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VARIATIONS IN TROPICAL CYCLONE CHARACTERISTICS DURING ENSO EVENTS

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1. INTRODUCTION

The EL Nino/Southern Oscillation phenomenon (ENSO phenomenon) has been a topic of much research during the past 10 to 15 years. The scientific community has attempted to solve what has become an incredibly complex puzzle by explaining how the interaction between the El Nino and the Southern Oscillation works to produce strong sea surface temperature anomalies across the equatorial Pacific Ocean.

Most of the earlier theories concentrated on the equatorial Pacific (Bjerknes, 1969). Researchers observed large variations from the normal rainfall distribution over the equatorial Pacific during ENSO events. Arid regions received unusually heavy rainfall, while moist regions saw little if any rainfall. After further research and examination of ENSO events, computer models were implemented. These models produced significant results which described changes that were occurring in the boundary layer and upper atmosphere (Julian and Chervin, 1978).

Great strides have been made toward understanding the ENSO system. Its effects upon the general circulation and the global climate, however, has been a more difficult problem to resolve. One relationship, established through observation, has been that tropical cyclone activity, and overall characteristics in the North Atlantic Basin, have been noticeably different during ENSO events (Gray, 1984a,b). Gray has developed a forecast scheme for predicting the number of storms in the North Atlantic Basin by using the occurrence of a moderate or strong ENSO event as one of the predictors.

This paper will examine changes in storm characteristics, strictly as a function of the occurrence of a moderate or strong ENSO event. The data presented will cover all named tropical cyclones in the North Atlantic Basin from 1954 to 1989.

First, a brief discussion of the ENSO phenomenon will be given, followed by a discussion on the atmospheric changes that occur downwind over the Atlantic Ocean. Then this author's research will be used to examine the various changes in storm characteristics that occur during an ENSO event, as well as significant changes that occur during the seasons following the event.

2. THE ENSO PHENOMENON

The ENSO phenomenon describes two separate processes which, on occasion, may enhance each other and result in widespread warming across three-forths of the equatorial Pacific Ocean. During moderate and strong ENSO events, the warming may exceed 2 to 4°C. This author makes no attempt to fully describe the phenomenon, but simply offers this brief overview as a starting point for individuals who may not be that familiar with the phenomenon. For a more comprehensive discussion of ENSO, consult Lussky (1989), or Wyrtki (1986).

2.1 The Southern Oscillation

The Southern Oscillation refers to a see-saw in surface pressure that occurs over a 2 1/2 year period between the Subtropical Ridge of the southeast Pacific, and the Indonesian Low. The oscillation begins during the late summer months, with a fall in pressure in the southeast Pacific. This oscillation is monitored by the Southern Oscillation Index (SOI). The index is calculated by subtracting sea level pressures from two equatorial Pacific stations. Darwin, Australia and Santiago, South America are often used (Julian and Chervin, 1978). When the SOI becomes negative, it reflects the lowering pressure in the vicinity of the Subtropical Ridge and rising pressure in the vicinity of the Indonesian Low. The corresponding rise near the Indonesian Low is thought to cause the Indonesian Low to migrate eastward into the western Pacific (Wyrtki, 1986).

The movement of the Indonesian low into the western Pacific creates an anomalous westerly wind flow in the boundary layer over the Western Pacific. This causes the "pooling" of warm ocean water in the vicinity of the low, a rise in sea level, and the development of surface wind stress (Covey and Hastenrath, 1978). By early October, the wind stress becomes so strong that the atmosphere responds by developing a Kelvin wave. The primary purpose for this wave is to release the surface wind stress. The release of this stress results in a surging of the warmer waters in the western Pacific eastward, toward the eastern Pacific (Harrison and Schopf, 1984; Gill, 1982). This eastward moving Kelvin wave takes approximately 2 to 3 months to reach the South American coastline (Cane, 1983; Cane and Zebiah, 1985). As the Kelvin wave moves east, it develops an anomalous ocean current of warm water toward the South American coast, which results in a dramatic lowering of the thermocline. The first wave usually reaches the coastline in early December, which is when the seasonal warming, El Nino, is already in progress.

2.2. El Nino

The El Nino refers to the seasonal warming of the coastal waters along the South American coastline. The trade winds blow across the coastline, from east to west, during most of the year. This results in upwelling of colder water from below the ocean surface. During December, the trade winds relax, and the upwelling ceases. This results in the return of warmer water to the region and a lowering of the thermocline. This period, when warmer water returns to the coastline, is called El Nino, which in Spanish means Little Christ Child, named because of its occurrence around Christmas time (Wyrtki, 1986).

During a normal El Nino, the period of warming will last from December to approximately February. Then, as the trade winds increase during the spring, the upwelling resumes, and colder water reappears. However, it is during an ENSO event that, through the passage of the Kelvin wave, the warming along the coast is greatly enhanced. Warm water is present well below the surface layer due to a drastic lowering of the thermocline. Therefore, when the trade winds resume there is no longer cold water below the surface to well upward. As the trade winds increase, advection of this warm water across the Pacific occurs.

The system will maintain itself into the following winter, until the SOI becomes positive. The low will then begin its movement back to the west, while the ridge strengthens over the southeast Pacific. The anomalous warm water region rapidly decreases so that, once the trades increase by early spring, a more normal upwelling pattern develops.

It has been observed that following this warm episode, the sea surface temperature profile becomes several degrees colder than normal along the South American coastline, representing a total reversal of conditions that were present one year earlier (Lussky, 1989). The occurrence of colder than normal temperatures has recently been termed "La Nina", opposite of El Nino. The cold episodes were not given much attention until the late 1980s, when researchers determined that La Nina may have a greater affect on the global weather than was previously thought.

3. OBSERVED CHANGES OVER THE TROPICS IN RESPONSE TO AN ENSO EVENT

Several pronounced changes occur in the Tropics at the surface and aloft during the progression of an ENSO event. An anomalous upper level ridge develops over the central or eastern Pacific. The Subtropical ridge of the north Atlantic is usually stronger than normal, and further south. Lastly, the Intertropical Convergence Zone is displaced southward of its normal position. These anomalous conditions develop during the spring and last into the winter season of the Northern Hemisphere.

Anomalous conditions also develop over North America such as; an anomalous upper level ridge over western North America, and an upper level trough along the southeast coast of the United States (Lussky, 1989). These conditions usually don't develop until the fall season, and are not thought to have much of an influence on the environment over the tropics during the Atlantic hurricane season.

