8.5 DIAGNOSIS AND PREDICTION OF THE 3-4 JUNE 2002 IOWA-ILLINOIS FLOOD

James T. Moore* Ray A. Wolf† Brad L. Mickelson* Jeff A. Zogg†
Charles E. Graves*

*Saint Louis University
Earth and Atmospheric Sciences
St. Louis, MO

†National Weather Service Forecast Office
Davenport, IA

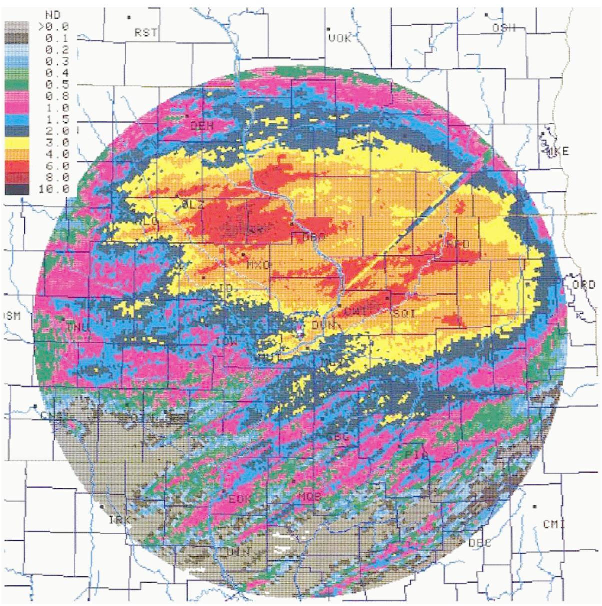

Figure 1: Storm total rainfall derived from the KDVN WSR-88D radar. The legend in the upper left hand corner displays the color scale indicating the rainfall amounts in inches.

1. INTRODUCTION

During the time period from approximately 1800 UTC 3 June to 2100 UTC 4 June 2002, heavy convective rainfall resulted in significant flash flooding and river flooding over portions of east-central Iowa and northwest Illinois. Rainfall amounts over four inches were common in these areas with extreme amounts (as high as eight to eleven inches) reported in Delaware and Dubuque counties in Iowa (Fig. 1). The maximum rainfall for this event equaled or exceeded the 1 in 100 year event for a 48-h period (Huff and Angel 1992). According to Storm Data (NOAA 2002), the Rock River reached flood levels near Joslin, while the Maquoketa and Wapsipinicon Rivers rose well above flood stage. The Maquoketa River rose high enough to shut down the water treatment plant in Monticello, in northeastern Jones county, which did not even occur during the historic floods of 1993. President Bush declared 17 counties in eastern Iowa disaster areas as over $7.2 million dollars of property damage occurred. In northwest and west-central Illinois rainfall of 6-10 inches also resulted in significant property damage (around $3 million dollars) associated with heavy rainfall, rivaling that of the summer of 1993 and the spring snowmelt of April 2001 (Zogg et al. 2002). During the height of the storm, rainfall rates of over two inches per hour were recorded.

The goal of the present work is to document the unique physical processes which interacted to force and focus heavy convective precipitation into a relatively small area over this 27 h period. Section two will describe the synoptic-scale regime within which deep convection occurred. Section three reveals the mesoscale characteristics of this event through an examination of the WSR-88D radar. Section four briefly addresses the utility of the operational model forecasts to anticipate this event. Finally, section five summarizes our results and qualitatively compares them to the conceptual model described by Moore et al. (2003) for elevated thunderstorms.

2. SYNOPTIC-SCALE ENVIRONMENT

As most of the convective precipitation fell on and after 0000 UTC 4 June, our discussion of the synoptic environment attending this case begins at this time. Surface conditions (Fig. 2) reveal a stationary front draped across the central Plains from the Oklahoma panhandle northeastward into south-

Corresponding author address: James T. Moore Earth and Atmos. Sciences, Saint Louis University, St. Louis MO 63103; email: moore@eas.slu.edu

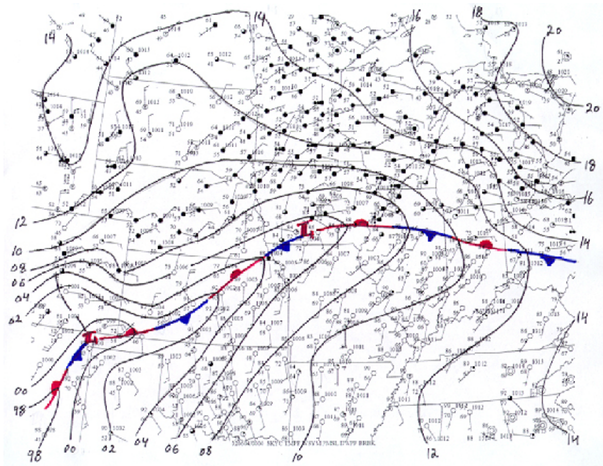

Figure 2: Surface chart for 0000 UTC 4 June 2002.

