Hurricane Ike

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1. INTRODUCTION

Hurricane Ike was an expansive category II hurricane when it came ashore along the Texas coast on 13 September 2008 between 4 and 5 AM. The storm was downgraded to a Tropical Storm by 5 PM 13 September 2008 over Texas and a tropical depression by 5 AM 14 September along the border of Missouri and Arkansas.

The storm was so large that winds and waves affected the Gulf Coast from Florida to Texas while the storm was well offshore. As the storm approached it pushed water into the eastern Texas coast and the storm surge destroyed homes along the coast (Fig. 1). The storm came ashore a few hours before sunrise on 13 September (Saturday) with 110 mph winds, large waves, and heavy rainfall. The water flooded and destroyed thousands of homes while the strong winds blew out windows in skyscrapers in downtown Houston. The winds and falling trees downed power lines cutting off power to more than 3 million people.

As documented by Pielke and Pielke (1997)hurricanes can have significant societal impacts.These storms can and do produce a wide range of weather including coastal flooding, flooding due to rainfall, wind damage and tornadoes. Thus, like many hurricanes, Ike had significant societal impacts on the eastern coast of Texas and portions of Louisianna.

Figure 1. Crystal Beach, on the Bolivar Peninsula, before and after the hurricane U.S. Geological Survey pictures from NY Times website.

In addition to the damage caused in the Gulf of Mexico, Ike produced heavy rainfall (Fig. 2) along the Texas coast. As shown by the inset in Figure 2, some regions of eastern Texas received in excess of 400 mm (18 in) of rainfall. Heavy rain is a common impact of land falling hurricanes (Pielke and Pielke RA (1997).

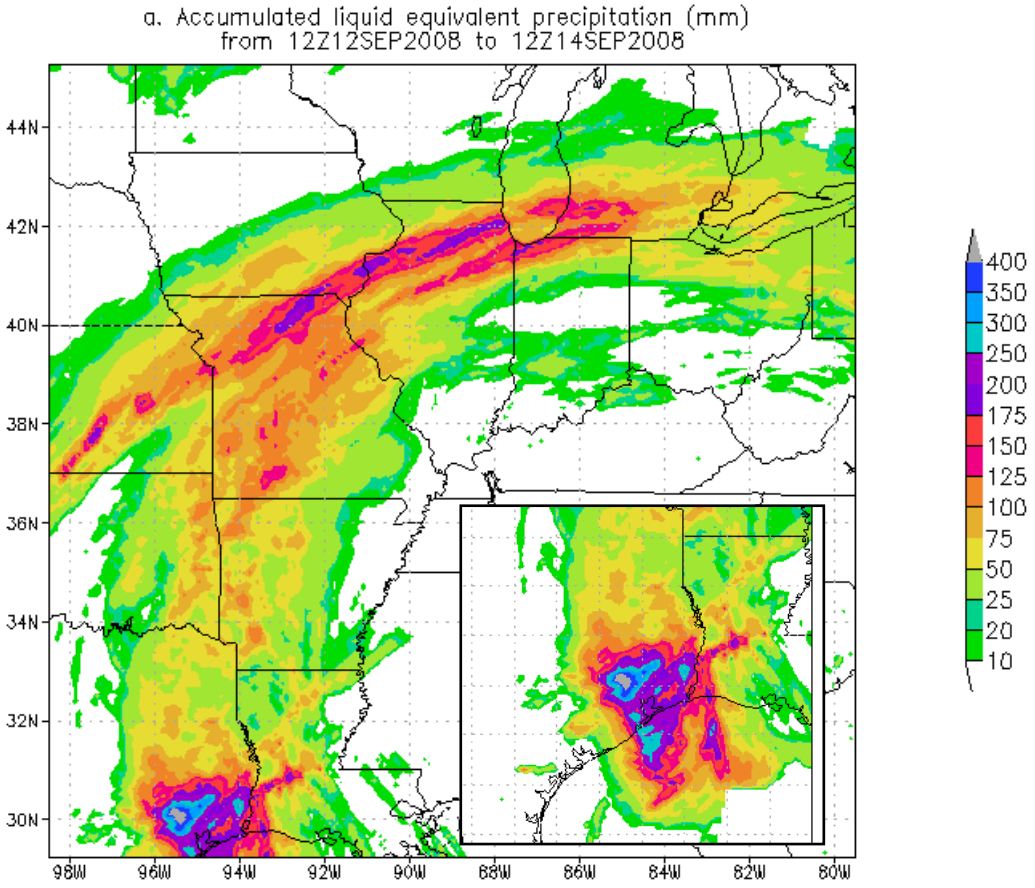

Figure 2. Total rainfall (mm) associated with Hurricane Ike and the frontal system to the north. The inset shows the rainfall over eastern Texas using the same color scale. Data are from the Stage-IV rainfall estimates valid from 1200 UTC 12-14 September 2008.

In addition to the coastal flooding, wind damage, and heavy rainfall (Fig. 2), Ike spawned tornadoes in Louisiana on the 12th and 13th and in Arkansas on the 13th. All the tornadoes and severe weather were on the east side of the storm. Severe weather was observed in the Ohio valley on the 14th and straight line wind damage was associated with system from the Ohio Valley to western New York on the 14th.

Verbout et al. (2007) showed that many hurricanes can produce tornadoes when the bands move over land. They found about 78% of the outbreaks were associated with category 2 or greater hurricanes. They also found, for southern coast landfalls, re-curving storms had a higher probability of producing tornadoes. Ike clearly re-curved after land fall as it tracked rapidly to the northeast across Ohio and western New York.

This note will document the weather and patterns associated with hurricane Ike. The focus will be on the meteorological setting, the impacts of Ike using NCEP model and ensemble prediction output data.

2. METHODS

Data for this study include re-analysis climatological data from the NCEP/NCAR global re-analysis project (GR: Kalnay et al 1996). The means and standard deviations were used to compute standardized anomalies, displayed in standard deviations from normal (SDs).

The 00-hour forecasts from the NCEP North American Meso-model (NAM) is used to provide an overview of the large scale pattern and the evolution of the rain event.

Ensemble data shown here were primarily limited to the NCEP GEFS and SREF. Displays will focus on the forecasts of the pattern

conducive for heavy rain the EPS probabilities of heavy rainfall.

The climatological data used to compute anomalies was restricted to those produced by the NCEP/NCAR GR data set (Hart and Grumm 2001). They will be presented in relation to both NAM and GEFS output.

