CERES Angular Distribution Model Working Group Report

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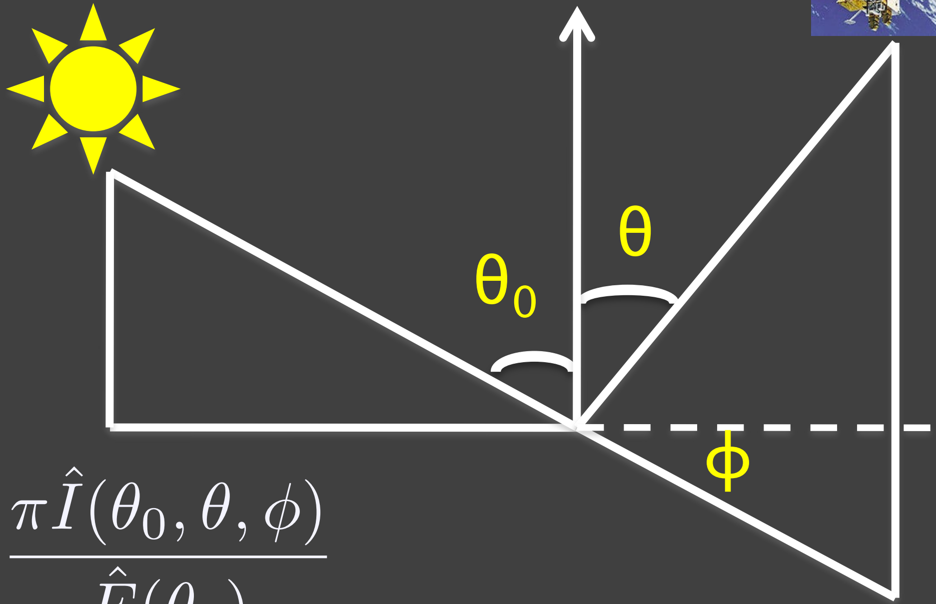
From radiance to flux: angular distribution models

- Sort observed radiances into angular bins over different <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:

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

AVHRR land cover classification from USGS (Belward, 1996, Loveland et al. 2000)

- The 1 km global land cover database was developed through a continent-by-continent unsupervised classification using monthly AVHRR NDVI composites covering 1992-1993.
- AVHRR NDVI data were formed into the bimonthly composite images to derive the maximum NDVI composites. Every composite image was manually checked for navigation accuracy by comparing the mapped data to a reference coastline for every continent.
- The maximum value NDVI composite dataset were produced without any atmospheric correction except during El Chichon and Mt Pinatubo volcanic stratospheric aerosol periods.
- Cloud screening was provided by using a thermal mask from 10.8μm channel, 0°C was used for all continents except Africa, where a cloud mask of 10°C was used.
- Maximum value compositing was used to simultaneously minimize atmospheric and directional reflectance effects.
- Monthly maximum NDVI composites were clustered using an unsupervised classification strategy based on the K-Means technique.
- This dataset is no longer available for download!

MODIS Land Cover Product (Sulla-Menashe et al. 2019)

- Collection 6 MODIS Nadir BRDF-Adjusted Reflectance (NBAR) products and ancillary information (NDSnowI, EVI, NDWaterI, ect.) are used as inputs.
- The C6 NBAR product provides cloud-screened and atmospherically-corrected daily surface reflectances that have been adjusted to provide consistent view and solar geometry in the seven MODIS 'land' bands.
- The System for Terrestrial Ecosystem Parameterization (STEP) database provides high quality training examples that are representative of each land cover type in the MODIS land cover product.
- Land cover classifications were performed using the Random Forest algorithm.

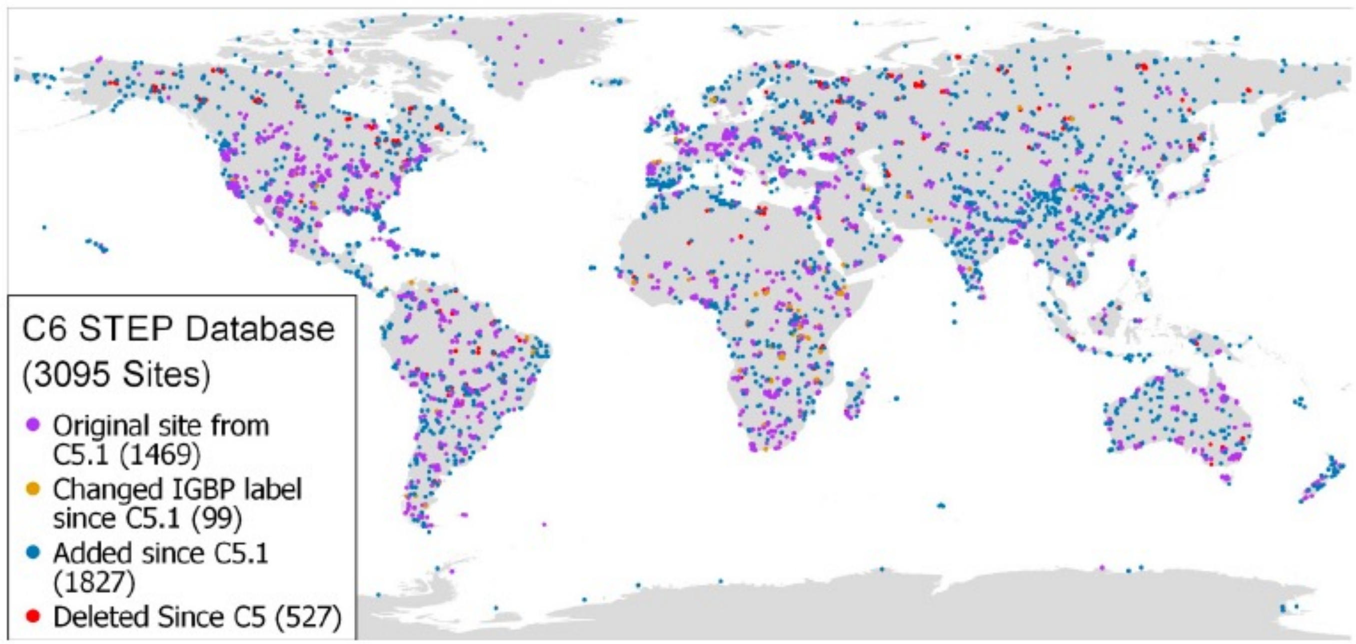
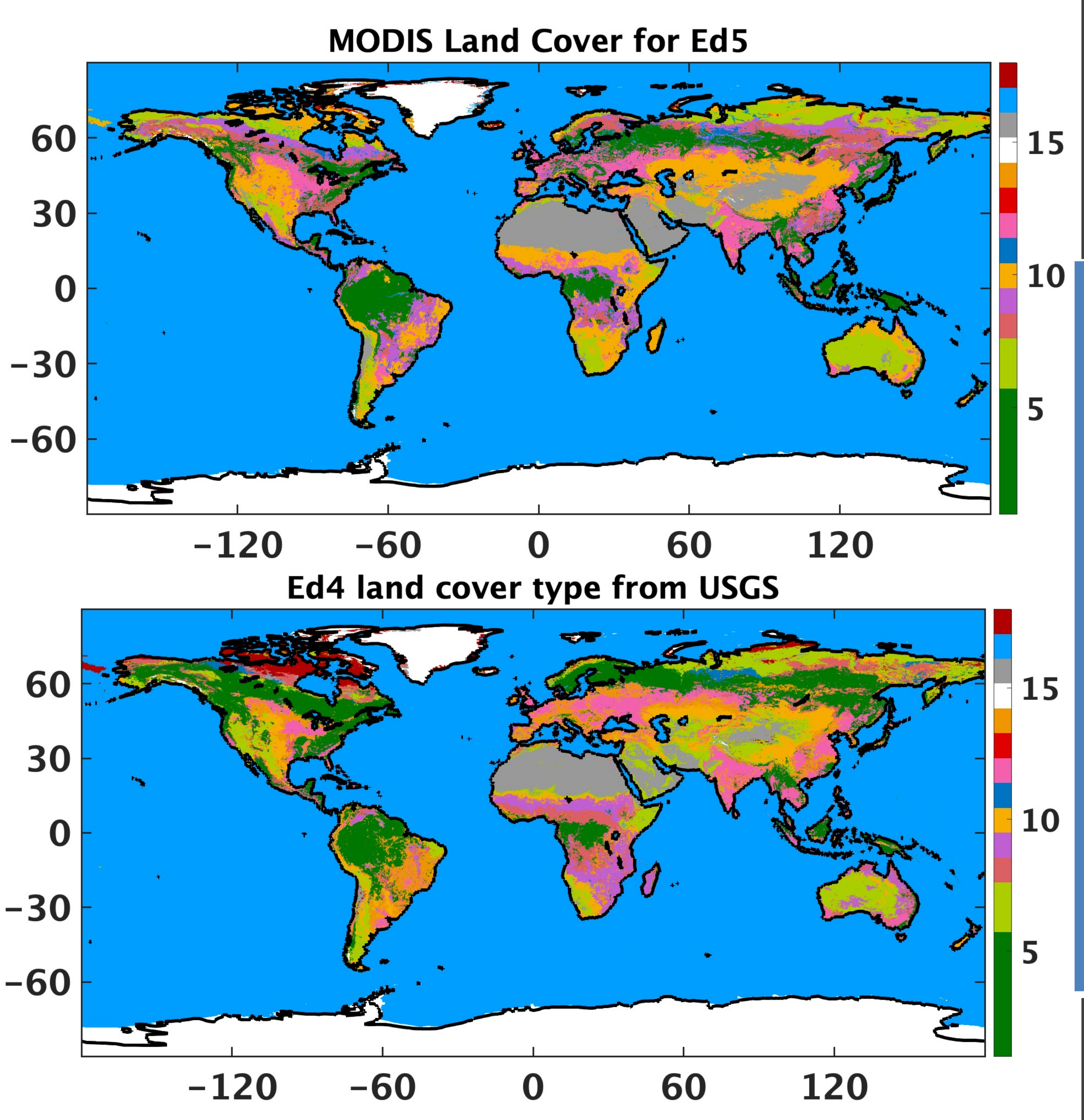


