GPCI Tropical Cloud and Subtropical Cloud Transitions Simulated from CAM5, SPCAM and SPCAM-IPHOC

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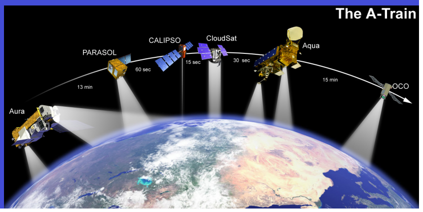
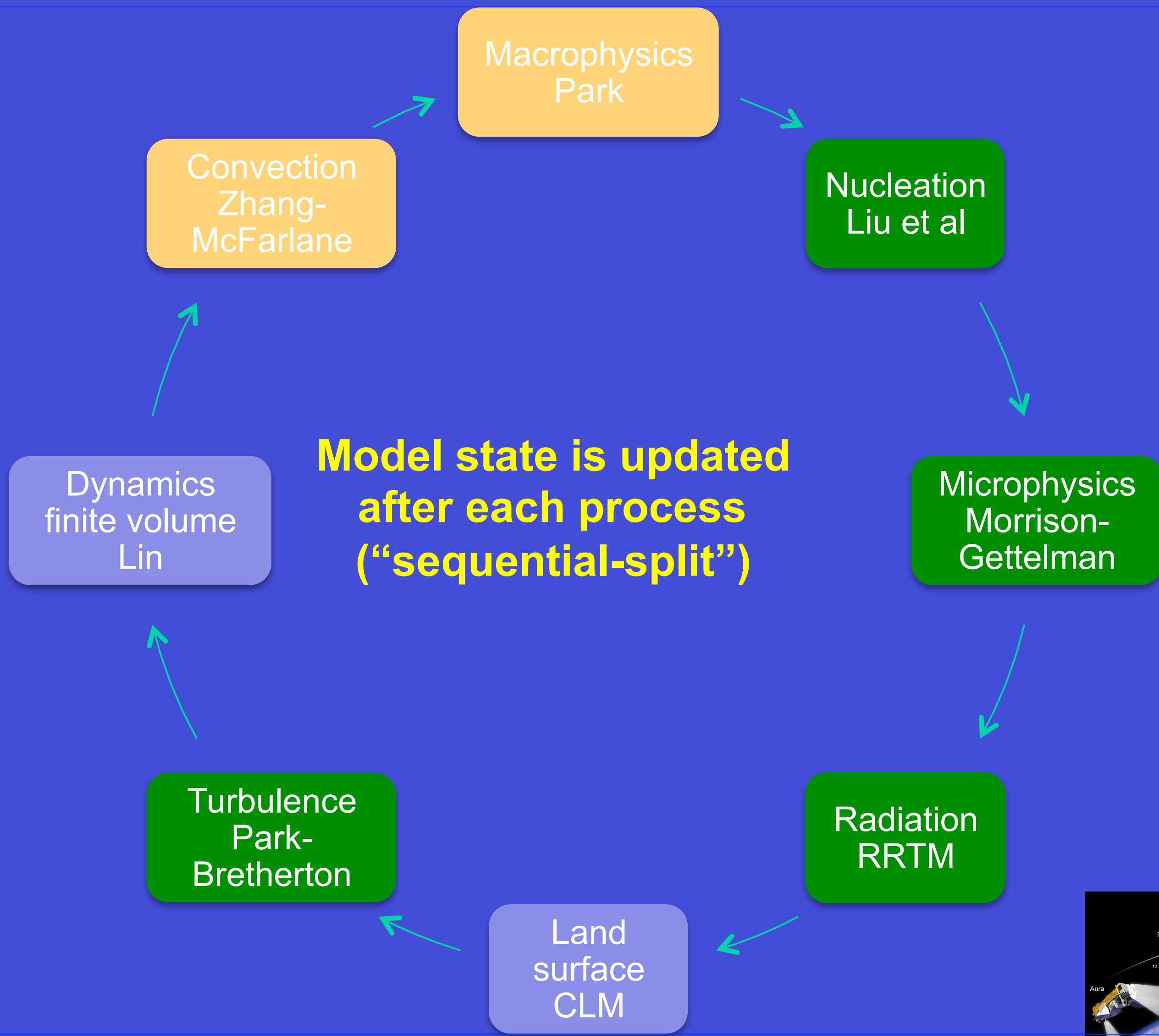
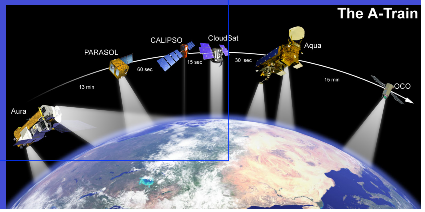
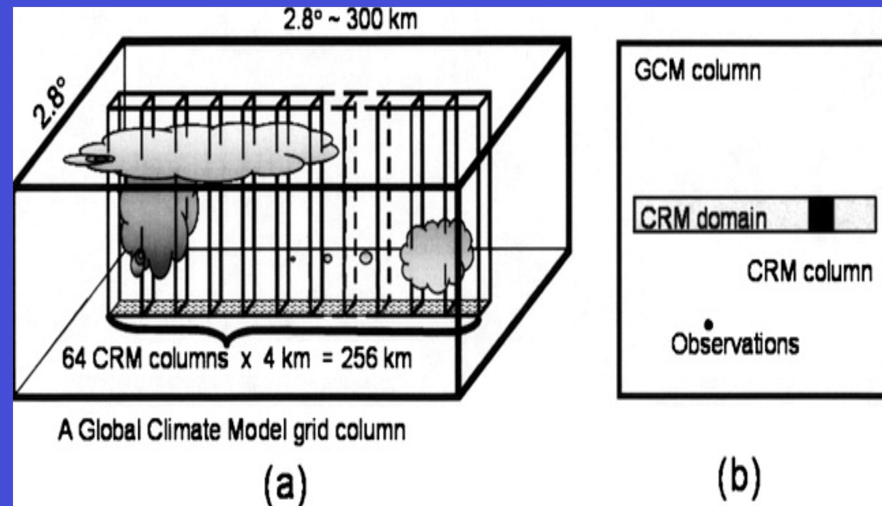


CAM5 (Community Atmosphere Model version 5)





Multiscale Modeling Framework
(Grabowski 2001; Khairoutdinov and Randall 2001)



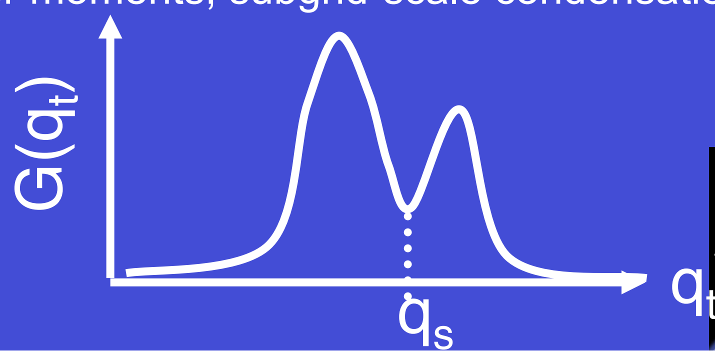
SPCAM: SAM CRM

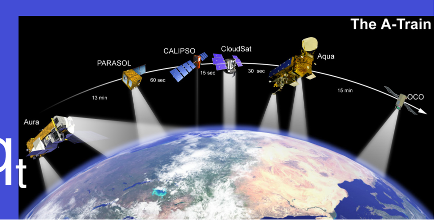
- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1s km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)

