SUMMARY OF 1984 ATLANTIC SEASONAL TROPICAL CYCLONE ACTIVITY AND VERIFICATION OF AUTHOR'S FORECAST

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ABSTRACT

This paper summarizes tropical cyclone activity which occurred in the Atlantic in 1984 and verifies the author's forecast of this activity that was issued last May. This forecast was based on the author's previous research (Gray, 1983, 1984a) which relates seasonal Atlantic hurricane activity to: 1) the El Nino (EN); 2) the Quasi-Biennial Oscillation (QBO) of equatorial 30 mb stratospheric wind; and 3) the April-May Caribbean Basin-Gulf of Mexico Sea-Level Pressure Anomaly (SLPA).

Information received by the author as of 24 May 1984 indicated that the 1984 hurricane season should have been a slightly above average year with about 7 hurricanes (6 is average), 10 hurricanes and tropical storms (9 is average), and 30 hurricane days (25 is average). The actual number of hurricanes which occurred in 1984 was 4 (2 below average); actual number of hurricanes and tropical cyclones was 11 (2 above average); and actual number of hurricane days was 18 (7 below average). The actual number of hurricane and tropical cyclone days was 56 (16 above average).

This paper gives a brief summary of the 1984 tropical cyclone season and discusses how each of the predictive parameters were verified. Reasons for observed versus forecast differences are discussed. An outlook for Atlantic tropical cyclone activity in 1985 is also given.

TABLE OF CONTENTS

1. 1984 Atlantic Tropical Cyclone Activity

The 1984 Atlantic hurricane season officially ends on 1 December. There were four hurricanes (maximum sustained winds $\geq$ 75 mph) and 18 hurricane days during 1984. This is below the last 35 years seasonal average of 6 hurricanes and 25 hurricane days.* By contrast tropical storm activity (tropical storms are tropical cyclones with maximum sustained surface winds between 39-74 mph) was very much above normal. There were 8 named tropical storms in the Atlantic and 35 tropical storm days. The average number of tropical storms which failed to reach hurricane intensity is about 3 and the average number of tropical storm days about 15. The combined number of hurricanes and tropical storms was 11 (2 above average), the combined number of hurricane and tropical storm days was 56 (16 above average).

The 1984 Atlantic tropical cyclone season may thus be summarized as one in which hurricane activity was below average (-2) but tropical storm activity substantially (+5) above average. The author overpredicted hurricane activity and underpredicted tropical storm activity. On the average about two-thirds of all tropical cyclones will reach hurricane intensity and typically about two-thirds of all named storm days are hurricane days and the remaining one-third tropical storm days. These ratios did not apply to 1984, however.

If one accepts a combination of hurricane and tropical storm activity as indicative of the full range of seasonal tropical cyclone

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* A hurricane day or a tropical storm day is defined as a day during which a tropical cyclone has measured or estimated maximum sustained surface winds $\geq$ 75 mph, or 39-74 mph respectively. Any portion of a GMT day meeting these conditions is accepted as a day of these conditions.

activity then one might conclude that the 1984 season was a slightly above average one.

Table 1 and Fig. 1 give a summary of all 1984 Atlantic season tropical cyclone systems.

Of the four hurricanes only two (Diana and Josephine) were of notable intensity. Diana had an intense inner-core of strong winds and reached a minimum central pressure of 949 mb before it went inland in North Carolina. Josephine was noted for its very broad and strong outer circulation and long lifetime. It reached a minimum central pressure of 965 mb. Hortense was a hurricane for only 12 hours and had a minimum pressure of only 993 mb. Klaus was a late season hurricane which reached a minimum pressure of 971 mb as it moved poleward over the open Atlantic.

Besides the usually high 1984 ratio of tropical storms to hurricanes, a number of other interesting features are to be noted about the 1984 Atlantic season.

1) 1984 was an especially late starting season. No named storms occurred until the 29th of August. 1984 was the latest starting of any season of this century with anything close to this number of named tropical cyclones (11). The second latest starting and most active season of this century was 1949 which recorded its first named storm on August 21st and which had 13 named storms.

2) The period of 29 August through 30 September was especially active. Nine named storms formed during the 29 day period of 29 August to 26 September and seven named storms formed during the 21 day period of 29 August to 18 September. Records dating back over a century

TABLE 1
1984 TROPICAL CYCLONE SEASON

Cyclone No.	Cyclone Name	Date Named	Last Day of Name Storm Category	Name Storm Days	Hurricane Days
1.	TS Arthur	29 AUG	31 AUG	3	--
2.	TS Bertha	31 AUG	1 SEPT	2	--
3.	TS Cesar	31 AUG	1 SEPT	2	--
4.	HUR Diana	8 SEPT	16 SEPT	9	4
5.	TS Edouard	14 SEPT	15 SEPT	2	--
6.	TS Fran	18 SEPT	20 SEPT	3	--
7.	TS Gustav	18 SEPT	19 SEPT	2	--
8.	HUR Hortense	25 SEPT	3 OCT	9	1
9.	TS Isidore	26 SEPT	30 OCT	5	--
10.	HUR Josephine	8 OCT	18 OCT	11	8
11.	HUR Klaus	6 NOV	13 NOV	8	5
			TOTAL	56	18

TS means Tropical Storm
HUR means Hurricane

indicate that there has never before been a period when as many as 9 named storms formed in the Atlantic in just 29 days.

3) Twice two storms formed on one day (Bertha and Cesar on 31 August and Fran and Gustav on 18 September) during the 1984 season.

