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Technical Attachment

Observations Associated with Tropical Storm Isidore in Middle Tennessee

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1. Introduction

Although not common, the remnants of tropical systems sometimes pass directly over Tennessee. Due to their tropical origin, the atmosphere surrounding these systems may maintain tropical characteristics for a considerable distance after moving inland, before remnants of the system gradually become extratropical. The potential for flooding is high with these moisture-laden systems, so accurate radar rainfall estimates are important for flood warnings and river forecast operations. The most accurate WSR-88D rainfall estimates while in tropical air masses can usually be obtained by using the “tropical” radar reflectivity-rain rate (Z-R) relationship $Z = 250R^{1.2}$. Knowing when to switch operations from the standard (default) Z-R ($Z = 300R^{1.4}$) to the tropical Z-R is the question. Experience plays a major role in answering the question, and study of a number of cases from one’s area of forecast responsibility can help provide a definitive answer. This paper will discuss when that switch might best be made from the perspective of forecast operations in Nashville.

2. Discussion

Tropical storm Isidore made landfall over southeast Louisiana around 0900 UTC on September 26, 2002. The National Hurricane Center predicted the center of Isidore would move northeast across middle Tennessee early on the 27th (Fig. 1). This would mean parts of Tennessee would likely receive very heavy rain, along with a potential for damaging winds and perhaps even a few tornadoes. Rainfall attributable to the storm circulation moved into middle Tennessee early on September 25, well in advance of the center of Isidore, which was still offshore over the northern Gulf of Mexico. By 1100 UTC, light to moderate rain was located over the far south and southeast sections of middle Tennessee, as shown by the Nashville WSR-88D (Fig. 2). As the precipitation spread over middle Tennessee it was thought that a switch from the standard Z-R to the tropical Z-R ($Z = 250R^{1.2}$) would provide more accurate radar rainfall estimates. The switch was made around 1620 UTC on the 25th, or about 40 hr before the center of the storm moved to a point just west of Nashville.

Late on the 25th it became obvious, when comparing rain gauge reports to radar rainfall estimates, that the radar algorithm was overestimating by as much as two- or three times the actual rainfall. Upon investigation of the Nashville 1200 UTC sounding on the 25th (Fig. 3) it was apparent the atmosphere was not at all atypical for the time of year. The air mass was stable, with a surface dew point in the low 50s. The precipitable water of 1.36 in was about 150 percent of normal. No doubt this was due to the moisture which had advected northward into our area ahead of Isidore, as represented by the rain that moved into middle Tennessee earlier in the day.

Although the precipitable water was above normal, the sounding depicted an atmosphere that did not yet exhibit what might be considered tropical characteristics, such as very high precipitable water, warm mid- and upper-level temperatures, and a high freezing level. In other words, the radar overestimation was most likely due to the use of the tropical Z-R while in a non-tropical air mass. Clearly, the standard Z-R ($Z = 300R^{1.4}$) would have provided better rainfall estimates up to this time. Noticing the overestimation, forecasters switched back to the standard Z-R late on the 25th and the radar remained in that mode for the rest of the event.

As the center of Isidore moved closer to middle Tennessee, however, the Nashville sounding for 0000 UTC on September 27 (Fig. 4) showed a much different picture than the sounding taken 36 hr earlier. The surface dew point had risen from the lower 50s into the middle 60s and precipitable water rose from 1.36 to 2.12 in (235 percent of normal). The freezing level rose from 12,945 to 15,595 ft, and the lifted index increased from 2.5 to 6.5. Even more notable changes were:

1) Massive warming in mid- and upper-levels due to the warm-core nature of the tropical system,
2) A large increase in wind velocities in low-and mid-levels, and
3) A tremendous increase in 0-3 km storm relative helicity.

