Ongoing super-parameterization work at CSU

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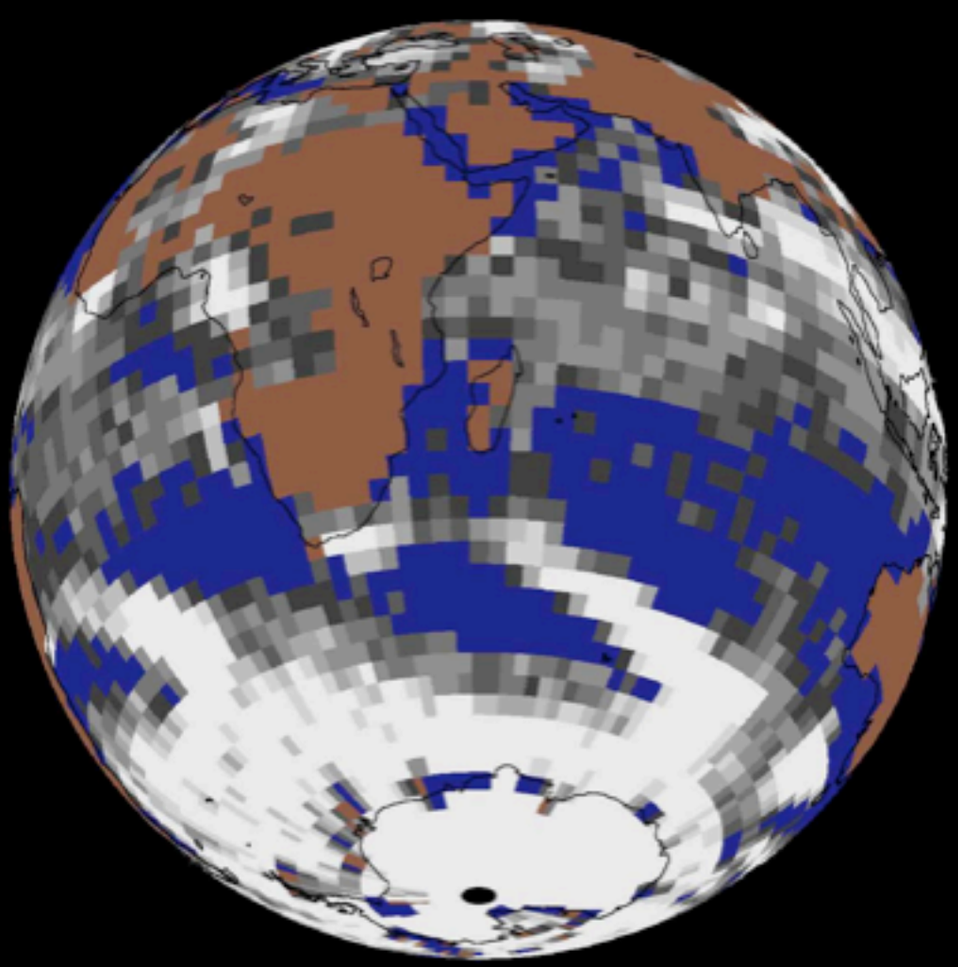


- No clouds are explicitly resolved by GCMs.
- All the effects of clouds have been parameterized.
- The (sign of) cloud feedback is (still) highly uncertain;
- Simulated cloud feedbacks may be predetermined by a parameterization used.
- A Global Cloud-Resolving Model would take at least 1,000,000 times as much computer power as a typical climate model.

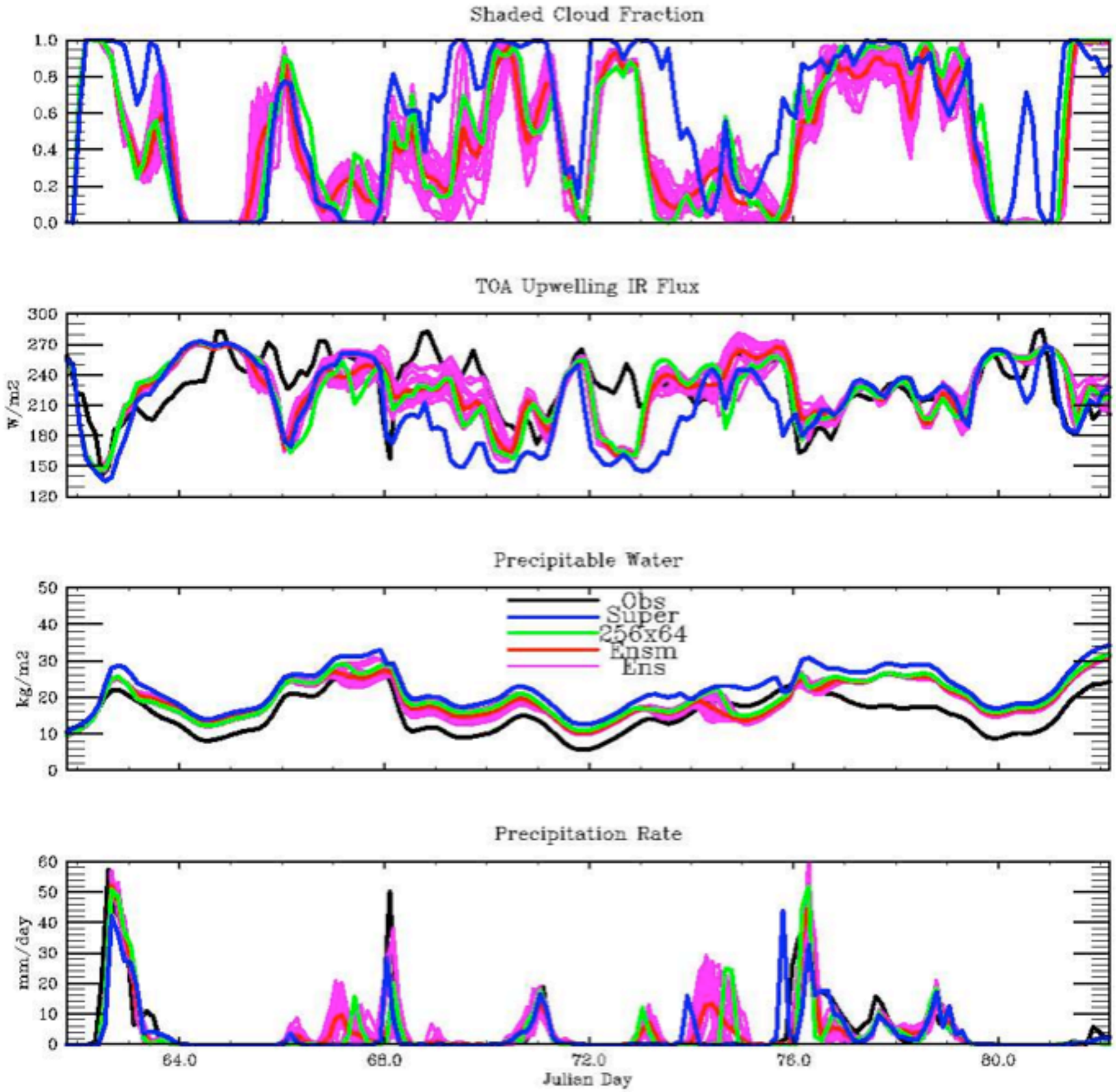
A Cloud-Resolving Model as a Parameterization

- Any convective parameterization works to stabilize the resolved-scale environment destabilized by radiation, surface fluxes, etc.
- Any cloud-resolving model (CRM) embedded into each GCM grid column can do the same thing, that is to compute mean heating and moistening rates needed to stabilize the resolved-by-GCM environment.
- From a GCM's prospective, the embedded CRM is just another (very slow) parameterization.
- Similarly, CRMs are aware of a GCM only through "large-scale" tendencies applied in a horizontally uniform manner.
- Conceptually simple; solves, e.g., the equations of motion in anelastic approximation with a few equations for thermodynamic variables and a bulk microphysics scheme to predict conversion of vapor to precipitation, etc.
- More than just a cloud model; a natural framework for coupling various physical processes on virtually all scales of non-hydrostatic motions - from PBL turbulence to MCSs.
- BUT, much more computationally expensive than conventional parameterizations, potentially hundreds of times as expensive.

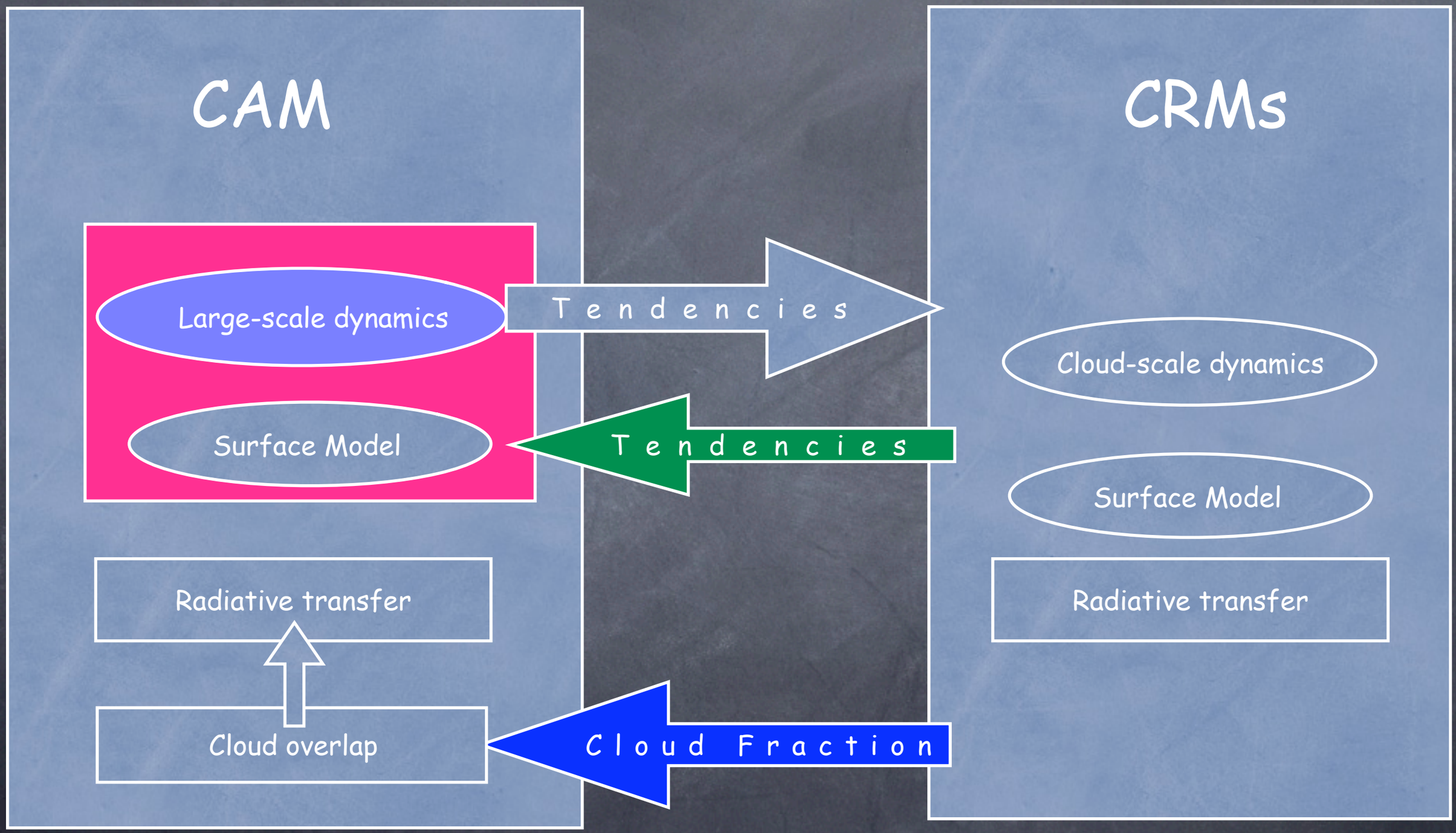
SP-CAM

- CAM - NCAR Community Atmosphere Model (version 1.8);
- Semi-Lagrangian; T42 resolution (2.8x2.8 deg.), 26 vertical levels; Dt = 1 hour;
- CRM - 64 x 24 gridpoint periodical domain, Dx=4km; Dt = 20 sec;
- Non-hydrostatic equations in anelastic approximation;
- Prognostics: Liquid/ice water static energy; total non-precipitating water, total precipitating water;
- Partition between liquid and ice phases depends on temperature;
- Bulk microphysics prognostics: cloud water/ice, rain, snow, and graupel;
- 8192 CRMs embedded into the CAM global grid - 524,288 CRM columns.

