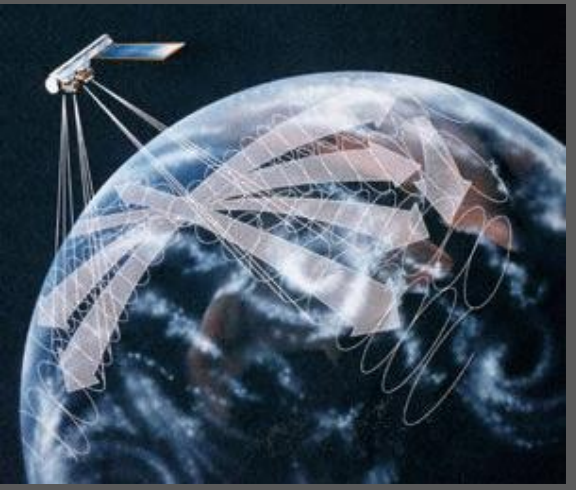

CERES Angular Distribution Model Working Group Report

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CERES Science Team Meeting, May 13-15, 2025
NASA Langley Research Cetner, Hampton, VA

Outline

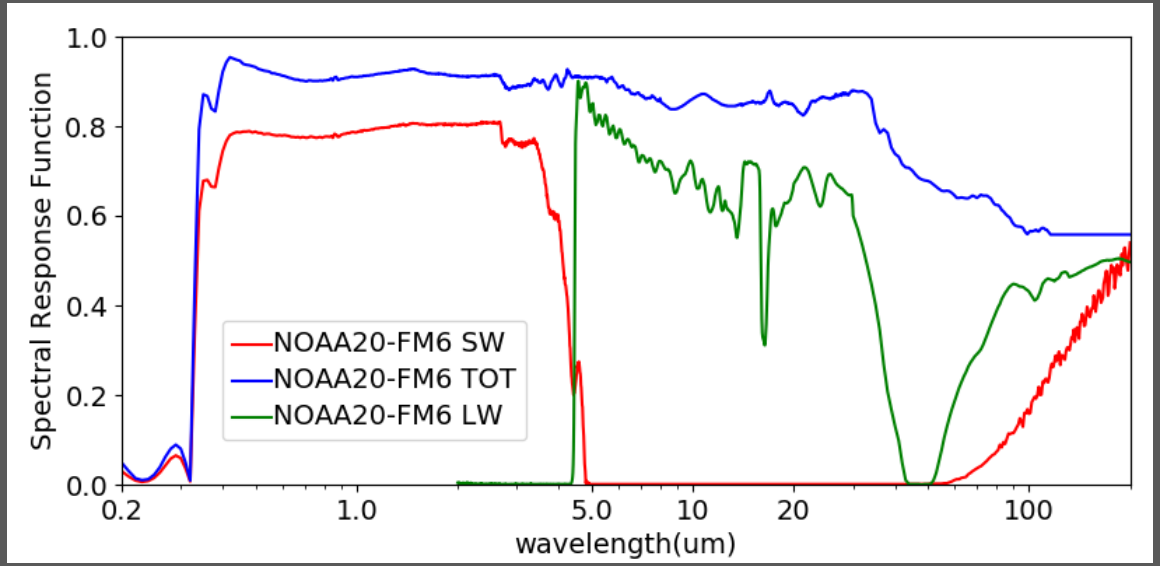
- NOAA20 CERES LW radiance unfiltering
- Split-SW flux retrieval
- Sensitivity of CERES ADMs to different climate states

  (Sergio Sejas' presentation on Thursday)

NOAA20 CERES LW radiance unfiltering

CERES unfiltering algorithm

- CERES instruments measure SW, LW/WN, and TOT radiances after they have passed through the instrument's optical system. The modifications of these radiances after entering the optical system are characterized by the instrument's spectral response functions.



- What we need for scientific research are the radiances prior to entering instrument optical systems.

- The CERES radiance unfiltering process converts the "filtered" radiances to "unfiltered" SW/LW/WN radiances by regression relationships between filtered and unfiltered radiances from theoretical radiative transfer simulations.

NOAA20 CERES unfiltering algorithm

SW radiance unfiltering

Unfiltered reflected SW radiances are calculated from filtered reflected SW radiances:

$$m_u^{SW} = a_0 + a_1 m_f^{SW_r} + a_2 \left(m_f^{SW_r}\right)^2$$

LW radiance unfiltering

Unfiltered emitted LW radiances are calculated from filtered reflected SW and TOT radiances during daytime, and TOT radiances at night:

$$m_u^{LW_{SW\_TOT}}(DAY) = b_0 + b_1 m_f^{SW_r} + b_2 m_f^{TOT}$$
$$m_u^{LW_{SW\_TOT}}(NIGHT) = c_0 + c_1 m_f^{TOT}$$

LW unfiltered radiances can also be calculated from filtered LW radiances:

$$m_u^{LW_{LW}} = d_0 + d_1 m_f^{LW} + d_2 \left(m_f^{LW}\right)^2$$

CERES unfiltering algorithm

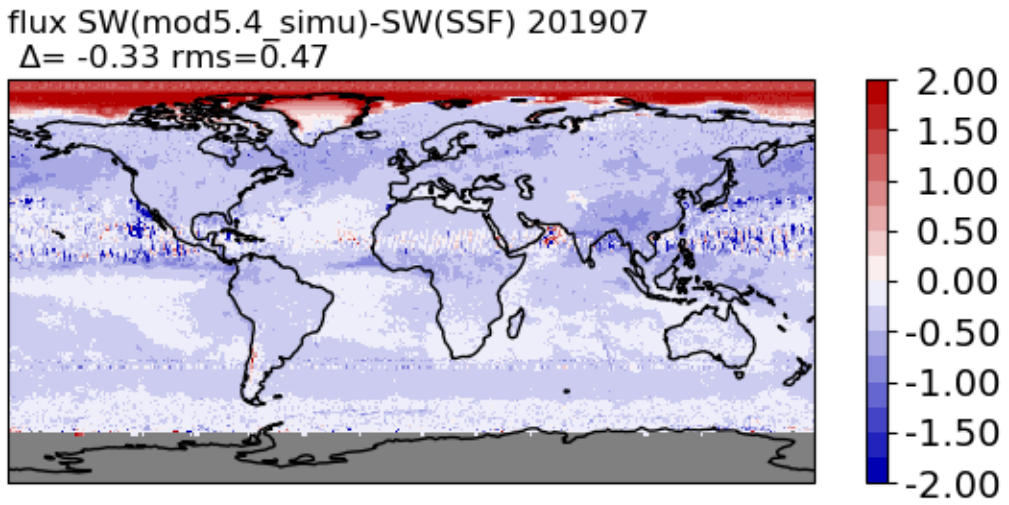
- The radiance unfiltering process are scene dependent. Regression coefficients were constructed for land, ocean, and snow/sea ice, and further separated into clear and cloudy cases.

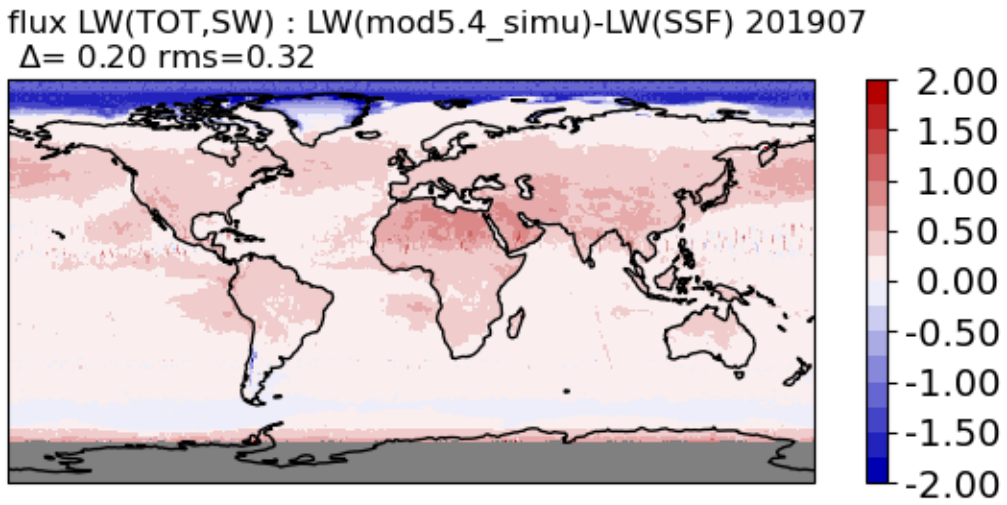
- Updates as compared to the Ed4 radiance unfiltering process:

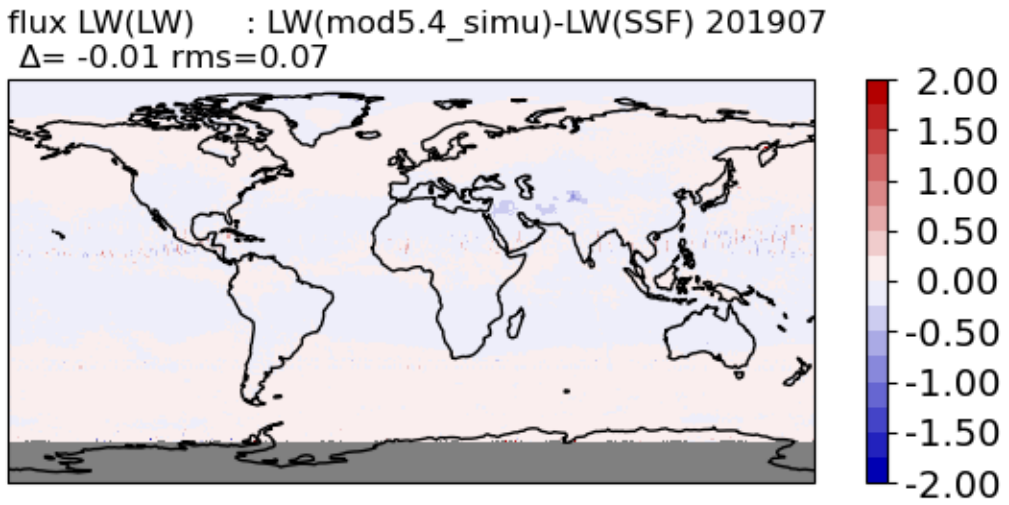
	Ed4	Ed5
model	MODTRAN 3.7	MODTRAN5.4
Cloud's optical property	MODTRAN default clouds	Ping Ying's clouds
VZA	5-bins (0, 30, 45, 60, 90)	7-bins (0, 15, 30, 45, 60, 70, 90)
SZA	5-bins (0, 41, 60, 75, 90)	13-bins (0, 8.3, 16.6, 23.6, 29, 35.7, 41.4, 51.3, 60, 68, 75.5, 80.3, 85)
Land/snow characterization	Lambertian	MODIS BRDF kernels

Changes due to

- switching from MODTRAN 3.7 to MODTRAN 5.4 simulations

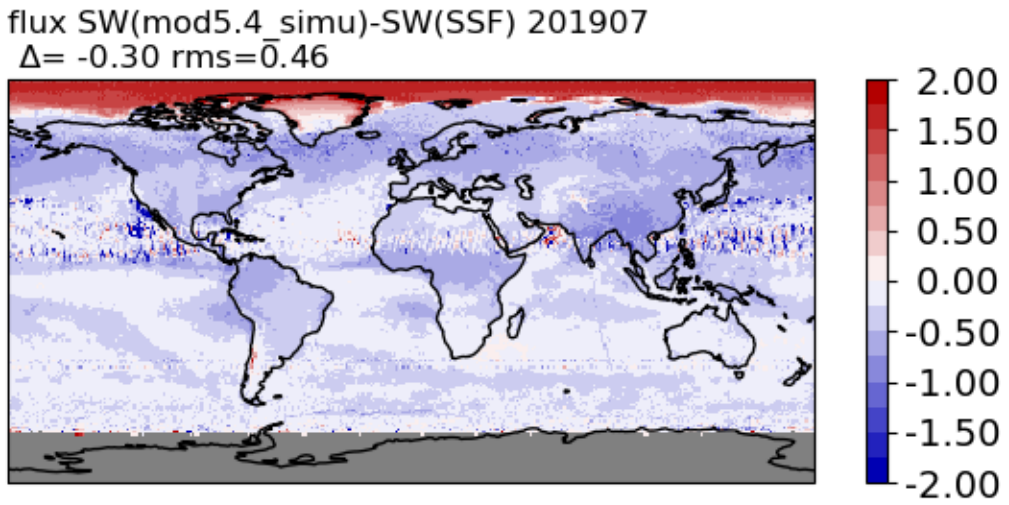


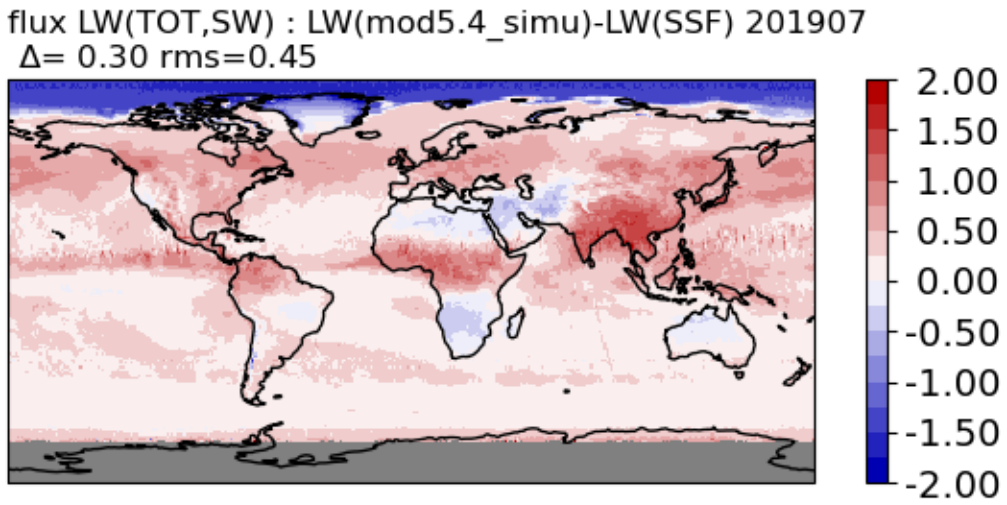


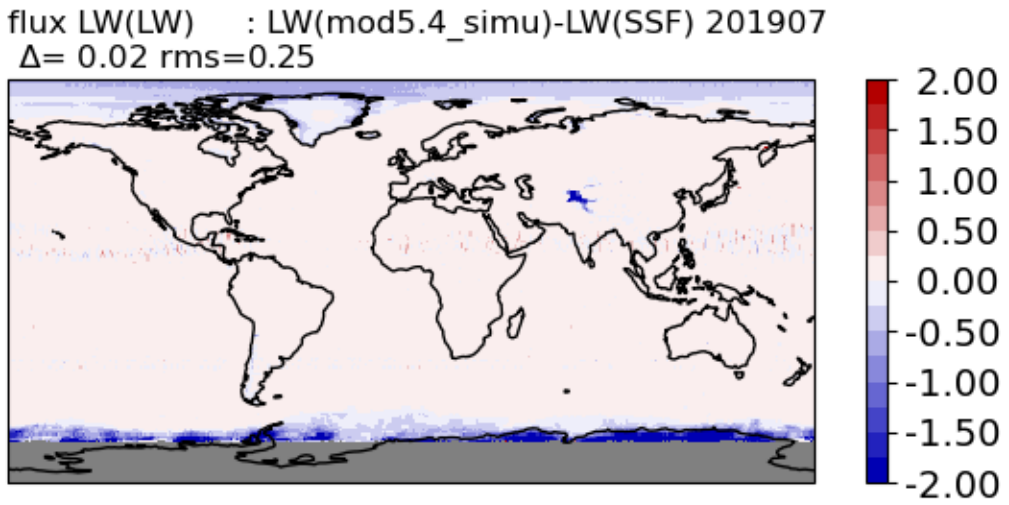


Changes due to

- switching from MODTRAN 3.7 to MODTRAN 5.4 simulations
- cloud property
- VZA/SZA







Flux difference between LW(LW) and LW(TOT,SW)

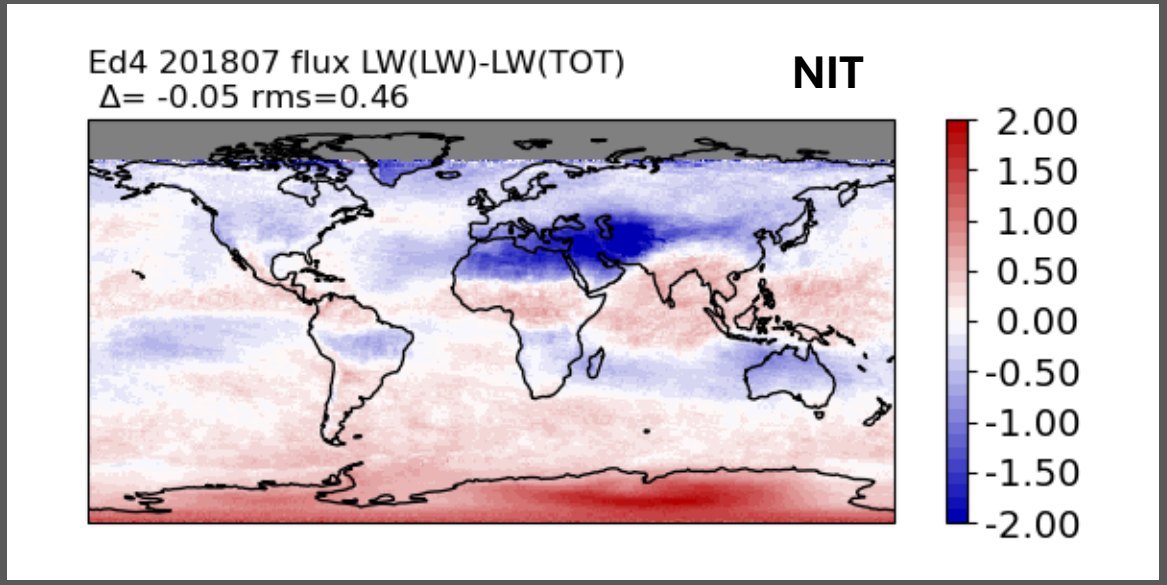
NOAA20 CERES has two approaches for the LW radiance unfiltering.

