A Numerical Investigation of a Mesoscale Convective System

DONALD J. PERKEY

Department of Physics and Atmospheric Science, Drexel University, Philadelphia, PA 19104

ROBERT A. MADDUX

NOAA, Environmental Research Laboratories, Weather Research Program, Boulder, CO 80303

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ABSTRACT

On 25 April 1975, as part of the National Aeronautics and Space Administration's Atmospheric Variability Experiment IV, frequent upper-air soundings were taken at eastern United States synoptic sounding sites. An intense, long-lived mesoscale convective weather system developed late in the AVE IV period and moved eastward during the remainder of the experiment. With the use of dry and moist numerical simulations, performed with Drexel University's Limited Area and Mesoscale Prediction System (LAMPS), interaction between the widespread, long-lived convective complex and its large-scale environment are examined.

Dissecting the differences between moist and dry simulations reveals that, within the moist numerical simulation, significant upscale feedbacks occur between the convective system and its large-scale meteorological setting. Pronounced differences in temperature, divergence, vorticity, and height develop between the two simulations. Physical reasons for these differences are discussed. Comparison of the model forecast with analyses of the actual evolution of large-scale features indicates that this type of weather event cannot be properly simulated without inclusion of the effects of the latent-heat driven, mesoscale convective system.

1. Introduction

Recent studies indicate the need for improving operational quantitative precipitation forecasts; especially of heavy precipitation events (amounts greater than 1.5 cm) that are often primarily convective precipitation (e.g., Bosart, 1979; Zurndorfer, 1980; Charba and Klein, 1980). Charba and Klein (1980) attribute a noticeable disparity between the National Weather Service's skill at predicting rain/no-rain versus predicting substantial quantitative precipitation amounts to the differences in the meteorological scales typically involved. Heavy precipitation events usually occur on scales one to two orders of magnitude smaller than lighter precipitation events; i.e., heavy precipitation events are associated with mesoscale convective systems as contrasted with synoptic-scale stratiform precipitation systems. (Mesoscale, as used here, reflects scales termed meso-α by Orlanski, 1975, i.e., lengths of 250–2500 km.) Thus, a better understanding of mesoscale systems is essential if our predictive skill is to improve. It has been suggested that one type of precipitation system that might be better forecast is the mesoscale convective system (e.g., Mesoscale Convective Complexes or MCCs as discussed by Maddox, 1980, 1983; Fritsch et al., 1981; and Wetzel et al., 1983).

The development of widespread, organized midlevel moist ascent appears to distinguish these systems from both intense severe thunderstorms and linear squall lines that are also primarily characterized by convective activity. Using a two-dimensional numerical model, Kreitzberg and Perkey (1977) studied a mesoscale system characterized by widespread midlevel ascent. Their conclusions stressed the importance of the region of midlevel moist adiabatic ascent in producing the bulk of the precipitation.

Maddox et al. (1981) using data from National Aeronautics and Space Administration's (NASA) Atmospheric Variability Experiment IV (AVE IV) case (Hill and Turner, 1977) examined the development of upper-tropospheric wind, temperature, and pressure patterns in the region of a MCC. They used both meteorological observations and numerical model simulation results to deduce that observed mesoscale upper-tropospheric features were indeed convectively induced circulations in response to the MCC and that these features significantly altered the large-scale upper-tropospheric fields.

However, most of our understanding about the development and evolution of mesoscale convective systems is at present primarily hypothetical. Standard upper-air observations spaced at 12 h intervals can do little more than provide "snapshots" of these systems; they cannot provide the needed observational foundation for answering questions about the evolutionary life cycle of MCCs. The purpose of the research reported here was to use numerical model
simulations of a MCC to fill in the gaps in such "snapshots," thereby helping us build a four-dimensionaI picture of a mesoscale convective system. A MCC event was chosen because its large size and extended lifetime seemed ideal for numerical simulation and investigation. A thorough understanding of the MCC's life cycle and its impact on the larger-scale environment represents one important step toward their prediction in real time (Zipser, 1982).

