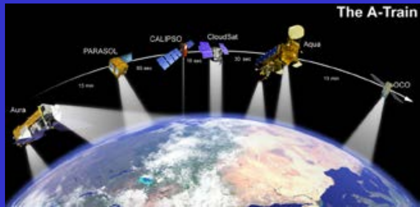
Cloud Regime Transition along GPCI Line in CAM5 with a Higher-order Turbulence Closure

Anning Cheng[1,2] and Kuan-Man Xu[1]

1. NASA Langley Research Center, Hampton, VA
2. Science Systems and Applications, Inc., Hampton, VA



CAM5
(Community Atmosphere Model version 5)

CAM5:

- ✦ Park-Bretherton Macrophysics and turbulence, Zhang-Macfarlene deep convection, Morrison-Genttleman microphysics, Liu et al. nucleation, RRTM radiation, CLM, and Lin finite-volume dynamic core
- ✦ Model state is updated after each physical process

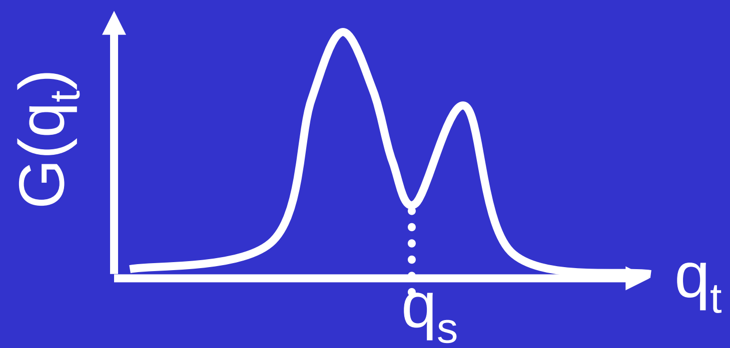
CAM5-IPHOC:

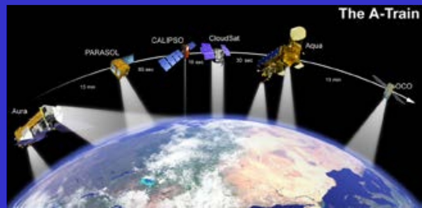
A third-order turbulence closure (IPHOC) replaces Macrophysics, shallow cumulus and stratocumulus, and turbulence parameterization

✦Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity

✦Skewnesses, i.e., the three third-order moments, and PBL height diagnosed

✦All first-, second-, third- and fourth-order moments, subgrid-scale condensation (cloud fraction) and buoyancy based on the same PDF

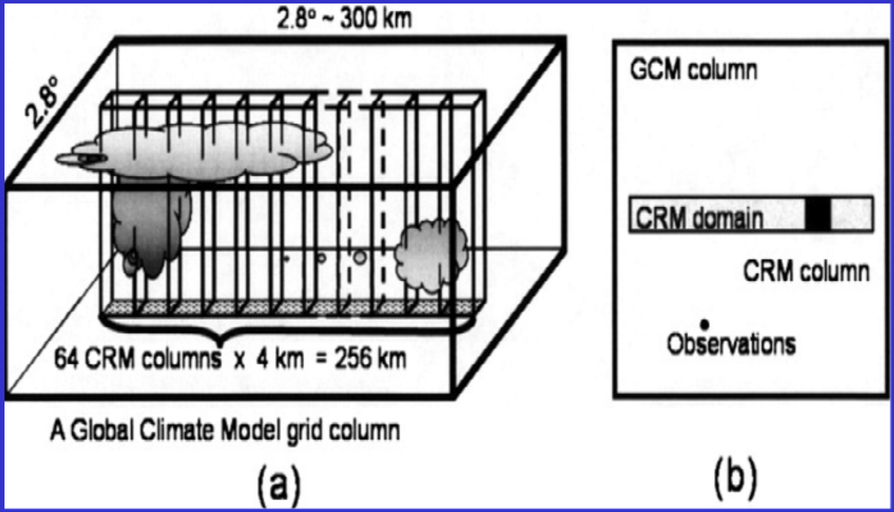




Multiscale Modeling Framework
(Grabowski 2001; Khairoutdinov and Randall 2001)

SPCAM: SAM CRM

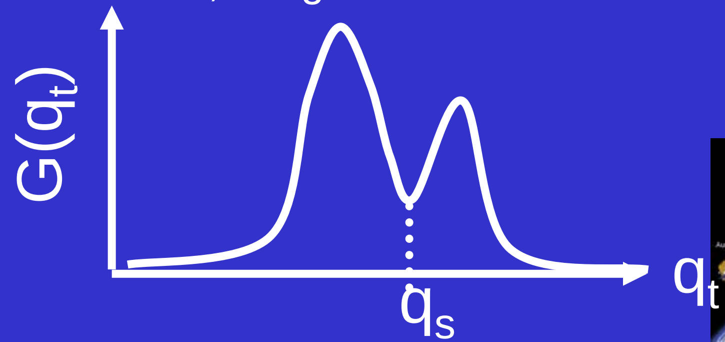
- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1 km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)

