FORECAST OF ATLANTIC SEASONAL HURRICANE ACTIVITY FOR 1989

By

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(This forecast is based on ongoing research by the author at Colorado State University, together with new April-May 1989 meteorological information)

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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 (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, including hurricanes, tropical storms 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.

Named Storm - A hurricane or a tropical storm.

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.

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

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

Millibar - A measure of atmospheric pressure which is often used as a vertical height designator. Average surface values are about 1000 mb; 200 mb is about 12 kilometers and 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.

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.

SLPA - Sea Level Pressure Anomaly. Deviation of Caribbean and Gulf of Mexico sea level pressure from long term average conditions. SLPA in the spring and early summer has an inverse correlation with late summer and early autumn hurricane activity.

ZWA - Zonal Wind Anomaly. A measure of upper level ($\sim$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 presents details of the author's forecast of tropical cyclone activity for the Atlantic Ocean region (including the Caribbean Sea and the Gulf of Mexico) during 1989. This forecast is based on the author's ongoing research (Gray, 1984a, 1984b, 1988a, 1988b, 1988c, 1988d; Gray et al., 1987) which relates the amount of seasonal 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 Anomalies (SLPA); and 4) lower latitude Caribbean Basin 200 mb Zonal Wind Anomalies (ZWA).

Information received by the author up to 26 May 1989 indicates that the 1989 hurricane season can be expected to have about 4 hurricanes, 7 total named storms of both hurricane and tropical storm intensity, and about 15 hurricane days. This means that the 1989 Atlantic hurricane season will likely be a below average hurricane season. This suppression is due to the expected unfavorable influences of an easterly phase QBO and higher than normal SLPA.

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 other background information on hurricane activity over the last 40 years.

TABLE OF CONTENTS

1. Introduction

The Atlantic basin (including the Atlantic Ocean, Caribbean Sea and Gulf of Mexico) experiences a larger seasonal variability of hurricane activity than any other global hurricane basin. The number of hurricanes per season can be as high as 12 (as 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 recently there has been no objective method for indicating whether a coming hurricane season was likely to be an active one or not. Recent and ongoing research by the author (Gray, 1984a, 1984b, 1988a, 1988b, 1988c; Gray, et al., 1987) indicates that there is a surprising 3-5 month atmospheric predictive signal available for the Atlantic basin from global and regional predictors which are generally not operative in the other global hurricane basins or in the middle latitudes.

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

The author's Atlantic seasonal hurricane forecast is based on the current values of indices derived from two global and two regional scale predictive factors which the author has previously shown to be statistically related to seasonal hurricane variations. Current values of these predictive factors are available either 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. The four predictive factors are:

a) The presence or absence of a moderate or strong warm water event (El Nino) in the eastern tropical Pacific. Atlantic hurricane seasons during moderate or strong El Nino events average only about 40 percent as much hurricane activity as occurs during non-El Nino seasons. This difference is related to 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). Currently 1989 is not expected to be a strong or moderate El Nino year.

b) The direction of the stratospheric Quasi-Biennial Oscillation (QBO) which circles the globe over the equator - See Fig. 2. On average, there is about twice as much Atlantic hurricane activity during seasons when equatorial winds at 30 mb and 50 mb (23 and 20 km altitude respectively) blow from a relatively westerly direction as compared when they are from a relatively easterly direction. In seasons of westerly phase equatorial winds, stratospheric winds at latitudes near 10°N latitude are weakly from the east (right diagram of Fig. 2). These

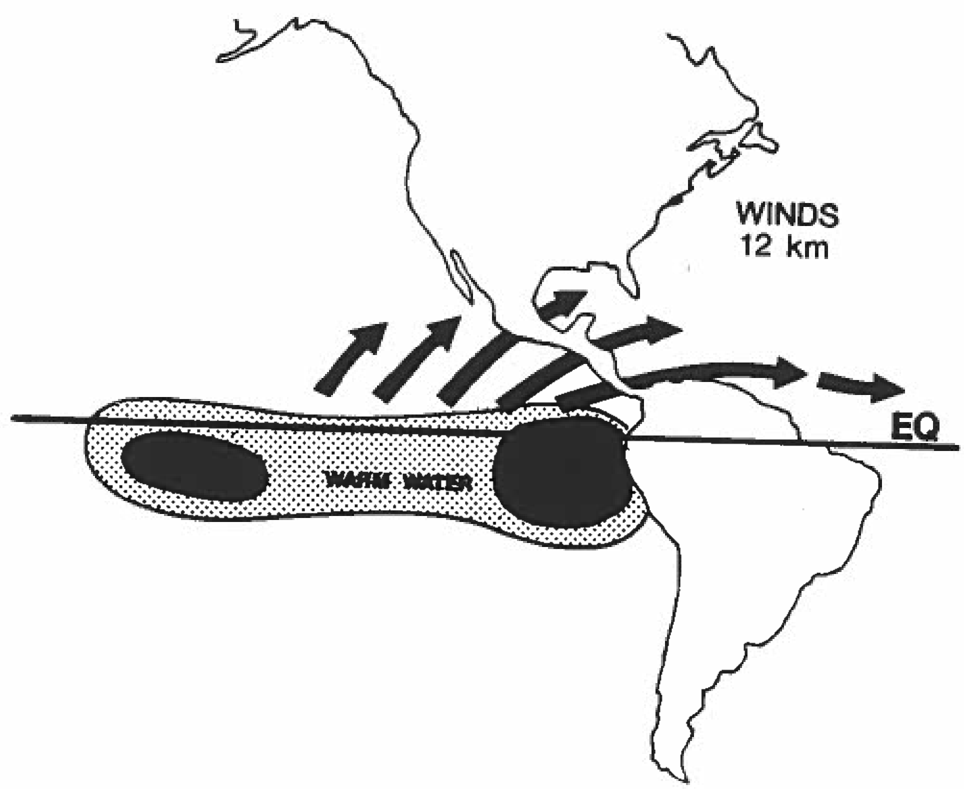

Fig. 1. Illustration of anomalously warm surface temperatures in the equatorial eastern Pacific which are associated with El Nino events. Dark regions have the warmest water. Arrows show the resulting anomalous upper tropospheric westerly winds which result from the enhanced deep cumulus convection which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

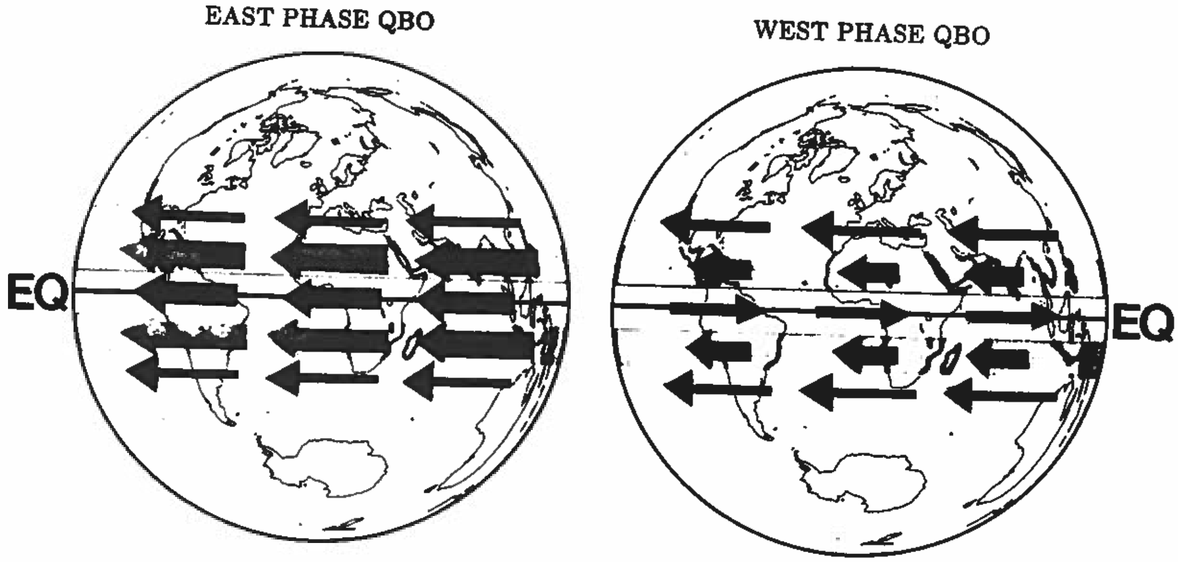

Fig. 2. Illustration of the two basic stratospheric Quasi-Biennial Oscillation (QBO) wind conditions which occur over the tropics at 50 mb or 20 km altitude during the summer seasons of both hemispheres. The left diagram shows conditions during the easterly phase of the QBO when easterly winds occur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

seasons are different from those easterly equatorial phase seasons wherein stratospheric winds near 10°N are strongly from the east (left diagram of Fig. 2). Strong stratospheric easterlies at 10°N are associated with reduced hurricane activity. Weak stratospheric easterly winds at 10°N are associated with enhanced seasonal hurricane activity. This season's stratospheric winds are expected to be stronger from the east.

c) Sea Level Pressure Anomaly (SLPA) in the Caribbean Basin. Other factors aside, negative pressure anomalies in the Caribbean basin are associated with active hurricane seasons and vice-versa. Pressure anomalies for April through July are well correlated with August to October surface pressures and offer a degree of seasonal hurricane predictive signal. April-May 1989 SLPA is high and should be a suppressing influence on the upcoming hurricane activity.

d) Lower latitude Caribbean Basin upper tropospheric (∿ 200 mb or 12 km altitude) west to east or zonal wind anomaly (ZWA). Stronger westerly 200 mb zonal wind anomalies are associated with suppression of seasonal hurricane activity and vice-versa. April-May ZWA have been about neutral.

