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Can High Resolution WRF Simulations be used for Short-term Forecasting of Lightning?

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1. INTRODUCTION

Recent research (Cecil et al. 2005; Petersen et al. 2005) reinforces the strong relationships between lightning flash rates and total ice mass aloft in storms. With the increased use of cloud-resolving numerical models and the implementation of the Weather Research and Forecasting (WRF) Model into NWS forecast operations, it is appropriate to determine whether these models can provide useful skill in short-term forecasting of the threat from lightning. In this paper, we begin to investigate this question..

2. METHODOLOGY

We have begun to examine the output from 2-4 km horizontal resolution runs of WRF that cover the Southeastern United States, where we have access to lightning flash data. One set of WRF runs under study is that produced by the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma during the Spring of 2005. These 30-h runs were conducted over the entire eastern U.S., using 2 km resolution and 50 vertical levels. Ice microphysics featured representation of cloud ice, snow and graupel, in the WRF Single Moment 6-Species parameterization. We have focused our analysis efforts on a simulation initialized at 00 UTC 22 April 2005, a day characterized by several convective events in the Tennessee Valley region, accompanied by numerous severe weather reports. Isolated severe storms were present in western Alabama during the early part of the day, but these storms eventually gave way to a larger squall line event some 12 h later. Then, by 23 UTC, a third outbreak of storms occurred in eastern Alabama and Tennessee along a rare dryline intrusion into the area. All these storms were documented by the total lightning data collected by the North Alabama Lightning Mapping Array (LMA).

Additional WRF simulations for which LMA lightning data were available were those for the hailstorms of 10 December 2004 in northern Alabama. These simulations were performed at the National Space Science and Technology Center (NSSTC) using 4 km horizontal resolution and 37 vertical levels. A third set of WRF simulations – at 2 km resolution - over Florida for May 2004 are also available to us, but only cloud-to-ground lightning flash data from the National Lightning Detection Network (Cummins et al. 1998) are available for comparison. We are currently in the process of performing a number of additional 2 km WRF runs over the Tennessee Valley region for a variety of other storm cases documented by our LMA.

For the first phase of this research, the WRF output is evaluated subjectively regarding its ability to represent accurately the evolution of the convective storm field. For lightning threat, we give special consideration to the WRF vertical fluxes of graupel in the vicinity of –15 C, the layer where charge separation processes are thought to be most active in storms. Accuracy of the WRF results is assessed by comparing the field of WRF graupel fluxes with actual lightning flash extent density fields from LMA. In assessing the WRF output, consideration is given to storm cell location, size, intensity, number, arrangement, and movement. Subjective evaluations will ultimately be replaced by more objective methods currently under development.

3. RESULTS

The WRF model produces deep convective storms in all cases, and shows consistent ability to generate convective storms of a proper vertical depth, with reasonable amounts of graupel near –15 C and reflectivities in excess of 35 dBZ there, consistent with exoectations of lightning. However, there are some deficiencies in the WRF depiction of storm location, size, number and arrangement. For example, the 3-h WRF forecast for 03 UTC 22 April 2005 in the Tennessee Valley area depicts a cluster of large storms over western middle Tennessee (Fig. 1), whereas the LMA lightning analysis for this time period (Fig. 2) shows instead a line of storms from western Kentucky southeastward to the Alabama-Tennessee border. The centroid of WRF activity appears to be a close match to the actual centroid of observed activity, but the actual cell sizes and arrangements exhibit considerable differences. WRF peak updrafts in these storms reach 18 m/s, likely an underestimate because of the 2 km model grid resolution.

A similar mix of successes and failures is found in the other cases examined thus far. For the 10 December 2004 case, WRF correctly predicts storms in northeast Alabama, along with sizeable reflectivity aloft (not shown). However, WRF peak updrafts reach only 6-7 m/s on the 2 km grid, which is almost certainly too small, given that CAPE was approximately 800 J/kg, hailstones of one inch diameter fell from the storms, and a simulation using another cloud model run at 500 m resolution gave updrafts of 19 m/s. For storms in Florida on 1 May 2004, a 2 km WRF run gave deep storms with peak updrafts of 21 m/s in approximately the right location, but expanding westward in an unrealistic fashion as the system grew.

