Aerosol effects on cloud field properties and precipitation of tropical convective clouds

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Introduction

- The effect of aerosol on deep convective clouds is poorly understood

- Aerosol is thought to invigorate deep convective clouds (e.g., Koren et al. 2005; Rosenfeld et al. 2008; Li et al. 2012) but distinct changes in *total* precipitation have not been demonstrated

- There must have been microphysical compensation processes, considering the well-proven aerosol-induced autoconversion suppression (e.g, Lee et al., 2011)

- Compensation may affect the spatial/temporal distribution of precipitation

Goals

- Consider aerosol-cloud interactions for a *cloud system* over days
- Explore aerosol-induced changes in organization and precipitation in a cloud system comprising multiple clouds

Model Description

- Goddard Cumulus Ensemble (GCE) model coupled with double-moment microphysics (Saleeby and Cotton, 2004)

- Interactive aerosol

Case

- A mesoscale system of deep convective clouds (reaching the tropopause)

- Based on observations during TWP-ICE Darwin, Australia (Fridlind, 2009)

- Two-day simulations (most convective period)

- Conditions as prescribed by GCSS TWP-ICE case study

Simulations

2-D domain: 256 x 20 km^2

Δx = 500 m and Δz = 200 m

PBL aerosol number concentration:

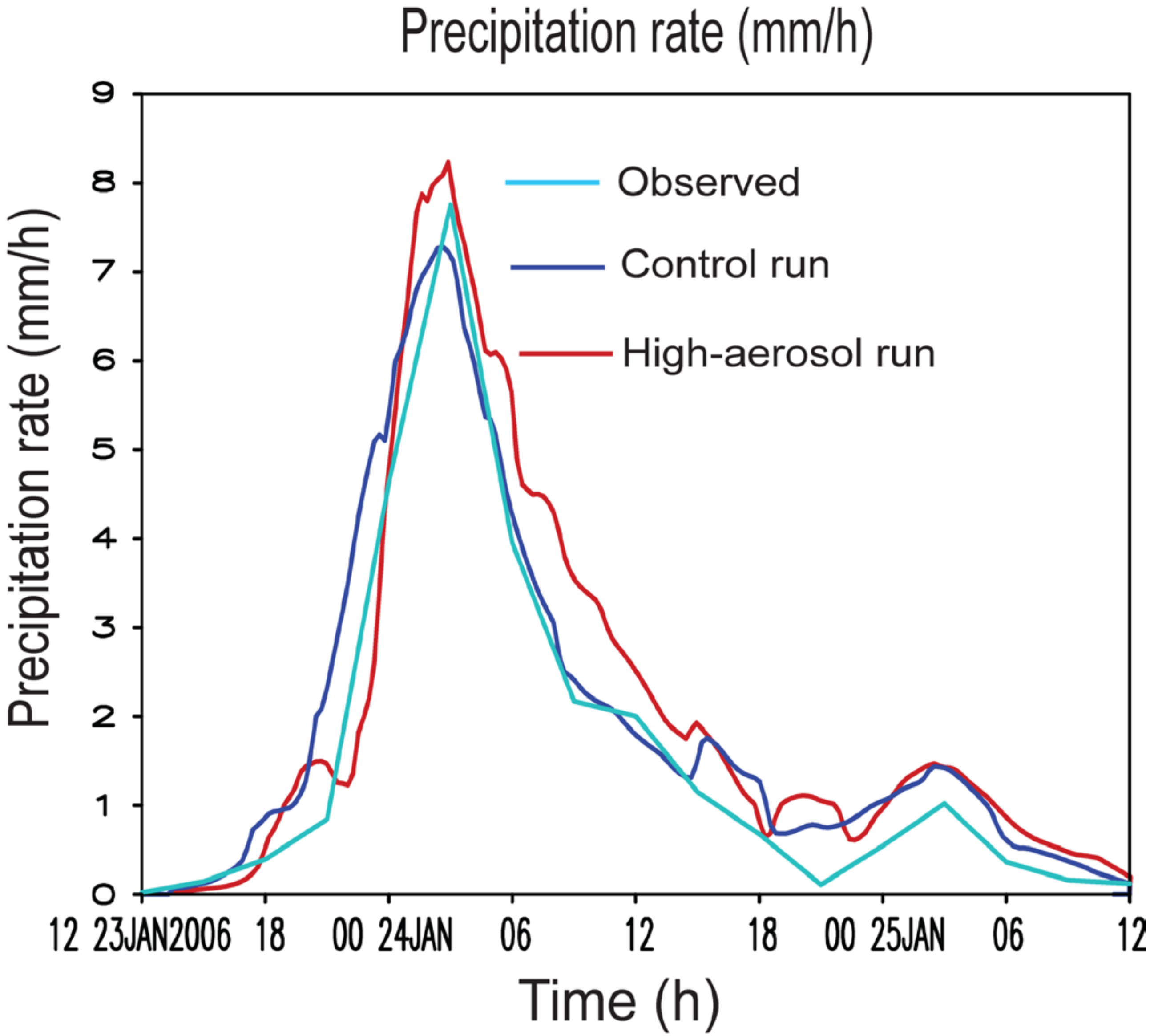
◦ Control run : ~ 400 cm^{-3} (Control)

◦ High-aerosol run: ~ 4000 cm^{-3} (High Aerosol)

