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

A near average hurricane season and with average probability for US landfall, reflecting a modest downward adjustment from our earlier December 2001 and April 2002 forecasts.

This forecast is based on ongoing research by the authors utilizing meteorological information as available through May 2002

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[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:

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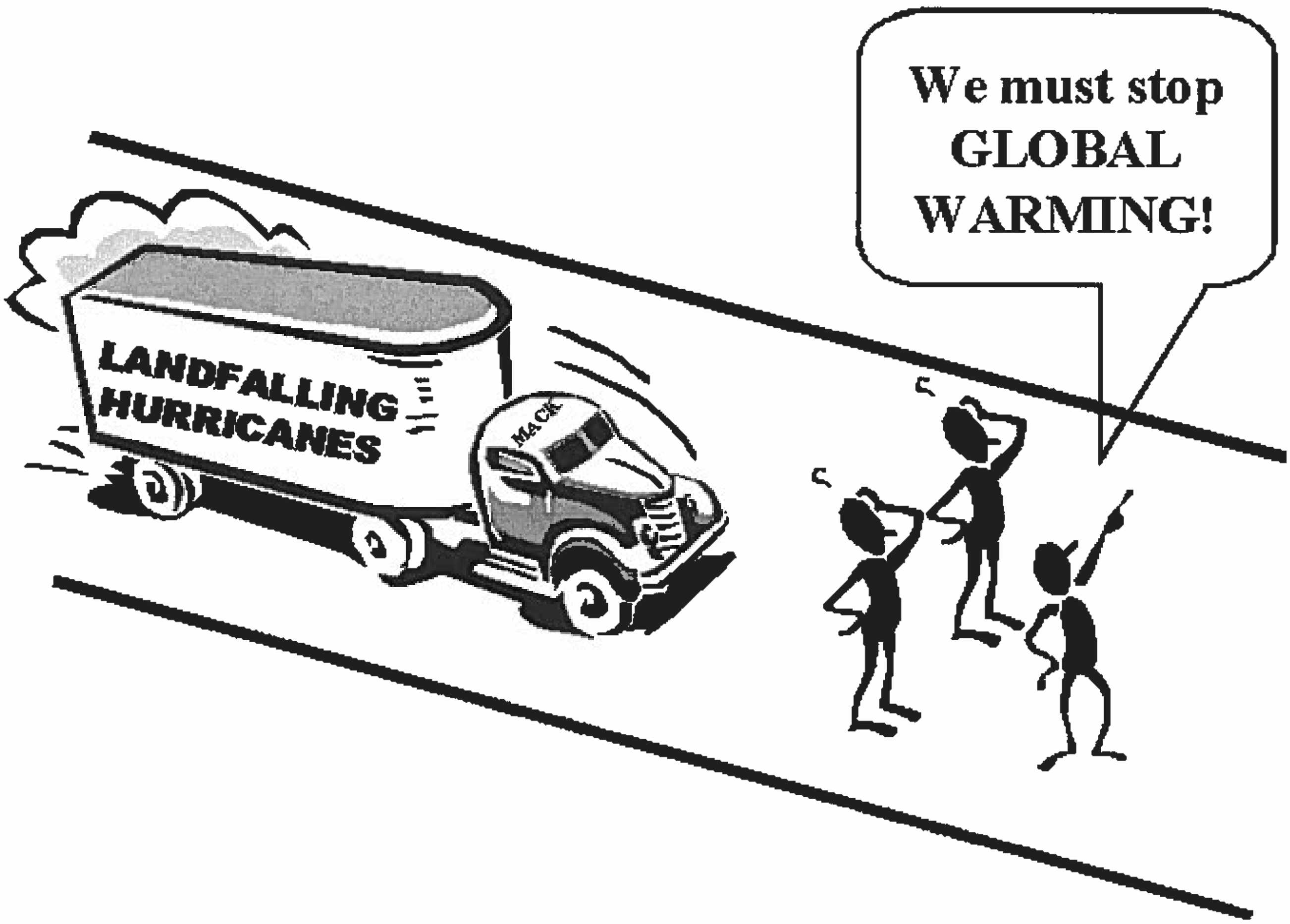
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2002 ATLANTIC BASIN SEASONAL HURRICANE FORECAST

