Sensitivity of Explicitly Simulated Convection to Mother Domain Cumulus Parameterization Schemes

Alfred M. Klausmann[1], Francoise Robe, Mahesh Phadnis, and Joseph Scire

Earth Tech, Inc.

1. Introduction

MM5 simulations recently conducted over various geographical regions have revealed some problems with the explicit simulation of convection on fine scale (i.e. <5 km) nested grids. These simulations using the Kain-Fritsch cumulus parameterization scheme on the mother domain showed an almost complete absence of precipitation within these fine scale grids even though precipitation occurred on the mother domain. In fact, in many cases well-developed areas of abundant precipitation was predicted by MM5 on the mother domain. This behavior was observed in simulations conducted over Thailand and Florida.

This paper presents some results for a specific convective event that occurred over eastern Florida on April 14, 2002. Three test simulations are examined, each with a different cumulus parameterization scheme implemented on the mother domain. The objective is to illustrate the problem encountered using the Kain-Fritsch Scheme and then test the effect of implementing other cumulus parameterization techniques on the mother domain In addition to the Kain-Fritsch scheme, the Grell scheme and the Betts-Miller schemes were also examined.

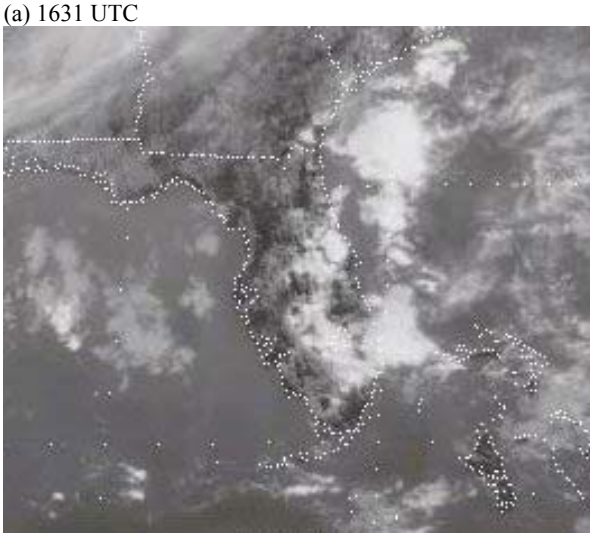
2. April 14, 2002 Convective Event

An outbreak of deep convection occurred over eastern Florida early in the day on April 14, 2002. This case was chosen to illustrate the problem found in our MM5 imulations when convection was explicitly forecast by MM5. The synoptic conditions were characterized by a southeast flow across Florida with a weak upper level trough over northwest Florida. Convective activity already started just east of Lake Okeechobee during the pre-dawn hours and evolved into a north-south band of activity that extended off the Florida east coast into the adjacent Atlantic Ocean. Between 1200 UTC and 1500 UTC additional convection developed rapidly to the southeast of Lake Okeechobee and extended inland to the west and north. Figure 1 shows infrared satellite images at 1631 UTC and 1731 UTC on April 14, 2002 clearly showing the convective activity over eastern Florida.

3. Data and Model Configuration

MM5 Version 3.5 was run with one-way triply nested grids using Lambert Conformal Coordinates (LCC) with a nest ratio of 3:1 and 27 vertical layers. Grid sizes of 36, 12, and 4 kilometers were used for domains 1, 2 and 3, respectively. For domain 3, the 1 km terrain and land use data was used.

(a) 1631 UTC



(b) 1731 UTC

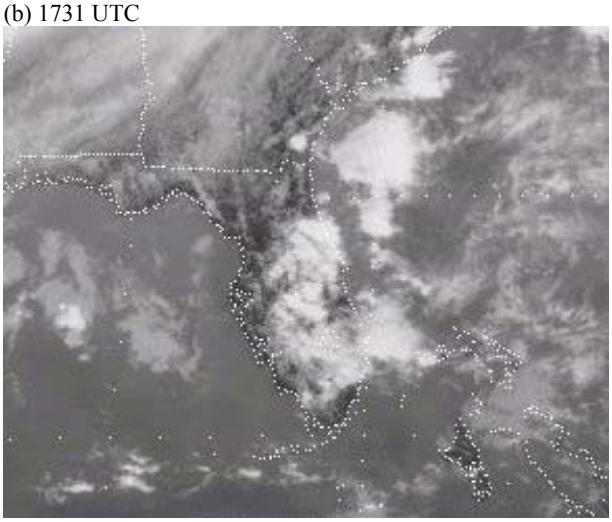


Figure 1 GOES-8 infrared images at (a) 1631UTC and (b) 1731 UTC on April 14, 2002

