1.2 SIGNIFICANT TORNADO EVENTS ASSOCIATED WITH TROPICAL AND HYBRID CYCLONES IN FLORIDA

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1. INTRODUCTION

The original climatology of Florida tornadoes associated with tropical cyclones (TC) and hybrid cyclones (Hagemeyer and Hodanish 1995) was updated through 1996 for this paper. Information contained in Storm Data (NOAA 1994-1996) was used to document six additional tropical/hybrid cyclone tornado events for a total of 67 cases (270 tornadoes) between 1882 and 1996.

Considering the historical record, it is likely that Florida tornadoes associated with tropical cyclones are seriously under reported prior to the 1950's, either due to sparsity of population or lack of detailed storm surveys. Hybrid cyclones, which have tropical and extratropical characteristics and include subtropical cyclones (see NOAA 1993, Hagemeyer and Matney 1993, and Hagemeyer 1997), were not documented until the late 1960's (NOAA 1993) and details of their effects, especially tornadoes, is poor. Concerns about the efficacy of the national tornado data base are well documented (Grazulis 1993), however, it is reasonable to assume that over the years the killer tornadoes and tornadoes that caused significant injury and damage were reported. For example, 71% of the TC and ybrid tornado events reported prior to 1950 caused death/injury compared to 34% since1950.

Five modernized National Weather Service (NWS) offices (Friday 1994) now exist in Florida. Each office has a Warning and Coordination Meteorologist (WCM) responsible for accurately completing Storm Data, and a meteorological staff engaged in local operational research. Prior to 1992, one person compiled Storm Data for the entire state of Florida. Modernization will result in more accurate documentation of the effects of tropical and hybrid cyclones in Storm Data and case studies of significant events by NWS staff. Perhaps any tropical or hybrid cyclone that affects Florida is capable of producing at least one tornado. Tropical Depression Jerry (August 1995), which produced one, weak, short-lived F0 tornado that touched down in an empty field is an example of the lowest end of the tornado event spectrum. The Tampa Bay killer tornadoes of up to F3 intensity associated with the hybrid cyclone of October 1992, or the F3 killer tornadoes associated with Hurricane Agnes in June 1972 are examples of the extreme end of the tornado spectrum. Forecaster awareness of the threat of tornadoes from tropical/hybrid cyclones has increased in recent years, but regional refinements are necessary.

It would not be prudent to issue a tornado watch for every TC/hybrid cyclone that affects Florida. However, the ability to better quantify a significant tornado threat as far in advance as possible with strongly worded hazardous weather outlooks by local NWS offices and tornado watches would be beneficial to the people of Florida. To this end, a study of "significant" tropical and hybrid cyclone tornado events was undertaken. This brief paper presents a climatology of significant tropical/hybrid cyclone tornado events, basic forecast guidelines, and some ideas for furthering our knowledge of this important forecast challenge.

2. CLIMATOLOGICAL CHARACTERISTICS OF SIGNIFICANT TORNADO EVENTS

The first task was to define a significant tropical/hybrid cyclone tornado event. The definition should cover the occurrence of one significant tornado and/or a tornado outbreak. An analysis of the 67 cases revealed that over half consist of one or two tornadoes. An analysis of the number of tornadoes per case (Fig. 1) indicated that the occurrence of 5 or more tornadoes was a reasonable definition of a TC/hybrid outbreak. The definition of a significant tropical/hybrid cyclone tornado event was subjectively determined to be one with any F3 tornado,

