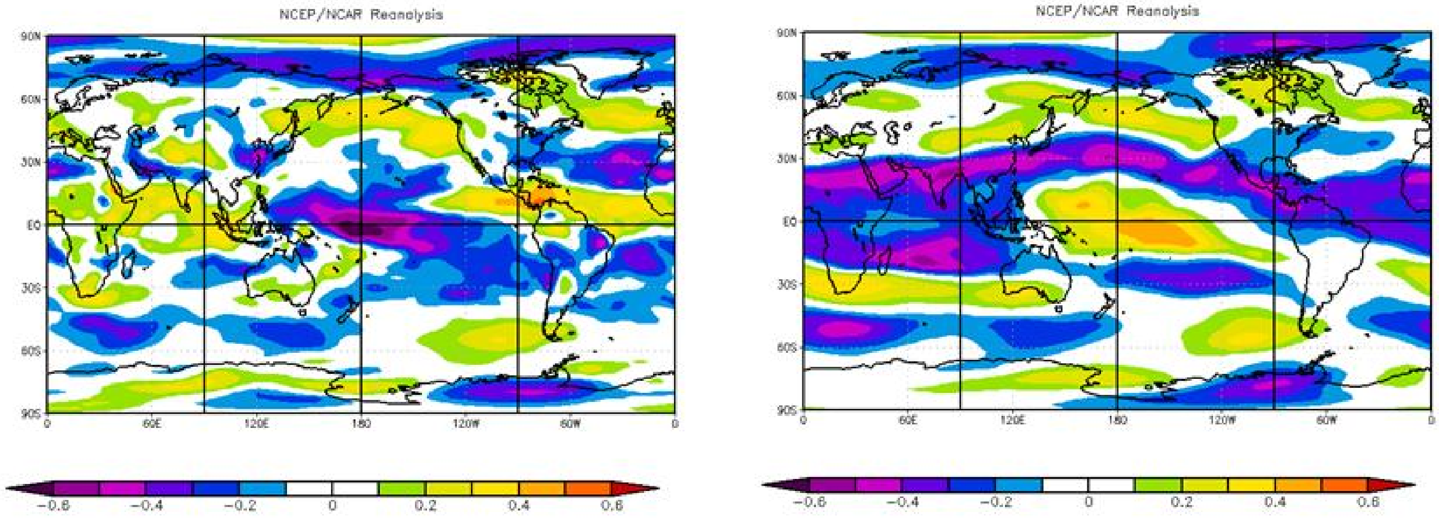


Figure 11: Linear correlations between May 925 mb zonal wind in the central tropical Pacific (Predictor 2) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity. Zonal wind values have been multiplied by -1 to allow for easy comparison with Figure 1.

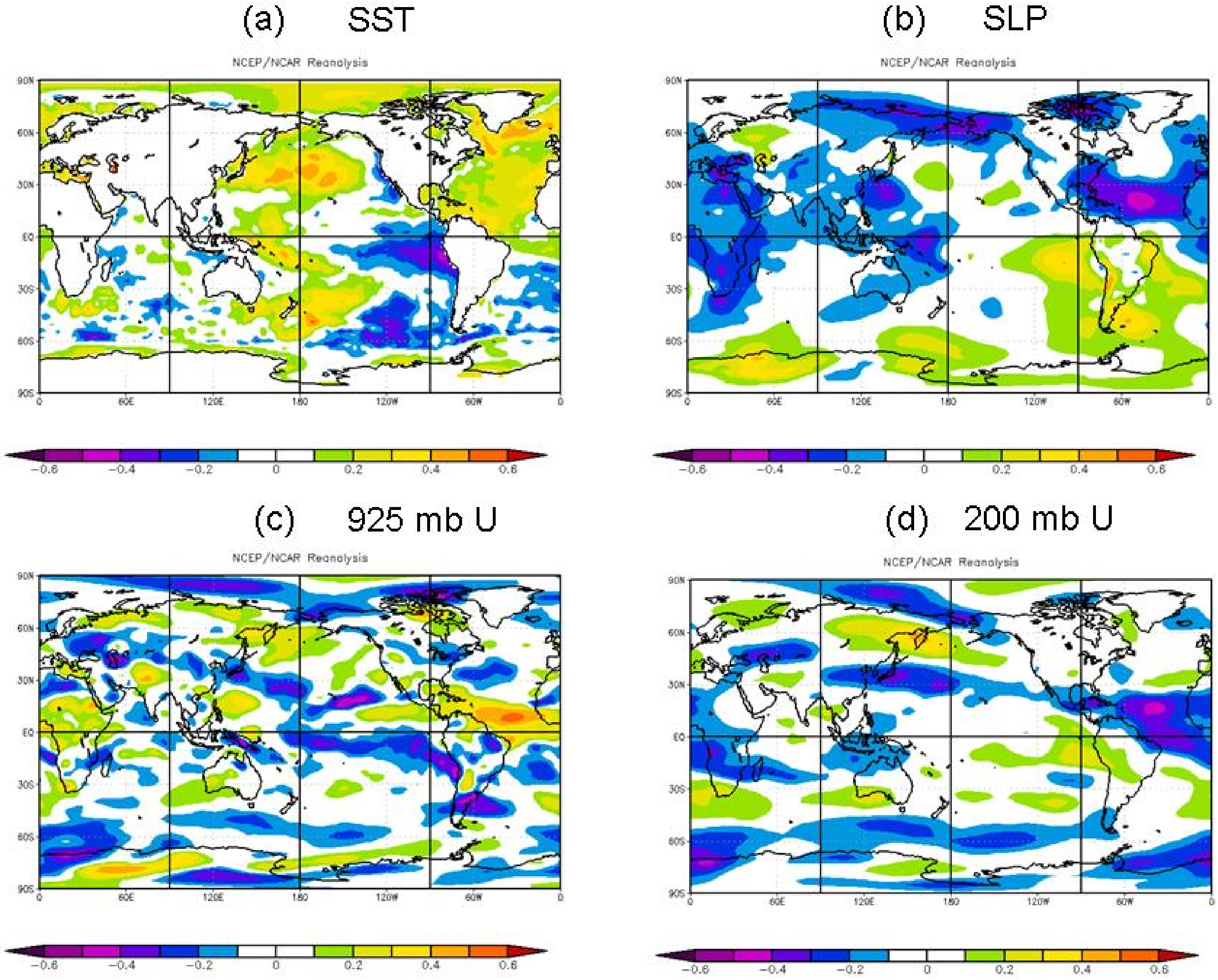


Figure 12: Linear correlations between April-May 200 mb meridional wind in the Caribbean (Predictor 3) and August-October sea surface temperature (panel a), August-October sea level pressure (panel b), August-October 925 mb zonal wind (panel c) and August-October 200 mb zonal wind (panel d). All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

5 Analog-Based Predictors for 2010 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2010. These years also provide useful clues as to likely trends in activity that the forthcoming 2010 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 2010 conditions. Table 10 lists our analog selections.

We select prior hurricane seasons since 1949 which have similar atmospheric-oceanic conditions to those currently being experienced. We searched for years that were generally characterized by weak El Niño or neutral conditions, well above-average tropical Atlantic SSTs and above-average far North Atlantic SSTs during April-May.

There were four hurricane seasons since 1949 with characteristics most similar to what we observed in April-May 2010. The best analog years that we could find for the 2010 hurricane season were 1958, 1966, 1969, and 2005. We anticipate that 2010 seasonal hurricane activity will have activity in line with what was experienced in the average of these four years. We believe that 2010 will thus be a very active hurricane season.

Table 10: Best analog years for 2010 with the associated hurricane activity listed for each year.

