FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1993

By
*William M. Gray**

(This forecast is based on ongoing research by the author and his research colleagues at Colorado State University, together with current April–May 1993 meteorological information)

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 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 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.

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 1993. This forecast is based on the author and colleague's ongoing research relating the amount of seasonal Atlantic tropical cyclone activity to five basic forecast 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 of the previous year, 4) West African west to east gradients of anomalous surface pressure and surface temperature (ΔPT) 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 3 June 1993 indicates that the 1993 hurricane season should overall be about an average season with about 7 hurricanes, 11 named storms of at least tropical storm intensity, a total of about 25 hurricane days, 55 named storm days and total Hurricane Destruction Potential (HDP) of 65. It is also expected that there should be two intense or major hurricanes of Saffir/Simpson intensity category 3, 4 or 5 this season and about 3 intense hurricane days. These parameters represent an overall measure of hurricane activity about 95% of the last 42-year average. The amount of intense or major hurricane activity has been reduced from that given in the author's 24 November 1992 forecast. This reduction is due to the slow dissipation of the current El Niño and to new estimates of West African drought conditions.

Hurricane activity in 1993 will be enhanced by favorable stratospheric QBO westerly phase winds and low values of Caribbean Basin Sea Level Pressure. It will be reduced by expected West Sahel drought conditions, and by a weakening El Niño event. The November forecast had anticipated cold ENSO conditions.

This forecast will be updated on 5 August, 1993, just before the beginning of the most active part of the hurricane season. The updated 5 August forecast will make use of June and July data and should provide a more reliable forecast, particularly with regard to the African rainfall as it relates to prospects for intense hurricane activity. The updated forecast will also provide a much better gage on the extent of dissipation of the current El Niño event.

1 Introduction

The Atlantic basin, including the Atlantic Ocean, Caribbean Sea and Gulf of Mexico, experiences more seasonal variability of hurricane activity than any other global hurricane basin. The number of hurricanes per season can range as high as 12 (as in 1969), 11 (as in 1950, 1916), 10 (as in 1933), 9 (as in 1980, 1955), or as low as zero (as in 1914, 1907), 1 (as in 1919, 1905), or 2 (as in 1982, 1931, 1930, 1922, 1917, 1904). 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 colleagues (see Gray, 1984a, 1984b, 1990; Landsea, 1991; Gray *et al.*, 1992) 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

The author's early June Atlantic seasonal hurricane forecast is based on the current values of indices derived from two global and three regional scale predictive factors which the author and colleagues have previously shown to be statistically related to seasonal variations of hurricane activity. The current values of these predictive factors are available either by early June, the official start of the hurricane season, or by early August, the start of the most active portion of the hurricane season. The five predictive factors are:

a) The stratospheric Quasi-Biennial Oscillation (QBO) influence. The QBO refers to east–west 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 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 1993 season, these QBO winds will be from a westerly direction. This is expected to be an enhancing 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. Westerly winds are enhanced during El Niño seasons, during La Niña or cold years, westerly winds are reduced. It is expected that the current El Niño event will be weakening rapidly over the next three months and will cause only a small inhibiting influence on this season's hurricane activity.

c) African Rainfall (AR) influence. Atlantic intense hurricane activity is typically enhanced during those seasons when the Western Sahel and Gulf of Guinea regions of West Africa (shaded area in Fig. 1) had above average late summer and fall precipitation during the previous year (i.e., in this case during the fall of 1992). Hurricane activity is typically suppressed if the prior fall rainfall in these two regions has been below average. Conditions last year (1992) were dry, indicating that West Africa will likely again have below normal rainfall this year. The expectation that precipitation amounts this year will be below average and more in line with the generally suppressed precipitation years of 1970-87 and 1990-92 implies a suppression in this season's intense hurricane activity.

