CERES Angular Distribution Model Working Group Report

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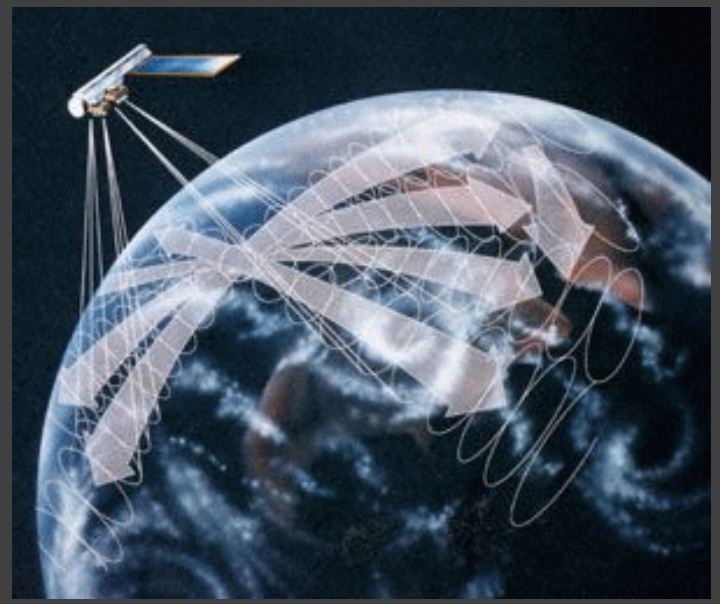
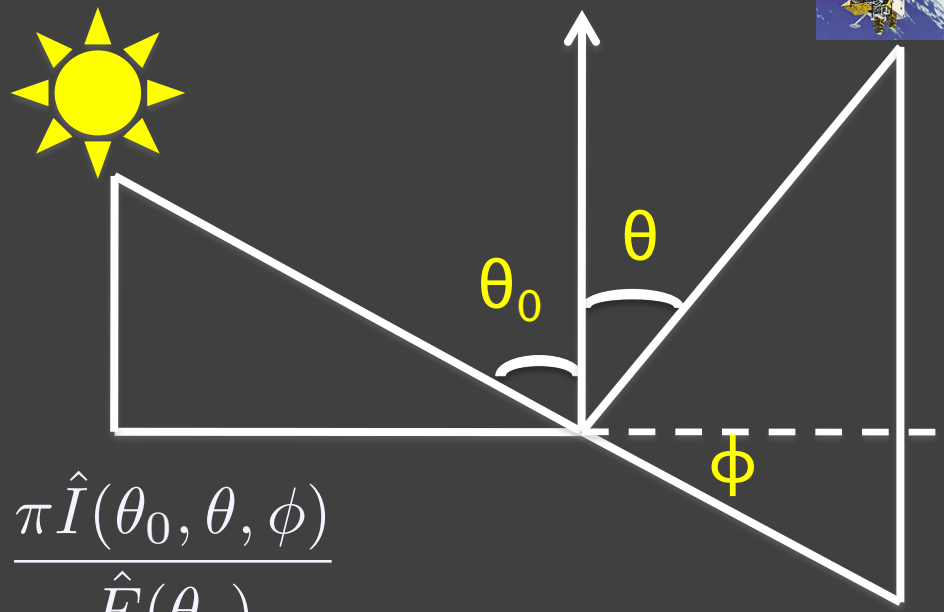


From radiance to flux: angular distribution models

- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type:



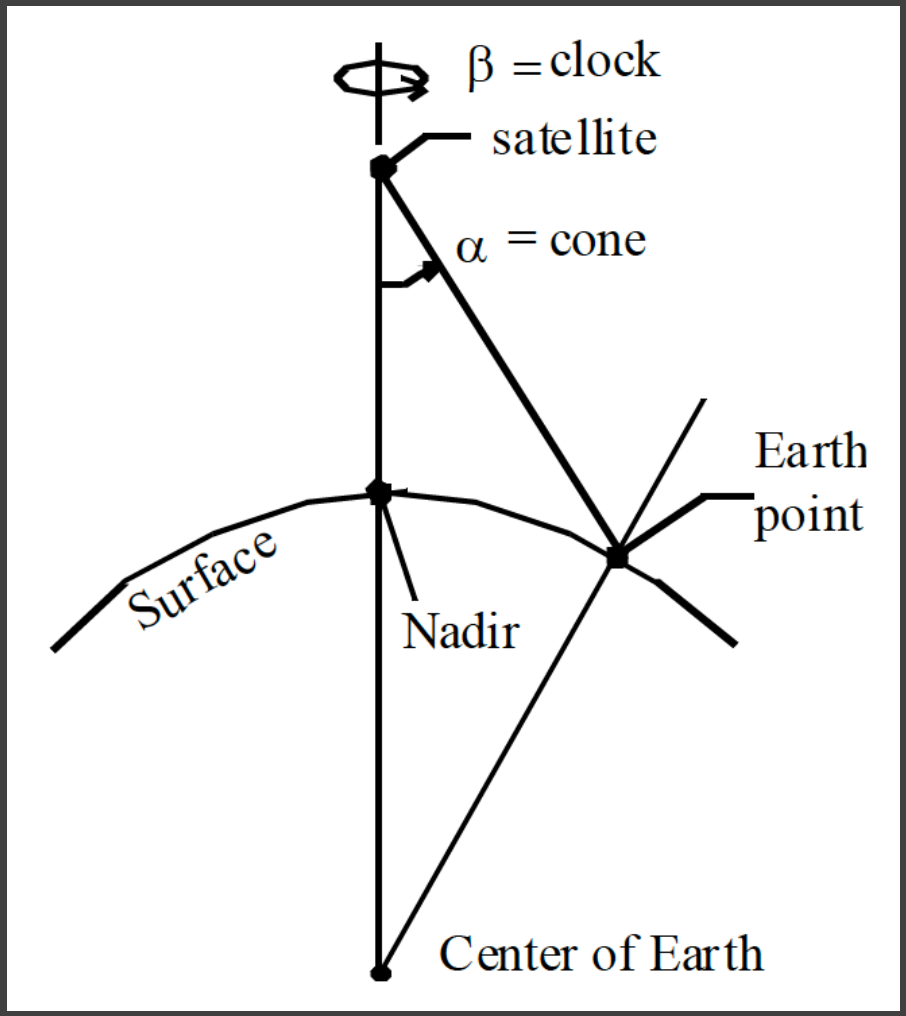
$$R(\theta_0,\theta,\phi)=\frac{\pi\hat{I}(\theta_0,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}}\hat{I}(\theta_0,\theta,\phi)cos\theta sin\theta d\theta d\phi}=\frac{\pi\hat{I}(\theta_0,\theta,\phi)}{\hat{F}(\theta_0)}$$

