CLOUD-SYSTEM RESOLVING MODEL SIMULATIONS OF AEROSOL INDIRECT EFFECTS ON TROPICAL DEEP CONVECTION AND ITS THERMODYNAMIC ENVIRONMENT

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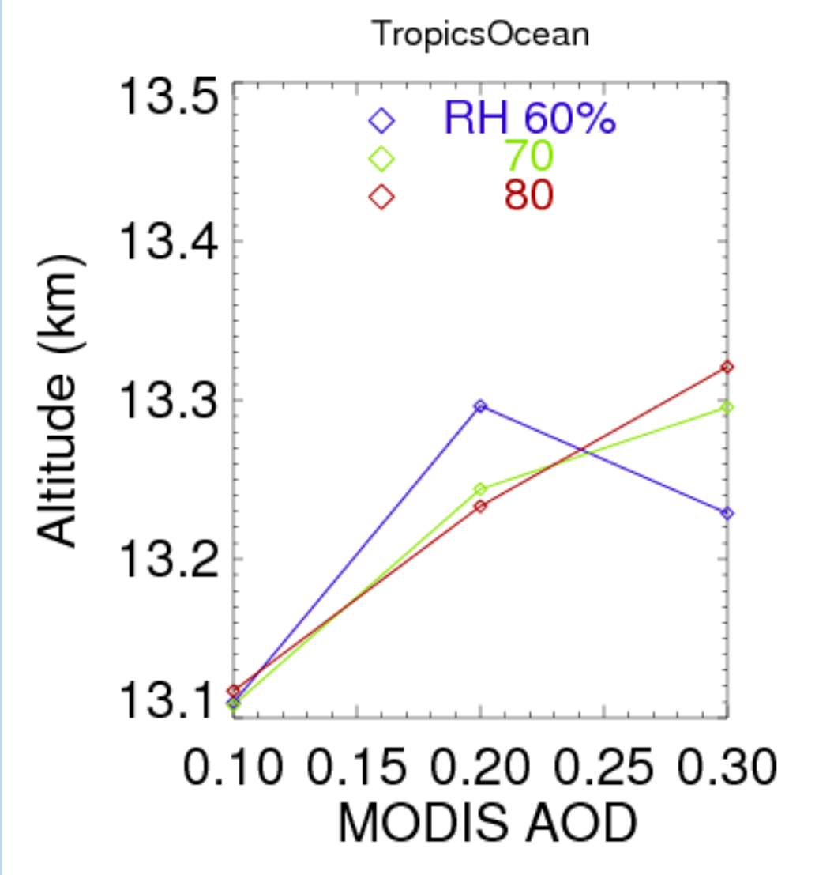
Overview

Previous studies have hypothesized that aerosols can have a large impact on the character of deep convection and its associated precipitation (e.g., Levin and Cotton 2009).

Studies have suggested that pollution can invigorate convection by delaying warm-rain production and increasing latent heat release by freezing of liquid water (Rosenfeld 2008). However, most of these studies have looked at the impact of aerosols of individual convective clouds, neglecting feedback with the environment.

Satellite studies have examined correlations between cloud height, cloud fraction, and aerosols to infer that convection is invigorated in polluted conditions (Koren et al. 2010). However, observations of aerosol impacts are confounded by issues related to causation versus correlation and confounding meteorological factors.

Fig. 1. MODIS-derived cloud top height as a function of aerosol optical depth (AOD), binned for different relative humidities.



The goal of this study is to examine aerosol impacts on tropical deep convection using multi-day simulations in a large domain with feedback on the thermodynamic environment.

Description of the Microphysics Scheme

2-moment bulk liquid+ice scheme (prediction of mass mixing ratio and number concentration)

- **Liquid scheme:** Morrison and Grabowski (2007, 2008a)
- **Ice scheme:** Morrison and Grabowski (2008b)

In the new ice scheme, different ice types are not separated into different species (e.g., cloud ice, snow, graupel) a priori as in traditional schemes. Instead, ice growth via riming and vapor diffusion follows from the conceptual model of Heymsfield (1982), based on separate prediction of rime and vapor deposition mass mixing ratios.

Cloud-Aerosol Coupling

- Ice nucleation from heterogeneous immersion freezing of cloud droplets (Bigg 1953), deposition/condensation-freezing (Meyers et al. 1992), and homogeneous freezing. Ice nucleation is not explicitly coupled to aerosol.
- Wet scavenging by precipitation below cloud base is neglected. Background aerosol is assumed to be constant in time.

