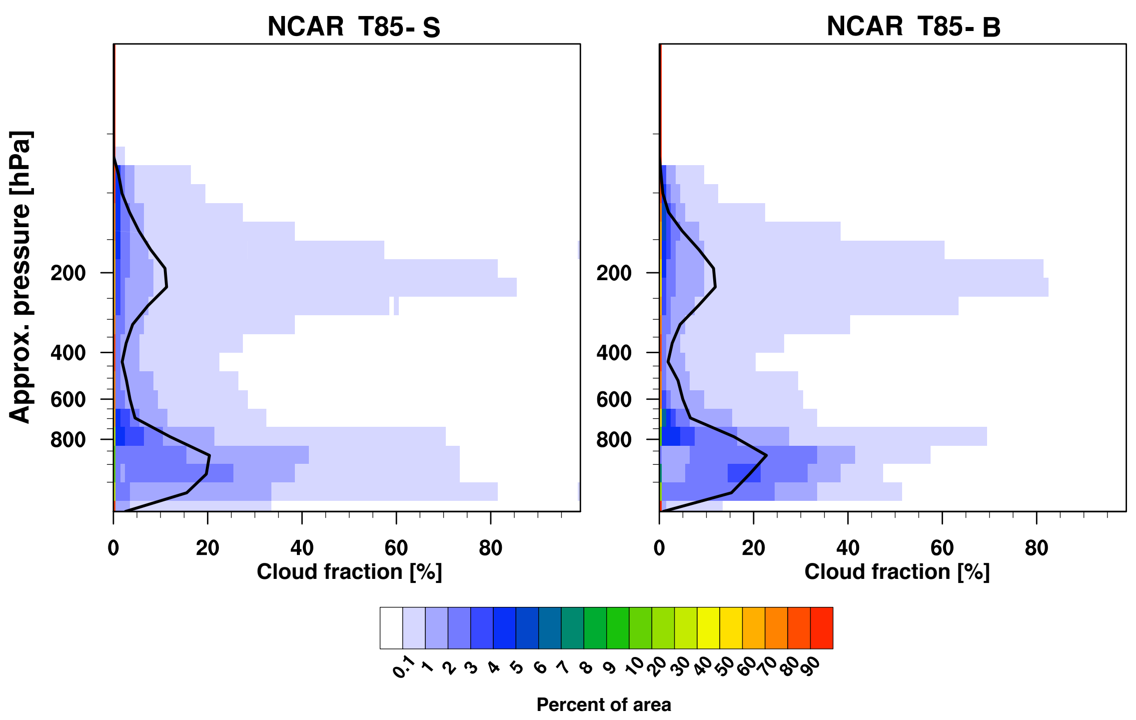
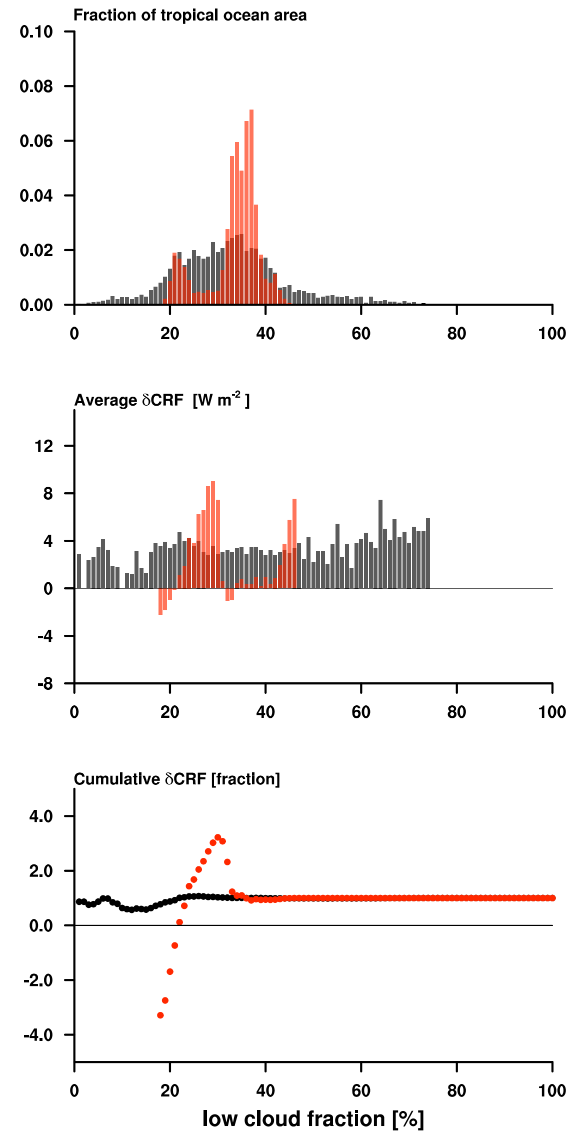

Microphysical issues in the representation of shallow cumulus convection.
--Bjorn Stevens, UCLA

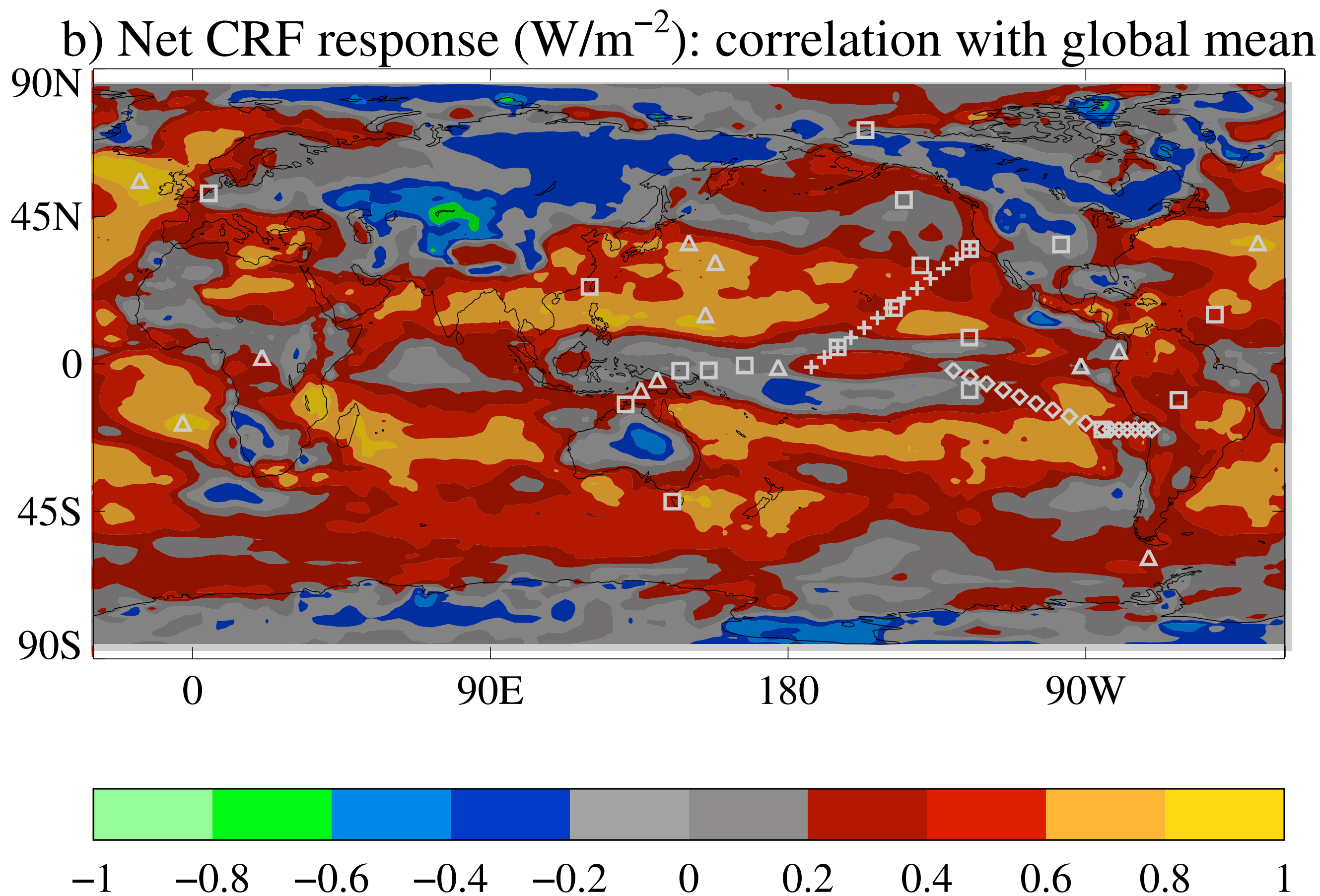
why the trades?





