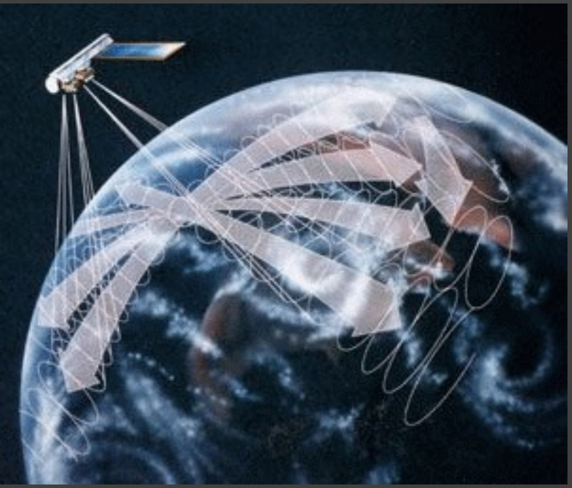

CERES Angular Distribution Model Working Group Report

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CERES Science Team Meeting, Oct 1-3, 2024
Lawrence Livermore National Laboratory, Livermore, CA

From radiance to flux: angular distribution models

- Sort observed radiances into angular bins over different scene types and calculate the averages:

$$\hat{I}(\theta_o,\theta,\emptyset)$$

- Integrate radiances to get flux:

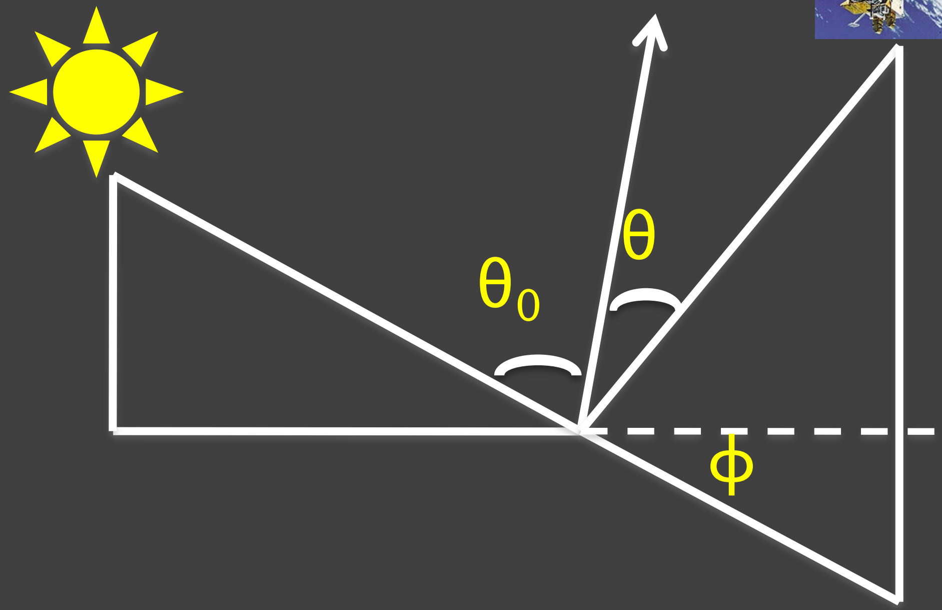
$$\hat{F}(\theta_o) = \int_0^{2\pi}\int_0^{\pi/2}\hat{I}(\theta_o,\theta,\emptyset)cos\theta sin\theta d\theta d\phi$$

- Estimate the anisotropic factor for each scene type:

$$\hat{R}(\theta_o,\theta,\emptyset)=\frac{\pi\hat{I}(\theta_o,\theta,\emptyset)}{\hat{F}(\theta_o)}$$

- For each radiance measurement, apply scene type dependent anisotropic factor to observed radiance to derive TOA flux:

$$F(\theta_o)=\frac{\pi I^o(\theta_o,\theta,\emptyset)}{\hat{R}(\theta_o,\theta,\emptyset)}$$



Outline

- Sensitivity of CERES ADMs to different climate states
- Impact of Terra orbital drifting on SW CERES ADMs

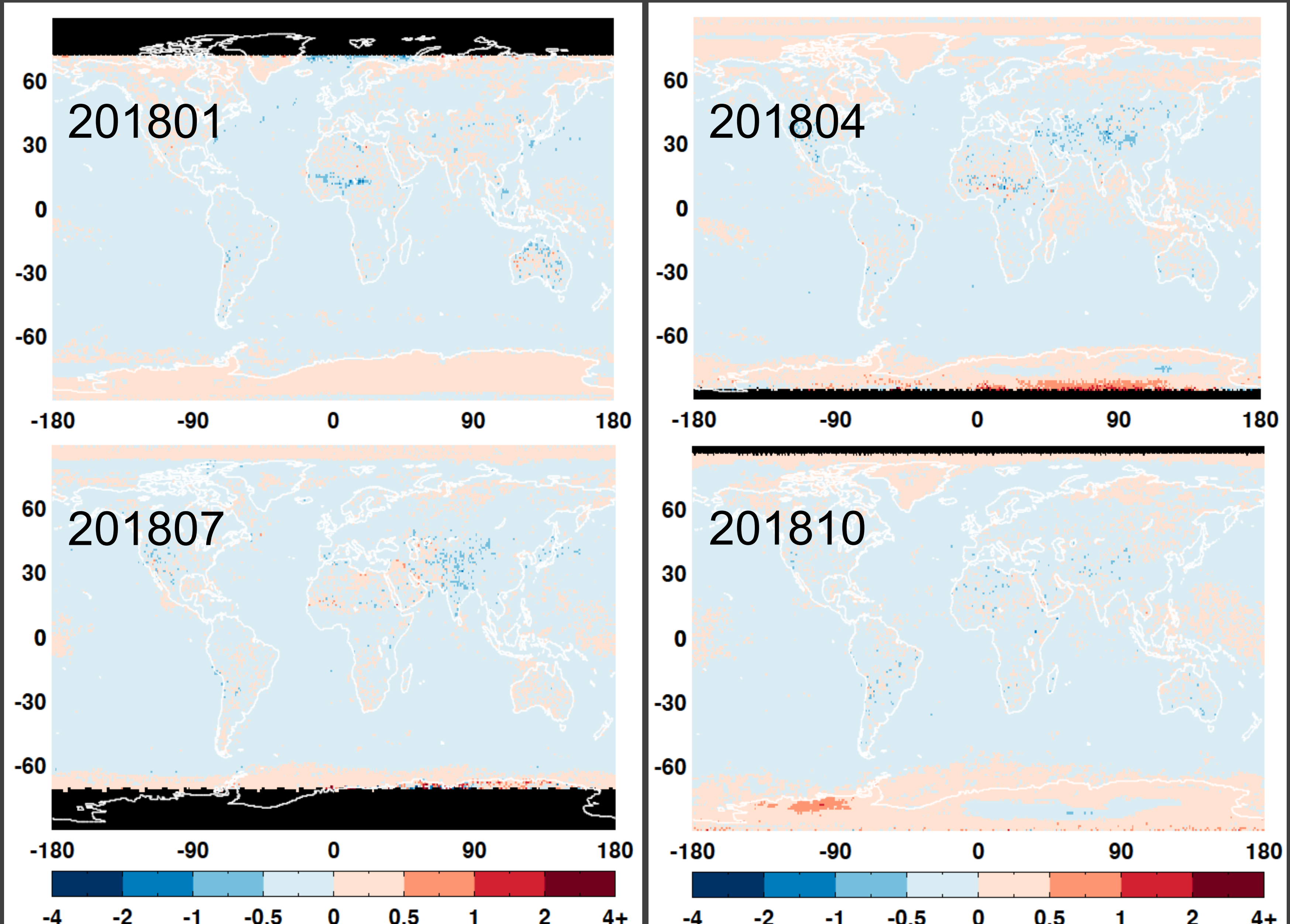
Sensitivity of CERES ADMs to different climate states

How resilient are ADMs to climate variability and change?

- As the mean climate state shifts, can the Terra/Aqua ADMs constructed using data taken in the early 2000s be used for flux inversion now and in the coming decades?

- Using data taken during different ENSO phases to test ADM sensitivity to climate variability:
  - Build a set of "El Niño ADMs" and a set of "La Niña ADMs".
  - NOAA Physical Sciences Laboratory Multivariate ENSO Index (MEI) v2 is to characterize ENSO phase for data selection to build ADMs; use MEI > 0.5 for the "El Niño ADMs" and MEI < 0 for the "La Niña ADMs".
  - LW ADMs use Ed4 ADM approach.
  - SW ADMs over ocean/land use TRMM ADM approach to mitigate the sampling limitation;
  - SW ADMs over snow are modified to achieve sampling symmetric by using MEI > 0 for the "El Niño ADMs" and MEI < 0 for the "La Niña ADMs", and by using different numbers of months for the two ADMs.
  - Examine fluxes inverted by the two ADMs during different ENSO phases.

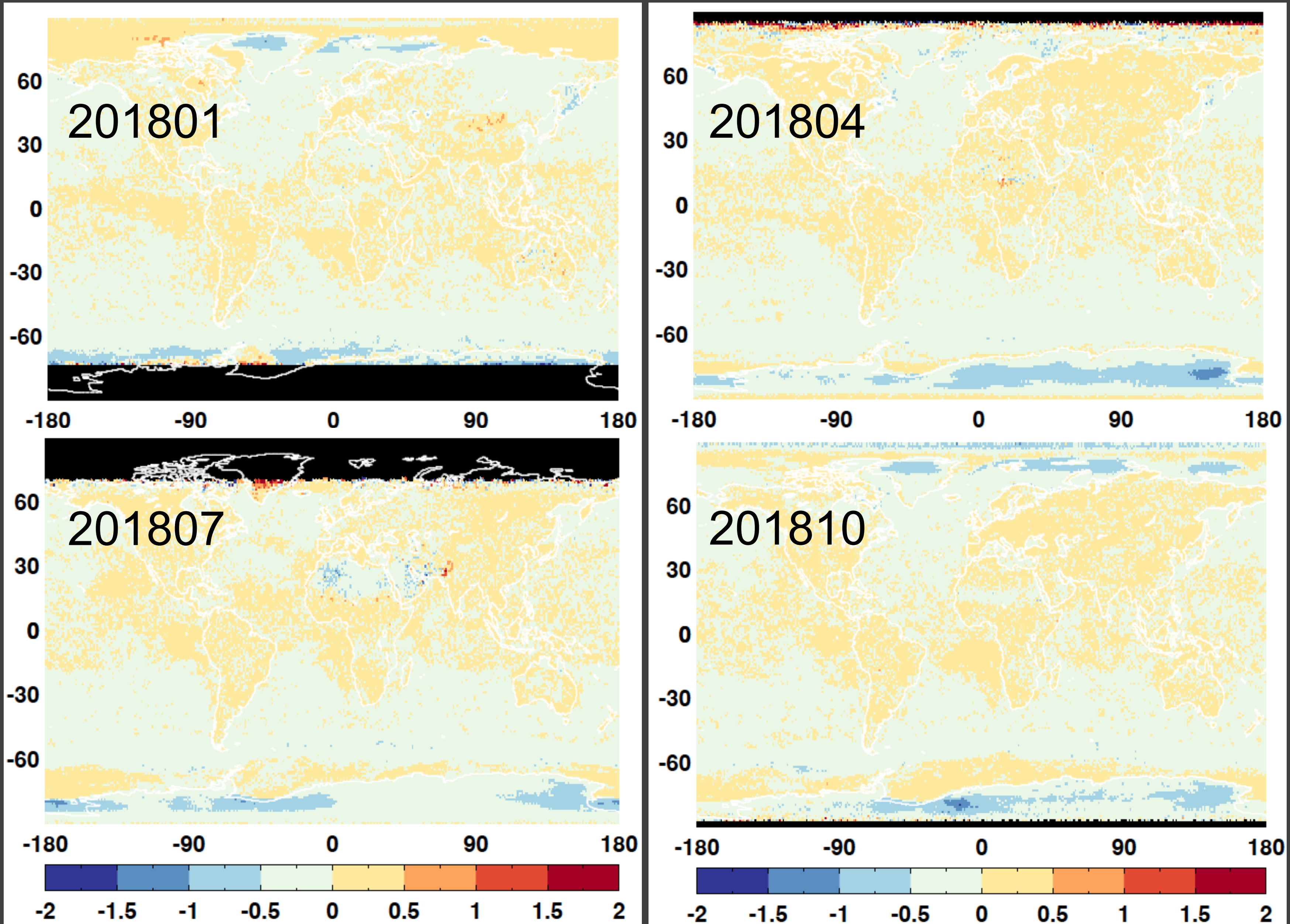
Terra all-sky daytime LW flux difference: El Niño - La Niña ADMs



	All-sky bias (W m^{-2}, %)	All-sky RMS
201801	0.13 (0.06%)	1.08 (0.45%)
201804	0.13 (0.05%)	1.17 (0.48%)
201807	0.14 (0.06%)	1.17 (0.47%)
201810	0.12 (0.05%)	1.09 (0.45%)

LW ADMs constructed using data taken during El Niño phase and La Niña phase have a minimal impact on flux.

