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THE INFLUENCE OF THE GREAT LAKES ON WARM SEASON WEATHER SYSTEMS DURING BAMEX

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1. INTRODUCTION:

The Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX) was conducted from 18 May to 7 July 2003 out of Mid America Airport (BLV) located approximately 40 km east of St. Louis, Missouri (see Davis et al. 2004 for an overview of BAMEX). The period 5-14 June 2003 during BAMEX was noteworthy for a strong subtropical jet (STJ) that dominated the large-scale flow pattern (Galarneau and Bosart 2004). The STJ was positioned from southeast of Hawaii east-northeastward to the Mississippi Valley, and then northeastward to the North Atlantic. The STJ provided a freeway for mesoscale convective systems (MCSs) to propagate across the central US. These MCSs were associated with multiple convective modes, including several mesoscale convective vorticies (MCVs) and bow echoes.

By early July 2003 the STJ had dissipated and convective systems were occurring much further north than during the 5-14 June 2003 period. The large-scale pattern favored the occurrence of MCSs and bow echoes (see Johns 1982, 1984) that propagated from Nebraska and Iowa to the Great Lakes from 3-7 July 2003. Of interest for our purposes is that both of these active weather periods during BAMEX featured multiple convective systems that interacted with the Great Lakes.

In this paper, two case studies from the aforementioned periods will be shown to demonstrate the interaction of convective system with the Great Lakes. The first case (11-13 June 2003) was associated with a long-lived MCV. MCVs have been documented to develop in the stratiform region of MCSs (e.g., Jorgenson et al. 1997). Davis and Weisman (1994) suggested that the longevity of MCVs may be controlled by vertical shear. Weak but well-defined shear confined to low levels appears to optimize longevity, whereas moderate shear extending throughout the depth of the vortex weakens the MCV. Long-lived MCVs that last through several diurnal heating cycles can be responsible for reorganizing convection (e.g., Menard and Fritsch 1989). The reorganized convection can provide a positive feedback mechanism by sustaining or reinvigorating the MCV (e.g., Trier et al. 2000). This particular long-lived MCV was noteworthy for lasting several diurnal heating cycles, reorganizing convection and acquiring baroclinic structure as it interacted with boundaries associated with Lake Erie-induced surface temperature contrasts.

The second case (4-5 July 2003) was associated with several squall lines and bow echoes that interacted with the Great Lakes. Noteworthy was a squall line that appeared to intensify as it reached and crossed lower Lake Michigan near 1200 UTC 4 July. Subsequently, this squall line raced eastward across lower Michigan and extreme northwestern Ohio before it weakened. Also of interest is that when this convective line reached western Lake Erie it dissipated most rapidly over the lake waters.

The purpose of this paper is to illustrate the interaction of MCSs with the Great Lakes in both aforementioned cases by means of detailed surface and radar analyses. Surface thermal boundaries play an important role in focusing the development of new convection in the periphery of MCVs (as was noted during the 11-13 June 2003 case) and in conjunction with advancing squall lines (as was noted during the 4-5 July 2003 case).

2. DATA SOURCES:

The data used in this study were obtained from the BAMEX field catalog (http://www.ofps.ucar.edu/bamex/catalog), the archives at the University at Albany/SUNY and NWS 88D Doppler radar observations.

3. RESULTS:

(a) Case of 11-13 June 2003:

Convection began over the higher terrain of New Mexico at 0000 UTC 10 June in response to daytime heating (not shown), and subsequently organized into an MCS by 0300 UTC 10 June (not shown). As this MCS propagated southeastward, remnant mid-level vorticity associated with the aforementioned convection traveled northeastward into Oklahoma where it triggered new convection at 0000 UTC 11 June. This retriggering of convection was followed by a reintensification of the mid-level vorticity maximum and resulted in an MCV by 0600 UTC 11 June. This convective retriggering is consistent with the positive feedback mechanism suggested by Trier et al. (2000).

The remnant vorticity/MCV track is shown in Fig. 1 and is based upon an analysis of the 600 hPa

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absolute vorticity field. Mid-level vorticity is first evident at 0600 UTC 10 June over eastern New Mexico in association with a squall line and trailing stratiform region (not shown). The vorticity maximum travels eastward with its associated squall line, then turns northeastward immediately after 1200 UTC 10 June as the squall line turns southeastward. The remnant vorticity maximum retriggers convection, as mentioned above, and moves east-northeastward, then northeastward towards Lake Erie.

West to east cross sections of potential vorticity (PV), potential temperature (θ), and wind are shown on Fig. 2. At 1200 UTC 10 June (Fig. 2a) an upshear tilt configuration of the mid- and upper-level disturbances is evident and are connected with a small PV filament of approximately 1.0 PVU. At 0600 UTC 11 June, the mid-level disturbance is located over central Oklahoma and has strengthened (Fig. 2b). At this time the mid-level PV anomaly is showing the classic signature of an interior PV anomaly seen in Fig. 21 of Hoskins et al. (1985), with uplifted (downlifted) θ surfaces beneath (above) the disturbance. At 1800 UTC 11 June, the PV anomaly has grown further while a secondary anomaly has developed at 800 hPa (Fig. 2c). At this point, the MCV is in its mature stage, is growing upscale and is retriggering convection. Upshear tilt is evident in the wind field. By 0000 UTC 13 June, the upper-level PV disturbance has moved ahead of the mid-level PV disturbance, resulting in a forward tilt, and subsequent weakening of the MCV (Fig. 2d).