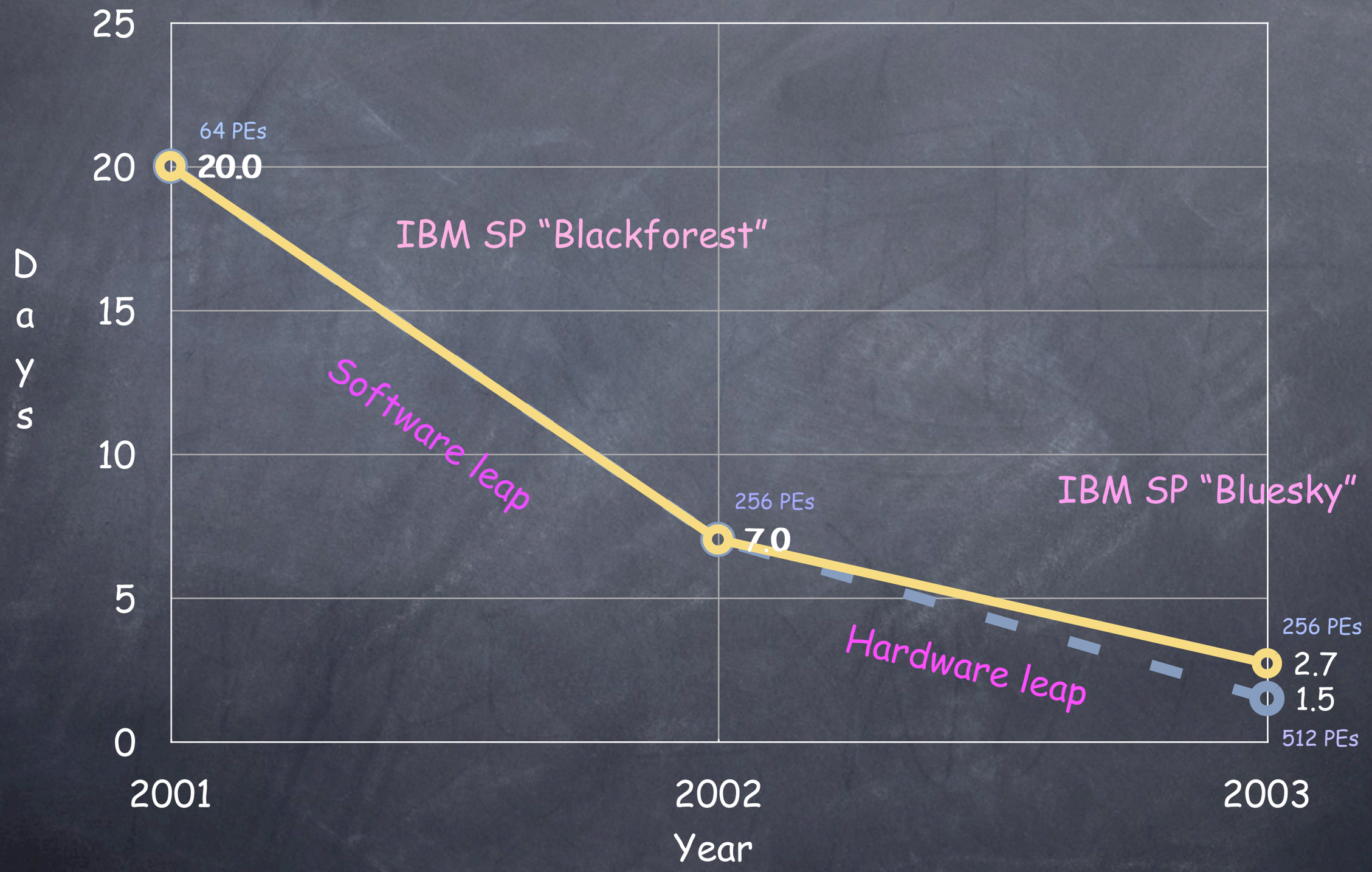
ARM March 2000 IOP



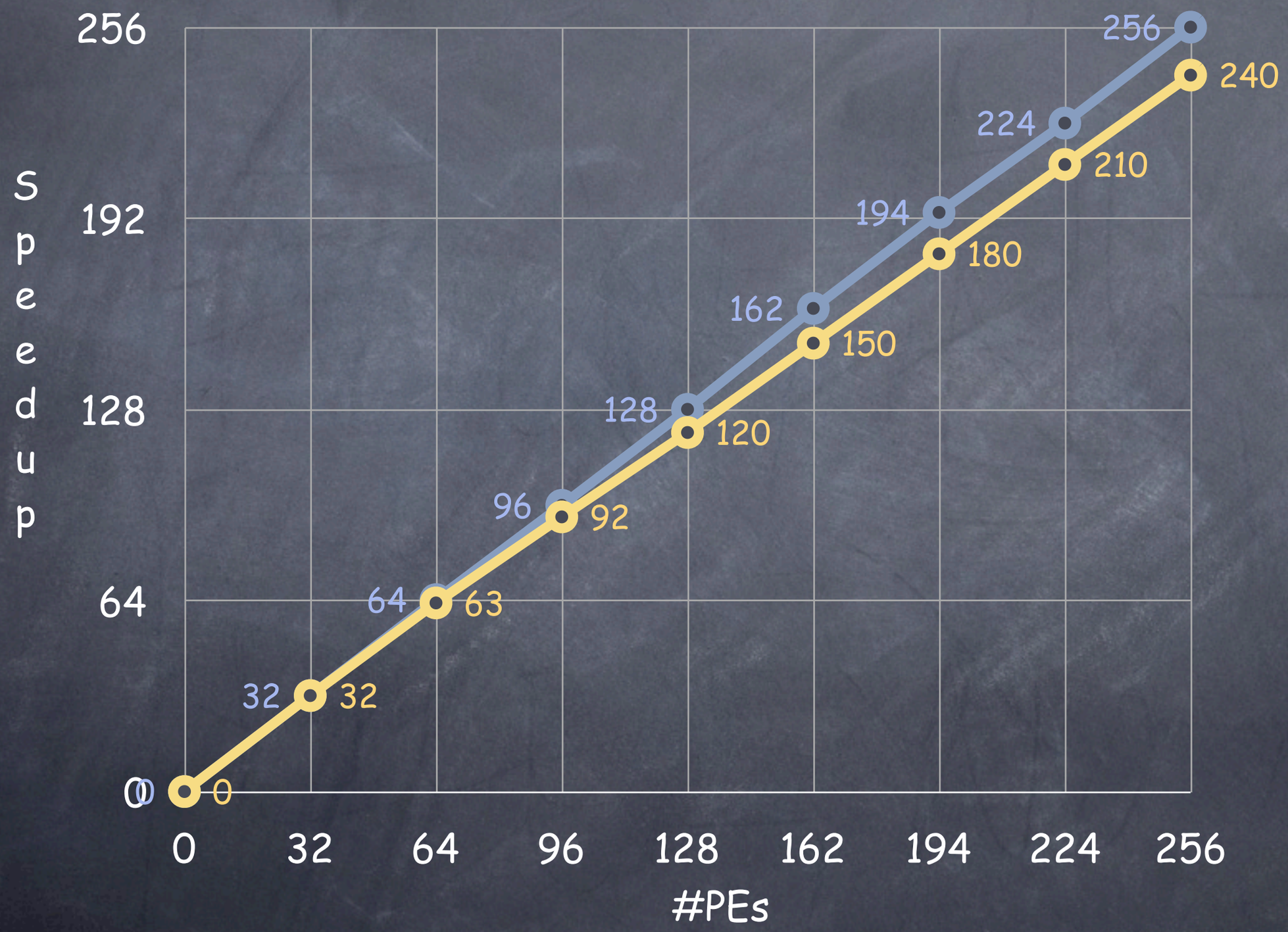
Original Coupling



Wall-clock time per simulated year



Scalability of SP-CAM on "Blackforest"



Cases (about 500-days each)

CAM-SLD	Standard physics
SP-NOR	SP with "original" coupling ("non-interactive radiation")
SP-RAD	SP with radiation transfer ("interactive radiation")
SP-SNW	Same as SP-RAD, but ice-to-snow aggregation rate is increased ten-fold ("microphysics")
SP-99	Same as SP-SNW, but for Sep. 1998-Jan. 2000 SSTs

Results

Global Annual Averages

Imbalances

	Obs	CAM-SLD	SP-NOR	SP-RAD	SP-SNW
TOA energy budget (W/m2)	-	4.4	7.6	-2.1	-3.0
TOM energy budget (W/m2)	-	2.6	5.7	-3.9	-4.8
SFC energy budget (W/m2)	-	2.6	6.2	-3.6	-4.3
P-E (mm/day)		0.001	0.01	0.01	0.01

Global Annual Averages

Surface

	Obs	CAM-SLD	SP-NOR	SP-RAD	SP-SNW
Precipitation (mm/day)	2.61	2.81	2.73	2.85	2.97
Precipitable water (mm)	24.57	23.8	25.6	25.43	24.41
Sensible heat flux (W/m2)	24.0	21.6	20.1	20.0	21.1
Latent heat flux (W/m2)	78.0 - 90.0	81.3	78.7	82.3	86.0
Ts (K)	287.7	288.9	289.5	289.3	289.3
Ts_land (K)	281.2	285.1	286.4	286.1	286.1

