P1.5 EVOLUTION OF A MESOSCALE CONVECTIVE VORTEX OVER NORTHERN ARIZONA

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1. INTRODUCTION

The development of mesoscale convective systems (MCSs) and mesoscale convective complexes (MCCs) has been extensively studied in the literature over the past two decades. Considerable advances have been made in understanding the initiation, maturation, and decay of these systems (Maddox 1980, 1983; Velasco and Fritsch 1987; Cotton et al. 1989).

Less well understood and documented are mesoscale convective vortices (MCVs), an occasional feature of MCSs and MCCs (Johnston 1981; Bartels and Maddox 1991; Trier et al. 2000). MCVs are often identified on visible satellite imagery after the MCS/MCC has dissipated and the thick anvil shield has either thinned or moved downstream. Then the residual circulation can often be identified by the presence of spiral bands associated with the mid-level vortex.

There have been a few published climatologies of MCV environments (Bartels and Maddox 1991; Trier et al. 2000). In these studies, the area of focus was limited such that systems over the relatively flatter terrain of the central United States from Texas northward to the Canadian border were examined. MCVs that occurred outside this domain were not documented. The climatologies indicate that the majority of North American MCVs occur south of 42.5° N and west of 87.5° W. No southern or western boundaries are given but are assumed to be the Gulf Coast and the Rocky Mountains. Using visible imagery as their primary tool, Bartels and Maddox (1991) found an average of three MCVs per year for their dataset (1981–1988) but left open the possibility of additional undetected systems. Trier et al. (2000) used a variety of data systems, including visible and infrared satellite imagery, Doppler wind profilers, and radar data from the WSR-88D network. Consequently, they were able to detect a total of 19 MCVs during the 1998 warm season.

Although MCVs are considerably less common outside of the central United States, they do occasionally occur. Trier et al. (2000) note that observations and numerical simulations suggest that midlevel convectively generated vortices are ubiquitous features of MCSs, and range from transient small-scale features to long-lived, larger-scale circulations. On 20 August 2001, a MCS developed in northern Arizona and southern Utah. As this system matured, an MCV developed that persisted long after the original convection had weakened. Satellite imagery, Doppler radar data, surface METAR reports, and upper air rawinsonde data were analyzed in the documentation of this system.

2. A CASE STUDY: 20 AUGUST 2001

During the afternoon and evening hours of 19 August 2001, convection developed over northwestern Arizona and southwestern Utah. This convection was in response to the presence of deep moisture and moderate instability associated with the North American Monsoon [also known as the Southwestern Monsoon and Mexican Monsoon (Douglas et al. 1993; Adams and Comrie 1997)]. There was little that was extraordinary about this convection during the early hours of its development (Fig. 1). By 0300 UTC 20 August 2001, convection had begun to coalesce into a mesoscale convective system over northwestern Arizona and southwestern Utah. A second convective system was located over east-central Arizona. Most of the low elevation deserts, especially in southwest Arizona, experienced little or no convective activity.

Upper air plot data and analyses for 0000 UTC 20 August (not shown) indicated a region of high pressure located over the Gulf of Mexico with a ridge axis extending west-northwestward over Mexico and the southwestern United States. The development of the MCS occurred in this ridge within a region of weak inertial stability, a favored location for upscale growth of isolated convection into larger, longer-lived mesoscale systems (Blanchard et al. 1998). This location within a region of anticyclonic curvature is also consistent with the results from Trier et al. (2000) for the development of the MCV within the MCS.

The convective system continued through the night while other surrounding convection slowly diminished. By early morning, only the MCS in northwestern Arizona remained (Fig. 2). The convection began to diminish in intensity after sunrise and the upper level anvil cloud was advected downstream revealing banded structure in the mid-level clouds (Fig. 3). Long before this clearing occurred, however, the development of the vortex had been noted in the radar imagery. Based on the existence of the MCV, it was expected that new convection would develop downstream of the vortex during the day as deep moisture and moderate instability remained over the region. Secondary convection associated with MCVs is common and has been noted by many researchers, including Menard and Fritsch (1989) and Trier et al. (2000).

