UPDATED FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND US LANDFALL STRIKE PROBABILITIES FOR 2002

A continued upturn of the recent six (1995-96-98-99-00-01) busy hurricane seasons is expected.
Above average probability of US landfall is forecast.

This forecast is based on ongoing research by the authors along with meteorological information through March 2002

By
William M. Gray[1], Christopher W. Landsea[2],
Eric Blake[3] and Philip Klotzbach[4]

with advice and assistance from William Thorson[5] and Jason Connor[6]

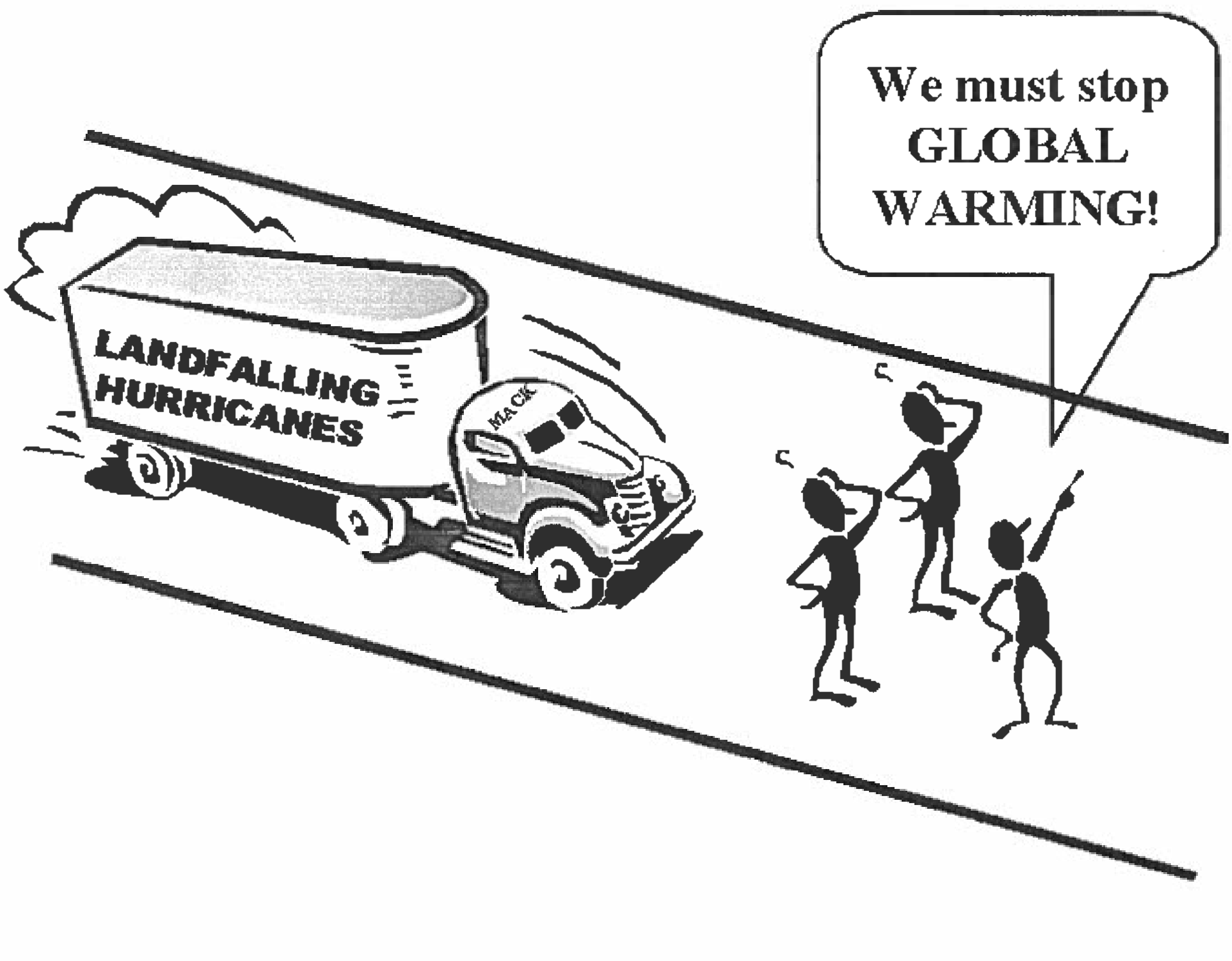
[Both this and prior forecasts are available at the following World Wide Web address: http://tropical.atmos.colostate.edu/forecasts/index.html] — also you may contact:

Brad Bohlander and Thomas Milligan, Colorado State University media representatives who are available to answer various questions about this forecast (970-491-6432).

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523
Phone Number: 970-491-8681

5 April 2002

[1]Professor, Department of Atmospheric Science
[2]Meteorologist with NOAA/AOML HRD Lab., Miami, FL; former project member
[3]Meteorologist with NOAA/TPC, National Hurricane Center, Miami, FL; former project member
[4]Graduate Student, Department of Atmospheric Science
[5]Research Associate
[6]Research Associate


We must stop GLOBAL WARMING!
LANDFALLING HURRICANES
MACK

2002 ATLANTIC BASIN SEASONAL HURRICANE FORECAST

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 December 2001 Forecast for 2002	Updated 7 April 2002 Forecast
Named Storms (NS) (9.6)	13	12
Named Storm Days (NSD) (49.1)	70	65
Hurricanes (H)(5.9)	8	7
Hurricane Days (HD)(24.5)	35	30
Intense Hurricanes (IH) (2.3)	4	3
Intense Hurricane Days (IHD)(5.0)	7	6
Hurricane Destruction Potential (HDP) (72.7)	90	85
Net Tropical Cyclone Activity (NTC)(100%)	140	125

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

1) Entire U.S. coastline – 75% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida – 57% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville – 43% (average for last century is 30%)

4) Expected above-average major hurricane landfall risk in the Caribbean

DEFINITIONS

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

El Niño - (EN) 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 or so 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 estimated to have hurricane intensity winds.

Hurricane Destruction Potential - (HDP) A measure of a hurricane's potential for wind and storm surge destruction defined as the sum of the square of a hurricane's maximum wind speed (in 10^4 knots^2) for each 6-hour period of its existence.

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

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

MATL - Sea surface temperature anomaly in the sub-tropical Atlantic between 30-50°N, 10-30°W

MPD - Maximum Potential Destruction - A measure of the net maximum destruction potential during the season compiled as the sum of the square of the maximum wind observed (in knots) for each named storm. Values expressed in 10^3 kt.

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

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

NATL - Sea surface temperature anomaly in the Atlantic between 50-60°N, 10-50°W

NTC - Net Tropical Cyclone Activity - Average seasonal percentage mean of NS, NSD, H, HD, IH, IHD. Gives overall indication of Atlantic basin seasonal hurricane activity (see Appendix B).

ONR - previous year October-November SLPA of subtropical Ridge in eastern Atlantic between 20-30°W.

QBO - Quasi-Biennial Oscillation - A stratospheric (16 to 35 km altitude) oscillation of equatorial east-west winds which vary with a period of about 26 to 30 months or roughly 2 years; typically blowing for 12-16 months from the east, then reverse and blowing 12-16 months from the west, then back to easterly again.

Saffir/Simpson (S-S) Category - A measurement scale ranging from 1 to 5 of hurricane wind and ocean surge intensity. One is a weak hurricane whereas 5 is the most intense hurricane.