Year	NS	NSD	H	HD	MH	MHD	ACE	NTC
1958	10	55.50	7	30.25	5	9.50	121	144
1966	11	64.00	7	41.75	3	8.75	145	140
1969	18	91.50	12	40.00	5	6.75	166	182
2005	28	131.50	15	49.75	7	17.75	250	279
Mean	16.8	85.6	10.3	40.4	5.0	10.7	171	187
2010 Forecast	18	90	10	40	5	13	185	195

6 ENSO

Moderate-to-strong El Niño conditions were in place during the winter of 2009-2010. These conditions have weakened significantly over the past several months. SSTs are generally about average across the eastern and central tropical Pacific, indicating that El Niño has transitioned to neutral conditions. Table 11 displays March and May SST anomalies for several Nino regions. Note that all regions except for Nino 1+2 have experienced considerable cooling since March.

Table 11: March and May SST anomalies for Nino 1+2, Nino 3, Nino 3.4, and Nino 4, respectively. May-March SST anomaly differences are also provided.

Region	March SST Anomaly (°C)	May SST Anomaly (°C)	May – March SST Anomaly (°C)
Nino 1+2	-0.2	0.0	+0.2
Nino 3	0.7	0.0	-0.7
Nino 3.4	1.1	-0.1	-1.2
Nino 4	1.1	0.4	-0.7

We have increased confidence that we will have weak La Niña conditions (August-October-averaged Nino 3.4 between -1.0° and -0.5°C) during the peak of this year's hurricane season. We are approaching the end of the ENSO springtime predictability barrier, and therefore, statistical and dynamical models of ENSO show improved skill from a May initialization period compared with models initialized earlier in the spring. All statistical and dynamical models are calling for either neutral conditions (Nino 3.4 SSTs between -0.5°C and 0.5°C) or a transition to La Niña by the August-October period (Nino 3.4 SSTs < -0.5°C) (Figure 13). In general, the dynamical models are calling for a greater likelihood of La Niña conditions by August-October, while the statistical models tend to maintain more neutral conditions. We believe that we will experience a weak La Niña event by September.

We find that, in general, the European Centre for Medium-Range Weather Forecasts (ECMWF) shows the best prediction skill of the various ENSO models that are currently available. The ECMWF model is calling for an August-October-averaged Nino 3.4 SST anomaly of -0.9°C, giving us increased confidence that El Niño conditions will not have a detrimental role on this year's hurricane season as they did during last year's hurricane season. Note that none of the ECMWF ensemble members have El Niño conditions beyond July, with most members calling for either a weak or moderate La Niña by September.

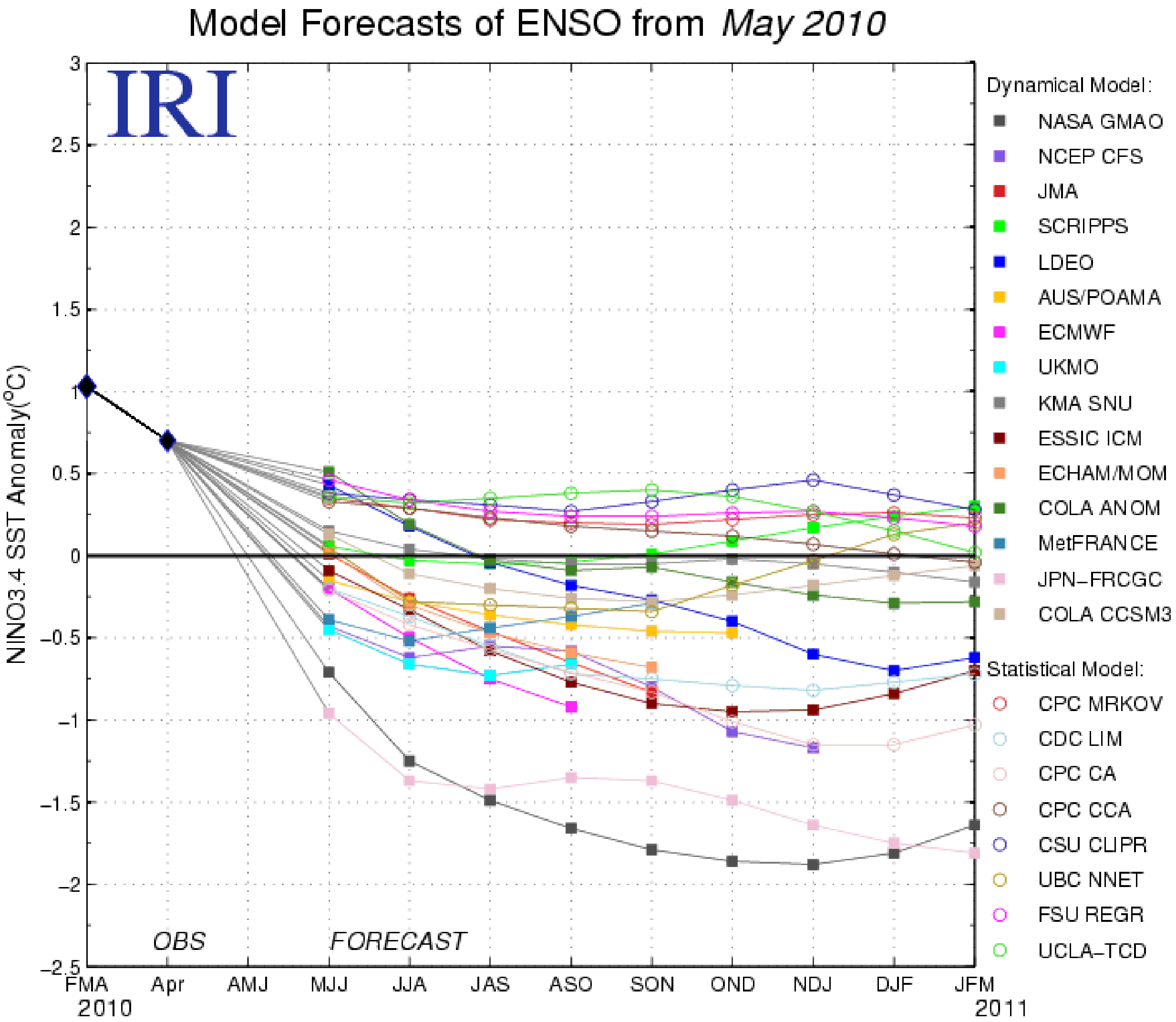


Figure 13: ENSO forecasts from various statistical and dynamical models. Figure courtesy of the International Research Institute (IRI). All forecast models are calling for either neutral or La Niña conditions during August-October.

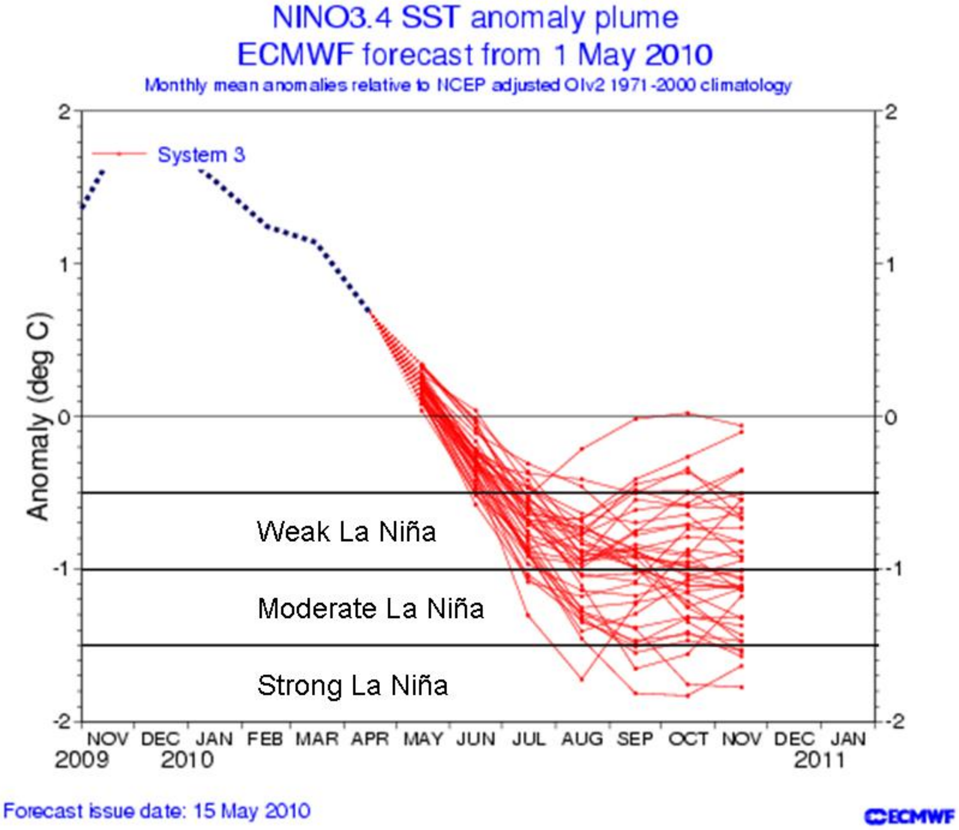


Figure 14: ECMWF ensemble model forecast for the Nino 3.4 region. All ensemble members predict below-average SSTs in the Nino 3.4 region by September, with most ensemble members calling for either a weak or moderate La Niña event.

