SUMMARY OF 1990 ATLANTIC TROPICAL CYCLONE ACTIVITY AND SEASONAL FORECAST VERIFICATION

(A Year of Many Wimpy Storms)

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(As of 28 November 1990)

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DEFINITIONS

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

Hurricane - A tropical cyclone with sustained low level winds of 74 miles per hour (33 ms^{-1} or 64 knots) or greater.

Hurricane Day - 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 - 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 - A hurricane or a tropical storm.

Named Storm Day - 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 - A hurricane reaching at some point in its lifetime a sustained low level wind of at least 111 mph (96 kt or 50 m s^{-1}). This constitutes a category 3 or higher on the Saffir/Simpson scale.

Intense Hurricane Day. 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 Nino - (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 Nino events occur irregularly, about once every 5-6 years or so on average.

Potential Damage (PD) - Potential damage from a hurricane's wind and ocean surge. Damage is assumed to increase with the square of the Saffir-Simpson 1 to 5 intensity scale.

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 (1 to 5) of a hurricane's wind and ocean surge intensity. 1 is the weakest hurricane, 5 the most intense hurricane.

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

ZWA - Zonal Wind Anomaly. A measure of upper level (~ 200 mb) west to east wind strength. Positive 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 summarizes the tropical cyclone (TC) activity which occurred in the Atlantic Basin during 1990, and verifies the author's seasonal forecast of such activity that was issued in early June, and updated on 3 August before the start of the active part of the hurricane season. This forecast was based on the author's past research (Gray, 1983, 1984a, 1984b; and new research Gray, 1990; Landsea, 1991) which relates seasonal Atlantic hurricane activity to: 1) the El Nino (EN); 2) the Quasi-Biennial Oscillation (QBO) of equatorial 30 mb and 50 mb stratospheric winds; 3) Caribbean Basin-Gulf of Mexico Sea-Level Pressure Anomaly (SLPA) in spring and early summer; 4) lower latitude Caribbean Basin 200 mb (12 km altitude) zonal wind anomaly in early summer, and 5) the new and very important parameter of West African rainfall.

Information received by the author as of 5 June 1990 indicated that the 1990 hurricane season should have been an above average season with about 7 hurricanes, 11 named storms of hurricane and tropical storm intensity, 30 hurricane days, 55 named storms days and 3 intense hurricanes. The 3 August updated forecast, utilizing information of decreased amounts of June-July West African rainfall, reduced the number of forecast hurricanes to 6, of intense hurricanes to two, and of hurricane days to 25. See Table 8 on page 10 for full forecast and verification information.

The actual number of hurricanes which occurred in 1990 was 8; the number of named storms was 14; number of hurricane days was 27.5 and number of named storm days was 68. But most of this year's many cyclones were weak and do not represent a high value of potential destructive power. There was only one intense hurricane (Saffir/Simpson category 3) this year and this storm held its category 3 intensity for only one day. Hurricane Destruction Potential (HDP), which is a measure of the sum of all hurricane intensity maximum wind speeds squared was 57. This was below the long period average of 74. This reduction in this season's intense hurricane activity is well related to the low amounts of African precipitation which fell in the Western Sahel region throughout the whole of the June through September period. This is in contrast to the 1988 and 1989 seasons when we saw very heavy amounts of precipitation.

This hurricane season was also characterized by a lack of many low latitude hurricanes or of any US vicinity or Caribbean basin hurricanes. It is the low latitude hurricanes which typically are the most intense. Most of this season's tropical cyclone activity occurred in the central Atlantic at latitudes above 25°N.

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1. 1990 Atlantic Tropical Cyclone Activity

The 1990 Atlantic hurricane season officially ends on 30 November. There were eight hurricanes (maximum sustained wind >73 mph) and 27 hurricane days during 1990. Total named storms (or the sum of the number of hurricanes and tropical storms) was 14, one of the highest seasonal numbers of the last 40 years. In terms of tropical cyclone (TC) intensity, however, this was not an active hurricane season. Only one intense (Saffir/Simpson Category 3-4-5) hurricane (Gustav) formed this year and this hurricane had but 1 day of maximum sustained winds of 100 knots (115 mph) or greater. This season contrasts sharply with the seasons of 1988 and 1989 when there were 5 category 4-5 hurricanes (Gilbert, Helene, Joan, Gabrielle, Hugo) and a total of 18.75 intense hurricane days.

The 1990 hurricane season was distinguished primarily by the large number of named storms and hurricanes which formed in comparison with low amounts of intense hurricane activity. This was largely a consequence of the favorable stratospheric QBO and ENSO conditions which existed and which were conducive to the formation of named storms and of the severe Western African drought conditions which act to suppress intense hurricane activity.

Figure 1 and Table 1 give the tracks and statistical summaries of all 1990 Atlantic named storms. Table 2 contrasts the tropical cyclone statistics of this season with recent past seasons and past climatology. Note how the 1988 and 1989 hurricane seasons had fewer named storms and named stormed days than 1990 had but substantially higher numbers of intense hurricanes (category 3-4-5) days and Hurricane Destruction

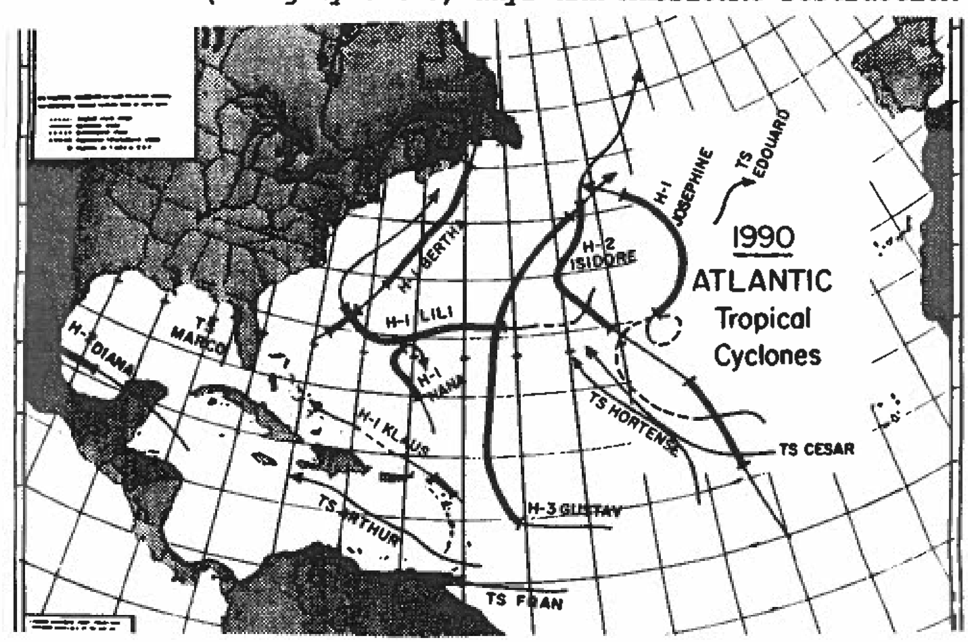

Fig. 1. Tracks of tropical cyclones for 1990. Dashed lines show periods of depression stage, solid lines indicate the periods of tropical storm intensity (maximum sustained winds with 39-73 mph), and thick lines show the periods of hurricane intensity (maximum sustained winds greater than 73 mph).

Table 1: Summary of information on named tropical cyclones occurring during the 1990 Atlantic tropical cyclone season. Hurricane (H) and Tropical Storm (TS) information has been supplied by courtesy of the National Hurricane Center.