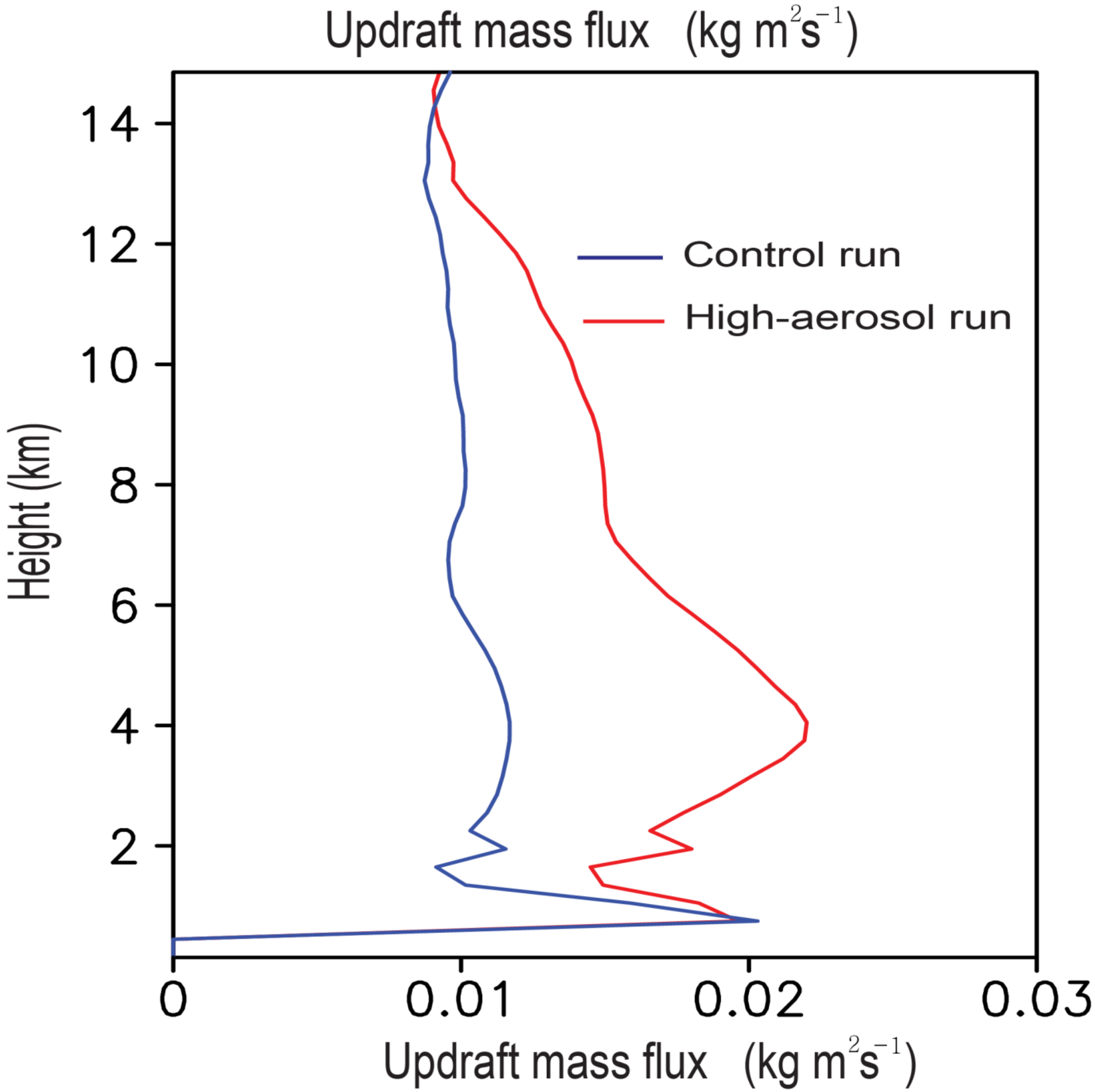
Small Differences in Total Precipitation

Cumulative Precipitation (mm)

Control: 88.6
High-aerosol: 95.7
(9% increase)



