# EXTENDED RANGE FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND U.S. LANDFALL STRIKE PROBABILITY FOR 2003

The recent upturn in Atlantic basin hurricane activity which began in 1995 is expected to continue through 2003. We anticipate an above-average probability for Atlantic basin tropical cyclones and U.S. hurricane landfall.

(as of 4 April 2003)

This forecast is based on new research by the authors, along with current meteorological information through March 2003

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[This forecast as well as past forecasts and verifications are available via the World Wide Web: http://tropical.atmos.colostate.edu/forecasts/index.html] — also,

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

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## ATLANTIC BASIN SEASONAL HURRICANE FORECAST FOR 2003

| Forecast Parameter and 1950–2000 Climatology (in parentheses) | 6 December 2002 | 4 April 2003 |
|---|---|---|
| Named Storms (NS) (9.6) | 12 | 12 |
| Named Storm Days (NSD) (49.1) | 65 | 65 |
| Hurricanes (H)(5.9) | 8 | 8 |
| Hurricane Days (HD)(24.5) | 35 | 35 |
| Intense Hurricanes (IH) (2.3) | 3 | 3 |
| Intense Hurricane Days (IHD)(5.0) | 8 | 8 |
| Hurricane Destruction Potential (HDP) (72.7) | 100 | 100 |
| Net Tropical Cyclone Activity (NTC)(100%) | 140 | 140 |

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

1) Entire U.S. coastline – 68% (average for last century is 52%)

2) U.S. East Coast Including the Florida Peninsula – 48% (average for last century is 31%)

3) Gulf Coast from the Florida Panhandle westward to Brownsville – 38% (average for last century is 30%)

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

## DISTINCTION BETWEEN CSU SEASONAL HURRICANE FORECASTS AND THOSE ISSUED BY NOAA

Seasonal hurricane forecasts have now been issued for 20 years by the tropical meteorology research group of Prof. William Gray of the Department of Atmospheric Science, Colorado State University (CSU). The forecasts, which are issued in December of the prior year, and in April, June, August and September of the current year, have steadily improved through continuing research. These forecasts now include predictions of Atlantic basin activity and U.S. and Caribbean hurricane landfall probabilities for seasonal as well as individual monthly periods.

The National Oceanic and Atmospheric Administration (NOAA) has also recently begun to issue Atlantic basin seasonal hurricane forecasts. The NOAA forecasts are independent of our CSU forecasts although they utilize prior CSU research augmented by their own insights. The NOAA and the CSU forecasts will typically differ in some aspects and details. Chris Landsea and Eric Blake, former CSU project members presently employed by NOAA, have made important contributions to both forecasts.

# 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 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 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 five 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 2003 indicates that the 2003 Atlantic hurricane season will be an active one. We estimate that 2003 will have about 8 hurricanes (average is 5.9), 12 named storms (average is 9.6), 65 named storm days (average is 49), 35 hurricane days (average is 24.5), 3 intense (category 3-4-5) hurricanes (average is 2.3), 8 intense hurricane days (average is 5.0) and a Hurricane Destruction Potential (HDP) of 100 (average is 71). We expect Atlantic basin Net Tropical Cyclone (NTC) activity in 2003 to be about 140 percent of the long-term average. The probability of U.S. major hurricane landfall is estimated to be 30 percent above the long-period average. We foresee an above-average probability of U.S. and Caribbean landfall. This 1 April forecast is based on an older (1994) statistical scheme and a newly devised extended range statistical forecast. We also utilize an analog technique which selects prior years which have global conditions similar to this year. Our final forecast consists of a qualitative adjustment of these three separate methodologies. The influence of El Niño conditions are implicit wihtin our statistical schemes. We do not utilize a specific ENSO forecast as one of our predictors. We anticipate that the current weakening El Niño will be largely dissipated by this summer.

# 1 Introduction

This is the 20th year in which the first author has made forecasts of the coming season's Atlantic basin hurricane activity. Our Colorado State University research project has shown that a sizable portion of the year-to-year variability of Atlantic tropical cyclone (TC) activity can be hindcast with skill significantly exceeding climatology. These forecasts are based on two statistical methodologies derived from 45 (older scheme) and 52 (newer scheme) years of past data and a separate study of analog years which have similar precursor circulation features to this year. Qualitative adjustments are added to accommodate additional processes which may not be explicitly represented by our statistical analyses. These evolving forecast techniques are based on a variety of climate-related global and regional predictors previously shown to be related to the forthcoming seasonal Atlantic tropical cyclone activity and landfall probability.