3.1. Increased Upper Level Shear

The anomalous warming, which occurs during the ENSO event, results in a large increase in convection over the central and eastern equatorial Pacific. The increased convection causes large amounts of mass to be transported into the upper atmosphere. The outflow from the convection creates an anomalous anticyclonic circulation over the central and eastern Pacific, which then intensifies the upper level westerlies downwind over the western Atlantic (Gray, 1984a). This pattern becomes most pronounced during the middle and late summer, which is also the most active time for tropical storm activity in the Atlantic. For example, Figure 1 shows the mean 200 mb wind pattern for September 1982 (Clark, 1983). Notice the strong westerlies present across most of the equatorial Atlantic, south of 20°N.

An increase in the upper level westerlies creates large scale vertical shear of the horizontal wind over a large portion of the Atlantic (Gray, 1984a). The presence of upper tropospheric vertical shear is one of the primary inhibiting factors to tropical cyclone development and intensification (Anthes, 1982). Figure 2 shows the element of the vertical shear, as calculated during the 1983 hurricane season. The shear is calculated by subtracting the 1000 mb to 600 mb mean wind from the 600 mb to 200 mb mean wind (Case and Gerrish, 1984). Notice the large positive values present across much of the same region, south of 20°N. Researchers have determined that when the shear approaches 8 m/s, storm development becomes restricted (Case and Gerrish, 1984).

During ENSO events, when strong vertical shear is present, shearing of the deep layer convection within tropical systems away from the low level storm circulation is a noticeable signature on visible satellite imagery. Visible imagery frequently displays an exposed low level circulation, while the organized convection is displaced several hundred miles downwind. Figure 3 shows an example of this during the 1982 episode (Clark, 1983). The photos are of Tropical Storm Alberto. Notice that in the top photo most of the convection is surrounding the center, located north of the western tip of Cuba. In the second photo, however, strong vertical shear has blown the deep layered convection well east of the center, exposing the low level circulation. Rapid weakening of the system almost always follows this observation.

In order for tropical disturbances to intensify into a depression and beyond, the vertical wind shear must be small. When weak shear is present, heat and moisture fields stay in close proximity to the moving disturbance, resulting in a favorable environment for further intensification. When strong shear is present, however, the heat and moisture fields are advected away from the system, resulting in an unfavorable environment for development (Anthes, 1982).

As the ENSO event weakens, and cooler water redevelops off the South American coast (La Nina period), the anomalous conditions begin to relax. By the start of the Northern Hemisphere summer, opposite conditions begin to develop. The anomalous upper level ridge over the tropical Pacific weakens. The anomalous upper level westerly wind flow over the Tropical Atlantic diminishes, which stops the strong vertical shear once present over the region.

3.2. Displacement of The Subtropical Ridge/Intertropical Convergence Zone Couplet

Another frequently observed feature during an ENSO event, is the displacement of the Inter-Tropical Convergence Zone (ITCZ) over the tropical Atlantic and the southward displacement of the subtropical ridge (Lawrence, 1978). The subtropical ridge is often found several degrees of latitude south of its normal summertime position. This results in a region of anomalous positive sea level pressure (SLPA) over much of the equatorial Atlantic (Covey and Hastenrath, 1978). The presence of higher sea level pressures inhibits the tropical cyclone formation and intensification.

Another inhibiting feature, that develops due to the displacement of the subtropical ridge, involves the intrusion of dryer air caused by the large scale subsidence associated with this ridge. Normally, the most subsidence would occur further north, in the vicinity of 30°N. However, during an ENSO event, the displaced ridge creates subsidence further south over the western Atlantic, where tropical cyclone development and intensification normally occurs. The subsidence results in lower relative humidities in the middle troposphere. The convection necessary for intensification of tropical systems is eroded by the entrainment of this dry middle tropospheric air. This slows the intensification process by halting the development of the deep layer convection that causes the increased latent heat release which is needed for intensification of the tropical system (Anthes, 1982).

As mentioned previously, when the warming off the South American coast ends, and the cool period begins, surface features in the Atlantic reverse themselves. The ITCZ moves north of its normal climatological position, while the subtropical ridge over the Atlantic weakens and moves further north. Therefore, after a period of unfavorable conditions, a period of very favorable environmental conditions occurs.

4. VARIATIONS IN STORM CHARACTERISTICS

4.1. Data

The data set examined in this study covers all named tropical storms and hurricanes in the North Atlantic Basin from 1954 to 1989 (National Weather Service, 1985). This period covers eight moderate and strong ENSO events, occurring during 1953, 1957, 1965, 1972, 1976, 1982, 1983, and 1987 (Gray 1984a, 1988). While the 1953 hurricane season is not included in this study, the 1953 ENSO event is included for the purpose of classifying 1954-1956. Therefore, 1954 is 1 year following an ENSO event. The sample is small, but persistent patterns in several storm characteristics appear both during and following each ENSO event.

In the following diagrams, "years" have been used to separate the tropical storms and hurricanes into specific groups. These groups, designated as "Year0" through "Year7", correspond to the number of years between a given hurricane season and the previous moderate or strong ENSO event. For example, all tropical storms and hurricanes which formed in a hurricane season during an ENSO event are grouped into "Year0". All storms forming during hurricane seasons which occurred 1 year after an ENSO event are grouped under "Year1". All storms which occurred two years after the ENSO event are grouped under "Year2", and so on, as listed in Table 1 below.

	YEAR 0	1	2	3	4	5	6	7
NUMBER OF STORMS:	39	66	68	42	34	23	20	9
NUMBER OF SEASONS:	7	7	7	6	3	3	2	1

TABLE 1. The number of named tropical cyclones which formed 0 to 7 years following an ENSO event. Also given are the number of hurricane seasons which occurred 0 to 7 years after an ENSO event.

In 1982 a strong ENSO event occurred that carried into 1983. Since 1983 has been classified as a moderate ENSO event (Gray, 1984a), for the purposes of this study, the 2 years will be considered as separate ENSO events, with both years classified as "Year0." The time interval between ENSO events varied considerably during the 36 year period, ranging from as little as 1 year to as many as 7 years. The average interval was four years. As a result, the number of hurricane seasons that occurred in each "Year" of the ENSO cycle varied. These hurricane seasons are listed as Seasons in Table 1. Notice that 7 seasons occurred during "Year0"; thus corresponding to the 7 ENSO events (not including 1953) as previously mentioned. As the time interval increased, the number of seasons decreased. In fact, on only one occasion has there been a 7 year interval between ENSO events, therefore only one hurricane season. This author has lower confidence in the results beyond "Year3" because of the limited amount of hurricane seasons examined and the unlikelihood that an ENSO event would still be affecting the storm environment so far out in time.

