Cloud system-resolving model simulations of aerosol indirect effects on tropical deep convection and its thermodynamic environment

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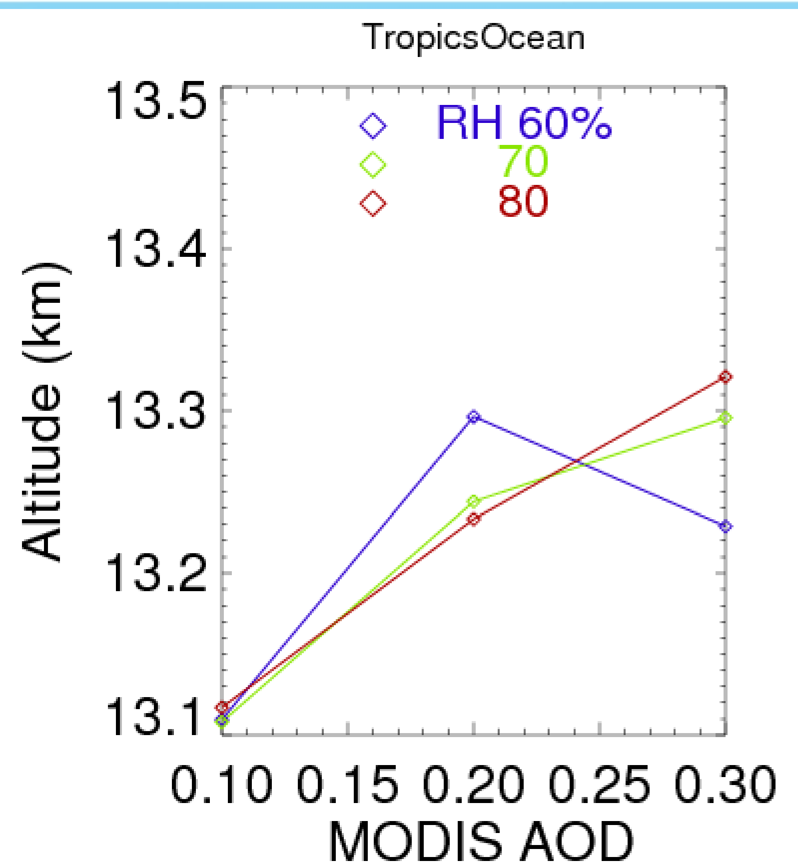
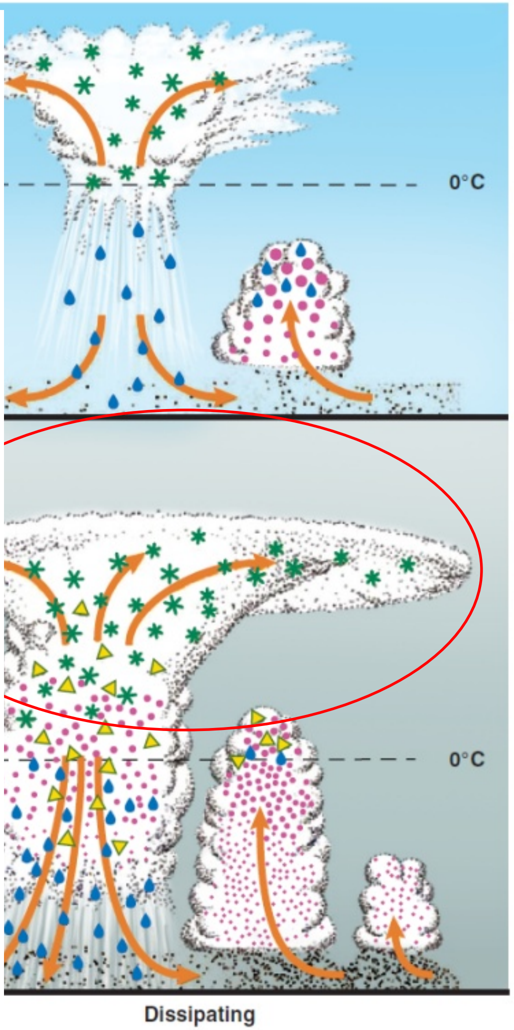
Rosenfeld et al.
Science, 2008

Koren et al. (2010)