Figures 3a-d document the evolution of the surface features associated with the MCV (the corresponding radar imagery is available at www.atmos.albany.edu/student/tomjr/coast.html). At 0000 UTC 11 June (Fig. 3a), a broad area of low pressure is positioned over south-central Oklahoma. A weak surface trough oriented south-southwest to north-northeast was embedded within this low pressure area over central Oklahoma. This low has a surface pressure deficit of approximately 2 hPa with respect to the surrounding environment. A squall line, triggered by remnant mid-level vorticity seen in Fig. 2b, has developed along this surface trough. The squall line develops a trailing stratiform region in which an MCV develops by 0600 UTC 11 June (not shown).

At 1800 UTC 11 June (Fig. 3b), the MCV is now in the mature stage with a surface pressure deficit of approximately 3-4 hPa. The MCV, while in Missouri and Arkansas, was embedded in a region of weak θ gradient. Convection is redeveloping in the inflow region of the MCV. A wind shift boundary lies over central Illinois to the north and east of the MCV and extends northeastward to the southern edge of the Great Lakes (Fig. 3b). At 0000 UTC 12 June (not shown), the MCV's circulation area has grown, and surface pressure has dropped to almost 1004 hPa. Precipitation has shifted to the northern side of the MCV, in response to a shift in the main ascent region to the northwest side (not shown) and the aforementioned boundary over central Illinois. The MCV is beginning to interact with this boundary and is transitioning into a baroclinic system.

By 1200 UTC 12 June the MCV has reached central Indiana (Fig. 3c). Of interest is the weak baroclinic zone that stretches from just west of the MCV center northeastward to western New York. Enhanced cyclonic curvature in the sea-level isobars at this time is indicative of warm frontogenesis ahead of the path of the MCV. The shift of the precipitation to the north and east of the track ,of the MCV is consistent with the warm frontogenesis

At 2100 UTC 12 June (Fig. 3d), the MCV has continued moving northeastward and is now situated over northern Ohio. The area of cyclonic circulation associated with the MCV has strengthened and expanded. The MCV has now attached itself to the aforementioned surface baroclinic zone just south of Lake Erie (Fig. 3d). The surface θ gradient was likely enhanced in the warm frontogenesis region because the warm southerly flow ahead of the MCV was able to interact with the cooler air situated over the still chilly waters of Lake Erie. Precipitation continues to be found on the poleward side of the MCV in the vicinity and to the north of the surface boundary along the south shore of Lake Erie at this time.

At 0000 UTC 13 June, the upper-level disturbance has moved eastward of the MCV, resulting in downshear tilt of the system. Subsequently, the MCV dissipated, and the remnants can be tracked into southern Canada (not shown).

(b) Case of 4-5 July 2003:

Radar imagery for the period 0830 to 1650 UTC 4 July 2003 can be found at www.atmos.albany.edu/student/tomjr/coast.html. Of interest is the squall line that moves from eastern Iowa at 0600 UTC 4 July to extreme western lower Lake Michigan near 1200 UTC 4 July. The radar imagery suggests that the squall line became better organized as it started to cross the chilly waters of Lake Michigan. This reorganization occurred as the convective elements that formed ahead of the line were ingested into the line. As the squall line continues eastward across Lake Michigan it appeared to weaken just before reaching the eastern shore and subsequently reintensifying as it came on shore over western Michigan. The squall line then moved southeastward across lower Michigan, northwestern Ohio and western Lake Erie as it dissipated (not shown). The portion of the squall line that crossed western Lake Erie dissipated most rapidly.

A series of surface maps beginning 0600 UTC 4 July and ending 2100 UTC 4 July is shown in Fig. 4. At 0600 UTC 4 July a squall line is organizing over northwestern Iowa and southwestern Minnesota where sustained winds of 30-40 kt are reported (Fig. 4a). A weak baroclinic zone is evident in the potential temperature field in conjunction with the outflow boundary that stretches southwestward into eastern Nebraska (Fig. 4a).

By 1200 UTC 4 July the squall line has reached coastal southeastern Wisconsin and extreme northeastern Illinois. Of interest is the southerly flow over lower Lake Michigan and along the western shore of lower Michigan, suggestive of enhanced surface convergence at the leading edge of the squall line (Fig. 4b). Subsequently, the squall line advanced into lower Michigan by 1500 UTC 4 July (Fig. 4c). Differential heating between the rain-cooled air to the west and the strongly heated air to the east helped to contribute to increased baroclinicity across the western part of lower Michigan (Fig. 4c). An important difference from the 1200 UTC 4 July map was that surface winds ahead of the squall line over lower Michigan were mostly from the west-southwest and southwest instead of southerly over the open waters of Lake Michigan, suggestive of less surface convergence and a weaker wind veering profile by 1500 UTC 4 July (fig. 4c). Note also a new area of convection over northwestern Iowa and southwestern Minnesota and its associated outflow boundary at 1500 UTC (Fig. 4c).

