

Sensitivity of CERES Angular Distribution Models to ENSO Phase



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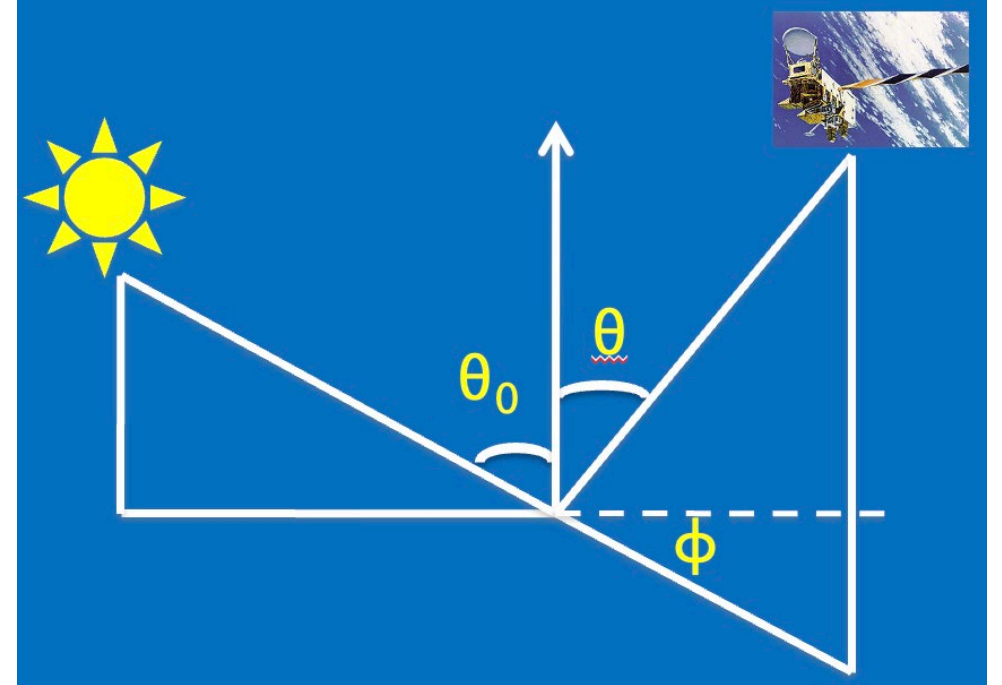
Introduction

- CERES instruments onboard Terra and Aqua measure broadband radiances.
- Scene-dependent Angular Distribution Models (ADMs) are used to convert CERES radiances to irradiances.
- ADMs account for the angular dependence in the observed radiance field, which is a strong function of the physical and optical characteristics of the scene (e.g., surface type, cloud fraction, cloud/aerosol optical depth, cloud phase, etc...) and solar zenith angle.
- CERES ADMs are developed from rotating azimuth plane (RAP) and cross-track scan data from Terra and Aqua satellites for the static period between 2000-2005. The ADMs from this static period are used to produce the fluxes given for the whole CERES period (2000 – present).
- Are ADMs developed from a static period appropriate to calculate fluxes for other periods in the presence of climate variability and change?

Methodology

- For every scene type, bin observed radiances over all relative azimuth (φ), viewing (θ) and solar zenith angles (θ_0) and calculate the mean radiance ($\hat{I}$) for all bins.
- Ratio of isotropic flux to the integrated radiance over the angular space gives the anisotropic factor (R):

$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \hat{I}(\theta_0, \theta, \phi) \cos\theta \sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}$$

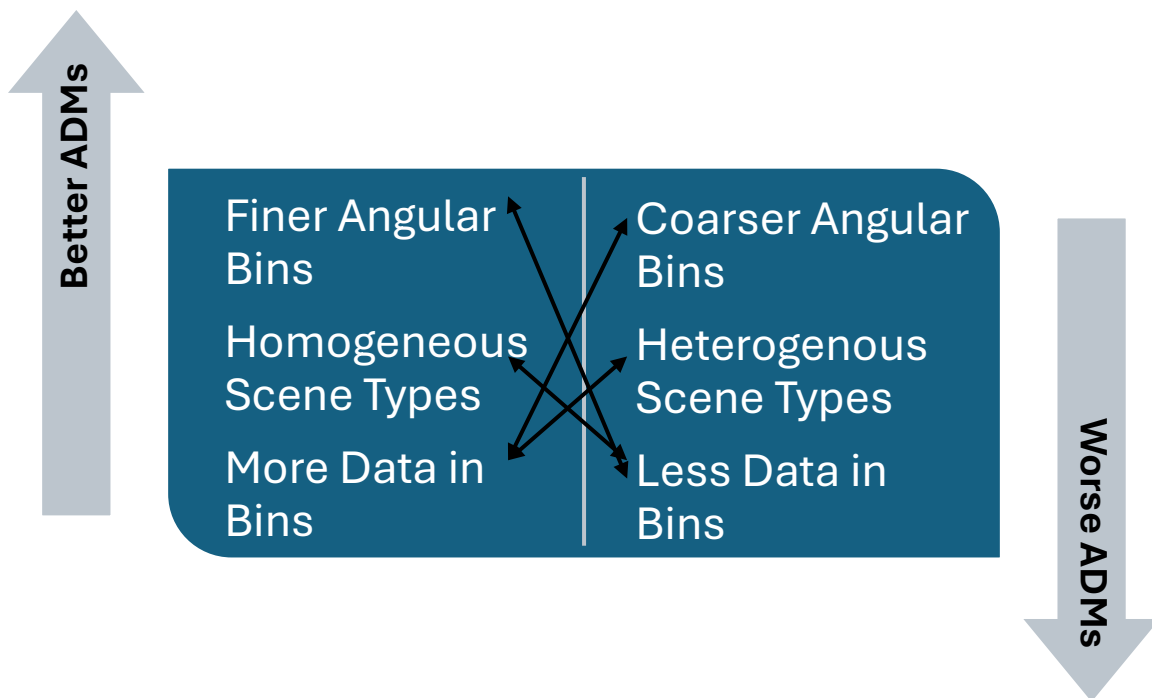


- For each radiance measurement, first determine the scene type, then apply scene type dependent anisotropic factor (i.e., the ADM) to observed radiance to derive TOA flux:

$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

ENSO Climate Variability

- Leverage ENSO variability during the ADM development period (2000-2005) to investigate ADM sensitivity to climate variability.
- Develop two sets of ADMs: La Niña ADMs and El Niño ADMs.