All data was displayed using GrADS (Doty, et al 1995). Anomalies were computed as described Hart and Grumm (2001) and Grumm and Hart (2001). Shaded values show the standardized anomalies computed as:

$$SD = (F - M)/\sigma \quad (1)$$

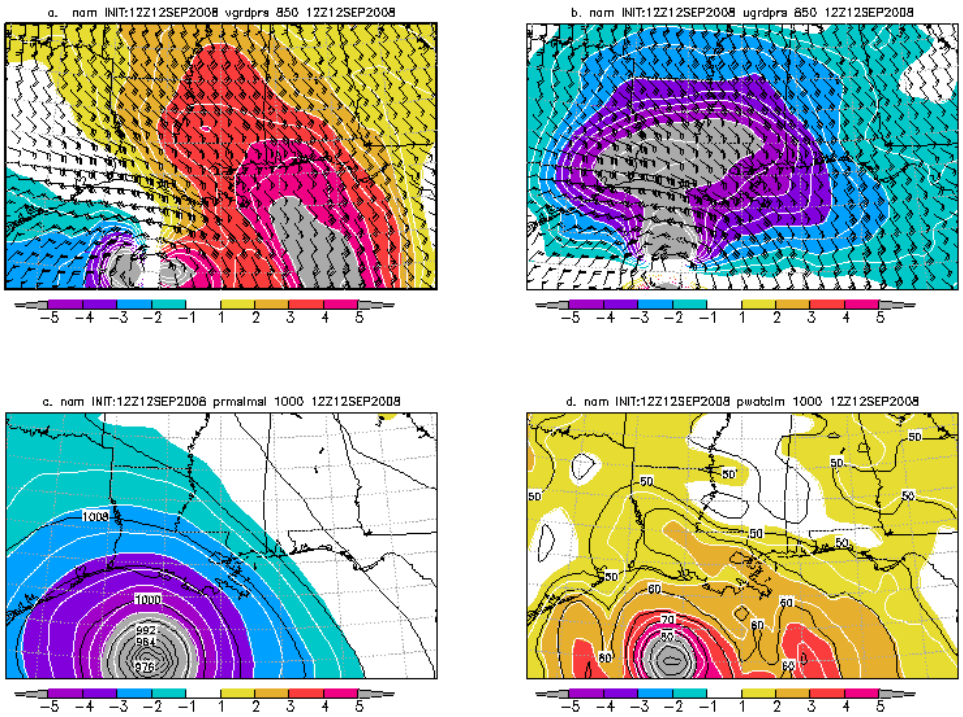

Figure 3. NAM 00-hour forecasts valid at 1200 UTC 12 September 2008 showing a) 850 hPa winds and v-wind anomalies, b) 850 hPa winds and u-wind anomalies, c) mean sea-level pressure (hPa) and pressure anomalies, and d) precipitable water (mm) and precipitable water anomalies.

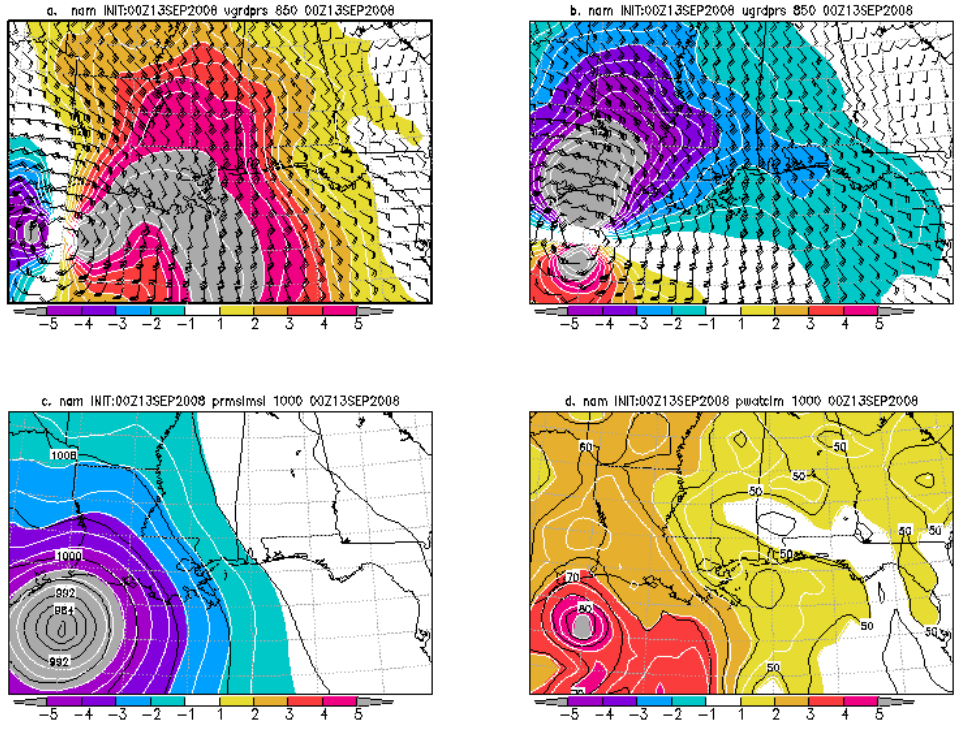

Figure 4. As in Figure 3 except valid at 0000 UTC 13 September 2008.

Where **F** is the value from the reanalysis data at each grid point, **M** is the mean for the specified date and time at each grid point, and σ is the value of 1 standard deviation at each grid point.

For brevity times are presented in the format of 13/1200 UTC which signifies 13 September 2008 at 1200 UTC. Forecasts from both model and EPS initial and valid times are presented in this format.

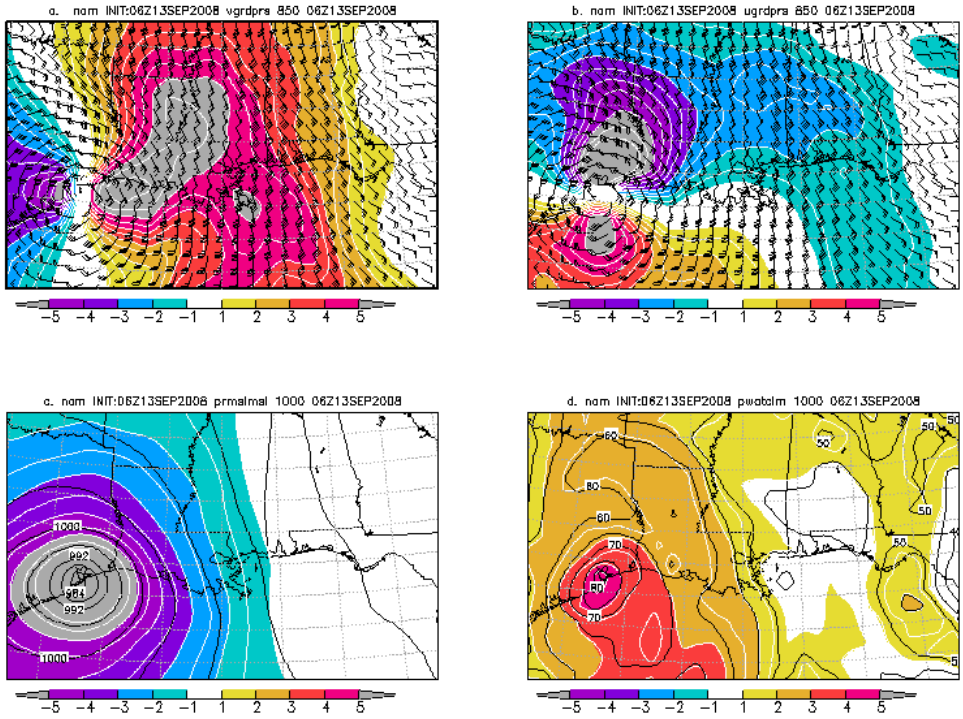

Figure 5. As in Figure 3 except valid at 0600 UTC 13 September 2008.