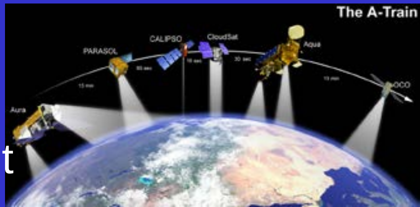


SPCAM-IPHOC: SAM CRM

upgraded with a third-order turbulence closure (IPHOC)

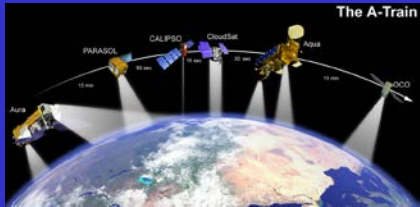
- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity
- Skewnesses, i.e., the three third-order moments, predicted
- All first-, second-, third- and fourth-order moments, subgrid-scale condensation (cloud fraction) and buoyancy based on the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





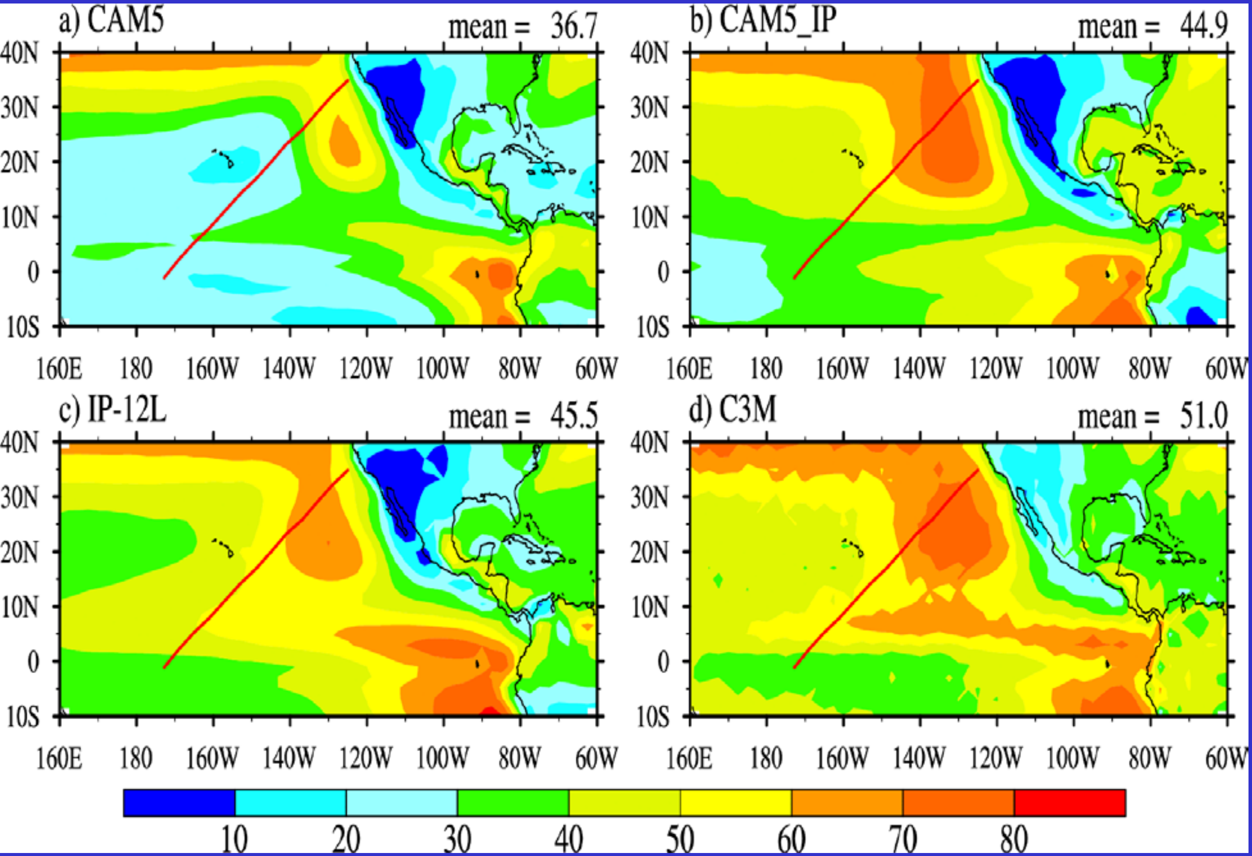
CAM5, CAM5-IPHOC, SPCAM-IPHOC climate simulation

- CAM5-IPHOC predicts PBL top for the coarse vertical GCM grid
- The MMF model is 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) with IPHOC, the grid spacing is 4 km, with 32 columns within a GCM grid box.
- All simulations: grid spacing of 1.9° x2.5° ; 30 levels in CAM5 and CAM5-IPHOC, but 12 levels below 700 hPa with total 32 vertical layers for SPCAM-IPHOC.
- The simulations are forced with climatological SST and sea ice distributions (not an AMIP simulation).
- Simulation duration is 10 years and 3 months, with last nine years analyzed for SPCAM-IPHOC and CAM5; 2 years and 3 months for CAM5-IPHOC, with last two years presented.