Tropical Cyclone Parameters and 1950-2000 Climatology (in parentheses)	7 December 2001 Forecast for 2002	Updated 5 April 2002 Forecast	Updated 31 May 2002 Forecast
Named Storms (NS) (9.6)	13	12	11
Named Storm Days (NSD) (49.1)	70	65	55
Hurricanes (H)(5.9)	8	7	6
Hurricane Days (HD)(24.5)	35	30	25
Intense Hurricanes (IH) (2.3)	4	3	2
Intense Hurricane Days (IHD)(5.0)	7	6	5
Hurricane Destruction Potential (HDP) (72.7)	90	85	75
Net Tropical Cyclone Activity (NTC)(100%)	140	125	100

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 – 63% (average for last century is 52%)

2) U.S. East Coast Including Peninsula Florida – 42% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville – 35% (average for last century is 30%)

4) Expected near-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 May 2002 indicates that the 2002 Atlantic basin seasonal hurricane activity will be near the average of the 1950-2000 period. The fairly active season anticipated in our earlier 7 December 2001 and 5 April 2002 forecasts is now less likely. Predictive signals from around the globe have become mixed. Whereas neutral (no longer warm) tropical Atlantic sea surface temperatures and favorable stratospheric winds are assured, a modest suppressing influence for this year's hurricane activity will result from a weak to moderate El Niño developing in the eastern Pacific. This El Niño event is much less likely to diminish this year's hurricane activity to the extent of the more powerful 1997, 1986-87, and 1982-83 El Niño events. Most other 2002 TC predictors now indicate a near average hurricane season. It is anticipated that 2002 will have 11 named storms (average is 9.6), 55 named storm days (average is 49.1), 6 hurricanes (average is 5.9), 25 hurricane days (average is 24.5), 2 intense (category 3-4-5) hurricanes (average is 2.3), 5 intense hurricane days (average is 5.0), a Hurricane Destruction Potential (HDP) of 75 (average is 72.7) and overall Net Tropical Cyclone (NTC) activity of about 100 percent of the average year for the period between 1950-2000. U.S. landfall probability is estimated to be somewhat above the long-term average, reflecting both global and overall multi-decadal Atlantic basin meteorological conditions.

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 U.S. landfall probability. This report presents details of our most recent observations as well as the rationale for our 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 and end of season verifications 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, late May and early August. Qualitative forecast adjustments are added to accommodate additional processes which are not incorporated into our statistical and analog models. As in most seasons, the two most prominent influences which will largely determine the trend in this year's Atlantic hurricane activity are:

(1) The status of El Niño-Southern Oscillation (ENSO) and,

(2) the configuration of Atlantic Sea Surface Temperature Anomaly (SSTA) conditions.

As noted above, a weak to moderate El Niño event is likely to be in place during August through October. This should act as a modest inhibiting influence on Atlantic TC activity. Atlantic SSTA patterns are expected to be neutral, causing little enhancing of 2002 hurricane activity. The great enhancing effects of warm Atlantic SSTs during the last seven years are now not expected to be in place. 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 TC enhancing westerly mode this year.

(4) Two measures of West African rainfall during the prior year (Figs. 1a and 1b). These rainfall indices have been quite dry and hence are less favorable for an active hurricane season. Note however, the forecast utility of these African rainfall 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 during 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 higher than average and hence slightly unfavorable for TC activity this summer.

(6) Anticipated slightly below-average Caribbean and western tropical Atlantic Sea Level Pressure Anomaly (SLPA) for August through October 2002. A small enhancing factor.

(7) The strength of the east to west temperature and pressure gradient over the western Sahel region during February through May. Estimated to be a neutral factor this year.

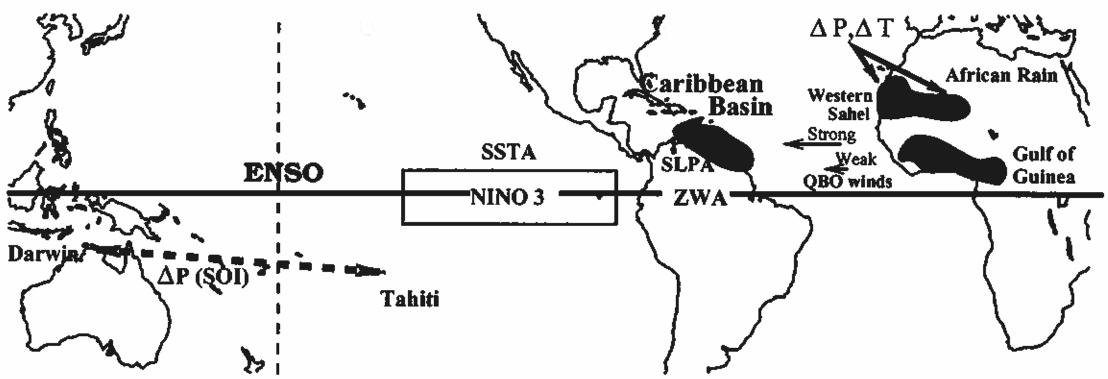

Figure 1: (a) Meteorological parameters used in various versions of our older early August (Gray et al. 1994a) seasonal forecast.