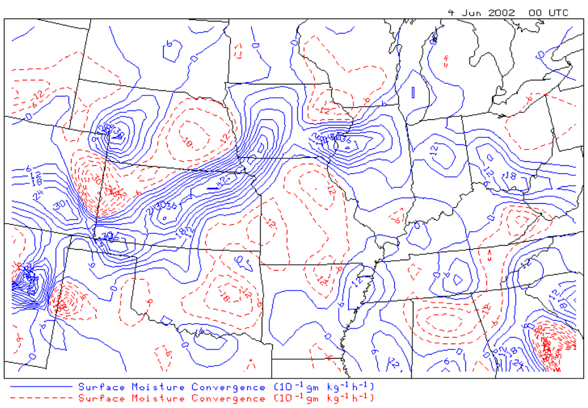

Figure 3: Surface moisture convergence for 0000 UTC 4 June 2002.

central Iowa and then eastward into west-central Ohio. The thermal gradient across the boundary was quite strong, especially across the state of Iowa, where temperatures ranged from the low 60s (°F) in the north to the mid 80s (°F) in the south. A weak area of cyclonic circulation had been anchored in southwest Iowa since 2000 UTC 3 June. The stationary boundary to the east of this weak low was a focus for strong low-level moisture convergence (Fig. 3) where values over 3.0 g (kg - h)$^{-1}$were diagnosed. Over the previous two hours (2200 and 2300 UTC) a moisture convergence maximum of over 3.5 g (kg - h)$^{-1}$was located in south-central Iowa, thereby confirming the spatial and temporal continuity of the maximum seen in Fig. 3. Dew points in the low 70s (°F) were located just southwest of the weak cyclone, nearly coincident with the warmest surface air. The surface equivalent potential temperature

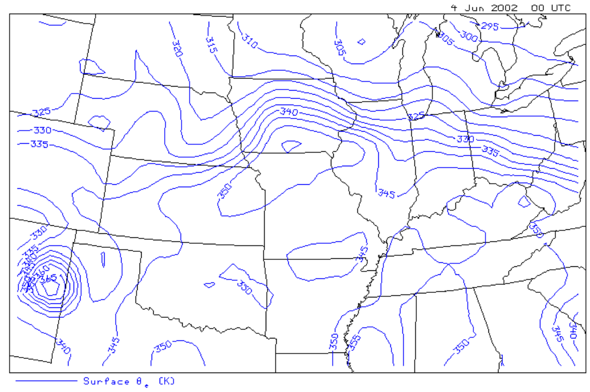

Figure 4: Surface equivalent potential temperature for 0000 UTC 4 June 2002.

(θ_e) field for 0000 UTC (Fig. 4) reveals values over 350 K over a broad area to the south of the surface front in Iowa, with a maximum of 355 K in southern Iowa.

Analyses of the 850, 500, and 250 hPa surfaces (Figs. 5-7) revealed important clues related to the environment supportive of convective development. At 850 hPa (Fig. 5) a weak inverted trough was found from New Mexico northeastward into Minnesota. Warm (temperatures greater than 20°C), moist (dew points greater than 15°C) air was being advected into southwest Iowa by southwesterly flow of about 10 m s^{-1}(20 knots). An 850 hPa frontal boundary can be identified in central Iowa extending into northern portions of Illinois and Indiana. The 500 hPa flow (Fig. 6) reveals a broad ridge of west-southwesterly flow dominating the north-central Plains states with a weak trough well upstream from the incipient convection. As has been noted by many authors (e.g., Maddox et al. 1979, Moore et al. 2003) heavy convective rainfall often takes place near the inflection point in the mid-tropospheric flow, in a region of weak to neutral absolute vorticity advection. At 250 hPa, the objective analysis (Fig. 7) diagnosed a similar flow as at 500 hPa, with a weakly anticyclonically-curved upper-level jet (ULJ) streak over the Dakotas extending into Minnesota. This would place the Iowa heavy convective rainfall event on the anticyclonic side of the ULJ, south of the maximum mean 300-200 hPa divergence (Fig. 8). Junker et al. (1999) and Moore et al. (2003) have noted this relationship of maximum upper-tropospheric divergence to heavy convective rainfall in composite studies.

