# FORECAST OF ATLANTIC SEASONAL HURRICANE

# ACTIVITY FOR 1984

By

William M. Gray

(This paper is based on background material contained in the Colo. State Univ. Dept. of Atmospheric Science Report No. 370--by W. Gray--together with new May 1984 meteorological information)

Department of Atmospheric Science

Colorado State University

Fort Collins, CO 80523

(As of 24 May 1984)

## ABSTRACT

This paper discusses the author's forecast of the amount of seasonal hurricane activity which can be expected to occur in the Atlantic Ocean region in 1984. This forecast is based on the author's previous research (Gray, 1983) which relates seasonal amount of Atlantic hurricane activity to the three factors: 1) the El Nino (EN); 2) the Quasi-Biennial Oscillation of equatorial stratospheric wind (QBO); and 3) the April-May Caribbean Basin and Gulf of Mexico Sea-Level Pressure Anomaly (SLPA).

Information received by the author as of 24 May 1984 indicates that the 1984 hurricane season can be expected to be a slightly above normal year with about 7 hurricanes (6 is normal), 10 hurricanes and tropical storms (9 is normal), and 30 hurricane days (25 is normal).

This paper gives a brief background description of the methodology of this objective forecast scheme and presents information on the expected influence of each of these forecast parameters for the coming 1984 season. Prediction is also given in terms of the percentage probability of specific number of hurricanes, hurricane days, etc. This forecast has been prepared for the official start of the hurricane season on 1 June. It will be updated again on 1 August, near the beginning of the most active part of the hurricane season.

# OUTLINE

## 1. Background

The Atlantic experiences a larger seasonal variability of hurricane 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 skillful method for indicating whether a coming hurricane season was going to be an active one or not. Recent research by the author (Gray, 1983) indicates that there are three atmospheric parameters (out of a large number studied) which have a reasonably high 4-6 month lag correlation with the following season's hurricanes activity. If these three predictive parameters 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 three seasonal hurricane predictors and give information as to what these predictors indicate for the level of hurricane activity in the coming 1984 season.

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

## 2. Discussion of the Three Atmospheric Parameters Which Have a 4-6 Month Predictive Signal for Atlantic Hurricane Activity

The three predictors are the El Nino (EN), the Equatorial Stratospheric Quasi-Biennial-Oscillation (QBO) of east-west or zonal Wind, and the Caribbean-Gulf of Mexico April-May Sea Level Pressure Anomaly (SLPA).

### a. The El Nino

These special long time scale (12-18 month) tropical eastern and central Pacific sea surface temperature (SST) warming events which are named 'El Nino' cause a general reduction in hurricane activity in the Atlantic basin during the season following the onset of such an event.

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 68 non-El Nino years of this century. Figure 1 is a plot of the seasonal number of hurricane days for the years of 1900-1983 with El Nino years shown by the thick vertical 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 are El Nino years.

A ranking of the number of hurricanes per year gives similar results. Of the 28 years with three hurricanes or less, 12 years (or 43%) were moderate or strong El Nino years. Of the 56 seasons with four or more hurricanes only four (or 7%) were El Nino years. There are

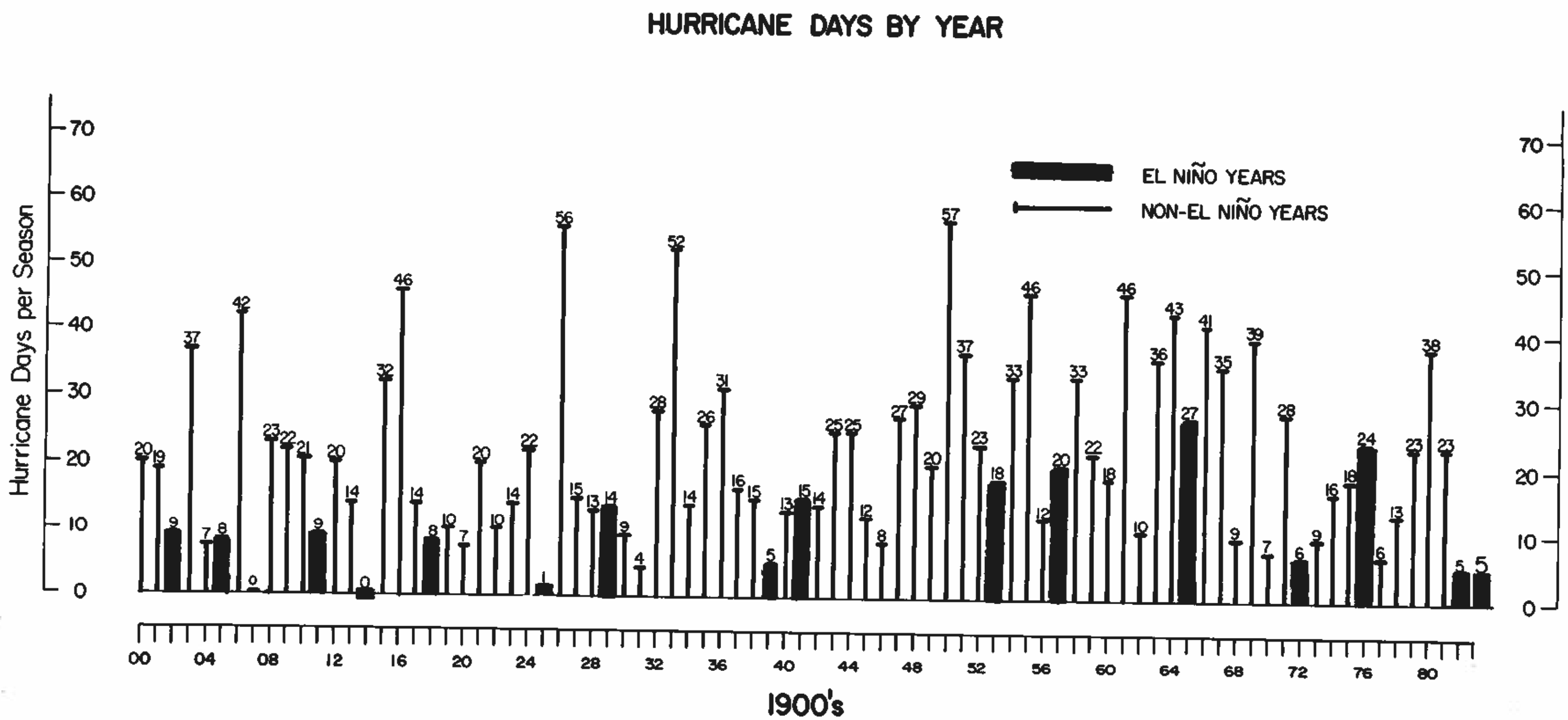


Fig. 1. Number of hurricane days (figure at top of lines) in El Nino/non-El Nino years by year from 1900-1983.

only about half as many hurricanes per season during El Nino as compared with non-El Nino years.

