THE RAMS CLOUD MICROPHYSICS PARAMETERIZATION IN WRF: CURRENT STATUS

Laura D. Fowler
DoD Center for Geosciences/Atmospheric Research
Cooperative Institute for research in the Atmosphere
Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

It has become increasingly common for bulk cloud microphysics schemes to predict a second moment, the number concentration, to simulate the activation of aerosols to form cloud droplets and ice crystals (Cohard and Pinty 2000; Cotton et al. 2003; Morrison et al. 2005; Philips et al. 2007).

Prognostic Cloud Condensation Nuclei (CCN) and Ice Formation Nuclei (IFN) have a strong impact on the development of deep convection, as recently discussed by van den Heever et al (2006a; 2006b) and Phillips et al. (2007). Cloud resolving scale simulations of storms observed during CRYSTAL-FACE showed that varying concentrations of CCNs and IFNs influenced significantly the storm dynamics. Increased CCNs led to an increase in the updraft strength during the initiation of the storm. Increased IFNs had the greatest effect during the mature and decaying stages (van den Heever et al. 2006a). Phillips et al. (2007) addressed the role of cloud water and ice nucleation processes on the simulation of deep convection over the Tropical Western Pacific region. In particular, they discussed the impact of initial CCNs for determining in cloud concentrations of super-cooled cloud droplets and ice crystals from homogeneous freezing in the anvil section of the clouds.

Sensitivity studies, as the ones described in van den Heever et al. (2006a) and Phillips et al. (2007), show that nucleation processes are fundamental microphysics processes that must be routinely included in cloud schemes to capture the lifecycle of convective clouds.

We are currently implementing the two-moment bulk cloud microphysics scheme developed for the Regional Atmospheric Modeling System (RAMS; Cotton et al. 2003) in the Advanced Research-Weather Research Forecast model (ARW).

Our main objectives are twofold. First, we plan to compare the performance of the RAMS cloud microphysics scheme against cloud schemes available in the WRF physics package. Here, we are interested in assessing differences between one-moment (Lin et al. 1983; Tao et al. 1989; Hong et al. 2004; Thompson et al. 2004 for the warm phase) and two-moment microphysics schemes on the simulations of convective cloud systems. Second, we plan to couple the RAMS cloud microphysics to an observational radiation operator to simulate top-of-the-atmosphere cloud-free and cloudy infrared radiances for four-dimensional variational (4D-VAR) data assimilation research using ARW.

Here, we provide a short description of the RAMS cloud microphysics scheme, and discuss results obtained from the simulation of an idealized two-dimensional (2D) squall line available with the WRF dynamical core.

2. MODEL DESCRIPTION

The RAMS cloud microphysics scheme includes prognostic equations for the mass mixing ratio of water vapor, and the mass mixing ratio and number concentration of small and large cloud droplets, rain water, ice crystals, snow, aggregates, graupel, and hail. Saleeby and Cotton (2004) describe the two-moment scheme for the warm phase. Small and large cloud droplets are nucleated via a parameterized activation of CCNs and giant CCNs (GCCNs). Small cloud droplets are droplets with diameters ranging between 2 and 40 μm whereas large cloud droplets are droplets with diameters ranging between 40 and 80 μm. The inclusion of two cloud modes is a major improvement over the one-moment scheme described by Walko et al. (1995), for it allows the bimodal distribution of cloud droplets that is often seen in clouds (Hobbs et al. 1980). The activation of CCNs and GCCNs to form cloud droplets depends on the temperature, the vertical velocity, and the CCN concentration and median radius. Homogeneous and heterogeneous nucleation of pristine ice are discussed in Demott et al. (1994) and Meyers et al. (1992, 1997). All eight water species are allowed to grow by vapor diffusion, as described in Walko et al (2000). Other cloud microphysics processes, such as collection, accretion, sedimentation, are described in Walko et al. (1995).

Hydrometeors are assumed to conform to a generalized gamma distribution (Flatau et al. 1989; Verlinde et al. 1990) given by

$$f_{gam}(D) = \frac{1}{\Gamma(\nu)}\left(\frac{D}{D_n}\right)^{\nu-1}\frac{1}{D_n}\exp\left(-\frac{D}{D_n}\right) \quad (2.1)$$

where D is the diameter, ranging from zero to infinity, D_n is the characteristic diameter, and ν is the shape parameter of the complete gamma distribution, $\Gamma(\nu)$.