SPCAM-IPHOC: SAM CRM

upgraded with a third-order turbulence closure (IPHOC)

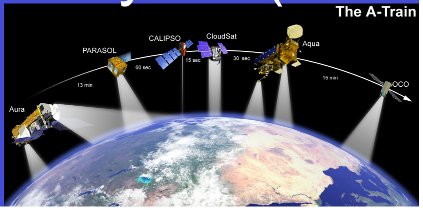
- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity
- Skewnesses, i.e., the three third-order moments, predicted
- All first-, second-, third- and fourth-order moments, subgrid-scale condensation (cloud fraction) and buoyancy based on the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





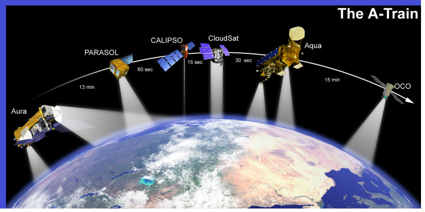
CAM5, SPCAM, SPCAM-IPHOC climate simulation

- The MMF models are based on CAM3.5 with finite-volume dynamic core as the host GCM.
- The CRM is the 2-D version of System for Atmospheric Modeling (SAM) in SPCAM, but SAM with IPHOC higher-order turbulence closure in SPCAM-IPHOC, the grid spacing is 4 km, with 32 columns within a GCM grid box.
- All simulations: grid spacing of 1.9°x2.5°; doubling the number of levels below 700 hPa (6 to 12); the total number of vertical layers is 32 in both MMF models, but 30 in CAM5.
- The simulations are forced with climatological SST and sea ice distributions (not an AMIP simulation).
- Simulation duration is 10 years; with last nine years analyzed (Xu and Cheng 2012a,b; *J. Climate*, submitted).



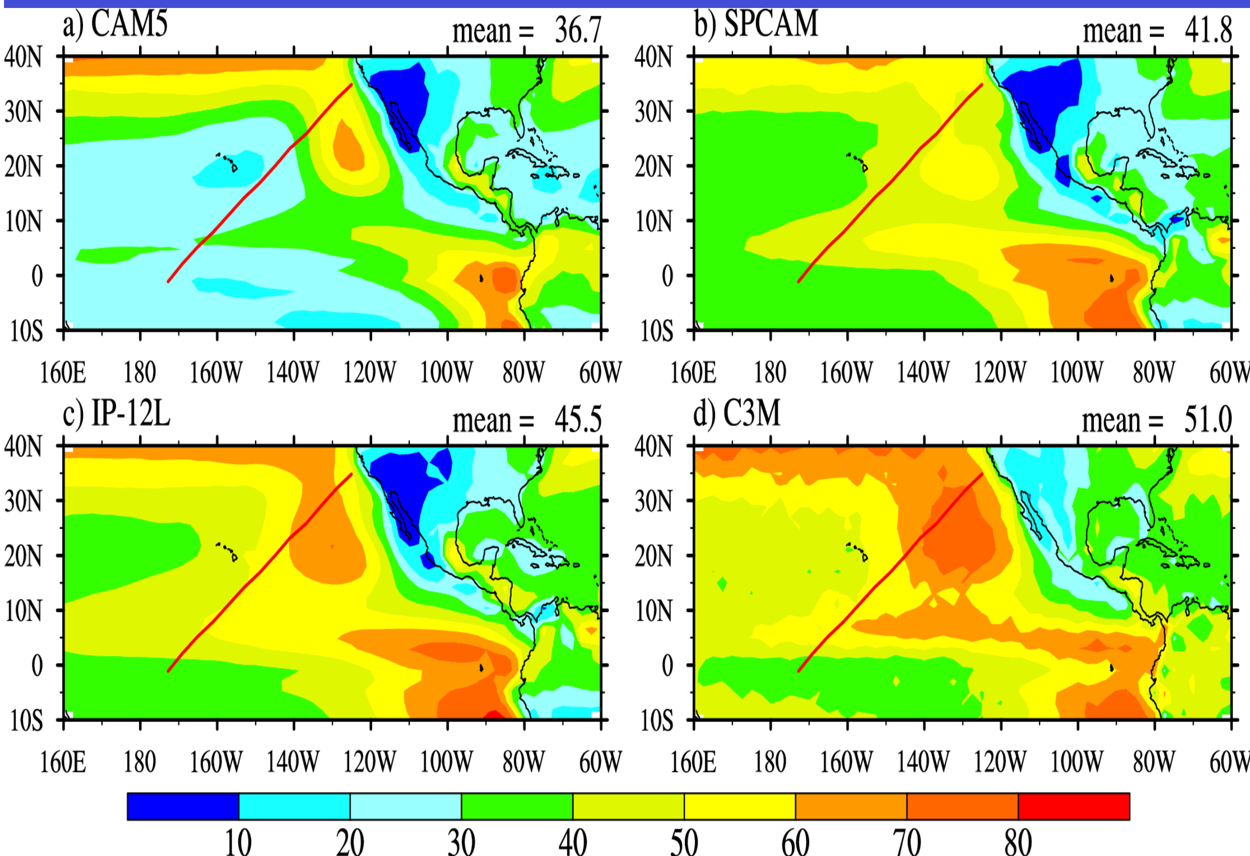
Results presented in this study

- Seasonal means: 27 months integrations of CAM5, SPCAM and SPCAM-IPHOC, omitting the first three months.
- Statistics of instantaneous transition: tenth year of CAM5 and SPCAM-IPHOC integrations (hourly output); SPCAM (SL dycore) from Teixeira et al. (2012)' s GCPI intercomparison study.

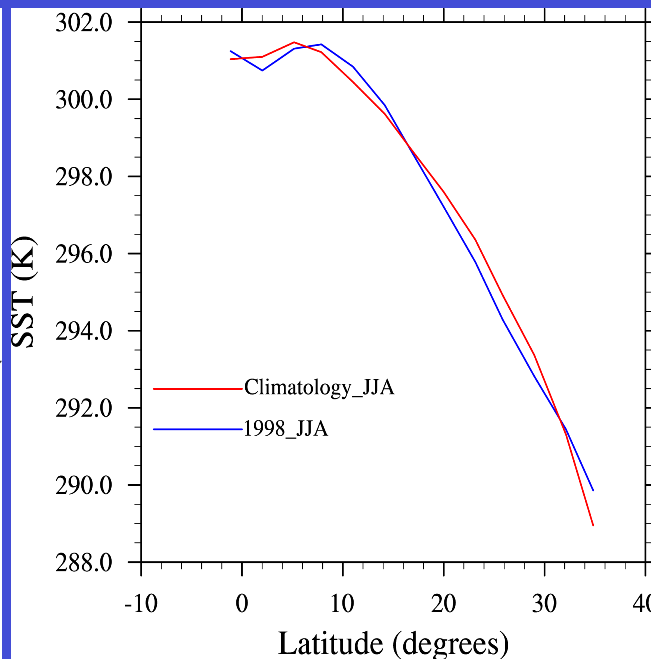


Why the GPCI transect? Transitions from tropical deep convection, tradewind cumulus to stratocumulus

