

1. Background

- NASA's Clouds and the Earth's Radiant Energy System (CERES) provides satellite-based observations of SW fluxes around the globe.
- CERES uses satellite measurements of broadband radiance and angular distribution models (ADMs) to estimate observed SW and LW fluxes.
- ADMs account for the angular dependence in the 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?
- This study analyzes the sensitivity of ADMs to climate variability, using ENSO variability as a proxy.

2. Data and Methodology

For every scene type, bin observed radiances over all relative azimuth, viewing and solar zenith angles (φ , θ , and θ_o) and calculate the mean radiance ($\hat{I}$) for all bins. Integrate $\hat{I}$ over all φ and θ to estimate the SW flux ($\hat{F}$). Then the ratio of the isotropic flux to that of $\hat{F}$ gives the anisotropic factor (R) for each scene type.

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

For each radiance measurement, first determine the scene type, finally apply the scene type dependent anisotropic factor (R) to the observed radiance to derive the reflected TOA SW flux (as shown below).

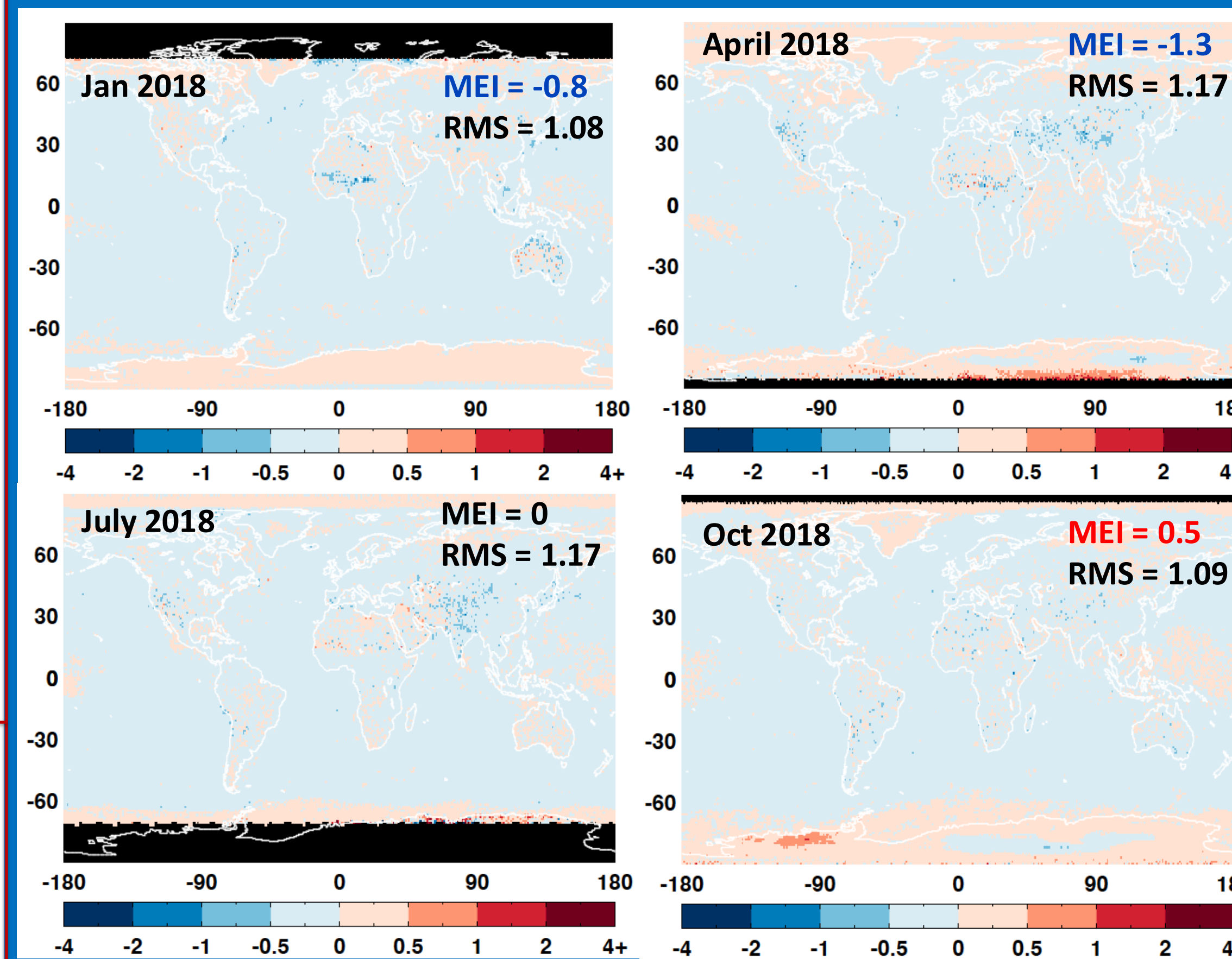
$$F(\theta_o) = \frac{\pi I_o(\theta_o, \theta, \phi)}{R(\theta_o, \theta, \phi)}$$

