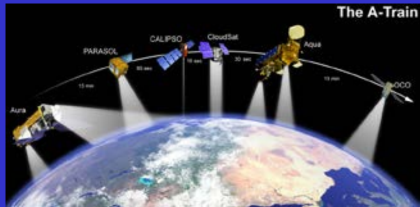
Climate Simulation of the Seasonal Variations of the Eastern Pacific Deep Convection and Low Clouds with a Multiscale Modeling Framework Model

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

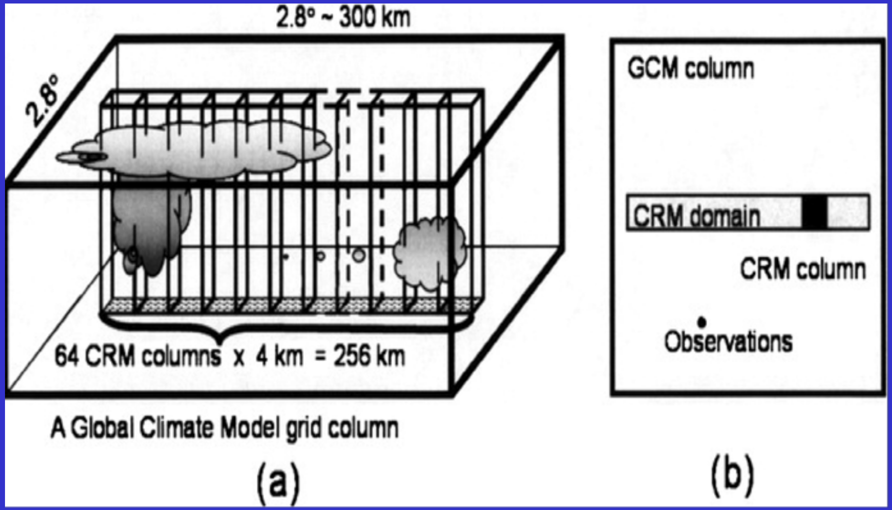
1. NASA Langley Research Center, Hampton, VA
2. Science Systems and Applications, Inc., Hampton, VA



Multiscale Modeling Framework

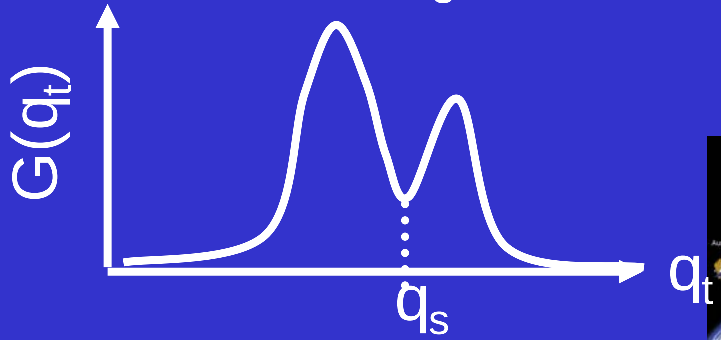
(Grabowski 2001; Khairoutdinov and Randall 2001)

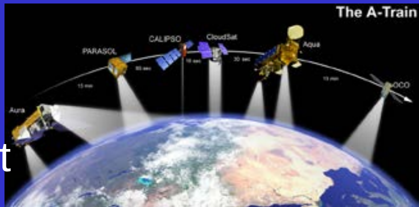
- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1s km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)



Upgraded CRM with a third-order turbulence closure (IPHOC):

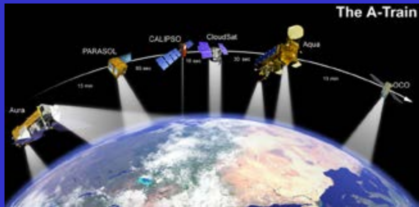
- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity
- Skewnesses, i.e., the three third-order moments, predicted
- All first-, second-, third- and fourth-order moments, subgrid-scale condensation and buoyancy based on the same PDF