No.	Storm Name	Dates of Name Storm Intensity	Named Storm Days	H Days	Hurr. Dest. Pot. (HDP)	Cat. 3-4-5 Days	Max Wind kts	Minimum Central Pressure (mb)	Saffir Simpson Cat.	From Cape Verde Wave
1.	TS Arthur	Jul 24-27	2.75	—	—	—	60	995	—	Yes
2.	H Bertha	Jul 28-August 2	5.25	4.25	6.05	—	70	974	1	No
3.	TS Cesar	Aug 1-5	4.50	—	—	—	45	1000	—	Yes
4.	H Diana	Aug 5-8	3.50	0.75	1.71	—	85	980	marginal 2	Yes
5.	TS Edouard	Aug 8-10	1.75	—	—	—	40	1003	—	No
6.	TS Fran	Aug 13-14	1.00		—	—	35	1007	—	Yes
7.	H Gustav	Aug 25-Sept 3	9.25	7.25	20.89	1.0	105	956	3	Yes
8.	TS Hortense	Aug 26-30	3.75	—	—	—	55	993	—	Yes
9.	H Isidore	Sept 5-16	12.00	8.25	15.73	—	85	978	marginal 2	Yes
10.	H Josephine	Sept 24-25, Oct 1-6	5.25	1.50	2.88	—	75	980	1	Yes
11.	H Klaus	Oct 3-7	4.25	0.75	1.40	—	70	985	1	Yes
12.	H Lili	Oct 6-15	8.75	2.50	4.22	—	65	987	marginal 1	No
13.	TS Marco	Oct 10-11	1.75	—	—	—	55	989	—	No
14.	H Nana	Oct 16-20	4.25	2.25	4.49	—	75	989	1	Yes
		Total	68.0	27.5	57.4	1				

Potential. These 1990 versus 1988-1989 differences are well related to the differences in amounts of Western Sahel precipitation which fell.

The 1990 season was special because of the large number of weak hurricanes which were spawned and existed at high latitudes in the central Atlantic. It is known that high latitude hurricanes are typically not very intense. Most intense hurricanes are spawned and live the major portions of their lifetimes at latitudes below 20 or 25°. Seventy-three percent of the 27.5 hurricane days which occurred this season were from hurricanes at latitudes greater than 25°N, 57% of the hurricane days were storms at latitudes higher than 30°N.

TABLE 2

Comparison of 1990 Hurricane Activity Forecast With Previous Years' Activity.

	1990	1989	1988	Average Season 1982-87	Average Season 1970-87	Average Season 1950-69
Hurricanes	8	7	5	4.0	4.9	6.5
Named Storms	14	11	12	7.5	8.3	9.8
Hurricane Day	27.5	32	24	10.7	15.5	30.7
Named Storm Days	68	66	47	32.0	37.3	53.4
Hurr. Dest. Pot. (HDP)	57	108	81	27.0	42.7	100.0
Major Hurricanes (Cat. 3-4-5)	1	2	3	1.2	1.6	3.4
Major Hurricane Days	1	10.75	8.0	1.1	2.1	8.8

The middle and east Atlantic concentration of hurricane activity is demonstrated by the statistics that 92% of all hurricane days occurred at longitudes east of 70°W.

There were 8 cyclones of hurricane intensity. Since 1961 there have only been two seasons (1969 with 12, and 1980 with 8) which experienced as many hurricanes in one season. But in contrast with these other seasons the hurricanes of 1990 were weak. There were a total of 14 named storms in 1990. Since 1937 there has been only two previous seasons with as many named storms as this year - 1969 with 18, and 1953 with 14.

But these statistics on named storms and hurricanes are deceiving. Except for Gustav (a marginal category 3 cyclone) none of the other seven hurricanes obtained maximum winds greater than 85 knots (98 mph). And, only Gustav had a central pressure below 978 mb. Five of the hurricanes (Bertha, Josephine, Klaus, Lili, and Nana) were marginal hurricanes obtaining maximum winds no greater than 65 to 75 knots. Diana was a hurricane for only three-quarters of a day,; Klaus for one day; Josephine for 1.5 days; Nana and Lili for only two and three days, respectively.

The seven weak hurricanes of Bertha, Diana, Isidore, Josephine, Klaus, Lili and Nana had an average maximum wind of but 75 knots (86 mph) and average minimal pressure of 982 mb. Of the 6 non-hurricane named storms (Arthur, Cesar, Edouard, Fran, Hortense, Marco) only Arthur was anywhere near hurricane intensity. Cesar, Edouard, Fran had maximum intensities of but 45, 40, and 35 knots. Edouard formed at high latitude over cooler water near the Azores. It was a hybrid subtropical cyclone throughout its lifetime and was not of true tropical cyclone structure.

This season was also characterized by the lack of any hurricane intensity storms to impact the US or the Caribbean basin.

One of the best measures of seasonal hurricane activity is given by the total potential for wind and storm surge damage. The author has proposed such a measure in the form of a parameter called HDP*. The total HDP for 1990 was 57. The last 42 year average is 74. This below average value of HDP this year agrees with the low values of West African rainfall that occurred. HDP values for 1988 and 1989 when Western Sahel region had bountiful rainfall were 81 and 108. By contrast, during the drought years of 1982-1987 HDP values were only 18 (1982), 8 (1983), 42 (1984), 61 (1985), 23 (1986) and 11 (1987).

In terms of Hurricane Destruction Potential (HDP) or the number of intense hurricane (category 3-4-5) days 1990 was an inactive season. There have been very few hurricane seasons where the ratio of named storms to intense hurricane days (14 to 1) or of number of hurricanes to number of intense hurricane days (8 to 1) was as high as this season. The 1950-90 average ratio of these values is 1.6 to 1 and 1 to 1. The 1990 season might be characterized as a seasonal of many wimpy storms.

2. Brief Summary of Individual Named Storm Characteristics

1. TS Arthur. This TS originated from an African wave that by late July had moved to the east of Trinidad. It then moved through the eastern Caribbean and reached maximum intensity of 60 knots and minimum central pressure of 995 mb before it dissipated to the south of Hispaniola due to strong upper tropospheric shearing conditions.

2. Hurricane Bertha. Originating off the east coast of Florida in late July from the remnants of a tropical low pressure that had formed southeast of Cape Hatteras ahead of a cold front, Bertha gradually developed into a named storm. It then tracked slowly and then more rapidly northeastward. It had two periods of hurricane intensity. Bertha developed maximum winds of 70 knots and had minimum central pressure of 974 mb. It maintained hurricane intensity until becoming extratropical off of the Maritime Provinces.

3. TS Cesar. This was a minimal named storm that developed in the eastern Atlantic from an African wave in early August. It was initially steered to the northwest and then began to encounter upper level westerly winds on its northwest flank. These upper level winds prevented its further intensification and then lead to its dissipation through shearing

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* Hurricane Destruction Potential (HDP) = $\sum V^2_{max}$ for each $V_{max} \geq 65$ kts for each 6-hour period which the hurricane is in existence. HDP is expressed in units of $10^4 kt^2$. For instance, a hurricane of 100 knots existing for 1 full day (or four 6-hr time periods) would accrue 4 HDP units.

action. Cesar never obtained maximum winds greater than 45 kts or central pressure below 1000 mb.

4. Hurricane Diana. This system formed from an easterly wave which moved across the Atlantic and through the Caribbean by early August. It had an unusually long westerly track before intensification into a named storm. After crossing the Yucatan Peninsula, Diana intensified into a minimal hurricane in the Gulf of Campeche. It then moved into Mexico and dissipated. Diana obtained maximum winds of 85 kts and minimum central pressure of 980 mb. It was of hurricane intensity for only three-quarters of a day.

5. TS Edouard. This cyclone formed far out in the north Atlantic within a wave along a cold front. It intensified in early August a few hundred miles west of the Azore Islands when deep convection began to break out near its center. Surface temperatures were never higher than 23°C. This is too cold to be a true tropical cyclone. Edouard was really a hybrid middle latitude subtropical system. It reached estimated maximum winds of 45 knots and had estimated minimum pressure of 1000 mb. It was classified as a tropical cyclone for 1 3/4 days. Under many conditions Edouard would not have been named.

6. TS Fran. This very minimal named storm system formed at low latitude in mid-August from a Cape Verde wave to the east of the Windward Islands. It sustained maximum winds of just 35 knots for 1 day with minimum estimated central pressure of but 1007 mb. It dissipated due to too strong vertical wind shear.

