Implementation of a Cubed-sphere Finite-volume Dynamical Core into CAM

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AMWG Winter Meeting, February 18th, 2015

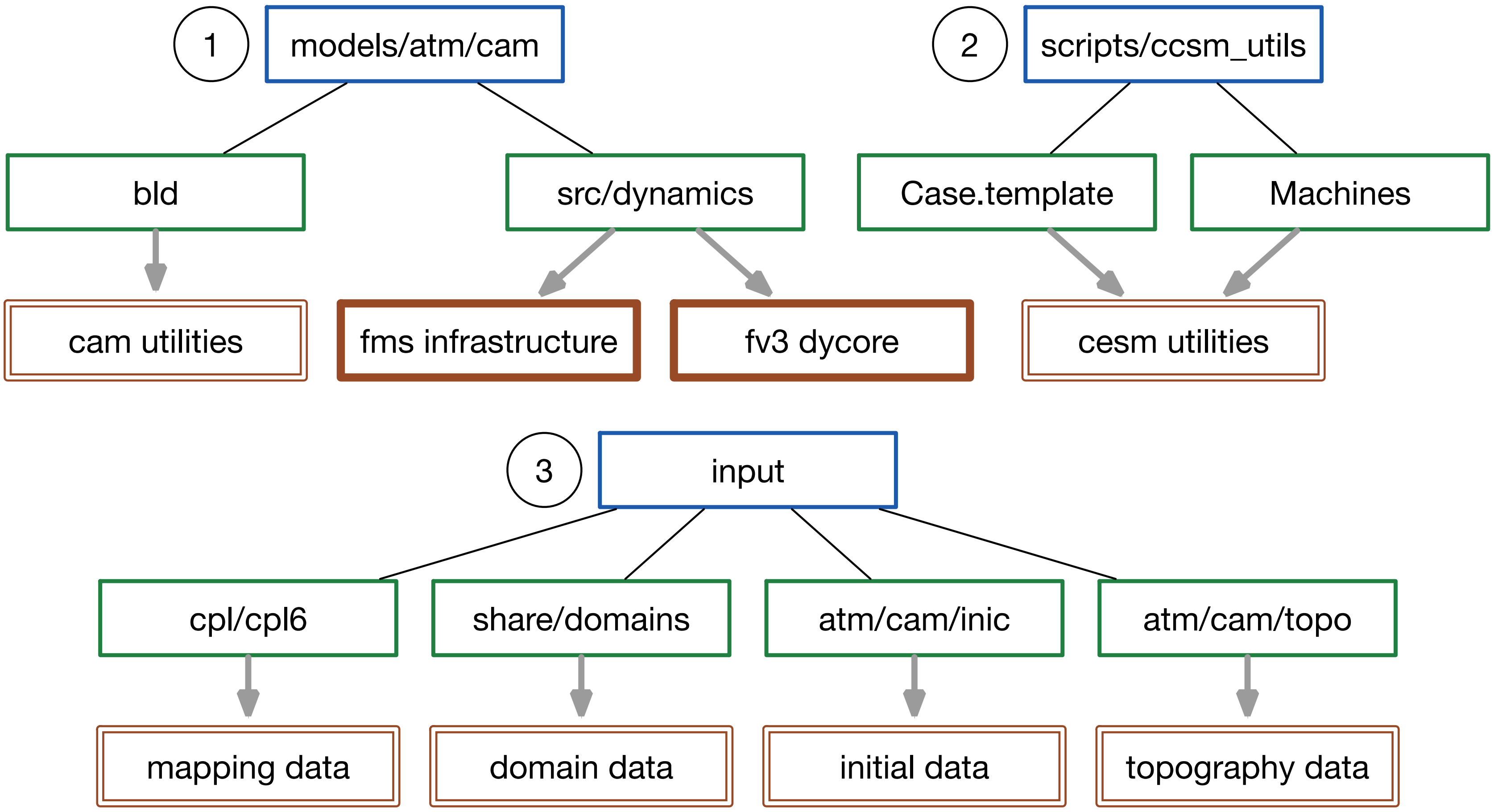
Motivation

- Cubed-sphere FV dynamical core (FV3) is the latest dynamical core developed in GFDL that already been employed in the AM3/HiRAM. The Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS) is evaluating several dynamical cores for high resolution atmospheric simulations.

- The mainly updates from FV to FV3 are:
  - Replace lat-lon grid with cubed-sphere grid (Putman and Lin, 2007)
  - The flux-form semi-Lagrangian extension (Lin and Rood, 1996) needed to stabilize the (large time step) transport processes in FV near the poles is no longer needed (Donner et al., 2011) in FV3
  - The polar Fourier filtering is no longer needed in FV3 (Donner et al., 2011)

Advantage: 1) improved computational efficiency and communication load balancing
2) higher efficiency in high resolution integration

What We Have Done



Under the instruction from Steve Goldhaber.

Computational Performance

CESM1.2.2

Dynamics	Resolution	Model Speed*	CPU Amount
FV3	C48_f19_g16 (200km)		96
FV	f19_g16 (200km)		64
SE	ne16_g37 (200km)		64
FV3	C96_f09_g16 (100km)		216
FV	f09_g16 (100km)		128
SE	ne30_g16 (100km)		128
FV3	C192_f05_g16 (50km)		384
FV	f05_g16 (50km)		256
SE	ne60_g16 (50km)		NA

Component Setting: FAMIP/FAMIPC5 (CAM4/5+CLM4.0+RTM+DOCN+CICE)
Machine: Storm, Local Cluster in SoMAS, Stony Brook University
* Units: Model Year / Wall-clock Day (CAM4 / CAM5)

Computational Performance

CESM1.2.2

Dynamics	Resolution	Model Speed*	CPU Amount
FV3	C48_f19_g16 (200km)	3.60 / 2.14	96
FV	f19_g16 (200km)	10.08 / 3.08	64
SE	ne16_g37 (200km)	2.91 / 1.77	64
FV3	C96_f09_g16 (100km)		216
FV	f09_g16 (100km)		128
SE	ne30_g16 (100km)		128
FV3	C192_f05_g16 (50km)		384
FV	f05_g16 (50km)		256
SE	ne60_g16 (50km)		NA

Component Setting: FAMIP/FAMIPC5 (CAM4/5+CLM4.0+RTM+DOCN+CICE)
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Computational Performance

CESM1.2.2

Dynamics	Resolution	Model Speed*	CPU Amount
FV3	C48_f19_g16 (200km)	3.60 / 2.14	96
FV	f19_g16 (200km)	10.08 / 3.08	64
SE	ne16_g37 (200km)	2.91 / 1.77	64
FV3	C96_f09_g16 (100km)	4.64 / 1.85	216
FV	f09_g16 (100km)	1.72 / 0.58	128
SE	ne30_g16 (100km)	0.99 / 0.65	128
FV3	C192_f05_g16 (50km)	1.34 / 0.66	384
FV	f05_g16 (50km)	0.50 / 0.05	256
SE	ne60_g16 (50km)	NA	NA

Component Setting: FAMIP/FAMIPC5 (CAM4/5+CLM4.0+RTM+DOCN+CICE)
Machine: Storm, Local Cluster in SoMAS, Stony Brook University
* Units: Model Year / Wall-clock Day (CAM4 / CAM5)

Computational Performance

CESM1.2.2

Dynamics	Resolution	Model Speed*	CPU Amount	Rate#
FV3	C48_f19_g16 (200km)	3.60 / 2.14	96	37.5 / 22.3
FV	f19_g16 (200km)	10.08 / 3.08	64	157.5 / 48.1
SE	ne16_g37 (200km)	2.91 / 1.77	64	45.5 / 27.7
FV3	C96_f09_g16 (100km)	4.64 / 1.85	216	21.5 / 8.6
FV	f09_g16 (100km)	1.72 / 0.58	128	13.4 / 4.5
SE	ne30_g16 (100km)	0.99 / 0.65	128	7.7 / 5.1
FV3	C192_f05_g16 (50km)	1.34 / 0.66	384	3.5 / 1.7
FV	f05_g16 (50km)	0.50 / 0.05	256	2.0 / 0.2
SE	ne60_g16 (50km)	NA	NA	NA

Component Setting: FAMIP/FAMIPC5 (CAM4/5+CLM4.0+RTM+DOCN+CICE)
Machine: Storm, Local Cluster in SoMAS, Stony Brook University
* Units: Model Year / Wall-clock Day (CAM4 / CAM5)
# Rate: Model Speed * 1000 / CPU Amount. The higher the better!