Medeiros et al., J Clim (2008, submitted)

this in from IPCC/CFMIP

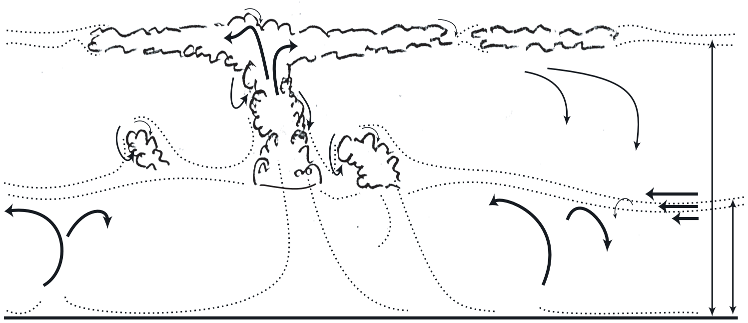


CFMIP-2 Fig. 10

a feature or a complication?

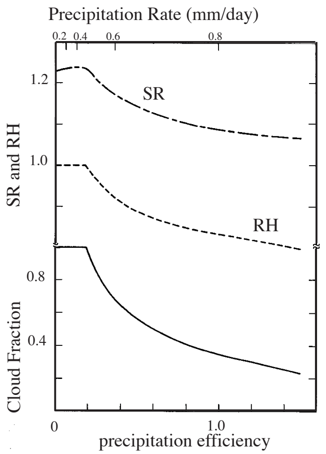
Maritime clouds with tops above 2500 m “usually rain within half an hour” Squires, *Tellus*, **10**, 1958.

possible effects of the aerosol



Simple Two Layer Model With

$C = q_l/(q_t - q_v\ RH)$



"Increases in aerosol concentrations over the oceans may increase the amount of low-level cloudiness through a reduction in drizzle."

Albrecht, *Science* (1989)

justifications (i)

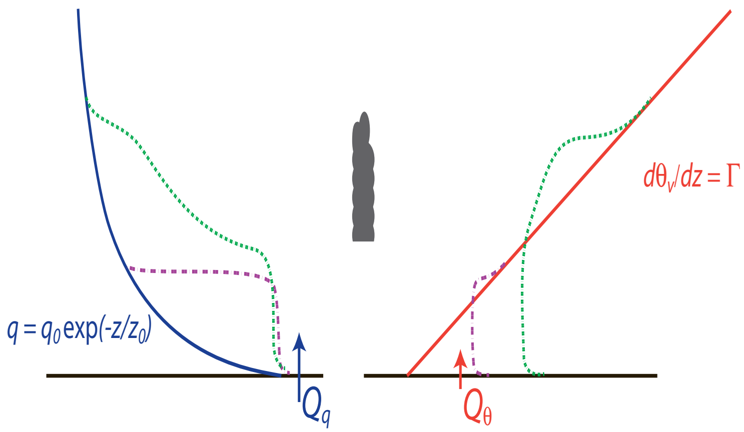
- The trades cover a large-part of the globe, where there is an ample distribution of available sunlight and rather little surface reflection. Changes to clouds in the trades thus have the possibility of having a large effect *(a priori justification)*.

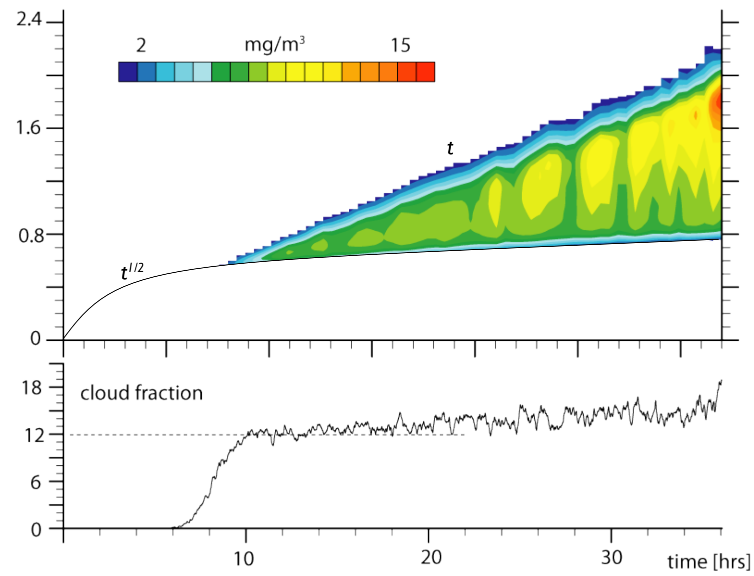
- Our uncertain representation of clouds in the trades appears to be a leading cause of varying climate sensitivity estimates, so improvements in this respect could do good *(a posteriori justification)*.

- The idea that the aerosol regulates rain production dates back half a century, whether or not this might be important for climate remains unknown. Trade cumulus, because of their simplicity and potential importance provide an appealing laboratory for studying these and related issues more deeply *(intellectual content)*.

- The idea of the MMF as a physics coupler is one of its more attractive facets, but how does this work for shallow convection where the coarse-grid representation is more marginal *(near-field rationalization)*.

prototype non-precipitating cumulus convection





- moist analog to dry convection (linear stratification, constant buoyancy flux).
- large-eddy simulation, without precipitation.
- suggests that moist layers grow linearly in time, *t*

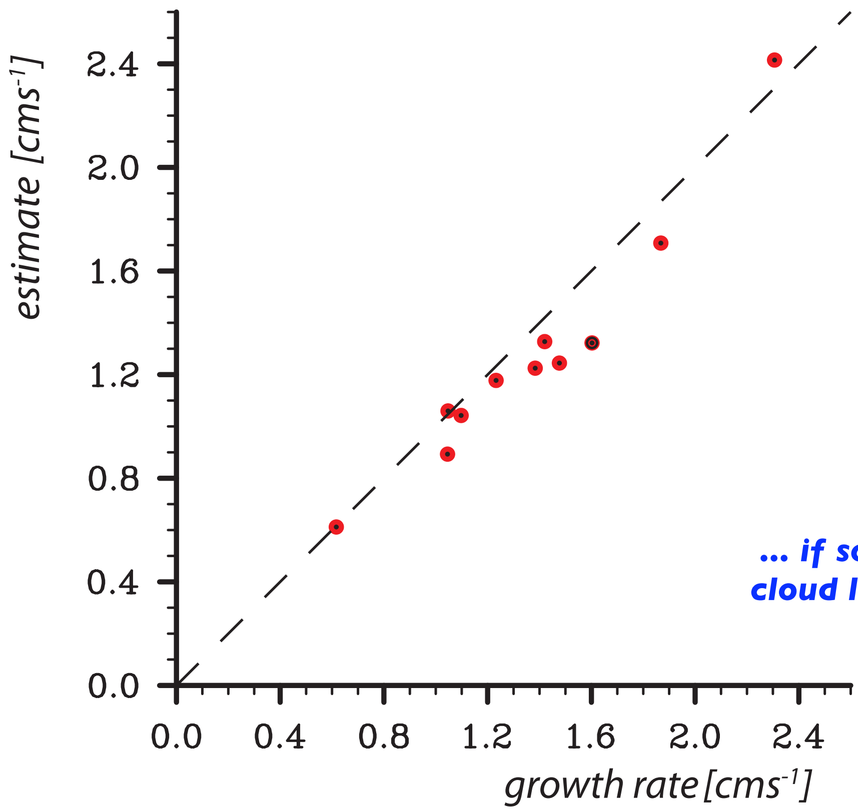
Stevens, *JAS* **64** (2007)

on the growth of the cumulus layer

3 assumptions

1. sub-cloud layer <=> dry cbl
2. cloud water *in cloud layer* is stationary
3. cloud layer density slaved to sublcoud layer