The 900-700 hPa averaged frontogenesis field reveals two maxima; one centered in southeast South

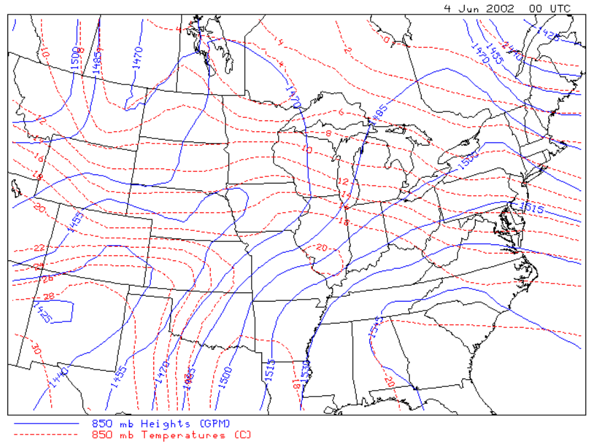

Figure 5: 850 hPa upper air analysis for 0000 UTC 4 June 2002.

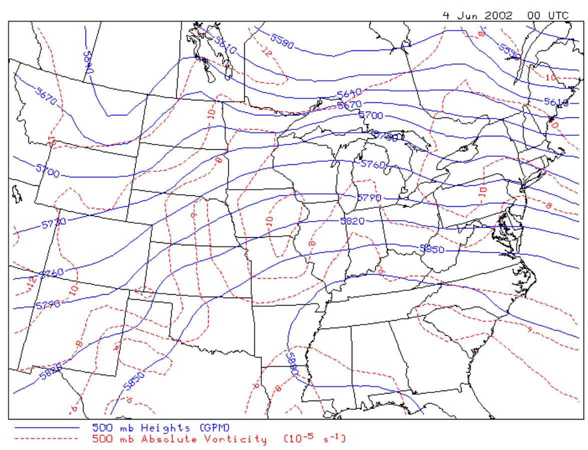

Figure 6: 500 hPa upper air analysis for 0000 UTC 4 June 2002.

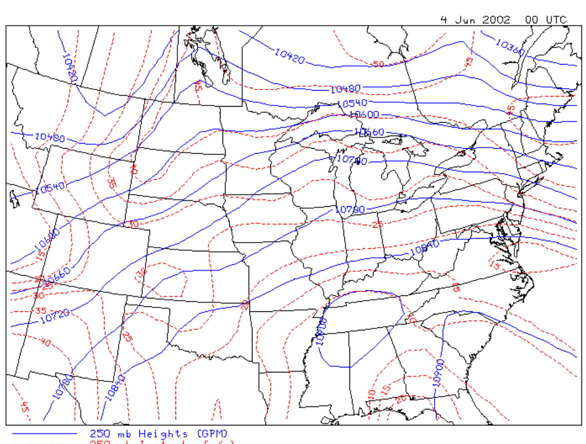

Figure 7: 250 hPa upper air analysis for 0000 UTC 4 June 2002.

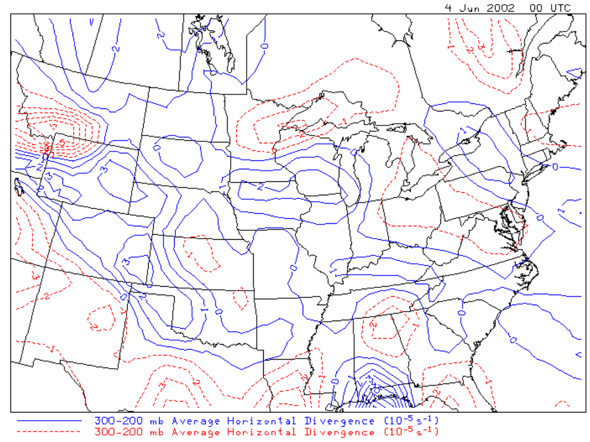

Figure 8: Average divergence over the 300-200 hPa layer for 0000 UTC 4 June 2002.

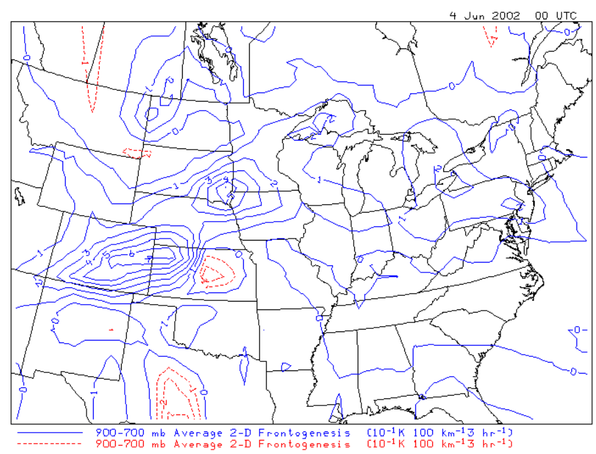

Figure 9: Average frontogenesis over the 800-600 hPa layer for 0000 UTC 4 June 2002.