SLPA - Sea Level Pressure Anomaly - The deviation of Caribbean and Gulf of Mexico sea level pressure from observed long term average conditions.

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

SST(s) - Sea Surface Temperature(s).

SSTA(s) - Sea Surface Temperature(s) Anomalies.

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 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.

TATL - Sea surface temperature anomaly in the Atlantic between 8-22°N, 10-50°W.

ZWA - Zonal Wind Anomaly - A measure of upper level ($\sim$ 200 mb) west to east wind strength. Positive anomaly values mean winds are stronger from the west or weaker from the east than normal.

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

ABSTRACT

Information obtained through March 2002 indicates that the 2002 Atlantic basin seasonal hurricane activity will, as with six of the last seven hurricane seasons, be above average. Though predictive signals from around the globe are mixed, most favor a continuation of above average hurricane activity. We believe we will have a warm Atlantic and favorable stratospheric winds are assured. The primary potential suppressing influence for this year's hurricane activity is the further intensification of a weak El Niño. The predicted intensity of this El Niño event is likely to diminish this year's hurricane activity but not nearly to the extent of the more powerful 1997, 1986-87, and 1982-83 El Niño events. We are lowering our 7 December 2001 forecast for 2002 by one storm. Most of our other TC predictors are still in line with an above-average hurricane season. We estimate that 2002 will have 12 named storms (average is 9.6), 65 named storm days (average is 49.1), 7 hurricanes (average is 5.9), 30 hurricane days (average is 24.5), 3 intense (category 3-4-5) hurricanes (average is 2.3), 6 intense hurricane days (average is 5.0), a Hurricane Destruction Potential (HDP) of 85 (average is 72.7) and overall Net Tropical Cyclone (NTC) activity of 125 percent of the average year for the period between 1950–2000. U.S. landfall probability is forecast to be above the long-term average owing to the combined effects of above-average NTC activity and the anticipated continuation of an above-average Atlantic Ocean thermohaline circulation and warm Atlantic sea surface temperatures.

1 Introduction

Our evolving forecast techniques are based on a variety of global and regional predictors previously shown to be related to forthcoming seasonal Atlantic tropical cyclone activity and landfall probability. This paper presents details of our observations as well as the rationale for this extended range forecast of the 2002 Atlantic hurricane season. This forecast is based on both statistical and analog analyses of prior hurricane seasons which had atmospheric and oceanic conditions similar to what we anticipate to be in place during the 2002 hurricane season. Summaries of our three most recent seasonal hurricane activity forecasts are presented in the Appendix.

Useful long-range predictive signals exist for seasonal tropical cyclone activity in the Atlantic basin. Our research has shown that a sizeable portion of the season-to-season variability of Atlantic tropical cyclone activity can be forecast with skill exceeding that of the climatological average by early December of the prior year with increasing forecast skill by early April, early June and early August. Qualitative adjustments are added to accommodate additional processes which are not incorporated into our statistical models. Two influences which will largely determine the trend in this year's Atlantic hurricane activity are:

1. The status of El Niño-Southern Oscillation (ENSO).
2. The configuration of Atlantic Sea Surface Temperature Anomaly (SSTA) conditions which provide a proxy signal for the strength of the Atlantic Ocean thermohaline circulation.

Presently, a weak to moderate El Niño event is likely for the summer of 2002. We anticipate that this ENSO warming will act as a modest inhibiting influence on 2002 activity whereas North Atlantic SSTA patterns are expected to continue to be an enhancing influence on hurricane activity as they have been during the last seven years. Other meteorological factors anticipated to influence 2002 hurricane activity include the following:

3. The phase of the stratospheric Quasi-Biennial Oscillation (QBO) of zonal winds at 30 mb and 50 mb (which can be extrapolated six months into the future). These winds will be in the favorable westerly mode for this year.

4. Two measures of West African rainfall during the prior year (Figs. 1a and 1b). These have been quite dry and hence are not considered favorable for an active hurricane season. However, the forecast utility of these parameters has been of little value in recent years.

5. The strength of the Azores high surface pressure anomaly in March of this year and October-November of last year and the configuration of current and forecast future broad scale Atlantic sea surface pressure (see Fig. 1c). Ridge values are presently neutral.

6. A forecast of the Caribbean and western tropical Atlantic Sea Level Pressure Anomaly (SLPA) for the months of August through October. Our predictions indicate below average SLPA which is indicative of an active hurricane season.

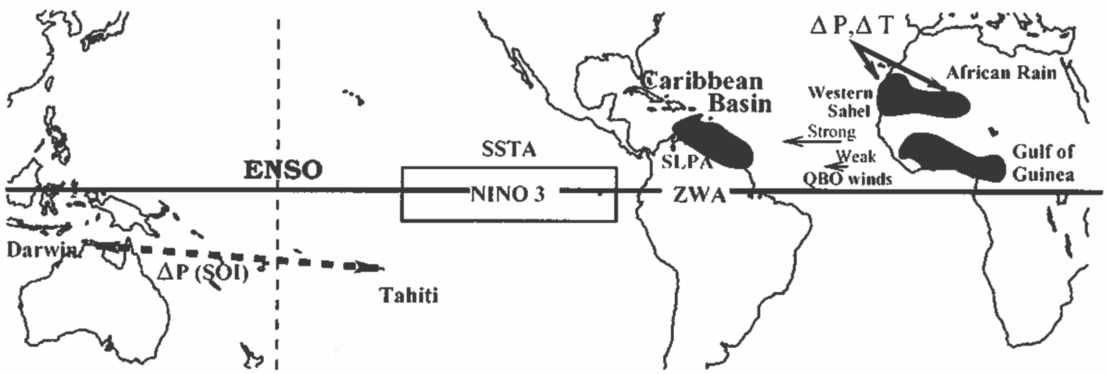


Figure 1: a: Meteorological parameters used in various versions of our older early August (Gray et al. 1994a) seasonal forecast.

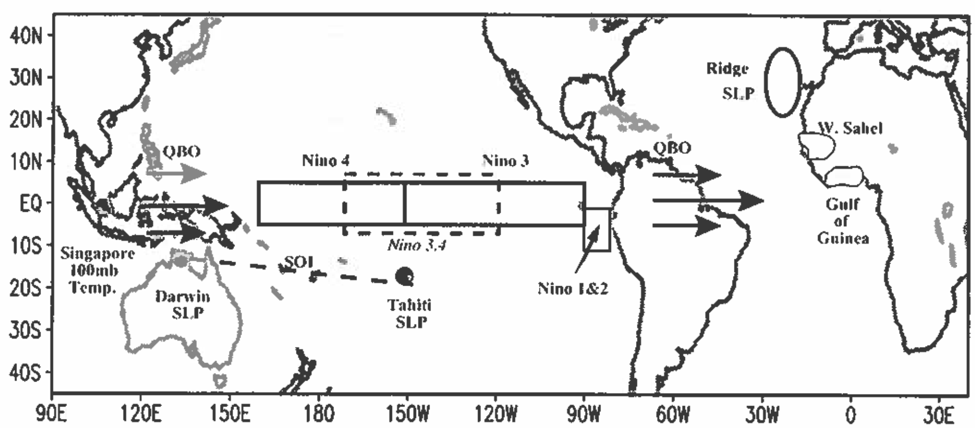


Figure 1: b: Additional parameters used or consulted in our extended-range forecasts.

