The Water and Energy Cycles in an Upcoming NASA Reanalysis

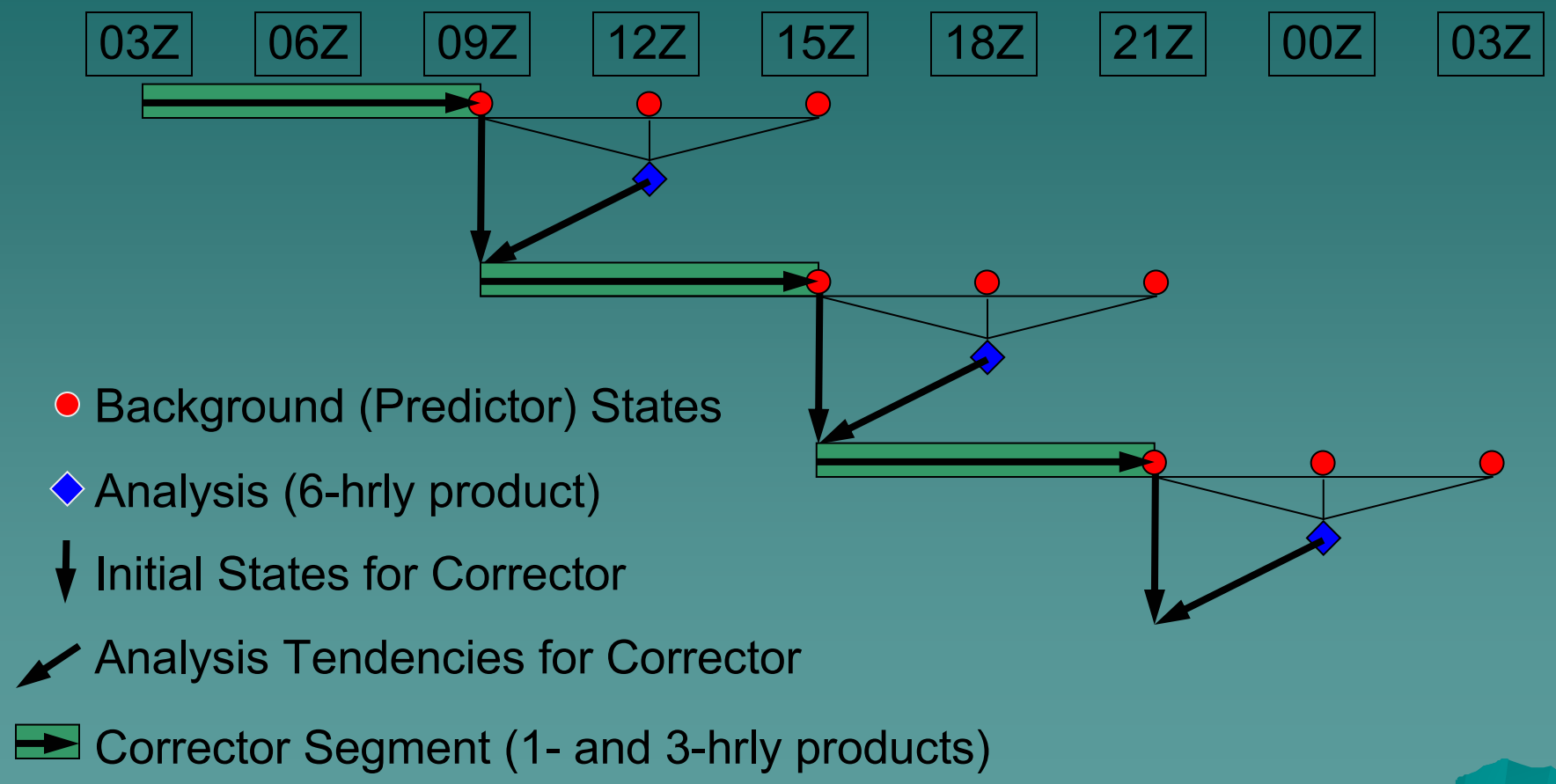
Junye Chen[1,2] and Michael G. Bosilovich[2]

[1]ESSIC, University of Maryland; [2]GMAO, GSFC NASA

New NASA reanalysis: Modern Era Retrospective-analysis for Research and Applications (MERRA)

- Based on newly developed Goddard Earth Observing System Atmospheric Data Assimilation System (GEOS-5).
- Time period: 1979 ~ present.
- 1/3° by 1/2° by 72 levels.
- Incremental Analysis Updates (IAU) to slowly adjust the model states toward the observed state.
- Adaptive Biases Correction to keep temporal homogeneity in each observation.

Centered IAU Implementation



Michele Rienecker et al., GSFC, 2007

Adaptive bias correction:

J_b: background constraint for x

J_β: background constraint for β

$$J(x, \beta) = (x_b - x)^T B_x^{-1} (x_b - x) + (\beta_b - \beta)^T B_\beta^{-1} (\beta_b - \beta)$$
$$+ \left[y - b_o(x, \beta) - h(x)\right]^T R^{-1} \left[y - b_o(x, \beta) - h(x)\right]$$

J_o: bias-corrected observation constraint

Dick Dee, ECMWF, 2007

Water and energy cycles are good general measures for the quality of a reanalysis

- Global water and energy cycles are tightly related and involve in almost all physical processes.
- A reanalysis = optimal combination { deficient model; uncompleted and/or biased observation}. No global constraint on water and energy budget.
- Thus the global water and energy cycles can act as general indicators for the performance of a reanalysis system.

Other data used in this study

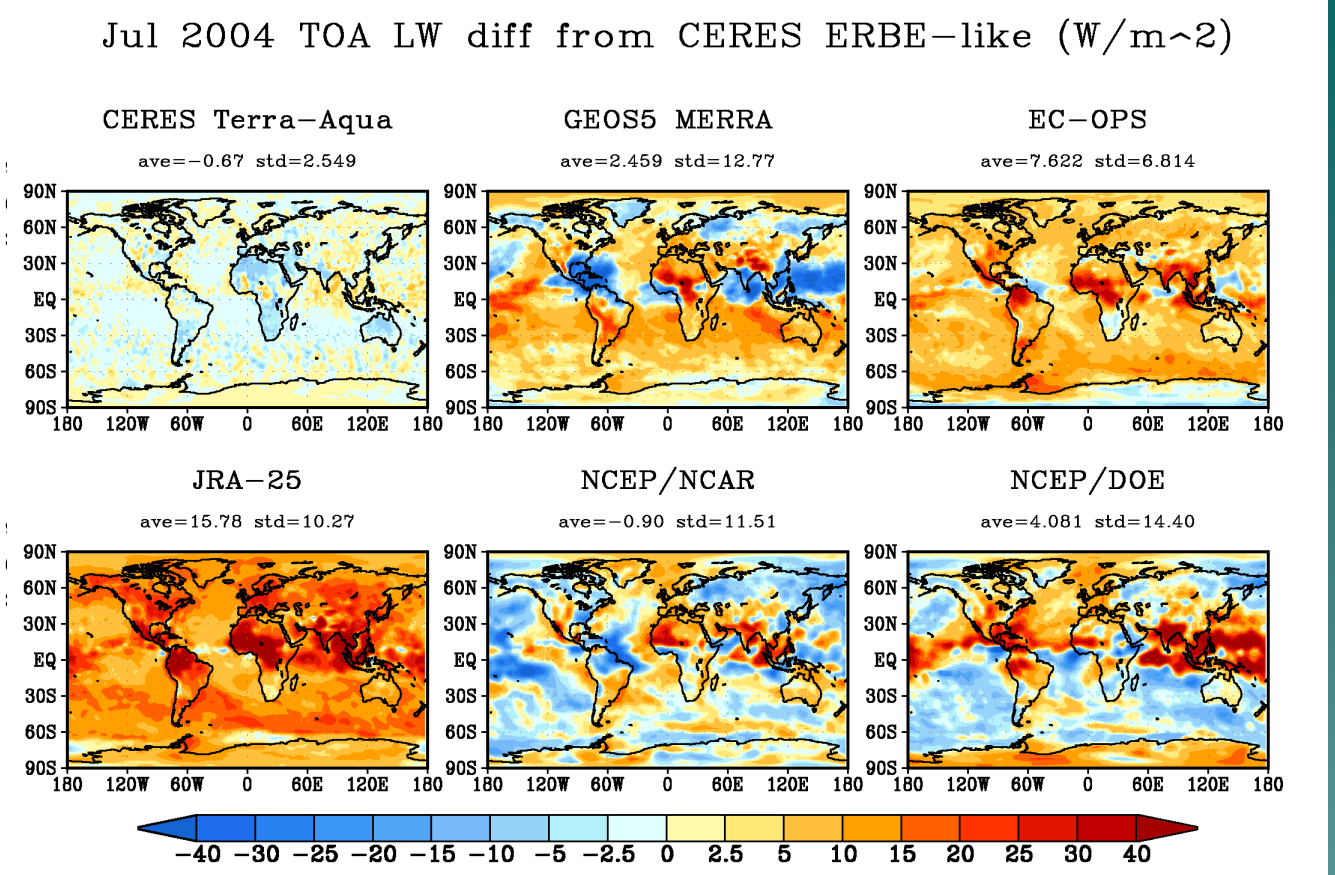
Observations

- TOA radiation fluxes: Clouds and the Earth's Radiant Energy System (CERES) ERBE-like TOA radiation fluxes data from Terra and Aqua satellites.
- Precipitation: Global Precipitation Climatology Project (GPCP) and CPC Merged Analysis of Precipitation (CMAP).

Reanalyses

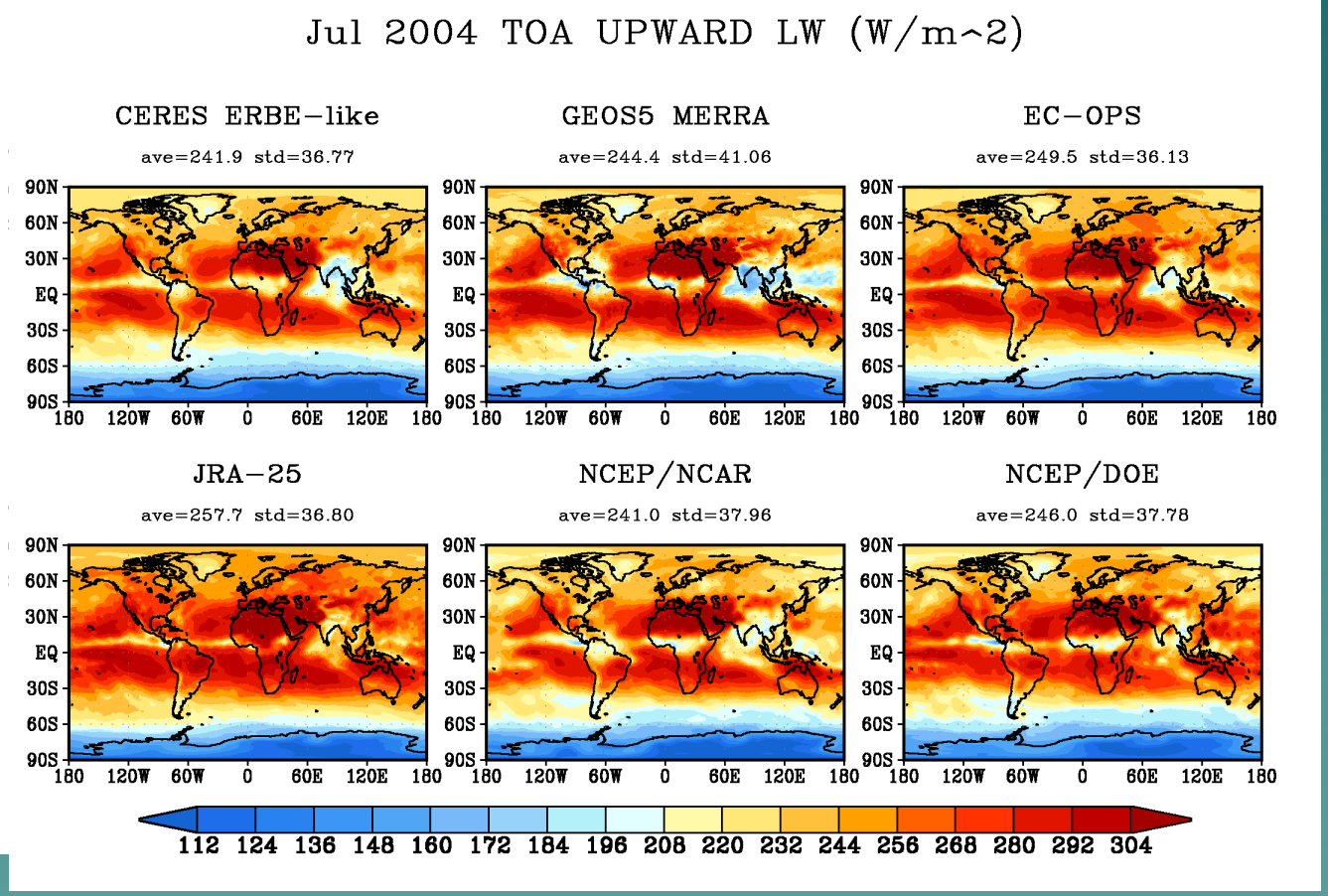
- NCEP/NCAR Reanalysis (NCEP1)
- NCEP-DOE Reanalysis (NCEP2)
- ECMWF 40 Year Reanalysis (ERA-40) and/or ECMWF operational analysis
- Japanese 25-year Reanalysis (JRA-25)