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

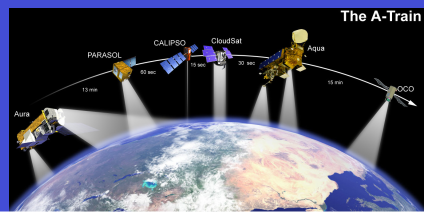


Sea surface temperature

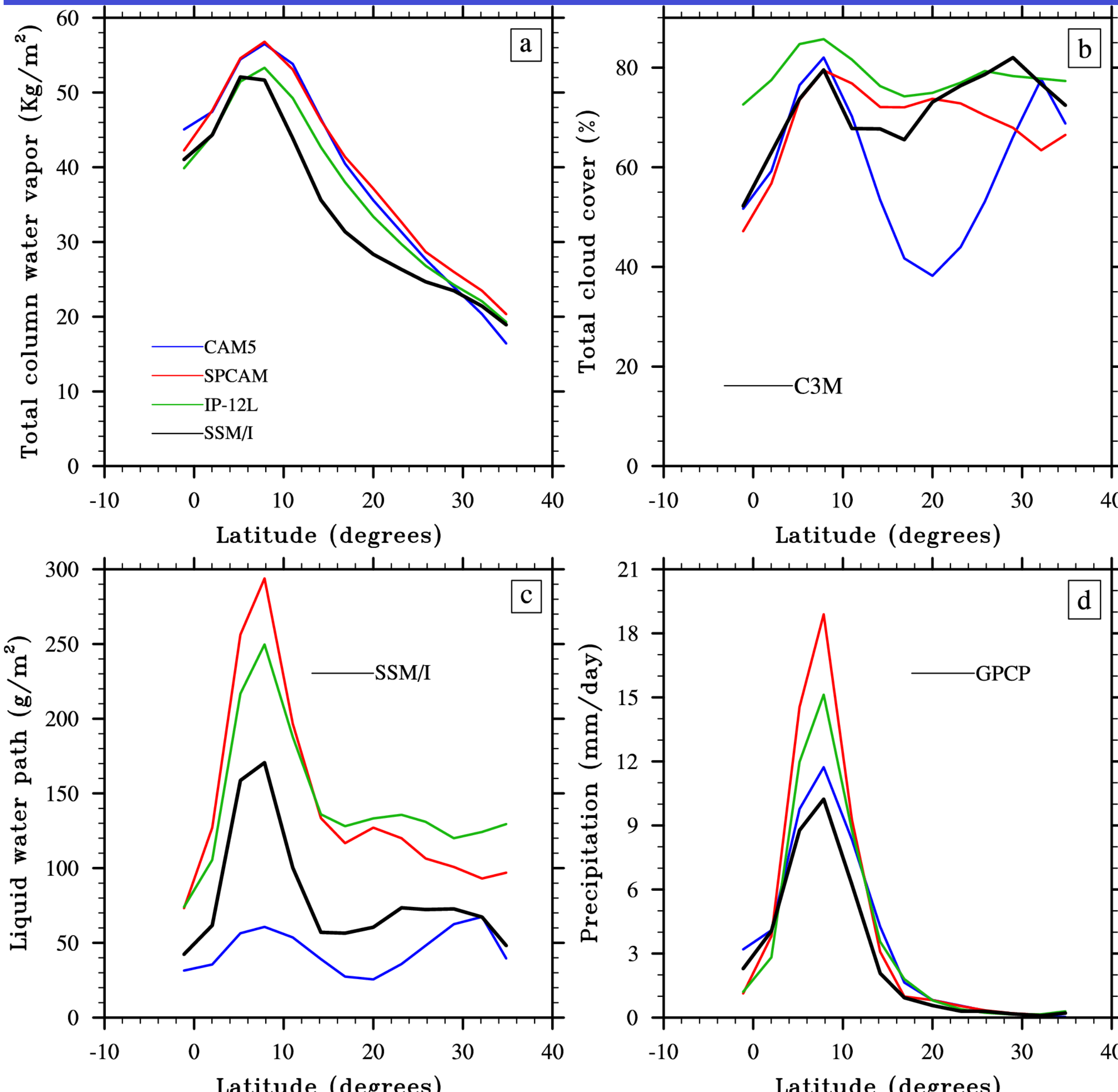


Similarity of the MMF simulations with Cloudsat, CALIPSO, CERES and MODIS (C3M) observations