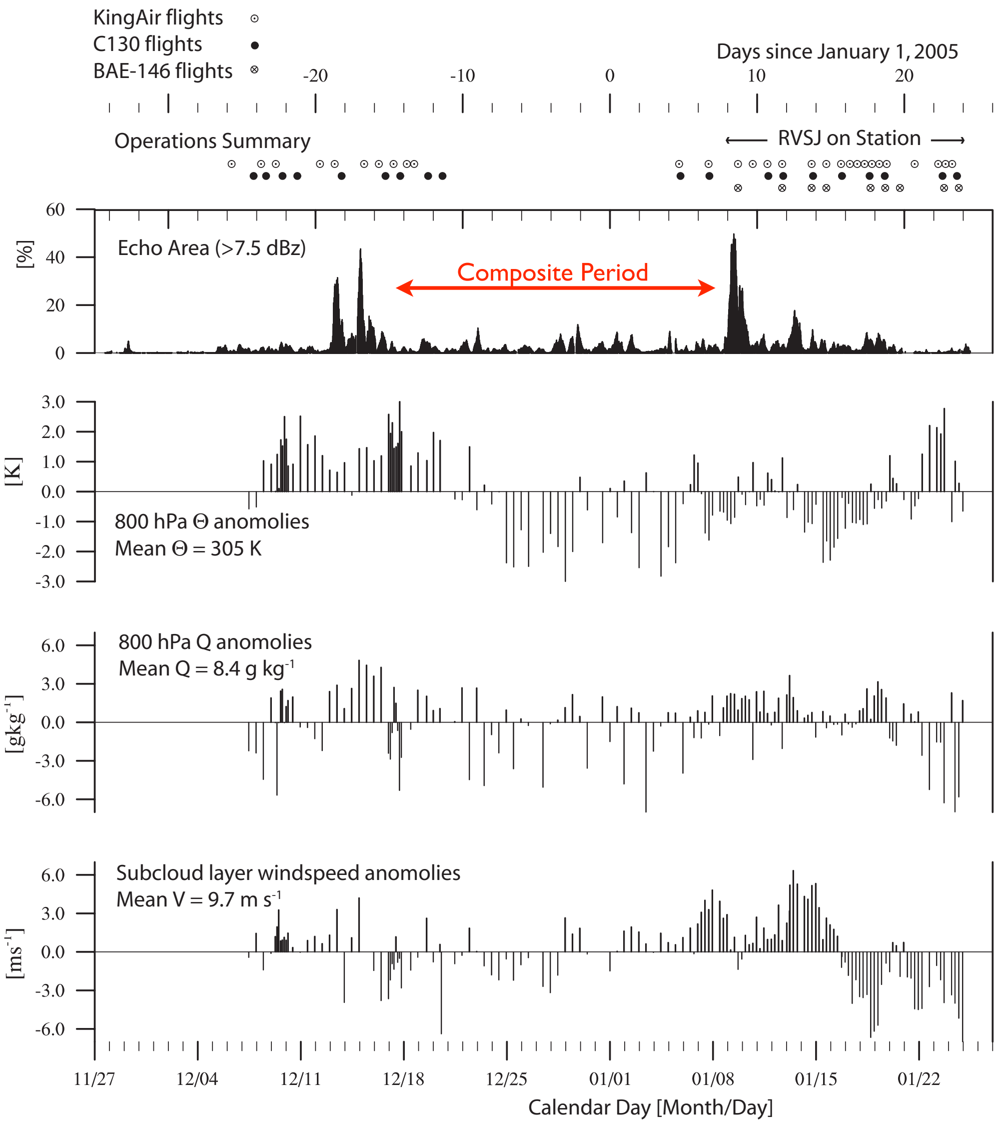
the cloud layer grows by the injection and evaporation of liquid water into the trade inversion.

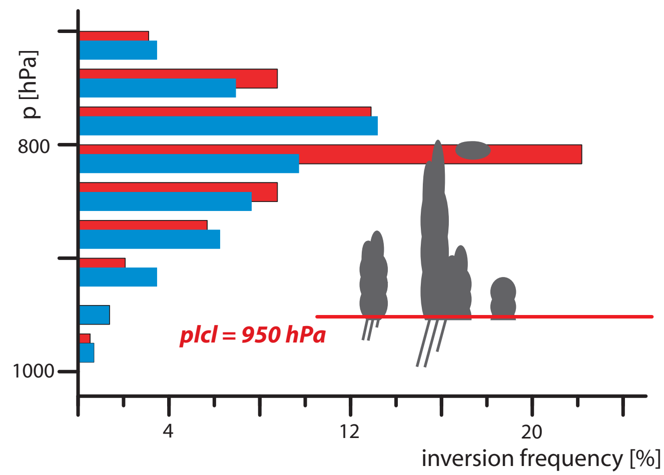


... if so precipitation should help arrest the growth of the cloud layer.

Stevens, *JAS* **64** (2007)

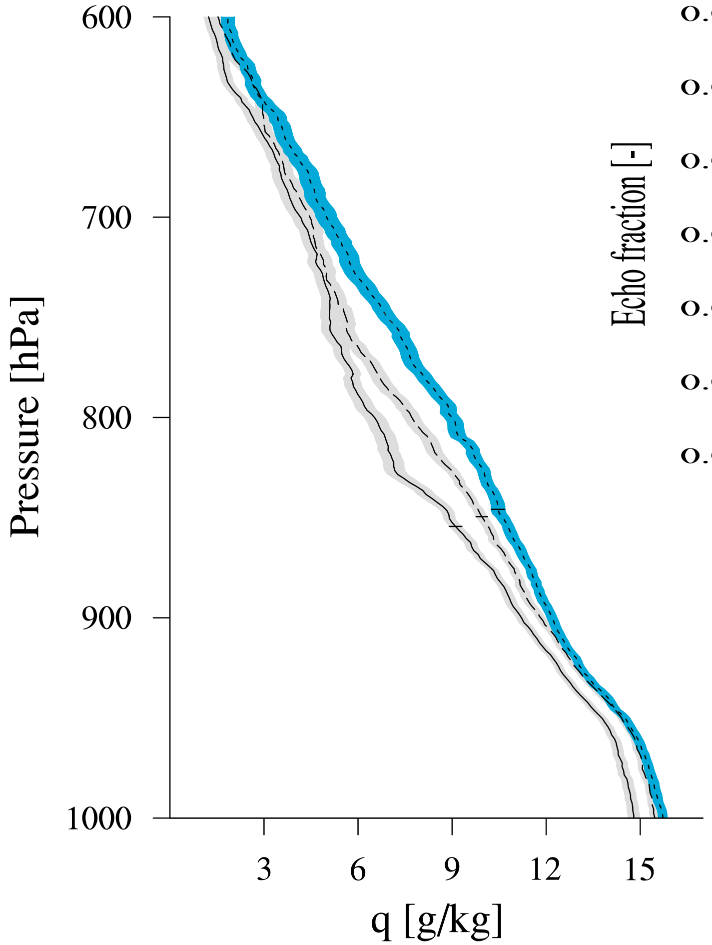
Rain in Cumulus Over the Ocean (RICO)

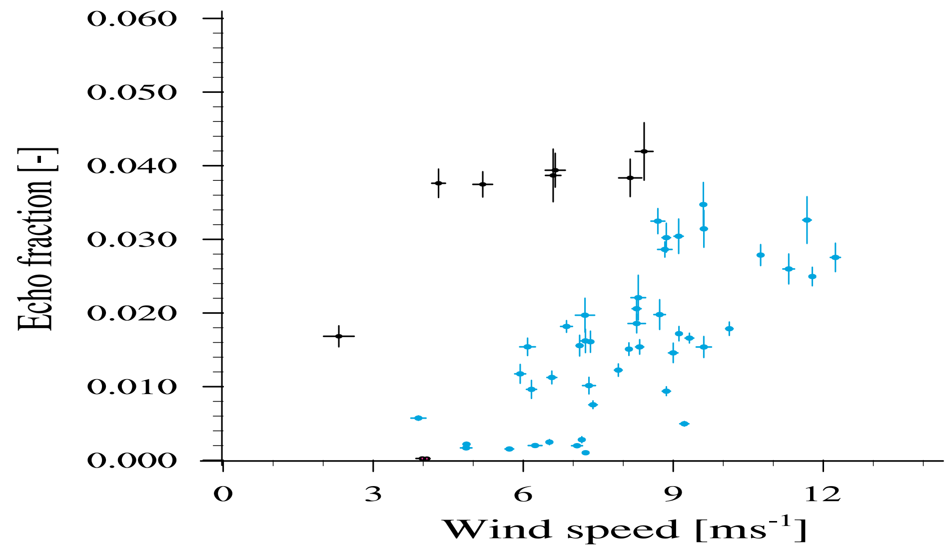




Rauber, Stevens, Ochs, and Knight *et al.*, *BAMS*, **88** (2008)

Rain in Cumulus Over the Ocean (RICO)

