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REAL-DATA NUMERICAL SIMULATIONS OF SEVERE BOW ECHOES OBSERVED DURING BAMEX

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1. INTRODUCTION

A growing body of observational evidence has confirmed the role of low-altitude mesovortices in the production of damaging surface winds within bow echoes (e.g., Atkins et al. 2005; Wheatley et al. 2005). A fundamental explanation of this mesovortex–high-wind association was proposed by Trapp and Weisman (2003), through analyses of a bow echo simulated in a highly idealized environment. Herein, we seek to better understand the production of damaging surface winds within a real-data numerical modeling framework.

The bow echo of 5-6 July 2003, observed during the Bow Echo and MCV Experiment (BAMEX), is the subject of this study. Throughout its lifetime, this convective system produced a number of high wind reports, and caused widespread F0-intensity wind damage across eastern Nebraska and western Iowa. It possessed a well-defined rear-inflow jet (RIJ) and also a wide variety of low-altitude mesovortices. A real-data numerical simulation of this bow echo event has been performed using the Weather Research and Forecasting (WRF) model, and the preliminary results are presented.

2. EXPERIMENTAL DESIGN

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The WRF Version 2.0.3.1 modeling system is applied to a domain that covers the Great Plains, upper Midwest and the lower Ohio River. In this parent domain, the gridpoint spacing is 9 km (Fig. 1). A subnest with a horizontal gridpoint spacing of 3 km is centered about eastern Nebraska and western Iowa. (The placement of this grid is chosen such that it covers the area of convective initiation, over south-central South Dakota and northeastern Nebraska.) The model grid includes 35 levels in the vertical, with monotonic stretching, increasing from 0.2 km near the surface to 1.5 km near the model top (i.e., the 50-hPa pressure surface).

The model is initialized at 0000 UTC 5 July 2003 using the 40 km Eta model run, with the boundary conditions updated on a 3-h interval using the Eta model forecasts. The model is integrated in time using two-way interactive grid nesting.

3. SYSTEM-SCALE STRUCTURE

At approximately 2100 UTC 5 July, consistent with single-Doppler reflectivity data, several individual convective cells initiate over south-central South Dakota (not shown). By 0000 UTC, these cells have begun to interact with one another, producing a mesoscale convective system (MCS) greater than 100 km in length, as evidenced by a continuous line of simulated radar reflectivity in excess of 40 dBZ (Fig. 2a). Over the next 2 h, this system grows upscale into a mature, extensive bow echo approximately 150-200 km in length (Fig. 2b).

This horizontal scale compares favorably with that of the observed system. The timing of the simulated bow echo, though, lags the observed system by about 1 h. Also at this time, the rainwater mixing ratio field now extends tens of kilometers rearward of the leading edge convection (not shown). A midlevel RIJ resides in this trailing region, and is clearly identifiable in the storm-relative wind field at 3 km (not shown).

Simulated radar reflectivity at 0500 UTC shows the bow system during its decaying stage (Fig. 2c). The highly asymmetric nature of the convective system evidences the dominant cyclonic vortex on the northern end of the system. This system-scale feature, possessed by the observed system as well, is apparent in the storm-relative wind field at 3 km, where there is only weak evidence of an anticyclonic vortex on the southern end of the system (not shown). The horizontal scales of the observed and simulated bow echoes are again consistent (greater than 200 km in length), but the timing of the simulated bow echo stills lags the observed system by about 1 h. This system continues to weaken beyond this time.

4. SUBSYSTEM-SCALE STRUCTURE

This numerical simulation demonstrates the ability of the WRF model to capture subsystem-scale features such as low-altitude mesovortices. At 0300 UTC, several cyclonic vortices are apparent along the leading edge of the system, as evidenced by the vertical vorticity field at 0.25 km (Fig. 3). More specifically, these vortices are located just behind the leading edge of the cold pool. Three of the four cyclonic vortices are located along the northern flank of the system (looking downwind). At this time, these vortices are characterized by horizontal scales of 5-10 km, and possess vertical vorticity magnitudes on the order of 400×10^{-5} s^{-1}. Vertical vorticity magnitudes are most significant near the surface, and extend to 5 km in the vertical. The northernmost and southernmost low-altitude mesovortices persist throughout the lifetime of the system. We note here that the aforementioned low-altitude mesovortices are only marginally resolved using a horizontal gridpoint spacing of 3 km. If we assume a characteristic length scale of 10 km for low-altitude mesovortices, these circulation features are then sampled by at most 3 gridpoints. Subject to this limitation, one would expect damped values of positive vertical vorticity.

