FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1988

By

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(This forecast is based on past and current research by the author at Colorado State University together with new April-May 1988 meteorological information)

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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 + 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 (~ 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.

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ABSTRACT

This paper discusses the author's forecast of the amount of tropical cyclone activity which might be expected to occur in the Atlantic Ocean region (including the Caribbean Sea and the Gulf of Mexico) in 1988. This forecast is based on the author's previous and current research (Gray, 1983, 1984a, 1984b, 1988; Gray et al., 1987) which relates seasonal amount of Atlantic tropical cyclone activity to four factors: 1) the El Nino (EN); 2) the Quasi-Biennial Oscillation of equatorial stratospheric wind (QBO); 3) Gulf of Mexico and Caribbean Basin Sea-Level Pressure Anomaly (SLPA); and 4) lower latitude Caribbean Basin 200 mb zonal wind anomaly.

Information received by the author up to 26 May 1988 indicates that the 1988 hurricane season can be expected to have about 7 hurricanes, 11 total named storms of both hurricane and tropical storm intensity, and about 30 hurricane days. 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. Seasonal 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. 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.

This forecast will be updated on 1 August before the start of the most active part of the hurricane season. The updated 1 August forecast will make use of June and July data should be more reliable.

This paper also gives a background description of the methodology of this objective forecast scheme and verification information on the author's seasonal forecasts for the 1984-1987 seasons.

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 in 1969, 11 (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 briefly discusses the nature of these four seasonal hurricane predictors and what they indicate for the level of hurricane and tropical storm activity for the coming 1988 season.

This paper has been prepared for the professional meteorologist, civil defense person, 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 - See Fig. 2. 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. In those westerly phase seasons, stratospheric winds at latitudes near 10°N are weakly from the east (right diagram of Fig. 2). These seasons are differentiated from those easterly equatorial phase seasons when stratospheric winds near 10°N are strongly from the east (left diagram of Fig. 2). Strong stratospheric easterly winds at 10°N are associated

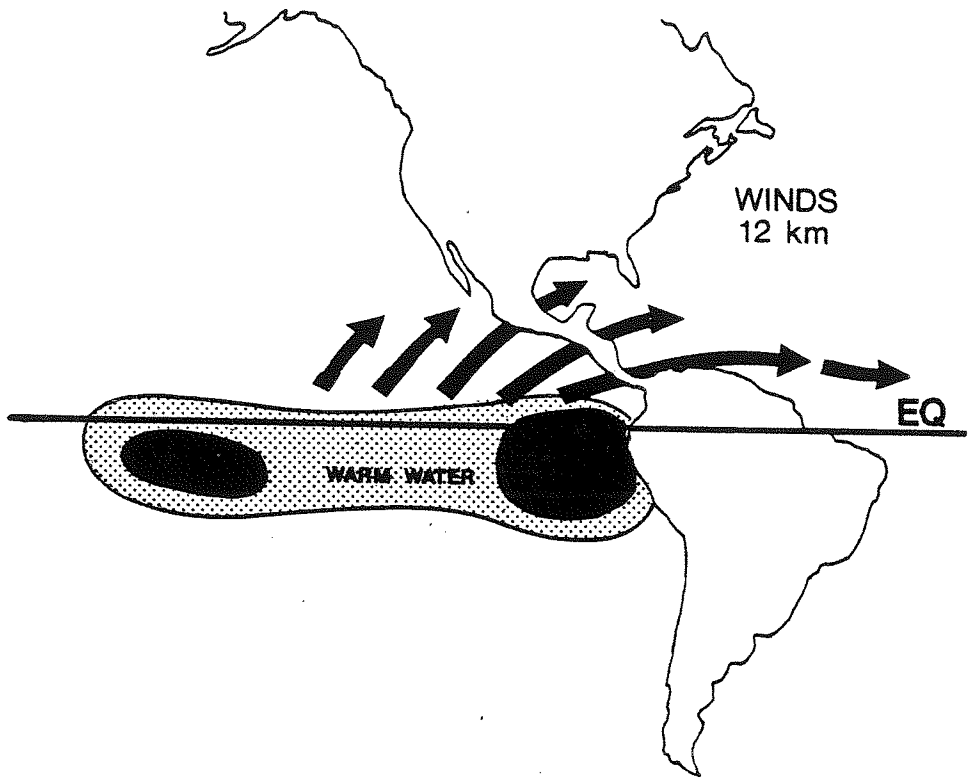

Fig. 1. Illustration of anomalously warm oceanic sea-surface temperature in the equatorial eastern Pacific which are associated with El Nino events. Arrows show the resulting anomalous upper tropospheric westerly winds which result from the enhanced deep cumulus convection which occurs in the equatorial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

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, the 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 predictive signal.

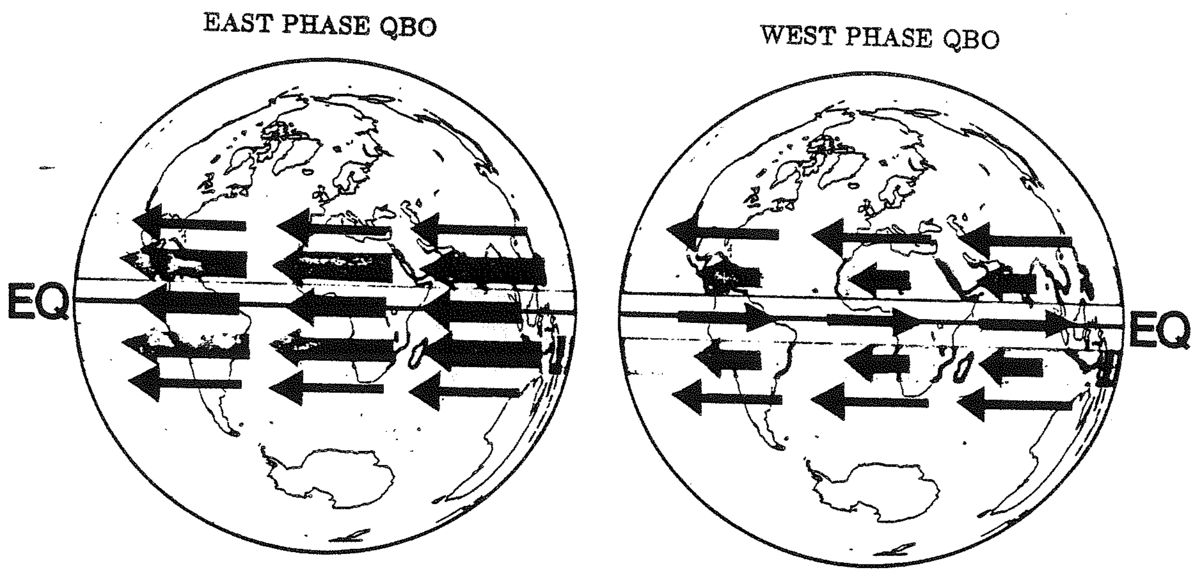

Fig. 2. Illustration of the two basic stratospheric Quasi-Biennial Oscillation (QBO) wind conditions which occur over the tropics at 50 mb or 20 km altitude during the summer seasons of both hemispheres. The left diagram shows conditions during the easterly phase of the QBO when easterly winds occur 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.

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 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 predictive signal.

3. Physical Reasons for Predictor Influences on Seasonal Hurricane Activity Alterations

Our knowledge of hurricane structure and environmental interaction is advancing. We now have better physical explanations for why these just discussed physical factors cause season to season variations in Atlantic hurricane activity.

