FORECAST OF ATLANTIC SEASONAL HURRICANE

ACTIVITY FOR 1985

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 1985 meteorological information)

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DEFINITIONS

El Nino - 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 (20 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 the reverse themselves and blow 12-16 months from the west and then back to the east again.

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 meters/s) or greater.

Tropical Storm - a tropical cyclone with maximum sustained winds between 39 (17 m/s) and 73 (31 m/s) miles per hour.

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

Hurricane Day - any part of a day in which a tropical cyclone is observed or estimated to have 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, 30 mb at about 23 kilometers altitude. Monthly averages of surface pressure in the tropics show maximum seasonal summer variations of about ± 2 mb. These small pressure variations are very important however. Average surface pressure is slightly over 1000 mb.

OUTLINE

ABSTRACT

This paper discusses the author's forecast of the amount of tropical cyclone activity which can be expected to occur in the Atlantic Ocean region (including the Caribbean Sea and the Gulf of Mexico) in 1985. This forecast is based on the author's previous and current research (Gray, 1983, 1984a, 1984b, 1985) 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) Caribbean Basin and Gulf of Mexico Sea-Level Pressure Anomaly (SLPA); and 4) lower latitude Caribbean Basin 200 mb zonal wind anomaly.

Information received by the author up to 28 May 1985 indicates that the 1985 hurricane season can be expected to be an above average year with about 8 hurricanes (6 is average), 11 hurricanes and tropical storms (9 is average), and about 35 hurricane days (25 is average). 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 which will make use of June and July data should be more reliable.

This paper also gives a brief background description of the methodology of this objective forecast scheme and discusses reasons for the usually low amount of hurricane activity which has occurred in the last three 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 11 per season (as in 1950, 1916), 10 (1969, 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 now 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, 1985) indicates that there are four atmospheric parameters (out of a large number studied) which can be evaluated in spring and early summer and are correlated with the following season's tropical cyclone activity. If these four predictors are used in combination, then it is possible to explain about half or more of the seasonal variability in Atlantic hurricane activity on a statistical multi-year basis.

This paper will briefly discuss the nature of these four seasonal hurricane predictors and what these predictors indicate for the level of tropical cyclone activity in the coming 1985 season. A brief discussion of the abnormal tropical cyclone activity of the 1982, 1983, and 1984 seasons are also given.

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

2. Atmospheric Parameters of Atlantic Hurricane Activity

The four predictors are the El Nino (EN), the Equatorial Stratospheric Quasi-Biennial-Oscillation (QBO) of east-west or zonal Wind, the Caribbean-Gulf of Mexico springtime and early summer Sea Level Pressure Anomaly (SLPA), and southern Caribbean Basin springtime and early summer 200 mb zonal wind anomaly.

a. The El Nino

At irregular intervals of 3-8 years, sea surface temperatures over the central and eastern tropical Pacific Ocean rise to several degrees Celsius above average levels, and remain so for 12-18 months. Associated with this phenomenon, named El Nino, are disruptions of weather patterns worldwide, particularly in the tropics and subtropics. One consequence of El Nino is reduced hurricane frequency in the Atlantic basin.

Strong and moderate El Nino events (as defined by Quinn et al., 1976) have occurred during 16 hurricane seasons of this century. One can compare the number of hurricanes, hurricane days, etc., occurring in each of these 16 El Nino years to the number of such events occurring during the other 69 non-El Nino years of this century. Figure 1 is a plot of the seasonal number of hurricane days for the years of 1900-1984 with El Nino years shown by the thick circled lines. It can be seen that in most El Nino years hurricane activity as measured by the number of hurricane days is typically much less than for non-El Nino years. Of the 16 years of this century with the lowest number of hurricane days, 9 are strong or moderate El Nino years. Of the 22 years with the largest number of hurricane days, none were El Nino years.

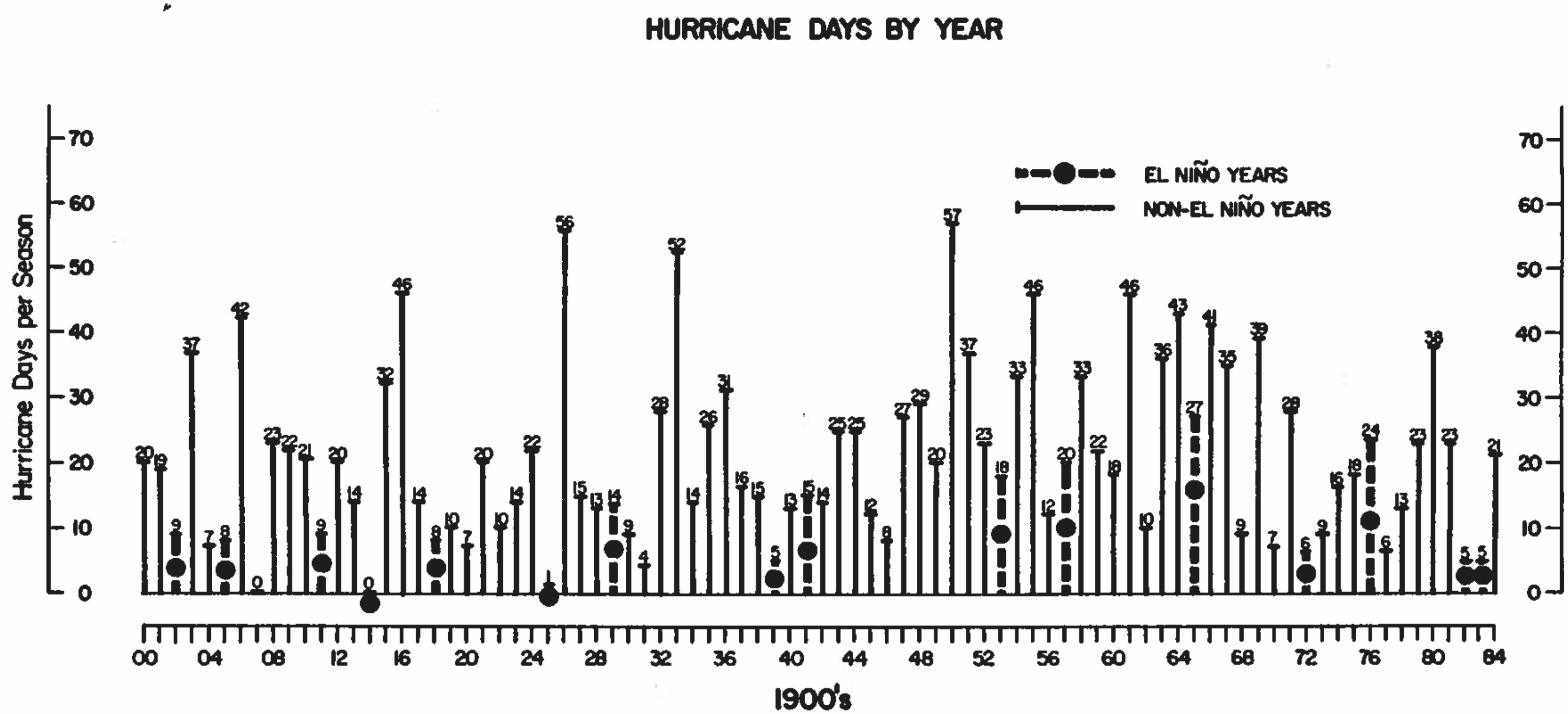

Fig. 1. Number of hurricane days (figure at top of lines) in El Nino/non-El Nino years by year from 1900-1984.