Likely El Niño Conditions for 2002. ENSO is one of the principal global-scale environmental factors affecting Atlantic seasonal hurricane activity. Hurricane activity is usually suppressed during El Niño events (e.g., 1997). Conversely, activity tends to be enhanced during seasons with cold (or La Niña) water conditions (i.e., 1998–2000). We expect that this hurricane season will experience a weak to moderate El Niño event. This will likely be a modest suppressing influence on 2002 hurricane activity but is not expected to be a major inhibiting influence as were the very strong El

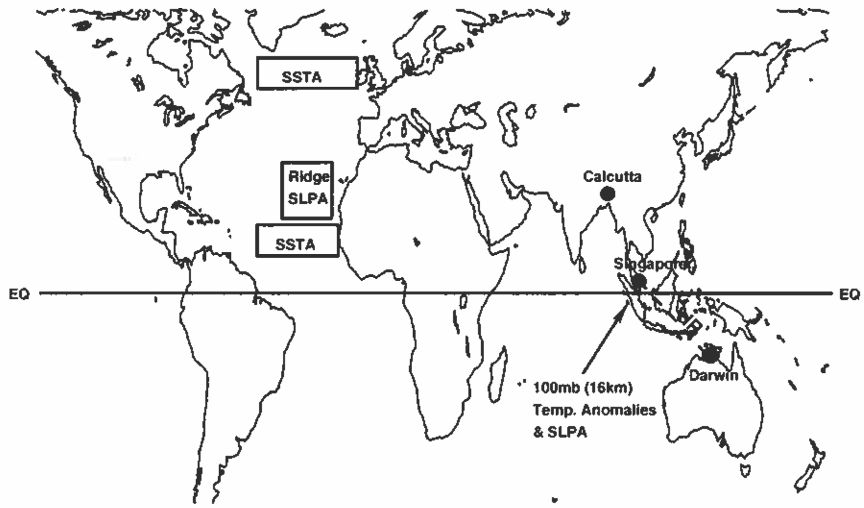


Figure 1: c: Additional (new) predictors which have recently been noted to be related to the upcoming Atlantic hurricane activity.

Niño events during either 1997 or the events during 1986-87, 1982-83, and 1972 when the Atlantic thermohaline circulation was weak. Rather, we anticipate the El Niño characteristics during 2002 will be more typical of the weaker Nino events of the 1950s and 1960s (i.e., 1951-53-57-63-65-69). El Niños also tend to be weaker when a westerly QBO is present and when the Pacific Decadal Oscillation (PDO) is negative, as it is now. Moreover, although ENSO conditions can be the single most important parameter dictating Atlantic seasonal hurricane variability when large warm or cold events occur, other properties of the atmosphere and ocean can be preeminent in years with weak to moderate El Niño or La Niña conditions.

2 Prediction Methodology

In certain climatological contexts, the atmosphere and oceans function as one unit. Current circulation features have considerable precursor information for the coming month's or seasons's amount of hurricane activity. We forecast nine measures of seasonal Atlantic basin tropical cyclone activity including Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), Hurricane Destruction Potential (HDP), Net Tropical Cyclone Activity (NTC), and Maximum Potential Destruction (MPD). (Definitions for these indices are given on page 3). For each of these measures of activity, we choose the three to six best predictors (i.e., those resulting in optimum prediction skill) from a group of 13 possible forecast parameters which are known to be related to tropical cyclone activity.

We search for global atmospheric and oceanic individual parameters or groups of parameters which, in the past, have shown significant associations with 'active' versus 'inactive' hurricane seasons at various time lags. A variety of statistical tests and numerical manipulations are needed to optimize the best combination of these precursor signals as determined from the analysis of past data sets. Assuming that the atmosphere will behave in the future as it has in past years, hindcast skill developed on past years of data should be applicable to future years.

3 Recent Advancements in the Potential for Improved Empirical Climate Prediction

The last few years have seen tremendous growth in the accessibility of global atmospheric data on the Internet. An example of this accessibility is the NOAA/NCEP reanalysis which archives historical atmospheric and ocean surface data and makes this data easily available on the Internet. Other countries or international groups are also developing similar reanalysis programs. These reanalysis data sets are available from the late 1940s and offer exciting and unique new opportunities for the development of new and skillful extended range empirical climate forecast schemes. This development is very useful for the improvement of both empirical climate prediction and understanding.

4 Initial 1 April Statistical Forecast Scheme

Our first 1 April hurricane forecast scheme was developed in 1994, and the initial 1 April forecast was made in 1995. The current set of potential predictors for this year's 1 April forecast is shown in Table 1. The statistical skill of this forecast in hindcast data is summarized in Table 2 with the specific number of predictors used for each seasonal forecast parameter given in parentheses. We attempt to minimize the skill degradation (i.e., limit statistical "overfitting") of these equations when making independent forecasts by optimizing the least number of predictors for the highest amount of hindcast skill. We stop adding predictors when the hindcast improvement does not significantly improve the total explained variance.

Table 1: Pool of predictors (and their values as of 1 April 2002) used to develop the 2002 prediction based from meteorological data available through March 2002. See Figs. 1a-c for the locations of these predictors.

For 1 April 2002 Prediction (see Figs. 1a-c for location)	Specific 1 April Fcst Parameters
1) U50 (Mar extrapolated to Sep) – Actual	0 m/s
2) U30 (Mar extrapolated to Sep) Actual	–4 m/s
3) AbsShe - absolute shear (Mar extrapolated to Sep)	4 m/s
4) Balboa - U50 (June-Aug, 2000)	–19.0 m/s
5) Rain - Aug-Nov Guinea Coastal Area	–1.25 SD
6) Rain - Aug-Sep West Sahel Area	–1.25 SD
7) R-ON - Ridge SLPA (Oct to Nov)	+0.15 SD
8) R-M - Ridge SLPA (Mar)	+0.25 SD
9) NATL (Jan to Mar) SSTA (50-60°N, 10-50°W)	+0.6°C
10) TATL (Jan to Mar) SSTA (8-22°N, 10-50°W)	+0.9°C
11) Nino 3.4 Mar SSTA	+0.2°C
12) Nino 3.4 (Mar minus Feb) SSTA	+0.0°C
13) Nino 4 (Jan, Feb, Mar minus Oct, Nov, Dec) SSTA	+0.2°C

We have also studied schemes which use various numbers of predictors. This procedure investigates how hindcast variance (not necessarily true skill) increases as the number of predictors increases from 4 to 6. Although independent forecast skill (i.e., "true skill") typically degrades in approximate proportion to the increased number of predictors, it is of interest to determine the degree of hindcast "improvement" which occurs with added predictors. Individual year forecast skill degradation from application of hindcast statistics can never be accurately specified. Additional

Table 2: Hindcast (i.e., regression testing on data for past years) statistical predictor skill (measure of agreement or r^2) of our separate 1 April hindcasts for 1950-1997. Column (a) gives our best prediction with the minimum number of predictors shown in parentheses. Columns (b) and (c) give our hindcast skill obtained with the best 4 and 6 predictors, respectively.

		Fixed Number of predictors	
	Variable Predictors	4	6
	(a)	(b)	(c)
N	.531 (4)	.531	.569
NSD	.541 (5)	.489	.559
H	.459 (4)	.459	.506
HD	.505 (5)	.460	.517
IH	.510 (4)	.520	.552
IHD	.362 (3)	.378	.465
HDP	.504 (5)	.455	.518
NTC	.566 (6)	.490	.573
MPD	.613 (5)	.573	.630

forecast parameters representing conditions in the Atlantic and Pacific Ocean basins and in the Asia-Australia regions (Figs. 1a-c) are also consulted for further qualitative perspective and for our final "adjusted" forecast.

