Evolution of a mesoscale convective complex:
The role of inertial instability

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Introduction

The development of nocturnal mesoscale convective systems (MCSs) has been shown to be a function of both large-scale synoptic patterns and terrain-induced features, such as elevated heat sources (Maddox 1980; Cotton et al. 1983; Tripoli and Cotton 1989). Using objective analysis and compositing techniques for ten mesoscale convective complexes (MCCs), a subset of MCSs, Maddox (1983) identified several distinctive features at the surface and in the lower, middle, and upper troposphere during the formation, maturation, and dissipation stages of MCCs. Classification as an MCC was based on characteristics observable in satellite imagery because of the wide range of atmospheric scales that could be monitored, but did not address internal structural characteristics. More recently, Cotton et al. (1989), using compositing techniques that permit greater temporal resolution, examined 134 MCC events. Their results are similar to those of Maddox, but are more detailed regarding the temporal evolution of the system. Like Maddox, however, Cotton et al. did not directly address the question of variable structures within the MCCs. Blanchard (1990) has shown there are three basic, recurring mesoscale patterns of convection associated with MCSs, while Houze et al (1990) have introduced a complex classification system for mesoscale convection associated with springtime rainstorms (i.e., at least 25 mm or rain in 24 h over an area exceeding 12,500 km2). None of these studies, however, have addressed the dynamic and kinematic evolution associated with the upscale development of individual cloud elements into the mesoscale system; instead they all focus on the organization of the convection after it has already developed into a mesoscale system. Tripoli and Cotton (1989), using the CSU RAMS model, investigated the genesis of an MCC that had its origins in the Colorado mountains. They were able to simulate a mountain-generated solenoid and the solenoid that resides over the High Plains. Their results indicated that both features are important in the genesis of the MCC. The simulation, however, was restricted to two dimensions and could not accurately model the low-level jet, a feature of importance for MCC intensification.

Much of the work on MCC/MCS development and evolution has concentrated on systems exhibiting a strong degree of linearity (e.g., Smull and Houze 1985, 1987; Rutledge et al. 1988; Johnson and Hamilton, 1988). These linear systems can attribute a significant portion of the mesoscale organizing mechanisms to surface boundaries driven, in part, by baroclinic synoptic waves traversing the region. The frontogenetical nature of these waves can produce linear patterns of upward motion on the synoptic scale, resulting in similarly shaped regions of strong instability which is released by the passage of the boundary. As the convection matures, a large cold pool may develop that plays a significant role in the generation of horizontal vorticity (Rasmussen and Rutledge, 1991), tilted updrafts (Rotunno et al, 1988) and rear-inflow jets (Smull and Houze, 1987). This development contributes to the generation of regions of trailing stratiform precipitation in which mesoscale updrafts and downdrafts play an important role in the generation and maintenance of the MCS.

In contrast to the linear systems developing in an environment with strong embedded short waves and cyclonic vorticity, many MCCs and MCSs have been observed to form in environments where the absolute vorticity may have values that approach zero, resulting in regions with weak inertial (or symmetric) stability. It has been demonstrated that for a given amount of convective available potential energy (CAPE), deep convective circulations can be modified and enhanced as the symmetric stability is reduced. Consequently, there has been speculation that the mesoscale organization of these MCCs and MCSs may be related to the existence of an environment in which the inertial stability is weak (Emanuel, 1979, 1980, 1982, 1983; Jascourt et al., 1988; Seman, 1990). Emanuel (1979) has shown that in an environment with conditional symmetric instability (CSI) the atmosphere is stable to upright convection, but is unstable to slant convection. In some mesoscale environments, the atmosphere is unstable to both modes of convection. In this situation, it is hypothesized that the initial upright convection is instrumental in releasing the mesoscale inertial instability. Air parcels move upright vertically, expand outward at the equilibrium level and begin their descent on slant trajectories, taking the path of least resistance. The coupling of the vertical updraft and slant downdraft (referred to as convective-symmetric instability) begins to drive a solenoidal circulation that might be partly responsible for the continued generation of new convection. To explore the hypothesis that inertial instability may play a role in the development of mesoscale organization of convection, MCSs that occurred in the PRE-STORM network were examined. Special high temporal and spatial density rawinsonde data were objectively analyzed on isentropic surfaces and the ratio of absolute vorticity to Coriolis was computed. A necessary condition for inertial (or symmetric) instability is an environment in which the ration is less than zero; days that satisfied this condition were selected for further study. Twenty-one MCCs/MCSs occurred in the network during PRE-STORM and 17 were during IOPs with special data sets. Of these, nearly 25% (4 of 17) of the MCCs/MCSs showed evidence of inertial instability.