Localized Coastal Flooding along Florida's West Coast

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1. Introduction

An early January 1999 squall line moved eastward across the Gulf of Mexico and onto the western shores of Florida producing localized coastal flooding. A radar feature known as a "Bow Echo" (Fig. 1.) developed as the squall line approached the west coast of Florida just north of Tampa Bay. Bow echoes are features that develop over several hours and often produce a localized area of sustained strong winds for a period of several hours. This bow echo produced an area of 30 ms^{-1} winds over the shallow Gulf shelf waters producing a localized surge of 2 m above astronomical tide. This surge flooded over 350 homes causing around $2.5M in damage. This study looks at: 1) the pre surge setup, 2) the particular characteristics of the bow echo including maximum wind direction and speed areas, and 3) past cases from which relationships, may be derived and incorporated into "Smart Tools" for use in the new National Weather Service Graphical Forecast Editor (NWS GFE.)

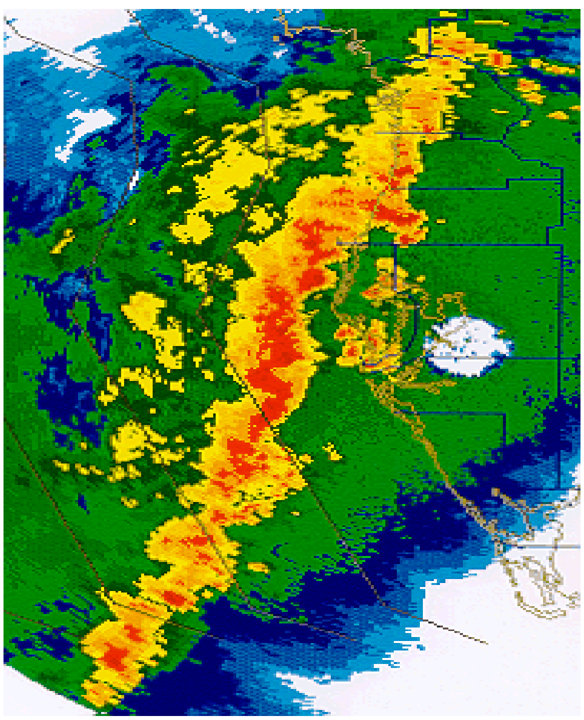

Figure 1. TBW WSR-88D Composite Reflectivity from 0321 UTC 03 Mar 1999.

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2. Surge Factors

Primary factors in surge production are wind velocity, wind stress, Ekman flow, pressure troughs, shelf depth, coastline shape and diurnal tides. Wind stress on the ocean induces a geostrophic current 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. 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 and a net transport of water mass to the right of the surface wind results. Water advancing shoreward from the central Gulf of Mexico (where it is much deeper than along the west Florida Shelf) encounters less and less volume due to the increasing elevation of the ocean floor. This forces coastal water levels to rise. For this reason the component of the wind blowing parallel to the shore has the most influence on water levels. Since water mass transport is to the right of the surface wind in this situation, southerly winds will accumulate water on west-facing beaches and, northerly winds will drain water from west-facing beaches. Typical response times are on the order of 12 to 24 hours.

Atmospheric pressure contributes to oceanographic response by the "inverted barometer" effect. On average, ocean level rises approximately 0.3 m per 30 mb decrease in the surface atmospheric pressure directly above the water surface. Paxton and Sobien, (1998) illustrated the effect of a pressure perturbation moving at a particular velocity over a certain shallow depth of water to produce a shallow water gravity wave with surge capability.

Jacobs (1998), developed a statistical model to predict water level changes based on altimeter-measured sea surface height variations collected by the TOPEX POSEIDON satellite. This model predicted changes off the west coast of Florida during an event beginning Friday March 7, 1998. Southerly wind stress increased in strength resulting in water levels increasing to 57 cm by 48 hours. Although southerly winds were converging towards Mobile Bay, the highest water level anomalies were generated along Florida's west coast due to the Ekman flow towards the coast. In a related study, Jacobs (1998) found the fraction of coastal water level variability in the northeast Yellow Sea explained by the instantaneous response to the local wind stress is generally between 10% and 20% in shallow with a peak in the northeast Yellow Sea nearing 40%.

2. Pre-Surge Conditions

Figure 2. shows a synoptic scale surface chart with a low pressure system over the Great Lakes and a trailing cold front extending southward along the east coast, across Florida, and over the Gulf. During the morning preceding the surge, surface winds were generally offshore from an easterly direction around 2 ms^{-1}. During the day the winds became more southerly and increased to 5 ms^{-1}.

