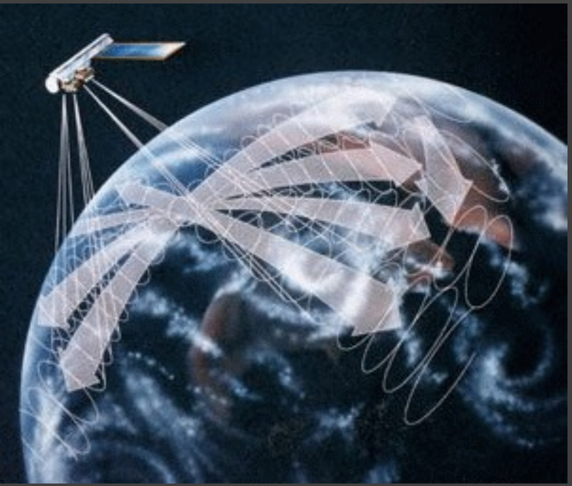

CERES Angular Distribution Model Working Group Report

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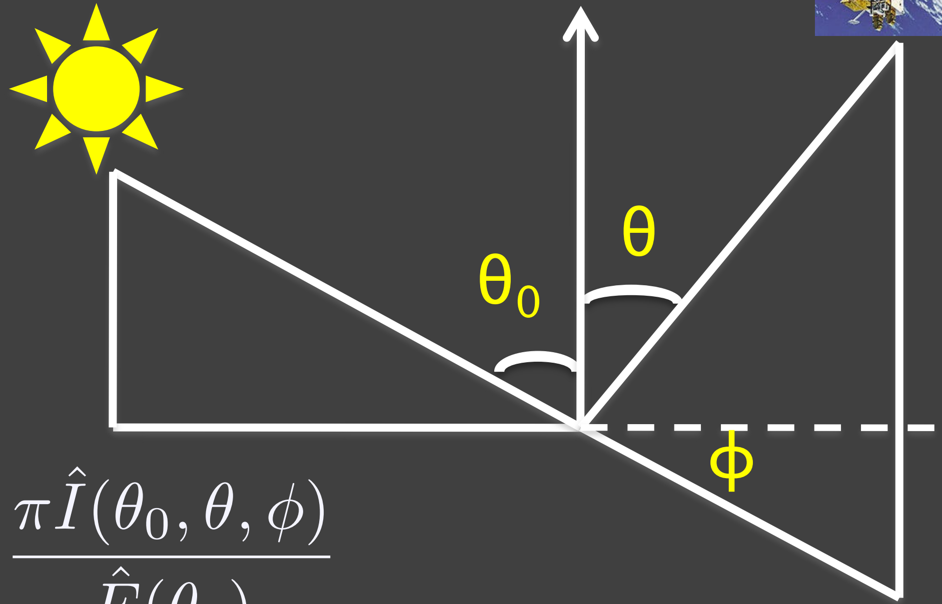
From radiance to flux: angular distribution models



- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type:

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

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

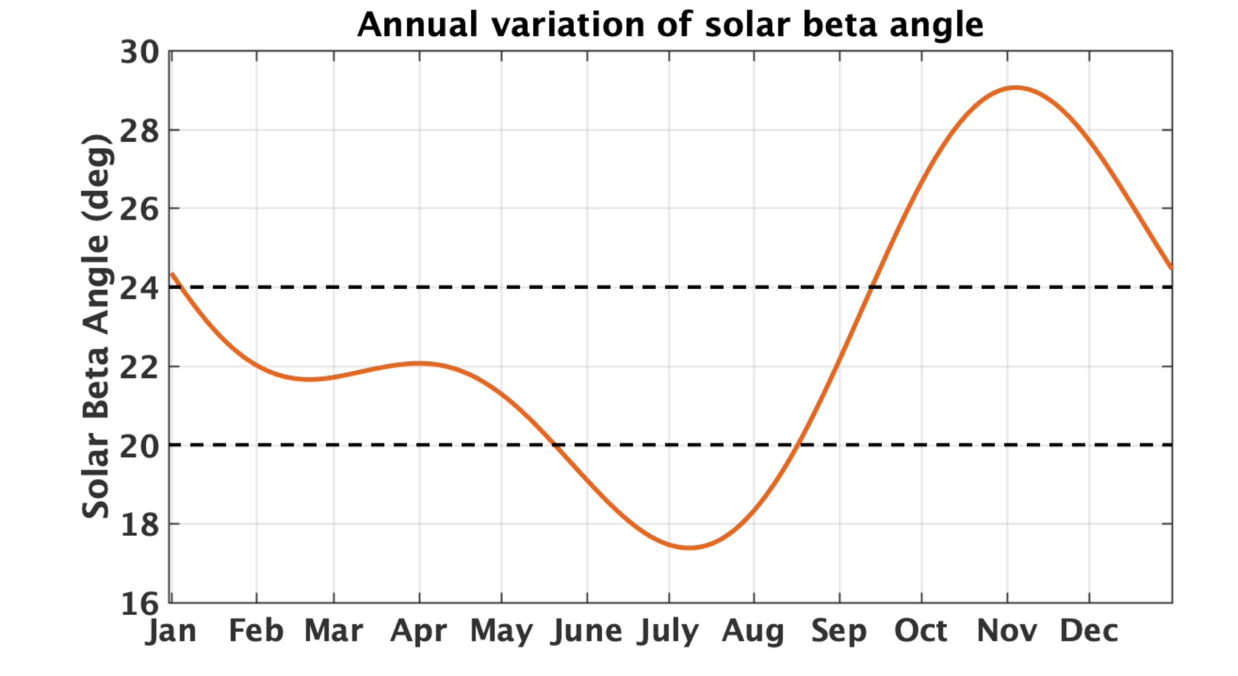
$$F(\theta_0) = \frac{\pi I_o(\theta_0,\theta,\phi)}{R(\theta_0,\theta,\phi)}$$

Outline

- CERES NPP SW and LW ADMs and their impact on inverted fluxes
- Sensitivity of CERES ADMs to different climate states
- Proposed improvement for Ed5 CERES ADMs

NPP CERES ADMs

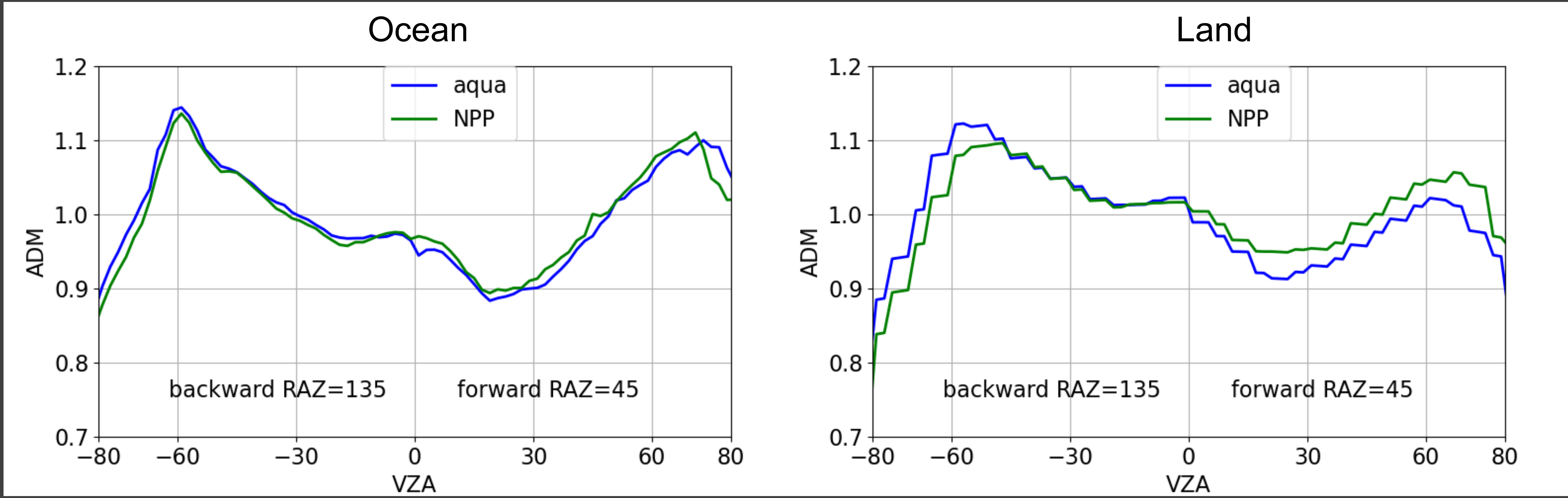
- NPP FM5 started to collect RAPS data in fall of 2019.
- CERES instrument on NPP is in biaxial scan since March 24, 2020, to avoid viewing the spacecraft antenna, and to minimize the instrument degradation.
  - For solar beta angle < 24° :
    Clock angle: 25° — 169° , cone angle: 0° — 64°
    Clock angle: 205° — 349° , cone angle: 0° — 64°
  - For solar beta angle ≥ 24°
    Clock angle: 25° — 180° , cone angle 0° — 64°
    Clock angle: 205° — 360° , cone angle 0° — 64°



