The Sources of Uncertainties in Simulating Shallow Cumulus-to-Stratus Cloud Transitions in MMF and CAM5

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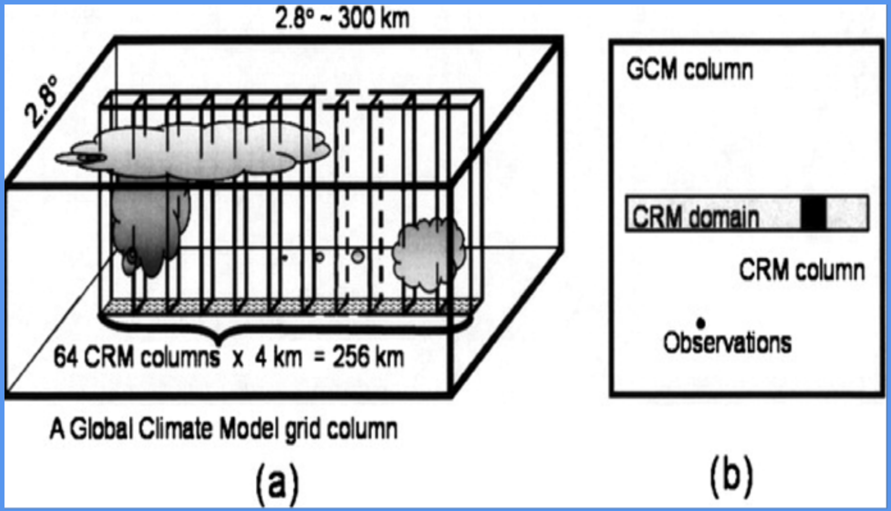
Multiscale Modeling Framework

(Grabowski 2001; Khairoutdinov and Randall 2001)

SPCAM: SAM CRM

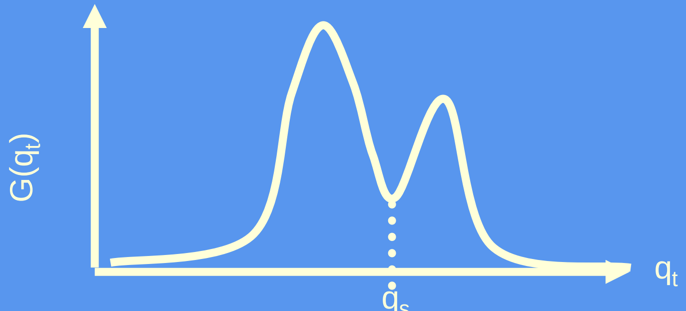
- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1 km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)



SPCAM-IPHOC: SAM CRM

upgraded with a third-order turbulence closure (IPHOC)

- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity
- Skewnesses, i.e., the three third-order moments, predicted
- All first-, second-, third- and fourth-order moments, subgrid-scale condensation (cloud fraction) and buoyancy based on the same PDF

