EARLY AUGUST
UPDATED FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1994

By

*William M. Gray**

(This update of the author's 19 November 1993 and 7 June 1994 seasonal forecasts of 1994 hurricane activity is based on new June–July meteorological conditions and recent studies by the author and his Colorado State University research colleagues.)

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

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*Professor of Atmospheric Science

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 (in 10^4 $knots^2$)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/Sim 5 pson 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 anomalous west to east surface pressure (ΔP) and surface temperature (ΔT) 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.

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

1 knot = 1.15 miles per hour = .515 meters per second.

ABSTRACT

This paper presents details of the author's forecast for the amount of tropical cyclone activity expected to occur in the Atlantic Ocean region including the Caribbean Sea and the Gulf of Mexico during 1994. This forecast is based on the author and colleague's ongoing research relating the amount of seasonal Atlantic tropical cyclone activity to five basic physical parameters. These are: 1) the Quasi-Biennial Oscillation (QBO) of equatorial stratospheric wind; 2) the El Niño Southern Oscillation (ENSO); 3) West African Rainfall (AR) anomalies, 4) Anomalous west to east gradients of surface pressure and surface temperature (ΔPT) in West Africa during February through May, and 5) Caribbean Basin Sea Level Pressure and Upper Level Zonal Wind Anomalies (SLPA and ZWA respectively).

Information received by the author through 4 August 1994 indicates that the overall 1994 hurricane season should be below average with about 4 hurricanes (average is 5.7), 7 named storms (average is 9.2) of at least tropical storm intensity, a total of about 12 hurricane days (average is 23), 30 named storm days (average is 46) and total Hurricane Destruction Potential (HDP) of 35 (average is 69). It is also expected that there should be only one intense or major hurricane of Saffir/Simpson intensity category 3, 4 or 5 this season (average is 2.1) and only about 1 major hurricane day (average is 4.5). These parameters represent an overall measure of total hurricane and tropical cyclone activity which is only about 55% of the last 44-year average. The amount of hurricane activity in this forecast has been reduced from that in the author's 19 November 1993 forecast and update 7 June 1994 forecast. This forecast reduction is due to the slower than anticipated dissipation of the current El Niño, new estimates of below average West African rainfall, and much above average values of June-July Caribbean basin sea level pressure.

1 Introduction

The Atlantic basin, including the Atlantic Ocean, Caribbean Sea and Gulf of Mexico, experiences more season-to-season variability of hurricane activity than any other global hurricane basin. The number of hurricanes per season in recent years has ranged as high as 12 (as in 1969), 11 (as in 1950) and 9 (as in 1980, 1955), and as low as 2 (as in 1982) and 3 (1987, 1983, 1972, 1962, 1957). Until recently there has been no objective method for determining whether a forthcoming hurricane season was likely to be active, inactive, or near normal. Recent and ongoing research by the author and his colleagues (see Gray, 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992, 1993a, 1994) indicates that there are surprisingly skillful 3 to 11 month (in advance) predictive signals for Atlantic basin seasonal hurricane activity.

2 Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

This early August Atlantic seasonal hurricane forecast is based on end of July values of indices derived from various global and regional scale predictive factors which the author and his colleagues have previously shown to be statistically related to seasonal variations of hurricane activity. Successive sets of values for these predictive factors are obtained by late November of the previous year, then again during early June, the official start of the hurricane season, and beginning in early August at the start of the most active portion of the hurricane season. These predictive factors include the following.

(a) The stratospheric Quasi-Biennial Oscillation (QBO) influence. The QBO refers to variable east–west oscillating stratospheric winds which circle the globe over the equator. On average, there is nearly twice as much intense Atlantic basin hurricane activity during seasons when equatorial stratospheric winds at 30 mb and 50 mb (23 and 20 km altitude, respectively) are more westerly as compared to when they are more easterly directed. During the 1994 season, these QBO wind anomalies will be from an easterly direction and are expected to be a suppressing influence on this season's hurricane activity.

(b) El Niño Southern Oscillation (ENSO) influence: ENSO characterizes the presence of either warm or cold sea surface temperature anomalies in the eastern equatorial Pacific. The effects of a moderate or strong El Niño (warm water) event in the eastern equatorial Pacific act to reduce Atlantic basin hurricane activity. By contrast, seasons with cold sea surface temperatures, or La Niña years, have enhanced hurricane activity. These differences are related to alterations of upper tropospheric (200 mb or 12 km) westerly winds over the Caribbean Basin and western Atlantic. These westerly winds are enhanced during El Niño seasons. This condition creates strong vertical wind shear over the Atlantic which inhibits hurricane activity. During La Niña (or cold) years, these westerly winds and the associated vertical wind shear are reduced and hurricane activity is typically greater. The unusually long lasting and moderate intensity El Niño event of 1991-92-93 still has not fully dissipated. Overall ENSO conditions are anticipated to be slightly on the warm side during August and September of this year. Last fall and early this year (1994) it was anticipated that cold ENSO conditions would be in place by the active part of the 1994 hurricane season. New June-July data indicates that such cold conditions will definitely not develop. ENSO conditions are now judged to be only a small suppressing influence on this year's hurricane activity.

(c) African Rainfall (AR) influence: The incidence of intense Atlantic hurricane activity is typically enhanced during those seasons when the Gulf of Guinea region of West Africa (shaded area in Fig. 1) has above average August through November precipitation during the previous year (in this case during the fall of 1993) and the Western Sahel has above average precipitation in June and July. Hurricane activity is typically suppressed if rainfall in these two regions is below average. Rainfall amounts in the Gulf of Guinea rainfall was –0.05 S.D. in August through November 1993. Rainfall estimates for June-July of this year indicate rainfall of –0.58 Standard Deviation below normal. We had earlier anticipated that 1994 Western Sahel rainfall conditions would not be so dry as in the previous years of 1991-92-93. But recent June-July meteorological data from Western Sahel has lead us to alter this assessment. Such suppressed West African early season rainfall conditions are an indication of reduced intense hurricane activity for this year.