This El Nino-Atlantic hurricane activity association appears to be related to the anomalously strong westerly upper tropospheric (12 km height or 40,000 ft) wind patterns which become established over the Caribbean Sea and equatorial Atlantic Ocean during El Nino years. Such westerly wind patterns have been known to inhibit hurricane activity. Figures 2-4 show composites of hurricane intensity storm tracks for 14 seasons one year before, during, and one year after each El Nino season between 1900 and 1976. Note the fewer hurricane tracks in seasons when an El Nino is present as compared with the before and after groups of non El Nino seasons. Note that it is the low latitude westward tracking tropical cyclones of the western Atlantic and Caribbean Sea which are most suppressed in El Nino years as compared with non-El Nino years. The best estimate by those who study El Ninos is that <u>1985 will not be an El Nino year</u>. In fact, conditions quite opposite to those associated with an El Nino event appear to be becoming established in the Pacific. A definite judgement on this can be made with the 1 August updated forecast.

b. <u>Q</u>uasi-<u>B</u>iennial <u>O</u>scillation (QBO)

With the beginning of systematic wind measurements in the tropical stratosphere in the early 1950's, a periodic reversal of winds equatorward of 15^{o} latitude and at altitudes of 50-10 mb (20-35 km or 69,000-110,000 ft) from year to year was noted.

The winds change from westerly to easterly and back again in just over two years or so. This wind reversal has been termed the <u>Q</u>uasi-<u>B</u>iennial <u>O</u>scillation (or QBO) by scientists who study it. This QBO

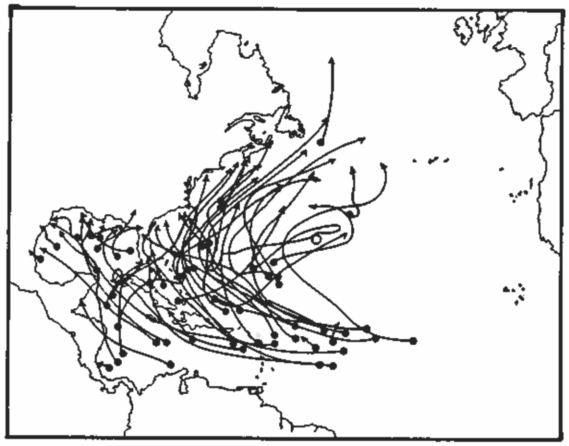

Fig. 2. Fourteen years of hurricane intensity storm tracks occurring one year before each of 14 El Nino years between 1900-1976.

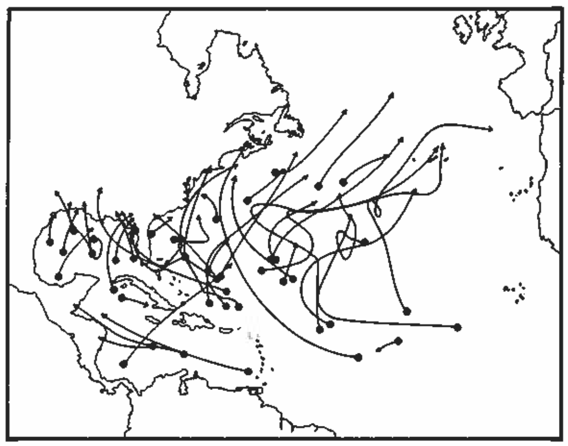

Fig. 3. Fourteen years of hurricane intensity storm tracks during 14 El Nino years between 1900-1976.

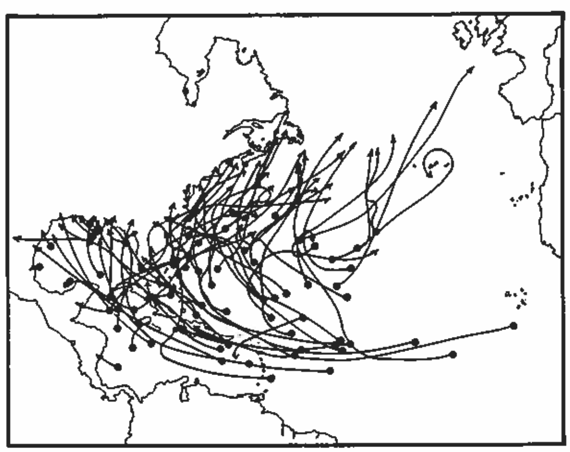

Fig. 4. Same as Fig. 2 but for hurricane intensity tracks one year

stratospheric wind oscillation encompasses the globe and at individual stratospheric levels is present at all equatorial observing stations - see Fig. 5.

The direction of the stratospheric winds at 30 mb (23 km altitude) has a surprising correspondence with Atlantic hurricane activity. Hurricane activity is, in general, nearly twice as great when these stratospheric winds blow from a westerly direction in comparison to when they blow from an easterly direction. Figure 6 shows the number of hurricane days per year from 1949 through 1984 by east and west wind category. Notice how the west wind seasons (dashed line) usually have a higher number of hurricane days than east wind cases (solid line). Disregarding El Nino years (which due to their strong suppressing effect bias the data set) this ratio of seasonal hurricane days for west wind vs. east wind cases is 34:18. Though not yet understood, the association between stratospheric flow and hurricane activity is significant.

As with the El Nino years,it is the low latitude westward tracking systems through the tropical western Atlantic and Caribbean Sea which are most suppressed in east wind QBO seasons.

Figure 7 shows the QBO equatorial stratospheric winds up through April of this year and the extrapolated values for this coming season. <u>Note that in the coming 1985 hurricane season these winds will be from the west</u>. Because the winds change so slowly it is usually possible to anticipate their direction for several months into the future.