Another reason why we believe that weak La Niña conditions will be present during this year's hurricane season is due to the current sub-surface ocean temperature anomaly pattern. Note that below-normal equatorial heat anomalies have reached the eastern Pacific. This reduction in upper-ocean heat content is typically seen with the transition from a weak El Niño to neutral conditions (Figure 15).

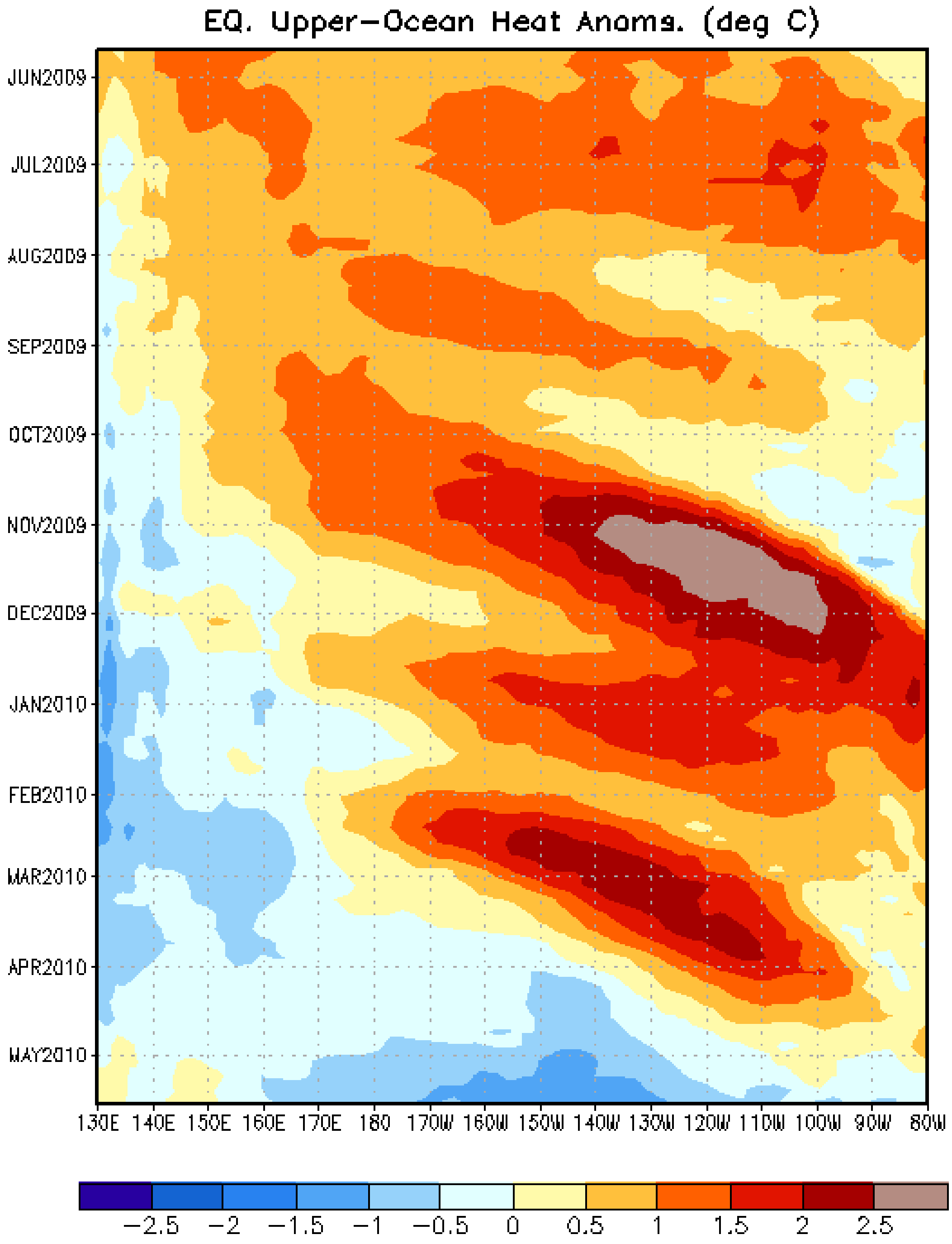


Figure 15: Current equatorial sub-surface upper-ocean (top 300 meters) heat anomaly (°C) pattern in the tropical Pacific.

Based on this information, we believe that the transition to neutral conditions will continue for the next couple of months with weak La Niña conditions likely developing thereafter. El Niños typically increase levels of vertical wind shear in the tropical

Atlantic, causing detrimental conditions for Atlantic tropical cyclone formation and intensification. Since we do not expect El Niño this year, we do not expect to see the high levels of vertical shear across the Main Development Region that we experienced last year.

7 Current Atlantic Basin Conditions

Conditions in the Atlantic remain quite favorable for an active season. SST anomalies across the Main Development Region for May are near their highest levels on record. Figure 16 displays the currently-observed SST anomaly pattern across the Atlantic. Note the very strong positive anomalies throughout the tropical Atlantic and the cool anomalies in the Gulf of Mexico and off the East Coast of the United States. This SST anomaly pattern is characteristic of the negative North Atlantic Oscillation (NAO) index values that have tended to be present over the past several months. A negative NAO is characterized by anomalous high pressure in the northern Atlantic and anomalous low pressure near the Azores High (Figure 17). This pressure gradient pattern causes a reduction in the trade winds across the tropical Atlantic (Figure 18). Reduced trade winds drive less upwelling and evaporation from the sea surface, typically resulting in a warming of SSTs. Warmer Atlantic SSTs in the MDR are associated with an active THC/positive AMO, weaker tropospheric vertical wind shear, weaker trade winds, increased instability and lower-than-normal sea level pressures. All of these conditions are generally associated with much more active Atlantic basin hurricane seasons.

Another parameter that we are currently monitoring is the amount of dust being advected off of the west coast of North Africa from the Sahara. The correlation between May Saharan Air Layer (SAL) dust loadings across the Main Development Region and NTC is -0.40 based on the period from 1982-2008. The dust loadings from the SAL this May have been approximately 0.5 standard deviations above average across the Main Development Region; however, the current outlook for dust across the Main Development Region for the 2010 hurricane season is for average to below-average dust content, another slightly enhancing factor for an active hurricane season (Amato Evan, 2010, personal communication).