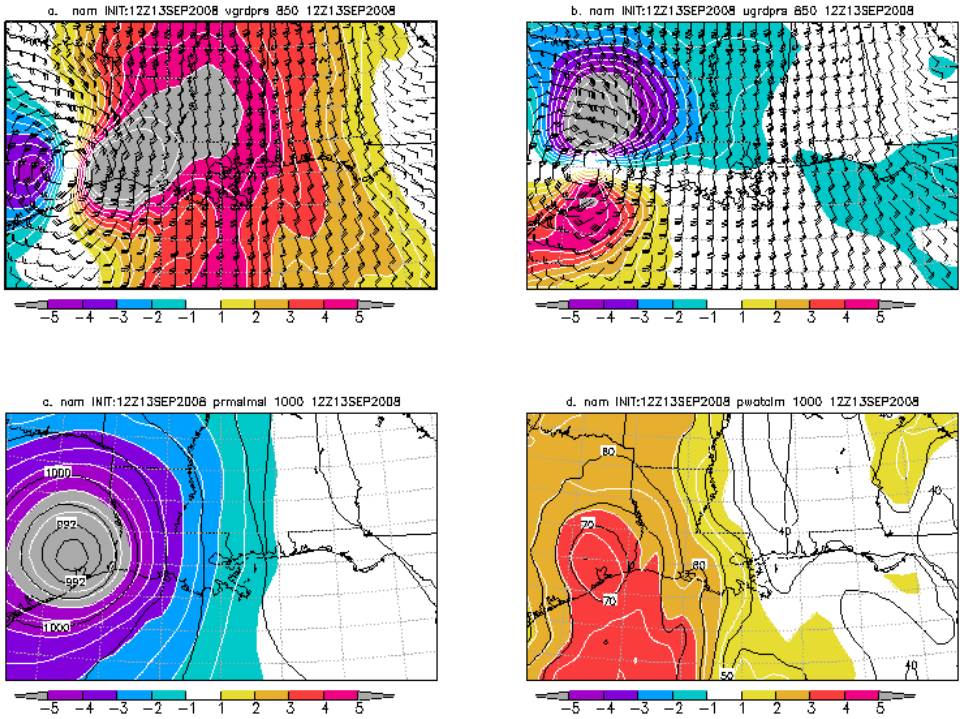

Figure 6. As in Figure 3 except valid at 1200 UTC 13 September 2008.

The 4km precipitation data was obtained from the multi-sensor State-IV data (Seo 1998 and Seo et al. 1999). The summed data was shown in Figure 1, over the eastern United States. The 6-hourly data were used to make the totals. These data is available in 1,6, and 24-hour increments.

3. RESULTS

i. nam 00-hour analysis

The NAM 00-hour analysis at discrete times from 12/1200 UTC through 13/1800 UTC are shown in Figures 3-7. These data show the large circulation associated with Ike at 12/1200 UTC and 13/0000 UTC. The strong winds north of the storm produced the surge of water, and coastal flooding along the coast from western Florida to eastern Texas on Friday 12 September 2008. Note the +5 SD southerlies aimed at Louisiana at 12/1200 UTC, which shifted westward 12 hours later.

The NAM showed the storm onshore at 13/0600 UTC (Fig 5) and then accelerate northward into eastern Texas by 13/1200 UTC (Fig. 6) and 13/1800 UTC (Fig. 7).

By 14/1200 UTC the storm was still detectable in the analysis (Fig. 8) and still contained a compact circulation of anomalous winds about the circulation center with strong southwesterly winds in the warm humid air. By 14/1800 UTC the cyclone was over Indiana with deep pressure anomalies and very anomalous (+6SD above normal) v-wind anomalies. This storm produced considerable wind damage during the afternoon hours of 14 September over the Ohio Valley, much of it unassociated with convection or rainfall.

Figure 10 shows the storm over southern Ontario at 15/0000 UTC. The circulation associated with Ike still contained strong winds and there was a larger scale wind anomaly area displaced to the east. The system continued to produce sporadic wind damage in western Pennsylvania during the evening hours of 14 September (after 0000 UTC 15 September) 2008.

ii. Forecasts

There were many aspects of Ike worthy of investigation from a forecast perspective. The track of the storm varied markedly over Ike's long period of existence. As the storm approached Cuba the NCEP models began to quickly converge on a track of the cyclone center into Texas. The information here will focus on the landfall forecasts.

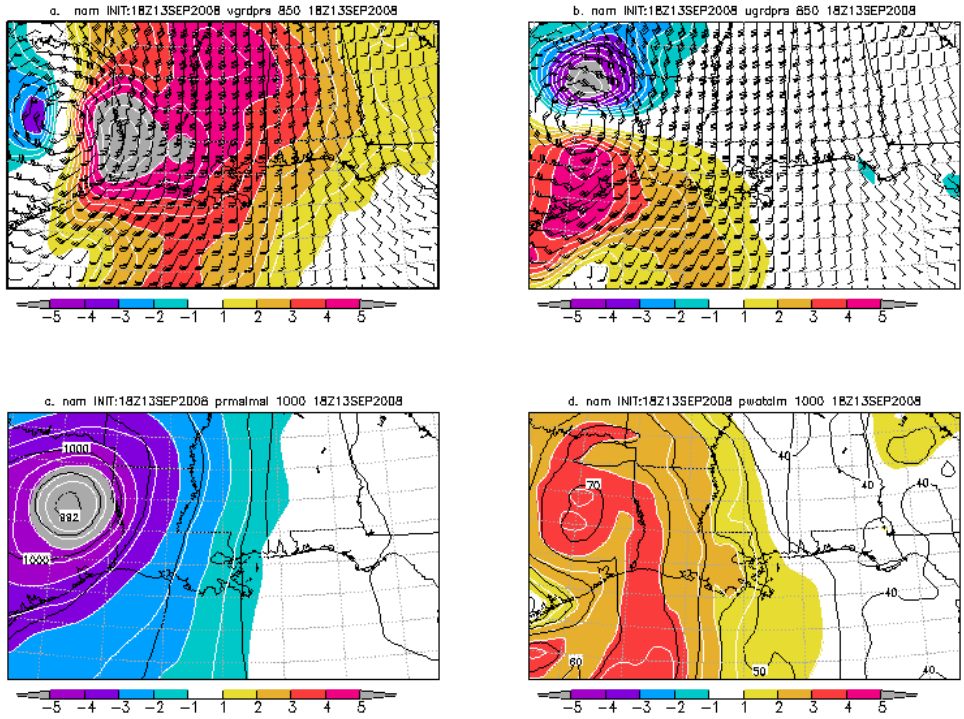

Figure 7. As in Figure 3 except valid at 1800 UTC 13 September 2008.