Significant Increase in Updraft Mass Flux



Cloud Response to an Increase in Aerosol

↑ Condensation ⟶ ↑ Cloud liquid

∝ Accretion of cloud liquid

⟶ ↑ Accretion of cloud liquid

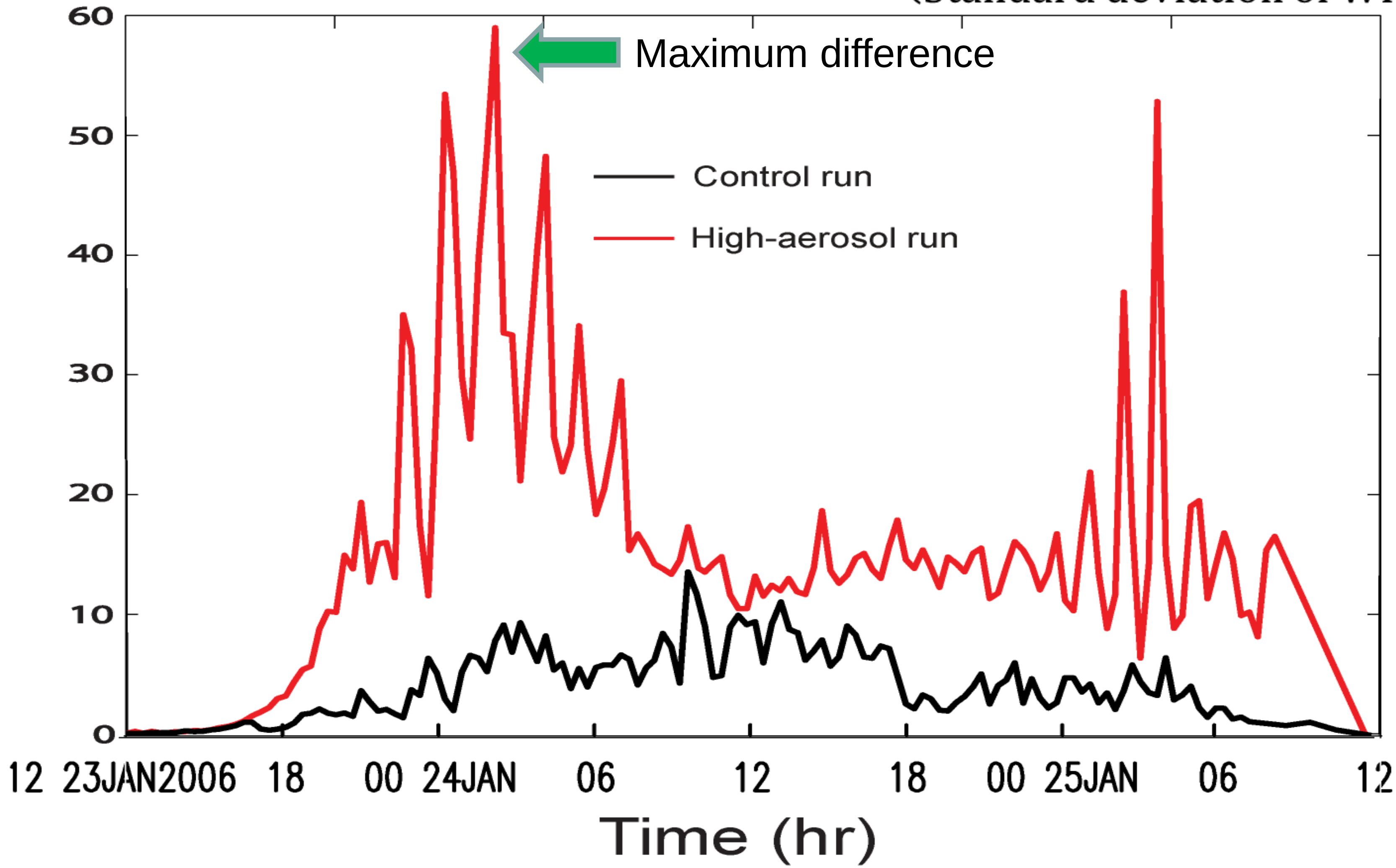
➢ **Precipitation Budget (High - Control)**

