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The October 3-4 2000 Heavy Precipitation/Flash Flood Event Across South Florida

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1. Introduction

A significant heavy tropical rain event occurred over southeast Florida on October 3 and 4, 2000 that caused extensive flooding to homes and businesses. The event resulted in damages estimated at $700 million, $500 million of which were agricultural losses, and three deaths indirectly attributable to the flooding, two from drowning as a result of driving vehicles into deep water, and one from a fall. An estimated 93,000 residences, housing about 214,000 persons, were flooded or isolated by the flood waters and power was cut to 13,000 people. Rainfall totals ranged from 12 to 18 inches for the 24 hours period from 1200 UTC October 3 to 1200 UTC October 4. Over 90% of that fell during the afternoon and evening hours of October 3, particularly along a swath extending from southwest Miami Dade County to extreme southeast Broward County (Figure1, Table 1). This paper presents an analysis of the antecedents of such event; comparisons between rain gauge data and WSR-88D rainfall estimates; and a brief analysis of the National Weather Service Weather Forecast Office (WFO) Miami performance during the event.

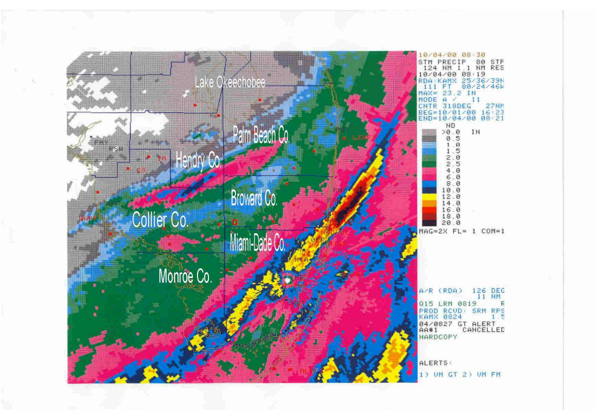


Figure 1. WSR 88-D Rainfall estimates from 1600 UTC October 1 2000 to 0800 UTC October 4 2000 across South Florida. Over 95% of the rain fell during the 24 hours period from 1200 UTC October 3 to 1200 UTC October 4.

Miami Canal	13.05	South Miami	15.75
Near Miami Shores	12.64	Cooper City	6.90
Tamiami and Krome	12.80	West Homestead	10.20
Everglades W Dade	10.50	Cutler Ridge	10.54
North Miami	9.09	South Miami	13.80
Everglades Krome	9.61	Miami Springs	8.03
Homestead FS	7.50	Hollywood	13.38
Perrine	10.55	Pompano Beach	6.27
Tamiami Airport	11.13	Fort Lauderdale Water Plant	6.17
Miami FS	13.27	Fort Lauderdale Executive Airport	4.74
Miami International	12.48	Fort Lauderdale FS	8.03
Miami Beach	4.25	Coral Springs	6.65
Fort Lauderdale Airport	8.32	Hollywood WP	15.26
Homestead General	9.37	17W Miramar	4.20
Opa Locka Airport	10.81	Fort Lauderdale Beach	7.32
Pembroke Pines	7.73	Key Biscayne	7.60
14NW of Sweetwater	5.00	Tamiami Canal	5.63
North Miami Beach	6.70	4W Coral Springs	4.74
East Hollywood	8.77	11W Coral Springs	3.60
South Miami	17.50	Coopertown	4.04
NWS Miami	12.95		

Table 1. Gauge Rainfall totals for selected sites across Miami Dade and Broward Counties from 1200 UTC October 3 to 1200 UTC October 4.