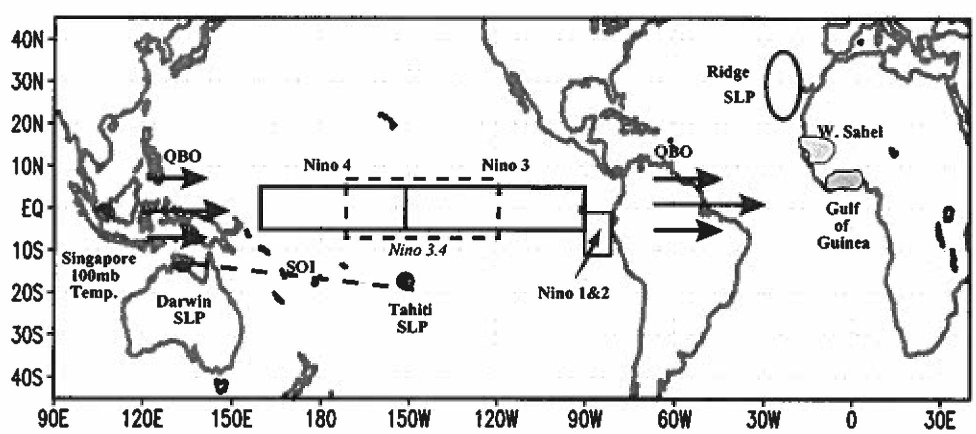

Figure 1: (b) Additional parameters used or consulted in our extended-range forecasts.

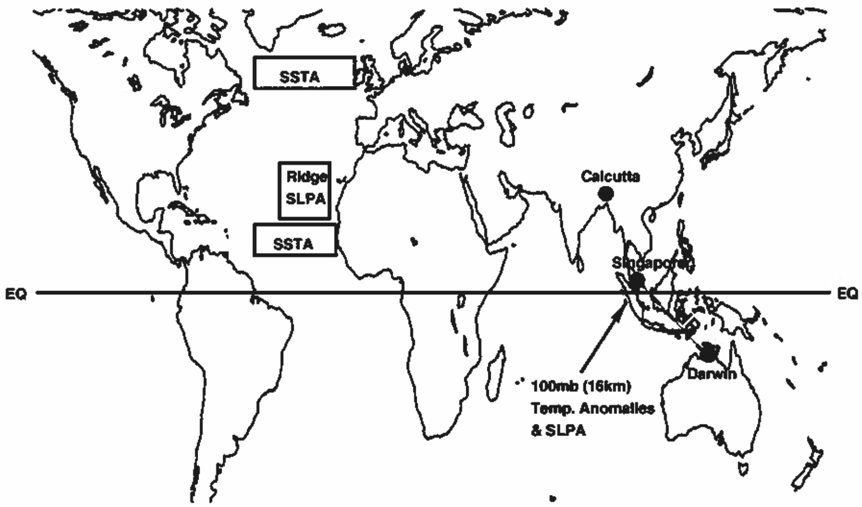

Figure 1: (c) Additional (new) predictors which have recently been noted to be related to the upcoming Atlantic hurricane activity.

2 Recent Advancements in the Potential for Improved Empirical Climate Prediction

The last few years have seen a tremendous growth in the accessibility of global atmospheric data sets. An example of improved accessibility is the NOAA/NCEP global reanalysis data sets which archive and analyze historical atmospheric and ocean surface data and makes this data easily available on the Internet. Other countries or international groups are developing similar reanalysis programs. Most of these reanalysis data sets are available from the late 1940s to the present and offer exciting opportunities for the development of new and improved extended range empirical climate forecast schemes. These data analyses developments are also useful for better understanding of the global atmosphere-ocean functioning as one unit. Broadscale circulation features identifiable in the reanalysis data fields have considerable precursor information for the coming month's or season's amount of hurricane activity.

3 Prediction Methodology

Our forecasts consider eight measures of forthcoming 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). (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 10 to 15 possible forecast parameters which are known to be related to tropical cyclone activity.