Experiments for Evaluation

CESM1.2.2

Experiment	Dynamical Core	Physical Package	Analysis Period
FV3_C4*	Cubed-sphere Finite-volume	CAM4	1981-1995 (15yrs)
FV_C4*	Lat-lon Finite-volume	CAM4	1981-1995 (15yrs)
SE_C4#	Spectral Element	CAM4	1981-1995 (15yrs)

Experiment	Dynamical Core	Physical Package	Analysis Period
FV3_C5*	Cubed-sphere Finite-volume	CAM5 (with Chem.)	1981-1995 (15yrs)
FV_C5*	Lat-lon Finite-volume	CAM5 (with Chem.)	1981-1995 (15yrs)
SE_C5#	Spectral Element	CAM5 (with Chem.)	1981-1995 (15yrs)

Component Settings:

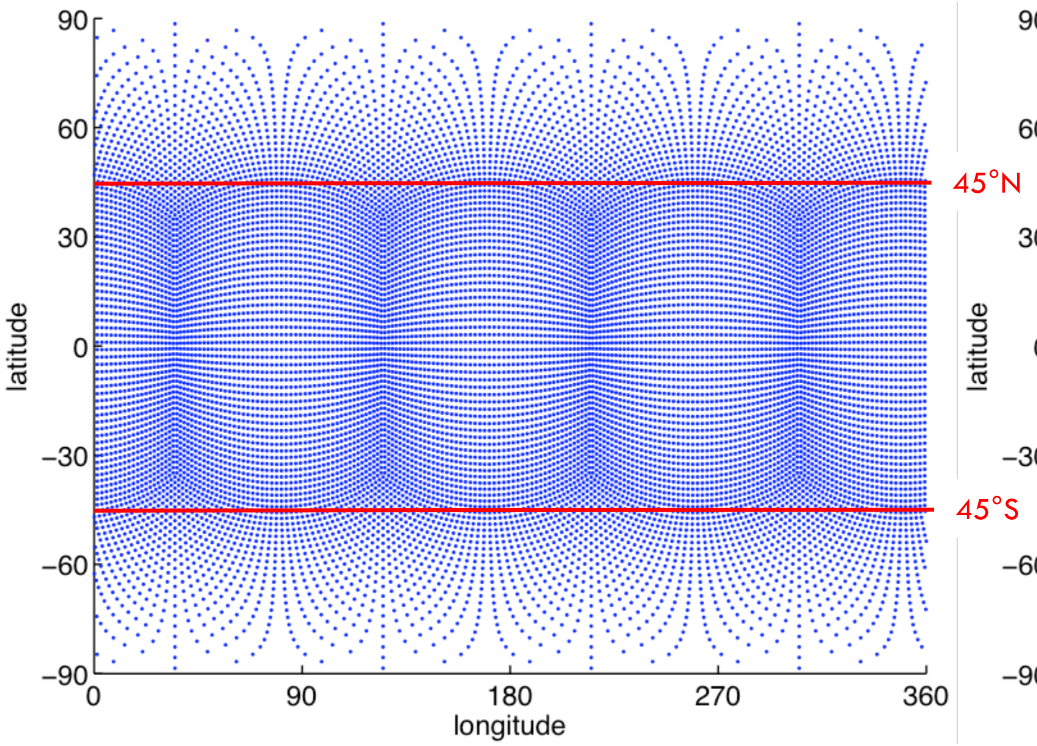
C4: FAMIP (CAM4+CLM4.0+RTM+DOCN+CICE)

C5: FAMIPC5 (CAM5+CLM4.0+RTM+DOCN+CICE)

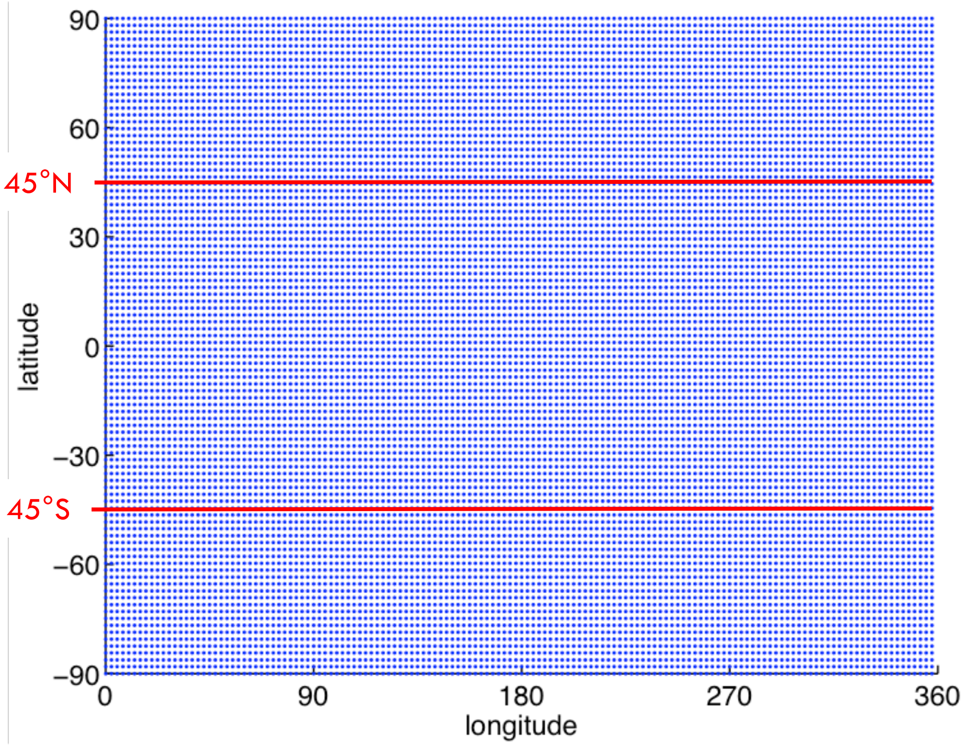
*: 200km; #: 100km

Cubed-sphere Grid & Lat-lon Grid

Cubed-sphere Grid (C48)



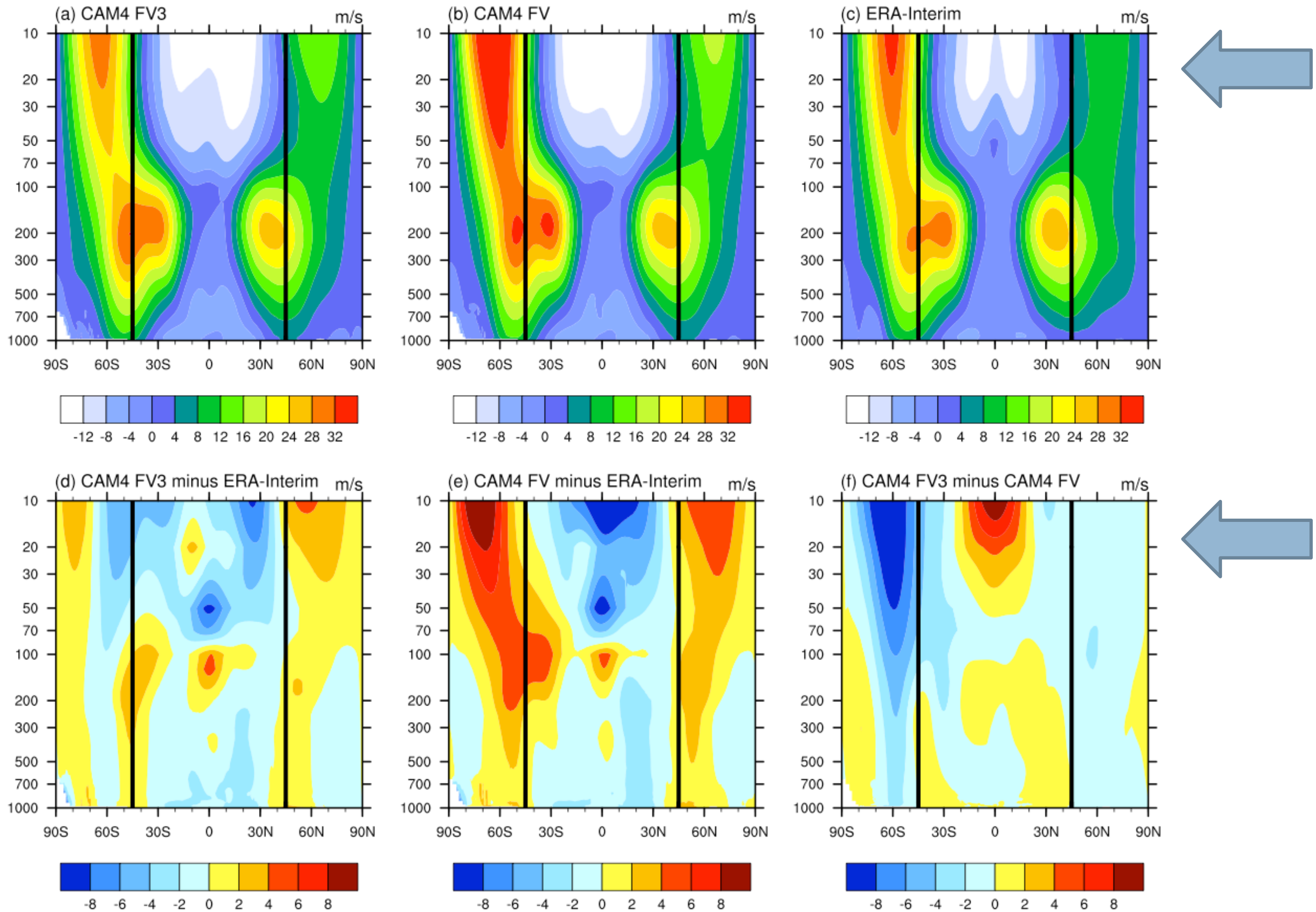
Lat-lon Grid (1.9x2.5)