Fig. 3. A map showing the extent of updates to the System for Terrestrial Ecosystem Parameterization (STEP) database between C5 and C6 (2010–2017). Only 1469 of the 3095 sites in STEP remain from C5 (purple), 99 sites were changed to a different IGBP class (orange), 527 sites were deleted (red), and 1827 new sites were added to the database (blue).

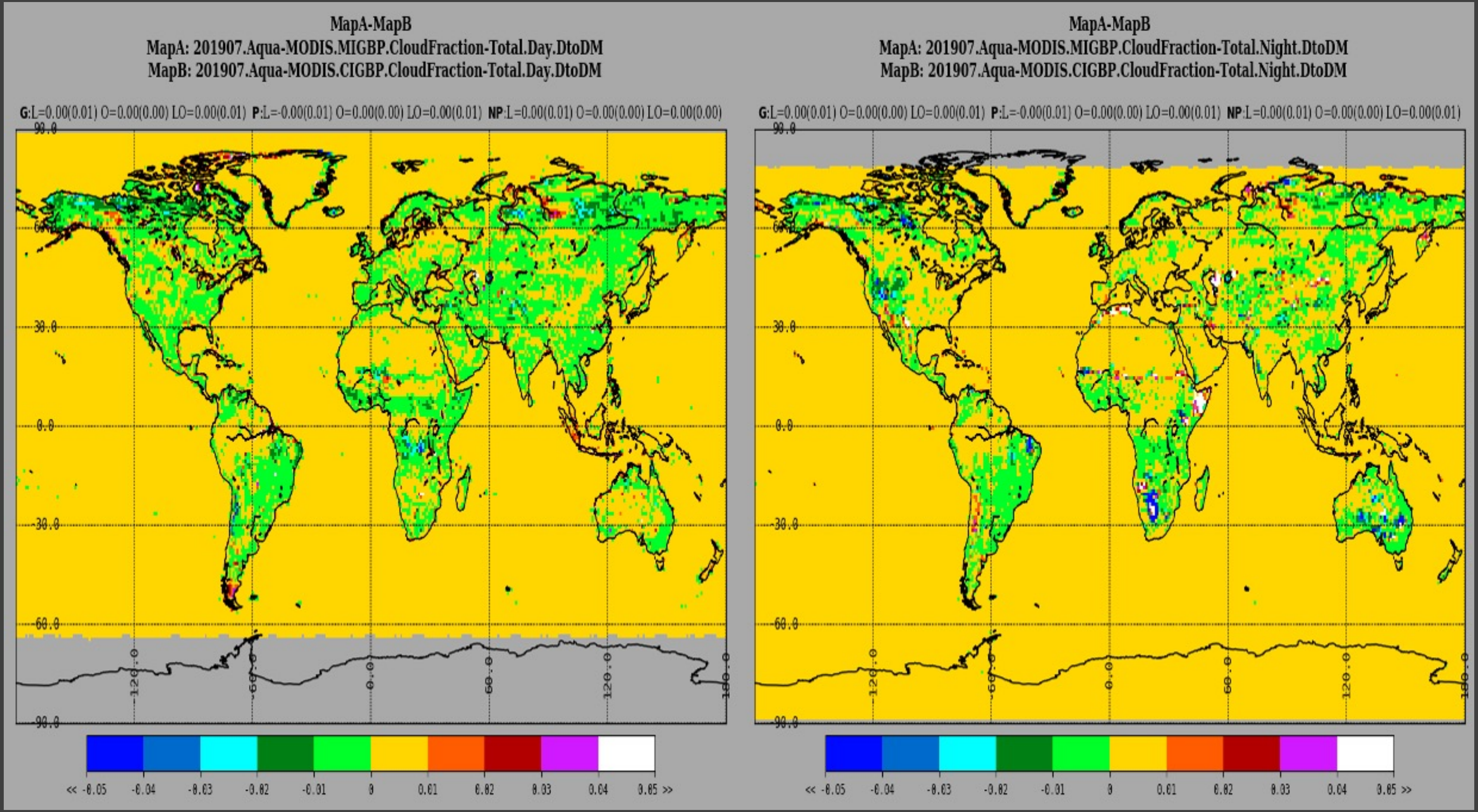
Surface type data for Ed5

- MODIS team does not recommend using this product for mapping land cover changes because the overall accuracy of the product and the coarse spatial resolution (500 m).
- Using data from 2001 to 2020, and the mode of each grid is assigned as the land cover climatology.
- Average the MODIS 0.05° land cover data into 1/6° resolution to maintain consistency.
- Reassign barren land cover over high latitude (>50°N) to tundra as we did for the original land cover map.



1	evergreen needleleaf forest
2	evergreen broadleaf forest
3	deciduous needleleaf forest
4	deciduous broadleaf forest
5	mixed forests
6	closed shrubland
7	open shrublands
8	woody savannas
9	savannas
10	grasslands
11	permanent wetlands
12	croplands
13	urban and built-up
14	cropland/natural vegetation mosaic
15	snow and ice
16	barren or sparsely vegetated
17	Water body
18	tundra

New land cover has small impact on cloud mask



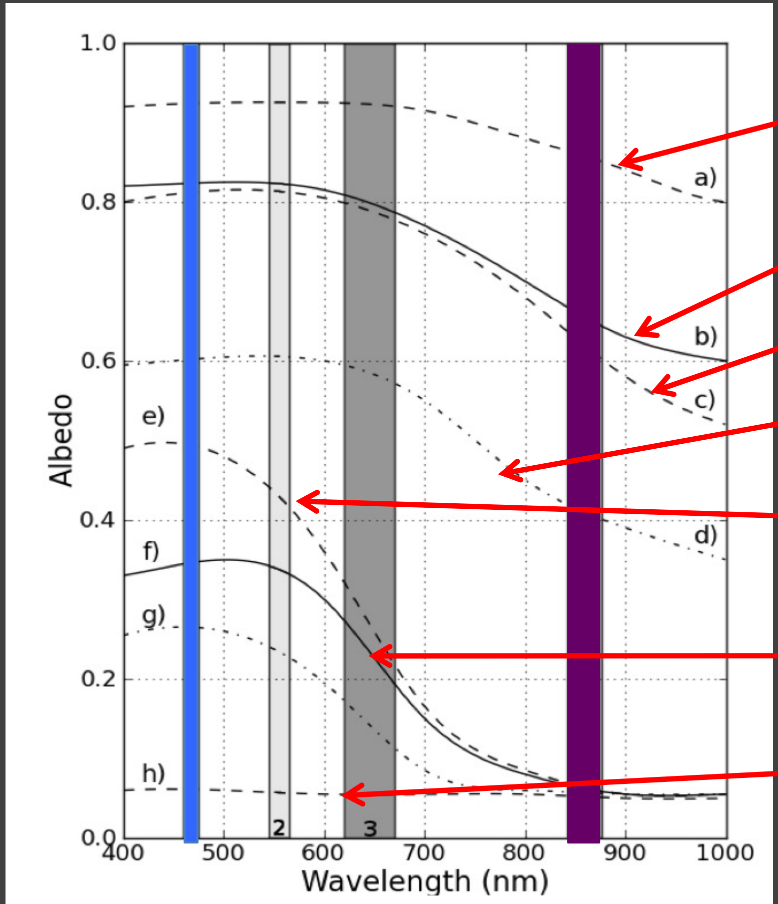
Courtesy of S. Sun-Mack

Snow and ice fraction used for scene identification

- Microwave-based snow/ice fraction from NSIDC/NESDIS
  - The NSIDC (National Snow and Ice Data Center) snow/ice map is from the Near-Real-Time SSM/I-SSMIS EASE-Grid Daily Global Ice Concentration and Snow Extent product (Near-real-time Ice and Snow Extent, NISE).
  - NESDIS snow/ice map is also produced using microwave data. It is only used when NSIDC data is not available.
- Imager-based snow/ice fraction from cloud mask algorithm
  - Snow/ice tests only apply to clear MODIS pixels
  - Snow/ice detection algorithms were developed separately for polar and non-polar regions using combinations of reflectance at 0.6 μm, 1.38 μm, 2.1 μm, and temperatures at 3.7 μm, 11 μm, 12 μm.

