2.3 AEROSOL-CLOUD INTERACTIONS: A SENSITIVITY STUDY WITH A 1-DIMENSIONAL MODEL AND THE MESOSCALE COMPRESSIBLE COMMUNITY MODEL (MC2)

Irena T. Paunova,* and Henry G. Leighton

McGill University, Montréal, Québec

1 INTRODUCTION

Despite observational studies having firmly established that higher aerosol concentrations increase cloud albedo and reduce rainfall (e.g., King et al. 1993; Hudson and Li 1995; Rosenfeld 2000), the numerical estimates of the influence of anthropogenic aerosol on the radiative budget for cloudy skies remain uncertain. Global estimates of the indirect radiative forcing have an unacceptably large uncertainty for the indirect aerosol effect to be included in climate change calculations. Aerosol-cloud interactions are also expected to be important at regional scales and regional scale models are more amenable to studying these interactions. Therefore, it is reasonable to consider a limited-area model such as the Mesoscale Compressible Community (MC2) model with an advanced bulk microphysical scheme to fill the gap between the simpler Kessler-type cloud schemes used in large scale models and the computationally demanding bin microphysical models.

The present work investigates what details of the cloud condensation nuclei (CCN) activation process, which is not routinely included in global and mesoscale models, are necessary for simulating aerosol-cloud interactions. The answer to this question is expected to improve the simulation of the indirect effect in large scale models.

We focus on summertime midlatitude marine stratus clouds. There is as much stratus in midlatitude oceans during summer as there is in the subtropical stratus regions, the earth's radiation budget is strongly influenced by the marine stratus clouds, and the reflectance of thin stratus layers is more succeptible to "brightening" with an increase in the scattering optical thickness.

2 CASE STUDY

On 1 September 1995 during the Radiation, Cloud and Aerosol Experiment (RACE) a Twin Otter aircraft, operated by the National Research Council of Canada, observed a single layer stratus cloud over the Bay of Fundy (near Nova Scotia). This region of the midlatitude North Atlantic is impacted by air masses with widely varying aerosol and trace gas loading originating from the eastern coast of North America (Banic et al. 1996). The experiment provides in-situ cloud and aerosol measurements suitable for testing cloud and radiation schemes.

We intend to simulate at high resolution with the MC2 model the physical processes that govern the aerosol-cloud interactions in the stratus clouds observed during the RACE experiment. The present work, however, only presents a preliminary study of the sensitivity of the utilized cloud parameterization to the aerosol distributions collected by the Particle Measuring System (PMS) Passive Cavity Aerosol Spectrometer Probe (PCASP) during the experiment.

3 MODEL DESCRIPTION

3.1 Nucleation Parameterization

The cloud droplet number concentration (CDNC) is largely determined by nucleation, although droplet collision-coalescence, collection by rain, and mixing/evaporation can deplete droplet numbers. To simulate the explicit formation of cloud droplets we implement a detailed aerosol nucleation parameterization (Abdul-Razzak et al. 1998, 2000, hereafter referred to as AG98 and AG00) which applies the Köhler theory to a lognormal aerosol size distribution. The number nucleated depends primarily on aerosol number concentration and updraft velocity, but also on aerosol composition and size distribution. The parameterization is very useful for determination of the CDNC at the cloud base. The single mode version of the scheme (AG98) can represent an internal mixture of aerosol particles following a unimodal lognormal distribution. The multimode version of the parameterization (AG00) is suitable for representing several externally mixed aerosol species competing as CCN. Unlike the simple Twomey power law, widely applied in large scale models, this parameterization contains information about the aerosol spectrum which may change due to anthropogenic influences and, hence, allows the studying of aerosol-cloud interactions.

