Decomposition of TOA shortwave flux variability into atmospheric and surface contributions: an evaluation of reanalyses and GCM simulations using CERES observations

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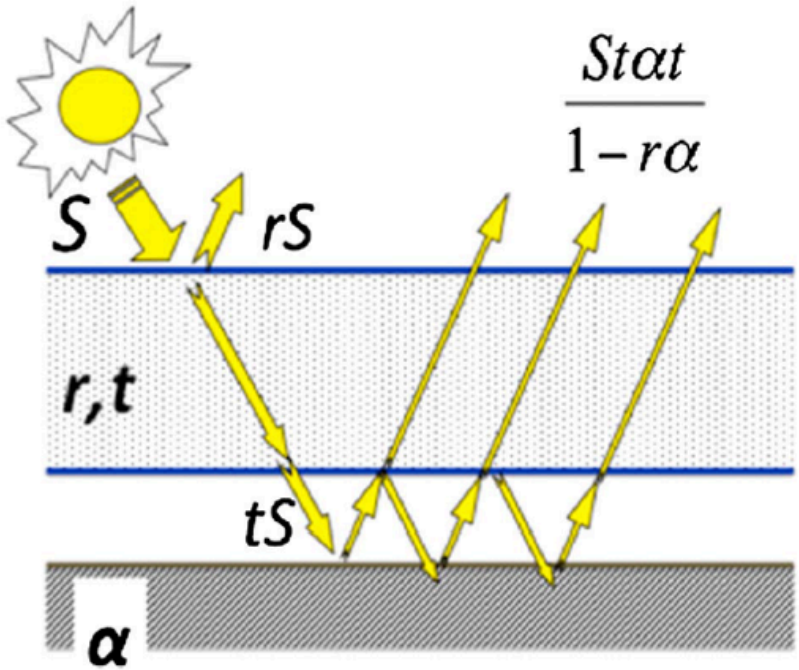
Diagnostic Framework for Atmosphere-Only and Atmosphere-Surface Contributions to SW TOA Flux



- Single scattering and absorbing layer of atmosphere over a reflecting surface of albedo α.
- The total reflected flux of the system is given by the sum of the reflected energy from the layer plus the multiple scattering between the surface and atmosphere:

$$F_T^{\uparrow} = rS + T\left(\frac{1-\alpha R}{1-\alpha^2 T^2}\right)F_S^{\uparrow}$$

$$r = R - t\alpha T$$

$$t = T\frac{1-\alpha R}{1-\alpha^2 T^2}$$

Stephens et al., Rev. Geophys. 2015

Surface-Only and Atmospheric-Only Contributions to SW TOA Flux and Net Surface Downward SW Flux Variability

- Deseasonalized anomaly in SW TOA flux:

$$\delta F_T^{\uparrow} = \left(\frac{\overline{F_S^{\downarrow}}\bar{t}}{1-\bar{\alpha}\bar{r}}\right)\delta\alpha + \left(\bar{S} + \frac{\bar{\alpha}\overline{F_S^{\uparrow}}\bar{t}}{1-\bar{\alpha}\bar{r}}\right)\delta r + \left(\overline{F_S^{\uparrow}} + \frac{\bar{\alpha}\bar{S}\bar{t}}{1-\bar{\alpha}\bar{r}}\right)\delta t + \left(\bar{r} + \frac{\bar{\alpha}\bar{t}^2}{1-\bar{\alpha}\bar{r}}\right)\delta S$$

Surface Atmosphere Solar

- Deseasonalized anomaly in net surface downward SW flux:

$$\delta(F_S^{\downarrow} - F_S^{\uparrow}) = \left[\left(\frac{\bar{r}-1}{1-\bar{\alpha}\bar{r}}\right)\overline{F_S^{\downarrow}}\right]\delta\alpha + \left[\left(\frac{1-\bar{\alpha}}{1-\bar{\alpha}\bar{r}}\right)\overline{F_S^{\uparrow}}\right]\delta r + \left[\left(\frac{1-\bar{\alpha}}{1-\bar{\alpha}\bar{r}}\right)\bar{S}\right]\delta t + \left[\left(\frac{1-\bar{\alpha}}{1-\bar{\alpha}\bar{r}}\right)\bar{t}\right]\delta S$$

