**EARLY AUGUST FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY AND US LANDFALL STRIKE PROBABILITIES FOR 1999**

**A year for which both overall hurricane activity and US hurricane landfall probability are above average**

This forecast is based on ongoing research by the authors, along with meteorological information through July 1999

By


William M. Gray,* Christopher W. Landsea**, Paul W. Mielke, Jr. and Kenneth J. Berry***

* Professor of Atmospheric Science
** Meteorologist with NOAA/AOML HRD Lab., Miami, FL
*** Professors of Statistics

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

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


6 August 1999

---

# UPDATED 1999 ATLANTIC BASIN SEASONAL HURRICANE FORECAST AS OF 6 AUGUST 1999

Tropical Cyclone Seasonal Forecast for 1999 (Climatological mean values are shown in parenthesis)

| | |
|---|---|
| Named Storms (NS) (9.3) | 14 |
| Named Storm Days (NSD) (46.9) | 75 |
| Hurricanes (H)(5.8) | 9 |
| Hurricane Days (HD)(23.7) | 40 |
| Intense Hurricanes (IH) (2.2) | 4 |
| Intense Hurricane Days (IHD)(4.7) | 10 |

| | |
|---|---|
| Hurricane Destruction Potential (HDP) (70.6) | 130 |
| Maximum Potential Destruction (MPD) (61.7) | 130 |
| Net Tropical Cyclone Activity (NTC)(100%) | 160 |

(These values are the same as those in our initial seasonal forecast for 1999 which was issued on 4 December 1998, 7 April and 4 June 1999)

## SUMMARY OF PROBABILITIES FOR ONE OR MORE 1999 MAJOR HURRICANE LANDFALLS ON THE FOLLOWING COASTAL AREAS. (100-YEAR AVERAGE PROBABILITY VALUES ARE SHOWN IN PARENTHESIS)

1. U.S. East Coast including Peninsula Florida £#54 percent (31%).
2. Gulf Coast from the Florida Panhandle westward to Brownsville £#40 percent (30%).
3. Entire U.S. coastline £#72 percent (50%).
4. Caribbean and Bahamas land areas £#72 percent (51%).
5. East Coast of Mexico £#28 percent (18%).

## DEFINITIONS


ABSTRACT

Information obtained through July 1999 indicates that 1999 Atlantic tropical cyclone activity is likely to be above the 1950-1990 average. Predictions for 1999 include 9 hurricanes (average is 5.8), 14 named storms (average 9.3), 75 named storm days (average is 47), 40 hurricane days (average is 24), 4 intense (category 3-4-5) hurricanes (average is 2.2), 10 intense hurricane days (average is 4.7) and a Hurricane Destruction Potential (HDP) of 130 (average is 71). Collectively, net tropical cyclone activity is expected to be about 160 percent of the long term average. This season is expected to be comparable to the recent busy 1996 and 1998 hurricane seasons but less active than 1995. This report also presents estimates of the probability of U.S. Caribbean basin, and Mexican East Coast hurricane landfall during 1999. Landfall probabilities this year are substantially above the last 100-year average. These forecasts are based on the results of our statistical forecast schemes plus qualitative adjustments which reflect additional effects associated with supplementary global atmospheric and oceanic information which are not yet explicitly incorporated in our statistical models.

# 1 Introduction

Very useful long-range predictive signals exist for Atlantic basin seasonal tropical cyclone activity. Our research shows that a sizeable portion of the season-to-season variability of nine indices of Atlantic tropical cyclone activity can be skillfully estimated in hindcast tests (i.e., skill exceeding climatology) as early as December of the prior year. The forecast is based on experiments which yield prediction schemes for estimating hurricane activity in the following months plus qualitative adjustments for processes not yet incorporated into our statistical models. Our statistical forecast has been developed from hindcast data for the 48-year period spanning 1950-1997. Extended-range predictors include the phase of the stratospheric Quasi-Biennial Oscillation (QBO) of zonal winds at 30 mb and 50 mb (which can be readily extrapolated ten months into the future), two measures of Western Sahel rainfall during the prior year (Figs. 1 and 2), extended-range estimates of El Niño-Southern Oscillation (ENSO) variability (Fig. 2), the October-November strength of the Azores high surface pressure and the configuration of broad scale Atlantic sea surface temperature anomaly patterns and strength of the Azores anticyclone through May (see Fig. 3). A brief summary of these predictor indices and their specific implications for 1999 are provided in the following.

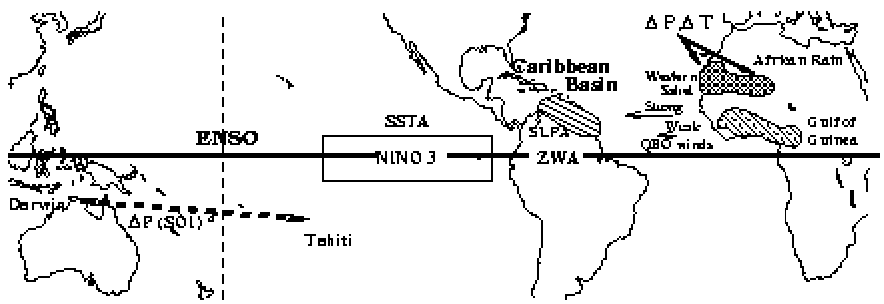


Figure 1: Meteorological parameters used in various versions of our older early August (Gray et al. 1994a) seasonal forecast.

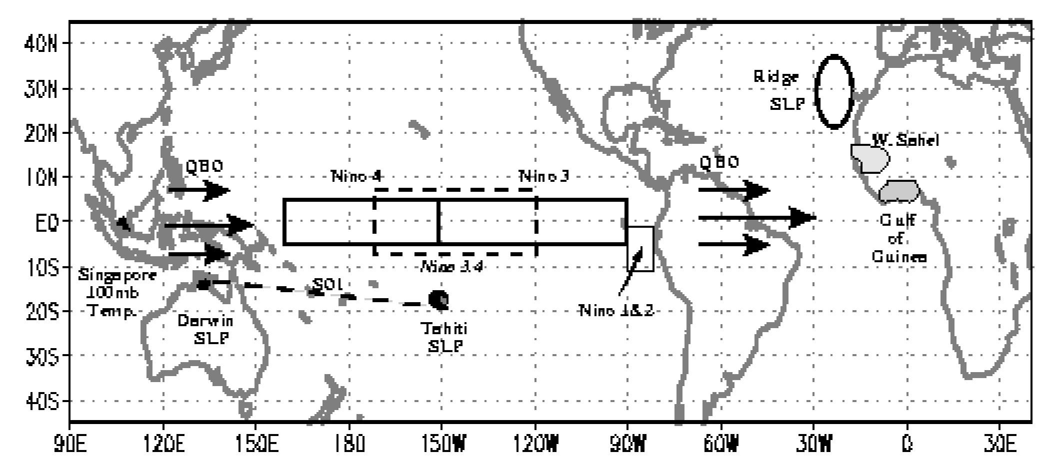


Figure 2: Additional parameters used or consulted in our extended-range forecasts.