To facilitate a comparison of the soundings, and the significant changes noted above, Fig. 5 shows the soundings from 1200 UTC on the 25th and 0000 UTC on the 27th, while Fig. 6 shows derived parameters from those soundings. During this 36-hr period, the atmosphere stabilized further, making widespread convection an even more remote possibility. But in addition to very high precipitable water, the 0000 UTC sounding on the 27th showed other important ingredients for heavy rainfall. These included a moist ambient environment (little or no entrainment of dry air), a stable atmosphere with few if any convective updrafts (minimal detrainment and hence minimal evaporation), and a deep (greater than 4 km) above freezing cloud layer (Kelsch 2000a).

At 0000 UTC on the 27th a shallow layer of cool air was still in place (from the sounding 36-hr previous), but the vertical temperature profile from around 850 through 300 mb was nearly moist adiabatic. This closely matches the thermal structure of the rain area in hurricanes as described by Riehl (1954, p. 314).

The center of what remained of Isidore's circulation moved across the west part of middle Tennessee early on September 27. We estimate the center passed just to the west of Nashville around 0800 or 0900 UTC. Figure 7 shows the 0827 UTC 0.5 deg reflectivity image from the Nashville radar, with "L" marking the estimated location of the center of circulation. The NHC forecast track (Fig. 1) was very close to the actual path taken by the storm.

Strong dynamic lift caused by strong low-level convergence and upper-level divergence, coupled with the other heavy rainfall ingredients previously mentioned, meant that the precipitation efficiency of the air mass was very high. Therefore, most of the moisture that entered the system would fall out as rainfall, and not be wasted on evaporation and mixing (Kelsch 2000a). The air mass indeed proved to be an efficient rain producer, with the heaviest rain occurring west and northwest of the storm path. For this event, a storm total of 10.52 in was measured at Big Sandy in Benton County in northwest middle Tennessee (Fig. 8). Tennessee Ridge in Houston County, also in northwest middle Tennessee, received 8.67 in. Both these sites were located to the west of the path of the storm. Near the beginning of the event, using a tropical Z-R, the radar was overestimating rainfall. After the event, a comparison was made between radar rainfall estimates from the standard Z-R (Fig. 9), which was used for most of the event, and observed rainfall (Fig. 8). The comparison showed that for the entire event, the radar underestimated rainfall by a factor of about two. The uncertainty or lack of confidence in the accuracy of rainfall estimates using the tropical Z-R, lead to a switch back to the standard Z-R, but this ultimately resulted in inaccurate rainfall estimates.

3. Severe Weather Possibilities

The Storm Prediction Center indicated a slight risk of severe weather extending northward into southern middle Tennessee during the period when the center of Isidore was to pass across middle Tennessee. The SPC discussion mentioned that even though instability was lacking, helicity values were high, and water vapor imagery showed drier air rotating around the base of the storm and heading northward across eastern Mississippi and Alabama. It was thought that the drying aloft would produce convective instability, and that any convective updraft, even without thunder, might have the potential to spawn a tornado in the highly sheared environment.

This event was mostly a heavy rainfall episode, not a severe weather event. Much of this event was devoid of thunderstorms. Not until later on the 26th and early on the 27th did thunderstorms occur, and then they were isolated. No tornadoes were reported. A few trees were reported down, but these reports were very isolated in nature, and most likely the result of strong gradient winds.

4. Summary of Hydrologic Products

The following summarizes hydrologic products issued by WFO Nashville during this event.

September 24 - Issued a <u>Hydrologic Outlook</u> (MEMESFBNA) for the possibility of heavy rain and flooding.

September 25 - Issued a <u>Flood Watch</u> (MEMFFABNA) for the threat of heavy rain and flooding. A call-to-action statement to check preparedness for flooding and to keep informed was included in the Watch.

September 16 - Issued follow-up Flood Statements (MEMFLSBNA) to update the Flood Watch. Issued a River Flood Warning (MEMFLWBNA) for the Buffalo River. Issued a River Statement (MEMRVSBNA) for the Harpeth River. Issued Flash Flood Warnings (MEMFFWBNA) for Benton, Stewart, Humphreys, and Houston counties in northwest middle Tennessee. Issued a Flash Flood Statement (MEMFFSBNA) to update the Flash Flood Warnings.

