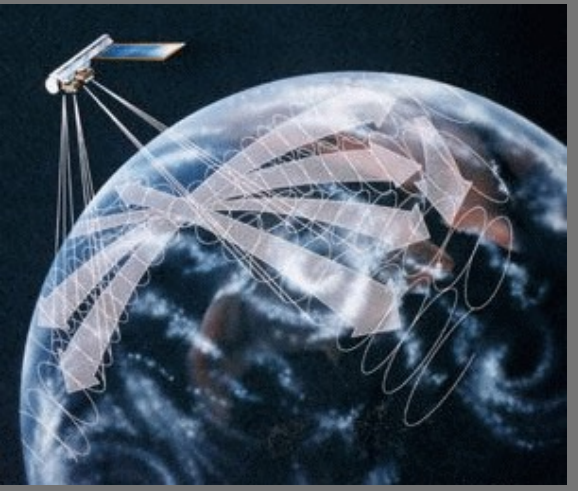


# CERES Angular Distribution Model Working Group Report


Lusheng Liang[1]

Lusheng.Liang@nasa.gov

Sergio Sejas[2] Zachary Eitzen[2]

1. Analytical Mechanics Associates, Inc., Hampton, VA
2. ADNET Systems, Inc., Hampton, VA



CERES Science Team Meeting, Oct 27-29, 2026
NASA Langley Research Center, Hampton, VA

# Outline

ADM Improvements in

- Clear-sky ADMs over ocean
- Cloudy-sky ADMs over ocean

Progress in LUT-approach for split-SW flux retrievals

# 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:

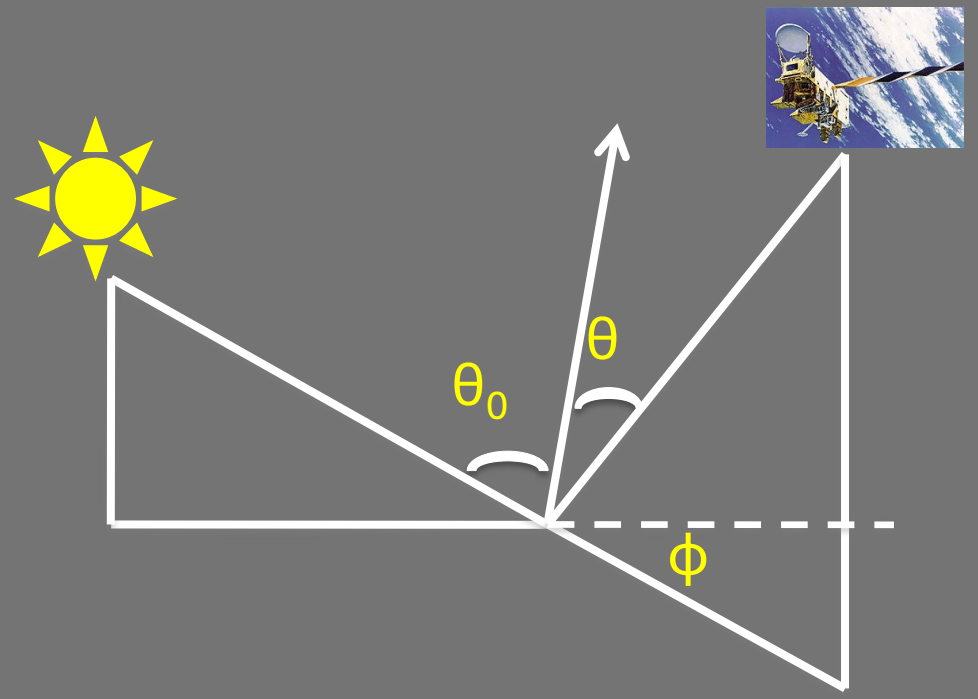
$$\hat{F}(\theta_o) = \int_0^{2\pi}\int_0^{\pi/2} \hat{I}(\theta_o,\theta,\emptyset)cos\theta sin\theta d\theta d\phi$$

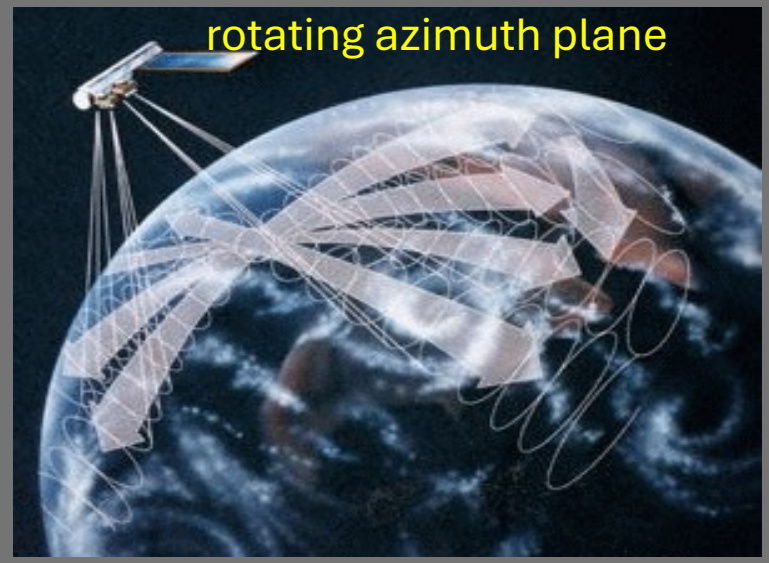
- Estimate the anisotropic factor for each scene type:

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

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

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



# Improvements in clear-sky ADMs over ocean

## Existing Ed4 SW clear-sky over ocean ADMs

- For imager observations outside sun glint regions
  The ADMs use 6 ocean wind speed bins, 2 aerosol types, and 3 AOD bins.
- For imager observations within sun glint regions:
  ADMs use 6 ocean wind speed bins, 1 type of aerosol, and 3 AOD bins.

## Ed4 algorithm

- AOD percentile approach is used to group observations. The thresholds for grouping is calculated with one year of AOD samples for each SZA bins.

## Ed5 improvements

- The AOD percentile thresholds for grouping can be calculated for both SZA and ocean wind speed bins.

- Conclusion: no substantial change in terms of flux retrievals.

# Jan

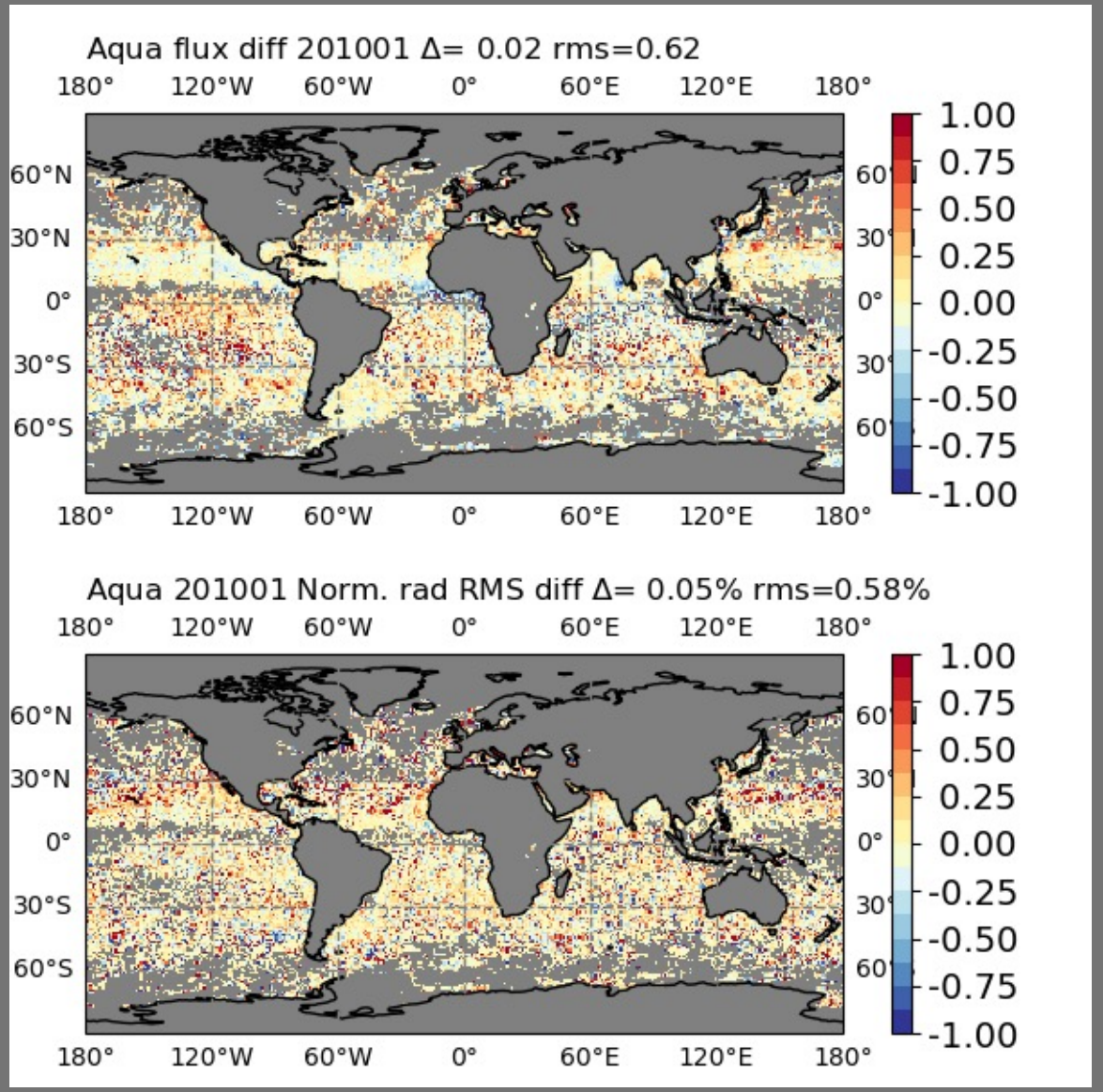
## Flux differences

AOD percentiles calculated for SZA-WS bins –
AOD percentiles calculated for SZA bins

## Normalized radiance RMS

AOD percentiles calculated for SZA-WS bins –
AOD percentiles calculated for SZA bins

$$\mathrm{rms} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\bar{\hat{I}}} - \frac{I_j^{\mathrm{o}}}{\bar{I}^{\mathrm{o}}}\right)^2}.$$




Ed5 will calculate the AOD percentile thresholds for SZA-WS bins to be consistent with ADM binning scheme.

# Jul

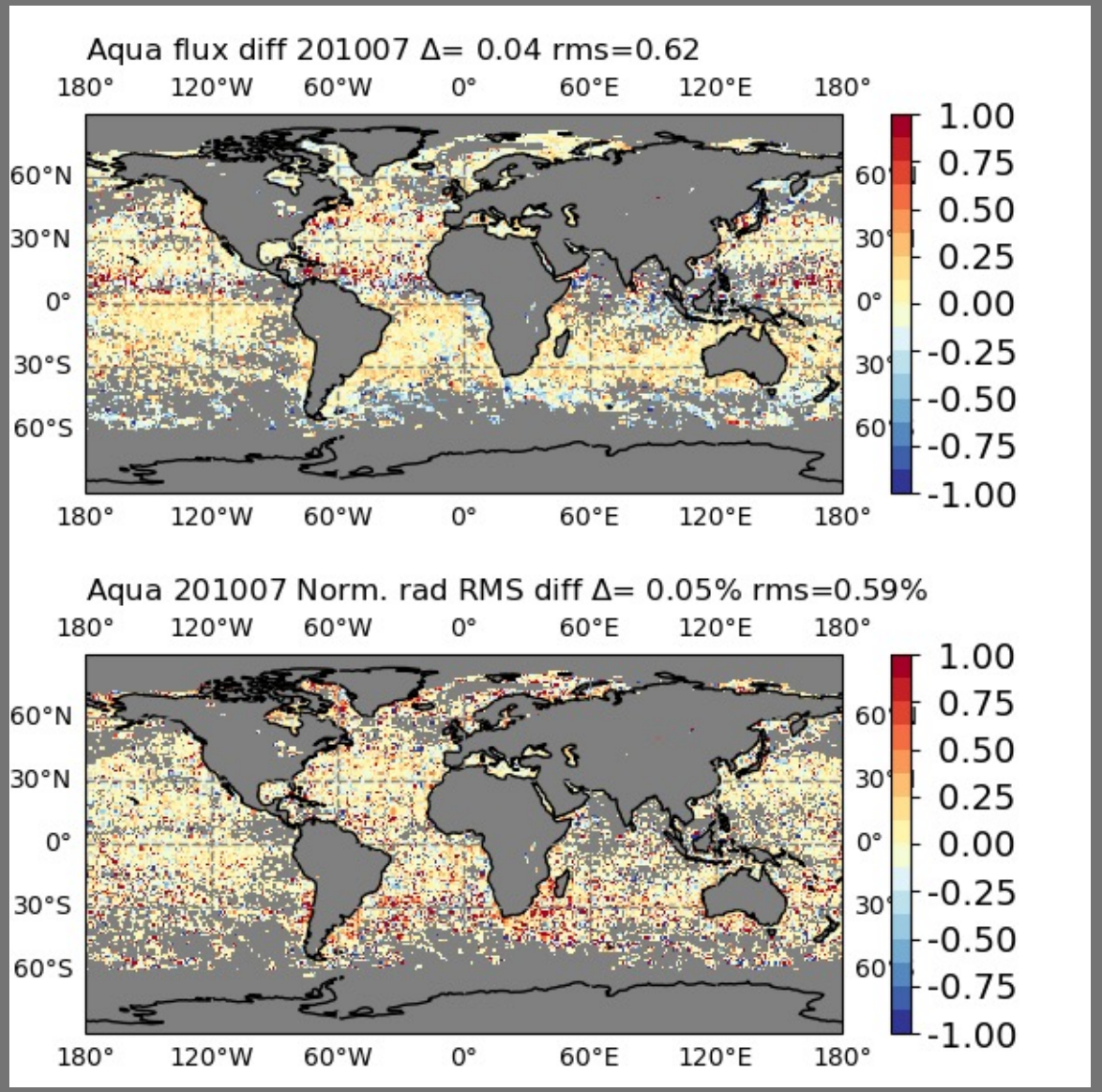
## Flux differences

AOD percentiles calculated for SZA-WS bins –
AOD percentiles calculated for SZA bins

## Normalized radiance RMS

AOD percentiles calculated for SZA-WS bins –
AOD percentiles calculated for SZA bins

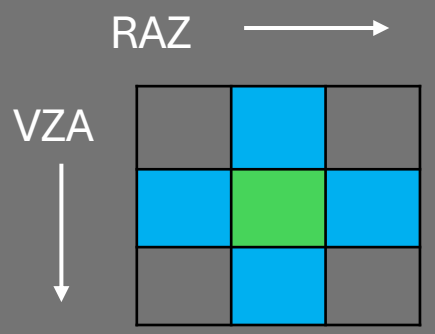
$$\mathrm{rms} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\bar{\hat{I}}} - \frac{I_j^{\mathrm{o}}}{\bar{I}^{\mathrm{o}}}\right)^2}.$$




Ed5 will calculate the AOD percentile thresholds for SZA-WS bins to be consistent with ADM binning scheme.

# Quantification of ADM viewing angular variation

Outside of the sun-glint regions, the mean radiances should vary smoothly with VZA or RAZ if the radiances are well sampled.