4. SUMMARY

The WRF 2 km runs show some promise of providing assistance in addressing the short-term lightning threat forecast problem, but limitations of the technique must be addressed if the approach is to achieve maximum utility. It is our impression that the inadequacies of the model stem from three main sources. The most significant source, and perhaps the most difficult to correct, is that of initialization of the model using data that are incomplete with respect to representation of the mesoscale structure of the atmosphere. Assimilation of satellite and radar data, along with ensemble simulations, may proved helpful in addressing this problem. A second important source of error in the model forecasts is model resolution; 2 km can show storm structure, but cannot always show realistic storm intensity. The third major source of model error is the overly simplistic cloud and precipitation microphysics scheme. It would be highly desirable to have a microphysics scheme that distinguishes the two principal species of large precipitating ice, graupel and hail.

5. REFERENCES

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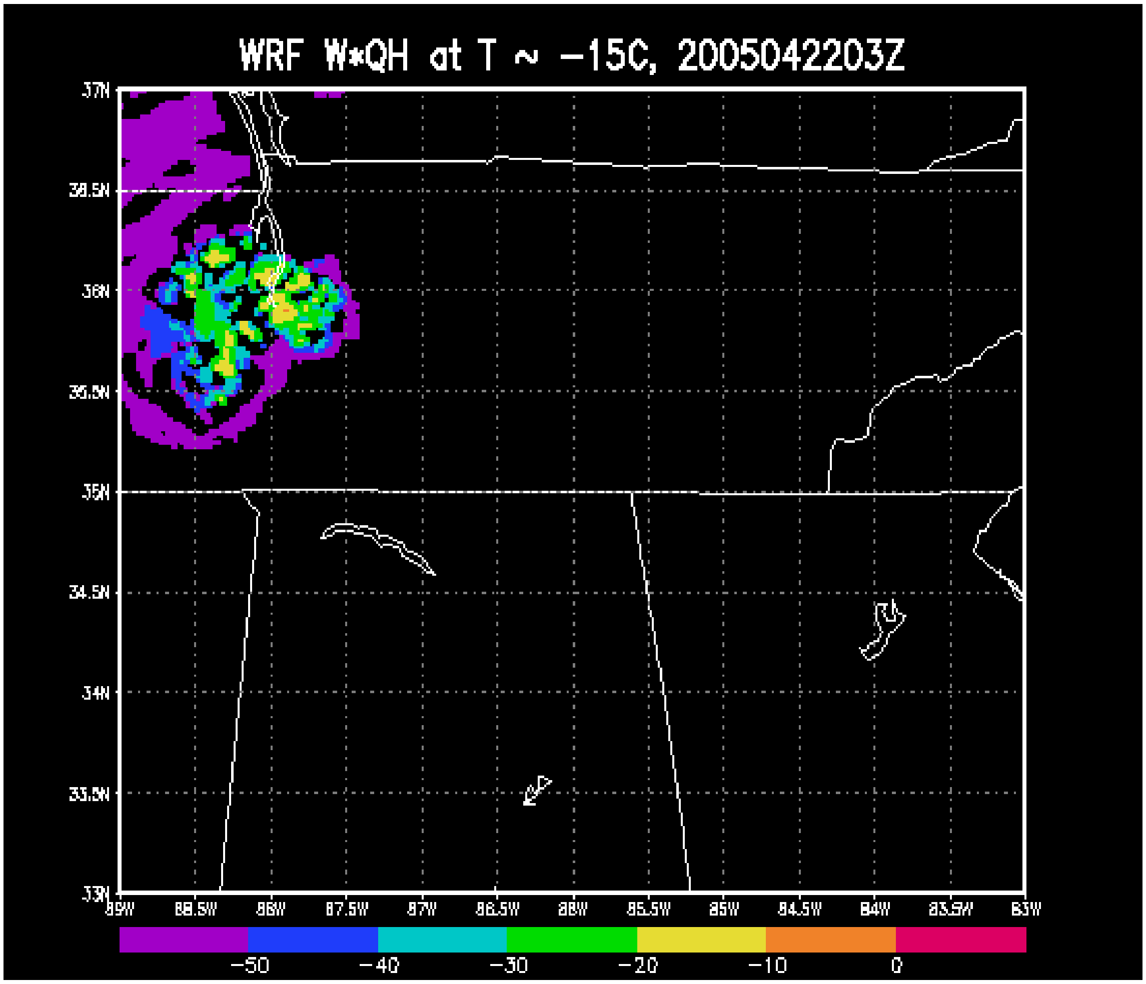

Fig. 1. WRF depiction of graupel flux at model level where T = -15 C, for 03 UTC 22 April 2005. Flux is rendered like reflectivity to compress the large dynamic range, using 10 log10(flux).

