High-resolution Multiscale Modeling Framework Simulation of Low Clouds

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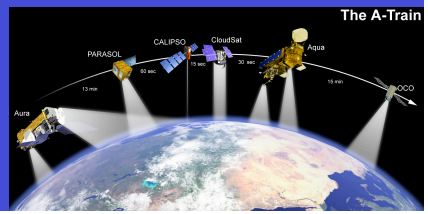
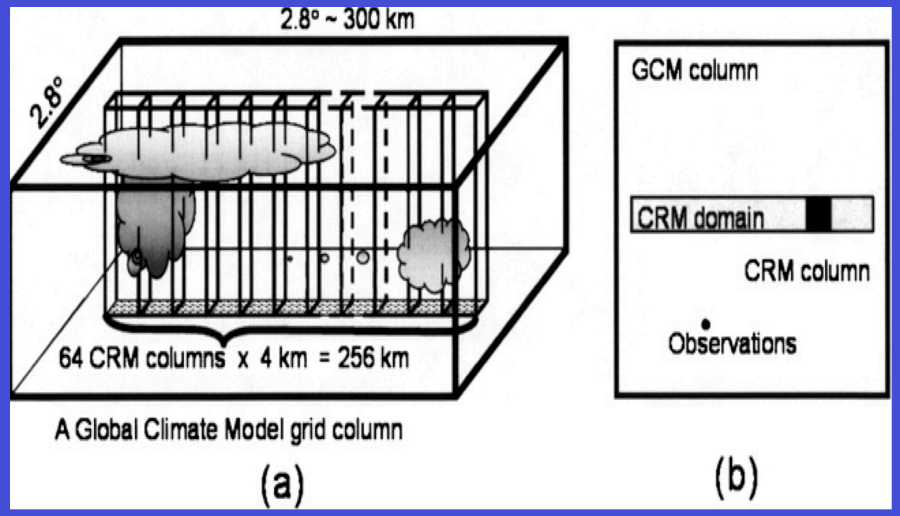


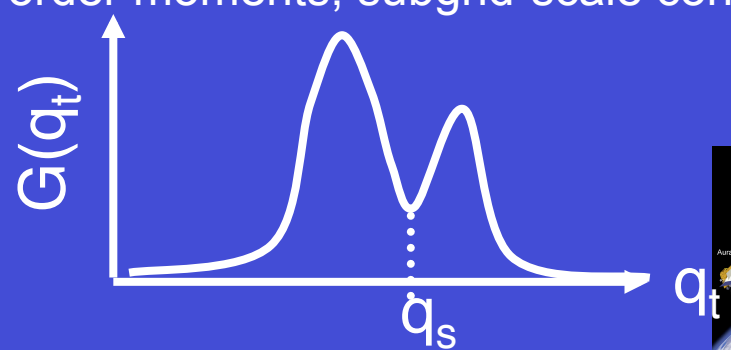
Multiscale Modeling Framework
(Grabowski 2001; Khairoutdinov and Randall 2001)

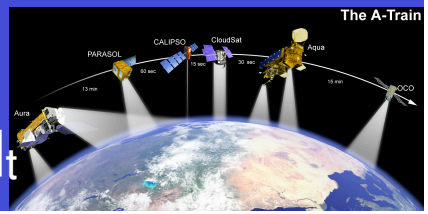
- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1s km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)



Upgraded CRM 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 and buoyancy based on the same PDF



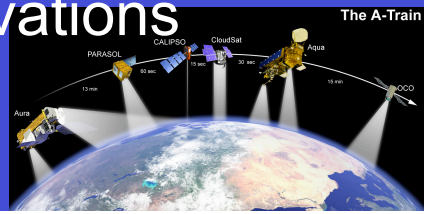


Objectives for MMF climate simulation

- ✦ to improve the simulation of low-level clouds in an MMF
- ✦ to evaluate and compare the performance of model simulations against state-of-the-art observations

Models and observational data

- Standard SPCAM, at T21 resolution, 2-yr run (semi-Lagrangian)
- Upgraded SPCAM, called SPCAM-IPHOC, at T21 resolution (with semi-Lagrangian dynamic core); 2-yr run
- SPCAM-IPHOC-hires: SPCAM-IPHOC with finite-volume dynamic core (1.9°x2.5°); doubling the number of levels below 700 hPa (6 to 12); 10-yr run
- C3M (CloudSat, CALIPSO, CERES, MODIS) observations

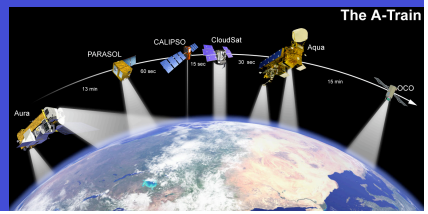


Highlights of results

- Improved low cloud simulation from the upgraded CRM and the higher-resolution finite-volume dynamic core-based SPCAM-IPHOC model, compared to the standard SPCAM and the lower-resolution SPCAM-IPHOC with semi-Lagrangian dynamic core, respectively
- Improved surface precipitation distributions, esp., in the tropics
- Radiative energy balance, compared to CERES observations
- Overall performance from the higher-resolution SPCAM-IPHOC is better than SPCAM and SPCAM-IPHOC

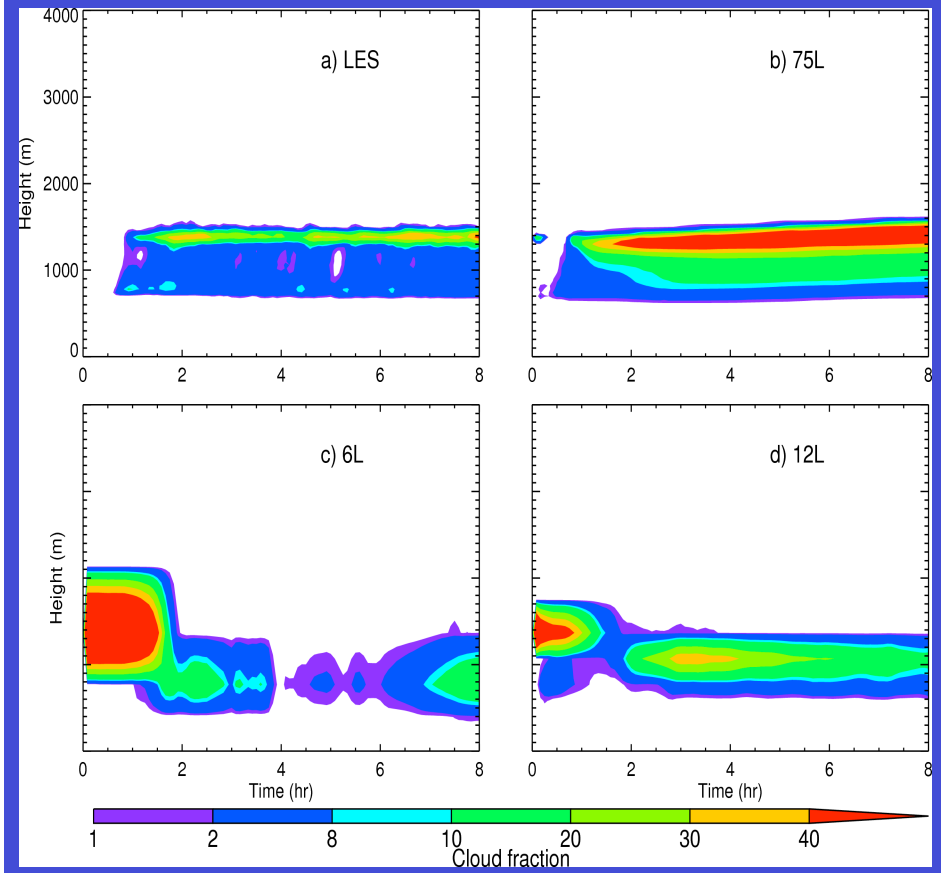
Cheng, A. and K.-M. Xu, 2011: Improved low-cloud simulation from a multiscale modeling framework with a third-order turbulence closure in its cloud-resolving model component. *J. Geophys. Res.*, *116, D14101, doi:10.1029/2010JD015362.*

Xu, K.-M., and A. Cheng, 2011: Further improvement of low-cloud simulation from a multiscale modeling framework with a third-order turbulence closure in its cloud resolving model component (in preparation).