2. Antecedents

Around 1200 UTC on October 2, 2000, a low to mid level circulation developed along the axis of a tropical wave just south of western Cuba. This circulation moved north and by 1200 UTC October 3 it had reached the southeastern Gulf of Mexico. At the same time, a stalled old frontal boundary was located across South Florida (Figure 2) with plenty of shower and thunderstorm activity to the east of the mid level circulation and to the south of the front across the Florida Straits, the Keys, and extreme Southern Florida (Figures 3 and 5). As the mid level circulation tracked north northeast toward the West Florida coast, it interacted with the old frontal boundary resulting in a band of very heavy rain falling during the mid to late afternoon and through the evening hours on October 3 from southwestern Miami-Dade county to extreme southeastern Broward County. The mid level circulation eventually made landfall near Sarasota Florida around 0600 UTC October 4.

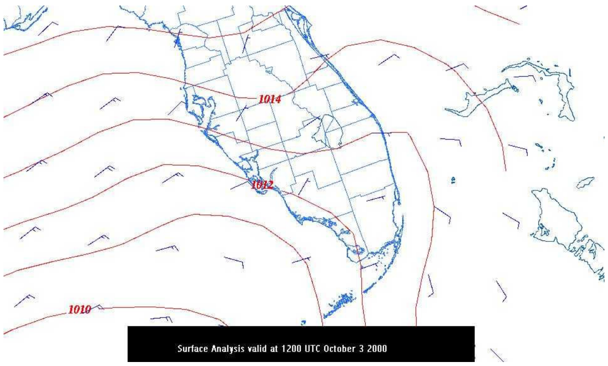


Figure 2. Surface analysis valid at 1200 UTC October 3, 2000**.**

The interaction of the mid level circulation with the frontal boundary as it moved north of extreme southern Florida created a secondary band of localized heavy rainfall south of Lake Okeechobee from northeastern Collier County through southwestern Palm Beach County. By 1800 UTC October 4, the mid level circulation had exited the east central Florida coast and received a subtropical classification by the Tropical Prediction Center. It became Subtropical Depression One and eventually Tropical Storm Leslie (Franklin and Brown, 2000). Rainfall accumulations from 1200 UTC October 3 to 1200 UTC October 4 were as high as 17.50 inches within the heavy band in Miami-Dade county as reported from rain gauges (Table 1).

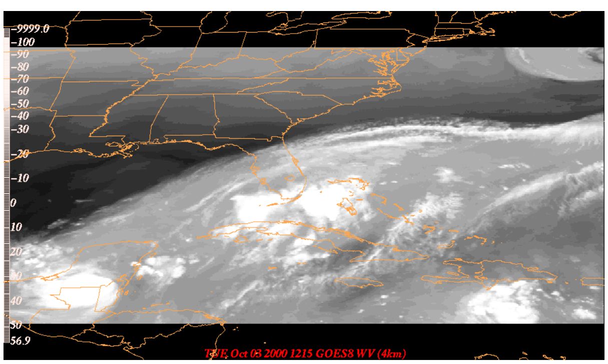


Figure 3. Water Vapor image valid at 1215 UTC on October 3, 2000.

Figure 3 shows the water vapor image valid around 1200 UTC on October 3. It shows the tropical wave (that eventually became Sub-tropical Depression One and then Tropical Storm Leslie) just to the west of Key West. The other notable feature in this figure is the water vapor plume (WVP) transporting abundant mid and upper level moisture from Tropical Storm Keith over the Yucatan Peninsula (Beven, 2001) into South Florida.

