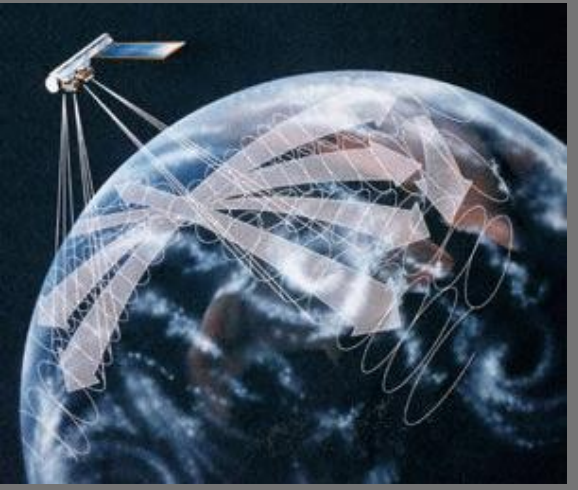

CERES Angular Distribution Model Working Group Report

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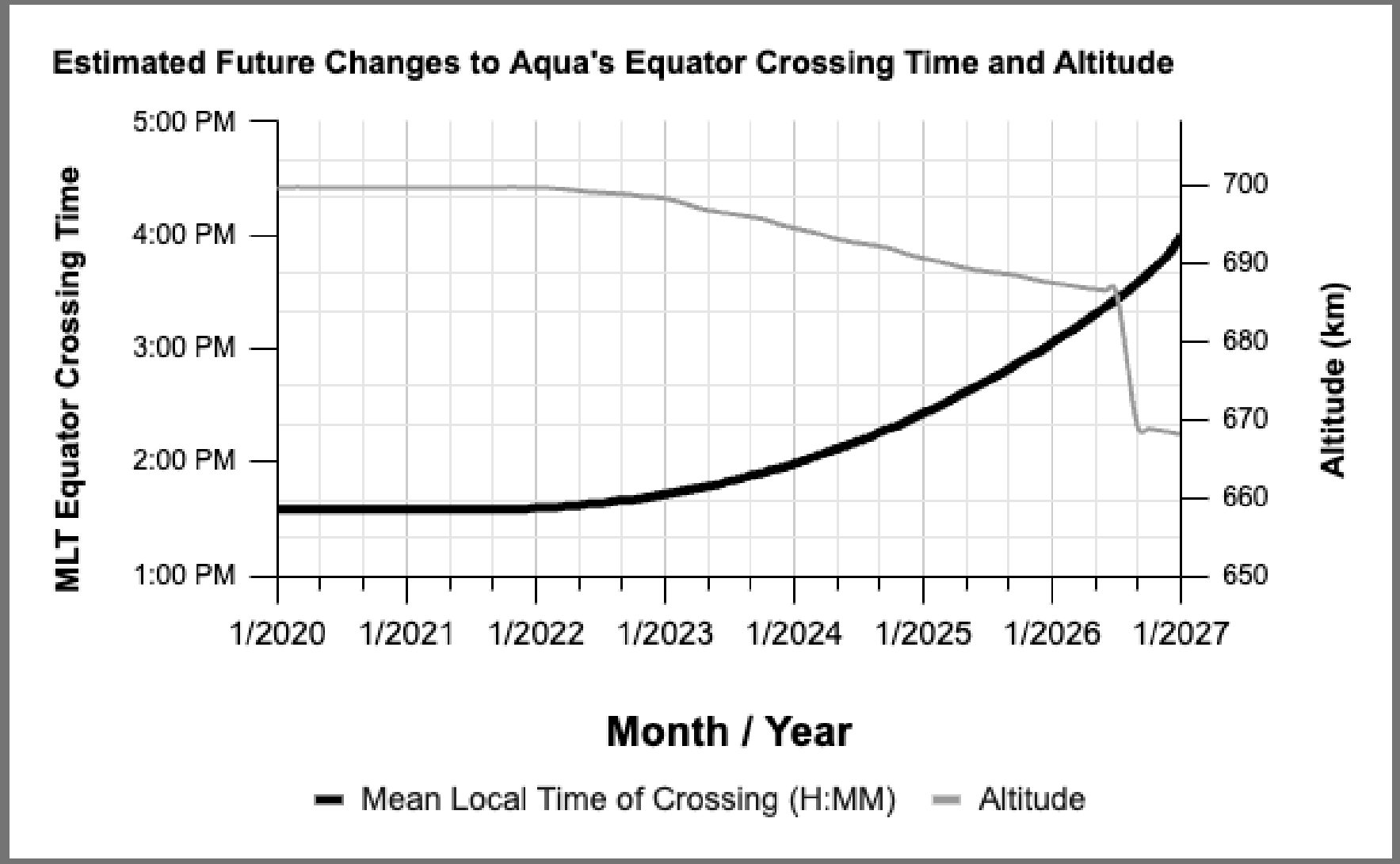
CERES Science Team Meeting, May 12-14, 2026
NASA Langley Research Cetner, Hampton, VA

Outline

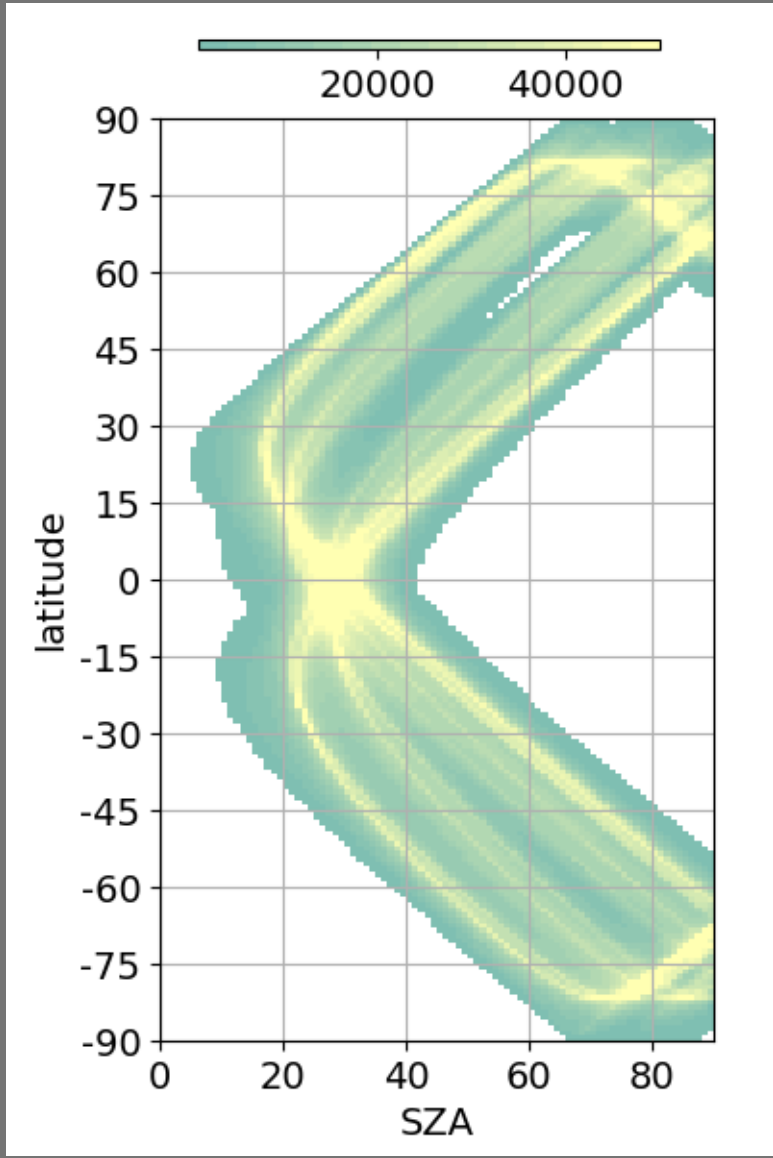
- Impact of Terra/Aqua orbital drifting on the CERES ADMs
- LUT approach for Split-SW flux retrieval

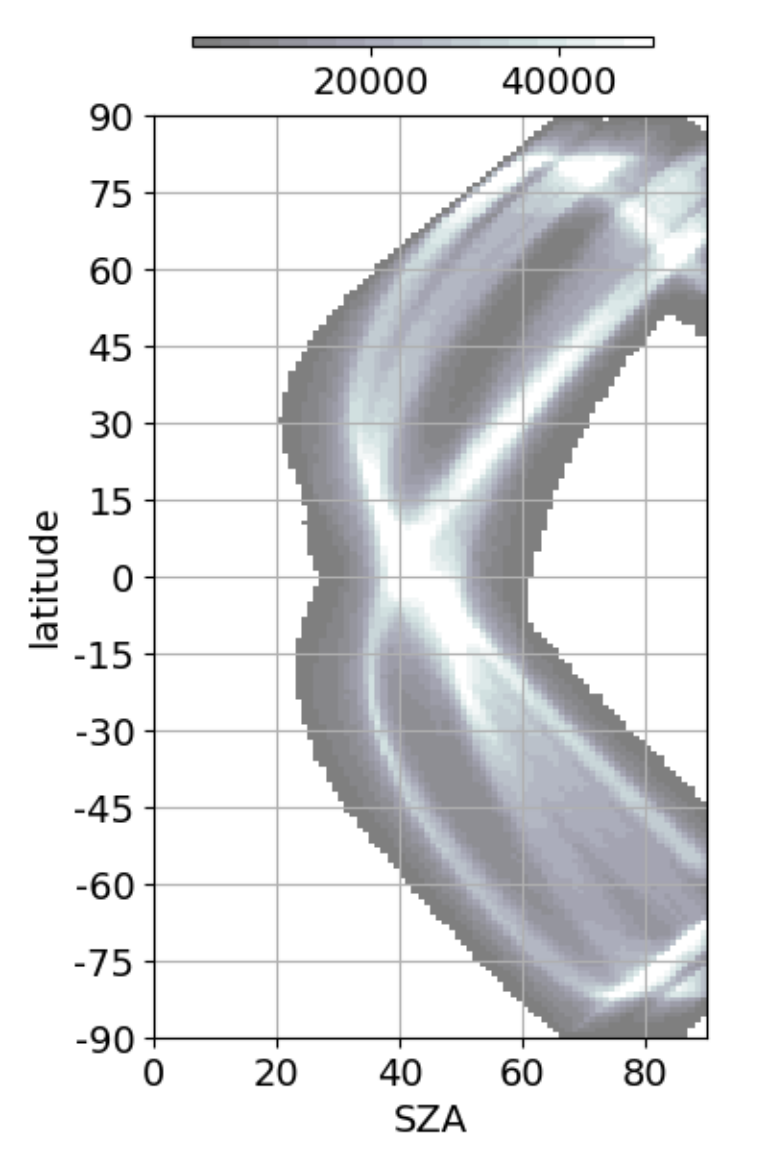
Impact of Terra/Aqua orbital drifting on the CERES ADMs

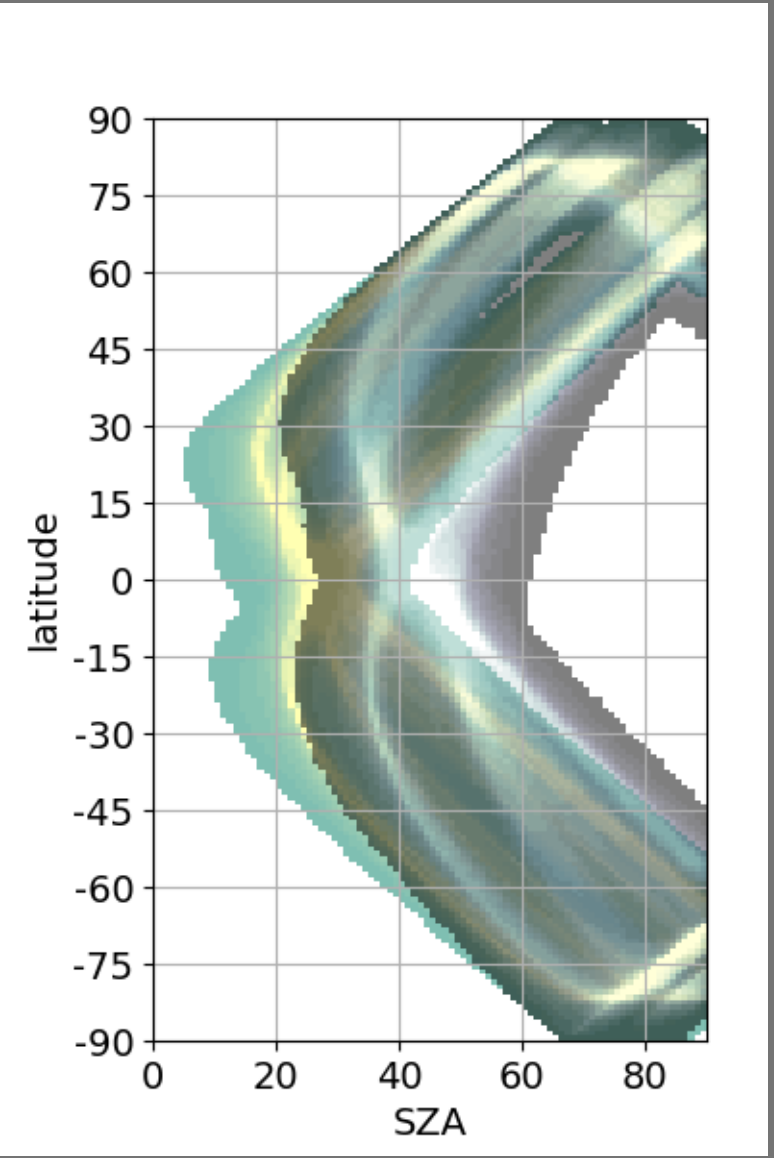


https://aqua.nasa.gov/

AQUA SZA sampling counts collected in 2004 Jan, Apr, Jul, and Oct





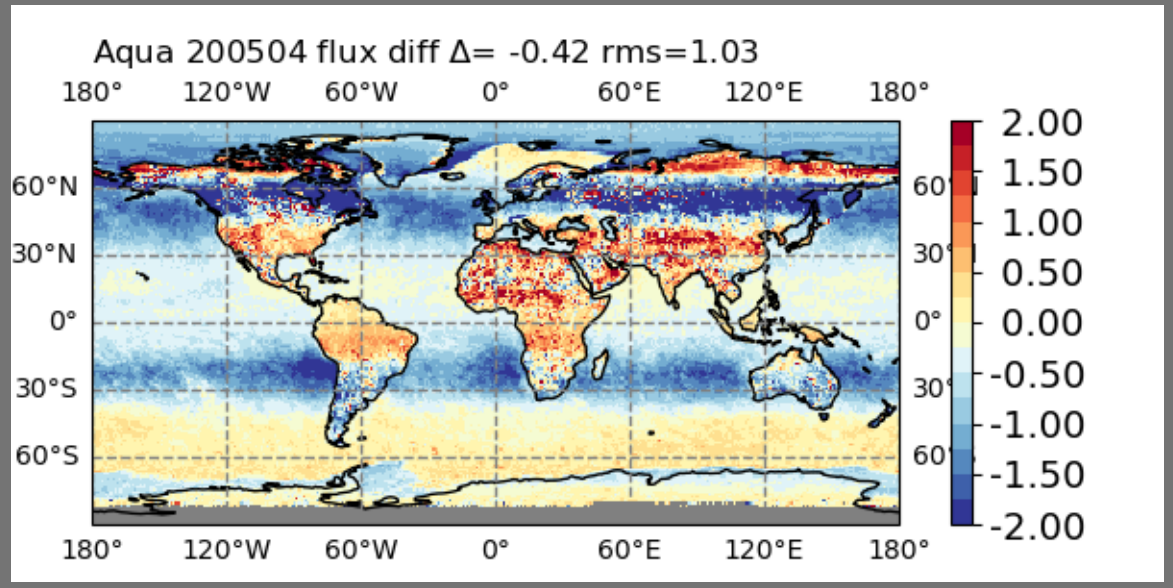


ADMs

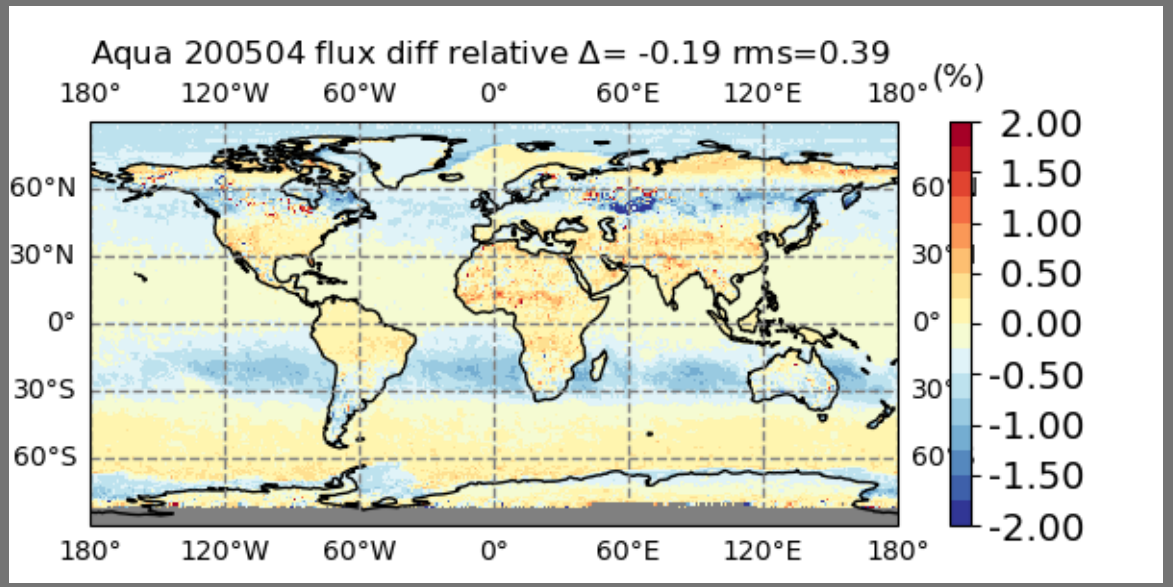
- Aqua Edition 4 ADMs were constructed from cross-track and RAPs data from Aug 2002 to Mar 2005.