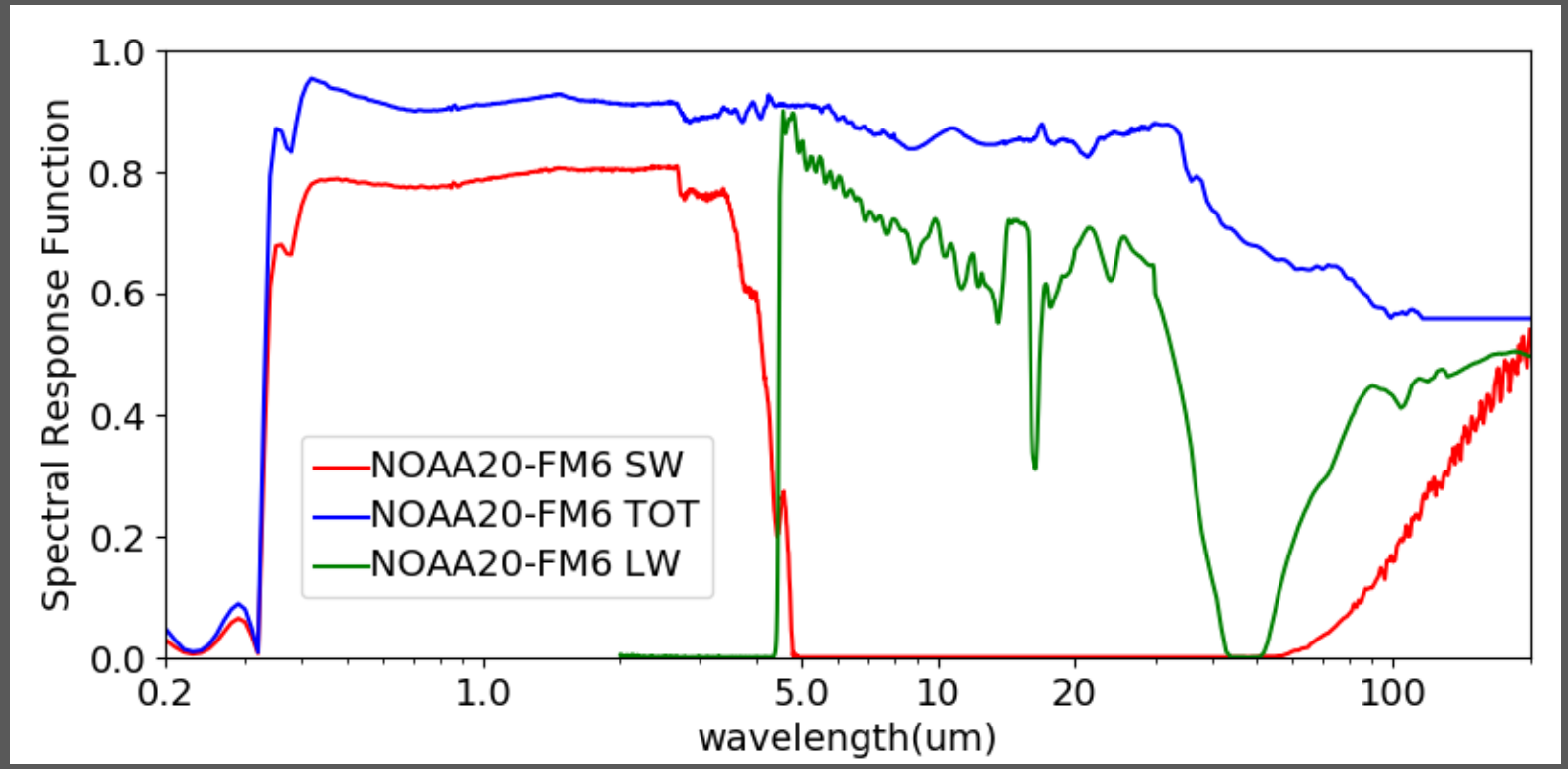
- By SW and TOT channel filtered radiances during daytime, and TOT at night

$$m_u^{LW_{SW\_TOT}}(DAY) = b_0 + b_1 m_f^{SW_r} + b_2 m_f^{TOT}$$
$$m_u^{LW_{SW\_TOT}}(NIGHT) = c_0 + c_1 m_f^{TOT}$$

- By LW channel filtered radiances:

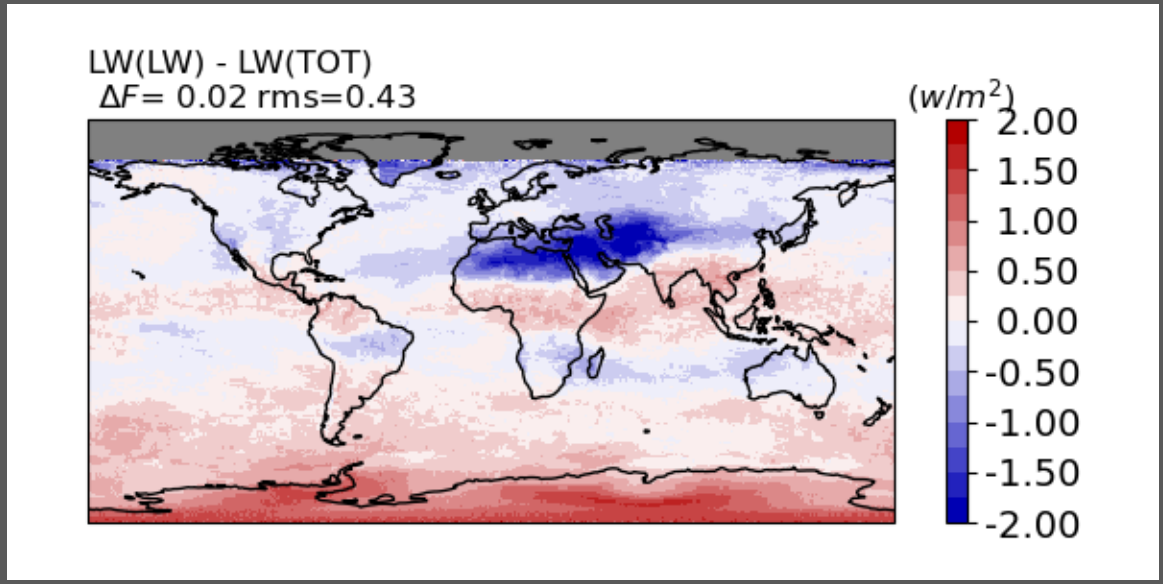
$$m_u^{LW_{LW}} = d_0 + d_1 m_f^{LW} + d_2 \left(m_f^{LW}\right)^2$$





Flatter shape of TOT channel than LW channel suggests we may use LW(TOT) as a proxy to the truth if LW (TOT) is not sensitive to the unfiltering algorithm.

Reducing the differences between LW(LW) and LW(TOT) at night

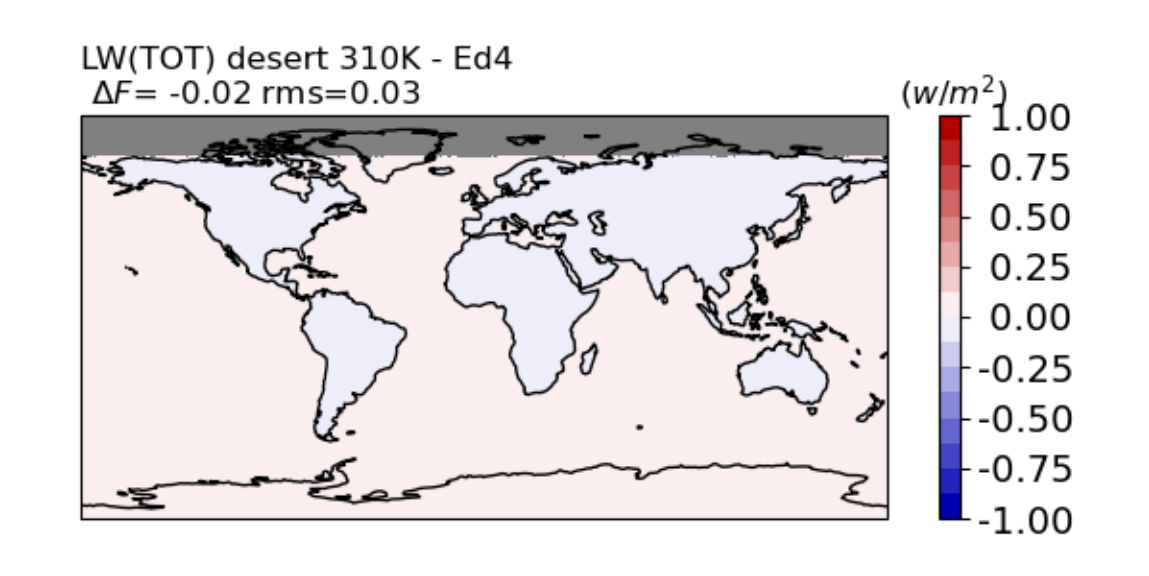


- Constructed 3 sets of coefficients based on simulations for
  1. vegetation with a surface temperature of 295K
  2. desert with a surface temperature of 310K
  3. dry meadow grass with a surface temperature of 275K

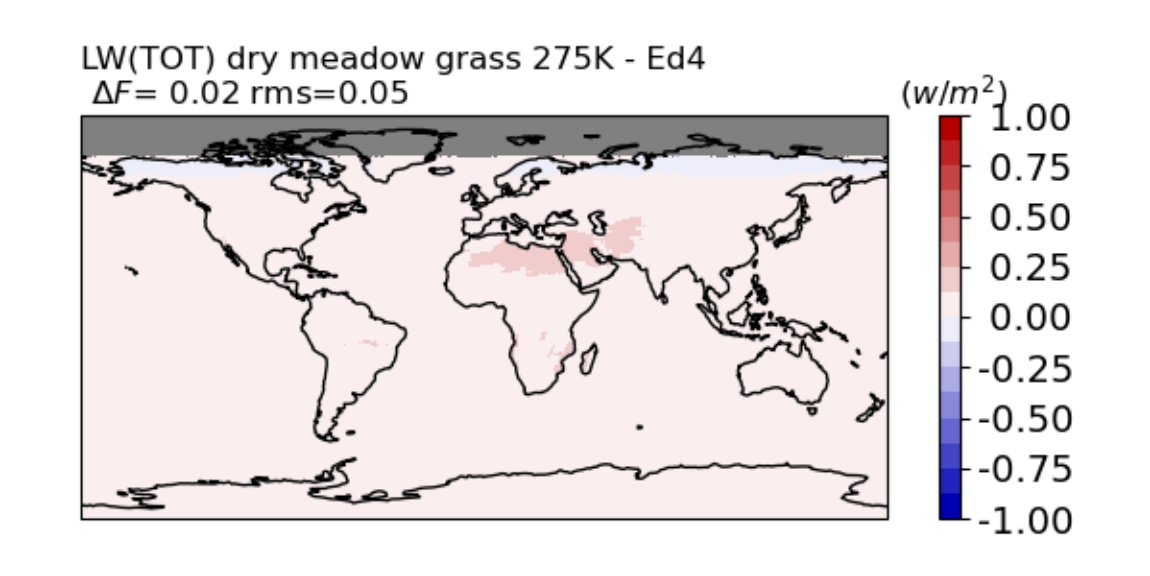
- Check LW(LW)-LW(TOT) for each option.

Sensitivity of LW(TOT) to the simulations

(desert 310K)- (Ed4 veg. 295K)



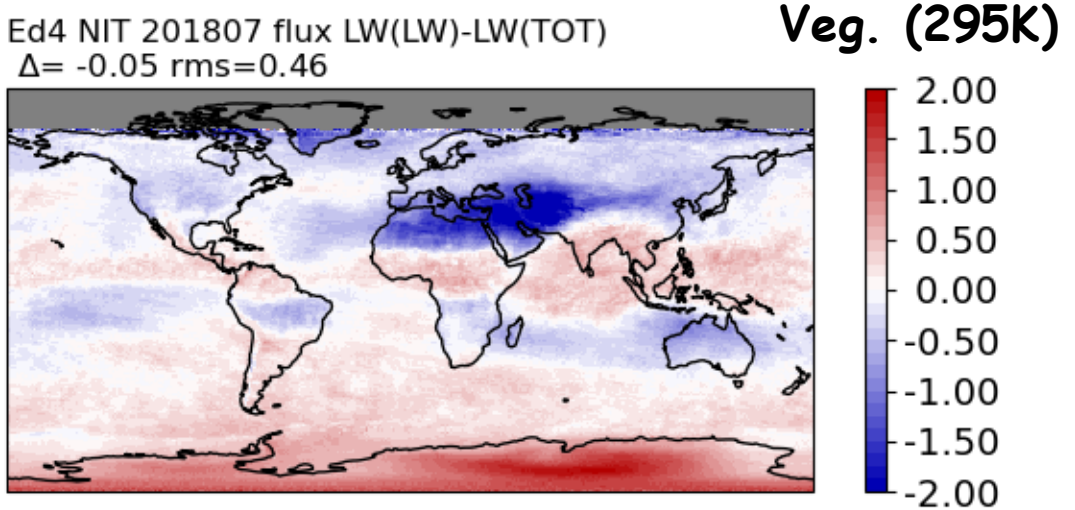
(dry meadow grass 275K)- (Ed4 veg. 295K)