Over the high-latitude region: Coarse resolution

Over the Cubed-sphere boundary region: Fine resolution

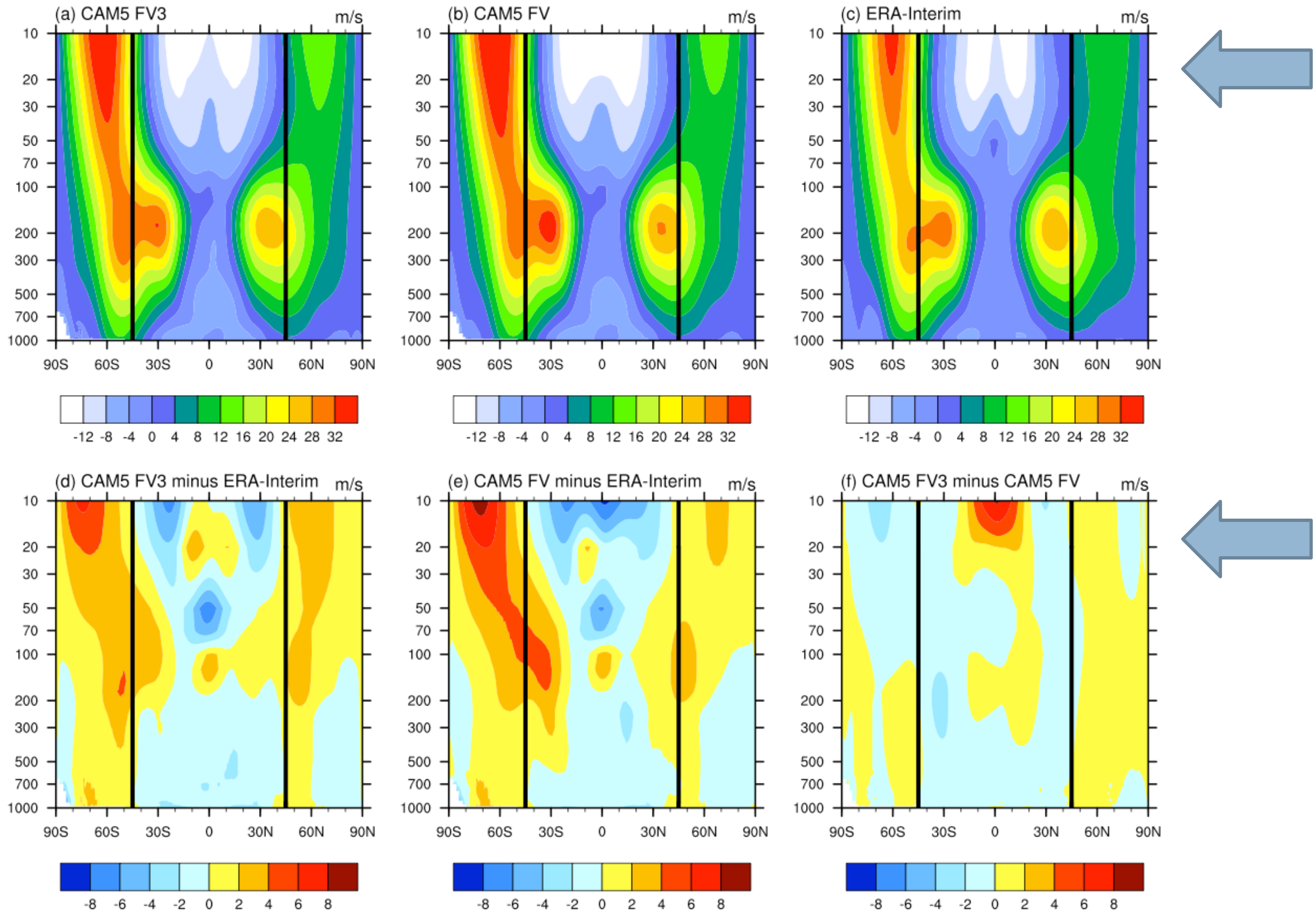
CAM4 Zonal Wind (m/s)



Simulation of Polar Jet in CAM4 FV3 is much better

plot_06

CAM5 Zonal Wind (m/s)



Simulation of Polar Jet and Equatorial zonal wind in CAM5 FV3 is slightly better

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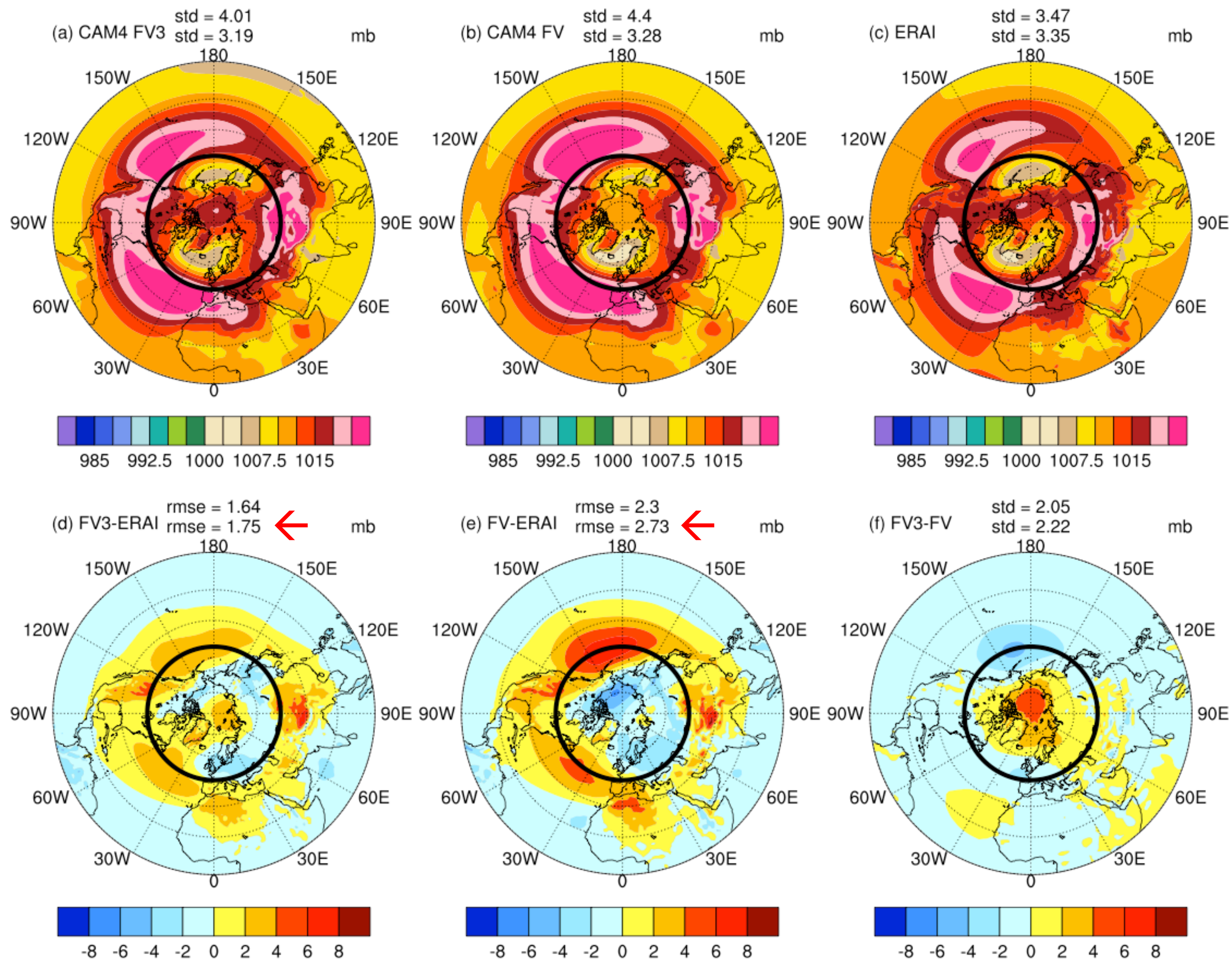
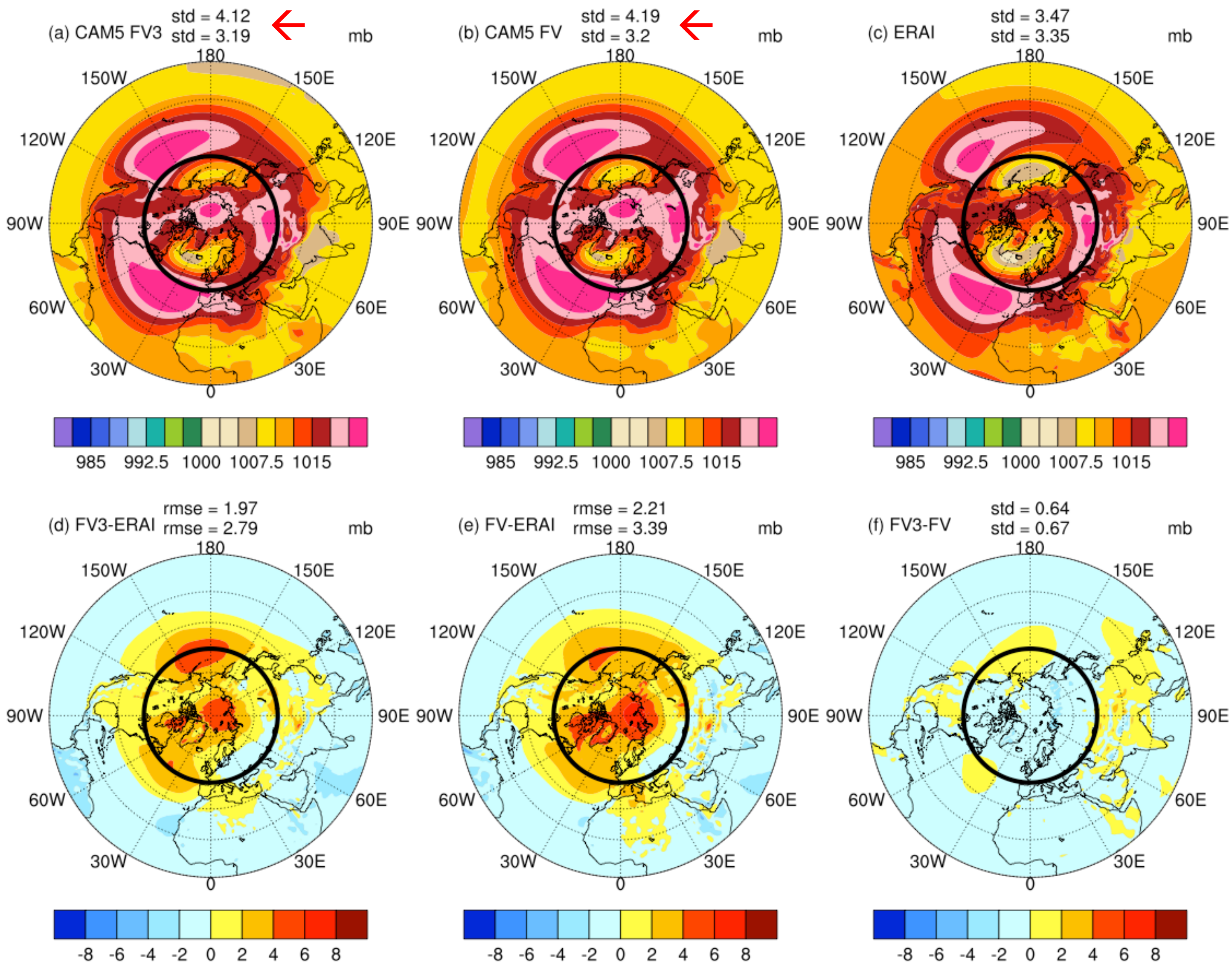
CAM4 Sea Level Pressure (mb)