- A set of new ADMs is constructed by adding additional ~2.5 years of Aqua-FM3 RAPs data from Apr 2023 to Nov 2025.

Flux differences



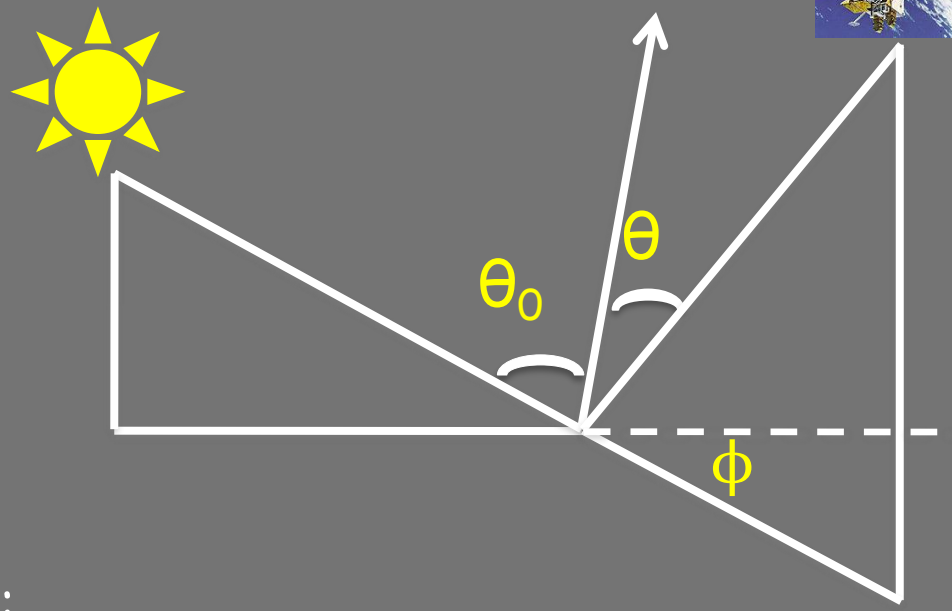
Flux Relative differences



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:

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

One of basis of ADMs is the averaging of radiances in a finite bin.
Are the radiance sampled well? Alternatively, to what extent is the mean radiance close to the truth?

Radiance Margin of Error (MoE)

Given a set of radiances in an ADM bin, the MoE can be estimated as

$$E = t^* \times \left(\frac{s}{\sqrt{n}} \right)$$

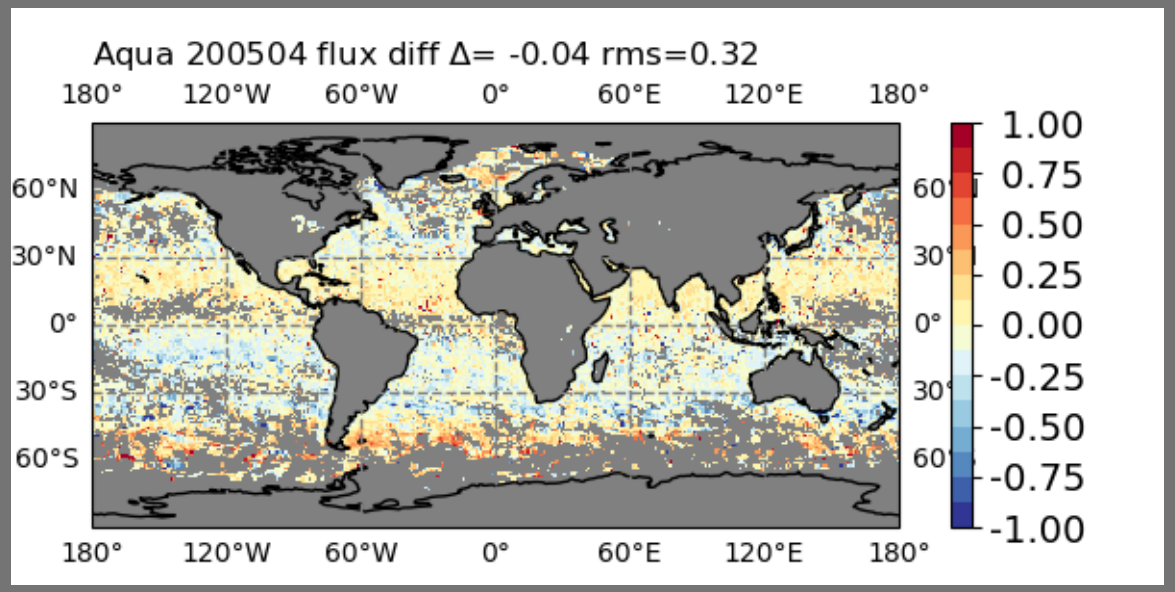
$\frac{s}{\sqrt{n}}$ is the standard error calculated from standard deviation and sampling counts.

critical t* value is calculated from the Student's t-test depending on the number of samples and pre-set significant level (usually, it is 5%).

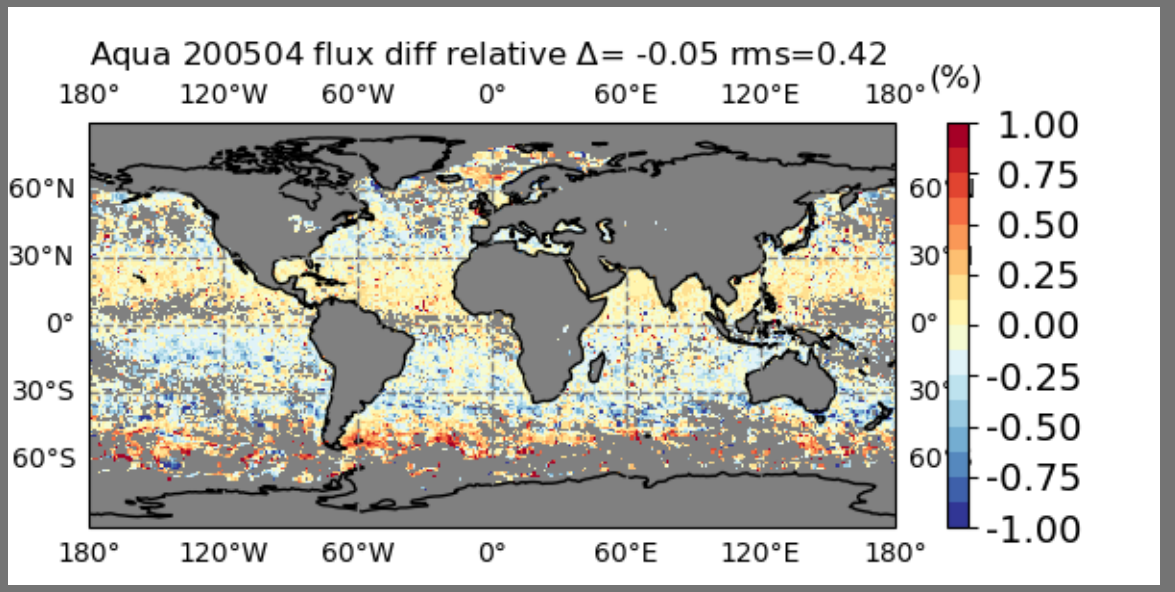
The confidence interval = estimated mean $\pm$ E
(the estimated mean is within the interval for 95% of time to the truth).

Clear-sky over ocean

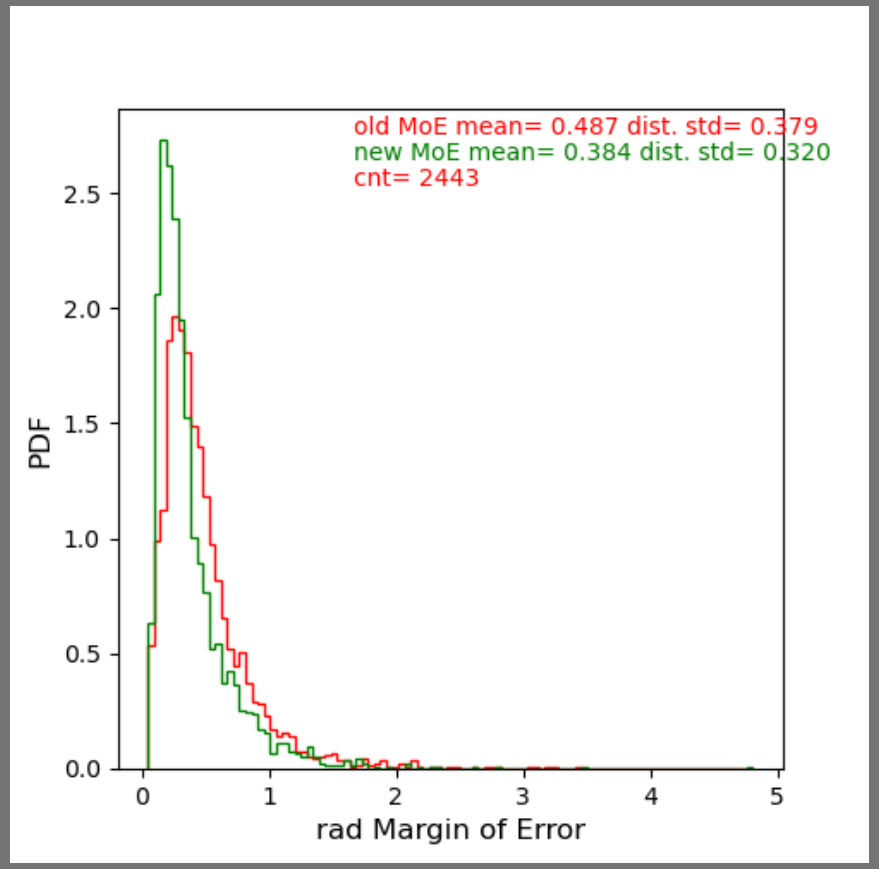
Flux differences



Flux Relative differences

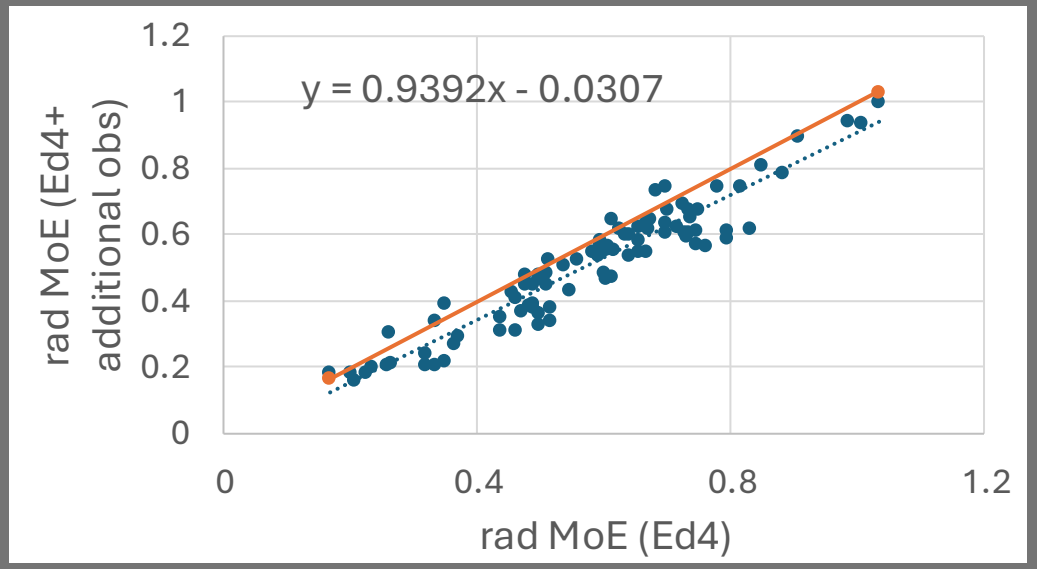


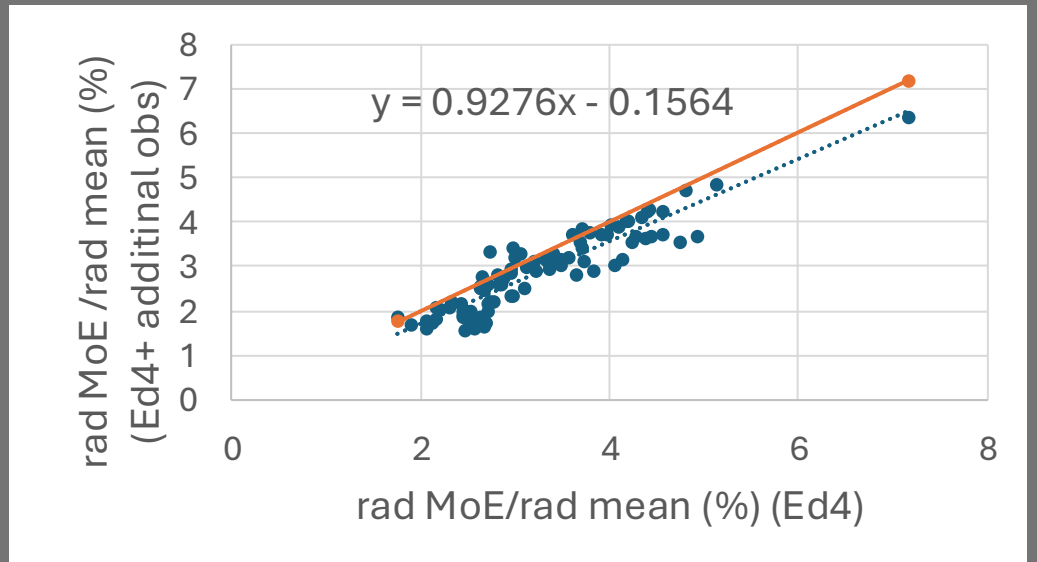
Clear-sky over ocean



MoE distribution across viewing angles (45 VZA x 90 RAZ) for SZA = 38-40, ocean wind-speed=4-6 m/s, coarse model aerosols, and sampling counts > 10 in each viewing angle.