# 2 Forecast Methodology

We believe that seasonal forecasts must be based on methods showing significant hindcast skill in application to long periods of prior data. It is only through hindcast skill that one can demonstrate that seasonal forecast skill is possible. This is a valid methodology provided the atmosphere continues to behave in the future as it has in the past. We have no reason for thinking that it will not. Our initial early April seasonal hurricane forecast scheme demonstrated hindcast skill for the period of 1950–1994. Our new, recently developed forecast scheme uses more hindcast years (1950-2001) and shows improved hindcast skill and better physical insights into why such precursor relationships have an extended period memory.

## 2.1 Newly Developed 1 April Forecast Scheme

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 cooperative research groups are developing similar reanalysis products. Many of these reanalysis data sets are available from the late 1940s and offer exciting and unique opportunities for the development of new and skillful extended range empirical climate forecasts. This development is very useful for the improvement of both empirical climate prediction and understanding.

Through extensive analyses of NOAA/NCEP reanalysis products, Phil Klotzbach of our forecast team has recently developed a new set of 1 April extended range predictors which shows superior hindcast prediction skill over our previous 1 April forecast scheme. Our earlier 1 April statistical scheme used West African rainfall data as an important predictor. We do not understand why, but the previously observed (1950-1994) strong association between West Africa rainfall and Atlantic hurricanes has not worked since 1995. Our newer 1 April forecast scheme does not use West African rain as a predictor.

The location of each of these new predictors is shown in Fig. 1. The pool of six predictors for this new extended range forecast is given in Table 1a, and forecast values based on the new April 1 forecast scheme are given in Table 1b. Strong statistical relationships can be extracted via combinations of these predictors (which are available by the end of March) and the Atlantic basin hurricane activity occurring that summer and fall.

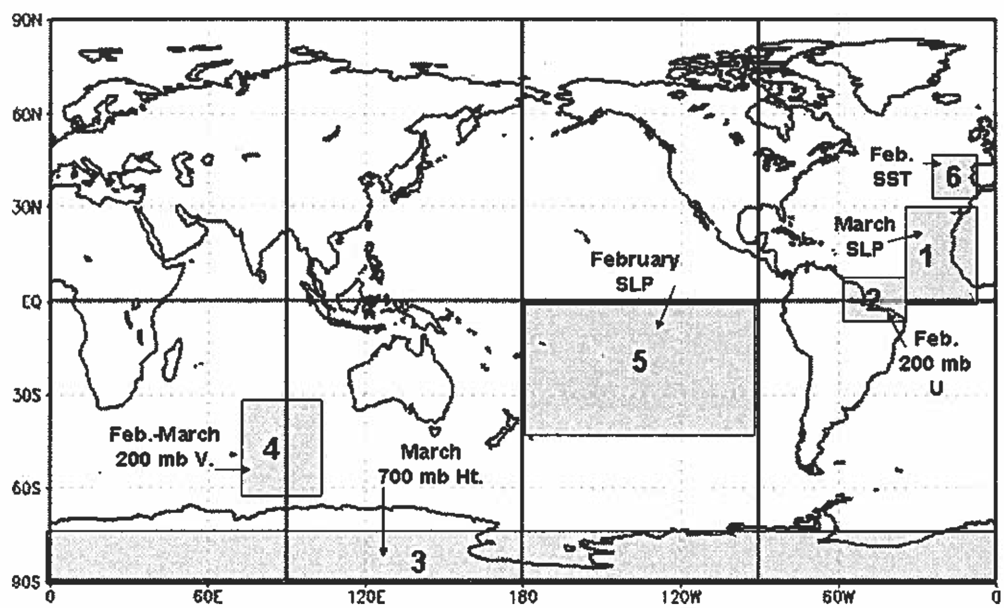


Figure 1: Location of predictors for our new early April forecast for the 2003 hurricane season.

## 2.2 Physical Associations among Predictors Listed in Table 1

Brief descriptions of our new early April predictors follow:

Table 1: (a) Listing of our new 1 April 2003 predictors for this year's hurricane activity. A plus (+) means that positive values of the parameter indicate increased hurricane activity this year, and a minus (–) means that positive values of the parameter indicate decreased hurricane activity this year.

| | 2003 Observed Values |
|---|---|
| (1) – March SLP (0–30°N, 7.5-35°W) (–) | 0.0 SD |
| (2) – February 200 MB U (5°S-10°N, 35-55°W) (–) | +0.6 SD |
| (3) – March 700 mb geopotential height (75-90°S, 0-360°) (+) | +0.2 SD |
| (4) – February-March 200 MB V (35-62.5°S, 70-95°E) (–) | +0.6 SD |
| (5) – February SLP (0-45°S, 90-180°W) (+) | +0.2 SD |
| (6) – February SST (35-50°N, 10-30°W) (+) | +0.7 SD |

