3.1

Probing Rotationally Dominated Mesoscale Convective Systems

Christopher A. Davis
National Center for Atmospheric Research[1]
Boulder, Colorado

1. BAMEX

Long-lived mesoscale convective systems (MCSs), defined as having lifespans greater than the local inverse Coriolis parameter, tend to exhibit rotation about a vertical axis (Cotton et al. 1989, Bartels and Maddox 1991, Skamarock et al. 1994). System- and sub-system-scale vortices commonly form during all phases of the system lifecycle, however, smaller-scale vortices (10-30 km radius) are favored when convection is more intense and system-scale vortices (30-200 km radius) are favored during the mature and decaying stages (Weisman and Davis, 1998). Intense, small-scale vortices rooted within and near the boundary layer may augment severe winds produced within the descending rear-inflow current. Larger-scale vortices tend to dominate the horizontal circulation within mature and decaying MCSs (Cotton et al. 1989, Fritsch and Forbes 2001). Furthermore, they are dynamically balanced and capable of persisting for many hours beyond the decay of the MCS from which they arose. To the extent that these system-scale vortices (also known as mesoscale convective vortices (MCVs) can persist into the peak heating of the diurnal cycle on the day after formation, they can participate in the initiation and organization of new convection, possibly leading to a multi-day series of nocturnal MCSs linked by MCVs (Fritsch et al. 1994, Trier et al. 2000).

In recent years, numerical simulations have produced a wealth of vortical structures on different scales within MCSs. However, observations are inadequate to assess the accuracy of formation processes and the subsequent interaction between vortices and convection that has been simulated. There are many outstanding questions related to the interplay between vortices and convection, a central problem in atmospheric dynamics, within the context of MCSs. Examples are:

- What is the mechanism of vortex formation on different scales?
- How do coherent vortices affect convection? In particular, do mesoscale vortices promote longevity of the convective systems in which they are embedded?
- What controls the upscale growth of vortical circulations?
- What is the relationship between vortices and damaging surface winds?
- How can long-lived MCSs, and their attendant effects on severe weather be better predicted?
- How do tornadoes form within quasi-linear convective systems?

In order to obtain observations adequate to address the above questions, a field study is planned to study the life cycle of two archetypical forms of organized convection characterized by a dominance of rotation. The Bow Echo and MCV Experiment (BAMEX, see http://www.mmm.ucar.edu/bamex/science.html for an overview of the project) seeks to document thermodynamic and kinematic structure within long lived convective systems forming in highly-sheared environments (bow echoes) and often-larger MCSs in weaker shear than form long-lived coherent vortices (MCVs). While the environments of each archetype are generally distinct, there are cases of bow echoes that grow upscale and spawn long-lived MCVs.

To maximize the probability of intercepting MCSs of interest, and to allow extensive sampling during much of the life cycle of individual systems, BAMEX is designed with a system-following strategy using highly mobile platforms:

Aircraft:

- NOAA P-3 (tail Doppler radar, microphysical instruments, microwave temperature profiler (MTP))
- NRL P-3 (ELDORA radar)
- Lear Jet (dropsondes)

Ground Based Observing Systems (GBOS):

- SMART-radars (2) (Texas A&M)
- Mobile Integrated Profiling System (MIPS, U. Alabama, Huntsville)
- Mobile soundings (2) (NCAR)
- Mobile mesonet vehicles (4) (NSSL)

---

[1]The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Corresponding Author:
Christopher A. Davis
P.O. Box 3000
Boulder, Colorado 80307
cdavis@ucar.edu

Additional surface mesonet stations, as well as additional launches of rawinsondes from selected National Weather Service sites are also proposed.

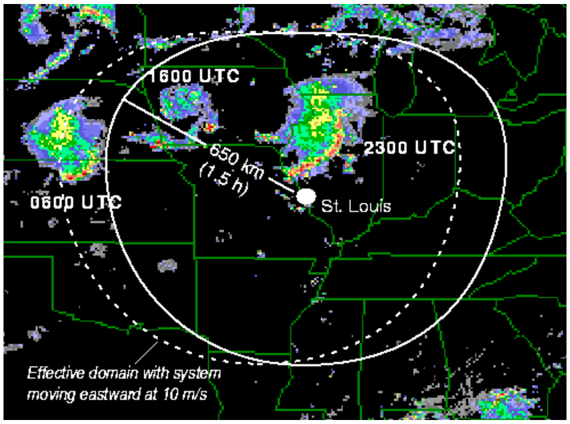

Figure. 1 *Snapshots of radar reflectivity at three times, composited onto a single map, during the lifecycle of an MCS observed on 23 June, 2000. The times shown, 0600 UTC, 1600 UTC and 2300 UTC, indicate the structure during the first nocturnal mature stage, the remnant vortex stage and the regenerative stage, respectively. The area enclosed by the solid white line is the area that can be sampled by BAMEX aircraft assuming a maximum of a 1.5 h ferry. The region enclosed by the dashed line represents the effective BAMEX area for a system moving eastward at 10 m s^{-1}, the speed of the 23 June case.*

The BAMEX domain (Fig. 1) covers much of the center of the U. S. The choice of St. Louis for the base of operations is based on the climatology of MCVs (Sec. 2) and bow echoes (Evans and Doswell, 2001). Given a 1.5 h ferry for the P-3, the BAMEX domain extends roughly 600 km in all directions from St. Louis. However, Given that systems progress from west-to-east (sometimes at more than 20 m s-1 in the case of bow echoes), the domain can be extended westward as depicted.