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

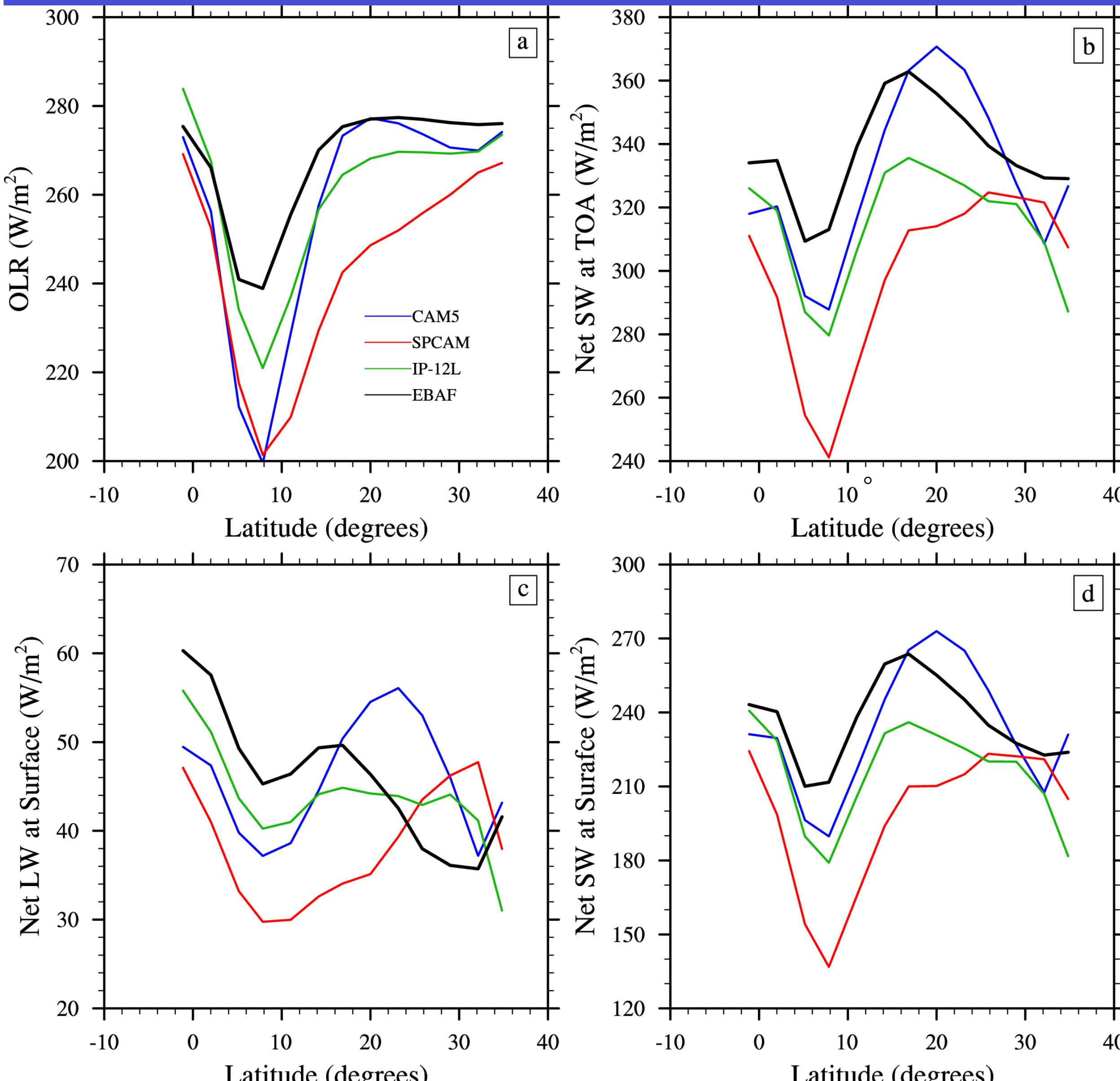


Water vapor, total cloud cover, LWP and precipitation

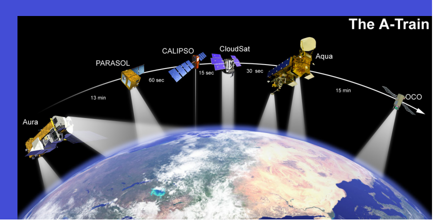


- The decrease of column water vapor from the tropics to the subtropics is well simulated, with the smallest overestimate in IP-12L (i.e., SPCAM-IPHOC)
- Large differences in total cloud cover of different regions along the transect among the models;
  - underestimates for CAM5 (except for tropics) and stratocumulus regions of SPCAM;
  - overestimates in the tropics and trade cumulus regions of IP-12L and trade cumulus regions of SPCAM
- Large differences in liquid water path from observations by a factor of two or more; with underestimates in CAM5, but overestimates in both MMFs
- Precipitation is generally overestimated in all models

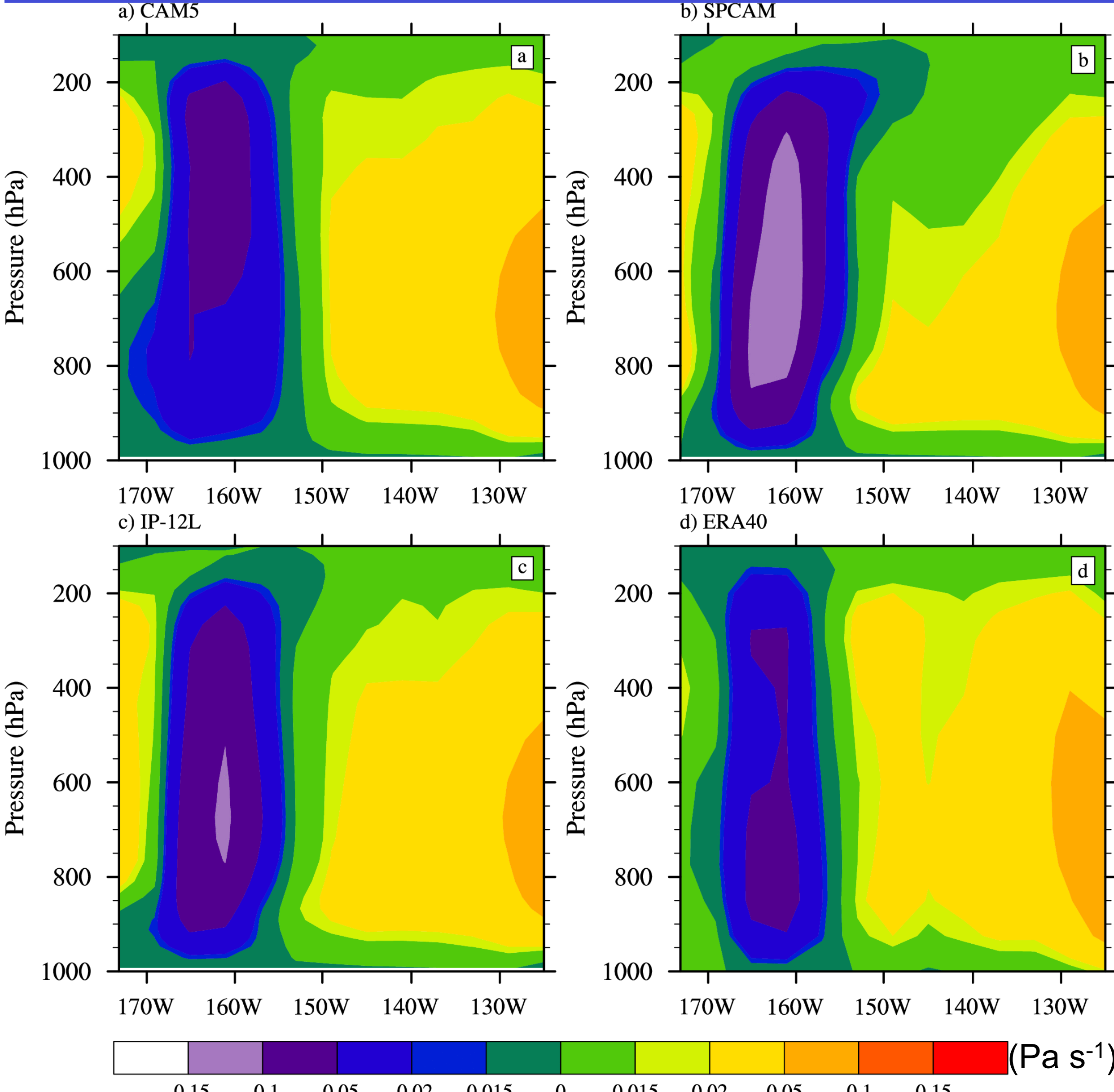
LW and SW radiative fluxes at top of the atmosphere (TOA) and surface, compared to CERES observations



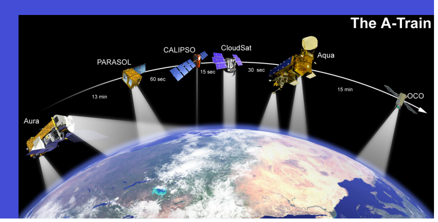
- SPCAM-IPHOC (IP-12L) simulates the cloud-regime transitions rather well, but underestimates the SW fluxes;
- CAM5 simulates the SW fluxes at TOA and surface well (CAM5 are tuned with CERES data but MMFs are not tuned), but stratocumulus-to-cumulus transition is poorly simulated (4-8° offset in the peaks);
- SPCAM has a reasonable simulation of stratocumulus region (near the coast), but the intense deep convection causes large discrepancies from CERES EBAF (Energy balanced and filled) observations.