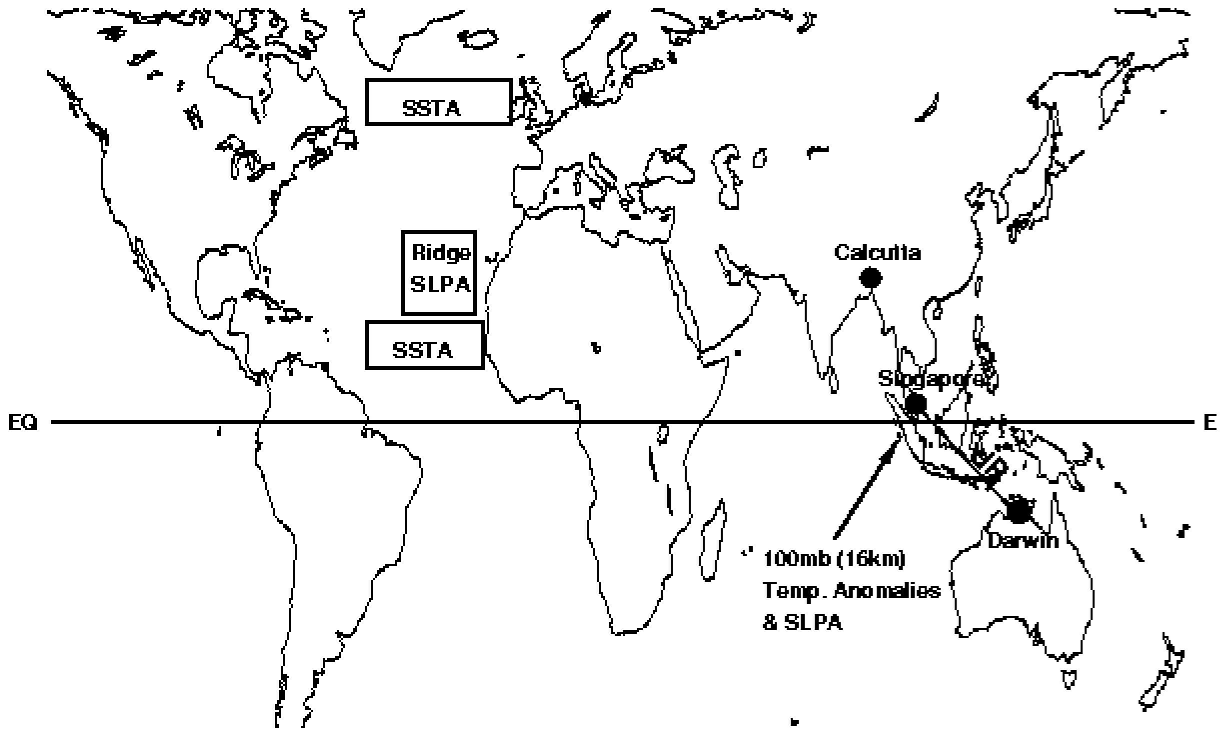


Figure 3: Additional (new) predictors which have recently been noted to be related to the upcoming Atlantic hurricane activity.

a) QBO-Tropical Cyclone Lag Relationship

The easterly and westerly modes of stratospheric QBO zonal winds which encircle the globe over the equatorial regions have a substantial influence on Atlantic tropical cyclone activity (Gray, 1984a; Shapiro, 1989). Typically, 50 to 75 percent more hurricane activity (depending on the specific activity index considered) occurs during those seasons when stratospheric QBO winds between 30 mb and 50 mb are anomalously westerly and, consequently, when the vertical wind shear (ie., the variation of wind speed with height) between these two levels is comparatively small. Conversely, seasonal hurricane activity is typically reduced when the stratospheric QBO is in an easterly phase and the wind shear between 30 mb and 50 mb is large. During 1999 QBO winds are projected to be westerly with small wind shear between these two levels. We extrapolate the 30 mb and 50 mb actual zonal winds near 11-13°N in September 1999 will be near zero at 50 mb (this equates to a +10 m/s zonal wind speed relative to the average September wind) and only -2 m/s at 30 mb (+15 m/s relative wind speed). These anomalously westerly winds should be an enhancing influence on this year's hurricane activity, especially for major hurricane activity.

b) African Rainfall-Tropical Cyclone Lag Relationship

As discussed by Landsea (1991), Gray and Landsea (1992) and Gray et al. (1992), strong predictive signals for seasonal hurricane activity can be found in West African rainfall data for the mid-summer to fall periods of the prior year. These rainfall-linked signals include the following:

(1) June-July Western Sahel Rainfall. The incidence of intense Atlantic hurricane activity is strongly enhanced during those seasons when West Africa June-July Western Sahel rainfall and previous year August-November Gulf of Guinea region rainfall (shaded area in Fig. 2) have above average precipitation. Hurricane activity is typically suppressed if the rainfall in these two regions was below average. This year's rainfall for the Western Sahel during June-July 1999 was -0.21 SD below average and thus is a neutral factor for 1999 hurricane activity. But rainfall amounts are much higher than last year. June rainfall was below average but July rainfall above. We expect this upward trend to continue.

(2) August-November Rainfall in the Gulf of Guinea. Landsea (1991) and Gray and Landsea (1992) documented a strong African rainfall - intense hurricane lag relationship using August through November rainfall along the Gulf of Guinea (see Fig. 2). Intense hurricane activity during seasons following the ten wettest August-November Gulf of Guinea years is many times greater than occurs during hurricane seasons following the ten driest August-November periods in the Gulf of Guinea. Rainfall in the Gulf of Guinea region in August to November 1998 was near average, -0.28 SD.

c) The El Niño-Southern Oscillation (ENSO) relationship

ENSO is one of the principal global scale environmental factors affecting Atlantic seasonal hurricane activity. Hurricane activity is usually suppressed (eg., 1997) during El Niño seasons when anomalously warm water temperatures are present in the equatorial eastern and central Pacific. Conversely, activity tends to be enhanced during seasons with cold (or La Niña) water conditions. We expect the current cool ENSO conditions (June-July Nino 3.4 = -0.70˚C) to persist through the key months of August through October 1999 and thus be an enhancing influence for 1999 hurricane activity. Nearly all ENSO prediction, both statistical and numerical, foresee the continuation of cool ENSO conditions remaining through the fall of this year. And, the last two weeks has seen a reintensification of this cooling.

d) Strength of the Atlantic Subtropical Ridge (Azores High) Between 20-30˚W during (the prior) October-November 1998 and March 1999.

High surface pressure associated with this atmospheric ridge feature is positively related to stronger east Atlantic trade winds which, in turn, enhance upwelling of cold water off the northwest African coast when surface pressure associated with the Azores high is anomalously high. Colder sea surface temperatures created by this enhanced ocean upwelling can cause higher surface pressures to develop during the spring which then create a self-enhancing (positive feedback) response resulting in higher Caribbean pressures during the following summer (Knaff 1998). The long-term memory and feedbacks in this association make it a useful parameter for predicting next year's seasonal hurricane activity. Higher than normal surface pressure during the prior fall is correlated with reduced hurricane activity the subsequent year and vice versa. Ridge strength during this October-November (1998) was slightly above the long-term mean (+0.45 SD) but decreased sharply to a value of -1.49 SD during March of this year. The fall season ridge values were a consequence of a stronger than normal NAO which has now completely reversed itself. Consequently, this effect should be a strong enhancing influence for this year's hurricane activity. Although above average SLPA has been experienced in June and July throughout the Caribbean basin and the Southeast U.S., we are presently seeing a sharp drop in these pressures typical of past active hurricane seasons. We anticipate that Western Atlantic and Caribbean pressure will be below average for August through October of this year.

e) Sea Surface Temperature Anomalies (SSTA) in the North (50-60°N, 10-50°W) and the Tropical Atlantic (6-22°N, 18-80°W) during the last 19 months provide a predictive signal for the following hurricane season. Warmer SSTAs are associated with enhanced hurricane activity and colder SSTAs are associated with reduced seasonal hurricane activity. These North and Tropical Atlantic SSTAs for April through July were near average (-0.2°C in the North and +0.20°C in the tropics). We expect these currently slightly positive SSTAs in the tropical Atlantic to become more positive by the active part of the hurricane season.

# 2 Prediction Methodology

We forecast nine measures of seasonal Atlantic basin tropical cyclone activity including seasonal numbers of the following: Named Storms (NS), Named Storm Days (NSD), Hurricanes (H), Hurricane Days (HD), Intense Hurricanes (IH), Intense Hurricane Days (IHD), the Hurricane Destruction Potential (HDP), Net Tropical Cyclone activity (NTC), and the Maximum Potential Destruction (MPD). Definitions for these indices are given on page 3. For each of these measures, we choose the best three to six predictors (i.e., those resulting in optimum prediction skill) from a group of 16 potential forecast parameters known to be related to tropical cyclone activity. The current set of potential predictors used to develop our early August forecast and their specific values are shown in Table 1.

A number of statistical forecasts are made for each activity parameter. Table 2 lists the seasonal hurricane indices that we predict, the number of forecast parameters we use in each forecast and which forecast parameters these are. Our hindcast skill (between 50-60 percent) for the 48-year period of 1950-97 is shown in the right column. These prediction equations are established for our variable 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. We stop adding predictors when the hindcast improvement of the next best predictor adds less than a 0.025 improvement to the total variance explained. These equations are also constrained to have regression coefficients whose sign match those when analyzed in isolation.

Our early August seasonal forecast scheme has the following general form:

*Adjustment Terms*

(Predicted Amount
of TC Activity = Ave. Season + ( QBO + EN + AR + ONR + MATL , TATL etc. ) (1)
Per Season)

Research has shown that pre-season atmospheric and oceanic conditions associated with active hurricane seasons differ from those associated with inactive seasons. Moreover, hurricanes forming from African waves typically have longer tracks and more days of activity than do hurricanes forming at higher latitudes. Hence, a tendency for more low latitude storms carries specific forecast implications. As hurricane damage typically increases as the square (or higher power) of wind speed, we have developed specific parameters such as HDP and MPD to better reflect this relationship.