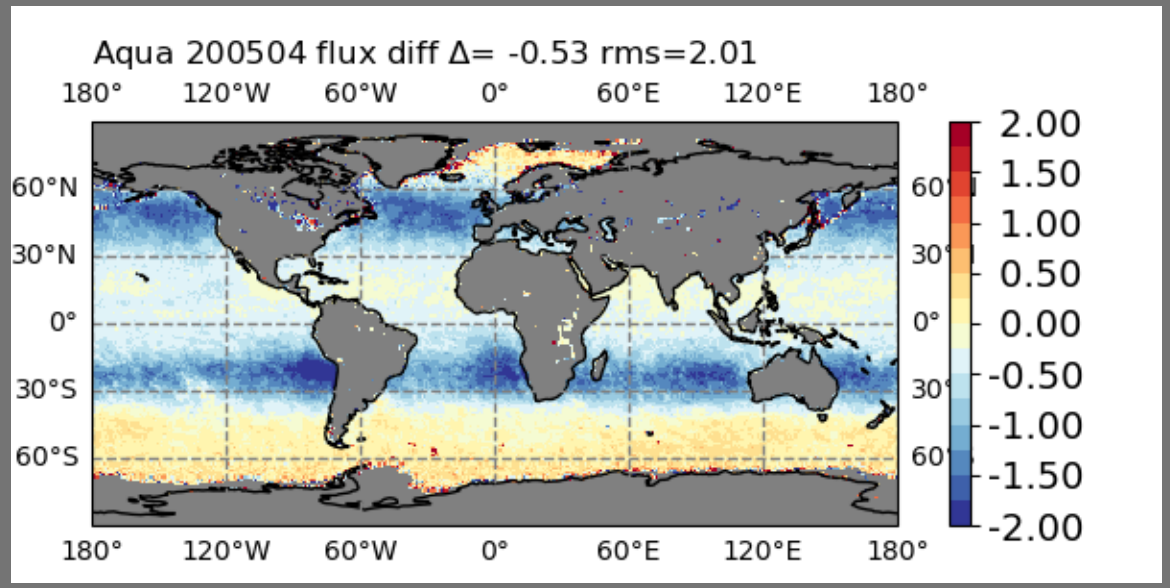
Collect mean MoE values from the MoE distributions for 7 SZA bin intervals from 15 to 71, 6 ocean wind speed bins, and both coarse model and fine model aerosols.



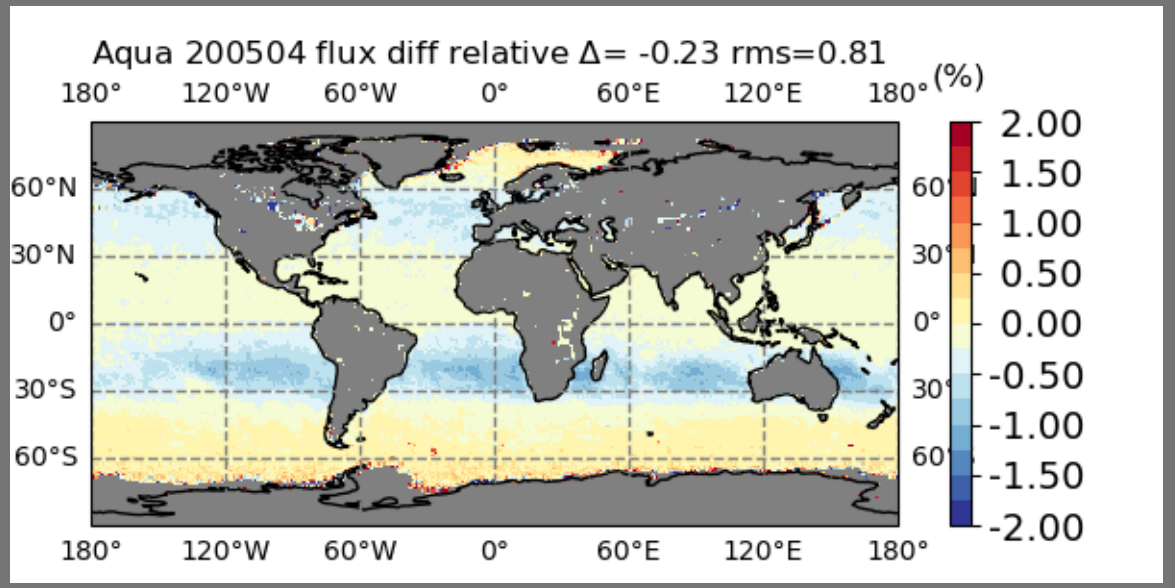


Cloudy-sky over ocean

Flux differences

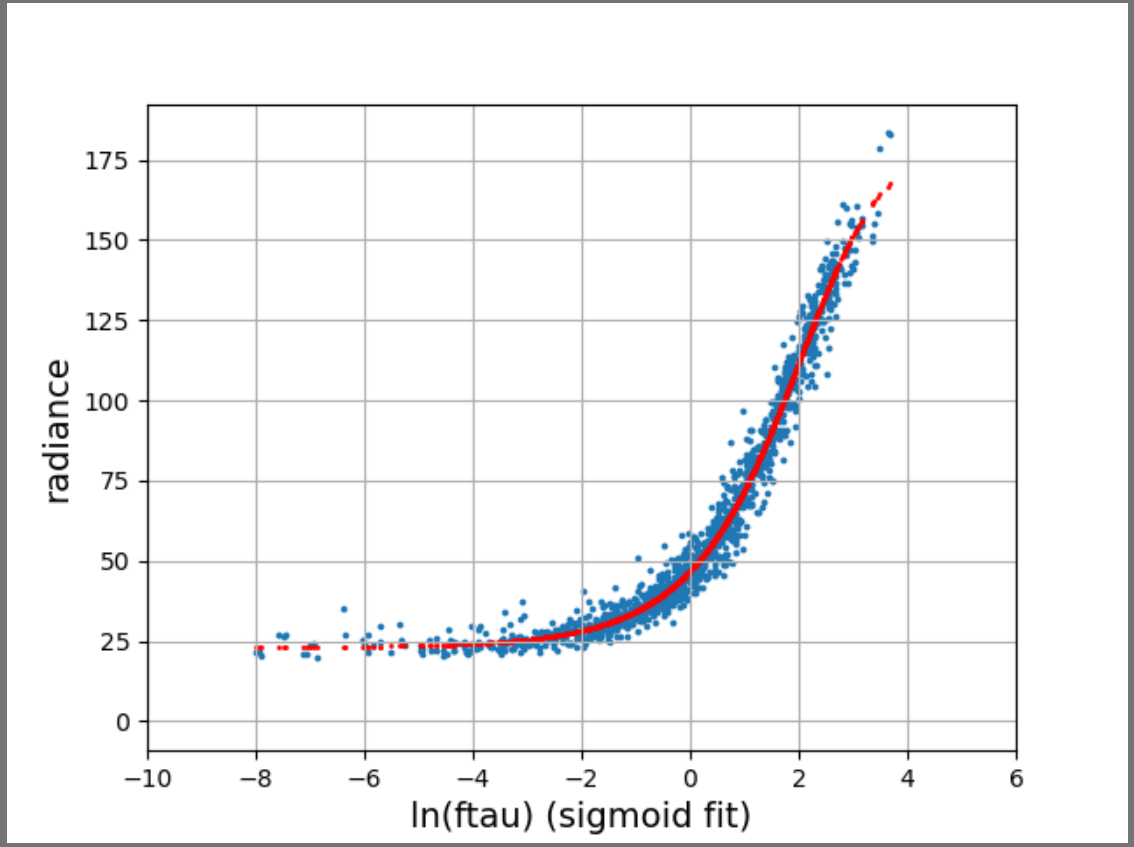


Flux Relative differences



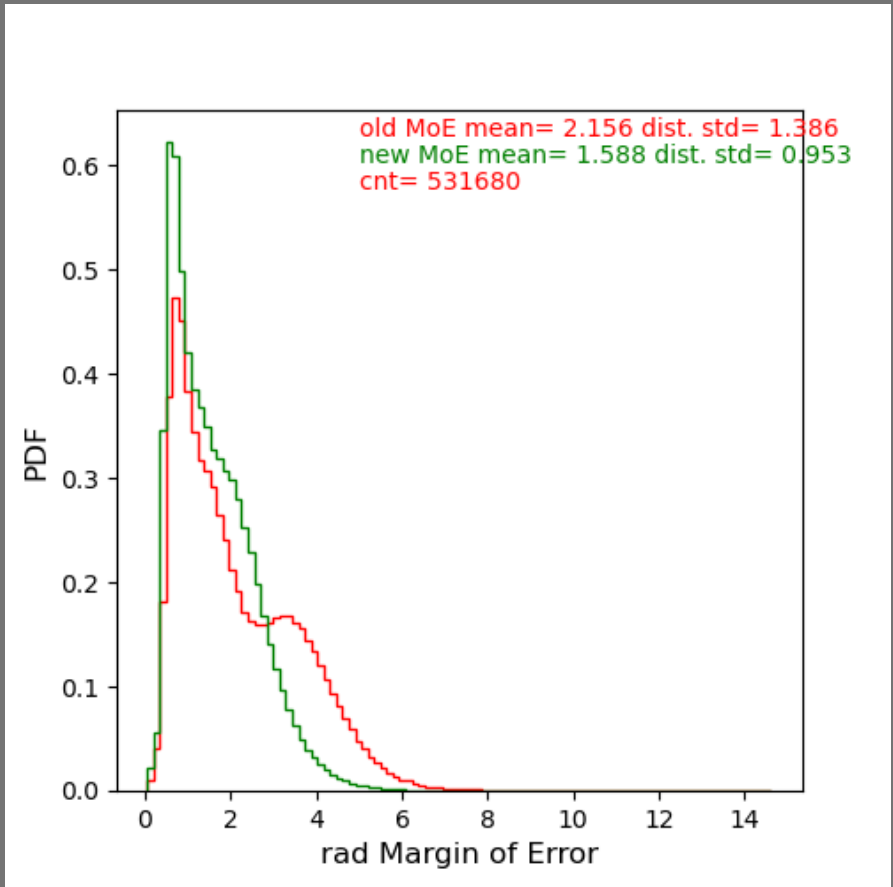
Cloudy-sky over ocean

Processing of cloud-sky over ocean ADMs
In a given angular bin, radiances are averaged in ln(ftau) intervals, and sigmoid fit is used to relate the mean radiances and ln(ftau) bin values.



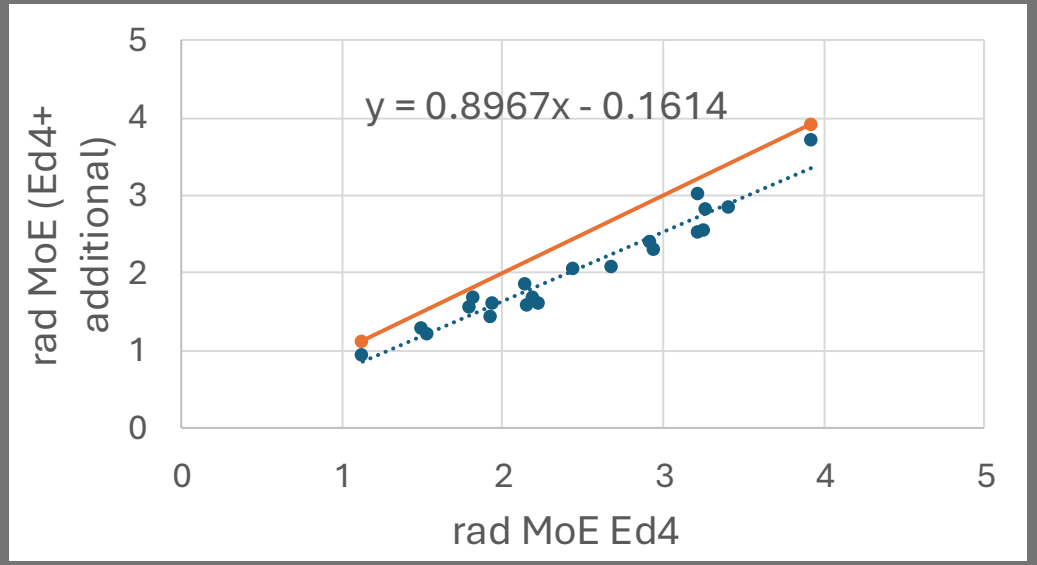
SZA=38-40, VZA=66-68 and RAZ=68-70 for water clouds
f is the cloud fraction and tau is the cloud optical depth.

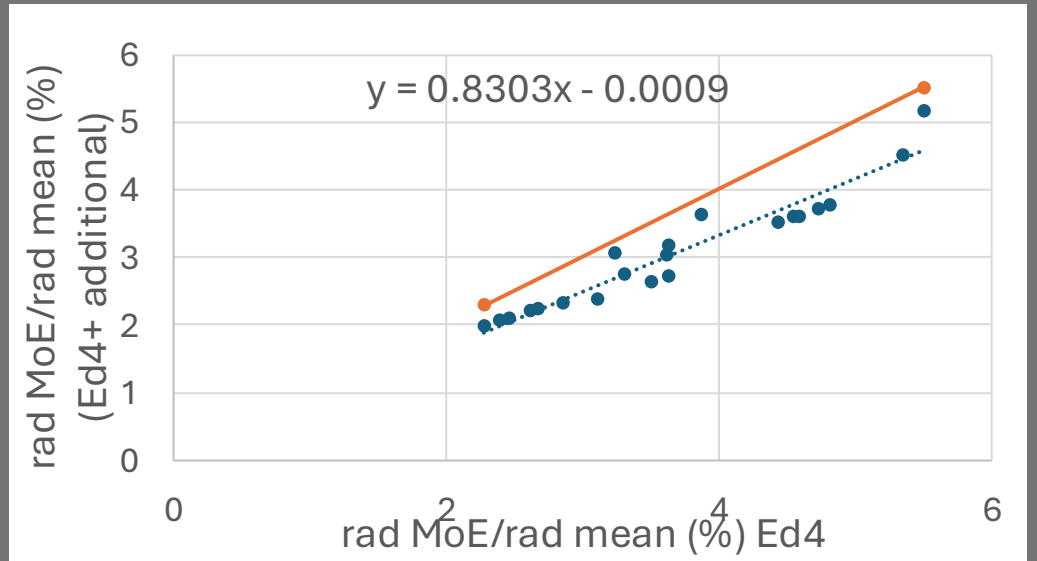
Cloudy-sky over ocean



MoE distribution of optically thick clouds for viewing angles and ln(ftau) bins (45 VZA x 90 RAZ x 775 ln(ftau)) for solar zenith angle = 38-40 and within non-glint region.

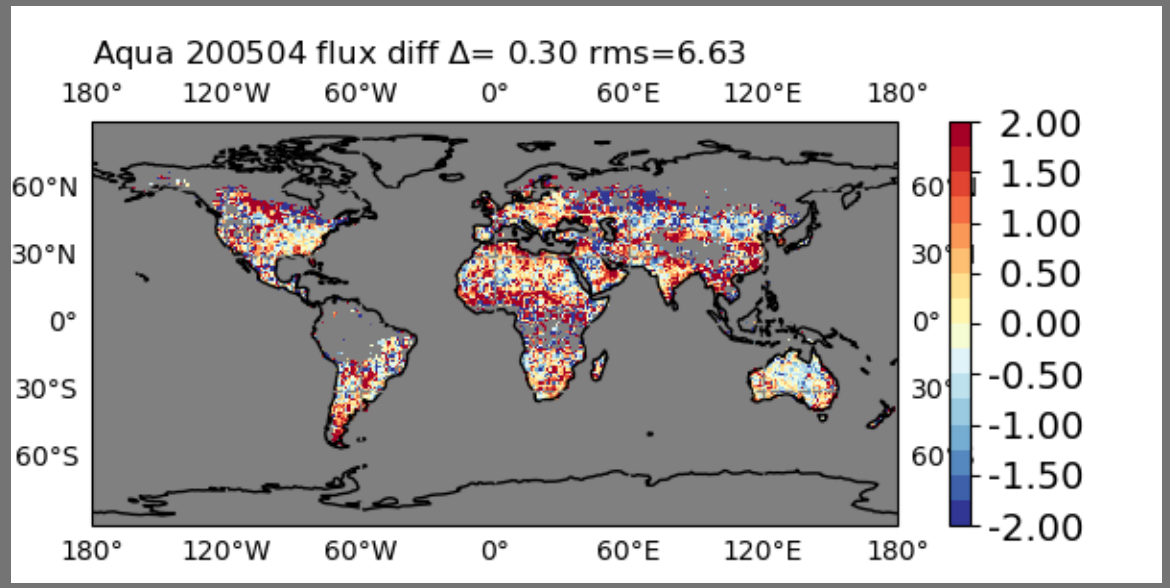
Collect the mean MoE values from MoE distributions for 7 SZA bin intervals from 15 to 71 for water, mix and ice clouds.