Our studies have identified global atmospheric and oceanic parameters (and groups of parameters) which, in the past, have shown statistically significant and physically plausible associations with 'active' versus 'inactive' hurricane seasons at various time lags. A variety of statistical tests and numerical manipulations optimize the best combination of these precursor signals. Assuming that the atmosphere continues to behave in the future as it has in past years, hindcast skill developed on these historical data are applicable in forecasting future activity.

Although the probability of hurricane landfall is distinctly higher in active versus inactive Atlantic basin hurricane seasons, there are exceptions. Damaging landfalling hurricanes can occur during inactive years (eg., Andrew 1992) and no hurricane landfall events can sometimes occur during active seasons such as 2000 and 2001. But this is not typical. One of the major reasons for issuing these forecasts is to serve the innate curiosity of many as to the likelihood of an active or inactive season. Nearly everyone along the south and eastern U.S. coastline is curious as to how active the coming hurricane season is likely to be. The Atlantic is the most variable of the global TC basins. It is well known that some seasons have little activity. For example, official records show that there were no hurricanes in 1914, only one in 1925, and only two hurricanes in 1930, 1931 and 1982. By contrast, each of the years 1950, 1969, and 1995 had 11 (or more) hurricanes.

The potential predictors currently used to develop our end of May forecast are shown in Table 1. The specific values of these parameters used for 2002 are shown in the right-hand column. These predictors are used to make a number of statistical forecasts for each of several TC activity parameters. Table 2 lists the seasonal hurricane indices that we use to predict each TC index. Our hindcast skill (between 50-60 percent) for the 42-year period of 1950–1991 is shown in the right column. These prediction equations are established for our "variable" (number of) parameter forecast model. This represents our best statistical forecast where, so as to minimize the skill degradation of these equations when making independent forecasts via statistical "overfitting", we include the least number of predictors for the highest amount of hindcast variance.

Table 1: Pool of predictive parameters and their estimated values for the late May 2002 prediction based on meteorological data through May 2002. See Figs. 1 to 3 for the locations of these predictors.

Predictive Parameter	
1 = QBO 50 mb 4-month extrapolation of zonal wind at 12°N to Sept. 2001	–0 ms^{-1}
2 = QBO 30 mb 4-month extrapolation of zonal wind at 12°N to Sept. 2001	–4 ms^{-1}
3 = QBO absolute value of shear between 50 and 30 mb at 12°N to Sept. 2001	–4 ms^{-1}
4 = Rgc AN Gulf of Guinea rainfall anomaly (Aug-Nov of 2001)	–1.25 SD
5 = Rws West Sahel rainfall anomaly (June-Sept 2001)	–1.25 SD
6 = Temp East-West Sahel temperature gradient(Feb-May 2002)	+0.1 SD
7 = SLPA April-May Caribbean basin sea level pressure anomaly	+0.6 mb
8 = ZWA April-May Caribbean basin zonal wind anomaly	+1.0 ms^{-1}
9 = R-ON: Azores surface pressure ridge strength in Oct-Nov 2001	+0.15 SD
10 = R-M: Mar Azores surface pressure ridge strength in Mar 2002	+0.25 SD
11 = SST3.4 Nino 3.4 SSTA in April-May 2002	+0.4°C
12 = D-SST3.4: Nino 3.4 SSTA for April-May minus Feb-Mar 2002	+0.15°C
13 = TATL Tropical Atlantic SSTA anomaly (10-22°N,18-50°W) (Apr-May)	0.0°C
14 = NATL North Atlantic SSTA anomaly (50-60°N,10-50°W) (Apr-May)	0.0°C
15 = SATL Mid Atlantic SSTA anomaly (5-18°S,50°W-10°E) (Apr-May)	+0.3°C

Probability dictates that, on average, a net degradation of hindcast skill of between 10-20 percent of total variability will likely occur. The amount of degradation (if any) for an individual year forecast is a random process. In some years, when conditions include strong trends that are similar to past years, forecasts will do quite well, perhaps better than the skill of the hindcast scheme. In other years, a given forecast can perform quite poorly. This is because our 42-year (1950-1991) predictor database likely does not contain realizations expressing the full range of independent possibilities. Our 1997 forecast is a good example. No year in our 1950 through 1991

Table 2: Listing of predictors chosen for each parameter that is forecast and the total hindcast variance explained by these predictors for the enclosed updated 31 May forecast.

