# SUMMARY OF 1992 ATLANTIC TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S FORECAST

**(A Year of no hurricane activity in the tropics but exceptional South Florida destruction from an unusual higher latitude intense hurricane)**

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## DEFINITIONS

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

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)Four 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

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.

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

Named Storm Day - (NSD) Four 6-hour periods during which a tropical cyclone is observed or estimated to have attained tropical storm or 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 for each 6-hour period of its existence.

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

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

Millibar - (mb) A measure of atmospheric pressure which is often used as a vertical height designator. Average surface values are about 1000 mb; the 200 mb level is about 12 kilometers and the 50 mb is about 20 kilometers altitude. Monthly averages of surface values in the tropics show maximum summertime variations of about $\pm$ 2 mb which are associated with variations in seasonal hurricane activity.

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 5-6 years or so on average.

Delta PT - A parameter which measures the west to east surface pressure ($\Delta P$) and surface temperature ($\Delta T$) gradient across West Africa.

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

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

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

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

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

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 = .515 meters per second.

ABSTRACT

This paper summarized the tropical cyclone (TC) activity which occurred in the Atlantic Basin during 1992, and verifies the author's seasonal forecasts of such activity which were issued on 26 November of last year an on 5 June and 5 August of this year.

Information received by the author as of 26 November, 1991, indicated that the Atlantic should experience a below average season with about 4 hurricanes, 8 named storms of hurricane and tropical storm intensity, 15 hurricane days, 35 named storm days, one intense hurricane of Saffir/Simpson category 3-4-5, and a Hurricane Destruction Potential (HDP) of 35. The 5 June and 5 August updated forecasts, utilizing a variety of late spring and early summer meteorological data, maintained the late November forecast with no change.

The forecast verified very well. Five of the seven forecast parameters were unusually accurate. There were no hurricanes in the tropics and no tropical cyclone activity at all in the Caribbean. The key to this inactive season (except for hurricane Andrew) was the lack of the development of African wave systems. The one major hurricane (Andrew of maximum Category 4) intensified above 25°N. Besides the lack of low latitude hurricanes, the 1992 season was characterized by an especially large number (4) of high latitude forming hurricanes whose development (except for Andrew) was influenced by middle-latitude baroclinic processes.


# 1. 1992 Atlantic Tropical Cyclone Activity

The 1992 Atlantic hurricane season officially ends on 30 November. There were four hurricanes (maximum sustained wind >73 mph) and 15.75 hurricane days during 1992. Total named storms (or the sum of the number of hurricanes and tropical storms) was 6 and there were 38.25 named storm days. Figure 1 and Table 1 give the tracks and statistical summaries of all 1992 Atlantic named storms. Table 2 contrasts the tropical cyclone statistics for this season with recent past seasons and with climatology. During the last two years hurricane season, no hurricanes have formed equatorwards of 25°N.

In terms of all seasonal tropical cyclone parameters, 1992 was an inactive hurricane season. The one intense (Saffir/Simpson Category 3-4-5) hurricane that developed (Andrew) intensified at high latitudes (26°N). This lack of low latitude hurricane activity was a consequence of a variety of unfavorable conditions such as easterly stratospheric QBO winds at 50 mb, a warm ENSO event, below average Western Sahel rainfall, generally high values of Caribbean basin surface pressure and 200 mb wind anomalies, and unfavorable springtime West African west to east gradients of surface pressure and surface temperature. All six of these climate factors had an inhibiting influence upon the formation of Atlantic basin low latitude named storms and hurricanes. These unfavorable low latitude conditions were in contrast with the more favorable high latitude (> 25°N) activity.

# 2. Brief Summary of Individual Named Storm Characteristics

1. **Intense Hurricane Andrew** was a small and ferocious hurricane that caused unprecedented economic devastation to South Florida and lesser but still quite large damage amounts to south Louisiana. Andrew was a special class of "Bermuda Triangle" intense