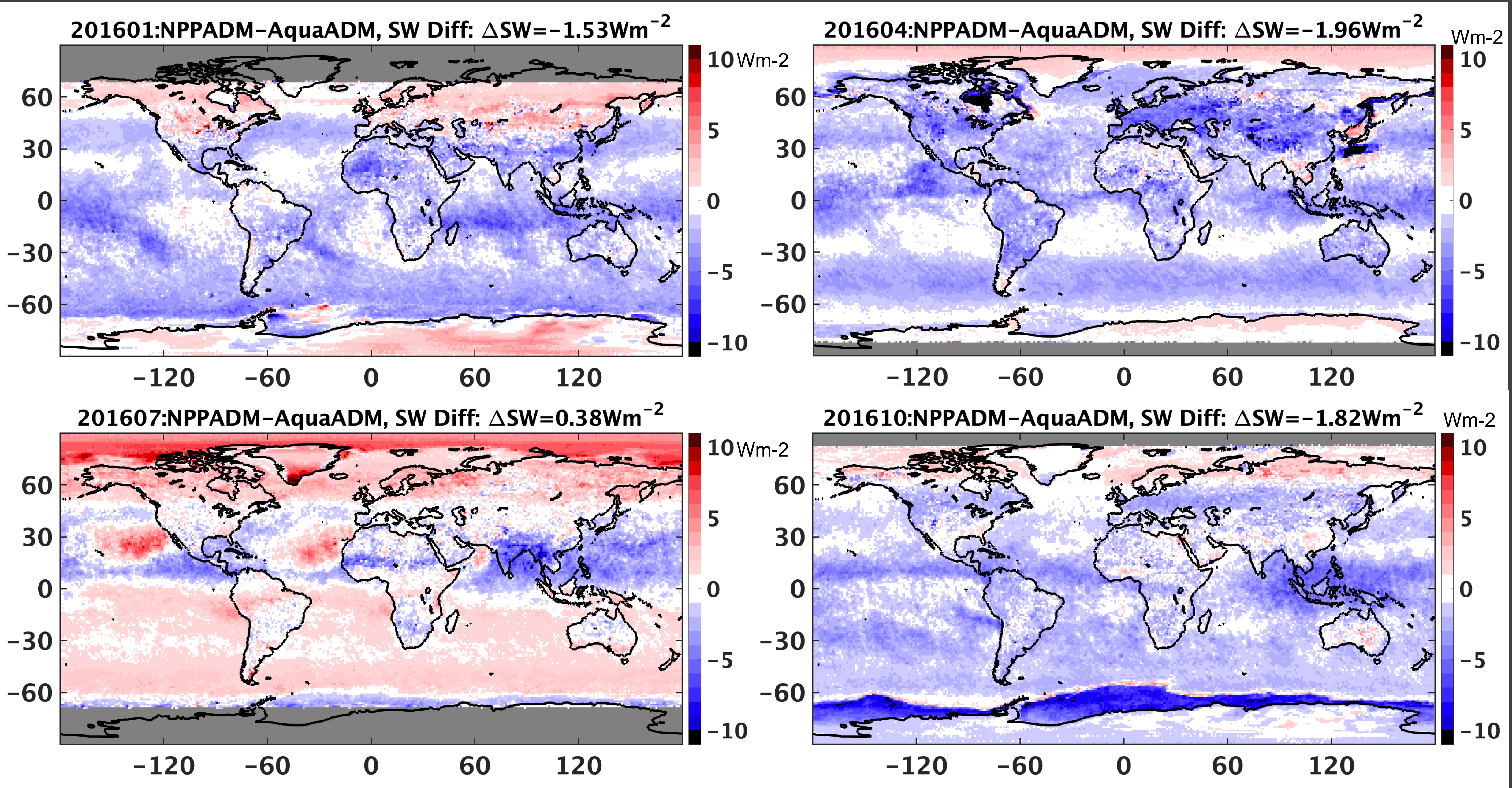
Developing NPP SW ADMs

- Using NPP FM5 Ed2A data from 201601-202307 to develop NPP SW and LW ADMs using the Ed4 Terra/Aqua methodology.
- NPP fluxes inverted using NPP ADMs are compared with fluxes in NPP Ed2A product that used Ed4 Aqua ADMs.

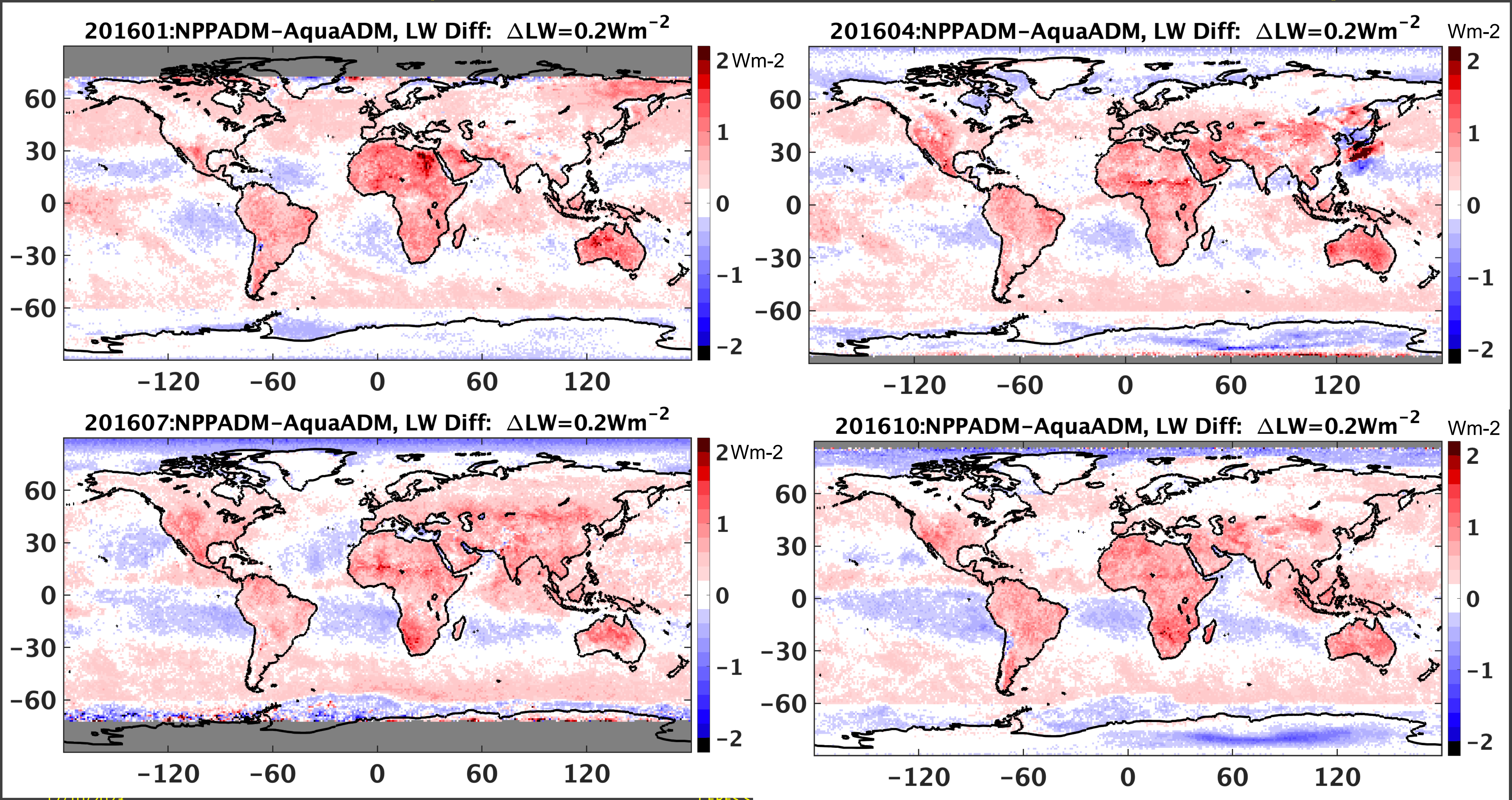
SZA=40° Overcast with cloud optical depth of 10