Massie et al. (2011), JGR, submitted



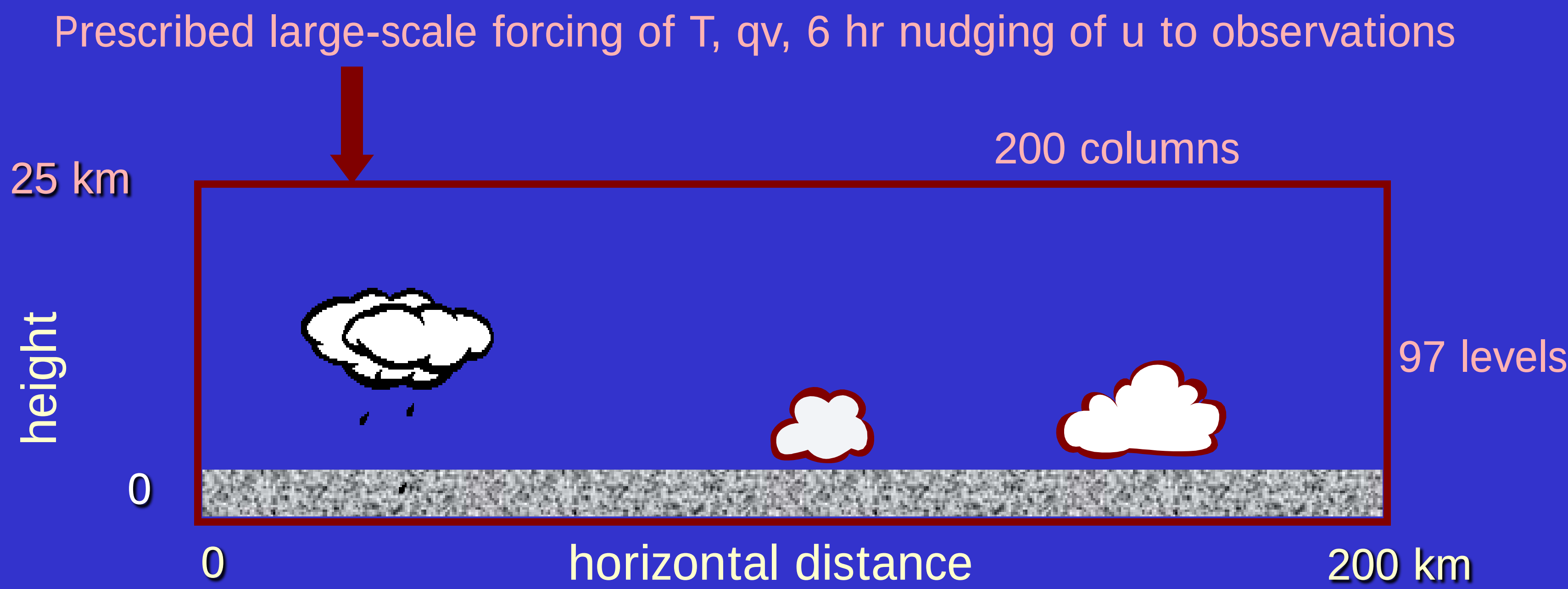
Example of hypothesized aerosol-microphysics-dynamics interactions in deep convection

What are impacts over longer timescales, where interactions between clouds and their environment are key?

7.5-day, 2D simulations of TWP-ICE, using observed large-scale forcing

(Morrison and Grabowski, 2011, ACP, submitted)

- similar setup to ARM/GCSS CRM intercomparison (Fridlind et al., in prep)



horizontal grid spacing of order 1 km

Surface temperature = 29° C

Numerical model:

Dynamics: 2D super-parameterization model (Grabowski 2001)

Microphysics: two-moment bulk scheme (Morrison and Grabowski 2007; 2008a, 2008b)

Radiation: NCAR’s Community Climate System Model (CCSM) (Kiehl et al 1994) in the Independent Column Approximation (ICA) mode