Global Annual Averages

Clouds

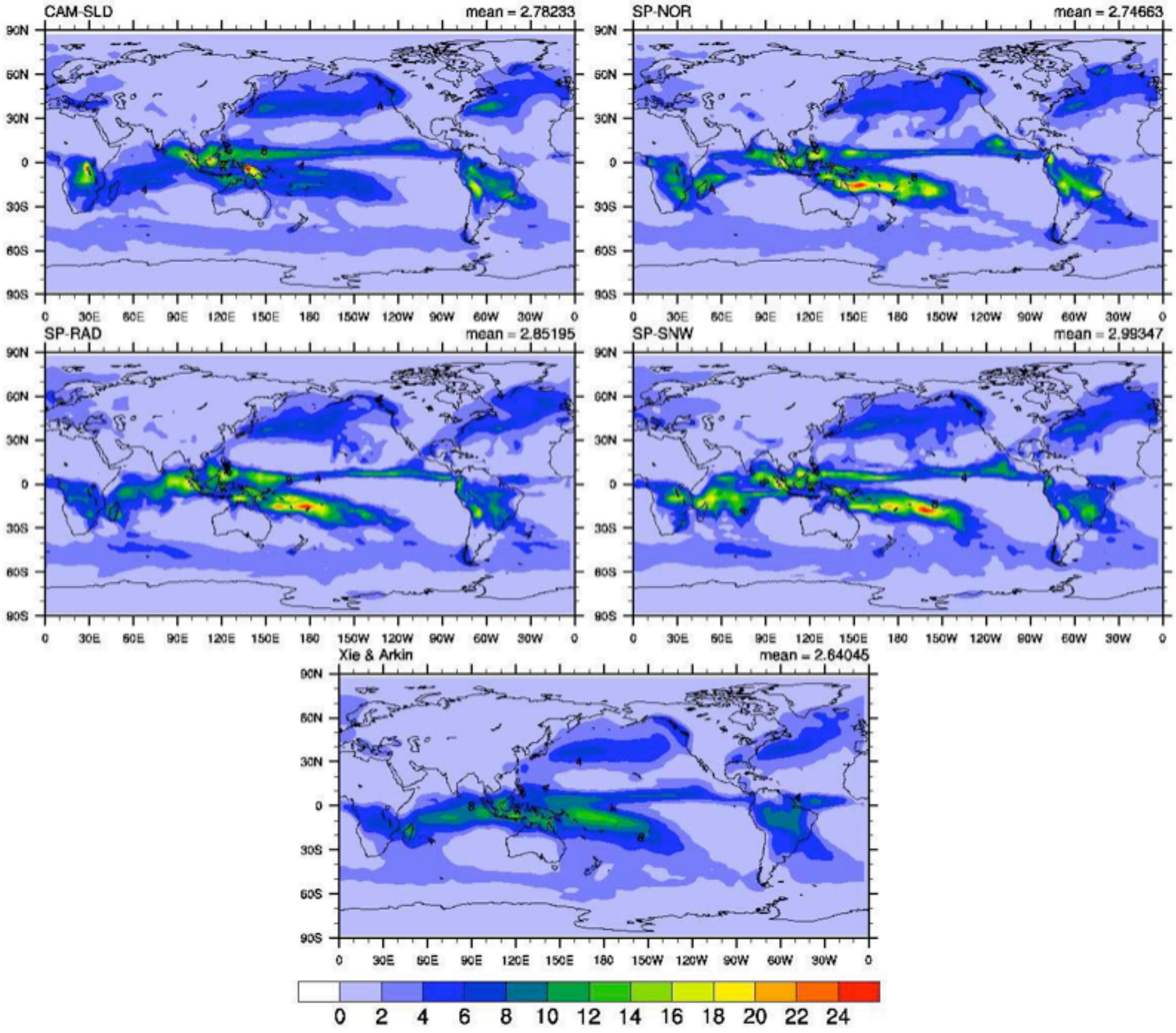
	Obs	CAM-SLD	SP-NOR	SP-RAD	SP-SNW
High cloud fraction (%)	14.0	42.6	38.5	14.9	10.4
Middle cloud fraction (%)	18.0	20.2	15.8	14.8	13.0
Low cloud fraction (%)	26.0	31.0	25.3	29.8	29.0
Total cloud fraction (%)	52.2 - 62.5	61.0	53.4	43.3	39.5

Global Annual Averages

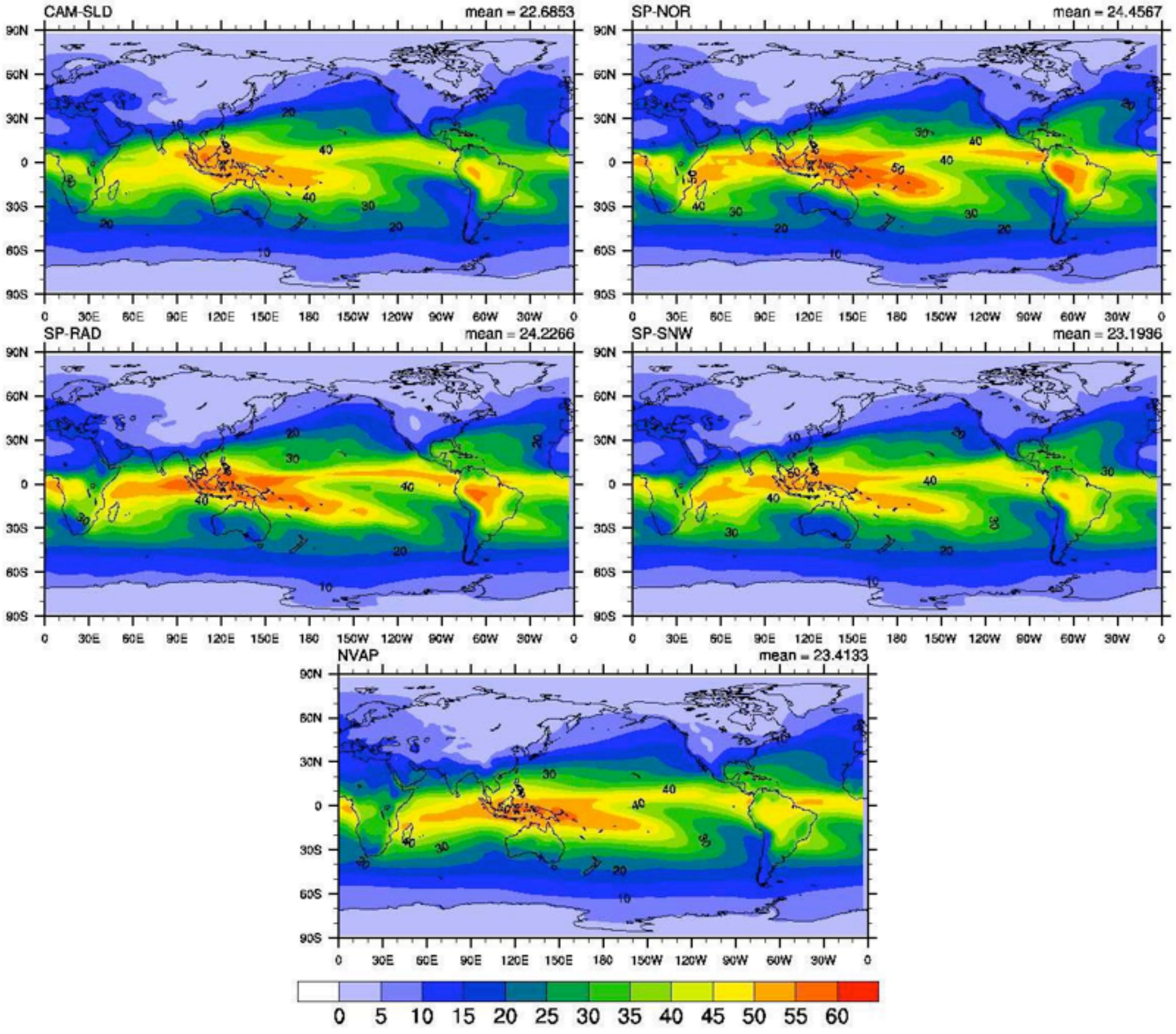
Radiation

	Obs	CAM-SLD	SP-NOR	SP-RAD	SP-SNW
All-sky outgoing LW radiation (W/m2)	234.8	234.8	233.2	231.8	238.6
All-sky Absorbed SW radiation (W/m2)	238.1	239.2	240.8	229.7	235.6
Clear-sky outgoing LW radiation (W/m2)	264.0	264.7	266.2	266.2	266.7
Clear-sky Absorbed SW radiation (W/m2)	286.3	286.6	286.2	286.4	286.2
Longwave cloud forcing (W/m2)	29.2	29.9	33.1	34.4	28.1
Shortwave cloud forcing (W/m2)	-48.2	-47.4	-45.4	-56.7	-50.6
Cloud Forcing (W/m2)	-19.0	-17.5	-12.3	-22.3	-22.5