It is also interesting to note that of the 54 major hurricanes[1] striking the United States coast (as determined by Hebert and Taylor, 1978) during the period of 1900 to 1976 and with added years of 1977-1983 (by the author), only four occurred during these 16 strong and moderate El Nino years. During the other 68 non-El Nino years from 1900 to 1983, there were 50 major hurricane strikes on the US Coast. The ratio of major hurricane strikes on the US per El Nino year is .25 while that of major hurricanes per non-El Nino year is .74, a three to one difference.

The very small Atlantic hurricane activity during the 1982 and 1983 seasons appears to be largely a result of the unusually strong and long lasting El Nino (strongest of this century) event which spanned these two hurricane seasons.

A total of 706 hurricane related deaths have occurred in the US during the 16 years of strong and moderate El Nino events of this century or an average of 44 deaths per El Nino year. By contrast there have been 12,232 deaths in the 68 other non-El Nino years or an average of 180 deaths per year--about a four to one difference. Even discounting the high non-El Nino death years of 1900 (6000 deaths) and 1928 (1836 deaths), El Nino years are still much safer as far as loss of US life is concerned.

---

(1) Saffir/Simpson Hurricane scale classification of 4 or 5 [surface pressure $< 944$ mb, sustained winds $> 130$ mph].

This El Nino-Atlantic hurricane activity relationship appears to be related to the associated extra deep cumulus convection found in the eastern Pacific during these warm water episodes. This additional enhanced convection appears to cause, in turn, anomalously strong westerly upper tropospheric (12 km height or 40,000 ft.) wind patterns over the Caribbean Basin and equatorial Atlantic. These enhanced westerly wind patterns are believed to be the major cause of the reduction in hurricane activity.

b. Equatorial Quasi-Biennial Oscillation (QBO) of Stratospheric Zonal (East-West) Winds.

An unusual 24-30 month oscillation period of stratospheric global east-west or zonal winds exist between 0-15$^{\circ}$ latitude on either side of the equator at pressure levels of 50 to 10 mb (or 20-35 km -- 65,000-110,000 ft. height). This wind oscillation was first detected in the late 1950's and early 1960's. The near biennial (or close to 2 year period) of these wind variation have been termed Quasi-Biennial Oscillation (or QBO) by scientists who analyzed this oscillation in the 1960's. This QBO stratospheric wind oscillation encompasses the globe and at individual stratospheric levels is present at all equatorial observing stations.

Information on the Quasi-Biennial Oscillation (QBO) of the stratospheric equatorial zonal winds is available only since 1949-1950. Continuous and reliable equatorial wind information were not available before that time. Typical zonal wind oscillations from 1950 to early 1978 is shown in Fig. 2. The shaded areas on this figure denote periods when the global equatorial stratospheric winds are from a westerly

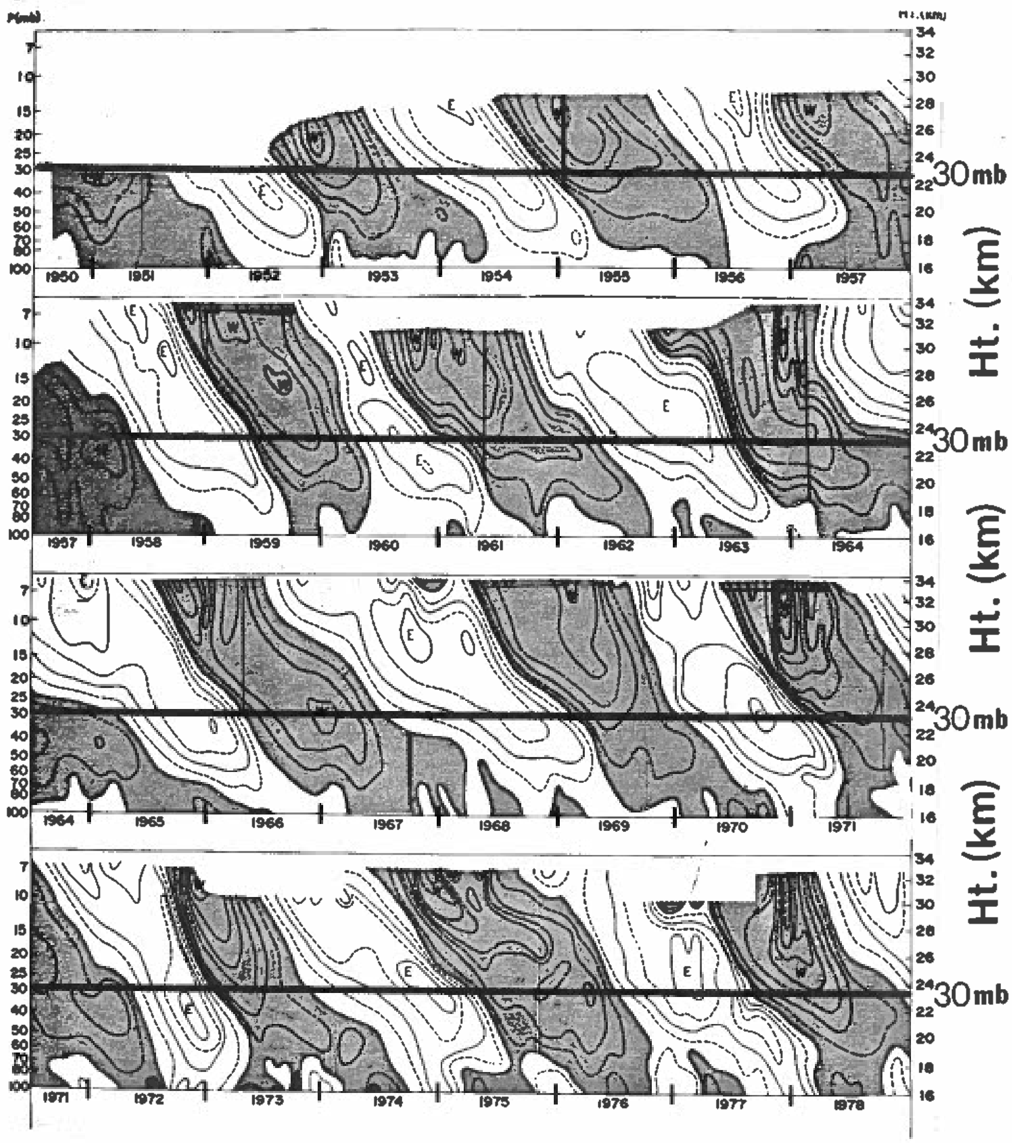


Fig. 2. Vertical plot of stratospheric zonal wind (in knots) from 1950 to 1978. Westerly winds are shaded. (From Coy, 1979). The solid line denoted the 30 mb pressure level (~23 km). It is the winds at this level which best correlate with hurricane activity.

direction. No shading denotes times when equatorial winds are from the east. The near biennial (or 2 - 2 1/2 year period) of this wind oscillation is obvious.