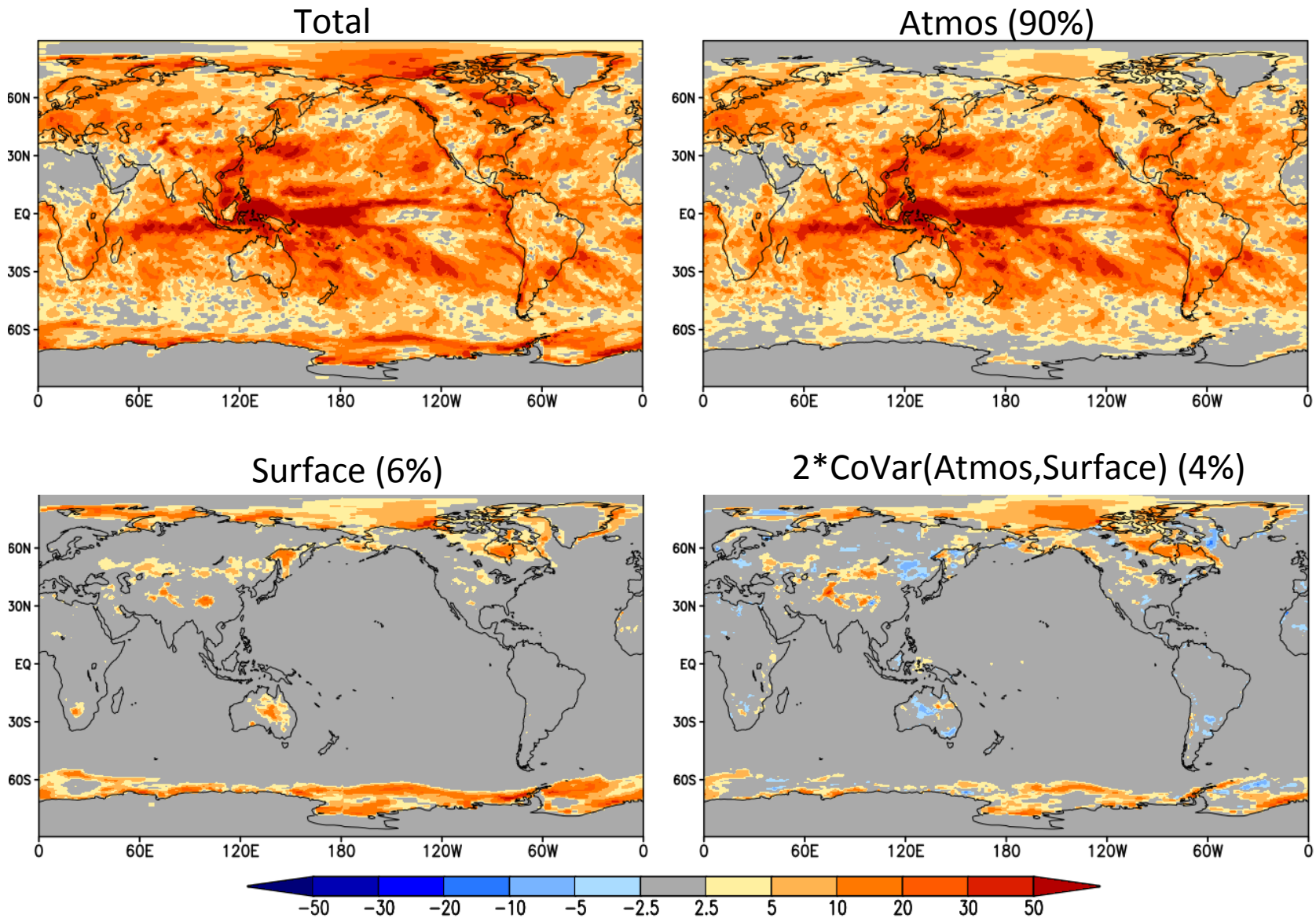
Surface Atmosphere Solar

TOA SW decomposition using CERES observations

- CERES EBAF Ed4.0
  - TOA: $SW_{incoming}$, SW_{up}
  - Surface: SW_{up}, SW_{down}

- Monthly over 01/2001-12/2008

Variance in All-Sky SW TOA Flux Annual Anomaly (2001 – 2008)