Use sea ice brightness index to classify clear-sky ADMs

$$\eta = 1 - \frac{\rho_{0.47} - \rho_{0.86}}{\rho_{0.47} + \rho_{0.86}}$$



Rosel et al 2012, surface values

High sea ice index

Snow

Bare ice

Wet snow

Melting first year ice

~0.8-1.0

Young melting pond

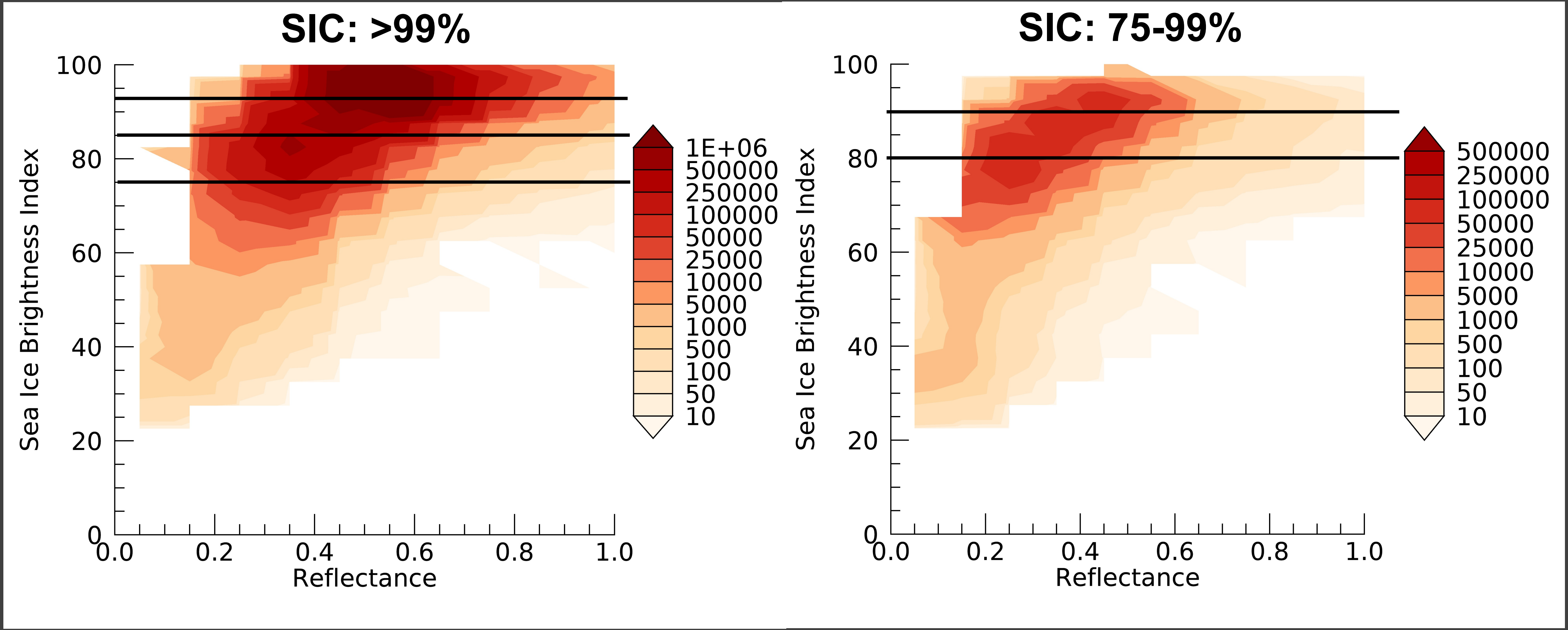
Melting ponds

Open water

~0.1-0.5

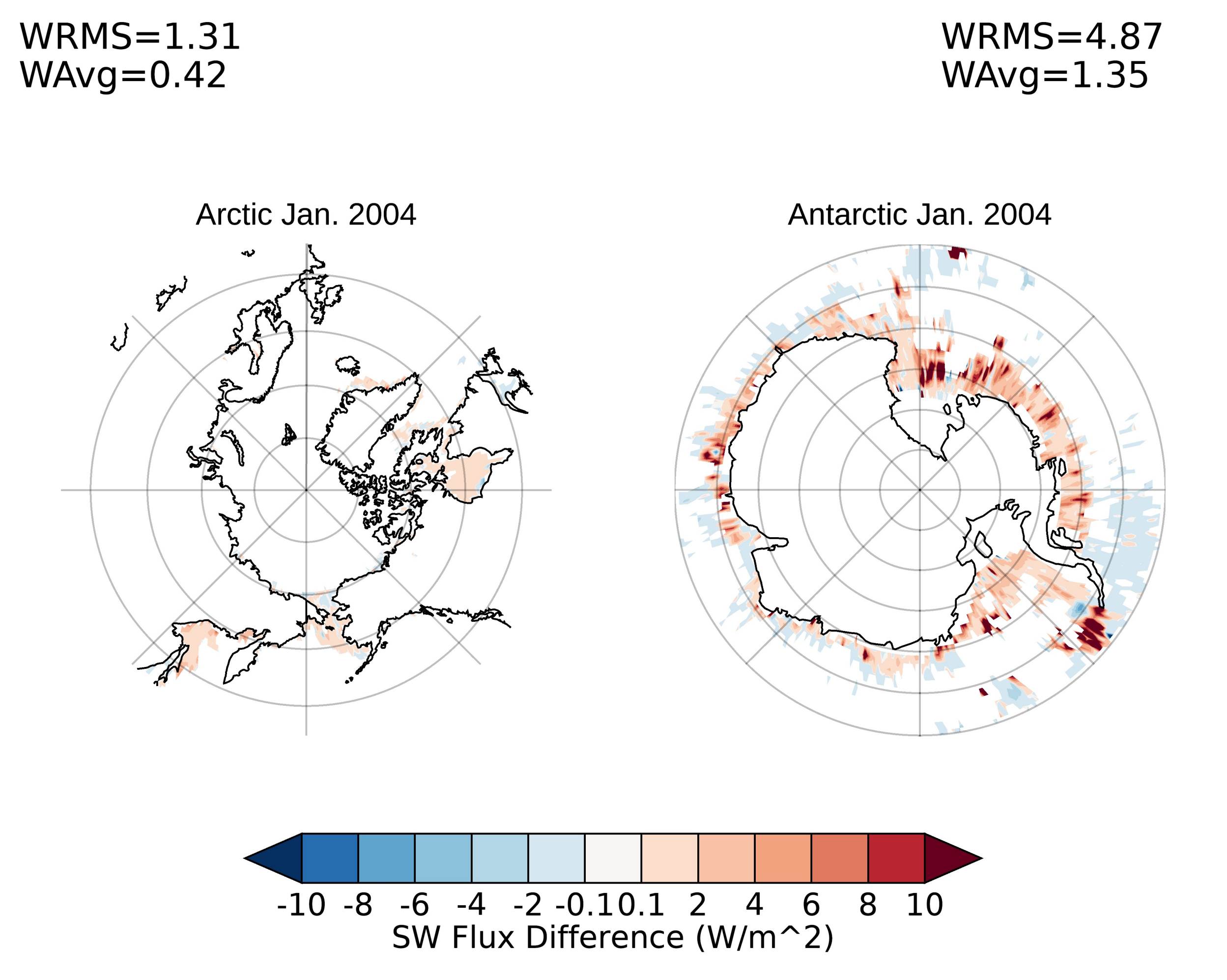
Low sea ice index

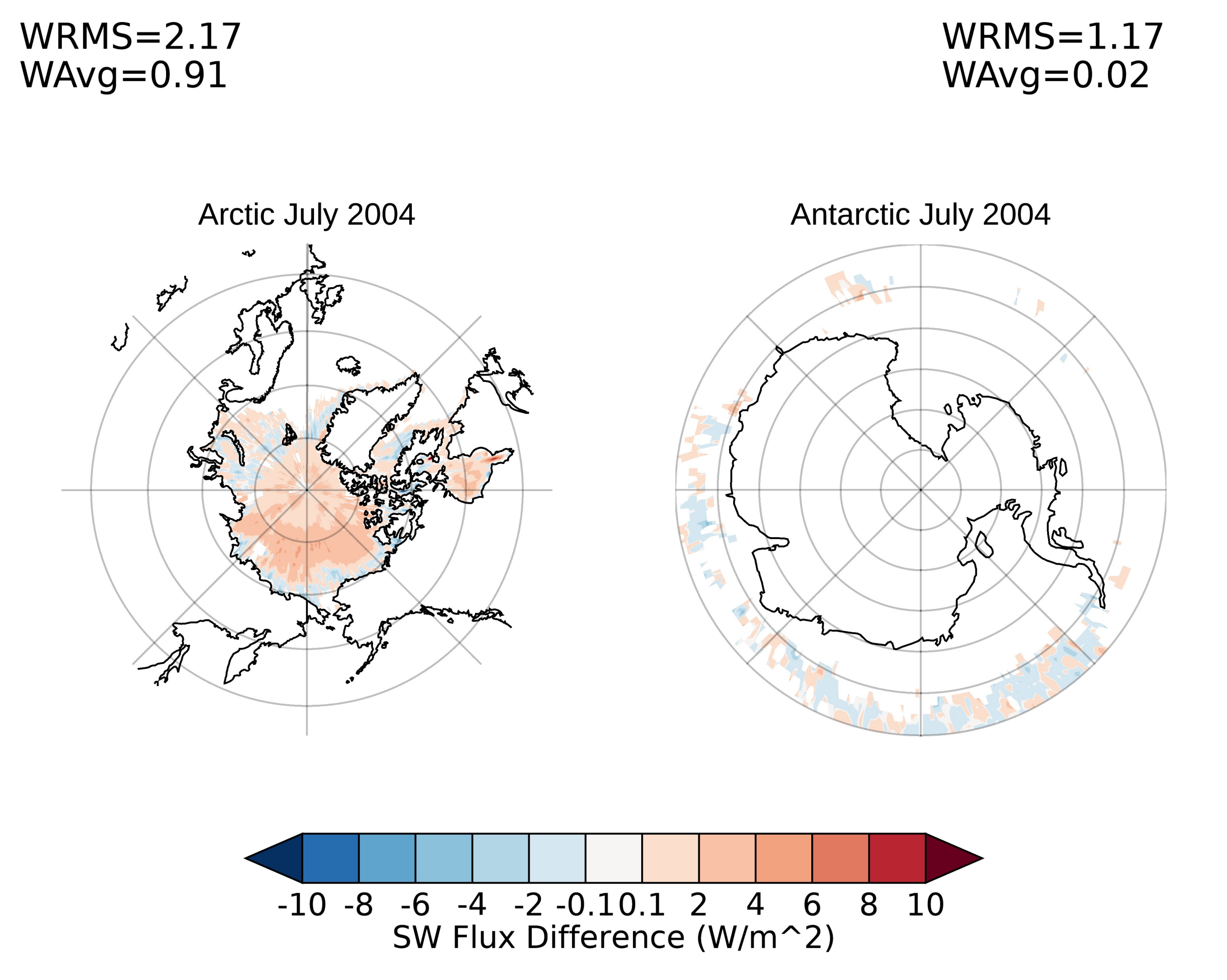
