Report on the Implementation of an Aerosol Dependent Ice Nuclei Parameterization into the Thompson Microphysics Scheme in WRF

Trude Eidheimer
National Center for Atmospheric Research

NCAR MD&E Deliverable
09.5.8.3

1. Introduction

In many regional and global scale models, the number of predicted ice crystals is a function of only temperature or ice saturation. However, the number of ice crystals that can form is in reality dependent on the number of particles that can act as ice nuclei (IN). The concentration of IN can be highly variable, depending on location and season. For example, Figure 1 shows measurements of IN obtained in different field campaigns at different locations. As can be seen, for a given temperature the number of IN can span over several orders of magnitude. One of the main contributions to this large variation is the variation of the general aerosol concentration. The work described here is the implementation of new ice nucleation schemes in the Thompson microphysics package in WRF, which takes the aerosol variation into account.

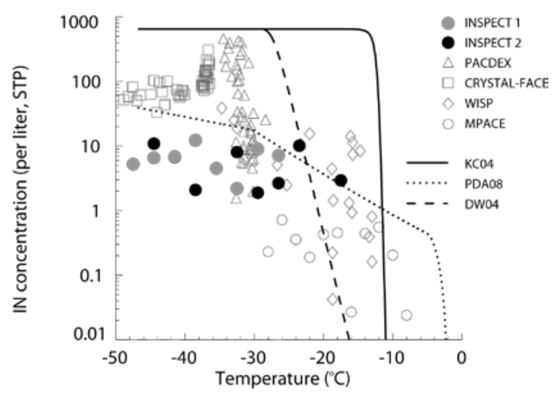

Figure1. Measured IN concentration as a function of temperatures in different field campaigns at different locations. Solid lines shows predicted IN, using different ice nucleation parameterizations (see Eidhammer et al. 2009a for more details)

2. **Implementation of dust**

The ice nucleation schemes included in WRF are dependent on aerosol concentration. We have therefore included one new variable into the Thompson microphysics scheme in the WRF modeling system: number concentration of aerosols available for ice nucleation. One of the most abundant types of aerosols that can serve as IN is dust particles and these particles typically enter into the atmosphere in arid regions and during strong wind events. These particles can be transported in the atmosphere far from the source region. Therefore a dust module accounting for emission of dust and dry deposition of dust is included. This module is based on the GOCART aerosol module which is implemented in the WRF-chem modeling system. The original GOCART module use several size bins to account for dust. However, each new advected variable included in WRF increases the computational time. In order to not increase the computational time too much, we must for simplicity assume a constant size distribution of dust. Therefore the original GOCART module has been modified to accommodate a constant size distribution. Wet deposition, which is the main removal process for the dust sizes that influence ice nucleation, is not included in GOCART. The implementation of wet deposition by rain and snow scavenging is currently ongoing. The wet removal module will be based on other modules that are implemented in WRF-chem, but again, modified for our simple treatment of dust.

Further, the model is initialized with a “background” dust profile, which for now decreases exponential with height, but is constant throughout the model domain. This background dust also contributes to ice nucleation. Later we will also include the possibility of initializing dust from the boundaries conditions. Figure 2 shows a simple example of a dust plume transported over a hill, and dust emitted from the ground.

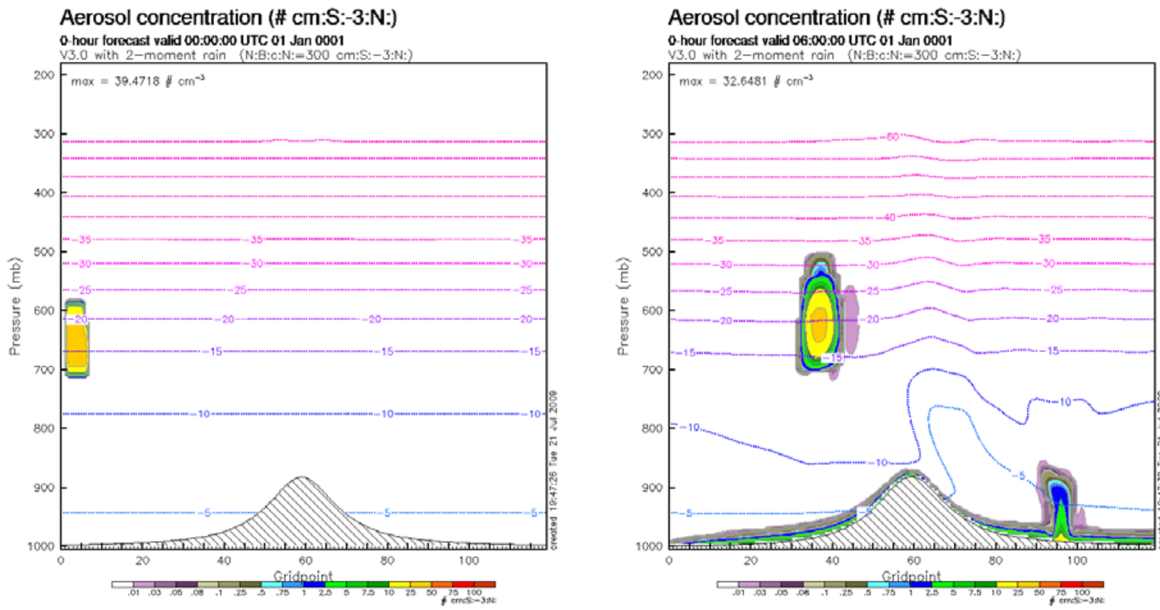

Figure 2 Example of a simple simulation with the model initialized with a dust plume, and dust emitted from the surface. Left figure is at initial time, while the right figure is at six hours later.