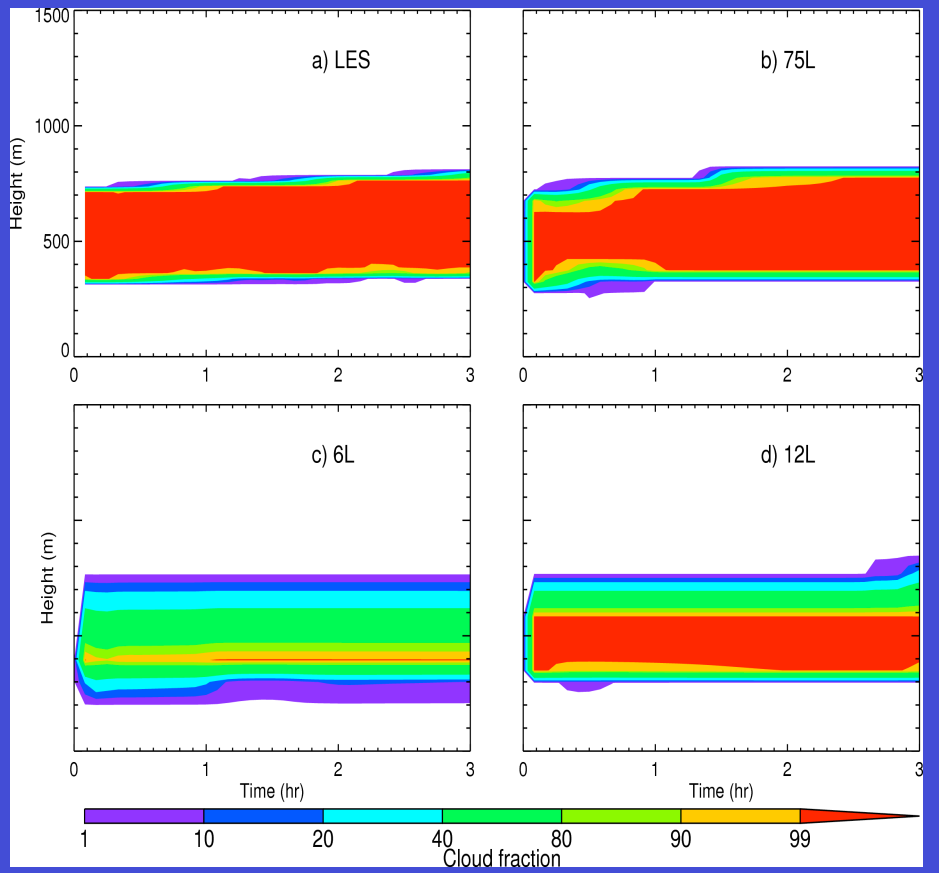


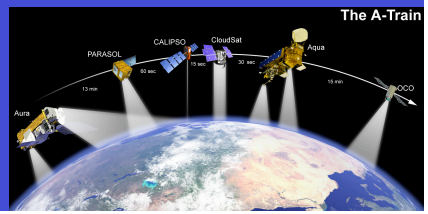
Off-line sensitivity test to vertical resolution

ATEX Cumulus

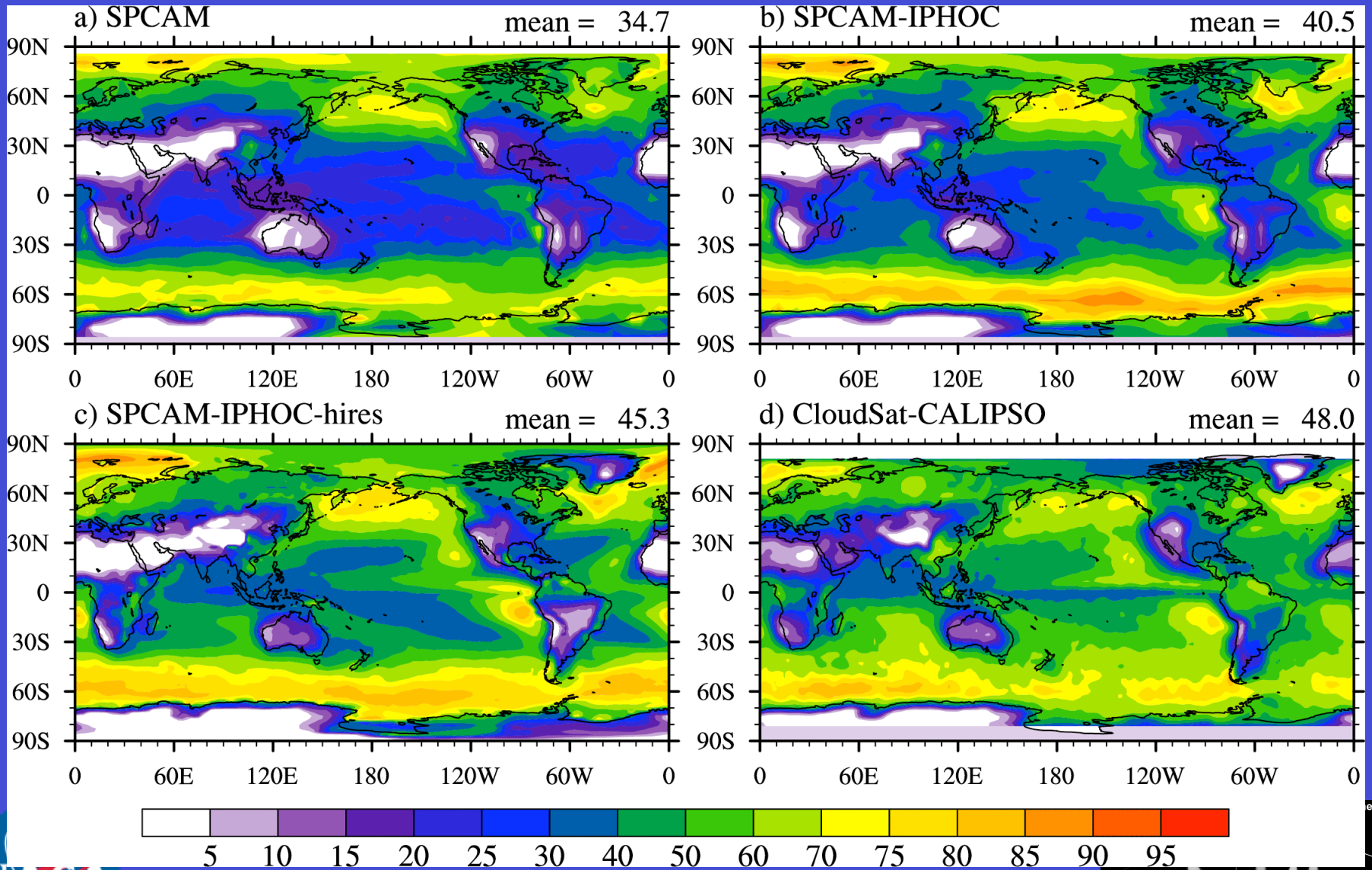


ASTEX Stratocumulus

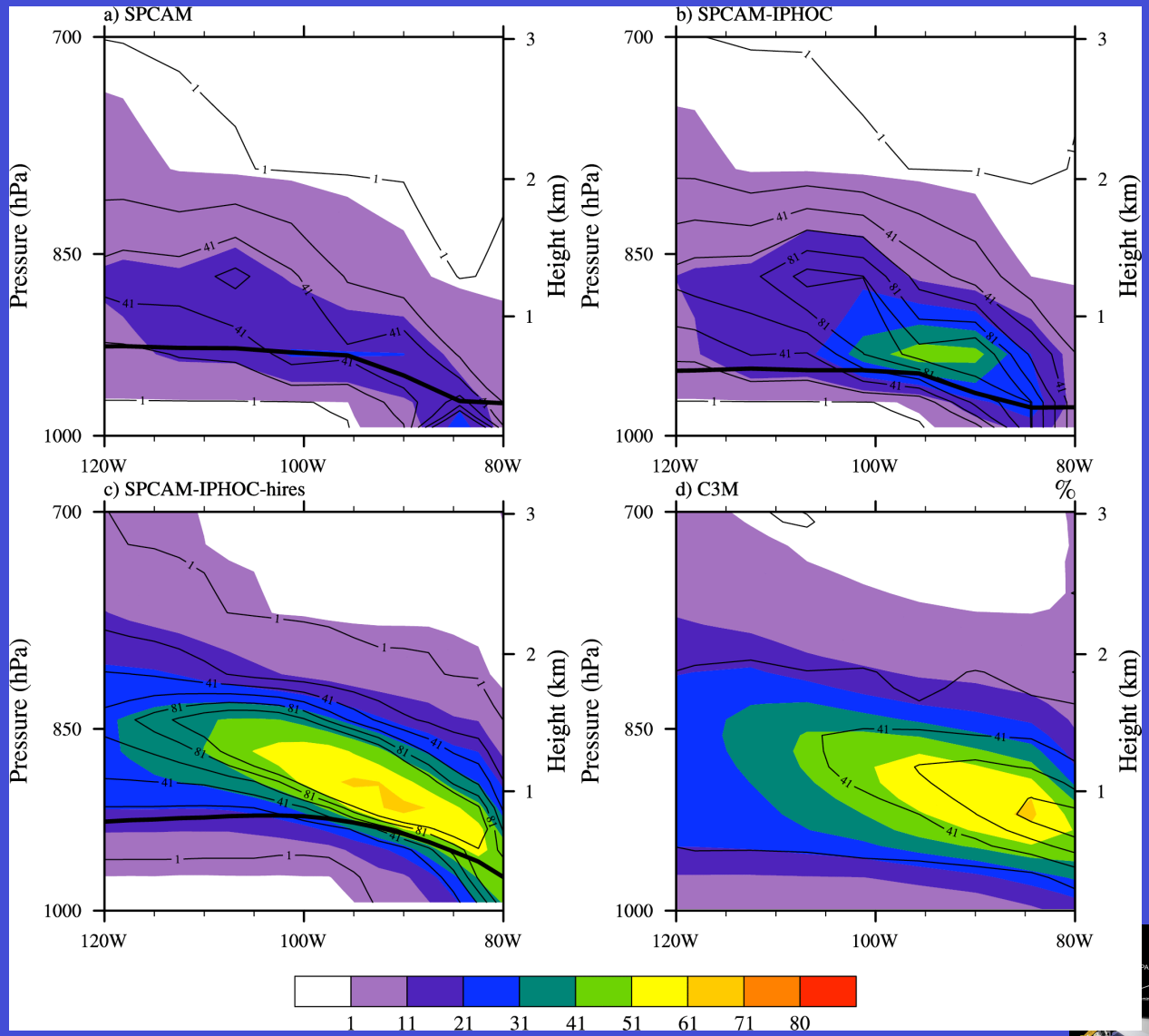


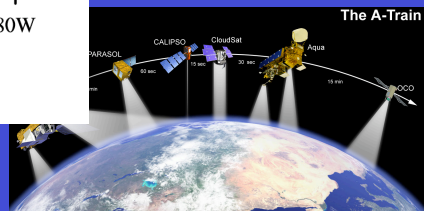


Low-level (sfc - 700 hPa) cloud amount (%)