4.2. Frequency of Development

The most publicized correlation, relative to ENSO events and storm characteristics, concerns the frequency of storm development (Gray, 1984a,b). Figure 4 shows the frequency of storm development over the 36 year period. The average frequency over this period is 8.4. Notice that the lowest frequency (5.6) occurs in "Year0"; hurricane seasons affected by the ENSO event. A marked increase in frequency occurs during the next 2 years, after the ENSO event, with both seasons averaging over 9 storms. This is nearly twice the number of storms that form during an ENSO episode. Beyond the 2 year interval, the pattern fluctuates between active and semiactive seasons all of which have a higher frequency of development than during the ENSO season.

The oscillating pattern would suggest that other factors, which are likely independent of the ENSO, are playing an important role in the atmospheric environment over the North Atlantic Basin. An examination of the environment over the North Atlantic Basin is needed in order to develop a better understanding of why these minor pertibations are occurring and if they are related to the ENSO cycle.

The decrease in storm frequency occurring 3 years after the event is quite interesting. One might assume that a weak or very weak ENSO was occurring during the years involved, but this is not the the case. The pattern is persistent, although the reasons behind this pattern are unknown at the present time. The range of storms per hurricane season, in "Year3", is small; varying from six to eight over the six seasons.

The large fluctuations beyond the fourth year may not be that significant, due to the limited number of events that occurred and the large ranges which were present. As an example, there were only three hurricane seasons that occurred 5 years after a given ENSO event. The number of storms per season ranged from 5 to 11; resulting in an average of about 8 which is also the average number of storms per season over the 36 year period. Therefore, it is rather difficult to place much significance on so few events with such a large range.

4.3. Monthly Distribution

The monthly distribution of the 301 storms which formed during the period studied is shown in Figure 5. The date at which the system became a named tropical storm was used to compile this figure. Notice the nearly normal distribution from May to December, with the most activity during August, September, and October.

Further investigation showed that ENSO seasons, (Year0) are shorter with fewer storms developing later into the year (Figure 6). Year0 has 10 percent of its storms developing after September 31st, while all non-ENSO seasons have at least 20 percent, with the exception of season 3 which also has 10 percent. The latest date of development during ENSO seasons is October 23. All other seasons had at least 2 storms develop well after this date.

4.4. Location of Development

During ENSO events, another variation occurs concerning the regions in which the tropical cyclones develop. Forty one percent of all storms studied developed at or south of 20°N. This area was examined because the northward extent of upper level directional shear generally occurred in the vicinity of 20°N. Over 40 percent of the storms during each non-ENSO season developed south of this location relative to storm frequency (see Figure 7). The average percentage per "Year" is 41%. Notice that during the ENSO season, there is a noticeable absence of storms developing in this region. There is also a minor decrease in storm formation three years after the ENSO event (Year3).

4.5. Intensity

The lowest estimated or measured central pressure of the tropical cyclones studied was used to examine variations in storm intensity. Figure 8 presents the total number of category 4 and 5 hurricanes during each "year". Only two storms of this intensity have occurred during the seven ENSO events. All other seasons have had at least 5 storms of this intensity. The exception occurs beyond the forth year interval. Keep in mind that beyond 4 years, there were much fewer hurricane seasons to examine.

The two storms that occurred during an ENSO event were Hurricane Audrey in June of 1957, and Hurricane Betsy in August of 1965, both of which were category 4 storms. Hurricane Betsy developed just north of the Lesser Antilles and moved rather erratically into the Bahamas. The storm then recurved toward the west, passing across the Florida Keys, and eventually making landfall on the Louisiana coast . The lowest central pressure in Betsy was 940 mb (Sugg, 1965). Audrey formed in the Bay of Campeche and made landfall on the Texas-Louisiana border. The lowest central pressure in Audrey, estimated from an offshore oil rig, was 925 mb (Moore, 1957).

Figure 9 shows the percentage of storms in each "Year" that obtained category 4 or 5 strength, with the average being 12%. Again, there is an absence of storms during "Year0", the ENSO season. Each of the following years has a much higher percentage of storms, with the exception occurring during season 5.

It was found that 86% of all category 4 and 5 storms studied developed in the region at or south of 20°N. One would then expect to see a decrease in strong storms due to the inhibiting synoptic scale conditions which are present over this region during ENSO events as discussed in Section 4.4.

4.6. Tendency of Recurvature

Forecasters had noted that there seemed to be some tendency for tropical cyclones to recurve northward, sooner, and with more frequency during ENSO events (Lawrence, 1977). Figure 10 supports this observation. The basic tracks that were considered are shown in Figure 11. Figure 10 indicates that 23 percent of all storms during ENSO events recurved to the north at or east of 65°W longitude. This is substantially higher, compared to all other seasons. The average per "Year" is 14%.

The recurvature is most likely related to the increased westerly wind component that develops over the tropical Atlantic during the ENSO event, as stated earlier. In forecasting short range tropical cyclone movement, the pressure weighted mean wind over a certain layer of atmosphere is often used. Mean winds over layers from 900 mb to 400 mb and 900 mb to 200 mb are often used; they show the best correlation to actual storm movement (Chan and Gray, 1982). Results from these techniques show that, in most cases, storms will move at or just to the right of the mean wind in the layer. As the upper tropospheric winds increase from the west, vertical shear of the horizontal wind is created. This results in more of a component toward the north and a greater likelihood for earlier recurvature. During an ENSO season, this is exactly what occurs. The upper tropospheric winds, between 400mb and 200mb, increase not from the east but from the west. A tendency is created for the system to recurve back to the north earlier than would normally be the case if light westerly or easterly upper tropospheric winds existed.

5. CONCLUSION

Significant changes in tropical cyclone characteristics have been observed in the Atlantic Basin during ENSO events. Not only is there a marked decrease in storm development, but there is also an absence of intense storms. The tracks are varied as well, with a tendency for earlier northward recurvature. Conditions reverse themselves during the next 2 years following the event, allowing for above normal storm development. This rapid reversal in storm development may very well be related to La Nina, but more research is needed in order to develop a more complete understanding.