Analysis over spatial domain: TOA LW

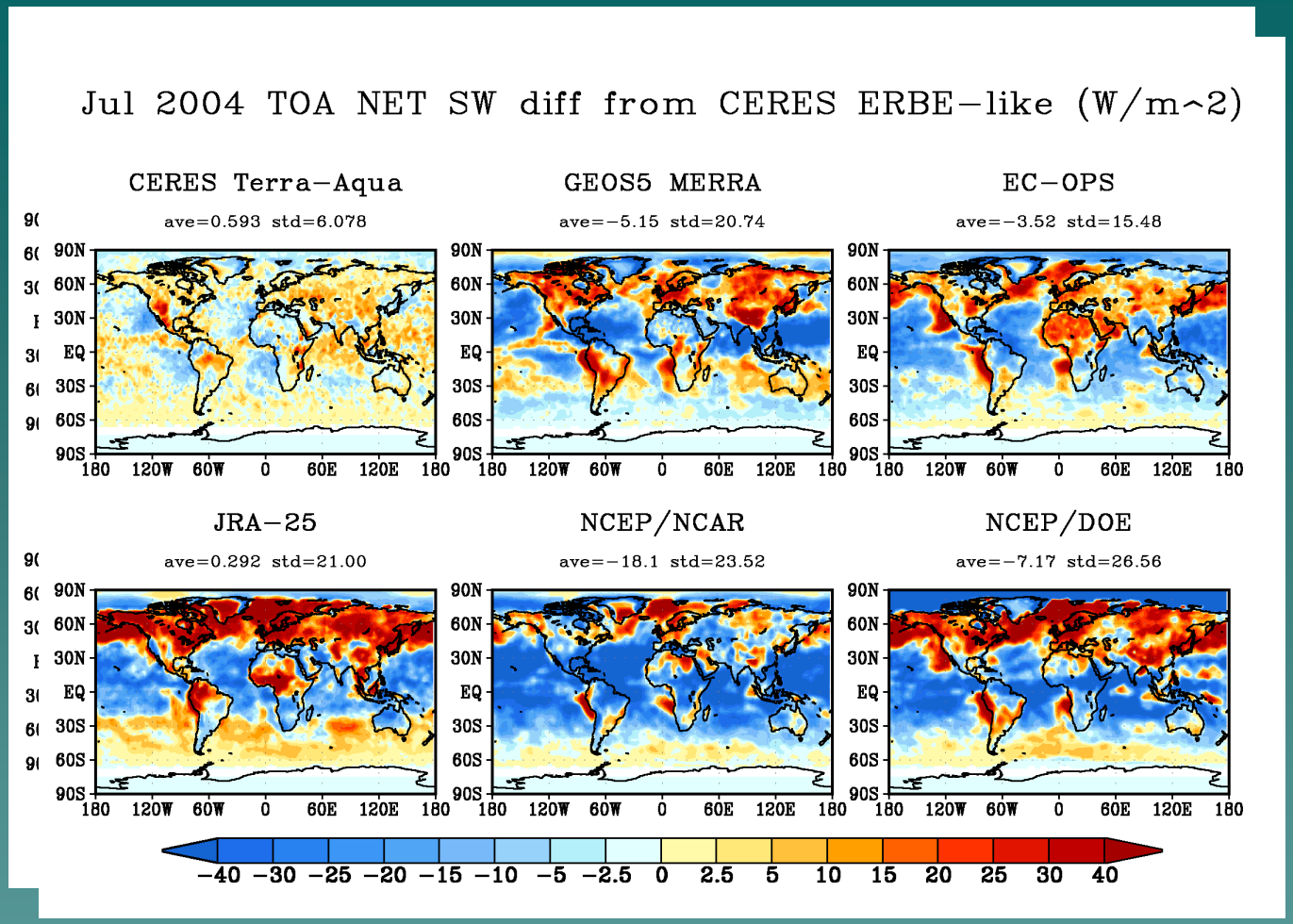


- All reanalyses get similar patterns as observation.
- The difference between observations can be a reference for the uncertainty in reanalyses.
- For all reanalyses, strongest error happens over tropical convective regions.
- MERRA TOA LW flux bias mean and standard deviation are moderate among reanalyses.

TOA LW difference (W/m^2)	Jan, 2004		Jul, 2004	
	Ave	STD	Ave	STD
CERES Terra - Aqua	-0.8	2.4	-0.7	2.5
MERRA - CERES	5.4	9.1	2.5	12.8
ECOPS - CERES	8.9	7.3	7.6	6.8
JRA25 - CERES	16.2	9.0	15.8	10.3
NCEP1 - CERES	-0.5	11.4	-0.9	11.5
NCEP2 - CERES	4.6	14.4	4.1	14.4

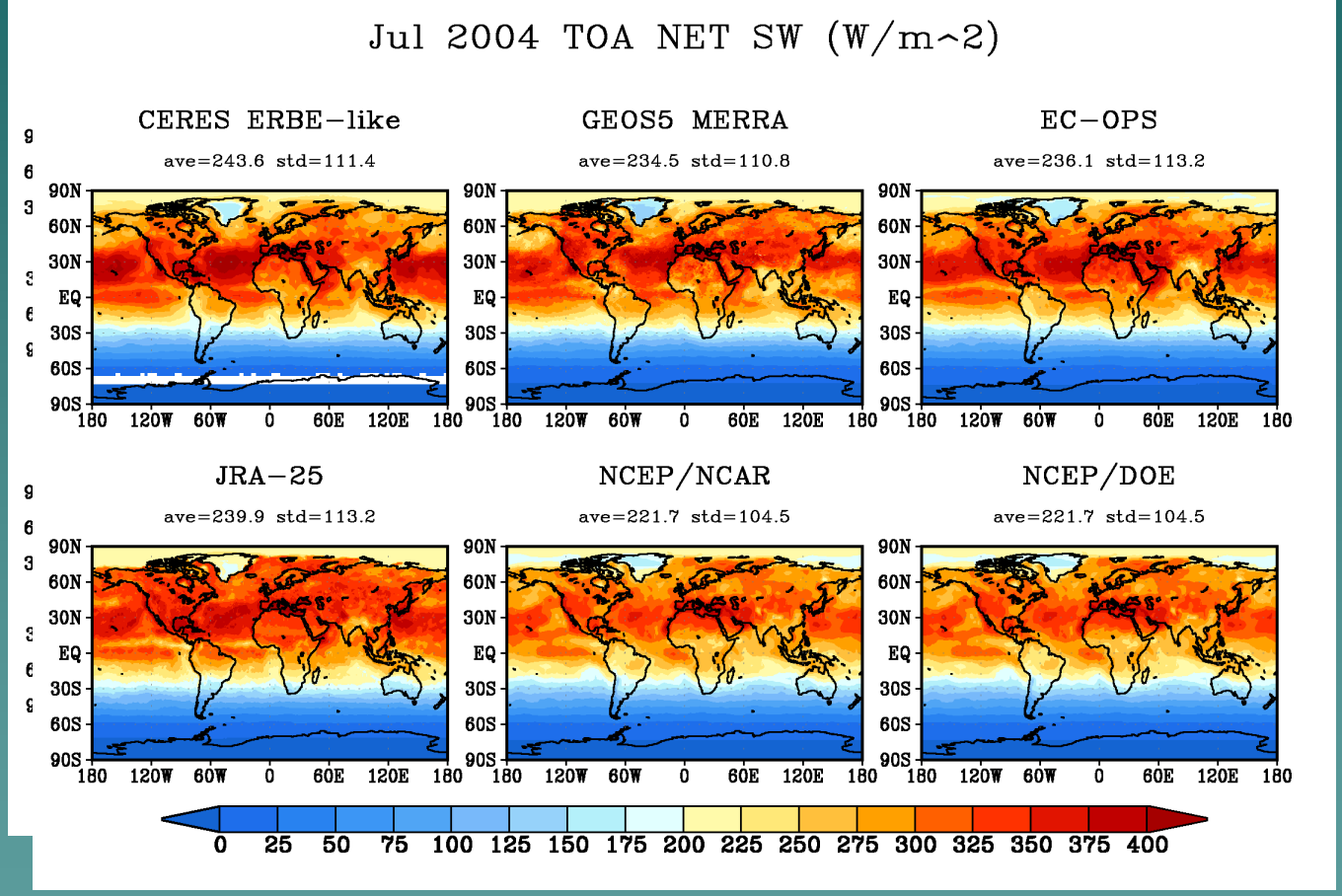

Jul 2004 TOA UPWARD LW (W/m^2)
CERES ERBE-like
ave=241.9 std=36.77
GEOS5 MERRA
ave=244.4 std=41.06
EC-OPS
ave=249.5 std=36.13
JRA-25
ave=257.7 std=36.80
NCEP/NCAR
ave=241.0 std=37.96
NCEP/DOE
ave=246.0 std=37.78
90N 60N 30N EQ 30S 60S 90S
180 120W 60W 0 60E 120E 180
112 124 136 148 160 172 184 196 208 220 232 244 256 268 280 292 304

