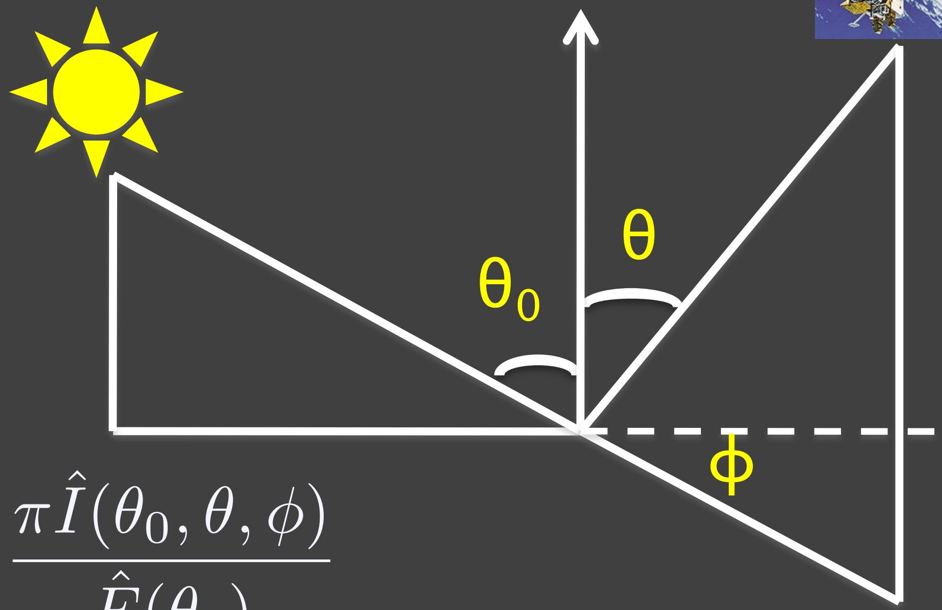
CERES Angular Distribution Model Working Group Report

Wenying Su
Wenying.Su-1@nasa.gov
NASA LaRC, Hampton VA

Lusheng Liang   Zachary Eitzen   Sergio Sejas
SSAI, Hampton VA



From radiance to flux: angular distribution models



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

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

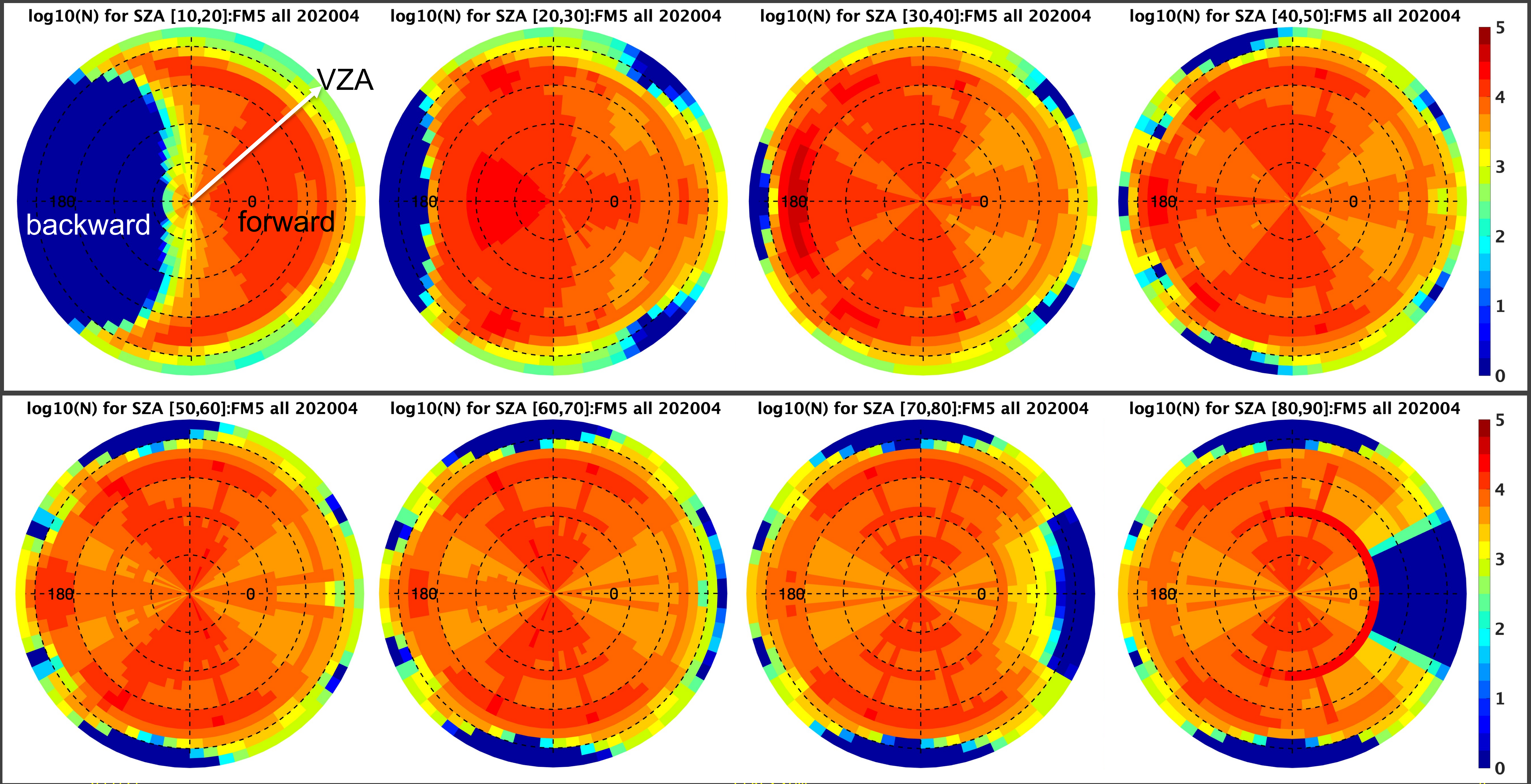
- For each radiance measurement, first determine the <u>scene type</u>, then apply scene type dependent anisotropic factor to observed radiance to derive TOA flux:

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

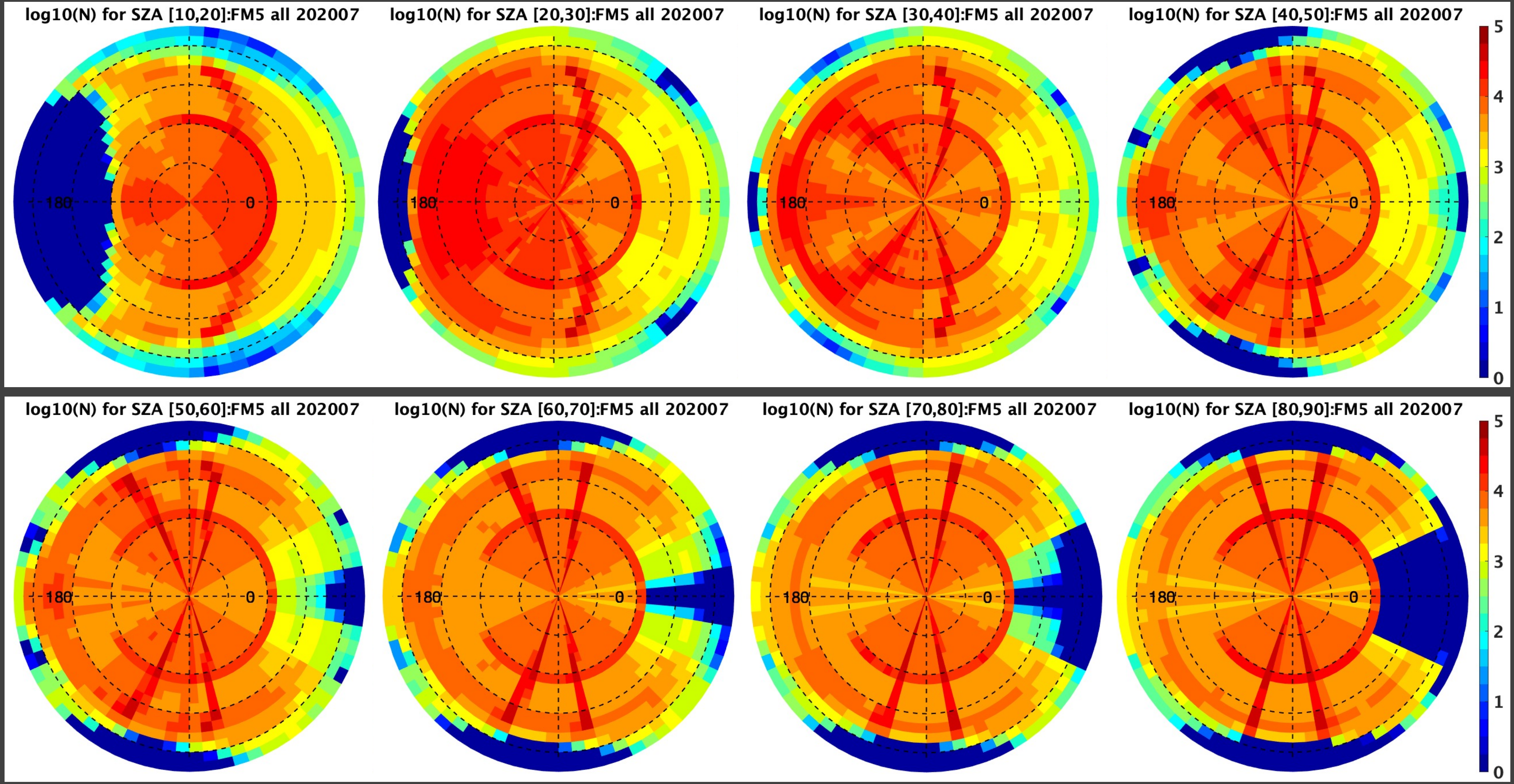
Outline

- CERES instrument on NPP is taking RAP measurements.
- CERES instrument unfiltering algorithm update.
- Clear-sky LW ADM over ocean → flux uncertainty over dust outflow regions.
- Apply CERES ADMs to DSCOVR observations.

NPP normal RAP sample distribution: 202004

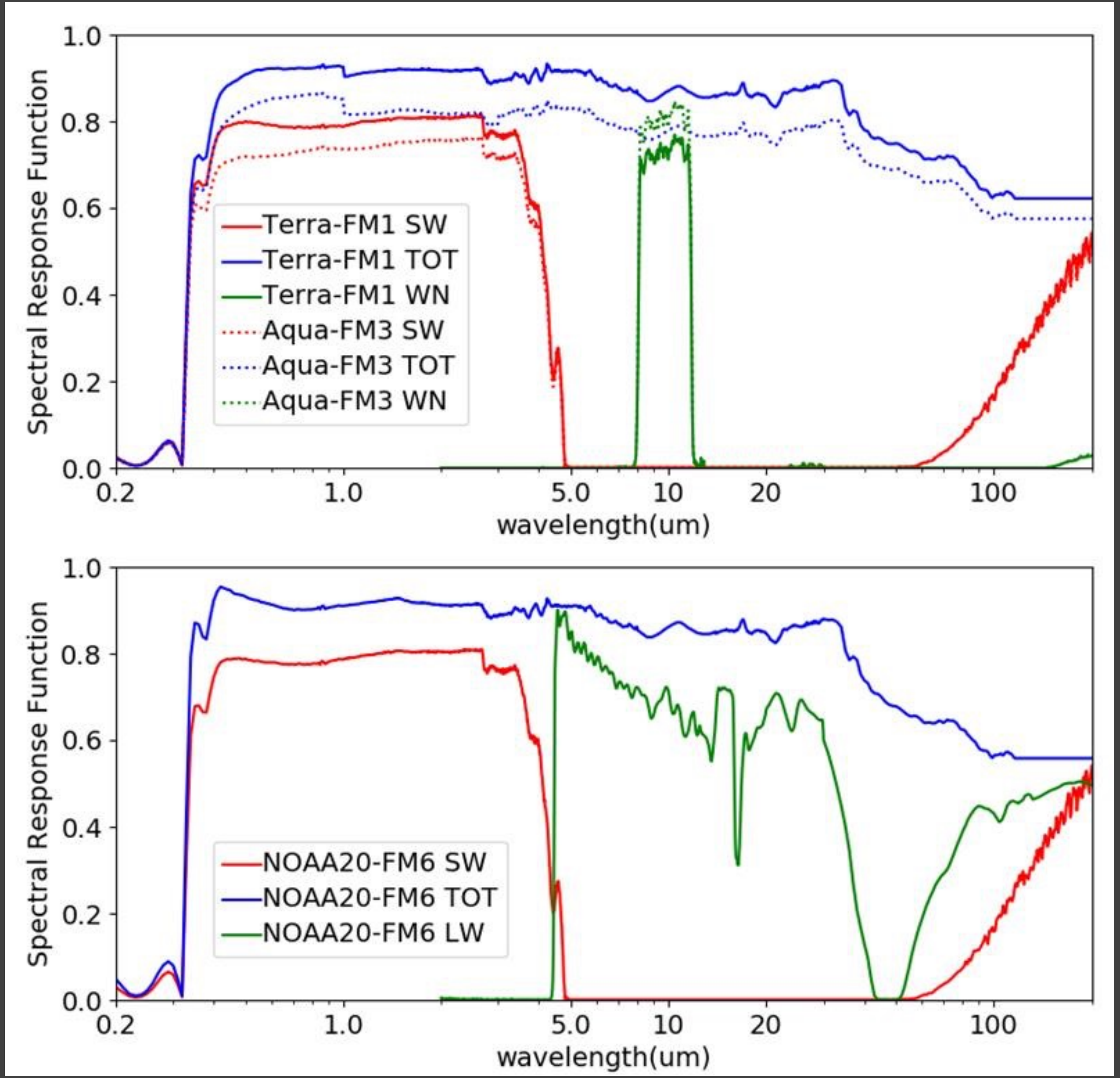


NPP restricted RAP sample distribution: 202007



CERES unfiltering algorithm

- Filters are placed in front of the radiometers to measure the energies from the SW, WN/LW, and total portions of the spectrum.
- These filtered radiances are dependent upon how the radiation is filtered through the instrument optics.
- A procedure is applied that corrects for the spectral response of the instrument to produce "unfiltered" radiances that represent the radiation received by the instrument prior to entering the optics.
- A database of spectral radiances calculated using a radiative transfer model (MODTRAN5.4) is used to describe the relationship between filtered and unfiltered radiances.



Spectral radiance database over ocean

Solar zenith angle	Viewing zenith angle	Relative azimuth angle
0, 29, 41.4, 51.3, 60, 68, 75.5, 80.3, 85	0, 30, 45, 60, 90	0, 7.5, 37.5, 90.0, 142.5, 172.5

	Optical depth (@0.55μm)	Surface temp. (K)	Cloud
Clear	0	320	
	0.055	310	
	0.09	300	
	0.16	295	
	0.30	290	
	0.67	285	
	1.2	280	
Overcast	4.0	280	Ice cloud
	5.6	280	Ice cloud
	14	280	Stratus
	217	280	Cumulus

- Clear-sky over ocean
  - Cox-Munk BRDF model with wind speed=5m/s
  - Maritime aerosols
  - Tropical profile
- Cloudy-sky over ocean
  - Combine overcast simulation with clear ocean simulations to construct partly cloudy cases with cloud fractions of 0.25, 0.50, 0.75

Spectral radiance database over land

- Clear-sky over land:
  - Seasonal simulations for five surface types: forest, savanna, grassland/crops, dark desert, and bright desert
  - Land surface BRDFs are from MODIS Ross-Li Kernels for each month derived from 10-year average
  - Median surface temperature derived from 5-years climatology are used for each surface type. Simulations for daytime and nighttime use different surface temperatures.
  - Different aerosol types/loading are used over different surface types.
- Cloudy-sky over land:
  - For each clear sky case, add overcast cloud simulations as defined over ocean

Bright desert

Wind speed (m/s)	Atmospheric profile Jan-Apr-July-Oct	Surface temp. (K) Day:Jan-Apr-July-Oct Ngt:Jan-Apr-July-Oct
1	MLW-Std-Std-Std	285-302-317-301 276-288-301-289
10	MLW-Std-Std-Std	285-302-317-301 276-288-301-289
30	MLW-Std-Std-Std	285-302-317-301 276-288-301-289
1	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297
10	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297
15	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297
20	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297
25	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297
30	Trop-Trop-Trop-Trop	295-310-318-309 284-296-304-297

MLW: mid-latitude winter
Std: standard
Trop: Tropical

Spectral radiance database over snow

- Snow models are from Warren & Wiscombe, and MODIS Arctic and Antarctic BRDF model
- Surface temperature is based on 5-year climatology of fresh snow and permanent snow
- Sub-Arctic winter atmosphere is used
- Four types of clouds are used for overcast simulation
  - Thin Cirrus with optical depth of 0.3
  - Cirrus with optical depth of 2
  - Stratus with optical depth of 90
  - Stratocumulus with optical depth of 4