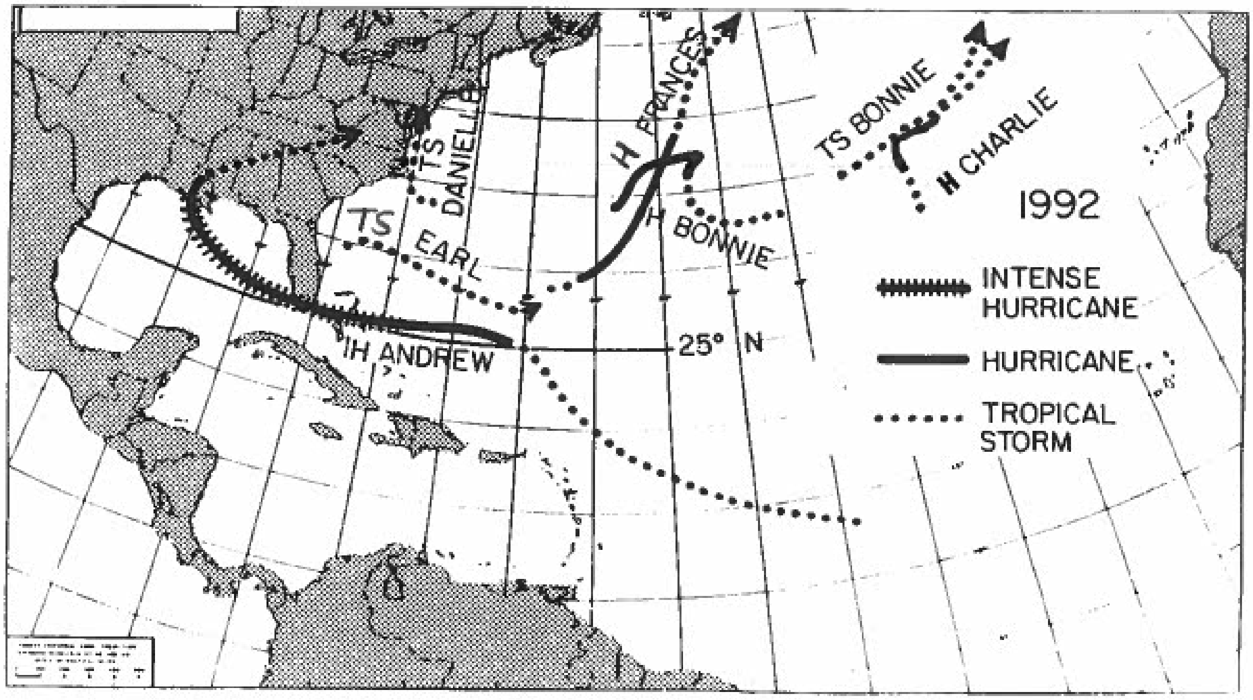


Figure 1: Tracks of tropical cyclones for 1992. Dotted lines indicate periods of tropical storm intensity (maximum sustained winds with 39-73 mph), and thick lines show the periods of hurricane intensity (maximum sustained winds greater than 73 mph) and railroad track lines indicate periods of intense (Category 3-4-5) hurricane activity.

Table 1: Summary of information on named tropical cyclones occurring during the 1992 Atlantic tropical cyclone season. Hurricane (H) and Tropical Storm (TS) information has been supplied by courtesy of the National Hurricane Center.

| NAME and CATEGORY | DATES | TS DAYS | HUR. DAYS | INT. HUR. DAYS | HDP | MIN. CENTRAL PRESS. (mb) | MAX. WIND (kts) |
|---|---|---|---|---|---|---|---|
| H-4 Andrew | Aug. 15-28 | 9.75 | 4.25 | 3.25 | 20.6 | 922 | 135 |
| H-2 Bonnie | Sept. 17-30 | 12.00 | 6.00 | - | 17.3 | 965 | 95 |
| H-2 Charlie | Sept. 21-27 | 5.25 | 3.50 | - | 9.0 | 965 | 95 |
| TS Danielle | Sept. 22-26 | 3.75 | - | - | - | 1001 | 55 |
| TS Earl | Sept. 26-Oct. 3 | 4.00 | - | - | - | 990 | 55 |
| H-1 Frances | Oct. 23-26 | 3.50 | 2.00 | - | 3.8 | 976 | 75 |
| TOTAL | | 38.25 | 15.75 | 3.25 | 50.7 | | |
| 6 Named Storms; 4 Hurricanes; 1 Intense Hurricane | | | | | | | |

Table 2: Comparison of 1992 hurricane activity forecast with previous years' activity.

| | 1992 | As % of the long term Average | Last three seasons 1991 | 1990 | 1989 | Average Season 1970-87 | 1950-69 | Long Term 1950-90 Ave. |
|---|---|---|---|---|---|---|---|---|
| Hurricanes | 4 | 68 | 4 | 8 | 7 | 4.9 | 6.5 | 5.9 |
| Named Storms | 6 | 61 | 8 | 14 | 11 | 8.3 | 9.8 | 9.9 |
| Hurricane Days | 15.75 | 66 | 8.25 | 27.5 | 32 | 15.5 | 30.7 | 23.8 |
| Named Storm Days | 38.25 | 81 | 22.25 | 68 | 66 | 37.3 | 53.4 | 47.2 |
| Hur. Dest. Pot. (HDP) | 50.7 | 68 | 23 | 57 | 108 | 42.7 | 100.0 | 74.5 |
| Major Hurricanes (Cat. 3-4-5) | 1 | 40 | 2 | 1 | 2 | 1.6 | 3.4 | 2.5 |
| Major Hurricane Days | 3.25 | 57 | 1.25 | 1 | 10.75 | 2.1 | 8.8 | 5.5 |

hurricanes which undergo their intensification at a subtropical latitude while moving westward. The famous Labor Day Storm of 1935 which was the most intense cyclone ever to strike the US was this type of hurricane. There have been about 12 of these Bermuda Triangle type intense hurricanes of this century. They are possible when a strong 200 mb anticyclone becomes established off the US East Coast. They can occur only when a broad upper tropospheric easterly current is established to the east of Florida and the Bahamas for a number of days. This is an atypical upper tropospheric flow regime for this region. Such upper level easterly flow overlays the regular trade winds and causes very small or near zero tropospheric vertical wind shear conditions. Such special and favorable long lasting vertical wind shear conditions and an inner-core concentration of convection allowed for Andrew's center pressure to decrease 82 mb in 48 hours—a remarkable but not unprecedented deepening rate. Andrew measured minimum central pressure was 922 mb and its estimated maximum sustained winds were about 135 knots ($\sim$ 155 mph).

Andrew was not typical of the type of intense hurricane which does major damage along the US East Coast and Peninsula Florida. Most US coastal damage from intense hurricanes occur from those hurricanes which become hurricanes within the tropics. Andrew and other similar types of Bermuda Triangle hurricanes become intense hurricanes out of the tropics.