Although a large portion of western middle Tennessee received 6 to 8 in of rain in a 48-hr period, no river flooding was observed. The most significant river rise was noted on the Red River at Port Royal in eastern Montgomery County where water levels rose 15 ft in less than 24 hr (Fig. 10). The Red River at Port Royal crested well below the flood stage. General flooding of low lying areas and reports of water over roadways was most widespread across Benton, Houston, and Montgomery counties in northwest middle Tennessee. One fatality occurred when a man drowned after he drove around a barricade into 8 to 10 ft of water near Clarksville in Montgomery County.

5. Determining When to Switch to the Tropical Z-R Relationship

Knowing the drop-size distribution of precipitation is very important in producing accurate radar rainfall estimates. Because drop-size distribution of precipitation cannot be measured by weather radars, the relationship between radar reflectivity and rain rate (Z-R) cannot be defined with certainty (Kelsch 2000b). Empirical relationships have therefore been developed to define various radar reflectivity-rain rates. The standard Z-R ($Z = 300R^{1.4}$) has been found to be a good overall relationship to use. For systems that exhibit tropical characteristics, however, using a tropical Z-R ($Z = 250R^{1.2}$) produces more rainfall for a given reflectivity value, and therefore more accurate rainfall estimates than the standard Z-R (Kelsch 2000b).

Some guidelines we believe may be helpful in determining when to switch to the tropical Z-R relationship include the following.

1) Examine soundings upstream and nearby for any tropical characteristics, such as:
   a) High surface dew points.
   b) Moist ambient environment (little or no entrainment of dry air).
   c) Very high precipitable water.
   d) Very warm mid- and upper-level temperatures.
   e) High freezing level.
   f) A stable environment (few if any convective updrafts, hence minimal detrainment and therefore minimal evaporation).
   g) Deep (3 km or more) above freezing cloud layer (greater than 4 km in the Southeast).

2) Estimate arrival time of tropical air mass within your radar umbrella. This might be accomplished by determining when upstream sounding takes on tropical characteristics in relation to location of storm center at surface. Then apply similar

relationship to your location. For example, if an upstream sounding begins exhibiting tropical characteristics when storm moves to within 200 miles of that location, one might assume that air mass will become tropical over at least part of your radar's umbrella when the storm is within a similar distance.

3) Use AWIPS WHFS HydroView program and make frequent comparisons between radar rainfall estimates and actual rainfall from rain gauges to determine success of current Z-R being employed.

6. Conclusion

As the remnants of tropical storm Isidore approached middle Tennessee, the decision was made to switch from the standard Z-R to the tropical Z-R ($Z = 250R^{1.2}$) to provide the most accurate radar rainfall estimates. It was later observed that the radar was overestimating rainfall amounts by a factor of between two and three. Sounding data showed an atmosphere that apparently had not yet taken on sufficient tropical characteristics to warrant the tropical Z-R relationship. A switch back to the standard Z-R was made. After the event, a comparison of radar rainfall estimates and actual ground truth reports showed that for the entire event, the radar underestimated rainfall by a factor of about two. A sounding taken closer to the time of the passage of the center of Isidore across middle Tennessee, revealed that the atmosphere had taken on a more tropical nature, indicating that a switch back to the tropical Z-R later in the event would probably have provided more accurate rainfall estimates overall.

7. References

Kelsch, M., 2000a: Heavy/intense precipitation, the precipitation part to the flash flood problem. COMET COMAP Symposium 00-3, Heavy Precip/Flash Flood.

_______, 2000b: Radar-derived precipitation. COMET COMAP Symposium 00-3, Heavy Precip/Flash Flood.

Riehl, H., 1954: *Tropical Meteorology*. McGraw-Hill Book Company, New York, New York, 392 pp.