The remainder of this paper focuses on both the numerical forecast and various diagnostic analyses of the convective weather events of 25 April 1975. Section 2 discusses the numerical experiments that were conducted, and Section 3 describes the synoptic setting for this investigation. The results of the numerical simulations are contrasted with analyses of NASA AVE data in Section 4.

2. Description of the numerical model and experiments

Drexel University's Limited-Area Mesoscale Prediction System (LAMPS) was used for the numerical simulations employed in this study. There are three features of LAMPS which make it ideal for the study of severe weather and, in particular, mesoscale convective systems:

1) A multi-level, optimal interpolation, moisture analysis method (Perkey, 1976) that provides moisture information at five to six levels in the boundary layer as well as nine to ten middle and upper tropospheric levels.

2) An explicit calculation of both cloud water and rainwater as time-dependent variables. The moisture processes of condensation, evaporation, collection, and conversion are parameterized following Kessler (1969).

3) A sequential plume cumulus parameterization scheme (Kreitzberg and Perkey, 1976) that has demonstrated in Kreitzberg and Perkey (1977), Maddox et al. (1981) and Chang et al. (1981, 1982) that it is capable of simulating systems with heavy convective precipitation amounts such as squall lines and MCC systems.

It should be noted that for model calculational convenience, precipitation is divided into two categories: one, model-resolvable precipitation and the other, parameterized precipitation. These artificially categorized types are frequently referred to as "stable" and "convective" precipitation, respectively. These names should not be construed as strictly describing the physical processes that are involved with the precipitation dynamics. An overview of additional LAMPS features is presented in Chang et al. (1981) and Maddox et al. (1981).

The following LAMPS simulations were conducted:

1) 140-km fine-mesh full physics 24-h simulation, and

2) 140-km "dry" 24-h simulation. The simulation is forced to be "dry" by maintaining relative humidity at 10% or less. This effectively removes all latent heat processes. Care has been taken not to perturb the hydrostatic pressure field, i.e., virtual temperature was preserved while sensible temperature was slightly adjusted.

The model was initialized at 0000 GMT 25 April 1975, using standard raob data archived by the National Center for Atmospheric Research (NCAR). Figure 1 depicts the simulation domain (cross-sectional analyses along A-B will be discussed in subsequent sections). Three-hour "snapshot" histories were saved for each simulation and were used to contrast the dry and moist simulation and to investigate the evolution of the MCC's environment and feedbacks to its larger-scale environment.

3. Synoptic discussion of 25 April 1975

Dupuis and Scoggins (1979), Maddox (1979), Wilson (1980), Maddox et al. (1981), Keyser and Johnson (1982) and others have discussed the large-scale features of this event. Therefore, only a brief overview of the synoptic-scale setting for the convective activity will be presented in this paper. Comparisons with Maddox (1983) indicate that the environmental setting and evolution of this system were similar to typical conditions associated with MCC cases.

The initial thunderstorms that played a role in the evolution of the simulated mesosystem developed over northeastern Oklahoma late on the afternoon of 24 April. The surface pattern was quite complex, as also described in the other studies referenced. Although individual thunderstorms were most intense early in the period, the mesosystem grew largest and

FIG. 1. Model simulation domain (heavy solid line). Meteorological fields along cross section A-B are discussed in text.
was apparently highly organized during the late night and early morning hours. Figure 2 shows a satellite depiction of the system at 0600 GMT on the 25th. As the system expanded eastward a mesoscale low pressure area developed at the surface. During its life, this system produced a number of severe thunderstorms and tornadoes, in addition to widespread heavy rain and localized flooding.

It is of interest that this particular convective system did not develop in a region of strong 500 mb positive vorticity advection as Miller (1967) often found. Rather it formed ahead of weak, midlevel short-waves over the northern and southern Plains that were coming into phase and merging over the Mississippi Valley. The system did occur in a region of distinct 850 mb and 700 mb positive temperature advection. This scenario, as described by Maddox and Doswell (1982), is quite often associated with both severe and heavy precipitation producing thunderstorm systems. The thunderstorm generation region was, naturally, characterized by high values of hydrostatic instability as defined by positive buoyant energy (Wilson, 1980).

