PROGRESS AND CHALLENGES IN CLOUD-RESOLVING NUMERICAL SIMULATIONS

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I. INTRODUCTION

In spite of the rapid progress in numerically simulating convective systems, significant challenges remain in seeking to advance the numerical prediction of convective-scale weather. Most mesoscale models that represent convective systems explicitly have been adapted from larger-scale models, for which parameterizations of model physics have been developed and tested on applications with horizontal grids of several tens of kilometers. As the model grids have been refined to several kilometers or less, the uncertainties and approximations in the physics parameterizations have become significant contributors to model error. The cloud microphysics become increasingly important in explicit simulations of convection, and multi-species microphysics schemes with more accurate particle size distribution models and/or multiple moment schemes should be refined and verified against observations for different types of storms. The planetary boundary layer (PBL) also plays a strong role in the development of convective systems; new PBL schemes are required that are suitable for kilometer-scale resolutions where a significant portion of convective boundary layer mixing is achieved by resolvable eddies. Subgrid-scale turbulence closure models suitable for non-LES resolutions also require further research. Because of the important small-scale structure in convective storms, both advanced variational data-assimilation and ensemble Kalman filter approaches should be explored in seeking a complete and dynamically consistent representation of the initial atmospheric structure. Model numerics also require careful scrutiny to ensure that important convective structures near the grid scale are resolved as well as possibile.

II. CONVECTION-RESOLVING SIMULATIONS

We have begun testing the capabilities and limitations of the Advanced Research version of the Weather Reseach and Forecasting (WRF-ARW) model (Skamarock et al. 2005) in forecasting convective events with horizontal grids of 4 km and below, relying on the explicit treatment of convection, without cumulus parameterization. As part of this testing, real-time forecasts have been conducted during the spring and early summer months in the central U.S. for the past three years. An illustration of the capabilities of the convection-resolving forecasts is displayed in figure 1, depicting the 36-hour 4 km WRF forecast for radar reflectivity valid on 10 June 2003 at 12 UTC. While there was little convective activity early in the forecast, a strong baroclinic system developed during the forecast period, producing a concentrated line of convection extending across Illinois and Missouri at 36 h. At this resolution the cellular structure of the squall line is quite apparent.

Overall, these simulations reveal a surprising ability to forecast convective systems out to 36 hours, and to

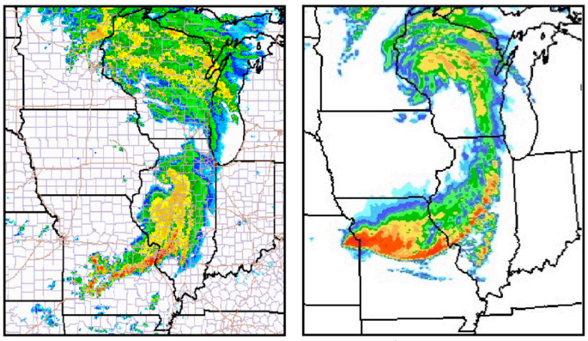

FIG. 1: 36 h WRF-ARW 4 km reflectivity forecast and composite NEXRAD reflectivity valid 10 June 2003 12 UTC (Klemp. 2006)

provide realistic representations of the observed convection. In comparison with coarser-grid forecasts, the 4 km WRF forecasts provide a much better indication of the likely mode of convection (bow echoes, mesoscale convective vortices, supercell lines) as well as the timing and location of convective initiation. Beginning with coarse resolution (40 km) initial data, we found that realistic convective scale structure spins up quickly over the first 6 hours of the forecasts. The higher resolution forecasts also produced more accurate representation of surface cold pools, gust fronts, and system propagation, although there was occasional development of some spurious isolated convection. There are some systematic biases in the forecasts in that they tend to overpredict precipitation and convective systems tend to decay more slowly than observed. Senstivity to PBL, land-surface conditions, microphysics, and resolution failed to account for the larger forecast errors, suggesting that more detailed observations (and data assimilation) may be needed to significantly improve the ability to more accurately simulate observed convective systems.

III. ROLE OF MODEL NUMERICS

The choice of model numerics can also have a significant influence on the simulation of atmospheric convection. Since the smallest scales tend to be the most unstable in moist convection, significant thermal forcing through latent heating often occurs near the grid scale in the model. This places a priority emphasis on retaining numerical accuracy at higher wave numbers in the model and on controlling small-scale numerical dissipation. To enhance the numerical accuracy, the WRF-ARW model employs a third order split-explicit time integration scheme and fifth order spatial accuracy for advection.

Another measure of the realism in representing the smaller scales in a model can be provided by evaluating the spectra of horizontal kinetic energy. Observational evidence suggests that throughout the mesoscale (order one to several

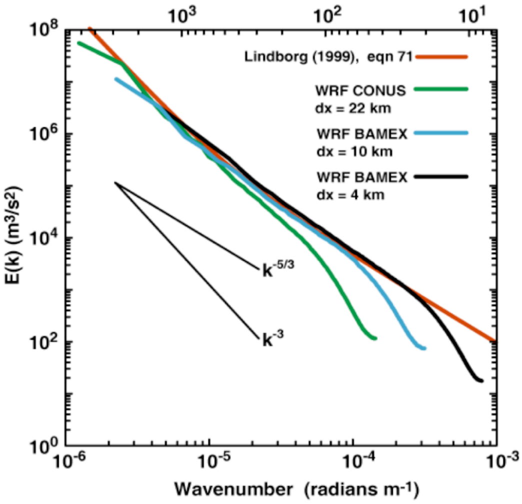

FIG. 2: Kinetic energy spectra for WRF-ARW simulations with horizontal grids of 22, 10, and 4 km (Skamarock 2004).

hundred kilometers) the kinetic energy spectra exhibit a $k^{-5/3}$ dependence on horizontal wave number k. Plotting kinetic energy spectra derived from model simulations, the deviation of the spectra at high wave numbers provides an indication of the amount of numerical dissipation in the model. Figure 2 displays the kinetic energy spectra from WRF-ARW simulations at three horizontal resolutions (22, 10, and 4 km), and reveals that the WRF simulations follow the $k^{-5/3}$ dependence for scales larger than about 6 Δx. These results are encouraging for mesoscale convection-resolving applications in that they generally produce dynamically consistent finescale structure and produce the climatologically appropriate energy spectrum.

IV. REFERENCES

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