Examining Aerosol Indirect Effects on Tropical Deep Convection

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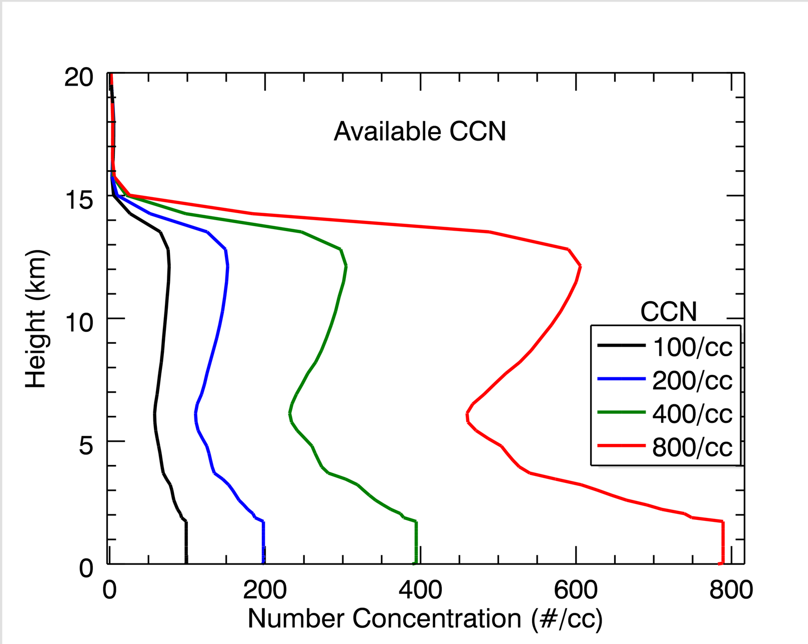
Introduction

The effects of aerosols on clouds is a large uncertainty in our understanding of the climate. Deep convective clouds are particularly challenging in this regard, due to their strong dynamics and the complications of mixed phase microphysics. This study seeks to classify aerosol indirect effects on tropical deep convective storms. These effects will be investigated in a series of large-scale 2-dimensional runs which are conducted using a radiative-convective equilibrium framework. The model used is the Regional Atmospheric Modeling System (RAMS) (Cotton et al. 2003).