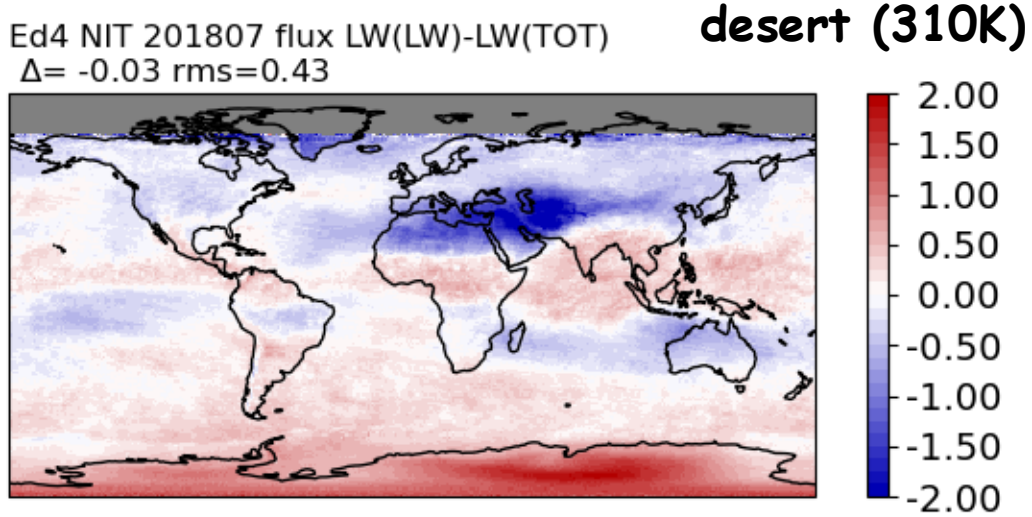


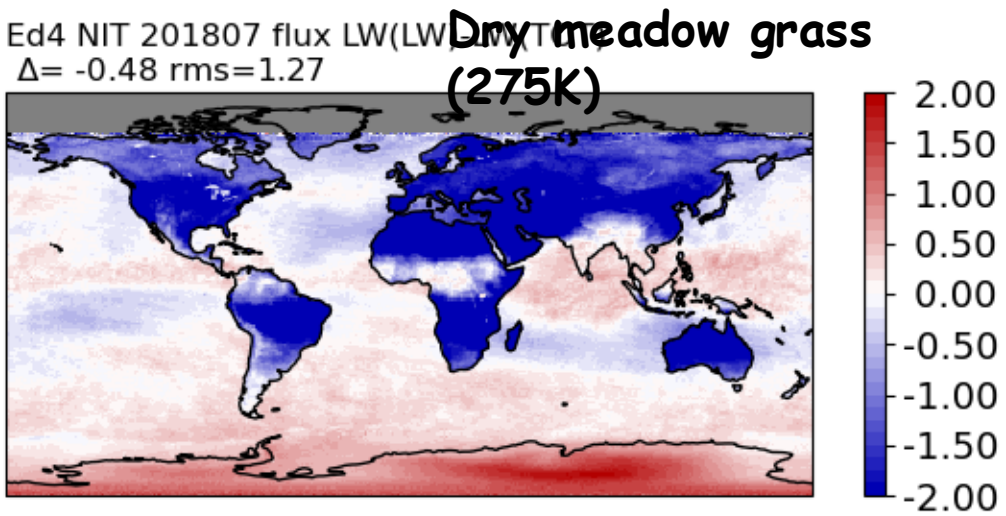
Less sensitivity is due to

1. Flat TOT channel SRF
2. unfiltered LW and filtered TOT are highly linear

$$m_u^{LW_{SW\_TOT}}(NIGHT) = c_0 + c_1 m_f^{TOT}$$





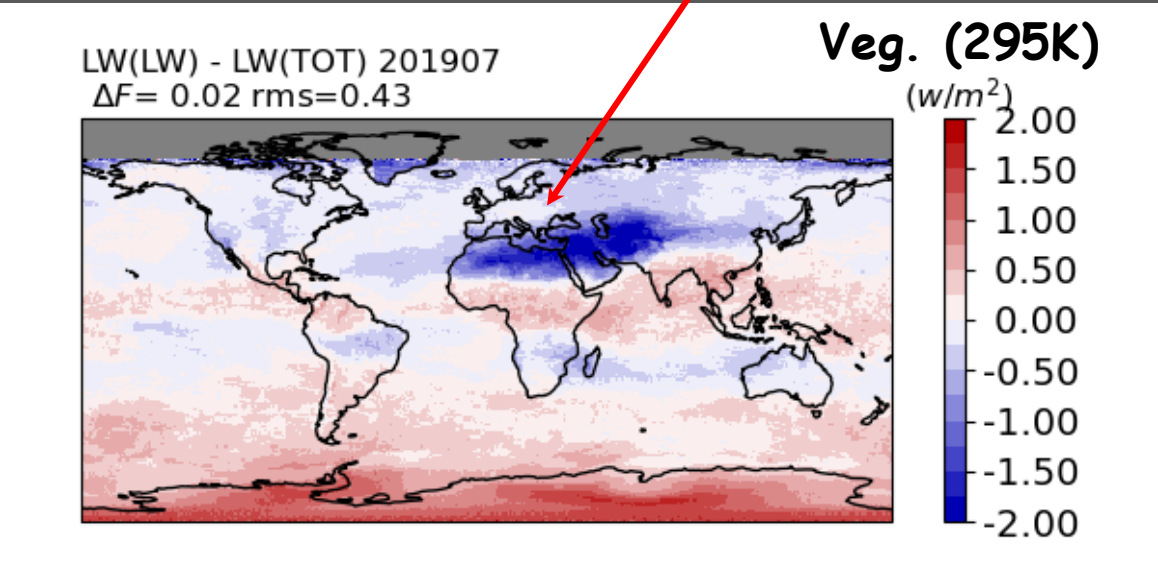


using simulations for a hotter surface reduces the differences

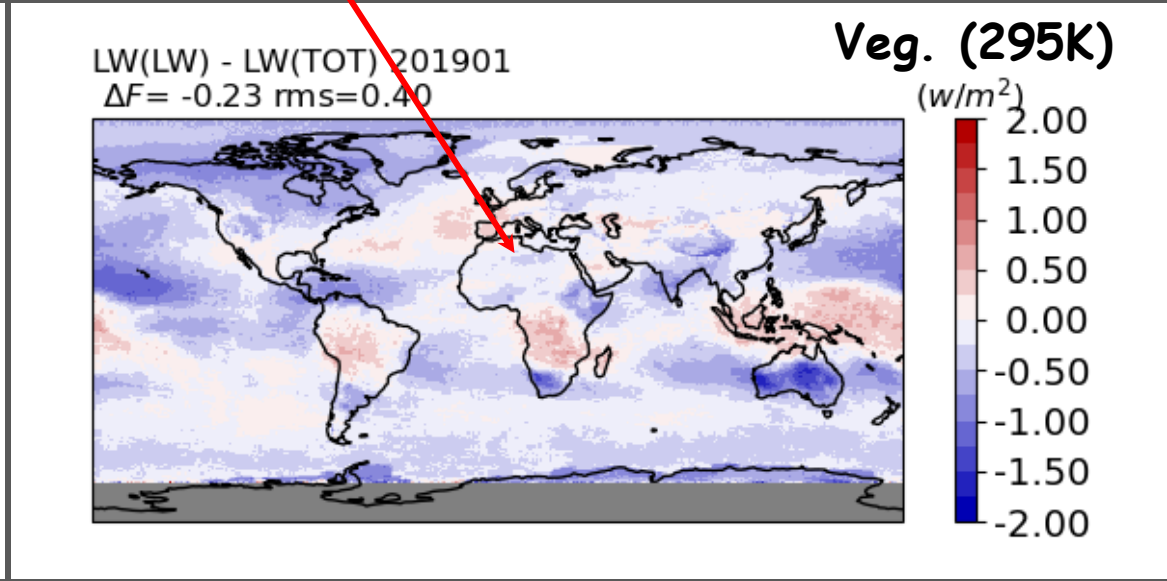
using simulations for a colder surface increases the differences

seasonal changes

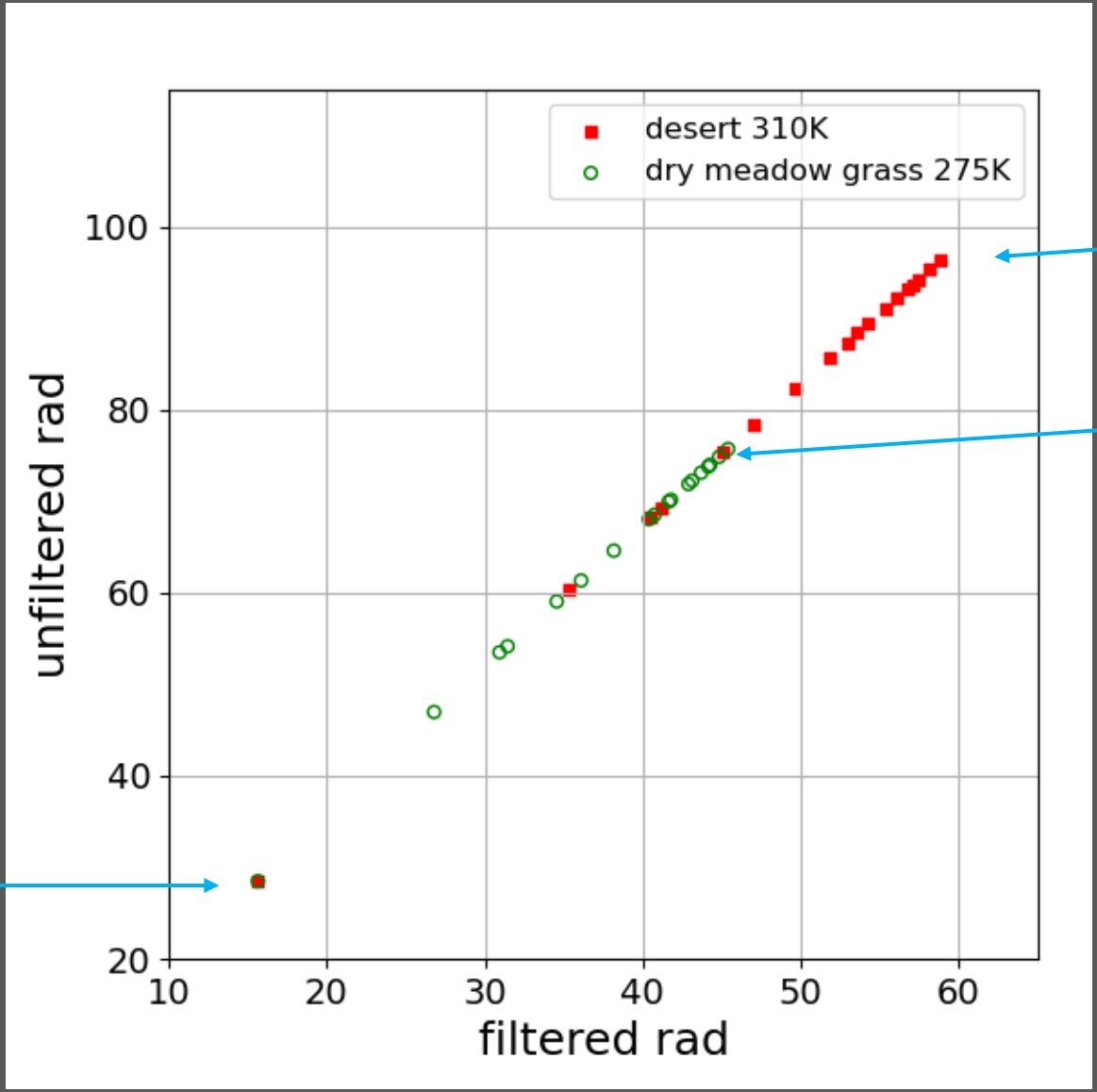
under-estimated over hot surface



small differences over colder surface



Explanation of errors over hotter surface



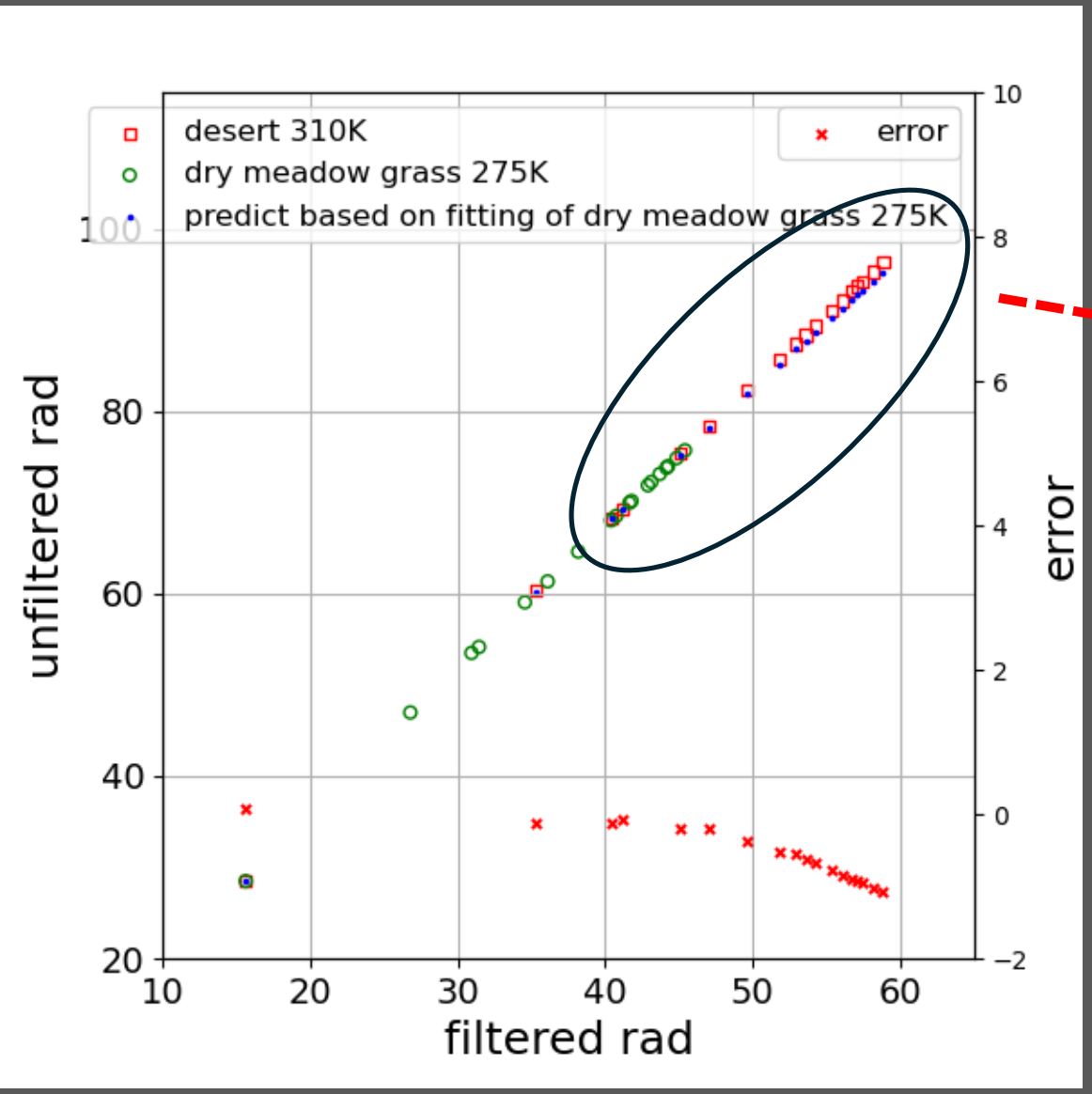
Clear sky for desert 310K

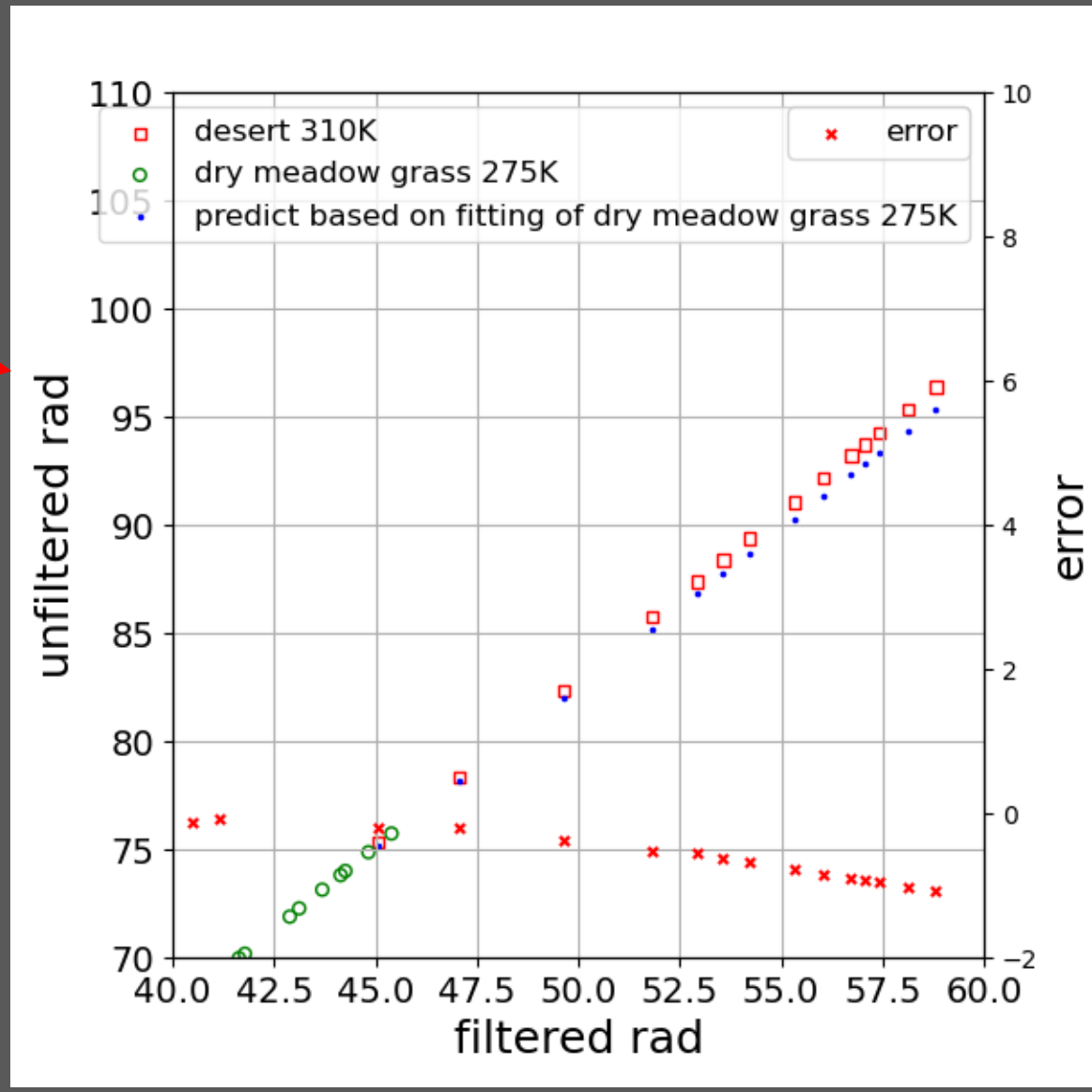
Clear sky for dry meadow grass 2750K

Deep convective overcast

LW regression samplings:
1 clear + 4 overcast clouds x 4 cloud fractions (0.25, 0.5, 0.75, 1.0) + 1 deep convective overcast = 18