The operational 12 h forecasts of the National Weather Service Limited Fine Mesh (LFM) numerical model valid at 1200 GMT (i.e., for same period examined with LAMPS) are shown in Fig. 3. The 500 mb forecast (Fig. 3a) shows the weak short-wave trough associated with this event over the Mississippi Valley. The surface forecast (Fig. 3b) valid at the same time dramatically illustrates the unobtrusive character of this event's meteorological setting; indeed, the LFM had forecast the middle level trough eastward of the surface low over northwestern Arkansas leaving a weakening wave that sloped eastward with height (at least through 500 mb). Also illustrated in Fig. 3b is the LFM forecast of accumulated precipitation for the 12 h period 0000–1200 GMT 25 May 1975. The LFM forecast the general rainfall pattern quite well (contrast Fig. 3b with Fig. 4 which shows actually observed rain amounts); however, the maximum observed rainfall exceeds the LFM forecast of 38 mm by 600%. In addition, the region of the central United States that received >25 mm of precipitation exceeded the LFM forecast area by a factor of 4 to 5. Both the need and opportunity for improving operational numerical forecasts of quantitative precipitation amount seem obvious.

4. Simulation results

a. Comparison with observed large-scale system

Figure 5 shows the three-hourly evolution of the convective precipitation rate. For the purposes of this paper, the convective precipitation is defined as that

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Fig. 2. Satellite image, enhanced infrared mode, of the mesoscale convective system at 0600 GMT 25 April 1975.
precipitation calculated by the model's convective parameterization scheme. Stable precipitation (precipitation explicitly forecast by the model primitive equations) did not begin until just before 0600 GMT (not shown on Fig. 5), i.e., 6 h into the simulation.

The model convective system organized and grew over the central Mississippi Valley early in the simulation (Fig. 5). It then developed eastward from 0900 to 1500 GMT. Eventually (by 1800 GMT) the model system had elongated and stretched from Arkansas to the southern Appalachians. Detailed comparisons of model predicted surface pressure pat-

tern, convective and stable rain rates with actual observations are illustrated in Figs. 6 and 7 for 0600 and 1200 GMT. At 0600 GMT, stable precipitation had just begun over southeastern Missouri while a substantial region of convective rain was occurring in the middle Mississippi Valley (Fig. 6a). The observed fields (see Fig. 7a) at the same time show that a considerably larger area of rainfall actually existed, especially over Illinois, Indiana and Kentucky. The surface pressure patterns are generally similar. The notable exception is the distinct mesohigh low-pressure couplet associated with the convective activity over Arkansas and Kentucky.

By 1200 GMT (see Figs. 6b and 7b), the model predicts large areas of both convective and stable precipitation. These rainfall regions are again basically similar to those revealed by the observations. The main exception being that the actual convective line seems to have moved southward and eastward more rapidly than the comparable model feature; the numerical forecast now indicates a surface low-pressure center near that actually observed. By this time though, the model indicates a much larger region with pressure lower than 1008 mb than actually observed. Again, the mesoscale high pressure area had not been forecast by the model. The stable precipitation rate maximum was located to the northeast of the convective maximum by 1–2 grid points throughout the simulation. The 1200 GMT surface map (Fig. 7b) seems to indicate that this may also have been the actual case. The reason for this spatial relationship is not evident, other than (at least in the model simulation) that it may reflect a tendency for the latent warming input by convection to be advected east-northeastward by the larger-scale flow.

Note that by 1800 GMT the line of model forecasted convection is very similar to the line of observed thunderstorms at 1200 GMT. Indeed, certain aspects of this numerical simulation (widespread rain, movement of system, development of intense upper-level outflow, and so on) tended to lag actual developments

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**Fig. 3a.** Ten-hour LFM forecast of 500 mb heights and vorticity valid at 1200 GMT 25 April 1975.