Use SIBI to further classify scenes within each sea ice fraction bin



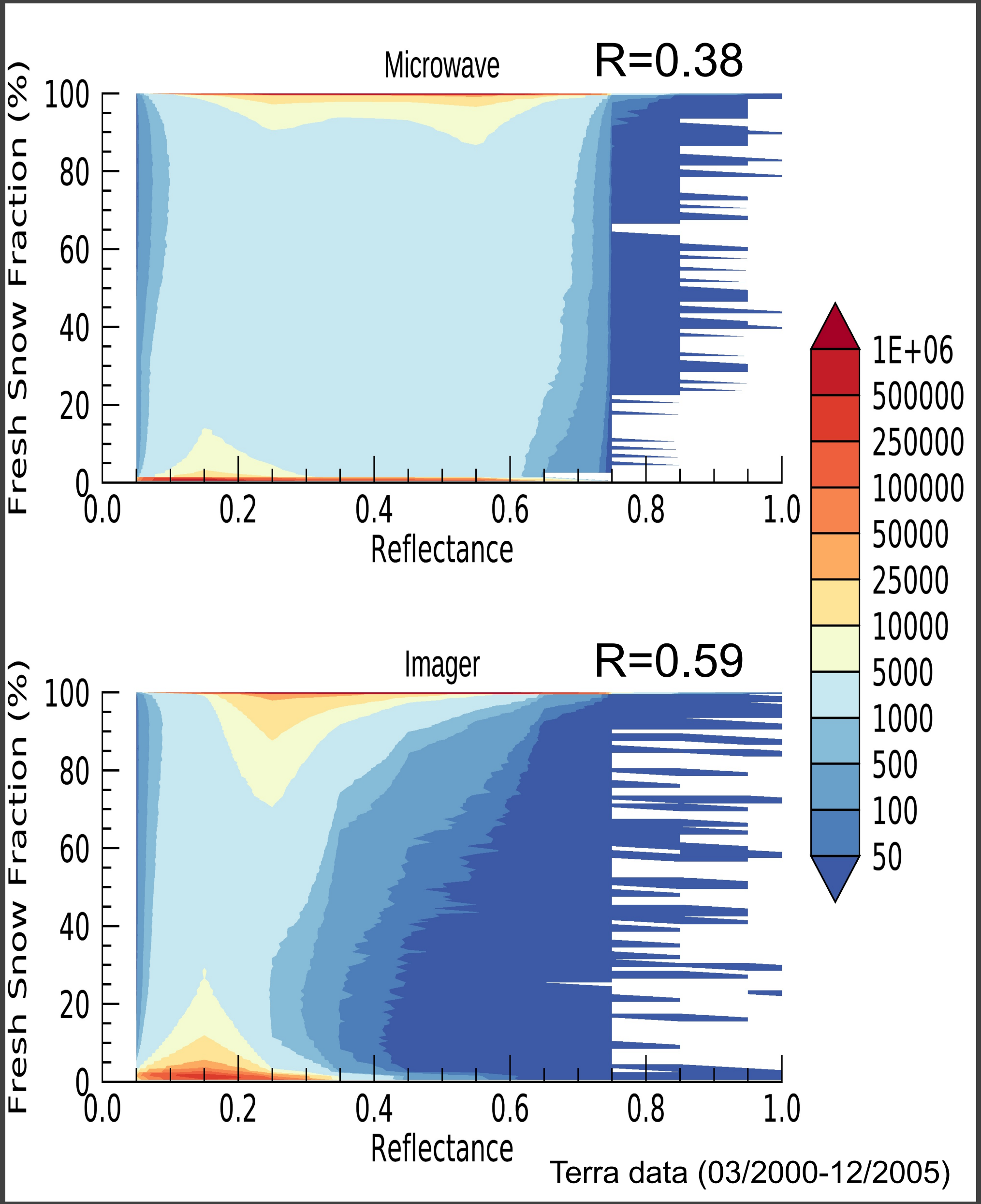
Using SIBI to classify the clear-sky sea ice ADMs increases flux consistency by ~5% for clear sea ice scenes.

Impact on clear-sky sea ice flux





Correlation between fresh snow fraction and reflectance under clear-sky condition



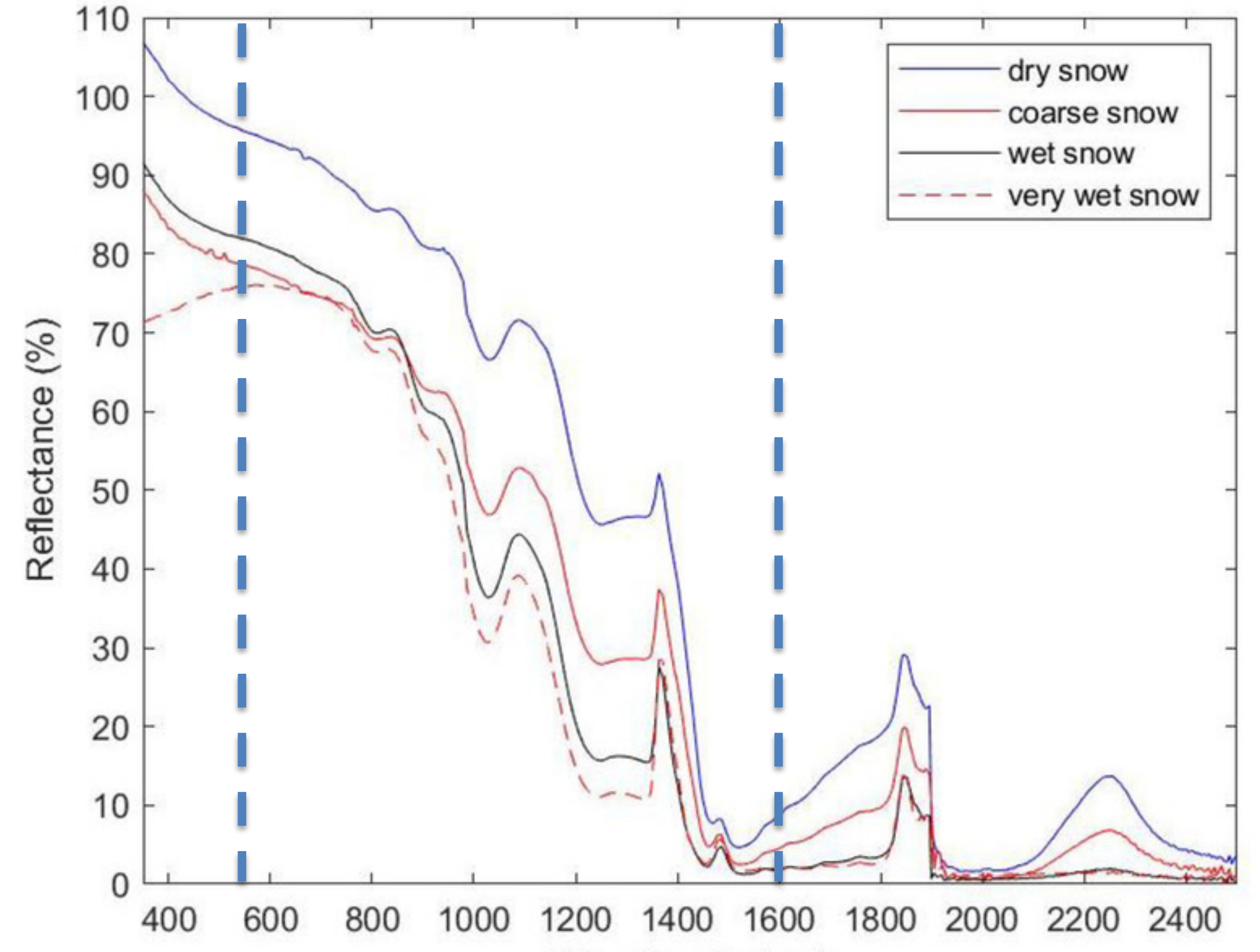
Fresh snow fraction distribution based on microwave and imager