Forecast signals for 2002 for this first 1 April statistical scheme contain a mix of positive and negative influences. Of the 13 potential predictors listed in Table 1, six indicate above-average hurricane activity, two are negative and five are neutral. However, we believe the positive regional Atlantic factors largely associated with the stronger Atlantic thermohaline circulation more than balance the negative parameters, leading to the prospect of a slightly above-average hurricane season for 2002.

Table 3: April statistical forecasts for 2002. These forecasts include one forecast obtained with a variable number of predictors (column 1) and two other forecasts with 4 and 6 fixed predictors (columns 2 and 3). Column 4 gives climatology.

	(1)	(2)	(3)	(4)
Full		Fixed predictors		
Forecast	Variable	4	6	1950-2000
Parameter	Predictor	Predictors	Predictors	Climatology
Named Storms (NS)	10.7 (4)	10.7	12.7	9.6
Named Storm Days (NSD)	74.4 (5)	72.2	76.3	49.1
Hurricanes (H)	5.3 (4)	5.3	5.4	5.9
Hurricane Days (HD)	9.4 (5)	8.6	18.3	24.5
Intense Hurricanes (IH)	2.1 (4)	2.4	2.3	2.3
Intense Hurricane Days (IHD)	3.2 (3)	3.6	1.7	5.0
Hurricane Destruction Potential (HDP)				72.7
Net Tropical Cyclone Activity (NTC) - constructed from first six parameter forecasts	88.0 (6)	93.2	97.8	100

Table 3 lists our April statistical predictions for the 2002 hurricane season. These include variable (column 1) and fixed predictors (columns 2 and 3) in comparison with climatological values shown in column 4. Since the observed shift of Atlantic Ocean SST in 1995, our statistical forecasts have rather consistently underpredicted Atlantic basin hurricane activity.

On average, a net degradation of hindcast skill of between 5-15 percent of the variance is to be expected. Degradation (if any) for an individual forecast is a random process, however. In some years when conditions include consistent strong trends in predictor signals, forecasts tend to do quite well while in other years with weak and mixed signals, a given forecast can perform quite poorly. Typically, the latter tend to be due to our limited (47-year; 1950-1996) database of predictors which likely does not yet contain realizations of the full range of independent possibilities. Our 1997 forecast is a good example of this problem. No year in our 1950 through 1996 developmental data sets contained an El Niño event of comparable intensity (by a factor of 2) as occurred during the summer-fall 1997 El Niño. This event had the strongest eastern-equatorial Pacific SST anomalies ever observed and, our 1997 forecast failed.

5 New 1 April Statistical Forecast Scheme

Project member Philip Klotzbach has recently developed a new 1 April statistical forecast scheme using NCEP reanalysis data for the period of 1950-2000. This new forecast uses five predictors as indicated in Fig. 1d and Table 4. This scheme uses the best three or four predictors to obtain considerable 1 April forecast skill as illustrated in Table 5. Klotzbach's scheme is in approximate agreement with our early 1 April scheme except for the forecasts of NS and NSD. Both statistical schemes predict a below average 2002 for most hurricane parameters. Details of the predictors used for this scheme are given in Table 6 and the initial seasonal forecast for 2002 is shown versus climatology in Table 7.

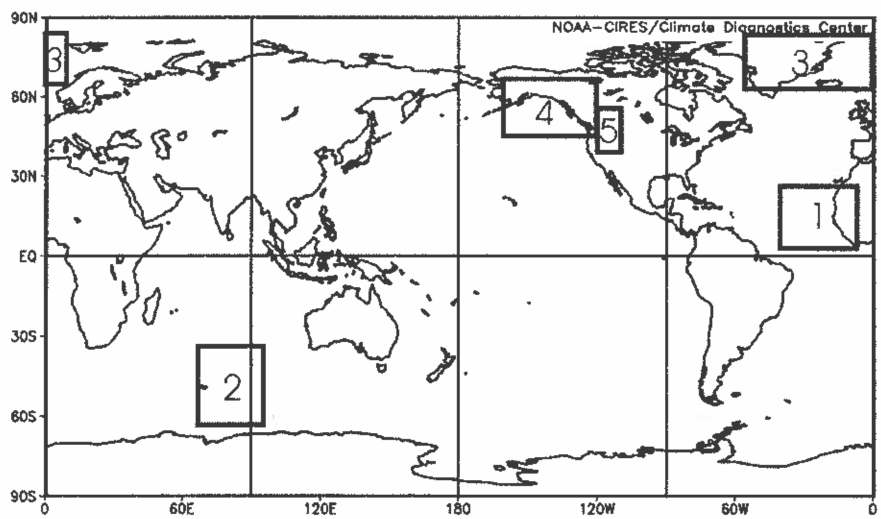


Figure 1: d: April predictor map.

6 Individual Prediction of Caribbean Basin SLPA

Another 1 April predictor not yet quantitatively incorporated into our statistical forecast scheme is the estimated June through September Caribbean basin SLPA. Lower SLPA in this area

Table 4: Five predictors used in our new early April forecast (1950-2000). The sign of the predictor associated with increased tropical cyclone activity is shown in parentheses.

1 - March SLP (5-25N, 10-35W) (-)
2 - February-March 200 mb V (35-5S, 70-95E) (-)
3 - November 500 mb geopotential height (67.5-85N, 50W-10E) (+)
4 - October-November SLP (45-65N, 120-160W) (+)
5 - September 500 mb geopotential height (35-55N, 100-120W) (+)

Table 5: Variance explained based upon 51 years (1950-2000) of hindcasting.

Variables Selected	Variance (r^2) Explained	Jackknife Skill (Year of Forecast Not in the Developmental Data Set
NS- 2 3 4	0.439	0.341
NSD- 1 2 3 5	0.477	0.351
H- 3 4 5	0.481	0.394
HD- 1 3 5	0.469	0.384
IH- 1 2 3 5	0.602	0.506
IHD- 3 4 5	0.414	0.310
HDP- 1 2 3 5	0.543	0.431
NTC- 1 2 3 5	0.606	0.509

Table 6: The predictor values of the new 1 April forecast scheme for the 2002 forecast. The locations of these predictors are shown in Fig. 1d.

Predictor Values	2002 Values
March SLP (5-25N, 10-35W) -	1014.06 mb (+0.5 SD)
February-March 200 mb V (35-5S, 70-95E) -	0.8 m/s (-0.9 SD)
November 500 mb geopotential height (67.5-85N, 50W-10E) +	5118.4 m (-1.8 SD)
October-November SLP (45-65N, 120-160W) -	1007.76 mb (-0.7 SD)
September 500 mb geopotential height (35-55N, 100-120W) +	5786.1 m (+1.2 SD)

Table 7: New April statistical forecast for 2002 with climatology.

