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DOCUMENTATION OF THE OVERLAND REINTENSIFICATION OF TROPICAL STORM ERIN OVER OKLAHOMA, AUGUST 18, 2007

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1. INTRODUCTION

During the evening hours of 18 August 2007 to the early morning hours of the 19^{th}, Tropical Depression Erin dramatically reintensified over Oklahoma, after having apparently dissipated (Fig. 1) over west Texas and eastern New Mexico. The remnants of Erin reintensified about 500 mi (~800 km) in linear distance from landfall, after traveling approximately 700 mi (~1100 km) on a curving overland path.

Maximum sustained winds of nearly 90 km h^{-1} (with gusts to over 120 km h^{-1}) were recorded by the Oklahoma mesonet (Fig. 2). In addition, 24 h rainfall totals 4 to 8 inches (102-203 mm) of rain were common over most of central Oklahoma (Fig. 3). The storm yielded a cluster of severe thunderstorm events, including tornado and convective wind gust reports (Fig. 4 and Table 1).

During its transit across Oklahoma, Erin developed warm core characteristics, and showed a radar and satellite evolution consistent with that of nascent tropical cyclones. Nevertheless, this storm was never reclassified a tropical storm by the National Hurricane Center, chiefly because the reintensification did not take place over the ocean.

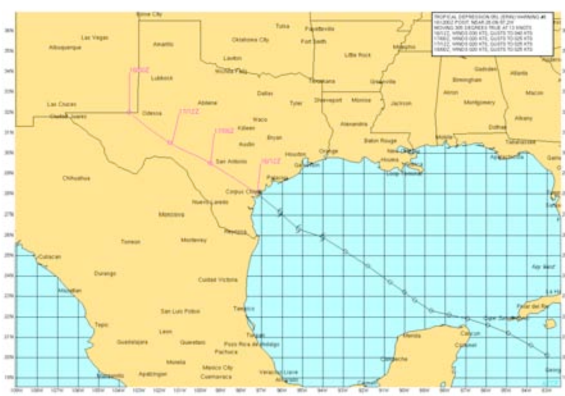

Figure 1. Track of Erin's center at 6 h intervals (black symbols) and forecast of 12 h positions after 12 UTC 18 August 2007 (Source: U.S. Navy).

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Previous studies (e.g., Bassill and Morgan 2006) have shown that when surface conditions over the continent are favorable, reformation of a tropical system can take place. However, documentation of such redevelopment has been sparse. This study documents this remarkable redevelopment of a tropical system over land.

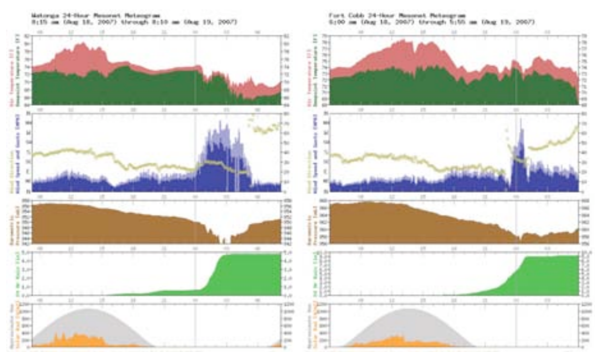


Figure 2. Oklahoma Mesonet meteograms from Watonga and Ft. Cobb, OK, showing sharp pressure fall and strong wind shift between 1000 and 1300 UTC (0300 to 0600 CDT) as eye of redeveloped Erin passed. Note wind gusts between 70 and 80 mph (31-36 m s^{-1}) at both locations.

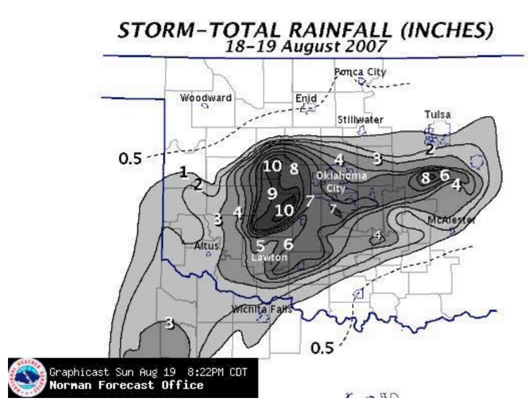


Figure 3. Total rainfall (inches) observed by Oklahoma Mesonet, 0000 UTC 18 to 0000 UTC 19 August 2007.