By 1800 UTC 4 July the squall line is beginning to weaken over western Lake Erie and vicinity. An outflow boundary in the surface potential temperature field stretches from extreme southern Lake Michigan to northwestern Ohio and from there northeastward to central Lake Erie (Fig. 4d). The aforementioned second outflow boundary now stretches from extreme southwestern Wisconsin to eastern Nebraska (Fig. 4d). Finally, by 2100 UTC 4 July the squall line over Ohio has dissipated, leaving behind an outflow boundary that extends southwestward from western New York to extreme southern Ohio. From there the boundary abruptly turns northward toward Lake Huron (Fig. 4e). The latter portion of the boundary is acting like a warm front with the thermal gradient likely reinforced by rain-cooled air to the east that is unable to recover to ambient values because it is residing over the relatively cool waters of Lake Erie (Fig. 4e). Meanwhile, the second boundary to the west has weakened in response to strong heating on both sides of the boundary.

4. CONCLUSIONS:

The period 5-14 June 2003 during BAMEX featured a strong STJ from southeast of Hawaii, stretching across the southern US, then northeastward to the North Atlantic. Transient disturbances embedded within the STJ acted to trigger multiple convective systems across the US. These disturbances were unable to trigger convection until they crossed to the eastern side of the Rockies and tapped the moist unstable air and thus increasing the Rossby penetration depth.

A long-lived MCV formed from a squall line triggered by remnant mid-level vorticity over Oklahoma on 0600 UTC 11 June. This MCV can be tracked northeastward to Ohio. It is noteworthy for tilting upshear, reorganizing convection, growing upscale, and acquiring baroclinic structure. The latter is of special interest because the baroclinic structure was a direct result of a quasi-stationary surface boundary that formed across the lower Great Lakes in response to differential heating between the heated land and the cooler waters over the Great Lakes. This surface thermal boundary served as a focus for new precipitation growth in response to warm air advection as the MCV acquired frontal structure.

The period 3-6 July 2003 during BAMEX featured a parade of MCSs, bowing squall lines and derechoes that moved from Iowa, Nebraska and Minnesota eastward across the lower Great Lakes. Noteworthy was the squall line of 4 July that underwent modest intensity changes as it approached and crossed lower lake Michigan near 1200 UTC. This squall line first appeared to strengthen somewhat over western Lake Michigan before weakening somewhat over eastern Lake Michigan and then briefly strengthening again over western lower Michigan. An analysis of surface observations suggested that enhanced southerly flow over lower Lake Michigan and extreme western Michigan may have provided enhanced low-level convergence and more favorable veering wind profiles for organized deep convection. An unknown factor was whether there was a strengthened low-level southerly jet over Lake Michigan that might have contributed to squall line modulation.

