6.5 ENVIRONMENTAL PRECURSORS TO MESOSCALE CONVECTIVE SYSTEM DEVELOPMENT

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1. INTRODUCTION

Mesoscale convective systems (MCSs) are important weather phenomena to predict for a couple of reasons. On the positive side, they generate essential rainfall for the central United States (Fritsch et al. 1986, Jirak et al. 2003). On the negative side, they devastate property by producing severe weather over a large area (Houze et al. 1990, Jirak et al. 2003). Regardless of whether the impact of MCSs is primarily beneficial or harmful, advance knowledge of their development is desirable.

Forecasting for MCSs is very challenging because it requires knowledge of areas favorable for convective initiation, organization, and sustenance. A few studies (e.g., Maddox 1983, Cotton et al. 1989, Augustine and Caracena 1994) have examined environmental conditions prior to and during MCS development. The low-level jet (LLJ), short-wave troughs, and warm air advection are some of the features identified in these studies as being important to MCS development. These findings provide some guidance for forecasters when contemplating possible MCS development. Additionally, quantitative precipitation forecast fields from operational numerical models often provide some indication (i.e., overnight meso-β maxima) when conditions are favorable for MCS occurrence. However, there is an overall lack of specific methods for predicting MCSs (Ziegler 2000).

The objective of this study is to perform a detailed observational analysis of hundreds of MCSs to identify environmental signals that precede MCS development. This study builds on previous studies by including the analysis of many more and varied systems and by using data of higher temporal and spatial resolution. The overall goal is to develop a MCS index comprised of predictive parameters that indicate areas favorable for MCS development. This paper examines some of the most significant precursors to MCS development.

2. DATA AND METHODS OF ANALYSIS

The MCS sample used for this study was selected by Jirak et al. (2003) in their classification study on MCS development. This sample includes more than 300 systems that occurred over the central United States during the warm seasons (April-August) of 1996-1998. Analyses generated by the Eta Data Assimilation System (EDAS) were used to examine the environment prior to the development of these systems. These analyses are of relatively high resolution at 40 km in the horizontal and 3 h intervals.

Numerous basic and derived fields were examined at six hours prior to initiation, three hours prior to initiation, and the time of initiation to determine their importance in MCS development. Three different methods were used to analyze the data and look for predictive signals. One method involves simply taking a single value of a given field at the centroid of each MCS. This single-value method allows for a statistical analysis of typical parameter values for MCSs. A second method involves compositing data from fixed grid points over the U.S. on days with and without MCSs. This fixed-point composite method smoothes out small-scale features and provides an idea of the basic flow pattern. The third method entails averaging data from a movable grid centered on the MCS. This MCS-relative composite method allows for the retention of some of the mesoscale features important to MCS development.

3. SINGLE-VALUE DATA ANALYSIS

For each MCS, a single value of a given environmental parameter was retrieved from the centroid of the system and taken as a representative value for the system. This type of analysis provides a typical range of values for various fields prior to MCS development. A couple of parameters stood out as the best indicators of MCS development, as they were present six hours prior to initiation for at least three-quarters of the systems. One of these parameters is warm air advection at 700 mb. The presence of low-level warm air advection prior to MCS initiation provides the environmental upward vertical motion necessary for development. The other significant parameter is southerly flow at 850 mb. This parameter is a proxy for the LLJ, which advects warm, moist air into the area of interest to help sustain the system.

Some other parameters were present for more than half of the MCSs six hours prior to initiation: 300 mb divergence, 700 mb Q-vector convergence, 850 mb frontogenesis, 850 mb warm air advection, and low-level (i.e., 850 mb and surface) convergence. Other median values include surface-based convective available potential energy (CAPE) of 1300 J kg^{-1} and surface specific humidity of 15 g kg^{-1}.

4. FIXED-POINT COMPOSITES

Fixed-point composites allow for the comparison of general flow patterns and conditions between days with MCS development and days without any MCSs. Height, wind, and moisture fields at several levels were composited at fixed grid points for 330 MCSs at six hours prior to initiation, three hours prior to initiation, and the time of initiation. The same fields were also composited at 200 times (either 00Z or 12Z) when MCSs were not present across the central U.S. (at least 6 h after dissipation and 12 h prior to initiation of MCSs).