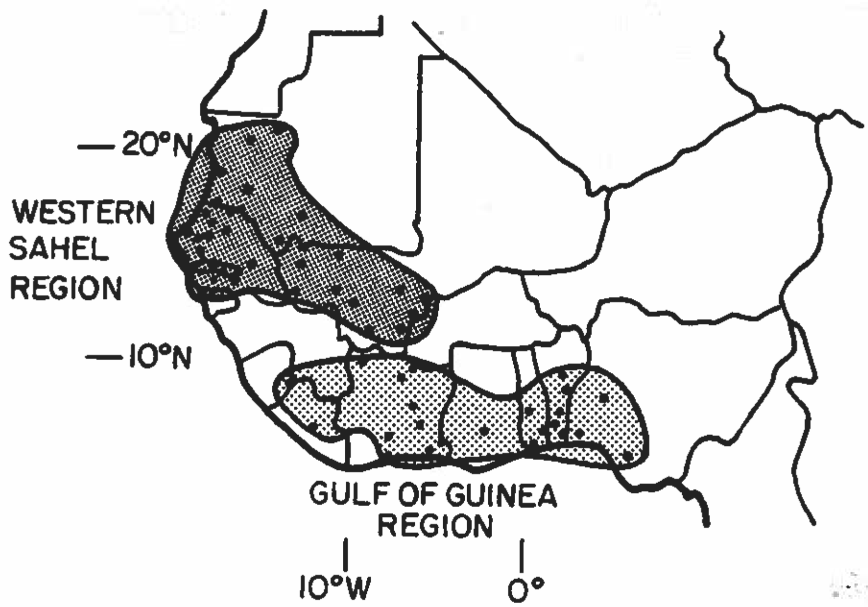

Figure 1: Locations of rainfall stations which make up the 38–station Western Sahel precipitation index and the 24-station Gulf of Guinea precipitation index. August to November rainfall within the Gulf of Guinea region provides a predictive signal for the following years hurricane activity as does prior 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 temperature gradients (Δ PT) influence. Recent project research by C. Landsea is showing 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. We find that Atlantic hurricane activity is enhanced when the east (Region B—see 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. Pressure and temperature gradients between February and May of this year were such as to indicate a somewhat below average hurricane season.

e) Caribbean basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric (12 km) Zonal Wind Anomaly (ZWA) influence. April and May values of SLPA and ZWA have a modest predictive potential for the following season hurricane activity. Negative anomalies imply an enhanced seasonal hurricane activity while positive values imply suppressed hurricane activity. April-May 1993 values of SLPA were quite negative while ZWA were only slightly positive.

Figure 3 shows the location of the various forecast parameters which go into the early June forecast.

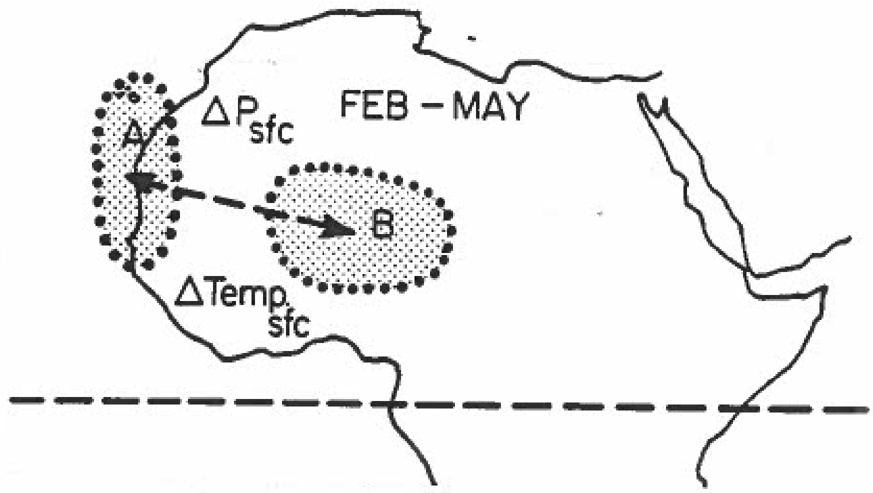

Figure 2: Portrayal of the two West African regions—west (Area A) and east (Area B)—from which multi-station surface pressure and temperature values are computed to form combined west-to-east pressure and temperature gradients or Δ PT parameter. (Gray et al. 1993b).