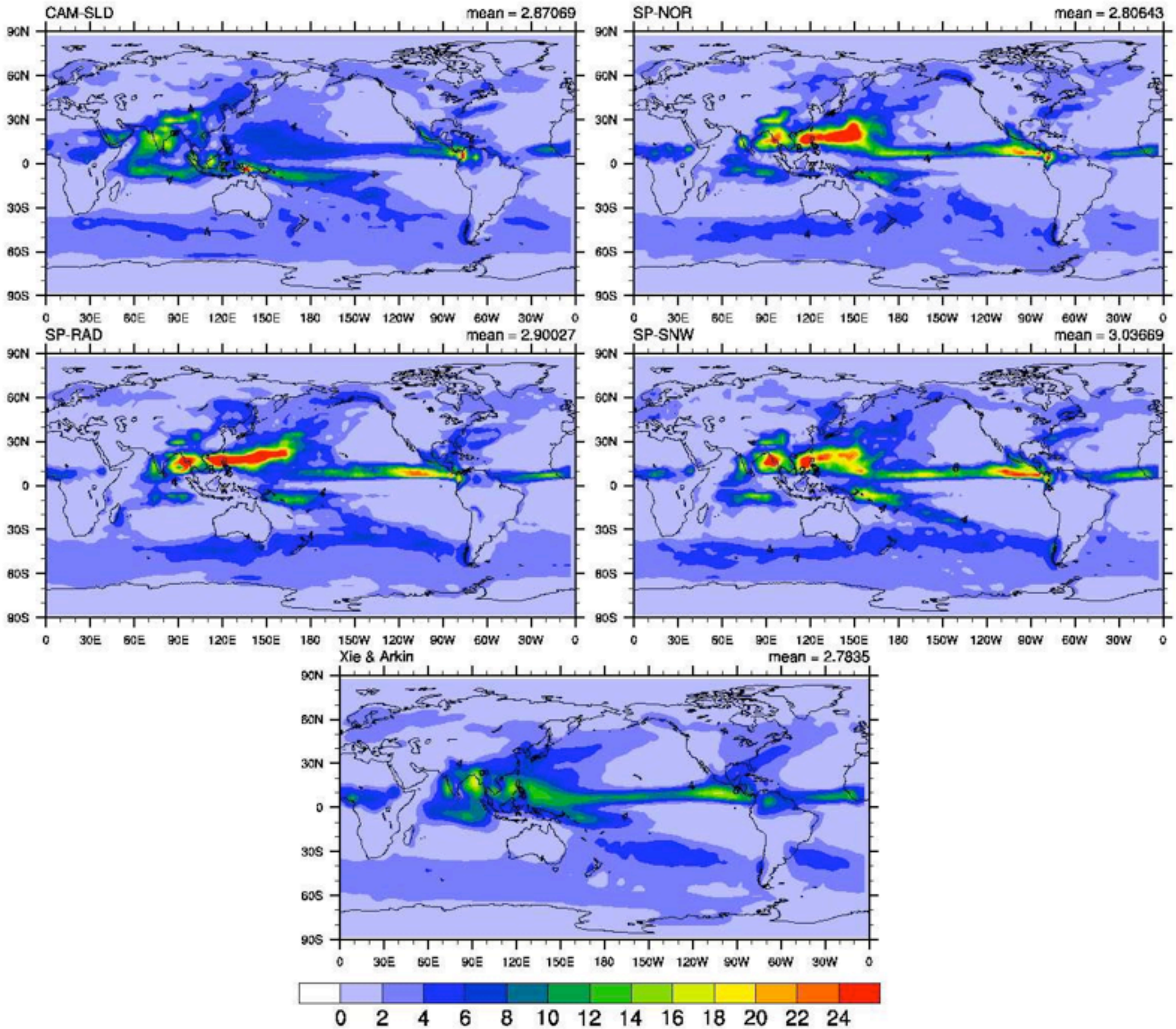
DJF Precipitation Rate, mm/day



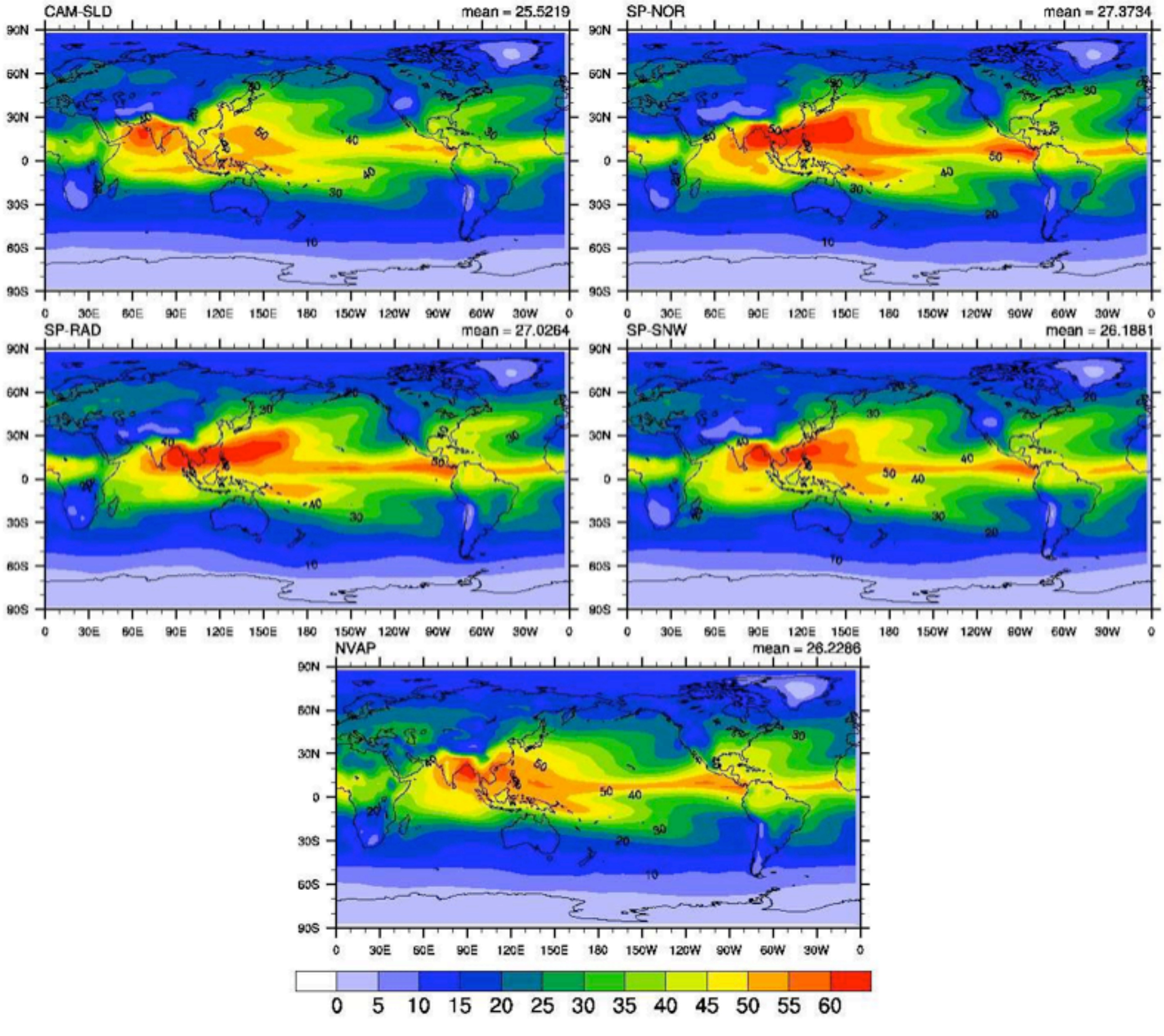
DJF Precipitable Water, mm



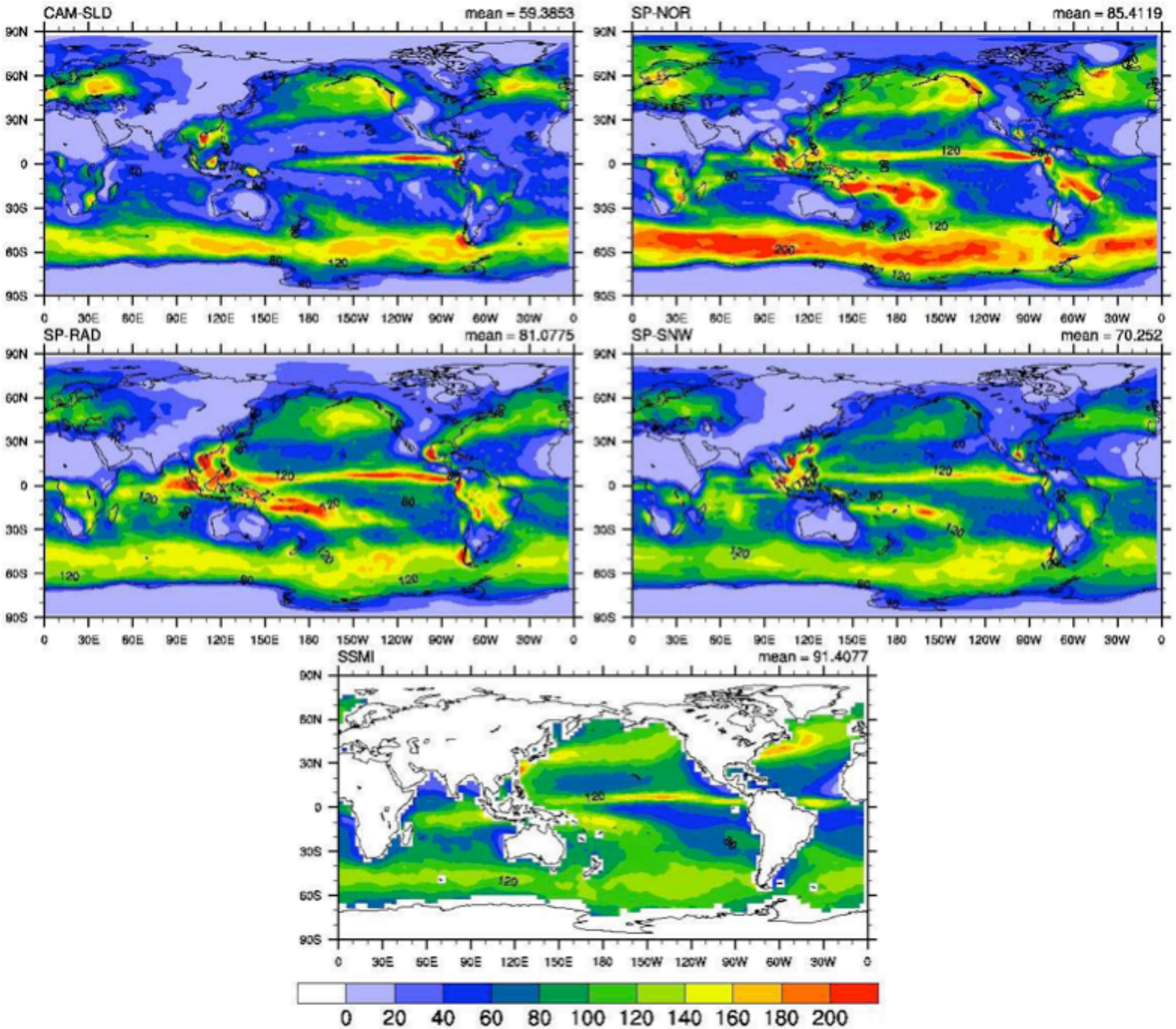
JJA Precipitation Rate, mm/day



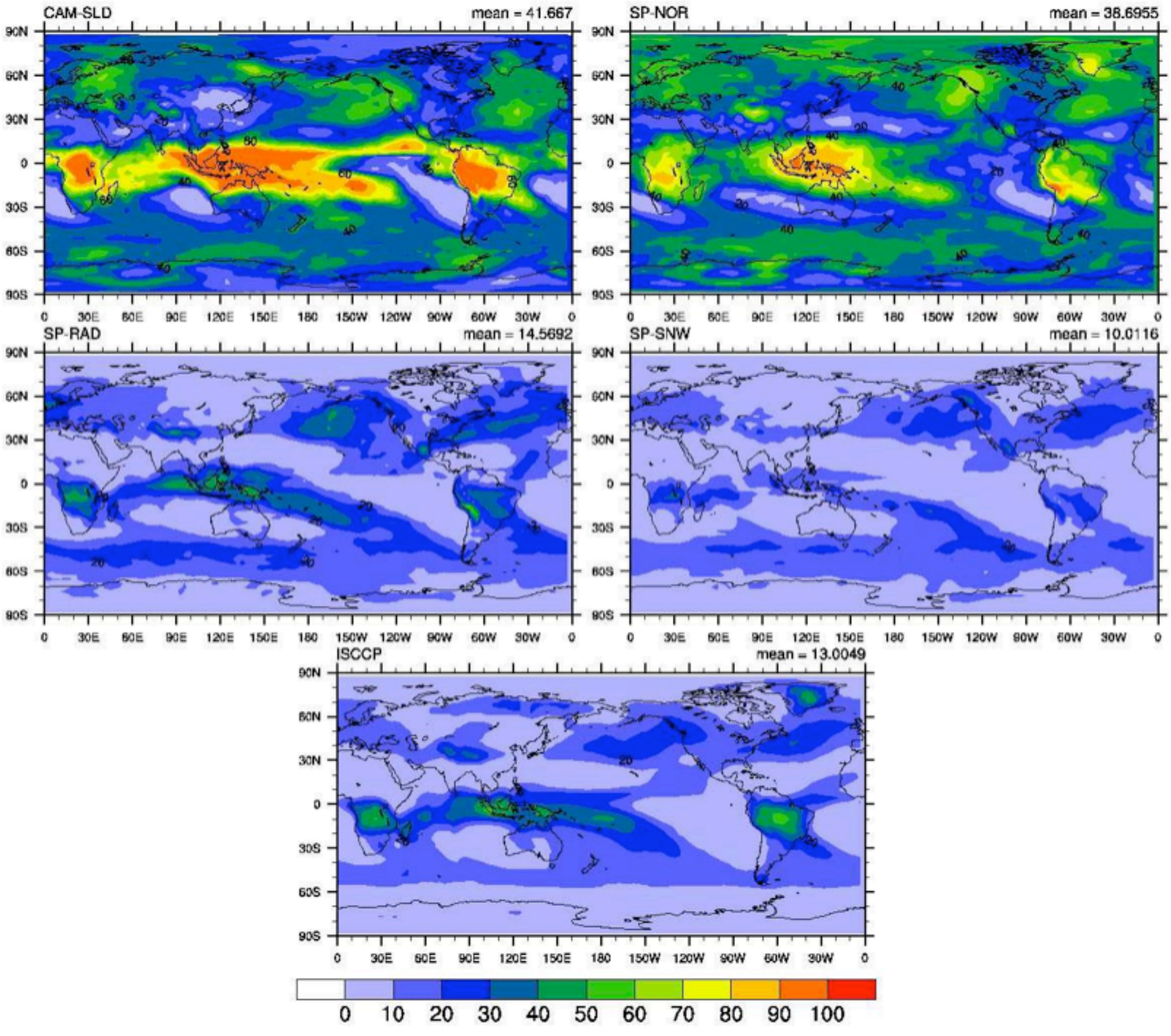
JJA Precipitable Water, mm



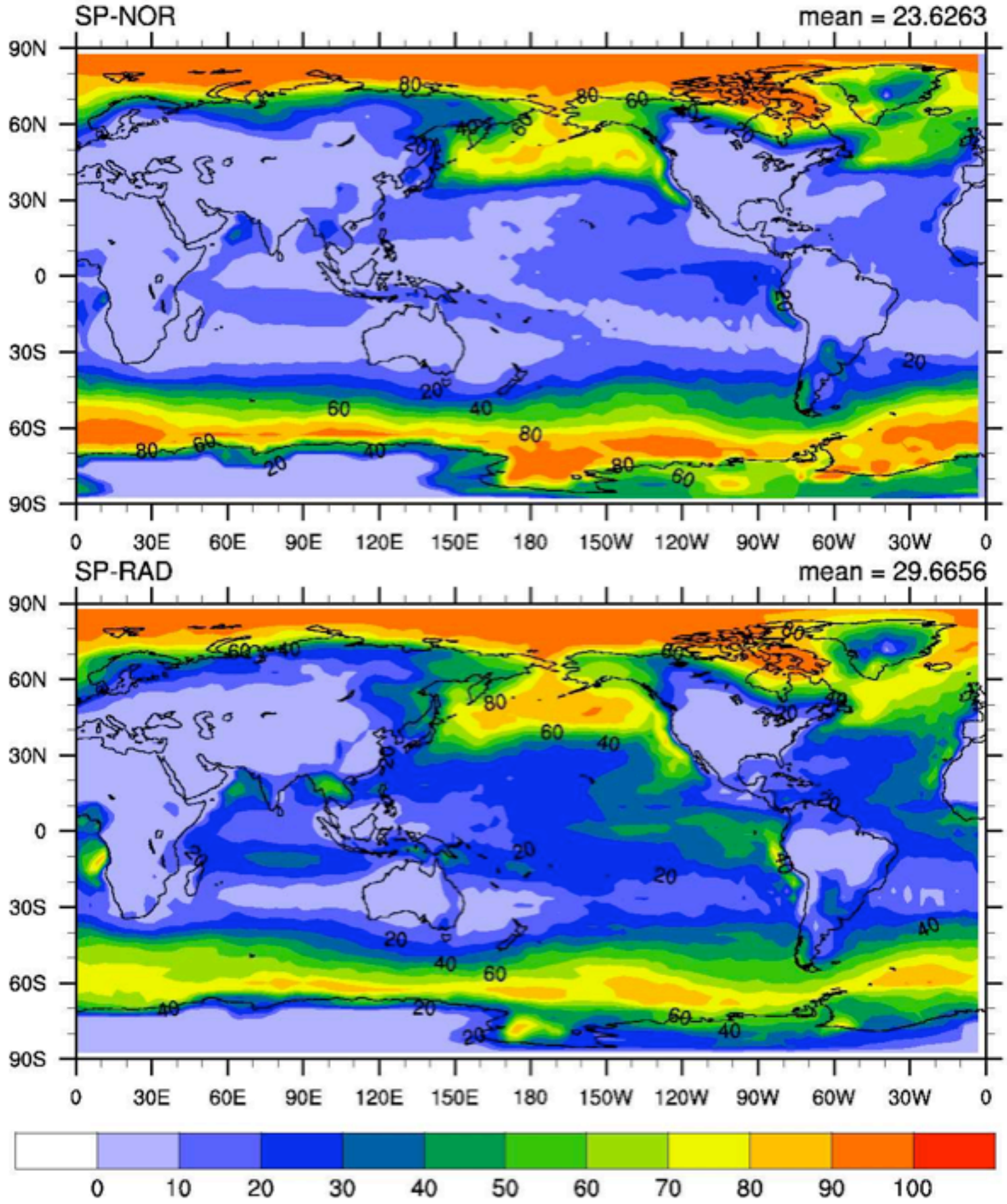
DJF Liquid-Water Path, mm