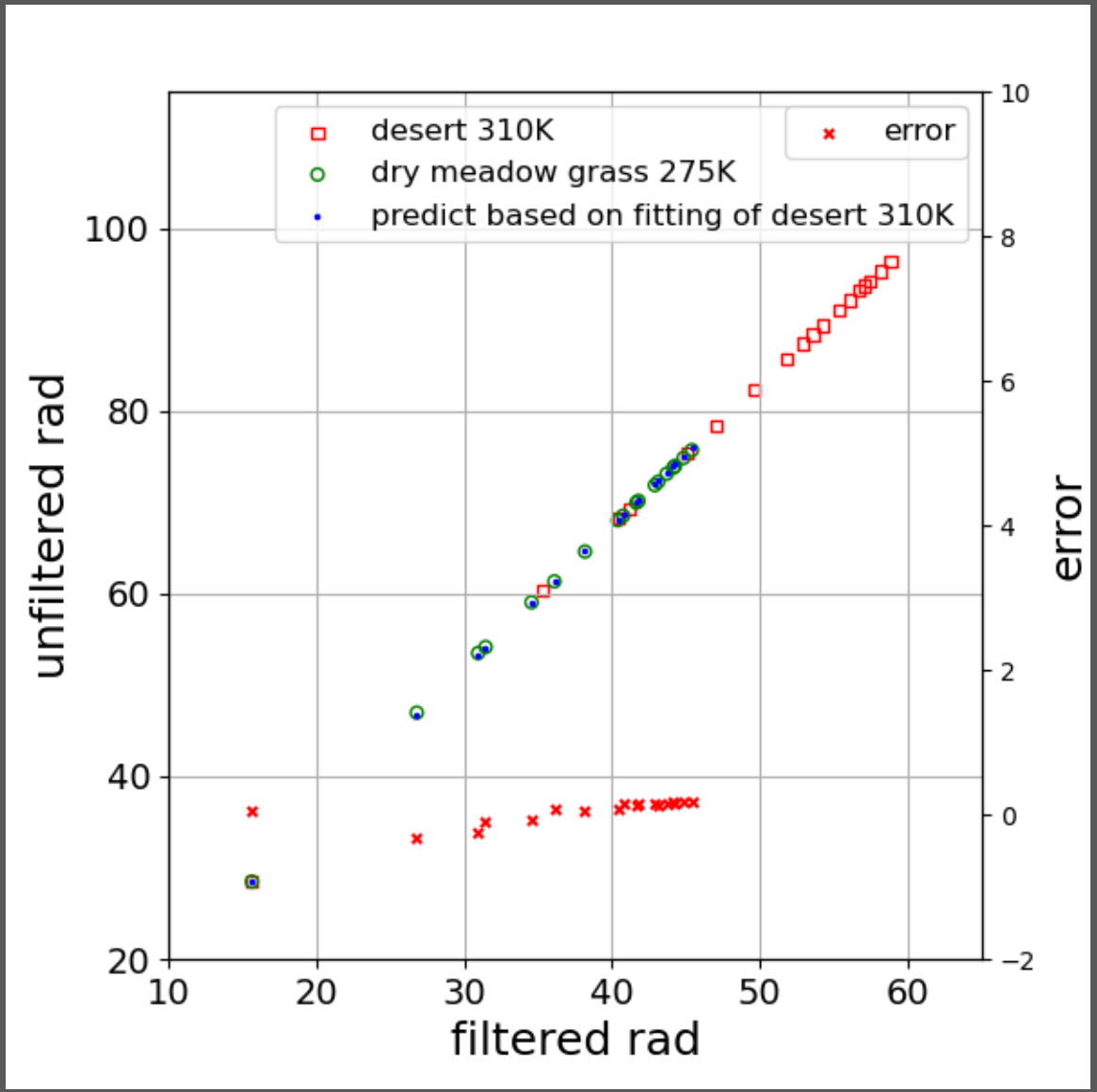
Explanation of errors over hotter surface





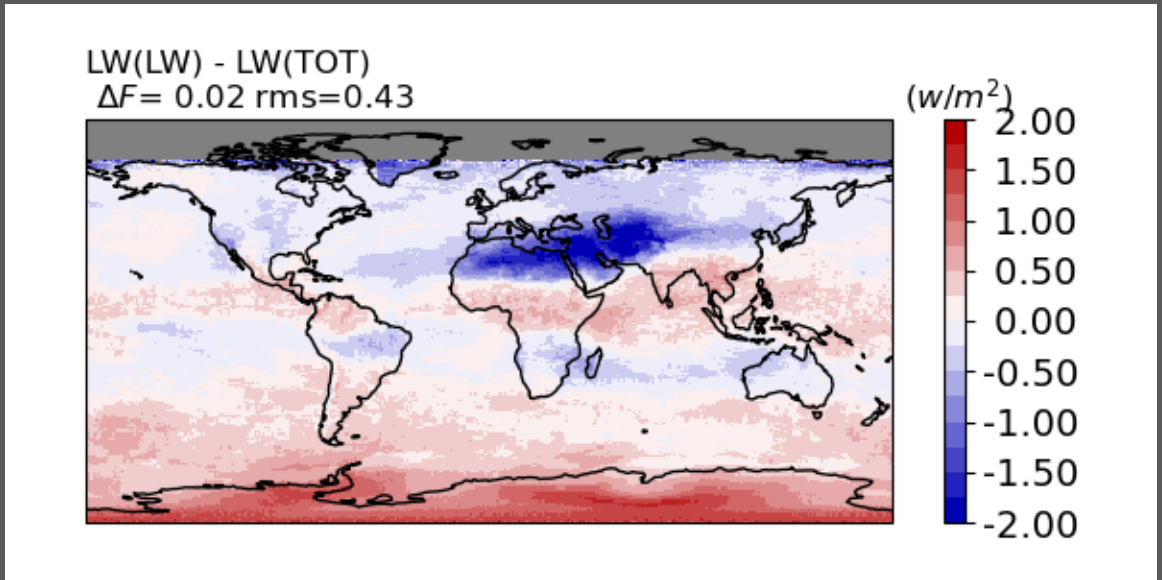
$$m_u^{lW}(by\ LW) = d_0 + d_1 m_f^{LW} + d_2 \left(m_f^{LW}\right)^2$$

Explanation of errors over hotter surface



$$m_u^{lW}(by\ LW) = a_0 + a_1 m_f^{LW} + a_2 \left(m_f^{LW}\right)^2$$

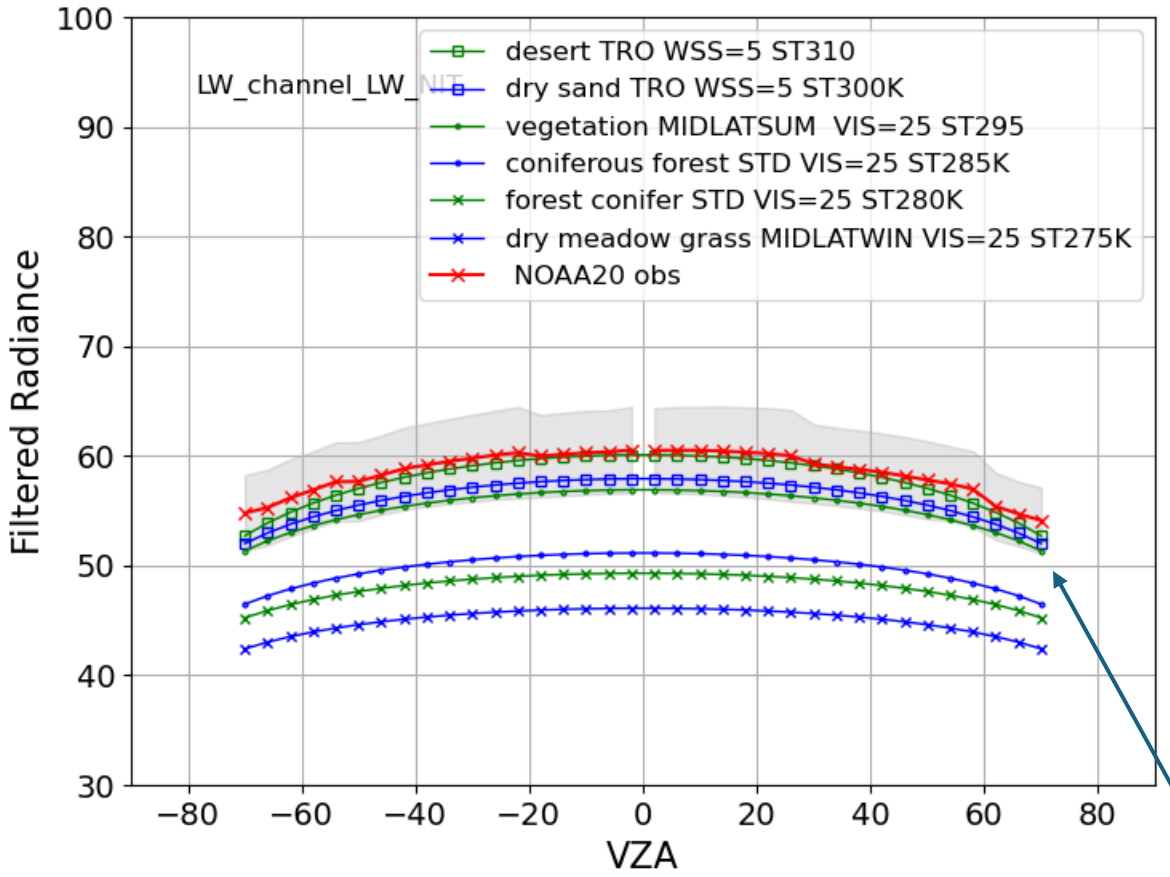
Reducing the differences between LW(LW) and LW(TOT) at night

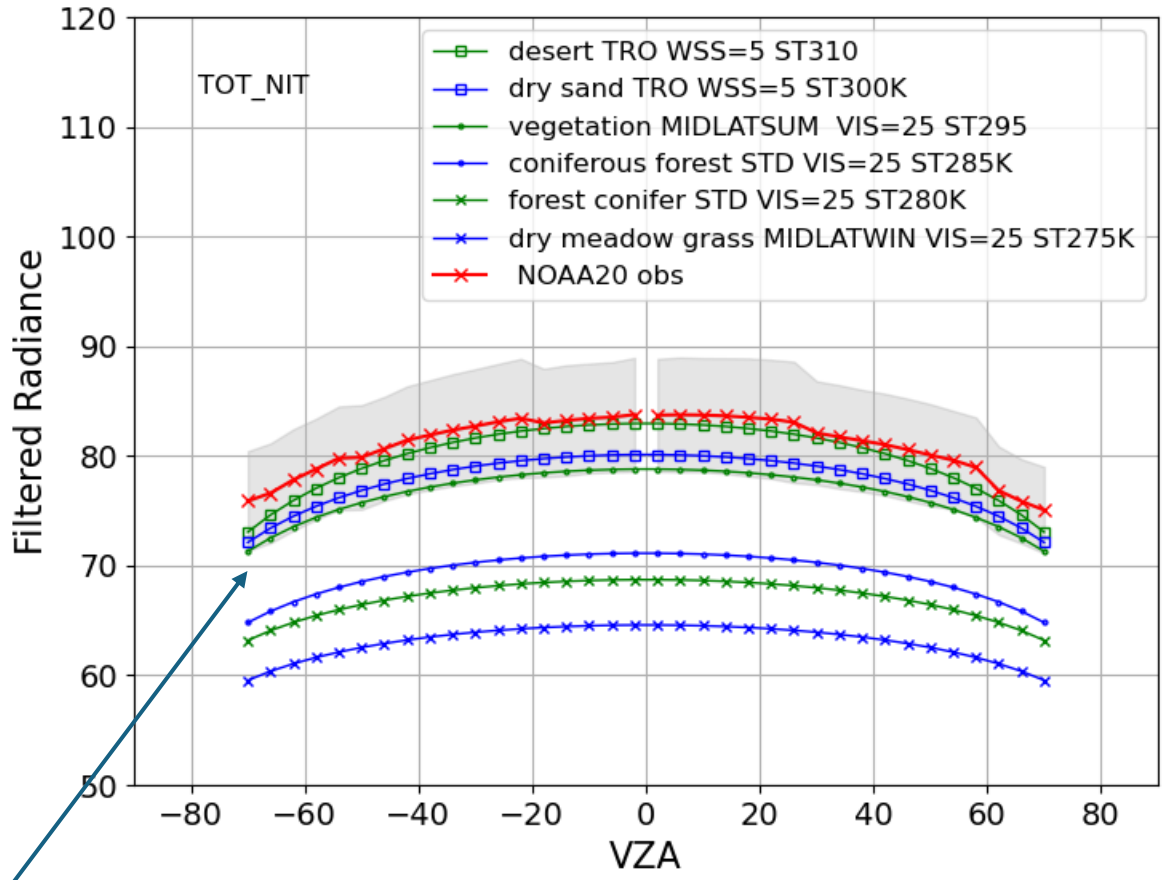


Conclusions:

1. The error over the hot surfaces is caused by using simulations for cooler surfaces.
2. The errors are limited over the colder surfaces even by using simulations for hotter surfaces.

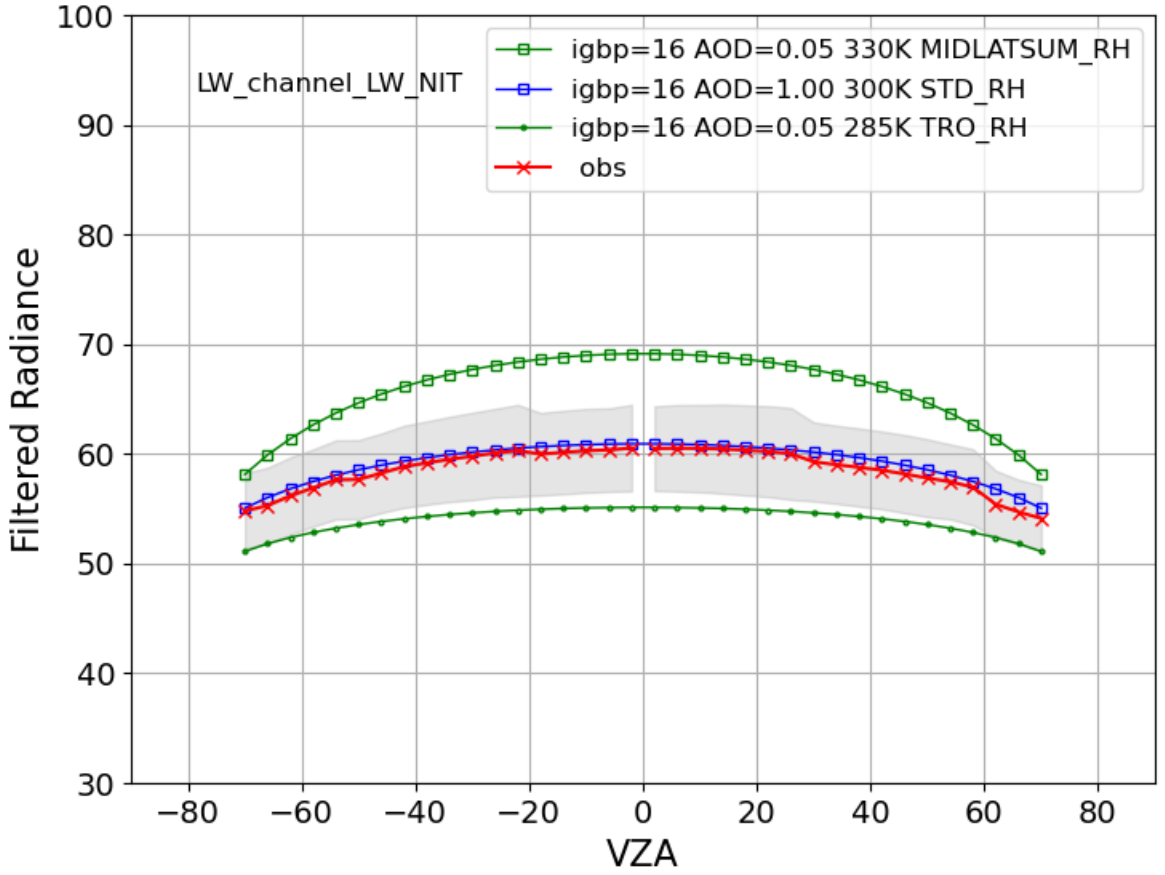
Simulations compared to observations over bright desert regions in July