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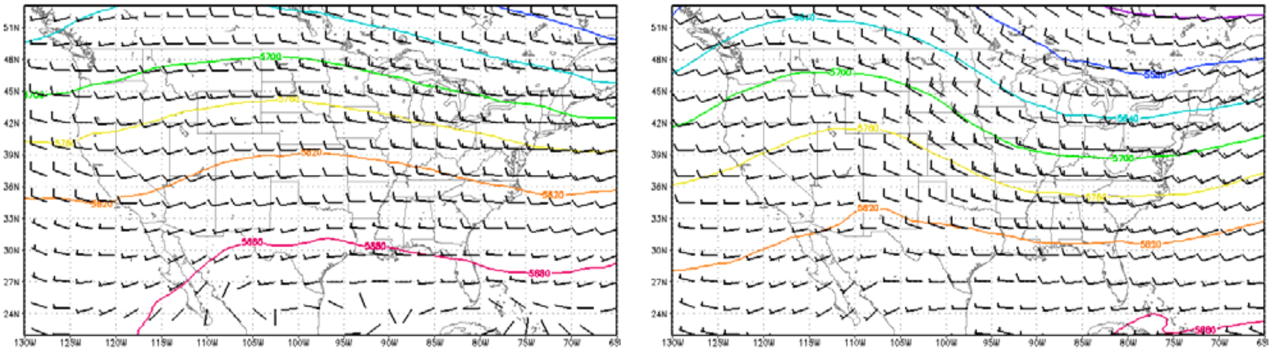

Figure 1. 500 mb fixed-point composite of the height (m) and wind (m s^{-1}) fields 6 hours prior to MCS initiation (left panel). The right panel shows the same fields except for days without MCS occurrence over the central U.S.

The fixed-point composites of the height and wind fields at 500 mb (see Fig. 1) show very different flow patterns between days with MCSs and days without MCSs. Prior to MCS initiation, a weak ridge is centered near the middle of the U.S. (left panel) while the ridge is much stronger and farther west on days without MCSs (right panel). A similar pattern extends through the upper-troposphere.

At 850 mb, significant differences also exist in the height and wind fields between days with and without MCSs (see Fig. 2). The trough in the vicinity of the Rocky Mountains is much more organized prior to MCS development than on days without convective organization. This results in a broader area of strong, southerly winds that extends well into the Central Plains. This setup is favorable for supporting convection through the advection of warm, moist air from the Gulf of Mexico into the plains.

The composite surface map (not shown) displays a well-organized trough along the Rocky Mountains generating strong southerly winds through the Central Plains prior to MCS development. On days without MCSs, the surface trough is farther west and the Bermuda High exists farther east resulting in weaker southerly flow into the plains. Composite maps of low-level moisture and CAPE (not shown) reveal a tongue of moist, unstable air that extends from the Gulf of Mexico into the Central Plains preceding MCS formation that doesn't exist on days without convective organization.

5. MCS-RELATIVE COMPOSITES

MCS-relative composites allow for the analysis of mesoscale features important to MCS development. Basic fields were composited by averaging data for all 330 MCSs on movable grids (20° lon x 15° lat) centered on each system at six hours prior to initiation, three hours prior to initiation, and the time of initiation. A simple filter was then used to remove some of the small-scale noise that results from compositing. The basic fields were analyzed along with numerous derived quantities to detect common environmental conditions prior to MCS development. The map background in these composites (Figs. 3-6) does not have any physical significance, as systems from all across the central U.S. were included in the composite. However, the map does provide a reference of the average initiation location of the MCSs, which is demarcated by a white diamond.

The 300 mb MCS-relative composite reveals weak upper-level forcing six hours prior to MCS initiation. Figure 3 shows that MCSs typically form just upstream of a weak upper-level ridge in an area of weak divergence. Previous studies (Maddox 1983; Cotton et al. 1989; Anderson and Arritt 1998) have shown that a deep tropospheric circulation is important to the development of MCSs. The upper-level divergence maximum associated with this circulation intensifies toward the time of initiation. This indicates that the upper-level divergence maximum is a response to deep