Hurricanes form only in conditions when tropospheric vertical wind shear is a minimum as shown by the left diagram of Fig. 3. When vertical wind shears are too strongly positive (as indicated by the right diagram) hurricane formation and intensity is inhibited. El Nino events and seasons of strong Zonal Wind Anomaly (ZWA) cause environmental vertical wind shear conditions as shown by the right diagram. This is why there is usually a large reduction in Atlantic hurricane activity in El Nino and strongly positive ZWA seasons.

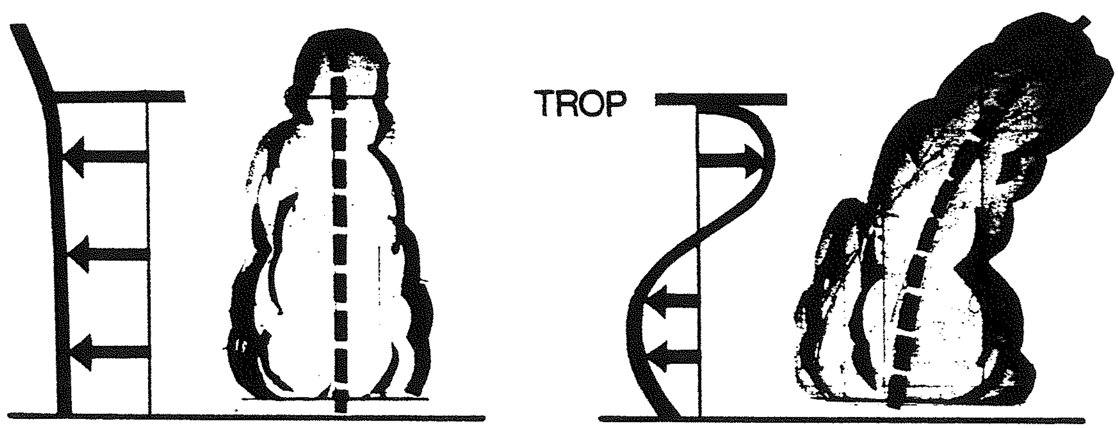

Fig. 3. Illustration of the types of tropospheric vertical winds which are conducive to hurricane formation (left diagram) and the type of westerly vertical wind shear which is inhibiting to hurricane formation. The right diagram portrays conditions of too strong westerly wind shear with height. Those wind shear conditions cause the tropical disturbance to be sheared to the east with height. This inhibits hurricane formation. The unsheared conditions of the left diagram do not.

Hurricane formation and hurricane intensity is also influenced by vertical wind shear conditions in the lower stratosphere. Atlantic hurricane formation is inhibited when lower stratospheric winds (or winds just above the tropopause (TROP.) blow too strongly from the east as shown by the upper left diagram of Fig. 4. This causes the central cloud convection and the influences of such convection to be sheared off to the west as shown by the lower left diagram of this figure. These conditions are inhibiting to hurricane formation and to the development of intense hurricanes. By contrast, when lower stratospheric zonal winds blow only lightly from the east as shown by the upper right

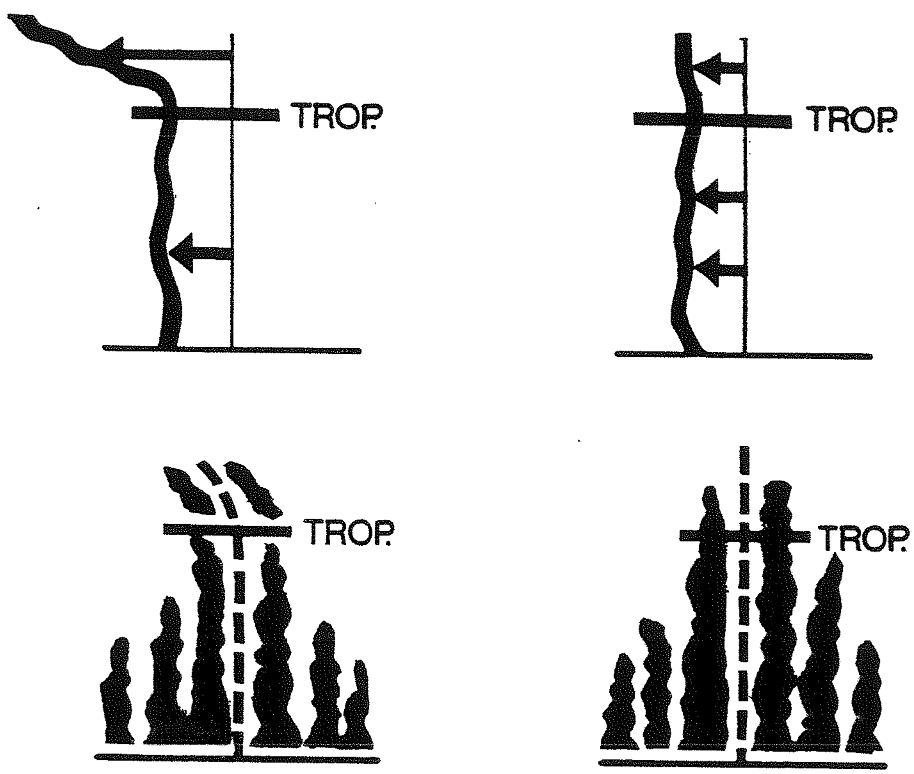

Fig. 4. Illustration of the types of vertical wind shear and cloudiness which extend above the tropopause (TROP.) into the stratosphere. Conditions of the right diagrams are conducive to hurricane formation and more intense hurricanes than conditions of the left diagrams.

diagram of Fig. 4, vertical wind shear conditions remain weak and hurricane inner-core deep convection and the influences of such convection is not sheared off to the west in the lower stratosphere. Conditions of the right diagrams of Fig. 4 are more favorable for hurricane formation and for the development of more intense hurricanes. We observe more hurricane formation and more intense hurricanes in conditions when lower stratospheric winds at a latitude of about 10°N blow only weakly from the east during August and September (Quasi-Biennial Oscillation (QBO) west wind phase). These weak vs. strong stratospheric easterly wind velocity changes are directly associated with the zonal wind variations of the Quasi-Biennial Oscillation or QBO.

The two other influences on seasonal hurricane activity result from variations of Sea Level Pressure Anomaly (SLPA) and 200 mb (12 km) Zonal Wind Anomaly (ZWA). These influences are often but not always linked together. They are associated with the August-September latitude position at which the Intertropical Convergence Zone (ITCZ) establishes itself relative to the north coast of South America. When the ITCZ establishes itself at a position more equatorwards than normal, surface pressures are higher and upper tropospheric zonal winds are typically stronger than normal over the Caribbean as shown by the two left diagrams of Fig. 5. These conditions are an inhibiting influence on seasonal hurricane activity.