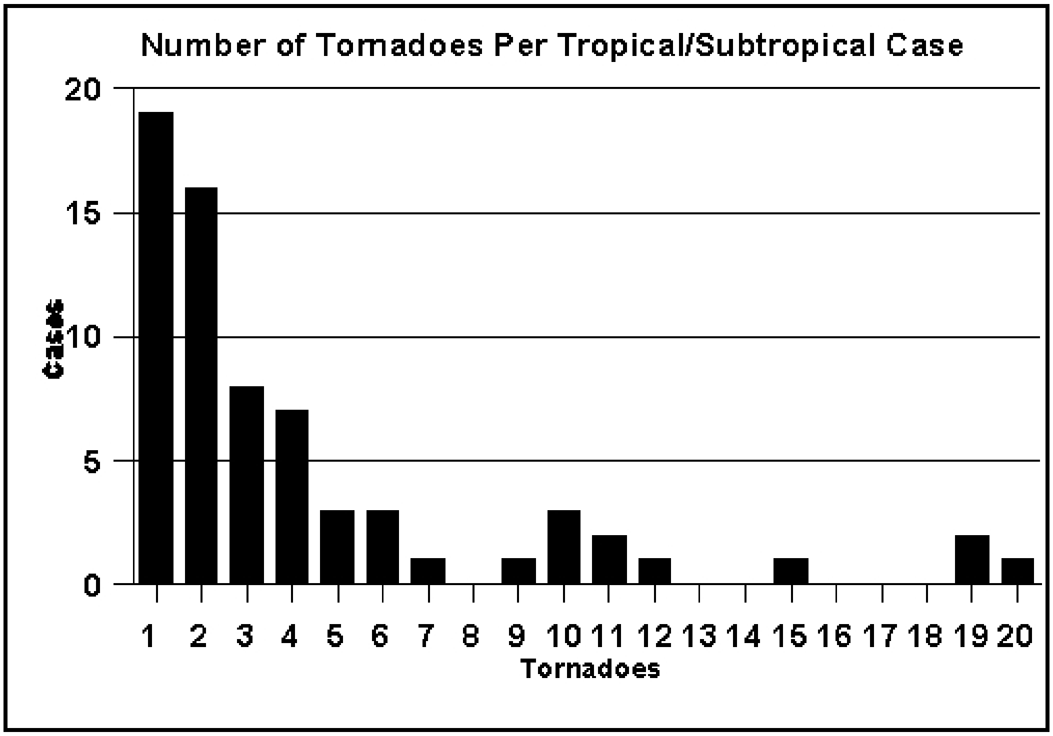

Fig. 1. Number of tornadoes per tropical/subtropical case.

any killer tornado, and any case with 5 or more tornadoes in 24 hours with at least one being rated F2. Sixteen of the 67 cases met the significant event criteria. Information on the case number (#), date, system type at the time of tornado occurrence, number of tornadoes (*indicates additional funnel clouds or waterspouts reported), maximum F-scale (F#), time period of occurrence, number of deaths and injuries, and location of tornadoes in Florida and in relation to storm center of each case are contained on Table 1.

Table 1
Florida Significant Tropical and Subtropical Cyclone Tornado Events (1882-1996)

case #	date	system type	#tors	f#	time (est)	death/ injury	location/stm ctr relative
1	9/9/1882	hurricane	5+	2	eve-am 10th	6/17	nw-n central/rf
7	10/20/41	t. storm	2	2	afternoon	1/1	n central/ rf
10	9/19/47	hurricane	1	3	0030	2/100	franklin/ rf
11	9/22/47	t. storm	11	2	eve-eve23rd	0/1	wc-n east/rf
15	9/4/48	hurricane	2	2	late eve	2/12	panhandle/rf
21	6/8/57	t. storm	6	2	evening	0/0	nc-n east/ rf
28	10/14/64	h. isbel	9+	2	aft-eve	0/48	se-e central/lf-rf
40	6/18/72	h. agnes	*15+	3	am-am19th	7/119	keys-ec/ rf
47	5/8/79	hybrid	*19	2	am-pm	1/47	centrl/rf
48	9/3/79	h. david	10+	2	am-am 4th	0/0	e coast/lf
52	6/17/82	st storm	12	2	am-am 18th	1/13	sw-e central/rf
53	9/26/82	hybrid	3	2	early am	1/7	southwest/rf
60	10/3/92	hybrid	10	3	am-pm	4/77+	w central/rf
62	11/15/94	ts gordon	*6	2	evening	1/40	e central/ rf
66	10/4/95	h. opal	* 10+	2	afternoon	1/3	panhandle/rf-cntr
67	10/7/96	ts josephine	20	2	am - aft	0/0	central-ne/rf

The 16 significant cases include 7 hurricanes, 5 tropical storms, and 4 unnamed hybrid cyclones. An analysis of synoptic conditions of the last 3 tropical storms to produce significant tornadoes (cases 21,62, 67) showed strong hybrid influences (see Hagemeyer and Matney 1993 and Hagemeyer 1997). Hurricane Agnes, which produced the worst tornado outbreak, exhibited hybrid influences well east of its center where the tornadoes occurred. If one were to ignore the official categorization of the 16 significant tornado producing cyclones, at least half appear to be "hybridized" cyclones that were quite weak relative to traditional tropical cyclone strength indicators. This is an important finding for forecasters, and a clear indication cyclone central strength and organization is a poor predictor of tornado potential. It should be stressed that tornado forecasting is a much different, and perhaps harder, challenge than predicting storm surge, coastal flooding, and radius of high winds from cyclones.