5. ACKNOWLEDGEMENT:

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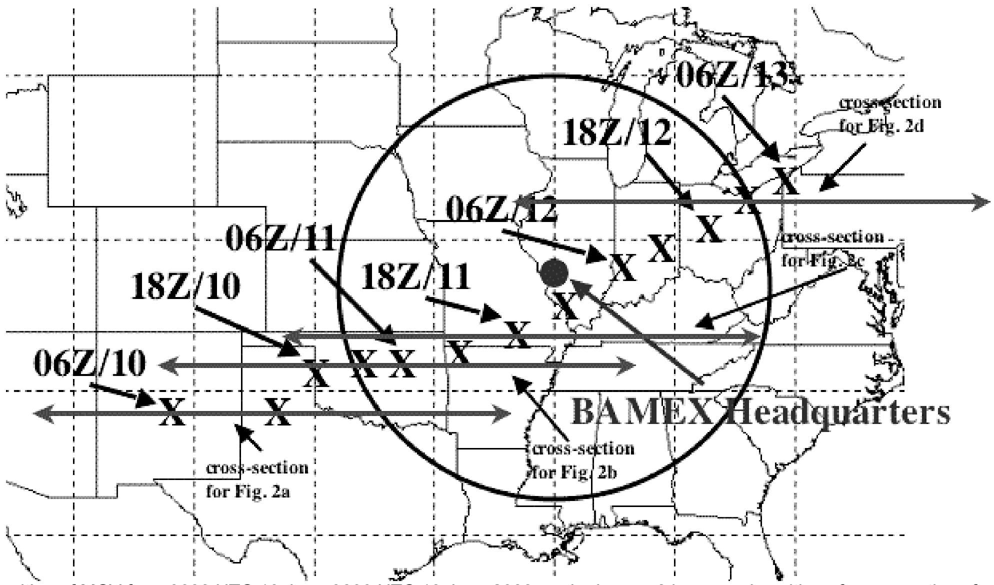
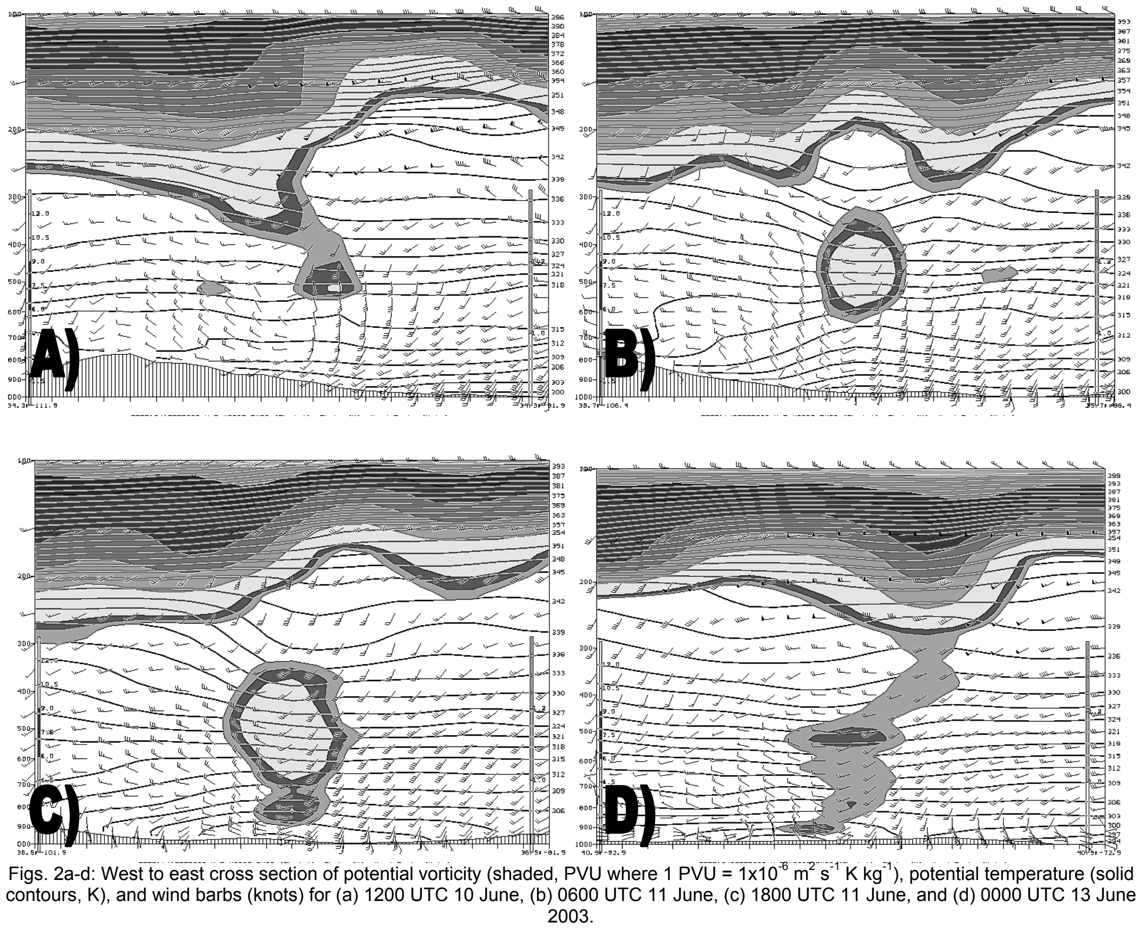


Fig. 1: Position of MCV from 0600 UTC 10 June-0600 UTC 13 June 2003 marked every 6 hours and position of cross sections for Figs. 2a-d (solid lines with arrows on endpoints).



Figs. 2a-d: West to east cross section of potential vorticity (shaded, PVU where 1 PVU = 1×10^{-6} m^2 s^{-1} K kg^{-1}), potential temperature (solid contours, K), and wind barbs (knots) for (a) 1200 UTC 10 June, (b) 0600 UTC 11 June, (c) 1800 UTC 11 June, and (d) 0000 UTC 13 June 2003.