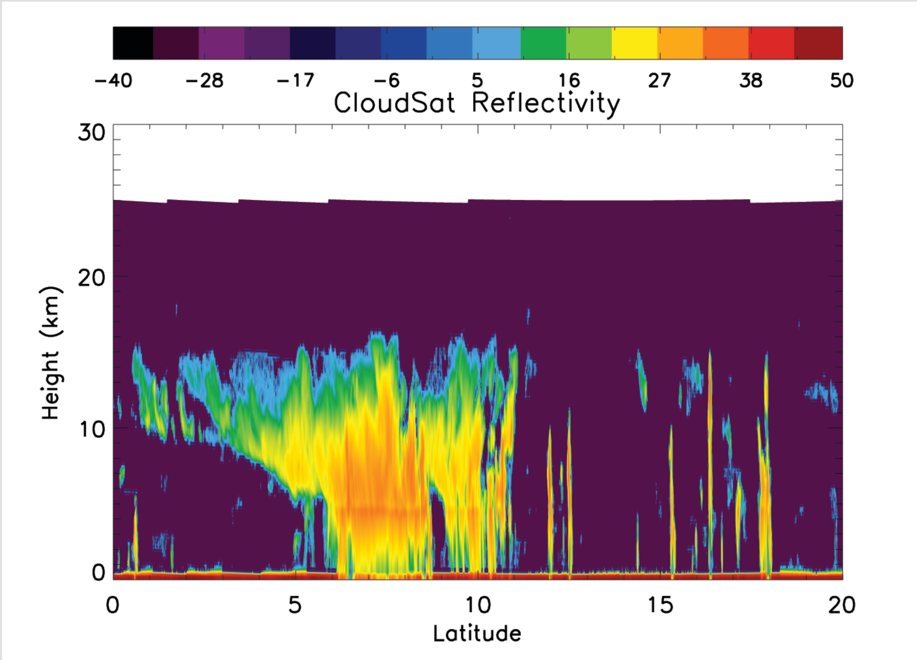
Model Setup

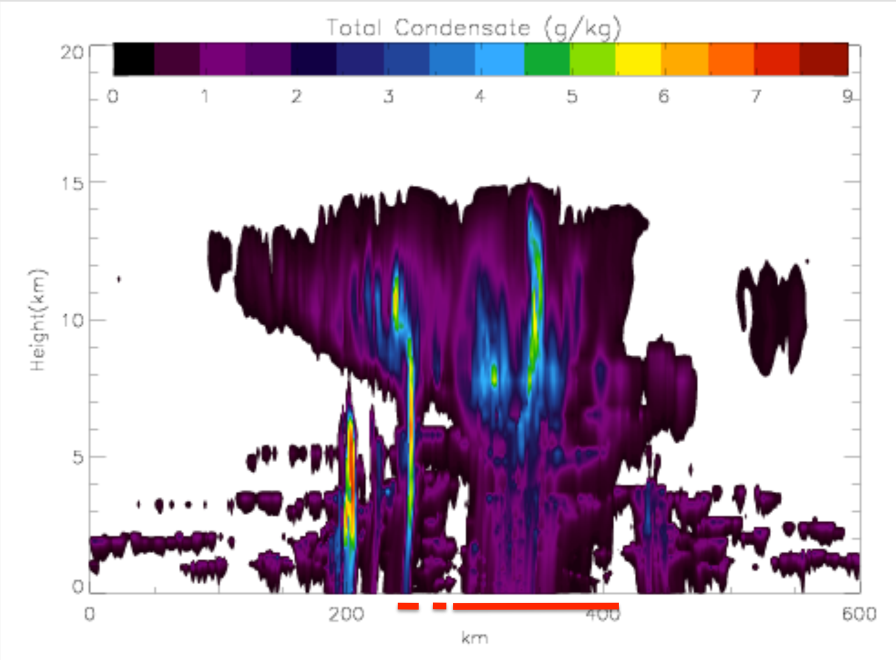
- Model domain – 7200km horizontal x 25km vertical
- Grid spacing – 1km (horizontal) and stretched vertical (min of 75m to a max of 750m)
- Cyclic Boundary Conditions
- Time step – 10s
- Microphysics –Two-moment bulk scheme that can activate available aerosols as CCN (Meyers et al. 1997, Saleeby et al. 2004)

Once the model reached a stable radiative-convective equilibrium, aerosols were introduced with each new time step between 0 and 2km in four different concentrations. A total of ten days has been analyzed after the introduction of the aerosols, with variables analyzed at each hour. Plots shown are averages over deep convective profiles.



Aerosols available to act as CCN are lofted through the entire height of deep convective clouds.