Analysis over spatial domain: TOA NET SW

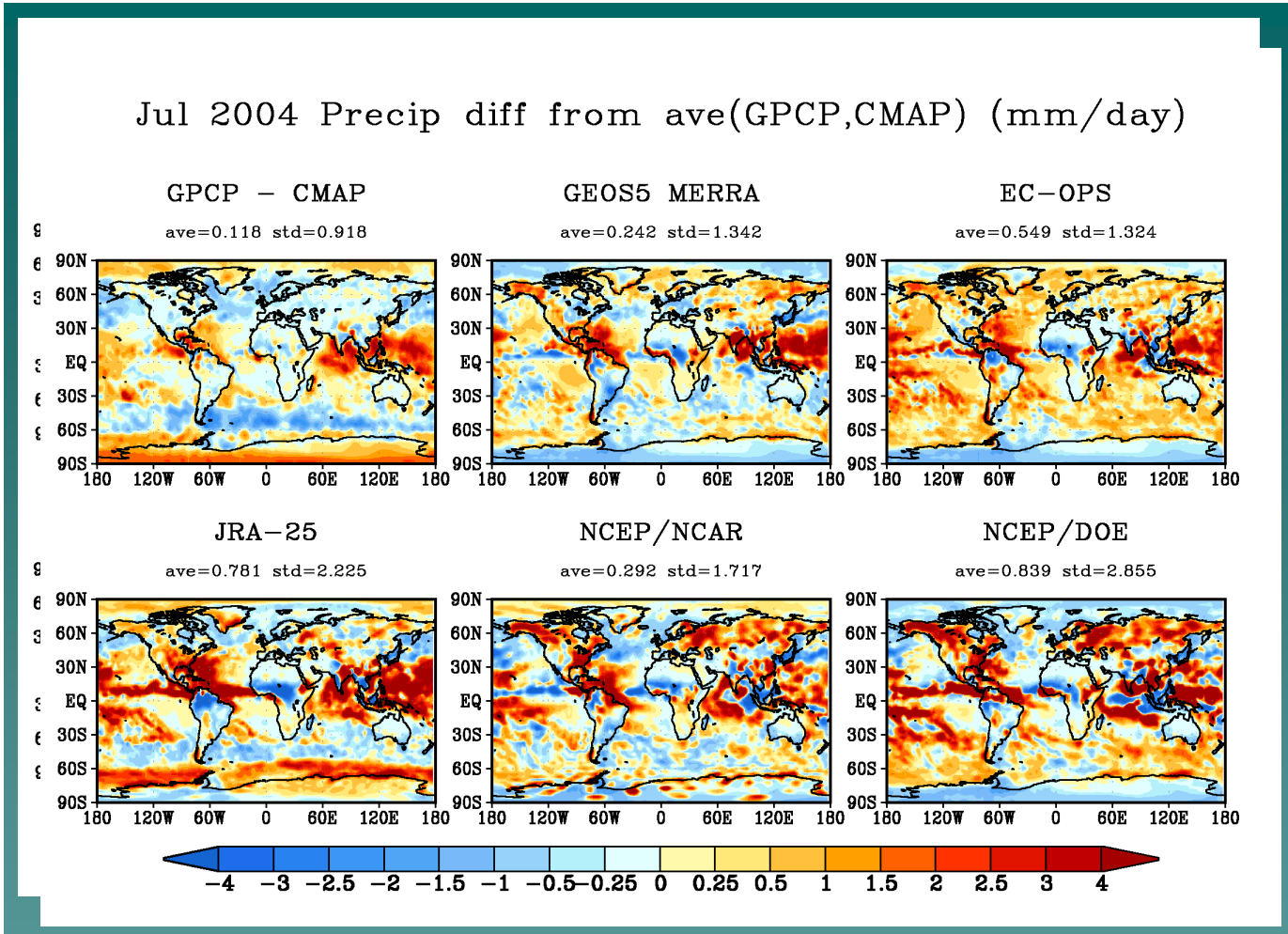


- SW uncertainty is larger in both observation and reanalyses.
- Except convective regions, strong biases happen over subtropics, South Ocean (January), and North Hemisphere high latitudes (July).
- MERRA TOA SW flux bias mean and standard deviation are also moderate among reanalyses.

TOA NET SW difference (W/m^2)	Jan, 2004		Jul, 2004	
	Ave	STD	Ave	STD
CERES Terra - Aqua	-1.7	9.3	0.6	6.1
MERRA - CERES	-3.2	17.2	-5.2	20.7
ECOPS - CERES	-2.6	16.7	-3.5	15.5
JRA25 - CERES	2.4	24.6	0.3	21.0
NCEP1 - CERES	-21.5	25.6	-18.1	23.5
NCEP2 - CERES	-7.9	29.8	-7.2	26.6

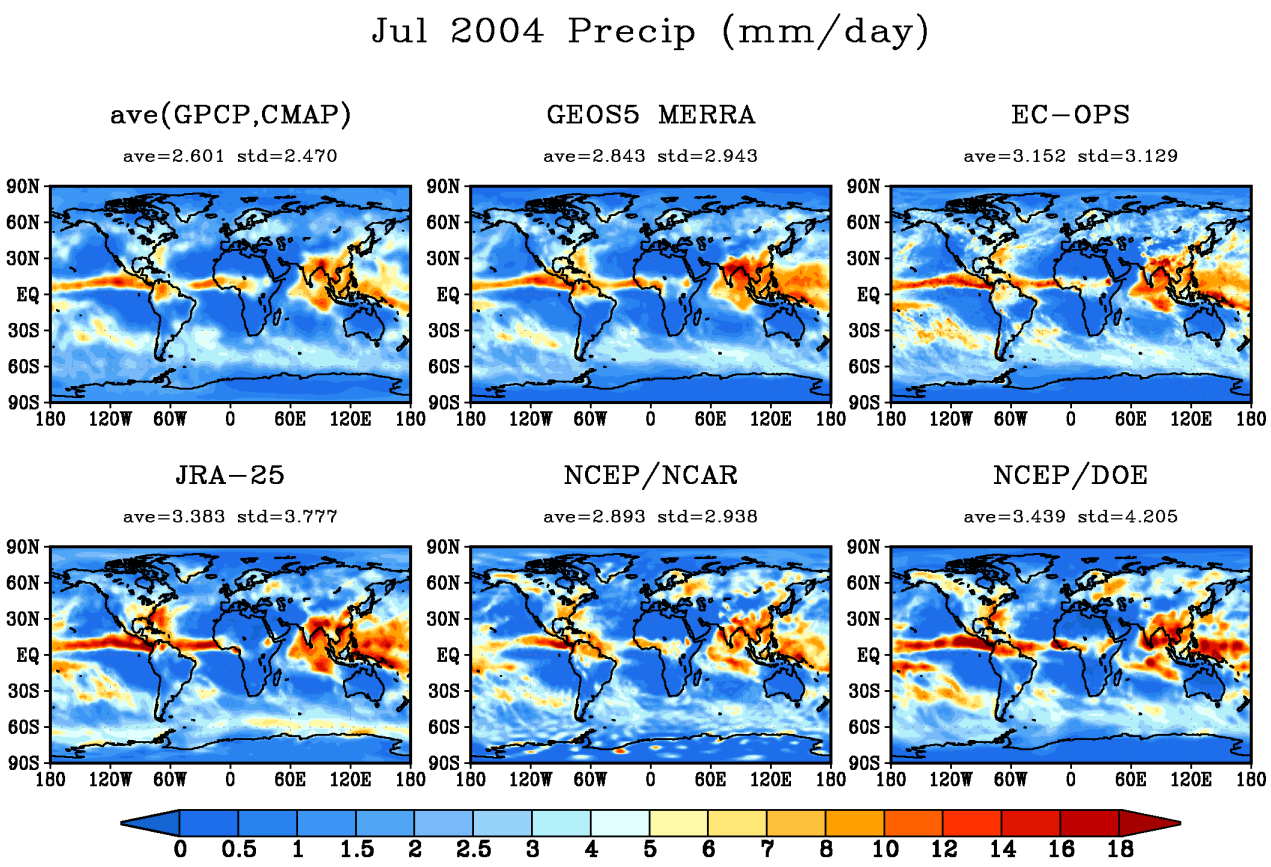

Jul 2004 TOA NET SW (W/m^2)
CERES ERBE-like
ave=243.6 std=111.4
GEOS5 MERRA
ave=234.5 std=110.8
EC-OPS
ave=236.1 std=113.2
JRA-25
ave=239.9 std=113.2
NCEP/NCAR
ave=221.7 std=104.5
NCEP/DOE
ave=221.7 std=104.5
90N 60N 30N EQ 30S 60S 90S
180 120W 60W 0 60E 120E 180
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400

Analysis over spatial domain: Precip

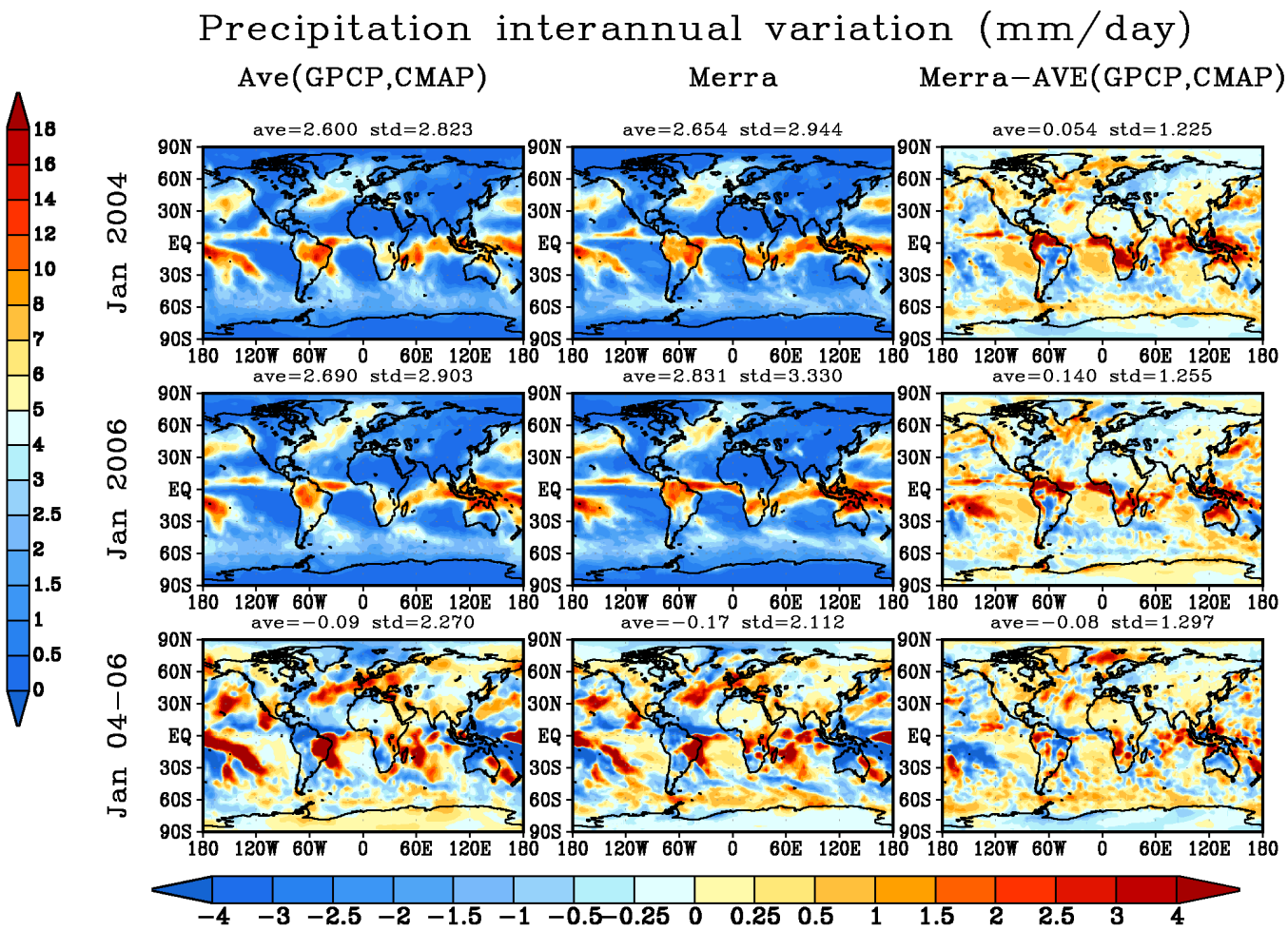


- Strong uncertainty over convective and storm track regions.
- Uncertainties in MERRA is just a little larger than in observation.