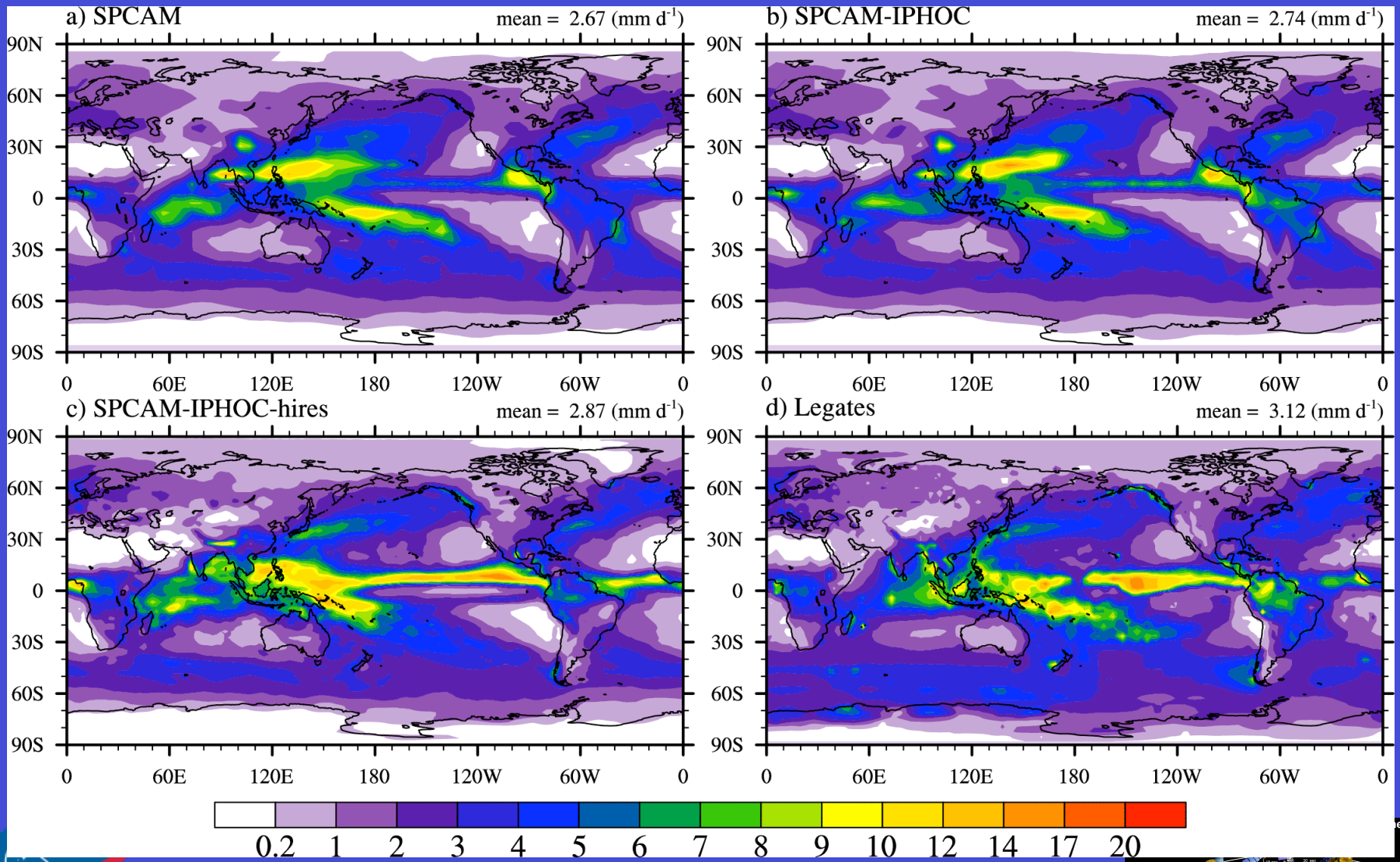


Annual mean cloud fraction (color) and cloud liquid water (contour) west of South America (15°S)

