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COASTAL FLOODING ALONG THE WEST-CENTRAL COAST OF FLORIDA

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1. Introduction

Along the shallow, slightly sloped continental shelf and coastal plain of west-central Florida, coastal flooding has been responsible for significant loss of life and property (NOAA Storm Reports). Most documented coastal flood events in west-central Florida have been induced by tropical cyclones making landfall from the Gulf of Mexico (Neumann 1993). Extratropical (ET) cyclones have caused significant coastal flooding as well. Florida's coastal population has more than quadrupled since 1950 (Sheets 1990). This unprecedented growth has resulted in an increased potential for damaging coastal flood scenarios. The coastal flood events of 12-13 March 1993 (Storm of the Century) and 7-8 October 1996 (Tropical Storm Josephine) are recent examples of such scenarios.

Coastal residents are more vulnerable now than ever to major coastal flooding from tropical cyclones. Jarrel, et al. (1995) indicate approximately 95 percent of the coastal population in west-central Florida has never experienced a direct hit by a major hurricane (category three or greater on the Saffir/Simpson Scale (Simpson 1974)). The Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model predicts a 2.7 to 5.0 m (9-16 ft) MSL storm surge with the landfall of a category three hurricane in west-central Florida and up to 10 m (30 ft) in some locations with the landfall of a category five hurricane (Jelesnianski et al. 1992). Clearly, landfall of a major hurricane along the west-central coast of Florida will produce widespread damage from coastal flooding (in addition to damage from high sustained winds, heavy rain, and tornadoes).

ET coastal flood events generally lack the potential for storm tide levels characteristic of a major hurricane. Coastal residents are less aware of the coastal flood potential from ET cyclones. This may be attributed to the rarity of ET cyclone coastal flood events. Another reason may be relatively less media attention given to ET cyclone weather events. Finally, coastal flooding gets overshadowed in the public eye by some of the other weather hazards inherent in a strong ET cyclone, such as tornadoes, severe thunderstorms, heavy rain, etc.

The necessity of alerting a growing and increasingly vulnerable coastal population to dangerous coastal flood conditions from both tropical and ET cyclones motivates the need for a better understanding of coastal flood behavior along the west-central coast of Florida. The purpose of this paper is to contribute to this understanding by explaining how coastal flood conditions commonly occur along the west-central coast of Florida, and to explore available data related to coastal floods in this region to gain an understanding of what types of synoptic conditions favor this phenomenon. To accomplish these goals, an atlas of coastal flood-producing cyclone tracks with documentation of the effects of each event was developed and is presented as a reference for making coastal flood forecasting decisions. These data are unique in that they have been compiled from a variety of published and unpublished local sources going back 150 years.

2. Data and Methodology

Increasing evidence suggests intermediate stages of cyclones exist that exhibit characteristics of both the classic tropical cyclone and classic ET cyclone. Some cyclones confronted by meteorologists elude a succinct description (e.g., the 2-3 October 1992 Gulf of Mexico cyclone). Spiegler (1972) indicates that it is too simplistic to consider only two cyclone types and that a more comprehensive nomenclature is needed that includes intermediate stages of cyclone development. It is not our objective to get involved with the details of accepted cyclone nomenclature here. Thus, the following definitions for tropical and ET cyclones are assumed.

Tropical Cyclone: A warm-core, nonfrontal low pressure system of synoptic scale that develops over tropical or subtropical waters and has a definite organized circulation (i.e, a tropical depression, tropical storm, or hurricane).

ET Cyclone: An atmospheric closed cyclonic circulation that does not meet the above definition for tropical cyclone.

Storm tide data were retrieved for the period 1848-1998 from NOAA *Storm Data*, NOAA storm reports, newspaper articles (*Tampa Tribune* and *Saint Petersburg Times*), and NWSO Tampa Bay local and regional records. Some tide gages supplying this data are no longer in operation and some operate presently under the aegis of the National Ocean Service (NOS) Tampa Bay Physical Oceanographic Real-Time System (PORTS). Water levels responsible for damage to life or property constitute a "coastal flood event," hence, these are the water levels archived. More numerous coastal flood events have been recorded in recent years as there are more people and structures in coastal Florida. Subjecting this archive of water level data to rigorous scientific analysis is not feasible here due to the quality of observations in earlier years. The data, however, are sufficient to provide the forecaster with a general reference of coastal flooding along the west-central coast of Florida. Modern improvements in data collection and communications will yield a more complete archive of water level data in the future.

3. Discussion and Results

a. Causes of coastal flooding along the west-central coast of Florida

Coastal flooding results from an interaction among surface wind stress on the ocean, atmospheric pressure, astronomic tides, and ocean floor/coastal topography (Sobien and Paxton 1998). The surface wind stress on the ocean is the most important force that affects ocean water levels in a coastal flood situation along the west-central coast of Florida. To understand why, one must consider the *Ekman spiral* (Sverdrup 1942; McLellan 1965).

Essentially, the Ekman spiral is an idealized representation of how wind-driven currents in the surface layers of the ocean vary with depth. Fig. 1 illustrates an Ekman profile. Consider a calm ocean area from the surface to a given uniform depth. When wind begins to blow over this surface, wind stress on the ocean induces a geostrophic current to form from the surface downward, decreasing in magnitude logarithmically. At the same time, the direction of this induced current is also changing from the surface downward. The induced current is being deflected to the right with time (and depth) due to the Coriolis force (in the Northern Hemisphere). At some depth, the induced current magnitude decreases to zero and the current direction becomes opposite to that of the original induced current at the surface. An Ekman Spiral profile opposite in direction to the previous (upper) Ekman Spiral sets up below with time.

In deep water, water levels are maintained at a relative equilibrium. This is because water mass transport to the right in association with the upper Ekman Spiral is compensated by water mass transport to the left in association with the lower Ekman Spiral. As the wind blows over a continental shelf, however, this equilibrium is disrupted. A net transport of water mass to the right of the surface wind results. For this reason the component of the wind blowing parallel to the shore has the most influence on water level rises. Since water mass transport is to the right of the surface wind in this situation, southerly (northerly) winds will accumulate water on west-facing (east-facing) beaches and, northerly (southerly) winds will drain water from west-facing (east-facing) beaches. As the wind increases in magnitude, the induced currents in the Ekman Spiral increase in magnitude. Thus, a greater net water mass transport results with greater wind speeds.

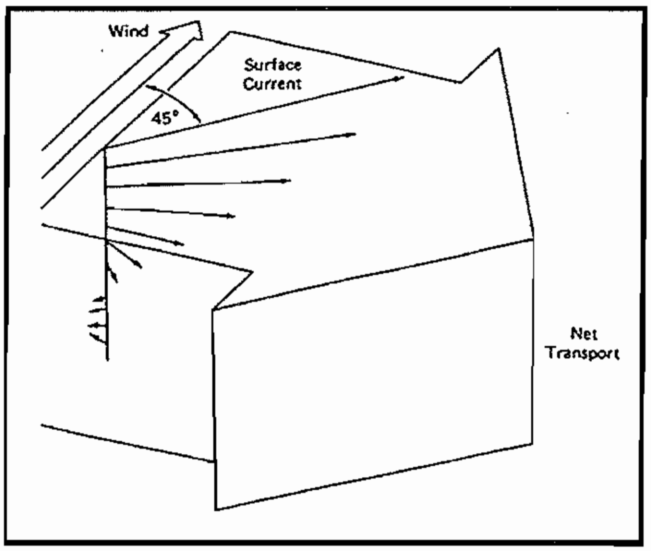

FIG. 1. The Ekman profile (Scoggins and Rinard 1996)

Atmospheric pressure contributes to oceanographic response by the "inverted barometer" effect. Atmospheric pressure exerted on the ocean is approximately balanced by the upward force exerted by the ocean. On average, ocean level rises approximately 0.3 m (1 ft) per 30 mb decrease in the surface atmospheric pressure directly above the water surface (Scoggins and Rinard 1996). For the most intense cyclones (i.e. a category five hurricane), this effect may be responsible for up to 0.9-1.2 m (3-4 ft) of the total storm surge, which is projected above 6 m (20 ft) for such a hurricane (Jelesnianski et al. 1992).

The west-central coast of Florida is particularly vulnerable to coastal flooding in part due to the relative shallow waters and gradual slope of the West Florida Shelf (WFS). Figs. 2 and 3 depict Gulf

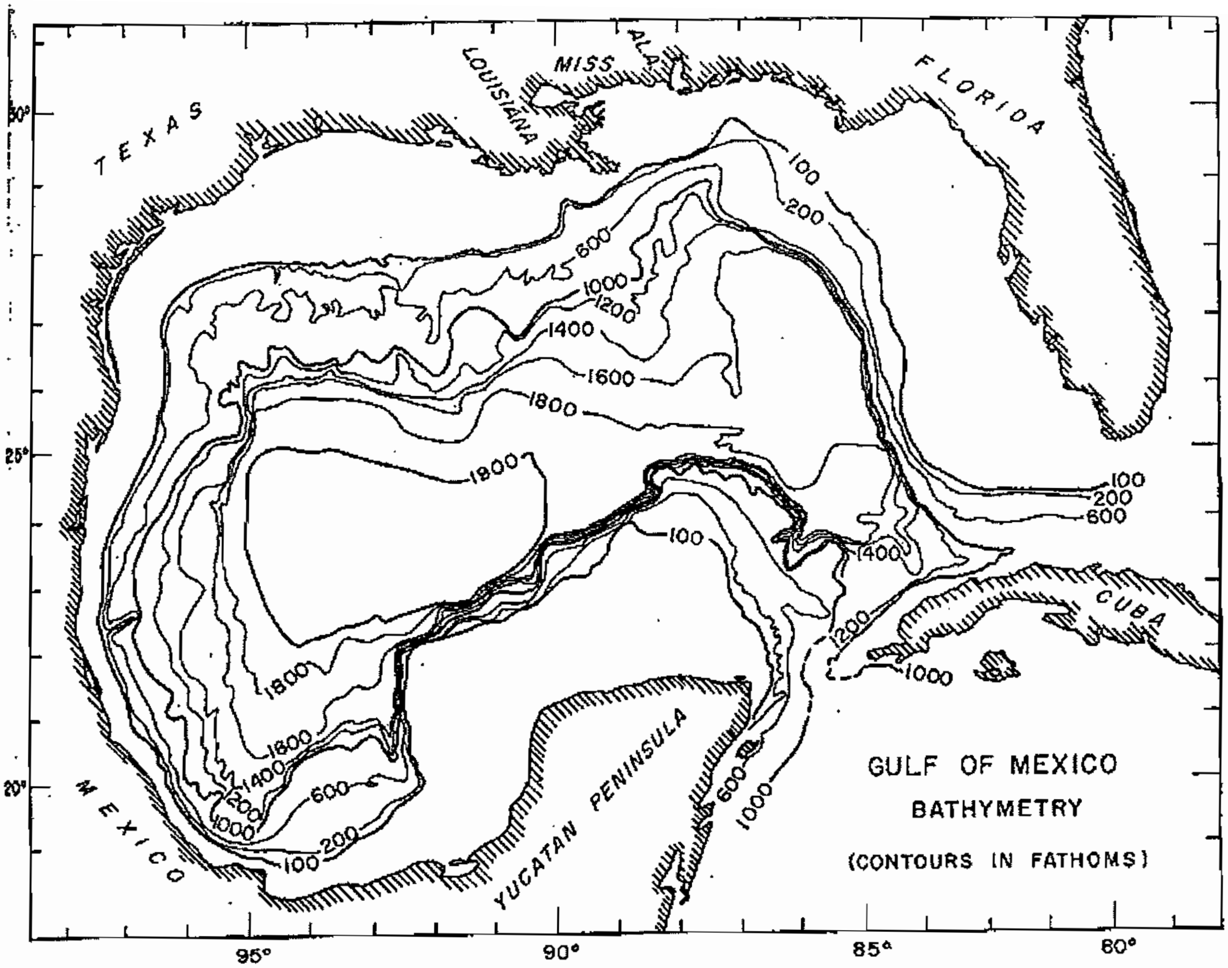

FIG. 1. Bathymetry of the Gulf of Mexico based on U.S. Coast and Geodetic Survey chart 1007 and soundings on file at the Department of Oceanography, Texas A&M University.

of Mexico bathymetry (depth) and ocean floor topography, respectively. Wind blowing over the WFS from the south will result in a net water mass transport or "pileup" of water along the coast, manifesting in coastal flooding. The vertical accumulation or "pileup" of water over the WFS is partly the result of a disruption in a deep water Ekman spiral-like circulation. Water advancing shoreward from the central Gulf of Mexico (where it is much deeper than along the WFS) encounters less and less volume due to the decreasing water depth. Since there is no means to evacuate water mass from beneath as there is in deep water, the water mass has no where to go but up. This concept is crucial in understanding coastal flooding along the west-central coast of Florida. The low grade of the WFS and the low elevation of the coastal plain assist in exploiting high water levels and producing coastal flooding.

Another important factor to consider when determining how a coastal flood event will evolve is the astronomic tide. If the maximum storm-induced water levels are occurring at the same time as high (low) astronomic tides, then obviously the projected storm tide will have to include the height of the storm surge plus (minus) the high (low) astronomic tide. For example, if a 1.2 m (4 ft) storm surges

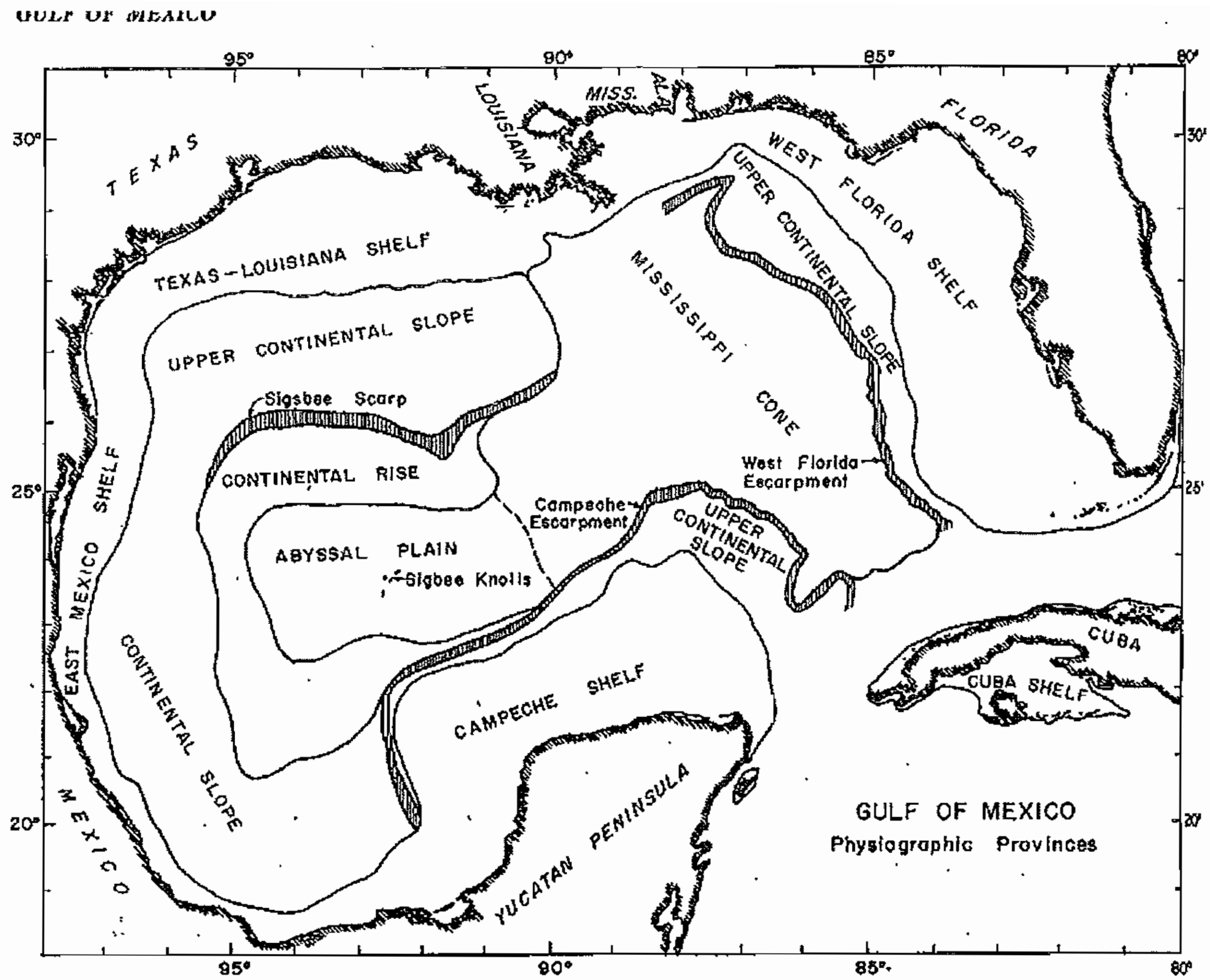

FIG. 3. Gulf of Mexico ocean floor topography (Fairbridge 1966)

projected at the same time as a high astronomic tide of 0.5 m (1.8 ft), then the total storm tide will be 1.8 m (5.8 ft). Similarly, if a 1.2 m (4 ft) storm surge is projected at the same time as a low astronomic tide of -1.2 (-4 ft), then the total storm tide will be 0.9 (2.8 ft).

Coastal flood events along the west coast of Florida often evolve from complex synoptic scenarios. Tropical cyclones at first may appear to present the simplest coastal flood scenario (i.e., a tropical cyclone moves ashore from the Gulf of Mexico, forcing a storm surge that increases storm tides in the vicinity of the eye, resulting in significant coastal flooding along a relatively small section of the coast before the storm moves away and/or weakens). In fact, other factors need to be considered: direction and speed of the cyclone, synoptic-scale pressure gradients, river levels, and coastal population.

The existence of an elevated water level is often not the only contributor to damage in a coastal flood situation. Elevated Gulf of Mexico water levels impede outflow from rivers resulting in higher river water levels. Also, elevated water level along the coast serves as a platform that allows waves (normally kept away from structures by a sufficient shoreline) to the height of structures and property. These waves then batter and destroy structures in their path (Simpson and Riehl 1981). Coastal flooding damages sea walls, roads, cars, buildings, boats, docks, and other marine accessories (boat lifts, fishing equipment, etc.). Sea walls and roads are damaged primarily by wave action (battering). Buildings may incur structural damage from wave action and flooding damage from elevated water levels. Boats moored at docks may either sink, pull pilings up, or drift free. Docks and marine equipment may suffer water and structural damage. In addition, debris from all of the aforementioned items may be exploited by high water levels and battering surf, causing further damage to various structures. Beach erosion and changes in coastal topography present additional difficulties after a coastal flood event. Coastal flooding can reshape the coastline, forming new inlets/passes and destroying older ones.

b. Tropical cyclone events

The majority of coastal flood events along the west coast of Florida are in association with tropical cyclones occurring from June to November (Appendix A). Historically, *tropical cyclone events have produced the greatest water level rises*. In 1848 a storm tide of 4.6 m (15 ft) was observed at Tampa in association with a landfalling hurricane. This remains the highest storm tide recorded along the west-central coast of Florida during the last 150 years. Theoretically, a storm tide greater than 9 m (30 ft) is possible in downtown Tampa if a Saffir/Simpson category five hurricane were to move ashore near Tarpon Springs traveling southwest to northeast (Jelesnianski 1992). The greatest threat of coastal flooding in association with a tropical cyclone usually occurs in the area near and to the right of the eye of the storm because this is usually where the combination of wind and pressure effects work best in tandem.

It is possible for a tropical cyclone to induce coastal flooding not directly related to its storm surge. Hurricanes Agnes (1972) and Opal (1995) are examples of this scenario. Hurricane Agnes moved northward from the southern Gulf of Mexico and then made landfall in the Florida panhandle. Agnes remained approximately 200 km offshore from Tampa Bay, but was responsible for significant coastal flooding (storm tides1.2 to 2.1 m or 4-7 ft above MSL) along the west-central coast of Florida. Southerly winds of 10.3 to 15.4 ms-1 (20 to 30 kt) persisted for enough time to result in a pileup of water in the eastern Gulf of Mexico and subsequent high water levels along the coast. Hurricane Opal (NWS 1996) meandered in the southwest Gulf of Mexico for a few days, gaining strength. It then quickly became an intense hurricane with a large surface wind field. The west coast of Florida was on the eastern fringes of the storm's southerly circulation. Winds persisted long enough (12-24 hours) for the Ekman effect to have maximum impact in elevating water levels. Maximum storm tides along the west coast of Florida were increased to near 1.5 m (5 feet) above MSL. Fig. 8 shows the evolution of this coastal flood event.

c. ET cyclone events

The wind field around an ET cyclone is sufficient to produce coastal flooding under similar circumstances. Indeed, the ET cyclone will *usually* affect a larger area than a tropical cyclone, however, no two storms are alike. Numerous synoptic scenarios exist that will produce coastal however, no two storms are alike. Numerous synoptic scenarios exist that will produce coastal flooding, some involving a classic hurricane storm surge, others associated with an ET cyclone, and still others that defy categorization (e.g, 5 September 1988 coastal flood event; see Appendices). Forecasting coastal flood events will be discussed in greater detail in section four.

Trajectories of the ET cyclones producing coastal flooding exhibited remarkable similarity (see Fig. 4). All but one traversed the Gulf of Mexico north of 25° N. Also, all but on crossed the Florida coastline between Pensacola and Sarasota. All ET cyclone tracks were oriented southwest to northeast and seven out of the eight ET cyclone tracks displayed a cyclonic curvature toward the northeast.

Specific information regarding the eight most recent ET cyclones is presented in Table 1. This information was compiled from *NOAA Daily Weather Maps Weekly Series*. The surface pressure listed was the lowest pressure associated with the cyclone as analyzed on the 1200 UTC surface chart on the day that coastal flooding was occurred. Cyclone Speed was deduced from three successive positions of the surface low on the three 1200 UTC analyses nearest in time to the given coastal flood event. Sustained wind speed is the average wind speed (using eastern Gulf of Mexico buoy observations and west Florida coastal surface observations) computed on the 1200 UTC surface analysis on the day that coastal flooding occurred. Maximum storm tides were obtained from the data in Appendix A.

Table 1. ET Cyclone pressure, wind, and storm tide data

Date	Surface Pressure (mb)	Cyclone Speed (ms^{-1})	Sustained Wind Speed (ms^{-1})	Maximum Storm Tide (m)
25 June 1974	1004	7 (14 kt)	11 (22 kt)	2.1 (7 ft)
17-18 June 1982	1004	11 (22 kt)	13 (25 kt)	1.5 (5 ft)
23 March 1983	1004	11 (22 kt)	13 (25 kt)	1.5 (5 ft)
5-6 Sept 88	1004	9 (18 kt)	9 (18 kt)	1.5 (5 ft)
5-6 Feb 92	992	9 (18 kt)	13 (25 kt)	1.2 (4 ft)
2-3 Oct 92	1000	9 (18 kt)	11 (22 kt)	1.5 (5 ft)
13 March 1993	972	16 (31 kt)	20 (39 kt)	3.7 (12 ft)
30 October 1993	1000	10 (20 kt)	15 (30 kt)	1.5 (5 ft)

Recent coastal flooding events (Storm of the Century, 1993 and Josephine, 1996) have increased awareness among the public and emergency management officials. Forecasters can learn from these events so that more accurate predictions may be realized in the future. The Storm of the Century was truly a unique and unprecedented meteorological event (Kocin et al. 1995 and NWS 1994). This full-latitude ET cyclone created a storm surge equal to that of a category one hurricane from Taylor to Hernando counties in Florida, a distance of nearly 100 km (see Figs. 5 and 9 for maximum storm tides along the coast and storm tide evolution at Saint Petersburg).

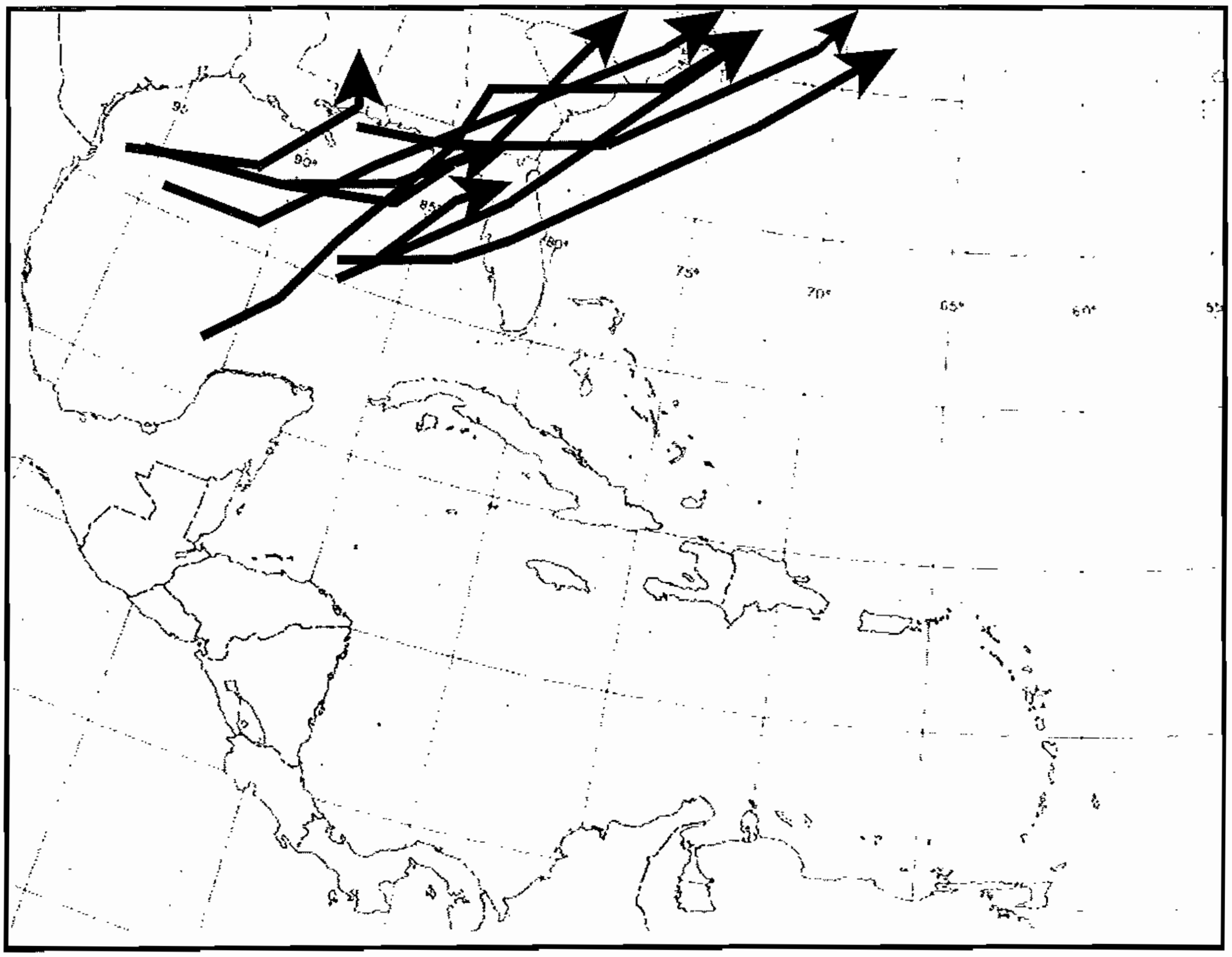

FIG. 4. ET cyclone trajectories (1924-1993)

Tropical Storm Josephine was evolving from tropical to ET while traversing the northeast Gulf of Mexico, responding to a vigorous mid-latitude upper level trough advancing southward from the Ohio Valley. Many of the Gulf of Mexico-born storm systems causing coastal flooding along the west-central coast of Florida seem to be characterized by an interaction with mid-latitude features. Since a Gulf of Mexico storm system must have some north or east component to its direction of motion in order to be responsible for west-central Florida coastal flooding, it may be surmised that it is indeed interacting with a higher latitude feature. For Josephine, the synoptic scale environment became rapidly more baroclinic as this trough interacted with Josephine and the storm consequently began deriving more and more of its energy from the baroclinic features in the southeast U.S. and less from latent heat produced by it's own convection. Convection around the storm's center decreased and the radii of the strongest winds around this center increased encompassing much of the eastern Gulf of Mexico and west-central Florida. The result was a moderate to severe coastal flood event from Levy County south to Sarasota County. See Fig. 10 for an illustration of the flood event from Levy County south to Sarasota County. See Fig. 10 for an illustration of the storm tides from Tropical Storm Josephine.

Fig. 5. Maximum storm tides (ft) recorded during the 12-13 March 1993 ET cyclone (adapted from NWS 1994)

d. Results

Of the coastal flood occurrences greater than 1.2 m (4 ft) MSL, 62 percent had storm tides of 1.2 to 1.8 m (4-6 ft). There was a significant percentage of events in which storm tides were between 2.1 and 3.7 m (7-12 ft) MSL (35 percent). Maximum storm tides greater than 3.7 m (12 ft) were *very rare* (see Fig. 6). The ET 12-13 March 1993 storm was one of these events.

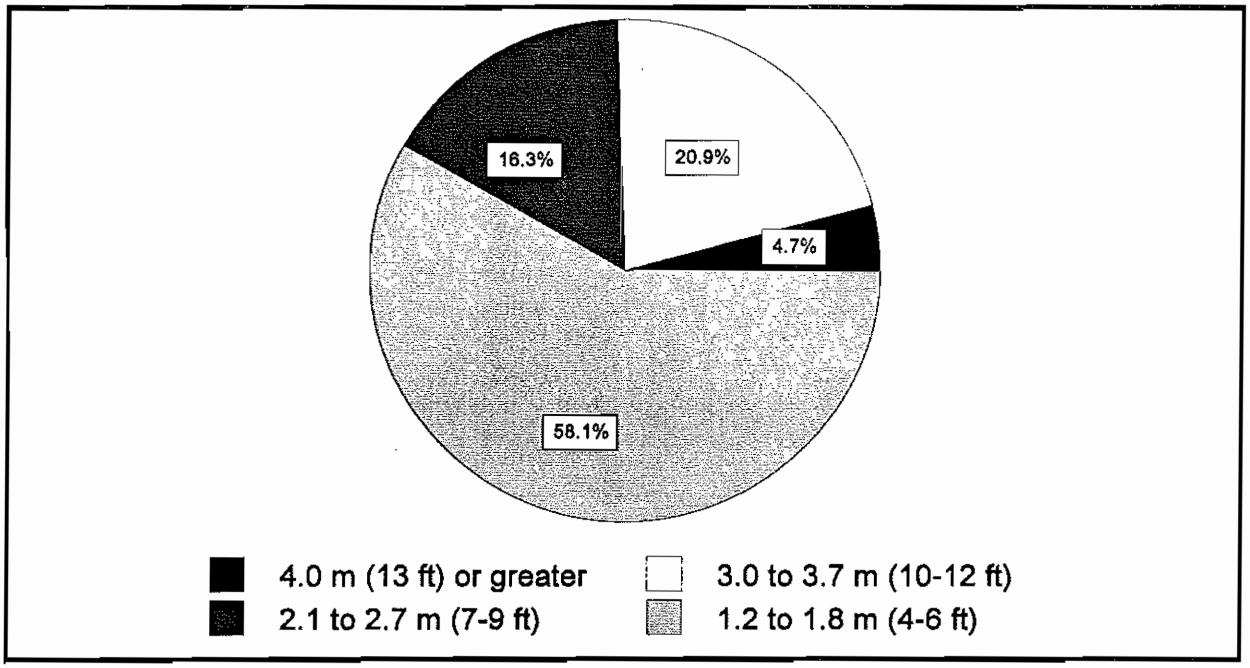

FIG. 6. Distribution of maximum storm tides recorded along the west-central coast of Florida (1848-1998). "Maximum storm tide" refers to the maximum storm tide recorded for an individual west-central Florida coastal flood event along the coast from Levy to Lee County. Only storm tides 1.2 m (4 ft) MSL or greater are included in the distribution because these are the storm tide values associated with significant flooding.

Of the 60 cyclones associated with coastal flooding along the west coast of Florida, 52 (86.7 percent) were tropical cyclones (35 hurricanes, 14 tropical storms, 2 tropical depressions, 1 unknown strength) and 8 (13.3 percent) were ET cyclones. The lack of ET cyclone data in earlier years is perplexing. We hypothesize that this is partially due to poorer data collection and reporting procedures in these past. As alluded to before, it is also possible that ET cyclones capable of producing modern-day coastal flooding existed, but that no coastal flooding occurred then due to a less inhabited coast.

Over half (63.3 percent) of the coastal flood events studied occurred in September and October, corresponding with the height of the Atlantic Basin tropical cyclone season. Fig. 7 illustrates this coastal flood season well. The origin of cyclone formation was examined as well. It was found that 37.9 percent formed in the *western* Caribbean Sea (west of 75° W). Only one cyclone originated in the *eastern* Caribbean Sea (east of 75° W). The Atlantic Ocean was the breeding ground for 32.8 percent of the cyclones, and 27.6 percent formed in the Gulf of Mexico. Half (8 out of 16) of the Gulf of Mexico cyclones were ET. It is unknown exactly where the two 1848 cyclones originated.