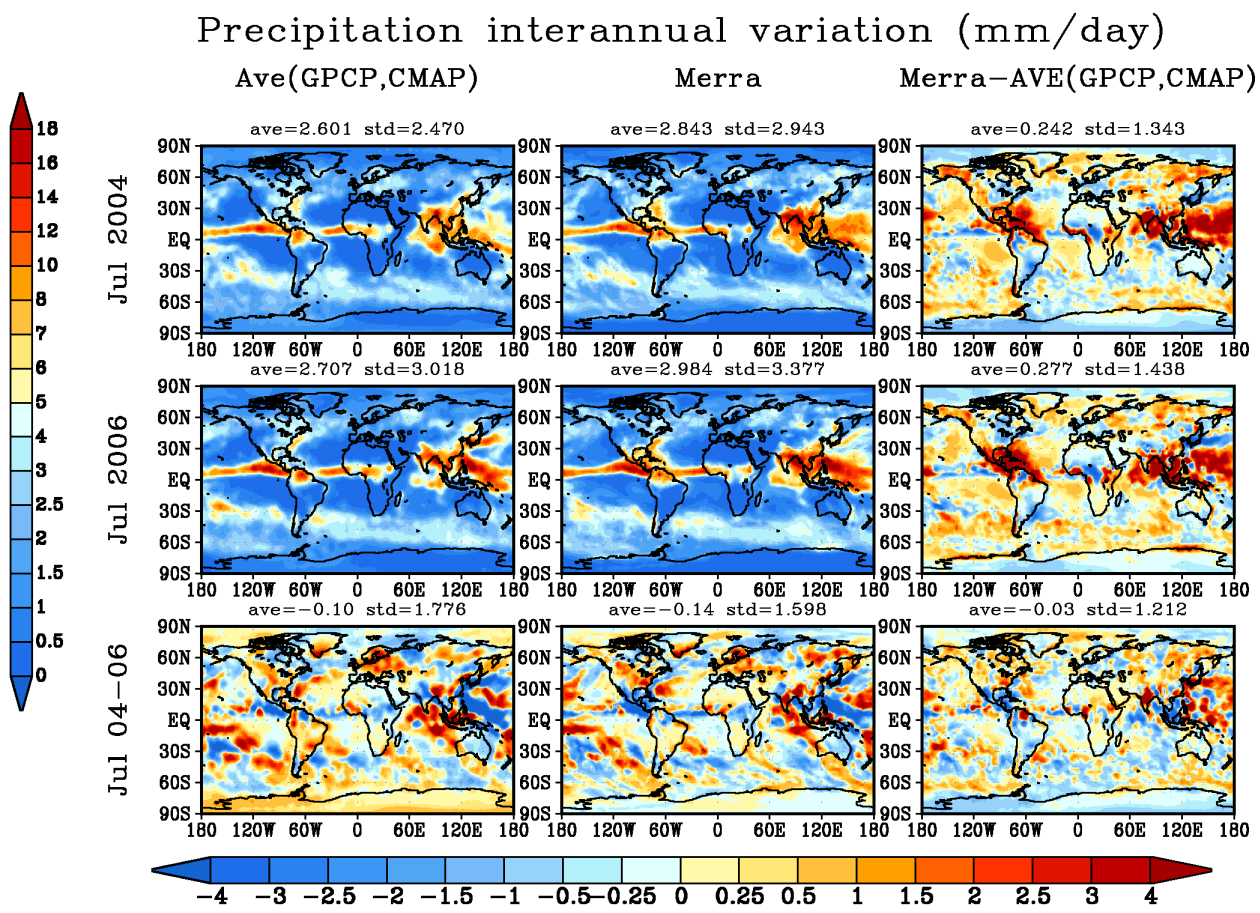
Precip difference (mm/day)	Jan, 2004		Jul, 2004	
	Ave	STD	Ave	STD
GPCP - CMAP	0.0	0.9	0.1	0.9
MERRA - ave(GP,CM)	0.1	1.2	0.2	1.3
ECOPS - ave(GP,CM)	0.5	1.3	0.5	1.3
JRA25 - ave(GP,CM)	0.6	1.6	0.8	2.2
NCEP1 - ave(GP,CM)	0.1	1.6	0.3	1.7
NCEP2 - ave(GP,CM)	0.6	2.4	0.8	2.9


Jul 2004 Precip (mm/day)
ave(GPCP,CMAP)
ave=2.601 std=2.470
GEOS5 MERRA
ave=2.843 std=2.943
EC-OPS
ave=3.152 std=3.129
JRA-25
ave=3.383 std=3.777
NCEP/NCAR
ave=2.893 std=2.938
NCEP/DOE
ave=3.439 std=4.205
90N 60N 30N EQ 30S 60S 90S
180 120W 60W 0 60E 120E 180
0 0.5 1 1.5 2 2.5 3 4 5 6 7 8 10 12 14 16 18

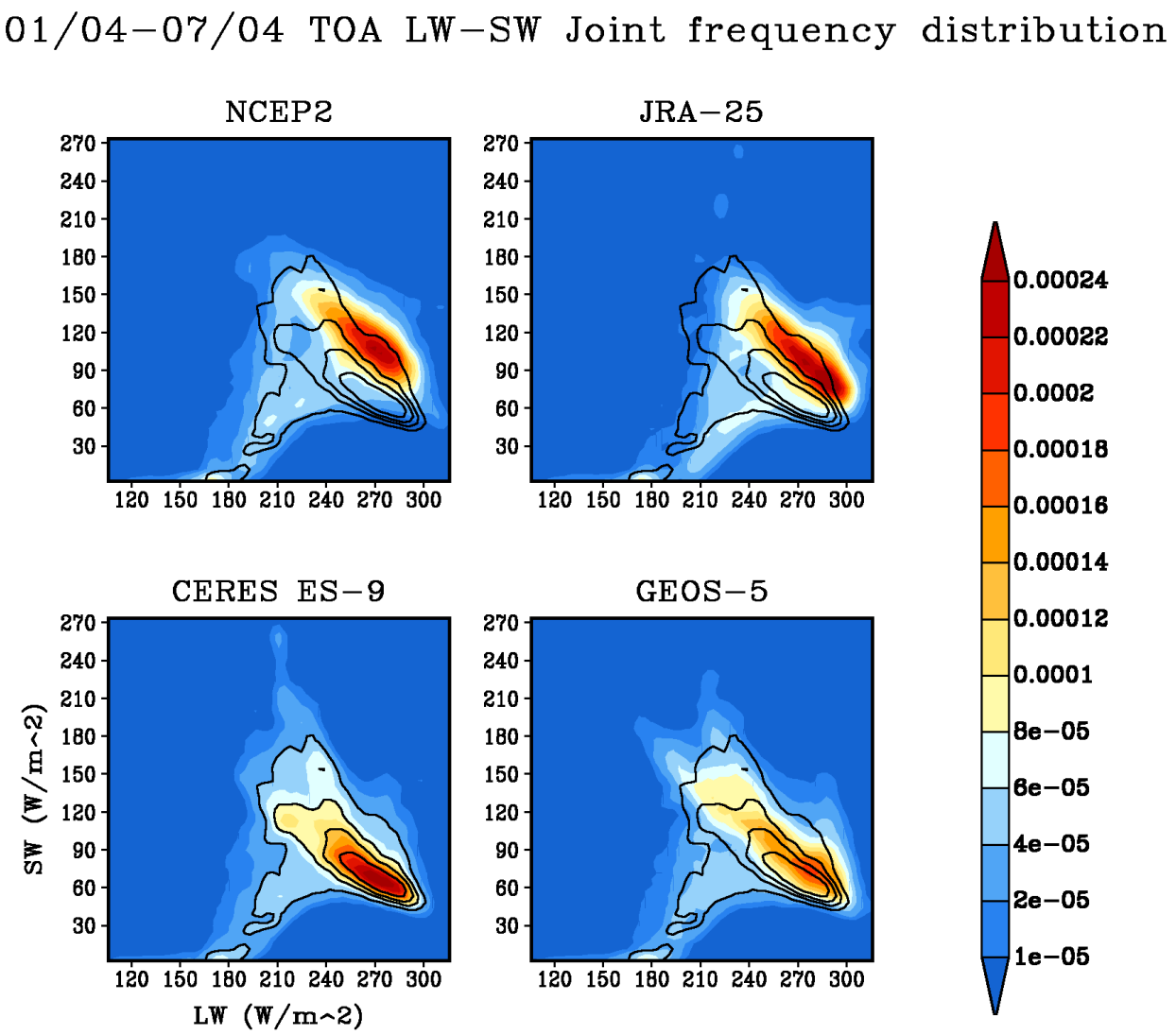
Interannual signal



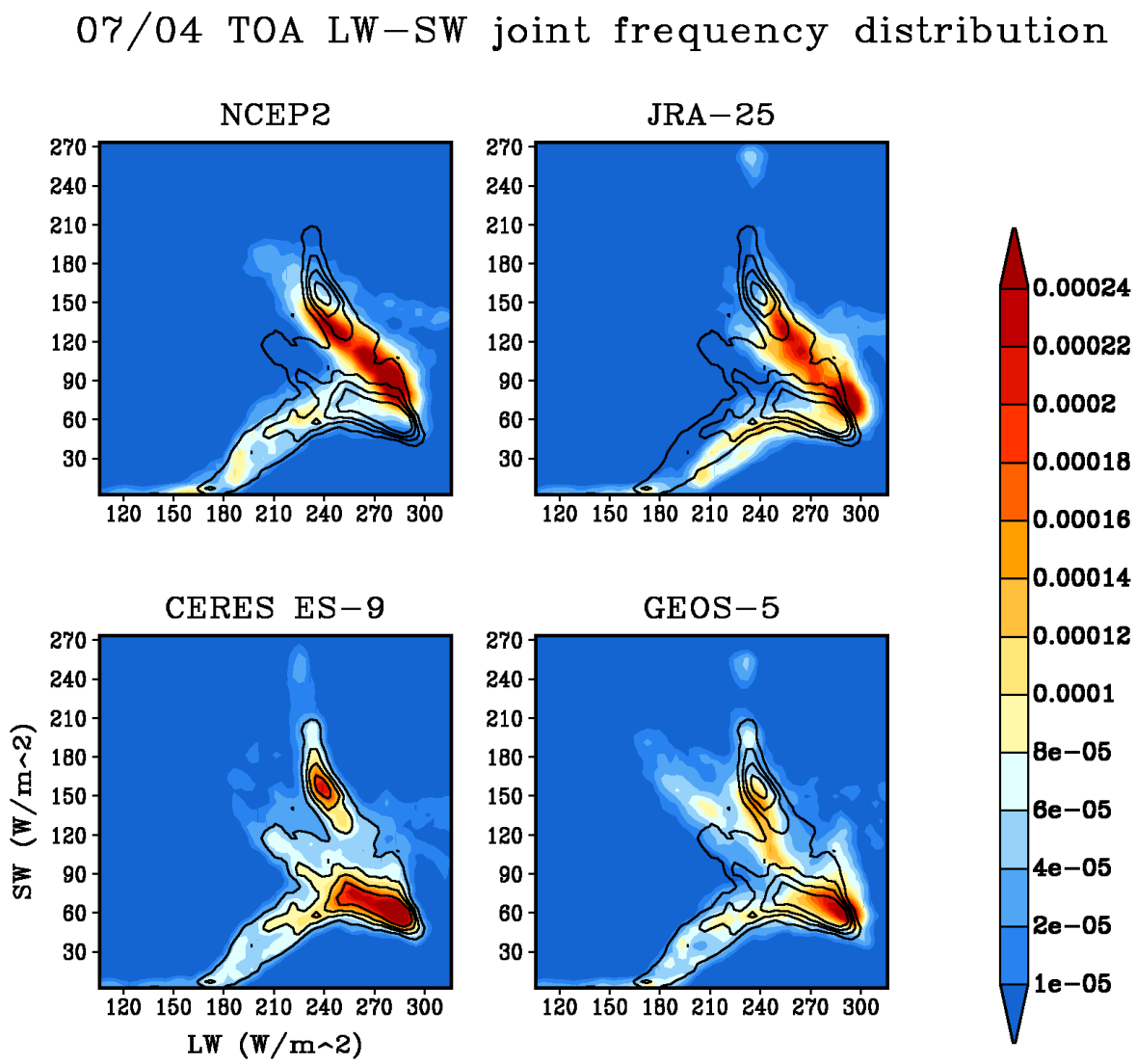
- MERRA bias patterns are relative stable in different years.
- MERRA can catch the interannual variation from 2004(moderate El Nino) to 2006(moderate La Nina).