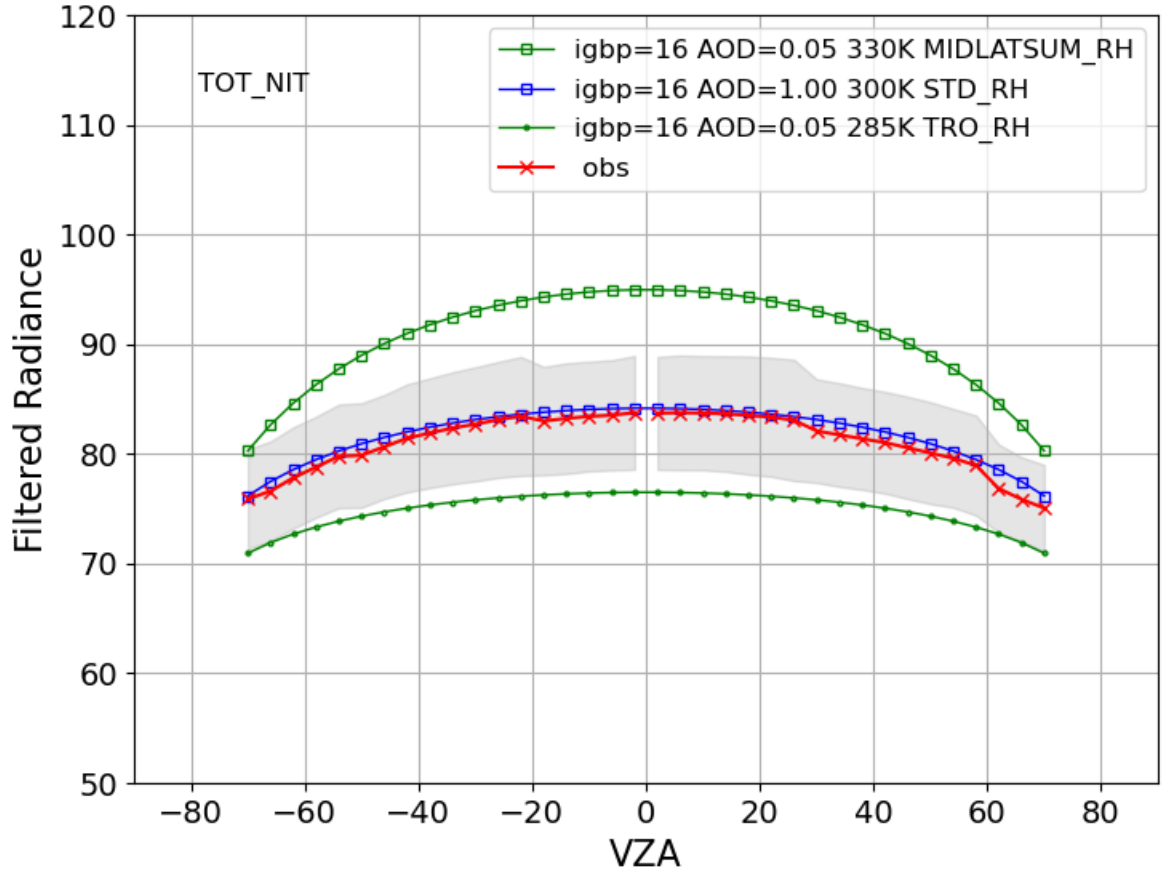




Veg. (295K) simulations

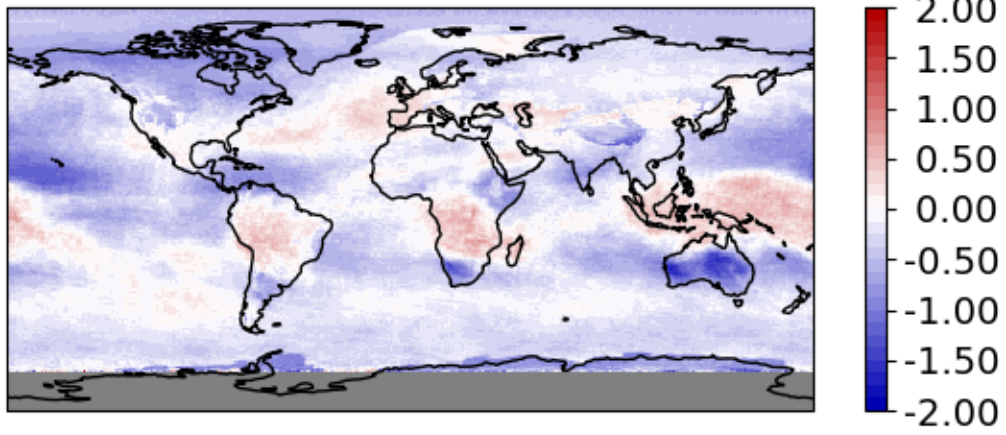
Simulations compared to observations over bright desert regions in July



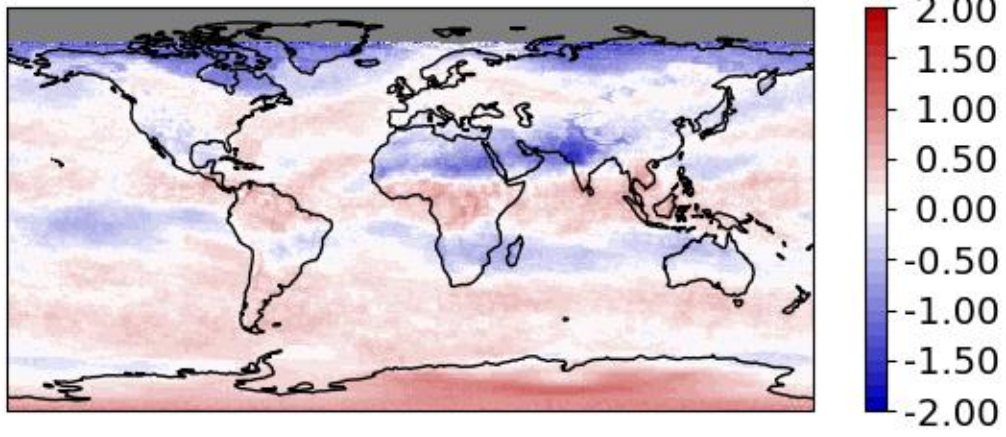


NIT flux
Ed4 LW (LW)- LW (TOT)

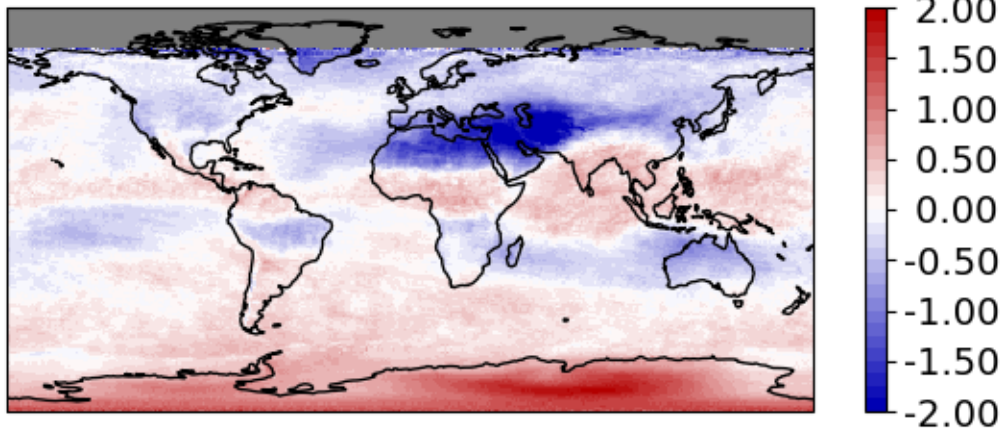
Ed4 201901 flux LW(LW)-LW(TOT)
Δ= -0.23 rms=0.40



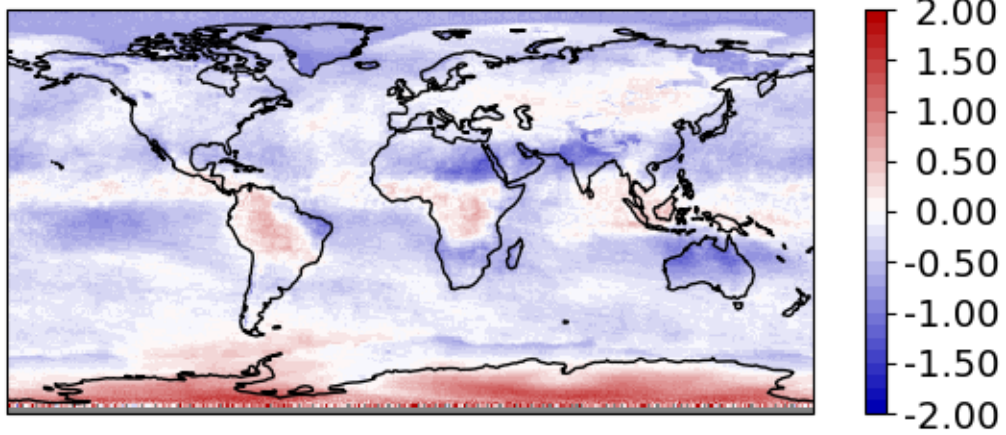
Ed4 201805 flux LW(LW)-LW(TOT)
Δ= 0.02 rms=0.34



Ed4 201807 flux LW(LW)-LW(TOT)
Δ= -0.05 rms=0.46

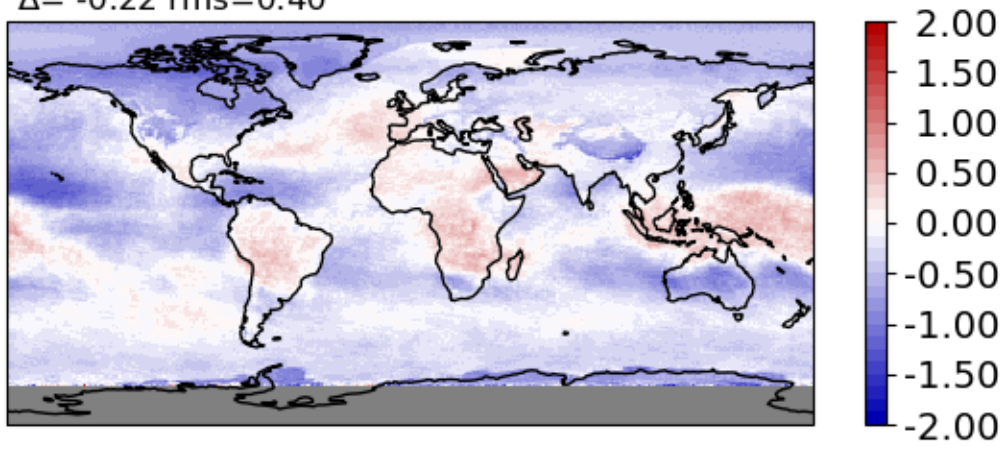


Ed4 201810 flux LW(LW)-LW(TOT)
Δ= -0.22 rms=0.37

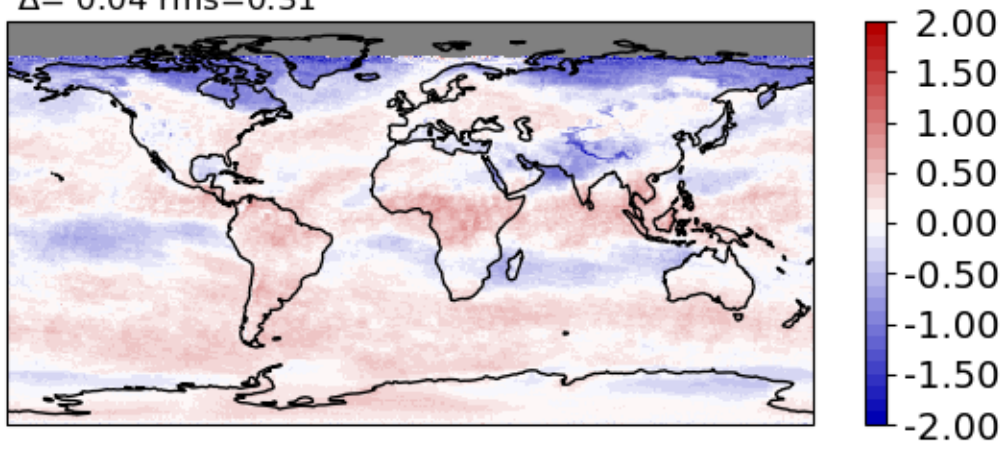


NIT flux
Ed5 LW (LW)- LW (TOT)

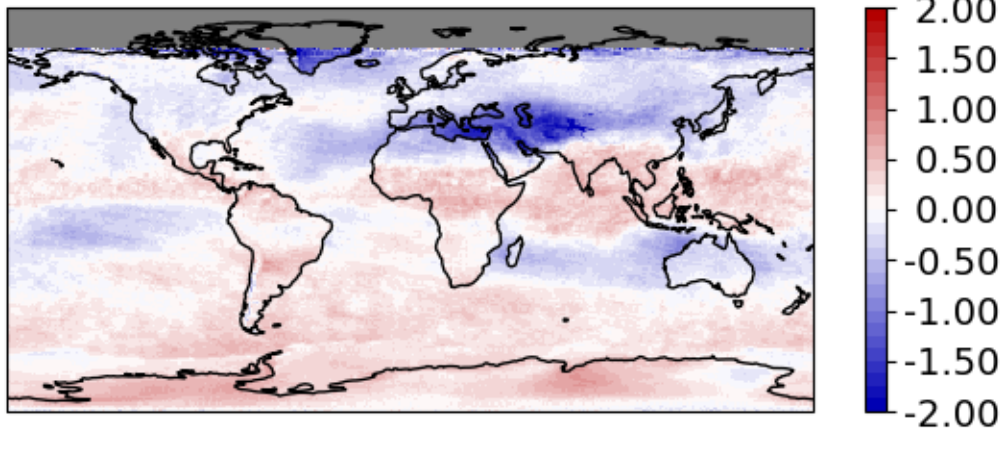
Ed5 201901 flux LW(LW)-LW(TOT)
Δ= -0.22 rms=0.40



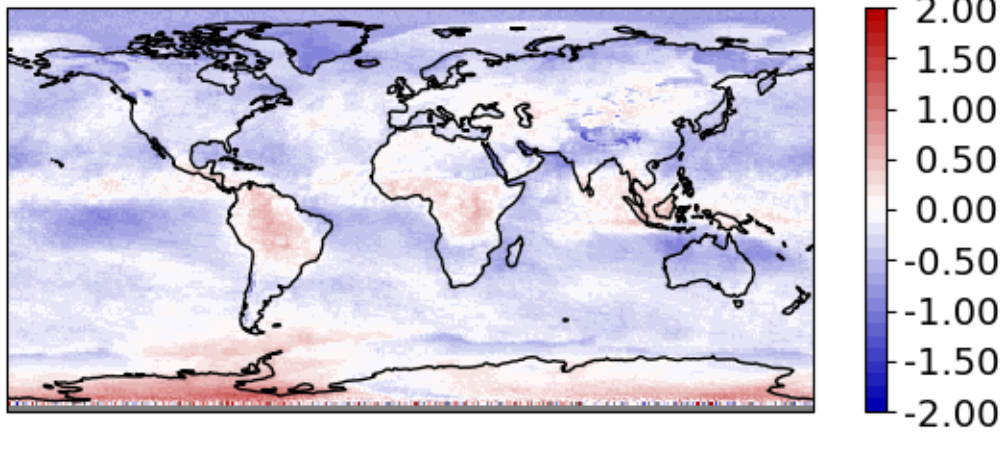
Ed5 201805 flux LW(LW)-LW(TOT)
Δ= 0.04 rms=0.31



Ed5 201807 flux LW(LW)-LW(TOT)
Δ= -0.01 rms=0.35

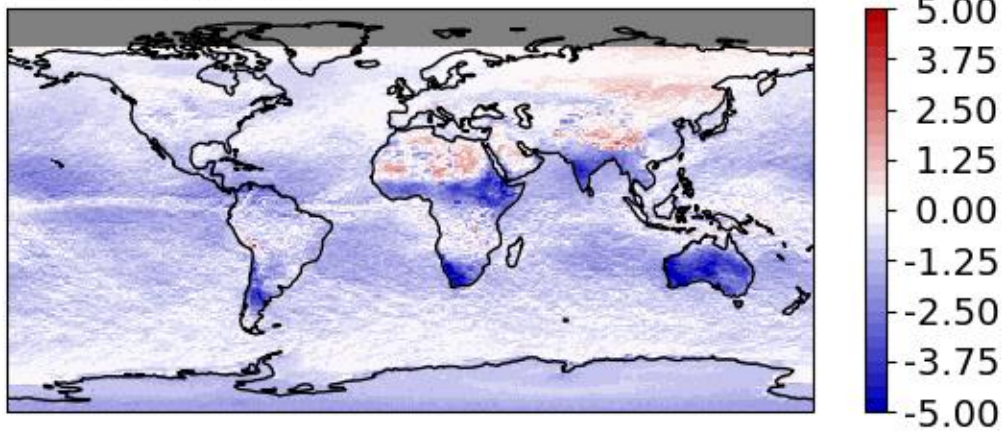


Ed5 201810 flux LW(LW)-LW(TOT)
Δ= -0.21 rms=0.33

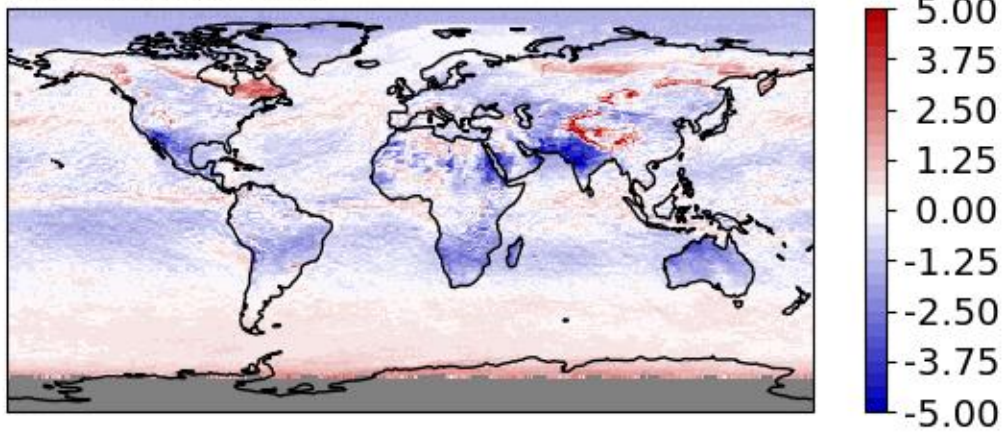


DAY flux
Ed4 LW (LW)- LW (TOT,SW)