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

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

CERES NPP is in full RAP scan

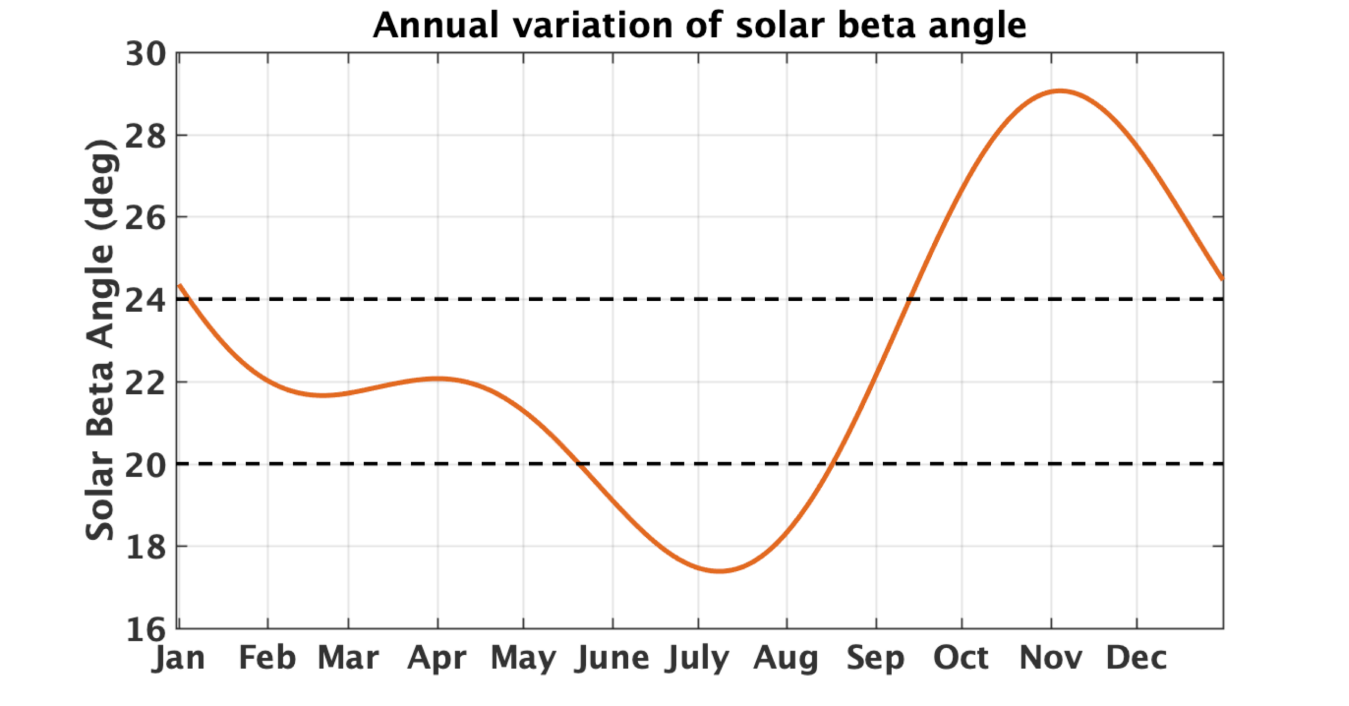
- CERES instrument on NPP is in full biaxial scan since March 24, 2020, after many months of coordination to get extra commands needed to avoid the solar danger zone.
- As biaxial scan was not planned for CERES instrument on NPP, CERES instrument doesn't have an unobstructed view from all angles.
- There is an antenna that needs to be avoided at clock angle of ~20° on NPP.
- The clock angle is the azimuth angle of the instrument view vector from the satellite to the Earth point relative to the inertial velocity vector.
- The cone angle is the angle between a vector from the satellite to the center of the Earth and the instrument view vector from the satellite to the Earth point.
- The clock angle and the cone angle define the direction of the instrument view vector to the Earth point.