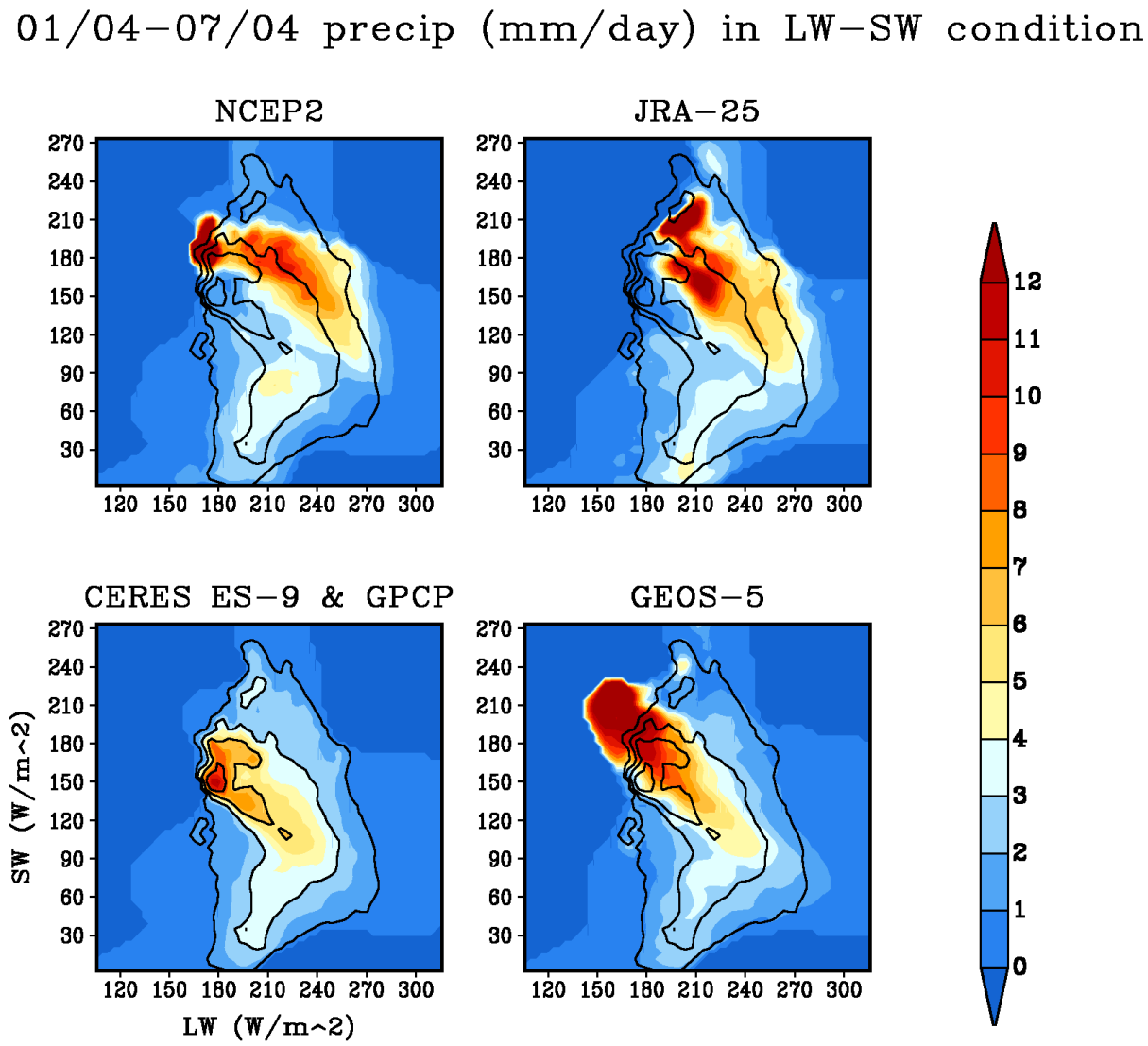

Precipitation interannual variation (mm/day)
Ave(GPCP,CMAP)
Merra
Merra−AVE(GPCP,CMAP)
Jul 2004
Jul 2006
Jul 04−06
ave=2.601 std=2.470
ave=2.843 std=2.943
ave=0.242 std=1.343
ave=2.707 std=3.018
ave=2.984 std=3.377
ave=0.277 std=1.438
ave=−0.10 std=1.776
ave=−0.14 std=1.598
ave=−0.03 std=1.212
90N 60N 30N EQ 30S 60S 90S
180 120W 60W 0 60E 120E 180
18 16 14 12 10 8 7 6 5 4 3 2.5 2 1.5 1 0.5 0
−4 −3 −2.5 −2 −1.5 −1 −0.5 −0.25 0 0.25 0.5 1 1.5 2 2.5 3 4

Interrelationship between TOA fluxes and precipitation



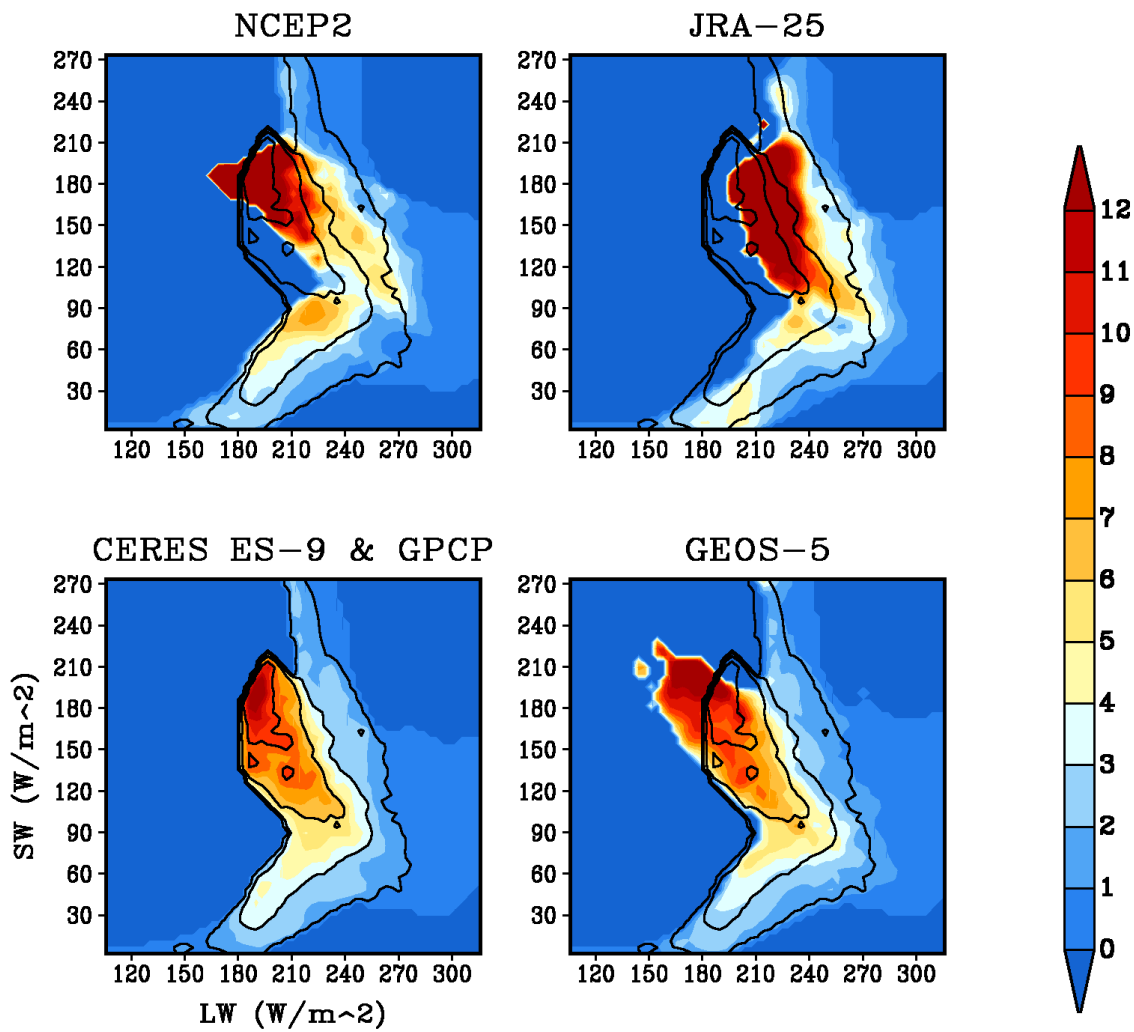
- LW-SW Joint Frequency Distribution (JFD) shows the relationship of LW and SW under different atmospheric states.
- The shape and location of MERRA LW-SW JFD is closer to CERES observation, while the MERRA pattern is a little stretched.

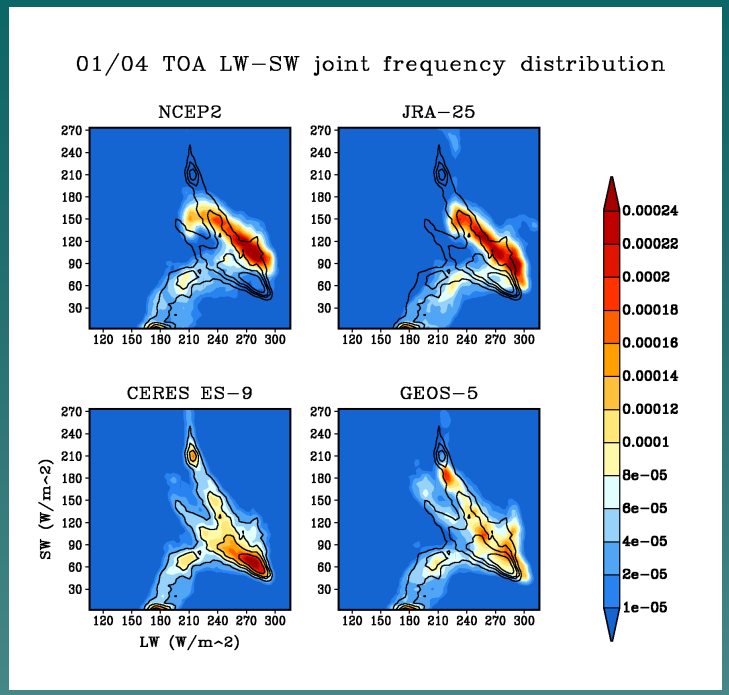

07/04 TOA LW−SW joint frequency distribution
NCEP2
JRA−25
CERES ES−9
GEOS−5
SW (W/m^2)
LW (W/m^2)
270
240
210
180
150
120
90
60
30
120 150 180 210 240 270 300
0.00024
0.00022
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
8e−05
6e−05
4e−05
2e−05
1e−05



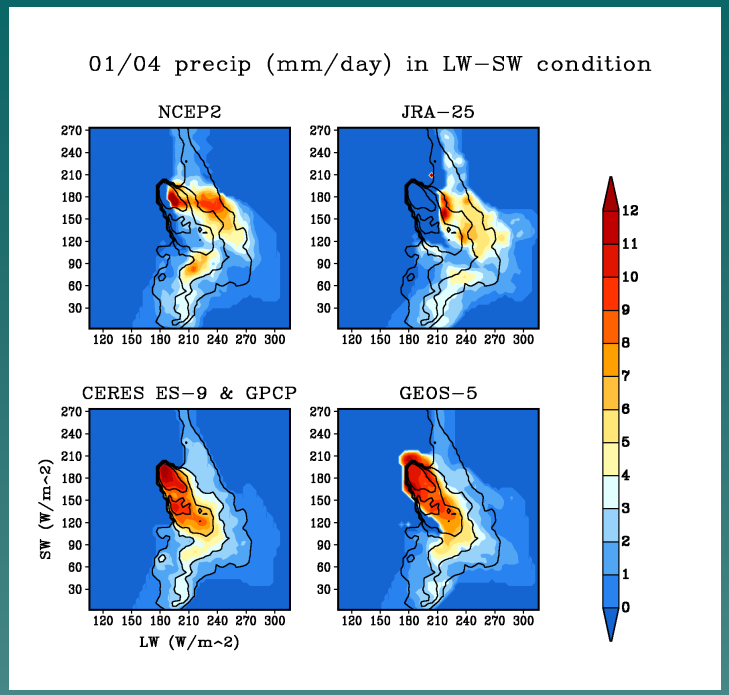
- Mean precipitation corresponding to LW-SW conditions: can we get right precip under different atmospheric states?
- MERRA: almost right on Jan 04; extreme high precip in high SW and low LW condition on July 04.
- NCEP2 and JRA-25 patterns shift to up-right side.