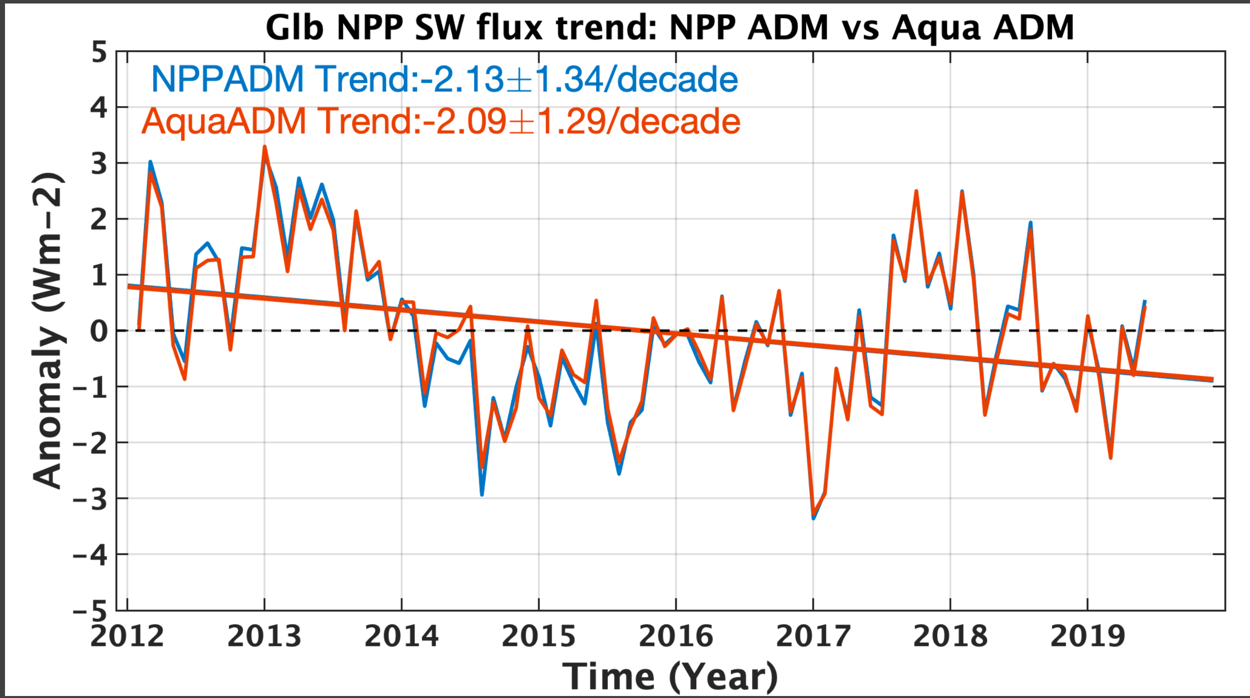
Instantaneous NPP SW flux difference due to ADMs: NPP ADM-Aqua ADM