Table 1: (b) New 1 April statistical forecast for 2003.

| Predictors | New 1 April Statistical Forecast for 2003 |
|---|---|
| Named Storms (NS) | 9.8 |
| Named Storm Days (NSD) | 46.9 |
| Hurricanes (H) | 5.9 |
| Hurricane Days (HD) | 20.4 |
| Intense Hurricanes (IH) | 2.3 |
| Intense Hurricane Days (IHD) | 5.6 |
| Hurricane Destruction Potential (HDP) | 63 |
| Net Tropical Cyclone Activity (NTC) | 104 |

Predictor 1. March SLP in the Eastern Tropical and Subtropical Atlantic (-)

(0-30°N, 7.5-35°W)

Low pressure in this region implies that the Azores High is weaker than normal and that consequently, trade winds across the Atlantic Ocean are weaker. Weaker trade winds reduce upwelling in the tropical Atlantic off northwest Africa and act to keep the ocean's temperature warmer than normal. The reduced trade wind-warm sea surface temperature feedback is likely to persist through the remainder of the spring and summer (Knaff 1998). Warm sea surface temperatures are known to be favorable for enhanced tropical cyclone activity.

Predictor 2. February 200 MB U in the Central Tropical Atlantic (-)

(5°S-10°N, 35-55°W)

Easterly upper-level zonal wind anomalies off the northeast coast of South America imply that the upward circulation associated with the Walker Circulation of a warm ENSO event has shifted westward and that cool La Niña conditions are likely to be present for the next 4-6 months. El Niño conditions shift the upward portion of the Walker Circulation eastward and cause 200 mb westerly anomalies in this area. Such 200 mb westerly wind anomalies are associated with increased upper-level divergence in the East Pacific which occurs with warm ENSO conditions.

Predictor 3. March 700 MB Antarctic Geopotential Height (+)

(75-90°S, 0-360°)

High heights near the South Pole result in weaker westerlies throughout most of the Southern Hemisphere midlatitudes. Anomalously cool upper-level temperatures and lower geopotential heights throughout the tropics are also associated with this feature. Cool tropical temperatures are associated with cool ENSO conditions. Weaker zonal winds and a more globally asymmetric Hadley Cell circulation help reinforce cool ENSO conditions.

Predictor 4. February-March 200 MB V in the Southern Indian Ocean (-)

(35-62.5°S, 70-95°E)

Anomalous southerly flow at 200 mb in the southern Indian Ocean is associated with a northeastward shift of the South Indian Convergence Zone (SICZ) (Cook 2000), a more longitudinally concentrated upward branch of the Hadley Cell near Indonesia and warm sea surface temperatures throughout most of the Indian Ocean. This implies that warm ENSO conditions have likely been prevalent throughout the past several months due to the lag teleconnected effect of a warm Indian Ocean with a warm eastern Pacific Ocean. Strong lag correlations ($r > 0.4$) with this predictor indicate that a change in phase of ENSO from warm to cool is likely during the coming summer if southerly 200 mb wind anomalies are observed in February-March.

Predictor 5. February SLP in the Southeast Pacific (+)

(0-45°S, 90-180°W)

High sea level pressure in the eastern Pacific south of the equator indicates a positive Southern Oscillation Index (SOI) and stronger-than-normal trade winds across the Pacific. Increased trades drive enhanced upwelling off the west coast of South American typical of La Niña conditions. Cool sea surface temperatures associated with this higher pressure tend to persist throughout the spring and summer thereby reducing vertical wind shear over the tropical Atlantic and providing more favorable conditions for tropical cyclone development.

Predictor 6. February SST off the Northwestern European Coast (+)

(35-50°N, 30-50°W)

Warm sea surface temperatures off the northwest coast of Europe correlate quite strongly with warm sea surface temperatures across the entire North Atlantic Ocean. A warm North Atlantic Ocean indicates that the thermohaline circulation is likely stronger than normal and the Azores subtropical high and trade wind strength across the Atlantic are weaker than normal. Weaker trade winds induce less upwelling which keeps the tropical Atlantic warmer than normal. This pattern tends to persist throughout the spring and summer and implies a warmer tropical Atlantic during the following hurricane season.

### 2.3 Hindcast Skill of New 1 April Scheme

Table 2 shows the degree of hindcast variance explained by our new 1 April forecast scheme based on a 52-year developmental dataset (1950-2001). To reduce overfitting, we use no more than five predictors. Note that there is substantial independent (jackknife) skill for predictions of NTC and HDP.