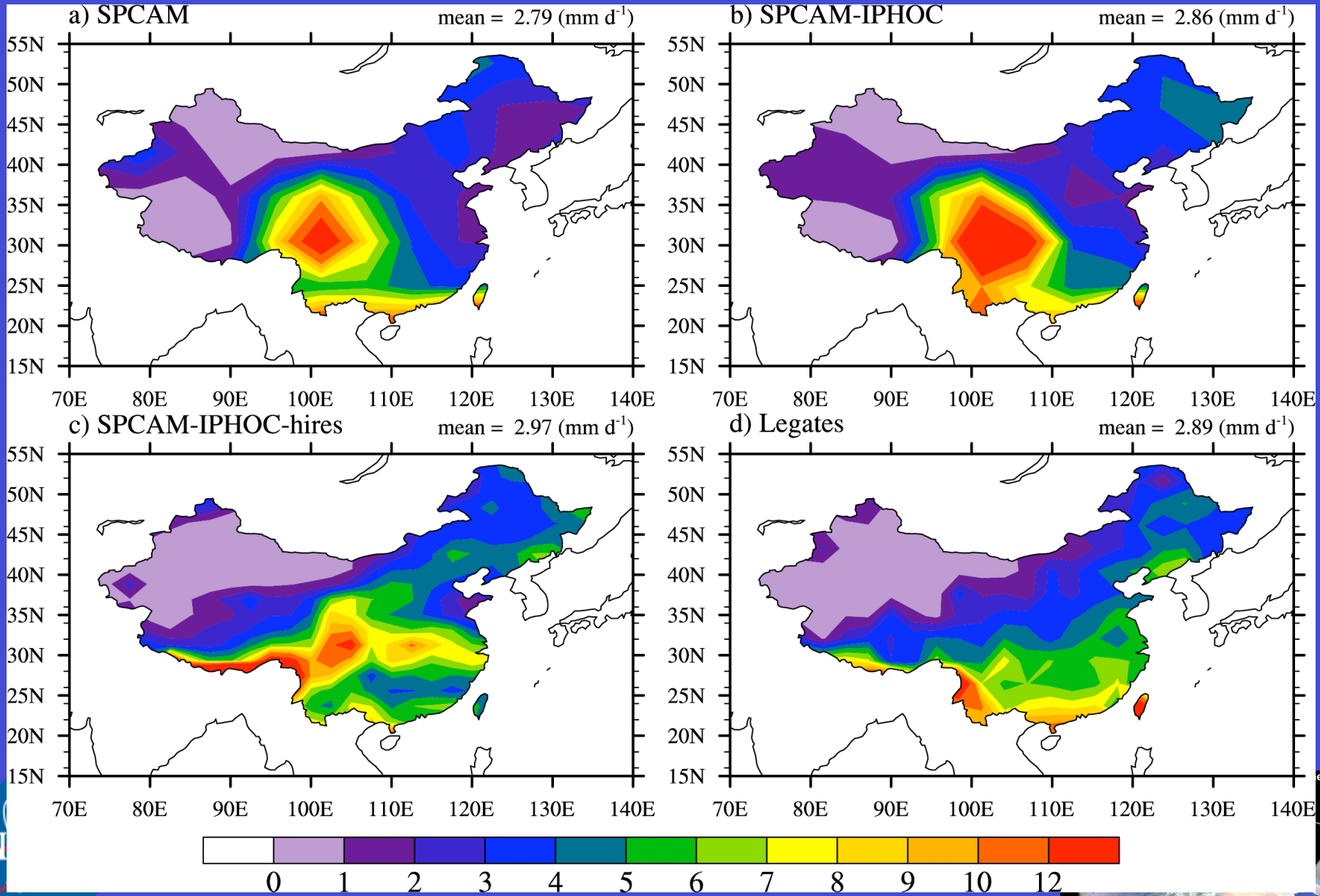




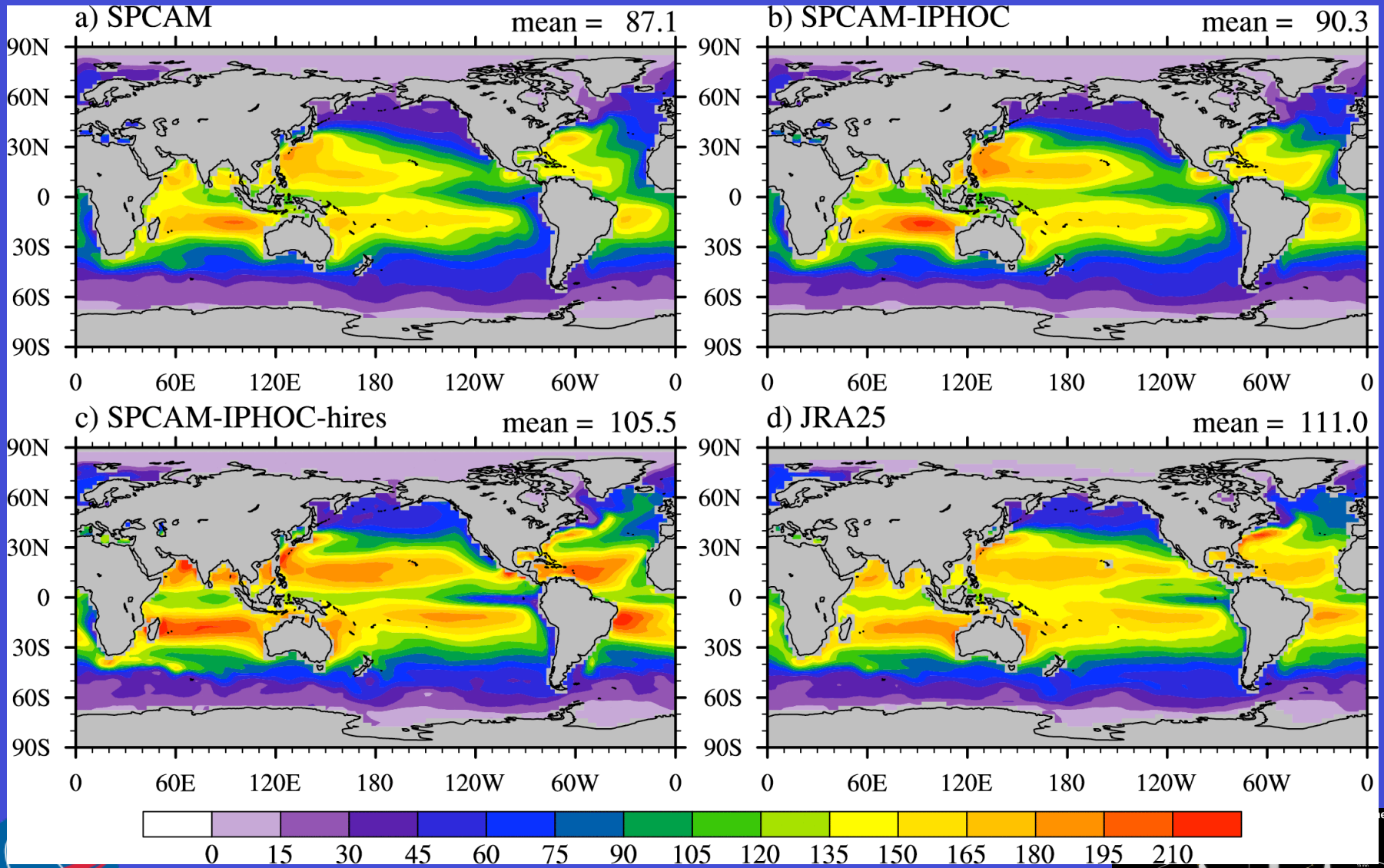
Annual-mean surface precipitation rate



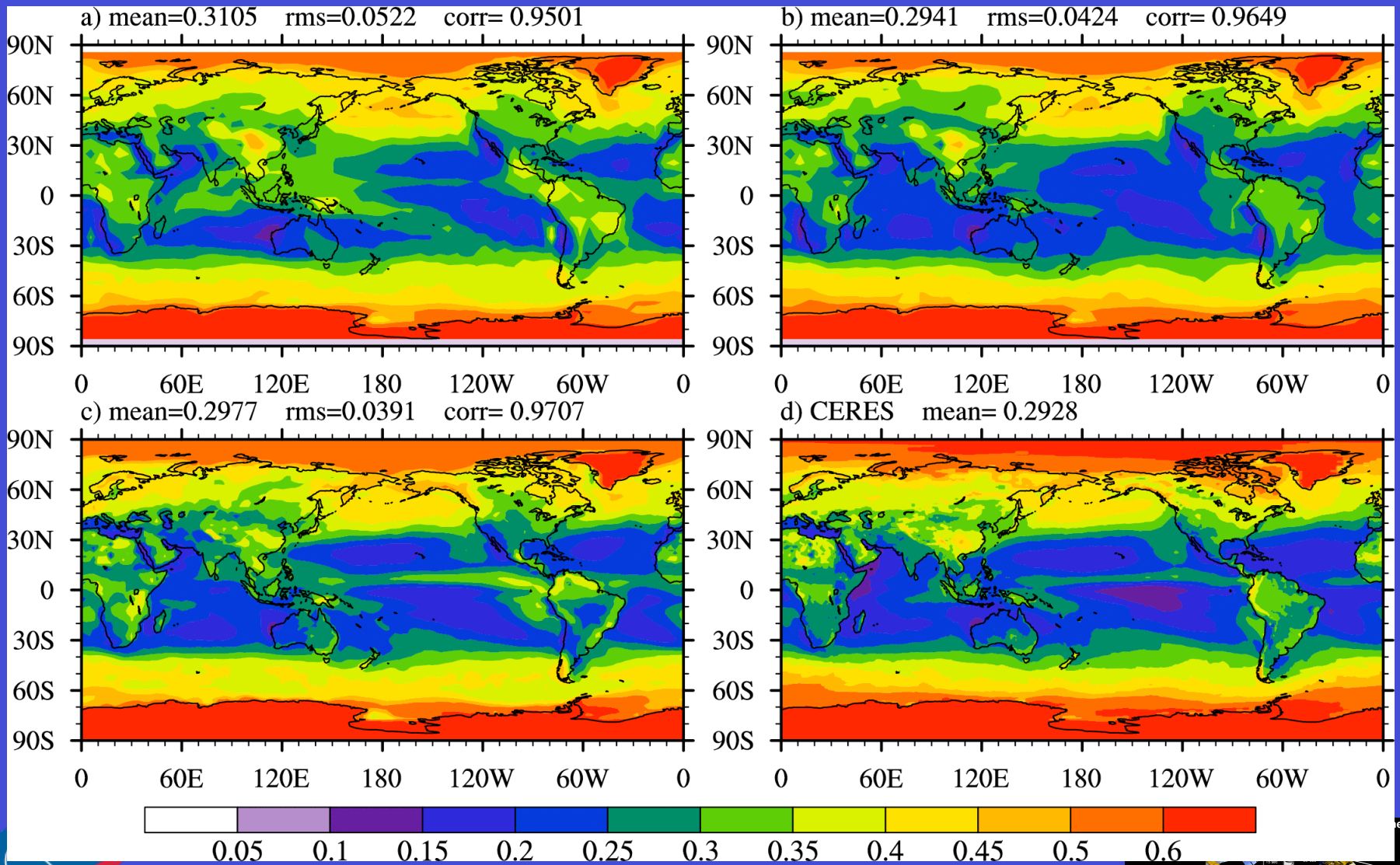
Summer precipitation in China



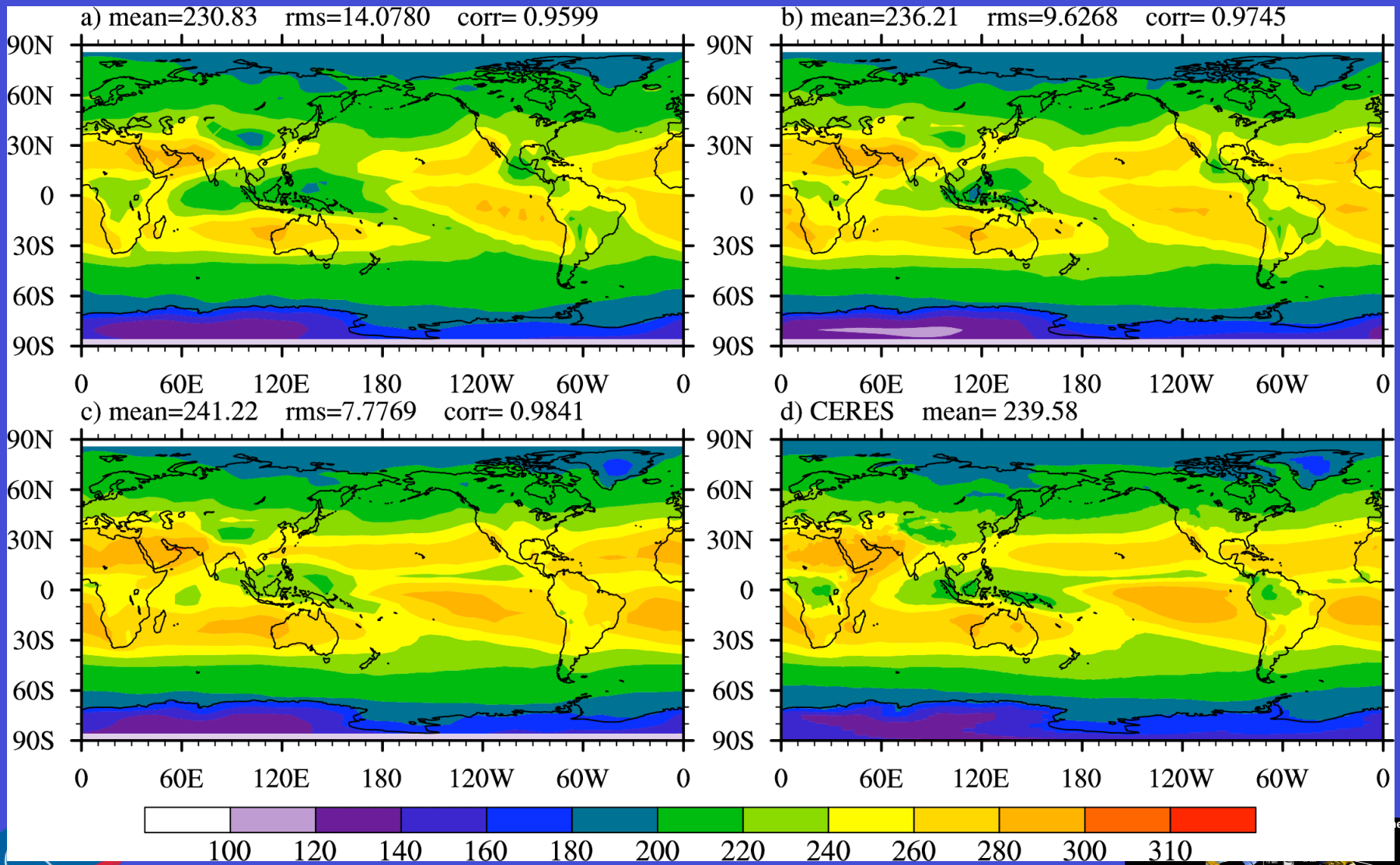
Oceanic surface latent heat flux