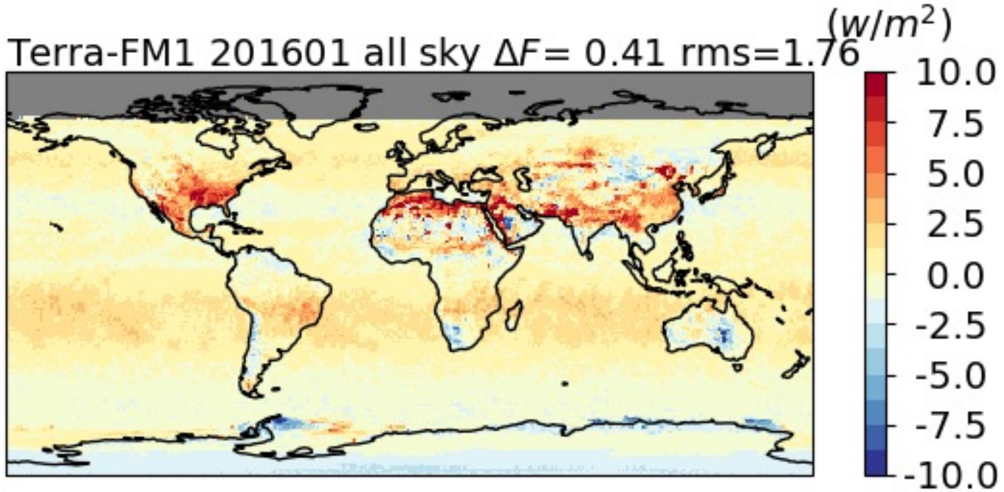
Terra all-sky night time LW flux difference: El Niño - La Niña ADMs



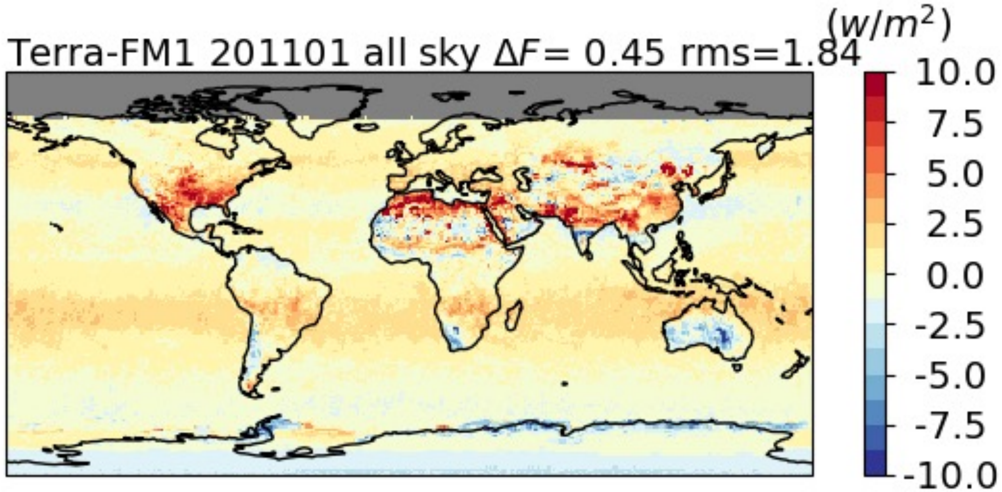
	All-sky bias (W m^{-2}, %)	All-sky RMS
201801	0.05 (0.02%)	0.89 (0.38%)
201804	0.04 (0.02%)	0.92 (0.39%)
201807	0.04 (0.02%)	0.95 (0.39%)
201810	0.04 (0.02%)	0.89 (0.37%)

LW ADMs constructed using data taken during El Niño phase and La Niña phase have a minimal impact on flux.

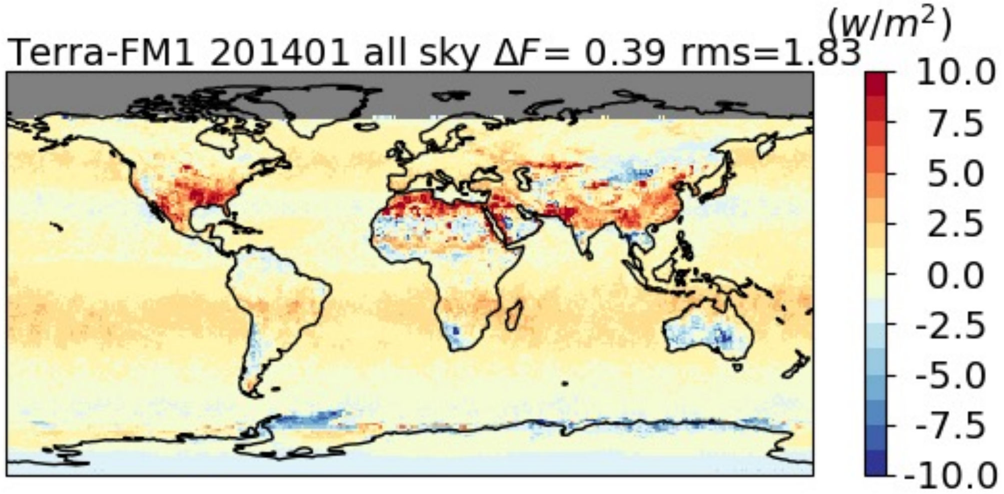
Terra all-sky SW flux difference: El Niño - La Niña ADMs



MEI= 2.0



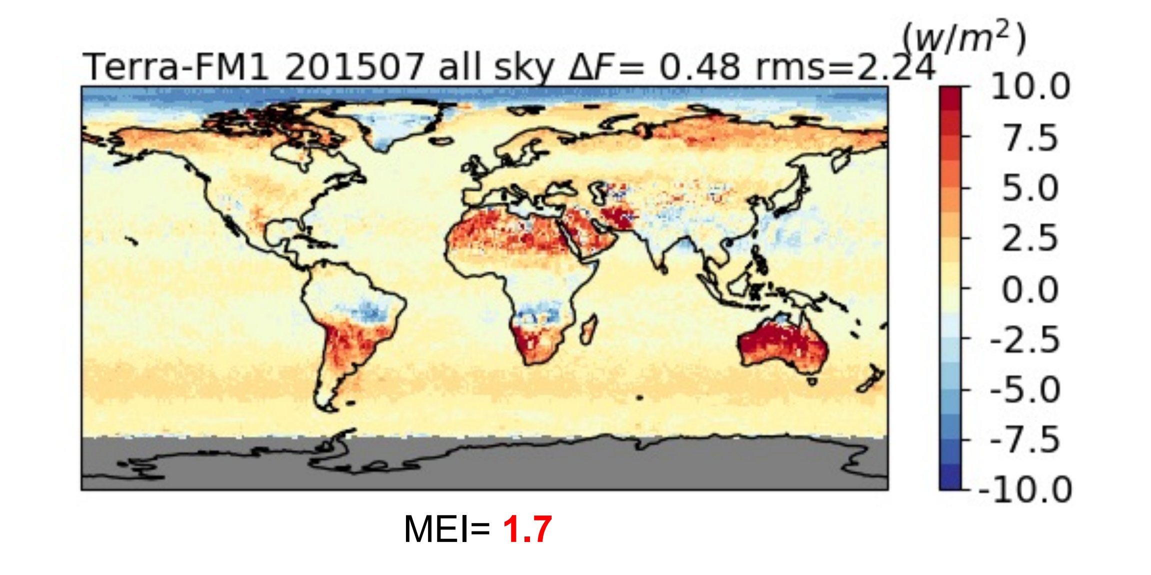
MEI= -1.8

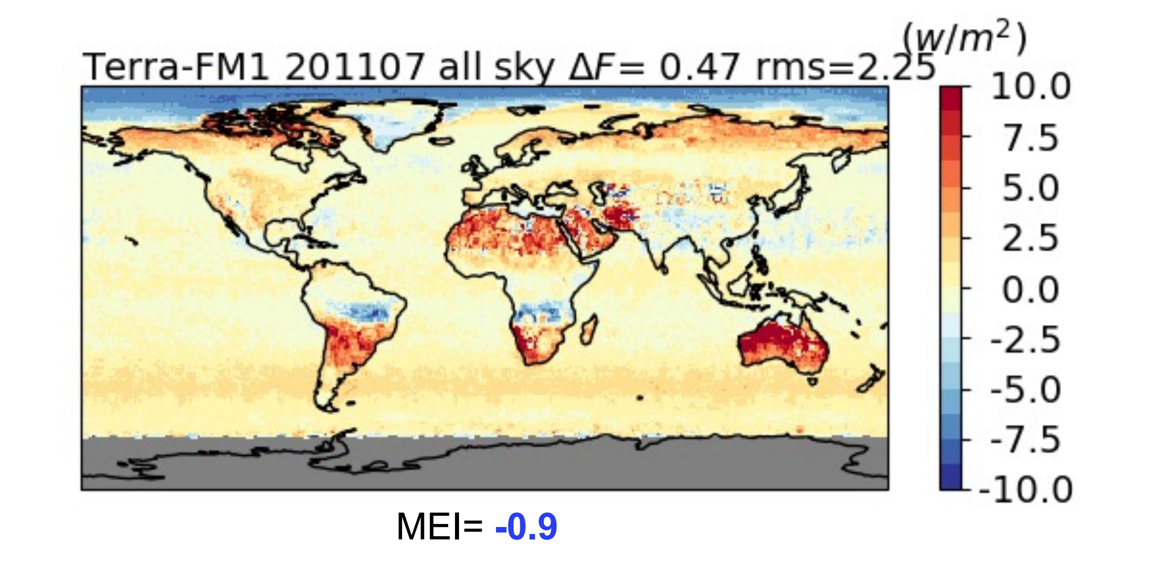


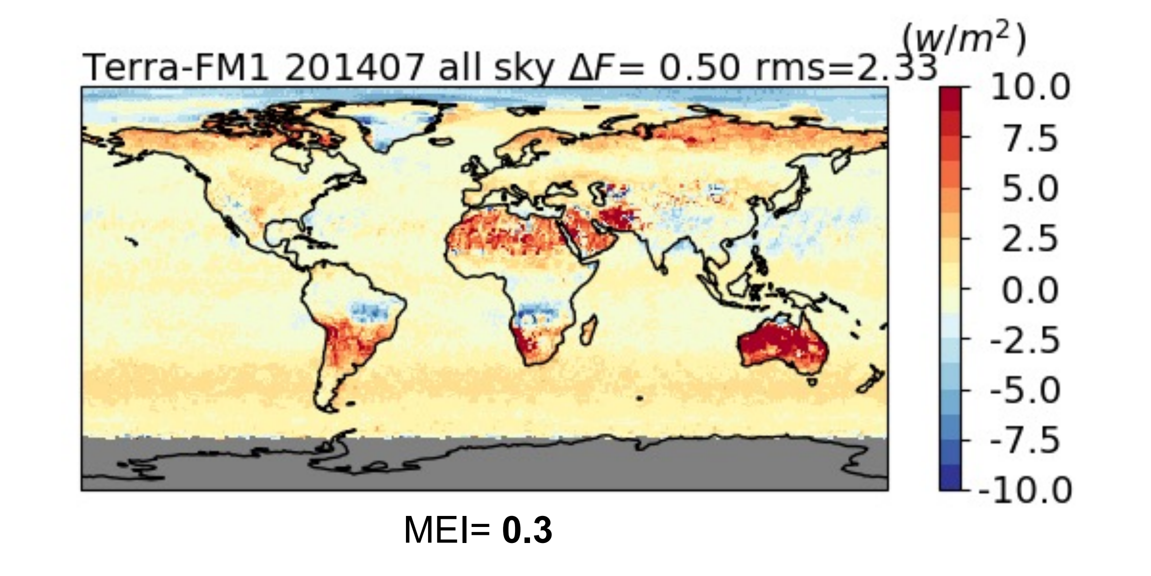
MEI= -0.5

- Flux differences vary by region.
- Flux difference patterns are similar for El Niño, La Niña, and neutral phases.
- Large regional differences over land are predominantly caused by sampling differences due to uneven seasonal coverage used to develop the two sets of ADMs.

Terra all-sky SW flux difference: El Niño - La Niña ADMs







- Flux differences vary by region.
- Flux difference patterns are similar for El Niño, La Niña, and neutral phases.
- Large regional differences over land are predominantly caused by sampling differences due to uneven seasonal coverage used to develop the two sets of ADMs.

SW flux consistency using MISR measurements over snow/ice

- Broadband SW radiances at multi-angles are estimated from MISR-measured narrow band radiances by regression.
- SW fluxes are inverted from each of MISR angles by the two sets of ADMs.
- Flux consistencies are evaluated.

SW Flux ADM Error	Clear	Single Cloud Layer	Multi-Cloud Layer	All
Ψ_{ADM} (%) (Ed. 4 snow/ice ADMs)	3.8	5.9	5.8	5.5
Ψ_{ADM} (%) (El Nino snow/ice ADMs)	4.9	6.4	6.2	6.1
Ψ_{ADM} (%) (La Nina snow/ice ADMs)	5.0	6.3	6.0	6.0

The El Niño and La Niña ADMs have nearly the same uncertainties.

Flux by direct integration

- Construct two sets of regional (10°x10°) all-sky ADMs by season (e.g., DJF, MAM, JJA and SON).

  (1) based on observed radiances

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

  (2) based on ADM-predicted radiances

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

- Both sets of ADMs have the same sampling.
- Apply regional ADMs to cross track data of the middle month of the season to determine the fluxes.
- Compare fluxes derived by "La Niña ADMs" to that by observed radiance ADM.
- Compare fluxes derived by "El Niño ADMs" to that by observed radiance ADM.
- Compare fluxes derived by "La Niña ADMs" to that by "El Niño ADMs".

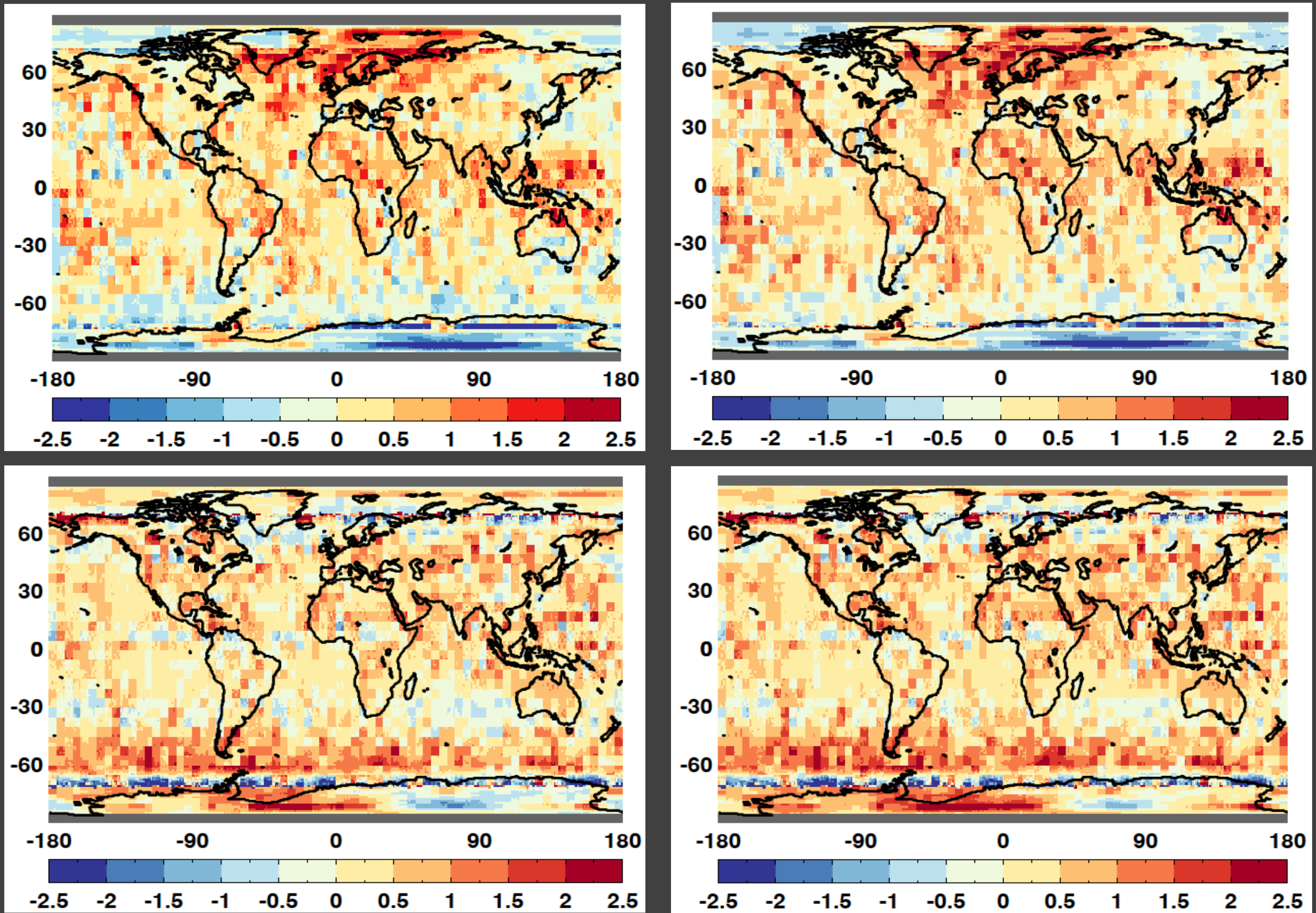
Direct integration LW flux errors
(flux from La Niña ADM predicted radiance – flux from observed radiance ADM)