200 x 25 km domain and 97 stretched levels

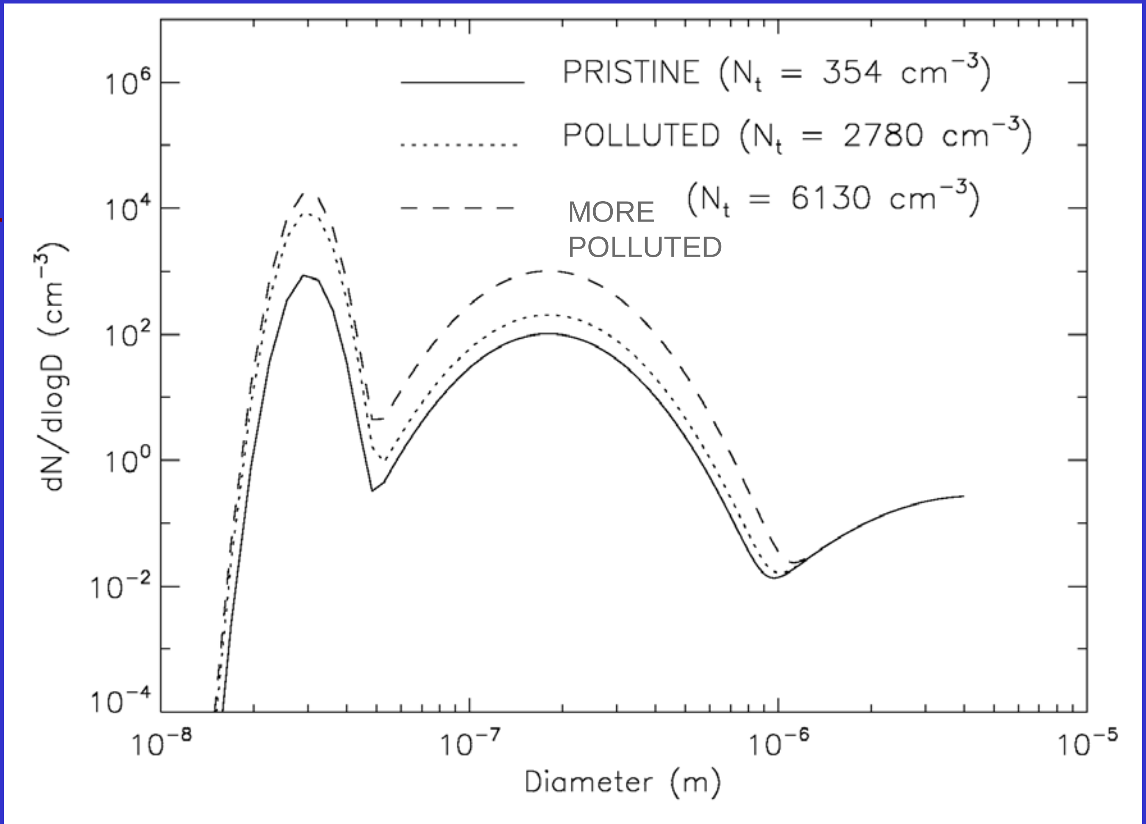
Note: only last 6 days are analyzed, giving 1.5 days of spinup…

• **BASE** → Baseline configuration (Morrison and Grabowski 2007; 2008a,b)

• **FRZ** → Heterogeneous droplet freezing of Bigg (1953) replaced by Barklie and Gokhale (1959), ~ factor of 10-100 reduction in freezing rate

• **GRPL** → Graupel density decreased by ~ factor of 3

• **Resolution** → Horizontal gridlength varied from 2 km to 500 m



Aerosol specification, similar to Fridlind et al. (2011 in prep)

No impact of aerosol on heterogeneous IN, no direct aerosol effect

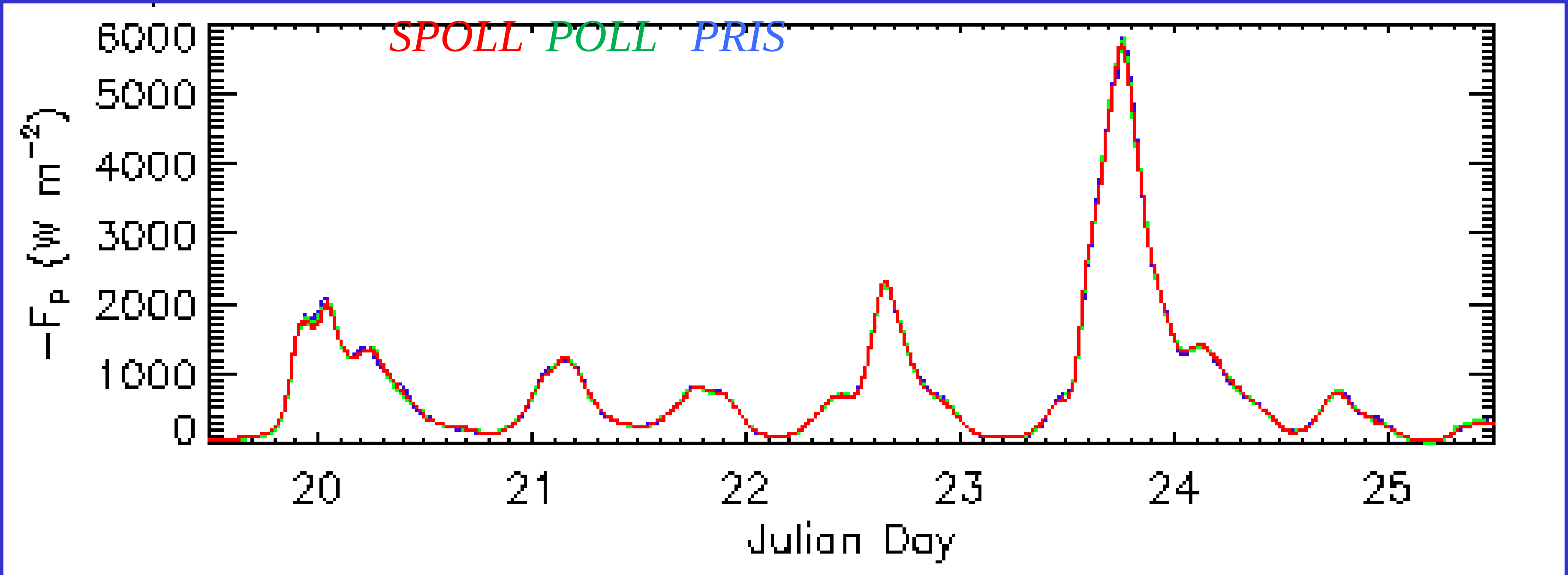
What is the role of internal model variability in driving differences between simulations?