The direction of the stratospheric zonal winds at 30 mb (23 km altitude) has a surprising correspondence with Atlantic hurricane activity. Hurricane activity is, in general 1 1/2 to 2 times more prevalent when these stratospheric winds blow from a westerly direction in comparison to when they blow from an easterly direction. Figure 3 shows a plot of the number of hurricane days per year from 1949 through 1983 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. This is a strong association.

About one and a half times more hurricane intensity tropical cyclones strike the US coast in QBO west wind cases than in east wind cases.

It is also observed that seasonal hurricane activity is related to the temporal changes of zonal wind during the hurricane season. Irrespective of wind direction, seasonal hurricane activity is enhanced when 30 mb winds are becoming more westerly, and suppressed when they are becoming more easterly. Figures 4 and 5 portray the tracks of hurricane intensity storms for 12 non-El Nino years between 1950-1982 when 30 mb zonal winds were increasing with time during the hurricane season vs. 12 non-El Nino years when 30 mb zonal winds were decreasing with time during the hurricane season. There were 42 percent more hurricanes and 60 percent more hurricane days in non-El Nino seasons with increasing 30 mb westerly winds (or decreasing easterly winds) than in seasons of increasing 30 mb easterly winds.

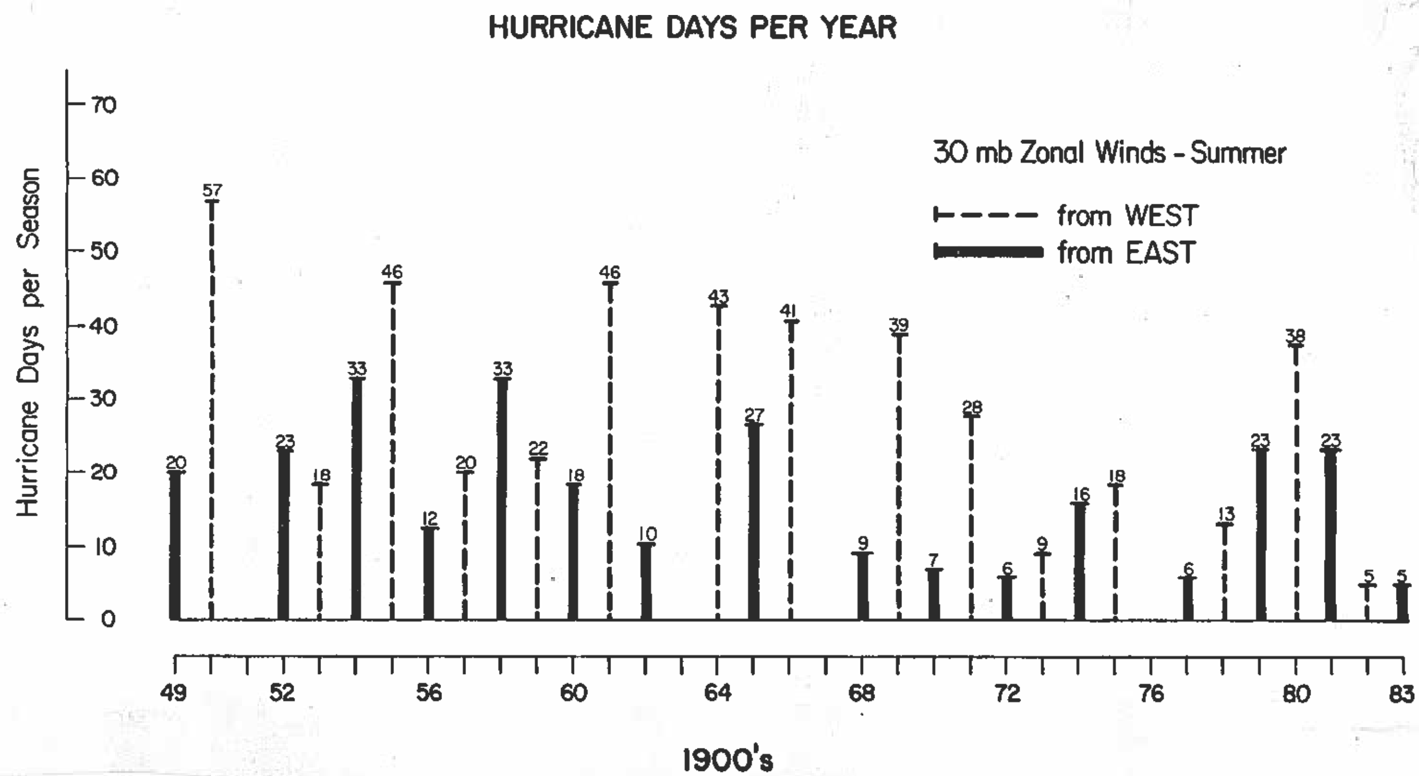


Fig. 3. Relationship between 30 mb stratospheric wind direction and seasonal number of hurricane days from 1949-1983. Years with no observation are those in which the 30 mb zonal wind is changing direction or is very weak.

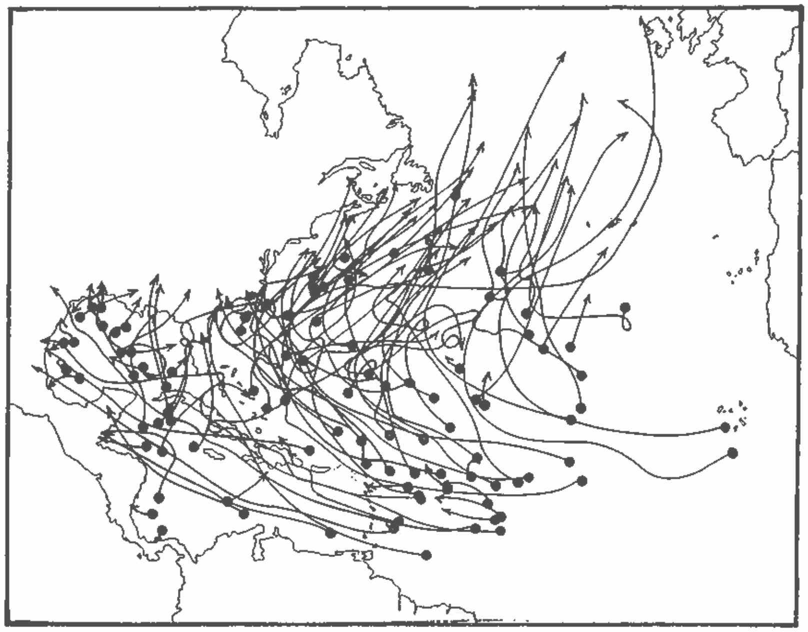

Fig. 4. Composite tracks of hurricane-intensity tropical cyclones during 12 non-El Nino years when 30 mb equatorial zonal winds were increasing during the hurricane season. The twelve years are: 1950, 1952, 1955, 1959, 1961, 1963, 1966, 1969, 1971, 1975, 1979, 1980.