Application to TWP-ICE

Simulations of the Tropical Warm Pool – International Cloud Experiment (TWP-ICE) have been conducted with a version of the anelastic Eulerian-Lagrangian (EULAG) cloud model (Grabowski and Smolarkiewicz 1999)

Similar setup as TWP-ICE cloud model intercomparison (Fridlind et al. 2010):

- Simulation period: Jan 18 to Jan 25, 2006, 10 mb V2 ARM forcing/initial dataset
- 2D, 97 vertical levels with stretched vertical coordinate, 200 x 25 km domain, 1 km grid spacing (baseline)

Due to large variability as a result of randomness of convection, we use an ensemble approach with 240 members. Different members are generated by applying different random number seed to small, random pertubrations of the low-level potential temperature field.

Three 240 ensembles are run with relatively pristine aerosol observed during TWP-ICE (PRIS), relatively polluted aerosol (POLL) observed in the region during the Nov. 2005 Aerosol and Chemical Transport in Tropical Convection experiment (ACTIVE), and highly polluted aerosol typical of urban conditions (SPOLL).

Fig. 2. Specified aerosol size distributions for PRIS, POLL, and SPOLL.

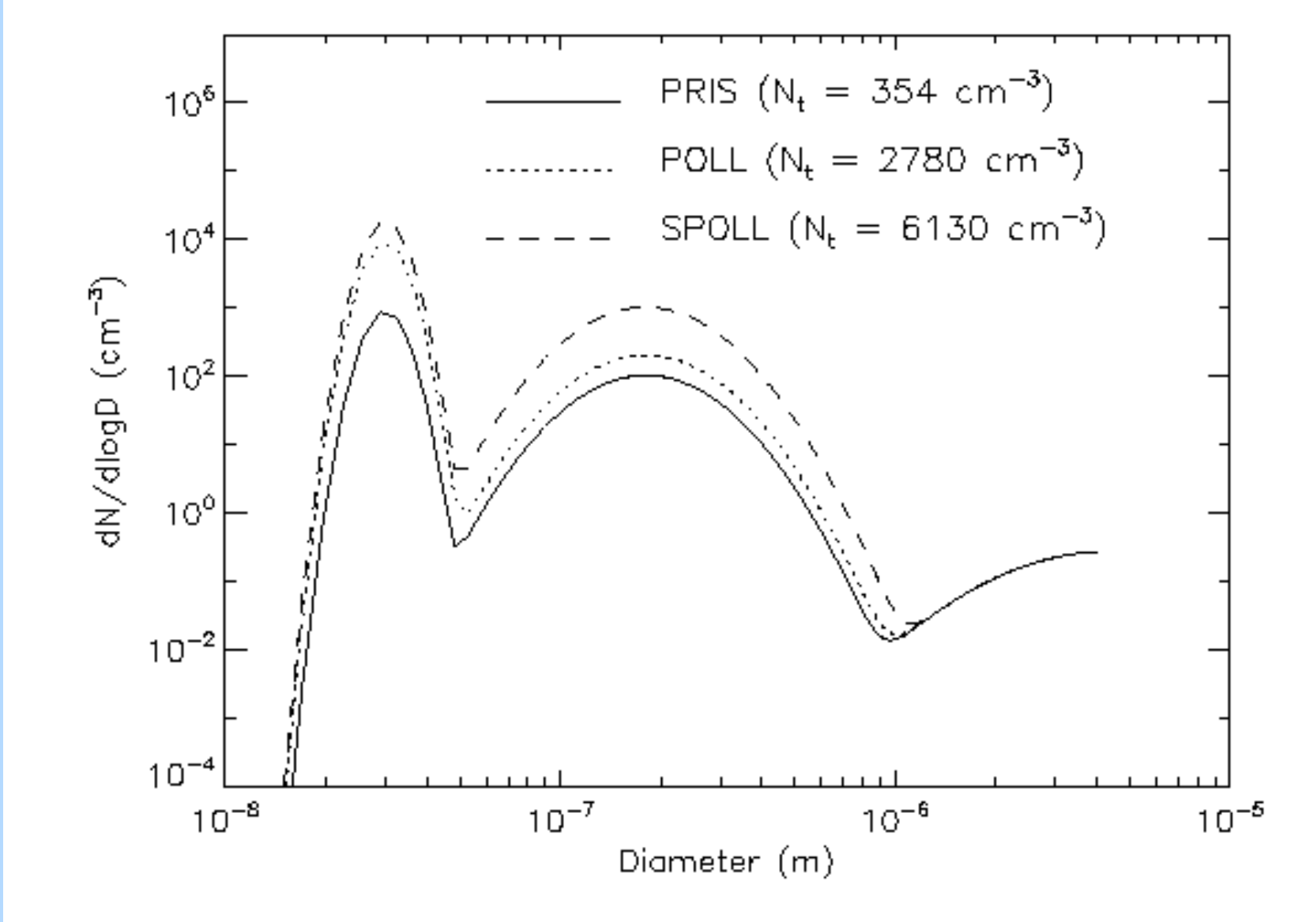


Table 1. Ensemble- and time-averaged top-of-atmosphere outgoing longwave radiation (OLR), reflected shortwave radiation (RSW), surface latent heat flux F_L, surface senisble heat flux F_S, tropospheric radiative flux divergence F_R, precipitation F_P, and change in column integrated dry static energy (ds/dt), water vapor (dw/dt), and moist static energy (dh/dt).

	OLR	RSW	F_L	F_S	F_R	F_P	ds/dt	dw/dt	dh/dt
PRIS	177.3 (4.9)	189.2 (4.3)	176.3 (5.2)	10.4 (0.7)	-43.7 (4.4)	807.2 (7.8)	1.4 (7.8)	-29.9 (6.6)	-28.4 (6.9)
POLL	166.7 (7.0)	199.9 (6.6)	174.6 (5.6)	9.9 (0.7)	-34.6 (6.4)	804.0 (8.2)	5.5 (8.2)	-26.9 (6.5)	-21.3 (8.2)
SPOLL	163.9 (6.4)	208.2 (7.7)	174.3 (5.2)	9.6 (0.7)	-32.2 (5.8)	803.5 (8.8)	6.1 (8.8)	-25.8 (6.3)	-19.6 (8.0)