7. Hurricane Gustav. This was the season's only intense hurricane. It was of Saffir/Simpson category 3 for four 6-hour periods. Its highest winds were 105 knots and its lowest central pressure 956 mb at 30° latitude on the last day of August. Gustav formed from an African wave which began intensifying 600 miles east of Barbados. The subtropical ridge to its north which had been steering the system westward within the deep tropics weakened. Gustav then began a long northward track near the 58th meridian. Gustav existed as a named storm for 9.25 days, and was of hurricane intensity for 7.25 days.

8. TS Hortense. This African origin wave closely followed the early track of Gustav and was eventually dissipated by Gustav's outflow. The weakening of the subtropical ridge to the north that had caused Gustav to be driven to the north also caused Hortense to turn north and then NW on the 26 and 27th of August but at a further east longitude. Hortense strengthened to 55 knots and obtained a minimal central pressure of 993 mb on 28 August. It then moved in the vicinity of Gustav's outflow and dissipated as a named storm on August 30th and as a depression the following day.

9. Hurricane Isidore. Like many of its predecessors, Isidore also developed from an African wave. And, like Gustav 10 days before it was caught by the semi-stationary mid-Atlantic upper trough which caused it to be steered on a very long NNW and then north track. Isidore existed in named storm stage for 12 days and hurricane stage for 8.25 days. Isidore's track was similar to that of Gustav's but 15° longitude further to the east. It did not move westward of 51°W. The mid-Atlantic trough which began to recurve Isidore on the 6th of September also produced enough vertical wind shear. This inhibited Isidore's intensification beyond maximum winds of 85 knots and of central pressure lower than 978

mb. Isidore had two separate periods of hurricane intensity winds.

10. Hurricane Josephine. This minimal hurricane was yet another tropical system which had its origin from an African wave in the central Atlantic. Like its immediate predecessor, Josephine was also influenced by a higher latitude mid-Atlantic trough which caused it to follow a long and oscillatory track to the north. Josephine remained very weak until it began to intensify on the 4th of October. It did not reach hurricane intensity until it had crossed 30° latitude. It never moved west of 43°W. Josephine was estimated to be of hurricane intensity for 1 1/2 days. Its maximum winds were 75 knots and minimum central pressure of 980 mb.

11. Hurricane Klaus. Another minimal hurricane formed in early October from a wave which had moved off the African coast in late September. Klaus intensified into a named storm just to the northeast side of the Leeward Islands. It maintained hurricane intensity for only 15 hours. Klaus' maximum winds were 70 knots and its minimal central pressure 985 mb. It did not become stronger or last longer because of the strong and persisting upper tropospheric wind shearing conditions which it encountered shortly after reaching hurricane intensity.

12. Hurricane Lili. This unusual high latitude mid-October minimal hurricane spent its whole life at or above 30° latitude. It started as a subtropical system that formed midway between Bermuda and the Azores. It then had a long westward track near 30° in response to a long E-W anticyclone to its poleward side. This anticyclone then weakened and moved eastward causing Lili to encounter westerly steering winds and recurve. Lili passed a few hundred miles off Cape Hatteras. The vertical shearing action causing this recurvature weakened Lili and accelerated its movement to the northeast. It dissipated near the Canadian Maritime provinces. Lili had estimated maximum winds of but 65 knots and minimum central pressure of 987 mb.

13. TS Marco. This was the only named tropical cyclone to influence the US. Marco began forming north of Cuba from the downward extension of a cold-core low on the 10th of October. It then began a long northward movement along the west Florida coast being only a few miles out to sea and once a few miles on shore. It came inland near Cedar Key, Florida. Marco's maximum winds were 55 knots and minimum central pressure 989 mb when it was just southwest of St. Petersburg. Marco existed as a named storm for 1 3/4 days. Most of Marco's damage was due to flooding along west Florida, in Georgia, and in North and South Carolina. Marco's rainfall helped alleviate a drought in this region.

14. Hurricane Nana. Nana formed northeast of Puerto Rico in mid-October from the northern portion of an African origin wave which had split and whose northern portion became associated with an upper-level trough. This interaction caused Nana to rapidly intensify to minimal hurricane intensity as it moved northwestward. It then dissipated due to upper level wind shearing conditions near Bermuda. It obtained maximum winds of 75 knots. It existed as a hurricane for 2 1/4 days and named storm category for 4 1/4 days.

3. Factors Known to be Associated With Atlantic Seasonal Hurricane Variability

The author's Atlantic seasonal hurricane forecast is based on the characteristics of two global and three regional environmental factors which have been shown to be statistically related to seasonal hurricane variations. These are:

a) The presence or absence of a moderate or strong El Nino warm water event in the eastern tropical Pacific off of Peru. Seasons during which an El Nino event is present are usually suppressed hurricane seasons.

b) The direction of the 30 mb (23 km altitude) and 50 mb (20 km altitude) stratospheric Quasi-Biennial Oscillation (QBO) winds which circle the globe over the equator. On average, there is nearly twice as much Atlantic hurricane activity (when the measure of hurricane activity is made in the number of hurricane days) in seasons when QBO winds are from a relatively westerly direction as compared with those seasons when QBO zonal winds are from a relatively easterly direction.

c) The Caribbean basin-Gulf of Mexico Sea Level Pressure Anomaly (SLPA). Other factors aside, the more negative the August-September sea surface pressure anomaly, the greater the Atlantic seasonal hurricane activity. Higher pressures are associated with reduced hurricane activity. Late spring and early summer values if often a good indicator of what August-September SLPA is going to be.

d) Lower latitude Caribbean Basin upper tropospheric (~200 mb or 12 km altitude) west to east or zonal wind anomaly (ZWA) in non-El Nino seasons in August and September. The stronger 200 mb zonal wind are from the west the generally greater the suppression of hurricane activity and vice-versa. Early summer ZWA values are often a good indication of August-September values.

e) West African rainfall (AR). There are more intense hurricanes and many more intense hurricane days in those seasons when West Africa experiences above average rainfall as compared to those seasons when drought conditions exist. Rainfall values prior to 1 August are a good indication of August-September rainfall amounts.

The author's Atlantic seasonal forecast scheme is thus of the following form:

$$\begin{pmatrix}\text{Predicted Amount}\\ \text{of Hurricane}\\ \text{Activity per Season}\end{pmatrix} = \begin{pmatrix}\text{Average}\\ \text{Season}\end{pmatrix} + \overbrace{(\text{ EN } + \text{QBO} + \text{SLPA} + \text{ZWA} + \text{AR })}^{\text{Adjustment Terms}} \quad (1)$$

where

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

QBO = 30 mb and 50 mb Quasi-Biennial Oscillation equatorial zonal wind corrections, positive for west phase, negative for east phase.

SLPA = Average SLPA for April-May from selected Caribbean-Gulf of Mexico stations. Reduce if SLPA is significantly above average, add if significantly below average.

ZWA = Zonal Wind Anomaly at 200 mb (12 km) for five low latitude upper air Caribbean stations. Hurricane activity is inversely correlated with this parameter. Applied only in non-El Nino years.

AR = African rainfall. Heavy summertime West African rainfall is associated with an increase of both the number and the intensity of Atlantic hurricanes; reduced rainfall with a decrease in hurricane number and intensity.

4. Characteristics of Known Seasonal Hurricane Predictors During 1990

a) El Nino.