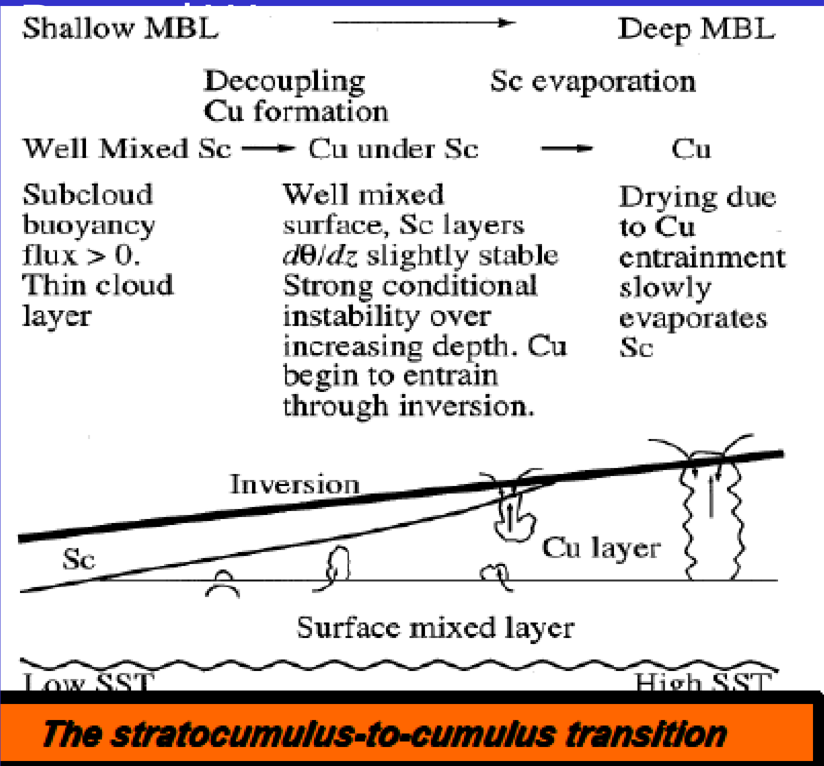


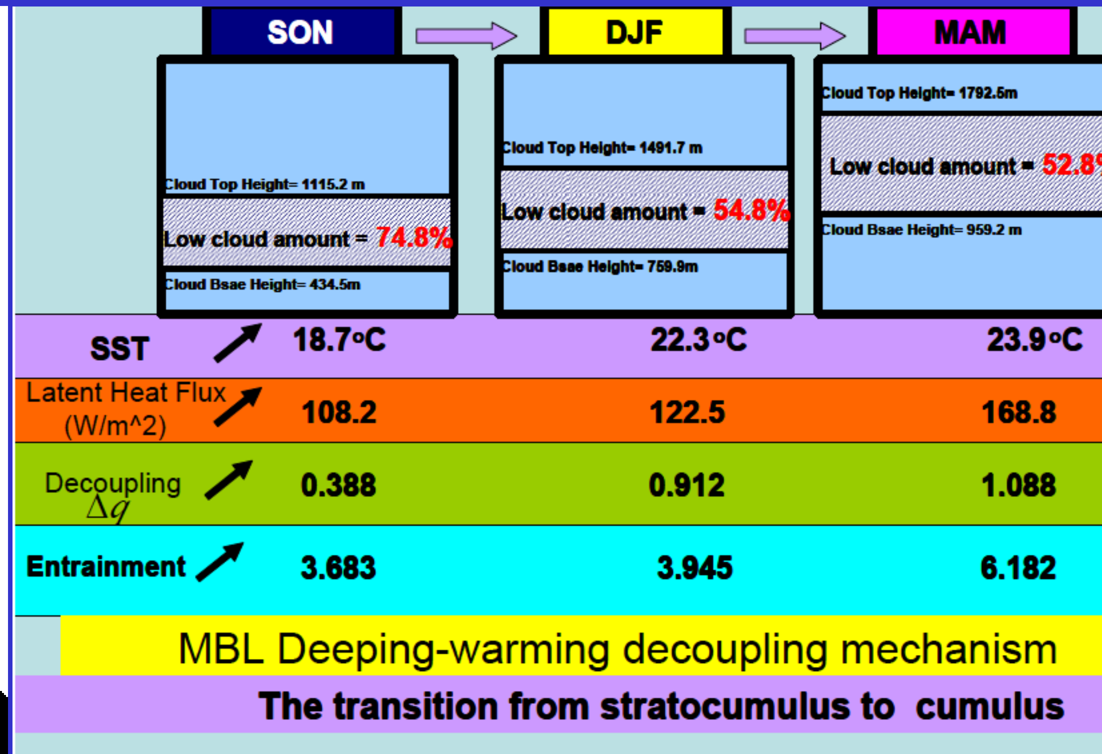
MMF climate simulation

- The model, SPCAM-IPHOC, is Community Atmosphere Model version 3.5 with finite-volume dynamic core as the host GCM.
- The CRM is the 2-D version of System for Atmospheric Modeling (SAM) with IPHOC higher-order turbulence closure, the grid spacing is 4 km, with 32 columns within a GCM grid box.
- Simulation IP-12L: SPCAM-IPHOC with 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.
- The simulation is 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).



Do seasonal variations of low clouds resemble the downstream stratocumulus-to-cumulus transition?



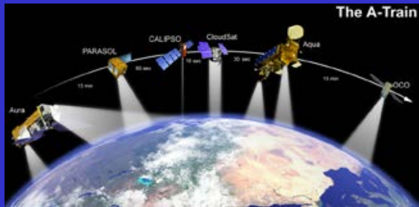


Bretherton and Wyant (1997) deepening-warming decoupling mechanism

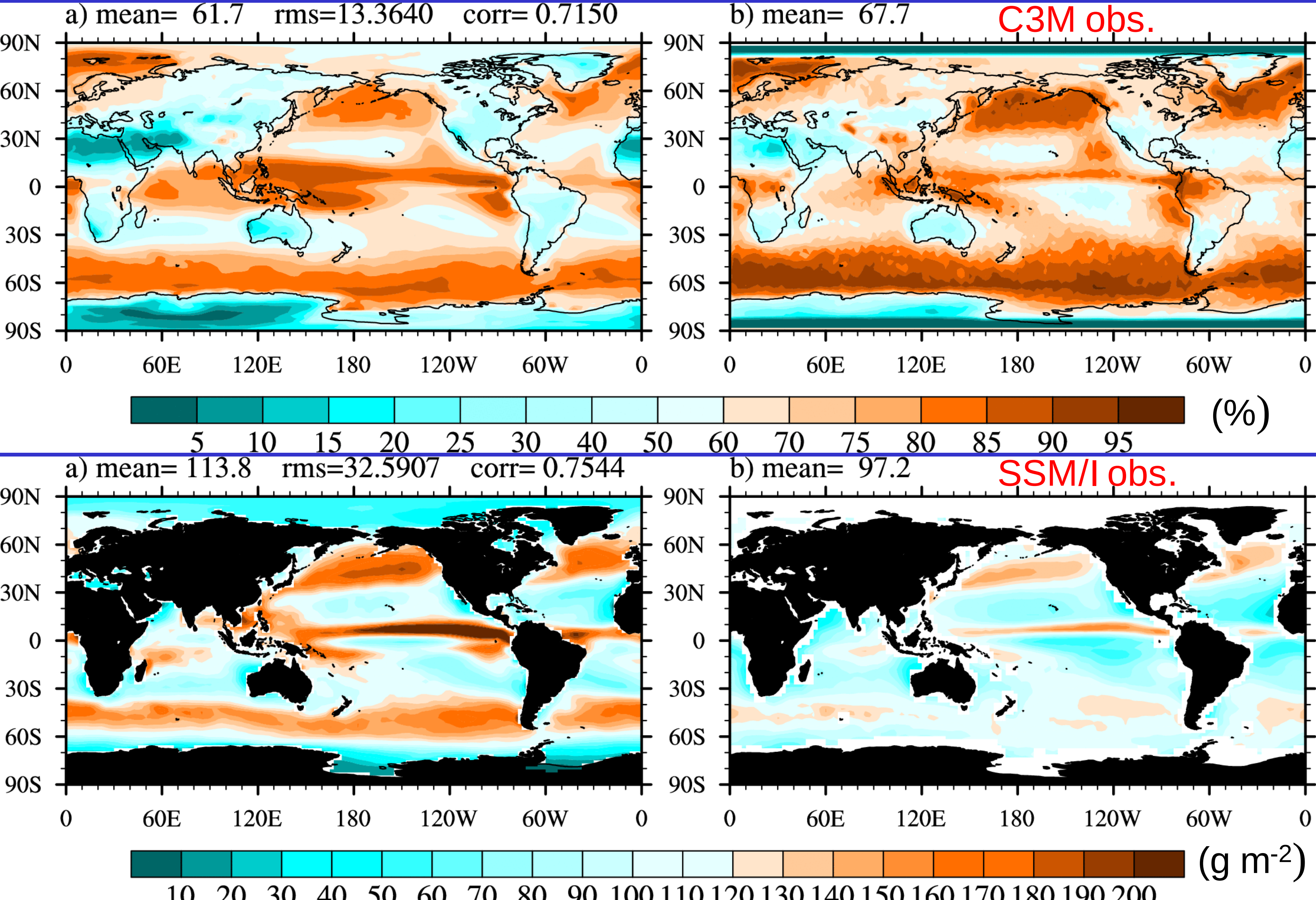
Wang et al. (2011) regional climate model results; also Lin et al. (2009) observational study of NE Pacific (JJA vs. DJF)