Snow model	Surface temp. day/night (K)	Snow grain size (μm)
Warren & Wiscombe snow model	231/224	50
	231/224	200
	231/224	1000
	245/244	50
	245/244	200
	245/244	1000
	262/264	50
	262/264	200
	262/264	1000
MODIS Greenland BRDF	231/224	
	245/244	
	262/264	
MODIS Antarctica BRDF	231/224	
	245/244	
	262/264	

A database of spectral radiances calculated using radiative transfer model is used to describe the relationship between filtered and unfiltered radiances

- Derive filtered and unfiltered radiances of each channel from the database:

$$m_u^j = \int_{\lambda_1}^{\lambda_2} I_\lambda^j d\lambda \qquad m_f^j = \int_{\lambda_1}^{\lambda_2} S_\lambda^j I_\lambda^j d\lambda$$

- Determine the unfiltered SW radiance from filtered SW radiance:
  - Separate the radiance measurements into reflected solar and emitted thermal energy:

$$m_f^{SW_r} = m_f^{SW} - m_f^{SW_e}$$

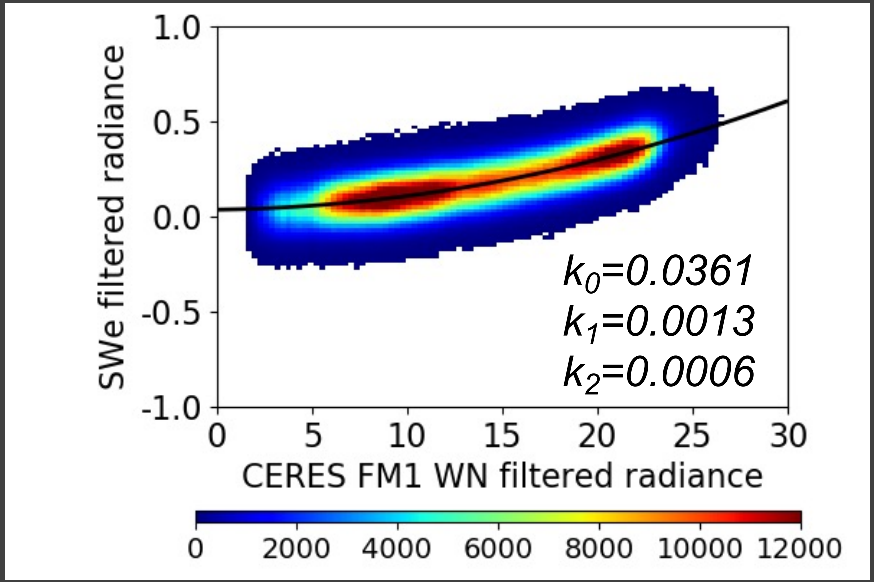
  - Determine emitted thermal energy using nighttime WN (FM1-FM5) and LW (FM6) measurements:

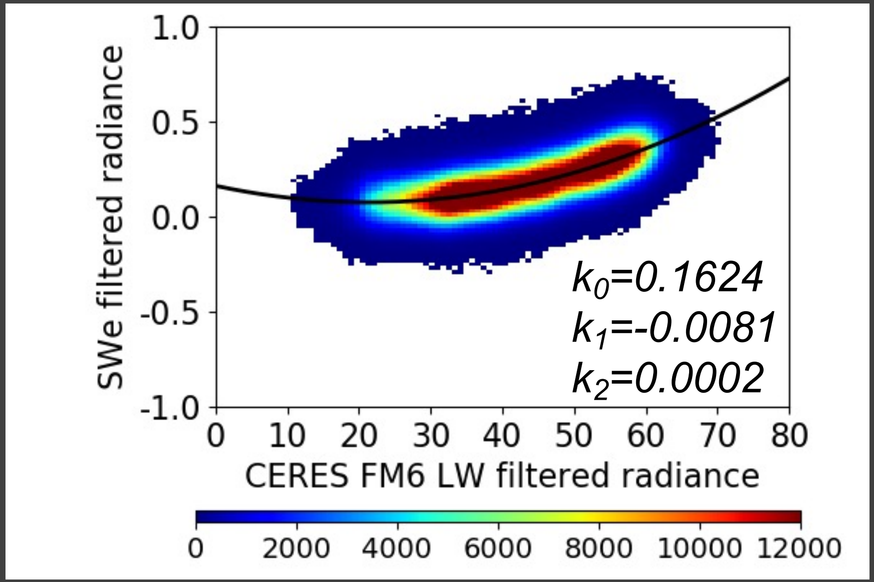
$$m_f^{SW_e} = k_0 + k_1(m_f^{WN}) + k_2(m_f^{WN})^2$$

$$m_f^{SW_e} = k_0 + k_1(m_f^{LW}) + k_2(m_f^{LW})^2$$

  - Derive the regression coefficients between reflected filtered and unfiltered SW radiance:

$$m_u^{SWr} = a_0 + a_1 m_f^{SWr} + a_2(m_f^{SWr})^2$$





Derive unfiltered WN and LW radiances for FM1-FM5

- Determine the unfiltered day/nighttime WN radiance from filtered WN radiance:

$$m_u^{WN} = b_0 + b_1(m_f^{WN}) + b_2(m_f^{WN})^2$$

- Determine the unfiltered daytime LW radiance from filtered total, SW, and WN radiances:

$$m_u^{LW}(D) = c_0 + c_1(m_f^{SW_r}) + c_2(m_f^{TOT}) + c_3(m_f^{WN})$$

- Determine the unfiltered nighttime LW radiance from filtered total and WN radiances:

$$m_u^{LW}(N) = d_0 + d_1(m_f^{TOT}) + d_2(m_f^{WN})$$

Derive unfiltered LW radiances for FM6

- Determine the unfiltered daytime LW radiance from filtered total and SW radiances:

$$m_u^{LW}(D) = c_0 + c_1(m_f^{SW_r}) + c_2(m_f^{TOT})$$

- Determine the unfiltered nighttime LW radiance from filtered total radiances for FM1-FM5:

$$m_u^{LW}(N) = d_0 + d_1(m_f^{TOT})$$

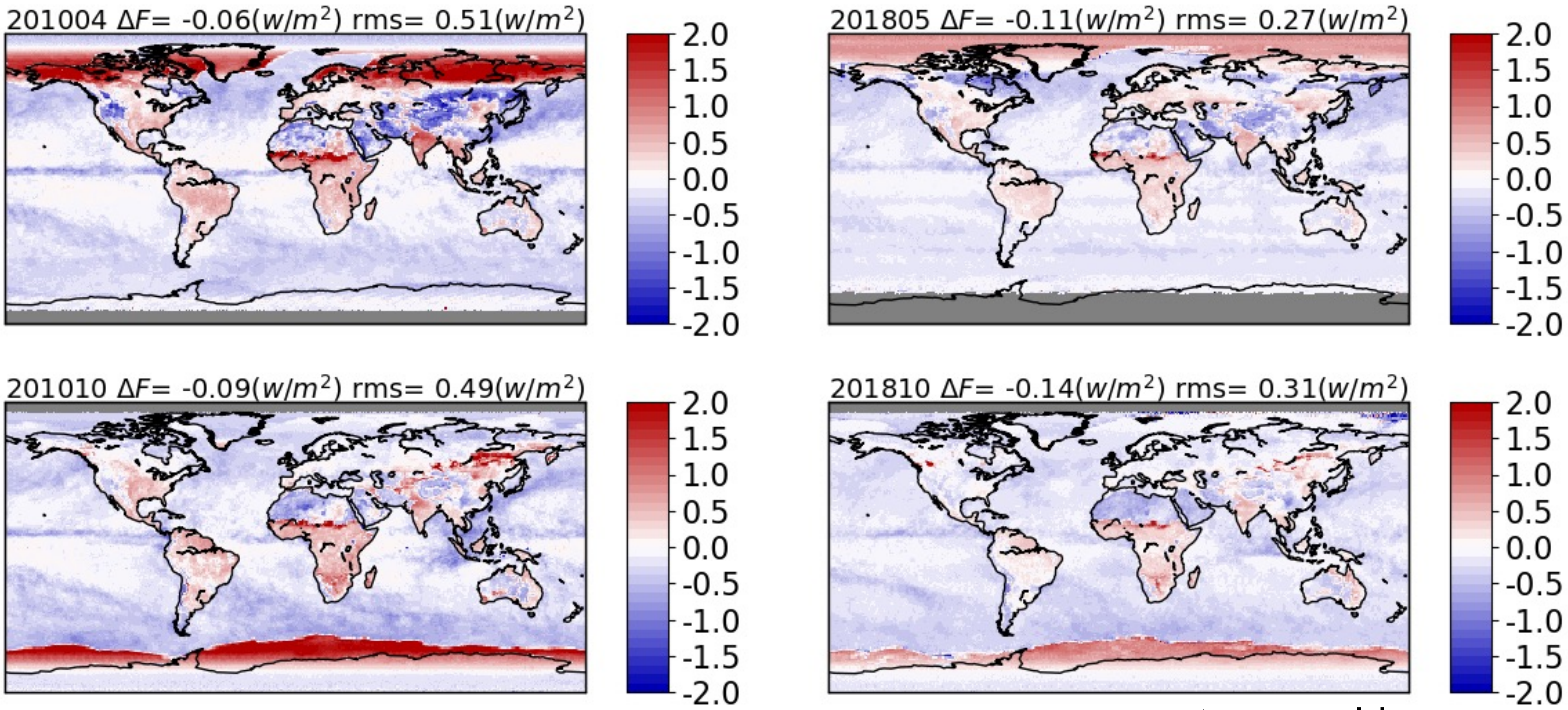
- Determine the unfiltered day/nighttime LW radiance from filtered LW radiance:

$$m_u^{LW}(D) = \beta_0 + \beta_1(m_f^{LW}) + \beta_2(m_f^{LW})^2$$

$$m_u^{LW}(N) = \beta_0' + \beta_1'(m_f^{LW}) + \beta_2'(m_f^{LW})^2$$

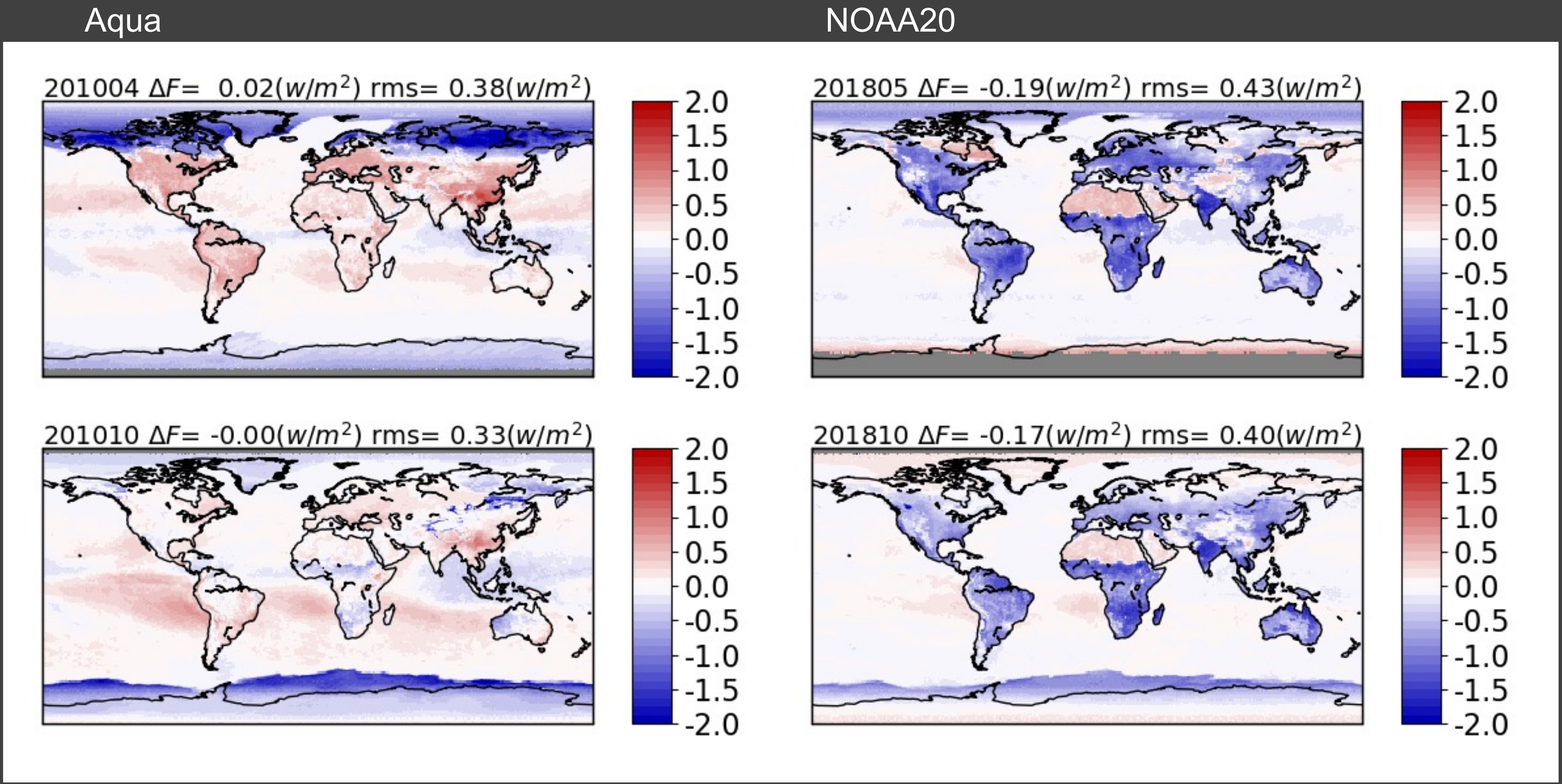
Impact of new unfiltering algorithm on instantaneous SW flux

Aqua NOAA20



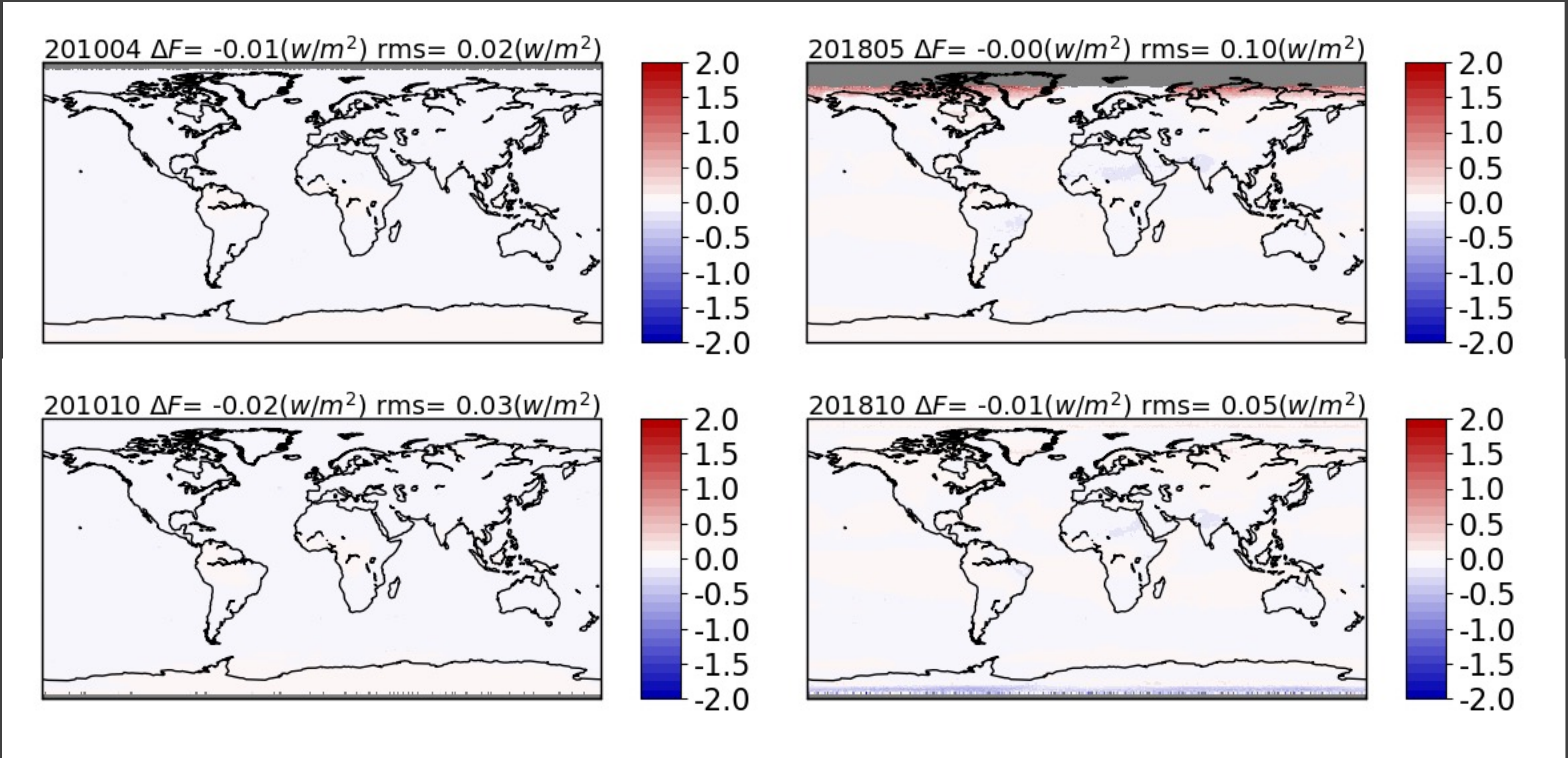
Δ=new-old

Impact of new unfiltering algorithm on daytime LW flux (TOT-SW)