Forecast Parameter	No. of Predictors	Predictors Chosen from Table 1	Variability Explained by Hindcast (1950-1991)	Likely Independent Forecast Skill
NS	3	1, 3, 9	.498	.322
NSD	6	3, 4, 5, 7, 9, 10	.562	.405
H	6	3, 4, 5, 7, 10, 11	.532	.361
HD	6	2, 4, 5, 6, 9, 14	.544	.379
IH	5	1, 4, 6, 9, 10	.557	.402
IHD	3	4, 6, 11	.443	.230
HDP	5	1, 4, 5, 6, 10	.532	.366
NTC	5	1, 4, 5, 6, 10	.554	.398
MPD	4	3, 4, 9, 14	.591	.453

developmental data sets had experienced an El Niño event nearly as intense (by a factor of 2) of any other on record.

Table 3 contains a summary of our statistical forecasts plus our best qualitatively adjusted "final" forecasts (column 3). Column 1 gives our statistical forecast wherin measured (-1.25 S.D) dry African conditions for last year for the western Sahel and the Gulf of Guinea. African rainfall was a very strong and reliable predictor prior to 1995. But African rainfall has not worked for predicting TCs since 1995; very active hurricane conditions have occurred with low values of measured African rainfall during this recent period which is opposite the association observed during the prior 45 years of measurement. We have also made a statistical forecast assuming average African rainfall conditions of last year. This would be more in keeping with the active 2001 hurricane season which occurred. We believe this is more typical of what we should see this year. Column 2 gives our prediction assumming that African rainfall were normal. Note that this statistical forecast substantially raises our prediction. Our statistical scheme had been heavily weighted to this parameter.

Additional qualitative information suggests that our statistical forecast with inclusion of last year's measured rainfall is again (as it has been since 1995) underestimating the amount of hurricane activity likely to occur this season. As a consequence, we have chosen to again make upward adjustments to bring closer our statistical forecast that assumes average rainfall conditions and is more in line with the results of analog scheme (discussed in Section 6). Consequently, data through the end of May indicate that 2002 will likely experience near average Atlantic basin hurricane activity (though still more active) than the average for hurricane seasons between 1970–1994. The later 25-year period showed a large suppression of major Atlantic basin hurricane activity.

4 Anticipated Weak El Niño Conditions During August-October 2002

We anticipate that only a weak El Niño warming event will be present in the tropical Pacific during the August to October period of 2002. Table 4 shows changes in Pacific equatorial SSTA conditions during the last five months. Note that the warming trend from March to May has not been very large. These SST trends (as well as in the subsurface thermocline temperature data) are not indicative of a very strong El Niño event developing during the 2002 hurricane season. Hence,

Table 3: Summary of 1 June statistical forecasts (columns 1 and 2) versus forecasts using 4, 6 and 8 fixed predictors forecast (columns 2, 3). Column 3 is our final adjusted 31 May forecast for 2002. Column 4 gives climatology.

Full Forecast Parameter	(1) With Measured Dry African Rainfall	(2) With Assumed Ave. African Rainfall Conditions	(3) Adjusted Actual Fcst	(4) 1950-1990 Climatology
Named Storms (NS)	12.0	12.0	11	9.6
Named Storm Days (NSD)	17.5	38.8	55	49.1
Hurricanes (H)	3.2	5.5	6	5.9
Hurricane Days (HD)	15.3	28.2	25	24.5
Intense Hurricanes (IH)	1.4	2.6	2	2.3
Intense Hurricane Days (IHD)	1.2	4.8	5	5.0
Hurricane Destruction Potential (HDP)	35.8	86.3	75	72.7
Net Tropical Cyclone Activity (NTC)	64.1%	116.4%	100%	100%

we do not expect the current ENSO warming to be of sufficient strength to cause a substantial reduction in this season's hurricane activity. Three additional considerations which argue against the development of a strong El Niño event this year include the following:

1. A westerly QBO year during 2002. El Niño intensification is typically weaker during the west phase of the QBO.
2. The PDO is negative. This condition of cold water temperature off the west coast of North America is expected to be an inhibiting influence for the development of a strong El Niño for this year.
3. El Niño like trends in related subsurface (equatorial Pacific thermocline) values since February have been small and are not favored for the formation of a large El Niño event.

Table 4: SSTA (°C) in the equatorial central and east Pacific during the last three-months. See Figure 1 for the locations of the Nino domains.