In those seasons when the ITCZ, by contrast, establishes itself more poleward than normal the reverse condition occurs, right diagrams of Fig. 5. In this case Caribbean Basin SLPA and ZWA are negative and

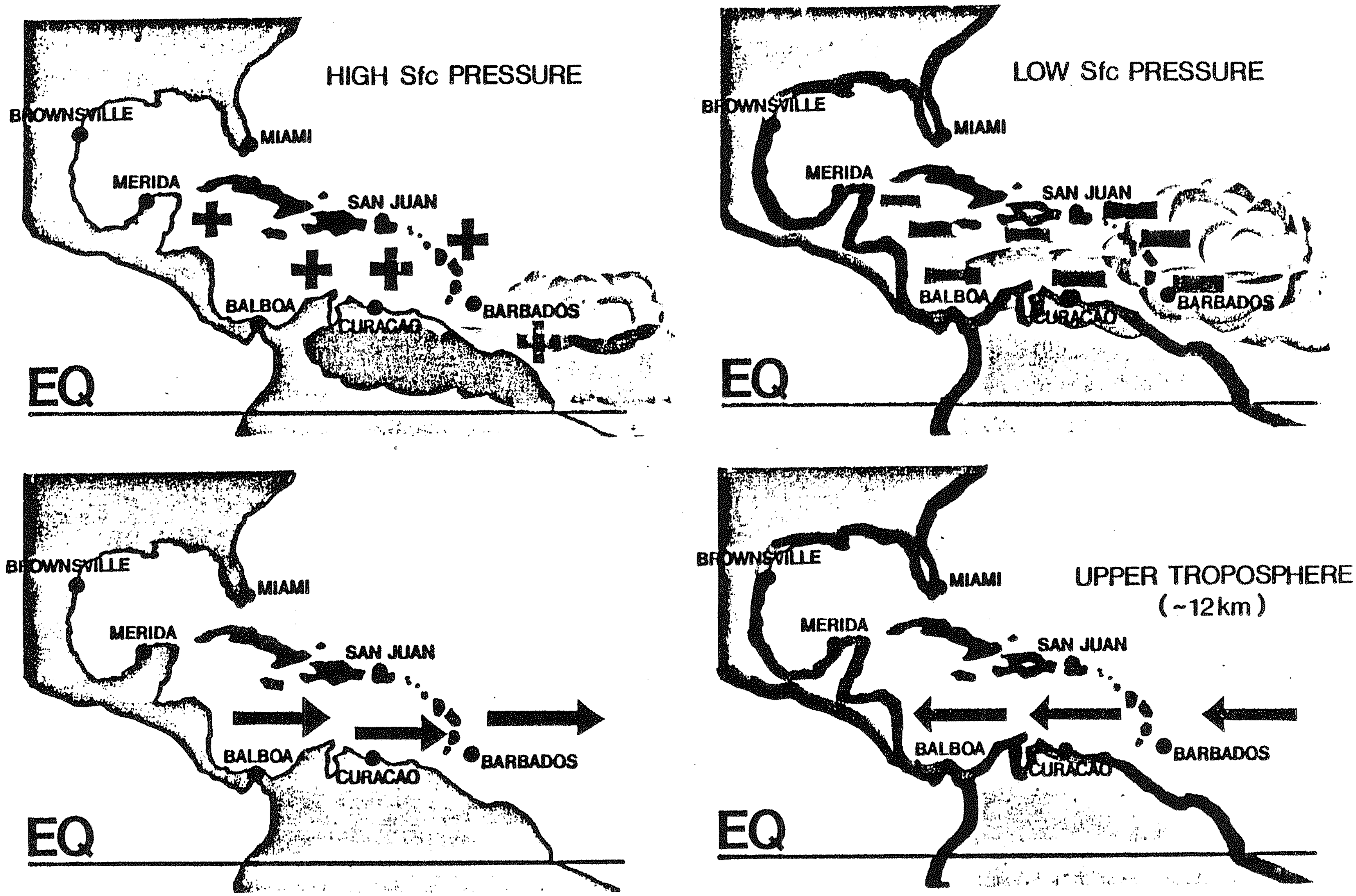

Fig. 5. Typical conditions during August-September when the Inter-tropical Convergence Zone (ITCZ) is further south than normal (left diagrams) resulting in positive Sea Level Pressure Anomaly (SLPA) and stronger than normal upper tropospheric zonal wind anomaly (ZWA). The opposite condition of the August-September position of the ITCZ being further poleward than normal is portrayed by the two right diagrams.

seasonal hurricane activity is usually enhanced. It is for these reasons that we closely monitor sea level pressure and upper tropospheric zonal wind conditions for their indication of the ITCZ's August-September latitude position and consequent influence on seasonal hurricane activity variations. These SLPA variations are generally independent of direct El Nino and QBO influences. ZWA is also generally independent of QBO influences.

The latitude position of the ITCZ in the western Atlantic has undergone multi-decadal changes since World War II. During the 1950's and 1960's the August-September position of the ITCZ was at a higher latitude in comparison with its position during the 1970's and 1980's. There was substantially more hurricane activity during the 1950's and 1960's than has occurred in the 1970's and 1980's.

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.

4. Hurricane Destruction Potential (HDP)

The wind and storm surge destruction of a hurricane is better related to the square of the storm's maximum winds $(V_{max})^2$ 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 6 shows seasonal values of Hurricane Destruction Potential (HDP) for the 41-year period of 1947 through 1987 in units of 10^4

