# JP2.5 TOWARD ASSESSING THE EFFECT OF AEROSOLS ON DEEP CONVECTION: A NUMERICAL STUDY USING THE WRF-CHEMISTRY MODEL

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## 1. INTRODUCTION

As the formative agents of cloud droplets and ice particles, aerosols play an undeniably important role in the development of clouds and precipitation. An increasing number of meteorological models (e.g. the Hebrew University Cloud Model, the Regional Atmospheric Modeling System) are being adapted to include treatment of cloud condensation nuclei (CCN) or aerosol in order to better quantify microphysical processes that are difficult to measure through direct observation. Through the work of researchers within the Pacific Northwest National Laboratory (PNNL) (Fast et al. 2006, Gustafson et al. 2007) and the Forecast Systems Laboratory (Grell et al. 2005), a chemistry module has been developed and linked with the Weather Research and Forecasting model (WRF-Chem). The WRF-Chem allows meteorological and chemical fields to evolve together, which makes investigation of feedbacks between aerosol chemistry, cloud physics, and dynamics tractable. This study makes use of the WRF-Chem to simulate two idealized cases of deep convection with simplified aerosol treatments.

Albrecht (1989) proposed that the presence of increased CCN concentrations leads to decreased coalescence efficiencies, and therefore decreased precipitation, in stratiform clouds. The effects of increased CCN or aerosol concentrations on deep convection are not so clear, however. A recent review paper (Rosenfeld 2008) notes numerous numerical and observational studies in which higher aerosol concentrations resulted in increased precipitation, rather than decreased, and describes physical mechanisms responsible for this apparent reversal. This study seeks to determine if the WRF-Chem is up to the task of representing deep convective cases spanning both increased and decreased precipitation scenarios by modifying aerosol types and number concentrations.

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## 2. METHODOLOGY

### 2.1 MODEL SETUP

Simulations of deep convection are performed with the most recent rendition of the WRF-Chem (V3.0.1). Details on the numerical methods and physics implemented in WRF are documented within Skamarock et al. (2008). Idealized 2D cases with two different thermodynamic environments are considered, initialized by a warm bubble in the center of the domain. Within the idealized scenarios, insolation and surface fluxes are omitted in order to better isolate microphysical processes. Horizontal grid spacing is set to 500 m to resolve processes on a convective scale, so a sub-grid cumulus parameterization, boundary layer model, and land-surface model are not required. The domain encompasses 40 km, and 61 vertical levels are used. A positive definite advection scheme is implemented for all prognostic variables including chemistry. Boundaries are open in the y-direction and periodic in the x-direction. All timesteps within the model are set to 1.0 s, data is output every 60 s, and the simulation is allowed to run for 90 minutes. 178 model runs were performed including sensitivity tests for aerosol number concentration.

### 2.2 CHEMISTRY, MICROPHYSICS, AND METEOROLOGY SETUP

The degree to which chemistry is included in this study is quite limited, as we seek to represent aerosol populations as simply as possible. For example, to approximate oceanic aerosol, atomic sodium was chosen (Na), and for continental

aerosol, sulfate was chosen ($SO_4$). The Module for Simulating Aerosol Interactions and Chemistry (MOSAIC) currently implemented within WRF-Chem includes 8 aerosol types, however, and represents them distributes their mass and number over either 4 or 8 bins. For this study, aerosol initialization for number concentration and mass in these idealized cases is determined by a user-defined power law for the desired aerosol type, and sets other aerosol types to zero. Upon initialization prescribed total aerosol concentrations within the boundary layer ranged from $1.5 \times 10^6$ to $1.5 \times 10^9$ $m^{-3}$. An example of aerosol number and mass distribution amongst 8 bins is presented in Figure 1. Aerosol number concentrations above the boundary layer are reduced by a factor of 10 of the concentration within the boundary layer. The WRF-Chem includes many chemistry-specific mechanisms and processes, but we preserve only the processes that are necessary for aerosol-cloud interaction, such as aerosol activation, water uptake, aerosol resuspension, and wet scavenging.

While the WRF-Chem has numerous intricate modules to handle aerosol chemistry, the microphysics parameterization is not as sophisticated as other models developed for examining aerosol-cloud interaction, such as those used in Lee et al. (2008), Khain et al. (2003), and van den Heever and Cotton (2004). The Purdue Lin bulk microphysics scheme (Chen and Sun, 2002), based upon the Lin et al. (1983) scheme, is the only microphysics parameterization currently compatible with the WRF-Chem. In order to accommodate for aerosol mass and number calculated by MOSAIC, PNNL researchers have modified the Purdue Lin microphysics to include a limited double-moment scheme for treatment of cloud droplet number in addition to droplet mass. It has also been modified to include the Liu et al. (2005) autoconversion scheme, which includes dependence on droplet number concentration.