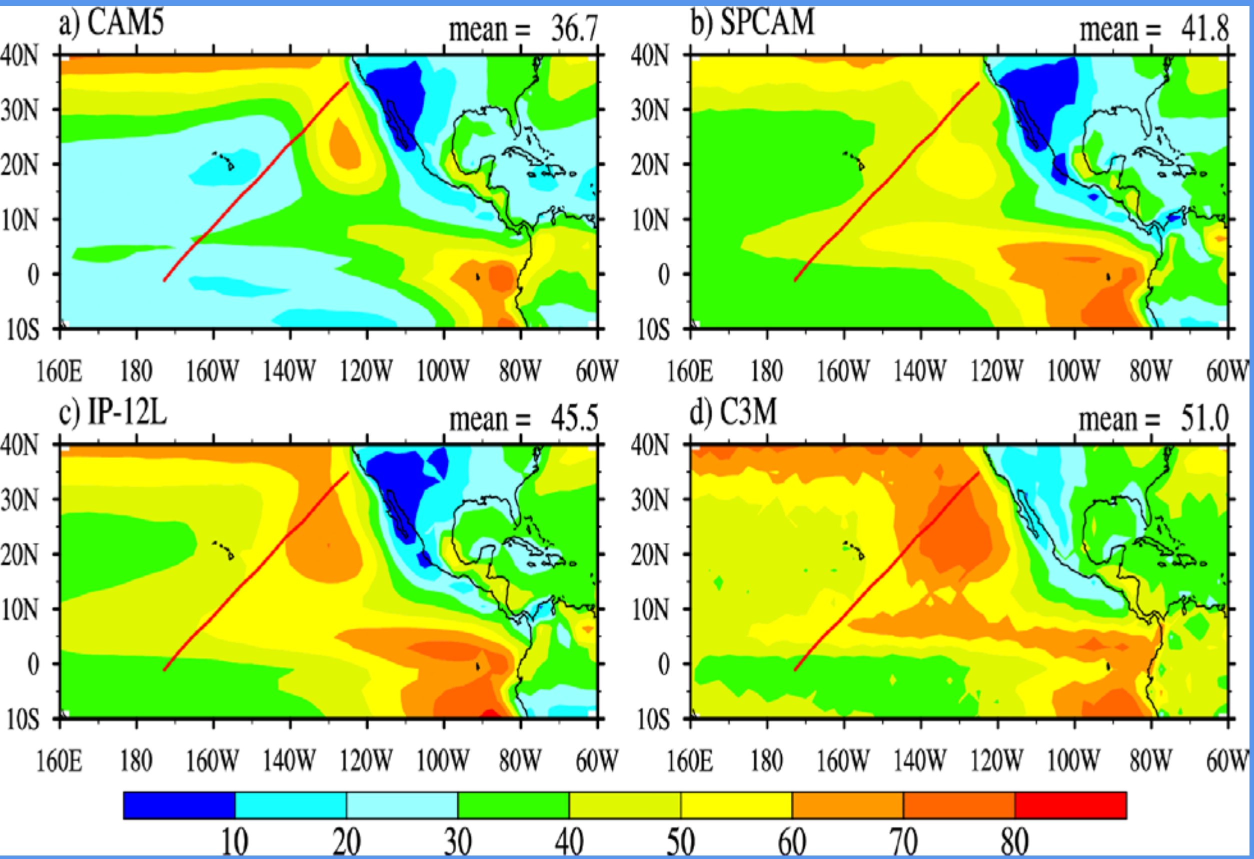


CAM5 PBL processes

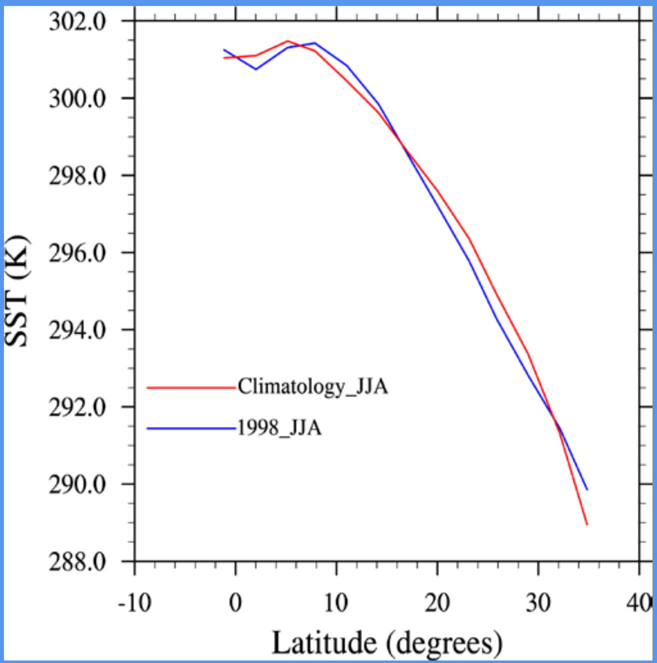
- Nonlocal turbulence diffusion.
- Mass flux type shallow cumulus cloud parameterization.
- Entrainment and detrainment parameterized by the buoyancy sorting.
- Model states updated by sequential-split approach.
- Triggers needed for shallow, stratus, and deep convection cloud transition.

Why the GPCI transect? Transitions from tropical deep convection, tradewind cumulus to stratocumulus

Low cloud cover for June-July-August (JJA)