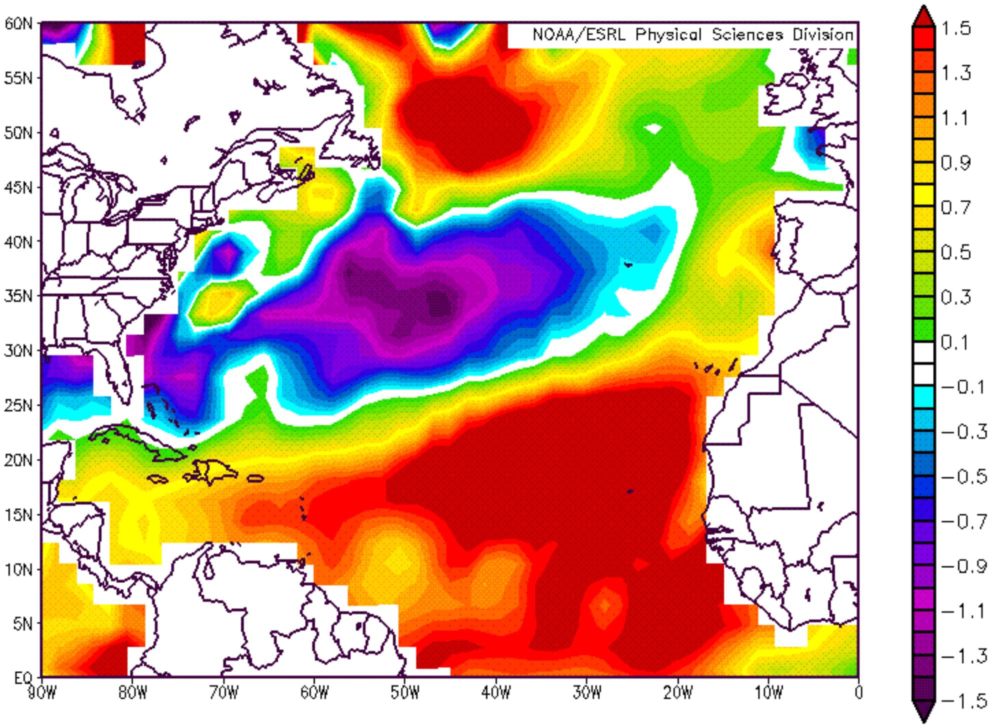


Figure 16: May 2010 SST anomaly (°C) pattern across the Atlantic Ocean.

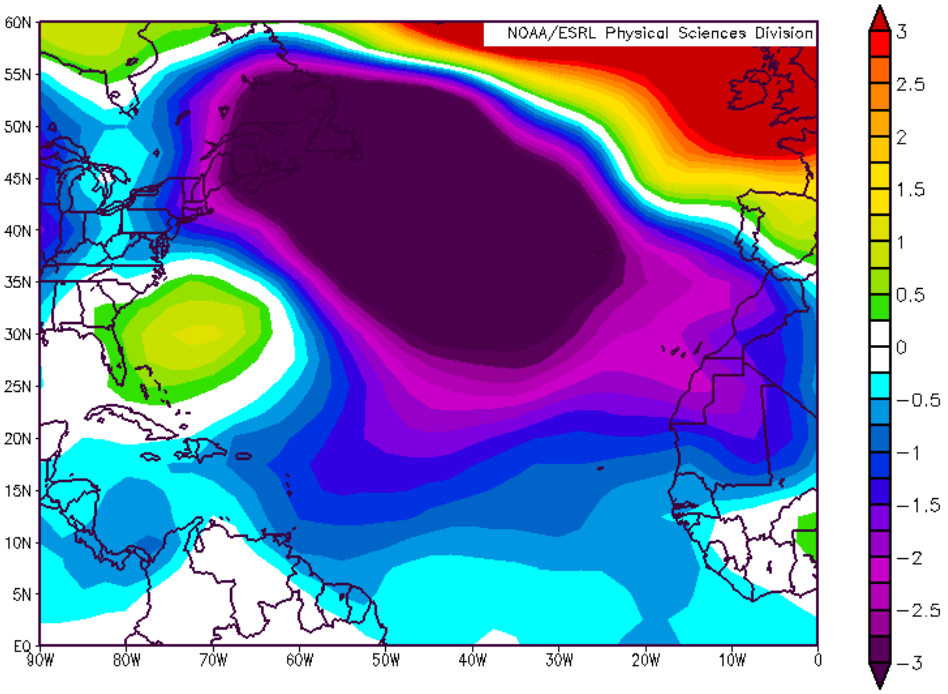


Figure 17: Sea level pressure anomaly (mb) pattern observed during April-May 2010.

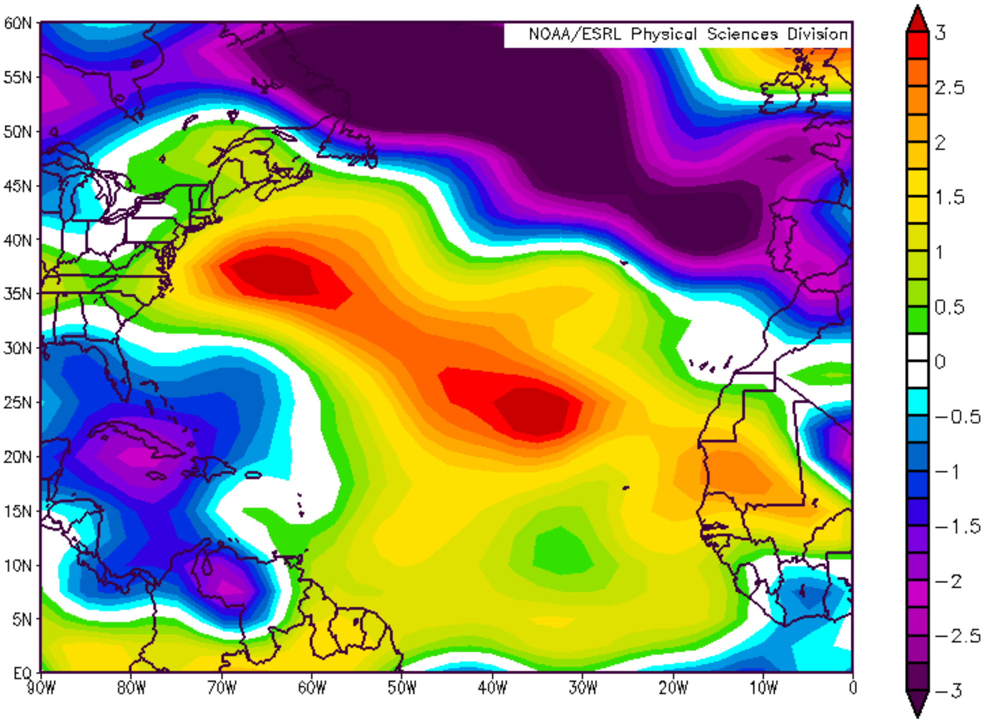


Figure 18: Anomalous low-level wind (ms^{-1}) observed during April-May 2010. Westerly anomalies were observed over the tropical Atlantic, indicating a reduction in the easterly trade winds. Weaker trades typically warm the tropical Atlantic.

8 Adjusted 2010 Forecast

Table 12 shows our final adjusted early June forecast for the 2010 season which is a combination of our statistical scheme, our analog forecast and qualitative adjustments for other factors not explicitly contained in any of these schemes. Our statistical forecast calls for a moderately active season, while our analog forecast indicates activity at well above-average levels. We favor our analog forecast technique with this particular prediction given the rapid cooling in the eastern and central tropical Pacific. We foresee a very active Atlantic basin hurricane season due to currently-observed very favorable conditions in the tropical Atlantic and the recent demise of El Niño.

Table 12: Summary of our early June statistical forecast, our analog forecast and our adjusted final forecast for the 2010 hurricane season.

Forecast Parameter and 1950-2000 Climatology (in parentheses)	Statistical Scheme	Analog Scheme	Adjusted Final Forecast
Named Storms (9.6)	10.5	16.8	18
Named Storm Days (49.1)	52.5	85.6	90
Hurricanes (5.9)	6.2	10.3	10
Hurricane Days (24.5)	25.3	40.4	40
Major Hurricanes (2.3)	2.7	5.0	5
Major Hurricane Days (5.0)	6.5	10.7	13
Accumulated Cyclone Energy Index (96.1)	103	171	185
Net Tropical Cyclone Activity (100%)	112	187	195

9 Landfall Probabilities for 2010

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, statistically, 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 13). 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 13: 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 14 lists strike probabilities for the 2010 hurricane season for different TC categories for the entire U.S. coastline, the Gulf Coast and the East Coast including the Florida peninsula. In our early June forecast of 2009, we initiated landfall probabilities for various islands and landmasses in the Caribbean and in Central America. Note that Atlantic basin NTC activity in 2010 is expected to be above its long-term average of 100, and therefore, landfall probabilities are above 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.