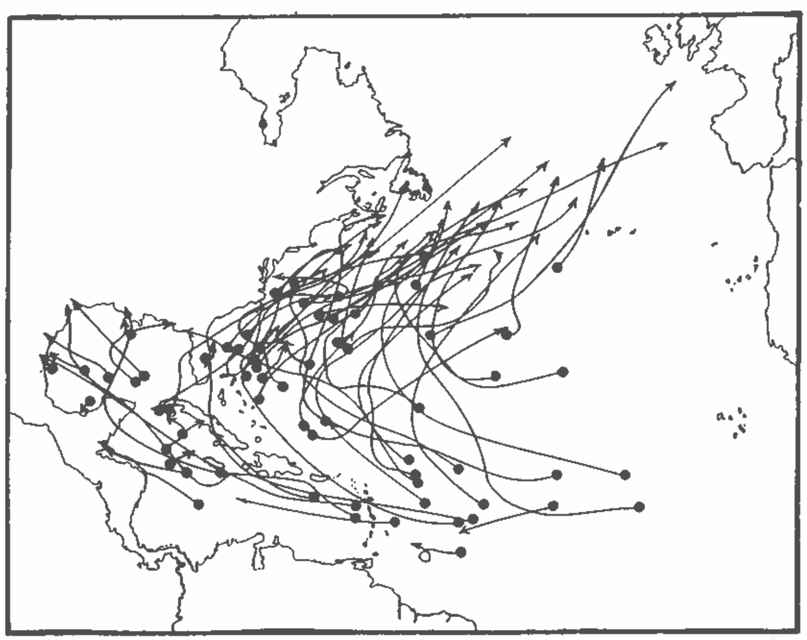

Fig. 5. Composite tracks of hurricane-intensity tropical cyclones during 12 non-El Nino years when 30 mb equatorial zonal winds were decreasing during the hurricane season. The twelve years are: 1951, 1956, 1958, 1962, 1964, 1967, 1968, 1970, 1973, 1974, 1978, 1981.

We have as yet no adequate physical understanding as to why this QBO and seasonal hurricane association exist. The relationship is much less pronounced in the other global tropical cyclone basins.

c. April-May Caribbean Basin Sea Level Pressure Anomaly (SLPA) and Seasonal Hurricane Activity

Although the influence of the QBO and El Nino events on hurricane frequency are of primary importance, the regional influences of springtime monthly Sea Level Pressure Anomaly (SLPA) also exerts a detectable and significant association with seasonal hurricane modulation.

Table 1 shows the monthly correlation of SLPA with seasonal numbers of hurricanes, hurricanes and tropical storms, and hurricane days for a 33 year period (1950-1982) and for the 27 non-El Nino years of this period. Non-El Nino years correlate best. As was expected the August-September SLPA showed the best correlation with hurricane activity. In a predictive sense, however, August-September cannot be used. It is of interest that May and April-May's SLPA correlate almost as well with seasonal hurricane activity as does the June-July SLPA. Note that the correlation of April-May SLPA with hurricanes and with hurricane and tropical storm activity for non-El Nino years is as high as -.48 to -.45. April pressure has a slightly higher correlation than does May pressure.

The fact that the hurricane activity correlation with May and April-May SLPA is as high as June-July SLPA is fortunate because of the longer forecast lead time which is possible. All information needed to make a seasonal forecast of hurricane activity is available on 1 June, the official start of the hurricane season. For these reasons it was

TABLE 1

Correlation of average Caribbean - Gulf of Mexico region SLPA and seasonal hurricane activity by month for the period 1950-1982. The correlation of the 27 non-El Nino years of this period with hurricane activity is shown in parentheses.

| | May | April-May | June-July | August-September |
|---|---|---|---|---|
| No. of Hurricanes | -.28<br>(-.45) | -.34<br>(-.48) | -.34<br>(-.40) | -.39<br>(-.61) |
| No. of Hurricanes and Tropical Storms | -.31<br>(-.36) | -.50<br>(-.45) | -.40<br>(-.34) | -.52<br>(-.51) |
| No. of Hurricane Days | -.12<br>(-.24) | -.20<br>(-.32) | -.36<br>(-.42) | -.61<br>(-.59) |

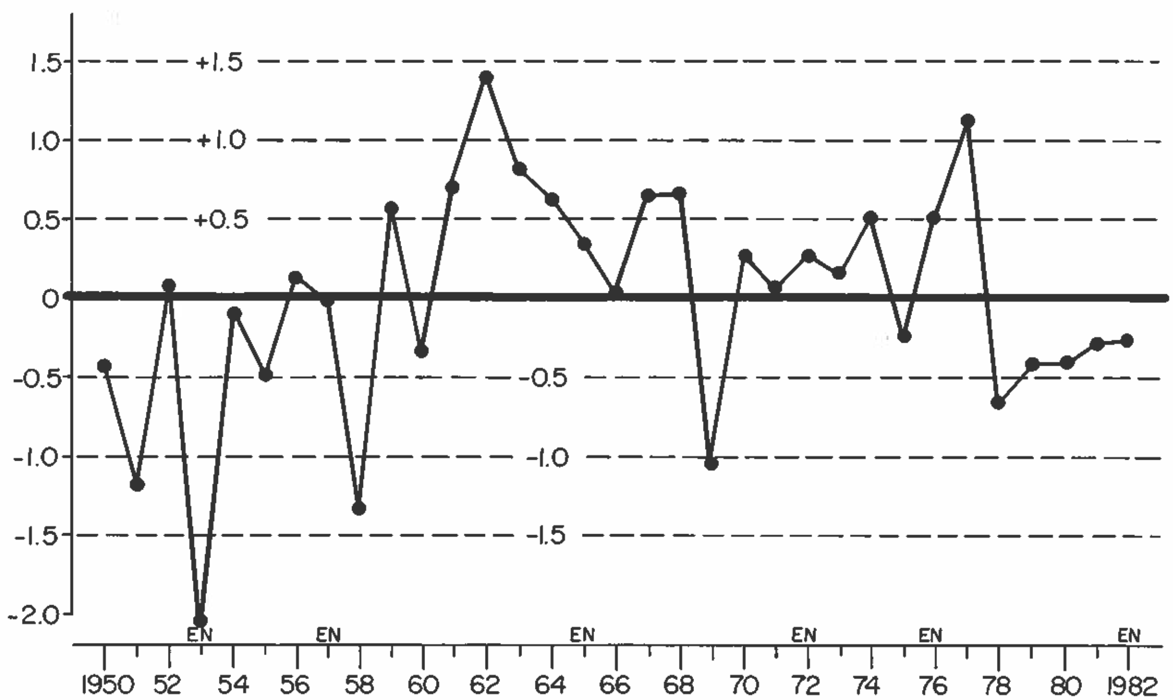


Fig. 6. Yearly variation of April-May mean Caribbean Basin SLPA for the period of 1950-1982.

decided to give primary attention to the year to year variation of April-May SLPA.