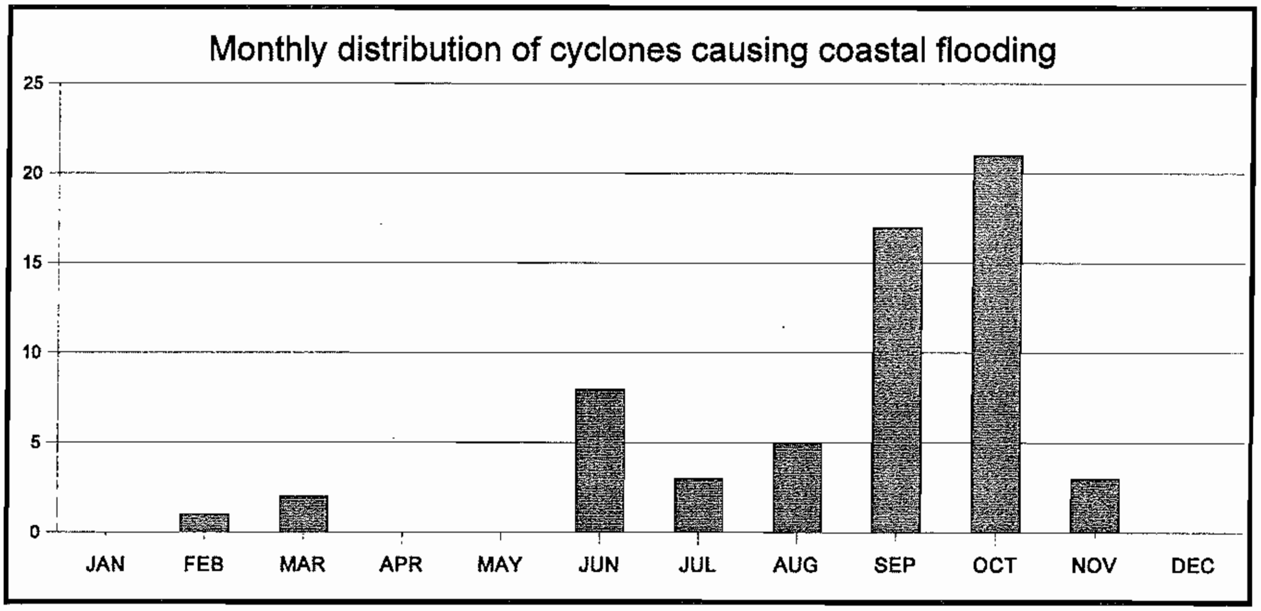

FIG. 7. Monthly distribution of all cyclones causing coastal flooding along the west-central coast of Florida (1848-1998)

4. Forecasting

Forecasting coastal flood events presents a challenge. Coastal flooding results from a complex interaction between the atmosphere and ocean, best described by a rigorous study of multi-scale nonlinear fluid mechanics. The lack of meteorological and oceanographic data across the Gulf of Mexico hampers efforts to understand a coastal flood situation as it unfolds. In addition, this lack of data renders NWP models less effective. Fortunately, this situation is improving. Currently, computer-generated guidance is available to NWS forecasters in the form of the Technique Development Laboratory (TDL) ET storm surge model. Forecasts are in text form for the East Coast, and the Gulf of Mexico. The winds and pressures needed to drive this surge model are acquired from the Aviation Model (AVN). Locally, the USF Department of Marine Science is currently conducting marine engineering and scientific studies of Tampa Bay with a numerical hydrodynamic model. USF is also developing a real-time Coastal Ocean Monitoring and Prediction System (COMPS) that will essentially be an adaption of PORTS technology for monitoring the West Florida Shelf. The COMPS is building on existing in-situ measurements and modeling programs. The additional data that will be available as a result will ultimately lead to a better understanding of how a coastal flood event evolves; hence, more accurate predictions of coastal flooding in the future.

Numerous factors deserve consideration when forecasting coastal flood events:

a) Delineate between tropical and ET cyclones, realizing that hybrid cyclones exist that exhibit characteristics of both. Especially note the breadth and strength of the cyclones as this will likely modulate the intensity and coverage of the coastal flood conditions.
b) Consult climatological studies to help discern possible future scenarios based on what has

actually occurred in the past.

c) Employ NWP model guidance to aid in understanding how the synoptic-scale situation may evolve.

d) Utilize other numerical oceanographic prediction guidance (e.g., TDL ET storm surge model, SLOSH).

e) Pay attention to real-time observations from West Florida COMPS, Tampa Bay PORTS, National Data Buoy Center (NDBC) observations, and Coastal-Marine Automated Network (C-MAN) observations.

f) As a coastal flood situation unfolds, take advantage of other reliable sources of real-time water level observations (SKYWARN spotters, Emergency Management Officials).

g) Consider how the astronomic tides will increase (decrease) storm tides.

h) Observe river levels and consider the possible effects that high water levels, and strong winds will have on river flooding.

i) Communicate threats of coastal flooding to Emergency Management Officials, the media, and the public (this is sometimes difficult because coastal flooding seems to compete with tornadoes, heavy rainfall, etc. for the public's attention).

5. Concluding Remarks

In light of unprecedented population growth in coastal Florida and recent significant tropical and ET cyclone coastal flood events, the NWSO Tampa Bay has collected all available storm tide data and assembled a storm surge atlas that includes the tracks of all cyclones known to have induced coastal flooding along the west coast of Florida since 1848. A qualitative assessment of this data has been made in order to gain understanding into the nature of west-central Florida coastal flood events. Ultimately, knowledge from this project and others will render more accurate predictions in the future that hopefully, will save lives and mitigate the harmful effects of coastal flooding.

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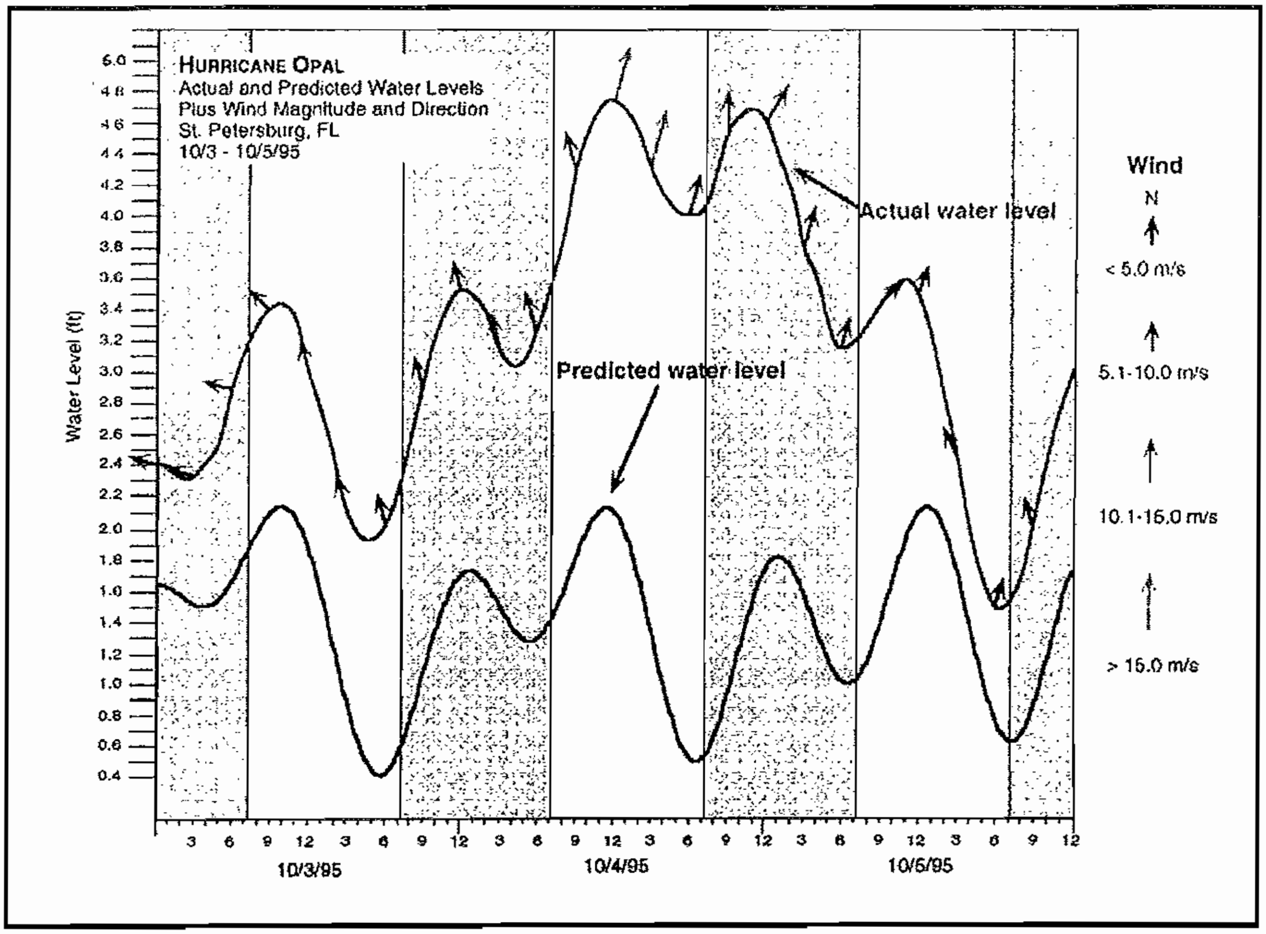


FIG. 8. Actual vs predicted water levels plus wind magnitude and direction during Hurricane Opal (3-5 October 1995 at Saint Petersburg (Department of Marine Science, University of South Florida)

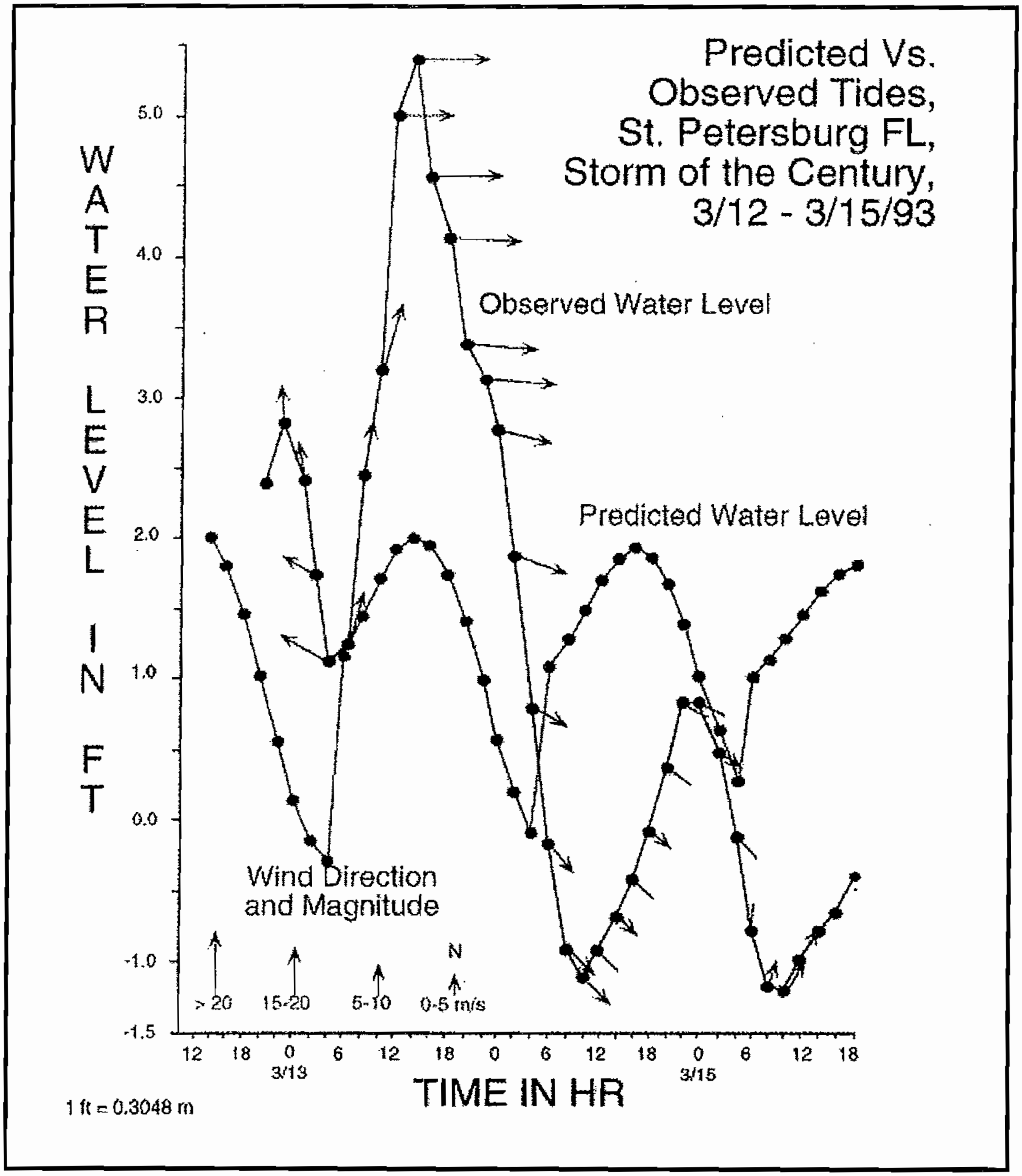


FIG. 9. Predicted vs observed tides at Saint Petersburg, Florida from 12-15 March 1993 (Department of Marine Science, University of South Florida)

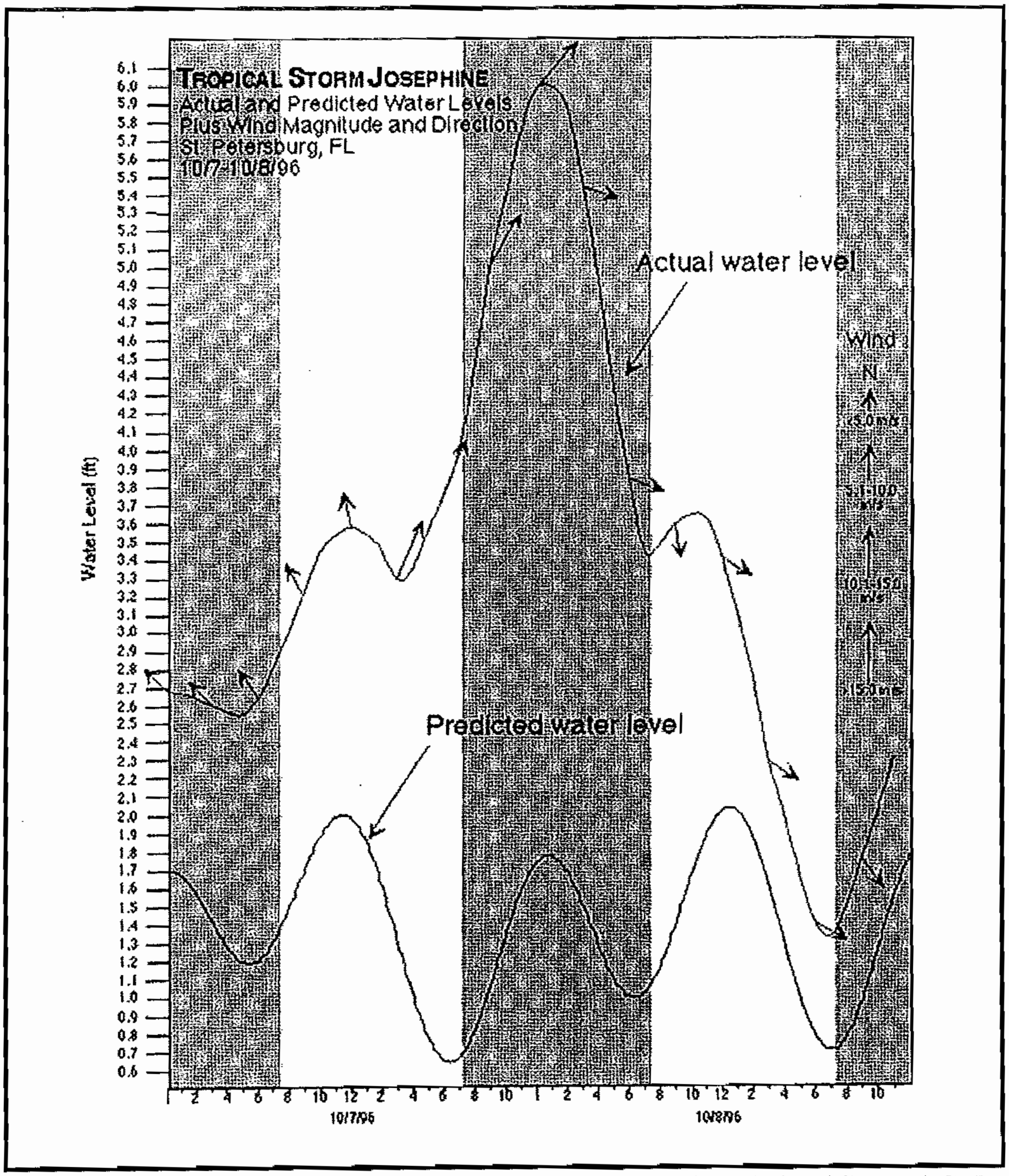


FIG. 10. Actual vs predicted water levels (Hillsborough Bay tide gage) and wind magnitude and direction (CCUT PORTS station) during Tropical Storm Josephine on 7-8 October 1996 (Department of Marine Science, University of South Florida)

Appendix A

Coastal flood occurrences (1848-1998) and associated maximum storm tides along the west-central coast of Florida with ancillary data.

Date(s)	Year	Storm	Maximum recorded Storm Tide in meters (m) and feet (ft)	Location(s)
28 September	1848	Hurricane	4.6 (15 ft)	Tampa
18 October	1848	Hurricane	3.0 (10 ft)	Tampa
3-8 October	1873	Hurricane	4.3 (14 ft)	Punta Rassa
27 October	1879	Hurricane	probably less than 0.9 m (3 ft)	Tampa Bay to Cedar Key
28-29 August	1880	Hurricane	0.9 m (3 ft)	West-central Florida
8 October	1880	Tropical Cyclone	probably less than 0.9 m (3 ft)	Cedar Key
10 October	1882	Hurricane	3.0 (10 ft)	Cedar Key
10-11 October	1885	Hurricane	probably less than 0.9 m (3 ft)	Pinellas County
17 June	1889	Tropical Storm	probably less than 0.9 m (3 ft)	West-central Florida
28-29 September	1896	Hurricane	3.0 (10 ft)	Cedar Key
2-3 August	1898	Hurricane	probably less than 0.9 m (3 ft)	West-central Florida
17-18 October	1910	Hurricane	3.0 (10 ft) 1.2 (4 ft) 0	Marco Island Tampa (at Hillsborough Bay) Tampa (at Hillsborough River, tides were 2.7 m (9 ft) below MSL)
3-4 September	1915	Hurricane	1.2 to 2.1 m (4-7 ft)	West-central Florida
29-30 September	1920	Tropical Storm	1.5 (5 ft)	Tampa

25 October	1921	Hurricane	3.4 (11 ft) 3.0 (10 ft) 2.7 (9 ft) 2.4 (8 ft) 2.1 (7 ft)	Punta Rassa Tampa Fort Myers Punta Gorda Clearwater, Boca Grande
29 September	1924	Tropical Storm/ ET cyclone	probably less than 1.5 m (5 ft)	Cedar Key
30 November	1925	Tropical Storm	0	Tampa (tides were 1.5 m (5 ft) below MSL)
19 September	1926	Hurricane	3.7 (12 ft) 2.1 (7 ft) 1.2 (4 ft)	Punta Rassa Fort Myers, Punta Gorda Tampa
16-17 September	1928	Hurricane	0.9 (3 ft) 0.6 (2 ft)	Tampa, Fort Myers, Punta Gorda Venice
28-29 September	1929	Hurricane	1.8 (6 ft) 1.5 (5 ft) 1.2 (4 ft) 0.6 (2 ft)	Everglades City Tampa Tarpon Springs Punta Rassa
3-5 September	1933	Hurricane	1.8 (6 ft)	Tampa
2-5 September	1935	Hurricane (category 5)	1.8 (6 ft) 1.5 (5 ft) 1.2 (4 ft)	Fort Myers, Punta Rassa Sarasota, Boca Grande Tampa
31 July	1936	Tropical Storm	1.2 m (4 ft)	Everglades City
6 October	1941	Hurricane	1.2 m (4 ft)	West-central Florida
20 October	1941	Tropical Storm	probably less than 0.9 m (3 ft)	West-central Florida
18-19 October	1944	Hurricane	2.7 (9 ft) 1.8 (6 ft) 1.2 (4 ft) 0.6 (2 ft)	Everglades City Fort Myers Tampa Sarasota
23-24 June	1945	Hurricane	1.8 (6 ft)	Pasco County
7-8 October	1946	Hurricane/ Tropical Storm	1.8 (6 ft) 1.5 (5 ft) 1.2 (4 ft) 0.9 (3 ft)	Punta Gorda Fort Myers Tampa, Sarasota Cortez Beach
17-18 September	1947	Hurricane	2.1 (7 ft) 0.9 (3 ft)	Everglades City Tampa
23 September	1947	Tropical Storm	"high" (probably less than 1.5 m (5 ft))	West-central Florida

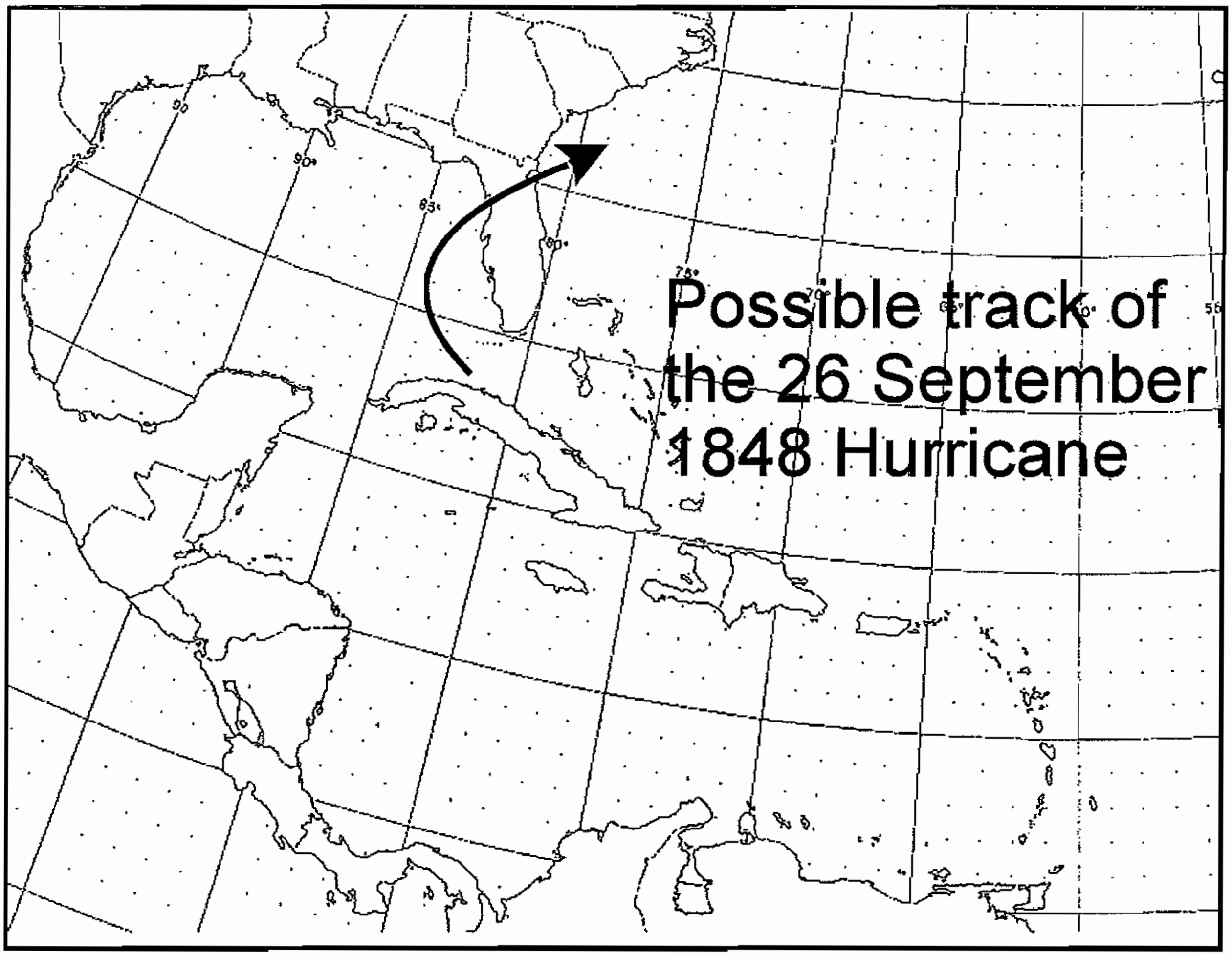
4-5 September	1950	Hurricane Easy (category 3)	3.0 (10 ft) 2.4 (8 ft) 1.5 (5 ft)	Cedar Key Tampa Clearwater
24 September	1956	Hurricane Flossy	1.2 m (4 ft) 0.9 (3 ft)	Tampa Saint Petersburg
17-18 June	1959	Unnamed tropical storm	0.9 (3 ft)	Naples, Bradenton Beach
18 October	1959	Tropical Storm Judith	0.9 (3 ft) 0.6 (2 ft)	Fort Myers Tampa
28 July	1960	Tropical Depression Brenda	probably less than 1.2 m (4 ft)	West-central Florida
10 September	1960	Hurricane Donna (category 4)	3.4 (11 ft) 0.9 (3 ft)	Fort Myers Tampa
4 June	1966	Hurricane Alma	3.0 (10 ft)	Tampa, Cedar Key
17-18 October	1968	Hurricane Gladys (category 2)	1.5 (5 ft) 0.9 (3 ft)	Tampa, Saint Petersburg Fort Myers
18-19 June	1972	Hurricane Agnes (category 1)	2.1 (7 ft) 1.8 (6 ft) 1.5 (5 ft) 1.2 (4 ft)	Cedar Key Tampa Pinellas County Fort Myers
24-25 June	1974	ET Cyclone (Subtropical Storm)	2.1 (7 ft) 1.2 (4 ft)	Fort Myers Beach Naples, Sanibel Island
17-18 June	1982	ET Cyclone (Subtropical Storm)	less than 1.5 m (5 ft)	West-central Florida
24 March	1983	ET Cyclone	1.5 (5 ft) 1.2 (4 ft) 0.6 (2 ft)	Citrus County Tarpon Springs Saint Petersburg
23 July	1985	Tropical Storm Bob	1.5 (5 ft)	Charlotte and Lee Counties
28 August- 2 September	1985	Hurricane Elena	1.5 (5 ft) 0.9 to 1.5 m (3-5 ft)	Sarasota County Manatee through Levy Counties
28-31 October	1985	Hurricane Juan	0.3 to 1.5 m (1-5 ft)	West-central Florida
21 November	1985	Hurricane Kate	0.3 to 1.2 m (1-4 ft)	West-central Florida
5-6 September	1988	ET Cyclone	0.9 (3 ft)	Pinellas and Pasco Counties
23 November	1988	Tropical Storm Keith	1.8 (6 ft) 0.9 (3 ft) 0.6 (2 ft)	Manatee County Tampa (Old Tampa Bay) Cedar Key

10-11 October	1990	Tropical Storm Marco	0.9 (3 ft) 0.6 (2 ft)	Sanibel Port Charlotte, Fort Myers, Anna Maria Island
5-7 February	1992	ET Cyclone	1.5 (5 ft)	Manatee through Collier Counties
3-4 October	1992	Hybrid ET Cyclone/ Subtropical Cyclone	1.5 (5 ft) 1.2 (4 ft) 0.6 (2 ft)	Hernando County Pasco County Pinellas through Sarasota Counties
13 March	1993	ET Cyclone	1.5 to 3.7 (5 to 12 ft); see Fig. 5	West-central Florida
30 October	1993	ET Cyclone	0.6 to 1.5 (2 to 5 ft)	West-central Florida
3-4 October	1994	Tropical Depression No. 10	0.3 to 1.2 m (1-4 ft)	Hillsborough through Levy Counties
5 June	1995	Hurricane Allison	0.6 to 1.5 m (2-5 ft)	Hillsborough to Levy Counties
2 August	1995	Hurricane Erin (category 1)	0.3 to 0.6 m (1-2 ft)	Hernando through Hillsborough Counties
24-25 August	1995	Tropical Storm Jerry	0.6 (2 ft)	Pinellas through Levy Counties
4-5 October	1995	Hurricane Opal (category 3 at landfall; category 4 for __ hours in the central Gulf of Mexico)	1.8 (6 ft) 1.2 (4 ft)	Levy County Tampa
7-8 October	1996	Tropical Storm Josephine	2.7 (9 ft) 1.8 (6 ft) 1.2 (4 ft)	Cedar Key Citrus through Hillsborough Counties Manatee through Lee Counties
3 September	1998	Hurricane Earl	1.5 to 1.8 m (5-7 ft) 1.2 to 1.5 m (4-5 ft) 0.9 to 1.2 m (3-4 ft) 0.6 to 1.2 m (2-4 ft) 0.6 to 0.9 m (2-3 ft)	Levy County Citrus County Hernando County Pasco, Pinellas, Hillsborough, and Manatee Counties Sarasota, Charlotte, and Lee Counties

Appendix B

Storm Tracks (1848-1996) of Tropical and ET cyclones that induced coastal flooding along the west-central coast of Florida. A short summary of the event is included. Storm tracks are from Neumann (1993) and NOAA Daily Weather Maps Weekly Series. Storm tide, wind, pressure, and other weather data are obtained from a variety of sources:

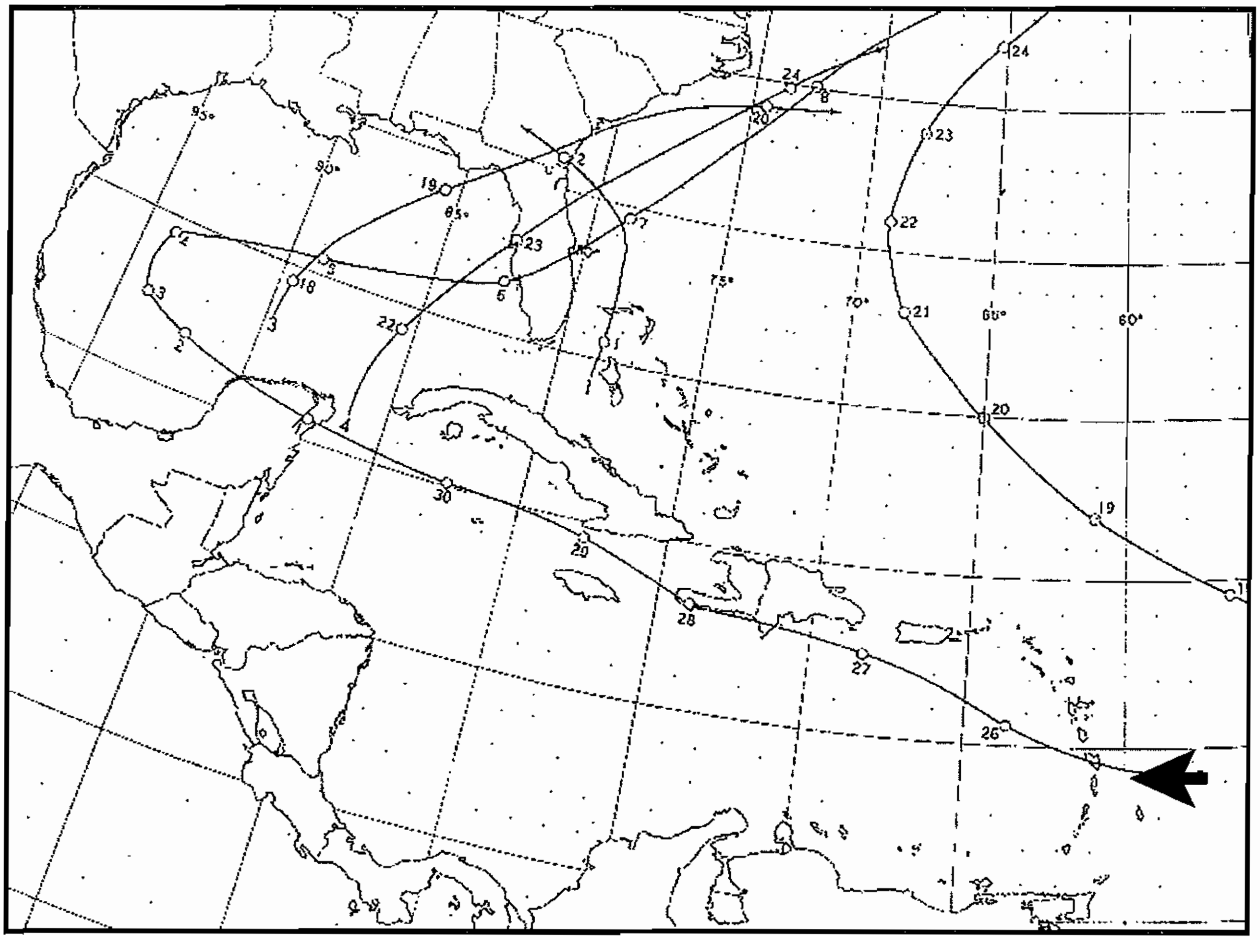
1) NOAA Storm Data
2) NOAA Climatological Data (Florida)
3) NOAA Daily Weather Maps Weekly Series
4) Tampa Tribune
5) Saint Petersburg Times
6) Neumann (1993)
7) Ludlum (1963)
8) Unpublished records at NWSO Tampa Bay



1848

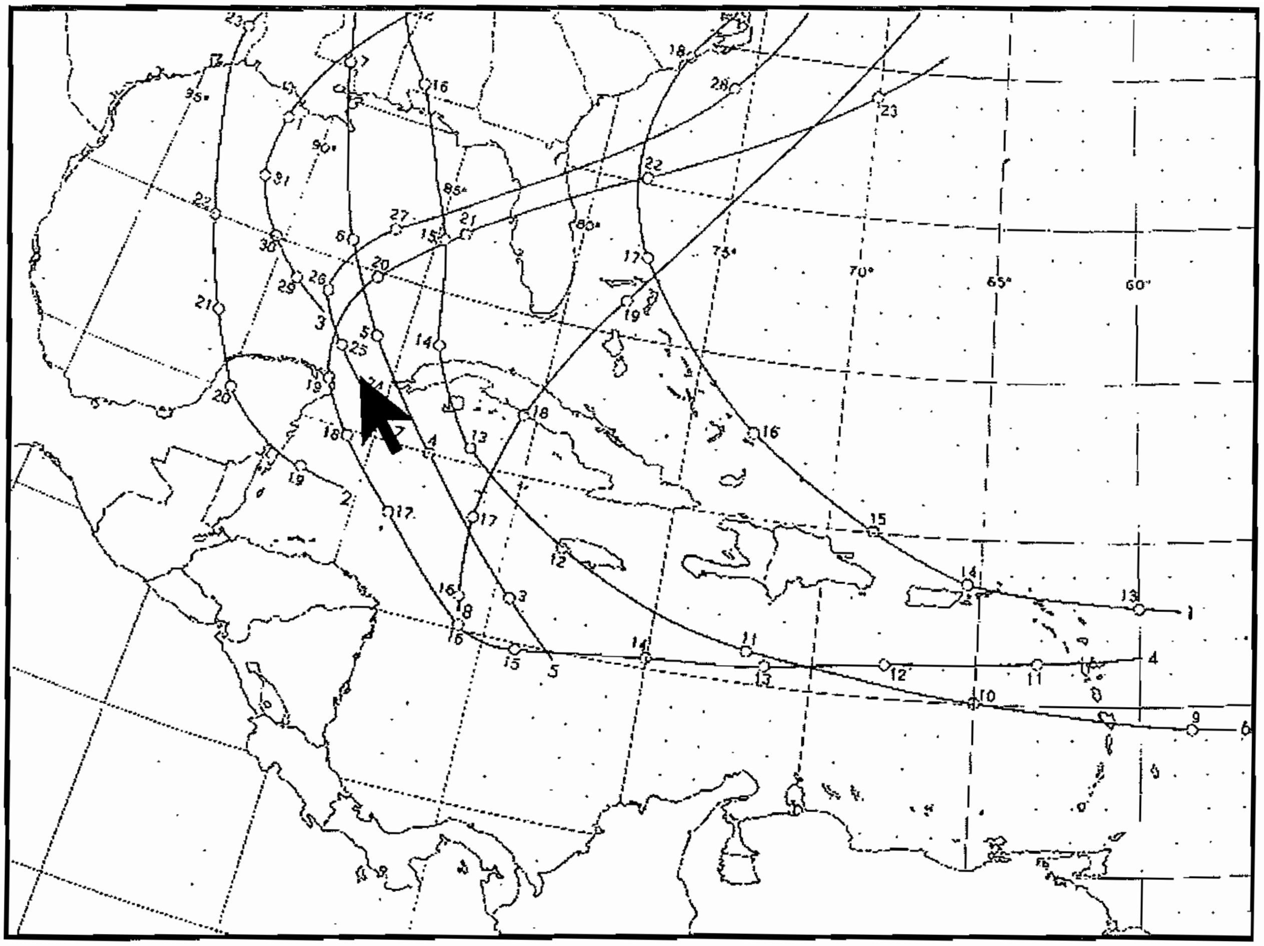
The "Tampa Bay Hurricane of 1848" Ludlum (1963) is noted for producing possibly the highest storm tides on record in the Tampa Bay area. It is also the first storm archived in this atlas. Most of what is known about this storm is contained in a letter by Major R.D.S. Wade, of the Fort Brooke, Florida Headquarters to his Commanding General in Washington, D.C. Major Wade reported, "the tide rose 15 feet above low water". This would indicate a storm tide of at least 4 m (13 ft) MSL. The track above is a speculation based on Wade's wind observations. It is estimated that this hurricane was at least of Saffir/Simpson category three strength from the water level observations and a minimum sea level pressure observation of 954 mb (28.18 in Hg) Ludlum (1963) sites other sources that indicate considerable coastal flooding and damage occurred along the west-central coast of Florida with this storm.