3. Physical Interpretation of Alterations in Seasonal Hurricane Activity

Our knowledge of hurricane structure and environmental interaction is advancing. We now have better explanations for why the physical factors just discussed can 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 top left diagram of Fig. 3. When vertical wind shears are too strongly positive, as indicated by the diagram on the right, hurricane formation and intensification is

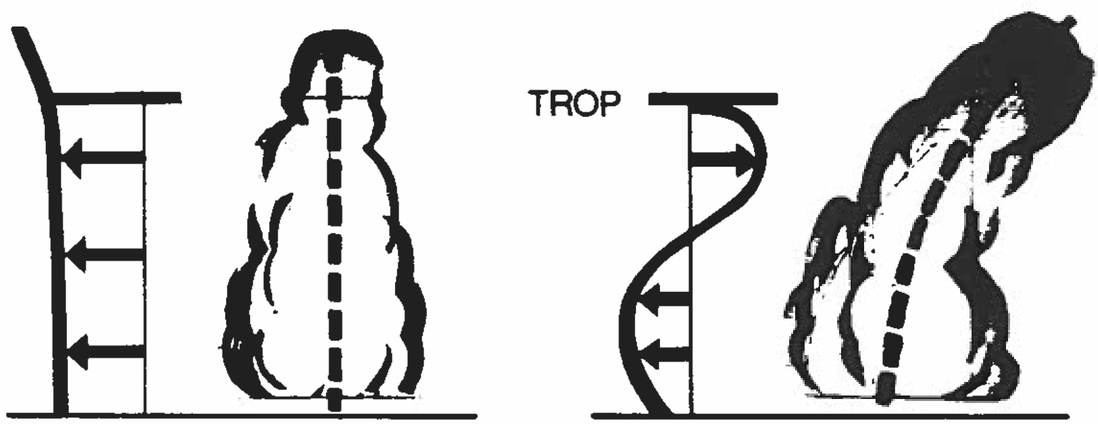

Fig. 3. Illustration of the type of tropospheric vertical wind shear which is (left diagram) and is not (right diagram) conducive to hurricane formation. The right diagram portrays conditions of excessive westerly wind shear with height which causes the tropical disturbance to be sheared to the east with height. This shearing inhibits hurricane formation while the unsheared conditions in the left diagram do not. Trop. signifies the top of the troposphere (∿ 16 km altitude).

inhibited. El Nino events and seasons of strong Zonal Wind Anomaly (ZWA) cause the environmental vertical wind shear conditions shown by the right diagram and contribute to a large reduction in Atlantic hurricane activity in El Nino and strongly positive ZWA seasons.

Hurricane formation and hurricane intensity is also influenced by vertical wind shear conditions in the lower stratosphere. Hurricane formation is inhibited when lower stratospheric winds just above the tropopause (TROP.) blow too strongly from the east, as shown by the upper left diagram of Fig. 4. This configuration causes central cloud convection and related effects to be sheared off to the west, as shown

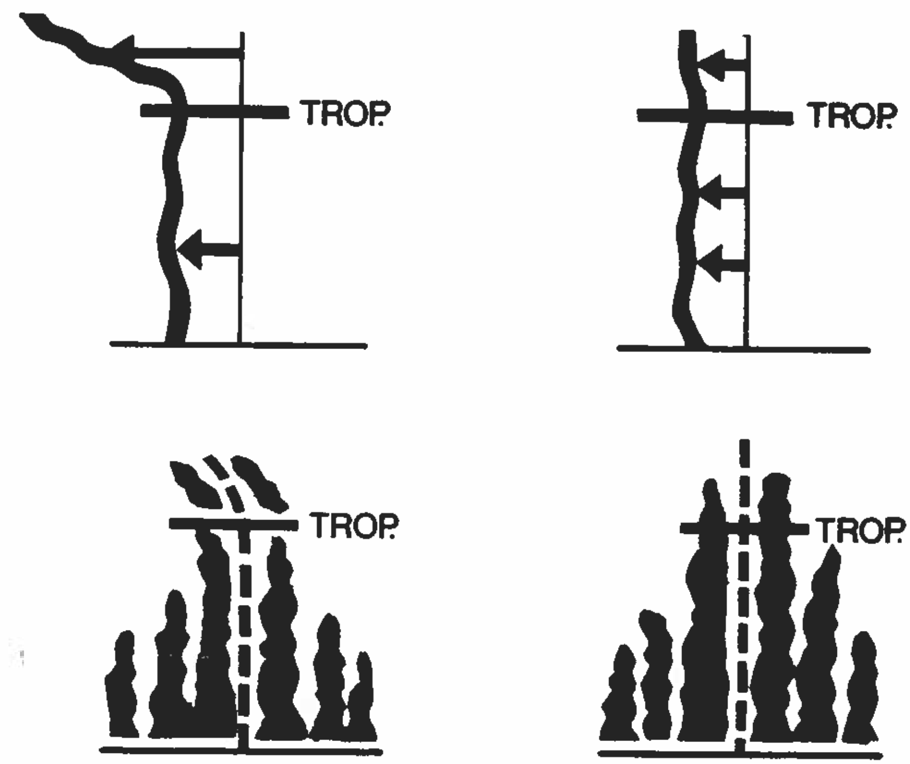

Fig. 4. Illustration of the types of vertical wind shear and cloudiness which extend through the tropopause (TROP.) into the stratosphere. Conditions in the diagrams on the right are conducive to hurricane formation and more intense hurricanes than conditions of the left diagrams.

by the lower left diagram of this figure. These conditions inhibit hurricane activity. The contrasting condition, when lower stratospheric zonal winds blow only lightly from the east, is shown by the upper right diagram of Fig. 4. In this case, vertical wind shear conditions remain weak and inner-core deep convection and related effects are not sheared off to the west in the lower stratosphere. Conditions illustrated on the right hand side of Fig. 4 are more favorable for hurricane formation and for the development of intense hurricanes. Consequently, we observe comparatively more hurricane formation and more intense hurricanes in conditions when lower stratospheric winds at about 10°N latitude blow only weakly from the east during August and September (Quasi-Biennial Oscillation (QBO) west wind phase) as to those times when they blow strongly from the east (QBO east wind phase). It is these weak vs. strong easterly wind velocity changes which are associated with the Quasi-Biennial Oscillation or QBO.

Figure 5 shows the time variation of average September easterly stratospheric winds measured at Balboa, Canal Zone (9°N). Seasons of strong easterly winds (dots) had slightly less than half as much hurricane activity as those seasons when the Balboa stratospheric winds were only weakly from the east (crosses), demonstrating that stratospheric wind speed is a strong influence on both hurricane activity and intensity. Note that in 1989 the September Balboa 50 mb zonal wind is expected to be strongly from the east and should contribute to a suppression of hurricane activity in general and of intense hurricane activity.

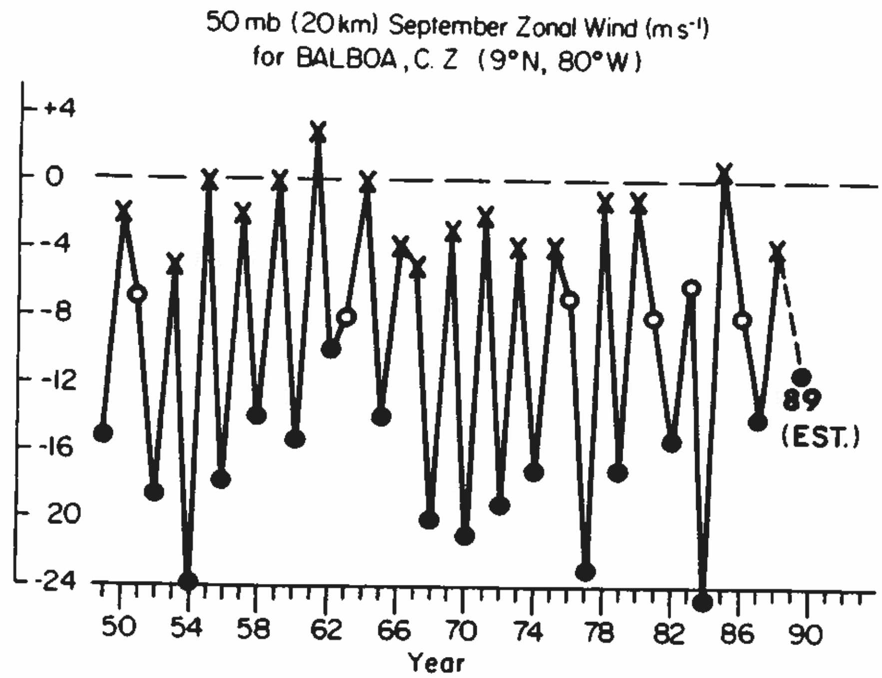

Fig. 5. 50 mb (20 km) September zonal wind (m s^{-1}) for Balboa, C.Z., (9°N, 80°W). Heavy dots show seasons of strong easterly stratospheric winds, X's represent seasons of weak easterly stratospheric winds and open circles indicate seasons with intermediate easterly winds.