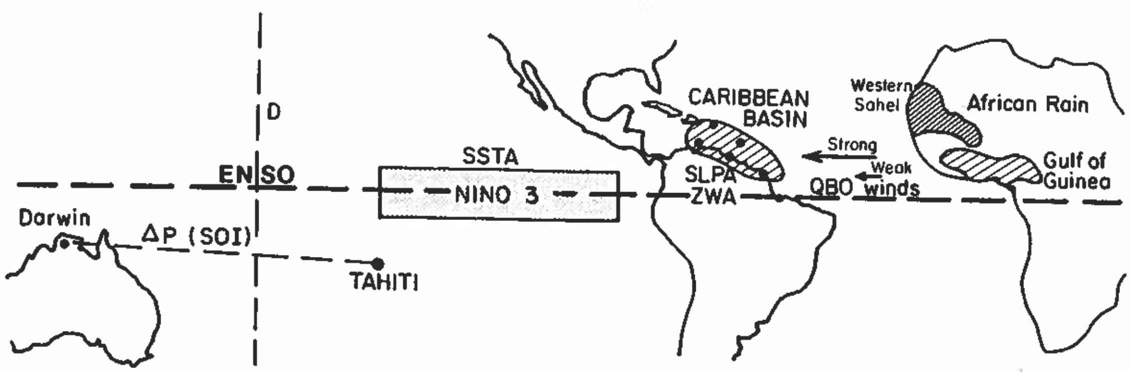

Figure 3: Locations of meteorological parameters used in the early June Atlantic basin seasonal forecast.

3 Current Characteristics and Discussion of the Five Primary (QBO, ENSO, AR, Δ PT, and SLPA-ZWA) Early June Predictors of 1993 Seasonal Hurricane Activity

3.1 QBO

Tables 1 and 2 show the absolute and relative values of the current and extrapolated 30 mb (23 km) and 50 mb (20 km) stratospheric QBO zonal winds near 11 to 13°N for 1992 during the primary hurricane period of August through October. These estimates are based on a combination of the current trends in the QBO winds 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 winds will be relatively westerly. Hence, stratospheric QBO wind conditions this year should enhance hurricane activity.

Table 1: April through October 1993 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} (supplied by James Angell and Colin McAdie).

	Observed			Extrapolated				
Level	March	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+10	+7	0	–4	–4	–6	–4	–5
50 mb (20 km)	+8	+7	+5	0	–3	–3	–2	–2

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)	+15	+15	+14	+13	+10	+8	+6	+2
50 mb (20 km)	+8	+8	+11	+11	+11	+10	+8	+5

3.2 ENSO

The Central and Eastern tropical Pacific are currently experiencing a resurgence of a warm El Niño event which first developed in late summer of 1991. This event weakened greatly during the second half of 1992 but has now strengthened again. April and May 1993 data show quite warm water temperatures and low values for the Southern Oscillation. It is unusual for an El Niño event to act in this way and for warm water conditions to persist for three consecutive years. The resurgence of the warm event in March through May surprised most El

Niño watchers who had been anticipating a change to cooler conditions by spring 1993. Most El Niño forecasters did not catch this warming resurgence. What will now happen? The most difficult aspect of this year's forecast is an evaluation of how ENSO conditions will change in the next four months.

Most changes in ENSO conditions occur between late spring and summer, during the establishment of the Asian summer monsoon. The author anticipates a strong cooling trend to occur during the next two to three months with the establishment of the Asian summer monsoon. Westerly QBO conditions, lack of a West Pacific Ocean warm pool buildup, and other current conditions favor a rapid depletion of the present El Niño. Only slight eastern Pacific warm water conditions are expected to be present during the height of the hurricane season which spans the period of mid-August to mid-October. We have already seen the beginning of a reduction in East Pacific warm water conditions in late May observations. Stronger trade winds are becoming established in the eastern and central Pacific and the Southern Oscillation is beginning to increase. It is anticipated that the current warm water El Niño will not be a major inhibiting influence on this year's hurricane activity. Should this assessment prove incorrect and moderately strong El Niño conditions persist during the early summer, the planned 5 August update forecast will be altered appropriately.

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 1970-87 was associated with a great suppression of intense hurricane activity during that 18 year period. A temporary (two year) interruption of African drought conditions occurred in 1988–89 and there was also a substantial increase in intense hurricane activity, including five Saffir/Simpson category 4-5 hurricanes. However, drought conditions returned again in 1990-1992. The assessment for 1993 (as of the end of May) is that we will again see well below average Western Sahel rainfall this year. It is expected that precipitation amounts will be more in line with the reduced precipitation years of 1970-87 and 1990-92. West African rainfall is thus judged to be an inhibiting influence for Atlantic intense hurricane activity for 1993.