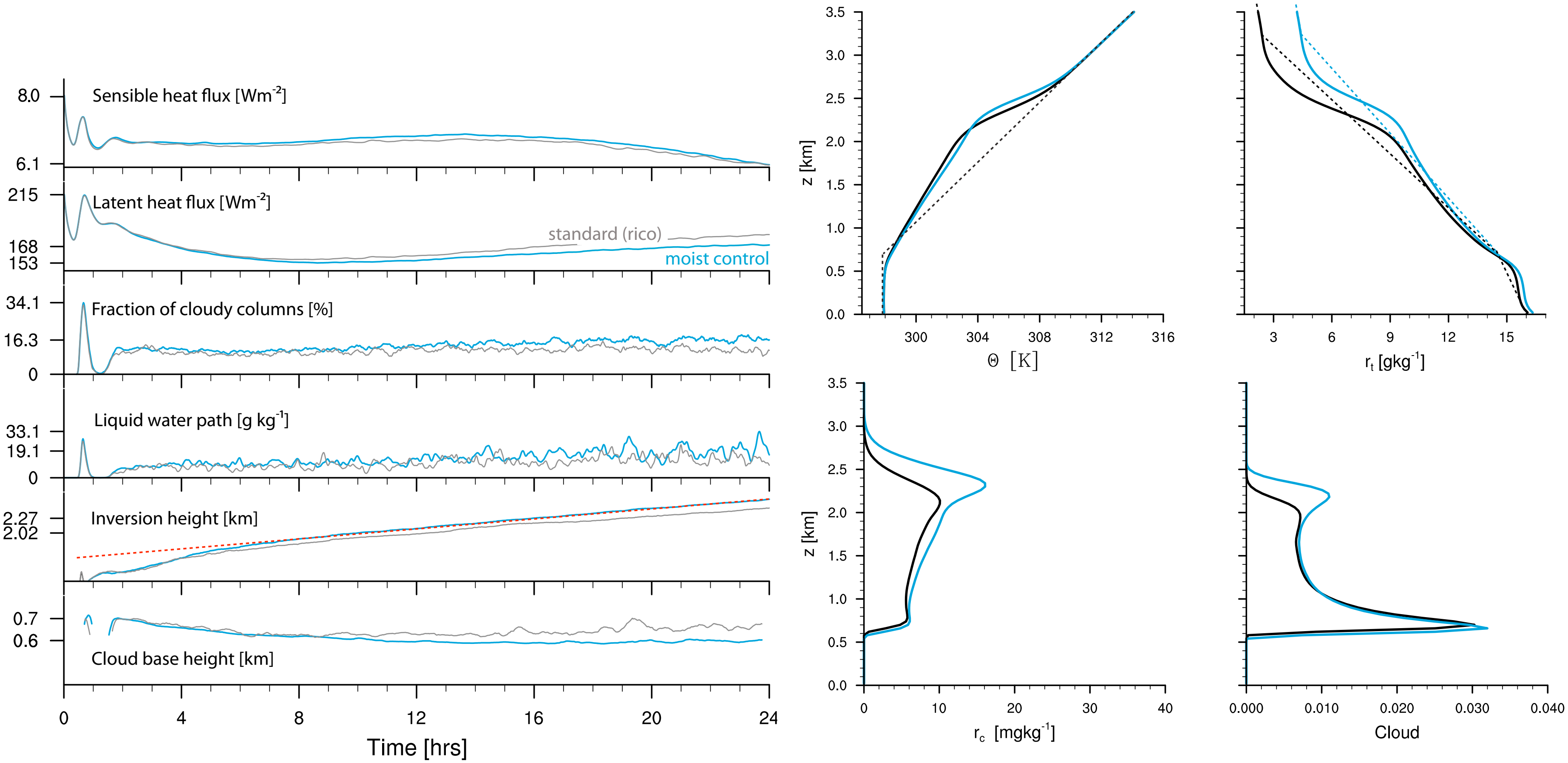




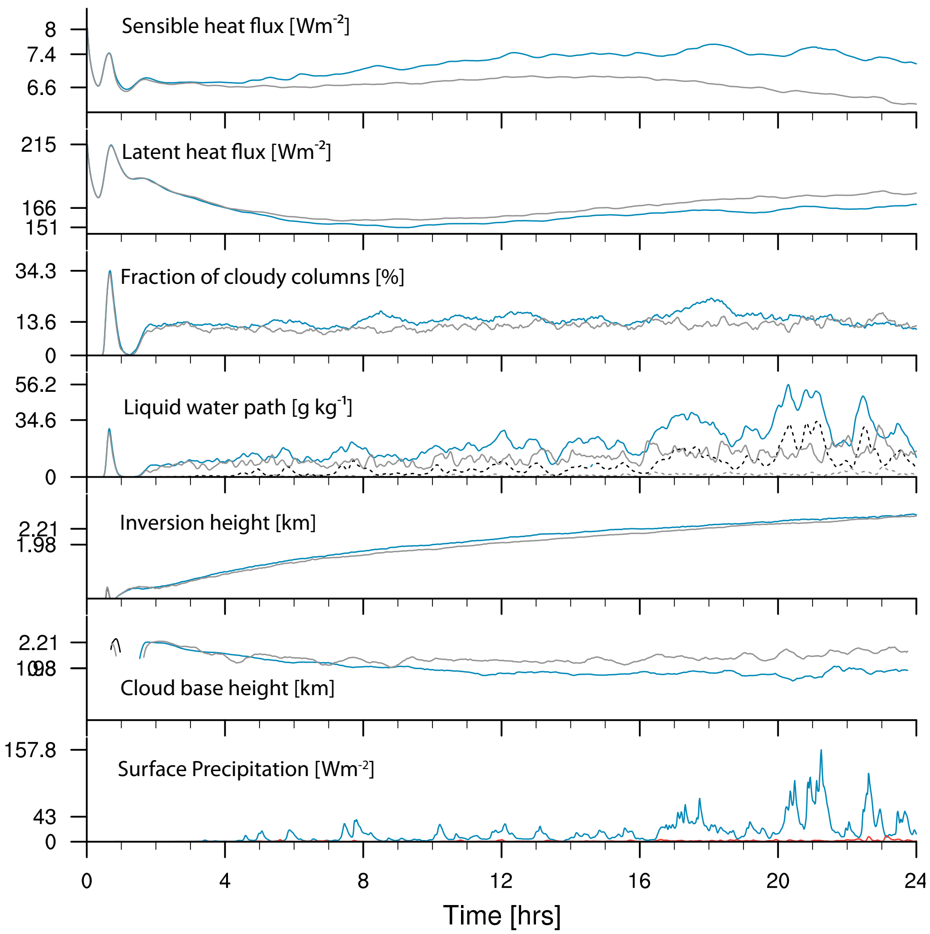
- rainy days are moister .. and windier
- CCN correlate well with windspeed
- meteorological dominance

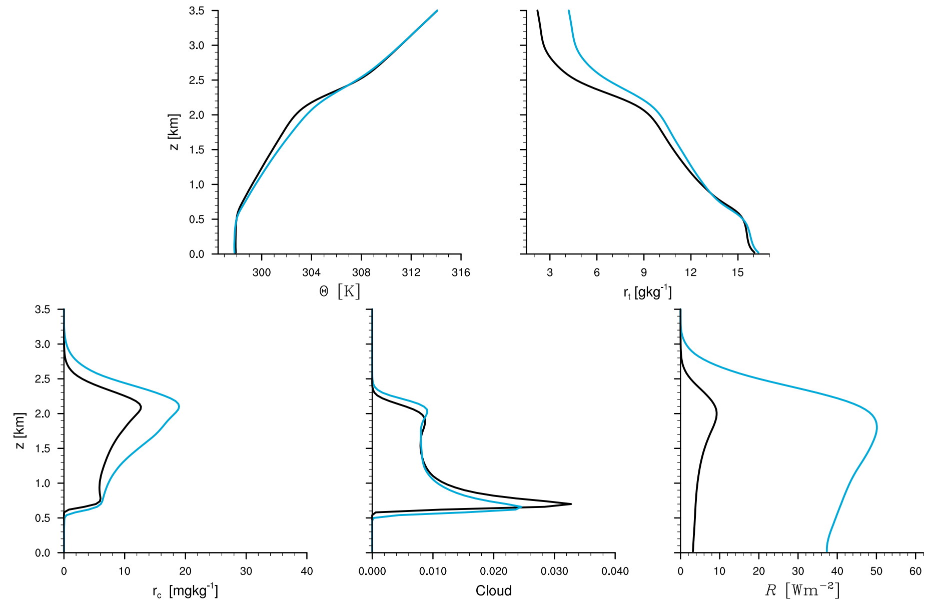
Nuijens *et al., in preparation*

GCSS working group case (non-precipitating)