The distribution of TC/hybrid tornado events by decade (Fig. 2) reveals that the 1940's and 1990's (1990 -1996) were the most active periods with 11 and 9 total tornado events respectively. The period from 1990 through 1996 has already equaled the decade of the 1940's 4 significant tornado events. The 1960s lead all decades with 16 tornado events, but only one was significant. The 16 cases in the 1960's make up 24% of the 67 total cases, but they account for none of the deaths and only 9% of the injuries. In contrast, the first 7 years of the 1990's account for 13% of all cases, 25% of significant cases, 22% of all deaths, and 19% of all injuries. This indicates there is benefit to be gained by the effort to identify significant TC/hybrid tornado potential and highlights the fact that Florida is more vulnerable than ever to the effects of increasing TC/hybrid cyclone activity.

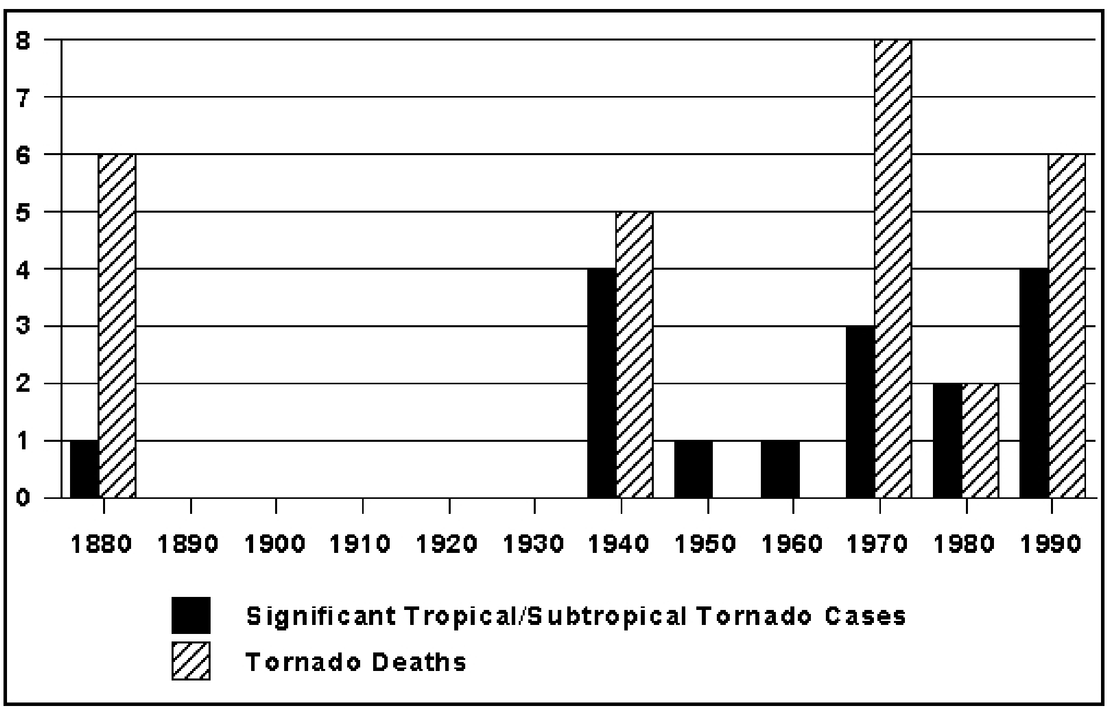

Fig. 2. Distribution of TC/hybrid tornado events by decade.

The monthly distribution (Fig. 3) of the 16 significant tornado events (May - 1 event, June - 3, September - 6, October - 5, and November - 1) illustrates the influence of hybrid cyclones (which are most likely early and late in the hurricane season), and hurricanes, which are most likely in September.