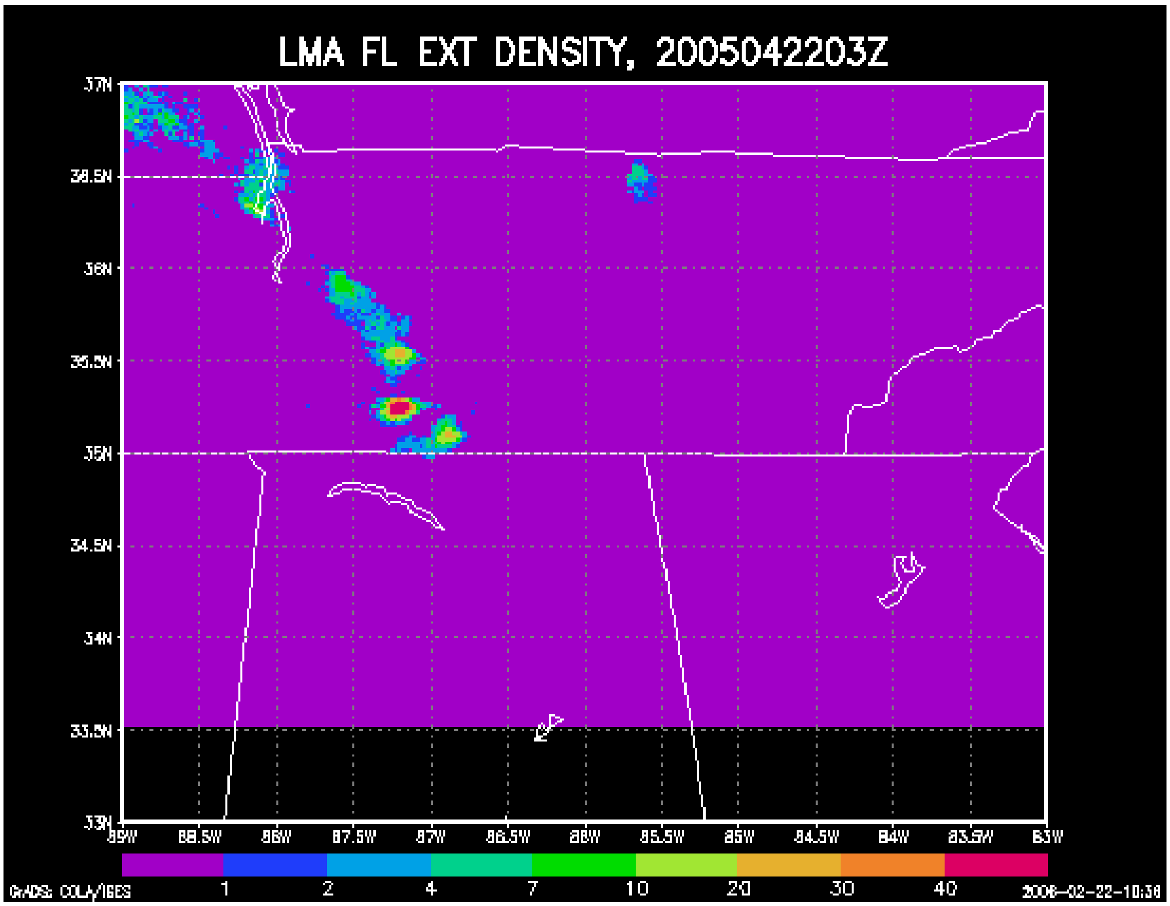

Fig. 2. LMA analysis of vertically integrated flash extent density for a 5-min time period containing 03 UTC 22 April 2005. Scale at bottom explains color shadings in plot. Units are flash elements per .01 deg x .01 deg grid box.