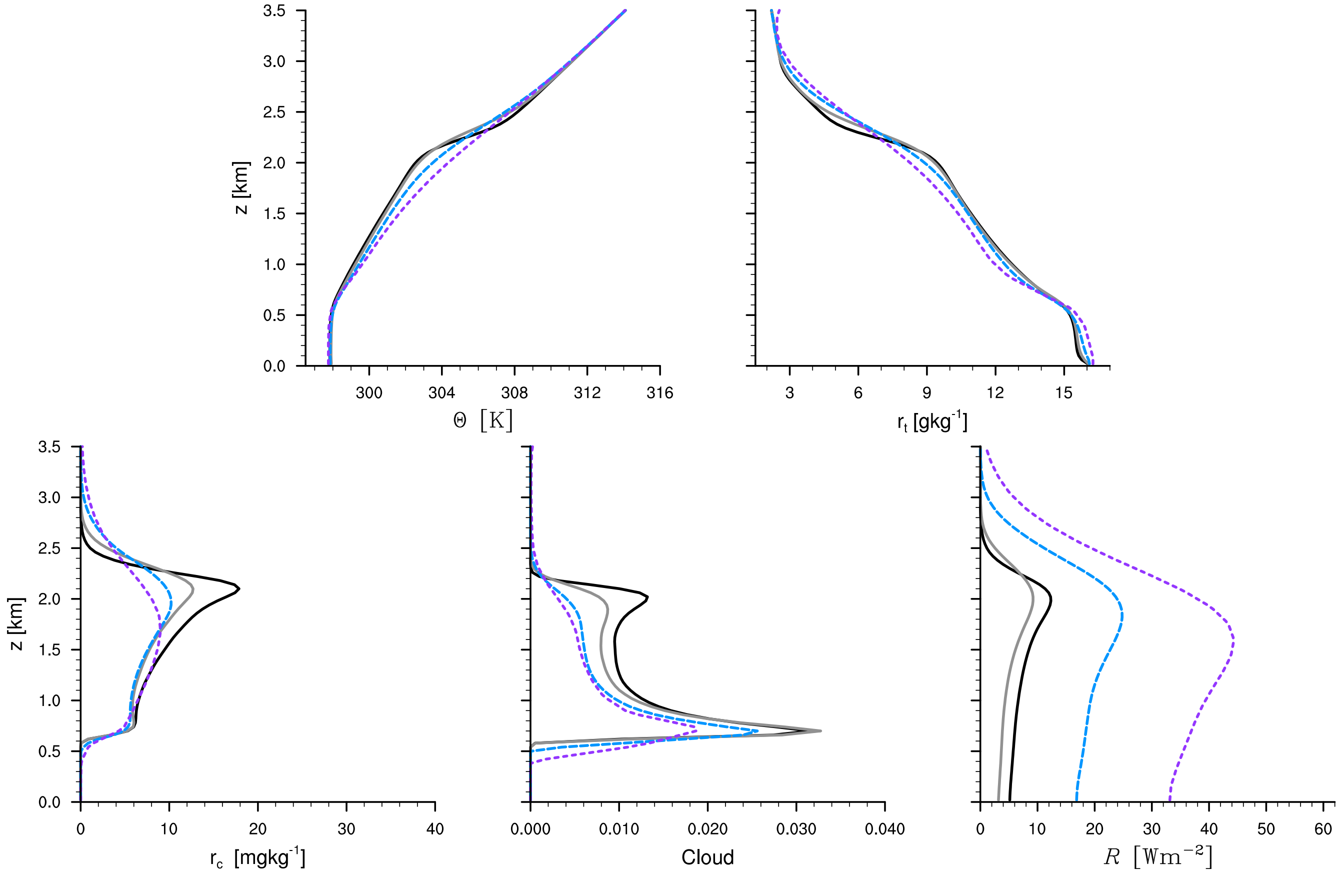


GCSS working group case (precipitating)