Figure 11 shows the NAM forecasts from 12/1200 UTC showing the MSLP and instantaneous precipitation valid at 13/0600 UTC and the accumulated QPF. The MSLP field shows that the short-range NAM did quite well with the timing and location of landfall. The QPF shield indicated that the NAM got the overall pattern of QPF quite well with an emphasis on the heaviest rainfall over southern Texas on the east side of the cyclone track. The NAM predicted too much QPF over Arkansas as the storm approached the large scale frontal system.

Figure 12 shows the GFS forecasts similar to those produced by the NAM. The GFS had a weaker cyclone and had the cyclone displaced farther to the south than the NAM. The coarser resolution GFS (~40km) had less detail and less overall QPF than the NAM and lacked the details or potential details in the locally heavy rainfall potential in southeastern Texas. Similar to the NAM, it produced heavy rainfall farther north and inland than was observed. The GFS pushed the QPF too far west of its observed location and notable lesser amounts.

The SREF MSLP forecasts initialized at 12/0900 UTC and valid at 13/0600 UTC are shown in Figure 13. Similar to the NAM and GFS, the SREF showed a deep cyclone moving ashore around 13/0600 and 13/0900 (not shown). It appears that forecasts from all forecasts systems were quite similar in the overall landfall and cyclone location.

Figure 14 shows the SREF probability of 4 inches or more QPF in the 24 hours ending 13/1800 and for the 48 hours ending at 14/1500 UTC. The SREF got the general area correct but under forecast the heavy rainfall potential relative to the NAM and GFS.

iii. Winds

Figure 15 shows plots of wind gusts associated with Ike as it moved through the Ohio Valley. The strong and gusty winds caused numerous power outages and did significant damage in Kentucky [1] and Ohio. The NWS Office in Louisville had a series of pictures and plots of damage to include wind gusts of 75 mph in Louisville and 81 mph in southern Indiana. Tragically, the strong winds in Kentucky and southern Indiana killed 4 people.

4. CONCLUSIONS

Hurricane Ike came ashore along the Texas coast during the morning hours of 13 September 2008. The NAM 00-hour analysis put the landfall near 0600 UTC while new reports suggested as late as 0900 UTC. Similar to the NAM analyses, the NHC bulletins implied Ike came ashore shortly after 0600 UTC on 13 September 2008. The impacts of the water and waves arrived nearly 24 hours before landfall. Coastal flooding along the Gulf coast was observed on Friday 12 September.

The storm produced massive coastal flooding which destroyed thousands of homes along the Texas Coast near Galveston. The storm also produced heavy rainfall over eastern Texas and spawned several tornadoes over Louisiana and Arkansas. Inland, the storm retained its identity and it produced widespread wind damage over the Ohio Valley with damaging winds observed in Kentucky, Indiana, Ohio, West Virginia, Pennsylvania and western New York.

The storm was relatively well forecast by the NCEP models and EPSs. Only MSLP forecasts and select QPFs were shown. These data suggest the utility of short-term forecasts of these NCEP prediction systems.

[1] no wind data was available to plot but an image from the NWS Louisville office is included in Figure 15 and the link to their write-up http://www.crh.noaa.gov/lmk/?n=sep_14_08.

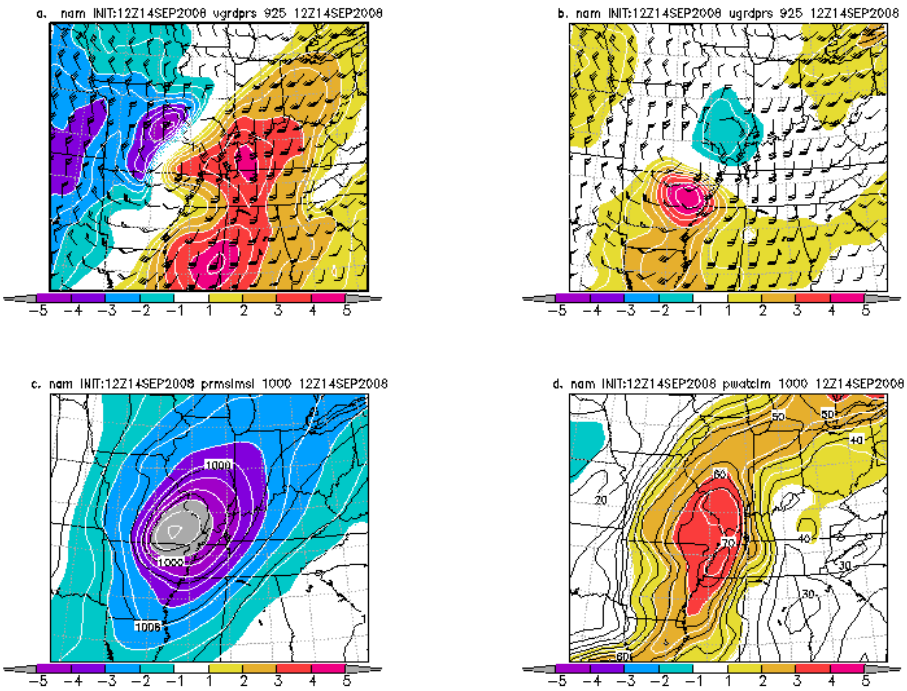

Figure 8. NAM 00-hour forecasts valid at 1200 UTC 12 September 2008 showing a) 925 hPa winds and v-wind anomalies, b) 925 hPa winds and u-wind anomalies, c) mean sea-level pressure (hPa) and pressure anomalies, and d) precipitable water (mm) and precipitable water anomalies.

