P1.47 COMPARISON OF SIMULATED TOP OF ATMOSPHERE RADIANCE DATASETS GENERATED FROM MM5 AND WRF NUMERICAL SIMULATIONS

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1. INTRODUCTION

SSEC/CIMSS at the University of Wisconsin-Madison is tasked with testing and developing the forward radiative transfer model and retrieval algorithms for the next generation of geostationary sounders, including the Hyperspectral Environmental Sounder (HES) and the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS). In support of this work, numerical model simulations with high spatial and temporal resolution are used to produce a "truth" atmosphere, which is then passed through the instrument forward model to generate simulated top of the atmosphere (TOA) radiances. Retrievals of temperature, water vapor and winds generated from these radiances are subsequently compared with the original simulated atmosphere to assess retrieval accuracy.

In this paper, we present a comparison of model output from high-resolution MM5 and WRF numerical model simulations of a major tornado outbreak that occurred over the Northern Plains on 24 June 2003. This comparison will allow us to assess the ability of each model to realistically simulate the fine-scale horizontal and vertical structure commonly observed in the atmosphere. The ability of the microphysical schemes in the MM5 and WRF to accurately simulate cloud microphysical structure will be evaluated through a comparison of certain microphysical quantities, such as mixing ratio and effective particle diameter. TOA radiances derived from the MM5 and WRF model output will also be examined.

2. CASE DESCRIPTION

During the evening of 24 June 2003, a major severe weather outbreak occurred over the Northern Plains. Over 100 tornadoes were reported across the region, including the devastating F4 tornado that completely destroyed the town of Manchester, SD. This severe weather event was characterized by the development of numerous tornadic thunderstorms within a very moist and unstable airmass extending from central Nebraska northeastward into central Minnesota (Fig. 1). Stratiform clouds with embedded convection were also present to the northwest of this region. The complex cloud microphysical structures associated with this event represent an important challenge both to accurately model and to test the forward radiative transfer models during very complex atmospheric conditions.

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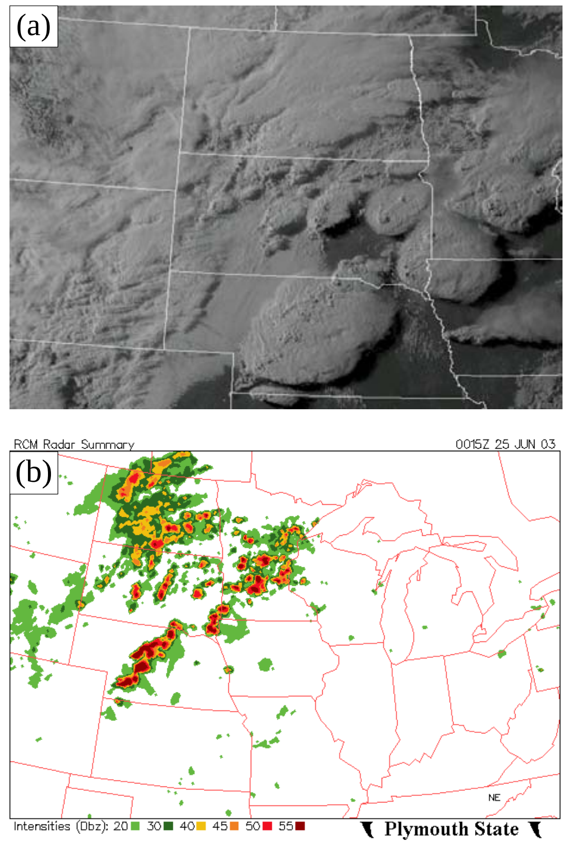

Figure 1. (a) Visible satellite image and (b) WSR-88D radar summary at 0015 UTC on 25 June 2003.

3. MODEL CONFIGURATION

Simulated atmospheric fields were generated using version 3.5.3 of the MM5 and version 2.0.2 of the WRF. Both model simulations were initialized at 1200 UTC 23 June 2003 using 1 degree GFS data. Each simulation was then run for 42 hours on a single 290 x 290 grid point domain with 4 km horizontal grid spacing and 50 vertical levels. The geographical region covered by this domain is shown in Fig. 2.