4) Tropical cyclone activity affecting the US east coast was higher than in recent years.

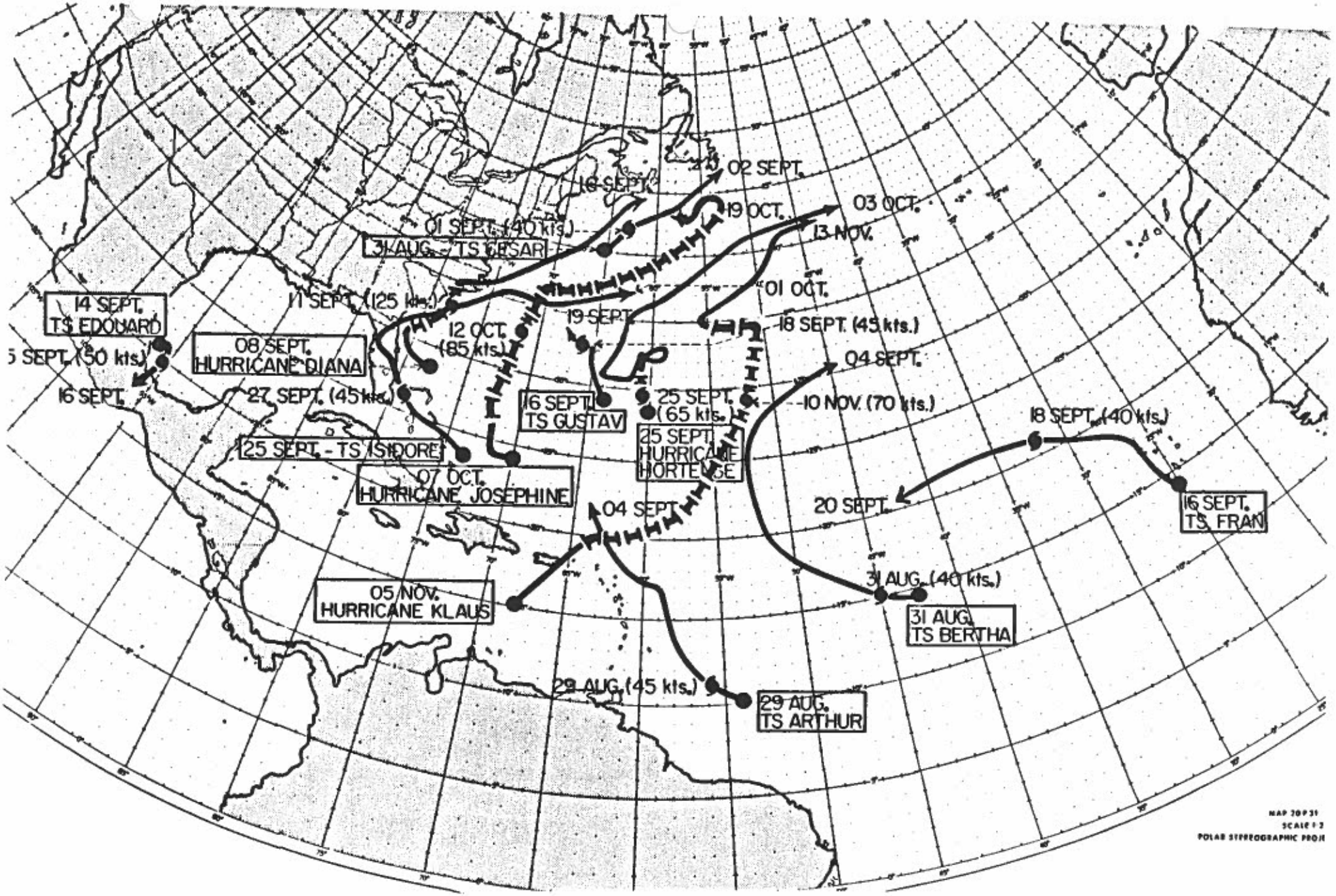

Fig. 1. Tracks of 1984 tropical storms and hurricanes. Periods of hurricane intensity are indicated by the thick dashed lines.

5) There were no westward tracking tropical cyclones in the Caribbean or Gulf of Mexico. Only the southerly tracked and short lived Tropical Storm Edouard in the southwest Gulf of Mexico and the northeast moving Klaus in its forming stages were present throughout 1984 in this normally storm prone Caribbean-Gulf of Mexico region. 1984 tropical cyclone development occurred at a much higher latitude than normal. The usual favorable hurricane formation region just to the east of the Lesser Antilles did not produce any low latitude hurricanes from westward tracking disturbances from the east Atlantic. Only weaker tropical storms Arthur, Bertha, and Fran developed from such low latitude westward traveling east Atlantic systems, and all three of these systems were sheared off and failed to reach maximum sustained surface wind velocities higher than 50 mph.

6) A number of the 1984 tropical cyclones formed from the remnants of weakening cold fronts or stationary upper trough systems.

As indicated in Table 2 Cesar, Diana, Hortense, Isidore, and Josephine formed within weakening middle latitude frontal zones. Edouard, Gustav, and Klaus formed from a combination of middle latitude and pure tropical influences. It is unusual to have so many tropical cyclones form within middle latitude frontal zones. The Atlantic typically has only 2-4 non-pure tropical formations per year. What was unusual about 1984 was the large number of tropical cyclones (8) which had some form of middle latitude influence as an important ingredient in their initial development.

