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EXAMINATION OF A TRAINING COLD SEASON HEAVY RAIN EVENT OVER THE OHIO RIVER VALLEY

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1. INTRODUCTION

During the period 3-4 January 2000 heavy convective precipitation exceeding 12.7 cm (5 inches) fell across northern Kentucky, southern Indiana, and southern Ohio (Fig. 1). This event basically fit the "synoptic type" heavy rain scenario described by Maddox et al. (1979), as it was associated with a quasi-stationary synoptic scale front and a weak low pressure system which traveled northeastward along this boundary. Heavy rainfall was the result of "training" of mesoscale convective systems (MCSs) over the aforementioned regions. Elevated convection was also observed during the latter part of this event. The persistence of a long-wave trough anchored 1300 km west of the Ohio River Valley slowed the forward movement of the synoptic-scale system.

Synoptic type cold season events are relatively common over this region of the United States and typically result in heavy precipitation (> 10 cm 24 h^{-1}) over a more widespread area than either the "frontal' or "mesohigh" heavy rain events (Maddox et al. 1979). This paper will explore the forcing mechanisms attending this event, including the wind profile that contributed to the training of MCSs, and the forcing and focusing mechanisms for the MCSs, which included elevated thunderstorms.

2. TRAINING MESOSCALE CONVECTIVE SYSTEMS

Figures 2 a-d display infrared (IR), MB-enhanced GOES-8 satellite images of the four major MCSs that passed over the Ohio River Valley during the time period 0000 UTC 3 January through 0000 UTC 4 January 2000. Looping the satellite imagery for this case definitively shows that each MCS formed to the southwest of the heavy rainfall region (approximately over southeast Missouri/northeast Arkansas) and then moved with the mean flow northeastward over the Ohio River Valley. Although each of these MCSs was relatively small in areal extent and unimpressive by warm season standards, each contributed both stable and convective precipitation which cumulatively resulted in excessive rainfall amounts.

The most impressive MCS of the four presented is the last one which developed near Missouri's bootheel and then moved northeastward into southern Indiana. It was accompanied by elevated convection associated with an extensive area of cold cloud tops (temperatures < -60° C). Kane et al. (1987) found the -52° C centroid track tends to bisect the rainfall area such that the heaviest rainfall is typically to the right (typically south) of the path of the centroid. As can be seen by comparing the satellite images with the rainfall distribution shown in Fig. 1, this appeared to be the case during this event.

As will be shown, this was a particularly unique event given that for this time of year absolute moisture and instability values were anomalously high.

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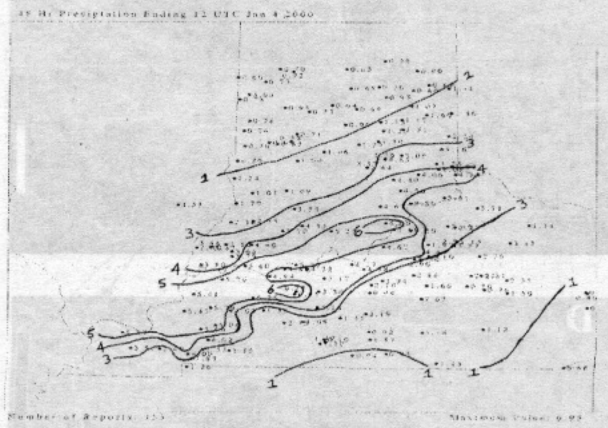
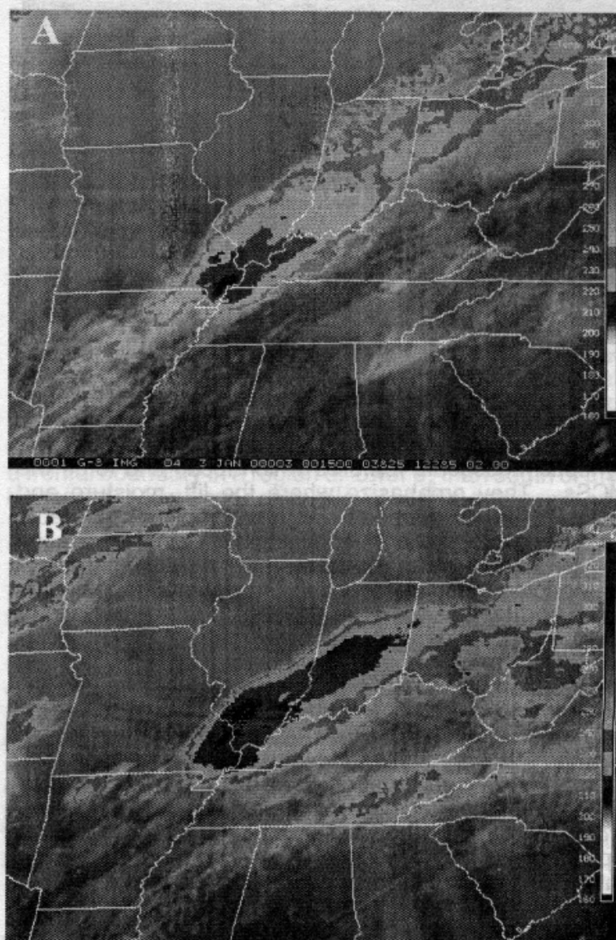