• Tests w/ small perturbations to initial/boundary conditions or tiny random noise indicate large variability for parameters like TOA radiative fluxes, *even when averaged over 6-days.* This variability overwhelms any aerosol effect for a given pair of realizations!!!

•We therefore run large-member (240) ensembles to determine a statistical significant aerosol effects.

• **Impact on surface precipitation (baseline)**

- limited impact of aerosols on forcing terms in the bulk moist static energy budget (tropospheric radiative cooling, surface fluxes) and rapid convective adjustment mean there is little change in surface precipitation, either by aerosols, microphysics, or among different realizations → largely constrained by prescribed large-scale forcing and SST



Budget thinking…

Rapid convective adjustment maintains consistency between s and q through Q_c / Q_{pre}

$$\cancel{\frac{\partial[s]}{\partial t}} + l.s.\cancel{adv} / \cancel{div}([s]) - RAD - SH = Q_c$$

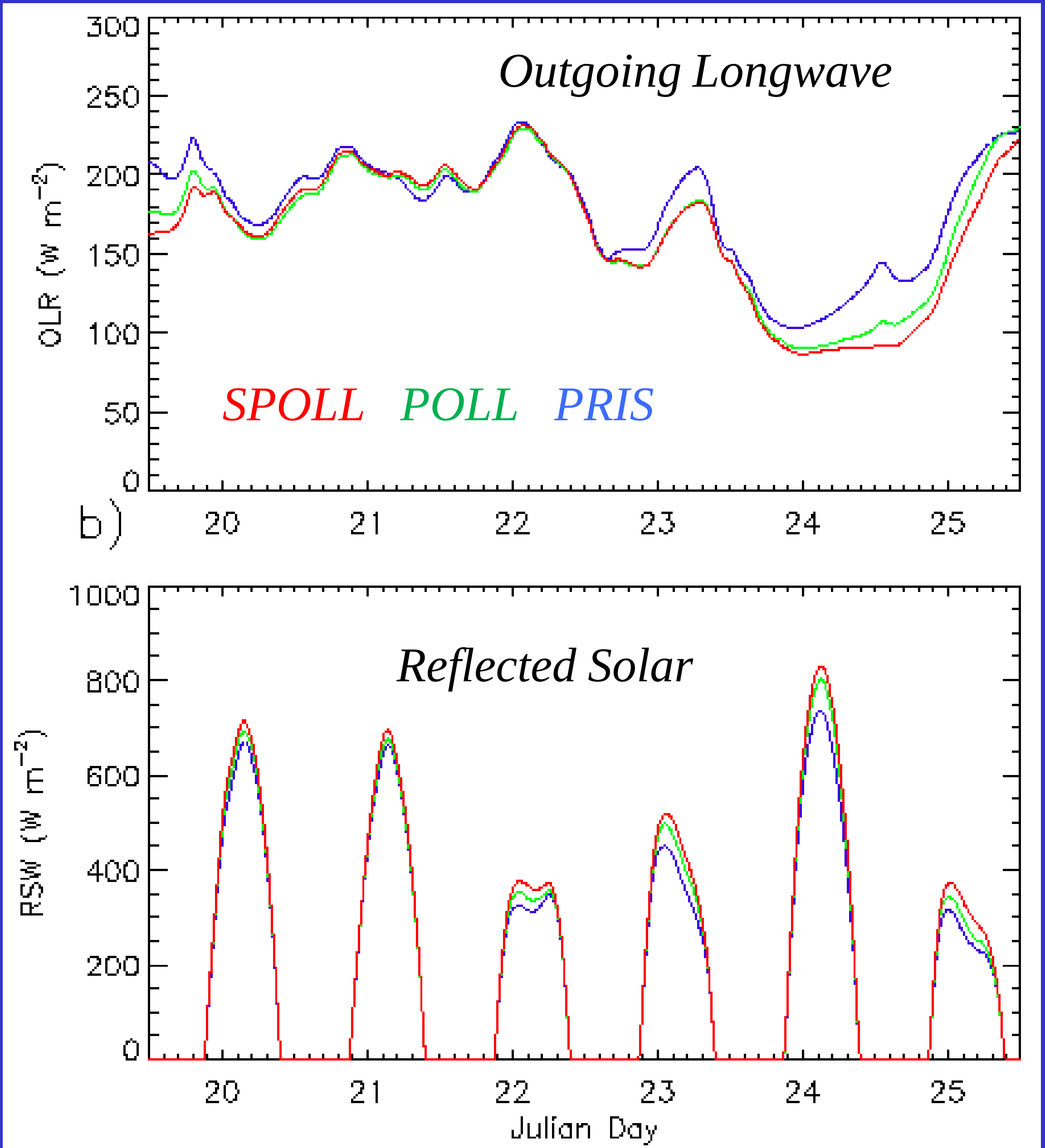
$$= -\left(\cancel{\frac{\partial[q]}{\partial t}} + l.s.\cancel{adv} / \cancel{div}([q]) - LH \right) = -Q_{pre}$$