Inspection of the April-May SLPA (as shown in Fig. 6) and tropical hurricane frequency indicates that SLPA acts to influence seasonal cyclone frequency by about one cyclone for every 0.4 mb of mean pre-season anomaly. In seasons where the SLPA is between -0.4 mb and -0.8 mb hurricane activity can be expected to increase by about one cyclone; when SLPA is less than -0.8 mb then seasonal hurricane activity (all other factors remaining constant) can be expected to be greater than the multi-year seasonal average by about two hurricanes. The reverse situation occurs with SLPA $>$ +0.4 mb and $>$ +0.8 mb respectively. No alteration of cyclone frequency should be considered if monthly SLPA is between $\pm$ 0.4 mb. Regardless of its magnitude the SLPA appears to influence Atlantic hurricane activity by not more than $\pm$2 cyclones.

d. Internal Correlation of EN, QBO, and SLPA 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 QBO, EN and SLPA 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.

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

A forecast scheme using this QBO, EN, and SLPA 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 community is able to detect the presence and intensity of an El Nino event by June 1 or August 1 at the latest.

3) information on the Caribbean Basin monthly average SLPA for the four pre-hurricane months of April to July is readily available to the hurricane forecaster.

Figure 7 shows the average distribution of hurricane and tropical storm activity by calendar date. 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.

f. Other Parameters Related to Seasonal Hurricane Activity

Other pre-hurricane season meteorological parameters such as rainfall, temperature, upper level heights, etc. do not contain a skillful predictive signal. Despite extensive analysis, we have also not been able to detect any pre-hurricane season tropospheric wind pattern features which have a predictive signal that is at all comparable to either the QBO, EN or SLPA predictive signals. For these reasons the seasonal hurricane forecast proposed in the next section will rely solely on information of the QBO, EN and SLPA.

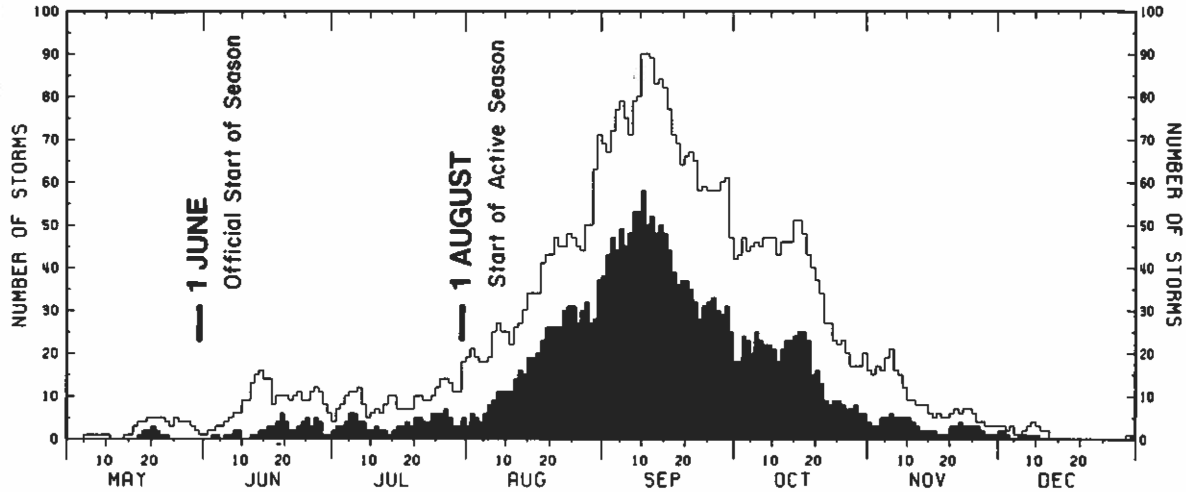


Fig. 7. Number of tropical storms and hurricanes (open curve) and hurricanes (solid curve) observed on each day, May 1, 1886 through December 31, 1980 (from Neumann, et al., 1981).

## 3. Seasonal Hurricane Activity Forecast Methodology

The following seasonal hurricane activity forecast equations have been developed from 33 years of dependent data as discussed in the author's previous paper (Gray, 1983). These equations predict the number of hurricanes per year, the number of hurricanes and tropical storms per year, and the number of hurricane days per year from QBO, EN and April-May SLPA information available on 1 June.

### a. Number of Hurricanes

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

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

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. The total QBO correction represents the sum of $QBO_1$ and $QBO_2$ and varies between $\pm$ 2.

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

SLPA = average SLPA for April-May, from the Caribbean-Gulf of Mexico stations. Add one or two if SLPA is 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. Do not accept any pressure correction greater or less than $\pm$ 2.

Special Correction. If Eq. (1) should indicate a value less than three during an El Nino year, then disregard and make a seasonal forecast for at least three hurricanes. If Eq. 1 indicates a value less than four for a non-El Nino year, then disregard and make the forecast for four hurricanes.

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

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

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 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 = 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 is SLPA is 0.4-0.8 mb or $> 0.8$ mb respectively. Make no correction for SLPA between -0.4 and 0.4 mb. Do not accept any pressure correction greater or less than $\pm$ 2.

Special Correction. If Eq. 2 gives a value less than five in a non-El Nino year then disregard and make a prediction of 5. Accept no value less than 4 in an El Nino year.

c. Number of Hurricane Days

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

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

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 two, if easterly subtract two. Set to zero if wind direction is in a change over phase from east to west or west to east during the season.

$QBO_2$ = 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 = El Nino correction factor. 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 = April-May Sea Level correction factor. Add 2, 1, 0, or -1, -2 depending upon whether the SLPA is $< -0.8$ mb, between -0.4 to -0.8 mb, -0.4 to 0.4 mb, or $> 0.4$ mb, $> 0.8$ mb respectively.

Special Correction. If correction factor is 3 or greater subtract one, if less than -3, set to -3.

d. Forecast Verification for Dependent Data

Using Eq. (1), the predicted to observed number of seasonal hurricanes in our developmental data set was within $\pm$ 2 in all years but three when the errors were 3. A plot of the predicted vs. observed number of hurricanes per season shows a correlation of .77 or a 59% reduction in variance.

Using Eq. (2), the predicted to observed number of hurricanes and tropical storms was in error by more than ± 2 in 4 of 33 years when errors were 3(2 years) and 4(2 years). A plot of the predicted vs. observed number of hurricanes and tropical storms per season gives a correlation of .82 or an explanation of 67% of the inter-year variance.

Errors in predicted to observed number of hurricane days exceeded ± 15 days in only 4 seasons. A plot of the predicted vs. observed number of hurricane days per season from the use of Eq. (3) gave a correlation of .68 or an explanation of about 46% or nearly half of the seasonal variance.