Recent research has been directed towards improving our 1 August forecast methodology. This work has involved adding new predictors and altering statistical procedures. A prior version of our 1 August forecast scheme (Gray et al. 1993) was developed on hindcast information for the 41-year period of 1950-1990. It used the same nine predictors for each forecast parameter, did not distinguish between hurricane activity occurring before and after 1 August, and did not predict Maximum Potential Destruction (MPD). We have recently developed a second (and improved) 1 August forecast scheme which includes three new predictors. This scheme also distinguishes between hurricane activity before and after 1 August and includes forecasts of MPD. This new 1 August forecast scheme also employs an improved statistical approach which chooses the best of 16 potential predictors (see Table 1) from a pool of known precursor signals. The predictors are ordered by the amount of added forecast skill which each contributes. This new prediction scheme allows us to reduce the number of predictors from a fixed set of nine to a variable selection of four to seven. This procedure retains greater true skill when applied to independent data. Other improvements involve optimizing our forecasts to include only hurricane activity occurring after 1 August and using 48 rather than 41 years in the developmental data set. This newer prediction scheme is superior to our earlier scheme of five years ago.

Table 1: Listing of the pool of predictive parameters and their estimated values for the early August 1999 prediction based on meteorological data available through July 1999. See Figs. 1 and 3 for the locations of these predictor data.

| Predictive Parameter | |
|---|---|
| 1 = QBO 50 mb 4-month extrapolation of zonal wind at 12°N to Sept. 1999 | 0 m $s^{-1}$ |
| 2 = QBO 30 mb 4-month extrapolation of zonal wind at 12°N to Sept. 1999 | -2 m $s^{-1}$ |
| 3 = QBO absolute value of shear between 50 and 30 mb at 12°N to Sept. 1999 | 2 m $s^{-1}$ |
| 4 = Rgc AN Gulf of Guinea rainfall anomaly (Aug-Nov of 1998) | -0.28 SD |
| 5 = Rws West Sahel rainfall anomaly (June-July 1999) | -0.21 SD |
| 6 = SST3.4 Nino 3.4 SSTA in June-July 1999 | -0.70°C |
| 7 = ZWA June-July 1999 Caribbean basin zonal wind anomaly | -1.2 m/s |
| 8 = SLPA June-July 1999 Caribbean basin sea level pressure anomaly | 0.0 mb |
| 9 = Temp West-East Sahel temperature gradient(Feb-May 1999) | -0.5 SD |
| 10 = NATL North Atlantic SSTA anomaly (50-60°N,10-50°W) (June-July) | -0.2°C |
| | |

| | |
|---|---|
| 11 = SATL South Atlantic SSTA anomaly (5-18˙S,50˙W-10˙E) (June-July) | +0.5˙C |
| 12 = TATL Tropical Atlantic SSTA anomaly (10-22˙N,18-50˙W) (June-July) | +0.2˙C |
| 13 = R-M: Mar Azores surface pressure ridge strength in Mar 1999 | -1.49 SD |
| 14 = R-ON: Azores surface pressure ridge strength in Oct-Nov 1998 | 0.45 SD |
| 15 = D-SST3.4: Nino 3.4 SSTA for June-July minus April-May 1999 | -0.1˙C |
| 16 = NSD-S: Named storm days south of 23.5˙N and east of 75˙W before 1 August | 0 |

Table 2a provides details of the predictors chosen for each of the different forecast measures of activity (NS, NSD, H, etc.) for the whole seasonal forecast. Some predictors (such as Gulf of Guinea rainfall or 30 mb zonal winds) are selected for nearly every measure of activity, while other predictors (such as SLPA or GT) are selected by only one or two of our forecast equations. Table 3 also lists the hindcast measure of agreement or amount of variance explained. Note that for HDP, NTC and MPD we explain nearly two-thirds of the hindcast variance. Table 2b refers to our separate after 1 August forecast. Note that all parameter values are above climatology averages.

Table 2: a: Details of our new 1 August forecast scheme which utilizes a variable selection of predictors so as to maximize forecast skill (hindcast variance explained) while limiting the number of predictors. See Figs. 1-3 for the locations of the predictors. The period 1950-1997 was used to develop these equations.

| **Forecast parameter** | **No. of Predictors** | **Hindcast Measure of Agreement** | **Expected Independent Fcst Skil** | **Predictors** |
|---|---|---|---|---|
| (NS) | 5 | .602 | .463 | $U_{50}$, Shear, $R_g$, R-ON, NSD-S |
| (NSD) | 3 | .518 | .363 | $U_{50}$, $R_g$, NSD-S |
| (H) | 5 | .560 | .406 | $U_{30}$, $R_g$, R-M, R-ON, NSD-S |
| (HD) | 4 | .513 | .341 | $U_{30}$, $R_g$ NATL, NSD-S |
| (IH) | 5 | .574 | .425 | $U_{50}$, $R_s$, $R_g$, D-T, R-M |
| (IHD) | 5 | .573 | .424 | $U_{50}$, $R_g$, D-T, R-M, NSD-S |
| (HDP) | 4 | .507 | .332 | $U_{30}$, $R_g$, NATL, NSD-S |
| (NTC) | 5 | .628 | .497 | $U_{30}$, $R_g$, R-M, R-ON, NSD-S |
| (MPD) | 6 | .672 | .548 | $U_{30}$, $R_g$, NATL, R-M, R-ON, NSD-S |

Table 2: b: 1 August Results - Remainder of Season Forecast

| | hindcast skill | expected skill | Predictors |
|---|---|---|---|
| NS | .543 | .386 | 4 - $U_{30}$, Shear, Rg, NSD-S |
| NSD | .539 | .376 | 5 - $U_{30}$, Rg, R-M, R-ON, NSD-S |

| | | | |
|---|---|---|---|
| H | .522 | .351 | 5 - $U_{30}$, Rg, DT, R-M, R-ON |
| HD | .461 | .262 | 3 - $U_{30}$, Rg, NATL |
| IH | .572 | .423 | 5 - $U_{50}$, Rs, Rg, DT, R-M |
| IHD | .556 | .405 | 4 - $U_{50}$, Rg, DT, NSD-S |
| HDP | .452 | .246 | 3 - Rg, DT, R-ON |
| NTC | .593 | .452 | 5 - $U_{30}$, Rg, R-M, R-ON, NSD-S |
| MPD | .620 | .490 | 4 - $U_{30}$, Rg, R-M, R-ON |

Table 2b also presents a summary of expected forecast skill degradation for application to independent data. As we gain more years of developmental data (now 48) and, as we reduce the number of variables, the amount of estimated real forecast skill, although impossible to determine for an individual year, should not significantly degrade.

# 3 Forecast Parameters for Early August 1999 Prediction

The following are the parameter values which go into our new 1 August forecast scheme. These are derived from meteorological data available through July, 1999.

## 3.1 QBO - An Enhancing Influence

On a statistical basis, the absolute and relative (i.e., anomalous) values of the current and extrapolated 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 12°N latitude during August through October 1999 have an influence on the seasonal hurricane activity equatorward of 25°N; westerly wind anomalies typically enhance hurricane activity while easterly wind anomalies usually suppress it. Estimates of these winds are based on a combination of the current trends plus the annual cycle of wind variations for low latitude stations at Curacao (12°N), Trinidad (11°N), and Barbados (13°N). During the August through October 1999 hurricane season, 30 mb and 50 mb zonal winds will be from a relative westerly direction and, hence, are an enhancing influence for this year's hurricane forecast. We project that 50 mb and 30 mb actual zonal winds for September 1999 will have values of 0 and -2 m/s respectively.

## 3.2 ENSO - Enhancing Influence for 1999

Sea surface temperature anomaly conditions (in °C) in Nino-1-2, 3, 3.4 and 4 (see Fig. 4), as well as the SOI values since April 1999 are shown in Table 3. Cooler water conditions are in all Nino areas. This cool water temperature should act to enhance this season's hurricane activity. These cool water conditions should lead to more low-latitude and longer-lived hurricane activity. Landfall probability is the U.S. and Caribbean basin is also greater in cold ENSO years.