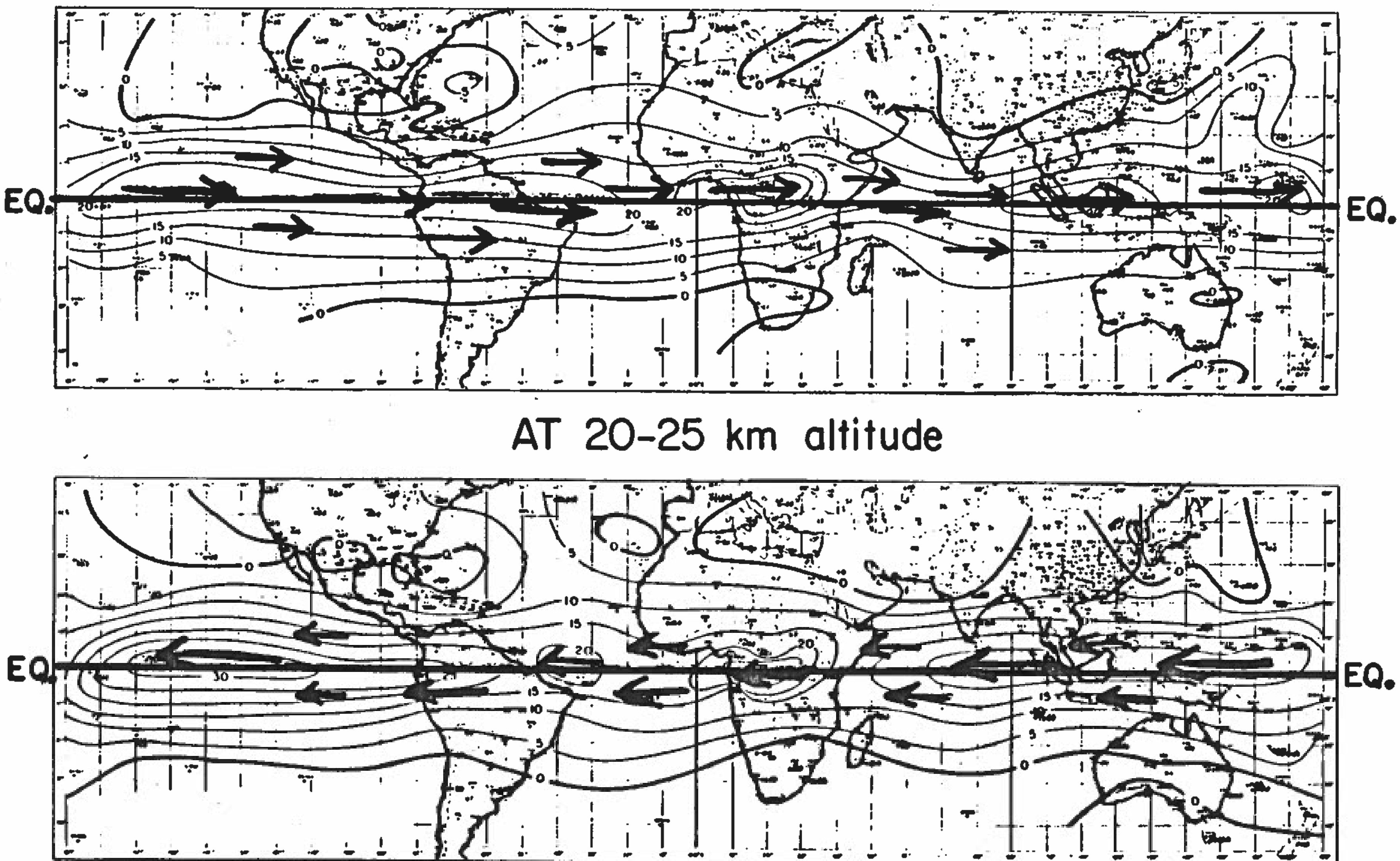

Fig. 5. Illustration of typical condition in the 20 to 25 km altitude layer in the tropics when QBO winds from the west (top diagram) vs. those conditions when they blow from the east (bottom diagram).

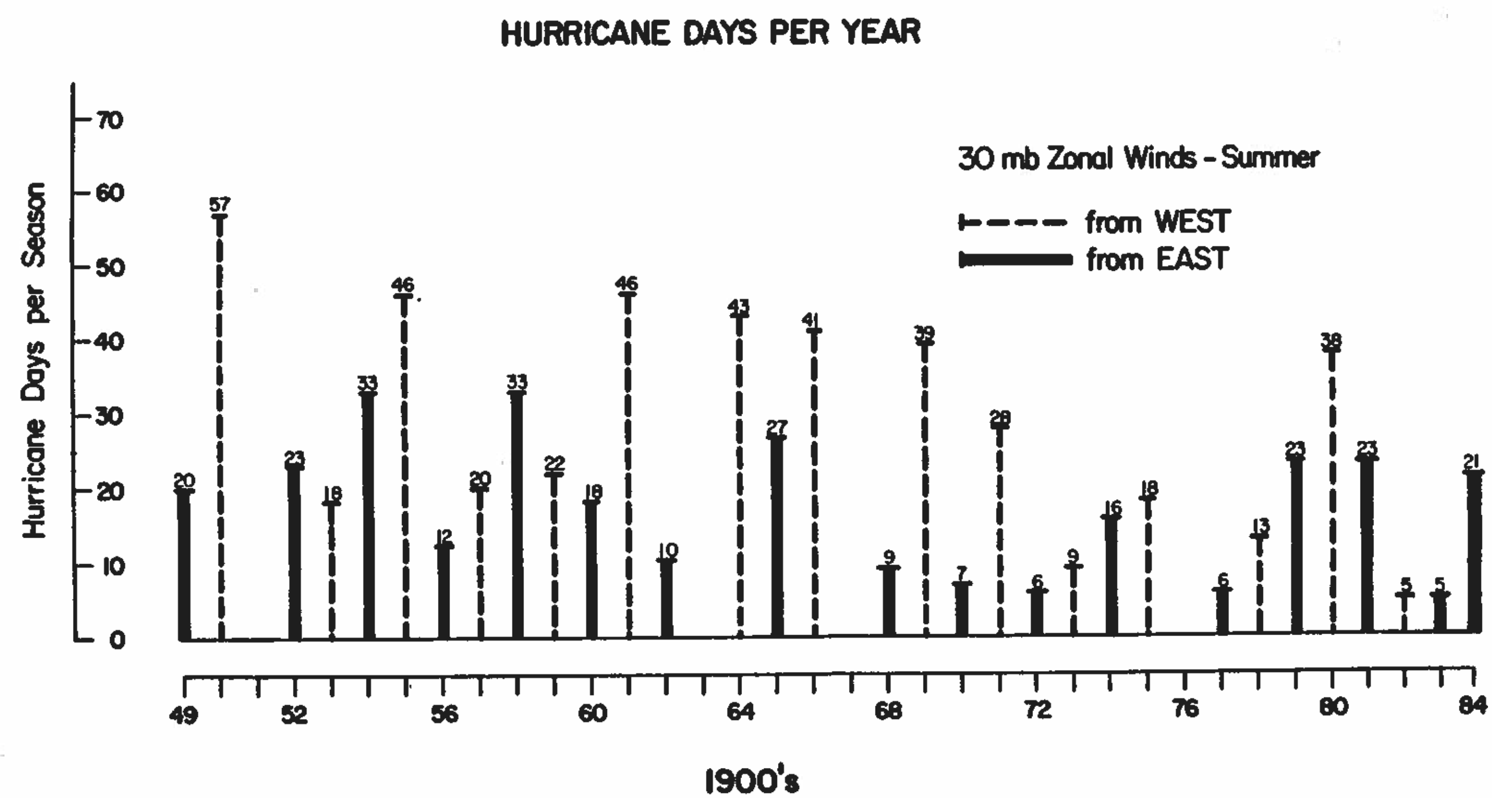

Fig. 6. Relationship between 30 mb stratospheric wind direction and seasonal number of hurricane days from 1949-1984. Years with no observation are those in which the 30 mb zonal wind is changing direction or is very weak.