The two other influences affecting 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 linked together and are associated with the latitude at which the Intertropical Convergence Zone (ITCZ) establishes itself relative to the north coast of South America during August-September. When the ITCZ establishes itself more equatorwards than normal, surface pressures and upper tropospheric zonal winds over the Caribbean are typically stronger than normal, as shown by the left diagram of Fig. 6. These conditions inhibit seasonal hurricane activity.

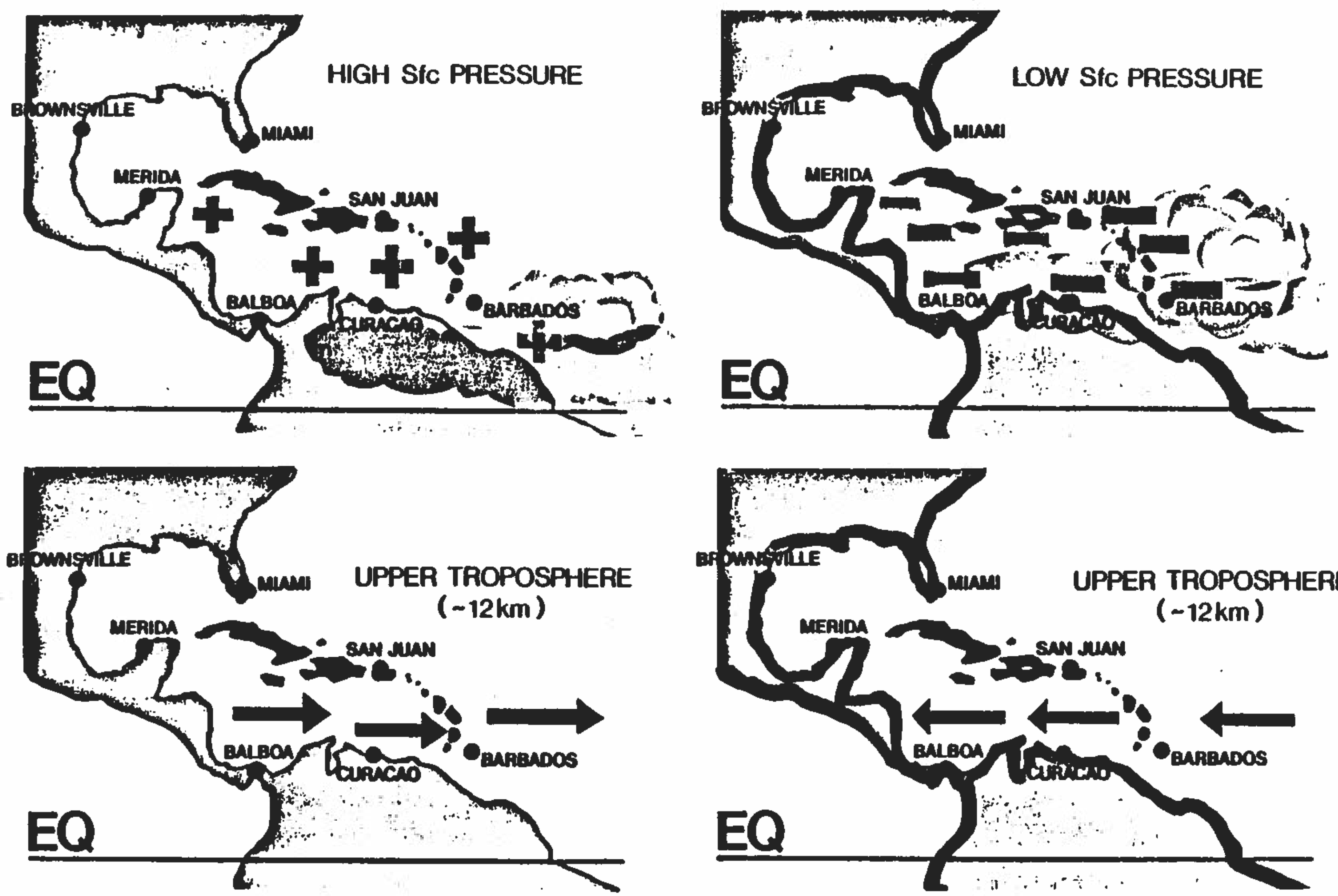

Fig. 6. Typical conditions for August-September when the Intertropical Convergence Zone (ITCZ) is displaced southward (left diagrams) resulting in positive Sea Level Pressure Anomaly (SLPA) and above normal upper tropospheric zonal wind anomaly (ZWA). The opposite conditions for August-September with the ITCZ displaced poleward is portrayed by the two right diagrams.

By contrast, in those seasons when the ITCZ establishes itself poleward of normal, the reverse condition occurs. Caribbean Basin SLPA and ZWA are negative and seasonal hurricane activity is usually enhanced. It is for these reasons that we closely monitor sea level pressure and upper tropospheric zonal wind conditions as indicators of the ITCZ's August-September position and consequent influence on seasonal hurricane activity variations. These SLPA and the ZWA variations (where ZWA is taken only in non-El Nino years) are independent of the El Nino and QBO influences.

As will be discussed, the mean 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 as compared to 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, except for the three seasons of 1980, 1985 and 1988.

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. Cyclical Trends in Atlantic Hurricane Destruction Potential (HDP)

The wind and storm surge destruction of a hurricane is better represented by the square of the storm's maximum winds than by the maximum wind itself. This potential for damage from hurricane winds and storm surge might be termed Hurricane Destruction Potential (HDP). We define Hurricane Destruction Potential (HDP) as

$$HDP = \sum (V_{max})^2$$

for V_{max} equal or greater 65 knots for each 6-hour period a hurricane is in existence.

In the 31-year period of 1886 through 1916 HDP was, as expressed in units of HDP (10^4 knots^2) about one-and-a-half greater than the 30-year period of 1917 through 1946. Similarly, the mean HDP for the 23-year period of 1947-1969 was more than twice that of the 18-year period of 1970-1987 (see Fig. 7). Hurricane activity as measured by the standard of HDP, been very low since 1970. Although the number of hurricanes per season averaged only 31% higher during the period of 1947-1969, as compared with 1970-1987 (see Table 1), the Hurricane Destructive Potential (HDP) was more than twice as great during the earlier period. Also, named storm activity was only 19 percent higher for the earlier period. By contrast, the potential destruction from hurricanes with maximum winds equal or greater than 100 knots (115 mph) was nearly 3 times greater in 1947-1969 as compared with 1970-1987.

Table 1 shows how many 6-hourly intense hurricane situations were reported in the 1947-1969 period in comparison with the period since 1970. Seasonal values have been normalized to the average for the period 1970-1987. There were, on average, nearly 3 times as many 6-hourly reports per season of hurricane maximum winds equal or greater than 100 knots (∿ 115 mph) in the early 1947-1969 period and over three times as many reports of hurricane winds greater than 120 knots (∿ 138 mph) per season in the earlier period. These striking differences are also verified in statistical analysis of minimum surface pressure data.

Another illustration of differences in hurricane intensity between the 1950s and 1960s and the 1970s and 1980s is the seasonal numbers of Saffir/Simpson (See Table 2) category 3, 4, and 5 hurricanes. Table 3 shows how many more seasons there were with multinumbers of category 3-4-5 hurricanes in the 1949-69 period in comparison with the 1970-87 period.