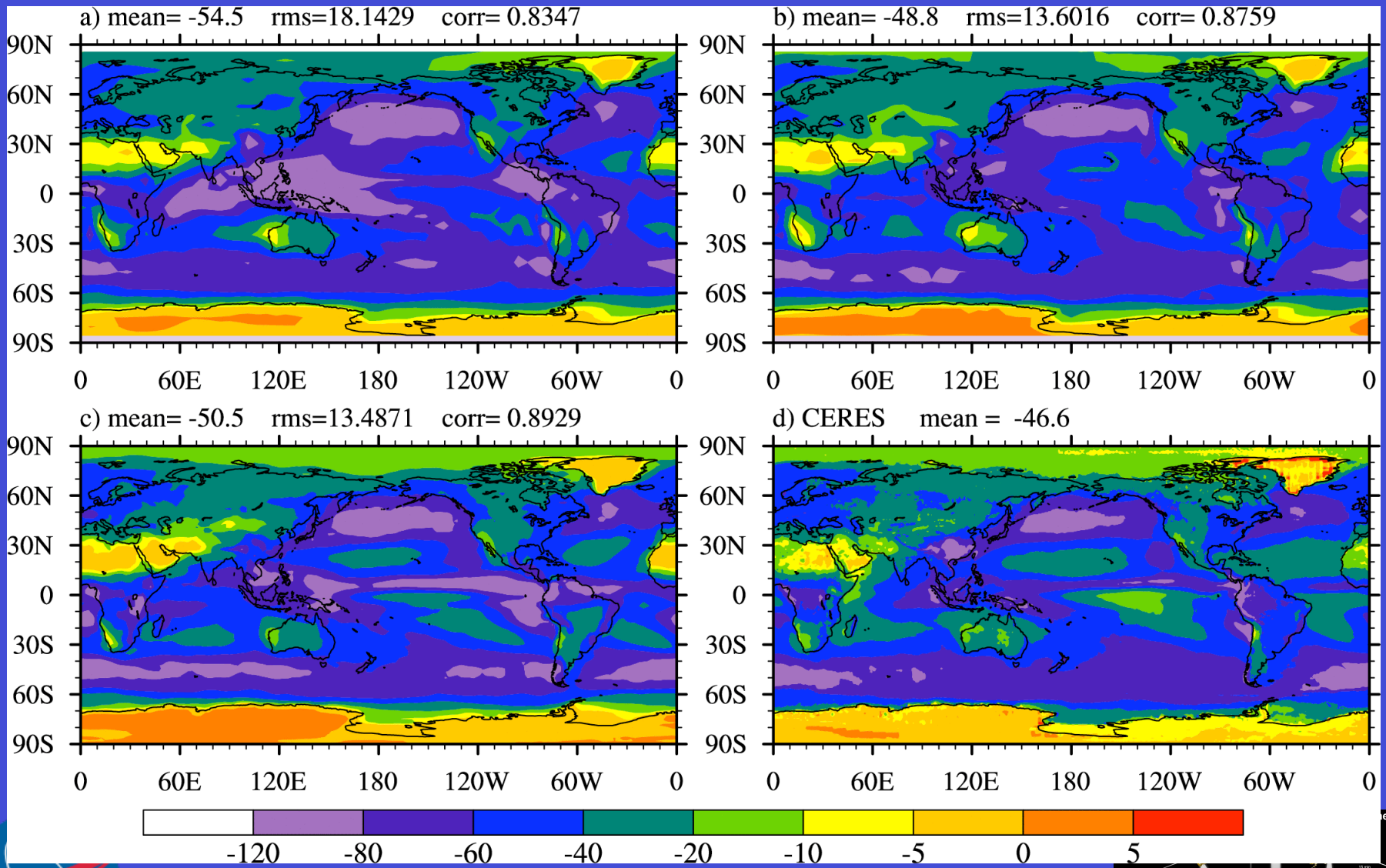
TOA albedo


a) mean=0.3105 rms=0.0522 corr= 0.9501
b) mean=0.2941 rms=0.0424 corr= 0.9649
c) mean=0.2977 rms=0.0391 corr= 0.9707
d) CERES mean= 0.2928
90N
60N
30N
0
30S
60S
90S
0
60E
120E
180
120W
60W
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.6