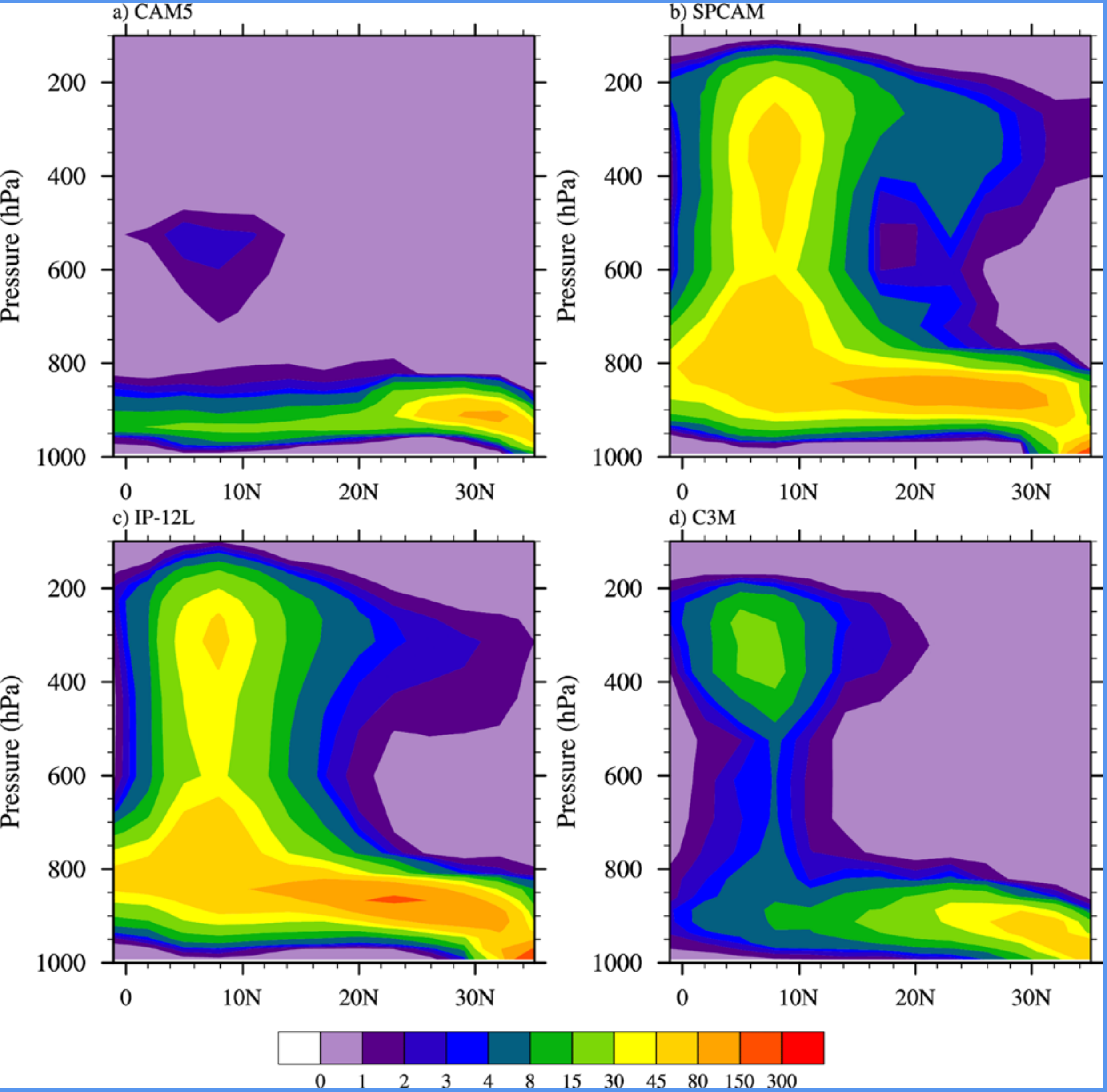
Sea surface temperature



Similarity of the MMF simulations with Cloudsat, CALIPSO, CERES and MODIS (C3M) observations

However, transition from stratocumulus (near coast) to cumulus occurs too early along the tradewind trajectory for CAM5

Total cloud condensate (liquid + ice)



- CAM5 simulates the liquid water content in the stratocumulus region well, but lacks condensate in the middle and upper troposphere of the convective region, which is a known issue that related to coupling between macro- and microphysical parameterizations;
- Both MMFs overestimate liquid (+ice) water content throughout the transect, some of which may be due to satellite retrieval limitations. Another reason is the cloud-radiation interactions resulted from inadequate treatment of subgrid-scale cloudiness.

Total cloud condensate (liquid + ice) from other GCMs

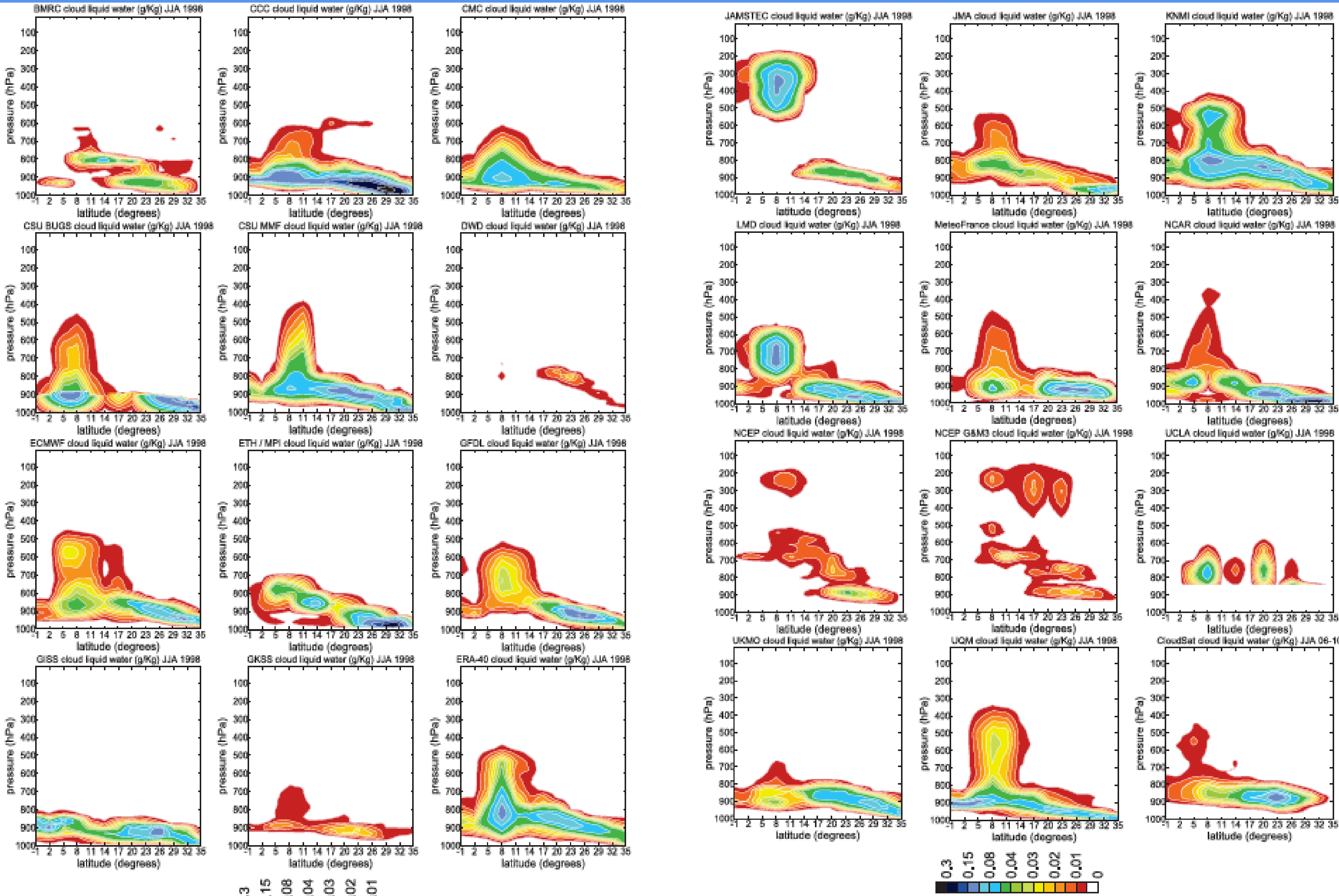
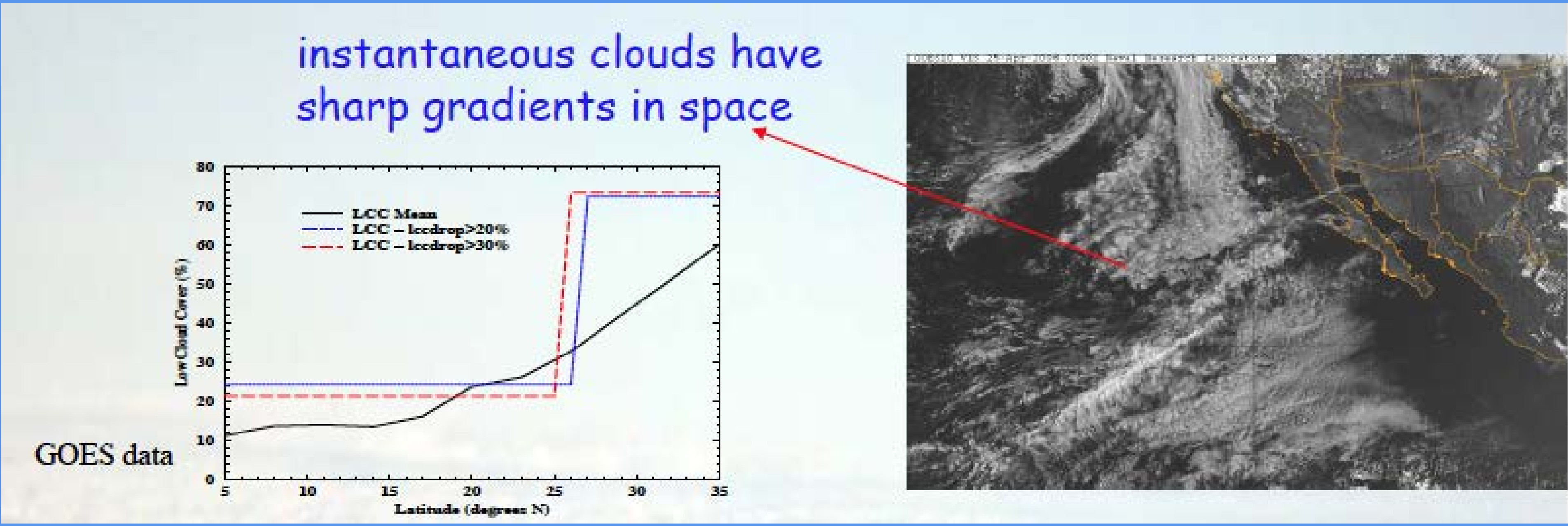