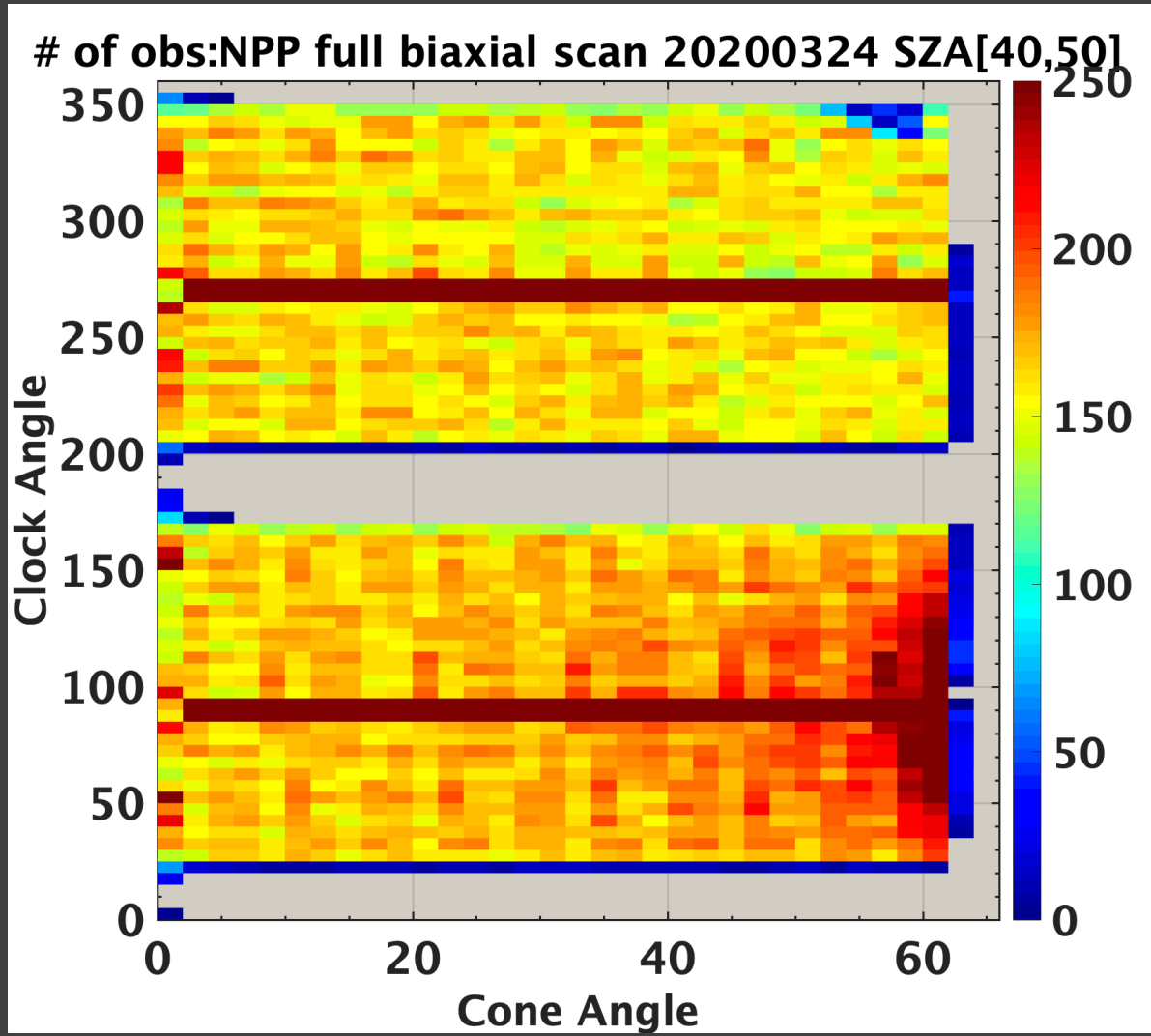


From SSF Collection Document

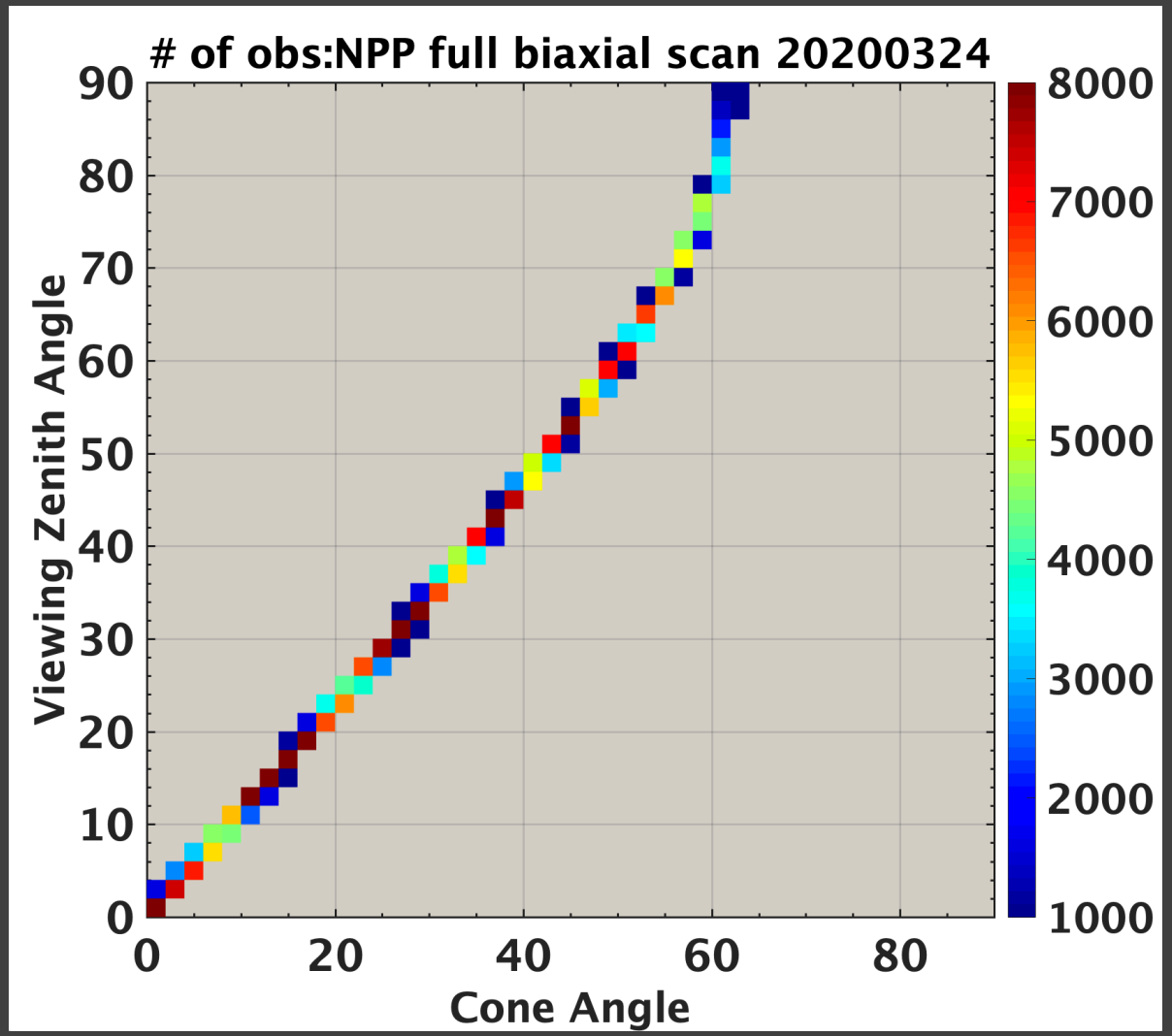
Cone angle and clock angle ranges to avoid the antenna