**Fig. 4.** Observed 12 h precipitation (cm) for period ending 1200 GMT 25 April 1975.

**Fig. 3b.** Twelve-hour LFM forecast of surface pressure field [solid line (mb minus 1000)] and 12 h accumulated rainfall [dashed line—in centimeters] valid at 1200 GMT 25 April 1975.
by as much as 6 h. For example, accumulated model rainfall at 1200 GMT is shown in Fig. 8. Although amounts are considerably more than the LFM forecast, actual accumulated rain at this time was on the order of 400% greater. However, while the total model rain rate was rapidly increasing at this time, the actual system would weaken markedly during the next several hours. Although the timing of the model system's development and evolution do not exactly replicate the observed system's behavior, the similarities are striking. Indeed, the authors feel that this case represents a reasonably accurate simulation of the observed weather and that it can be used as a diagnostic foundation for building on our understanding of mesoscale convective systems.

Comparisons of the observed and predicted (moist) large-scale features at 850, 500, and 200 mb for 0600 and 1200 GMT are illustrated by Figs. 9–11. At 850 mb at 0600 and 1200 GMT (Figs. 9a–d), the observed and predicted features are similar except for the following:

1) The observed 1470 m height contour depicts considerably more "mesoscale" structure in the central United States than does the model.

2) The weak low and high centers in Kansas and Missouri were not reflected in the model forecast, except that the model did forecast development of the low over Indiana by 1200 GMT.

3) The region characterized by wind speeds > 15 m s⁻¹ was considerably larger in the actual analyses [this may reflect the inability of the model to precisely replicate diurnal frictional effects on the low-level flow (see Perkey, 1976; Maddox et al., 1981, for description of the boundary layer and surface parameterization)].

4) The model forecasted temperatures tended to be too warm from Indiana westward across Kansas.

The observed and predicted features at 500 mb are presented in Fig. 10. At 0600 GMT (Fig. 10a and b), the charts are very similar with the exception that the actual short-wave trough is sharper (especially
over Iowa and Missouri) so that the observed height gradient and winds are considerably stronger than the forecast from eastern Oklahoma across Tennessee and Kentucky. At 1200 GMT, the forecast continues to be much like observed conditions except that the actual short-wave trough continues to have slightly more amplitude than does the model forecast. The region of strong flow is very similar and both charts indicate anomalously warm regions in their respective areas of convection (note that the model area lags somewhat behind the observed area of convection).

At 200 mb (see Fig. 11a–d) the most noticeable differences are that the upper-tropospheric pool of cooler temperatures and the pronounced jet stream around the northern periphery of the mesoscale convective system apparently develop more slowly in the forecast than they actually did.

b. The MCC's impact on its larger-scale environment

We will now consider the three-dimensional structure of the mesoscale system and its impact on the surrounding environment, first from the viewpoint of associated convergence/divergence fields. Figure 12 shows the difference (wet minus dry) in the simulated divergence field for 0600, 1200, and 1800 GMT at 200, 500, and 850 mb. A distinct vertical organization, together with coupling, was created when the latent heat released by precipitation was included in the simulation. A low-level convergence region topped by an upper-level divergence region is obvious in the

![Figure 6](image)

**Fig. 6.** Simulated surface pressure pattern (solid lines), convective precipitation rate (dashed), and stable precipitation rate (heavy solid—both in mm (10^{-3}) s^{-1}) for (a) 0600 GMT and (b) 1200 GMT.

![Figure 7](image)

**Fig. 7.** Observed surface pressure, observed weather conditions, and actual region covered with precipitation echo (stippled) for (a) 0600 GMT and (b) 1200 GMT 25 April 1975.
difference field. The precipitation induced low-level convergence was located ahead of the maximum of convective precipitation rate (refer to Fig. 5) by 100–250 km (1–2 grid points) throughout the simulation; not surprisingly its location corresponded with the maximum in the stable precipitation rate. The 200 mb divergence developed directly above the 850 mb convergence field. Thus, the induced modifications of the divergence pattern were essentially vertical, with little or no shearing at upper levels. In addition, the 200 mb panels illustrate the expansion (generally to the north of the divergence maxima in the moist forecast) and eastward shift of the region where wind speed exceeds 45 m s\(^{-1}\). At 500 mb, convergence also existed over the precipitation. Note that the direct impact of the latent heating, to a large extent, was limited to the area of precipitation. Wilson (1980) diagnosed strong low-level convergence and upper-level divergence, which resulted in large vertical dis-

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**Fig. 8.** Model forecast accumulated rainfall (cm) for 12 h ending at 1200 GMT.