In convective-radiative equilibrium

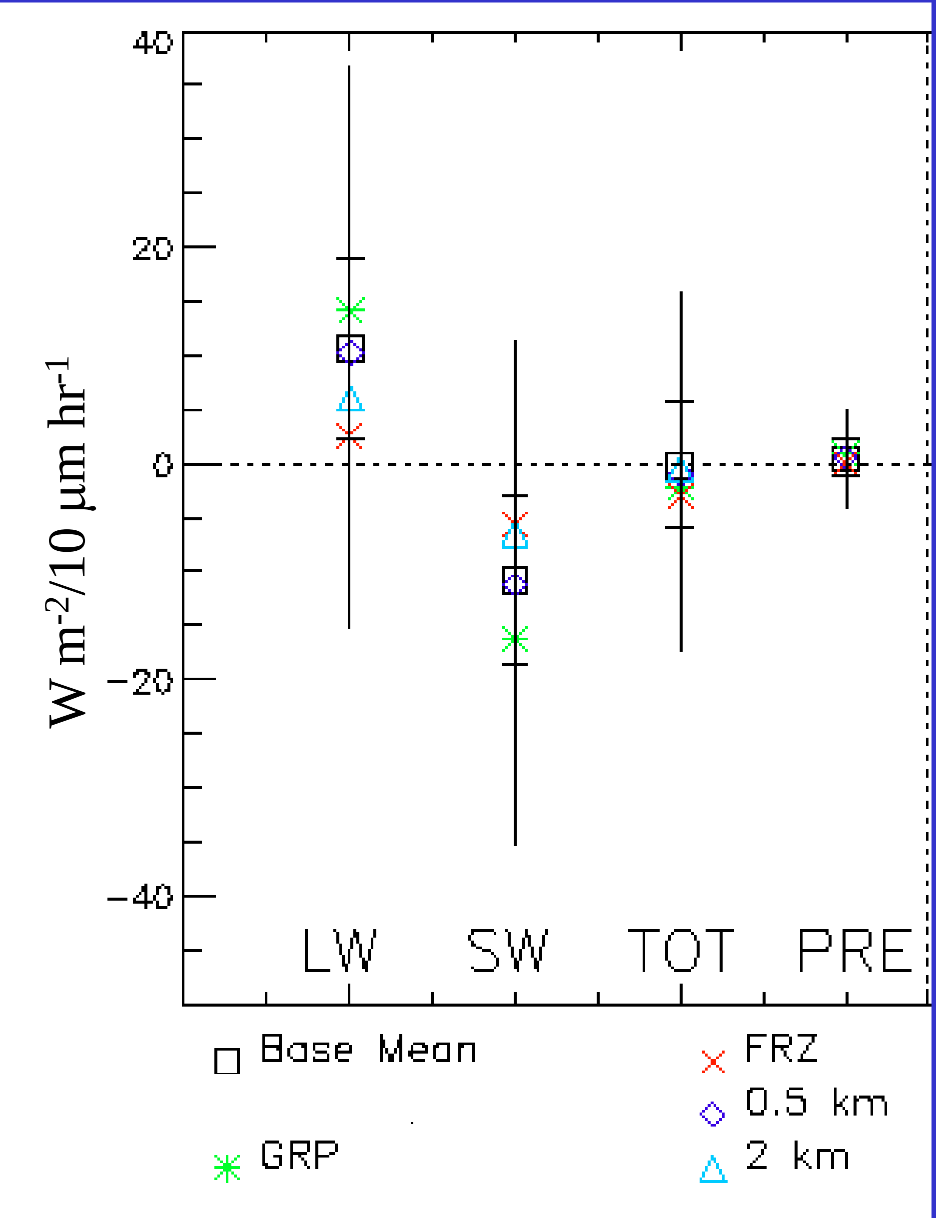
(Grabowski 2006; Grabowski and Morrison 2010):