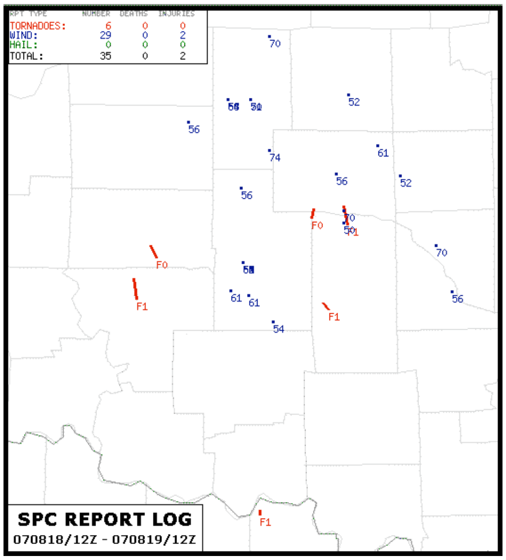
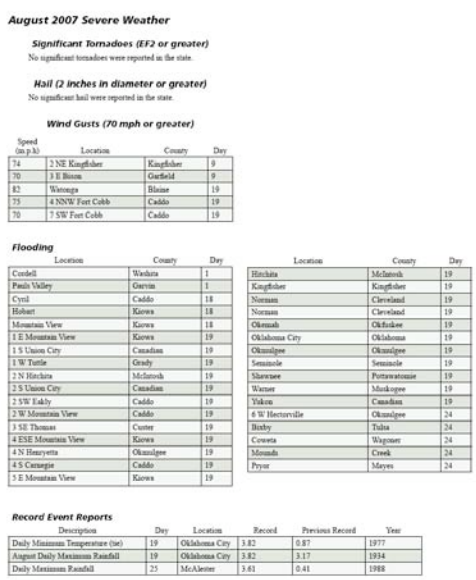


Figure 4. Severe weather reports for 8/18/07 to 8/19/07 from Storm Data, via SPC. Red paths denote tornadoes with F (EF) Scale ratings. Blue dots signify convective wind gusts ≥50 kt (25 m s^{-1}) severe criteria, with values in kt. No hail reports occurred with this phase of Erin's lifespan.

Table 1. Severe weather reports in Oklahoma associated with Erin (August 19) (Source: NWS Forecast Office Norman)



August 2007 Severe Weather

Significant Tornadoes (EF2 or greater)

No significant tornadoes were reported in the state.

Hail (2 inches in diameter or greater)

No significant hail were reported in the state.

Wind Gusts (70 mph or greater)

Speed (m.p.h)	Location	County	Day
74	2 NE Kingfisher	Kingfisher	9
70	3 E Bison	Garfield	9
82	Watonga	Blaine	19
75	4 NNW Fort Cobb	Caddo	19
70	7 SW Fort Cobb	Caddo	19

Flooding

Location	County	Day
Cordell	Washita	1
Pauls Valley	Garvin	1
Cyril	Caddo	18
Hobart	Kiowa	18
Mountain View	Kiowa	18
1 E Mountain View	Kiowa	19
1 S Union City	Canadian	19
1 W Tuttle	Grady	19
2 N Hitchita	McIntosh	19
2 S Union City	Canadian	19
2 SW Eakly	Caddo	19
2 W Mountain View	Caddo	19
3 SE Thomas	Custer	19
4 ESE Mountain View	Kiowa	19
4 N Henryetta	Okmulgee	19
4 S Carnegie	Caddo	19
5 E Mountain View	Kiowa	19

Location	County	Day
Hitchita	McIntosh	19
Kingfisher	Kingfisher	19
Norman	Cleveland	19
Norman	Cleveland	19
Okemah	Okfuskee	19
Oklahoma City	Oklahoma	19
Okmulgee	Okmulgee	19
Seminole	Seminole	19
Shawnee	Pottawatomie	19
Warner	Muskogee	19
Yukon	Canadian	19
6 W Hectorville	Okmulgee	24
Bixby	Tulsa	24
Coweta	Wagoner	24
Mounds	Creek	24
Pryor	Mayes	24

Record Event Reports

Description	Day	Location	Record	Previous Record	Year
Daily Minimum Temperature (tie)	19	Oklahoma City	3.82	0.87	1977
August Daily Maximum Rainfall	19	Oklahoma City	3.82	3.17	1934
Daily Maximum Rainfall	25	McAlester	3.61	0.41	1988

2. STORM EVOLUTION ON RADAR AND SATELLITE

Radar and satellite plots showed that the storm developed an eye about the time that near-hurricane force winds were being observed (Figs. 5, 6 and 7). The radar and satellite presentations of Erin during the period from 0000 UTC to 1100 UTC were consistent with the formation of strong convection and rapid surface development documented for developing tropical systems (see e.g., Zehr 1987).