Tropical Cyclone Seasonal Parameters (1950-2000)	Forecast	1950-2000 Climatology
Named Storms (NS)	9.3	9.6
Named Storm Days (NSD)	42.6	49.1
Hurricanes (H)	5.4	5.9
Hurricane Days (HD)	17.6	24.5
Intense Hurricanes (IH)	2.0	2.3
Intense Hurricane Days (IHD)	4.1	5.0
Hurricane Destruction Potential (HDP)	63	72.7
Net Tropical Cyclone Activity (NTC)	87	100

is typically associated with enhanced hurricane activity and higher SLPA typically occurs with reduced activity. This SLPA-linked predictor was developed by J. Knaff (1998), a former project member. These SLPA forecasts are based on the March Atlantic subtropical ridge, January through March SSTs in the North Atlantic (50-60°N, 10-50°W), and the January through March Niño 3.4 (5°N–5°S, 120°W–170°W) SST anomalies. Hindcasts using this SLPA parameter (since 1903) show good skill and a significant association with variations of seasonal hurricane activity. This year, the 1 April prediction of the Caribbean and western Atlantic SLPA for June through September 2002 (Table 8) indicates below average SLPA, giving more credence to our final adjusted forecast of an above-average hurricane season.

Table 8: April 1 multi-month independent statistical prediction of 2002 summertime Caribbean basin and Western tropical Atlantic Sea Level Pressure Anomaly (SLPA) expressed in mb from Knaff (1998). Separate regression analyses are made for each monthly category.

	June-July	August-September	June through September
SLPA	–0.33	–0.44	–0.66

7 Analog Based Estimates of Hurricane Activity During 2002

Certain years in the historical record have winter-spring global oceanic and atmospheric trends which are similar to those observed so far in 2002. These analog years provide useful clues as to the likely trends which the forthcoming 2002 hurricane season will take. Although some of the physical associations involved with these relationships may not be well understood, they are, through their lag associations, useful for extended range prediction. For this (1 April) extended range forecast, we subjectively project expected trends in atmospheric and oceanic conditions for the coming August through October period and determine which of the prior years in our database have similar overall atmospheric conditions. We then consider the trends in hurricane activity during these analog years.

Analog Years for 2002. Since 1950, we find four prior years wherein spring and the expected forthcoming summer-fall conditions appear similar to this year. These analog years are 1951, 1953, 1957, and 1969. Each of these four years had weak to moderate El Niño conditions. Three of these four 2002 analog seasons had above-average hurricane activity (see Table 9). We estimate that 2002 will approximate the average value for these four analogs years. This analog technique has yielded more reliable forecasts since the mid-1990s than has our statistical schemes, all of which indicate lower levels of hurricane activity. Primarily for this reason we believe an analog approach is more reliable, and we have chosen to weight its results above that of our two statistical schemes. We thus expect that 2002 should be about as active as an average of these four analog years and as such, more active than the average season during the inactive hurricane period 1970-1994.

We believe that the 2002 hurricane season will again be more active than is indicated by our statistical schemes, owing to several new likely hurricane enhancing features not fully incorporated in our statistical database. The latter include the persistence of warm SSTA patterns in both the north and tropical Atlantic (associated with an enhanced Atlantic thermohaline circulation) which are expected to continue, as well as expected below-average summer west Atlantic surface pressures.

Table 9: Best analog years for 2002 with the associated hurricane activity listed for each year.

	NS	NSD	H	HD	IH	IHD	HDP	NTC
1951	10	58	8	36	2	5.00	113	120
1953	14	65	6	18	3	5.50	59	120
1957	8	38	3	21	2	5.25	67	85
1969	17	83	12	40	3	2.75	110	155
Mean	12.2	61	7.2	28.8	2.50	4.6	87	120
2002 Forecast	12	65	7	30	3	6	85	125

8 Comparison of Forecast Techniques

Table 10 provides a comparison of all of our forecast techniques along with the final adjusted forecast and climatology. Columns 1-3 give our original 1 April statistical forecasts with both fixed and variable numbers of predictors. Column 4 is project member Philip Klotzbach's new 1 April statistical scheme, column 5 is our analog scheme, column 6 is our adjusted final forecast, and column 7 is the 1950-2000 climatology.

Table 10: Comparison of all our forecast techniques along with our final adjusted forecast.

Full Forecast Parameter	(1) Variable Predictor	(2) Fixed predictors 4 Predictors	(3) 6 Predictors	(4) New Klotzbach Scheme	(5) Analog Scheme	(6) Adjusted 1 April Actual Fcst	(7) 1950-2000 Climatology
Named Storms (NS)	10.7 (4)	10.7	12.7	9.3	12.2	12	9.6
Named Storm Days (NSD)	74.4 (5)	72.2	76.3	46.2	61.0	65	49.1
Hurricanes (H)	5.3 (4)	5.3	5.4	5.4	7.2	7	5.9
Hurricane Days (HD)	9.4 (5)	8.6	18.3	17.6	28.8	30	24.5
Intense Hurricanes (IH)	2.1 (4)	2.4	2.3	2.0	2.5	3	2.3
Intense Hurricane Days (IHD)	3.2 (3)	3.6	1.7	4.1	4.6	6	5.0
Hurricane Destruction Potential (HDP)				63.0	87	85	72.7
Net Tropical Cyclone Activity (NTC) constructed for first six parameter forecast values	88.0 (6)	92.3	97.8	87.0	120	125	100

9 Reasons for Upward Adjustment of the 2002 Forecast

We have chosen to increase the 2002 forecast from our statistical forecasts for the following reasons:

1. During six of the last seven years, our statistical schemes have underforecast active years. The last seven years have been the most active seven consecutive hurricane seasons on record and as such, are not well represented in the training data sets which were developed on observations which extend back 45 and 51 years. A major reason for the failure of the statistical schemes is the breakdown of the African rainfall and hurricane relationship which we presently cannot explain. By contrast, our analog method of prediction has worked quite well in recent years.

2. New satellite, aircraft and GPS dropwinsonde technology allow better detection and intensity measurements for tropical cyclones. We believe this new technology has and will continue to

cause a small upward shift in the amount of recently observed Atlantic basin tropical cyclone activity due purely to these better observations and especially for weaker tropical cyclone activity.

3. There are no compelling reasons why the recent seven years active period should not continue through the 2002 season.

10 Landfall Probabilities for 2002

A significant focus of our recent research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline. Whereas individual hurricane landfall events cannot be accurately forecast months in advance, the total seasonal probability of landfall can be forecast with statistical skill. With the observation that landfall probability varies as a function of varying climate conditions, a probability specification scheme has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the last 100 years (1900–1999). Specific landfall probabilities can be given for all cyclone intensity classes for a set of distinct U.S. coastal regions.

Net landfall probability is linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see explanation in caption of Table 11) and to climate trends associated with the multi-decadal variations of the Atlantic Ocean thermohaline circulation. The latter is measured in terms of North Atlantic SSTA*, an index of North Atlantic SSTA in the area between 50-60°N, 10-50°W. SSTA* is a combination average of North Atlantic SSTA for the last six years, last year's average SSTA and the difference of the last six months of the prior year in comparison with the first half of the prior year. A decreasing weighting is given to each of these three criteria.

Higher values of SSTA* generally indicate greater Atlantic hurricane activity, especially for major hurricanes. Hence, Atlantic basin NTC can be skillfully predicted and the strength of the Atlantic Ocean thermohaline circulation can be inferred as SSTA* from North Atlantic SST anomalies from prior years. These relationships are then utilized to make probability estimates for U.S. landfall. The current (March 2002) value of SSTA* is 91. This value, in combination with a new prediction of NTC of 125 for 2002, yields a combination of NTC + SSTA* of 125 + 91 = 216.