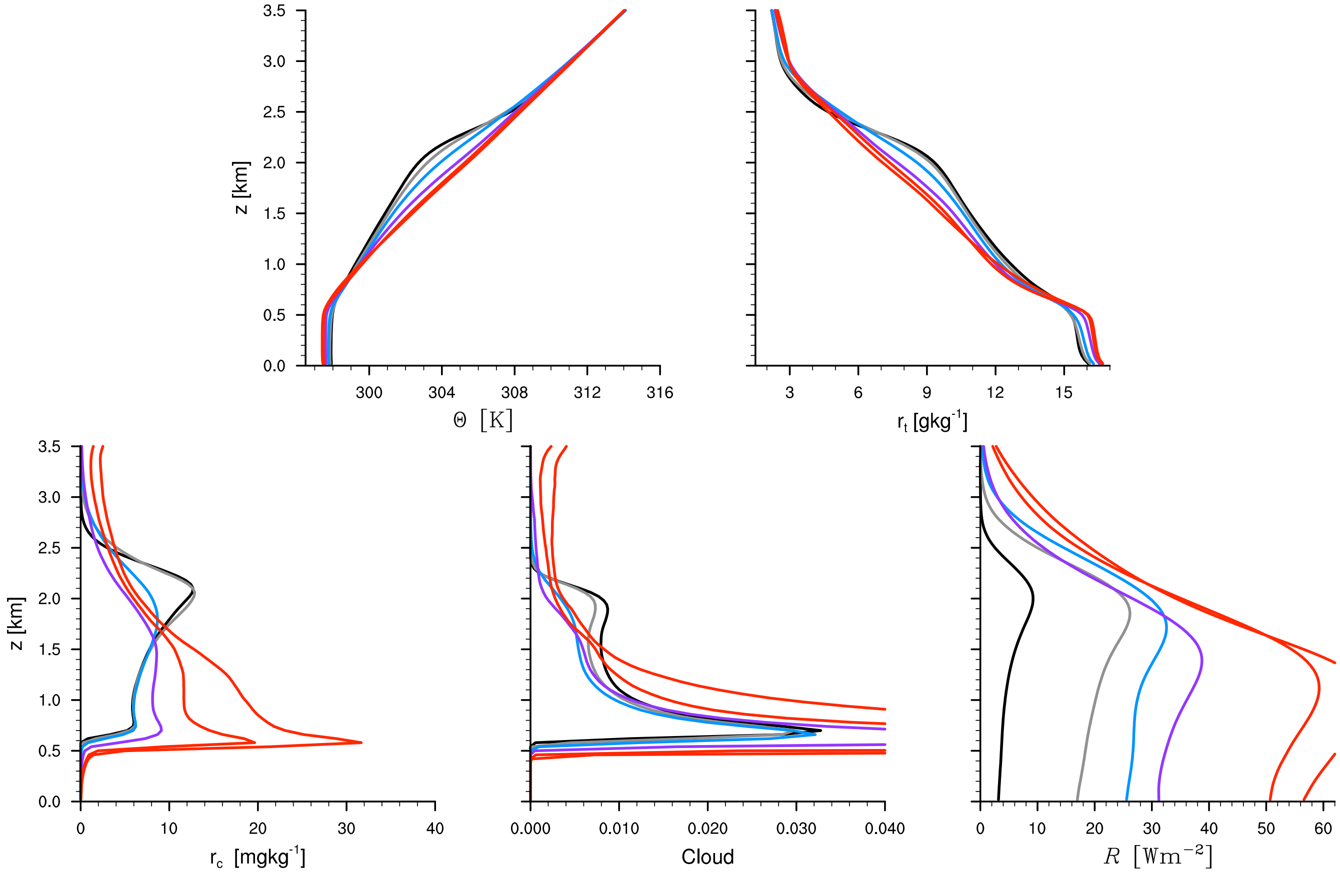


sensitivity to grid



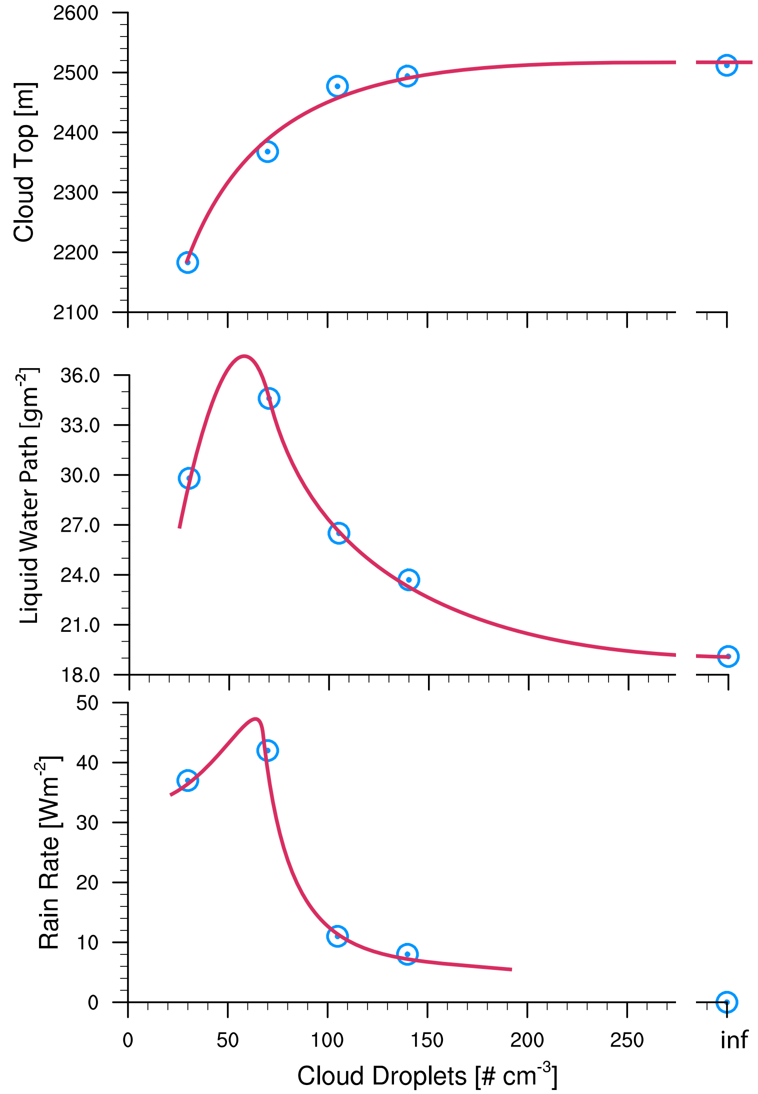
dx = *dy* = *2.5* dz = 50, 100, 200, 400 m.

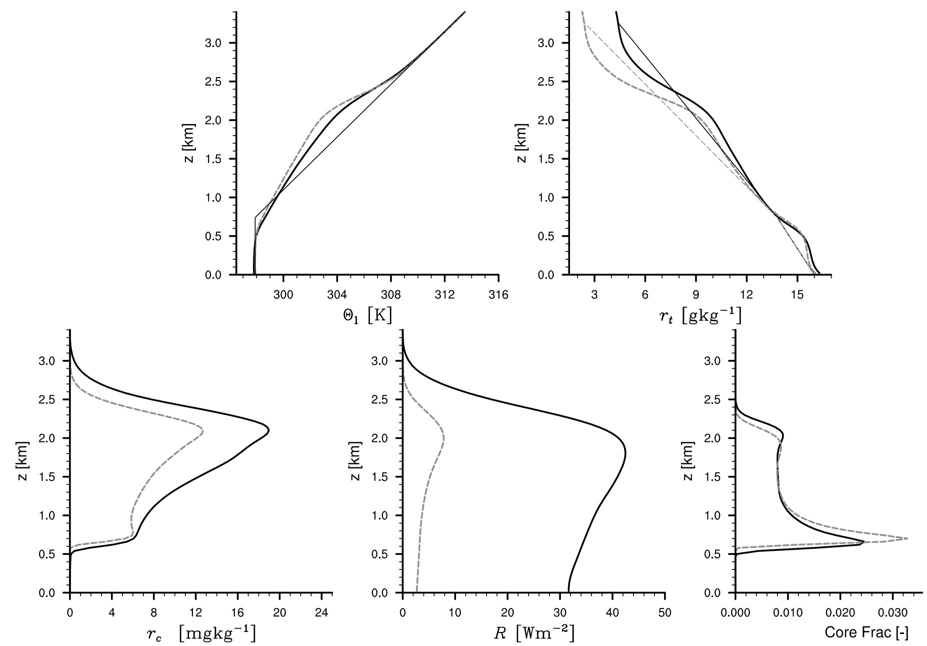
horizontal mesh sensitivity



dx = *dy* =100, 200, 400, 800, 1600, 3200 m.

showers...

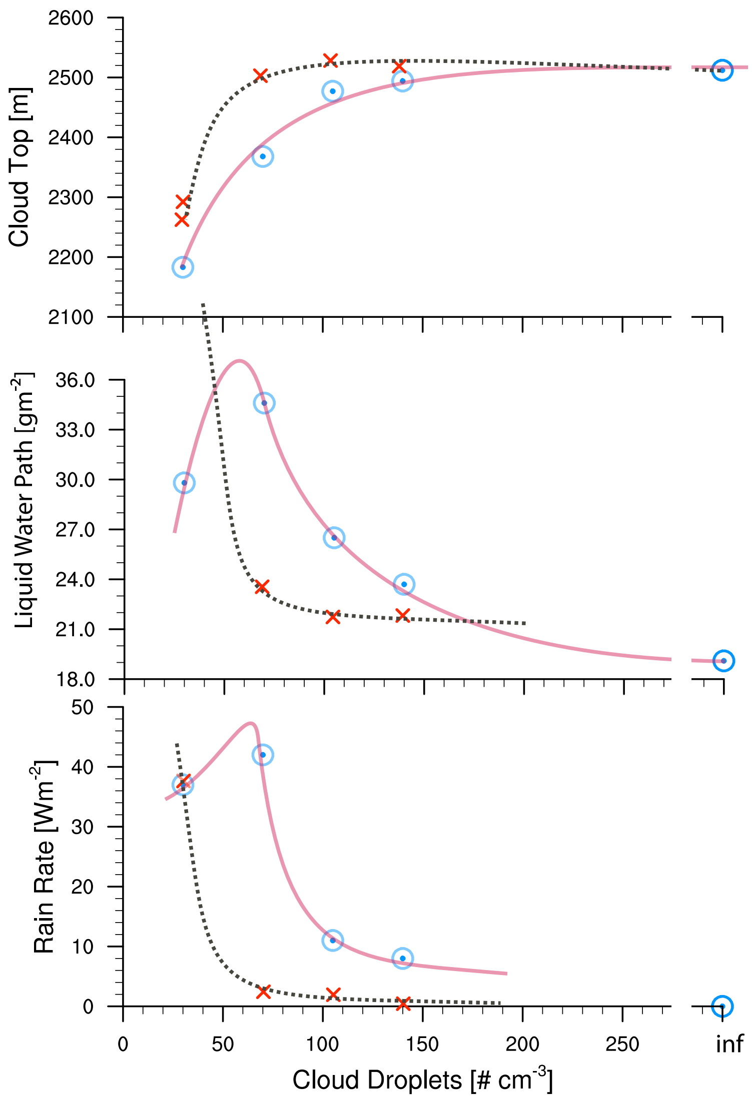


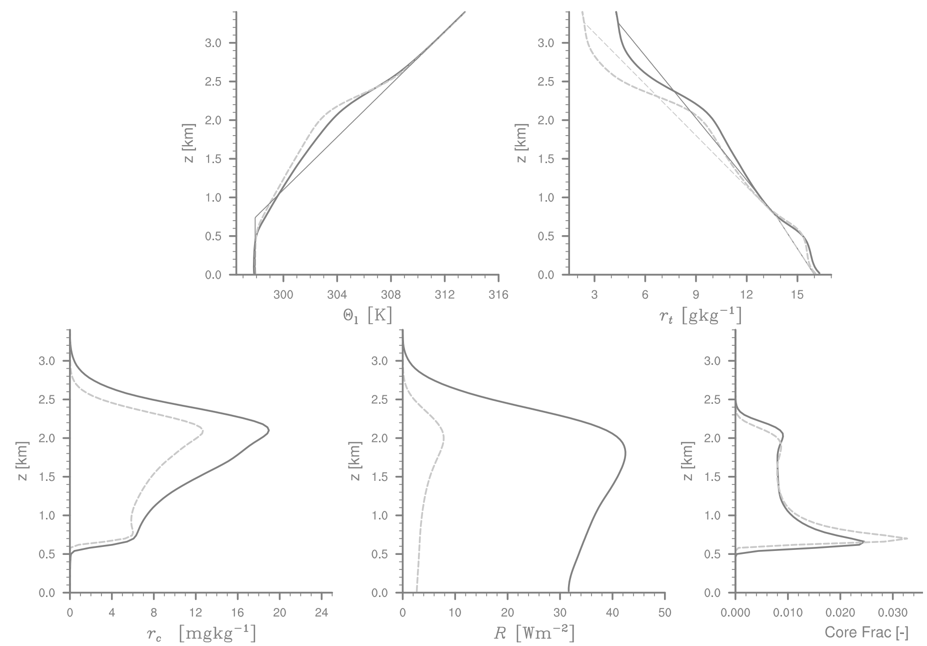


- deeper clouds make more rain, but so do less drops.
- more rain makes more cloud, or less.
- drops linger, so in general the association of cloud lifetime with rain appears to be misconceived.

