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EFFECT OF ABSORBING AEROSOLS ON CLOUD DROPLET SIZE DISTRIBUTION

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ABSTRACT

Numerical solutions are obtained for transient response of water droplets to radiative heating. Results are presented for evaporation of polydispersed droplets in the solar radiation field. The evolution of the temperature and size of the droplet are determined. The results are discussed based on cloud droplet evaporation in the presence of absorbing inclusions.

Keywords: Cloud droplets; Evaporation; Radiation.

INTRODUCTION

The interaction between radiation and cloud droplets results in the attenuation of radiative energy by scattering and absorption. If the absorbed energy is significant, droplet temperature increases and further perturb the equilibrium of water vapor with the cloud droplet. At the same time, the change in the droplet size further alters the radiation transfer parameters. These processes are governed by the energy and vapor transport between droplets and the environment. This heating and subsequent evaporation of droplets in a radiation field are important in many areas, such as fog clearance and cloud processes (Ackerman *et al.*, 2000; Koren *et al.*, 2004). In this paper, radiative evaporation of water droplets containing soluble salt (NaCl) and a black-carbon core is presented.

METHODOLOGY

Mass and energy balance of a single water droplet in gas irradiated by a uniform radiation field is considered here. Single droplet equations are then expanded to obtain the mass and energy balance of polydispersed droplets. For an incompressible droplet of density ρ_D and constant heat capacity C_D the energy conservation equation (Davis and Brock, 1987) is:

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$$C_D \frac{d(\pi D_p{}^3 \rho_D T_D / 6)}{dt} = \pi D_p{}^2 \left[K_g \left(\frac{\partial T_g}{\partial t}\right)_{D_p} \right] + L \frac{dM}{dt} + \frac{\pi D_p{}^2 Q_{abs} I_0}{4}$$

(1)

where T_D is the uniform droplet temperature, D_p is the droplet diameter, K_g is the heat conductivity, T_g gas temperature, t is the time, L is the heat of evaporation, M is the droplet mass, Q_{abs} is the radiation absorption efficiency and I_0 is the uniform beam intensity. On the right hand side of Eq. (1), the first term is the energy loss due to conduction, while the second term is due to latent heat loss. The last term in Eq. (1) represents the heat gain by radiation absorption. In the above formulation the convective energy transfer is neglected. Assuming steady state conditions, flux and gradient terms in the Eq. (1) are given by (Williams, 1965)

$$\frac{dM}{dt} = 2\pi D_p \rho_g D_v \ln\left(\frac{1 - Y_\infty}{1 - Y_s\left(D_p, T_D\right)} \right) = J \pi D_p{}^2 \tag{2}$$

$$K_g \left(\frac{\partial T_g}{\partial t} \right)_{D_p} = \frac{J(T_D - T_\infty)}{\exp\left[\frac{D_p J C_a}{2K_g} \right] - 1} \tag{3}$$

where $_g$ is the density of the host gas, D_v is the diffusivity of the water vapor in the gas, C_a is the heat capacity of the host gas, J is the mass flux, Y_∞ and T_∞ are the water vapor mass fraction and temperature far away from the droplet, and Y_s is the saturation mass fraction at the droplet surface.

The single droplet interaction with radiation and evaporation is extended to polydispersed droplets. The heating rate of the host gas which contains the droplet matrix per unit volume can be expressed as:

$$\frac{\partial T_\infty}{\partial t} = \frac{1}{\rho_g C_a} \left[q_a + \int_0^\infty N\left(D_p\right) \pi D_p{}^2 K_g \left(\frac{\partial T}{\partial r} \right)_{D_p} dD_p \right] \tag{4}$$

where $N(D_p)$ is the droplet size distribution, q_a is the absorption per unit volume by the host gas, $_g$ is the density of the host gas. Similarly, the water vapor mass fraction in the host gas:

$$\frac{\partial Y_\infty}{\partial t} = \frac{\rho_D \pi}{\rho_g 2} \int_0^\infty D_p{}^2 N\left(D_p\right) \frac{dD_p}{dt} \tag{5}$$

A sectional method with moving grid size structure was used to solve Eqs. (2) to (5) over droplet size distributions (Varghese and Gangamma, 2006). The solutions are determined by a public domain solver DVODE (Hindmarsh, 1983).

NUMERICAL RESULTS AND DISCUSSIONS

Evolution of droplet spectra by radiative heating

Absorption of solar radiation by polydispersed droplets suspended in air with absorbing inclusions is examined here. The radiation absorption coefficient is obtained for a layered sphere, with absorbing material in the core (black carbon, BC) and in the water shell outside (Toon and Ackerman 1981). The refractive index is assumed constant over the wavelength. This may induce error in the absorption efficiency of BC. However, for simplicity, a constant refractive index of (1.96, 0.66) is assumed for BC. A constant intensity of solar radiation 600 W/m^2 is assumed for the calculation. The absorption efficiency is calculated for a wavelength of 16 grids ranging from 0.2 to 2.2 m, and accounting for a solar constant of 1307 W/m^2. The absorption efficiency is weighted averaged over the solar insolation spectrum (Seinfeld and Pandis, 1998). The initial size distribution of the droplets is assumed as lognormal and has a number mean diameter (NMD) of 7.0 m and a GSD of 1.4. For present calculations, the size distribution is divided into five diameter bins. The number concentration of the droplet is assumed as 50 $/cm^3$. In each size bin,