Expansion and cooling of cloud tops occurred through 0840 UTC, with warming from about 1040 UTC onward (Fig.5). The near-explosive generation and expansion of the area of coldest cloud tops was simultaneous with the reintensification of the surface cyclone (seen below).

Radar imagery (Fig. 6) clearly shows an "eye" in the reflectivity field at the same time the storm strongly reintensified with a warm core structure. Plotted METAR and Oklahoma mesonet surface data (Fig. 7) illustrate the closed wind circulation collocated with Erin's redeveloped eye. The warm core structure was evident in the surface temperature observations, which showed no evidence of cold air intrusion into the western portions of the cyclone, as would be expected for a tropical system evolving into a middle latitude wave cyclone.

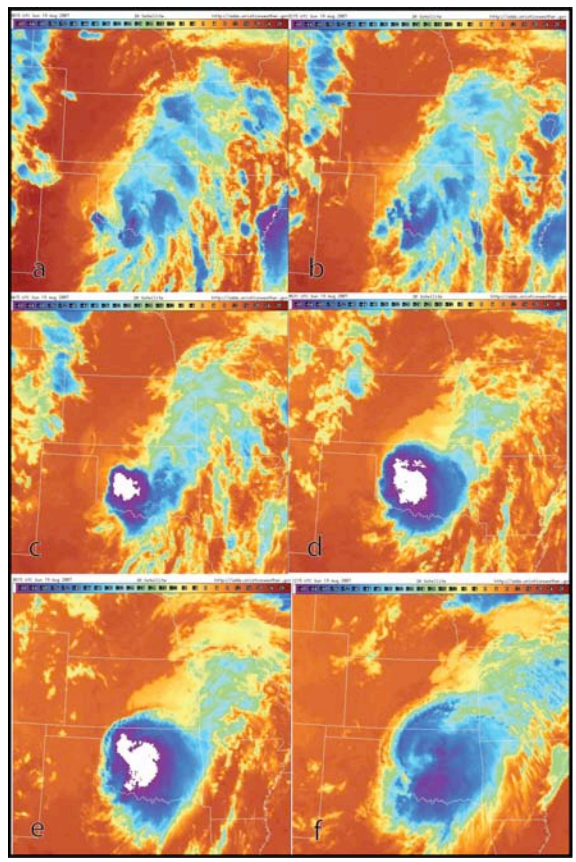
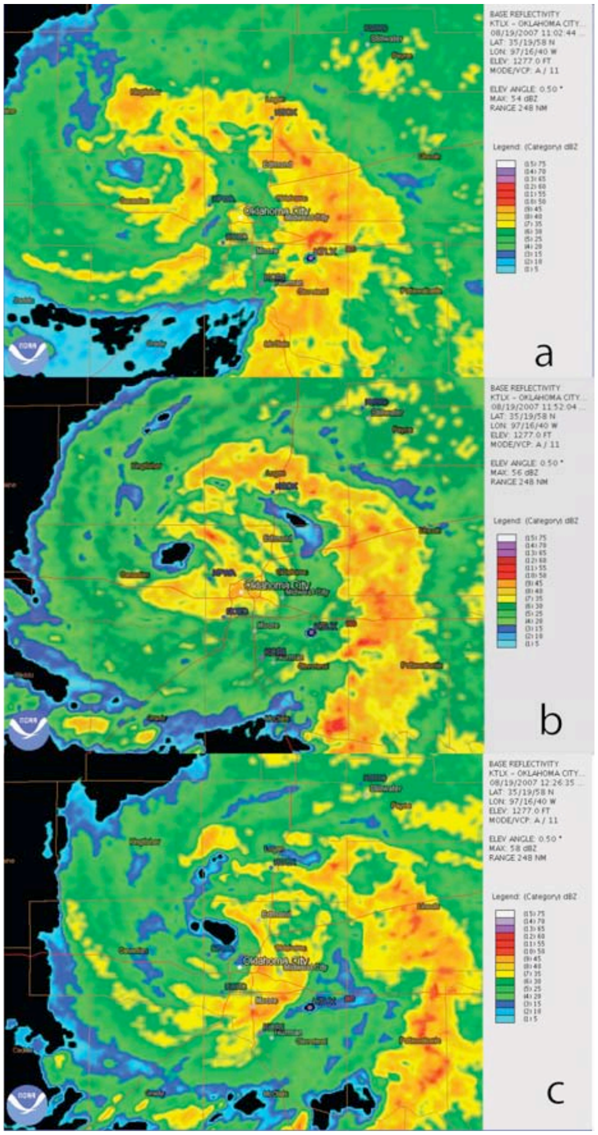