Less than a month later (18 October) another significant coastal flood event occurred in association with a hurricane in the eastern Gulf of Mexico. Fort Brooke reported a maximum storm tide of 3.0 m (10 ft).



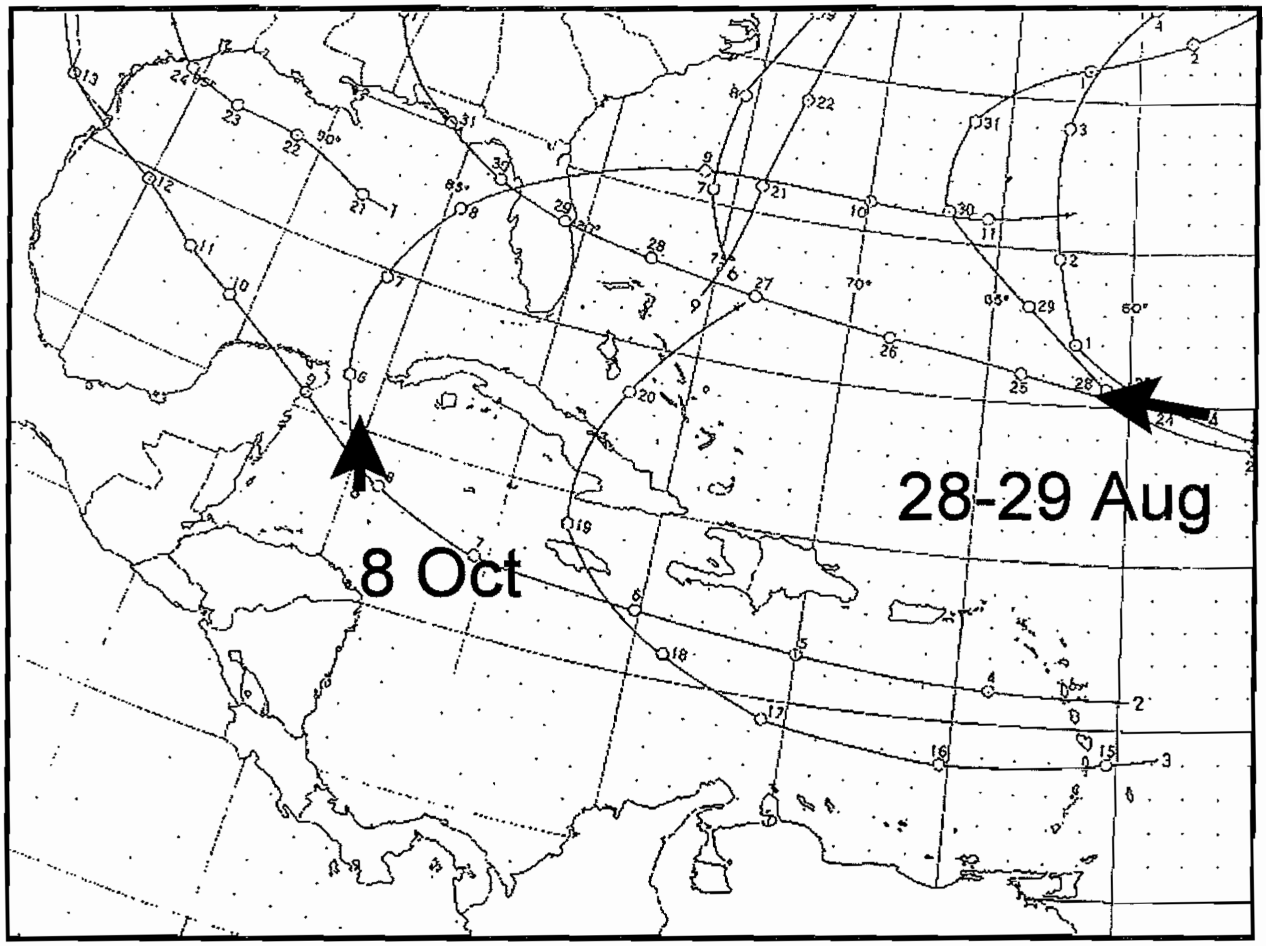
1873

The 3-8 October hurricane had its origins in the central Atlantic Ocean east of the Windward Islands. It moved across the Caribbean Sea and the Yucatan Peninsula, arriving in the Gulf of Mexico on 2 October. The hurricane made a sharp "u-turn" and then made a slow track for the west coast of Florida. The storm made landfall south of Tampa near Fort Myers. A maximum storm tide of 4.3 m (14 ft) MSL was recorded at Punta Rassa along with a maximum wind gust of 40 ms^{-1} (78 kt).



1879

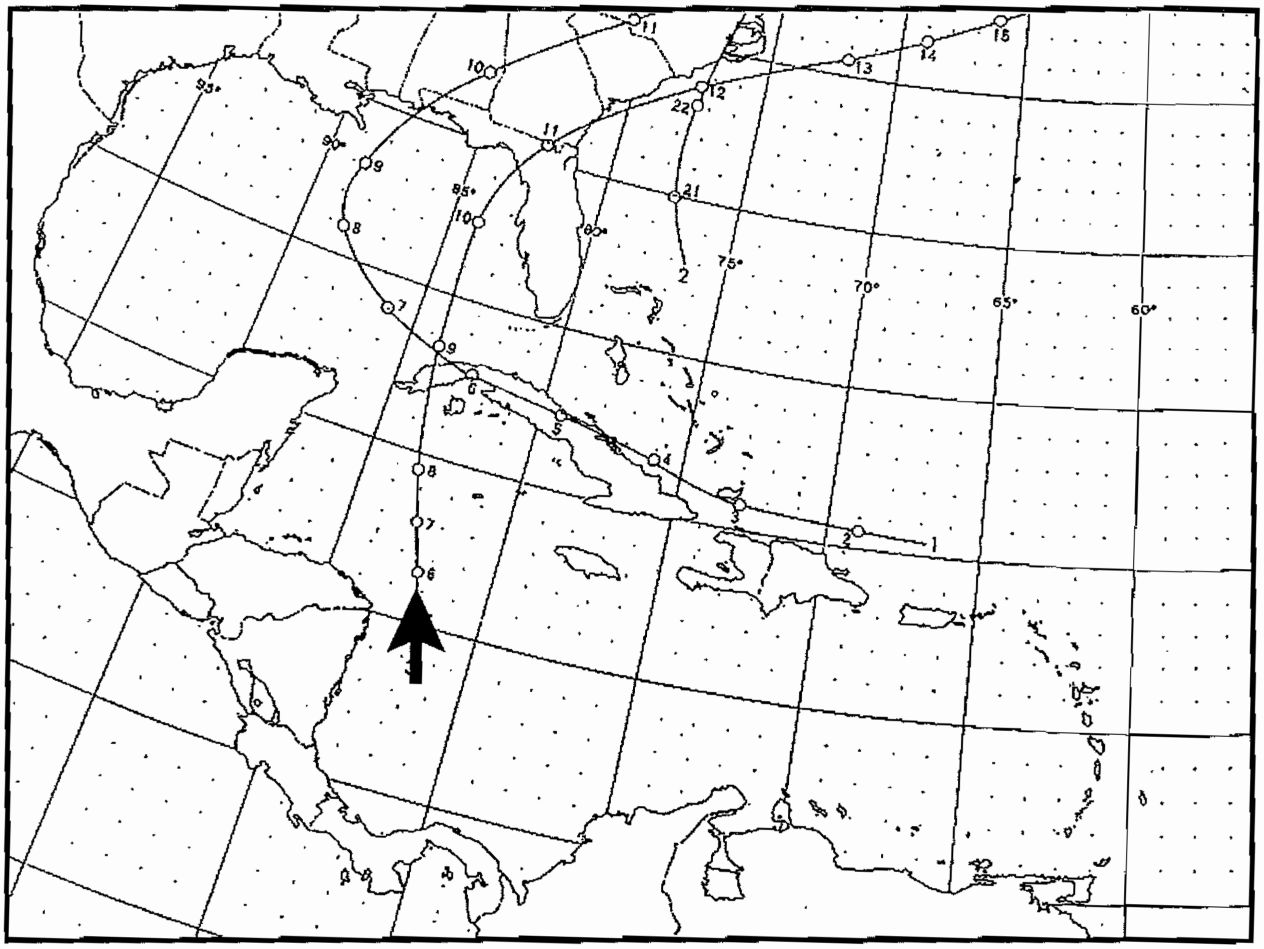
The 27 October tropical cyclone had its origins in the vicinity of the Yucatan Channel on 24 October. It initially moved northwest but then recurved and traveled northeast, making landfall just south of Cedar Key, Florida. The storm was reportedly of "minor" intensity, although residents from Cedar Key to Tampa were affected.



1880

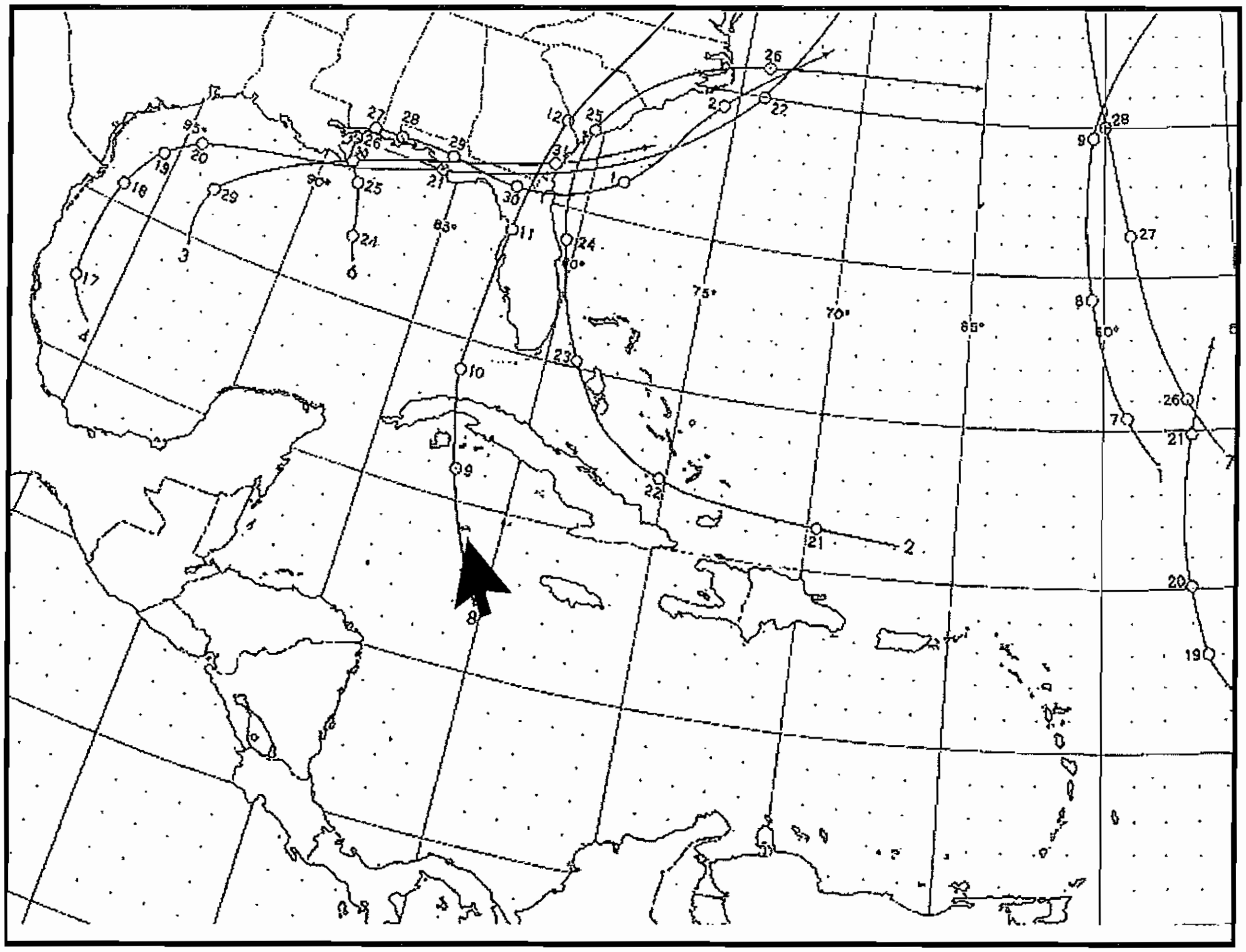
The 28-29 August tropical cyclone crossed the Florida peninsula from the Atlantic Ocean. Storm tides near 0.9 m (3 ft) MSL were reported along the west coast of Florida.

The 8 October tropical cyclone made landfall in the vicinity of Cedar Key. Its origins were in the northern Caribbean Sea.



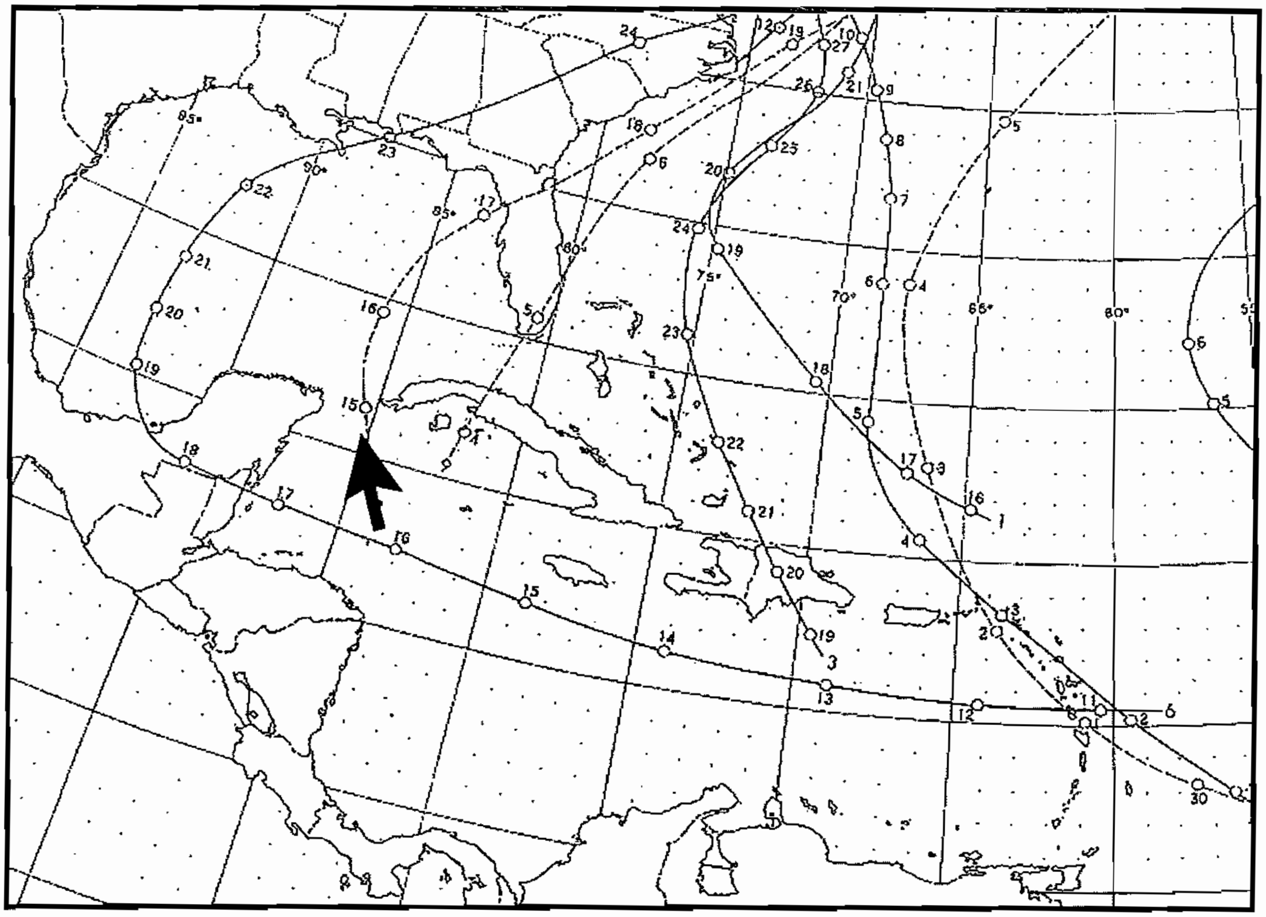
1882

The 10 October hurricane was born in the Caribbean Sea off the Honduras/Nicaragua coasts. It moved north, crossed the western end of Cuba and made landfall just north of Cedar Key, Florida. Cedar Key was reportedly "submerged" under a storm tide of 3.0 m (10 ft) MSL.



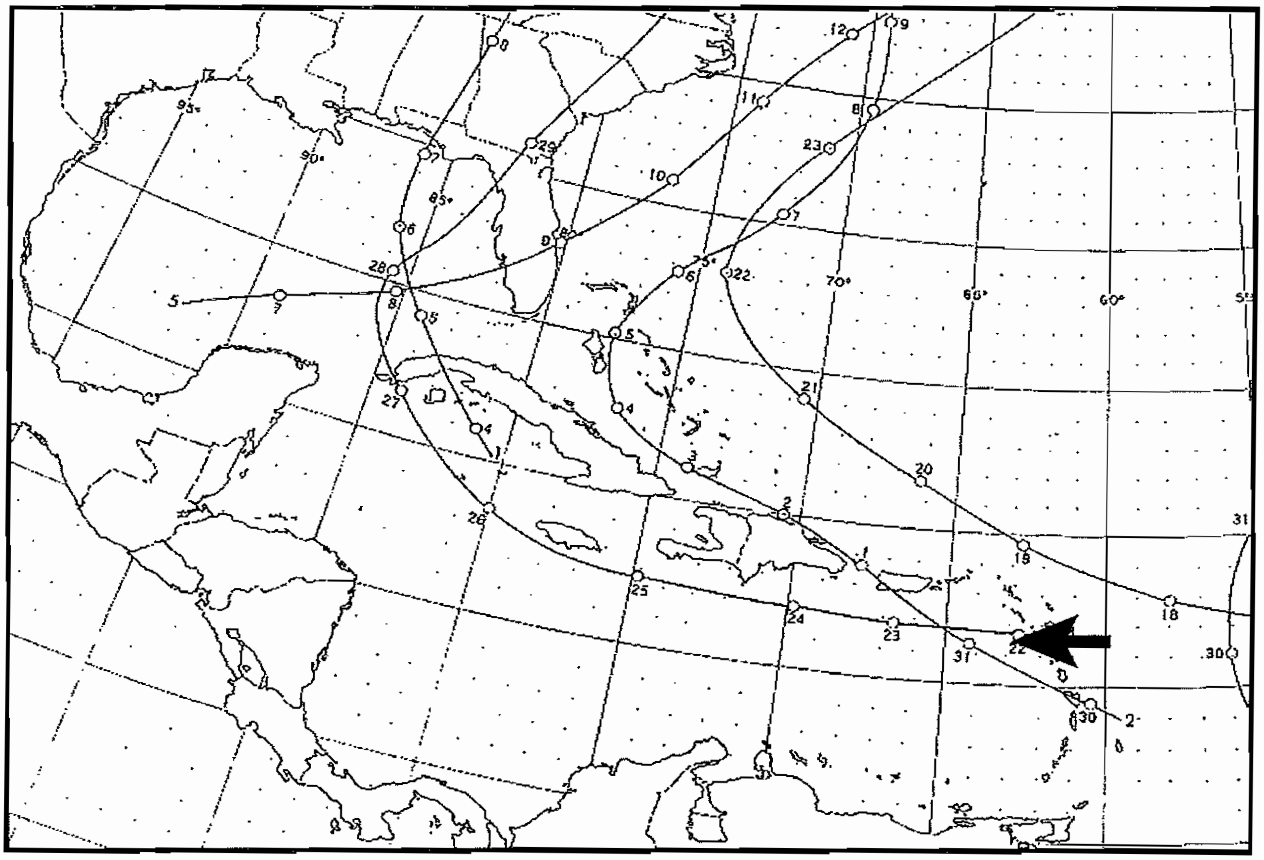
1885

The 10-11 October tropical cyclone formed in the Caribbean Sea west of Jamaica. It moved northwest, affecting the Cayman Islands, Isle of Pines, and western Cuba before making landfall at Pinellas County, Florida. The storm was reportedly of "minor" intensity, although "high tides" were reported in Pinellas County.



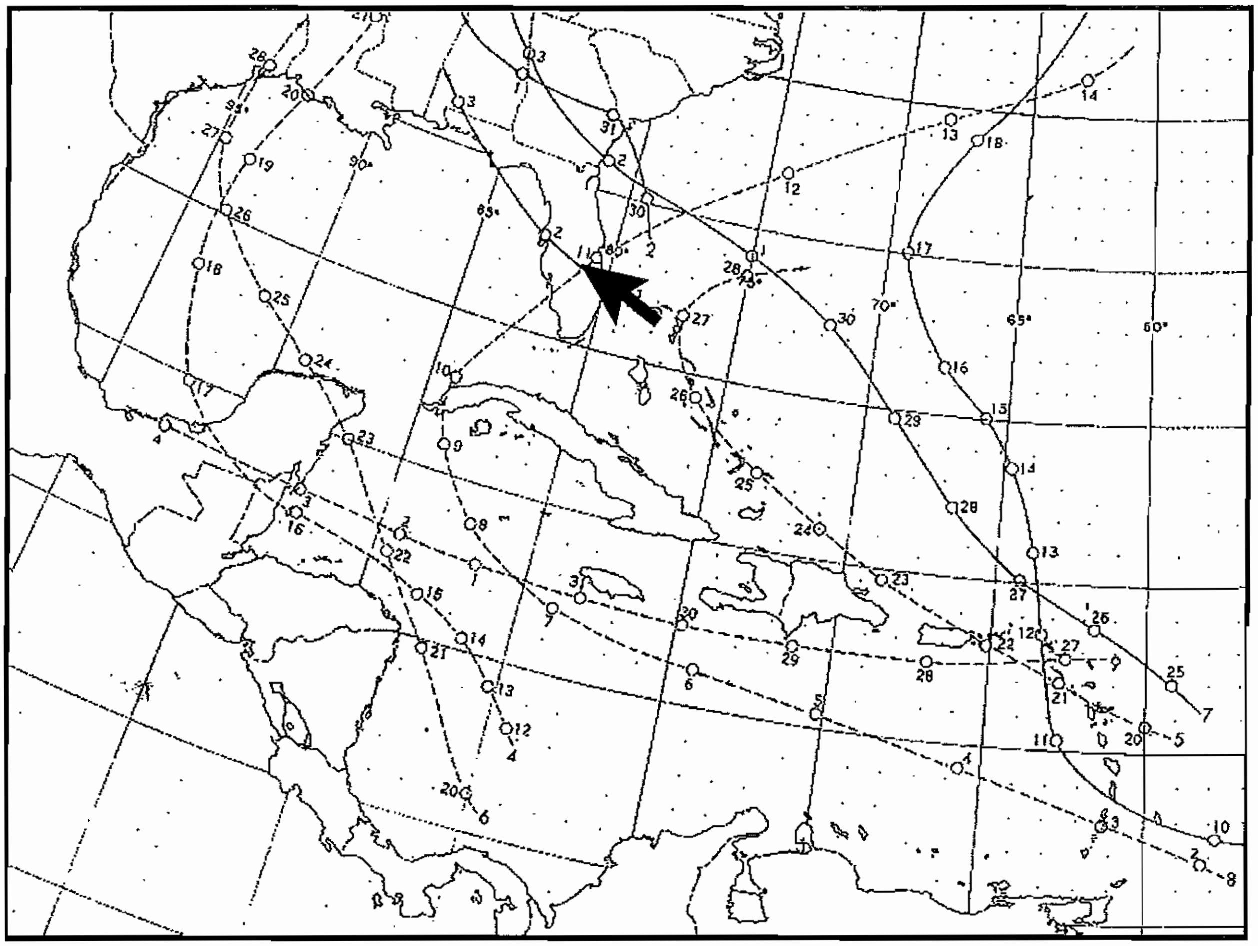
1889

The 17 June tropical cyclone developed initially in the northern Caribbean Sea between Cozumel, Mexico and the Cayman Islands. The storm moved generally north into the Gulf of Mexico and then curved to the northeast, making landfall just south of Cedar Key, Florida. The storm was reportedly of “minor” intensity.



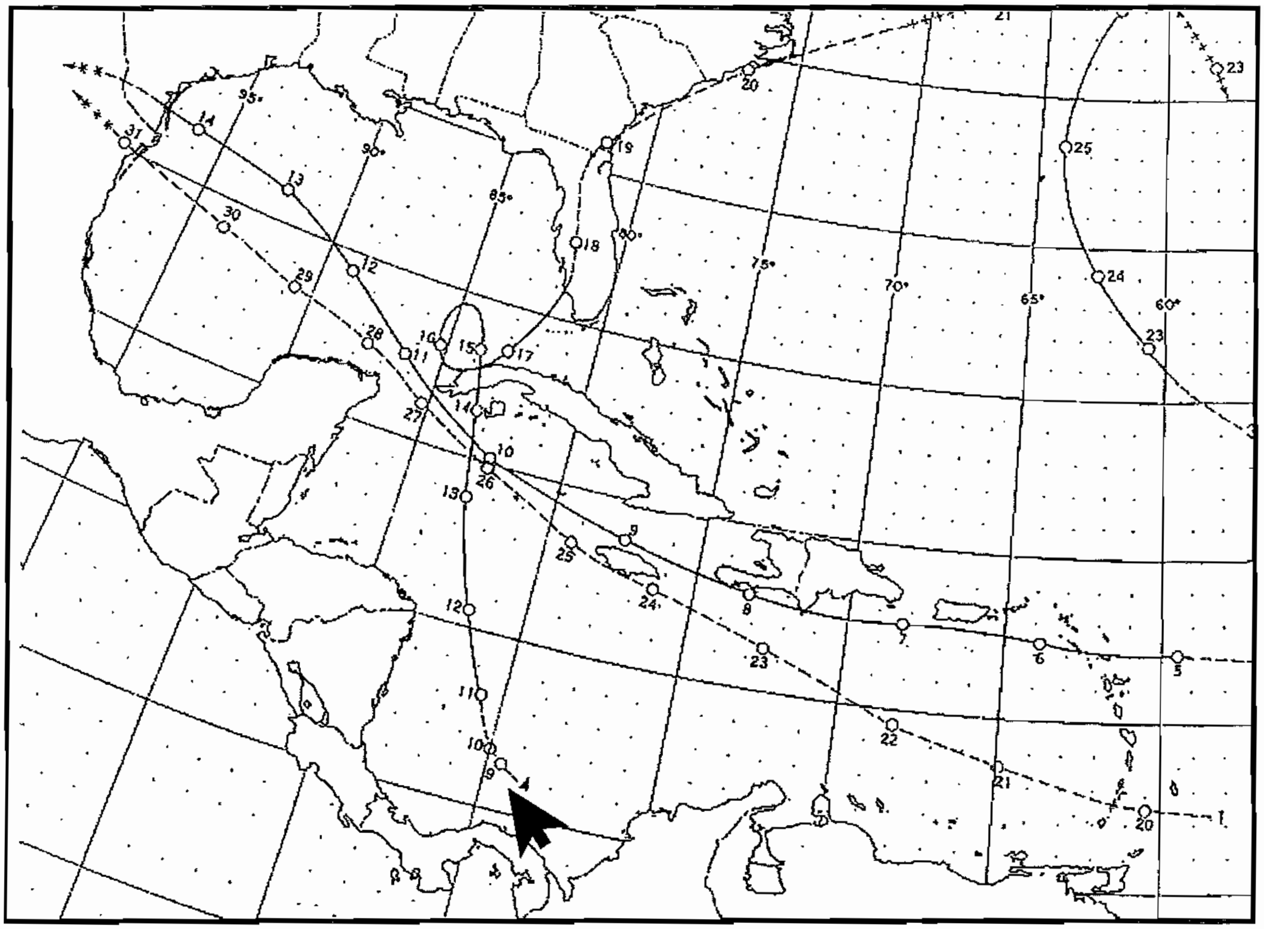
1896

The 28-29 September hurricane was born near the Leeward Islands. It travelled east across the Caribbean Sea before gradually recurving to the north and entering the Gulf of Mexico. The storm then continued its recurvature, moving toward the west coast of Florida and finally making landfall in the vicinity of Cedar Key, Florida. At Cedar Key, the maximum storm tide recorded was 3.0 m (10 ft) MSL. Over 100 storm-related deaths occurred in Florida.