A minor decrease in storm development, and development south of 20°N appeared in the data 3 years after the ENSO episode. It is unclear why this occurs. No connection was present between the variations and the presence of a weak or very weak ENSO episode, as one might expect.

This study included a period of rather inactive seasons in which the African Drought reduced the number tropical disturbances moving off the African coast and into the eastern Atlantic. Nevertheless, the data showed a remarkable increase in storms during the next 2 years following the ENSO event. However, since the drought has ended, we may begin to see an even greater number of storms developing during ENSO episodes as well as after (Gray, 1990). Consider that in the past 6 years, four of the six hurricane seasons had at least 11 named storms.

The current season of 1990 is of interest, as well. The 1990 season falls 3 years after the last ENSO episode. "Year3" indicated that there was a tendency for a near or slightly below normal hurricane season, all other factors being equal. As of September 1st, however, eight storms have already formed, and the season is only half over.

The ENSO phenomenon will continue to be one of the more intensely researched topics in the following years. Its effects on tropical cyclone characteristics of the North Atlantic Basin appears to have been validated by the observed data.

6. REFERENCES

Anthes, R. A., 1982: Tropical Cyclones, Their Evoloution, Structure, and Effects, Science Press, 208.

Bjerknes, J., 1969: Atmospheric teleconections from the equatorial Pacific, Mon. Wea. Rev., 97, 163-172.

Cane, M., 1983: Oceanographic events during El Nino, Science, 222, 1189-1194.

_____, and S. E. Zebiah, 1985: A theory for El Nino/Southern Oscillation, Science, 228, 1085-1087.

Case, R. A., 1987: Atlantic hurricane season 1986, Mar. Wea. Log., 37, 18-24.

_____, and H. P. Gerrish, 1984: Atlantic hurricane season 1983, Mon. Wea. Rev., 112, 1083-1092.

Chan, J. C. L., and W. M. Gray, 1982: Tropical cyclone movement and surrounding flow relationships, Mon. Wea. Rev., 110, 1954-1374.

Clark, G. B., 1983: Atlantic hurricane season of 1982, Mon. Wea. Rev., 111, 1071-1079.

Covey, D. L., and S. Hastenrath, 1978: The Pacific El Nino phenomenon and the Atlantic circulation, Mon. Wea. Rev., 106, 1280-1287.

Gill, A. E., 1982: Atmosphere-Ocean Dynamics, Academic Press, 320.

Gray, W. M., 1984a: Atlantic seasonal hurricane frequency. Part I: El Nino and the 30mb Quasi-Biennial Oscillation influences, Mon. Wea. Rev., 112, 1649-1668.

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

_____, 1988: Background for assessment of expected seasonal Atlantic hurricane activity for 1988.

_____, 1990: Updated Forecast of Atlantic Seasonal Hurricane Activity for 1990, Colorado State University, 15.

Harrison, D. E., and P. S. Schopf, 1984: Kelvin-Wave induced anomalous advection and the onset of surface warming in El Nino events, Mon. Wea. Rev., 112, 923-933.

Julian, P. R. and R. M. Chervin, 1978: A study of the Southern Oscillation and Walker Circulation phenomena, Mon.Wea. Rev., 106, 1433-1451.

Lawrence, M. B., 1977: Atlantic hurricane season of 1976, Mon. Wea. Rev., 105, 497-507.

_____, 1978: Atlantic hurricane season of 1977, Mon. Wea. Rev., 106, 477-491.

Lussky, G. R., 1989: Current issues relating to the El Nino/Southern Oscillation, Nat. Wea. Dig., 14, 26-31.

Moore, P. L., 1957: The hurricane season of 1957, Mon. Wea. Rev., 85, 401-408.

National Weather Service, 1985: A Tropical Cyclone Data Tape for the North Atlantic Basin, 1886-1983: Contents, Limitations and Uses, National Hurricane Center report.

Sugg, Arnold, L., 1965: The hurricane season of 1965, Mon. Wea. Rev., 94, 183-181.

Wyrtki, K., 1986: El Nino phenomenon and fluctuations and climate, WMO Publication #649.

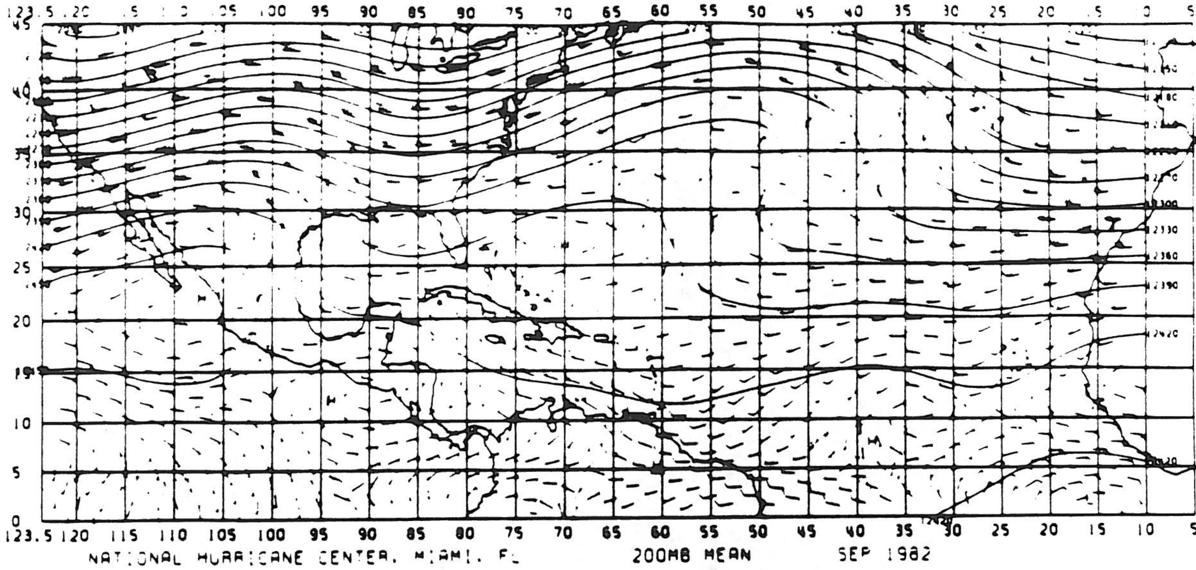

Figure 1 - Mean 200mb heights and wind field for September, 1982 (Clark, 1983). Note the strong westerlies across the tropical Atlantic.