The GBOS will not have a permanent base. Rather, it will be repositioned on a daily basis based on the 24-h forecast of the area where organized convection is likely. The GBOS can move about 500 km per day and can traverse the entire BAMEX domain in roughly 2 days. Thus, while we anticipate convection to be somewhat geographically confined on time scales of 2-4 days, the GBOS can make large adjustments

The remainder of this article is devoted to a summary of the science objectives pertaining to the study of MCV-producing MCSs.

2. MCVs

It has recently been found that mesoscale convective vortices (MCVs) which persist many hours beyond the

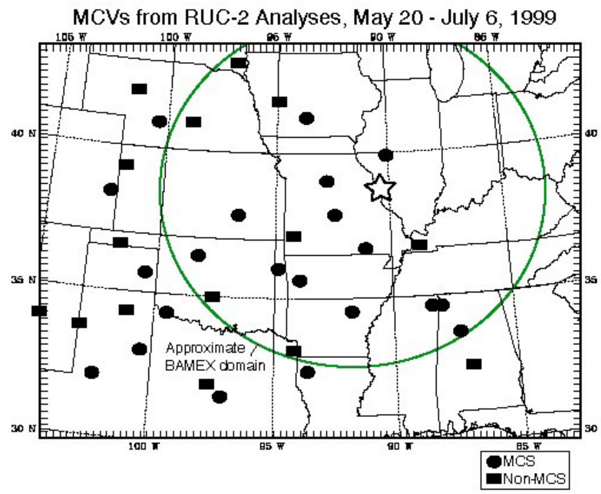

Figure 2. Positions of MCVs detected in Rapid Update Cycle (RUC 2) analyses during the period 20 May – 6 July, 1999. Circles indicate vortices forming in leading-line, trailing stratiform MCSs; rectangles denote MCVs forming within less organized convection.

decay of the mesoscale convective system (MCS) which gave rise to them are commonly observed features in the mid-troposphere during the warm season Trier et al. 2000, Davis et al. 2002). Estimates of 20-40 cases per season over the Central U.S. now exist. Furthermore, based on the results from the study by Davis et al. (2002), we anticipate roughly 10-20 MCVs within the BAMEX spatial and temporal domain (Fig. 2).

Operational analyses are now able to capture MCVs (Fig. 2), as is evident from Davis et al. (2002). While the ability of operational numerical models to predict MCV formation is relatively poor, cloud-scale numerical simulations in idealized environments produce MCVs in a variety of environments. This suggests that the preferred mode of organized convection is upscale growth and projection onto balanced modes. Further, it suggests that there are first-order deficiencies in the diabatic heating profiles and rates in the coarser-resolution operational models.

Perhaps the primary motivation for studying MCVs is that they can have a significant influence on convection downstream from their origin. Because MCVs represent coherent, long-lived structures, and because convection is systematically favored downshear from the MCV (Raymond and Jiang 1990, Trier et al., 2000), we believe that an enhanced "window of predictability" exists for the prediction of heavy rainfall on time scales of 6-12 h. However, the relative importance of mesoscale lifting and destabilization versus, or coupled with, diurnal boundary-layer features is remains unquantified, but is likely crucial for understanding how new convection initiates and organizes near MCVs.

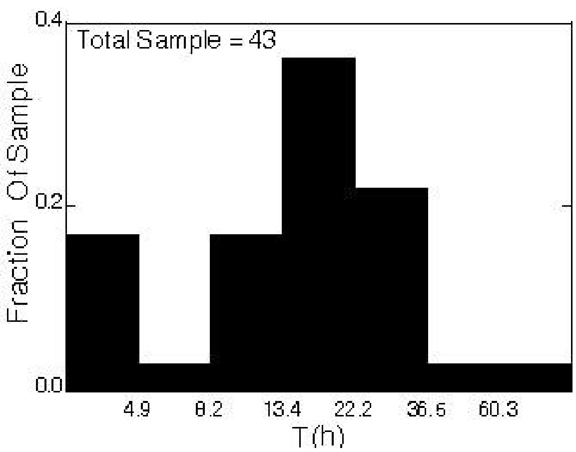

Figure 3. Histogram of MCV longevity following the initiation of new echo greater than 40 dBz within 200 km of the analyzed position of the MCV center in the RUC 2.