Impact of aerosols on microphysics, radiative heating, and convection

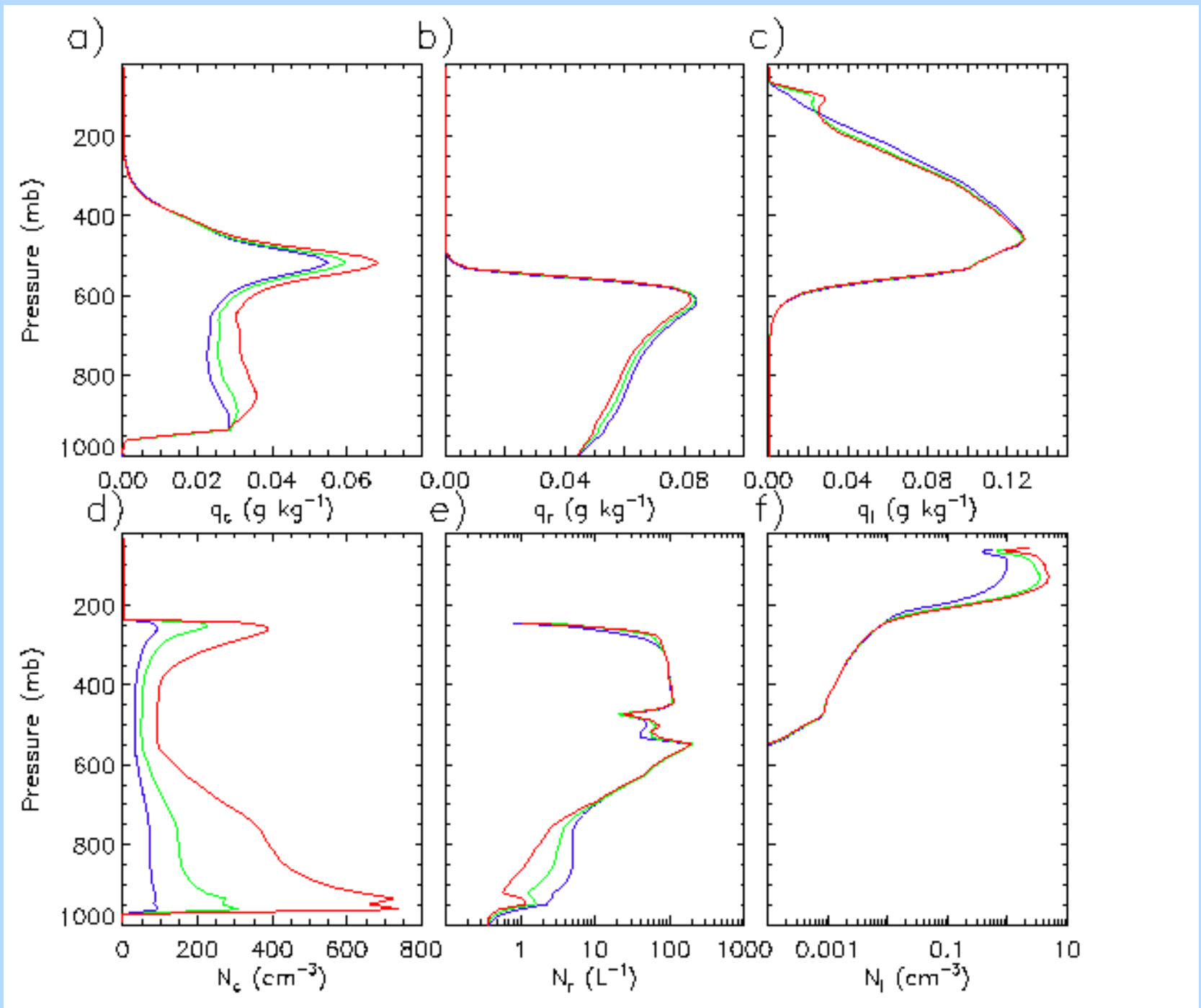


Fig. 3. Ensemble- and time-averaged profiles of a) cloud water mixing ratio, b) rain mixin ratio, c) ice mixing ratio, d) cloud droplet concentration, e) rain drop