07/04 precip (mm/day) in LW−SW condition

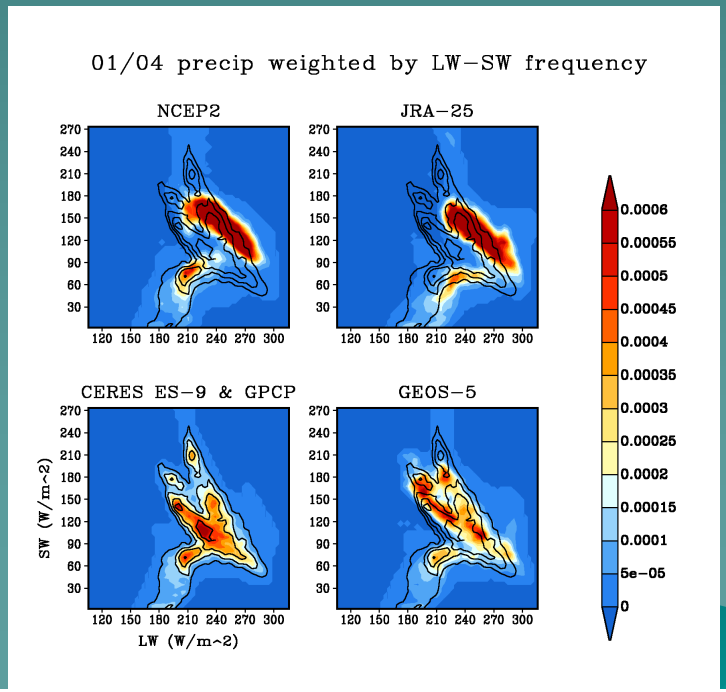




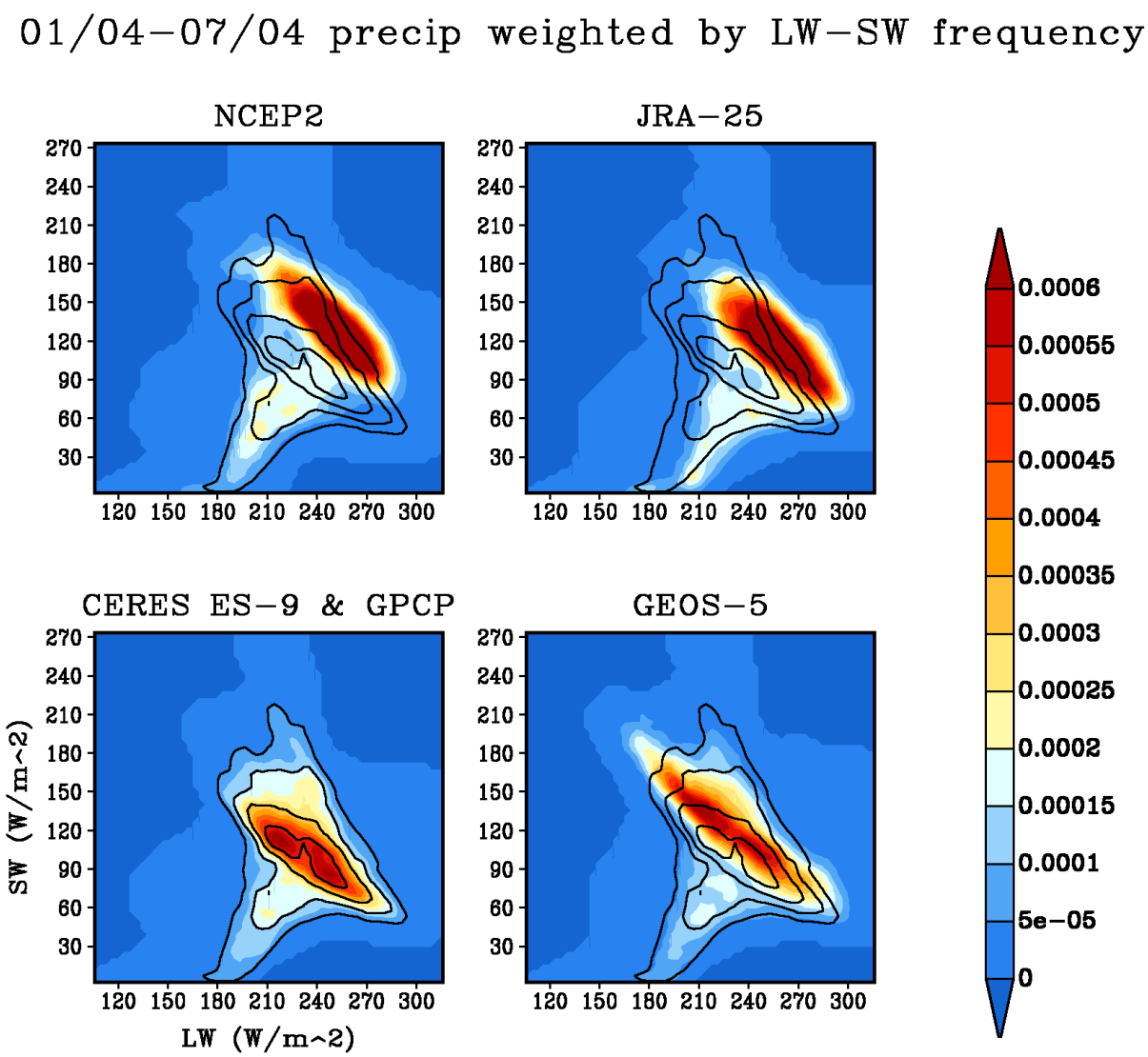
×



=

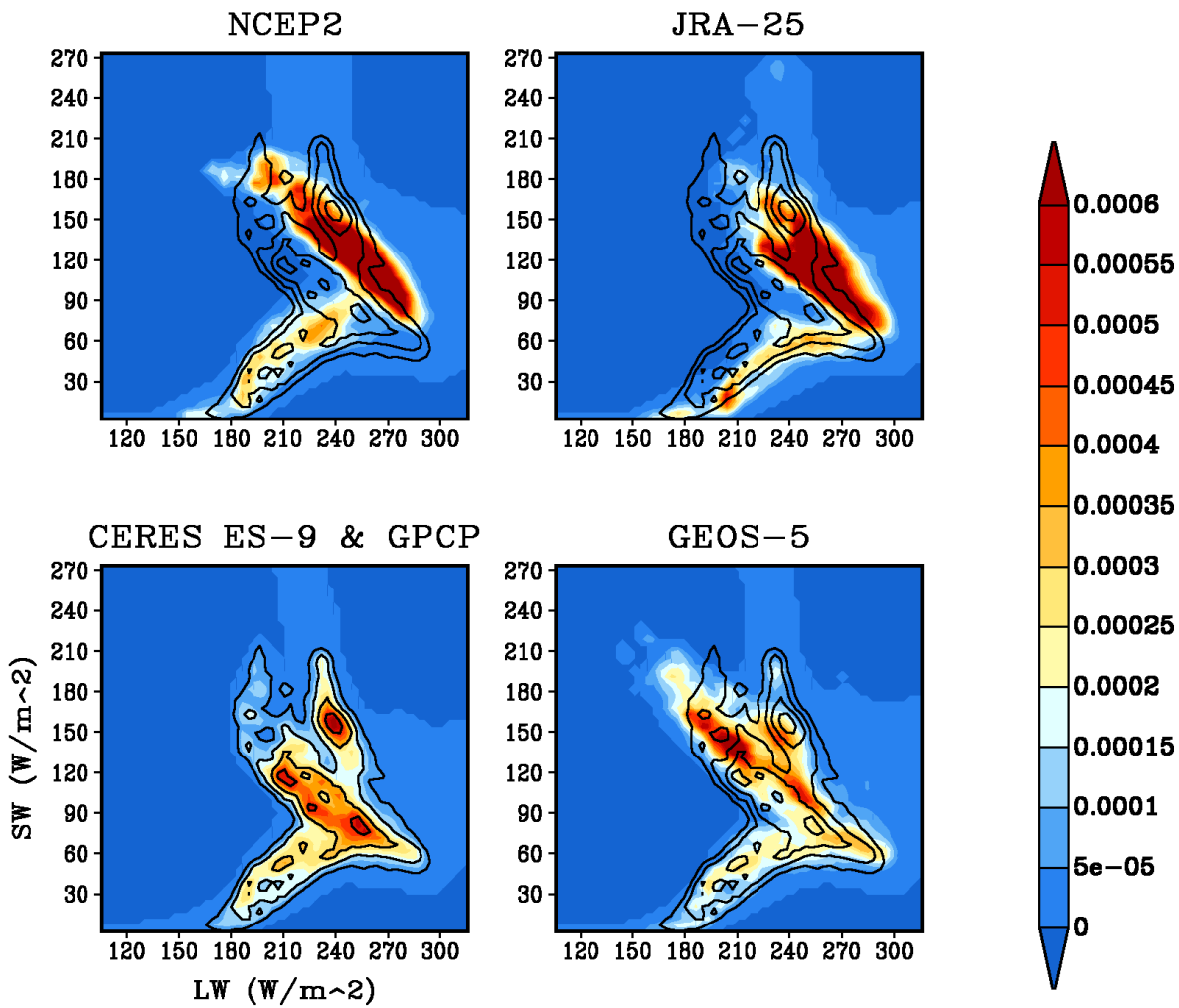


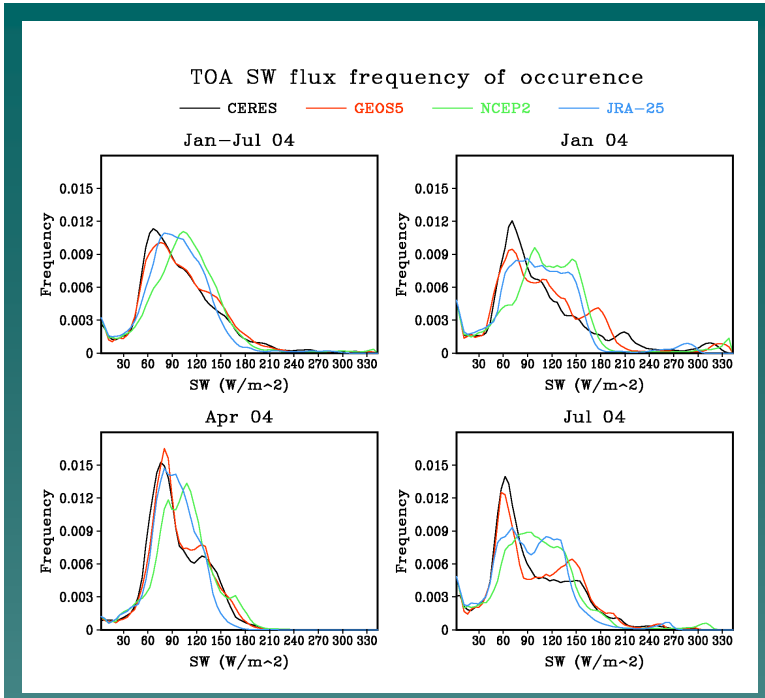
Precipitation weighted by the frequency of occurrence of LW-SW conditions: can we correctly distribute total precip to different atmospheric states?