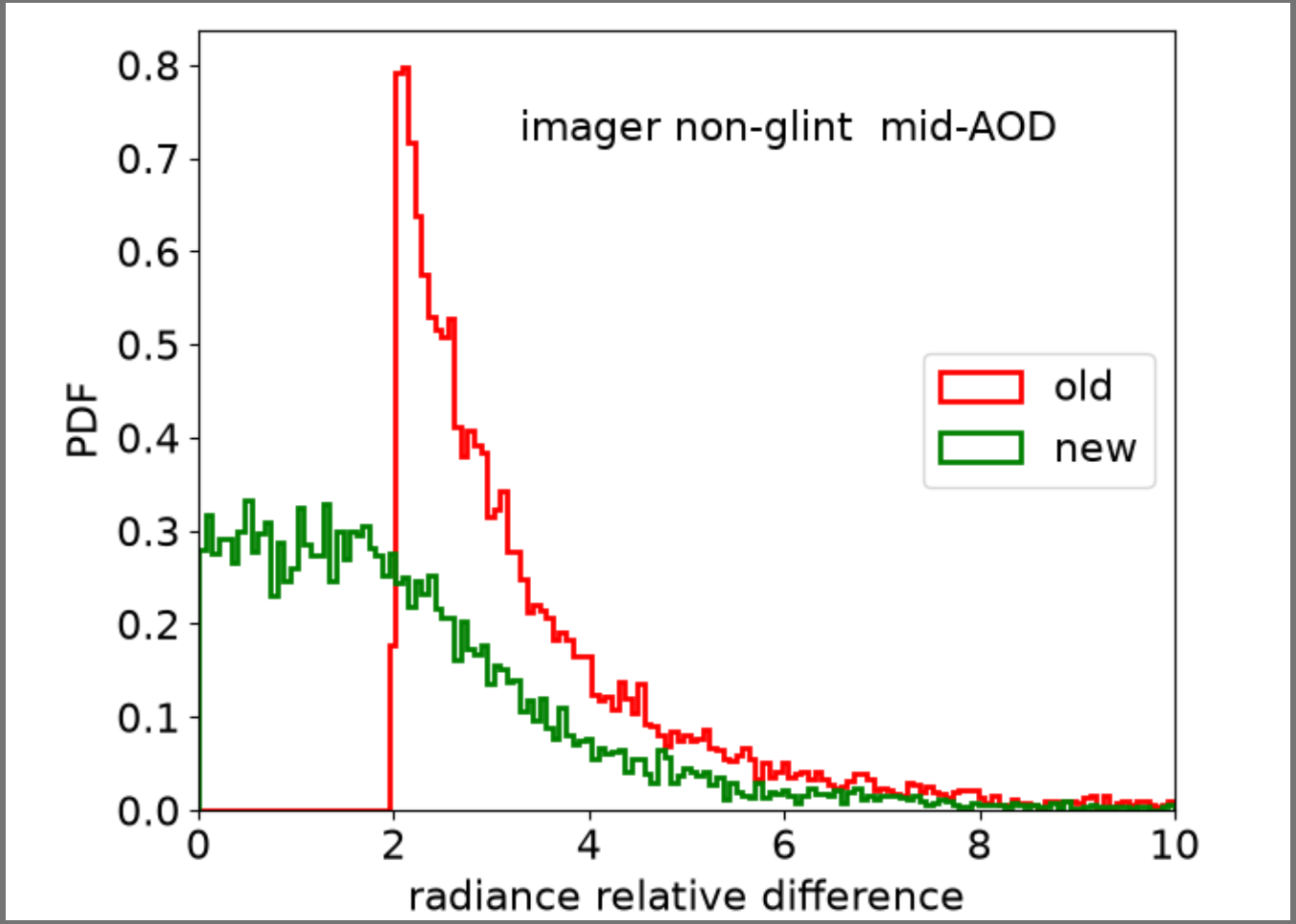

For a given viewing angle bin, define a variable to quantify the radiance variability around its neighboring bins:

- Collect radiances all 4 neighbor bins
- Calculate relative difference between the radiance of center bin to the mean radiance of its neighboring bins

$$\text{reldiff}=\frac{abs(I_{center}-\overline{I_{neighbor}})}{\overline{I_{neighbor}}}\text{x}100\%$$

# Reducing ADM viewing angular variation

For every viewing angular bin with a reldiff > **2%**, add additional observations from the orbital drifting period if the final total number of samples > **10**.

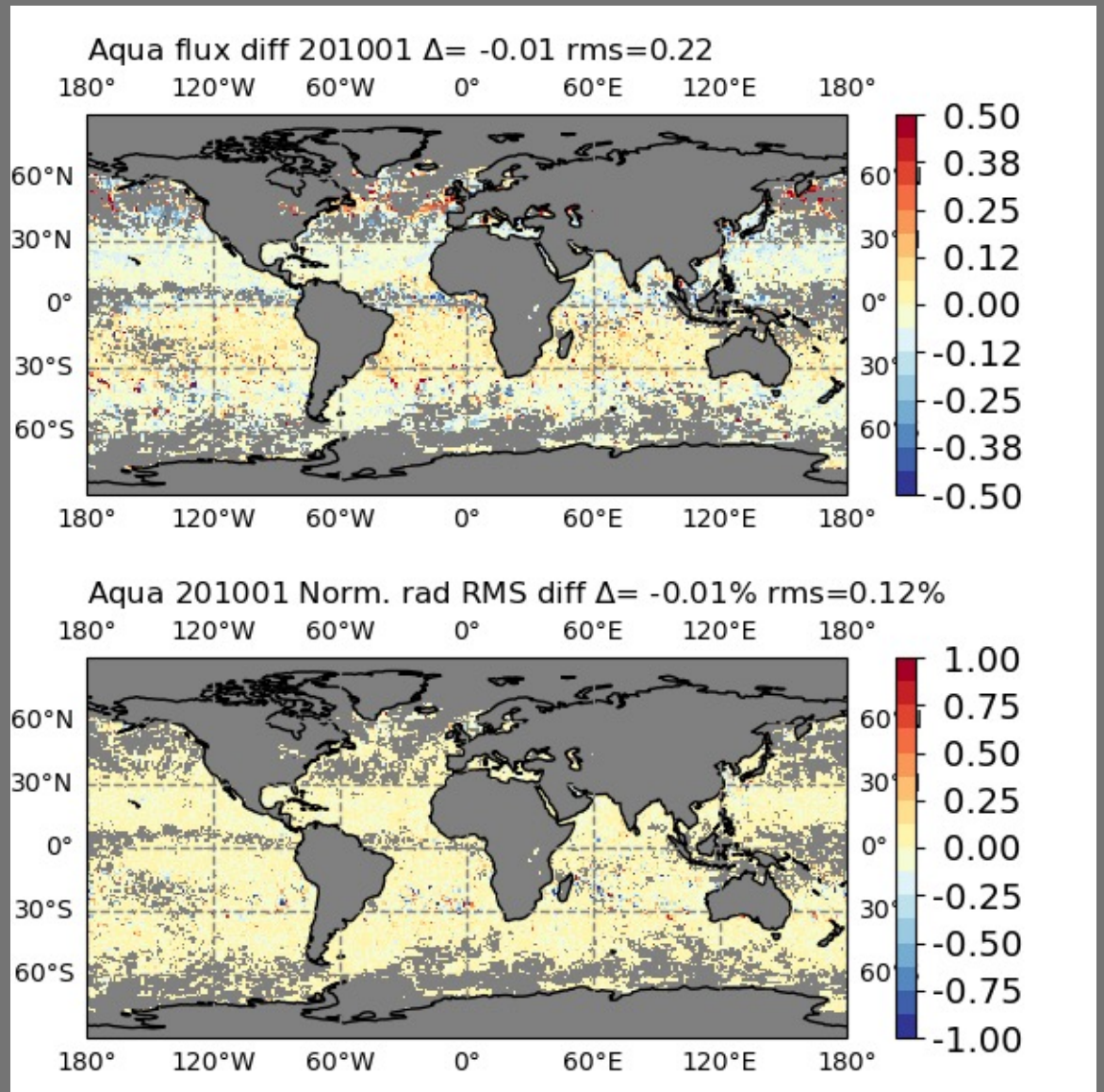



| Percent of angular bins are added with additional observation | | | |
|---|---|---|---|
| Imager within sun-glint | coarse model aerosol | Low-AOD | 9.3 |
| | | Mid-AOD | 9.5 |
| | | High-AOD | 20.9 |
| Imager outside sun-glint | coarse model aerosol | Low-AOD | 6.1 |
| | | Mid-AOD | 4.6 |
| | | High-AOD | 7.4 |
| | Fine model | Low-AOD | 8.0 |
| | | Mid-AOD | 15.9 |
| | | High-AOD | 17.9 |

~ 5% to 20% bins are added with additional observations from the orbital drifting period.

# Reducing ADM viewing angular variation

For every viewing angular bin with a reldiff > **2%**, add additional observations from the orbital drifting period if the final total number of samples > **10**.




$$\mathrm{rms} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\bar{\hat{I}}} - \frac{I_j^{\mathrm{o}}}{\bar{I}^{\mathrm{o}}}\right)^2}.$$

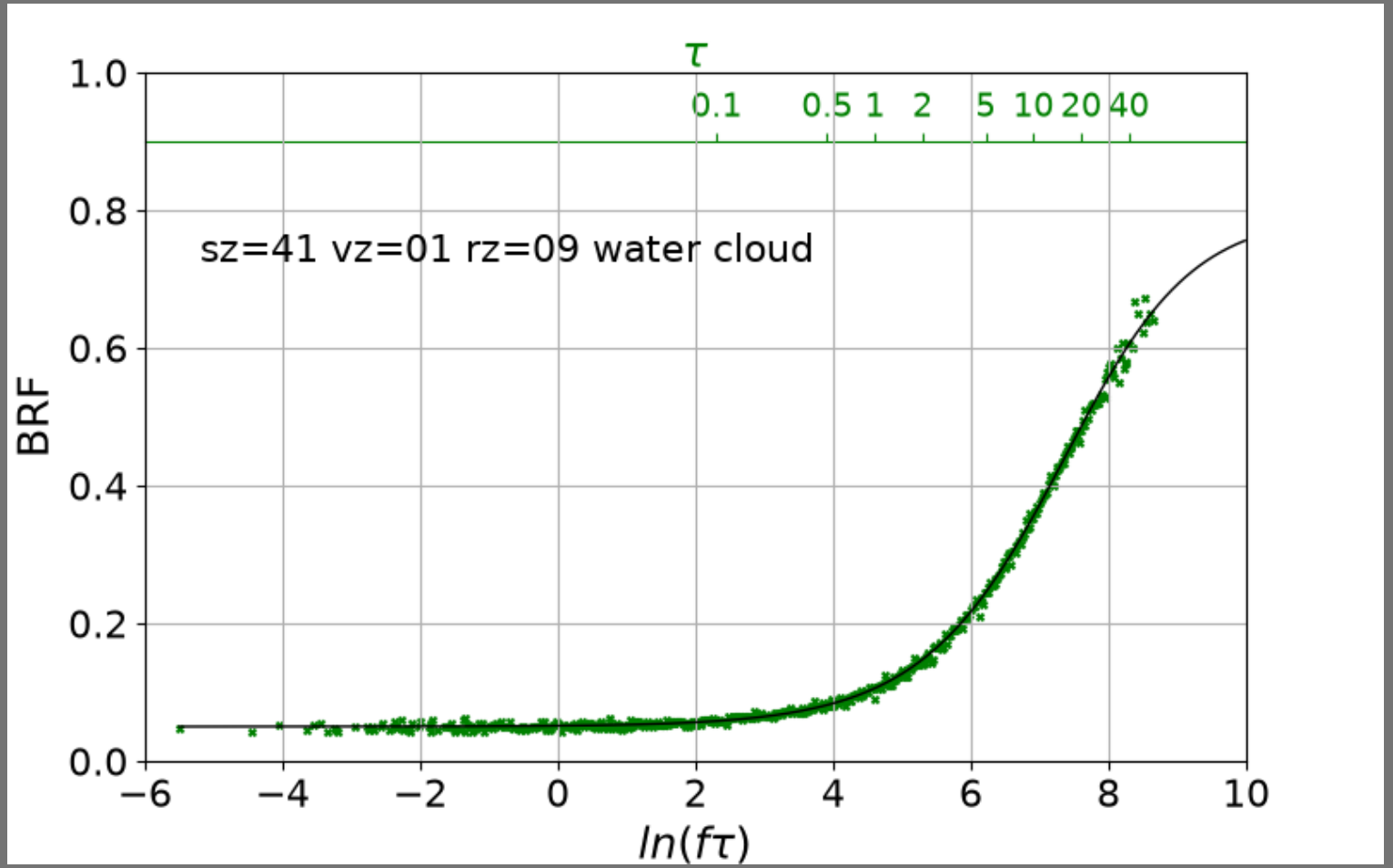
# Improvements in cloudy-sky ADMs over ocean

# Cloud ADM over ocean

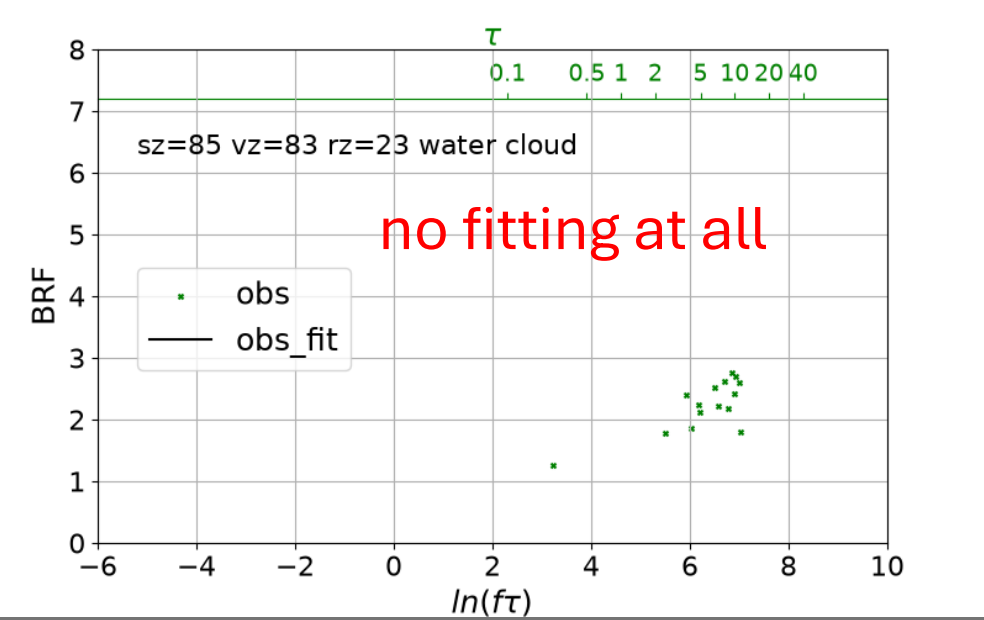
In an angular bin $(\theta_0, \theta, \emptyset)$,

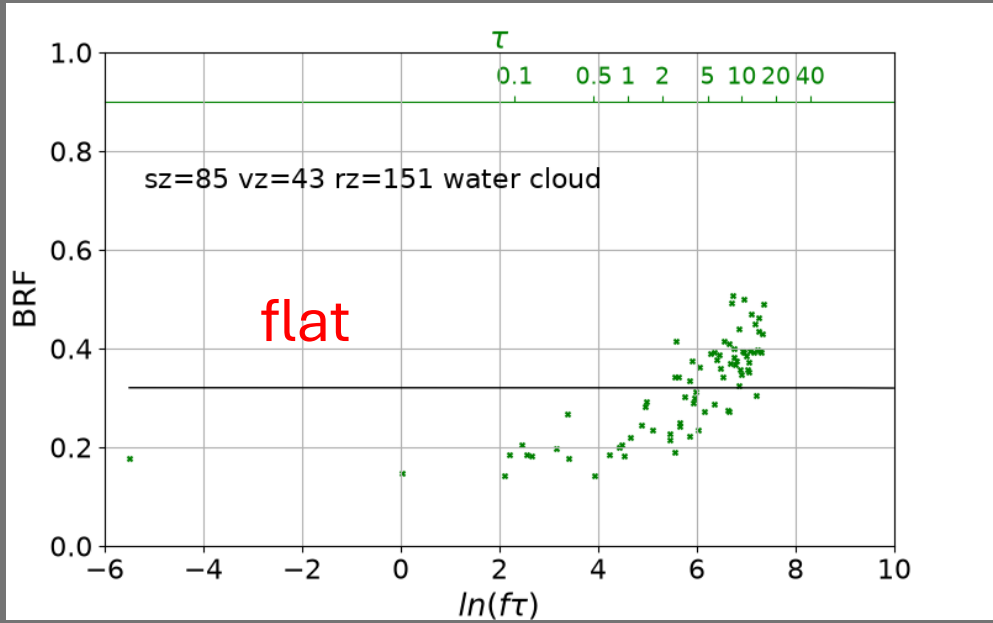
- collect CERES radiances in each ln(f$\tau$) bin, where f is cloud fraction and $\tau$ is the optical depth.
- A 5-parameter sigmoidal fit is used to describe the relationship between mean radiances and ln(f$\tau$).
- The radiances for ADM construction are evaluated by the fitting.