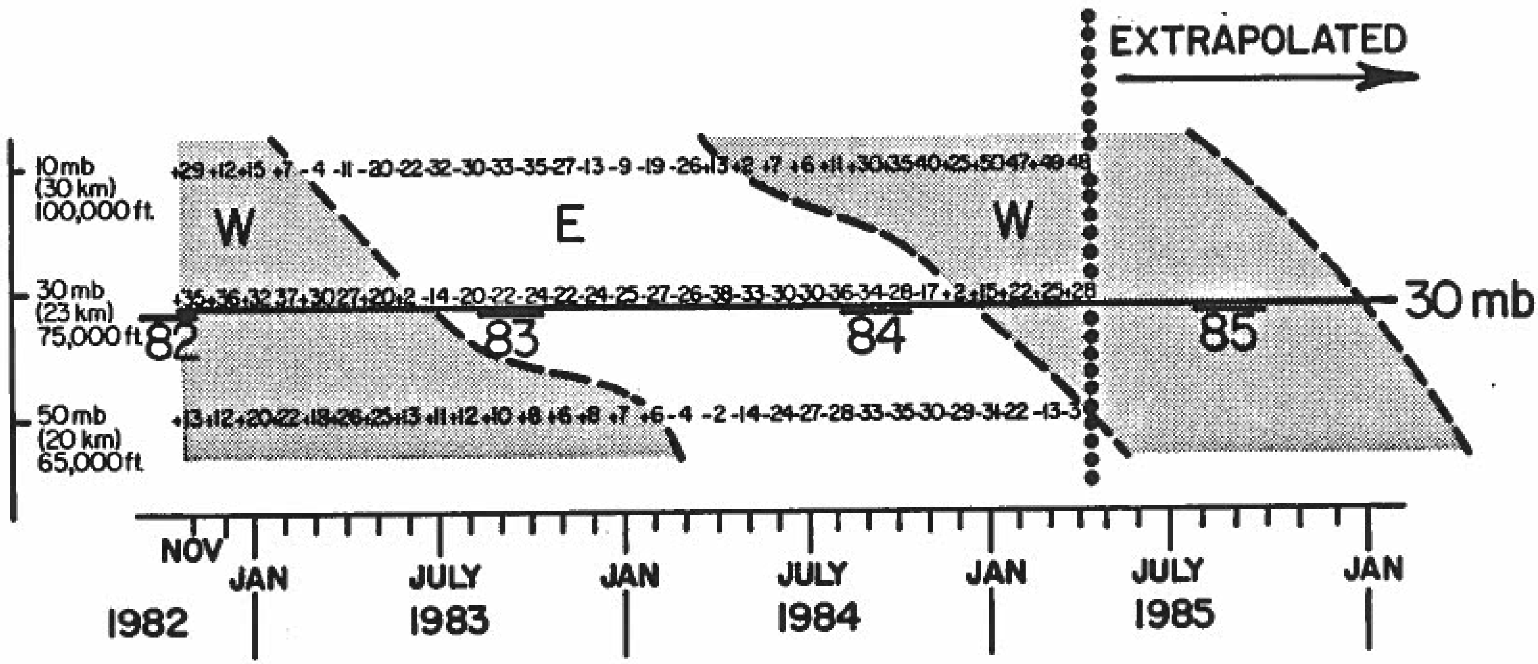

Fig. 7. Vertical cross-section of recent stratosphere monthly average QBO west to east or zonal wind (in knots). This figure represents an average of the Balboa, C.Z. (9^oN) and Ascension (8^oS) rawinsondes. The annual cycle has been removed from each sounding before averaging. Winds from a westerly direction have been shaded. Information beyond April 1985 has been extrapolated.

c. Caribbean Sea Sea Level Pressure Anomaly (SLPA)

Although the influence of the QBO and El Nino events on hurricane frequency are of primary importance, the regional influences of sringtime and early summer regional Sea Level Pressure Anomaly (SLPA) also exhibits a detectable and significant association with seasonal hurricane activity. SLPA acts to influence seasonal cyclone frequency by about one cyclone for every 0.4 mb of mean pre-season pressure anomaly. More hurricanes occur when pre-season Caribbean pressure anomaly is lower and fewer storms occur when pressure is higher than average. Lower pressure is typically associated with higher sea surface temperature and vice versa. As discussed by Shapiro (1982) one can account for much of the seasonal variation of sea temperature through the pressure measurement.

d. 200 mb Zonal Wind Anomaly (ZWA)

A study of hurricane frequency over the 35-year period of 1950-1984 shows that Atlantic hurricane activity is also associated with late spring and early summer upper tropospheric west to east zonal wind velocities at the low latitude Caribbean Sea stations of Balboa, C.Z. (9^{o}N), San Andres (12.5^{o}N), Curacao (12^{o}N), Trinidad (10.5^{o}N) and Barbados (13^{o}N). Stronger than average 200 mb (12 km or 40,000 ft level) winds from the west are associated with fewer hurricanes. By contrast, hurricane activity is more prevalent when early summer 200 mb winds at these stations are weaker than average from the west or stronger than average from the east. It is the June-July wind which are related to cyclone activity. These winds are not used for the 1 June forecast but assist with the 1 August updated forecast.

e. Internal Correlation of EN, QBO, SLPA, and ZWA Predictive Parameters

To try to better delineate the relationships between these combinations of predictors and seasonal hurricane activity a multiple linear regression analysis was made. It was found that a very low internal correlation exists between each of these predictors. This is very fortunate and is the basis of the forecast scheme to follow. These low internal correlations of predictors allow for a significant forecast improvement when all these predictors are used in combination.

f. The Rationale for Developing an Atlantic Seasonal Hurricane Activity Forecast

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

1) the sign (east or west) of the QBO wind directions changes on such a long period (~ 12-15 months) and in such a uniform manner, that it can be extrapolated for 3 to 6 months into the future.

2) the oceanography-meteorological community is able to detect the presence and 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 and 200 mb zonal winds for the four pre-hurricane months of April through July are readily available.

Figure 8 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.

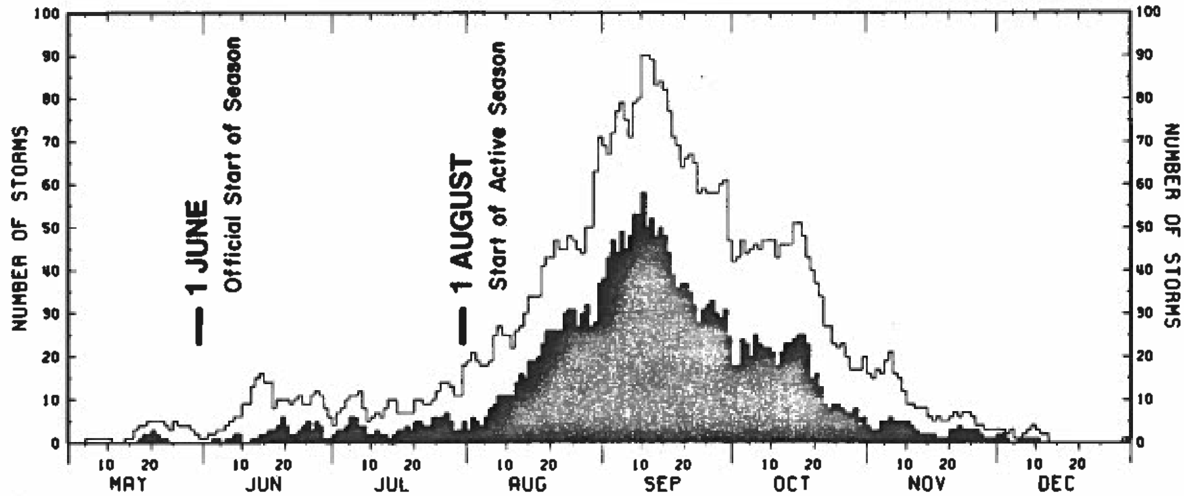

Fig. 8. Number of tropical storms and hurricanes (open curve) and hurricanes (solid curve) observed on each day, May 1, 1886 through December 31, 1980 (from Neumann, et al., 1981).

