UPDATED (as of 28 July 1988)

FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1988

By

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This updated forecast uses background material contained in the Colo. State Univ. Dept. of Atmospheric Science seasonal forecast report which was issued by the author on 28 May 1988. This current report utilizes additional new June and July 1988 meteorological information and is issued to coincide with the start of the more active part of the hurricane season (after 1 August).

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DEFINITIONS

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

Hurricane - A tropical cyclone with sustained low level winds of 74 miles per hour (32 ms^{-1} or 65 knots) or greater.

Tropical Cyclone - (TC) - a large-scale circular flow occurring within the tropics and subtropics which has its strongest winds at low levels. This includes tropical storms, hurricanes, and other weaker rotating vortices.

Tropical Storm - a tropical cyclone with maximum sustained winds between 39 (17 ms^{-1} or 35 knots) and 73 (31 ms^{-1} or 65 knots) miles per hour.

Hurricane Day - any part of a day in which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Named Storm Day - any part of a day in which a tropical cyclone is observed or estimated to have tropical storm or hurricane intensity winds.

Millibar - (abbreviated mb). A measure of atmospheric pressure. Often used as a vertical height designator. 200 mb is at a level of about 12 kilometers, 50 mb at about 20 kilometers altitude. Monthly averages of surface pressure in the tropics show maximum seasonal summer variations of about $\pm$ 2 mb. These small pressure variations are associated with variations in seasonal hurricane activity. Average surface pressure is slightly over 1000 mb.

El Nino - (EN) - a 12-18 month period in which anomalously warm sea surface temperatures occur in the eastern half of the equatorial Pacific. Moderate or strong El Nino events occur irregularly. Their average frequency is about once every 5-6 years or so.

QBO - Quasi-Biennial Oscillation. These letters refer to stratospheric (16 to 35 km altitude) equatorial east to west or west to east zonal winds which have a period of about 26 to 30 months or roughly 2 years. They typically blow for 12-16 months from the east and then reverse themselves and blow 12-16 months from the west and then back to the east again.

SLPA - Sea Level Pressure Anomaly. Caribbean and Gulf of Mexico sea level pressure difference from long term average conditions. SLPA in the spring and early summer has an inverse correlation with late summer and early autumn hurricane activity. The lower the pressure the more likely there will be hurricane activity.

ZWA - Zonal Wind Anomaly. A measure of upper level ($\sim$200 mb or 12 km altitude) 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.

OUTLINE

ABSTRACT

This paper discusses the author's updated forecast of the amount of seasonal hurricane and tropical storm activity which can be expected to occur in the Atlantic basin, Caribbean, and Gulf of Mexico region in 1988. This updated forecast is issued just before the start of the most active part of the hurricane season. The author's previous forecast for 1988 was issued on 1 June 1988 (Gray, 1988) and called for 7 hurricanes (1 above the average of the 1947-86 period), 11 named tropical storms (1 above the last 40-year average), and 30 hurricane days (5 above average), and a Hurricane Destruction Potential (HDP) of 75 (1 above last 40 year average). This updated forecast is based on the author's earlier forecast and more recent June and July meteorological data. This revised forecast is considered to be more reliable than the forecast issued at the end of May.

Statistical information received by the author as of 28 July 1987 indicates that the hurricane and tropical storm activity for 1988 can be expected to be as anticipated in late May. No update forecast alteration needs to be made. This means that the 1988 Atlantic hurricane season will likely be an above average season by the standards of the last 18 years and particularly so as regards to the hurricane activity of the last 6 seasons which has been very suppressed except for 1985. Intense hurricane activity during 1947-1969 was significantly higher than it has been since 1970. This season should likely have only slightly higher hurricane activity in comparison to the average conditions of the last 40 years, however. The probability is also high that this season will have a few more intense hurricanes than have occurred during the last few seasons. The Hurricane Destruction Potential (or HDP) of hurricanes in 1988 should be higher than in any previous season since 1981 except for the active season of 1985.

1. Background

The Atlantic basin (including the Atlantic Ocean, Caribbean Sea and Gulf of Mexico) experiences a larger seasonal variability of tropical cyclone activity than any other global tropical cyclone basin. The number of hurricanes per season can be as high as 12 per season as in 1969, 11 per season (as in 1950, 1916), 10 (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 the last few years there has been no objective and very skillful method for indicating whether a coming hurricane season was going to be an active one or not. Recent and ongoing research by the author (Gray, 1983, 1984a, 1984b, 1987; Gray et al., 1987) indicates that there are four atmospheric parameters (out of a large number studied) which can be evaluated in spring and early summer and which are correlated with the following season's tropical cyclone activity. If these four predictors are used in combination, then it is possible to explain about half or more of the seasonal variability in Atlantic hurricane activity on a statistical multi-year basis.

This paper will briefly discuss the nature of these four seasonal hurricane predictors and what these predictors indicate for the level of hurricane and tropical storm activity for the 1988 season.

This paper has been prepared for the professional meteorologist, the news media, and any interested layman.

2. Known Factors Associated With Atlantic Seasonal Hurricane Variability

The author's Atlantic seasonal hurricane forecast is based on the characteristics of two global and two regional environmental predictive factors which the author has previously shown to be statistically related to seasonal hurricane variations. Knowledge of these predictive factors is available by 1 June, the official start of the hurricane season, or on 1 August, the start of the more active part of the hurricane season. These four predictive factors are:

a) The presence or absence of a moderate or strong El Nino warm water event in the eastern tropical Pacific. Seasons during which a strong or moderate El Nino event are present have averaged only about 40 percent as much hurricane activity as non-El Nino seasons. This is related to the stronger upper tropospheric (200 mb or 12 km) westerly winds which typically occur over the Caribbean Basin and western Atlantic during El Nino seasons (See Fig. 1). These westerly winds inhibit hurricane activity.

b) The direction of the stratospheric Quasi-Biennial Oscillation (QBO) winds which circle the globe over the equator. On average, there is about twice as much Atlantic hurricane activity in seasons when 50 mb (or 20 km altitude) stratospheric winds on the equator are from the west as compared when they are from the east (see Fig. 2). In those westerly phase seasons, stratospheric winds at latitudes near 10°N are weakly from the east. These seasons are differentiated from those equatorial easterly phase seasons when stratospheric winds near 10°N are strongly from the east. Strong stratospheric easterly winds at 10°N are

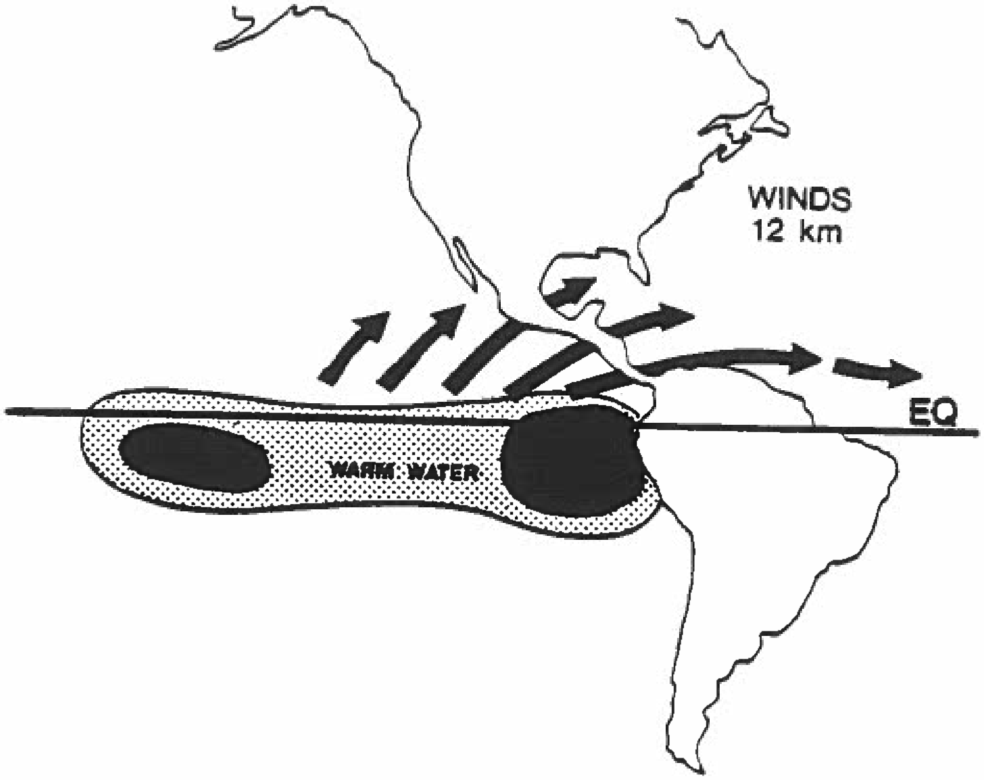

Fig. 1. Illustration of anomalously warm oceanic sea-surface temperature in the equatorial eastern Pacific which are associated with El Nino events. Arrows show the resulting anomalous upper tropospheric westerly winds which result from the enhanced deep cumulus convection which occurs in the equatorial Pacific as a result of these warm water events.

