Investigation of Aerosol-Cloud Interactions Using a New Cloud Parcel Model

Stony Brook University School of Marine and Atmospheric Sciences

Jingyi Chen[1], Yangang Liu[2] and Minghua Zhang[1]

[1] Stony Brook University, [2] Brookhaven National Lab

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Introduction

It has been increasingly recognized that aerosols can affect climate by indirectly alter cloud microphysical and radiative properties, however, the details of aerosol-cloud interactions remain largely elusive regarding the dispersion effect and separation of aerosol effects from cloud dynamics.

This work attempts to address these issues using a new parcel model with detailed bin microphysics. The new model treats coexisting dry aerosols, haze droplets and cloud droplets, and improves consideration of aerosol-cloud continuum. The combined effects of pre-cloud aerosol properties (aerosol concentration, mean radius, aerosol dispersion, and chemical composition) and updraft velocity on cloud microphysical properties (droplet concentration, standard deviation and relative dispersion) are examined by integrating a suite of numerical simulations of different aerosol properties and updraft velocities. The results are further used to extend previous regime classification of aerosol cloud interactions based on effects of cloud droplet concentration (e.g., aerosol-limited vs. updraft-limited regimes) by considering droplet relative dispersion as well. Also examined are the influences of aerosol mean radius, aerosol relative dispersion, and chemical composition on the relationships between aerosol concentration, droplet concentration and droplet relative dispersion. Results from the new model will also be compared with other parcel models in the context of understanding aerosol-cloud interactions and their parameterization in climate models.

Methods

The cloud parcel model simulates adiabatic ascending of an air parcel with evolution of atmospheric variables and vapor condensation using Lagrange method. In this work, a new cloud parcel model with aerosol deliquesces and effloresces [1] is used to separate impact of aerosol properties and vertical velocity on cloud properties. Cloud parcel model 1 [2] and cloud parcel model 2 [3] are used for comparison.

Results

As comparison of 3 models, particle spectrums are shown in figure 1a, 1b and 1c with all particles nucleated. New cloud parcel model generates less cloud droplets than cloud parcel model 1 with same aerosol radius in each bin. Cloud parcel model 2 uses different aerosol radius in each bin, resulting in significant difference. Haze droplets and cloud droplets can be differentiated in all three models.