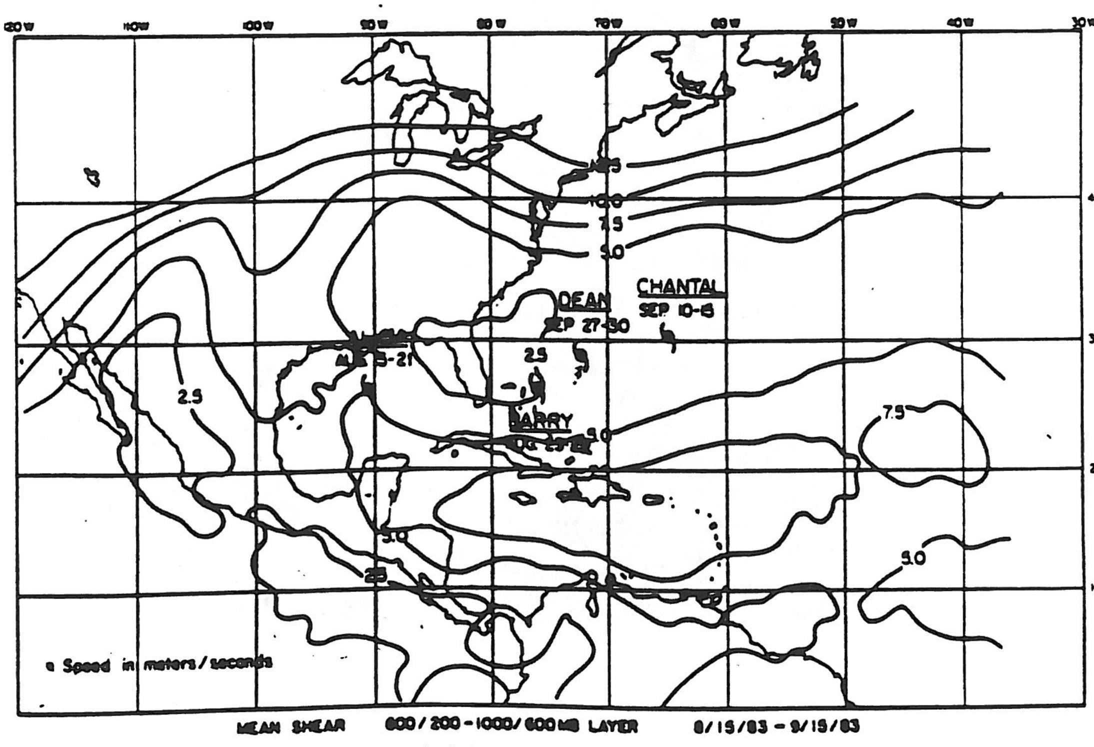

Figure 2 - Mean vertical shear of the horizontal wind from mid August to mid September, 1983 (Case and Gerrish, 1984).

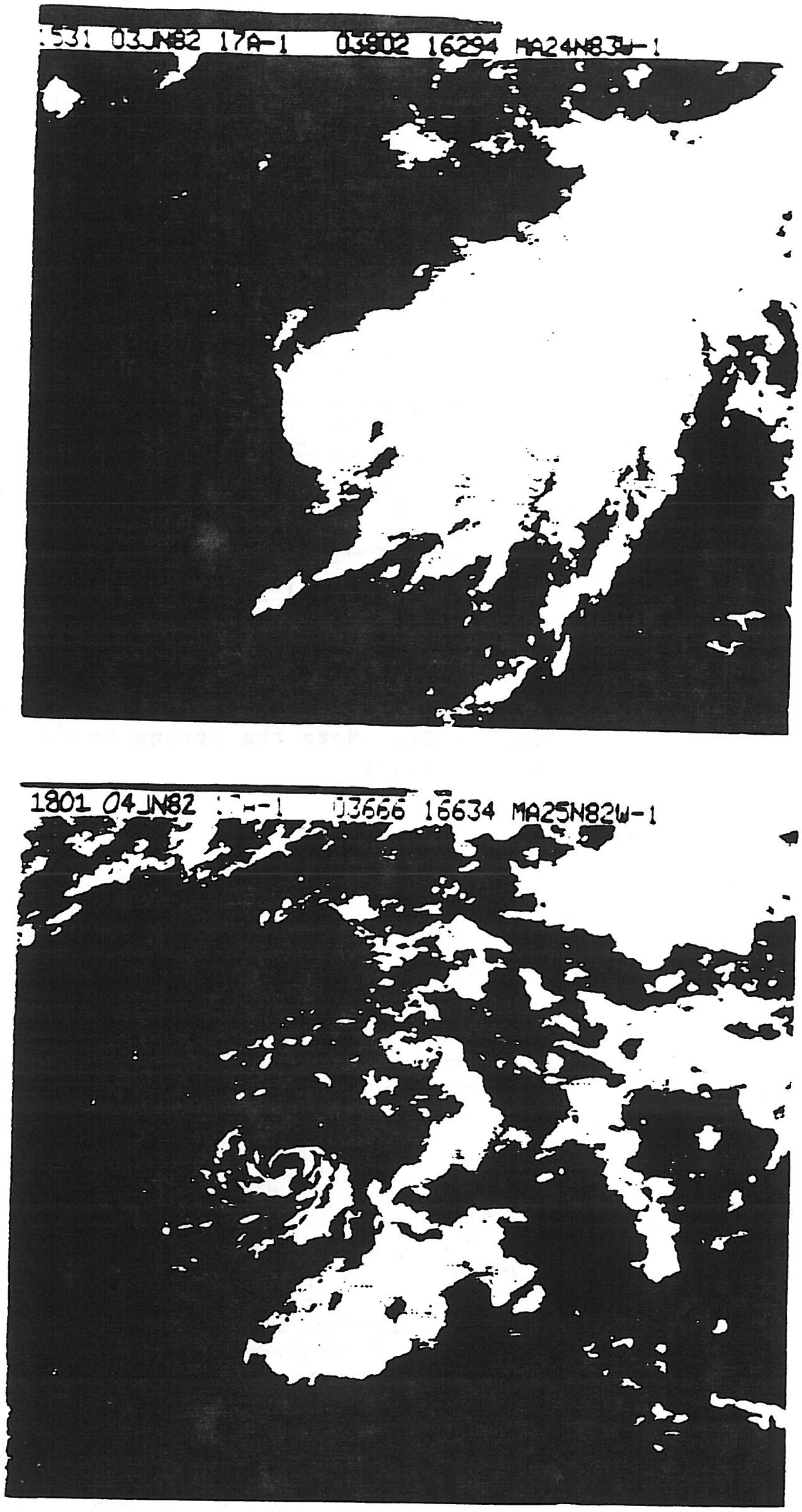

Figure 3 - Satellite photos of Tropical Storm Alberto, June, 1982 (Clark, 1983). Deep layer convection in top photo is sheared off to the east in the bottom photo, leaving an exposed low level circulation.