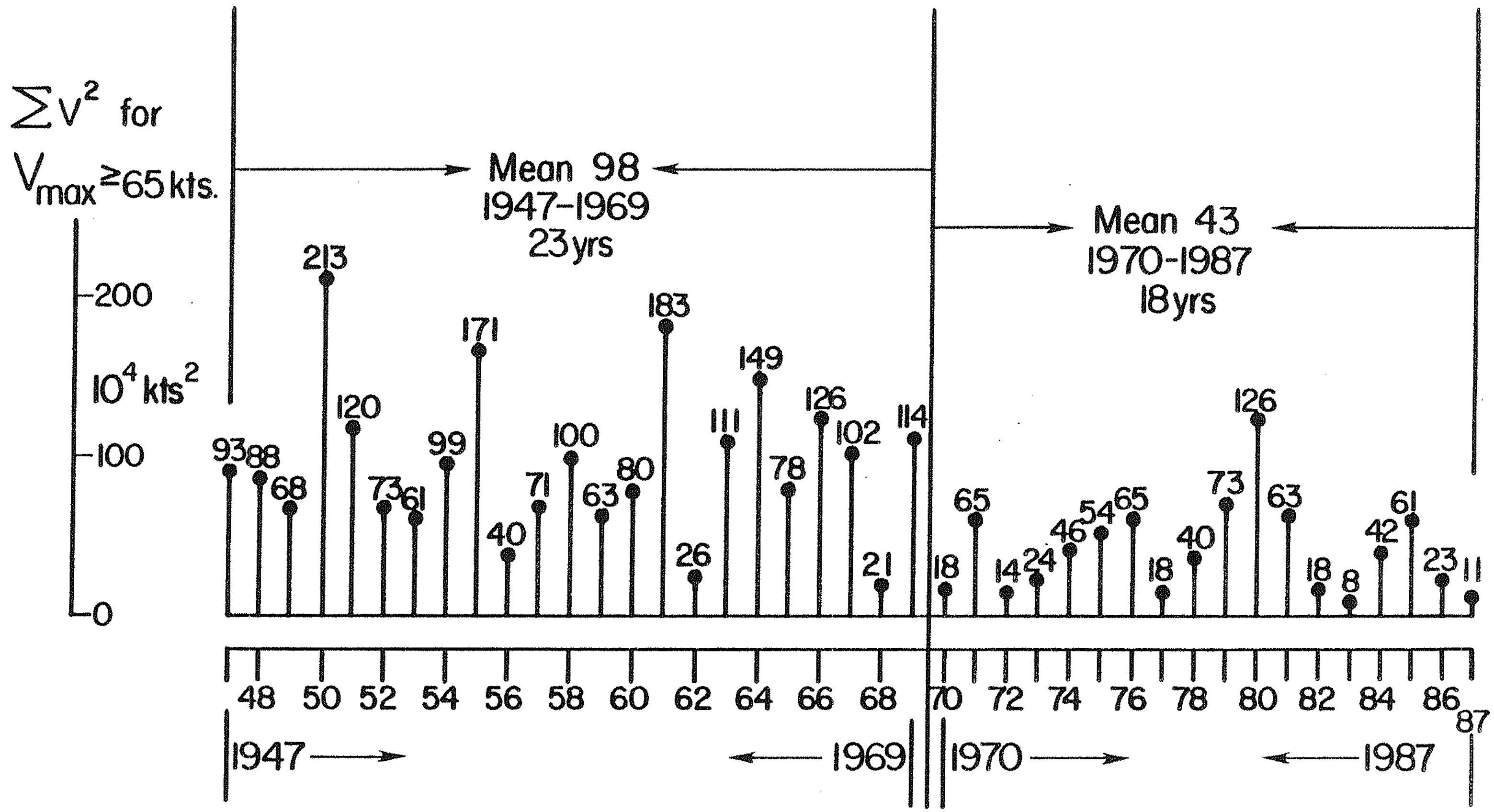

Fig. 6. Yearly variations in Hurricane Destruction Potential (HDP) defined as the sum of all hurricane maximum wind speeds squared for each 6-hour observing period throughout the hurricane season. Units 10^4 kts^2.

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 draught conditions which have prevailed during the period since 1970 and to higher Caribbean Basin SLPA and ZWA which have prevailed since 1970.

5. Contrast of Hurricane Activity in Strong vs. Weak 50 mb Easterlies QBO Seasons

Stratospheric wind velocities have a strong influence on hurricane activity. Figure 7 shows the 1949-87 September average easterly 50 mb (20 km) stratospheric winds as measured at Balboa, C.Z. (9°N). Those seasons of strong easterly winds in September (dots) had only half as many hurricane days and only half the average Hurricane Destruction Potential (HDP) as those seasons when the Balboa stratospheric winds were only weakly from the east (crosses). Table 1 shows that these differences are even higher for those most intense hurricanes ($V_{max} \geq$ 100 kts). Differences in number of hurricanes and number of named storms are significantly less.

Stratospheric winds are best related to an alteration of the most intense hurricane activity which is typically spawned from African origin systems. Stratospheric winds cause only small alterations in higher latitude and weaker intensity TCs. Note that in 1988 the September Balboa 50 mb zonal wind is expected to be only weakly from the east.

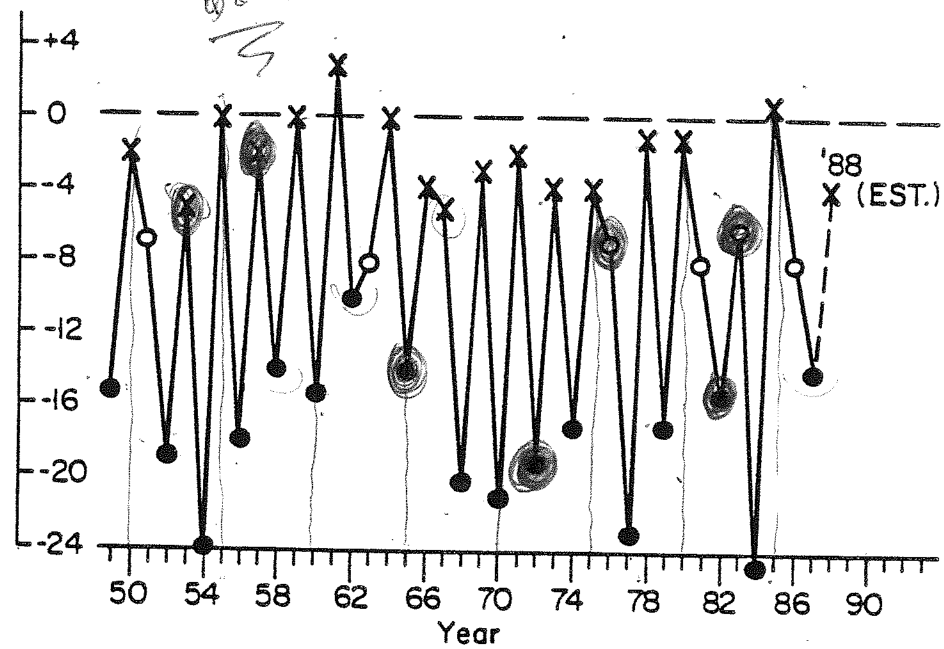

Fig. 7. 50 mb (20 km) September zonal wind (m s^{-1}) for Balboa, C.Z., (9°N,80°W). Heavy dots show seasons of strong eaterly stratospheric winds, X's give seasons of weak easterly stratospheric winds and circles indicate seasons of intermediate easterly wind strength.

TABLE 1

Comparison of Average Weak vs. Average Strong 50 mb (~ 20 km) Easterly Wind QBO Season for Years When the El Nino is Absent 1949-1987

	14 Weak Easterly Seasons	14 Strong Easterly Seasons	Ratio Weak/Strong
Named Storms	11.1	8.4	1.32
Hurricanes	7.3	5.0	1.46
Hurricane Days	33.4	17.0	1.96
Hurr. Dest. Pot. (HDP)	106	51	2.08
No. of Hurricanes with $V_{max} \geq 100$ kts	25	9	2.78

6. Possibilities of Hurricane Intensity Prediction

It is possible to offer a degree of forecast skill on the potential of the coming hurricane season having intense and long lived cyclones. For instance, the majority of intense hurricanes occur in seasons with weak as opposed to strong easterly 50 mb (12 km) zonal wind at stations near 10°N latitude. Table 2 shows that, of the 39 most intense hurricanes (V_{max} > 100 knots or 115 mph) in the 38-year period of 1950–1987, 27 of 39 or 69% occurred when the Balboa 50 mb zonal winds were only weakly from the east vs. only 9 of 39 or 23% in the seasons when these winds were strongly from the east. In the other 3 of 39 or 8% of the seasons, intermediately strong easterly winds were present.

It is possible to well estimate what the zonal wind direction is going to be before the start of the hurricane season. Because of its long record we have used the stratosphere measuring station of Balboa (9°N,80°W) in the Canal Zone. This station is very representative of the general western Atlantic latitude belt of 8 to 15°N where most of the intense hurricanes of African origin form.

TABLE 2

Intensity ranking of Atlantic hurricanes of 100 knots (115 mph) or greater intensity during 1950-1987 in relation to the strength of the Balboa, C.Z., 50 mb (20 km) easterly wind speed in September.

Ranking	Storm	Cyclone Maximum Wind	Years	Weak (W) Easterly Winds	Inter- mediate (I) Easterly Winds	Strong (S) Easterly Winds
1.	Allan	165	1980	W		
2.	Camille	165	1969	W		
3.	Dog	160	1950	W		
4.	David	150	1979			S
5.	Janet	150	1955	W		
6.	Carla	150	1961	W		
7.	Donna	140	1960			S
8.	Beulah	140	1967	W		
9.	Easy	140	1951		I	
10.	Cleo	140	1958			S
11.	Carrie	135	1957	W		
12.	Betsy	135	1965			S
13.	Cleo	135	1964	W		
14.	Inez	130	1966	W		
15.	Carol	130	1953	W		
16.	Carmen	130	1974			S
17.	Flora	125	1963		I	
18.	Esther	125	1961	W		
19.	Connie	125	1955	W		
20.	Gladys	125	1964	W		
21.	Hazel	120	1954			S
22.	Betsy	120	1961	W		
23.	Able	120	1950	W		
24.	Fox	120	1950	W		
25.	Gladys	120	1975	W		
26.	Charlie	115	1951		I	
27.	Faith	110	1966	W		
28.	Hannah	110	1959	W		
29.	Hilda	110	1955	W		
30.	Emily	110	1987			S
31.	Debbie	105	1969	W		
32.	Baker	105	1952			S
33.	Betsy	105	1956			S
34.	Debbie	105	1961	W		
35.	Diane	105	1955	W		
36.	Frances	100	1980	W		
37.	Inga	100	1969	W		
38.	Ethel	100	1964	W		
39.	Charlie	100	1950	W		

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

Except for 1985 the last 6 hurricane seasons have experienced a much reduced amount of hurricane activity as compared with the average activity of the last 40 years. Figures 8-10 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. 11.

