

# CERES Angular Distribution Model Working Group Report

Lusheng Liang<sup>1</sup>  
Lusheng.Liang@nasa.gov

Sergio Sejas<sup>2</sup> Zachary Eitzen<sup>2</sup>

1. Analytical Mechanics Associates, Inc., Hampton, VA
2. ADNET Systems, Inc., Hampton, VA
3. NASA Langley Research Center, Hampton, VA

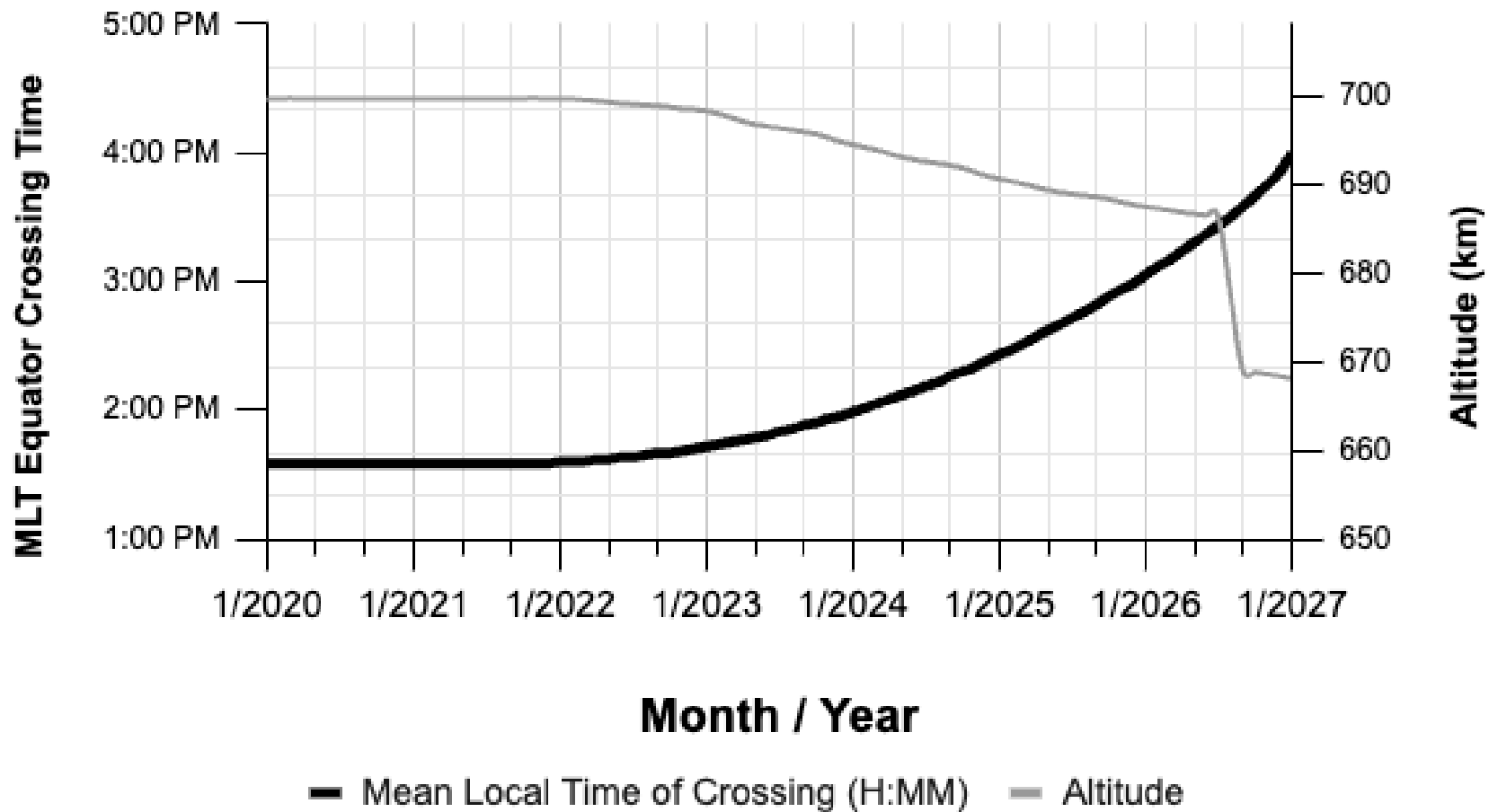
CERES Science Team Meeting, May 12-14, 2026  
NASA Langley Research Center, Hampton, VA

# Outline

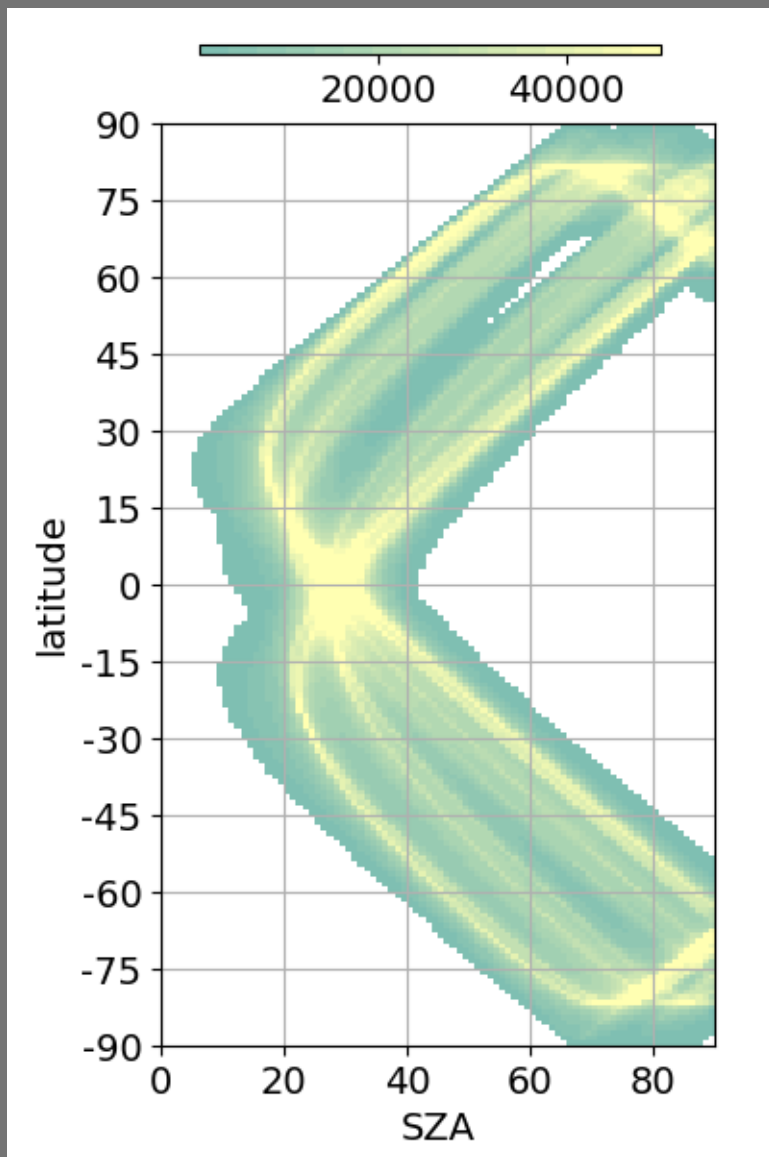
- Impact of Terra/Aqua orbital drifting on the CERES ADMs
- LUT approach for Split-SW flux retrieval

Impact of Terra/Aqua orbital drifting on the CERES ADMs

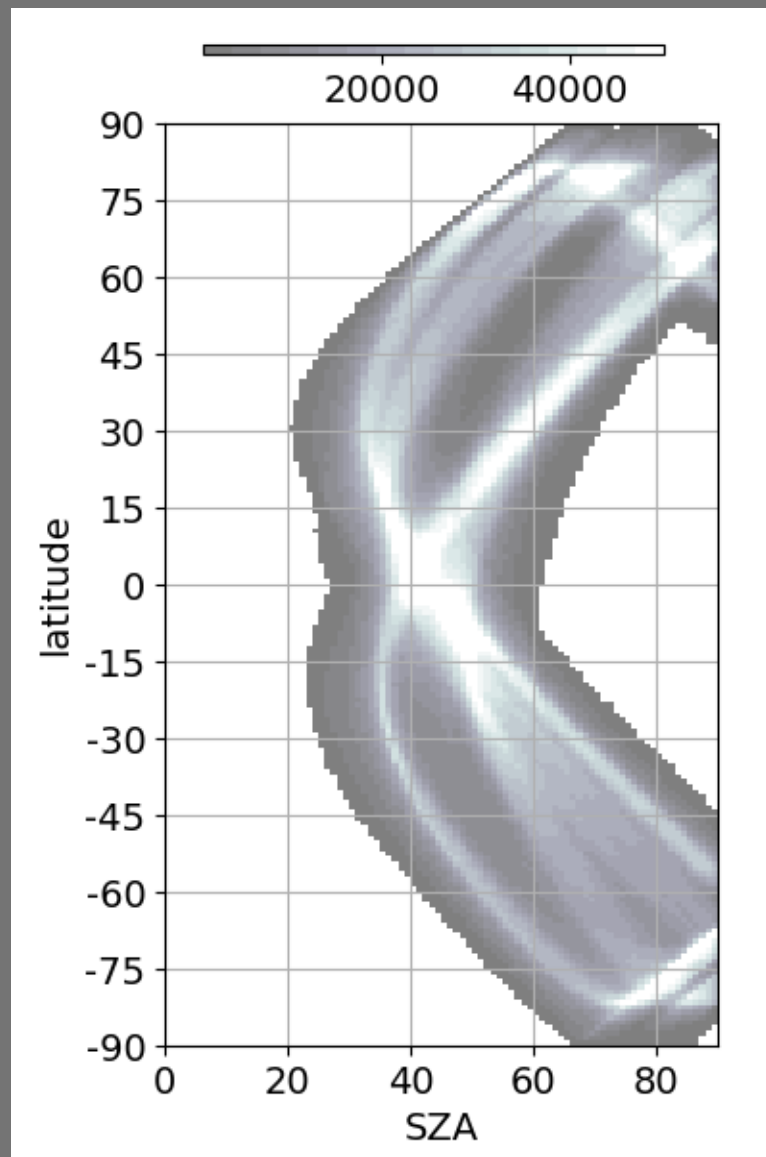
### Estimated Future Changes to Aqua's Equator Crossing Time and Altitude



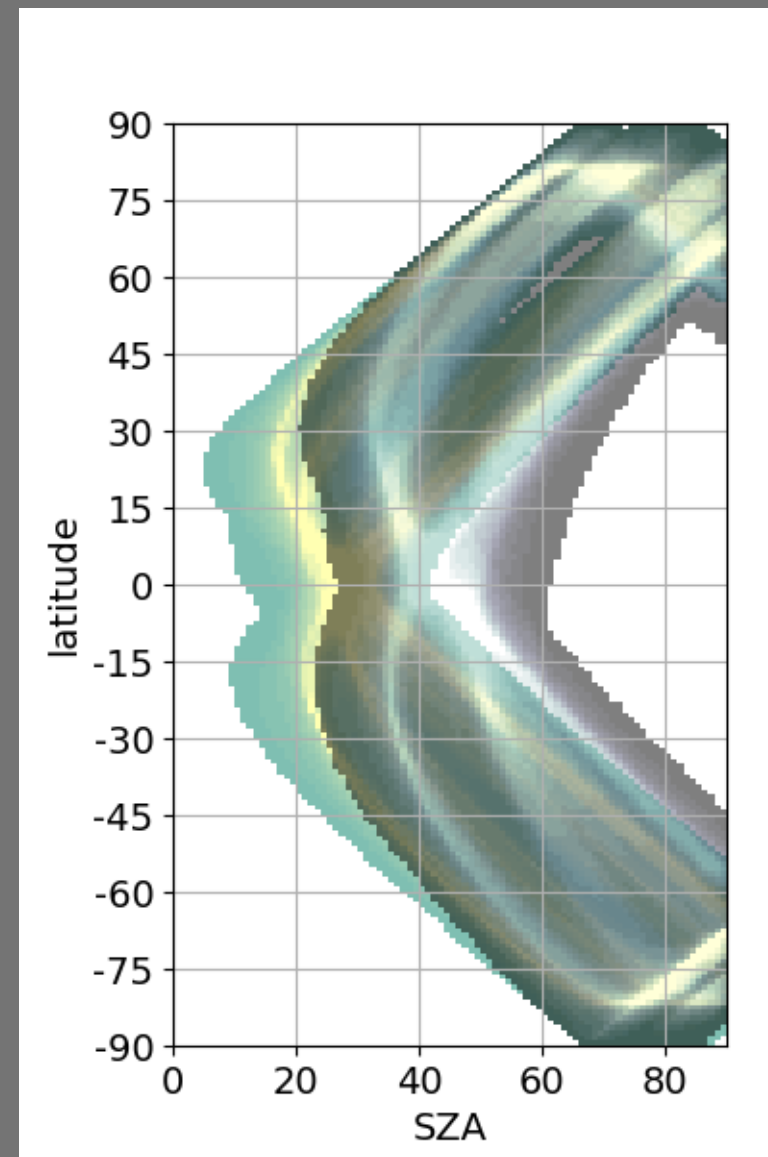
AQUA SZA sampling counts collected in Jan, Apr, Jul, and Oct