△Precipitation ≈ △ Autoconversion +
2.84 mm -21.08 mm

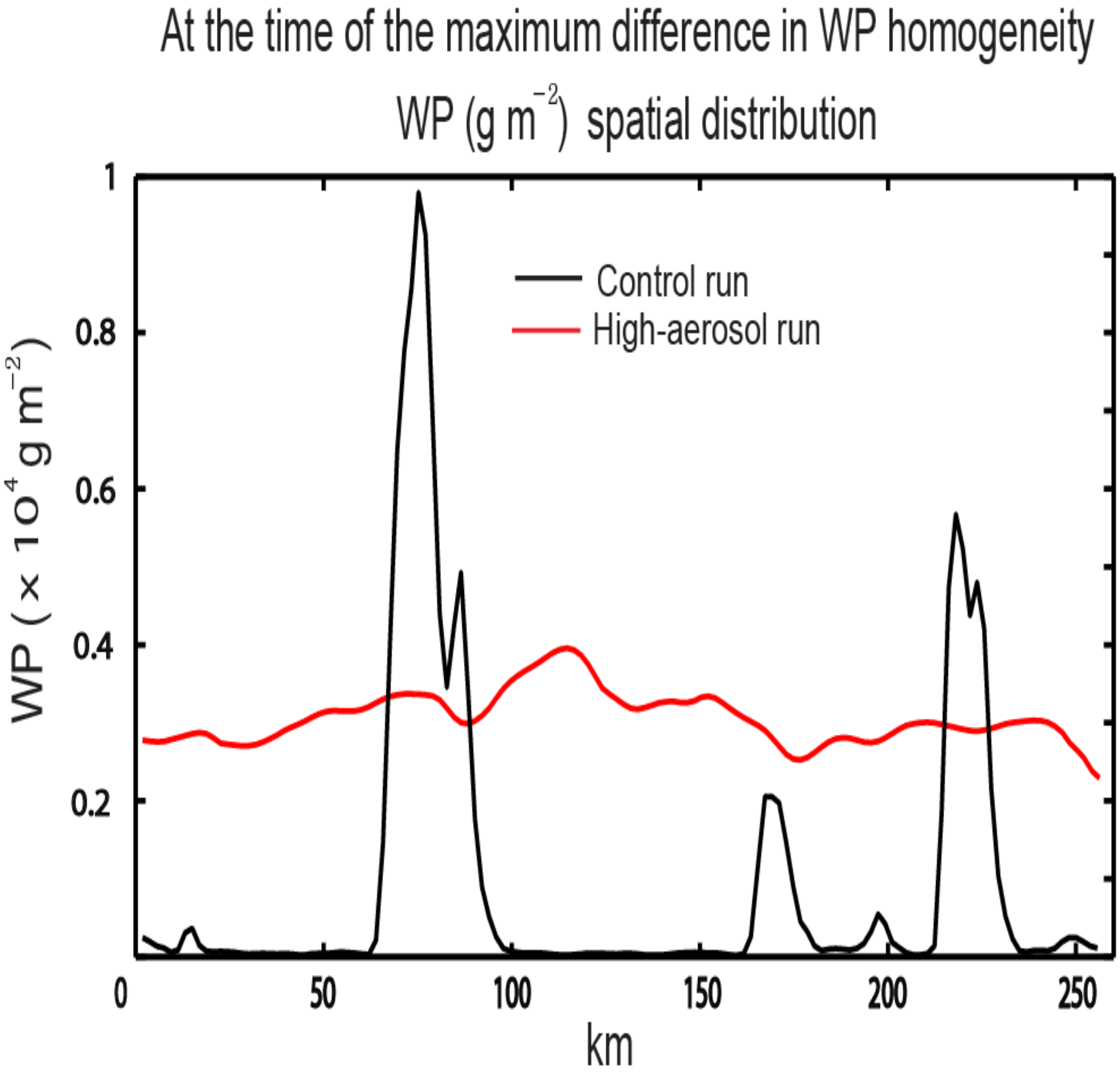
△ Accretion of cloud liquid
23.91 mm

Distinct Differences in Cloud Field Properties

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



Distinct Differences in WP Spatial Distribution

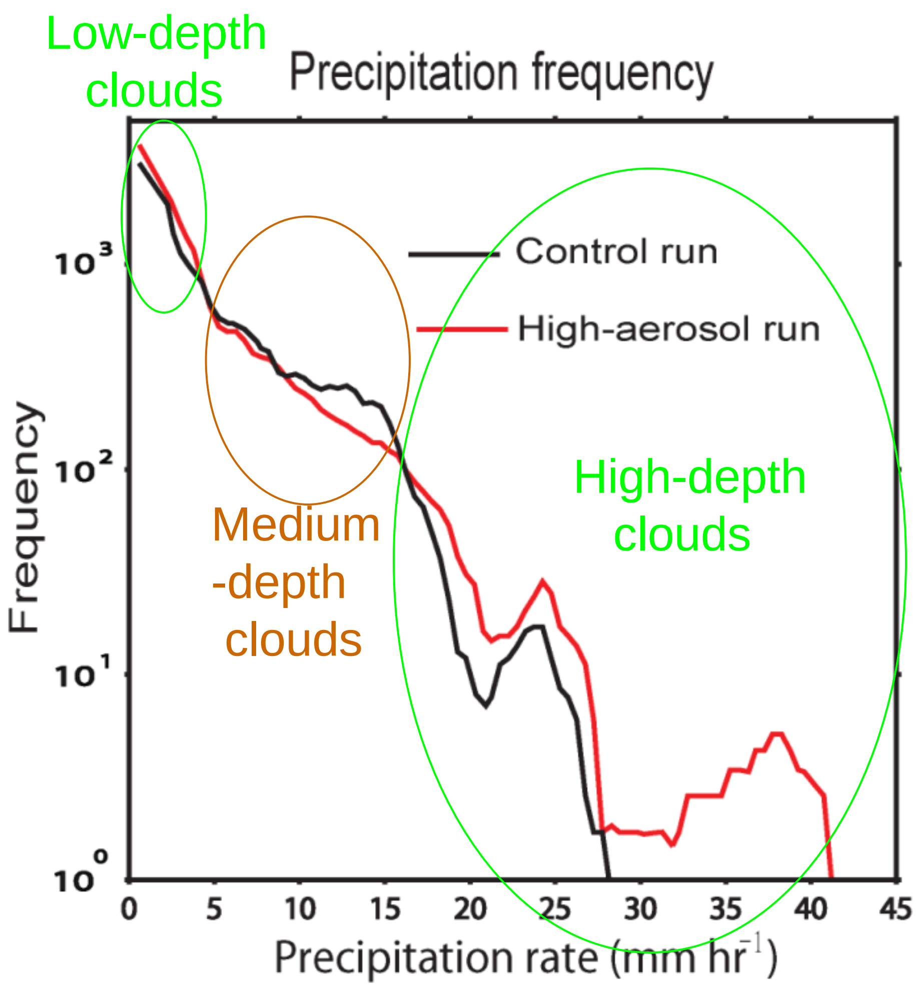


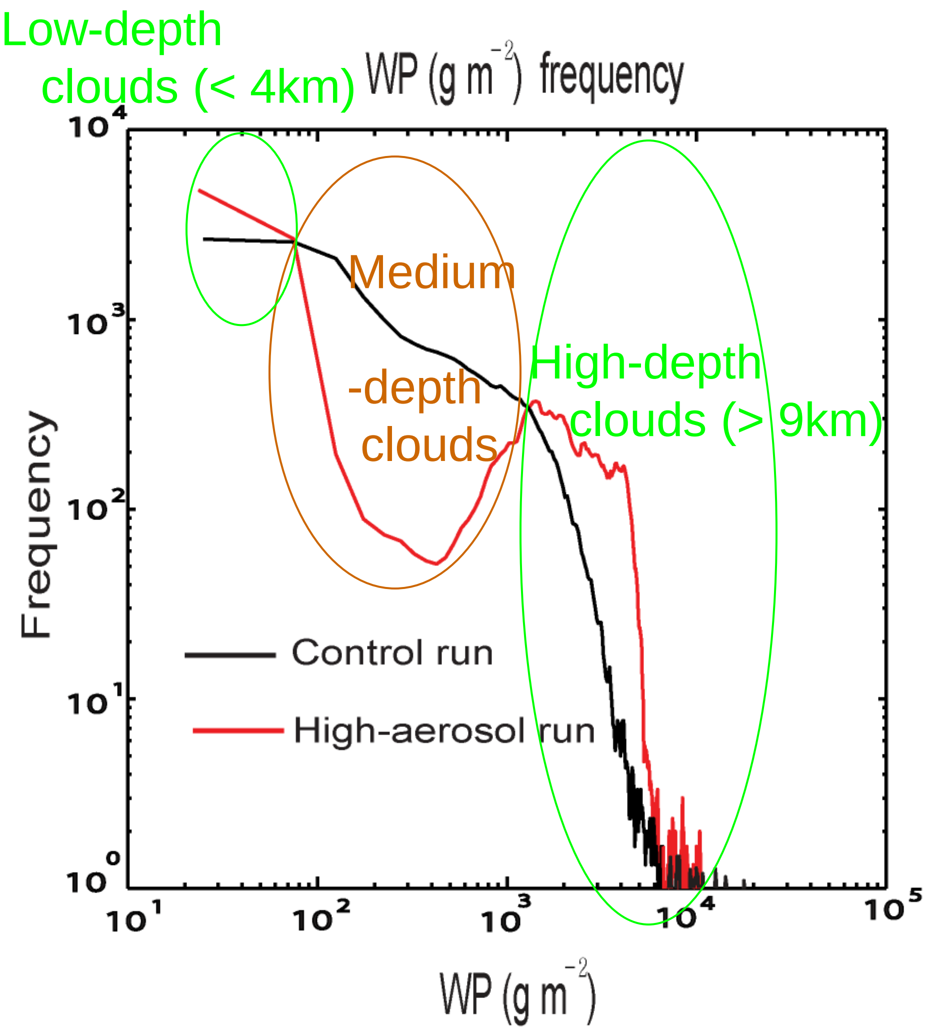
Total cloud population

Control run: 7

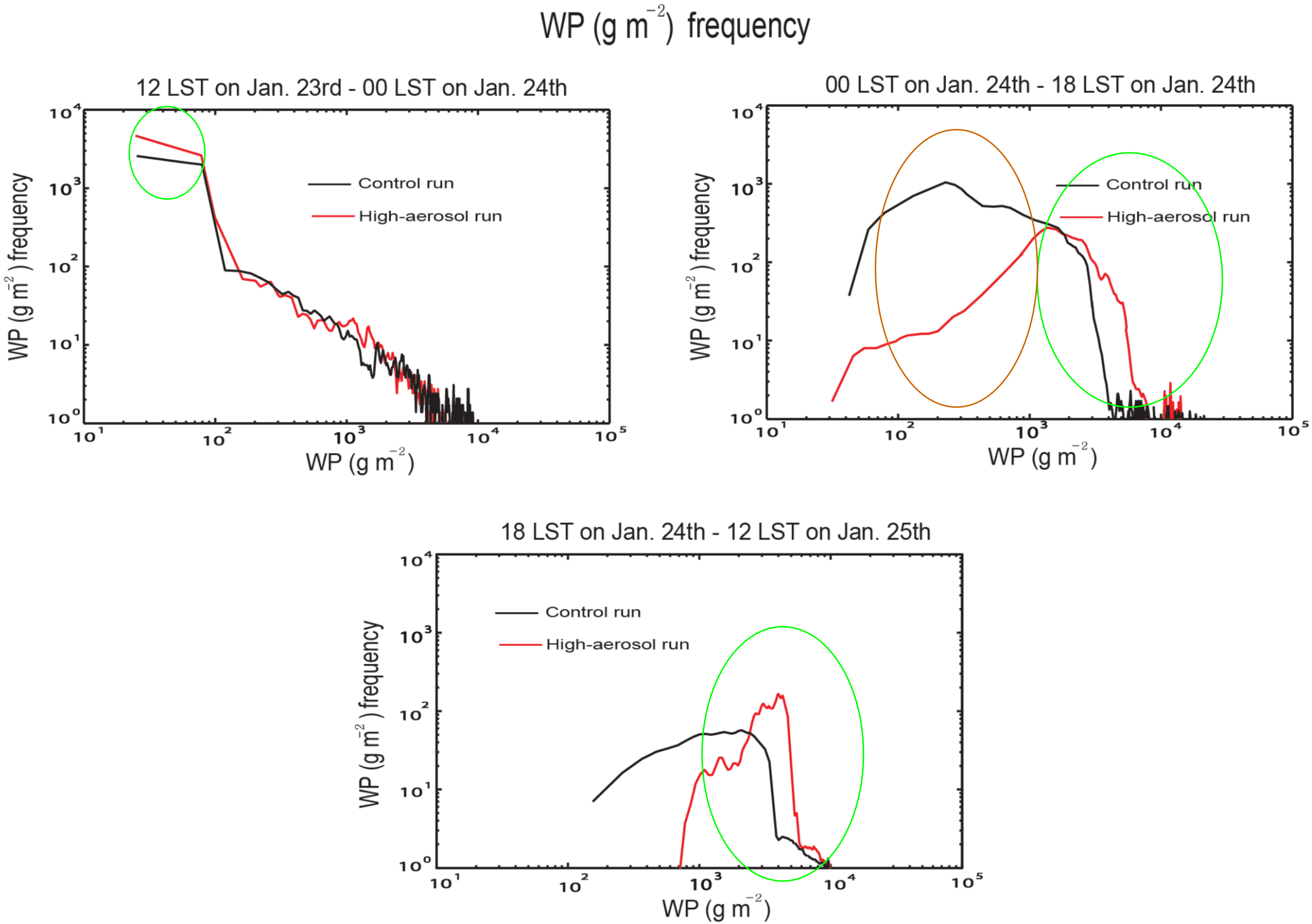