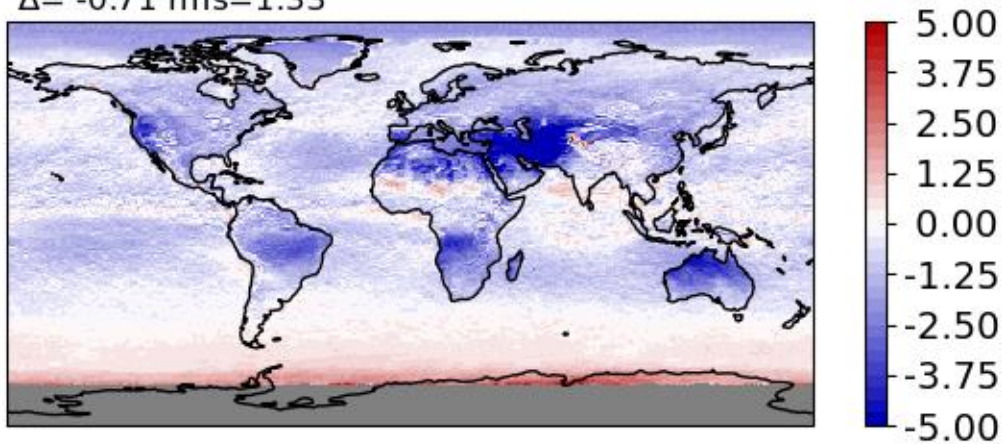
Ed4 201901 flux LW(LW)-LW(TOT,SW)
Δ= -0.86 rms=1.21



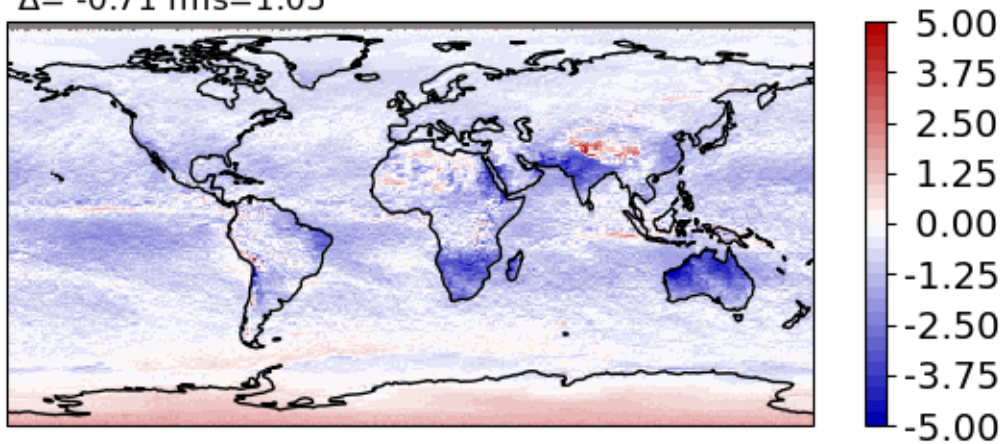
Ed4 201805 flux LW(LW)-LW(TOT,SW)
Δ= -0.28 rms=0.94



Ed4 201807 flux LW(LW)-LW(TOT,SW)
Δ= -0.71 rms=1.33

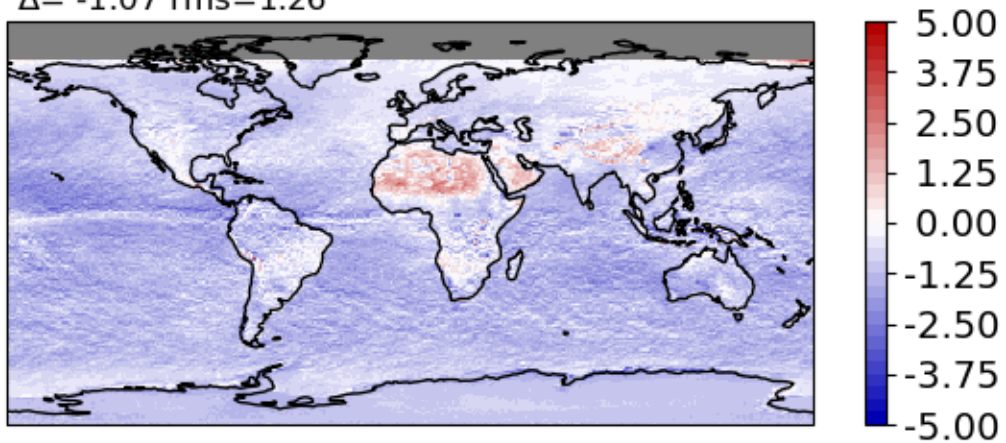


Ed4 201810 flux LW(LW)-LW(TOT,SW)
Δ= -0.71 rms=1.05

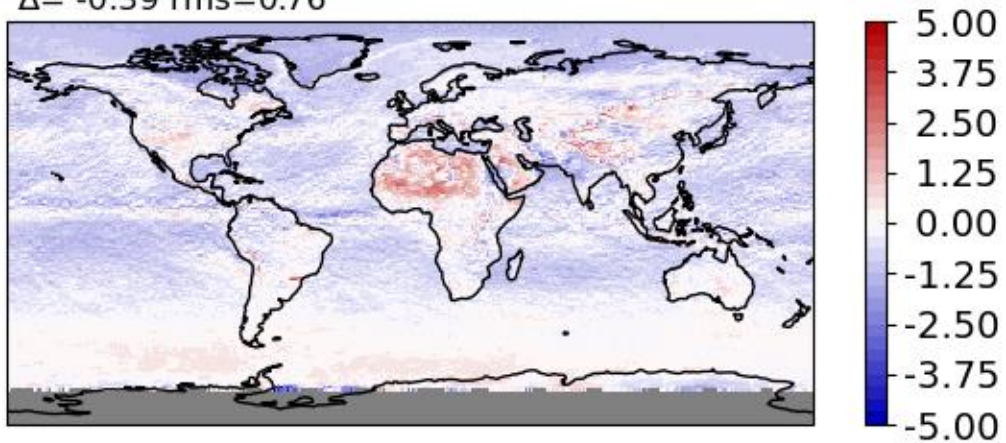


DAY flux
Ed5 LW (LW)- LW (TOT,SW)

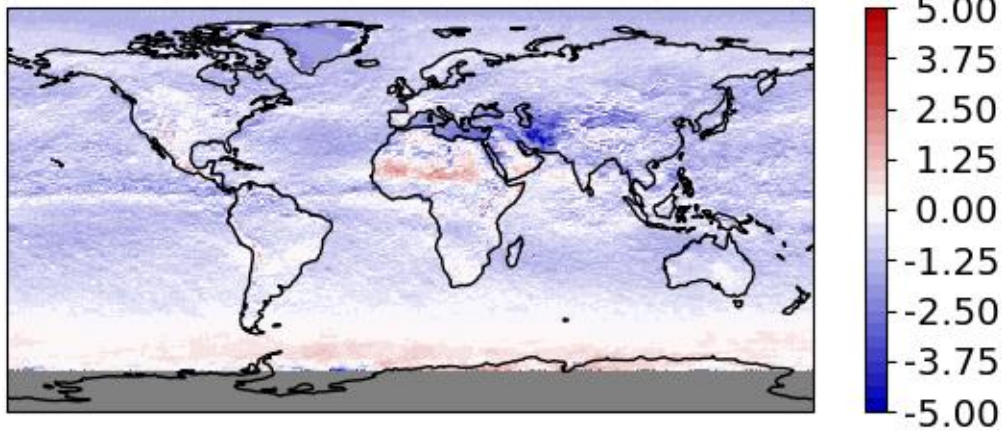
Ed5 201901 flux LW(LW)-LW(TOT,SW)
Δ= -1.07 rms=1.26



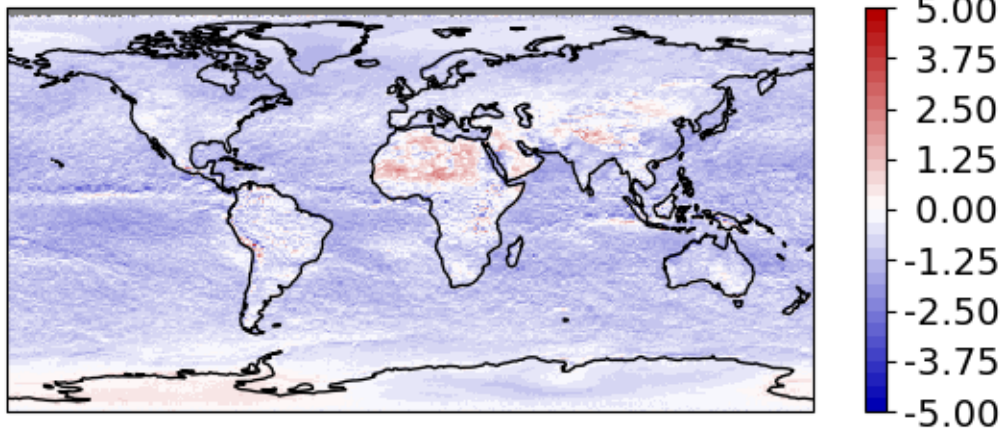
Ed5 201805 flux LW(LW)-LW(TOT,SW)
Δ= -0.39 rms=0.76



Ed5 201807 flux LW(LW)-LW(TOT,SW)
Δ= -0.71 rms=0.98



Ed5 201810 flux LW(LW)-LW(TOT,SW)
Δ= -0.88 rms=1.06



Split SW flux retrieval

Visible flux from Libera

- 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.

- Radiances in the visible band (0.3-0.7 μm) can be derived as:

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

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

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

Alternative approach for split SW flux retrieval

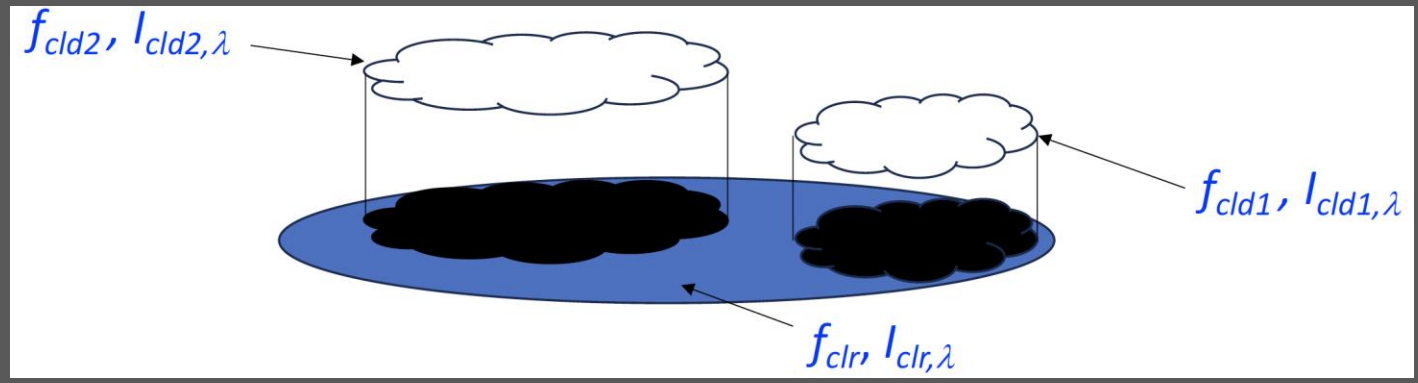
- Incoming energy in the range from 0.3-5.0um can be split by VIS (0.3-0.7um) and NIR (0.7-5.0um).
- Define an anisotropic factor ratio of NIR to VIS

  $\beta = R_{NIR}/R_{VIS}$
- the NIR flux relates to SW flux by

  $F_{NIR} = F_{SW}/(1+\alpha)$, where, $\alpha = (I_{VIS}/I_{NIR})\beta$,
- 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.
- In $\alpha = (I_{VIS}/I_{NIR})\beta$, I_{VIS} and I_{NIR} are derived from ratios of I_{VIS} to I_{SW} and I_{NIR} to I_{SW} based on theoretical simulations.

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} .

$$R_{VIS} = \pi I'_{VIS}/F_{VIS} \qquad R_{NIR} = \pi I'_{NIR}/F_{NIR}$$

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

MODTRAN simulations for β retrieval LUTs

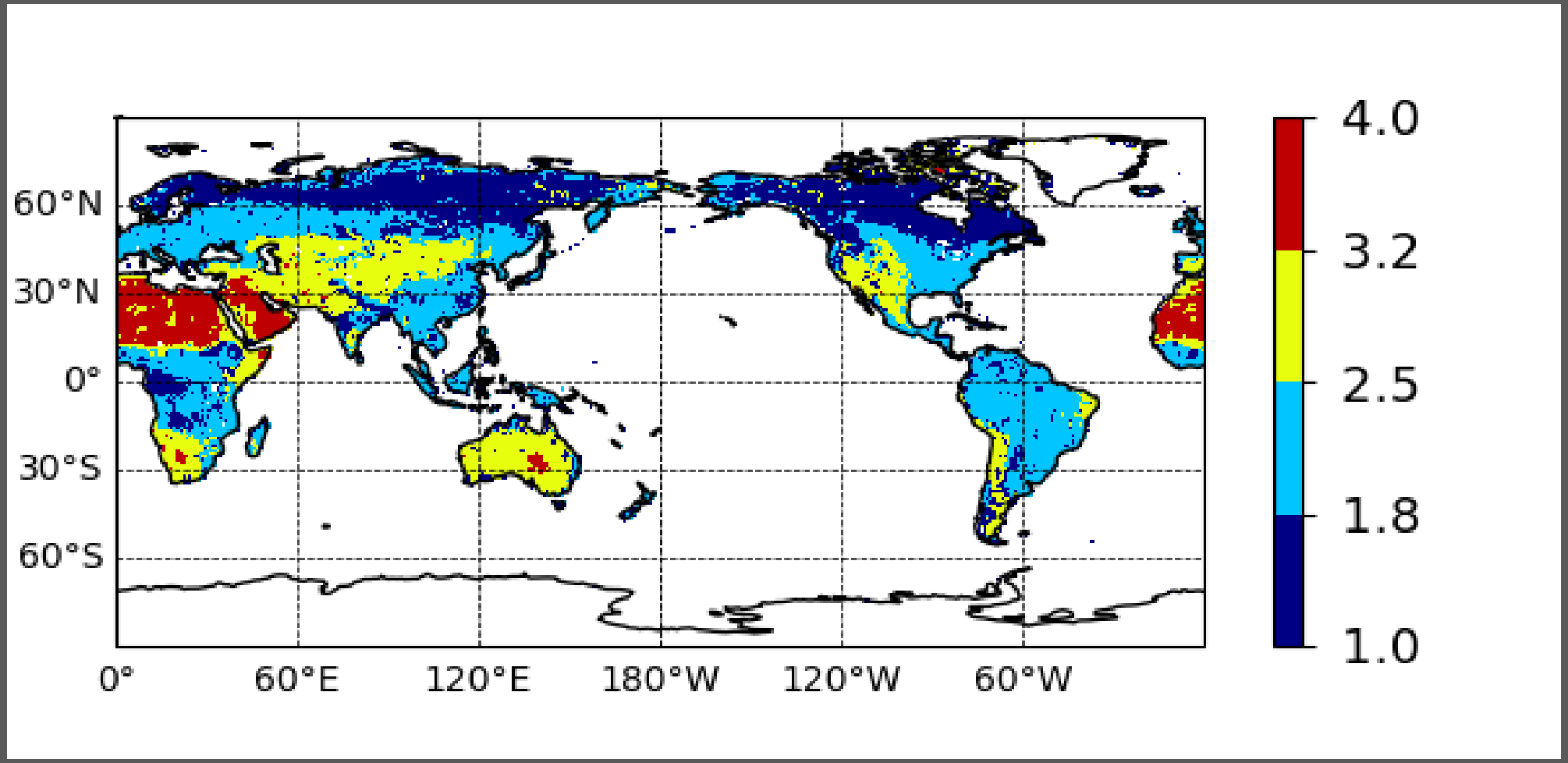
LUTs for β retrieval contain members according to sensitivity of β to scene Properties (e.g., cloud optical depth, aerosols, surface BRDF, etc.)