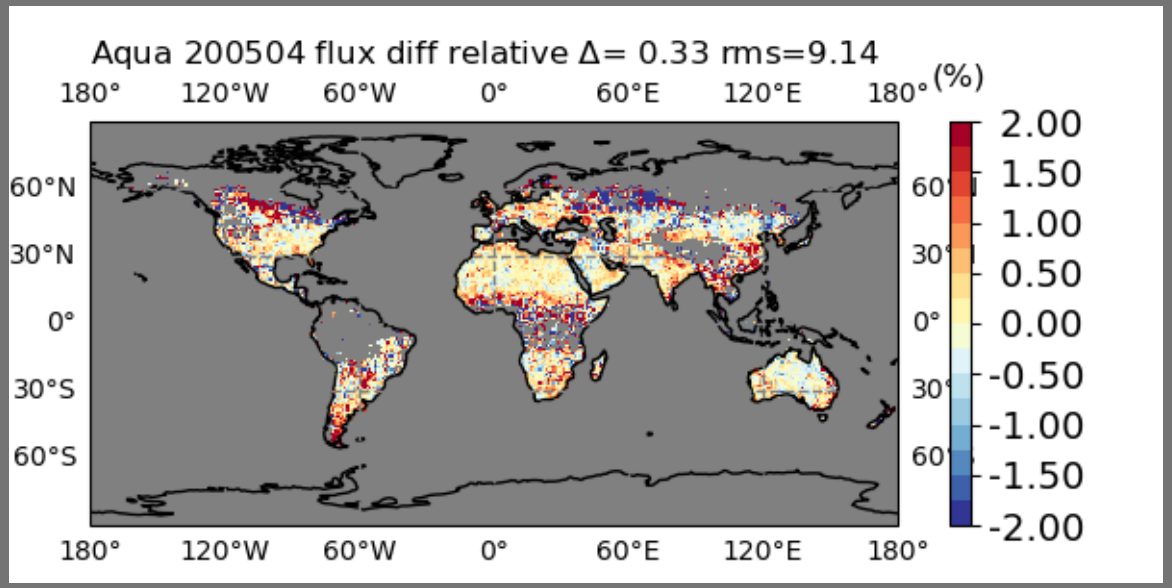


Clear-sky over land

Flux differences

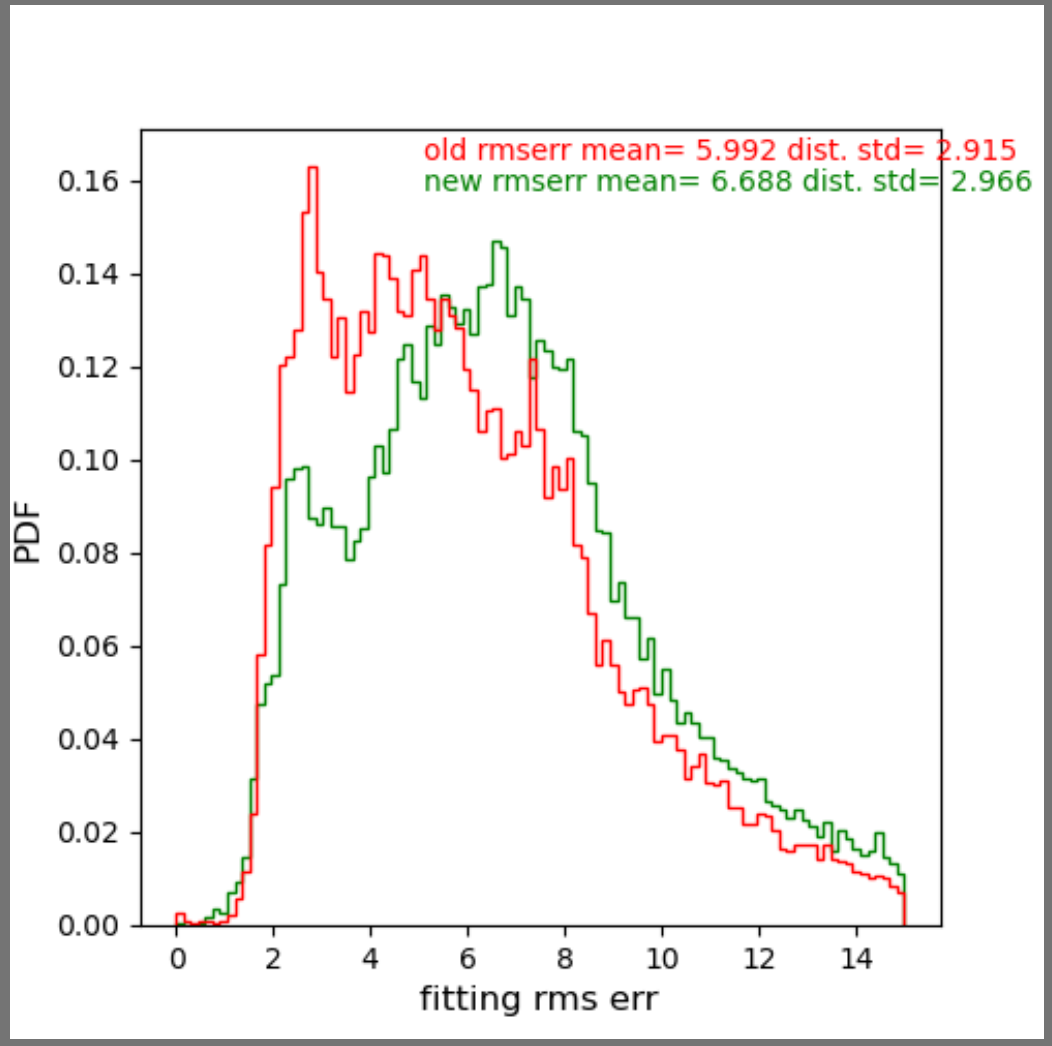


Flux Relative differences



Processing of clear-sky over land ADMs

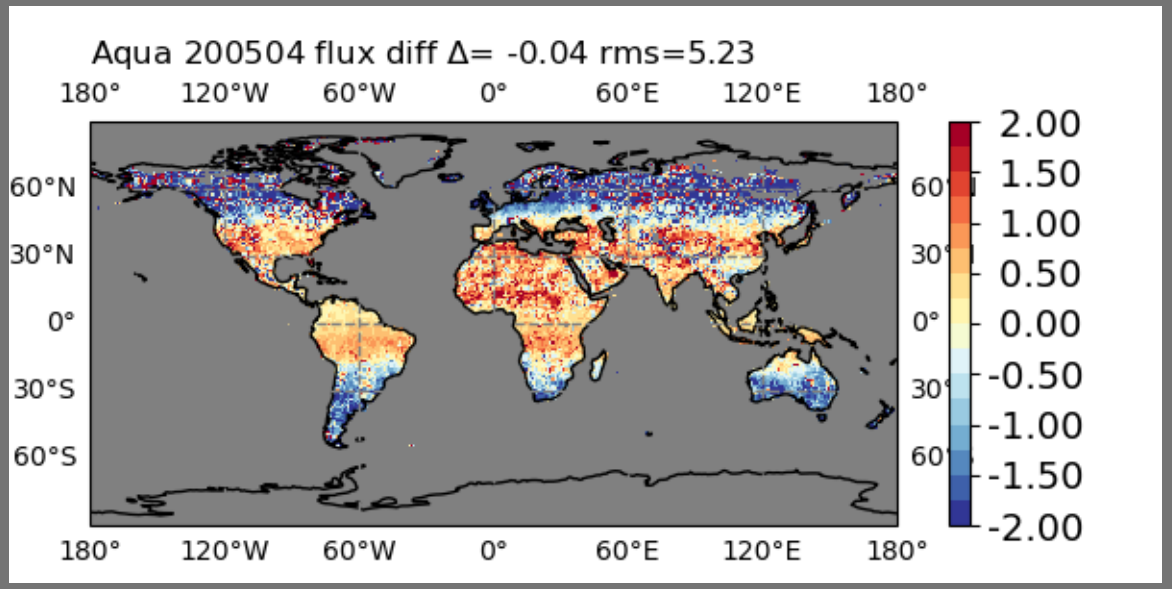
Within a SZA-NDVI bin interval, all observed radiances are used directly to fit the RossLi surface BRDF model. There is no radiance averaging involved.