No moderate or strong El Nino event occurred in the Pacific during the 1990 hurricane season. A weak abortive Sea Surface Temperature (SST) warming event occurred in the Pacific in January to March 1990. This was viewed by some as the beginning of a significant El Nino event. This did not materialize. April and May saw the return of cooler water, although weak positive SST anomalies have persisted in the central Pacific through the 1990 hurricane season. These central Pacific warm SSTs have not caused the typical global circulation pattern changes characteristic of a moderate or strong El Nino event however. This was verified by the lack of strong positive Caribbean basin 200 mb zonal wind anomalies that typically occur during hurricane seasons when a strong or moderate El Nino is present (see Table 6).

b. QBO

Tables 3 and 4 show the absolute and relative value of the 30 mb (23 km), 50 mb (20 km), and 70 mb (18.5 km) stratospheric QBO zonal winds in the lower Caribbean basin during the 1990 hurricane season. Note that during the primary August through October hurricane season that 30 to 70 mb stratospheric winds were in a relative westerly phase. This resulted in the absolute values of the QBO winds being only weakly from the east and also that 70 to 30 mb zonal wind shears be very small. Note that in September there was virtually no 70 to 30 mb vertical shear of the absolute winds. QBO conditions this season were near ideal for enhanced low latitude hurricane formation and for the facilitation of intense hurricane development. But low latitude hurricane activity was suppressed in the Atlantic. This enhancing QBO influence was counteracted and over ridden in the Atlantic basin by conditions accompanying the severe West African drought which developed. By contrast, the Northeast Pacific and the Northwest Pacific had many intense hurricanes and typhoons this year.

TABLE 3

April through October 1990 observed absolute value of stratospheric QBO zonal winds (U) in the critical latitude belts between 8-12°N as obtained from lower Caribbean basin stations of Curacao, Barbados and Trinidad. Values in m s^{-1} (as supplied by Colin McAdie and James Angell).

	Observed						
Level	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	-3	-9	-6	-7	-8	-6	-2
50 mb (20 km)	-11	-11	-10	-10	-10	-6	+1
70 mb (18.5 km)	-6	-8	-9	-11	-8	-6	-2

TABLE 4

Same as Table 1 but for the relative zonal wind where the annual wind cycle has been removed. Values in m s^{-1}.

	Observed						
Level	April	May	Jun	Jul	Aug	Sept	Oct
30 mb (23 km)	+5	+5	+11	+12	+13	+13	+14
50 mb (20 km)	-10	-5	0	+4	+5	+7	+7
70 mb (18.5 km)	-5	-8	-4	-1	+2	+2	+2

c. Sea-Level Pressure Anomaly (SLPA)

Table 5 gives information on SLPA during the 1990 season. It is the low latitude eastern Caribbean SLPA's which are most important. Note that these low latitude SLPA's were high in August but somewhat below average in September and October. Overall the August through October surface pressure anomaly was near neutral. This shows that the April through July SLPA values of near zero deviation were a good indication of what was to follow during the hurricane season.

These Caribbean basin SLPAs are lower than what would normally be expected considering the severe west African drought of this year. In general, Caribbean basin SLPA and western Sahel seasonal rainfall are inversely related to each other.

ZWA. Lower Caribbean Basin 200 mb zonal wind anomaly (ZWA) for April through October 1990 are often a good indication of western Atlantic tropospheric wind shear conditions. Table 6 shows that the upper tropospheric ZWAs were somewhat negative and not a strong inhibiting or enhancing influence as occurs in other seasons. ZWA conditions also help monitor the possible influences of a Pacific El Nino warm water event.

TABLE 5

1990 Average Eastern Caribbean Basin and Gulf of Mexico-E. Caribbean Basin Sea-Level Pressure Anomalies (SLPA) -in mb (as kindly supplied by Colin McAdie of NHC).

Low Latitude SLPA		Apr-May	Jun-Jul	Aug	Sept	Oct	Aug-Sept-Oct Average
San Juan	(19.5°N,66°W)	-0.3	-0.4	+0.6	-0.7	-1.8	-0.6
Curacao	(12°N,69°W)	+0.2	+0.2	+1.0	+0.2	-0.2	+0.3
Barbados	(13.5°N,60°W)	-0.5	-0.2	+0.3	-0.7	-0.8	-0.4
Trinidad	(11°N,62°W)	+0.2	+0.3	+1.0	+0.1	+0.3	+0.5
Cayenne	(5°N,52.5°W)	+0.1	-0.0	+0.7	-0.2	-0.3	+0.1
	Average	-0.1	0.0	+0.7	-0.3	-0.6	-0.0

Gulf of Mexico-Caribbean Basin	Apr-May	Jun-Jul	Aug	Sept	Oct
Brownsville (26°N)	-0.1	+1.3	+1.9	+1.9	+1.2
Merida (Mex.)(21°N)	+0.7	+1.4	+1.3	+1.5	+0.7
Miami (25.5°N)	+0.5	+1.0	+1.0	+1.3	0
San Juan (18.5°N)	-0.3	-0.4	+0.6	-0.7	-1.8
Curacao (12°N)	+0.2	+0.2	+1.0	+0.2	-0.2
Barbados (13.5°N)	-0.5	-0.2	+0.3	-0.7	-0.8
Average	+0.1	+0.6	+1.0	+0.6	-0.2

TABLE 6

1990 Caribbean Zonal Wind Anomaly (ZWA) in m s^{-1} (as supplied by Colin McAdie of NHC).

Station	April-May	June-July	Aug-Sept	Oct
Kingston (18°N, 77°W)	-2	+2	+2	-3
Curacoa (12°N, 69°W)	+2	-1	+2	-2
Barbados (13.5°N, 60°W)	+2	+1	-6	-3
Trinidad (11°N, 62°W)	0	0	-4	-6
Average	0	+1	-1.5	-3.5

ZWAs are strongly positive in El Nino seasons. These ZWA values verify that the possible hurricane suppressing influences from this year's weak central Pacific SST warming event did not cause strong wind shearing influences over the Caribbean basin.

This season's lower Caribbean basin 200 mb ZWA values were not representative of the wind shearing conditions occurring in the central Atlantic however where a Tropical Upper Level Tropospheric (or TUTT) was present during much of August and September.

In most seasons when West Africa is under strong drought conditions as 1990 was the Caribbean basin SLPA and 200 mb ZWA would be positive and an indication that the Intertropical Convergence Zone (ITCZ) in the Caribbean basin was anomalously displaced to the south. This was not the case with this year's African drought conditions. It was the Central Atlantic rather than the Caribbean basin which saw the southward displacement of the ITCZ in association with the African drought.

e) AR. African Rainfall (AR) is a new forecast parameter that we included in this year's forecast for the first time. We have only recently discovered that Atlantic intense hurricane activity is much enhanced when the Western Sahel region of West Africa (see area R3 in Fig. 2) has above average precipitation. Intense hurricane activity is much suppressed when precipitation in the Western Sahel is below average. The striking differences in Atlantic intense hurricane activity between wet and dry West African rainfall years is illustrated in Fig. 3. Recent analysis by Landsea (1991) is showing very high correlation of year-to-year variance in the number of intense (category 3-4-5) hurricane days over the last 42 years with year to year variations in West African rainfall. The rainfall which fell in the R1 region of Fig. 2 between August through November of the previous year in combination with R3 June-July precipitation is a very good predictor of the following August-October intense hurricane activity.

Table 6 and Fig. 4 compares the sum of rainfall of the August through November period of the previous year in the Gulf of Guinea (R1) precipitation - (weight one-third) and June-July Western Sahel (R3) precipitation weighted two-thirds and seasonal number of category 3-4-5 hurricane days. These combined rainfall amounts, available by 1 August explains 60% of the 1949-90 seasonal variance in intense hurricane days. It is amazing that African rainfall data prior to August would be so highly correlated with most of the hurricane activity which occurs after 1 August. Historically over 95% of all seasonal intense hurricane activity comes after 1 August, see Table 7. We believe that these strong rainfall precursor signals are a consequence of how the West African monsoon trough gets established in strength and latitude in June-July. A strong and high latitude establishment in June-July will lead to continued abundant rainfall for the remainder of the rainy season. Also the delayed influence of vegetation upon the following months evapotransportation appears to also be a significant precursor influence.