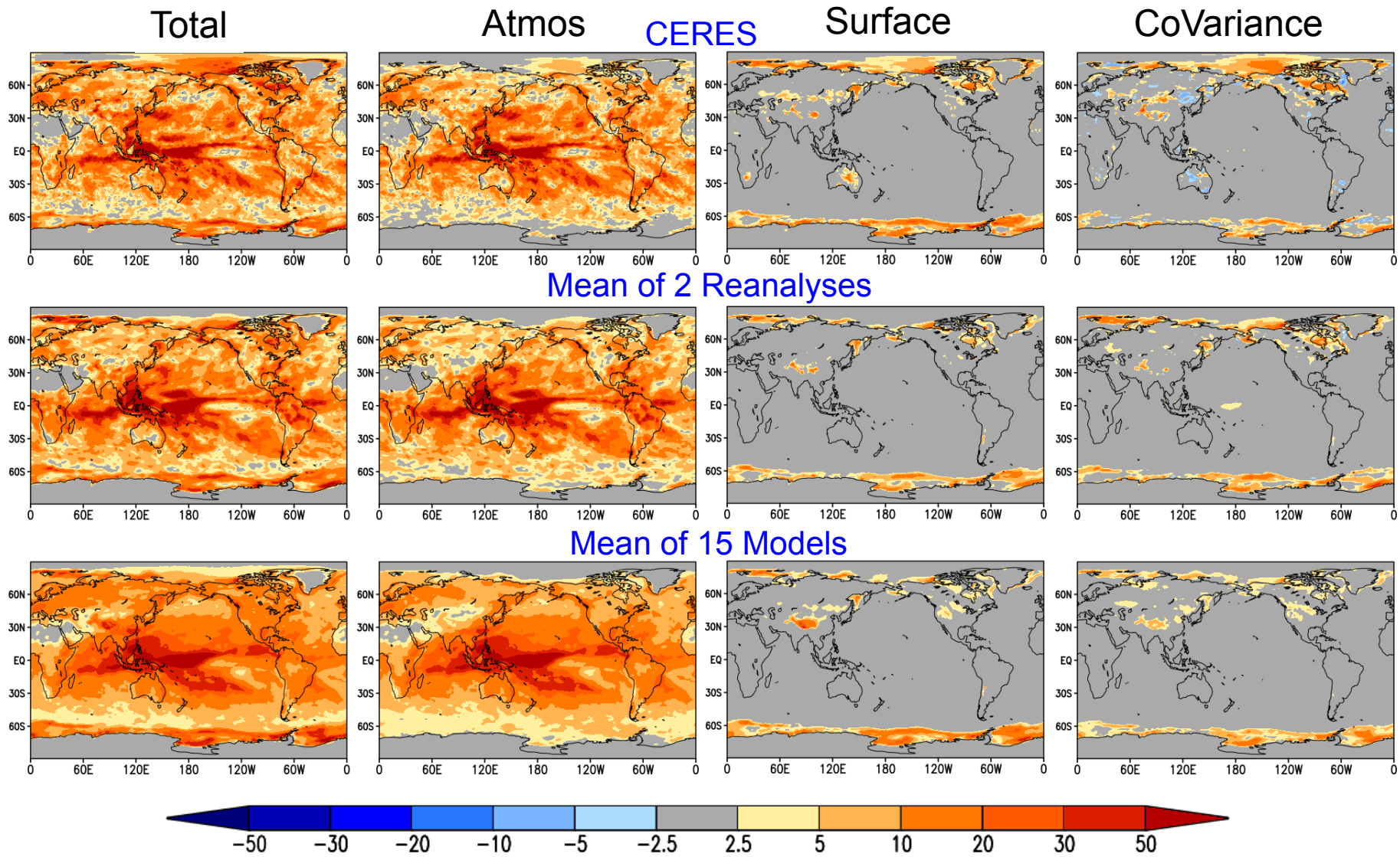
Reanalyses and Model Simulations

- Reanalyses:
  - ERA-Interim; MERRA-2
- Model simulations
  - AMIP simulations produced by 20 AGCMs
    - 19 CMIP5 AGCMs, NASA GEOS-5 AGCM
- Variables
  - <u>TOA</u>: $SW_{incoming}$, SW_{up}
  - <u>Surface</u>: SW_{up}, Sw_{down}
  - <u>Other</u>: LW at TOA and surface, LHFX, SHFX
- Monthly over 01/2001-12/2008