This assessment is based upon the following considerations:

- (a) The low values of the Western Sahel August-September precipitation last year (–0.95 Standardized Deviation) and the very low values of Gulf of Guinea region (Fig. 1) rainfall during August through November of last year (–0.90 S.D.).

- (b) The Landsea et al. (1993) early June forecast of –1.61 S.D. of West African rainfall conditions for this year. This forecast is based on most of the same factors as the current seasonal hurricane forecast and indicates quite dry conditions for this summer.

- (c) The present arrangement of global and Atlantic SSTA conditions which in past years have been associated with African drought conditions. These SSTA conditions include positive southwest Atlantic SSTA and negative SSTA anomalies off of West Africa. The UK Meteorological Office (1993) is also forecasting dry conditions this year for the Sahel. Meteorological Office forecasts are based on global SSTA patterns through April.

3.4 Δ PT

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 coming months. Figure 2 shows 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 most positive.

Given the typical inverse relationship between land surface temperature and surface pressure, positive west-to-east pressure gradients are typically associated with negative west-to-east temperature gradients and vice versa. A positive value of Δ PT would act to enhance southerly wind and thus a comparatively moist flow over West Africa. More African rain and Atlantic hurricane activity would result. When ΔPT is negative West Africa would have anomalously northerly and dry winds; this is conducive to dry conditions and fewer Atlantic seasonal hurricanes.

February through May 1993 Δ PT data were negative in comparison with the prior 42-year average. This influence is indicative of a suppressing influence on this season's hurricane activity, a lesser suppressing but still negative influence than our estimates of West African rainfall.

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. New research is showing these parameters are also useful for the early June forecast. The April-May 1993 five-station tropical (Trinidad, Barbados, Curacao, San Juan and Cayenne) SLPA's were quite low (-0.90 mb) and the five-station April-May (Trinidad, Curacao, Barbados, Kingston and Balboa) ZWA values had a small value of +0.5 m/s. These measurements suggest an enhancement of this season's hurricane activity. They also suggest that the current El Niño event is not adversely influencing Caribbean and tropical Atlantic upper level wind patterns.

4 Seasonal Predictants

The tropical cyclone predictants include the seasonal total numbers 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 predictants are contained in Gray et al. (1992, 1993a) and in Landsea (1993). Also included is a new parameter of seasonal activity termed the net tropical cyclone activity (NTC), which is defined as:

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

where each season's percentage departure values from the long term mean are used for 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, the number of hurricanes is not representative of the entire tropical cyclone activity for that year.

For instance, the 1977 season had 5 H but was otherwise an inactive year; only 7 HD, 1 IH, and 1 IHD. By contrast, 1988 which also had 5 H, was an active year in terms of the other seasonal parameters which included 24 HD, 3 IH and 8 IHD. These are examples of years having one identical parameter yet much different levels of other activity. To overcome these difficulties we propose the use of a single (NTC) index which is a combination of six measures of tropical cyclone activity. This single index also has quite high forecast skill.

Table 3: Listing of Seasonal Net Tropical Cyclone activity (NTC) values between 1950-1992.

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

5 New 1 June Forecast Scheme

Over the last year and a half the author and his CSU research colleagues, Christopher Landsea, Paul Mielke, Jr., and Kenneth Berry have been working to add more skill to the early June forecast. We have identified the additional predictor, ΔPT, and have found a way to quantitatively represent ENSO conditions. A new paper discussing these results has recently been sent for publication (Gray, Landsea, Mielke and Berry, 1993b). This new more skillful forecast takes the following form:

(Hurricane Activity) =

$$\begin{aligned} &\beta_0 + \beta_1(a_1 U_{50} + a_2 U_{30} + a_3|U_{50} - U_{30}|) \\ &\quad + \beta_2(a_4 R_s + a_5 R_g + a_6 \Delta_x \mathrm{P} + a_7 \Delta_x \mathrm{T}) \\ &\quad + \beta_3(a_8 \mathrm{SLPA} + a_9 \mathrm{ZWA} + a_{10} \mathrm{SST} + a_{11} \Delta_t \mathrm{SST} + a_{12} \mathrm{SOI} + a_{13} \Delta_t \mathrm{SOI}) \end{aligned} \quad (1)$$

where

β's and a's are empirically derived coefficients for prior years of data
U_{50}, U_{30} are extrapolated September QBO zonal winds at 30 and 50 mb at 10°N
$|U_{50} - U_{30}|$ absolute value of the extrapolated vertical wind shear between 50 and 30 mb
R_s is the western Sahel precipitation in the previous August and September
R_g is the previous year August to November precipitation in the Gulf of Guinea region