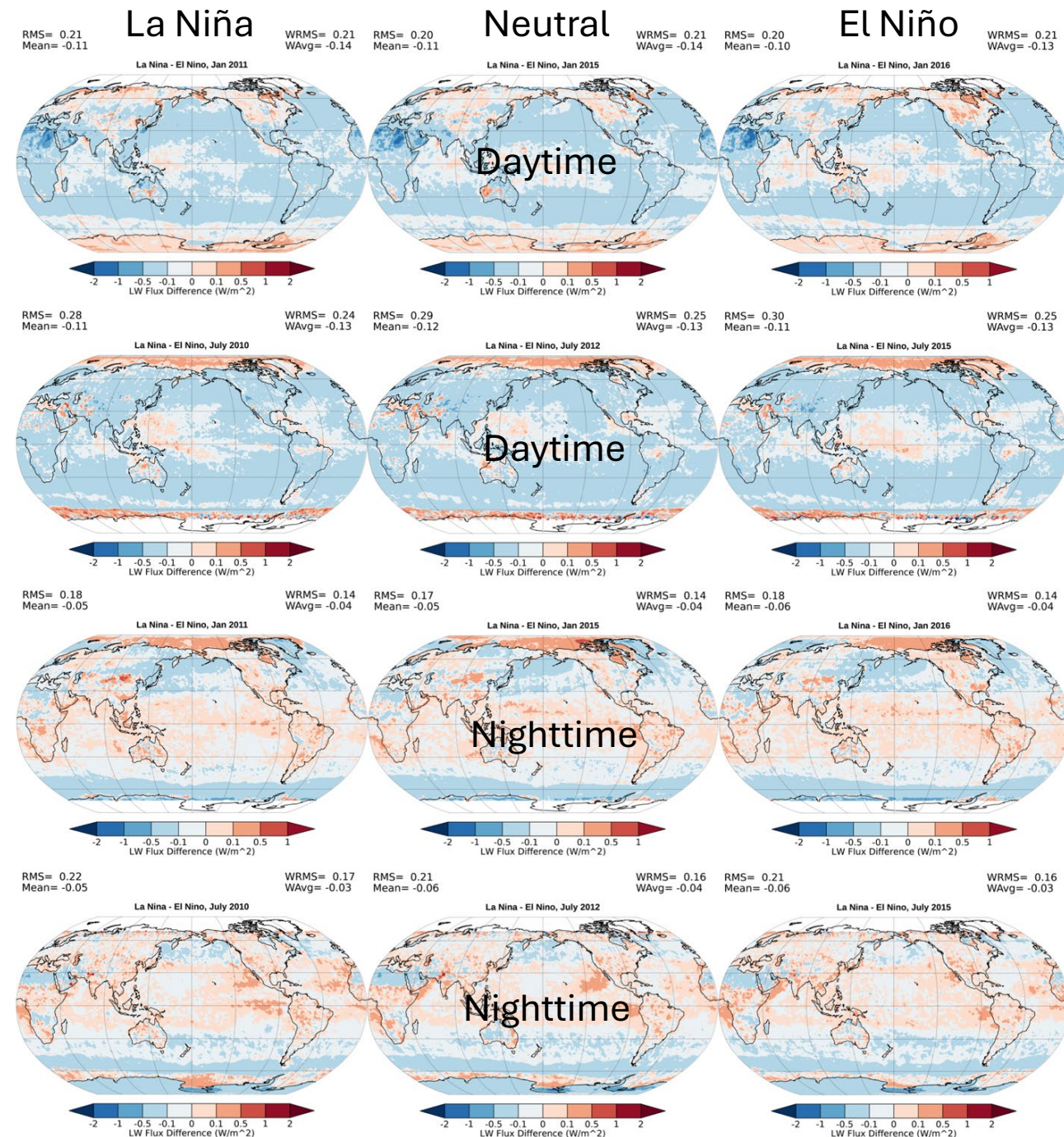
Multivariate ENSO Index :

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000				-0.9	-0.9	-1.2	-0.6*	-0.1	-0.3	-0.5*	-0.9*	-0.8*
2001	-0.8*	-0.9*	-0.8*	-0.6	-0.5	-0.7	0	0.4	-0.1	-0.2	-0.3	0.1
2002	0.1	-0.3	-0.2	-0.4	-0.1	0.3	0.4	1	0.9	0.8*	0.8*	0.9*
2003	0.8*	0.6*	0.5*	-0.1	-0.6	-0.1	0	0.1	0.2	0.3	0.3	
2004	0.2	0		-0.2	-0.5	-0.4	0.5*	0.8	0.6	0.4	0.6	0.5
2005	0.1			0.1	0.2							

- CERES Edition 4 methodology is used for LW and snow/ice SW ADMs, while the simpler CERES TRMM methodology is adopted for ocean and land SW ADMs.