Andrew as a Climatological Freak. There has been 32 major or intense (category 3-4-5) landfalling hurricanes to strike the US East Coast and Peninsula Florida during 24 of the 93 hurricane seasons of this century. In the majority of these 24 seasons the Western Sahel region of West Africa had above normal rainfall and cold water at La Niña condition existed in the East Pacific. Table 3 shows the distribution of Western Sahel rainfall and Eastern Pacific ENSO sea surface temperature anomalies (SSTA) during these 24 seasons of major East Coast and Peninsula Florida landfalling hurricanes. Note that landfall is much less frequent during warm ENSO seasons and in seasons when West Africa is dry. Of those 24 hurricane seasons of this century in which major hurricane landfall occurred in only one season (1992) did distinctly dry Western Sahel rainfall conditions exist in the same year with distinctly warm El Niño SSTA conditions. And, that year and storm was 1992 and Andrew.

Table 3: Summary of Western Sahel rainfall and ENSO conditions during those 24 years of this century when landfall of one or more major (category 3-4-5) hurricanes made landfall along the US East Coast or over Peninsula Florida.

| | No. of Years of Distinctly Warm Water | No. of Years of Somewhat Warm or Cold | No. of Years or Distinctly Cold Water |
|---|---|---|---|
| ENSO Conditions | 3(1919, 65, 92) | 9 | 12 |
| | Distinctly Dry | Somewhat Wet or Dry | Distinctly Wet |
| Western Sahel Rainfall | 1(1992) | 9 | 14 |
| Years: 1906, 10, 19, 21, 26, 28, 29, 33, 35, 38, 44(2), 45, 47, 48, 49, 50(2), 54(3), 55(2), 59, 60(2), 65, 85, 89, 92. | | | |

Andrew was a most unusual major hurricane to have made landfall under these conditions. In this sense, Andrew must be considered to be a statistical freak. It should not have occurred in the climatological conditions which existed this year. This century has no precedent for such a landfalling major hurricane along the US East Coast or over the Peninsula Florida under the seasonal climatological conditions. The probability of this happening again under similar climatological conditions is very, very low.

2. **H Bonnie** formed in mid-September in the middle Atlantic at the high latitude of 34°. Organized convection broke out in association with a stationary frontal zone. Bonnie gradually developed and moved northeastwards to reach a maximum intensity of 95 knots on the 21st of September at 37°N. Bonnie then weakened and moved southward. It then took on an eastward path through the Azores Islands before dissipating as a tropical system.

3. **H Charlie** formed in late September in the eastern Atlantic near 35°N from an upper level trough system which interacted with the northern portion of a tropical wave. Charlie moved north and then northeastward through the Azores Islands before weakening over cooler water. Charlie had satellite estimated maximum wind of 95 knots and existed as a hurricane for 3.5 days.

4. **TS Danielle** formed off the US East Coast in late September in association with a frontal system. It moved northward to threatened the upper US East Coast. Vertical wind shearing influences prevented it from intensifying beyond a maximum wind of 55 knots and a central pressure of 1001 mb.

5. **TS Earl** formed from an African easterly wave which moved with little intensification across the Atlantic and into the Bahamas. It then interacted with an upper level trough and became a named storm on the 29th of September. Westerly wind and shearing influences prevented it from obtaining a sustained wind greater than 55 knots.

6. **H Frances** formed around 27°N latitude to the east-southeast of Bermuda in late October. Development occurred near the back end of a weak quasi-stationary frontal trough. Frances moved slowly and then more rapidly northeastward attaining a maximum sustained wind of about 75 knots and being of hurricane intensity for two days.

   Figure 1 shows the tracks of all of these cyclones.

## 3. Verification of Author's 1992 Forecast

Table 4 gives statistical information of the author's seasonal forecast. Most parameters were well forecasted.

Table 4: Verification of 1992 hurricane activity forecast from various dates.

| | 1992 Fcst made on 26 Nov 1991 | 1992 Fcst as of 5 June | 1992 Fcst as of 5 Aug | 1992 Verification |
|---|---|---|---|---|
| Hurricanes | 4 | 4 | 4 | 4 |
| Named Storms | 8 | 8 | 8 | 6 |
| Hurricane Days | 15 | 15 | 15 | 15.75 |
| Named Storm Days | 35 | 35 | 35 | 38.25 |
| Hurr. Dest. Pot.(HDP) | 35 | 35 | 35 | 50.70 |
| Major Hurricanes (Cat. 3-4-5) | 1 | 1 | 1 | 1 |
| Major Hurricane Days | 2.0 | 2.0 | 2.0 | 3.25 |

## 4. Discussion

In those years, such as 1992 when African waves produce only a few named storms, we typically observe above average high latitude tropical cyclone development. The 1992 season was more typical of the seasons of 1968, 1972, 1977, 1982, 1983, 1986, and 1991 when very few African waves developed into named storms but appreciable amounts of higher latitude tropical cyclone activity occurred. Conversely, when African waves spawn a lot of low latitude named storms such as 1966, 1979, 1980, 1981, 1988 and 1989, sub-tropical development is typically reduced. There is often a degree of high versus low latitude compensation. This is the second consecutive year in which no hurricane activity occurred equatorwards of 25°N but more hurricane activity occurred poleward of this latitude.

The author's forecast scheme is primarily designed to predict the seasonal variation of the majority of hurricane activity which develops in the tropics. This forecast scheme shows skill because in most years, the majority of tropical cyclones which occur result from low latitude formations.