The number density concentration is described by

$$n(D) = N_t f_{gam}(D), \quad (2.2)$$

where N_t is the total concentration of each hydrometeor. We assume that the mass m and terminal velocity, v_t, of individual water species is expressed as power law formulas

$$m = \alpha_m D^{\beta_m}, \quad (2.3)$$

$$v_t = \alpha_{vt} D^{\beta_{vt}}. \quad (2.4)$$

In Eqs. (2.3) and (2.4), the coefficients and exponents in the mass and terminal velocity power law formulas are prescribed for each hydrometeor category. In individual layers, the mean mixing ratio $\overline{m}$ and mean terminal velocity $\overline{v_t}$ on which microphysics processes are applied are the concentration-normalized integrals of m and v_t over a category size distribution, or

$$\overline{m} = \alpha_m D_n^{\beta_m}\frac{\Gamma(\nu+\beta_m)}{\Gamma(\nu)}, \quad (2.5)$$

$$\overline{v}_t = \alpha_{v_t} D_n^{\beta_{v_t}}\frac{\Gamma(\nu+\beta_{v_t})}{\Gamma(\nu)}. \quad (2.6)$$

The parameterization of sedimentation follows a lagrangian scheme to transport the mass mixing ratio and number concentration from one layer to a lower layer in a given column. Before sedimentation, the mixing ratio is identified as a collection of volumes, each corresponding to a grid cell bounded by a top height z_{top} and bottom height z_{bot}. Each volume is assumed to fall at speed v_t for the time-step Δt, resulting in new heights for the top and bottom surfaces of the volume given by

$$z_{topnew} = z_{top} - \overline{v}_t\Delta t, \text{ and}$$
$$z_{botnew} = z_{bot} - \overline{v}_t\Delta t. \quad (2.7)$$

We then identify which grid cell or cells are overlapped by the displaced volume, and in what proportion. The mean mixing ratio is then transferred from the original cell to the new ones in the given proportions. This scheme allows sedimentation to occur more rapidly than one grid-level per time-step, as is the case in Eulerian methods. The number concentration is transported using the same proportion as the mass mixing ratio.

3. IMPLEMENTATION

In contrast to WRF, RAMS uses the ice-liquid potential (θ_{il}) and total water mixing ratio as prognostic variables, instead of the potential temperature (θ) and water vapor mixing ratio. As discussed in Tripoli and Cotton (1981), θ_{il} is a conservative variable under phase changes, but is not conservative under precipitation. In contrast, θ is not a conservative variable under phase changes, but is conserved during sedimentation. We replaced θ_{il} by θ throughout the sourcecode and computed the temperature tendencies of individual cloud microphysics processes.

In contrast to WRF, RAMS uses a σ_z instead of a σ_p vertical coordinate system to calculate the vertical displacement of hydrometeors due to precipitation fallout. We are analyzing the impact of temporally-varying instead of constant layer thicknesses on sedimentation rates.

4. PROJECT STATUS AND RESULTS

We tested the RAMS cloud microphysics scheme in ARW using the idealized case of a two-dimensional (2D) squall-line oriented in the x-direction, as provided in the dynamical core. The experiment was run for two hours