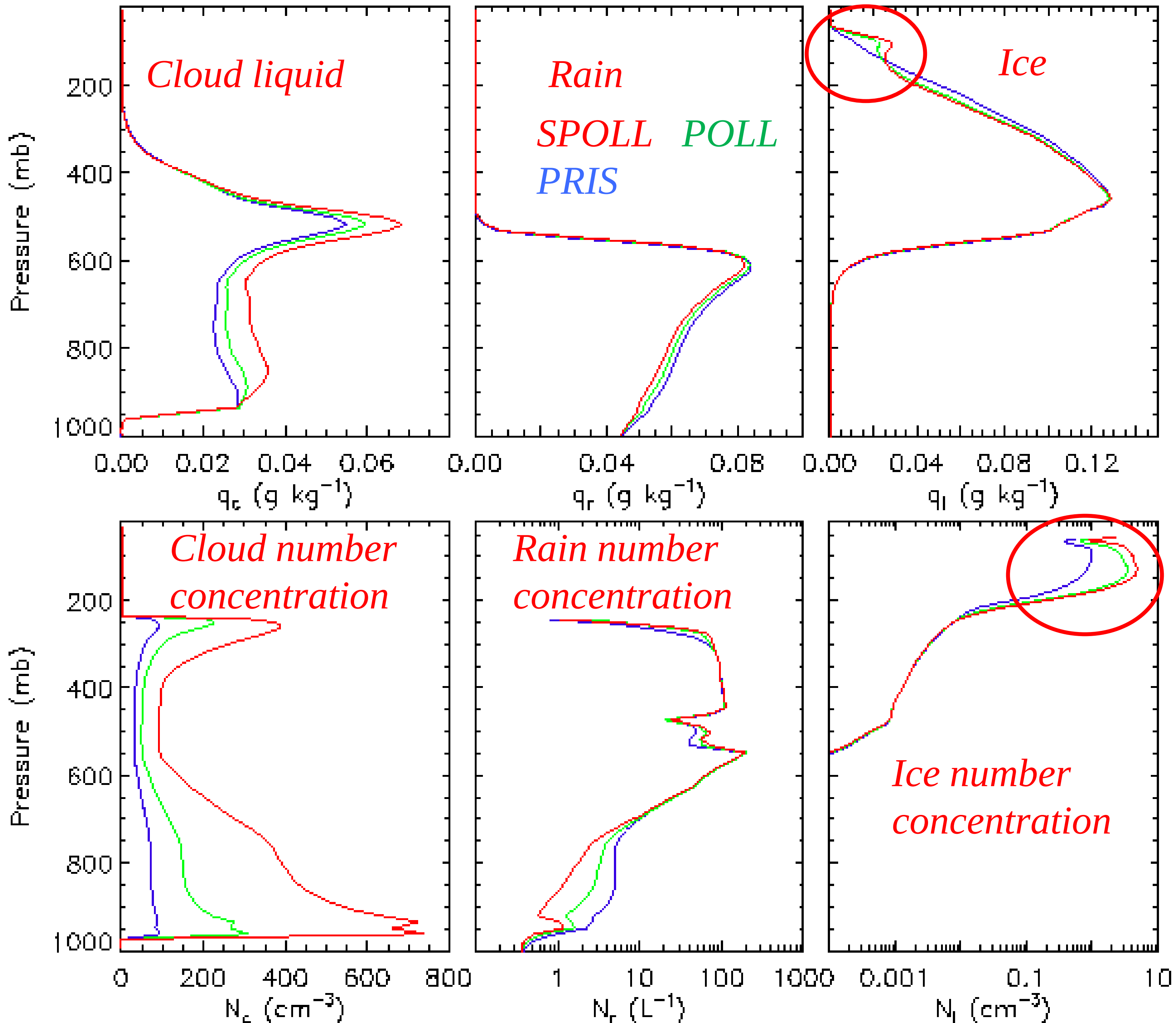
$$\cancel{\frac{\partial[h]}{\partial t}} + l.s.\cancel{adv} / \cancel{div}([h]) - RAD - SH - LH = 0$$