---

* *Corresponding author address:* Irena T. Paunova, Dept. of Atmospheric and Oceanic Sciences, McGill University, 805 Sherbrooke St. W., Montréal, Québec, H3A 2K6, Canada; e-mail: irena@zephyr.meteo.mcgill.ca

3.2 One-Dimensional Model

As a first test of the AG98/00 nucleation parameterization before implementing it in the MC2 model, we consider the prediction of droplet number in the framework of a one-dimensional (1-D) model. The model represents a simple kinematic column model, which treats the vertical advection with a semi-Lagrangian advection scheme using a prescribed vertical velocity profile. It employs an advanced two-moment warm microphysical scheme after Cohard and Pinty (2000a,b) (CP00) to to predict two moments, the number and the mass, of the droplet size distribution for cloud and rain. CP00 provides a detailed description of the scheme. The scheme is being implemented in the MC2 model, but here we present some preliminary results of 1-D sensitivity experiments to test the performance of the nucleation parameterization.

4 EXPERIMENTAL DESIGN

To initialize the nucleation parameterization, we assume an external mixture of sulfate and sea salt particles. The sulfate aerosol is represented by a lognormal size distribution with a number mode radius of 0.08 um and geometric standard deviations of 1.4 (O'Dowd and Smith 1993). The sea salt is represented in terms of two lognormal size distributions, one called the film drop mode, with a number mode radius of 0.1 um and a geometric standard deviation of 1.9 (O'Dowd et al. 1997), and another intermediate mode between O'Dowd's jet and spume drop modes, which is described below. These size distributions are fitted to the observed average aerosol spectrum below cloud base (Fig. 1).

The best fit has total number concentration of 1200 cm^{-3} for the sulfate mode and 17.1 cm^{-3} for the first sea salt mode (O'Dowd et al. 1997). For the coarse sea salt mode, a realistic lower and upper limit to the observed distribution, which is not completely covered by the PCASP channels, are considered the distributions SS1 to SS3 with a total number concentration from 1 cm-3 to 3 cm-3, a number mode radius from 2.0 um to 2.8 um, and a geometric standard deviation from 1.5 to 1.60 in the second sea salt mode. The distribution SS0 contains no coarse sea salt mode.

The model was initialized with a sounding extending to 1500 m from the Twin Otter measurements on 1 September during the RACE Flight 13C (Fig. 2). The updraft velocity profile is assumed to have sinusoidal shape with a maximum value of 0.3 m s^{-1}, which after 10 min from the beginning of the simulation decreases to zero following a sin^2 law. The top of the model domain is at 1200 m.

5 RESULTS

The nucleation model was tested for sensitivity to realistic changes of the parameters of the second sea salt mode which are associated with greatest uncertainty (Fig. 1). The results show high sensitivity to realistic changes of the parameters of the mode and are consistent with Ghan et al. (1998) findings with a binned version of AG98 model that for high sulfate number concentration and weak updraft the sea salt reduces the number concentration of the activated sulfate particles by reducing the maximum supersaturaiton (Fig. 3).

The 1-D cloud model was run for 30 min with AG00 nucleation parameterization and CP00 microphysics. Figure 4 and 5 show the simulated cloud droplet number concentration and the rain water path. It can be seen that in the conditions of high concentration of sulfate particles the sea salt acts to reduce the total number of cloud droplets (Fig. 4) which in turn acts to enhance the autoconversion and accretion processes (Fig. 5) . The simulations with higher number of sea salt particles exhibit earlier rain initiation and a more efficient conversion of cloud to rain (Fig. 6).

6 SUMMARY AND DISCUSSION

This work presents some preliminary results of sensitivity experiments with a detailed aerosol nucleation parameterization (AG00) and an advanced two-moment warm microphysical scheme (CP00). We demonstrated that the nucleation parameterization, which applies to a multi-mode lognormal aerosol distribution, exhibits the same behaviour in terms of competition between sea salt and sulfate particles as the binned version of the AG98 model (Ghan et al. 1998). The demonstrated high sensitivity of the number nucleated to the presence of the coarse sea salt mode shows the importance of the competition between sea salt and sulfate particles for the formation of cloud droplets in marine stratus clouds affected by urban pollution. This is potentially important for accurate prediction of the cloud properties. In the framework of a 1-D kinematic model we found that the shape of the aerosol size distribution has an important impact on the CDNC and the timing and the efficiency of rain formation.