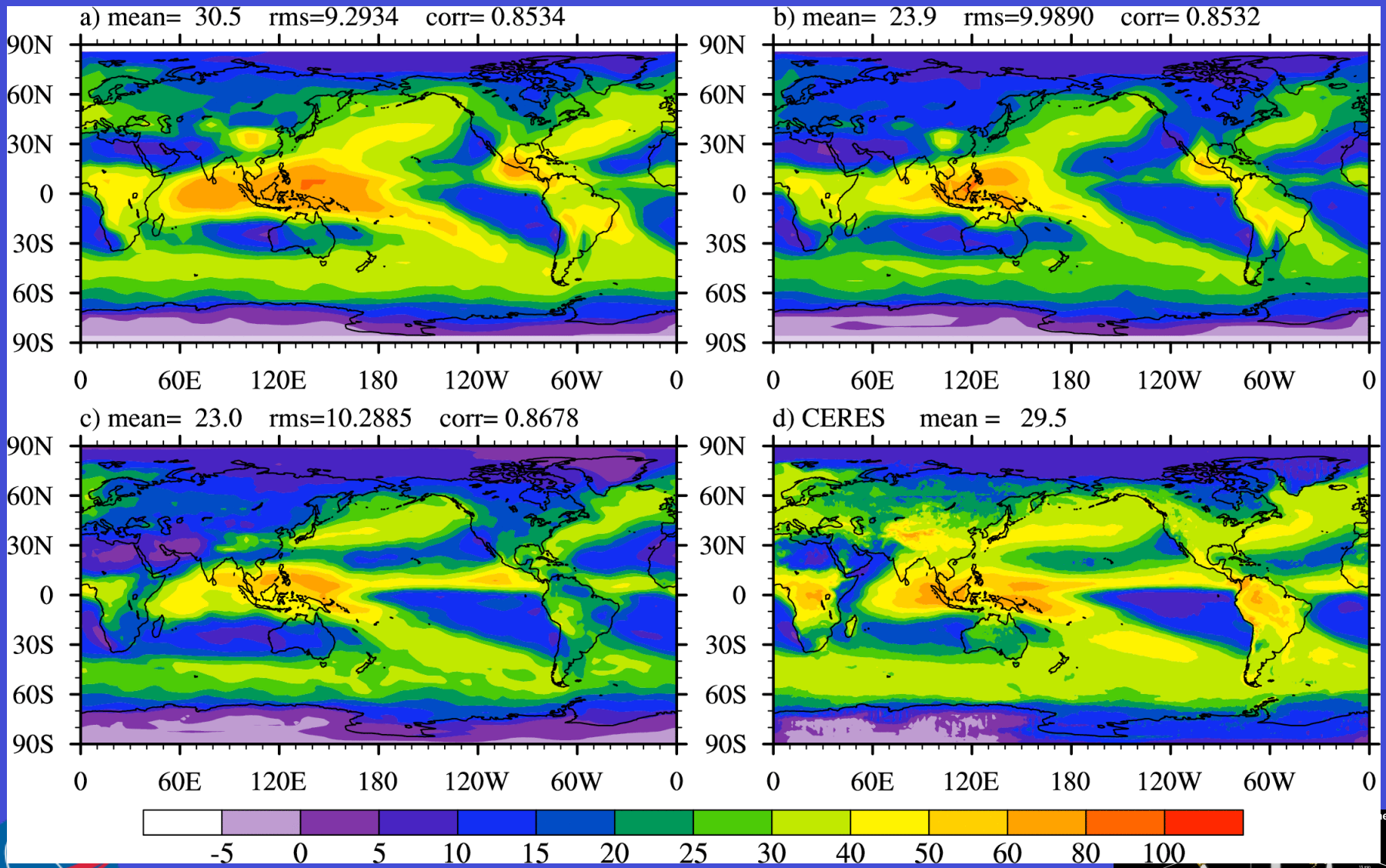
TOA outgoing LW flux



Shortwave cloud radiative effect



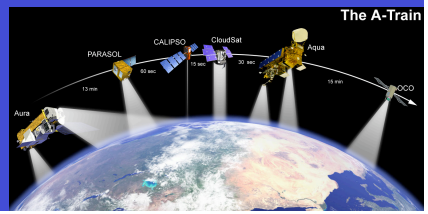
LW cloud radiative effect



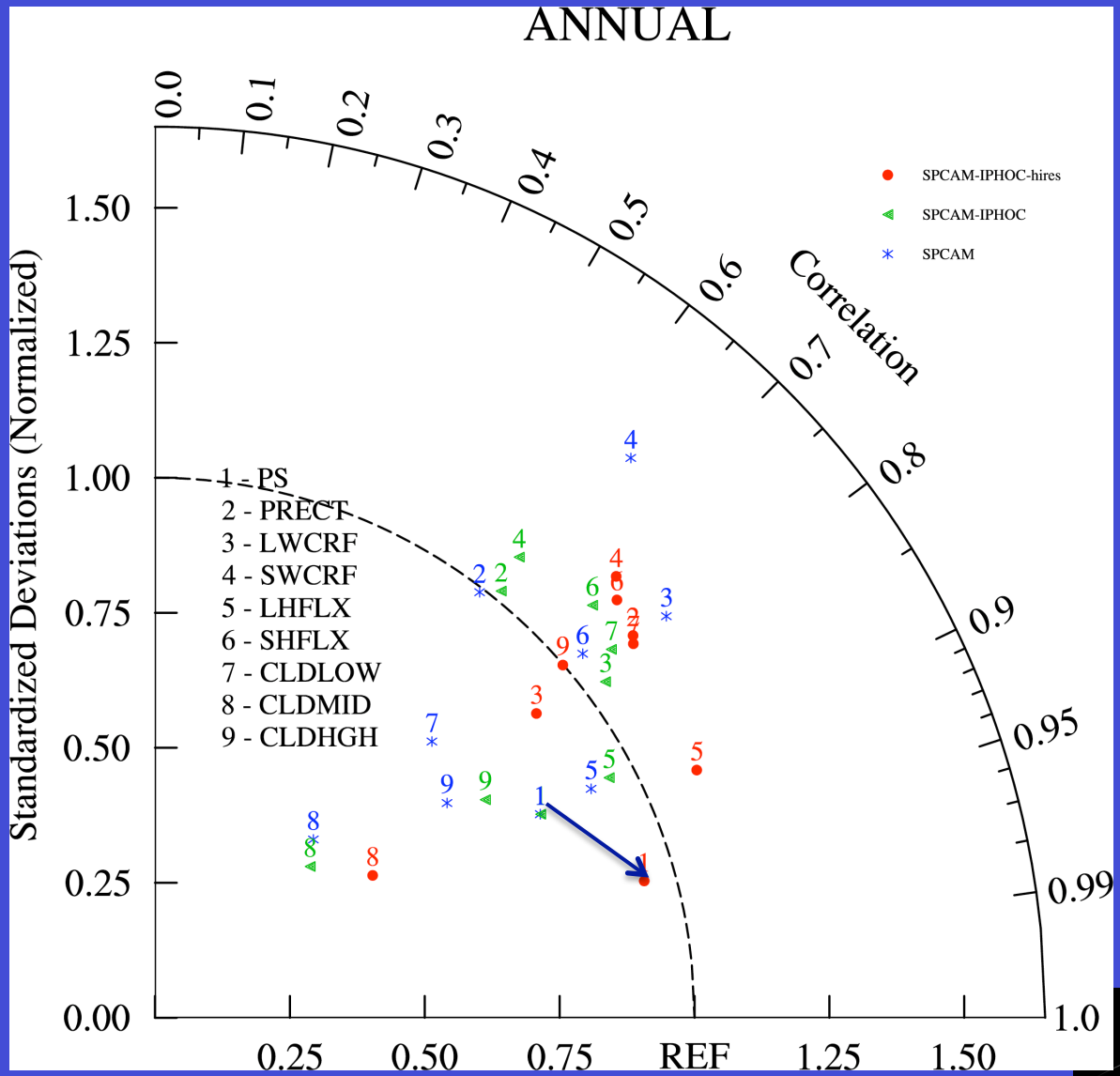
TOA and surface energy balance

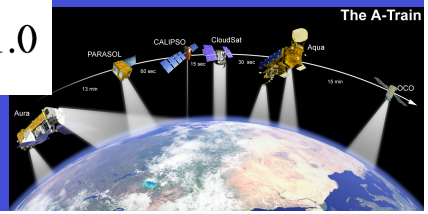
	SW	LW	Imbalance
SPCAM-IPHOC	241.33	235.17	6.16
SPCAM-IPHOC-hires	240.10	240.07	0.03

	SW-sfc	LW-sfc	LH	SH	Imbalance
SPCAM-IPHOC	161.34	55.16	81.65	23.03	-1.50
SPCAM-IPHOC-hires	161.47	57.21	88.97	23.06	7.77



Summary of results: the Taylor diagram





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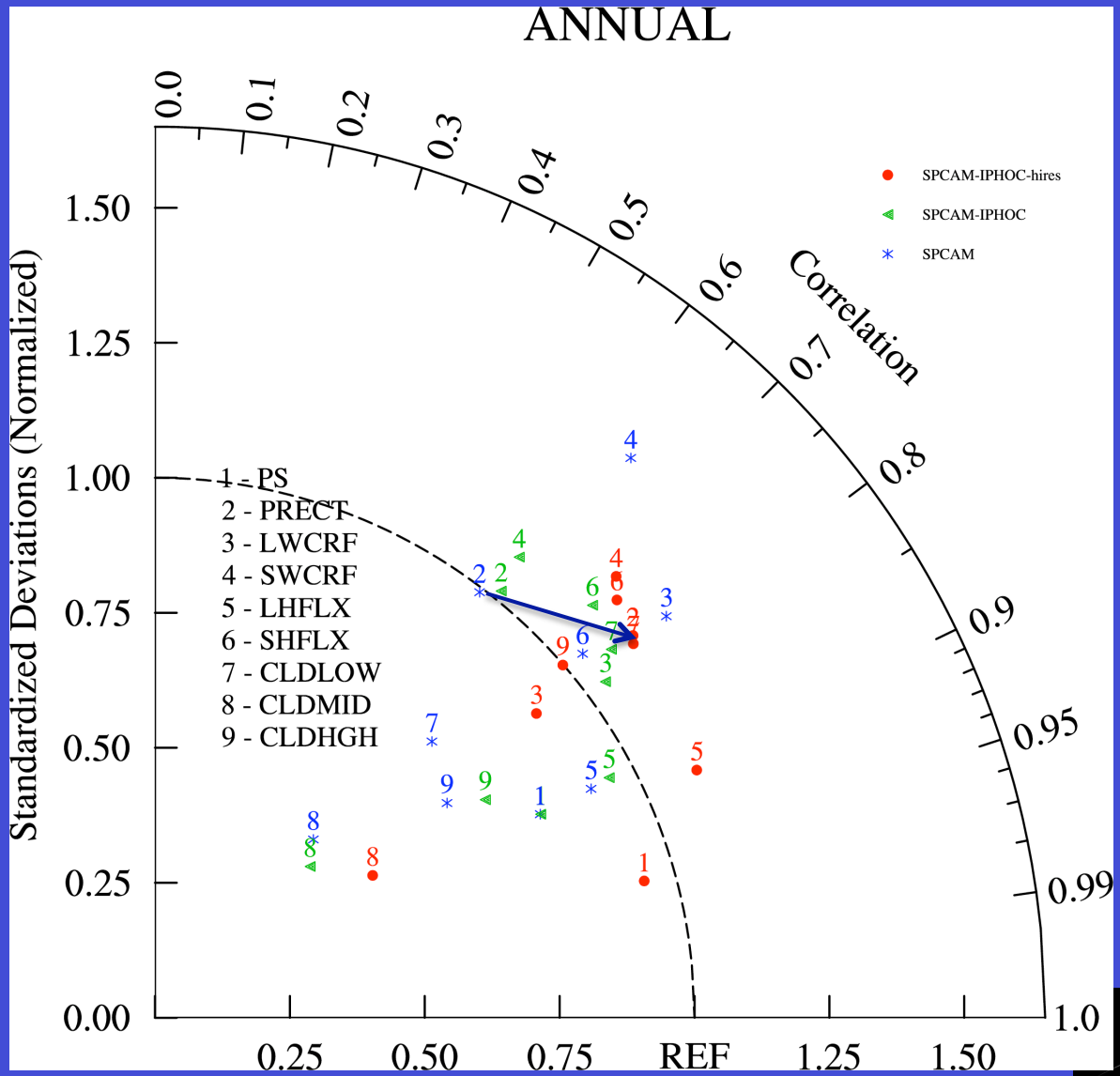

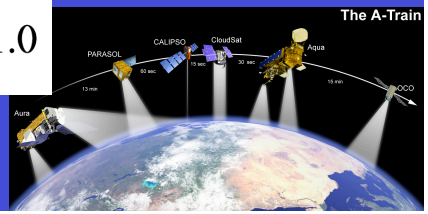

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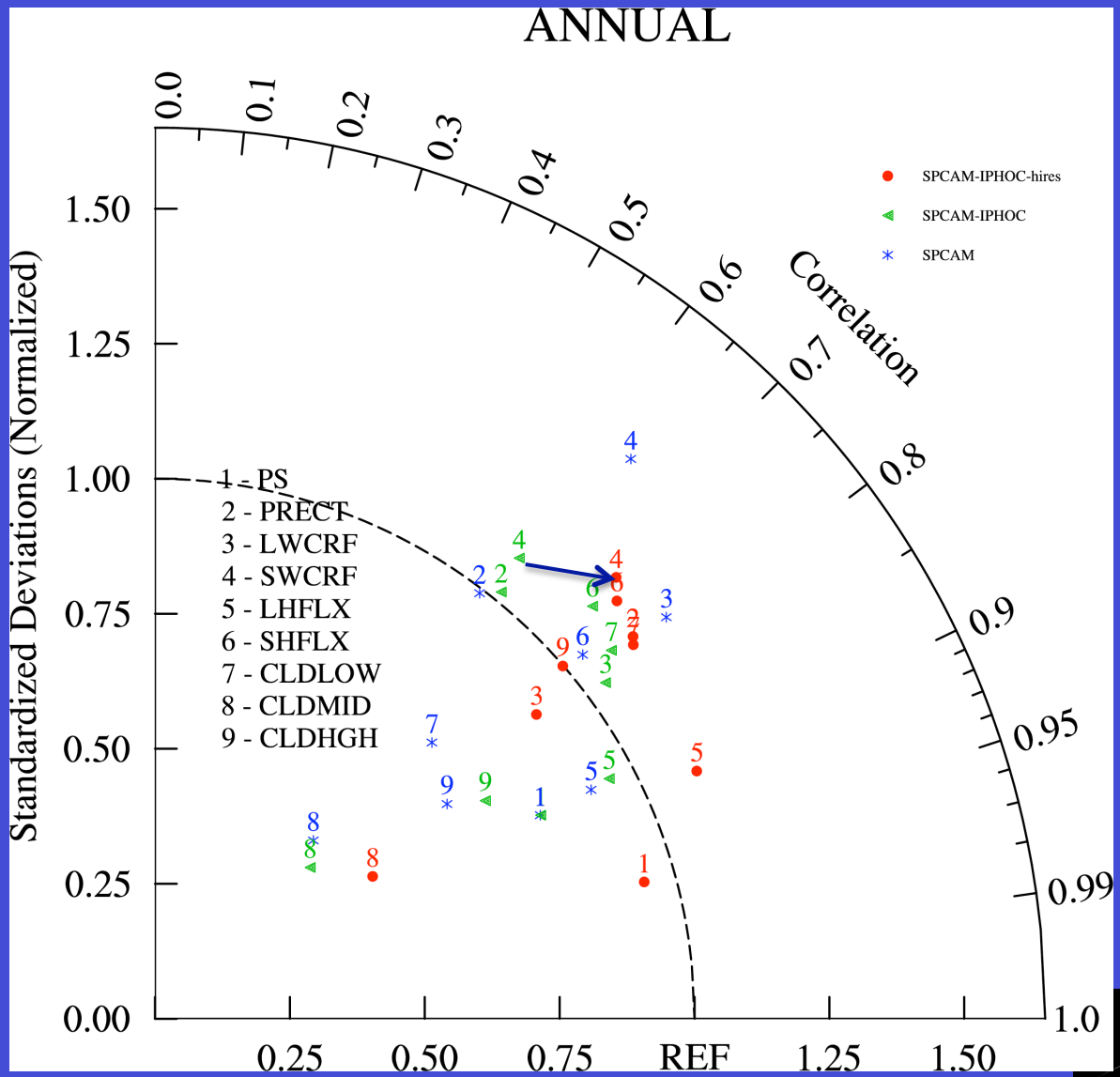