2) The 50 mb (12 km) stratospheric winds in the low latitude regions 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. 11.

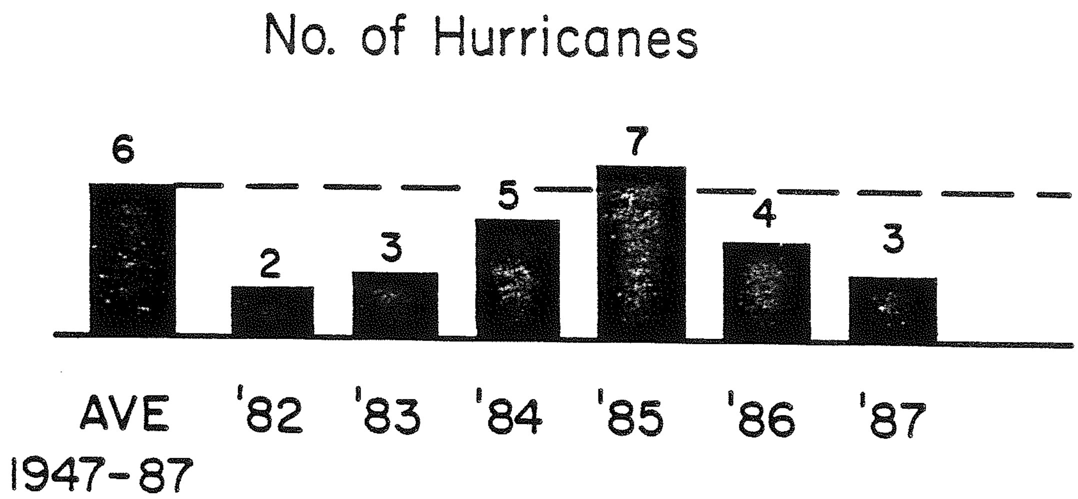

Fig. 8. Comparison of the number of hurricanes during each of the last 6 years with the last 40 years average.

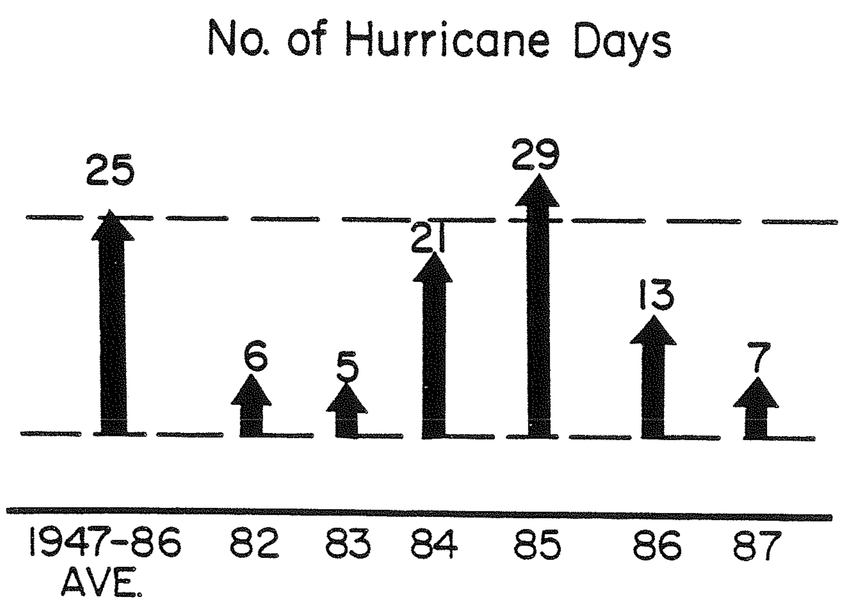

Fig. 9. Same as Fig. 8 but for the number of hurricane days.

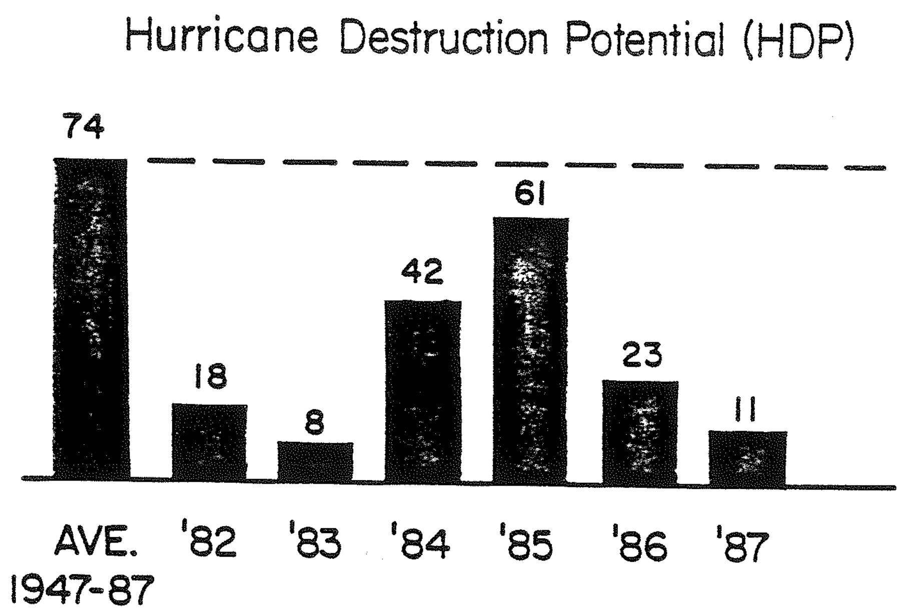

Fig. 10. Same as Fig. 8 but for the Hurricane Destruction Potential (HDP).