Two soundings were chosen from well-documented squall line cases to represent deep convection: an oceanic case from TOGA-COARE (Trier et al. 1996) and a continental case from the TRMM-LBA experiment (Lang et al. 2007). These soundings were chosen because they have similar CAPE values, warm cloud bases (>15°C), involve mixed phase processes, and have similar boundary layer heights of roughly 670 m.

## 3. RESULTS

Each of the two soundings are run using 16 different prescribed total aerosol number concentrations. For baseline comparisons, model simulations for both thermodynamic environments were run using the single-moment Purdue Lin microphysics scheme with no aerosol. Results of model simulations using the TOGA-COARE case, using Sodium (Na) as the aerosol type, are described below. Low aerosol number concentrations are referred to here as "maritime" and high aerosol number concentrations are referred to as "continental," even though the range in use are extreme cases of what might be typically considered "maritime" or "continental," and are used regardless of aerosol type.

As shown in Figure 2a), in maritime cases, the onset of rain occurs around 20 minutes into the simulation. The more continental cases, however, see a delay in timing of rain onset of nearly 15 minutes compared with the maritime case, presumably due to reduced coalescence (here, autoconversion) efficiency. At 80 minutes into the simulation, the continental cases overtake the maritime cases in domain total cumulative precipitation. This could be an instance of the "reversal" of the Albrecht effect as seen in other studies such as Lee et al. (2008) and Khain et al. (2003). Toward the end of the simulation, Figure 2c) shows that more continental cases are producing higher amounts of domain-total precipitation per minute.

Figures 2b) and 2d) show maximum updraft and maximum absolute values of downdraft speeds, respectively. It is interesting to note that both continental and maritime cases exhibit very similar characteristics early in the simulation, perhaps due to the way convection is initiated within the model itself. After the initial updraft, however, several updrafts follow. For continental cases, the third updraft present at ~70 minutes is nearly as strong as the initial updraft. A secondary peak in downdraft speed is noted at the same instance in time. Because this may be indicative of self-initiating secondary updrafts as described in Lynn et al. (2005), it is necessary to examine spatially where these maxima and minima of

vertical velocities exist.

Figure 3 reveals that at 70 minutes, the updraft is in the same location as the original updraft, and is not a result of secondary convection apart from the main storm, as was observed in Lynn (2005). The reinvigoration of the original updraft is still of interest, as is a secondary maxima above the freezing level where there are positive temperature perturbations aloft. Here, supercooled droplets may be freezing, releasing latent heat, and providing an extra boost to updrafts, similar to the scenario described in Rosenfeld (2008). While these results do not look identical to the results of more sophisticated microphysical parameterizations, they do merit further study.

Results of model simulations using the TRMM-LBA sounding are not detailed here, but resemble the Albrecht effect of increased aerosol number concentrations resulting in suppressed rainfall. Deep convection in this case is not able to reach a quasi-steady state.

## 4. FUTURE WORK

Simulation results indicate that with a few alterations to model code and methodology, further insights into aerosol-cloud interactions can be gained. Longer runs with a more restricted range of aerosol concentrations will be necessary, as 90 minutes is sufficient to capture initial development of deep convection but insufficient for capturing a representative sample of a quasi-steady state. A minimum of 6 hours of simulation time will be considered for future runs. Inclusion of latent heat release and capture by microphysical processes involving phase change will provide direct evidence for effects such as enhanced evaporative cooling or invigoration of updrafts due to freezing of droplets lofted above the freezing level. This additional data could point to implications for large-scale heating. Ongoing and future studies will also include extending model runs to three dimensions and testing for sensitivity to resolution.