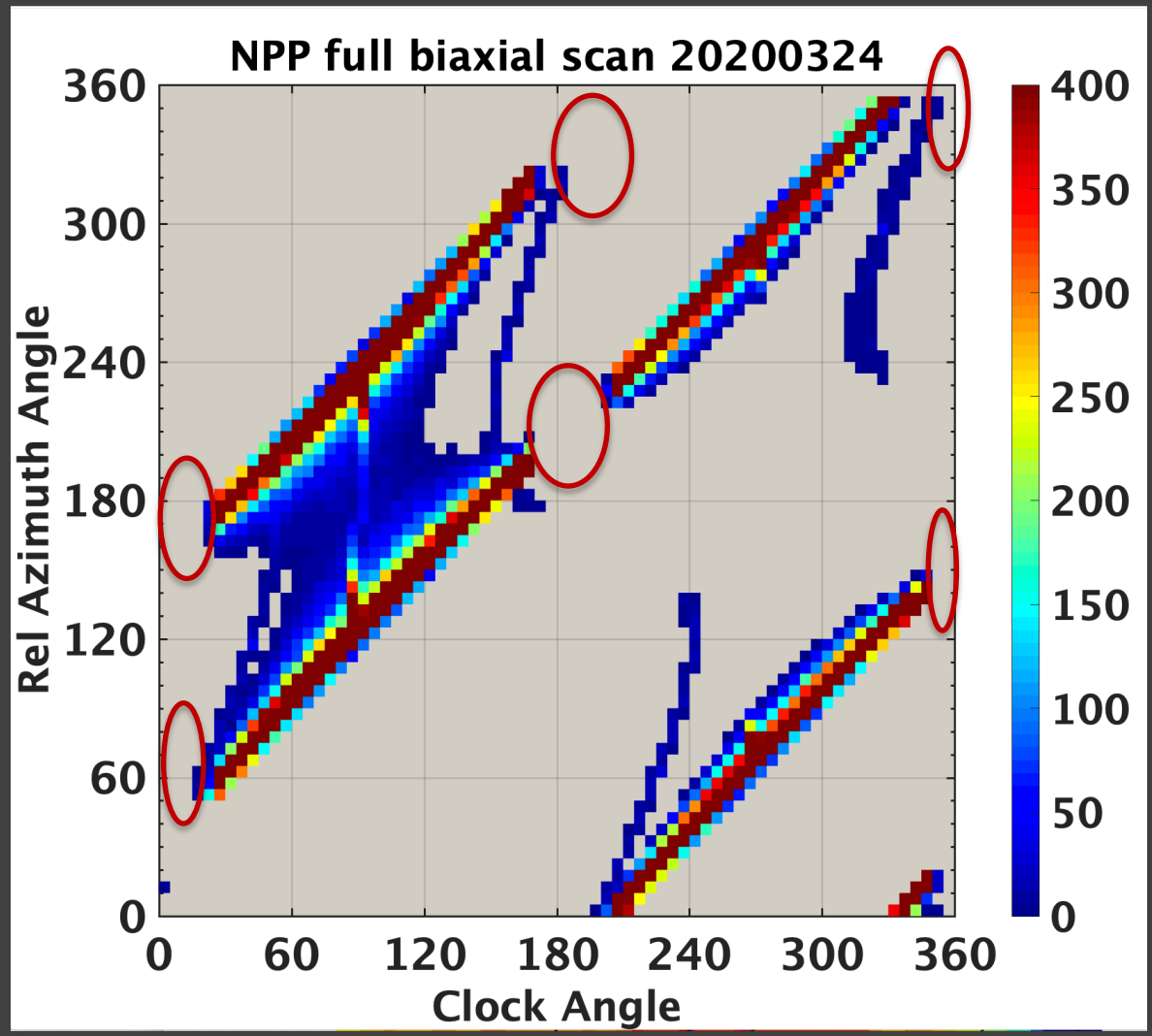
- For solar beta angle < 24°:
  - Clock angle: 25°-169°, cone angle: 0°-64°
  - Clock angle: 205°-349°, cone angle: 0°-64°
- For solar beta angle ≥ 24°
  - Clock angle: 25°-180°, cone angle 0°-64°
  - Clock angle: 205°-360°, cone angle 0°-64°