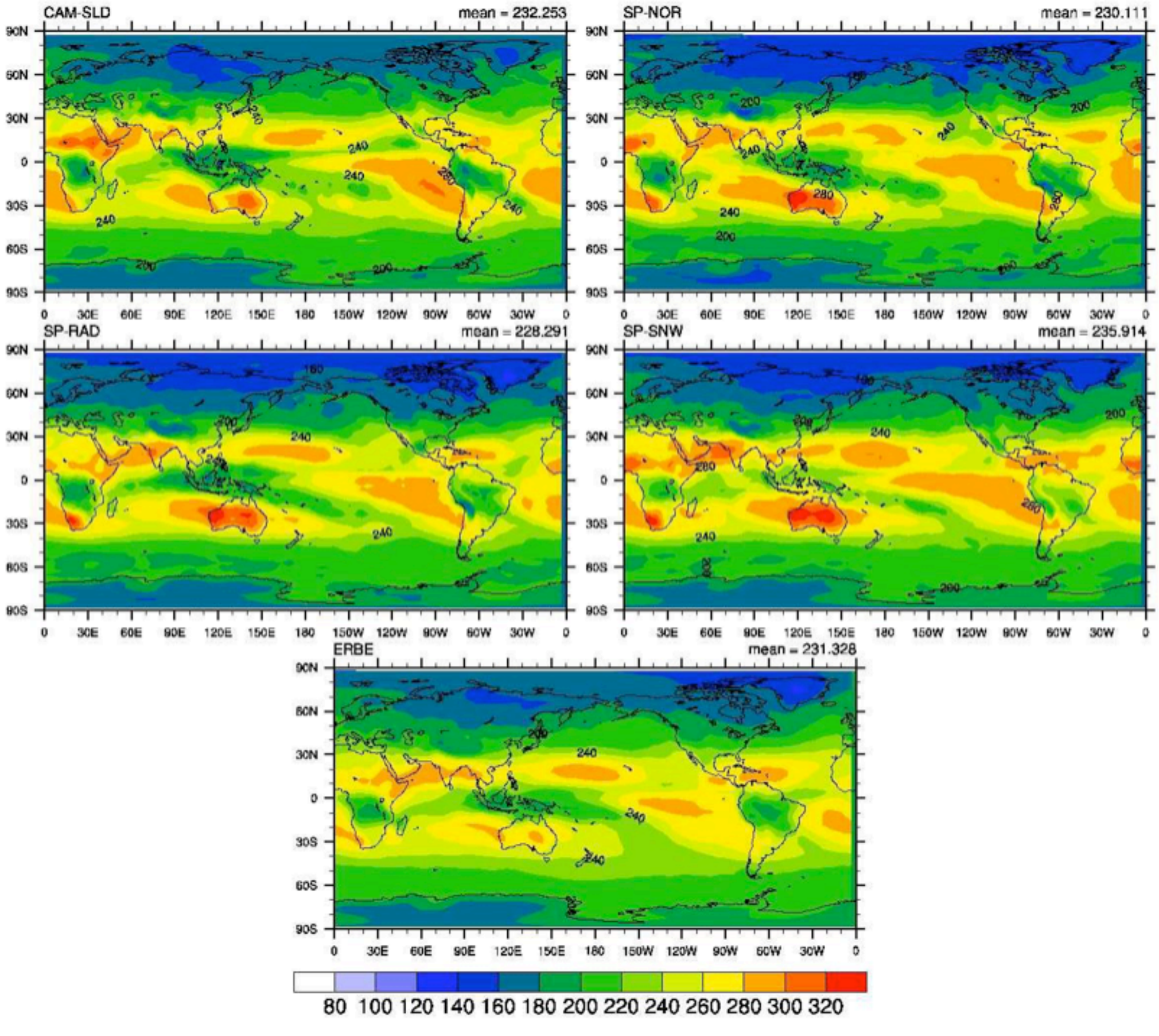
DJF High-Level Cloud Fraction



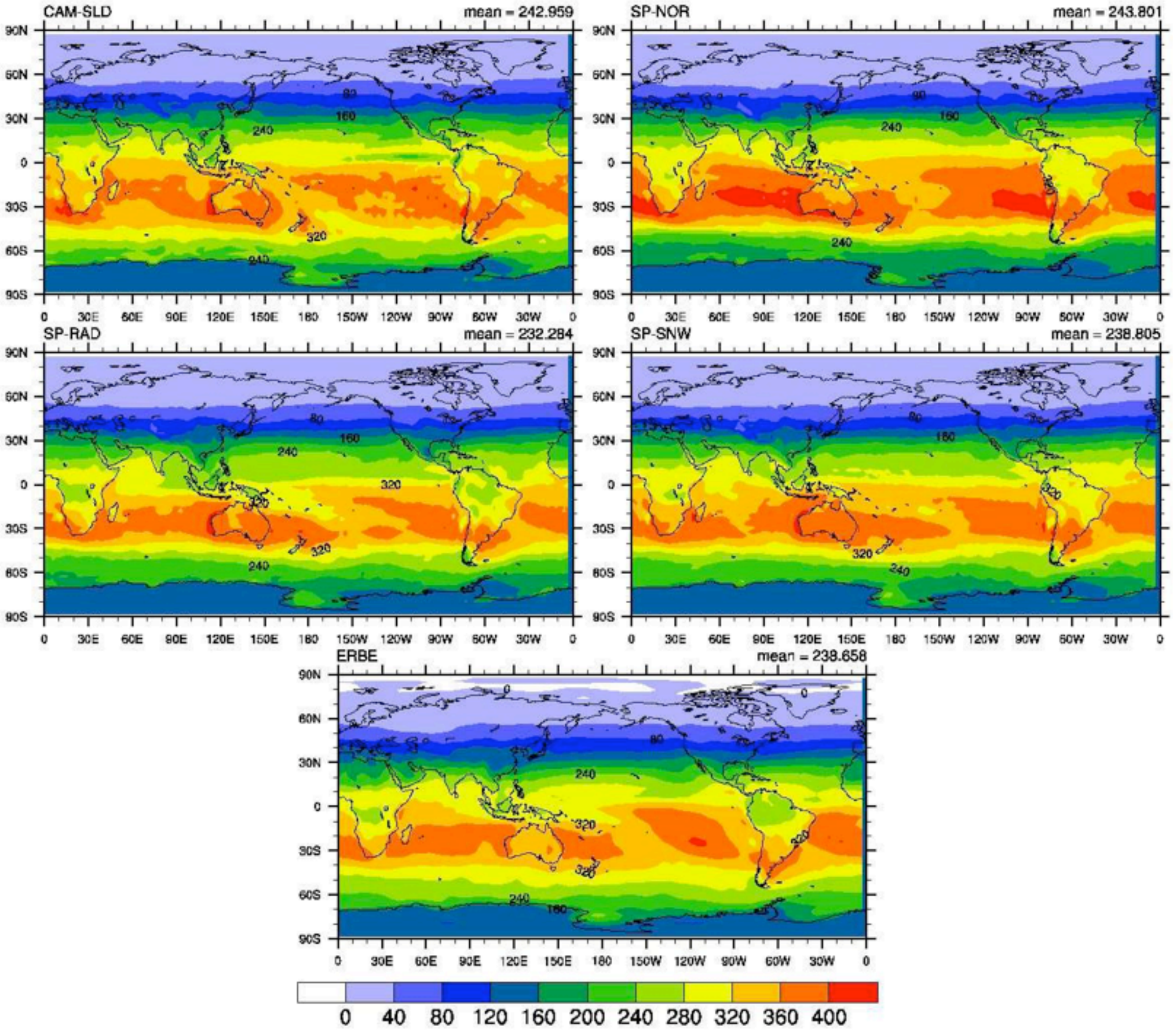
JJA Low-level Cloud Fraction



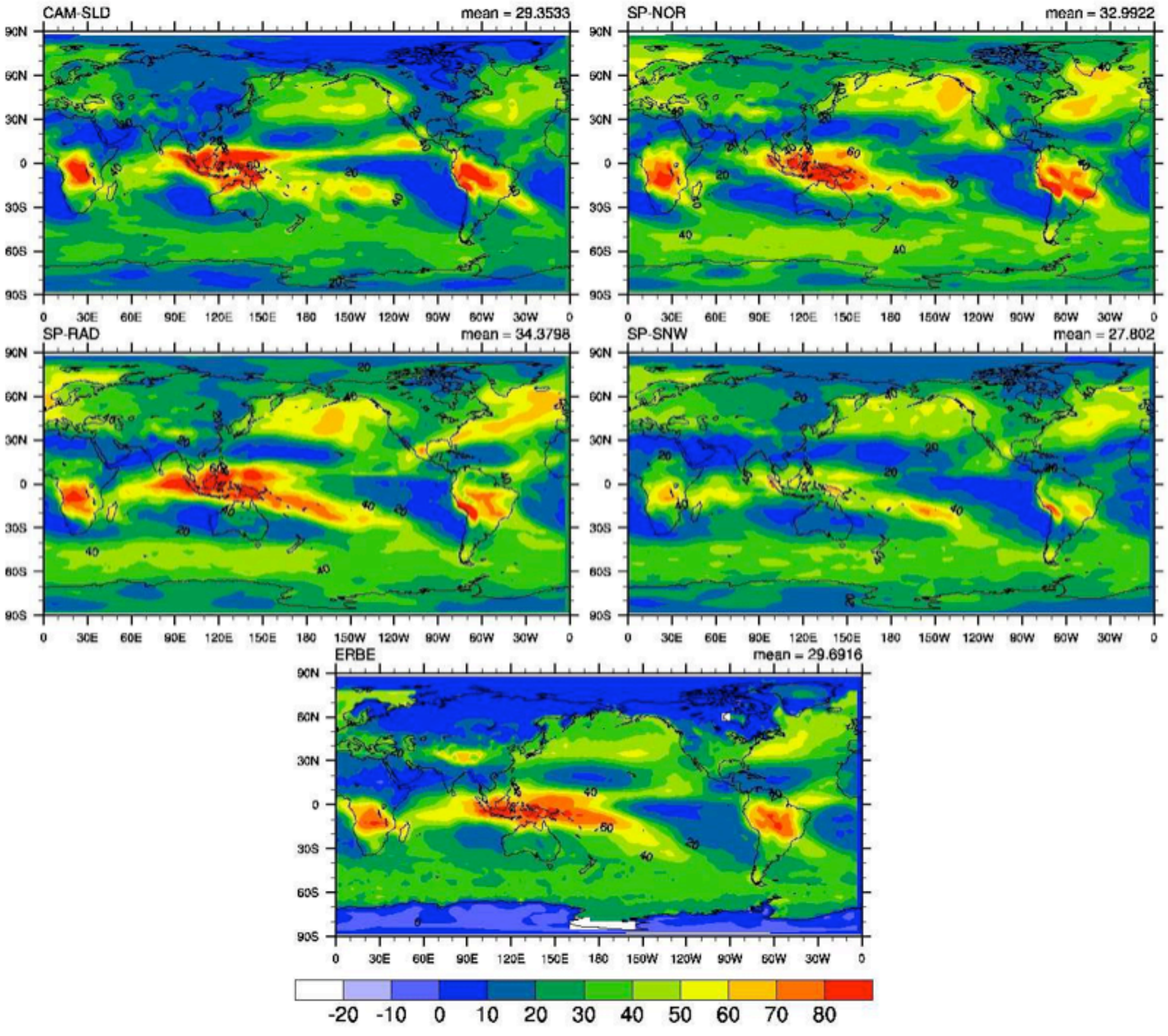
DJF Outgoing Longwave Radiation, W/m^2



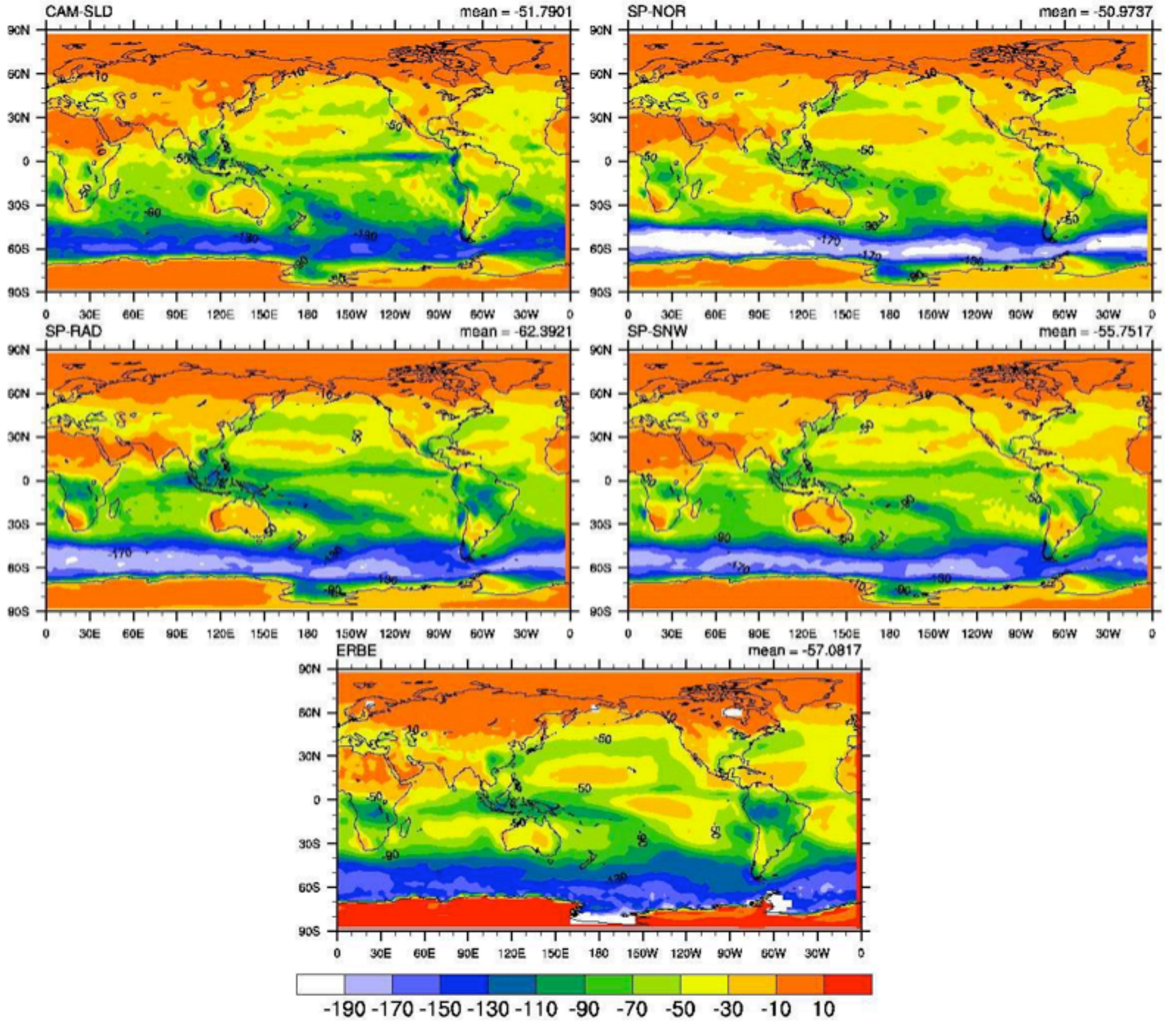
DJF Absorbed Shortwave Radiation, W/m^2



DJF Longwave Cloud Forcing, W/m^2