Adapted from Stevens and Seifert, *JMSJ* (2008, submitted)

showers...





- deeper clouds make more rain, but so do less drops.
- more rain makes more cloud, or less.
- drops linger, so in general the association of cloud lifetime with rain appears to be misconceived.
- but these results are model dependent.

remarks (ii)

- Relatively simple ideas about trade cumulus developed based on a prototype model have explanatory power for observed situations.
- Observations suggest that rain correlates well with lower-tropospheric water vapor (analogous to deep convection), microphysical effects are probably secondary.
- Response of simulations to rain is in accord with some expectations: more rain, shallower cloud layers, deeper/moister layers lead to more rain.
- Some uncanny physical sensitivity to rain (Xue-Feingold lingering effect).
- Quantitative sensitivities to both grid (qualitatively poor behavior for dx > 1 km) and microphysical representation.

warm-rain microphyiscal processes

$$\frac{\partial \psi}{\partial t} + \mathbf{u} \cdot \nabla \psi - \nabla \cdot \left(K_\psi \nabla \psi \right) = -w_\psi \frac{\partial \psi}{\partial z} + \mathcal{K}_\psi + \mathcal{T}_\psi \quad (1)$$

where $\psi \in \{n_r, r_r\}$

- condensation
- auto-conversion
- accretion
- self-collection
- evaporation (kinetic effects?)
- breakup

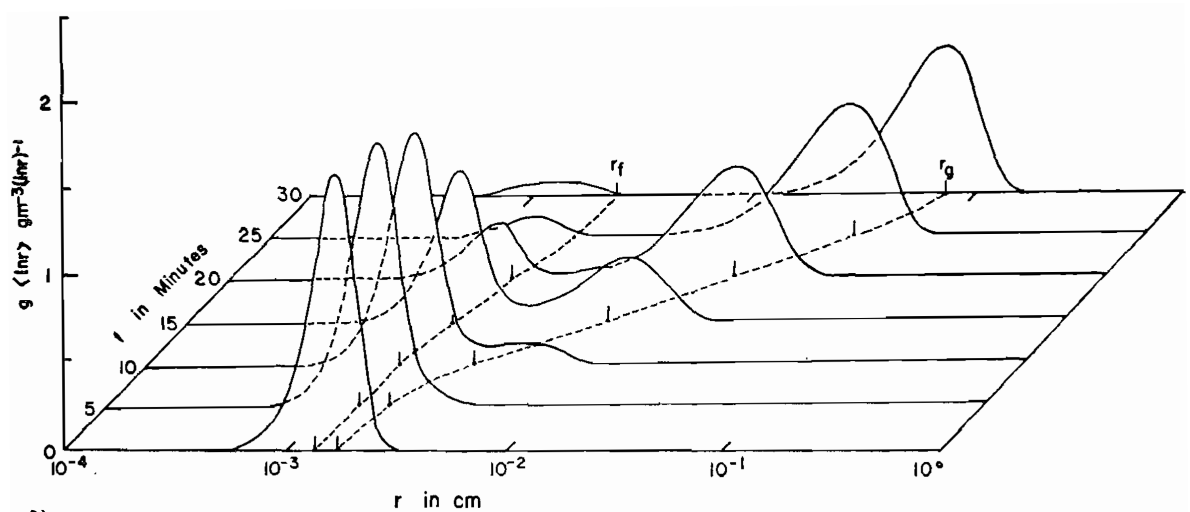
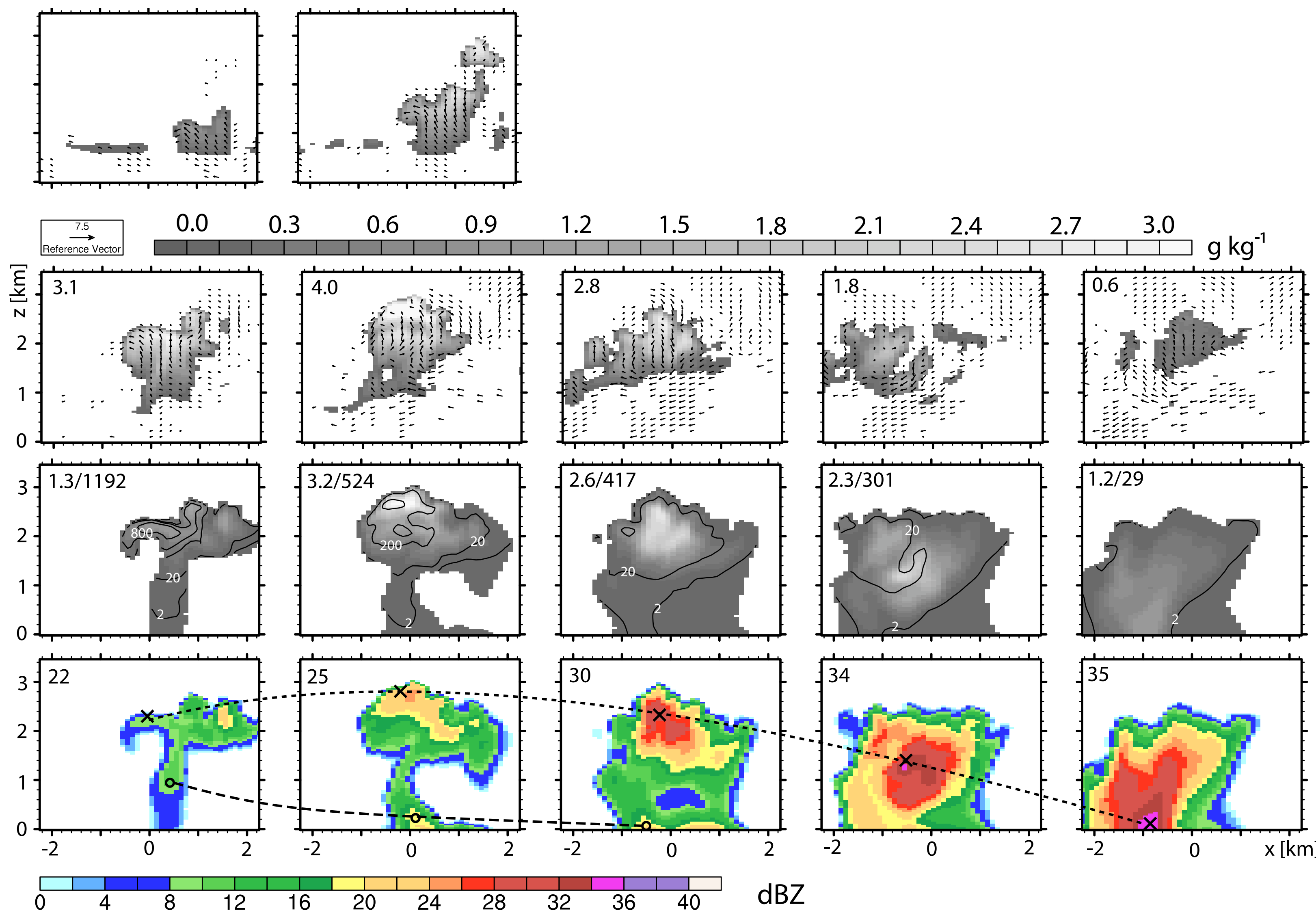


FIG. 4. Time evolution of the initial spectrum for $r_f^0 = 14\ \mu$m, var $x = 1$.