concentration, f) ice particle concentration

PRIS
POLL
SPOLL

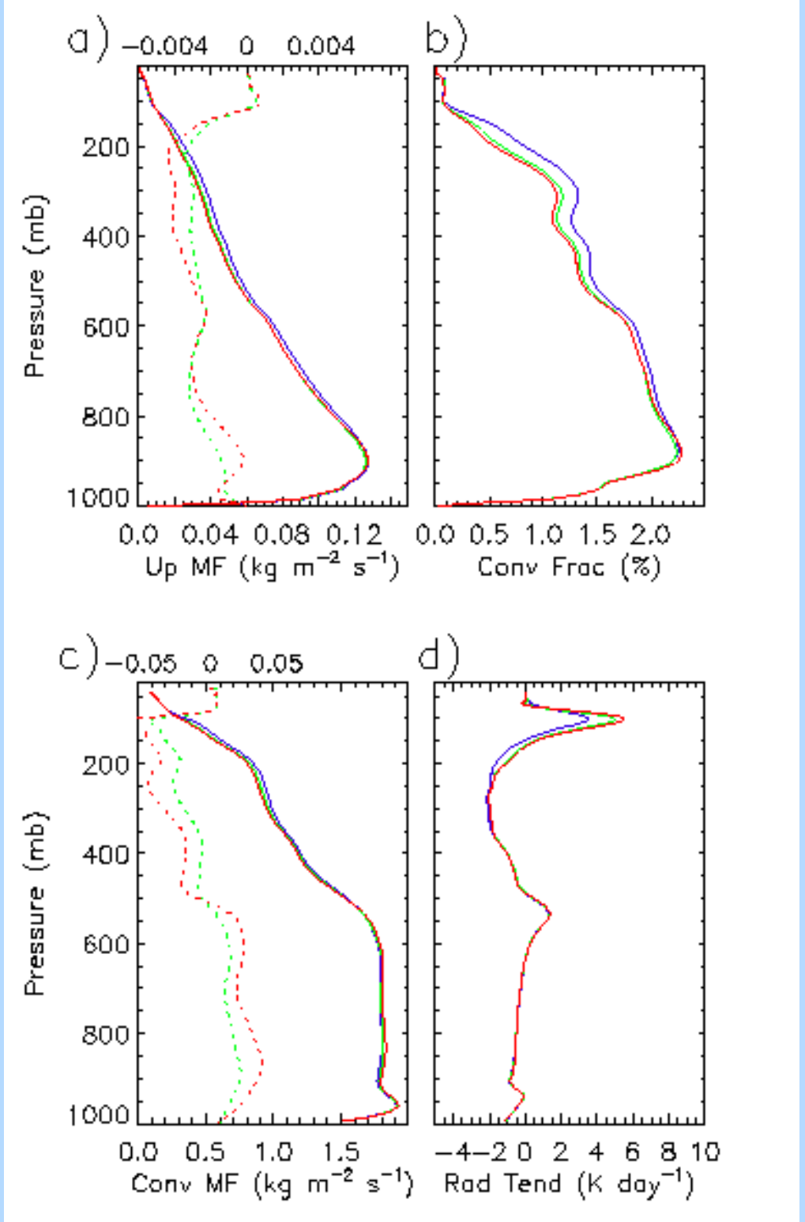


Fig. 4. Ensemble- and time-averaged profiles of a) updraft mass flux, b) fractional area of convective updrafts, c) mean convective updraft mass flux, d) radiative heating rate