using La Niña ADMs

using El Niño ADMs

Jan

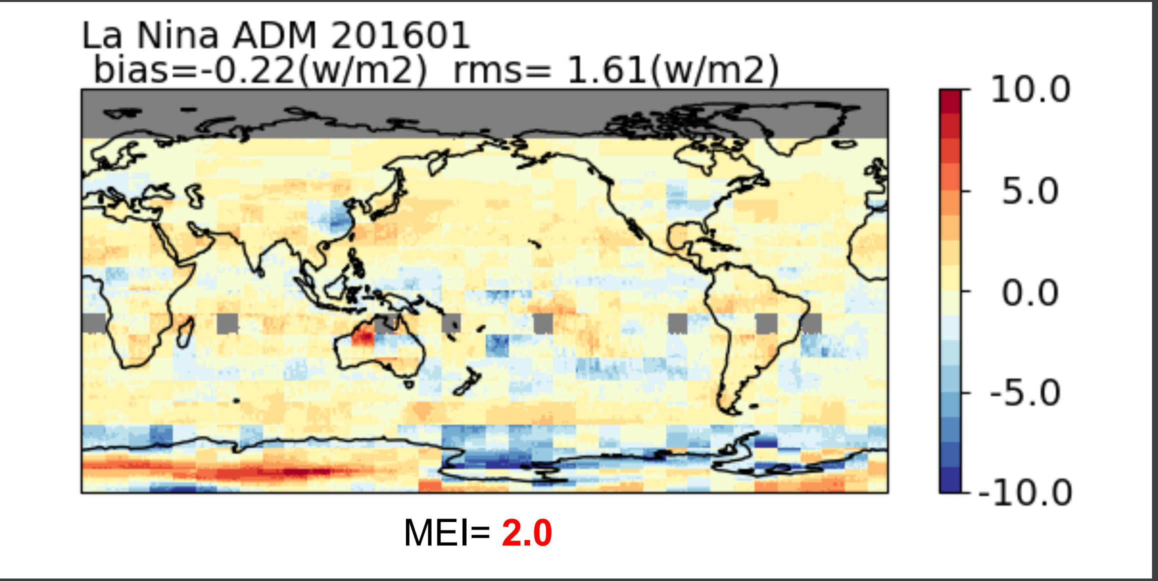
Jul

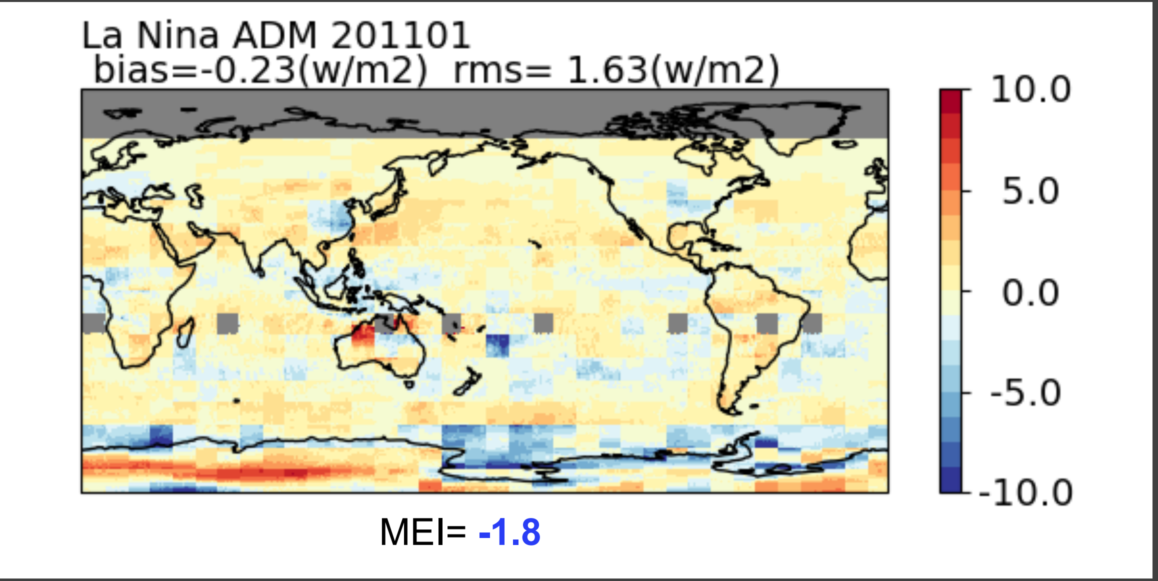


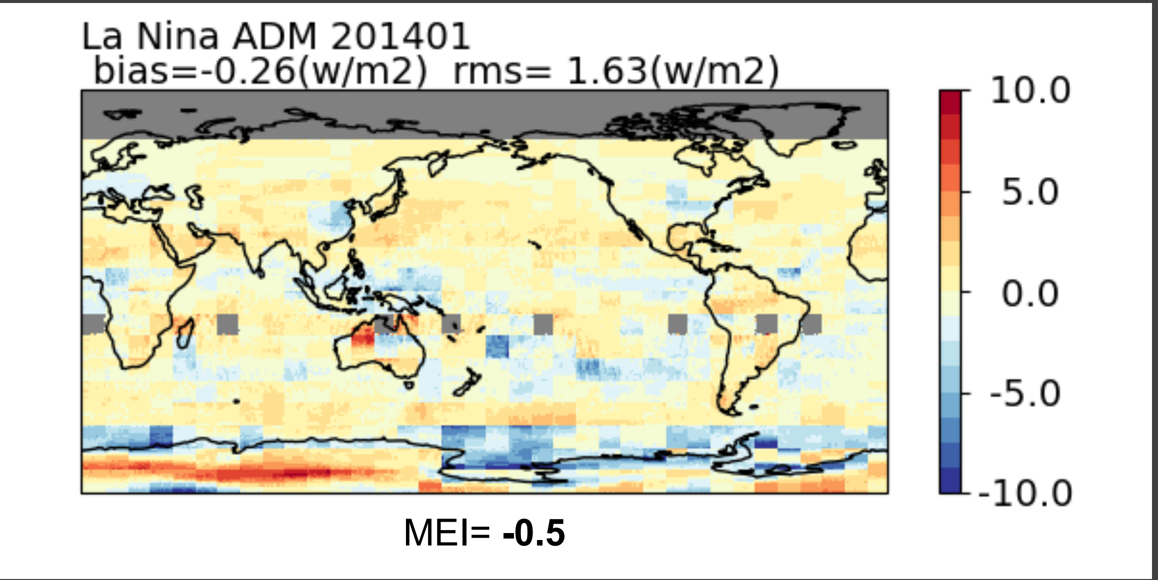
for 2002 Terra FM1

	La Nina	El Nino
Jan	0.20 (0.67)	0.36 (0.70)
Jul	0.34 (0.74)	0.43 (0.78)

Direct integration SW flux errors
(flux from La Niña ADM predicted radiance – flux from observed radiance ADM)

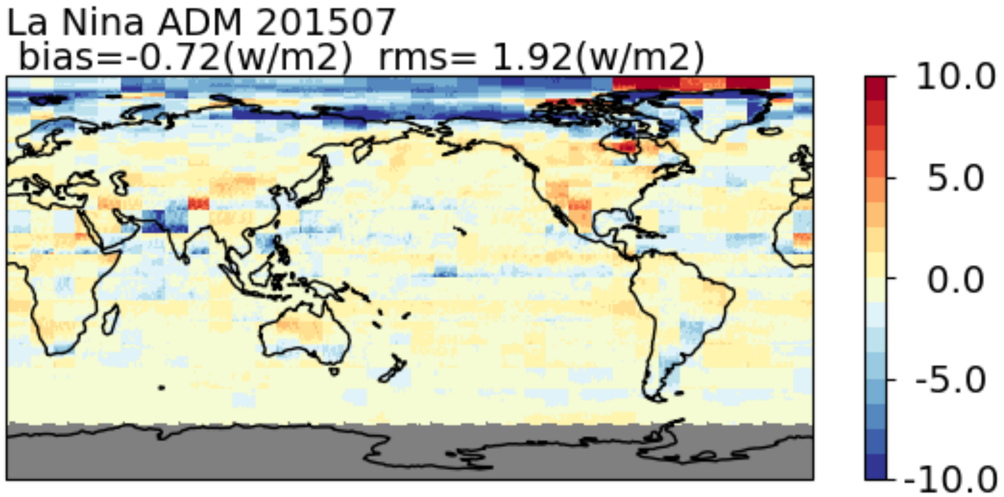




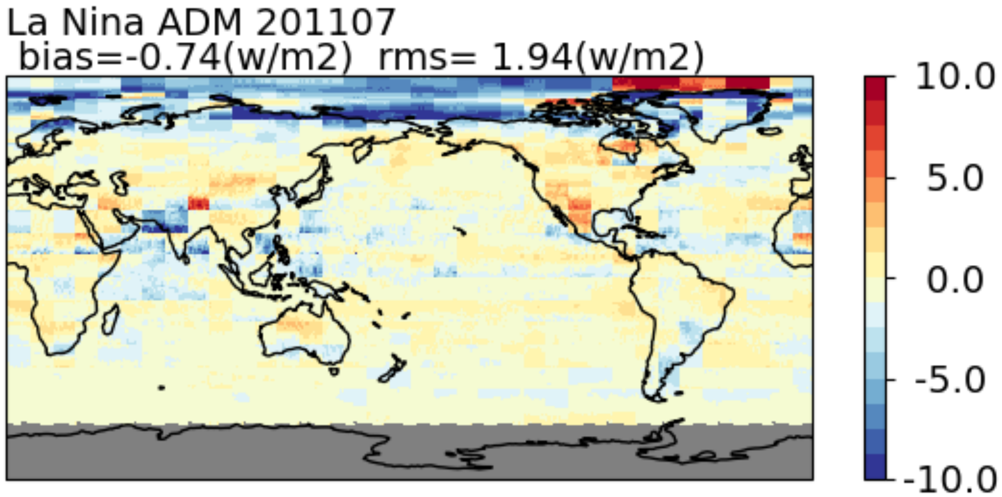


- Flux errors vary by region.
- Flux error patterns are similar for El Niño, La Niña, and neutral phases.

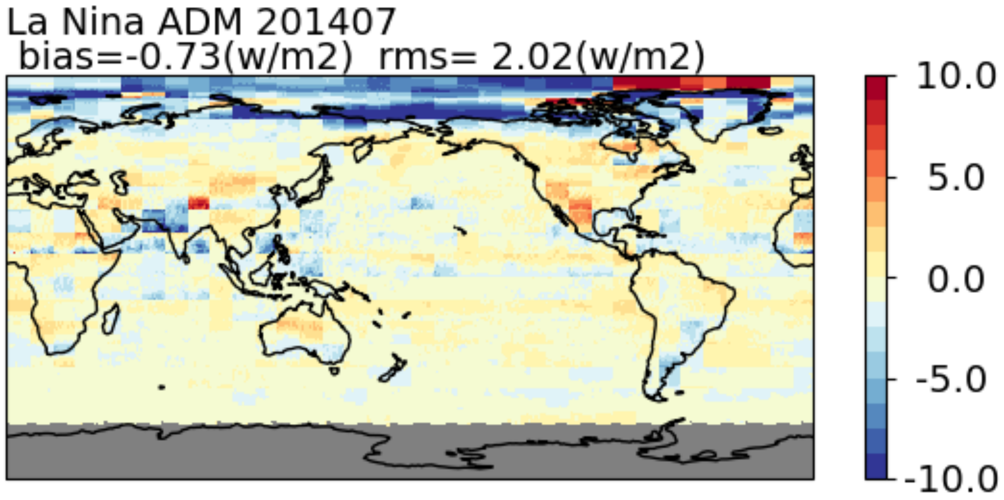
Direct integration SW flux errors
(flux from La Niña ADM predicted radiance – flux from observed radiance ADM)



MEI= **1.7**



MEI= **-0.9**

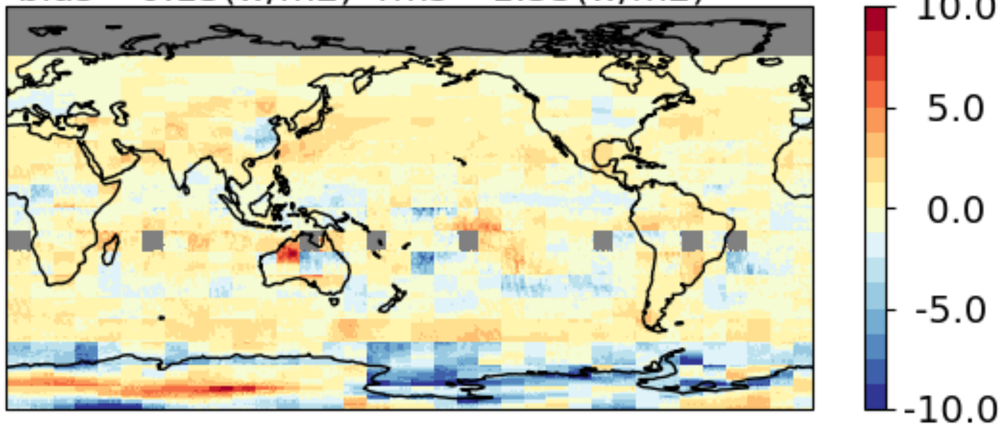


MEI= 0.3

- Flux errors vary by region.
- Flux error patterns are similar for El Niño, La Niña, and neutral phases.