Among the key science questions pertaining to MCVs are:

- How do long-lived MCVs form and what distinguishes MCVs which persist well beyond the decay of the parent convective system from those that do not?
- How do MCVs help induce new convection? What is the relative importance of processes within the boundary layer versus above the boundary layer?
- Why does new convection sometimes re-intensify MCVs, leading to a multi-day MCS/MCV cycle, while other times the MCV appears to decay immediately following the organization of new convection?
- Can focused *in situ* measurements, combined with radar information, improve the predictive skill of weather associated with long-lived MCSs and MCV?

The dichotomous fate of an MCV near newly formed convection (third bullet) was reported by Davis et al. (2002) and shown in Fig. 3 as a histogram of longevity following the development of secondary convection.

It is not known whether the apparent decay of MCVs immediately following the formation of new convection is an artifact of the analysis or a real affect. Theoretical studies of the effect of convection on vortices, in the context of tropical cyclogenesis, do show that a dichotomous behavior is possible depending on the strength of new convection and its radial displacement from the center of the vortex.

The importance of mesoscale ascent induced by an MCV in shear for initiating convection downshear from an MCV was shown by Fritsch et al. (1994) and Trier and Davis (2002). However, detailed thermodynamic information was not available in either case, and severely hampers the diagnosis of mesoscale vertical motion resulting from quasi-balanced processes. Furthermore, the role of the boundary layer and circulations within was speculated upon in Trier and Davis (2002), but probably requires more observations to be discerned.

A key observing platform in BAMEX is the Lear Jet and the GPS dropsondes. Using this platform, dropsondes can easily be dropped from 40,000 feet or even higher, thus providing thermodynamic and kinematic profiles throughout the depth of the MCS. Given the 4-5 hours on station expected for each case, roughly 30-35 sondes will be dropped.

In cases of mature MCSs, the dropsondes will be concentrated in the stratiform region where mesoscale circulations originate. Additional soundings will be dropped outside the MCS and help document its environment. In addition, missions will be flown into mature MCVs prior to and during the development of new convection in the afternoon in an attempt to document the mesoscale structure of the vortex and help diagnose the quasi-balanced mesoscale motions it induces.

Following the field phase of BAMEX, there will also be numerous investigations of the utility of dropsonde data for numerical weather prediction. Of particular emphasis will be the analysis and prediction of developing mesoscale rotation within MCSs and the associated first order asymmetries with respect to the vortex center that define the system-scale structure of the MCS in its mature and decaying stages.

4. REFERENCES

Bartels, D. L., and R. A. Maddox, 1991: Midlevel cyclonic vortices generated by mesoscale convective systems. *Mon. Wea. Rev*., **119**, 104-118.

Cotton, W. R., R. L. McAnelly, and C. J. Tremback, 1989: A composite model of mesoscale convective complexes. *Mon. Wea. Rev*., **117**, 765-783.

Davis, C. A., and M. L. Weisman, 1994: Balanced dynamics of mesoscale vortices produced in simulated convective systems*. J. Atmos. Sci*., **51**, 2005-2030.

Davis, C. A., D. A. Ahijevych, and S. B. Trier, 2002: Detection and prediction of warm season midtropospheric vortices by the Rapid Update Cycle. *Mon. Wea. Rev*., **130**, 24-42.

Evans, J.S. and C.A. Doswell III, 2001: Examination of derecho environments using proximity soundings. *Wea. and Forecasting,* **16**, 329-242.

Fritsch, J. M., R. J. Murphy, and J. S. Kain, 1994: Warm core vortex amplification over land. *J. Atmos. Sci*., **51**, 1781-1806.

Fritsch, J. M., and G. S. Forbes, 2001. 'Mesoscale Convective Systems'. In Charles Doswell (ed.) *Severe Convective Storms*. American Meteorological Monograph Series. **27**, no. 49, 323-358.

Raymond, D. J., and H. Jiang, 1990: A theory for long-lived mesoscale convective systems. *J. Atmos. Sci*., **47**, 3067-3077.

Skamarock, W. C., M. L. Weisman, and J. B. Klemp, 1994: Three-dimensional evolution of simulated long-lived squall lines. *J. Atmos. Sci*., **51**, 2563-2584.

Trier, S. B., C. A. Davis, and J. D. Tuttle, 2000: Long-lived mesoconvective vortices and their environment. Part I: Observations from the central United States during the 1998 warm season. *Mon. Wea. Rev*., **128**, 3376-3395.

Trier, S. B., and C. A. Davis, 2002: Influence of balanced motions on heavy precipitation within a long-lived convectively generated vortex. *Mon. Wea. Rev*., **130**, 877-899.

Weisman, M. L., and C. A. Davis, 1998: Mechanisms for the generation of meoscale vortices within quasi-linear convective systems. *J. Atmos. Sci*., **55**, 2603-2622.

Weisman, M. L., and C. A. Davis, 1998: Mechanisms for the generation of meoscale vortices within quasi-linear convective systems. *J. Atmos. Sci*., **55**, 2603-2622.