3. Seasonal Hurricane Activity Forecast Methodology

Seasonal hurricane activity forecast equations have been developed from 33 years of dependent data as discussed in the author's previous paper (Gray, 1984b). Recent research has led to some small modification of these formulas. The following equations show how the prediction of the number of hurricanes per year, the number of hurricanes and tropical storms per year, and the number of hurricane days per year is made from QBO, EN, SLPA and ZWA information.

a. Number of Hurricanes

Equation (1) gives a simple formula to predict the seasonal number of hurricanes

$$\begin{pmatrix}\text{Predicted No.}\\ \text{of Hurricanes}\\ \text{per season}\end{pmatrix} = 6 + (QBO_1 + QBO_2) + EN + SLPA + ZWA \qquad (1)$$

where

QBO_1 = 30 mb equatorial wind direction correction factor – if westerly add one, if easterly subtract one. Set to zero if zonal wind direction during the season is in a change over phase from east to west or west to east.

QBO_2 = correction factor for change in 30 mb equatorial zonal winds (u) during the hurricane season – if uniformally increasing westerly (positive $\partial u/\partial t$) then add one, if uniformally decreasing westerly (negative $\partial u/\partial t$) then subtract one. Set to zero if there is a change of sign of $\partial u/\partial t$ during the season.

EN = El Nino influence. If present subtract two for a moderate El Nino event, four for a strong El Nino event. Add one in non-El Nino years if QBO winds are from the west otherwise set to zero.

SLPA = average SLPA for April-May, from the 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. Used to update the 1 August forecast. Not 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 $\pm$ 1.

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

$$\begin{pmatrix}\text{Predicted No. of} \\ \text{Hurricanes and} \\ \text{Tropical Storms} \\ \text{per season}\end{pmatrix} = 9 + QBO + EN + SLPA + ZWA \qquad (2)$$

where

QBO = 30 mb equatorial wind direction correction factor - if westerly add 1.5, if easterly subtract 1.5. In El Nino years add 2 for west winds and subtract 2 for east winds. Set to zero if zonal wind direction is in a change over phase from east to west or west to east during the season. Make no correction for the change in QBO wind speed during the season.

EN = El Nino influence. If present subtract two for a moderate El Nino event, four for a strong El Nino event, otherwise add 0.7.

SLPA = Same as for hurricane forecast.

ZWA = Same as for hurricane forecast.

c. Number of Hurricane Days

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

$$\begin{pmatrix}\text{Predicted No. of}\\ \text{Hurricane Days}\\ \text{per season}\end{pmatrix} = 25 + 5\ [(QBO_1 + QBO_2)+EN+SLPA+ZWA] \qquad (3)$$

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, thus

QBO_1 = QBO correction factor due to 30 mb wind direction - if westerly add one, if easterly subtract one. Set to zero if wind direction is in a change over phase from east to west or west to east during the season. This correction factor for hurricane days has recently been changed from the previous value discussed last year.

QBO_2 = QBO correction factor due to uniform change in 30 mb zonal wind (u) speed during the hurricane season - if increasing westerly (positive $\partial u/\partial t$) then add one, if decreasing westerly (negative $\partial u/\partial t$) then subtract one. Set to zero if there is a change of sign of $\partial u/\partial t$ during the season.

EN = If El Nino year then subtract two for moderate El Nino or four for a strong El Nino. Add one in all non-El Nino years.

SLPA = Same as for hurricane forecast.

4. Seasonal Prediction for 1985

a. Background Observational Setting

This season of 1985 will be the first since 1980 when stratospheric QBO winds will be from the west and no El Nino influence is present. In 1980 there were 9 hurricanes (3 above average) and 38 hurricane days (13 above average). Since 1950 when stratospheric QBO wind data first became available there have been 13 of 35 seasons when QBO winds were from the west and no El Nino was present. Table 1 lists these years with number of hurricanes, hurricanes and tropical storms, and hurricane days. Only two of these years (1978, 1973) had less than 6 hurricanes, only 4 of these 13 years had less then 28 hurricane days. The average number of hurricanes, hurricanes and tropical storms, and hurricane days was 7.4, 11.1 and 33.6. The other 22 seasons which had either easterly or QBO winds indeterminate or an El Nino event averaged 4.9 hurricanes, 7.9 hurricanes and tropical storms and 18.6 hurricane days. The former group had an average of 80 percent more hurricane days. There were also other differences. Most of the westerly QBO without an El Nino seasons also showed an above number of low latitude long and westerly storm tracks across the Atlantic and the Caribbean. It is the lower latitude cyclones which tend to be more intense and which, because of their longer tracks, develop the greater number of hurricane days. These westerly QBO without an El Nino season are much in contrast to the last three years of 1982-83-84 when there were no low latitude westward tracking hurricanes at all in the western Atlantic or Caribbean. Figures 9 and 10 contrast the last 3 seasons (1982-84) of hurricanes and weaker cyclone system tracks with the 3 seasons prior to that period (1979-81). Note the large differences in low latitude westerly tracks in these two 3-year periods. With the return of QBO west winds and the current gradual building up of opposite anti-El Nino conditions in the Pacific the odds favor a return to a more typical and active hurricane season as representative of the storm tracks and storm frequency which occurred during most of the years listed in Table 1.

Because the major period for lower latitude cyclones of African origin is early August to mid-September, it should be expected that the active portion of the 1985 season should commence a few weeks earlier than the 1984 season did. This would be in contrast to the last three seasons when only one named storm formed prior to the middle of August and only 3 named storms in all three years formed before the 28th of August.

The Caribbean Basin in particular should expect an increased probability of tropical cyclone activity and increased probability of more westerly tracking tropical cyclones.

b. Springtime Sea Level Pressure Anomaly (SLPA) for 1985

Table 2 gives information on 1 April-28 May, 1985 Caribbean-Gulf of Mexico SLPA in mb. Data is derived from six key stations of this region. The average of these stations is only slightly negative for this period. This indicates that no correction due to SLPA is to be made.

TABLE 1

Seasons since 1950 when stratospheric QBO winds were from the west and no El Nino was present.