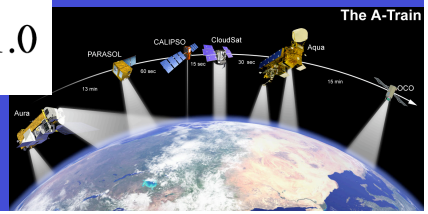

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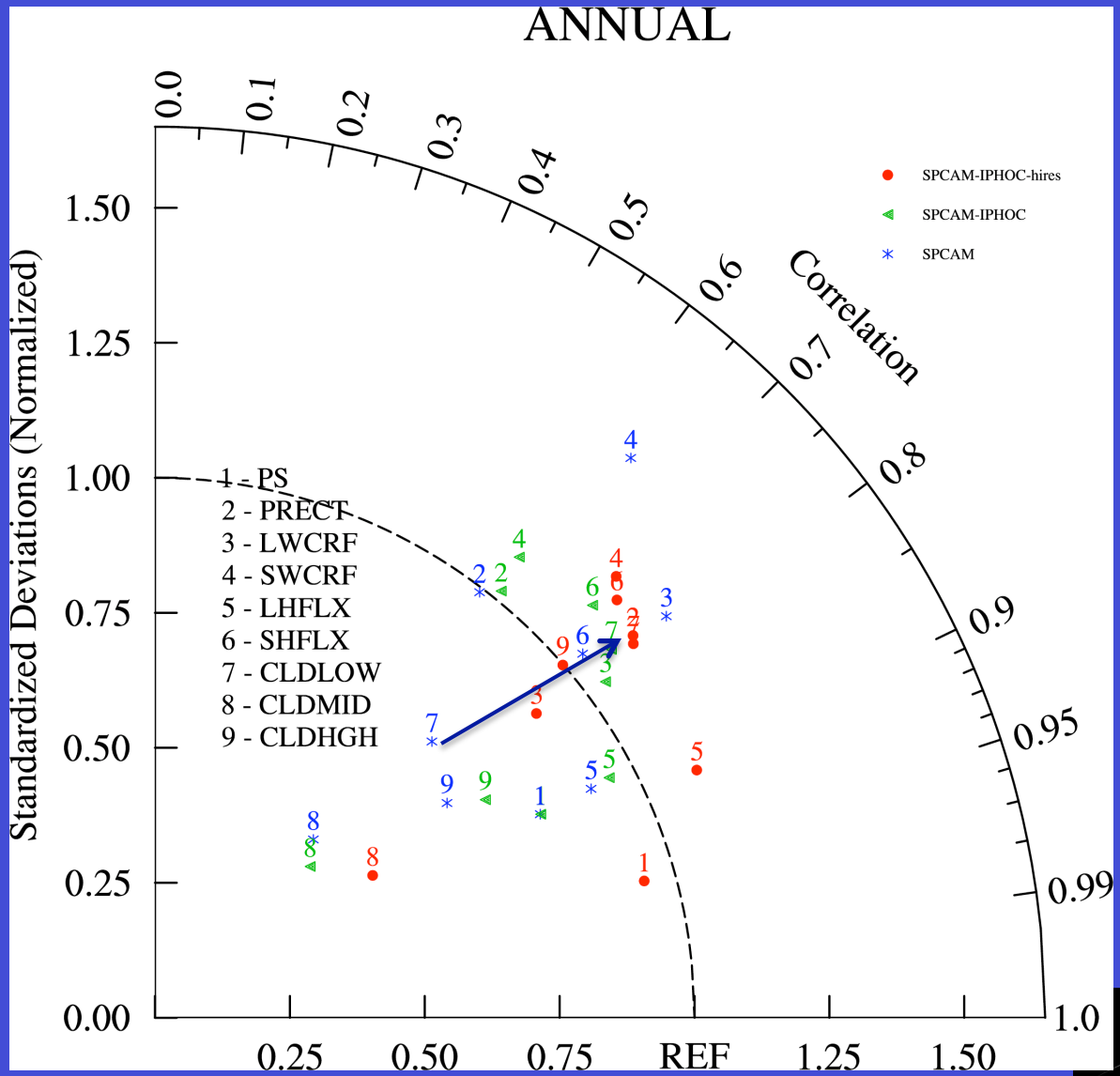

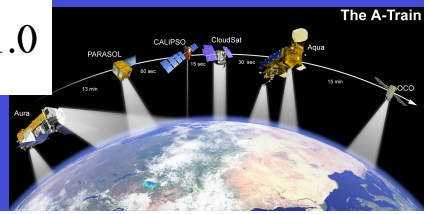

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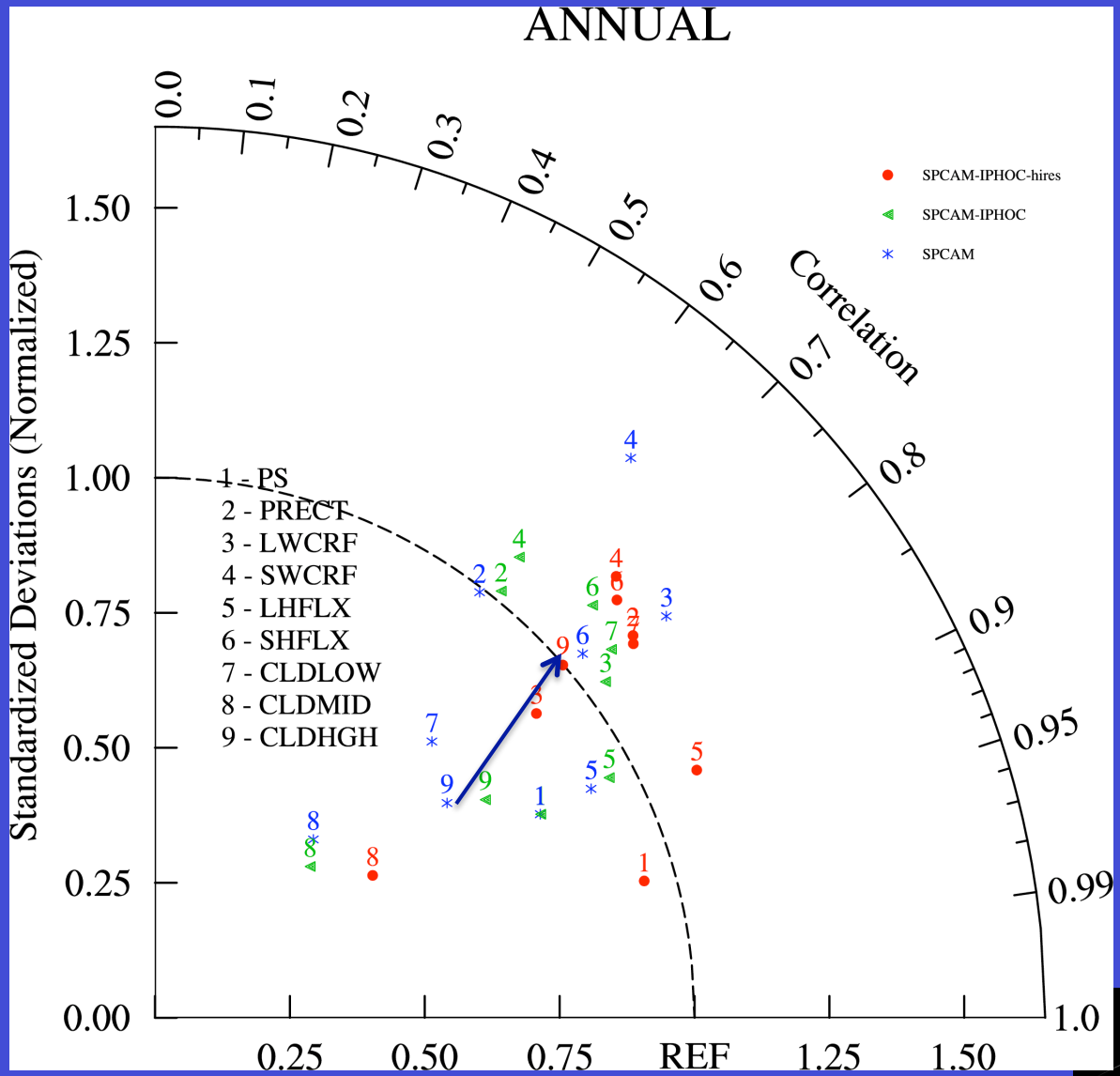
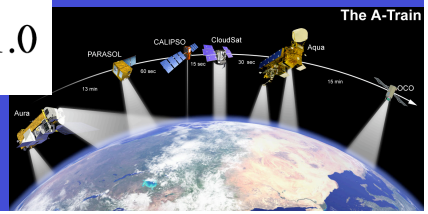
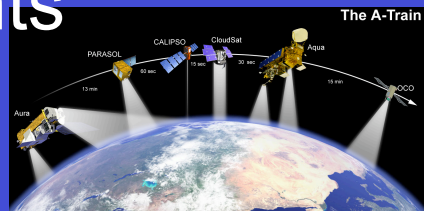