In order to determine the optimal model configuration for this case, sensitivity studies were performed using different combinations of physical parameterizations. The primary objective of this case study was to achieve a high degree of realism between the observed and model-simulated cloud and precipitation fields. Since observations of cloud microphysical properties are not available for this case, a subjective comparison between the simulated and observed composite reflectivity fields was undertaken in order to determine the optimal model configuration. Based upon this comparison, it was determined that the following configuration of physical parameterization schemes produced the most realistic simulations of the observed thunderstorm event. For the MM5:

- Goddard microphysics
- MRF planetary boundary layer
- RRTM/Dudhia radiation
- Explicit cumulus convection
- OSU land surface model

For the WRF:

- WSM6 microphysics
- YSU planetary boundary layer
- RRTM/Dudhia radiation
- Explicit cumulus convection
- NOAH land surface model

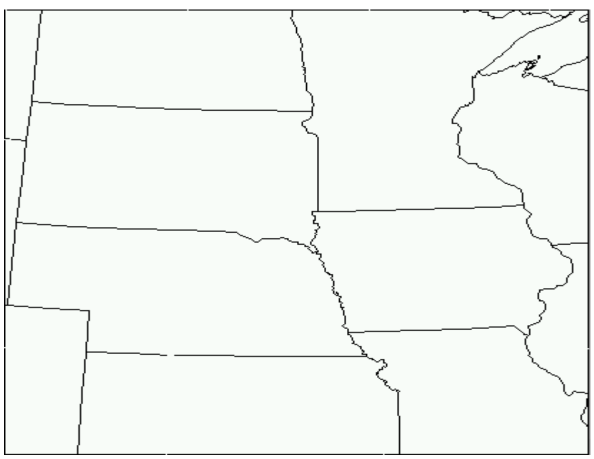

Figure 2. Model domain used by the MM5 and WRF simulations.

4. HORIZONTAL VARIABILITY

The development of the WRF model represents a major advancement in our ability to simulate mesoscale processes. The primary reason for this improvement is the adoption of numerical schemes that are more appropriate for the fine-scale horizontal resolution (< 20 km) that is routinely employed by modern mesoscale models. For instance, model diffusion and other numeric effects cause the effective resolution of the MM5 to be around ten times the horizontal grid spacing while the improved numerics of the WRF model lead to an effective resolution of around seven times the horizontal grid spacing. The improved resolution of the WRF model enhances its ability to accurately simulate mesoscale water vapor and cloud microphysical structures. Since our datasets are used to produce simulated radiances for a proposed instrument with 4-km horizontal resolution, this represents a very important improvement over prior numerical models since it allows us to generate simulated atmospheres with structures that are more representative of the real atmosphere. In Fig. 3, the very fine-scale horizontal structure in the water vapor and cloud water mixing ratio fields demonstrates the enhanced resolution of the WRF model.

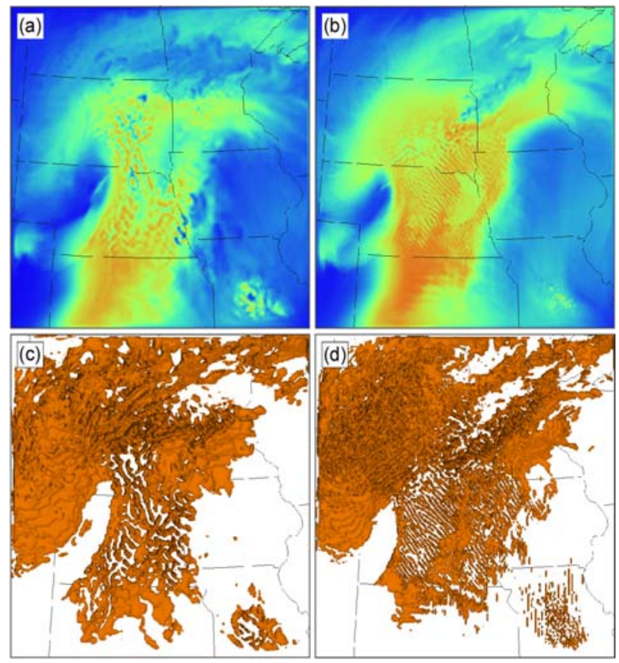

Figure 3. Water vapor mixing ratio at 2.5 km for the (a) MM5 and (b) WRF simulations. Isosurfaces of simulated liquid cloud water (mixing ratios greater than .1 g kg^{-1} shown in orange) for the (c) MM5 and (d) WRF simulations. All images valid at 2100 UTC 24 June 2003.

5. MICROPHYSICS

Detailed knowledge of the microphysical structure of clouds is necessary in order to generate reasonably accurate TOA radiances with the forward models. Since it is currently impossible to explicitly represent all microphysical quantities needed for a complete representation of a cloud, a less sophisticated but still physically realistic bulk approach is used. The bulk characteristics of a cloud are represented by the mixing ratios and effective mean diameters of five microphysical species (cloud water, rain water, ice, snow, and graupel). Sophisticated microphysical parameterization schemes in the MM5 and WRF models are capable of providing realistic mixing ratios for each of the required species. Effective diameters are then calculated using a gamma distribution that incorporates both the mixing ratio of a given species and various assumptions implicit to each microphysics scheme (such as the slope intercept parameter and density of a given microphysical species). Historically, we have utilized the Goddard microphysics scheme for our MM5 simulations. This scheme is not currently implemented in the WRF model so we have chosen to use the newly developed WSM6 microphysics scheme (Hong et al. 2004) for this work.