## 5. Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

This forecast was based on the author and his colleagues' past research (Gray, 1984a, 1984b); Gray (1990); Landsea and Gray (1992); Landsea *et al.* (1992); Gray *et al.* (1992, 1993a,b)) which relates seasonal Atlantic hurricane activity to: A) the El Niño (EN); B) the Quasi-Biennial Oscillation (QBO) of equatorial 30 mb and 50 mb stratospheric winds; C) Caribbean Basin-Gulf of Mexico Sea-Level Pressure Anomaly (SLPA) in spring and early summer; D) lower latitude Caribbean Basin 200 mb (12 km altitude) zonal wind anomaly in early summer, E) Western Sahel rainfall and F) the new parameter of west to east surface pressure and surface temperature gradient in February through May in West Africa. These six factors have been shown to be strongly related to seasonal variations in Atlantic tropical cyclone activity.

The author's seasonal forecast scheme has the following form:

$$\begin{array}{l} (Predicted\ Amount \\ \ \ of\ TC \\ Per\ Season) \end{array} = Ave.\ Season + \overbrace{(EN + QBO + SLPA + ZWA + AR + PT)}^{Adjustment\ Terms}$$

where

[EN] = El Niño influence. Warm East Pacific water reduces hurricane activity, cold water enhances it.

[QBO] = 30 mb and 50 mb Quasi-Biennial Oscillation equatorial zonal wind correction. Increased hurricane activity for westerly or positive phase, reduced hurricane activity for easterly or negative zonal wind.

[SLPA] = Average SLPA for Spring and early Summer. Reduce hurricane activity if SLPA is significantly above average, add activity if significantly below average.

[ZWA] = Zonal Wind Anomaly at 200 mb (12 km) for five low latitude upper air Caribbean stations. Reduce hurricane activity if positive, increase hurricane activity if negative.

[AR] = Western Sahel rainfall, increase activity if wet, reduce it if dry.

[PT] = West Africa west to east gradient of surface pressure and surface temperature during February through May. High values of pressure gradient and lower values of temperature gradient indicate more hurricane activity.

## 6. Characteristics of Known Seasonal Hurricane Predictors During 1992

A) El Niño

An El Niño formed late in 1991 and El Niño-type conditions have lasted through most of the 1992 hurricane season and have exerted an inhibiting influence on this season's Atlantic hurricane activity.

Quite consistent with this ENSO warming event has been the positive 200 mb zonal wind anomalies (ZWA) which have been observed throughout the Caribbean basin (see Table 8). Note that during all months from June through October above average 200 mb westerly wind anomalies were present. These winds acted as a suppressing influence on this season's low latitude tropical cyclone activity through their inhibiting vertical wind shear influences on African spawned easterly waves.

B) Stratospheric QBO Winds

Tables 5 and 6 show absolute and relative values of 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 11 to 13°N during the Spring and the primary hurricane period of August through October. Note that during the primary August through October hurricane season, 30 mb zonal winds experienced a shift to westerly phase but that 50 mb zonal winds, as anticipated, held persistently from an easterly direction.

Table 5: April through October 1992 absolute values of stratospheric QBO zonal winds (U) in the (critical) latitude belt between 11-13°N, as obtained from lower Caribbean basin stations Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in $ms^{-1}$ (as supplied by James Angell and Colin McAdie).

| | Observed | | | | | | |
|---|---|---|---|---|---|---|---|
| Level | April | May | Jun | Jul | Aug | Sept | Oct |
| 30 mb (23 km) | –18 | –21 | –23 | –20 | –17 | –11 | –6 |
| 50 mb (20 km) | –6 | –13 | –20 | –24 | –22 | –19 | –18 |

Table 6: As in Table 1 but for the "relative" (or anomalous) zonal wind values where the annual wind cycle has been removed. Values are in $ms^{-1}$.

| | Observed | | | | | | |
|---|---|---|---|---|---|---|---|
| Level | April | May | Jun | Jul | Aug | Sept | Oct |
| 30 mb (23 km) | –12 | –9 | –5 | –1 | +4 | +8 | +11 |
| 50 mb (20 km) | –5 | –7 | –8 | –9 | –8 | –7 | –8 |

Stratospheric QBO wind conditions for this season were in an intermediate or transitional stage, changing from easterly to westerly phase conditions at 30 mb but remained solidly from the east at 50 mb. Such zonal wind reversal at 30 mb and strong easterly 50 mb winds with attendant 30-50 mb shear were factors causing a reduction in this season's hurricane activity. There was a generally inhibiting influence on intense hurricane activity due to the easterly phase of the QBO below 50 mb. Over the last 42 years there have been only about half as many major

Atlantic hurricanes (Category 3-4-5) in those seasons when the 50 mb QBO absolute value of zonal winds were strongly from the east (as they were this year) than when they are weakly from the east (westerly phase).

C) Sea-Level Pressure Anomaly (SLPA)

Table 7 gives information on SLPA during the 1992 season. It is the Caribbean SLPA's which are most important. Note that most stations had higher SLPA during the months of June through October except for September. These somewhat higher surface pressure anomalies are consistent with the very low amount of tropical cyclone activity which occurred this year equatorwards of 25°N latitude.