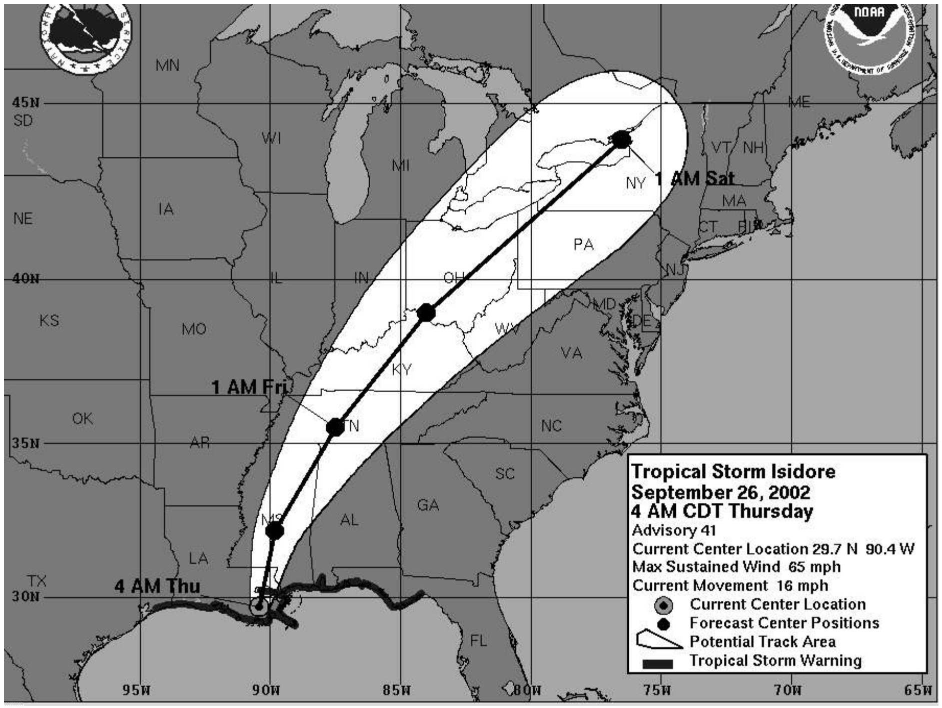

Fig. 1. NHC track forecast issued 4 a.m. September 26, 2002.

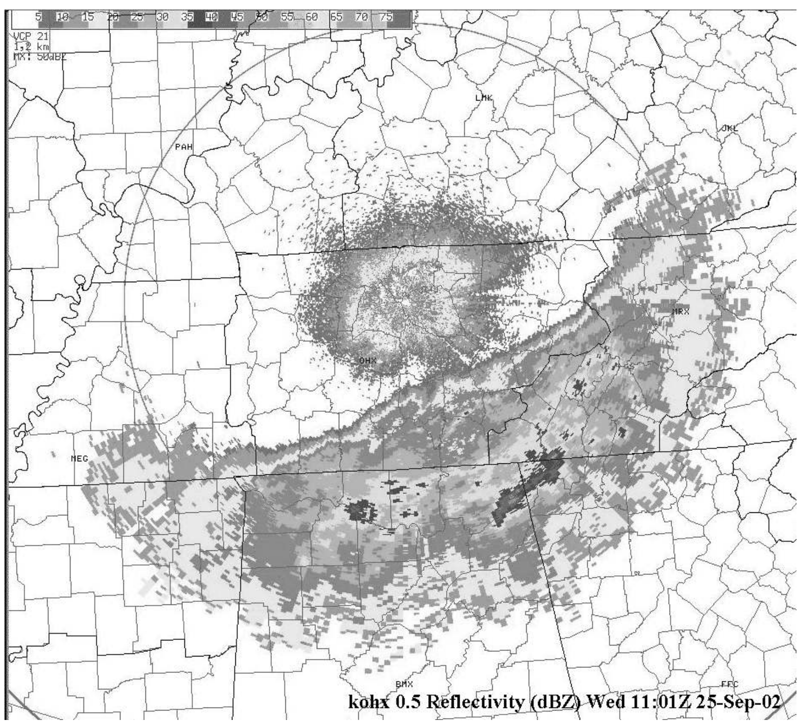

Fig. 2. Nashville WSR-88D 0.5 deg reflectivity, 1101 UTC September 25.