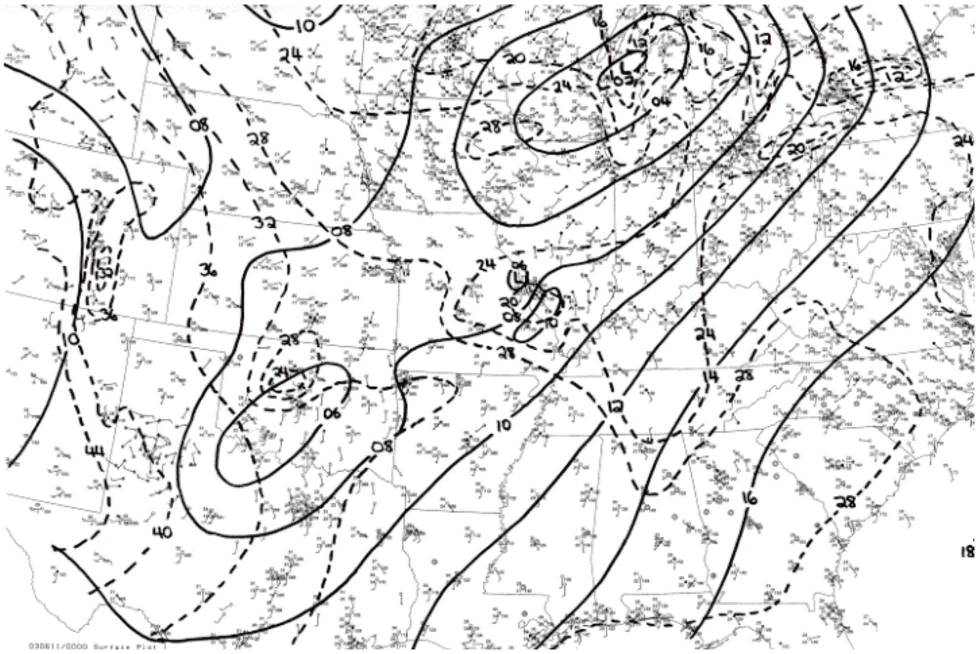


Fig 3a: Manual surface analysis of pressure (mb; solid contours) and potential temperature (°C; dashed contours) for 0000 UTC 11 June 2003.

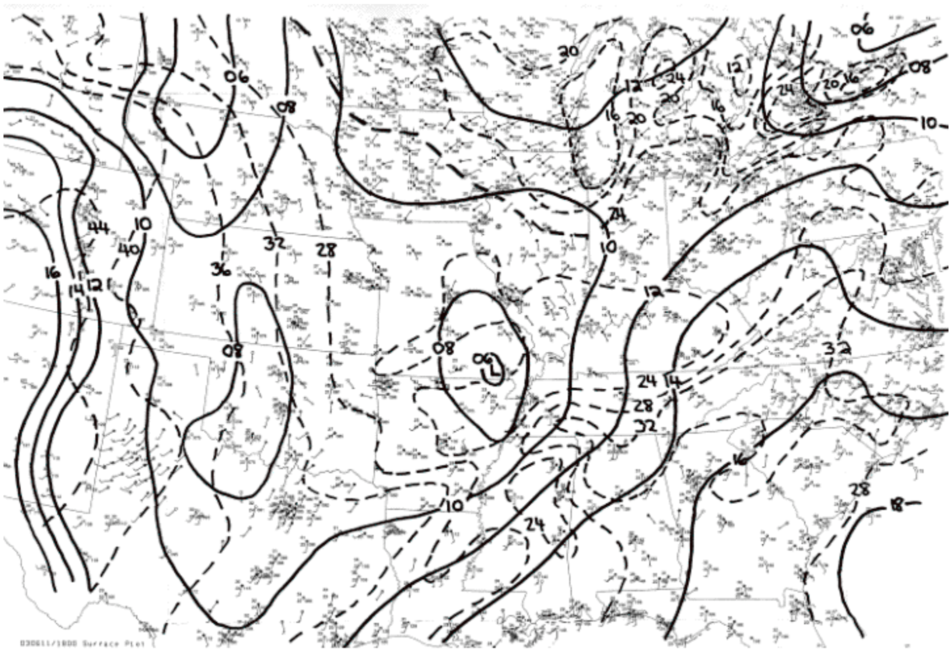


Fig. 3b: As in Fig. 3a, except for 1800 UTC 11 June 2003.

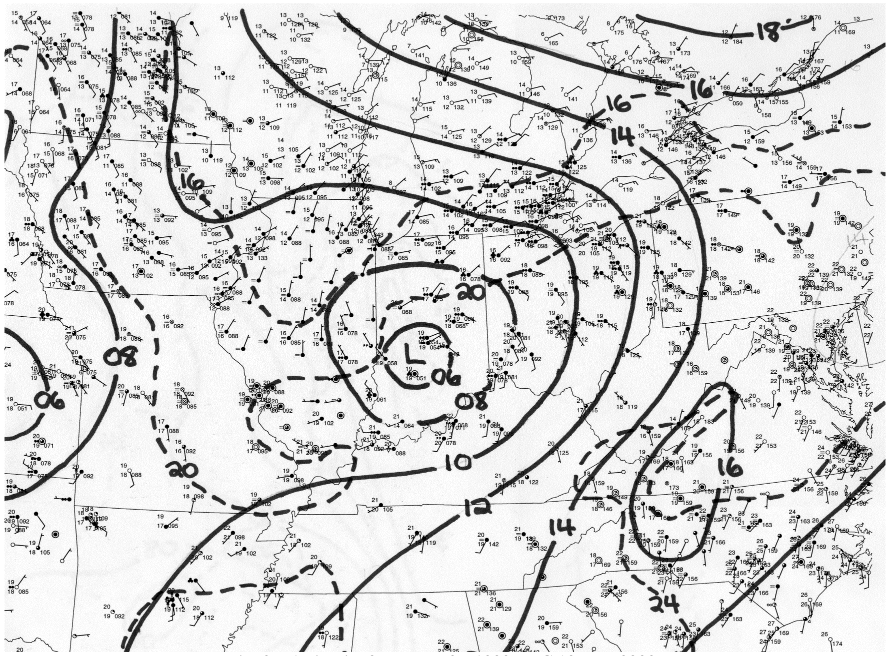


Fig. 3c: As in Fig. 3a, except for 1200 UTC 12 June 2003.