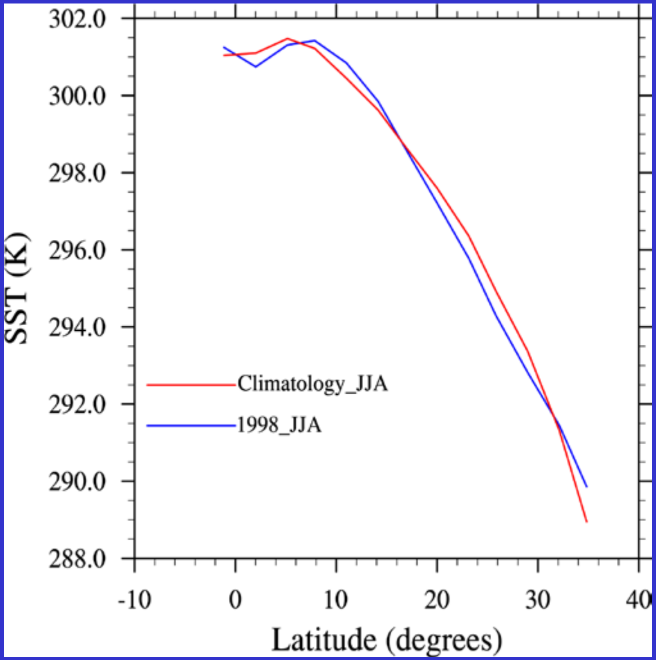


Why the GPCI transect? Transitions from tropical deep convection, tradewind cumulus to stratocumulus

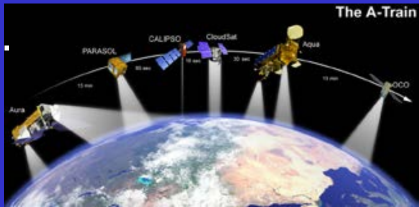
Low cloud cover for June-July-August (JJA)