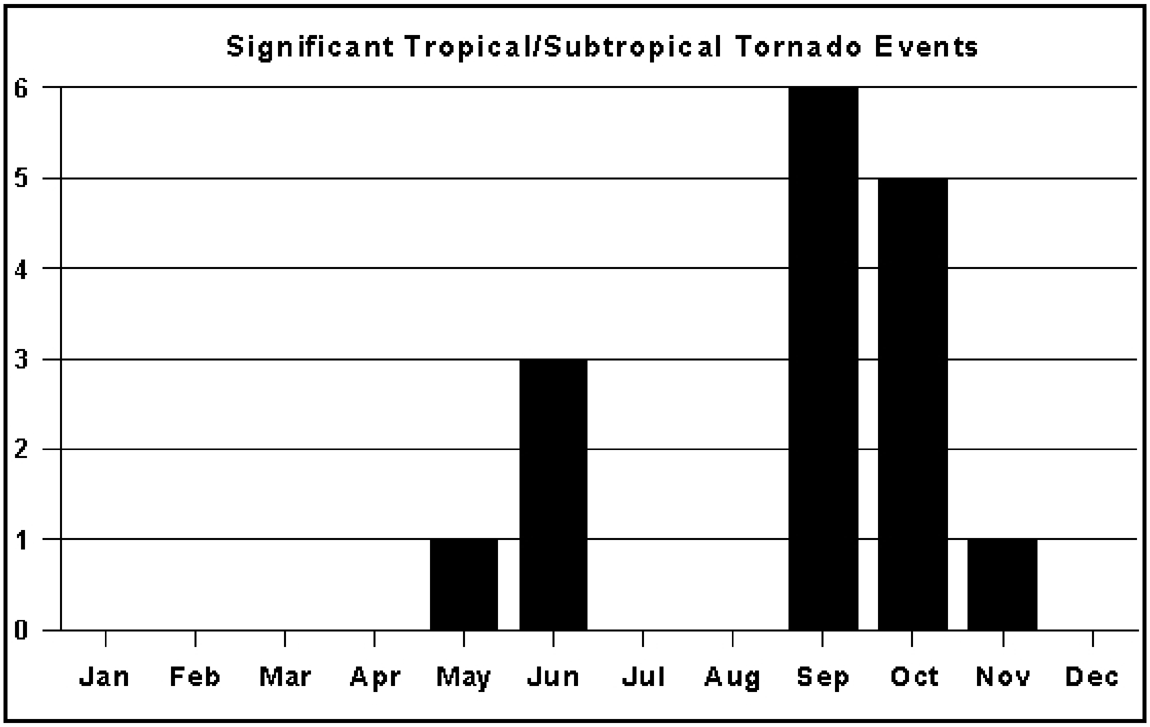

Fig. 3. Significant tropical/subtropical events by month.

The track segments of the 16 tropical/hybrid cyclones during their tornado-producing phase is shown in Figure 4. Four cyclones originated in the western Atlantic, 5 originated in the Caribbean, and 7 originated in the Gulf of Mexico. However, 15 of the 16 cyclones were in the Gulf of Mexico and one was in the Atlantic when tornadoes began. Fifteen produced tornadoes in outer rainbands in their right-front quadrant with respect to storm motion, only David (48), which moved parallel and just offshore the east coast of Florida, consistently produced tornadoes in the left front. David's tornadoes were restricted to the immediate east coast where outer rain bands in the right-front quadrant rotated on shore north of the center. Hurricane Isbel (28) also produced a few tornadoes in its left-front quadrant as Atlantic rain bands ahead of the center rotated onshore.