Berry and Reinhardt, JAS **31**, 1974

snapshots of a precipitating cell

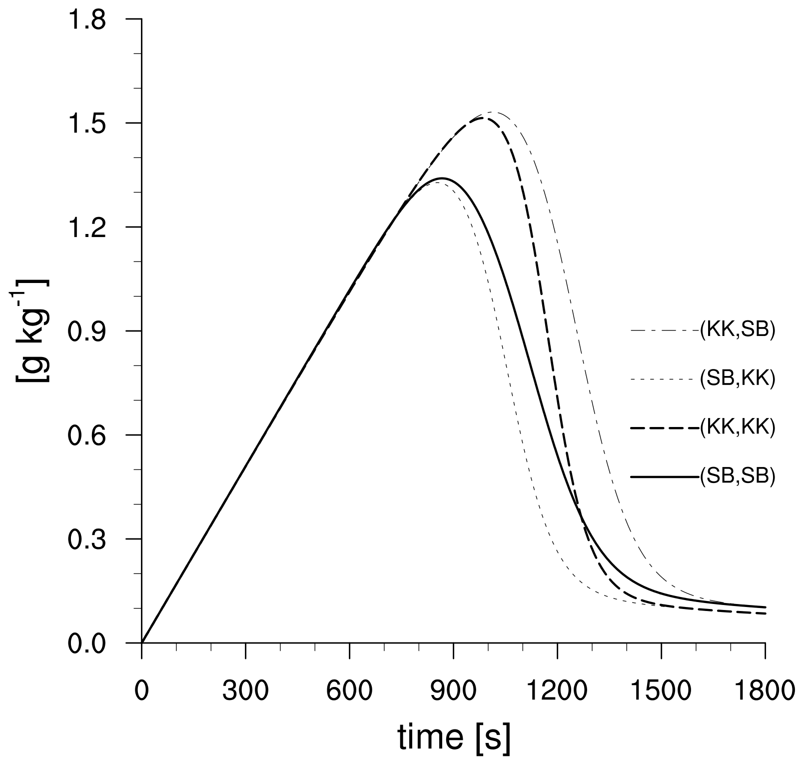


a simple model

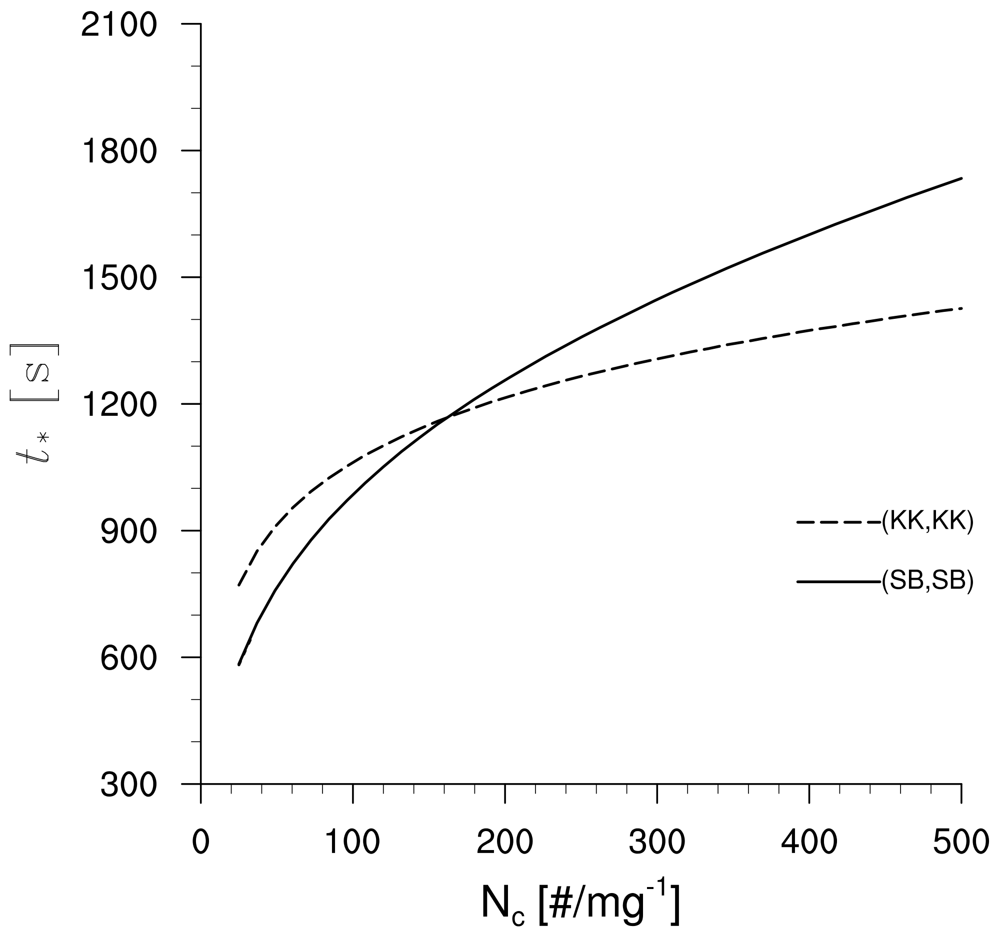
$$\frac{\partial \psi}{\partial t} + \mathbf{u} \cdot \nabla \psi - \nabla \cdot \left(K_\psi \nabla \psi \right) = -w_\psi \frac{\partial \psi}{\partial z} + \mathcal{K}_\psi + \mathcal{T}_\psi \tag{1}$$

where $\psi \in \{n_r, r_r\}$

$$\frac{dr_c}{dt} = \frac{1}{\tau_c} - \mathcal{K}_{r_r} \tag{2}$$

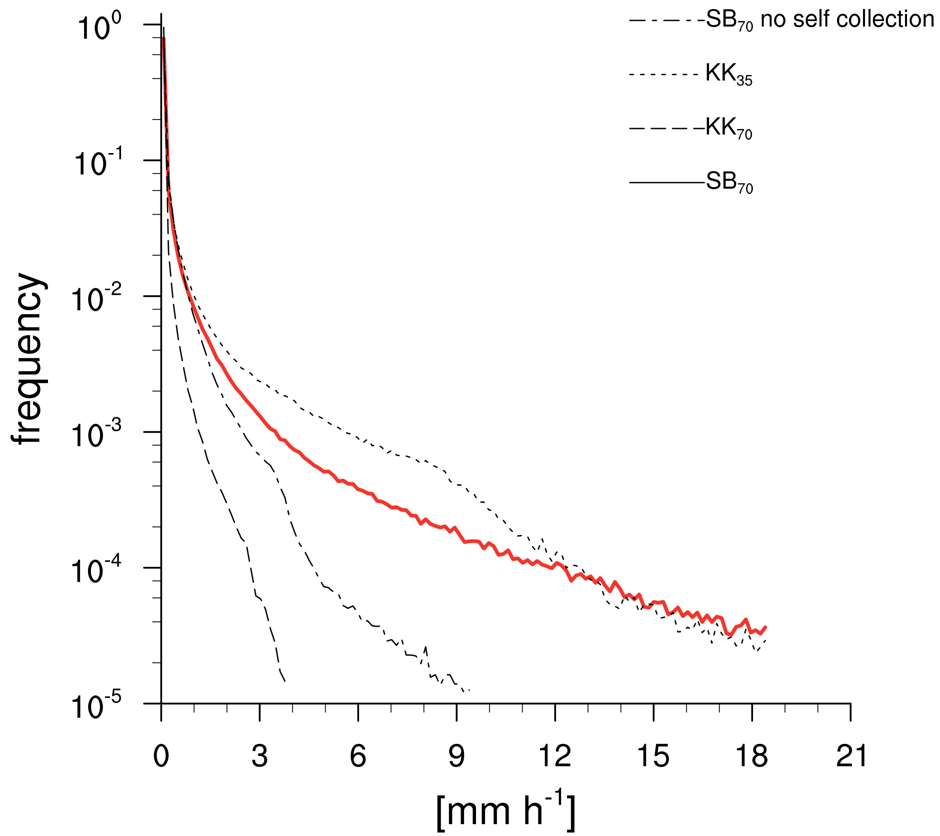


rain-production, drop-number scaling



- how rain-rate depends on drop number is model dependent.
- but the sensitivity is less than what previous analyses, which looked at a smaller part of the puzzle, suggest.

self-collection



remarks (iii)

- Micro-physical development of clouds within the simulations is qualitatively plausible, and seemingly simple.
- Simple models show some skill in predicting the impact of microphysical assumptions on the development of rain.
- These show that the relationship between rain and cloud droplets number, even in rather idealized contexts, remains poorly constrained but different than one would predict based on an analysis of single processes (auto-conversion) in isolation.
- Physical processes neglected for stratocumulus (self-collection) appear important for cumulus.

Summary

- Shallow cumulus appear to play an important and uncertain role in the climate system.
- The physics of non-precipitating shallow cumulus appears relatively straightforward.
- Precipitation acts to arrest the growth of the cloud layer, which is one reason the response of the clouds to precipitation is uncanny.
- But microphyiscal processes appear to play a non-trivial role but meteorological factors dominate those associated with the aerosol.

- Microphysical evolution of the clouds appears relatively simple and in accord with predictions of simpler models, but nonetheless model, and resolution dependent.
- The representation of such processes within the MMF is unlikely to be well done with horizontal grids coarser than a few hundred meters; d*x* = 1 km (with dz = 100 m or less) would be my plausibility boundary in the absence of more sophisticated sub-grid-scale physics.
- Full-featured microphysical representations are necessary to produce realistic distributions of the rain.