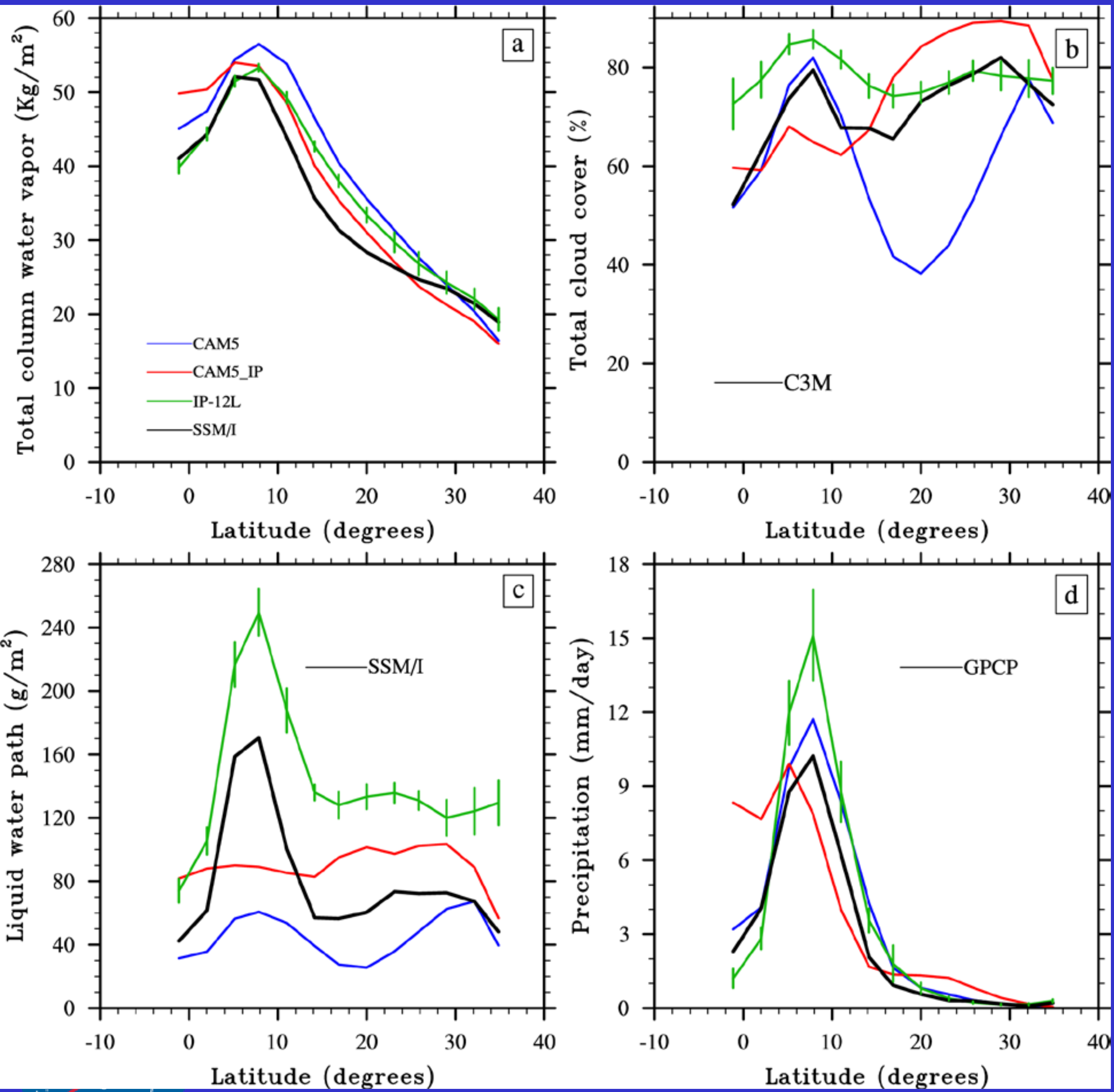
Sea surface temperature



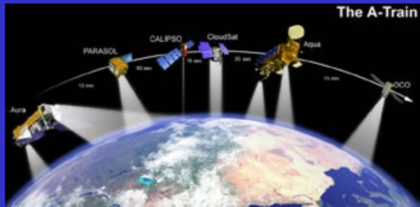
Similiarity from CAM5- and SPCAM- IPHOC simulations with C3M.
However, transition from stratocumulus (near coast) to cumulus occurs too early along the tradewind trajectory for CAM5



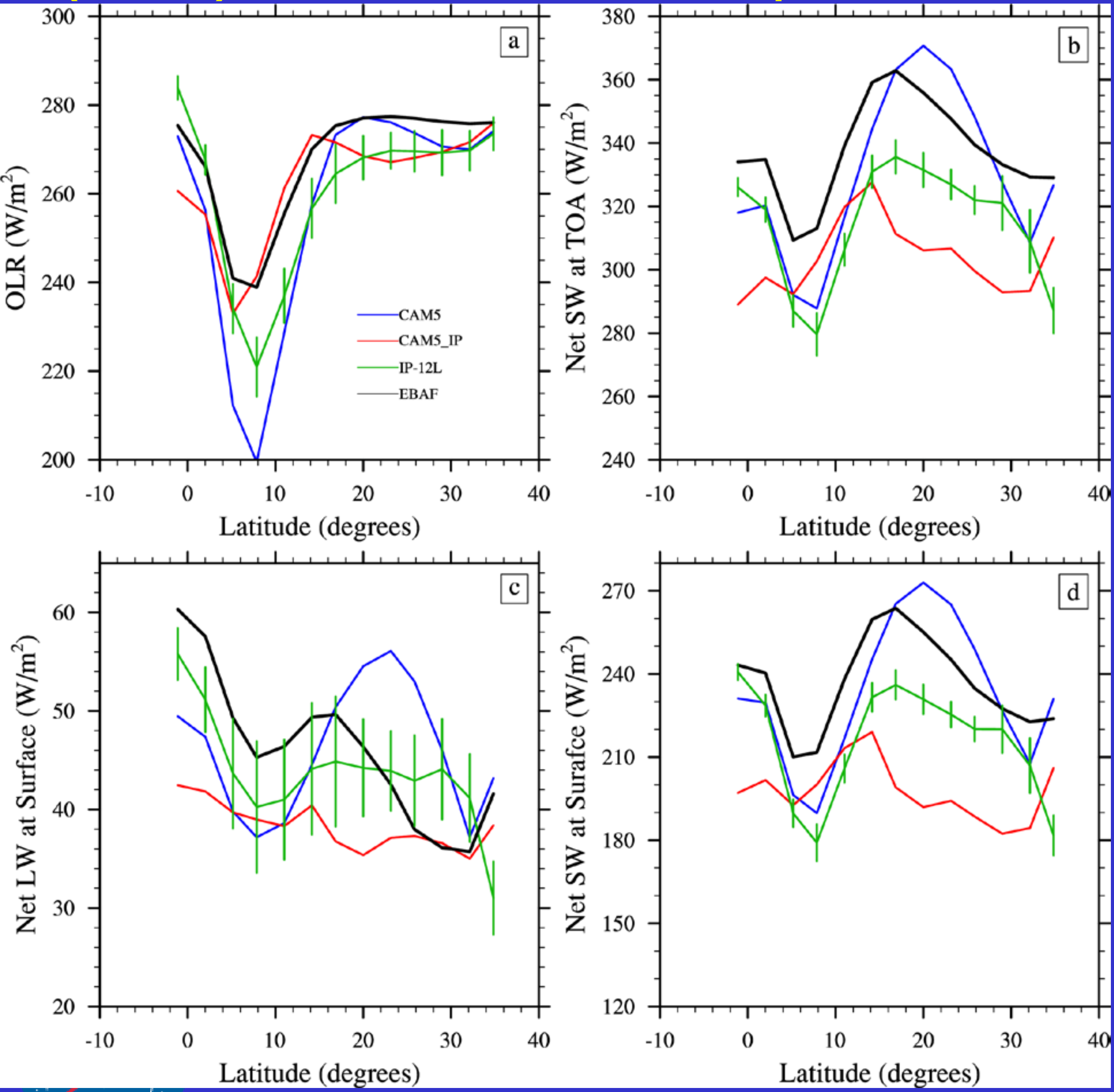
Water vapor, total cloud cover, LWP and precipitation