Table 7: 1991 Average Eastern Caribbean Basin and Gulf of Mexico-E. Caribbean Basin Sea-Level Pressure Anomalies (SLPA) - in mb (as kindly supplied by Colin McAdie from NHC analysis in combination with CSU analysis).

| Low Latitude SLPA | Apr-May | Jun-Jul | Aug | Sept | Oct | Aug-Sept-Oct Average |
|---|---|---|---|---|---|---|
| San Juan (19.5°N, 66°W) | –2.8 | –0.1 | +1.1 | –0.3 | 0.0 | +0.3 |
| Curacao (12°N, 69°W) | –0.9 | +0.8 | +0.6 | +0.4 | –0.8 | +0.1 |
| Barbados (13.5°N, 60°W) | –1.3 | –0.1 | +1.0 | –1.1 | 0.0 | 0.0 |
| Trinidad (11°N, 62°W) | –0.3 | +0.8 | +1.7 | –0.3 | +1.3 | +0.9 |
| Cayenne (5°N, 52.5°W) | 0.0 | +0.6 | +1.4 | –0.2 | +1.1 | +0.8 |
| Average | –1.1 | +0.4 | +1.2 | –0.3 | +0.3 | +0.4 |
| **Gulf of Mexico-Caribbean Basin** | **Apr-May** | **Jun-Jul** | **Aug** | **Sept** | **Oct** | **Aug-Sept-Oct Average** |
| Brownsville (26°N) | +1.7 | +1.7 | +1.9 | +1.1 | +0.1 | +1.0 |
| Merida (Mex.) (21°N) | +1.3 | +0.2 | +2.1 | +1.2 | +0.3 | +1.2 |
| Miami (25.5°N) | –0.2 | +1.9 | +1.7 | +1.0 | +1.1 | +1.3 |
| San Juan (18.5°N) | –2.8 | –0.1 | +1.1 | –0.3 | 0.0 | +0.3 |
| Curacao (12°N) | –0.9 | +0.8 | +0.6 | +0.4 | –0.8 | +0.1 |
| Barbados (13.5°N) | –1.3 | –0.1 | –1.0 | –1.1 | 0.0 | 0.0 |
| Average | –0.4 | +0.7 | +1.6 | +0.4 | +0.2 | +0.7 |

D) Zonal Wind Anomaly (ZWA)

Table 8 shows that the upper tropospheric Zonal Wind Anomalies (ZWA) were generally positive throughout the June through October period. These strong and positive upper tropospheric zonal wind anomalies brought about a general increase of tropospheric vertical wind shear in the low latitude Atlantic. This was a factor inhibiting this years low latitude tropical cyclone activity.

High Caribbean basin SLPA and positive 200 mb ZWA are associated with the Intertropical Convergence Zone (ITCZ) in the Western Atlantic being displaced somewhat further south from its normal position. This was the situation during the 1992 hurricane season.

Table 8: 1992 Caribbean Basin 200 mb (12 km) Zonal Wind Anomaly (ZWA) in $ms^{-1}$ (as supplied by Colin McAdie of NHC analyses in combination with CSU data).

| Station | April-May | June-July | Aug | Sept | Oct | Aug-Oct Ave. |
|---|---|---|---|---|---|---|
| Kingston (18°N, 77°W) | 0 | −2 | +2 | +2 | +2 | + 2 |
| Curacao (12°N, 69°W) | −1 | +1 | +8 | +5 | −1 | +4 |
| Barbados (13.5°N, 60°W) | +1 | +2 | −3 | 0 | +3 | 0 |
| Trinidad (11°N, 62°W) | +1 | +4 | +3 | +4 | +4 | +4 |
| Average | 0 | +1 | +2 | +3 | +3 | +2.5 |

E) African Rainfall (AR)

African Rainfall (AR) is a new forecast parameter that was included in this year's forecast for only the third time. In the last few years we have found (Gray, 1990; Landsea, 1991; Landsea and Gray, 1992; Landsea *et al.*, 1992) that Atlantic intense hurricane activity is much enhanced when the Western Sahel region of West Africa (see Fig. 2) has above average precipitation. Activity is much reduced during drought conditions. Intense hurricane activity shows special sensitivity to Western Sahel rainfall conditions. Our recent research shows a very high correlation between the year-to-year variance in the number of intense (Category 3-4-5) hurricane days and the year-to-year variations in Western Sahel rainfall. The rainfall which fell in the 38-station Western Sahel region (Fig. 2) between June and September, 1992, was -0.75 S. D. below average. This indicates that the long running drought is still continuing.

F) West to East Gradient of Surface Pressure and Surface Temperature (PT)

We find that the west to east gradients of surface pressure and surface temperature which become established over West Africa during February through May is a good indication of the coming season hurricane activity. This is a new forecast parameter that was used this year for the first time. Pressure and temperature gradients during February-May 1992 was such as to indicate a below average hurricane season for this year.

# 7. Synoptic Conditions Controlling 1992 Atlantic Tropical Cyclone Activity

During much of August and September the Atlantic upper level circulation was dominated by a mid-ocean semi-permanent Tropical Upper Tropospheric Trough (TUTT), as shown in an idealized rendering in the top diagram of Fig. 3. This was the primary synoptic feature explaining much of this season's dearth of low latitude tropical cyclone activity. The vertical wind shear induced by this TUTT feature prevented nearly all of the approximately 60 westerly moving African spawned wave systems from intensifying into named storms (except for tropical storm Andrew). Andrew became a hurricane only after it had moved poleward of 25°N.

The existence of such mid-Atlantic TUTTs are much more common during seasons of Western Sahel drought as this year was and in seasons of warm ENSO events as this year was. By contrast, during those seasons when the Western Sahel experiences above average rainfall and a cold ENSO is present, mid-Atlantic upper level shearing conditions are typically much reduced (see the idealized bottom diagram of Fig. 3) and African spawned westward traveling systems or Cape Verde easterly waves can more readily develop into named storms and then into intense hurricanes.

## 8. Forecast for 1993

New studies by the author and his research colleagues (Gray *et al.*, 1992) is showing that there are skillful seasonal prediction signals related to the QBO and West African rainfall that are available by late November of the prior year. The existence of these signals allows for statistically skillful predictions of next season's tropical cyclone activity. Using these prediction signals we project a somewhat above average Atlantic hurricane season for 1993. A separate report giving more background information on next year's seasonal hurricane activity has been prepared. A more detailed report of this extended range forecast scheme (Gray *et al.*, 1992) has recently been published.