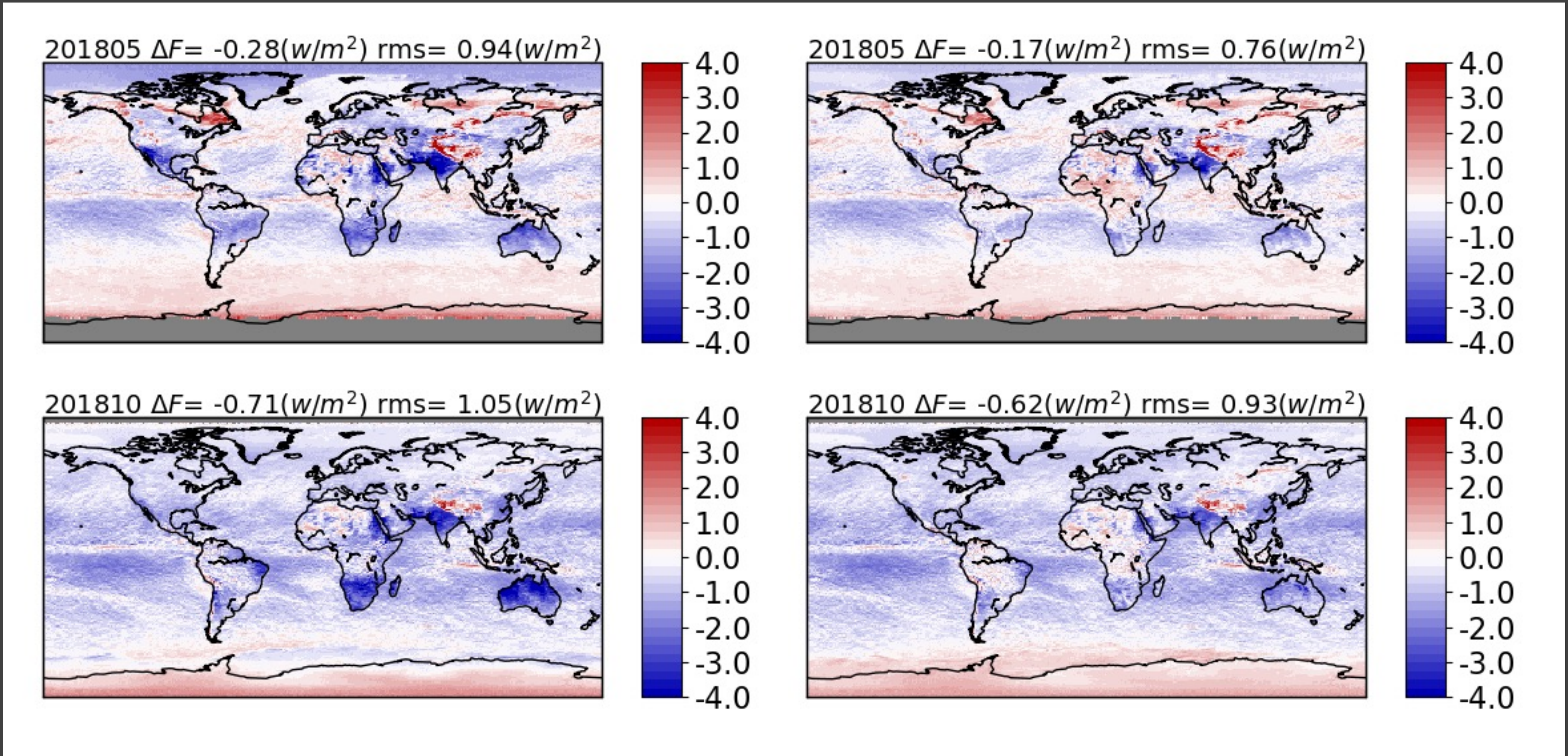
Impact of new unfiltering algorithm on nighttime LW flux (TOT)

Aqua | NOAA20



Consistency between NOAA20 LW and TOT-SW channels improved using the new unfiltering algorithm

Old New



Error analysis database

- Extreme cases for ocean and land
  - Large aerosol loading
  - Minimum/maximum, 25/75 percentile surface temperatures
  - Wind speeds of 2 m/s and 12 m/s over ocean
- Different aerosol types and atmospheric profiles
- Different cloud types and optical depths for cloudy ocean and land
- Different snow surface BRDF using MODIS fresh snow BRDF model and seasonal permanent snow BRDF model
- The spectrally integrated unfiltered radiances are then compared with the “unfiltered” radiance derived from filtered radiances by using the regressions

Clear-sky LW ADM

- CERES clear-sky LW ADMs are constructed separately over ocean, desert and non-desert land for discrete intervals of precipitable water, lapse rate, and surface skin temperature.
- What is the LW flux uncertainty caused by the lack of "dust-specific" LW ADMs over the dust outflow regions off the west coast of Africa (10-30°N, 15-50°W)?

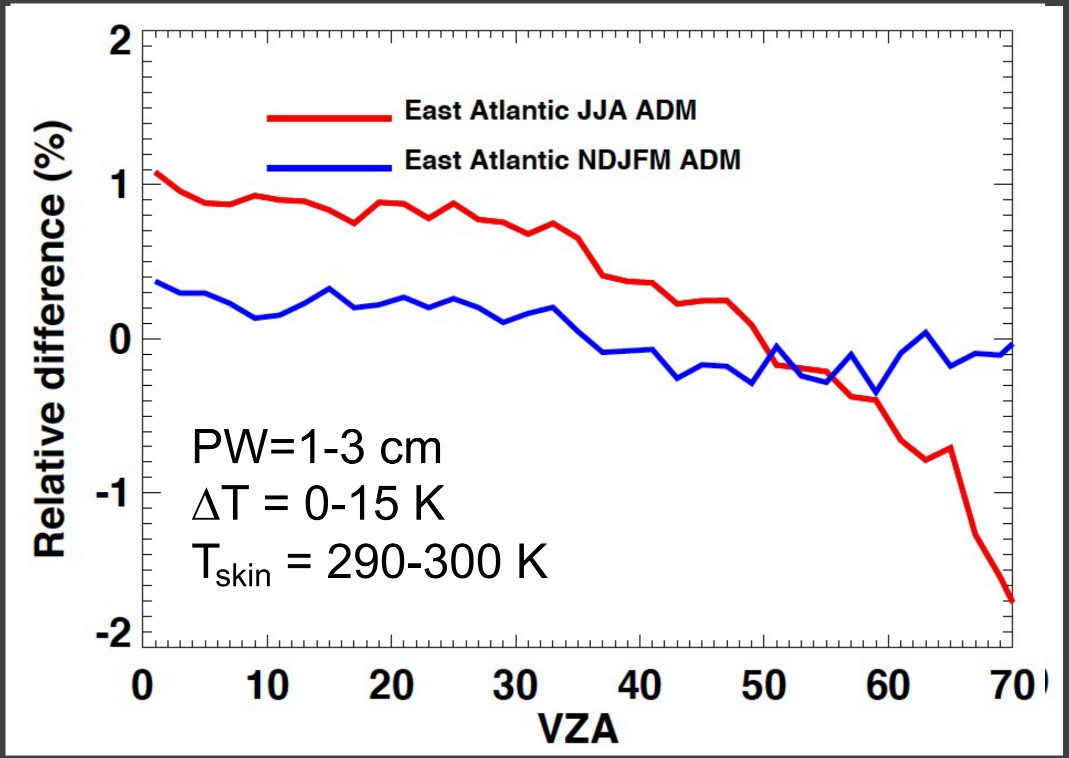
Table 3. Precipitable water (w), lapse rate (ΔT), and surface skin temperature (T_S) intervals used to determine LW and WN ADMs under clear-sky conditions over the ocean, land, and desert. There are 4 w bins, 4 ΔT bins, and 10 T_S bins.