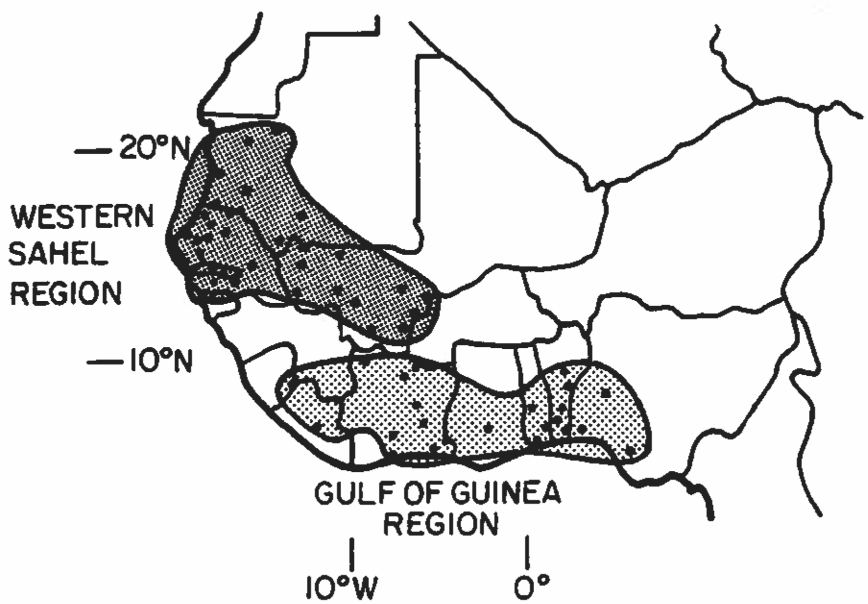

Figure 1: Locations of rainfall stations which make up the 38–station Western Sahel precipitation index and the 24-station Gulf of Guinea precipitation index. August to November rainfall within the Gulf of Guinea region provides a predictive signal for the following years hurricane activity as does prior year August-September rainfall in the Western Sahel (see Landsea, 1991; and Gray *et al.*, 1992).

(d) West Africa west-to-east surface pressure and surface temperature gradients (Δ PT) influence. Project research has shown that anomalous west-to-east surface pressure and surface temperature gradients across West Africa from February through May are strongly correlated with the hurricane activity which follows later in the year (see Gray *et al.*, 1994). We find that Atlantic hurricane activity is enhanced when the February to May east (Region B – in Fig. 2) minus west (Region A) pressure gradient is higher than normal and/or when the east minus west temperature gradient anomaly is below average. These pressure and temperature gradients during February through May 1994 indicated a weaker than normal North African monsoon and a below average amount of seasonal hurricane activity.

(e) Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA) influence. June and July values of SLPA and ZWA have a modest predictive potential for hurricane activity during the following season. Negative SLPA anomalies imply enhanced seasonal hurricane activity while positive anomaly values imply suppressed hurricane activity. June-July 1994 values of SLPA were quite high (+1.05 mb). This indicates a strong suppressing influence on this year's hurricane activity. June-July ZWA were near zero indicating little influence on this year's activity. Figure 3 provides a summary of the locations of the various forecast parameters which go into the early August forecast.

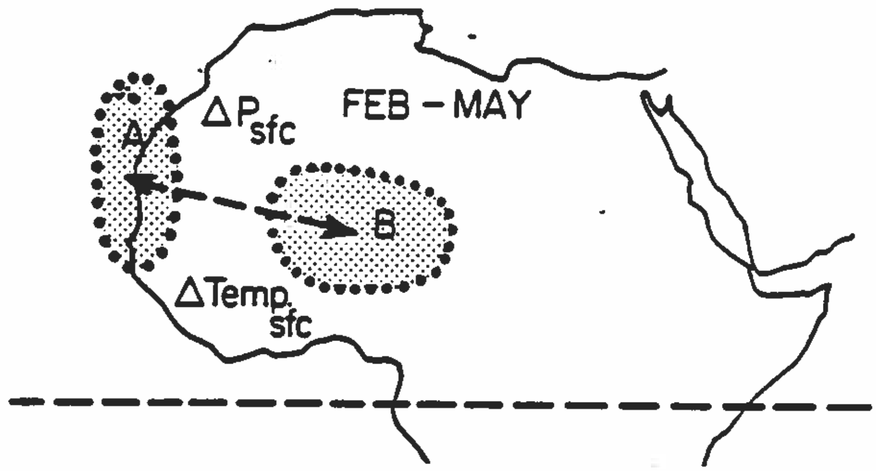

Figure 2: Portrayal of the two West African regions—west (Area A) and east (Area B)—from which multi-station surface pressure and temperature values are computed to form combined west-to-east pressure and temperature gradients or Δ PT parameter. (Gray et al. 1994).

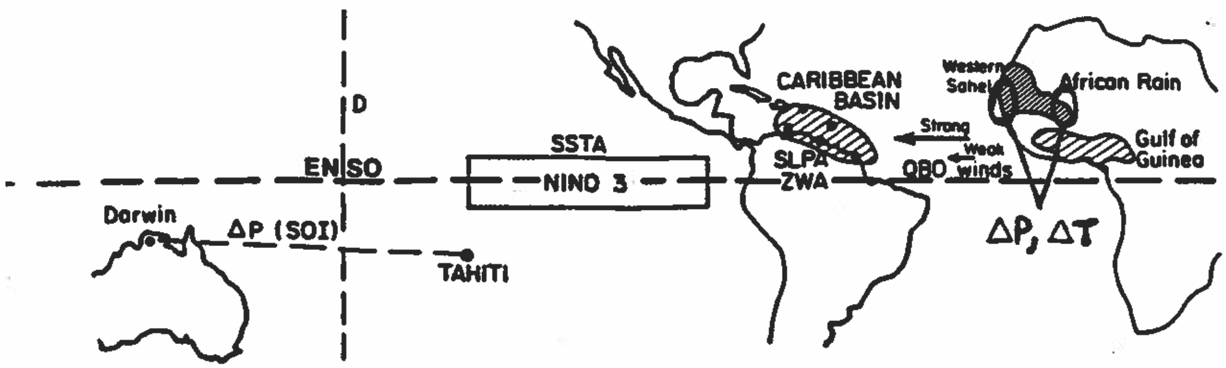

Figure 3: Locations of meteorological parameters used in the early August Atlantic basin seasonal forecast.

Our seasonal forecast scheme has the following general form:

$$\begin{array}{ll} & \textit{Adjustment Terms} \\ \left(\begin{array}{l}\textit{Predicted Amount} \\ \textit{of TC Activity} \\ \textit{Per Season}\end{array}\right) & = Ave.\ Season + (QBO + EN + AR + PT + SLPA + ZWA) \end{array} \quad (1)$$

where

QBO = 30 mb and 50 mb Quasi-Biennial Oscillation zonal wind anomaly influence. [(Increased hurricane activity for westerly (or positive) zonal wind anomalies; reduced hurricane activity for easterly or negative zonal wind anomalies.)]

EN = El Niño influence. (Warm surface water in the equatorial East Pacific reduces hurricane activity, cold water enhances it.)

AR = Western Sahel rainfall. (Increase activity if wet; reduced activity if dry.)