The 1 April forecast picks the best combination of five predictors from a pool of six predictors or until the hindcast variance explained increases less than three percent through the addition of another predictor.

Table 2: Variance explained based upon 52 years (1950-2001) of hindcasting.

| Variables Selected | Variance ($r^2$) Explained | Jackknife Skill (Year of Forecast Not in the Developmental Data Set) |
|---|---|---|
| NS- 4 5 6 | 0.372 | 0.277 |
| NSD- 2 4 5 6 | 0.571 | 0.482 |
| H- 1 3 4 5 | 0.499 | 0.398 |
| HD- 1 2 3 4 5 | 0.621 | 0.515 |
| IH- 1 4 5 6 | 0.563 | 0.483 |
| IHD- 4 5 6 | 0.460 | 0.388 |
| HDP- 1 2 4 5 6 | 0.629 | 0.531 |
| NTC- 1 3 4 5 6 | 0.650 | 0.570 |

# 3 New 1 April Forecast Scheme as Related to the Basic Bi-Modal Functioning of the Ocean-Atmosphere

The ocean-atmosphere global circulation has been observed to deviate from its long-term climatological average in two basic modes of opposite activity. These modes involve the temperature gradient between the tropics and poles. Tropical-polar temperature gradients are observed to vary inversely with the strength of the Atlantic Thermohaline Circulation (ATC).

A) Atlantic Thermohaline Circulation Weak:
The temperature gradient from the tropics to the polar regions becomes greater than average. The tropics are warmer than normal, and the poles are colder than normal. It is during this period that mid-latitude westerly winds are anomalously strong, and the AO and NAO are positive. The Eastern Hemisphere warms relative to the Western Hemisphere. El Niño activity is more frequent. The temperature of the globe becomes slightly warmer than normal. A weaker ATC results in less ocean energy being advected to the high latitudes in the Atlantic. This causes more energy to be concentrated in the tropics. This is the general condition we have been in for the quarter century periods between 1900-1925 and 1970-1994. It is at these times that Atlantic basin hurricane activity (particularly major or intense hurricane activity) is reduced.

B) Atlantic Thermohaline Circulation Strong:
The opposite of the above conditions occurs when the ATC is stronger than average. A stronger thermohaline circulation causes more ocean energy to be advected out of the tropics into the far North Atlantic. This reduces the tropical to polar atmospheric and oceanic temperature gradient and results in the earth's surface becoming slightly cooler than average. Although the small area of the Arctic is anomalously warm, the much larger area of the tropics, in net, loses more energy than the Arctic gains. The net effect is a slight cooling of the globe. It is during these times that Atlantic basin hurricane activity (particulary major or intense hurricane activity) becomes enhanced.

The atmosphere and the ocean are observed to swing back-and-forth between these two basic modes of circulation on yearly to multi-decadal time scales. We believe that the primary driver for these back-and-forth swings of global circulation is the varying strength of the ATC.

We hypothesize that the ATC variations on multi-decadal time scales is primarily driven by variations in Atlantic subtropical salinity content. Salinity will gradually build up when the ATC is weaker than average and will gradually be reduced when the ATC is stronger than average. Thus, the variation of salinity in the Atlantic subtropics is believed to be the primary driver for climate changes on mutli-decadal time scales that have been well documented in ice-core and ocean floor core measurements.

There is an inverse relationship between the strength of the ATC and the sign of the rate of change of Atlantic sub-tropical salinity. These salinity changes bring about the observed long period back-and-forth swings of the ATC and the accompanying lag response in the alteration of the functioning of the whole global ocean-atmosphere system. When the ATC is weaker than average, less salt is being advected to the Arctic region for subsidence. This causes a gradual buildup of oceanic salt content underneath the sub-tropical Atlantic anticyclones. The opposite occurs when the ATC is strong.

Global parameter changes occurring with these two basic global modes of atmosphere-ocean circulation are shown in Figure 2.

| Strong Atlantic Thermohaline | | Weak Atlantic Thermohaline |
|---|---|---|
| + | North Atlantic Sea Surface Temperature (SSTA) | — |
| — | Arctic Oscillation (AO) | + |
| — | North Atlantic Oscillation (NAO) | + |
| — | Pacific North America (PNA) Oscillation | + |
| — | Pacific Decadal Oscillation (PDO) | + |
| — | El Nino Activity | + |
| — | Symmetry of Southern Hemisphere Polar Vortex | + |
| — | Longitudinal Symmetry of the Global Hadley Cell | + |
| + | Indian Monsoon Rainfall | — |
| + | West Sahel Rain | — |
| + | Atlantic Hurricane Activity | — |
| — | Global Surface Temperature | + |

Figure 2: Features typically associated with a strong (left) and weak (right) thermohaline circulation, respectively. A plus (+) indicates that this parameter is typically stronger than average, and a minus (-) indicates that this parameter is typically weaker than average.