associated with reduced hurricane activity. Weak stratospheric easterly winds at 10°N are associated with enhanced seasonal hurricane activity.

c) Gulf of Mexico and Caribbean Basin Sea Level Pressure Anomaly (SLPA). Other factors aside, lower pressure favors Atlantic seasonal hurricane activity and vice-versa. April through July pressures statistically correlate with August to October surface pressures and offer a degree of seasonal hurricane predictability.

d) Lower latitude Caribbean Basin upper tropospheric ($\approx$ 200 mb or 12 km altitude) west to east or zonal wind anomaly (ZWA) in non El Nino

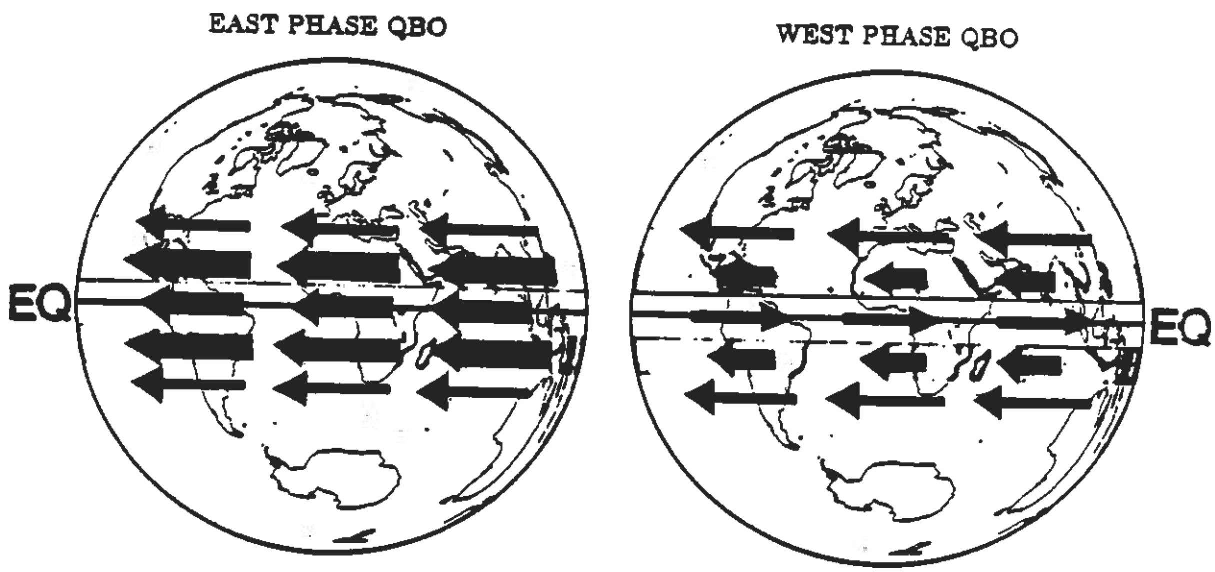

Fig. 2. Illustration of the two basic stratospheric Quasi-Biennial Oscillation (QBO) wind conditions which occur over the tropics at 50 mb or 20 km altitude during the summer seasons of both hemispheres. The left diagram shows conditions during the easterly phase of the QBO when easterly winds occur on the equator and winds at 10°N are strongly from the east. The right diagram, by contrast, shows conditions during the westerly phase of the QBO when stratospheric winds on the equator are from the west and winds at 10°N latitude are only weakly from the east. Atlantic hurricane activity is suppressed with conditions of the left diagram and enhanced with conditions of the right diagram.

years. The stronger the 200 mb zonal winds are from the west the greater the suppression of seasonal hurricane activity and vice-versa. June-July upper-level ZWA correlates with August-September ZWA values and offer a degree of hurricane predictability.

It is important to closely monitor the conditions of the El Nino, QBO, SLPA, ZWA in order to be able to better understand and predict the variations of Atlantic seasonal hurricane activity. For the physical reasons as to why these predictors are related to Atlantic seasonal hurricane variability the reader my refer to the author's 1 June forecast (Gray, 1988c) or to his presentations at the Atlanta, Georgia, 8 April 1988 10th Annual National Hurricane Conference (Gray, 1988a) or at the State of Florida's Govenor's Conference on Hurricanes, 3 June 1988 in Tampa, Florida (Gray, 1988c).

3. Hurricane Destruction Potential (HDP)

The wind and storm surge destruction of a hurricane is better related to the square of the storm's maximum wind $(V_{max})^2$ than to the maximum wind itself. This potential damage from hurricane high winds and storm surge might be termed Hurricane Destruction Potential (HDP). We define Hurricane Destruction Potential (HDP) as

$$\sum (V_{max})^2 \text{ for } V_{max} \geq 65 \text{ knots}$$

for each 6-hour period a hurricane is in existence.

Figure 3 shows seasonal values of Hurricane Destruction Potential (HDP) for the 41-year period of 1947 through 1987 in units of 10^4 knots^2. Note how much higher the Hurricane Destruction Potential was during the period of 1947-69 in comparison with the period of 1970-87. This reduction in recent year hurricane activity is well related to the West African drought conditions which have prevailed during the period since 1970 and to the generally higher Caribbean Basin SLPA and ZWA conditions which have prevailed since 1970.