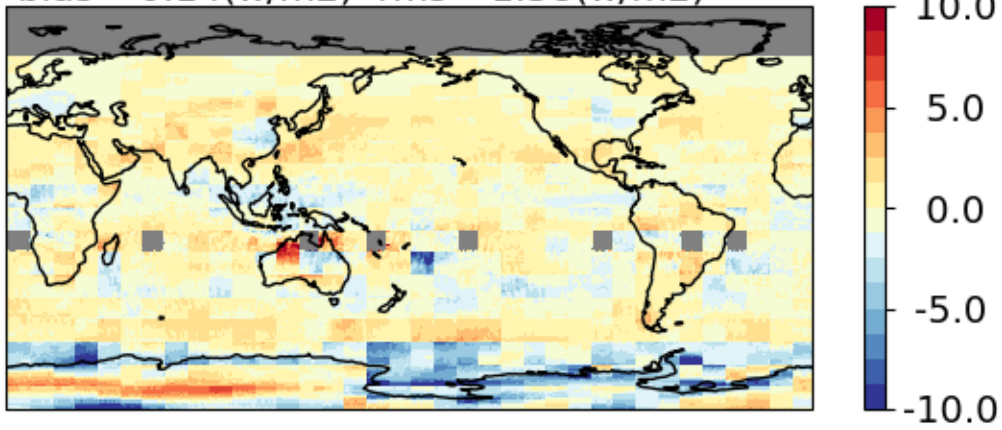
Direct integration SW flux errors
(flux from El Niño ADM predicted radiance – flux from observed radiance ADM)

El Nino ADM 201601
bias=-0.13(w/m2) rms= 1.55(w/m2)



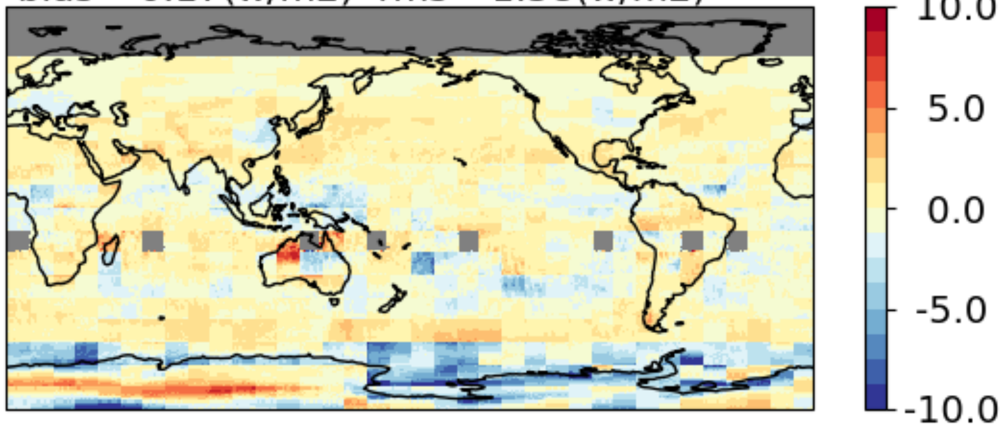
MEI= 2.0

El Nino ADM 201101
bias=-0.14(w/m2) rms= 1.58(w/m2)



MEI= -1.8

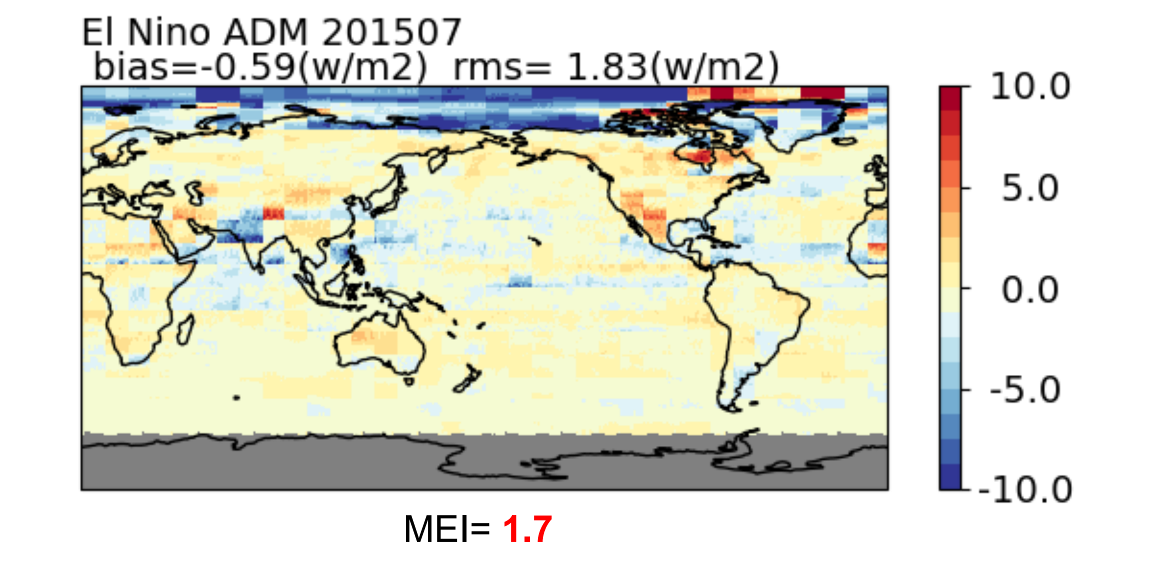
El Nino ADM 201401
bias=-0.17(w/m2) rms= 1.58(w/m2)

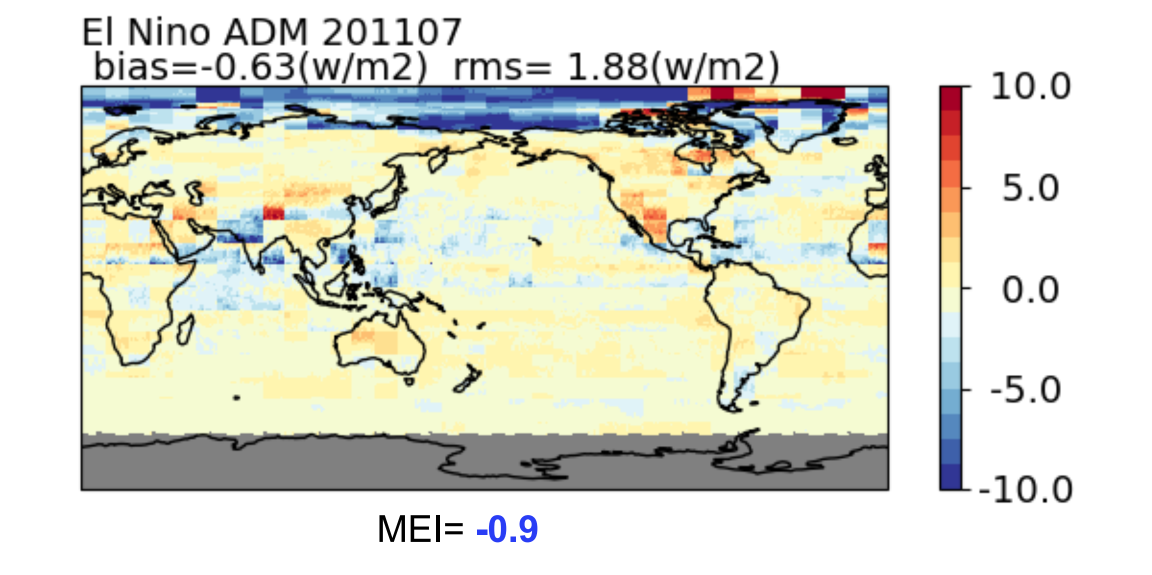


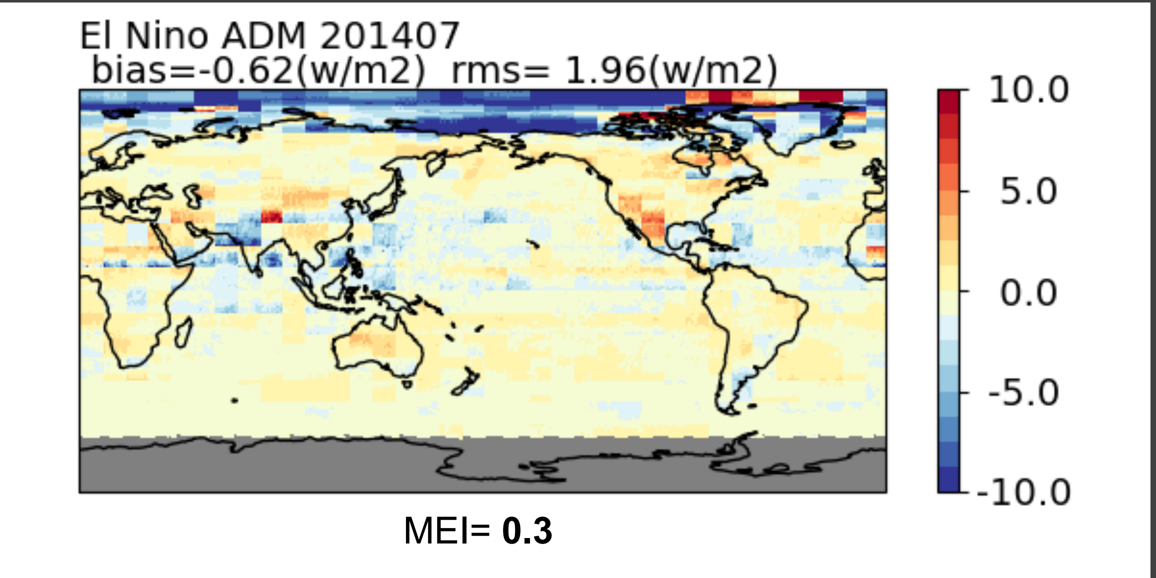
MEI= -0.5

- Flux errors vary by region.
- Flux error patterns are similar for El Niño, La Niña, and neutral phases.

Direct integration SW flux errors
(flux from El Niño ADM predicted radiance – flux from observed radiance ADM)

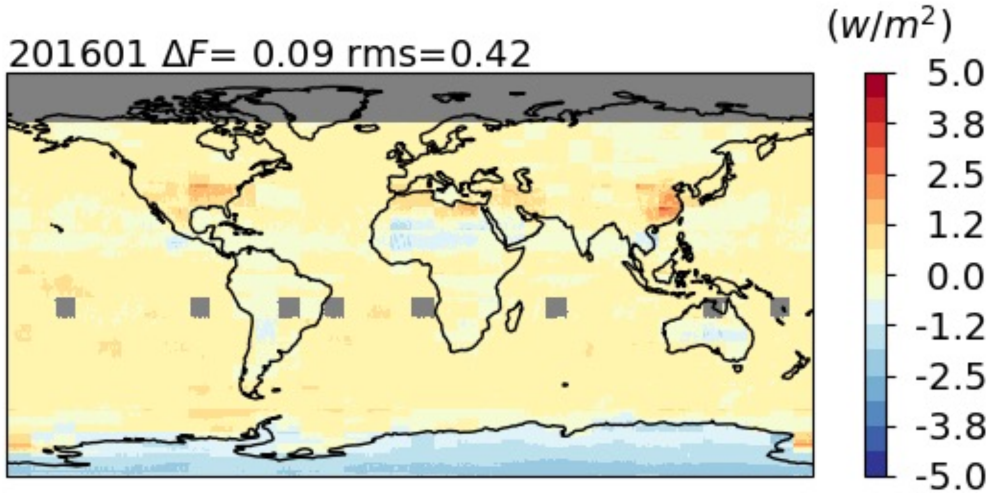




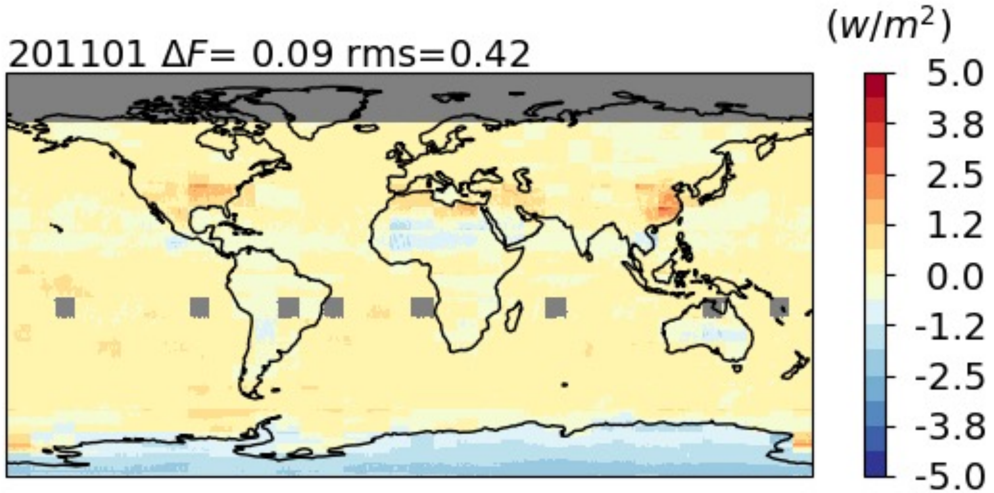


- Flux errors vary by region.
- Flux error patterns are similar for El Niño, La Niña, and neutral phases.