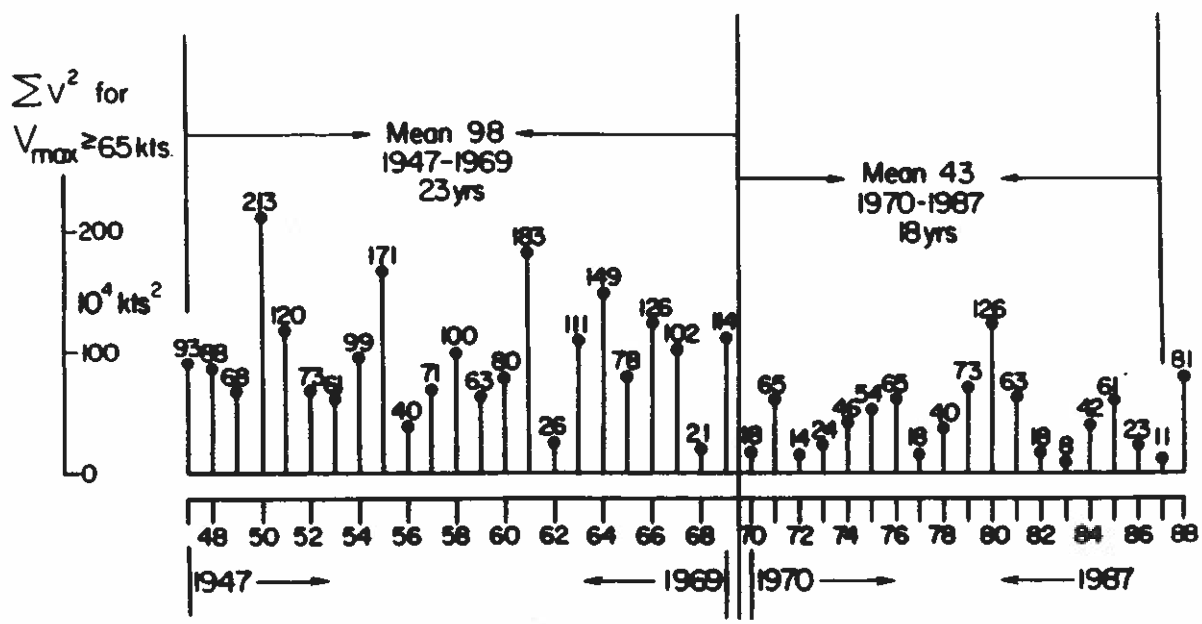

Fig. 7. Yearly variations of Hurricane Destruction Potential (HDP) for 1947-1988. HDP is defined as the sum of all hurricane maximum wind speeds squared for $V_{max} \geq 65$ knots for each 6-hour observing period throughout the hurricane season. Units 10^4 kts^2.

TABLE 1

Comparison of various measures of Atlantic tropical cyclone activity for the period of 1947-1969 to the period of 1970-1987. Values have been seasonally normalized relative to the 1970-1987 period. 1 knot (kt) = 1.15 miles per hour (mph).

Normalized Per Year	1947-1969	1970-1987
No. of Named Storms	1.19	1.00
No. of Hurricanes	1.32	1.00
Sum of all $V_{max} \geq 30$ kts	1.50	1.00
Sum of all $V_{max}^2 \geq 30$ kts	1.75	1.00
No. of Hurricane Days	1.83	1.00
Sum of all $V_{max} \geq 65$ kts	2.00	1.00
Sum of all $V_{max}^2 \geq 65$ kts	2.24	1.00
Sum of All $V_{max} \geq 100$ kts	2.93	1.00
Sum of All $V_{max}^2 \geq 100$ kts	3.06	1.00

TABLE 2
Saffir/Simpson Damage Potential Scale.

Scale Number Category	Central Pressure Millibars	Central Pressure Inches	Winds (mph)	Surge (ft)	Damage
1	≥980	≥28.94	74-95	4-5	Minimal
2	965-979	28.50-28.91	96-110	6-8	Moderate
3	945-964	27.91-28.47	111-130	9-12	Extensive
4	920-944	27.17-27.88	131-155	13-18	Extreme
5	< 920	<27.17	> 155	> 18	Catastrophic

TABLE 3

Number of hurricane seasons with various numbers of Saffir/Simpson category 3, 4, and 5 hurricanes by multi-decadal periods (data from C. Landsea).

Number of Seasons With	1949-1969	1970-1987
Two category 5 Hurricanes	2	0
Four category 4 or 5 Hurricanes	2	0
Three or more category 4 or 5 Hurricanes	4	0
Two or more category 4 or 5 Hurricanes	11	2
Four or more category 3, 4, or 5 Hurricanes	8	0

The most intense hurricanes usually form at low latitudes from disturbances propagating westward from Africa. Figure 8 shows hurricane intensity cyclone tracks equatorwards of 25°N in the period of 1970-1987 vs. the period of 1947-1969. Note the much larger concentration of low latitude hurricane tracks in the earlier period.

The more inactive hurricane period between 1970-1987 parallels with the extended period of west African drought which has occurred during these years - compare Figs. 7 and 9. This inactive period is also related to the occurrence of higher Caribbean Basin surface pressure (Table 4), and greater Caribbean Basin 200 mb (12 km or 40,000 ft) westerly zonal winds which have been present during the summer periods since 1970 in comparison with the summer periods of the 1950s and 1960s (see Table 5 and Fig. 10).

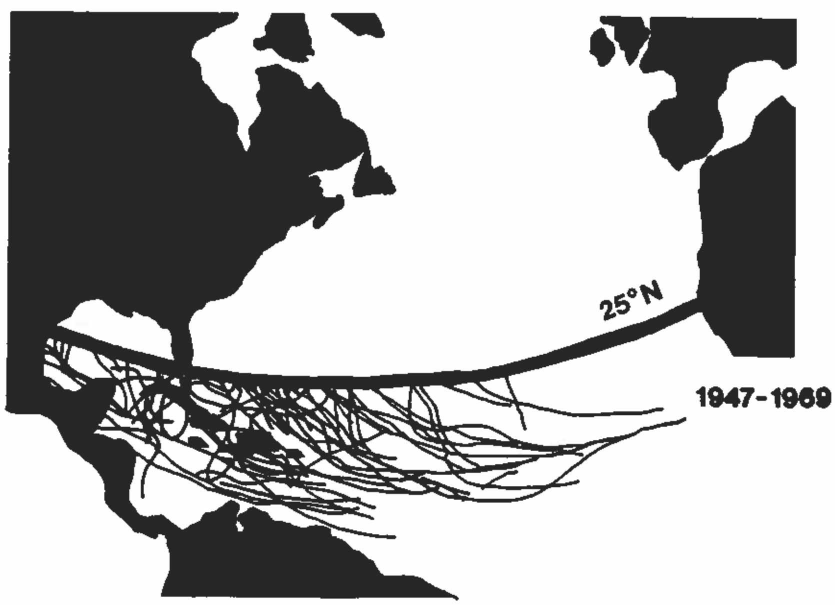

Fig. 8. Tracks of hurricane-intensity cyclones for the period of 1970 -1987 vs. that of the period of 1947-1969.

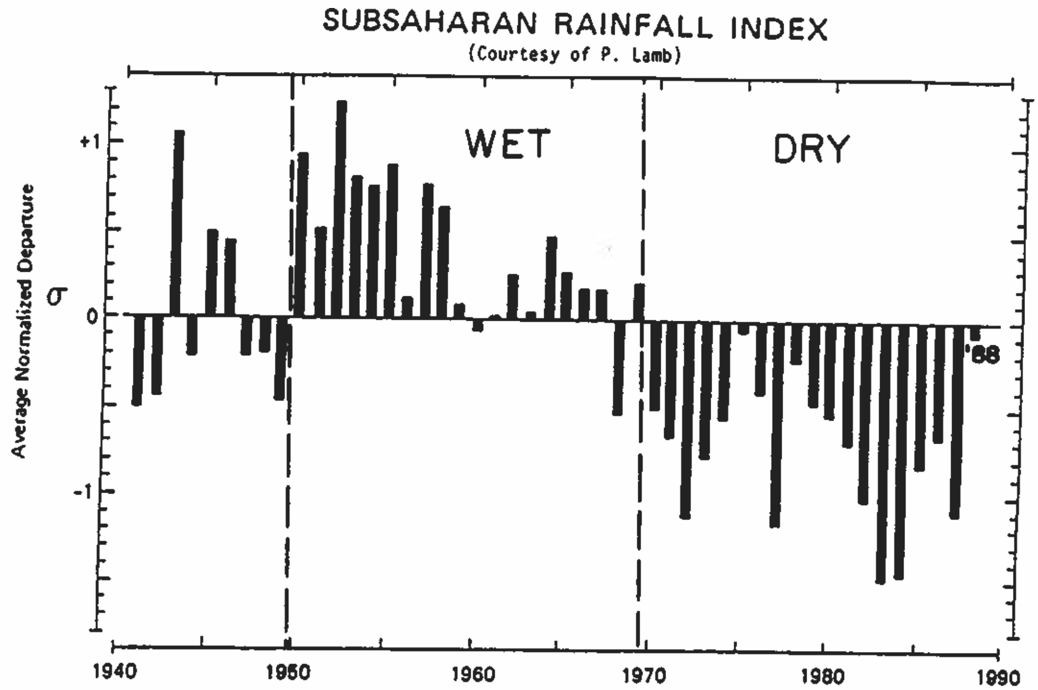

Fig. 9. An estimate of Lamb's West African rainfall index. Note the general drought conditions between 1970-1987.

TABLE 4

Average of Caribbean-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) for the period of 1950-1969 versus the period of 1970-1987. Values are in mb.