Table 14: 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 2010. 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)	95% (79%)	89% (68%)	76% (52%)	97% (84%)	99% (97%)
Gulf Coast (Regions 1-4)	82% (59%)	66% (42%)	50% (30%)	83% (60%)	97% (83%)
Florida plus East Coast (Regions 5-11)	74% (50%)	68% (44%)	51% (31%)	84% (61%)	96% (81%)
Caribbean (10-20°N, 60-88°W)	97% (82%)	81% (57%)	65% (42%)	93% (75%)	99% (96%)

10 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. In addition, three category 2 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 have been given much media attention; however, we believe that they are not valid, given current observational data.

There has, however, been a large increase in Atlantic basin major hurricane activity since 1995 in comparison with the prior 15-year period of 1980-1994 (Figure 19) and the prior quarter-century period of 1970-1994. It has been tempting for many who do not have a strong background in hurricane knowledge to jump on this recent 15-year increase in major hurricane activity as strong evidence of a human influence on hurricanes. It should be noted, however, that the last 15-year active major hurricane period of 1995-2009 has, however, not been more active than the earlier 15-year period of 1950-1964 when the Atlantic Ocean circulation conditions were similar to what has been observed in the last 15 years. These conditions occurred even though atmospheric CO_2 amounts were lower in the earlier period.

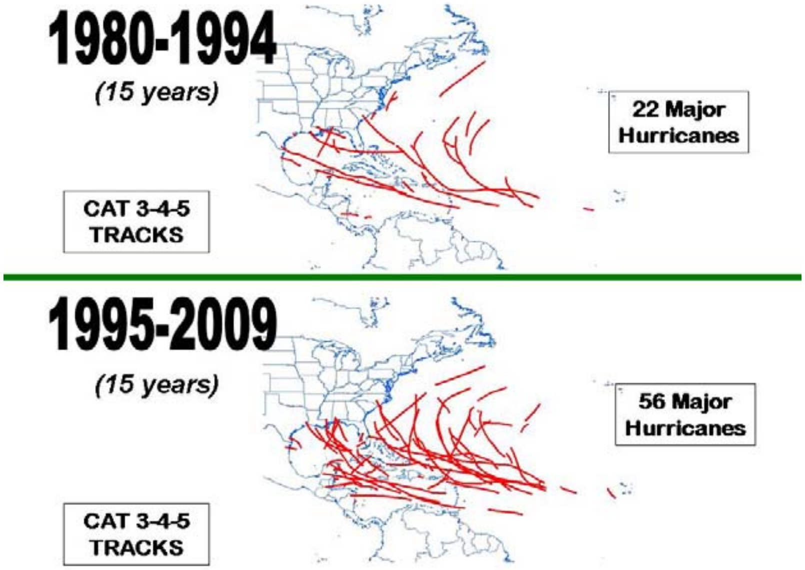


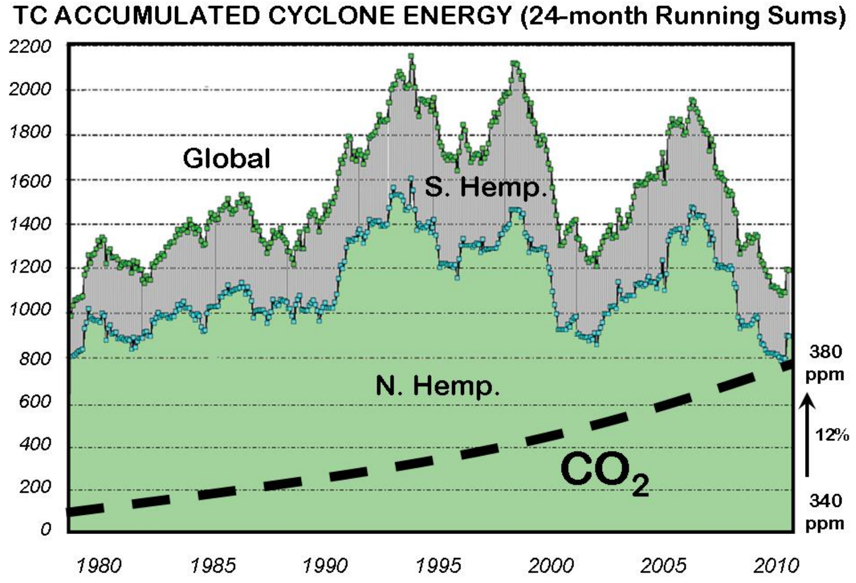
Figure 19: The tracks of major (Category 3-4-5) hurricanes during the 15-year period of 1995-2009 when the Atlantic thermohaline circulation (THC) was strong versus the prior 15-year period of 1980-1994 when the THC was weak. Note that there were more than 2.5 times as many major hurricanes when the THC was strong as when it was weak.

Table 15 shows how large Atlantic basin hurricane variations are between strong and weak THC periods. Note especially how large the ratio is for major hurricane days (3.8) during strong vs. weak THC periods. Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction even though these major hurricanes make up only 20-25 percent of named storms.

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 1979. Global Accumulated Cyclone Energy (ACE) shows significant year-to-year and decadal variability over the past thirty years but no increasing trend (Figure 20). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005.

Table 15: Comparison of Atlantic basin hurricane activity in two 15-year periods when the Atlantic Ocean THC (or AMO) was strong versus an intermediate period (1970-1994) when it was weak.

	THC	SST (10-15°N; 70-40°W)	Avg. CO_2 ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
1950-1964 (15 years)	Strong	27.93	320	9.9	53.6	6.5	30.5	3.8	9.8	122	134
1970-1994 (25 years)	Weak	27.60	345	9.3	41.9	5.0	16.0	1.5	2.5	68	75
1995-2009 (15 years)	Strong	27.97	372	14.5	73.9	7.7	31.9	3.7	9.2	140	151
Year Ratio Strong/Weak THC		Δ 0.35°C	~ 0	1.3	1.5	1.4	1.9	2.5	3.8	1.9	1.9



Adapted from Ryan N. Maue

Figure 20: Northern Hemisphere, Southern Hemisphere, and global ACE over the period from 1979-2009. Figure has been adapted from Ryan Maue, Center for Ocean-Atmospheric Prediction Studies, Florida State University.

Causes of 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 Atlantic Ocean thermohaline circulation (THC) (Figure 21). 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 sea surface temperature anomaly (SSTA) in the North Atlantic (Figure 22) 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 23). 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 Grossman and Klotzbach (2009) for more discussion.

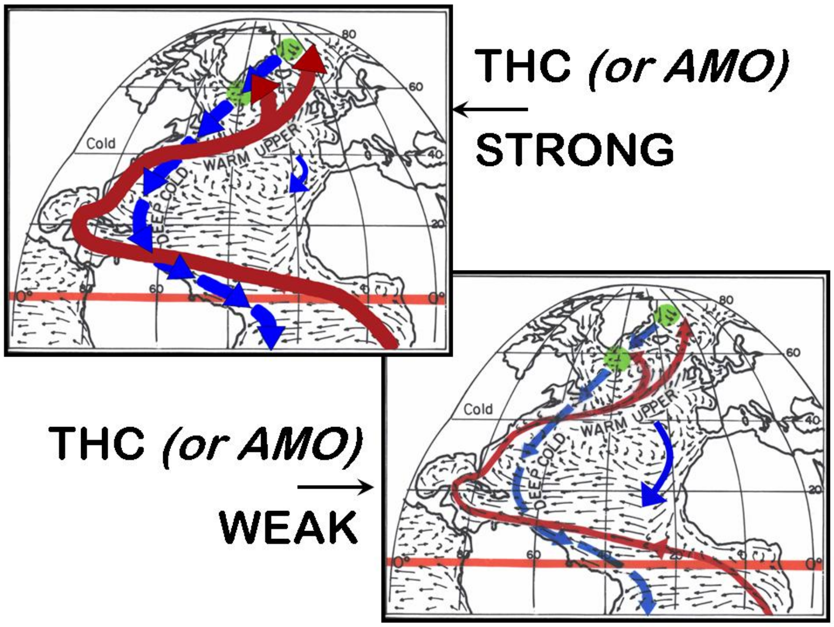


Figure 21: Illustration of strong (top) and weak (bottom) phases of the THC or AMO.