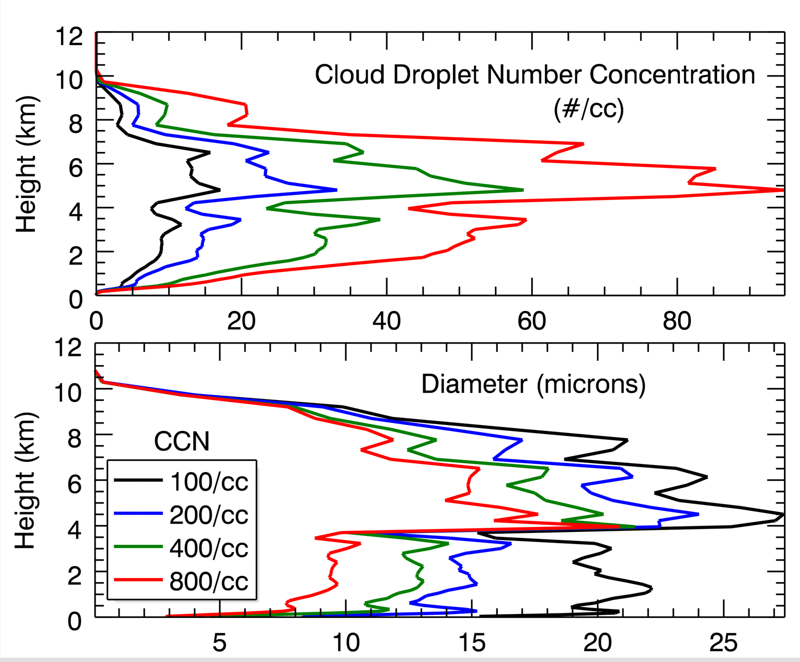


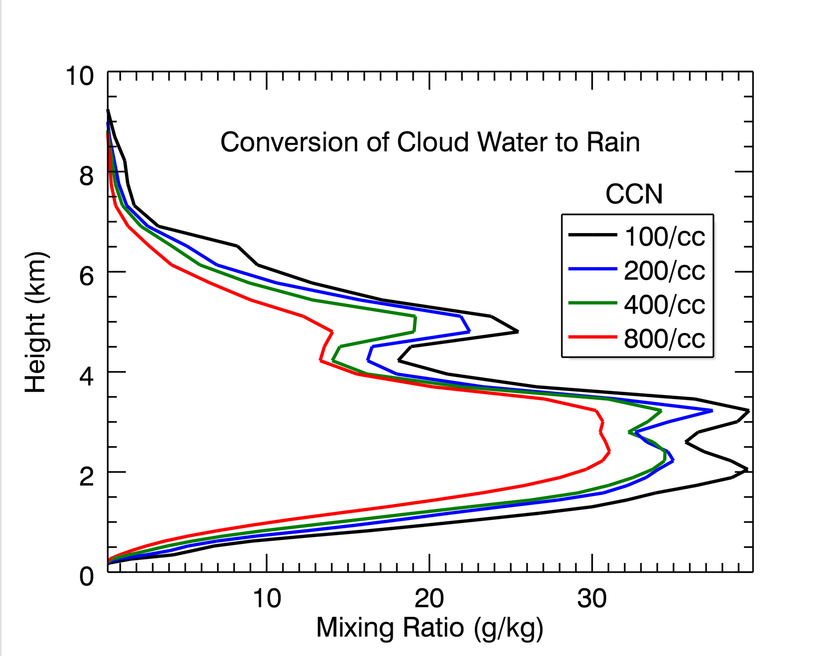


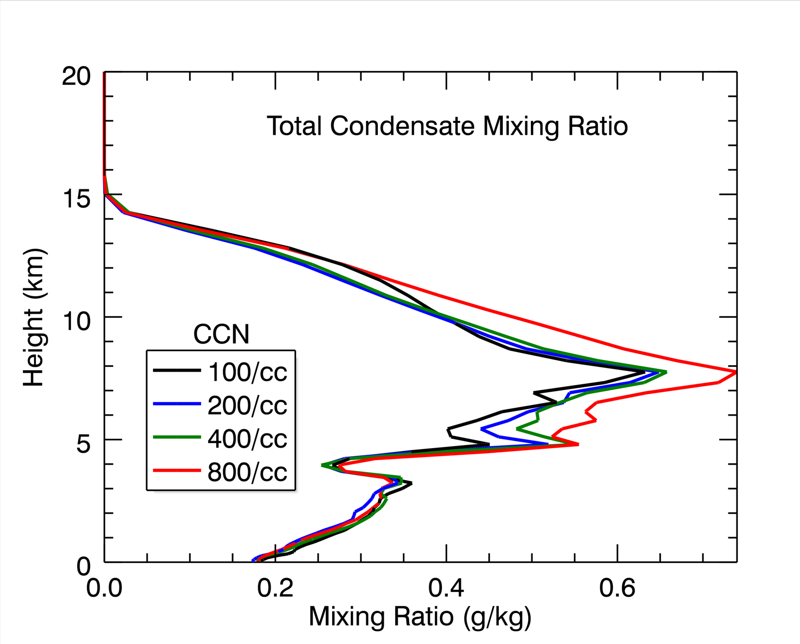
Left: An example of convection as seen by the CloudSat CPR.
Right: An example of convection as represented in the RAMS model. Profiles with a red line underneath are those classified as "deep convection".
Deep convection was chosen using the following definition:

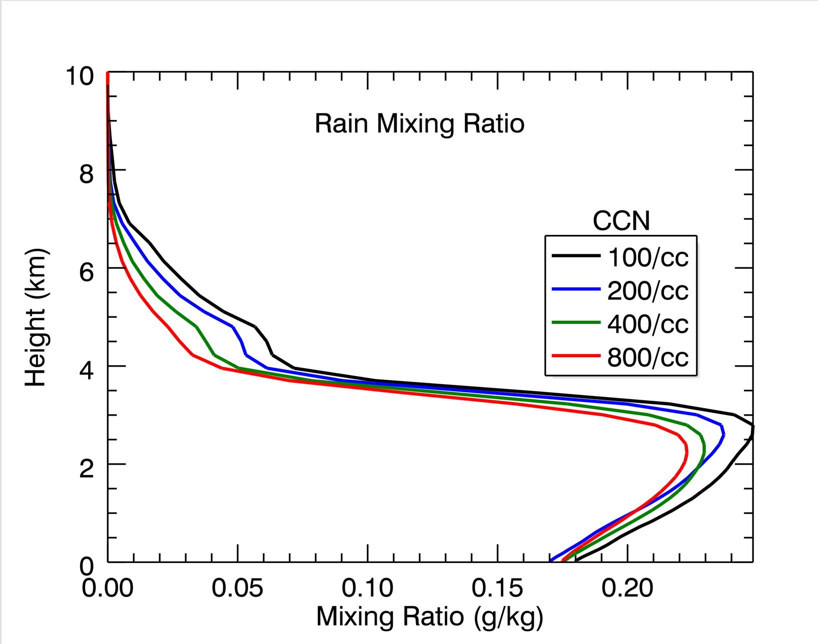
- Points with a mixing ratio of cloud hydrometeors greater than 0.01 g/kg are considered "cloud".
- "Deep convection" was defined as that which has a cloud top greater or equal to 10km and a thickness of at least 8km.