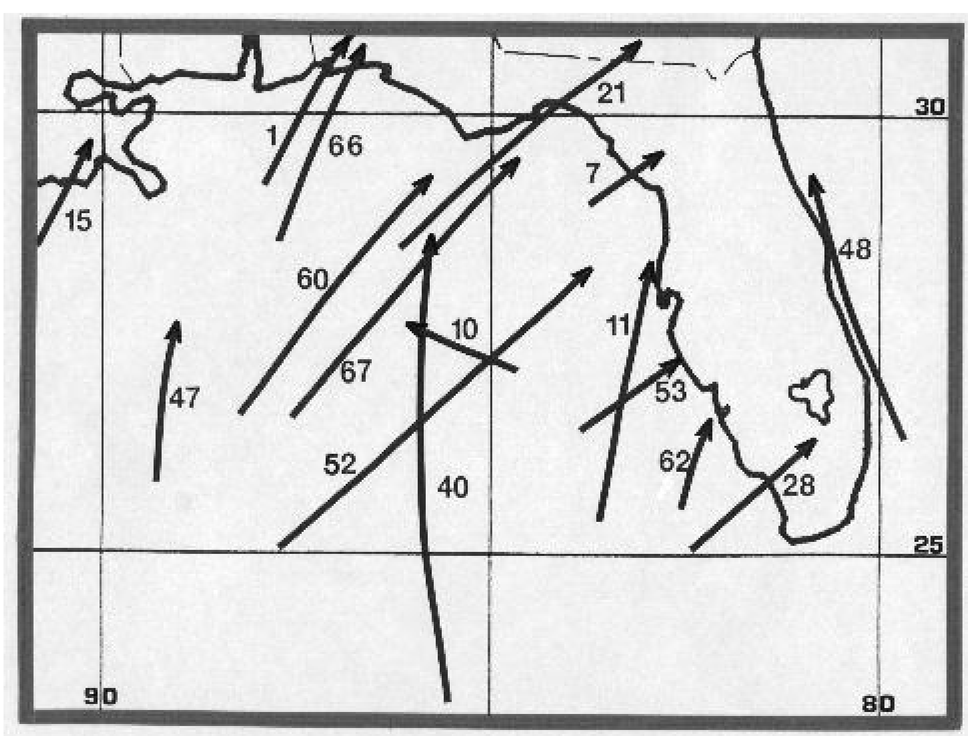

Fig. 4. Track segments of 16 tropical/hybrid cyclones during their tornado-producing phase.

The great majority of tornadoes occurred to the right of the cyclone track. In some cases such as Agnes (40), tornadoes occurred in outer rain bands 300 miles northeast of the center. Fourteen of 16 cyclones were moving between 360 and 60 degrees during tornado production. The only exceptions were previously mentioned Hurricane David (48) and the September 1947 Hurricane (10) where an outer rain band grazed the tip of Franklin County as the center passed over 200 nm south while moving northwest toward New Orleans. Thirteen cyclones made landfall in Florida, two made landfall in Louisiana and 1 dissipated in the Gulf of Mexico. All tornado events began before landfall, only 5 continued after landfall. Nine tornado events began and ended before landfall. There is little correlation between center landfall and tornado occurrence. The distance of the cyclone center from land when the first tornadoes are reported is generally a function of extent of convection of the system which is highly variable. Generally, convective rain bands are most extensive on the right side of a northward moving cyclone and cyclones in the eastern Gulf of Mexico put Florida in a favorable sector for tornado development.

Tornadoes were rarely reported with the passage of the eyewall or intense inner rain bands within the radius of maximum winds of well-organized tropical cyclones. However, it should be noted that the landfall of intense eyewall convection is much rarer than outer rainbands moving over land. Hurricane Opal (case #66) is the only cyclone that has documented significant eyewall tornadoes of the 16 significant cases. Opal produced tornadoes in outer rainbands prior to landfall and tornadoes in intense eyewall convection at landfall. Historically, there has probably been a strong bias against reporting tornadoes with intense inner rainbands because of the difficulty of distinguishing tornado damage from general wind damage without a detailed survey. Only recently Fujita (1993 - see also Grazulis 1997) documented the existence of significant tornadoes in intense eyewall convection of Hurricane Andrew after an exhaustive survey. These "miniswirl" caused the most extreme damage and a number of deaths, but were not officially documented in Storm Data as tornadoes.

The forecasting of inner rainband tornadoes in major TCs is perhaps a moot point since people in the path of the center prepare for tornado-like winds anyway. The essence of this forecast problem is predicting the occurrence of significant tornadoes outside the area where people are prepared for the maximum winds, and predicting significant outer rainband tornadoes, especially from weaker tropical and hybrid cyclones, where tornadoes, rather than storm surge and high winds, may pose the greatest threat to life and property.