Fresh snow Percentage	MW	Imager
0-1%	16%	7.7%
1-25%	3.6%	4.3%
25-50%	3.8%	1.3%
50-75%	3.4%	1.8%
75-99%	5.2%	4.4%
99-100%	68.0%	80.5%

Normalized difference snow index

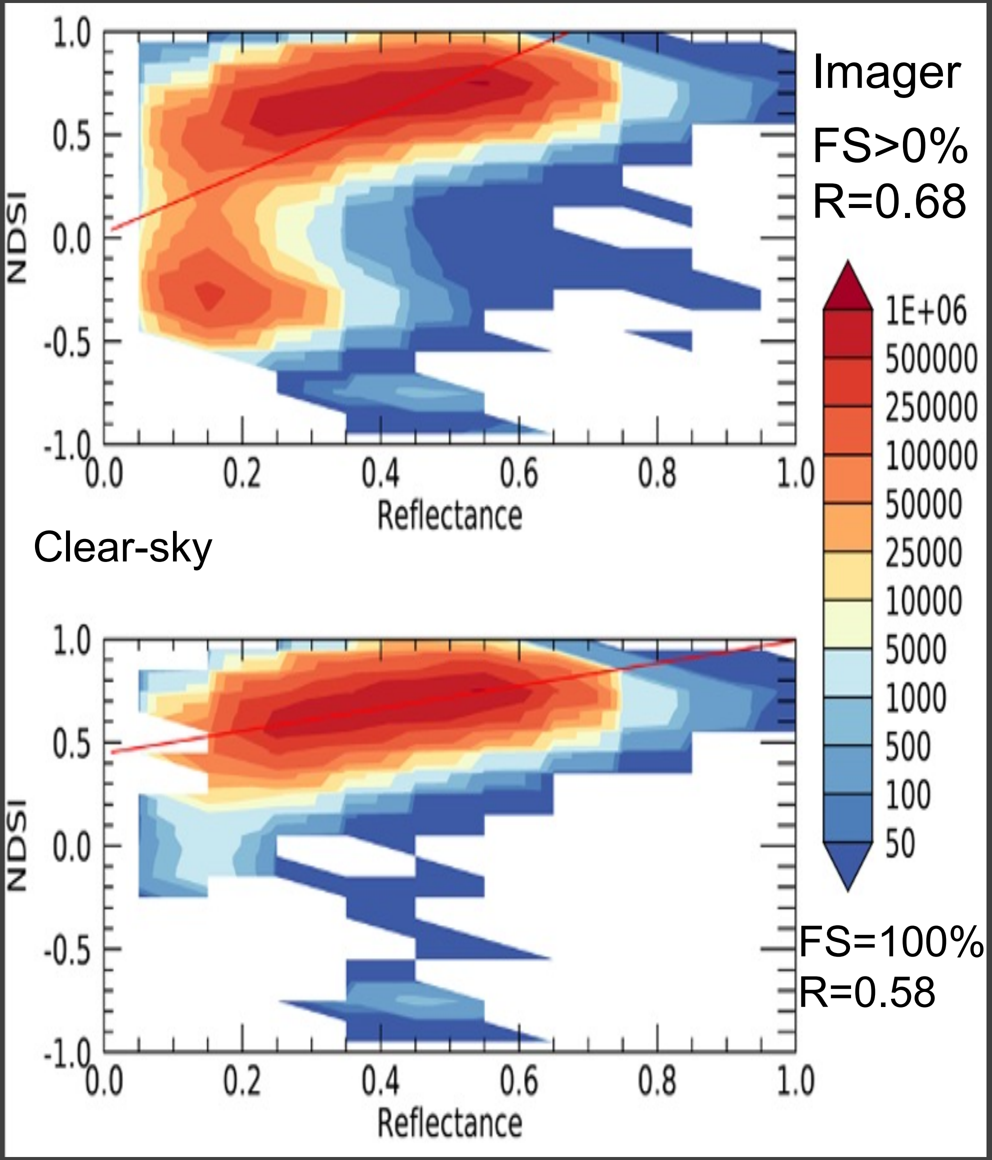
- Snow has a high reflectance in visible band and a low reflectance in near infrared band.
- MODIS team defined the following NDSI to monitor snow cover:

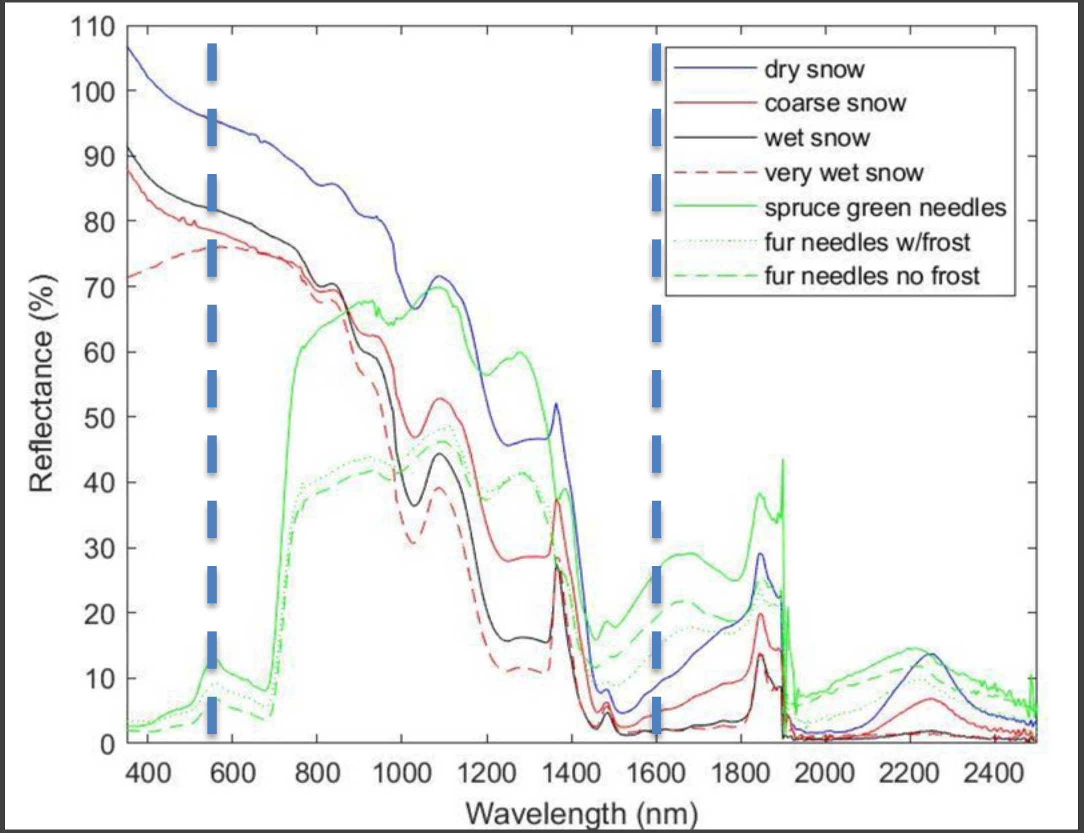
$$NDSI = \frac{\rho_{0.55} - \rho_{1.6}}{\rho_{0.55} + \rho_{1.6}}$$