2004



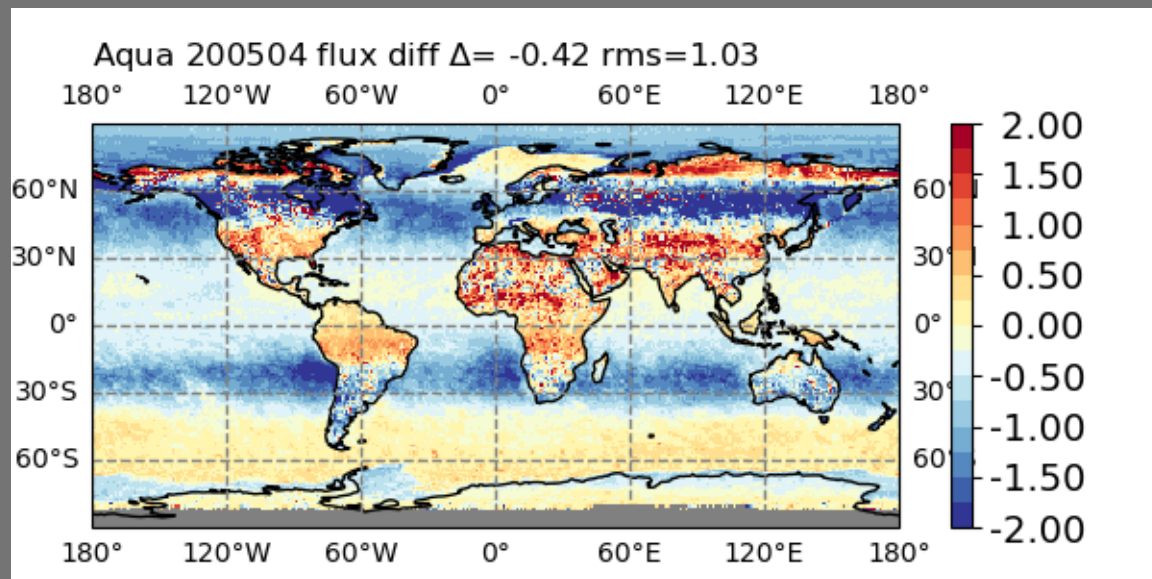
2024



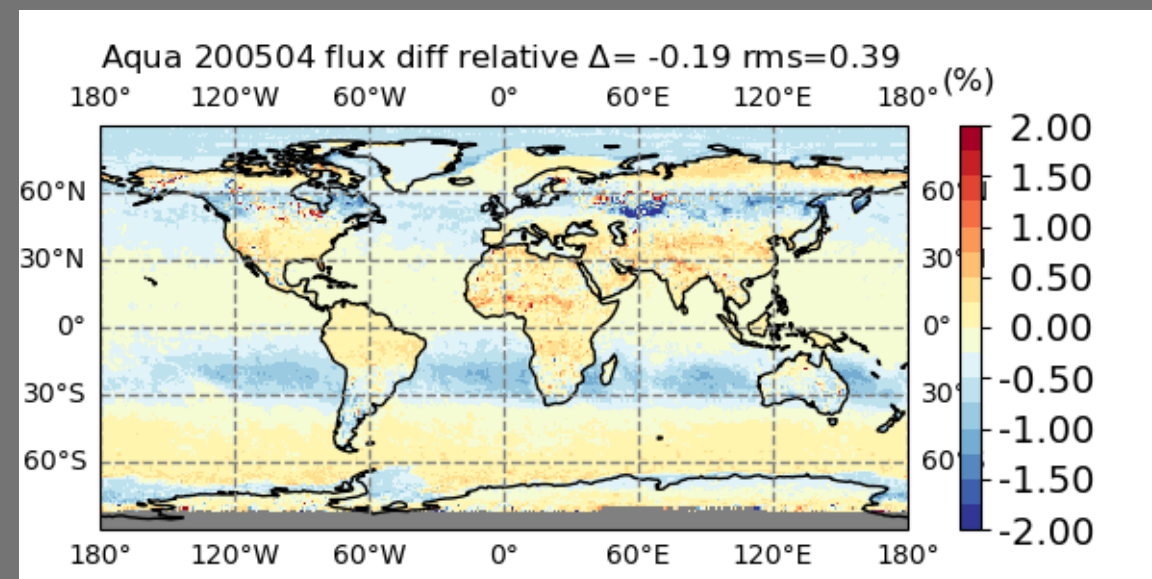
# ADMs

- 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:

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

- Integrate radiances to get flux:

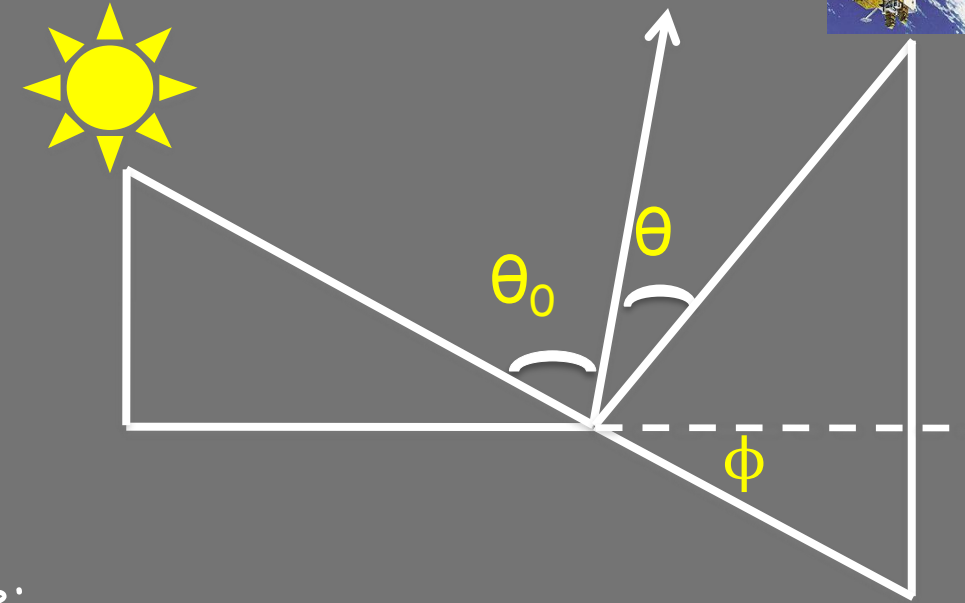
$$\hat{F}(\theta_o) = \int_0^{2\pi} \int_0^{\pi/2} \hat{I}(\theta_o, \theta, \phi) \cos\theta \sin\theta d\theta d\phi$$

- Estimate the anisotropic factor for each scene type:

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

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

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



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

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

$$\frac{s}{\sqrt{n}}$$

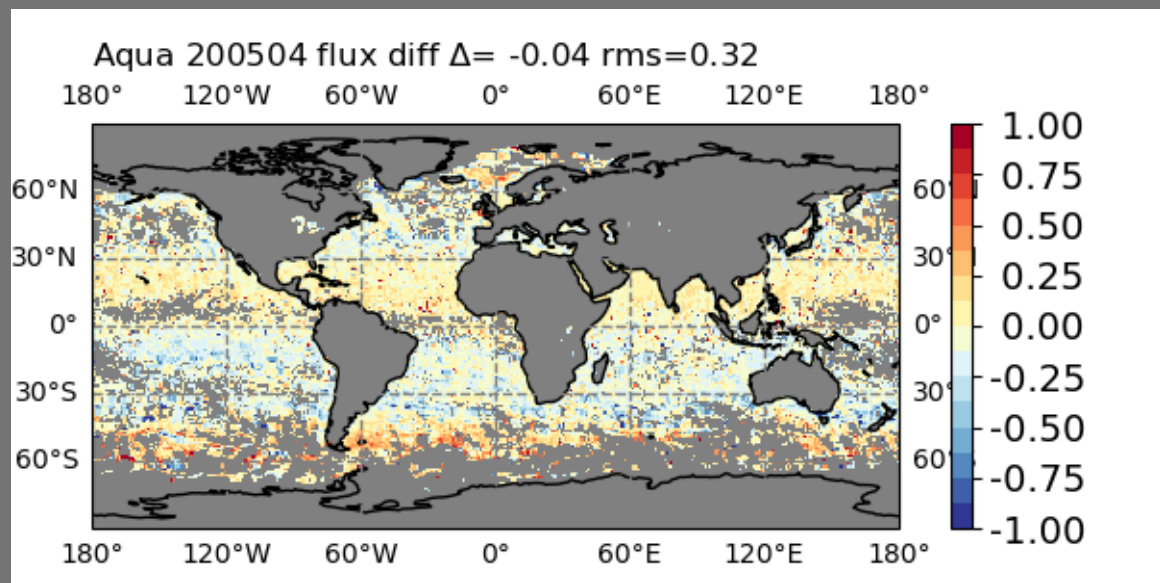
is the standard error calculated from standard deviation and sampling counts.

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%).

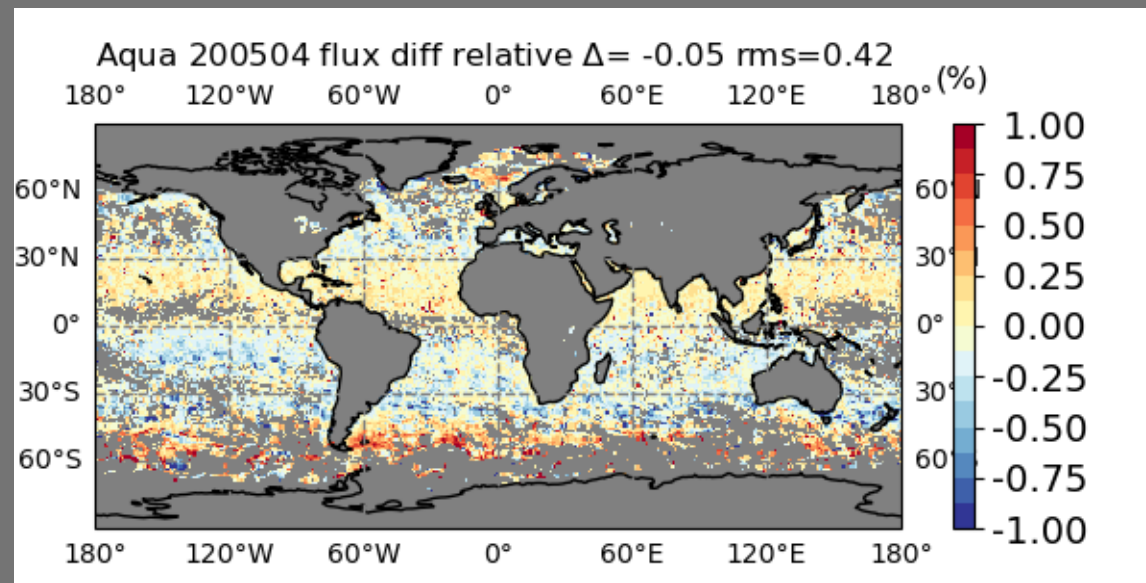
The confidence interval = estimated mean  $\pm E$   
(the estimated mean is within the interval for 95% of time to the truth).

# Clear-sky over ocean

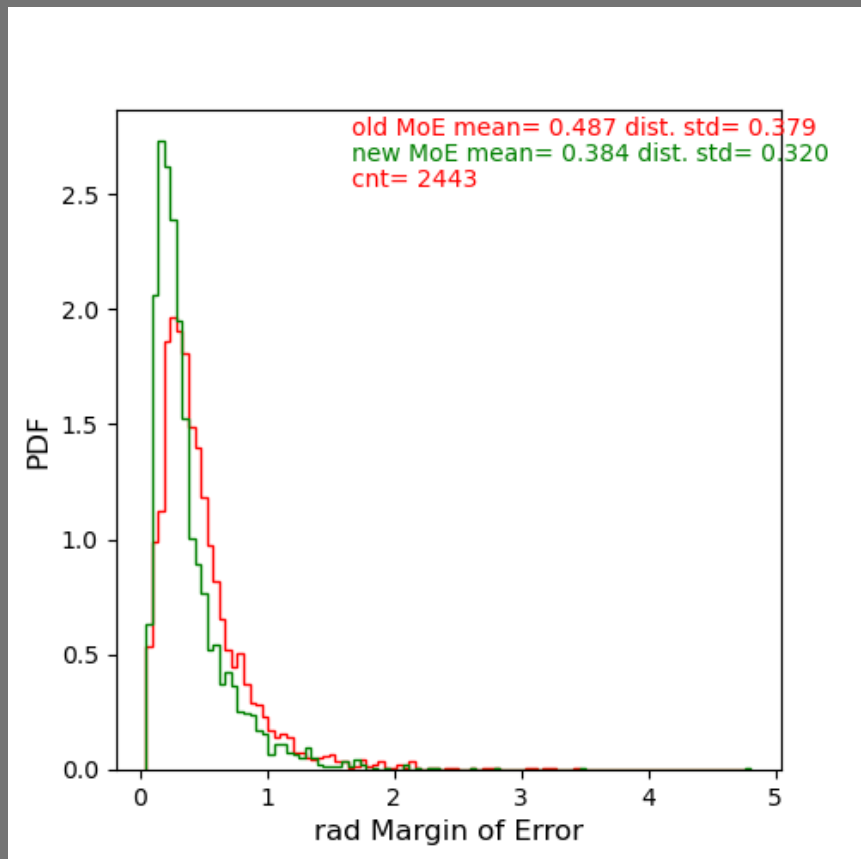
## Flux differences



## Flux Relative differences

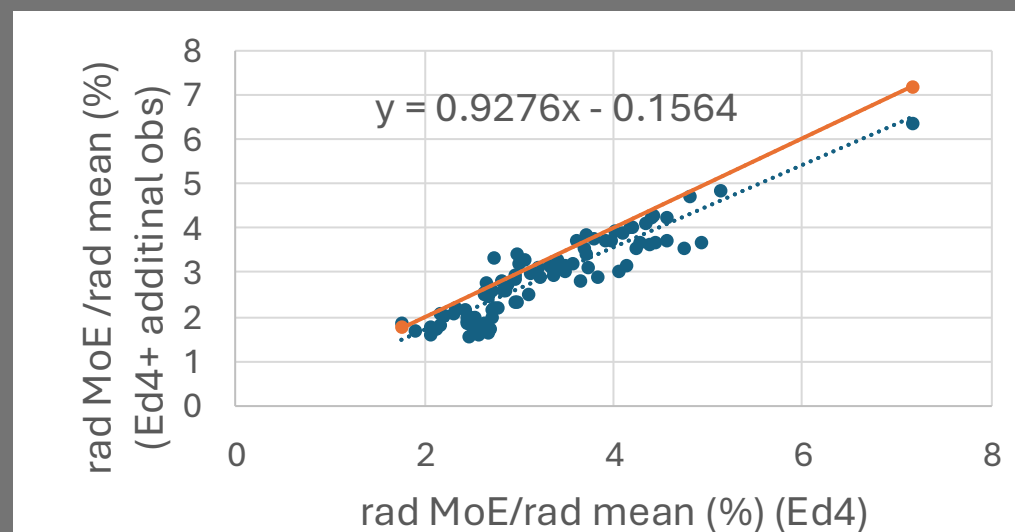
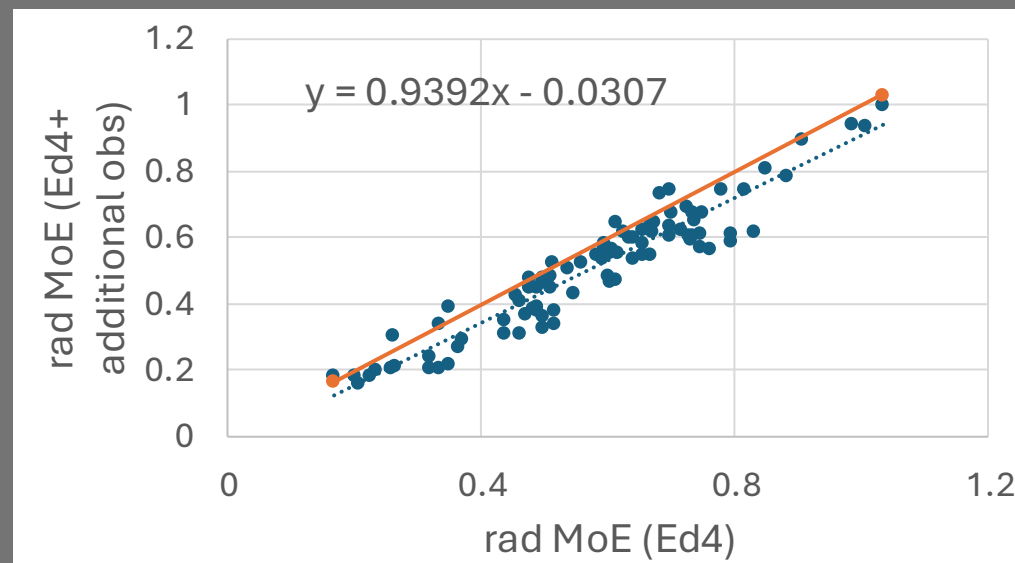