The Eastern Pacific Seasonal Cycle

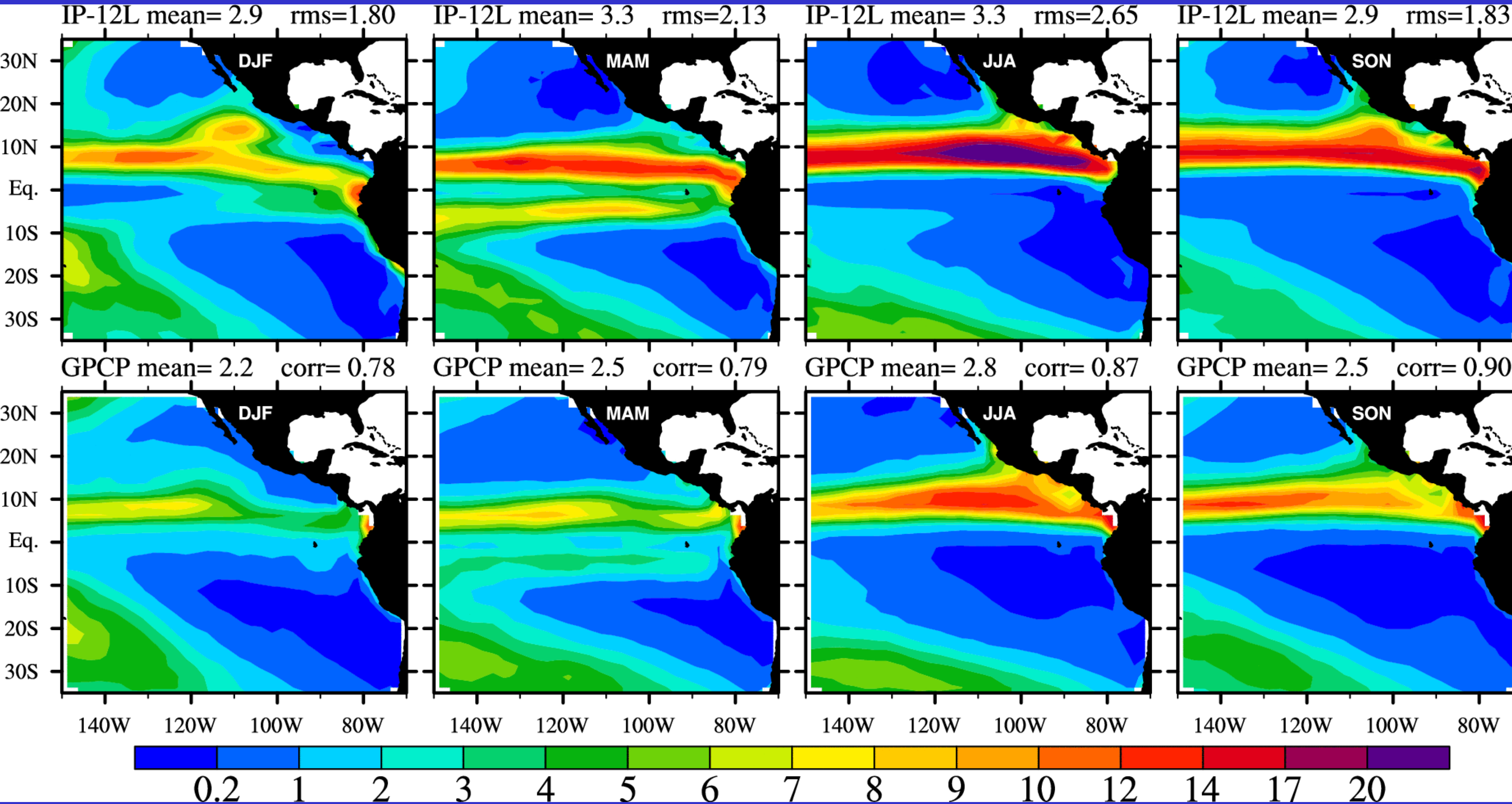
- All four seasons (DJF, MAM, JJA, and SON)
- Precipitation observations: Global Precipitation Climatology Project (GPCP; Adler et al. 2003)
- Low-level cloud amount: CloudSat, CALIPSO, CERES and MODIS merged data (C3M; Kato et al. 2010, 2011)
- Cloud radiative effects at the TOA and surface: CERES EBAF version 2.6r (TOA; Loeb et al. 2009) and surface EBAF2.6 (Kato et al. 2012)
- Liquid water path (LWP): SSM/I observations



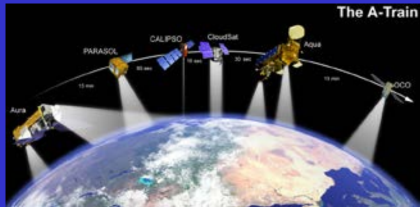
Annual-mean total cloud amount & LWP



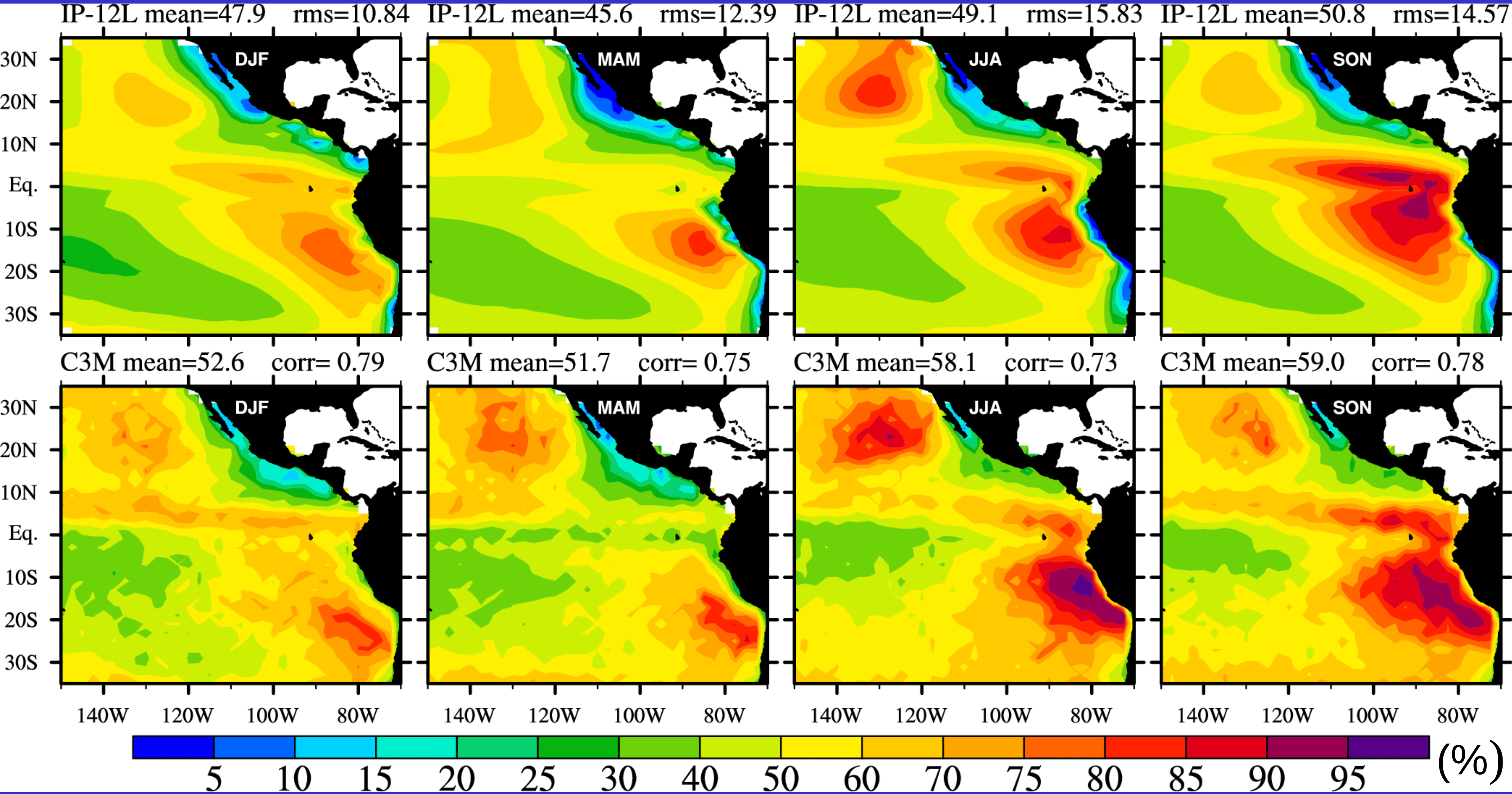
E. Pac. surface precipitation, MMF v GPCP

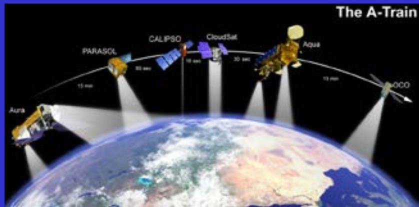


(mm/day)