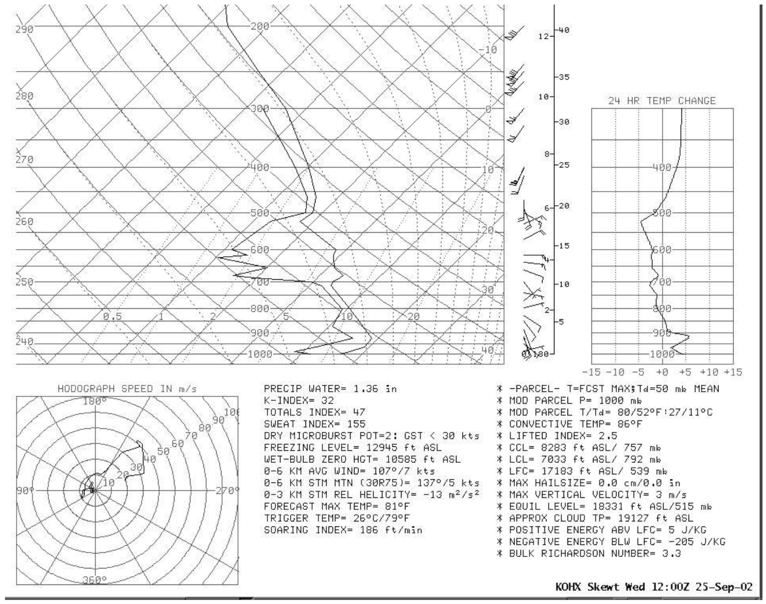

Fig. 3. Nashville sounding at 1200 UTC September 25.

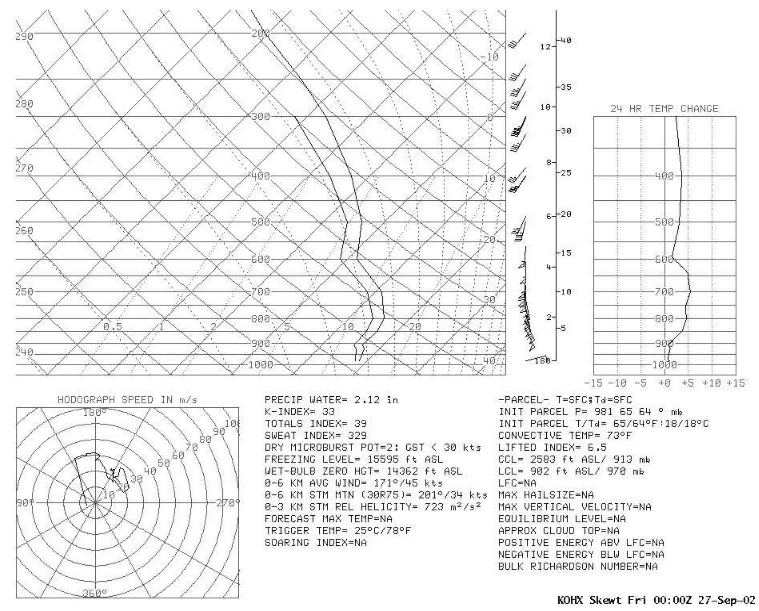

Fig. 4. Same as Fig. 3, but 0000 UTC September 27.