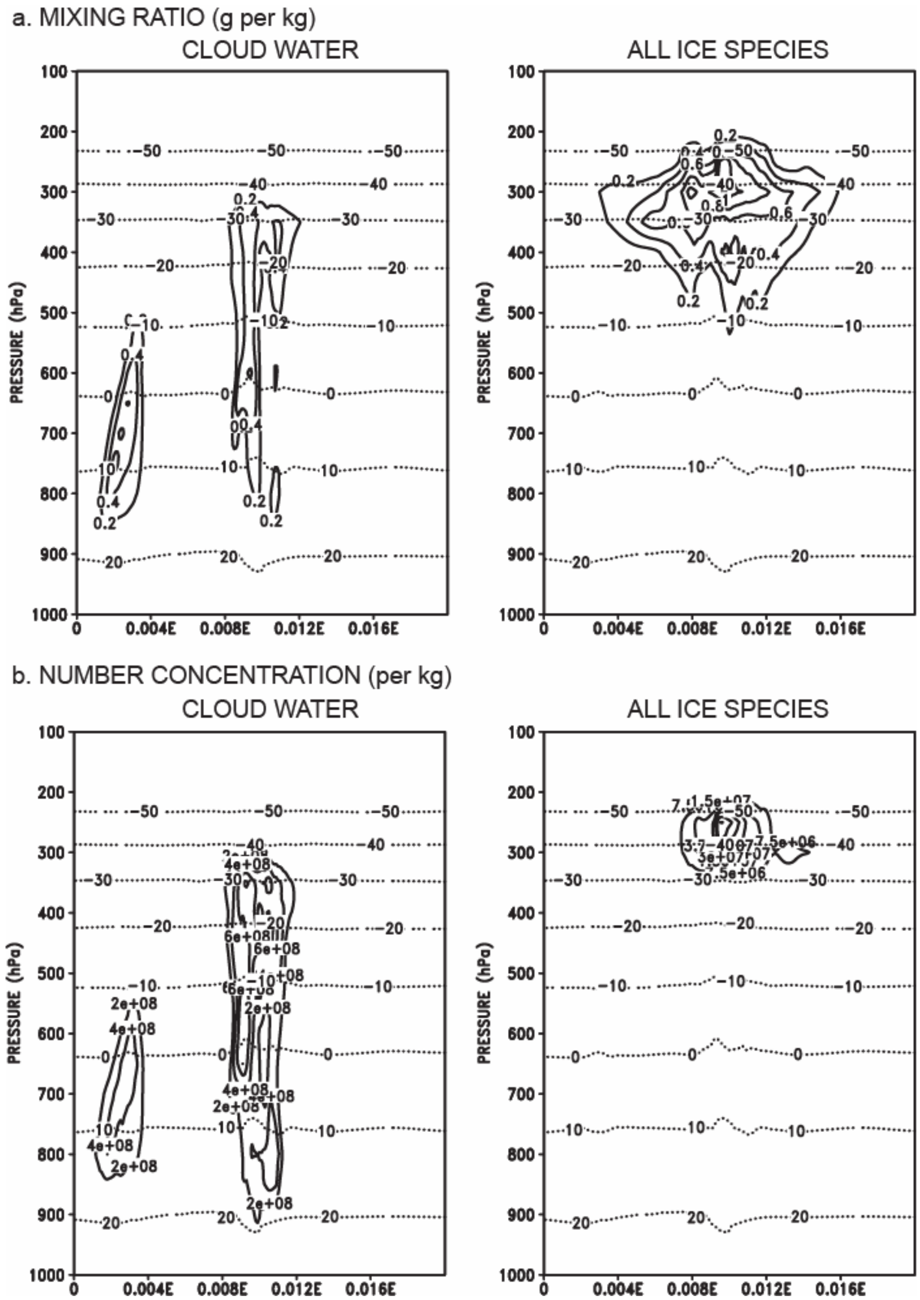

Figure 1: Longitude versus pressure cross sections of a) the mixing ratio, and b) the number concentration for the cloud water (left panels) and all ice species (right panels).