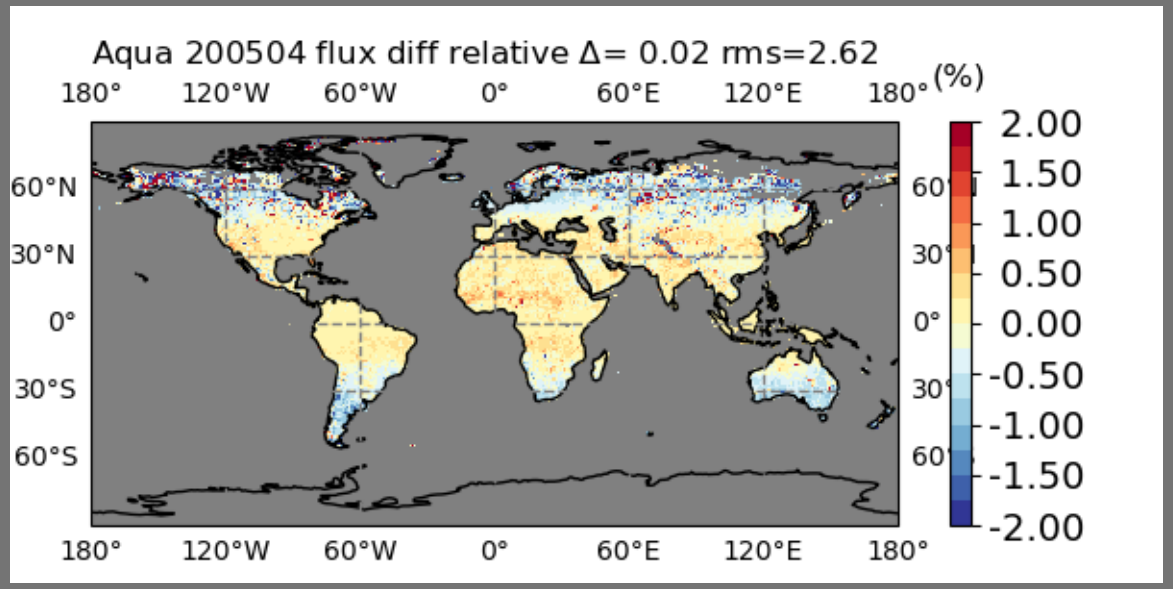
Fitting RMS errors for July

Cloudy-sky over land

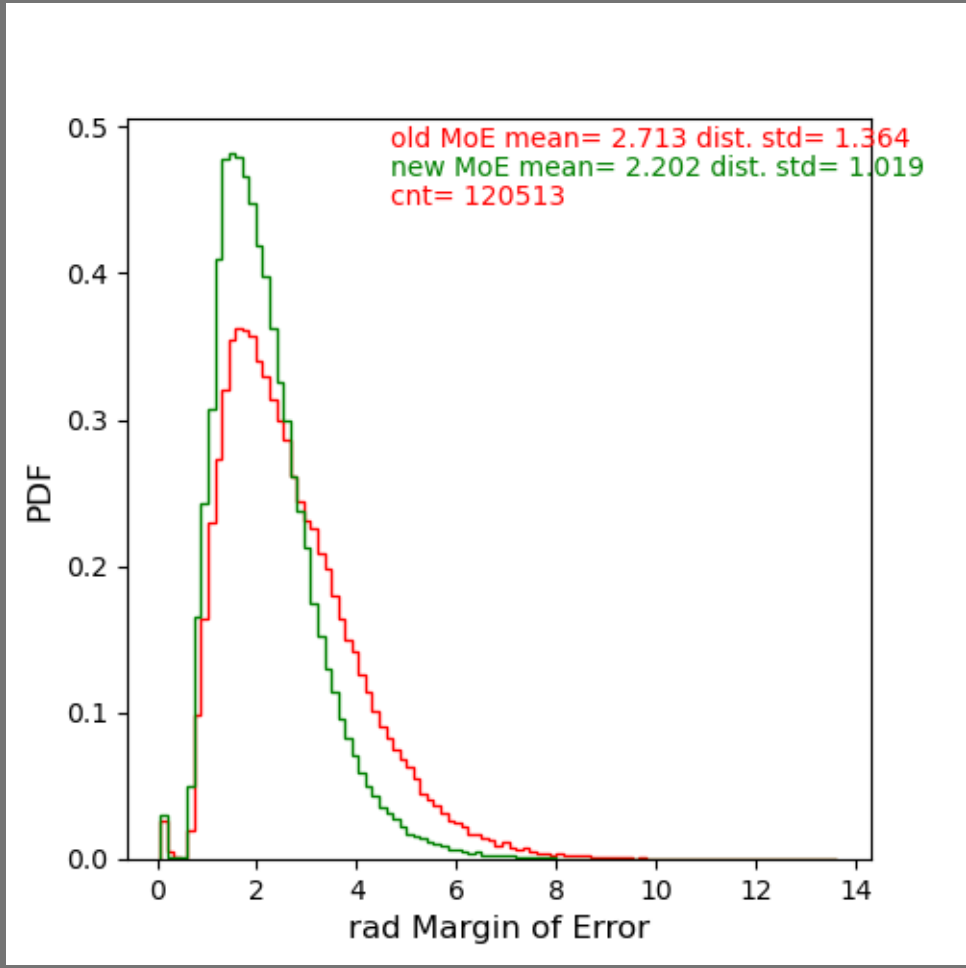
Flux differences



Flux Relative differences

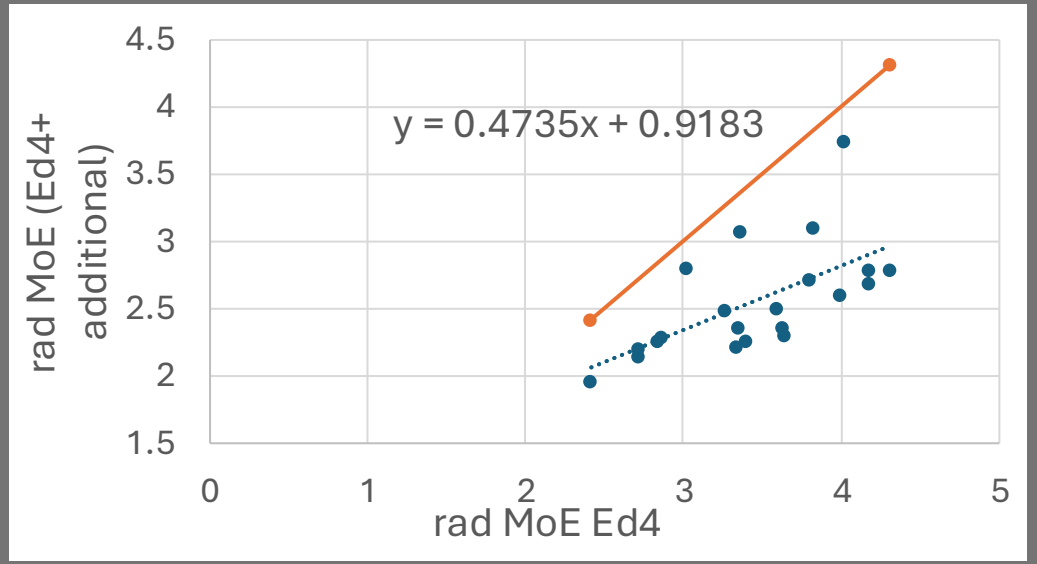


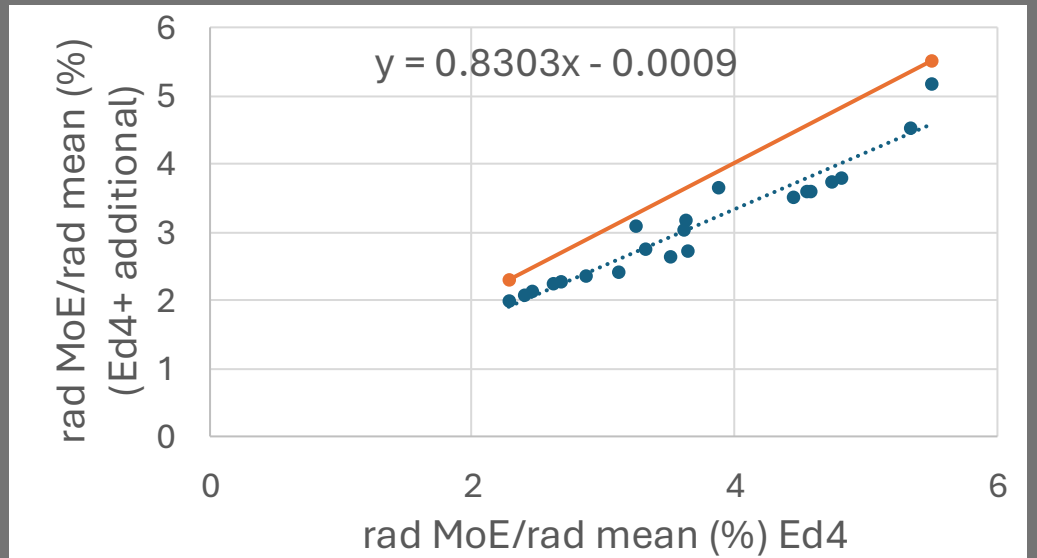
Cloudy-sky over land

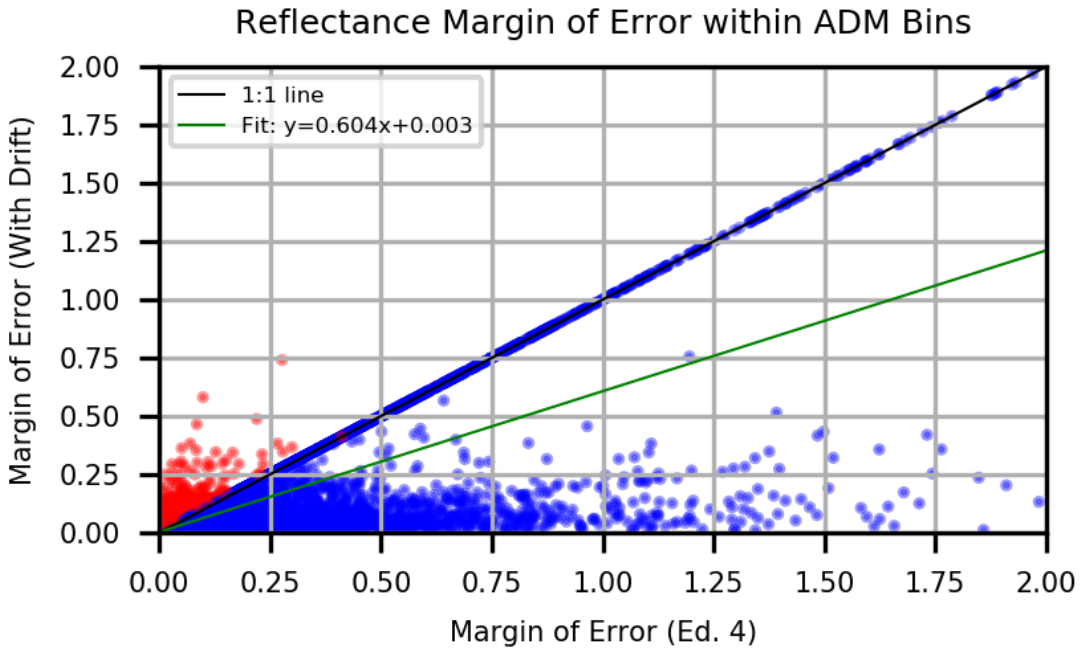


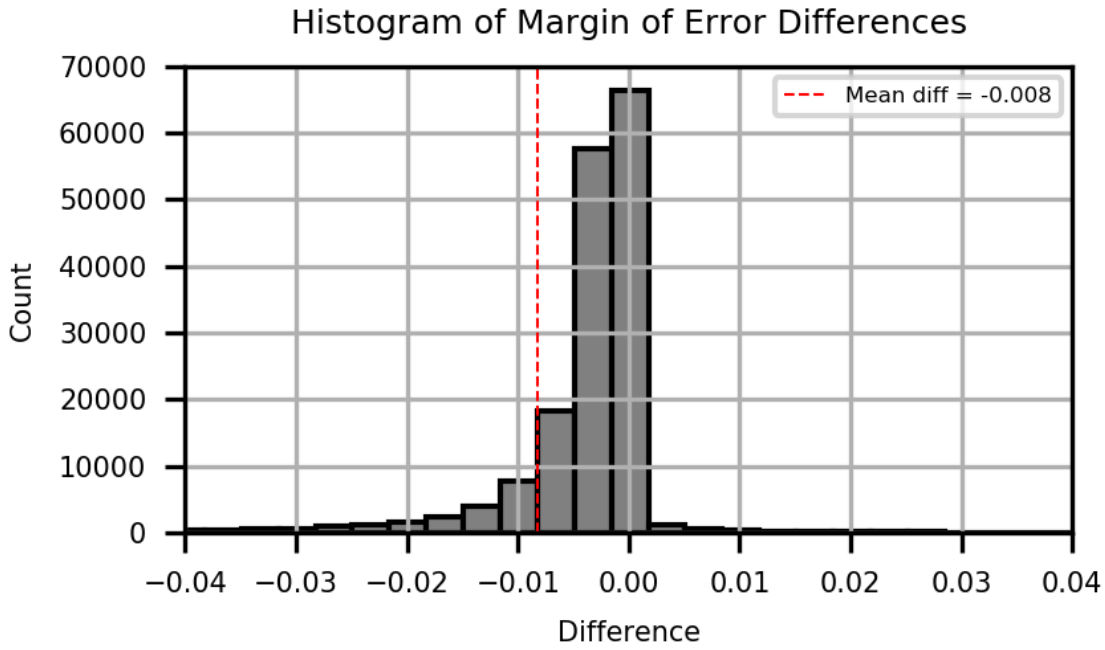
MoE distribution of water clouds for viewing angles and ln(ftau) bins (18 VZA x 36 RAZ x 380 ln(ftau)) for solar zenith angle=25-30.

Collect the mean MoE values from MoE distributions for 7 SZA bin intervals from 17.5 to 77.5) for water, mix and ice clouds





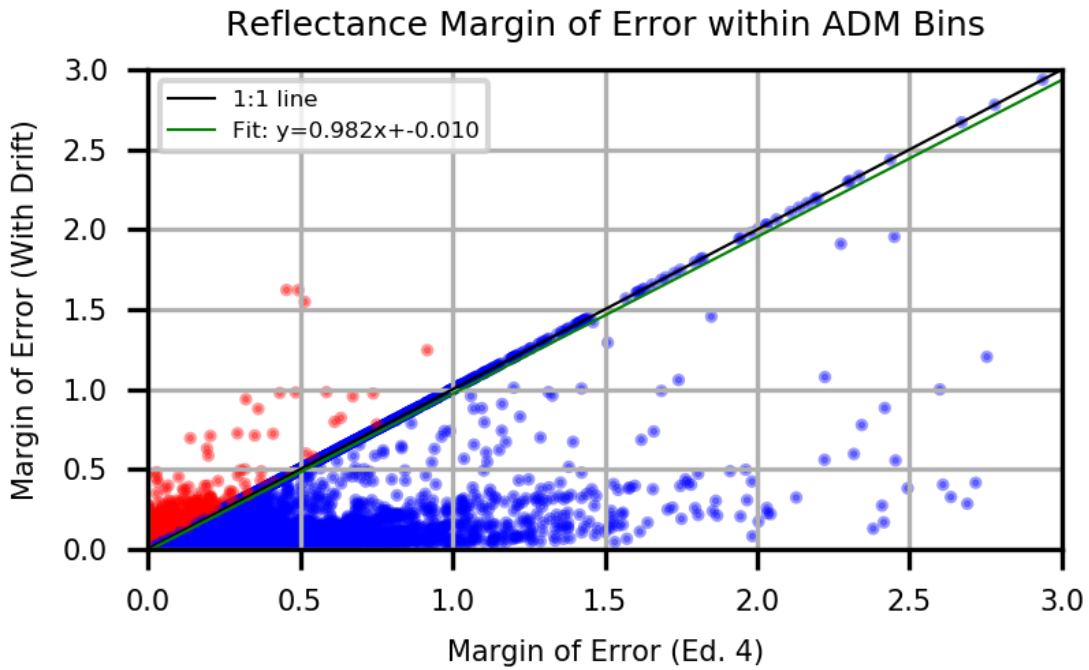


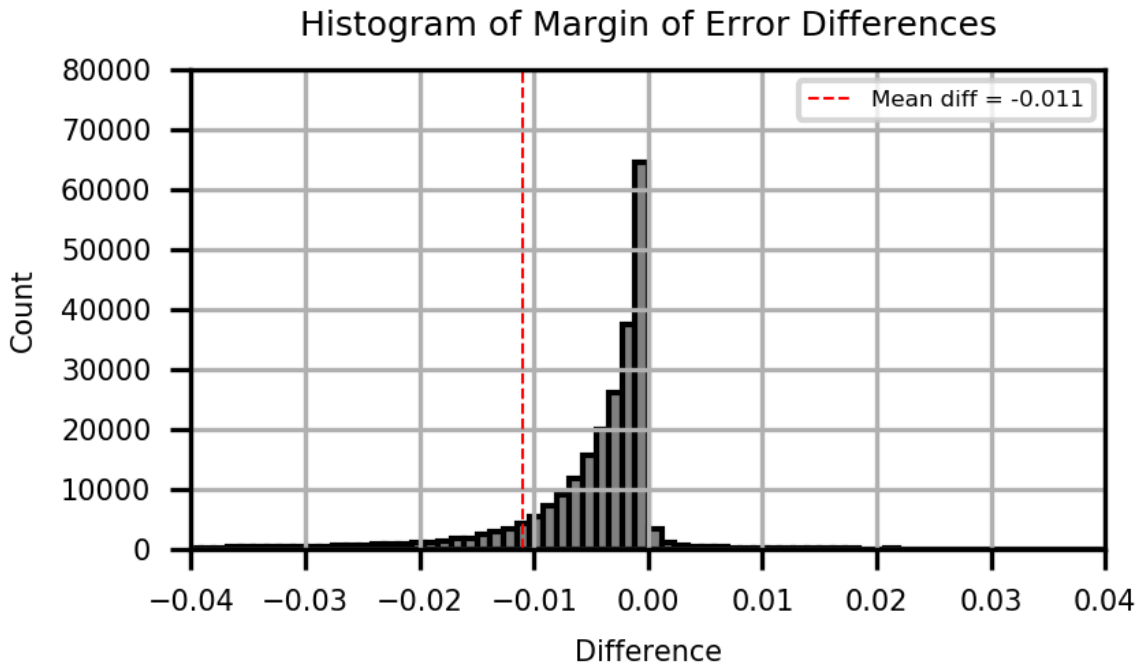


Cloudy Fresh Snow

STATISTICAL SUMMARY

Slope:	0.6041
Intercept:	0.0026
Correlation (r):	0.8033
Confidence Interval:	0.95
Mean diff:	-0.0082
Median diff:	-0.0021
% above 1:1:	3.60%
% below 1:1:	89.26%





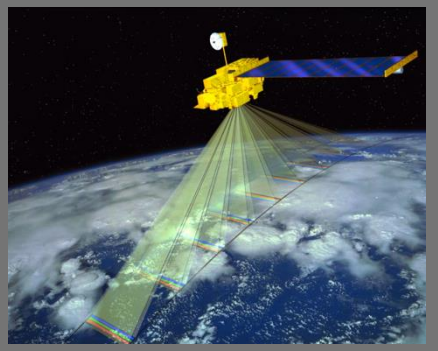
Partly Cloudy Sea Ice

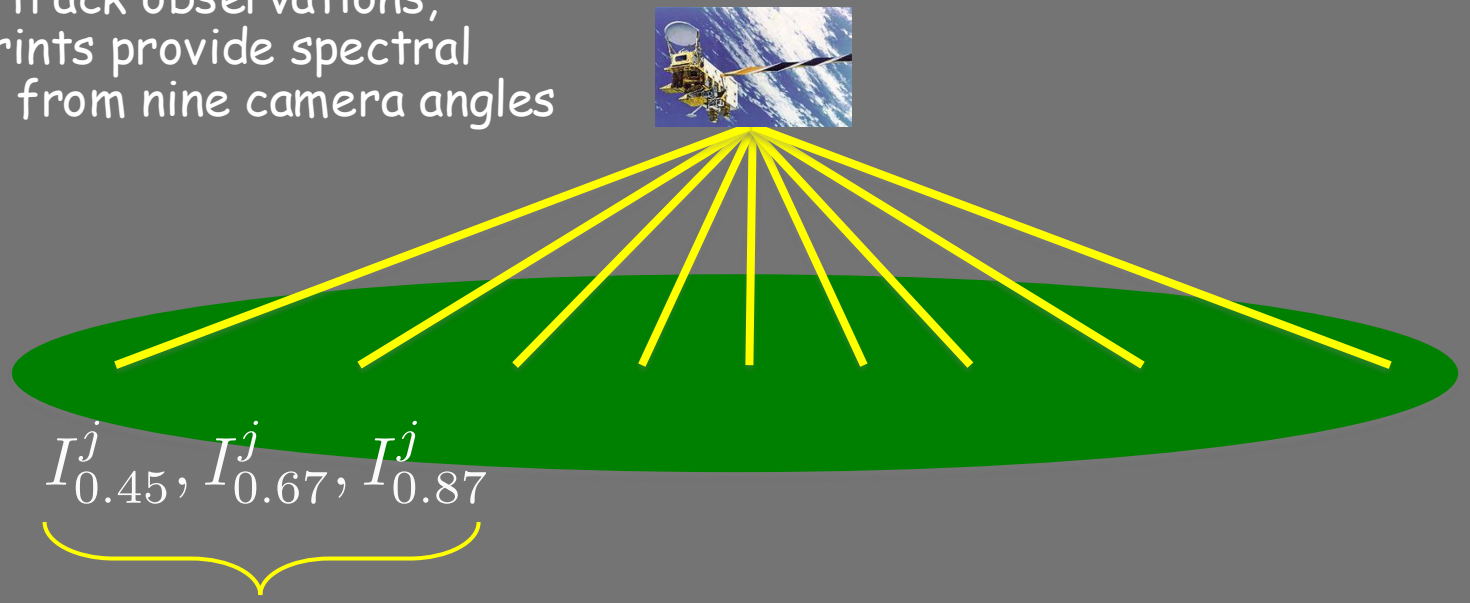
STATISTICAL SUMMARY

Slope:	0.9819
Intercept:	-0.0103
Correlation (r):	0.9923
Confidence Interval:	0.95
Mean diff:	-0.0109
Median diff:	-0.0027
% above 1:1:	4.03%
% below 1:1:	90.04%

SW Flux Consistency (MISR)

For Terra CERES along track observations, collocated MISR footprints provide spectral radiance measurements from nine camera angles





$$I^j_{0.45}, I^j_{0.67}, I^j_{0.87}$$

$$I^j_{sw} = c_0 + c_1 I^j_{0.45} + c_2 I^j_{0.67} + c_3 I^j_{0.87}$$

↓ CERES ADM

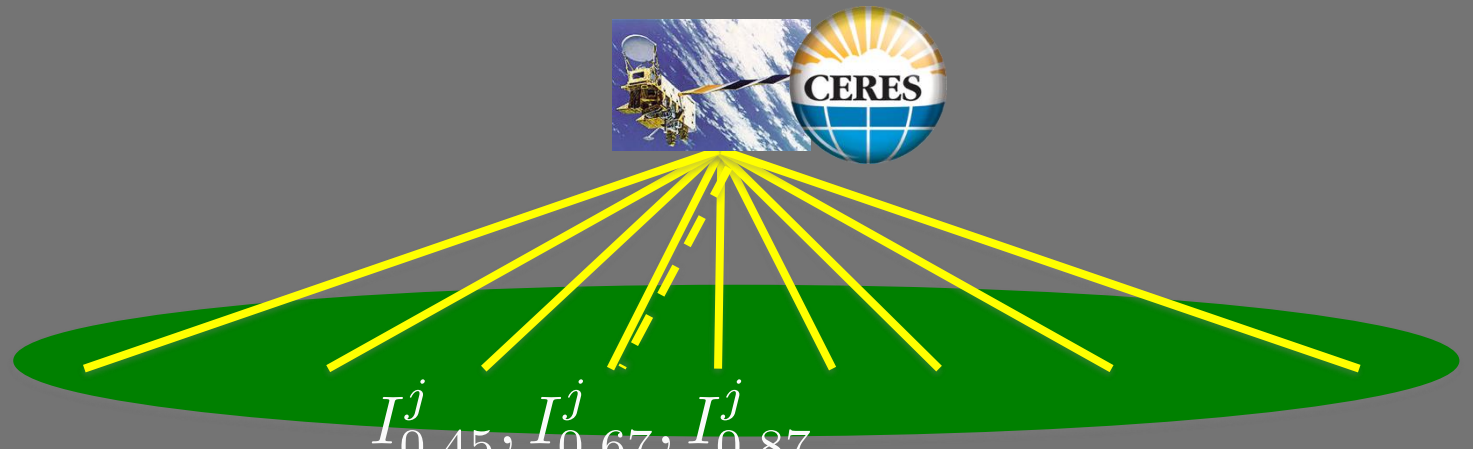
$$F^j_{sw} \longrightarrow \overline{F_{sw}} = \frac{\sum_{j=1}^{9} F^j_{sw}}{9} \longrightarrow s = \sqrt{\frac{\sum_{j=1}^{n} (F^j_{sw} - \overline{F_{sw}})^2}{n-1}}$$