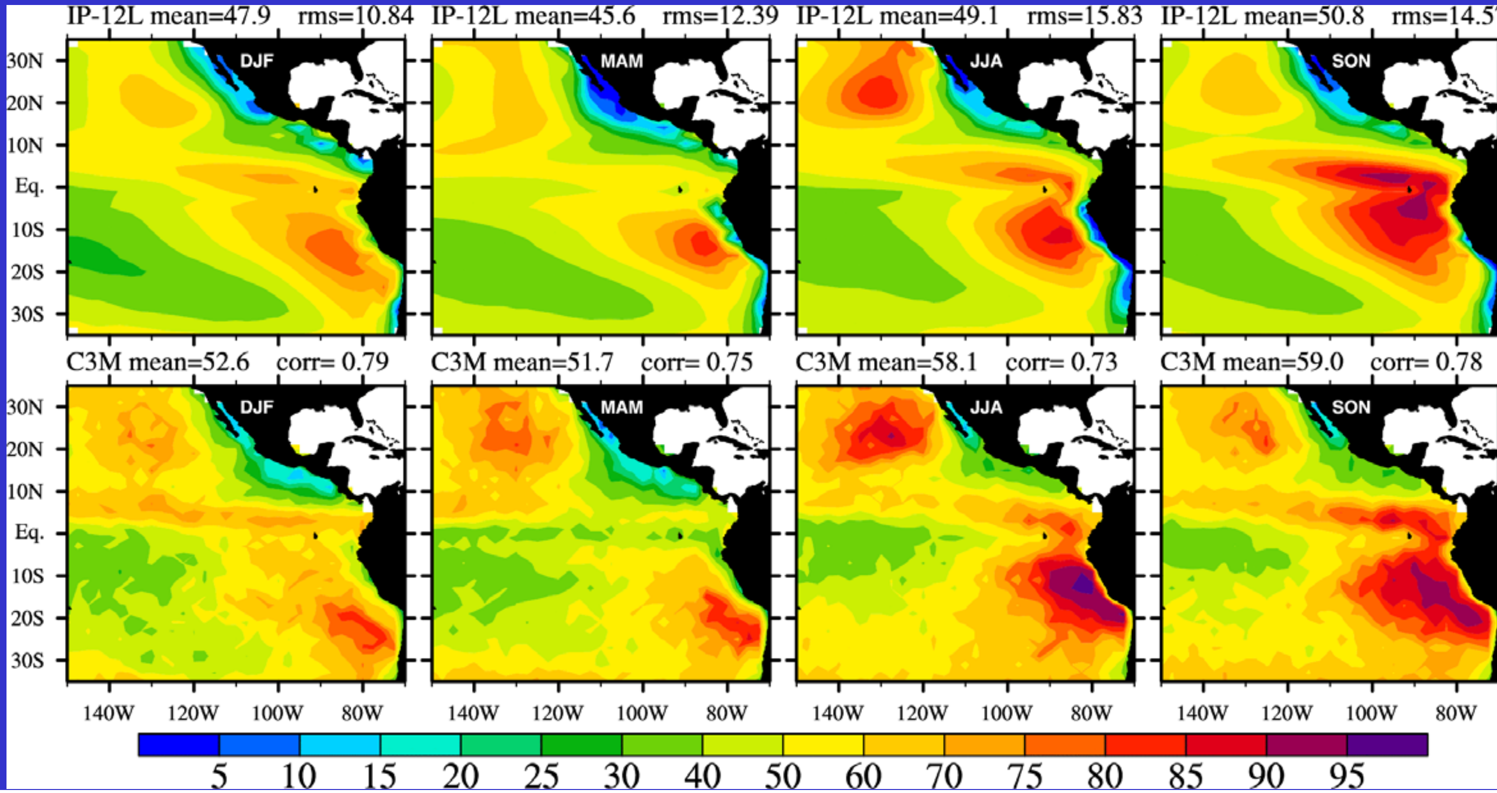


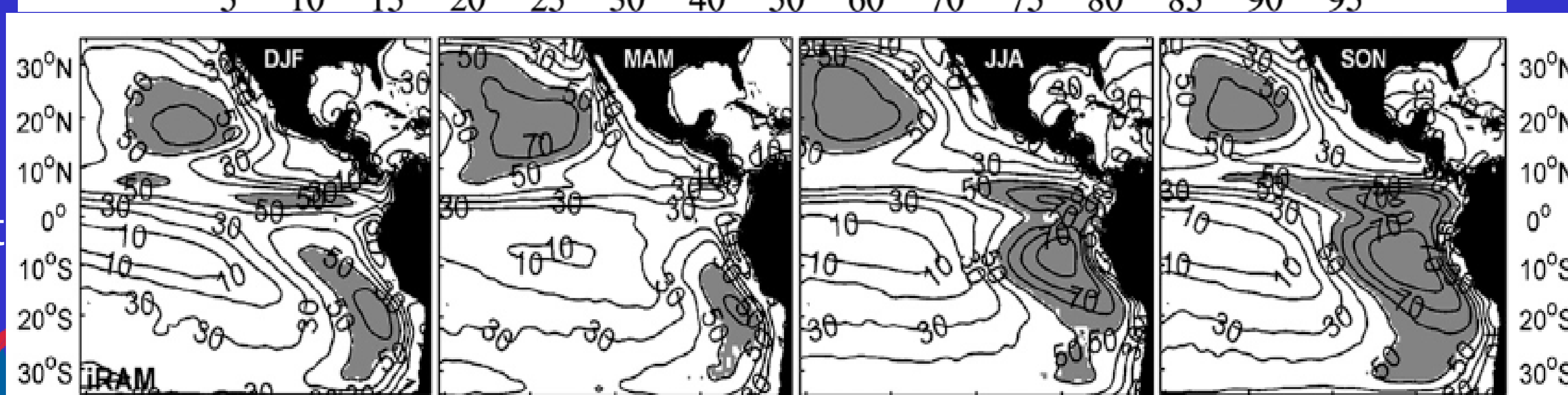
E. Pac. low cloud amount, MMF vs. C3M



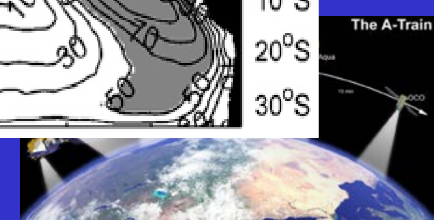


E. Pac. low cloud amount, MMF vs. C3M

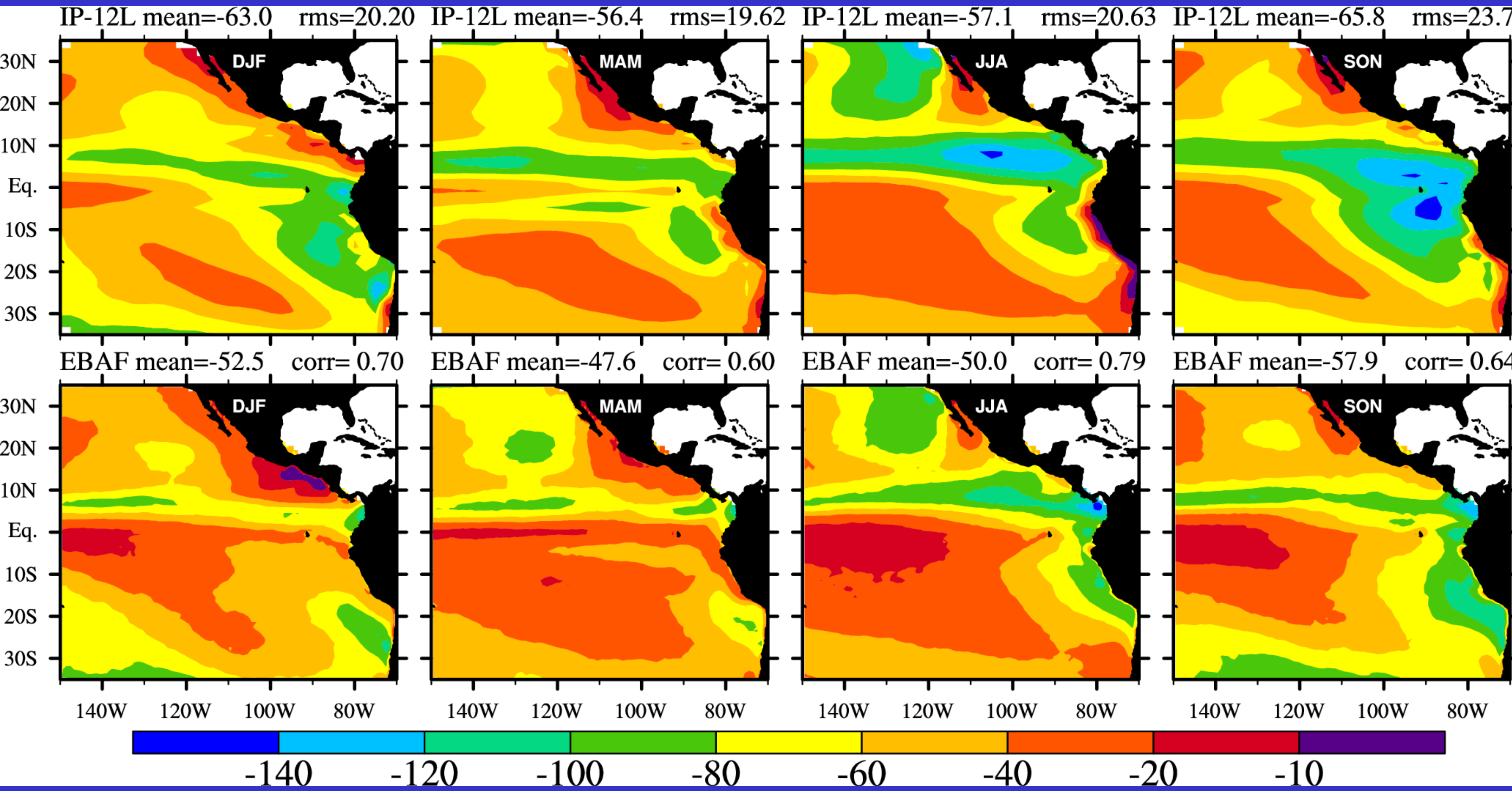


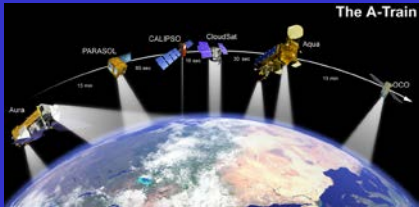


IPRC IRAM (Wang et al. 2011)