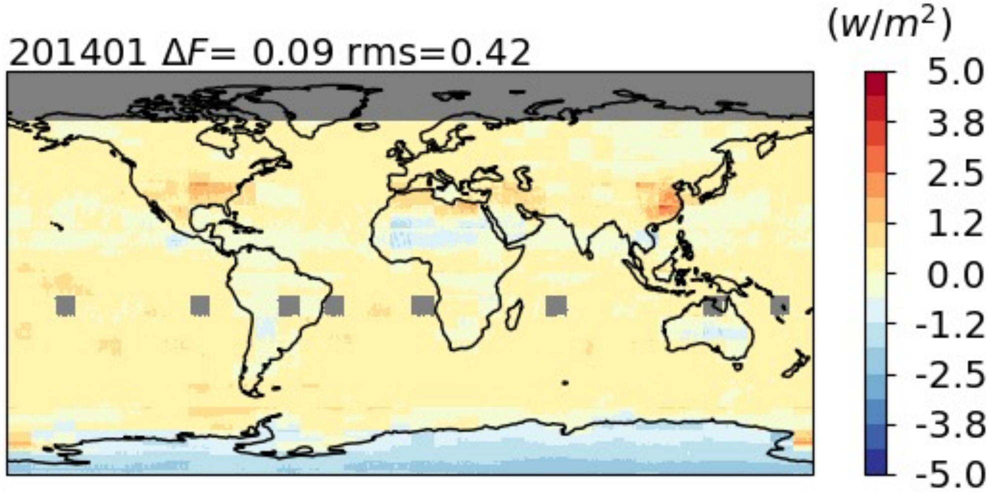
Direct integration flux differences
(flux from "El Niño ADMs" – flux from "La Nina ADMs")



MEI= **2.0**



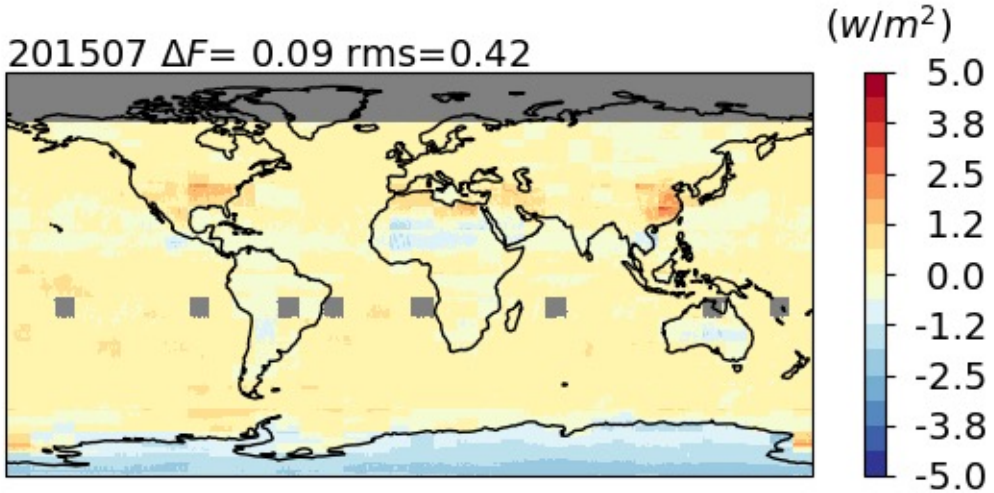
MEI= **-1.8**



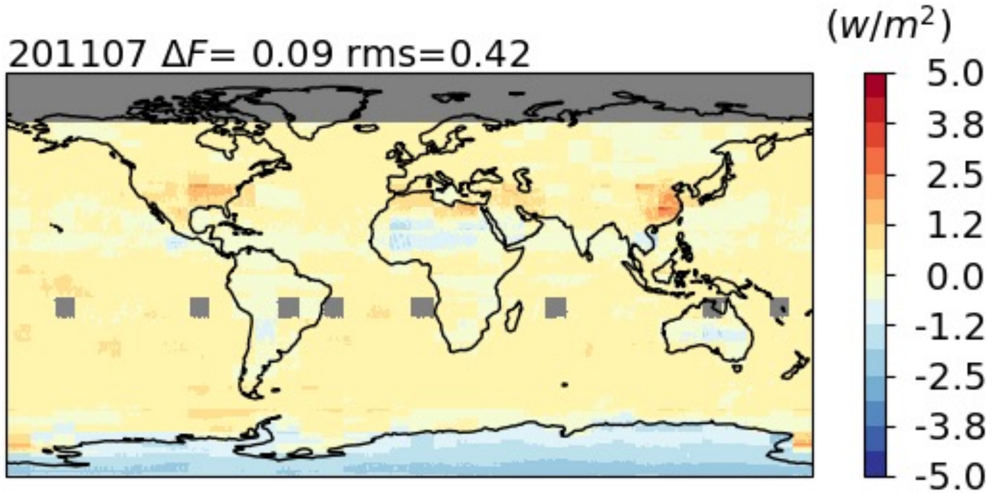
MEI= **-0.5**

- Flux differences vary by region.
- Flux difference patterns are similar for El Niño, La Niña, and neutral phases.

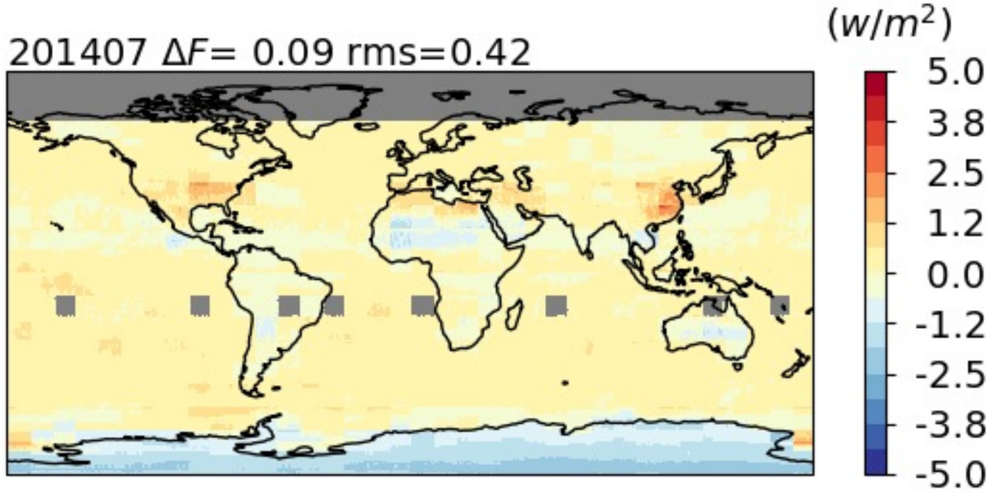
Direct integration flux differences
(flux from “El Niño ADMs” – flux from “La Nina ADMs”)



MEI= **1.7**



MEI= **-0.9**

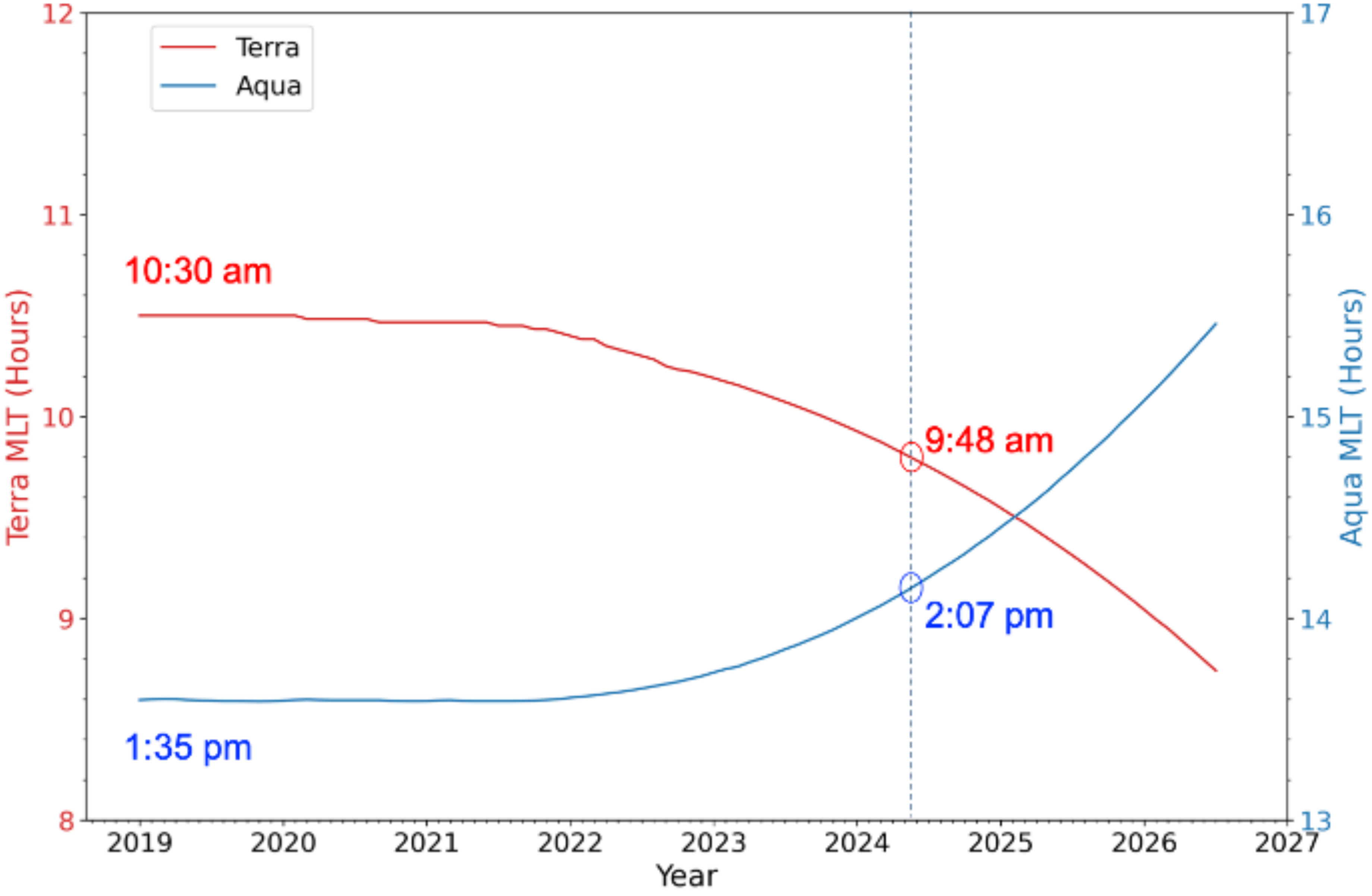


MEI= **0.3**

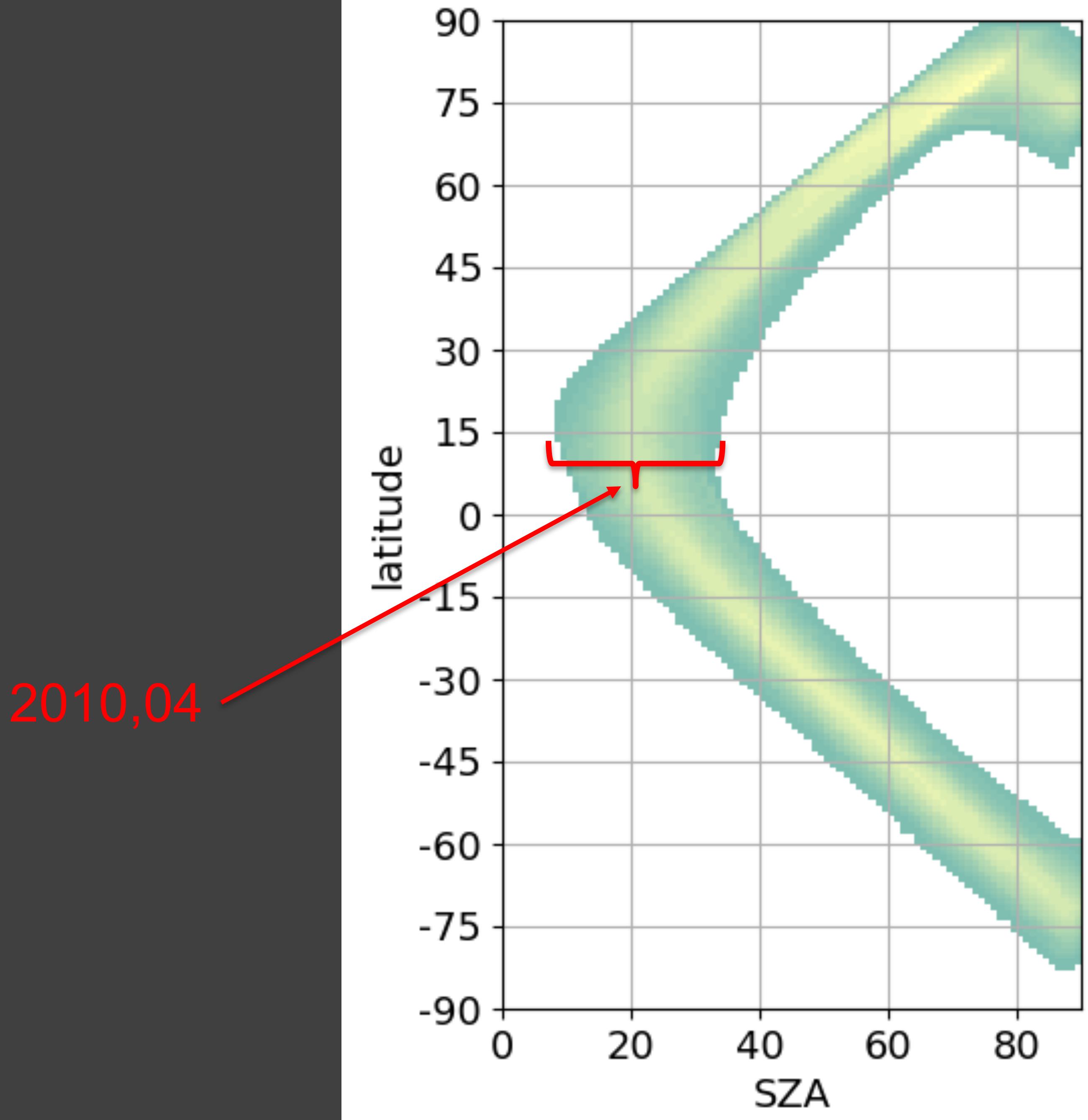
- Flux differences vary by region.
- Flux difference patterns are similar for El Niño, La Niña, and neutral phases.