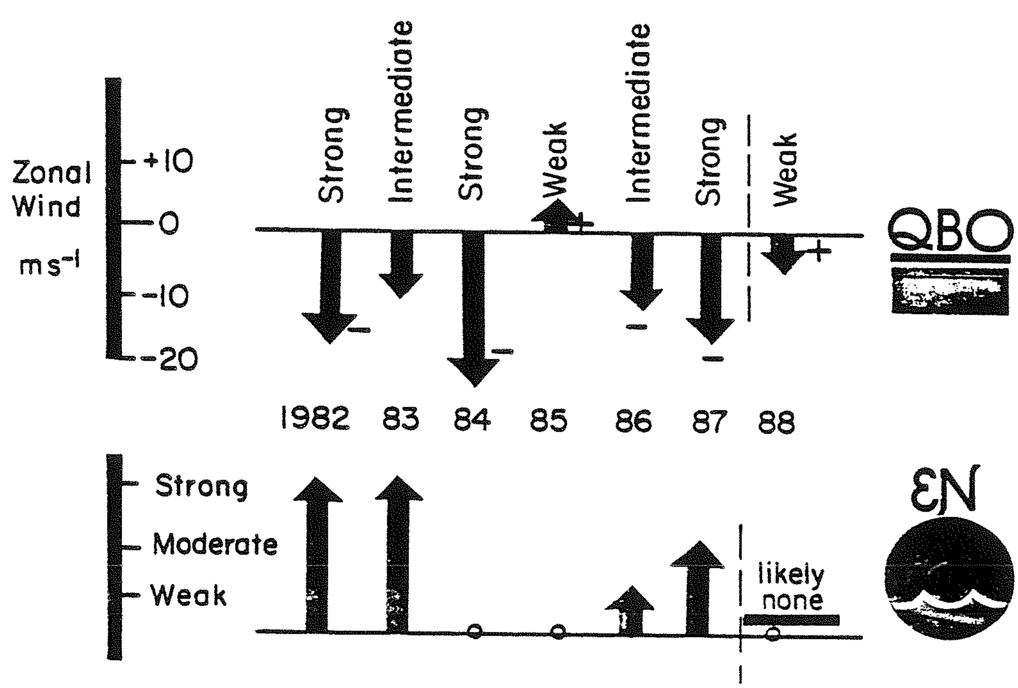

Fig. 11. Last six years magnitude of the Balboa 50 mb (20 km) September easterly wind component (top diagram) and the occurrence and relative magnitude of the El Nino events by year. Estimates for 1988 are also given.

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. 12).

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. 12). Higher than average zonal wind anomalies (ZWA) act to suppress hurricane activity.

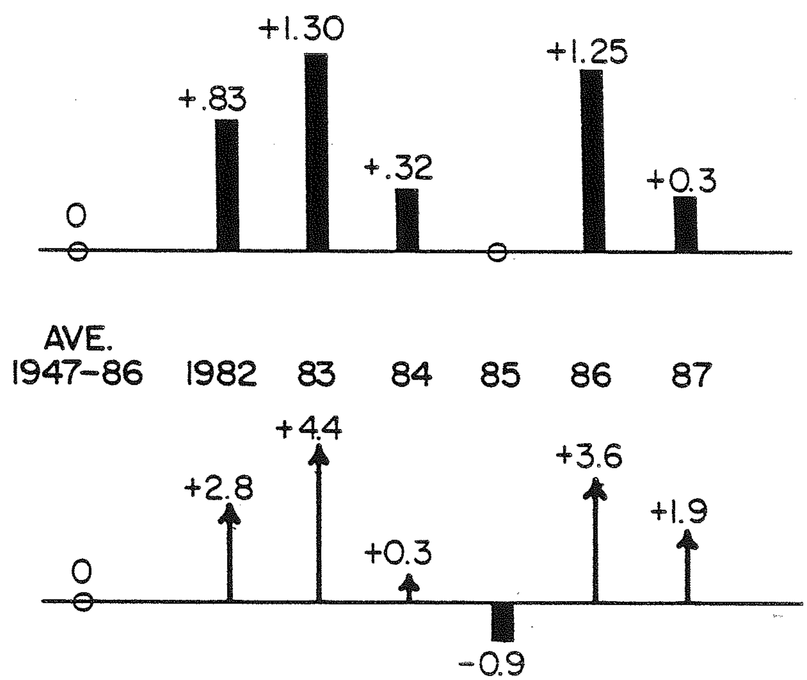

Fig. 12. Last six year Caribbean Basin-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) during August-October (top diagram) and low Caribbean Basin upper tropospheric (200 mb or 12 km) Zonal Wind Anomaly during these months (bottom diagram). SLPA in mb and ZWA in m s^{-1}.

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 during that season.

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

8. 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 13 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.

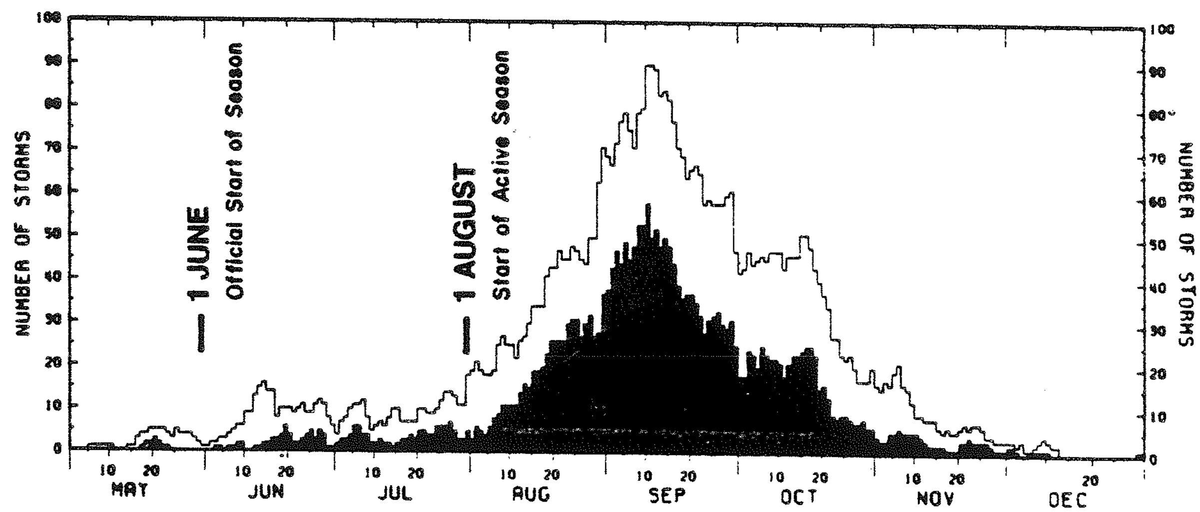

Fig. 13. Number of tropical storms and hurricanes (open curve) and hurricanes (solid curve) observed on each day, May 1, 1886 through December 31, 1980 (from Neumann, <u>et al</u>., 1981).

9. 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 indicate that the coming 1988 hurricane season will be more active than most of the recent hurricane seasons have been.

a) El Nino. Indications are very strong that the moderately intense El Nino (EN) event of late 1986 and 1987 will have dissipated by the start of the 1988 hurricane season. Cool sea surface temperature has already returned the equator in the eastern Pacific. Nearly all El Nino researchers are predicting a return to more normal non-El Nino conditions for this coming summer. The 1988 hurricane season is thus not expected to experience the suppressing influences of an El Nino event.

b) Stratospheric QBO in 1988. The stratospheric 50 mb (20 km) winds in August-September-October will be only weakly from the east and thus be more favorable for hurricane activity. Figure 14 shows the past and extrapolated global relative QBO zonal winds for the coming hurricane season. Note that lower stratospheric winds will be from a relative westerly direction. QBO winds have been extrapolated into the future on the basis of their average alteration since 1950.