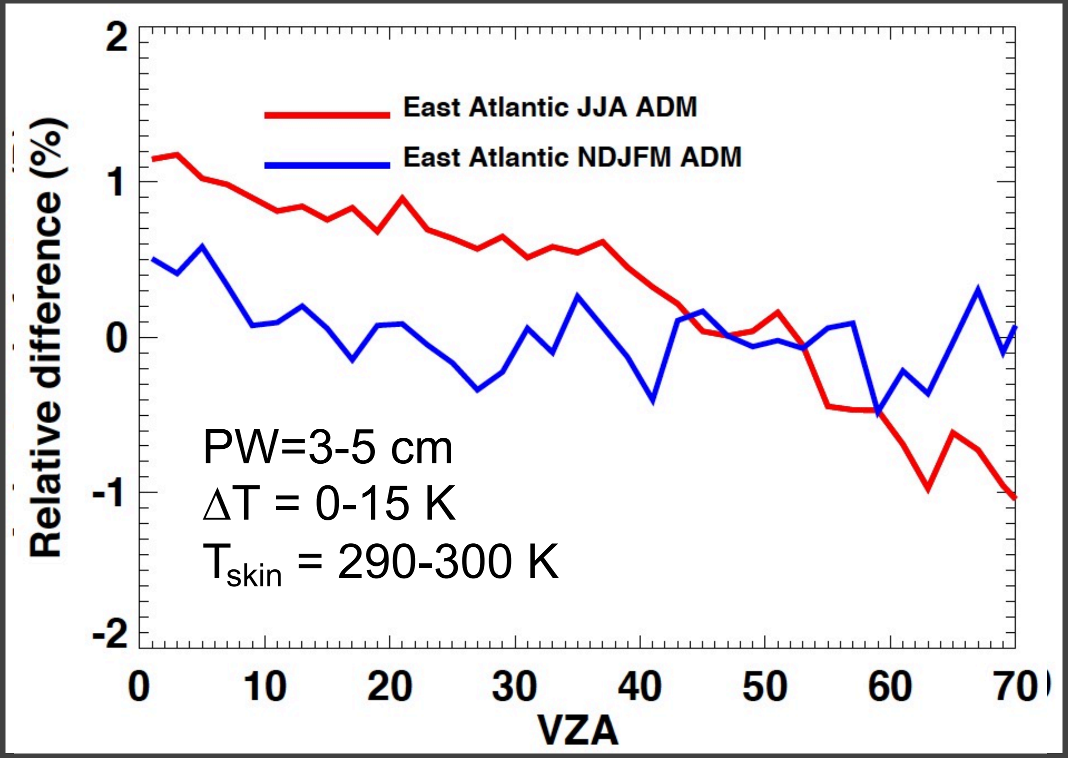
w (cm)	ΔT (K)	T_S (K)
0–1	< 15	< 260
1–3	15–30	260–340 every 10 K
3–5	30–45	> 340
> 5	> 45	

Su et al. (2015)

Clear-ocean dust LW ADM

- Develop a set of LW ADMs specifically for dust regions over ocean to test the sensitivity.
- Using Aqua data off the west coast of Africa (10-30°N, 15-50°W) during JJA 2002-2005 to construct the "dust" ADMs.
- LW dust anisotropic factor is about 1% larger than the ocean anisotropic factor at nadir.
- ADMs constructed using fall through spring data are very similar to clear-ocean ADMs.

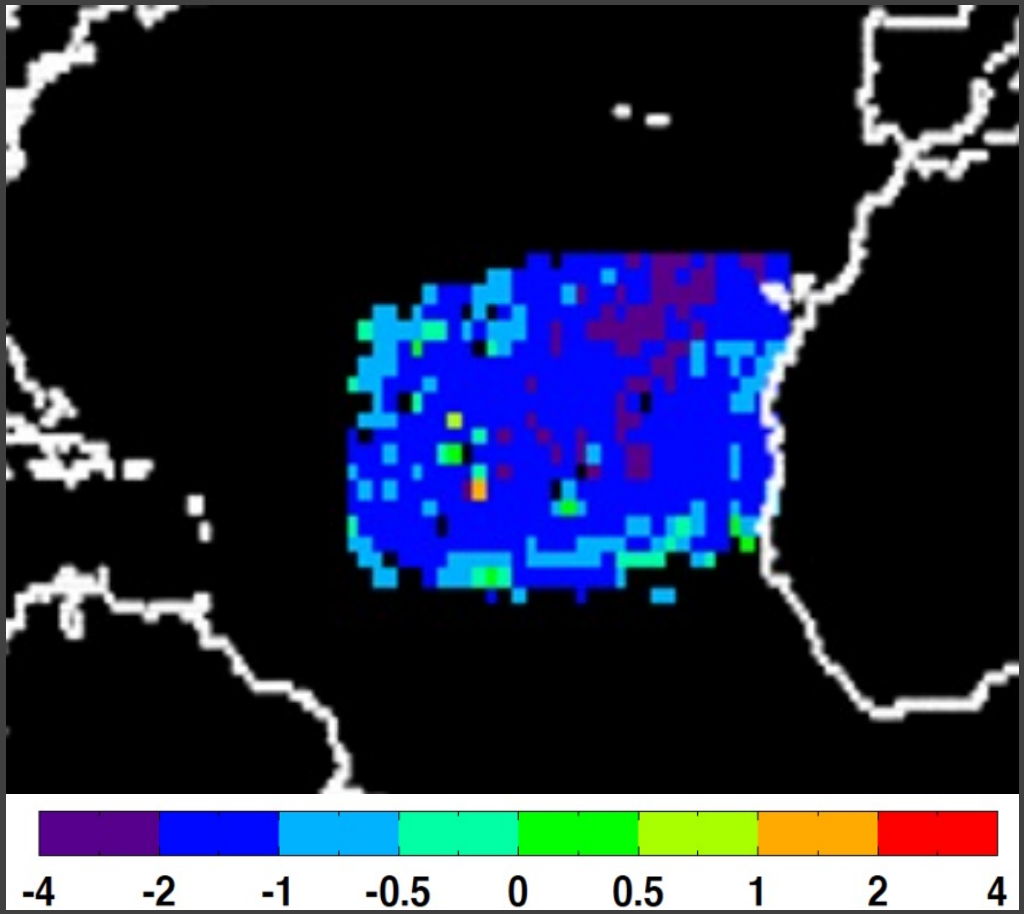




Appy the dust ADMs to the African dust outflow region for July 2018

- For July 2018, the mean MODIS AOD is 0.641 for the dust outflow region (10-30°N, 15-50°W).
- The mean MODIS AOD for other regions is 0.102.
- Using the "dust" ADMs for flux inversion instead of the general clear-ocean ADMs, reduced the daytime LW fluxes off the west coast of Africa by -1.5 Wm^{-2} (0.5%).
- The LW aerosol direct radiative effect off the west coast of Africa is about 4-5 Wm^{-2}. The ADM impact on LW dust ADRE can be as large as 30%.