The majority of the six forecast parameters listed in Table 1 are global responses related to the bimodal functioning of the ocean-atmosphere system. The basic mode of stronger ATC and reduced tropical to polar temperature gradient that we have been in since 1995 is the mode that causes an enhancement of Atlantic basin hurricane activity. It is to be noted that Atlantic basin hurricane activity during the last eight years (1995-2002) has been the highest of any eight consecutive year period on record.

## 4 Analog-Based Predictors for 2003 Hurricane Activity

Certain years in the historical record have global oceanic and atmospheric trends which are substantially similar to 2003. These years also provide useful clues as to likely trends in activity that the forthcoming 2003 hurricane season may bring. For this 1 April forecast, we project atmospheric and oceanic conditions for August through October 2003 and determine which of the prior years in our database have distinct ocean-atmosphere features which are similar to current 2003 conditions. Table 3 lists our analog selections.

Analog Years. We have found four prior hurricane seasons since 1949 which appear to be similar to current March 2003 conditions and projected 2003 August-October conditions. Specifically, we expect the North Atlantic (50-60°N, 10-50°W) warm SST anomalies to remain warm for the 2003 hurricane season indicative of a stronger than average thermohaline circulation. This assumption carries the implication that the recent global atmosphere and ocean circulation regimes which have been present in all but two of the last eight years will continue to be present in 2003. In addition, we look for years that had warm ENSO conditions the previous fall and winter with cooling sea surface temperatures in the eastern and central Pacific observed during the summer of the year being selected. Finally, years that tended to be in the east phase of the QBO were selected.

There were four hurricane seasons since 1949 with characteristics similar to what we have observed through March 2003 and what we anticipate will occur in the summer/fall 2003 period. These best analog years are 1952, 1954, 1958 and 1998 (Table 3). We expect that the 2003 seasonal hurricane conditions will be slightly above the average values for these four analog years due to an anticipated active thermohaline circulation. Thus, based on this analysis, we expect 2003 to be an active hurricane season and in line with the average of six of the last eight years (1995-1996; 1998-2001). We anticipate 2003 to be considerably more active than the average season during the inactive 1970-1994 period or during the two recent years of El Niño activity (1997 and 2002).

Table 3: Best analog years for 2003 with the associated hurricane activity listed for each year.

| | NS | NSD | H | HD | IH | IHD | HDP | NTC |
|---|---|---|---|---|---|---|---|---|
| 1952 | 7 | 40 | 6 | 23 | 3 | 4.00 | 70 | 93 |
| 1954 | 11 | 52 | 8 | 32 | 2 | 8.50 | 91 | 123 |
| 1958 | 10 | 56 | 7 | 30 | 4 | 8.25 | 94 | 133 |
| 1998 | 14 | 88 | 10 | 49 | 3 | 9.50 | 149 | 168 |
| Mean | 10.5 | 59.0 | 7.8 | 34.0 | 3.0 | 7.50 | 101 | 129 |
| 2003 Forecast | 12 | 65 | 8 | 35 | 3 | 8 | 100 | 140 |

## 5 Earlier 1 April Statistical Forecast Scheme

Our earlier 1 April hurricane forecast scheme was developed in 1994, and the initial 1 April forecast was made in 1995. The current set of predictors for this earlier 1 April forecast scheme are shown in Table 4. The statistical skill of this forecast in hindcast data for the years 1950-1997 is summarized in Table 5 with the specific number of predictors (three to six) used for each seasonal forecast parameter given in parentheses. We attempted 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 stopped adding predictors when the hindcast improvement did not significantly raise the total explained variance.

Table 4: Earlier pool of predictors (and their values as of 1 April 2003) used to develop the 2003 prediction based on meteorological data available through March 2003.

| For 1 April 2003 Prediction (see Figs. 1a-c for location) | 2003 Specific 1 April Fcst Parameters |
|---|---|
| 1) U50 (Mar extrapolated to Sep) – Actual | –7 m/s |
| 2) U30 (Mar extrapolated to Sep) – Actual | –18 m/s |
| 3) AbsShe - absolute shear (Mar extrapolated to Sep) | 11 m/s |
| 4) Balboa - U50 (June-Aug, 2002) | -2 m/s |
| 5) Rain - Aug-Nov Guinea Coastal Area | +0.25 SD |
| 6) Rain - June-Sep West Sahel Area | –1.00 SD |
| 7) R-ON - Ridge SLPA (Oct to Nov) | –0.55 SD |
| 8) R-M - Ridge SLPA (Mar) | –1.35 SD |
| 9) NATL (Jan to Mar) SSTA (50-60°N, 10-50°W) | +0.45°C |
| 10) TATL (Jan to Mar) SSTA (8-22°N, 10-50°W) | +0.00°C |
| 11) Nino 3.4 Mar SSTA | +0.60°C |
| 12) Nino 3.4 (Mar minus Feb) SSTA | –0.20°C |
| 13) Nino 4 (Jan, Feb, Mar minus Oct, Nov, Dec) SSTA | –0.30°C |