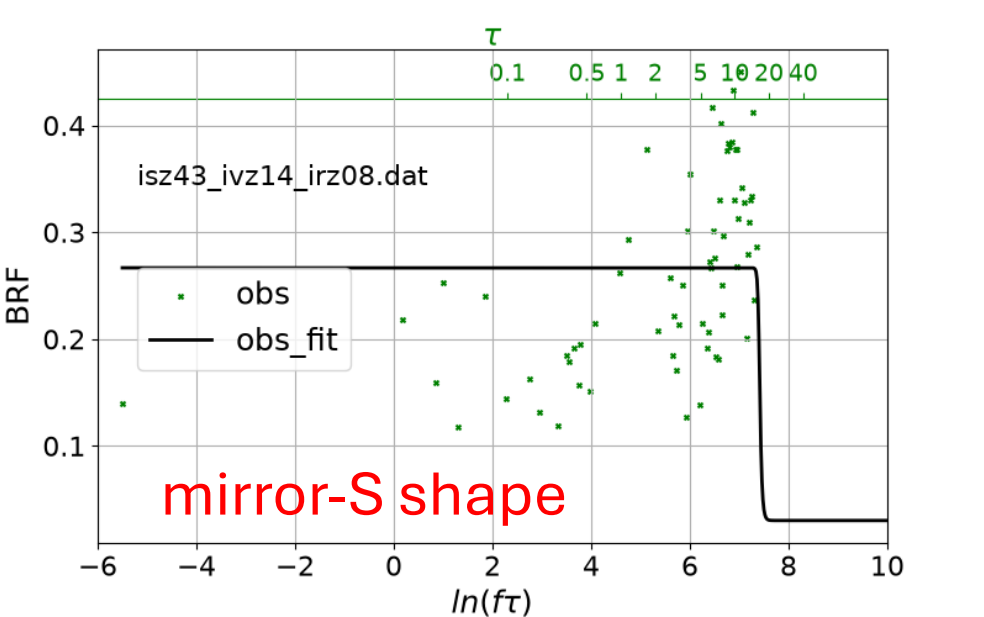
$$I = I_0 + \frac{a}{\left[1 + e^{-(x-x_0)/b}\right]^c},$$

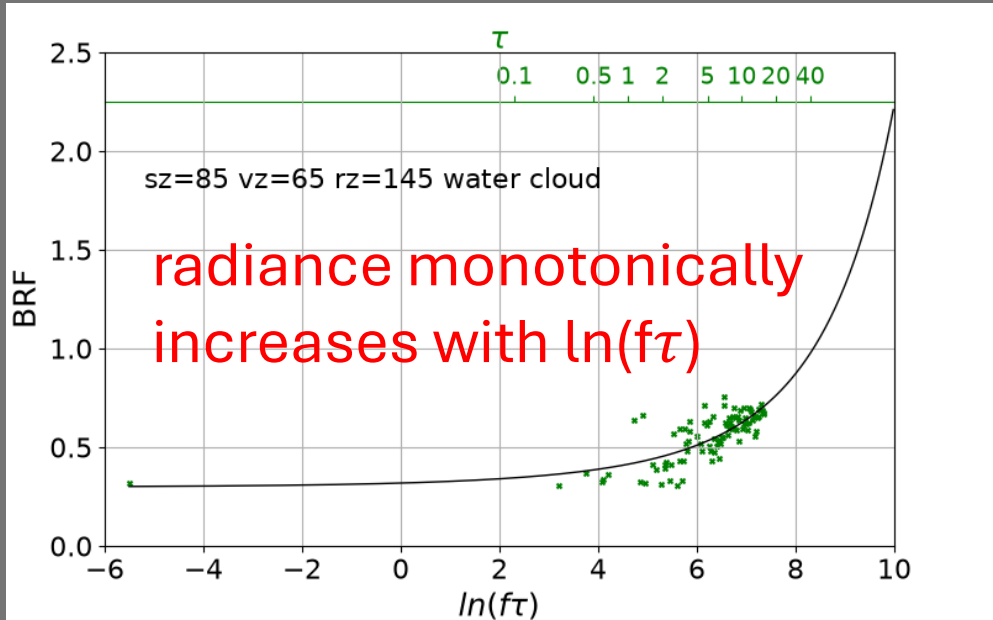


# Unstable fittings when radiances are not well sampled



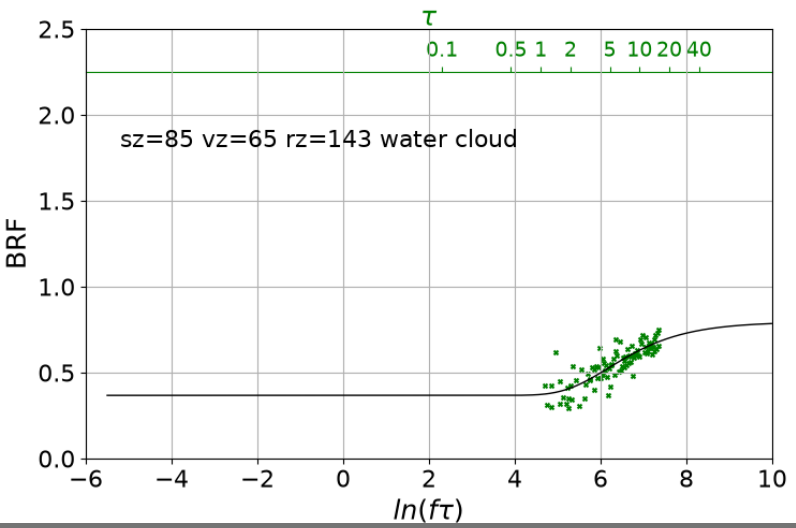



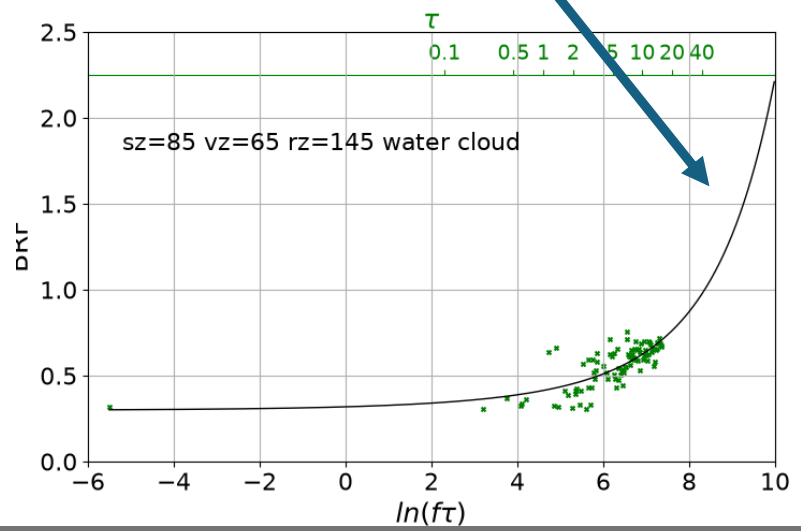



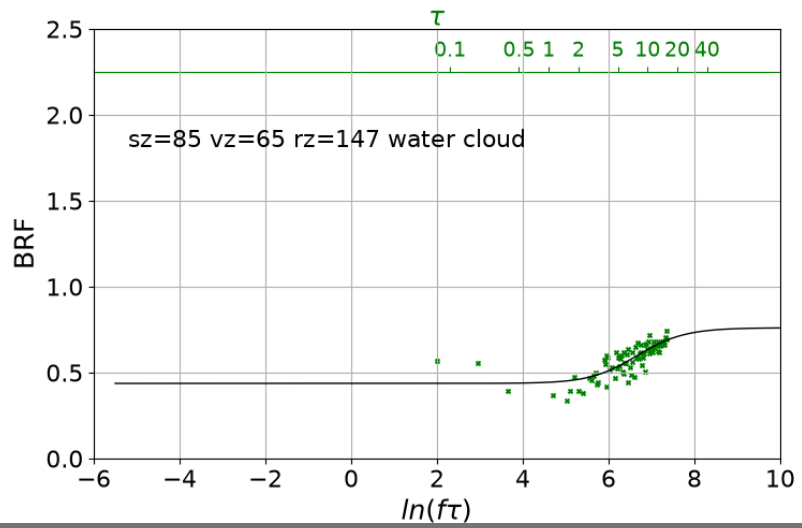



# Example of a fitting that radiance monotonically increases with ln(f$\tau$)

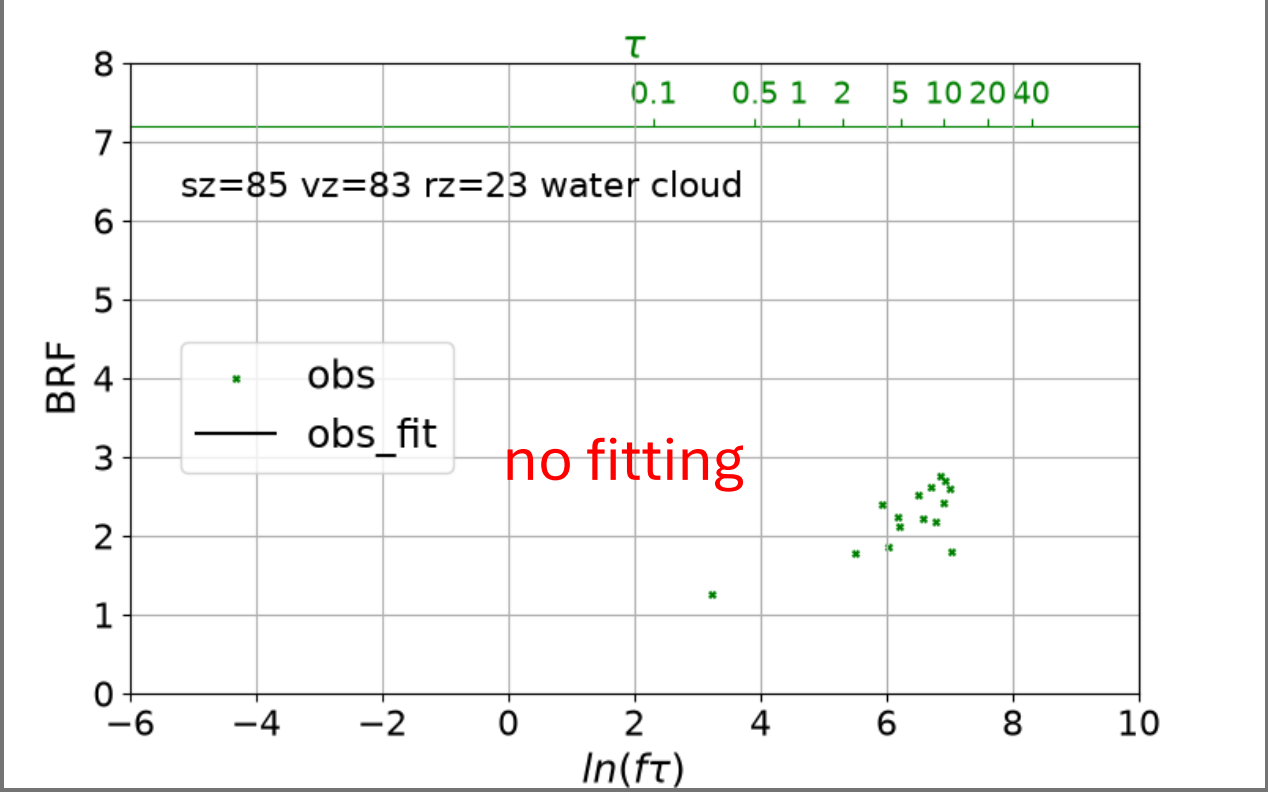
the fitting is not reasonable

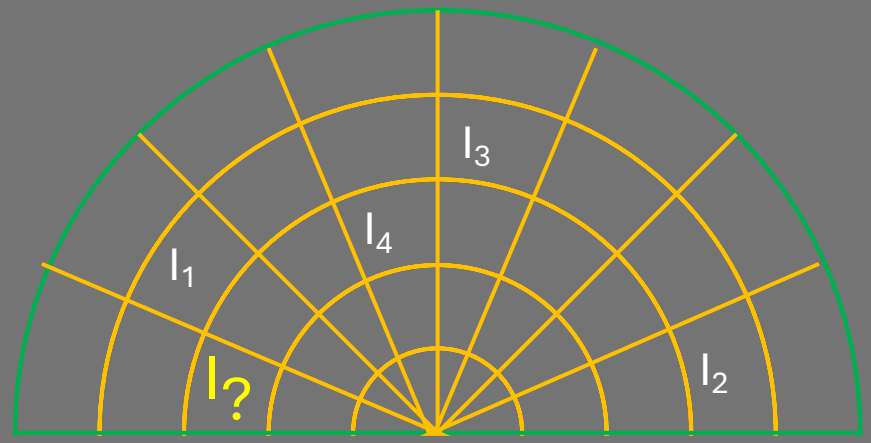


# Ed4 filling algorithm

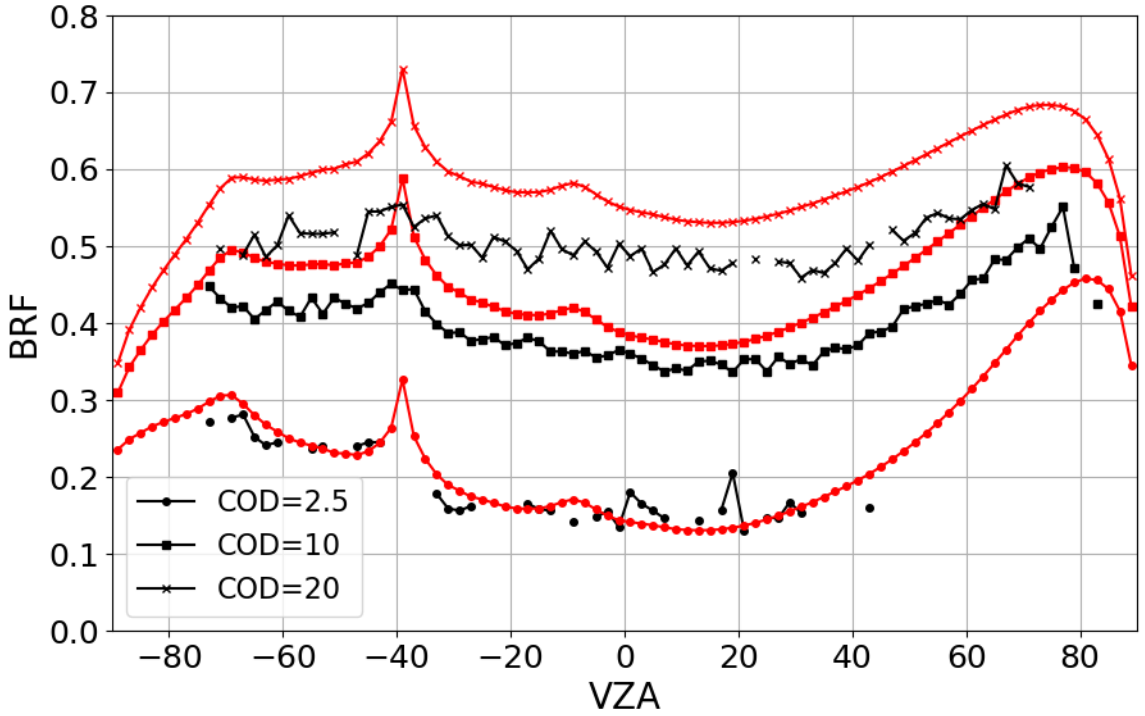



In a given angular bin, the radiance ($I_?$) in a ln(f$\tau$) bin was predicted by observed radiances in other viewing angles ($I_1$, $I_2$, $I_3$, and $I_4$) and simulated radiances.