**Fig. 9.** Observed 850-mb heights (solid contours, m) and temperature (dashed contours, °C). Stippled region is area where wind speed exceeds 15 m s\(^{-1}\); (a) at 0600 GMT and (c) at 1200 GMT. Forecast fields displayed in similar manner for (b) 0600 GMT and (d) 1200 GMT.
placements of air parcels, with this case. He also noted that these effects were only observed in the vicinity of the precipitation. The results of the wet and dry simulations indicate that the convergence-divergence patterns were caused by the parameterized convection.

Tables 1 and 2 present maximum differences between the wet and dry simulations. The general patterns for these differences are not unlike those shown in Fig. 12 for the divergence field, i.e., the patterns are essentially "bull's-eyes" centered over the precipitation area. For example, the divergence patterns of Fig. 12 are summarized in Table 1 for every 3 h. Maximum values of difference centers which dominated the field are shown in the table, i.e., for 0600 GMT, 850 mb, the dominant feature was a convergence center with a maximum value of $6.3 \times 10^{-5}$ s$^{-1}$; at 200 mb, the dominant pattern was a divergence region with a maximum difference of $16.6 \times 10^{-5}$ s$^{-1}$ between the moist and dry simulations.

During the first 9 h of the simulation, the convective precipitation rate increased to a maximum of 29.1 mm ($10^4$ s$^{-1}$) and then, decreased during the remaining 9 h. As stated above, stable precipitation did not begin until about 0600 GMT. It increased in intensity until 1500 GMT (15 h into the simulation) at which time it began to weaken.
The difference in temperature between the wet and dry simulations (Table 2) indicates that the inclusion of moist processes in the model generated a pool of relatively cool air at 200 mb. The model mechanisms responsible for this cooling are upward vertical motions and associated adiabatic cooling induced by the mesoscale convection and the evaporation into the environment of anvil cloud water (Fritsch and Brown, 1982) via the convective parameterization scheme (Kreitzberg and Perkey, 1976). The effects of radiational cloud top cooling are minimal in the model and contribute only slightly to this cooling.

In the middle troposphere, a warm region was created directly by latent heating. The development and importance of this region of midtropospheric warming was hypothesized by Fritsch (1975). Near the surface, 850 mb and below, the evaporation of precipitation falling through subsaturated air below cloud base caused a cool region to form in the wet simulation compared to the dry simulation. During this AVE IV period, Wilson (1980) observed that in the precipitation regions diabatic effects resulted in cooling from the surface to 800 mb, warming from 800 to about 300 mb and cooling above. Wilson attributed the observed upper-level cooling primarily to radiational effects (in contrast to this study) and the low-level cooling to subcloud evaporational cooling (similar to this study).

The vorticity structure (Table 2) shows increased cyclonic vorticity at low and middle levels with...
anticyclonic circulation at 200 mb, as would be expected given the persistent changes in divergence (Table 1 and Fig. 12). It should be noted that these differences reflect primarily the stronger vorticity forecast in the “moist” simulation, i.e., the “dry” case had very little vorticity associated with it. The maximum differences in wind speed indicate that the latent heat release apparently affected the wind speeds at upper levels more than at lower levels. However, this was true only in an absolute sense; that is, the percentage difference in wind speed was actually larger in the lower troposphere. At 200 mb, the maximum wind difference occurred to the northwest.

**Table 2.** Wet-minus-dry simulation values for temperature (°C), relative vorticity (10⁻² s⁻¹), height (m), sea-level pressure (mb), wind speed (m s⁻¹), and vertical velocity (cm s⁻¹).

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of the convection during the period 6–9 h into the simulation. By 12 h the maximum wind difference had rotated around to the north of the precipitation. In other words, an upper-level jet streak intensified to the northwest of the convection. This jet streak propagated anticyclonically to the north during the simulation. The left entrance region of this jet streak is manifested by the convergence over the Arkansas–Missouri border at 0600 GMT (Fig. 12) that moves clockwise around the strong divergence center to Virginia by 1200 GMT.