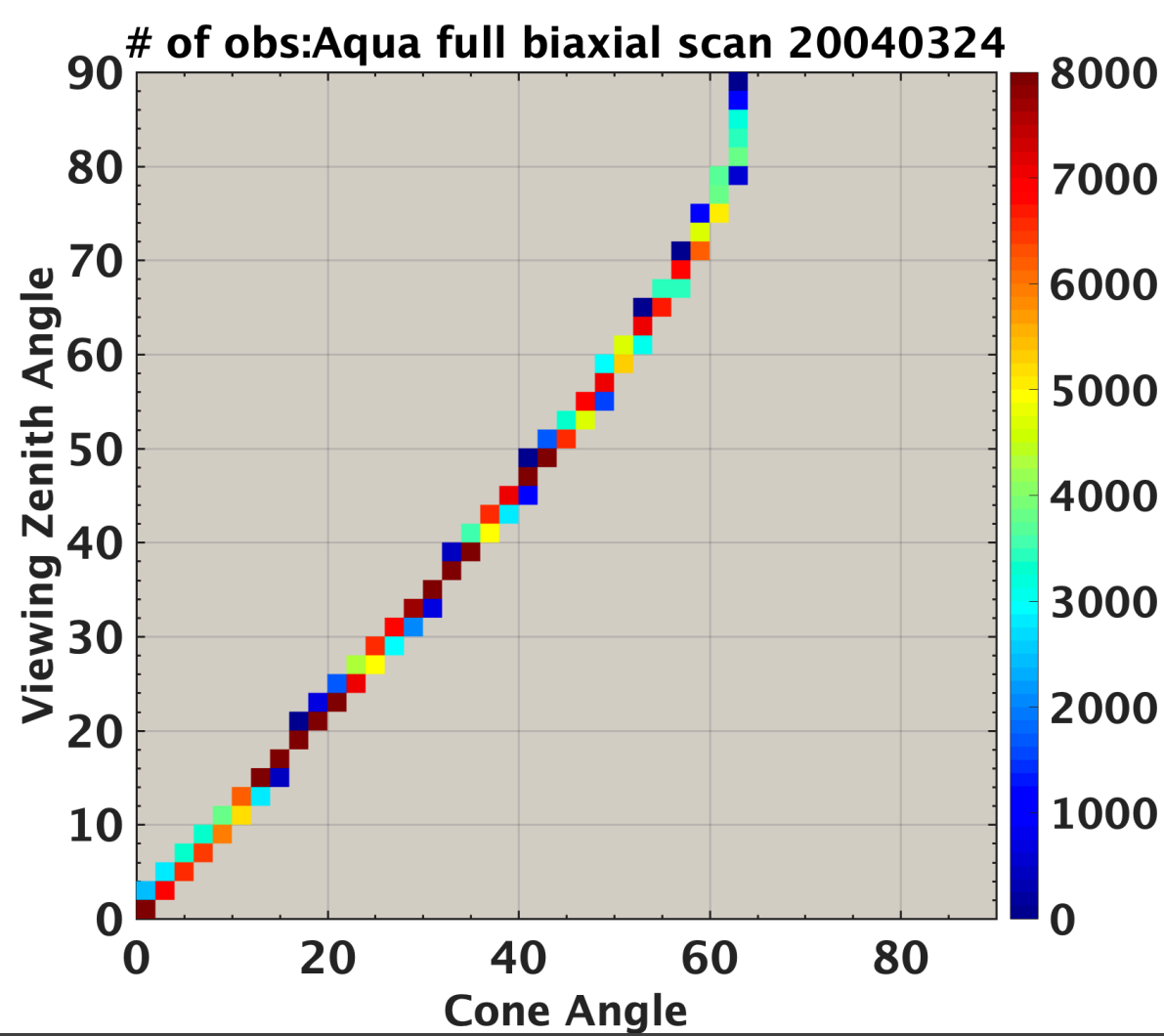
Relationship between cone angle and viewing zenith angle, clock angle and relative azimuth angle for NPP biaxial scan