Clouds considered "deep convection" covered 1.4-1-7% of the domain.

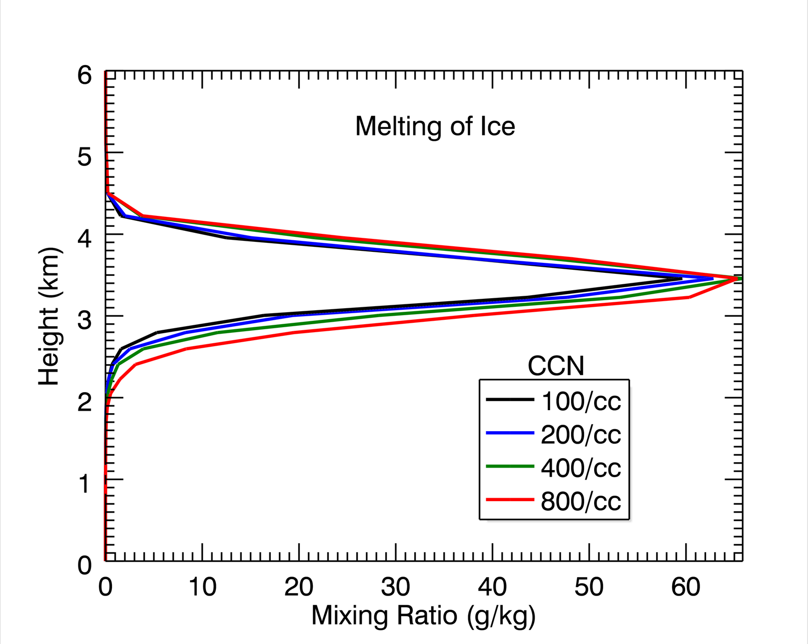


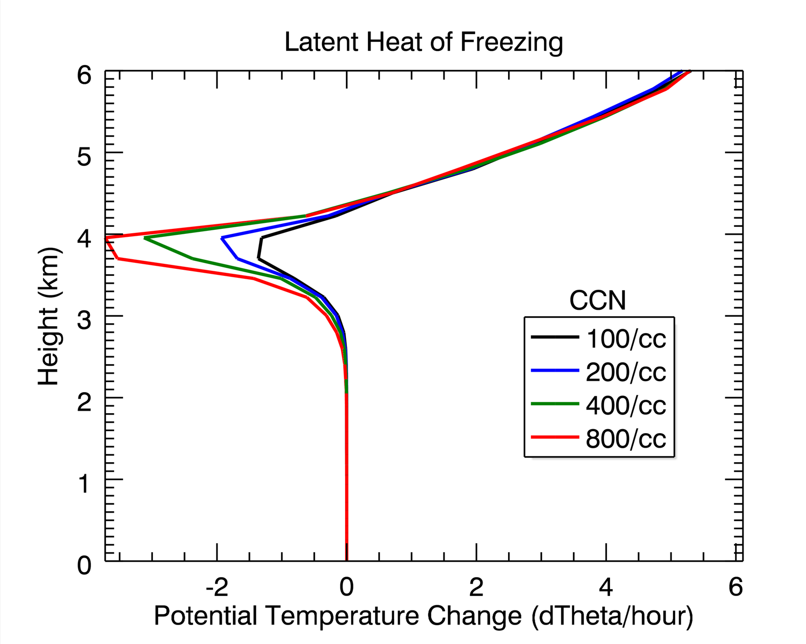




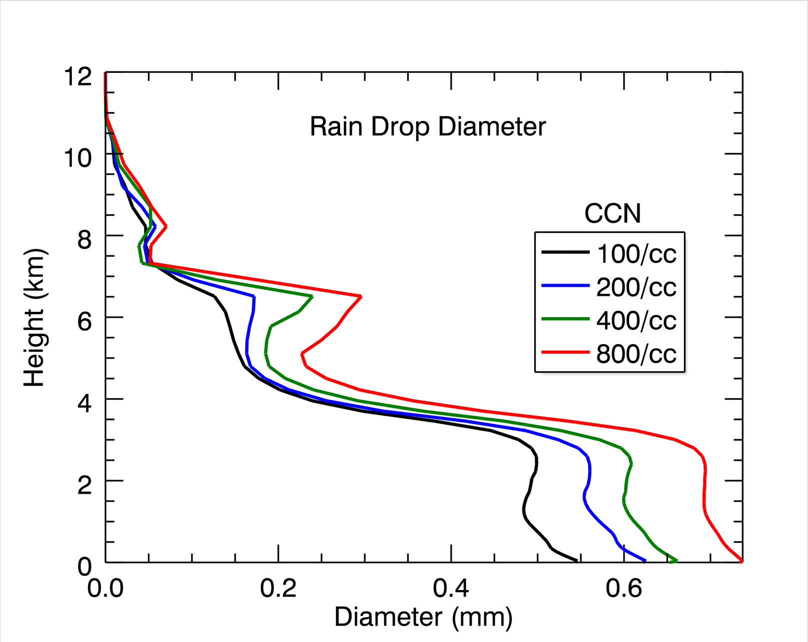


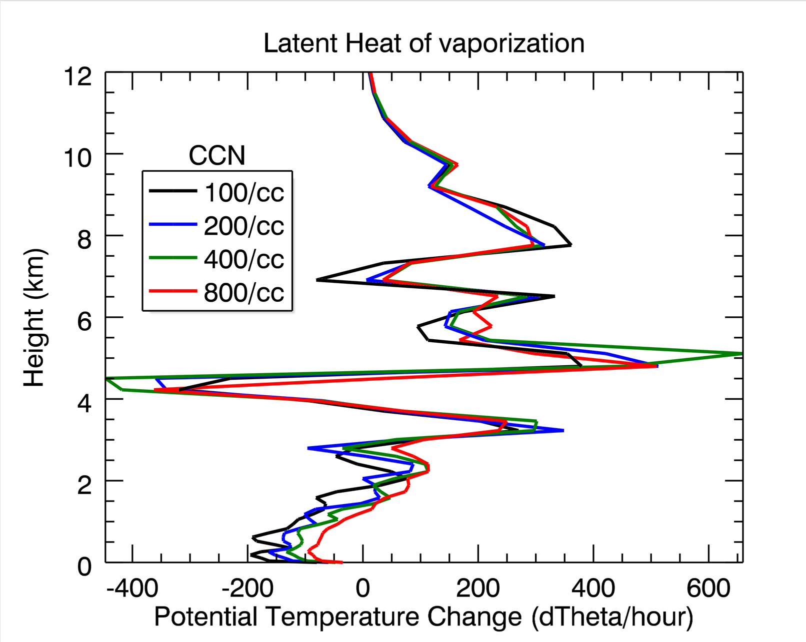
As expected, an increase in aerosol concentration leads to an increase in cloud droplet number concentration. The sizes of these drops are smaller, which decreases the efficiency of collision and coalescence. This can be seen in the upper right plot, which shows the microphysical budgeting term describing the mass of water being converted from cloud to rain. It is clear that less rain is being produced in polluted storms. The tendency for polluted storms to contain less rain, however, starts to fall apart near the surface. One possible explanation for this is the fact that the decrease in warm rain leads to a larger mass of both liquid and ice water being retained in the clouds (lower left), which means there is a larger mass of ice hydrometeors that are melting and adding to surface rainfall.





Simulations with higher aerosol concentration have deep convective storms that contain more ice mass. The increase in ice mass is associated with an increase in melting that occurs though a deeper layer (Not shown are the larger hail sizes that exist in polluted storms – hence the hail will fall farther and melt though a deeper layer.) Stronger cooling can be seen near the freezing level in simulations with higher aerosol concentrations which corresponds to this increase in melting.





Deep convective clouds produce less surface evaporation in simulations with higher aerosol concentrations. This is can likely be attributed to the significantly larger rain drop sizes that exist in these environments (seen before in Storer et al. 2010).

Discussion and Future Work

- The first and second aerosol indirect effects are represented well in these simulations. The new microphysical budgeting terms available in the RAMS model, such as the conversion of cloud water to rain shown here, will be a useful tool in understanding exactly how the microphysical processes of deep convective clouds are affected by increasing aerosol concentrations.
- No large differences exist in the average precipitation produced by deep convective storms between runs with different background aerosol concentrations, even though warm rain production is slowed considerably for storms with high concentrations of aerosols available to act as CCN. It is possible that the increase in ice hydrometeors helps to compensate for the loss of precipitation formed by collision/coalescence. This idea is under further investigation.
- There is likely a link between increased rain drop sizes and decreased near-surface evaporation. More work is under way examining the numerous microphysical processes that effect latent heating and changes to buoyancy.

References

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