Aerosol-induced changes in cloud field properties and precipitation of tropical convective clouds

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1. Introduction

The effect of aerosol on deep convective clouds is poorly understood. Aerosol is thought to invigorate deep convective clouds but distinct changes in total precipitation have not been demonstrated. Does this mean that the effect of aerosol on deep convection is negligible? The answer to this question is likely to be no, considering the well-proven aerosol-induced substantial suppression of autoconversion. This implies microphysical compensation processes yield the small change in total precipitation. These compensation processes may involve changes in dynamical processes, affecting cloud field properties and associated spatiotemporal distribution of precipitation.

2. Goals

- Consider aerosol-cloud interactions for a cloud system
- Understand mechanisms controlling aerosol-induced changes in cloud field properties and precipitation in a cloud system comprising multiple clouds.

3. Model

- Goddard Cumulus Ensemble (GCE) model coupled to two-moment microphysics (Tao and Simpson, 1993; Saleeby and Cotton, 2004)

4. Case

- A mesoscale system of deep convective clouds observed during TWP-ICE campaign over Darwin, Australia
- Environmental conditions follow the GCSS specifications

5. Simulations

- 2-D domain: 256 x 20 km^2
- Grid spacings: 500 m (horizontal), 200 m (vertical)
- Two-day duration

PBL aerosol number concentration (cm^{-3})

- Control run: ~ 400
- High-aerosol run: ~ 4000

6. Results

- **Cumulative precipitation (mm)**
  - Control: 88.6
  - High-aerosol: 95.7

This 9% difference in cumulative precipitation is quite small as compared to the 10- fold difference in aerosol concentration between the runs.

- The small difference in cumulative precipitation is closely linked to a significant increase in updraft mass flux (Fig .1)