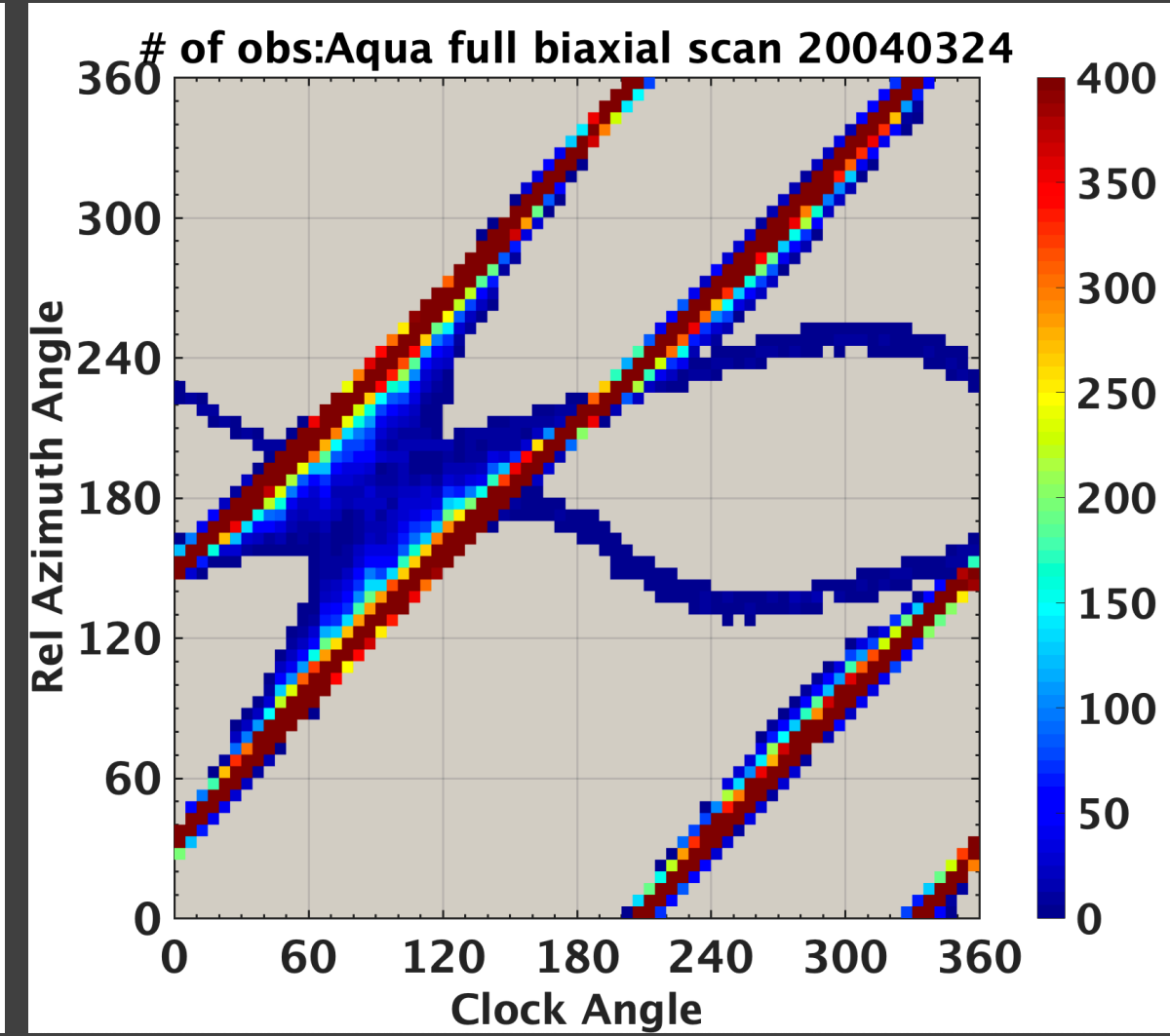




March 24, 2020, for SZA between 40-50 ˚

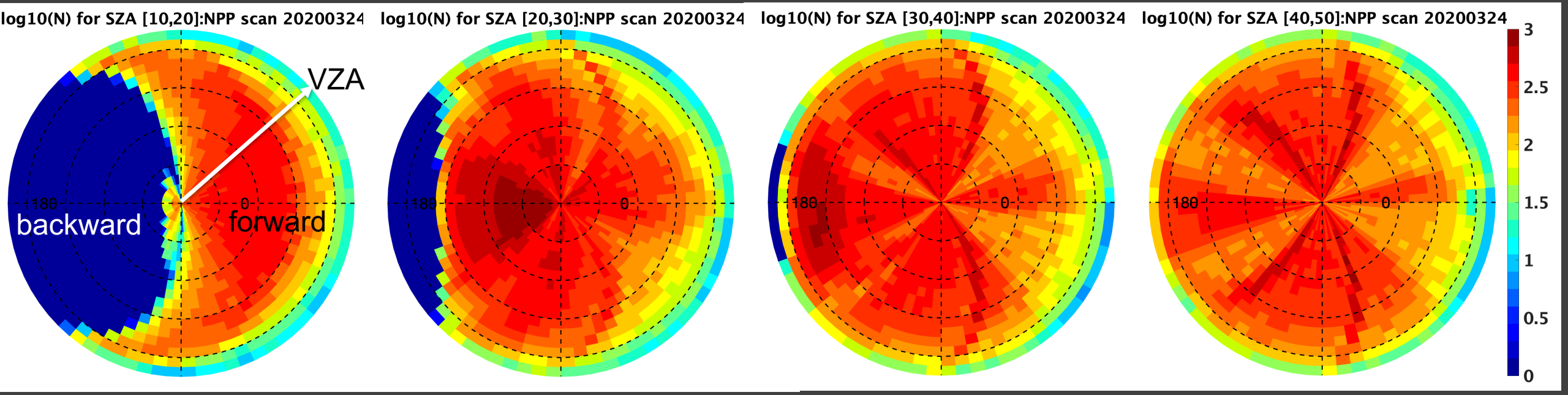
Relationship between cone angle and viewing zenith angle, clock angle and relative azimuth angle for Aqua biaxial scan