Analyses of Western Sahel precipitation through July of this year indicated that rainfall amounts for this year would be below normal. But these early estimates of dryness proved too conservative. August and September precipitation amounts were lower yet. The actual June through September Western Sahel precipitation was -0.95 standard deviations below

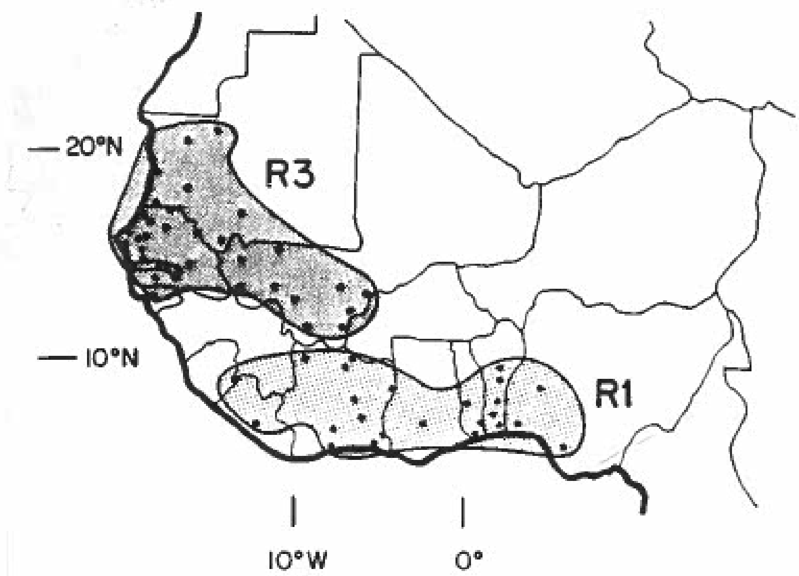

Fig. 2. Location of rainfall stations which make up the western Sahel precipitation index (R3). The R1 region along the Gulf of Guinea shows a predictive value for hurricanes using the August to November rainfall from the previous year (from Landsea, 1991).

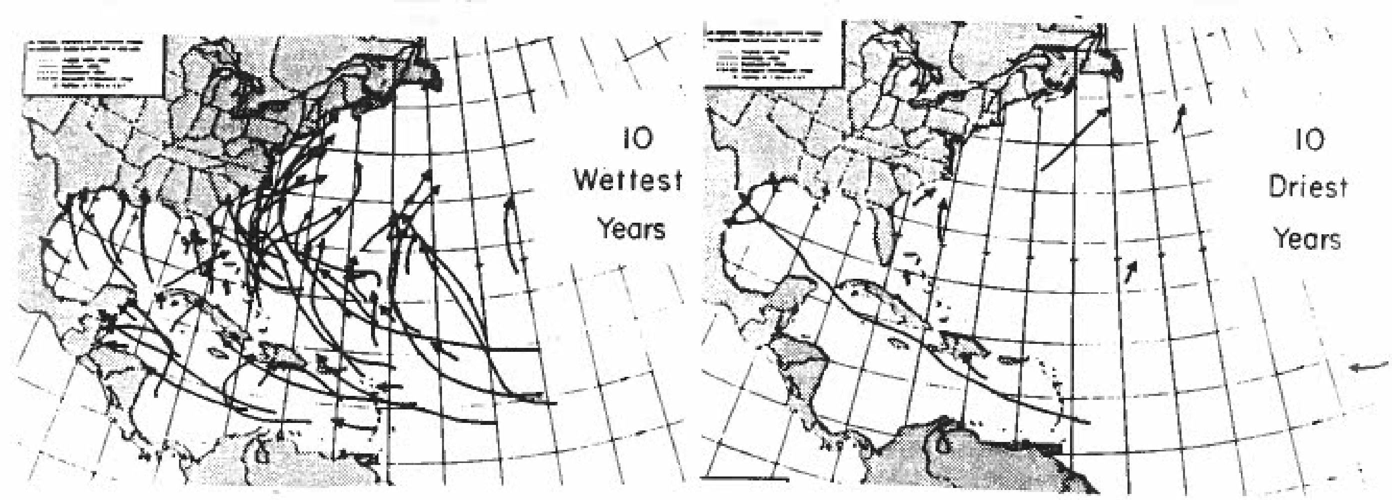

Fig. 3. Contrast of category 3-4-5 hurricane tracks in the 10 wettest years (a) versus the 10 driest years (b) during the 41-year period (1949-1989).

TABLE 6

Previous year period (1949-1989) August-November African rainfall from the Gulf of Guinea region (R1 of Fig. 1) weighted one-third and June-July Western Sahel rainfall (R3 of Fig. 1) weighted two-thirds versus seasonal intense hurricane (category 3-4-5) days. Rainfall is expressed as the standard deviation (σ) from the 41-year mean. These two quantities are correlated at r = .77 and explain about 60% of variance of intense hurricane days.

Year	Rainfall	Intense Hurricane Days	Year	Rainfall	Intense Hurricane Days
1949	-.16	5.25	1970	-.31	1.00
1950	.55	18.75	1971	-.31	1.00
1951	-.32	8.25	1972	-.66	0.00
1952	.61	6.75	1973	-.62	0.25
1953	.72	6.75	1974	-.20	4.25
1954	.38	9.50	1975	.38	2.25
1955	1.19	17.25	1976	-.50	1.00
1956	.15	2.75	1977	-.73	1.00
1957	-.03	6.50	1978	.01	3.50
1958	.54	9.50	1979	.04	5.75
1959	-.46	4.25			
1960	.53	11.00	1980	-.48	7.25
1961	.92	24.50	1981	.00	3.75
1962	-.32	0.50	1982	-.71	1.25
1963	.19	7.00	1983	-.78	0.25
1964	.98	14.75	1984	-.77	0.75
1965	-.29	7.50	1985	-.27	4.00
1966	-.38	8.75	1986	-.59	0.00
1967	.24	5.75	1987	-.56	0.50
1968	-.37	0.00	1988	.31	8.00
1969	.76	6.75	1989	.70	10.75
			1990	-.28	1.00

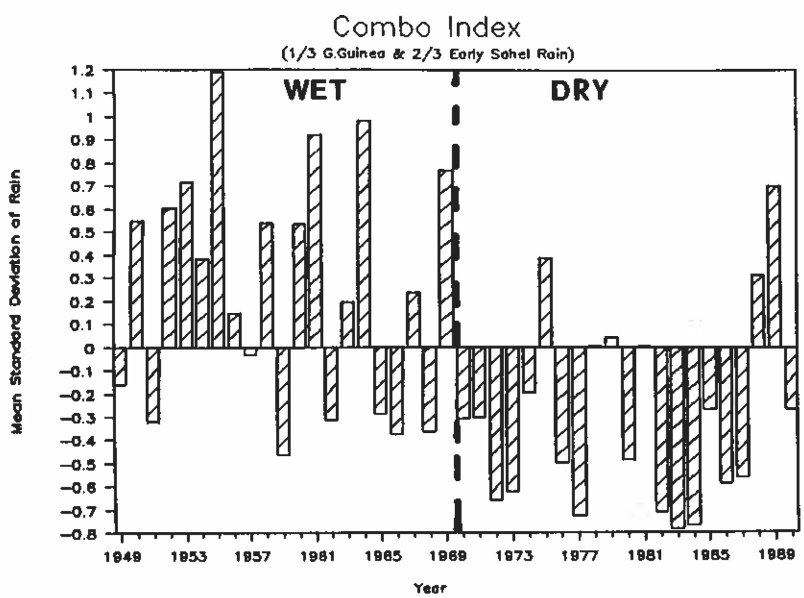

Fig. 4. Previous year August-November precipitation from the Gulf of Guinea (R1 of Fig. 2) weighted one-third and June-July Western Sahel rainfall (R3 of Fig. 2) weighted two-thirds vs. seasonal intense hurricane (category 3-4-5) days. Rainfall is expressed in standard deviation for the last 42 year average.

TABLE 7

Percent of seasonal Atlantic tropical cyclone activity which climatologically has occurred after 1 August.

	Seasonal Percentage After 1 August
Number of Named Storms	84
Number of Hurricanes	91
Number of Hurricane Days	90
HDP	94
Number of Intensity Hurricane	94
Number of Intense Hurricane Days	97

average. These low amounts of R3 June through September precipitation are well associated with the low amounts of intensity hurricane activity.