Dakota with an axis extending into central Iowa, and another in northwest Kansas (Fig. 9). The axis of the former maximum is located approximately 200 km north of the surface-based boundary and is associated with a direct thermal circulation, defined in Fig. 10, by the cross section of tangential ageostrophic winds and kinematic vertical motion taken along the 91° longitude meridian cutting through eastern Iowa.

Unfortunately, the rawinsonde for 0000 UTC 4 June from Davenport, Iowa prematurely ended at 733 hPa, probably because it encountered strong convection during ascent. However, it is instructive to look at the inflow air approximated by the Topeka, Kansas sounding (Fig. 11) as this represents the airmass being advected into east-central

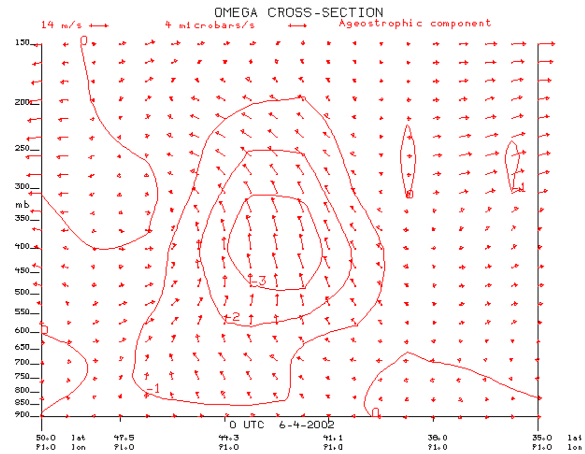

Figure 10: Vertical cross section of kinematic vertical motion (solid, μbar s^{-1}) and tangential ageostrophic wind for 0000 UTC 4 June 2002.

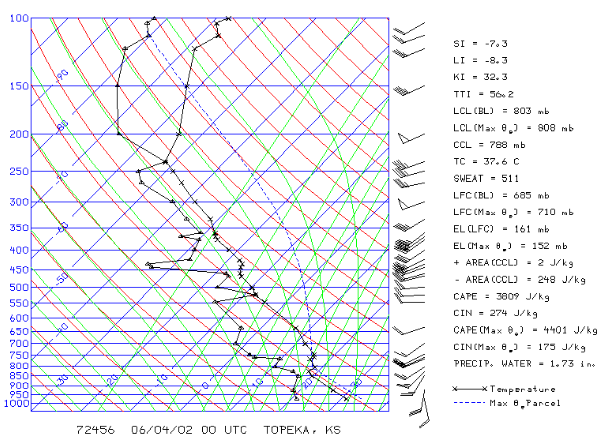

Figure 11: Skew T – Log P display of the sounding at Topeka for 0000 UTC 4 June 2002.

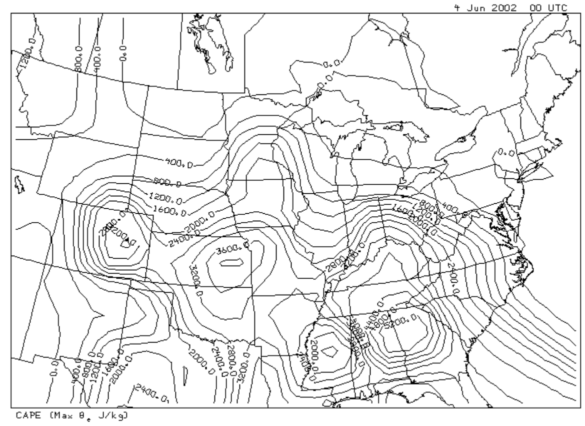

Figure 12: Objectively analyize plan view of maximum θ_e CAPE for 0000 UTC 4 June 2002.