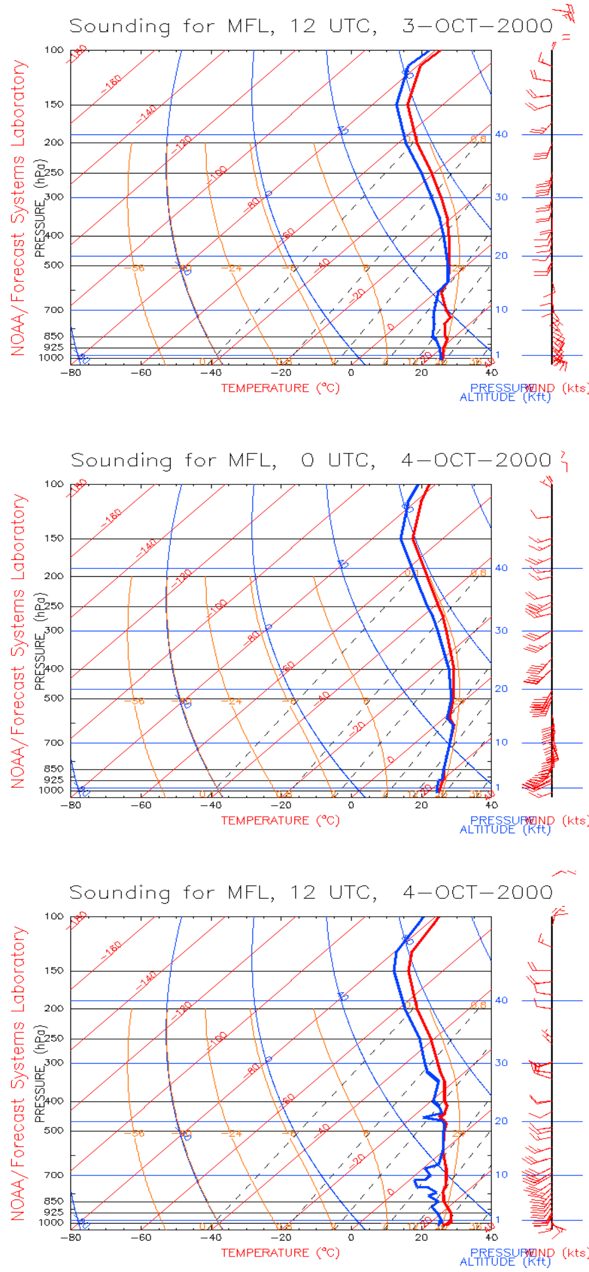
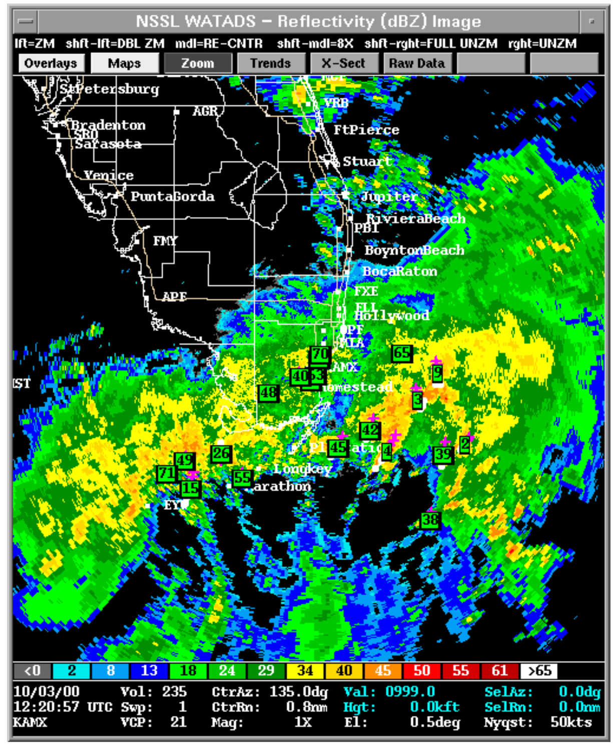


Figure 4. 1200 UTC October 3 (top), 0000 UTC October 4 (middle) and 1200 UTC October 4 (bottom) 2000 Miami soundings. Precipitable waters for the three soundings were 2.39, 2.73, and 2.26 inches, respectively. Although not visible in these figures, 0000 UTC from October 4 sounding had winds from the south at greater than 30 to 35 knots from 850 to 500 mb.