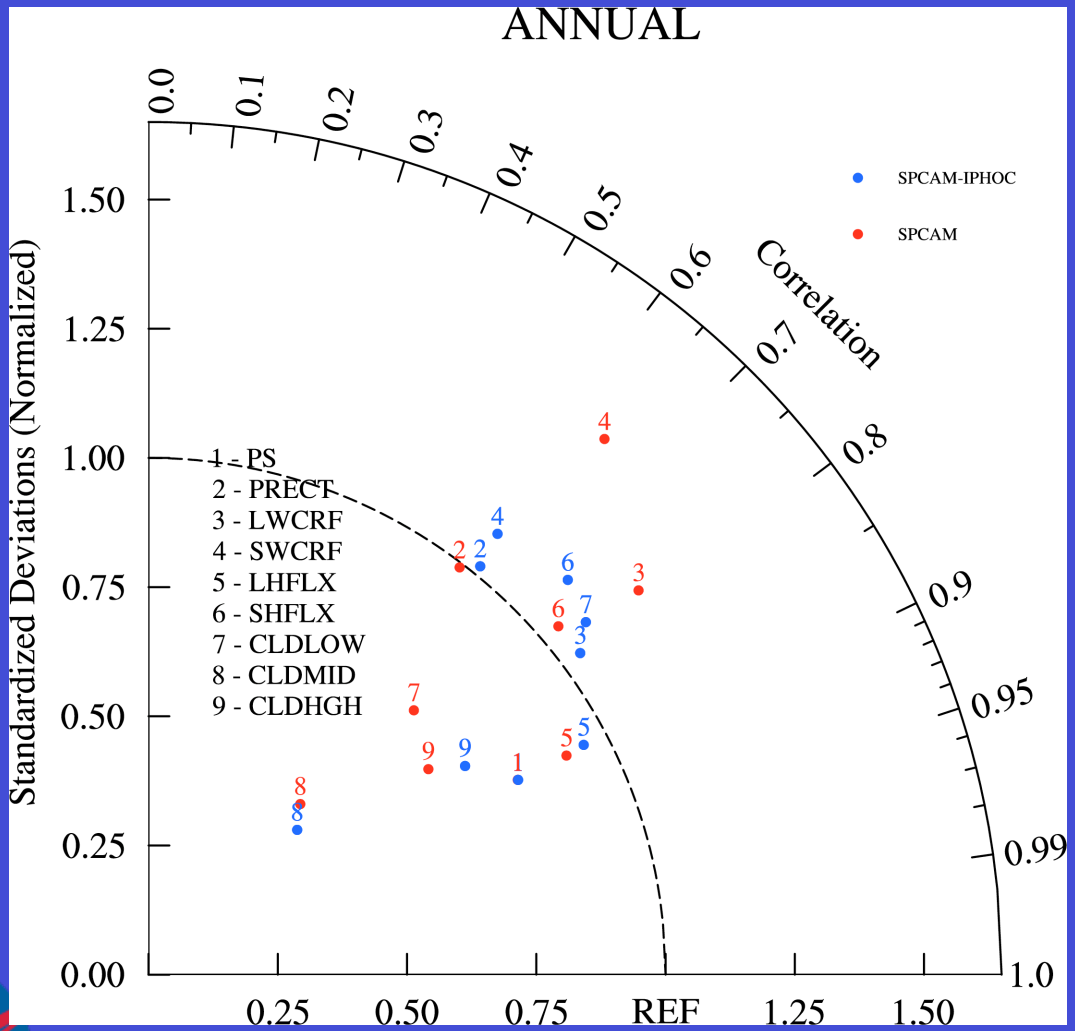


Summary and conclusions

- Both upgraded SPCAM-IPHOC simulations show improved representation of
  - the global distributions of low-level clouds
  - the amounts of low-level clouds in the subtropics
  - surface precipitation (for higher-resolution one)
- The comparison against C3M observations shows further improved results in the higher-resolution MMF, for example, near-coast thin stratus clouds and deep convection in the tropics
- The TOA radiative energy balance is nearly perfect in the higher-resolution simulation
- There are rooms for further improvements



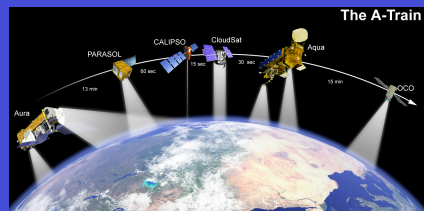
Summary of results: the Taylor diagram SPCAM-IPHOC vs. SPCAM



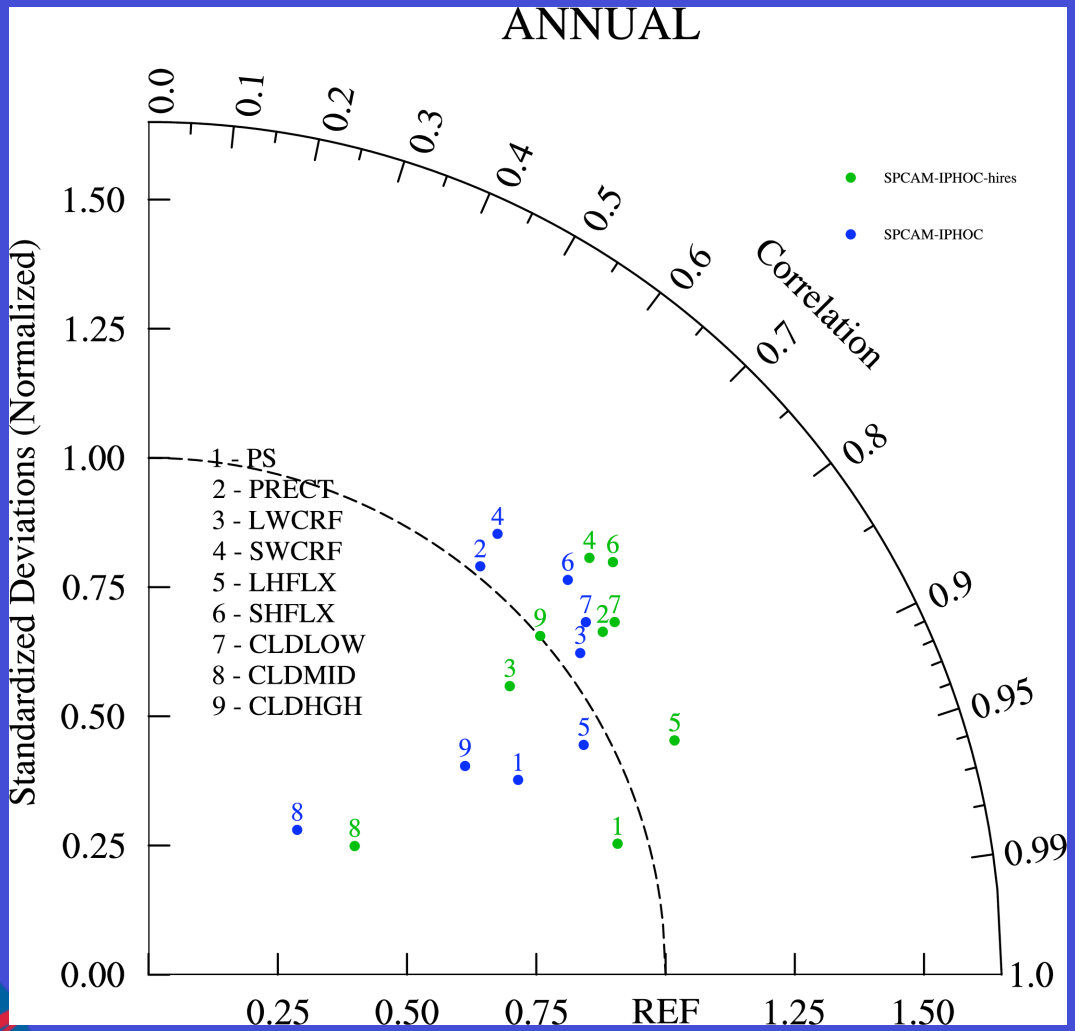
Significant improvement
Low-level cloud
SW CRF
LW CRF

Small/no improvment
Surface pressure
Middle-level cloud
High-level cloud
Surface precipitation
Latent heat flux

Degraded
Surface sensible flux



Summary of results: the Taylor diagram SPCAM-IPHOC-hires vs. SPCAM-IPHOC



Significant improvement
Surface pressure
Surface precipitation
Mid-level cloud
High-level cloud
Latent heat flux
SW CRF

Small/no improvement
Low-level cloud
LW CRF
Sensible heat flux