The pattern of CAM4 FV3 over the polar region is more similar to ERAI

plot_06

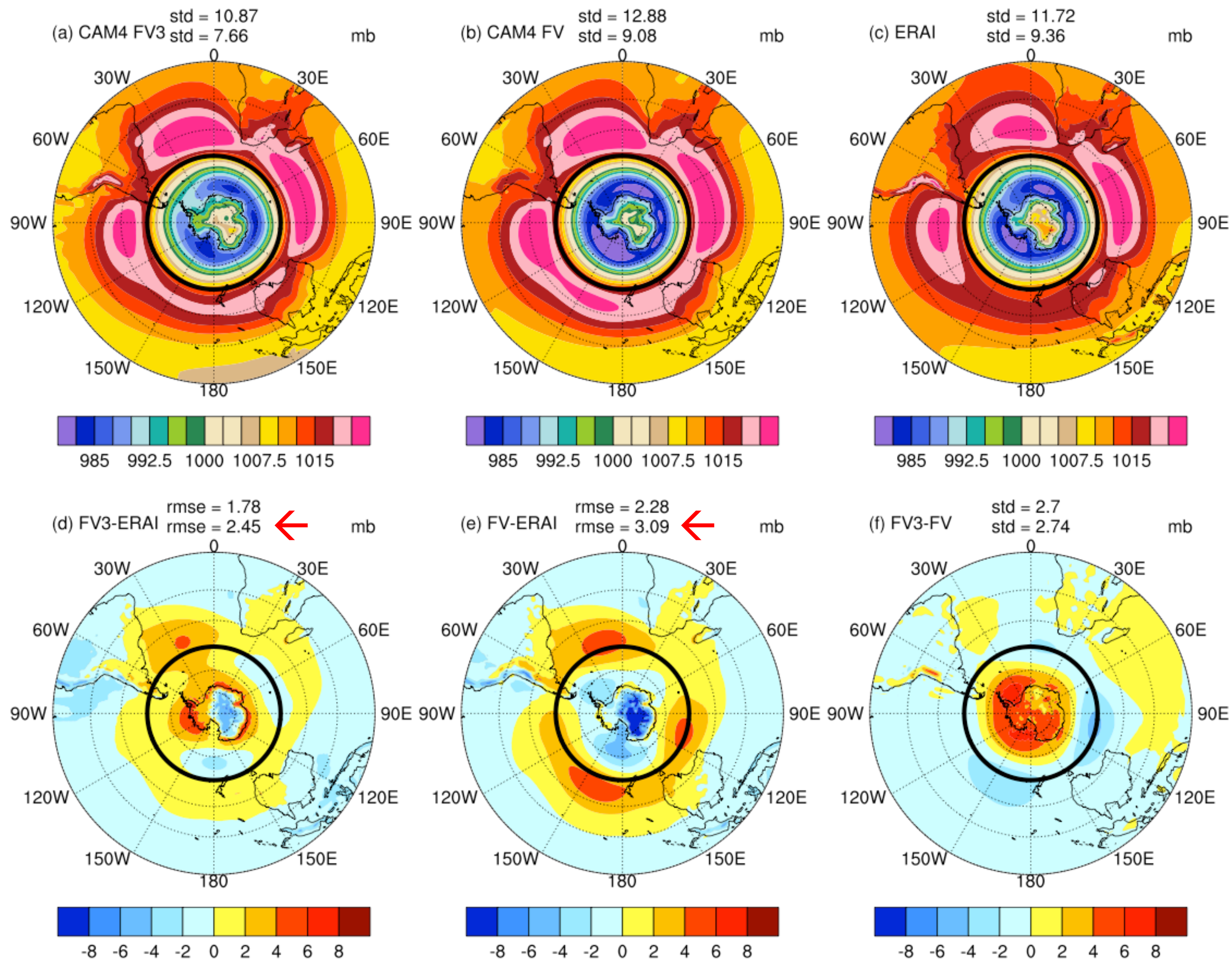
CAM5 Sea Level Pressure (mb)



The difference between FV3 and FV is much smaller in CAM5

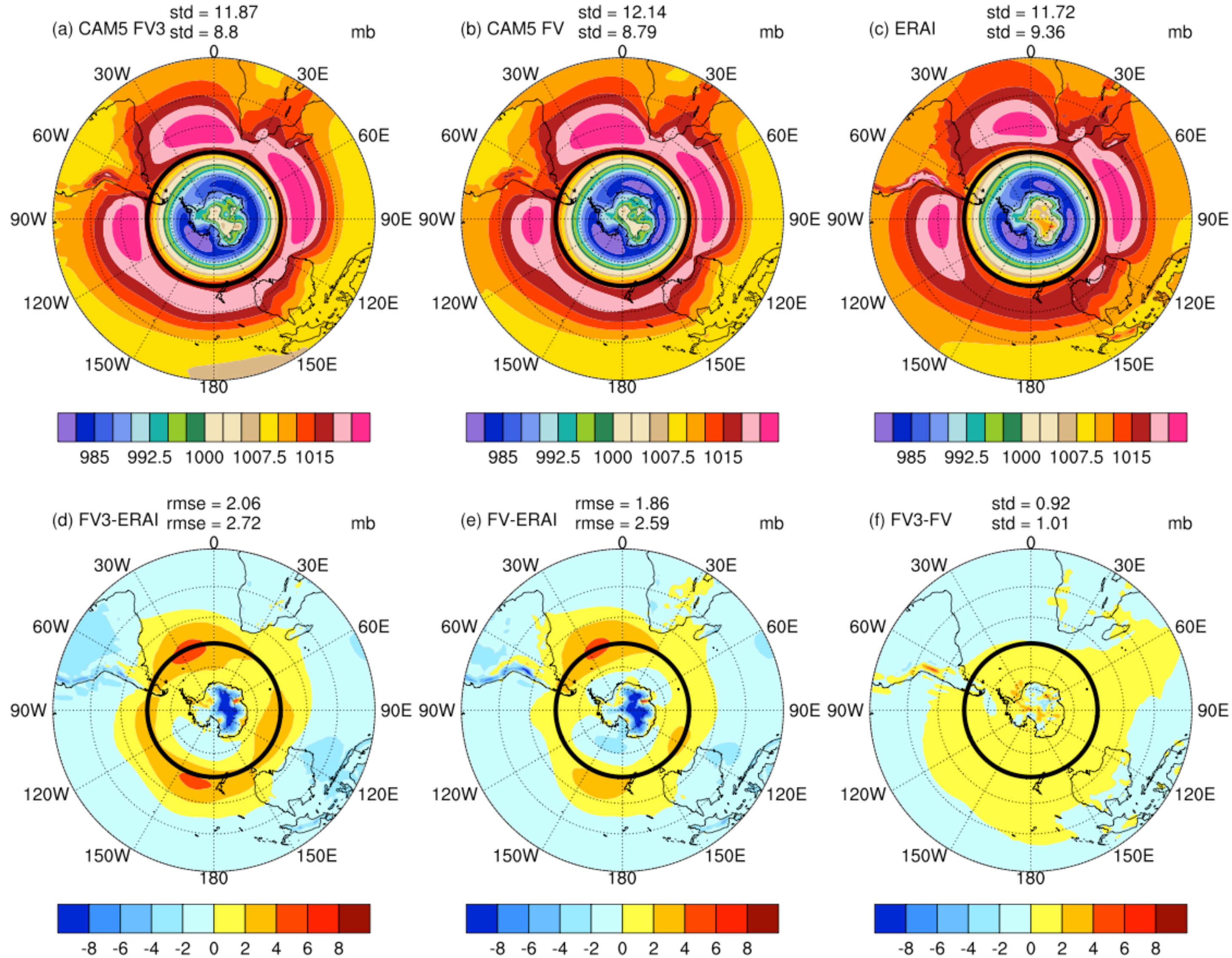
plot_06

CAM4 Sea Level Pressure (mb)