TABLE 2
Type of Formation of 1984 Atlantic Tropical Cyclones

Cyclone No.	Cyclone Name	Type of Synoptic Condition at Cyclone Formation
1.	TS Arthur	Pure Tropical Cloud Cluster
2.	TS Bertha	Pure Tropical Cloud Cluster
3.	TS Cesar	Mid. Lat. Front
4.	HUR Diana	Mid. Lat. Front
5.	TS Edouard	Combined Tropical-frontal Interaction
6.	TS Fran	Pure Tropical Cloud Cluster
7.	TS Gustav	Combined Tropical with Mid. Lat. Trough
8.	HUR Hortense	Mid. Lat. Front
9.	TS Isidore	Mid. Lat. Front
10.	HUR Josephine	Mid. Lat. Front
11.	HUR Klaus	Combined Tropical with Mid. Lat. Trough

2. Forecast Parameters

The three predictors of Atlantic seasonal hurricane activity (as discussed in the author's previous papers, Gray 1983, Gray 1984a) are the El Nino (EN), the Equatorial Stratospheric Quasi-Biennial-Oscillation (QBO) of 30 mb 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 period (12-18 month) equatorial eastern and central Pacific sea surface temperature (SST) warming events which are named 'El Nino' cause a general reduction in tropical cyclone activity in the Atlantic basin. An El Nino event occurs on average every 5-10 years.

b. Equatorial Quasi-Biennial Oscillation (QBO) of Stratospheric East-West Wind Direction

A regular 24-34 month oscillation of stratospheric global east-west winds exists between 0-15^{o} 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). These stratospheric wind measurements were first taken in 1950 and the cyclical change documented in the late 1950's and early 1960's. The nearly biennial (or close to 2 year) period of this wind variation has lead to it being termed the Quasi-Biennial Oscillation (or QBO) by scientists who analyzed this regular wind reversal in the 1960's. This QBO stratospheric wind oscillation encompasses the globe at low latitudes and is present at all equatorial observing stations.

The direction of the stratospheric zonal winds at 30 mb (23 km altitude) has a strong correspondence with Atlantic hurricane activity particularly at low latitudes. Hurricane activity is, in general one-

and-a half to two times more prevalent when 30 mb stratospheric winds blow from a westerly as comparison to an easterly direction.

c. April-May Caribbean Basin-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) and Seasonal Tropical Cyclone Activity

Although the influence of the QBO and El Nino events on tropical cyclone frequency are of primary importance, the regional association of April-May Caribbean-Gulf of Mexico monthly Sea Level Pressure Anomaly (SLPA) also exerts a detectable and significant association with Atlantic seasonal tropical cyclone frequency. SLPA acts to influence Atlantic seasonal tropical cyclone frequency by about one cyclone for every 0.4 mb of mean preseason pressure anomaly. In seasons where the SLPA is between -0.4 mb and -0.8 mb storm activity can be expected to increase by about one cyclone; when SLPA is less than -0.8 mb, then seasonal cyclone activity (all other factors remaining constant) can be expected to be greater than the climatological average by about two cyclones. The reverse situation occurs with higher than average SLPA.

d. Application of Forecast Parameters

A very low cross correlation exists between each of these QBO, EN, and April-May SLPA predictors. This low internal correlations of predictors allow for a significant forecast improvement when all three predictors are used in combination.

The author's seasonal tropical cyclone frequency forecast scheme is based on the premise that:

1) the sign (east or west) of the 30 mb QBO wind changes on such a long period (~ 12-15 months) and in such a uniform manner, that in most seasons it can be extrapolated for 3 to 6 months into the future.

2) the oceanography community is able to detect the presence of a strong or moderate El Nino event by June 1 or August 1.

3) information on the Caribbean Basin monthly average springtime SLPA is readily available to the hurricane forecaster.

This seasonal forecast scheme assumes an average number of hurricanes, hurricanes and tropical storms, and hurricane days, etc. It then applies positive or negative correction factors depending upon whether the 30 mb equatorial stratospheric winds are from the east or west (QBO_1); whether these winds are increasing from the west or east (QBO_2); whether a moderate or strong El Nino (EN) is expected to be present, and what the April-May Sea Level Pressure Anomaly (SLPA) is. Correction factors for QBO_1, QBO_2, and SLPA each range from ± 2 cyclones per season, the correction for the El Nino ranges from 0 to -4 cyclones per season. See the previous papers of the author (Gray, 1983, 1984a) for a more detailed discussion of this seasonal forecast scheme.

3. Discussion of 1984 Seasonal Forecast

Table 3 gives the author's 1984 Atlantic Seasonal Tropical Cyclone Forecast based on the three QBO, EN, and SLPA predictive parameters. This forecast was issued on 24 May 1984 and updated with no change on 30 July 1984.

Table 4 shows this forecast and its verification. The number of hurricane and tropical storm days is also listed for verification. Hurricane activity was overforecast and tropical storm activity underforecast. The underforecast 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. 2 easterly 30 mb QBO winds prevailed during the entire 1984 hurricane season. Such a long easterly QBO cycle (over 17 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) shifted to a westerly direction by late May (when corrected for the annual cycle) 30 mb winds (the level on which the forecast scheme is based) have inexplicitly remained strongly from the east into mid-November.

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 a change over cycle of QBO winds during August through October. The 1984 forecast of QBO was thus an especially difficult one not to be expected in most other years.