Month (2002)	Nino 4	Nino 3.4	Nino 3	Nino 1-2
January	0.7	0.0	–0.5	–0.9
February	0.8	0.3	–0.2	0.0
March	0.6	0.2	0.1	1.1
April	0.7	0.3	0.2	1.1
May	0.8	0.5	0.2	0.6
March to May Changes	0.05	0.15	0.25	0.3

5 Changes in the Atlantic

Since January 2002 the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) have been strongly positive. This condition is indicative of additional processes which tend to mask many of the effects of the strong Atlantic thermohaline circulation that has been present since 1995. North Atlantic surface trade winds are weaker during strong thermohaline conditions. These weaker winds are associated with the development of warmer Atlantic SSTA patterns and enhanced hurricane activity. By contrast, the enhanced North Atlantic surface winds which attend cooler SSTAs and reduce hurricane activity, occur when the NAO and AO are strong as during the last five months. Although in the Atlantic thermohaline circulation swings back and forth on multidecadal time scales, additional shorter term processes and effects can alter (cool) Atlantic SST conditions over appreciable areas for periods of several years. These intervals may be quite atypical of the overall multi-decadal period within which they reside. An example of one of these shorter term fluctuations was 1988-89 during the 25-year period of 1970-1994 when the thermohaline circulation was evaluated to have been very weak. The North Atlantic SSTA patterns in 1988-89 were warmer and a-typical of the overall weak thermohaline period of 1970-1994. The hurricane seasons of 1988-89 were observed to be active and not typical of the generally below average hurricane seasons of the 1970 to 1994 period. We had thought in 1989 that the very weak Atlantic thermohaline circulation of 1970-1987 might be reverting to a stronger one. This proved not to be the case. The Atlantic reverted to quite weak thermohaline conditions for another five years (1990-1994) before breaking out into a new longer-period stronger mode in 1995. We believe that 2002 is experiencing a temporary masking of strong thermohaline circulation and that within a year or two we will again see SST distribution more typical of stronger thermohaline circulation patterns and above average hurricane activity. This evaluation is the primary reason for our downward revision of our 5 April 2002 forecast.

6 Analog Based Estimates of Hurricane Activity During 2002

Certain years in the historical record have winter-spring global oceanic and atmospheric trends substantially similar to those observed thus 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 linkages involved with these relationships are as yet not well understood, they are, through their lag associations, useful for extended range prediction. Hence, for this (31 May) extended range forecast, we subjectively project expected trends in atmospheric and oceanic conditions for the coming August through October 2002 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 summer-fall trends are similar to observed/expected 2002 trends for several key regional and global ocean/atmosphere conditions. The four analog years are 1951, 1953, 1957, and 1980. Each of these analog years had a weak to moderate El Niño, westerly QBO and generally neutral Atlantic SSTA conditions. Three of these four 2002-analog seasons had above-average (by measure of NTC) hurricane activity (see Table 5). We thus can estimate that 2002 TC activity may approximate average values for these three analogs years. (Note that this analog technique has yielded more reliable forecasts since the mid-1990s than have our statistical schemes, all of which indicated lower than observed levels of hurricane activity.) We believe that this analog approach is more reliable, and we have chosen to weigh it above that of our statistical schemes.

7 Comparison of Forecast Techniques

Table 6 provides a comparison of all of our forecast techniques along with the final adjusted forecast and the last 51-year climatology. Columns 1-2 give our 31 May statistical forecasts where last year's measured dry African rainfall is included and where it is assumed that African rainfall (appearing to be unreliable in recent years) is assumed to be normal. Note that this greatly raises

Table 5: 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
1980	11	60	9	38	2	7.25	126	129
Mean	10.8	55	6.5	28.2	2.2	5.7	91	113
2002 Forecast	11	55	6	25	2	5	75	100

our statistical numbers. Column 3 is our analog scheme, column 4 is our adjusted final 31 May forecast. Column 5 gives the last 50-year climatology.

Table 6: Comparison of all our forecast techniques along with our final 31 May 02 adjusted forecast.

Full Forecast Parameter	(1) 11 June Statistical Scheme (with measured Dry African Rain	(2) 1 June Statistical Scheme (with assumed Ave. African Rain	(3) Analog Scheme	(4) Adjusted 31 May Actual Fcst	(5) 1950-2000 Climatology
Named Storms (NS)	12.0 (3)	10.7	10.8	11	9.6
Named Storm Days (NSD)	17.5 (6)	38.8	55.0	55	49.1
Hurricanes (H)	3.2 (6)	5.5	6.5	6	5.9
Hurricane Days (HD)	15.3 (6)	28.2	28.2	25	24.5
Intense Hurricanes (IH)	1.4 (5)	2.6	2.2	2	2.3
Intense Hurricane Days (IHD)	1.2 (3)	4.8	5.7	5	5.0
Hurricane Destruction Potential (HDP)	35.8 (5)	86.3	91	75	72.7
Net Tropical Cyclone Activity (NTC) constructed for first six parameter forecast values	64.1 (5)	116.4	113	100	100

8 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 will never be able to be accurately forecast months in advance, the seasonal probability of landfall can be forecast with useful 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 7) 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 six months of the prior year. A decreasing weighting is given to each of these three criteria.