At 500 mb, the maximum differences (Table 2) indicated the formation of a weaker (compared to 200 mb) jet streak ahead of the convection, i.e., in the mesosystem’s southeast quadrant. This jet moved cyclonically to the northeast quadrant during the simulation. At 850 mb, it appeared that a northerly jet was formed immediately behind the convection while the southwesterly jet formed slightly ahead of it. These two enhanced wind zones, although not always very distinct, persisted throughout the simulation. These low-level differences appear to “fuel” the MCC by enhancing the supply of warm, moist low-level air ahead of the system.

Keyser and Johnson (1982) indicate that observations establish “evidence for the direct link between diabatic heating within each MCC and the intensification of winds within each jet streak.” The results of the current simulations establish that the MCC caused the intensification of the jet streak as opposed to the intensification of the jet streak causing the MCC.

The differences in the height patterns indicate, at least in a relative sense, the formation of a low- and middle-level low pressure area and an upper level high pressure area (again, Table 2). It was noted that the strongest gradient in the 200 mb height difference was located 45 to 90 deg clockwise and ahead of the maximum change in the wind speed. This indicates that the wind changes have not reached geostrophic balance, but they are accelerating strongly toward lower heights. The strong ageostrophic nature of the 200 mb winds was also noted by Keyser and Johnson (1982). At the surface, it should be noted that the simulation did not develop the mesohigh areas as shown in Section 3. One explanation for this failure may be the lack of cold, convective-scale downdrafts in the model’s convective parameterization scheme (Fritsch and Chappell, 1980a,b).

The vertical structure is tied together by strong upward vertical motion during the development of the mesoscale system. This upward motion difference reaches a maximum at 1500 GMT (Table 2) that corresponded to the time of maximum stable precipitation. The implication is that the bulk of stratiform precipitation is produced by the moist mesoscale circulation within the simulation. The precise roles of detrainment of water substance from convective towers (see Houze, 1977; Zipser, 1977) in the stratiform precipitation region cannot be directly evaluated here.

Physically, middle-level warming due to convective latent heat release induced the formation of a relative upper-level high which in turn increased the upper-level divergence. An unbalanced removal of mass at upper levels hydrostatically resulted in the formation of relative low-level low pressure. Wind responses to the changing pressure field increased low-level cyclonic vorticity and convergence. As the mesoscale system increased in intensity, vertical motion attending the low-level convergence, upper-level divergence dipole and the latent heating, saturated the middle levels and initiated stable-type precipitation. Thus, in the model, latent heat released by parameterized convective clouds led to an organized mesoscale circulation. The dry simulation did not develop these mesoscale circulations. Indeed, the series of analyses of AVE data presented in earlier sections and Maddox (1979) indicate that the model simulated mesoscale characteristics of this event were quite realistic, at least to the degree that they were detected within the synoptic data.

c. Evolution of model-forecasted MCC precipitation fields

In response to initial weak low-level convergence, low-level moisture, and boundary-layer potential instability, model convection broke out over Arkansas. From an initially weak large-scale vertical velocity (17 cm s⁻¹ at 500 mb) in this region (see Fig. 13), a strong organized cell of upward motion developed because of latent heat release. This cell propagated with the precipitation almost due eastward, reaching its maximum intensity at approximately 1500 GMT. After about 3 h of strong upward motion, model resolvable stable precipitation began to reach the ground. By 1200 GMT, the large-scale precipitation rates were more than twice as large as the convective

![Fig. 13. Time sequence of model-forecasted maximum convective precipitation rate (line c), maximum stable precipitation rate (line s), and maximum vertical velocity at 500 mb (line v).](image-url)
rates and by 1500 GMT with the convective rates decreasing with time and the stable rates increasing, the ratio of stable to convective rainfall rates was almost four to one. After 1500 GMT, the stable precipitation rate decreased.