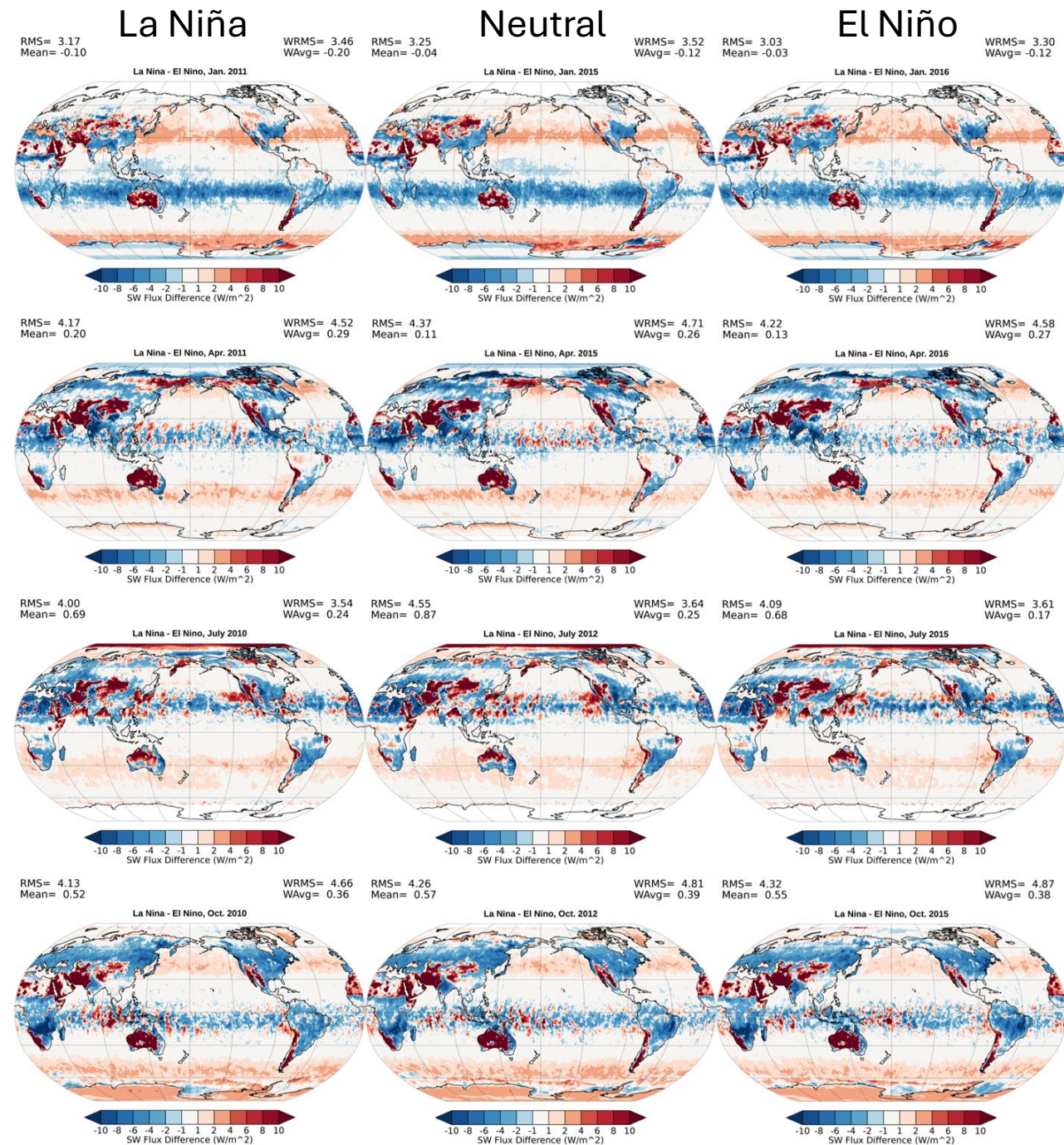
Longwave Flux Differences

- Difference between LW fluxes computed from La Niña ADMs and El Niño ADMs is small for both daytime (0.21-0.25 $\text{W}\cdot\text{m}^{-2}$) and nighttime (0.14-0.17 $\text{W}\cdot\text{m}^{-2}$).
- Differences display similar spatial patterns despite undergoing distinct phases of ENSO.



Shortwave Flux Differences

- Differences between SW fluxes computed from La Niña ADMs and El Niño ADMs are large for all seasons ($3.30\text{-}4.87\text{ W}\cdot\text{m}^{-2}$).
- Differences display similar spatial patterns despite undergoing distinct phases of ENSO.



Impacts of Seasonality on ADM Development

- Data used for the development of La Niña and El Niño ADMs is seasonally asymmetric.
- Does the seasonal asymmetry influence the flux differences between the two sets of ENSO ADMs?

Multivariate ENSO Index :

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000				-0.9	-0.9	-1.2	-0.6*	-0.1	-0.3	-0.5*	-0.9*	-0.8*
2001	-0.8*	-0.9*	-0.8*	-0.6	-0.5	-0.7	0	0.4	-0.1	-0.2	-0.3	0.1
2002	0.1	-0.3	-0.2	-0.4	-0.1	0.3	0.4	1	0.9	0.8*	0.8*	0.9*
2003	0.8*	0.6*	0.5*	-0.1	-0.6	-0.1	0	0.1	0.2	0.3	0.3	
2004	0.2	0		-0.2	-0.5	-0.4	0.5*	0.8	0.6	0.4	0.6	0.5
2005	0.1			0.1	0.2							