- For LW radiances and fluxes the process follows as above, but with no dependence on solar zenith and relative azimuth angles.
- The monthly Multivariate ENSO Index (MEI) Version 2 values were used to distinguish La Nina (MEI < -0.5) months from El Nino (MEI > 0.5) months during the period from 2000-2005.
- 15 (13) months of Terra RAP and cross-track data was used to construct the La Nina (El Nino) ADMs (i.e., the asymmetrical case). A second set of La Nina and El Nino ADMs were produced using 7 months of data to remove seasonal asymmetries between the two datasets (i.e., the symmetrical case).
- Due to the reduction in observational data used to develop the ENSO ADMs, the simpler and less data intensive CERES TRMM methodology (Loeb et al. 2003) for ADM development was used for land and ocean SW ADMs.
- CERES TRMM snow and ice SW ADMs rely solely on modeled values, so the Ed. 4 methodology (Su et al. 2015) is used. However, the development of clear-sky Antarctic permanent snow ADMs is simplified to match that of the Ed. 4 clear-sky Greenland permanent snow ADMs.
- Despite the reduction in data availability, the Ed. 4 approach is maintained in this analysis for LW ADMs, as less data is needed for development since there is no dependence on solar zenith and relative azimuth angles.

References:

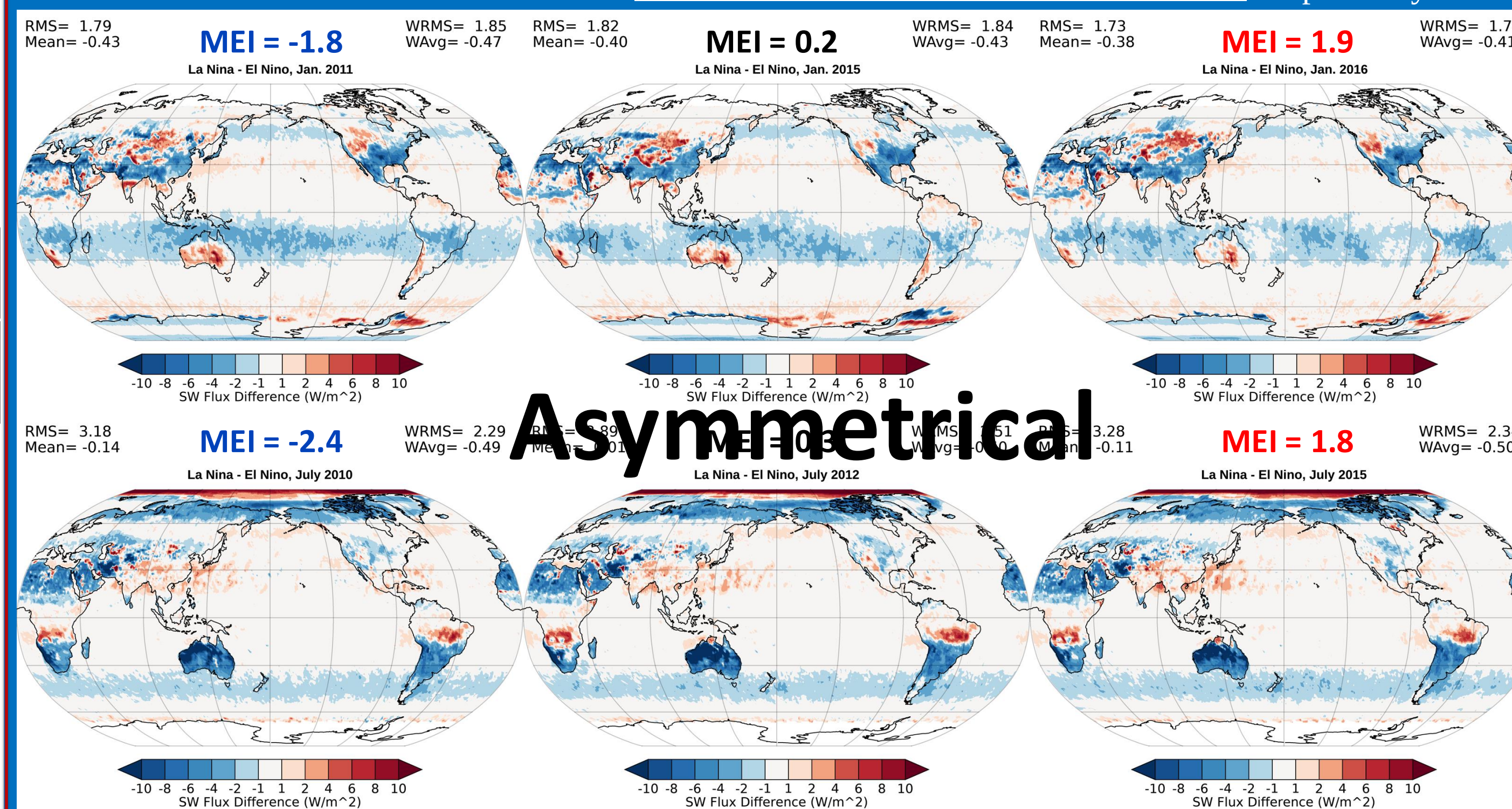
Loeb, N. G., Manalo-Smith, N., Kato, S., Miller, W. F., Gupta, S. K., Minnis, P., and Wielicki, B. A.: Angular Distribution Models for Top-of-Atmosphere Radiative Flux Estimation from the Clouds and the Earth's Radiant Energy System Instrument on the Tropical Rainfall Measuring Mission Satellite, Part I: Methodology, J. Appl. Meteorol., 42, 240–265, 2003.
Su, W., Corbett, J., Eitzen, Z., & Liang, L. (2015). Next-generation angular distribution models for top-of-atmosphere radiative flux calculation from CERES instruments: Methodology, Atmospheric Measurement Techniques, 8, 611–632. <https://doi.org/10.5194/amt-8-611-2015>

CERES ADMs display weak sensitivity to ENSO phase indicating that ADMs built from a static period in the early 2000s remain reliable for the whole CERES period in spite of climate variability and change during that period.