# Clear-sky over ocean



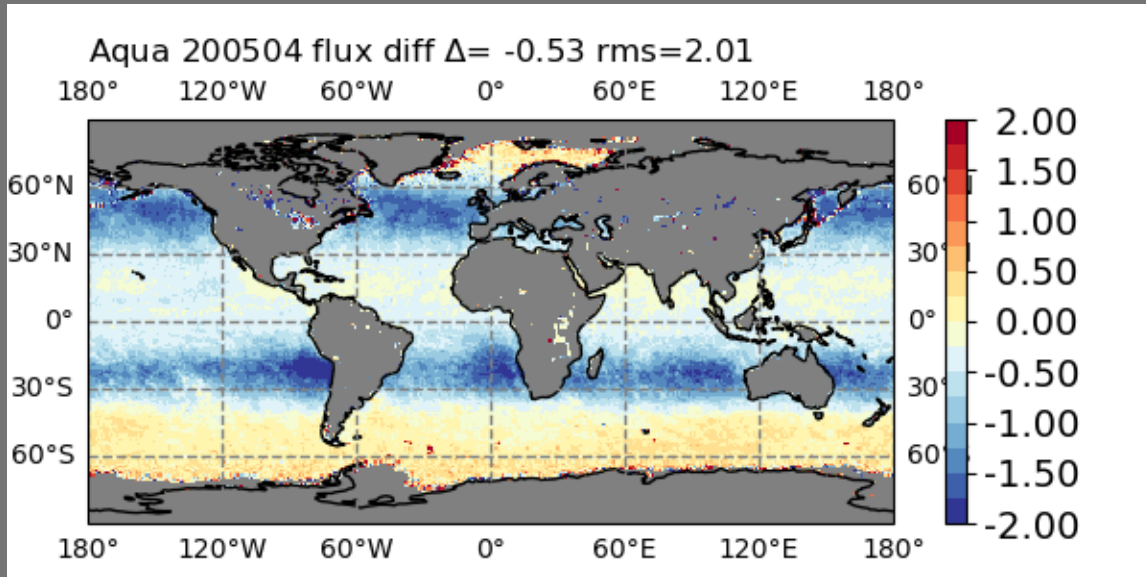
MoE distribution across viewing angles (45 VZA x 90 RAZ) for SZA = 38-40, ocean wind-speed=4-6 m/s, coarse model aerosols, and sampling counts > 10 in each viewing angle.

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.

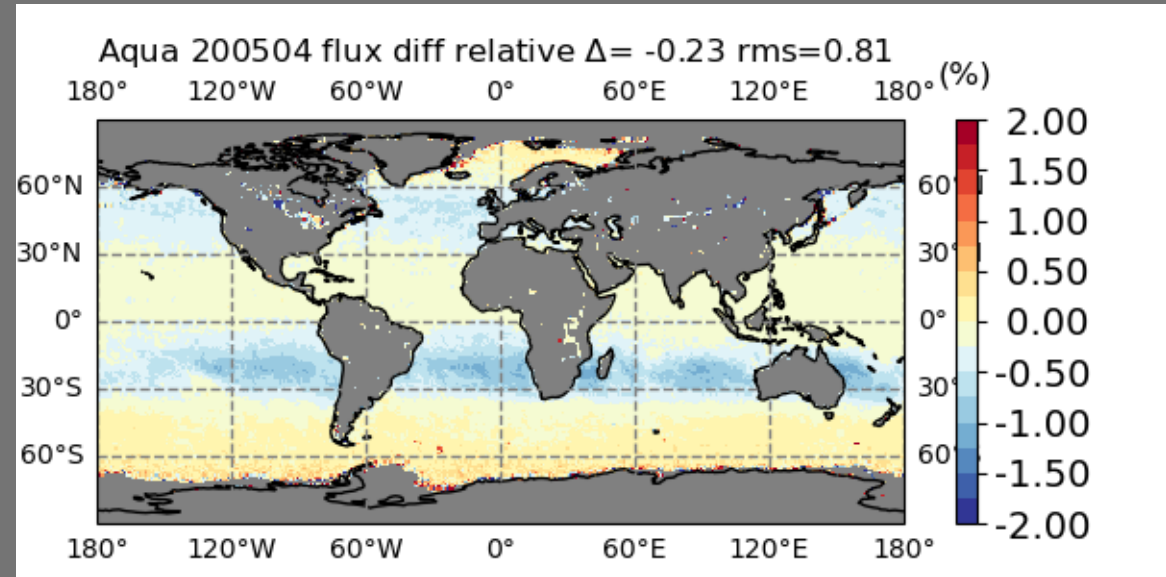


# Cloudy-sky over ocean

## Flux differences



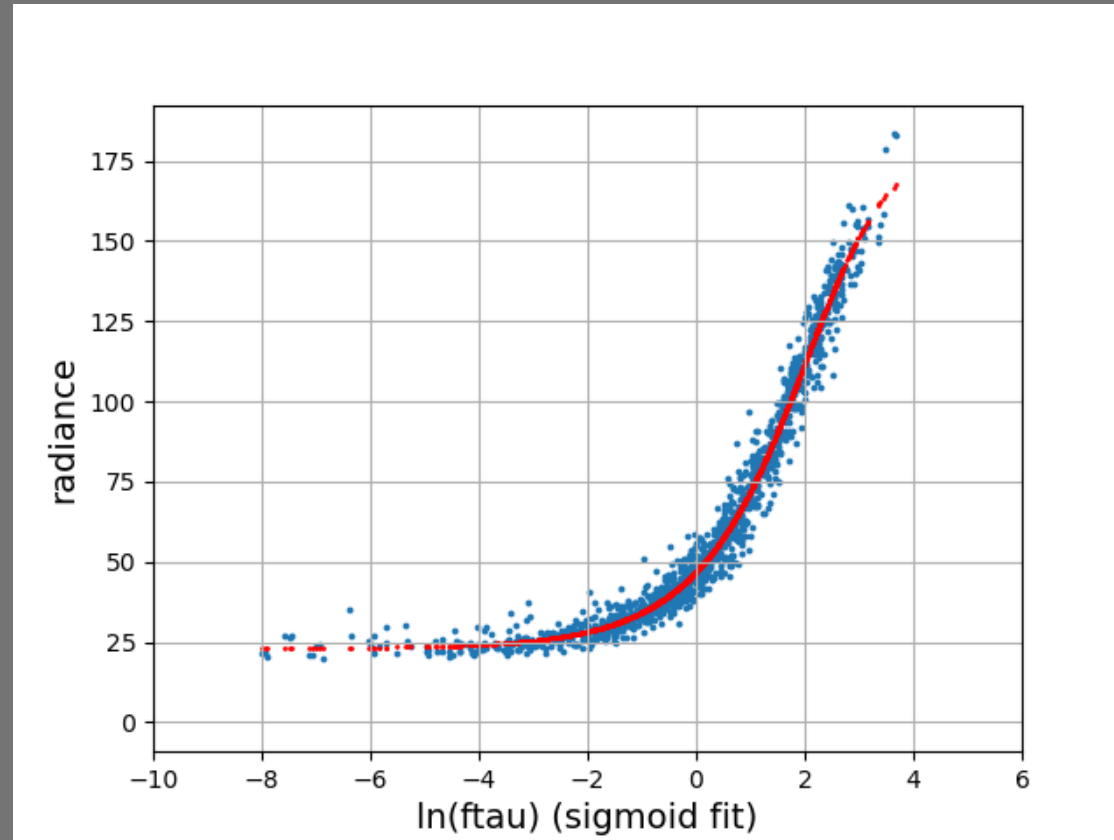
## Flux Relative differences



# Cloudy-sky over ocean

## Processing of cloud-sky over ocean ADMs

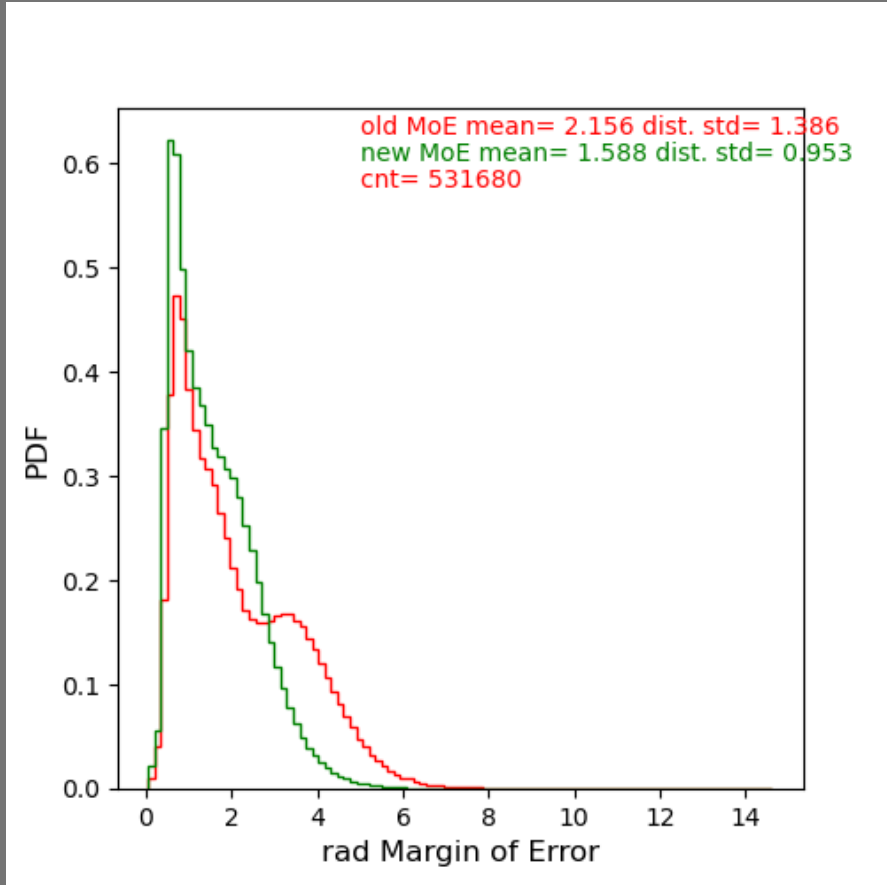
In a given angular bin, radiances are averaged in  $\ln(f\tau)$  intervals, and sigmoid fit is used to relate the mean radiances and  $\ln(f\tau)$  bin values.



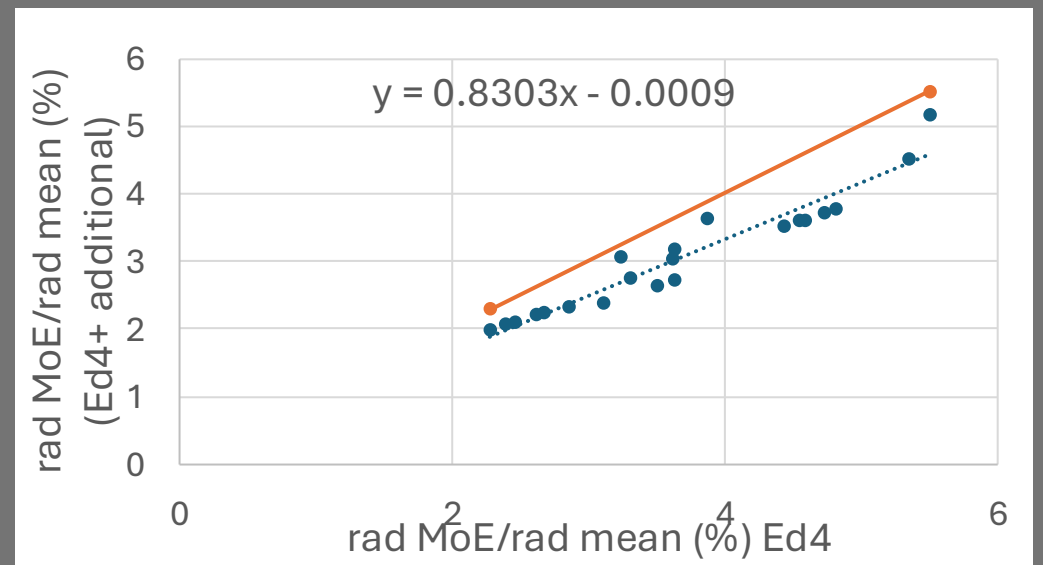
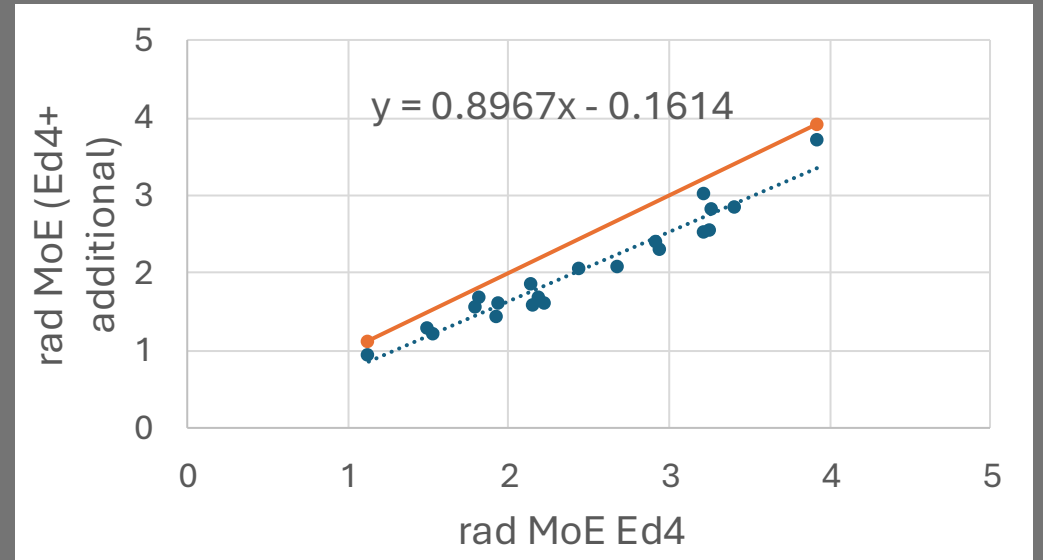
SZA=38-40, VZA=66-68 and RAZ=68-70 for water clouds  
 $f$  is the cloud fraction and  $\tau$  is the cloud optical depth.