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 while observed SLPA in August through October was +0.36 an opposite relationship. This is believed to have also contributed to the overforecast of hurricane activity for 1984. SLPA in August through October is very closely linked to Atlantic hurricane activity. Table 5 shows that 1984 August (+0.62 mb) and October (+0.45) Caribbean Basin-Gulf of Mexico SLPA was substantially above normal. It was only in September (.00) that SLPA was not positive and eight named storms formed from 31 August to 26 September. SLPA is a greater influence on low latitude than high latitude cyclone formation. The more intense low latitude hurricane is thus more effected by the yearly alterations of SLPA.

TABLE 3

1984 PREDICTED SEASONAL TROPICAL CYCLONE ACTIVITY

(PREDICTED NO. OF HURRICANES PER SEASON) $= 6 + (QBO_1 + QBO_2) + EN + SLPA$

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

(PREDICTED NO. OF HURRICANES AND TROPICAL STORMS PER SEASON) $= 9 + QBO + EN + SLPA$

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

(PREDICTED NO. OF HURRICANE DAYS PER SEASON) $= 25 + 5\,[(QBO_1 + QBO_2) + EN + SLPA\,]$

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

TABLE 4
Prediction vs. Observed Tropical Cyclone Activity for 1984

	Predicted	Observed	Yearly Climatological Average
No. of Hurricanes	7	4	6
No. of Hurricane Days	30	18	25
No. of Hurricane and Tropical Storms	10	11	9
No. of Hurricane and Tropical Storm Days	45 (implied from hurricane forecast)	56	40

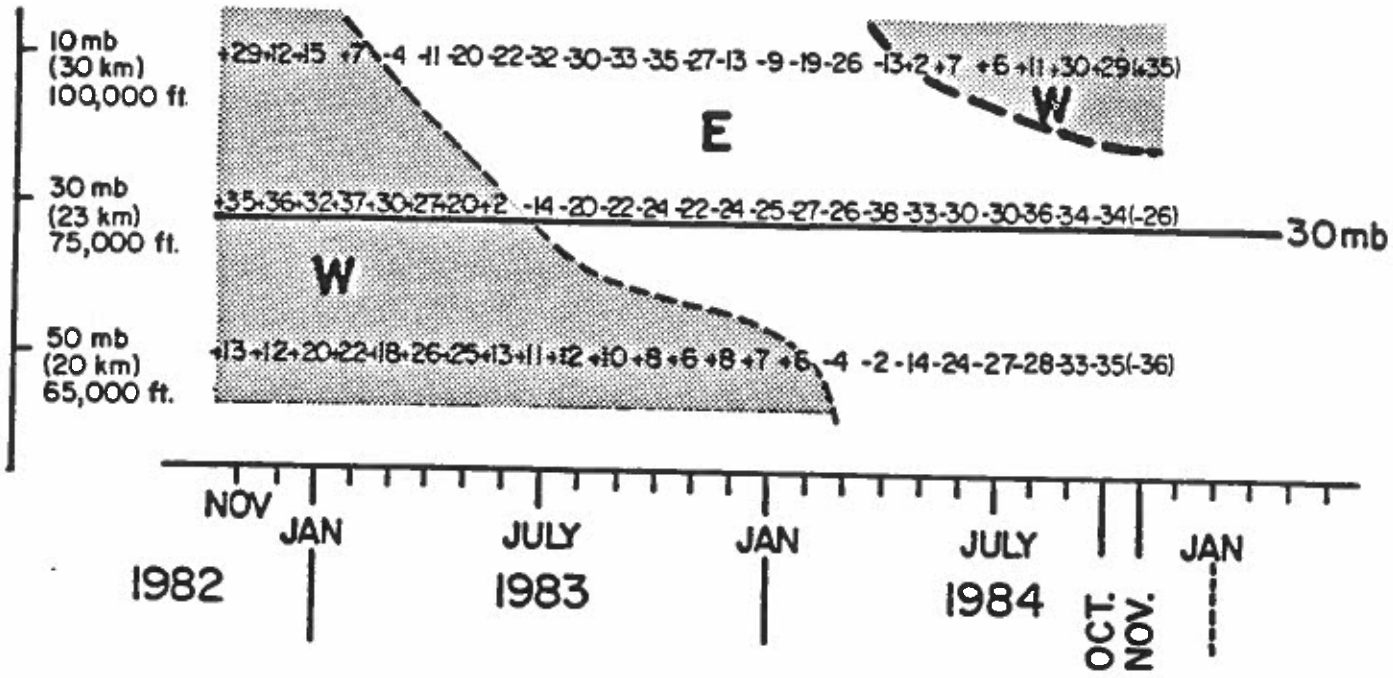

Fig. 2. Vertical cross-section of recent stratosphere monthly average QBO west to east or zonal wind (in knots). This figure represents an average of the Balboa, C.Z. (9°N) and Ascension (8°S) rawinsondes. The annual cycle has been removed from each sounding before averaging. Values in parentheses for November represent the first 15 days of the month. Winds from a westerly direction have been shaded.

In hindsight, the author is thus not surprised at his 1984 overforecast of the number of hurricanes and hurricane days. It could not be anticipated that 30 mb QBO winds would remain strong from the east the whole season or that August through October SLPA would be negatively related to April-May SLPA.

What is surprising is the substantially greater than normal number of weaker named storms which formed at subtropical latitudes from residual frontal systems and stationary upper trough systems. This greater number of formation in the subtropics more than balanced out the deficiency in hurricanes to make the 1984 season one with an overall above average number (± 2) of named tropical cyclones.