Selj and Mikkelsen (2012)

Using NDSI to classify fresh snow ADMs

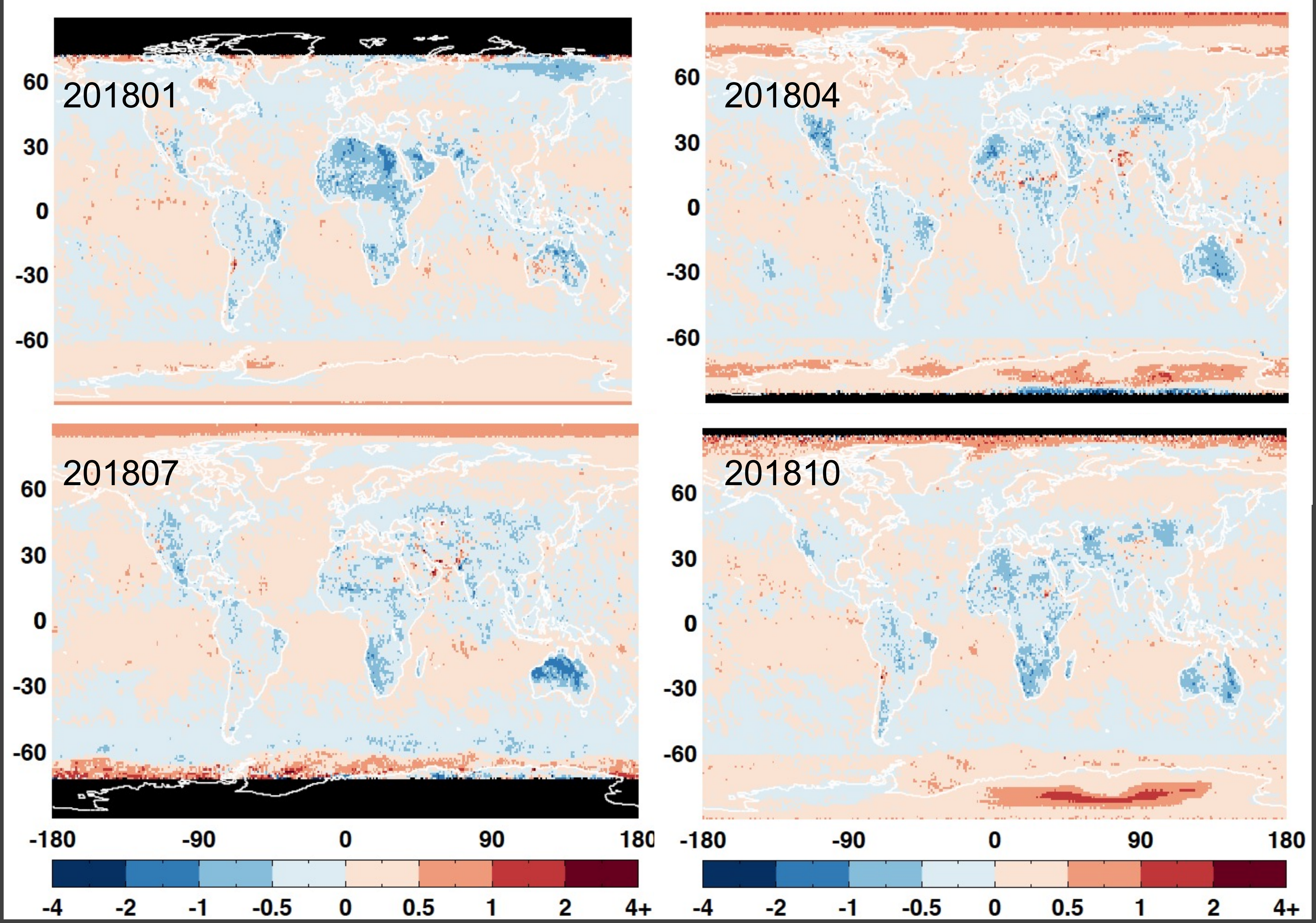




CERES S-NPP is in full RAP scan mode

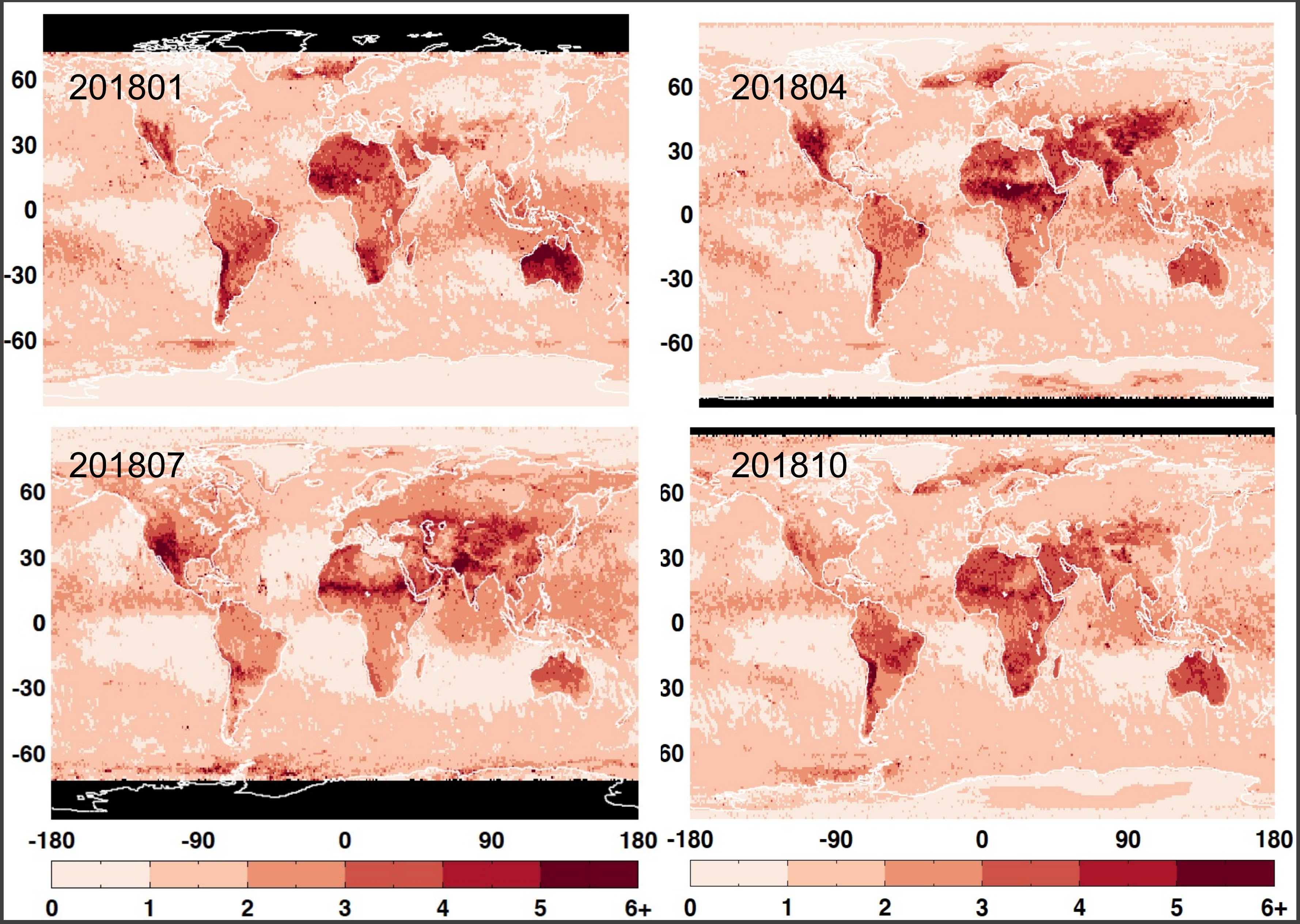
- CERES instrument on S-NPP is in quasi full biaxial scan mode since March 24, 2020.
- As biaxial scan was not planned for CERES instrument on NPP, CERES instrument doesn't have an unobstructed view from all angles.
- There is an antenna that needs to be avoided at clock angle of ~20° on S-NPP.
- Construct S-NPP LW ADMs based on the same methodology that we developed for Ed4 Aqua ADMs using all available cross-track and RAP data from CERES NPP (Feb. 2012 to Nov. 2021).
- Using these S-NPP LW ADMs to invert LW fluxes from S-NPP CERES observations and compare with the S-NPP CERES LW fluxes inverted using Aqua ADMs.