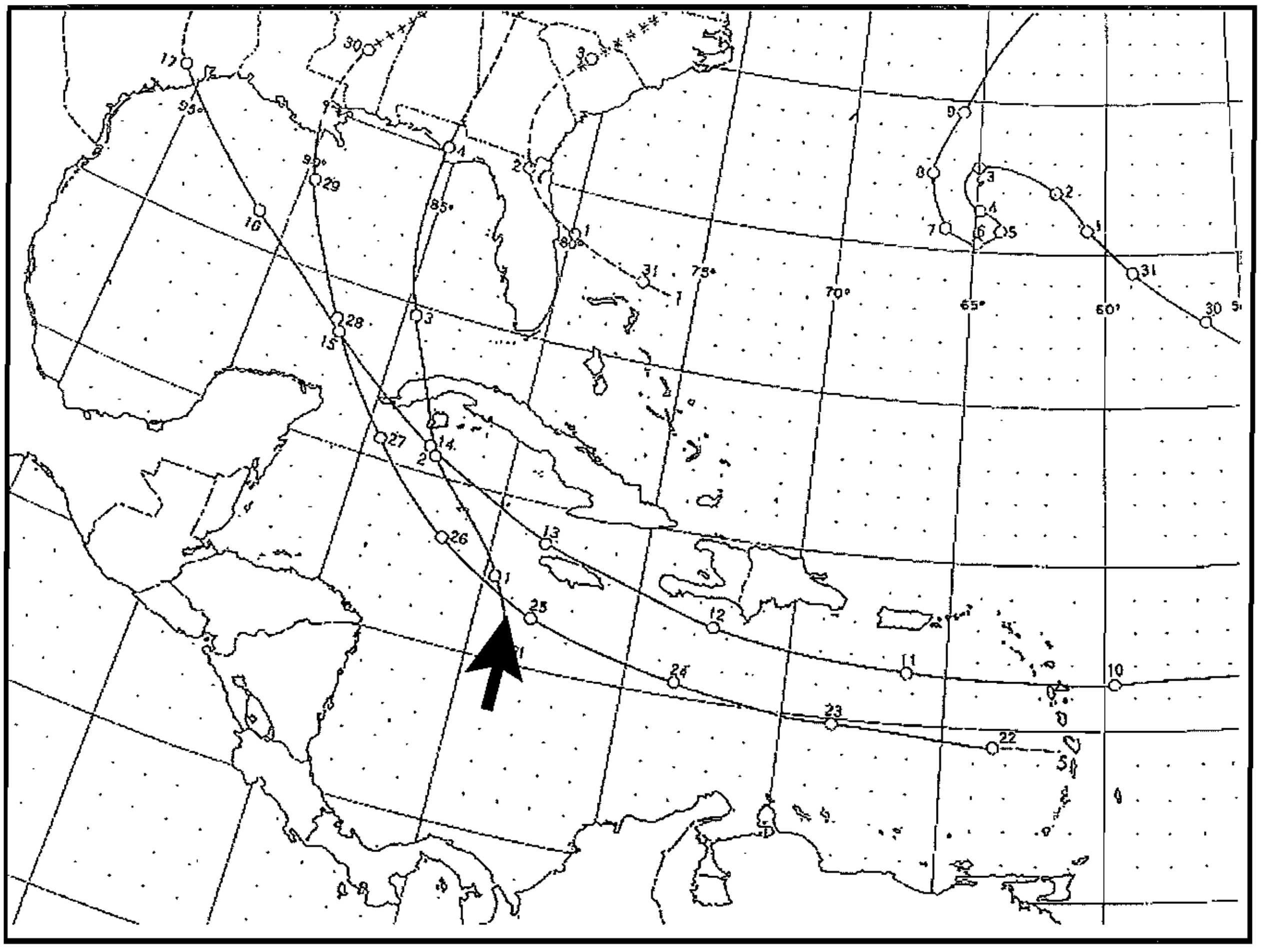
1898

The 2-3 August tropical cyclone formed just east of West Palm Beach, Florida and moved across the Florida peninsula and entered the Gulf of Mexico just north of Tampa. The storm made a second landfall in the state of Florida near Panama City. Over 12 storm-related deaths occurred with this storm.



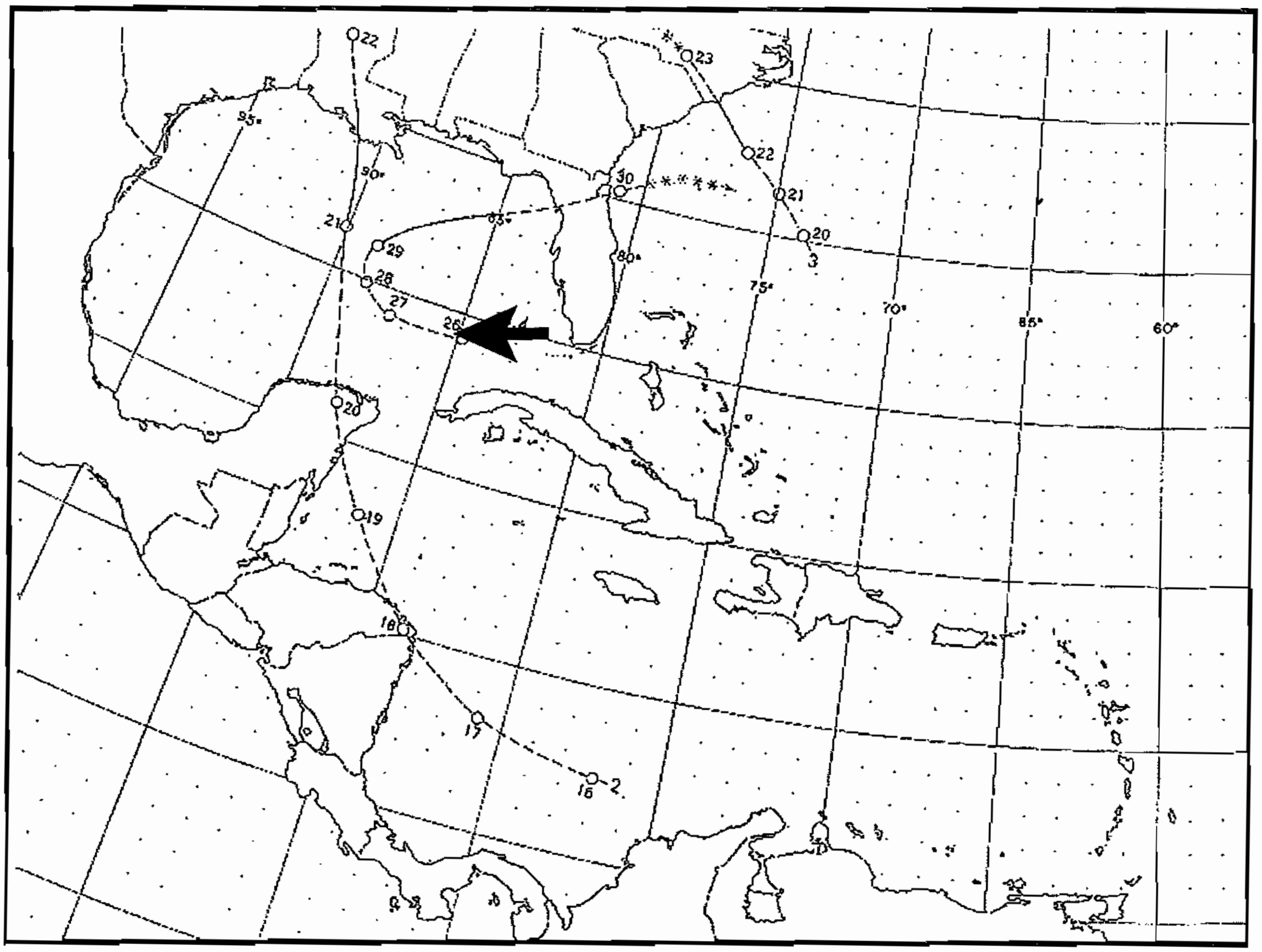
1910

The 17-18 October hurricane had its origins in the extreme southeastern Caribbean Sea north of Panama. The storm moved north-northwest crossing the west tip of Cuba. Curiously, it then made a counter-clockwise loop before moving northeast and making landfall near Naples, Florida. A 3.0 m (10 ft) MSL storm tide was recorded at Marco Island, Florida. At Tampa, the maximum wind gust was estimated to be out of the east at 40 ms^{-1} (78 kt). The strong easterly wind forced water out of the shallow Tampa Bay toward the Gulf of Mexico. In Tampa, near the mouth of the Hillsborough River, a storm tide 9 feet *below* normal was recorded. In the state of Florida, 30 storm-related deaths occurred and the citrus industry received a significant economic blow from this hurricane. Damage in Florida was estimated near $365,000. This storm was a Saffir/Simpson category three hurricane.



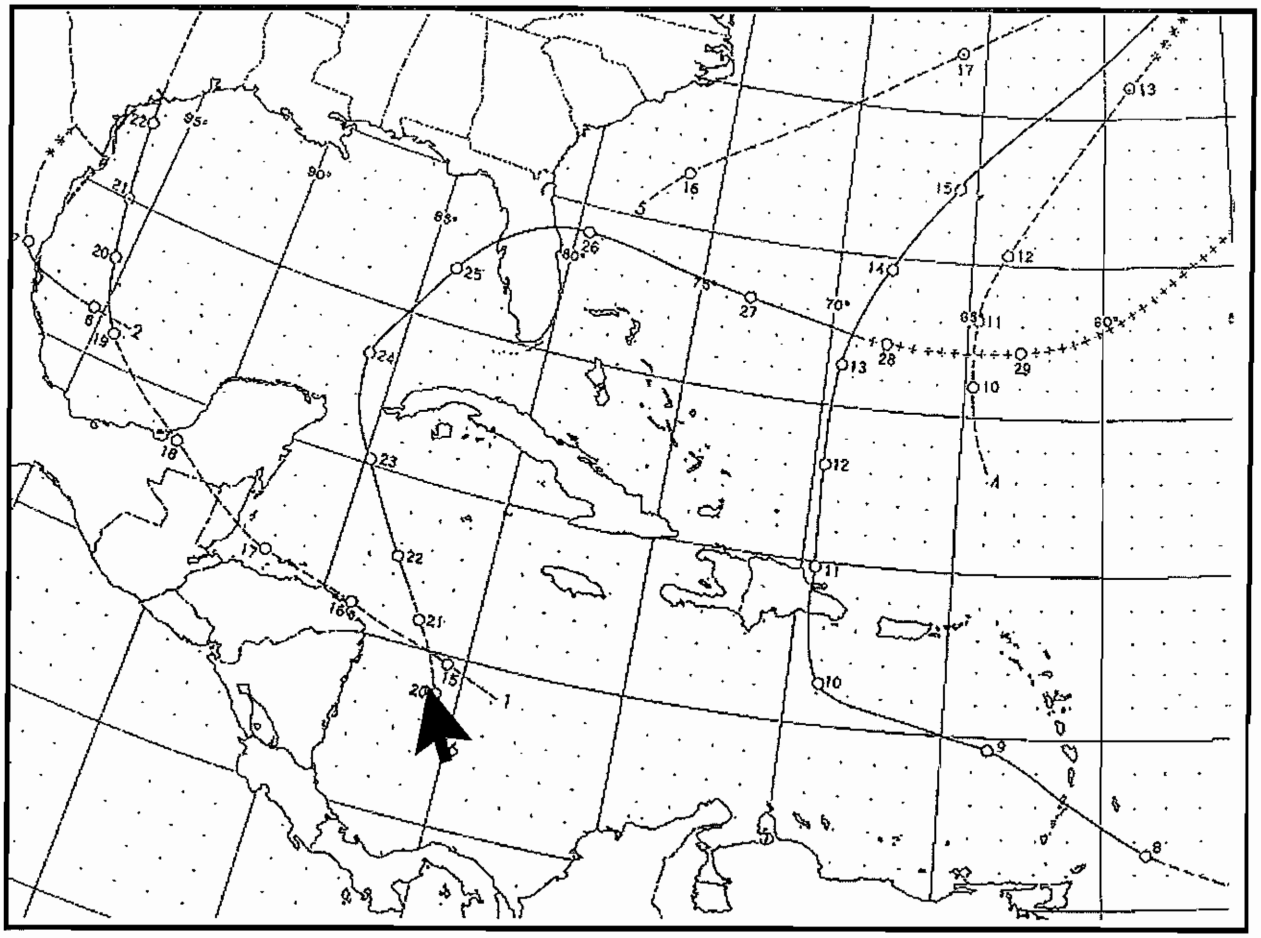
1915

The 3-4 September hurricane (Saffir/Simpson category one) had its origins in the Caribbean Sea. It traveled northwest, passing over the Isle of Pines and western Cuba before entering the Gulf of Mexico. It then traveled north, making landfall near Panama City, Florida. This storm produced a maximum wind gust at Tampa of only 16.5 ms^{-1} (32 kt) from the south-southeast; however, storm tides ranged from 1.2 to 2.1 m (4 to 7 ft) MSL along the west coast of Florida. Even though the storm remained well offshore (in the vicinity of the 85 ° W), significant storm tides occurred partly as a result of the storm's more than 24 hours in a northerly track adjacent and parallel to the west coast of Florida and the associated south-southeast wind. Twenty- one people died from this storm, most of them sponge crewmen from Tarpon Springs. Fifty-seven years later, another category one hurricane (Agnes) took a very similar track and surprised west-central Florida again with 1.2 to 2.1 m (4 to 7 ft) MSL storm tides along the west-central coast of Florida.



1920

The 29-30 September tropical storm was born just west of Dry Tortugas in the southeast Gulf of Mexico. It then proceeded to produce a horseshoe-shaped track across the eastern Gulf of Mexico before making landfall near Cedar Key, Florida. The storm had briefly attained hurricane strength while still over the central Gulf of Mexico. Tampa recorded a maximum wind gust on only 13 ms^{-1} (25 kt) from the southwest, but a maximum storm tide of 1.5 m (5 ft) MSL, flooding parts of Bayshore Boulevard near the downtown area. The storm meandered in the eastern Gulf of Mexico for nearly four days and the resulting fetch of south to southwest winds over such a long time proved sufficient to produce significant storm tides, even with the marginal wind speeds.

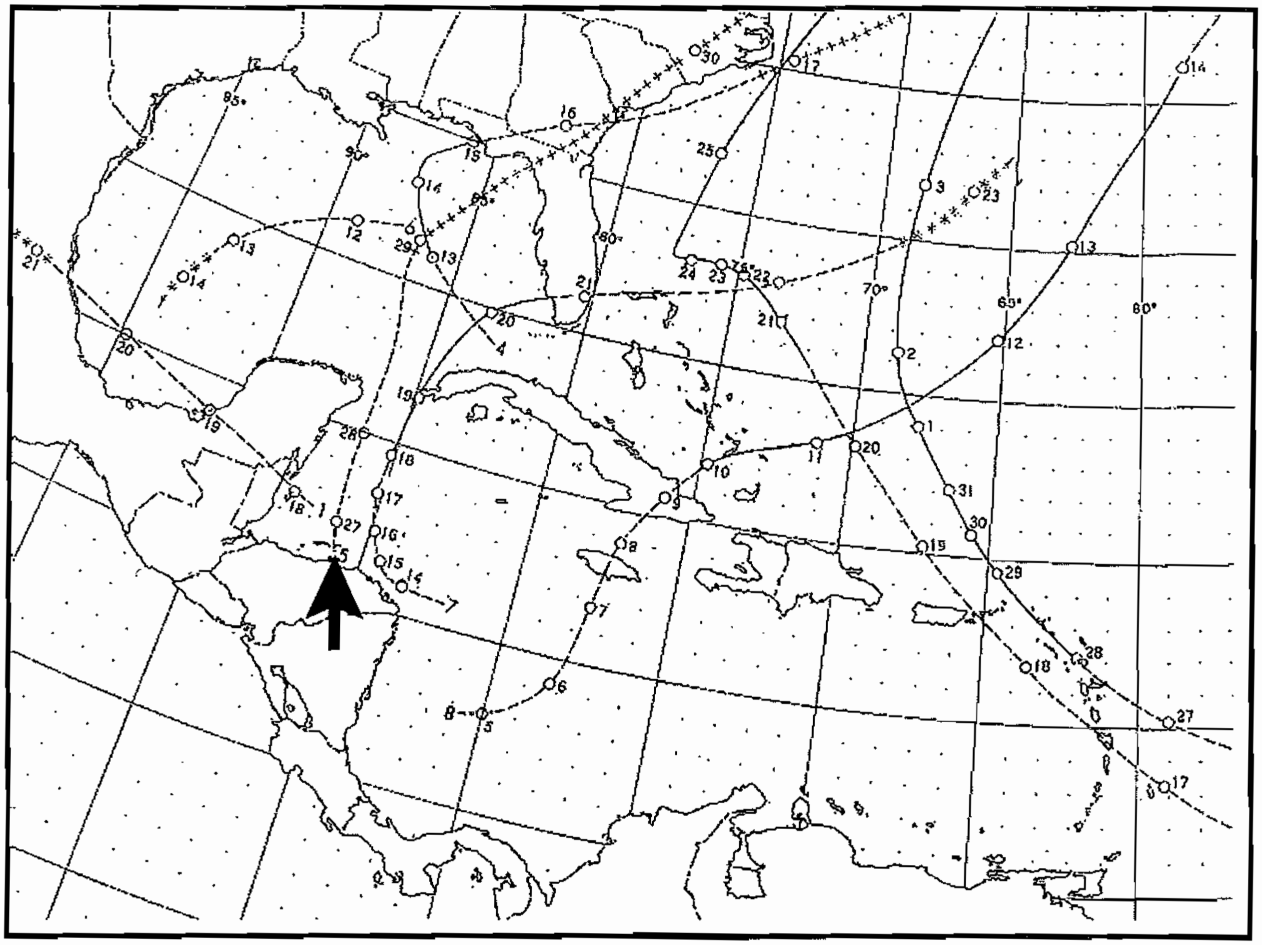


1921

The infamous 21 October hurricane (Saffir/Simpson category three) was born in the extreme western Carribean Sea and moved north into the Gulf of Mexico and then northeast, making landfall 48 km north of Tampa, Florida. Tampa recorded a maximum wind gust of 33.5 ms^{-1} (65 kt) from the south and a 3.0 m (10 ft) MSL storm tide. Egmont Key recorded a maximum wind gust estimated near 44.8 ms^{-1} (87 kt). Some other significant storm tides from this storm follow.

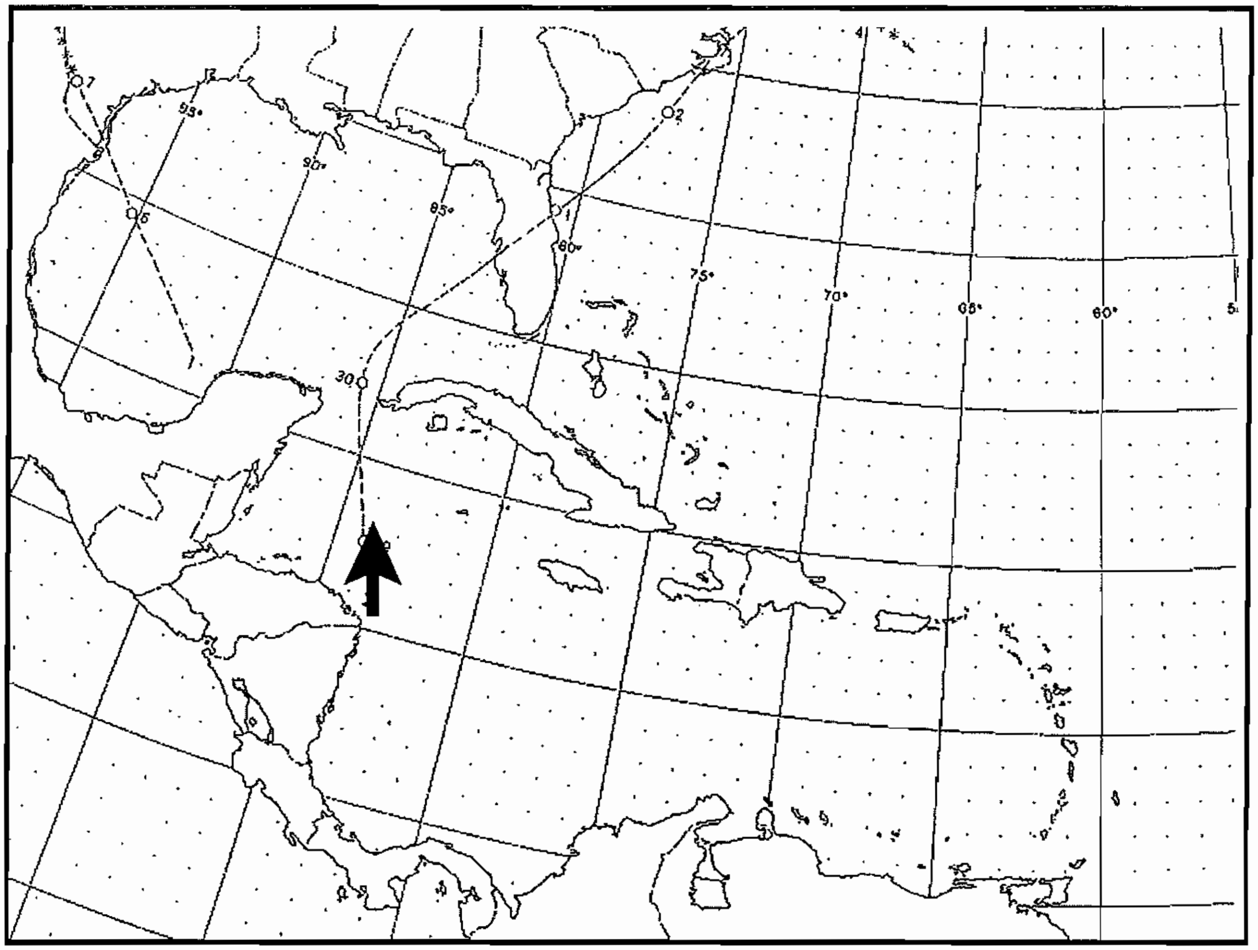
Punta Rassa:	3.4 m (11 ft) MSL
Fort Myers:	3.0 m (10 ft) MSL
Punta Gorda:	2.4 m (8 ft) MSL
Clearwater:	2.1 m (7 ft) MSL
Boca Grande:	2.1 m (7 ft) MSL

Sannibel Island was reportedly washed over by the storm surge. The storm was responsible for seven deaths in Florida. Damage was estimated at $1,000,000.



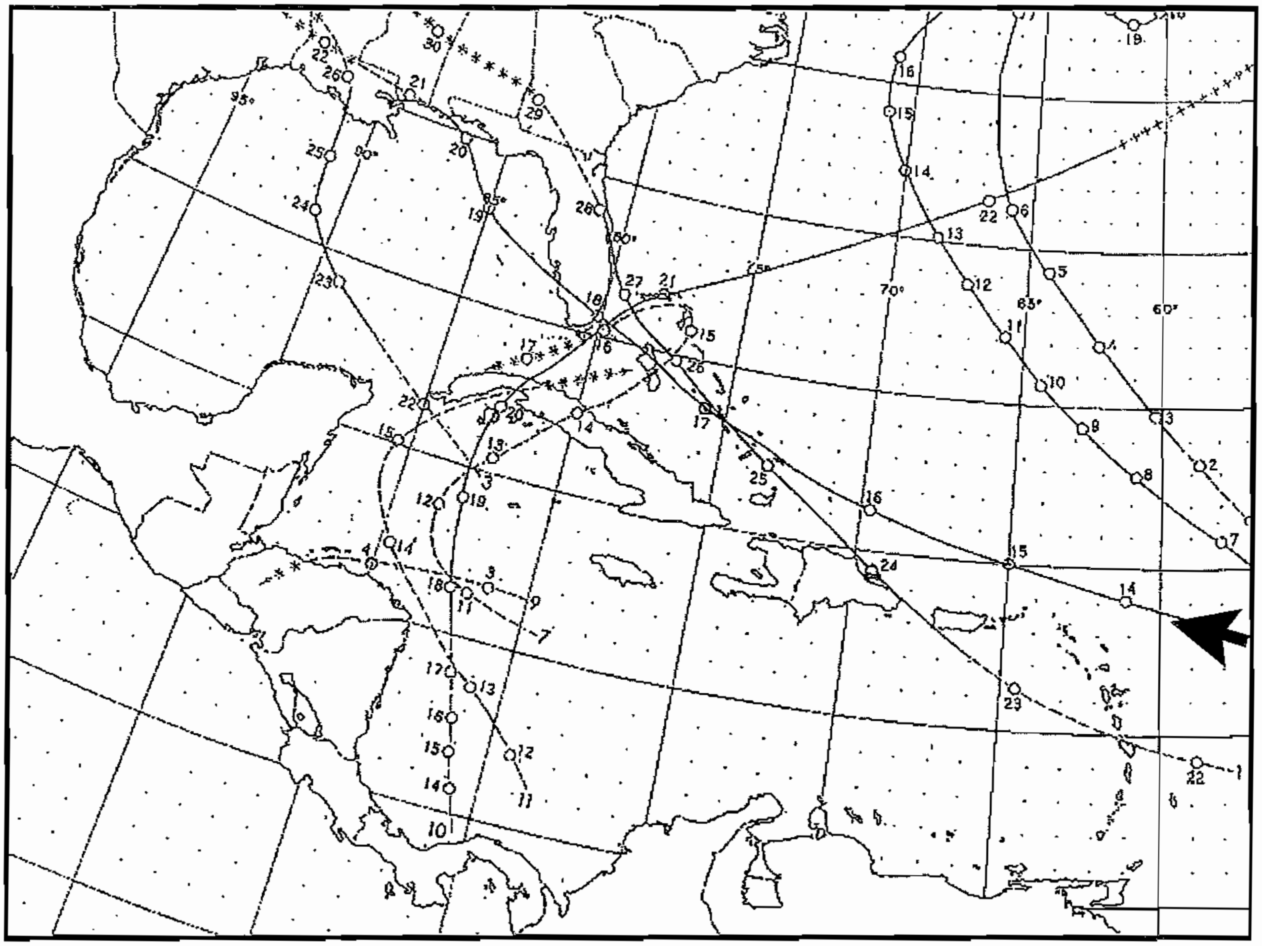
1924

The 29 September tropical storm had its origins along the northern coast of Honduras in the Caribbean Sea. The storm moved north through the Yucatan Channel and into the Gulf of Mexico. In the central Gulf of Mexico, this storm transformed into an ET cyclone. It then moved northeast and went ashore near Taylor and Dixie counties in Florida. Cedar Key reported some coastal flooding but no specific data are available.



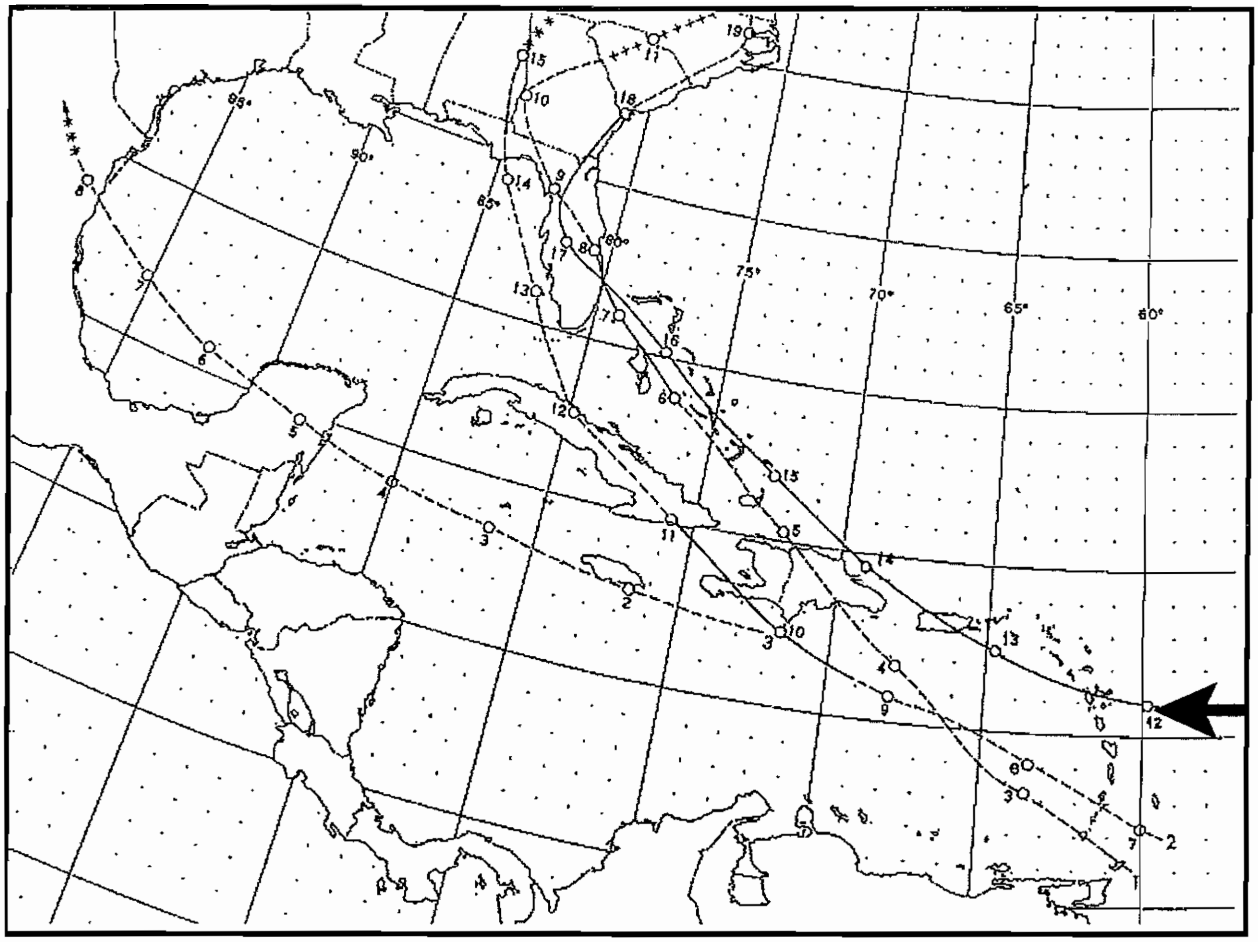
1925

This late season hurricane (30 November) originated as a tropical storm northeast of Honduras in the Caribbean Sea. The storm moved north through the Yucatan Channel and then northeast toward Florida. The storm obtained hurricane strength (Saffir/Simpson category one) just before making landfall south of Tampa, producing a maximum wind gust of 26 ms^{-1} (50 kt) and a storm tide 1.5 m (5 ft) *below* mean sea level at Tampa. The bottom of Tampa Bay was reportedly visible in some locations due to the extreme low water levels. Fort Myers reported a maximum wind gust of 16 ms^{-1} (31 kt), but no coastal flooding. Minor coastal flooding may have occurred just south of the eye, perhaps in Sarasota County but no data are available to support this speculation. In Florida, there were four storm-related deaths.



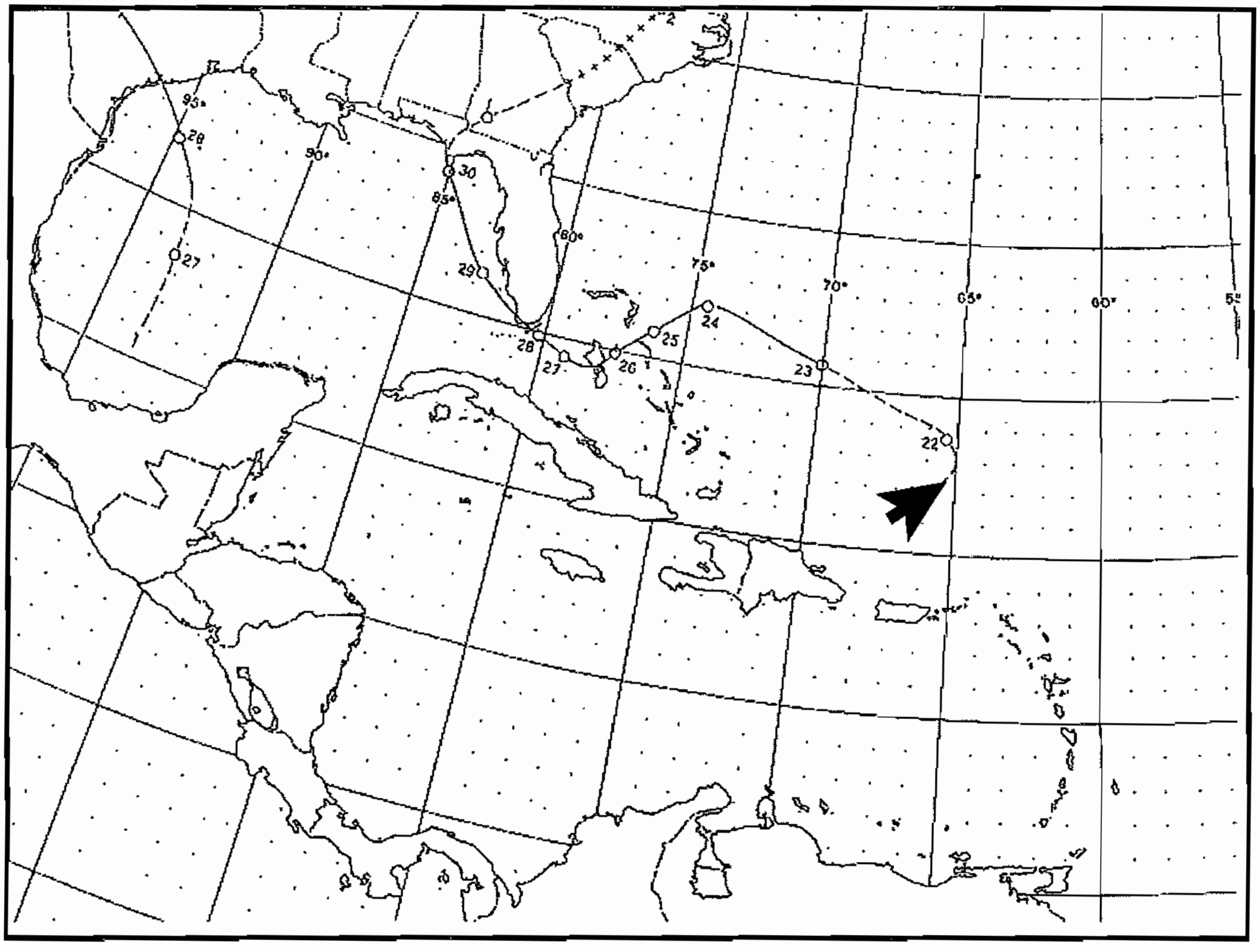
1926

The 19 September hurricane was born out over the central Atlantic Ocean and moved west-northwest until finally making landfall just south of Miami, Florida. It then moved across the Florida peninsula (maintaining hurricane strength) and exiting out into the Gulf of Mexico in the vicinity of Naples, Florida. It then traveled northwest eventually making landfall again on the Gulf coast near Mobile, Alabama. The maximum wind gust recorded at Tampa was 26 ms^{-1} (50 kt) from the *south-southeast* and the maximum wind gusts recorded at Fort Myers and Punta Gorda were estimated near 35.5 (69 kt). Maximum storm tides ranged from 1.2 m (4 ft) MSL at Tampa to 3.7 m (12 ft) MSL at Punta Rassa. More than 15 people perished from this storm in Florida. Most of the deceased were mariners.