Initially, the potential instability in the presence of weak lifting initiated and maintained convective-scale precipitation in the area. As these parameterized convective cells moistened and warmed the middle layers, a strong vertical motion field was initiated in response to increased low-level convergence. This organized mesoscale vertical motion field in turn partially counteracted the middle level warming through adiabatic cooling, but aided the moistening of the middle layers. Thus, after 3–6 h the middle layer became saturated. About 1–3 h later, the conversion and the collection processes (Kessler, 1969)

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**Fig. 14a.** Cross section of model initial vertical velocity (all cross sections are along line A–B shown in Fig. 1) in cm s⁻¹.

**Fig. 14b.** Diagnosed vertical motion along A–B at 0000 GMT in cm s⁻¹ (kinematically calculated using an O'Brien, 1970, adjustment—see Maddox, 1983, for details). Convective weather along the cross section, as indicated by radar, is shown.

**Fig. 15a.** Cross section of model forecast vertical velocity at 0600 GMT. Region in which model forecasts stable and/or convective precipitation is vertically hatched.

**Fig. 15b.** Diagnosed vertical motion at 0600 GMT.
managed to convert cloud water into rainwater that fell and began to reach the ground. By this time, the model forecasted thermodynamic structure was almost neutrally stable for moist motion and a cell of general stable rainfall, large enough to be resolved by the model developed.

The evolution of the vertical motion fields (along cross section A–B, shown on Fig. 1) accompanying the processes described here is illustrated by both the model forecasts and the diagnoses shown in Figs. 14–16. At initialization time (0000 GMT 25 April), both model and diagnosis indicate an upward cell of vertical motion in the area of observed thunderstorm activity. However, thunderstorms were already occurring at initialization time (Fig. 14b). This may partially account for the apparent “slowness” of the model forecast already discussed.

By 0600 GMT (Fig. 15), there is an amazing similarity between the forecast and the diagnosed vertical motion fields. This is also true of the location of precipitation along the cross section. However, the data used in the diagnoses are crudely spaced, relative to the grid mesh of the simulation. Thus, it seems that, regardless of the vagaries of small-scale details, the parameterization feeds the effects of convection up-scale into the atmosphere in a way that results in an excellent simulation of actually observed larger-scale features.

The vertical velocity cross sections for 1200 GMT do begin to show a considerable divergence between the forecast and concurrent diagnosis. The diagnosed region of upward motion associated with the mesoscale convective system has weakened considerably (~50%), whereas the model forecast circulation has intensified slightly. Interestingly, both analyses now depict a weak mesoscale downdraft at the rear of the mesoscale precipitation system. The differences at 1200 GMT are probably a result of both the apparent model time lag in forecasting the actual evolution of the mesosystem and the movement of the observed system farther east and south of where the forecast system was located.

5. Summary and conclusions

Frequent upper-air soundings (6 h apart) were taken at eastern United States synoptic sounding sites on 24 and 25 April 1975 as part of the National Aeronautics and Space Administration’s Atmospheric Variability Experiment IV (AVE IV). An intense, long-lived mesoscale convective weather system developed late in the AVE IV period and moved eastward during the experiment. Questions concerning how widespread and long-lived convective complexes interact with their large-scale environment were examined utilizing dry and moist numerical simulations of this weather event.

It was found that significant, up-scale feedbacks occurred, only within the moist numerical simulation, between the convective system and its large-scale meteorological setting. Pronounced differences in temperature, divergence, vorticity and height developed with time between simulations; for example, rapid changes in vorticity occurred within and near the convective system. These changes occurred in the presence of intense model divergence fields driven by the strong latent heat release by the convection. Indeed, with time, a pronounced lower-tropospheric cyclone developed in the core of the convective...
system. Comparisons of the moist and dry simulations with observations indicated that the large-scale dynamic fields were not properly simulated without the inclusion of the moist processes introduced by these mesoscale convective complexes.

The analyses and simulations indicate the potential for using numerical models to study the mesoscale structure of convective systems. The correspondence of observable features of the mesosystem and its effects on the synoptic environment with model features were striking. Thus, we believe that it is realistic to utilize such simulations to investigate details of the evolution of convective mesosystems that cannot currently be examined with synoptic data.

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