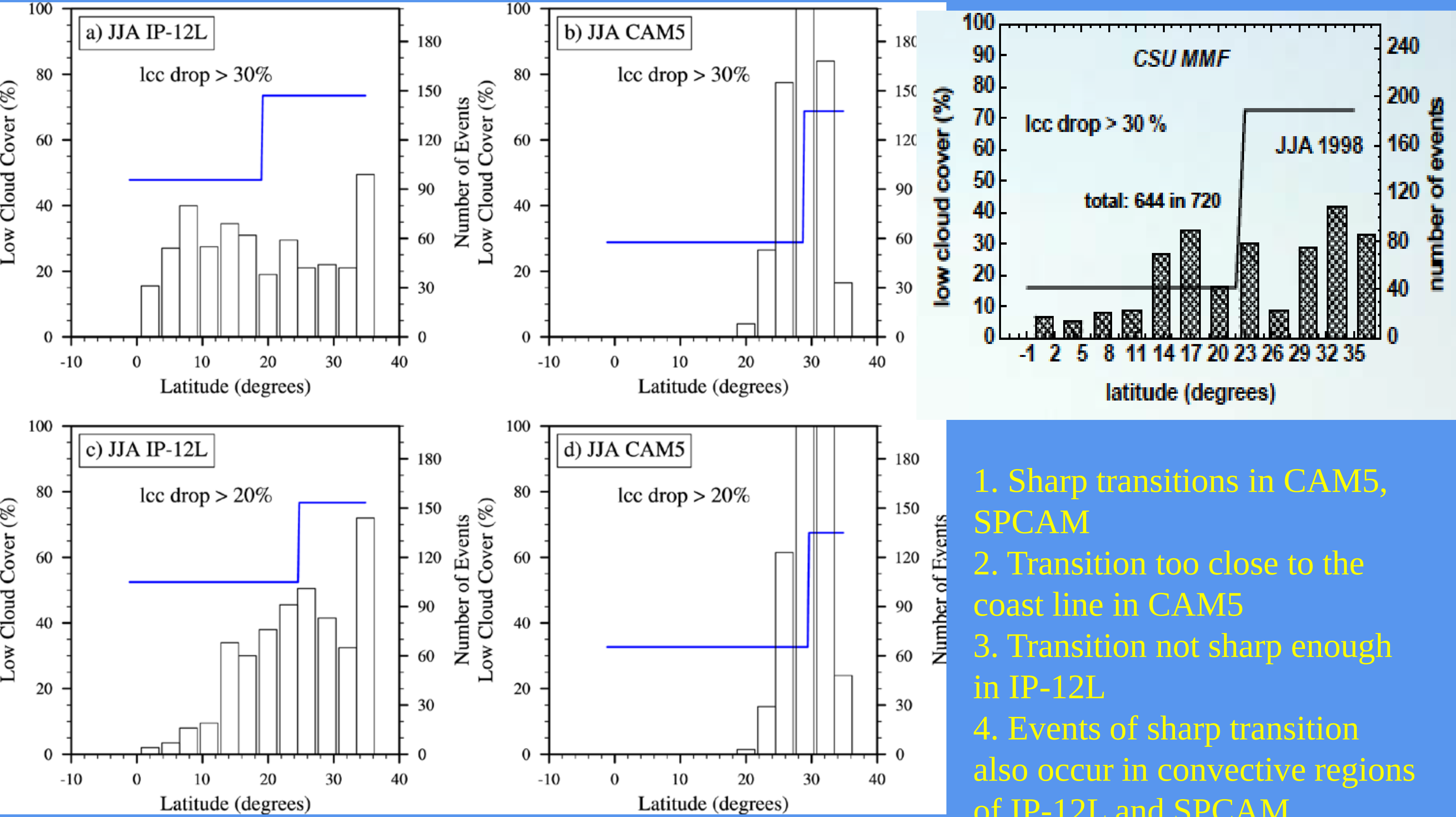
FIG. 12. (*Continued*)