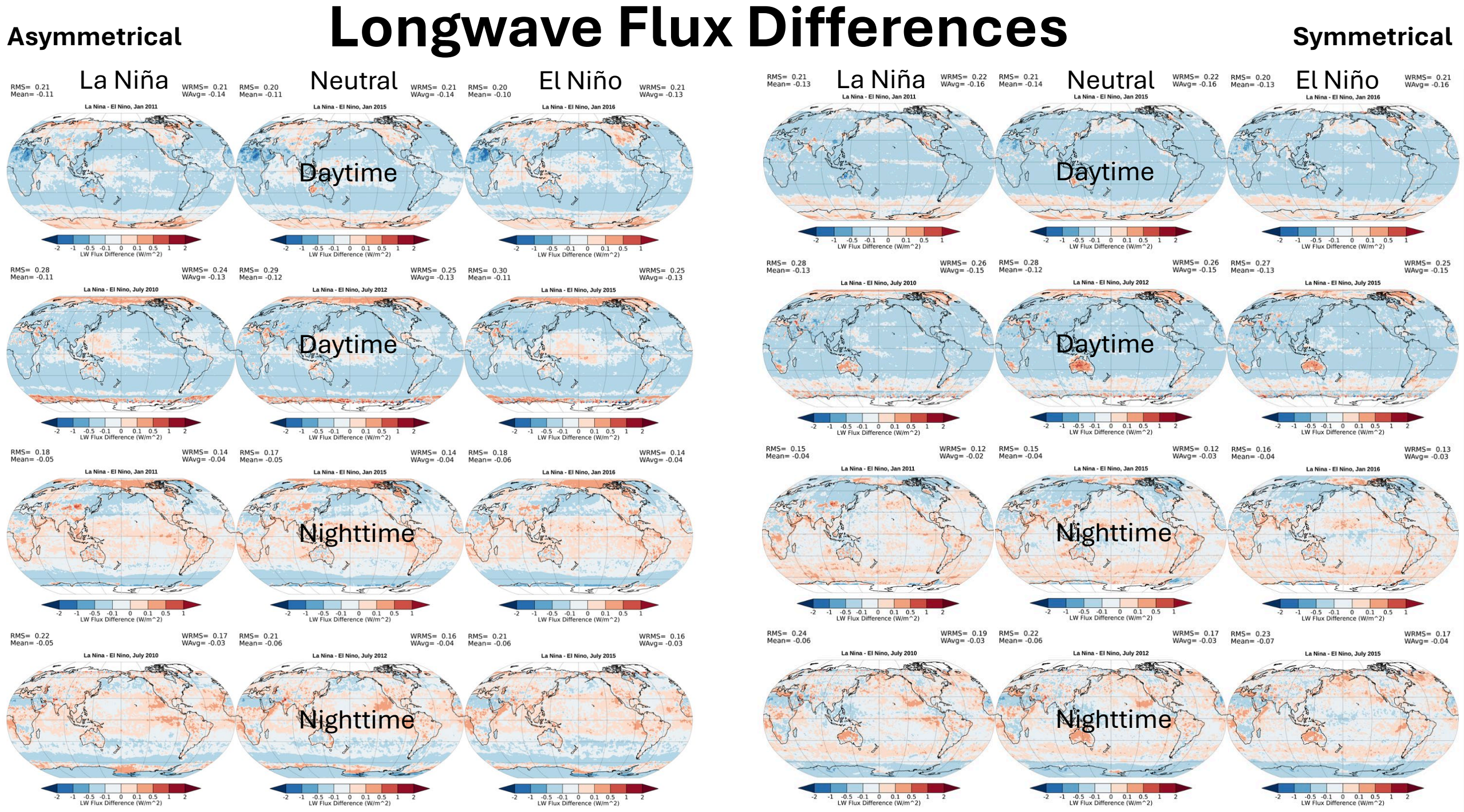
Better ADMs

Finer Angular
Bins
Homogeneous
Scene Types
More Data in
Bins

Coarser Angular
Bins
Heterogenous
Scene Types
Less Data in