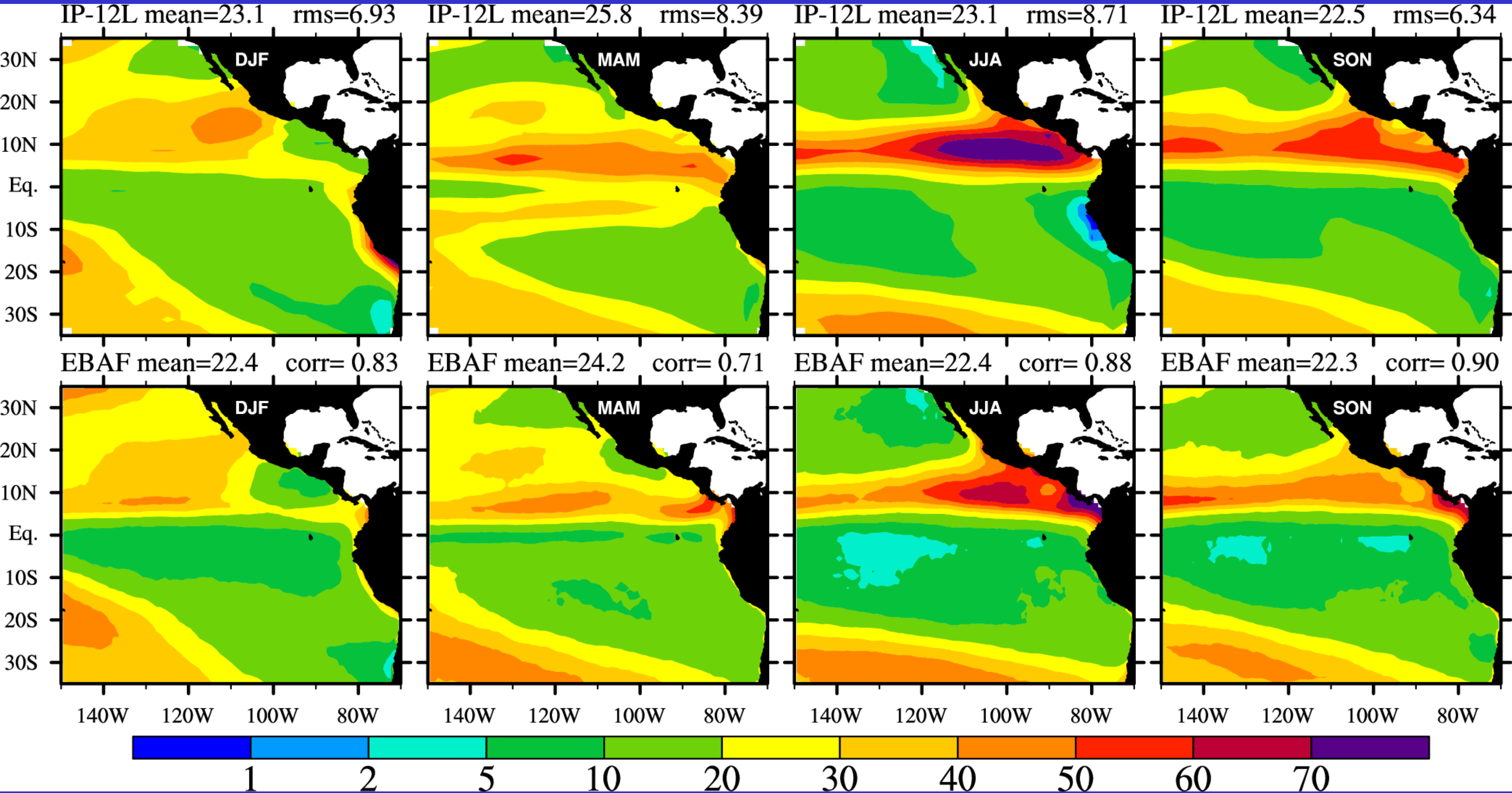


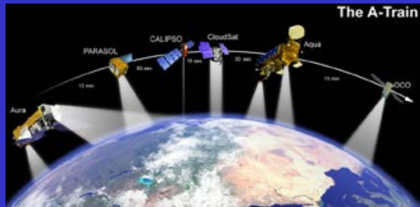
E. Pac. SW cloud radiative effect @ TOA



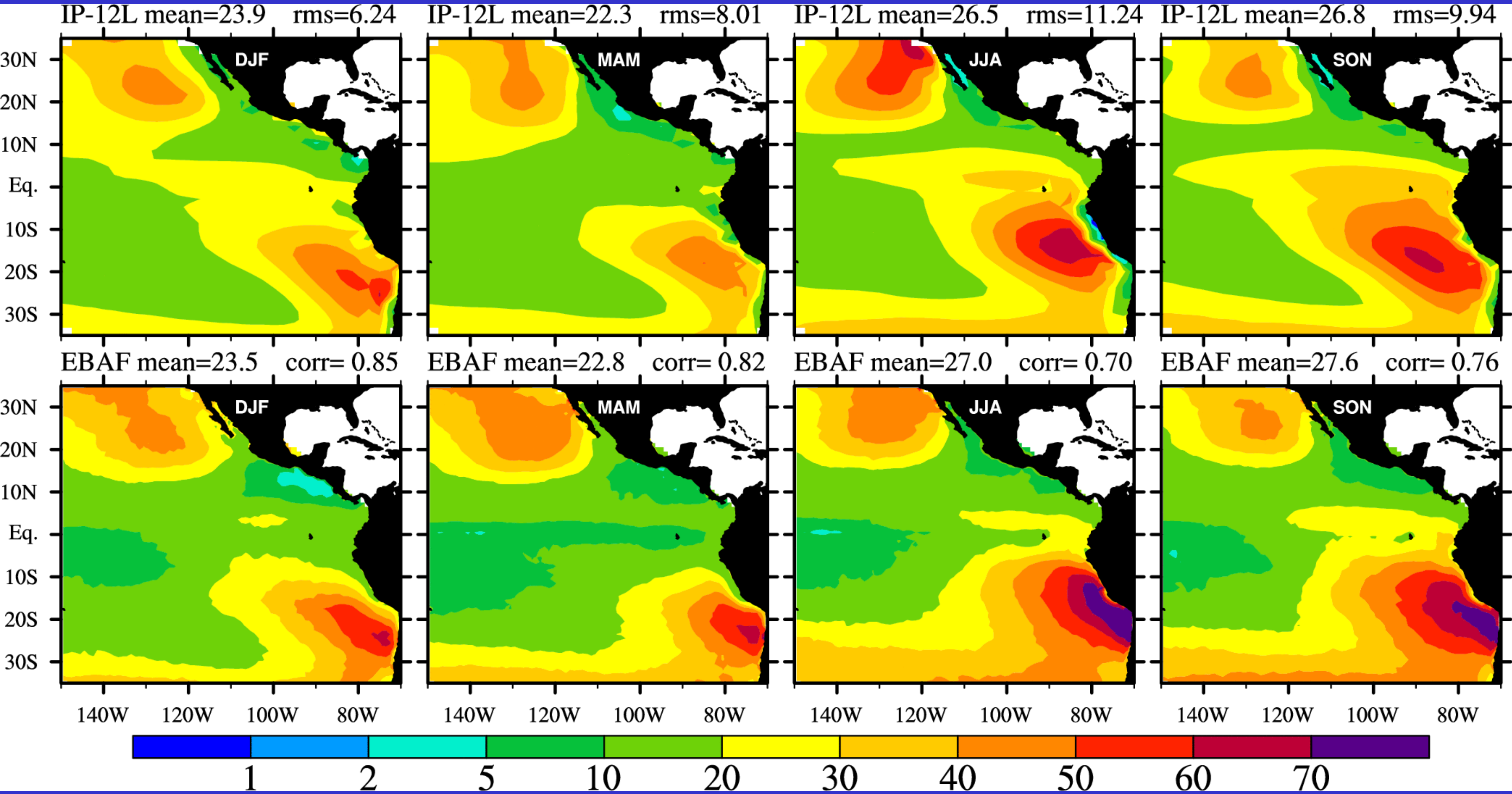


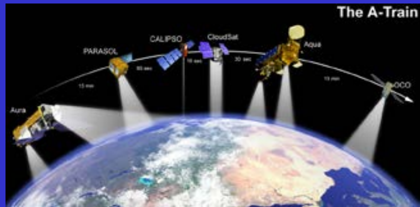
E. Pac. LW cloud radiative effect @ TOA





E. Pac. LW cloud radia. effect @ surface