Clear sky over ocean
- 6 AODs, 2 ocean wind speeds

Clear sky over land
- 4 surface types in each of 4 seasons (total 16, 6 completed), 3 AODs

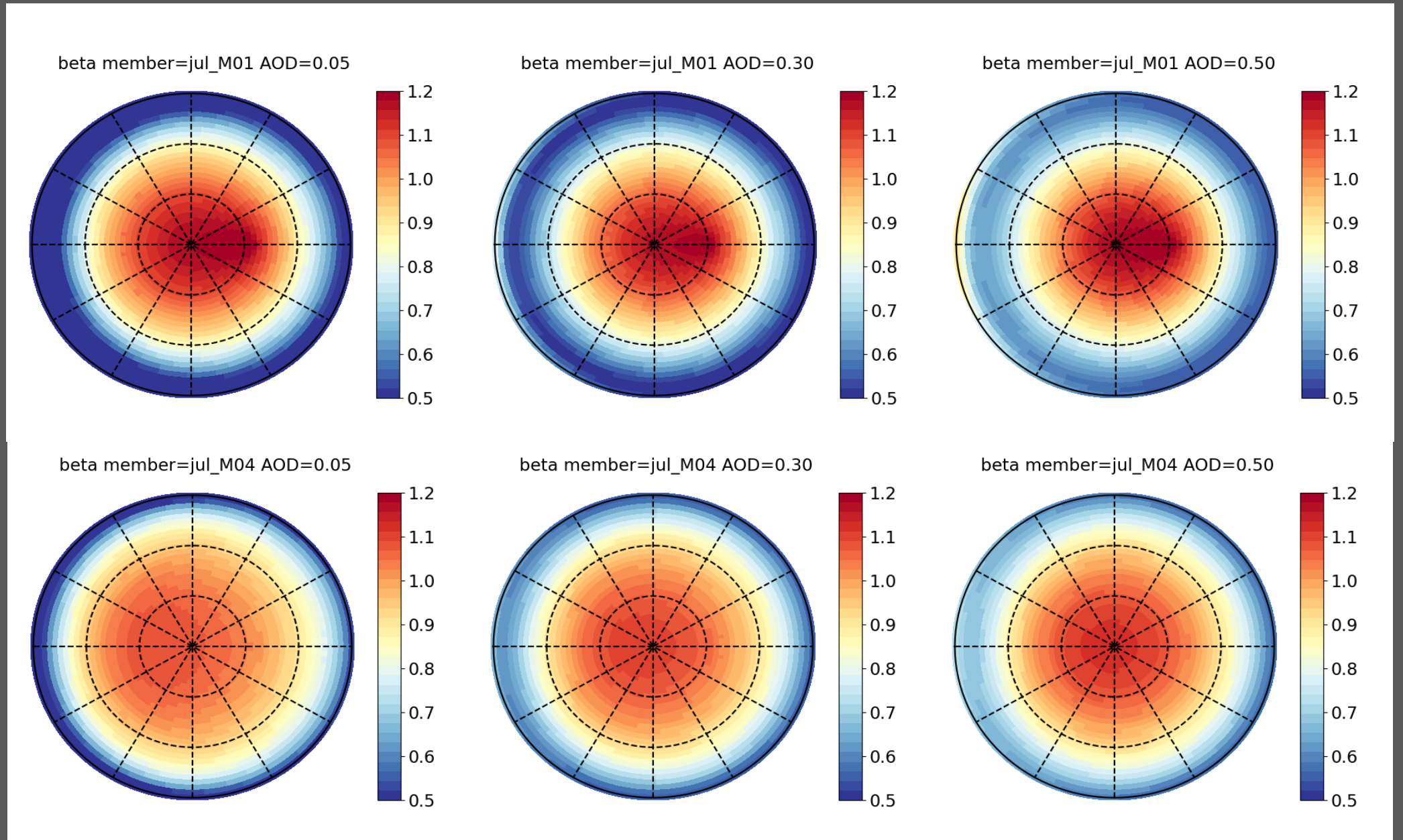
Overcast
6 CODs and 2 cloud phases.

Sensitivity of β to land surface

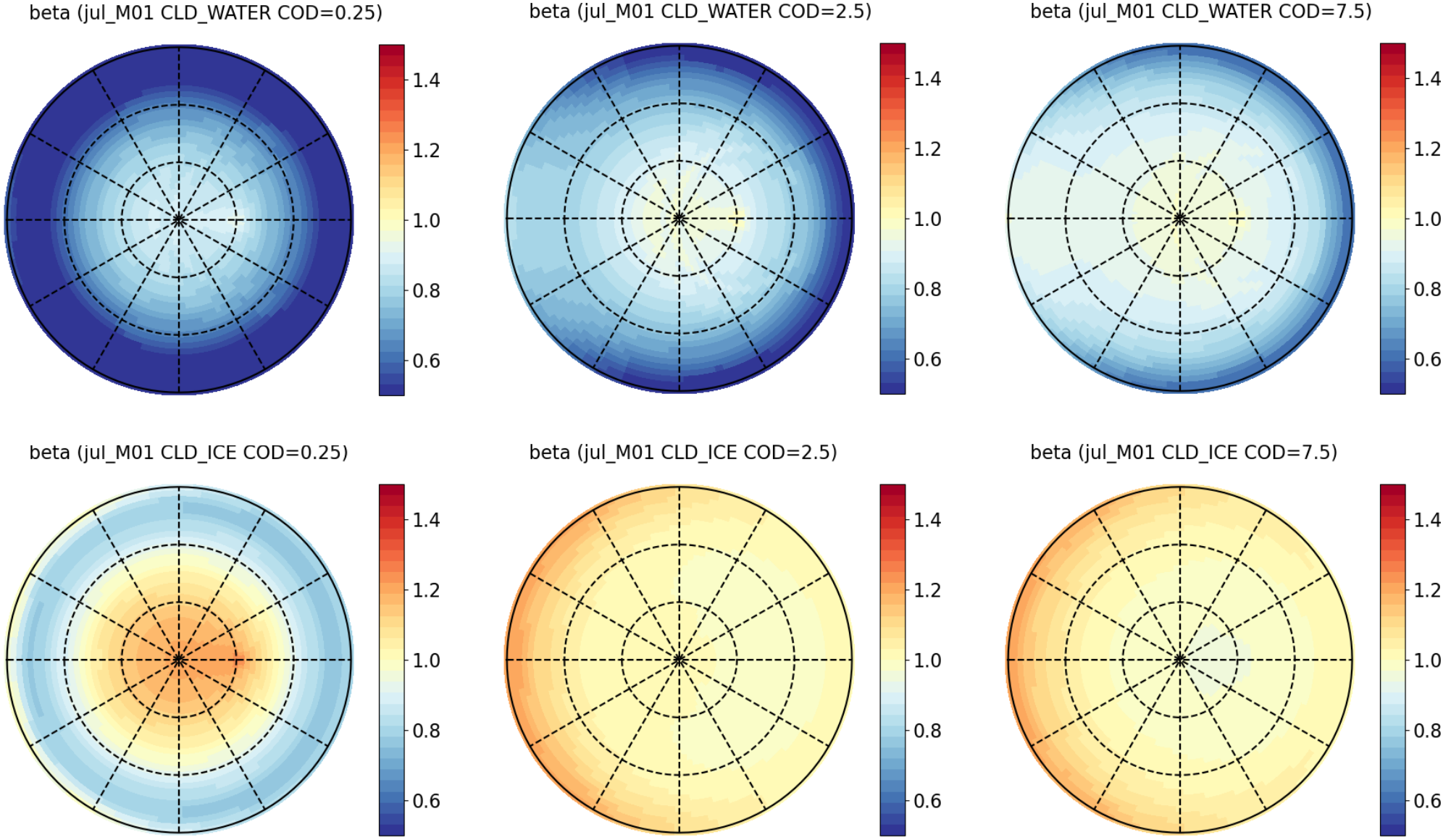


land surfaces are classified based on MODIS 5-year BRDF kernel climatology

Sensitivity of β to land surface and COD



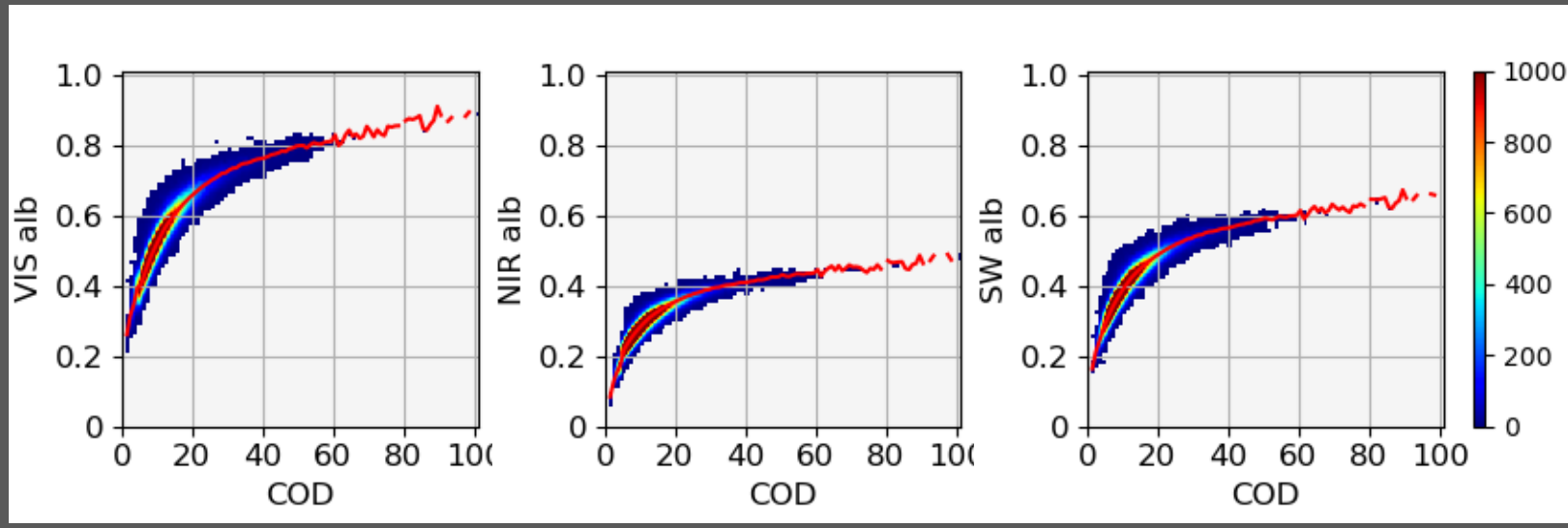
Sensitivity of β to cloud COD and phase over land



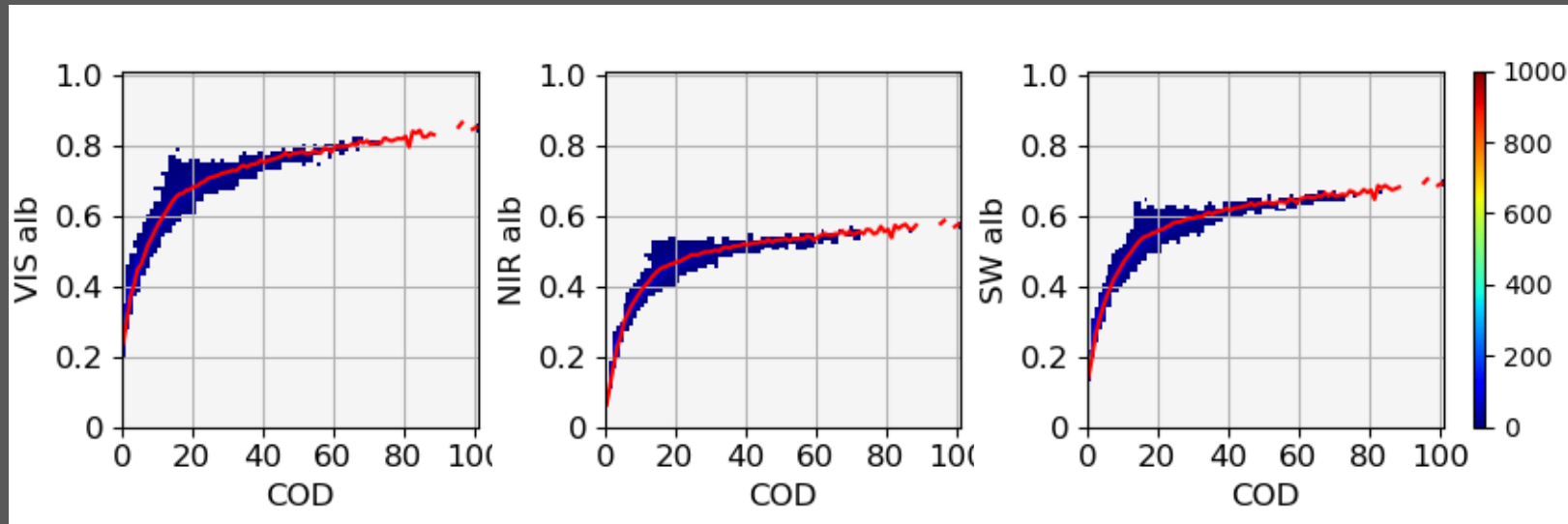
Ocean clouds 201407

- VIS albedo for water clouds is lower than ice clouds, because water clouds are less reflective.
- NIR albedo for water clouds is lower than ice clouds, because of water vapor absorption above clouds.
- Overall, SW albedo for water clouds is lower than ice clouds.

Water cloud (Phase < 1.01); Height: 1-2 km; SZA: 40-50°



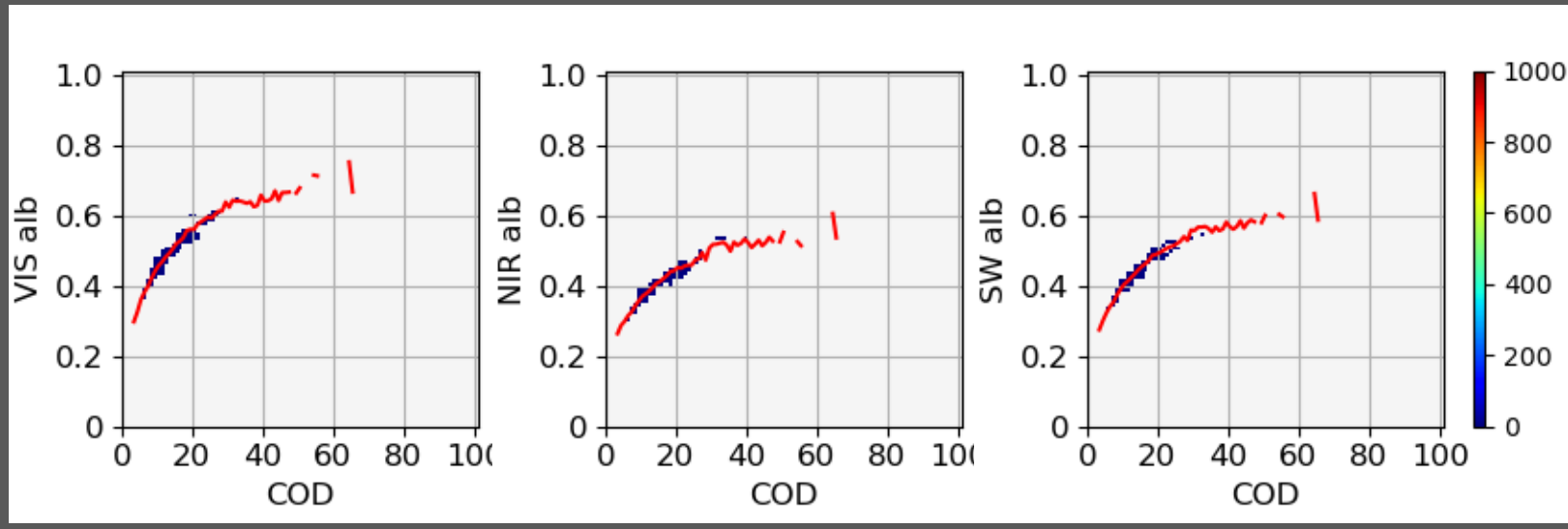
Ice cloud (Phase > 1.75); Height: 9-10 km; SZA: 40-50°