Bins

Worse ADMs

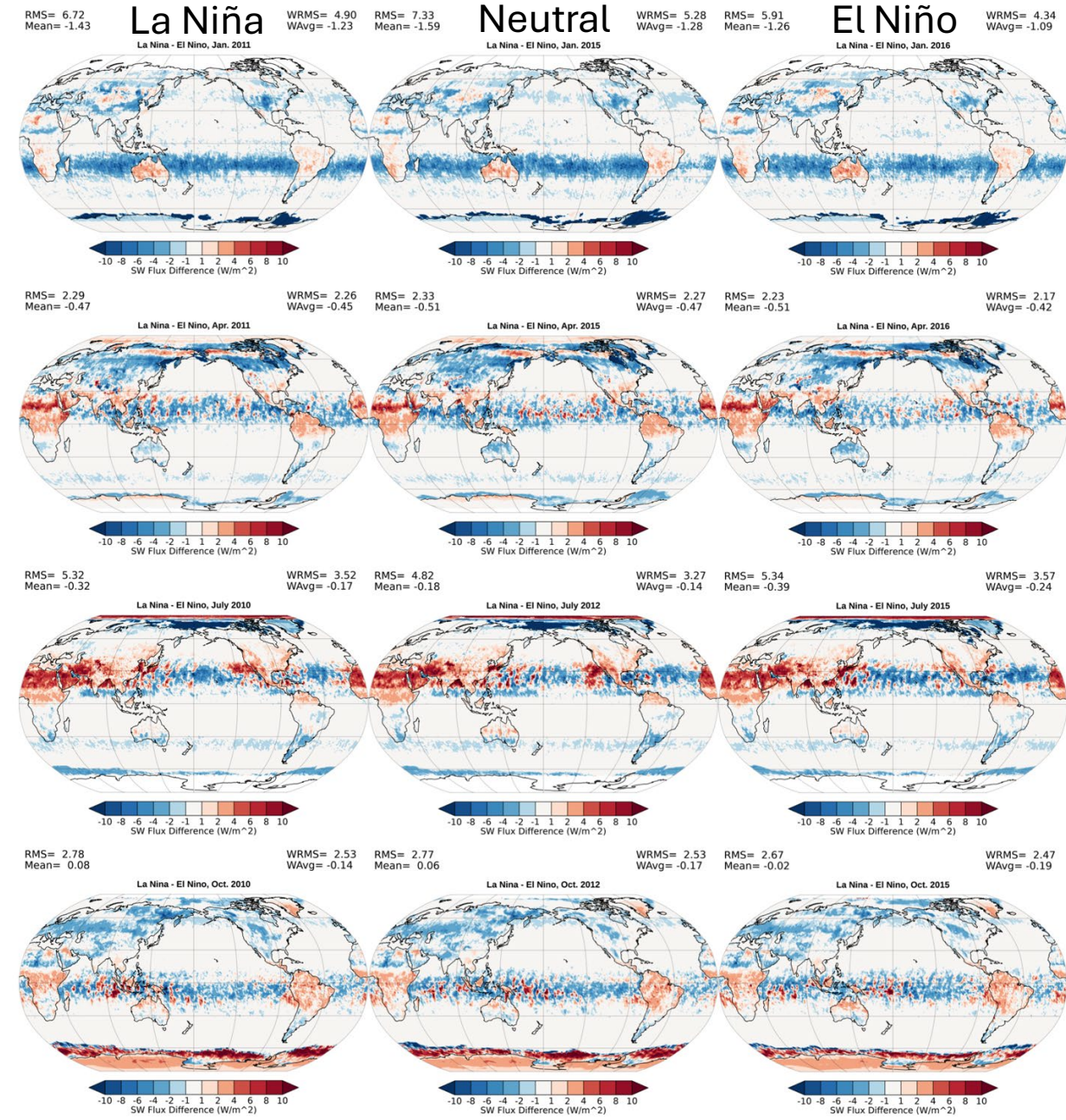
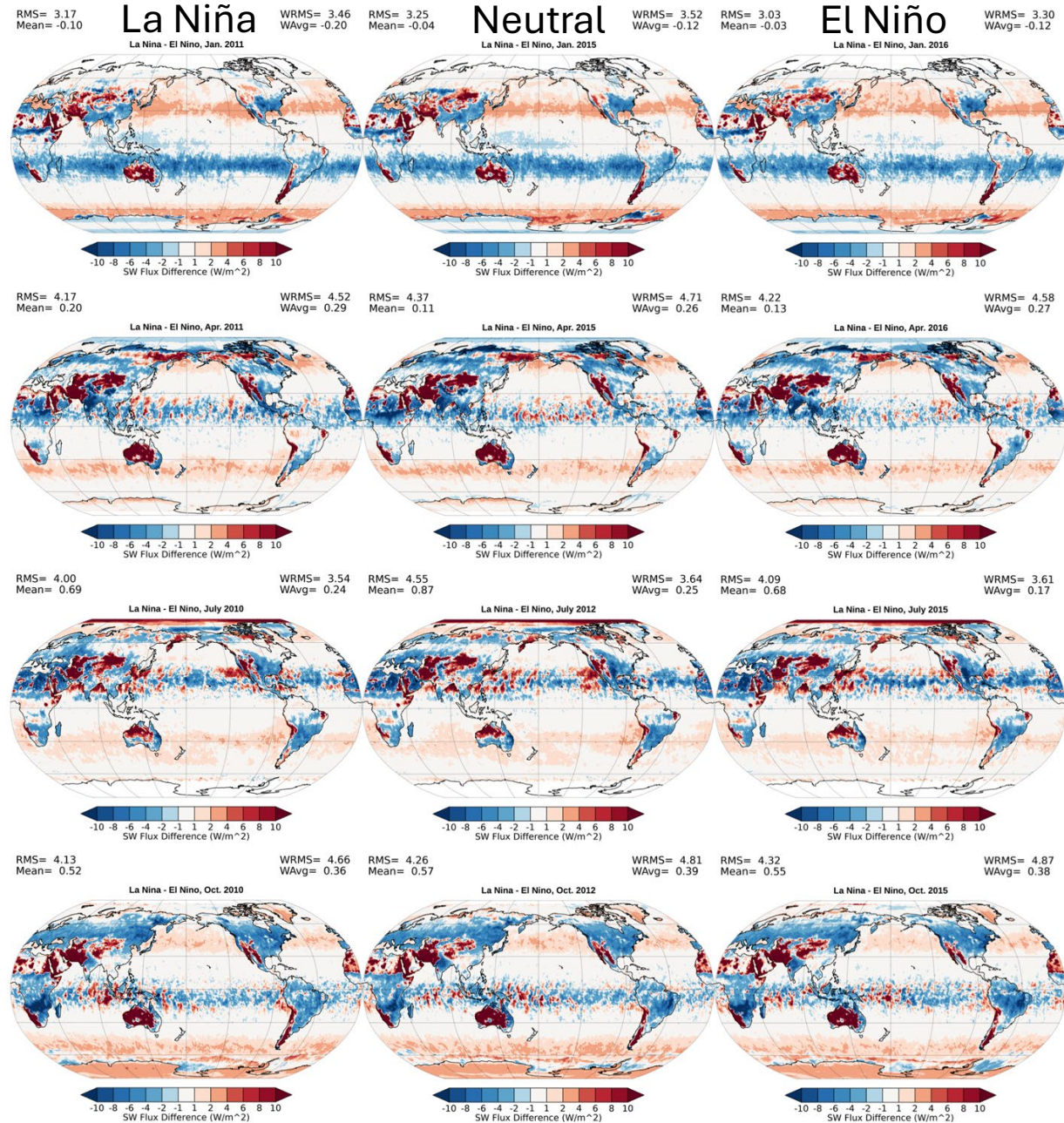
If seasonality has no influence, then differences should be larger!