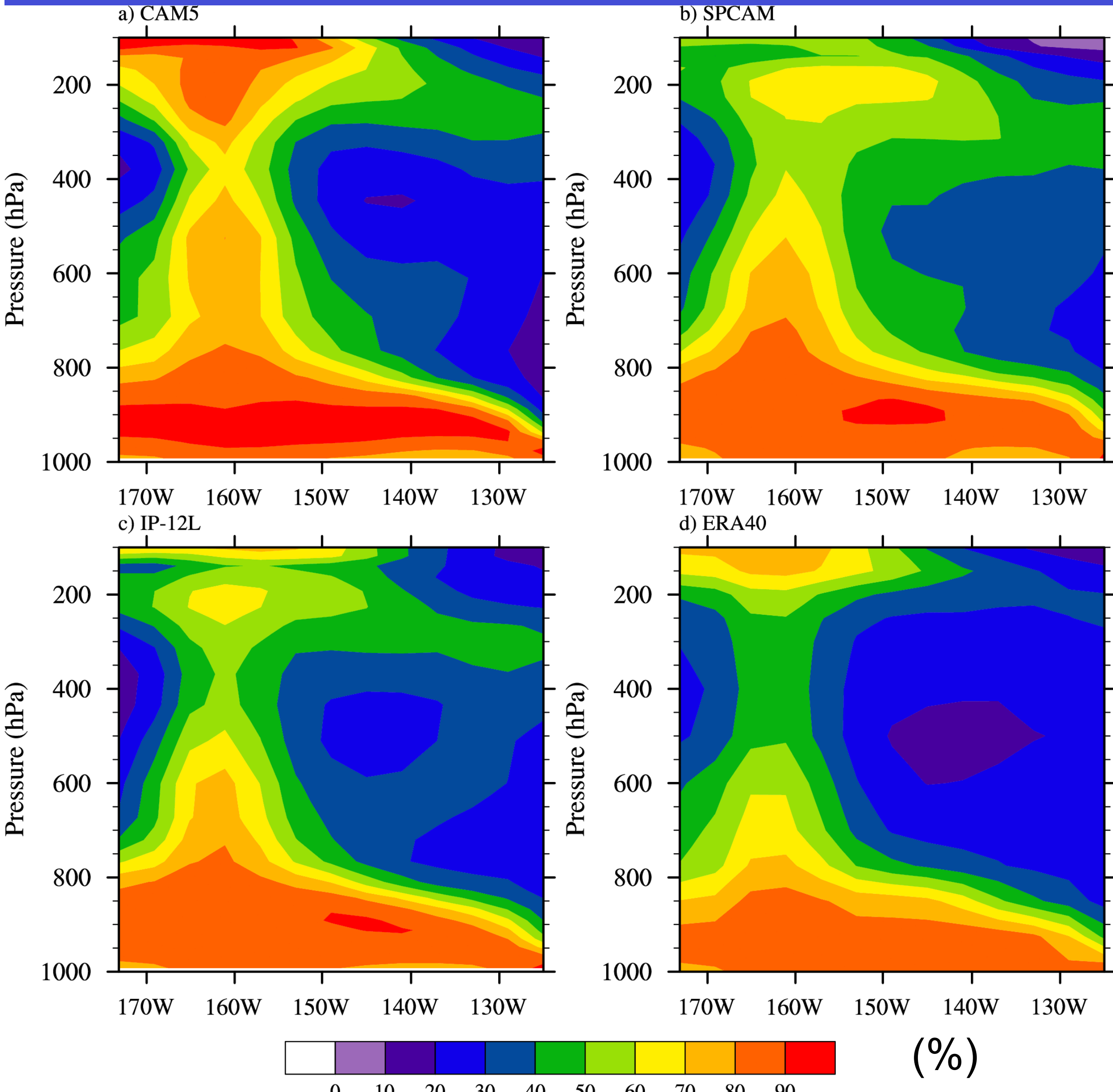
Pressure vertical velocity



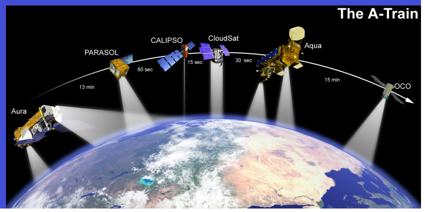
- The upward motion zone (convective region) is well simulated by SPCAM-IPHOC (IP-12L), but too wide in SPCAM, and lack of the lower tropospheric maximum in CAM5;
- The subsidence in the stratocumulus region is similar among the models;
- The subsidence in the transition region shows large differences among the models, particularly in SPCAM;
- The deep subsidence structure in the transition region of ERA40 is not duplicated by any of the climate models.



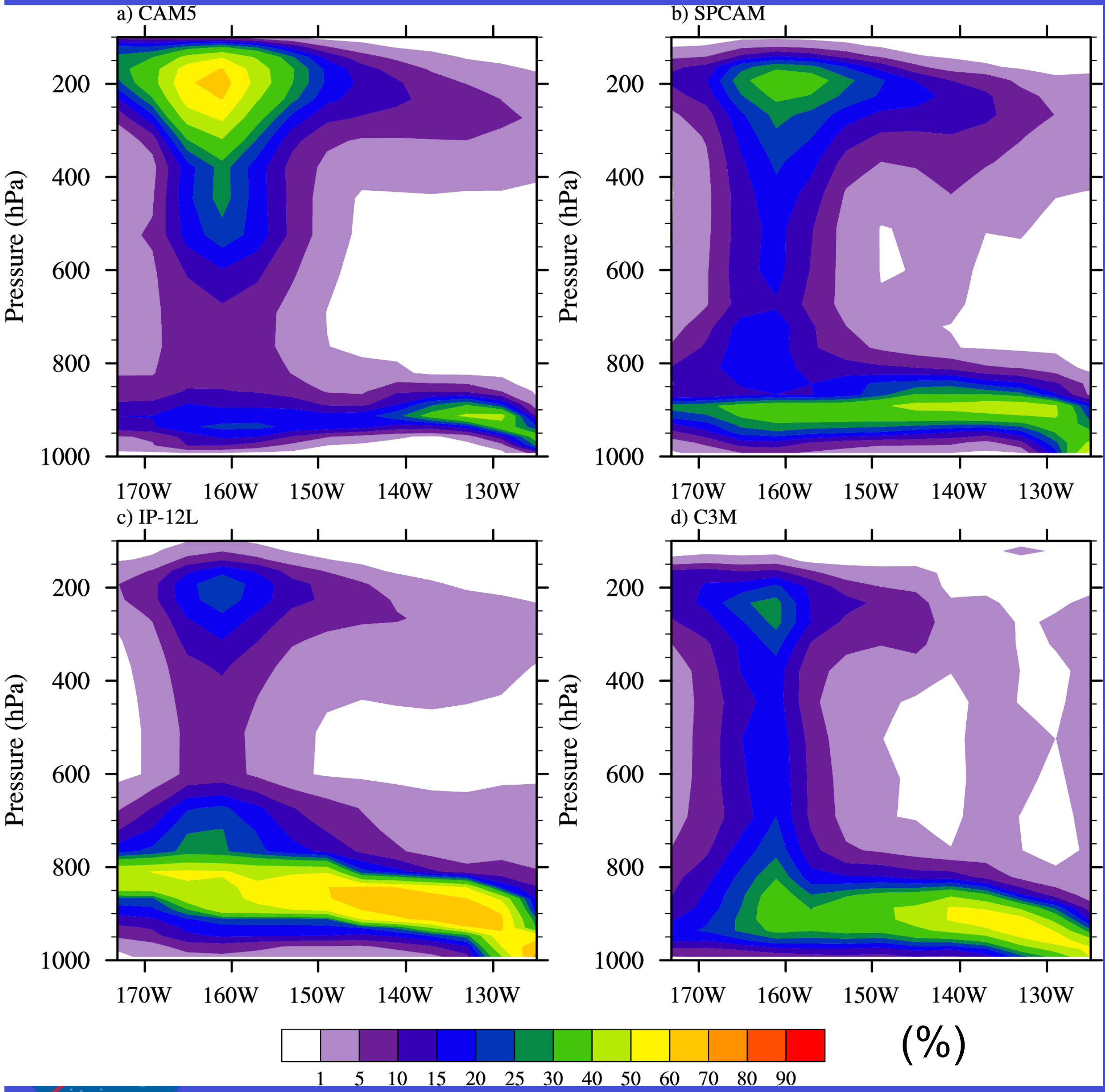
Relative humidity



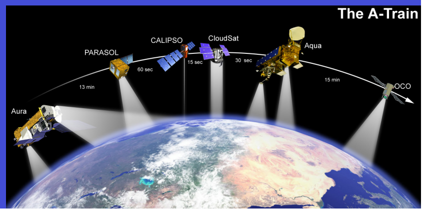
- Both the rising of boundary-layer height along the tradewind trajectory and the humid convective region are well simulated;
- The CAM5 boundary-layer and upper troposphere are more humid than the MMFs;
- The MMF middle tropospheric dry zone above the transition region is not as dry as that in CAM5 and ERA40.