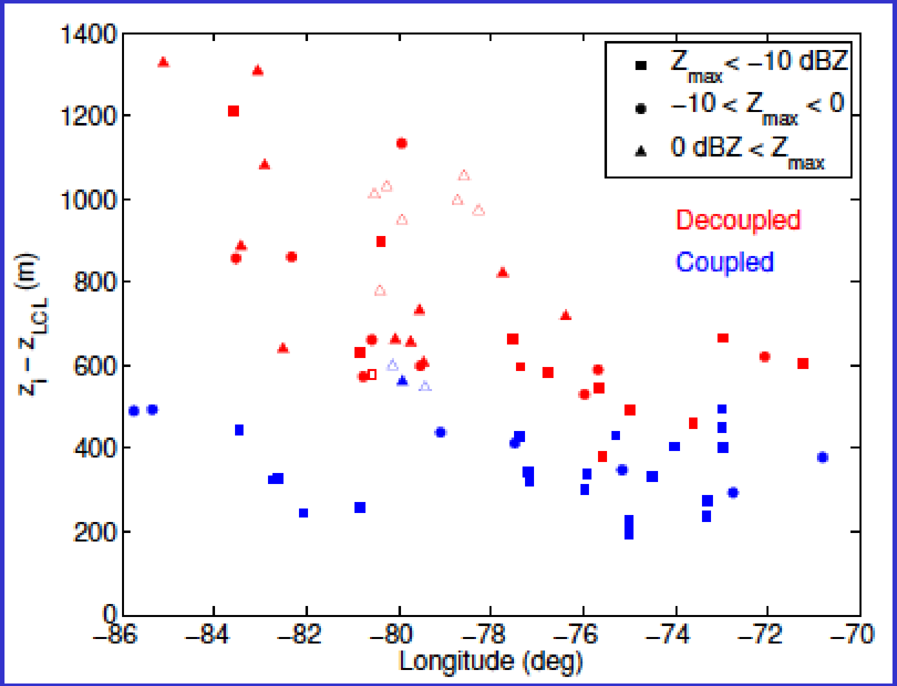
Decoupling measures

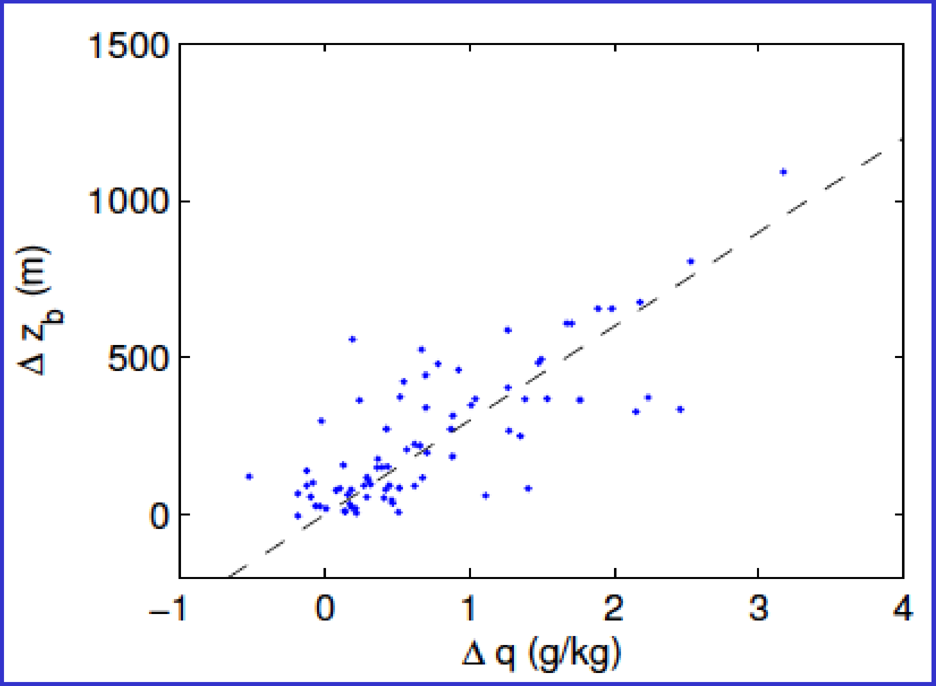
Profile-based (Wyant et al. 1997)

$$\Delta q = (q_t)_{sfc} - (q_t)_{CB},$$

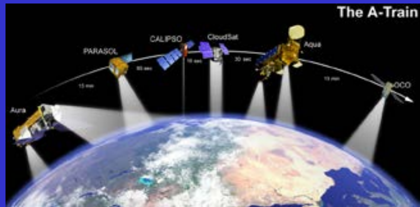
Subcloud-layer-based (Jones et al. 2011)