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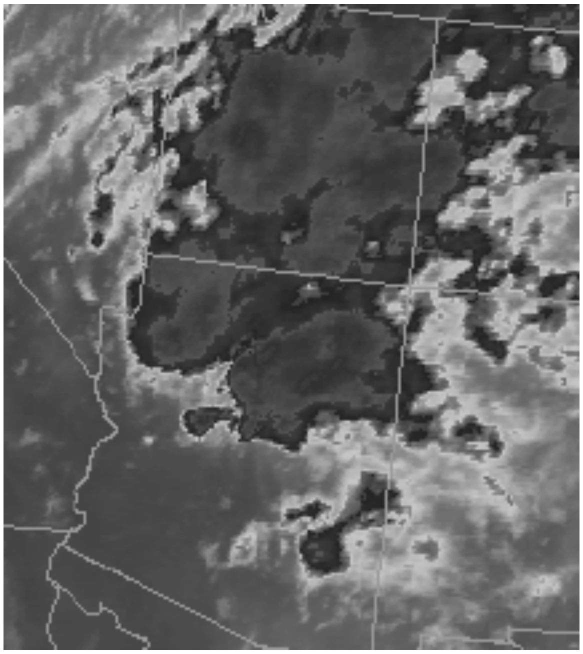

Figure 1. Infrared satellite image at 0300 UTC 20 August 2001 (2000 MST 19 Aug 2001).

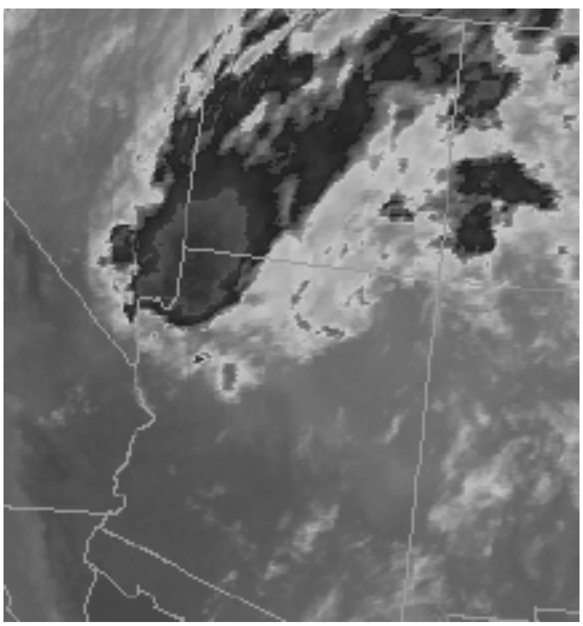

Figure 2. As in Figure 1 except for 1130 UTC 20 August 2001.

Weak convection continued in this system during the morning hours. Figure 4 is a base tilt (0.5°) reflectivity image from the Cedar City, Utah (KICX) WSR-88D radar and clearly shows banded structure in the reflectivity field as well as a convection-free center of the vortex. Already, secondary convection had begun to develop over portions of northern Arizona (Fig. 5). Even without the presence of the MCV,

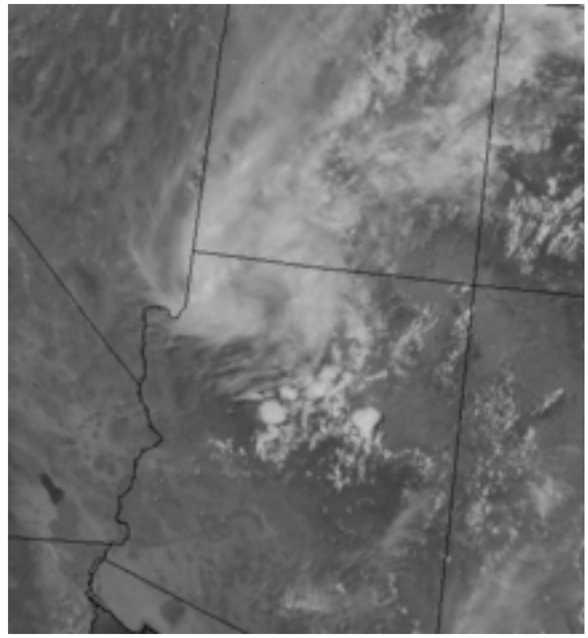

Figure 3. Visible satellite imagery at 1730 UTC 20 August 2001. Banded structure of both the original and secondary convection is evident in the mid-level and low-level cloud field over northwestern Arizona.

convection could be expected over this region since the combination of deep moisture, moderate instability, and elevated terrain provided the necessary ingredients for convective initiation. Analysis of animated radar loops (not shown) clearly indicated that the secondary convection was strongly modulated by the presence of the MCV. Instead of convection aligning with the elevated terrain or terrain-induced features such as the Mogollon Rim Convergence Zone (Blanchard 2000), as is often the case, convection was noted to form in NE–SW bands aligned with the low-level wind field associated with the MCV.