ΔP is West African anomalous east-west pressure gradient deviation in February through May
ΔT is West African anomalous west-east temperature deviation in February through May
SLPA is the Sea Level Pressure Anomaly in the lower Caribbean basin
ZWA is the Zonal Wind Anomaly in the Caribbean basin
SOI is the normalized Tahiti minus Darwin Sea Level Pressure differences
SSTA is the Sea Surface Temperature Anomaly in Nino 3
ΔSOI is the recent months change in SOI
ΔSSTA is the recent months change in SSTA.

Figure 3 illustrates the source areas from which the data for these predictors are obtained.

Based on cross-validated (or jackknife) hindcasts for the 42 seasons of 1950-1991 we find that we can explain a substantial amount of the variance in individual season forecasts (see Table 4). Although these 13 variables are not independent, when taken together, each variable contributes to the forecast skill.

Table 4: Percent of variance explained for hindcasts made with Eq. 1 for the period of 1950-1991 (see Gray et al., 1993b).

Forecast Parameter	Percent of Variance Explained
Named Storms (N)	51
Named Storm Days (NS)	66
Hurricanes (H)	62
Hurricane Days (HD)	70
Intense Hurricanes (IH)	64
Intense Hurricane Days (IHD)	61
Hurricane Destruction Potential (HDP)	71
Net Tropical Cyclone Activity (NTC)	72

Note that by 1 June we can independently hindcast over 60% of the variability for all but one (NS) of the eight predictants of Table 3. It is extraordinary that we are able to hindcast as much as 70% of the variability in HD, 71% in HDP and 72% in NTC. This appears to be a very powerful forecast technique. The probability of no hindcast statistical skill in any of these predictant variables is between 10^{-7} and 10^{-12}.

Based on data through the end of May 1993 , we observe the 1 June predictors of Equation (1) to have the values listed in Table 5. Substitution of these variables to equation (1) gives 1993 seasonal hurricane activity forecast as indicated in Table 6. The coefficients used in Equation (1) are given in Appendix A. Also shown in Table 6 is the seasonal hurricane activity which results from assuming half the amount of current ENSO activity and by assuming neutral or zero ENSO influences. Our present forecast equation (1) contains information only on current and past ENSO conditions, not future conditions. Because of the recent unusual and likely temporary enhancement of the ENSO in April and May the author does not believe that April-May ENSO conditions and their changes from January-February are representative of the ENSO conditions to be expected between mid-August through mid-October. I believe that the most accurate forecast will be representative of cooler or more neutral ENSO conditions.

Table 5: End of May predictors which are substituted into Equation (1).

U_{30}	–4 m/s	
U_{50}	–2 m/s	
$\|U_{50} - U_{30}\|$	2 m/s	extrapolated to Sept.
R_s	–0.95 S.D.	
R_g	–0.90 S.D.	Measured last year
ΔP	–0.65 mb S.D.	
ΔT	–0.20 ° S.D.	February through May
SLPA	–0.90 mb	
ZWA	+0.5 m/s	April-May values
SOI	–11.5 10^{-1}S.D.	
SSTA	+145 10^{-2} °C	April-May values
ΔSOI	+2.0 10^{-1} S.D.	
ΔSSTA	+ 125 10^{-2} °C	(Apr-May)-(Jan-Feb)

Table 6: The 1993 seasonal forecasts obtained by substitution of the parameters in Table 5 into Equation (1) with ENSO values as shown (i.e., Table 5) (Column A) and with the assumption neutral ENSO values (Column B). The author's qualitative adjustment and actual forecast is given in Column C.