# Cloudy-sky over ocean

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

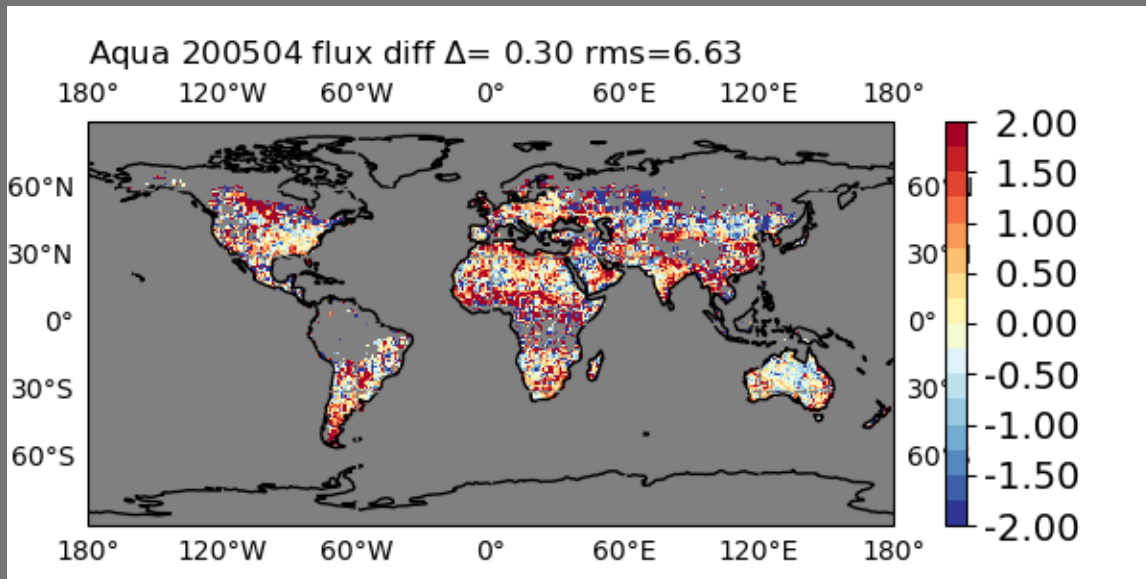


MoE distribution of optically thick clouds for viewing angles and  $\ln(\text{ftau})$  bins (45 VZA  $\times$  90 RAZ  $\times$  775  $\ln(\text{ftau})$ ) for solar zenith angle = 38-40 and within non-glint region.

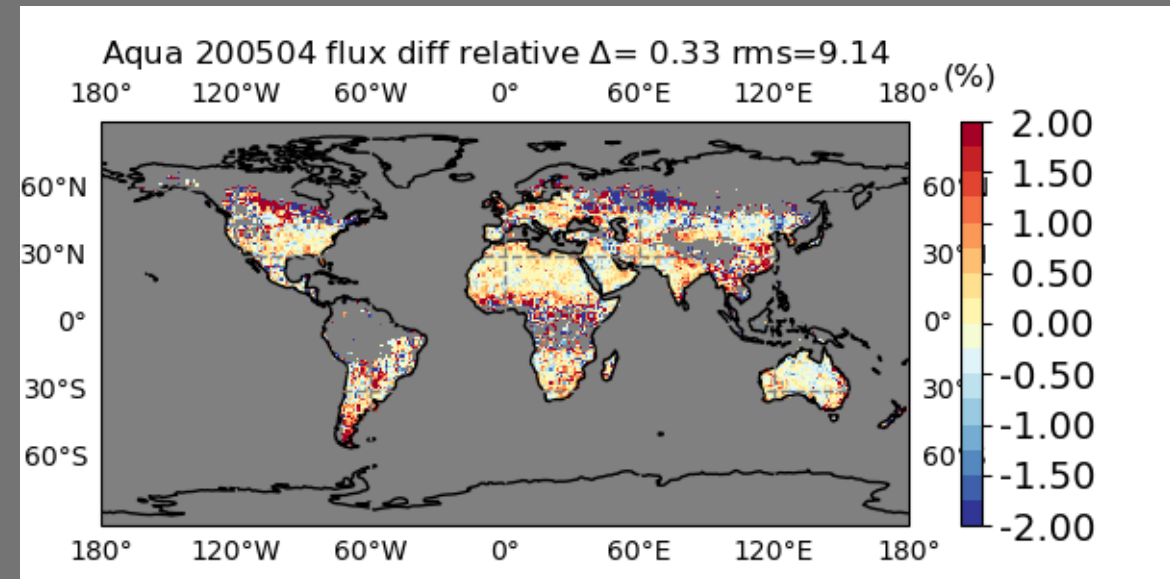


# Clear-sky over land

## Flux differences

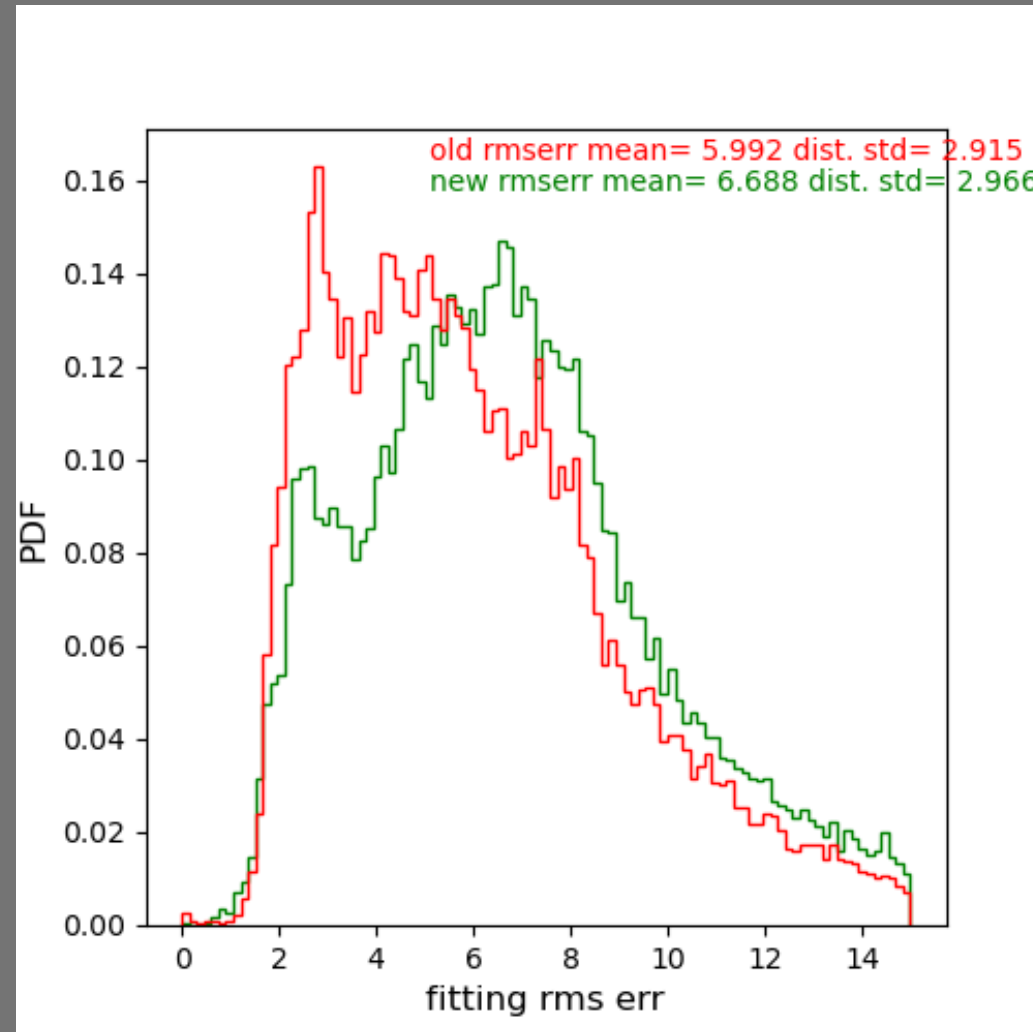


## Flux Relative differences



## Processing of clear-sky over land ADMs

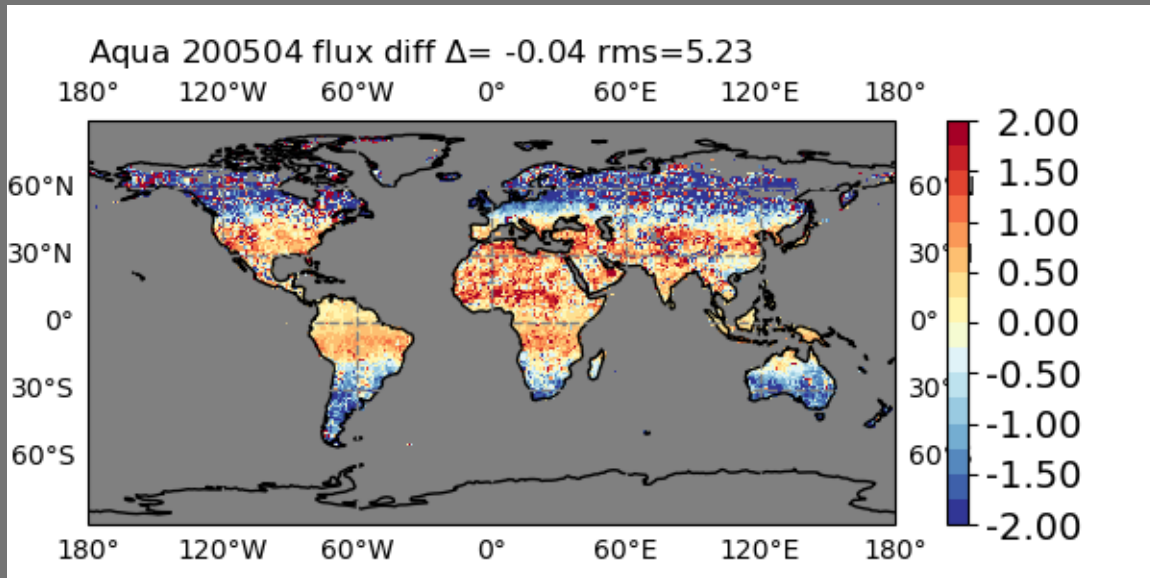
Within a SZA-NDVI bin interval, all observed radiances are used directly to fit the RossLi surface BRDF model. There is no radiance averaging involved.