PT = West Africa west-to-east gradients of surface pressure and surface temperature during February through May. (High values of west-to-east pressure gradient and lower values of west-to-east temperature gradient indicate more hurricane activity; less hurricane activity with opposite gradients)

SLPA = Average Caribbean Sea Level Pressure Anomaly (SLPA) for Spring and early Summer. (Reduce hurricane activity if SLPA is significantly above average; add activity if SLPA is significantly below average.)

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

3 Details of the Current Characteristics of the Five Primary Early August Predictors (QBO, ENSO, AR, Δ PT, and SLPA-ZWA) as Regards the Amount of Anticipated 1994 Seasonal Hurricane Activity

3.1 QBO

Tables 1 and 2 show the absolute and anomalous values (relative to long term means) of the current and forward extrapolated 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 11 to 13°N for 1994 during the primary hurricane period of August through October. These estimates are based on a combination of the current trends in the QBO winds in the lower stratosphere combined with the annual wind cycle variations for low latitude stations at Curacao (12°N), Trinidad (11°N), and Barbados (13°N). Note that during the primary August through October hurricane season, 30 mb and 50 mb zonal wind anomalies will be from an easterly direction. This should be a suppressing influence for this year's hurricane activity.

3.2 ENSO

ENSO is the most important global scale environmental factor affecting Atlantic seasonal hurricane activity. Hurricane activity during the last three seasons has been much suppressed because of the persistent, continuous warm water conditions which have been present in the Nino-3 and Nino-4 (see Fig. 4) regions of the equatorial Pacific and the continuous drought

Table 1: March through October 1994 observed and extrapolated absolute values of stratospheric QBO zonal winds (U) in the critical latitude belts between 11-13°N as obtained from Caribbean stations at Curacao (12°N), Barbados (13°N), and Trinidad (11°N). Values are in ms^{-1} (data supplied by James Angell and Colin McAdie).

	Observed					Extrapolated		
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	−16	−20	−24	−29	−31	−30	−28	−20
50 mb (20 km)	+3	−3	−9	−18	−24	−24	−22	−19

Table 2: As in Table 1 but for the "relative" (or anomalous) zonal wind values wherein the annual wind cycle has been removed. Values are in ms^{-1}.

	Observed					Extrapolated		
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	−11	−12	−11	−12	−13	−12	−11	−8
50 mb (20 km)	+3	−2	−3	−8	−10	−10	−12	−12

conditions which have been present in the Western Sahel region of Africa. Sea surface temperature anomaly (SSTA) conditions (in °C) in Nino-1-2, 3, and 4 since January 1994 have been as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul
Nino-1-2	0.8	0.6	−0.2	−0.3	−0.5	0.0	0.0
Nino-3	0.4	0.0	0.1	0.2	0.4	0.4	−0.2
Nino-4	0.4	0.0	0.2	0.3	0.6	0.6	1.0

The long running 3-year El Niño event of 1991-92-93 now appears to be slowly dissipating. But residual effects still exist and there has been recent warming conditions in the Nino-4 area near the Dateline. There appear to be no clear pattern for general cooling or general warming.

3.3 West African Rainfall (AR)

Substantially more intense Atlantic hurricane activity occurs when June through September West Sahel rainfall is above average as compared to those seasons when rainfall is below average (Gray, 1990; Landsea and Gray, 1992). The long running Sahel drought of 1970-93 has been associated with a great suppression of intense hurricane activity during this 24-year period. A temporary (two year) interruption of African drought conditions occurred in 1988–89, concurrent with a substantial increase in intense hurricane activity, including five Saffir/Simpson category 4-5 hurricanes (Fig. 5). However, drought conditions have returned again during 1990-1993. The assessment for 1994 (as of early August) is that we will again see below average Western Sahel rainfall. Western Sahel rainfall is thus judged to be a continuing inhibiting influence for Atlantic intense hurricane activity during 1994 in comparison to long term climatology.

This assessment is based upon the following considerations:

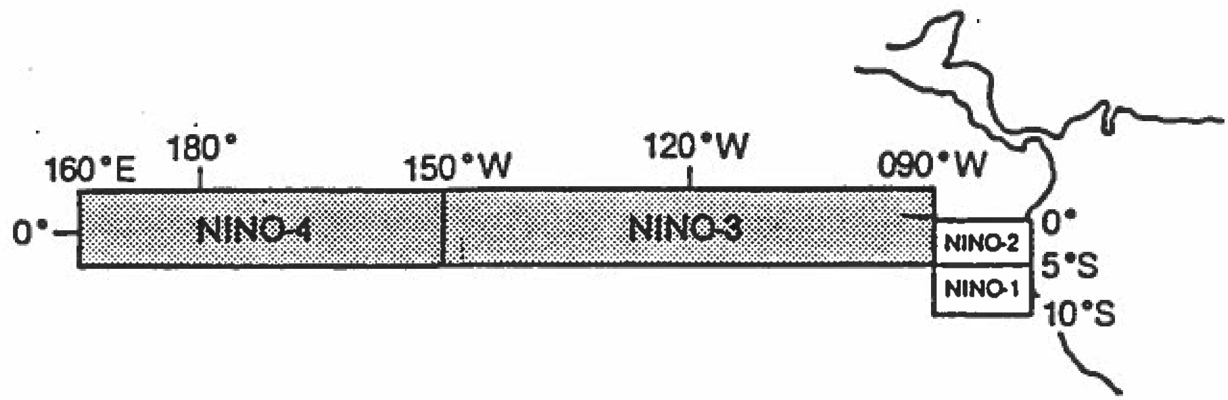

Figure 4: Equatorial Pacific sea surface temperature anomaly indices (°C) for the areas indicated.