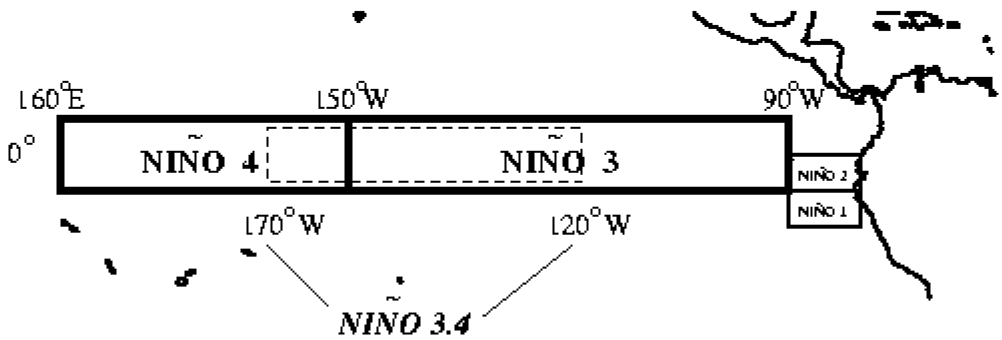


Figure 4: Equatorial Pacific sea surface temperature anomaly indices (˙C) represent the areas indicated. The dashed area is the (newer) Nino 3.4 index.

Table 3: Values for various April through July 1999 Niño sea surface temperature anomaly indices (in ˙C) and for Tahiti minus Darwin (SOI) surface pressure difference (in S.D.)

| | **Apr** | **May** | **June** | **July** |
|---|---|---|---|---|
| **Nino-1-2** | -1.0 | -0.5 | -0.8 | -1.0 |
| **Nino-3** | -0.6 | -0.3 | -0.6 | -0.6 |
| **Nino-3.4** | -0.7 | -0.6 | -0.8 | -0.6 |
| **Nino-4** | -1.0 | -0.7 | -0.5 | -0.6 |
| **SOI** | 1.4 | 1.3 | 0.5 | 0.5 |

### 3.3 West African Rainfall (AR) - A Slight Enhancing Influence

Western Sahel June-July 1999 rainfall data (as available) indicate average rainfall conditions (-0.21 SD) so far this season. We expect rainfall in August and September to pick up and seasonal rainfall totals for the Western Sahel to be somewhat above average. This is expected to be a small enhancing influence for this year's forecast of intense hurricane activity.

### 3.4 West African GT - Slight Negative Influence

There has been no change in these conditions since our early June forecast wherein the value of the west minus east Sahel temperature gradient anomaly was -0.50 SD. A negative value for this index cause West African winds to more out of the North than the South and is a suppressing influence for this season's hurricane activity.

### 3.5 June-July SLPA and ZWA - Combined Enhancing Influence

Two Caribbean basin parameters which contribute to the early August hurricane forecast are the Caribbean Basin Sea Level Pressure Anomalies (SLPA) and 200 mb (12 km) Zonal Wind Anomalies

(ZWA). The mean June-July 1999 five-station tropical (Trinidad, Barbados, Curacao, San Juan and Cayenne) SLPA was close to a zero anomaly. A second six-station higher latitude surface pressure average, made up of Brownsville, Miami, Merida (Yucatan), San Juan, Barbados, and Trinidad, yielded a surface pressure anomaly for June-July of +0.4 mb.

The mean five-station June-July (Trinidad, Curacao, Barbados, Kingston and Balboa) ZWA value gave a value of -1.2 m/s. We expect the neutral June-July SLPA pressures to become negative for the August-October 1999 period and that there will be an increase of more negative ZWA values. The combined influence should an enhancing influence on this season's hurricane activity.

### 3.6 Atlantic SSTA

Atlantic sea surface temperatures are generally above average and we project them getting warmer as the season progresses and the Atlantic SLPAs rearrange themselves and trade winds weaken.

### 3.7 Summary of 1 August Predictors

Table 1 provided information on the current values of the pool of sixteen 1 August predictors from which we choose the best predictors for each of our nine measures of seasonal hurricane activity. These forecast parameters exhibit mostly positive signals for this year's Atlantic basin hurricane activity. Seven parameters - (three QBO predictors, SST3.4, TATL, R-M, ZWA) indicate an enhancement of hurricane activity. Another three terms including one West African rainfall parameter, June-July SLPA and NATL indicate a neutral influence. Other parameters are typically less important and indicate a neutral or weak suppressing influence. We believe that, overall, forecast signals indicate a strong enhancement of this year's hurricane activity.

## 4 Forecast of 1999 Total Hurricane Activity and Activity Likely to Occur After 1 August

Table 4 lists both our original and revised quantitative forecasts for the post-1 August hurricane activity. Our forecast for the remainder of the hurricane season (i.e., August through November) is for much above average tropical storm and hurricane activity. Note that our revised post 1 August forecast (last column) is significantly greater than that specified by climatology (Column 3).

Table 4: Summary of forecasts for the entire season (column 1) using prior methodology and for activity after August 1 (columns 2-5) using a new scheme.

| Forecast Parameter | (1) New Variable Predictor Scheme All Season | (1) New Variable Predictor for Post 1 Aug Activity | (3) After 1 Aug Climatology | (4) Qualitative Adjusted After 1 Aug Activity |
|---|---|---|---|---|
| (NS) | 10.2 | 8.9 | 7.8 | 13 |
| (NSD) | 48.8 | 48.0 | 41.1 | 70 |
| (H) | 6.8 | 6.8 | 5.1 | 9 |

| | | | | |
|---|---|---|---|---|
| (HD) | 20.5 | 21.7 | 21.4 | 40 |
| (IH) | 2.9 | 2.9 | 2.0 | 4 |
| (IHD) | 4.5 | 3.4 | 4.4 | 10 |
| (HDP) | 55 | 38.2 | 64.4 | 130 |
| (MPD) | 65 | 74.2 | 67 | 127 |
| (NTC) | 129.5 | 117 | 97 | 157 |

Table 5: Summary of 1999 activity which occurred before August, early August forecast of hurricane activity based on variable number of predictors and total seasonal hurricane activity we expect in 1998.

| Forecast Parameter | Activity Before 1 August | After 1 August Adjusted Forecast | 1998 Total Seasonal Forecast | Seasonal Average 1950-1990 |
|---|---|---|---|---|
| Named Storms (NS) | 1 | 13 | 14 | 9.3 |
| Named Storm Days (NSD) | 5 | 70 | 75 | 46.9 |
| Hurricanes (H) | 0 | 9 | 9 | 5.8 |
| Hurricane Days (HD) | 0 | 40 | 40 | 23.7 |
| Intense Hurricanes (IH) | 0 | 4 | 4 | 2.2 |
| Intense Hurricane Days (IHD) | 0 | 10 | 10 | 4.7 |
| Hurricane Destruction Potential (HDP) | 0 | 130 | 130 | 70.6 |
| Maximum Potential Destruction (MPD) | 3 | 127 | 130 | 61.7 |
| Net Tropical Cyclone Activity (NTC) | 3 | 157 | 160 | 100% |

Table 5 shows pre-August 1 1999 activity and our forecast of post-August 1 forecast. The last column gives climatological values. Table 6 gives all of our 1999 seasonal forecasts. We are holding to the same numbers as we predicted in early December 1998, early April, and early June of this year. We foresee a very active hurricane season.

Table 6: Comparison of the current early August 1999 predictions of total seasonal activity versus our three prior forecasts made for 1999. The latter were issued on 6 December 1998, 7 April 1999 and 4 June 1999.

| | | | | |
|---|---|---|---|---|
| | | | | Current |
| | | | | Total |
| | Earlier Forecasts | | | Season |
| Forecast | 4 Dec 98 | 7 Apr 99 | 4 Jun 99 | 6 Aug 1998 |

| Parameter | Fcst | Fcst | Fcst | Fcst |
|---|---|---|---|---|
| Named Storms (NS) | 14 | 14 | 14 | 14 |
| Named Storm Days (NSD) | 65 | 65 | 75 | 75 |
| Hurricanes (H) | 9 | 9 | 9 | 9 |
| Hurricane Days (HD) | 40 | 40 | 40 | 40 |
| Intense Hurricanes (IH) | 4 | 4 | 4 | 4 |
| Intense Hurricane Days (IHD) | 10 | 10 | 10 | 10 |
| Hurricane Destruction Potential (HDP) | 130 | 130 | 130 | 130 |
| Maximum Potential Destruction (MPD) | 130 | 130 | 130 | 130 |
| Net Tropical Cyclone Activity (NTC) | 160% | 160% | 160% | 160% |

# 5 Suppressed Early Tropical Cyclone Activity

The observation of only one named storm (TS Arlene) up to the 6th of August 1999 is judged to have little or no relationship to whether we will have an overall active or inactive hurricane season. Many very active hurricane seasons have experienced little hurricane activity until mid or late August. Table 7 lists some of the most active hurricane seasons and the date of the second named storm. Many active seasons have had a late start.