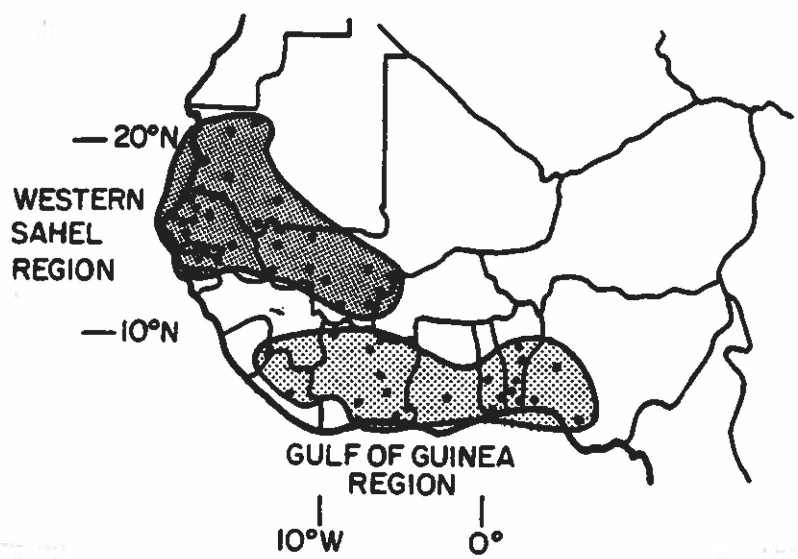


Figure 2: Location of rainfall stations which make up the Western Sahel precipitation index.

## 9. Verification of Previous Year Forecasts and General Potential for Seasonal Prediction

The author has now issued seasonal forecasts for 9 years. A record of these forecast verifications is given in Table 9. An evaluation of their skill in comparison with climatology, the only other previously available method of predicting future hurricane activity, is presented below.

This author's forecast scheme has evolved over the last nine years with the following changes:

1) In the more recent forecasts I have added seasonal predictors of Hurricane Destruction Potential (HDP), the number of intense or Saffir/Simpson category 3-4-5 hurricanes and of the

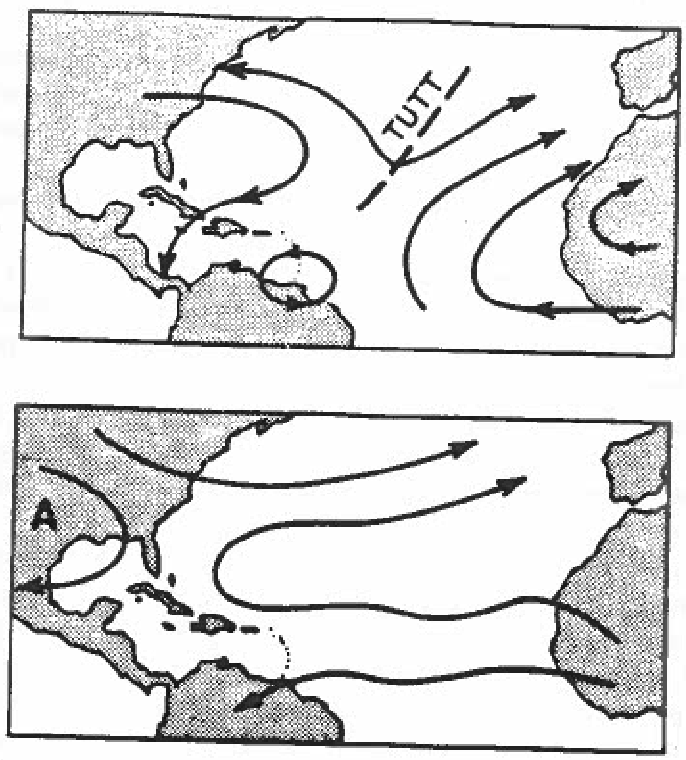


Figure 3: Illustration of the contrasting mean upper tropospheric flow conditions typically associated with August-September seasons when vertical shearing conditions prevent African waves from developing into named storms (top—as occurred in 1992) versus those seasons when vertical shearing influences are weak and many African wave systems develop into named storms (bottom).

Table 9: Verification of the author's previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1992.