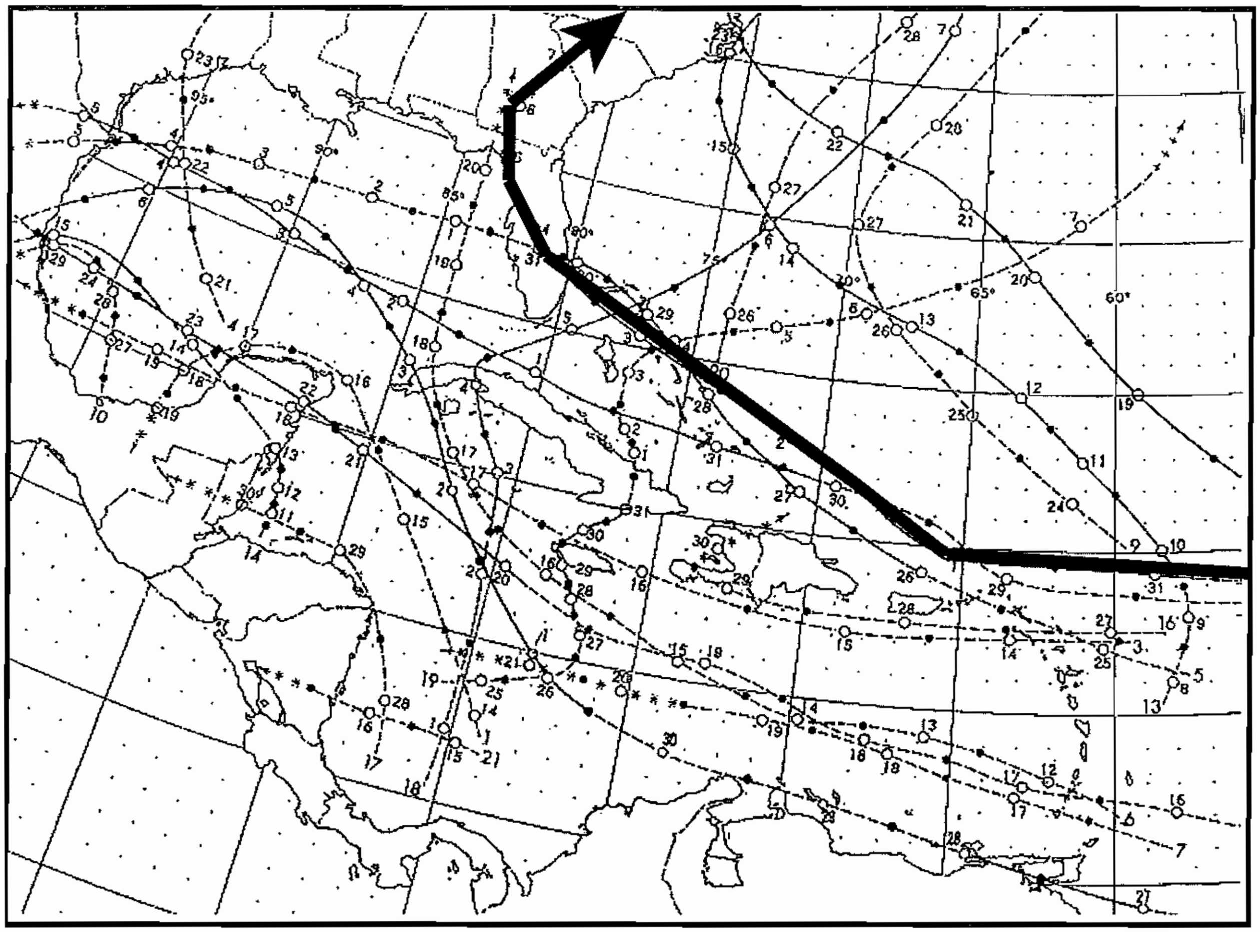
1928

The 16-17 September hurricane, also known as the "Great Lake Okeechobee Storm" was born far out in the Atlantic Ocean, near the west coast of Africa. It moved west and then west-northwest, eventually making landfall just north of Miami, Florida. It then moved northwest and then curved northeast, exiting the Florida peninsula just west of Jacksonville. In Florida, 1836 people died, the majority drowning in the Lake Okeechobee storm surge. Along the west coast of Florida, storm tides ranged from 0.6 to 0.9 (2-3 ft) MSL and maximum wind gusts were near 22.1 ms^{-1} (43 kt). This storm was a Saffir Simpson category four hurricane at one point.



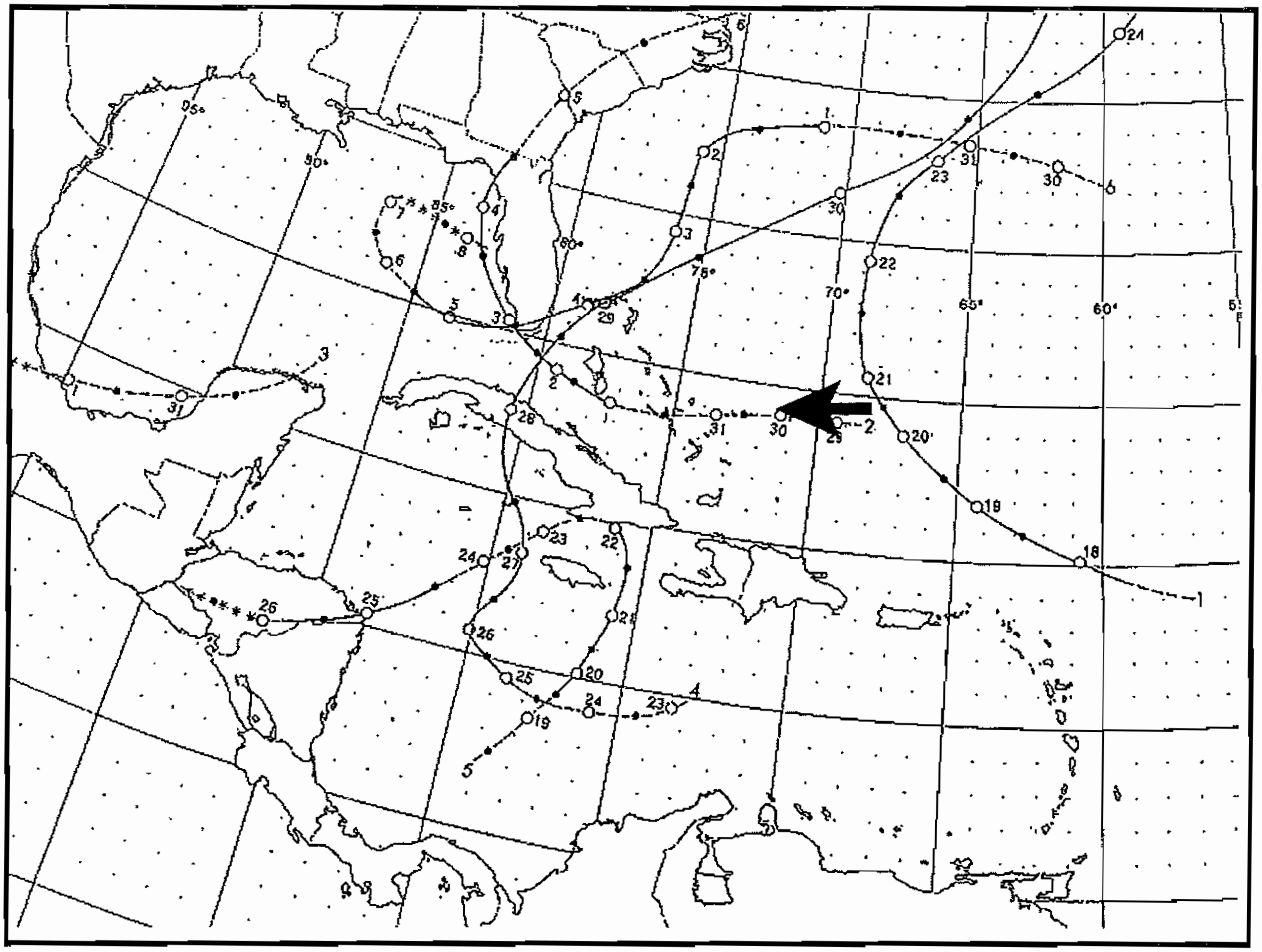
1929

The 28-29 September hurricane (Saffir/Simpson category three) formed originally in the western Atlantic Ocean and took a somewhat erratic path toward south Florida. It made landfall at the extreme southern tip of the Florida peninsula. It then moved northwest and made landfall again near Panama City, Florida. Maximum wind gusts along the west coast of Florida ranged from 14.9 ms^{-1} (20 kt) at Tampa (with the storm well offshore) to near 44.8 ms^{-1} (87 kt) at Everglades City (closer to the storm's eye). Maximum storm tides ranged from 0.6 m (2 ft) MSL at Punta Rassa to 1.8 m (6 ft) MSL at Everglades City.



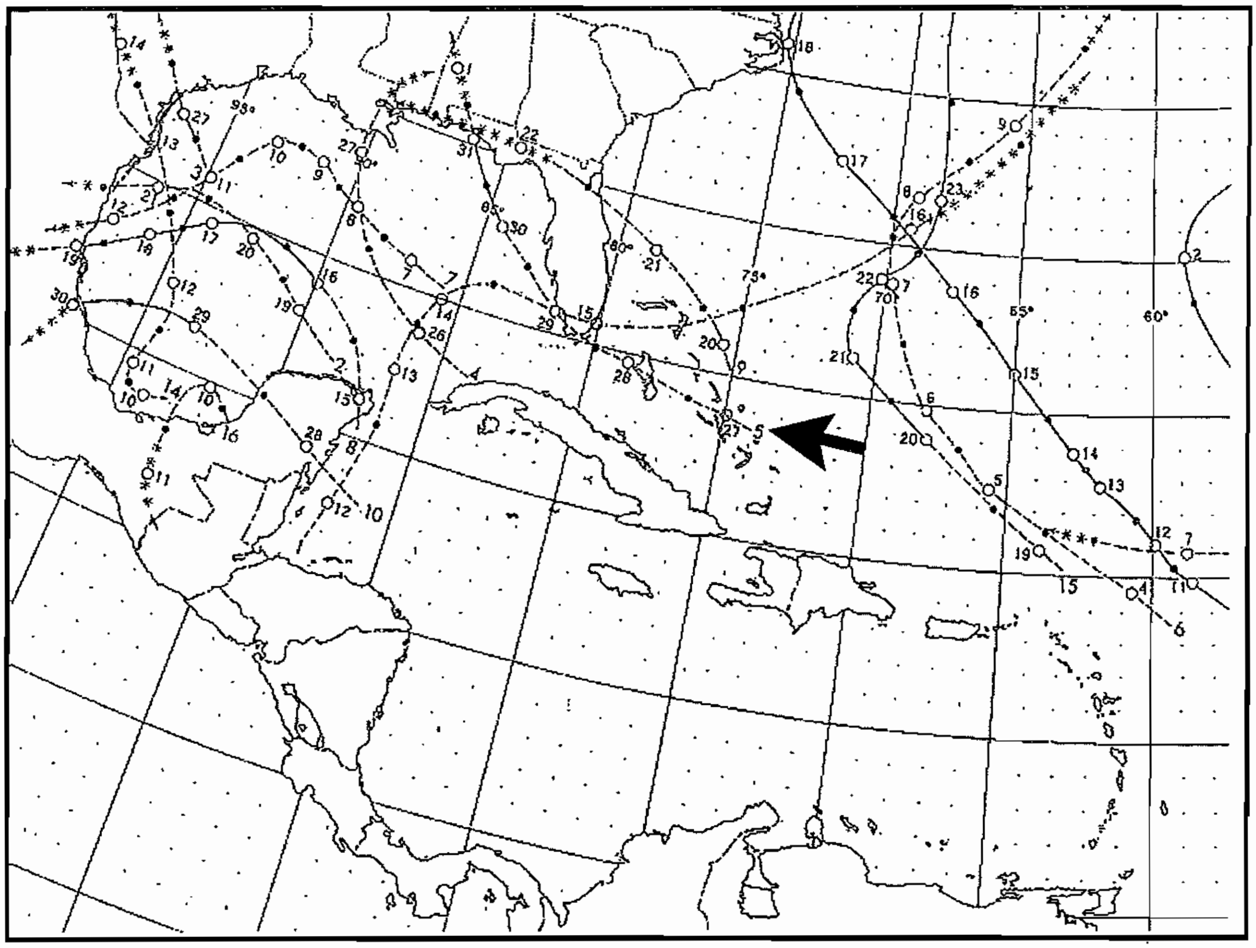
1933

In this very active year for tropical cyclones in the Atlantic Basin, the only one to significantly affect the west coast of Florida was on 3-5 September. This hurricane had its origins northeast of the Leeward Islands. It moved west and then northwest, across the Bahama Islands, making landfall in the vicinity of Miami, Florida. It then crossed the Florida peninsula, hugging the coastline of Apalachee Bay and then curving northeast just east of Tallahassee. Maximum storm tide at Tampa was 1.8 m (6 ft) MSL. Maximum storm wind gusts were near 56 ms^{-1} (109 kt) both at Jupiter and at a station 32 km east-northeast of Tampa (near the eye).



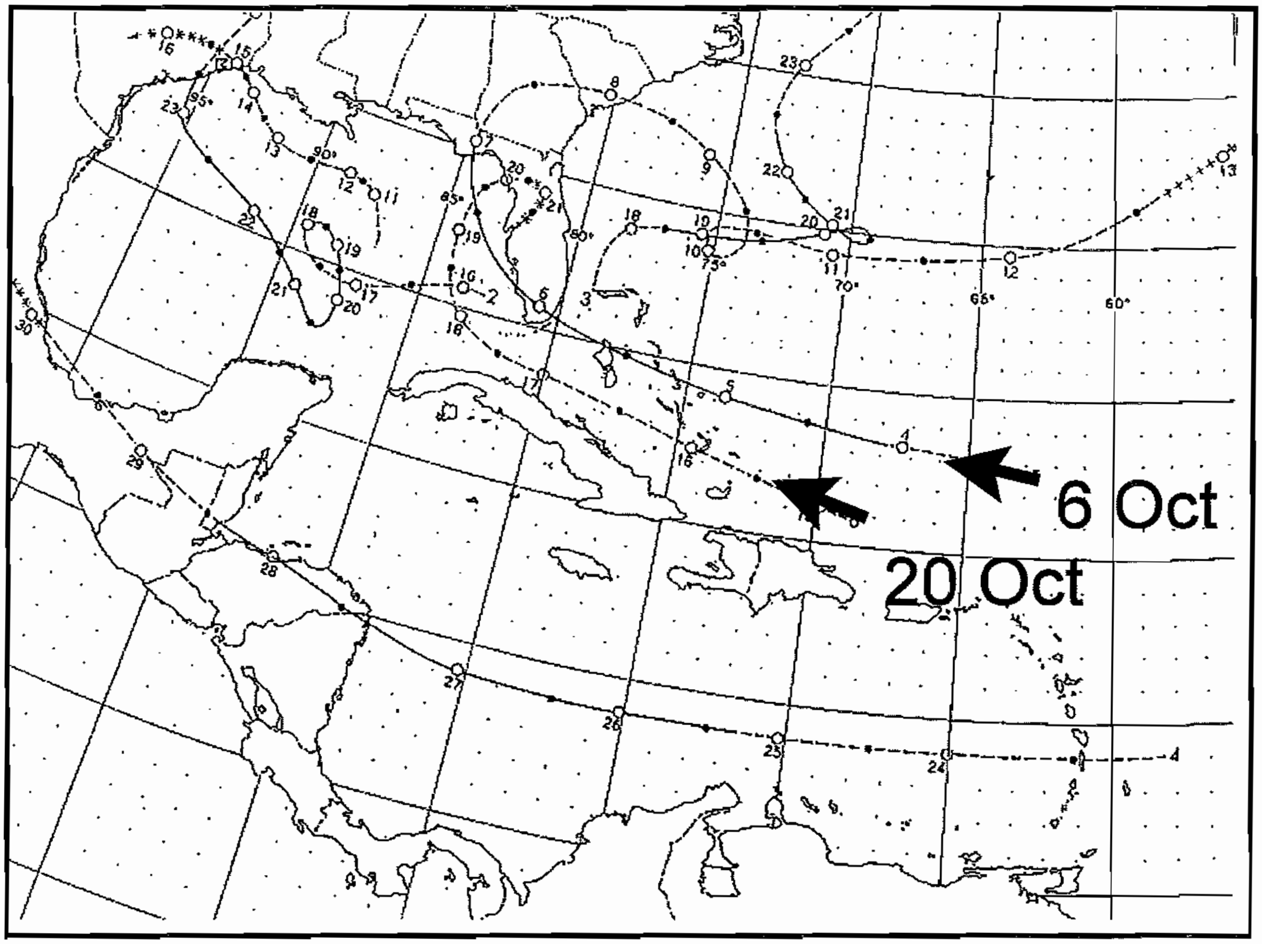
1935

The famous "Florida Keys Labor Day Storm" of 2-5 September 1935 was the most intense tropical cyclone ever to make landfall along the United States coastline (Saffir/Simpson category five). Winds near 89 ms^{-1} (173 kt) and a minimum sea level pressure of 892 mb were recorded in the Florida keys. The storm was born in the eastern Atlantic Ocean a few hundred miles east of the Bahama Islands. It moved west and then started "recurving", moving more northwest, over Marathon Key and clipping the extreme southern tip of the Florida peninsula. It then continued a slow recurvature, paralleling the west coast of Florida and then making landfall again in Taylor County. Maximum storm tides along the west coast of Florida were from 1.2 to 1.8 m (4-6 ft) MSL. The maximum wind gust at Tampa was estimated near 33.5 ms^{-1} (65 kt) from the south-southeast. The maximum storm tides reportedly occurred "after the storm had passed" to the north. Over 400 persons died and damage was estimated near $6,000,000.



1936

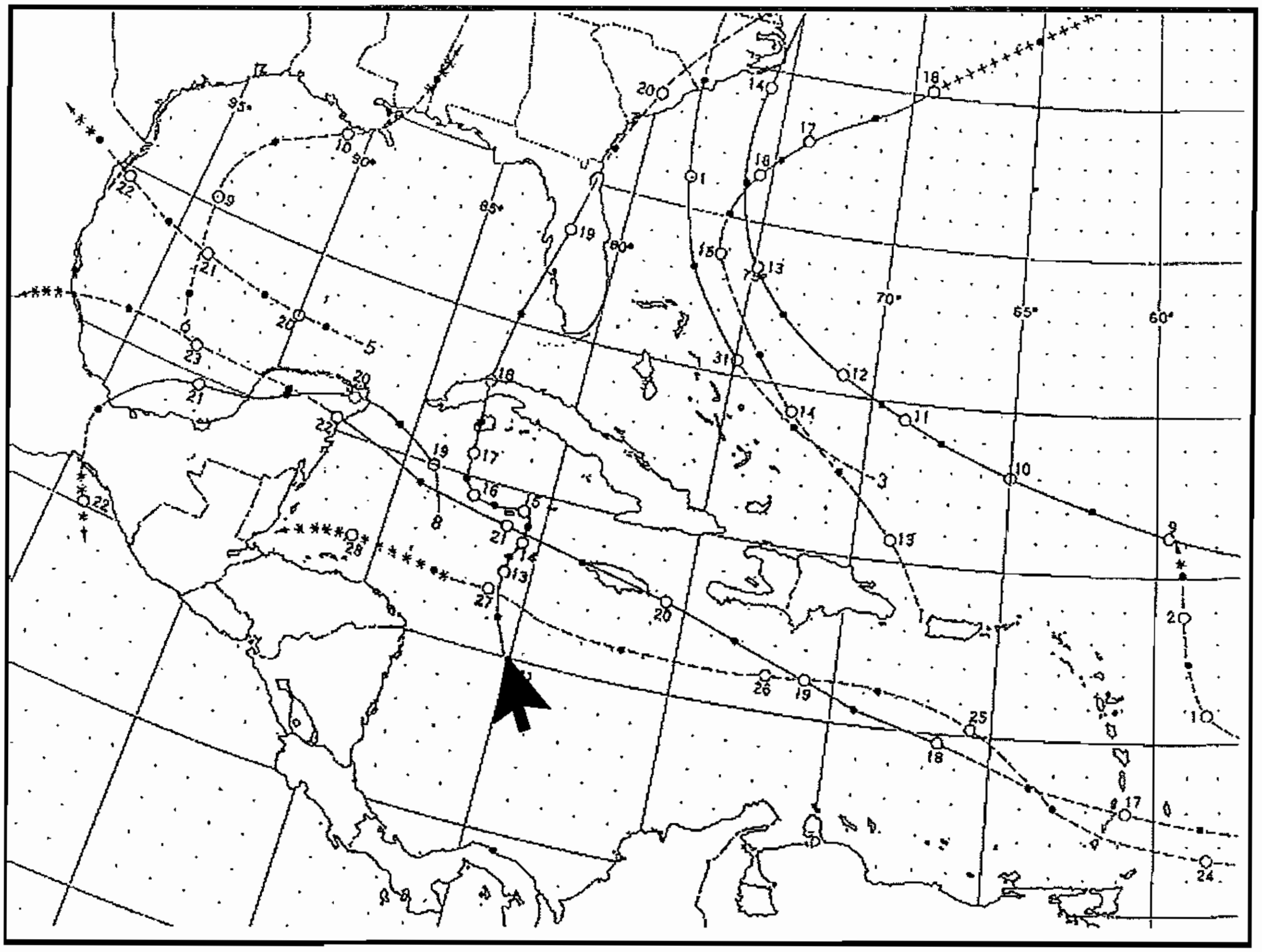
The 29 July tropical storm originated near San Salvador, just east of the main Bahama Island chain. It moved toward the west-northwest across Key Largo and Homestead, Florida. The storm then crossed the extreme southern tip of the Florida Peninsula, exiting near Everglades City, where a 1.2 m (4 ft) MSL storm tide was recorded along with a wind estimated near 25 ms^{-1} (48 kt). The storm then moved northwest across the eastern Gulf of Mexico (attaining Saffir/Simpson category three strength) and made a final landfall near Fort Walton Beach. The schooner *Ketchum* sank in the eastern Gulf of Mexico, and its crew of four were lost. Total storm damage in Florida was estimated near $150,000.



1941

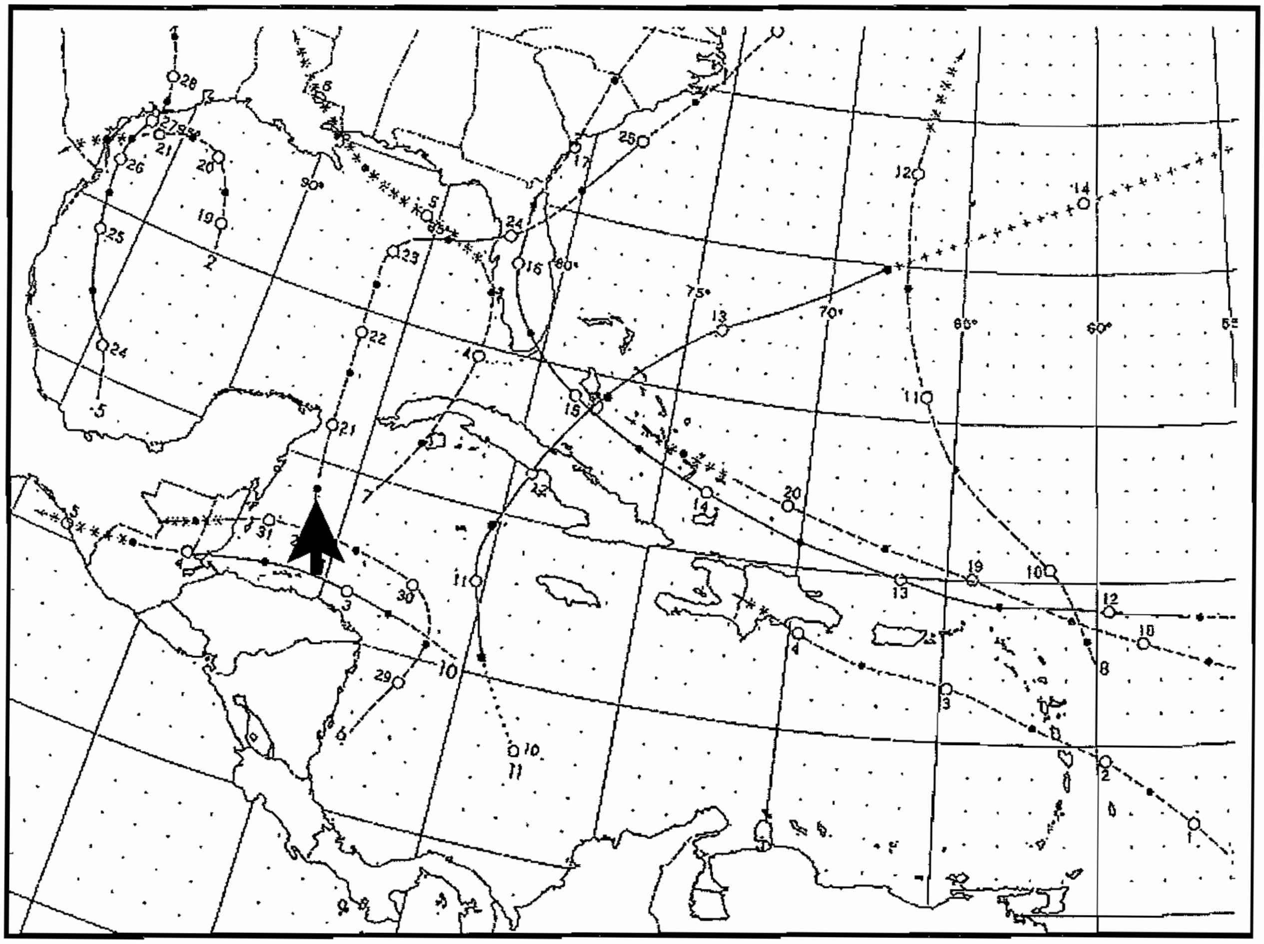
The 6 October hurricane formed over the eastern Atlantic Ocean, moved west-northwest making landfall just south of Miami, Florida, crossing the peninsula, and exiting into the Gulf of Mexico near Naples, Florida. The storm then curved north and made a second landfall just east of Panama City, Florida. The storm attained category two strength on the Saffir/Simpson scale. The maximum wind gust recorded at Tampa from this storm was 18.5 ms^{-1} (36 kt). Maximum storm tides in west-central Florida include 1.2 m (4 ft) in Everglades City, newspaper reports indicated that tides were "high" in Punta Rassa. Minor damage was reported.

The 20 October tropical storm was born just east of the Turks and Caicos Islands in the eastern Atlantic Ocean. It moved west-northwest, eventually recurving in the southeast Gulf of Mexico and then making landfall north of Cedar Key, Florida. A maximum wind gust of 15.4 ms^{-1} (30 kt) from the south was recorded at Tampa. Maximum storm tides were likely less than 1.2 m (4 ft).



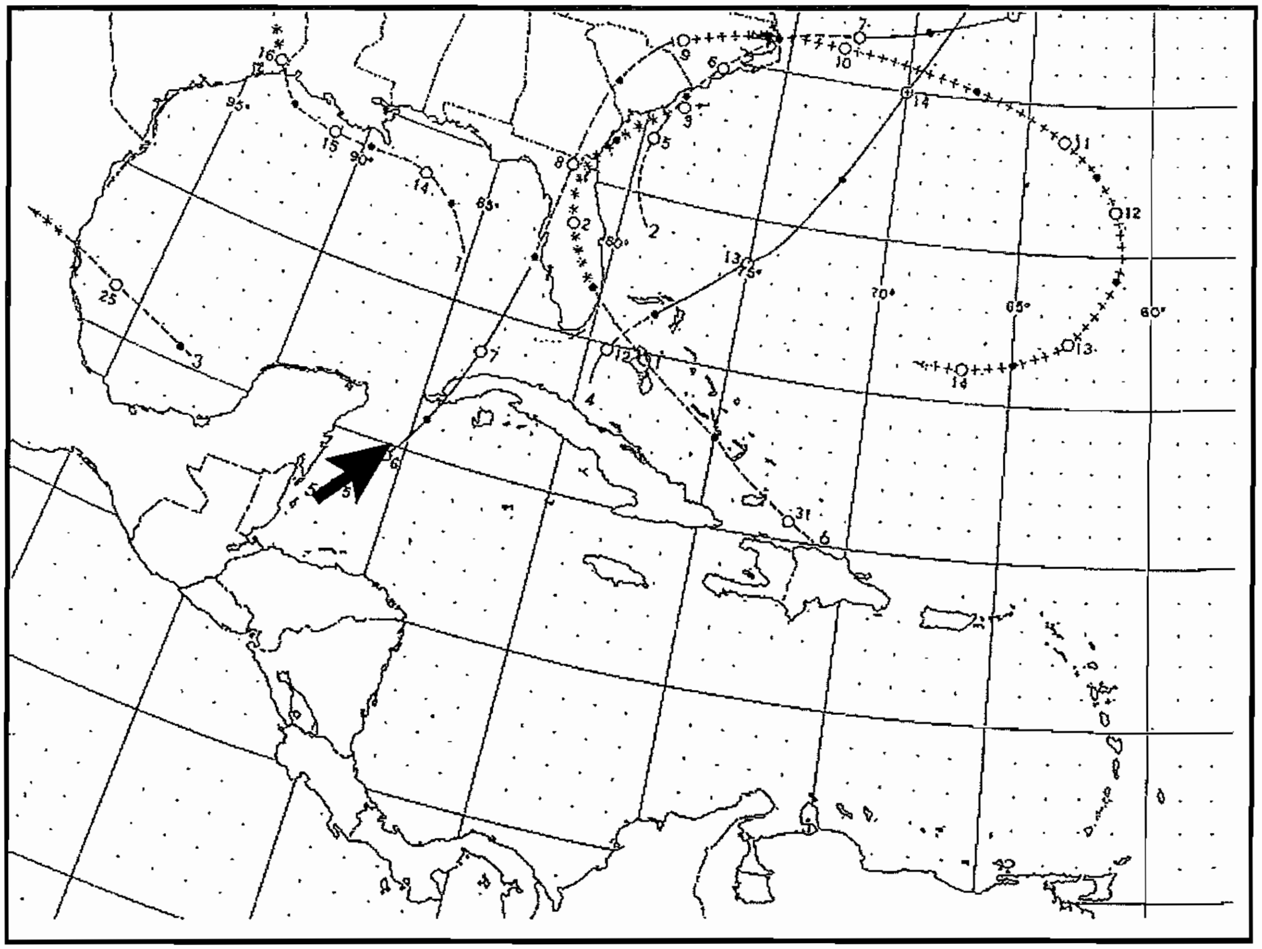
1944

The 18-19 October hurricane was born in the western Carribean, moved north, curving west through the Cayman Islands and then moving north again. The storm made land fall at the Isle of Pines and then again on the southwest coast of Cuba just east of Dayaniguas. It continued north and finally made landfall along the west coast of Florida near Sarasota. The storm was a major (Saffir/Simpson category three) hurricane at landfall. Maximum estimated wind gusts ranged from near 44.8 ms^{-1} (87 kt) at Tampa to 54 ms-1 (121 kt) at Dry Tortugas. Maximum storm tides ranged from 1.2 m (4 ft) MSL at Tampa to 3.0 m (10 ft) MSL at Naples. In Florida, there were 18 storm-related deaths.



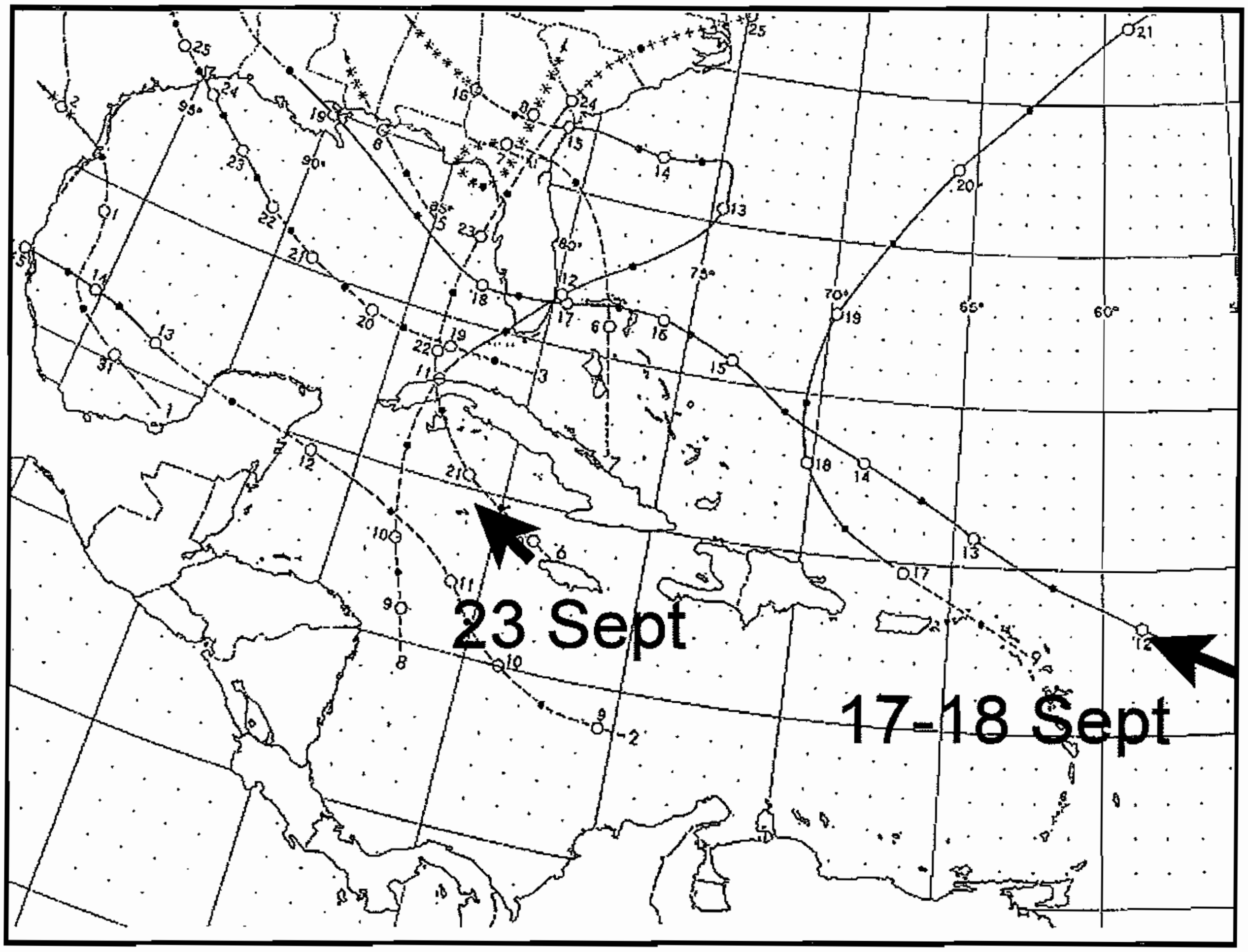
1945

The 23-24 June hurricane was born in the eastern Caribbean north of Honduras. It moved north into the Gulf of Mexico and then made nearly a 90 degree right turn toward the west coast of Florida, making landfall in Citrus County. Tampa recorded a maximum wind gust of 22 ms^{-1} (42 kt) from the west. Maximum storm tides from the Tampa Bay area north were around 1.8 m (6 ft) MSL . In addition, the storm produced over 254 mm (10 inches) of rain at Tampa.