[1] Corresponding author address: Alfred M. Klausmann, Earth Tech, Inc., email: aklaus@src.com, Telephone: 978-371-4327, Fax: 978-371-2468

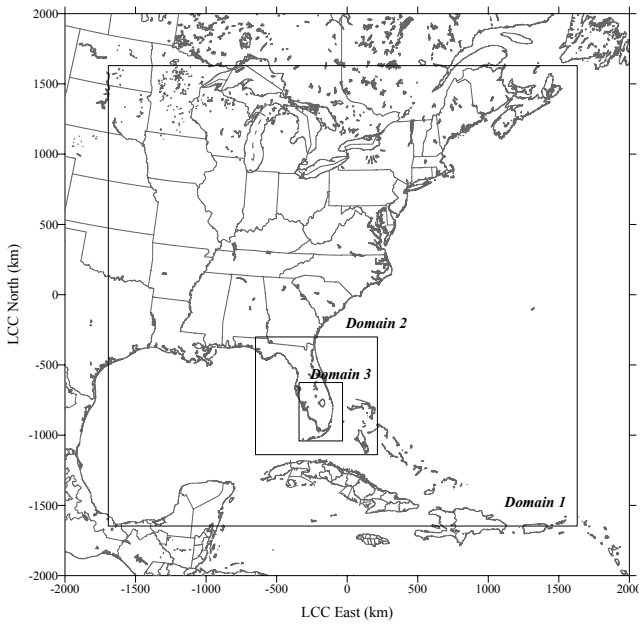


Figure 2 Schematic of MM5 domains 1, 2 and 3

Initial and lateral boundary conditions were provided by the twice daily "Aviation" run of the National Center for Environmental Prediction (NCEP) Global Spectral Model (AVN). These data were obtained from the National Weather Service (NWS) Office of Systems Operations server in Grib format with a resolution of 1.25 x 1.25 degrees. Sea surface temperature from the NCEP Global sea surface temperature data at a resolution of 0.5 degree x 0.5 degree files available once per day were used. The AVN model data and the sea surface temperature were interpolated to the model grid using the REGRID preprocessor. For these simulations no enhancement of the gridded AVN data was performed with rawinsonde data. This was due to the difficulties in obtaining rawinsonde data in real time.

MM5 was configured with the explicit moisture scheme with simple ice phase processes along with the MRF planetary boundary layer scheme. An upper radiative boundary condition was used to allow gravity waves to exit the top of the model domain.

Three test simulations were conducted with MM5 initialized with the 0000 UTC April 14, 2002 AVN model initial data. Each of the test simulations consisted of using the Kain-Fritsch, Grell and Betts-Miller cumulus parameterization schemes on domains 1 and 2. Convection was modeled explicitly on domain 3 for each of the three test simulations.

4. Results

Figure 3a-c shows plots of the surface wind field and the three hour total precipitation for domain 2 (12 km resolution domain) using the Kain-Fritsch, Grell, and Betts-Miller cumulus parameterization schemes. These plots represent 18 hour forecasts from MM5 valid at 1800 UTC on April 14, 2002. This forecast time was well into a convective outbreak that occurred over eastern Florida. The Kain-Fritsch results (Figure 3a) show convection occurring over various locations within and around Florida as indicated by the three hour total precipitation. The precipitation pattern over eastern Florida is generally consistent with satellite imagery (Figure 1) showing convection southeast of Lake Okeechobee with one band extending northwestward across the lake and then two bands extending northward. One north-south oriented band is just inland from the Florida east coast and a second band extends north-northeast from near West Palm Beach into the Atlantic Ocean. When the Grell scheme is implemented (Figure 3b) the spatial pattern of precipitation is not as consistent with satellite imagery. Here, the spatial pattern of precipitation appears more disorganized and precipitation amounts less than occurred with Kain-Fritsch. The simulation using the Betts-Miller scheme yields yet a different pattern of convection from either the Kain-Fritsch or Grell schemes. The Betts-Miller simulation (Figure 3c) predicted much less spatial coverage. Precipitation amounts were higher and concentrated in two distinct areas, one east of Lake Okeechobee and the other much farther north off the northeast coast of Florida.