Figure 4 shows the observed soundings at Miami for the morning and evening of October 3 and for the morning of October 4. Precipitable values ranged well above 2 inches throughout that period and on the evening of

October 3, it was 2.76 inches. Another noticeable feature in these soundings is the fact that the wind in the 850 to 500 mb layer was from the south, almost perpendicular to the low level boundary, at a speed equal to or greater than 30 to 35 knots on the evening of October 3. Also, the morning and evening soundings on October 3 showed a warm cloud layer deeper than 3.5 km. In the October 3 morning sounding, a dry layer was noticeable at low levels, whereas in the evening sounding that layer was no longer present. Although the heaviest rain fell in the late afternoon and early evening hours of October 3, it had began raining, mostly light to moderate rain, since the previous day on and off and almost steadily since early in the morning of October 3 (Figure 5). This moistened up the low levels and created an atmosphere with a very high precipitation efficiency (defined as the ratio of total rainfall to total condensation) that, coupled with strong low level warm and moist air advection almost perpendicular to the surface boundary, excellent moisture feed at mid and upper levels, and record levels of total precipitable water, led to a 100 year flood event (**Weather Bureau Technical Paper No. 40**).

A recent NOAA Technical Report (Scofield, R. et. al., 2000) on the use of water vapor imagery leading to heavy precipitation events highlighted, among other things, that some of the key ingredients one looks for these events are: 1) a tropical water vapor plume that increases the amount of mid and upper level moisture in the atmospheric column coupled with high amounts of total precipitable water; 2) depth of the cloud layer with a temperature warmer than 0 degrees C greater than 3 km because such warm-based clouds enhance the collision-coalescense process by increasing the residence time of droplets in clouds resulting in higher precipitation efficiencies; 3) duration of precipitation moistening up the troposphere which increases also the precipitation efficiency; and 4) the presence of low level moisture feeding jets. All these elements were present in this event (not to mention the presence of the frontal boundary) with the low level jet being directly linked to the low to mid level circulation mentioned earlier. Although an axis of maximum equivalent potential temperature is another element one looks for, this was not distinctive in any of the surface models available that date, including the surface Rapid Update Cycle (RUC) model. It is important to note that the presence of a WVP alone is not enough to produce a heavy precipitation event. One has to consider also all the elements mentioned above and in particular the total precipitable water in the atmospheric column.



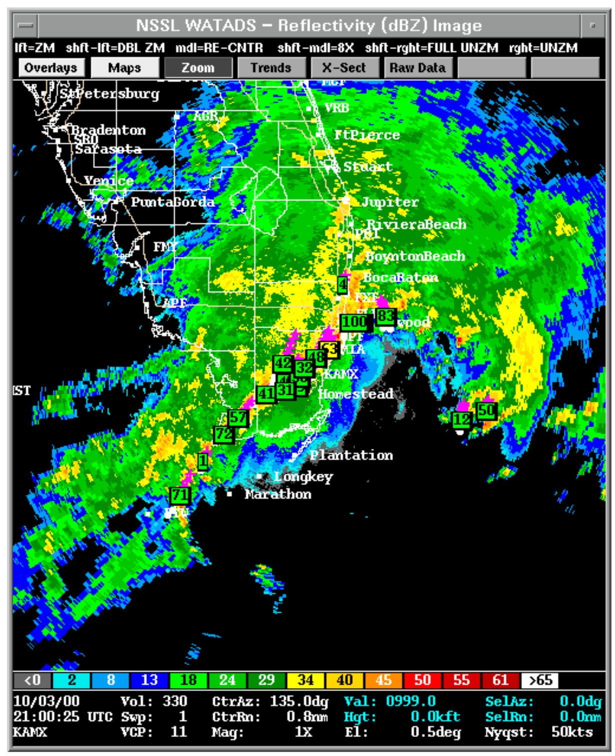


Figure 5. WSR-88D Base Reflectivity valid at 1220 UTC October 3 (top) and 2100 UTC October 3 (bottom), 2000.

In fact, an analysis of the climatology of precipitable water and rainfall across South Florida reveals that when precipitable water exceeds a threshold of around 2.3 inches, the chance of heavy precipitation increases dramatically. Figure 6 illustrates this point by showing the chance of precipitation increasing by as much as a factor of 4 for precipitable water values above 2.3 inches and for precipitation thresholds higher than 1 inch.