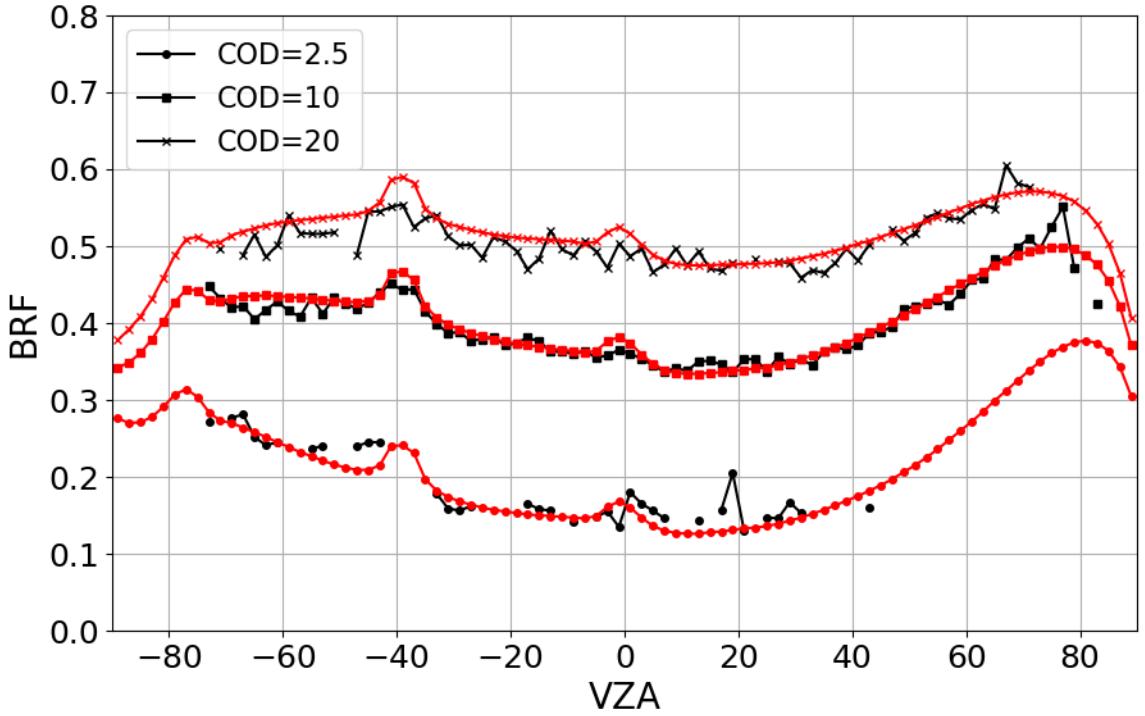
# Model compares to Ed4 observations: Water

## Nakajima model simulation (used for Ed4)




rstar4b code, one of varieties of discrete ordinate approach with special handling to truncate phase function for secondary or higher order of scattering. Tropical atmospheric profile with 50 layers. 38 bands within 0.2 to 5 um. 10 streams. Lowtran 7.

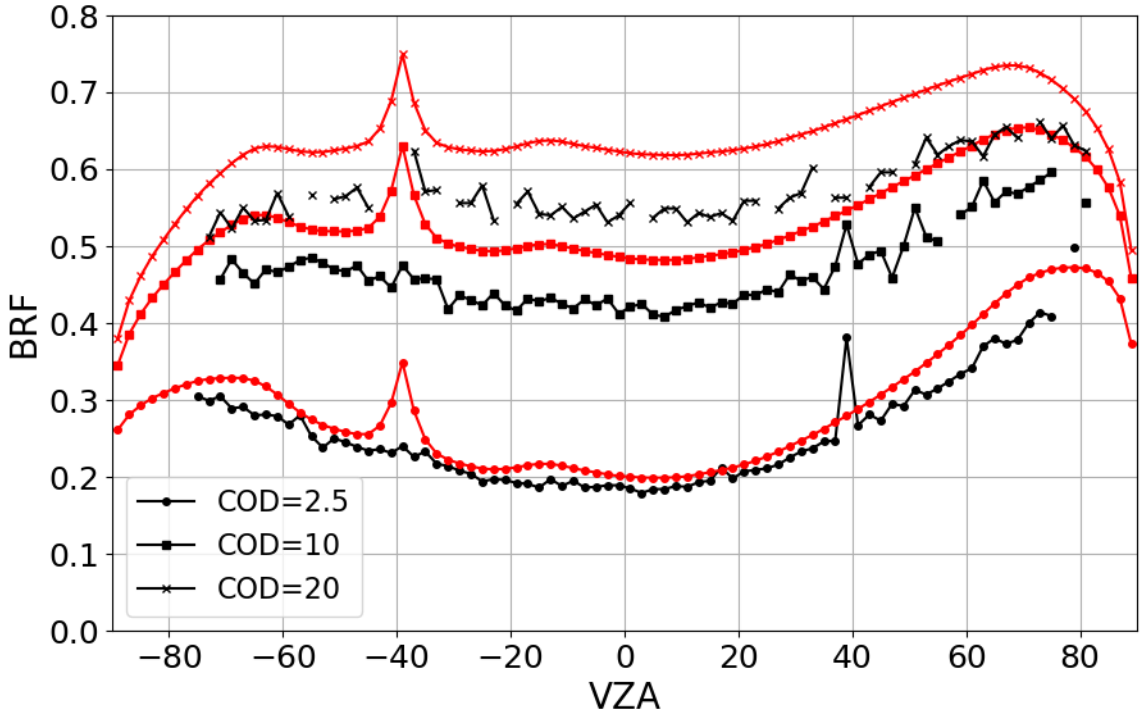
## DISORT simulation




Tropical atmospheric profile. 10 wavenumbers/cm from 0.2 to 5 um. HITRAN (2012). 16 streams for water clouds. Cox-Munk ocean surface model with wind speed of 7 m/s. Clouds placed at 500 to 1000 m with an effective diameter of 20um.

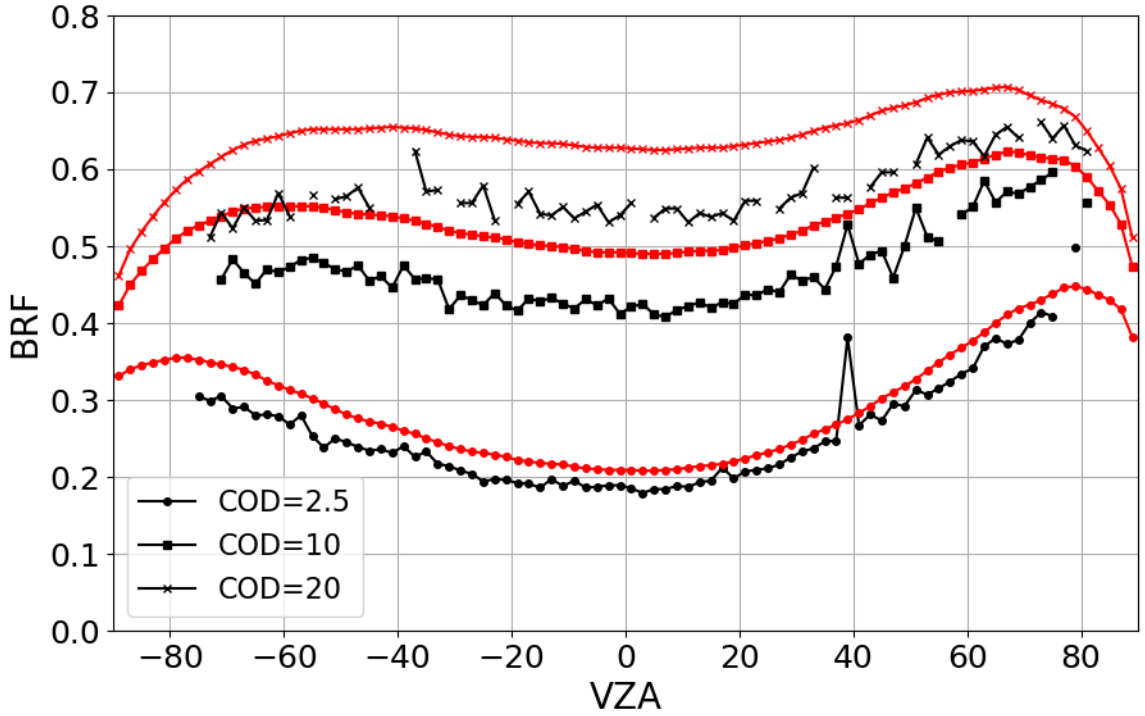
# Model compares to Ed4 observations: ICE

## Nakajima model simulation (used for Ed4)



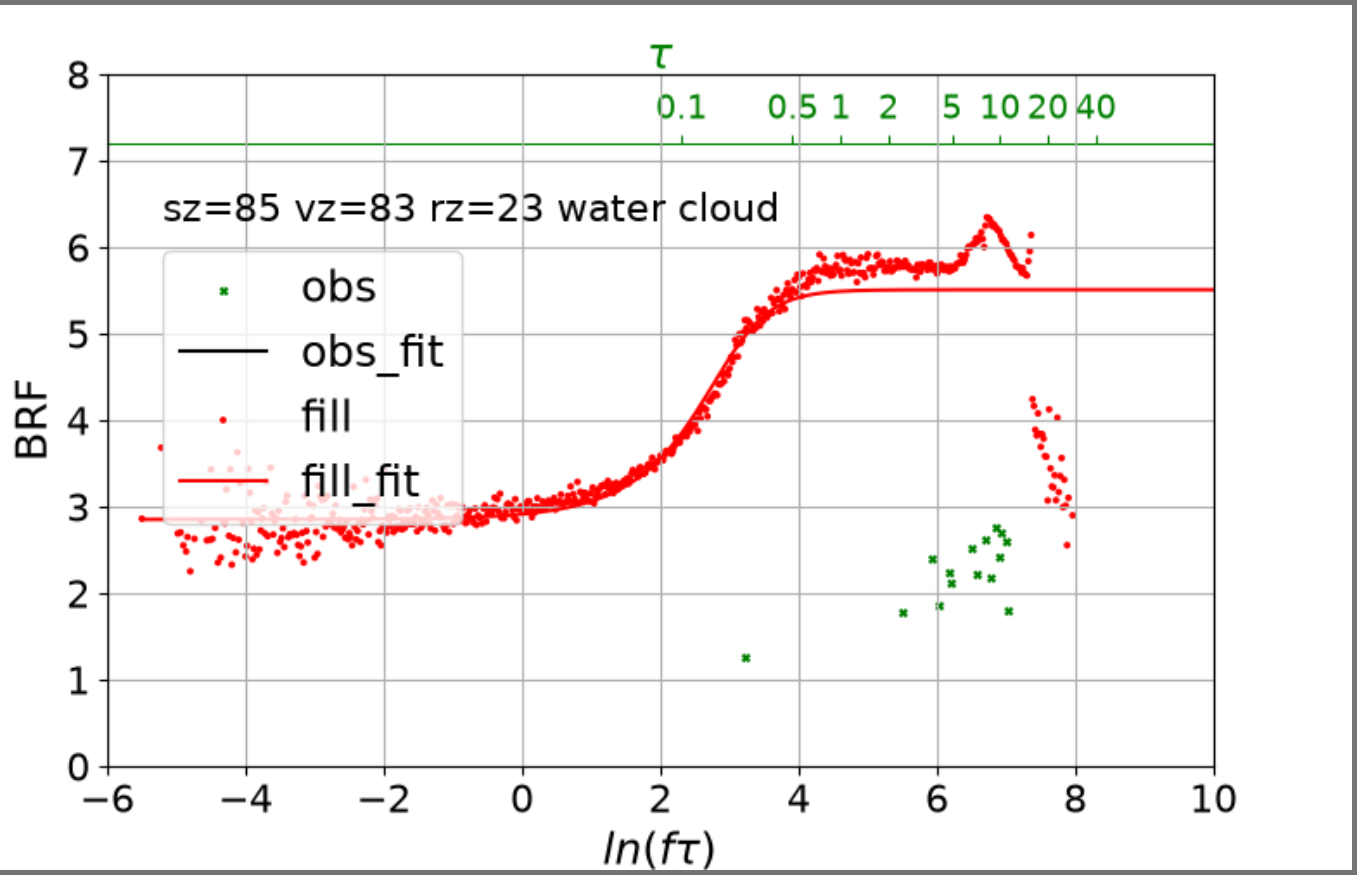

rstar4b code, one of varieties of discrete ordinate approach with special handling to truncate phase function for secondary or higher order of scattering. Tropical atmospheric profile with 50 layers. 38 bands within 0.2 to 5 um. 10 streams. Lowtran 7. FIRE-II Field campaign ice scattering properties (2nd ISCCP Regional Experiment, 1991)

## DISORT simulation

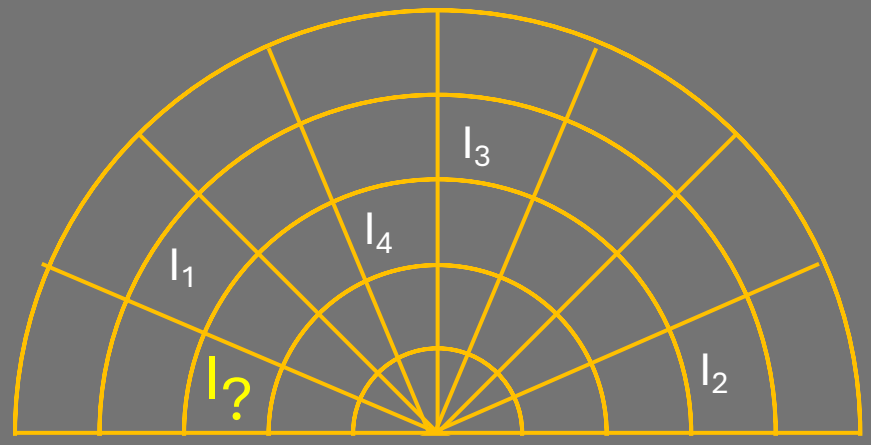



Tropical atmospheric profile. 10 wavenumbers/cm from 0.2 to 5 um. HITRAN (2012). 32 streams for ice clouds. Cox-Munk ocean surface model with wind speed of 7 m/s. Clouds placed at 7000 to 9000 m with an effective diameter of 46.34um (two habit model, PY, 2022)