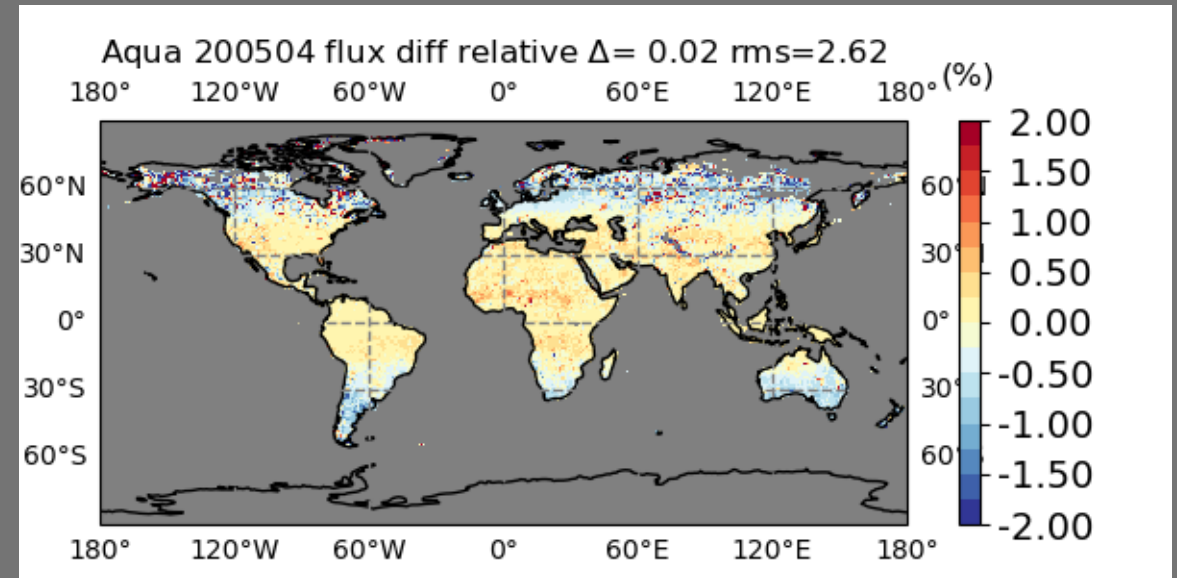
Fitting RMS errors for July

# Cloudy-sky over land

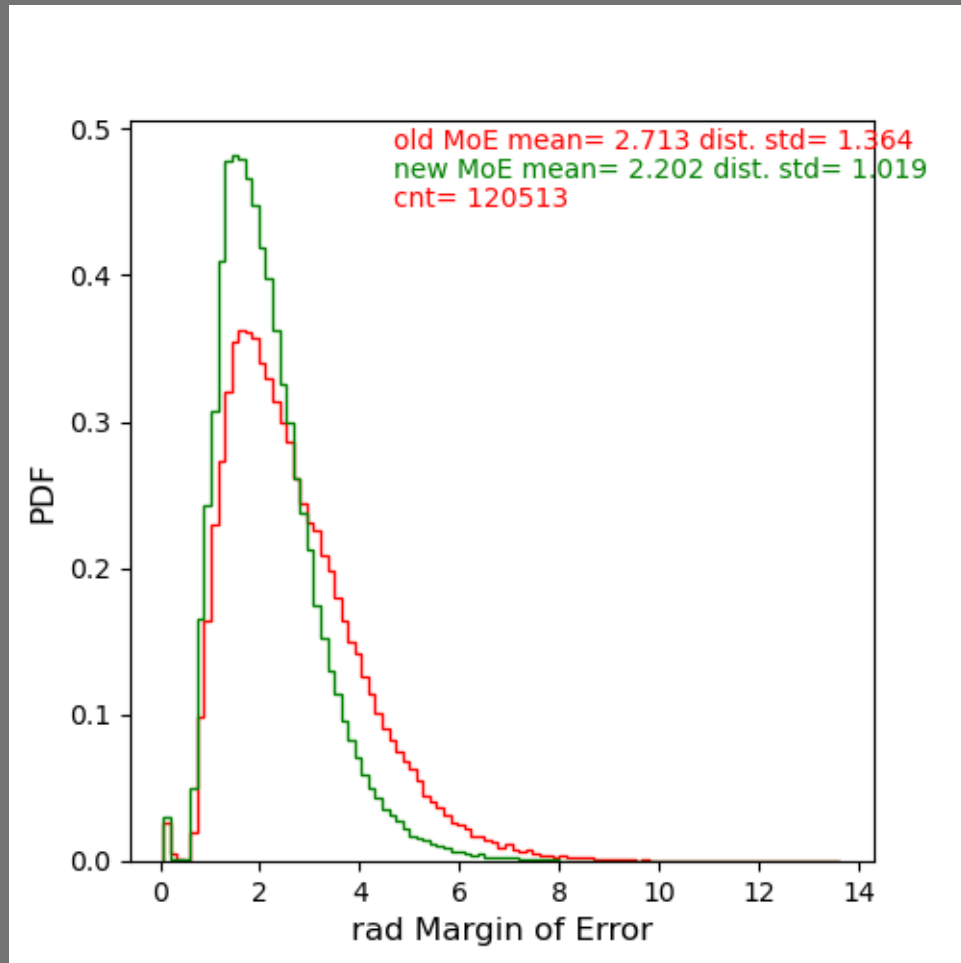
## Flux differences



## Flux Relative differences

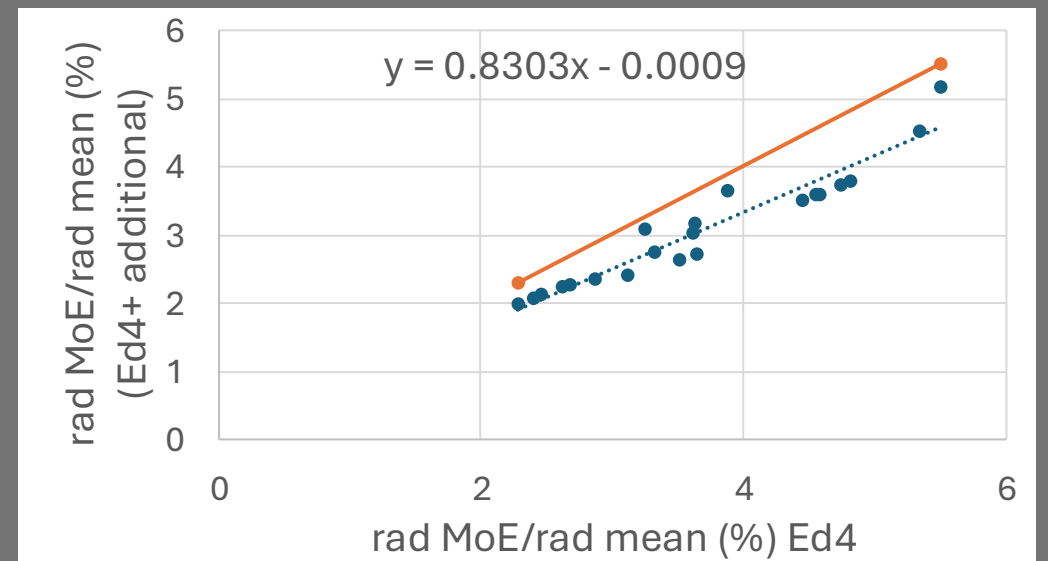
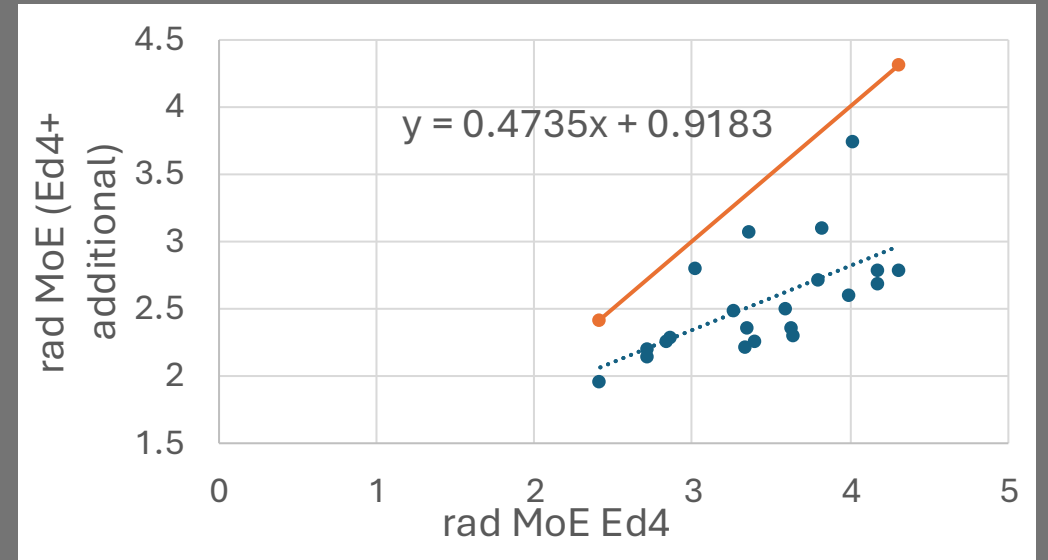


# Cloudy-sky over land

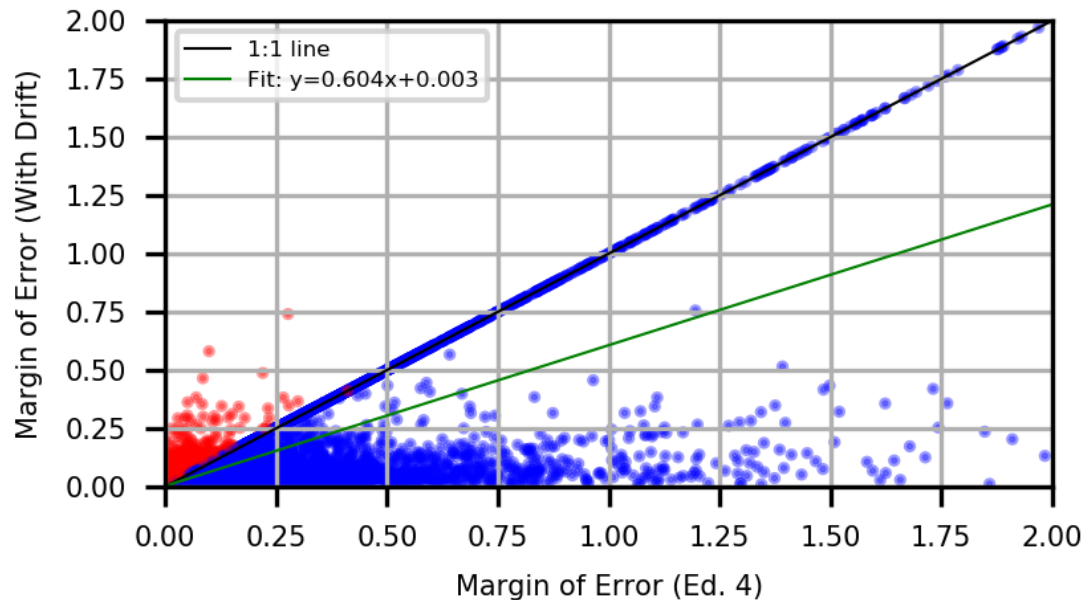


MoE distribution of water clouds for viewing angles and  $\ln(\text{ftau})$  bins ( 18 VZA  $\times$  36 RAZ  $\times$  380  $\ln(\text{ftau})$  ) for solar zenith angle=25-30.

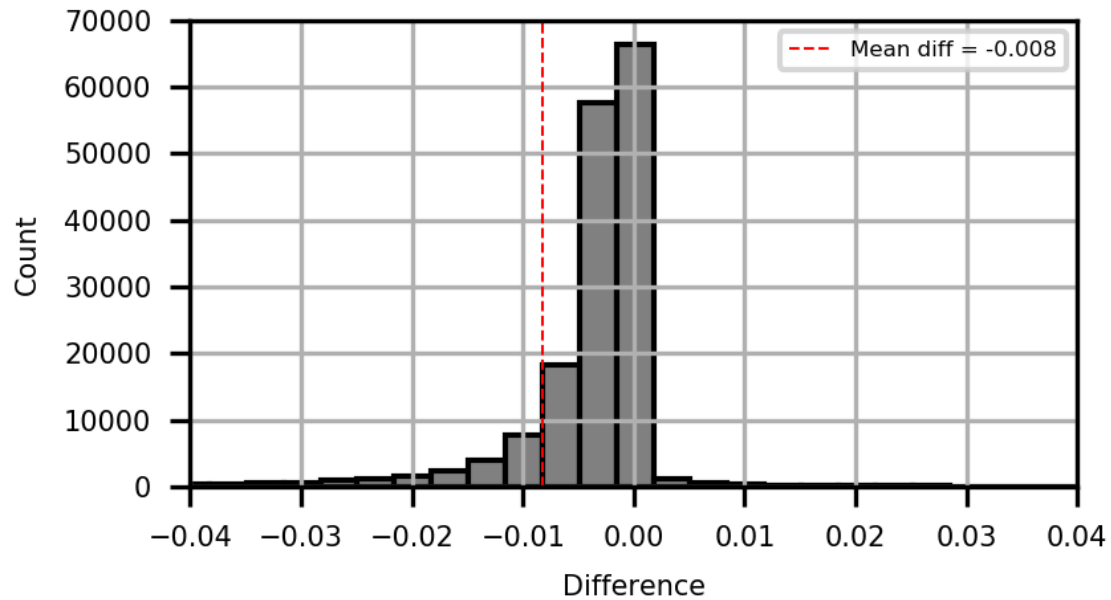
Collect the mean MoE values from MoE distributions for 7 SZA bin intervals from 17.5 to 77.5) for water, mix and ice clouds



Reflectance Margin of Error within ADM Bins



Histogram of Margin of Error Differences

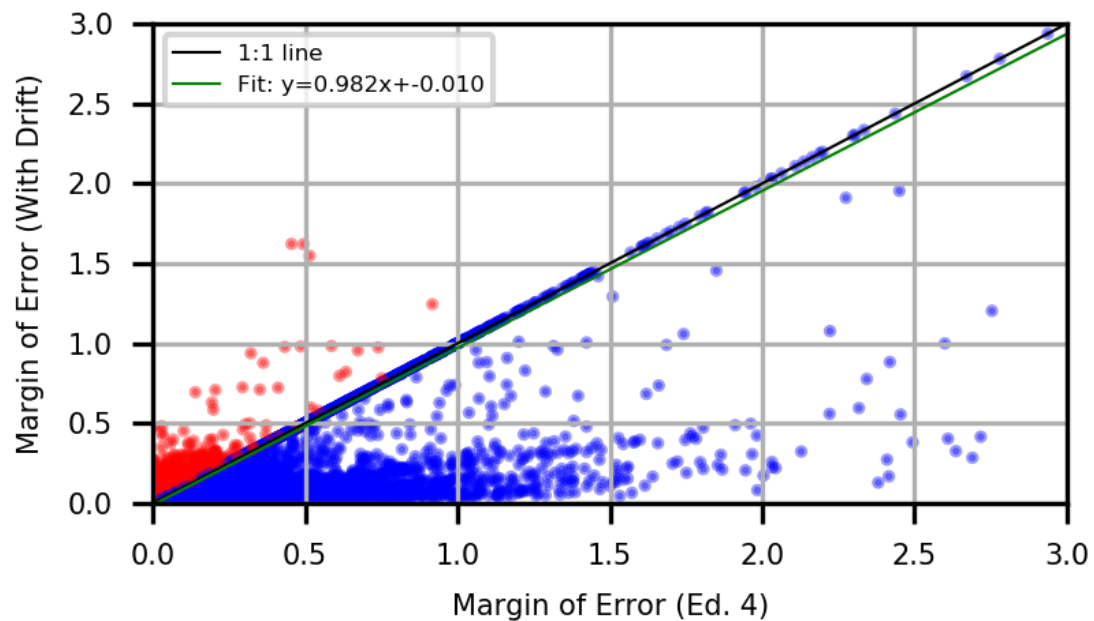


**Cloudy Fresh Snow**

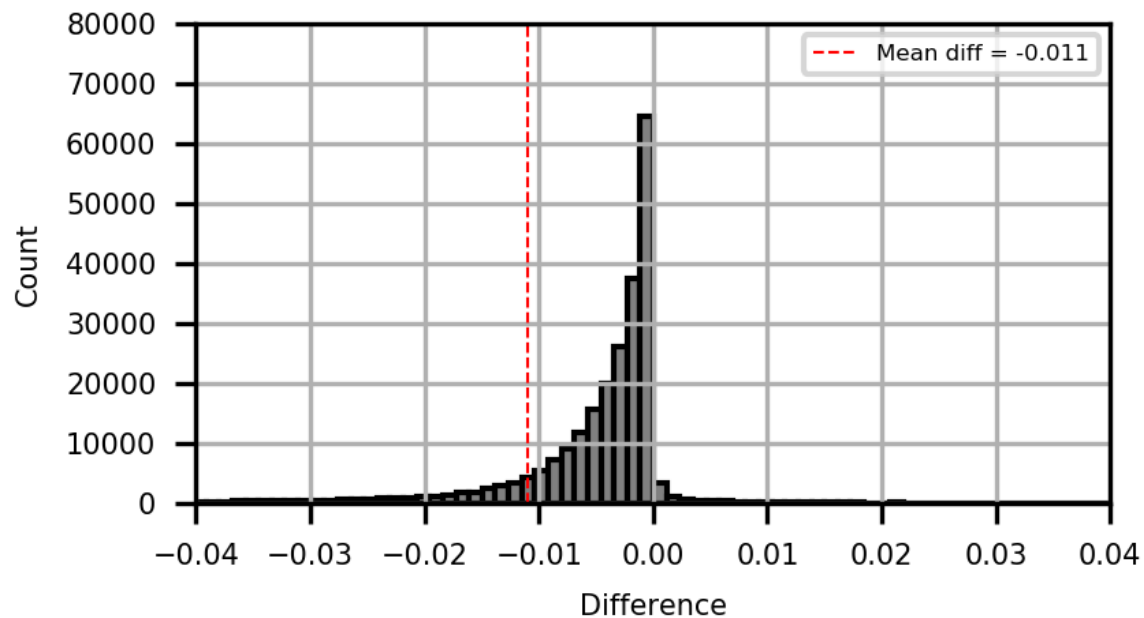
**STATISTICAL SUMMARY**

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%

Reflectance Margin of Error within ADM Bins



Histogram of Margin of Error Differences



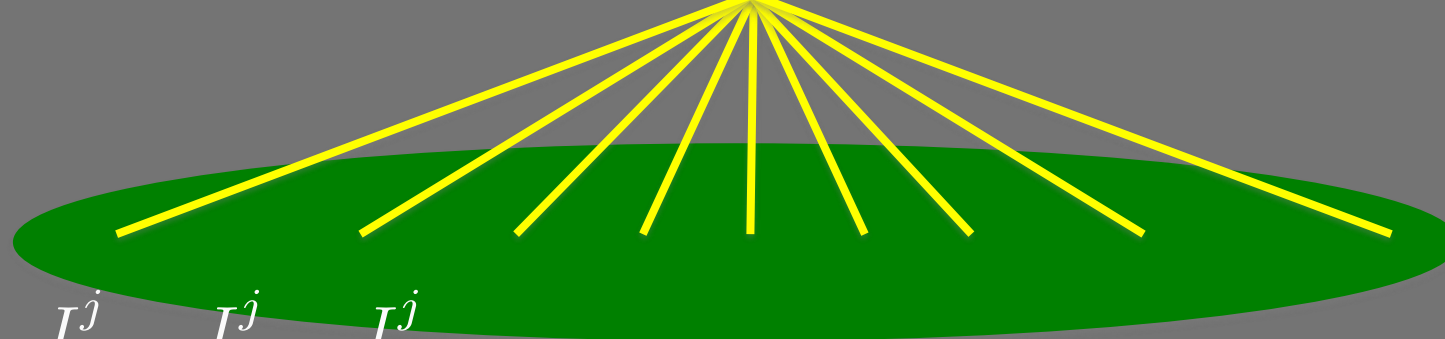
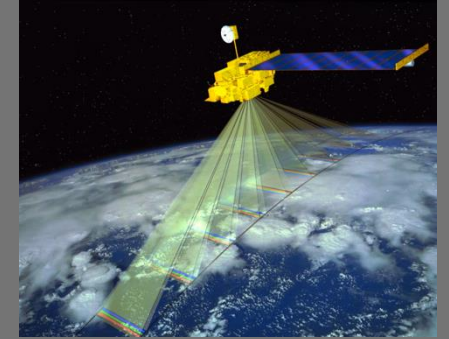
## Partly Cloudy Sea Ice