$$\Delta z_b = z_{CB} - z_{LCL}.$$

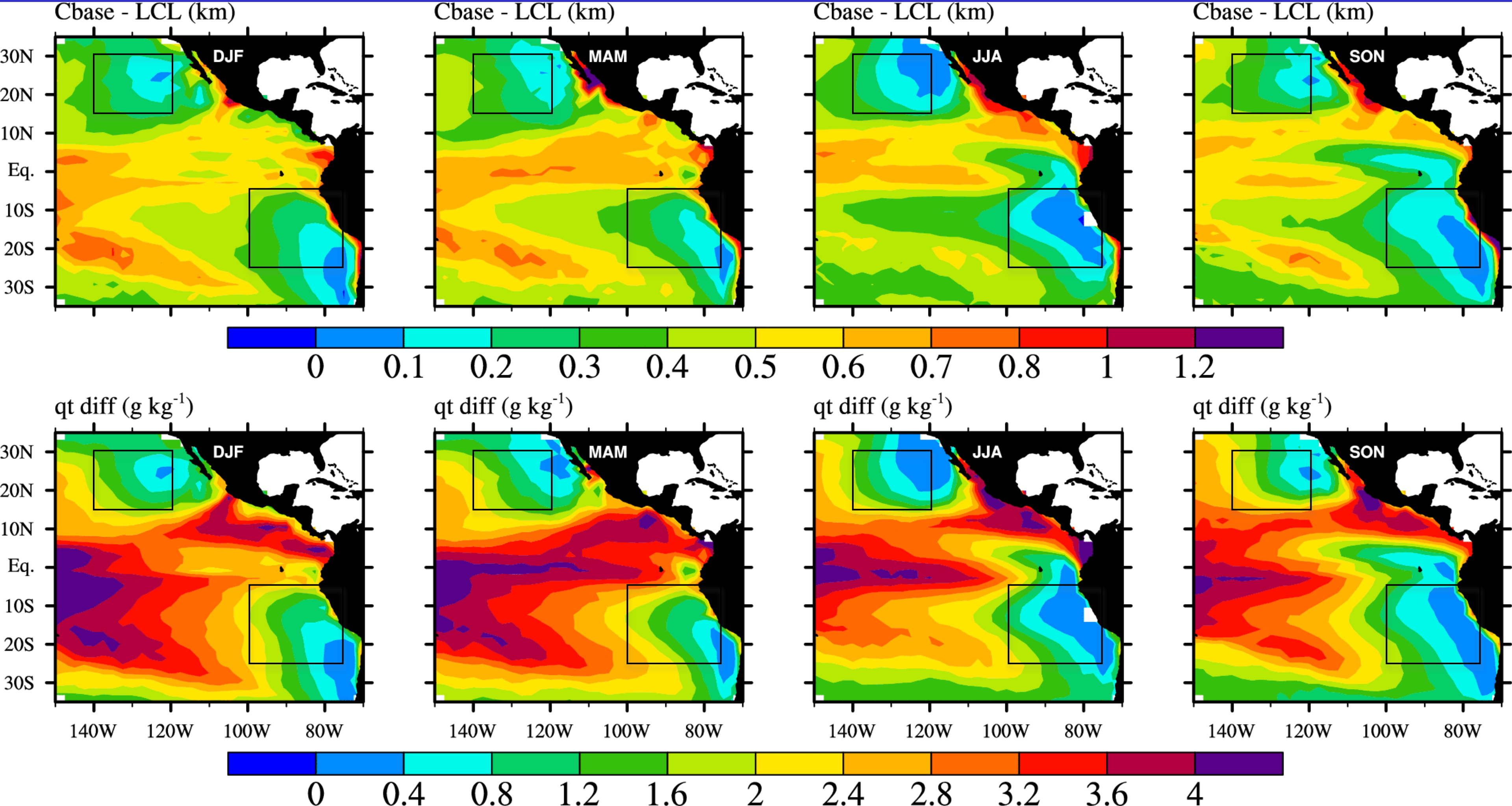


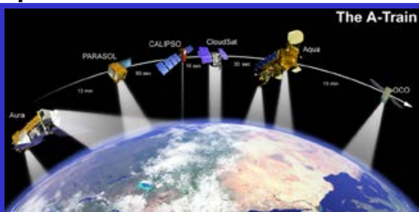


VOCLAS observations from Jones et al. (2011)