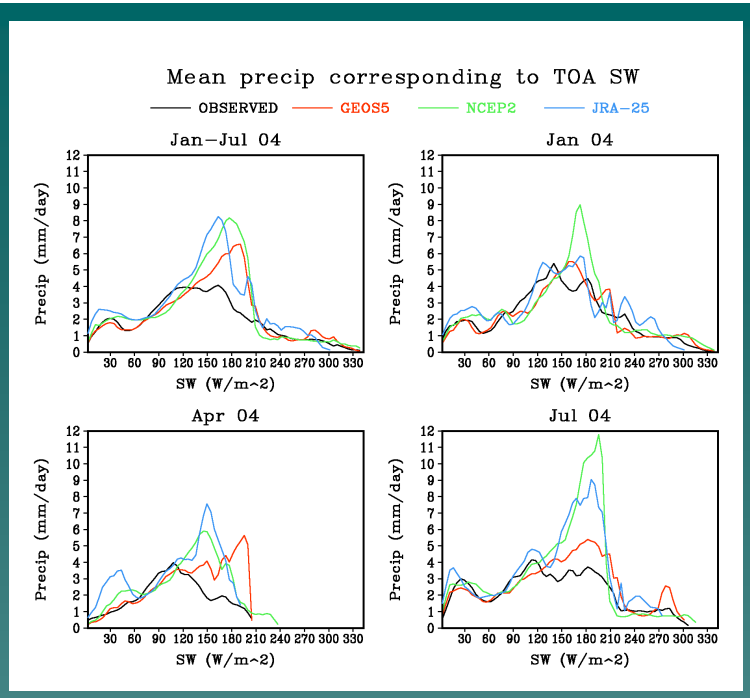
- Most of the precipitation happens in modest SW and LW condition.
- Again, MERRA is nearer to observation, while a little stretched.

07/04 precip weighted by LW−SW frequency

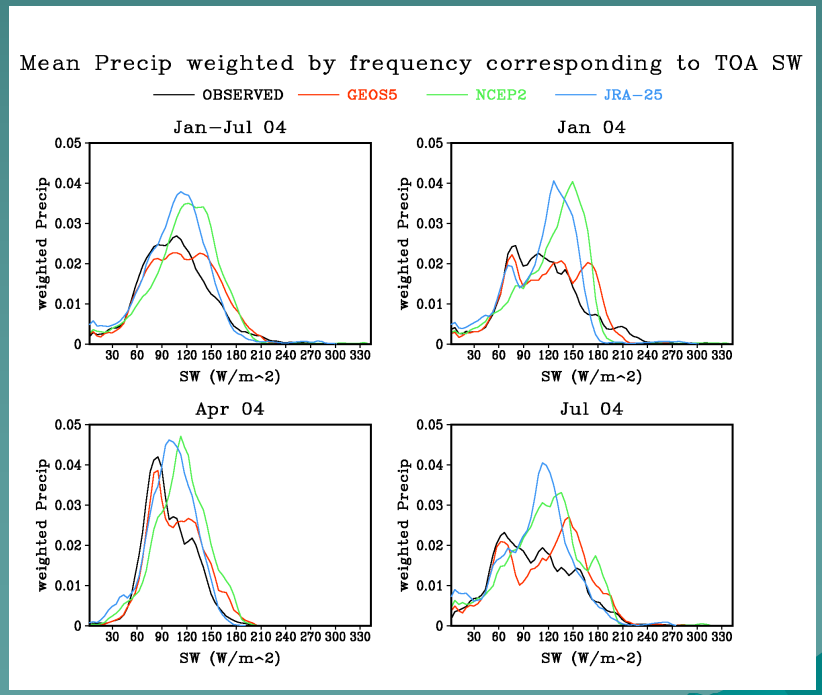




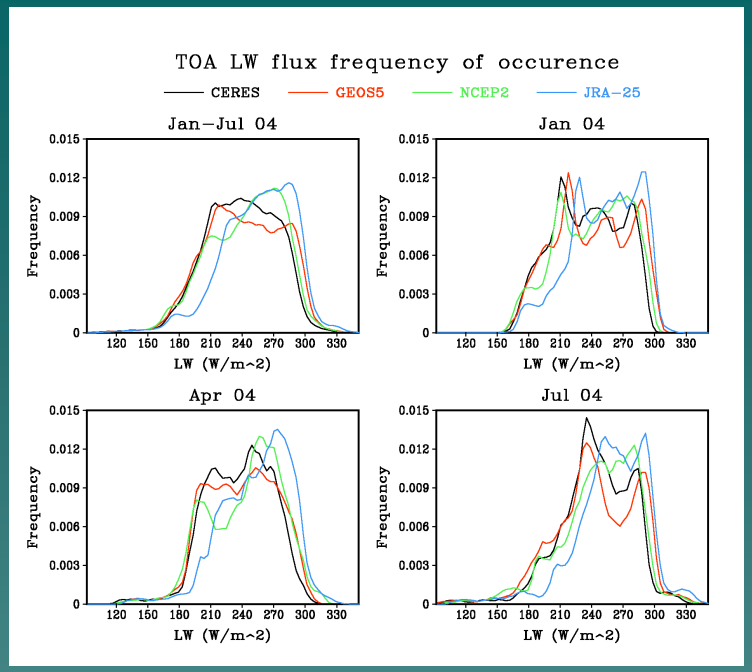
×



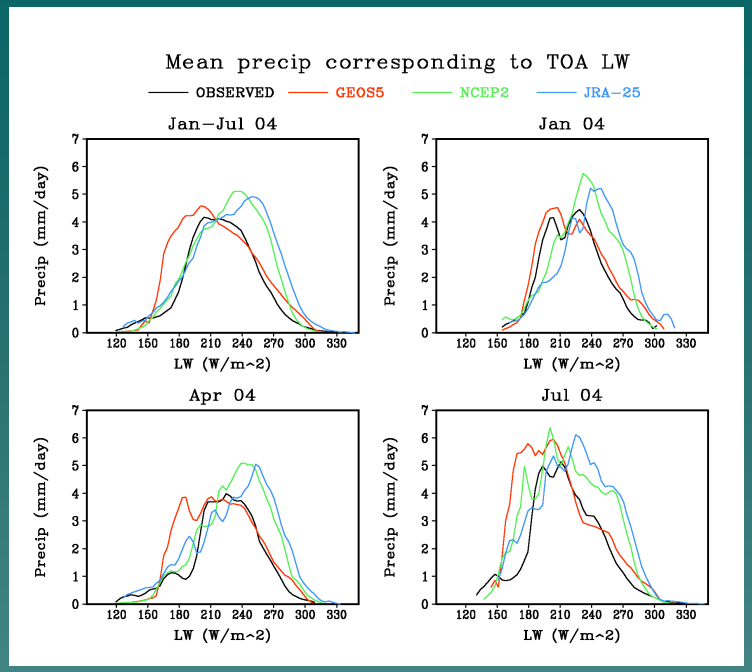
=



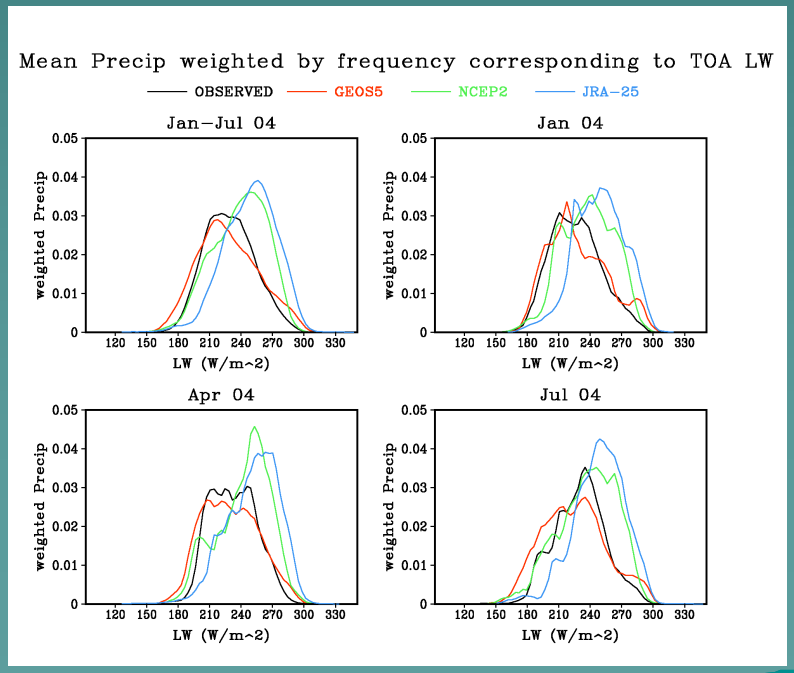
- One dimensional plots are more interpretable.

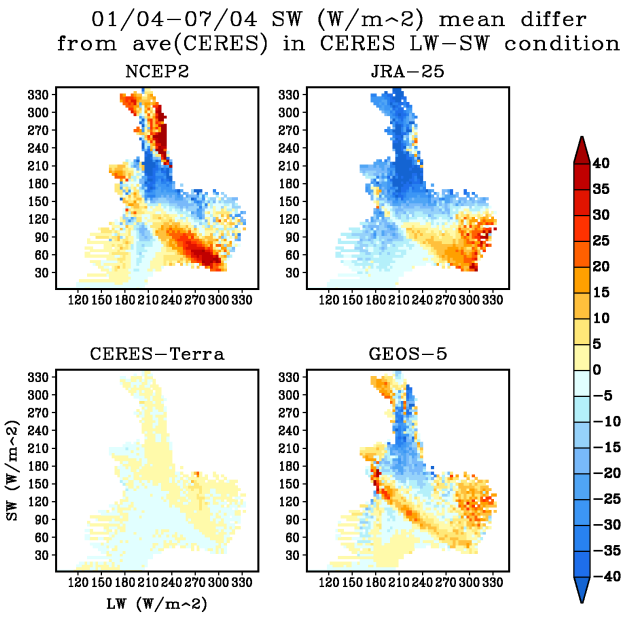

TOA LW flux frequency of occurence
CERES
GEOS5
NCEP2
JRA-25
Jan-Jul 04
Jan 04
Apr 04
Jul 04
Frequency
LW (W/m^2)

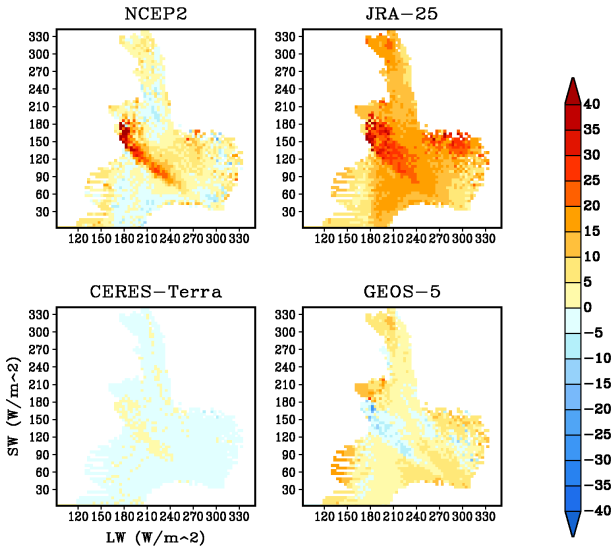
×

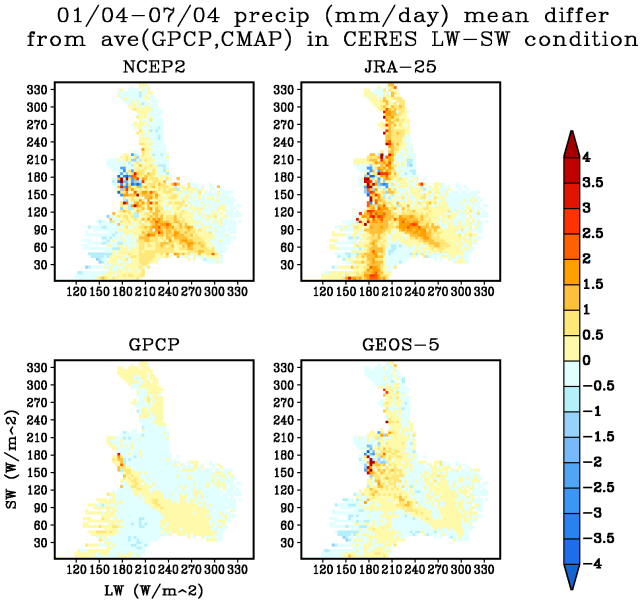

Mean precip corresponding to TOA LW
OBSERVED
GEOS5
NCEP2
JRA-25
Jan-Jul 04
Jan 04
Apr 04
Jul 04
Precip (mm/day)
LW (W/m^2)