Fig. 1 Total precipitation (in inches) for the 48 h period ending 12 UTC 4 January 2000.



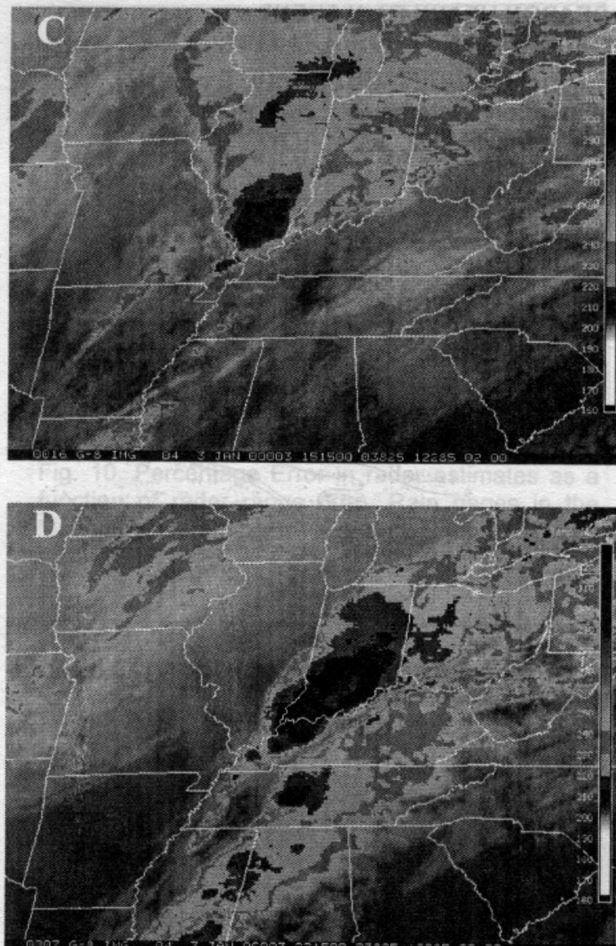


Fig. 2 a-d. GOES 8 IR imagery with MB enhancement for (a) 0015 UTC, (b) 0615 UTC, (c) 1515 UTC, and (d) 2215 UTC 3 January 2000.