Table 6 lists our 1 April statistical predictions for the 2003 hurricane season. These include the variable (column 1) and fixed predictors (columns 2 and 3) and the comparison with climatology (column 4). Since the observed shift of Atlantic Ocean SST in 1995 (and implied increase in strength of the ATC), our statistical forecasts have tended to consistently underpredict Atlantic basin hurricane activity.

We have less confidence in the earlier 1 April scheme compared with our new scheme because:

1. Our old scheme includes West African rainfall that has not been a skillful parameter since 1995.
2. Our new scheme has been developed on eight more years of data.
3. Our new scheme has been able to use the recently developed NOAA/NCEP reanalysis data that was not available to us at the time we developed our earlier scheme. The reanalysis has allowed us to more readily search for new forecast parameters.

# 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 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

Table 5: 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 |

Table 6: April 1 statistical forecasts for 2003. 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 Forecast Parameter | Variable Predictor | Fixed predictors<br>4 Predictors | 6 Predictors | 1950-2000 Climatology |
| Named Storms (NS) | 7.2 (4) | 7.2 | 7.2 | 9.6 |
| Named Storm Days (NSD) | 62.4 (5) | 61.2 | 63.6 | 49.1 |
| Hurricanes (H) | 5.8 (4) | 5.8 | 6.9 | 5.9 |
| Hurricane Days (HD) | 23.4 (5) | 24.6 | 12.8 | 24.5 |
| Intense Hurricanes (IH) | 2.0 (4) | 1.4 | 2.4 | 2.3 |
| Intense Hurricane Days (IHD) | 6.7 (3) | 6.9 | 0.9 | 5.0 |
| Hurricane Destruction Potential (HDP) | 48.1 | 39.6 | 43.2 | 72.7 |
| Net Tropical Cyclone Activity (NTC) | 82.9 (6) | 59.5 | 59.0 | 100 |

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 2003 (Table 7) indicates below-average SLPA, giving more credence to our final adjusted forecast of an above-average hurricane season.

Table 7: April 1 multi-month independent statistical prediction of 2003 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-September |
|---|---|---|---|
| SLPA | –0.47 | –0.33 | –0.67 |

## 7 Comparison of Forecast Techniques

Table 8 provides a comparison of all of our forecast techniques along with the final adjusted forecast and climatology. Columns 1-2 give our original 1 April statistical forecasts with our current estimates of West African rain (column 1) and assumed average (SD zero) African rain (column 2) and variable numbers of predictors. Column 3 gives our new 1 April statistical scheme, column 4 is our analog scheme, and column 5 is our qualitatively adjusted final forecast. The last column (6) on the right shows the 1950-2000 seasonal climatology.

Table 8: Comparison of all our forecast techniques along with our final adjusted forecast.

| Full Forecast Parameter | (1) Variable Predictor | (2) Variable Predictors Assuming West African Rainfall SD of Zero | (3) New April Scheme | (4) Analog Scheme | (5) Adjusted 4 April 2003 Actual Fcst | (6) 1950-2000 Climatology |
|---|---|---|---|---|---|---|
| Named Storms (NS) | 7.2 (4) | 8.0 | 9.8 | 10.5 | 12 | 9.6 |
| Named Storm Days (NSD) | 61.2 (5) | 61.2 | 46.9 | 59.0 | 65 | 49.1 |
| Hurricanes (H) | 5.8 (4) | 6.7 | 5.9 | 7.8 | 8 | 5.9 |
| Hurricane Days (HD) | 24.6 (5) | 28.8 | 20.4 | 34.0 | 35 | 24.5 |
| Intense Hurricanes (IH) | 1.4 (4) | 1.4 | 2.3 | 3.0 | 3 | 2.3 |
| Intense Hurricane Days (IHD) | 6.9 (3) | 6.2 | 5.6 | 7.5 | 8 | 5.0 |
| Hurricane Destruction Potential (HDP) | 39.6 | 56.4 | 63 | 101 | 100 | 72.7 |
| Net Tropical Cyclone Activity (NTC) constructed from first six parameters | 59.5 (6) | 75.8 | 104 | 129 | 140 | 100 |

## 8 Discussion

Our analysis through March and the last 50-100 year records indicate that we should have above-average Atlantic basin hurricane season for 2003. We expect the current El Niño event to dissipate by the beginning of the active part (mid-August onward) of the 2003 season and the atmosphere and oceans to return to the average conditions that were experienced in non-El Niño years since 1995 (1995-1996; 1998-2001). We foresee 2003 as being typical of hurricane seasons where the tropical-polar temperature gradient is weaker than average, vertical wind shear is reduced, and consequently hurricane activity is increased.

