Explicit Simulation of a Midlatitude Mesoscale Convective System

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Introduction

We have explicitly simulated the mesoscale convective system (MCS) observed on 23-24 June 1985 during PRE-STORM, the Preliminary Regional Experiment for the Stormscale Operational and Research and Meteorology Program (Cunning 1986). Stensrud and Maddox (1988), Johnson and Bartels (1992), and Bernstein and Johnson (1994) are among the researchers who have investigated various aspects of this MCS event. We have performed this MCS simulation (and a similar one of a tropical MCS; Alexander and Cotton 1994) in the spirit of the Global Energy and Water Cycle Experiment Cloud Systems Study (GCSS), in which cloud-resolving models are used to assist in the formulation and testing of cloud parameterization schemes for larger-scale models (Browning et al. 1993).

In this paper, we describe 1) the nature of our 23-24 June MCS simulation and 2) our efforts to date in using our explicit MCS simulations to assist in the development of a GCM parameterization for mesoscale flow branches. The paper is organized as follows. First, we discuss the synoptic situation surrounding the 23-24 June PRE-STORM MCS followed by a discussion of the model setup and results of our simulation. We then discuss the use of our MCS simulations in developing a GCM parameterization for mesoscale flow branches and summarize our results.

Synoptic Situation and Observations

The PRE-STORM 23-24 June MCS formed under classic synoptic conditions. At 1200 UTC 23 June a cold front trailed from a deep surface low near Hudson Bay, with the front becoming stationary across the central United States. By 0000 UTC 24 June the Nebraska surface low had deepened a bit with a dryline extending south from it into western Kansas. A stationary front snaked its way south-eastward into the low and east-northeastward out of the low (see Figure 1 of Stensrud and Maddox 1988). At this time, low-level air south of the front was hot and moist, with surface temperatures as high as 39°C and surface dewpoints as high as 24°C. Meanwhile, at 850 mb, a strong southerly jet (maximum wind speeds > 15 ms^{-1}) over the southern Plains states provided a continuing supply of warm, moist air. Convective cells first formed around 1900 UTC 23 June along the dryline and front. Convective cells in northern Kansas and southern Nebraska moved toward the east-southeast; those in central and southern Kansas moved toward the south. By 0000 UTC 24 June, convection in the northeastern part of the area had consolidated into a large MCS in eastern Nebraska and Iowa along and to the south of the front (courtesy of an old outflow boundary). Another area of thunderstorms was parked over west-central Kansas along the dryline, and eventually blossomed into a smaller MCS. Figure 1, a 0400 UTC infrared satellite image, shows the

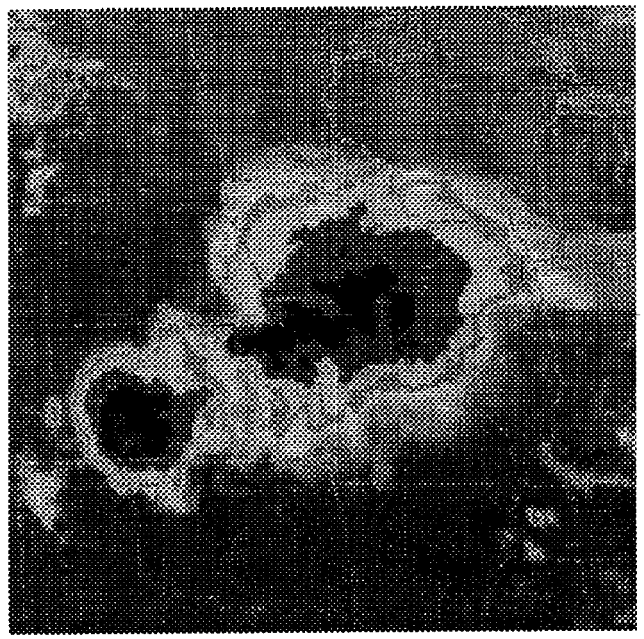

Figure 1. Infrared satellite imagery of the 23-24 June PRE-STORM MCS at 0400 UTC 24 June 1985. The portion of the PRE-STORM MCS that we simulate is near the intersection of Iowa, Missouri, and Illinois.

smaller MCS over western Kansas, and the larger one over northern Missouri and southern Iowa. Our fine grid zeroes in on the latter MCS.

Simulation

A discussion of the model setup is provided in this section. The discussion includes information on timestepping, boundary conditions, and the grid setup.

Timestepping

Prognostic model variables in the Regional Atmospheric Modeling System (RAMS) (Pielke et al. 1992) include the three velocity components; the perturbation Exner function; the ice-liquid potential temperature; the total water mixing ratio; and the mixing ratio of rain droplets, snowflakes, pristine ice crystals, graupel particles, and aggregates. The bulk hydrometeors have prescribed exponential size distributions. Prognostic equations use a time-splitting technique—allowing the model to explicitly compute on a small timestep those terms governing sound waves and to compute on a long timestep those terms governing other processes. Horizontal time differencing for long time steps is a flux conservative form of second order leapfrog (Tripoli and Cotton 1982). The long timesteps are 30, 15, and 7.5 seconds on grids with 25-km, 8.333-km, and 2.083-km horizontal grid spacing respectively; short timesteps are one-fifth this long.