Year	Number of Hurricanes	Number of Named Storms	Number of Hurricane Days
1980	9	11	38
1978	5	11	13
1975	6	8	18
1973	4	7	9
1971	6	13	28
1969	10	14	39
1966	7	11	41
1964	6	12	43
1961	8	11	46
1959	7	11	22
1955	9	12	46
1951	8	10	37
1950	11	13	57
13 Year Average	7.4	11.1	33.6
Average for Other 22 Years when either easterly or indeterminate QBO winds or an El Nino event was present	4.9	7.9	18.6

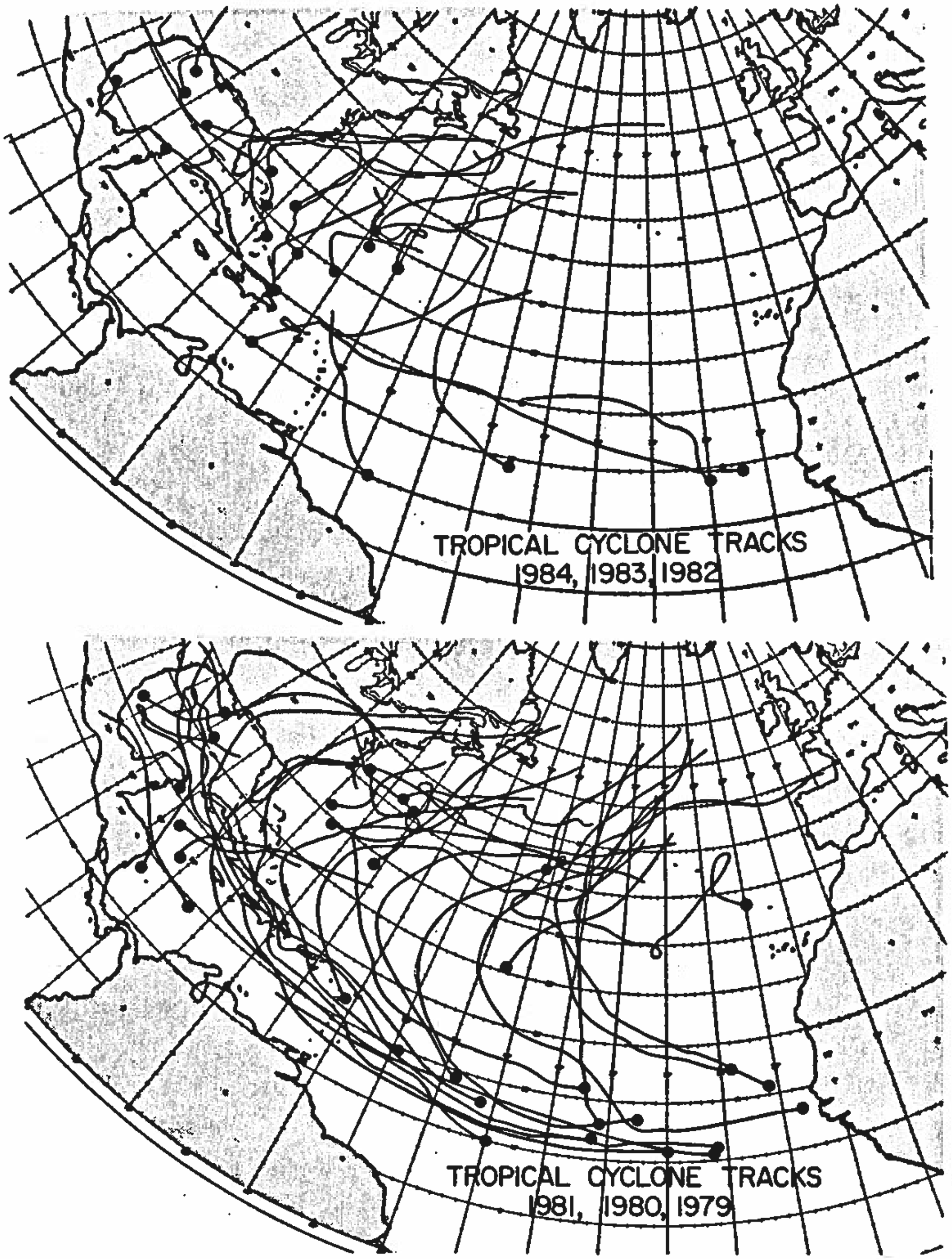

Fig. 9. Tracks of tropical cyclone or pre-tropical cyclone systems in 1982-83-84 (top diagram) in comparison with similar tracks during 1979-80-81.

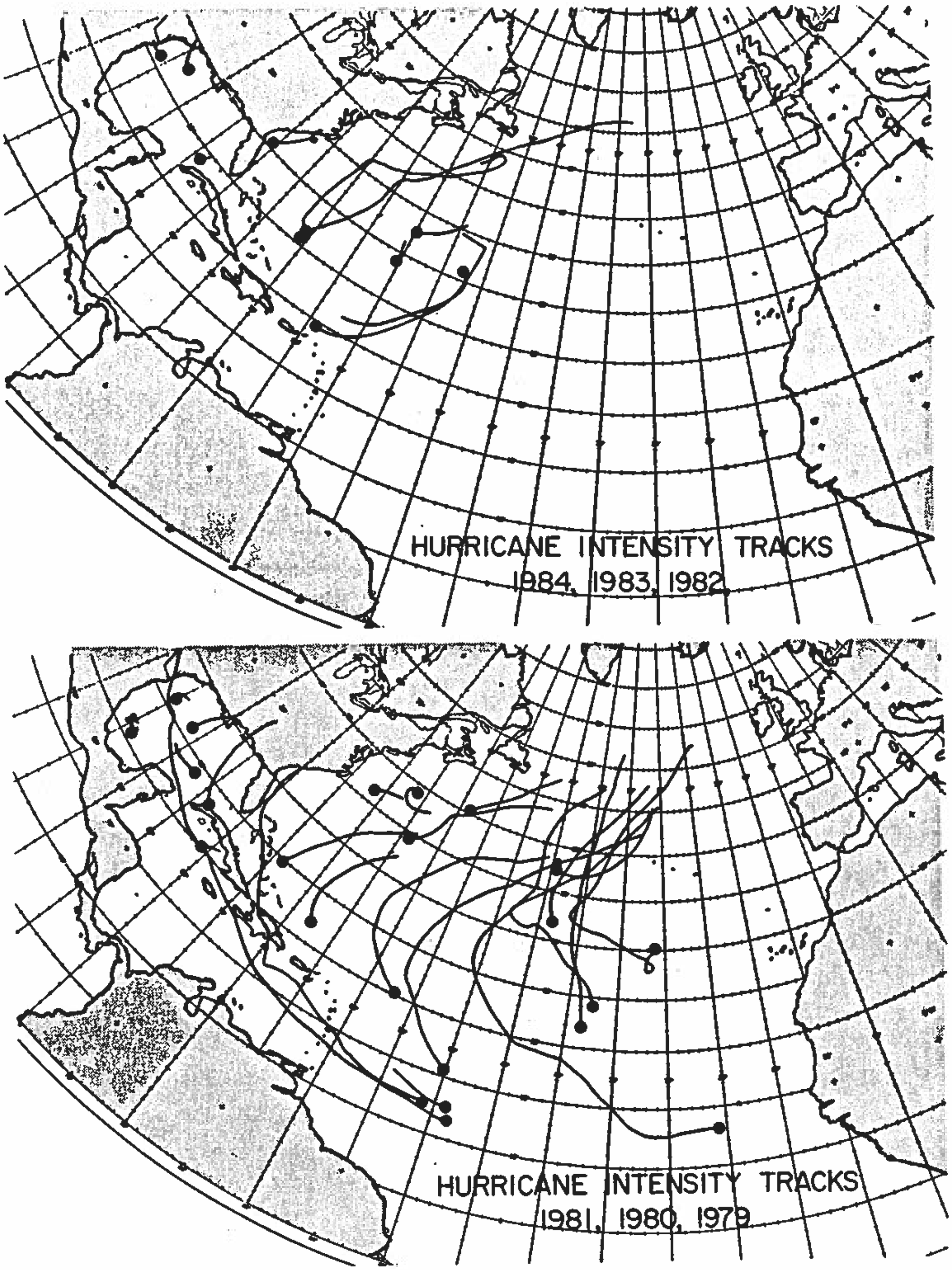

Fig. 10. Same as Fig. 9 but for tropical cyclones of hurricane intensity.