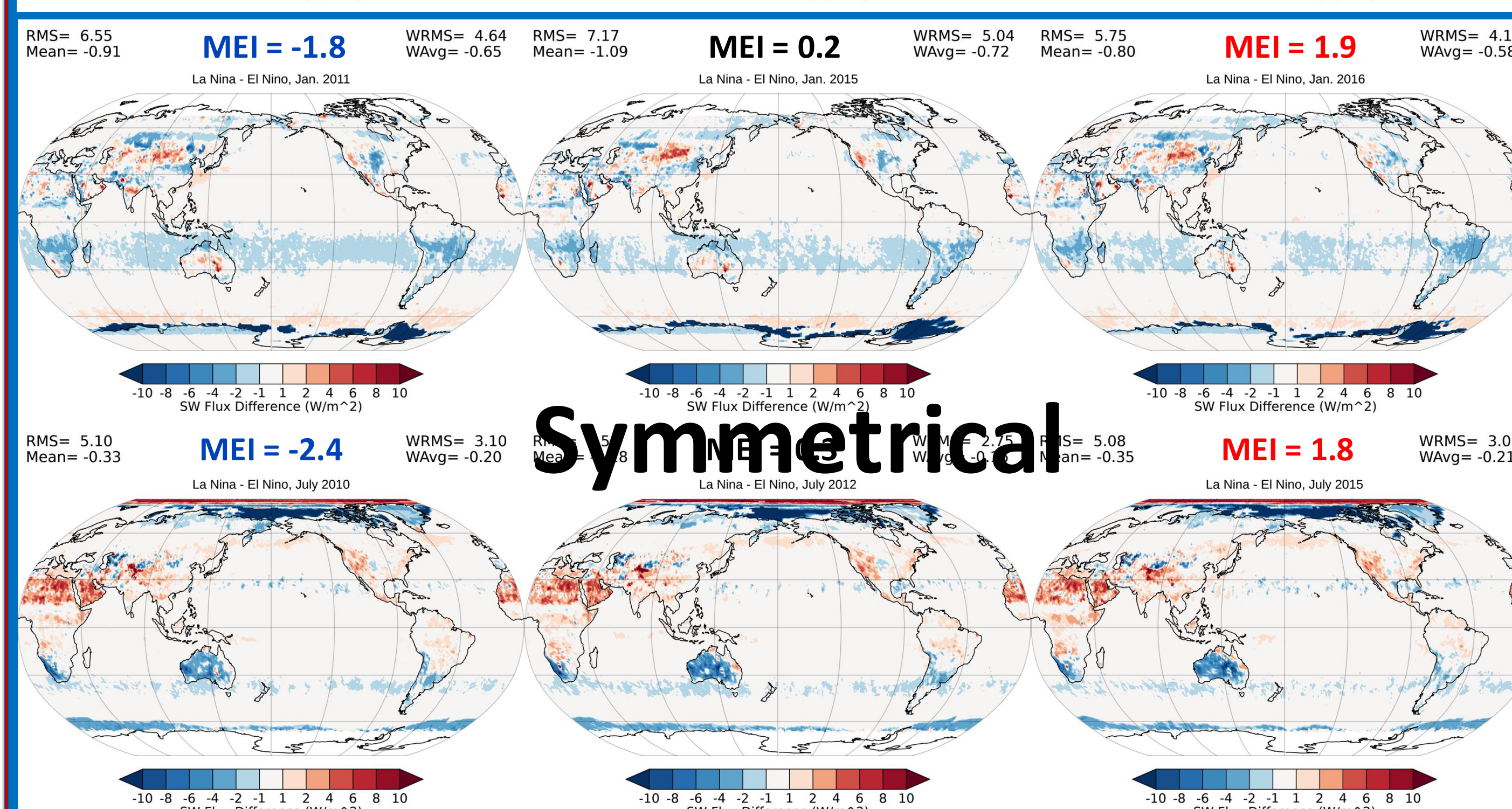


LW fluxes developed from La Nina and El Nino ADMs display small differences regardless of ENSO phase or seasonal timing.