	III 1950-1969	IV 1970-1987	Difference
June and July	-.24	+.29	+.53
Aug. through Oct.	-.27	+.34	+.61
June through Oct.	-.26	+.33	+.59

TABLE 5

Lower Caribbean Basin 200 mb Zonal Wind Anomaly (ZWA) for 1954-1969 versus 1970-1987. Values in m s^{-1}.

	III 1954-1969	IV 1970-1987	Difference
June and July	-.74	+1.30	+2.04
Aug. through Oct.	-1.10	+2.30	+3.40
June through Oct.	-.91	+1.77	+2.68

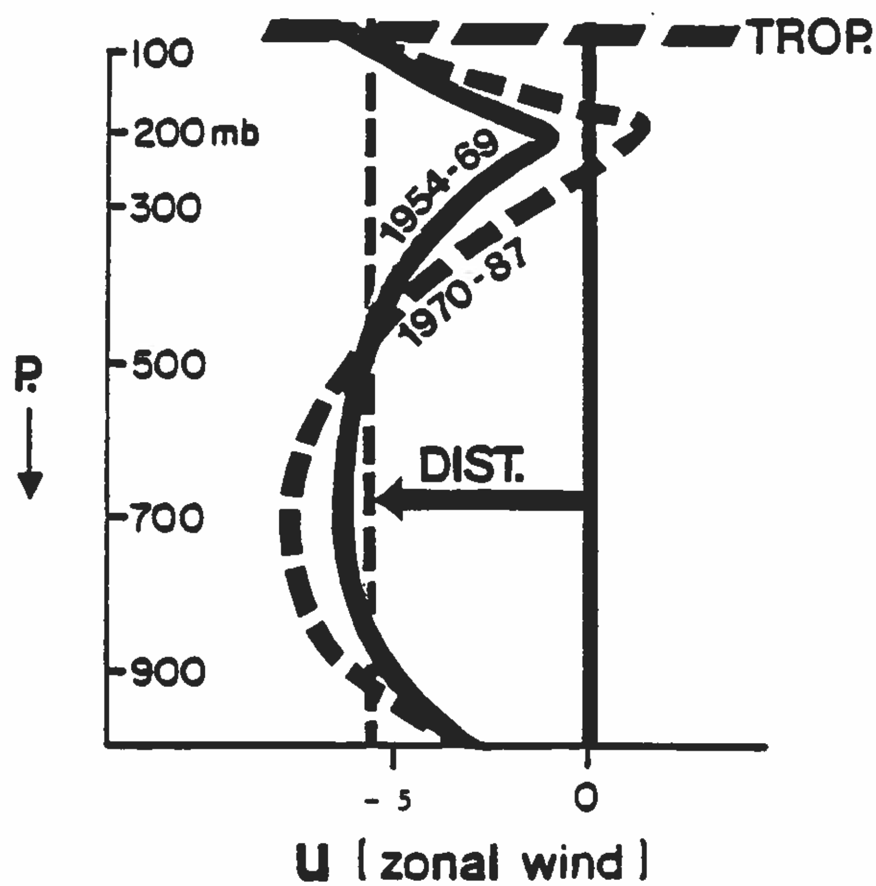

Fig. 10. Vertical profile of lower Caribbean Basin zonal winds for the August-September period of 1954-1969 vs. the period of 1970-1987. DIST. shows the typical westward velocity of a tropical disturbance. In m s^{-1}.

These changes represent a distinctive shift in the summer climatology patterns of West Africa and the Caribbean region.

The coastal populations of the US and Caribbean Basin have been fortunate that intense hurricane activity has been so low during the period of 1970-1987. It is to be expected that a return to more intense hurricane activity will occur when the atmosphere's global wind systems experience an expected change in their multi-decadal circulation patterns. The historical rainfall records of Africa indicate that such multi-decadal circulation changes have occurred many times in the past.

West Africa had near average amounts of rainfall in 1988. We cannot tell if 1988 represents the beginning of a new multi-decadal heavier rainfall regime, but it may. The next couple of years of West African rainfall need to be carefully monitored.

With the large increases of coastal populations and building construction which has taken place along the US southeast and Gulf coasts since 1970 and the increases that will likely occur in the future, we may well be in store for many more future hurricane problems than we have had in the recent past. Coastal populations, real estate, insurance interests, etc. should be made aware of this likely future increase in Atlantic hurricane activity.

5. Reasons for Concurrent Reduced African Rainfall and Atlantic Hurricane Activity during the 1970s and 1980s

It appears that the apparent climatological changes occurring during the last 18 years are a result of basic changes in the large-scale circulation patterns about the globe. These global general circulation changes may be related to observed warming tropical sea-surface temperatures (SST) in the Southern Hemisphere (SH) in comparison to Northern Hemispheric (NH) tropical SST patterns.

Recent research by the Folland et al. (1986), Palmer (1986), Owen, et al. (1988) and Parker, et al. (1988) shows that the multi-decadal West Africa Sahel drought conditions of the 1970s and 1980s are related to global changes in sea surface temperature (SST) anomalies which occurred during the last two decades. Figure 11 shows that warm SST anomalies associated with summer Sahel drought conditions are located in the South Atlantic, western Indian Ocean, and the eastern tropical Pacific Oceans while colder than average SST anomalies occur over the tropical NH Oceans. It is believed that such North to South SST gradients act to retard the normal northward progression and/or the strength of the summertime Inter-Tropical Convergence Zone (ITCZ) over West Africa and the westward extension of the ITCZ over the Atlantic and Caribbean. This general weakening of the ITCZ under these conditions manifests itself as higher than average surface pressures and higher than average tropospheric west wind shear over the Caribbean Basin and the western tropical Atlantic. Such conditions act to inhibit the development of hurricanes from African spawned tropical disturbances and generally reduce Atlantic hurricane activity, particularly low latitude and intense hurricane activity.

Figure 12 shows how multi-decadal wet and dry periods in West Africa relate to Atlantic Hurricane Destruction Potential (HDP) since 1900. Note that from 1900-1914 there was a similar Sahel dry period with concurrent reduced hurricane activity, similar to what has occurred during the more recent 1970-87 period.

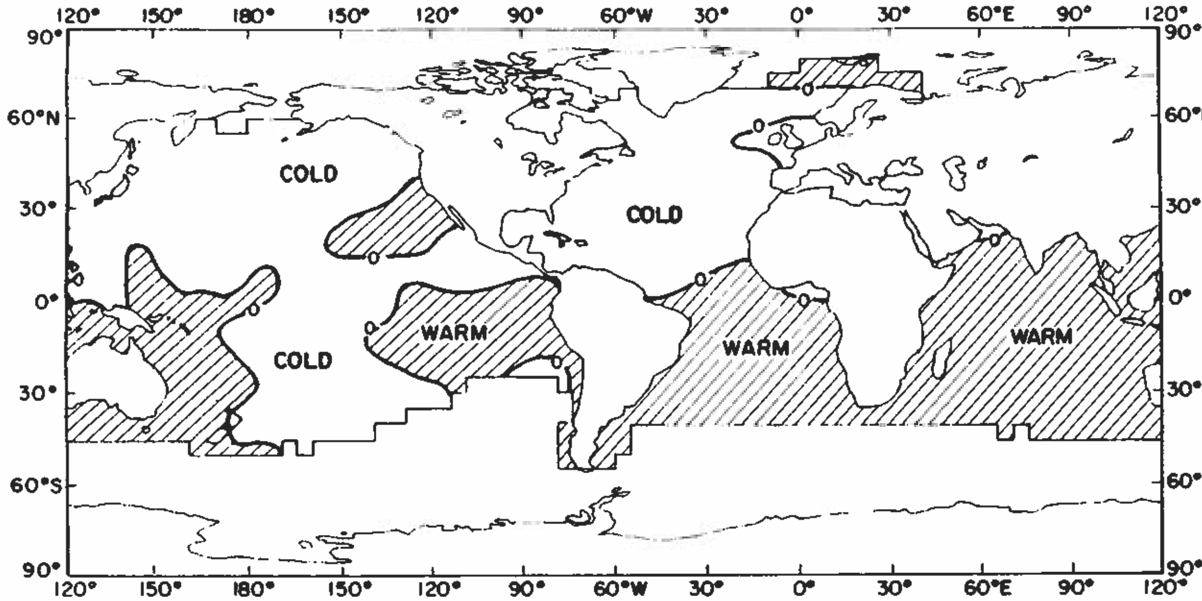

Fig. 11. Sea-surface temperature (SST) anomaly patterns for the 1970s and 1980s which are associated with Sahel drought conditions. Figure adopted from Parker et al. (1988).