Statistics of instantaneous transitions: Method



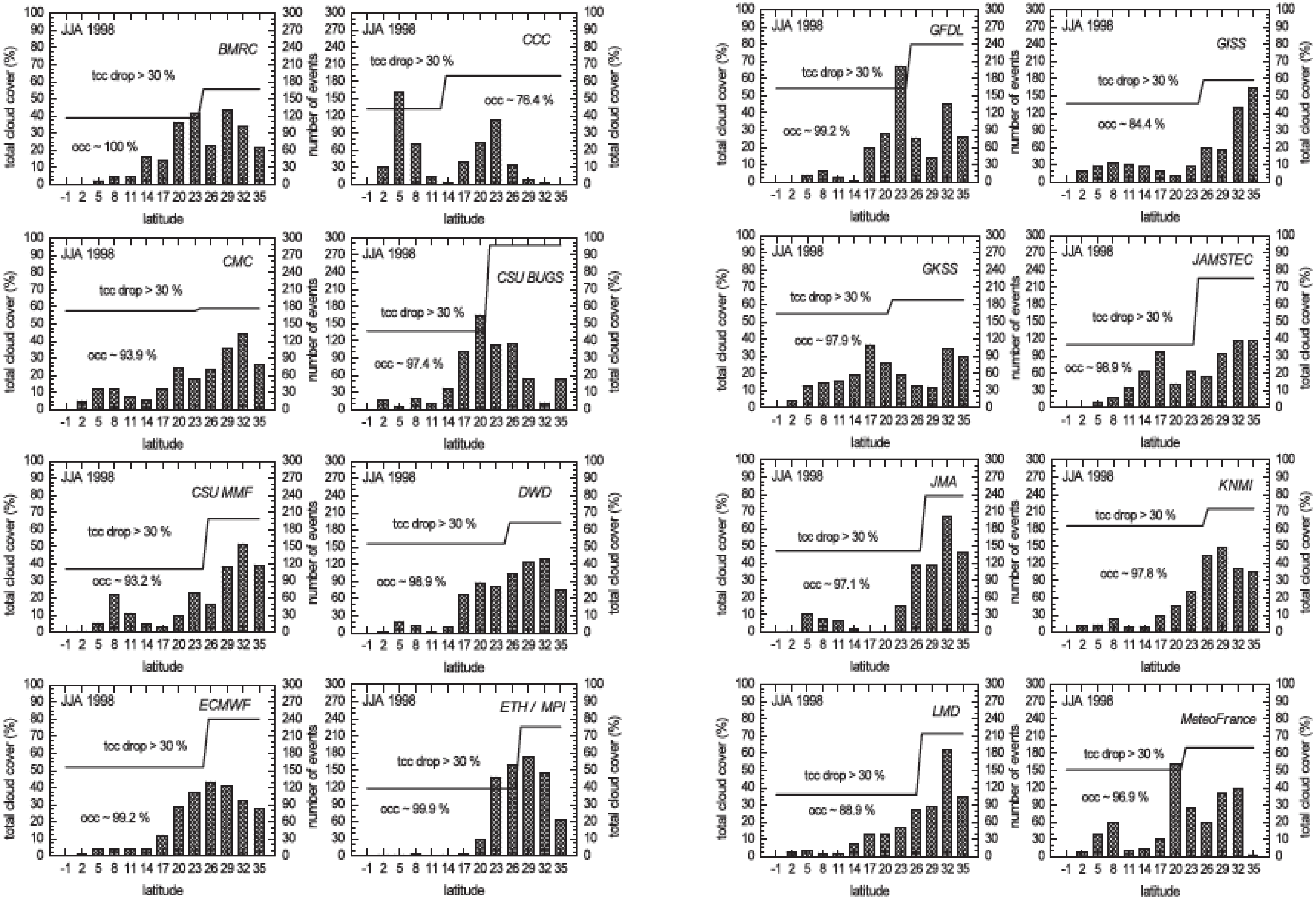
The Teixeira et al. (2011) method determines
i)the location of the first sharp gradient in LCC by 30% along the transect starting at the northernmost point in the stratocumulus region and
ii)uniform cloud cover to the northeast and southwest of the gradient's location by taking the spatial averages of LCC for all the points to each side of the location of the sharp gradient.