Iowa. The sounding had high precipitable water (PW; 1.73 inches) and a deep layer of high instability (maximum θ_e CAPE of 4401 J kg^{-1}). The inflowing PW values in northeastern Kansas were at least 130% of normal for this time of year (early June). However, two things likely prevented convection in northeast Kansas; the absence of a boundary along which to focus convection, and a substantial "lid" or "cap" of 175 J kg^{-1}. The plan view of maximum θ_e CAPE (Fig. 12) depicts a maximum of over 4000 J kg^{-1}in northeast Kansas with lower values to the northeast. Interestingly, the Lincoln, Illinois sounding (not shown) is much drier than the Topeka, Kansas sounding and has a maximum θ_e CAPE of 1603 J kg^{-1}. Thus, the objective analyzed plan view of maximum θ_e CAPE is likely not representative of the conditions in eastern Iowa as the Davenport sounding was not included in the objective analysis.

From the preceding discussion it can bee seen that the precursor conditions for heavy convective rainfall were present in eastern Iowa for this event - moisture, lift, and instability. High PW values and low-level θ_e were part of the inflow into the area. Lift was present in the form of a direct thermal circulation associated first with moderate low-level frontogenesis and later, by the outflow from subsequent thunderstorms. Lastly, high values of instability (maximum θ_e CAPE greater than 4000 J kg^{-1}) were streaming northeastward along and over the frontal zone.

3. MESOSCALE CONVECTIVE SYSTEMS DURING THE EVENT

MCSs for this event were monitored using archive level-II data captured from the WSR-88D radar at Davenport, Iowa. Analysis of the radar data was

MCS #	Formation Region/Time	Dissipation Region/Time	Movement
1	Northwest IL 19-20 UTC 3 June	Northwest IL 23-00 UTC 3-4 June	East at 13.3 m/s
2	East-Central IA 20-21 UTC 3 June	Northwest IL 03-04 UTC 4 June	East at 17.8 m/s
3	Northeast IA 01-02 UTC 4 June	Northeast IL 09-10 UTC 4 June	Southeast at 13.3 m/s
4a	Northeast IA 06-07 UTC 4 June	Northeast IL 17-18 UTC 4 June	Southeast at 13.3 m/s
4b	East-Central IA 14-15 UTC 4 June	Northeast IL 19-20 UTC 4 June	East at 17.8 m/s

Table 1: List of MCSs observed by WSR-88D during the heavy rainfall event near Davenport, Iowa.

done using the WATADS system both at the Davenport office and at Saint Louis University. During the event five MCSs were identified which affected the Davenport County Warning Area (CWA). Their characteristics are noted in Table 1. In this table the movement noted represents an average over the lifetime of the MCS.

Each MCS near its peak intensity is shown in Figs. 13-17 to illustrate the episodic nature of this event. Within each MCS there was training of individual cells (i.e., cell repeatedly moving over the same geographical area). Consequently the Davenport CWA experienced training of MCSs (often called “super-training”) combined with cell training within the individual MCSs. With the exception of MCS #4b, the areal extent of the MCSs increased through the nighttime hours. Although the MCS activity was mostly nocturnal, it is interesting to note that MCSs # 4a-b were quite active late into the second day (4 June), dissipating by early afternoon.

Estimates of storm motion were made using the Corfidi vector method (Corfidi et al. 1996) for 0000 UTC and 1200 UTC 4 June 2002 (Figs. 18-19). Storm motion for the two time periods were 286° at 9.7 m s^{-1}and 259° at 4.3 m s^{-1} for 0000 UTC and 1200 UTC, respectively. These figures display the shift of the storm motion from the northwest to the southwest over this time period. In addition, the estimated storm motion decreased in speed by 5.4 m s^{-1}.

As noted above, the motion of the MCSs was generally parallel to the surface front (Fig. 2). These elevated MCSs (see Rochette and Moore 1996) formed approximately 50 km north of the surface boundary to the northeast of the weak surface low. The surface moisture convergence fields for time periods after 0000 UTC 4 June revealed a periodicity which approximately parallels that of the MCS initiation. That is, surface moisture convergence values tended to increase substantially approximately an hour before MCS initiation, with the MCS forming in the gradient region downstream from the moisture convergence maximum.