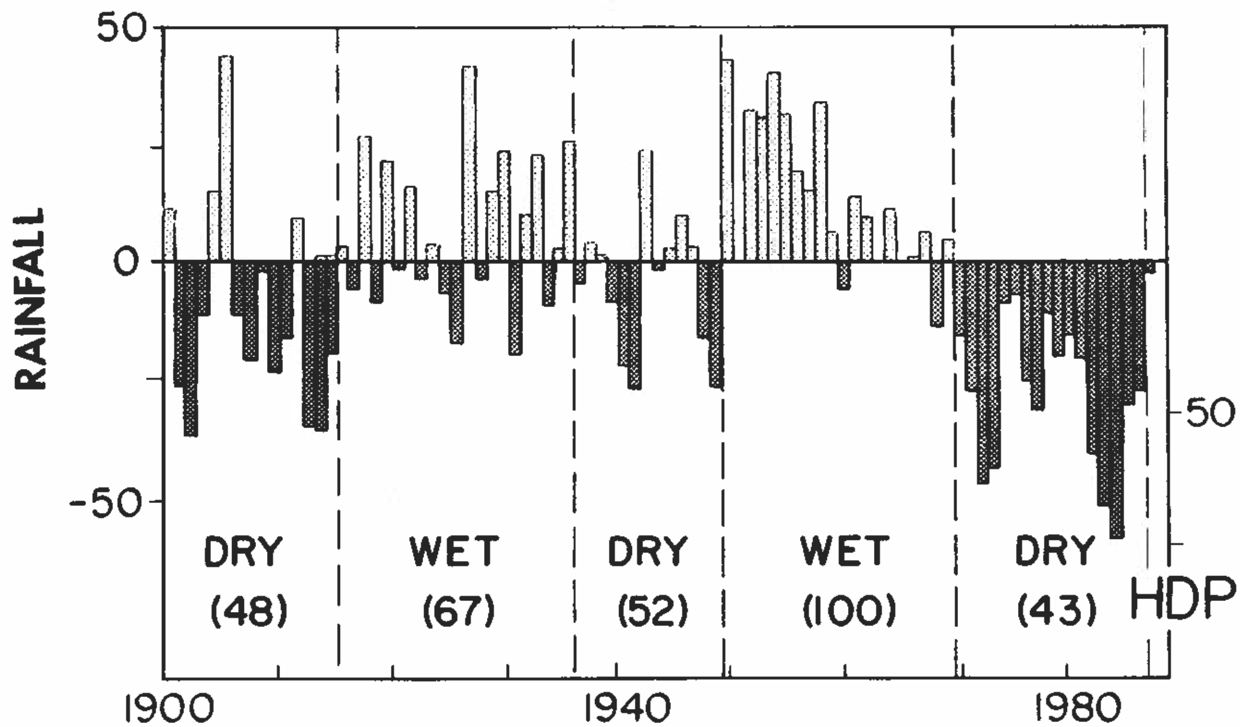

Fig. 12. Normalized percentage Sahel region yearly rainfall anomaly for 1900-1987 and the association of these multi-decadal wet and dry periods with the mean annual Atlantic Hurricane Destruction Potential (HDP) during each period. Data adopted from Entekhabi and Nicholson (1987).

6. Unlikely Association of Greenhouse Gases with Multi-decadal and Seasonal Hurricane Variability

It is unlikely that these seasonal and multi-decadal variations in Atlantic hurricane activity, as described above, are related to "Greenhouse" gas influences associated with the slow and steady increases in CO_2 and trace gases in recent decades. Similar multi-decadal African-drought hurricane activity changes have occurred earlier in this century and in previous centuries. It is highly unlikely that CO_2 and trace gas influence could be a significant influence in such changes in comparison to the many other factors which cause global climate change. Cumulative Greenhouse influences act much too slowly for the intense hurricane activity of 1988 to have been so abruptly affected as some Greenhouse enthusiasts have conjectured.

It has been hypothesized that Greenhouse influences should act to increase the intensity of hurricanes. This hypothesis makes the improbable supposition that all the many other factors causing hurricanes to form and intensify remain constant while SSTs increase. This is not possible. If SSTs in tropical regions should significantly increase due to Greenhouse influences (which the author doubts will happen for the next 50-100 years at least) then there must also be concomitant changes in the many other global circulation features of wind, wind shear, pressure, humidity, etc. which such SST changes would bring about. These other related changes could act to reduce rather than increase hurricane activity. Hence, scenarios can just as easily be made for reductions in hurricane activity due to Greenhouse influences as can be made for Greenhouse induced increases in such activity. The general reduction of Atlantic hurricane activity and intensity since 1970 described above also does not lend support to the Greenhouse hypothesis of expected increase in recent hurricane activity. Clearly, there are many other natural factors which bring about multi-decadal hurricane variability besides Greenhouse gas influences.

7. Possibilities for Seasonal Hurricane Intensity Prediction

It is possible to offer a degree of skillful probabilistic estimates on the potential of a coming hurricane season for having intense and long lived hurricanes. For instance, intense and long track hurricanes typically occur in seasons with weak, as opposed to strong easterly 50 mb (12 km) zonal winds at stations near 10°N latitude - see Fig. 5. The majority of intense hurricanes occur in weak 50 mb wind situations. Of the 101 most intense hurricanes (V_{max} equal or greater than 100 knots or 115 mph) in the 40-year period of 1949-1988, 59 (58%) occurred when 50 mb zonal winds at Balboa were only weak from the east vs. 29 (29%) in the seasons when they were strong from the east. In the other 13 (13%) intermediately strong easterly winds were present. It is also of interest to note that 69 of these 101 most intense hurricanes occurred during the 1950s and 1960s versus only 29 during the period of 1970-1987, the other 3 occurring in 1988.

The 50 mb zonal wind direction can be reliably forecast 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 fairly representative of the western Atlantic latitude belt between 8 to 15°N where most of the intense hurricanes of African origin form. In 1989 it is expected that the Balboa 50 mb zonal wind will be strong from the east and should act to reduce intense hurricane activity during this season.

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

Figure 13 shows the average annual 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. In consideration of the distribution in Fig. 13, a forecast scheme using QBO, EN, SLPA and ZWA information is based on several premises including:

1) the strength of the stratospheric 50 mb easterly QBO wind speed changes on such a long time interval (~ 14-18 months) and in such a uniform manner, that the trend in these wind speeds can be reliably extrapolated for 3 to 6 months into the future.

2) the oceanography and meteorological communities are normally able to detect the presence and approximate intensity of a forthcoming El Nino event by late May with good success or by late July with even more certainty.

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.

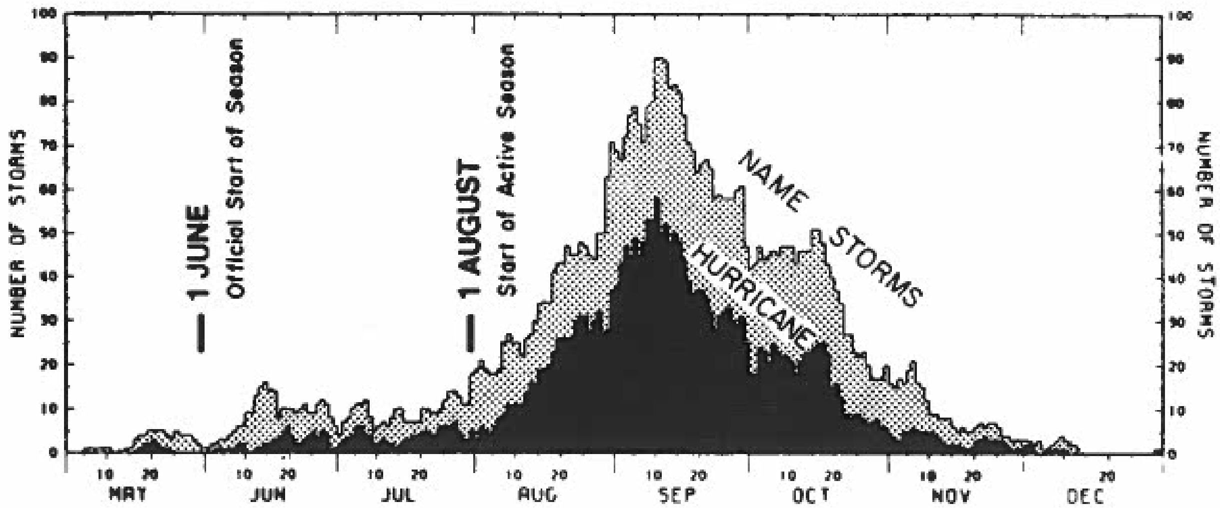

Fig. 13. Number of tropical storms and hurricanes (open curve) and hurricanes (solid curve) observed on each day, May 1, 1886 through December 31, 1980 (from Neumann, et al., 1981).

9. Characteristics of Four (EN, QBO, SLPA, ZWA) Predictors for the 1989 Hurricane Season

The two global predictors, El Nino (EN) and stratospheric QBO winds, indicate that the coming 1989 hurricane season will be a below average hurricane season.

a) El Nino.

The intense cold water of the La Nina (LN) event of 1988 has mostly dissipated and near normal sea surface temperatures have returned to much of the central and eastern tropical Pacific. Thermocline depths are also near normal. Therefore, the 1989 hurricane season is not expected to experience the influence of either a warm or a cold event and this factor is expected to be neutral.