| 1984 | | Prediction of 24 May and 30 July Update | | Observed |
|---|---|---|---|---|
| No. of Hurricanes | | 7 | | 5 |
| No. of Named Storms | | 10 | | 12 |
| No. of Hurricane Days | | 30 | | 18 |
| No. of Named Storm Days | | 45 | | 51 |
| **1985** | | **Prediction of 28 May** | **Updated Prediction of 27 July** | **Observed** |
| No. of Hurricanes | | 8 | 7 | 7 |
| No. of Named Storms | | 11 | 10 | 11 |
| No. of Hurricane Days | | 35 | 30 | 21 |
| No. of Named Storm Days | | 55 | 50 | 51 |
| **1986** | | **Prediction of 29 May** | **Updated Prediction of 28 July** | **Observed** |
| No. of Hurricanes | | 4 | 4 | 4 |
| No. of Named Storms | | 8 | 7 | 6 |
| No. of Hurricane Days | | 15 | 10 | 10 |
| No. of Named Storm Days | | 35 | 25 | 23 |
| **1987** | | **Prediction of 26 May** | **Updated Prediction of 28 July** | **Observed** |
| No. of Hurricanes | | 5 | 4 | 3 |
| No. of Named Storms | | 8 | 7 | 7 |
| No. of Hurricane Days | | 20 | 15 | 5 |
| No. of Named Storm Days | | 40 | 35 | 37 |
| **1988** | | **Prediction of 26 May and 28 July Update** | | **Observed** |
| No. of Hurricanes | | 7 | | 5 |
| No. of Named Storms | | 11 | | 12 |
| No. of Hurricane Days | | 30 | | 24 |
| No. of Named Storm Days | | 50 | | 47 |
| Hurr. Destruction Potential(HDP) | | 75 | | 81 |
| **1989** | | **Prediction of 26 May** | **Updated Prediction of 27 July** | **Observed** |
| No. of Hurricanes | | 4 | 4 | 7 |
| No. of Named Storms | | 7 | 9 | 11 |
| No. of Hurricane Days | | 15 | 15 | 32 |
| No. of Named Storm Days | | 30 | 35 | 66 |
| Hurr. Destruction Potential(HDP) | | 40 | 40 | 108 |
| **1990** | | **Prediction 5 June** | **Updated Prediction of 3 August** | **Observed** |
| No. of Hurricanes | | 7 | 6 | 8 |
| No. of Named Storms | | 11 | 11 | 14 |
| No. of Hurricane Days | | 30 | 25 | 27.5 |
| No. of Named Storm Days | | 55 | 50 | 68 |
| Hurr. Destruction Potential(HDP) | | 90 | 75 | 57 |
| Major Hurricanes (Cat. 3-4-5) | | 3 | 2 | 1 |
| Major Hurr. Days | | Not fcst. | 5 | 2 |
| **1991** | | **Prediction 5 June** | **Updated Prediction of 2 August** | **Observed** |
| No. of Hurricanes | | 4 | 3 | 4 |
| No. of Named Storms | | 8 | 7 | 8 |
| No. of Hurricane Days | | 15 | 10 | 8.25 |
| No. of Named Storm Days | | 35 | 30 | 20.25 |
| Hurr. Destruction Potential(HDP) | | 40 | 25 | 23 |
| Major Hurricanes (Cat. 3-4-5) | | 1 | 0 | 2 |
| Major Hurr. Days | | 2 | 0 | 1.25 |
| **1992** | **Prediction of 26 Nov 1991** | **Prediction 5 June** | **Updated Prediction of 5 August** | **Observed** |
| No. of Hurricanes | 4 | 4 | 4 | 4 |
| No. of Named Storms | 8 | 8 | 8 | 6 |
| No. of Hurricane Days | 15 | 15 | 15 | 15.75 |
| No. of Named Storm Days | 35 | 35 | 35 | 38.25 |
| Hurr. Destruction Potential(HDP) | 35 | 35 | 35 | 50.70 |
| Major Hurricanes (Cat. 3-4-5) | 1 | 1 | 1 | 1 |
| Major Hurr. Days | 2.0 | 2.0 | 2.0 | 3.25 |

number of category 3-4-5 days. There has not been a long enough period for a meaningful evaluation of the forecasts of these parameters.

2) West African rainfall, now known to be a fundamental component in variations in Atlantic hurricane activity has only been explicitly included in the last three years of forecasts. The first six forecasts were deficient in not including this very important but previously unknown parameter.

3) Until three years ago a hurricane day was accepted as a whole hurricane day if any 6-hour period of a day had hurricane intensity winds. This tended to inflate the number of hurricane days. We have now adopted the more desirable method of tabulating hurricane days by the number of 6-hour periods in which hurricane intensity conditions exist. A hurricane day now requires four 6-hour periods of hurricane intensity conditions. This has caused a downward alteration of the previous reported number of hurricane days per season by an average of 2.5.

It is impossible to give a really good assessment of the true potential of seasonal predictive skill from only the last nine (1984-1992) years of forecasts. This is too short a period for a very meaningful verification.

New statistical analysis of data for the 42 seasons of 1950-1991 by the author and colleagues Chris Landsea and CSU Statistics Professors Paul Mielke and Kenneth Berry show there is a likely a quite high potential for seasonal predictive skill (Gray, et al., 1992, 1993a,b). Our recent research is showing that surprisingly skillful long range hindcast skill is possible for Atlantic basin tropical cyclone activity. Table 10 gives our current hindcast skill at various forecast lag times. Note the high forecast skill for the period as early as late November. Also note that over two-thirds of the variance in the number of forecast parameter if possible by early June. These hindcast analyses utilize the jackknife method whereby forecasts are made on developmental data sets not utilized by the year being forecast. In this sense each year's forecast is made with independent data.

Table 10: Current degree of seasonal forecast skill or the amount of agreement or skill of our independent (Jackknife) analyses of the variance explained between 1950-1990 (or 1950-91) for seasonal forecasts from different lead times. The early June forecast represents our most recent improvement. (See Gray *et al.*, 1992, 1993a,b).

| | By Late Nov. of Previous Year | By Early June | By Early Aug.* |
|---|---|---|---|
| Named Storms | .440 | .514 | .451 |
| Named Storm Days | .514 | .660 | .611 |
| Hurricanes | .447 | .617 | .468 |
| Hurricane Days | .491 | .703 | .505 |
| Intense Hurricanes | .498 | .607 | .622 |
| Intense Hurricane Days | .451 | .679 | .611 |
| Hurricane Destruction Potential | .447 | .711 | .577 |

The early August forecast is currently being worked on to include new parameters which have just been incorporated in the early June forecast

This 42-year longer running and independent or jackknife statistical analyses are believed to be the best evaluation of the potential for seasonal hurricane forecasting.