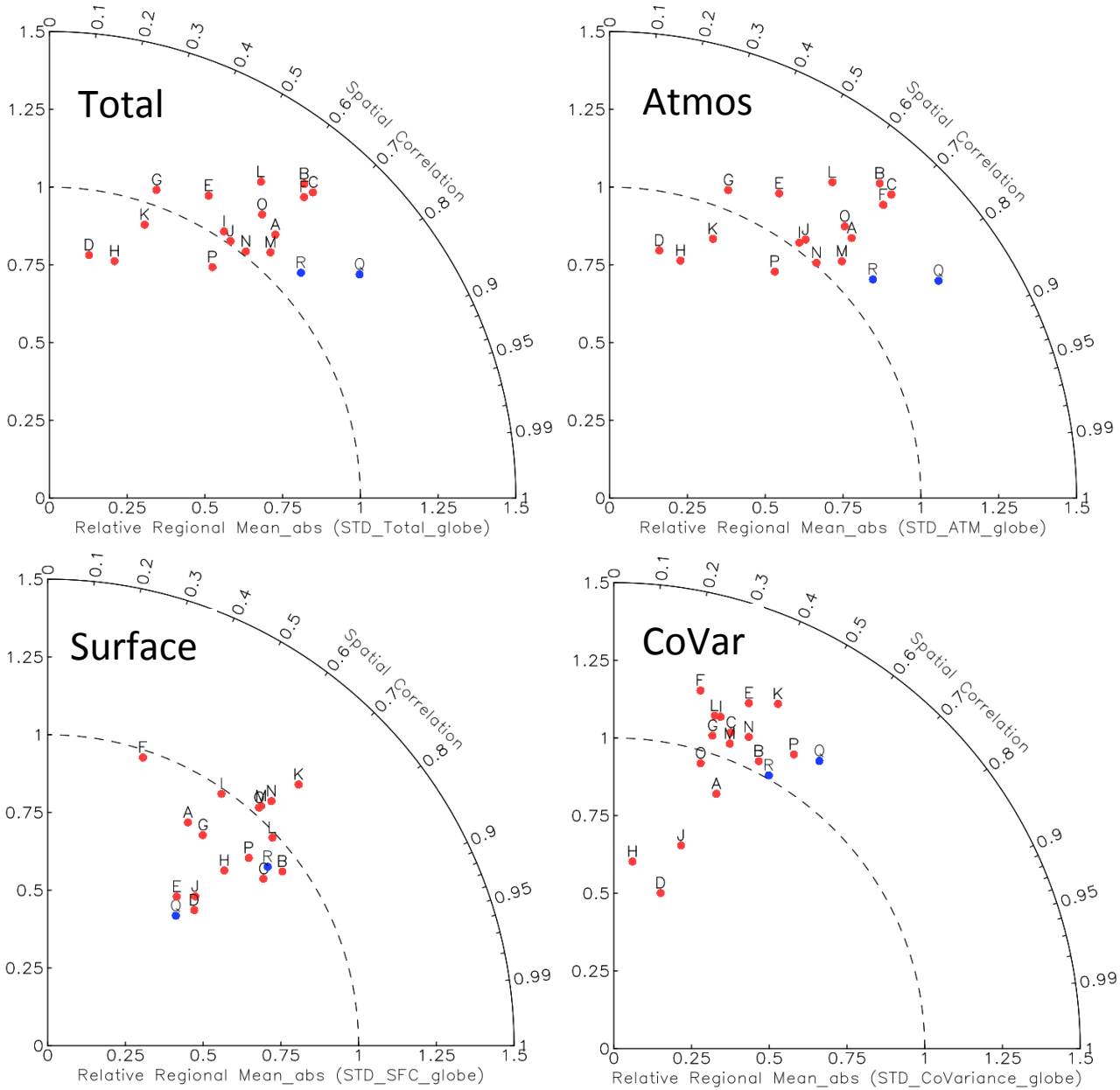
AGCMs

	Model	Country	Resolution	TOA-SFC Imbalance
	ACCESS1-3	Australia	1.875*1.25	1.16
A	CanAM4	Canada	2.8*2.8	0.16
B	CCSM4	USA	1.25*0.94	0.69
C	CMCC-CM	Italy	0.75*0.75	0.59
	CNRM-CM5	France	1.4*1.4	-2.89
D	CSIRO-Mk3-6-0	Australia	1.875*1.86	-0.20
E	GEOS-5*	USA	1.25*1.0	-0.39
F	GFDL-CM3	USA	2.5*2.0	0.79
G	GFDL-HIRAM-C180	USA	0.625*0.5	0.93
	GFDL-HIRAM-C360	USA	0.3125*0.25	1.06
H	GISS-E2-R	USA	2.5*2.0	0.81
I	HadGEM2-A	UK	1.875*1.25	0.94
J	IPSL-CM5A-LR	France	3.75*1.9	0.09
K	MIROC5	Japan	1.4*1.4	0.25
L	MPI-ESM-LR	Germany	1.875*1.86	0.31
M	MRI-AGCM3-2H	Japan	0.56*0.56	-0.14
N	MRI-AGCM3-2S	Japan	0.19*0.19	-0.30
O	MRI-CGCM3	Japan	1.125*1.12	0.51
	NorESM1-M	Norway	2.5*1.9	-1.29
	inmcm4	Russia	2.0*1.5	-3.45

Variance in All-Sky SW TOA Flux Annual Anomaly (2001 – 2008)