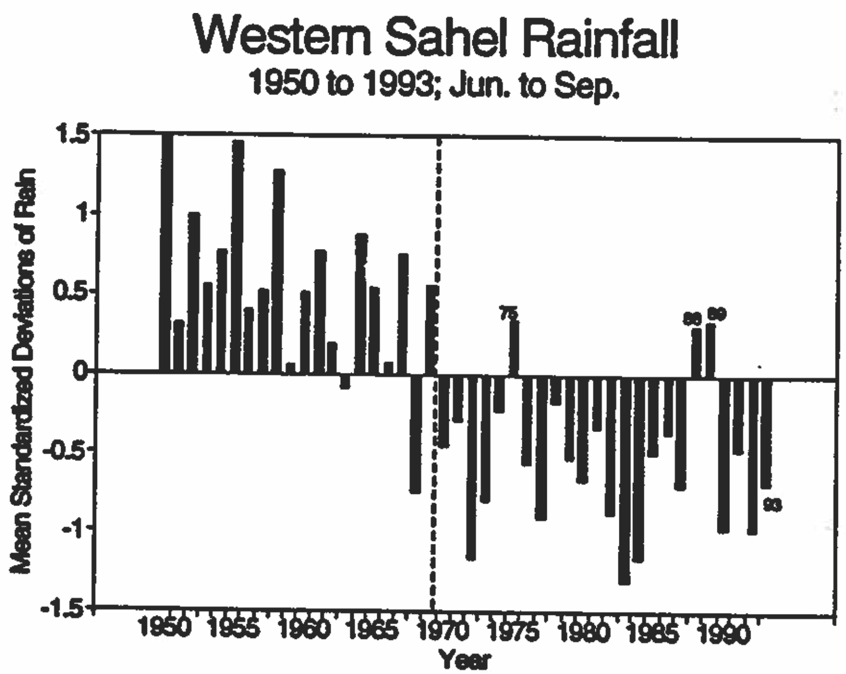

Figure 5: Rainfall anomalies in the Western Sahel during the last 47 years, expressed in terms of standardized deviations from the long period mean.

- (a) The measurement of –0.58 S.D. of Western Sahel rainfall conditions for this June and July of this year. Rainfall is distinctly below average in western and northern Senegal and southern Mauritania. Almost no rain has so far fallen at Dakar.
- (b) The present arrangement of global and Atlantic SSTA conditions, primarily in the tropical regions. The UK Meteorological Office (1994) is forecasting dry conditions for the Sahel region of West Africa. This forecast is based on global SSTA patterns of a warm Indian Ocean, warm central Pacific Ocean, warm South Atlantic, and cool North Atlantic through June of this year. This forecast was issued in mid-July.

Figure 6 shows June-July 1994 Western Sahel rainfall anomalies from the 1949-1994 average in standard deviation and in percent of long term average for these two months. Note the general dryness particularly in the western region.

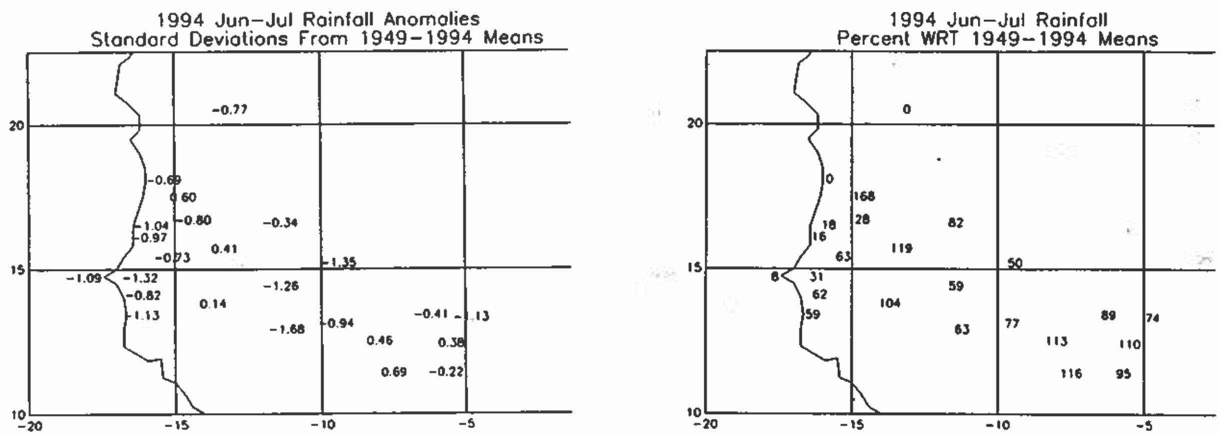

Figure 6: Western Sahel June-July average rainfall in standard deviation (left diagram) and in percentage of the 1949-1994 average (right diagram).

3.4 West Africa Δ P and Δ T

The anomalous west-to-east surface pressure and temperature gradients which become established across West Africa during February through May are good indicators of the hurricane activity to be expected in the late summer-fall period. Figure 2 showed the west-and-east areas of Africa from which these surface pressure and temperature gradients are taken. Hurricane activity is highest when the east (Region B) minus west (Region A) pressure gradient deviations are most positive and/or when the west-minus-east temperature gradients are positive.

Given the typical inverse relationship between land surface temperature and surface pressure, positive west-to-east pressure gradients are typically associated with positive east-to-west temperature gradients and vice versa. A positive value of west to east Δ P and east to west Δ T would act to enhance southerly winds and thus a comparatively moist low level flow over West Africa. More Sahel rainfall and Atlantic hurricane activity would result. When west to east ΔP and east to west Δ T are negative, West Africa would have anomalously northerly and dry winds; this is conducive to dry conditions and fewer Atlantic seasonal hurricanes. February through May 1994 west to east Δ P was −1.4 and Δ T was −0.3 S.D. Both of these values are indicative of a suppressing influence on this season's hurricane activity.

3.5 SLPA and ZWA

Two parameters which are very important for the early August forecast are Caribbean Basin Sea Level Pressure Anomalies and 200 mb (12 km) Zonal Wind Anomalies. The June-July 1994 five-station tropical (Trinidad, Barbados, Curacao, San Juan and Cayenne) SLPA's were very high (+1.05 mb – see Table 3). This indicates that the Intertropical Convergence Zone has moved further south and/or is weaker than normal. These high positive SLPA values should act as a suppressing influence on this year's hurricane activity. The five-station June-July (Balboa, Kingston, Trinidad, Curacao, and Barbados) ZWA values averaged out to be slightly negative (−0.5 m/s). The Caribbean pressures have been quite high in June and July. These values are near normal and indicate neither an enhancing or suppressing influence.

Table 3: Lower Caribbean basin Sea Level Pressure Anomalies (SLPA) for 1993 in mb (for San Juan, Barbados, Trinidad, and Cayenne) and Zonal Wind Anomaly (ZWA) in m/s for Kingston, Balboa, Curacao, Barbados, and Trinidad (as supplied by Colin McAdie of NHC and from our CSU analysis).