TABLE 5

1984 Caribbean-Gulf of Mexico Sea Level Pressure Anomaly (SLPA) by Month (in Millibars)

April-May	August	September	October
-.43	+.62	.00	+.45

It is important to remember that the author's seasonal forecast scheme is a statistical one which is expected to give a significant degree of forecast skill only when applied over a multi-year period. It is to be expected that this forecast scheme will fail in some years when the other unknown factors (besides the QBO, EN, and SLPA) which cause cyclone variability are dominant, or when QBO, EN, and SLPA are misforecast.

4. Hindcast of 1984 Atlantic Tropical Cyclone Activity

Observed in-season variations in the QBO, EN, and SLPA accounted for nearly sixty percent of the variability in Atlantic seasonal tropical cyclone activity over the last 35 years. If known as opposed to predicted values of these three parameters are applied to the 1984 season then the following 1984 season cyclone activity estimates results (see Table 6).

TABLE 6

EXPECTED 1984 SEASONAL TROPICAL CYCLONE ACTIVITY BASED ON IN-SEASON KNOWN (i.e., UNPREDICTED) VALUES OF QBO, EN, AND SLPA

(EXPECTED NO. OF HURRICANES PER SEASON) = 6 + (QBO_1 + QBO_2) + EN + SLPA

= 6 + (-1) + (+1) + (0) + (-1) = [5], Observed 4

(EXPECTED NO. OF HURRICANES AND TROPICAL STORMS PER SEASON) = 9 + QBO + EN + SLPA

= 9 + (-1) + (0) + (-1) = [7], Observed 11

(EXPECTED NO. OF HURRICANE DAYS PER SEASON) = 25 + 5 (QBO_1 + QBO_2) + EN + SLPA

= 25 + (-10) + (+5) + (0) + (- 5) = [15], Observed 18

Known 1984 values of QBO, EN, and SLPA specified one hurricane more than was observed, 3 less hurricane days than were observed, but four less tropical storms than observed.

These three seasonal parameters rather well specified the amount of hurricane activity which occurred in 1984 but substantially under specified the amount of tropical storm activity. As previously discussed 1984 was an unusual year for cyclone formation in the subtropics from middle latitude residual frontal activity.

5. Comparison of 1984 With 1982 and 1983 Tropical Cyclone Activity

Table 7 gives tropical cyclone statistics for each of the past three seasons. 1984 was much more active than 1982 and 1983. 1984 had twice as many hurricane days as the combined seasons of 1982 and 1983. The number of hurricanes and tropical storms and the number of hurricane and tropical storm days was two to three times greater in 1984 as compared with either 1982 or 1983. Hurricane activity in all three seasons, however, was only half (9 versus 18) what would have been expected from climatologically considerations (6 per season).

1982 was an unusually suppressed tropical cyclone season because of the presence of the last strong El Nino and the positive SLPA which occurred in this year throughout the Caribbean-Gulf of Mexico. 1983 was also an unusually suppressed tropical cyclone year because of the presence of the special combination of all three inhibiting components of the QBO, EN, and SLPA.

TABLE 7
Seasonal Atlantic Tropical Cyclone Statistics for 1982, 1983 and 1984

	1982	1983	1984
No. of Hurricanes	2	3	4
No. of Hurricane Days	6	5	18
No. of Hurricanes and Tropical Storms	5	4	11
No. of Hurricane and Tropical Storm Days	21	16	56

6. Outlook for the 1985 Season

Present information on the QBO and the El Nino indicate that if the Caribbean Basin-Gulf of Mexico sea-level pressure anomaly (SLPA) is not usually high next season then 1985 should be expected to be a season of above average hurricane activity. This is based on the following reasons:

1) 30 mb QBO winds in 1985 will most assuredly be from the west -- QBO west winds are associated with above normal hurricane activity. 30 mb QBO winds were from the east in both the 1983 and 1984 seasons.

2) It is to be expected that any tropical cyclone inhibiting influences of the El Nino should be gone by 1985. El Nino conditions were present during 1982 and 1983. An El Nino event comes only every 5 to 10 years.

If next season's Sea Level Pressure Anomaly (SLPA) should be very negative, then 1985 should be expected to be a very active tropical cyclone season indeed.

But irrespective of what the 1985 SLPA should be, it is anticipated that (with 30 mb QBO westerly winds and no El Nino influence) much more tropical cyclone development should occur at low latitudes from disturbances of African origin which have track westward across 50°W longitude. It should also be expected that a higher percentage of named storms should reach hurricane intensity than in 1984.

Because the major period for cyclones of African origin is late July 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 (Alberto 2-6 June 1982) 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 a more normal or above normal distribution of westerly tracking tropical cyclones especially in comparison with the last three seasons of 1982 - 1984 when no well organized westerly tracking tropical cyclones at all moved through the Caribbean.

Figure 3 shows the tracks of all tropical cyclone or pre-tropical cyclone systems which occurred during the three years of 1982-1984 in comparison with the previous three year period of 1979-1981. Figure 4 is a similar portrayal of the tracks of hurricane intensity tropical cyclones during these same two 3-year periods. Note how different the westward tracks of tropical storms and hurricanes are during the years of 1979-1981 in comparison with the years 1982-1984. The combination of an unusually strong multi-season El Nino event during 1982-1983 with an unusually long phased 30 mb QBO easterly winds during 1983-1984 appears to be the primary factors responsible for this very substantial three consecutive year suppression of Caribbean Basin westerly tracking cyclones.