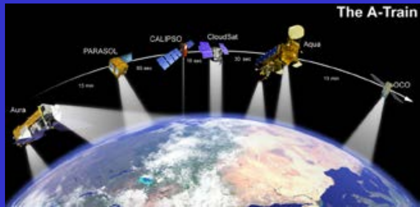
- The decrease of column water vapor from the tropics to the subtropics is well simulated.
- Large differences in total cloud cover of different regions along the transect among the models;
  - CAM5-IPHOC overestimates near coast clouds, but underestimates clouds in tropics
- Large differences in liquid water path from observations by a factor of two or more; CAM5-IPHOC between SPCAM-IPHOC and CAM5
- Precipitation is generally overestimated in all models



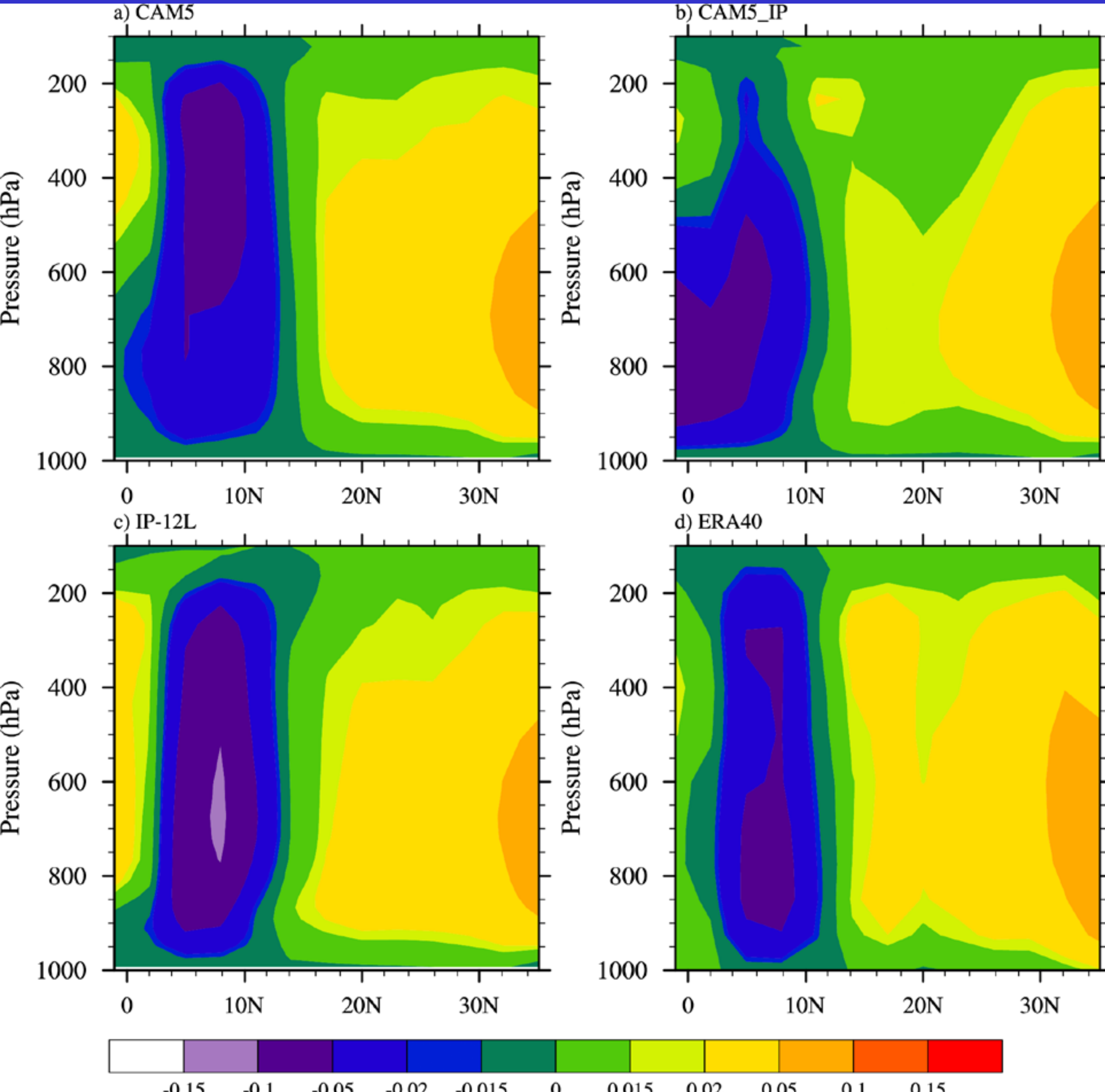
LW and SW radiative fluxes at top of the atmosphere (TOA) and surface, compared to CERES observations