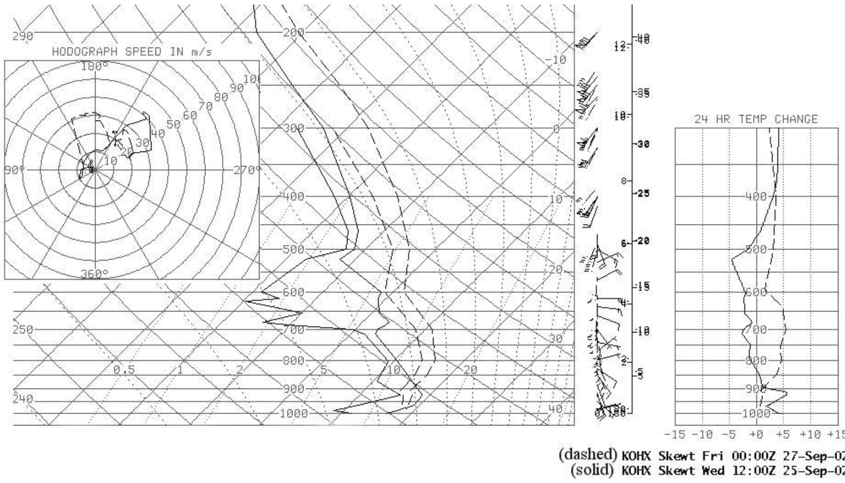

Fig. 5. Comparison of soundings from Nashville, 1200 UTC 9/25/02 (solid) and 0000 UTC 9/27/02 (dashed).

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PRECIP WATER= 1.36 in
K-INDEX= 32
TOTALS INDEX= 47
SWEAT INDEX= 155
DRY MICROBURST POT=2: GST < 30 kts
FREEZING LEVEL= 12945 ft ASL
WET-BULB ZERO HGT= 10585 ft ASL
0-6 KM AVG WIND= 107°/7 kts
0-6 KM STM MTN (30R75)= 137°/5 kts
0-3 KM STM REL HELICITY= -13 m²/s²
FORECAST MAX TEMP= 81°F
TRIGGER TEMP= 26°C/79°F
SOARING INDEX= 186 ft/min

* -PARCEL- T=FCST MAX;Td=50 mb MEAN
* MOD PARCEL P= 1000 mb
* MOD PARCEL T/Td= 80/52°F:27/11°C
* CONVECTIVE TEMP= 86°F
* LIFTED INDEX= 2.5
* CCL= 8283 ft ASL/ 757 mb
* LCL= 7033 ft ASL/ 792 mb
* LFC= 17183 ft ASL/ 539 mb
* MAX HAILSIZE= 0.0 cm/0.0 in
* MAX VERTICAL VELOCITY= 3 m/s
* EQUIL LEVEL= 18331 ft ASL/515 mb
* APPROX CLOUD TP= 19127 ft ASL
* POSITIVE ENERGY ABV LFC= 5 J/KG
* NEGATIVE ENERGY BLW LFC= -205 J/KG
* BULK RICHARDSON NUMBER= 3.3
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KOHX Skewt Wed 12:00Z 25-Sep-02

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PRECIP WATER= 2.12 in
K-INDEX= 33
TOTALS INDEX= 39
SWEAT INDEX= 329
DRY MICROBURST POT=2: GST < 30 kts
FREEZING LEVEL= 15595 ft ASL
WET-BULB ZERO HGT= 14362 ft ASL
0-6 KM AVG WIND= 171°/45 kts
0-6 KM STM MTN (30R75)= 201°/34 kts
0-3 KM STM REL HELICITY= 723 m²/s²
FORECAST MAX TEMP=NA
TRIGGER TEMP= 25°C/78°F
SOARING INDEX=NA

-PARCEL- T=SFC;Td=SFC
INIT PARCEL P= 981 65 64 ° mb
INIT PARCEL T/Td= 65/64°F:18/18°C
CONVECTIVE TEMP= 73°F
LIFTED INDEX= 6.5
CCL= 2583 ft ASL/ 913 mb
LCL= 902 ft ASL/ 970 mb
LFC=NA
MAX HAILSIZE=NA
MAX VERTICAL VELOCITY=NA
EQUILIBRIUM LEVEL=NA
APPROX CLOUD TOP=NA
POSITIVE ENERGY ABV LFC=NA
NEGATIVE ENERGY BLW LFC=NA
BULK RICHARDSON NUMBER=NA
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KOHX Skewt Fri 00:00Z 27-Sep-02

Fig. 6. Derived data from soundings shown in Fig. 5.