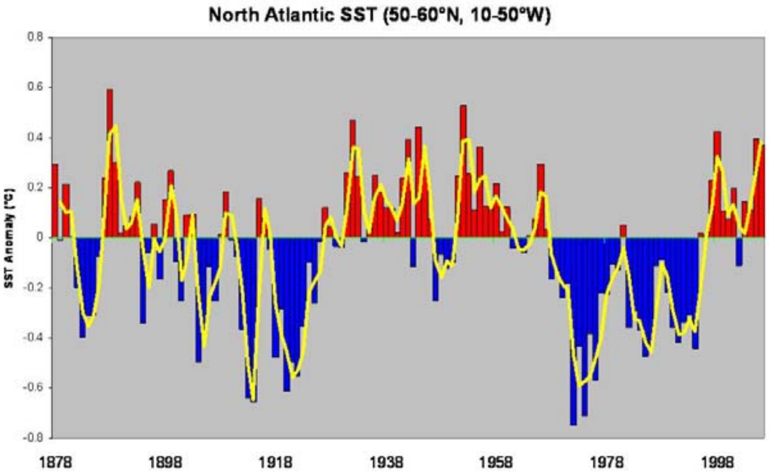


Figure 22: Long-period portrayal (1878-2006) of North Atlantic sea surface temperature anomalies (SSTA). The red (warm) periods are when the THC (or AMO) is stronger than average and the blue periods are when the THC (or AMO) is weaker than average.

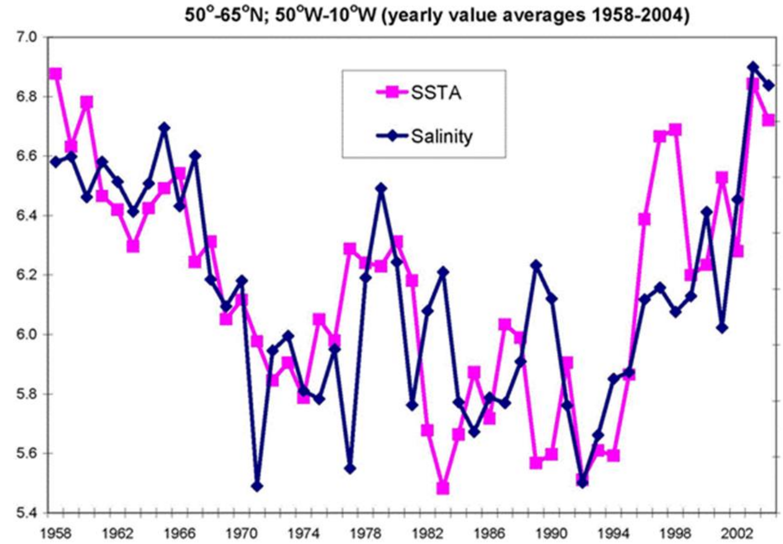


Figure 23: Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.

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 a rapid increase in hurricane intensity. Such observations have led many observers to directly associate SST increases with greater hurricane intensity potential. 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 effected (Figure 24).

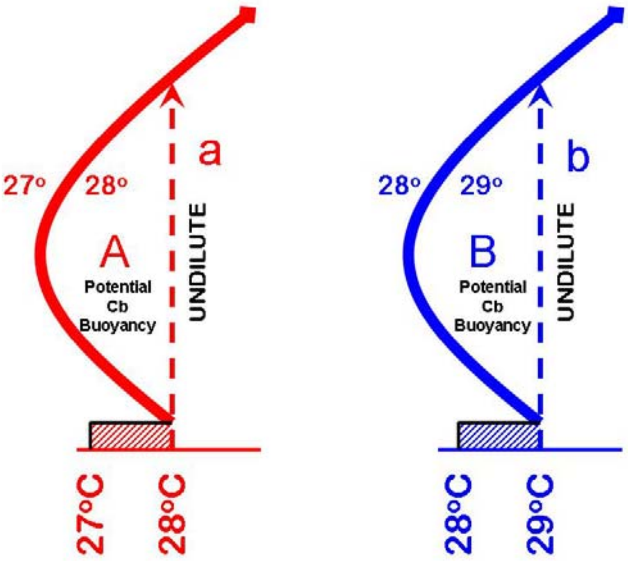


Figure 24: Illustration of how SST increases of 1°C will bring about higher planetary boundary layer (PBL) temperature and moisture increases that will also occur in small amounts throughout the troposphere. The combination of these changes is such that potential buoyancy for cumulonimbus (Cb) development is not much altered by increases in SST alone.

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 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 necessarily have more intense hurricanes due to lapse-rate alterations. We should not expect that the frequency and/or intensity of Category 4-5 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 slightly lower.

CO_2 Influence on Hurricane Activity. We have been performing research with the International Satellite Cloud Climatology Project (ISCCP) and the NOAA National Centers for Environmental Prediction (NCEP) Reanalysis data sets. We have used this data to make an annual average of the global tropical (30°N-30°S; 0-360°) energy budget (Figure 25) for the years from 1984-2004. Note that the various surface and top of the atmosphere energy fluxes are very large. For the tropical surface, for instance, there are 637 Wm^{-2} units of downward incoming solar and infrared (IR) energy. This downward energy flux is largely balanced by an upward surface energy flux of 615 Wm^{-2} which is due to upward fluxes from IR radiation, evaporated liquid water, and sensible heat. Similar large energy fluxes are present at the top of the atmosphere and within the troposphere.

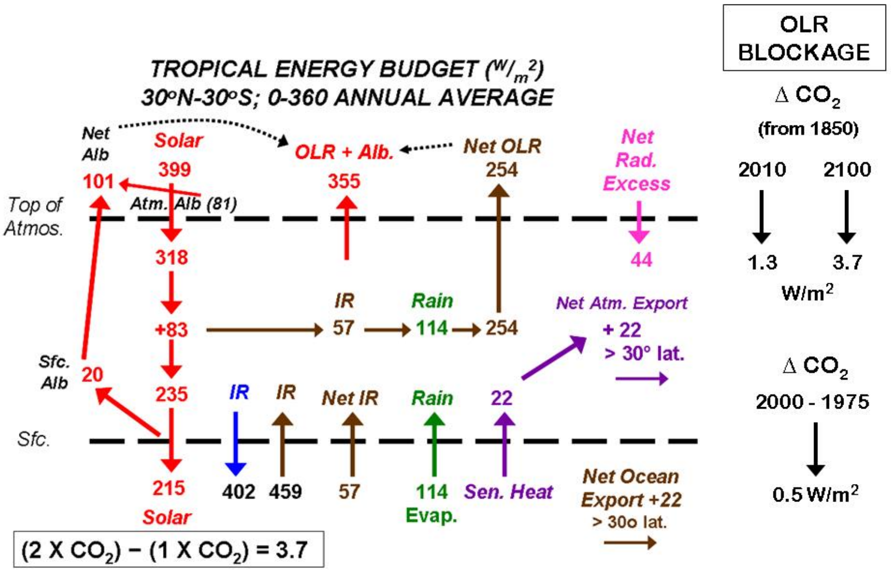


Figure 25: Vertical cross-section of the annual tropical energy budget as determined from a combination of ISCCP and NCEP Reanalysis data over the period of 1984-2004. Abbreviations are **IR** for longwave infrared radiation, **Alb** for albedo and **OLR** for outgoing longwave radiation. The tropics receive an excess of about 44 Wm^{-2} radiation energy which is convected and exported as sensible heat to latitudes poleward of 30°. Estimates are about half (22 Wm^{-2}) of this excess is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small an OLR blockage has occurred up to now due to CO_2 increases (~ 1.3 Wm^{-2}) and the blockage of 3.7 Wm^{-2} that will occur from a doubling of CO_2 by the end of this century.