LW Flux difference

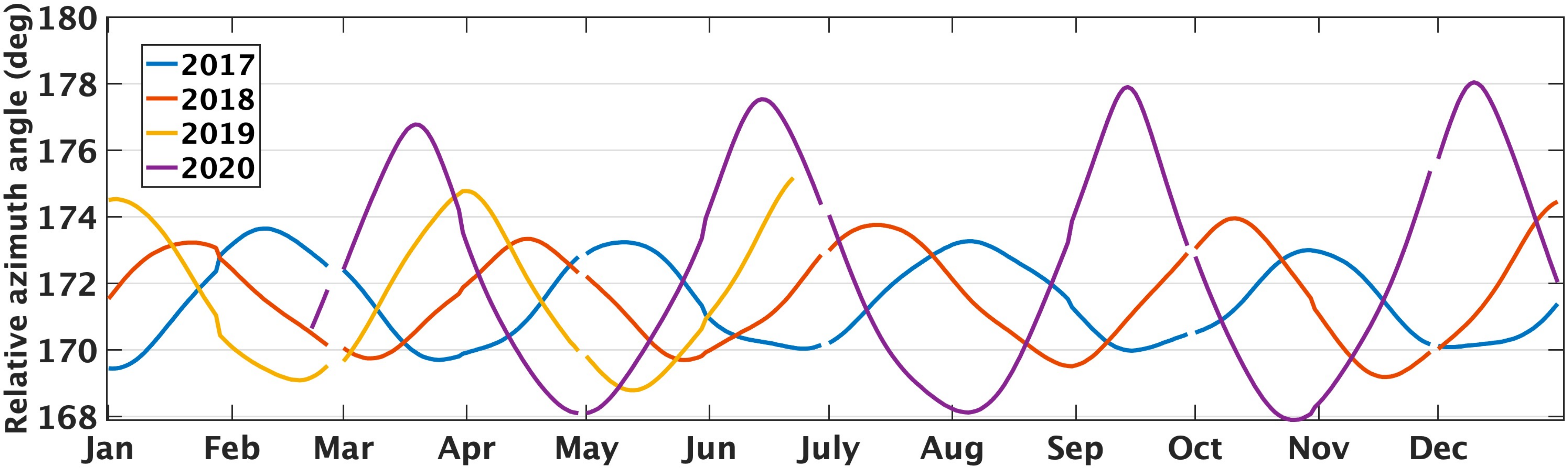


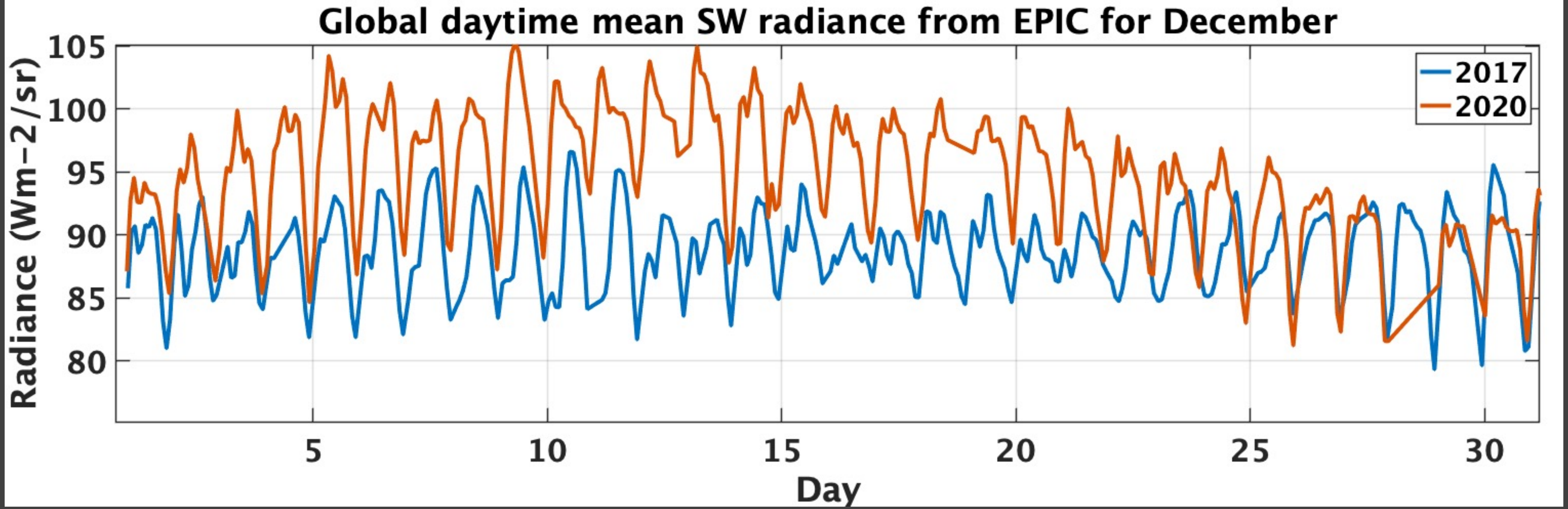
Deep Space Climate Observatory (DSCOVR)

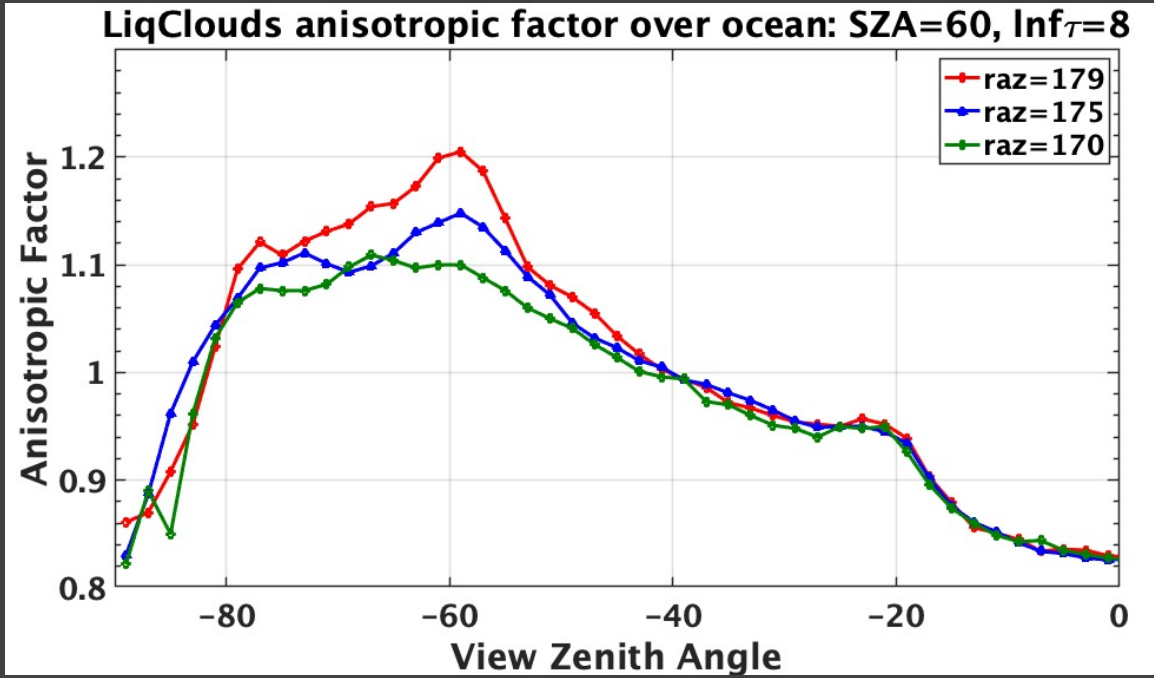
- DSCOVR was launched on Feb. 11, 2015 and is the first Earth-observing satellite at the Lagrange-1 (L1) point, about 1 million miles from Earth.
- L1 is a gravity neutral point in space, where DSCOVR orbits the Sun at the same rate as the Earth, allowing it to continuously monitor the sunlit side of the Earth.
- NISTAR provides continuous broadband radiance measurements from the sunlit side of the Earth as a single pixel.
- EPIC provides 10 narrow band spectral images of the entire sunlit side of the Earth using a 2048x2048 pixel CCD (Charge Coupled Device) detector.
- EPIC radiances of 443, 551, and 680 nm are converted to broadband radiances by using narrowband-to-broadband regression (Su et al. 2018).
- CERES ADMs are used to derive fluxes from EPIC broadband radiances.

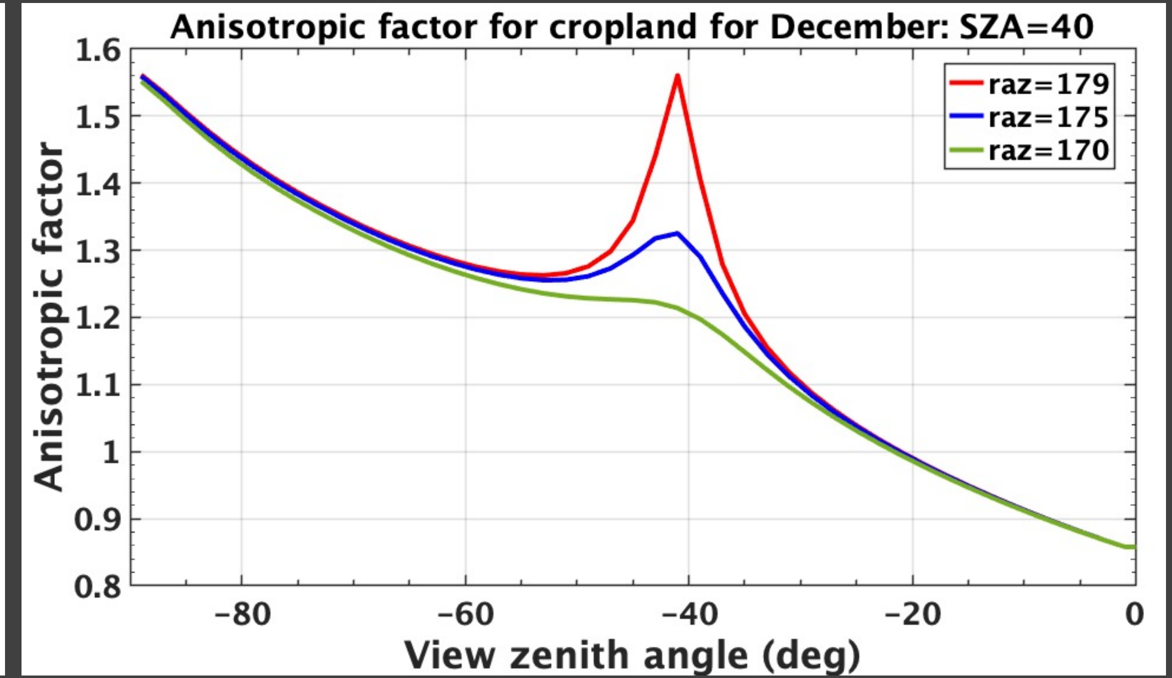
DSCOVR offers a testbed for CERES ADMs

- DSCOVR observes the Earth at near back-scatter direction in an elliptical Lissajous orbit.
- This quasi-periodic orbit experienced large changes in scattering angles in 2020.