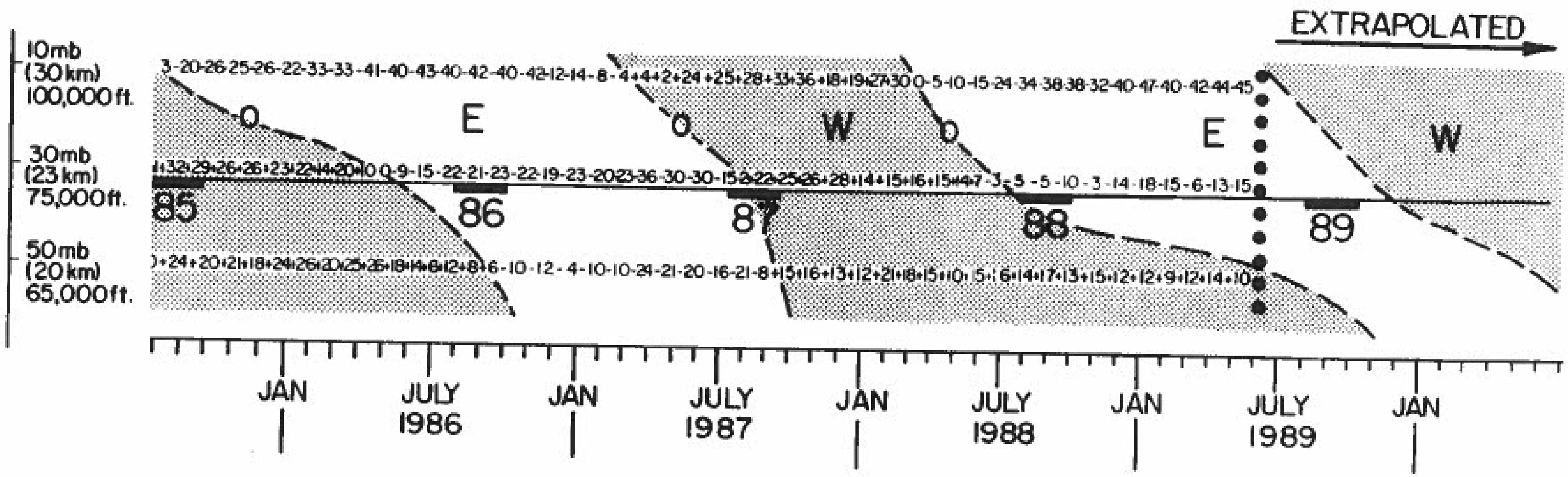

Fig. 14. Vertical cross-section of recent monthly average QBO west to east (or zonal) wind in knots. This figure represents an average of the Balboa, C.Z. (9°N) and Ascension (8°S) rawinsondes with Trinidad (11°N) being substituted for Balboa during part of 1989. The mean annual cycle has been removed from each sounding before averaging. Winds from a westerly direction have been shaded. Information beyond May 1989 has been extrapolated. Thick horizontal lines show the active portion of each hurricane season from 1986 to 1989.

b) QBO.

Stratospheric wind variations over the last year have been unusual. Temperatures and winds have not been in good agreement with each other. May 50 mb (20 km) winds remain weakly in the westerly phase. By mid season (September) 50 mb winds are expected to have shifted from the current westerly to an easterly phase. Figure 14 shows recent and anticipated (extrapolated) global relative QBO zonal winds for the coming hurricane season. Note that lower stratospheric winds will be changing from a relative westerly direction to a relative easterly direction. Stratospheric winds at 30 mb (23 km) over the lower Caribbean basin are now strongly from the east and have been in an easterly phase for nearly a year. Surprisingly, the 50 mb (20.5 km) and 70 mb (18.5 km) winds remain in a relatively westerly phase however. It is expected that these lower level winds will be shifting over to a relatively easterly direction for most of the coming hurricane season. All aspects considered, it is expected that the QBO will act as a generally suppressing influence on this season's Atlantic hurricane activity.

Table 6 shows the absolute value of the current and extrapolated QBO zonal winds near 10°N for August-October 1989 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 1989 hurricane season, the vertical wind shear in the lower stratosphere is expected to be large. Stratospheric zonal winds will thus be less favorable for hurricane formation and for intense hurricane activity when formation does occur.

TABLE 6

Absolute value of current and extrapolated 1989 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)	-17	-22	-25	-25
50 mb (20.5 km)	-2	-12	-12	-14
70 mb (18.5 km)	+2	-9	-8	-6

c) SLPA.

Table 7 shows 1 April-26 May 1989 SLPA from relevant tropical stations. Note that April-May SLPA is above average for all stations for both the Caribbean-Gulf of Mexico 6-station average and the special 5-station low latitude average. These SLPA are derivations from the last 40-year average. These higher pressure anomalies also indicate that 1989 hurricane activity will likely be reduced.

TABLE 7

1 April-26 May 1989 Average Gulf of Mexico-Caribbean Basin and Low Latitude Sea-Level Pressure Anomalies (SLPA) - in mb (as supplied by Colin McAdie of NHC).

Gulf of Mexico-Caribbean Basin	SLPA	Low Latitude	SLPA
Brownsville	+0.4	San Juan	+0.6
Merida (Mex.)	+1.2	Curacao	+0.7
Miami	+0.3	Barbados	+1.0
San Juan	+0.6	Trinidad	+1.5
Curacao	+0.7	Cayenne	+0.6
Barbados	+1.0		
Average	+0.7	Average	+0.9

d) ZWA.

Although not used in the 1 June forecast, the Lower Caribbean Basin 200 mb zonal wind anomaly (ZWA) for 1 April to 25 May 1989 is an indication of current tropospheric wind shear conditions. The ZWAs are about neutral in comparison with the average values for both the 1970-87 and 1954-69 periods (See Table 8). The neutral ZWA values indicate that strong suppressing or enhancing wind shear influences are not operating at this time. It is the June-July ZWAs which will be most closely monitored for assistance with the 1 August updated forecast.

TABLE 8

1 April-26 May 1989 Caribbean Zonal Wind Anomaly (ZWA) in m s^{-1} relative to 1970-87 and 1954-69 Average (as supplied by Colin McAdie of NHC).

Station	1970-88 Ave.	1954-69 Ave.
Balboa (9°N, 80°W)	+3	+1
Kingston (18°N, 77°W)	-2	0
Curacoa (12°N, 69°W)	+1	+3
Barbados (13.5°N, 60°W)	-1	0
Trinidad (11°N, 62°W)	0	-1
Average	+0.2	+0.6

10. Author's 1989 Forecast

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

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

where

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

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

SLPA = Average SLPA for April-May, from selected Caribbean-Gulf of Mexico and tropical stations. Subtract if SLPA is significantly above average, add if below average. Make no correction when SLPA is near normal (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 in non-El Nino years. Not directly used for the 1 June forecast.

MEM. = MEMORY correction term from last 5 years August-September values of SLPA and ZWA. Applied to HDP forecast.

The author and his CSU research colleagues, Paul Mielke and Kenneth Berry (of Dept. of Statistics) are currently refining techniques for forecasting seasonal Hurricane Destruction Potential (HDP) which is somewhat different than forecasts for the number of hurricanes and named storms. Although much too involved to describe here, the author is using this new information to help make the seasonal prediction of HDP for 1989. Our current research indicates that seasonal values of HDP can be predicted with as much skill, if not more skill, than the number of hurricanes.

Table 9 shows the author's seasonal forecasts for the number of hurricanes, named storms, hurricane days, named storm days and Hurricane Destruction Potential (HDP) for the coming 1988 hurricane season.

<u>Discussion</u>. It is anticipated that the upcoming 1989 hurricane season will be below average but still more active than the four recent hurricane seasons of 1982, 1983, 1986, and 1987. This assessment is based primarily on the anticipated QBO and SLPA suppressing influences. The Hurricane Destruction Potential (HDP) this year should be much lower than last season or in 1985.

TABLE 9

1989 PREDICTED SEASONAL HURRICANE ACTIVITY

(Predicted No. of Hurricanes per Season)	= 6 + QBO + EN + SLPA + ZWA		
	(-1) + (0) + (-1) + N/A	=	4
(Predicted No. of Hurricanes and Tropical Storms Per Season)	= 9 + QBO + EN + SLPA + ZWA		
	+ (-1) + (0)+ (-1) + N/A	=	7
(Predicted No. of Hurricane Days Per Season)	= 25 + 5 (QBO + EN + SLPA + ZWA)		
	(-1) + (0)+ (-1) + N/A	=	15
(Predicted No. of Named Storm Days)	= 2.0 x (No. of Hur. Days)	=	30
(Hurricane Destruction Potential - HDP)	= 75 + (QBO + EN + SLPA + ZWA + MEM.)		
	75 + -15 + 0 + -15 + N/A - 5	=	40

Data of Table 10 provides a comparison of this season's TC forecast with the TC activity of the last season, and the average of the 1982-87, 1970-87 and 1950-69 periods. Note how much more active the 1950-1969 seasons were in comparison with recent periods.