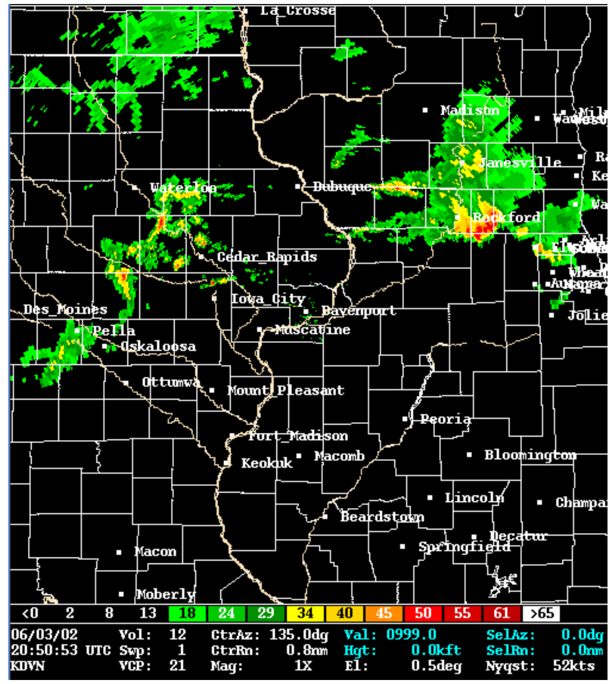

Figure 13: KDVN WSR-88D Radar reflectivity (0.5° elevation) for 2050 UTC 3 June 2002 depicting MCS #1.

4. UTILITY OF OPERATIONAL NUMERICAL MODEL FORECASTS

Six-hourly quantitative precipitation forecasts (QPF) from the Eta operational model run at 0000 UTC 4 June 2002 were reviewed in order to assess the model's ability to forecast the complexity of the five different MCSs. In general, the detail and magnitude of the QPF were poorly handled by the Eta. Two of the five MCSs were at least reflected qualitatively by the QPF fields. However, in particular, the MCS which caused the most serious flooding in the Quad Cities area (MCS # 4a) was not well forecast. Interestingly, this system propagated southeast, apparently developing along the cold outflow of the earlier MCS, while the mean flow

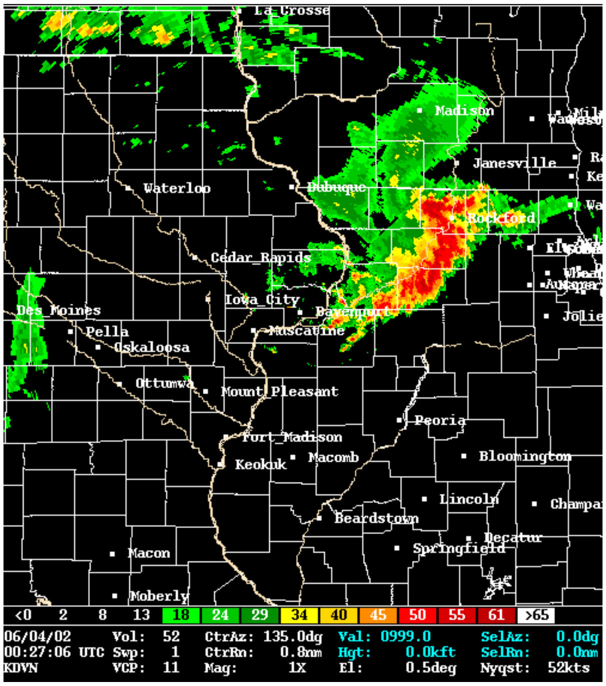

Figure 14: KDVN WSR-88D Radar reflectivity (0.5° elevation) for 0027 UTC 4 June 2002 depicting MCS #2.

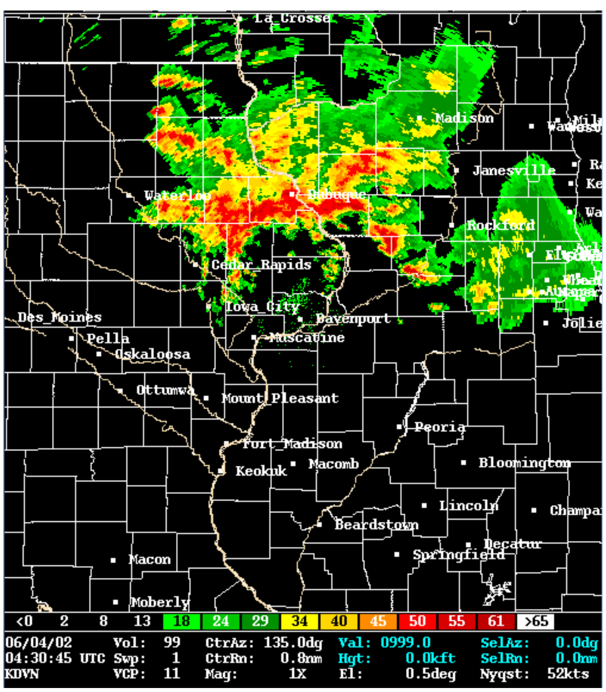

Figure 15: KDVN WSR-88D Radar reflectivity (0.5° elevation) for 0430 UTC 4 June 2002 depicting MCS #3.