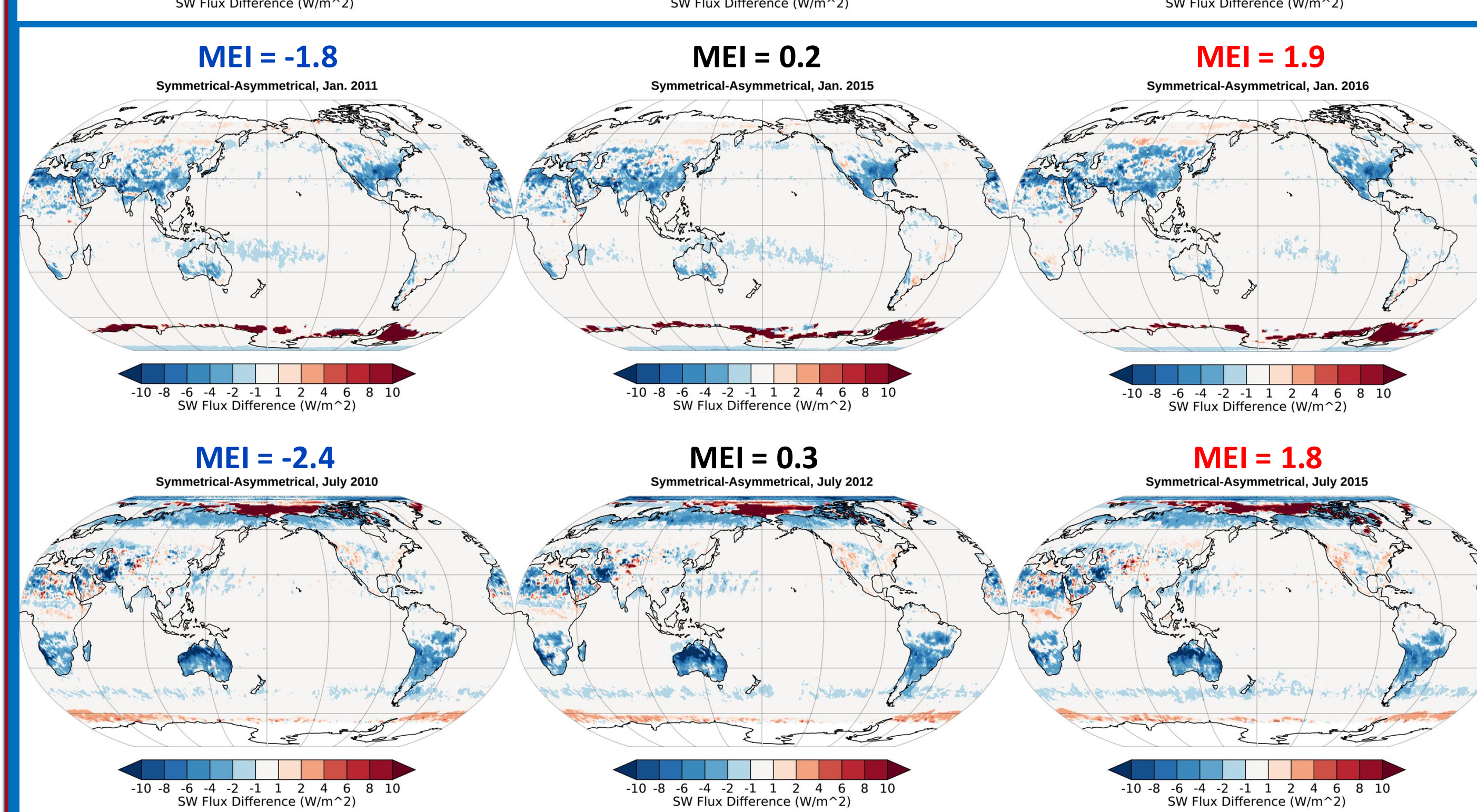
Fig. Monthly LW flux differences between LW fluxes calculated using El Nino and La Nina ADMs, respectively.



Asymmetrical



Symmetrical



For a given month, very similar pattern despite changes in ENSO phase. Largest differences over land, sea ice, and fresh snow areas.

Fig. SW flux differences between SW fluxes calculated using La Nina and El Nino ADMs for the asymmetrical case. SW flux differences for years with distinct ENSO phase are shown for January (top row) and July (bottom row).

For a given month, very similar pattern despite changes in ENSO phase. Very large differences over sea ice areas increase RMS.

Fig. SW flux differences between SW fluxes calculated using La Nina and El Nino ADMs for the symmetrical case. SW flux differences for years with distinct ENSO phase are shown for January (top row) and July (bottom row).

SW flux differences for symmetrical case are less than the asymmetrical case for land and ocean, but greater for sea ice regions.

Fig. The absolute difference between the SW flux differences given by the symmetrical case minus the SW flux differences given by the asymmetrical case.

3. Flux by Direct Integration

Construct two sets of regional (10°x10°) all-sky ADMs for each season (DJF, MAM, JJA and SON). Both sets of ADMs have the same sampling.