Note that we are calling for a more active hurricane season than indicated by our two statistical schemes but very much in line with the average of our four analog years. We do not feel that our statistical scheme fully accounts for all the positive environmental conditions that will likely be in place to make this an active hurricane season. These factors include:

1. The very warm North Atlantic SSTA conditions that are indicative of a strong Atlantic thermohaline circulation and the prospects for a significant warming of Atlantic tropical SSTAs by this summer (due to weak Azores High). We are in a new multi-decadal era for hurricane activity that is similar to that of the 1940s and 1950s. In six of the last eight years (1995, 1996, 1998-2001) when El Niño conditions were not present we have seen a yearly average of 9.2 hurricanes, 43 hurricane days, 4.33 major hurricanes and an NTC value of 177.
2. The low values of the March 2003 subtropical ridge (or Azores High) which are indicative of weaker trade winds this coming summer and fall.
3. The anomalously strong trade winds in the tropical eastern Pacific that should lead to the full dissipation of the El Niño event of the last year.
4. Knaff's forecast of below-average SLPA for 2003. This is consistent with the very high SSTA values we are observing and are anticipating for the low and high latitude Atlantic for this summer.

## 9 Landfall Probabilities for 2003

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, statistically, landfall is a function of varying climate conditions, a probability specification has been developed through statistical analyses of all U.S. hurricane and named storm landfall events during the last century (1900–1999). Specific landfall probabilities can be given for all cyclone intensity classes for a set of distinct U.S. coastal regions.

Figure 3 provides a flow diagram showing how these forecasts are made. Net landfall probability is shown linked to the overall Atlantic basin Net Tropical Cyclone activity (NTC; see Table 9) and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation which we infer from recent past years of North Atlantic sea surface temperature anomalies (SSTA*). SSTA* is expressed in units of hundredth ($10^{-2}$) of a °C for the ocean location of (50-60°N, 10-50°W) over the last six years with primary weight given to the most recent year. The long period average of SSTA* is zero.

Higher values of SSTA* indicate a stronger thermohaline circulation and higher amounts of Atlantic hurricane activity, especially for intense or major hurricanes. Atlantic basin NTC can be skillfully hindcast, and the strength of the Atlantic Ocean thermohaline circulation can be inferred from SSTA* which is a measure of North Atlantic SST anomalies over the past few years. The current (March 2003) value of SSTA* is 30 or 0.30°C. Hence, in combination with a prediction of NTC of 140 for 2003, the combination of NTC + SSTA* of (140 + 30)

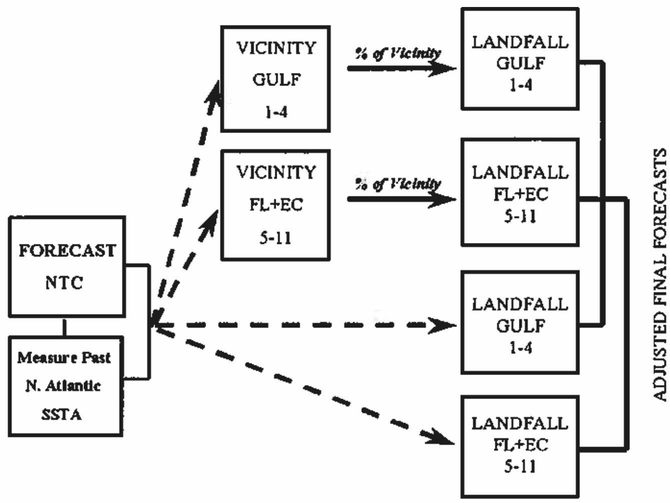


Figure 3: Flow diagram illustrating how forecasts of U.S. hurricane landfall probabilities are made. Forecast NTC values and an observed measure of recent North Atlantic (50-60°N, 10-50°W) SSTA* are used to develop regression equations for U.S. hurricane landfall. Separate equations are derived for the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

yields a value of 170. If NTC + SSTA* were averaged over 50 to 100 years its value would be 100. Regression equations have been developed to relate the seasonal value of NTC+SSTA* during the last 100 years to U.S. landfall probability.