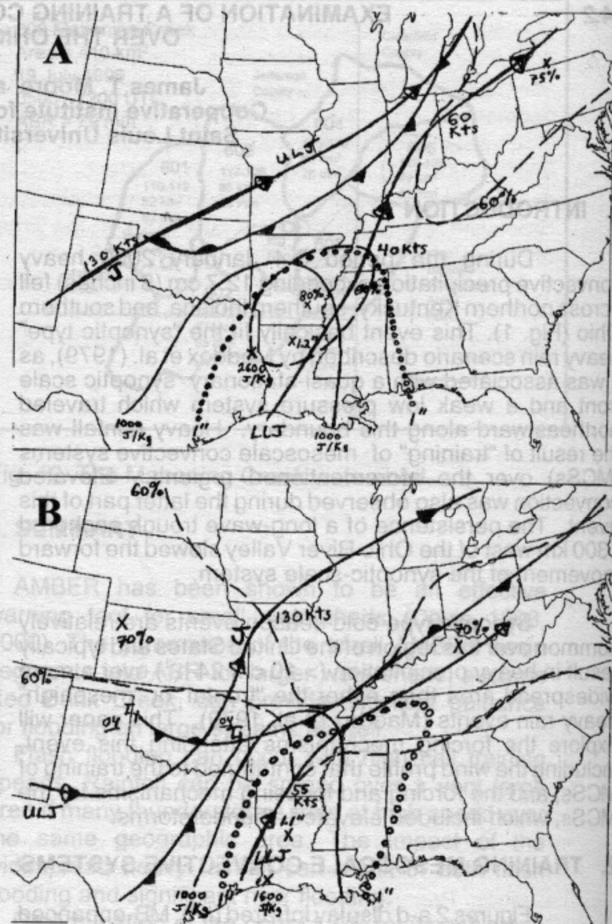


Fig. 3a-b. Composite charts for 3 January 2000 for (a) 0000 UTC and (b) 1200 UTC. Solid line is 1000 J kg^{-1} CAPE isopleth, dashed line is 60% mean surface-500 mb relative humidity, dotted line is 1 inch PW isopleth, arrows show position of ULJ and LLJ axes; frontal positions are shown using standard notation.

3. Synoptic Features Attending the Event

Figures 3a-b are composite charts which depict the major synoptic features associated with this event. The composite charts are helpful for identifying the major synoptic/mesoscale features which focus and force the MCSs. They emphasize where the lift, moisture and instability are juxtaposed to produce conditions favorable for the development of convection. Using composite charts follows naturally from the "ingredients-based" methodology for forecasting heavy rainfall events espoused by Doswell et al. (1996). Figure 3a, valid at 0000 UTC 3 January, shows that relatively large convective available potential energy (CAPE) values of greater than 1000 J kg^{-1}and high precipitable water (PW; greater than one inch) values were located to the south and west of the Ohio River Valley. In addition, mean surface-500 mb relative humidity values exceeding 60% were located over most of Arkansas. The low-level jet (LLJ) axis extended east of the slow-moving cold front from Louisiana northeastward into Ohio with a maximum speed of 30 m s^{-1} (60 knots) over northern Ohio. An interesting aspect of this case is that the upper-level jet (ULJ) was situated well west of the Ohio River Valley and its axis was oriented basically parallel to the LLJ axis. At this time MCS number 1 (Fig. 2a) was located east of the frontal zone, to the northwest of the LLJ axis, and north of the maximum CAPE, PW, and highest mean relative humidity.

Conditions are even more primed by 1200 UTC 3 January as the southern part of the LLJ axis has strengthened to 27 m s^{-1} (55 knots). The LLJ core is now located over northwest Louisiana and central Arkansas which is coincident with the maximum values of PW (exceeding 1 inch, ~200% of normal) and CAPE (exceeding 1200 J kg^{-1}). Also note how the mean surface-500 mb relative humidity values over the Ohio River Valley increase from 60% in central Arkansas to over 70% over northern Kentucky. It is likely that this region has been "pre-conditioned" by the previous MCS activity (MCSs 1, 2, and 3) as they enriched the environmental relative humidity both in the near-cloud environment as well as the sub-cloud layer. This acts to increase the precipitation efficiency of the subsequent convection. Also evident in the composite chart is the presence of a synoptic-scale trough noted by the undulation in the ULJ streak axis. A weak surface circulation located in eastern Oklahoma also increased the transport of moisture and instability northward into the Ohio River Valley, while slowing the forward motion of the frontal boundary eastward.

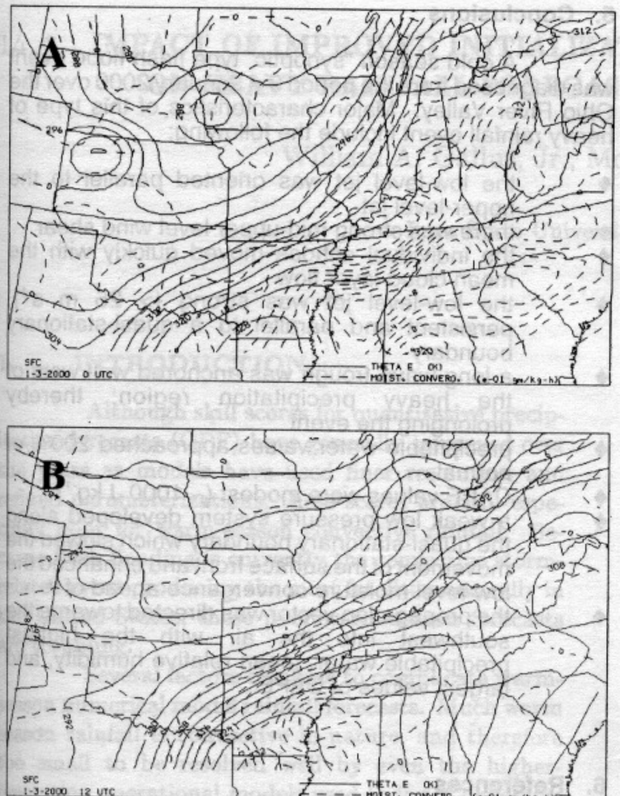


Fig. 4 a-b. Surface θ_e (K, solid lines) and moisture convergence (10^{-1} g kg^{-1} h^{-1}; dashed lines) for (a) 0000 UTC and (b) 1200 UTC 3 January 2000.