Figure 5. Enhanced infrared satellite images at (a) 0040, (b) 0240, (c) 0440, (d) 0640; (e) 0840; and (f) 1040 UTC during rapid intensification of Erin as the storm crossed into southwest Oklahoma. Expansion and cooling of cloud tops occurred through 0840 UTC, with warming from about 1040 UTC onward.



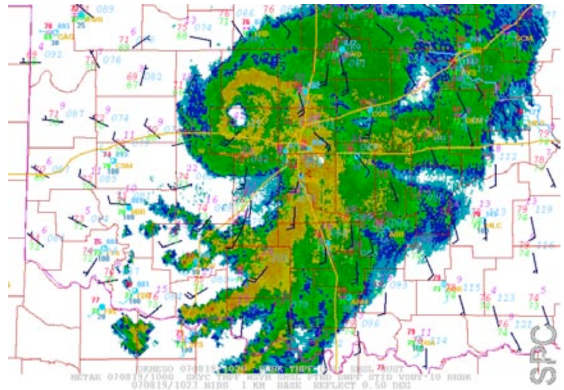


Figure 7 – Base reflectivity (1/2 deg tilt) from KTLX (Oklahoma City radar) at 1024 UTC overlain on conventionally plotted METAR and Oklahoma mesonet surface data, illustrating closed wind circulation collocated with Erin's redeveloped eye. Note also the warm core structure evident in the surface temperature observations (°F).

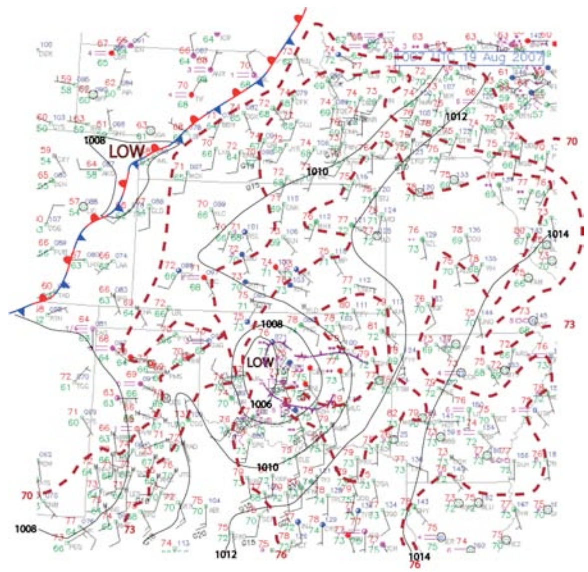


Figure 6. (Base reflectivity (0.5° tilt) from KTLX for (a) 1102; (b) 1152; and (c) 1224 UTC representing snapshots of the evolution of the precipitation-free eye over central Oklahoma.

Figure 8. Subjective analysis of isobars (black) and isotherms (dashed red) at 1007 UTC 19 August 2007. Outside storm-scale cold pools generated by convection around the center of the storm (and evidenced by the outflow boundaries), the surface temperature field indicates that the cyclone was warm core.

3. EVIDENCE OF WARM CORE STRUCTURE

Erin's Oklahoma stage exhibited many characteristics associated with warm core systems documented in many studies (e.g., Bosart and Bartlo 1991). These include: (a) surface low pressure areas weakening with height; (b) collocation of lows in the mid to lower troposphere with thickness ridges or tongues, θ maxima, and surface temperature maxima; (c) collocation of surface mass convergence fields with the center of the cyclones at each level in the troposphere; (d) a vertical "stacking" of the lows at successive height levels; and (e) a weakening wind field with height.