It has been estimated that a doubling of CO_2 (from the pre-industrial period) without any feedback influences would result in a blockage of OLR to space of about 3.7 Wm^{-2}. The currently-measured value of CO_2 in the atmosphere is 380 parts per million by volume (ppmv). If we take the background pre-industrial value of CO_2 to be 280 ppmv, then by theory we should currently be having (from CO_2 increases alone) about $(100/280)*3.7 = 1.3$ Wm^{-2} less OLR energy flux to space than was occurring in the mid-19th century.

This reduced OLR of 1.3 Wm^{-2} is very small in comparison with most of the other tropical energy budget exchanges. Slight changes in any of these other larger tropical energy budget components could easily negate or reverse this small CO_2-induced OLR blockage. For instance, an upper tropospheric warming of about 1°C with no change in moisture would enhance OLR sufficiently that it would balance the reduced OLR influence from a doubling of CO_2. Similarly, if there were a reduction of upper level water vapor such that the long wave radiation emission level to space were lowered about

7 mb (~ 140 m) there would be an enhancement of OLR (with no change of temperature) sufficient to balance the suppression of OLR from a doubling of CO_2. The 1.3 Wm^{-2} reduction in OLR we have experienced since the mid-19th century (about one-third of the way to a doubling of CO_2) is very small compared with the overall 399 Wm^{-2} of solar energy impinging on the top of the tropical atmosphere and the mostly compensating 356 Wm^{-2} of OLR and albedo energy going back to space. This 1.3 Wm^{-2} energy gain is much too small to ever allow a determination of its possible influence on TC activity. Any such potential CO_2 influence on TC activity is deeply buried as turbulence within the tropical atmospheres' many other energy components. It is possible that future higher atmospheric CO_2 levels may cause a small influence on global TC activity. But any such potential influence would likely never be able to be detected, given that our current measurement capabilities only allow us to assess TC intensity to within about 5 mph.

C. CONTRAST OF THEORIES OF HURRICANE ACTIVITY CHANGES

Theory of Human-Induced Increases due to Rising CO_2 Levels. Those who think CO_2 increases have and will cause significant increases in hurricane activity believe that the physics of the CO_2-hurricane association is directly related to radiation changes as indicated in Figure 26. They view CO_2 as blocking OLR to space. This acts to warm SSTs and add moisture to the boundary layer just above the ocean surface. These changes cause an increase in lapse rates (the lower levels warm while upper levels do not change much) which lead to more deep cumulonimbus convection (Cb). More Cb convection leads to a higher percentage of tropical disturbances forming into tropical cyclones and a greater spin-up of the inner-core of those systems which do form.

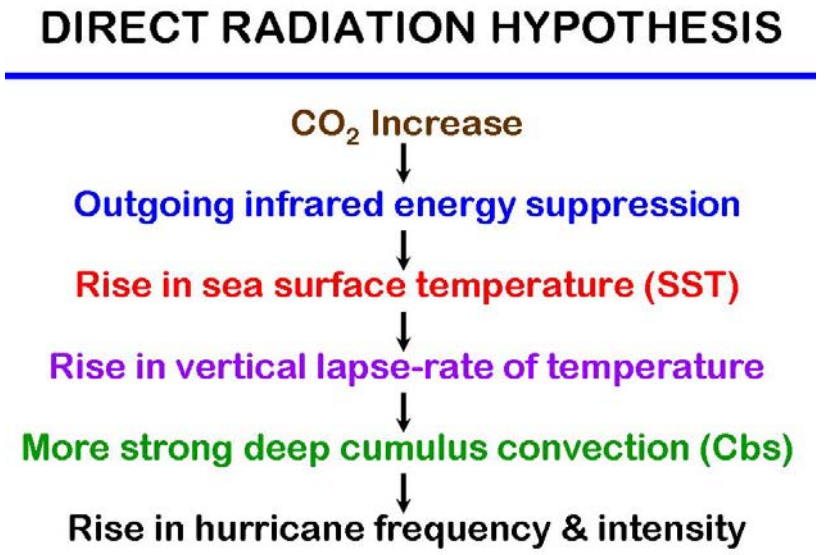


Figure 26: Physical linkage of those who believe that increases in CO_2 are making hurricanes more frequent and/or more intense.

This physical argument is too simplistic. It has no empirical verification in any other global TC basin except for the Atlantic. Table 16 shows the correlation of ACE with late summer-early fall SSTs in the Northeast Pacific, the Northwest Pacific and the Southern Hemisphere. Note the low (or even negative) correlations between ACE and SST in each of these three TC basins. It is obvious that other physical processes besides SST are primarily responsible for differences in hurricane activity in these basins.

Table 16: Correlation of ACE with late summer-early fall SSTs in three TC basins from 1980-2009.

	Yearly Mean ACE	**ACE vs. SST Correlation (r)**
Northeast Pacific	134	0.01
Northwest Pacific	310	-0.30
Southern Hemisphere	205	0.23
Globe (SST 20°N-20°S)	769	-0.08

<u>Theory of the THC (or AMO)</u>. We do not view seasonal hurricane variability in the Atlantic as being directly related to changes in CO_2-induced radiation forcing or to SST changes by themselves. For the Atlantic, we view long-period tropical cyclone variability primarily as a result of changes in the strength of the THC (or AMO). We hypothesize that these changes act as shown in Figure 27 and as discussed in the previous section. THC changes result in altering tropospheric vertical wind shear, trade wind strength, and SSTs in the Main Development Region (MDR) of 10-20°N; 20-70°W in the tropical Atlantic. A large component of the SST increase in this area is not a direct result of radiation differences but rather the combination of the effects of reduced southward advection of colder water in the east Atlantic and reduced trade wind strength. Weaker trade winds reduce upwelling and evaporation and typically act to increase SST.

The influence of the warmer Atlantic SST, as previously discussed, is not primarily to enhance lapse rates and Cb convection but rather as a net overall positive influence on lowering the MDR's surface pressure and elevating mean upward tropospheric vertical motion. This causes an increase in tropospheric moisture content.

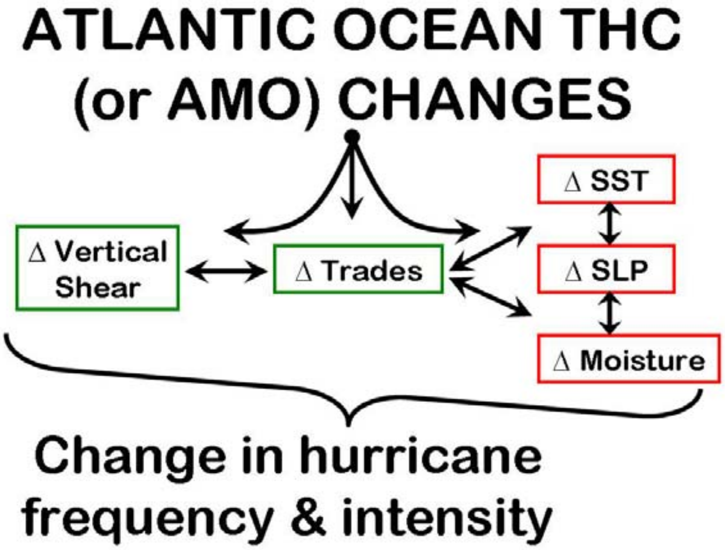


Figure 27: Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic's MDR. Vertical shear, trade wind strength and SST are the key parameters which respond to THC changes. Favorable SLP and mid-level moisture changes occur in association with the shear, trade wind and SST changes.

D. DISCUSSION

In a global warming or global cooling world, the atmosphere's upper air temperatures will warm or cool in unison with the SSTs. Vertical lapse rates will not be significantly altered. 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 28). Atlantic SSTs and hurricane activity do not follow global mean temperature trends.