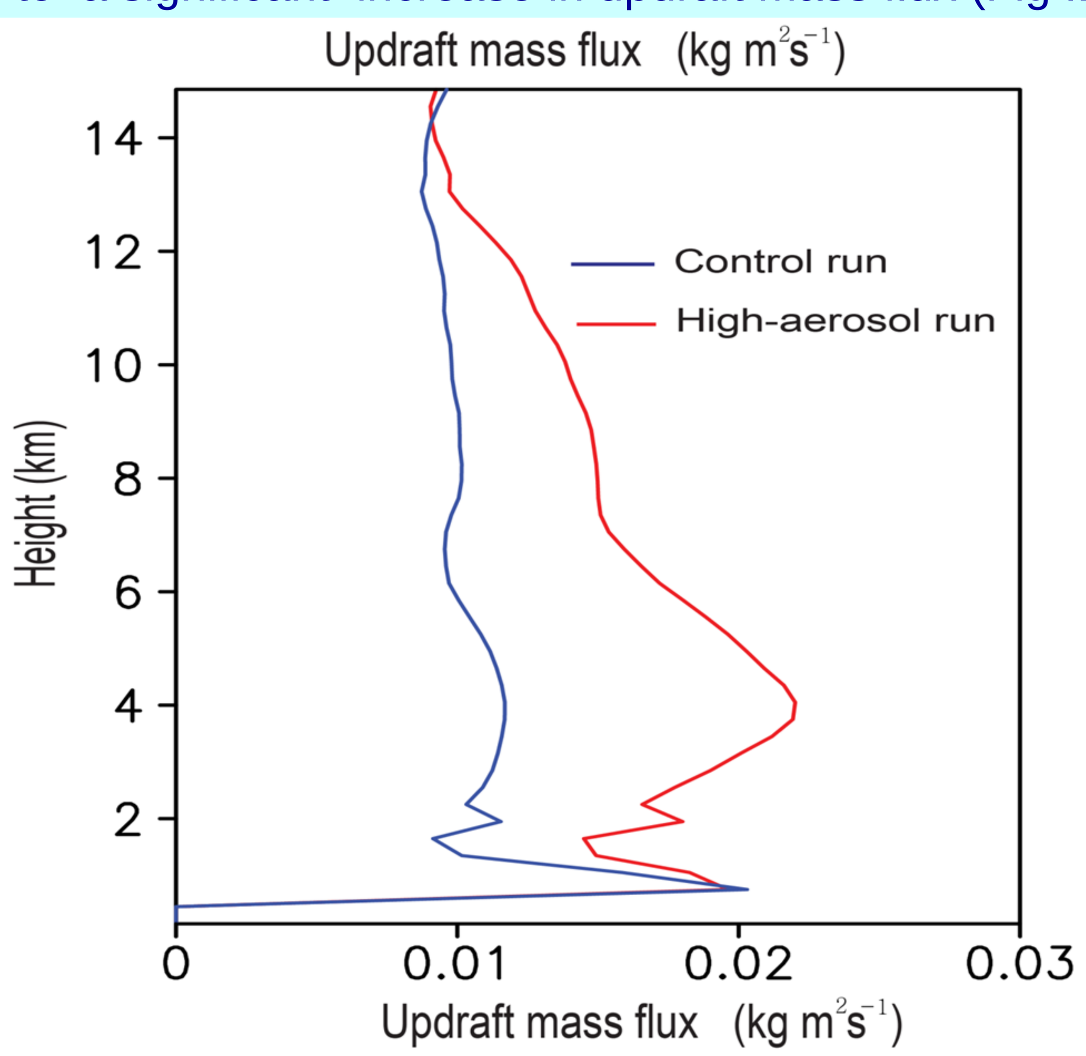

Fig. 1. Vertical distributions of the time- and domain-averaged updraft mass flux

Cloud Response to an Increase in Aerosol

→ More Condensation;
→ More Cloud Liquid; vs. **→ Suppressed Autoconversion**
→ More accretion of cloud liquid

➢Precipitation Budget (High - Control)

△Precipitation ≈ △Autoconversion + △Accretion of cloud liquid

2.84 mm ≈ -21.08 mm + 23.91 mm

Diagram 1. Cloud-process and precipitation-budget responses to aerosol perturbation

- Increasing updraft mass fluxes lead to increases in condensation, cloud liquid and accretion of cloud liquid by precipitation (Diagram 1).
- Increasing accretion of cloud liquid offsets the decreasing autoconversion with increasing aerosol, resulting in the small difference in total precipitation amount (Diagram 1).

WP (LWP+IWP) homogeneity $= \left(\frac{\text{Spatial mean of WP}}{\text{Standard deviation of WP}}\right)^2$