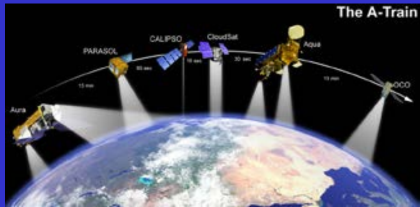
- CAM5-IPHOC simulates the cloud-regime transitions rather well, but underestimates the SW fluxes;
- CAM5 simulates the SW fluxes at TOA and surface well (CAM5 are tuned with CERES data but MMFs are not tuned), but stratocumulus-to-cumulus transition is poorly simulated (4-8° offset in the peaks);
- SPCAM-IPHOC 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.



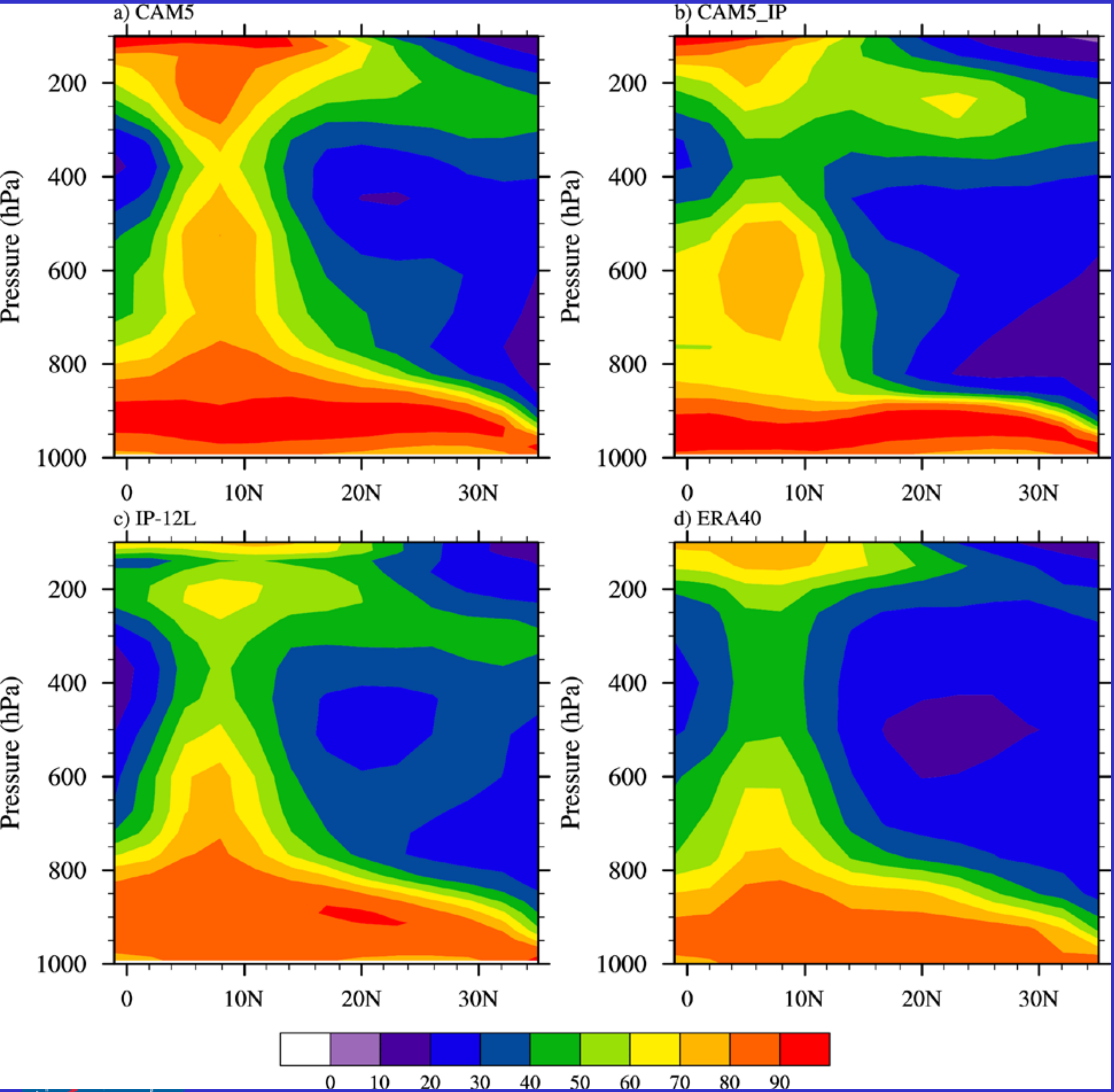
Pressure vertical velocity



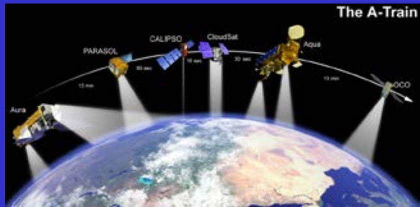
- The upward motion zone is too wide in CAM5-IPHOC, and lack of the lower tropospheric maximum in CAM5;
- The subsidence in the stratocumulus region is similar among the models;
- The subsidence in the transition region shows large differences among the models;
- The deep subsidence structure in the transition region of ERA40 is not duplicated by any of the climate models.