As shown in Table 11, NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, expressed as a percentage deviation from its long-term averages. Although many active Atlantic hurricane seasons have no landfalling hurricanes, and some inactive years have one or more landfalling hurricanes, long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season, the greater the probability of U.S. hurricane landfall. For example, landfall observations during the last 100 years show that a greater number of intense (Saffir-Simpson category 3-4-5) hurricanes strike the Florida and U.S. East Coast during years of (1) highest NTC and (2) above-average North Atlantic SSTA*. The 33 years with the combined highest NTC and strongest thermohaline circulation (during the last 100 years) had 24 category 3-4-5 hurricane strikes along the Florida and East Coast; whereas, the 33 years with the lowest NTC/weakest thermohaline circulation saw only three such intense hurricane landfall events, resulting in a difference of 8 to 1.

Tables 12 and 13 summarize the links between hurricane and tropical storm landfall and the combined influences of NTC and the thermohaline circulation (i.e., North Atlantic SSTA* effects) for Florida, the U.S. East Coast and for the Gulf Coast (NTC only). Landfall characteristics for the Gulf Coast (Fig. 2) (or regions 1-4) from north of Tampa, FL westwards to Brownsville, TX (36 total category 3-4-5 hurricane landfalls during the last century) have related landfall probabilities which are distinct from the rest of the U.S. coast from north of Tampa, FL to Eastport, ME (37

Table 11: 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 IH, and 5 IHD, 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 = 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)	Intense Hurricanes (IH)	2.3
6)	Intense Hurricane Days (IHD)	5.0

landfalls in regions 5-11). The differences are due primarily to the varying incidence of category 3-4-5 hurricanes in each of these areas. The locations of the 11 coastal zones for which regression equations have been developed are shown in Fig. 2.

Table 12: Number of Florida Peninsula and U.S. East Coast (regions 5 through 11) hurricane landfall events by intensity class occurring in the 33 highest versus the 33 lowest values of NTC plus Atlantic thermohaline circulation (SSTA*) or NTC + SSTA* during the last century.

Intensity Category	Sum of Highest 33 Years	Sum of Lowest 33 Years	Ratio of Highest/Lowest 33 Years
IH (Category 3-4-5)	24	3	8.0
H (Category 1-2)	29	12	2.4
NS	24	17	1.4

Table 13: Number of Gulf (regions 1 through 4) hurricane landfall events by intensity class during the seasons with the 33 highest and 33 lowest NTC values during this century.

Intensity Category	Sum of Highest 33 Years	Sum of Lowest 33 Years	Ratio of Highest/Lowest 33 Years
IH (Category 3-4-5)	18	5	3.6
H (Category 1-2)	22	11	2.0
NS	28	27	1.0

Figure 3 gives a flow diagram outlining the procedures by which these landfall forecasts are made. Using NTC alone, a similar set of regression relationships has been developed for the landfall probability of category 1-2 hurricanes and tropical storms along the Gulf Coast (regions 1-4) and along the Florida Peninsula and East Coast (regions 5-11). Table 14 lists strike probabilities for each TC category for the entire U.S. coastline, the Gulf Coast and Florida, and the East Coast for 2002. The mean annual probability of one or more landfalling systems is shown in parentheses. Note that Atlantic basin NTC activity for 2002 (125) is expected to be greater than the long-term average. U.S. hurricane landfall probability is expected to be above average owing to North Atlantic SSTAs being above average in recent years. During periods of positive North Atlantic SSTA*, a

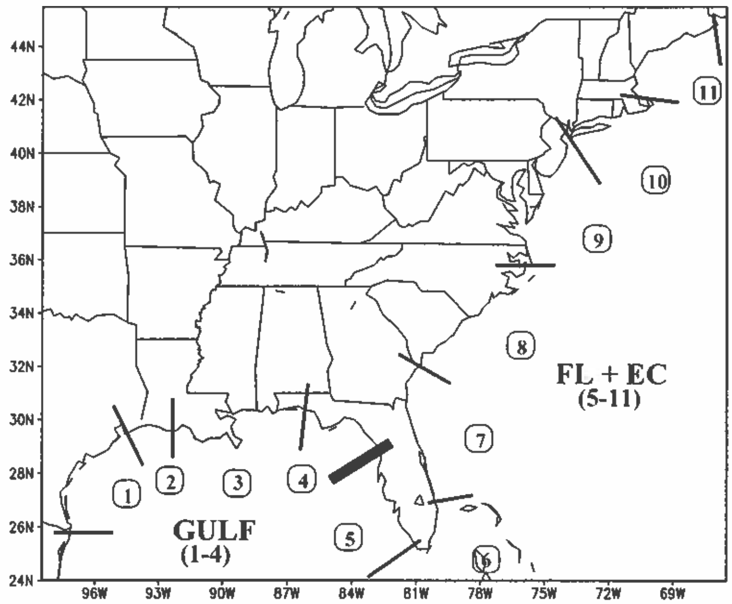


Figure 2: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. The heavy bar delineates the boundary between the Gulf (regions 1-4) and the Florida Peninsula and East Coast (regions 5-11).

higher percentage of Atlantic basin major hurricanes cross the U.S. coastline for a given level of NTC.

Table 14: Estimated probability (expressed in percent) of one or more U.S. 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 (region 1-4), and along the Florida and the East Coast (Regions 5-11) during 2002. The long-term mean annual probability of one or more landfalling systems during the last 100 years is given in parentheses.

Coastal Region	TS	Category 1-2 HUR	Category 3-4-5 HUR	All HUR	All Named Storms
Entire U.S. (Regions 1-11)	88% (80)	84% (68)	75% (52)	96% (84)	99% (97)
Gulf Coast (Regions 1-4)	70% (59)	56% (42)	43% (30)	75% (61)	93% (83)
Florida plus East Coast (5-11)	60% (51)	63% (45)	56% (31)	84% (62)	94% (81)

11 Increased Level of Atlantic Basin Hurricane Activity During the Last Seven Years - But Decreased U.S. Landfalls

A major reconfiguration of the distribution of Atlantic SST anomalies began in mid-1995 and has persisted through the present. SSTs over much of the North Atlantic have become 0.4 to 0.6°C warmer than normal. This trend is well associated with increased major hurricane activity in the Atlantic basin during the last seven years. We hypothesize that these persistent broadscale SST changes are associated with basic changes in the strength of the Atlantic Ocean thermohaline ("conveyor belt") circulation. This interpretation is consistent with changes in a long list of global

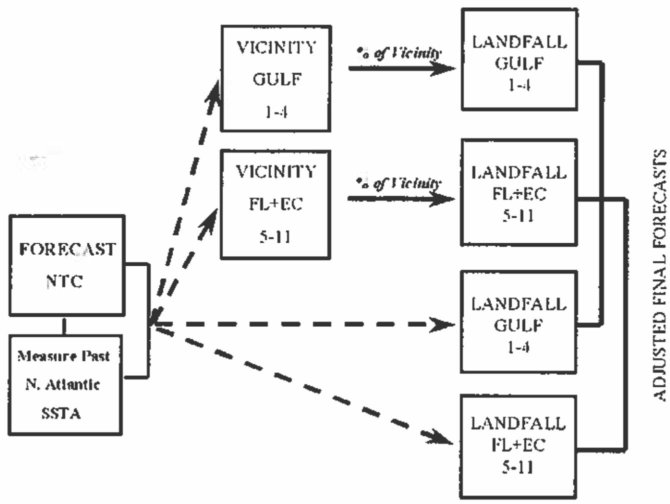


Figure 3: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations from U.S. hurricane landfall measurements of the last 100 years. Separate equations are derived for the Gulf and for Florida and the East Coast (FL+EC).

atmospheric circulation features during the last seven years which conform to a prominent shift into Atlantic hurricane-enhancing circulation patterns, the effects of which are reflected in Fig. 4. Historic and geographic evidence going back thousands of years indicate that variations of the Atlantic multi-decadal thermohaline circulation tend to occur on periods of 25-50 years. If the recent 7-year shift follows prior trends, then it is likely that the recent generally enhanced intense Atlantic basin hurricane activity will persist through the early decades of the 21st century. Such a trend is in contrast with the diminished hurricane activity which persisted from 1970-1994 and during the first quarter of the 20th century.