These various analyses of dependent forecast verification show that Atlantic seasonal hurricane activity hindcast predictions can be made (at least in a statistical multi-year fashion) with a quite respectable degree of skill and reliability. Although some degradation in forecasting skill is to be expected when this forecast scheme is applied to future (and independent) data, this degradation will likely not significantly reduce the skillfullness of this forecast method.

What has previously been missing from forecast considerations of Atlantic seasonal hurricane variability has been the more reliable memory of the atmosphere for its larger time and space scales as manifested by the El Nino/Southern Oscillation and the equatorial stratospheric QBO. These more global circulation features appear to exercise a stronger and more persistant association with Atlantic tropical cyclone activity than the more regional parameters.

## 4. Estimates of Predictive Parameters for the 1984 Hurricane Season

### a. QBO Influence

Figure 8 is a vertical cross-section of observed equatorial stratospheric zonal winds as derived from recent stratospheric wind information from the stations of Balboa, C.Z. ($9^{\circ}$N), Ascension Island ($8^{\circ}$S) and Singapore ($1.5^{\circ}$N). Data has been taken up until 21 May 1984. These winds have been corrected for the seasonal cycle. The best estimates as to the extrapolated 30 mb level zonal wind patterns for the months of August through October 1984 are also given in this figure. It is anticipated that in the hurricane season months of August through October 1984 the 30 mb equatorial stratospheric easterly winds will likely be changing sign from an easterly to a westerly wind direction. There is thus (from the author's previous analysis) no suppression or enhancement of hurricane activity due to QBO wind direction. 30 mb QBO winds are expected to be increasing more from a westerly direction during the hurricane season, however. This should lead to a small enhancement of 1984 hurricane activity to the extent of about one hurricane, and 5 hurricane days.

### b. El Nino Influence

Some minor residual influences from the extremely strong and long lasting El Nino event of 1982-1983 appears to be persisting into 1984. As of the end of April warm SST anomaly of $1^{\circ}$C was still present over a broad region from 5-$20^{\circ}$S latitude and extending $30^{\circ}$ longitude west of the South American west coast. Although the majority of the warm-water from the strong 1982-1983 El Nino event is mostly gone the typical cold water conditions associated with more normal anti-El Nino conditions have not yet been established. As the largest part of the SST changes associated with El Nino phenomena typically occur in the winter half of the year it is expected that some residual but weak El Nino influences will persist into the 1984 hurricane season. This is estimated to cause a minor suppression of the Atlantic hurricane season to the extent of one less hurricane, one less hurricane and tropical storm, and five less hurricane days.

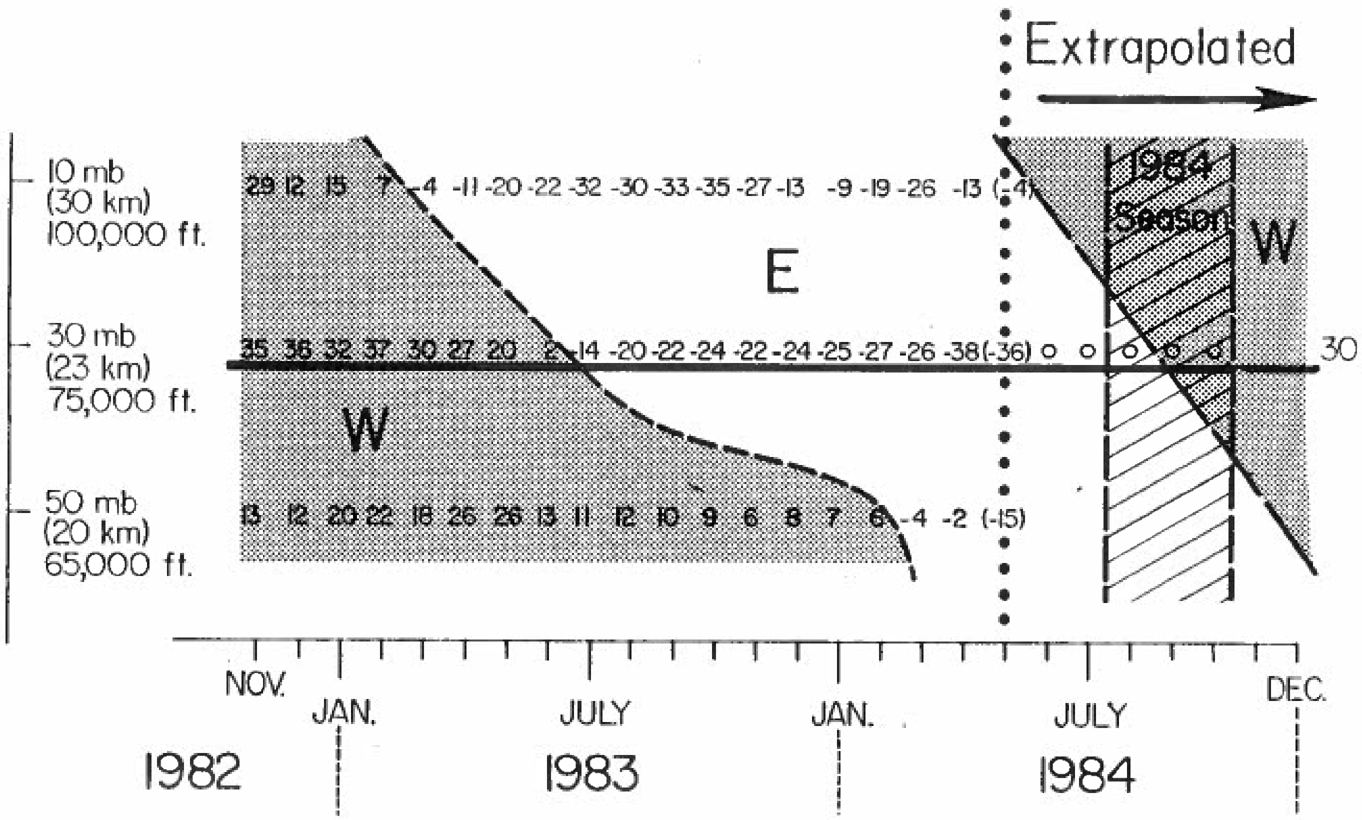


Fig. 8. Vertical cross-section of recent stratosphere monthly average QBO west to east or zonal wind (in knots). This figure represents an average of the Balboa, C.Z. ($9^{o}$N) and Ascension ($8^{o}$S) rawinsondes. The annual cycle has been removed from each sounding before averaging. May values are in parentheses. Winds from a westerly direction have been shaded. Information beyond May 1984 has been extrapolated.

c. Sea Level Pressure Anomaly (SLPA)

Table 2 gives information on 1 April–22 May, 1984 Caribbean- Gulf of Mexico SLPA in mb. Data is derived from six key stations of this region. The average of these stations were substantially more than 1 mb below average in April. Values from 1-22 May have been about 0.4 mb above normal however. It is estimated that the entire April-May mean SLPA will average about the same value as from 1 April to 22 May or be about 0.6 mb below average. Such negative springtime SLPA (other factors remaining constant) indicates, as previously discussed, a higher than normal level of hurricane activity by about one hurricane, one hurricane and tropical storm, and 5 hurricane days.