7 ACKNOWLEDGMENTS

The authors wish to thank Mark Couture of the Meteorological Service of Canada for providing the RACE data and his helpful comments on the aircraft measurements and Jason Milbrandt of McGill University for providing the 1-D kinematic model and implementing the CP00 microphysics scheme.

References

Abdul-Razzak, H., S. J. Ghan, and C. Rivera-Carpio, 1998: A parameterization of aerosol activation 1. Single aerosol type. *J. Geophys. Res.*, **103,** 6123–6131.

Abdul-Razzak, H., S. J. Ghan, and C. Rivera-Carpio, 2000: A parameterization of aerosol activation 2. Multiple aerosol types. *J. Geophys. Res.*, **105,** 6837–6844.

Banic, C. M., W. R. Leaitch, G. A. Isaac, and M. Couture, 1996: Transport of ozone and sulfure to the North Atlantic atmosphere during the North Atlantic Regional Experiment. *J. Geophys. Res.*, **101,** 29091–29104.

Cohard, J.-M. and J.-P. Pinty, 2000b: A comprehensive two-moment warm microphysical bulk schem. II: 2D experiments with a non-hydrostatic model. *Quart. J. Roy. Meteor. Soc.*, **126,** 1843–1859.

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

Ghan, S. J., G. Guzman, and H. Abdul-Razzak, 1998: Competition between sea salt and sulfate particles as cloud condensation nuclei. *J. Atmos. Sci.*, **55,** 3340–3347.

Hudson, J. G. and H. Li, 1995: Microphysical contrasts in atlantic stratus. *J. Atmos. Sci.*, **52,** 3031–3040.

King, M. D., L. F. Radke, and P. V. Hobbs, 1993: Optical properties of marine stratocumulus clouds modified by ships. *J. Geophys. Res.*, **98,** 2729–2739.

O'Dowd, C. D., I. E. Consterdine, and J. A. Lowe, 1997: Marine aerosol,sea-salt, and the marine sulfure cycle: A short review. *Atmos. Environ.*, **31,** 73–80.

O'Dowd, C. D. and M. H. Smith, 1993: Physicochemical properties of aerosols over the northeast Atlantic: Evidence for wind speed related submicron sea-salt aerosol production. *J. Geophys. Res.*, **98,** 1137–1149.

Rosenfeld, D., 2000: Suppression of rain and snow by urban and industrial air pollution. *Science*, **287,** 1793–1796.

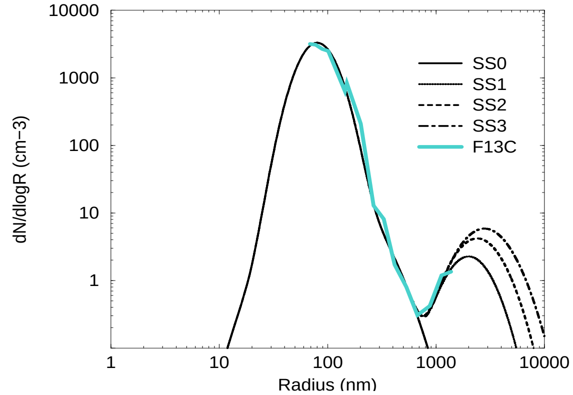

Figure 1: Observed (gray) and fitted (black) lognormal aerosol number distribution (see text for details).