It is the El Nino events and the 30 mb QBO east wind situations which are most associated with a suppression in low latitude westward tracking Atlantic tropical cyclones. This rare 1982 through 1984 combination of multi-season QBO east winds and EN suppressing factors should not be expected to continue into 1985, however. Also, because

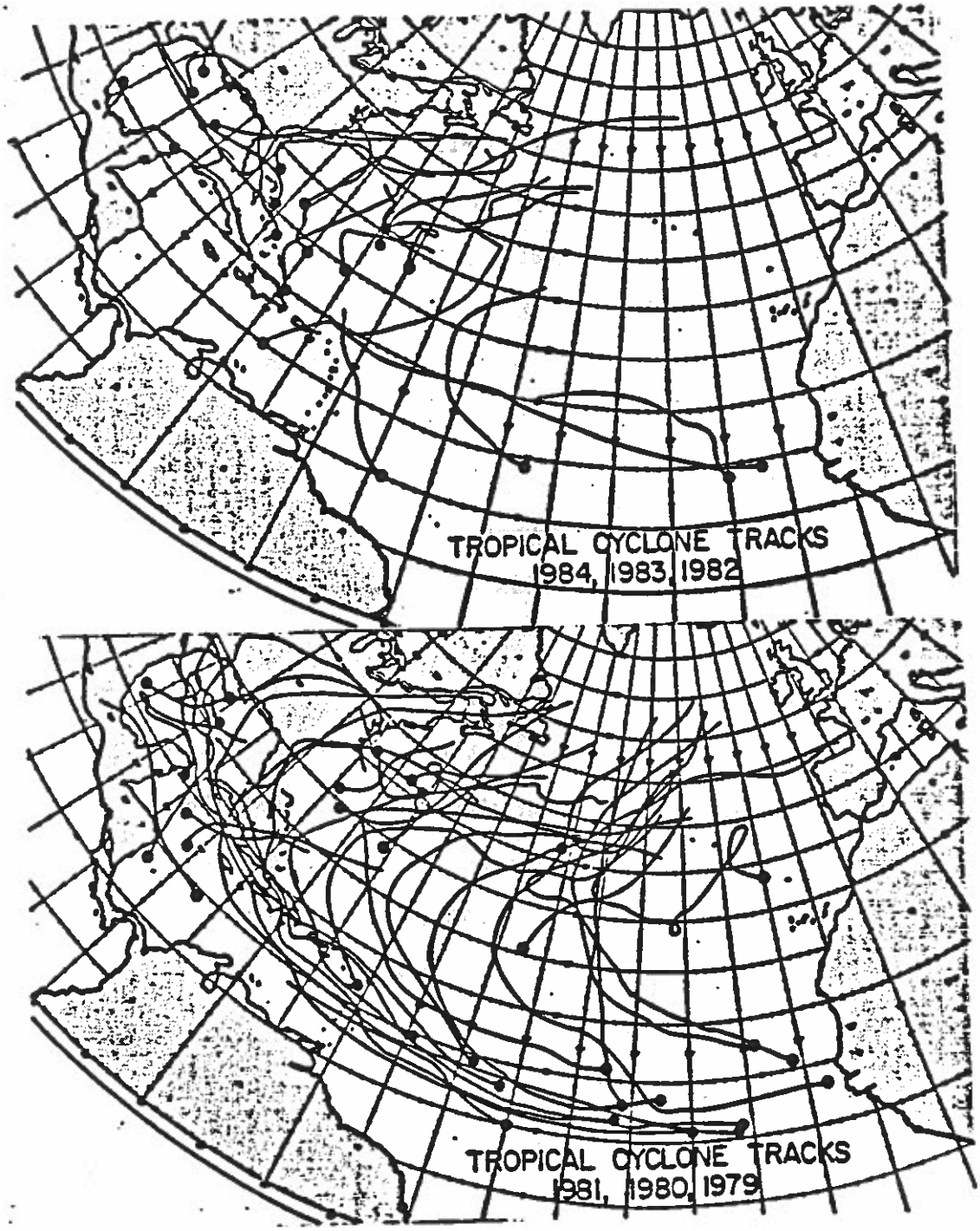

Fig. 3. Tracks of tropical cyclone or pre-tropical cyclone systems in 1982-83-84 (top diagram) in comparison with similar tracks during 1979-80-81.