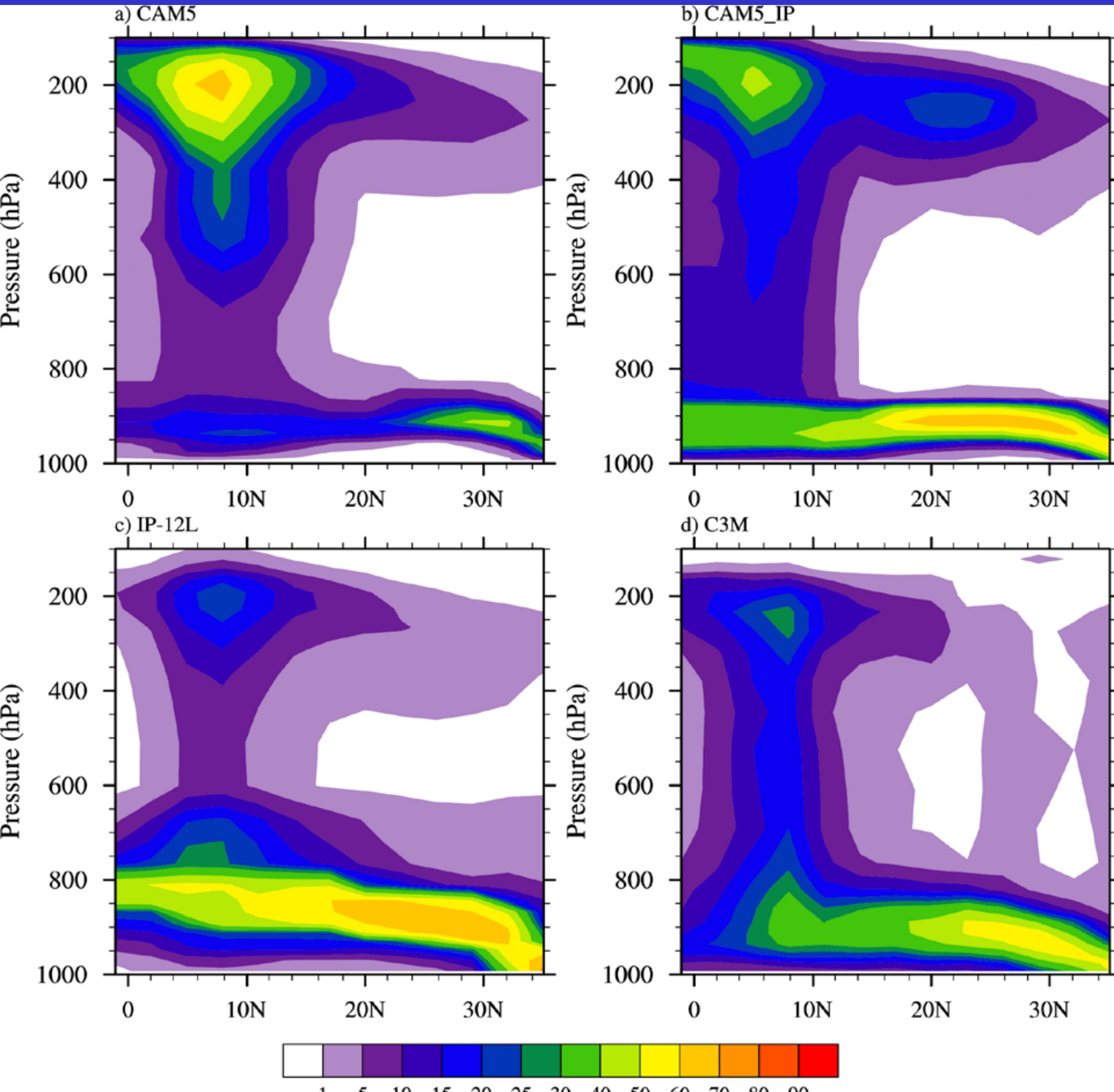
Relative humidity



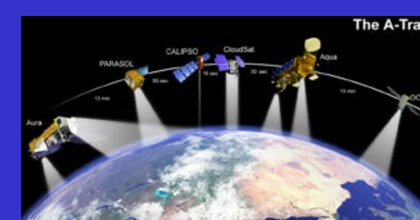
- Both the rising of boundary-layer height along the tradewind trajectory and the humid convective region are well simulated;
- The CAM5-IPHOC boundary-layer and upper troposphere are more humid than the MMFs;
- The MMF middle tropospheric dry zone above the transition region is not as dry as that in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