1946

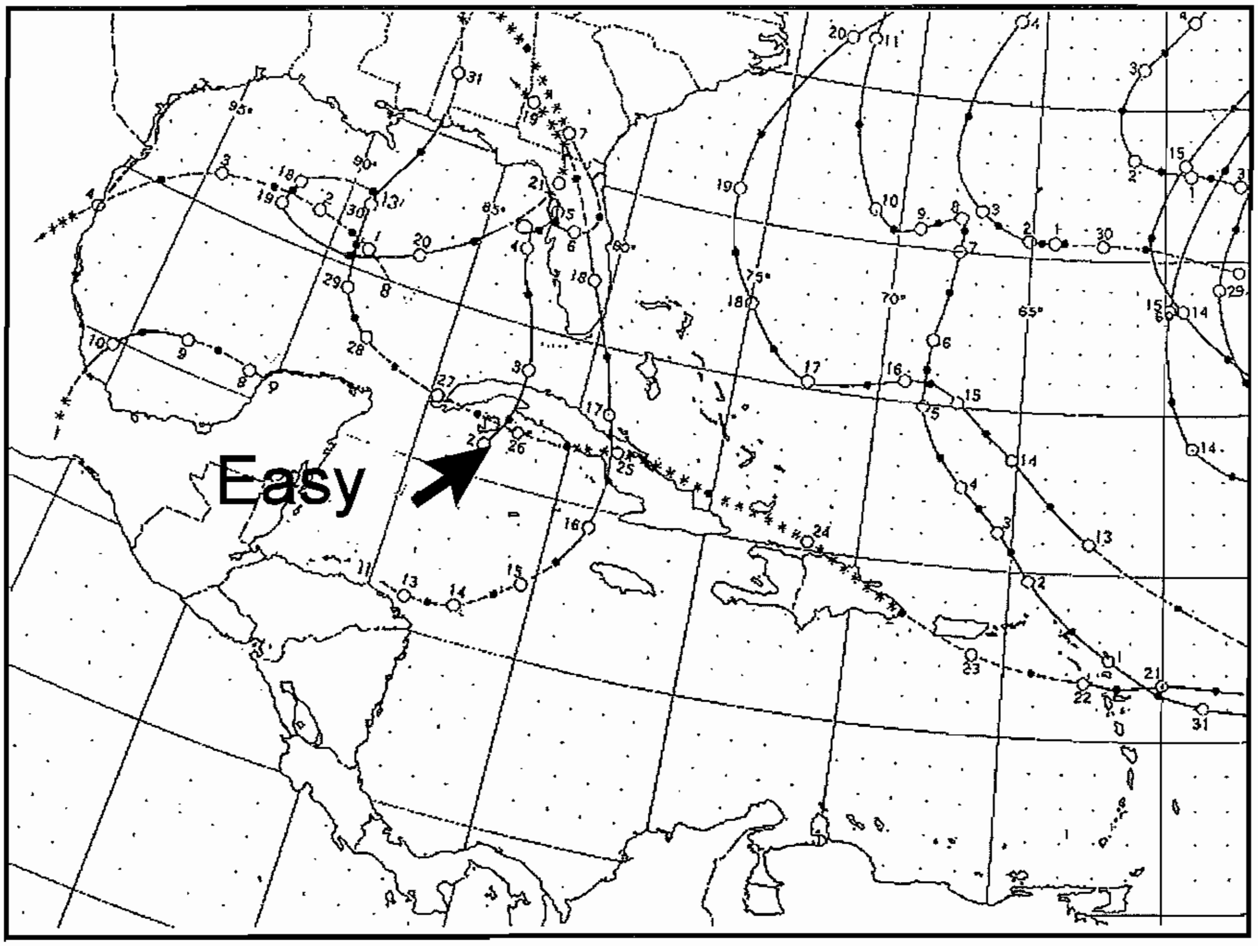
The 7-8 October hurricane was born off the coast of Belize, moved northeast, making landfall just west of Las Martinas, Cuba and continuing north-northeast into the eastern Gulf of Mexico. The storm then made landfall near Tampa, Florida. Maximum wind gusts ranged from near18 ms^{-1} (35 kt) at Cedar Key to 35.5 ms^{-1} (69 kt) at Fort Myers. Maximum storm tides ranged from 0.9 to 1.8 m (3-6 ft) MSL from Tampa south to Fort Myers. Streets were flooded from high storm tides at Cortez Beach and Fort Myers. Parts of Punta Gorda and Everglades were flooded as well.



1947

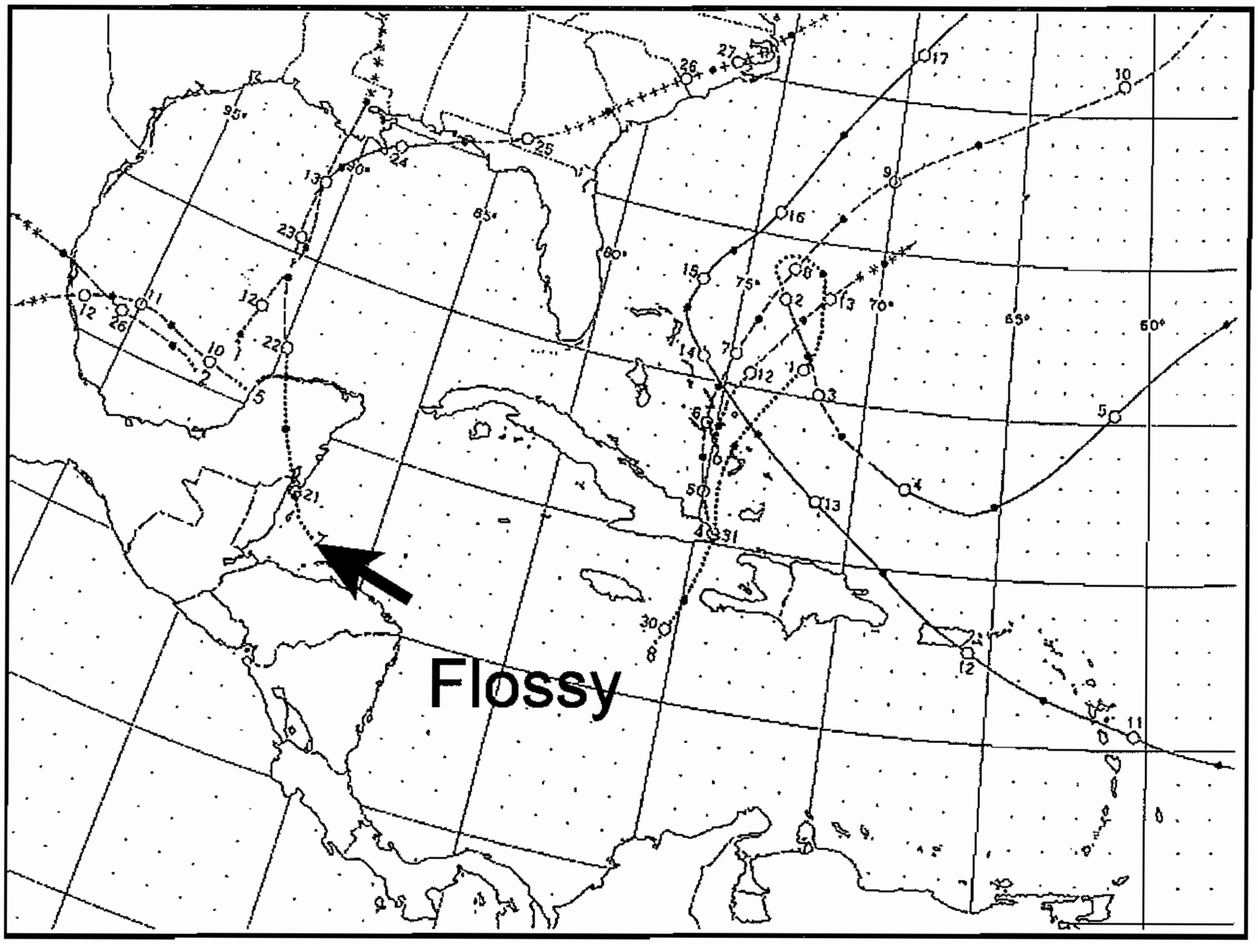
The 17-18 September hurricane was born in the eastern Atlantic near the Cape Verde Islands. It traveled west and then northwest, eventually passing through the Bahama Islands. It then traveled *west-southwest*, making landfall near Miami, Florida. The storm passed over the Florida Peninsula, exiting into the Gulf of Mexico near Naples before moving northwest and making a final landfall in Louisiana. Some maximum wind gusts from this storm include: an estimated 22.1 ms^{-1} (43 kt) at Tampa, 49 ms^{-1} (96 kt) at Fort Myers, and 64 ms^{-1} (143 kt) at the Hillsborough Lighthouse on the east coast of Florida. Storm tides along the west coast of Florida ranged from 0.9 to 2.1 m (3-7 ft) MSL. The storm reached Saffir/Simpson category four strength for a time.

The 23 September tropical storm was born in the eastern Caribbean Sea near Jamaica. It moved northwest, clipping the eastern edge of the Isle of Pines and western Cuba. It continued north into the eastern Gulf of Mexico, making landfall near Levy County, Florida. Maximum wind gusts ranged from 28.8 ms^{-1} (56 kt) at Tampa to 38.1 ms^{-1} (74 kt) at Fort Myers. "Damage to beaches" occurred from Bradenton to Tarpon Springs.



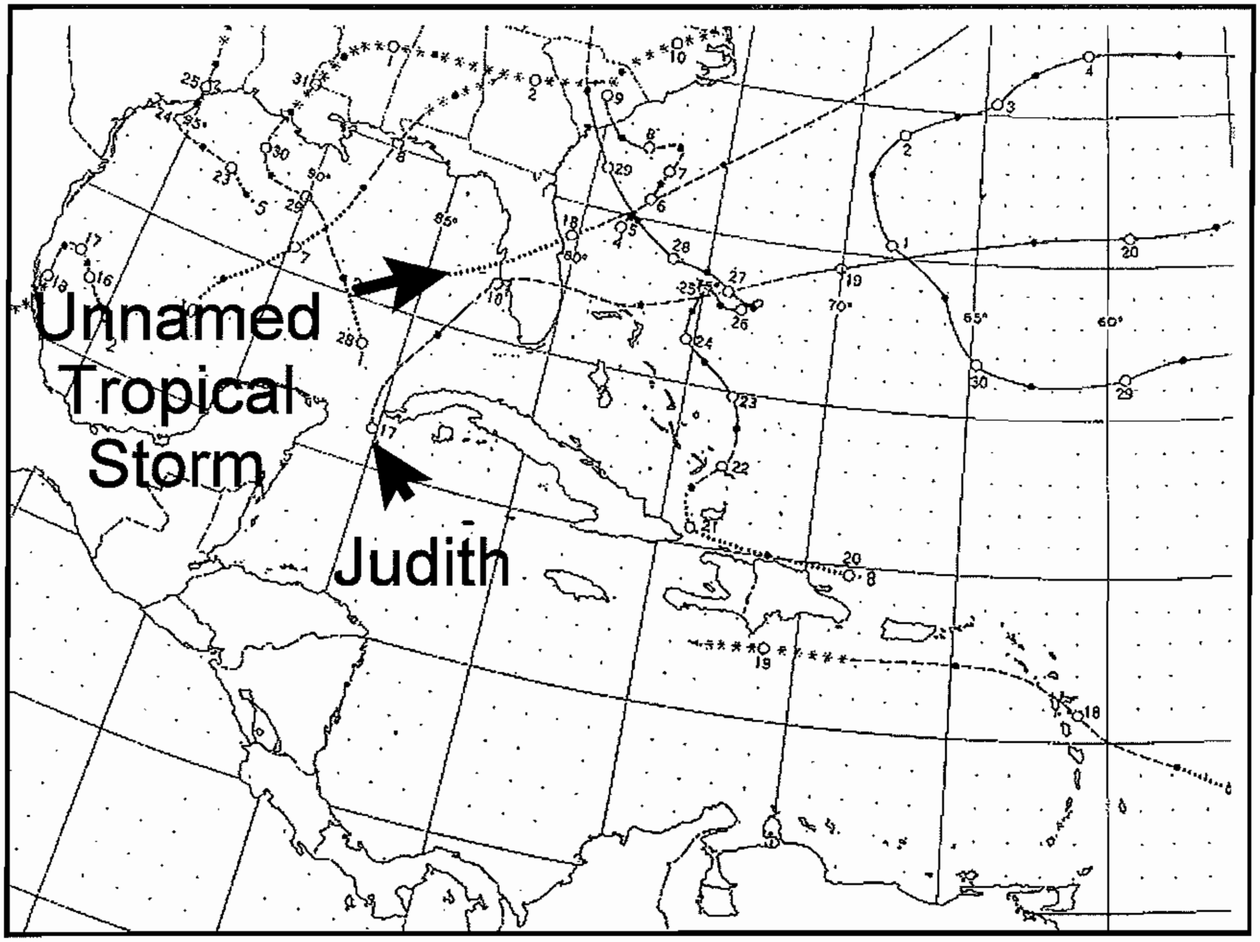
1950

Hurricane Easy (4-5 September) formed over the northwest Carribean Sea and moved north toward Florida, crossing over Cuba along the way. Easy made two complete loops near Tampa Bay, one while the storm was still offshore and one right along the west central coast of Florida. Easy was a major (Saffir/Simpson category three) hurricane and was Tampa's worst hurricane since 1921. Maximum wind gusts ranged from 22.7 ms^{-1} (44 kt) to 56 ms^{-1} (109 kt) and maximum storm tides were from 1.5 to 3.0 m (5-10 ft) MSL. Cedar Key was reportedly "submerged" during the storm. Yankeetown, Florida recorded an incredible 983 mm (38.70 in) of rain during the storm. In Florida, two persons were killed and damage was estimated at $3,300,000. In Cedar Key, the entire town fishing fleet was destroyed and 90 percent of the homes sustained damage or were destroyed.



1956

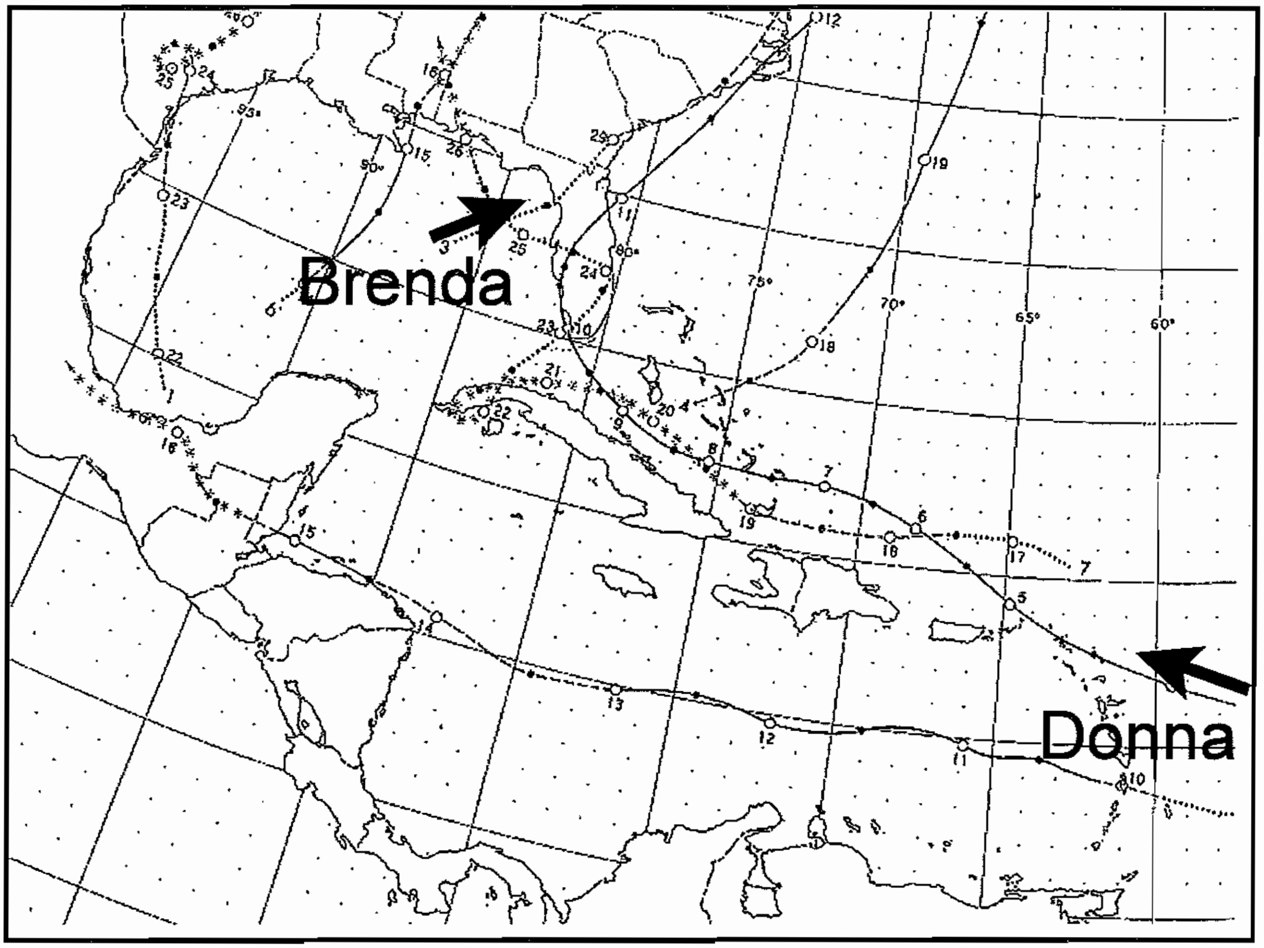
Hurricane Flossy had its origins in the Gulf of Honduras as a tropical depression. It moved north-northwest over the Yucatan Peninsula, entering the Gulf of Mexico and becoming a tropical storm on 22 September. It then slowly moved north, traversing the central Gulf of Mexico. Just south of Louisiana, Flossy curved to the northeast and then east-northeast, making landfall in the Florida panhandle. While in the Gulf of Mexico, Flossy had attained Saffir/Simpson category two strength. Even though Flossy made landfall in the Florida panhandle, Tampa still reported a maximum storm tide of 1.2 m (4 ft) MSL and Saint Petersburg recorded a storm tide of 0.9 m (3 ft) MSL! Almost 39 years after Flossy made landfall, another storm took a similar track and made landfall in the panhandle of Florida. This storm was a little stronger and induced storm tides of 1.5 to 1.8 m (5-6 ft) in the Tampa Bay area. The storm's name was Hurricane Opal.



1959

On 17 June, an unnamed tropical storm made landfall near Bradenton, Florida. The storm formed as a tropical depression in the central Gulf of Mexico and quickly developed and moved east-northeastward. Wind gusts were estimated to be from 22.1 ms^{-1} (43 kt) in Tampa to 28.8 ms^{-1} (56 kt) at Anna Maria Island, in Manatee County. Maximum storm tides of 1.5 m (3 ft) MSLl accompanied the storm from Saint Petersburg to Naples. This storm eventually reached hurricane strength several hundred kilometers northeast of the state of Florida in the western Atlantic Ocean. Rainfall amounts of 70 to 150 mm (3-6 in) accompanied the storm as well.

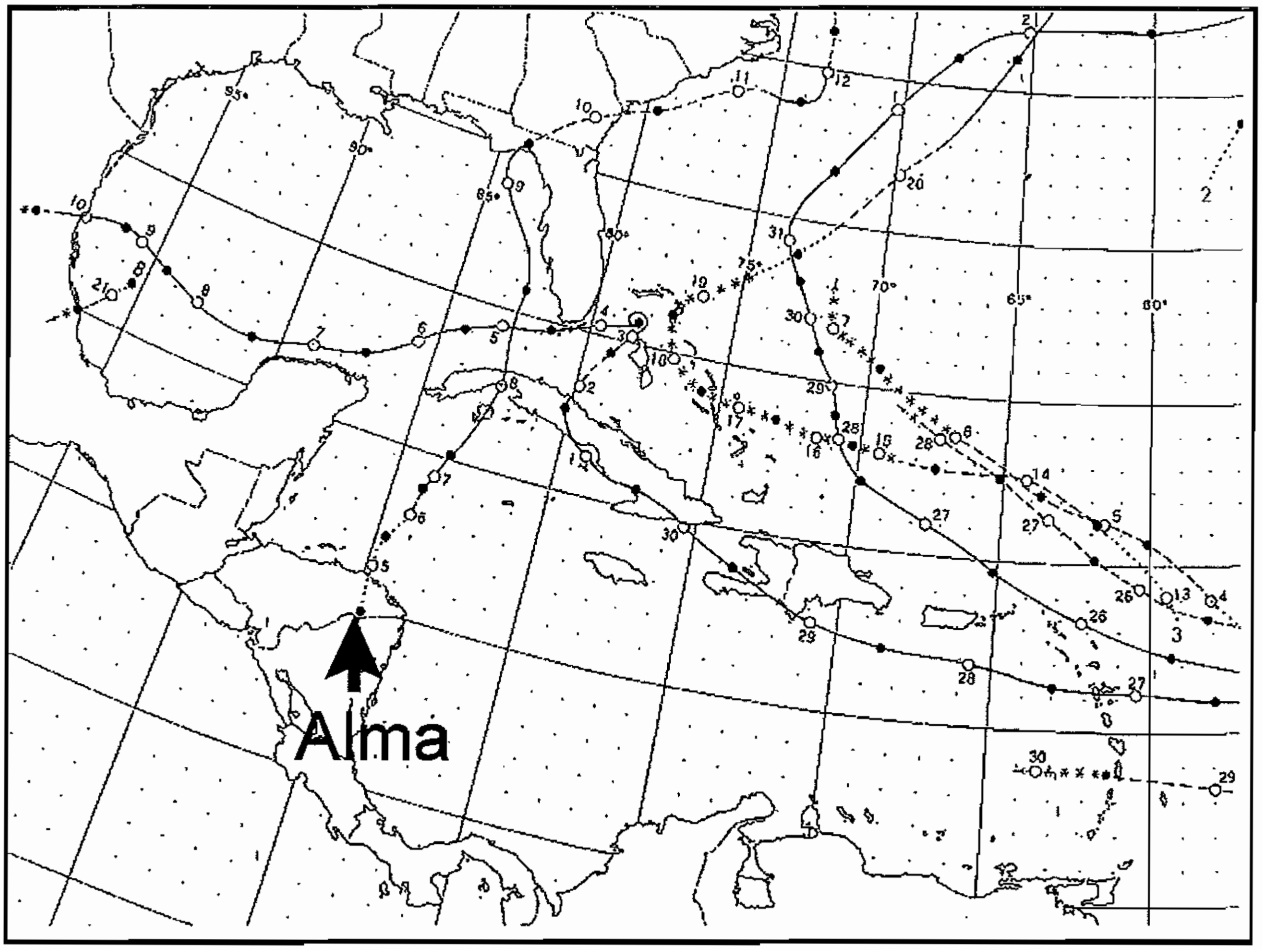
On 11 June, Tropical Storm Judith was born near the Yucatan channel. Judith moved northeast and was briefly a hurricane before making landfall as a tropical storm just north of Fort Myers, Florida on 18 October. Maximum storm tides of 1.5 m (3 ft) MSL were reported from Fort Myers to Venice. Fort Myers reported a maximum wind gust of 23.7 ms^{-1} (46 kt).



1960

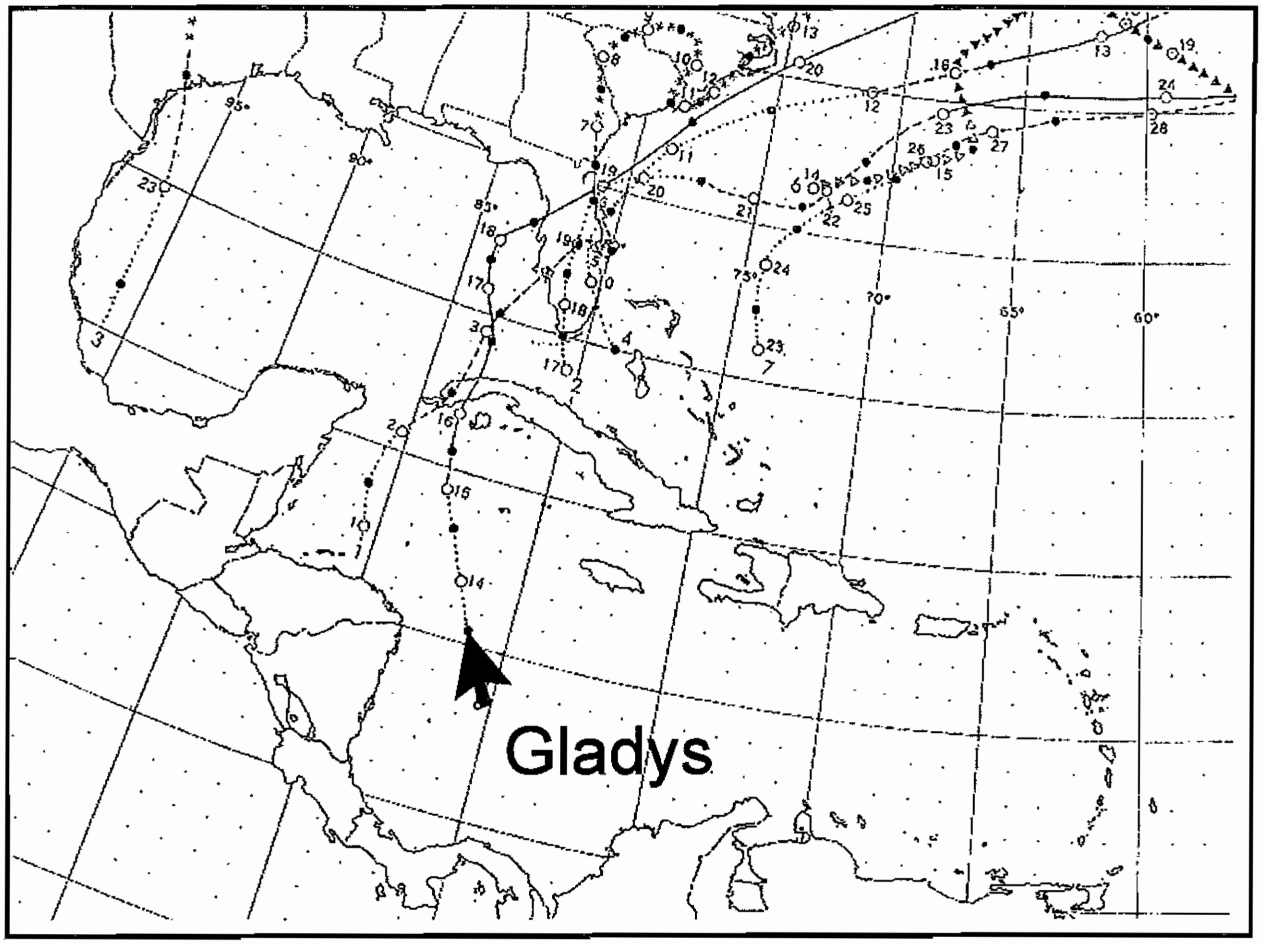
On 28 July, the tropical depression that would eventually become Tropical Storm Brenda developed in the east-central Gulf of Mexico. The depression moved quickly northeast, making landfall near Cedar Key and then continuing northeast across the Florida peninsula. Substantial beach erosion was reported in Tampa although no official storm tide reports are available. Also, Tampa received over 330 mm (13 in) of rain from this storm.

Hurricane Donna was born in the middle of the Atlantic Ocean, moved west-northwest until recurving just southwest of Florida and making landfall near Fort Myers on 10 September. Donna was a major (Saffir/Simpson category four) hurricane and generated a maximum storm tide of 3.4 m (11 ft) MSL at fort Myers along with wind gusts that ranged from 33.5 ms^{-1} (65 kt) at Tampa to 58 ms^{-1} (130 kt) at Naples. Maximum storm tides near in the Fort Myers, Naples, and Everglades City vicinities were from 1.2 to 3.4 m (4-11 ft). Tides initially were below normal in Tampa and then increased as Donna moved north over the peninsula. Maximum tides from Bradenton north including the Tampa Bay area were from 0.3 to 0.9 m (1-3 ft).



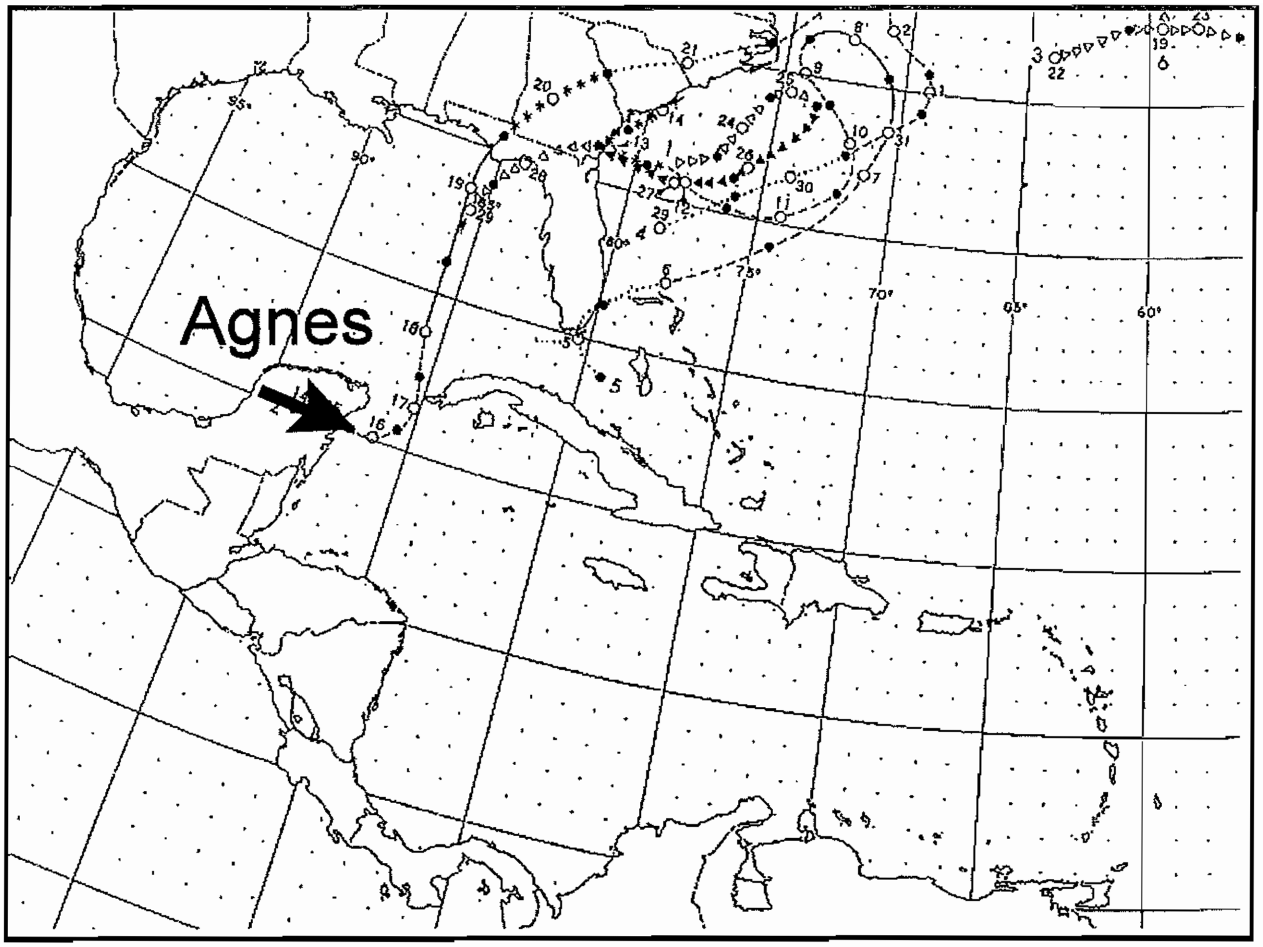
1966

Hurricane Alma (4 June) was first detected as a weak tropical disturbance off the northern coast of Honduras. As Alma slowly moved north over the western Caribbean Sea, she became stronger. Alma became a hurricane before passing over the Isle of Pines and making landfall near Guira de Melena, Cuba. Alma then continued north paralleling the west coast of Florida before making final landfall south of Tallahassee. Hurricane Alma attained Saffir/Simpson category two strength while over the eastern Gulf of Mexico. Tampa recorded a maximum wind gust of 42 ms^{-1} (82 kt). Maximum storm tides of 1.8 to 3.0 m (6-10 ft) were common from Tampa north to Cedar Key and maximum storm tides of 0.9 to 1.8 m (3-6 ft) were prevalent from Tampa south to Everglades City. Much of the monetary losses incurred from Alma were due to "salt-water flooding and beach erosion".