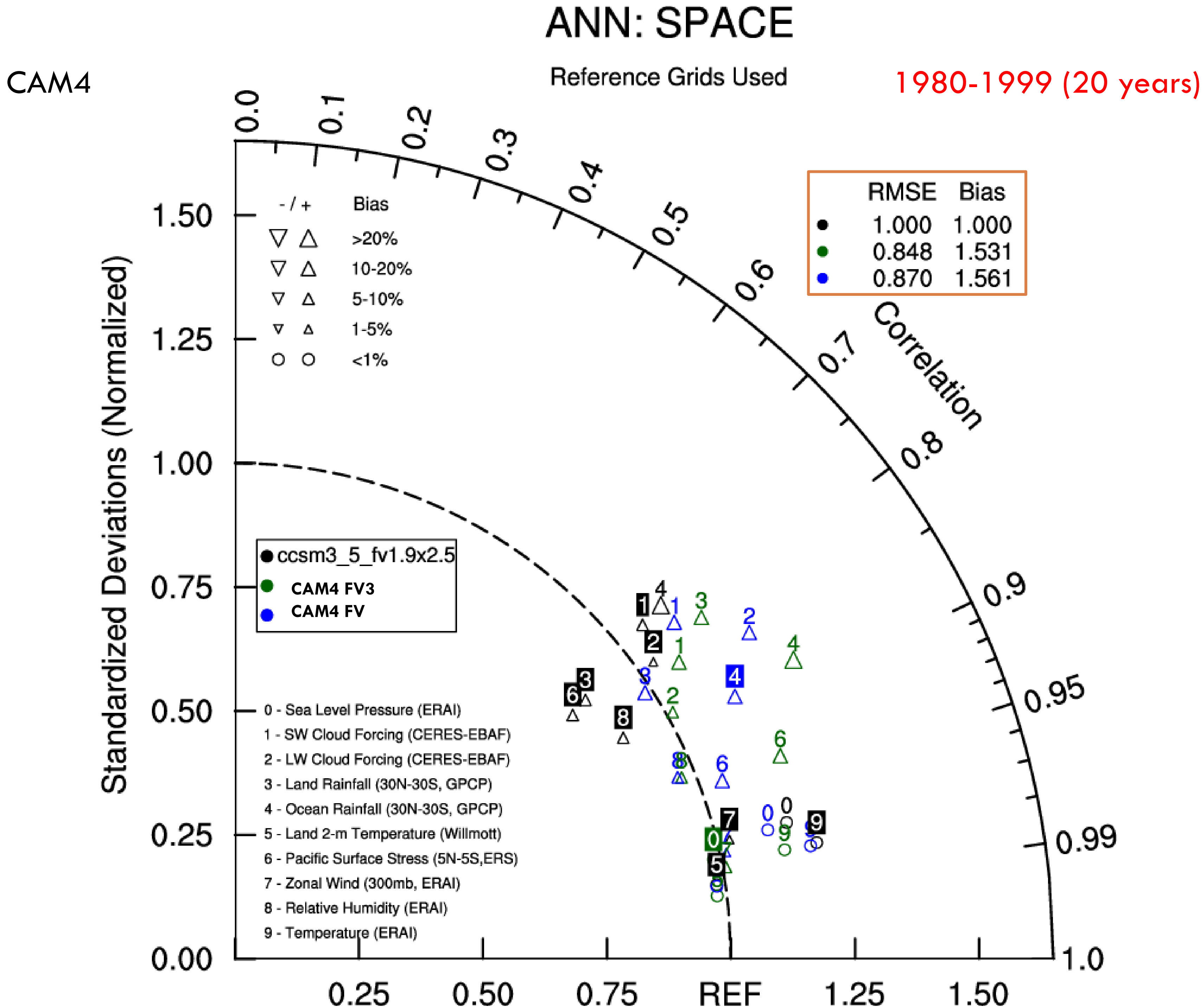
The pattern of CAM4 FV3 over the polar region is more similar to ERAI

CAM5 Sea Level Pressure (mb)

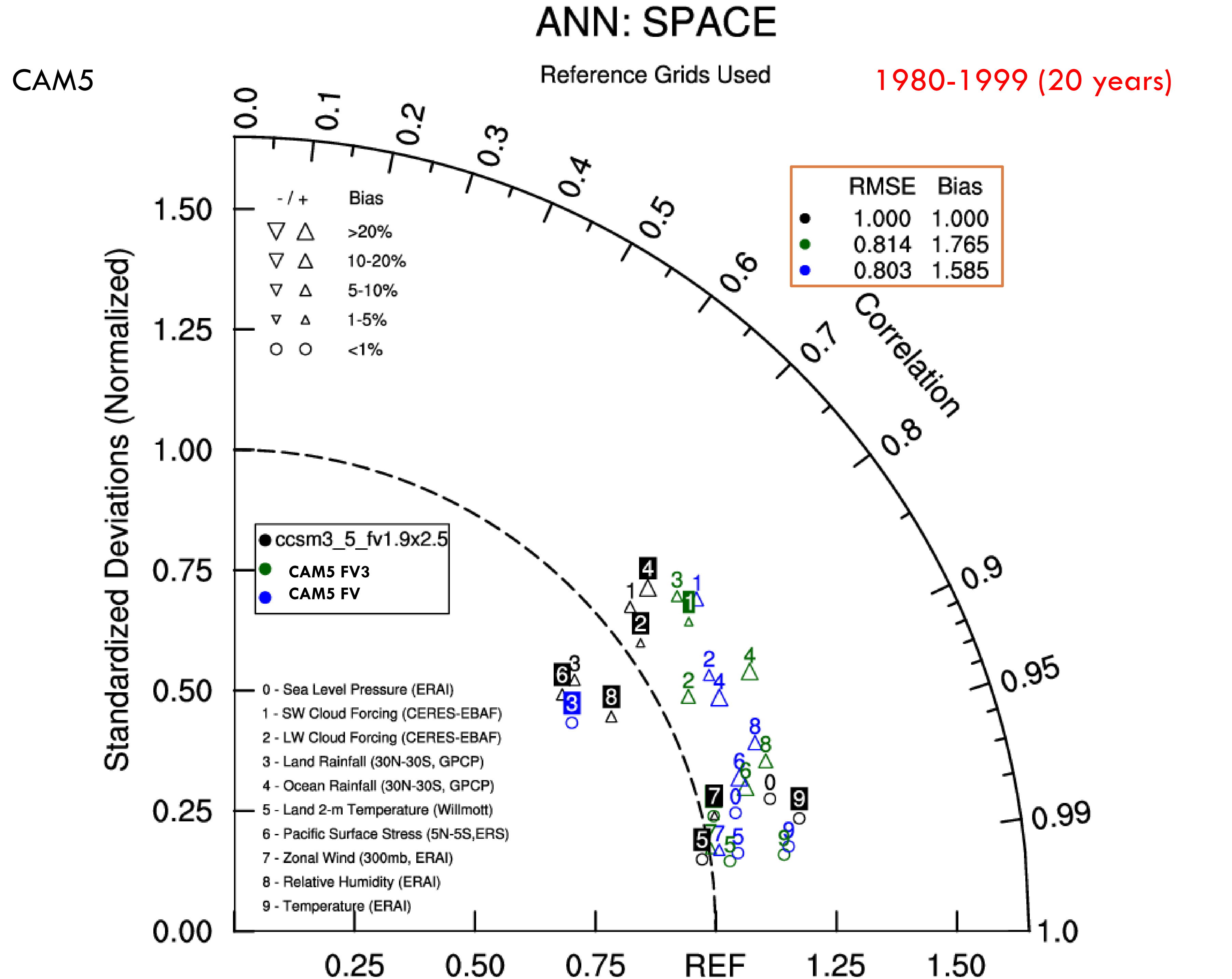


The difference between FV3 and FV is much smaller in CAM5

plot_06



ANN: SPACE
CAM4
Reference Grids Used
1980-1999 (20 years)
RMSE Bias
1.000 1.000
0.848 1.531
0.870 1.561
Correlation
Standardized Deviations (Normalized)
- / + Bias
>20%
10-20%
5-10%
1-5%
<1%
ccsm3_5_fv1.9x2.5
CAM4 FV3
CAM4 FV
0 - Sea Level Pressure (ERAI)
1 - SW Cloud Forcing (CERES-EBAF)
2 - LW Cloud Forcing (CERES-EBAF)
3 - Land Rainfall (30N-30S, GPCP)
4 - Ocean Rainfall (30N-30S, GPCP)
5 - Land 2-m Temperature (Willmott)
6 - Pacific Surface Stress (5N-5S,ERS)
7 - Zonal Wind (300mb, ERAI)
8 - Relative Humidity (ERAI)
9 - Temperature (ERAI)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
REF
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.0