Considering the history of cyclone tracks during tornado production (Figure 4) it is clear that all but one are recurving or moving northeast indicating the influence of an upper low northwest of Florida. It is likely that there are certain synoptic patterns that favor significant tornado events in Florida such as surface cyclone development in the southern Gulf of Mexico or northwest Caribbean and south to southwest steering currents. A review of the official annual tropical cyclone tracks for the 13 years with significant tropical/hybrid cyclone tornado events revealed some interesting patterns. Eight of the 13 years averaged less than 1 Cape Verde cyclone per year (3 with none, 5 with one). Four of the 13 significant tornado years had active Atlantic seasons, 1964 and 1994-96, but all 4 significant events in these years were late season events (October and November) that developed in the Gulf and Caribbean. The years 1947 and 1982 (Fig. 6) had two significant tornado events each and in both years only one cyclone formed in the tropical Atlantic. However, the one Atlantic TC in 1947 produced a significant outer rainband tornado (10) that just brushed the tip of Franklin County - the only westward moving cyclone to produce a significant tornado. Five tornado events occurred in 1968 (Figure 5), the most for any year, none were significant, but only one Atlantic TC formed. The worst tornado event occurred in 1972 and no Atlantic TCs occurred that year.

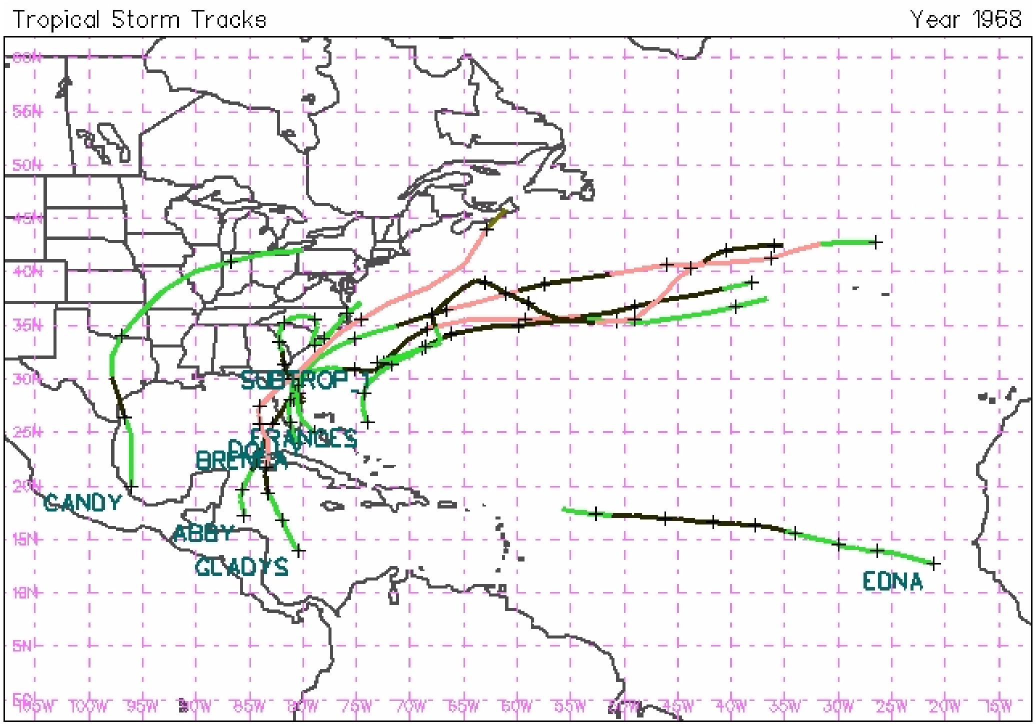

Fig. 5. Tropical Cyclone Tracks 1968.

It appears that conditions that inhibit Cape Verde type Atlantic TCs would be more favorable for cyclone development in the Gulf of Mexico and Caribbean which then have a greater chance of affecting Florida and encountering westerly shear and hybrid influences favoring the development of stronger tornadoes. Strong El Ninos which tend to inhibit Cape Verde TCs were recorded in 1972 and 1982 (Figure 6). In 1982 the foci of cyclone formation remained in the Gulf of Mexico, in 1972, after Agnes formed in the Gulf of Mexico early in the season, the foci for cyclone development shifted to the Atlantic off the Southeast coast. This cursory review reveals some interesting climatic features that are worthy of further investigation.