# Ed4 filling algorithm
# With Nakajima model simulations

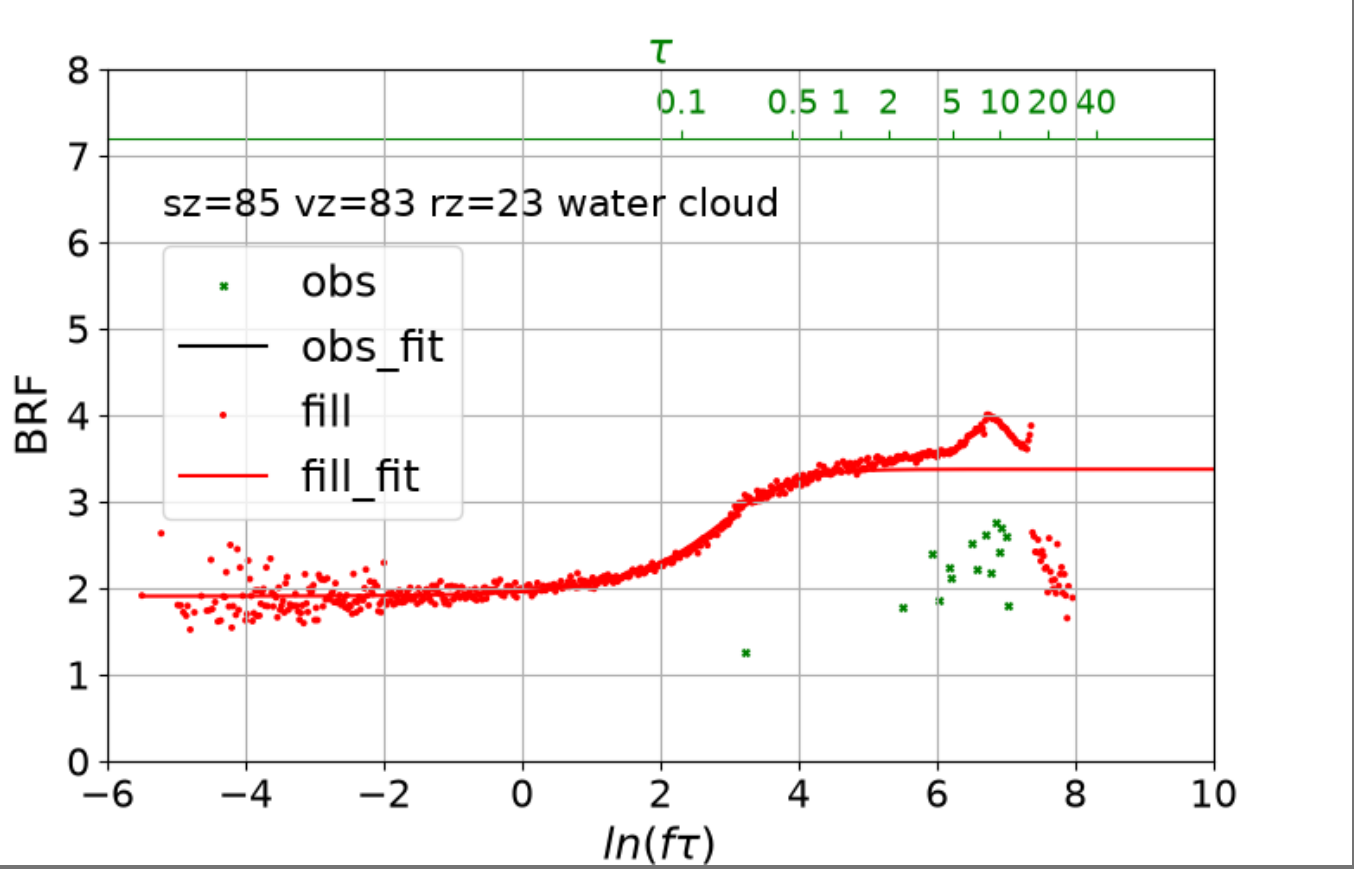



Simulation was selected directly by ln(fτ) value

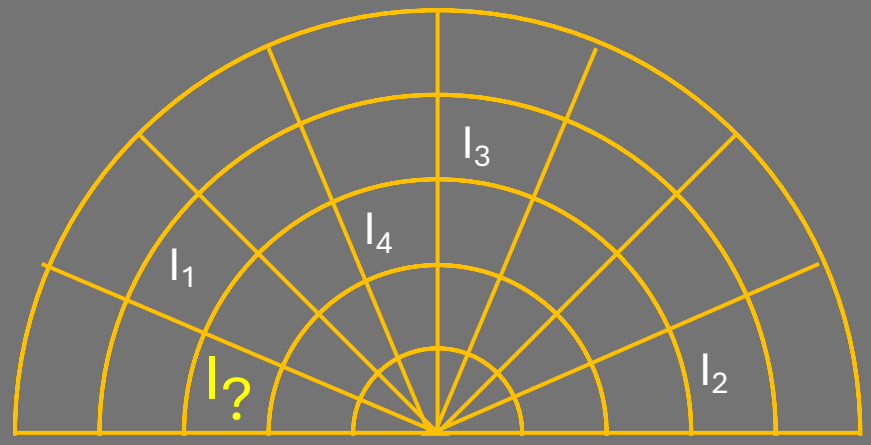



In a given angular bin, the radiance ($I_?$) in a ln(fτ) bin was predicted by observed radiances in other viewing angles ($I_1$, $I_2$, $I_3$, and $I_4$) and simulated radiances.

# Ed4 filling algorithm
# With DISORT model simulations

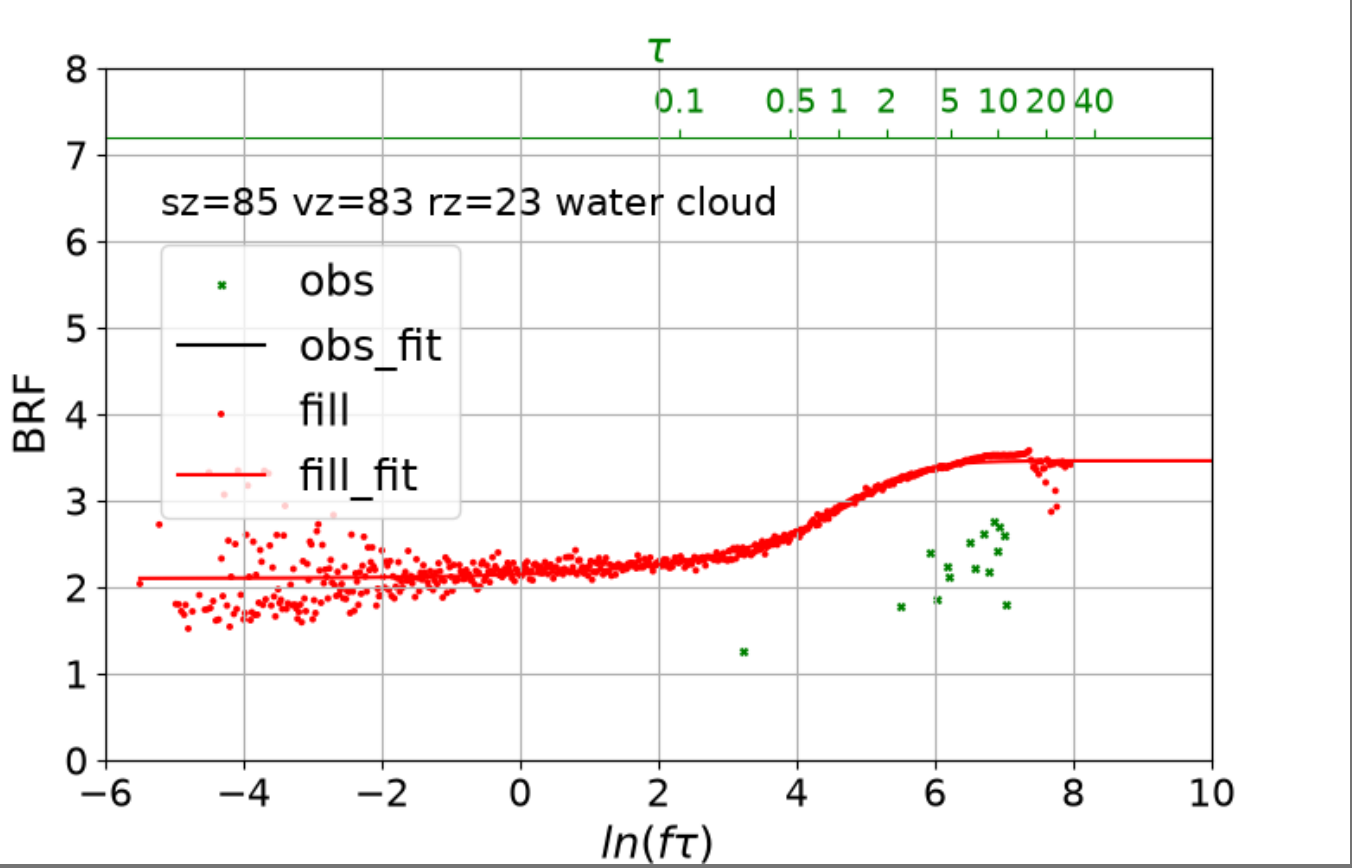



Simulation was selected directly by ln(fτ) value

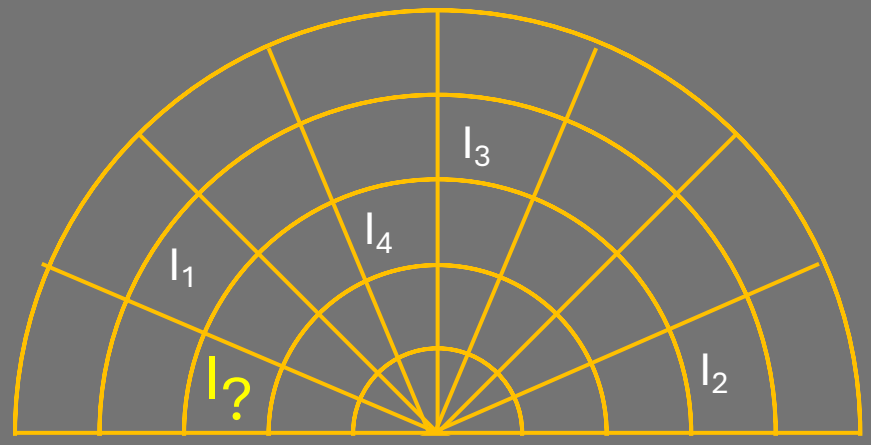



In a given angular bin, the radiance ($I_?$) in a ln(fτ) bin was predicted by observed radiances in other viewing angles ($I_1$, $I_2$, $I_3$, and $I_4$) and simulated radiances.

# New filling algorithm
# With DISORT simulations

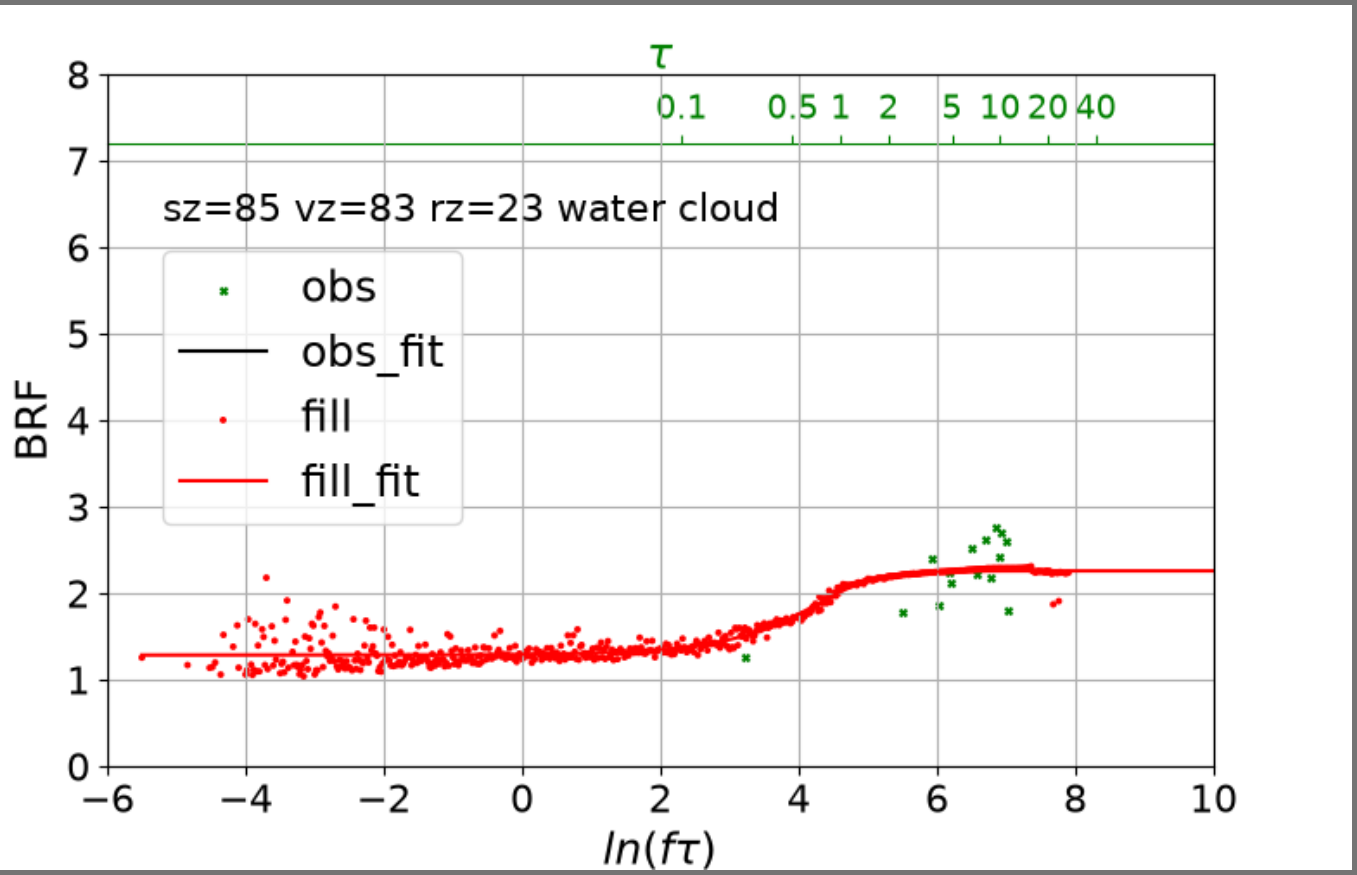



Simulation was selected by matching simulated radiances to observations, not directly by ln(fτ) value.

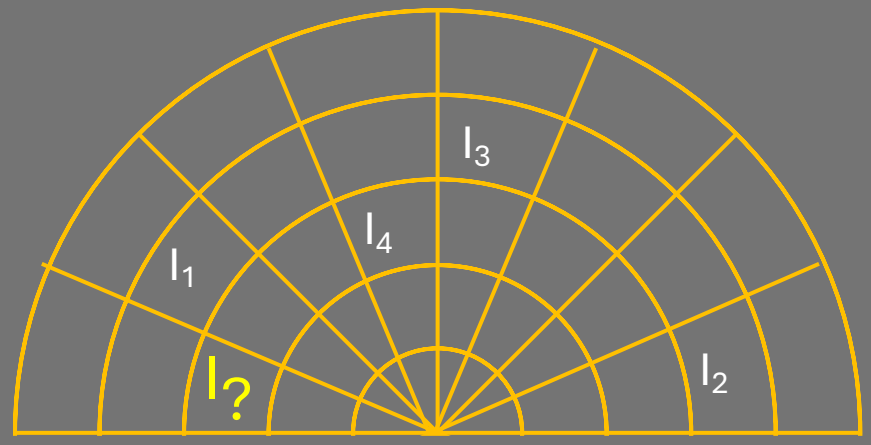



In a given angular bin, the radiance ($I_?$) in a ln(fτ) bin was predicted by observed radiances in other viewing angles ($I_1$, $I_2$, $I_3$, and $I_4$) and simulated radiances.

# New filling algorithm
# With DISORT simulations

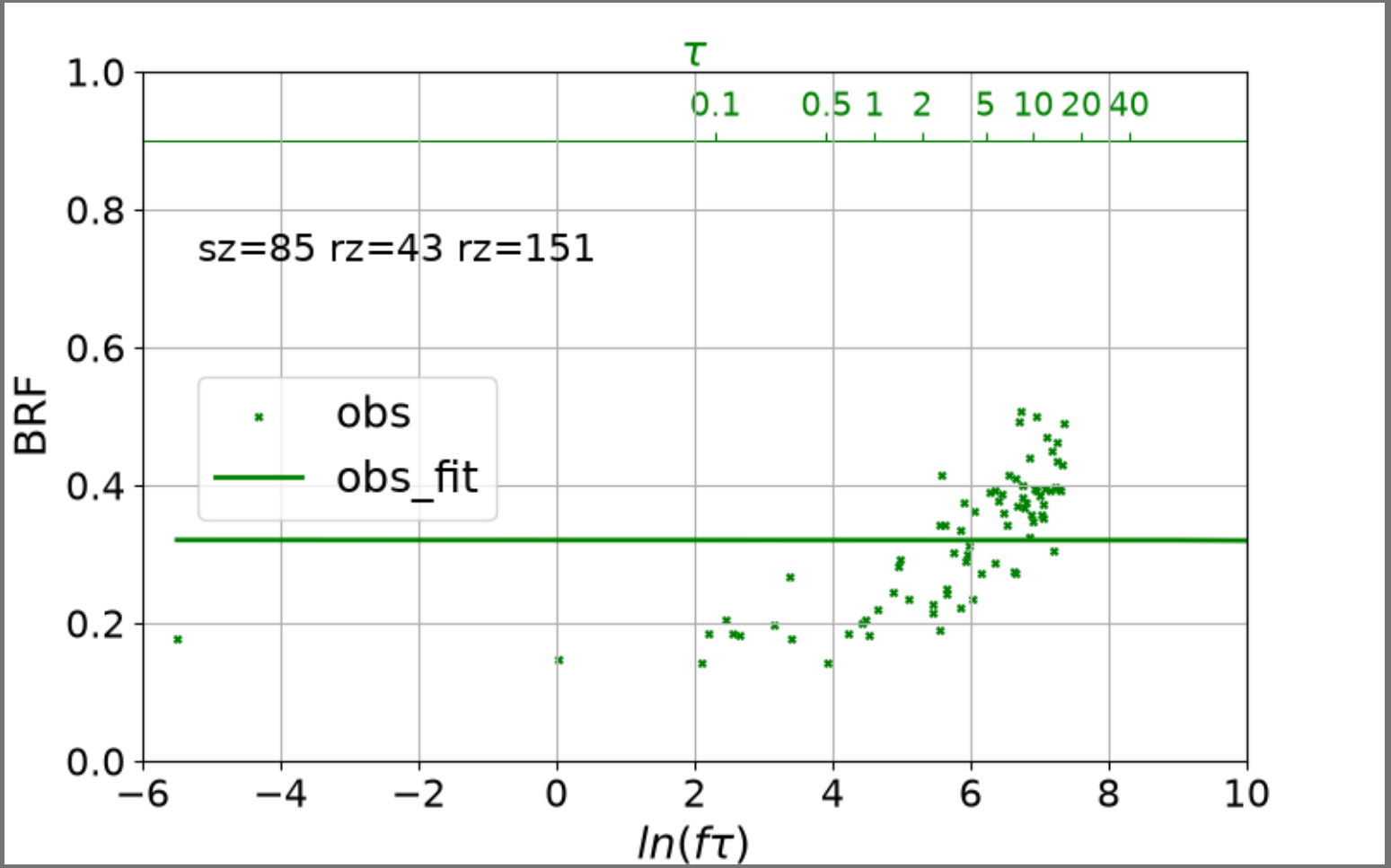



Simulation was selected by matching simulated radiances to observations.
Predicted radiances are further scaled by all valid radiances (green points).




