Cloud system-resolving model simulations of aerosol indirect effects during TWP-ICE

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Question: How does parameterization of microphysics and model resolution impact simulation of aerosol effects on clouds and precipitation?

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

- similar setup to ARM/GCSS intercomparison

Prescribed large-scale forcing of T, qv, 6 hr nudging of u to observations

200 columns

25 km

height

97 levels

0

0   horizontal distance   200 km
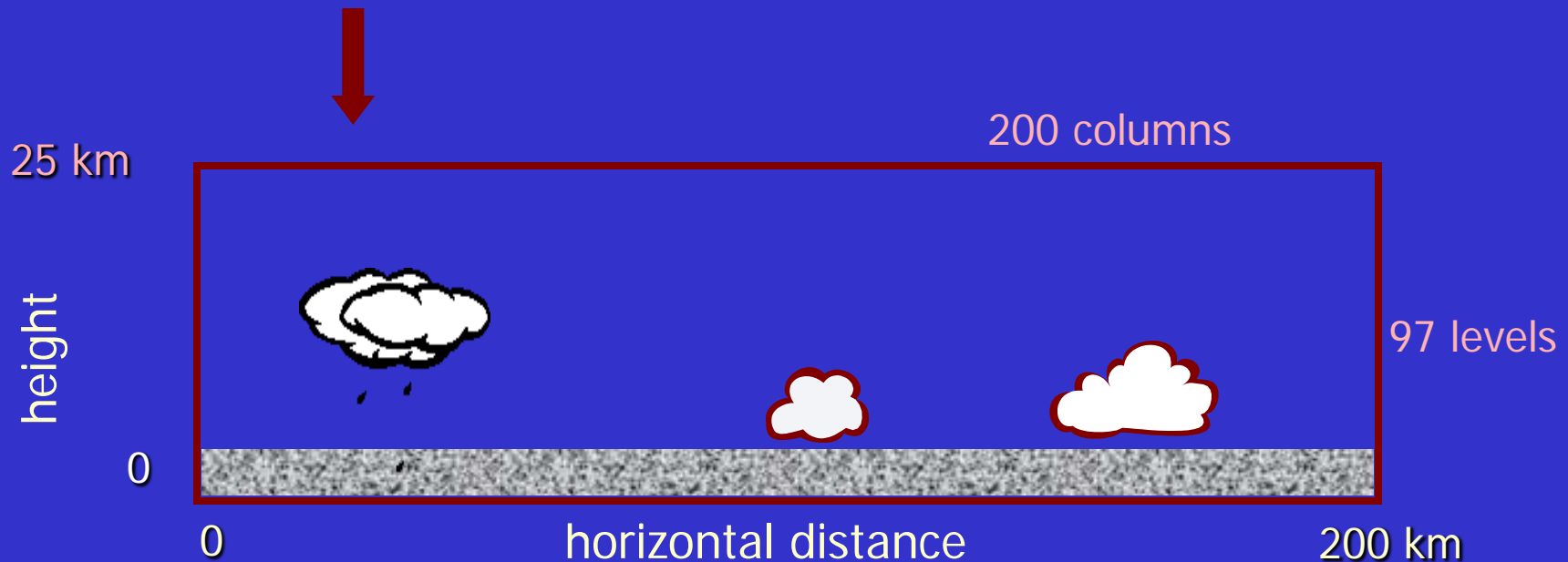
horizontal grid spacing of order 1 km

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

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

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

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

- Resolution → Horizontal gridlength varied from 2 km to 500 m
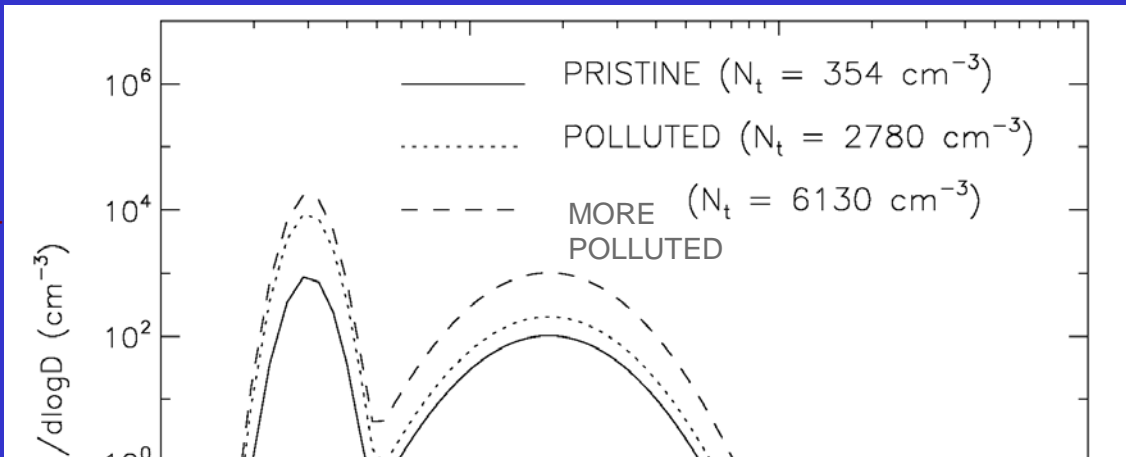
Aerosol specification, similar to Fridlind et al. (2010, in prep)