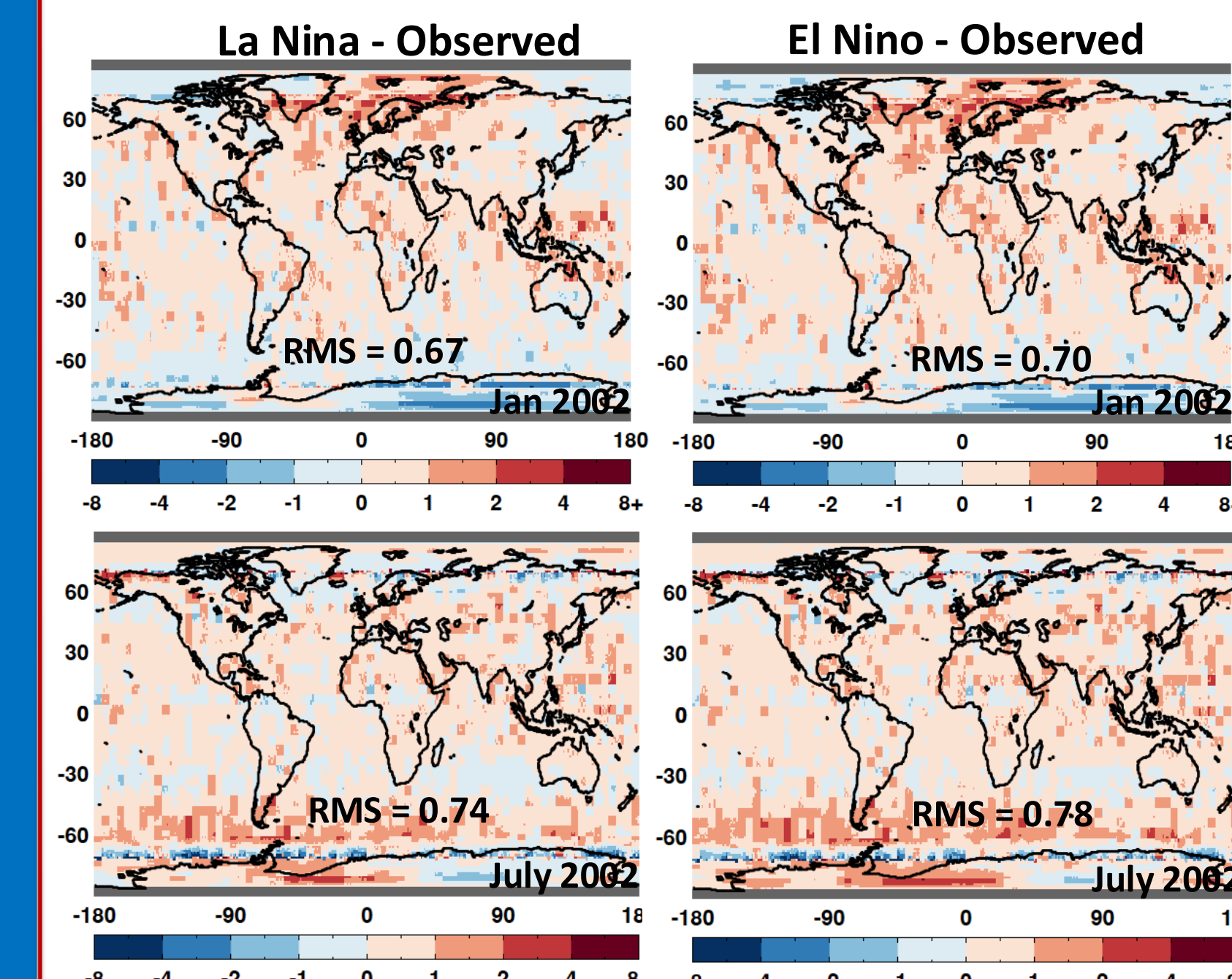
(1) ADMs based on observed radiances

$$R_o(\theta_o, \theta, \phi) = \frac{\pi I_o(\theta_o, \theta, \phi)}{F_o(\theta_o, \theta, \phi)}, \text{ where } F_o = \int_0^{2\pi} \int_0^{\pi/2} I_o(\theta_o, \theta, \phi) \cos\theta \sin\theta d\theta d\phi$$