	April	May	June	July
SLPA	+0.82	+0.90	+1.06	+1.04
ZWA	+1.6	+1.8	+0.9	−1.9

4 Statistical Forecast for 1994

The author and his research colleagues Chris Landsea, Paul Mielke and Ken Berry have recently developed a quantitative forecast scheme specifically for the prediction of Atlantic seasonal hurricane activity from early August (see paper by Gray, Landsea, Mielke, and Berry, 1993). These collaborative research activities have yielded new quantitative prediction equations which better refine and maximize our early August predictions. This prediction equation is of the form

$$\tilde{y} = b_o + b_1\left[a_1 U_{50} + a_2 U_{30} + a_3 |U_{50} - U_{30}|\right]$$

$$+ b_2\left[a_4 R_S + a_5 R_G\right]$$

$$+ b_3\left[a_6(SLPA) + a_7(ZWA) + a_8(SOI) + a_9(SSTA)\right] \quad (1)$$

where

$\tilde{y}$ is the predictant (NS, NSD, H, etc.),
a's and b's are empirically derived coefficients,
U_{50}, U_{30} are extrapolated September QBO zonal winds at 30 and 50 mb at 10°N (Table 1),
$|U_{50} - U_{30}|$ absolute value of the extrapolated vertical wind shear between 50 and 30 mb,

R_S is the Western Sahel June–July precipitation,
R_G is the previous year August to November precipitation in the Gulf of Guinea region,
SLPA is the Sea Level Pressure Anomaly in the lower Caribbean basin in June–July,
ZWA is the Zonal Wind Anomaly in the Caribbean basin in June–July.
SOI is the normalized Tahiti minus Darwin Sea Level Pressure differences for June–July,
SSTA is the Sea Surface Temperature Anomaly in Nino 3 in June and July,

The a and b coefficients vary for each forecast parameter and are given in Table 4. Figure 3 shows the regions from where the data for these predictors was obtained.

Cross-validated (or jackknife) hindcasts for the 42 seasons of 1950-1991 show that we can explain a substantial amount of the variance in individual season forecast trials (Gray *et al.*, 1993a). Although these nine variables are not independent, when taken together, each variable contributes to the forecast skill. Based on data through the end of July, 1994, we find that the 1 August predictors in Equation (1) have the values listed in Table 5. Substitution of these variables into equation (1) gives 1994 seasonal hurricane activity forecast which is summarized in column A of Table 6.

Table 4: Constants and coefficients for 1 August statistical forecasts (from Gray *et al.* 1993a, 1994). Asterisk refers to the removal of a small bias in intense hurricane (cat. 3-4-5) maximum winds in the years of 1950-1969 (see Landsea, 1993).

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
NS	1.000	0.711	−0.082	1.000	−1.260	1.000	0.106	−0.275	0.046
NSD	1.000	0.560	−0.358	1.000	1.109	1.000	0.096	−0.864	−1.489
H	1.000	1.928	0.284	1.000	17.876	1.000	−1.172	−1.966	−0.025
HD	1.000	0.894	0.266	1.000	0.613	1.000	0.182	−0.050	−0.075
IH*	1.000	2.448	−0.876	1.000	0.689	1.000	0.166	0.476	1.462
IHD*	1.000	0.195	0.929	1.000	0.222	1.000	0.286	3.045	1.270
HDP*	1.000	0.550	0.649	1.000	0.186	1.000	0.497	1.978	3.327
NTC*	1.000	1.056	1.013	1.000	1.815	1.000	1.709	13.791	21.775

	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
NS	11.228	0.100	−0.757	−0.931
NSD	68.890	1.029	5.106	−5.309
H	7.410	0.046	0.050	0.239
HD	33.509	0.493	4.503	−4.318
IH*	3.000	0.013	0.745	−0.290
IHD*	4.806	0.109	4.933	−0.569
HDP*	85.835	1.615	30.989	−4.038
NTC*	122.819	1.481	11.310	−0.619

The right hand column of Table 6 reflects the author's qualitative adjustment to the statistical forecast which yields the actual forecast for this season. Table 7 compares this early August forecast to earlier forecasts for 1994 which were made in late November and early June.

Table 5: The nine predictor variables for the 1994 early August forecast are as follows.

U_{50}	=	–22 m/s
U_{30}	=	–28 m/s
$\|U_{50} - U_{30}\|$	=	6 m/s
R_s	=	–0.58 S.D.
R_g	=	–0.05 S.D.
SLPA	=	+1.05 mb
ZWA	=	–0.5 m/s
SOI	=	–1.3 S.D.
SSTA	+	–0.10°C

Table 6: The 1994 seasonal forecasts obtained by substitution of the parameters in Table 4 into Equation (1). The author's qualitative adjustment and actual forecast is given in Column B.

Forecast Parameter	A Table 5 Values in Eq. 1	B Qualitative Adjustment and Actual Forecast
Named Storms (N)	6.1	7
Named Storm Days (NS)	12.6	30
Hurricanes (H)	4.9	4
Hurricane Days (HD)	3.9	12
Intense Hurricanes (IH)	1.2	1
Intense Hurricane Days (IHD)	1.3	1
Hurricane Destruction Potential (HDP)	22	35
Net Tropical Cyclone Activity (NTC)	60.2	55%

Note that the forecast has been revised downward from the late November 1993 and early June 1994 forecasts. This is due to the high values of Caribbean basin surface pressure and the more tardy retreat of the El Niño. Table 7 also gives values for each parameter of this season's forecast expressed as a percentage of the last 44-year average. Table 8 shows a comparison of this year's early August forecast with the amount of hurricane activity of past years.

Forecast Skill. The forecast equation used for this early August update forecast (Eq. 1) is based upon prior research as discussed by Gray et al. (1993). We indicated in this paper an early August cross-validated hindcast skill of about 50-60 percent of the variance of 7 measures of hurricane activity for the period 1950-1990. New research is indicating that we have neglected some of the expected cross-validated degradation. We now believe that our expected forecast skill for future data sets to be only about 88-90% of that skill indicated in the 1993 paper or to be in the approximate range of 45-55% rather than 50-60 percent.

Table 7: Comparison of current early August 1994 seasonal predictions with the seasonal predictions made in late November 1993 and early June and the percent of normal of the early August forecast.

Forecast Parameter	Late Nov. 1993 Fcst.	Early June Fcst.	Current Early Aug. Fcst.	Early Aug. Fcst. As percent of long term mean
Named Storms (N)	10	9	7	76
Named Storm Days (NS)	60	35	30	65
Hurricanes (H)	6	5	4	70
Hurricane Days (HD)	25	15	12	52
Intense Hurricanes (IH)	2	1	1	45
Intense Hurricane Days (IHD)	7	1	1	22
Hurricane Destruction Potential (HDP)	85	40	35	51
Net Tropical Cyclone Activity (NTC)	110	70%	55%	55%

Table 8: Comparison of early August 1994 seasonal prediction with activity in previous years.