Forecast Parameter	A Table 5 Values in Eq. 1	B Table 5 Values in Eq. 1 but with half present ENSO Conditions	C Table 5 Values in Eq. 1 but With Neutral ENSO Conditions	D Qualitative Adjustment and Actual Forecast
Named Storms (N)	11.7	11.0	10.3	11
Named Storm Days (NS)	53.6	64.6	71.9	55
Hurricanes (H)	9.0	10.0	10.9	7
Hurricane Days (HD)	12.5	28.4	43.5	25
Intense Hurricanes (IH)	–0.3	0.4	1.0	2
Intense Hurricane Days (IHD)	–2.1	1.3	4.4	3
Hurricane Destruction Potential (HDP)	21.8	65.8	107.3	65
Net Tropical Cyclone Activity (NTC)	73%	98%	121%	95%

The right column of Table 6 shows the author's qualitative adjustment of the statistical forecast and the actual forecast for this season. Table 7 compares each parameter of this season's forecast as a percentage of the last 42-year average. Table 8 compares this early June forecast to the author's late November forecast (Gray, 1992). Note that less intense hurricane activity is now forecast in early June than was forecast in late November 1992. The November 1992 forecast anticipated cold ENSO conditions to be in place during 1993 in contrast to the neutral or slightly warm conditions now expected. Table 9 shows a comparison of this year's seasonal activity forecast with the amount of hurricane activity of past years.

Table 7: 1993 Atlantic basin seasonal forecast values and the percent of the long term (1950-1992) average.

	Forecast	%
Named Storms (N)	11	119
Named Storm Days (NS)	55	119
Hurricanes (H)	7	122
Hurricane Days (HD)	25	107
Intense Hurricanes (IH)	2	93
Intense Hurricane Days (IHD)	3	65
Hurricane Destruction Potential (HDP)	65	94
Net Tropical Cyclone Activity (NTC)	95%	95%

Table 8: Comparison of current early June 1993 seasonal predictions with the seasonal predictions made in late November 1992.

Forecast Parameter	Late Nov. 1992 Fcst.	Current 1993 Early June Fcst.	Difference From Late Nov. 1992 Fcst.
Named Storms (N)	11	11	0
Named Storm Days (NS)	55	55	0
Hurricanes (H)	6	7	+1
Hurricane Days (HD)	25	25	0
Intense Hurricanes (IH)	3	2	-1
Intense Hurricane Days (IHD)	7	3	-4
Hurricane Destruction Potential (HDP)	75	65	-10
Net Tropical Cyclone Activity (NTC)	–	95%	–

Table 9: Comparison of early June 1993 seasonal prediction with activity in previous years.

	4 June Forecast 1993	Observed 1992	1991	1990	Average Season 1970-87	Average Season 1950-69	43-Year Ave.
Hurricanes	7	4	4	8	4.9	6.5	5.7
Named Storms	11	6	8	14	8.3	9.8	9.2
Hurricane Days	25	16	8	28	15.5	30.7	23.3
Named Storm Days	55	38	20	68	37.3	53.4	46.1
Hurr. Dest. Pot. (HDP)	65	51	23	57	42.7	100.0	69.0
Major Hurricanes (Cat. 3-4-5)	2	1	2	1	1.6	3.4	2.1
Major Hurricane Days	3	3	1	1	2.1	8.8	4.7
Net Tropical Cyclone Activity (NTC)	95%	62%	59%	104%	73%	123%	100%

6 Summary Discussion

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This is the 10th season that the author has made an Atlantic Basin seasonal hurricane forecast and one of the most difficult forecasts. This is due to the uncertainty concerning the resurgence of warm El Niño conditions in April and May. The author and most El Niño researchers did not anticipate this recent warming. The author does not believe that these warm sea surface temperature conditions will persist through the height of the hurricane season from mid-August through mid-October, however. A rather rapid and progressive cooling is anticipated in the next 3-4 months. There is a difference of opinion among El Niño experts as to the rapidity of this cooling. Table 6 lists statistical forecasts assuming current ENSO conditions are representative of August to October conditions, and other calculations assuming the ENSO effect is half of current conditions and if there were no warming at all. The author has chosen to accept ENSO conditions which are about half as strong as current conditions.

The reader should note that this forecast rests on a number of other parameters in addition to the ENSO. Name storm and hurricane numbers are expected to be somewhat above average for this season. African rainfall and surface pressure and temperature gradient conditions are indicative of a suppressed intense (or major category 3-4-5) hurricane activity, however. The 1993 season should definitely have more name storms and hurricanes than have the last two seasons of 1991 and 1992. The coming hurricane season is expected to be somewhat analogous to the 1990 hurricane season which had a large number of name storms (14) and hurricanes (8) but only one intense hurricane.