Table 7: Active hurricane seasons since 1930 wherein the second named storm occurred after 1 August.

| Year | Seasonal Number of Named Storms | Date of Second Named Storm |
|---|---|---|
| 1932 | 11 | 11 August |
| 1950 | 13 | 20 August |
| 1953 | 14 | 11 August |
| 1955 | 12 | 3 August |
| 1961 | 11 | 2 August |
| 1969 | 17 | 10 August |
| 1980 | 11 | 13 August |
| 1988 | 12 | 9 August |
| 1998 | 14 | 19 August |

# 6 Analog Years

Since 1950 there have been five seasons with similar basic early season atmospheric and oceanic conditions to this year. Table 8 lists these five years and compares their variables. Similarities include the following:

1. Ideal QBO wind conditions for hurricane activity with the extrapolated zonal wind in September at 50 mb and 30 mb being as positive as possible, and the vertical wind shear between these two levels as low as possible. Activity is highest with the lowest negative enhanced values of September $U_{50mb} + U_{30mb} - (U_{50} - U_{30})$. Any value higher than -30 is favorable for enhanced hurricane activity.
2. Active multi-decadal hurricane periods as characterized by a strong Atlantic thermohaline or ``conveyor'' as gaged by a proxy measurement of SSTA in the North Atlantic (50-60˙N, 10-50˙W) during the prior 19-month period. Warm SSTA's indicate an above average strength conveyor, cold anomalies, below average strength conveyor. Hurricane activity is enhanced with a strong conveyor circulation.
3. Cool ENSO conditions as measured by the June-July SSTA in Nino 3.4.
4. Negative lower Caribbean basin ZWA in June-July.
5. Negative lower Caribbean basin SLPA in June-July.

Table 8: Five analog years since 1950 which had early season conditions generally similar to this year.

| Year | Sept QBO | Strong Conveyor Belt Circulation | June-July Nino 3.4 (˙C) | ZWA (m/s) | SLPA (mb) |
|---|---|---|---|---|---|
| 1950 | -2 | yes | -.52 | -2.50 | -.30 |
| 1955 | -4 | yes | -.63 | -5.20 | -.70 |
| 1961 | -6 | yes | .24 | -1.00 | .30 |
| 1964 | -22 | yes | -.61 | -2.20 | -.90 |
| 1995 | -12 | yes | .24 | -2.50 | -.60 |
| Average | -9.6 | All Yes | -0.3 | -2.7 | -0.44 |
| | | | | | |
| 1999 | -4 | yes | -0.60 | -1.1 | 0 |

Table 9: Listing of hurricane activity in analog years and comparison with our 1999 forecast.

| Year | NS | NSD | H | HD | IH | IHD | HDP | NTC |
|---|---|---|---|---|---|---|---|---|
| 1950 | 13 | 98 | 11 | 60 | 7 | 15.5 | 200 | 240 |
| 1955 | 12 | 83 | 9 | 47 | 5 | 13.75 | 158 | 196 |
| 1961 | 11 | 71 | 8 | 48 | 6 | 20.75 | 170 | 220 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1964 | 12 | 71 | 6 | 43 | 5 | 9.75 | 139 | 167 |
| 1995 | 19 | 121 | 11 | 62 | 5 | 11.5 | 172 | 231 |
| Average | 13.4 | 88.6 | 9 | 52 | 5.6 | 14.25 | 168 | 211 |
| | | | | | | | | |
| 1999 Fcst as a | 14 | 75 | 9 | 40 | 4 | 10 | 130 | 160 |
| percent of the average | 104% | 85% | 100% | 77% | 71% | 70% | 77% | 76% |
| of five analog years | | | | | | | | |

Table 9 lists the seasonal hurricane activity during these five analog years and compares this activity with our 1999 forecast. Note that our typical forecast values for 1999 average about 82 percent of the average for the analog years.

# 7 Reasons for Upward Adjustment of Forecast from Statistical Prediction

Our statistical scheme has not worked well during the last four years. Part of the explanation lies with deficiencies of the model. At best our statistical model, on a long term basis, can only explain about 50-60 percent of the season-to-season variance. Another difficulty is likely due to the onset of a new more active multi-decadal period for hurricane activity four years ago (1995). A third factor is a result of our statistical scheme picking the August-November Guinea rainfall 1998, Del-T for February-May 1999, NATL for June-July and the October-November 1998 ridge. These four parameters turn out to be negative for this year and a typical of most active seasons. By contrast, certain favorable activity predictors such as NINO 3.4, ZWA, and SLPA are not often picked by our statistical model. We believe that our statistical scheme for this year is not fully representative of the activity we may have. We believe that the five analog years to 1999 are more representative. For these reasons, we have raised our forecast for this season above that specified by our statistical model.

# 8 Landfall Probabilities for 1999

A new aspect of our research involves efforts to develop forecasts of the probability of hurricane landfall along the U.S. coastline, the Caribbean and Bahamas, and along the Mexican East Coast. Whereas hurricane landfall can never be accurately forecast for individual years, yearly probability of landfall can be specified with some statistical skill. Landfall is a function of varying climate signals. Probability specification can be accomplished by statistical study of all Atlantic hurricane landfall named storms for the last 100 years (1899-1998). Specific landfall probabilities can be given for all cyclone intensity classes. Landfall probability has been found to be (statistically) related to the overall Atlantic basin Net Tropical Cyclone Activity (NTC) and to climate trends linked to multi-decadal variations of the Atlantic Ocean thermohaline circulation. NTC gives an overall measure of Atlantic basin seasonal hurricane activity in any year. Distinctive landfall characteristics occur for the Gulf Coast or (regions 1-4) extending just north of Spring Hill, FL and westwards to Brownsville, TX (35 total category 3-4-5 landfalls of this century) and the rest of the U.S. coast from Spring Hill, FL to Eastport, ME (38 landfalls in regions 5-11) (Fig. 6).

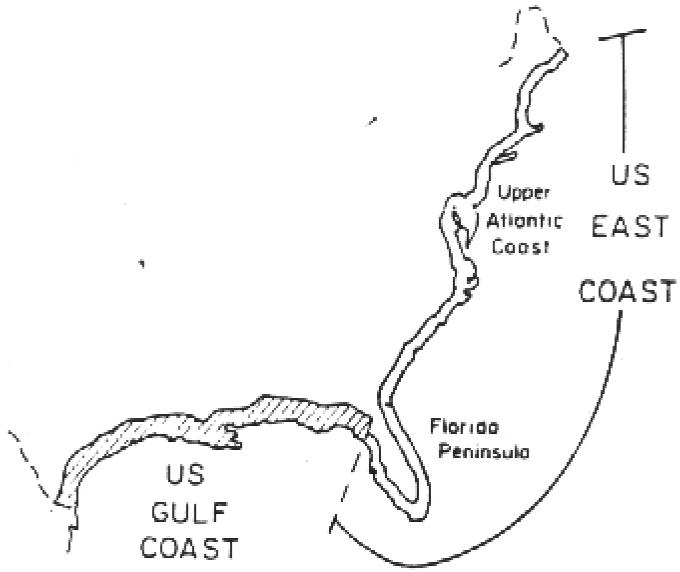


Figure 5: Separation of the two basic U.S. coastal areas which have different climate associations with their landfalling major hurricanes.

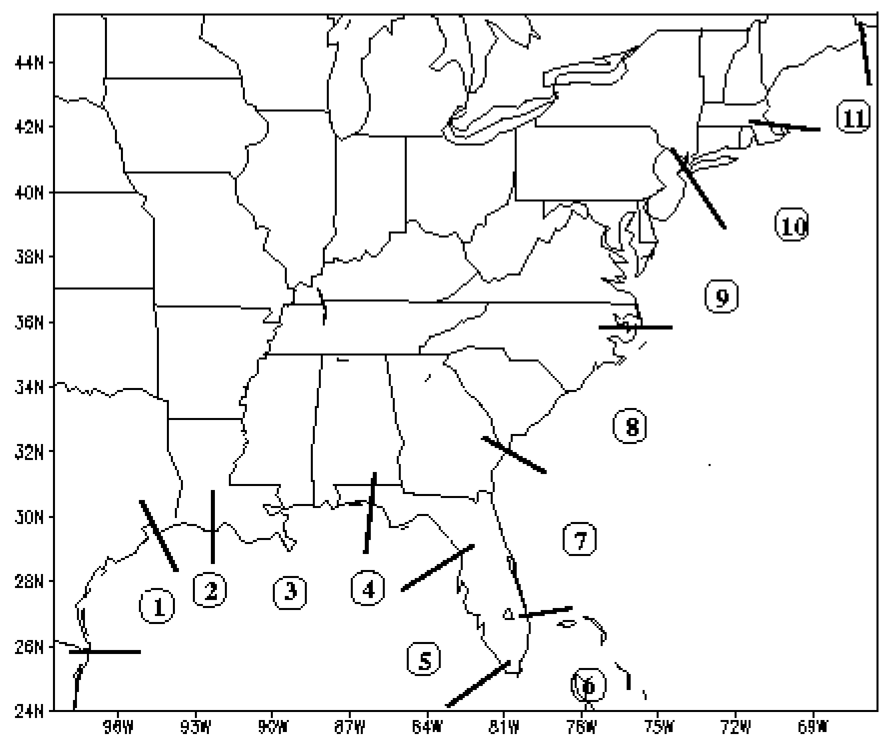


Figure 6: Location of the 11 coastal regions for which separate probability estimates are made.