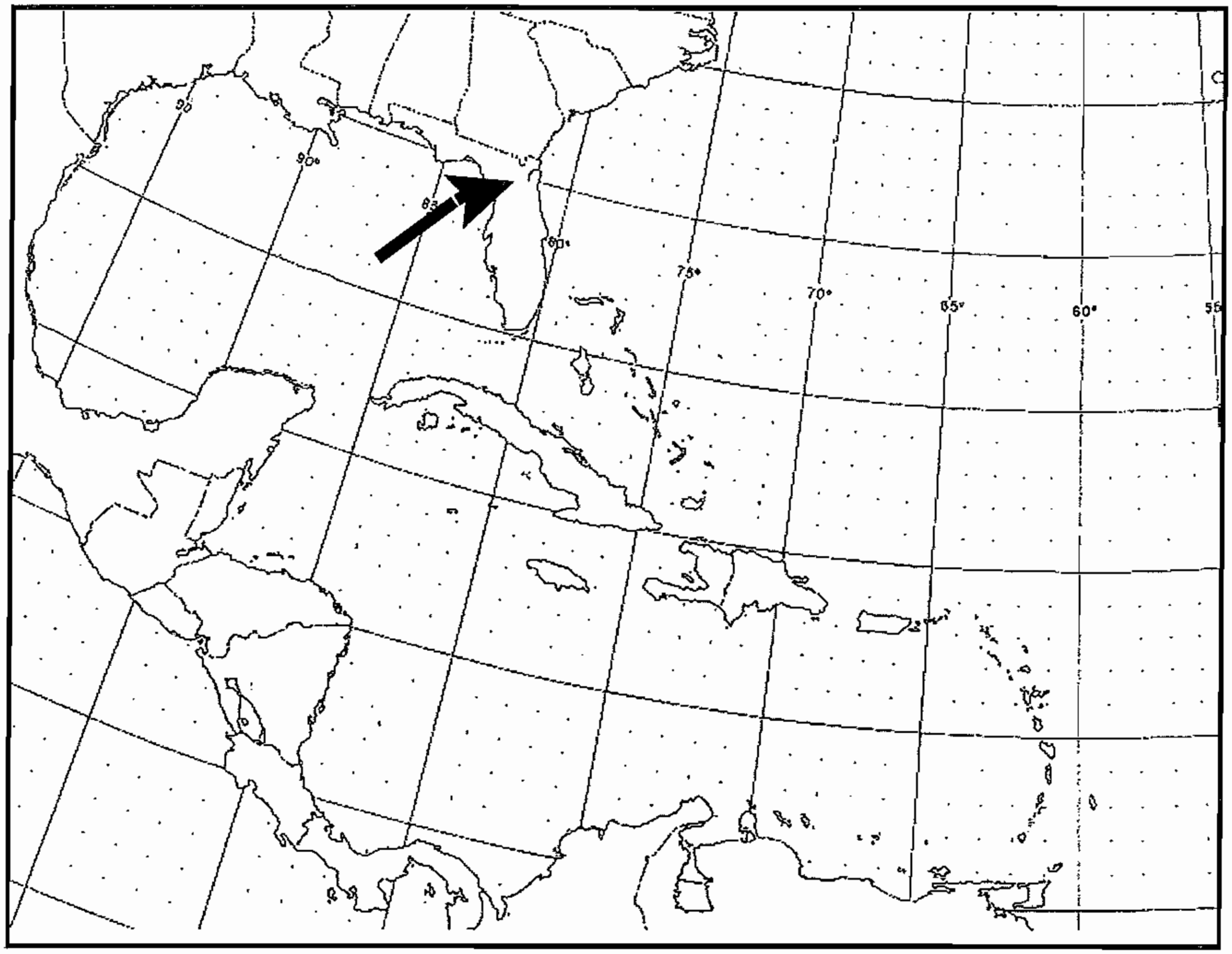
1968

Hurricane Gladys (17-18 October) originated as a tropical disturbance in the southwest Caribbean Sea. Gladys moved slowly northward, passing over western Cuba and entered the Gulf of Mexico. Gladys achieved Saffir/Simpson category two strength in the eastern Gulf and eventually turned northeast, making landfall north of Tampa Bay. Gladys was accompanied by maximum storm tides 0.9 to 1.5 m (3-5 ft) MSL from Tampa to Fort Myers. Considerable beach erosion and coastal flooding was reported. For example, Tarpon Springs and much of western Pinellas county reported street flooding (including reports of sand being washed onto Gulf Boulevard in Madeira Beach).



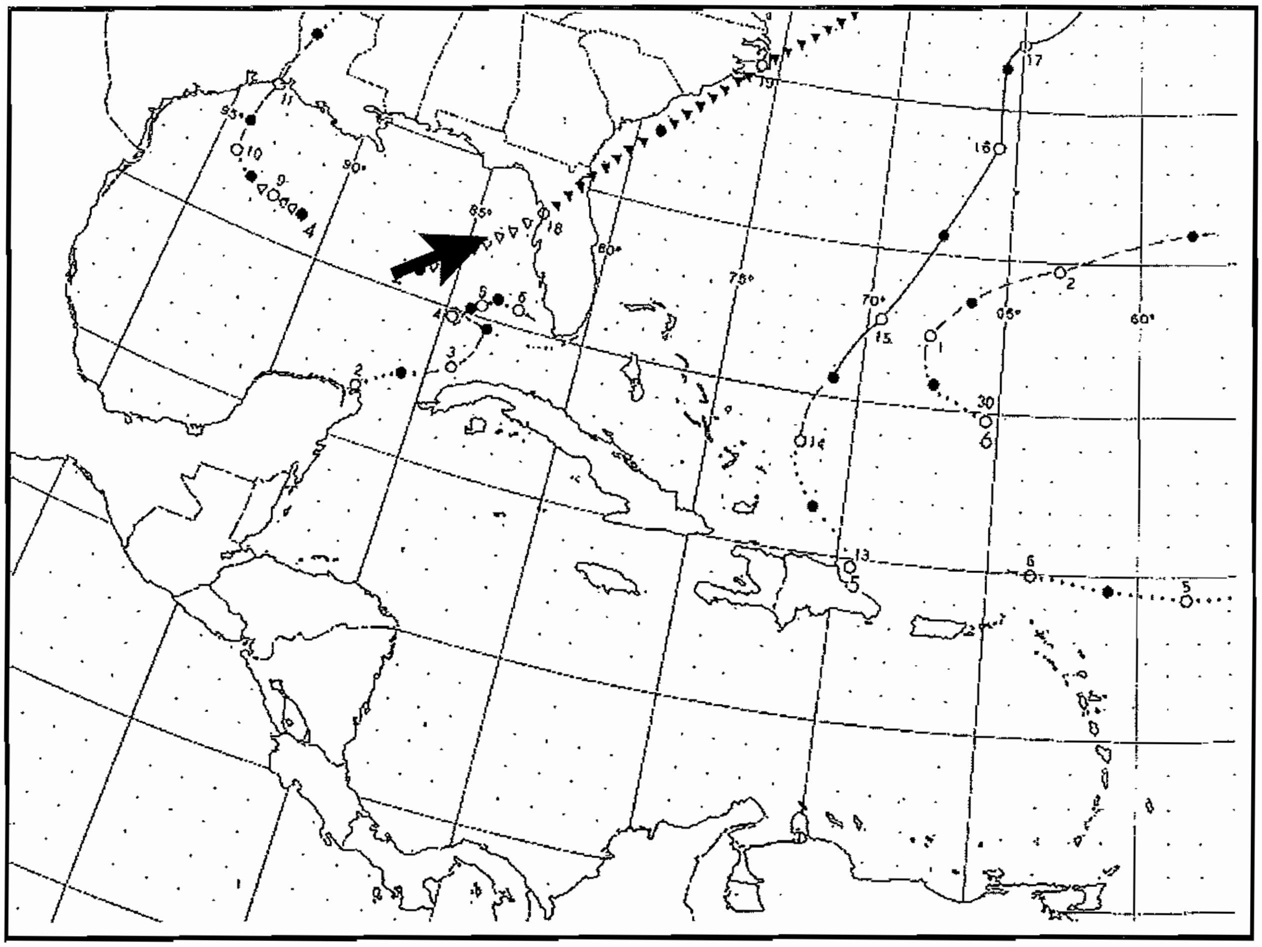
1972

Hurricane Agnes (18-19 June) originated near the Yucatan Peninsula as a tropical depression and became a hurricane over the southern Gulf of Mexico. Agnes moved north, making landfall east of Panama City, FL as a Saffir/Simpson category one hurricane. Maximum storm tides along the west coast of Florida ranged from 1.2 to 2.1 (4-7 ft) MSL from Fort Myers to Cedar Key. Maximum wind gusts at Tampa and Fort Myers were 19 ms^{-1} (37 kt) and 23.7 ms^{-1} (46 kt), respectively. Agnes was a large storm and its circulation covered most of the Gulf of Mexico and all of Florida. Gales extended out 320 km north and east of the center at one point in time. Pinellas County was hit hard with 1.5 m (5 ft) MSL storm tides affecting Saint Petersburg and the Gulf beaches. Much of the $12,000,000 damage Agnes caused in Pinellas County was attributed to severe beach erosion and damaging flood waters.



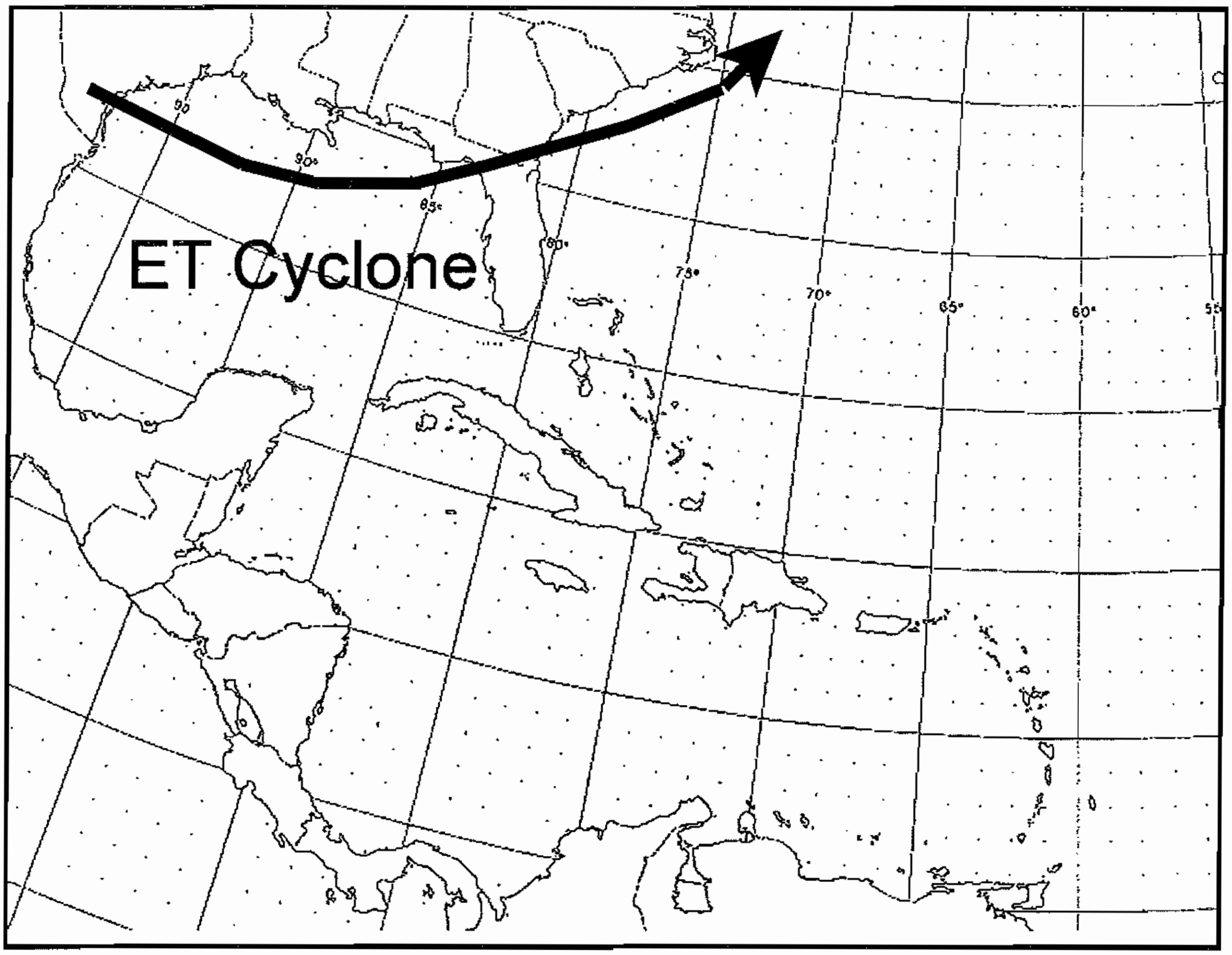
1974

On 25 June, a subtropical storm developed in the central Gulf of Mexico and moved northeast, coming ashore near Cedar Key, Florida. This storm produced a maximum storm tide of 1.2 m (4 ft) MSL from Cedar Key to near Naples. Coastal flooding and beach erosion occurred all along the west-central coast of Florida with damaged boats and flooded streets reported in Hudson, Tarpon Springs, Clearwater Beach, Indian Rocks Beach, Saint Petersburg, and areas of Manatee County.



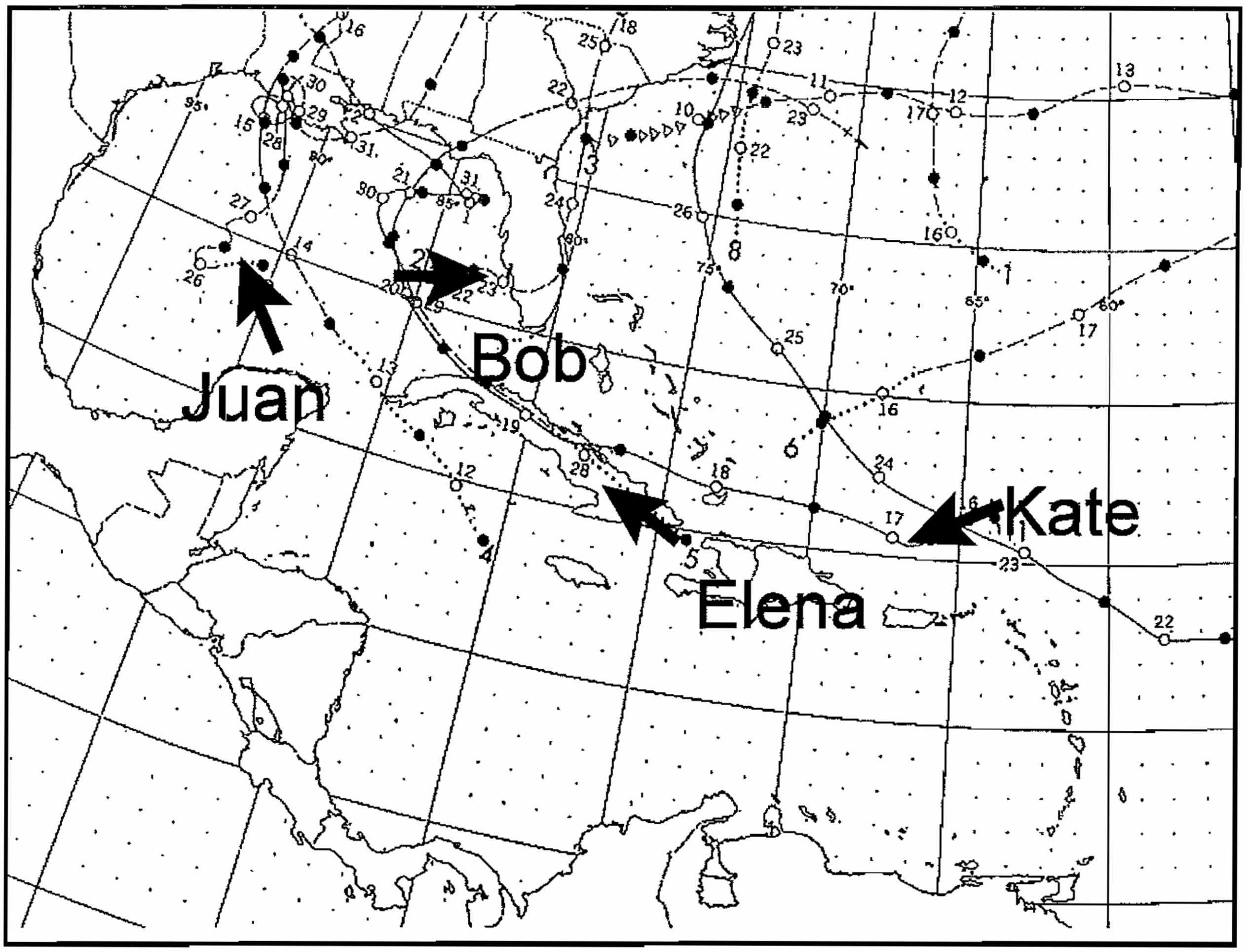
1982

On 17-18 June a subtropical storm affected the west coast of Florida from Naples to Tampa. The storm originally developed in the central Gulf of Mexico and moved northeast crossing the Florida peninsula around Hernando County and exiting near Jacksonville. The storm moved rather quickly but still produced maximum storm tides of around 0.6 to 0.9 m (2-3 ft) MSL from Tampa to Naples. The maximum wind gust in Tampa from this storm was only 13.4 ms^{-1} (26 kt) from the west. Coastal flooding caused widespread damage to marinas, small boats, and some buildings along the west-central coast of Florida. Significant beach erosion resulted as well.



1983

The most significant coastal flooding event in 1983 occurred in association with a midlatitude frontal ET cyclone that developed in southeast Texas on 23 March and moved rapidly across the northern Gulf of Mexico. This storm crossed the Florida peninsula in the Big Bend region and then deepened rapidly as it generated northeast off the coast of the Carolinas. This storm induced maximum storm tides of 0.6 m (2 ft) in Saint Petersburg, 1.2 m (4 ft) in Tarpon Springs, and 1.5 m (5 ft) in Citrus, Hernando, and Pasco Counties. Widespread beach erosion, street flooding, and damage to small boats and some buildings occurred with this storm. Winds gusted over 18 ms^{-1} (35 kt) in many areas.



1985

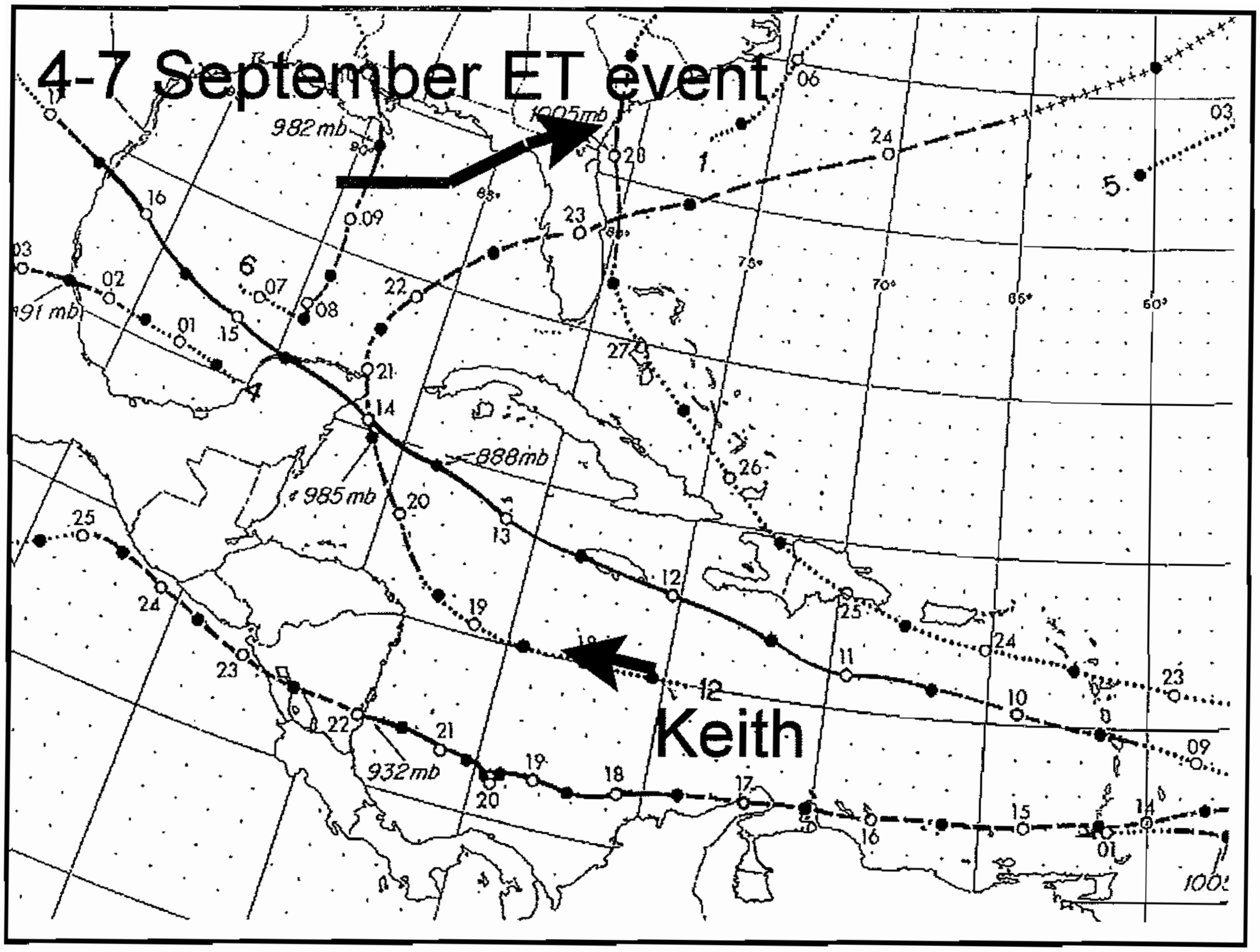
The year 1985 was a rather active coastal flood year for the west coast of florida with 4 tropical systems affecting the area between July and November. Tropical storm Bob (23 July) formed in the southeastern Gulf of Mexico, briefly became a Saffir/Simpson category one hurricane, and then moved slowly eastward, dropping back to tropical storm strength before making landfall along the west coast of Florida near Fort Myers. Tropical Storm Bob produced maximum storm tides of 1.5 m (5 ft) MSL in Collier and Charlotte counties as well as approximately 330 mm (13 in) of rain in Naples. Several beaches suffered erosion from Port Charlotte to Marco Island and heavy surf flooded streets in Naples and Everglades City.

1985 (continued)

Hurricane Elena (28 August - 2 September) formed originally from a tropical disturbance east of Cuba. Elena was named over Cuba and moved northwest into the northern Gulf of Mexico. At that time, Elena curved dramatically toward the east, moved to just offshore of Cedar Key, Florida, stalled, made a loop, and finally resumed a northwest track until finally making landfall in southern Mississippi. Elena produced maximum storm tides of 1.2 to 2.1 m (4-7 ft) MSL from Sarasota to Apalachicola. Moderate to severe beach erosion resulted along the coast in these locales. Maximum wind gusts along the coast were generally around 27 ms^{-1} (60 kt). Elena attained a maximum Saffir/Simpson strength of category three while in the Gulf of Mexico.

Hurricane Juan (28-31 October) formed originally as a tropical storm in the central Gulf of Mexico, made an erratic path toward Louisiana, making landfall along the western Gulf coast of Louisiana. Juan then made a couple of loops before moving back out into the Gulf of Mexico just offshore of the Louisiana coast. Juan then moved eastward and then northeastward before making a final landfall near the Alabama-Florida border. From 27 to 31 October, Hurricane Juan (a Saffir/Simpson category one hurricane) induced persistent 9 to13 ms^{-1} (20-30 kt) south to southeast winds in the eastern Gulf of Mexico and west-central Florida. Tampa reported a maximum wind gust of 17 ms^{-1} (39 kt). Maximum storm tides were generally less than 1.5 m
(5 ft) MSL along the coast, however, minor beach erosion and some coastal flooding resulted all along the entire west coast of Florida.

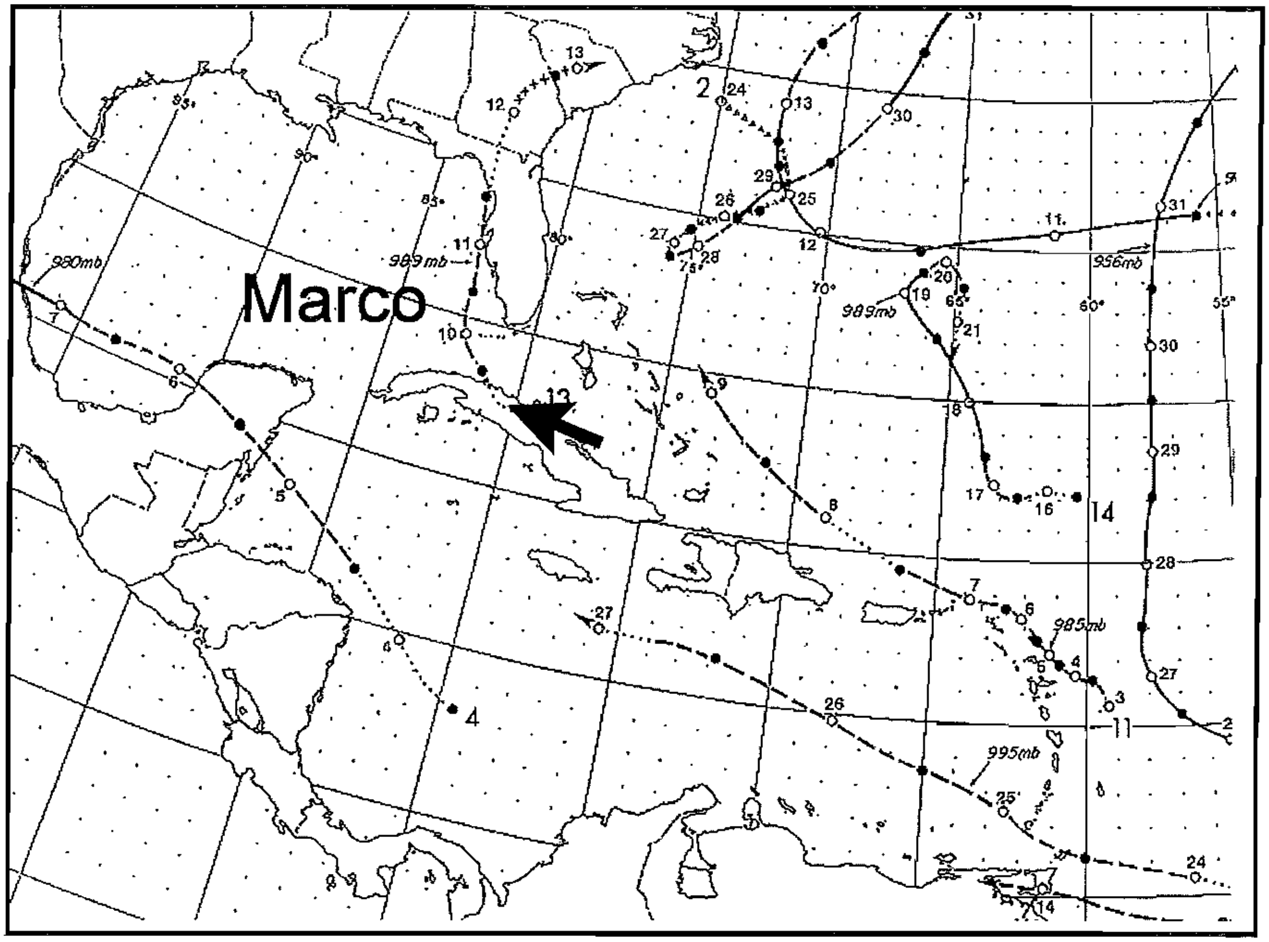
Hurricane Kate (21 November), a late season tropical system, developed initially as a tropical storm in the western Atlantic Ocean north of Puerto Rico. Kate quickly developed into a hurricane, moved westward over Cuba and then northwest into the Gulf of Mexico where she became a Saffir/Simpson category two storm. Kate finally recurved fully to the northeast and made landfall near Panama City, Florida. Although the worst coastal flooding with this storm occurred in the Florida panhandle, higher than normal water levels were reported along the west coast of Florida (generally less than 1.2 m (4 ft) MSL). Some minor beach erosion and flooding did occur. Tampa recorded a maximum wind gust of 12 ms^{-1} (29 kt).



1988

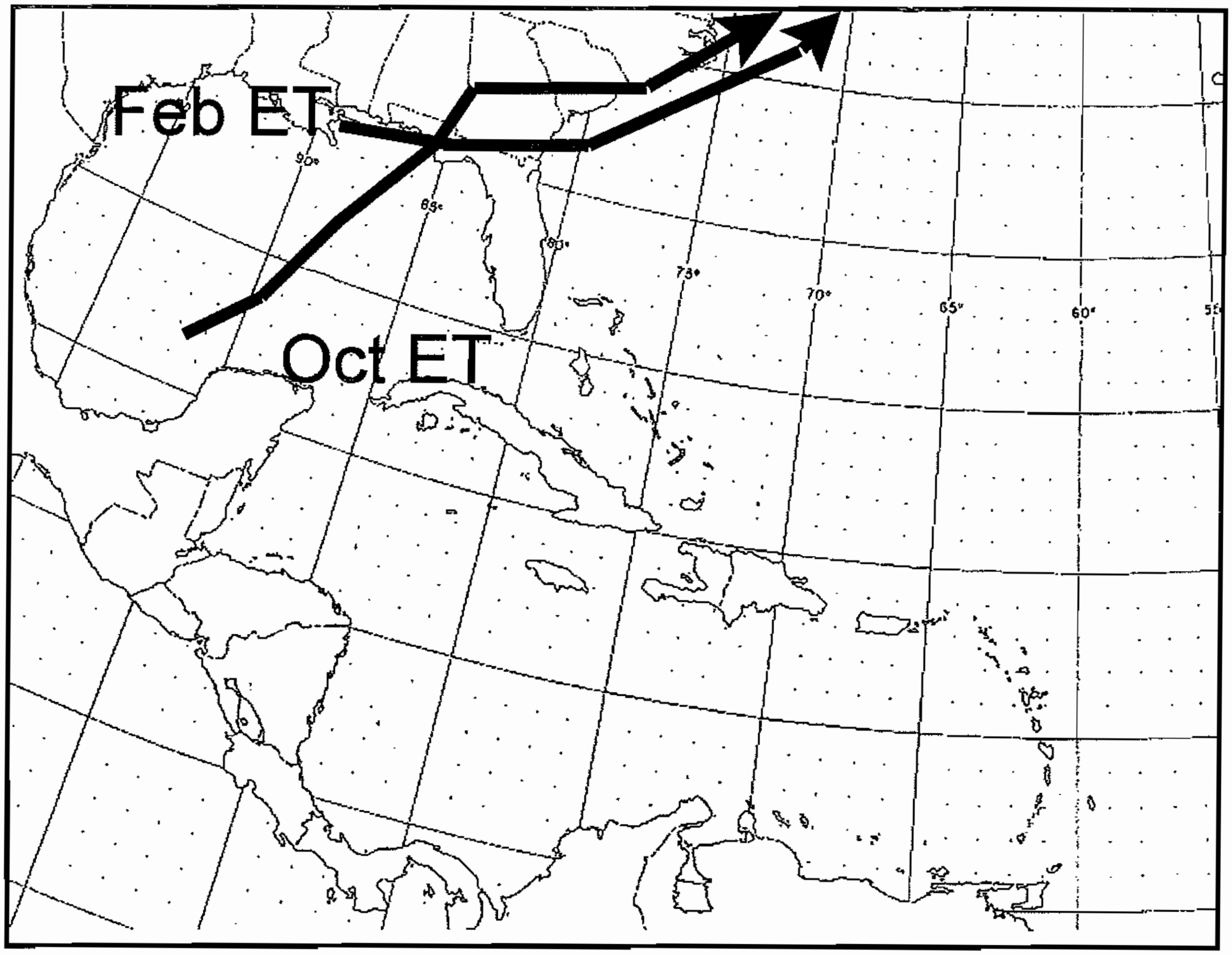
On 4 September, remnants of a tropical depression located near the Louisiana coast began to be absorbed into a baroclinic zone, moving slowly southeast from 4 to 7 September over central and southern Florida. West-central Florida received up to 500 mm (20 in) in some areas. In addition, persistent southwest winds developed over the east-central Gulf of Mexico along the southwest to northeast-oriented frontal zone. Tampa recorded a wind gust to 20 ms^{-1} (45 kt). Water levels were 0.3 to 0.9 m (1-3 ft) above normal with a 1.2 m (4 ft) surf on top. Widespread beach erosion and coastal flooding occurred all along the west-central coast of Florida. Moreover, all rivers in central Florida were at or above flood stage. High storm tides, heavy surf, and persistent southwest winds exacerbated flooding problems near the rivers with mouths at the Gulf of Mexico or Tampa Bay.

Tropical Storm Keith (23 November) formed in the Carribean Sea, moved west, then northwest through the Yucatan Channel before recurving to the northeast and making landfall in Manatee County. Keith produced maximum storm tides of 0.6 to 1.8 (2-6 ft) MSL from Tarpon Springs to Fort Myers. Maximum wind gusts recorded at Tampa and Fort Myers were 21 ms^{-1} (41 kt) and 24 ms^{-1} (46 kt) miles per hour, respectively. Moderate beach erosion resulted as well as coastal street flooding and some structural damage.