	5 Aug. Forecast 1994	Recent 1993	1992	Seasons 1991	Average Season 1970-93	Average 1950-69	1950-1993 Ave.
Hurricanes	4	4	4	4	5.0	6.5	5.7
Named Storms	7	8	6	8	8.7	9.9	9.2
Hurricane Days	12	10	16	8	16.5	30.7	23.0
Named Storm Days	30	30	38	22	39.3	53.4	45.7
Hurr. Dest. Pot. (HDP)	35	23	51	23	46.3	94.0	68.0
Intense Hurricanes (Cat. 3-4-5)	1	1	1	2	1.6	2.8	2.1
Intense Hurricane Days	1	0.75	3.25	1.25	2.6	6.9	4.6
Net Tropical Cyclone Activity (NTC)	55	55%	62%	59%	79%	127%	100%

5 Analog Years

Since 1950 there have been four years during which each of these basic hurricane modulating parameters by 1 August were similar to the anticipated conditions for 1994. Prior early August analog years for 1994 are 1962, 1968, 1974, and 1977. Each of these four years had nearly identical 70 mb to 10 mb stratospheric QBO wind conditions. Each of these four years had dry June-July Western Sahel rainfall values and other similar forecast parameters. Table 9 shows the nine forecast parameters for these analog years. Note how close their average value are to the nine early August forecast values for 1994. Table 10 shows what the eight seasonal hurricane parameters were during each of the four analog to 1994 years. Note how the four-year average value of each of these parameters is very close to this year's early June forecast. It is gratifying that these analogue years agree so well with the current forecast.

Table 9: Atlantic basin end of July forecast parameters in four prior years that were very similar to the end of July forecast parameters for 1994.

	September (estimated) QBO zonal wind at 10°N - (ms^{-1})			Observed rainfall		Observed Caribbean basin		Observed ENSO	
Year	1 50 mb	2 30 mb	3 Absolute shear |50-30 mb|	4 Western Sahelian (std. dev.) Jun-Jul	5 Gulf of Guinea previous year (std. dev.) Aug-Nov	6 SLPA (mb) Jun-Jul	7 ZWA (ms^{-1}) June-July	8 SOI (std. dev.) Jun-Jul	9 SSTA (°C) Jun-Jul
1962	22	26	4	–.12	–.74	0.2	–3.5	0.2	–.20
1968	16	32	16	–.29	–.51	1.0	–1.0	0.8	.25
1974	13	27	14	–.42	.74	0.4	2.8	0.6	–.29
1977	22	27	5	–.77	–.59	0.5	–0.7	–1.5	.20
Average	–18	–28	10	–.40	–.35	.52	–0.6	0.0	0.0
1994 Early Aug. Fcst. Parameters	–22	-28	6	–.58	–.05	1.04	–0.5	–1.3	–0.1

Table 10: Atlantic basin tropical cyclone activity which occurred during four previous analog years when end of July forecast parameters were similar to end of July values of these parameters for 1994.

Year	NS	NSD	H	HD	IH	IHD	HDP	NTC
1962	5	22	3	11	0	0	26	33
1968	7	26	4	10	0	0	18	41
1974	7	32	4	14	2	4.25	46	76
1977	6	14	5	7	1	1	18	46
Analog Average	6.2	23.5	4.0	10.5	.75	1.3	27.0	49.9
Eq. (1) Fcst. Value	6.1	12.6	4.9	3.9	1.2	1.3	22.0	60.2
Adjusted 1994 Fcst.	7	30	4	12	1	1	35	55

6 Strong Suppression of Intense (or Major) Low Latitude Atlantic Basin Hurricane Activity During the Last Three Years (1991-1993)

There has been a total of only four intense (or major) category 3-4-5 hurricanes and only 5.25 intense hurricane days during the last three years. The climatology of the last 44 years would have specified 6.6 intense hurricanes (65 percent more) and 13.5 (105 percent more) intense hurricane days during this period. Additionally all of the intense (category 3-4-5) hurricanes during 1991-1993 developed into intense storms at locations poleward of 25°N. Climatology would specify that only about one-third, or about 1.3 intense or major hurricanes (maximum sustained winds > 115 mph) would reach this level of intensity at these higher latitudes. There is an inverse association between low latitude (< 25°N) and high latitude (> 25°N) Atlantic basin hurricane activity; when the low latitudes are active, higher latitude areas are typically suppressed. When the low latitudes are inactive, as during the last three seasons, then hurricane activity at higher latitudes is typically enhanced. The two seasons of 1988 and 1989 saw the formation of a total of five intense (or major) hurricanes at latitudes equatorwards of 25°N. Goldenberg and Shapiro (1993) have provided strong evidence that interannual vertical shear differences force this inverse association between the low and high latitudes.

Table 11 illustrates the unusually large reduction in hurricane activity south of 25°N during the last three hurricane seasons in comparison with the average three year period between 1950-1990. Only one hurricane (Gert 1993, southwestern Gulf of Mexico) formed south of 25°N during these three years when, from climatology, one would have expected about 11 hurricanes to form. No major hurricanes formed during this three-year period south of 25°N when, from past climatology, one would have expected 4.5 major hurricanes to form.

Table 11: Summary of latitude during distribution of Atlantic basin hurricane activity north or south of 25°N including the Gulf of Mexico during the three seasons of 1991-1993

	No. becoming of hurricane intensity		No. becoming intense (or major) cat. 3-4-5 hurricanes	
	South of 25°N	North of 25°N	South of 25°N	North of 25°N
1991	0	4	0	2
1992	0	4	0	1
1993	1	3	0	1
Total	1	11	0	4
Expected three-year total based on the period 1950-1990	11.4	6.0	4.5	1.8

The recent long running El Niño has been a major suppressing influence for low latitude and Caribbean basin hurricane activity during the last three years. Continued Western Sahel drought conditions have also been an important contributing factor to the suppression of low latitude Atlantic hurricane activity. Hurricane Andrew (1992) developed into an intense hurricane at relatively high latitudes and, given the environmental conditions of an El Niño and West African dry weather during 1992, was an anomaly. We suggest that only 1 to 2 hurricanes of the four that are forecast will form equatorward of 25°N.

Latitudinal Variations. Nearly 60 percent of all named storms and nearly 50% of all hurricanes form equatorwards of 25°N in the South area of Fig. 6. Seasonal numbers of named storms and hurricane formations in the South Region are very well related to prior large-scale flow parameters and quite skillful seasonal predictions are possible for this South region. By contrast, the seasonal numbers of named storms and hurricanes which form in the North region (poleward of 25°N) often have an association with the characteristics of middle-latitude upper wave activity that is much less related to prior global climate features that can be forecast. Formations in the Gulf of Mexico are related to ENSO activity and have an intermediate amount of seasonal predictability potential.