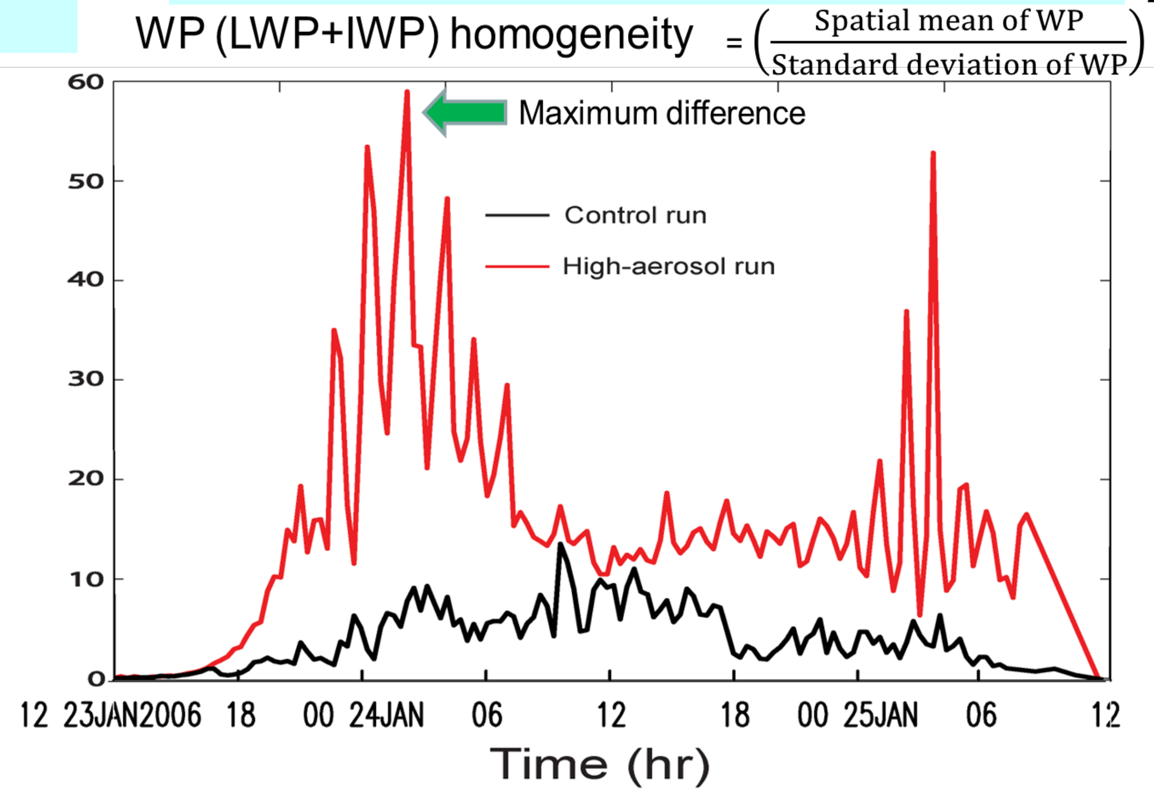

Fig. 2. Time series of WP (water path) homogeneity

- More condensation and stronger updrafts in the high-aerosol run are closely associated with substantial differences in cloud field properties (represented by water path homogeneity) between the runs.
- Much higher homogeneity for the high-aerosol run (Fig. 2).

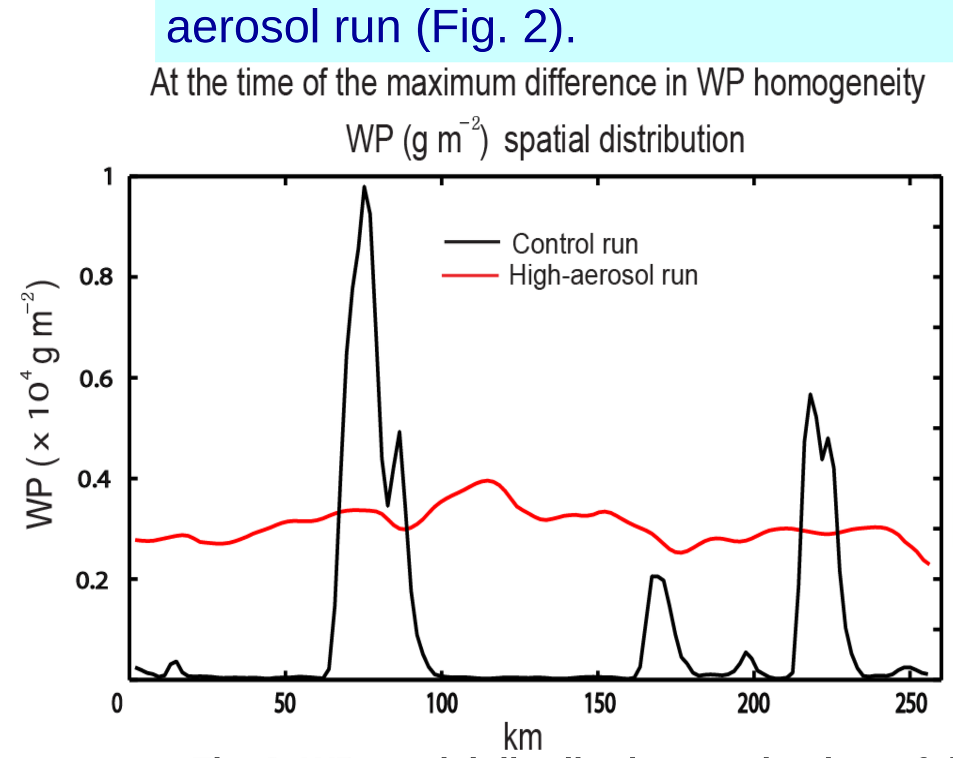

Fig. 3. WP spatial distributions at the time of the maximum difference in the WP homogeneity between the runs

Total cloud population

Control run: 7
High-aerosol run: 22

- High-aerosol run: Larger number of clouds of smaller size occupy the domain with small WP fluctuations relative to the mean (Fig. 3)
- Control run: Smaller number of clouds with larger size occupy a small portion of domain with large WP fluctuations (Fig. 3)
- High-aerosol run: Larger number of clouds involving larger number of updraft cores produce larger domain-averaged updrafts and condensation

