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NUMERICAL MODELLING OF THE 31 MAY 1998 SEVERE BOW ECHO

James Correia Jr* and Raymond Arritt
Department of Agronomy, Iowa State University, Ames, IA

1. Introduction

On 31 May 1998, a series of tornadic supercell storms formed in South Dakota and eventually merged ahead of a cold front into a squall line. This squall line immediately began producing severe winds, hail and tornadoes for the following 12 hours, decayed, then regenerated to cause an outbreak of severe weather across New York state. Fiorino and Correia (2001) suspected this event to be enhanced by inertia-gravity waves.

A mesoscale analysis of the wind and pressure fields associated with this storm resembled classic features of MCS's: wake low, bubble high, presquall low. Time series at individual stations resembled gravity wave time series where large pressure jumps and falls occurred on time scales of 20 minutes.

Wake lows have been shown to be regions where gravity waves may develop (Bosart and Seimon 1988). This region may only be favorable provided a stable layer exists with sufficient depth near the ground. Typical wake low formation occurs on the back edge of a precipitation and cloud shield where downdrafts are causing strong adiabatic warming possibly in the presence of evaporation of precipitation. This leads to strong downdrafts impinging upon a stable layer leading to the generation of a gravity wave (Jewett et al. 2003).

Here we model the 31 May 1998 severe bow echo case to determine if gravity waves played a role in this severe windstorm. We have adopted a physics ensemble approach where different microphysics, boundary layer schemes and convective parameterizations are coupled. The focus of this study will be on the numerical results generated by the simulations and their implications for mesoscale modeling.

2. Data and methodology

The NCAR/Penn State University Mesoscale Model version 5 (MM5) was used to model this event. The model was run at 10 km grid point spacing with 38 vertical levels covering a domain of 90×100 grid points. Over all, 10 simulations are analyzed here. The tenth simulation was run at increased vertical resolution (57 levels). The physical parameterizations used in these simulations are shown in Table 1.

3. Model simulations

3.1 Microphysics comparison

Table1: Characteristics of the 10 model runs.

simulation	CUPA	MICRO	PBL	Levels
R2blk	KF2	Reisner 2	Blackadar	38
Rblk	KF2	Reisner	Blackadar	38
WRblk	KF2	Warm Rain	Blackadar	38
SIblk	KF2	Simple Ice	Blackadar	38
MrfR	KF2	Reisner	MRF	38
EtaR	KF2	Reisner	ETA	38
GrBR	Grell	Reisner	Blackadar	38
BMBR	Betts-Miller	Reisner	Blackadar	38
No Evap	KF2	Reisner	Blackadar	38
BRKL	KF2	Reisner	Blackadar	57

The first "ensemble" (runs R2blk, Rblk, WRblk, SIblk) compared the microphysical parameterizations. The warm rain scheme neglects ice processes, simple ice neglects supercooled liquid water and melts snow immediately if warmer than freezing, Reisner scheme adds ice and supercooled water but neglects graupel and the Reisner 2 scheme predicts graupel and ice number concentration.

For this comparison we look at results 11 hours into the run. Prior to this time and very early in the simulation a microphysics induced gravity wave formed (not shown). This gravity wave propagated from Minnesota to Lake Michigan by 1100 UTC when the comparison is made. The gravity wave was located on the eastern shore of Lake Michigan and had an extension to the first gravity wave trough to the northwest (figure 1). Vertical motion lagged the sea level pressure field by one-quarter wavelength consistent with linear gravity wave theory (Eom 1975). The most obvious difference was between the warm rain and other microphysics in both strength and extent of the gravity wave. The simple ice scheme has the greatest amplitude within the wake low. The Reisner schemes are fairly close in amplitude of the pressure field and location and magnitude of the vertical motion field.

Another simulation, BRKL, was configured similar to Rblk but included 19 additional vertical levels that doubled the resolution of the boundary layer. This simulation formed the initial gravity wave due to the microphysics and is thus comparable to the lower vertical resolution simulations. The simulation valid at 1100 UTC (Figure 2) was slightly different than the Rblk simulation. The vertical motion field has been modified so that strong ascent behind the mesolow is absent. It also appears that the wavelength of the wave is substantially reduced. The amplitude of the wave, as seen in the sea level pressure field, was reduced and shifted westward relative to Rblk. This implies that vertical resolution was a major factor in the development of this wave.