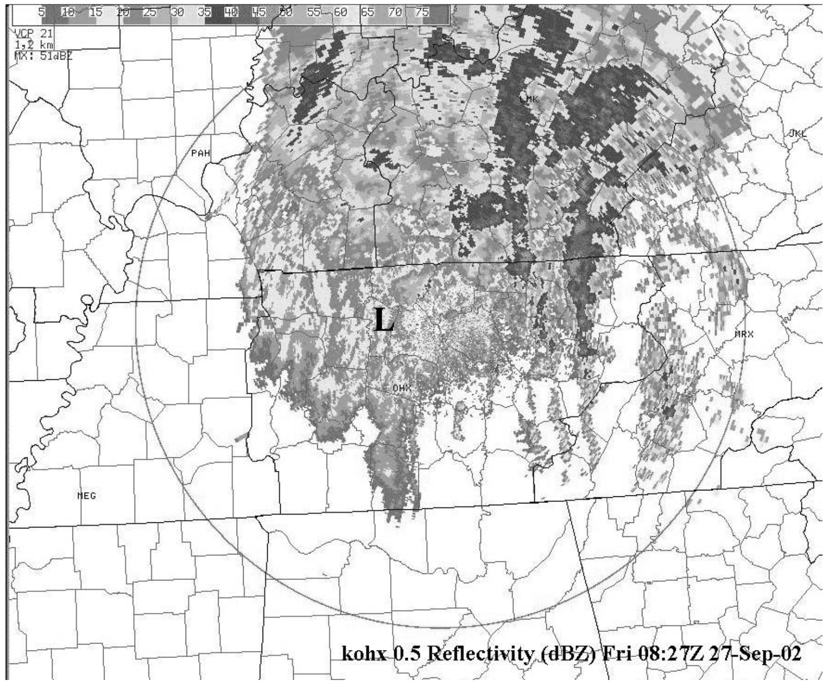

Fig. 7. Nashville WSR-88D 0.5 deg reflectivity, 0827 September 27.
"L" indicates estimated center of circulation of Isidore remnants.

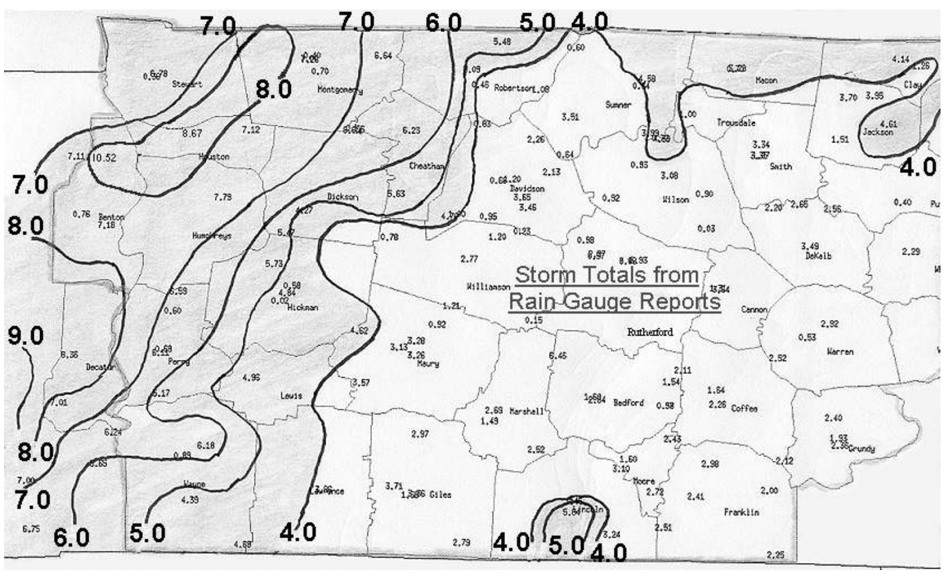

Fig. 8. Observed event rainfall (inches).