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

• Impact on surface precipitation

- limited impact on terms in the bulk moist static energy budget (tropospheric radiative cooling, surface fluxes) and rapid convective adjustment lead to mean surface precipitation rates → constrained by prescribed large-scale forcing and SST
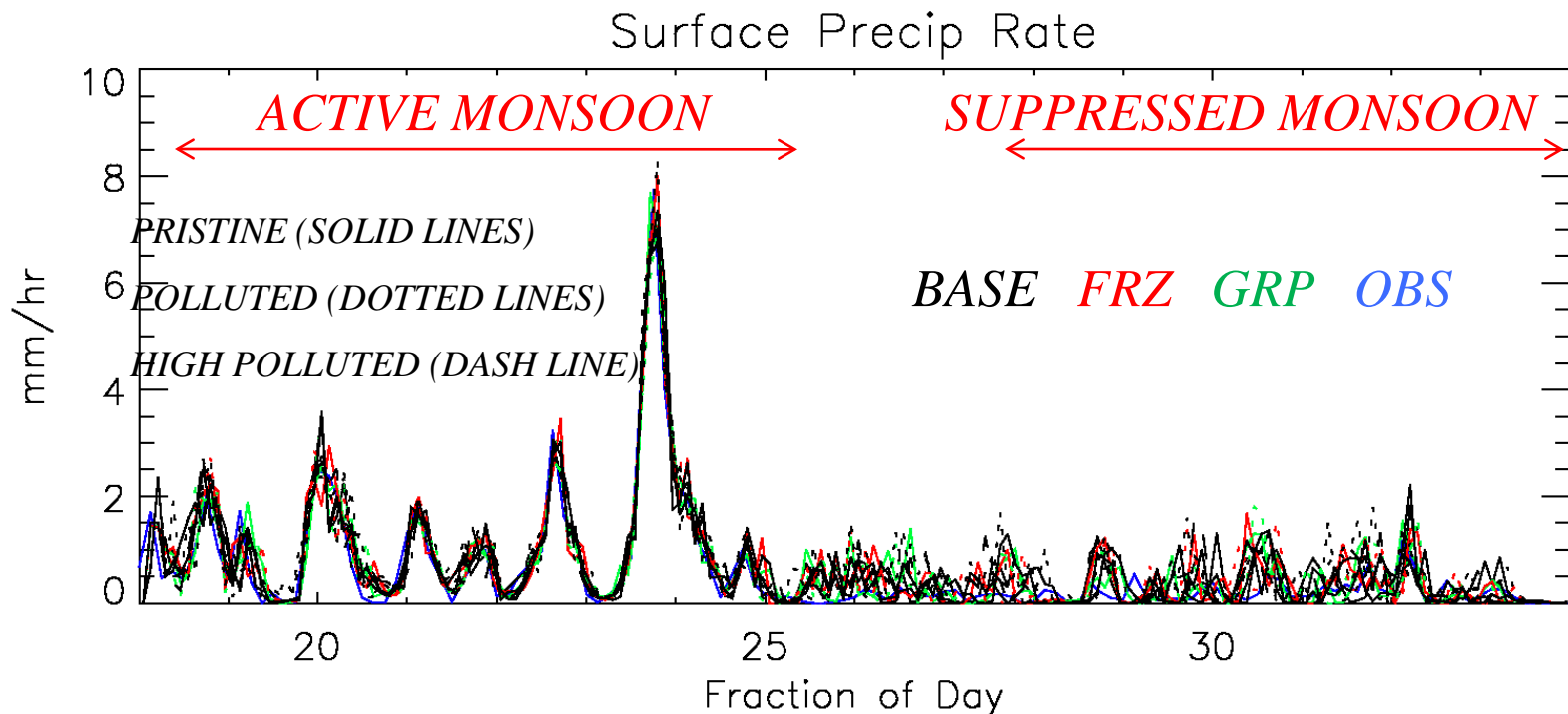
Budget thinking…

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

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

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

In convective-radiative equilibrium

(Grabowski 2006; Grabowski and Morrison 2010):

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

• Impact on TOA radiative fluxes

TOA upwelling SW

*FRZ* *GRP* *OBS*

PRISTINE (SOLID LINES)

POLLUTED (DOTTED LINES)

What is the role of internal variability in explaining these differences?

• **Tests w/ vanishingly small perturbations to initial/boundary conditions or tiny random noise indicate large internal variability for parameters like TOA radiative fluxes,** *even when averaged over 16-days*.