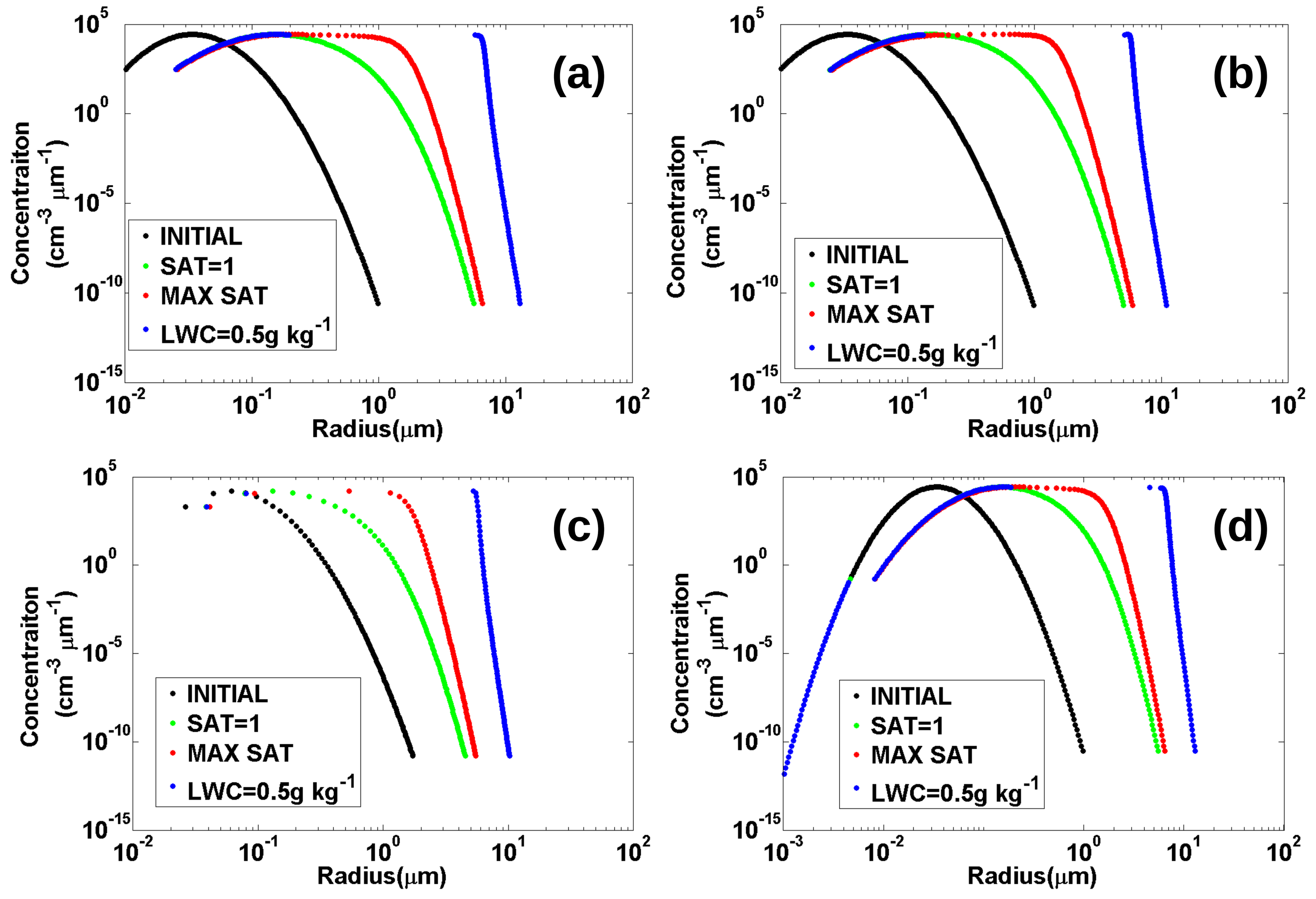

Figure 1: Particle spectrum from (a) new cloud parcel model (b) cloud parcel model 1 and (c) cloud parcel model 2 with aerosol radius 0.01—1 μm. (d) Particle spectrum from new cloud parcel model with aerosol radius 0.001—1 μm.