Despite El Niño-linked reduction of hurricane activity during 1997, the last seven years (1995–2001) constitute the most active seven consecutive years on record. A summary of how this increased activity has affected the long-term TC climatology is shown in the Appendix. Table 15 provides a summary of the total number of named storms (94), named storm days (524), hurricanes (58), hurricane days (266), major hurricanes (27), major hurricane days (61.25) and Net Tropical Cyclone activity (1085) which occurred during 1995–2001. Despite the inactive 1997 season, the annual average values for NS, NSD, H, HD, IH, IHD and NTC during 1995-2001 were much above the average of the prior 25-year period of 1970-1994. Similarly, these same parameters were significantly higher than the climatological average for the period 1950-2000 with the greatest increase occurring for IH and IHD activity. These trends toward increased hurricane activity give strong support to the suggestion that we have entered a new era of greatly increased major hurricane activity. As noted, NTC activity during the seven-year period has averaged 215 percent of the level observed during the 1970-1994 period. Excluding 1997, average NTC for the other six years from (1995-2001) was 246. There have been as many Atlantic basin intense hurricanes during the seven years between 1995-2001 as occurred during the eighteen years between 1977-1994.

Beginning in 1990, we suggested that the 20-plus year era of greatly reduced intense Atlantic category 3-4-5 hurricane activity was likely coming to an end and that the U.S. and Caribbean coastal regions should expect a long term increase in major landfalling hurricanes (Gray 1990). Such an increase is an ominous prospect considering the strong increases in U.S. and Caribbean

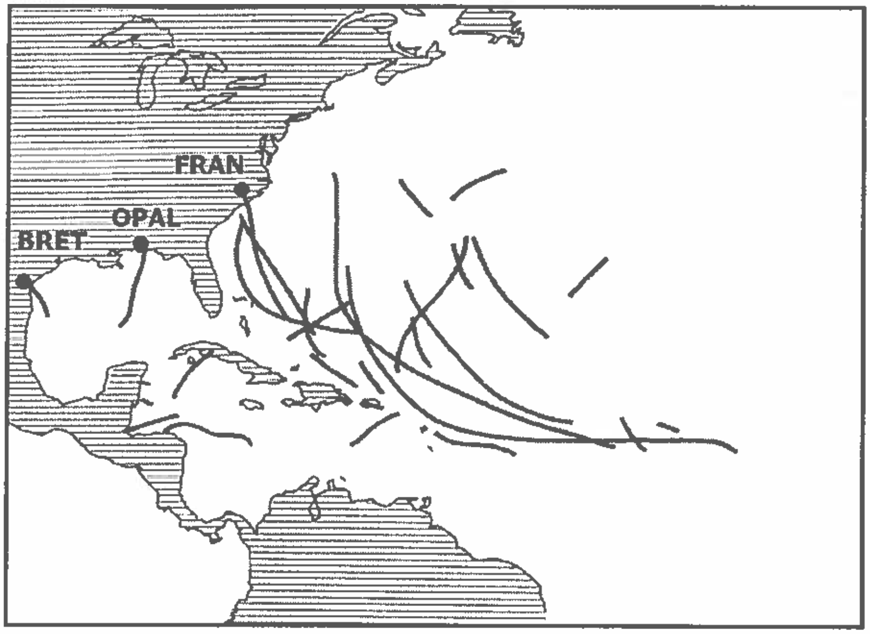


Figure 4: Intense (Cat 3-4-5) hurricane tracks during the period from 1995-2001. Note that despite twenty-seven intense hurricanes during this period that only three (Bret, Opal and Fran) made US landfall. Bret made landfall at the least vulnerable location in the US, and Opal and Fran made landfall in areas that were not densely populated.

Table 15: Comparison of recent seven-year (1995–2001) hurricane activity with climatology and prior quarter century period of 1970–1994.

Year	Named Storms (NS)	Named Storm Days (NSD)	Hurricanes (H)	Hurricane Days (HD)	Cat 3-4-5 Hurricanes (IH)	Cat 3-4-5 Hurricane Days (IHD)	Net Tropical Cyclone Activity (NTC, 1950-2000)
1995	19	121	11	60	5	11.50	221
1996	13	78	9	45	6	13.00	192
1997	7	28	3	10	1	2.25	51
1998	14	80	10	49	3	9.25	168
1999	12	77	8	43	5	15.00	181
2000	14	77	8	32	3	5.25	130
2001	15	63	9	27	4	5.00	142
TOTAL	94	524	58	266	27	61.25	1085
Seven-year Ave. 1995-2001	13.4	74.9	8.3	38.0	3.86	8.75	155
Ratio 1995-01/ climatology (1950-2000) in percent	140	153	141	155	168	172	155
Ratio 1995-01/1970-94 in percent	144	198	143	235	254	347	215

coastal populations in recent years and that when hurricane destruction is normalized for coastal population, inflation, and wealth per capita [see Pielke and Landsea (1998)], it is found that major hurricanes cause about 85 percent of all U.S. tropical cyclone-linked destruction.

Good fortune has been manifest during the last seven years in the form of a persistent upper-air trough along the U.S. East Coast during much of each hurricane season. The presence of this upper-level trough has caused a large portion of otherwise northwest moving major hurricanes to recurve to the north before they reached the U.S. coastline as is evident in Fig. 4. Also, more systems have formed at higher latitudes and these storms tended to move away from the U.S. Note that though many major hurricanes passed close to the U.S. coastline, only three made landfall. This run of good luck cannot be expected to continue.

Table 16 further demonstrates the good luck of the last seven years (1995-2001) expressed in terms of the number of U.S. major hurricane landfalls per year during the 95-year period 1900–1994. Along the Florida Peninsula and the East Coast, major hurricane landfall per year has been only 38 percent as great as in the average year between 1900-1994 and 58 percent as large for the whole U.S. coastline.

In terms of the ratio of the number of U.S. major hurricane landfalls per number of Atlantic basin major hurricanes, the last seven years have witnessed a very strong downturn. Table 17 shows that the U.S. Gulf in the last seven years has experienced only 46 percent as many major hurricane landfall events per Atlantic basin major hurricanes as during the average of the previous 95 years. The Florida and the East Coast rate of landfalling major hurricanes the last seven years has been only 22 percent as great and the whole U.S. coastline 35 percent as great. This fortuitous landfall downturn is unlikely to persist.

Table 16: The incidence of U.S. average major hurricane landfall per year. Number in parentheses indicate the percentage ratio for 1995-2001 versus 1900-1994).