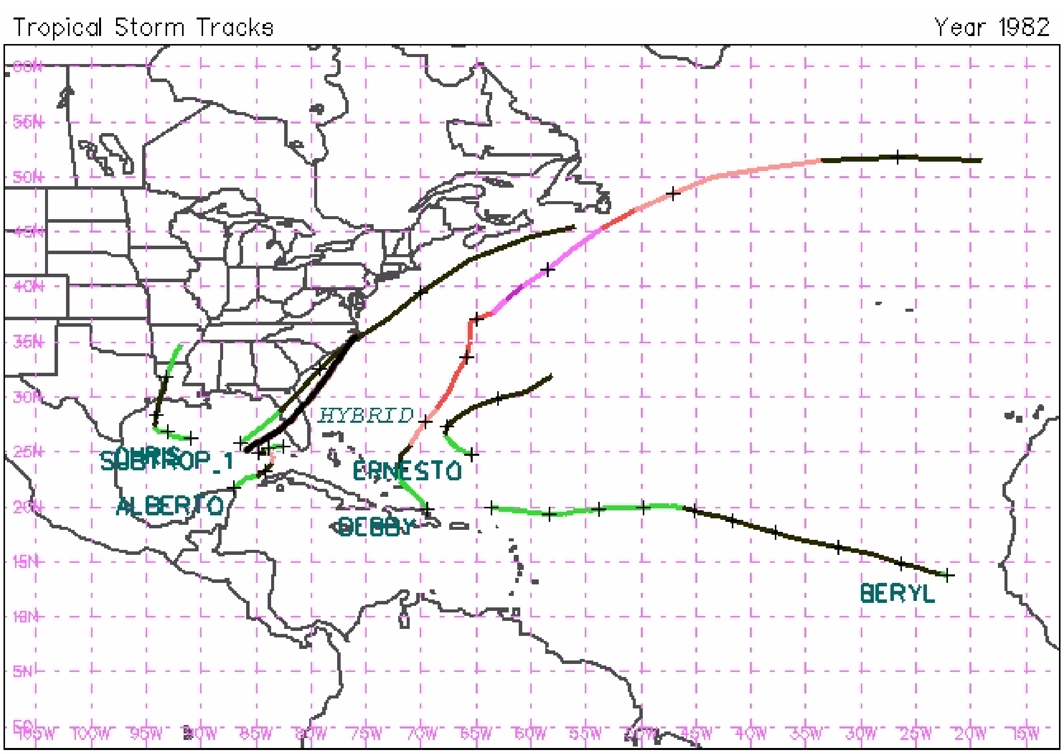

Fig. 6. Tropical Cyclone tracks 1982.

3. SUMMARY OF FORECAST GUIDELINES

The following general guidelines are based on climatological analyses and are intended for forecaster and public education and preparedness prior to an event: June, September and October are peak months for tropical and hybrid cyclone tornadoes. These tornadoes tend to be stronger than "typical" Florida tornadoes. Significant tropical cyclone tornadoes are most likely in September and October. Significant hybrid cyclone tornadoes are most likely in June and October. Significant tornadoes are most likely with intense eye wall convection of strong hurricanes and in higher reflectivity cells in clearly defined outer rain bands in the right-front quadrant of north to northeast moving tropical or hybrid cyclones in the Gulf of Mexico, regardless of central convection and central pressure. Hybrid cyclone tornadoes are, on average, stronger than hurricane tornadoes. Fast-moving tropical and hybrid cyclones are more likely to produce significant tornadoes. Outer rainband of tropical cyclones with some discernable hybrid characteristics (not purely tropical) are generally more likely to produce significant tornadoes.

Climatological information is crucial to being prepared for an event, but the WSR-88D is the primary forecast tool for diagnosing significant tornado potential on the time scale of individual tornado watches (0-6 hours) and warnings (0-1 hour). NWS Melbourne has already used locally developed climatological information on tropical/hybrid cyclone tornadoes (Hagemeyer and Hodanish 1995 and Hagemeyer 1997) combined with local studies of tornadic signatures in outer rainbands (Spratt et al 1997 and Sharp et al 1997) to successfully predict the tornado outbreak associated with Tropical Storm Josephine (Spratt and Sharp 1997). There is much more to understand about the detailed structure of TC and hybrid cyclones, especially with regard to diagnosing local effects such as tornadoes and excessive rainfall. The recent increase in TC and hybrid cyclone activity, and the completed coastal WSR-88D network, has spurred radar studies documenting tornadogenisis and intense interest in the subject has developed. To take advantage of this momentum the focus for future research should be on mesoscale aspects of TC/hybrid rainbands. This is an area of research that would benefit from a dedicated field research effort and coordination of local operational research projects at coastal NWS offices toward a common goal.

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