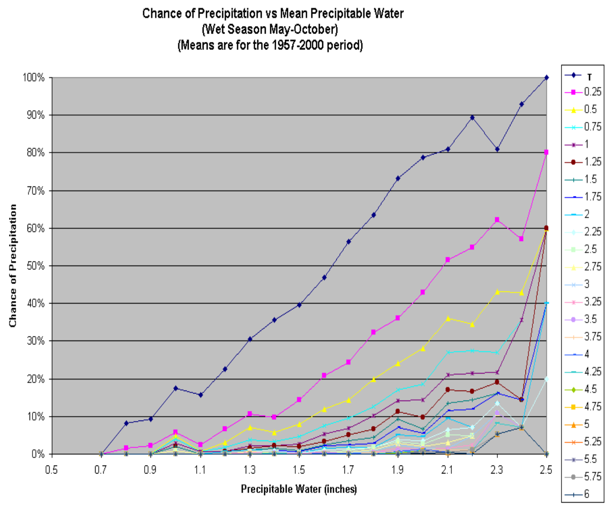


Figure 6. Chance of Precipitation (Y) versus Mean Precipitable Water (X) during the Wet Season (May-Oct) for the time period of 1957 through 2000 for different precipitation thresholds ranging from a trace, to 6 inches.

In summary, the combination of a WVP across Southern Florida, climatologically extremely high precipitable water values, a low level moisture and warm air feeding jet almost perpendicular to a surface frontal-trough boundary, and an atmosphere with high values of precipitation efficiency led to the nearly 100 year flood event of October 3 and October 4 of 2000 across South Florida. The preliminary analysis showed in this paper represents an application of findings found in numerous previous studies and summarized in a recent NOAA Technical Report (Scofield et. al., 2000). It also confirms the importance of looking at total precipitable water in the atmosphere and the effects of storm scale processes that impact the thermodynamic structure of the environment besides the normal synoptic (WVP and surface fronts or boundaries) and mesoscale (low and mid level circulations and low level jets) features one looks for.

3. Validation of WSR-88D Rainfall Estimates

a. Methodology

As noted earlier, rain gauges reported rainfall amounts as high as 17.50 inches for the 24 hours period ranging from 1200 UTC October 3 to 1200 UTC October 4, whereas the WSR-88D measured rain totals as high as 12 to 15 inches for the same period. In order to verify quantitatively the performance of the WSR-88D, simple statistics were calculated using Storm Total Precipitation (STP) from the 88D and rainfall accumulations from 68 rain gauges from different sources (National Weather Service gauges, South Florida Water Management District gauges, and weather spotters) across Broward and Miami Dade counties for the 24 hours period above. The 88D data used for the validation was processed using the WSR-88D Algorithm Testing and Display System (WATADS) available from the Storm Scale Applications Division of the National Severe Storms Laboratory in Norman, OK. The statistical analysis was done as prescribed by the Operational Support Facility (OSF) (Klazura and Kelly, 1995) and as performed previously by WFO Melbourne (Glitto and Choy, 1997). It consisted of calculating the Mean Radar Bias (MRB) using equation (1):

$$MRB = \frac{1}{N}\sum_{i=1}^{N}\frac{G_i}{R_i} \tag{1}$$

where N is the number of data points (68 for number of gauge/radar bin pairs), G refers to rain gauge estimate, and R to radar estimate or STP. MRB values higher (lower) than 1 indicate underestimation (overestimation) by the radar. Once the MRB was calculated, the percentage or average difference (AD) by which the radar varied from the gauges (higher or lower) was computed using equation (2):

$$AD = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{(G_i - R_i)}{G_i}\right|100\% \tag{2}$$

Then, AD was recomputed with the MRB from equation (1) applied as a correction:

$$ADMRB = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{(G_i - (MRB)R_i)}{G_i}\right|100\% \tag{3}$$