TABLE 2

PRE-1985 HURRICANE SEASON
SEA LEVEL PRESSURE ANOMALY (SLPA) - IN MB
(from data kindly supplied by Arthur Pike of NHC)

	1 April-28 May
BROWNSVILLE	+0.4
MERIDA	-0.1
MIAMI	-0.6
SAN JUAN	-0.6
CURACAO	+0.5
BARBADOS	+0.3
MEAN	-0.0

c. Estimation of the Correction Terms for Equation (1) to (3) for the Coming 1985 Tropical Cyclone Season

1. (QBO) - stratospheric equatorial winds will be from the west. Correction is +1.

2. $(QBO)_2$ - 30 mb westerly stratospheric winds should peak sometime during the 1985 hurricane season with no systematic increase or decrease. Correction is thus expected to be zero.

3. EN - no El Nino event is expected for this year. With QBO winds from the west the EN correction is $\underline{+1}$ for the number of hurricanes, $\underline{0.7}$ for the number of hurricanes and tropical storms, and $\underline{+1}$ for number of hurricane days.

4. SLPA - values less than ± 0.4 mb. No correction is made.

5. ZWA - value not applicable for 1 June forecast. Information from June-July data will be applied for the updated 1 August forecast.

d. Actual Prediction for 1985

Table 3 gives the author's numerical estimates of each term of the three prediction equations (1-3) for the 1985 season. Number of hurricanes, number of hurricanes and tropical storms, and number of hurricane days are forecast to be 8 (2 above average), 11 (2 above average), and 35 (10 above average) respectively. The 1985 hurricane season is thus predicted to be a season of above average hurricane activity.

TABLE 3

1985 PREDICTED SEASONAL HURRICANE ACTIVITY

$$\left(\begin{array}{l}\text{PREDICTED NO.}\\ \text{OF HURRICANES}\\ \text{PER SEASON}\end{array}\right) = 6 + (QBO_1 + QBO_2) + EN + SLPA + ZWA$$

$$= 6 + (+1) + (\ 0) + (+1) + (\ 0) + (0) = \boxed{8}$$, 2 Above Average

$$\left(\begin{array}{l}\text{PREDICTED NO. OF}\\ \text{HURRICANES AND}\\ \text{TROPICAL STORMS}\\ \text{PER SEASON}\end{array}\right) = 9 + QBO + EN + SLPA + ZWA$$

$$= 9 + (1.5) + (0.7) + (\ 0) + (0) = \boxed{11}$$, 2 Above Average

$$\left(\begin{array}{l}\text{PREDICTED NO. OF}\\ \text{HURRICANE DAYS}\\ \text{PER SEASON}\end{array}\right) = 25 + 5\ (QBO_1 + QBO_2) + EN + SLPA + ZWA$$

$$= 25 + (+5) + (\ 0) + (+5) + (\ 0) + (0) = \boxed{35}$$, 10 Above Average

An average of about two-thirds of all name storm days are hurricane days. If 1985 follows the average pattern than one might expect about 50 to 55 named storm days.

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5. Seasonal Forecast and Verification for 1984

Table 4 gives the author's 1984 Atlantic Seasonal Tropical Cyclone Forecast for a slightly above average season and its verification. This forecast was issued on 24 May 1984 and updated with no change on 30 July 1984. Hurricane activity was overforecast and tropical storm activity underforecast. Considering the larger number of named storms (12-3 above average) and name storm days (61-23 above average) 1984 might be considered to be a slightly above average tropical cyclone season but slightly below average hurricane season.

The overforecast of hurricane activity is believed to be a result of two factors:

1) The timing of the change of 30 mb QBO winds from an easterly to a westerly direction was misforecast. The change in easterly to westerly winds had been anticipated to occur around the middle of the hurricane season in September. This did not happen. As seen in Fig. 7 easterly 30 mb QBO winds prevailed during the entire 1984 hurricane season. Such a long easterly QBO cycle (18 months) is very unusual and could not be anticipated in late May when this forecast was issued or in late July when the forecast was updated. Although 10 mb winds (30 km altitude) had shifted to a westerly direction by May (when corrected for the annual cycle) 30 mb winds (the level on which the forecast scheme is based) inexplicitly did not become firmly established from the west until January.

It is in those seasons when the QBO winds are undergoing a change in direction that their forecast becomes most difficult. Most hurricane seasons do not have such an expected change over cycle of QBO winds during August through October. The 1984 forecast of the QBO wind direction was thus an especially difficult one not to be expected in most other years. By contrast, westerly winds can confidently be anticipated at 30 mb throughout the entire 1985 season.

2) The long term statistical correlation of April-May Caribbean Basin-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) with August-September SLPA did not hold for 1984. Caribbean Basin SLPA in April-May was -0.43 mb while observed SLPA in August through October was +0.36 mb an opposite relationship. This is believed to have also contributed to the overforecast of hurricane activity for 1984. SLPA in August through October is usually well linked to Atlantic hurricane activity.

TABLE 4
Prediction vs. Observed Tropical Cyclone Activity for 1984

	Predicted	Observed	Yearly Climatological Average
No. of Hurricanes	7	5	6
No. of Hurricane Days	30	21	25
No. of Hurricane and Tropical Storms	10	12	9
No. of Hurricane and Tropical Storm Days	45 (implied from hurricane forecast)	61	38

6. Application of Statistical Probability for Seasonal Forecast

To apply this forecast scheme in a practical way for a seasonal forecast, it is important that the user have some quantitative measure of the expected accuracy of the forecast scheme for that year. This requires that forecasts be presented in some probabilistic form, i.e.- statistical chance of having 4 or more hurricanes per year, 5 or more hurricanes per year, 6 or more hurricanes per year, etc.

The expected statistical accuracy of this forecast method in a particular year might be estimated from an analysis of the individual year forecast errors of this scheme in the 33 year developmental data set. An example will now be given as to how this forecast scheme might be used to predict the probability of the Atlantic having more than a specified number of hurricanes per season.

The climatological probability of the Atlantic having a particular number of Atlantic hurricanes per season is shown in Fig. 11. Note the broad distribution range. The long term average of seasonal hurricane activity indicates that the probability of receiving 4 or more hurricanes per season is about 90%, 6 or more hurricanes per year 55%, 8 or more hurricanes per year 25%, etc.

An analysis of the 33 years of seasonal forecast errors in the developmental data set shows that this scheme correctly predicted the number of hurricanes in a hindcast mode within ± 1 in 22 of 33 years. It was in error by ± 2 hurricanes in 8 or 24% of these years, and ± 3 storms in 3 of the 33 years. No forecasts were in error by more than 3.