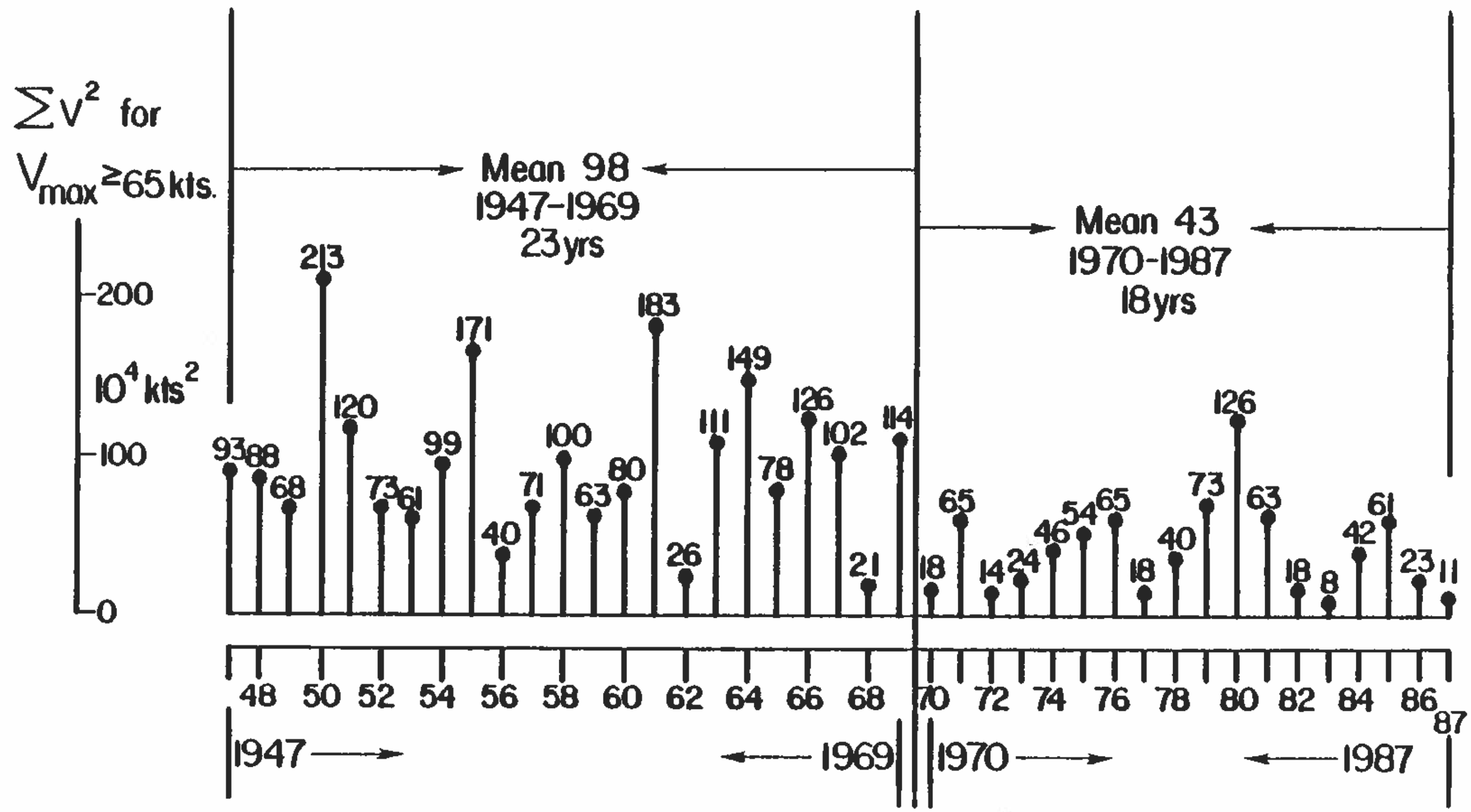

Fig. 3. Yearly variations in Hurricane Destruction Potential (HDP) defined as the sum of all hurricane maximum wind speeds squared for each 6-hour observing period throughout the hurricane season. Units 10^4 kts^2.

4. Unusually Low Atlantic Hurricane Activity of the Last 6 Years

Except for 1985 the last six storm seasons have experienced a much reduced amount of hurricane activity as compared with the average activity of the last 40 years or of the last 18 years. Figures 4-6 compare the seasonal number of hurricanes, number of hurricane days, and Hurricane Destruction Potential (HDP) of the last 6 hurricane seasons. Note that only 1985 has had an above average number of hurricanes and hurricane days. And even in 1985 the Hurricane Destruction Potential (HDP) was less than the annual average of the last 40 years. Why have there been these large decreases in hurricane activity? There are solid meteorological reasons for this reduced hurricane activity.

1) Four of the last 6 hurricane seasons have been influenced by El Nino events. The century's strongest El Nino of 1982-83 had a very strong suppressing influence on the 1982 and 1983 hurricane seasons. The moderate El Nino event occurring during the 1986-87 period had a suppressing influence on the hurricane seasons of 1986 and 1987 - see Fig. 7.

2) The 50 mb (12 km) stratospheric winds in the low latitude regions of 10°N where the most intense hurricanes typically form have been strongly from the east in September in 3 (1982, 1984, 1987) of the last 6 hurricane seasons and intermediately from the east in two seasons (1983, 1986). Only in the active 1985 season were 50 mb stratospheric winds weakly from the east - see Fig. 7.

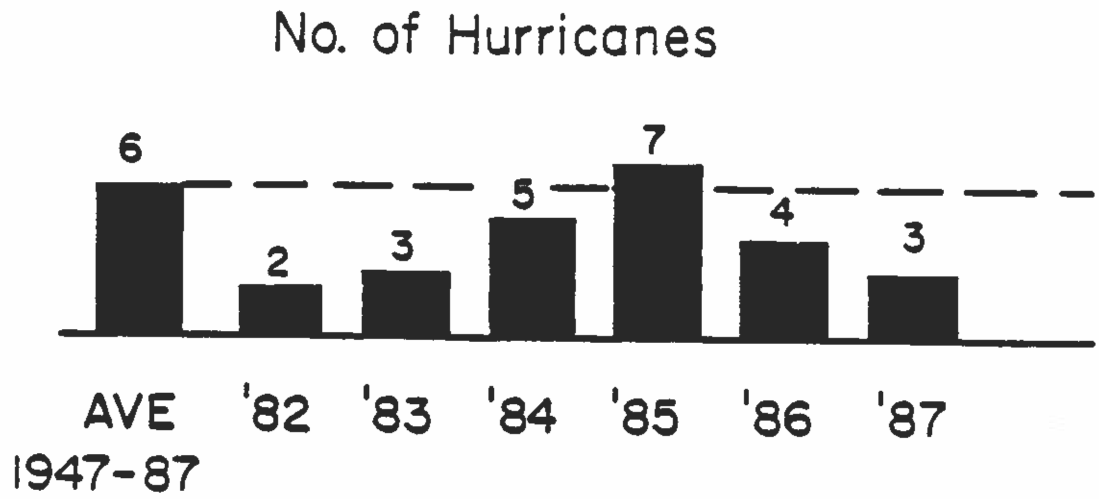

Fig. 4. Comparison of the number of hurricanes during each of the last 6 years with the last 40 years average.

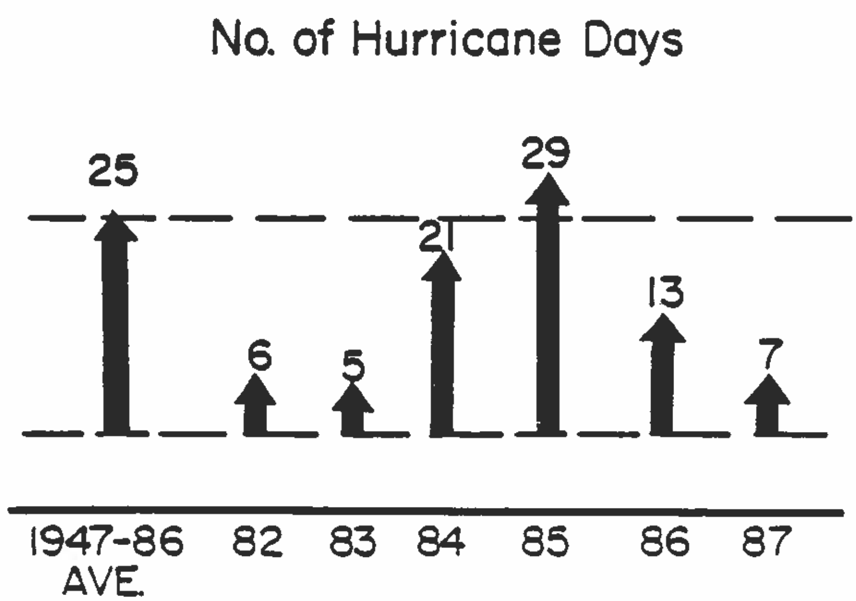

Fig. 5. Same as Fig. 4 but for the number of hurricane days.

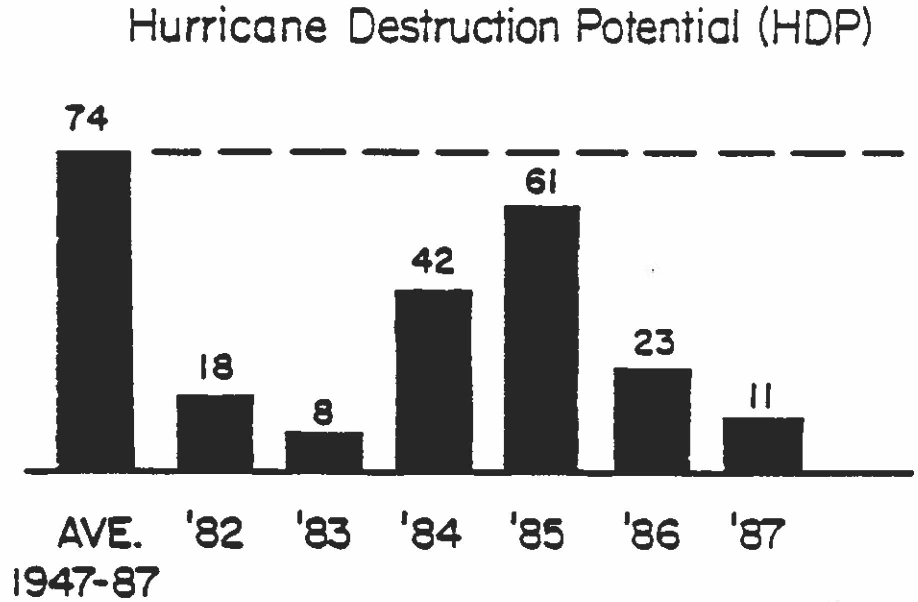

Fig. 6. Same as Fig. 4 but for the Hurricane Destruction Potential (HDP).