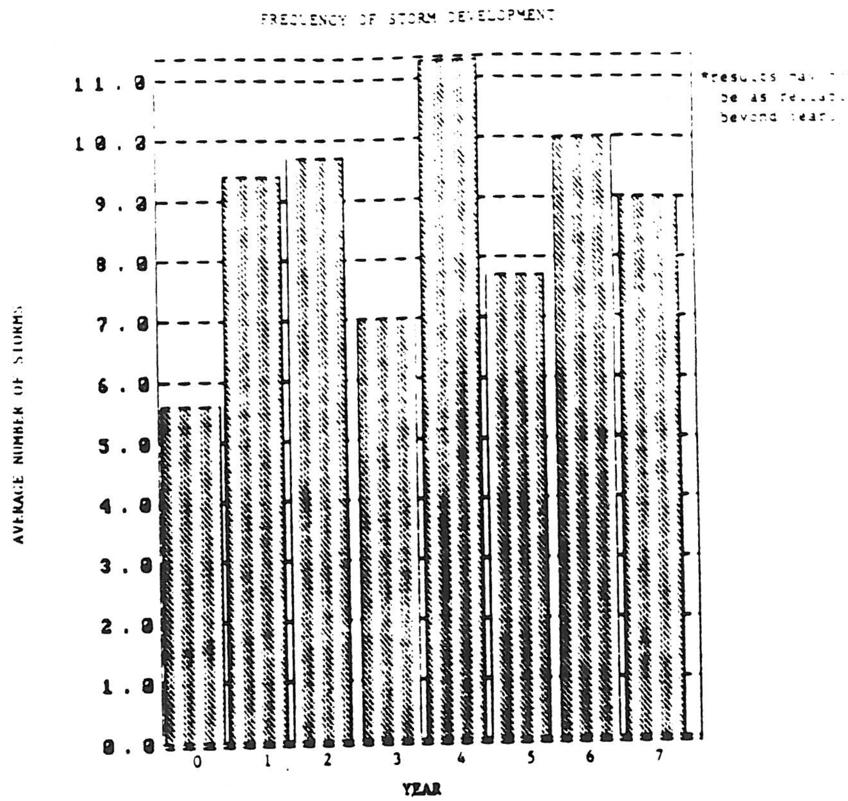

Figure 4 - Average number of tropical cyclones per "Year" developing 0 to 7 years after an ENSO event.

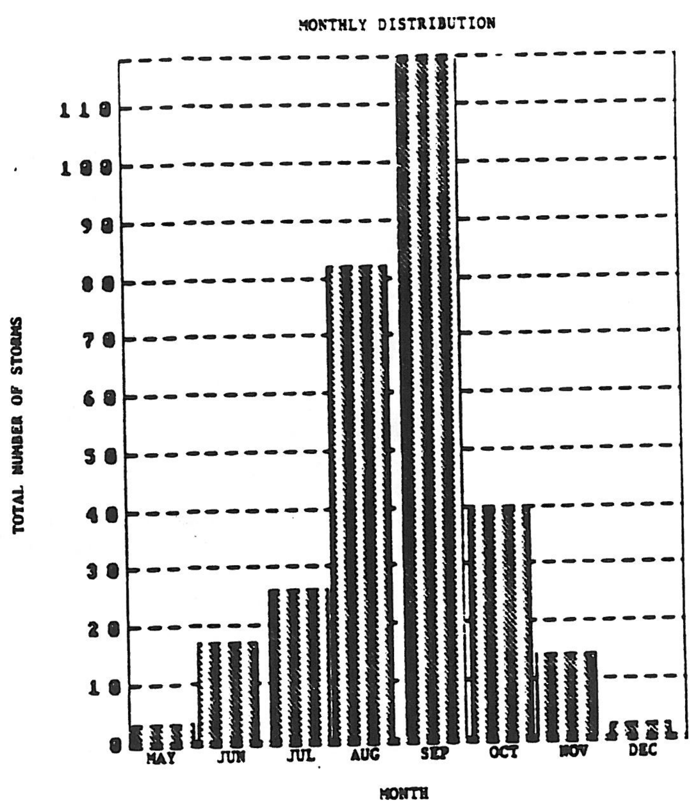

Figure 5 - Monthly distribution of tropical cyclones from 1954 to 1989.