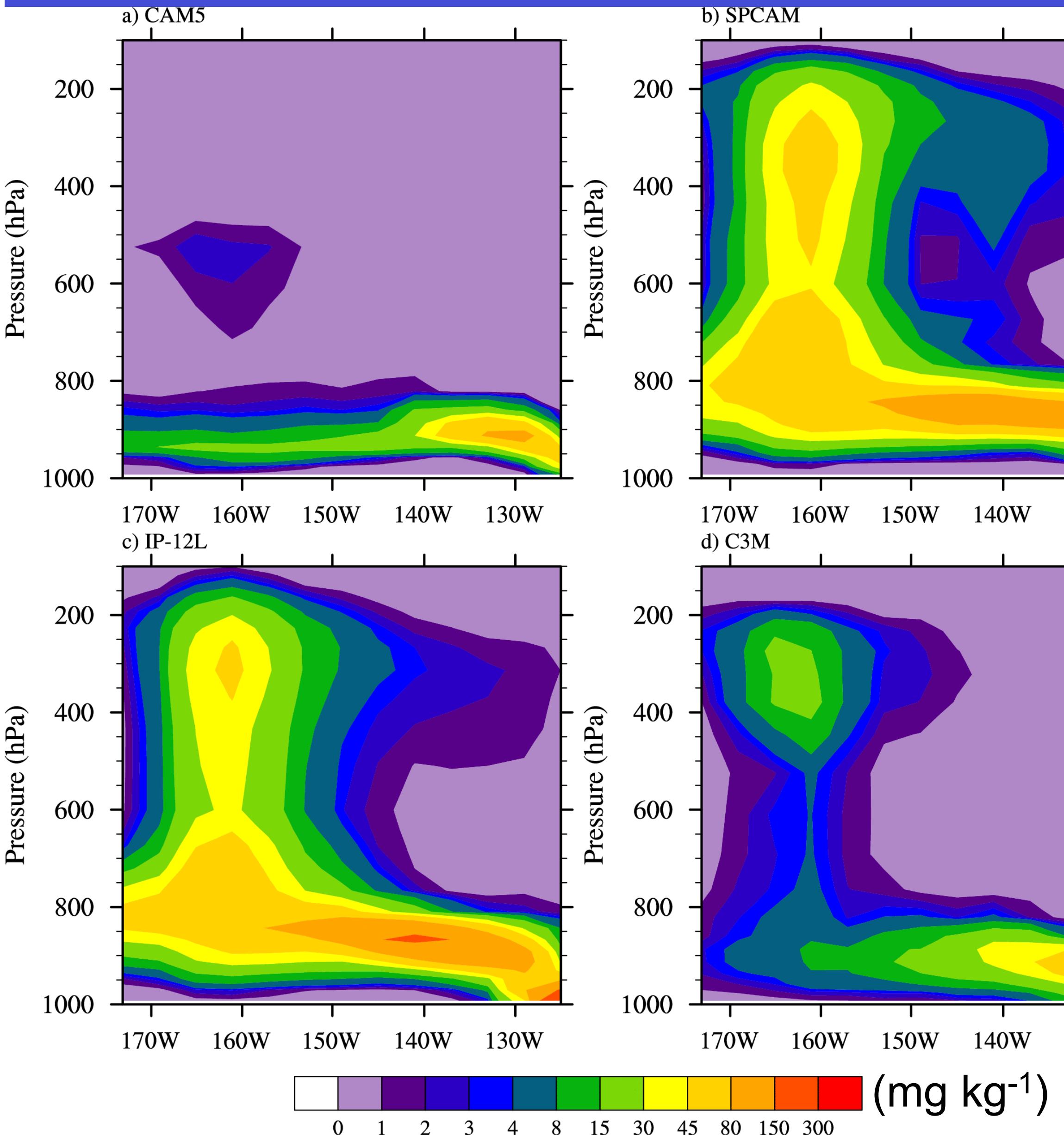
Cloud fraction



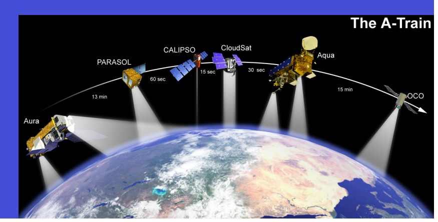
- There are great similarities in the distributions of cloud fraction with the C3M observations for all three models;
- CAM5 produces too much upper tropospheric convective anvils, but too little boundary-layer clouds, which are also vertically too thin;
- Upper tropospheric clouds in SPCAM are overestimated, but boundary-layer clouds are overly too thin and underestaimted;
- Boundary-layer clouds in IP-12L have similar thicknesses with observations, but overestimated in cloud fraction.



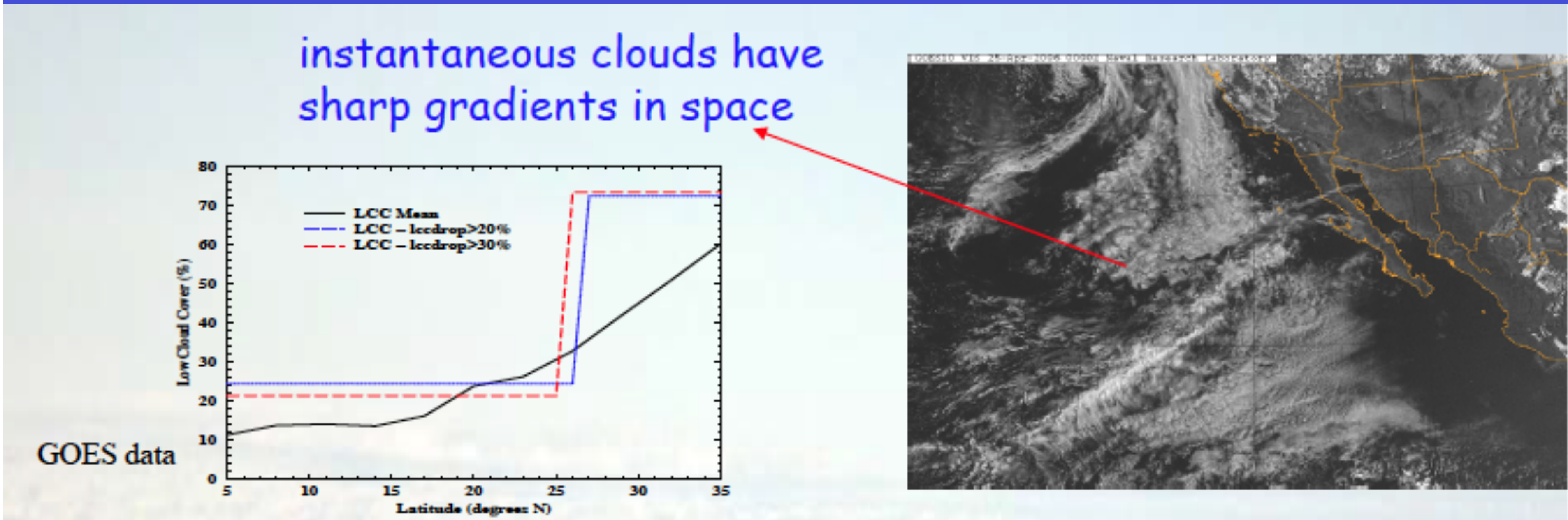
Total cloud condensate (liquid + ice)



- 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.