In a given angular bin, the radiance ($I_?$) in a ln(f$\tau$) bin was predicted by observed radiances in other viewing angles ($I_1$, $I_2$, $I_3$, and $I_4$) and simulated radiances.

# flat fit fix




$$y = y_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

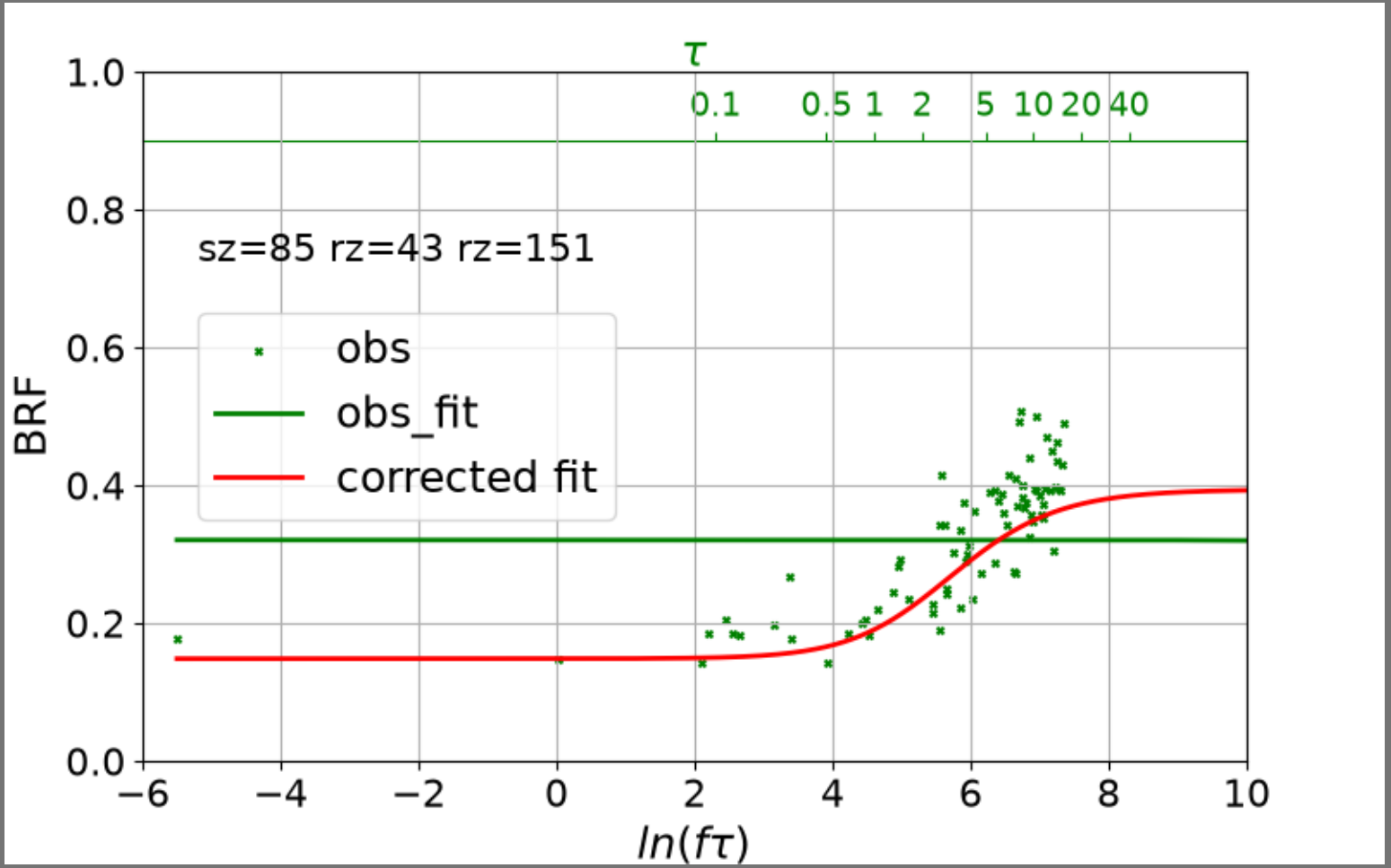
In the sigmoidal fitting, parameter “a” has a physical meaning to characterize the S-shape curve height. The resulted fitting could have a negative “a”.

One of solutions is to perform the fitting

$$y = y_0 + \frac{a^2}{[1 + e^{-(x-x_0)/b}]^c}$$

and report ”$a^2$” to replace “a”.

# flat fit fix




$$y = y_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

In the sigmoidal fitting, parameter “a” has a physical meaning to characterize the S-shape curve height. The resulted fitting could have a negative “a”.

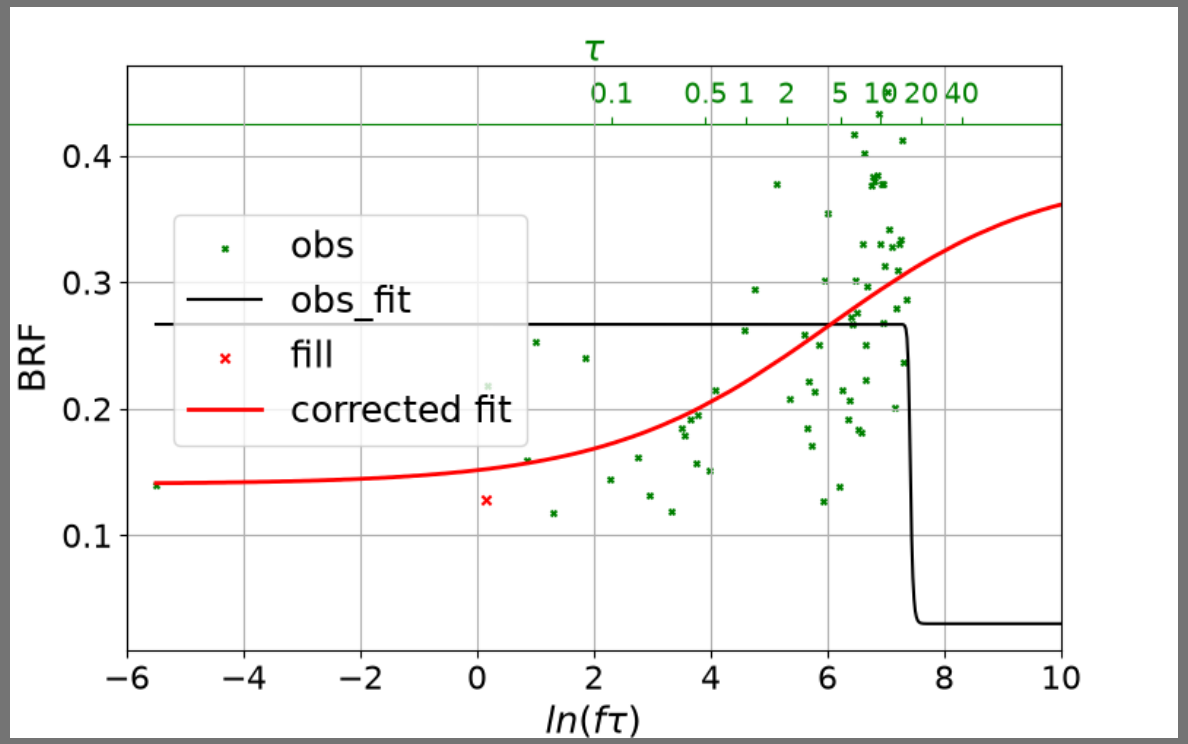
One of solutions is to perform the fitting

$$y = y_0 + \frac{a^2}{[1 + e^{-(x-x_0)/b}]^c}$$

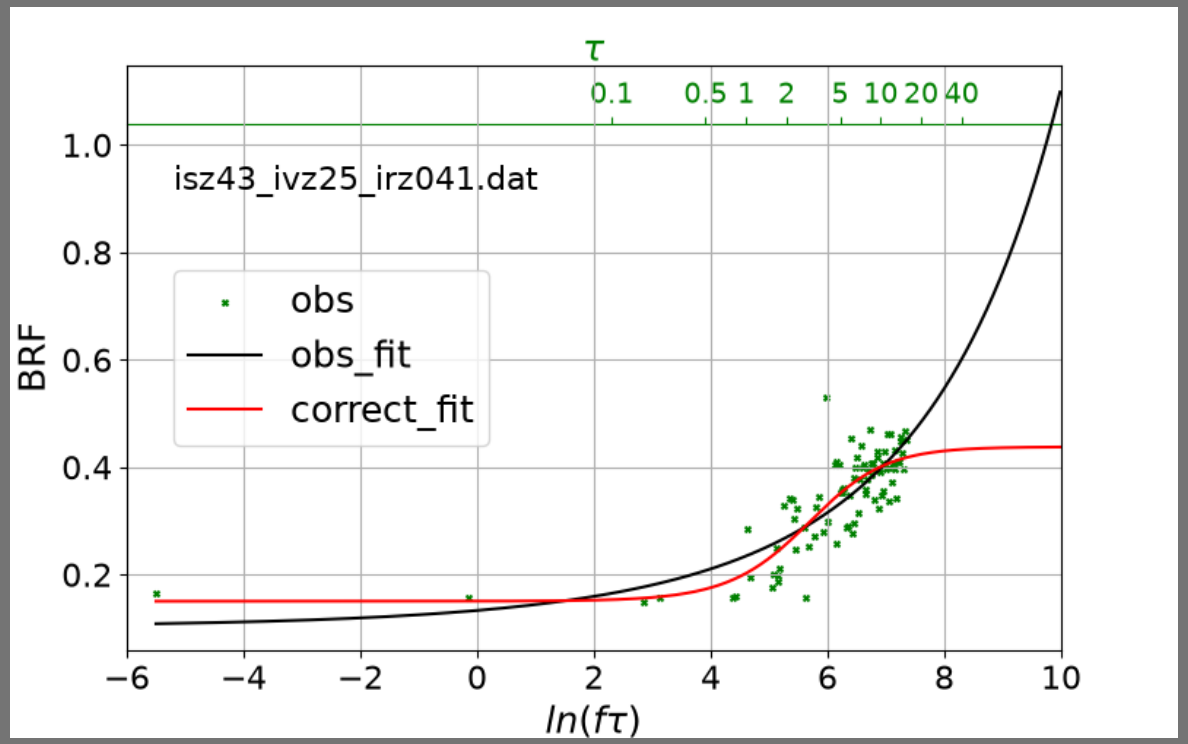
and report ”$a^2$” to replace “a”.

"$a^2$" method can also fix some cases

Fitting of mirror-S shape

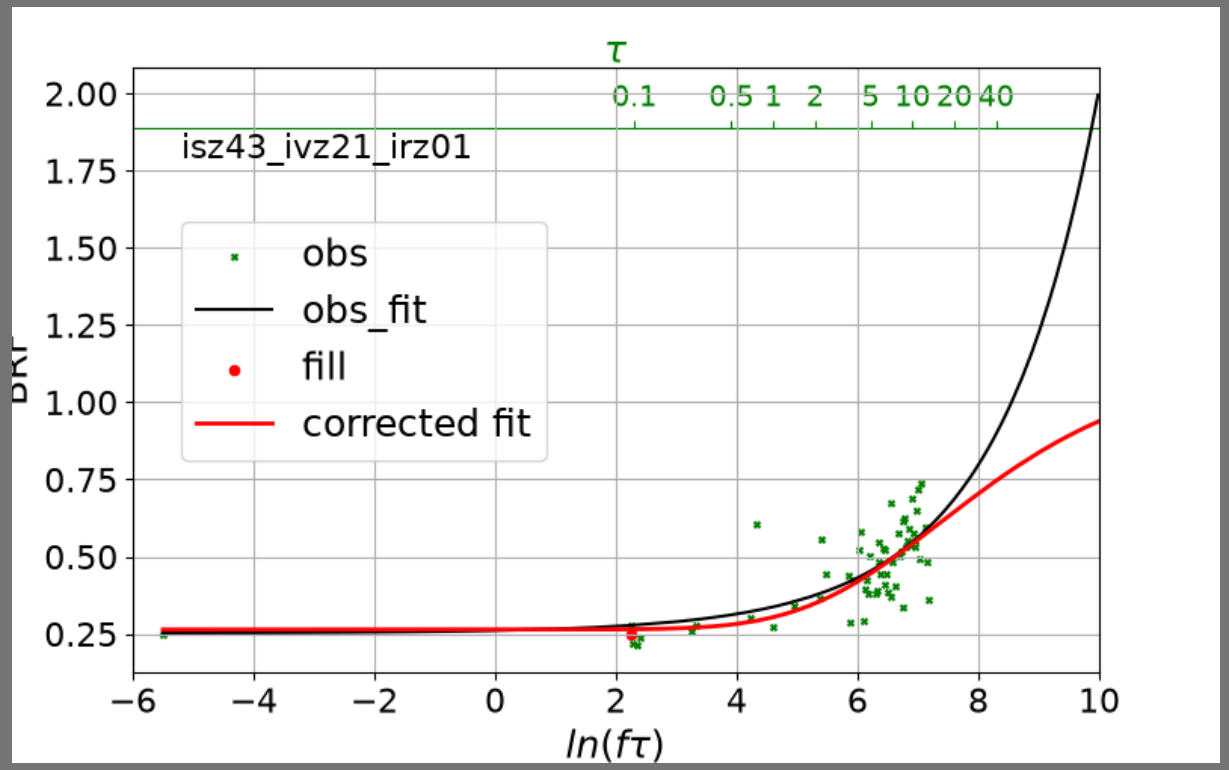


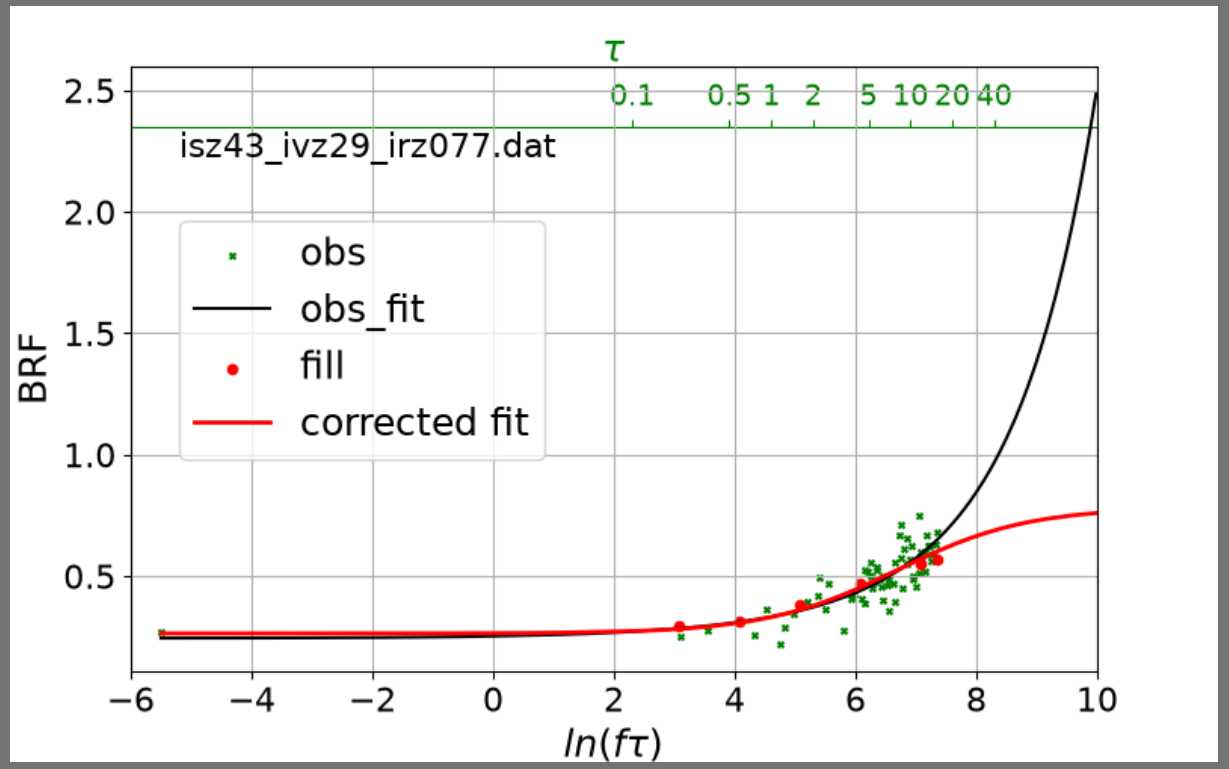

Fitting of radiance monotonically increasing with ln(f$\tau$)