1990

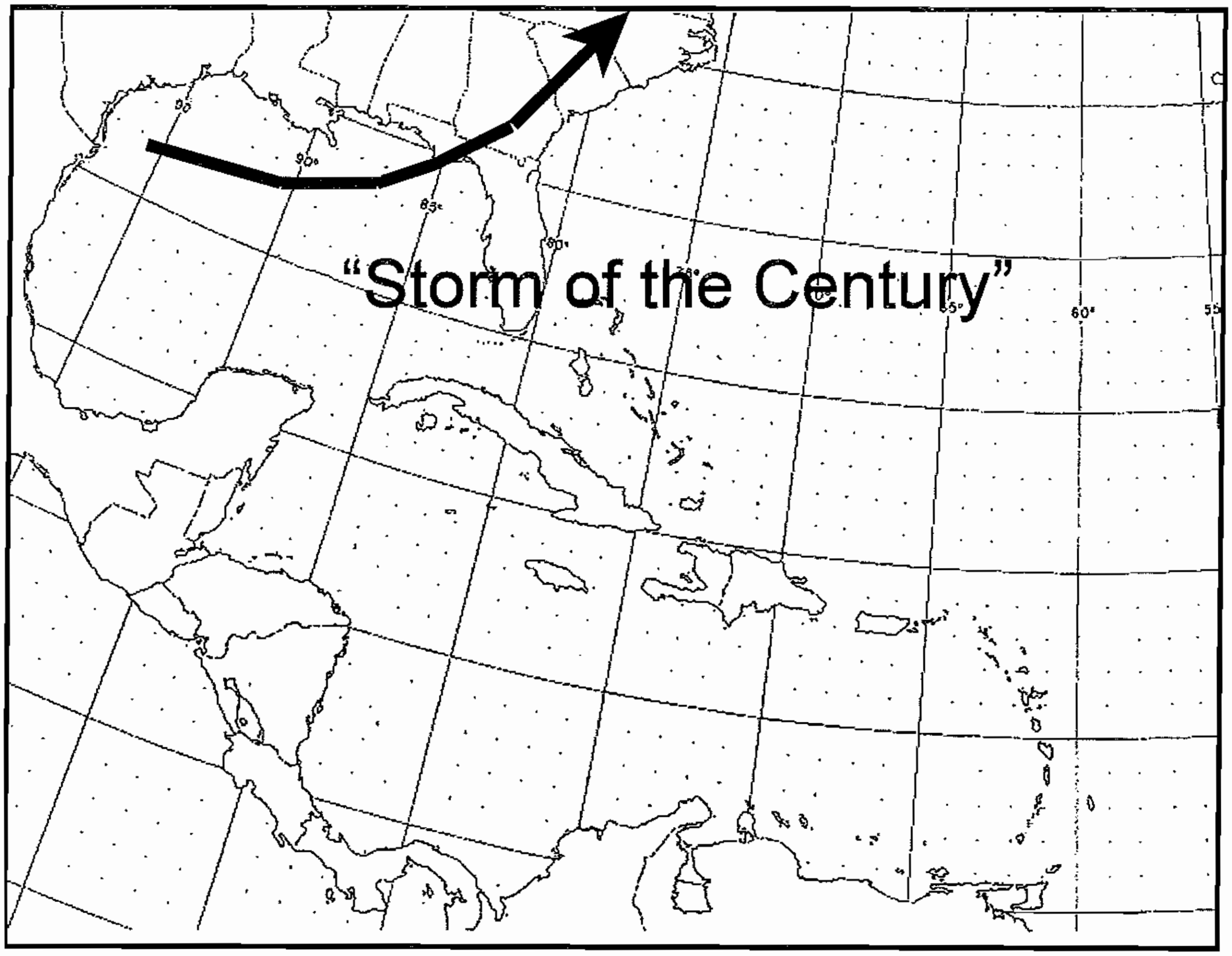
Tropical Storm Marco (10-11 October) originated from a tropical depression over Cuba. Marco was named in the Gulf of Mexico, just west of Key West and moved generally north parallel to the west coast of florida. Marco weakened to a tropical depression south of Cedar Key before making landfall in this vicinity. Maximum storm tides along the west coast of Florida were from 0.6 to 1.2 m (2-4 ft) MSL from Tampa to Fort Myers. Minor beach erosion was reported at Sannibel Island and some flooding of homes occurred in Sarasota, Hillsborough, and Citrus counties. Maximum wind gusts ranged from 15 ms^{-1} (29 kt) at Fort Myers to 38 ms^{-1} (74 kt) at Sanibel Island.



1992

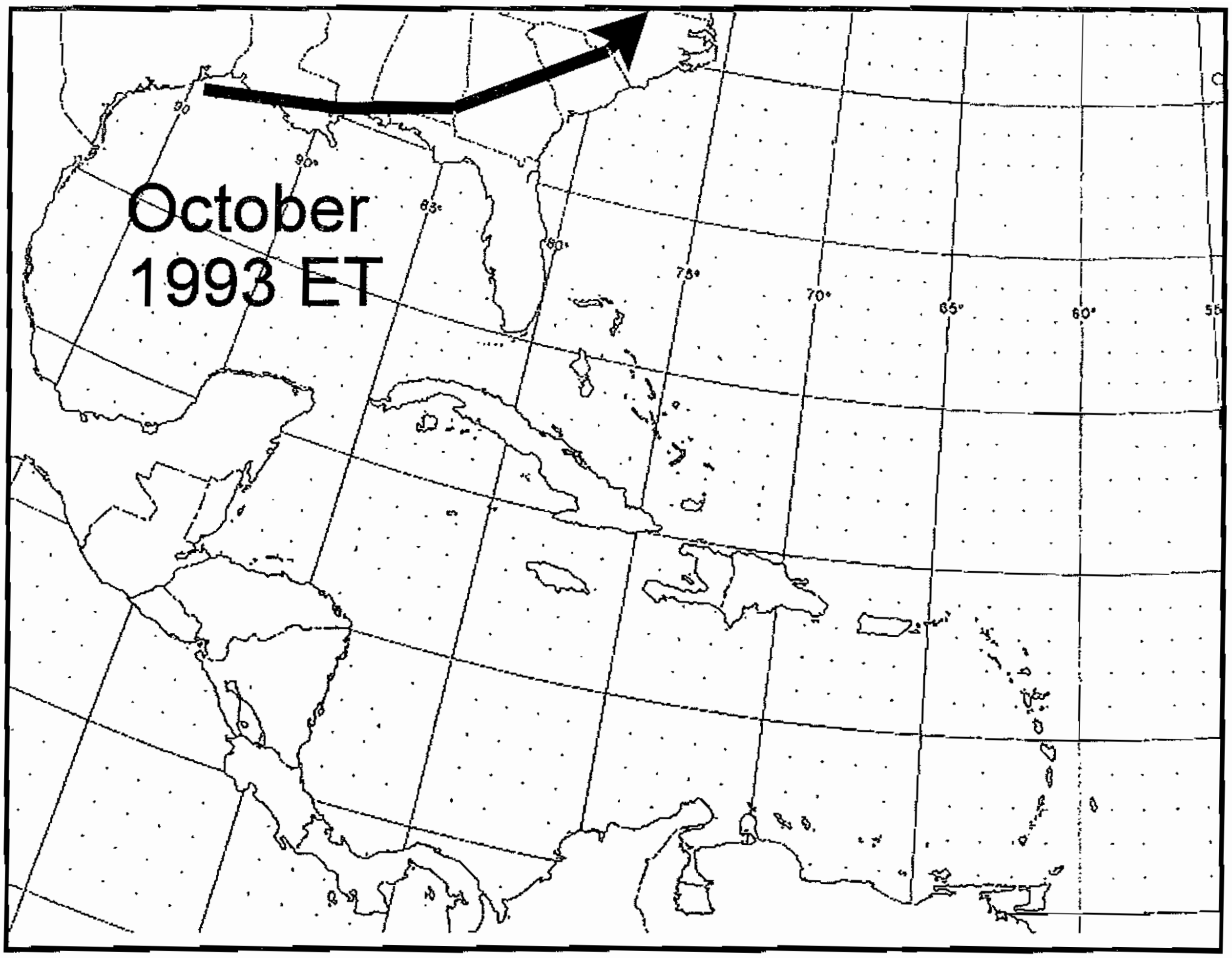
An extra-tropical storm (6-7 February) formed in the northern Gulf of Mexico and developed eastward during the next few days, becoming mature over northern Florida (sea-level low pressure: 992 mb) before moving northeastward over the western Atlantic Ocean. This system produced maximum storm tides of 1.5 m (5 ft) MSL from Manatee county to Collier county. The storm's south to southwest winds were at or above 11 ms^{-1} (25 kt) for 24 hours along the west coast of Florida. Minor beach erosion was reported along with some washed out roads and flooded homes.

In late September a surface low pressure area began to develop near the Yucatan Peninsula along an old, weak baroclinic zone. This low developed northeast into the central Gulf of Mexico and then across the Florida peninsula by 3 October. Strong southwest flow (9 to 13 ms^{-1} (20-30 kt) over the eastern Gulf of Mexico and west-central coast of Florida) developed ahead of the cyclone and was responsible for maximum storm tides of 0.6 to 1.5 m (2-5 ft) MSL along the west coast of Florida. In addition, a few strong tornadoes occurred in Pinellas county near Pinellas Park, killing four people. Coastal flooding was minor with mainly beach erosion and some flooded streets.



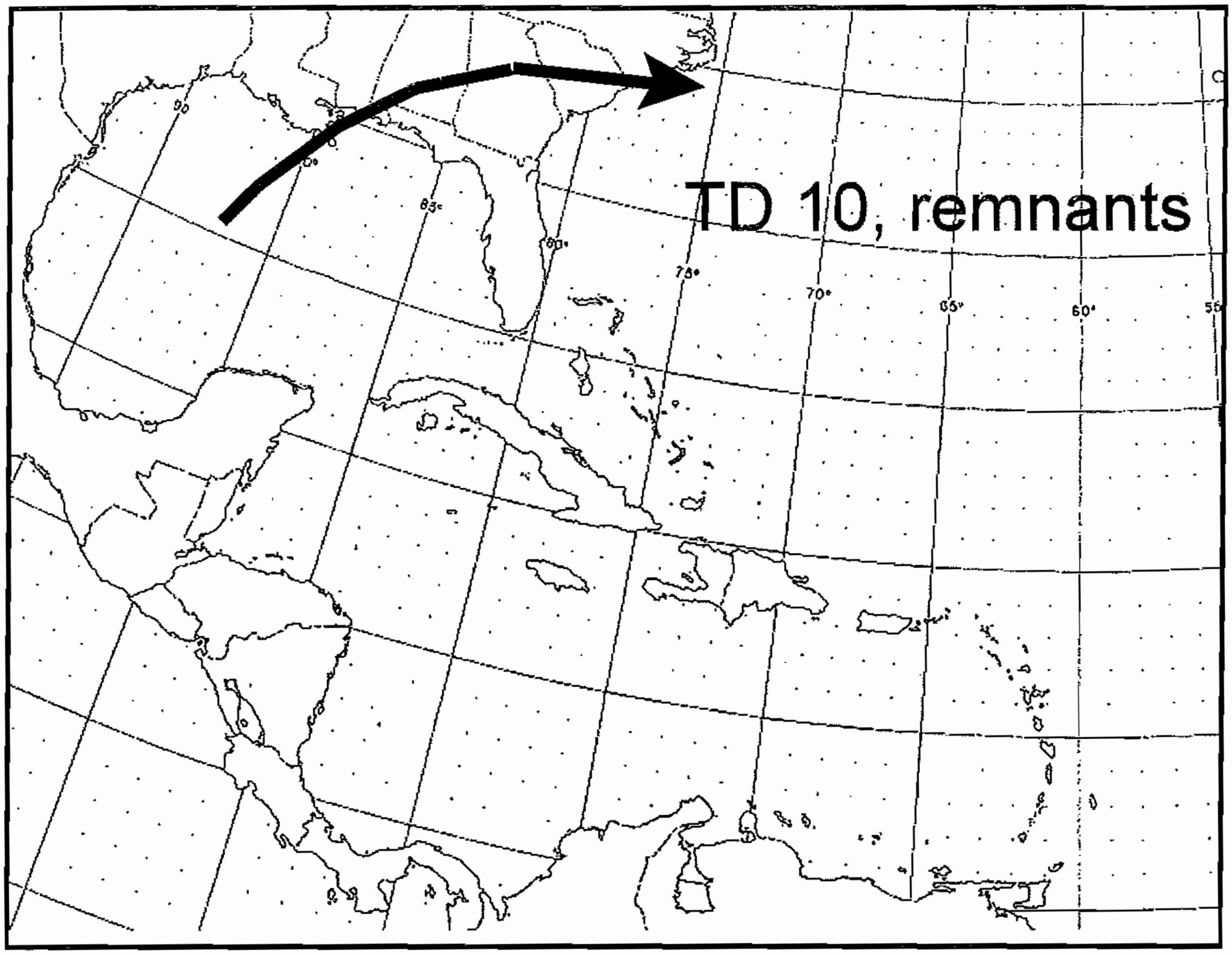
1993

The "Storm of the Century" (12-13 March) was one of the most intense ET cyclones ever affect the Florida peninsula (minimum central surface pressure while storm was in south Georgia: 972 mb). The storm was responsible for severe thunderstorms, tornadoes, high winds, record low minimum surface pressures, and coastal flooding in the state of Florida. Maximum storm tides ranged from 1.5 m (5 ft) MSL in Tampa to 3.7 m (12 ft) MSL in Taylor county. The high water levels were produced initially by persistent southwest winds (9 to 13 ms-1 (20-30 kt)) during the day and into the evening on 12 March. In addition, on 13 March, very strong westerly winds developed as the storm developed rapidly northeast. Tampa recorded a gust of 26 ms-1 (50 kt) and Cedar Key reported a gust of 40 ms-1 (78 kt) during this time. These winds served to created very heavy surf, which exploited an existing platform of high water along the coast. Widespread, severe coastal flooding resulted all along the west-central coast of Florida, including beach erosion, flooded homes, washed out roads, severe damage to small and medium sized boats, and other damage to marinas. The "Storm of the Century" demonstrated the potential of an ET cyclone to create severe destruction from coastal flooding.



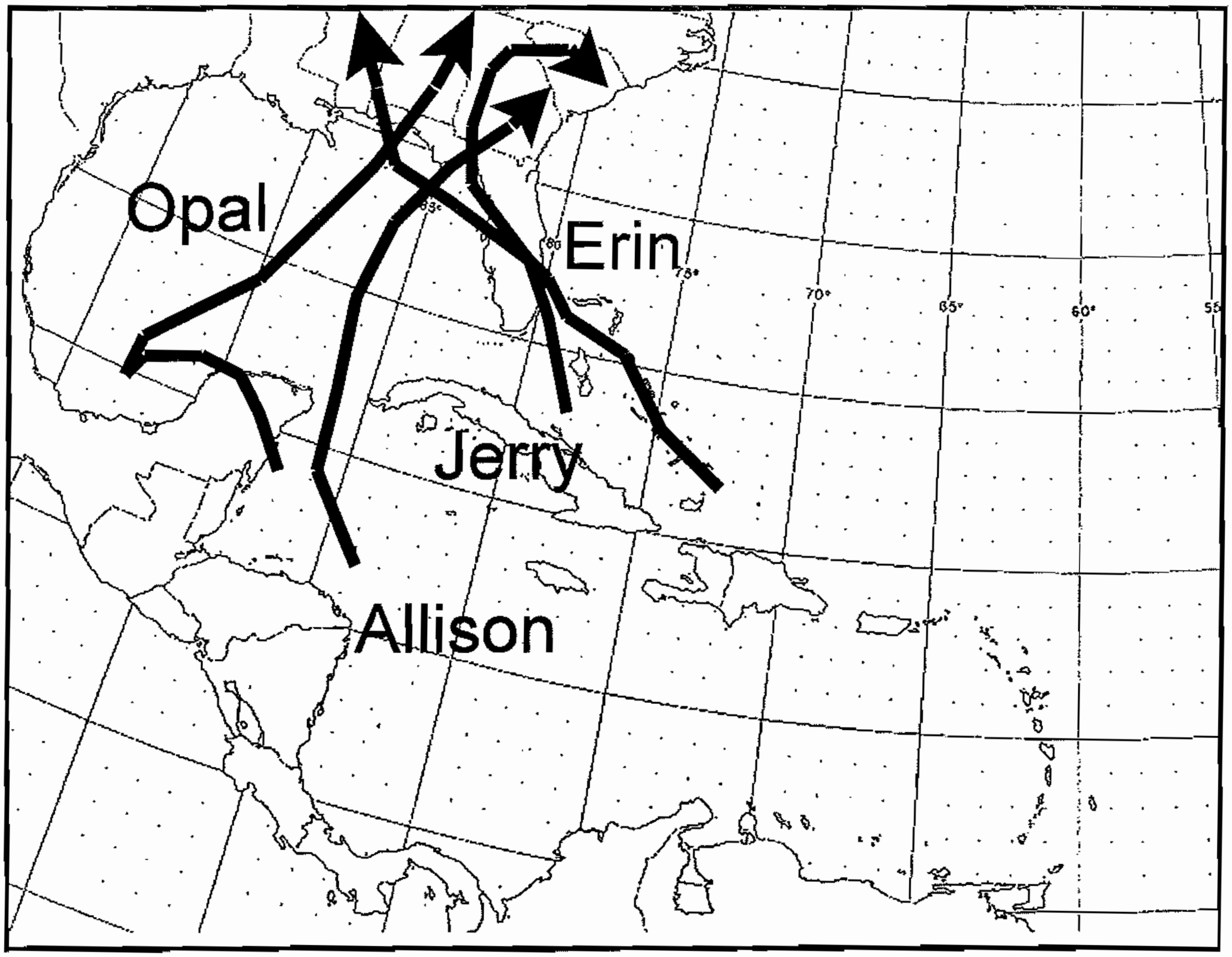
1993

Less than seven months after the 12-13 March "Storm of the Century", another ET cyclone produced coastal flooding along Florida's west-central coast, although not near as severe. On 29 October, a surface low pressure area developed in vicinity of Houston, Texas. This ET cyclone generated east-northeast. As it did, strong south-southwest winds (9 to 13 ms^{-1} (20-30 kt)) developed in the eastern Gulf of Mexico on 30 October. Maximum storm tides ranged from 0.6 to 1.5 m (2-5 ft) MSL from Manatee County to Collier County. Damage was minor with the main problems being beach erosion and minor street flooding in vulnerable locations.



1994

Tropical Depression No. 10 and its remnants created minor coastal flood conditions along the west-central coast of Florida on 2-4 October. Maximum storm tides were generally from 0.3 m to 1.2 m (1-4 ft) MSL. The high water levels were induced by persistent mainly southerly winds in the eastern Gulf of Mexico and along the west coast of Florida from 9 to 11 ms^{-1} (20-25 kt). Minor beach erosion and some tidal flooding occurred along with very rough seas in the eastern Gulf of Mexico.



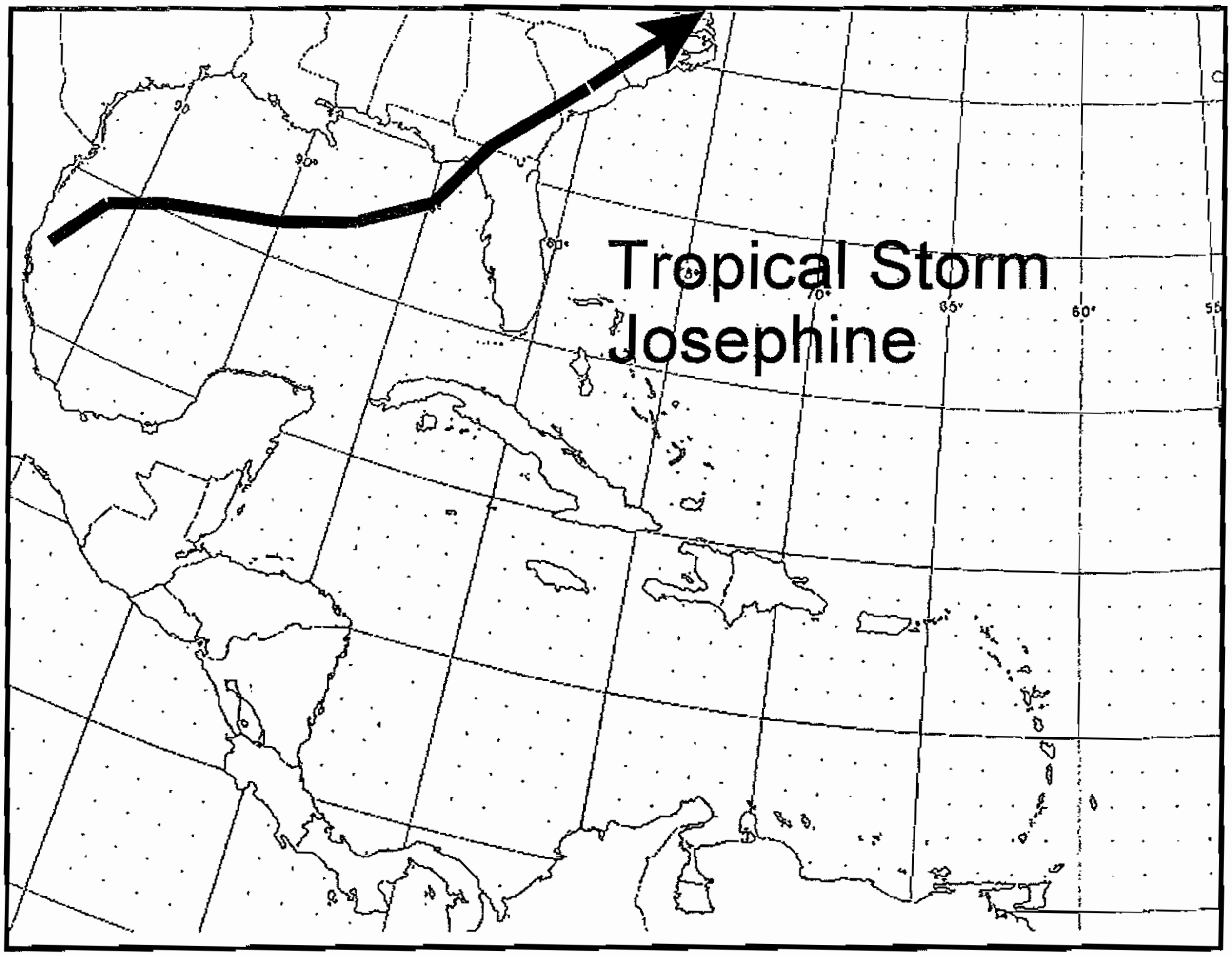
1995

The year 1995 was a very active year for tropical cyclones in the Atlantic Basins and it was also an active year for coastal flood events along the west coast of Florida. A total of 4 systems induced coastal flooding along the west coast of Florida in 1995. The year's first storm, Allison (5 June) formed as a tropical storm in the extreme eastern Carribean Sea, then moved north through the Yucatan Channel before curving slightly to the northeast and making landfall in the Big Bend region of northern Florida. Allison was briefly a Saffir/Simpson category one hurricane in the east-central Gulf of Mexico. Allison induced maximum storm tides from 0.6 to1.5 m (2-5 ft) MSL from Hillsborough to Levy counties. Minor to moderate beach erosion, flooded roads, and some structural damage were reported from Levy to Pinellas Counties.

Hurricane Erin (2 August) originated as a tropical storm in the western Atlantic Ocean in the vicinity of San Salvador Island, Bahamas. It then moved northwest and made landfall in Brevard County, Florida. Erin crossed the Florida peninsula and exited back into the Gulf of Mexico in the vicinity of the Hernando-Pasco county line. The storm then moved northwest, making a final landfall in the extreme northwestern Florida panhandle region. Maximum storm tides from Clearwater north to Cedar Key were from 0.3 to 0.6 m (1-2 ft). Minor beach erosion occurred in these in these locales.

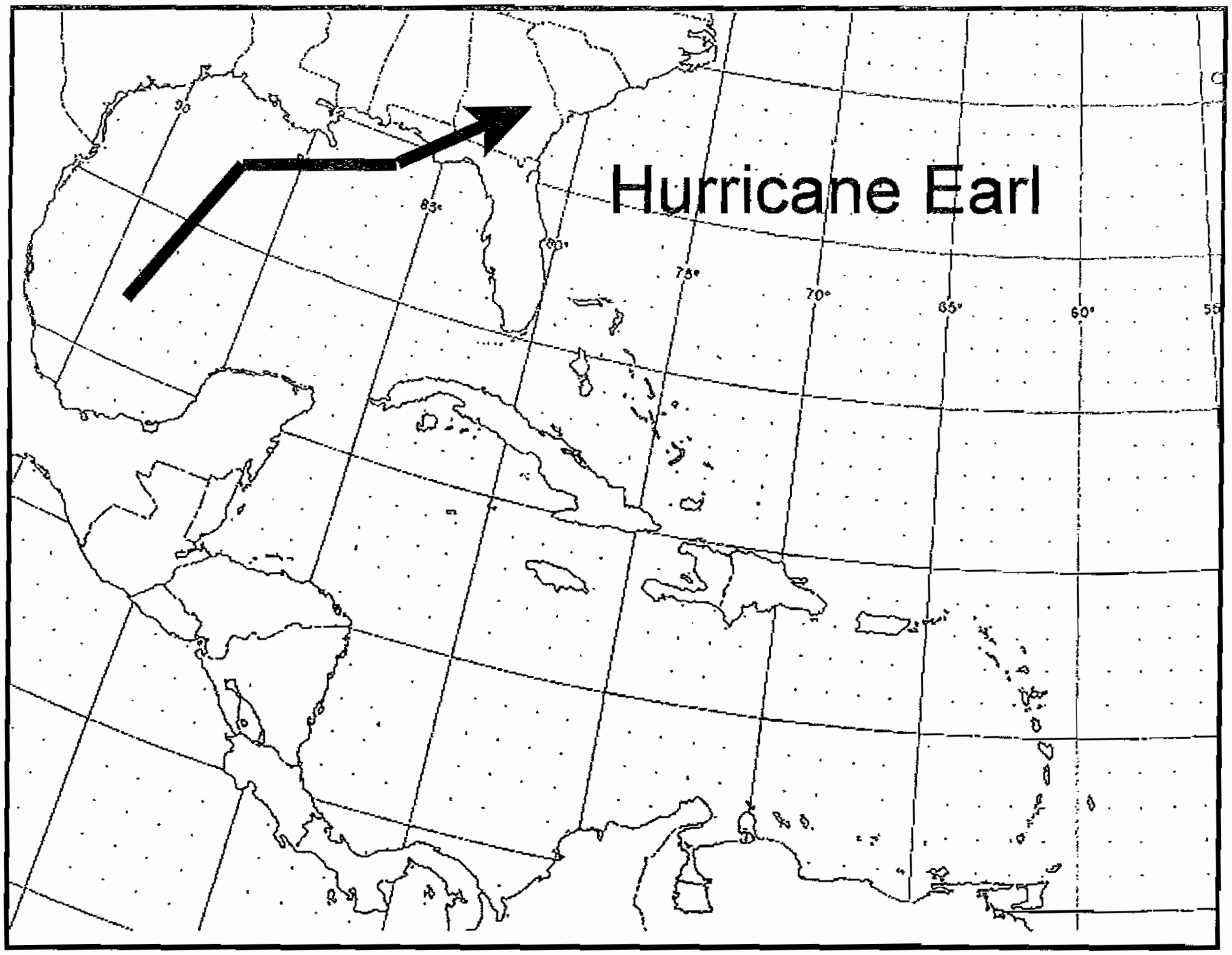
Tropical Storm Jerry (24-25 August) formed just north of Cuba, traveled north for a short distance before making landfall along the southeastern coast of Florida and then dissipating as is moved north over the peninsula. Maximum storm tides from Englewood Beach north to Cedar Key were 0.6 to 1.5 m (2-3 ft) MSL. Minor beach erosion occurred in these locales. Also, some streets were flooded from high tides and heavy surf in New Port Richey (Pasco County).

Hurricane Opal (4-5 October) was a Saffir/Simpson category 3 hurricane at landfall and for a brief time it was a category 4 hurricane in the central Gulf of Mexico. Opal was born as a tropical storm near Cozumel, Mexico and moved northwest over the Yucatan peninsula before eventually making it to the Bay of Campeche, where it meandered for a few days. Opal then began to move slowly toward the northeast. While in the central Gulf of Mexico, Opal underwent rapid intensification. From 00:00 UTC and 12:00 UTC on 4 October, minimum sea level pressure in the eye dropped 34 mb (~5.7 mb/hr), from 953 mb to 919 mb. (See Lawrence et al. 1998 for details). Opal then began to move rapidly northeast, but weakened to category three strength before making landfall. Although the west-central coast of Florida was not under the direct influence of Hurricane Opal, Opal's large and intense circulation in the central Gulf of Mexico worked in concert with a broad ridge of high pressure in the eastern Atlantic to produce a significant fetch of south-southwest winds over the eastern Gulf of Mexico, which induced significant coastal flooding along the west-central coast of Florida. Maximum wind gusts ranged from 11 ms^{-1} (22 kt) in Tampa to 23 ms^{-1} (45 kt) in Sarasota. Sustained winds around 10 ms^{-1} (20 kt) were prevalent along the immediate coast. Maximum storm tides were 1.2 to 1.8 m (3-6 ft) from Sarasota to Levy Counties. Significant beach erosion occurred along with some washed out roads and flooding of homes in these locales. The Hurricane Opal coastal flood event suggests that anytime a large and/or intense hurricane is in the Gulf of Mexico, marine forecasters along the west coast of Florida should be especially alert. This event also promulgates the realization of hurricane-induced coastal flooding not in association with its storm surge.



1996

Josephine was responsible for the most significant coastal flooding event along the west-central coast of Florida since the 12-13 March 1993 "Storm of the Century". She also eluded a permanent cyclonic identity, being categorized as tropical depression, tropical storm, hybrid cyclone, and extratropical storm at one point or another. Josephine had her origins in the southwest Gulf of Mexico as Tropical Depression No. 10 on 4 October. Over the next several days, Josephine moved across the Gulf of Mexico, undergoing various forms cyclone metamorphosis and confusing forecasters all along the Gulf coast. Josephine exhibited tropical characteristics in the beginning (convection near the center of circulation, little vertical shear), however, as she moved east, it became apparent that a vigorous mid-latitude trough moving south from the Ohio Valley would be responsible for Josephine's transition to an ET cyclone. By the time Josephine made landfall in the Big Bend region of Florida, little tropical characteristics were left, however, her radius of tropical storm force winds had expanded to nearly 400 km! The result was moderate to severe coastal flooding all along the west-central coast of Florida. Maximum storm tides ranged from 0.9 m (3 ft) in Lee County to 3.4 m (11 ft) in Levy County. Highest sustained winds ranged from 11 ms^{-1} (21 kt) in Brooksville to 20 ms^{-1} (39 kt) at the Sunshine Skyway (mouth of Tampa Bay).



1998

Hurricane Earl's origins were noted as early as late August when a very disorganized but persistent tropical wave traversed the Caribbean Sea and finally settled in the Bay of Campeche in the southwestern Gulf of Mexico. This tropical disturbance finally became a tropical storm on 31 August. Earl was a somewhat disorganized tropical storm for the next day and he seemed to move in a general north-northeast direction, but it was very difficult to discern a definite center of circulation at any one point. Earl was upgraded to hurricane strength (category one on the Saffir/Simpson scale) at 15:00 UTC on 2 September and attained Saffir/Simpson category two strength before making landfall at around 05:00 UTC on 3 September. Maximum storm tides did not occur in west-central Florida until around 16:00 UTC on 3 September, some 10 hours after landfall because the maximum storm tides seemed to be in association with a storm surge that was defined by an unusual long band of convection in association with a southwest-northeast oriented trough extending southwest from Earl. Before this band moved ashore, winds across west-central Florida were mainly out of the south-southeast. As the band moved ashore, the winds shifted to mainly south-southwest. The maximum storm tides then quickly materialized as high astronomical tides were occurring at this time as well.. Winds over the eastern Gulf of Mexico were observed via buoy observations to be southerly at between 10 to 15 ms^{-1} (20-30 kt) over a fetch that was approximately 400 km for more than 24 hours previous to the onset of coastal flooding. In addition, this fetch was over the western part of the West Florida Shelf. Water probably "piled up" over the eastern Gulf of Mexico during this period and then was pushed east by a combination of Ekman-induced net water mass transport and a south-southwest wind shift in association with a convective band extending along a trough south from Hurricane Earl.

It should be mentioned that Hurricane Earl was clearly not a classic tropical cyclone. Earl's wind field was quite asymmetric and most of the convection was in the eastern half of the storm. In addition, Earl appeared to strengthen despite an environment of strong vertical shear. Baroclinic enhancement is a possible culprit (possible increased angular momentum transport?).

Coastal flooding along the west-central Florida in association with Hurricane Earl was minor. Highest storm tides were in Levy County (1.5 to 2.1 m or 5-7 ft MSL). Maximum storm tides were much lower as one moved south along the coast. Lee County experienced virtually no problems with maximum storm tides of only around 0.6 m (2 ft) MSL.

The Tampa Bay NWSO had anticipated a possible coastal flood problem as early as 31 August and issued a coastal flood watch more than 24 hours before the onset of any coastal flooding. A coastal flood warning was issued more than 12 hours in advance of the first reports of coastal flooding. In addition, continuous surveillance of eastern Gulf of Mexico water level observations was maintained throughout the duration of Earl's life and excellent communication was maintained with Emergency Management Officials and SKYWARN storm spotters living along the coast. Clearly, this coastal flood event was a forecasting success.