At the surface (Fig. 8), except for the storm-scale cold pools generated by convection around the center of the storm (and evidenced by the outflow boundaries), the temperature field indicates that the cyclone had a warm core. Despite the relatively high ambient relative humidity and θ_e of tropical cyclones (TCs), cold pools have been documented to develop within spiral rainbands of hurricanes over water, e.g., the 12K subcloud layer θ_e deficits found by Barnes et al (1983). The presence of convective cold pools, therefore, does not preclude tropical character or classification of the TC at large. Over the 10 h of Erin's transit time over Oklahoma, wind fields were strongest near the ground, and weakened with height, as is expected for warm core lows (Fig.9).

An interesting facet of this storm was illustrated by constructed trajectories computed using the HYSPLIT (Draxler and Rolph 2003) model vertical velocity (Fig. 10). These show that parcels entering the circulation of the storm when it was over southwest Oklahoma had been moist parcels the entire length of the trajectory from the Gulf coast area into the core region of Erin.

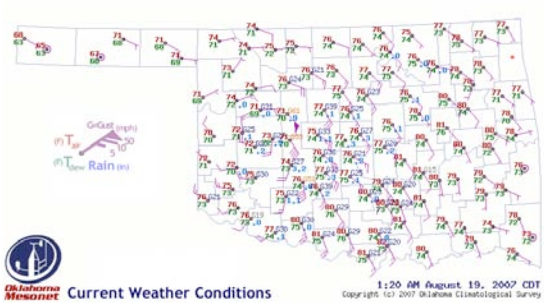


Figure 9. Conventional plot of Oklahoma Mesonet observations at 0620 UTC 19 August 2007. Wind barbs represent gusts in mph, with temperature and dew point values in °F. Over the next 10 h wind fields were strongest near the ground, and weakened with height, as is expected for warm core lows.

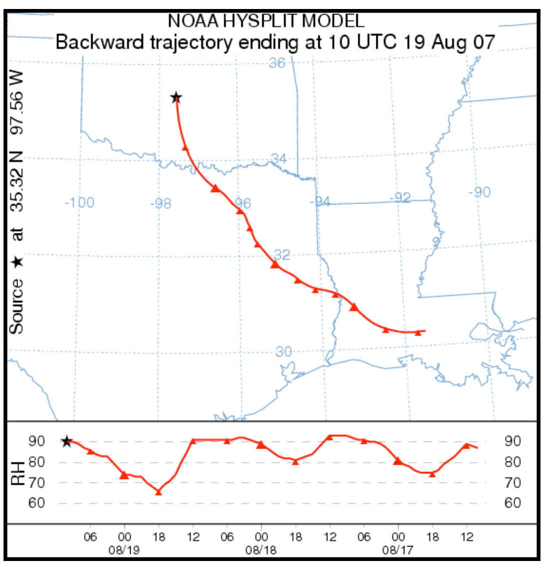


Figure 10. 72 h backward trajectory analysis (tick marks at 6 h intervals) of the 10 m AGL (surface) parcel, ending at the star (Oklahoma City) at 1000 UTC 19 August. The graph below, read from right to left, shows relative humidity of the parcel with time following the trajectory, with tick marks corresponding to those on the planar map. Courtesy NOAA.

The ending time and location of the trajectory (19/1000 UTC at Oklahoma City) were chosen to match most closely the formation of the radar eye seen on Fig. 6 and to represent the immediate inflow sector of Erin. One easily can infer the three prior diurnal heating cycles in the along-trajectory relative humidity calculations. Even at 18 UTC the day before, when the parcel appeared to be in a pronounced relative humidity dip related to traveling in a diurnally heated boundary layer, it kept an relative humidity above 60%, and the parcel value remained between 75%-90% for most of the 72 h prior to its arrival in Erin's core region. The trajectory analysis is consistent with that which is expected in the spiral arms of convection of a developing tropical system (Barnes et al. 1983; Powell 1990).