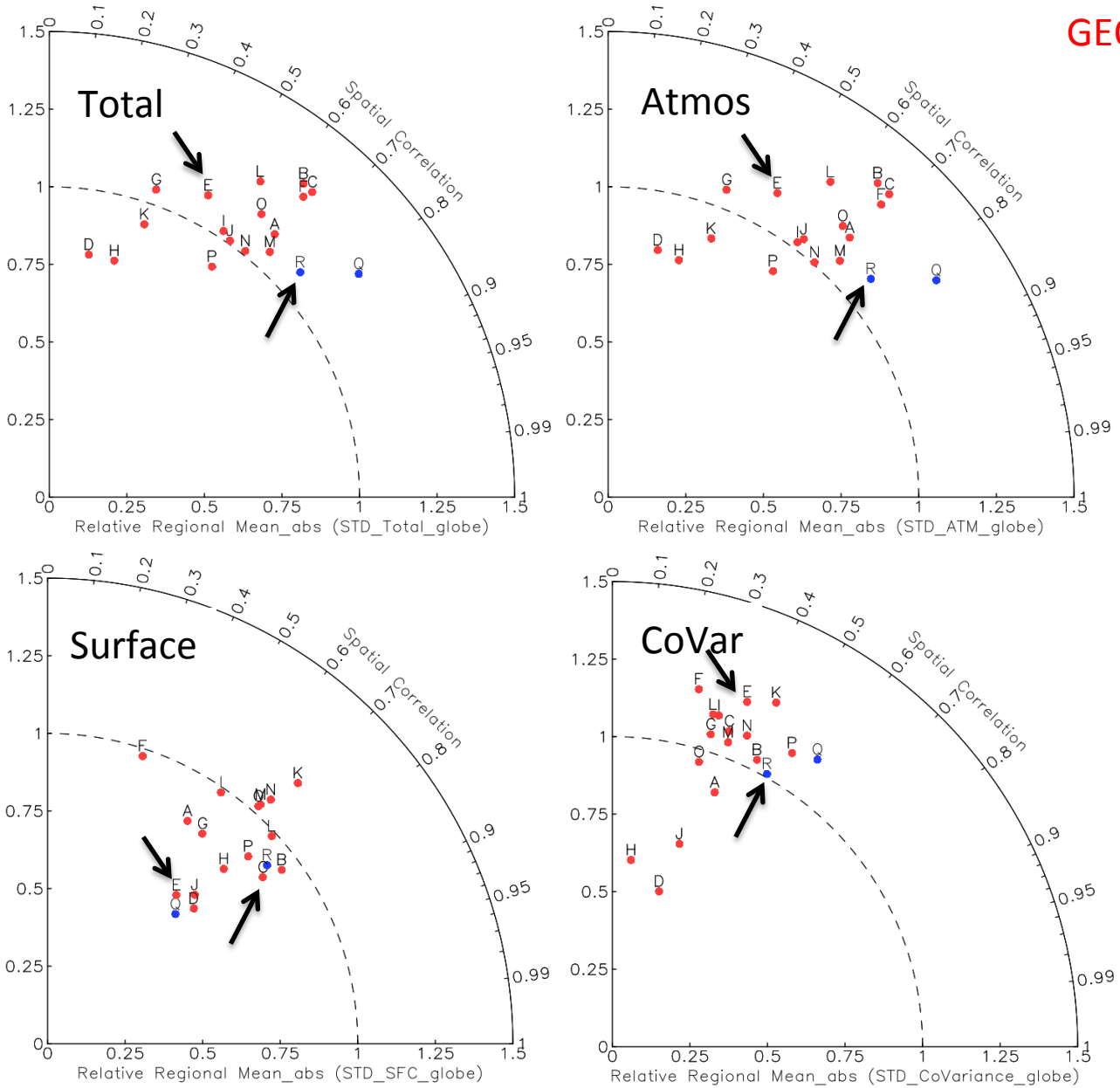
Variance in All-Sky SW TOA Flux Annual Anomaly (2001 – 2008)



A: CanAM4
B: CCSM4
C: CMCC–CM
D: CSIRO–Mk3–6–0
E: GEOS5m2
F: GFDL–CM3
G: GFDL–HIRAM–C180
H: GISS–E2–R
I: HadGEM2–A
J: IPSL–CM5A–LR
K: MIROC5
L: MPI–ESM–LR
M: MRI–AGCM3–2H
N: MRI–AGCM3–2S