For M CERES footprints, the total relative consistency is:

$$CV_T = \left(\frac{\sqrt{\frac{1}{M}\sum_{i=1}^{M} s_i^2}}{\frac{1}{M}\sum_{i=1}^{M} \overline{F_{sw}^i}} \right) \times 100\%$$

It quantifies

1. how well the CERES SW ADMs represent the anisotropy of a scene and
2. the accuracy in the narrow-to-broadband regression.



$$I^c_{sw} \quad I^j_{sw} = c_0 + c_1 I^j_{0.45} + c_2 I^j_{0.67} + c_3 I^j_{0.87}$$

CERES ADM ↓

$$F^c_{sw} \quad F^j_{sw}$$

$$CV_{NB} = \left(\frac{\sqrt{\frac{1}{m}\sum_{i=1}^{m} (F^j_{sw} - F^c_{sw})^2}}{\frac{1}{m}\sum_{i=1}^{m} F^c_{sw}} \right) \times 100\%$$

$$CV_{ADM} = \sqrt{CV_T^2 - CV_{NB}^2}$$

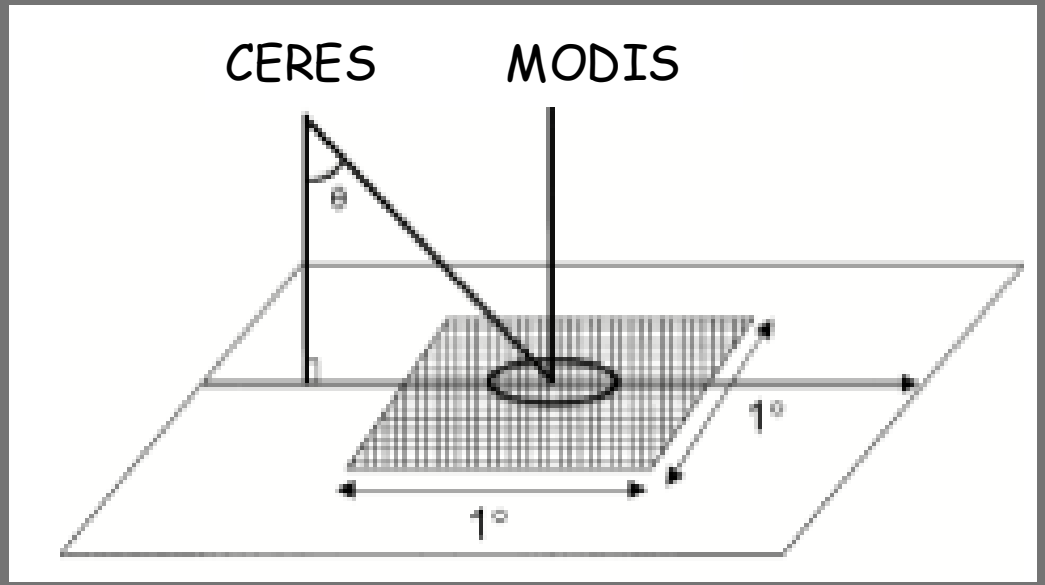
SW Flux Consistency (MISR)

CERES-MISR SW Flux Consistency Test for Terra during period May 2000 – February 2005

	Ocean				Land				Snow/Ice			
	Clear	S	M	All	Clear	S	M	All	Clear	S	M	All
N	200	200	200	200	25	50	50	50	50	50	50	50
$\Psi_{ADM}^{No\_Drift}$ (%)	3.28	4.62	8.41	6.19	2.04	4.94	6.56	3.99	4.77	6.26	5.92	5.92
Ψ_{ADM}^{Drift} (%)	3.28	4.62	8.41	6.19	2.02	4.93	6.51	3.97	4.72	6.18	5.93	5.86

S: single layer clouds; M: multiple-layer clouds

SW Flux Consistency (MODIS)



1. For CERES along-track observations, CERES viewed a footprint @60 VZA and MODIS viewed it near nadir for the same footprint.
2. Convert MODIS narrow-band radiances R_{MOD_NB}, to broad-band radiances R_{MOD_BB}. Retrieve flux based on R_{MOD_BB} with MODIS viewing-geometries, treating it like CERES observations.
3. Compare F_{MOD_BB} (near nadir) and F_{CERES_BB} (@60 VZA).

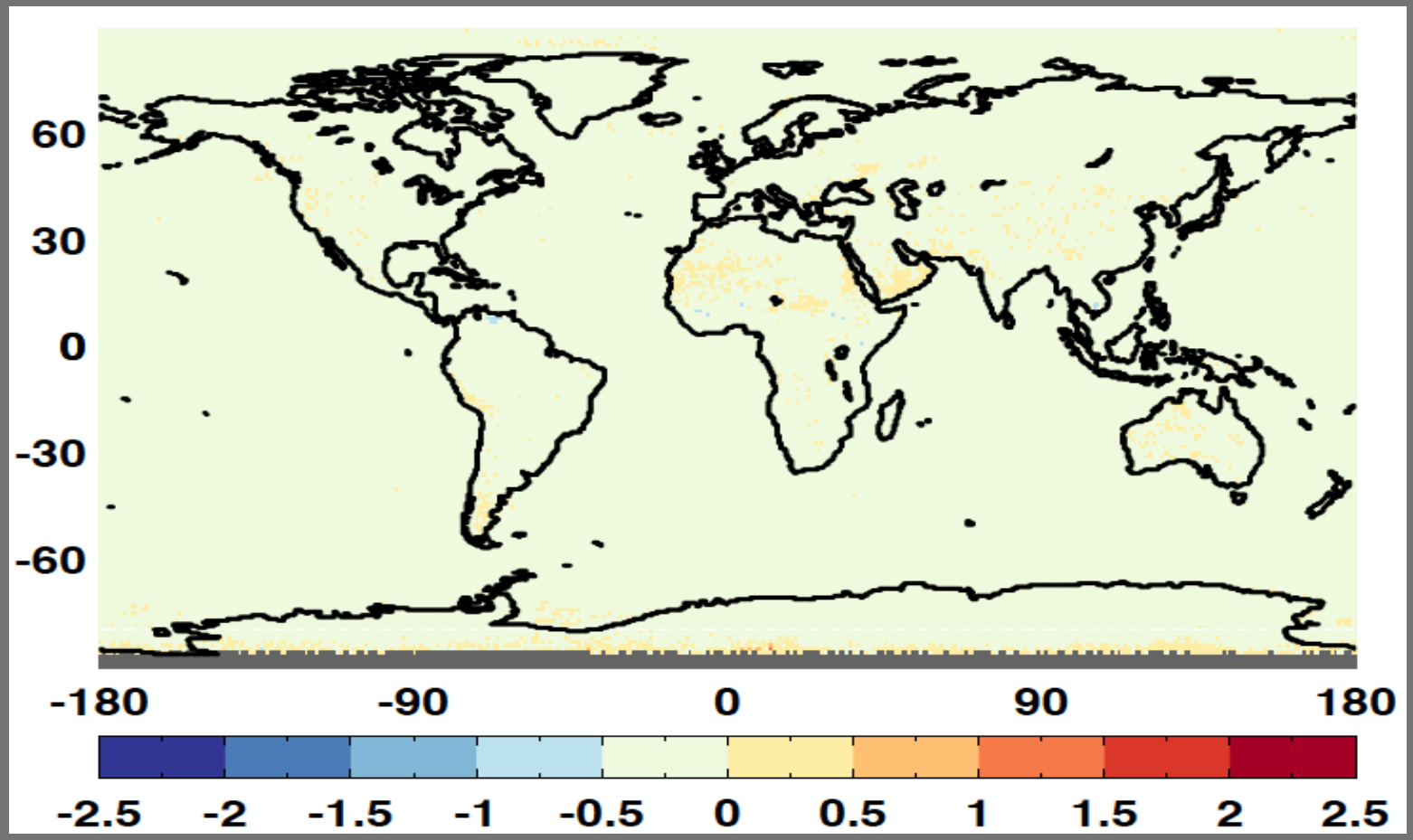
SW RMS errors between F_{MOD_BB} (near nadir) and F_{CERES_BB} (@60 VZA)

Ocean RMS error (%)		
	Ed4	Ed4 + additional RAPs
clear	4.4	4.3
single-layer	5.2	5.2
Multiple-layer	9.7	9.7
all	6.0	6.0

Land RMS error (%)		
	Ed4	Ed4 + additional RAPs
clear	3.8	3.8
single-layer	6.0	6.0
Multiple-layer	8.4	8.3
all	5.9	5.9

LW flux differences (all-sky)

Aqua 201504 Daytime Avg diff: -0.16 W m^{-2} RMS diff: 0.18 W m^{-2}



LUT approach for split SW flux retrieval

Visible flux from Libera

- Incoming energy in the range from 0.3-5.0um can be split by VIS (0.3-0.7um) and NIR (0.7-5.0um).

- Libera has a split-shortwave channel (NIR: 0.7-5 μm), in addition to the traditional shortwave (0.3-5 μm), longwave (5-50 μm), and total (0.3-100 μm) channels.

$$I_{VIS} = I_{SW} - I_{NIR}$$

- Radiances in the visible band (0.3-0.7 μm) is:

$$F_{VIS} = R(I_{VIS})$$

- F_{VIS} can be converted from I_{VIS} if visible ADMs are available.

Alternative approach for split SW flux retrieval

- Define an anisotropic factor ratio of NIR to VIS

  $\beta = R_{NIR}/R_{VIS}$

- The NIR flux relates to SW flux by

  $$F_{NIR} = \frac{F_{SW}}{1+\alpha}, \qquad \text{where, } \alpha = \frac{F_{VIS}}{F_{NIR}} = \left(1 + \frac{I_{VIS}}{I_{NIR}}\beta\right),$$

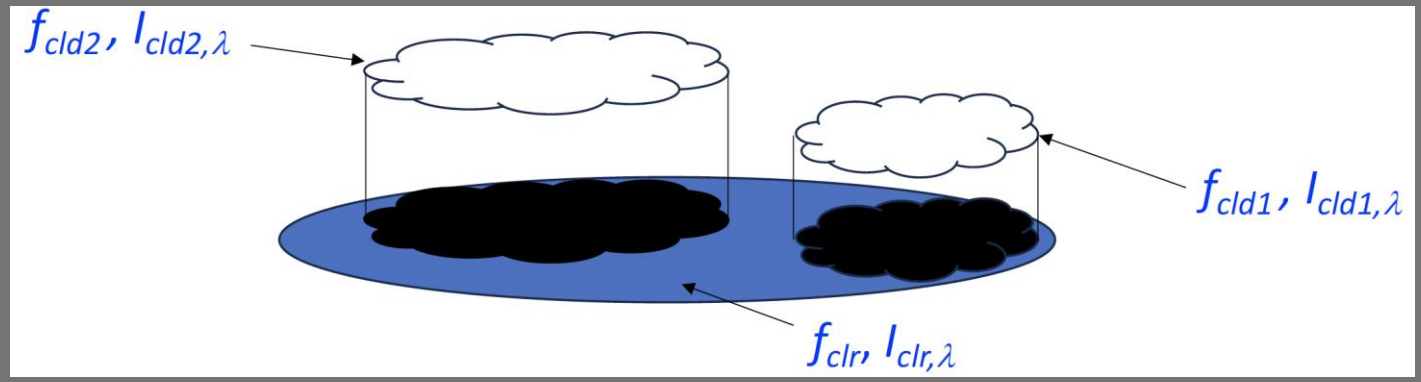
- The VIS flux is then determined by

  $F_{VIS} = F_{SW} - F_{NIR}$

- β is retrieved from radiative transfer model LUTs by minimizing the errors between simulated and observed narrow-band radiances.

- Currently, I_{VIS} and I_{NIR} are derived from ratios to I_{SW} based on theoretical simulations to calculate $\alpha = (I_{VIS}/I_{NIR})\beta$, respectively.

Matching of narrow-band simulations and observations



- Matching spectral simulations to the observations for each sub-footprint, then calculate the total footprint I'_{VIS}, I'_{NIR}, F'_{VIS}, F'_{NIR} by area-weighting sub-footprint values:

$$I'_x = [f_{clr} I'_{clr,x} + f_{cld1} I'_{cld1,x} + f_{cld2} I'_{cld2,x}]/(f_{clr} + f_{cld1} + f_{cld2})$$

$$F'_x = [f_{clr} F'_{clr,x} + f_{cld1} F'_{cld1,x} + f_{cld2} F'_{cld2,x}]/(f_{clr} + f_{cld1} + f_{cld2})$$

- Anisotropic factors for visible and NIR can be derived from I'_{VIS}, I'_{NIR}, F'_{VIS}, F'_{NIR} .

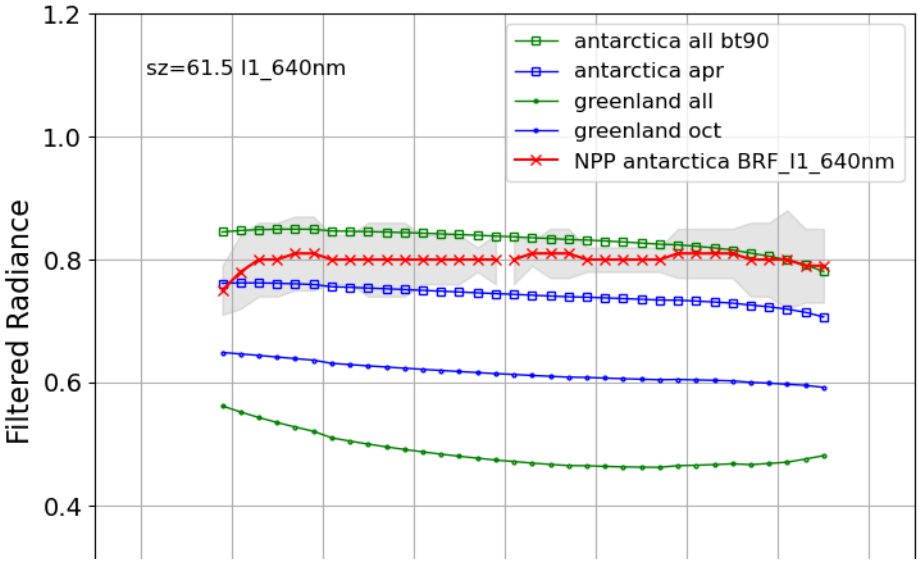
$$R_x = \pi I'_x / F'_x$$

- Retrieve $\beta = (R_{NIR}/R_{VIS})$

MODTRAN simulations for β retrieval LUTs

β retrieval LUTs contain members according to sensitivity of β to scene Properties (e.g., cloud optical depth, aerosols, surface BRDF, etc.)