Since the Goddard and WSM6 schemes treat certain microphysical processes differently, it is important to identify any basic differences that may exist in the microphysical data. A preliminary assessment revealed qualitative differences in both the mixing ratios and effective diameters of several microphysical species. In order to quantify these variations, domain-averaged vertical profiles and frequency distributions for four separate layers of the atmosphere were calculated for each microphysical quantity once each hour from 2100 UTC 23 June until 0300 UTC 24 June. Average values were then calculated from these hourly data.

Figure 4 presents the domain-averaged vertical profiles of ice mixing ratio for the WRF and MM5 simulations. It is evident that the MM5 Goddard scheme generates a much greater amount of ice mass in the upper troposphere than the WSM6 scheme. The abundance of ice suggests that the Goddard scheme tends to produce deeper and more optically thick cirrus clouds than the WSM6 scheme. It should be noted that the WSM6 scheme includes a new diagnosis of ice crystal concentration that reduces (increases) the amount of ice at colder (warmer) temperatures than prior schemes, such as the Goddard scheme. The presence of substantially less ice in the upper troposphere and slightly more ice in the middle troposphere in the WRF simulation is consistent with this new approach to ice crystal development.

Another notable difference in Fig. 4 is the much lower altitude of the ice mixing ratio maximum in the WRF simulation. Though difficult to conclusively prove without performing sensitivity tests, it is suggested that this altitude difference is related to changes in the ice sedimentation rate. Unlike the Goddard scheme, which assumes a constant sedimentation rate of 20 cm s^{-1}, a variable rate based upon the work of Heymsfield and Donner (1990) is used in the WSM6 scheme. The Heymsfield and Donner method relates the mean sedimentation rate of ice crystals to the amount of available ice mass and generally produces a faster fall speed than that assumed by the Goddard scheme. With the WSM6 scheme, the sedimentation rate generally ranges from 10 to 75 cm s^{-1} in the upper troposphere.

The domain-averaged snow mixing ratio profiles for the MM5 and WRF simulations are shown in Fig. 5. Overall, these profiles exhibit substantial differences with the Goddard scheme generating substantially more snow in the middle troposphere and slightly less snow in the upper troposphere than the WSM6 scheme. Unlike the Goddard scheme, which generates the maximum amount of snow at a much lower altitude than the maximum ice mass, the WSM6 scheme generates the maximum snow amount at the same or slightly higher altitude than the maximum ice amount (Fig. 4). Although the accuracy of such a situation is questionable, it is consistent with the expected generation of less ice and more snow at colder temperatures by this scheme.

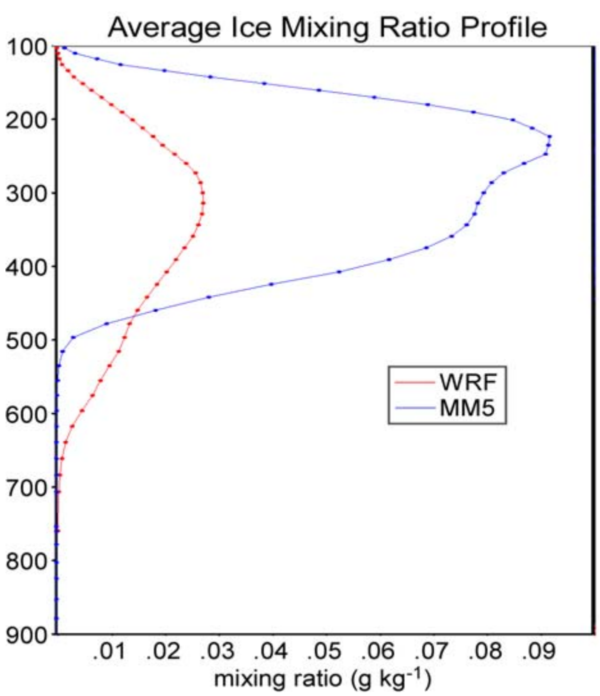

Figure 4. Domain-averaged vertical profiles of ice mixing ratio for the WRF (red line) and MM5 (blue line) simulations.