As shown in Table 9, NTC is a combined measure of the year-to-year mean of six indices of hurricane activity, each expressed as a percentage difference from the long-term average. Whereas many active Atlantic hurricane seasons feature no landfalling hurricanes, some inactive years have experienced one or more landfalling hurricanes. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of U.S. hurricane landfall. 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) increased NTC and (2) above-average North Atlantic SSTA* conditions.

Table 9: NTC activity in any year consists of the seasonal total of the following six parameters expressed in terms of their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 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, 5/5.0 = 100, divided by six, yielding an NTC of 107.

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

Table 10 lists strike probabilities for different TC categories for the entire U.S. coastline, the Gulf Coast and Florida, and the East Coast for 2003. The mean annual probability of one or more landfalling systems is given in parentheses. Note that Atlantic basin NTC activity in 2003 is expected to be greater than the long-term average (140), and North Atlantic SSTA* values are measured to be above normal (30 units or 0.30°C). U.S. hurricane landfall probability is thus expected to be above average owing to both a higher NTC and above-average North Atlantic SSTAs. During periods of positive North Atlantic SSTA*, a higher percentage of Atlantic basin major hurricanes cross the Florida and eastern U.S. coastline for a given level of NTC.

Table 10: 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. coast, along the Gulf Coast (region 1-4), and along the Florida and East Coast (Regions 5-11) for 2003. 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 | Named Storms |
|---|---|---|---|---|---|
| Entire U.S. (Regions 1-11) | 85% (80) | 79% (68) | 68% (52) | 93% (84) | 99% (97) |
| Gulf Coast (Regions 1-4) | 66% (59) | 51% (42) | 38% (30) | 70% (61) | 90% (83) |
| Florida plus East Coast (5-11) | 56% (51) | 56% (45) | 48% (31) | 77% (62) | 90% (81) |

## 10 The 1995–2002 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 this recent upward shift in Atlantic hurricane activity can be made. Please see our recent 21 November 2002 verification report for more discussion on this subject.
[http://tropical.atmos.colostate.edu/forecasts/index.html]

## 11 Forecast Theory and Cautionary Note

Our forecasts are based on the premise that those global oceanic and atmospheric conditions which precede comparatively active or inactive hurricane seasons in the past provide meaningful information about 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. The probability of landfall for any one location along the coast is very low and reflects 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. However, it must also be emphasized that a low landfall probability does not insure that hurricanes will not come ashore. Regardless of how active the 2003 hurricane season is, a finite probability always exists that one or more hurricanes may strike along the US coastline or the Caribbean Basin and do much damage.

## 12 Forthcoming Update Forecasts of 2003 Hurricane Activity

We will be issuing seasonal updates of our 2003 Atlantic basin hurricane activity forecast on Friday 30 May (to coincide with the official start of the 2003 hurricane season on 1 June), Wednesday 6 August and Wednesday 3 September 2003. The 6 August forecast will include separate forecasts for 2003 August-only and September-only activity and probabilities of U.S. landfall during these individual months. The 3 September update will include a separate updated forecast for 2003 September-only activity and an outlook for the October-November period. 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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# 15 Verification of Previous Forecasts

Table 7: Summary verifications of the authors' four previous years of seasonal forecasts of Atlantic TC activity between 1999-2002.

| 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 | 145 |
| Major Hurricanes (Cat. 3-4-5) | 4 | 4 | 4 | 4 | 5 |
| Major Hurr. Days | 10 | 10 | 10 | 10 | 15 |
| Net Trop. Cyclone (NTC) 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 (NTC) 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 | 63 |
| 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 (NTC) Activity | 90 | 100 | 120 | 120 | 142 |

| 2002 | 7 Dec 2001 | Update 5 April | Update 31 May | Update 7 August | Update 2 Sept | Obs. |
|---|---|---|---|---|---|---|
| No. of Hurricanes | 8 | 7 | 6 | 4 | 3 | 4 |
| No. of Named Storms | 13 | 12 | 11 | 9 | 8 | 12 |
| No. of Hurricane Days | 35 | 30 | 25 | 12 | 10 | 11 |
| No. of Named Storm Days | 70 | 65 | 55 | 35 | 25 | 54 |
| Hurr. Destruction Potential(HDP) | 90 | 85 | 75 | 35 | 25 | 31 |
| Major Hurricanes (Cat. 3-4-5) | 4 | 3 | 2 | 1 | 1 | 2 |
| Major Hurr. Days | 7 | 6 | 5 | 2 | 2 | 2.5 |
| Net Trop. Cyclone (NTC) Activity | 140 | 125 | 100 | 60 | 45 | 80 |