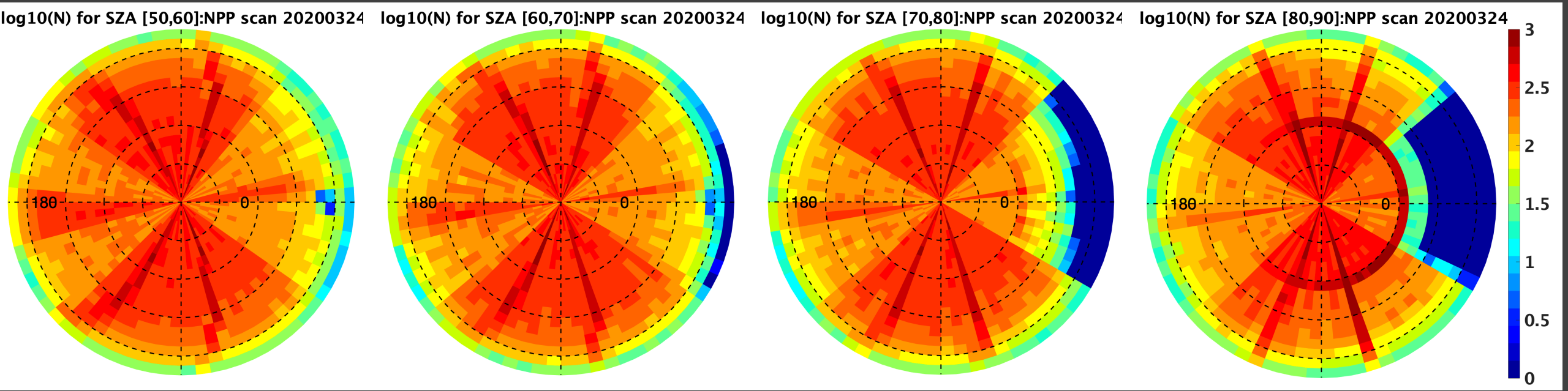




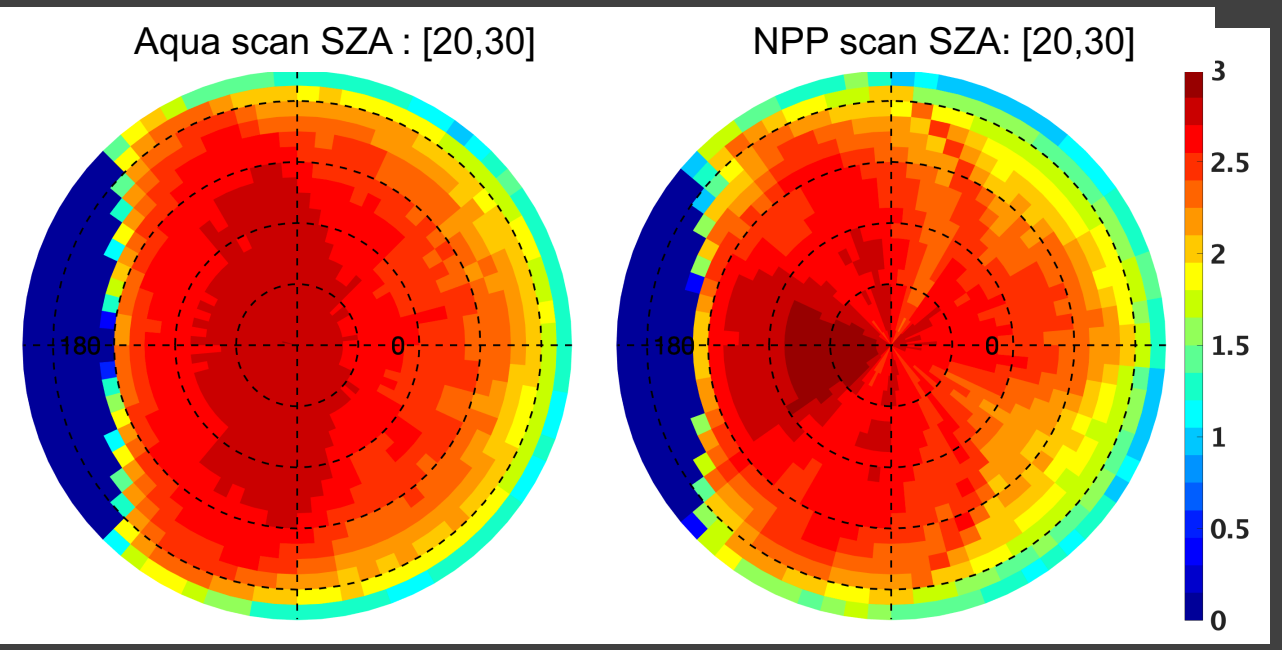
March 24, 2004, for SZA between 40-50 °

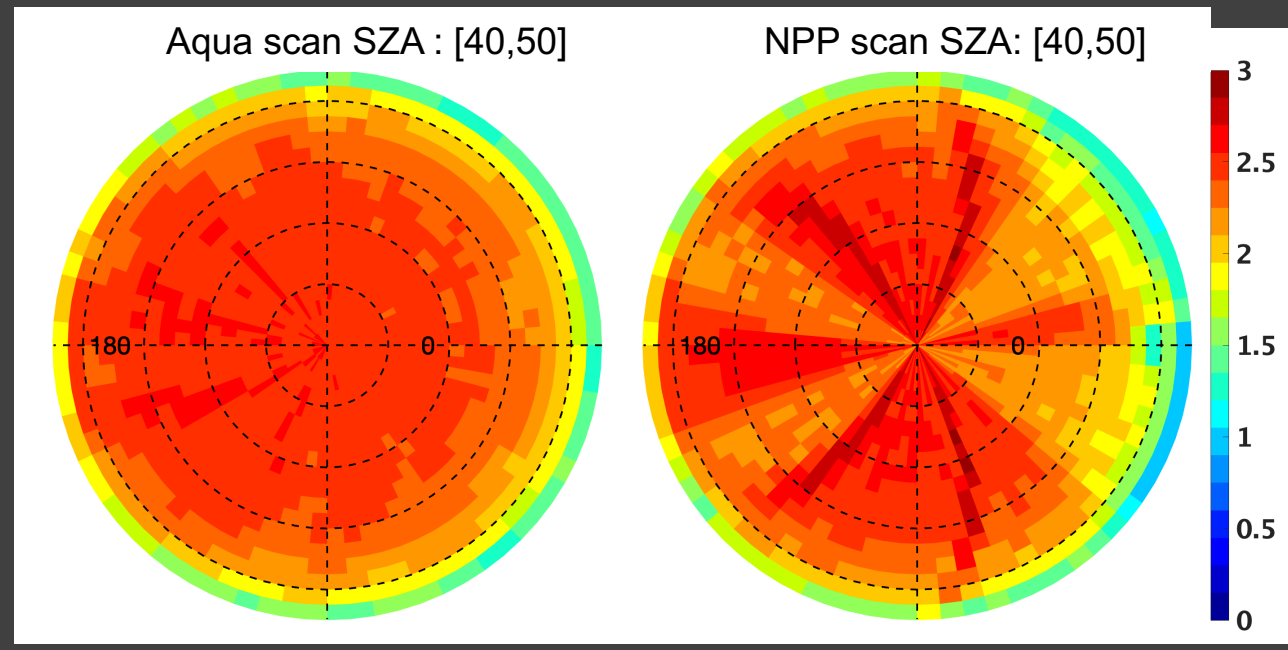
NPP biaxial scan sample distribution for 20200324