Table 3 shows the absolute value of the current and extrapolated QBO zonal winds near 10°N 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) and Trinidad (11°N). Note that during the 1988 hurricane season the vertical wind shear in the lower stratosphere is expected to be small and that the lower stratospheric zonal winds will not be very different than the mean

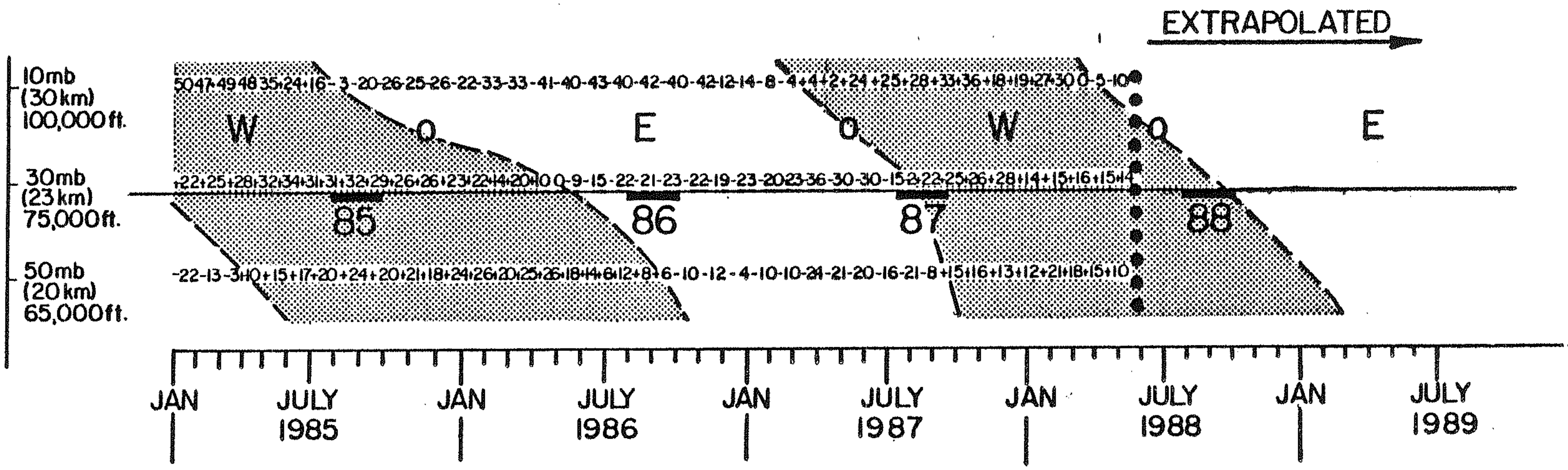

Fig. 14. Vertical cross-section of recent stratosphere's monthly average QBO west to east or zonal wind (in knots). This figure represents an average of the Balboa, C.Z. (9°N) and Ascension (8°S) rawinsondes with Trinidad (11°N) being substituted for Balboa during part of 1988. The climatological annual cycle has been removed from each sounding before averaging. Winds from a westerly direction have been shaded. Information beyond May 1988 has been extrapolated. Thick horizontal lines show the active portion of each hurricane season from 1985 to 1988.

TABLE 3

Absolute value of current and extrapolated 1988 QBO zonal winds in the lower Caribbean Basin near 10°N in m s^{-1}.

Level	1 April-25 May	August	September	October
30 mb (23 km)	-2	-13	-17	-17
50 mb (20.5 km)	+2	-7	-4	-2
70 mb (18.5 km)	0	-6	-4	0

tropospheric zonal winds of the typical low latitude tropical disturbance moving westward in the trade winds. These are similar to conditions shown in the right diagram of Fig. 4. Stratospheric wind conditions during 1988 will thus be favorable for the development of the more low latitude tropical cyclones which originated from west African disturbances. These disturbances, as previously discussed, typically produce the most intense cyclones.

c) Sea Level Pressure Anomaly (SLPA) in April-May 1988. Figures 15 and 16 show the stations from which SLPA is obtained. Figure 15 shows stations used in the author's previous forecasts. Figure 16 shows the 5 lower latitude stations which are now more consulted. It is the low latitude SLPA which is most related to the north-south position of the Intertropical Convergence Zone (ITCZ) and the frequency and intensity of the low latitude TCs spawned by tropical disturbances coming out of West Africa.

Table 4 shows 1 April-26 May 1988 SLPA from all of these stations. Note that SLPA is near average for both the previously used 6-station average and the 5-station low latitude average. These SLPA are derivations from a 40-year average. These SLPA are slightly lower than

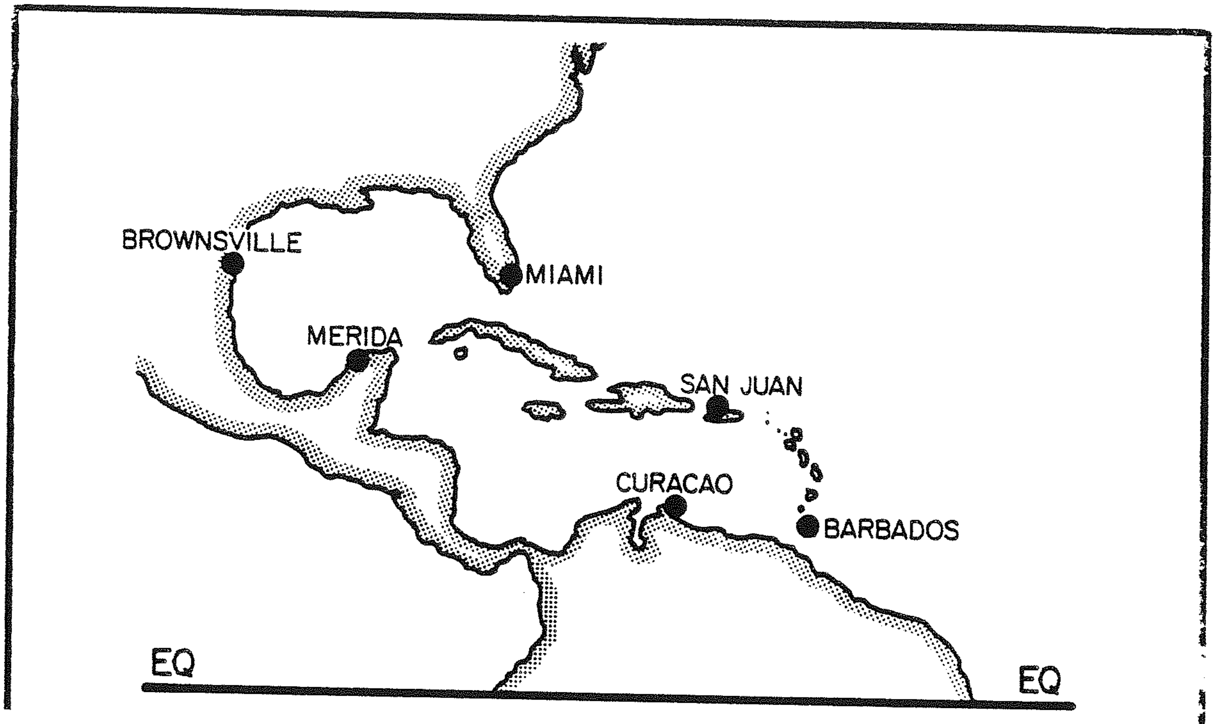

Fig. 15. Location of meteorological stations used for determining the 6-station mean monthly SLPA for the Caribbean Basin region.