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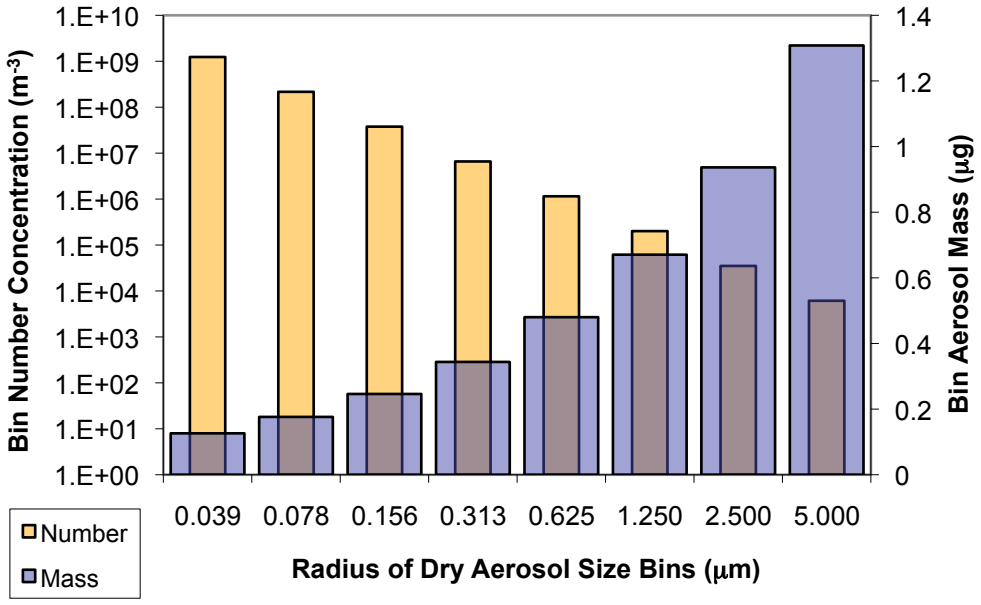


Figure 1. An example of how aerosol number and mass are allocated into eight size bins as implemented with MOSAIC in the WRF-Chem. Bins are initialized according to a power-law relationship. This example demonstrates an initialization of "oceanic" aerosol comprised solely of Sodium (Na), with a total number concentration of 1.5e9 $m^{-3}$. Aerosol mass and number concentration are allowed to evolve with time.