### 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



$$I_{0.45}^j, I_{0.67}^j, I_{0.87}^j$$

$$I_{sw}^j = c_0 + c_1 I_{0.45}^j + c_2 I_{0.67}^j + c_3 I_{0.87}^j$$

↓ CERES ADM

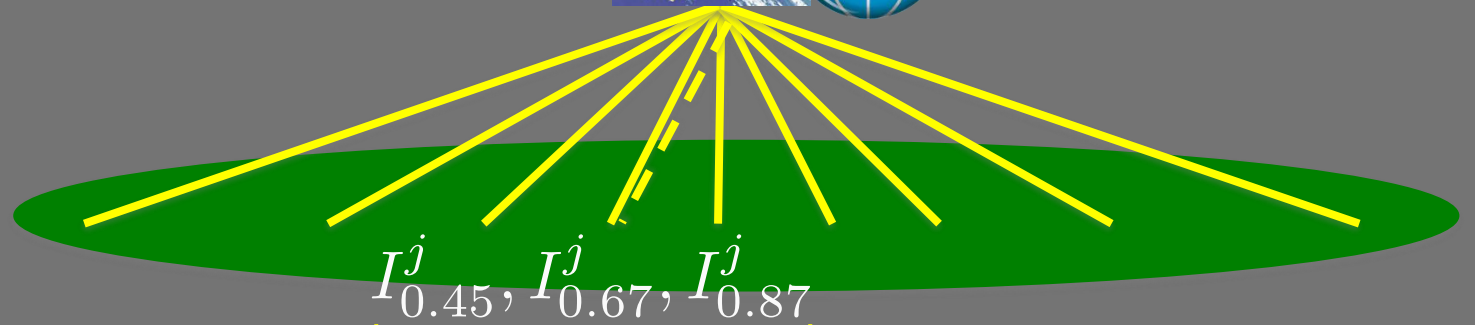
$$F_{sw}^j \longrightarrow \overline{F_{sw}} = \frac{\sum_{j=1}^9 F_{sw}^j}{9} \longrightarrow s = \sqrt{\frac{\sum_{j=1}^n (F_{sw}^j - \overline{F_{sw}})^2}{n-1}}$$

For  $M$  CERES footprints, the total relative consistency is:

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

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.



$$I_{0.45}^j, I_{0.67}^j, I_{0.87}^j$$

$$I_{sw}^c \quad I_{sw}^j = c_0 + c_1 I_{0.45}^j + c_2 I_{0.67}^j + c_3 I_{0.87}^j$$

CERES ADM

$$F_{sw}^c \quad F_{sw}^j$$

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

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

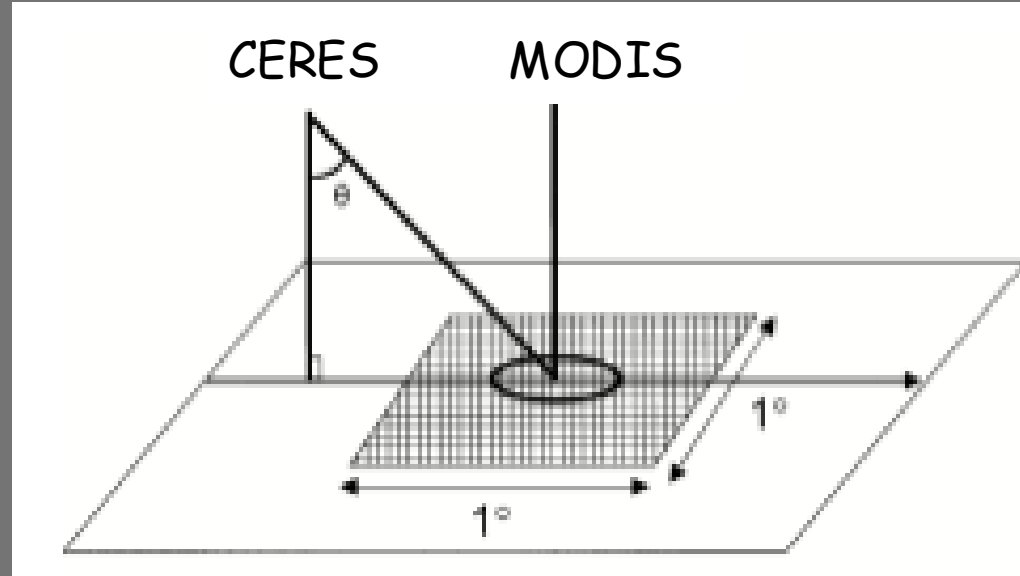
# SW Flux Consistency (MISR)

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
<b>N</b>	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
$\Psi_{ADM}^{Drift}$ (%)	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  $R_{\text{MOD\_NB}}$ , to broad-band radiances  $R_{\text{MOD\_BB}}$ . Retrieve flux based on  $R_{\text{MOD\_BB}}$  with MODIS viewing-geometries, treating it like CERES observations.
3. Compare  $F_{\text{MOD\_BB}}$  (near nadir) and  $F_{\text{CERES\_BB}}$  (@60 VZA).

SW RMS errors between  $F_{\text{MOD\_BB}}$  (near nadir) and  $F_{\text{CERES\_BB}}$  (@60 VZA)

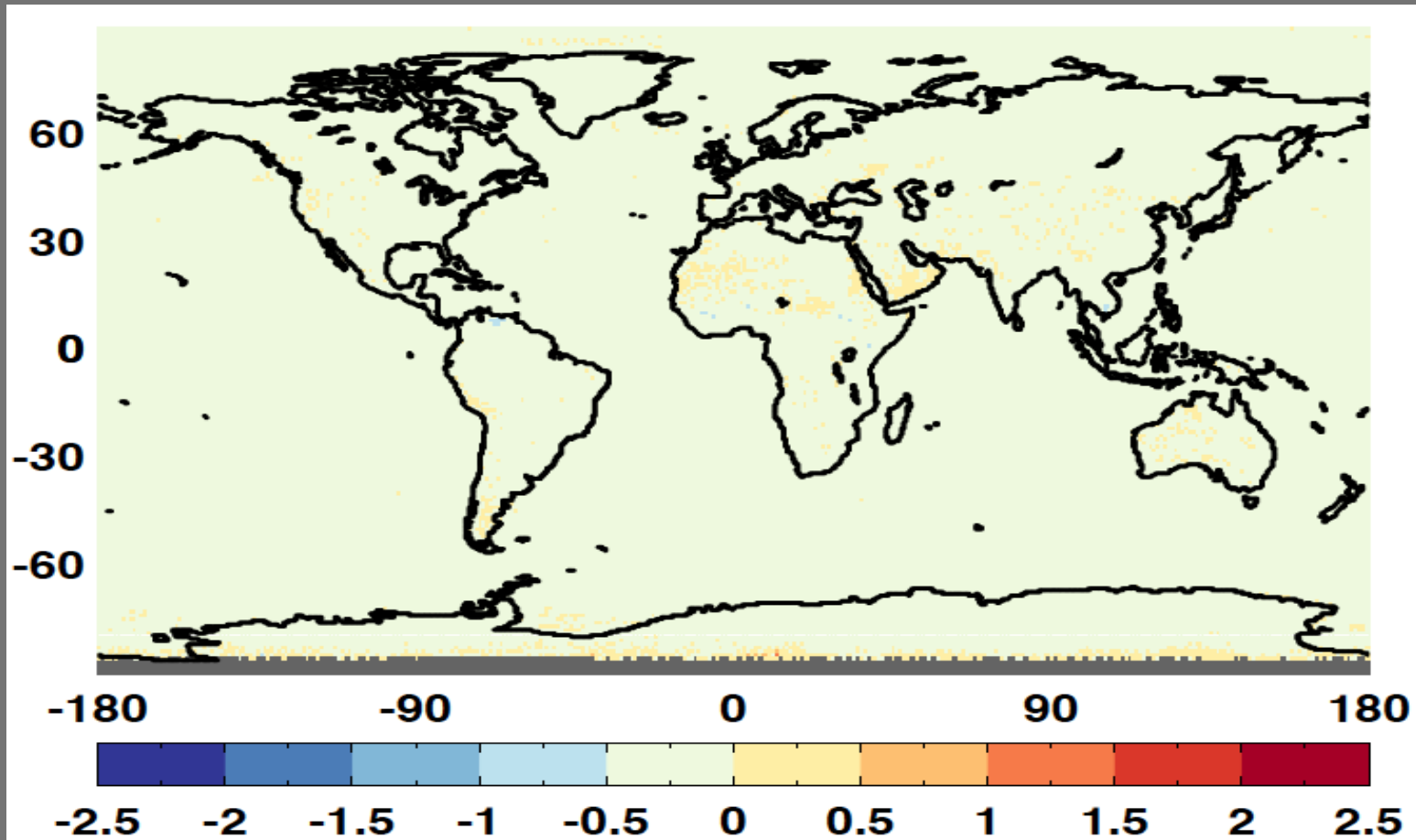
Ocean RMS error (%)		
	Ed4	Ed4 + additional RAPs
clear	4.4	4.3
single-layer	5.2	5.2
Multiple-layer	9.7	9.7
all	6.0	6.0

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:  $-0.16 \text{ W m}^{-2}$  RMS diff:  $0.18 \text{ W m}^{-2}$



LUT approach for split SW flux retrieval

## Visible flux from Libera

- Incoming energy in the range from 0.3-5.0 $\mu\text{m}$  can be split by VIS (0.3-0.7 $\mu\text{m}$ ) and NIR (0.7-5.0 $\mu\text{m}$ ).
- Libera has a split-shortwave channel (NIR: 0.7-5  $\mu\text{m}$ ), in addition to the traditional shortwave (0.3-5  $\mu\text{m}$ ), longwave (5-50  $\mu\text{m}$ ), and total (0.3-100  $\mu\text{m}$ ) channels.

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

- Radiances in the visible band (0.3-0.7  $\mu\text{m}$ ) 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

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

- The NIR flux relates to SW flux by

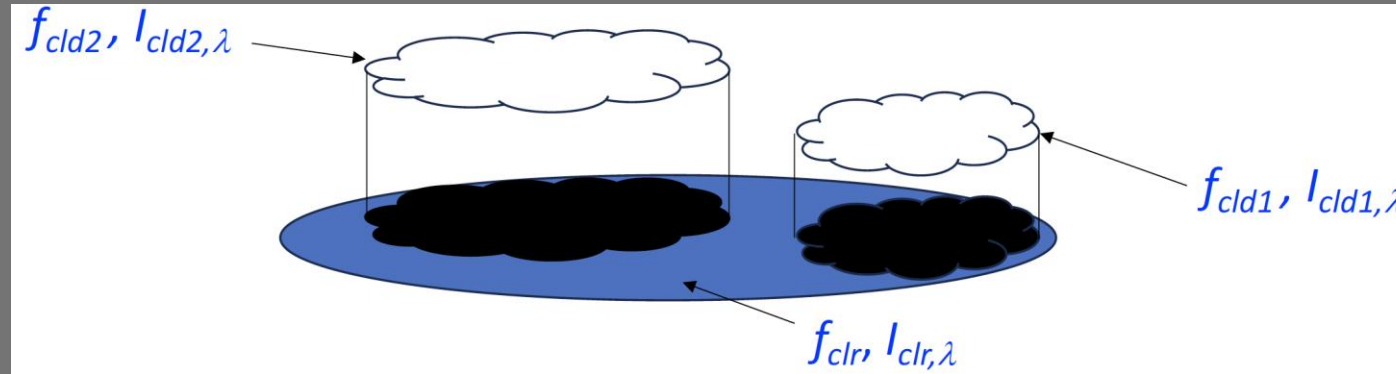
$$F_{\text{NIR}} = \frac{F_{\text{SW}}}{1 + \alpha}, \quad \text{where, } \alpha = \frac{F_{\text{VIS}}}{F_{\text{NIR}}} = \left( 1 + \frac{I_{\text{VIS}}}{I_{\text{NIR}}} \beta \right),$$

- The VIS flux is then determined by

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

- $\beta$  is retrieved from radiative transfer model LUTs by minimizing the errors between simulated and observed narrow-band radiances.
- Currently,  $I_{\text{VIS}}$  and  $I_{\text{NIR}}$  are derived from ratios to  $I_{\text{SW}}$  based on theoretical simulations to calculate  $\alpha = (I_{\text{VIS}} / I_{\text{NIR}}) \beta$ , 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  $I'_{VIS}, I'_{NIR}, F'_{VIS}, F'_{NIR}$ .