O: MRI–CGCM3
P: 15ModelMean
Q: ERA–I
R: MERRA–2

Variance in All-Sky SW TOA Flux Annual Anomaly (2001 – 2008)

GEOS-5 AGCM vs. MERRA-2



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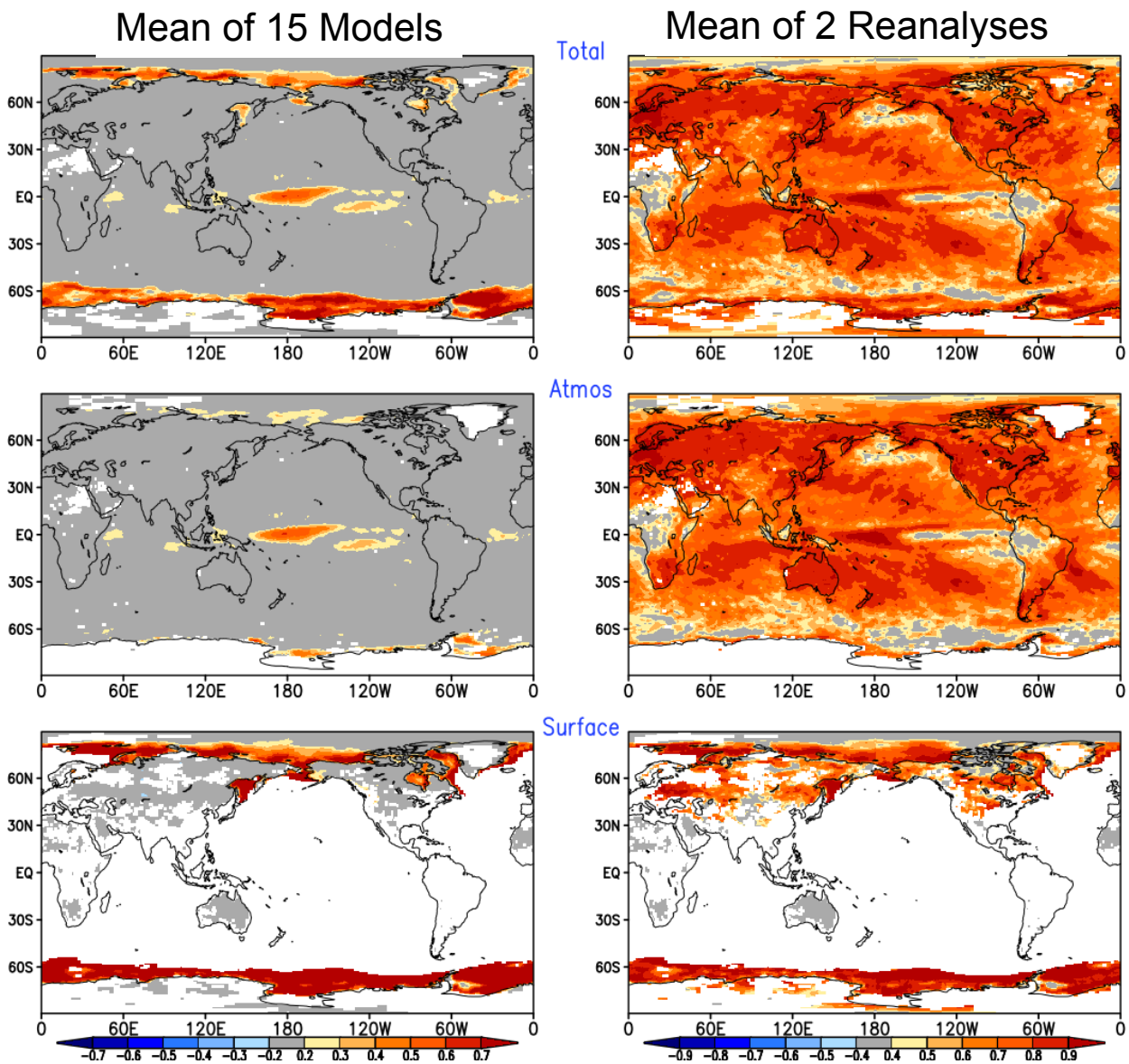
Temporal Correlation with CERES EBAF4 over 01/2001-12/2008