To extract the radar bin rainfall estimates, the rain gauge application accompanying WATADS was utilized. This application provides, given the latitude and longitude of the rain gauges, with a center bin radar estimate and the surrounding 5 X 5 radar bins. The statistics computed with equations (1)-(3) were computed using the center bin or the bin closest to the rain gauge and the best bin from the inner most 9 (3 X 3) bins. Then, gauge/radar pairs with G/R values not within 2 standard deviations of the mean were removed and the statistics from equation (1)-(3) recomputed.

b. Results and Analysis

Figures 7a and 7b show plots of the radar estimates as a fraction of the gauges measured rain.

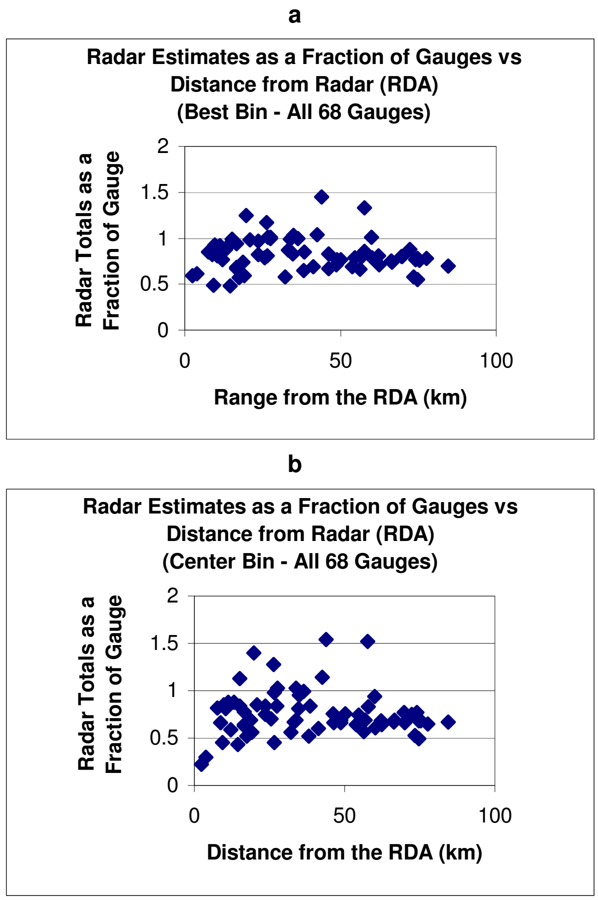


Figure 7. Radar/Gauge Ratio as a function of distance to RDA for best bin (**a**) and center bin (**b**).

This figure highlights that overall the 88D underestimated rainfall at all distances from the radar. The underestimation seems to be greatest closer to the RDA.

MRB	AD	AD-MRB	MRB	AD	AD-MRB
Best Bin			Center Bin		
Points within the entire range of the RDA					
1.27	21.43	17.17	1.47	30.33	24.86
*1.25	19.75	14.79	1.39	29	22.38
Points within 50 km of the RDA					
1.25	20.01	19.66	1.48	29.31	30.31
*1.22	18.55	17.44	1.36	27.23	25.26
Points beyond 50 km of the RDA					
1.31	24.22	11.34	1.45	32.31	14.78
*1.31	22.81	7.59	1.46	30.51	9.06

Table 2. Results from equations 1, 2, and 3. Rows with an asterik were recomputed after removing G/R values not within two standard deviations of the MRB.

Table 2 shows that the MRB was 1.25 for the best bin and 1.47 for the center bin. These values were slightly lower and higher for points within 50 km and beyond 50 km of the RDA, respectively. The average difference (AD) between the 88D estimates and the gauges was around 21% for the entire radar range, 20% within 50 km of the RDA, and 24% beyond 50 km of the RDA. These numbers were quite a bit higher for the center bin case, 30%, 29%, and 32%, respectively. All of these numbers were slightly lower when removing gauge/radar pairs whose ratio was not within 2 standard deviations of the MRB. When the MRB was applied as a correction and the average difference recomputed (ADMRB), a dramatic improvement was noticed for bins beyond 50 km of the RDA. The average difference for the best bin dropped from 24% to 11% and for the center bin from 32% to 15%.