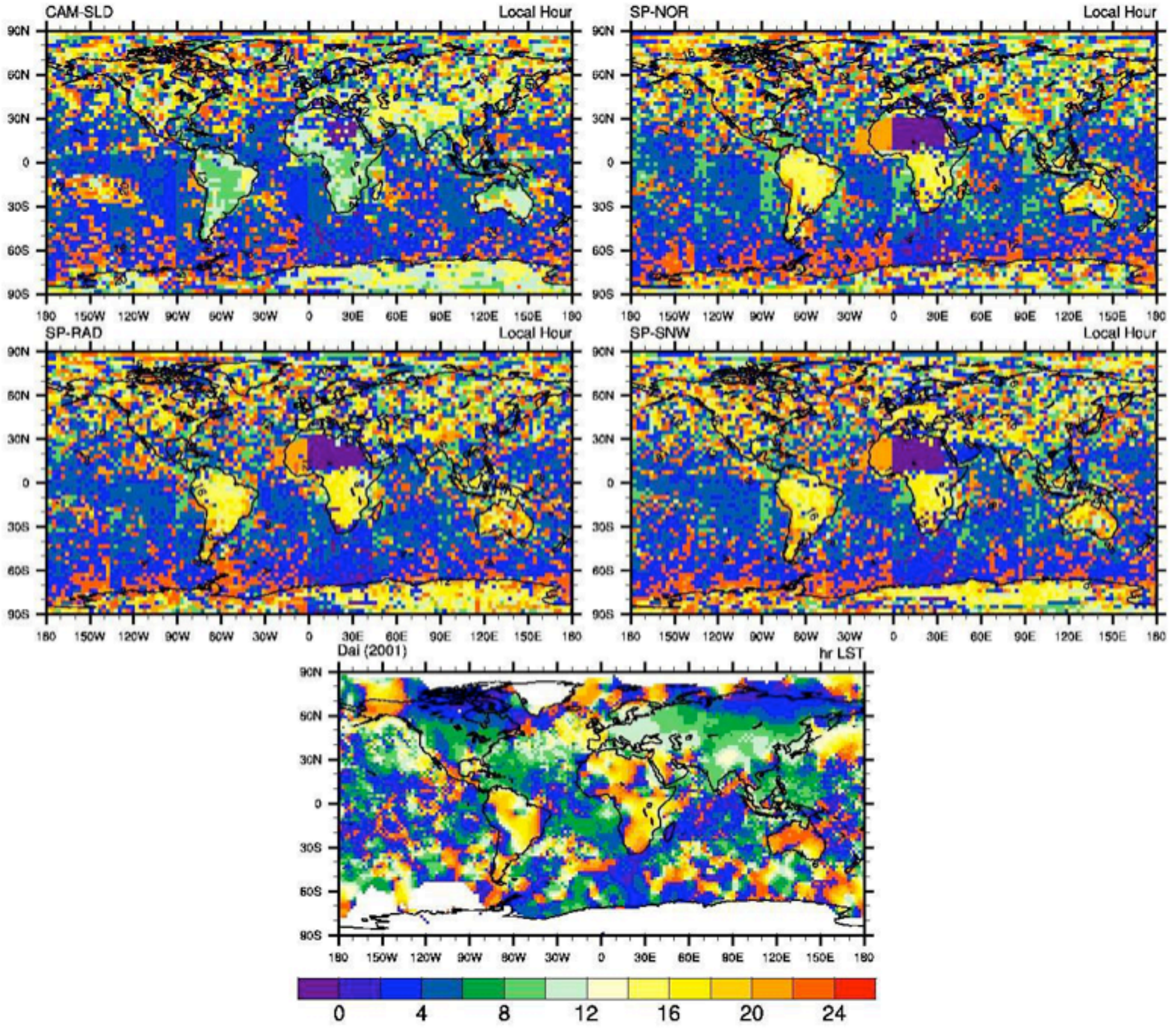
DJF Shortwave Cloud Forcing, W/M^2



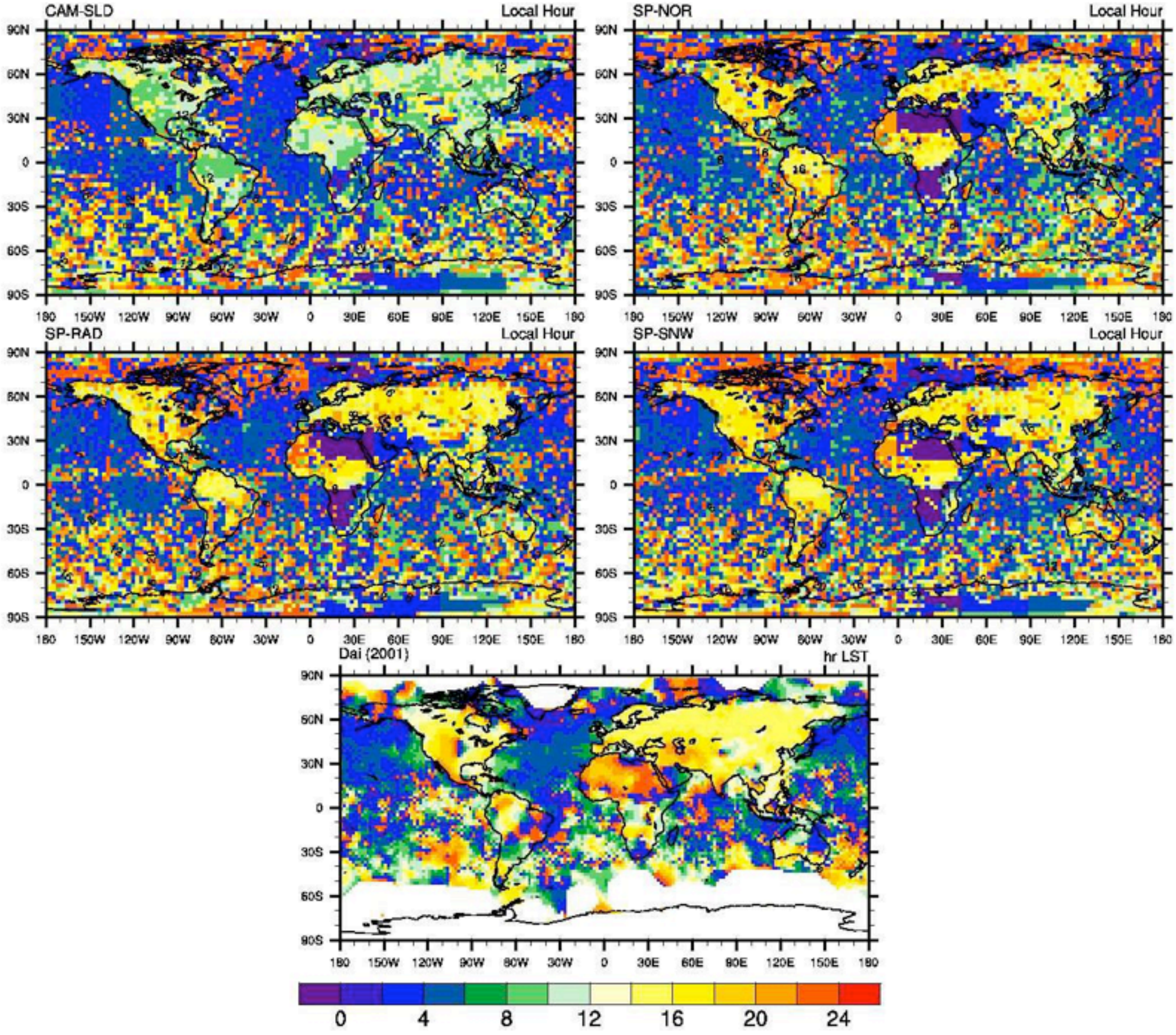
Diurnal cycle and frequency of non-drizzle precipitation

- 3-hourly global sampling of model precipitation.
- 1 mm/day for 3-hour-mean precipitation rate was used as a non-drizzle threshold.