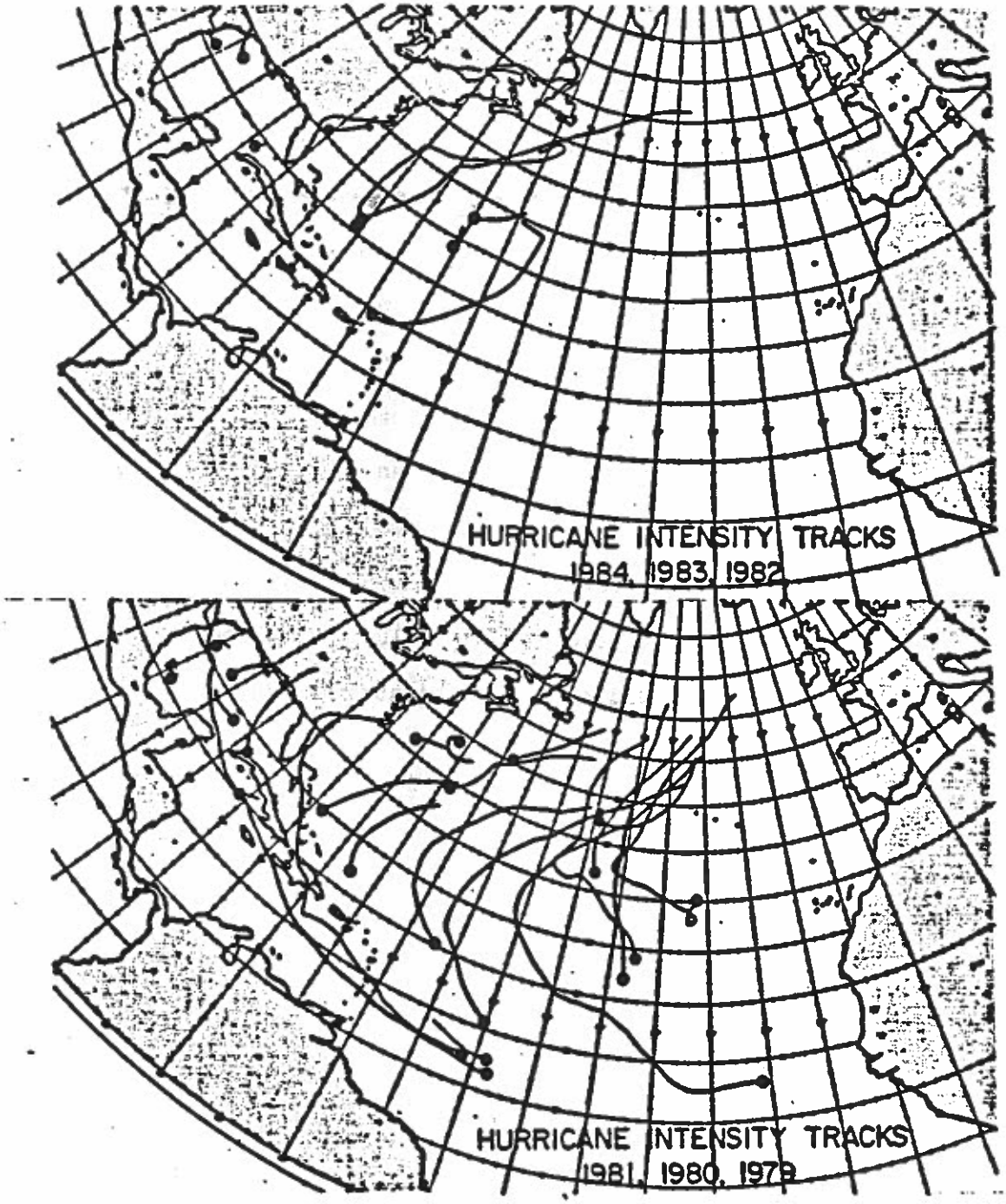

Fig. 4. Same as Fig. 3 but for tropical cyclones of hurricane intensity.

more low latitude cyclone development is anticipated in 1985, it is to be expected that tropical cyclones of 1985 will, on the average, be of greater intensity than those during the 1982 to 1984 period.

Figure 5 illustrates how many more westward tracking tropical cyclones there were in the Caribbean and the region to its east during 12 non-El Nino seasons of 30 mb QBO west winds as compared with 12 non-El Nino seasons when 30 mb QBO winds were from the east. Figures 6 to 8 illustrate how westward tracking hurricane intensity tropical cyclone activity was suppressed in the Caribbean region in the 14 strong and moderate El Nino seasons (Fig. 7) in comparison with 14 non-El Nino years one year before (Fig. 6) and one year after each of (Fig. 8) these El Nino seasons. Such suppressing influences to low latitude Atlantic cyclone activity should not be anticipated for 1985, however.