- Clear sky over ocean
  6 AODs, 2 ocean wind speeds
- Clear sky over land
  4 surface types characterized by MODIS RossLi BRDF models in the season of JJA and DJF, respectively, and 3 AODs
- Clear sky over snow/ice
  4 surface types to characterize permanent snow (Greenland and Antarctica), sea-ice, and fresh snow
- Overcast
  6 CODs and 2 cloud phases.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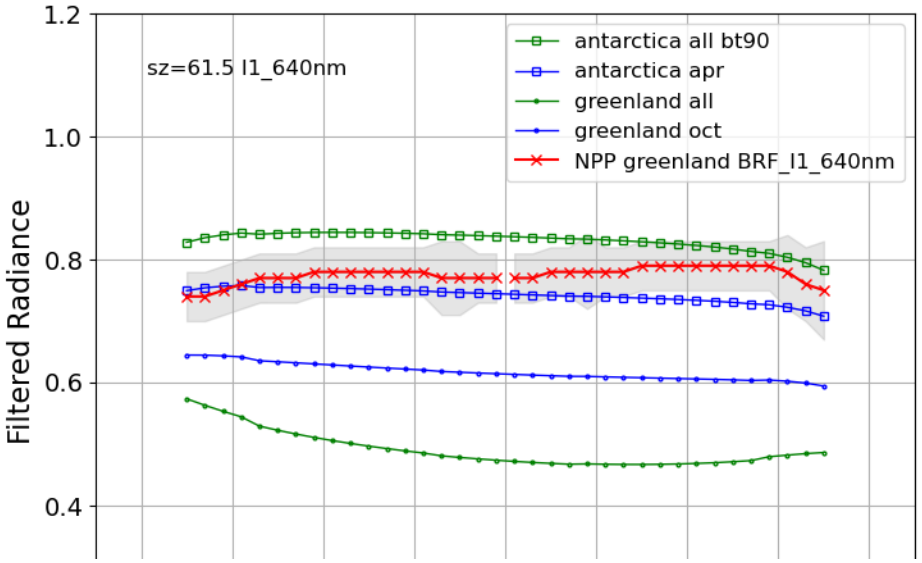
0.6
0.4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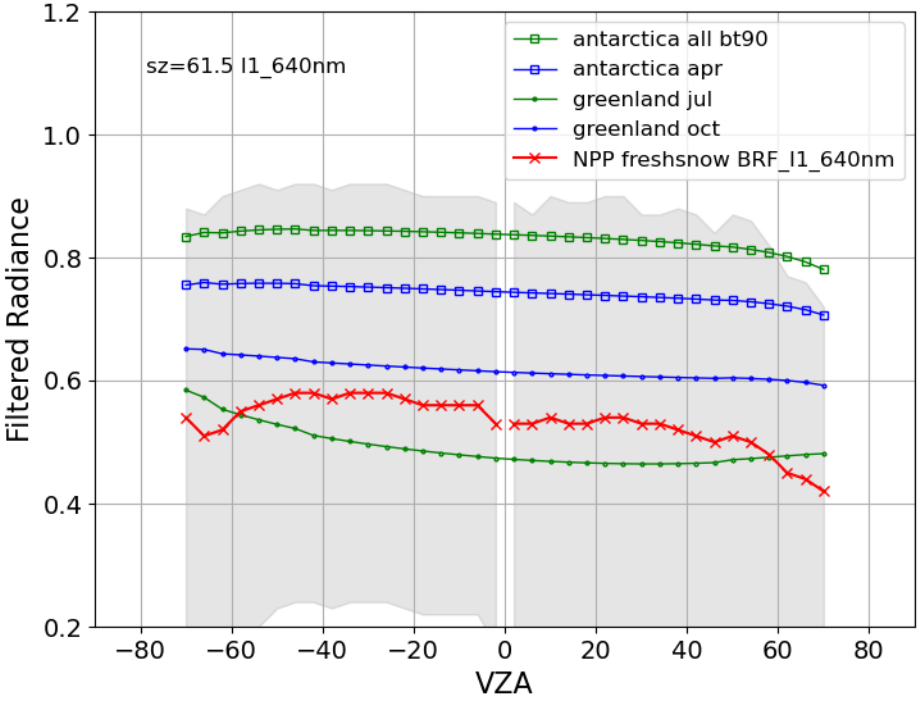
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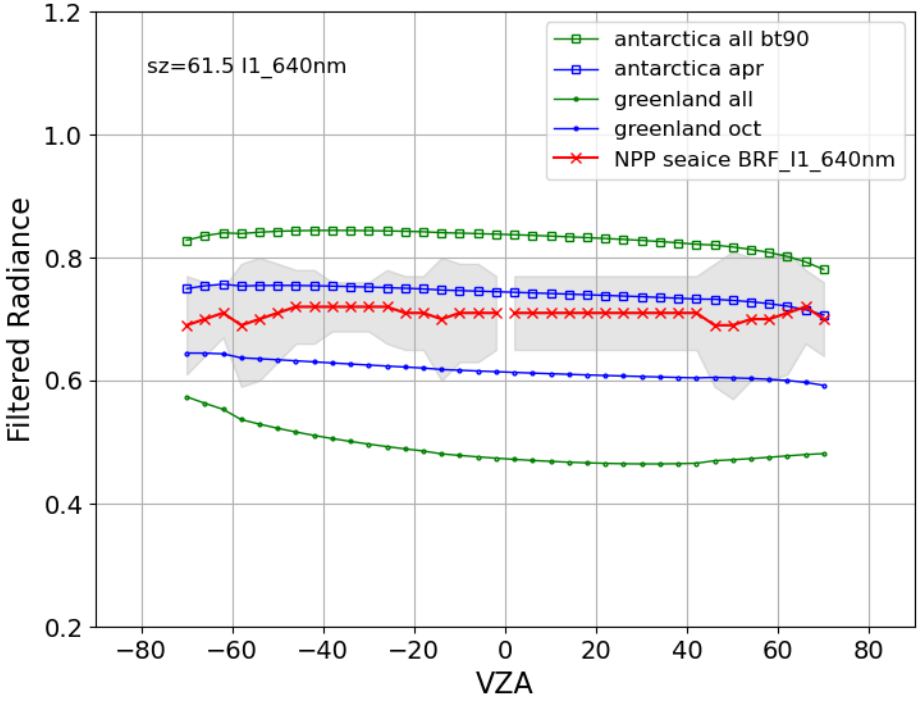
−60
−40
−20
0
20
40
60
80
VZA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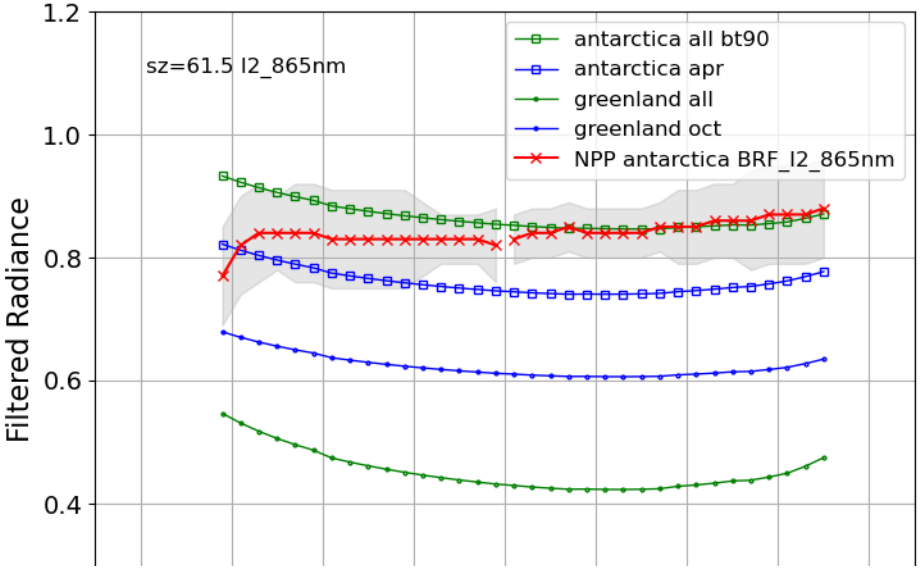
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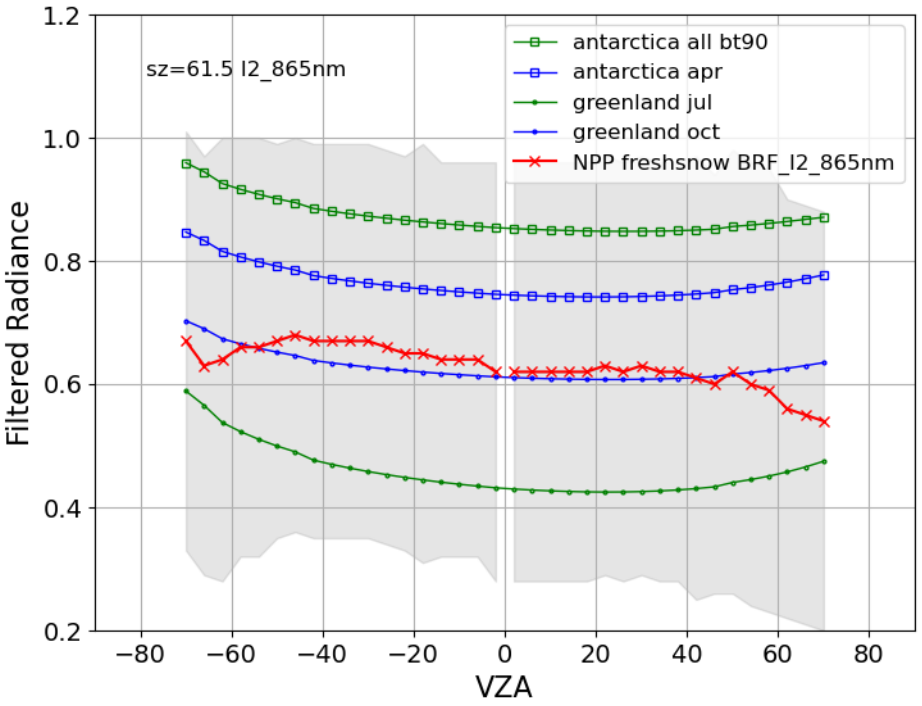
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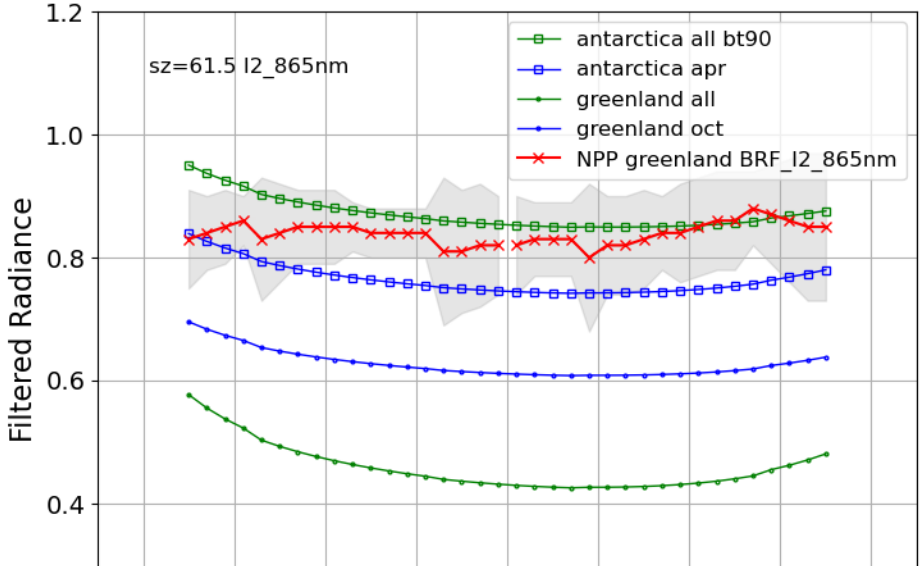
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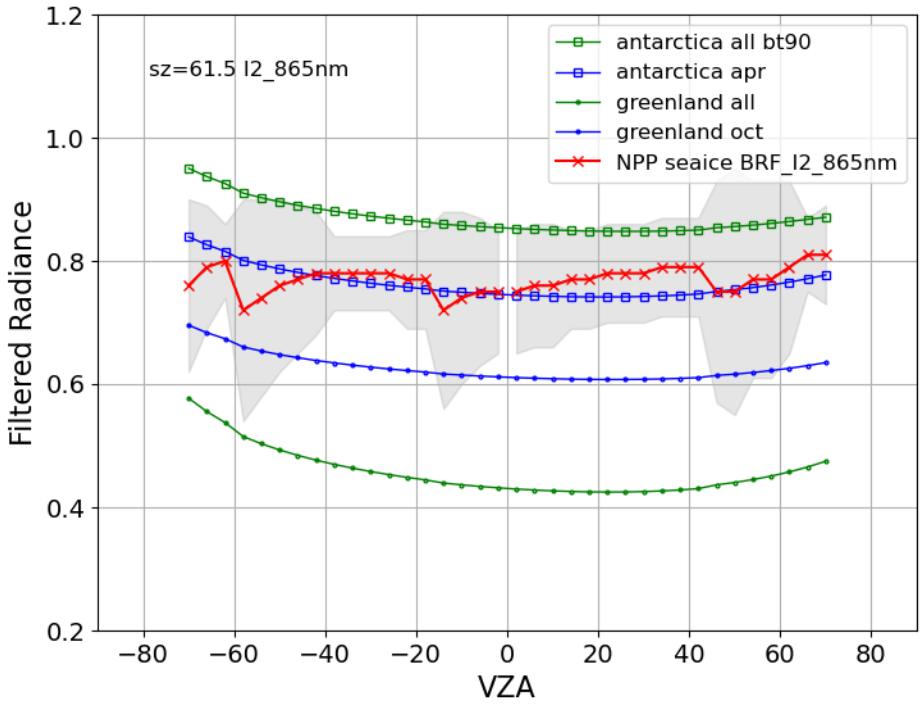
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NPP seaice BRF_I2_865nm
Filtered Radiance
1.2
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0.6
0.4
0.2
−80
−60
−40
−20
0
20
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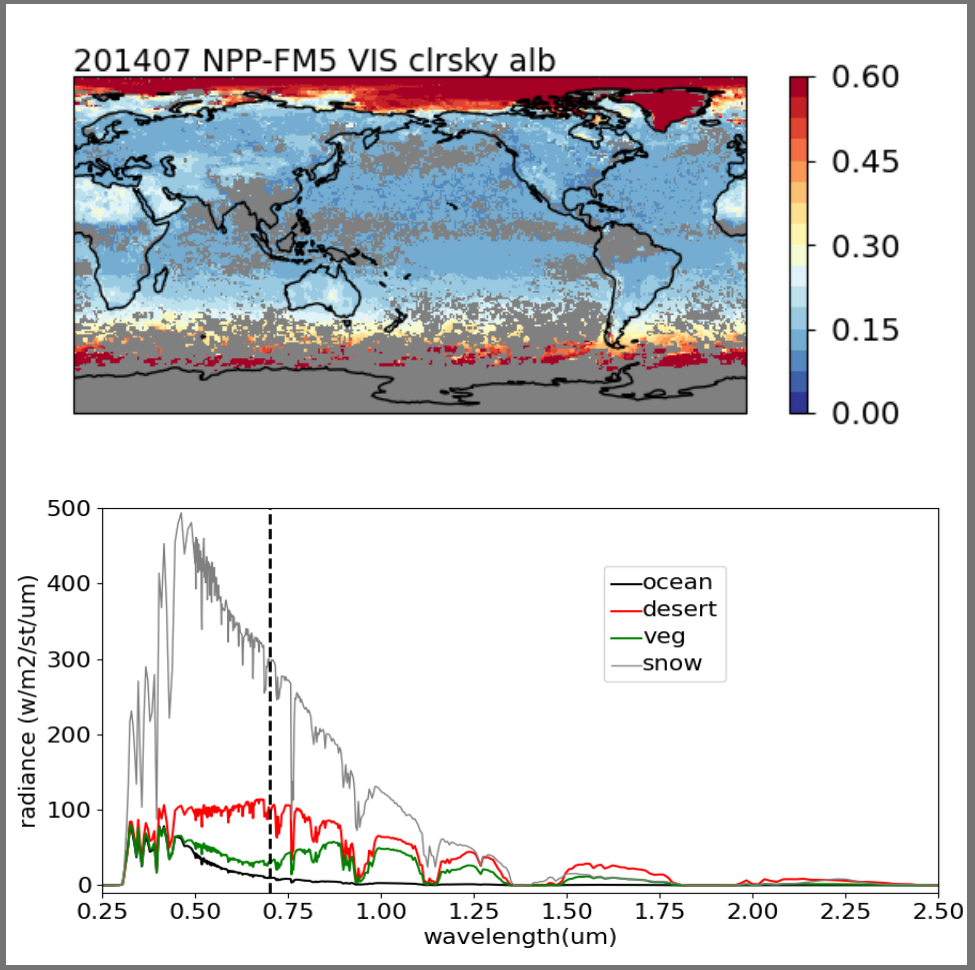
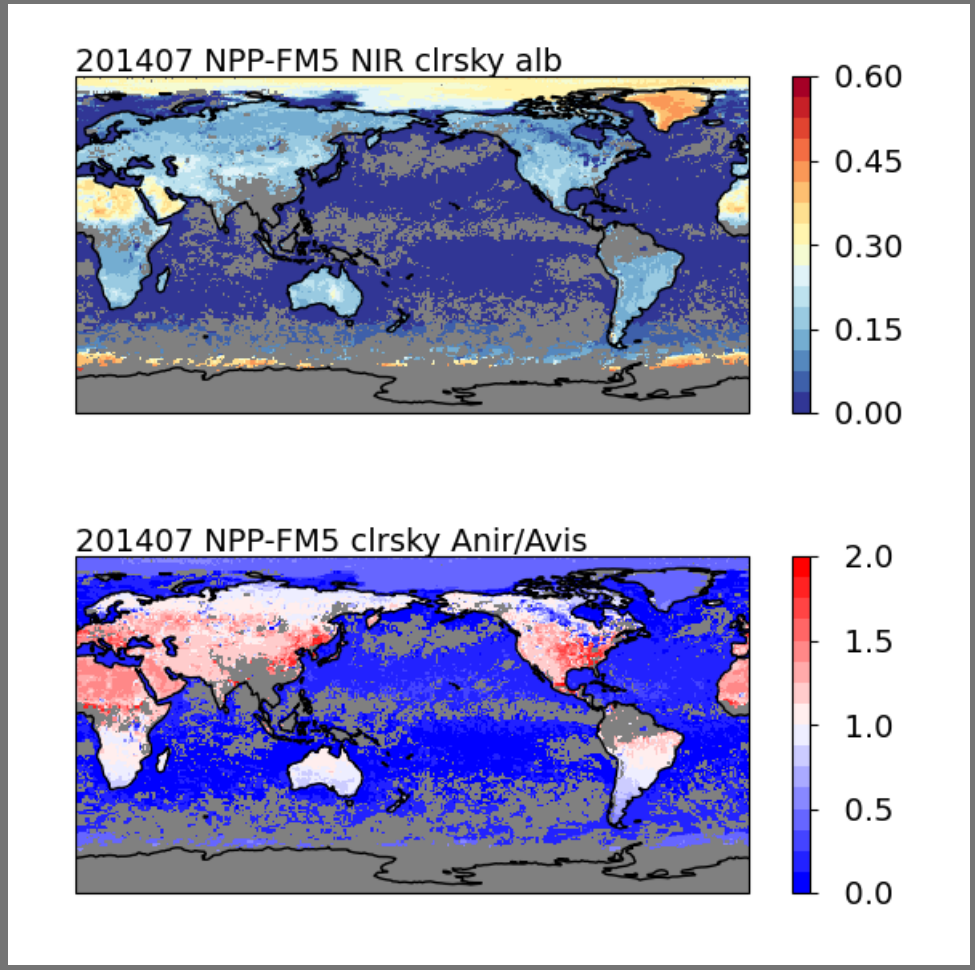
80
VZA