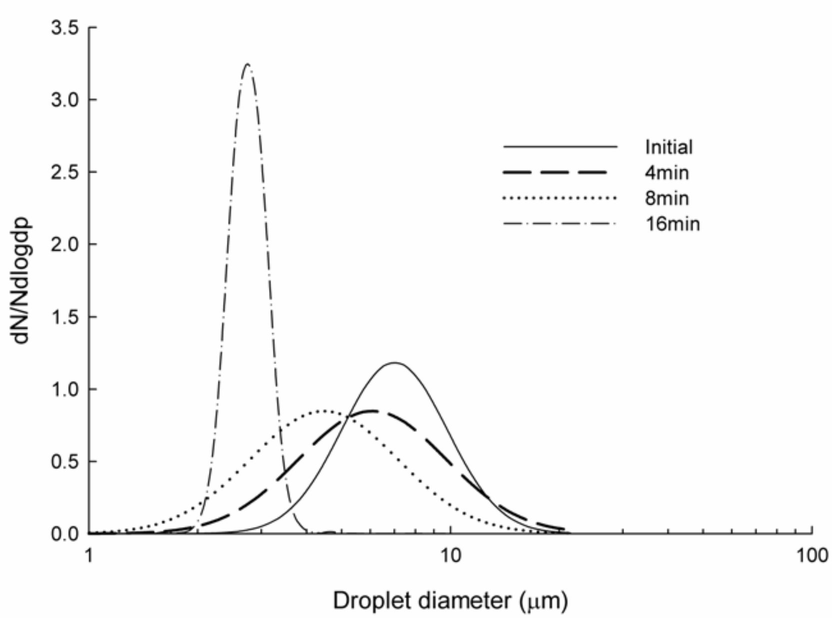

Fig. 4. Evolution of water droplet size distribution in the presence of absorbing inclusion and soluble salt.

the droplets contain a constant absorbing core of diameter of 0.2 μm of BC. The salt (NaCl) is a variable in the size bin. The largest bin is assumed to contain a salt mass equivalent to 0.2 μm in diameter of the NaCl particle. It assumes that all the droplets are in equilibrium initially. The droplet size distribution evolution is shown in Fig. 4. The lognormal function is fitted over the size distribution at each time step. The figures are plotted using fitted lognormal distribution parameters. Initially, the droplet distribution widens (high GSD) and finally the polydispersity of the droplets decreases (low GSD) considerably. The NMD of the droplet is decreased from 7 to ~[illegible] μm, due to evaporative loss by heating.

CONCLUSIONS

These results are important for cloud droplet size distribution evolution. Cloud albedo is a strong function of the polydispersity of cloud droplets. The dispersion of cloud droplet size has significant effect on earth's radiation balance (Liu and Daum, 2002; Peng and Lohmann, 2003). Even though the center core assumption of the inclusion may not accurately represent the absorption (Jacobson, 2006), the preliminary results show that the size and polydispersity of the droplets can be modified in the presence of absorbing material. Earlier studies on cloud droplet evaporation were made for cloud droplets immersed in high concentration of the absorbing aerosols (Ackerman *et al.*, 2000). Aerosols were treated as externally mixing with the droplets. These studies showed the effect on cloud lifetime due to increased heating in the presence of absorbing aerosols and consequently affect radiation balance of earth. Similar magnitude of radiative forcing may be possible if the cloud droplets contain radiation absorbing compounds.

REFERENCE

1. Ackerman, A.S., Toon, O.B., Stevens, D.E., Heymsfield, A.J. Ramanathan, V. and Welton E.J. (2000). Reduction of Tropical Cloudiness by Soot. *Science* 288: 1042-1047.
2. Davis, S.C. and Brock, R.J. (1987). Laser Evaporation of Droplets. *Appl. Opt.* 26: 786-793.
3. Hindmarsh, A.C. (1983). ODEPACK: A Systematized Collection of Ode Solvers, Scientific Computing, Edited by R. S. Stepleman., North-Holland Publishing Company, New York. p. 55
4. Jacobson, M.Z. (2006). Effects of Externally-Through-Internally-Mixed Soot Inclusions within Clouds and Precipitation on Global Climate. *J. Phys. Chem.* A. 110: 6860-6873.

5. Koren, I., Kaufman, Y.J., Remer, L.A. and Martins, J.V. (2004). Measurement of the Effect of Amazon Smoke on Inhibition of Cloud Formation. *Science* 303: 1342-1345.
6. Liu, Y., and Daum, P.H. (2002). Indirect Warming Effect from Dispersion Forcing. *Nature* 419: 580–581.
7. Peng, Y. and Lohmann, U. (2003). Sensitivity Study of the Spectral Dispersion of the Cloud Droplet Size Distribution on the Indirect Aerosol Effect. *Geophys. res. Lett.* 30: 1507-1510.
8. Seinfeld, J.H. and Pandis, S.N. (1998). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. Wiley Interscience publication. New York. p. 601-607.
9. Toon, O.B. and Ackerman, T.P. (1981). Algorithms for the Calculation of Scattering by Stratified spheres. *Appl. Opt.* 20: 3657-3660.
10. Varghese, S.K. and Gangamma, S. (2006). Modeling of Aerosol Formation and Growth in a Laminar Flow Generator Using Sectional Method. Submitted to Aerosol Air Qual. Res.
11. Williams, F.A. (1965). On Vaporization of Mist by Radiation. *Int. J. Heat Mass Transfer*. 8: 575-587.