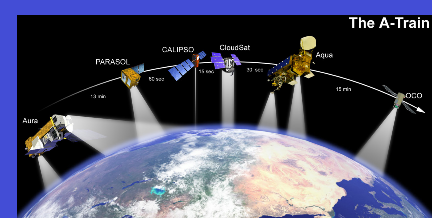
Statistics of instantaneous transitions: Method



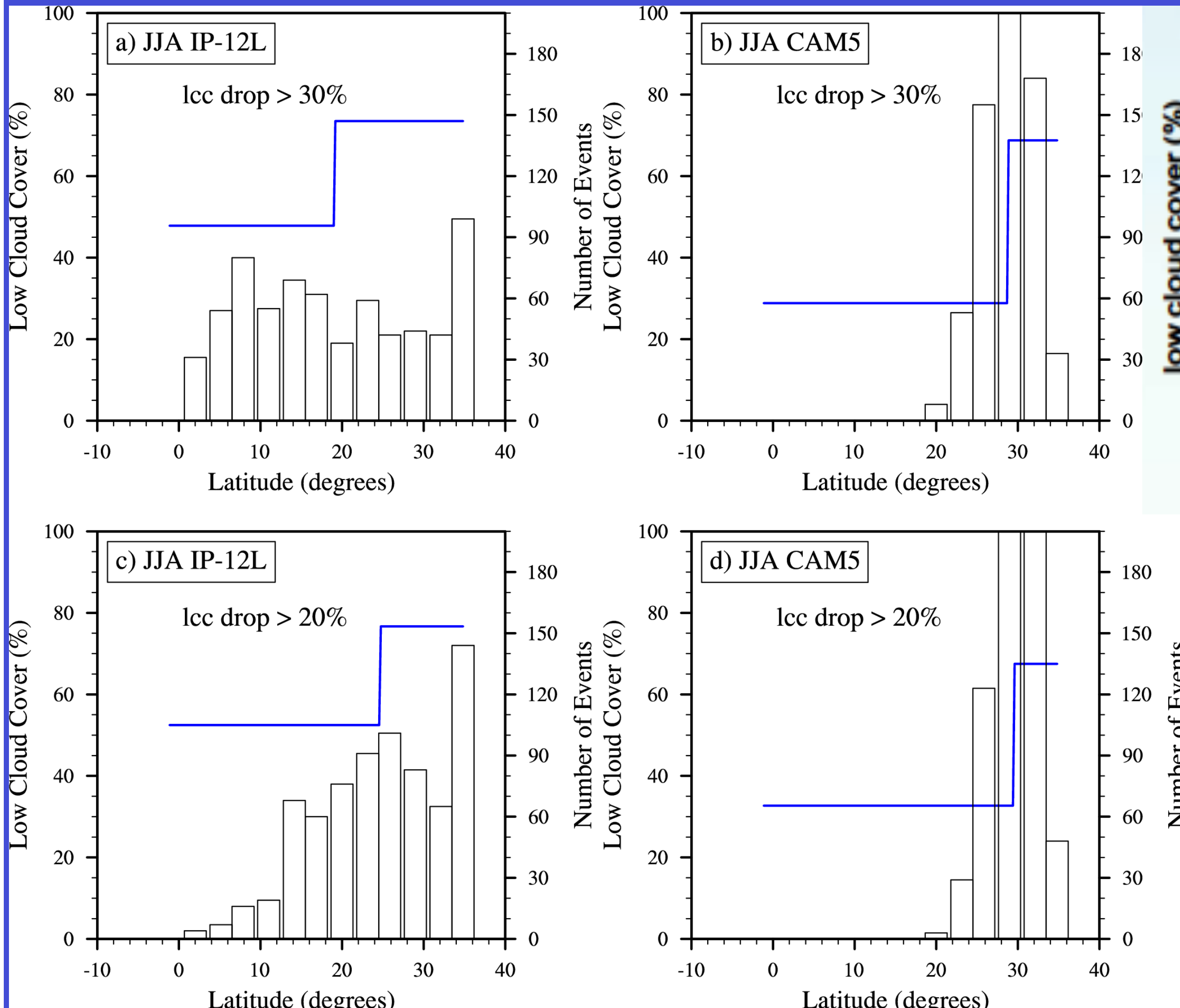
The Teixeira et al. (2011) method determines

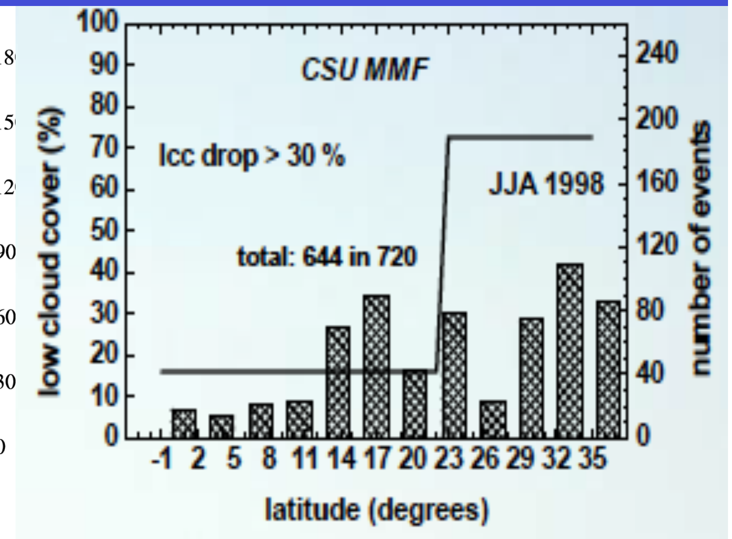
i) the location of the first sharp gradient in LCC by 30% along the transect starting at the northernmost point in the stratocumulus region and

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.