Impact of Terra orbital drifting on SW CERES ADMs

Terra and Aqua Mean Local Equatorial Crossing Times (MLTs)



- **MLT updates available at: https://terra.nasa.gov & https://aqua.nasa.gov**


90
75
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30
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0
-15
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-75
-90
latitude
0
20
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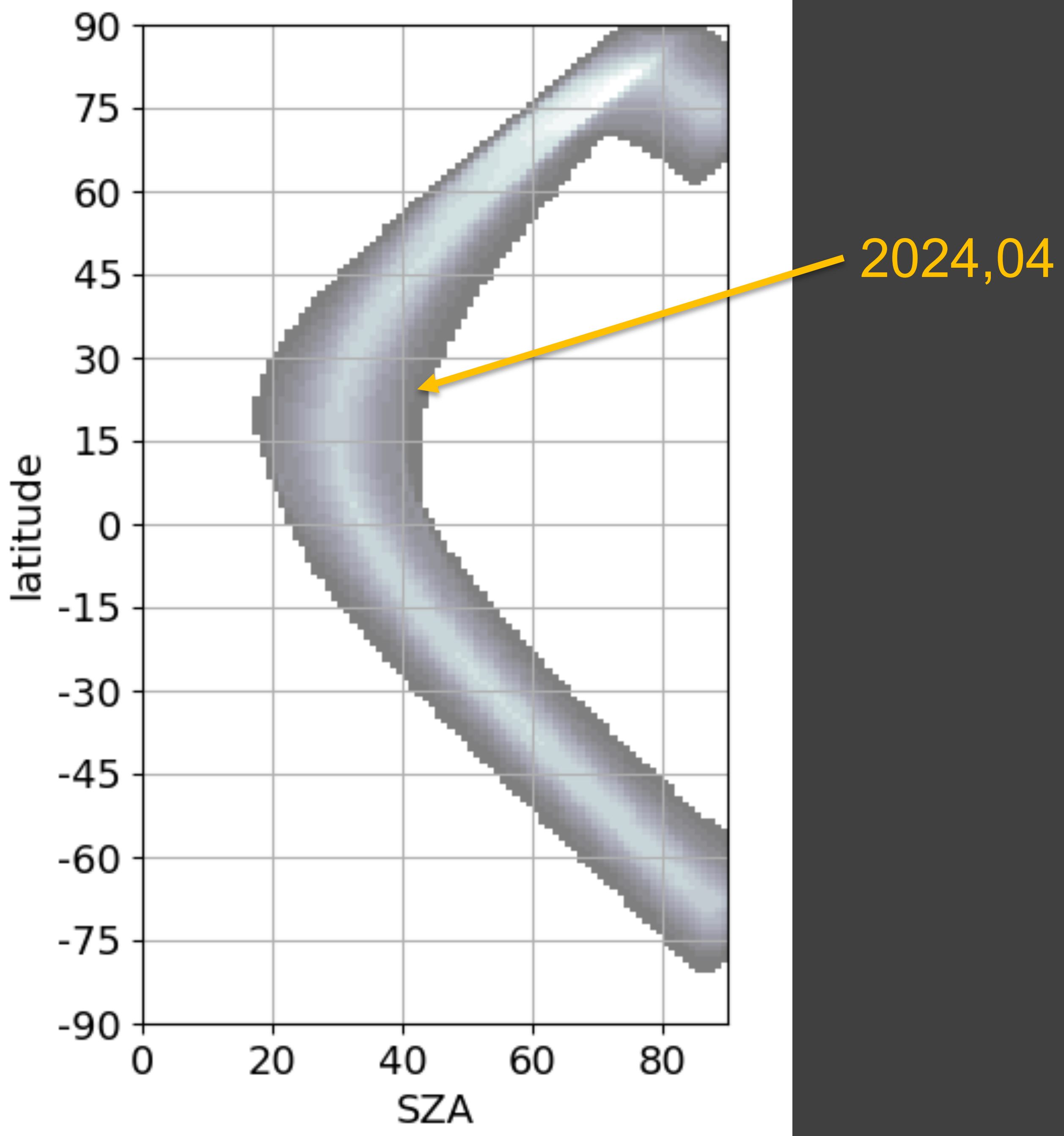
60
80
SZA
2010,04



2024,04
latitude
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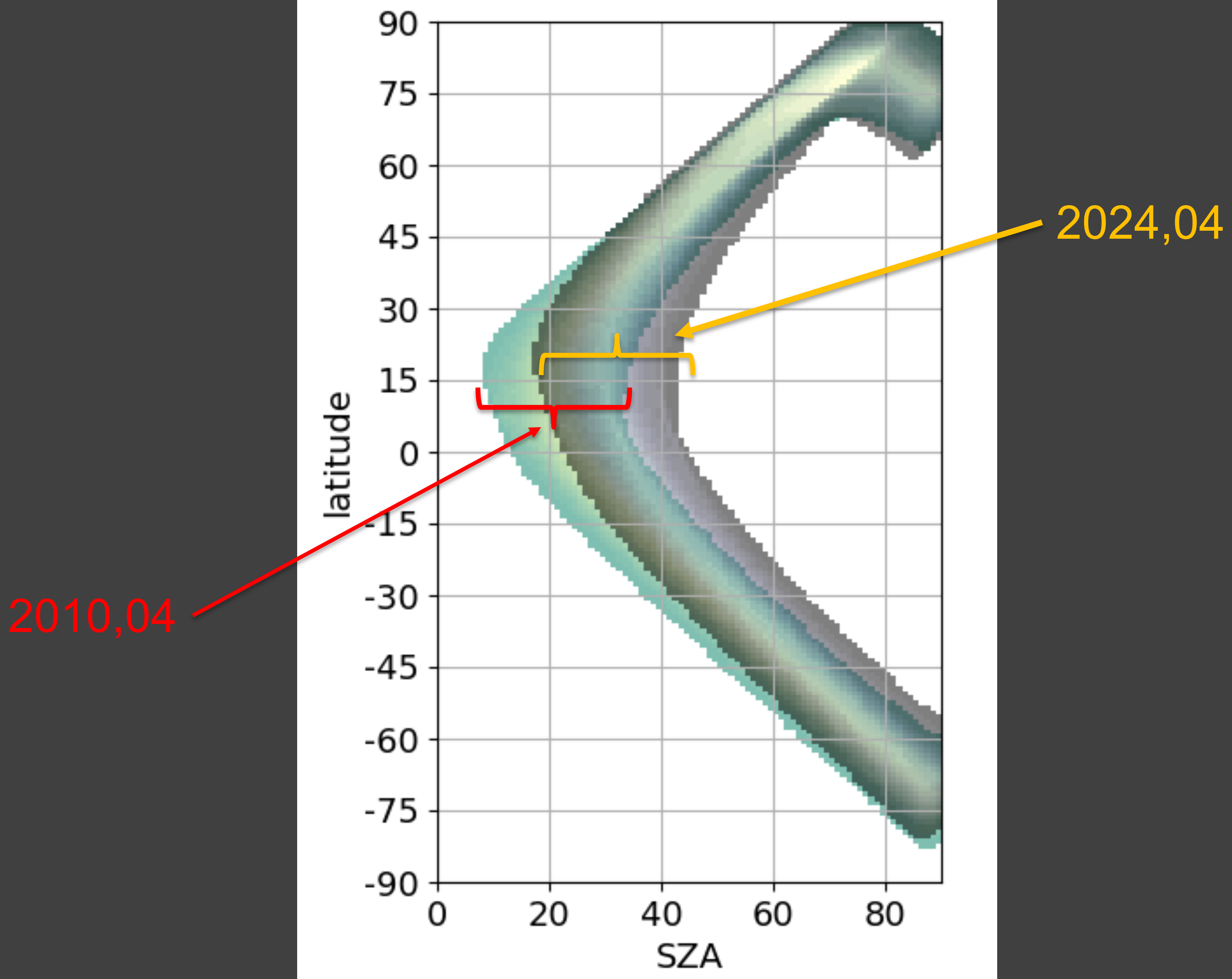

2024,04
2010,04
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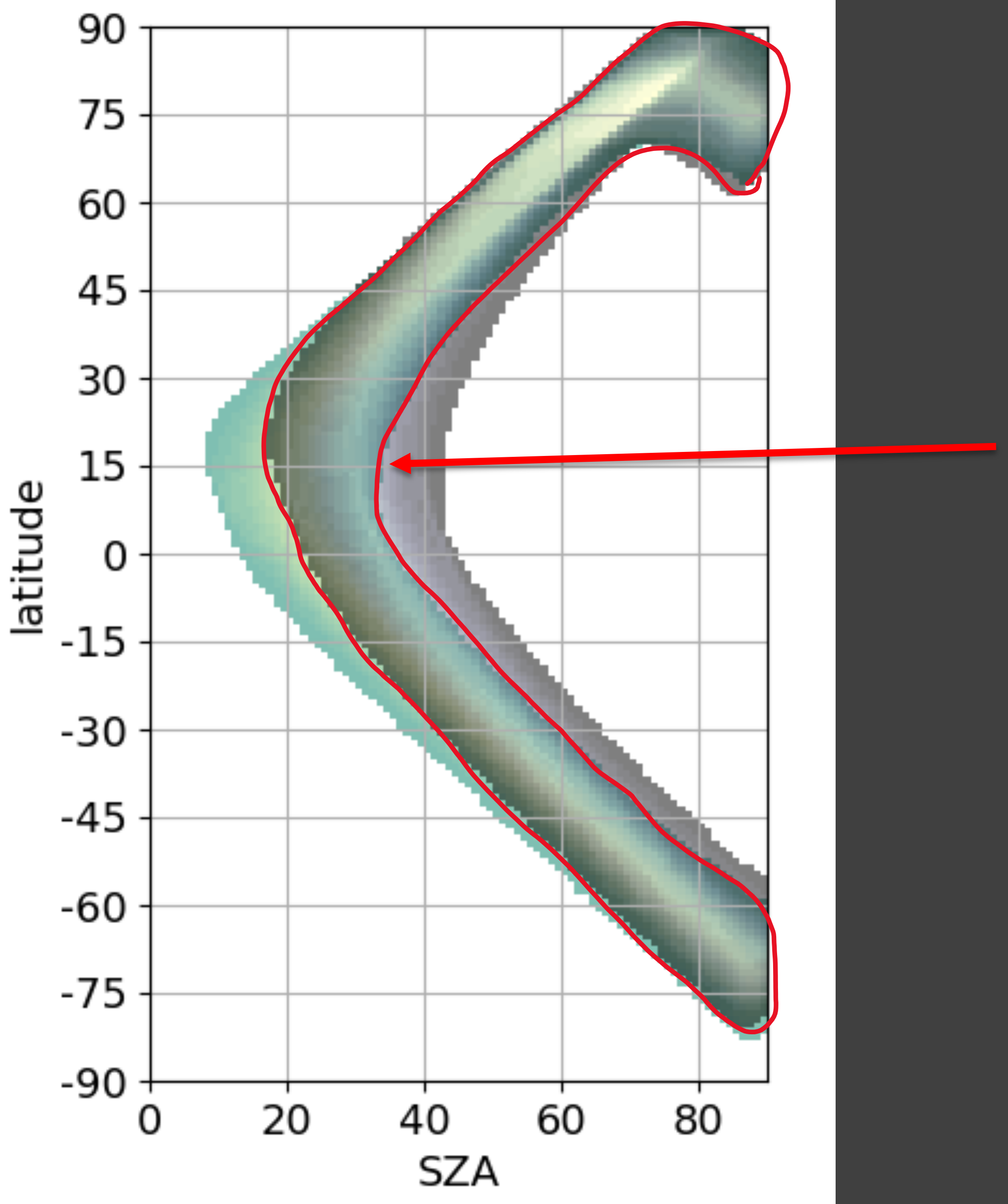
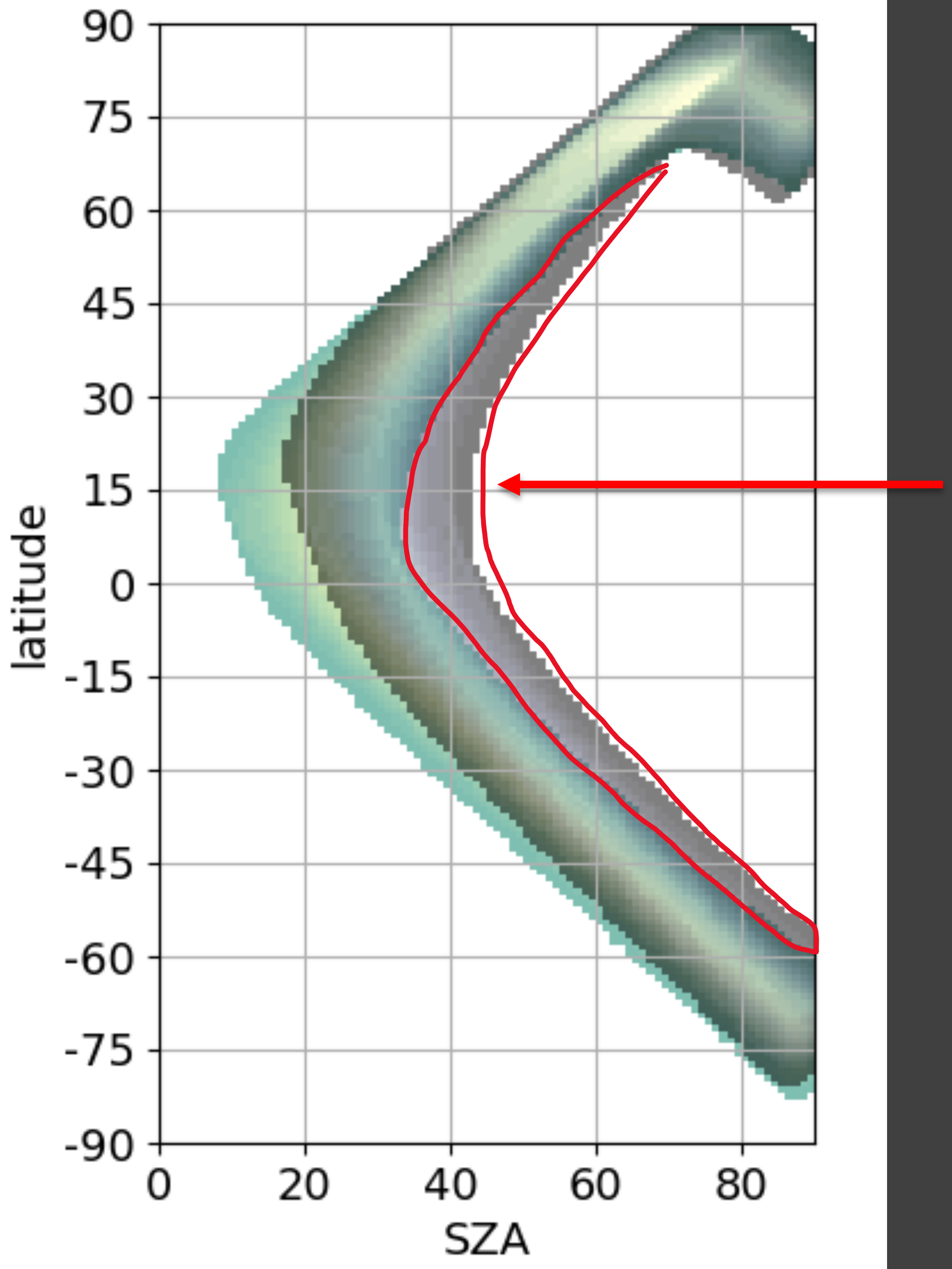


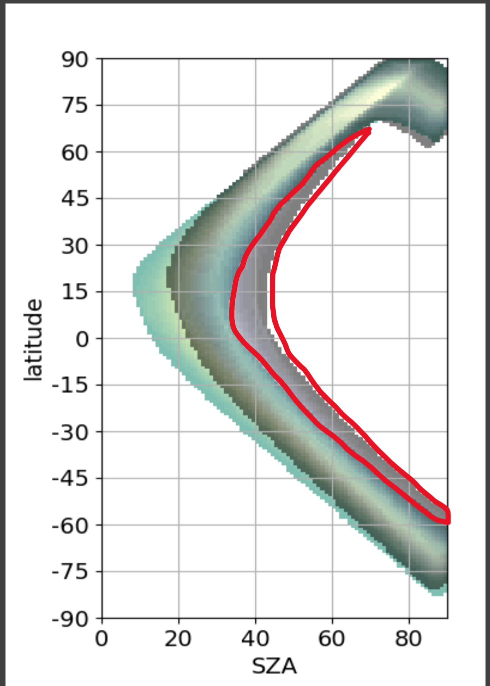
SZAs are seen in both April 2010 and April 2024



Larger SZAs are only seen in 2024 but not in April 2010.