Trier et al. (2000) examined characteristics of the environment in which MCVs developed and moved during the course of the day. In particular, they were able to determine the mean instability and shear profiles. They found that MCVs were most likely to persist in environments of weak vertical shear with moderate-to-high CAPE, substantiating the results of Menard and Fritsch (1989), Bartels and Maddox (1991), and Fritsch et al. (1994). They determined the mean CAPE of environments in the paths of MCVs to be 1895 J kg^{-1}. The nearest sounding to the MCV was located at Flagstaff, Arizona (KFGZ; Fig. 6) and had CAPE of about 900 J kg^{-1}. Although this is about 1/2 of their value, it must be understood that the KFGZ sounding starts at about 795 mb (7152 feet MSL) and the computed CAPE will be substantially reduced. More comparable, however, is the low-level and deep-layer shear. Trier et al. (2000) computed a mean low-level shear of 4.1×10^{-3} s^{-1} and a deep-layer shear of 1.7×10^{-3} s^{-1}. This compares with low-level shear of about 4×10^{-3} s^{-1} and a deep-layer shear of 1.5×10^{-3} s^{-1} for the MCV in northwestern Arizona.

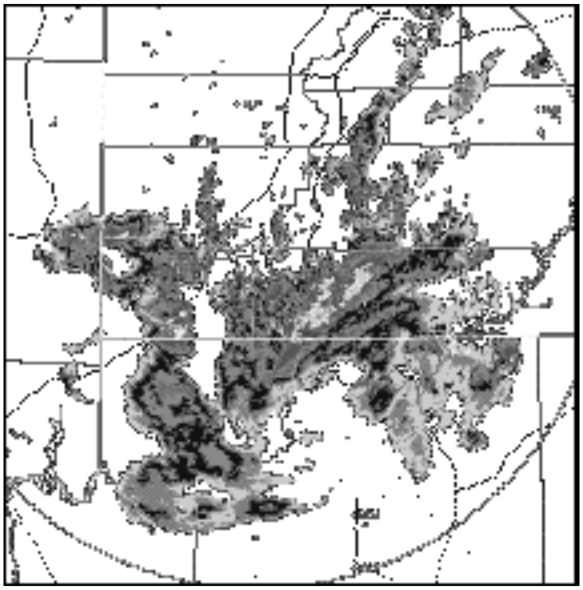

Figure 4. Base tilt reflectivity from the Cedar City, Utah (KICX) WSR-88D radar at 1830 UTC 20 August 2001. Note the slightly curved bands to the north and northeast of the circulation center, seen here as a reflectivity “hole” in the lower center of the image.

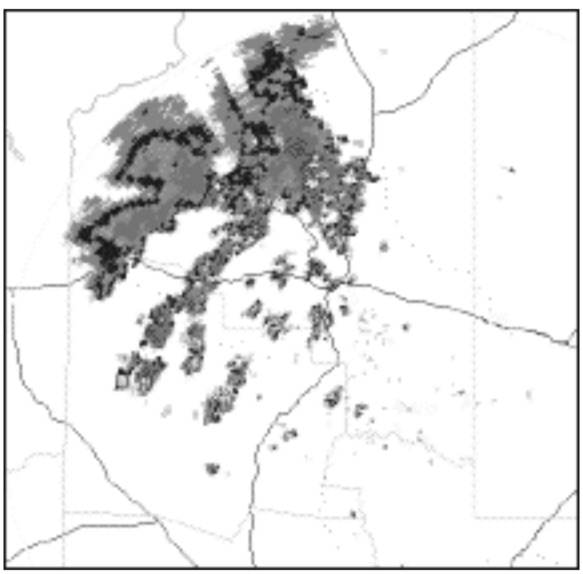

Figure 5. Base tilt reflectivity from the Flagstaff, Arizona (KFSX) WSR-88D radar at 1645 UTC 20 August 2001. New convection is developing over the higher terrain but is strongly modulated by the presence of the MCV and has begun to form NE–SE bands.

It is instructive to examine the difference between the model initialization fields at 1200 UTC 20 August and model forecast fields from 1200 UTC 19 August and 0000 UTC 20 August. The 12-h and 24-h forecast fields for 500-mb geopotential height (not shown) do not indicate a circulation or lower heights in northwestern Arizona, while the analysis

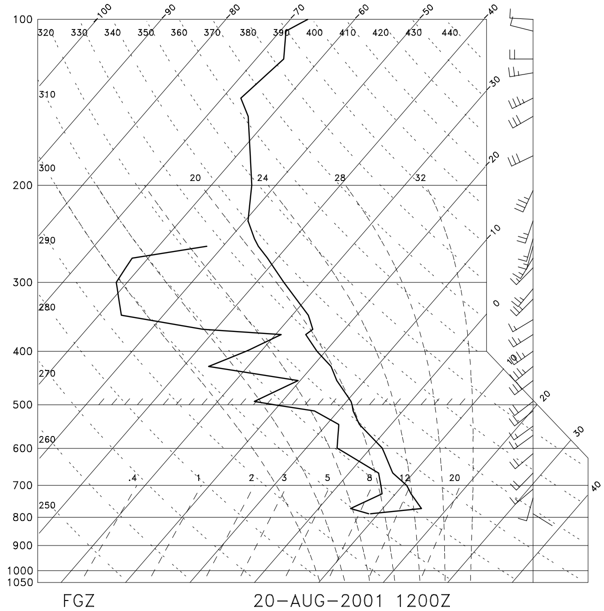

Figure 6. Skew-T log p obtained from Flagstaff, Arizona (KFGZ) at 1200 UTC 20 August 2001.