=


Mean Precip weighted by frequency corresponding to TOA LW
OBSERVED
GEOS5
NCEP2
JRA-25
Jan-Jul 04
Jan 04
Apr 04
Jul 04
weighted Precip
LW (W/m^2)

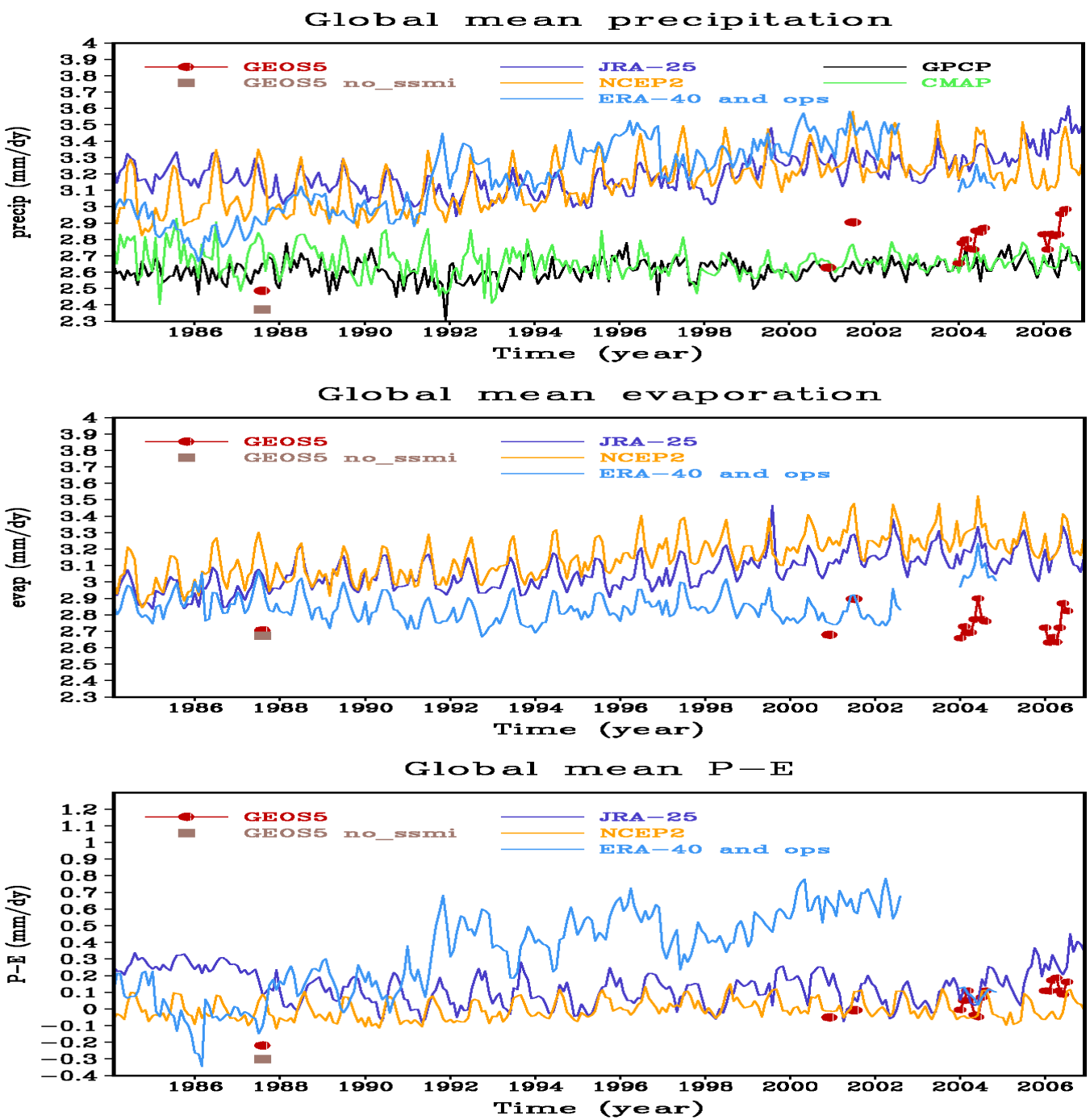






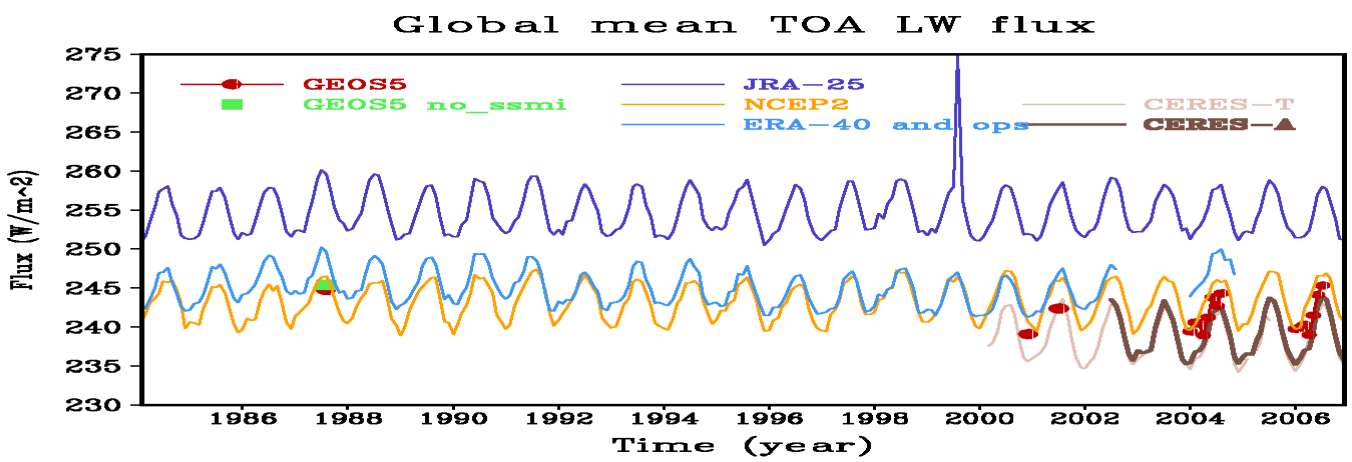
- The biases in SW, LW and precip do not necessarily happened at the same time or the same LW-SW condition in the CERES observation domain.
- MERRA has smaller biases.
- These information are useful to explore the biases in assimilation with the help of independent observation.

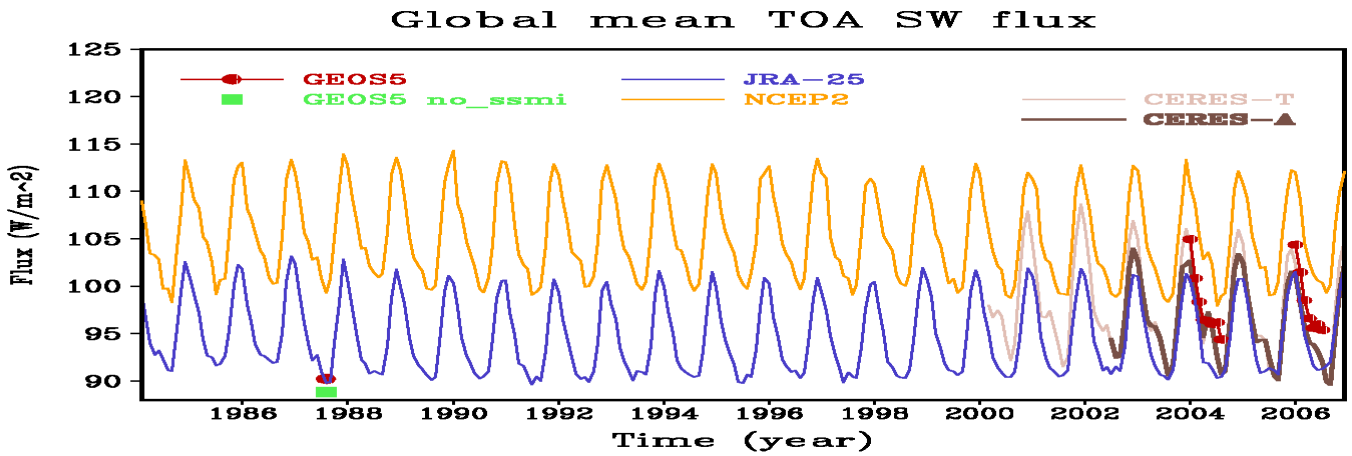
Global mean water budget

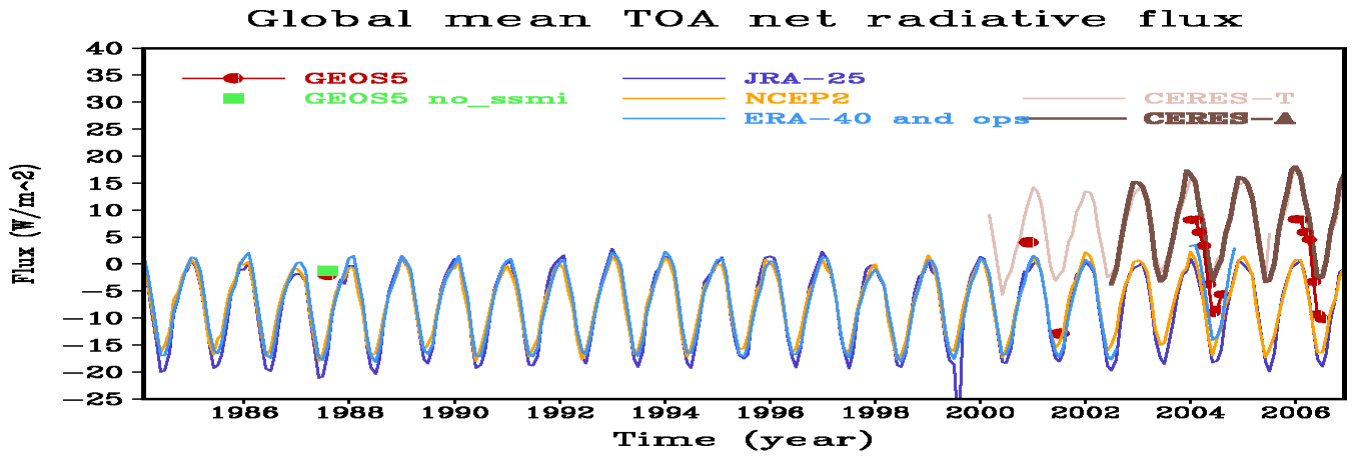


- MERRA global mean Precip and Evap are close to balance with right P and E amplitudes.
- SSM/I impact still exists.

Global mean TOA energy budget







- MERRA global mean TOA fluxes are close to observation with right annual amplitude and nearly balanced.
- Impact of SSM/I on TOA fluxes is very small.

Conclusion

- MERRA shows good results in global water and energy cycle, especially on the interrelationships among LW, SW and precipitation, and global mean water and TOA energy budget.
- More room for improvement is still available, especially over tropical and subtropical region, storm track region, and high latitudes of summer hemisphere.

The End

Thank you!

MERRA home page: http://gmao.gsfc.nasa.gov/research/merra/

MERRA data site: http://disc.sci.gsfc.nasa.gov/MDISC/

MERRA blog: http://merra-reanalysis.blogspot.com/