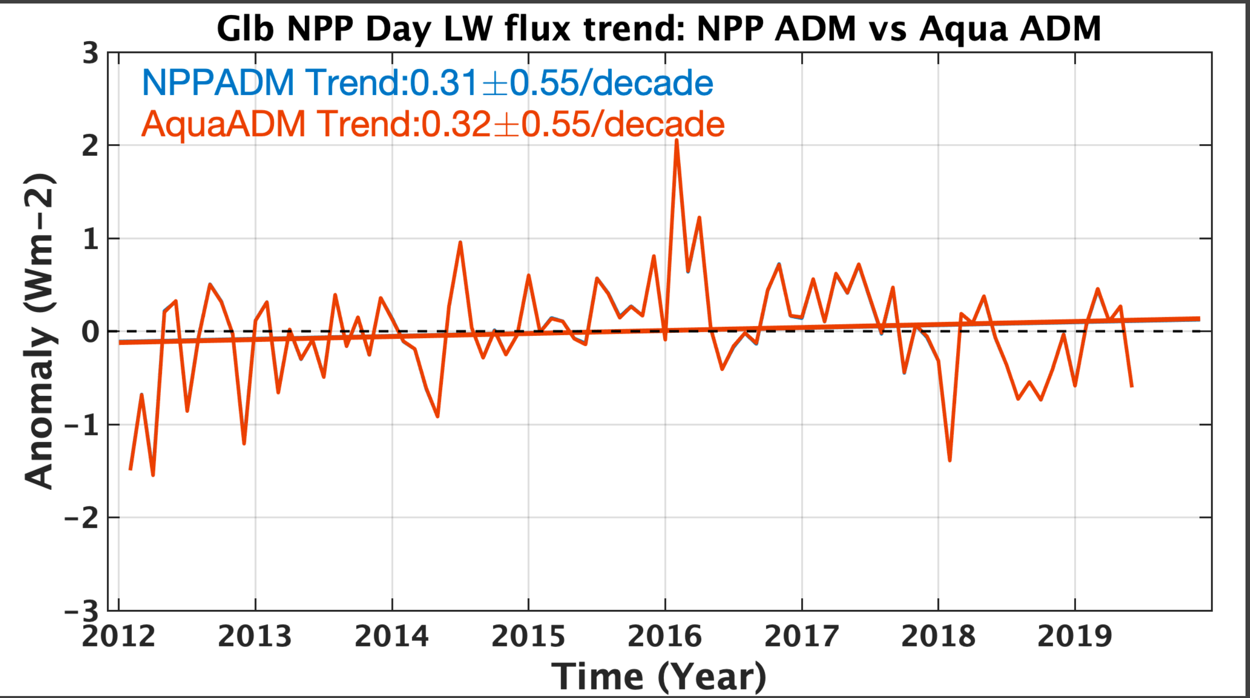


Instantaneous NPP daytime LW flux difference due to ADMs: NPP ADM-Aqua ADM

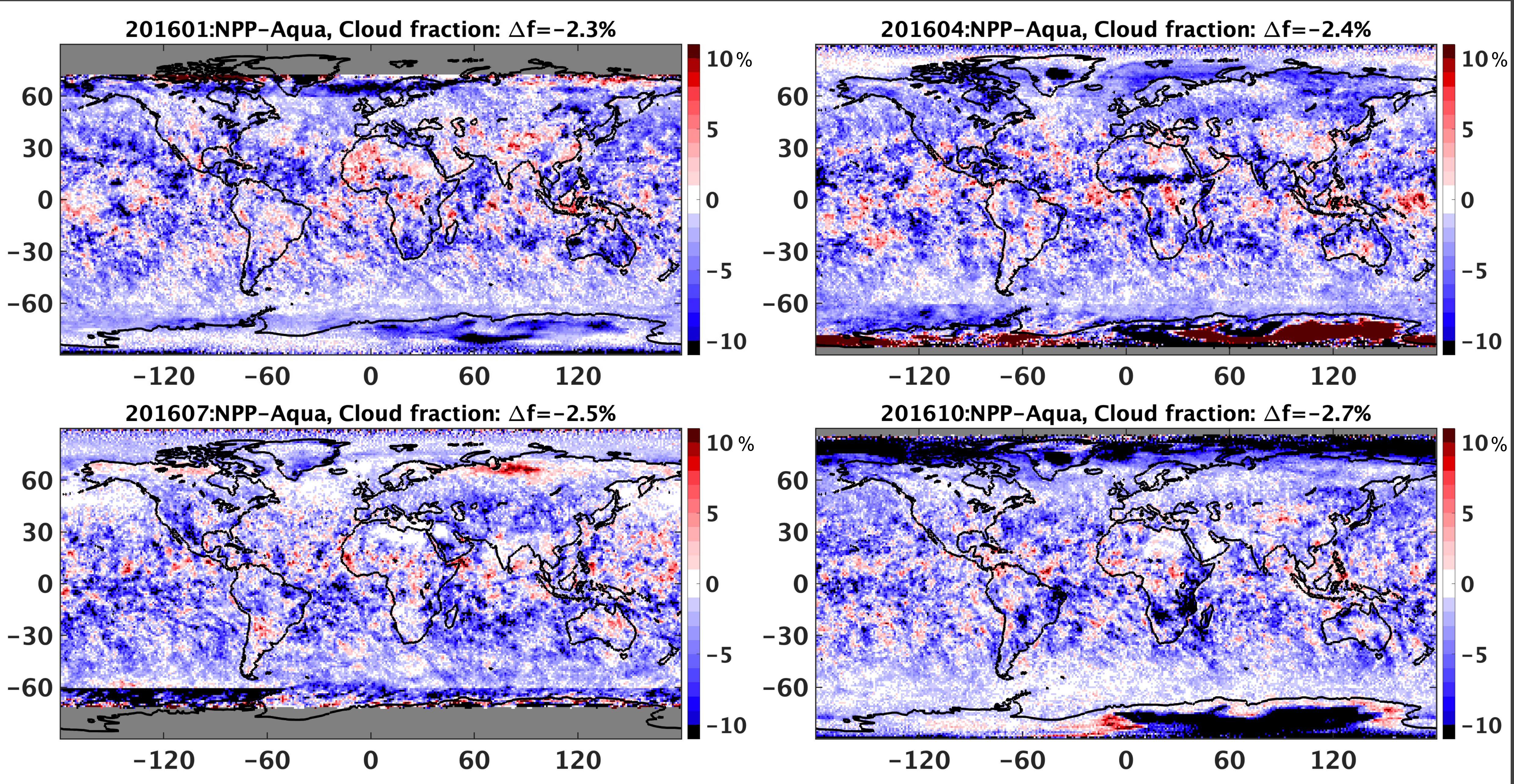


NPP instantaneous flux trends from NPP ADMs and Aqua ADMs are almost identical

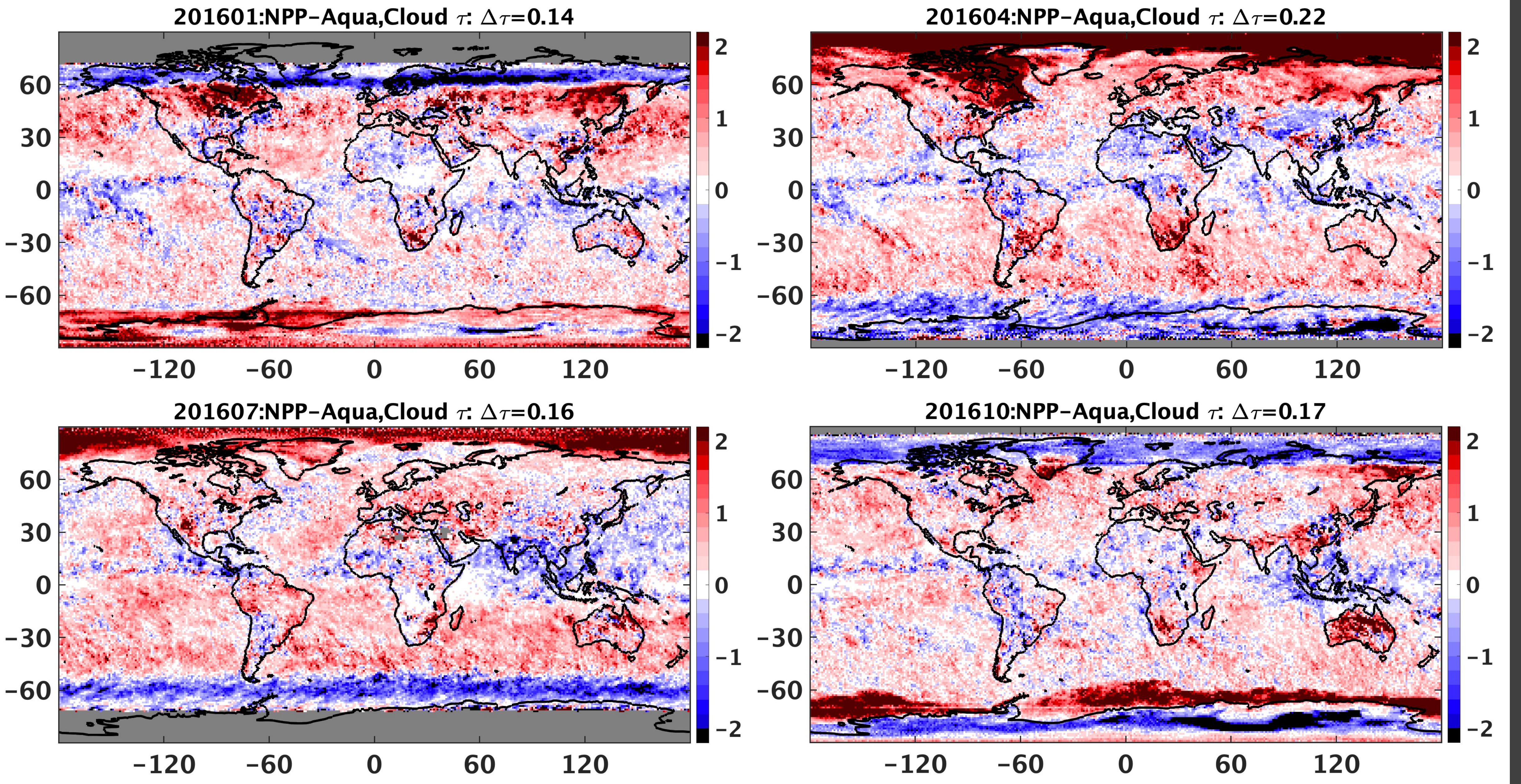




Daytime cloud fraction difference between NPP and Aqua