- Frequency is defined as number of non-drizzle samples over total number of samples for a given location and local solar time period (3 hours).
- Dai (2001) dataset was used for comparison.

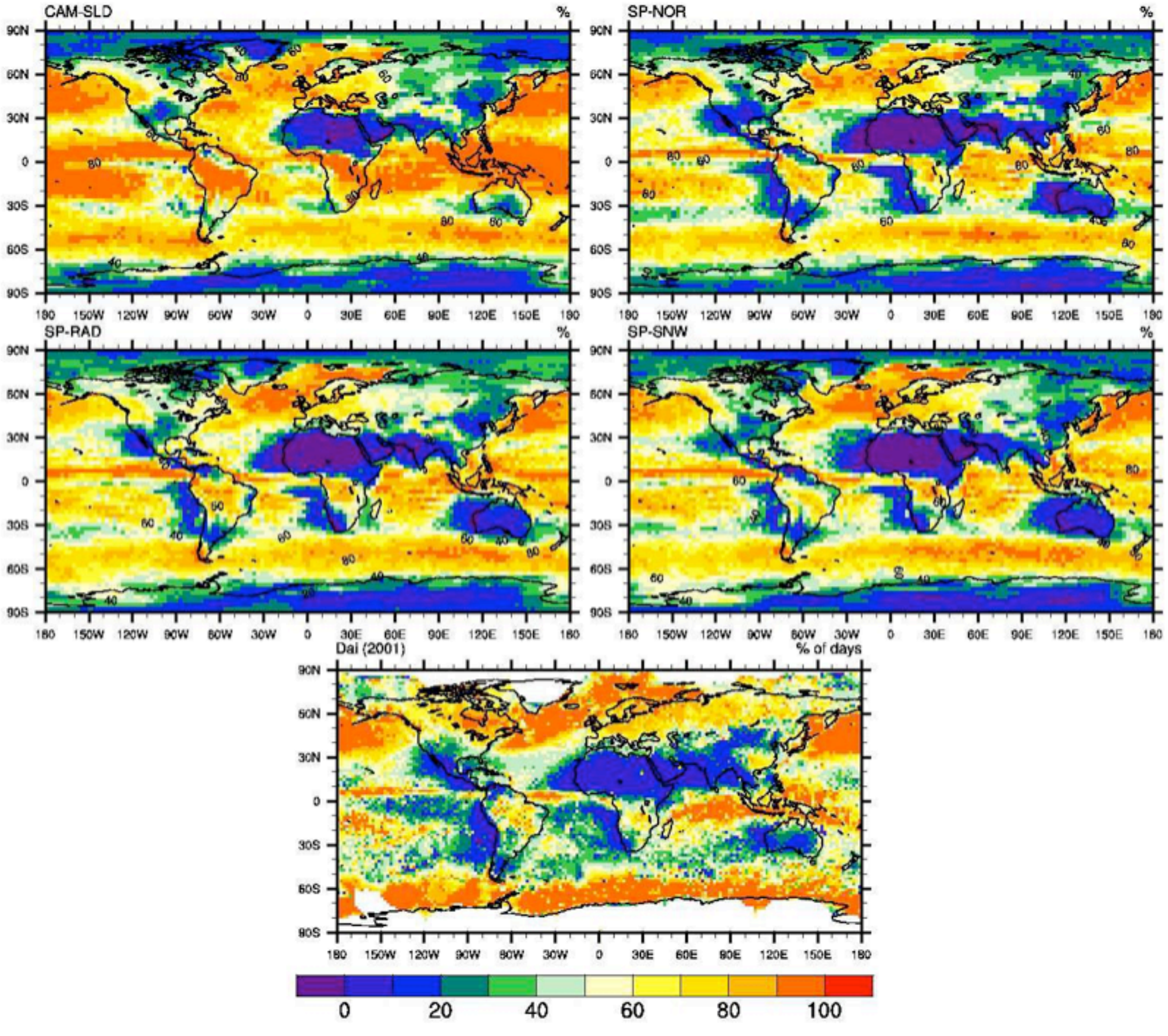
DJF Local time of Precipitation Frequency Maximum



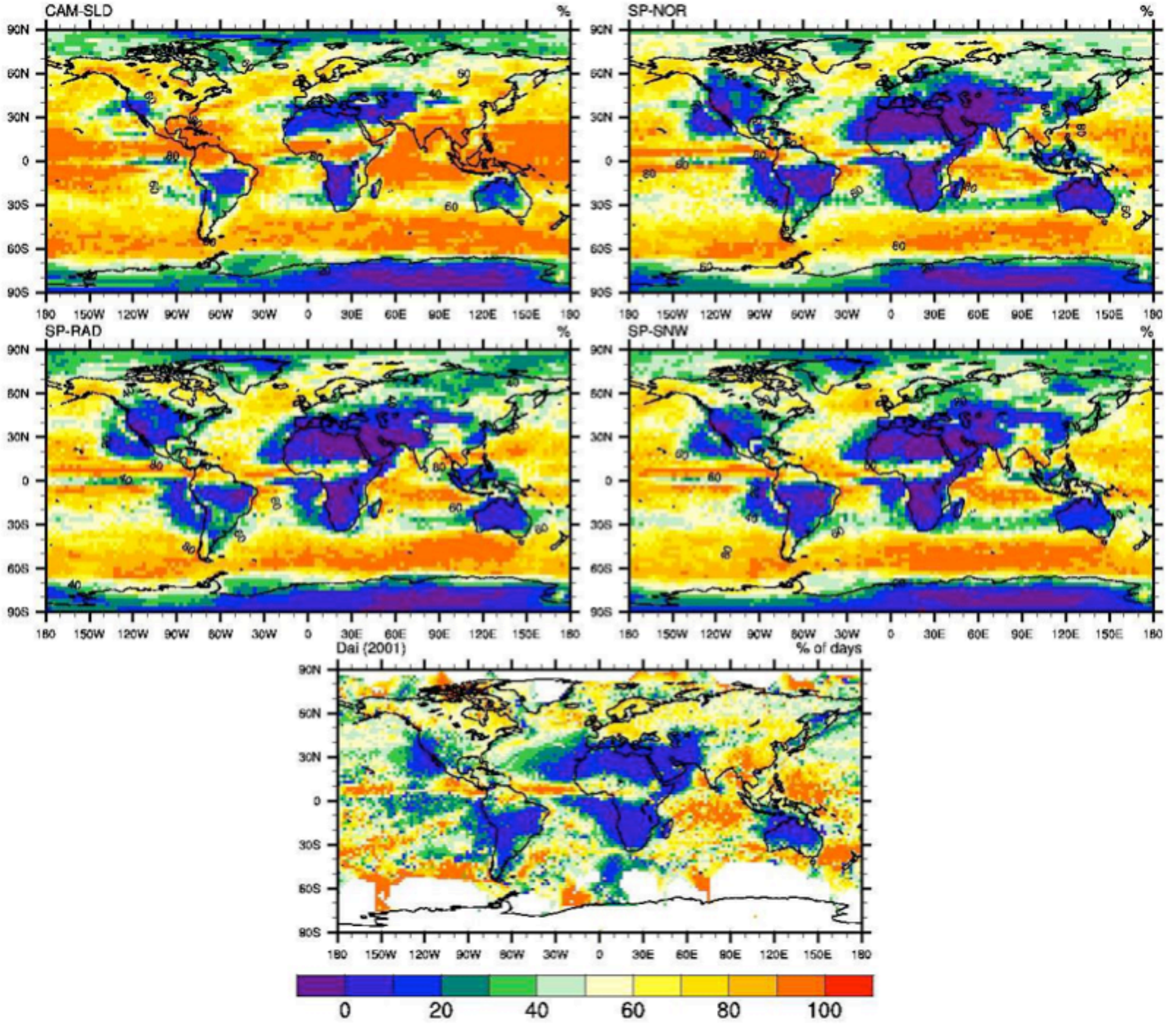
JJA Local time of Precipitation Frequency Maximum