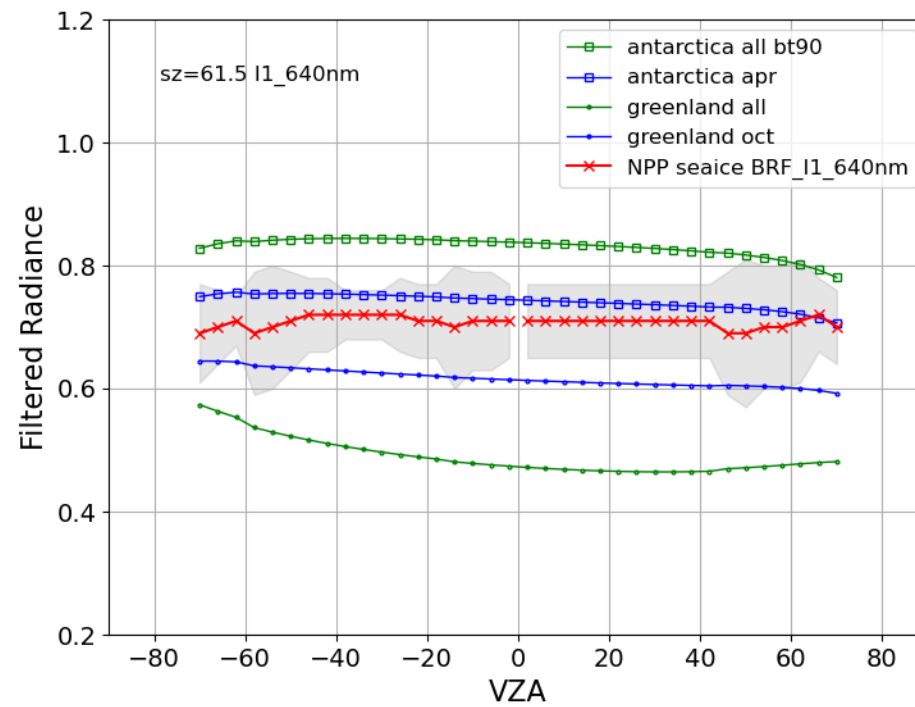
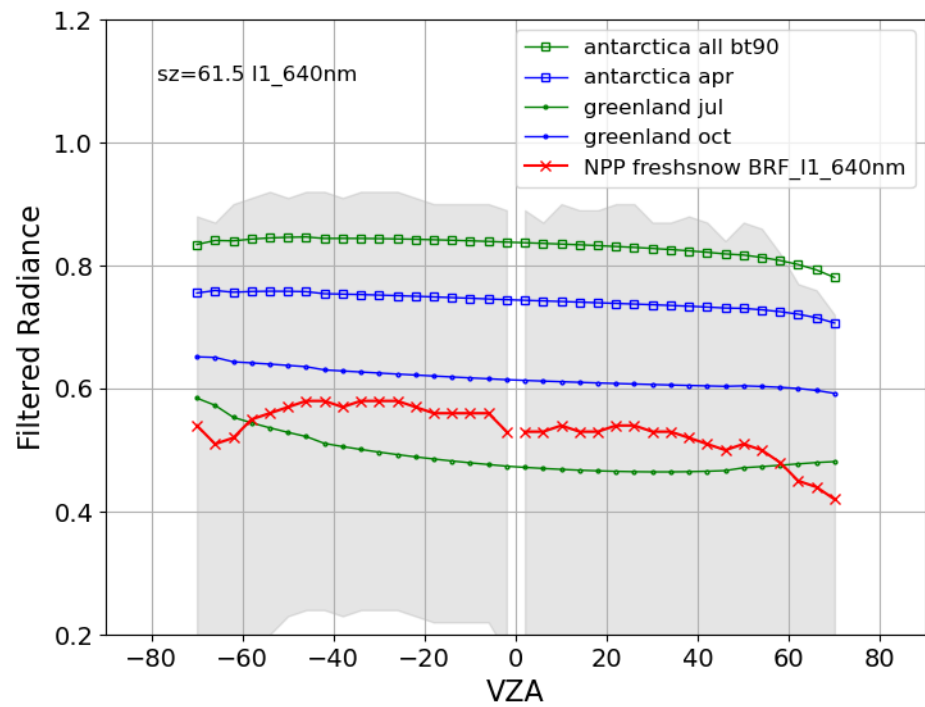
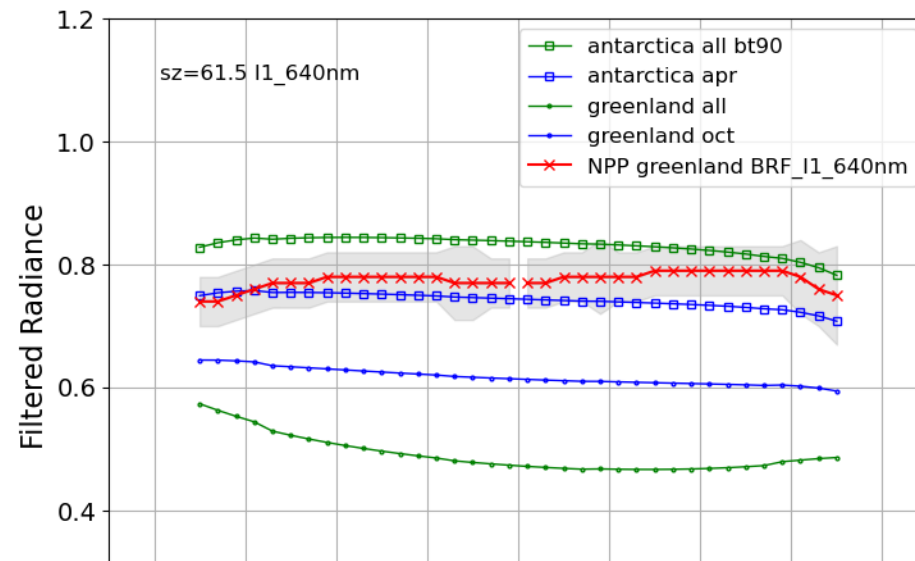
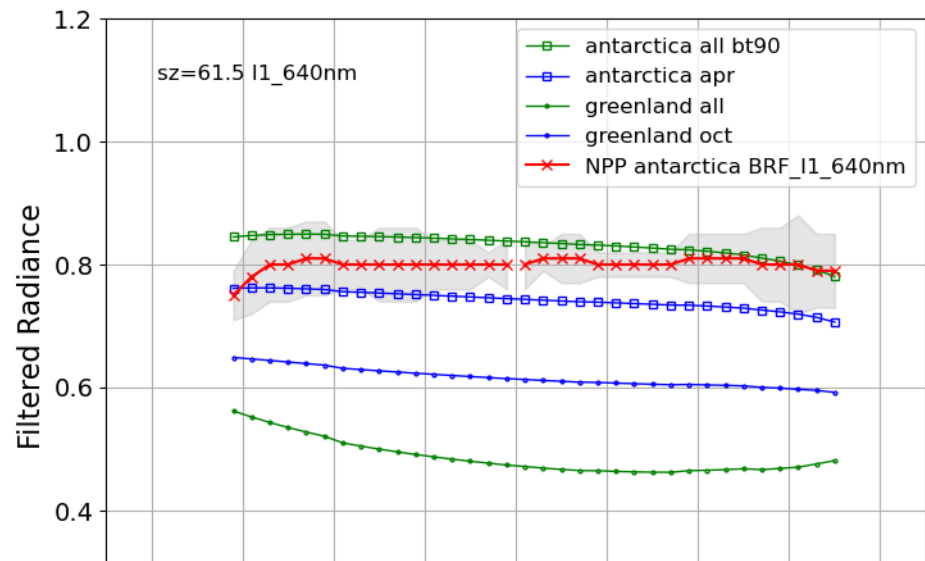
$$R_x = \pi I'_x / F'_x$$

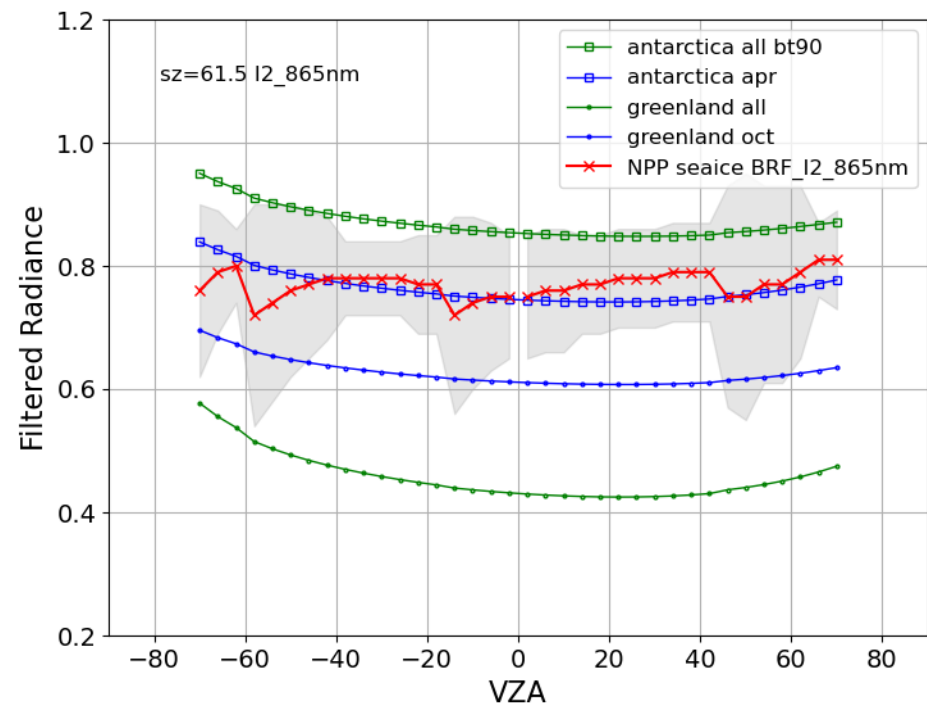
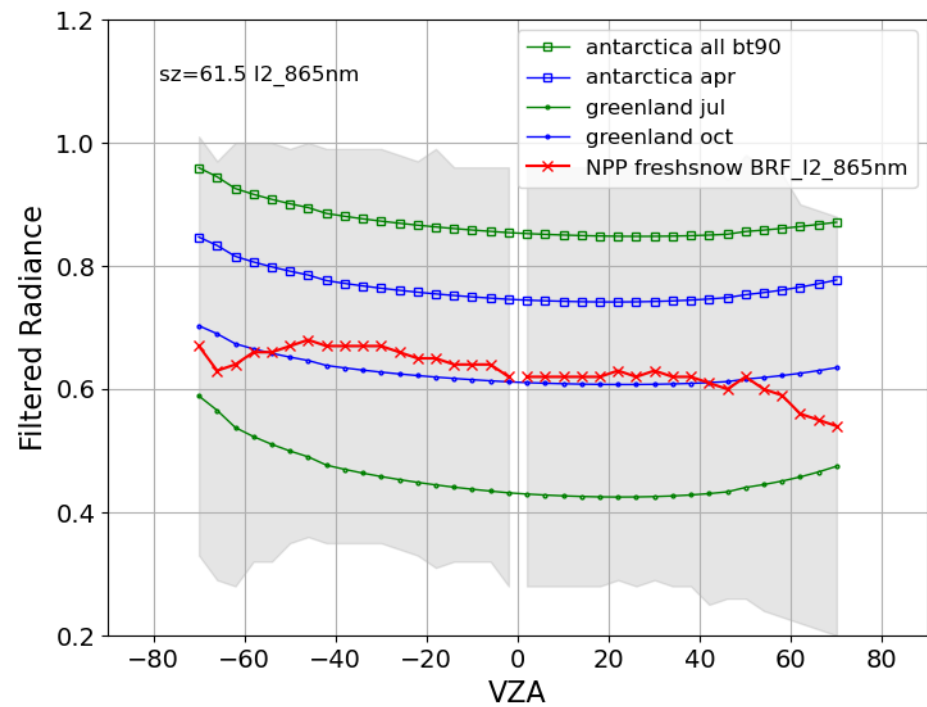
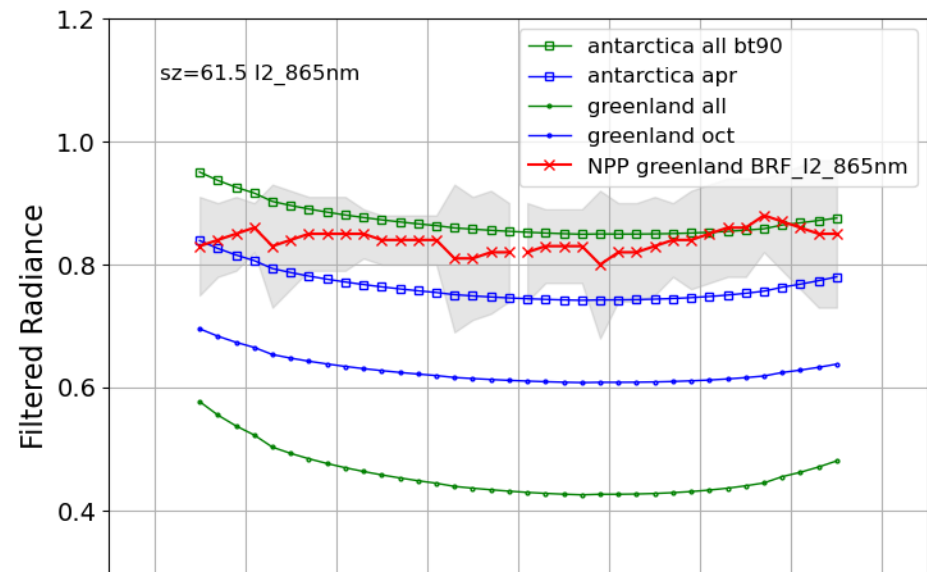
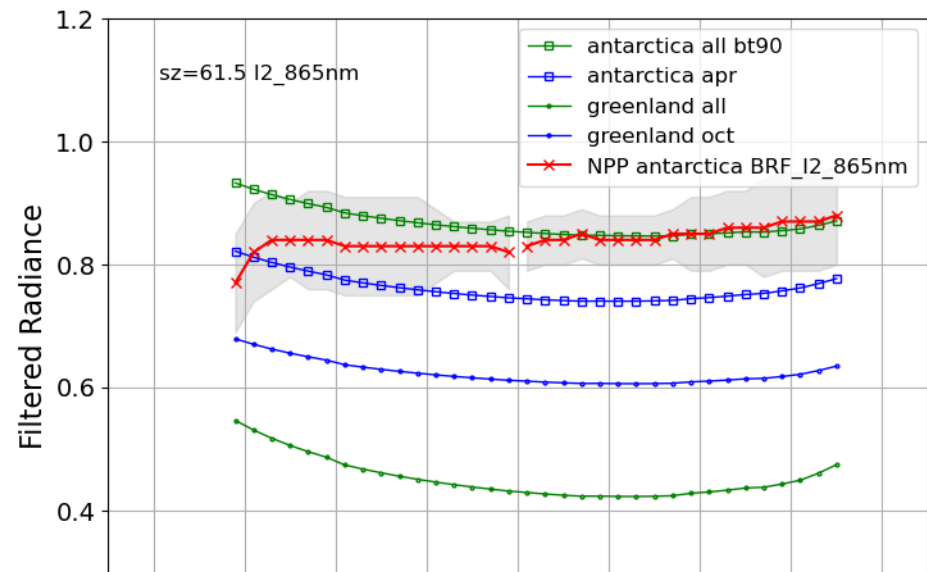
- Retrieve  $\beta = (R_{NIR} / R_{VIS})$

## MODTRAN simulations for $\beta$ retrieval LUTs

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

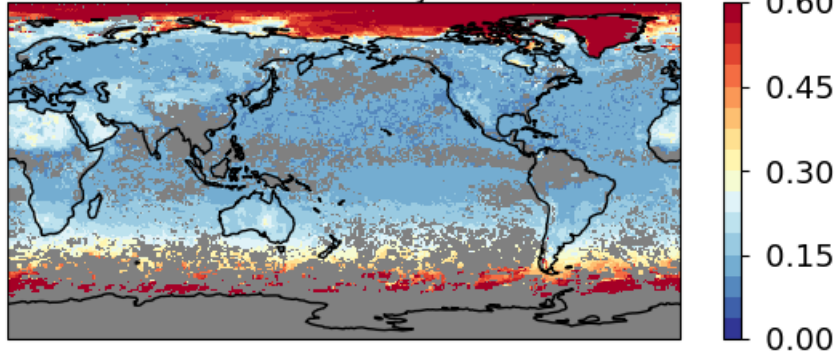
- Clear sky over ocean
  - 6 AODs, 2 ocean wind speeds
- Clear sky over land
  - 4 surface types characterized by MODIS RossLi BRDF models in the season of JJA and DJF, respectively, and 3 AODs
- Clear sky over snow/ice
  - 4 surface types to characterize permanent snow (Greenland and Antarctica), sea-ice, and fresh snow
- Overcast
  - 6 CODs and 2 cloud phases.