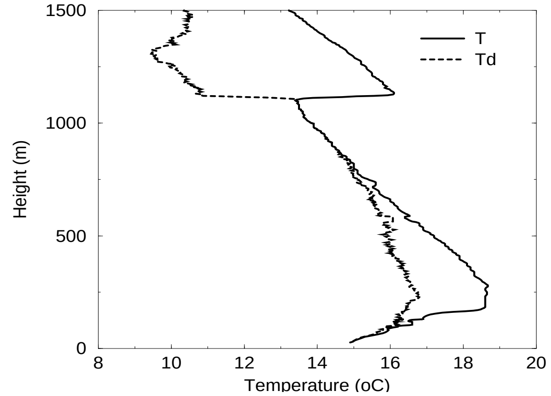

Figure 2: Vetical profile of temperture (solid) and dew point temperature (dashed) in °C as observed on 1 September 1995 during RACE.

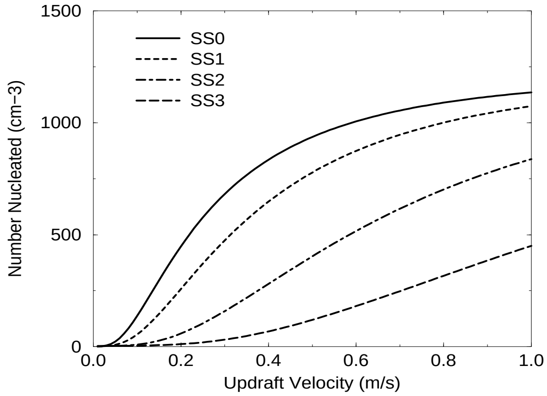

Figure 3: Number concentration of aerosol particles activated in cm^{-3} as simulated by the nucleation model.

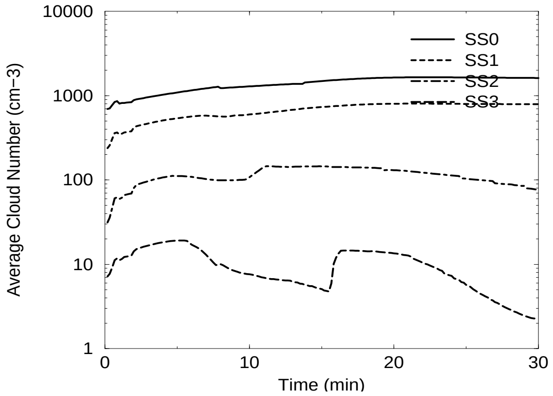

Figure 4: Cloud droplet number concentration in cm^{-3} simulated by the 1-D cloud model.

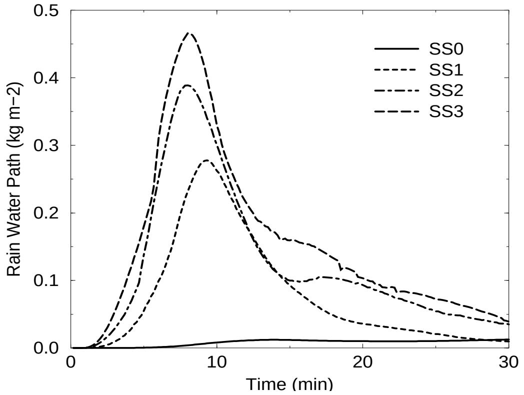

Figure 5: Rain water path in kg m^{-2} simulated by the 1-D cloud model.

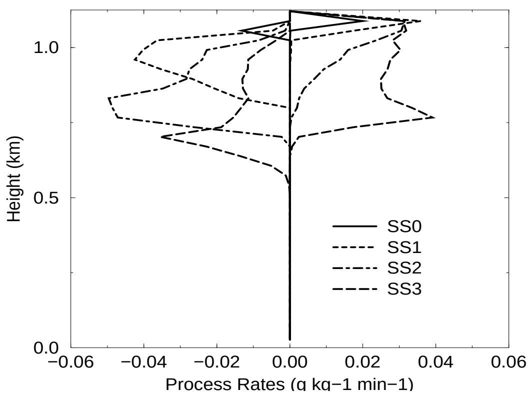

Figure 6: Time averaged cloud autoconversion (Q^{aut}) multiplied by -1 and accretion rates (Q^{acc}) as simulated by the 1-D model.