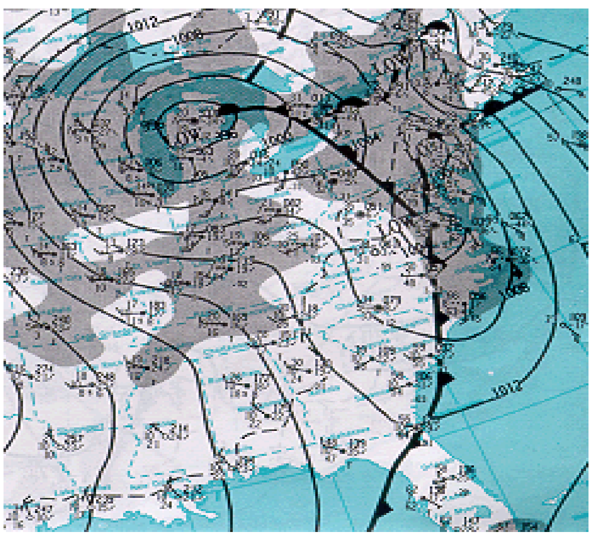

Figure 2. Surface pressure and fronts.

Tables 1. and 2. show winds above the surface and the related pressure levels and height above the surface from the Ruskin, FL (TBW) radiosonde data (Fig 2.) Winds in the levels above the surface are often more representative of winds over the open Gulf. Those winds increased significantly during the day leading up to the event.

Table 1. Low level winds 1200 UTC 02 Jan 1999

Level	Pressure	Height (m)	Direction (Degrees)	Speed (ms^{-1})
2	981	296	129	6
1	1000	131	118	4
Sfc	1014	13	110	2

Table 2. Low level winds 0000 UTC 03 Jan 1999

Level	Pressure	Height (m)	Direction (Degrees)	Speed (ms^{-1})
2	933	699	173	18
1	1000	95	175	9
Sfc	1009	17	180	5

3. Surge Event

Bow echoes typically evolve over several hours time and produce strong winds in a wide swath over a several hour period. This bow echo developed over the Gulf and moved toward shore. By the time the bow echo was well developed it moved over the shallow shelf waters. Figure 1. shows a WSR-88D Composite Reflectivity radar depiction of the bow echo moving onshore north of Tampa Bay. WSR-88D Radial Velocity (Fig. 4.) shows higher values along the convection's leading edge in the vicinity of the highest surge values.

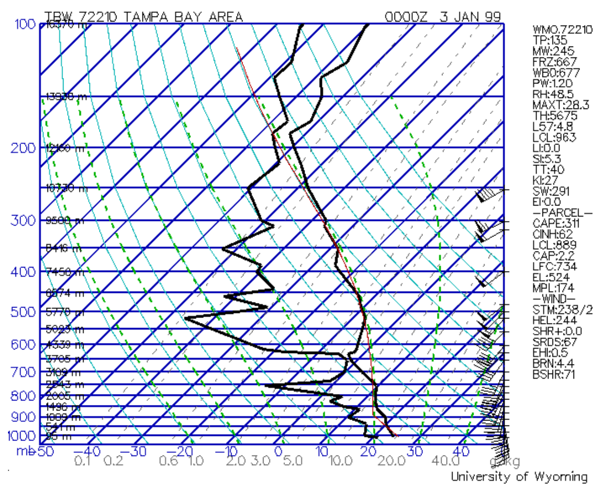

Figure 2. Tampa Bay Area – Ruskin, FL Skew T from 0000 UTC 03 Mar 1999.

Surface wind from Clearwater Beach (Table 3.) shows hourly wind speeds remained from a southerly direction above 10 ms for nine consecutive hours prior to a wind shift to the northwest and a 24 ms^{-1} gust. Figures 5 and 6 show Clearwater Beach wind speed red) and direction and surface pressure (red) prior to, and after the surge event. Winds steadily increased up to the time of the surge then suddenly decreased. Pressure steadily fell then rapidly rose near the surge event time. The rapid fall in pressure prior to the surge likely contributed to elevated water levels. This decrease in pressure along with the rapid onset of a strong westerly wind component associated with the Bow echo helped to transport above normal water levels onshore.