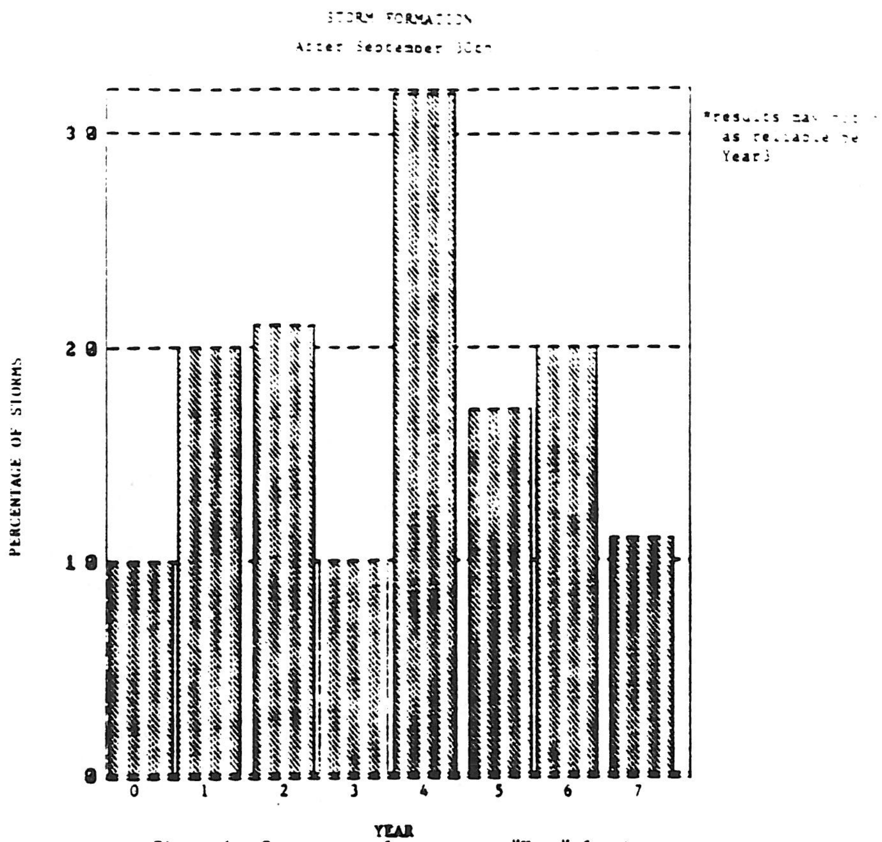

Figure 6 - Percentage of storms per "Year" forming after September 30th.

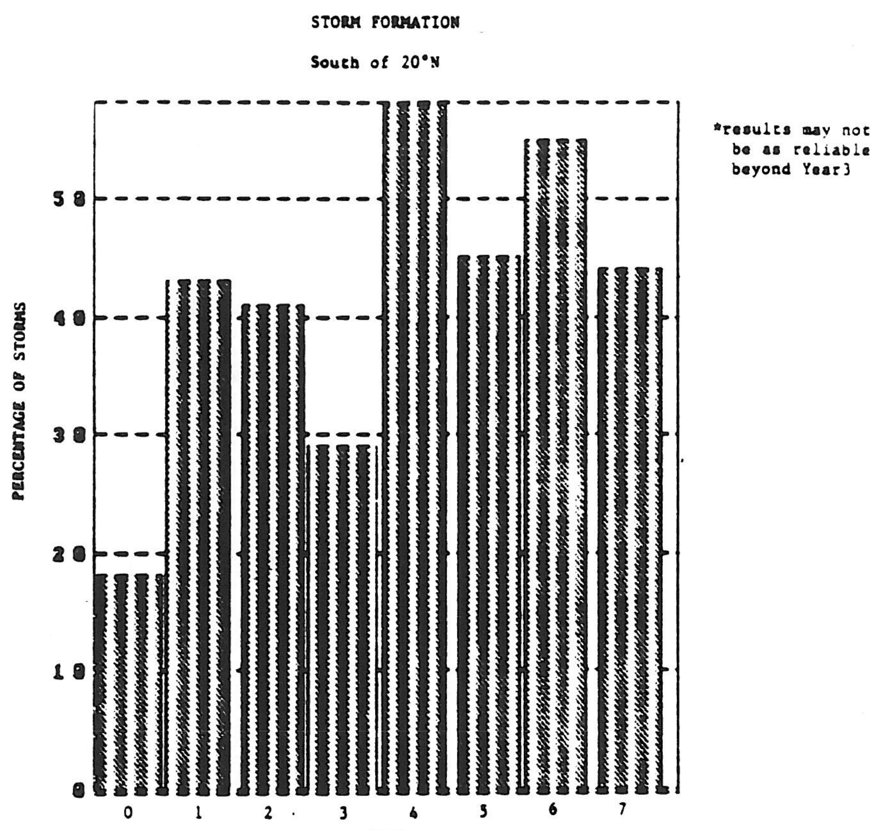

Figure 7 - Percentage of storms per "Year" forming south of 20°N.

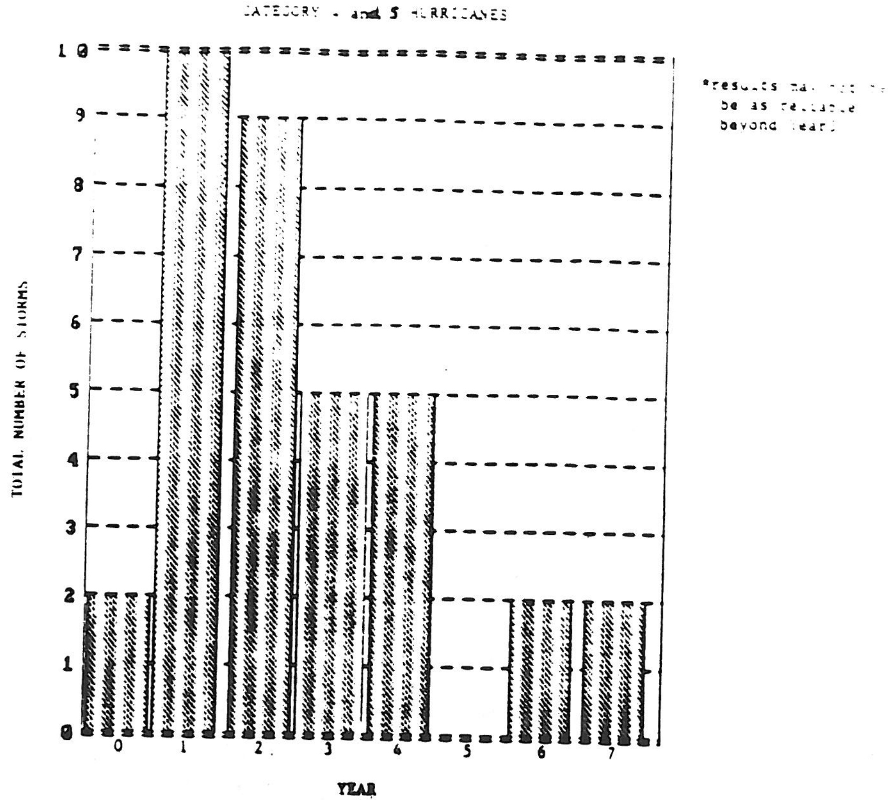

Figure 8 - Total number of category 4 and 5 hurricanes by "Year"