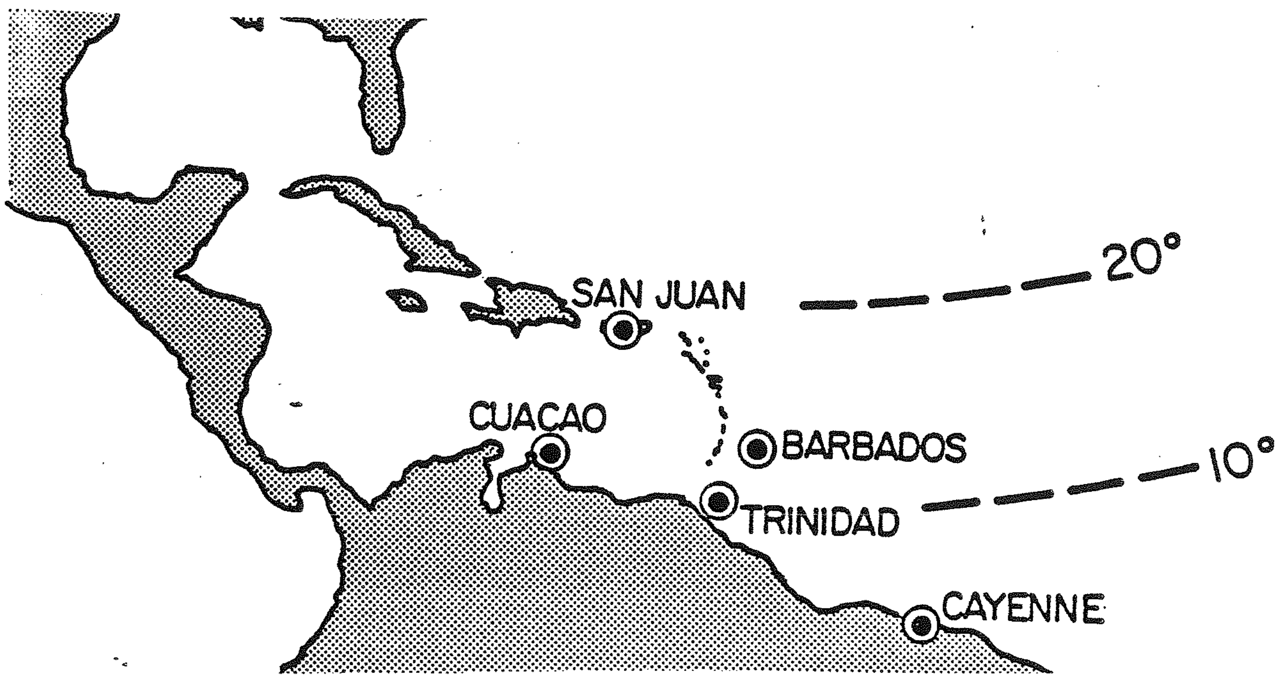

Fig. 16. Five stations used for the determining of Sea Level Pressure Anomaly (SLPA).

TABLE 4

1 April-26 May 1988 Average Gulf of Mexico-Caribbean Basin (Fig. 12) and Low Latitude (Fig. 13) Sea-Level Pressure Anomalies (SLPA) - in mb (as supplied by Arthur Pike of NHC).

Gulf of Mexico-Caribbean Basin	SLPA	Low Latitude	SLPA
Brownsville	+0.2	San Juan	-0.7
Merida (Mex.)	+0.3	Curacao	0
Miami	-1.5	Barbados	+0.2
San Juan	-0.7	Trinidad	+0.4
Curacao	0	Cayenne	+0.3
Barbados	+0.2		
Average	-0.2	Average	0

the average of the last 18 years, however (See Fig. 12). Being near normal no SLPA correction will be made to the forecast.

d) April-May Lower-Caribbean Basin Zonal Wind Anomaly (ZWA). Although not used in the 1 June forecast, the Lower Caribbean Basin 200 mb zonal wind anomaly (ZWA) for 1 April to 26 May 1988 is negative in comparison with the average values of 200 mb ZWA for both the 1970-87 and 1954-69 periods (See Table 5). This is indicative that the influence of the 1986-87 El Nino event on enhanced lower Caribbean Basin 200 mb zonal winds has likely dissipated and that the 1988 season will be free of El Nino produced positive zonal wind anomalies.

TABLE 5

1 April-26 May 1988 Caribbean Zonal Wind Anomaly (ZWA) in m s^{-1} relative to 1970-87 and 1954-69 Average (as supplied by Arthur Pike of NHC).

Station	1970-87 Ave.	1954-69 Ave.
Kingston (18°N, 77°W)	0	+2
Curacoa (12°N, 69°W)	-4	-2
Barbados (13.5°N, 60°W)	-3	-1
Trinidad (11°N, 62°W)	-4	-2
Average	-3	-1

April-May ZWAs typically do not correlate well with the following seasonal Atlantic Hurricane activity. It is the June-July ZWAs which will be most closely monitored for assistance with the 1 August updated seasonal forecast.

10. 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 50 mb (20 km) zonal winds rather than the more global 30 mb (23 km) level relative zonal winds as previously applied;

2) the low-latitude sea-level pressure anomaly (SLPA) values of Fig. 16 are more representative for predicting the west African spawned more intense TC activity than the pressure data of Fig. 15;

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 was 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 SLPA and ZWA in the coming hurricane season to be above average and (other factors aside) a reduction in hurricane activity.

The author and his CSU research colleagues, Paul Mielke and Kenneth Berry (of Dept. of Statistics) are currently making a new statistical analysis 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 it 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 skill as can the number of hurricanes.

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

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

where

QBO = 50 mb equatorial wind direction correction factor - if Balboa, C.Z. wind is weakly from the east add one, 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 only weakly from the east and no El Nino is forecast.

EN = El Nino influence. If present subtract two for a moderate El Nino event, four for a strong El Nino event.

SLPA = average SLPA for April-May, from selective Caribbean-Gulf of Mexico stations. Add one or two 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 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:

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

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,

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

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. $$\begin{pmatrix}\text{Predicted No. of}\\ \text{Named Storm Days}\end{pmatrix} = 1.7\ (\text{No. of Hurricane Days})$$

There has been, an 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.

$$\begin{pmatrix}\text{Hurricane}\\ \text{Destruction}\\ \text{Potential}\end{pmatrix} = \begin{pmatrix}\text{Average}\\ \text{Season}\end{pmatrix} + K\,\overbrace{\begin{pmatrix}\text{Same correction term as for}\\ \text{hurricane determination}\\ \text{except for the memory term}\end{pmatrix}}^{\text{Correction Terms}} \quad (4)$$

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.

11. 1988 Forecast

Table 6 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 6

1988 PREDICTED SEASONAL HURRICANE ACTIVITY

(Predicted No. of Hurricanes per Season) = 6 + QBO* + EN + SLPA + ZWA + MEM.

(+2) + (0) + (0) + N/A −1 = 7

(Predicted No. of Hurricanes and Tropical Storms Per Season) = 10 + QBO* + EN + SLPA + ZWA + MEM.

+ (+2) + (0)+ (0) + N/A −1 = 11

(Predicted No. of Hurricane Days Per Season) = 25 + 5 (QBO* + EN + SLPA + ZWA + MEM.

(+10) + (0)+ (0) + N/A −5 = 30

(Predicted No. of Named Storm Days) = 1.7 x (No. of Hur. Days) = 50

(Hurricane Destruction Potential - HDP) = 74 + K (QBO + EN + SLPA + ZWA + MEM.)

74 + 30 + 0 + 0 + N/A − 29 = 75

Discussion. 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. It is also likely that tropical cyclone activity will start earlier this year than it has in the last few years. QBO conditions will be more favorable earlier in the season.

Table 7 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 above the average of the last 18 seasons and slightly above the average of the mean of the last 41 seasons.

TABLE 7

Comparison of 1988 Forecast Number
With Previous Years

	1 June 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	43.0	74.0

12. Verification of Author's Previous Seasonal Forecasts

Table 8 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 9 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 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.

TABLE 8
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 9

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)

Forecasts for 1984-1987 have thus been a significant improvement over climatology, the previous only objective seasonal prediction that was available.

13. Cautionary Note

It is important that the reader realize that the author's forecast scheme, although showing quite promising statistical skill in the typically 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 many of these TCs will necessarily strike along vulnerable coastlines. Conversely, if there were only one Atlantic hurricane this year, but it happened to go over your house or business, then for you, 1988 would be a very active season.

14. Acknowledgements

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