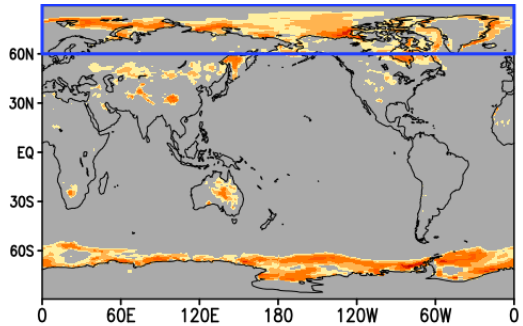
Total

Atmos

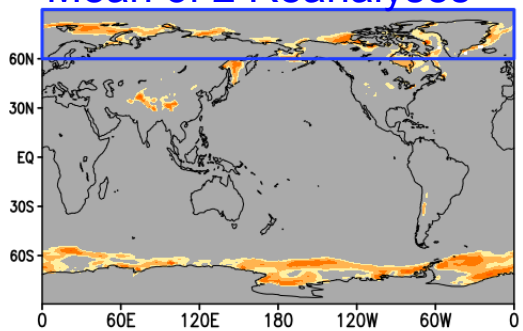
Surface

Surface Contribution

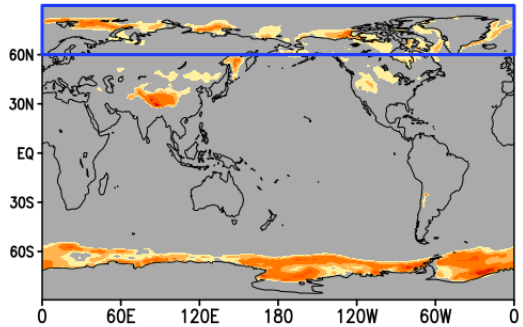
CERES

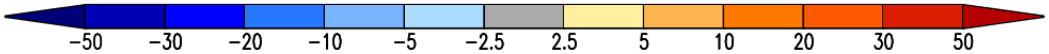


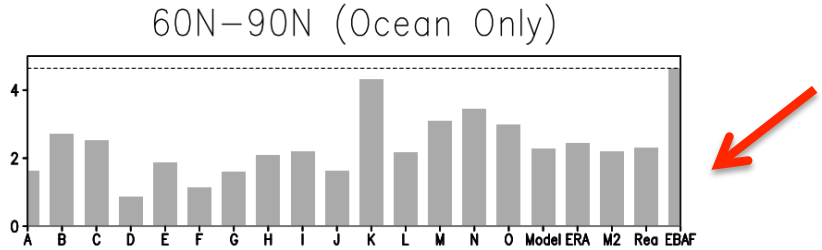
Mean of 2 Reanalyses

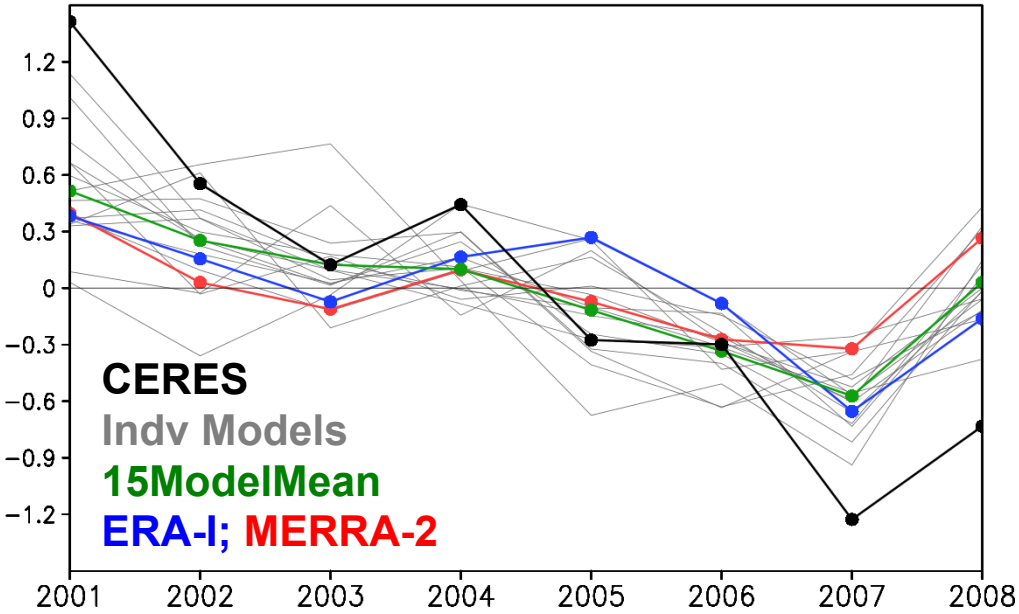


Mean of 15 Models

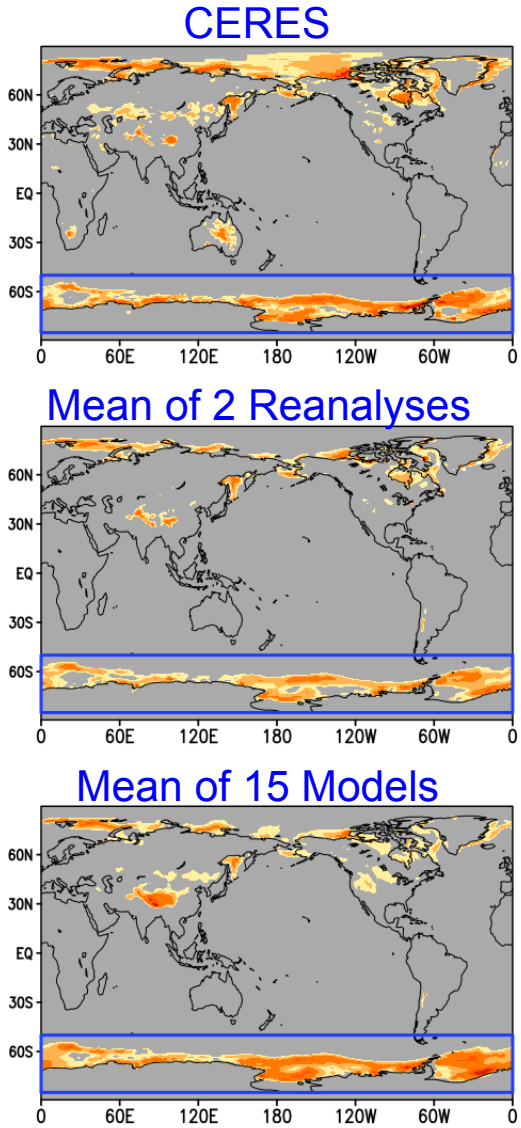


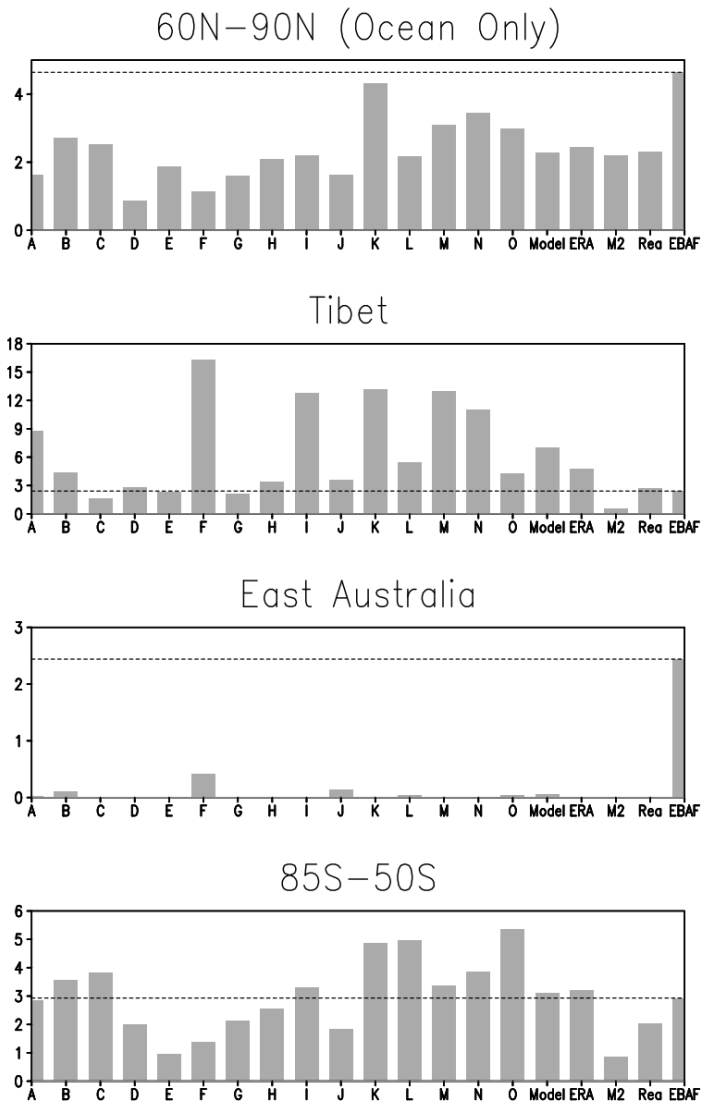






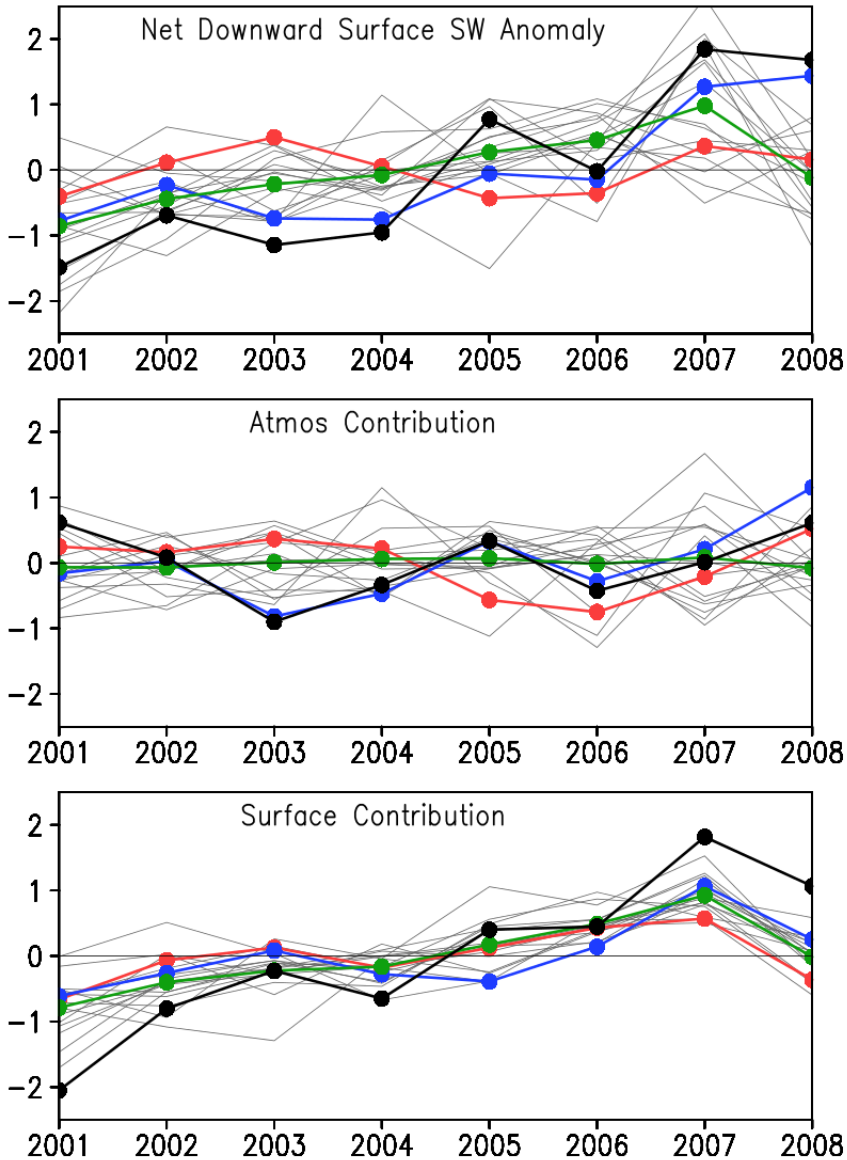
Surface Contribution





Summary

- A diagnostic tool is developed to determine surface and atmospheric contributions to SW TOA flux and net surface downward SW flux variability.
- Both reanalyses and AMIP simulations broadly agree with CERES observations in that atmospheric (surface) contribution dominates over non-polar (polar) regions.
- Most CMIP5 models tend to overestimate atmospheric contribution while underestimate surface contribution.
- The assimilation of observations substantially improves the spatial correspondence of SW flux variations with observations, but does not improve aspects that are fundamentally limited by issues in the assimilating models (e.g. lack of dynamic vegetation).

Extra Slides

Net Downward Surface SW Flux Anomaly (60N-90N; Ocean Only)