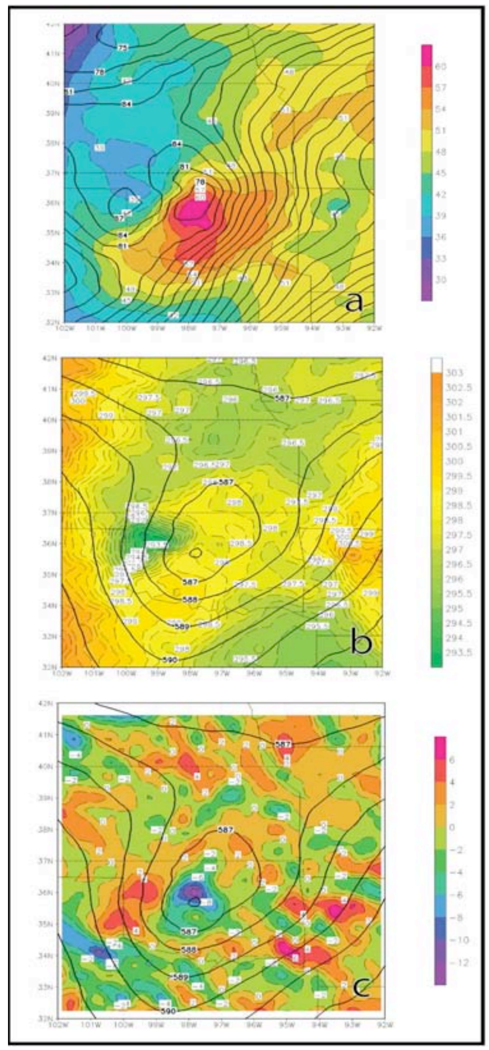


Figure 11. Plots obtained by NCEP reanalysis for 12 UTC 19 August 2007 of (a) 1000 mb heights (m) overlain with total precipitable water in the column from the surface to the top of the atmosphere (kg m^{-2}); (b) 500 mb heights (dm) overlain with θ (K); and (c) 500 mb heights (dm) overlain with 1000 mb divergence (10^{-5}s^{-1}).

The authors constructed a number of charts by NCEP reanalysis of the 1200 UTC data to illustrate some of the features that were consistent with a tropical system with warm core characteristics (Fig. 11). For example, the strongest ascent was near the center of the surface cyclone associated with a maximum in the precipitable water field (Fig. 11a)

In addition, peaks in the θ (Fig. 11b) and surface mass convergence (Fig. 11c) fields were collocated with the center of the cyclone at each analysis level. Finally, there was no evidence of the transition to baroclinic processes that often characterize tropical systems evolving away from barotropy (Fig. 12).

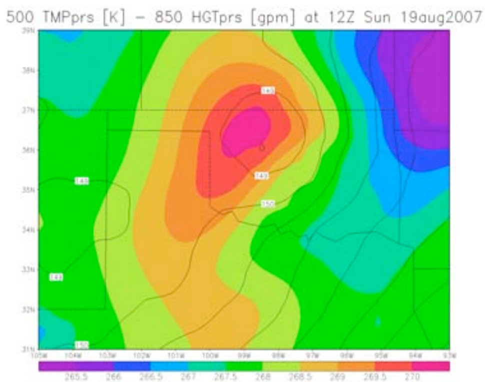


Figure 12. 500 mb temperatures (^{o}C) and 850 mb heights (dm) at 12 UTC 19 August 2007, obtained by NCEP reanalysis. Note the collocation of the warmest temperatures 500 mb temperatures with the lowest heights at 850 mb (and other lower levels, not shown). Baroclinic systems would show colder temperatures on the western portion of such cyclones.

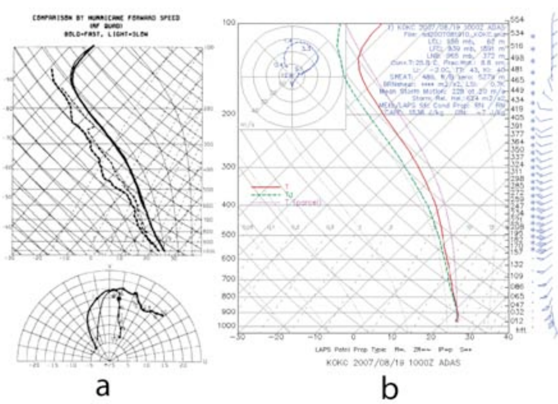
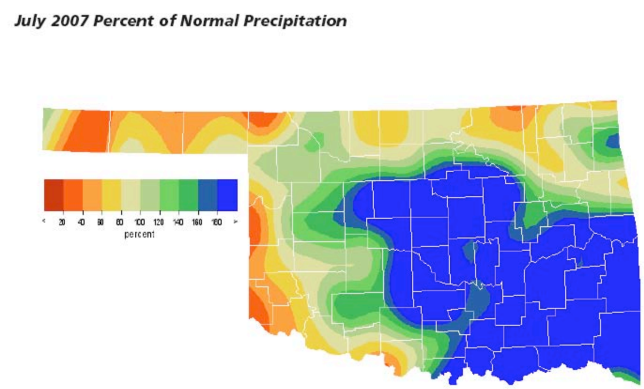