Daytime all-sky monthly gridded LW flux difference: Aqua ADM - NPP ADM



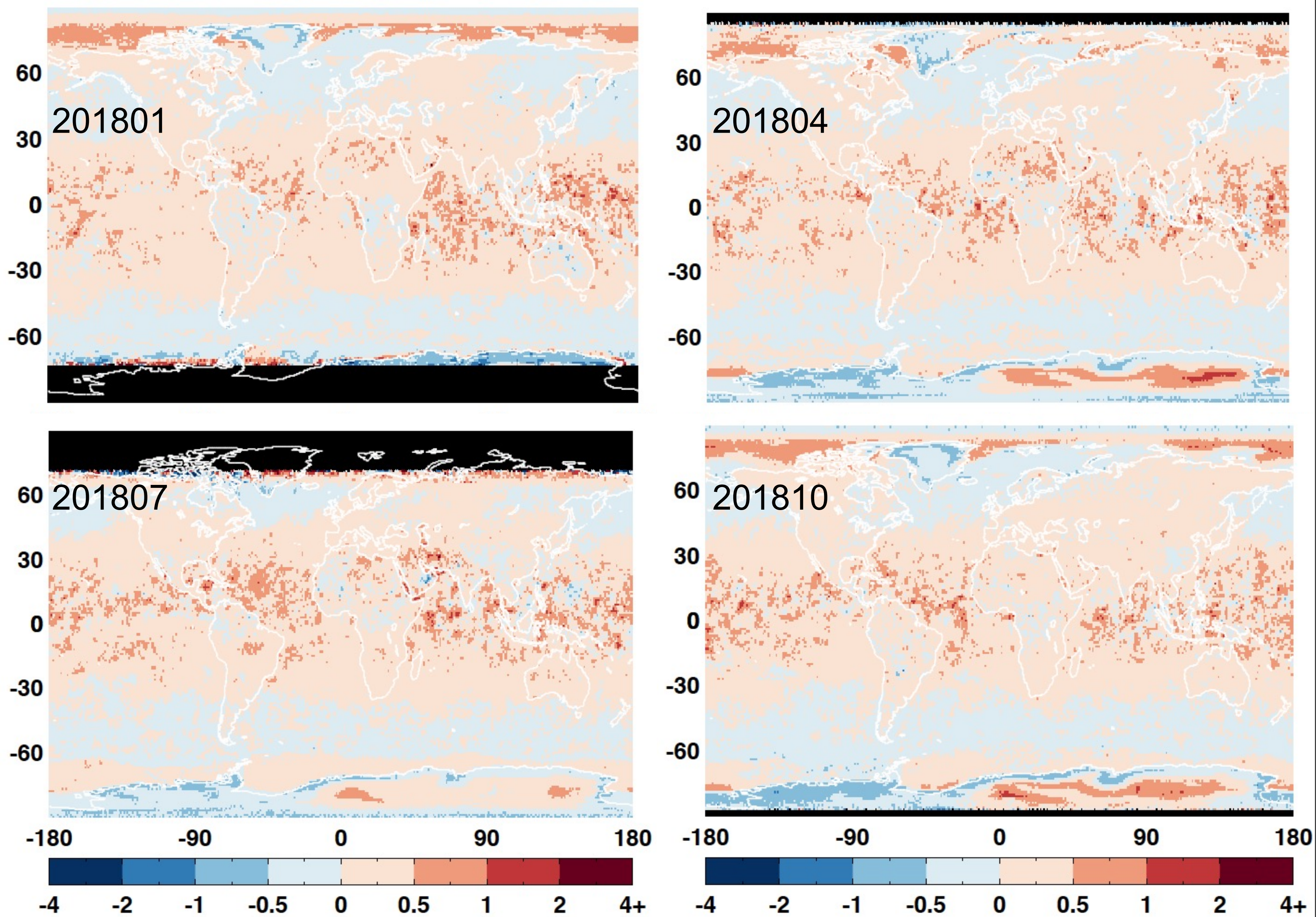
	Bias (W m^{-2})	RMS (W m^{-2})
201801	-0.02	1.7
201804	-0.01	1.8
201807	-0.02	1.8
201810	-0.01	1.7

Daytime all-sky monthly gridded LW flux RMS



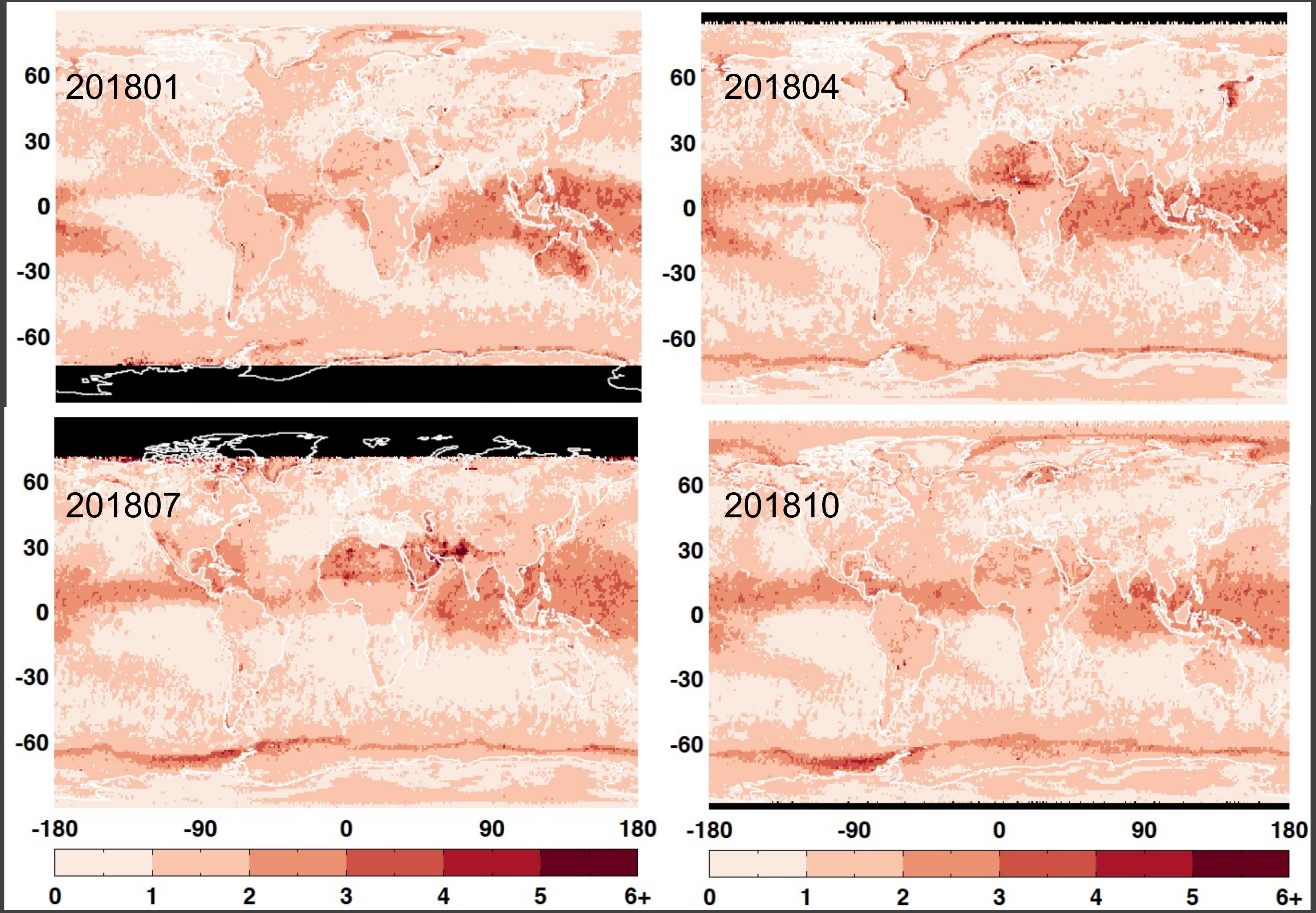
	Bias ($W\ m^{-2}$)	RMS ($W\ m^{-2}$)
201801	-0.02	1.7
201804	-0.01	1.8
201807	-0.02	1.8
201810	-0.01	1.7