Figures 4 a-b display the surface θ_e and moisture convergence at 0000 and 1200 UTC 3 January 2000. Of interest here is the fact that the MCS activity was located north and west of the θ_e ridge axis in the gradient region. Also, it is evident that these backbuilding MCSs were associated with maxima in the surface moisture convergence field that extended southwest of the Ohio River Valley, a sure sign that convective activity is not ending. Junker and Schneider (1997) noted, in their study of MCSs during the summer months of 1993 in the Midwest, that when high values of surface moisture convergence are located upstream from the initial convection, backbuilding convection is most likely. Maxima of moisture convergence around 2 g kg^{-1} h^{-1} were located upstream from western Kentucky into Arkansas at both time periods.

To understand the nature of the backbuilding MCS activity it is useful to analyze cell motion, storm motion, and propagation vectors using the method described by Corfidi et al. (1996). In the present case rawinsonde data were subjectively interpolated to the position of Paducah, Kentucky (southwest Kentucky) close to the position of redeveloping MCS activity. At 0000 UTC 3 January the propagation vector, which is assumed to be equal and opposite to the 850 mb LLJ, is directed to the southwest, while storm motion is to the northeast at about 14.5 m s^{-1}. This vector diagram displaying the cell, storm and propagation vectors is typical for cold season, synoptic type heavy rain scenarios (Chappell 1986). Twelve hours later a similar vector diagram is seen with the exception being that the storm

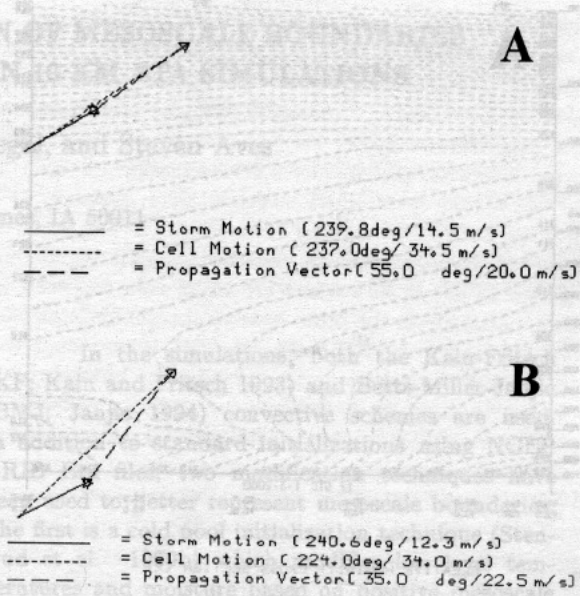


Fig. 5 a-b. Vector method applied to region near Paducah, Kentucky for (a) 0000 UTC and (b) 1200 UTC 3 January 2000. Values for winds at 850, 700, 500, and 300 mb were interpolated to Paducah, Kentucky using surrounding observed rawinsonde data.

motion vector is a little weaker and the propagation vector is directed 20° more to the south.

The above discussion shows that there were many parameters which would point towards the likelihood of training MCSs during this event, alerting the forecaster to the possibility of heavy rain, eventually leading to flash flooding.

4. Elevated Convection

The third MCS depicted in Fig. 2c at 1515 UTC 3 January was comprised of elevated thunderstorms that initiated over north-central Arkansas, north of the frontal boundary at around 1200 UTC 3 January. Elevated thunderstorms have been discussed by Colman (1990), who defined them as thunderstorms which form north of a frontal boundary in a region of lower θ_e than south of the boundary. Most importantly, elevated thunderstorms are not "rooted" in the boundary layer. Rochette and Moore (1996) discussed an elevated MCS that formed over Missouri on 6 June 1993, producing a swath of 5-10 cm (~2-4 inches) of rain across central Missouri. They noted that the pre-convective environment was characterized by a layer of convectively stable air (i.e., θ_e increasing with height) at low levels overlain by a substantial layer of convectively unstable air (i.e., θ_e decreasing with height). If this convectively unstable layer is subjected to lifting to condensation, it will become unstable and support convection. Thus, many elevated thunderstorms, which often produce heavy rainfall and sometime large hail, are associated with this characteristic intrusion of a convectively unstable layer northward above the frontal boundary.