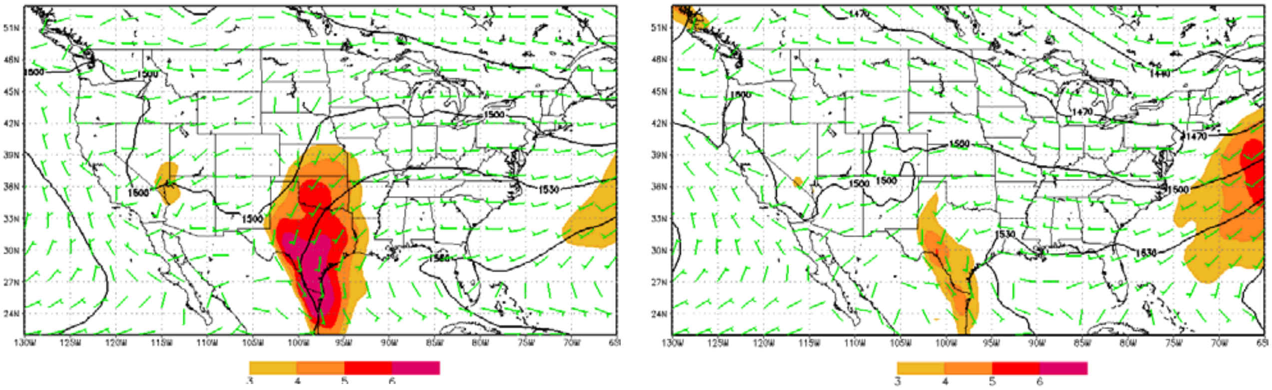

Figure 2. 850 mb fixed-point composite of the height (m) and wind (m s^{-1}) fields 6 hours prior to MCS initiation (left panel). The right panel shows the same fields except for days without MCS occurrence over the central U.S. The shaded areas indicate regions of southerly winds >3 m s^{-1}.

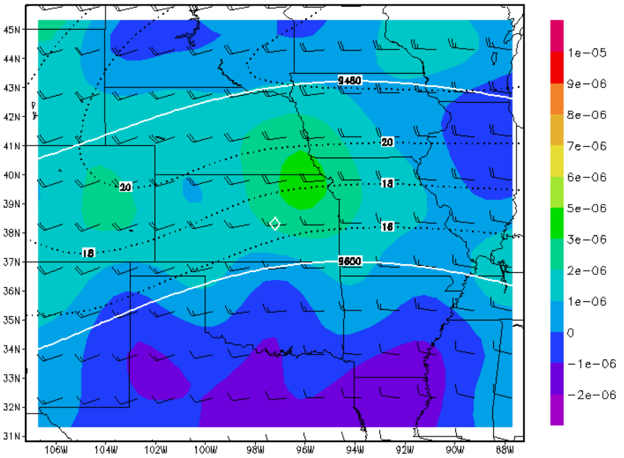

Figure 3. 300 mb MCS-relative composite of the height (m) and wind (m s^{-1}) fields 6 hours prior to MCS initiation. The solid white lines are the height contours; the dotted black lines are the isotachs; and the divergence is shaded with the scale on the right in s^{-1}. The white diamond indicates the average location of MCS initiation.

tropospheric ascent as the system develops and cannot be used effectively as a predictive indicator. The jet streak may provide some support to MCS development by inducing upward motion in the right entrance region (see Fig. 3).

A stronger signal is shown in the 700 mb temperature advection field in Fig. 4. As Maddox (1983) and others have indicated, low-level warm air advection provides the lifting necessary for the development and organization of MCSs. Warm air advection at 700 mb appears to be a particularly good indicator, as the maximum coincides with the location of MCS initiation six hours later (see Fig. 4). In addition, the warm air advection pattern is interesting with a sharp decrease to the west, but a broad area of high values that extends to the east, which indicates that eastward-moving MCSs will remain in an environment favorable for survival.

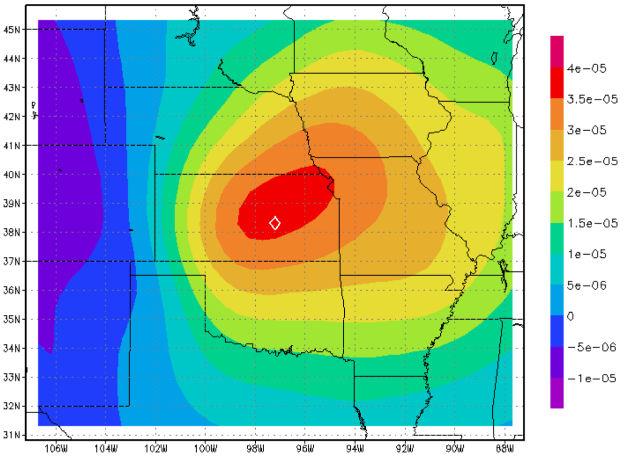

Figure 4. 700 mb MCS-relative composite of temperature advection (K s^{-1}) 6 hours prior to MCS initiation. The white diamond indicates the average location of MCS initiation.