Nighttime all-sky monthly gridded LW flux difference: Aqua ADM - NPP ADM



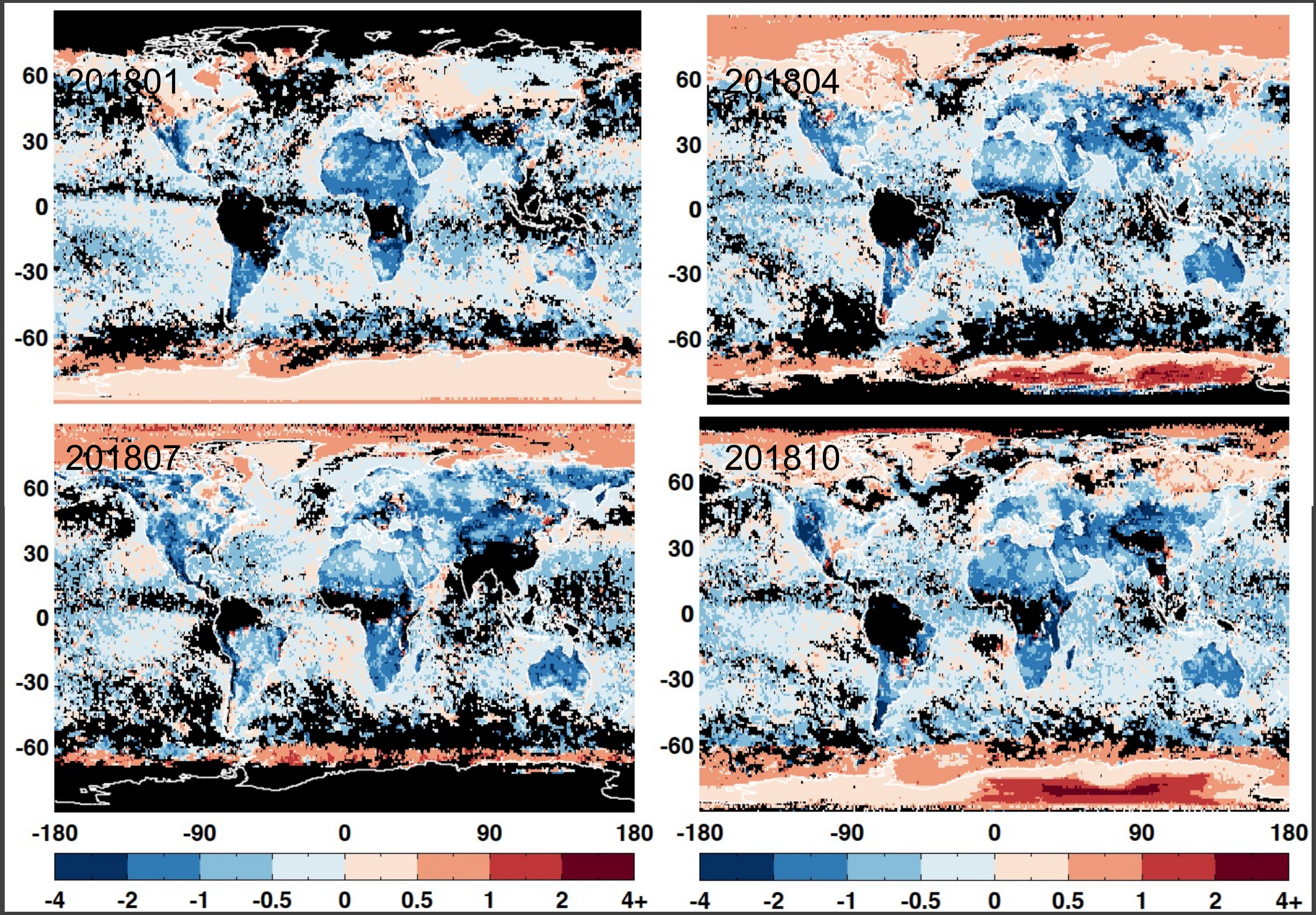
	Bias ($W\ m^{-2}$)	RMS ($W\ m^{-2}$)
201801	0.2	1.3
201804	0.2	1.4
201807	0.2	1.4
201810	0.2	1.4

Nighttime all-sky monthly gridded LW flux RMS



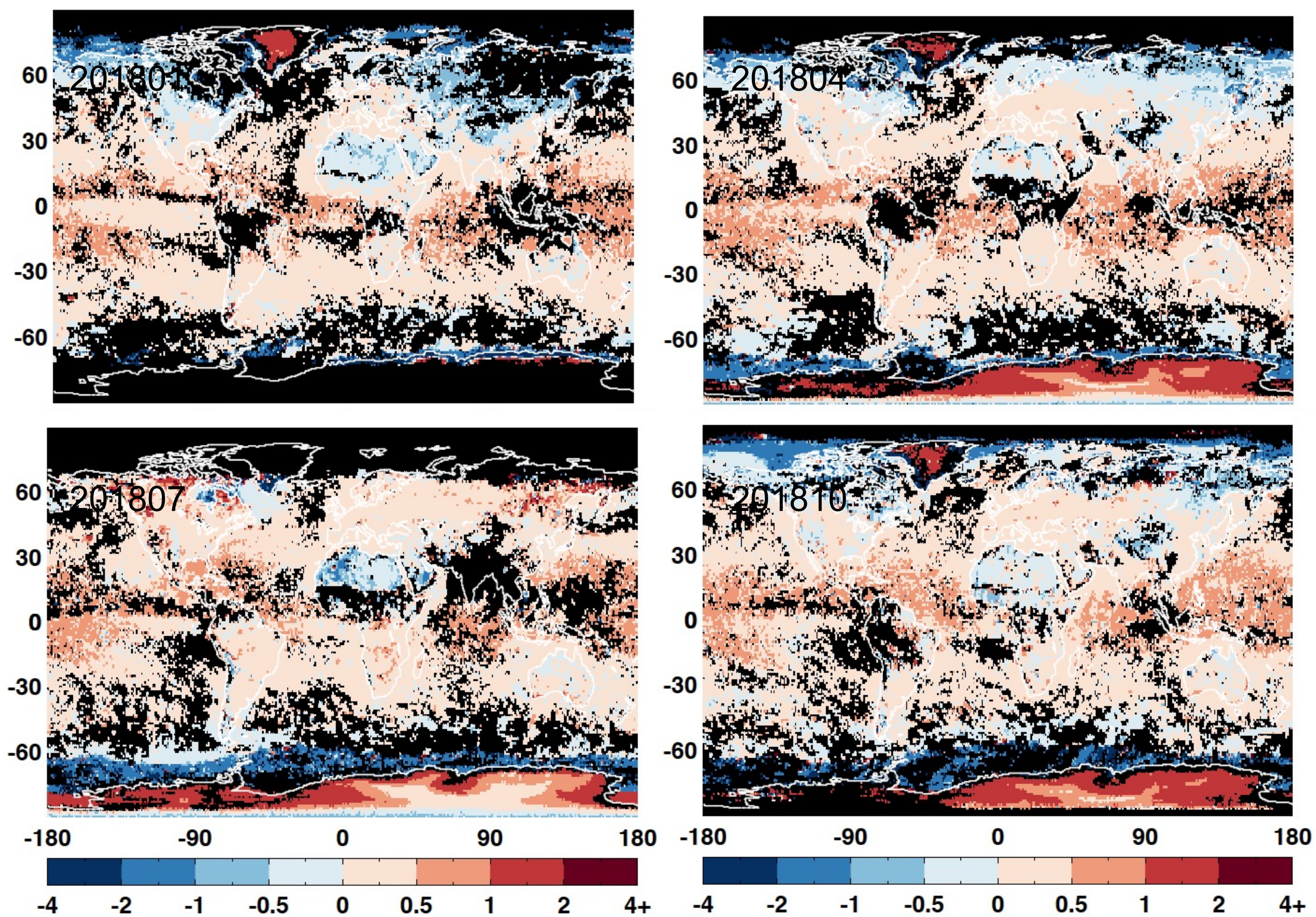
	Bias ($W\ m^{-2}$)	RMS ($W\ m^{-2}$)
201801	0.2	1.3
201804	0.2	1.4
201807	0.2	1.4
201810	0.2	1.4

Daytime clear-sky monthly gridded LW flux difference: Aqua ADM - NPP ADM



	Bias (W m^{-2})	RMS (W m^{-2})
201801	-0.4	0.8
201804	-0.4	0.8
201807	-0.4	0.8
201810	-0.4	0.8

Nighttime clear-sky monthly gridded LW flux difference: Aqua ADM - NPP ADM



	Bias (W m^{-2})	RMS (W m^{-2})
201801	0.1	0.4
201804	0.1	0.5
201807	0.2	0.5
201810	0.1	0.5

S-NPP ADMs

- Global monthly mean RMS error for S-NPP all-sky LW flux from using inconsistent ADMs are 1.6 Wm^{-2}.
- Global monthly LW ADM uncertainty is estimated to be 0.8 Wm^{-2} using direct integration.
- This emphasize the importance of using consistent scene identifications when developing and applying the ADMs.

- Later this year and early next year, we will examine if S-NPP has enough RAP observations to develop a set of S-NPP SW ADMs.

Summary

- Use sea ice brightness index and normalized difference snow index to mitigate the uncertainty in the snow and ice datasets that are current included in the CERES data processing. NOAA sea ice concentration CDR and National ice center snow fraction are considered for Ed5.
- MODIS land cover data will be used in the Ed5 processing for land surface type classification.
- Using Aqua ADMs for NPP flux inversion has small impact on global mean all-sky daytime and nighttime LW fluxes but can lead to >2 Wm^{-2} bias for monthly gridded mean LW flux. The global mean RMS error is about 1.6 Wm^{-2}, which is a factor of two of the ADM uncertainty.
- Using Aqua ADMs for NPP flux inversion underestimates global mean clear-sky daytime LW flux by 0.4 Wm-2 and overestimate the nighttime LW fluxes by 0.2 Wm^{-2}, and the monthly gridded mean LW flux biases exceed 4 Wm^{-2}.