As shown in Table 10, NTC is a combined measure of the year-to-year mean of six indices of hurricane activity expressed in percentage differences from the long-term average. Many active Atlantic hurricane seasons may bring no landfalling hurricanes, and some inactive seasons experience one or more landfalling intense hurricanes; however, the latter is not typical. Long-term statistics show that, on average, the more active the overall Atlantic basin hurricane season is, the greater the probability of landfall. Less active Atlantic basin seasons have (on average) a greatly reduced occurrence of landfall. For example, landfall observations during the last 100 years show that more intense (Saffir-Simpson category 3-4-5) hurricanes strike the Florida and U.S. East Coast during years of highest NTC and when above average North Atlantic SSTA conditions were in place. The 33 years (out of the last 100) with the combination of highest NTC and North Atlantic SSTA experienced 24 category 3-4-5 hurricane strikes along the Florida and East Coast whereas the 33 years with the lowest NTC and the weakest inferred thermohaline circulation saw only 3 such intense hurricane hits; a ratio of 8 to 1. Tables 11 and 12 summarize the links between hurricane and tropical storm landfall, showing how the combined influences of NTC and North Atlantic SSTA cause very large differences in landfall, especially along the Florida and the U.S. East coast. Atlantic basin NTC can be skillfully predicted and the strength of the Atlantic Ocean thermohaline circulation can be inferred from prior years of North Atlantic Sea Surface Temperature (SST) anomalies. These predictive relationships can, therefore, be utilized to make probability estimates of U.S. landfall.

Table 10: NTC activity in any year consists of the seasonal average of the following six parameters in comparison to their long-term averages. A season with 10 NS, 50 NSD, 6 H, 25 HD, 3 IH, and 5 IHD, would then be one-sixth of the percentage of the sum of the following ratios: 10/9.3 = 108, 50/46.6 = 107, 6/5.8 = 103, 25/23.9 = 105, 3/2.3 = 130, 5/4.7 = 106, or an NTC of 110.

| | | 1950-1990 Average |
|---|---|---|
| **1)** | Named Storms (NS) | 9.3 |
| **2)** | Named Storm Days (NSD) | 46.6 |
| **3)** | Hurricanes (H) | 5.8 |
| **4)** | Hurricane Days (HD) | 23.9 |
| **5)** | Intense Hurricanes (IH) | 2.3 |
| **6)** | Intense Hurricane Days (IHD) | 4.7 |

Table 11: Number of Florida Peninsula and U.S. East Coast (regions 5 through 11 in Fig. 6) hurricane landfall events by intensity class for the 33 years with the highest versus the 33 years with the lowest values of NTC plus Atlantic thermohaline circulation (SSTA) of 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 12: Number of hurricane landfall events in Gulf regions (1 through 4) intensity class during the seasons with the 33 highest and 33 lowest values of NTC 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 |

The analysis of a century of U.S. hurricane landfall data suggests that 11 different coastal regions be specified as having distinctive values of hurricane landfall activity during the last century. These differences are due primarily to the varying incidence of category 3-4-5 hurricanes. Figure 6 shows the locations of these 11 coastal zones. Research is progressing on landfall probabilities for each of these 11 U.S. coastal locations.

Table 13 lists landfall probabilities for TS, Cat 1-2, Cat 3-4-5, NS, and total hurricanes impacting the entire U.S. coastline, the Gulf Coast (Regions 1-4) and Florida and the East Coast (Regions 5-11) for 1999. The average annual probability of the last 100 years is given in parentheses.

Table 14 gives a similar probability values for Caribbean and Bahama hurricane passage and for landfall on the Mexican East Coast. Figure 6 shows these Caribbean-Bahama and Mexican East Coast regions.

Table 13: Estimated percent probability of one or more landfalling Tropical Storms (TS), category 1-2 hurricanes, and category 3-4-5 hurricanes, total hurricanes and named storms along the entire U.S. coastline, the Gulf Coast (region 1-4), and the Florida and the East coastline (Regions 5-11) for 1999. The last 100 year mean annual probability of one or more landfalling systems is given in parentheses.

| **Coastal** | | | **Category 1-2** | | **Category 3-4-5** | | **All** | | **Named** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Region** | **TS** | | **HUR** | | **HUR** | | **HUR** | | **Storms** | |
| | **1999** | **Ave** | **1999** | **Ave** | **1999** | **Ave** | **1999** | **Ave** | **1999** | **Ave** |
| Entire U.S. | 87% | (84%) | 81% | (67%) | 72% | (50%) | 94% | (84%) | 99% | (97%) |
| Gulf Coast | 69% | (59%) | 55% | (42%) | 40% | (30%) | 73% | (60%) | 91% | (83%) |
| Florida plus East Coast | 58% | (49%) | 60% | (43%) | 54% | (31%) | 81% | (61%) | 92% | (79%) |

Table 14: Estimated percent probability of the center of one or more hurricanes (of any intensity) and/or of category 3-4-5 hurricanes passing through the various regions shown in Fig. 7 for 1999. The values in parentheses represent the average annual probability for the last 100 years. Calculations were made for hurricanes. The probability of major (category 3-4-5) hurricanes was determined under the assumption that major hurricanes make up 38 percent of all hurricane numbers.

| **Region** | **Hurricanes** | **Major (cat 3-4-5) Hurricanes** |
|---|---|---|
| **Northern (N)** | 86% (64%) | 52% (33%) |
| **Eastern (E)** | 47% (29%) | 21% (12%) |
| **Southern (S)** | 3% (2%) | 1% ( ?#0.6%) |

| | | |
|---|---|---|
| **Western (W)** | 41% (25%) | 19% (11%) |
| **Mexican Coast (M)** | 56% (37%) | 28% (16%) |
| **Sum of N+E+S+W** | 97% (84%) | 73% (50%) |
| **Sun of Five Regions** | 98% (90%) | 80% (59%) |

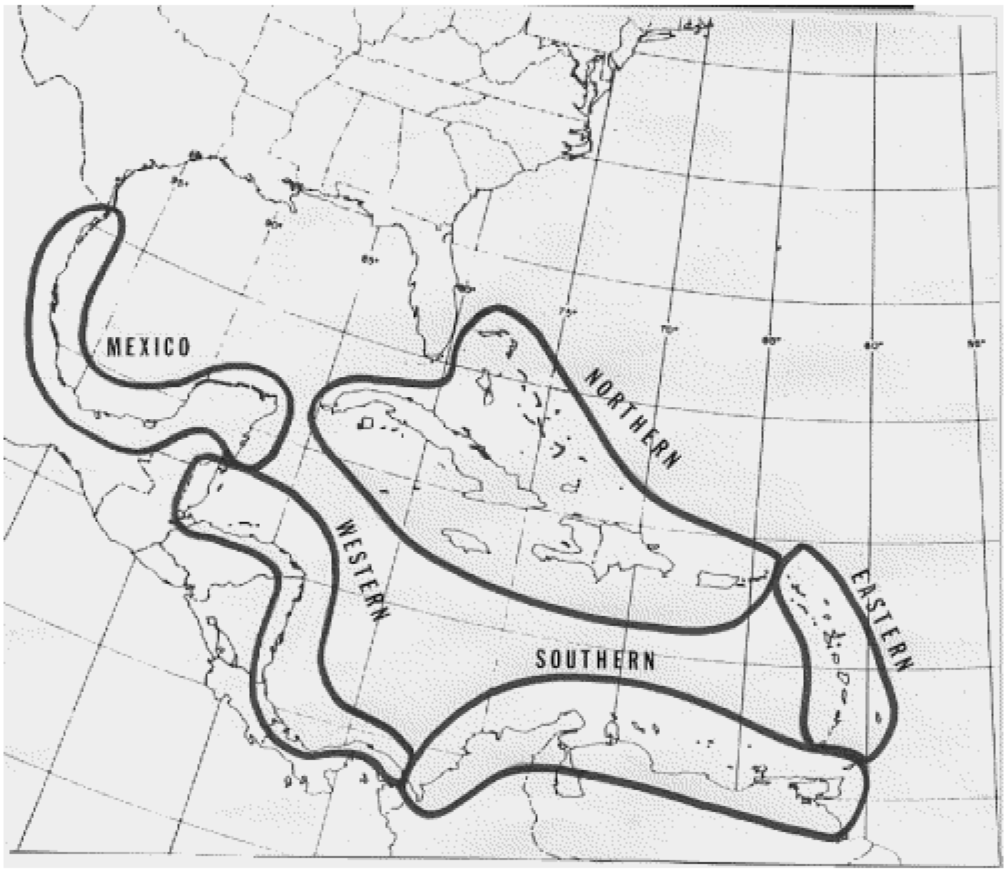


Figure 7: Caribbean basin areas for which the probability of the passage of hurricanes and major hurricanes are specified in Table 12.

