A comparison of bulk microphysical schemes for cloud resolving NWP

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1 Introduction

The impact of cloud microphysics on cloud resolving simulations is an important issue in numerical weather prediction and regional climate modeling. To investigate the effects of cloud microphysics on WRF forecasts with explicit convection four cases from the BAMEX 2003 field phase were simulated with a 4-km WRF using different microphysical schemes, including a sophisticated two-moment five-class scheme.
In this extended abstract we will present only a few results of the June 10th 2003 case.

2 Model description

For this study we applied WRF 1.3 in the configuration as it was used for the quasi-operational cloud-resolving forecasts during the BAMEX field experiment in Summer 2003. The model domain used here was 1600 km $\times$ 1600 km domain over the continental U.S. with 4 km resolution (400$\times$400$\times$30 grid points). The simulations were initialized from interpolated ETA model forecast (without clouds). We applied the YSU boundary layer scheme and no cumulus parameterization scheme. Although using WRF 1.3 we included three additional microphysical schemes: the WRF single-moment scheme WSM-6 by Hong et al. (2004) taken from WRF 2.0, a WRF version of the Reisner scheme (Thompson et al. 2004) provided by Bill Hall, and the Seifert and Beheng (2005, SB hereafter) two-moment scheme. In contrast to the standard bulk schemes, the latter includes number concentrations for all microphysical species (cloud droplets, raindrops, cloud ice, snow and graupel). Hence, it is able to explicitly predict mean sizes of all hydrometeors.

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3 Bow echo of June 10th

On 10th of June 2003 around 00 UTC convective cells develop over NE-Nebraska/SE-South Dakota and organize into two squall lines which propagate SE through SW-Iowa/Missouri (see black isochrones in Fig. 4 of Davis et al. 2004). By 06 UTC the two lines merge into a single double-bow echo as shown in Fig. 5 of Davis et al. (2004). The WRF simulations were initialized at 10th June 00 UTC, hence at a time when the convective system of interest already exists (although as 'unorganized' cells). The control run, using the Purdue Lin scheme, spins up quickly and at 02 UTC a single, strong echo has formed slightly west of the observed northern squall line. The simulated system propagates SE with about the same speed as the observed bow echo, but lags about 2 hours behind mostly due to the spin-up and the position of the initial cell that formed too far west.
Figure 1 shows reflectivity composites at 11 UTC. At this time the observed convective system has reached NE-Missouri with a stratiform region extending northwards into W-Illinois. The simulated squall line extends over most of southern Iowa and the location and spatial extent is almost identical for all microphysical schemes. The results of the four microphysical schemes differ mostly in their representation of the structure of the squall line itself, i.e. in the extent of the convective region with intense precipitation (roughly identified by reflectivity values $>$ 45 dBZ), the stratiform regions with light precipitation (25-45 dBZ) and the non-precipitating cloud shields ($<$ 30 dBZ).
Compared to the radar observations all three one-moment schemes predict a convective region which is too broad, and the main difference between those schemes is the amount and distribution of low-reflectivity clouds. For instance, the WSM-6 produces much larger cloud anvils/shields. Obviously a result of the very different treatment of small ice particles (ice nucleation, number concentrations) in the WSM-6