Asymmetrical

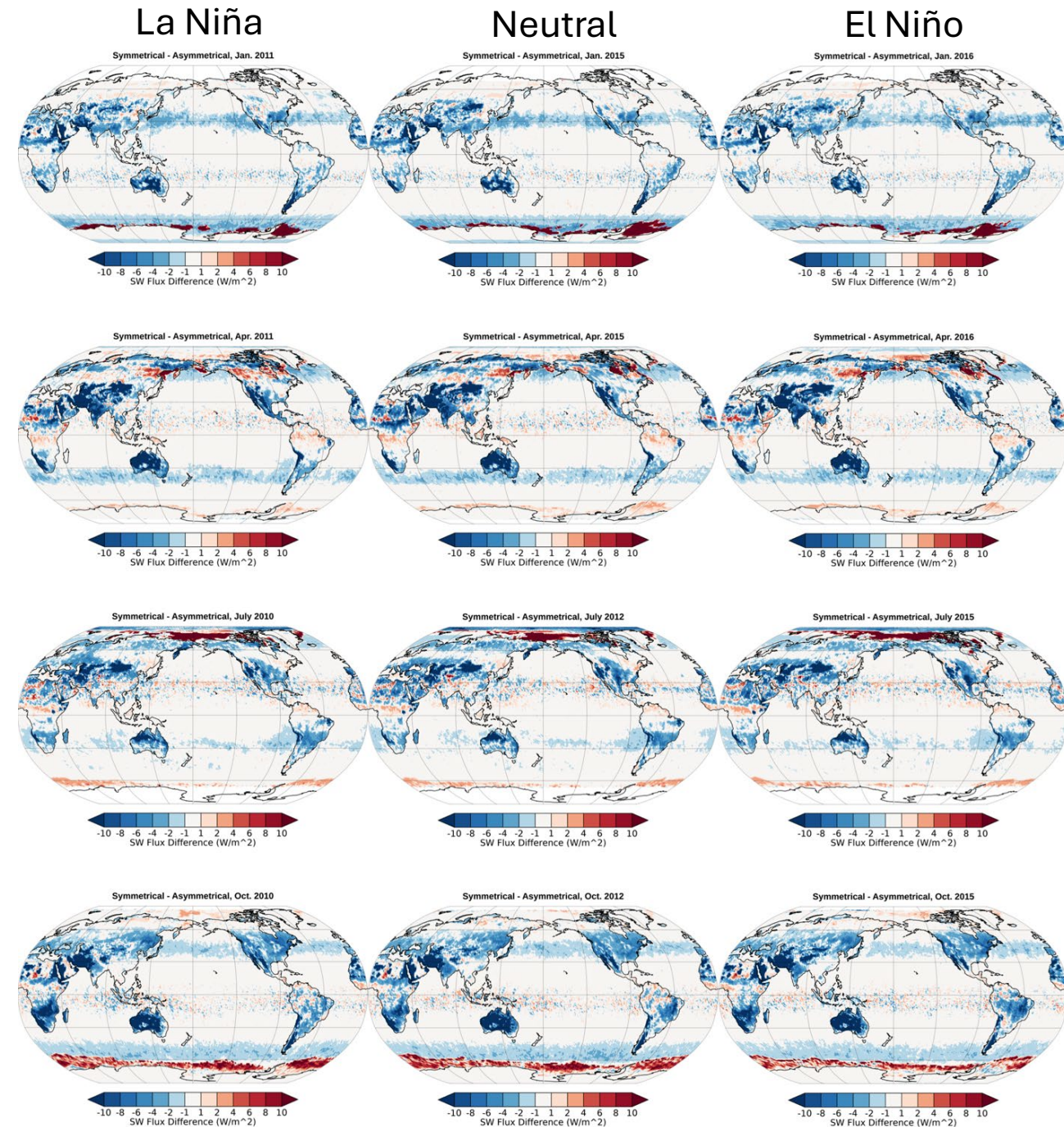
Shortwave Flux Differences

Symmetrical



Impact of Seasonality on ADM Development

- Blue (red) regions indicate the seasonally symmetric ENSO ADMs have smaller (larger) SW flux differences than the seasonally asymmetric ENSO ADMs.
- Symmetric case generally has smaller differences except over sea ice regions.



Additional Lines of Evidence

Direct Integration

- Integrate cross-track and RAP radiance measurements composited in 3-month intervals (DJF, MAM, JJA, SON) over a 5° latitude x 5° longitude (10° latitude x 10° longitude) region for LW (SW).

$$F_{LW} = 2\pi \int_0^{\frac{\pi}{2}} I_o(\theta_v) \cos \theta_v \sin \theta_v d\theta_v$$

$$F_{SW}(\theta_o) = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} I_o(\theta_o, \theta_v, \varphi) \cos \theta_v \sin \theta_v d\theta_v d\varphi$$

- Compare LW flux given by La Niña and El Niño ADMs, respectively, with the observed direct integration (DI) approach.
- For SW fluxes, the standard DI approach cannot be applied since the sun-synchronous orbit of Terra introduces a strong correlation between latitude and solar zenith and relative azimuth angles. Instead, DI ADMs are developed:

$$R_o(\theta_o, \theta_v, \varphi, \text{reg}) = \frac{\pi I_o(\theta_o, \theta_v, \varphi, \text{reg})}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} I_o(\theta_o, \theta_v, \varphi, \text{reg}) \cos \theta_v \sin \theta_v d\theta_v d\varphi}$$

