Simulating moist convection with a quasi-elastic sigma coordinate model

M BOPAPE, F ENGELBRECHT, AND D RANDALL
CSIR Natural Resources and the Environment
PO Box 395, Pretoria 0001
Email: mbopape@csir.co.za – www.csir.co.za

INTRODUCTION

The development of nonhydrostatic atmospheric models for research purposes has been ongoing since the 1960s. However, with the advent of ever faster computers, the operational numerical integration of weather prediction models at spatial resolutions beyond the hydrostatic limit has become a reality. This has led to a renewed and worldwide effort to develop Cloud Resolving Models (CRMs). A CRM called the Nonhydrostatic Sigma-coordinate Model (NSM) is currently being developed at the Council for Scientific and Industrial Research (CSIR) and University of Pretoria in South Africa. The PURDUE-LIN (Sun and Chen, 2002) and SBU-YLIN (Lin and Colle, 2011) microphysics schemes obtained from the National Centre for Atmospheric research (NCAR) Weather Research and Forecasting (WRF) have been introduced to the NSM.

Synoptic and mesoscale motions play a major role in the formation and maintenance of thunderstorms. During the past few decades CRMs have been used to quantify the cumulative large-scale effects of cloud systems and to examine the role in which large-scale processes relate to the development, maintenance and structure of deep convective cloud systems. These studies have been conducted over the tropics using driving and validation observation datasets of Global Atmospheric Research Program's (GARP) Atlantic Tropical Experiment (GATE) (e.g. Grabowski et al., 1996) conducted in the summer of 1974 and Tropical Oceans Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE) (Webster and Lukas, 1992) conducted over the western Pacific ocean (e.g. Wu et al., 1998) in November 1992 to February 1993. Simulations have also been made over the mid-latitudes using field data from the Southern Great Plains site of the Atmospheric Radiation Measurement (ARM) program (e.g. Xu and Randall, 2000). CRMs were able to successfully simulate the statistical properties of cumulus ensembles, and this shows that CRMs are useful tools for the understanding of convective processes in both the tropics and mid-latitudes. In this study we use the NSM to study its response to the TOGA COARE large scale forcing when suppressed convection dominated, using two microphysics schemes similar to studies of the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) (Woolnough et al., 2008).

METHOD

We make simulations with the NSM with a domain size of 256 km in horizontal extent, with a 2 km horizontal resolution, for a period of 12 days. The model top is situated at 10 hPa and the model surface is the observed surface pressure which is prescribed at every time step with higher resolution closer to the surface. We make use of two microphysics schemes, PURDUE-LIN (Chen and Sun, 2000) and SBU-YLIN (Lin and Colle, 2011). The PURDUE-LIN scheme assumes that precipitating particles (rainwater, snow and graupel) follow a gamma distribution and it predicts the mixing ratios of six water species. Cloud water and ice are assumed to be mono-dispersed and to have a negligible terminal speed. Simulations with the PURDUE-LIN scheme will be made with graupel (called PURDUE-LIN1 from now on) and without graupel (PURDUE-LIN2). The SBU-YLIN scheme was developed using the PURDUE-LIN scheme as a starting point. Snow and graupel share the same category and it uses formulations that consider the influence of riming intensity and temperature on precipitating ice particles.

The large scale advective tendencies prepared by Ciesielski et al. (2003) of potential temperature and water vapour which are provided six hourly are interpolated linearly to the NSM's vertical grid and every time step and applied directly to the NSM. The model's simulated horizontal winds are relaxed towards the observed horizontal wind with a timescale of 2 hours at every time step. The Sea Surface Temperatures (SSTs) and surface pressure are prescribed at every time step. Surface fluxes are calculated using aero dynamic equations as described in Holtslag and Boville (1993) and a sponge layer that uses vertical and horizontal diffusion is applied from 17 km above sea level.

RESULTS

The twelve day simulation includes a period of deep convection during the initial dates, followed by a period of suppressed convection and ends at the start of a subsequent period of deep convection. The simulated temperatures are generally lower than the observations in the lower atmosphere and higher than observations towards the top the domain (**Figure 1**). All the microphysics schemes simulated a drier atmosphere compared to observations. The three microphysics schemes captured the period of deep convection during the initial dates as shown in **Figure 2** by higher amounts of simulated ice and water. During the period of suppressed convection smaller convective processes occurred.