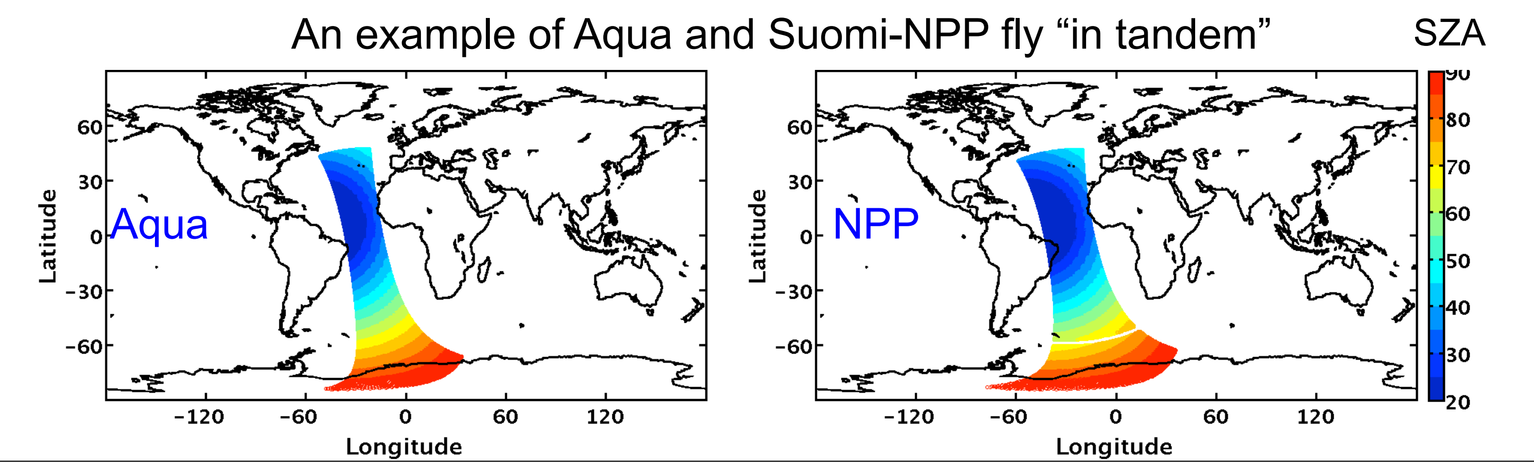


Daytime cloud optical depth difference between NPP and Aqua



Radiance and flux comparison using simultaneous observations

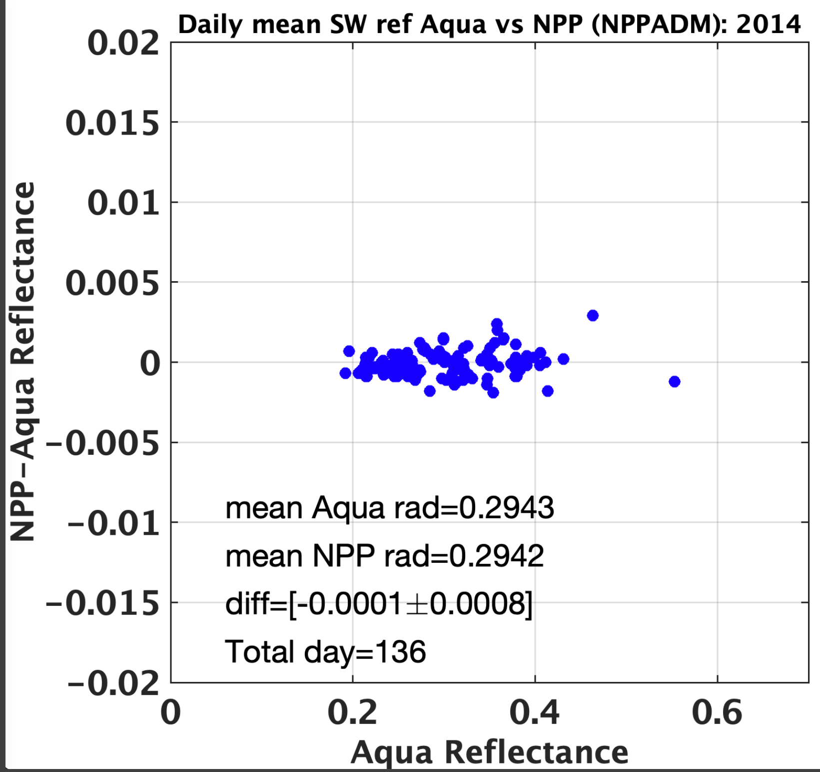
- About every 64 hours, Aqua and NPP fly "in tandem".
- These simultaneous observations from Aqua and NPP are matched to compare SW and LW radiances and fluxes.