TABLE 2

PRE-1984 HURRICANE SEASON
SEA LEVEL PRESSURE ANOMALY (SLPA) - IN MB
(FROM DATA SUPPLIED BY A. PIKE OF NHC)

| | APRIL | MAY (1-22 MAY) | 1 APRIL-22 MAY |
|---|---|---|---|
| BROWNSVILLE | -3.0 | -0.4 | -1.8 |
| MERIDA | -2.3 | -0.3 | -1.5 |
| MIAMI | -2.3 | +1.8 | -0.5 |
| SAN JUAN | -0.7 | +0.7 | -0.1 |
| CURACAO | -0.3 | +0.7 | +0.1 |
| BARBADOS | +0.5 | +0.1 | +0.4 |
| MEAN | -1.6 | +0.4 | -0.6 |

d. 1984 Seasonal Prediction

Table 3 gives the author's numerical estimates of each term of the three prediction equations (1-3) for the 1984 season. Number of hurricanes, number of hurricanes and tropical storms, and number of hurricane days are forecast to be 7 (1 above normal), 10 (1 above normal), and 30 (5 above normal) respectively. The 1984 hurricane season is thus predicted to be a season of slightly above normal hurricane activity.

TABLE 3

1984 PREDICTED SEASONAL HURRICANE ACTIVITY

$$\begin{pmatrix}\text{PREDICTED NO.}\\ \text{OF HURRICANES}\\ \text{PER SEASON}\end{pmatrix} = 6 + (QBO_1 + QBO_2) + EN + SLPA$$

$$= 6 + (\ 0) + (+1) + (-1) + (+1) = \boxed{7}, \text{ 1 Above Normal}$$

$$\begin{pmatrix}\text{PREDICTED NO. OF}\\ \text{HURRICANES AND}\\ \text{TROPICAL STORMS}\\ \text{PER SEASON}\end{pmatrix} = 9 + QBO + EN + SLPA$$

$$= 9 + (\ 0) + (-0) + (+1) = \boxed{10}, \text{ 1 Above Normal}$$

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

$$= 25 + (\ 0) + (+5) + (-5) + (+5) = \boxed{30}, \text{ 5 Above Normal}$$

e. Modification of Previous 1984 Seasonal Forecast

Based on an assumption of normal April-May Caribbean-Gulf of Mexico SLPA, the author made a speculative prediction (in July 1983) that the 1984 hurricane season would have 8 hurricanes, 11 hurricanes and tropical storms and 40 hurricane days. This forecast is also contained in the proceedings of the Miami AMS tropical meteorology conference (Gray, 1984) and was repeated at the Tampa, Florida National Hurricane Conference in April of this year.

This previous long-range and speculative forecast for 1984 has had to be revised downward by 1 hurricane, 1 hurricane and tropical storm, and 10 hurricane days because of new observational data which the author has received in the last month. This new observational data indicates that:

1) the period of the current QBO oscillative is more like 30 months rather than the average of 26 months which had been anticipated last year. This means that the expected changeover of 30 mb easterly winds to a westerly direction will now likely take place sometime around September of this year rather than in July as had been previously anticipated. It now is almost certain (based on 10 mb and 20 mb wind information) that 30 mb westerly wind will not be well established by August or September of this year.

The previously anticipated 30 mb westerly winds and increasing westerly wind for the 1984 seasons are thus not going to materialize. Those who monitor the QBO cycle have no explanation as to why the current QBO period is longer than normal. Longer QBO periods like this have occurred in the past, however; especially during the 1960's.

2) the expected establishment of the normal cold SST or anti-El Nino conditions in the eastern tropical Pacific in 1984 has not yet taken place and may not now occur until next autumn or winter. The powerful inhibiting influence of eastern Pacific SST on Atlantic hurricane activity dictates that a small reduction in Atlantic hurricane activity should likely be anticipated until it can positively be established that normal cold water conditions are definitely in place.

New data thus indicates that QBO and EN influences will each cause a small reduction in seasonal hurricane activity from what was anticipated last year. By contrast new SLPA information indicates a small increase in hurricane activity from what had been previously projcted. The combination of these three factors suggests a small net reduction in hurricane activity from last year's projction but still a slightly above normal hurricane season.

f. Analysis of 1983 Forecast

The author issued his first seasonal hurricane forecast in July of last year. He predicted 5 hurricanes (1 below normal), 8 hurricanes and tropical storms (1 below normal), 15 hurricane days (10 below normal) for 1983. The verification was 3 hurricanes (3 below normal), 4 hurricanes and tropical storms (5 below normal), and 5 hurricane days (20 below normal).

Although the author's forecast for the 1983 season was below normal in all three categories, the actual amount of tropical cyclone activity was considerably below normal. This overforecast in 1983 hurricane activities can (in retrospect) be largely attributed to the unexpected persistence and the unexpected strength of the El Nino through the 1983 hurricane season. The 1982-83 El Nino has baffled most of the experts in the date of its onset, its mode of development, its strength, and its multi-year nature.

The strong suppressing influence of El Nino events on Atlantic hurricane activity can lead to a significant overestimate of storm activity should such an El Nino event be underestimated.

Of the three seasonal prediction parameters the El Nino is the most difficult to assess.

## 5. 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 can be determined 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 observed probability of the Atlantic having a particular number of Atlantic hurricanes per season is shown in Fig. 9. 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 past 33 years of seasonal forecast errors showed that this prediction scheme correctly predicted the number of hurricanes 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.

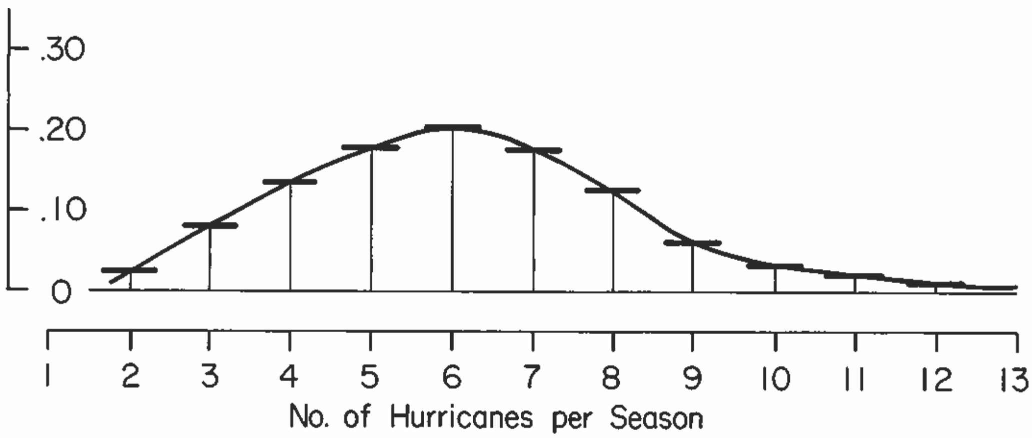


Fig. 9. Mean probability distribution of observed number of hurricanes per season.