Table 8 and Fig. 5 show the correlation of June through September Western Sahel R3 rainfall with seasonal number of intense hurricane days. This also has a high correlation (r = .76 or 58% of the seasonal variance) but surprisingly somewhat less than the correlation of the pre-1 August rainfall amounts.

Table 9 demonstrates how strong a forecast signal these "early season" rainfall amounts are. There were over 10 times as many intense hurricane days during the 10 wettest as compared to the ten driest seasons in the last 42 years. In terms of HDP these differences are 3.6 to 1. This combination of "early season" rainfall amounts that are available by early August are a very good indication (or forecast) of the expected amount of intense hurricane activity to follow after 1 August.

Knowledge of how the African rainfall is shaping up by early August should now be a carefully monitored parameter for indications of how much intense hurricane activity will follow later in the season. The "early season" rainfall of this year was -0.28σ and an indication that this year's intense hurricane activity would be below average. The June-July R3 region value of -0.46σ was more representative of what happened than the R1 region previous year August to November value of $+0.16\sigma$. The June through September value was -0.95σ, the 5th driest of the last 42 years.

5. Controlling Synoptic Conditions of 1990

During much of August and September the Atlantic upper level circulation was dominated by a mid-ocean semi-permanent Tropical Upper Trough (TUTT) as idealized in the top diagram of Fig. 6. The influence of this TUTT often extended down to middle levels. This was the dominant synoptic feature explaining much of this season's tropical cyclone characteristics. This mid-Atlantic trough caused many of this season's

TABLE 8

June through September rainfall within the Western Sahel region (R3) for the period of 1949-1990 versus seasonal intense hurricane (category 3-4-5) days. Rainfall is expressed as the standard deviation (σ) from the 42-year mean. These two quantities are correlated at r = .76 and explain about 58% of variance of intense hurricane days.

	Rainfall	Intense Hurricane Days		Rainfall	Intense Hurricane Days
1949	-.10	5.25	1970	-.47	1.00
1950	1.48	18.75	1971	-.32	1.00
1951	.30	8.25	1972	-1.19	0.00
1952	.99	6.75	1973	-.83	0.25
1953	.54	6.75	1974	-.25	4.25
1954	.76	9.50	1975	.34	2.25
1955	1.46	17.25	1976	-.58	1.00
1956	.38	2.75	1977	-.93	1.00
1957	.51	6.50	1978	-.20	3.50
1958	1.27	9.50	1979	-.56	5.75
1959	.04	4.25			
1960	.49	11.00	1980	-.70	7.25
1961	.76	24.50	1981	-.36	3.75
1962	.18	0.50	1982	-.90	1.25
1963	-.11	7.00	1983	-1.34	0.25
1964	.87	14.75	1984	-1.19	0.75
1965	.52	7.50	1985	-.52	4.00
1966	.06	8.75	1986	-.39	0.00
1967	.74	5.75	1987	-.78	0.50
1968	-.77	0.00	1988	.17	8.00
1969	.54	6.75	1989	.55	10.75
			1990	-.95	1.00

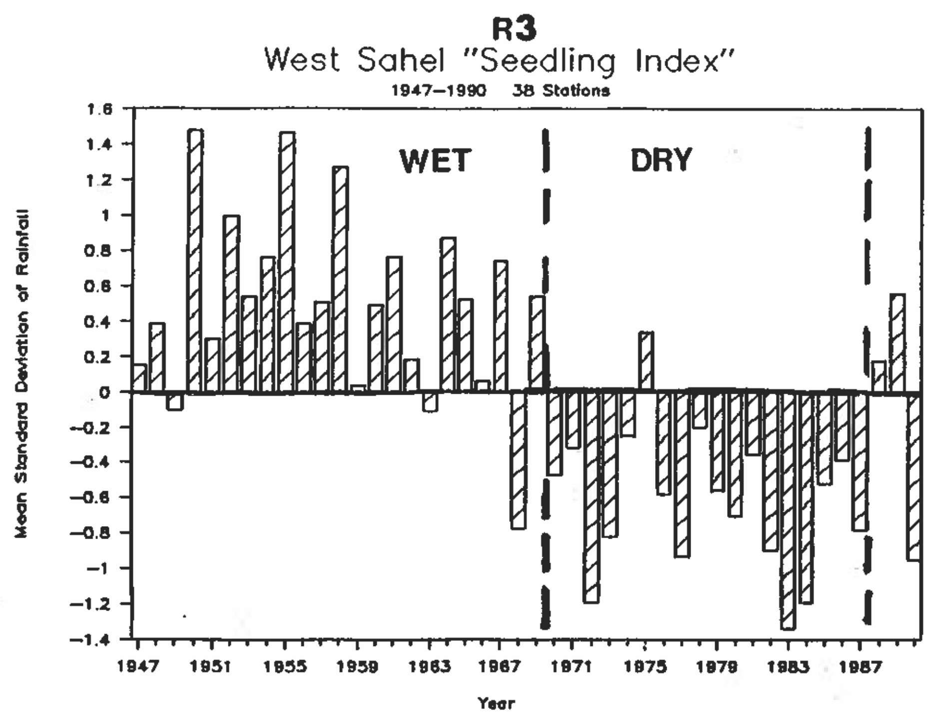

Fig. 5. Standard deviation of June through September average annual western Sahel precipitation for the R3 stations shown in Fig. 2 (from Landsea, 1991).

TABLE 9

Contrast the "early season" (prior to 1 August) combination index in the 10 driest versus the 10 wettest season in the last 42 years with number of hurricanes, intense hurricane days and Hurricane Destruction Potential (HDP). Early season rainfall is made up of the R1 region Gulf of Guinea August through November previous year weighted one-third and the June-July R3 region rainfall weighted two-thirds.

10 Driest Years

Ranking of Dry Year	Standard Deviation of Rainfall	No. of Hurricanes	Intense Hurricane Days (cat. 3-4-5)	HDP
1983	-0.78	3	0.25	8
1984	-0.77	5	0.75	42
1977	-0.73	5	1.00	18
1982	-0.71	2	1.25	18
1972	-0.66	3	0.00	14
1973	-0.62	4	0.25	24
1986	-0.59	4	0.00	23
1987	-0.56	3	0.50	11
1976	-0.50	6	1.00	65
1980	-0.48	9	7.25	126
Mean	-0.64	4.4	1.23	35

10 Wettest Years

Ranking of Wet Year	Standard Deviation of Rainfall	No. of Hurricanes	Intense Hurricane Days (cat. 3-4-5)	HDP
1955	1.19	8	17.25	171
1964	0.98	7	14.75	149
1961	0.92	8	24.50	183
1953	0.72	6	6.75	61
1989	0.70	7	10.75	108
1952	0.61	6	6.75	73
1950	0.55	11	18.75	213
1958	0.54	7	9.50	100
1960	0.53	4	11.00	80
1954	0.38	8	9.50	99
Mean	0.71	7.2	13.0	124
Ratio wet/dry		1.6/1	10.6/1	3.6/1

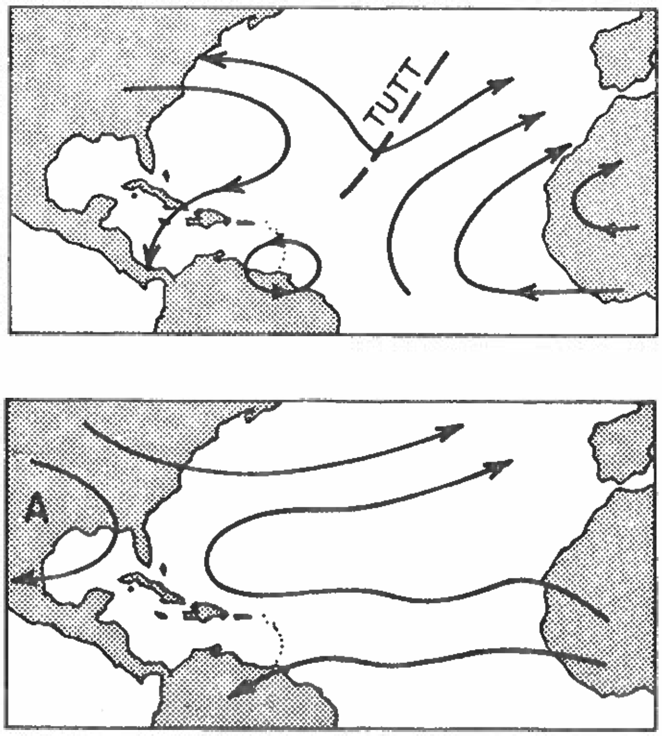

Fig. 6. Illustrating the typically contrasting mean upper tropospheric flow conditions associated with August-September seasons when the western Sahel of Africa is in drought conditions (top diagram) versus those seasons when the western Sahel has abundant rainfall. Less vertical shearing occurs during wet conditions.