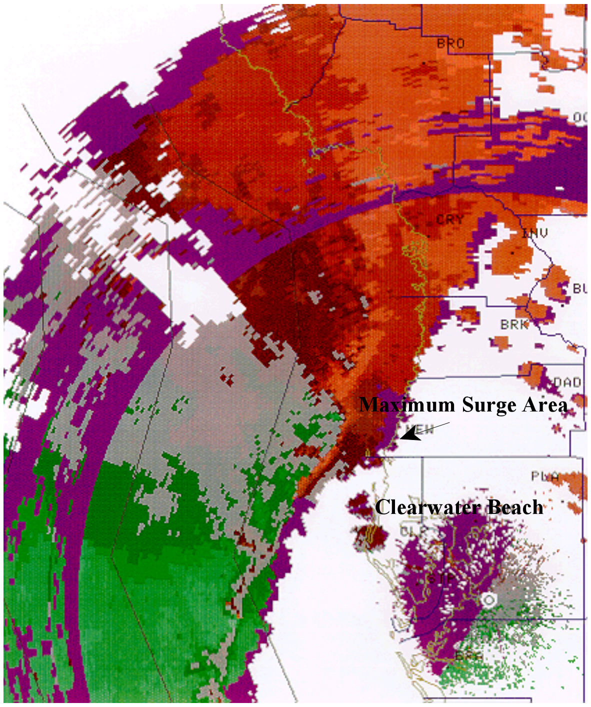

Figure 4. TBW WSR-88D 0.5 degree Radial Velocity from 0252 UTC 03 Mar 1999.

Table 3. Clearwater Surface wind 1900 UTC 02 Jan 1999 – 0500 UTC 03 Jan 1999

Date	Ending Time	Direction (Degrees)	Speed (ms^{-1})	Gust (ms^{-1})
1999/01/02	19:00	168.0	10.1	14.4
1999/01/02	20:00	173.0	10.4	15.2
1999/01/02	21:00	167.0	10.4	15.0
1999/01/02	22:00	168.0	10.7	15.6
1999/01/02	23:00	168.0	10.9	15.0
1999/01/03	00:00	168.0	10.1	16.3
1999/01/03	01:00	162.0	11.2	14.9
1999/01/03	02:00	165.0	10.4	18.2
1999/01/03	03:00	166.0	12.0	15.7
1999/01/03	04:00	321.0	13.7	24.3
1999/01/03	05:00	351.0	8.4	14.8

4. Conclusions

Historically, west central Florida coastal flood values greater than 1.2 m MSL are likely to cause some coastal flooding. Of the events on record, 62 percent had storm tides of 1.2 to 1.8 m. Table 4 shows recent significant events in which storm tides were between 1.2 and 3.7 m MSL. Maximum storm tides greater than 3.7 m, such as those produced by the

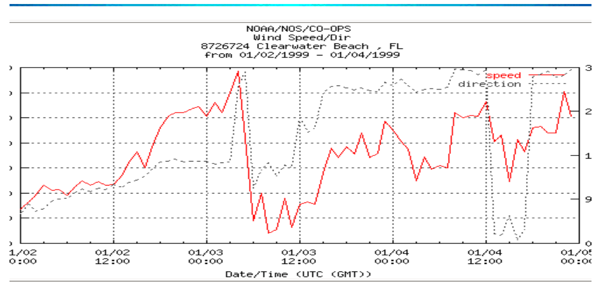

Figure 6. Clearwater Beach wind direction and speed (red.)

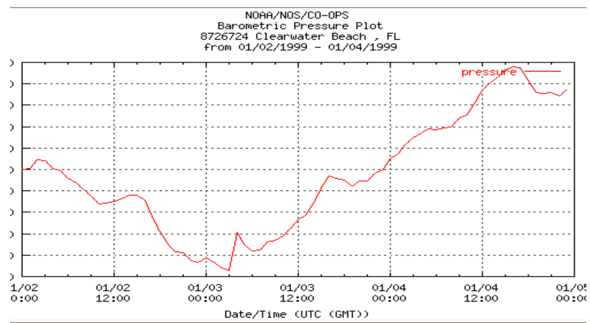

Figure 6. Clearwater Beach surface pressure (red.)

extratropical, March 1993 are very rare. What sets this case apart from others is the localized nature of this event. The set-up conditions of winds greater than 10 ms-1 elevating tide levels less than 1 m were similar to other events. But, the rapid shift to a strong westerly component pushing water onshore was confined to a relatively small area. Exact contributions of wind, pressure, bathymetry are unknown but with the compilation of cases these simple relationships can be built into NWS GFE Smart Tools.

Table 4. Recent extratropical storm surge events.

Date	Surface Pressure (mb)	Cyclone Speed (ms^{-1})	Sus-tained Wind Speed (ms^{-1})	Max Storm Tide (m)
1974/06/25	1004	7	11	2.1
1982/06/17-18	1004	11	13	1.5
1983/03/23	1004	11	13	1.5
1988/09/5-6	1004	9	9	1.5
1992/02/5-6	992	9	13	1.2
1992/10/2-3	1000	9	11	1.5
1993/03/13	972	16	20	3.7
1993/10/30	1000	10	15	1.5

5. References

Available upon request.