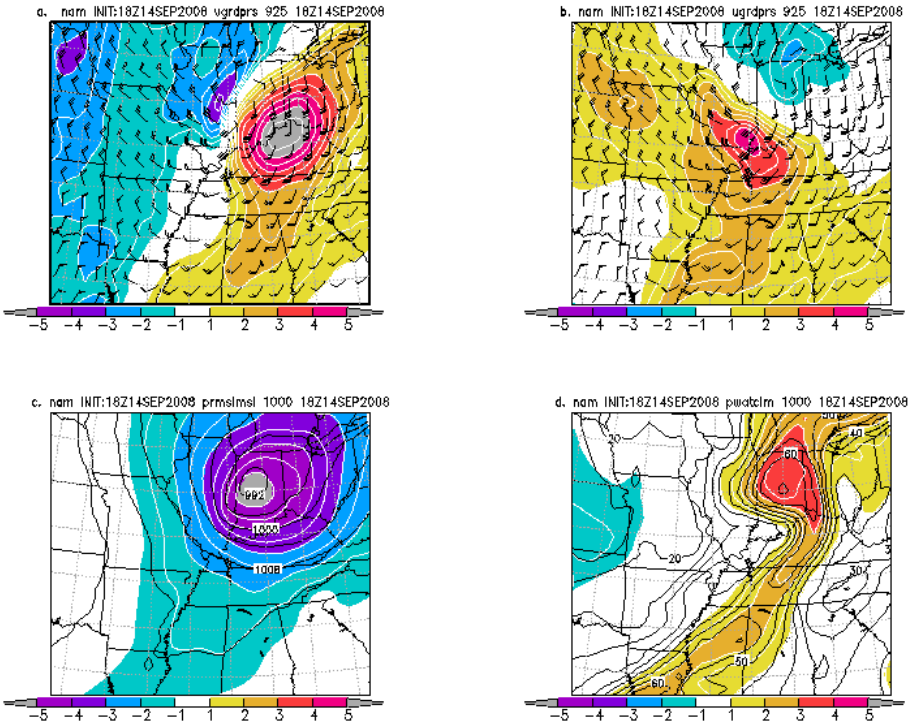

Figure 9. As in Figure 8 except valid at 1800 UTC 14 September 2008.

The storm came ashore and produced typical weather expected with a category 2 storm (Pielke and Pielke 1997). Strong winds, tornadoes in the rainbands to the northeast, heavy rains, and coastal flooding were all observed with hurricane Ike.

As shown in Figure 1, Ike produced heavy rainfall with over 400 mm of rainfall

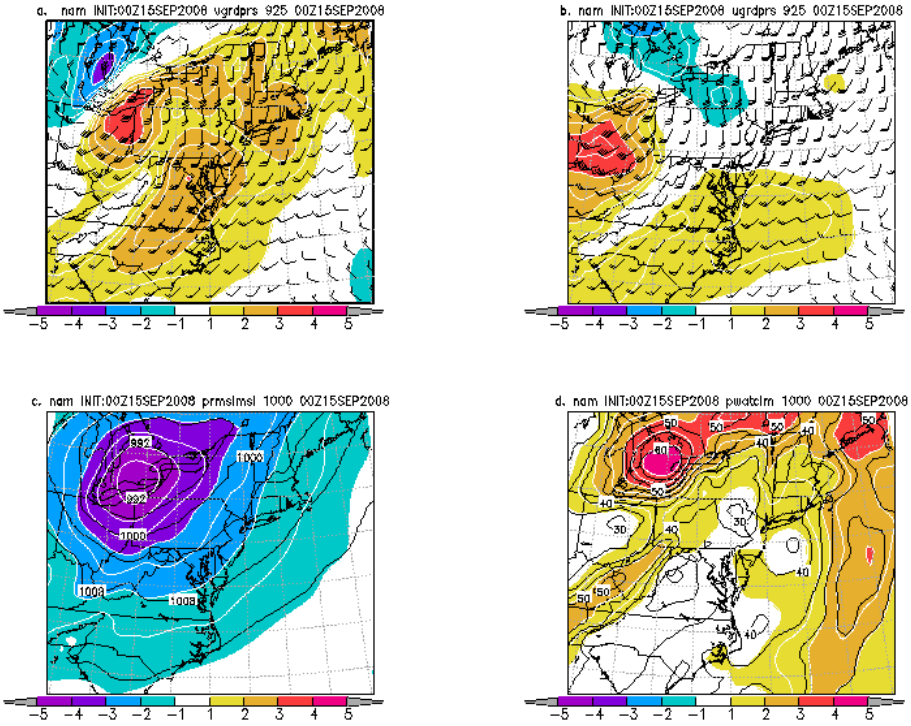

Ilustração 10. As in Figure 8 except valid at 0000 UTC 15 September 2008.

observed along and east of the track of Ike. The storm weakened and moved rapidly northward and interacted with a frontal system (Figs 3-9). The associated rainfall lessened markedly in northern areas of Texas, Louisiana, and Arkansas (Fig.1).

5. Acknowledgements

WFO Louisville for their webpages and data on the impacts of the windstorm in Kentucky. To all the NWS WFOs who made PNS and LSR products which could be decoded and used to plot wind gusts of this event.