	Gulf Coast Regions 1-4	Florida Peninsula and East Coast Regions 5-11	Whole U.S. Coast Regions 1-11
1900-1994	.358	.379	.737
1995-2001	.258(80%)	.143(38%)	.429(58%)

Table 17: The incidence of U.S. average major hurricane landfall per year expressed as percent of Atlantic basin total major hurricanes. Number in parenthesis indicate the annual percentage ratio for 1995-2001 to 1900-1994).

	Gulf Coast Regions 1-4	Florida Peninsula and East Coast Regions 5-11	Whole U.S. Coast Regions 1-11
1900-1994	.162	.172	.321
1995-2001	.074(46%)	.037(22%)	.111(35%)

12 The 1995–2001 Upswing in Atlantic Hurricanes and Global Warming

Various groups and individuals have suggested that the recent large upswing in Atlantic hurricane activity (since 1995) may be in some way related to the effects of increased man-made greenhouse gases such as carbon dioxide (CO_2). There is no reasonable scientific way that such an interpretation of the recent upward shift in Atlantic hurricane activity can be made. Please see our recent 20 November 2001 verification report (http://tropical.atmos.colostate.edu/forecasts/index.html) for more discussion on this subject.

13 Forecast Theory and Cautionary Note

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 likely similar trends in future seasons. It is 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. Landfall probability estimates for any one location along the coast are very low and reflect the fact that, in any one season, most US coastal areas will not feel the effects of a hurricane no matter how active the individual season is. It must also be emphasized that a low landfall probability does not insure that a hurricane will not come ashore. Regardless of how active the 2002 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the US or Caribbean Basin coastline and do much damage.

14 Forthcoming Update Forecasts of 2002 Hurricane Activity

We will be issuing seasonal updates of our 2002 Atlantic basin hurricane activity forecast on 31 May (to coincide with the official start of the 2002 hurricane season on 1 June) and 7 August 2002. The latter will include separate forecasts for August-only and September-only activity during 2002. These monthly forecasts will also include a forecast of U.S. landfall probability. All these forecasts will be available at our web address given on the front cover.

(http://tropical.atmos.colostate.edu/forecasts/index.html)

15 Acknowledgments

John Sheaffer and John Knaff have made many important contributions to the conceptual and scientific background for these forecasts. The authors are indebted to a number of meteorological experts who have furnished us with the data necessary to make this forecast or who have given us valuable assessments of the current state of global atmospheric and oceanic conditions. We are particularly grateful to Arthur Douglas, Richard Larsen, Vern Kousky, Ray Zehr and Mark DeMaria for very valuable climate discussions and input data. We thank Colin McAdie, Jiann-Gwo Jiing, and Gary Padgett who have furnished us with data. Richard Taft has provided help with African rainfall collection. In addition, Barbara Brumit and Amie Hedstrom have provided excellent manuscript, graphical, and data analysis assistance. We have profited over the years from many indepth discussions with most of the current NHC hurricane forecasters. These include Lixion Avila, Miles Lawrence, Richard Pasch, Jack Beven, James Franklin and Stacy Stewart. The first 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, former directors of the National Hurricane Center (NHC), and from the current director, Max Mayfield. We also thank Bill Bailey of the Insurance Information Institute for his sage advice and encouragement.

The financial backing for the issuing and verification of these forecasts has in part been supported by the National Science Foundation. But this NSF support is insufficient. We are very grateful to the Research Foundations of the United Services Automobile Association (USAA) and to State Farm Insurance who have provided substantial support to the first author's research project. It is this support which is allowing our seasonal predictions to continue and expand.

16 Citations and Additional Reading

Blake, E. S., 2001: Prediction of August Atlantic basin hurricane activity. Dept. of Atmos. Sci. Paper, Colo. State Univ., Ft. Collins, CO.

DeMaria, M., J. A. Knaff and B. H. Connell, 2001: A tropical cyclone genesis parameter for the tropical Atlantic. *Wea. Forecasting*, 16(2), 219–233.

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

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

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

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

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

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

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

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

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

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

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

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

Knaff, J. A., 1997: An El Niño-southern climatology and persisitence (CLIPER) forecasting scheme. *Wea. and Forecasting*, 12, 633–652.

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

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

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

Landsea, C. W. and J. A. Knaff, 2000: How much skill was there in forecasting the very strong 1997–1998 El Niño? *Bull. Amer. Meteor. Soc.*, Vol. 81, 9, 2107–2119.

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

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

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

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

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

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

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

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

Ramage, C., 1983: Teleconnections and the siege of time. *J. Climatology*, 3, 223–231.

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

Sheaffer, J. D., 1995: Associations between anomalous lower stratospheric thickness and upper ocean heat content in the West Pacific warm pool. Presentation at the 21st AMS Conference on Hurricanes and Tropical Meteorology, Miami, FL, April 22-28.

Sheaffer, J. D. and W. M. Gray, 1994: Associations between Singapore 100 mb temperatures and the intensity of subsequent El Niño events. Proceedings, 18th Climate Diagnostics Workshop, 1-5 November, 1993, Boulder, CO.

APPENDIX A

Table 1: Summary verifications of the authors prior three seasonal forecasts of Atlantic TC activity (1999-2001).

1999	5 Dec 1998	Update 7 April	Update 4 June	Update 6 August	Obs.
No. of Hurricanes	9	9	9	9	8
No. of Named Storms	14	14	14	14	12
No. of Hurricane Days	40	40	40	40	43
No. of Named Storm Days	65	65	75	75	77
Hurr. Destruction Potential(HDP)	130	130	130	130	140
Major Hurricanes (Cat. 3-4-5)	4	4	4	4	5
Major Hurr. Days	10	10	10	10	15
Net Trop. Cyclone Activity	160	160	160	160	193

2000	8 Dec 1999	Update 7 April	Update 7 June	Update 4 August	Obs.
No. of Hurricanes	7	7	8	7	8
No. of Named Storms	11	11	12	11	14
No. of Hurricane Days	25	25	35	30	32
No. of Named Storm Days	55	55	65	55	66
Hurr. Destruction Potential(HDP)	85	85	100	90	85
Major Hurricanes (Cat. 3-4-5)	3	3	4	3	3
Major Hurr. Days	6	6	8	6	5.25
Net Trop. Cyclone Activity	125	125	160	130	134

2001	7 Dec 2000	Update 6 April	Update 7 June	Update 7 August	Obs.
No. of Hurricanes	5	6	7	7	9
No. of Named Storms	9	10	12	12	15
No. of Hurricane Days	20	25	30	30	27
No. of Named Storm Days	45	50	60	60	62
Hurr. Destruction Potential(HDP)	65	65	75	75	71
Major Hurricanes (Cat. 3-4-5)	2	2	3	3	4
Major Hurr. Days	4	4	5	5	5
Net Trop. Cyclone Activity	90	100	120	120	142

Table 2: Alteration of Atlantic basin tropical cyclone climatology when the base period is changed from 1950-1990 to 1950-2000.

	1950–1990	1950–2000	Difference
No. of Hurricanes	5.8	5.9	0.1
No. of Named Storms	9.3	9.6	0.3
No. of Hurricane Days	23.7	24.5	0.8
No. of Named Storm Days	46.9	49.1	2.2
Hurr. Destruction Potential(HDP)	71.7	72.7	11.0
Major Hurricanes (Cat. 3-4-5)	2.2	2.3	0.1
Major Hurr. Days	4.7	5.0	0.3
Net Trop. Cyclone Activity	100	100	0