ADMs

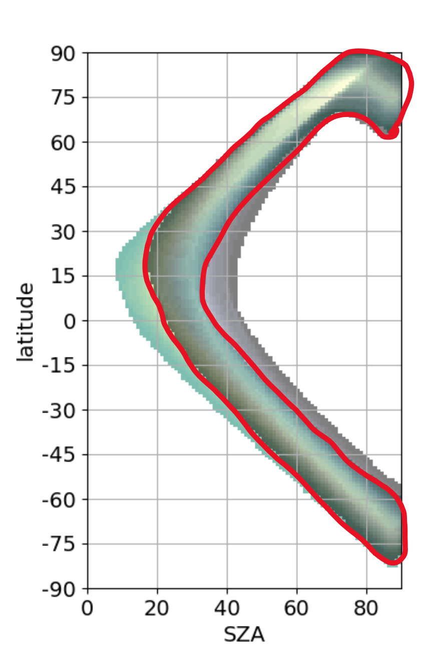
- Terra Edition 4 ADMs were constructed from cross-track and RAPS data from April 2000 to May 2005.
- A set of new SW ADMs is constructed by adding additional ~2.5 years of Terra-FM2 RAPS data from Nov 2021 to Apr 2024.
- Compare fluxes derived from the two sets of ADMs for data with larger SZAs seen in April 2024 but not in Apr 2010.

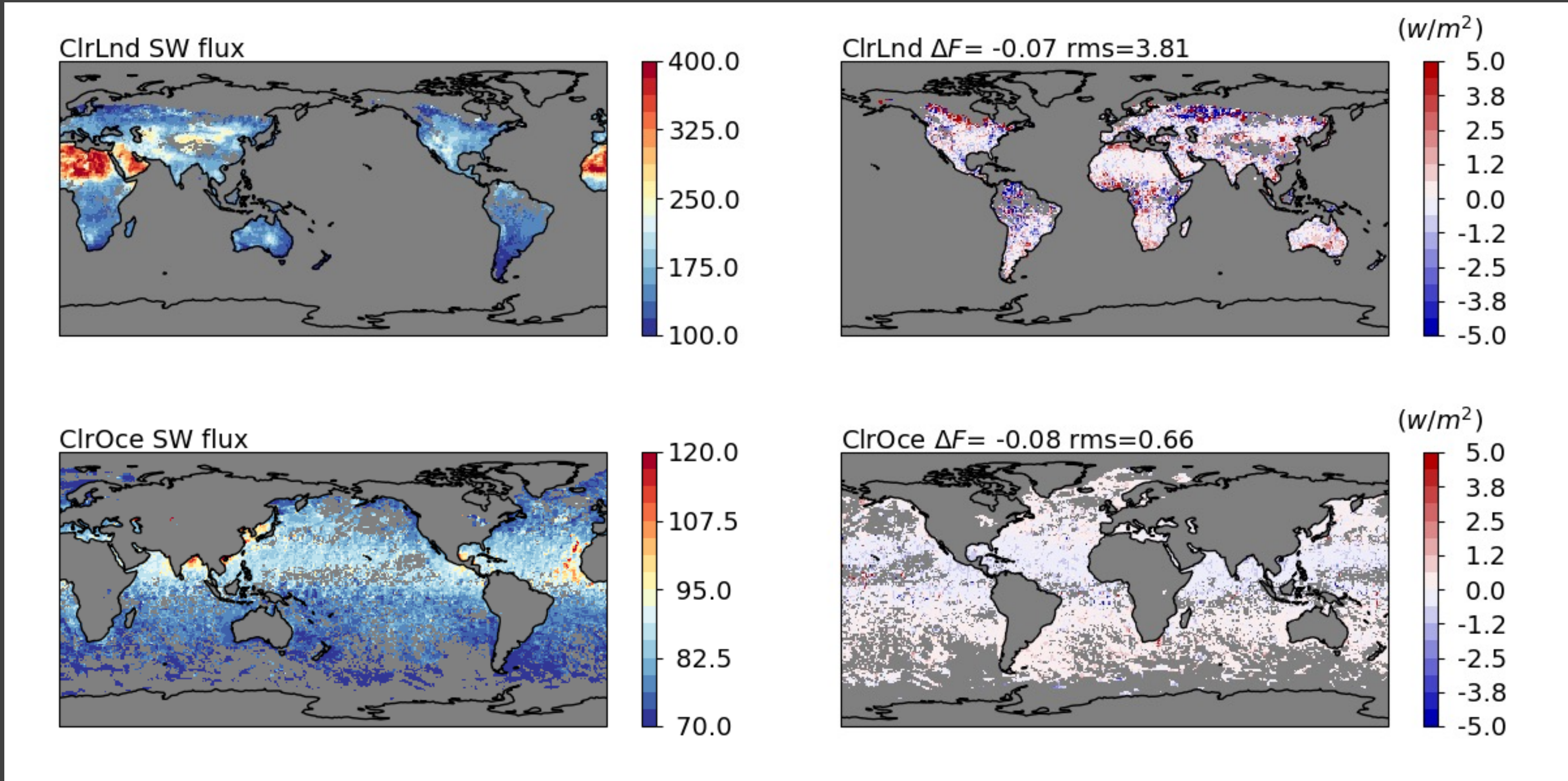


Clear-sky Fluxes and differences
data with SZAs covered in both April 2010 and April 2024

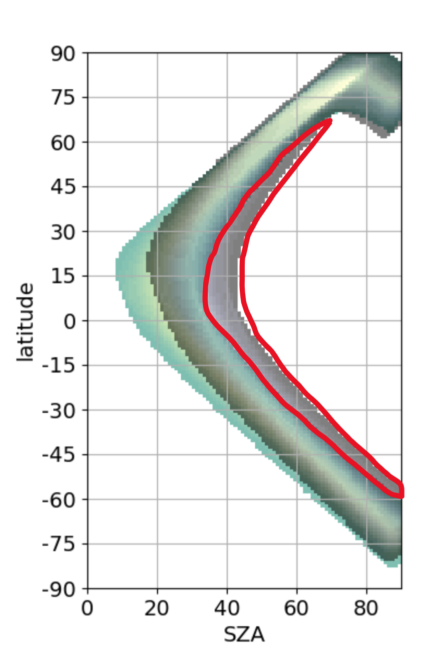
Flux by Ed4 ADMs

New ADMs- Ed4 ADMs



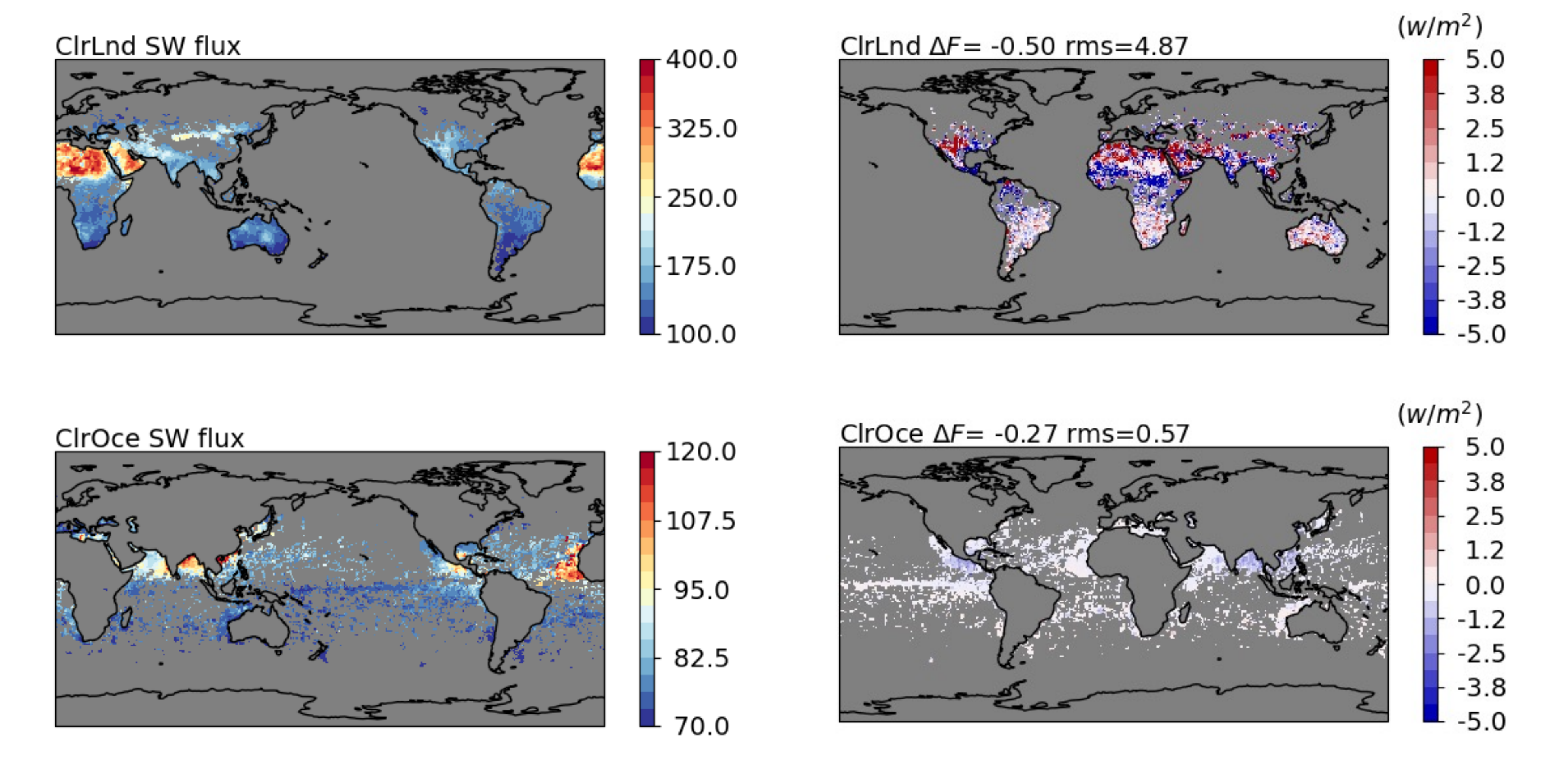


Clear-sky fluxes and differences
data with larger SZAs covered in April 2024 but not in April 2010



By Ed4 ADMs

New ADMs- Ed4 ADMs



Why do we see large differences for clear-sky land?

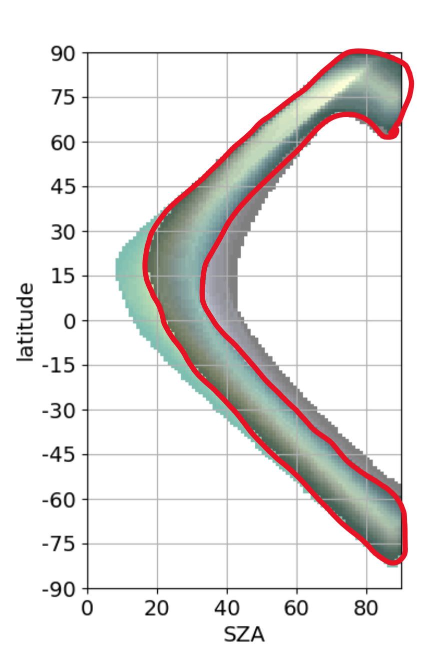
- Within each 1x1-degree region, ADMs are available for SZA-NDVI bins.

example	**SZA bins**				**ADM selection**		
	Bin1	Bin2	Bin2	Bin4	Step1	Step2	step3
Ed4	ΔI_1	ΔI_2			$\min(\Delta I_1, \Delta I_2)$	Searching neighboring grids by $\min(\Delta I_1, \Delta I_2, \ldots, \Delta I_n)$	TRMM
new ADM	ΔI_1	ΔI_2	ΔI_3	ΔI_4	$\min(\Delta I_1, \Delta I_2, \Delta I_3, \Delta I_4)$		

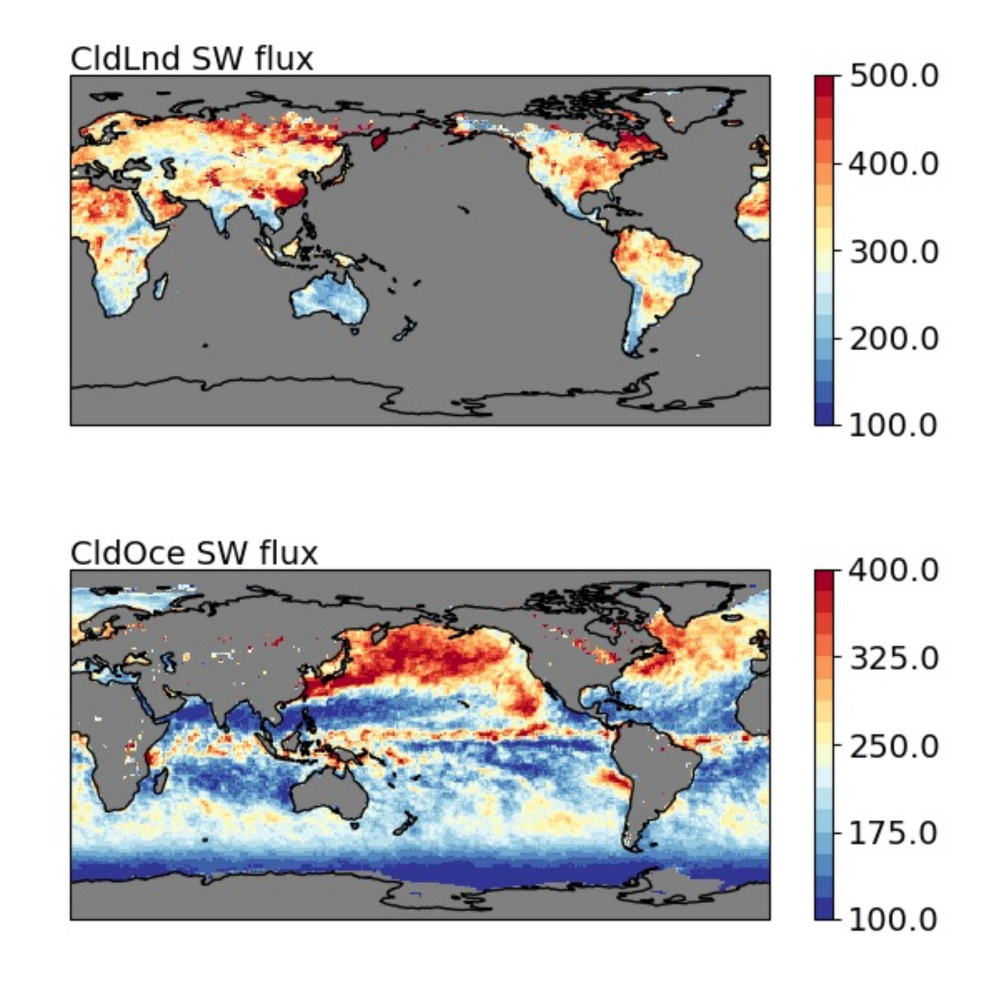
where, ΔI_j is the radiance difference between observed and ADM-predicted

- Given an observation with a large SZA,
- In the Ed4 ADM, ΔI_3 and ΔI_4 are not available; Step 1 fails automatically and Steps 2 and 3 are used instead.
- In the new ADM, ΔI_1 *to* ΔI_4 are available in Step 1.
- The flux differences are caused by the Ed4 ADM using Steps 2 and 3 and the new ADM using Step1.