High-aerosol run: 22

Correlation between Precipitation and WP Frequency





Evolution of the Differences in WP Frequency



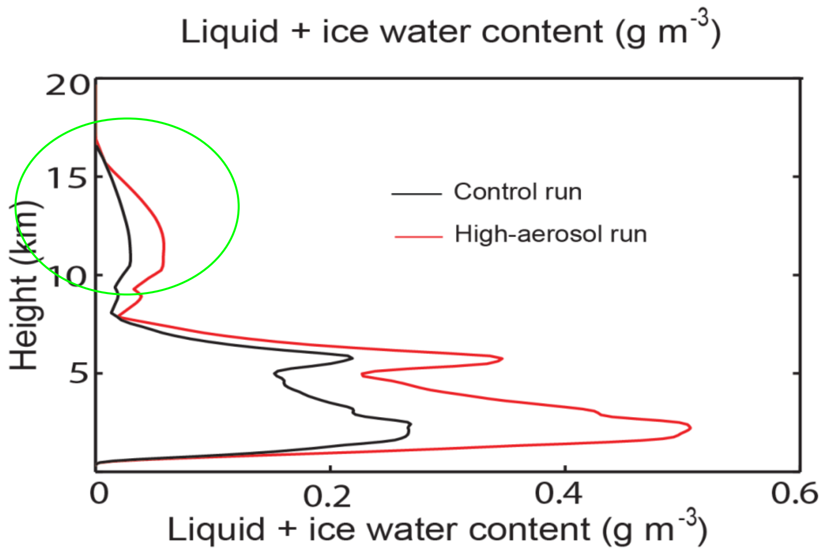
Discussions and Conclusions

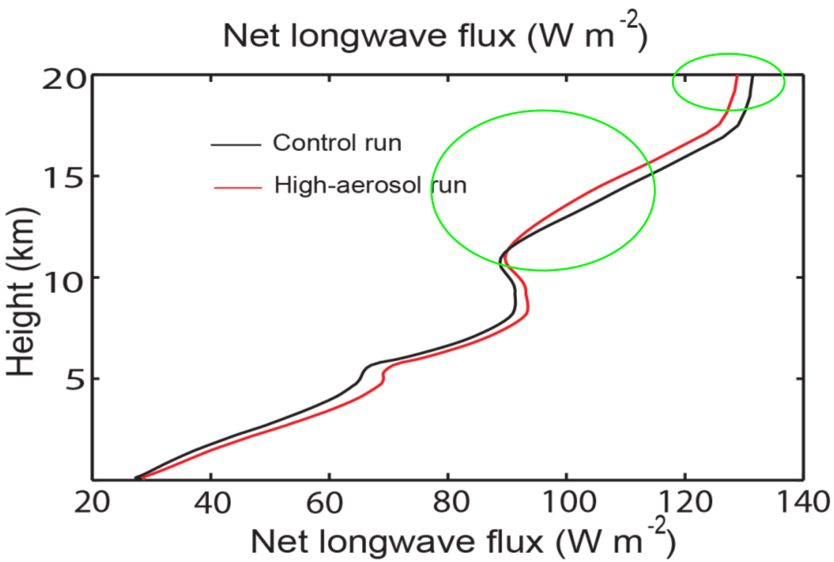
- ➢ For 2-day TWP-ICE simulations a 10-fold aerosol perturbation has a small effect on total precipitation (+9%)
- ➢ Substantial aerosol-induced enhancement in updrafts and cloud mass
- ➢ This enhancement accompanies significant changes in cloud field properties
  - Increase in WP homogeneity and in high and low WP; decrease in moderate WP
  - Increase in light and heavy rain; decrease in moderate rain
  - Increase in cloud population
- ➢ A meteorologically constrained cloud system achieves the approximately same amount of integrated precipitation

Substantial Offset of Aerosol-Induced Change in Solar Radiative Fluxes by That in Longwave Fluxes