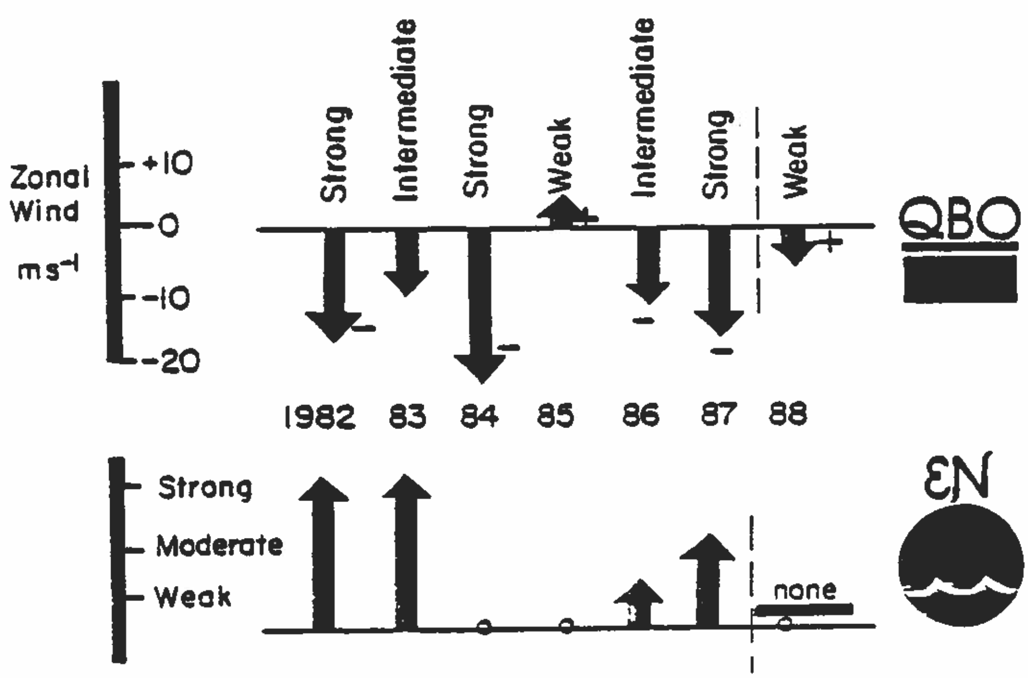

Fig. 7. Last six years magnitude of the Balboa 50 mb (20 km) September easterly wind component (top diagram) and the occurrence and relative magnitude of the El Nino events by year. Estimates for 1988 are also given.

3) Sea Level Pressure Anomaly (SLPA) in the Caribbean and Gulf of Mexico region has been high in all seasons but 1985. Higher pressure suppresses seasonal hurricane activity (see the top diagram of Fig. 8).

4) Lower Caribbean basin upper tropospheric 200 mb (12 km) zonal winds have been stronger than average in all but the 1985 season (see bottom diagram of Fig. 8). Higher than average zonal wind anomalies (ZWA) act to suppress hurricane activity.

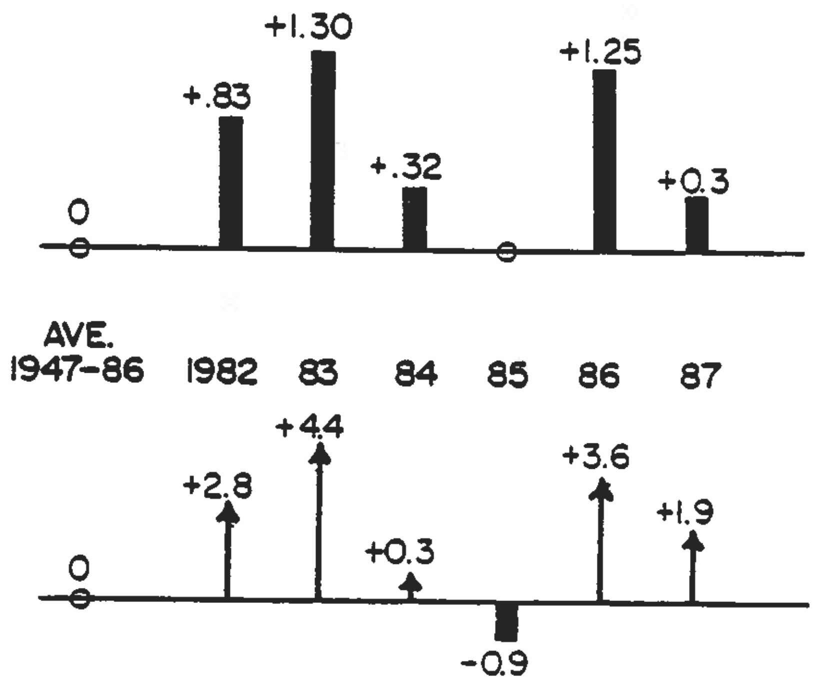

Fig. 8. Last six year Caribbean Basin-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) during August-October (top diagram) and low Caribbean Basin upper tropospheric (200 mb or 12 km) Zonal Wind Anomaly during these months (bottom diagram). SLPA in mb and ZWA in m s^{-1}.

Only 1985 can be classified as an active hurricane season.* It is to be noted that 1985 was the only recent season which did not have anomalously high surface pressure and Caribbean Basin positive 200 mb zonal wind anomaly. The 1985 season also had favorable weak easterly stratospheric winds and no El Nino event occurred that season.

We thus have physical explanations for why 5 of the last 6 hurricane seasons have been so inactive. It is not expected that this low seasonal hurricane activity will continue into 1988, however.

5. Rationale for Making a Forecast of Atlantic Seasonal Hurricane Activity

A forecast scheme using this QBO, EN, SLPA and ZWA information is based on the premise that:

1) the strength of the stratospheric 50 mb easterly QBO wind speed changes on such a long time interval ($\sim$14-17 months) and in such a uniform manner, that these wind speeds can be extrapolated for 3 to 6 months into the future.

2) the oceanography-meteorological community is able to detect the presence and approximate intensity of an El Nino event by 1 June or 1 August at the latest.

3) information on the Caribbean Basin-Gulf of Mexico sea level pressure anomaly (SLPA) and 200 mb zonal wind anomaly (ZWA) for the four pre-hurricane months of April through July are readily available. This information allows seasonal hurricane forecasts to be made on 1 June with an updated forecast on 1 August.

Figure 9 shows the average distribution of hurricane and tropical storm activity by calendar date for a 95 year period. Note that although the official start of the hurricane season is 1 June, the active part of the hurricane season does not begin in earnest until after the 1st of August.

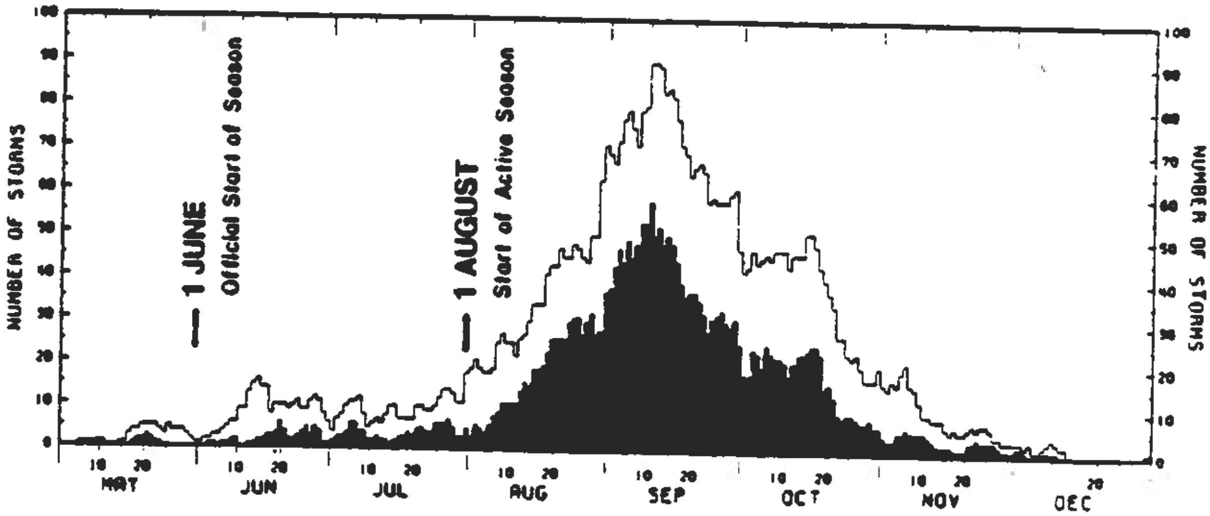

Fig. 9. Number of tropical storms and hurricanes (open curve) and hurricanes (solid curve) observed on each day, May 1, 1886 through December 31, 1980 (from Neumann, et al., 1981).