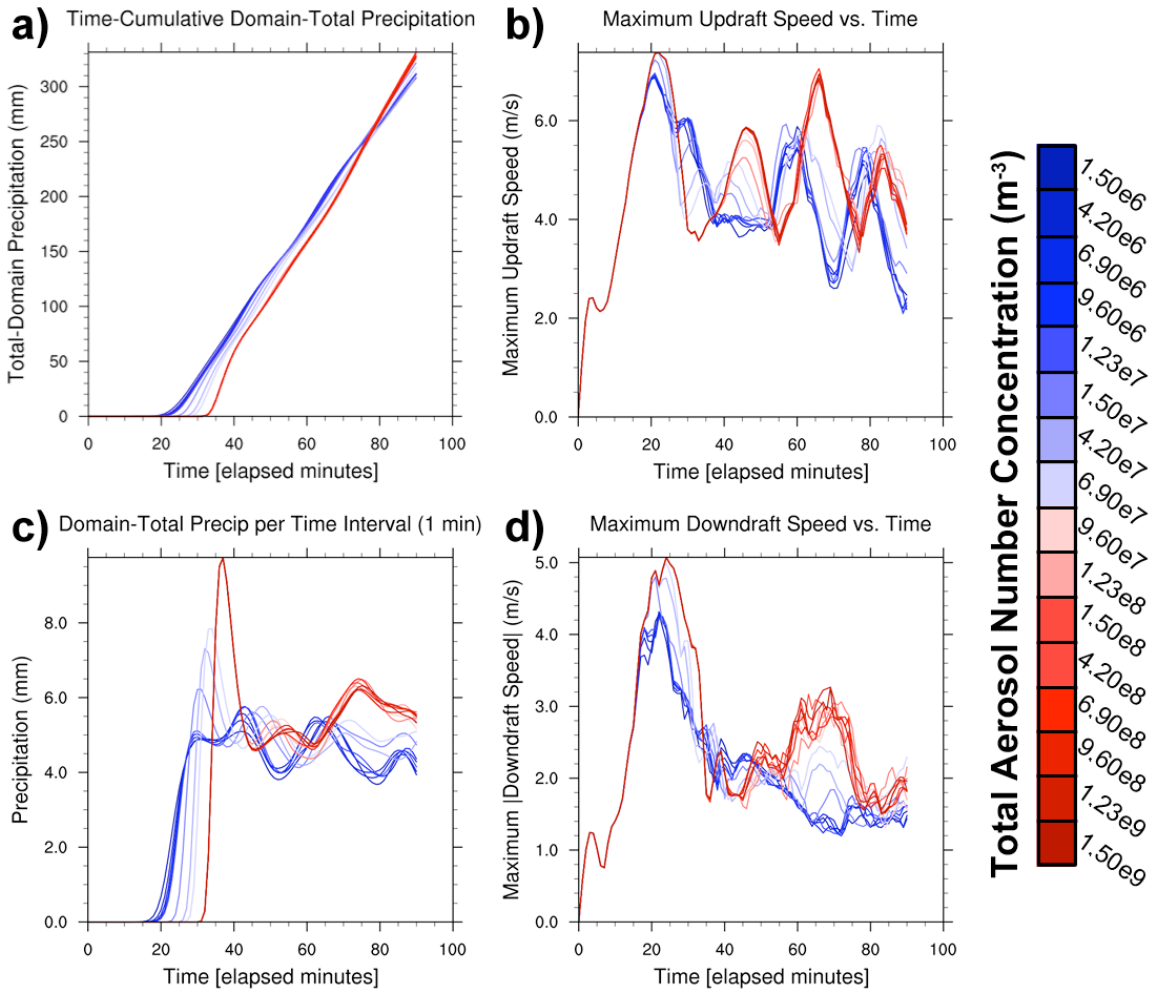


Figure 2. Each color represents a separate model run with total number concentration. Blue colors represent extremely clean aerosol environments, and red represents more polluted aerosol environments. All plots were created using the TOGA-COARE sounding and Sodium (Na) as the aerosol type.

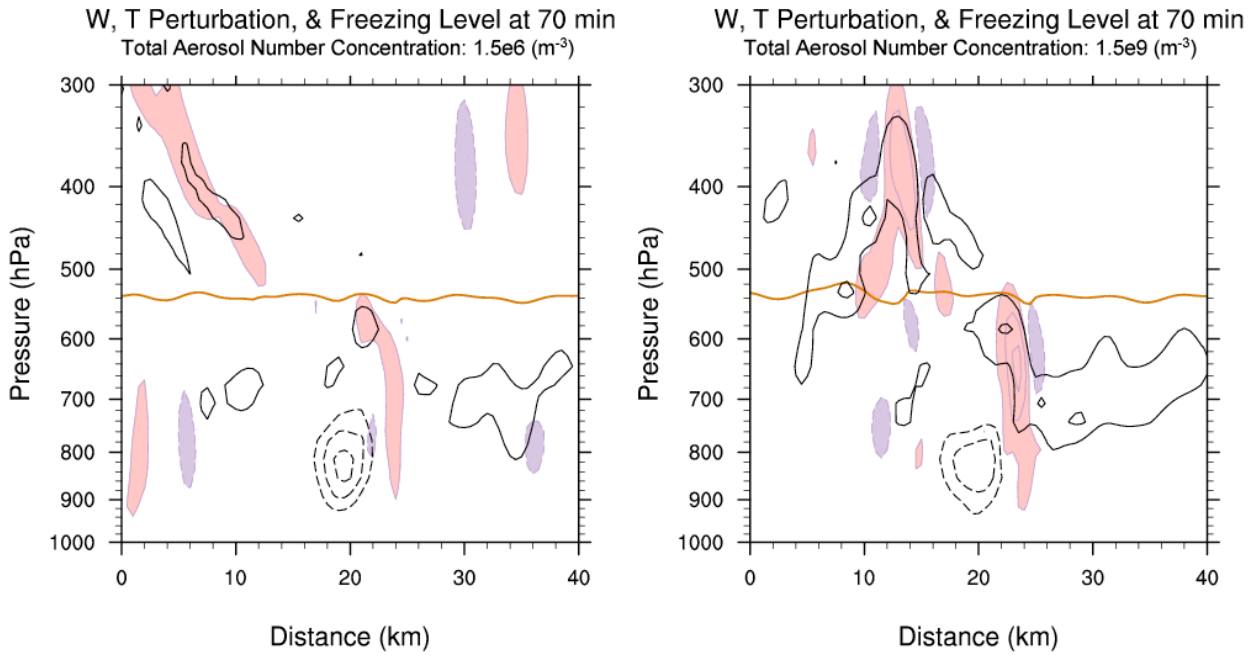


Figure 3. Comparative plots of vertical velocity, temperature perturbation, and height of freezing level (orange) at 70 minutes. The plots are the results of (left) maritime aerosol concentrations, and (right) continental aerosol concentrations. Vertical velocity greater than 1 m/s is shaded in red, less than -1 m/s is shaded in blue, and both are contoured in gray every 1 m/s. Solid black contour lines indicate positive temperature perturbations and dashed black lines indicate negative temperature perturbations, every 1°C. All plots were created using the TOGA-COARE sounding and Sodium (Na) as the aerosol type.