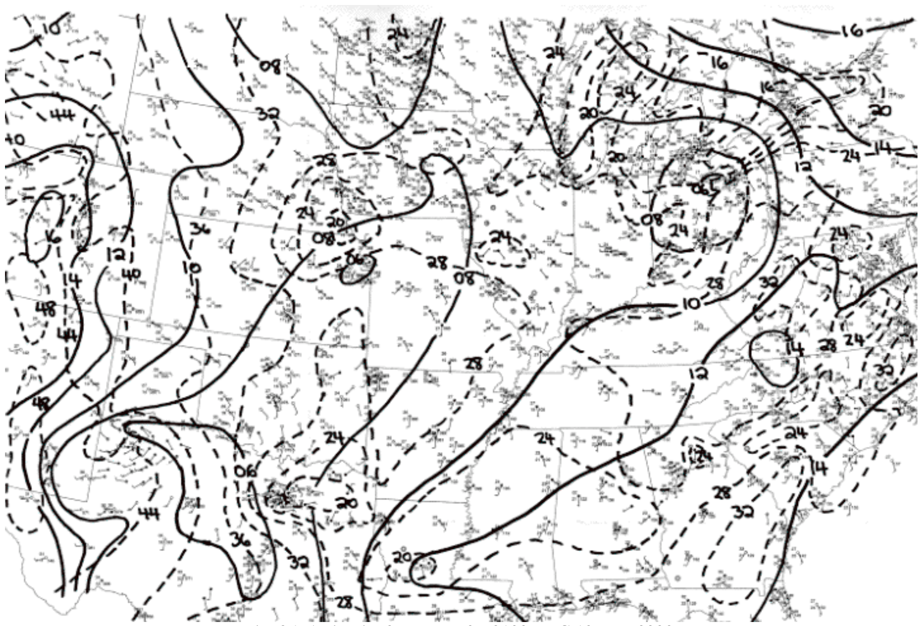


Fig. 3d: As in Fig. 3a, except for 2100 UTC 12 June 2003.

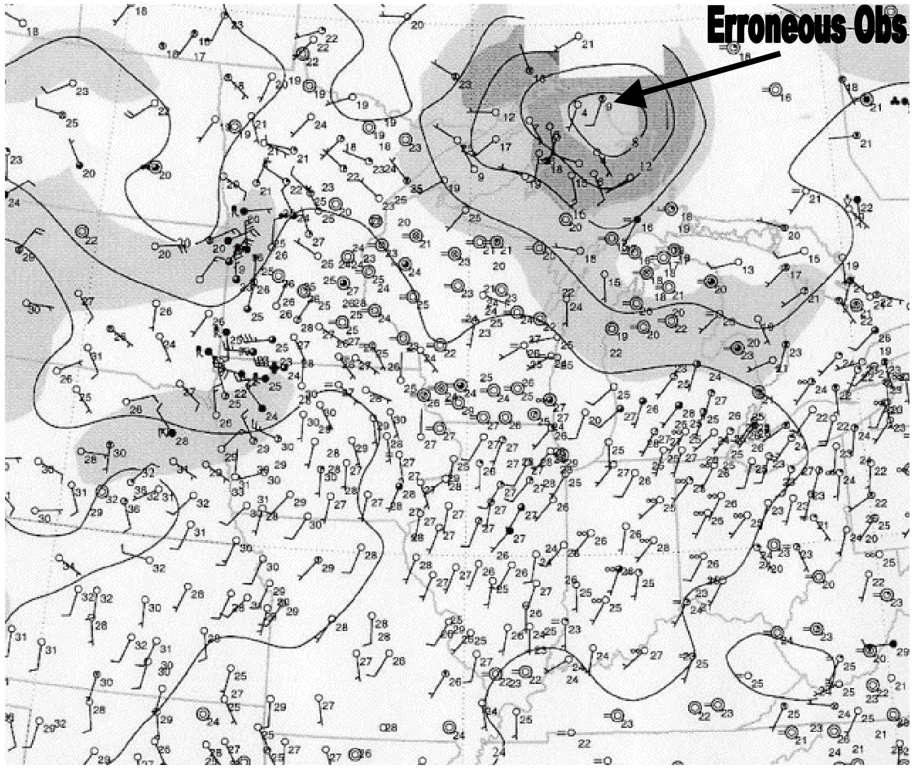


Fig. 4a: Surface plot of potential temperature (°C; solid contours) and gradient (shaded; light gray - 2.5°C/100 km, medium gray 5°C/100 km, dark gray 7.5°C/100 km) for 0600 UTC 4 July 2003.