6. Characteristics of 4 (EN, QBO, SLPA, ZWA) Predictors for the 1988 Hurricane Season

The two global predictors of El Nino (EN) and stratospheric QBO winds in combination indicate that the coming 1988 hurricane season will likely be more active than most of the recent hurricane seasons have been.

a) El Nino. The moderately intense El Nino (EN) event of late 1986 and 1987 has dissipated and quite cool sea surface temperature (SST) has now returned to the equatorial regions of the eastern Pacific. Recent conditions are even indicative of an anti-El Nino event. Note in Fig. 10 the strong contrast of equatorial Pacific SST conditions in the first half of July 1987 (top figure) in comparison with the same period of 1988 (bottom figure). At some equatorial locations SSTAs are 4-5°C cooler than last year. These are very large differences. The 1988 hurricane season will definitely not experience the suppressing

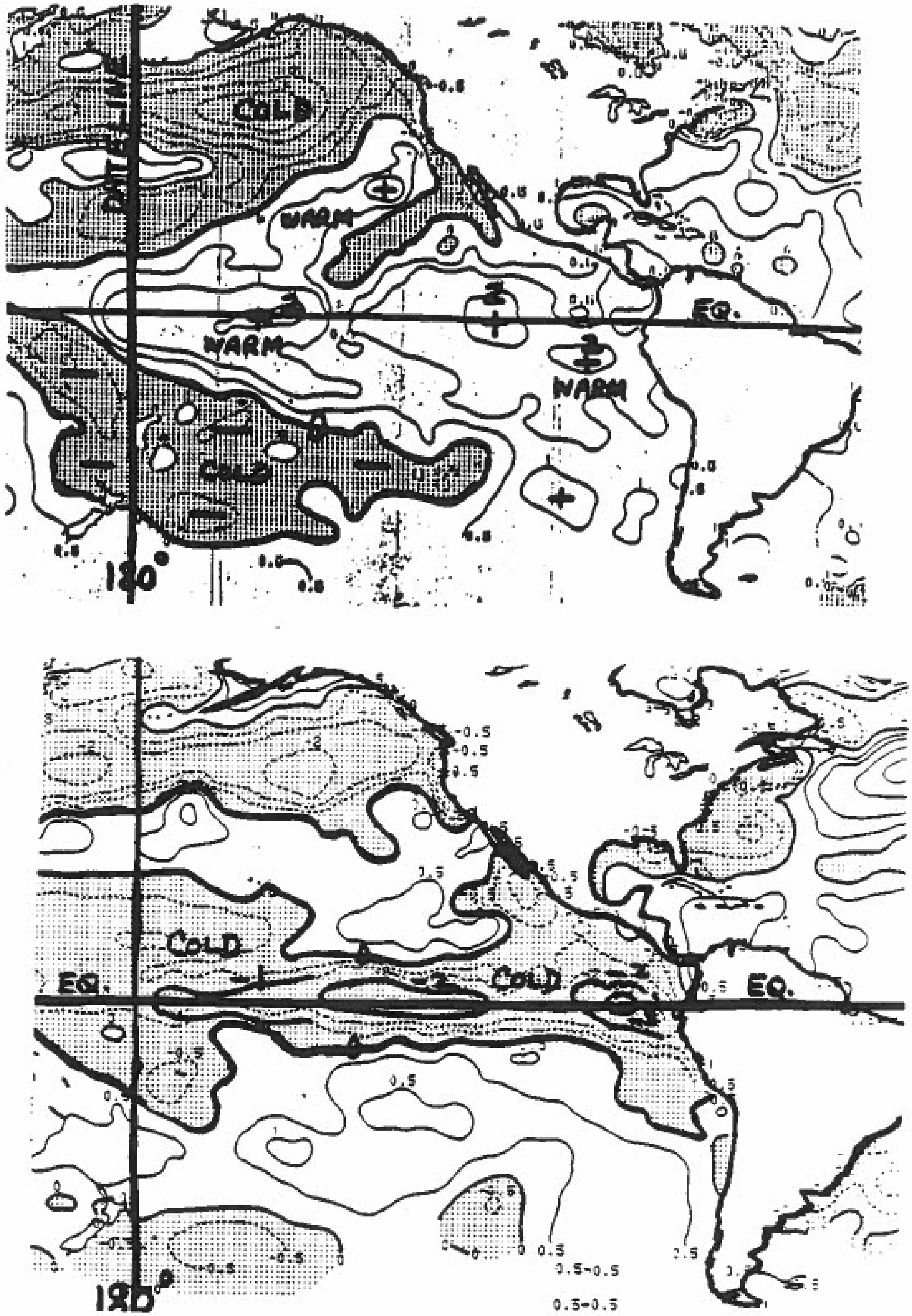

Fig. 10. 1-16 July Sea Surface Temperature Anomaly (SSTA) in °C for 1987 (top diagram) and 1988 (bottom diagram). Dotted areas show cold anomaly (-), unshaded areas positive anomaly (+) - from NOAA blended SST anomaly analyses.

influences of an El Nino event. The lack of an El Nino event for 1988 is further verified by the presence of easterly anomalous Caribbean Basin 200 mb (12 km altitude) winds. These easterly anomalous winds have existed since April. In El Nino seasons Caribbean Basin 200 mb zonal winds are typically anomalously from the west.

b) Stratospheric QBO in 1988. Figure 11 shows the past and extrapolated global relative Quasi-Biennial Oscillation (QBO) zonal winds for the coming hurricane season. Stratospheric winds have been extrapolated into the future on the basis of their typical alteration since 1950 and annual seasonal variation. Although the relative zonal component of the QBO has already shifted from a westerly to an easterly direction at 10 mb (30 km) and is now beginning to shift to the east at 30 mb (23 km) the lower stratospheric winds will be from a relative westerly direction during August and September. The expected stratospheric 50 mb (20 km) and 70 mb (18.5 km) winds in the period of August-September-October of this season will thus not be strongly from the east. This will be favorable for more hurricane activity than average. New June-July stratospheric wind data indicate that the westerly wind phase of the QBO will be shorter than normal this year. It appears that the enhancing influence of the QBO on hurricane activity as anticipated by the author in early April and late May of this year will be somewhat reduced. It was not expected in the spring that the shift of the 30 mb relative zonal winds from westerly to easterly would occur so rapidly. The 30 mb easterly phase winds were present for only 10 months when the usual easterly wind phase lasts for 13-16 months.