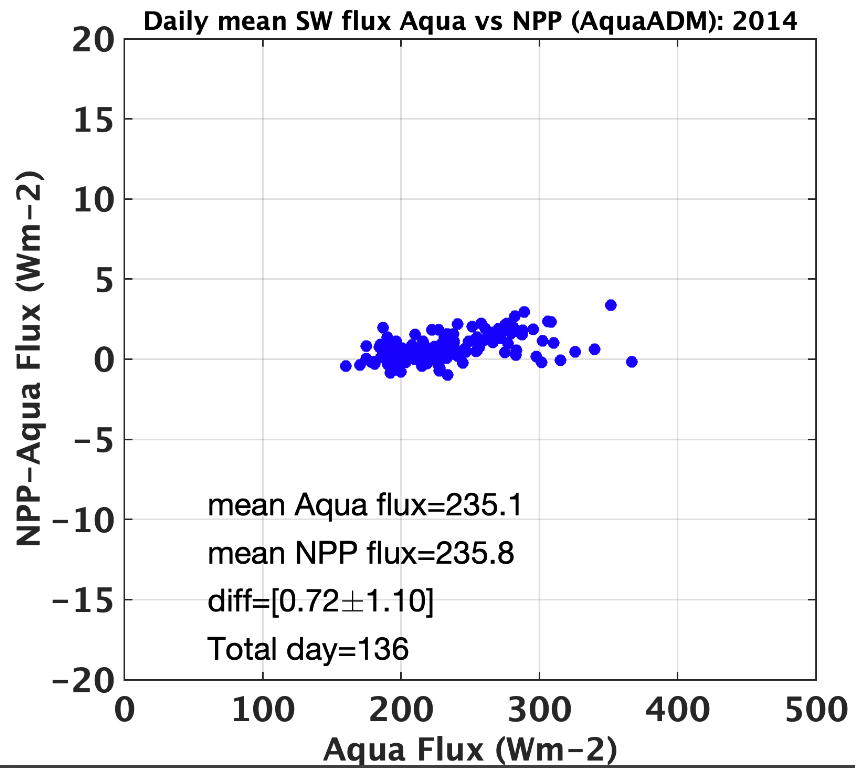
- Matching criteria used for SW and LW radiances are:
  - Latitude and longitude differences are less than 0.05 degree;
  - Solar zenith angle and viewing zenith angle differences are less than 2 degrees, relative azimuth angle difference is less than 5 degrees.
- For each day that NPP and Aqua fly in tandem, average the matched radiances/fluxes from Aqua and NPP and calculate the daily means of them.
- Use daily means of radiance and flux to calculate the bias and RMS.

SW reflectance and flux comparison between collocated Aqua and NPP footprints

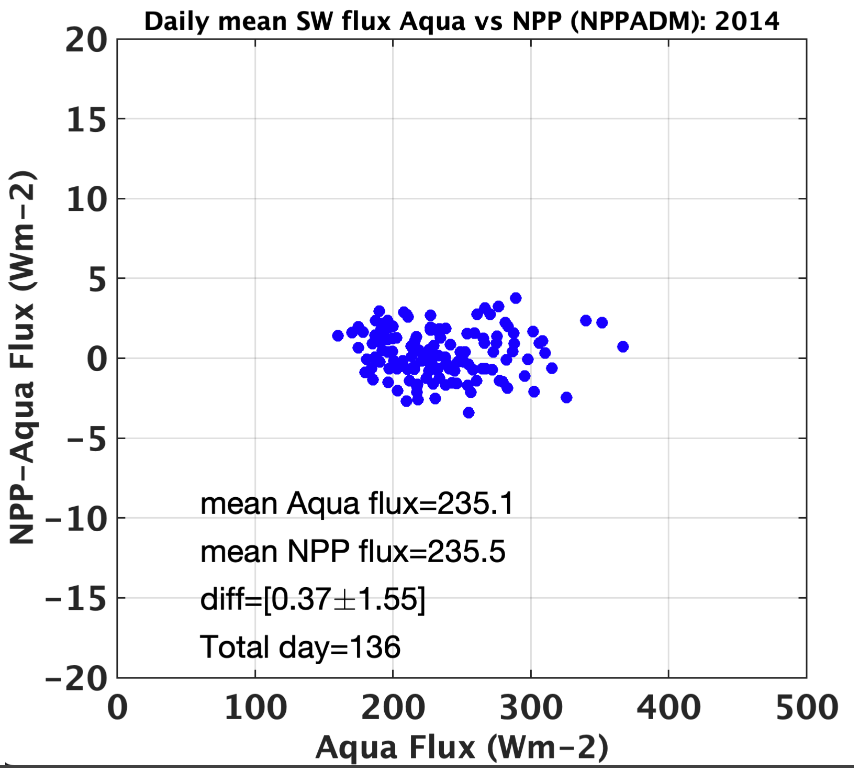
Reflectance btw Aqua and NPP



NPP flux from Aqua ADMs

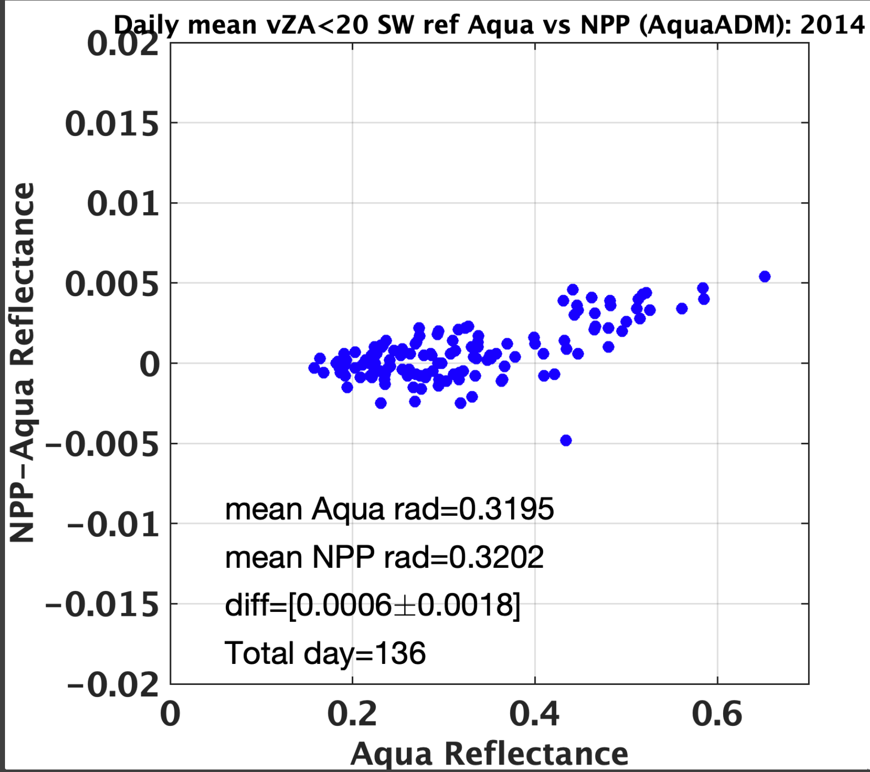


NPP flux from NPP ADMs

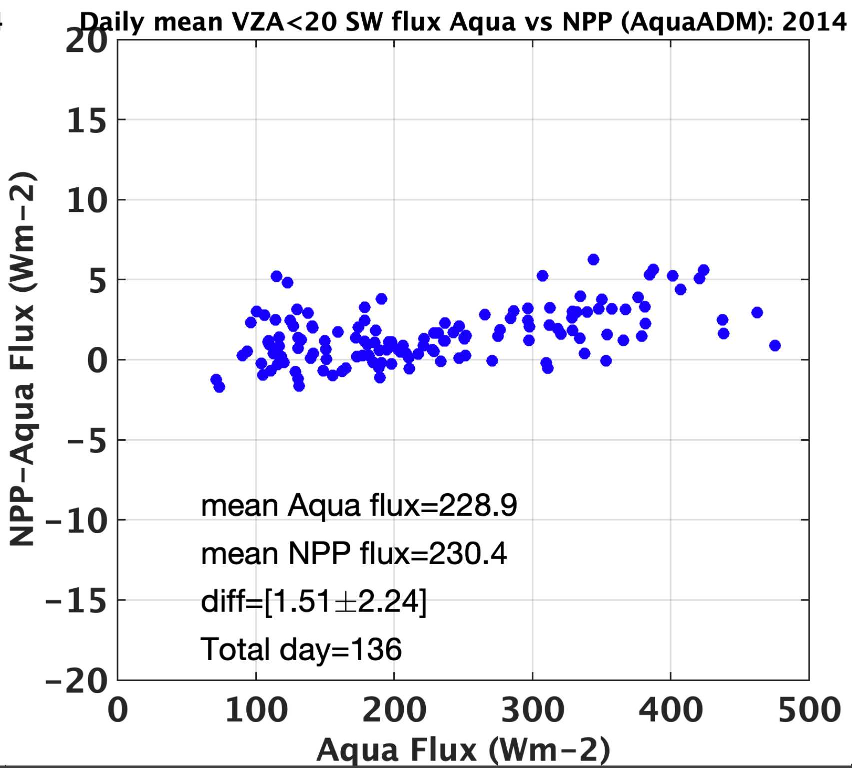


SW reflectance and flux comparison between collocated Aqua and NPP nadir (VZA<20°) footprints