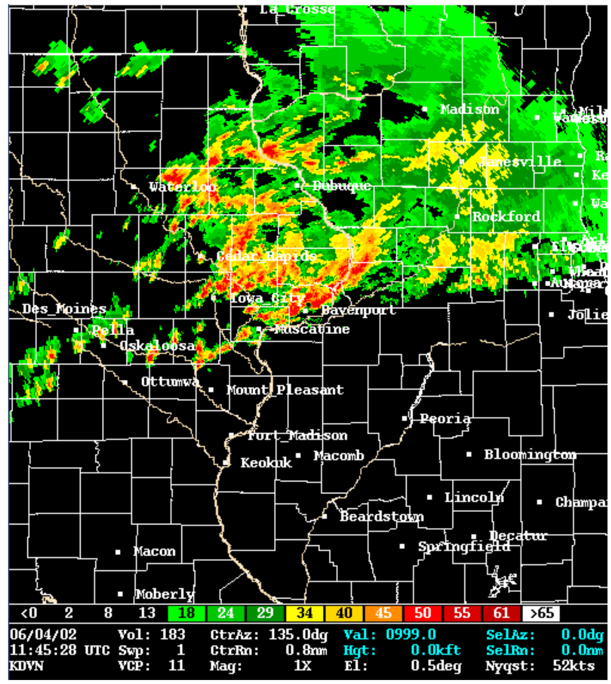

Figure 16: KDVN WSR-88D Radar reflectivity (0.5° elevation) for 1145 UTC 4 June 2002 depicting MCS #4a.

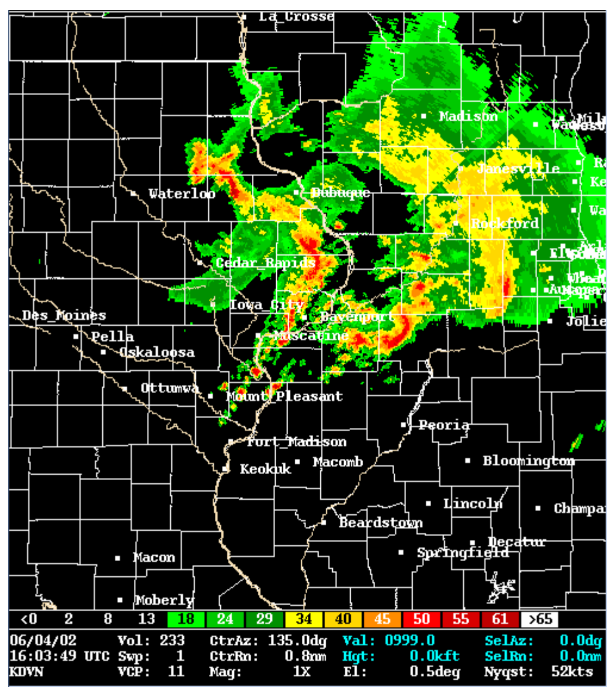

Figure 17: KDVN WSR-88D Radar reflectivity (0.5° elevation) for 1603 UTC 4 June 2002 depicting MCS #4b.

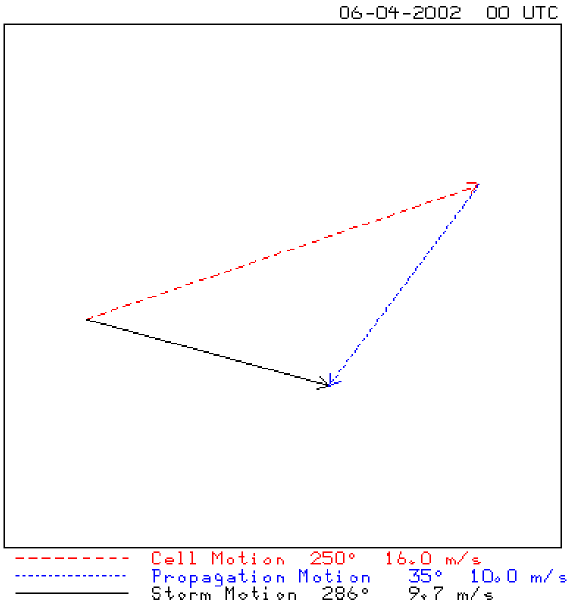

Figure 18: Storm, cell, and propagation motion vectors estimated using the Corfidi vector method for 0000 UTC 4 June 2002.