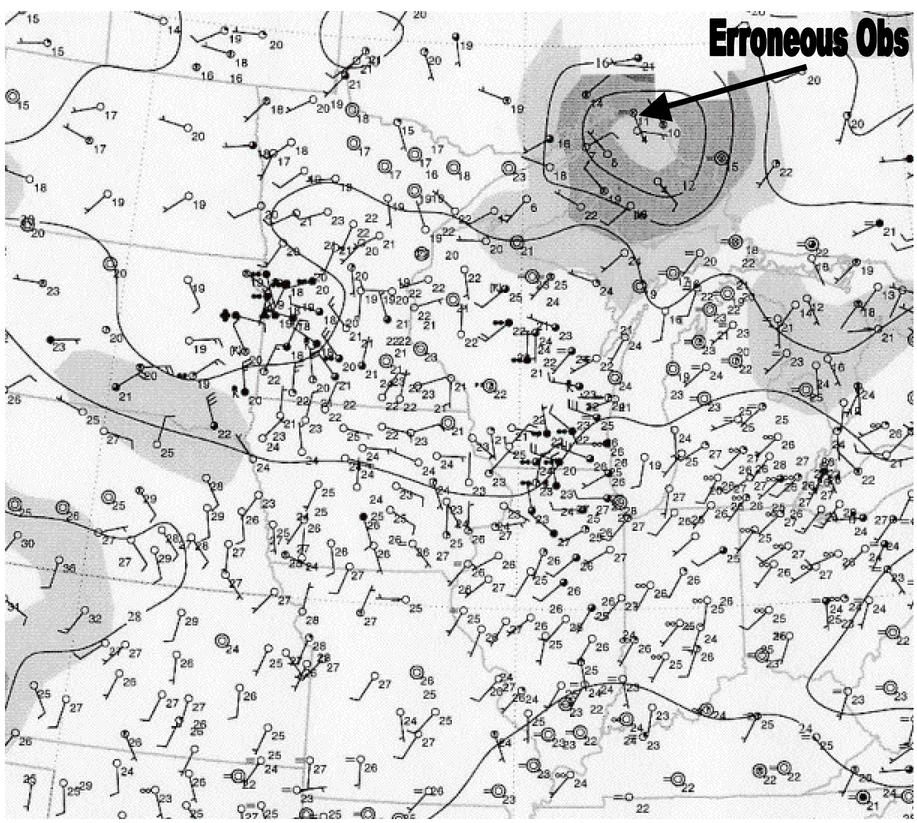


Fig. 4b: Same as Fig. 4a, except for 1200 UTC 4 July 2003.

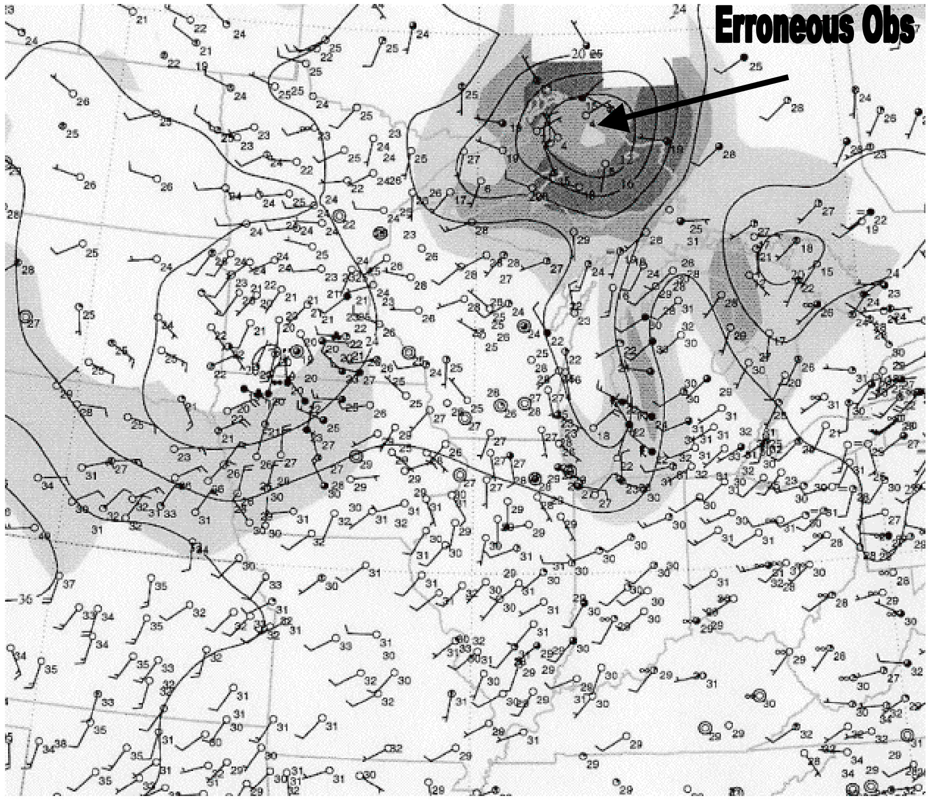


Fig. 4c: Same as Fig. 4a, except for 1500 UTC 4 July 2003.