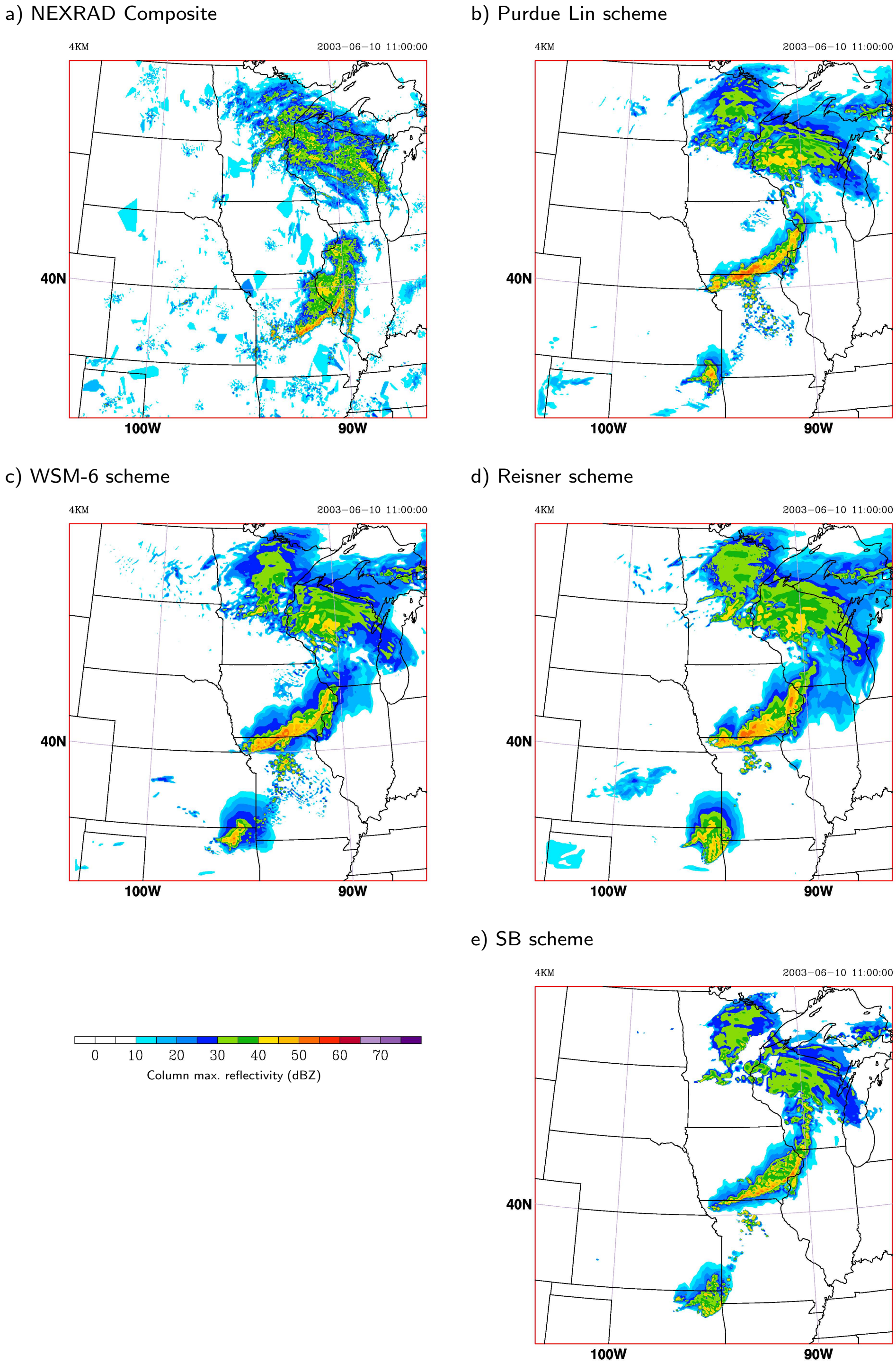

Figure 1: Comparison between radar observations and simulated reflectivity from WRF using different microphysical schemes for the 10th June 2003 (00 UTC + 11 h). Shown is the whole model domain, 1600×1600 km^2.

scheme (see Hong et al. 2004). The Reisner schemes gives a result similar to WSM-6, but with slightly higher reflectivity values. The Purdue Lin scheme predicts the least amount of anvil clouds. Using the SB two-moment scheme WRF develops a different and more realistic structure of the simulated squall line showing a very narrow line of high reflectivities at the leading edge of the convection and a trailing stratiform region with lower reflectivities. The latter is not as extended as in the observations, but qualitatively the cloud structure resembles the radar observations better than any of the one-moment scheme. The two-moment scheme produces cloud anvils more similar to the Lin scheme and, looking only at the radar observations, one might think that the WSM-6 and Reisner scheme overestimate upper level cloudiness. Satellite images (not shown here) reveal that the cloud shields did in fact extend far ahead of the convective core and covered a large area over Iowa, N-Missouri and NW-Illinois. This shows that the WSM-6 and Reisner scheme are probably not completely wrong in the spatial extent of the upper level clouds, but maybe the ice water content / reflectivity of the those clouds is overestimated. Note that the SB scheme did also predict extended cloud shields, but with mixing ratios and especially particle sizes being much lower this doesn't show up as radar reflectivities > 10 dBZ as in the Reisner and WSM-6 schemes. Without a detailed analysis of mixing ratios or optical depth, e.g. by calculating artificial satellite images from the WRF results, final conclusions cannot be made on the representation of upper level clouds in the microphysics schemes.

Please note that all model derived radar reflectivities have been calculated using the assumptions made in each individual microphysical parameterization. Hence, the reflectivities are fully model consistent. Using empirical relations instead would lead to very different reflectivity estimates and wouldn't allow a meaningful intercomparison of the results. In addition, Mie calculations have been applied to improve the representation of large particles, but this is of minor importance in this case.

For all four microphysics schemes WRF predicts a spurious convective cell at the Kansas/Oklahoma-border propagating eastward.

Figure 2 shows the observed and simulated accumulated precipitation during a period of 23 h starting from 00 UTC. The multi-sensor STAGE IV precipitation estimate is the most reliable measurement of the surface precipitation in the region. The precip pattern clearly shows the signature of the two isolated convective cells in E-Nebraska with a high rain accumulation exceeding 50 mm at some points. Later on, after the system merged into the double-bow echo, it produced between 10-30 mm along a broad pathway over Iowa and Missouri. The stratiform frontal system in the northern part of the region also produced a significant amount of surface precipitation over a large area. For comparison we also show the STAGE II radar-only precipitation estimate which uses only reflectivity data and is based on a standard Z-R-relation. This dataset gives a much higher precip estimate, roughly by a factor of two. The large difference compared to the STAGE IV, shows that all precip estimates, STAGE II and STAGE IV, should be interpreted carefully and even the error within the STAGE IV product might be quite large.