• **Need to run large-member ensembles to determine statistical significance of aerosol effects!**

- **240-member ensembles of simulations (pristine and polluted) with different initial seed for random noise**
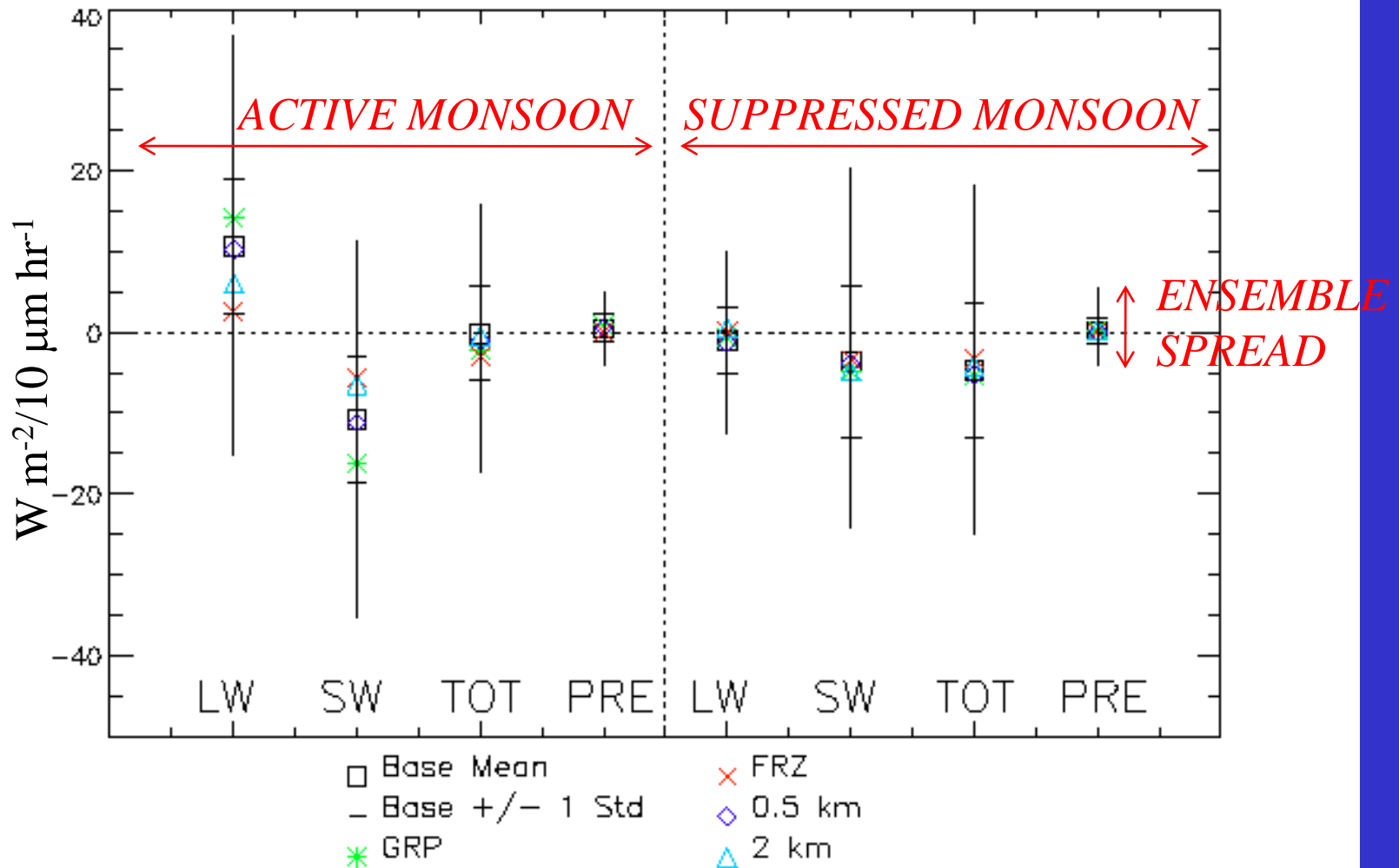
- **With little impact of aerosol on the moist static energy budget, there is almost no change in mean updraft mass flux with changes in aerosol.**

- **However, the strength/area of convective drafts may still differ (i.e., same mass flux can result from smaller but more intense updrafts)…**

- **Variability of convective draft characteristics is large but we still need to see if there are statistically significant differences between pristine/polluted.**

Conclusions

• **There is little impact of aerosol on the moist static energy budget, and hence the mean surface precipitation rate and updraft mass flux → strongly constrained by prescribed large-scale forcing and SST.**

• **Changes induced by aerosol may feed back to surface/large-scale dynamics and thus impact surface precipitation (an effect not considered in this study).**

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

Conclusions

• SW and LW fluxes and strength/area of convective drafts are less constrained than precipitation by MSE budget terms and are therefore more sensitive in this framework, but these quantities are also subject to large internal model variability (less problematic in 3D?).

• Statistically-significant aerosol effects on net TOA flux:

   - active monsoon ~ 0 W m^{-2} (LW and SW effects approximately cancel)
   - suppressed monsoon ~ -5 W m^{-2} (SW effects dominate)

• Sensitivity to microphysics and resolution: means from all tests lie within the baseline ensemble standard deviation, but statistically significant differences are apparent for active monsoon.

   - also sensitivity tests to domain size and other microphysics parameters