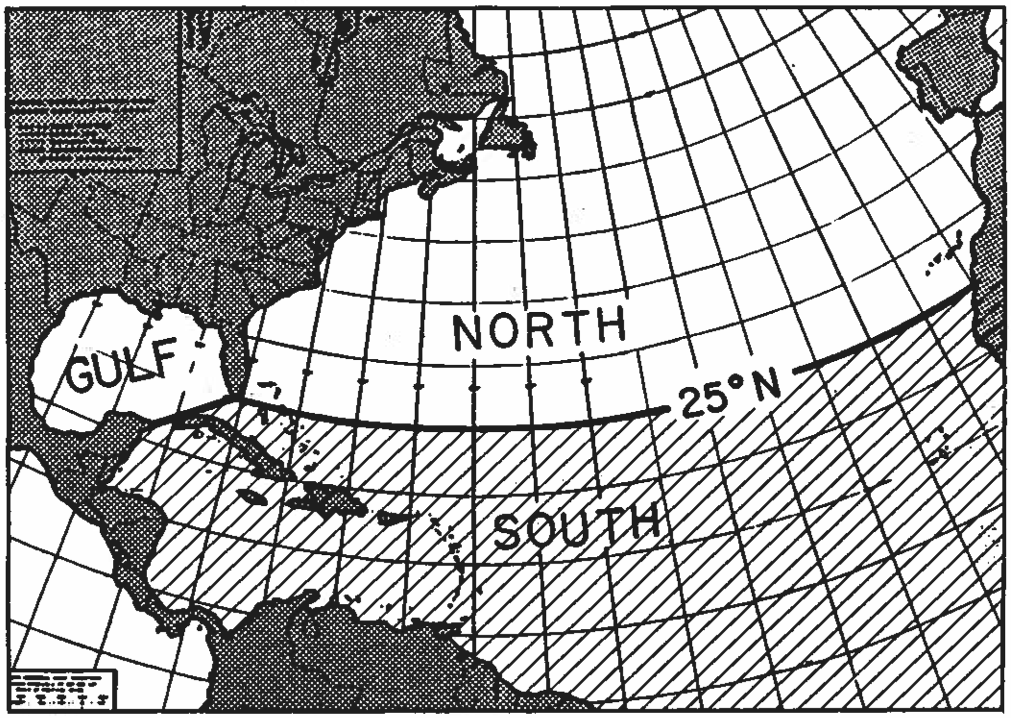

Figure 7: Illustration of Atlantic Basin regional breakdown.

There is a surprisingly strong inverse relationship between North versus South hurricane formation frequency. In those seasons when a lot of named storms and hurricanes form in the South region, few storms occur in the North region. By contrast, when seasonal numbers of tropical cyclone formations in the North are greatest, formations in the South is usually suppressed.

The left side of Fig. 8 shows the contrast in the North versus South region number of hurricane formations stratified for those 18 years between 1950-1993 wherein the North region had one hurricane formation or less per season versus those 18 years where in the North region had three or more hurricane formations per season. There were nearly twice as many (61 versus 34) hurricane formations in the South region when the North region had fewer storms. The right portion of this figure shows that in those 16 seasons between 1950-1993 when the South was very active (four or more hurricane formations) that the number of hurricane formations in the North region was only 72 percent as much as in those 16 seasons when the South was very inactive (one hurricane per year or less). Although the numbers of hurricanes in the North versus South during these two contrasting 16 season periods was 6 versus 82, there were 39% more hurricane formations in the North during those seasons when the South was inactive. The past three seasons of 1991-92-93 well illustrates this opposite North versus South relationship (see Table 11).

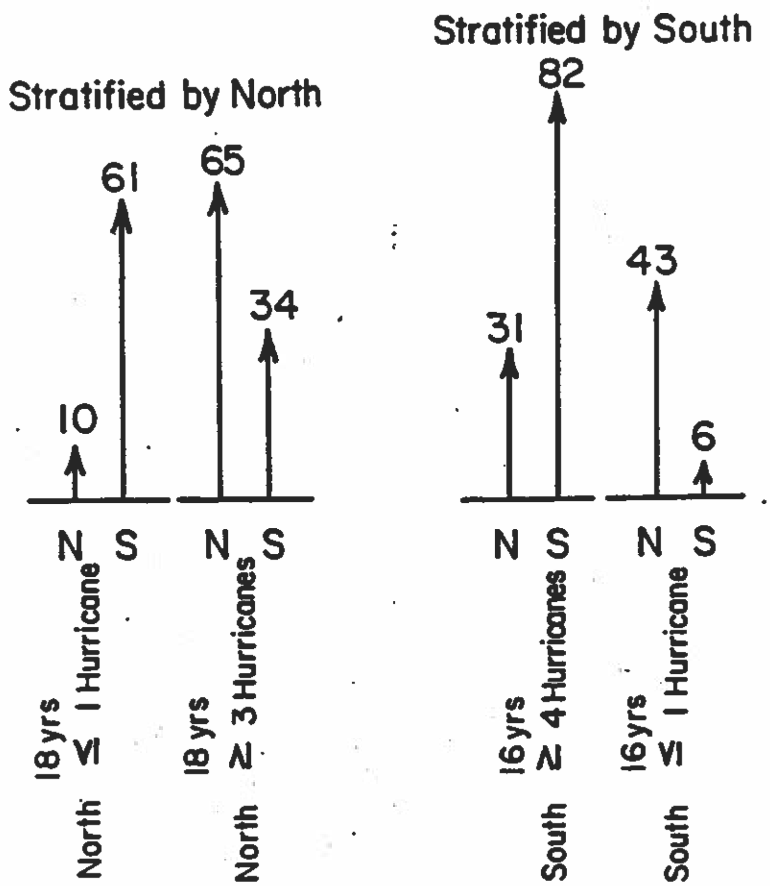

Figure 8: North (N) (> 25°N) region versus South (S)(< 25°N) region contrast in numbers of hurricane formations stratified by 18 years when the North region was inactive and 18 years when it was active (left diagram). The right diagrams show a similar stratification for conditions during 16 years when the South region was active versus 16 other years when the South region was inactive.

These inverse North-South formation differences appear to result from the 200 mb WSW to ENE orientation of the Tropical Upper Tropospheric Trough (TUTT) which is typically present in those summer and early fall periods when warm ENSO conditions are present and/or the Western Sahel is dry. This typical WSW to ENE elongation of the TUTT axis causes 200 mb westerly winds and high tropospheric vertical wind shear at low latitudes. These high shears inhibit low latitude hurricane formation. By contrast, easterly 200 mb wind flow conditions typically exist North of the TUTT axis. These upper level easterly winds together with the low level trade winds make for low tropospheric vertical wind shear and act to help enhance hurricane formation potential at higher latitude.

Goldenberg and Shapiro (1993) have recently demonstrated how variations in Western Sahel rainfall and cold and warm ENSO events are associated with such North-South tropical versus sub-tropical tropospheric vertical wind shear variations. It is quite consistent that the Atlantic should have such opposite North versus South latitudinal variations in hurricane activity.