6. References

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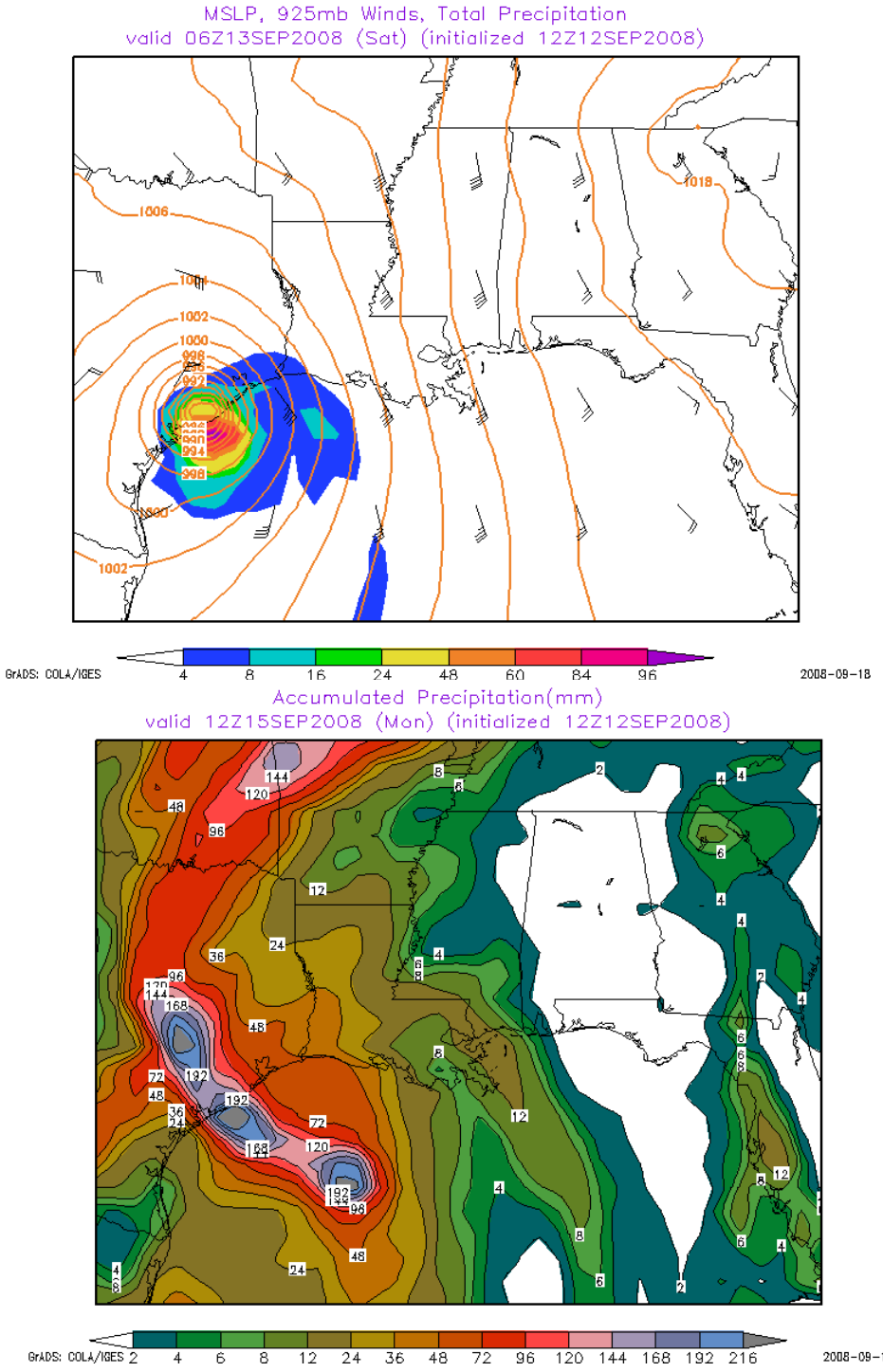
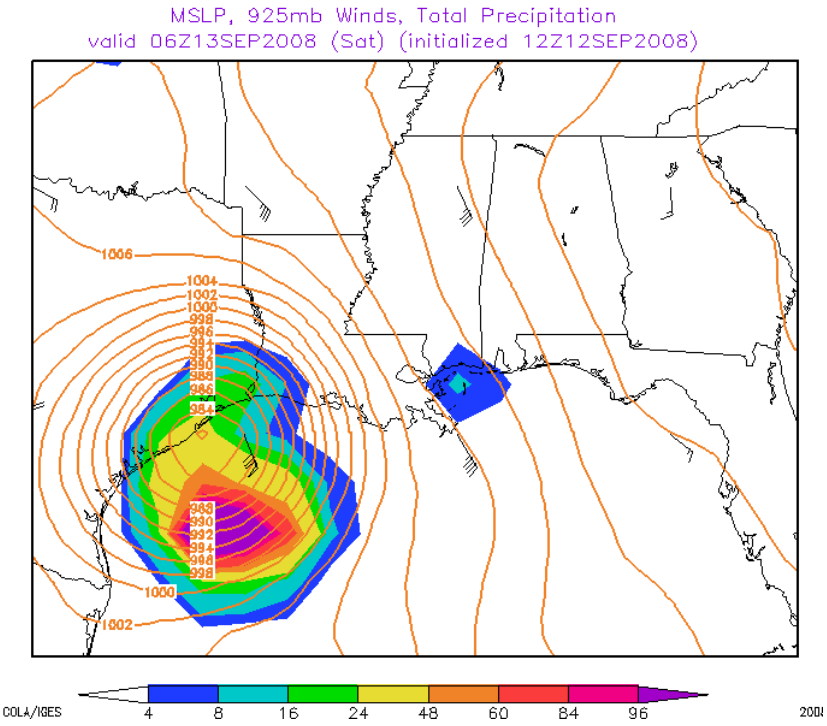


Figure 11. NAM forecasts initialized at 1200 UTC 12 September 2008 showing (upper) the MSLP (hPa), 925 hPa winds, and instantaneous precipitation (mm) at 0600 UTC 13 September 2008. The lower panel show the total accumulated rainfall for the event (mm).

USAF photos of Ike.
rainfall along coast before 13/0000 UTC moving inland fast



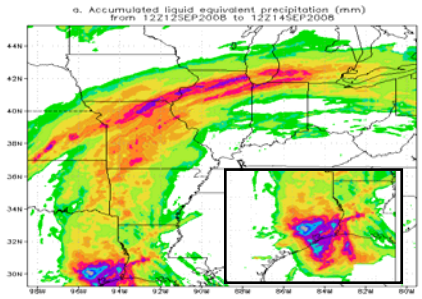


Ilustração 1. Total rainfall (mm) associated w
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The inset shows the rainfall over eastern Tex
using the same color scale. Data are from the
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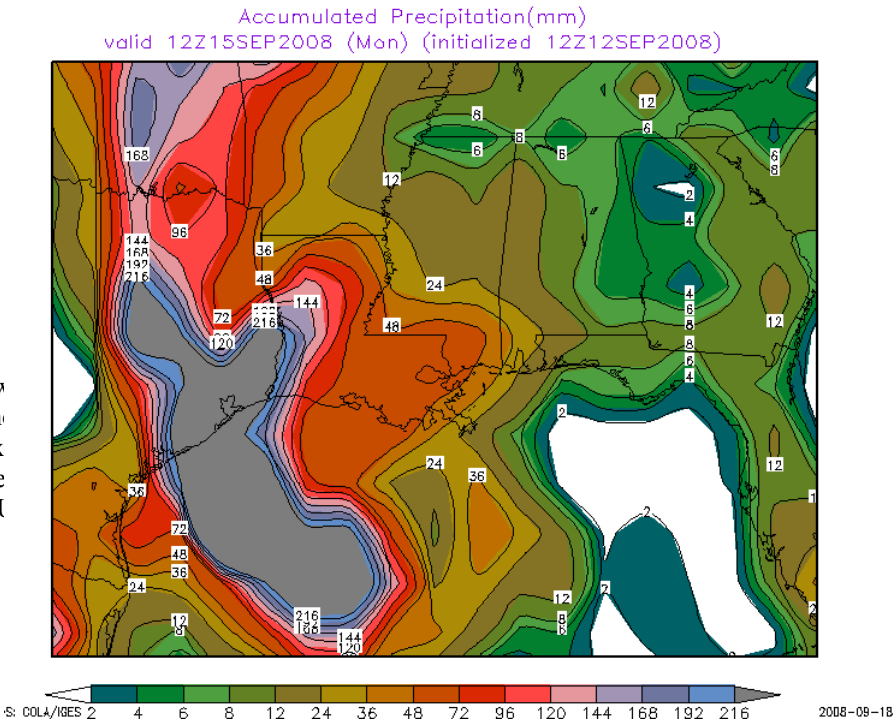


Figure 12. As in Figure 11 except for GFS forecasts.