These basic calculations give us, the operational forecasters, a quantitative estimate of how much the 88D is underestimating rainfall. This in turn can help us make better use of the radar rainfall estimates to issue more accurate flood statements and ultimately timely flood warnings, particularly during heavy precipitation events. The authors plan to build up a case verification data set that enables us to calculate the radar biases with a more solid and robust statistical analysis under different weather scenarios. As stated in Glitto and Choy (1997), in “Florida these events would include tropical moisture feeding along a stalled frontal boundary, the influence of a nearby tropical upper tropospheric trough, and heavy rain associated with tropical waves”, among others. This can then be used to coordinate with the OSF for recommendations on applying the bias corrections to the radar on a real time basis.

4. Performance of WFO Miami During the Event

The National Weather Service Weather Forecast Office (WFO) in Miami forecast the event very well, although the amount of rain received was nearly double the 8 to 9 inches originally expected and advertised in statements issued during the day and night of October 2 and during the morning hours of October 3. The WFO issued a Flood Watch for this event at 1109 AM EDT Monday, October 2, which was in effect through Tuesday and was extended on Tuesday, October 3, through midnight EDT. An Urban Flood Advisory was issued for eastern Broward and eastern Miami-Dade counties at 344 PM EDT on October 3, followed by the first Flood Warning for eastern Broward and all of Miami-Dade counties at 441 PM EDT. The Flood Warning was reissued at 817 PM EDT and 1130 PM EDT for the same areas. Reports of Water first moving into home and businesses were received at the WFO around 615 PM EDT. This means warning lead times were as high as one hour and 35 minutes. Considering that the flood event actually occurred during the evening hours of October 3 2000 and that the Flood Watch first went out at 1109 AM EDT on October 2, the lead time for the flood watch was around 30 hours. Given that this was a 100 year flood event, the performance of the WFO Miami office during the event was very good. The analysis of this event in this paper and an upcoming more detailed paper on the event will be used as training material to help forecasters in the future look for signs that will help them better anticipate the magnitude of these events. It is worth noting at this point that none of the computer models handled this event well and the forecast products issued by WFO Miami were for the most part against what the computer models were forecasting.

5. Summary

The combination of a WVP with climatological high values of precipitable water, a low and mid level jet associated with a mid level circulation/tropical disturbance tracking north across the Southeast Gulf of Mexico, low and mid level flow almost perpendicular to a surface front across South Florida, and long durations of precipitation and warm cloud layers deeper than 3.5 km enhancing precipitation efficiencies, led to a nearly 100 year flood event across South Florida on October 3 and 4 of 2000.

The WSR-88D rainfall estimates underestimated rainfall during the 24 hours period of 1200 UTC October 3 to 1200 UTC October 4 by as much as 20% in the best bin case and 30% in the center bin case. Applying bias corrections to the 88D rainfall estimates showed a considerable improvement, as much as 10% to 15% particularly for ranges beyond 50 km of the RDA.

WFO Miami issued timely watch, warning, and forecast products with lead times as high as 30 hours for the flood watch and one hour and 35 minutes for the flood warning previous to the main event in the afternoon and evening hours of October 3, but underestimated rainfall amounts by nearly 50%. This paper is a preliminary version of work in preparation for publication where a detailed analysis of the event is presented. The authors believe that such analysis provides good training material to help forecasters better anticipate the magnitude of an event like this in the future.

Future work involves the creation of a WSR-88D verification database that helps forecasters have a quantitative idea of the biases in the 88D rainfall estimates during different weather scenarios. This can help the forecasters issue more timely and accurate flood watches, warnings, and statements. It is also the hope of the authors that the development of such a database will allow for application of bias corrections to real time 88D rainfall estimates with the proper approval from the OSF.

6. References

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