ANN: SPACE
CAM5
Reference Grids Used
1980-1999 (20 years)
Standardized Deviations (Normalized)
Correlation
RMSE Bias
1.000 1.000
0.814 1.765
0.803 1.585
- / + Bias
>20%
10-20%
5-10%
1-5%
<1%
ccsm3_5_fv1.9x2.5
CAM5 FV3
CAM5 FV
0 - Sea Level Pressure (ERAI)
1 - SW Cloud Forcing (CERES-EBAF)
2 - LW Cloud Forcing (CERES-EBAF)
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7 - Zonal Wind (300mb, ERAI)
8 - Relative Humidity (ERAI)
9 - Temperature (ERAI)
REF

Conclusion and Discussion

- The computational efficiency of CAM FV3 becomes attractive as model resolution increases. Especially compared with CAM FV.

- With CAM4 physics, FV3 improves FV simulations; with CAM5 physics, FV3 has similar or slightly worse than FV. We don’t know why. Insights from you are welcome and appreciated.

On the Incident Solar Radiation in Some CMIP5 Models

Linjiong Zhou[1,2] and Minghua Zhang[1]

[1] SoMAS, Stony Brook University
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Zonal Oscillations in Some CMIP5 Models

Color Interval: 2 W/m^2

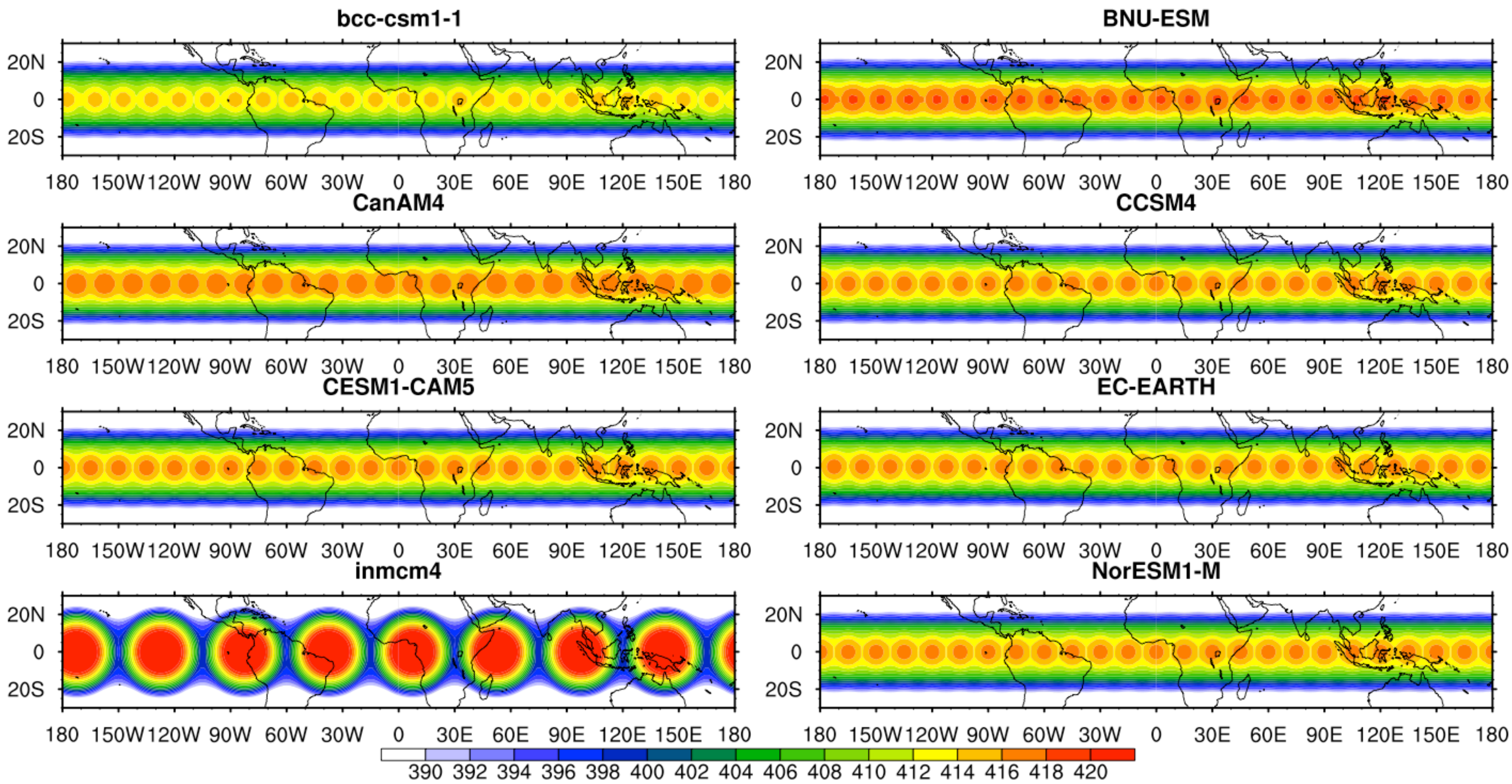

Fig. 1. Annual-mean incident solar radiation at the top of atmosphere from 8 climate models in CMIP5. Units: W/m^2.

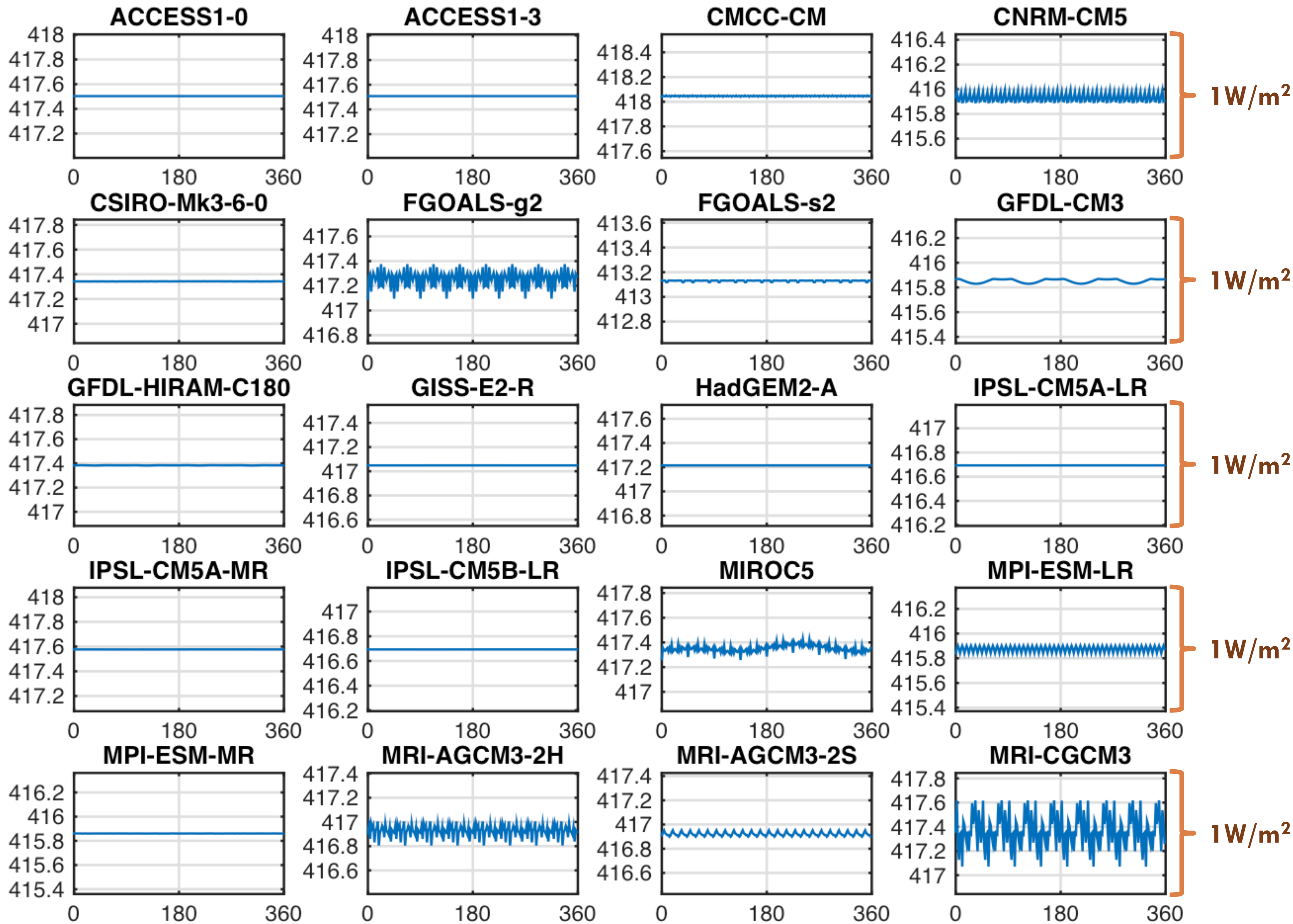

Fig. S1. Annual-mean incident shortwave radiation at the top of atmosphere along the Equator from the general circulation models in CMIP5. Units: W/m^2.