SCL- and profile-based decoupling measures

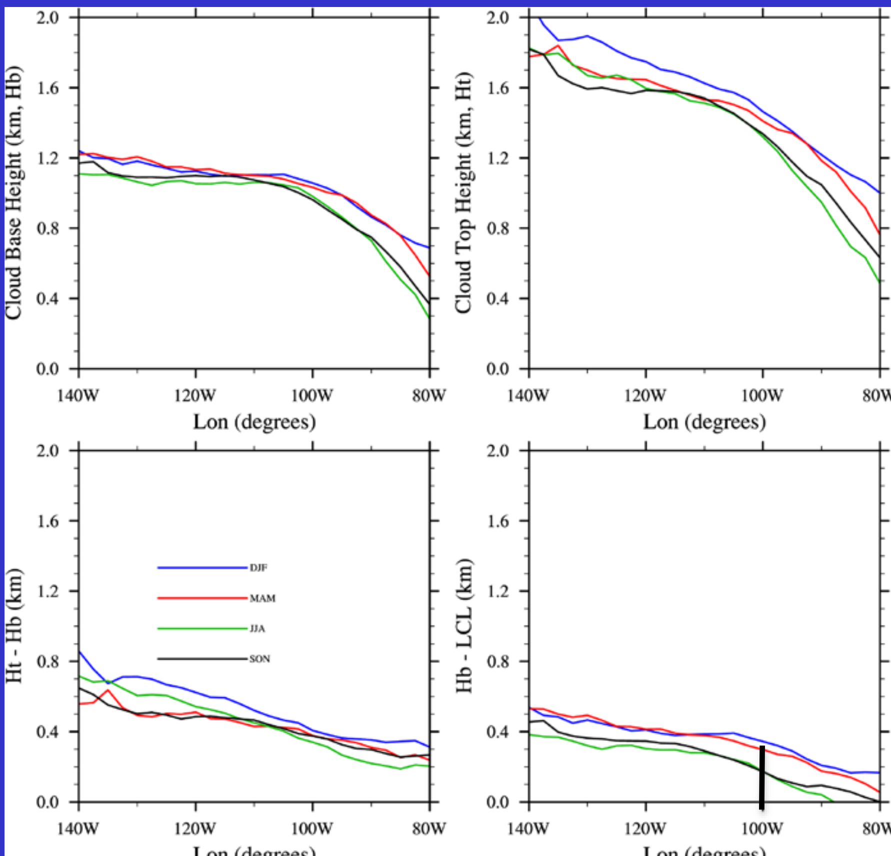


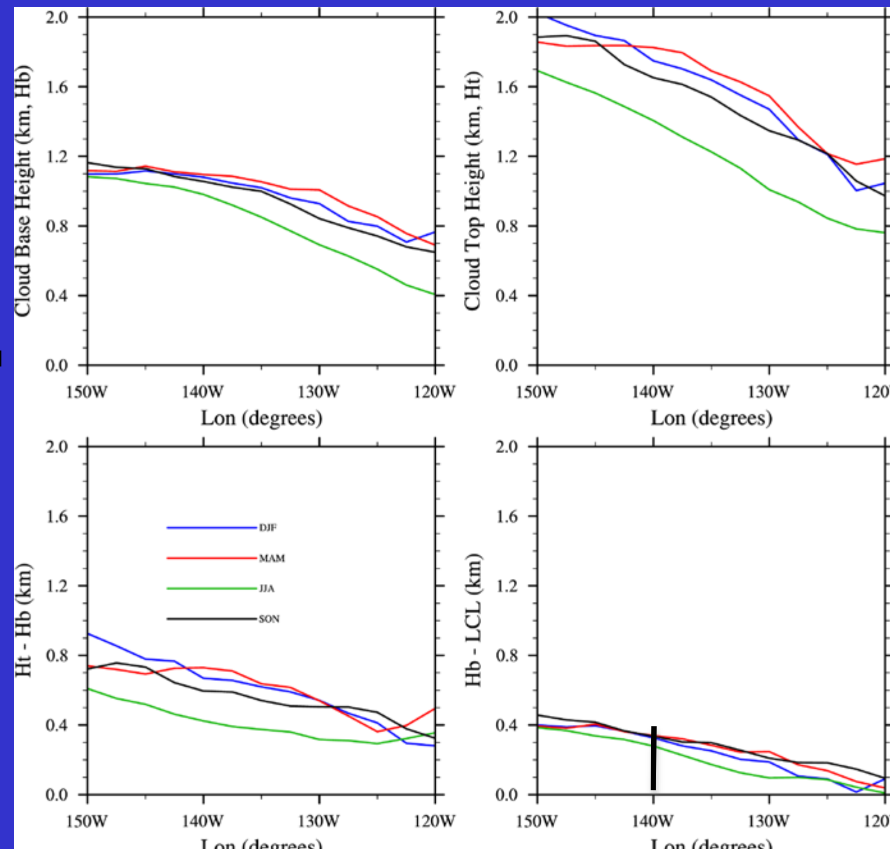


Decoupling measure and cloud macrophysics

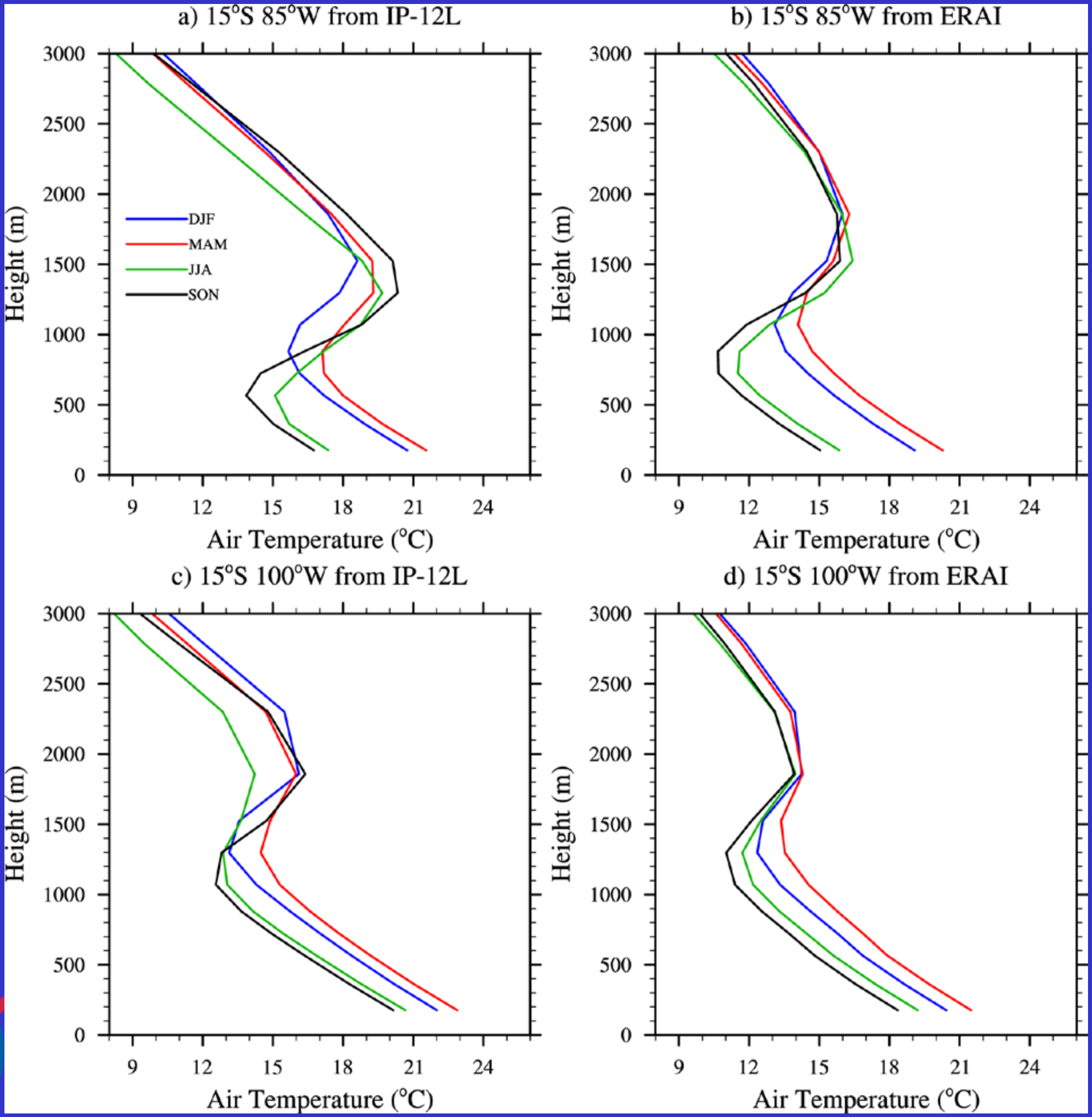
@ 15˚S

@ 25˚N



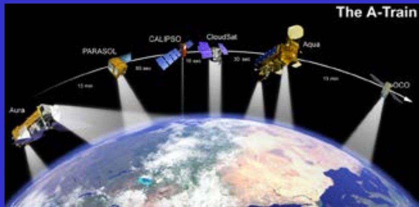


Temperature profiles at two points along 15°S



Interior of SE Pacific deck; well mixed

west edge of SE Pacific deck; more decoupled



Seasonal variation mechanisms

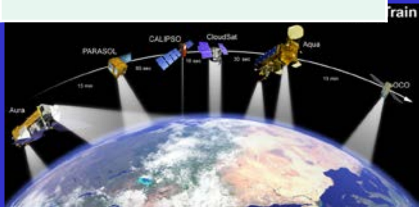
SE Pacific

Season/Parameter	SON	DJF	MAM
Cld amt (%)	67.6	64.6	59.7
Cld thick (m)	490	570	530
SST (K)	292.4	295.1	296.0
LH (W/m2)	111.6	103.0	135.6
Δq (g/kg)	0.88	1.31	1.44
Δz_b (m)	219	286	286

NE Pacific

Season/Parameter	JJA	SON	DJF
Cld amt (%)	73.4	59.3	56.9
Cld thick (m)	407	598	628
SST (K)	296.2	296.9	294.7
LH (W/m2)	115.6	139.1	161.8
Δq (g/kg)	0.82	1.38	1.05
Δz_b (m)	139	227	185

Factors	SON	DJF	MAM		JJA	SON	DJF
Solar	-	- -	-		- -	-	
LW	++	+	+		+++	+	+
Subsidence	+	+	+		++	+	
Mixing/sst	+++	++	+		+	+	+



Summary and conclusions

- The MMF climate simulation has biases that are similar to (but slightly smaller than) those in CMIP3 and CMIP5 ensembles; but it reduces regional biases associated with low-level clouds.
- The seasonal cycle of the eastern Pacific is rather well simulated, except for the exact locations of low-level clouds in the southeast Pacific and overestimated intensity of deep convection.
- The seasonal variations of low clouds are determined by the inversion strength and the height of inversion; they may not be explained by the deepening-warming mechanism.