Results

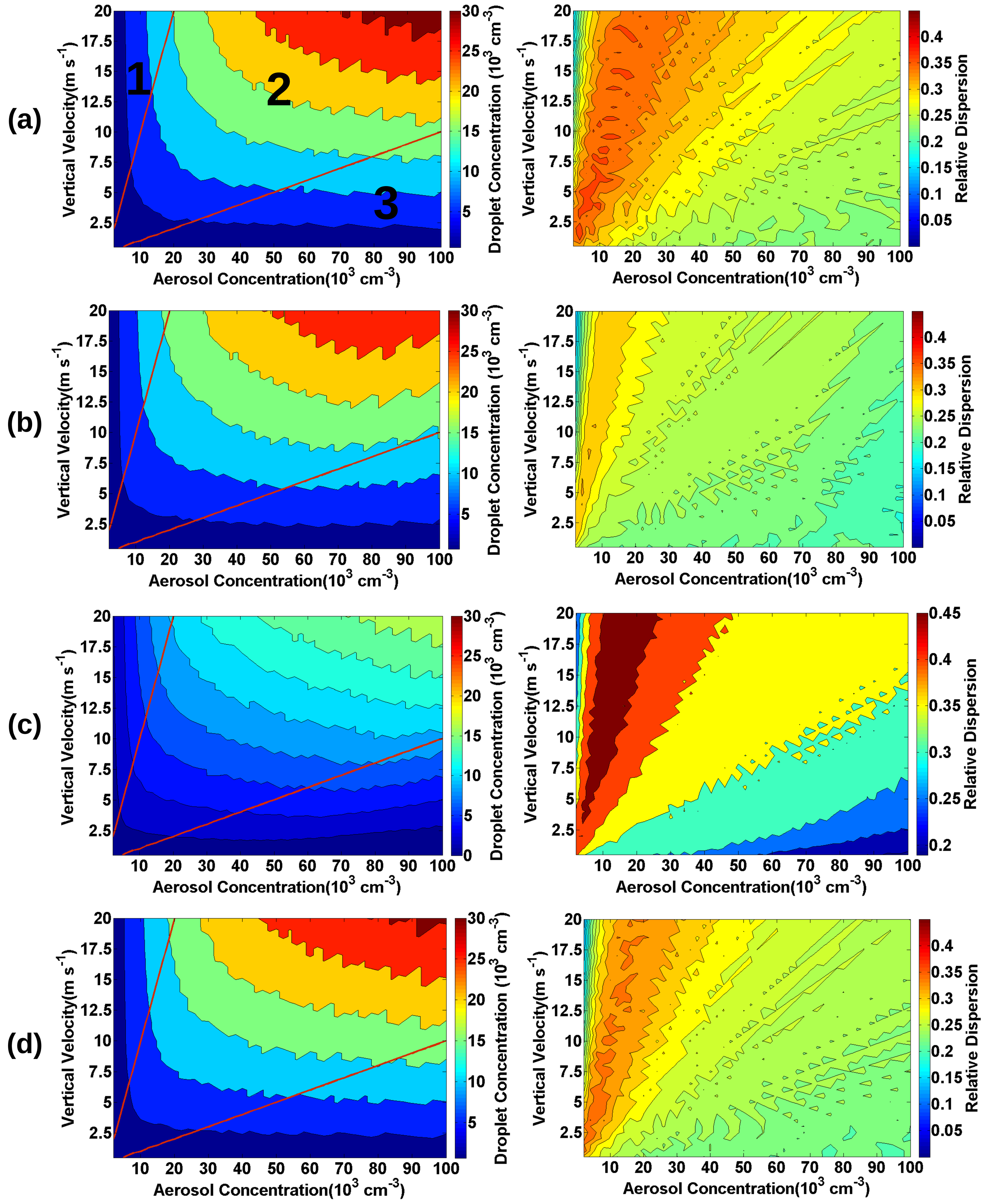

Figure 2: Droplet concentration (left) and relative dispersion (right) dependence on aerosol concentration and vertical velocity. Aerosol distribution are log-normal with (a) r_d = 0.04 μm, σ = 1.5 and κ = 0.67 (b) r_d = 0.08 μm (c) σ = 2.2 and (d) κ=1.34. Other parameters for (b)(c)(d) are as same as (a). r_d is aerosol median aerosol radius. σ is aerosol standard deviation. κ is aerosol hycroscopicity parameter.

Results

New cloud parcel model has potential ability dealing with small aerosols, which can not nucleate in updraft cooling. Figure 1d shows three aerosol groups: dry aerosol, haze droplets and cloud droplets.

2000(50×40) cases study confirms the three regime of cloud droplet concentration [4] with expending to relative dispersion [5] (ratio of cloud droplet standard deviation and mean radius). Aerosol median radius, aerosol standard deviation and aerosol hygroscopicity characteristics are examined separately (Figure 2) by new cloud parcel model. Large value of relative dispersion in transitional regime and sensitivity of aerosol properties on cloud properties can also be seen from cloud parcel model 1 simulations (not shown).

Conclusions

This study confirms the three distinct regimes of cloud droplet concentration dependence on aerosol concentration and vertical velocity. Relative dispersion dependence on aerosol concentration and vertical velocity shows complicated pattern with large value in transitional regime. Droplet concentration is negatively correlated to aerosol standard deviation. Relative dispersion is negatively correlated to hygroscopicity and aerosol median radius, but positively correlated to aerosol standard deviation.

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