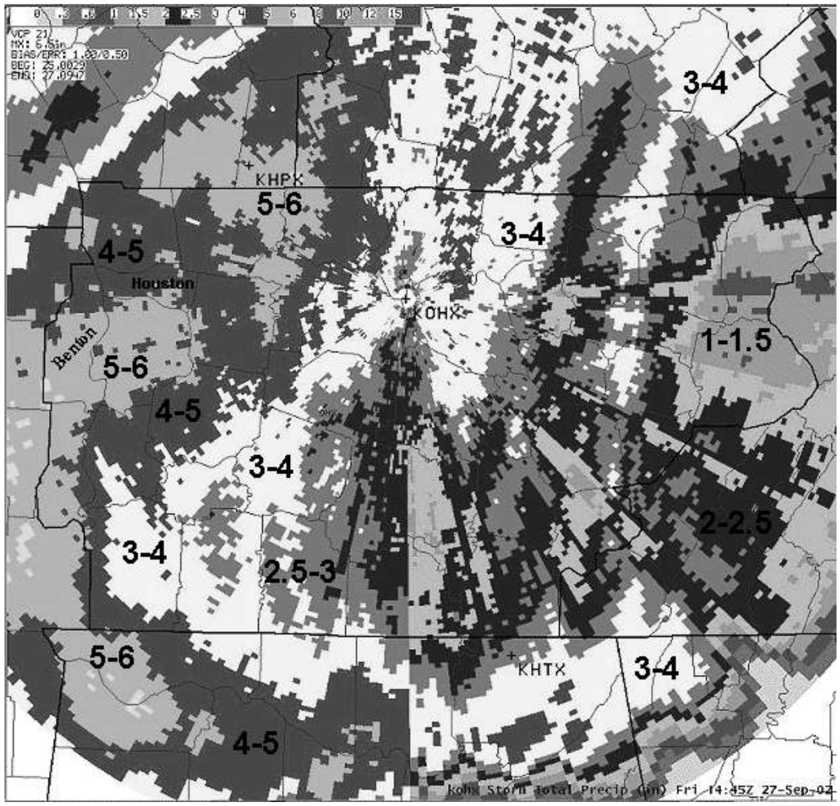

Fig. 9. WFO Nashville radar - estimated storm-total rainfall.

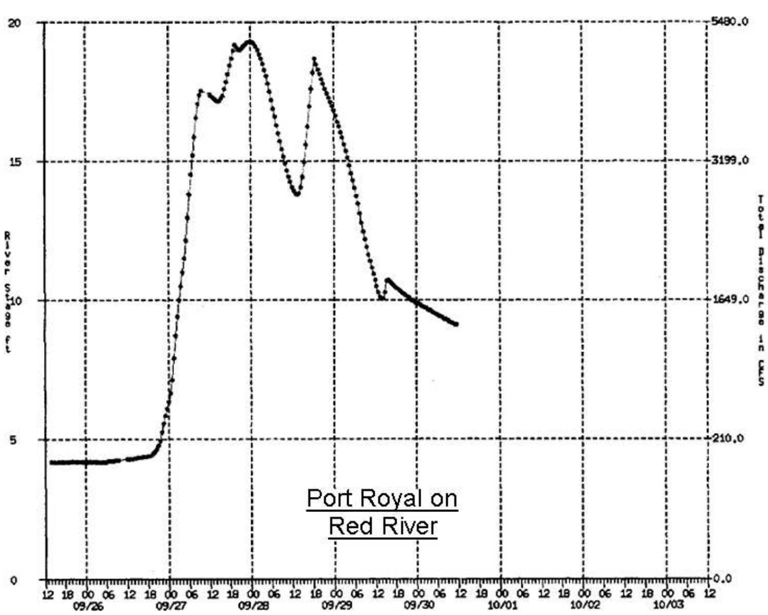

Fig. 10. Hydrograph for Port Royal on the Red River.