5. CONCLUSIONS AND FUTURE WORK

Preliminary results from a real-data simulation of the 5-6 July 2003 bow echo over eastern Nebraska and western Iowa have been presented. Notably, this simulation replicates the characteristics of highly organized, severe bow echoes, and thus captures the salient features of the observed system.

The model produces a mature, extensive bow echo with a horizontal scale well in excess of 100 km. On the system-scale, this simulated bow system possesses a dominant cyclonic vortex and weaker anticyclonic vortex on its northern and southern flanks (looking downwind), respectively, as well as a concentrated RIJ tens of kilometers rearward of the leading edge convection. The geographic location and horizontal scale of the simulated bow echo were consistent with those of observed system, but the timing of the simulated bow echo preceded that of the observed system by about 1 h.

On the subsystem-scale, several low-altitude mesovortices (with horizontal scales of 5-10 km) form on the leading edge of the simulated bow echo. Only one of these vortices forms on the southern flank of the system (looking downwind). The positive vertical vorticity associated with these circulations was maximized near the surface, and extended into the midlevels of the troposphere.

A real-data simulation of this bow echo event is now being performed using the WRF Version 2.1 modeling system. Again, we use two-way interactive grid nesting to resolve convection-permitting scales, but at higher resolution (~1 km). The results from this real-data WRF case, and other simulated bow echo events, will allow us to test the generality of idealized modeling-based theories that link low-level mesovortices to damaging, straight-line winds, and of proposed mesovortexgenesis mechanisms.

6. REFERENCES

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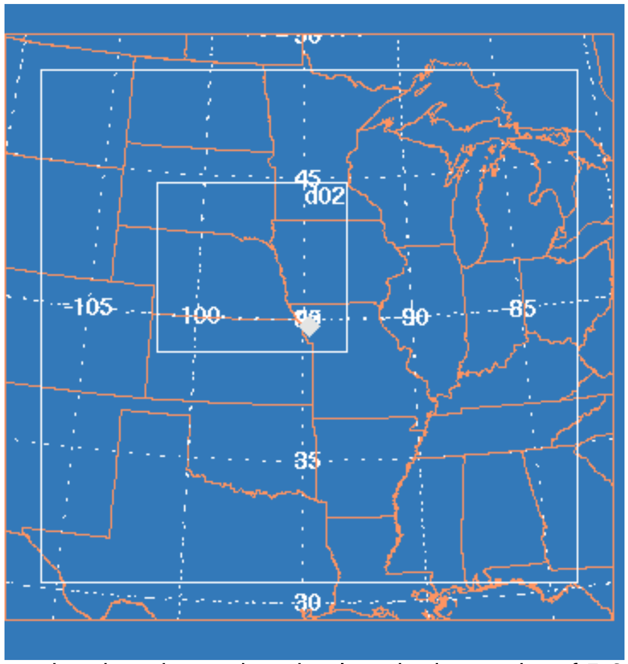

Fig. 1. Integration domain used to simulate the bow echo of 5-6 July 2003.