Warm SSTA* values generally indicate greater Atlantic hurricane activity, especially for major hurricanes. Hence, Atlantic basin NTC can be skillfully predicted and the recent strength of the Atlantic Ocean thermohaline circulation can be inferred from positive SSTA values in the North Atlantic during recent years. These relationships are then utilized to make estimates of landfall probability for the U.S. coast. The current value of SSTA* is 91. Following the discussion in Section 4 it is likely that the very high value of SSTA* = 91 which has been constructed from the past six years of very warm North SST will be too high and unrepresentative of 2002 conditions. In light of the unexpected high values of Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) since January which have caused the Atlantic SSTs to be cooler than they have been in recent seasons we have decided to reduce the very high SSTA* value of 91 to a value of half this amount or 45. This leads to a new value of NTC + SSTA*. We now anticipate an NTC for this season of 100, and with a SSTA* of 45 will yield a combination of NTC + SSTA* of 100 + 45 = 145.

As shown in Table 7, 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 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 + SSTA* 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 + SSTA* saw only three such intense hurricane landfall events, resulting in a difference of 8 to 1.

Table 7: 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

Tables 8 and 9 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 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 also shown in Fig. 2.

Figure 3 gives a flow diagram outlining the procedures by which these landfall forecasts are

Table 8: 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 9: 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

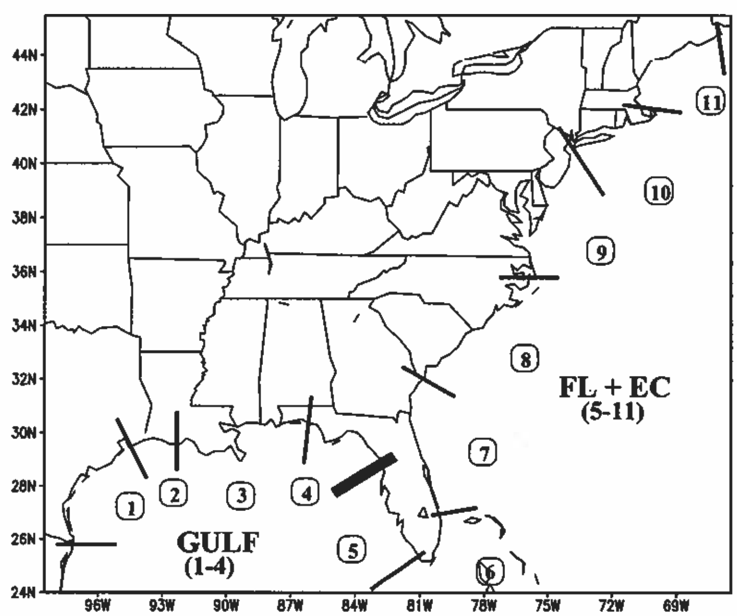

Figure 2: Location of the 11 coastal regions for which separate hurricane landfall probability estimates are made. The heavy bar delineates the boundary between the Gulf (regions 1-4) and the Florida Peninsula and East Coast (regions 5-11).

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 10 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 forecast NTC activity for 2002 (100) is expected to be about that of 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 significantly higher percentage of Atlantic basin major hurricanes cross the Peninsula Florida and the U.S. East Coast.

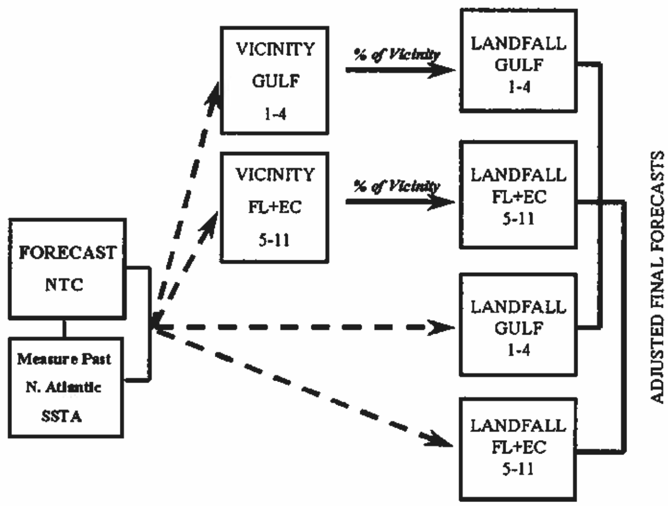

Figure 3: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations from U.S. hurricane landfall measurements of the last 100 years.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