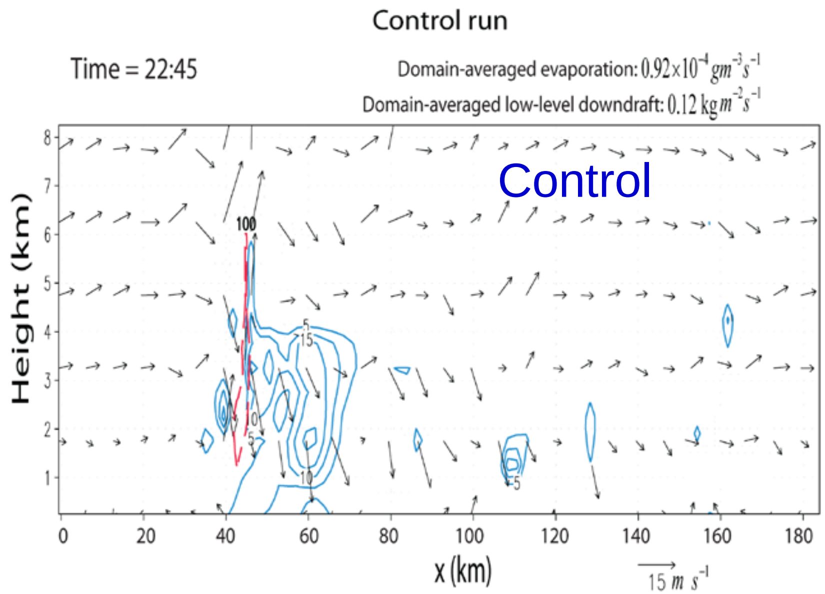
Solar (longwave) radiative fluxes at the top (W m^{-2})

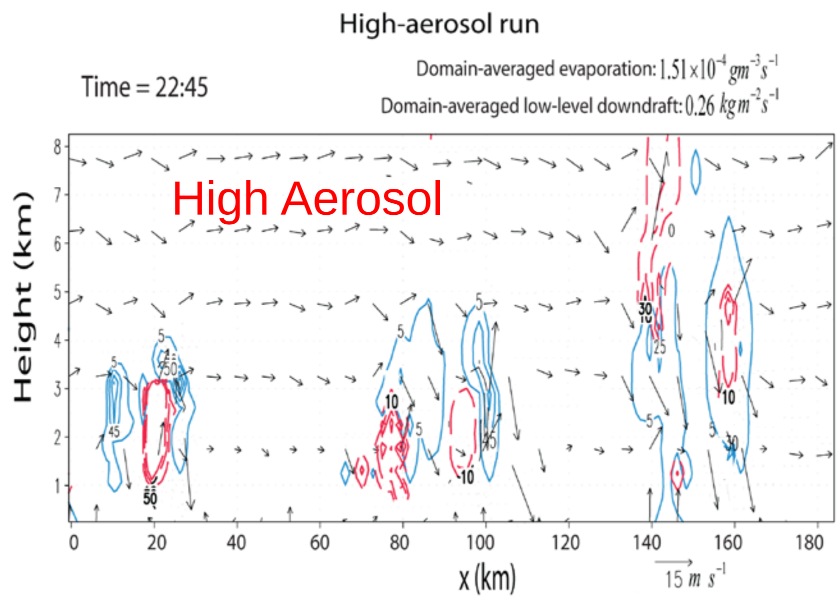
Control run: -118.5 (133.2)
High-aerosol run: -109.2 (129.5)





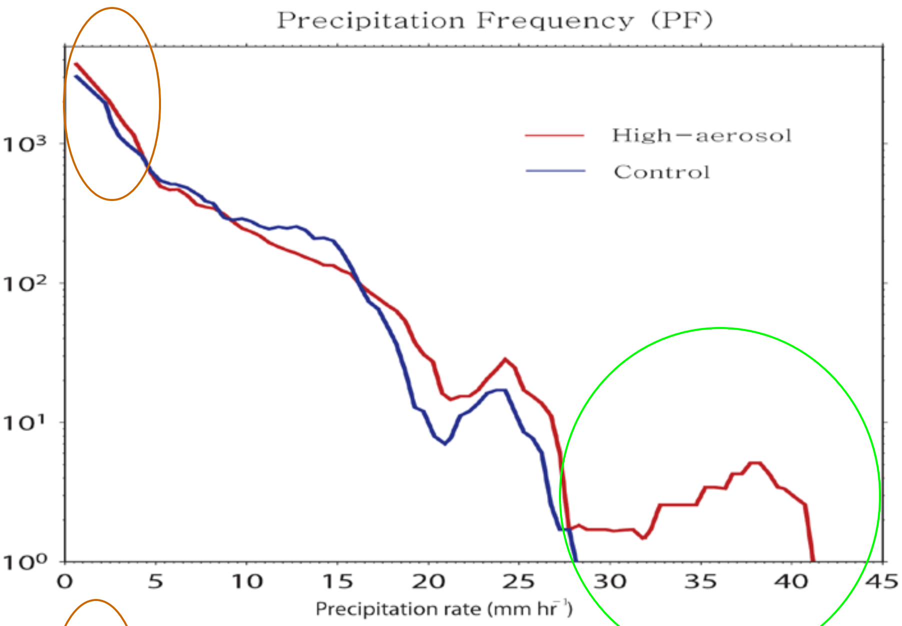
Distinct Differences in Cloud Field Properties