• **Impact on TOA radiative fluxes (ensemble mean)**



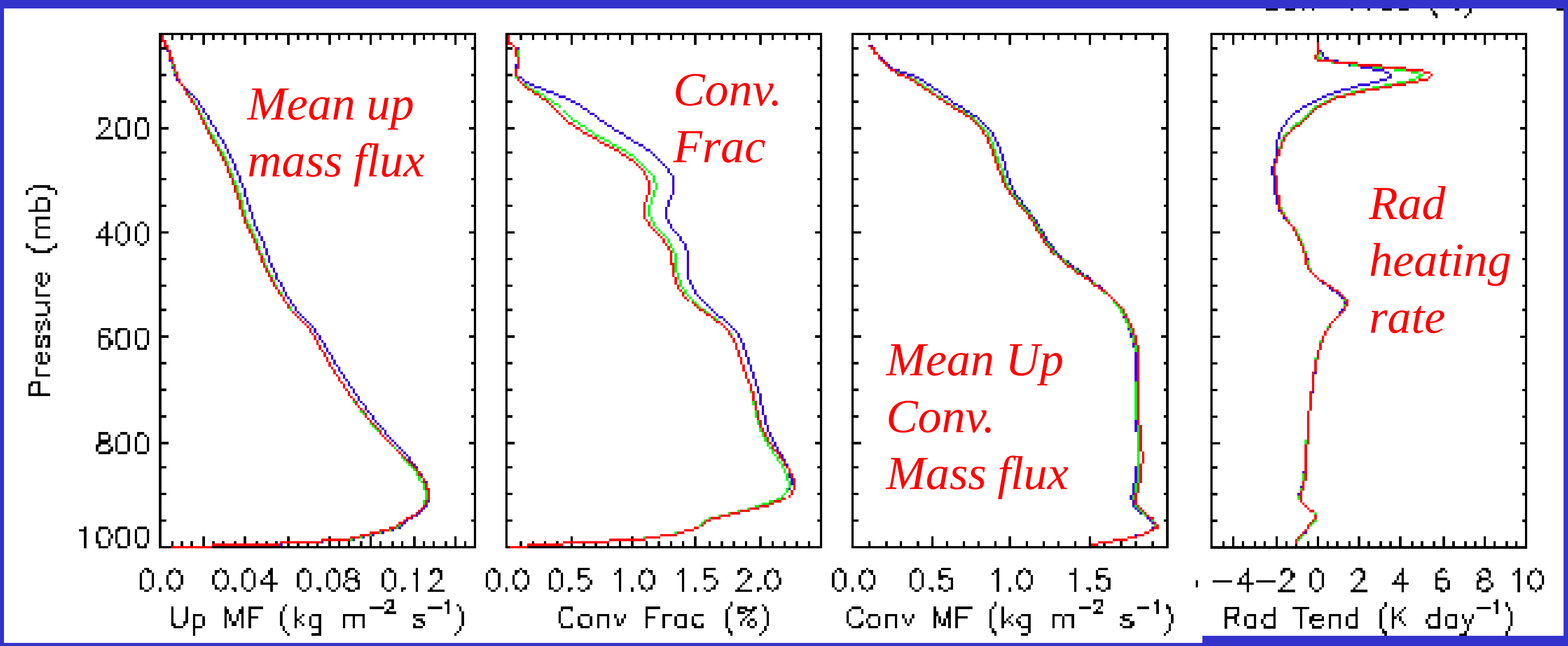
• **Sensitivity of aerosol effects to model configuration (pristine minus polluted)**





Cloud liquid
Rain
SPOLL
POLL
PRIS
Ice
Cloud number concentration
Rain number concentration
Ice number concentration
Pressure (mb)
200
400
600
800
1000
0.00
0.02
0.04
0.06
0.08
0.12
q_c (g kg^{-1})
q_r (g kg^{-1})
q_i (g kg^{-1})
0
200
400
600
800
1
10
100
1000
0.001
0.1
10
N_c (cm^{-3})
N_r (L^{-1})
N_i (cm^{-3})

• **Aerosol effects on ensemble- and time-mean convective characteristics and radiative heating**



• Model produces a small increase in anvil thickness/height in polluted conditions consistent with some observations (Massie et al. 2011).

• However, this does *not* occur due to convective invigoration, but rather is a direct result of changes in ice number concentration due to higher concentration of droplets in polluted conditions and their subsequent freezing.

• These results suggest a possible alternative to convective invigoration in explaining small increases anvil height/thickness suggested by satellite.

Conclusions

- There is limited impact of aerosol on forcing terms in the moist static energy budget, and hence not much change in the mean surface precipitation rate and updraft mass flux → strongly constrained by prescribed large-scale forcing and SST. Overall there is a small net upper tropospheric radiative heating with increased aerosols which slightly weakens convection.

- This study did not consider feedback with the surface or large-scale dynamics, which may be important for aerosol effects on convective strength/precipitation.