Calculation of Solar Zenith Angle

Original Algorithm

The formula is

$$\cos z_n = \sin\delta \sin\phi + \cos\delta \cos\phi \cos H(t_n), \quad (1)$$

where z is solar zenith angle, ϕ is the latitude, δ is the declination of the Sun, $H \in [-\pi, \pi)$ hour angle of the sun.

In the CESM, the solar zenith angle at each location is calculated at instantaneous time t_n and its value persists until the next radiation time step.

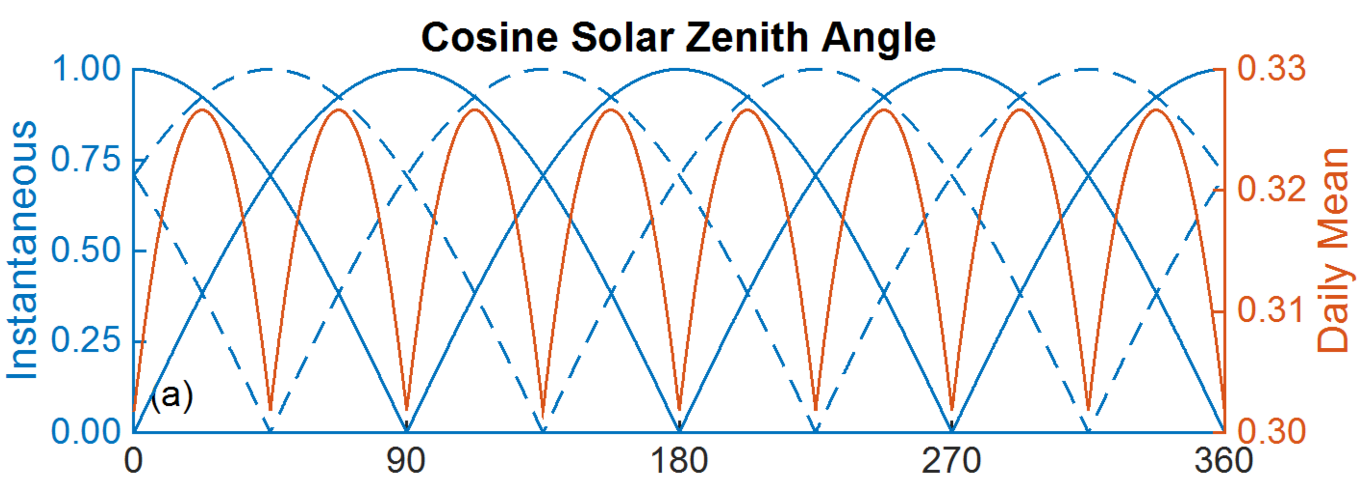

Fig. 2a. Equatorial instantaneous (blue solid and dashed lines) and daily-mean (red line) cosine solar zenith angle for 3-hour radiation time step based on original algorithm.

Calculation of Solar Zenith Angle

Original Algorithm

The formula is

$$\cos z_n = \sin\delta \sin\phi + \cos\delta \cos\phi \cos H(t_n), \qquad (1)$$

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In the CESM, the solar zenith angle at each location is calculated at instantaneous time t_n and its value persists until the next radiation time step.

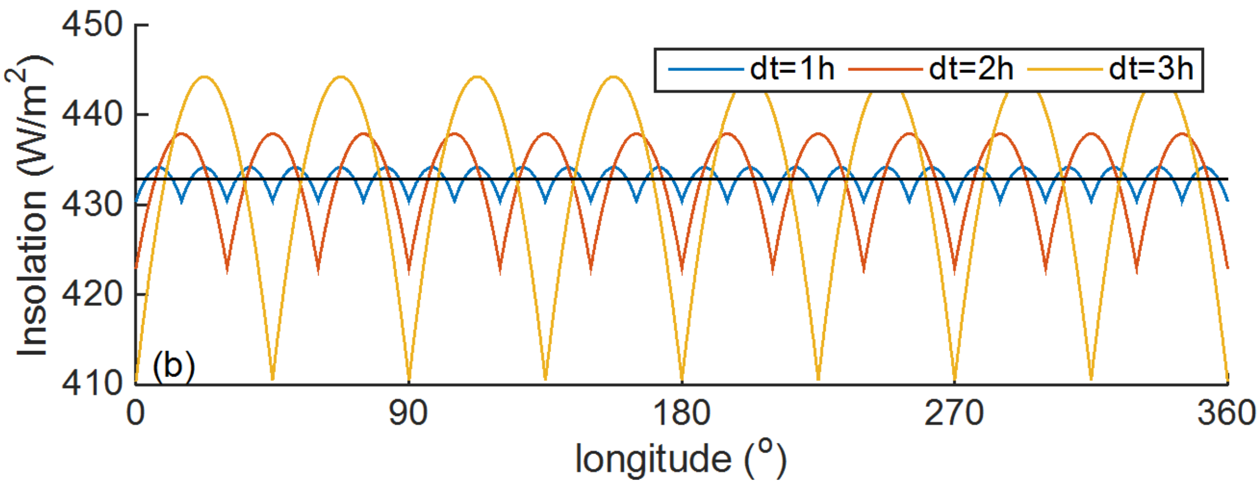

Fig. 2b. Insolation for 1-hour, 2-hour and 3-hour radiation time step based on the original algorithm (blue, green, red lines).

Calculation of Solar Zenith Angle

Revised Algorithm

The formula is

$$\overline{\cos z_n} = \frac{1}{\Delta t}\int_{t_n}^{t_n+\Delta t}\cos z(t)\,dt = \frac{H_+^* - H_-^*}{H_+ - H_-}\sin\delta\sin\phi + \frac{\sin H_+^* - \sin H_-^*}{H_+ - H_-}\cos\delta\cos\phi \qquad (2)$$

where $H_- \in [-\pi,\pi)$ and $H_+ \in [-\pi,\pi)$ are hour angles at t_n and $t_n+\Delta t$ at each location, and $H_-^* = \max[-h,\min(H_-,h)]$, $H_+^* = \max[-h,\min(H_+,h)]$. h is the hour angle at sunset.

Similar time-averaged algorithms have been used in other models (*Russell et al.*, 1995).

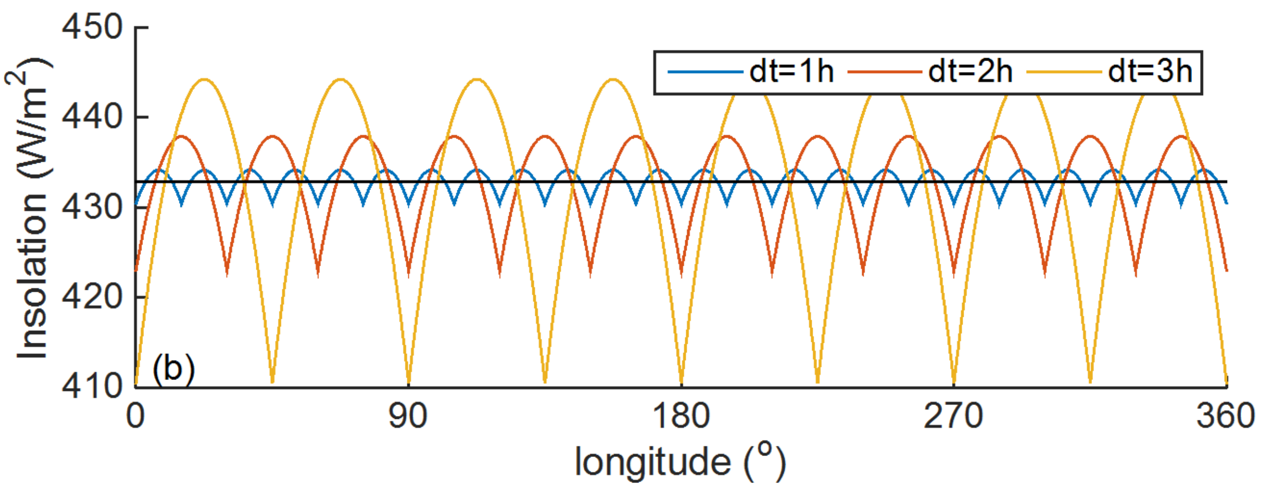

Fig. 2b. Insolation for 1-hour, 2-hour and 3-hour radiation time step based on the revised algorithm (black lines).