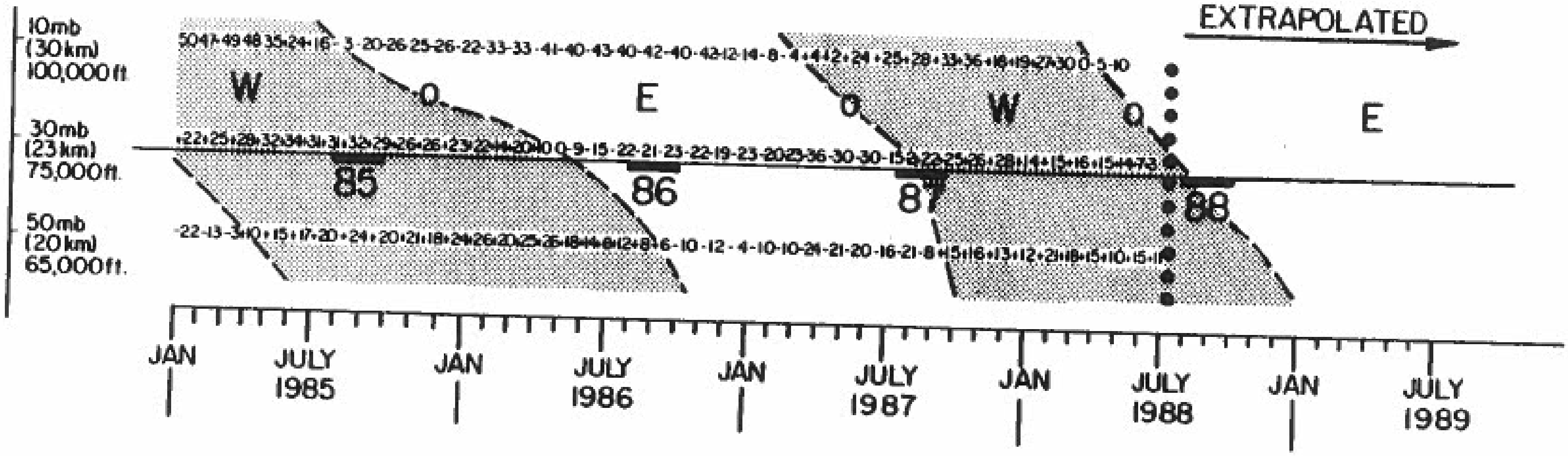

Fig. 11. Vertical cross-section of recent stratosphere's monthly average QBO west to east or zonal wind (in knots). This figure represents an average of the Balboa, C.Z. (9°N) and Ascension (8°S) rawinsondes with Trinidad (11°N) being substituted for Balboa during part of 1988. The climatological annual cycle has been removed from each sounding before averaging. Winds from a westerly direction have been shaded. Information beyond July 1988 has been extrapolated. Thick horizontal lines show the August-October active portion of each hurricane season from 1985 through 1988.

The author is consequently reducing his 1 June QBO forecast correction from a 1 June value of +2 to a 1 August value of +1 units. This reduction is being compensated by the negative values of the ZWA, however.

Table 1 shows the absolute value of the current and extrapolated QBO zonal winds near 10°N in the Atlantic region for August-October 1988 based on a combination of the QBO relative wind alteration and annual wind cycle variations at the low latitude stations of Balboa (9°N), Curacoa (12°N), Trinidad (11°N), and Barbados (13°N). Note that during the 1988 hurricane season the vertical wind shear in the lower stratosphere is not expected to be very large. Table 2 portrays this same zonal wind information in relative wind components where the annual cycle has been removed. These wind projections show that the lower stratospheric zonal winds will not be very different from the mean tropospheric zonal winds of the typical low latitude tropical disturbance moving westward in the trade winds. Low latitude stratospheric wind conditions during 1988 are judged to be favorable (or at worse not unfavorable) for the development of the more low latitude tropical cyclones which originate from west African disturbances. These disturbances, as previously discussed, typically produce the most intense cyclones.

TABLE 1

April through October observed and extrapolated absolute value of stratospheric zonal wind (U) in the latitude belt between 8-12°N as obtained from lower Caribbean basin stations of Kingston, Curacoa, Barbados, Trinidad, and Balboa. Values in m/s.

	Observed				Extrapolated		
Level	Apr	May	Jun	Jul	Aug	Sept	Oct
30 mb	-1	-6	-15	-20	-23	-25	-24
50 mb	+3	-1	-3	-9	-10	-8	-6
70 mb (18.5 km)	+2	-1	-3	-8	-8	-7	-3

TABLE 2

Same as Table 1 but for the relative zonal wind where the annual wind cycle has been removed.

Level	Apr	May	Jun	Jul	Aug	Sept	Oct
30 mb	+7	+8	+3	-1	-5	-8	-12
50 mb	+4	+5	+7	+5	+4	+2	0
70 mb	+2	+4	+4	+3	+3	+2	+2

c) Sea Level Pressure Anomaly (SLPA) in April-May and June-July 1988. The Caribbean and Gulf of Mexico SLPA is related to the north-south position of the western Atlantic Intertropical Convergence Zone (ITCZ) and the frequency and intensity of tropical cyclones and hurricanes. Figures 12 and 13 show the stations from which SLPA is obtained. Figure 12 shows stations used in the author's previous forecasts. Figure 13 shows the 5 lower latitude stations which are now

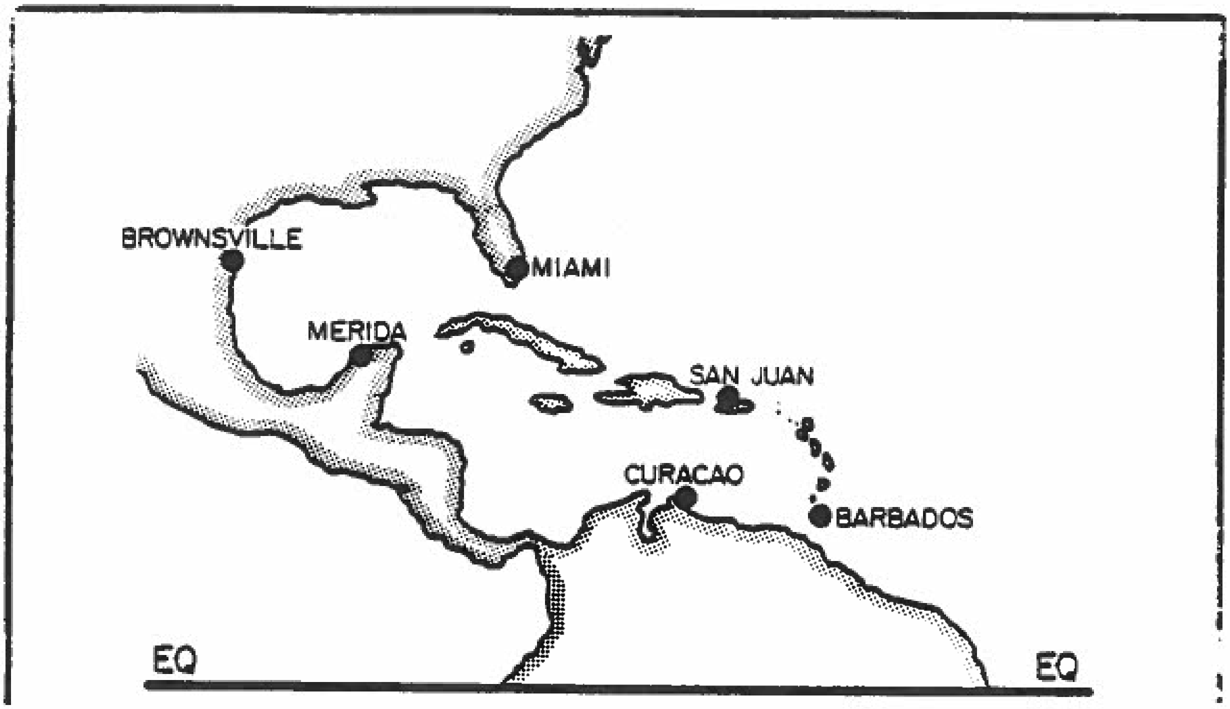

Fig. 12. Location of meteorological stations used for determining the 6-station mean monthly SLPA for the Caribbean Basin region.

Fig. 13. Five stations used for the determining Sea Level Pressure Anomaly (SLPA) at lower latitudes.

consulted more.

Table 3 shows April-May and 1 June-27 July 1988 SLPA for the stations of interest. Note that SLPA is near average for both the previously used 6-station average and the 5-station low latitude stations. These 5 low latitude stations are more related to the low latitude TCs spawned by tropical disturbances coming out of West Africa.

TABLE 3

Average April-May and 1 June-27 July Gulf of Mexico-Caribbean Basin and Low Latitude Sea-Level Pressure Anomalies (SLPA) (data from Arthur Pike of NHC) from data of 1950-1987 - in mb.