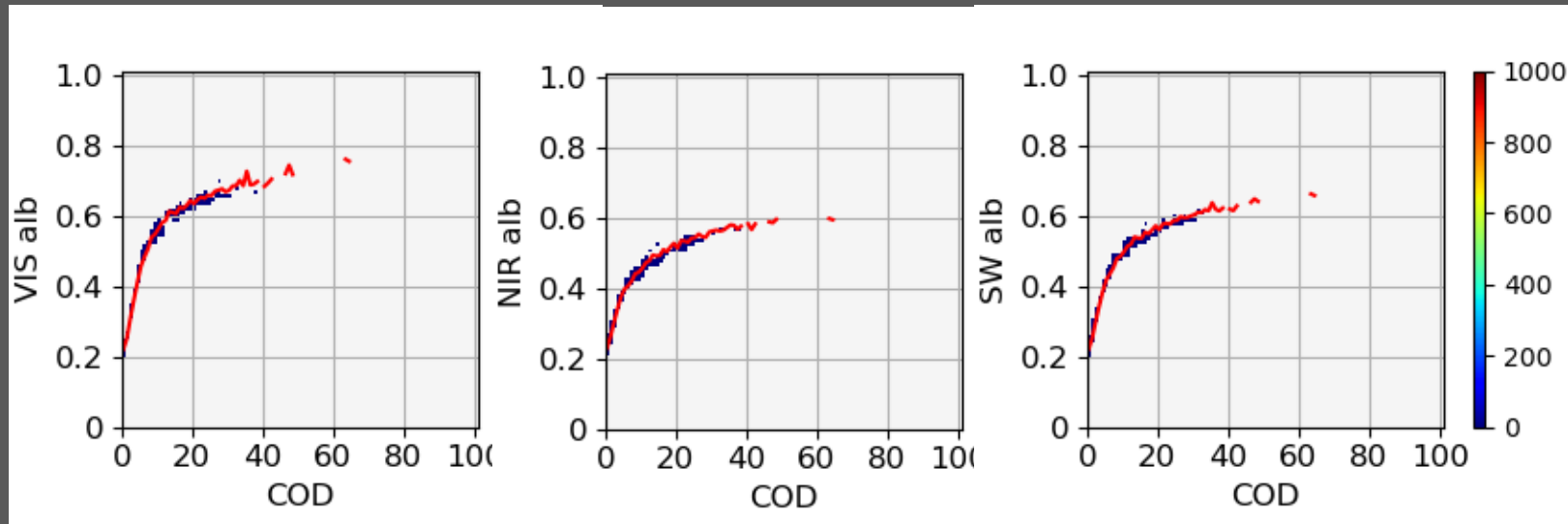
Land M03 clouds 201407

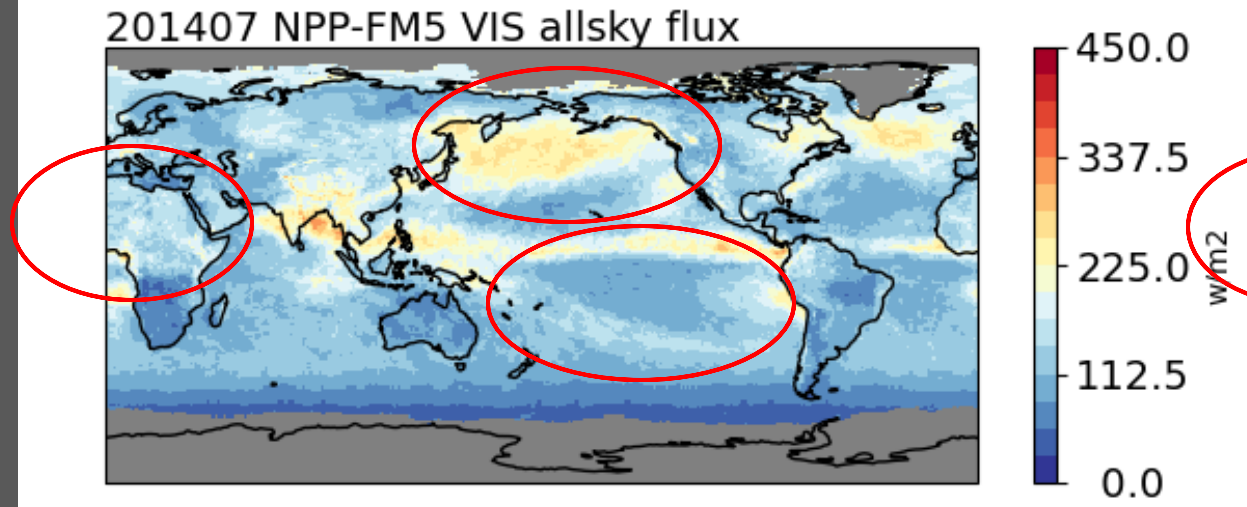
- VIS albedo for water clouds is lower than ice clouds, because water clouds are less reflective.
- NIR albedo for water clouds is lower than ice clouds, because of water vapor absorption above clouds.
- Overall, SW albedo for water clouds is lower than ice clouds.

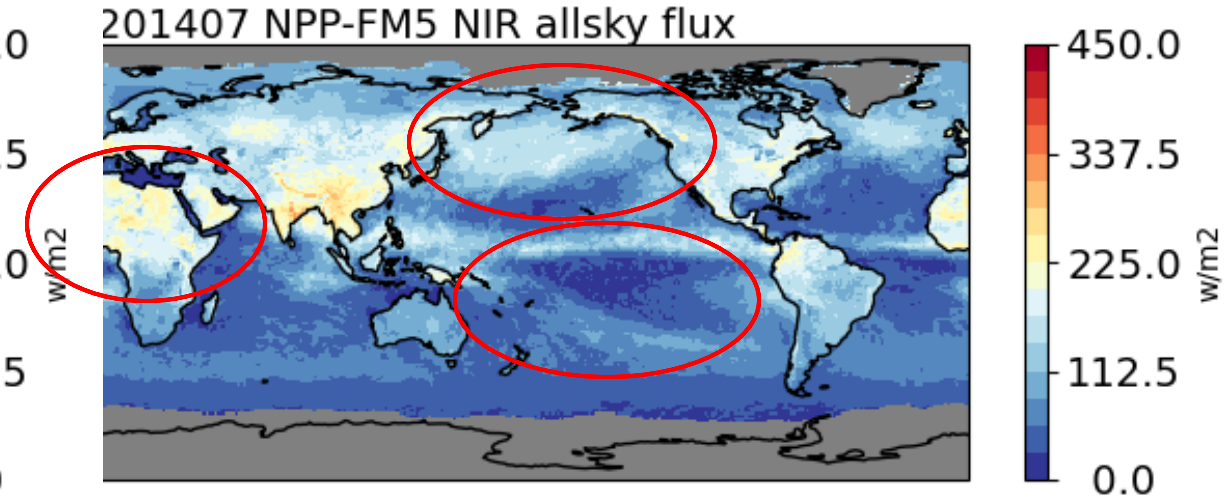
Water cloud (Phase < 1.01); Height: 1-2 km; SZA: 40-50°

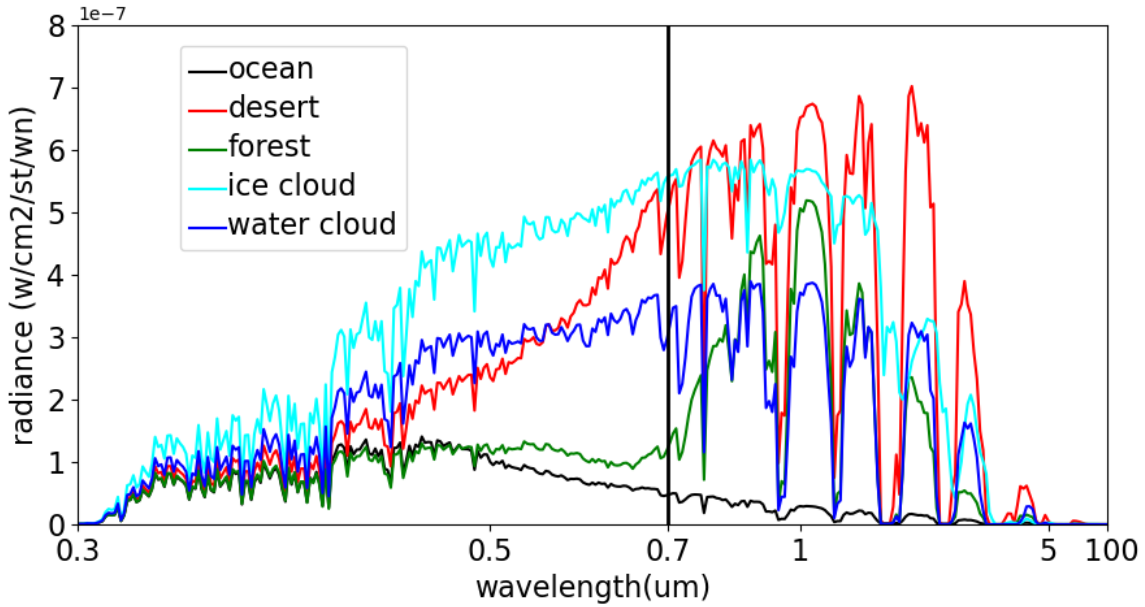


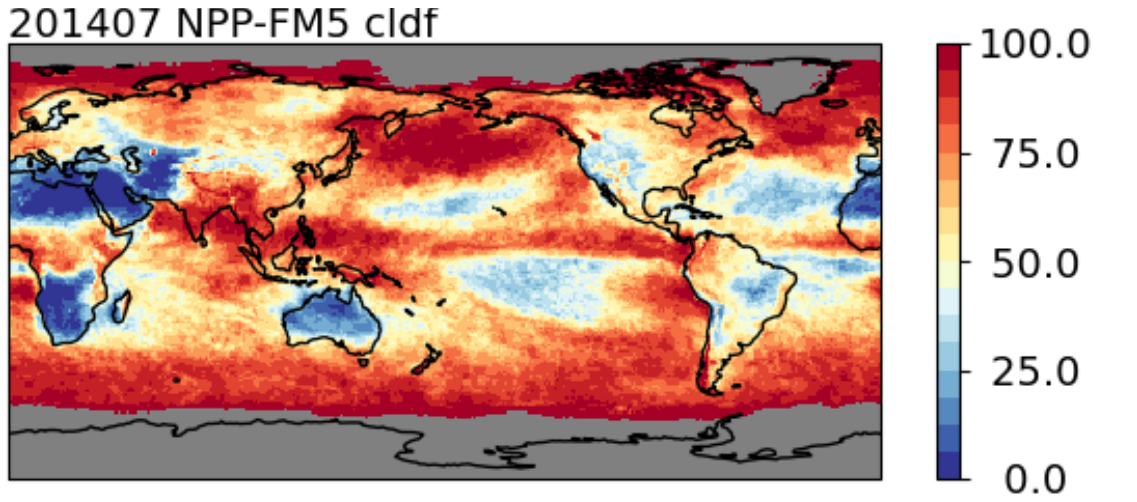
Ice cloud (Phase > 1.75); Height: 9-10 km; SZA: 40-50°











Clouds: VIS > NIR Clear-sky Forest, desert: VIS < NIR Clear-sky ocean: VIS > NIR

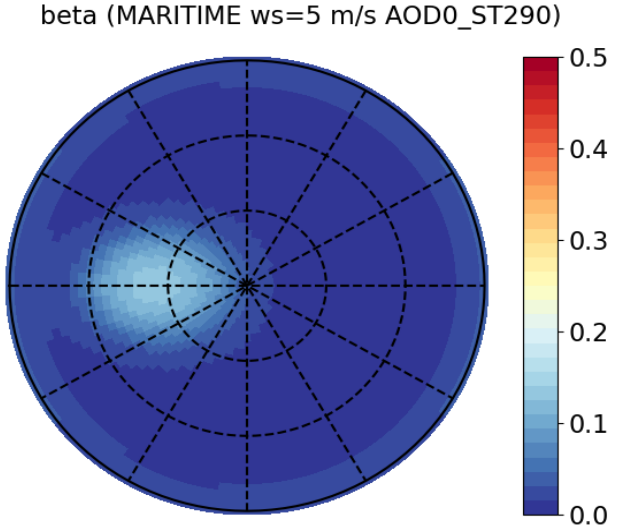
Summary

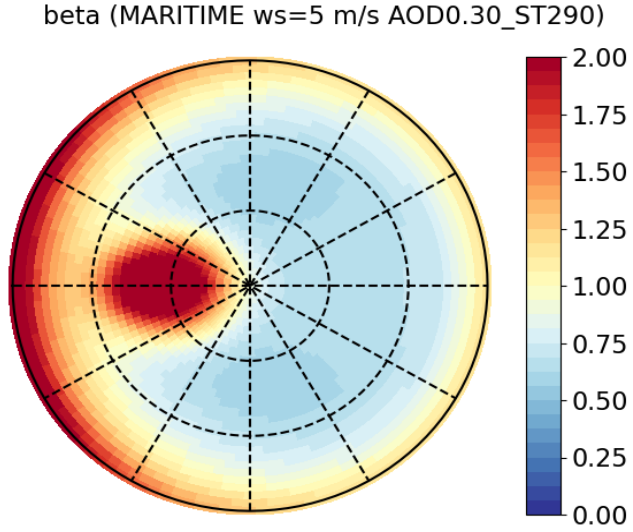
- Updated radiance unfiltering process improved regional consistencies over land between LW unfiltered radiance from LW channel and that from TOT channel at night (TOT and SW channels during daytime).

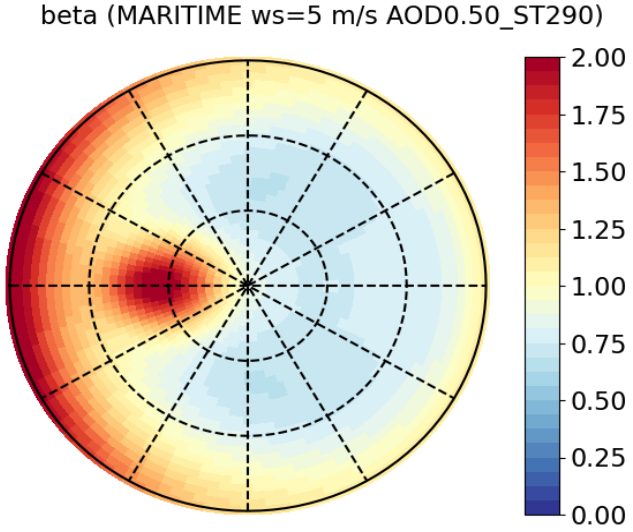
- Continued to develop an alternate method to retrieve instantaneous split SW flux; results over ocean/land showed confidence and viability of this approach.

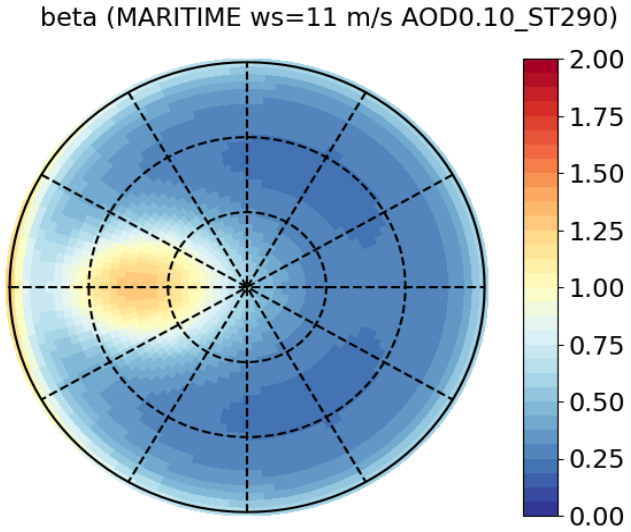
- Confirmed the reliability and robustness of CERES ADMs by evaluating their sensitivity to ENSO climate variability. The analysis has been documented and will be submitted for publication.

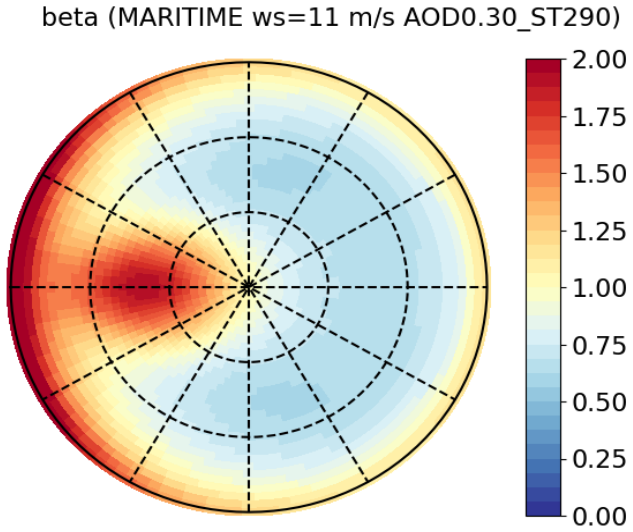
Sensitivity of β to ocean wind speed and AOD

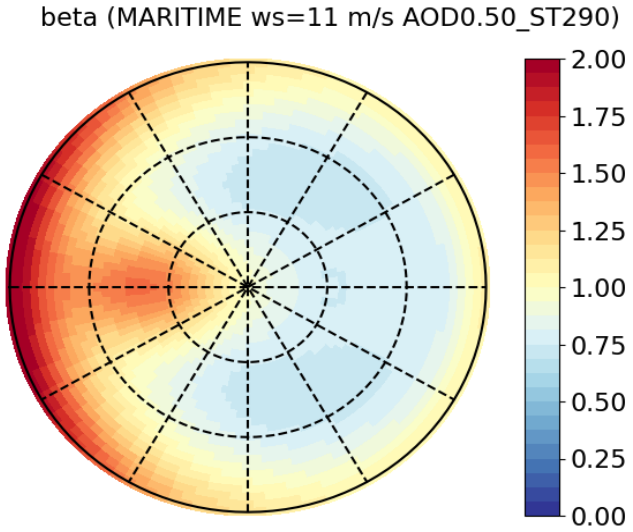












Sensitivity of β to cloud COD and phase over ocean