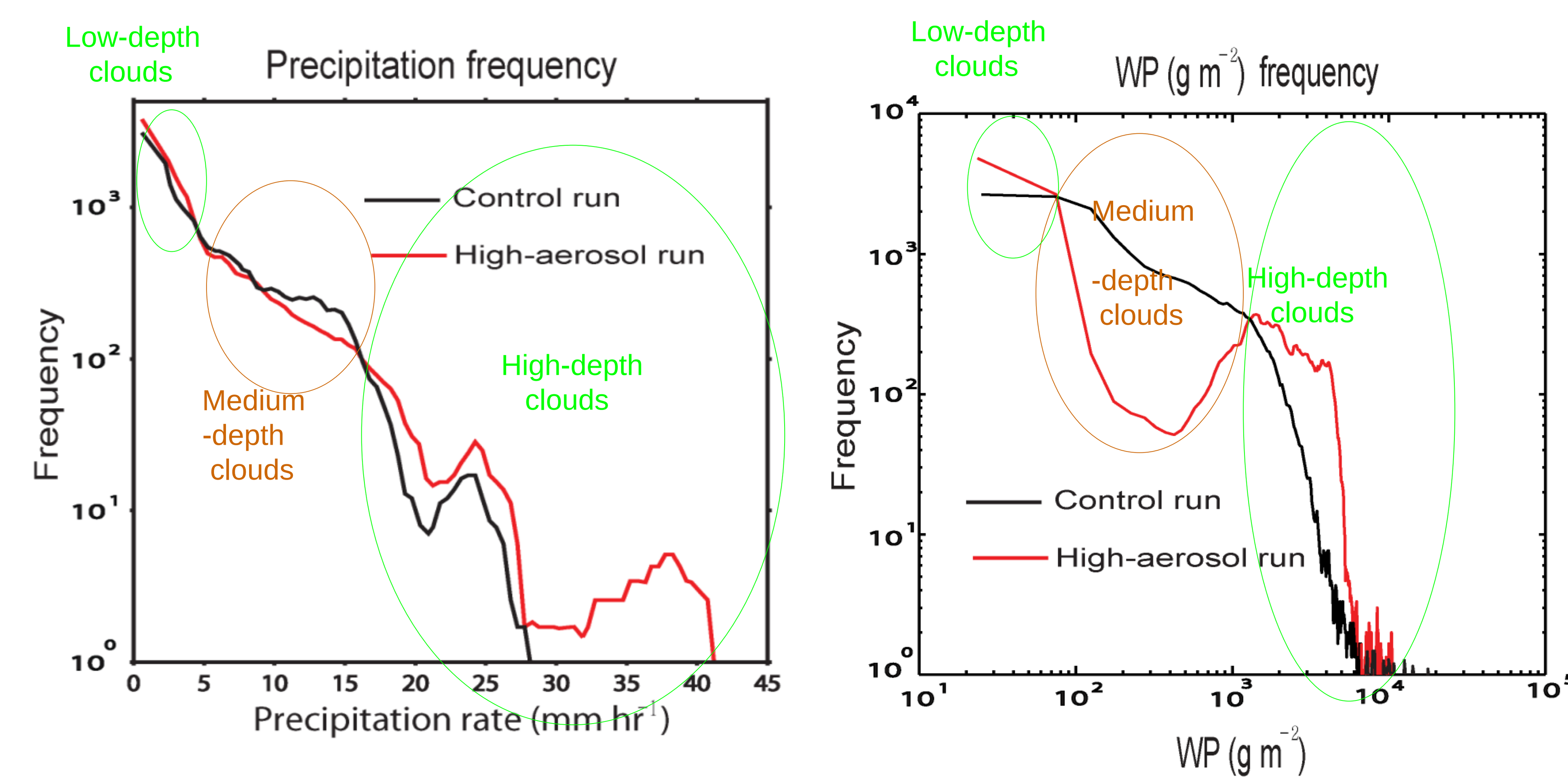

Fig. 4. WP and precipitation frequency distributions averaged over the 2-day simulation period and domain.

- More numerous high-depth clouds (> 9 km) and low-depth clouds (< 4 km) produce more frequent high- and low-level WP and precipitation in the high-aerosol run (Fig. 4)
- Less numerous medium-depth clouds (between 4 and 9 km) produce less frequent medium-level WP and precipitation in the high-aerosol run (Fig. 4)

7. Summary and conclusions

- For the 2-day TWP-ICE simulations, a 10-fold aerosol perturbation has a small effect on total precipitation
- Substantial aerosol-induced enhancement in updrafts and cloud mass, accompanied by significant changes in cloud field properties
  - Increase in WP homogeneity and high and low WP; decrease in moderate WP
  - Increase in light and heavy rain; decrease in moderate rain
  - Increase in cloud population
- The meteorologically-constrained regime achieves approximately the same amount of integrated precipitation
- A by product of this is a substantial change in updraft, cloud mass, and cloud field properties

Lee, S. S., Feingold, G.: Aerosol effects on cloud-field properties of tropical convective clouds, Atmos. Chem. Phys. Discuss., 13, 2997–3029, 2013.
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Tao, W.-T., and Simpson, J.:The Goddard Cumulus Ensemble model. Part I: Model description, Terr. Atmos. Ocean. Sci., 4, 19-54, 1993.