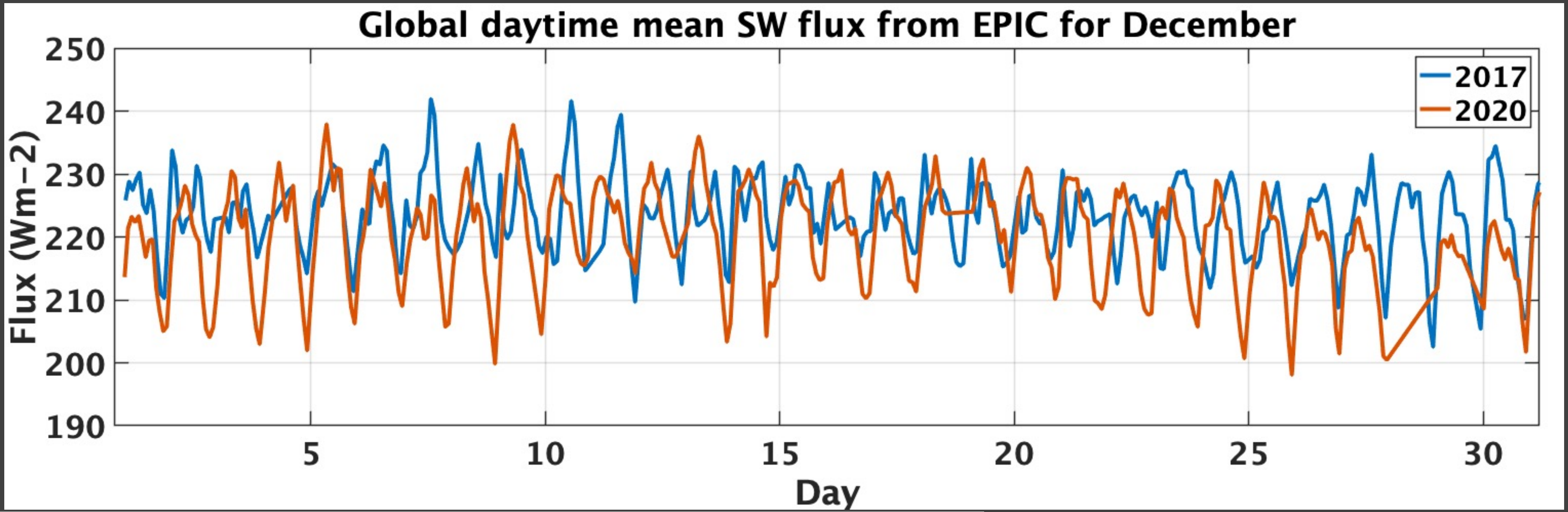


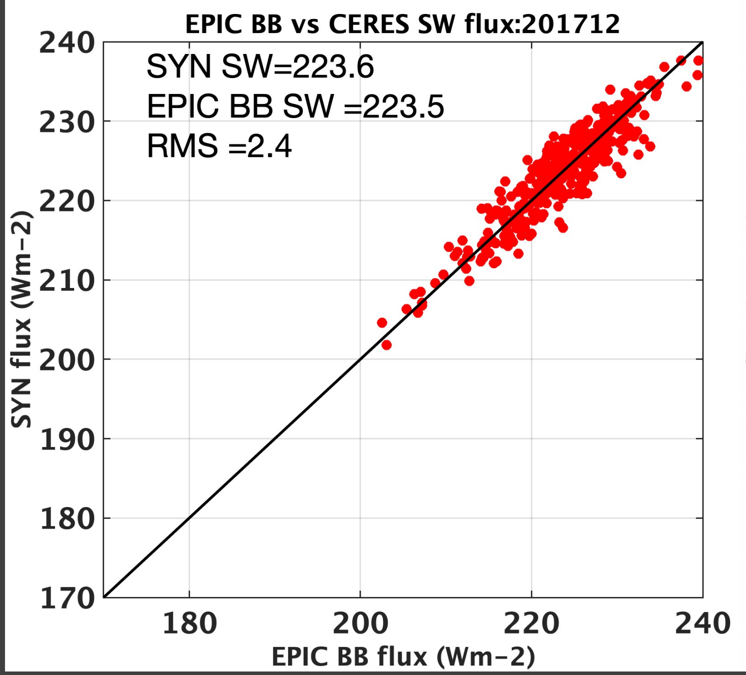

Global daytime mean SW radiance from EPIC for December
Radiance (Wm−2/sr)
105
100
95
90
85
80
5
10
15
20
25
30
Day
2017
2020

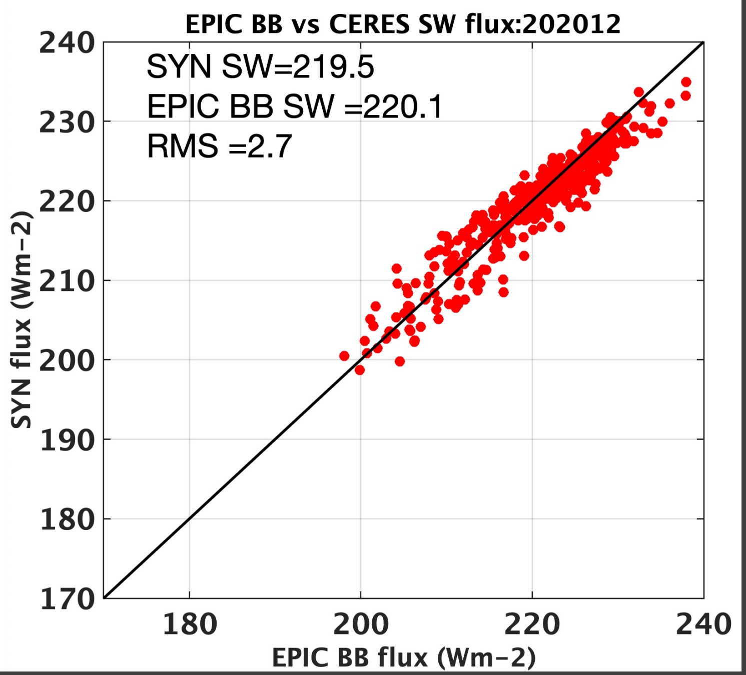

LiqClouds anisotropic factor over ocean: SZA=60, lnfτ=8
Anisotropic Factor
1.2
1.1
1
0.9
0.8
−80
−60
−40
−20
0
View Zenith Angle
raz=179
raz=175
raz=170


Anisotropic factor for cropland for December: SZA=40
Anisotropic factor
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
−80
−60
−40
−20
0
View zenith angle (deg)
raz=179
raz=175
raz=170

Comparisons with CERES SYN show good agreement for both years







Comparison against CERES SYN hourly flux shows good agreement for both 2017 and 2020.

Summary

- CERES NPP has been in RAPS mode since the end of March 2020. These RAPS measurements together with the cross-track data will be used to develop a set of ADMs specifically for NPP/VIIRS.
- The updated unfiltering algorithm will be used for CERES Ed5.
- The uncertainty of the current LW ADMs over dust outflow oceanic regions is less than 1% for instantaneous LW inversion, and about 0.5% for regional monthly mean LW flux.
- DSCOVR observes the Earth at the near-backscattering directions. Global daytime mean SW fluxes inverted from EPIC instrument onboard DSCOVR using CERES ADMs agree well with the hourly flux from CERES SYN.

CERES NPP has more observation for near-overhead sun conditions