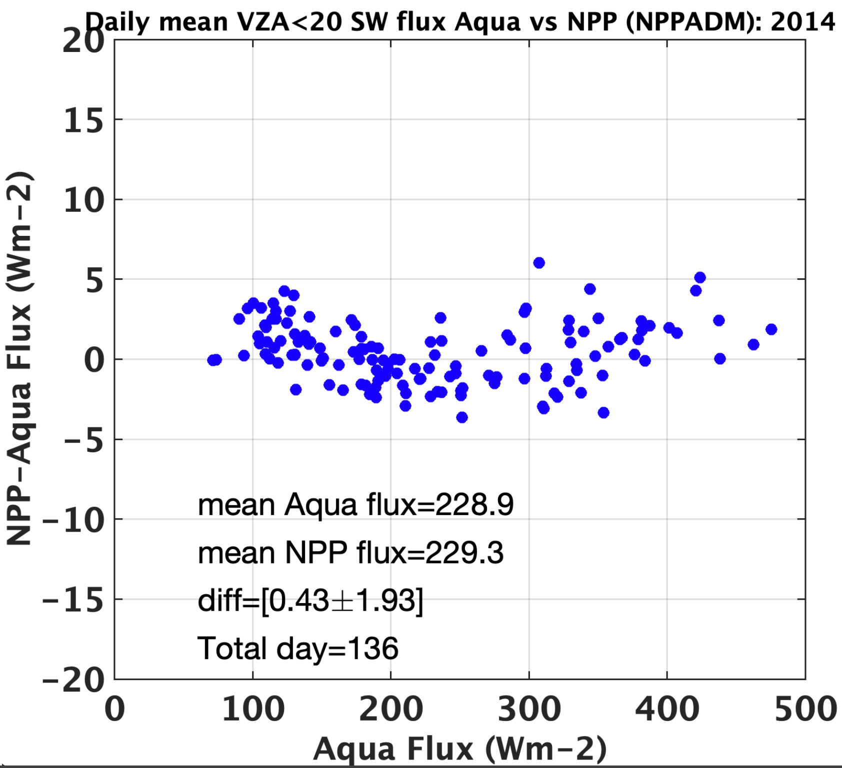
Reflectance btw Aqua and NPP



NPP flux from Aqua ADMs



NPP flux from NPP ADMs

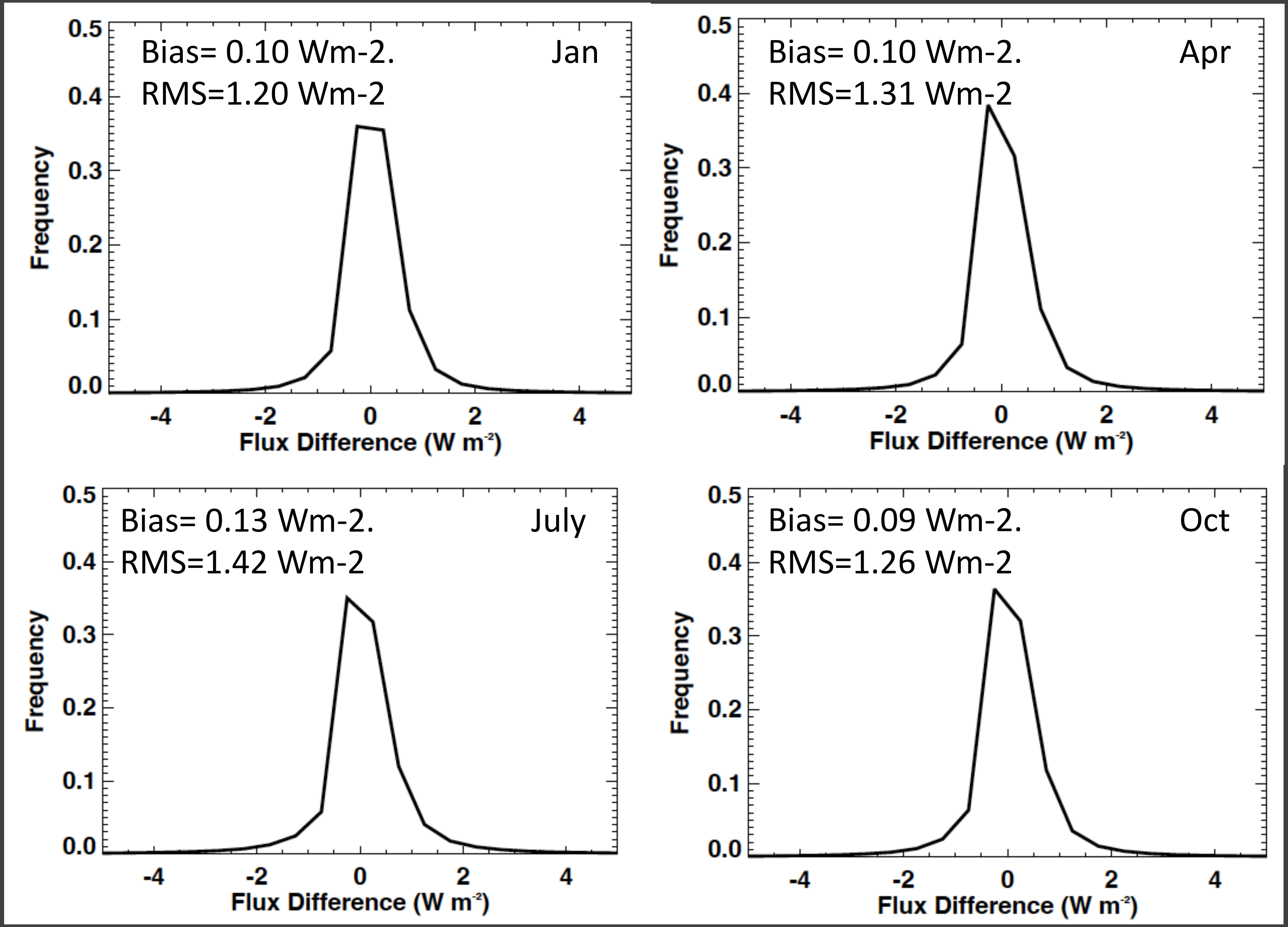


Sensitivity of CERES ADMs to different climate states

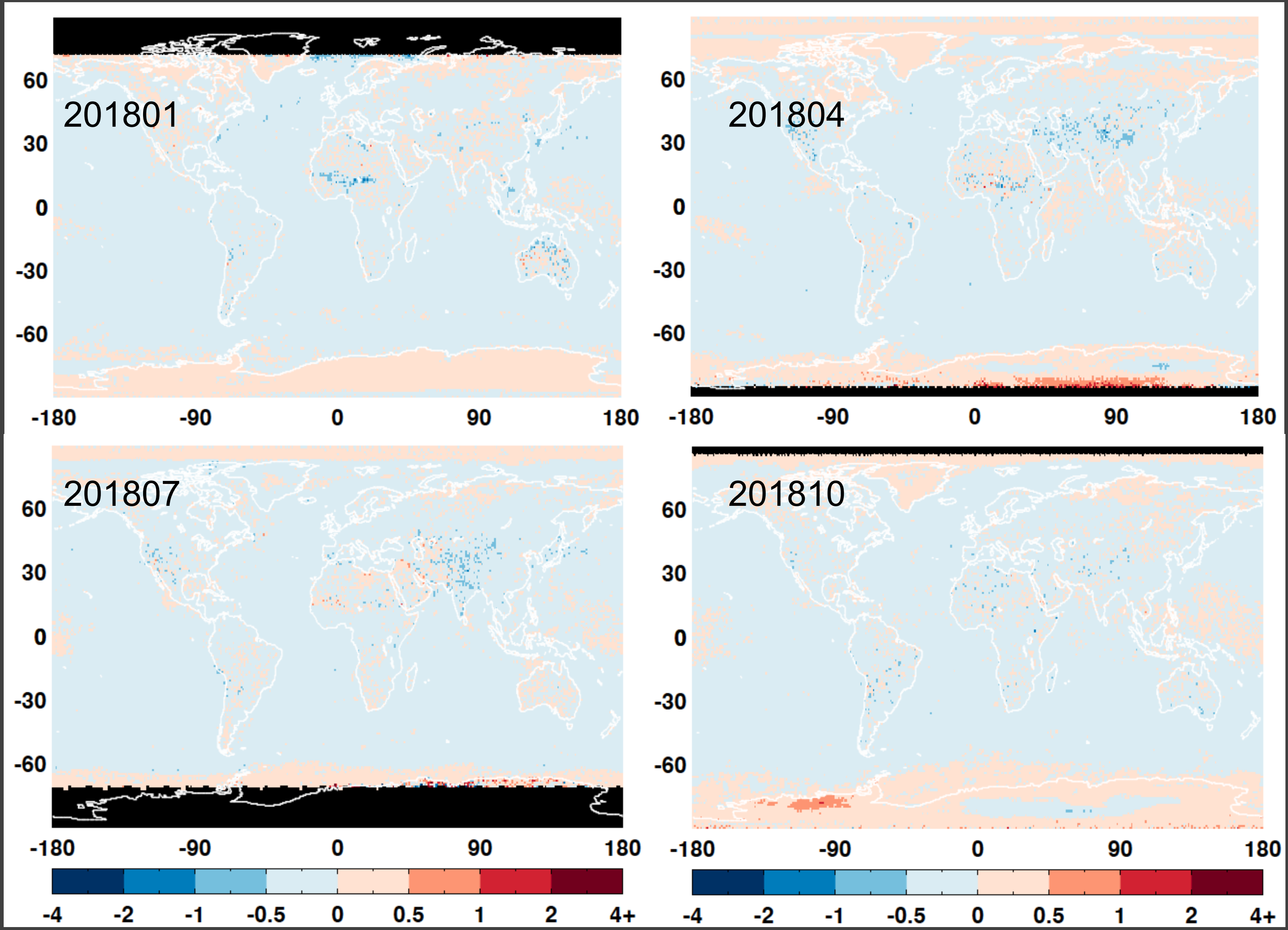
How resilient are ADMs to climate variability and change

- 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 phases of ENSO to test LW ADM sensitivity to climate variability:
  - Use the NOAA Physical Sciences Laboratory Multivariate ENSO Index (MEI) v2 to characterize ENSO phase.
  - A set of "El Niño ADMs" was constructed using 12 months of Terra RAPS data plus 12 months of Terra cross track data with MEI > 0.5.
  - A set of "La Niña ADMs" was constructed using 12 months of Terra RAPS data plus 12 months of Terra cross track data with MEI < -0.5.
- The Ed4 inversion code was run for Jan/Apr/July/Oct 2018 with these two sets of ADMs and the fluxes were compared against each other.

Terra all-sky daytime LW flux difference at the footprint level: El Niño - La Niña ADMs

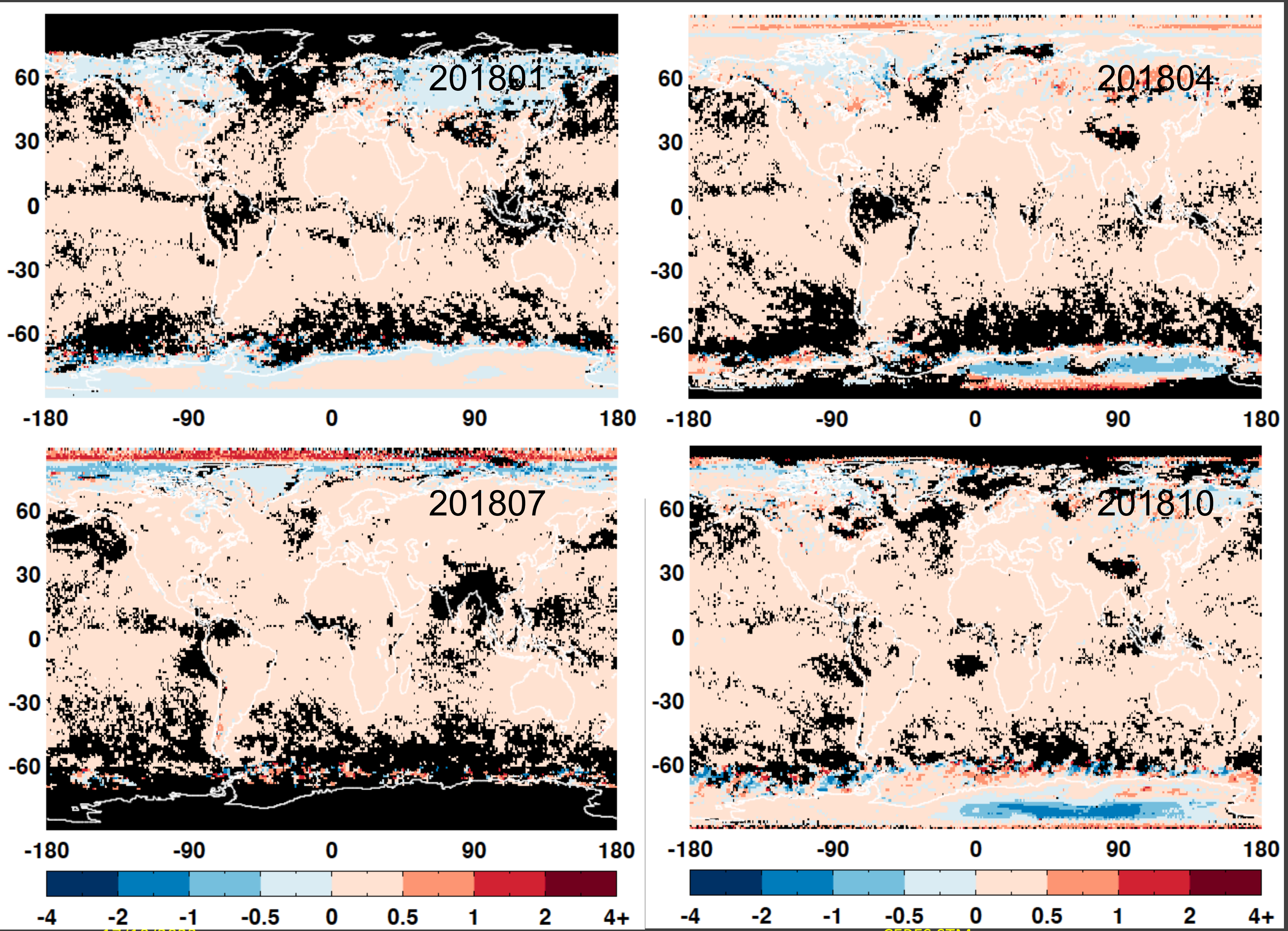


Terra all-sky daytime LW flux difference: El Niño - La Niña ADMs



	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%)

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



	Clear-sky bias	Clear-sky RMS
201801	0.02 (0.01%)	0.08 (0.03%)
201804	-0.01 (~0.0%)	0.10 (0.04%)
201807	~0.00 (~0.0%)	0.04 (0.01%)
201810	~0.00 (~0.0%)	0.08 (0.03%)