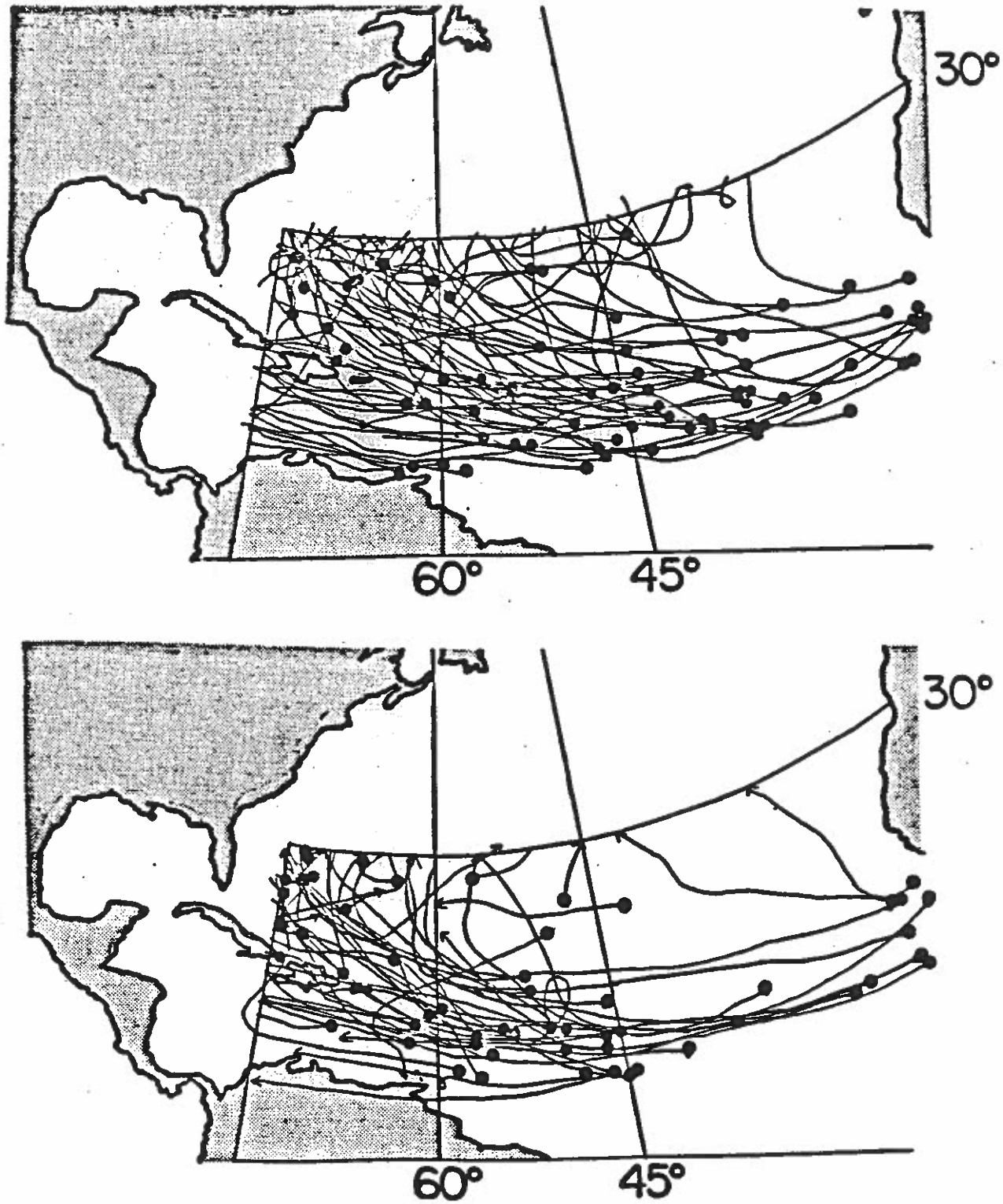

Fig. 5. Tracks of tropical cyclones during 12 non-El Nino years between 1950-1981 when 30 mb QBO winds were from the west (top diagram) vs. 12 non-El Nino years when 30 mb QBO winds were from the east.

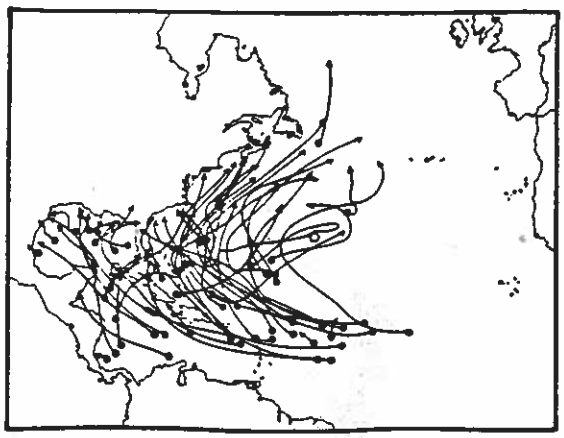

Fig. 6. Fourteen years of hurricane intensity storm tracks occurring one year before each of 14 strong and moderate El Nino seasons between 1900-1976.

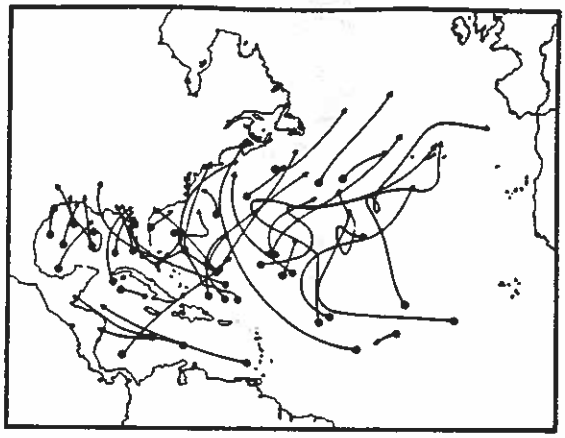

Fig. 7. Fourteen years of hurricane intensity storm tracks during 14 strong and moderate El Nino years between 1900-1976.

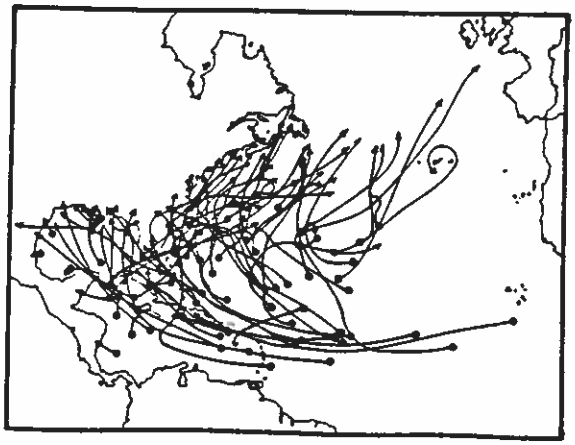

Fig. 8. Same as Fig. 6 but for hurricane intensity tracks one year after each of these 14 El Nino years.

7. Acknowledgements

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