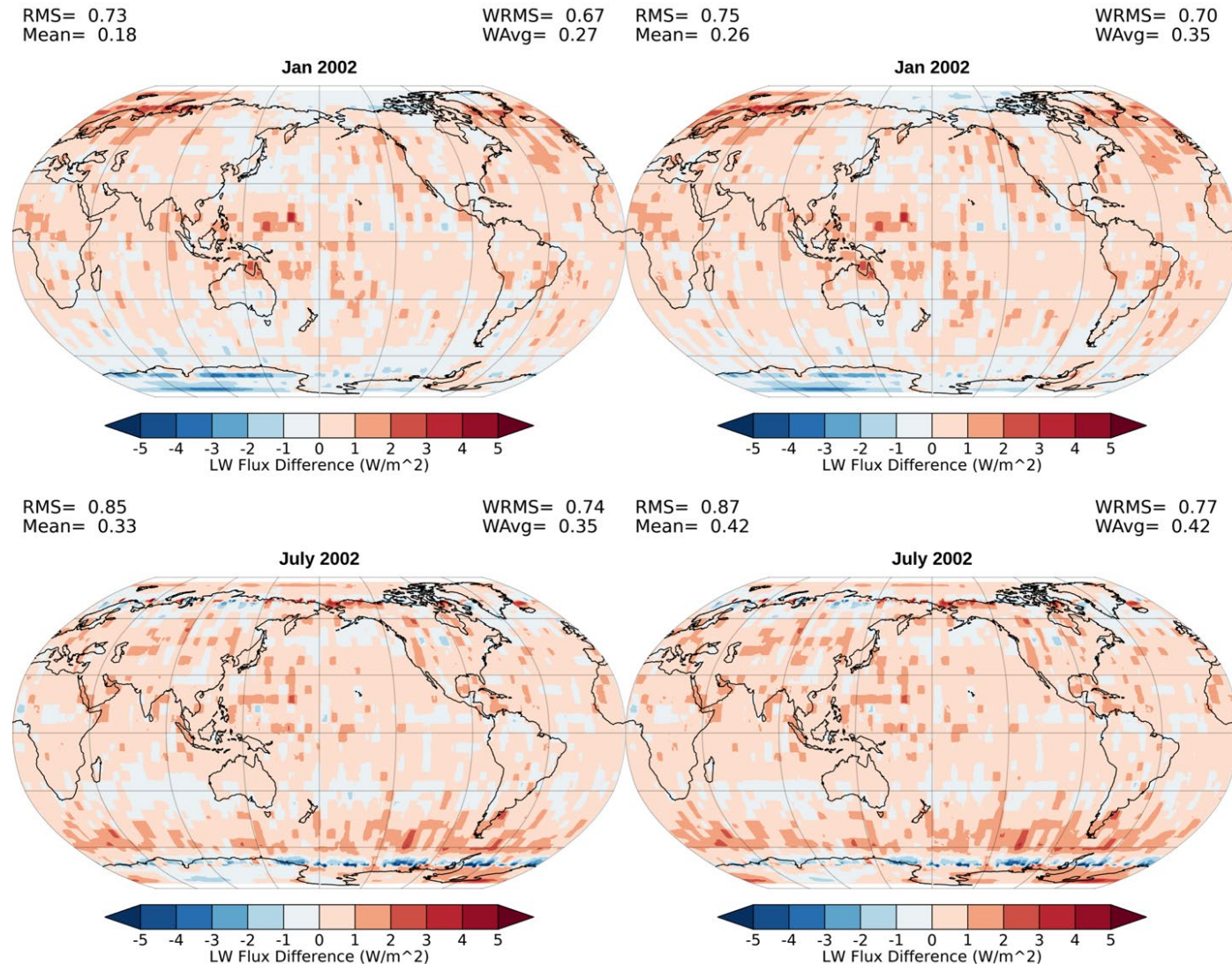
Observed DI ADM

$$\hat{R}(\theta_o, \theta_v, \varphi, \text{reg}) = \frac{\pi \hat{I}(\theta_o, \theta_v, \varphi, \text{reg})}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \hat{I}_j(\theta_o, \theta_v, \varphi, \text{reg}) \cos \theta_v \sin \theta_v d\theta_v d\varphi}$$

ENSO DI ADM

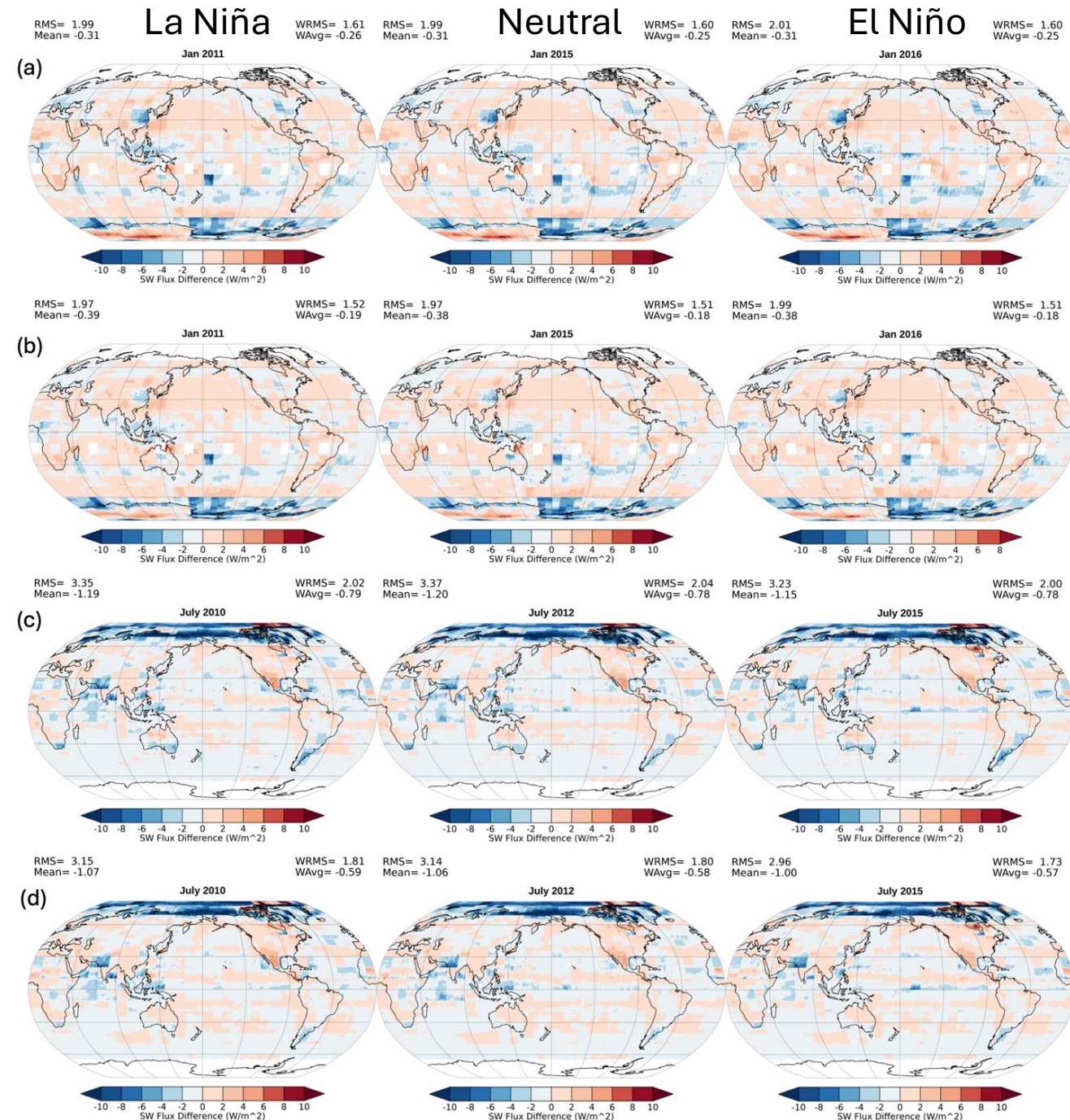
DI Longwave Flux Differences

- LW fluxes computed from La Niña ADMs and El Niño ADMs display similar differences relative to that given by DI approach (0.67-0.77 $\text{W}\cdot\text{m}^{-2}$). Very similar spatial patterns.
- ENSO ADMs tend to overestimate LW fluxes relative to the observed DI approach. El Niño ADMs overestimate LW fluxes slightly more than La Niña ADMs.