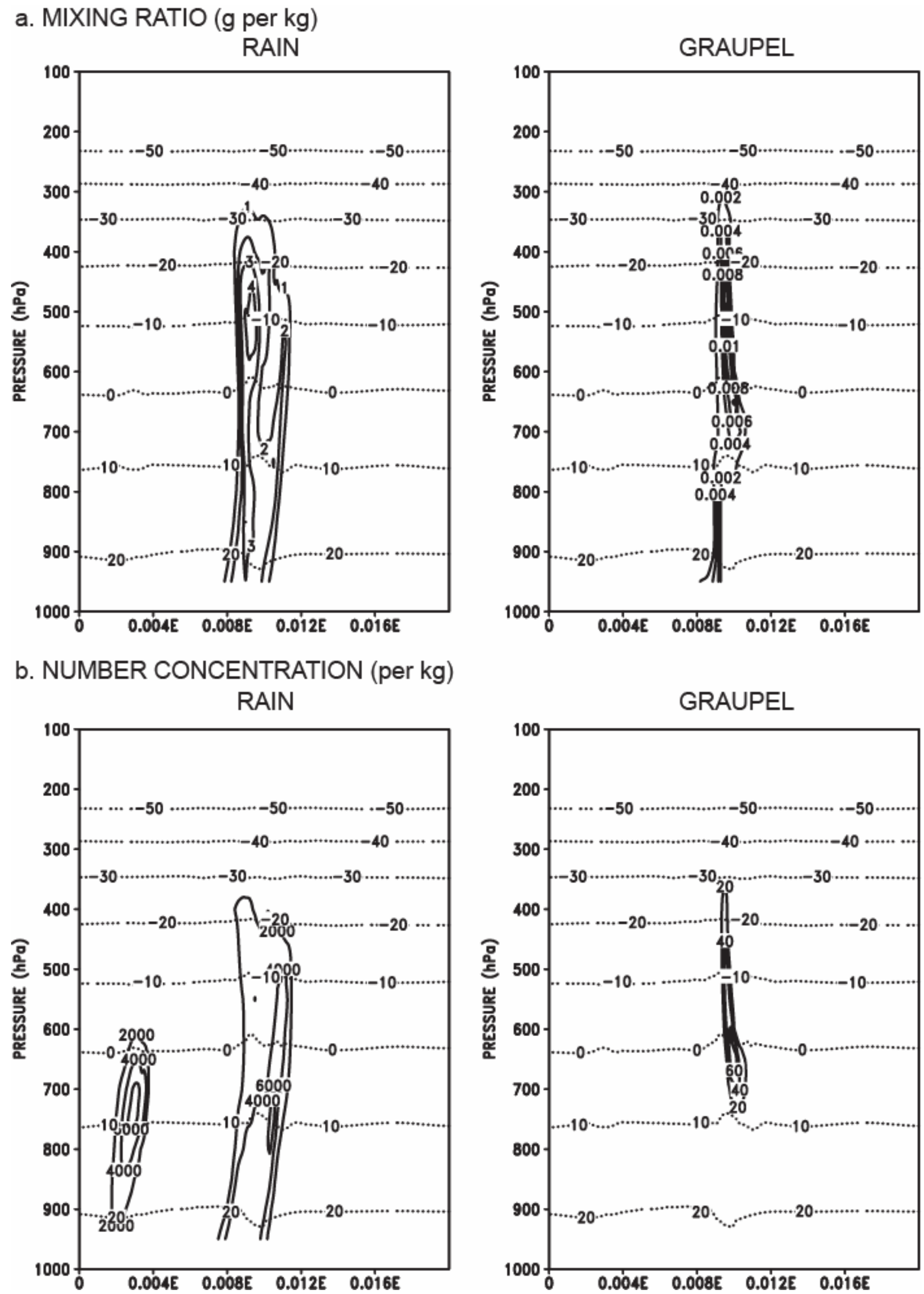

Figure 2: Longitude versus pressure cross sections of a) the mixing ratio, and b) the number concentration for rain (left panels) and graupel (right panels

to ensure that the development of each water species and that the cloud microphysics was acting properly inside ARW.

Figures 1 and 2 show longitude versus pressure time-averaged cross sections for the mixing ratios and number concentrations of cloud water, ice species (pristine ice, snow, aggregates), rain, and graupel. The mixing ratio and number concentration for hail are not shown because the collection of rain by each ice species was not implemented at the time of the experiment. The time-average is an average over the second half-hour of the experiment. Results show the formation of a narrow convective updraft at the center of the domain, and the horizontal spreading of an ice anvil at the top of the cloud. At cloud top, homogeneous nucleation converts cloud water to pristine ice below -30 °C. Pristine ice is converted to snow during sublimation, following Harrington et al. (1995). Pristine ice melts to form cloud water while falling through the convective updraft. Graupel that forms by collection and melting of snow and aggregates is not allowed to melt in the form of rain at present. Sedimentation is shown to work properly.

We are confident that the RAMS cloud microphysics scheme interacts satisfactorily with the ARW dynamics. We are finishing implementing the formation of hail through collection of rain by individual ice species, and melting processes of graupel and hail to form rain. We are verifying the temperature budget. Additional results will be presented at the workshop.

Acknowledgments: We would like to thank Dr. Robert Walko and Dr. William Cheng, for helping the author understand the details of the RAMS cloud microphysics scheme. This research is funded by the DoD Center for Geosciences/Atmospheric Research at Colorado State University under the Cooperative Agreement DAAD19-02-2-2005 and W911NF-06-2-0015 with the Army Research Laboratory.

REFERENCES

Cohard, J.M., and J.P. Pinty, 2000: A comprehensive two-moment warm microphysical bulk scheme. I: Description and tests. *Quart. J. Roy. Meteor. Soc*., **126**, 1815-1842.