Figure 3d-f shows the corresponding wind field and precipitation plots for 4 km nested grid (domain 3) with convection modeled explicitly. The simulation with the Kain-Fritsch scheme implemented on the mother domain shows virtually no precipitation on the 4 km resolution grid at 18 hours into the simulation. Additional hours into the simulation continued to predict no precipitation anywhere over Florida. This is inconsistent with satellite imagery and observations over eastern Florida. For example peak hourly rainfall rates observed at West Palm Beach were on the order of 40 mm during this event. A different result for the 4 km grid is shown when the Grell scheme is implemented on the mother domain (figure 3e). This plot shows three well developed areas of convection as indicated by the precipitation maximums. The southern most area is near West Palm Beach, another area just east of Lake Okeechobee and a third area to the north. The predicted wind field shows well-developed and merging outflow boundaries spreading outward from these areas of precipitation. When the Betts-Miller scheme was used (figure 3f) on the mother domain, the 4 km nest showed much smaller areas of convection with less precipitation. In this simulation, only two distinct areas of precipitation are forecast with much less spatial coverage than forecast when the Grell scheme was used on the mother domain.

It appears the vertical stability on the mother domain, modified by the parameterization of moist convection, and then transferred as boundary conditions into the fine scale nest could play a role in the evolution of explicitly simulated convection. This process may occur differently depending on what cumulus parameterization scheme is implemented on the mother domain. It is also likely that this is not the only process contributing to the problem.

Molinari (1990) suggests that fully explicit simulations do best when the grid scale forcing is large. The April 14, 2002

event was characterized by weak large scale forcing. It is possible that part of the problem could be related to how the dynamic forcing within the fine scale nest is resolved and not completely due to the cumulus parameterization scheme on the mother domain. For the convective event discussed in this paper, the dimensions of the fine scale nest may be too small to properly simulate the dynamic forcing triggering the convection. The inconsistencies in convection between the various domains may also be partly due to use of 1-way versus 2-way nesting. With 2-way nesting, explicit convection in the fine scale nest could be transmitted back into the mother domain, possibly resulting in more consistent convective patterns between these nested grids. Additionally, the use of 4 km resolution may be too coarse to properly resolve convection explicitly. Explicit simulations of moist convection at resolutions of 2 km or less may yield more favorable results. The vertical resolution may also be significant. Increased vertical resolution may be necessary to properly represent the vertical temperature and moisture profiles that will influence convection in the model. Also, recent studies (Lynn et al 2001) have shown that improved treatment of land surface and planetary boundary layer processes and soil moisture can lead to improved forecasts of moist convection. All of these additional factors must be considered when evaluating the interaction between cumulus parameterization and its impact on explicitly simulated convection.

5. Conclusions

The results of these test simulations showed a confusing result with different cumulus parameterization schemes resulting in different and inconsistent precipitation forecasts between the 4 km resolution nested grid where convection was treated explicitly and the mother domain. The parameterization scheme used on the mother domain modifies the explicit treatment of convection on a fine scale nested grid. Explicit treatment of convection on the 4 km resolution grid, when the Kain-Fritcsh scheme was used on the 12 km mother domain resulted in an almost complete absence of precipitation in the 4 km grid.

It appears the vertical stability on the mother domain, modified by the parameterization of moist convection, and then transferred as boundary conditions into the fine scale nest could play a role in the evolution of explicitly simulated convection. This likely occurs to differing degrees depending on the choice of cumulus parameterization scheme.