Gulf of Mexico-Caribbean Basin SLPA	April -May	1 June -27 July
Brownsville	+0.2	0
Merida (Mex.)	+0.3	0
Miami	-1.5	-0.7
San Juan	-0.7	-0.7
Curacao	0	+0.2
Barbados	+0.2	-0.3
Average	-0.2	-0.2

Low Latitude SLPA	April -May	1 June -27 July
San Juan	-0.7	-0.7
Curacao	0	+0.2
Barbados	+0.2	-0.3
Trinidad	+0.4	+0.5
Cayenne	+0.3	0
Average	0	-0.1

Pressure anomalies are slightly lower than the last 40-year average. They are somewhat lower than this when compared to the average of the surface pressure since 1970 however. SLPA since 1970 have been somewhat higher than it was during the period of 1947-1969. Being only marginally below normal no SLPA correction will be made to this updated forecast.

d) April-May and 1 June-27 July Lower-Caribbean Basin Zonal Wind Anomaly (ZWA). Although not explicitly used in the 1 June forecast, the

Lower Caribbean Basin 200 mb zonal wind anomaly (ZWA) for June-July are important for the updated 1 August forecast. Table 4 shows these and the April-May 200 mb ZWA values. Note that ZWA values are negative in comparison with the average values of 200 mb ZWA for both the 1970-87 and 1954-69 periods. Spring and early summer low Caribbean Basin 200 mb ZWA values are typically correlated with August-September ZWA values. There is typically more low latitude hurricane activity when ZWA is negative and less when these values are positive.

TABLE 4

Lower Caribbean Zonal Wind Anomaly (ZWA) for 1988 relative to 1970-87 and 1954-69 Average (data from Arthur Pike of NHC). Values in m s^{-1}.

Station	1970-87 Ave.		1954-69 Ave.	
	April -May	1 June -27 July	April -May	1 June -27 July
Kingston (18°N, 77°W)	0	-4	+2	-2
Curacoa (12°N, 69°W)	-4	-9	-2	-7
Barbados (13.5°N, 60°W)	-3	-10	-1	-8
Trinidad (11°N, 62°W)	-4	-7	-2	-5
Balboa, C.Z.,9°N,80°W (Many missing obs.)	---	-4	---	-2
Average	-3	-7	-1	-5

These negative ZWA values are also an indication that the monsoon trough over West Africa may be stronger than it has been in recent years.

Rainfall and crop information for June and July from US embassies in West Africa indicates that (as reported to the author by Vernon Kausky of the NOAA Climate Analysis Center) West African rainfall and vegetation appear, in general, to be higher and more advanced for this time of year than in most recent years. A study of the upper and lower tropospheric daily circulation patterns over west Africa support this assessment. The western African monsoon trough in June and July appears, in general, to be stronger than it has been in recent years. This is an indication that some of the usual westward propagating disturbance systems coming out of Africa may be somewhat more intense this season. This increases the probability of a few more low latitude and more intense tropical cyclones for this season than have occurred in recent years.

7. New Formulation of Prediction Equations

More recent research by the author and his colleagues is showing that it is desirable to make certain changes in how the author applies his seasonal prediction scheme. It appears that:

1) Atlantic hurricane activity can be slightly better related to the actual low latitude ($\sim$10°N) Balboa-Curacoa-Trinidad 70 mb (18.5 km) and 50 mb (20 km) zonal winds rather than the global 30 mb (23 km) relative zonal winds as previously applied;

2) the low-latitude sea-level pressure anomaly (SLPA) values of Fig. 13 are more representative for predicting the west African spawned more intense TCs than the pressure data of Fig. 12;

3) there is a multi-season memory of August-September SLPA and ZWA from previous seasons. If Sea Level Pressure Anomaly (SLPA) and Zonal Wind Anomaly (ZWA) in the previous 5 hurricane seasons were higher (or lower) than normal in the lower Caribbean basin, then the probability of the coming August-October hurricane season also having a higher (or lower) than average SLPA and ZWA is strong. SLPA and ZWA in the Caribbean Basin the last 5 years has averaged much higher than normal. On this basis one would expect the August-September SLPA and ZWA in the coming hurricane season to be higher than expected and (other factors aside) imply a slight reduction in hurricane activity.

The author and his CSU research colleagues, Paul Mielke and Kenneth Berry (of Dept. of Statistics) are currently making new statistical analyses of ways to forecast seasonal Hurricane Destruction Potential (HDP) which are somewhat different than the forecasts of the number of hurricanes and named storms. Although this current research is too involved to describe here, the author will use it to help make the seasonal prediction of HDP for 1988. Our current research is indicating that seasonal values of HDP can be predicted with as much or slightly more skill as can the number of hurricanes and with superior skill to the number of named storms or hurricane days.

These three changes in the author's forecast scheme lead to a somewhat different set of forecast equations:

$$\begin{pmatrix}\text{Predicted No.}\\ \text{of Hurricanes}\\ \text{per season}\end{pmatrix} = \begin{pmatrix}\text{Ave.}\\ \text{Season}\end{pmatrix} + \underset{\text{Correction Terms}}{(\text{QBO} + \text{EN} + \text{SLPA} + \text{ZWA} + \text{MEM})} \qquad (1)$$

where

QBO = 50 mb equatorial wind direction correction factor - if Balboa, C.Z. wind is weakly from the east add <u>one</u>, if 50 mb wind is strongly from the east subtract one. Set to zero if 50 mb zonal wind speed during the season is forecast to be from an intermediate easterly wind speed. Add an additional number if 50 mb QBO winds are anticipated to be very weakly from the east and no El Nino is forecast.

EN = El Nino influence. If present subtract two for a moderate El Nino event, <u>four</u> for a strong El Nino event, otherwise set to zero.

SLPA = average SLPA for April-May, from selective Caribbean-Gulf of Mexico stations. Add <u>one</u> or <u>two</u> if SLPA is < -0.4 mb or < -0.8 mb respectively. Subtract one or two if SLPA is 0.4-0.8 mb or > 0.8 mb, respectively. Make no correction for SLPA between -0.4 and 0.4 mb.

ZWA = Zonal Wind Anomaly at 200 mb (12 km) for five low latitude upper air Caribbean stations. Valid for June and July wind data only in non-El Nino years. Not directly used for the 1 June forecast. Forecast an additional hurricane or unit if the mean June-July zonal wind anomaly for these 5 stations is less than -1 m/s. Decrease the hurricane forecast by one if June-July zonal wind anomaly is greater than +1. Make zero if anomaly is less than $\pm$ 1 m/s.

MEM. = MEMORY correction term from last 5 years August-September values of SLPA and ZWA. Subtract or add one if the last 5 years August-September SLPA and ZWA have been significantly above or below average.

b. Number of Hurricanes and Tropical Storms

Equation (2), similar to Eq. 1 gives the formula for the prediction of the number of hurricanes and tropical storms:

$$\begin{pmatrix}\text{Predicted No. of}\\ \text{Hurricanes and}\\ \text{Tropical Storms}\\ \text{per season}\end{pmatrix} = \begin{pmatrix}\text{Ave.}\\ \text{Season}\end{pmatrix} + \overset{\text{Correction Terms}}{(QBO + EN + SLPA + ZWA + MEM)} \quad (2)$$

where correction terms are applied similar to those for Eq. (1).

c. Number of Hurricane Days

Equation (3) gives a prediction of the number of hurricane days per season,

$$\begin{pmatrix}\text{Predicted No. of}\\ \text{Hurricane Days}\end{pmatrix} = \begin{pmatrix}\text{Ave.}\\ \text{Season}\end{pmatrix} + 5\ \overset{\text{Correction Terms}}{(QBO + EN + SLPA + ZWA + MEM)} \quad (3)$$

where the meaning of the symbols are similar to Eq. 1 but each unit of correction factor will be multiplied by 5 instead of 1 as with the two previous determinations.

d. $\left(\begin{array}{l}\text{Predicted No. of}\\ \text{Named Storm Days}\end{array}\right) = 1.7\ (\text{No. of Hurricane Days})$

There has been, on average, about 43 named storm days per season or about 1.7 named storm days per hurricane day. There is less predictive signal for named storm days than hurricane days. This ratio changes with seasonal hurricane activity. Those seasons with high (low) hurricane activity have a lower (higher) ratio of named storms to hurricane days. For the amount of hurricane activity expected this season this ratio is judged to be about the average or 1.7.

e. Seasonal Average of Hurricane Destruction Potential (HDP)

Equation (4) gives a prediction of the seasonal average HDP.

$$\left(\begin{array}{l}\text{Hurricane}\\ \text{Destruction}\\ \text{Potential}\end{array}\right) = \left(\begin{array}{l}\text{Average}\\ \text{Season}\end{array}\right) + K \begin{array}{l}\text{Correction Terms}\\ \text{(Same correction term as for}\\ \text{hurricane determination}\\ \text{except for the memory term)}\end{array} \qquad (4)$$

where K = 15 and the memory term is taken to be -29 or the difference between HDP for 1970-87 minus HDP 1947-87. HDP has been much reduced since 1970. There is no reason for thinking that this multi-decadal slump in hurricane activity since 1970 will reverse itself this year. This season's memory correction is thus taken to be -29, alternatively, a value of 43 could be used for the average season with no memory correction.