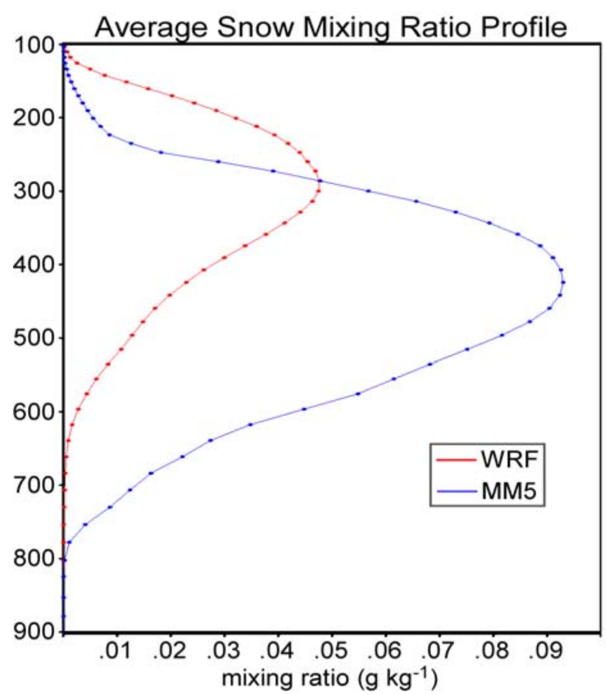

Figure 5. Domain-averaged vertical profiles of snow mixing ratio for the WRF (red line) and MM5 (blue line) simulations.

Figure 6 shows the frequency distribution of cloud ice effective diameters for the MM5 and WRF simulations. Unlike the Goddard scheme, which assumes a constant ice diameter of 20 microns, the WSM6 scheme employs a method that relates the mean ice diameter to the amount of ice mass and the number concentration of ice particles. It is evident from Fig. 6 that this method generates a much more realistic distribution of ice particle sizes, with ice diameters that are generally larger than the constant ice diameter assumed by the Goddard scheme. The larger ice diameters generated by the WSM6 scheme compare very favorably to a recent observational study that found mean ice diameters in the 20 to 35 micron range (Korolev et al. 2002). The improved representation of ice diameter size results in a more realistic simulation of ice microphysical processes.

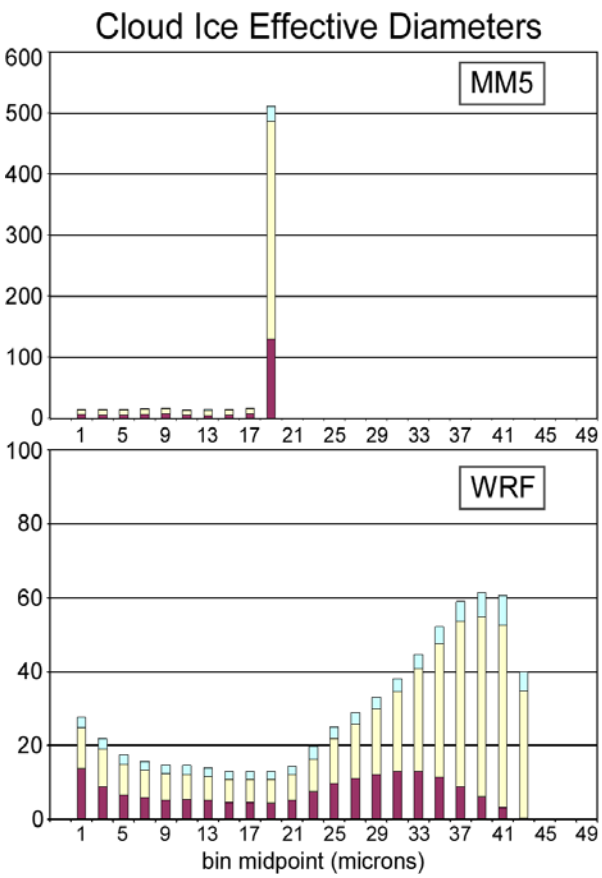

Figure 6. Frequency distribution of cloud ice effective diameters for the MM5 (top) and WRF (bottom) simulations. The number of observations (in thousands) is indicated along the ordinate. The mid-point value of each 2-micron-wide bin is indicated along the abscissa. Purple corresponds to the number of observations in the 50 to 200 hPa layer, yellow to the 200 to 500 hPa layer, and light blue to the 500 to 800 hPa layer.

During the course of this study it was found that the Goddard scheme produced anomalous raindrops in the upper troposphere. Detailed analysis revealed that these raindrops tended to develop at the top of strong convective updrafts that extended into the upper troposphere. Although the mixing ratios remained small (generally one to two orders of magnitude less than the rain water mixing ratios in the lower troposphere), these droplets could acquire a rather large size (Fig. 7). This situation appears to represent a significant shortcoming of the Goddard microphysics scheme.