Statistics of instantaneous transitions: Results

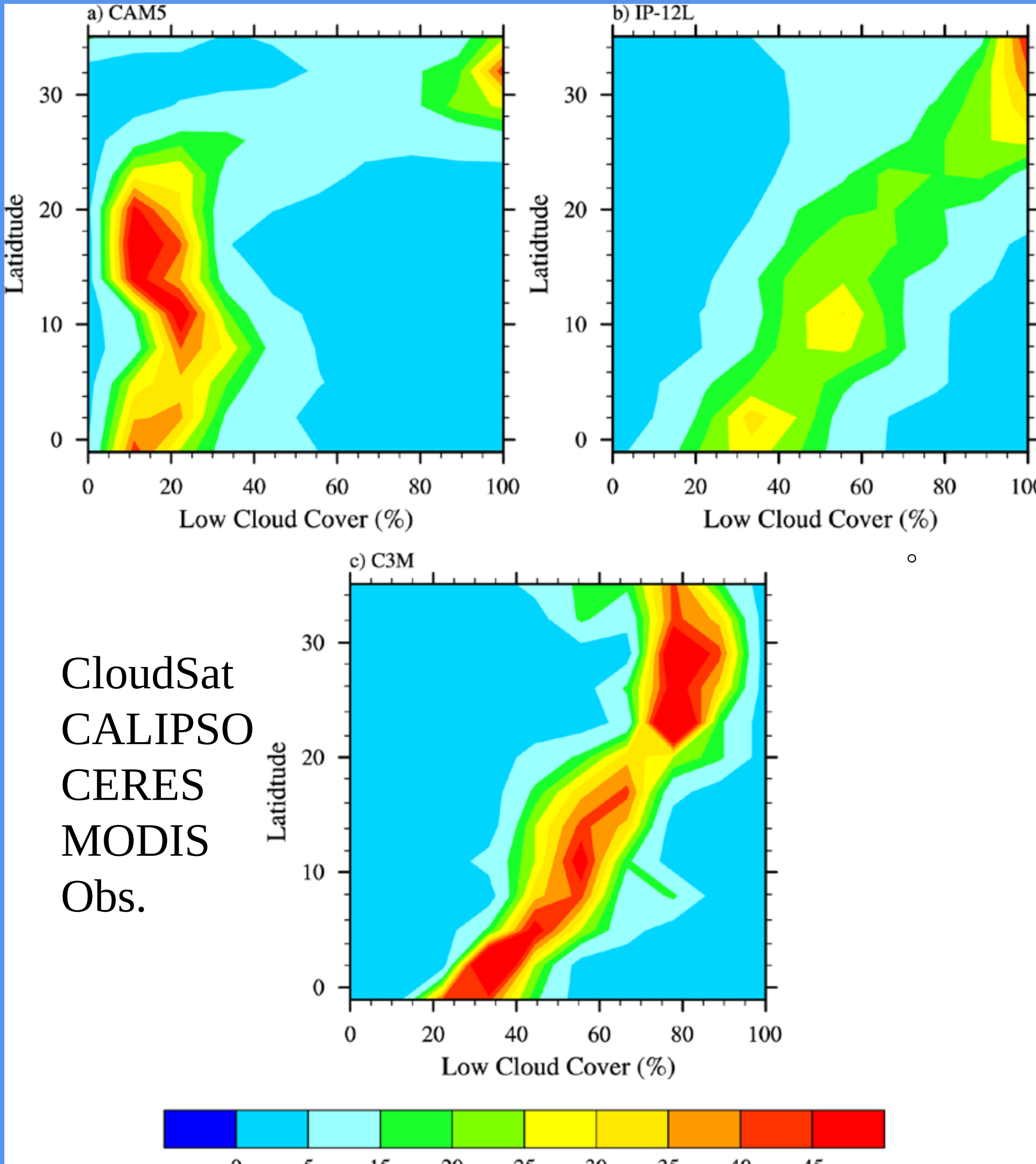


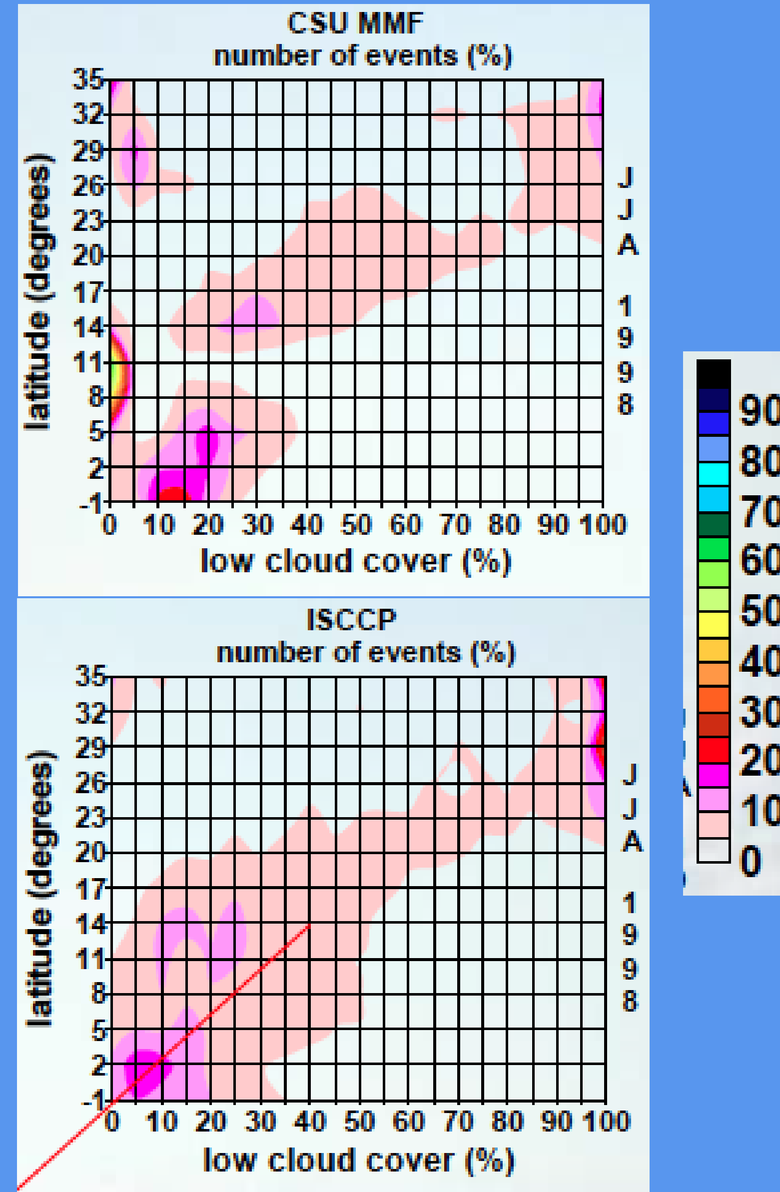
1. Sharp transitions in CAM5, SPCAM
2. Transition too close to the coast line in CAM5
3. Transition not sharp enough in IP-12L
4. Events of sharp transition also occur in convective regions of IP-12L and SPCAM