(2) ADMs based on ADM-predicted radiances

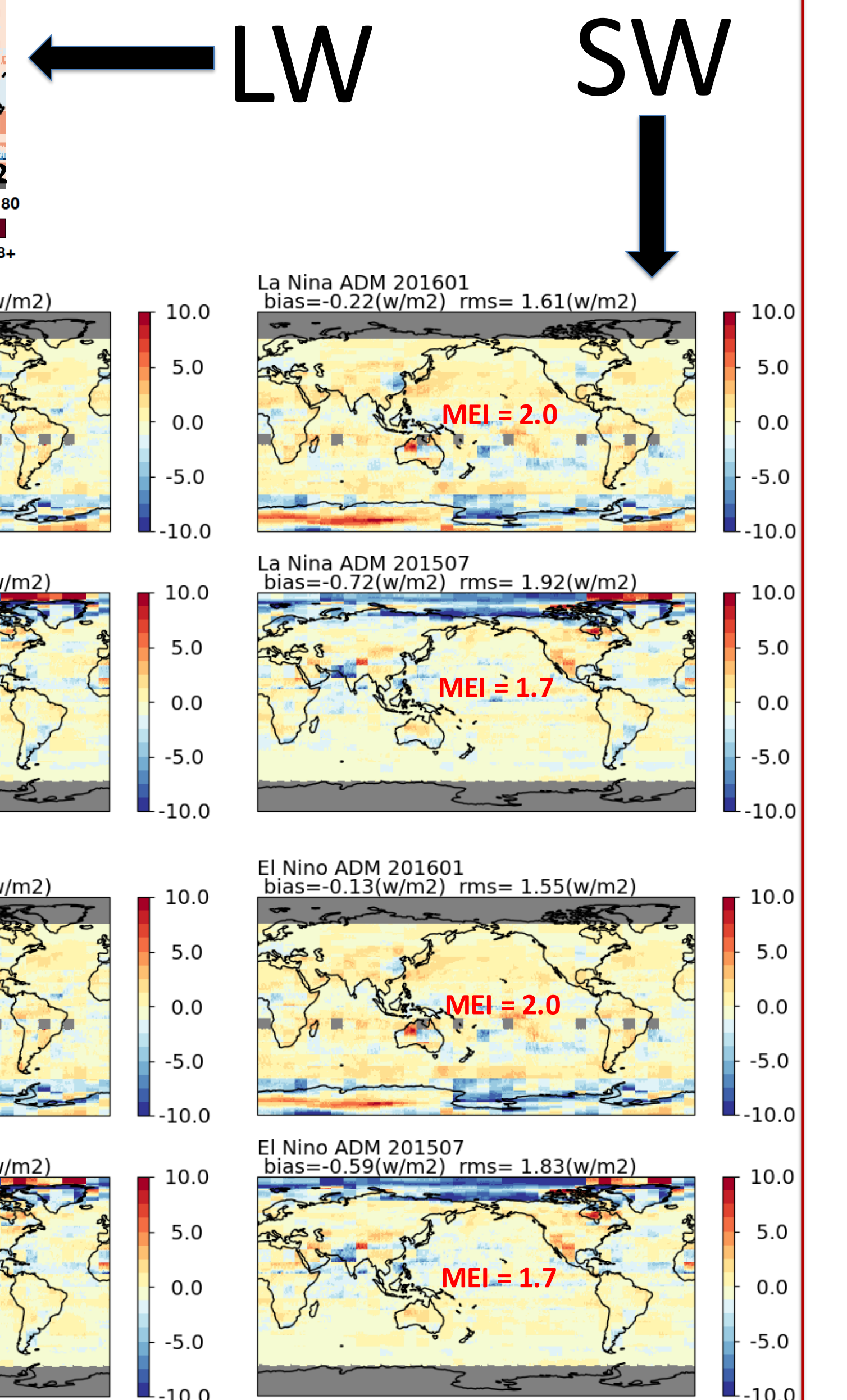
$$\hat{R}(\theta_o, \theta, \phi) = \frac{\pi \hat{I}(\theta_o, \theta, \phi)}{\hat{F}(\theta_o, \theta, \phi)}, \text{ where } \hat{F} = \int_0^{2\pi} \int_0^{\pi/2} \hat{I}(\theta_o, \theta, \phi) \cos\theta \sin\theta d\theta d\phi$$

For (2), we develop two sets of ADMs for La Nina and El Nino ADM-predicted radiances, respectively.



LW and SW flux differences from (2) – (1) are shown for La Nina and El Nino ADMs.

For a given month, La Nina and El Nino have similar spatial patterns and magnitudes.



4. Conclusions

- Relative to observed radiances the El Nino and La Nina ADM-derived radiances produce a similar spatial pattern and magnitude for the LW and SW flux differences given by direct integration.
- LW fluxes display small differences indicating weak sensitivity to ENSO phase.
- For a given month, years undergoing distinct ENSO phases display similar SW flux difference patterns and magnitude for both El Nino and La Nina ADMs indicating weak dependence on ENSO phase.
- Large SW flux differences between symmetric and asymmetric cases are predominantly due to data scarcity issues and the influence of the seasonal cycle.
- CERES ADMs developed from the early 2000s remain reliable despite climate change, at least for changes on the order of the climate variability experienced from El Nino to La Nina.
- CERES ADMs, however, are sensitive to changes on the order of seasonal changes.