7 Verification of Previous Forecasts

Table 10 gives verification data for the author's previous nine years of seasonal forecasts. The late July forecasts have been superior to the early June forecasts and the forecasts of named storm activity have been the most skillful. Last year's forecast went very well. Except for 1989, these forecasts are an improvement over climatology - the only objective seasonal prediction that had previously been available. The lack of accuracy for the 1989 forecast is attributed to heavy rainfall which fell in the West Sahel. Prior to 1990 this rainfall was not explicitly included in the author's forecast scheme. However, this rainfall is now included and its influence is becoming better understood.

8 Early August Update of Seasonal Forecast

This forecast will be updated on 5 August 1993. The updated forecast will make use of June–July values for meteorological parameters and should be more accurate. In particular, we will have much better information on the lingering El Niño and June–July Western Sahel rainfall information which is a very good predictor of the likely amount of intense hurricane activity.

9 Forecast for 1994

A forecast for seasonal hurricane activity of 1994 will be issued in late November, 1993, at the time of verification of this year's forecast.

Table 10: 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	28
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
No. of Named Storm Days		35	30	20
Hurr. Destruction Potential(HDP)		40	25	23
Major Hurricanes (Cat. 3-4-5)		1	0	2
Major Hurr. Days		2	0	1
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	2	2	3

10 Cautionary Note

It is important that the reader realize that this seasonal forecast is 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 1993 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 1993 should prove to be a very active hurricane season there is no assurance that any storms will come ashore.

11 Likely Increase in Landfalling Major Hurricanes in Coming Decades

There has been a great lull in US East Coast, Florida and Caribbean Basin major (category 3-4-5) landfalling hurricanes over the last 25 years. We see this as a natural consequence of the slowdown in the Atlantic Ocean thermohaline Conveyor Belt circulation and its closely related consequences for Sahel drought, increased El Nino activity and other global scale circulation changes which have occurred over the last 25 years.

Historical and geological records indicate that this lull in major landfalling hurricane activity should not be expected to indefinitely continue. A return of increased major landfalling hurricane activity is to be expected in the next few decades. When this happens, (because of the large coastal development during the last 25-30 years), the US will see hurricane destruction as never before experienced. Research on the causes and the likely time frame for this change-over is desperately needed. This is a real and more of an immediate natural threat to the US than that of greenhouse gas warming and other environmental problems which are receiving so much more attention in comparison to the hurricane threat.

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APPENDIX A

Weights of β_i and a_i coefficients used in Eq. (1).

	β_0	β_1	β_2	β_3
NS	12.3781	.1651	.6312	-.2714
NSD	68.8556	1.0409	.7985	-19.5133
H	9.7544	.1389	.5074	-2.5884
HD	41.2690	.6513	3.8807	-13.1287
IH	2.5199	.0252	-.4059	.0187
IHD	6.3386	.1527	-1.6019	-1.0636
HDP	112.9477	1.5122	8.5714	-34.8274
NTC	146.7669	2.0802	-2.2472	-17.0237

	NS	NSD	H	HD	IH	IHD	HDP	NTC
QBO								
a_1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
a_2	-.0714	-.0729	-.3662	-.3971	.4160	-.2182	-.3153	-.1021
a_3	-.9199	-1.2538	-2.1072	-2.0173	.2899	-.7551	-1.8143	-1.1884
a_4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
a_5	2.4308	8.4673	.5335	.5796	-2.4883	-1.0317	1.3122	-7.7489
a_6	-.0478	1.0972	-1.3485	-.4836	-2.4395	-1.6112	.2809	-5.4734
a_7	-.6367	7.2463	.8690	1.4982	-.6668	-.9943	2.7448	-9.3565
a_8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
a_9	-.1987	-.0294	.0667	-.0667	5.8344	-.6537	-.0889	-.0824
a_{10}	.0713	.0054	-.0012	-.0055	-.6297	.0103	-.0016	.0098
a_{11}	-.0430	.0002	.0016	.0113	.0171	.0167	.0088	.0024
a_{12}	.7902	-.0037	-.0521	-.1327	-1.4853	-.1748	-.1166	-.0687
a_{13}	-.4711	.0437	.0631	.1258	.1546	.2521	.1199	.1416