At 850 mb, a well-defined short-wave trough and its associated convergence are clearly evident prior to MCS development (see Fig. 5). Six hours before initiation, the trough and convergence maximum are west of the point of MCS initiation, but they strengthen and advance eastward with time. This evidence suggests that the convergent area at 850 mb may be a preferred location for convective initiation of initial convective cells that move eastward into an area favorable for upscale growth into MCSs. The LLJ is also apparent in Fig. 5 and has been noted as a recurrent feature of the antecedent environment of MCSs (Maddox 1983; Augustine and Caracena 1994).

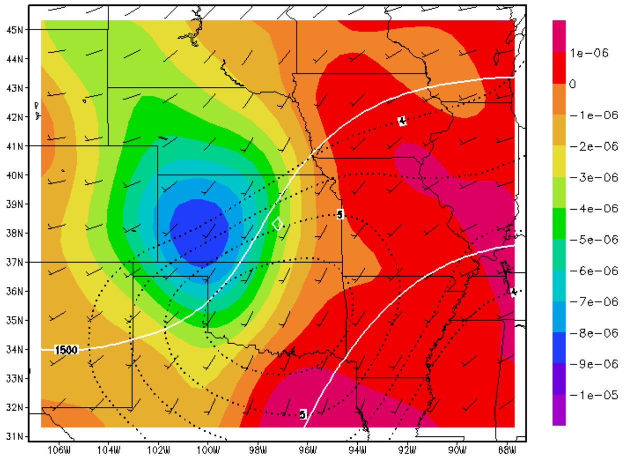

Figure 5. Same as Fig. 3 except for 850 mb.

The moisture and stability composites all tend to demonstrate the same basic pattern of a tongue of moist, unstable air extending from the southeast (i.e., Gulf of Mexico) to the northwest (i.e., plains). Figure 6 shows the composite of the lifted index (LI) prior to MCS development. Not surprisingly, MCSs generally develop in a moderately unstable environment. Comparison of stability parameters reveals that the LI appears to be a better indicator of MCS development than CAPE. The CAPE composite (not shown) exhibits increasing CAPE values to the southeast of the initiation location; whereas, the LI remains approximately constant to the southeast. This provides some evidence that “skinny CAPE” profiles are likely not as conducive for MCS development as broader CAPE profiles (i.e., larger LI).

6. SUMMARY AND CONCLUSIONS

Environmental conditions prior to the development of a large sample of MCSs were examined. The data were analyzed using a few different methods to try to uncover predictive signals of MCS development. The overall mid- to upper-tropospheric forcing was found to be weak with systems typically forming just upstream of a ridge at these levels. The lower-tropospheric forcing was much stronger and provided a better indicator of MCS development. Warm air advection at 700 mb, convergence at the nose of the LLJ, and convectively unstable conditions were normally present before MCS development.

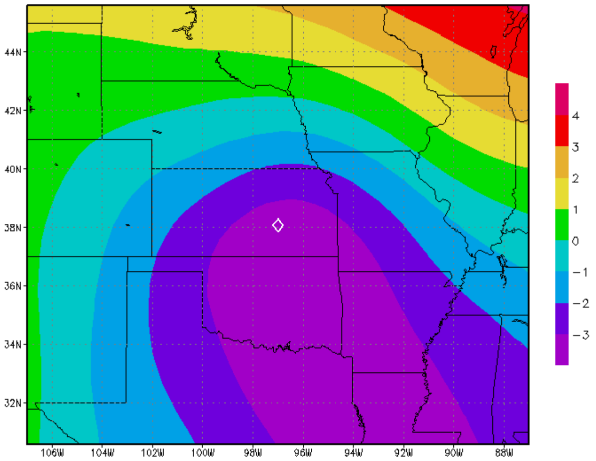

Figure 6. Lifted index MCS-relative composite 6 hours prior to MCS initiation. The white diamond indicates average center of MCS initiation.

The ultimate goal of this research is to formulate an index that indicates areas favorable for MCS development. This MCS index will consist of the most significant precursors to MCS development, including some of the parameters examined in this paper. Current attempts at creating a MCS index have been successful in identifying when and where a MCS will form, but with a very high false alarm rate. Hopefully, a useful MCS index will result from this work and aid forecasters in predicting MCS development.

Acknowledgements. This research was supported by a National Science Foundation (NSF) Graduate Fellowship and NSF grant ATM-0324324.

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