Figure 13. (a) Composite soundings and hodographs for right-front quadrant of landfalling tropical systems (from McCaul 1991) (bold—fast moving systems; light—slow moving systems); and (b) ADAS sounding and hodograph for KOUN (Norman, OK) at 1000 UTC 19 August 2007.

4. THERMODYMAMIC STRUCTURE

Soundings and hodographs, both for the period of time prior to and following the passage of the storm, closely resembled composite soundings for tropical cyclone environments, in particular for those responsible for tornadic supercells in a composite sense (Fig. 13). Wind fields were strongest near the ground, and weakened with height, as is expected for warm core lows. Strong veering of the wind and wind shear vectors occurs across the lowest 3 km. The envieronmental lapse rate was nearly wet adiabatic with weak to moderate surface based CAPE. The Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS) sounding shown corresponded very closely to the composites for the right-front quadrants of slow-moving tropical systems.



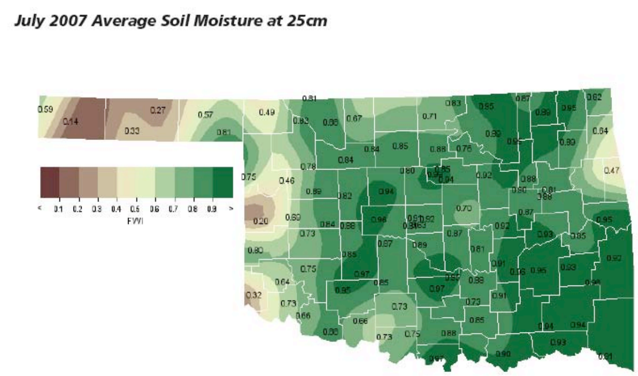


Figure 14. Percentage of normal precipitation (top) and observed soil moisture (Fire Weather Index units, FWI) over Oklahoma for July 2007 (Source: Oklahoma Climatological Survey).

5. PREEXISTING LAND/SURFACE CONDITIONS MIMICKED SEA-SURFACE

Widespread heavy rainfall (Figs. 14 and 15), flooding and saturated the Oklahoma ground during the weeks and months prior to Erin's arrival. Rainfall over central Oklahoma averaged nearly 200% of the long term average during the six months prior to the arrival of Erin. This probably provided a continental thermodynamic environment resembling that of the warm, tropical ocean surface. The authors believe that this, in turn, favored a period of inland behavior characteristic of an immature but deepening tropical cyclone over water.

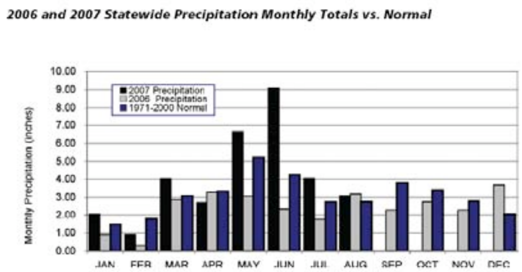


Figure 15. 2006 and 2007 Oklahoma precipitation monthly totals relative to normal (Source: Oklahoma Climatological Survey).

6. CONCLUSIONS

Erin never was reclassified a tropical storm by the National Hurricane Center, chiefly because the reintensification did not take place over the ocean. Yet the storm had pronounced warm core structure and had developed radar and satellite characteristics of a tropical system.

The authors hypothesize that the widespread flooding and saturated ground observed over Oklahoma during the extended period prior to Erin's arrival provided a continental thermodynamic environment resembling that of the warm, tropical ocean surface, which in turn favored a period of inland behavior characteristic of an immature but deepening tropical cyclone over water. Thus, latent heat release was likely the culprit for Erin's redevelopment and marked intensification.

7. REFERENCES

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