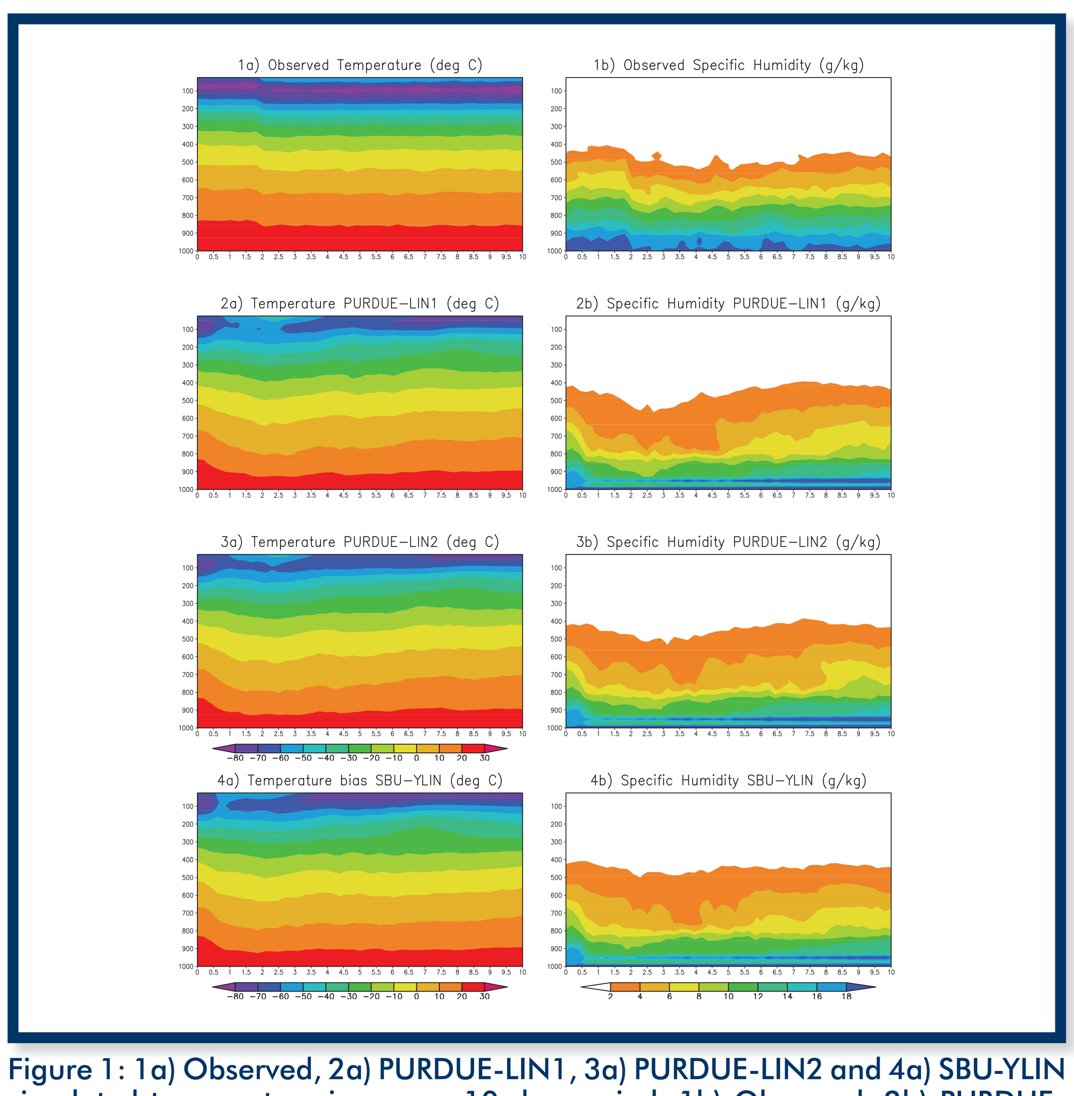

Figure 1: 1a) Observed, 2a) PURDUE-LIN1, 3a) PURDUE-LIN2 and 4a) SBU-YLIN simulated temperature in over a 10-day period. 1b) Observed, 2b) PURDUE-LIN1, 3b) PURDUE-LIN2 and 4b) SBU-YLIN simulated Specific Humidity over a 10-day period. The x-axis is days and y-axis is Pressure in hPa

The amount of rainfall that reached the surface is the same for the PURDUE-LIN1 and SBU-YLIN schemes, and it is smaller in the PURDUE-LIN2 simulations (**Figure 3**). This shows that graupel is effective in producing more rainfall that snow, when neither of the two reaches the surface. The PURDUE-LIN1 scheme simulated less ice during the suppressed period (**Figure 2**).