Instantaneous Transitions from other GCMs



Histogram of low cloud cover



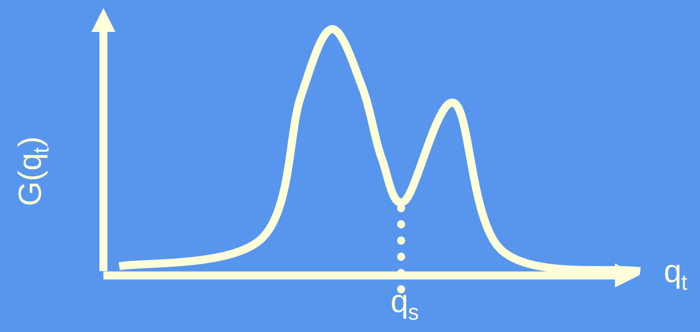


Discussions

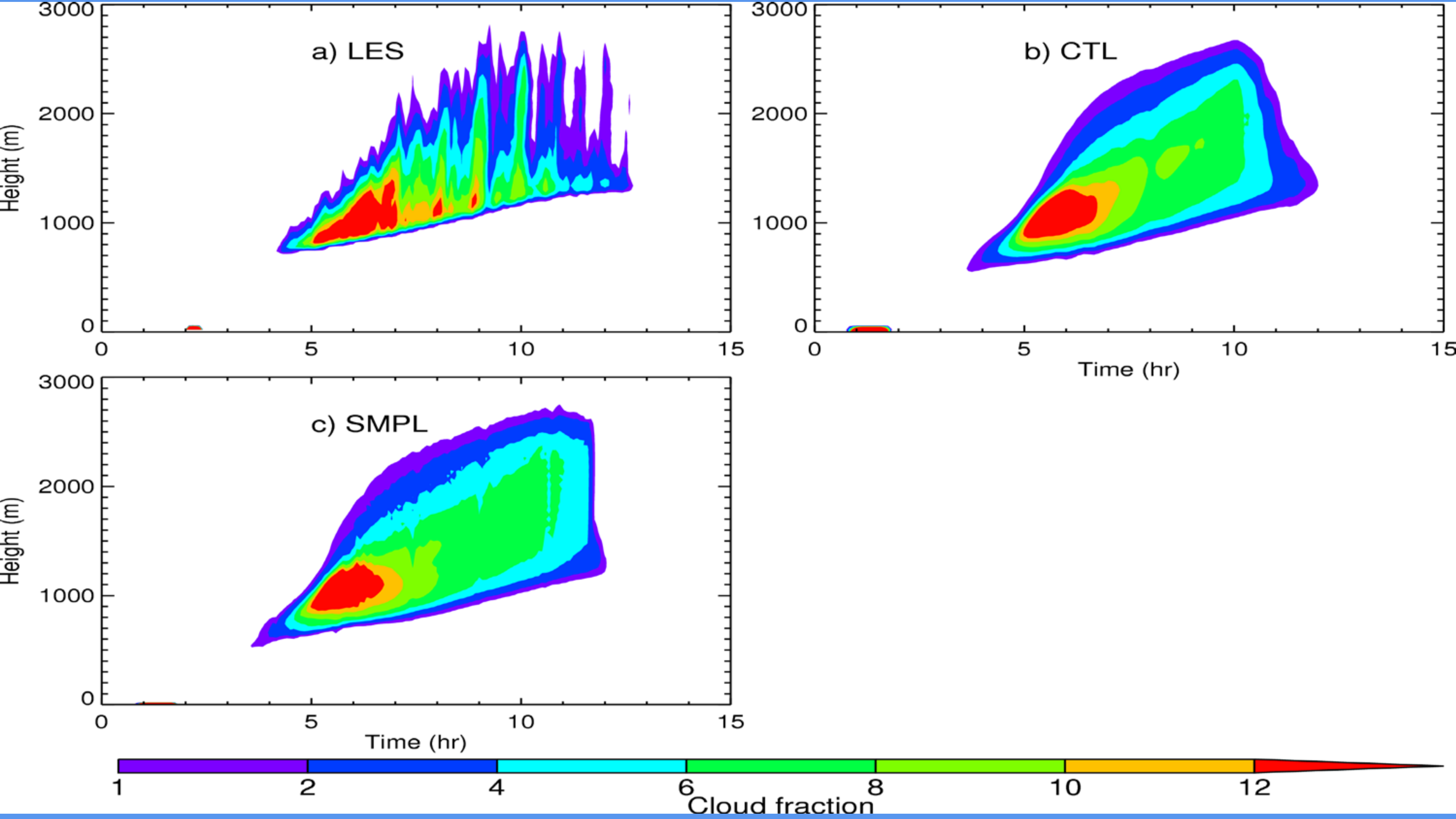
- There are large uncertainties in simulating shallow cumulus to stratus cloud transition for both MMFs and traditional GCMs.
- The uncertainties from IPHOC (Intermediately Prognostic Higher-order Turbulence Closure) to simulate the transition closely tied to the joint pdf and higher-moments. Entrainment and detrainment are implicitly represented, although they are major sources of uncertainties for mass flux schemes. The results are highly sensitive to vertical resolution for all approaches.
- IPHOC shows strong abilities to simulate shallow cumulus to stratus cloud transition along GPCI transect from an upgraded MMF.
- How about implementing it directly in CAM5 bypassing CRM?