8. 1988 Forecast

Table 5 shows the author's predictions of seasonal number of hurricanes, named storms, hurricane days, named storm days, and Hurricane Destruction Potential (HDP) for the coming 1988 hurricane season.

TABLE 5

1988 PREDICTED SEASONAL HURRICANE ACTIVITY

$$\left(\begin{array}{l}\text{Predicted No.}\\ \text{of Hurricanes}\\ \text{per Season}\end{array}\right) = 6 + QBO + EN + SLPA + ZWA + MEM.$$

$$(+1) + (0) + (0) + (+1) \quad (-1) = \quad \underline{7}$$

$$\left(\begin{array}{l}\text{Predicted No. of}\\ \text{Hurricanes and}\\ \text{Tropical Storms}\\ \text{Per Season}\end{array}\right) = 10 + QBO + EN + SLPA + ZWA + MEM.$$

$$(+1) + (0) + (0) + (+1) \quad (-1) = \quad \underline{11}$$

$$\left(\begin{array}{l}\text{Predicted No. of}\\ \text{Hurricane Days}\\ \text{Per Season}\end{array}\right) = 25 + 5\,(QBO + EN + SLPA + ZWA + MEM.)$$

$$(+5) + (0) + (0) + (+5) \quad (-5) = \quad \underline{30}$$

$$\left(\begin{array}{l}\text{Predicted No. of}\\ \text{Named Storm Days}\end{array}\right) = 1.7 \times (\text{No. of Hur. Days}) = \underline{50}$$

$$\left(\begin{array}{l}\text{Hurricane Destruction}\\ \text{Potential - HDP}\end{array}\right) = 74 + K\,(QBO + EN + SLPA + ZWA + MEM.)$$

$$74 + (15) + (0) + (0) + (+15) + (-29) = \underline{75}$$

<u>Summary</u>. The El Nino and ZWA conditions are very favorable for hurricane activity. The June-July conditions of the monsoon trough in West Africa appear favorable. The QBO conditions are slightly favorable and the SLPA conditions are neutral to marginally favorable. Statistical odds indicate an active hurricane season.

<u>Discussion</u>. It is thus expected that 1988 will be a more active

hurricane season than any season since 1981 except for the active season of 1985. Activity should be especially higher than it has been for the last two seasons. Statistical odds favor more 1988 low latitude tropical cyclones (TCs) which develop from African spawned disturbances. It is these tropical cyclones which typically develop into the most intense hurricanes. There has been a great reduction of these types of cyclones since 1980. Only one hurricane (Emily, 1987) has moved through the Caribbean Sea from the east since Allan in 1980. There is a higher probability that this season will have more African origin hurricanes than in recent years and in association with this a higher probability of more intense TCs than has occurred during the last 6 hurricane seasons except for 1985. The Hurricane Destruction Potential (HDP) of TCs this year should be appreciably higher than it has been in recent years except for the 1985 season.

The fact that there has been no named tropical cyclones (TC) so far this year should not be taken as an indicator that this may not be an active hurricane season. June-July tropical cyclone activity is not correlated with August through October activity. There have been a number of very active hurricane seasons in which the first named storm has not started until near to the middle of August. Conversely, there have been a number of hurricane seasons which have had 2-3 named storms occurring in June-July but much reduced TC activity followed during the remainder of the season.

Table 6 compares this season's TC forecast with the TC activity of the last season, average of last 6 seasons, averages of last 18 seasons (1970-87) and average of last 41 seasons (1947-87).

Hurricane activity in 1988 can be expected to be well above the average of the last 18 seasons but only slightly above the average of the last 41 seasons.

TABLE 6

Comparison of 1988 Forecast Number
With Previous Years

	1 August Updated Forecast 1988	Last Year	Last 6 Seasons Average 1982-87	Last 18 Seasons Average 1970-87	Last 41 Seasons Average 1947-87
No. of Hurricanes	7	3	4.0	4.9	6.0
No. of Named Storms	11	7	7.5	8.3	9.8
No. of Hurricane Days	30	7	13	16.2	24.9
Hurr. Dest. Pot. (HDP)	75	11	27	43	74

9. Verification of Author's Previous Seasonal Forecasts

Table 7 gives the verification of the four previous years in which the author has formally made his seasonal forecast of Atlantic hurricane activity. Also note that the variance of observed seasonal hurricane activity from seasonal cyclone climatology. Over the last 40 years there have been on average 6 hurricanes per year, 10 named cyclones of tropical storm or hurricane intensity, 25 hurricane days, and about 45 named storm days.

Table 8 gives the ratio of the author's forecast variance from observation to the variance of individual season tropical cyclone activity from climatology for the four years of 1984 through 1987. This table shows that the observed yearly variance of tropical cyclone

TABLE 7
Verification of the author's previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1986.

1984	Predicted 24 May and in 30 July Update	Observed
No. of Hurricanes	7	5
No. of Hurricane Days	30	21
No. of Hurricane and Tropical Storms	10	12
No. of Hurricane and Tropical Storm Days	45 (implied from hurricane forecast)	61

1985	Prediction as of 28 May 1985	Updated Prediction of 27 July 1985	Observed
No. of Hurricanes	8	7	7
No. of Hurricane Days	35	30	29
No. of Hurricane and Tropical Storms	11	10	11
No. of Hurricane and Tropical Storm Days	55 (implied from hurricane forecast)	50	60

1986	Original Forecast as of 29 May 1986	Revised Forecast as of 28 July 1986	Observed
No. of Hurricanes	4	4	4
No. of Named Storms (Hurricanes and Tropical Storms)	8	7	6
No. of Hurricane Days	15	10	13
No. of Hurricane and Tropical Storm Days	35	25	27

1987	Original Forecast as of 26 May 1987	Revised Forecast as of 28 July 1987	Observed
No. of Hurricanes	5	4	3
No. of Named Storms (Hurricanes and Tropical Storms)	8	7	7
No. of Hurricane Days	20	15	7
No. of Hurricane and Tropical Storm Days	40	35	36

TABLE 8

Ratio of variance of author's seasonal forecast from observation to the variance of observed seasonal cyclone activity from climatology for the seasons of 1984 through 1987.

	No. of Hurricanes	No. of Hurricanes and Tropical Storms	No. of Hurricane Days
For Late May Forecast	2.25/3.75 (.60)	2.25/7.5 (.30)	72.5/125 (.58)
For Late July	1.25/3.75 (.33)	1.5/7.5 (.20)	38.75/125 (.31)

activity from climatology during 1984-87 has been considerably larger than has the variance of the author's forecasts from observation. The late July forecasts have been superior to the late May forecasts. Forecasts for 1984-1987 have thus been a significant improvement over climatology, the previously only objective seasonal prediction that was available.

10. Cautionary Note

It is important that the reader realize that the author's forecast scheme, although showing quite promising statistical skill in the typical meteorological sense, can only predict about 50% of the total variability in Atlantic Seasonal hurricane activity over a long period. This is nevertheless a substantial improvement over the previous lack of any very skillful seasonal forecast scheme.

This forecast scheme will likely fail in some years when the other unknown factors (besides the QBO, EN, SLPA and ZWA) which cause storm variability are more dominant.

This forecast scheme does not specifically predict which portion of the hurricane season will be most active or where within the Atlantic Basin the storm will strike. Even if 1988 should numberwise prove to be an active TC season, there is no assurance that any of these TCs will necessarily strike along vulnerable coastlines.

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