DI Shortwave Flux Differences

- SW fluxes computed from La Niña ADMs and El Niño ADMs display similar differences relative to that given by the observed DI ADMs (1.51-2.04 $W \cdot m^{-2}$).
- Both ENSO ADMs tend to underestimate the SW fluxes. La Niña ADMs tend to underestimate the SW fluxes slightly more.
- Differences display similar spatial patterns despite undergoing distinct phases of ENSO.
- La Niña (El Niño) ADMs do not perform better during La Niña (El Niño) conditions



Leveraging MISR

For a CERES footprint, MISR provides spectral radiance measurements from nine camera angles. Narrow-to-broadband regressions are applied to convert MISR narrowband radiances to broadband.

$$I_{SW}^j = c_0 + c_1 I_{0.45}^j + c_2 I_{0.67}^j + c_3 I_{0.87}^j$$



CERES ADMs



F_{SW}^j

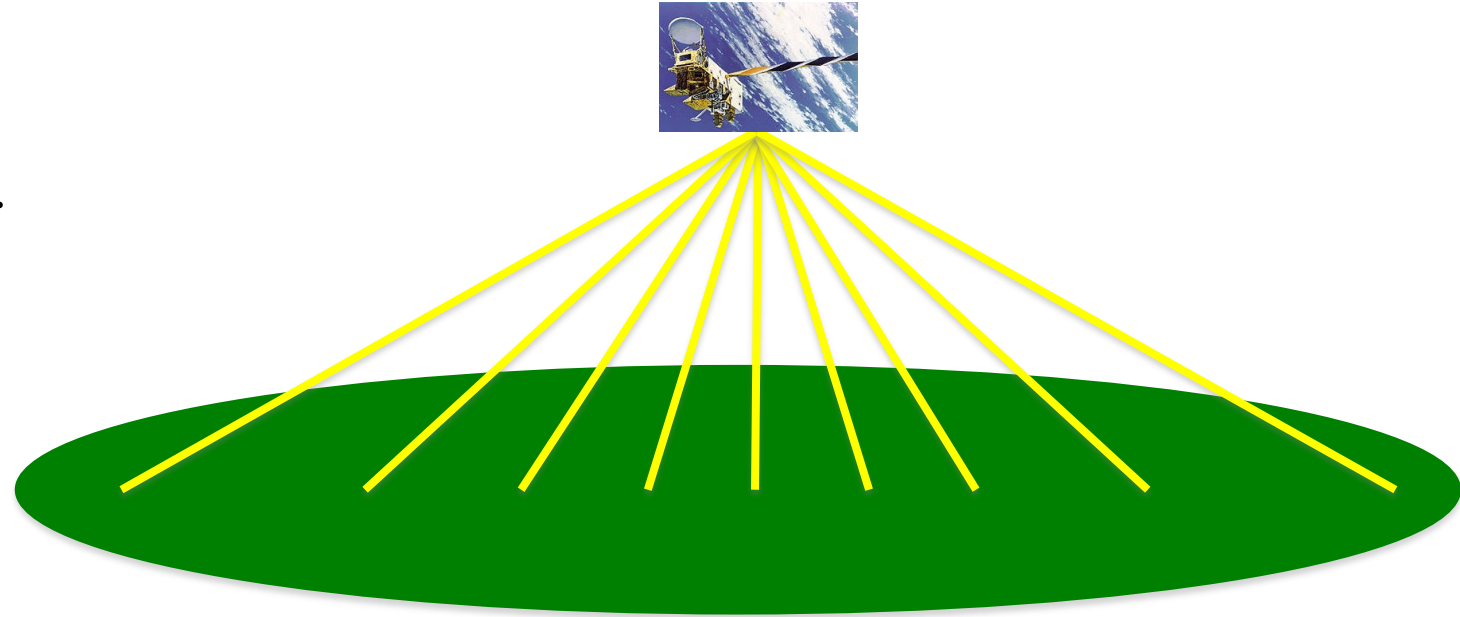


$$\langle F_{SW} \rangle = \frac{\sum_{j=1}^N F_{SW}^j}{N}$$



$$s = \sqrt{\frac{\sum_{j=1}^N (F_{SW}^j - \langle F_{SW} \rangle)^2}{N - 1}}$$

Standard Deviation
of Sample



The SW flux calculation should not be dependent on viewing geometry.

Leveraging MISR

For M CERES footprints, the relative consistency of the SW TOA fluxes is given by:

$$CV_T = \frac{\sqrt{\sum_{i=1}^M (s_i)^2}}{\sum_{i=1}^M \langle F_{SW} \rangle_i} * 100\%$$

To remove the error contribution of the narrow-to-broadband regression calculate standard deviation of the MISR SW flux calculations from that given by CERES (F_{SW}^C):

$$s_c = \sqrt{\frac{\sum_{j=1}^N (F_{SW}^j - F_{SW}^C)^2}{N - 1}}$$

The contribution of the narrow-to-broadband regression to the relative consistency of the SW TOA flux is:

$$CV_{NB} = \frac{\sqrt{\sum_{i=1}^M (s_{c,i})^2}}{\sum_{i=1}^M F_{SW,i}^C} * 100\%$$

The contribution of the ADMs to the relative consistency of the SW TOA flux is therefore:

$$CV_{ADM} = \sqrt{CV_T^2 - CV_{NB}^2}$$

SW Flux Consistency Test

Snow & Ice SW Flux ADM Error	Clear	Single Cloud Layer	Multi-Cloud Layer	All
Ψ_{ADM} (%) (Edition 4 ADMs)	3.82	5.94	5.81	5.55
Ψ_{ADM} (%) (Symmetrical Case; El Niño ADMs)	4.93	6.48	6.33	6.16
Ψ_{ADM} (%) (Symmetrical Case; La Niña ADMs)	5.08	6.52	6.22	6.18
Ψ_{ADM} (%) (Asymmetrical Case; El Niño ADMs)	5.05	6.47	6.20	6.15
Ψ_{ADM} (%) (Asymmetrical Case; La Niña ADMs)	4.94	6.26	5.91	5.95

- Snow and Ice El Niño and La Niña ADMs have similar SW flux ADM errors.
- Snow and Ice Edition 4 ADMs have smaller SW flux ADM error, as expected.

Summary and Conclusions

- LW flux differences are small, indicating LW ADMs have weak sensitivity to ENSO phase.
- La Niña ADMs and El Niño ADMs do produce substantial SW flux differences.
 - Symmetrical case indicates these differences are reduced when the influence of the seasonal cycle on ADM development is removed.
 - Years undergoing distinct ENSO phases display similar difference patterns indicating a weak sensitivity to ENSO phase.
 - Direct integration and SW flux consistency tests also indicate weak sensitivity to ENSO phase.
- CERES ADMs demonstrate robustness to ENSO climate variability.
- SW ADMs do demonstrate sensitivity to changes on the scale of the seasonal cycle.
- Overall, the analysis provides confidence in the reliability and robustness of CERES ADMs and thus the climate data record of CERES fluxes.