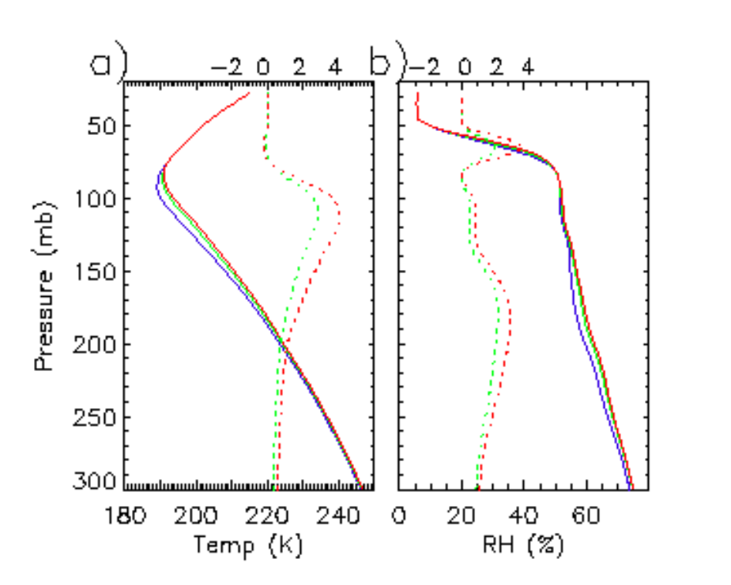
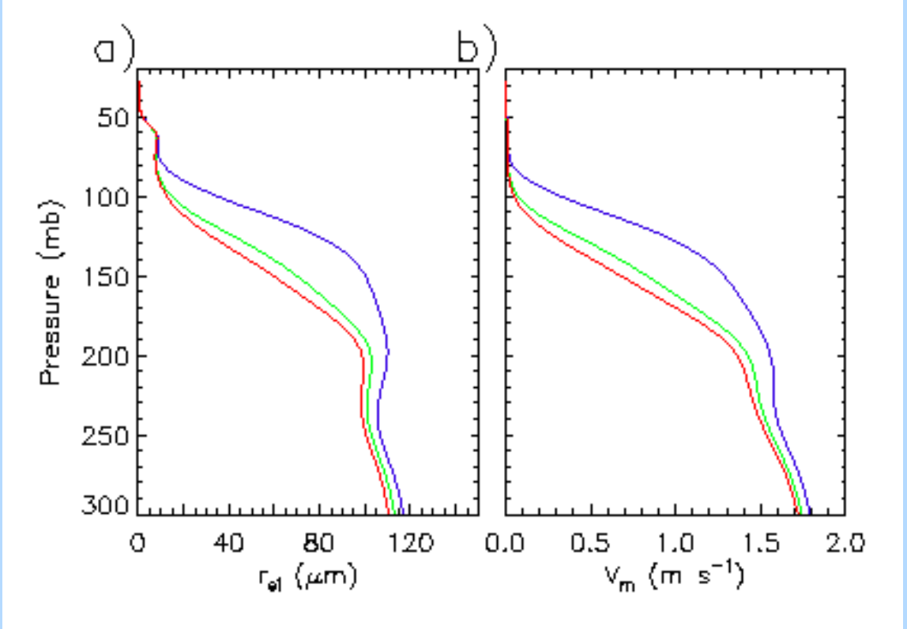


Fig. 5. Ensemble- and time-averaged profiles of a) temperature and b) relative humidity

Fig. 6. Ensemble- and time-averaged mass-weighted ice effective radius and particle fallspeed.



Aerosols result in larger concentration of droplets (Fig. 3d) that subsequently freeze, producing high concentration of ice (Fig. 3f). This results in smaller effective radius and fallspeed (Fig. 6), which leads to enhanced ice mixing ratio near the tropopause and higher anvil cloud top (Fig. 3c). These changes in upper-tropospheric ice result in increased radiative heating (Fig. 4d) and *weaker* convection (Fig. 4). This provides an alternative explanation for satellite-observed changes in cloud top with pollution (Fig. 1), in contrast to previous studies of convective invigoratoin in polluted conditions.

Conclusions

- There is little difference in precipitation with aerosol loading, which is mostly determined by large-scale forcing and SST which are fixed in the simulations.
- There are large differences in TOA radiative forcing with aerosol loading, reflecting impacts on both outgoing longwave and shortwave radiation.
- For these multi-day simulations, convection is weakened because of increased upper-tropospheric radiative heating and subsequent stabilization in polluted conditions. Increased radiative heating occurs because anvil clouds are higher and thicker, which is a direct result of higher droplet concentrations that freeze and produce high ice particle concentrations, small effective radius, and small fallspeed.

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