Clear sky





VIS > NIR

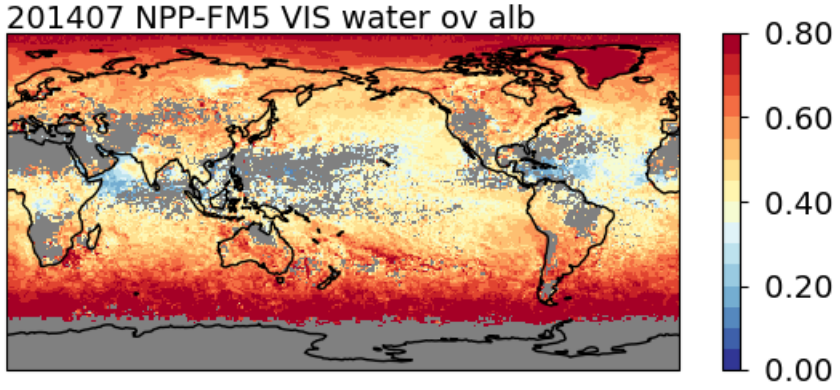
- ocean: high absorption by atmosphere and ocean water in the NIR spectral range
- snow: dominated by high reflectivity in the VIS spectral range and increased absorption in the NIR spectral range

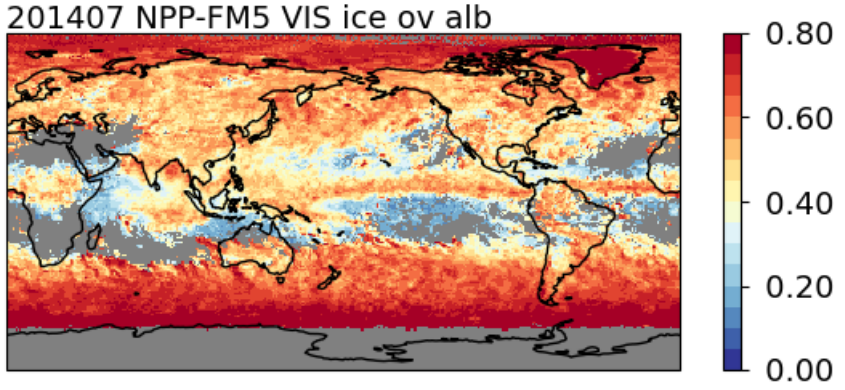
VIS < NIR

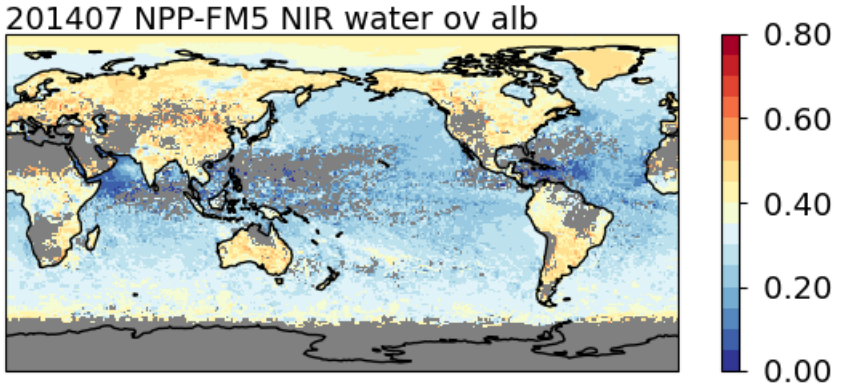
- desert: less absorption by dry atmosphere and higher reflectivity in the NIR spectral range.
- vegetation: high absorption in VIS spectral range for photosynthesis.

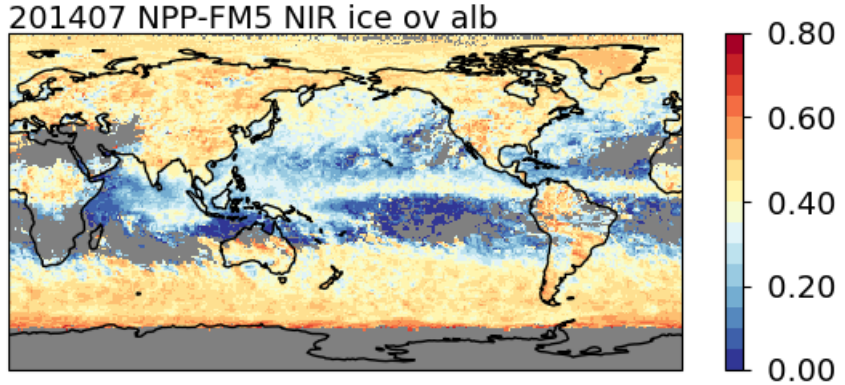
Overcast

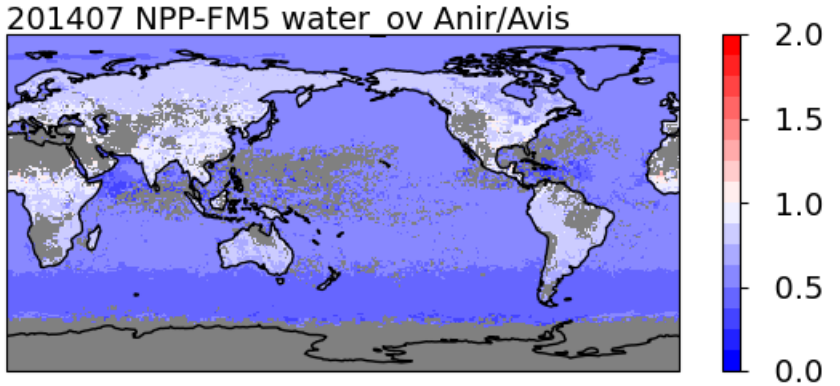
VIS > NIR: higher reflectivity of clouds in VIS than NIR range

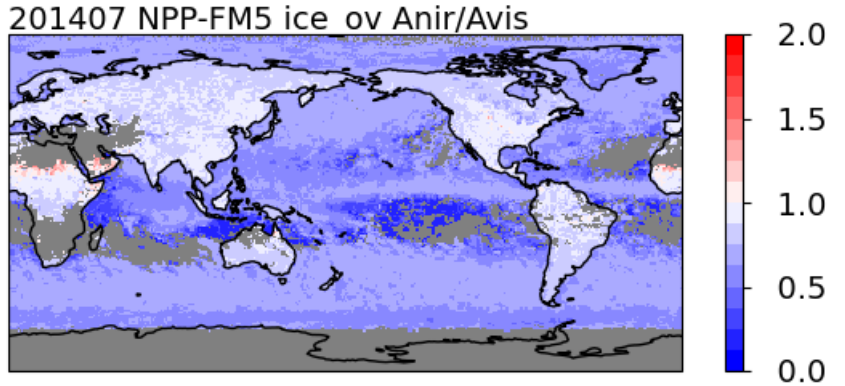




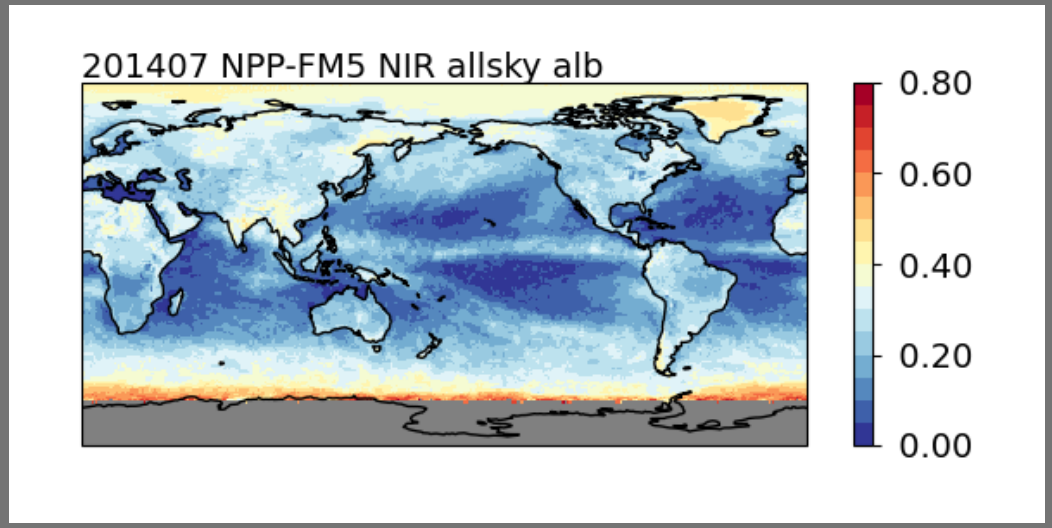


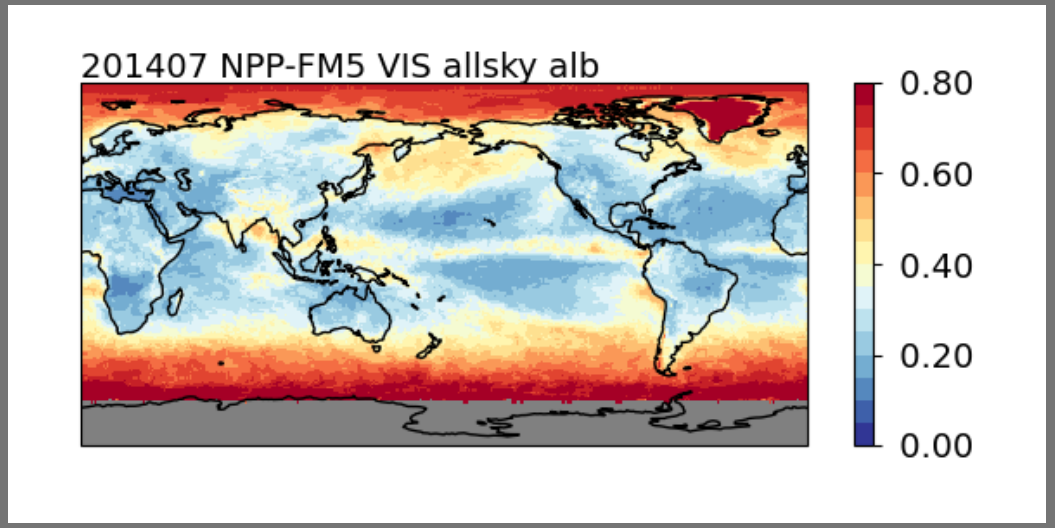


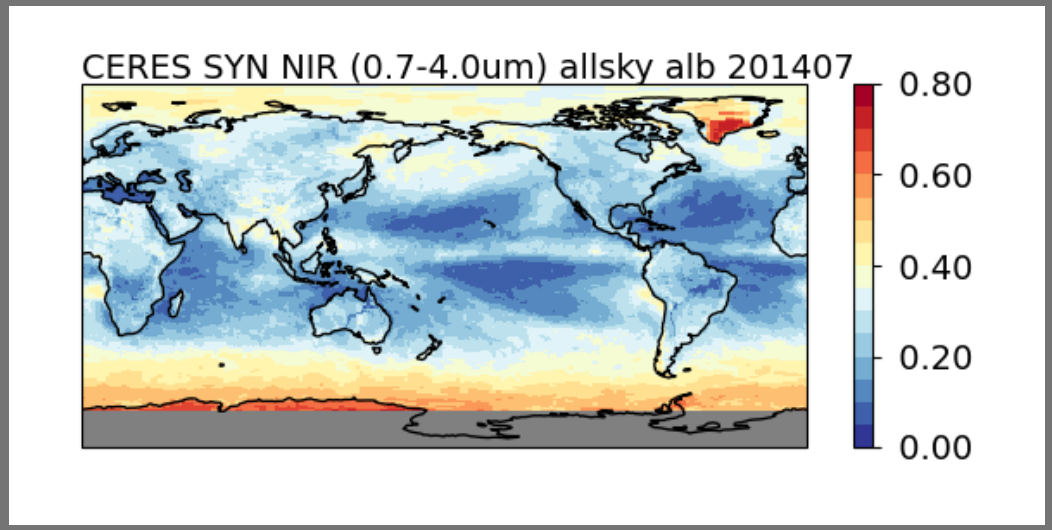


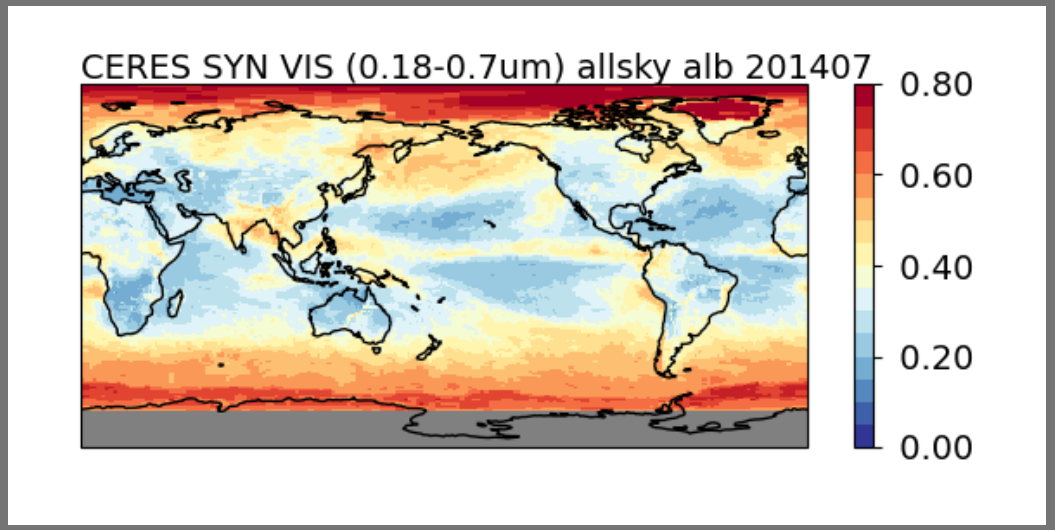


Comparison to CERES SYN calculation









Summary

- Adding additional CERES RAPs observations during Terra/Aqua orbital drifting period reduced errors in mean radiances for LW and SW ADMs.
- Additional CERES RAPs observations during Terra/Aqua orbital drifting period increases coverage of radiance binned-means and thus improved CERES directional model.
- As expected, the LUT approach retrieved Clear-sky TOA VIS fluxes are greater than NIR fluxes over ocean and snow and smaller over desert and vegetation; and VIS fluxes are greater than NIR fluxes for overcast cloudy scenes.
- The LUT approach retrieved VIS and NIR albedos agree well with that by the CERES SYN model-based albedos, adding confidence to the validity of the method that we developed.