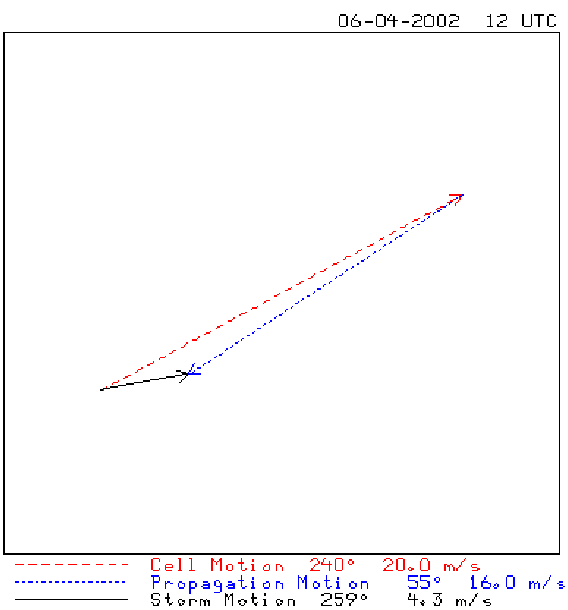

Figure 19: Storm, cell, and propagation motion vectors estimated using the Corfidi vector method for 1200 UTC 4 June 2002.

pattern supported more of a east-northeast movement (as "forecast" by the Corfidi vectors). Baldwin et al. (2002) has documented that the Eta convective parameterization scheme (CPS; the Betts-Miller-Janic scheme) does not include convective downdrafts. Thus, this weakness in the model CPS was likely a factor in the model's ability to correctly forecast the strength and movement of MCS # 4a.

5. CONCLUSIONS

The synoptic environment associated with heavy rainfall in eastern Iowa and northwestern Illinois was examined to highlight those features contributing to this record rainfall event. Elevated thunderstorms formed north of a quasi-stationary front draped from west to east just south of the Davenport CWA. Episodic MCS activity was associated with strong moisture convergence located to the northeast of a weak cyclonic circulation in southwest Iowa. Warm moist unstable air was advected into the region by a southwesterly low level jet. Upward vertical motion associated with a mid-tropospheric frontogenetical zone supported the development of convection along and north of the surface boundary. All these synoptic characteristics agree with the conceptual model described by Moore et al. (2003).

An examination of the WSR-88D radar imagery revealed a sequence of training MCSs over the CWA of varying size and intensity over the 27 hour period. Computation of Corfidi storm motion vectors showed that initial MCS motion was northwesterly but slowed significantly while also backing with time to the southwest.

Finally, operational Eta-model QPF were found to be of marginal utility is assessing the heavy rain potential.

6. ACKNOWLEDGEMENTS

The authors would like to thank the Cooperative Program for Meteorology, Education, and Training (COMET) for its support of this research effort under UCAR subaward S03-44682. This work was also partly supported by the NOAA Collaborative Science, Technology, and Applied Research (CSTAR) program under award NA03-NWS4680019. The authors gratefully acknowledge the support of the UCAR Unidata program for supplying data for this project via the Internet Data Distribution (IDD) network and the Local Data Manager (LDM).

*

REFERENCES

Baldwin, M. E., J. S. Kain, and M. P. Kay, 2002:

Properites of the convection scheme in NCEP's eta model that affect forecast sounding interpretation. *Wea. Forecasting*, **17**, 1063–1079.

Corfidi, S. F., J. H. Merritt, and J. M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. *Wea. Forecasting*, **11**, 41–46.

Huff, F. A., and J. R. Angel, 1992: Rainfall frequency atlas of the midwest. Tech. rep., Illinois Water Survey.

Junker, N. W., R. S. Schneider, and S. L. Fauver, 1999: A study of heavy rainfall events during the Great Midwest Flood of 1993. *Wea. Forecasting*, **14**, 701–712.

Maddox, R. A., C. F. Chappell, and L. R. Hoxit, 1979: Synoptic and meso-α scale aspects of flash flood events. *Bull. Amer. Meteor. Soc.*, **60**, 115–123.

Moore, J. T., F. H. Glass, C. E. Graves, S. M. Rochette, and M. J. Singer, 2003: The environment of warm-season elevated thunderstorms associated with heavy rainfall over the central United States. *Wea. Forecasting*, **18**, 304–321.

NOAA, 2002: Storm data. Tech. rep., National Climatic Data Center.

Rochette, S. M., and J. T. Moore, 1996: Initiation of an elevated mesoscale convective system associated with heavy rainfall. *Wea. Forecasting*, **11**, 443–457.

Zogg, J. A., R. A. Wolf, A. C. Young, B. M. Astifan, and T. C. Nock, 2002: Service assessment for the 2001 Mississippi River spring flood in the NWS Davenport, Iowa, hydrologic service area. *Preprints, 16th Conference on Hydrology*, Amer. Meteor. Soc., Orlando, FL, pp. 150–154.