African spawned wave systems to come under the inhibiting influence of upper level shearing conditions. This prevented many of the strong African spawned wave systems from intensifying into named storms and into intense hurricanes while they were in the central and western Atlantic. This was also the primary reason why so many of this season's named storms such as Cesar, Gustav, Hortense, Isidore and Josephine recurved in the central Atlantic without having the more typically long and westward tracks into the Caribbean or into the Bahama Island region.

The existence of such mid-Atlantic upper level TUTTs are much more common during seasons of Western Sahel drought as this year was. By contrast, during those seasons when the Western Sahel experiences above average rainfall, mid-Atlantic upper level shearing conditions are typically reduced (see the idealized bottom diagram of Fig. 6) and African spawned westward traveling systems or Cape Verde waves can more readily develop into named storms and then into intense hurricanes. Also, during those seasons when West Africa is wet, it is less probable that upper level shearing conditions will recurve the African spawned tropical cyclones before they reach the western Atlantic or the Caribbean as occurred this year.

This was one of those unusual seasons when August-September lower Caribbean basin 200 mb zonal wind anomalies were not representative of the wind shearing conditions in the central Atlantic and at higher latitudes.

There were 69 detectable waves that moved out of Africa this year (Avila 1990 - personal communication). Although 10 of these 69 waves developed into named storms only three of the named systems, Diana, Arthur and Klaus made it west of the 67°W - the approximate longitude of Bermuda. This was indicative of the upper level shearing conditions and the weaker subtropical ridge which were present during the height of this year's hurricane season. It is not the number of waves coming off Africa which is important but the strength of these waves and the environment into which these waves move.

Active Northeast Pacific Hurricane Season. Many of the African spawned easterly waves of 1990 moved entirely across the Atlantic basin and into the eastern Pacific without intensifying. A number of these African spawned systems acted as an initiation mechanism for many of the northeast Pacific tropical cyclones which formed this year. The northeast Pacific had a record number of 16 hurricanes and 22 named storms in 1990. In contrast to the Atlantic basin which had but 1 category 3 hurricane the NE Pacific basin had 5 category 3-4-5 hurricanes with two reaching category 5 and two other systems reaching category 4. The Northwest Pacific also had a number of supertyphoons this year in conformity with the favorable character of the stratospheric QBO.

6. Verification of Author's 1990 Forecast

Table 8 gives information on the author's seasonal forecast. The number of hurricanes, named storms, and named storm days was underestimated, and the various measures of intense hurricane activity such as HDP, number of category 3-4-5 hurricanes, and number of category 3-4-5 days were overestimated. The number of hurricane days were well forecast. Tropical storm Edouard was not a bonified warm core cyclone. The true number of named storms should be 13 and not 14.

TABLE 8
Forecast and verification of 1990 seasonal forecasts.

	Original 5 June Forecast	Updated 3 August Forecast	Verification
Hurricanes	7	6	8
Named Storms	11	11	14
Hurricane Days	30	25	27.5
Named Storm Days	55	50	68
Hurr. Dest. Pot. (HDP)	90	75	57
Major Hurricanes (Category 3-4-5)	3	2	1
Major Hurricane Days	Not fcst.	5	1

This season's verification agrees with the previous discussion of what type of hurricane season this was and well fits the 5 known forecast factors which influence seasonal variability. The key variable and also the most difficult forecast parameter to assess was the amount of West African rainfall that would fall. Given the last 2 years of above average Western Sahel summer rainfall conditions which were the highest two years totals since the middle 1960s, I had thought that the long running 18 year (1970-87) West African drought might be breaking up. The Gulf of Guinea (R1 rainfall of Fig. 2) August through November precipitation of 1989 - a typically good indication of the following year R3 Western Sahel June-July rainfall was $+0.16\sigma$. This was a good indication of average rainfall for 1990. Eastern Atlantic sea surface temperature conditions through May were not those of a drought year. The UK Meteorological Office's global model indicated near normal West African rainfall conditions although their statistical model indicated below average rainfall.

The author's early June forecast was thus made for average West Africa rainfall. With average anticipated African rainfall, neutral values of SLPA and ZWA, very favorable stratospheric QBO winds, and no anticipated moderate or strong El Nino conditions the 5 June seasonal forecast was made for slightly above the 40-year average of hurricane and intense hurricane conditions. But as June and July progress it became evident that quite below average amounts of Western Sahel precipitation were falling. The June-July precipitation amounts were -0.46σ standard deviation below the long term average. This was a tip off that 1990 was not going to have very much intense hurricane activity. I consequently reduced my 3 August updated forecast of intense hurricane activity by one third and slightly reduced the other forecast parameters.

These dry June-July conditions continued even stronger through August and September. The net June through September Western Sahel R3 region rainfall was $-.95\sigma$ below average. It is thus not surprising that so little intense hurricane activity occurred this year.

The physical linkage between dry Sahel conditions and reduced intense hurricane activity this year are believed to be through the association of drought conditions with the global and Atlantic upper level circulation anomaly patterns as previously discussed. It was these drought associated shearing conditions which lead to the suppression of this year's intense hurricane activity and of the frequent mid-Atlantic recurvature of so many of this year's tropical cyclones.

The author's forecast of the El Nino, QBO, SLPA, and ZWA went quite well. It was the inability to properly assess the coming season Western Sahel rainfall conditions by early June which lead to the underestimation of the amount of intense hurricanes this season. A major goal of our current research is to try to make a better seasonal forecast of Western Sahel seasonal rainfall by early June.

7. Outlook for 1991

The odds favor a below average hurricane season for next year. This assessment is based on the following considerations:

1) the stratospheric QBO which has been especially favorable for hurricane activity this year, should not be so next year. It is expected that the QBO will shift around to an easterly direction by next season.

Easterly stratospheric QBO conditions should act as a suppressing influence on next season's hurricane activity. Already the high 10 mb (30 km) winds have just began to blow from a relative easterly direction.

2) Information on the August through November rainfall in the R1 area of the Gulf of Guinea (see Fig. 2) has been very low this year (-0.79σ). Similar R1 region August through November rainfall for the past three years were $+1.44\sigma$ in 1987, $+0.33\sigma$ in 1988 and $+0.16\sigma$ in 1989. Late season rainfall in this Gulf of Guinea R1 region correlates very well with the following year's Western Sahel June-July rainfall and less so with the Western Sahel's following years full season precipitation. We thus project below normal (42-year average) Western Sahel rainfall conditions for next season but likely not as low as this year. This should be an important factor in suppressing next year's intense hurricane activity. August through November 1990 rainfall information data has only recently been obtained. It appears that the long running West African drought is, despite 1988 and 1989 heavy rainfall amounts, still not broken.

3. Although not for certain, there is a good possibility that a moderate or strong El Nino will develop by next year. If this happens this will be an important and further suppressing influence on 1991 hurricane activity. Some El Nino forecasters are already predicting an El Nino for next year. The last significant El Nino to occur was in 1986. Five years is the typical period between significant El Nino events. Nothing can be said about the two local regional predictors of SLPA and ZWA.

Thus, the three large-scale predictors of the QBO, the EN, and Western Sahel rainfall all indicate a suppressed hurricane season for next year.