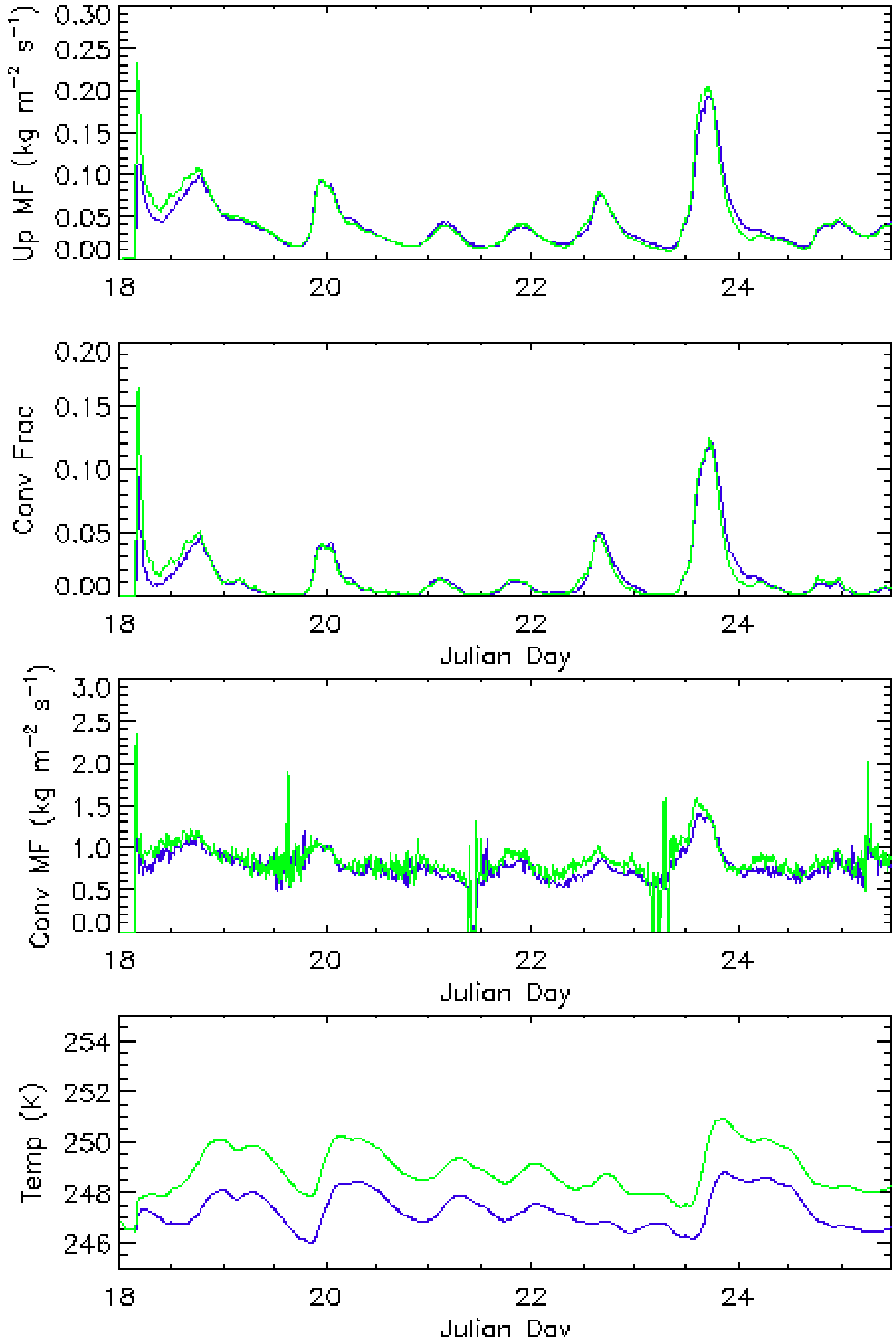
- This study did not consider how plumes of aerosols might affect precipitation locally.

Conclusions

- **SW and LW fluxes are less constrained than precipitation by static energy and water budgets and are therefore more sensitive in this framework, but these quantities are also subject to large internal model variability (less problematic in 3D?).**

- **This work does not necessarily contradict previous studies showing convective invigoration *for single cloud or convective systems*, since we analyzed aerosol effects over a large domain and multi-day period with numerous interacting clouds at various stages in their lifecycle.**

- **Current work is exploring the relationship between enhanced latent heating (forced), convective invigoration, and the timescale of the environmental response, to better understand the relationship between impacts on a single convective clouds versus a system of numerous clouds with environmental feedback.**



Up MF (kg m^{-2} s^{-1})
0.30
0.25
0.20
0.15
0.10
0.05
0.00
18
20
22
24
Conv Frac
0.20
0.15
0.10
0.05
0.00
18
20
22
24
Julian Day
Conv MF (kg m^{-2} s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
18
20
22
24
Julian Day
Temp (K)
254
252
250
248
246
18
20
22
24
Julian Day