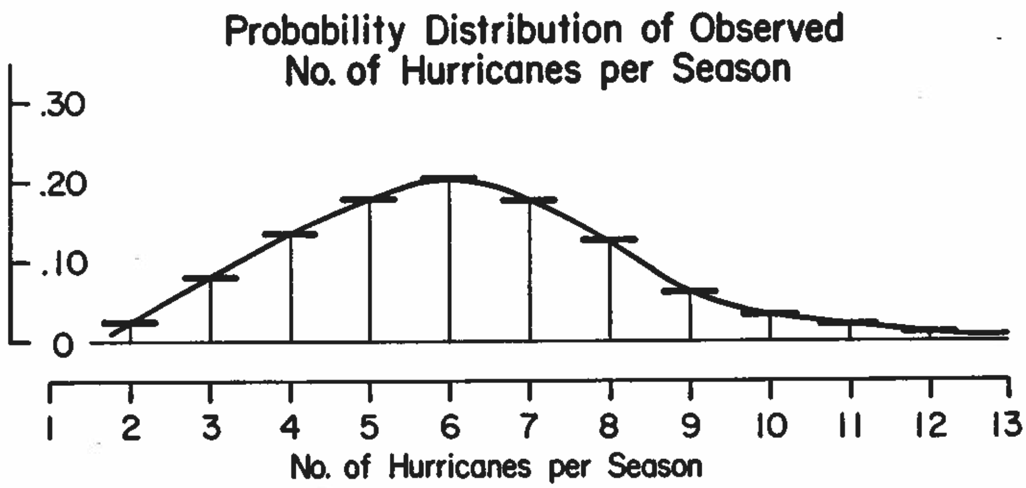

Fig. 11. Mean probability distribution of observed number of hurricanes per season.

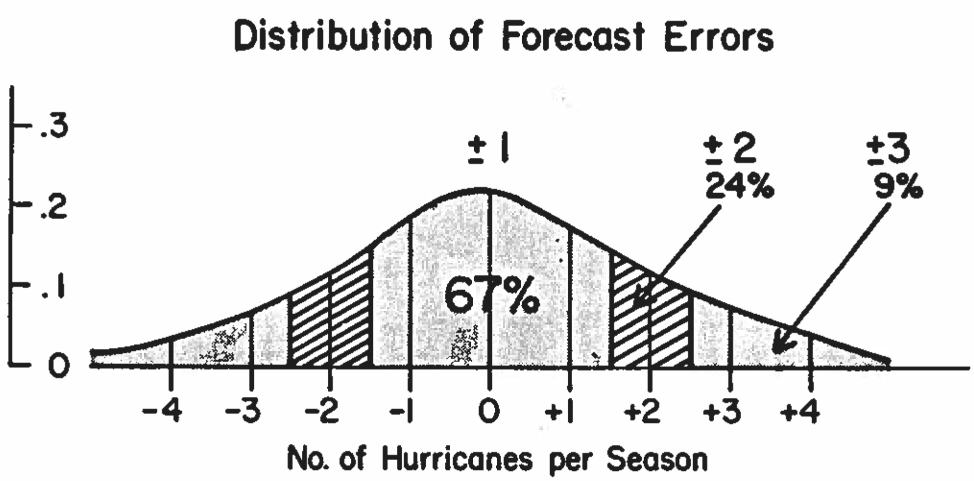

Fig. 12. Probability distribution of forecast errors of seasonal number of hurricanes.

Assuming that these statistics give a representative measure of this scheme's typical distribution of individual year hurricane forecast errors, one might construct a forecast error probability distribution function as shown in Fig. 12.

Probabilities for the 1985 Season. Assuming these typical forecast error statistics for each of the three season hurricane activity parameters the following forecast probabilities for the coming 1985 hurricane season have been generated and are portrayed in Table 5. These statistics are based on the forecast of the number of hurricanes being 8, the number of hurricanes and tropical storms being 11, and the number of hurricane days being 35.

TABLE 5

1985 Forecast Percentage (%) Probabilities for Seasonal Number of Hurricanes, Seasonal Number of Hurricanes and Tropical, Storms, and Seasonal Number of Hurricane Days.

No. of Hurricanes	Percentage Probability	No. of Hurricanes and Tropical Cyclones	Percentage Probability	No. of Hurricane Days	Percentage Probability
		15 or more	1		
12 or more	1	14 or more	5	60 or more	2
11 or more	5	13 or more	15	55 or more	5
10 or more	20	12 or more	35	50 or more	10
9 or more	40	11 or more	55	45 or more	15
8 or more	55	10 or more	70	40 or more	35
7 or more	70	9 or more	85	35 or more	50
6 or more	85	8 or more	90	30 or more	60
5 or more	95	7 or more	95	25 or more	80
4 or more	99	6 or more	90	20 or more	90
3 or more	>99	5 or more	>99	15 or more	95
2 or more	>99	4 or more	>>99	10 or more	99
				5 or more	>99

7. Updated 1 August Forecast

More recent research by the author is indicating that there is a greater predictive signal from low latitude June and July surface pressure and 200 mb zonal wind data than had previously been found. The update of this forecast which I will make on 1 August (just before the beginning of the active portion of the hurricane season where June and July meteorological data will be available) is likely to be more reliable than this 1 June forecast. This 1 August updated forecast will be sent to all those currently on the author's mailing list.

8. Cautionary Note

It is important that the reader realize that this 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. This forecast scheme will likely fail in some years when the other unknown factors (besides the QBO, EN, SLPA and ZWA) which cause cyclone variability are more dominant, or if the QBO, EN, SLPA and ZWA conditions should be misforecast. It is impossible to determine beforehand which years this 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, 1981 was a moderately active season (7 hurricanes, 12 hurricanes and tropical cyclones) but only two of the weaker systems affected the US). 1983 was one of the most inactive seasons on record but Hurricane Alicia caused over a billion dollars of damage to the Houston.

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10. Bibliography

Gray, W. M., 1983: Atlantic seasonal hurricane frequency, Part I and II. Dept. of Atmos. Sci. Paper No. 370, Colo. State Univ., Ft. Collins, CO, 100 pp.

Gray, W. M., 1984: Forecasting Atlantic seasonal hurricane frequency. Proceedings of American Meteorological Society, 15th AMS Conference on Hurricanes and Tropical Meteorology, 56-63, (Available from AMS, 45 Beacon St., Boston, MA 02108).

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency: Part I: El Nino and 30 mb quasi-biennial oscillation influences. Mon. Wea. Rev., 112, 1649-1668.

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. Mon. Wea. Rev., 112, 1669-1683.

Gray, W. M., 1985: Large-scale conditions influencing the suppression of Atlantic hurricane activity during 1982-1984. Paper presented at the 16th AMS Conference on Hurricanes and Tropical Meteorology, May 14-17, Houston, TX.

Neumann, C., G. Cry, E. Caso and B. Jarvinen, 1981: Tropical Cyclones of the North Atlantic Ocean, 1871-1977. National Climatic Center, Asheville, NC, 170 pp. (Available from the Superintendent of Documents, US Government Printing Office, Washington, DC, 20402, Stock Number 003-017-00425-2.)

Quinn, W. H., D. O. Zopf, K. S. Short and R. T. W. Kuo Yang, 1978: Historical trends and statistics of the Southern Oscillation, El Nino, and Indonesian droughts. Fish. Bull., 76, 663-678.

Shapiro, L., 1982: Hurricane climatic fluctuations, Part II: Relation to large-scale circulation. Mon. Wea. Rev., 110, 1014-1023.

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