Table 10: Estimated probability (expressed in percent) of one or more U.S. landfalling tropical storms (TS), category 1-2 hurricanes, 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)	83% (80)	75% (68)	63% (52)	91% (84)	98% (97)
Gulf Coast (Regions 1-4)	64% (59)	48% (42)	35% (30)	67% (61)	88% (83)
Florida plus East Coast (5-11)	54% (51)	52% (45)	42% (31)	73% (62)	88% (81)

9 Increased Level of Atlantic Basin Hurricane Activity During the Last Seven Years - But With Concurrent 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 the mean conditions of the last 50 years. This sort of trend is well associated with increased major hurricane activity in the Atlantic basin, both during the last seven years and in prior decades. 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 atmospheric circulation features during the last seven years previously associated with a prominent shift to Atlantic hurricane-enhancing circulation patterns. 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.

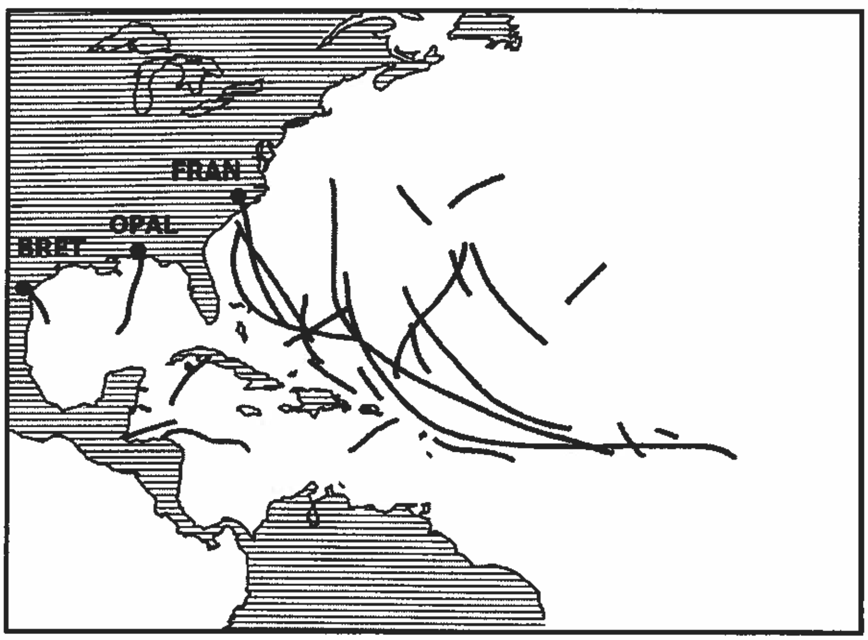

Figure 4: Intense (Cat 3-4-5) hurricane tracks during the period from 1995-2001. Note that despite twenty-seven intense hurricanes during this period, only three (Bret, Opal and Fran) made US landfall. Bret made landfall at the least vulnerable location in the US, and Opal and Fran made landfall in areas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

Despite El Niño-linked suppression 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 presented in the Appendix. Table 11 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 172. 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.

Table 11: 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

Good fortune has been manifest during the last seven years in the form of frequent upper-air trough along the U.S. East Coast during much of each hurricane season. The presence of these upper-level troughs have caused a large portion of the west Atlantic's northwest moving 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 even 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.

10 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 basis for such an interpretation of the recent upward shift in Atlantic hurricane activity. Please see our recent 20 November 2001 verification report (http://tropical.atmos.colostate.edu/forecasts/index.html) for more discussion on this subject.

11 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 for any one location along the coast are very low and reflect the fact that, in any one season, most U.S. coastal areas are unlikely to feel the effects of a hurricane even during the most active seasons. Conversely, it must also be emphasized that a low landfall probability does not insure that a hurricane will not come ashore at any specific location. 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.

12 Forthcoming Update Forecast of 2002 Hurricane Activity

We will issue an updated version of this 2002 Atlantic basin hurricane activity forecast on 7 August 2002, just before the start of the most active portion of the Atlantic hurricane season. This 7 August forecast will also include separate one-month forecasts for August-only and September-only hurricane activity. These monthly forecasts will also include one-month forecasts 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)

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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