The equations specifying these probability values are discussed in a forthcoming paper to be posted on our Web site. Probability values are given by an equation of the general form:

$$( \text{Annual} \quad \text{Number} ) = T ( 1 + K F ) \qquad (1)$$

where

T = the average annual number of various category cyclones for the last 100 years (1899-1998)

K = an empirically determined constant from statistics of the last 100 years

$F = [ [((NTC + SSTA^*) - 100)/ 100] ]$ .

The 1999 values of F using the NTC forecast of 160 and SSTA* of 36 is thus 0.96. The average values of F and SSTA* over the last 100 years are zero. The average value of NTC over the last 100 years is 100.

Substituting the current 1999 forecast value of F (0.96) into the various forecast, specifications of the number of current year IH, Category 1-2 hurricanes, TS, NS and total hurricanes are obtained. This number is then multiplied by 100 and a Poisson distribution is calculated to specify the probability of one or more landfalling cyclones along a specified coastline or of the passage of cyclones through a specified area as seen for the Caribbean Basin.

# 9 Comparison of 1999 Landfall Probabilities With Values for Earlier Periods

The expected major hurricane landfall probabilities by the above method for Florida and the U.S. East Coast for 1999 is between 3 and 4 times larger than the landfall probability in the average season for the quarter century period 1970-1994 when the mean NTC was 75 (instead of the forecast value of 160 for this year) and there was a weak (rather than strong) Atlantic Ocean thermohaline circulation was in place. North Atlantic SST anomalies during 1970-1994 were negative. Thus, our forecast numbers of category 3-4-5 hurricane landfalls for the Gulf Coast for 1999 are 3-4 times higher than they were during the typical hurricane season as much as the mean between 1970-1994.

When the Atlantic Ocean thermohaline circulation is strong (as during the 48-year period of 1926-1969, and 1995-1997) 27 category 3-4-5 hurricane landfalls occurred along the Florida and East Coast versus only 11 landfalls during 52 years (1900-1925, 1970-1994) when it was weak. This Atlantic thermohaline influence on intense hurricane landfall shows a weak inverse influence along the Gulf Coast (regions 1-4), however.

# 10 Forthcoming Information on Prediction for U.S. Hurricane Landfall Probabilities

Full documentation of this hurricane landfall probability methodology is not complete at this time. The first author will try to finish this study within the next month and make it available on the internet. These landfall probabilities will include probability forecasts for tropical storms (TS) and hurricanes of category 1, 2, 3, 4-5 for the following specific areas: the entire U.S. coastline, the Florida Coast and U.S. East Coast separately and the Gulf Coast in 11 U.S. coastal units as shown in Fig. 6, and for each 100 km (65 mile) segment of U.S. coastline.

These U.S. landfall probability forecasts will be converted to probabilities for each 100 km wide coastal segment receiving gale force winds ( ,40 mph), sustained hurricane force winds ( ,75 mph) and major hurricane (category 3-4-5) winds ( ,115 mph). Funding problems have slowed up this effort.

# 11 Evidence of Persistent Multi-Decade Enhancement of Atlantic Hurricane Activity Associated With a Major Reconfiguration of Atlantic Basin SSTs

Recent observations indicate increased salinity in the upper layers of the tropical and North Atlantic. Higher salinity increases water density in these surface layers which then can sink to great depth, thereby increasing equatorward flow of deep water and a compensating northward flow of warm (and comparatively salty) replacement water near the surface. The resulting net northward transport of upper-layer warm water into the high North Atlantic and sub-surface equatorward transport of deep cold water is the principal manifestation of the Atlantic Ocean thermohaline (``conveyor'') circulation. A strong ``conveyor'' circulation increases surface water temperatures in the high latitude areas of the North Atlantic and thus transports more heat to these high latitude areas. Hence, slowly increasing salinity values in the far North Atlantic during the last 15 years suggest the development of conditions whereby the Atlantic Ocean has recently tended to a stronger thermohaline circulation.

Figure 8 shows the difference between the mean SST anomalies for 1991 to 1994 versus 1995 to 1998. Note the general warming of the North Atlantic that has taken place during the last four years during which time the incidence of major hurricanes has also increased to levels similar to the period spanning the 1930s through 1950s. The presence of these new SSTA patterns typically manifests itself in the form of more hurricanes forming at low latitudes and, especially, more intense low latitude hurricanes and more major hurricanes landfalling along the US East Coast, Florida, and the Caribbean basin. We expect that this trend will continue for several decades.

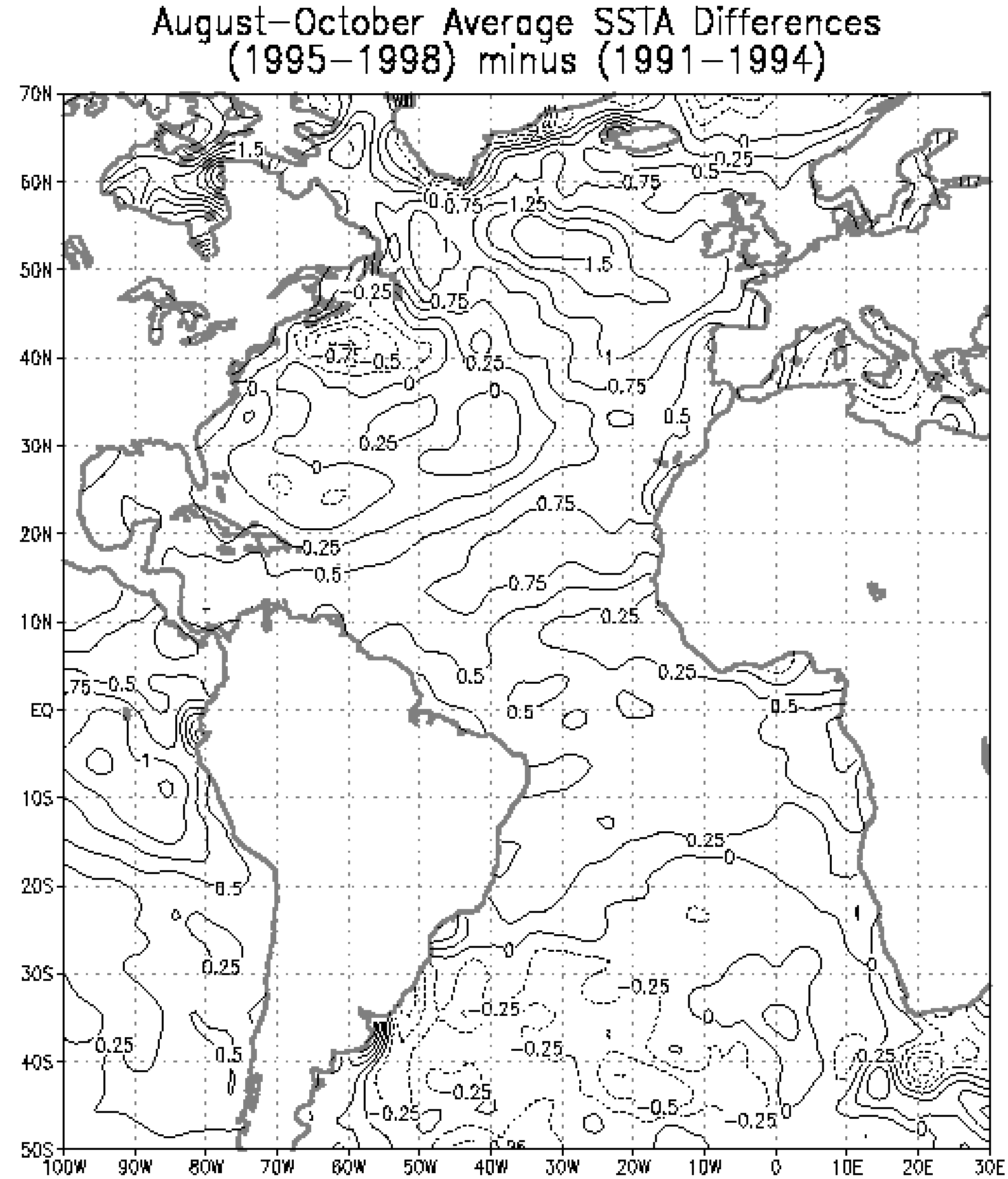


Figure 8: August through October SST differences in ˚C for 1995 to 1998 minus 1991 to 1994. Solid contours show areas of warming; dashed contours indicate cooling.