Boundary Conditions

Lateral boundary conditions are the Klemp and Wilhelmson (1978a,b) radiative type, in which the normal velocity component specified at a lateral boundary is effectively advected from the interior assuming a specified propagation speed. We also use a Davies nudging condition, which causes model data at and near the lateral boundaries to be forced toward available observations. At the top boundary, we use a rigid lid, in concert with a Rayleigh friction absorbing layer. The latter damps gravity wave and other disturbances which approach the top boundary. At the lower boundary, we provide the model with topographic data, which has a horizontal spacing of 10 minutes latitude/longitude on Grid #1 and 30 seconds latitude/longitude on the other grids. A vegetation type data set from the National Center for Atmospheric Research with 11 primary vegetation types at a 5-minute latitude/longitude resolution is interpolated onto the model grids and then converted to the vegetation classification used in the model (the model recognizes 18 vegetation types). In addition, horizontally variable soil moisture is based on the soil moisture analysis in the United States Department of Agriculture publication, Weekly Weather and Crop Bulletin (WWCB). The WWCB soil moisture index data was manually transferred to a latitude/longitude gridded data set at 1° resolution. This data set was then filtered and interpolated onto the model grid where it was converted into a soil moisture percentage.

Grid Setup

We initialize the model with the National Meteorological Center analyses, which provide the horizontal wind components, temperature, and relative humidity at 2.5° latitude/ longitude intervals and at the mandatory pressure levels. We start the simulation at 1200 UTC (0600 LST over the MCS region) 23 June 1985. The simulation actually uses two grid setups. Prior to 0000 UTC, we run the model with three grids, with horizontal grid spacings of 75 km, 25 km, and 8.333 km. After 0000 UTC, we add another fine grid (2.0833 km), but eliminate the coarse 75-km grid. Thus, after 0000 UTC, the model's horizontal grid spacing on the three grids is 25 km, 8.333 km, and 2.083 km. Hereafter, we call these grids Grid #1, #2, and #3, respectively (Figure 2). We use 32 vertical levels, stretched from a spacing of 175 m near the surface to 1000 m at the model top (~21 km). During the first 9 hours of the simulation, we use only the two coarsest grids. We activate Grid #3 at the 9-hour mark and Grid #4 at the 10-hour mark. Between

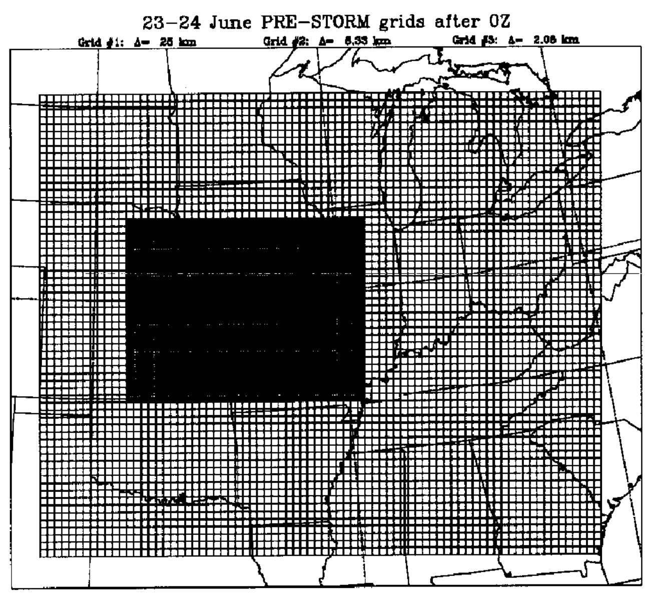

Figure 2. Grid setup for the PRE-STORM simulation after 0000 UTC 24 June 1985. The horizontal grid spacing is 25, 8.333, and 2.083 km on Grids #1, #2, and #3, respectively.

1900 and 2230 UTC, we use the Level 2.5w convective parameterization scheme (Weissbluth and Cotton 1993) on the 8.333-km grid; thereafter, we turn it off on all grids. Thus, we explicitly simulate the PRE-STORM 23-24 June 1985 MCS (no convective parameterization) between 2230 and 0400 UTC, writing analysis files to disk every 15 minutes. All of the model results we show are from Grid #4 between 0000 UTC and 0400 UTC 24 June 1985.