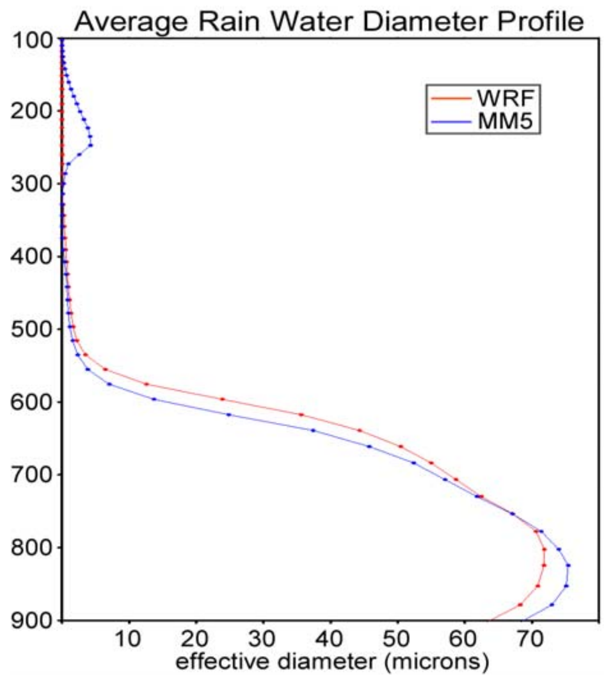

Figure 7. Domain-averaged vertical profiles of raindrop diameter for the WRF (red line) and MM5 (blue line) simulations.

6. TOA RADIANCES

Simulated TOA radiances are generated using a forward radiative transfer model specifically tailored to the GIFTS satellite. This model ingests vertical profiles of temperature, water vapor mixing ratio, and the mixing ratios and effective particle diameters of five microphysical species. These data are either provided by or derived from numerical model output. Each of these profiles, along with model-derived cloud top pressure, liquid and ice water paths, and climatological profiles of ozone, are ingested into the radiative transfer model to generate TOA radiances in the GIFTS spectral range. These radiances are then used to retrieve profiles of atmospheric temperature and water vapor, which are then compared with the original atmospheric fields to assess the robustness of the retrieval methods.

Simulated TOA radiances from the MM5 and WRF simulations are shown in Fig. 7. The fine-scale structure in the radiance field over Nebraska and South Dakota clearly demonstrates the improved resolution of the WRF model.

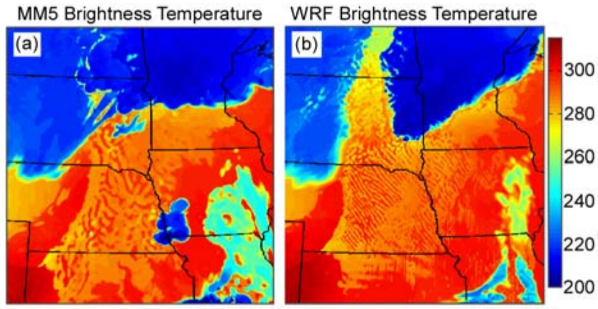

Figure 7. Simulated brightness temperatures at 834 cm^{-1} for the (a) MM5 and (b) WRF simulations. Images are valid at 2100 UTC 24 June 2003.

7. DISCUSSION

Although both the Goddard and WSM6 schemes are capable of generating realistic cloud microphysical structures, bin microphysics schemes that explicitly calculate both the mixing ratios and particle diameters of microphysical species would more accurately simulate microphysical processes. The prohibitive computational cost of such schemes, however, precludes their use in most mesoscale models. As computational power increases, a transition to more realistic bin microphysics schemes would be a notable improvement over the bulk microphysics schemes routinely employed today.

Qualitative evaluation of the model output demonstrated the superior performance of the advanced numerical methods employed by the WRF model in generating fine-scale atmospheric structures. This observation, along with the improved microphysics in the WSM6 scheme, illustrates the advanced capabilities of the WRF model. The WRF model, however, currently has several shortcomings when compared to the MM5. For instance, the memory footprint of the WRF model is nearly twice as large as the MM5. The larger memory requirement drastically limits the maximum domain size that can be used on a given platform and also leads to a slower simulation. Another problem with the WRF model is the presence of negative mixing ratios in the model output, which are most likely due to the advection scheme. Unlike the MM5, the WRF model currently does not include a physical check for negative mixing ratio values. The presence of these unrealistic quantities represents a serious flaw in the WRF model.

8. ACKNOWLEDGEMENTS

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