Latitudinal Variations of Hurricane Activity for 1994. It is expected that most of the anticipated suppression of 1994 hurricane activity will take place in the South region. Hurricane formation potential in the North region is expected to be somewhat above average. We have no special insights for the probability of formation in the Gulf of Mexico.

7 Discussion

If this suppressed hurricane forecast for the 1994 season is verified, then we will have had four consecutive years of below average hurricane seasons. It is unusual to have four consecutive seasons in which hurricane activity and particularly low latitude hurricane activity to be so low. This is attributed to the exceptionally long running El Niño event of 1991-94, in combination with continuous and strong Western Sahel drought conditions. The weakening of the El Niño this year does not greatly improve the prospects for enhanced 1994 hurricane activity over that of 1991-93 seasons because this season's QBO will be strongly from the east (suppression influence), western Sahel drought conditions are anticipated and anomalously high values of SLPA are now present in the Caribbean basin. These are all inhibiting factors.

8 Schedule of Forecast Verification and Seasonal Hurricane Forecasts for 1995

A verification of the 1994 hurricane season and a forecast for the 1995 hurricane season will be issued in late November of this year. In addition seasonal forecasts for 1995 ENSO conditions and 1995 Sahel rainfall conditions will also be issued in late November.

9 Cautionary Note

It is important that the reader realize that this seasonal forecast is based on a statistical scheme which will fail in some years. This forecast also does not specifically predict where within the Atlantic basin storms will strike. Even if 1994 should prove to be a below average hurricane season, there are no assurances that several hurricanes will not strike along the US or Caribbean Basin coastline and do much damage. Or, if 1994 should prove to be a very active hurricane season there is no assurance that any storms will come ashore.

10 Outlook for 1995

It is anticipated that the 1995 hurricane season will be much more active than have the hurricane seasons of 1991-1993 and the expected activity of the 1994 season. The stratospheric QBO will be in a more favorable (for hurricane activity) westerly phase during 1995. These stratospheric wind conditions will also be favorable for the enhancement of cool ENSO conditions. Cool ENSO conditions and a westerly stratospheric QBO also act to enhance Sahel rainfall. Such cool ENSO, westerly QBO and reduced African drought conditions are typically associated with greater hurricane activity.

11 Verification of Seasonal Forecasts for Prior Seasons

The author has now issued seasonal hurricane forecasts for the last eleven years. In the majority of prior forecasts, predictions have been superior to climatology, which was previously the only way to estimate future hurricane activity (see Table 11). The six seasonal forecasts for 1985, 1986, 1987, 1988, 1991 and 1992 were quite accurate; the forecasts for 1984 and 1990 were only marginally successful and the two seasonal forecasts for 1989 and 1993 were failures. The 1989 forecast was a failure because of the excessive amounts of rainfall which fell in the Western Sahel that year. Prior to 1990, our seasonal forecast did not include African rainfall as a predictor. We have corrected this important omission and forecasts since 1990 have included Western Sahel rainfall estimates. Extended range seasonal hurricane forecasts from late November have only been issued for the 1992, 1993, and 1994 seasons. The failure of the 1993 seasonal forecast is attributed to our failure to anticipate the resurgence and continuation of El Niño conditions through the whole of the 1993 hurricane season. In particular, the author failed to anticipate the re-emergence of stronger El Niño conditions after the middle of August 1993. It is very unusual to have an El Niño last as long as the recent event has. This failure motivated us to develop a new extended range ENSO prediction scheme.

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Table 12: Verification of past year forecasts (1984-1993).

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
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	1.00
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
No. of Named Storm Days		35	30	22
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	16
No. of Named Storm Days	35	35	35	38
Hurr. Destruction Potential(HDP)	35	35	35	51
Major Hurricanes (Cat. 3-4-5)	1	1	1	1
Major Hurr. Days	2.0	2.0	2.0	3.25
1993	**Prediction of 24 Nov 1992**	**Prediction 4 June**	**Updated Prediction of 5 August**	**Observed**
No. of Hurricanes	6	7	6	4
No. of Named Storms	11	11	10	8
No. of Hurricane Days	25	25	25	10
No. of Named Storm Days	55	55	50	30
Hurr. Destruction Potential(HDP)	75	65	55	23
Major Hurricanes (Cat. 3-4-5)	3	2	2	1
Major Hurr. Days	7	3	2	0.75

APPENDIX A

Measures of seasonal tropical cyclone activity include the seasonal total number of named storms (NS), hurricanes (H), intense (or major) hurricanes (IH), named storm days (NSD), hurricane days (HD), intense hurricane days (IHD), and hurricane destruction potential (HDP). Definitions of these hurricane indices are given at the beginning of this report. More detailed information is contained in Gray et al. (1992, 1994) and in Landsea (1993).

It is desirable to define a single number which provides a simple but comprehensive expression of net season tropical cyclone activity in terms of a percentage difference from a long term mean. To this end, we propose a new parameter of seasonal activity termed the "Net Tropical Cyclone activity" (NTC) which is defined as:

$$NTC = (\%NS + \%H + \%IH + \%NSD + \%HD + \%IHD)/6$$

Table 13: Listing of Seasonal Net Tropical Cyclone activity (NTC) values between 1950-1993.

Year	NTC (%)	Year	NTC (%)	Year	NTC (%)
1950	243	1964	168	1978	86
1951	121	1965	86	1979	96
1952	97	1966	140	1980	135
1953	121	1967	97	1981	114
1954	127	1968	41	1982	37
1955	198	1969	157	1983	32
1956	69	1970	65	1984	77
1957	86	1971	95	1985	110
1958	140	1972	28	1986	38
1959	99	1973	52	1987	48
1960	101	1974	76	1988	121
1961	222	1975	92	1989	140
1962	33	1976	85	1990	104
1963	116	1977	46	1991	59
				1992	62
				1993	55

where each season's percentage departure values from the long term mean are used as the six measures of seasonal activity. The NTC value is useful as a seasonal tropical cyclone measure because it combines most of the other tropical cyclone parameters of interest into a single measure of activity. There are many seasons in which a single parameter, say for example, the number of hurricanes, is not well representative of the actual character of the overall tropical cyclone activity for that year. We propose the use of this single (NTC) index as a measure of tropical cyclone activity. This single index has the highest forecast skill. Table 11 lists the values of NTC for 1950-1993.

Note that the last three hurricane seasons have had net seasonal hurricane activity averaging only 59 percent of the 1950-1993 average, when the seasonal hurricane activities in the previous three seasons of 1988-1990 averaged 122 percent or twice as much.