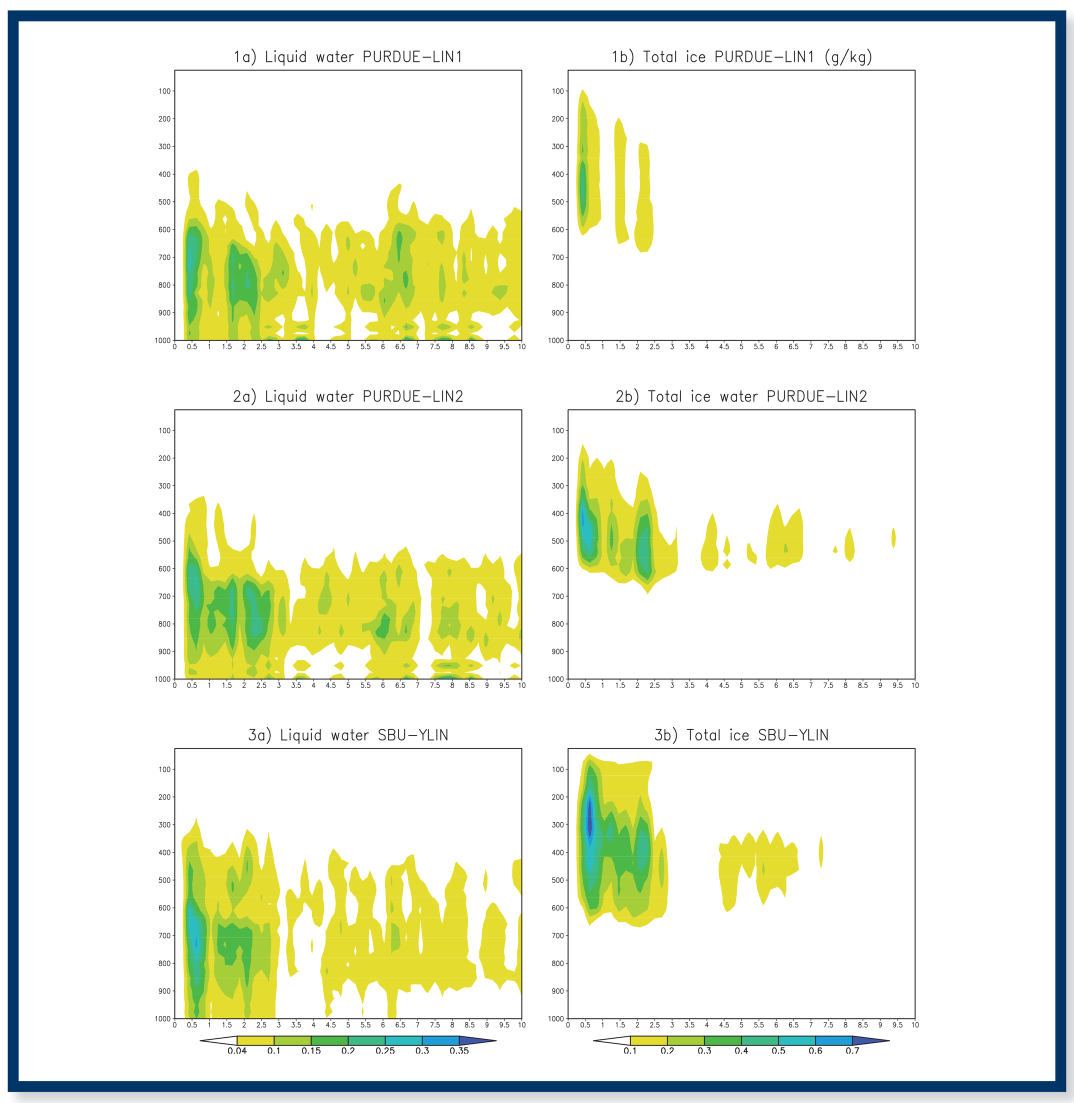

Figure 2: Simulated total liquid water (1a,2a,3a) and total ice (1b,2b,3b) by the 1) PURDUE-LIN1, 2) PURDUE-LIN2 and SBU-YLIN microphysics schemes