Cotton, W.R., R.A. Pielke Sr., R.L. Walko, G.E. Liston, C.J. Tremback, H. Jang, R.L. McAnelly, J.-Y. Harrington, M.E. Nicholls, G.G. Carrio, and J.P. McFadden, 2003: RAMS 2001: Current status and future directions. *Meteorol. Atmos. Phys*., **82**, 5-29.

Demott, P.J., M.P. Meyers, and W.R. Cotton, 1994: Parameterization and impact of ice initiation processes relevant to numerical model simulation of cirrus clouds. *J. Atmos. Sci*., **51**, 77-90.

Flatau, P.J., G.J. Tripoli, J. Verlinde, and W.R. Cotton, 1989: The CSU-RAMS cloud microphysical module; general theory and documentation, Colorado State University, Dept. Atmos. Sci., Fort Collins, 88pp.

Harrington, J.L., W.R. Cotton, M.P. Meyers, and R.L. Walko, 1995: Parameterization of ice crystal conversion processes due to vapor deposition for mesoscale models using double moment basis functions. Basic formulation and parcel model results. *J. Atmos. Sci*., **52**, 4344-4366.

Hobbs, P.V., M.K. Politovich, and L.F. Radke, 1980: The structure of summer convective clouds in eastern Montana. I: Natural clouds. *J. Appl. Meteor*., **19**, 645-663.

Hong, S.-Y., 2004: A revised approach to ice microphysical processes for the bulk Mon. Wea. Rev., 132, 103-120.

Lin, Y.-L., R.D. Farley, and H.D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. *J. Climate Appl. Meteor*., **22**, 1065-1092.

Meyers, M.P., P.J. Demott, and W.R. Cotton, 1992: New primary ice nucleation parameterizations in an explicit cloud model. *J. Appl. Meteor*., **31**, 708-721.

Meyers, M.P., R.L. Walko, J.Y Harrington, and W.R. Cotton, 1997: New RAMS cloud microphysics parameterization. Part II: the two moment scheme. *Atmos. Res*., **45**, 3-39.

Morrison, H., J.A. Curry, V.I. Khvorostyanov, 2005: A new double-moment microphysics parameterization for application in cloud and climate models. Part I: Description. *J. Atmos. Sci*., **62**, 1665-1677.

Philips, V.T.J., L.J. Donner, and S.T. Garner, 2007: Nucleation processes in deep convection simulated by a cloud-system-resolving model with double moment bulk microphysics. *J. Atmos. Sci.*, **64**, 738-761.

Saleeby, S.M., and W.R. Cotton, 2004: A large-droplet mode and prognostic number concentration of cloud droplets in the Colorado State University Regional Modeling System (RAMS).

Tao, W.-K, J. Simpson, and M. Mc Cumber, 1989: An ice-water saturation adjustment. *Mon. Wea. Rev.*, **117**, 231-235.

Thompson, G., R.M. Rasmussen, and K. Manning, 2004: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. *Mon. Wea. Rev.*, **132**, 519-542.

Tripoli, G.J., and W.R. Cotton, 1981: The use of ice-liquid potential temperature as a thermodynamic variable in deep atmospheric models. *Mon. Wea. Rev.*, **109**, 1094-1102.

Van den Heever, S.C., G.G. Carrio, W.R Cotton, P.J. Demott, and A.J. Prenni, 2006a: Impacts of nucleating aerosols on Florida Storms. Part I: Mesoscale simulations. *J. Atmos. Sci.*, **63**, 1752-1775.

Van den Heever, S.C., G.L. Stephens, and N.B. Wood, 2006b: Radiative and microphysical impacts on tropical convective clouds. *Western Pacific Geophysics Meeting, 24-27 July 2006, Beijing, China, AGU.*

Verlinde, J., P.J. Flatau, and W.R. Cotton, 1990: Analytical solutions to the collection growth equation: Comparison with approximate methods and application to cloud microphysics parameterization schemes. *J. Atmos. Sci.,* **47**, 2871-2880.

Walko, R.L., W.R. Cotton, M.P Meyers, and J.Y. Harrington, 1995: New RAMS cloud microphysics parameterization. Part I: The single-moment scheme. *Atmos. Res.*, **38**, 29-62.

Walko, R.L., W.R Cotton, G. Feingold, and B. Stevens, 2000: Efficient computation of vapor and heat diffusion between hydrometeors in a numerical model. *Atmos. Res.,* **53**, 171-183.