8. Outlook for the 1990s and Early Years of the 21st Century

The long running Western Sahel drought since 1970 with three years of interruption in 1975 and 1988-89 (see Figs. 4 and 5) should not be expected to continue indefinitely. Such long running multi-decadal drought conditions have been observed in past weather record of this and the 19th century. It is likely that we will see a return in a spell of normal or above normal Western Sahel rainfall conditions in the next few years. When and if this happens we will have an inevitable return to a period of more intense hurricanes along the East Coast, in Florida and within the Caribbean basin as these regions experienced during the last West African wet period of the 1950s and 1960s. One should not expect the next decade or two to have as few intense hurricanes as have occurred in the last two decades.

9. Forecast Verification

Seasonal forecasts have been issued for the last 7 years. A record of these forecast verifications is given in Table 10. It is reasonable that an evaluation be made of their skill in comparison with climatology, the only other previously available method of predicting future hurricane

TABLE 10

Verification of the author's previous seasonal predictions of Atlantic tropical cyclone activity for 1984-89. New counting (n.c.).

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	21* (18 by n.c.)
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	27* (21 by n.c.)
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	13* (10 by n.c.)
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	7* (5 by n.c.)
No. of Named Storm Days	40	35	37

1988	Prediction of 26 May and 28 July Updat	Observed
No. of Hurricanes	7	5
No. of Named Storms	11	12
No. of Hurricane Days	30	26* (24 by n.c.)
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

activity.

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

1) I have added seasonal predictors of Hurricane Destruction Potential (HDP) for the last three seasons and this year of the number of intense or Saffir/Simpson category 3-4-5 hurricanes and of the number of category 3-4-5 days were added to the prediction. There has not been a long enough period for a evaluation 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 this year's forecast. The first six year forecasts and particularly last year's forecast were deficient in not including this very important but previously unknown parameter.

3) Up until two 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 good assessment of the true potential of seasonal predictive skill from only the last seven (1984-1990) years of forecasts. This is too short a period for a very meaningful verification.

New statistical analysis of data for the 41 seasons of 1949-89 by the author and statistician colleagues (CSU Statistics Professors Paul Mielke and Kenneth Berry) show there is a very high predictive skill in the forecast of intense hurricane activity (Gray, et al., 1990). Using 41 years of newly acquired African rainfall data in combination with previously used parameters, we find that it is possible to predict between 40-45% of the seasonal variability of HDP, intense hurricanes (category 3-4-5) and intense hurricane days with the early June forecast. Hurricane and named storm number can be forecast by 1 June with a skill of 35-40%.

These analyses utilized 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.

Forecasts which are made with July information show that it is possible to explain approximately 60 percent of the coming season's variance of HDP, intense hurricanes and intense hurricane days. 1 August forecast skill for seasonal variations in the numbers of hurricane, named storms, and hurricane days varies between 50-55%.

This longer running and independent or jackknife statistical analyses are believed to be the best evaluation of the potential forecasting skill. Verification of only seven of the author's forecasts are not nearly as reliable a sample, particularly in that 6 of these last 7 years did not utilize the new information we have recently uncovered concerning the substantial influence of West Africa rainfall on hurricane activity. I will nevertheless attempt to verify my last 7 years of forecasts.

Skill of Last Seven Year Forecast. There have only been three parameters that have been predicted during all of the last 7-year forecasts - number of hurricanes, number of named storms, and hurricane days. Table 11 gives the ratios of the mean variance of the author's seasonal forecast errors to the mean of the individual seasonal variances from climatology for the period of 1949-90. Values less than 1.00 show forecast skill. Values greater than 1.00 lack any skill. For all three forecast parameters and for both forecast periods the variance of the errors of the author's predictions were less than the average year to year parameter variances from climatology.

TABLE 11

Seven Year (1984-90) forecast skill or the ratio of variance of mean forecast error to the mean seasonal variance from climatology for the period 1949-90.

Forecast Parameter	1 June Forecast	1 August Forecast
Number of Named Storms	.56	.31
Number of Hurricanes	.69	.75
Number of Hurricane Days		
Original Counting	.50	.38
New Counting	.74	.54

But the proper comparison of the last 7 years of forecast error should likely be made using only the average variances from climatology of the last seven rather than the last 41 seasons. Seasonal variances from climatology of the last 7 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" in the last 7 years in comparison to the previous 34 years. For instance, the yearly numbers of hurricanes during the period of 1984-90 has been 5, 7, 4, 3, 5, 7, 8 and average variance from the long term mean has been 2.86. The 41 year mean variance of hurricanes has been 4.77 or 67% greater. Seasonal hurricane numbers between 1949-90 range from 2 to 12. The greater the variance from climatology, the greater is the potential forecast skill. It thus has ben more difficult to demonstrate forecast skill over the last 7 years when the variance from the mean has been smaller than normal.

Table 12 shows the mean 7-year forecast skill using the mean variance from climatology only of the period 1984-90. There was forecast skill for named storms but no skill for the forecasts of hurricanes and hurricane days. This lack of hurricane and hurricane day forecast skill was due entirely to the disastrous forecast of 1989 when a below average hurricane season was forecast but an above average season occurred. This bust is attributed to the unusually heavy amounts of rainfall which fell in the Western Sahel in 1989 which were, at the time of last year's forecast issuance unanticipated and whose influence on Atlantic hurricane activity was not understood. Western Sahel 1989 rainfall was the highest than it has been in any year since 1967. It was this large forecast bust in 1989 that has stimulated the author's project to perform new research towards a better understanding of this strong relationship between Western Sahel

TABLE 12

Seven year (1984-90) forecast skill or the ratio of variance of mean forecast error to the mean variance from climatology for the period 1984-90.

Forecast Parameter	1 June Forecast	1 August Forecast
Number of Named Storms	.73	.41
Number of Hurricanes	1.15	1.00
Number of Hurricane Days		
Original Counting	1.36	1.04
New Counting	1.38	1.00

relationship between Western Sahel rainfall and hurricane activity. A similar African rainfall forecast error should (now that we are obtaining an understanding of the phenomena) not occur again.

It is the single year of 1989 that has prevented the demonstration of significant forecast skill with the climatology of the last 7 seasons. If I were permitted to disregard 1989 and evaluate my other 6 seasonal forecasts then very significant forecast skill is obtained.

These seven years of forecast might also be qualitatively evaluated from inspection of all forecast parameters at both forecast periods. My own evaluation of the last 7 seasons based on a rating of very good, good, fair, poor and terrible are given in Table 13. I rate myself as making 3 very good forecasts, 2 good forecasts, 1 fair forecast, and 1 terrible forecast. I believe my forecasts have demonstrated an overall qualitative skill. Readers can make their own evaluation.

Regardless of how one might rate my forecast skill over the last 7 years, I am very confident that future forecasts will stand the test of

TABLE 13

Gray's qualitative summary evaluation of his seven seasonal forecasts.

Year	Rating
1984	Fair
1985	Very Good
1986	Very Good
1987	Very Good
1988	Good
1989	Terrible
1990	Good

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.

10. Acknowledgements

The author is indebted to many meteorological experts who have furnished me with the data necessary to make this forecast or who have given me their assessments of the current state of global atmospheric and oceanic conditions. Chris Landsea has contributed very valuable statistical analyses and given much beneficial discussion on this topic. Landsea's forthcoming MS thesis throws much new light on the strong West African rainfall-hurricane association.

The author is most thankful to Colin McAdie of NHC who has furnished me with a great deal of tropical data. Vern Kousky and John Janowiak have 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 Peter Lamb have given rainfall assessment discussions. I have also appreciate discussions with Neal Ward of the 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 and Robert Case. The author has also gained from the quite indepth interchange he has had with his project colleagues John Sheaffer, Ray Zehr, and Stephen Hodanish. I have also appreciated the statistical insights and the voluminous statistical calculations on this topic that have been performed by CSU statistics Professors Paul Mielke and Kenneth Berry. William Thorson and Richard Taft has provided valuable computer assistance. 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.

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