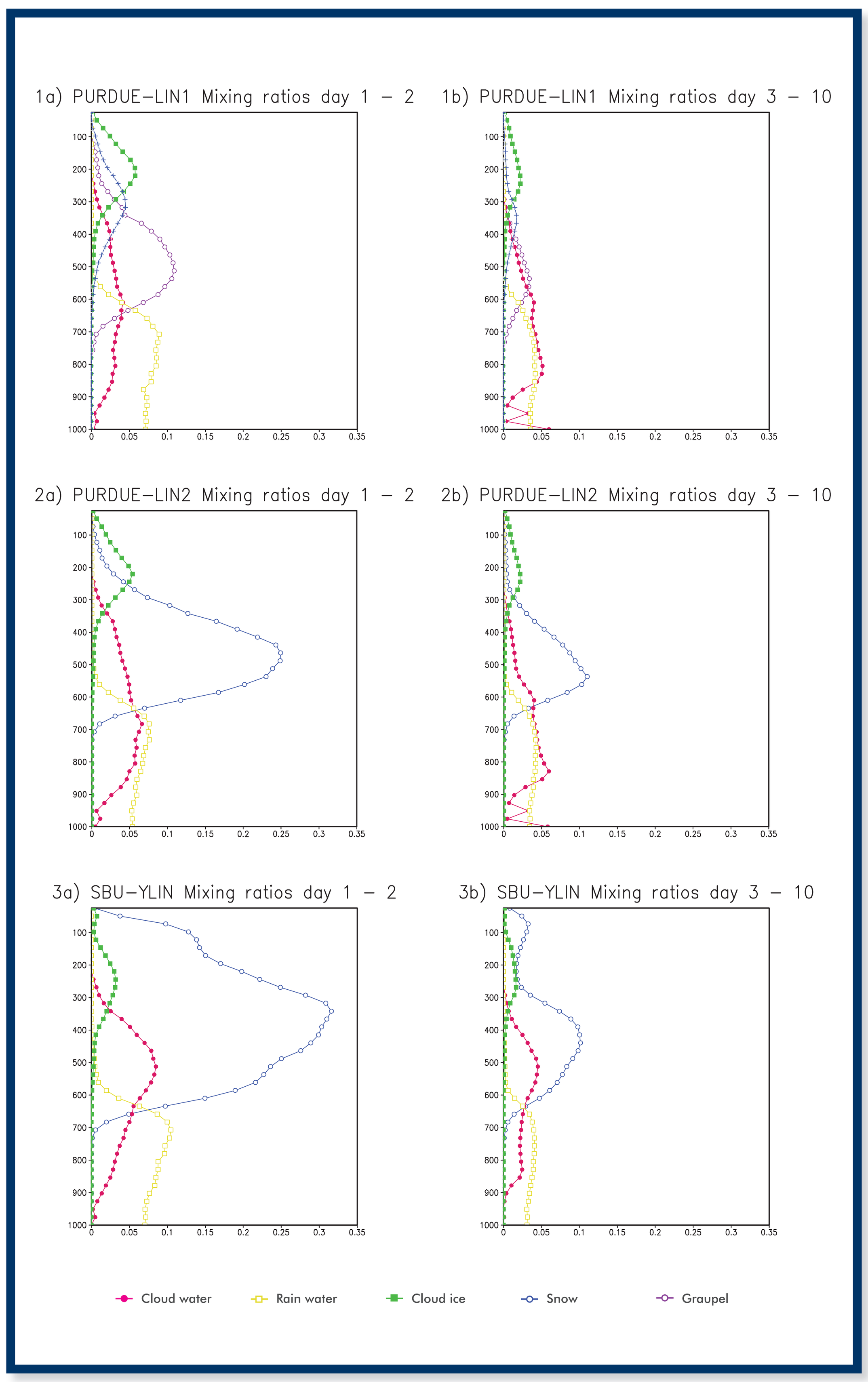

Figure 3: Average mixing ratios for day 1 to 2 (1a,2a,3a), and day 3 to10 (1b,2b,3b) with the 1) PURDUE-LIN1, 2) PURDUE-LIN2 and 3) SBUYLIN

CONCLUSION

Simulations made with the NSM using different microphysics schemes show that the NSM is able to capture large scale forced convective systems. PURDUE-LIN1 simulates more rainfall that PURDUE-LIN2 showing the importance of adding graupel in the simulation of deep thunderstorms.

As part of ongoing model development work being done at the CSIR, we developed a model that can be used to study thunderstorms. In this case we are showing its application over the Western Pacific ocean in the tropics where observation data is available to force and verify the model.

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