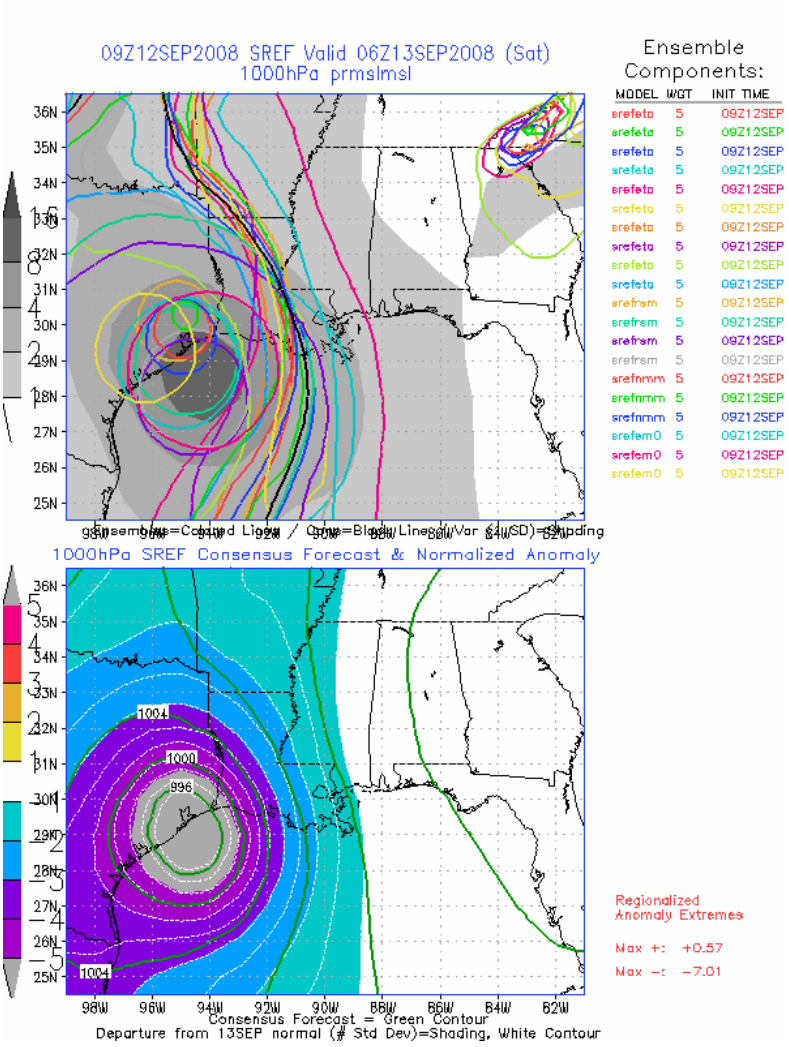


Figure 13. NCEP SREF forecasts initialized at 0900 UTC 12 September 2008 and valid at 0600 UTC 13 September 2008. Upper panel shows the spread (shaded) and each members forecasts of the 992 and 1008 hPa contour. The lower panel shows the ensemble mean pressure field (hPa) and the departure of this field in standard deviations from normal.