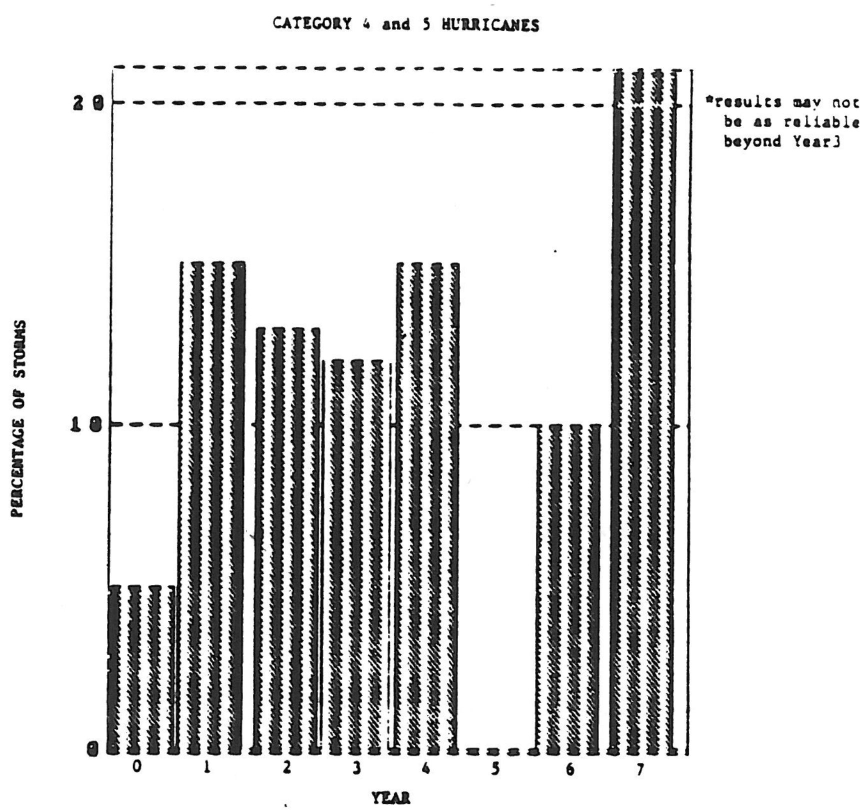

Figure 9 - Percentage of category 4 and 5 hurricanes by "Year".

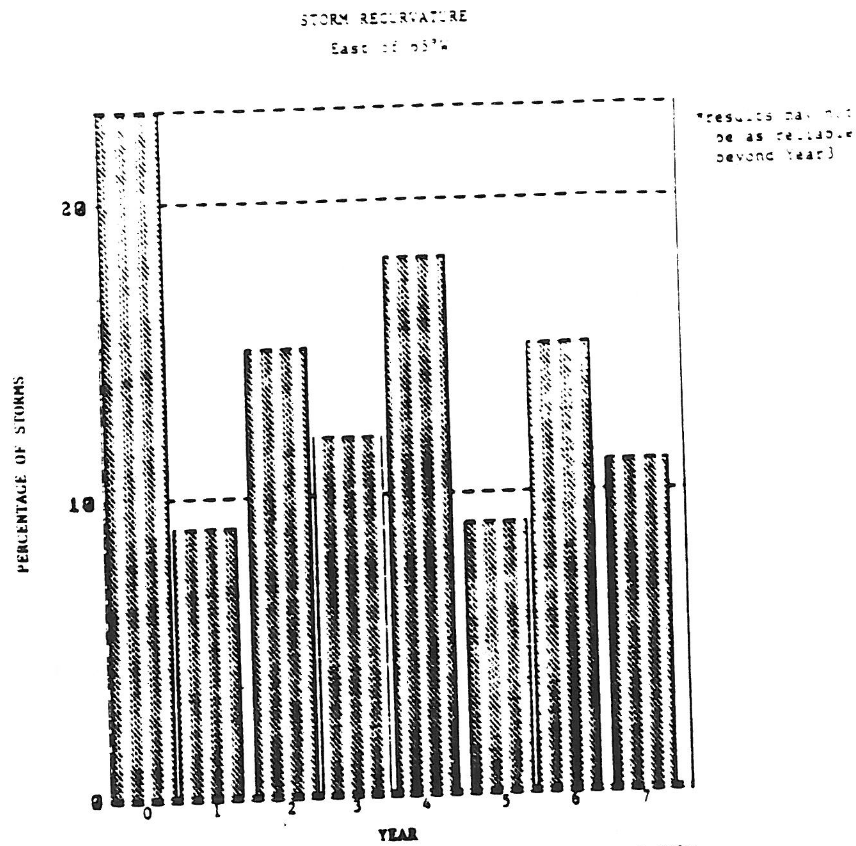

Figure 10 - Percentage of storms recurving east of 65°W by "Year".

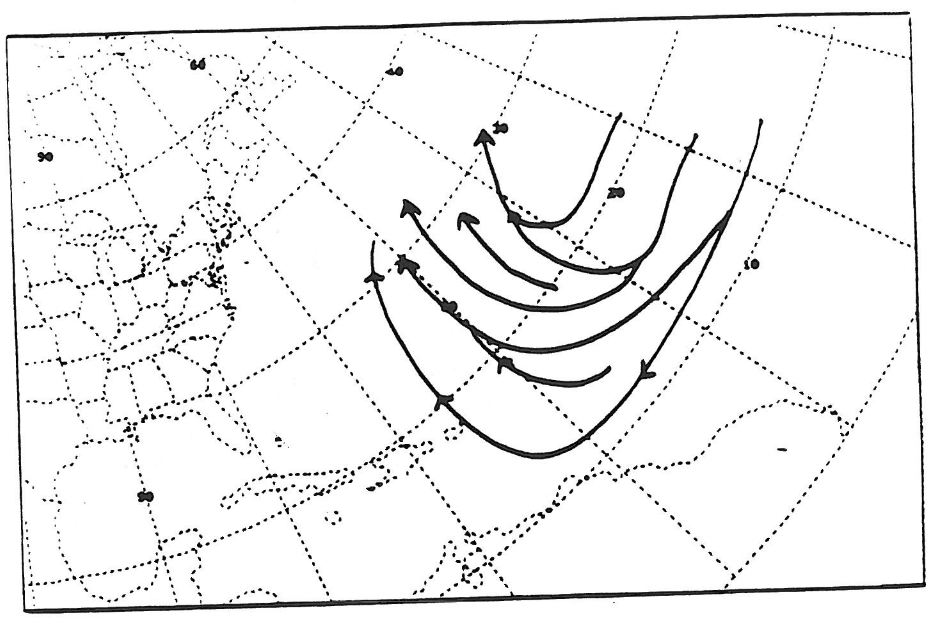

Figure 11 - Basic storm tracks included in the examination of recurving storms east of 65°W.