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*Corresponding author address: James Correia Jr. Dept. of Agronomy, Iowa State Univ., Ames, IA 50010. email address: jimmyc@iastate.edu

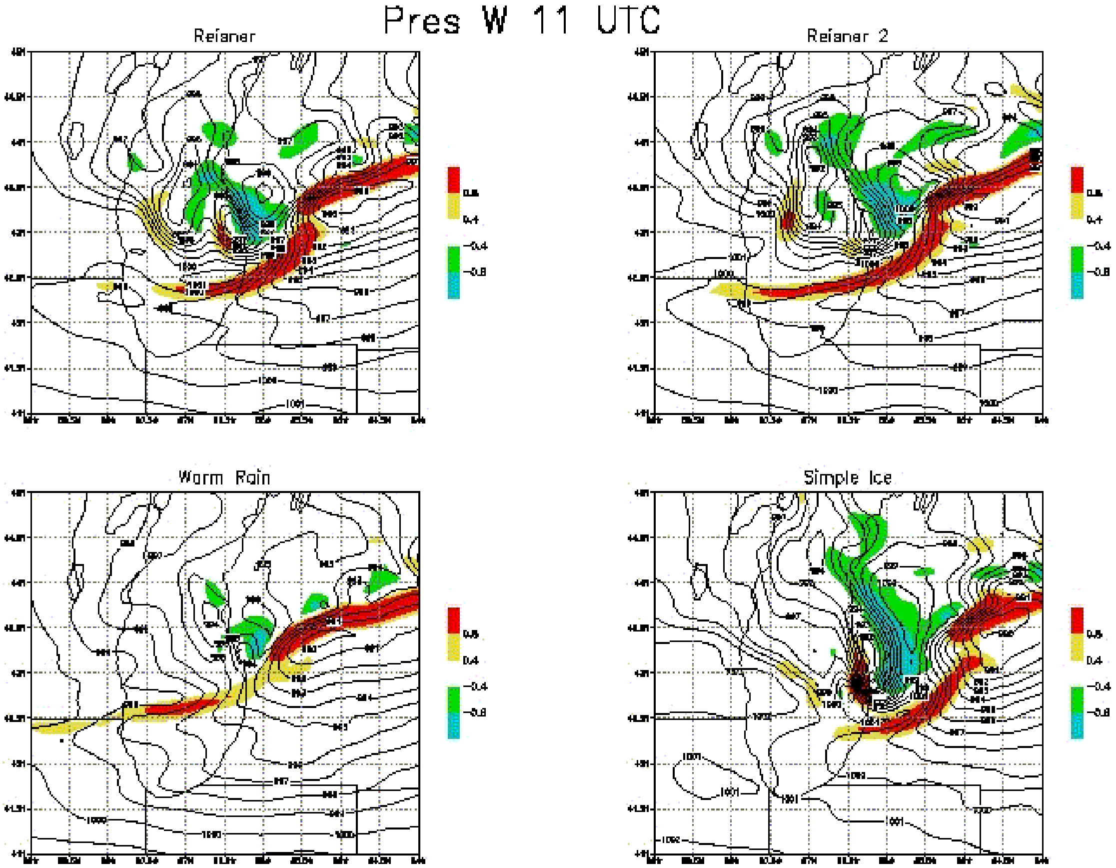

Figure 1: Sea level pressure (contoured every 1 hPa) and vertical velocity (shaded according to the color bar in ms^{-1}) at 1100 UTC 31 May 1998 for simulation: A. Rblk, B. R2blk, C. WRblk, D. SIblk.

Another way to assess the relative role of microphysics is presented in figure 3. Comparing the rainwater mixing ration on the lowest sigma level, we see that the mesolow resides on the back edge of the rainwater. When evaporation of precipitation was omitted in the whole simulation, the mesolow failed to form but the spatial pattern remained similar. It would appear that evaporation is playing a role in the gravity wave's development. To examine if the number of vertical levels plays an important role in evaporation we examine the BRKL simulation (Figure 2). Although the gradient of rainwater mixing ratio is reduced its position relative to the mesolow is similar, which suggests that evaporation may be reduced in this simulation.