3. **<u>Ice nucleation schemes</u>**

A variety of new ice nucleation schemes that take into account aerosols serving as IN have been implemented into the Thompson microphysics scheme within the modeling system WRF. Previous, ice nucleation was predicted with two different parameterizations, one temperature dependent relation and one rain/droplet volume dependent relation. Now, deposition freezing is accounted for through a modified parameterization developed by Phillips et al. (2008). Condensation and immersion freezing is accounted for through a new parameterization by DeMott et al. (2009). Immersion freezing is still dependent on rain/droplet volume, as in the original Thompson scheme, but is constrained by the available IN, as determined with the DeMott et al parameterization. Both the parameterizations used here are based on empirical data obtained from field measurements of IN. In a recent parcel model study, both parameterizations shows predictions of IN and ice crystal concentrations in good agreements with measurements of IN and ice crystal concentrations from the ICE-L campaign (Eidhammer et al. 2009b).

With the inclusion of the new heterogeneous ice nucleation parameterizations, homogeneous nucleation of deliquescent aerosols (typically responsible for cirrus clouds) had to be included. This is done with a parameterizations based on Koop et al. (2000). Previously, cirrus clouds would implicitly be predicted through the temperature dependent parameterization. Figure 3 shows an example of the predicted ice crystal concentration with the new ice nucleation parameterizations (left plot), and with the original Thompson scheme (right plot). The influence of the dust plume at six hour can clearly be seen with high ice crystal concentration (left cloud, left figure). The right cloud is formed mainly by homogeneous freezing of deliquescent aerosols and is in reasonable good comparison with the original Thompson scheme.

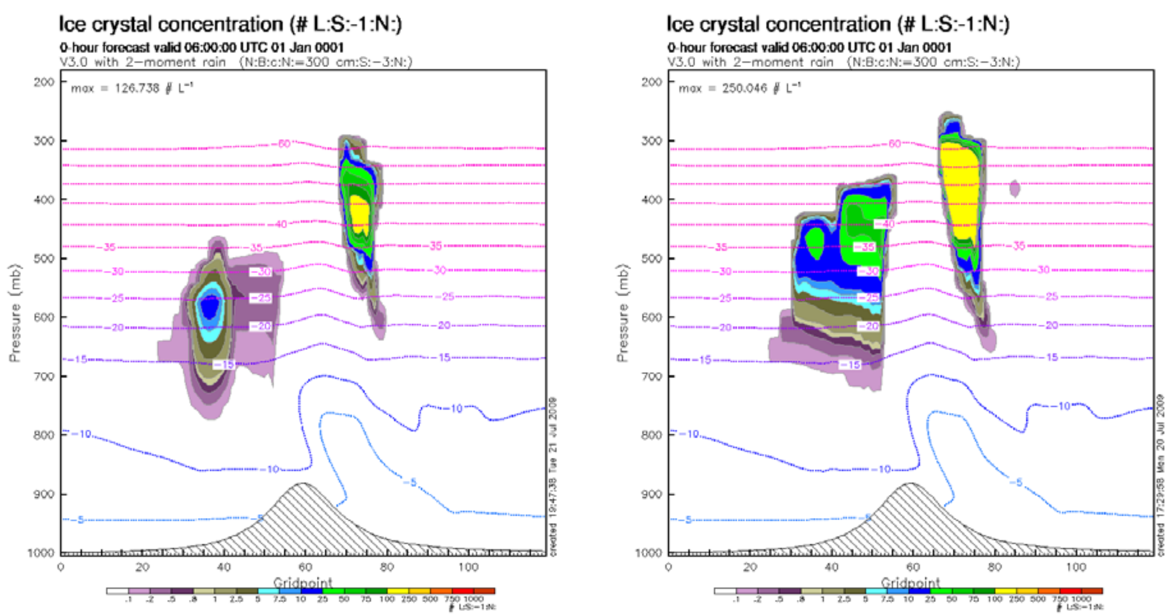

Figure3 Predicted ice crystal concentration with the aerosol dependent ice nucleation parameterizations (left plot) and the original Thompson microphysics scheme (right plot).

4. Summary and Future Work

A new ice nucleation scheme has been implemented into the Thompson microphysics scheme. This scheme uses the latest scientific developments regarding ice nucleation, and includes a new dependence on aerosol concentration. Future work will involve testing this scheme for a variety of case studies, and working with GSD to evaluate the scheme in a real-time mode.

5. References

DeMott, P. J. et al., 2009: Advances toward predicting global ice nuclei distributions. *Submitted to Science.*

Eidhammer, T., P. J. DeMott, and S. M. Kreidenweis, 2009a: A comparison of heterogeneous ice nucleation parameterizations using a parcel model framework, *J. Geophys. Res.* **114,** D06202, doi:10.1029/2008JD011095.

Eidhammer, T., P. J. DeMott, A. J. Prenni, M. D. Petters, C. H. Twohy, D. C. Rogers, J. Stith, A. Heymsfield, Z. Wang, K. A. Pratt, K. A. Prather, S. M. Murphy, J. H. Seinfeld, R. Subramanian and S. M. Kreidenweis, 2009b: Ice Initiation by Aerosol Particles: Measured and Predicted Ice Nuclei Concentrations Versus Measured Ice Crystal Concentrations in an Orographic Wave Cloud, *Submitted to J. Atmos. Sci.*

Koop, T., B. P. Luo, A. Tsias, and T. Peter, 2000: Water activity as the determinant for homogeneous ice nucleation in aqueous solutions. *Nature*, **406,** 611-614

Phillips, V. T. J., P. J. DeMott, and C. Andronache, 2008: An empirical parameterization of heterogeneous ice nucleation for multiple chemical species of aerosol, *J. Atmos. Sci*., **65**, 2757 – 2783, doi:10.1175/2007JAS2546.1.