Proposed improvement for Ed5 CERES ADMs

SW ADMs over different scene types

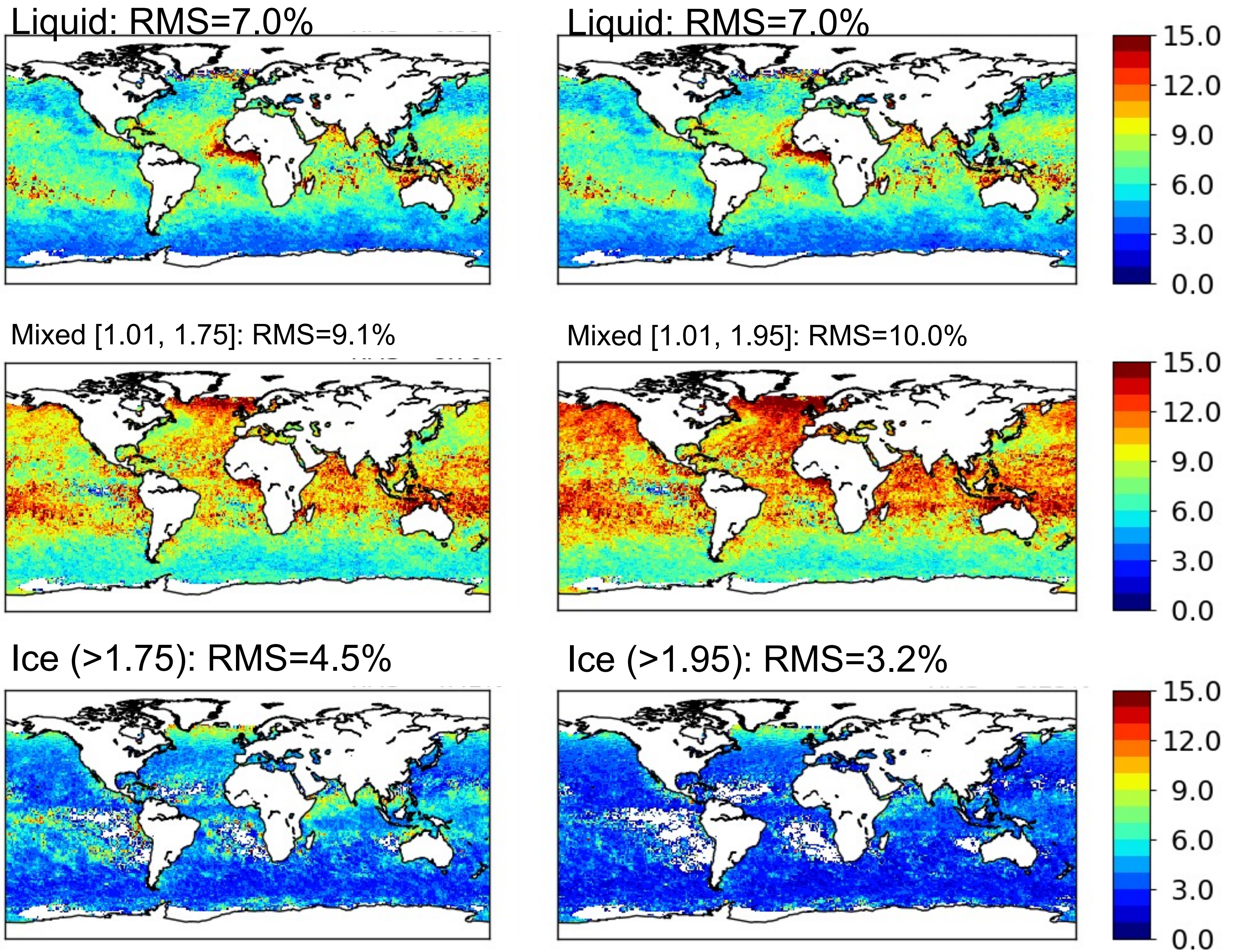
Scene	Ed4	Ed5
Clear Land	1° regional monthly ADM using modified Ross-Li 3-parameter fit for different NDVI (0.1), cosθ (0.2), and surface roughness;	Same as Ed4.
Clear Ocean	Function of wind speed, AOD, and aerosol type;	Same as Ed4.
Cloud Ocean	Continuous 5-parameter sigmoid function of ln(fτ) for three phases ($p<1.01$, $1.01 \le p<1.75$, $p>1.75$);	Continuous 5-parameter sigmoid function of ln(fτ) for four phases ($p<1.01$, $1.01 \le p<1.30$, $1.30 \le p \le 1.95$, $p>1.95$); mean radiance is calculated at ln(fτ) interval of 0.04
Cloud Land	Continuous 5-parameter sigmoid function of ln(fτ) for three phases(($p<1.01$, $1.01 \le p<1.75$, $p>1.75$); background albedo from clear land;	Continuous 5-parameter sigmoid function of ln(fτ) for four phases ($p<1.01$, $1.01 \le p<1.30$, $1.30 \le p \le 1.95$, $p>1.95$); mean radiance is calculated at ln(fτ) interval of 0.04

Redefine the mixed and ice clouds

- Cloud phases are defined as:

$$
\begin{array}{rr}
\overline{\rho} < 1.01 & \overline{\rho} < 1.01 \\
1.01 \leq \overline{\rho} \leq 1.75 & 1.01 \leq \overline{\rho} \leq 1.95 \\
\overline{\rho} > 1.75 & \overline{\rho} > 1.95
\end{array}
$$

- Changing the ice phase definition towards higher phase value (less mixed clouds) reduced the RMS error between observed and ADM predicted radiances from 4.5% to 3.2%;
- However, the RMS error for the mixed phase increased from 9.1% to 10.0%.

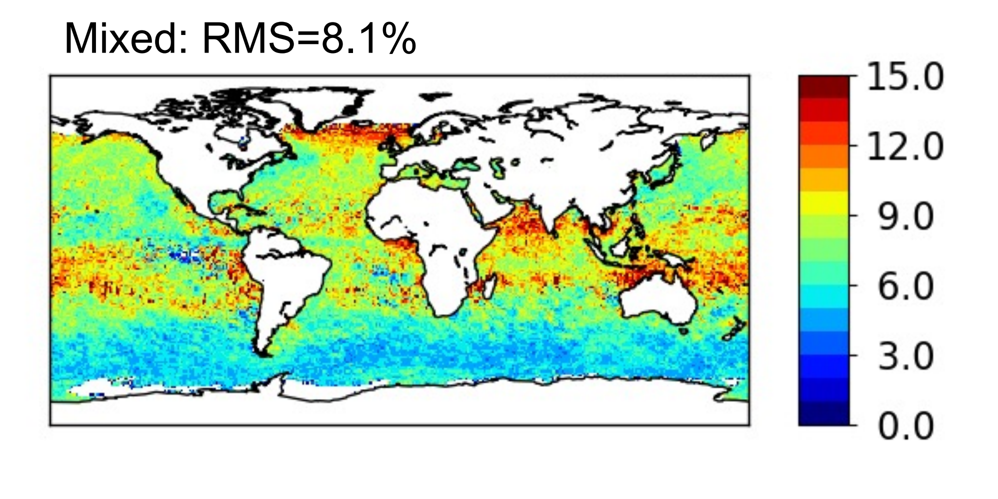


Split mixed clouds into two categories

- As most of the mixed clouds are from ice over water case, mixed clouds are further stratified into two categories:

Liquid:	$\overline{\rho} < 1.01$
Mixed 1:	$1.01 \leq \overline{\rho} < 1.30$
Mixed 2:	$1.30 \leq \overline{\rho} \leq 1.95$
Ice:	$\overline{\rho} > 1.95$

- The RMS error for the mixed phase clouds is the lowest among the different stratifications that we tested.



LW ADMs over different scene types

Scene	Ed4	Ed5
Clear Ocean/Land	Discrete bins of precip. water, lapse rate, skin temp. for six surface types, interpolation between bins	Similar to Ed4, but use percentile-based bins for precip. water. Explore using new land emissivity instead of /in addition to land surface type for scene classification.
Cloudy Ocean/Land	Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ and use polynomial fit with linear interpolation between pseudoradiance Ψ and radiance as a backup. This is done for discrete intervals of precip. Water, surface skin temp., sfc-cld temp. difference, and cloud fraction (0.1-25%, 25-50%, 50-75%, 75-99.9%, overcast).	Intervals for Ψ are expanded to 2 W m^{-2} sr^{-1} and precip. water bins are based on percentiles. Polynomial fit is now eliminated, and the linear extrapolation is forced to physically based limits. Definition of Ψ is now slightly altered.

Clear ocean/land

w (cm)	ΔT (K)	T_s (K)
0–1	< 15	< 260
1–3	15–30	260–340 every 10 K
3–5	30–45	> 340
> 5	> 45	

LW ADMs over different scene types

Scene	Ed4	Ed5
Fresh Snow	Clr: Add Ts bins and interpolation	Clr: Similar to Ed4
	Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;	Cld: Expand Ψ intervals to 2 W m^{-2} sr^{-1}
Permanent Snow	Clr: Add Ts bins and interpolation	Clr: Similar to Ed4
	Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;	Cld: Expand Ψ intervals to 2 W m^{-2} sr^{-1}
Sea-Ice	Clr: Add Ts bins and interpolation	Clr: Similar to Ed4
	Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;	Cld: Expand Ψ intervals to 2 W m^{-2} sr^{-1}

Summary

- Global monthly mean instantaneous NPP SW fluxes inverted from NPP ADMs can differ from those inverted from Aqua ADMs by more than 1.5 Wm^{-2}, with the regional fluxes differing by up to 10 Wm^{-2}. Large regional differences are mostly over snow/ice surfaces due to significant cloud property differences between VIIRS and MODIS.
- Global monthly mean instantaneous NPP LW fluxes inverted from NPP ADMs differ from those inverted from Aqua ADMs by 0.2 Wm^{-2}, with the regional fluxes differing by 2 Wm^{-2}.
- NPP SW and LW flux trends (02/2012-06/2019) remain almost identical when replacing Aqua ADMs with NPP ADMs.
- Fluxes are more consistent between collocated Aqua and NPP footprints when applying their respective ADMs than using Aqua ADMs for both.
- The impact of ADMs on flux is expected to decrease once a consistent cloud retrieval algorithm is applied to MODIS and VIIRS.
- LW ADMs constructed using data taking during El Niño phase and La Niña phase have a minimum impact on flux.