3.2 Boundary layer comparison

The ensemble members Rblk, EtaR, and MrfR were analyzed. At 1130 UTC, the outflow boundary evident 30 minutes earlier in the vertical motion field was evident in the pressure field (not shown). The maximum updraft mass flux (over the last 30 minutes) from the Kain-Fritsch 2 scheme indicated that the convective scheme was active in and near the gravity wave region. It appears that the convective scheme

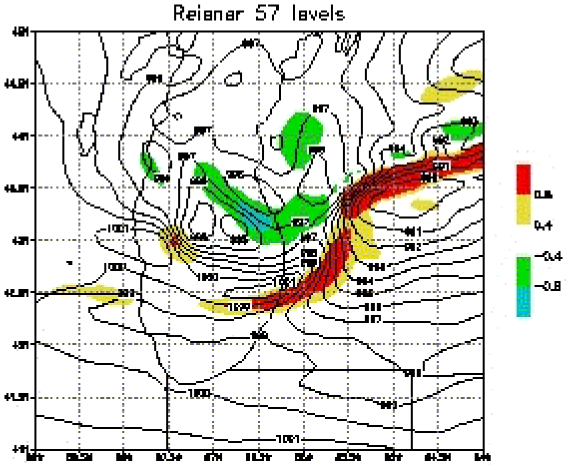

Figure 2: Same as figure 1 except for simulation BRKL.