# Not all unstable fittings can be fixed by "$a^2$" method

## filling bins to correct fitting

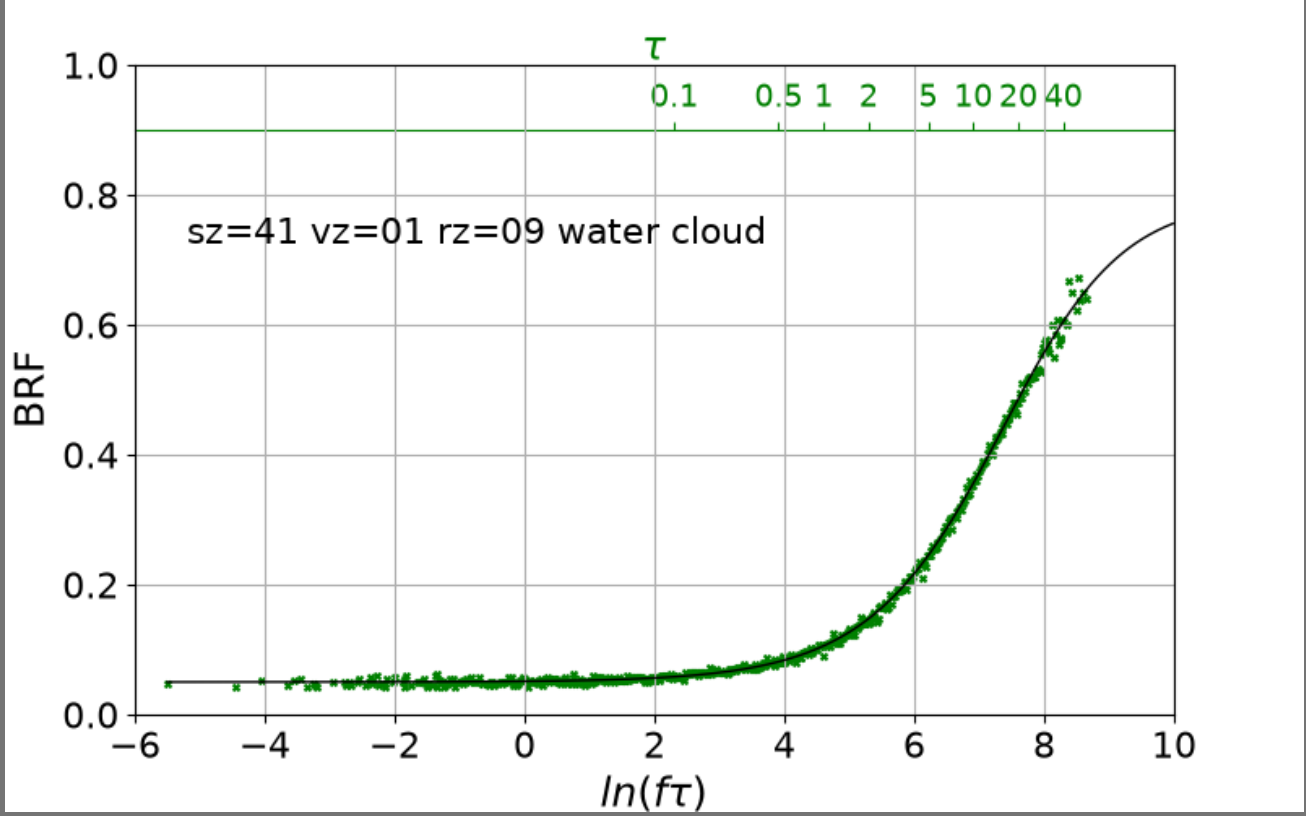



Adding a point at a time. The ln(f$\tau$) interval between added points is 1.
Stop adding once the new fitting passing the fitting curve shape check.

# Contribution of additional observations

The fitting is based on the averaged radiances in each ln(f$\tau$) bin. Therefore, in a ln(f$\tau$) bin, the radiance Margin of Error quantifies how well the mean can predict the true radiance.

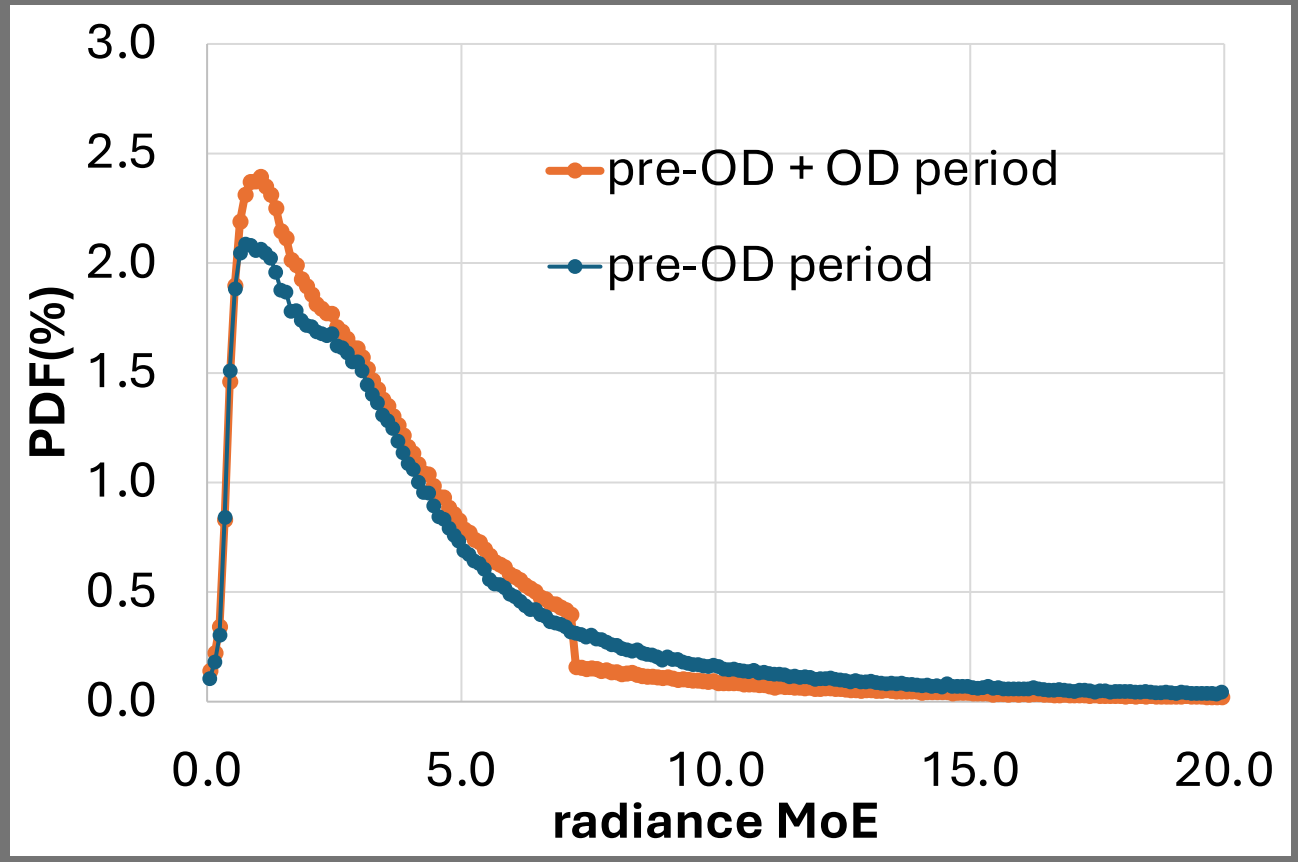



$$E = t^* \times \left( \frac{s}{\sqrt{n}} \right)$$

$\frac{s}{\sqrt{n}}$ the radiance standard error

t*: Student's t-test critical value of pre-set significant level (usually, it is 5%)

# Contribution of additional observations




For a given SZA bin, there are 45x90x775 bins (VZA x RAZ x ln(f$\tau$)).
Collect all radiance MoE values for this SZA bin,
Calculate a MoE threshold such that 20% bins have the MoE value greater than the threshold,
Supply additional observations from the orbital drifting period.

# ADM of water cloud over ocean

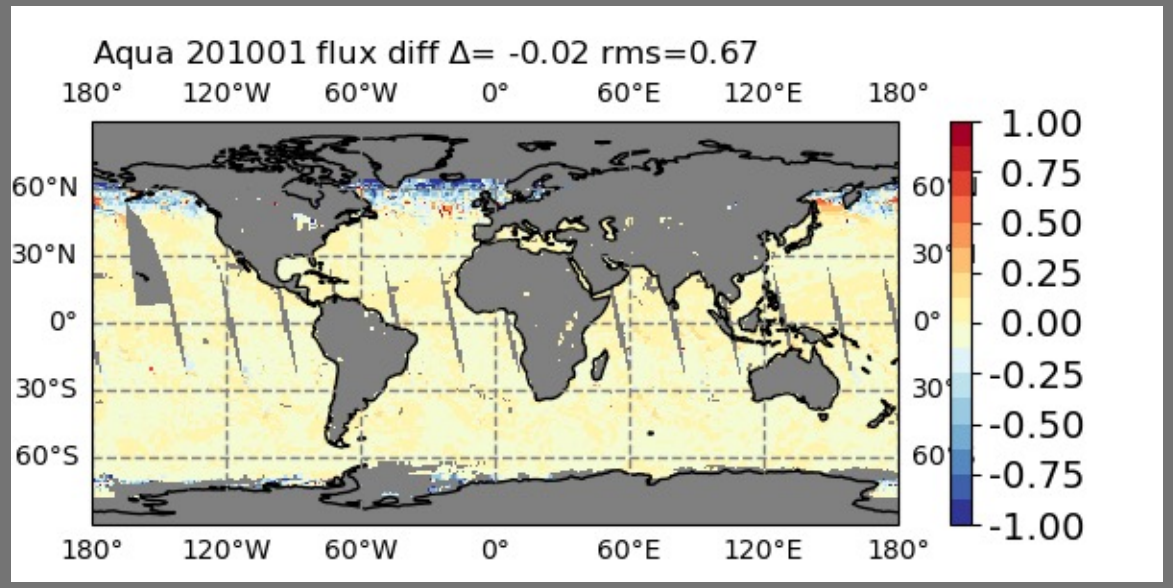
| ADM data used | fitting method | Stable fitting | Flat fitting | Rad. Mono. Increasing fitting |
|---|---|---|---|---|
| pre-OD period | Ed4 | 166973 | 5703 | 8584 |
| | new | 178837 | 173 | 2130 |
| Pre-OD period + OD period | Ed4 | 169458 | 4003 | 8129 |
| | new | 179640 | 139 | 1702 |

pre-OD (pre-orbital drifting) period: Aqua XT+RAP data from Aug 2002- Mar 2005
OD (orbital drifting) period : Aqua RAP data from Apr 2023 to Nov 2025