Last Nine-Year Forecast Skill. Only four parameters have been predicted during all of the last 9-years of forecasts—number of hurricanes, number of named storms, number of named storm days, and number of hurricane days. Table 11 shows the ratios of the mean variance of the author's seasonal forecast from observations to the mean of the individual seasonal variances from climatology for the period of 1950-91. Values less than 1.00 show forecast skill over climatology. Values greater than 1.00 lack skill over climatology. For all four forecast parameters and for both forecast periods the variance of the errors of the author's predictions were considerably less than the average year to year variances from climatology over this 42-year period.

Table 11: Nine year (1984-92) forecast skill expressed as the ratio of variance of mean forecast error to the mean seasonal variance from climatology for the period 1950-1991.

| Forecast Parameter | 1 June Forecast | 1 August Forecast |
|---|---|---|
| Number of Named Storms | .51 | .33 |
| Number of Named Storm Days | .54 | .40 |
| Number of Hurricanes | .53 | .53 |
| Number of Hurricane Days | .62 | .43 |

Considerations of statistical independence suggests that the proper comparison of the last 9 years of forecast error should likely be made using only the average variances from climatology of the last nine rather than the last 42 seasons. Seasonal variances from climatology during the last 9 years were only 60% as large as were the seasonal variances from climatology of the data of the last 41 years. In other words, climatology has done a better job "forecasting" during the last 9 years in comparison to the previous 33 years. For instance, the yearly numbers of hurricanes during the period of 1984-92 has been 5, 7, 4, 3, 5, 7, 8, 4, and 4 and average variance from the long term mean has been 3.22. The 42-year mean variance of hurricanes has been 4.84, or 50% greater. Seasonal hurricane numbers between 1950-91 range from 2 to 12. The greater the variance from climatology, the greater is the potential forecast skill. It thus has been more difficult to demonstrate forecast skill over the last 9 years when the variance from the mean has been smaller than normal.

Table 12 shows the mean 9-year forecast skill using the mean variance from a climatology based only on the period 1984-92. Note the lower improvement of forecast variance over observed variation. Much of this reduction in forecast skill is due to the very poor forecast of 1989 when a below average hurricane season was forecast but an above average season occurred. This bust is attributed to conditions accompanying the unusually heavy amounts of rainfall which fell during June to September in the Western Sahel in 1989 which were, at that time not anticipated and whose influence on Atlantic hurricane activity was then not included in our forecast as it has been since. The inclusion of West African rainfall since 1990 has added significant forecast skill and the type of forecast error made in 1989 will likely not now be made. Values in parenthesis show this ratio of forecast to climatology variance when 1989 is deleted from the 9-year 1984-92 forecasts. Quite substantial skill is shown for the combination of 8 of the last 9 forecast seasons.

Regardless of how one might rate these seasonal forecasts over the last 9 years, we are very confident that future forecasts will stand the test of time and will demonstrate an ever improving skill. Our 41-year jackknife statistical analyses well demonstrates that substantial potential predictive skill exists over a more representative period of 41 years.

Table 12: Nine-year (1984-92) forecast skill expressed as the ratio of variance of mean forecast error to the mean variance from climatology for the period 1984-92. Values in parenthesis show this ratio when 1989 is deleted.

| Forecast Parameter | 1 June Forecast | 1 August Forecast |
|---|---|---|
| Number of Named Storms | .54 (.33) | .35 (.30) |
| Number of Named Storm Days | .82 (.32) | .62 (.25) |
| Number of Hurricanes | .83 (.53) | .83 (.53) |
| Number of Hurricane Days | .98 (.75) | .69 (.42) |

## 10. Acknowledgements

The author is indebted to many meteorological experts who have furnished the data necessary to make this forecast or who have given their assessments of the current state of global atmospheric and oceanic conditions. Chris Landsea, in particular, has contributed much to this forecast through the valuable statistical analyses and very beneficial discussion he has given me throughout all aspects of the making and verifying of this forecast. Landsea's (1991) MS thesis throws much new light on the strong West African rainfall-hurricane association. I have also received much benefit from the statistical insights and the voluminous statistical calculations on this topic that have been performed by CSU statistics Professors Paul Mielke and Kenneth Berry. Richard Taft and William Thorson have provided valuable computer assistance on West African rainfall, pressure and temperature data.

The author is most thankful to Colin McAdie of NHC who has furnished me with a great deal of tropical data. Vern Kousky has given me many helpful discussions. I thank James Angell for stratospheric QBO data and beneficial discussions. Dave Miskus and his colleagues at CAC have kindly furnished the author's project with a large amount of much needed West African rainfall data. Douglas LeComte and Graham Farmer have given rainfall assessment discussions. I have also appreciated the information I have received from U.K. Meteorological Office concerning their forecasts of West African rainfall. I have profited from discussions of African wave activity with Lixion Avila and other NHC forecasters Hal Gerrish, Miles Lawrence, Max Mayfield, Ed Rappaport, and Richard Pasch. The author has also gained from the quite indepth interchange he has had with his project colleagues John Sheaffer, John Knaff and Ray Zehr. Barbara Brumit and Laneigh Walters have provided important manuscript and data reduction assistance.

I would further like to acknowledge the encouragement I have received over recent years for this type of forecasting research application from Neil Frank and Robert Sheets, former and current directors of the National Hurricane Center (NHC) and from NHC Assistant Director Jerry Jarrell.

This research analysis and forecast has been supported by the National Science Foundation and NOAA.

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