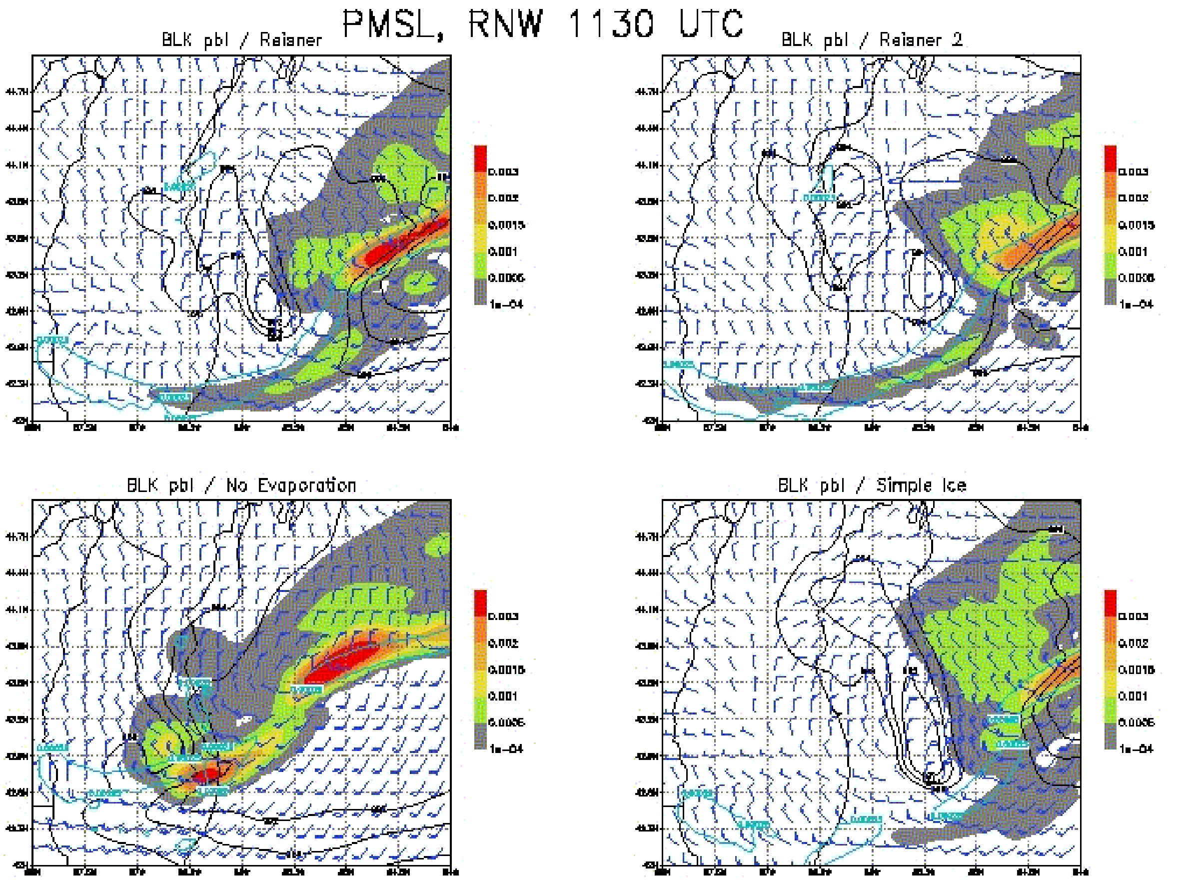

Figure 3: Sea level pressure (contours of 992,994, and 996 hPa), rainwater mixing ratio (shaded according to color bar in kg kg^{-1}), wind barbs (ms-1), and potential temperature gradient (light blue contour) at 1130 UTC 31 May 1998 for simulations: A. Rblk, B. R2blk, C. No evap., D. SIblk.

contributed to the downward vertical motion via local cooling on the lowest sigma level.

The difference in pressure between the two (Eta and Blackadar) schemes merely showed the horizontal displacement between the two simulations. The Blackadar simulation was warmer than the Eta, which explains why the pressure is much lower between the simulations. In general, the 3 schemes produced similiar horizontal structures but the timing was slightly different, with the MRF evolving the fastest and the Blackadar scheme the slowest.

3.3 Cumulus parameterizations

Different cumulus schemes (runs GRBR, BMBR, Rblk) were coupled to the Blackadar and Reisner schemes in order to see how the convective parameterization influenced the evolution of the primary gravity wave. It was found that the primary gravity wave develops in the three cumulus schemes due to the onset of grid resolved rainfall, and midlevel development of ice processes (warming due to freezing in a saturated environment). Since the convective schemes were most active very early in the simulations and had a dramatic effect on the integration, there is little insight to be gained by comparison of results at 11 hours into the simulation (not shown).

4. Summary and Conclusions

The interaction between physics packages has been explored in the context of a gravity wave/bow echo case study simulation. In this case, the microphysics package controls the amplitude of pressure perturbations through latent heating/cooling. The pbl schemes control the speed at which these processes affect the simulations. The coupling between the microphysics and pbl schemes seems to exert control on the low level propagation of outflow. The KF2 scheme also affects the low level cooling imposed by its reduction of CAPE. Therefore the physics schemes all play a part in determining this particular gravity wave event.

By far the most important effect is controlled by the cumulus scheme. The cumulus scheme

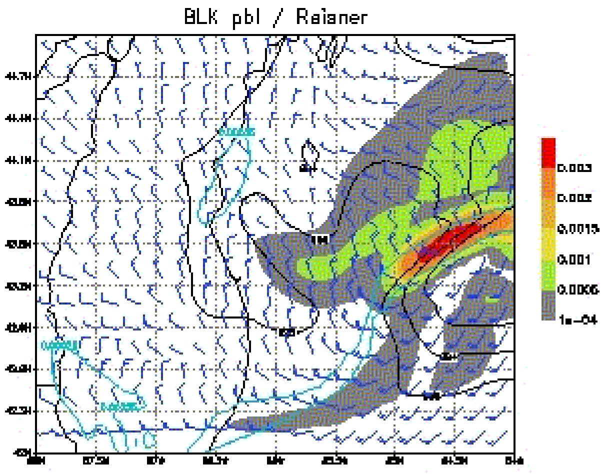

Figure 4: Same as figure 3 except for simulation BRKL.

determined when and where the first gravity wave developed. It also played a major role in determining its strength. The Grell scheme simulation developed grid resolved rainfall earlier than the KF2 and BM schemes and therefore had a much stronger gravity wave but broke down into smaller waves 8 hours later. The Betts Miller scheme failed to generate a strong gravity wave, thus the wave was damped and failed to have a strong impact.

The BRKL simulation formed the initial gravity wave due to microphysics but altered the development of the second gravity wave. It appears that the second gravity wave may have been forced by evaporation and strong adiabatic warming due to descent (Gallus 1996). This may be a case where strong non-linear interactions between the physics packages amplifies into a gravity wave. We can not tell if this should be thought of as a new numerical instability or something that is realistic. Future work will attempt to answer this question in the hope that it will result in a better simulation for this event.

Acknowledgments

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