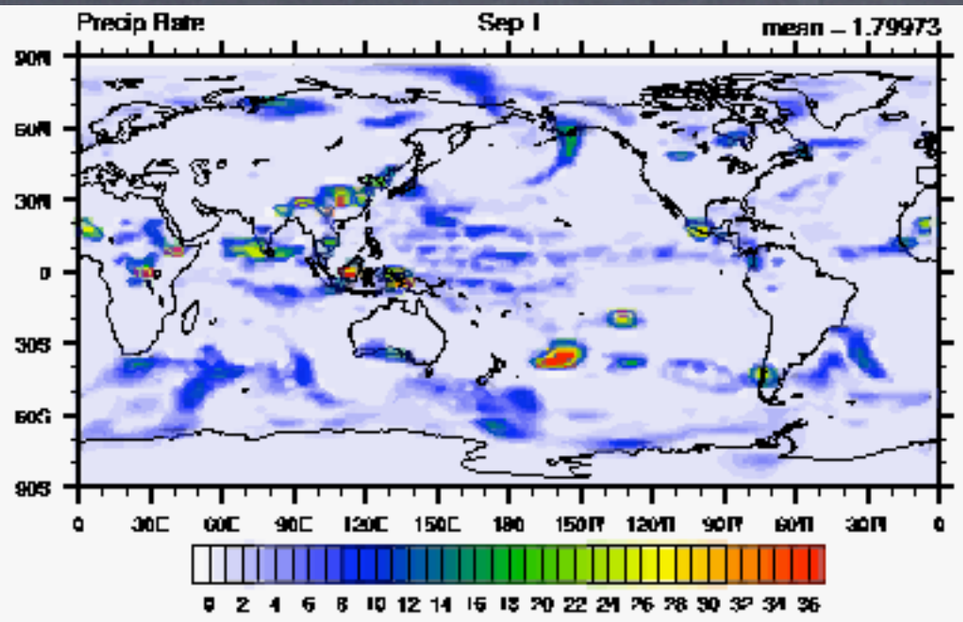


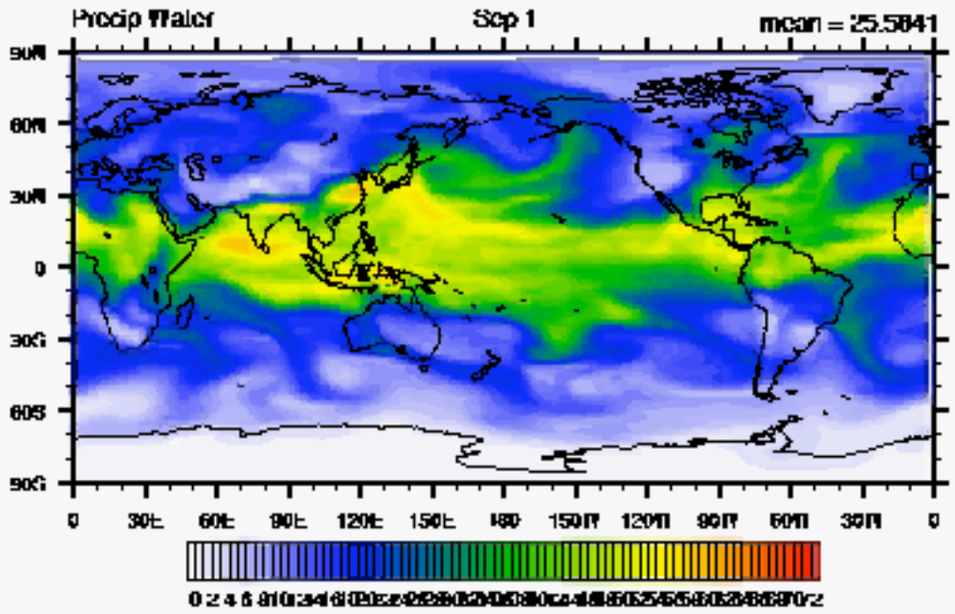
DJF Percent of Days with Precipitation

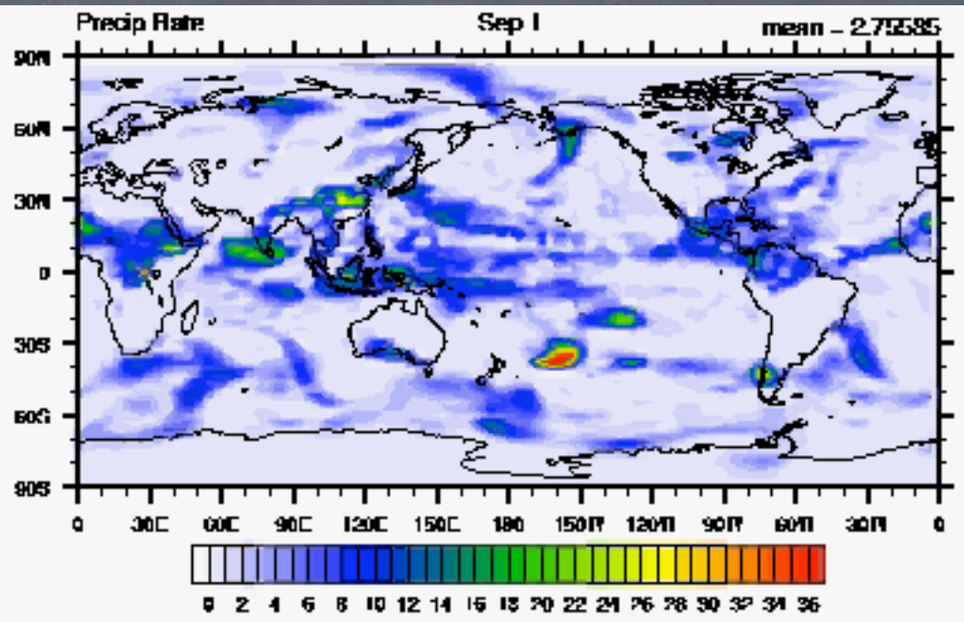


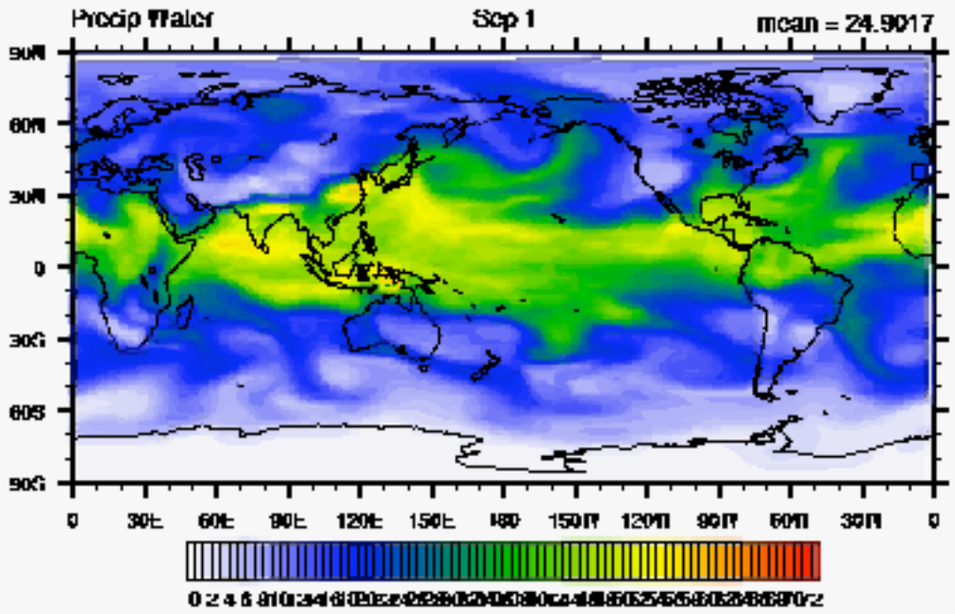
JJA Percent of Days with Precipitation





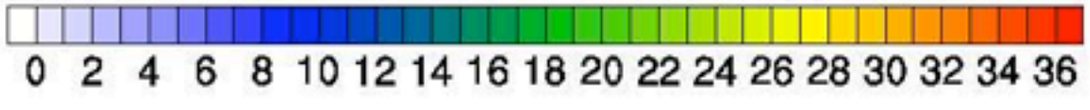






Super-CAM

CAM


0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36

Summary

- Yearly runs with SP have become routine!
- Radiative transfer is computed within the SP framework.
- SP-CAM produces reasonable distributions of precipitation, precipitable water, high-cloud amount, TOA radiative fluxes, and cloud radiative forcing.
- SP-CAM model exhibits much improved diurnal variability of non-drizzle precipitation frequency in terms of the diurnal cycle and wet-day probability over the standard model.
- A major bias is associated with anomalously strong precipitation in the Western Pacific for the summer months; the anomaly reduces qute notably in the experiment with increased ice-to-snow convergence rates.
- Increase in ice-to-snow conversion rates affects the global hydrological cycle, and dries the atmosphere by a global average of about 1 mm in terms of the precipitable water.
- Computation of radiative transfer within the SP framework increases low-cloud fraction quite notably, most likely as the result of direct cloud-radiation interactions.

Near-Future Plans

- Cloud-Feedback runs in collaboration with the NCAR's Climate and Global Dynamics Division: at least two 5-year runs.

- AMIP2 run.

- Port Land-Surface Model into SP.

- Change the DyCore from Semi-Lagrangian to Lin-Rood (Finite Volume).

- Arakawa Quasi-3D Global CRM in Cartesian coordinates to test the concept.