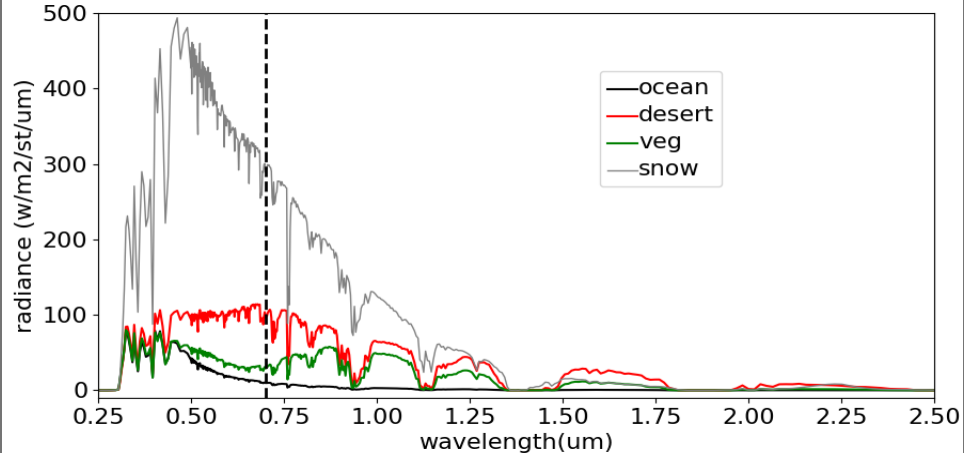
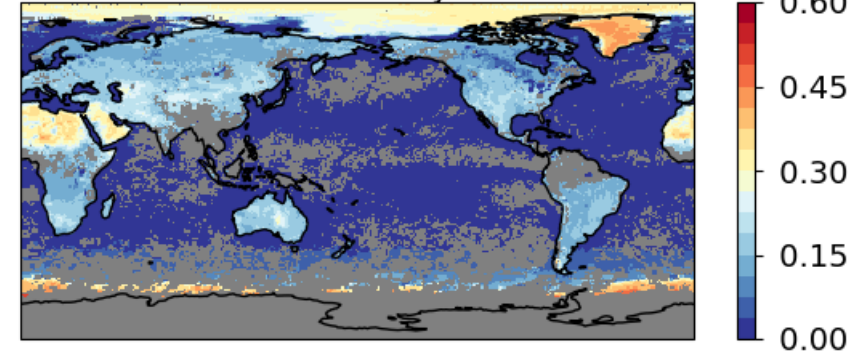


Clear sky

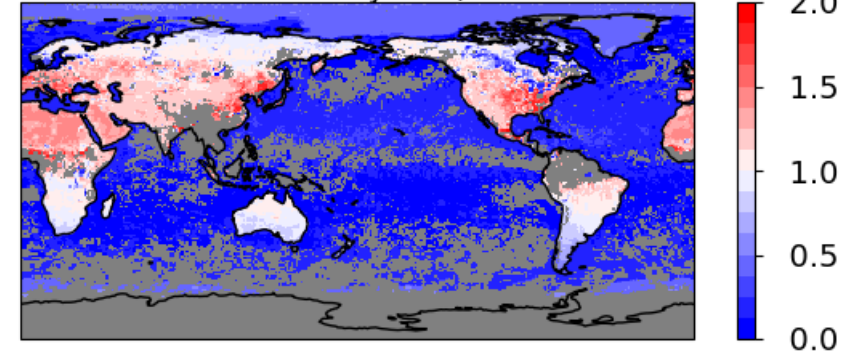
201407 NPP-FM5 VIS clrsky alb



201407 NPP-FM5 NIR clrsky alb



201407 NPP-FM5 clrsky Anir/Avis



## VIS > NIR

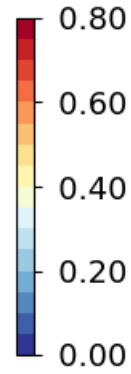
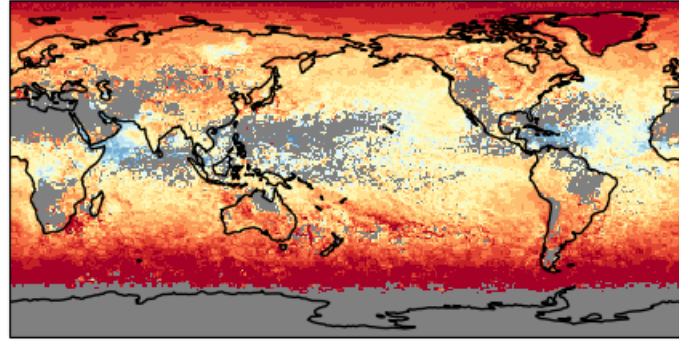
- **ocean**: high absorption by atmosphere and ocean water in the NIR spectral range
- **snow**: dominated by high reflectivity in the VIS spectral range and increased absorption in the NIR spectral range

## VIS < NIR

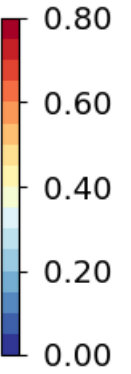
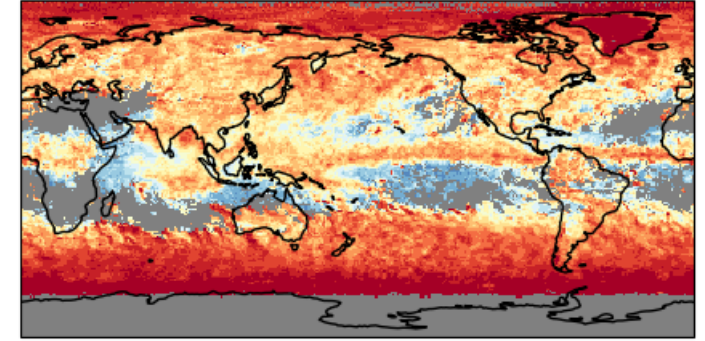
- **desert**: less absorption by dry atmosphere and higher reflectivity in the NIR spectral range.
- **vegetation**: high absorption in VIS spectral range for photosynthesis.

Overcast

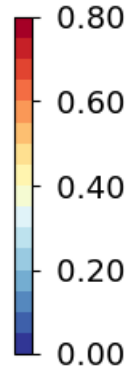
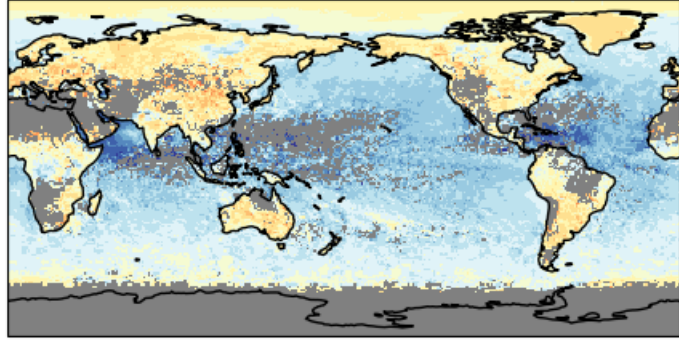
201407 NPP-FM5 VIS water ov alb



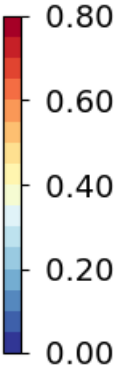
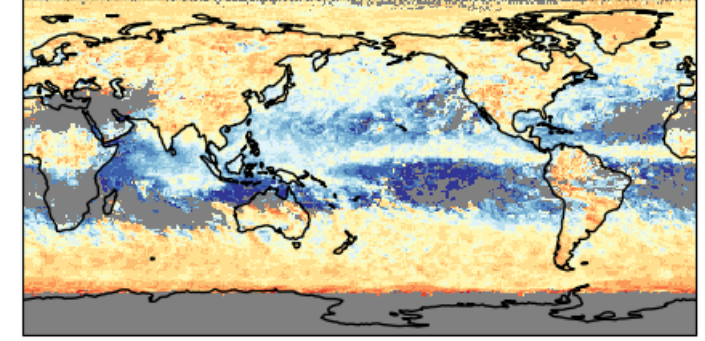
201407 NPP-FM5 VIS ice ov alb



201407 NPP-FM5 NIR water ov alb

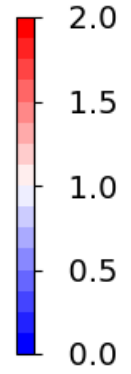
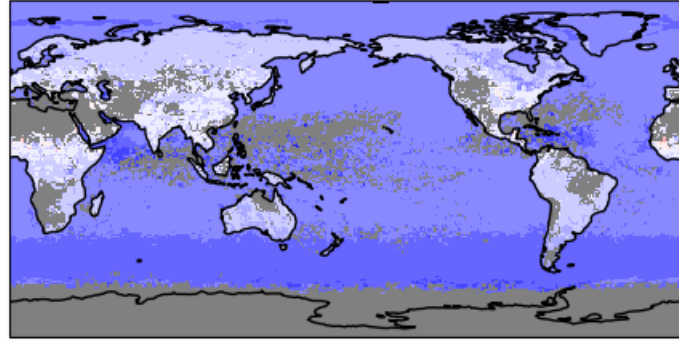


201407 NPP-FM5 NIR ice ov alb

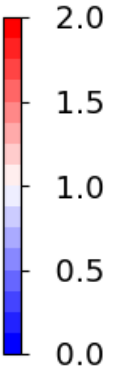
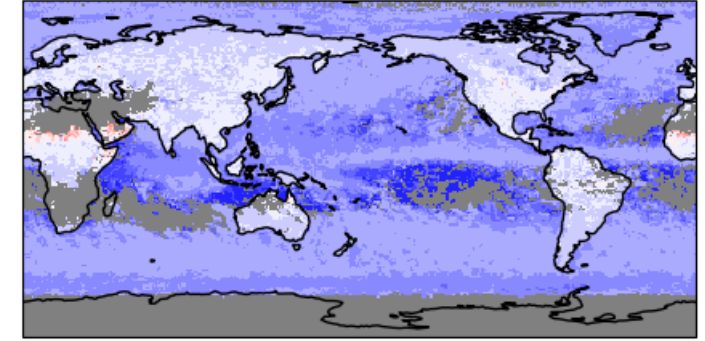


VIS > NIR: higher reflectivity of clouds in VIS than NIR range

201407 NPP-FM5 water ov Anir/Avis

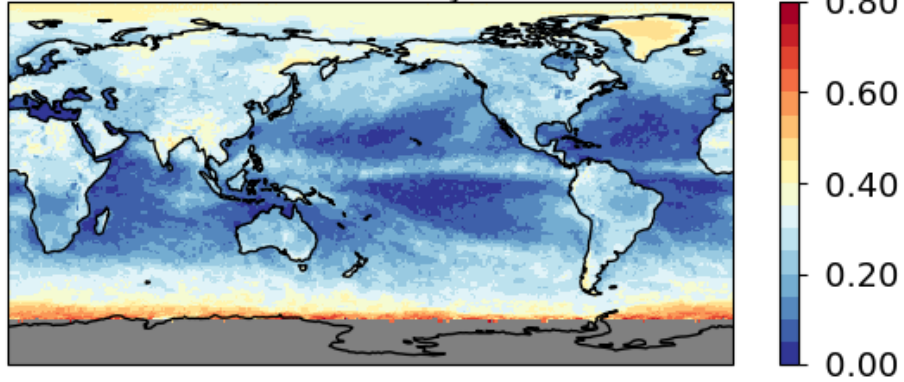


201407 NPP-FM5 ice ov Anir/Avis

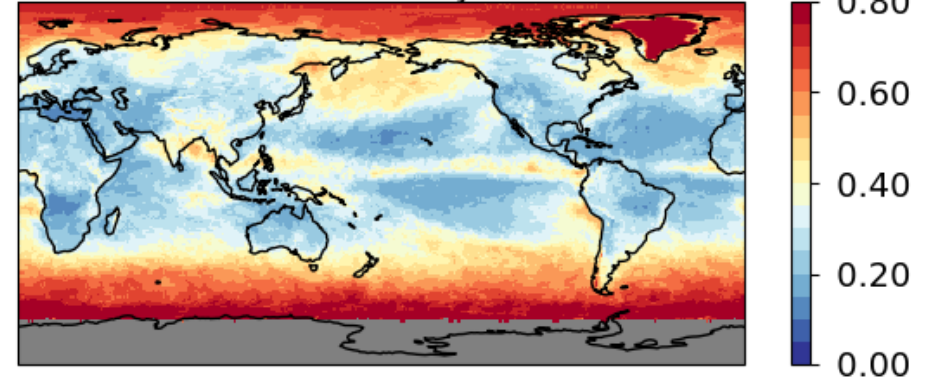


# Comparison to CERES SYN calculation

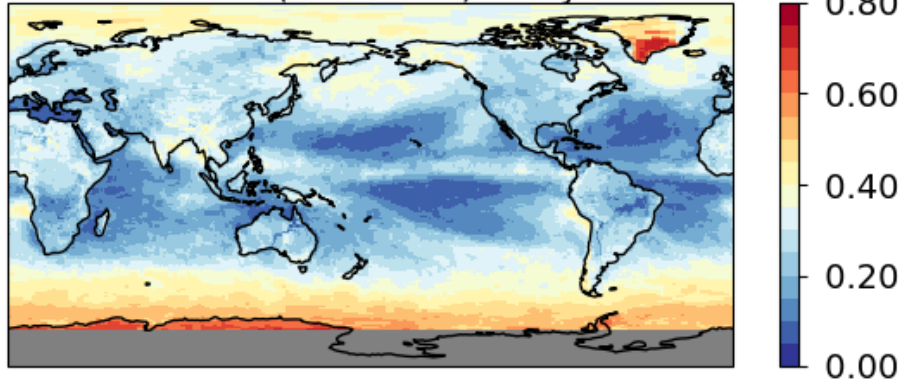
201407 NPP-FM5 NIR allsky alb



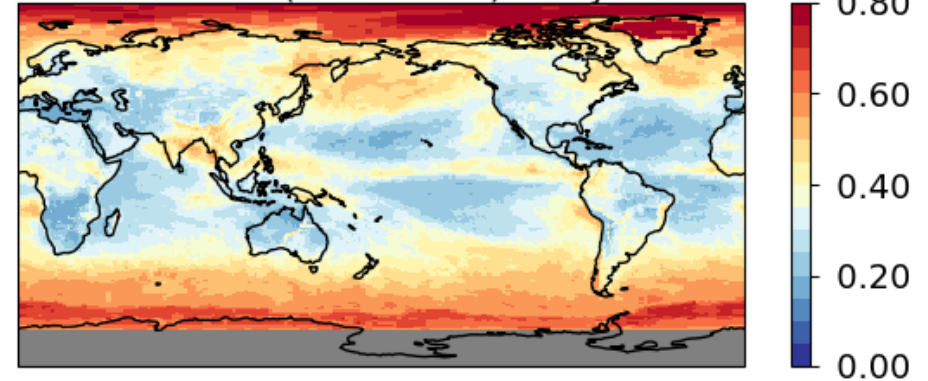
201407 NPP-FM5 VIS allsky alb



CERES SYN NIR (0.7-4.0um) allsky alb 201407



CERES SYN VIS (0.18-0.7um) allsky alb 201407



# 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.