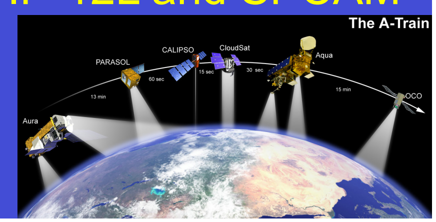


Statistics of instantaneous transitions: Results

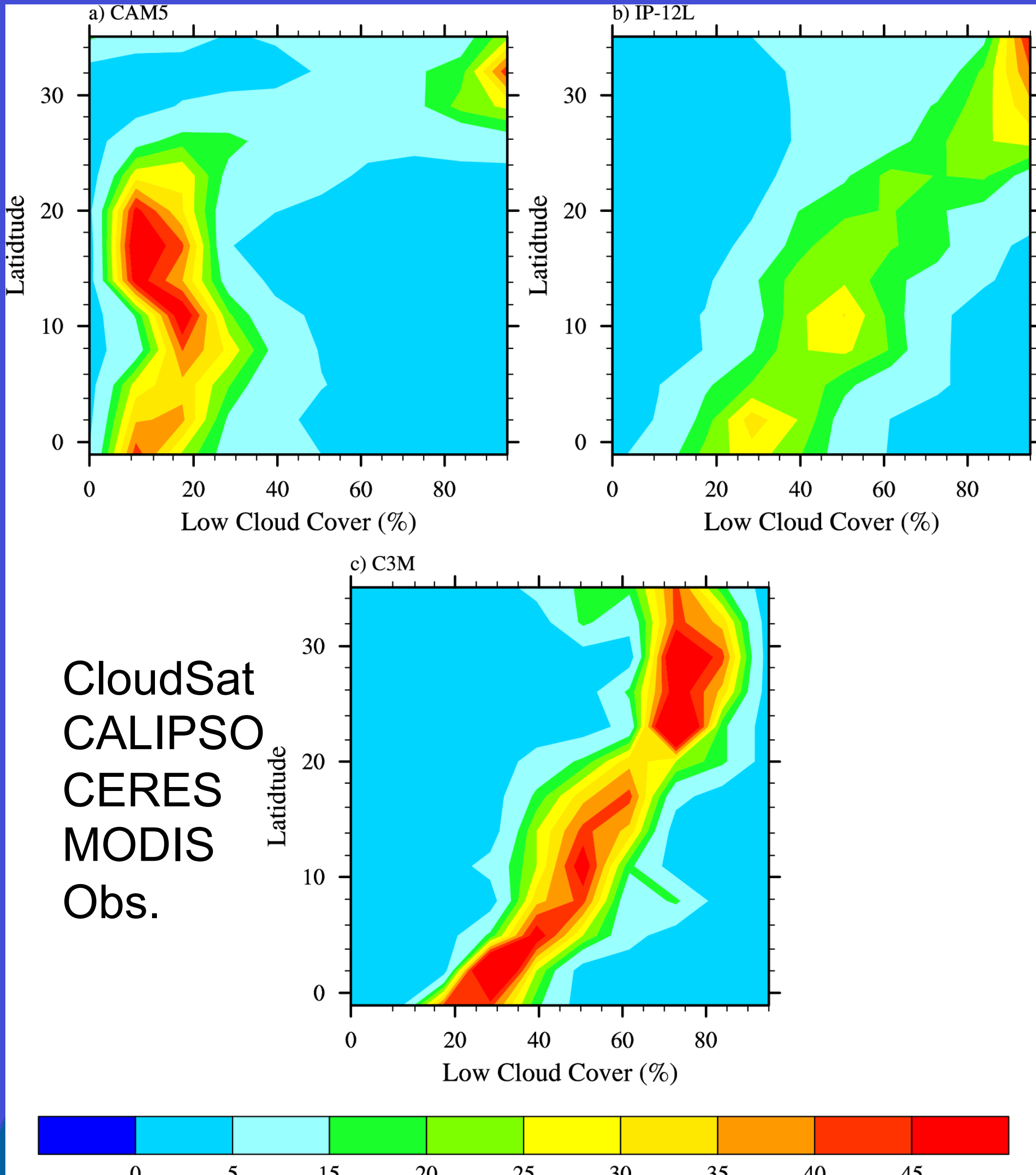


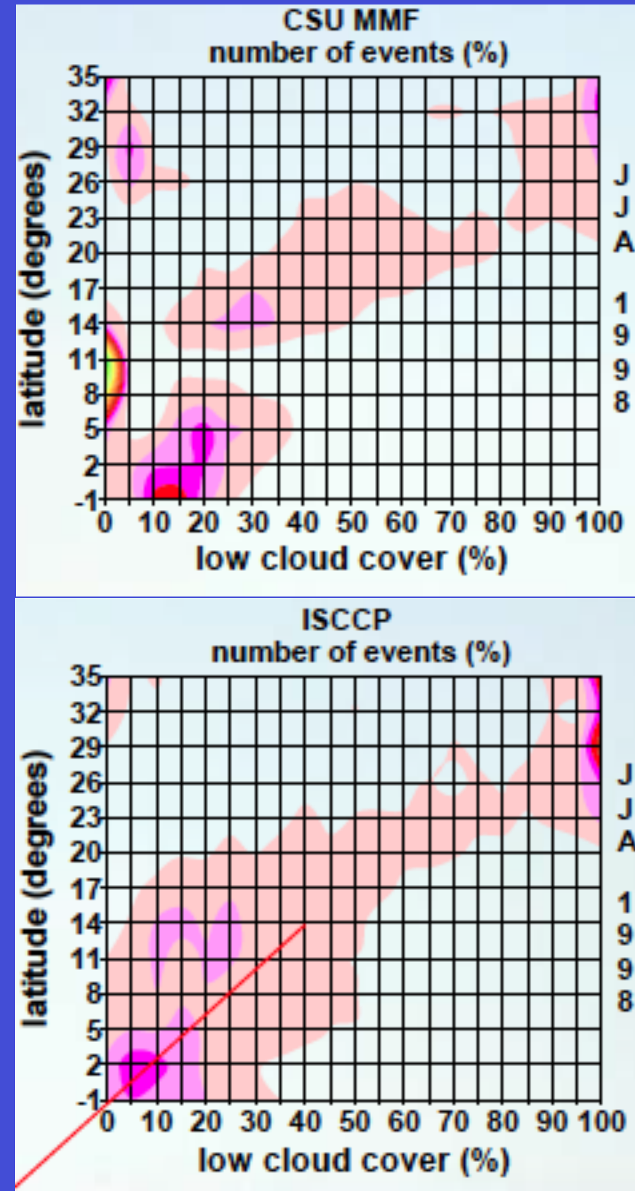


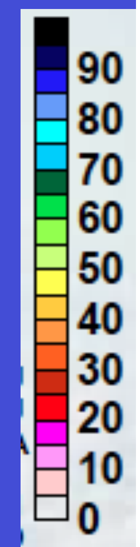
1. Sharp transitions in CAM5, SPCAM
2. Transition too close to the coast line in CAM5
3. Transition not sharp enough in IP-12L
4. Events of sharp transition also occur in convective regions of IP-12L and SPCAM



Histogram of low cloud cover







Summary and conclusions

- The seasonal mean transitions of cloud regimes from convective, tradewind cumulus to stratocumulus are well simulated with the upgraded MMF, but stratocumulus-to-cumulus transitions occur too early along the tradewind trajectory for CAM5 and SPCAM.
- Other than the location of the transition, there are a number of major deficiencies in the simulations:
  - CAM5: abundance of upper tropospheric anvils, but not much condensate; insufficient low-cloud amount and layer thickness;
  - SPCAM: overactive convective region; optically thick clouds;
  - SPCAM-IPHOC: overestimate of condensate in the boundary layer.
- The instantaneous transition statistics confirm the seasonal mean characteristics and also reveal the causes of model deficiencies.
- The overestimate of condensate in the boundary layer can be reduced by modifying the treatment of radiative transfer related to subgrid-scale cloudiness. (McICA; Pincus *et al.* 2003)
- The potential for realistic simulation of cloud processes is great with the MMF approach. But there is need for refinements in a few aspects of model physics and configurations.