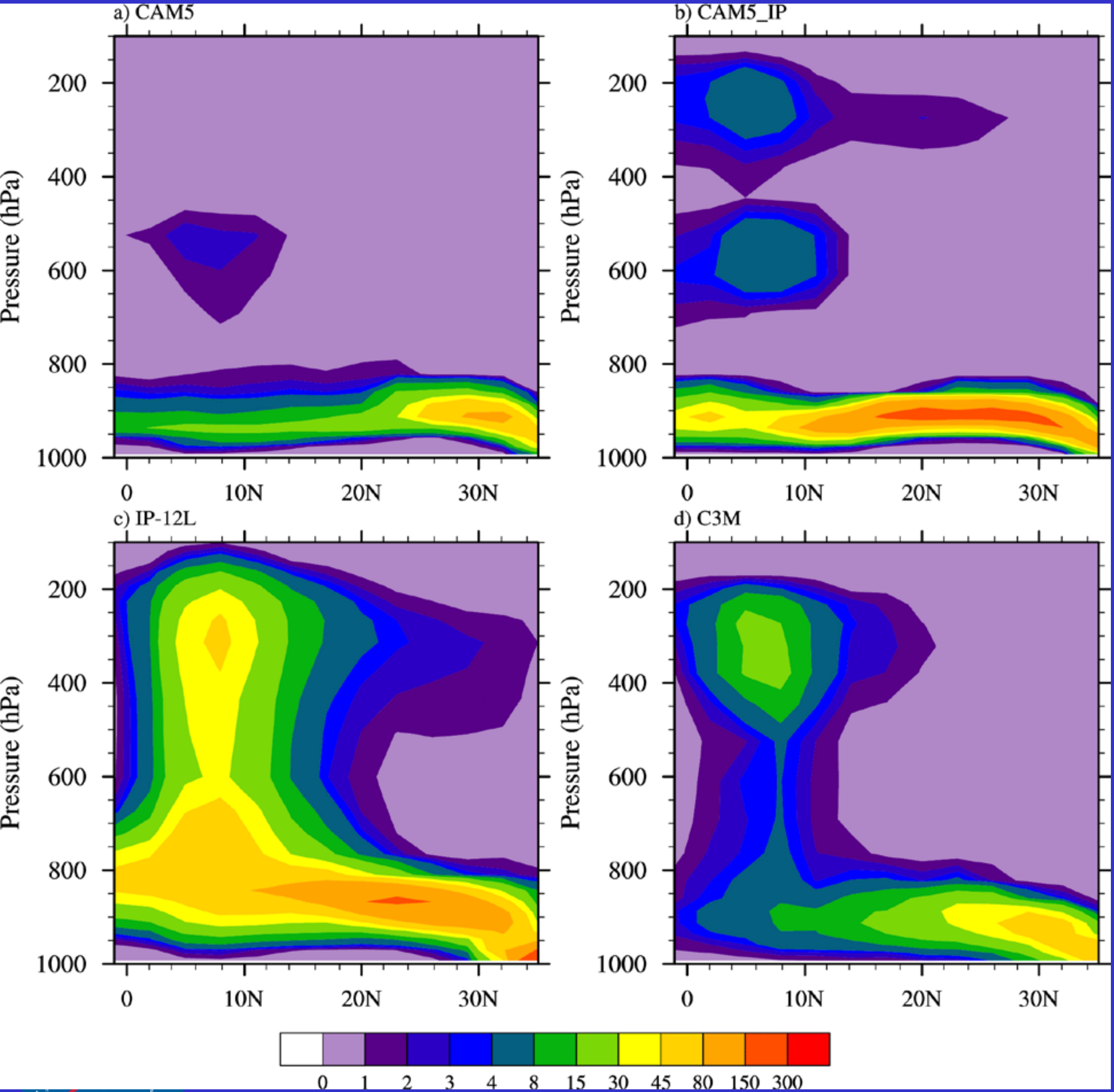
Cloud fraction



- There are great similarities in the distributions of cloud fraction with the C3M observations for all three models;
- CAM5-IPHOC produces realistic low-level and middle level clouds;
- CAM5 produces too much upper tropospheric convective anvils, but too little boundary-layer clouds, which are also vertically too thin;
- Boundary-layer clouds in SPCAM-IPHOC 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;
- CAM5-IPHOC produces more condensate in middle and upper troposphere than CAM5, and in low level than SPCAM-IPHOC
- SPCAM-IPHOC 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.

Summary and conclusions

- The seasonal mean transitions of cloud regimes from convective, tradewind cumulus to stratocumulus are well simulated with the CAM5-IPHOC and SPCAM-IPHOC, but stratocumulus-to-cumulus transitions occur too early along the tradewind trajectory for CAM5.
- 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;
  - CAM-IPHOC: wide convective region in tropics;
  - SPCAM-IPHOC: overestimate of condensate in the boundary layer.
- The potential for realistic simulation of cloud processes is great with the IPHOC approach. But there is need for refinements in a few aspects of model physics and configurations.