More in depth analysis of the interaction of the various grids and parameterization schemes are needed to resolve these issues. The use of 1-way versus 2-way nesting, increased horizontal resolution on the fine scale grids where convection is explicitly treated, increased vertical resolution, and improved land surface processes needs to be examined to better understand how model explicit convection with cumulus parameterization on the mother domain.

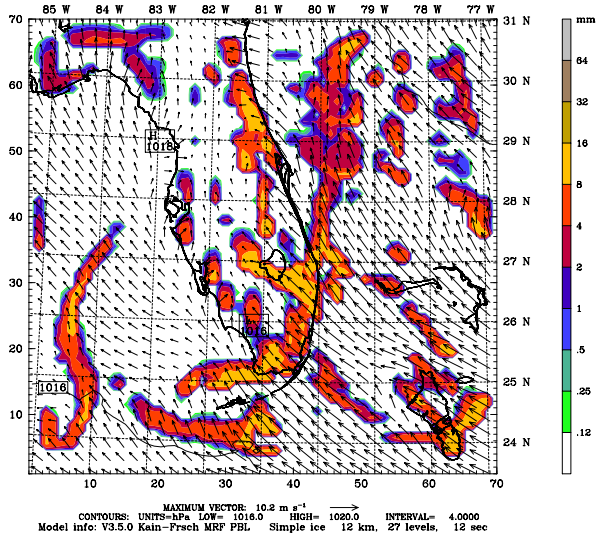
6. References

Lynn, B.H., D.R. Stauffer, P. J. Wetzel, W. Tao, P. Alpert, N. Perlin, R.D. Baker, R. Munoz, A. Boone, and Y. Jia, 2001: Improved Simulation of Florida Summer Convection Using the PLACE Land Model and a 1.5-Order Turbulence Parameterization Coupled to the Penn State-NCAR Mesoscale Model. Monthly Weather Review, **129**, 1441-1461.

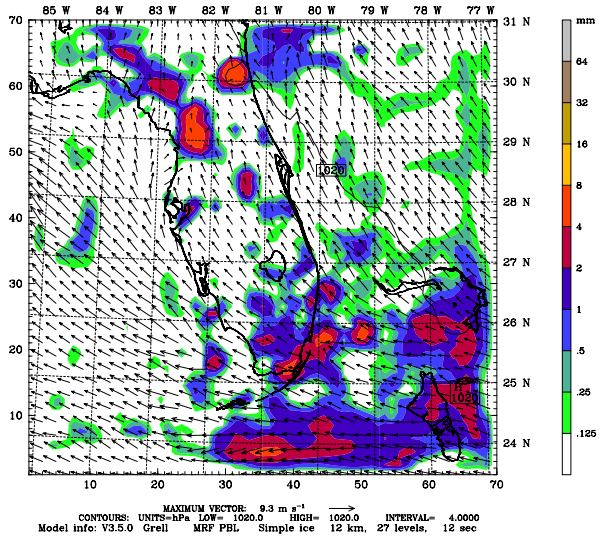
Molinari, J. and M. Dudek, 1990: Parameterization of Convective Precipitation in Mesoscale Numerical Models: A Critical Review. Monthly Weather Review, **120**, 326-344.

Acknowledgments. The authors thank VAS-DAS Inc, for the infrared satellite imagery.

