Simulating moist convection with a quasi-elastic sigma coordinate model

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Introduction

Cloud Resolving Models (CRMs) employ microphysics parameterisations which are grouped into bin and bulk approaches. A bin approach divides the particle distribution into 20 or more finite sizes and categories. This division of particle distribution into numerous bins requires much larger memory and computational capabilities, and poor knowledge of ice phase physics hampers the accurate representation of evolving ice particle concentrations (Stensrud, 2007).

Bulk Microphysics Parameterisation (BMP) schemes specify a functional form for the particle distribution and predict one or more characteristics of a particle category such as the mixing ratio and concentration (Chen and Sun, 2002; Lin and Colle, 2011; Stensrud, 2007). Single-moment schemes predict only the mixing ratio, while double moment schemes predict both the mixing ratio and the particle concentration.

Due to their computational advantage over bin schemes, BMPs have been widely incorporated into CRMs, mesoscale research and operational models, and climate models. A Nonhydrostatic Sigma-coordinate Model (NSM) (Engelbrecht et al., 2007) is currently being developed at the Council for Scientific and Industrial Research (CSIR) and University of Pretoria. Two BMP schemes have been introduced to the NSM for the explicit simulation of clouds.

The BMP schemes in the NSM

The first BMP scheme is called the PURDUE-LIN scheme (Chen and Sun, 2002), is single-moment and predicts six mixing ratios. The second scheme is called the SBU-YLIN scheme (Lin and Colle, 2011) and was developed using the PURDUE-LIN scheme as a starting point. The SBU-YLIN scheme includes five mixing ratios, water vapour (qv), cloud ice (qi), precipitating ice (pi), cloud water (qc) and rain (qr). Dry ice, rimed ice, and graupel are included in the precipitating ice category. The PURDUE-LIN scheme predicts six mixing ratios with snow(qs) and graupel (qg) being predicted separately. The scheme can also be used with graupel deactivated (five-class).

Two-dimensional thunderstorms initiated by a warm perturbation of 2K with a 1400m radius at the centre of the domain (Weisman and Klemp, 1982) are simulated with the NSM using the two BMP schemes. A domain that is 100 km in horizontal extent and that extends to 25 km above sea level is used. A sponge layer that uses horizontal and vertical diffusion is applied over a third of the vertical domain to prevent outward-propagating disturbances from reflecting back into the domain. Horizontal resolutions of 500 m, 1 km and 2 km are used and a constant vertical resolution of approximately 200 m is applied. A vertical local diffusion scheme that depends on the Richardson number is applied for all the simulations. Simulations with the PURDUE-LIN BMP scheme were made both with graupel (six-class) and without graupel (five-class).

Results

At the beginning of the simulation only water vapour was provided to the model and hydrometeors were simulated by microphysics processes in the BMP schemes. For the most part, the six-water class PURDUE-LIN BMP simulation (Figure 1a) produced more rainfall (qr) than the five-class one (Figure 1b). More water vapour (qv) was lost in the simulation that produced the most rainfall, and warming due to latent heating was more in the simulation that lost the most water vapour. The updrafts (Figure 1d) and downdraft are the same at the beginning of the simulation and start looking different after hydrometeors form which shows that the microphysics processes play an important role in the dynamics of clouds. Towards the end of the simulation, a second updraft develops in both runs, and for the most part it is stronger in the five-class simulation (YLIN_g).

The precipitating ice (pi) (graupel and snow) simulated by the NSM with the SBU-YLIN scheme (Figure 1c) follows more the behaviour of snow in the five-class PURDUE-LIN scheme simulations than graupel in the six-class scheme. For all three simulations

(PURDUE-LIN five-class (Figure 1b), PURDUE-LIN six-class (Figure 1a) and SBU-YLIN) (Figure 1c), the largest precipitating ice was the dominating hydrometeor.

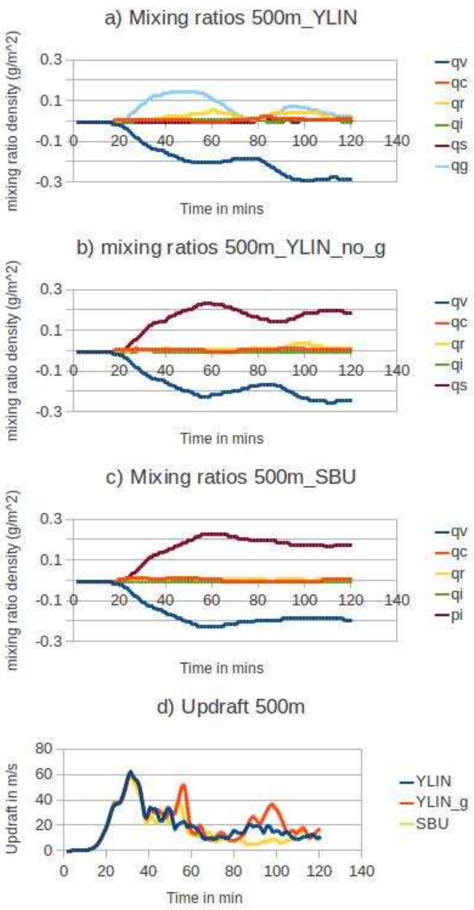

Figure1: The simulated water vapour (qv), cloud water (qc), rain water (qr), cloud ice (qi) snow (qs) and graupel (qg) using the a) six-class PURDUE-LIN scheme, b) five class PURDUE-LIN scheme and c) SBU-YLIN scheme. d) The simulated updraft with six-class PURDUE-LIN (YLIN), five-class PURDUE-LIN, SBU-YLIN (SBU) BMP schemes.

Graupel was found to be the most variable, it reached a maximum faster and as soon as the updraft was reduced it started falling. As it falls it gets converted into rainfall and water vapour while cooling the atmosphere at the same time because of latent heat absorption. Snow (qs)(Figure 1b) and precipitating ice (pi) (Figure 1c) reach a maximum at the same time which is a bit later compared to graupel (qg)(Figure 1a) . When the updraft gets weaker they both start to reduce, however snow reduces faster than precipitating ice. The updraft that developed towards the end of the simulation in the PURDUE-LIN simulations is found in the SBU-YLIN simulations (SBU) (Figure 1d) although it is much weaker.

We also tested the effect of resolution on thunderstorm simulations. The lower the resolution the smaller the updraft and downdraft maxima. The change in updrafts also influenced the hydrometeors. In the 2 km resolution simulations, the second graupel maximum disappears (not shown) because the updraft towards the end of the simulation is not strong enough to transport moisture to higher altitudes where temperatures are much lower that enable the formation of ice. When the updraft is smaller and in the lower atmosphere, more cloud and rain water form.

Conclusions

Weisman and Klemp (1982) found that with no shear, there was no redevelopment, however we found thunderstorm redevelopment which varied depending on the microphysics scheme used and horizontal resolution. Weisman and Klemp (1982) used the Kessler scheme which does not include ice, while we had ice in all our simulations. The second redevelopment possibly occurs because of a stronger downdraft in the simulations with ice which acts as a trigger for new cell development. In all the simulations, ice never reached the ground, it melted and evaporated and therefore cooled the air more than a simulation without ice would.

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