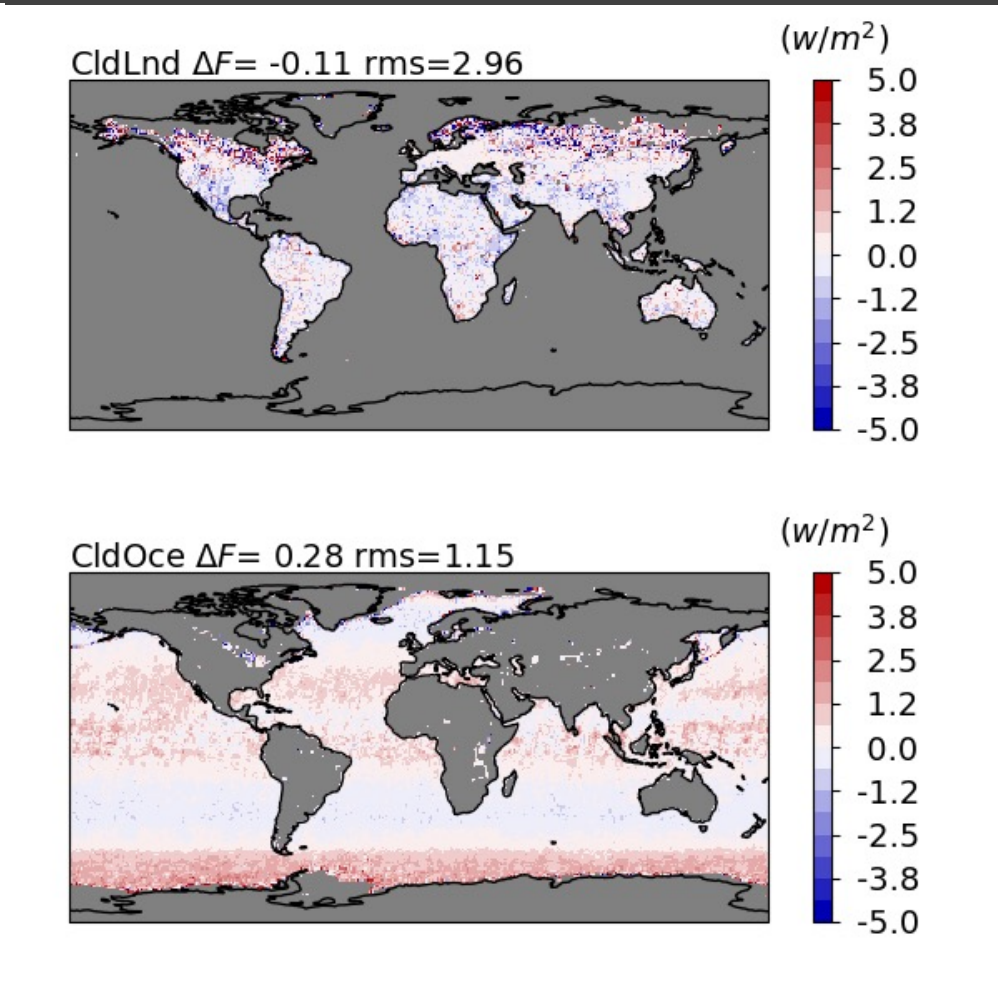
Cloudy-sky Fluxes and differences
data with SZAs covered in both April 2010 and April 2024



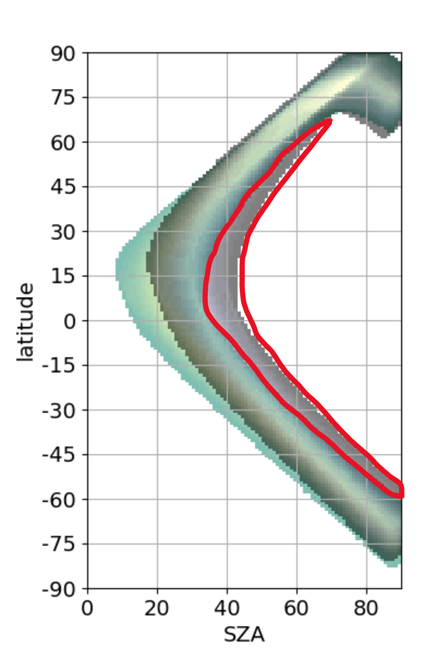
By Ed4 ADMs



New ADMs- Ed4 ADMs

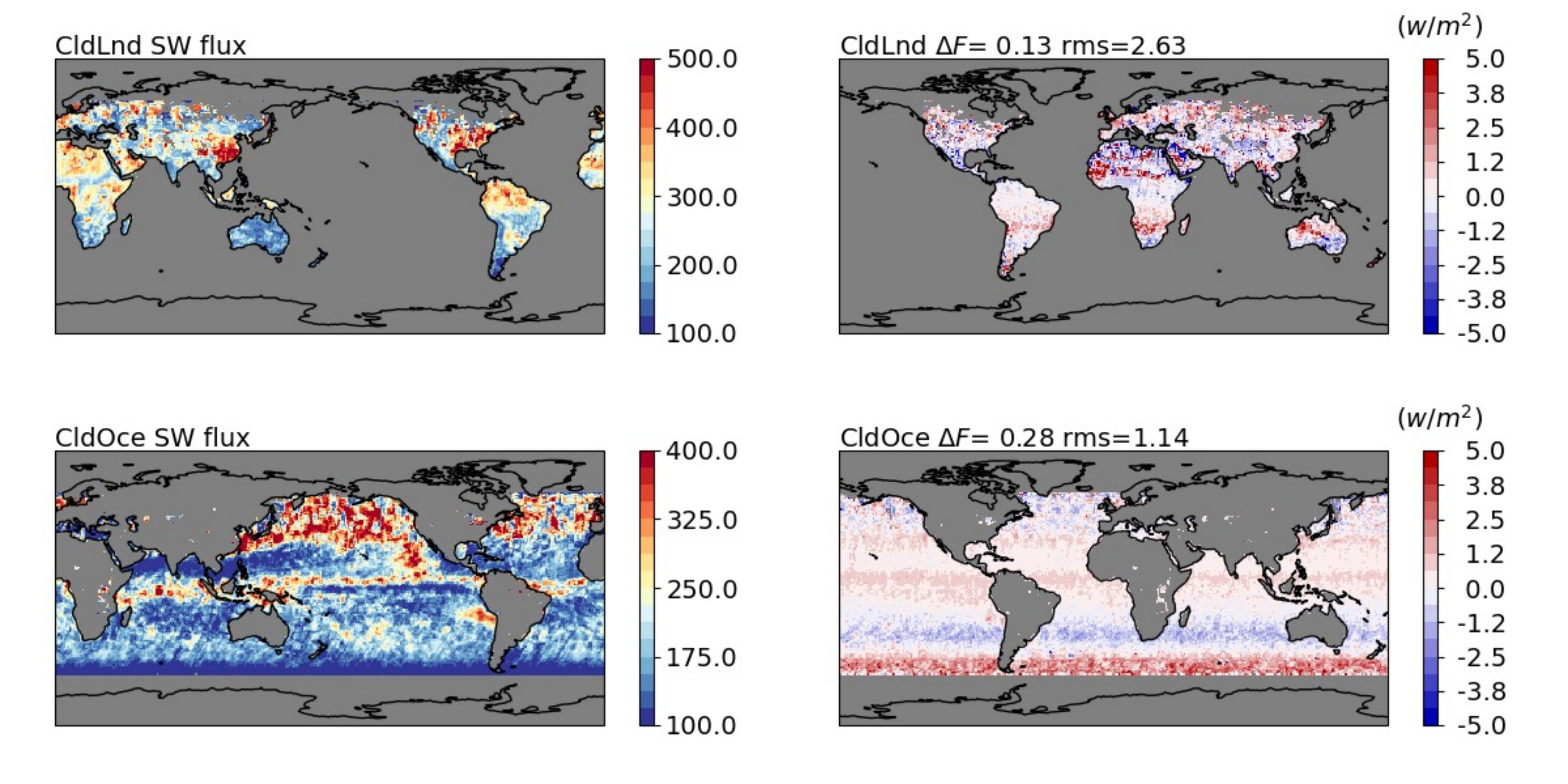


Cloudy-sky fluxes and differences
data with larger SZAs covered in April 2024 but not in April 2010

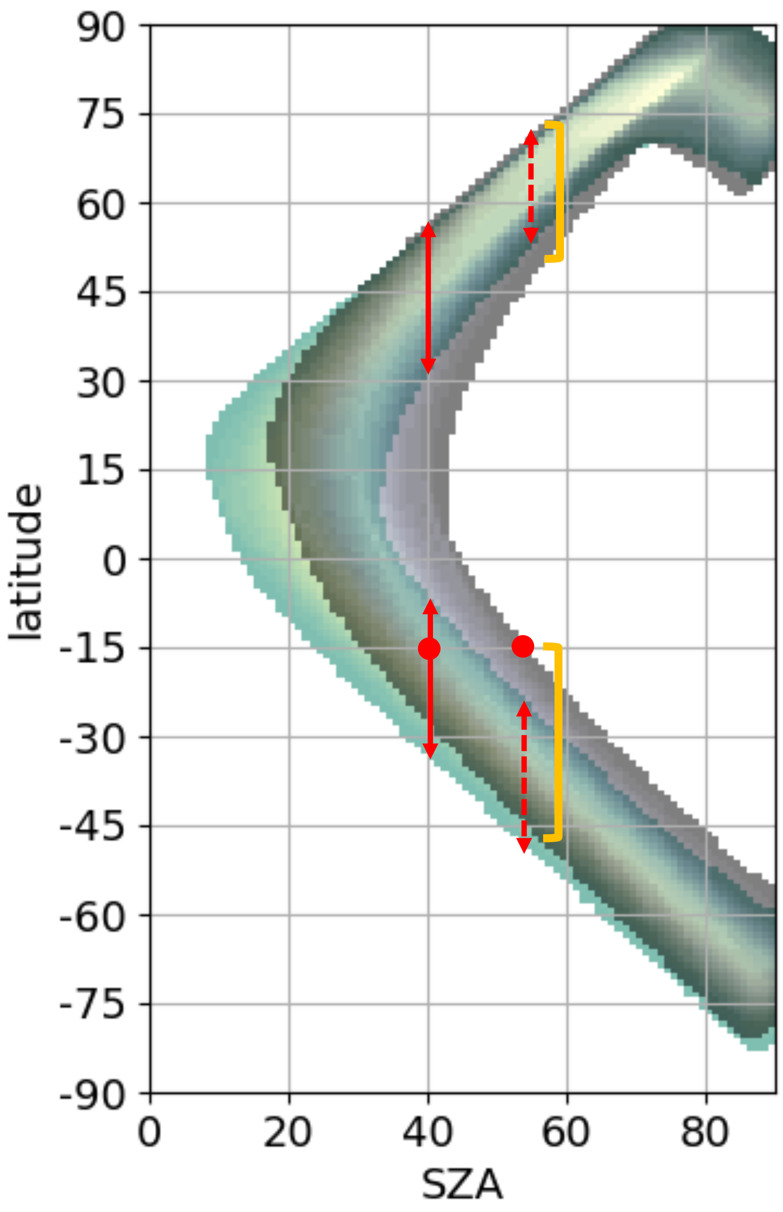


By Ed4 ADMs

New ADMs- Ed4 ADMs



Why do we see large differences for cloudy-sky over ocean?



- SZA correlates to latitude.
- ADM for a SZA bin is constructed by observations at certain latitudinal regions.
- For an observation at 15S with SZA=40 degree, the selected ADM is constructed including observations in regions within ~5-35S and 30-55N in this month.
- For an observation at same latitude with SZA=55 degree, the selected ADM is constructed including observations within 25-50S and 55-70N in the Ed4 ADM.
- But in the new ADM, the selected ADM is constructed including observations within 15-45S and 50-70N.
- The sampling differences cause the flux differences between the two ADMs.

Summary

- Used data taken during different ENSO phases to test SW and LW ADM sensitivity to climate variability.
- LW ADMs constructed using data taken during El Niño phase and La Niña phase have a minimal impact on flux.
- SW fluxes inverted from El Niño and La Niña ADMs show consistent regional difference features that are independent of the ENSO phase of each month.
- Flux inverted by the direct integration approach from El Niño and La Niña ADMs show consistent regional difference features that are independent of the ENSO phase of each month.
- Adding RAPS data during Terra/Aqua orbital drifting period has noticeable impact on flux inversion for clear sky over land and cloud sky over ocean, and less impact over clear sky over ocean and cloudy sky over land.