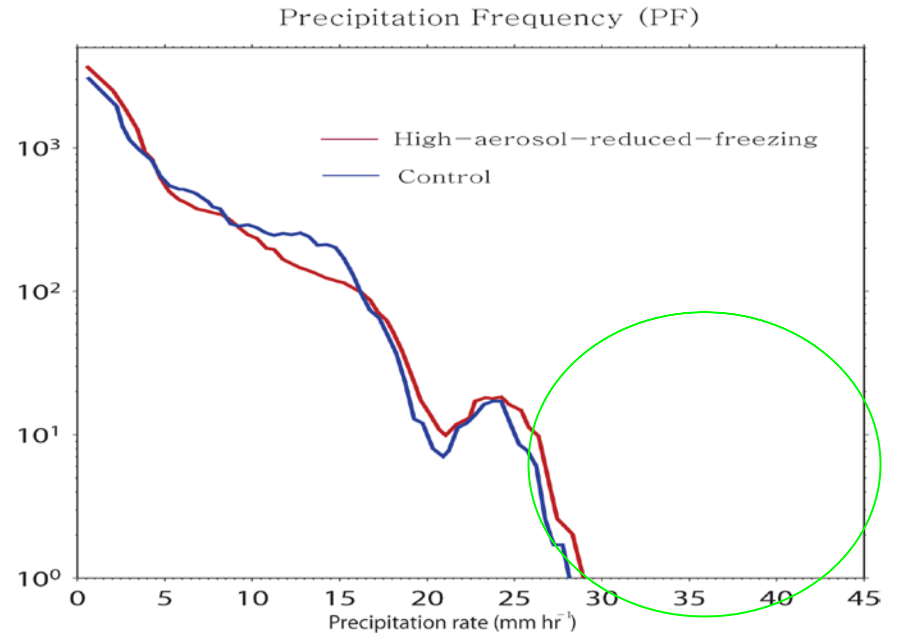


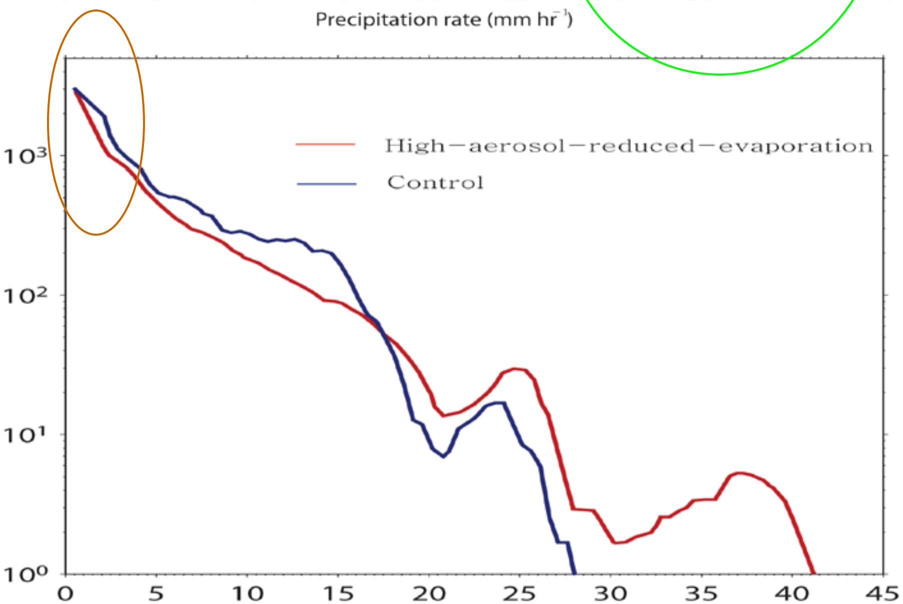


Condensation/evaporation rates and wind flow

Precipitation Frequency







Precipitation rate, mm h $^{-1}$

Cumulative precip (mm) (cloud radius, km)

- Control: 88.6 (7.1 km)
- High-aerosol: 95.7 (5.6 km)
- High-aerosol-reduced-: 80.7 (7.5 km) evaporation
- High-aerosol-reduced-: 94.2 (5.3 km) freezing

Discussions and Conclusions (I)

- For 2-day TWP-ICE simulations a 10-fold aerosol perturbation has a small effect on total precipitation (+9%)
- More significant changes to cloud system organization and the frequency distribution of rain rates
  - High aerosol simulations have larger number of small clouds (delayed autoconversion, more evaporation, stronger gustiness)
  - Aerosol-enhanced evaporation creates smaller clouds with lower rainrates
  - Aerosol-induced increase in freezing causes intermittent heavy precipitation, however, its impact on cloud-system organization is negligible
- We stress the importance of considering aerosol-precipitation interactions in cloud systems of long duration

- For 2-day TWP-ICE simulations a 10-fold aerosol perturbation has a small effect on total precipitation (+9%)
- Substantial aerosol-induced enhancement in updrafts and cloud mass
- This enhancement accompanies significant changes in cloud field properties
  - Increase in WP homogeneity and in high and low WP; decrease in moderate WP
  - Increase in light and heavy rain; decrease in moderate rain
  - Increase in cloud population
- A meteorologically constrained cloud system achieves the approximately same amount of integrated precipitation
- By-products of this system's effort for the achievement are substantial changes in updrafts, cloud mass and cloud field properties