Results

The RAMS simulation captures many of the key features of the 23-24 June 1985 MCS. At 2000 UTC 23 June, an east-west oriented line of parameterized convection had developed in east-central Iowa along the simulated frontal boundary. The overall pattern of parameterized convection agreed well with observed convective activity at this time. Shortly thereafter, at 2230 UTC, a new band of convection developed in extreme southeast Nebraska, while the convection in Iowa intensified. At this time, simulated rainfall rates in south-central Iowa exceeded 5 cm^{-1}, in good agreement with observations. Storm reports in this region indicate over 12 cm of rainfall in Madison, Clark, and Warren counties of Iowa in the late afternoon. For the next several hours (until the end of the simulation, at 0400 UTC), in agreement with observations, the simulated convection propagated southeast at about 30 knots. Comparison of simulated convection with contemporaneous radar observations shows generally good agreement between the simulation and observations, although the simulated convection does not extend quite as far west as the actual convection. Figure 3 shows the 500-mb condensate mixing ratio at 0400 UTC, corresponding to the time of the satellite image in Figure 1.

Analysis of Simulation Results

We intend to use output from both of our explicit MCS simulations (this one and a tropical MCS simulation) to calibrate a CGM convective parameterization scheme which accounts for mesoscale flow branches (i.e., mesoscale updrafts and downdrafts). The parameterization scheme is still under development, although its framework is largely complete. The convective part of the scheme is the Arakawa-Schubert parameterization (e.g., Arakawa and Cheng 1993) modified to account for the effects of convective downdrafts following Johnson (1976). In order to account for a more physically realistic coupling between cumulus convection and associated mesoscale cloudiness, the scheme employs a prognostic closure (as opposed to a quasi-equilibrium closure), as described by Randall and Pan (1993). The parameterized convection provides condensed water, ice, and water vapor which drives a parameterization

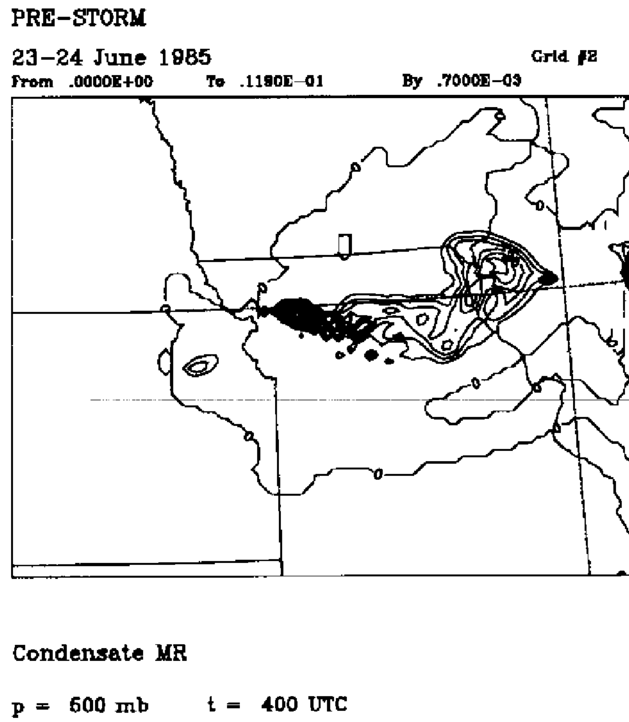

Figure 3. Condensate mixing ratio at 500 mb on Grid #3 at 0400 UTC 24 June 1985.

for the large-scale effects of mesoscale circulations associated with the convection. We conditionally sample mesoscale updrafts and mesoscale downdrafts within our explicit simulations in order to calibrate the shape and magnitude of the vertical profiles of mesoscale ascent, descent, phase transformations, and eddy flux convergences of moisture and entropy within parameterized mesoscale updrafts and downdrafts. Our scheme accounts for the effect of organized convection on the large-scale wind field by employing a cumulus momentum parameterization which includes the convective-scale pressure-gradient force, following Wu and Yanai (1994).

A key part of our parameterization, naturally, will be to determine when and where it will be necessary to activate the mesoscale part of the scheme. We have hypothesized that potential vorticity (PV) could be used as a marker of MCS activity. In an attempt to explore this possibility of using PV as a marker in the decision-making process of when and where to activate the MCS parameterization scheme, the vertical integration of area averaged PV variance $(\overline{q'q'})$ was calculated over a mid-tropospheric layer for the output from an explicit simulation of the 10-11 June 1985 PRE-STORM squall line for the time period while the squall line evolved from its initial stages to the beginning of its dissipating stage. The PV variance evolved from a small positive value at the initial stage to the maximum value when the convection was the strongest. The center of the maximum was located to the north end of the squall line and highly correlated with the squall line thereafter. The above results are encouraging in that PV variance has reflected the life-cycle of the squall line from the preliminary analysis of one case. Further analysis and study of more cases are under way in order to determine whether it is possible to use PV as a marker.

Conclusions

We have used RAMS to perform a three-dimensional simulation of the PRE-STORM 23-24 June 1985 mesoscale convective system. RAMS successfully captures the observed characteristics of the MCS, including temporal initiation, geographic location, speed and direction of motion of the system, and spatial arrangement of the convective cells and stratiform region. We intend to use output from both of our explicit MCS simulations (this one and a tropical MCS simulation) to tune a convective parameterization scheme which includes mesoscale effects.

Acknowledgments

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