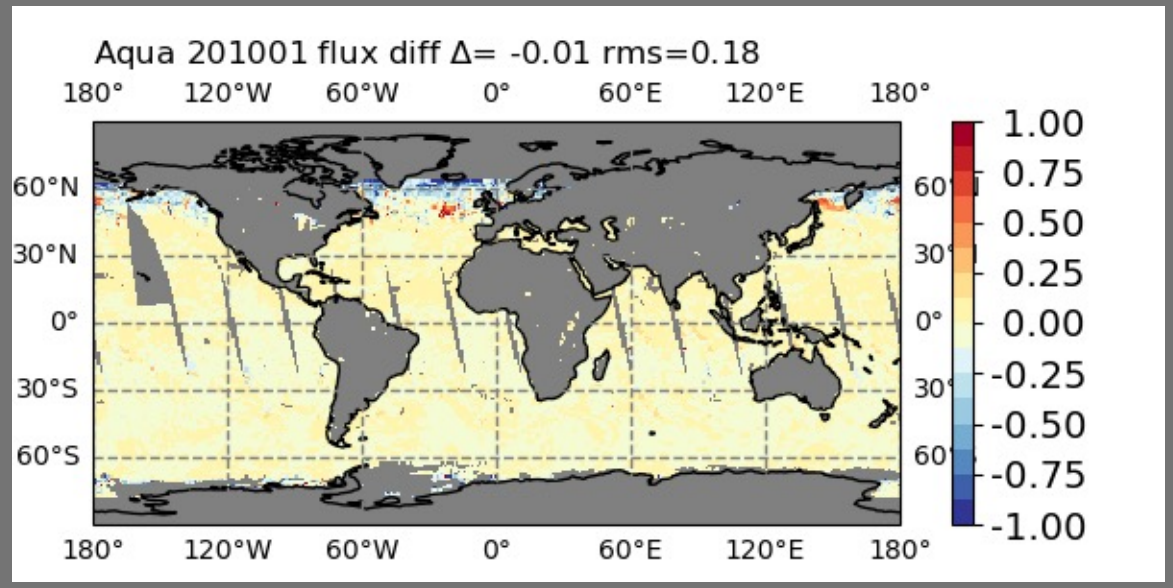
# Flux difference due to fitting method

## new method – Ed4 method

ADMs built with data from pre-OD period

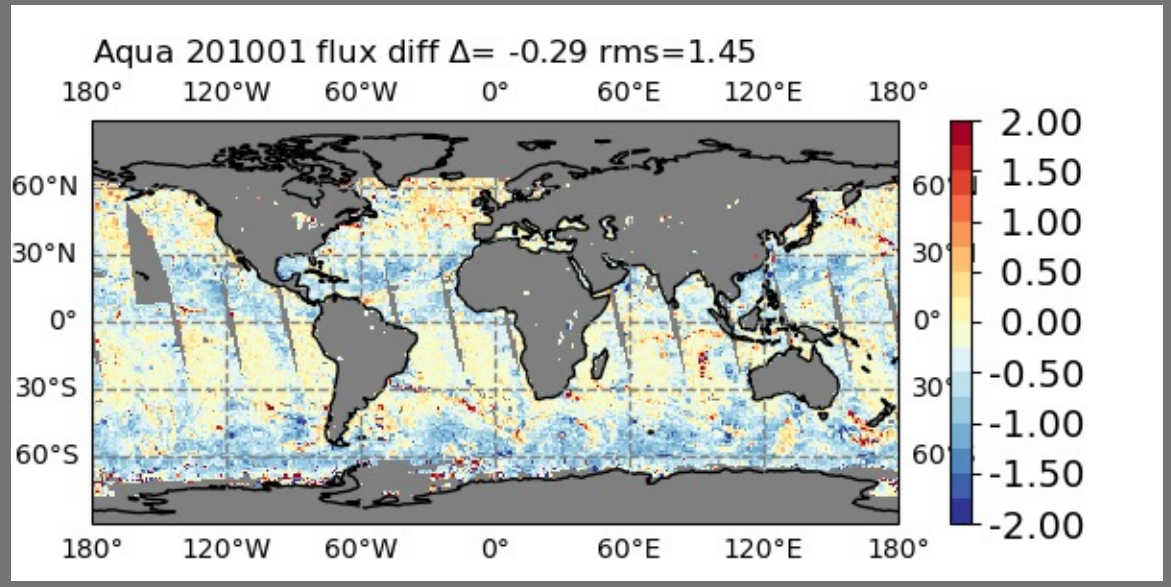



ADMs built with data from pre-OD and OD periods



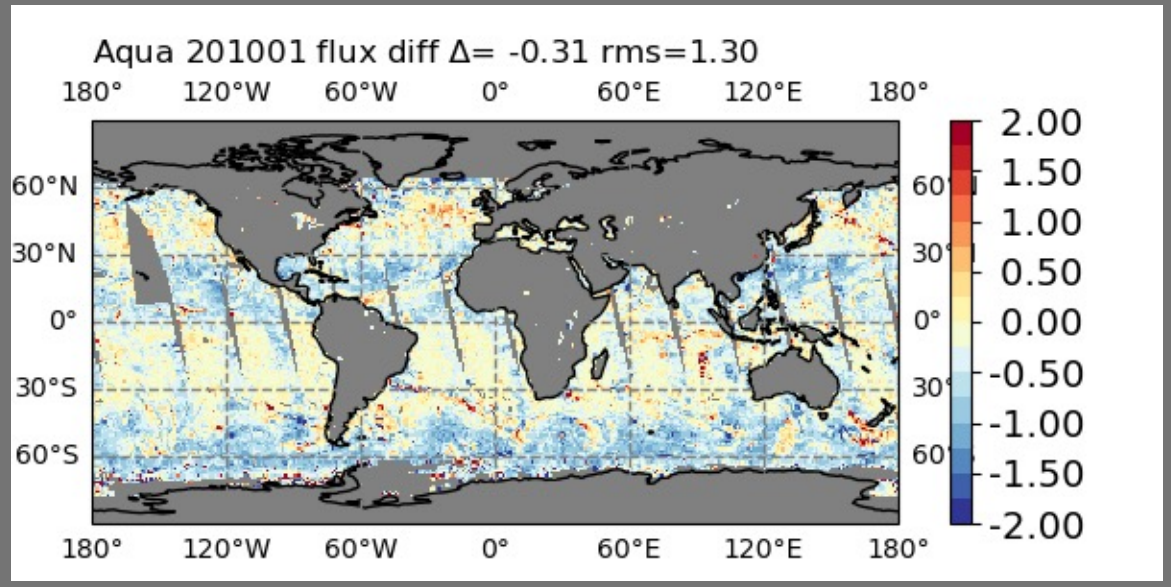
# Flux difference due to data used to construct ADMs

ADMs built with data from pre-OD and OD periods —
ADMs built with data from pre-OD period



# Flux difference due to fitting and data to construct ADMs

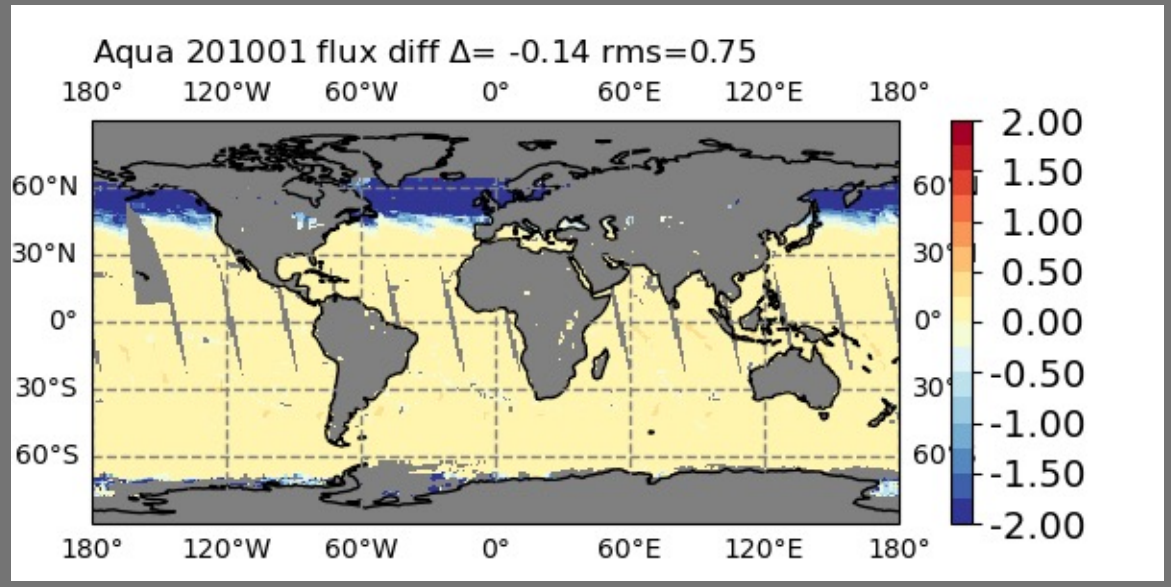
New fitting method, ADMs built with data from pre-OD and OD periods —
Ed4 fitting method , ADMs built with data from pre-OD period



# Flux difference due to model simulation used

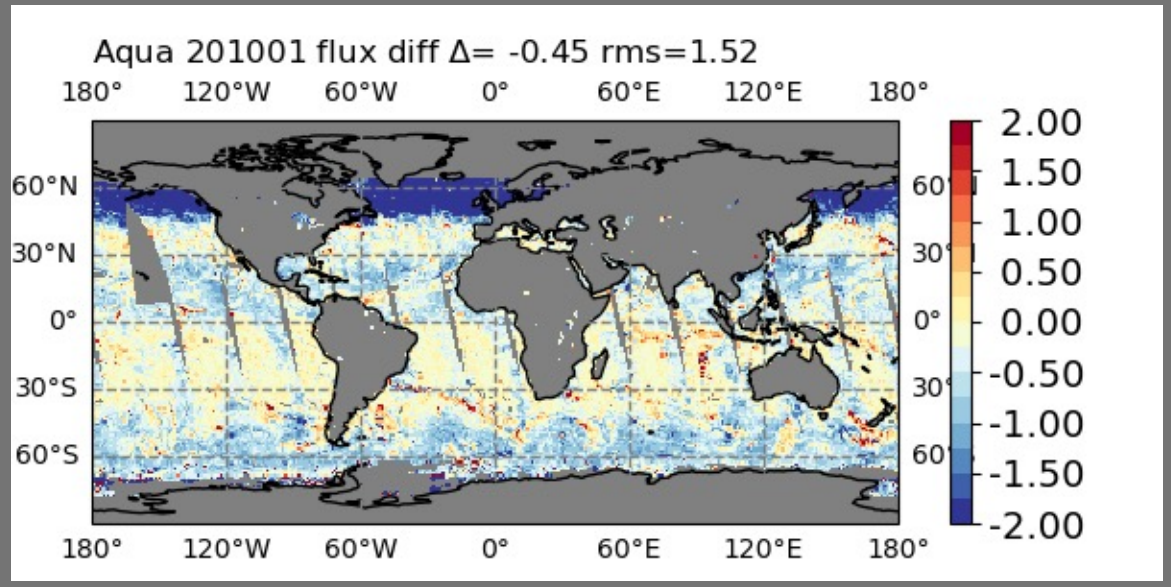
## DISORT – Nakajima

ADMs built with data from pre-OD period and Ed4 fitting method



# Overall Flux difference

New fitting method, ADMs built with data from pre-OD and OD periods, DISORT model simu — Ed4 fitting method, ADMs built with data from pre-OD period, Nakajima model simu.



# Progress in split-SW flux retrievals

# Retrieval of $F_{VIS,}$ and $F_{NIR}$

- Define the anisotropic factor ratio of NIR to VIS

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

- $\beta$ can be retrieved by minimizing narrow-band radiance differences between imager and simulations in LUTs.

- With $\beta$, calculate

  $\alpha = \frac{I_{VIS}}{I_{NIR}}\beta$. The physical meaning of $\alpha = \frac{F_{VIS}}{F_{NIR}}$

- NIR flux relates to SW flux by

  $F_{NIR} = \frac{F_{SW}}{1+\alpha}$,

- The VIS flux is then determined by

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

# 24hr-averaged fluxes

- With $F_{VIS}$ and $F_{NIR}$ in the simulation LUT, calculate $F_{VIS24hr}$ and $F_{NIR24hr}$, and therefore,

$$\alpha_{24hr} = \frac{F_{VIS24hr}}{F_{NIR24hr}}$$

- Calculate $F_{SW24hr}$ by using directional model approach

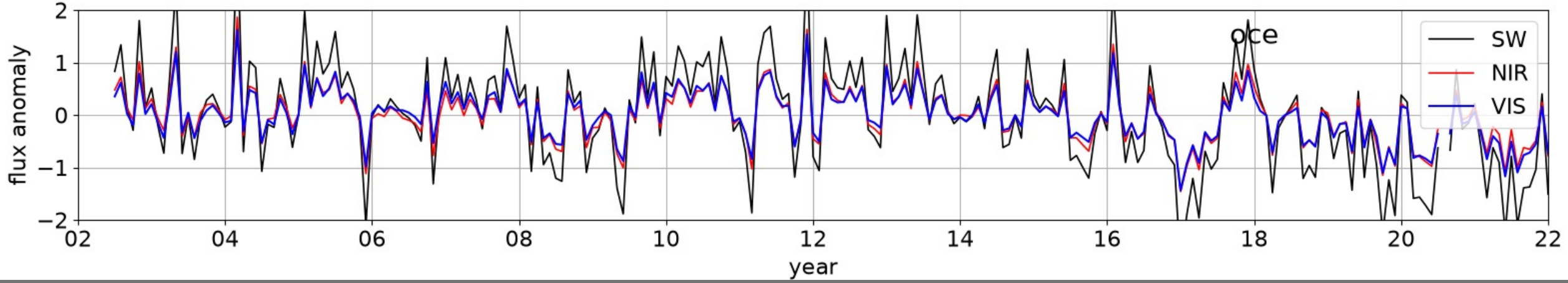
- Calculate $\mathbf{F_{NIR24hr}} = \frac{F_{SW24hr}}{1+\alpha_{24hr}}$

- $F_{VIS24h} = F_{SW24h} - F_{NIR24h}$

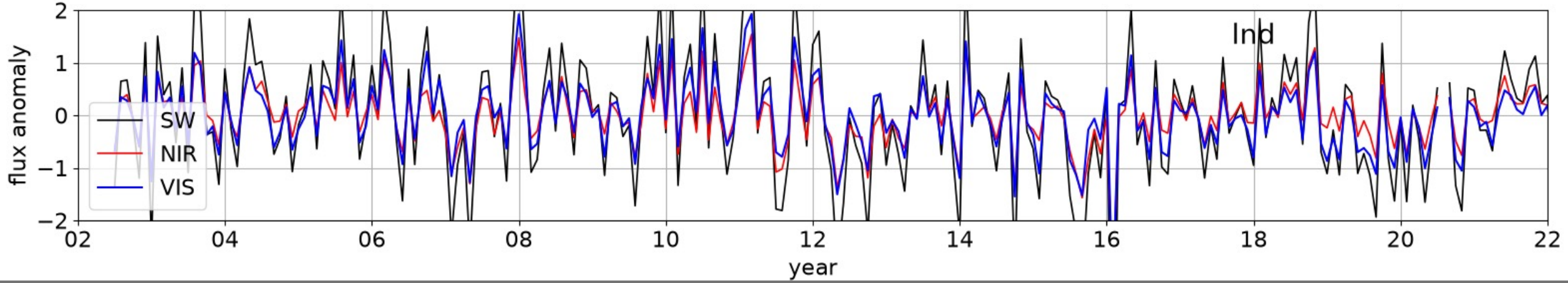
- Monthly mean Gridded $F_{sw24hr}$, $F_{VIS24h}$ and $F_{NIR24hr}$ are calculated from daily averages in (region, GMT-hour) and scaled by the monthly mean solar insolation, respectively.

CERES SYN trend over 45N-54S

Trend (W/m$^2$/decade): NIR -0.3074 VIS -0.3344 SW -0.6008



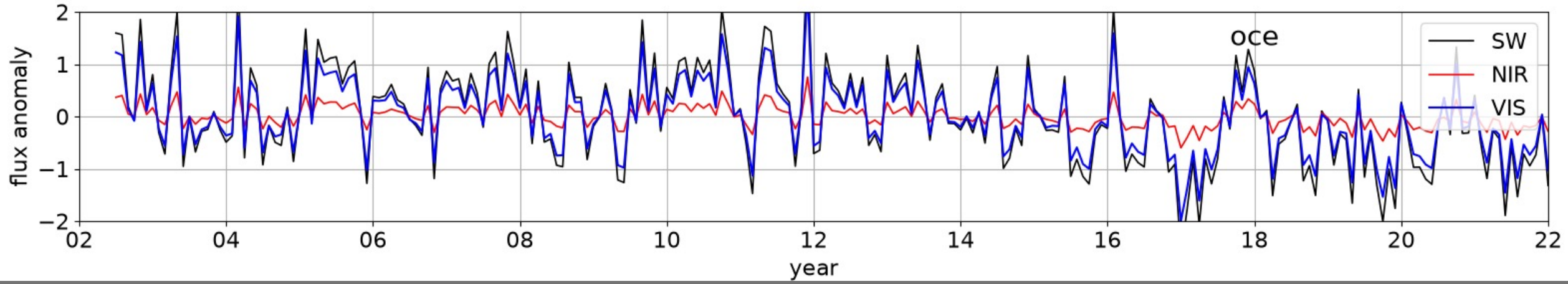

Trend (W/m$^2$/decade): NIR -0.0753 VIS -0.2169 SW -0.2923



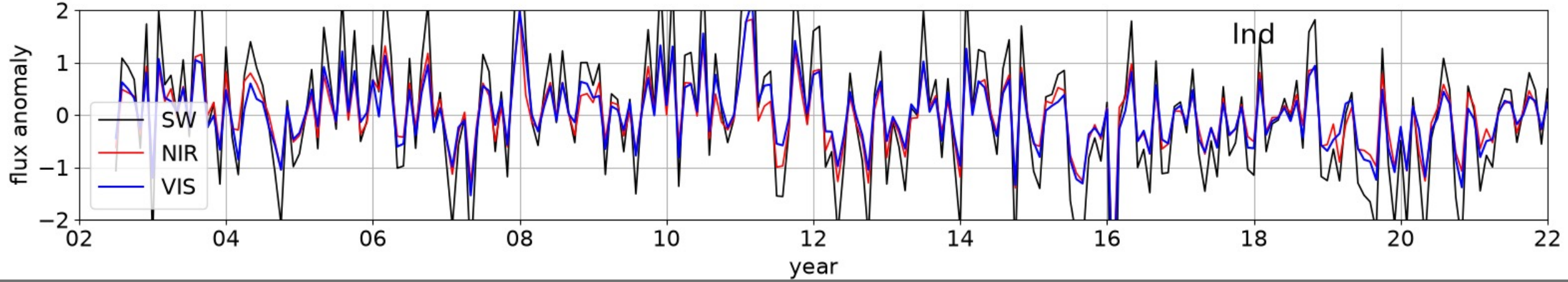

CERES_SYN1deg-Month_Terra-Aqua-NOAA20_Ed4.2x2-NOGEOx2_Subset_200207-202203

Split-SW trend over 45N-54S

Trend (W/m$^2$/decade): NIR -0.1489 VIS -0.4832 SW -0.6309




Trend (W/m$^2$/decade): NIR -0.2699 VIS -0.2803 SW -0.5495




Split-SW monthly, 24hr-averaged, Aqua cross-track

# Summary

- Improved accuracy of ocean clear-sky ADMs by reducing radiance angular variabilities with contributions of additional observations from Terra/Aqua orbital drifting period.

- Improved accuracy of ocean cloud ADMs by (1) correcting unphysical sigmoidal fittings between cloud property and radiance and (2) using new DISORT theoretical radiative transfer simulation lookup-table.

- The LUT approach to retrieve split SW flux of VIS and NIR provides an additional tool to validate CERES SYN spectral fluxes. In terms of global flux trend, over 45N-45S, CERES SYN shows similar magnitude of trends between VIS and NIR fluxes over ocean, but not over land; while the LUT approach shows the opposite. Further analysis is required to identify the discrepancies.