Simplified IPHOC

- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity.
- Forecasted second moment of vertical velocity, and vertical fluxes of liquid water potential temperature and total water.
- Diagnosed all other higher-order moments needed to determine the pdf.

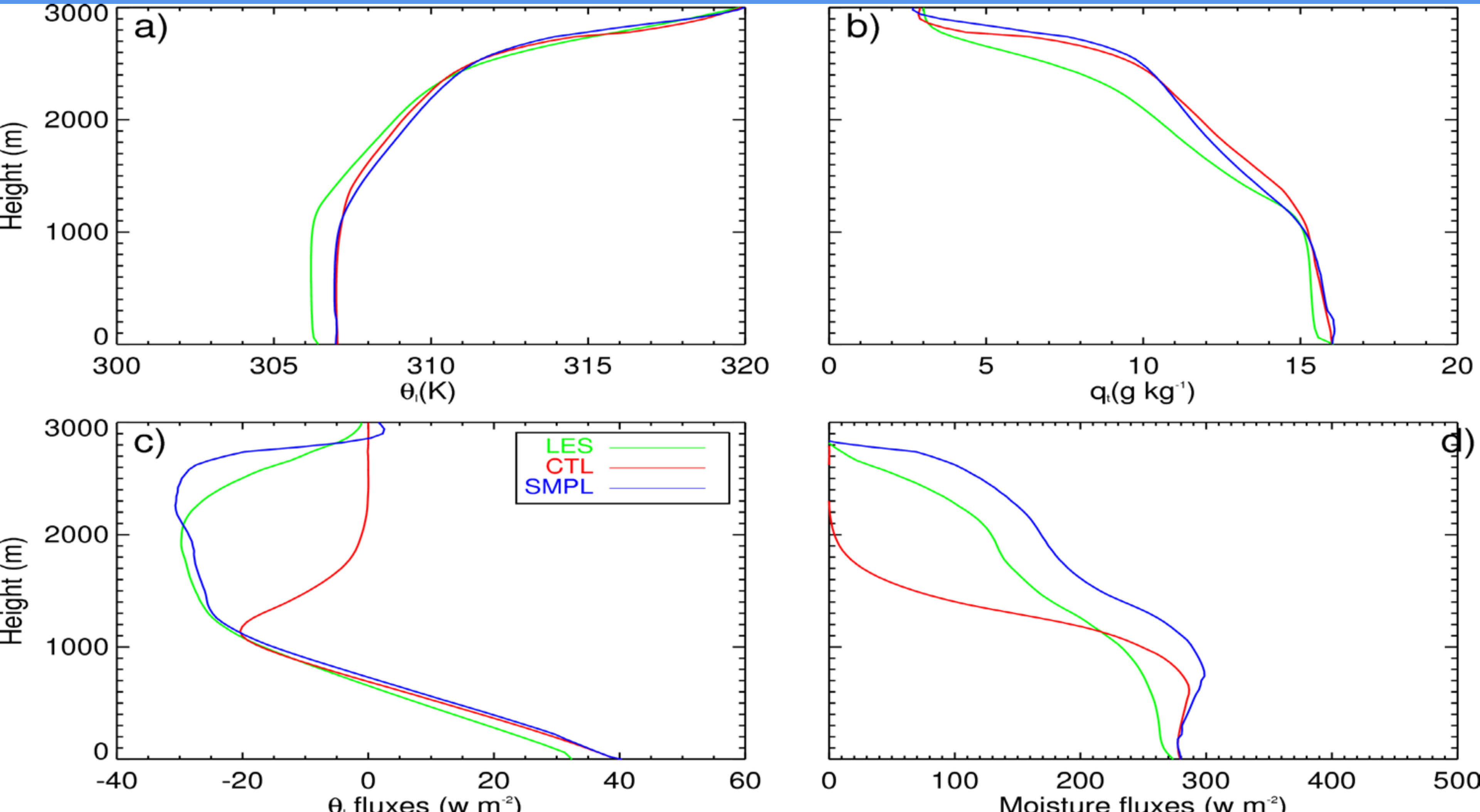


Cloud evolutions for ARM



Clouds from SMPL lasted longer

Mean Profiles and Fluxes at Hours 11 for ARM



Fluxes from SMPL compared well with LES.

Discussions

- Simplification of IPHOC does not necessarily deteriorate results in some cases.
- Forecasting the turbulence kinetic energy and the vertical liquid water potential temperature and moisture fluxes reasonably well is important for a reasonable simulation of the ARM case
- The parameterization of the dissipation rate and the evolution of the joint pdf are major sources of uncertainties in IPHOC.
- More observational data such as the higher-order moments and the joint pdfs of many variables from ASR are needed to further constrain the assumptions of the IPHOC parameterization.