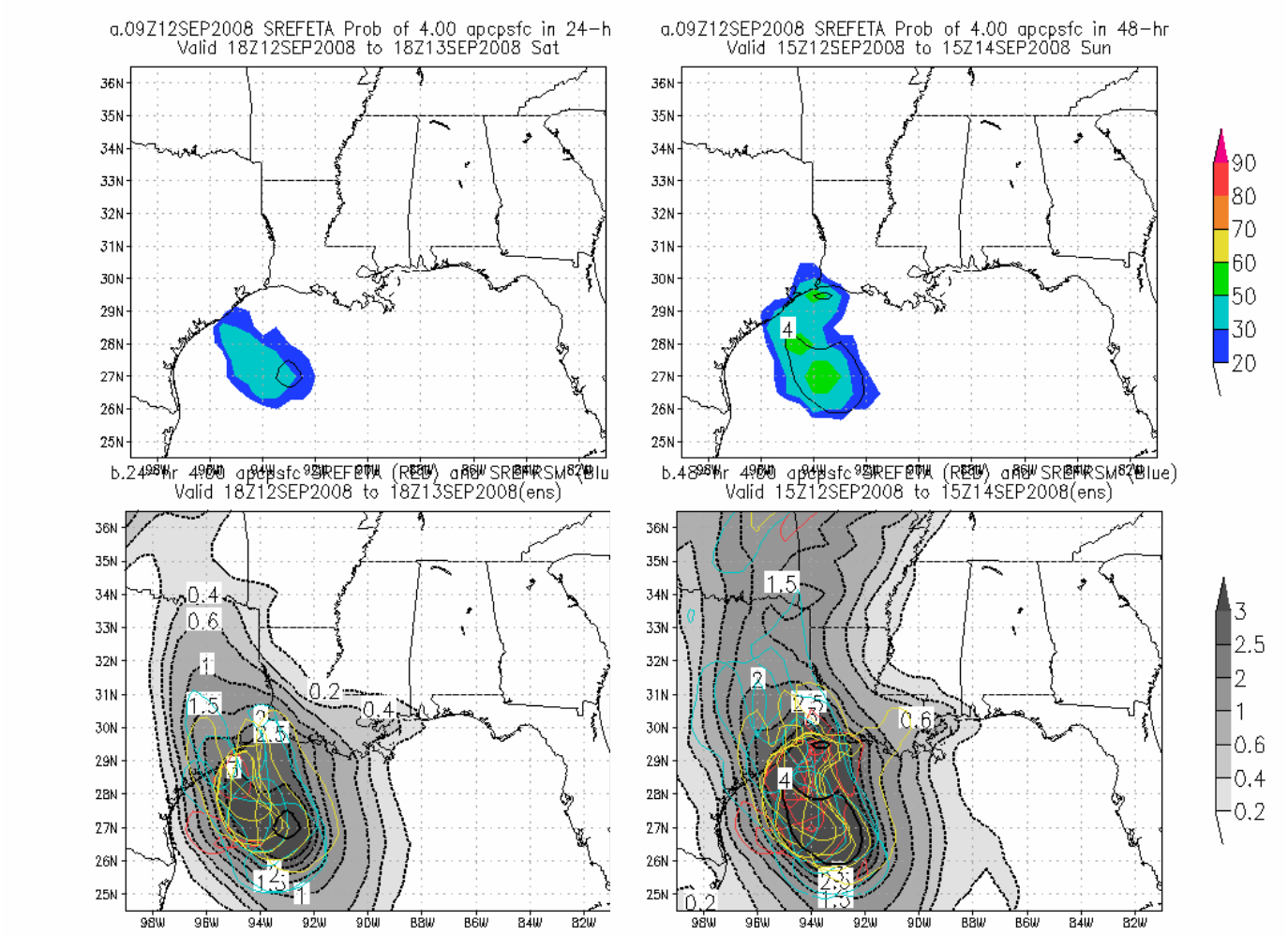
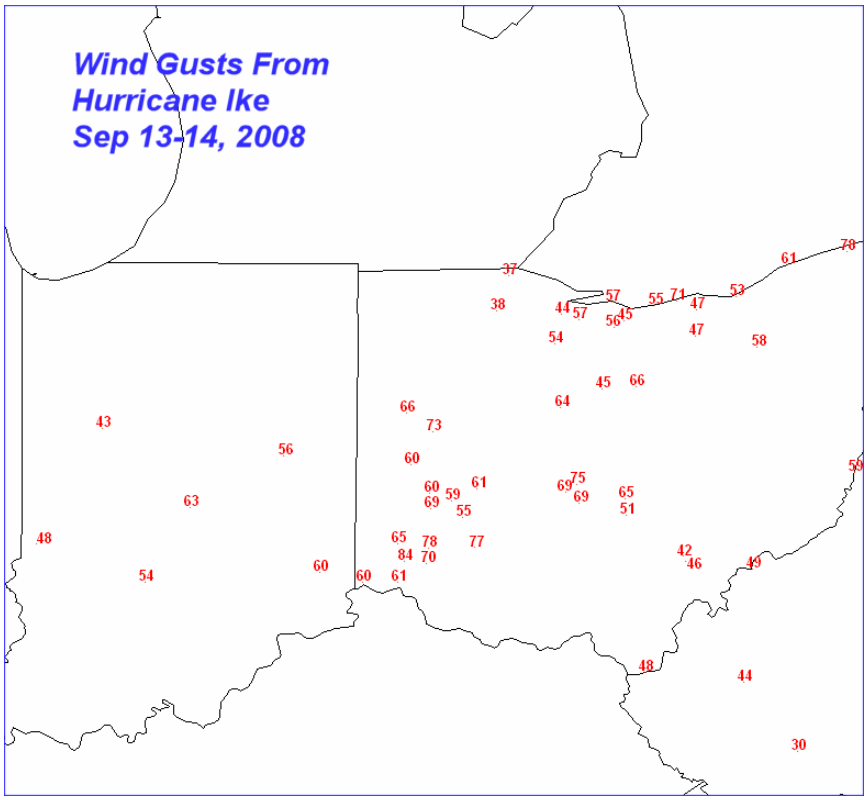
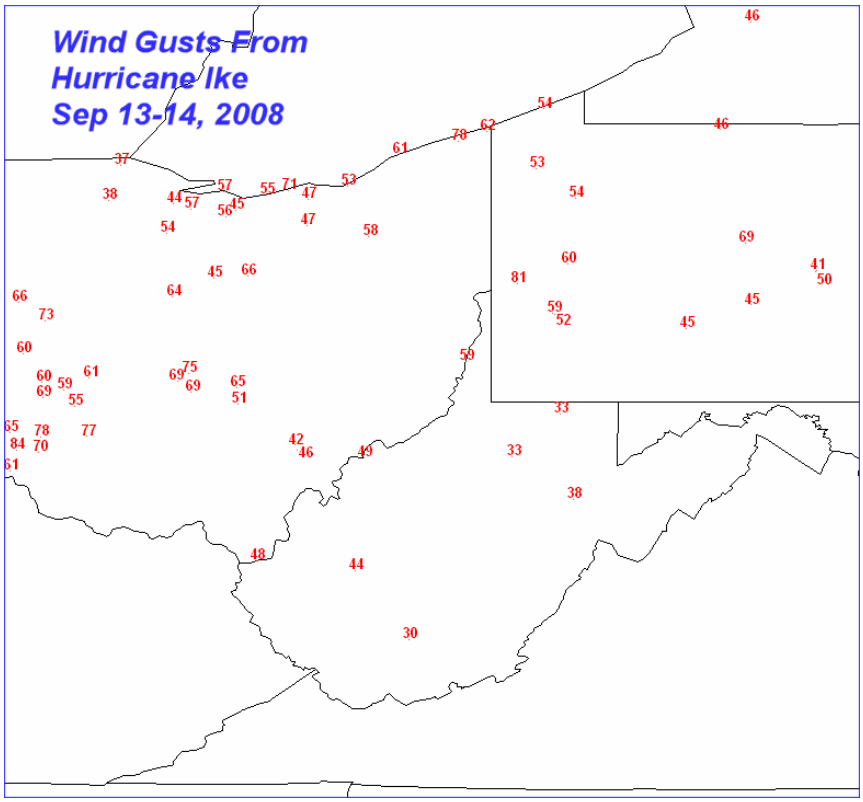


Figure 14. As in Figure 13 except showing the SREF probability (upper panels) of 4 inches or more QPF and the ensemble mean QPF (shaded) and each members 4 inch contour. Right side is the QPF for the 24 hours ending at 18Z 13 September 2008 and right side is 48-hour QPF ending at 15Z 14 September 2008.





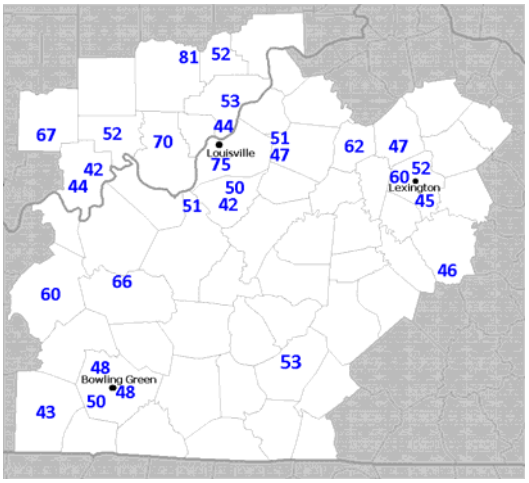


Figure 15. Wind gusts with Ike after it moved inland. Panels on the right are from the WFO in Louisville, KY. The upper image shows the typical wind damage observed in the Louisville area and the lower images shows wind gust report in the Louisville County Warning area.