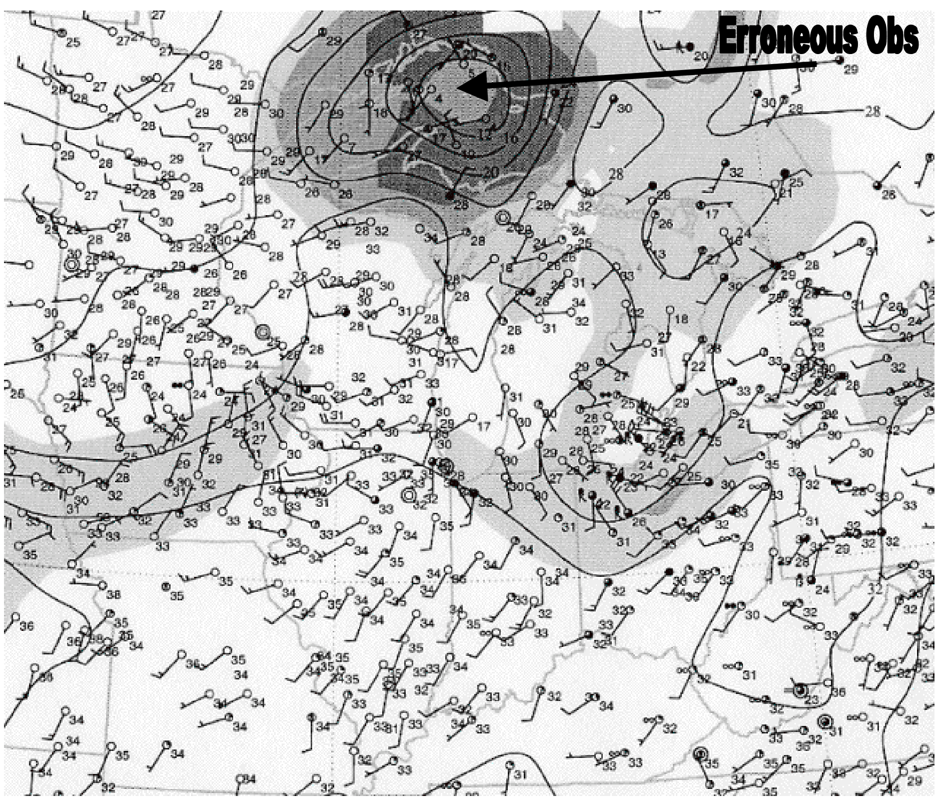


Fig. 4d: Same as Fig. 4a, except for 1800 UTC 4 July 2003.

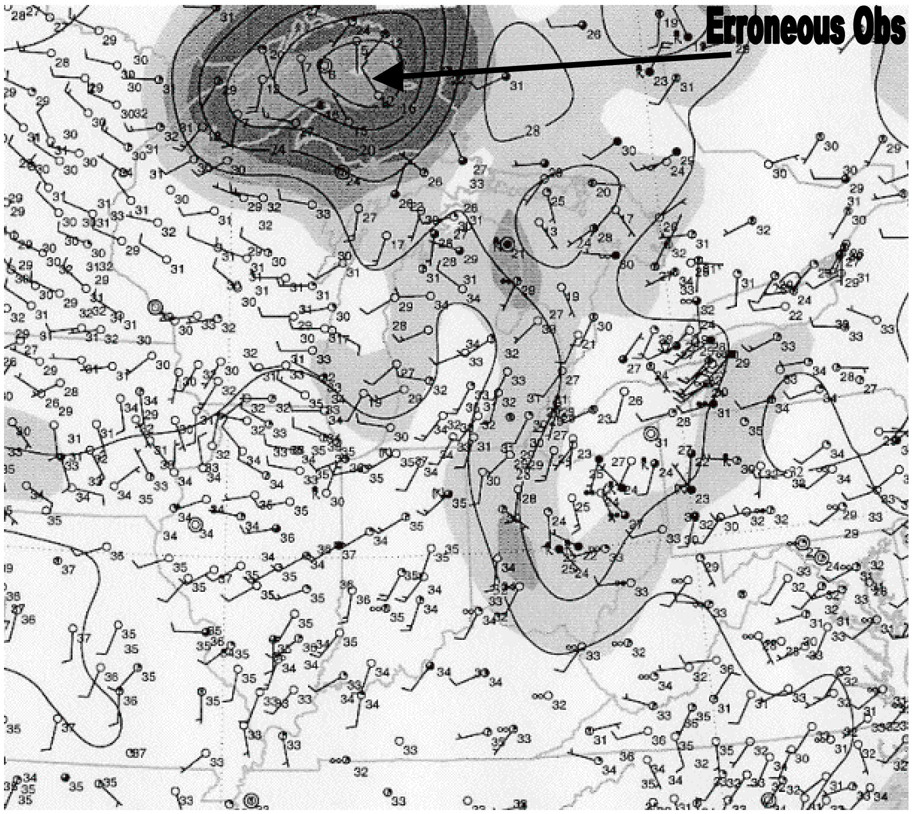


Fig. 4e: Same as Fig. 4a, except for 2100 UTC 4 July 2003.