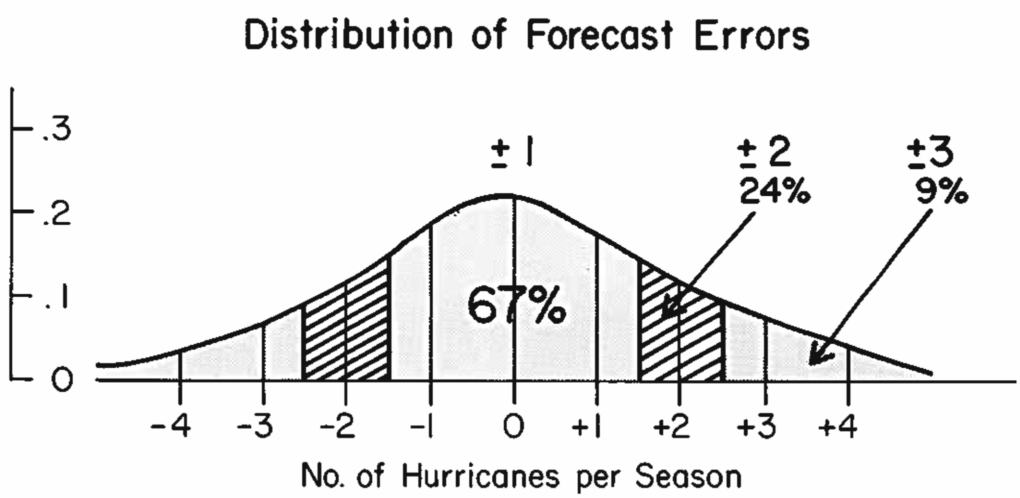


Fig. 10. Probability distribution of forecast errors of seasonal number of hurricanes.

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. 10.

Figure 11 illustrates how the author suggests that these forecast probabilities might be presented for the individual seasonal forecast if for instance the seasonal forecast were for 8 hurricanes (2 above normal), or for 4 hurricanes (2 below normal). For example if a prediction of 8 hurricanes were made the probability of getting 8 or more hurricanes would be 55% vs. the long term observed probability of 25%. The probability of obtaining 8 or more hurricanes per year in a year when 8 are forecast is well over 50 times greater than if the forecast was for 4 hurricanes.

Identical probabilities have been generated for the seasonal number of hurricanes and tropical storms and the seasonal number of hurricane days. It is recommended that the application of this forecast scheme be made in this general manner.

a. Probabilities for the 1984 Season

Given these typical forecast error statistics for each of the three season hurricane activity parameters the following approximate percentage probability statistics for the coming 1984 hurricane season have been generated and are portrayed in Table 4. These statistics are based on the seasonal forecast of the number of hurricanes being 7, the number of hurricanes and tropical storms being 10, and the number of hurricane days being 30.

| Seasonal Hurricane Number | PERCENTAGE PROBABILITY Observed | If Forecast were for 8 (2 above normal) | If Forecast were for 4 (2 below normal) |
|---|---|---|---|
| 12 or more | <1 | 1 | |
| 11 or more | 2 | 5 | |
| 10 or more | 5 | 20 | <<1 |
| 9 or more | 10 | 40 | <1 |
| 8 or more | 25 | 55 | 1 |
| 7 or more | 40 | 70 | 5 |
| 6 or more | 55 | 85 | 20 |
| 5 or more | 70 | 95 | 40 |
| 4 or more | 90 | 99 | 55 |
| 3 or more | 98 | >99 | 80 |
| 2 or more | >99 | >>99 | >99 |

Fig. 11. Percentage probability of obtaining this number or more seasonal hurricanes as a function of whether the seasonal forecast of hurricanes is 8 (center column) or 4 (right column). The long term mean observed probability is given in the left column.

The 1984 hurricane season should definitely be expected to be significantly more active than 1982 and 1983 seasons which had the lowest consecutive two year average of hurricane activity of this century.

An updated version of this forecast will be issued on 1 August at the beginning of the most active portion of the hurricane season.

TABLE 4

1984 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 |
|---|---|---|---|---|---|
| 12 or more | < 1 | 14 or more | 1 | 60 or more | < 1 |
| 11 or more | 1 | 13 or more | 5 | 55 or more | 2 |
| 10 or more | 5 | 12 or more | 15 | 50 or more | 5 |
| 9 or more | 20 | 11 or more | 35 | 45 or more | 10 |
| 8 or more | 40 | 10 or more | 55 | 40 or more | 15 |
| 7 or more | 55 | 9 or more | 70 | 35 or more | 35 |
| 6 or more | 70 | 8 or more | 85 | 30 or more | 50 |
| 5 or more | 85 | 7 or more | 90 | 25 or more | 60 |
| 4 or more | 95 | 6 or more | 95 | 20 or more | 80 |
| 3 or more | 99 | 5 or more | 99 | 15 or more | 90 |
| 2 or more | >99 | 4 or more | >99 | 10 or more | 95 |
| | | 3 or more | >>99 | 5 or more | 99 |

b. Cautionary Note

It is important that the reader realize that this forecast scheme, although showing quite respectable statistical skill in the normal meteorological sense can only predicts about 50% of the variability in Atlantic Seasonal hurricane activity. This forecast scheme will likely fail in some years. It is impossible to determine beforehand which years in which this scheme will work best or worst.

This forecast scheme also does not predict which portion of the 3-5 month 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 storm seasons on record but Hurricane Alicia caused over a billion dollars of damage to Houston.

Acknowledgements

The author is grateful to the following NOAA personnel for the information furnished to him and/or beneficial discussions on: 1) the characteristics of the stratospheric QBO from James Angell and Rod Quiroz; 2) on the El Nino from Eugene Rasmusson; and 3) on Caribbean Basin springtime sea level pressure information from Arthur Pike and Charles Neumann. TSgt Bruce Brooks of Offutt AFB relayed current May QBO wind information to the author.

The author would also like to acknowledge the very beneficial encouragement he has received for this type of research and attempted forecast application from Neil Frank, Director of the US National Hurricane Center and a number of other forecasters at the Miami hurricane center.

This research has been funded by the National Science Foundation.

Bibliography

Coy, L., 1979: An unusually large westerly amplitude of the quasi-biennial oscillation. J. Atmos. Sci., 36, 174-176.

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. (Being published in the Mon. Wea. Rev. in late 1984)

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).

Hebert, P. J. and G. Taylor, 1978: The deadliest, costliest and most intense United States hurricanes of this century. NOAA Technical Memorandum NSW NHC 7, 23 pp. (Available from the National Hurricane Center, Miami, FL).

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.

Author - The author of this paper is a Professor in the Dept. of Atmospheric Science at Colorado State University.