field at 1200 UTC depicts these features (not shown). Figure 7 is a difference field between the Eta model 00-h initial field from 1200 UTC 20 August and the 24-h forecast field from 1200 UTC 19 August. There is a well-defined circulation center located in northwestern Arizona. Figure 8 shows the 12-h differences. Again, the difference field shows a circulation. Note that the convection was already underway when this model was initialized and run at 0000 UTC, yet it still did not capture the evolution of this MCS and MCV.

An important result of the difference fields indicates that there probably was not a pre-existing mid-latitude or subtropical short-wave trough that was responsible for this circulation feature and that it is primarily the result of a vortex spinup from the MCS. In that regard, this MCV fits the specifications used by Trier et al. (2000) to remove systems that were the result of pre-existing waves arriving from either the mid-latitudes or subtropics so that the composite results typified vortices that were a result of mesoscale processes within the MCS/MCC.

3. SUMMARY

Convection that developed in northwestern Arizona on 19 August 2001 evolved into a mesoscale convective system (MCS) similar to those that are more common over the central United States. During the mature phase of the MCS, a mesoscale convective vortex (MCV) developed. This vortex was first observed with the WSR-88D Doppler radars located in and adjacent to northern Arizona. During the morning hours, the convection weakened and upper-level clouds diminished, revealing spiral bands in the low and mid-level clouds. A sounding taken nearby indicated that both the low-level shear and deep-layer shear closely matched those found by Trier et al. (2000) in their study of 19 MCVs during the warm season in 1998.

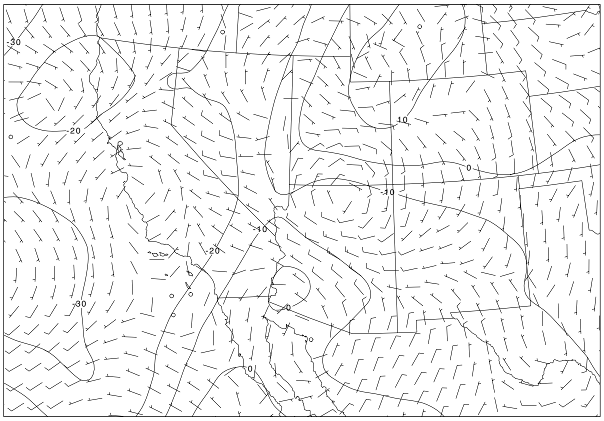

Figure 7. Vector wind differences and geopotential height differences between the 24-h forecast and the 00-h analysis, both valid at 1200 UTC 20 August 2001.

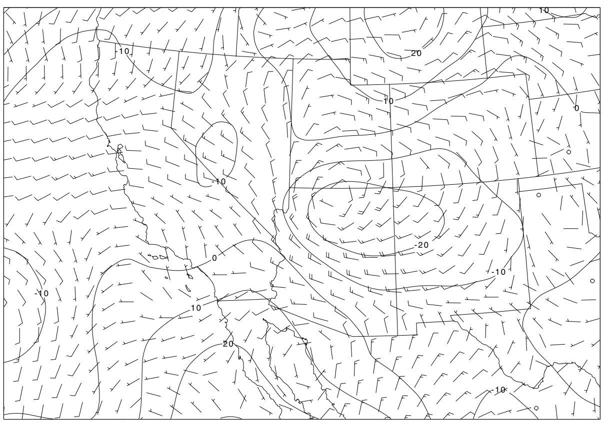

Figure 8. Vector wind differences and geopotential height differences between the 12-h forecast and the 00-h analysis, both valid at 1200 UTC 20 August 2001.

Forecasters working the midnight shift were able to follow the evolution of this MCS and MCV. Based on the results of previous studies by Menard and Fritsch (1989), Bartels and Maddox (1991), and Trier et al. (2000), it was expected that secondary convection would develop and be modulated by the presence of the vortex. Midnight shift forecasters were able to brief incoming day forecasters on the evolution of the system overnight and offer ideas on subsequent redevelopment during the day. Based on this information, forecasters were able to anticipate development of convection that was atypical for the region and time of season.

The documentation shows that in terms of location within a region of anticyclonic curvature, instability (i.e., CAPE), and shear that this MCV was strikingly similar to those more frequently observed over the central United States. That is, given the appropriate combination of large scale environment, instability, and shear, convective systems more common in the middle third of the country can also be observed elsewhere and lessons learned from the more frequent systems in the Plains can be applied to any location.

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