For some years we have been suggesting (eg., Gray 1990, Gray et al. 1996) that the recent era of reduced Atlantic intense hurricane activity (which appears to have occurred between approximately 1970-1994) would inevitably end and that Atlantic coastal region should expect an eventual long-term increase in landfalling major hurricane activity. This outlook is especially ominous because, when normalized by increased coastal populations, inflation, and wealth per capita, [see Pielke and Landsea (1998) and Gray (1998)] major hurricanes are observed to cause 80 to 90 percent of all US tropical cyclone linked destruction.

Despite El Niño-linked suppression of hurricane activity during 1997, the last four years (1995-1998) are together the most active four (consecutive) year period on record. Total numbers include 53 named storms, 33 hurricanes, 15 major hurricanes, 36 major hurricane days and Net Tropical Cyclone activity value of 653 during the last four years. Despite the weak 1997 hurricane season, the annual average NS, H, IH, IHD and NTC values during the last four years are 142, 142, 170, 191 and 163 percent (respectively) of the average hurricane activity for 1950-1990. The annual average values for NS, H, IH, IHD and NTC during the last four years were 154, 160, 250, 419 and 216 percent of the average for the previous 25-year (1970-1994) period; the greatest increases occurring for IH and IHD activity. The three recent active hurricane seasons (1995, 1996 and 1998) had 311 and 524 percent of average intense hurricanes and intense hurricane days (respectively) relative to the means prior 25-year period 1970-1994. This trend towards increased hurricane activity supports the notion that an abrupt climate shift began during 1995, one manifestation of which is increased major hurricane activity that was typical of the 1940s and 1950s.

# 12 The 1999 Hurricane Season and Global Warming

Some individuals will interpret the great upswing in hurricane activity since 1995 as being related in some way to increased man-made greenhouse gases like carbon dioxide ($CO_2$). Such individuals are sometimes driven by a more political than scientific agenda or do not fully understand the physics of tropical cyclones. There is no reasonable way that such an interpretation can be made. Anthropogenic greenhouse gas warming, even if a physically valid hypothesis, is a very slow and gradual process that, at best would only be expected to bring about small changes in global circulation over periods of 50 to 100 years. This would not result in the abrupt and dramatic one year upturn in hurricane activity as occurred between 1994 and 1995. And, even if man induced greenhouse increases were to be interpreted as causing global mean temperature increase over the last 25 years, there is no way to relate such a small global temperature increases to more intense Atlantic basin hurricane activity during this same period. Atlantic intense (or category 3-4-5) hurricane activity showed a substantial decrease during 1970-1994 to only about 40 percent of the amount of intense hurricane activity which occurred 25-50 years ago. These up-and-down multi-decadal changes have occurred many times in the past and are considered to be natural.

# 13 Forecast Theory and Cautionary Note

These forecasts are based on the premise that trends in global environmental conditions which preceded comparatively active or inactive hurricane seasons in the past provide meaningful information about trends in future seasons as well. 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 explicitly predict specifically where within the Atlantic basin 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 an individual season is. And, it must be emphasized, that a low probability does not insure that a hurricane will not come ashore. Regardless of how active 1999 hurricane season should be, a finite probability also exists that one or more hurricanes may strike along the US or Caribbean Basin coastline and do much damage.

# 14 Schedule of Verification and First Forecast for the 2000 Season

This 6 August 1999 updated seasonal forecast will be verified in late November 1999 and a seasonal forecast for the 2000 hurricane season will, as in the past, be issued in early December, 1999.

# 15 Acknowledgements

John Knaff, John Sheaffer, Todd Kimberlain and Eric Blake have made major contributions to the background information necessary to these forecasts. We have also greatly benefited from background discussion with CSU project members William Thorson and Matt Eastin. The authors are indebted to a number of meteorological experts who have furnished 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, Ray Zehr and Vern Kousky for very valuable climate discussion and input data. We thank Colin McAdie and Jiann-Gwo Jiing who have furnished data necessary to make this forecast and to Gerry Bell, James Angell, and Stan Goldenberg for input data and helpful discussions. Richard Taft has provided valuable data development and computer assistance. We wish to thank Tom Ross of NCDC and Wassila Thiao of the African Desk of CPC who provided us with West African and other meteorological information. In addition, Barbara Brumit and Amie Hedstrom have provided manuscript 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, Edward Rappaport, John Guiney, and Jack Beven. The first author would further like to acknowledge the encouragement he has received for this type of forecasting research applications from Neil Frank, Robert Sheets, and Robert Burpee, former directors of the National Hurricane Center (NHC) and from current NHC director, Jerry Jarrell, and the Deputy Director, Max Mayfield.

This research was funded in part by the National Science Foundation with supplementary funding from the Reinsurance Australia Corporation Limited.

# 16 Additional Reading

**Verification of All Past Seasonal Forecasts**

See our verification of the 1998 season on this same Web site along with verification tables and figures which discuss our forecast verifications for the period 1984-1998. Figures 9 and 10 show graphical plots of our prediction of named storms and hurricanes during the last 15 years.

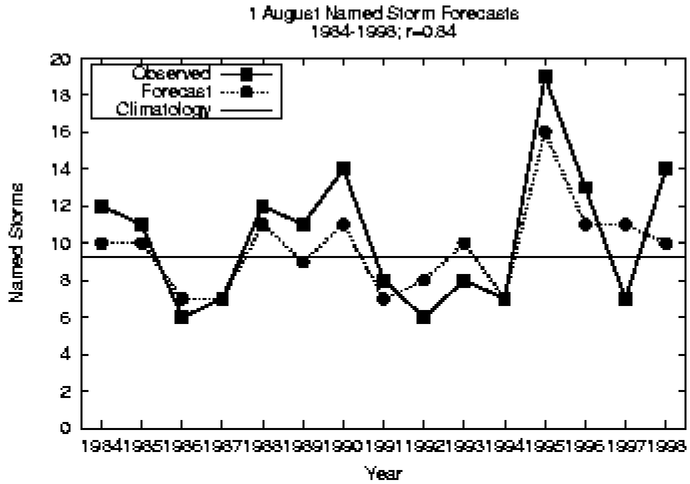


Figure 9: 1 August prediction of total named storms versus the number of actually observed versus long-term climatological mean (r = 0.85) for period 1984-1998.

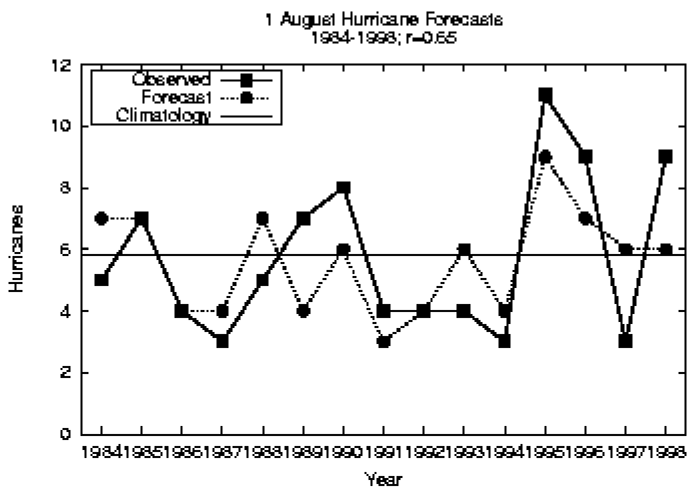


Figure 10: 1 August prediction of total hurricanes versus the number of actually observed versus climatological long-term mean (r = 0.65) for period 1984-1998.