TABLE 10

Comparison of 1989 Forecast Number
With Previous Years

	1 June Forecast 1989	Last Year	Seasonal Average 1982-87	Seasonal Average 1970-87	Seasonal Average 1950-69
No. of Hurricanes	4	5	4.0	4.9	6.5
No. of Named Storms	7	12	7.5	8.3	9.7
No. of Hurricane Days	15	26	13.0	16.2	30.2
Hurr. Dest. Pot. (HDP)	40	81	27.0	43.0	100.3

Although it is too early to predict West African drought conditions, an analysis of recent sea surface temperature (SST) indicate that Southern Hemisphere SSTs are presently above average and Northern Hemisphere SSTs generally below average. This condition indicates that the West African region is unlikely to receive the increased amounts of precipitation in 1989 that it did in 1988. This SST anomaly configuration is then another likely suppressing influence on the 1989 Atlantic hurricane activity, although it is still too early to be overly confident of this assessment.

11. Verification of Author's Previous Seasonal Forecasts

Table 11 gives verification data for five previous formal seasonal forecasts of Atlantic hurricane activity by the author. Note the difference between observed seasonal hurricane activity and climatology. Over the last 40 years there have been an average of 6 hurricanes per year, 9 named cyclones of tropical storm or hurricane intensity, 25

TABLE 11

Verification of the author's previous seasonal predictions of Atlantic tropical cyclone activity for 1984-1988.

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
No. of Named Storm Days	45		61

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	29
No. of Named Storm Days	55	50	60

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
No. of Named Storm Days	35	25	27

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
No. of Named Storm Days	40	35	36

1988	Prediction of 26 May and 28 July Update	Climatology	Observed
No. of Hurricanes	7	(6)	5
No. of Named Storms	11	(9)	12
No. of Hurricane Days	30	(25)	26
No. of Named Storm Days	50	(45)	56
Hurr. Destruction Potential (HDP)	75	(75)	81

hurricane days, 45 named storm days, and an HDP of 75.

Data in Table 12 compare the ratio of variance of the author's 1984-1988 forecasts (relative to observation) to forecasts based on climatology for the yearly activity variances of 1984-88 and relative to the seasonal activity variances of 1949-88 (in parentheses). This table shows that the observed yearly variance values of the author's forecasts from climatology have been considerably lower than have the observed hurricane seasonal

TABLE 12

Ratio of variance of author's seasonal TC forecasts from observation to the variance of observed seasonal TC activity from climatology during the 1984-88 period and to the variances from climatology during the period 1949-88 (in parenthesis).

	No. of Hurricanes	No. of Named Storms	No. of Hurricane Days
For Late May Forecast	.94 (.55)	.29 (.23)	.71 (.35)
For Late July Forecast	.65 (.38)	.21 (.16)	.40 (.20)

variances from climatology. The late July forecasts have been superior to the late May forecasts and the forecasts of named storm activity have been especially successful. Forecasts for 1984-1988 have thus been a significant improvement over climatology, the only objective seasonal prediction that had previously been available.

The results in Tables 11 and 12 represent only a 5-year forecast sample. Additional hindcast forecast analyses are being made of the potential for seasonal TC activity prediction on 40 years (1949-1988) of prior data by Professors Paul Mielke and Kenneth Berry of the CSU

Statistics Department, in conjunction with the author (see Gray et al., 1987b). A large number of recent tests have examined new forecast parameters and alterations of the present procedures. A "jackknife" (see Efron, 1982) approach has been adopted wherein forecast test statistics are developed from all years of data except the year which is being forecast. In this way each forecast is excluded from the developmental data set and in this sense may be considered to be independent. These new statistical tests indicate a potential for independently forecasting about 40 percent of the seasonal TC variance using forecast indices available in late May and about 50 percent of the variance with the late July forecast update.

12. Outlook for the Coming Years

It is impossible to say how long the diminished amount of Atlantic hurricane activity of recent years will last. Evidence of cyclical or multi-decadal trends (see Fig. 12) in activity during the past century indicate that it is reasonable to expect an eventual return to seasons with both more hurricanes and more intense hurricanes. The near average West African rainfall season of 1988 may or may not represent the beginning of a break in both the multi-decadal West African drought and the suppression of Atlantic hurricane activity. Because of the rapid growth in US coastal populations and property investment in recent years (see Fig. 15), it would appear that major increases in hurricane spawned coastal destruction may be inevitable.

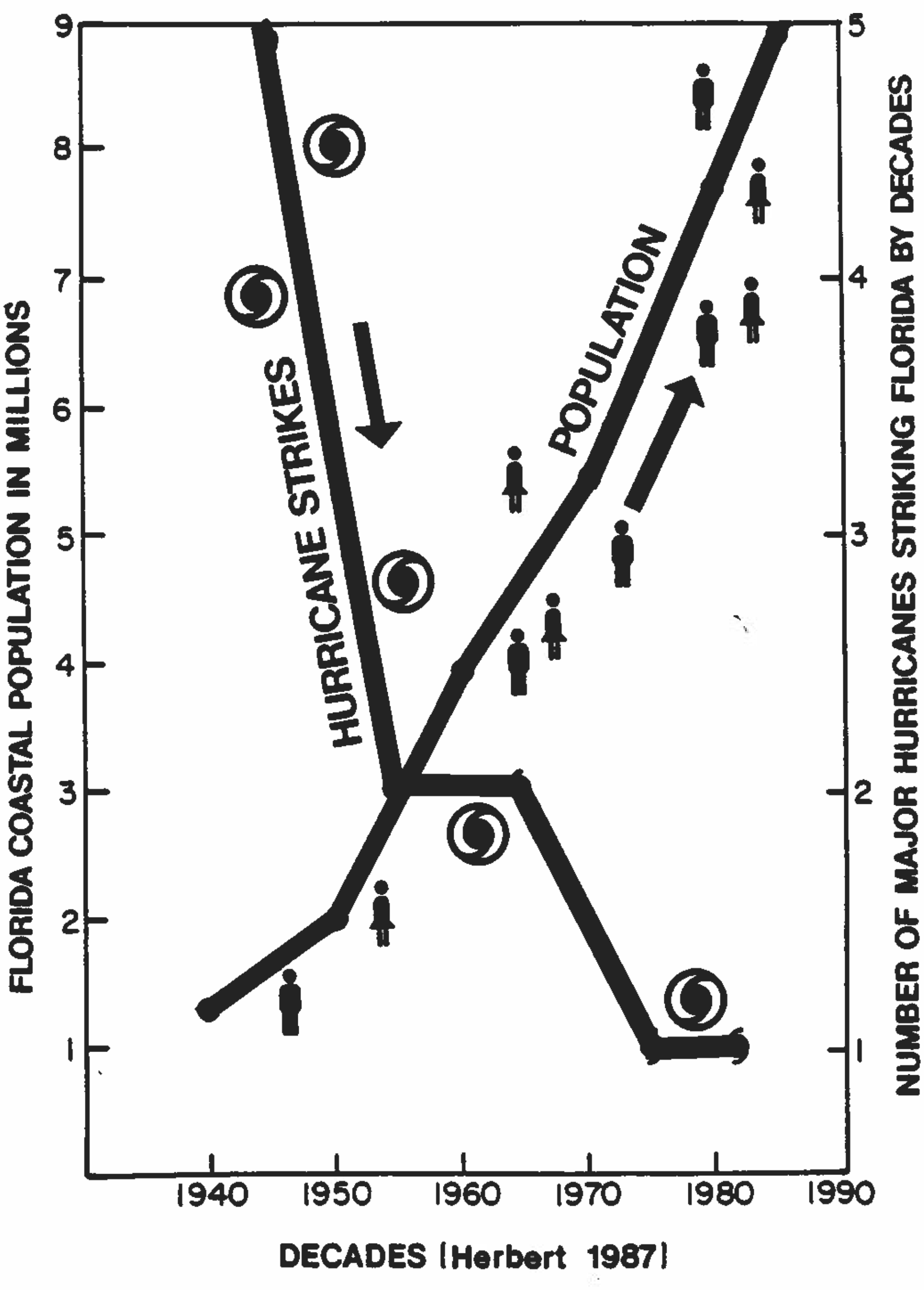

Fig. 15. Illustration of mean decadal number of hurricane strikes in Florida vs. the increase in Florida coastal population (adopted from Hebert, 1987).

13. 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. This forecast scheme will likely fail in some years when the other unknown factors (besides the QBO, EN, SLPA and ZWA) which cause hurricane variability are more dominant. It is impossible to determine beforehand in which years the author's forecast scheme will work best or worst.

This forecast scheme also does not specifically predict which portion of the hurricane season will be most active or where within the Atlantic Basin the storms will strike. For instance, although 1983 was one of the most inactive seasons on record, Hurricane Alicia caused over a billion dollars of damage to the Houston area.

14. Acknowledgements

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