The accumulated precipitation predicted by WRF using the Purdue Lin scheme exceeds the STAGE IV estimate, and is more similar to the STAGE II radar-only product. This is not surprising, since the model precipitation and reflecitivities in a one-moment scheme are coupled by constraints similar to a Z-R-relation as used in the radar-only product. Hence, with a good agreement of the simulated and observed radar reflectivities, we would expect the model to reproduce the radar-only product, but not necessarily the STAGE IV estimate. It is interesting to see that WRF was in fact able to spin up two separate convective cells over Nebraska, but the southern cell was not intense enough. The precipitation originating from the stratiform system in the northern part of the domain is also overestimated. The accumulated precipitation also shows the pathway of the spurious Kansas cell, and an overestimation of the precipitation over southern Missouri - result of an overprediction of the convective activity in that region during the last 6 hours of the simulation. Using the WSM-6 or Reisner scheme results in a very similar precip pattern, but especially the Reisner scheme predicts somewhat less accumulated precipitation. The SB scheme shows a precip pattern with the lowest maximum values and the broadest area of precipitation originating from the bow echo. The difference from the Lin result is most striking. Overall the two-moment scheme seems to predict smaller particles than assumed in one-moment schemes resulting in lower peak precip rates and a stronger horizontal drift of the particles, i.e. a slightly larger area of surface precipitation.

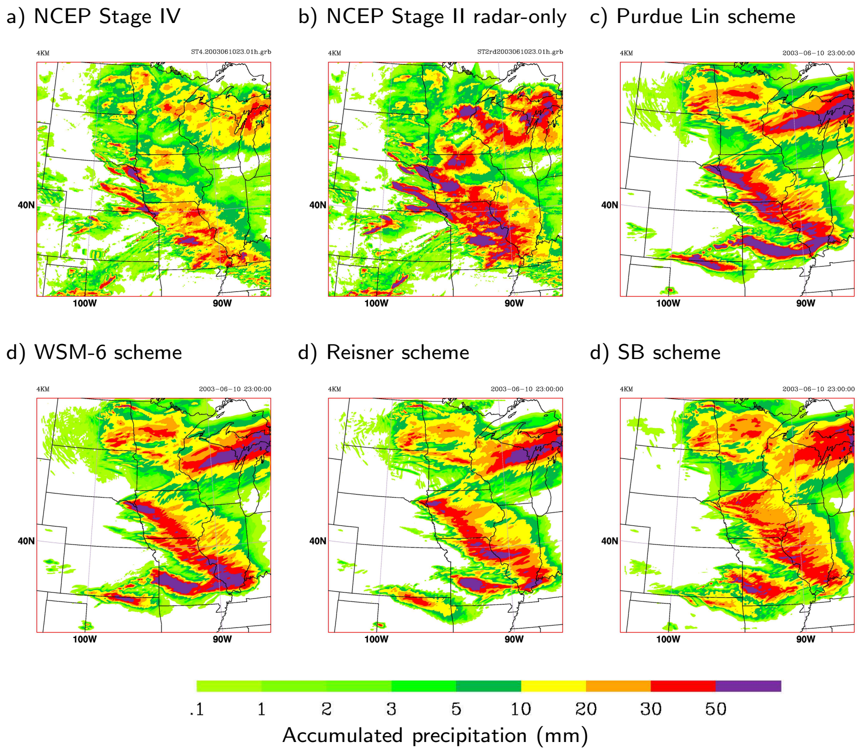

Figure 2: Observed and simulated surface precipitation (10th June 2003, 00 UTC + 23 h).

4 Conclusions

Comparing the effect of various bulk microphysical schemes on cloud-resolving mesoscale forecasts, we found (surprisingly) little differences within the first 12 h, e.g. the structure and propagation speed of the simulated convective systems is almost identical. The solutions become more different after 20-24 h forecast time, though. A main result was that all one-moment schemes show broad convective regions with high reflectivities while the two-moment scheme gives more realistic cloud structure and is able to distinguish better between the high reflectitvities at the leading edge of the convective system and a trailing stratiform region. In all four cases surface precip is most intense for the Lin scheme, while the Reisner and SB schemes maybe more realistic (WSM-6 somewhere inbetween). We found significant differences in stratiform regions and in the extent of upper level clouds, i.e. storm anvils. These features are also sensitive to the assumptions within each scheme. In general, mixing ratios of snow, ice, cloud water can show large differences, even for simulations with similar surface precipitation.

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