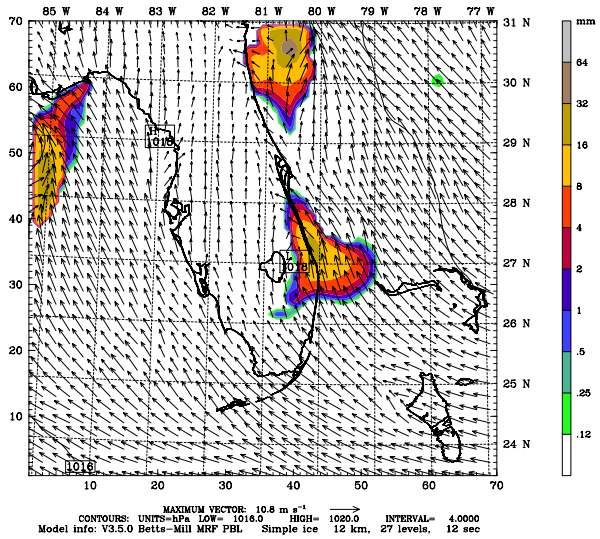
(a) 12 km grid, Kain-Fritsch



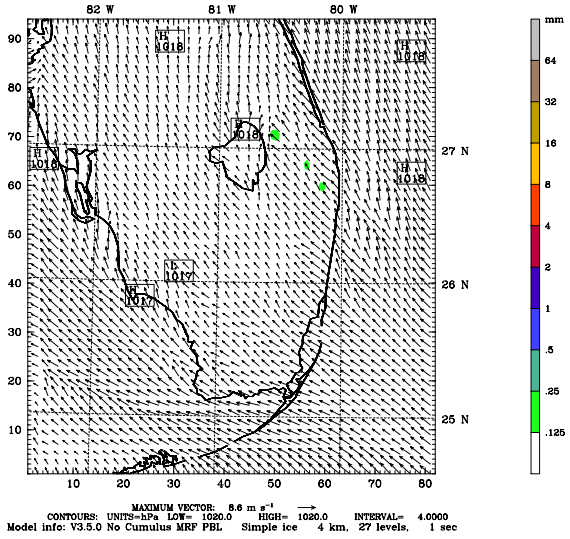
(b) 12 km grid, Grell



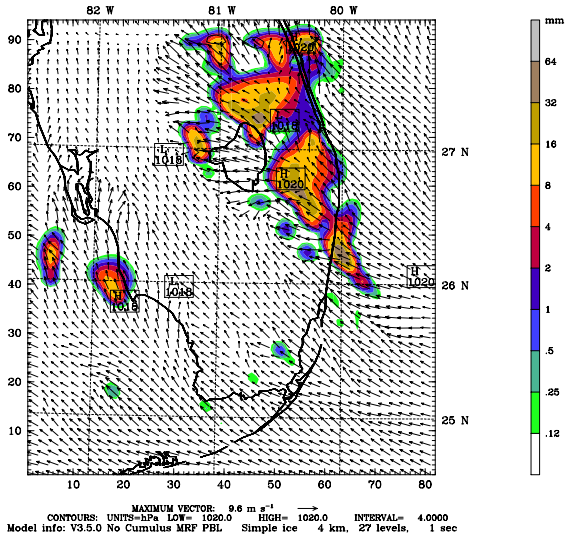
(c) 12 km grid, Betts-Miller



(d) 4 km grid, Explicit Convection



(e) 4 km grid, Explicit Convection



(f) 4 km grid, Explicit Convection

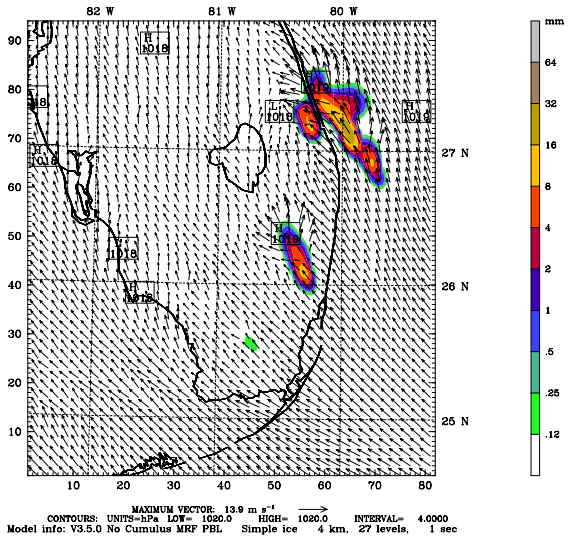


Figure 3. Plots of MM5 predicted surface wind field and precipitation valid at 1800 UTC April 14, 2002. Simulations initialized at 0000 UTC April 14, 2002.