Figure 6a illustrates the θ_e profile at 1200 UTC 3 January along a basically north-south cross section taken from south-central Iowa to south-central Arkansas. At this

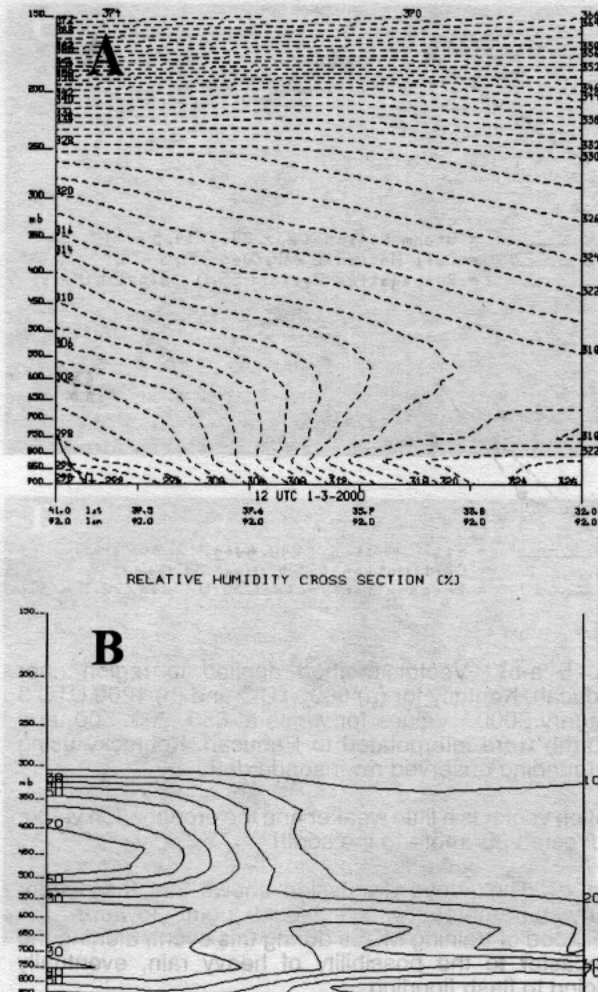


Fig. 6 a-b. (a) Cross section of θ_e along a north-south line from south-central Iowa to south-central Arkansas at 1200 UTC 3 January 2000. Convectively unstable zone is where the isopleths of θ_e "fold" underneath themselves; in these regions θ_e is decreasing with height. (b) Cross section of relative humidity along the same path as in (a) in intervals of 10% for 1200 UTC 3 January 2000.

time the elevated MCS was located over north-central Arkansas, north of the frontal boundary depicted in Fig. 3b. It is easily seen in the diagram that the isopleths of θ_e "fold" underneath themselves in the center of the cross section, where the elevated thunderstorms developed. The relative humidity along the same cross section (Fig. 6b) reveals a region of relative humidity greater than 60% in low levels capped by drier air. This decrease in relative humidity with height agrees with the decrease in θ_e noted in Fig. 6a.

It is likely that the MCS seen in the last satellite image in Fig. 2d was also comprised of elevated thunderstorms. It is important to look for signs favoring the development of elevated thunderstorms as they are often prolific rain producers, as this case demonstrates.

5. Conclusions

A cold season "synoptic" type flash flood event was diagnosed from the period 3-4 January 2000 over the Ohio River Valley. Major characteristics of this type of heavy rainfall event include the following:

- the low-level jet was oriented parallel to the upper-level jet
- there was strong mid-upper level wind shear
- the individual echoes moved quickly with the mean cloud-layer flow
- the low-level jet was strong (> 25 m s^{-1}), persistent and parallel to a quasi-stationary boundary
- a long-wave trough was anchored well west of the heavy precipitation region; thereby prolonging the event
- precipitable water values approached 200% of normal
- CAPE values were modest (~ 1000 J kg^{-1})
- a weak low pressure system developed along the quasi-stationary boundary which slowed the movement of the surface front and enhanced the low-level moisture convergence ahead of it
- the propagation vector was directed towards the southwest into the air with the highest precipitable water, mean relative humidity, and largest values of CAPE

6. References

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