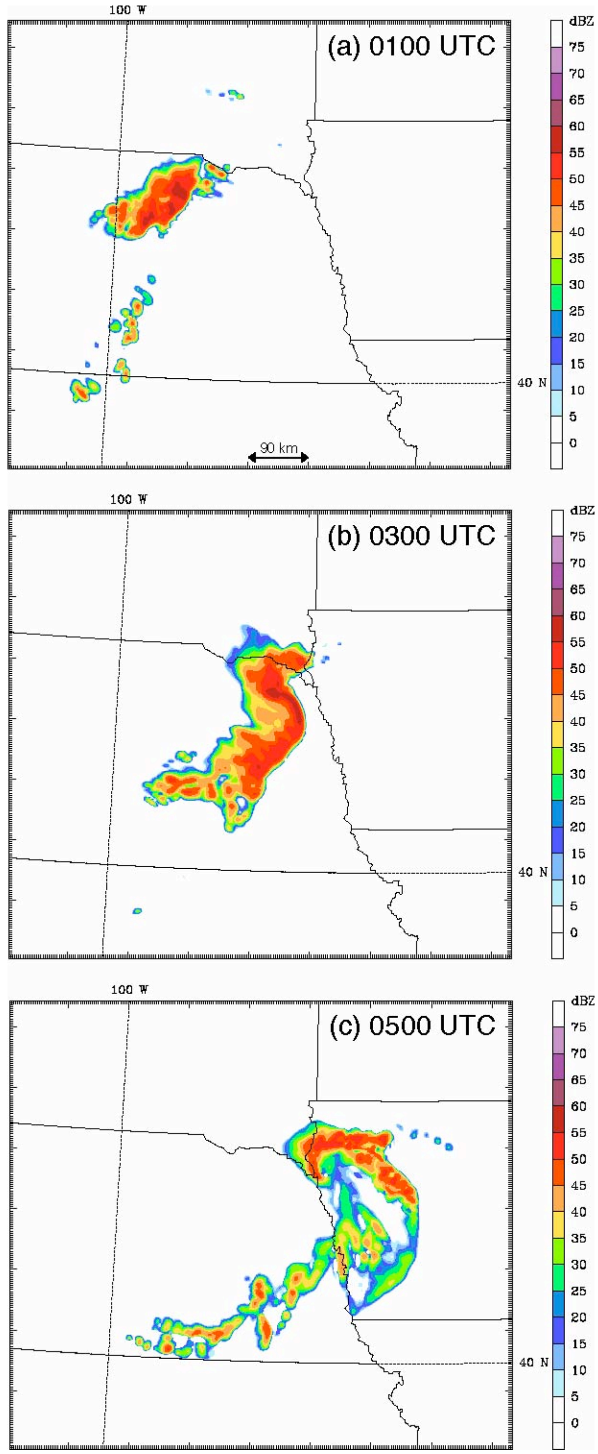

Fig. 2. Simulated radar reflectivity at (a) 0100 UTC, (b) 0300 UTC and (c) 0500 UTC 6 July 2003.

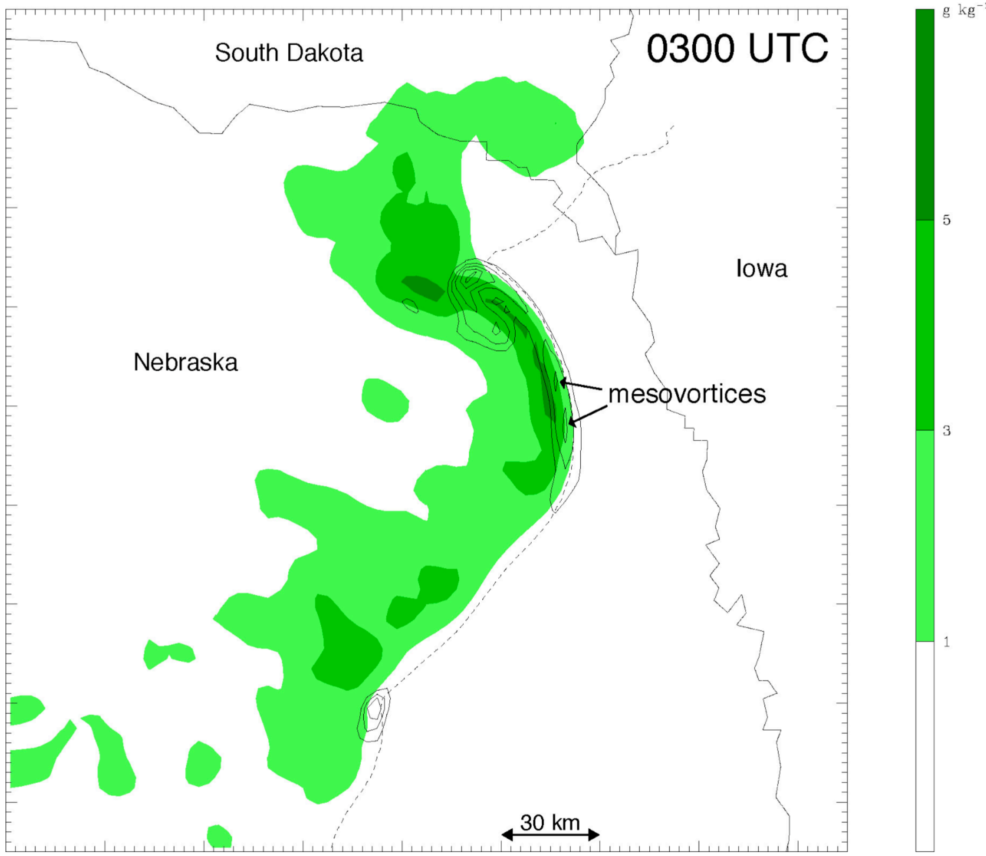

Fig. 3. Horizontal cross section, at z = 0.25 km, of vertical vorticity (solid lines; contour interval of 0.001 s^{-1}) and the 1, 3, and 5 g kg^{-1} rainwater contours (see label bar) at 0300 UTC 6 July 2003. The –1-K perturbation temperature isotherm is denoted with a dashed line.