Experiments

CESM1.2.2

Experiment Name	Algorithm	Radiation Time Step	Integration
exp1	Original Algorithm	3 hours	AMIP 4 years
exp2	Original Algorithm	1hour	AMIP 4 years
exp3	Revised Algorithm	3 hours	AMIP 4 years
exp4	Revised Algorithm	1 hour	AMIP 4 years

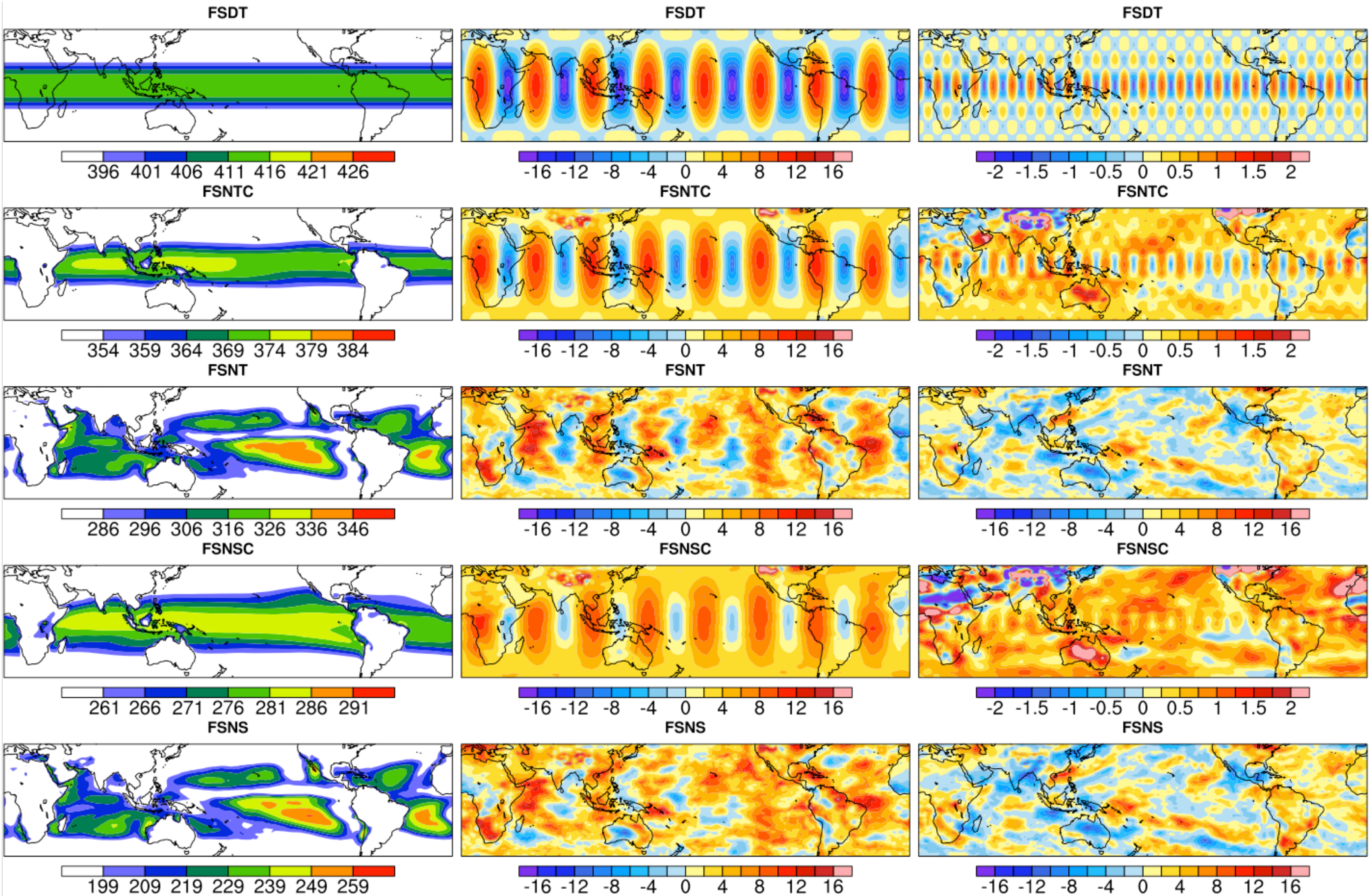

Fig. 3. Annual-mean FSDT, FSNTC, FSNT, FSNSC, FSNS for (left column) 1-hour radiation time step based on the revised algorithm, (middle column) the original algorithm minus the revised algorithm for 3-hour radiation time step, (right column) the original algorithm minus the revised algorithm for 1-hour radiation time step. Units: W/m^2.

Conclusion and Discussion

- Annual-mean insolation at TOA in many CMIP5 models display spurious zonal oscillations with amplitude up to $30W/m^2$.

- We implemented a revised algorithm in the CESM that corrects the bias from both spatial and temporal sampling errors in the original algorithm.

- The regionally biased algorithm can cause up to $24W/m^2$ and $3W/m^2$ difference of net surface clear-sky shortwave radiation at the Equator when 3-hourly and hourly radiation time steps are used respectively.

- Should be corrected in the next version of CAM and CESM.

(GRL. Zhou, Zhang et al., in revision)

THANK YOU!

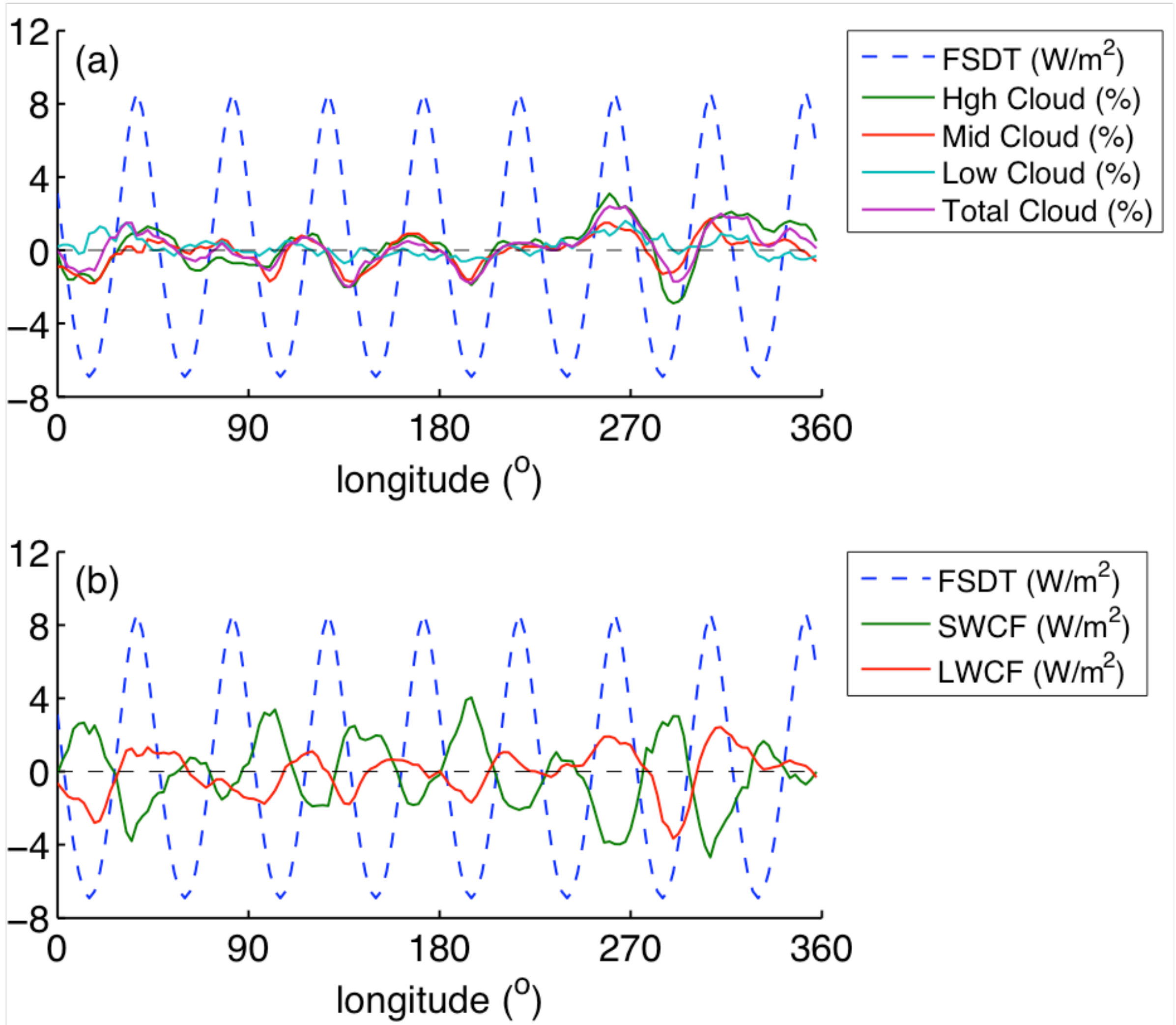

Fig. 4. Difference of annual-mean downward shortwave radiation at TOA averaged between 40°S to 40°N (FSDT, dashed blue line), and the corresponding (a) differences in the amount of high, middle, low and total clouds; (b) differences in TOA shortwave and longwave cloud radiative forcing (SWCF and LWCF) using 3-hour radiation time step.