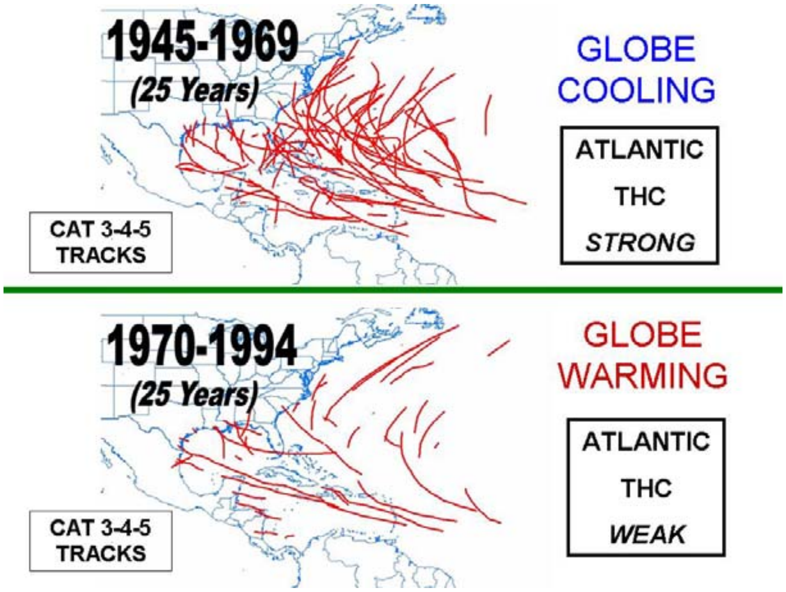


Figure 28: Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming. CO_2 amounts in the later period were approximately 18 percent higher than in the earlier period. Major Atlantic hurricane activity was only about one-third 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 17). Although global mean ocean and Atlantic SSTs have increased by about 0.4°C between these two 55-year periods (1900-1954 compared with 1955-2009), 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 44-year period of 1922-1965 (24 landfall events) and the 44-year period of 1966-2009 (7 landfall events) was especially large (Figure 29). For the entire United States coastline, 38 major hurricanes made landfall during the earlier 44-year period (1922-1965) compared with only 26 major hurricanes for the latter 44-year period (1966-2009). 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 17: U.S. landfalling tropical cyclones by intensity during two 55-year periods.

YEARS	*Named Storms*	*Hurricanes*	*Major Hurricanes (Cat 3-4-5)*	*Global Temperature Increase*
1900-1954 (55 years)	208	113	44	+0.4°C
1955-2009 (55 years)	184	90	36	

We should not read too much into the three very active hurricane seasons of 2004, 2005, and 2008. 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.

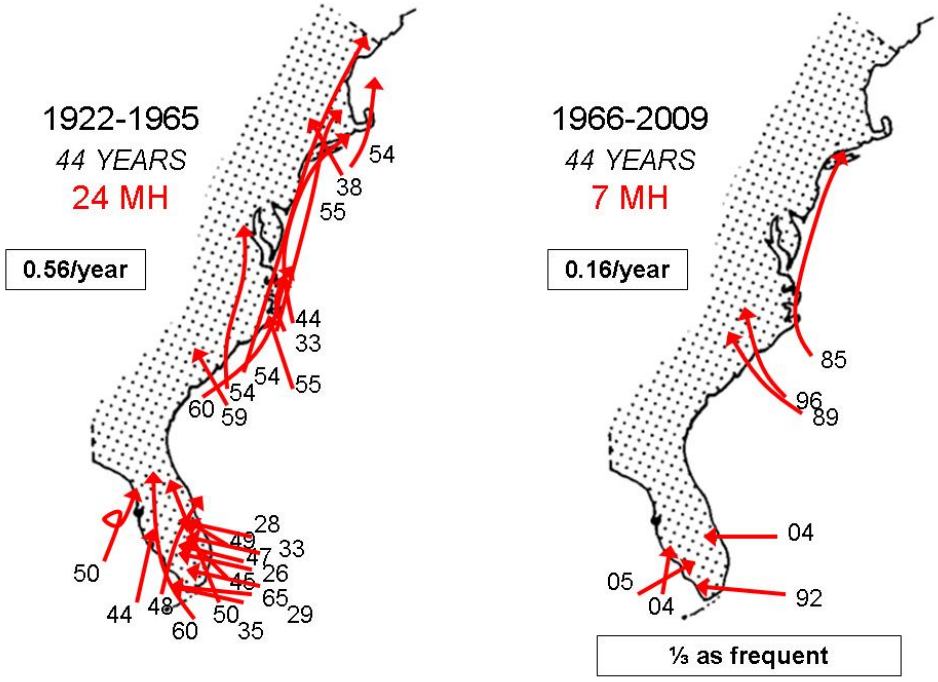


Figure 29: Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 44-year period of 1922-1965 versus the most recent 44-year period of 1966-2009.

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 21 named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 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) – the same number as was observed to occur 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 thousand of years. These changes are natural and have nothing to do with human activity.

11 Forthcoming Updated Forecasts of 2010 Hurricane Activity

We will be issuing a seasonal update of our 2010 Atlantic basin hurricane forecast on **Wednesday 4 August**. We will also be issuing two-week forecasts for Atlantic TC activity during the climatological peak of the season from August-October. A verification and discussion of all 2010 forecasts will be issued in late November 2010. Our first seasonal hurricane forecast for the 2011 hurricane season will be issued in early December 2010. 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 and Ethan Gibney. 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, and Max Mayfield, former directors of the National Hurricane Center (NHC) as well as Bill Read, current director of the NHC. Uma Shama, Larry Harman and Daniel Fitch of Bridgewater State College, MA have provided assistance and technical support in the development of our Landfalling Hurricane Probability Webpage.

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14 Verification of Previous Forecasts

Table 18: Summary verification of the authors' six previous years of seasonal forecasts for Atlantic TC activity between 2004-2009.

		Update	Update	Update	
2004	5 Dec. 2003	2 April	28 May	6 August	Obs.
Named Storms	13	14	14	13	15
Named Storm Days	55	60	60	55	93
Hurricanes	7	8	8	7	9
Hurricane Days	30	35	35	30	45.50
Major Hurricanes	3	3	3	3	6
Major Hurricane Days	6	8	8	6	22.25
Net Tropical Cyclone Activity	125	145	145	125	232

		Update	Update	Update	
2005	3 Dec. 2004	1 April	31 May	5 August	Obs.
Named Storms	11	13	15	20	28
Named Storm Days	55	65	75	95	131.50
Hurricanes	6	7	8	10	15
Hurricane Days	25	35	45	55	49.75
Major Hurricanes	3	3	4	6	7
Major Hurricane Days	6	7	11	18	17.75
Net Tropical Cyclone Activity	115	135	170	235	279

		Update	Update	Update	
2006	6 Dec. 2005	4 April	31 May	3 August	Obs.
Named Storms	17	17	17	15	10
Named Storm Days	85	85	85	75	52.75
Hurricanes	9	9	9	7	5
Hurricane Days	45	45	45	35	21.25
Major Hurricanes	5	5	5	3	2
Major Hurricane Days	13	13	13	8	2
Net Tropical Cyclone Activity	195	195	195	140	85

		Update	Update	Update	
2007	8 Dec. 2006	3 April	31 May	3 August	Obs.
Named Storms	14	17	17	15	15
Named Storm Days	70	85	85	75	37.75
Hurricanes	7	9	9	8	6
Hurricane Days	35	40	40	35	12.25
Major Hurricanes	3	5	5	4	2
Major Hurricane Days	8	11	11	10	6
Net Tropical Cyclone Activity	140	185	185	160	99

		Update	Update	Update	
2008	7 Dec. 2007	9 April	3 June	5 August	Obs.
Named Storms	13	15	15	17	16
Named Storm Days	60	80	80	90	88.25
Hurricanes	7	8	8	9	8
Hurricane Days	30	40	40	45	30.50
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

		Update	Update	Update	
2009	10 Dec. 2008	9 April	2 June	4 August	Obs.
Named Storms	14	12	11	10	9
Named Storm Days	70	55	50	45	30
Hurricanes	7	6	5	4	3
Hurricane Days	30	25	20	18	12
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