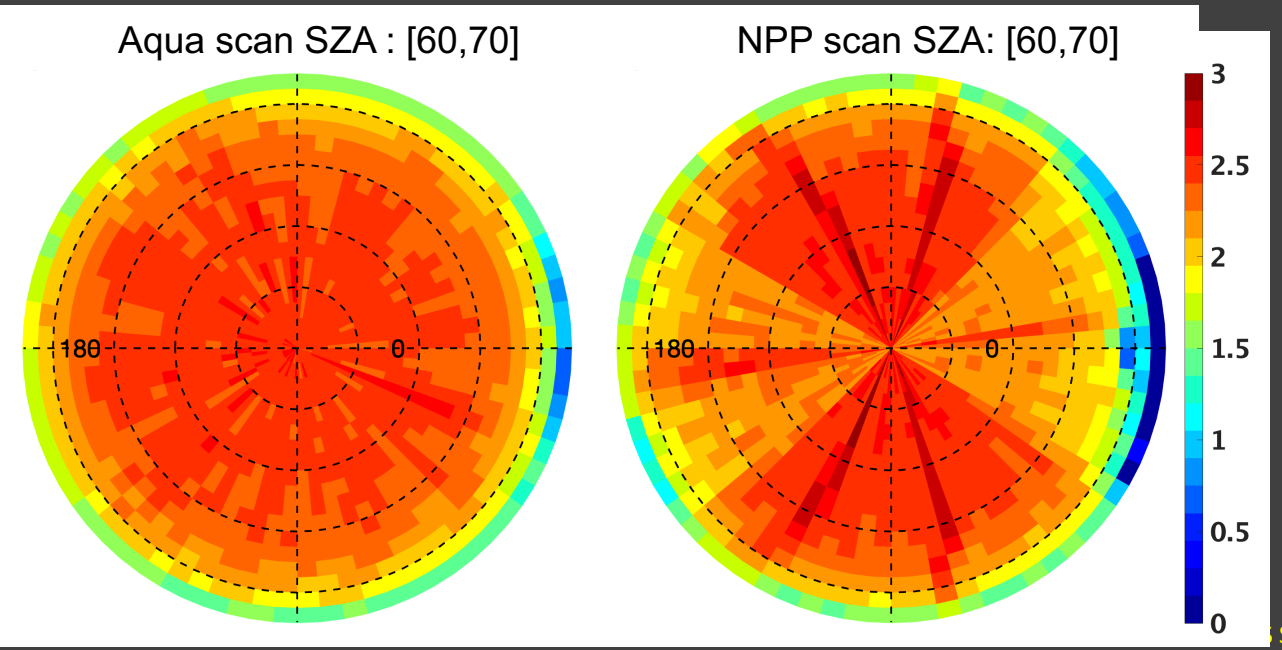


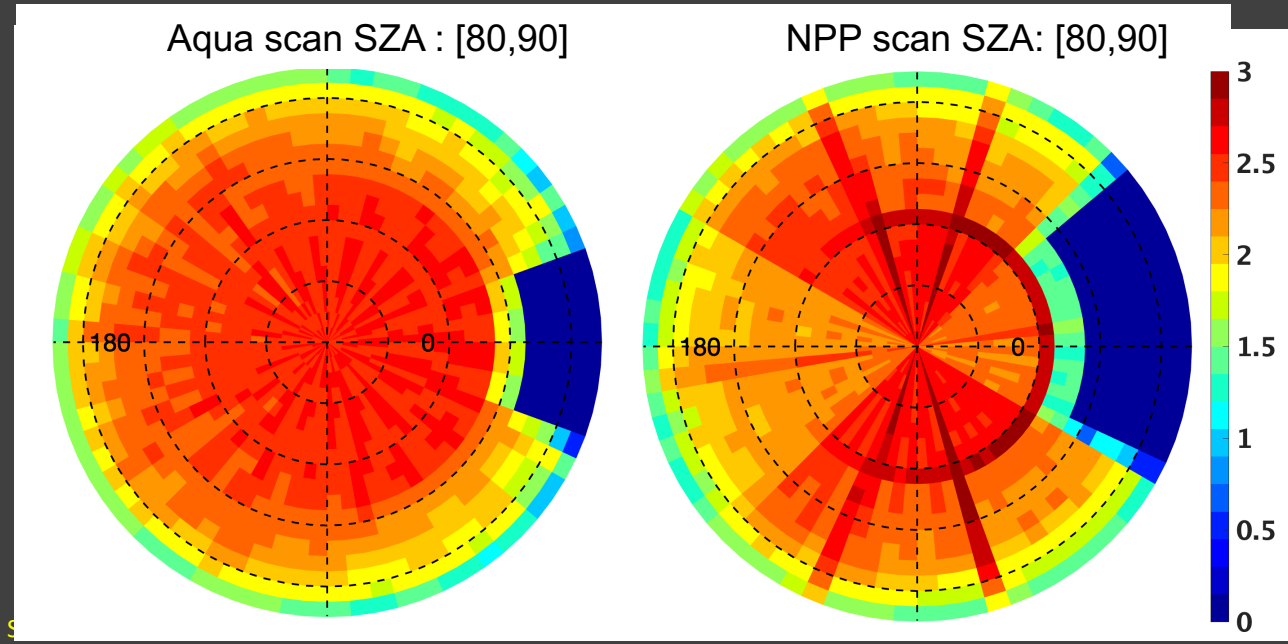


Comparison with Aqua biaxial scan sample distribution for 20040324

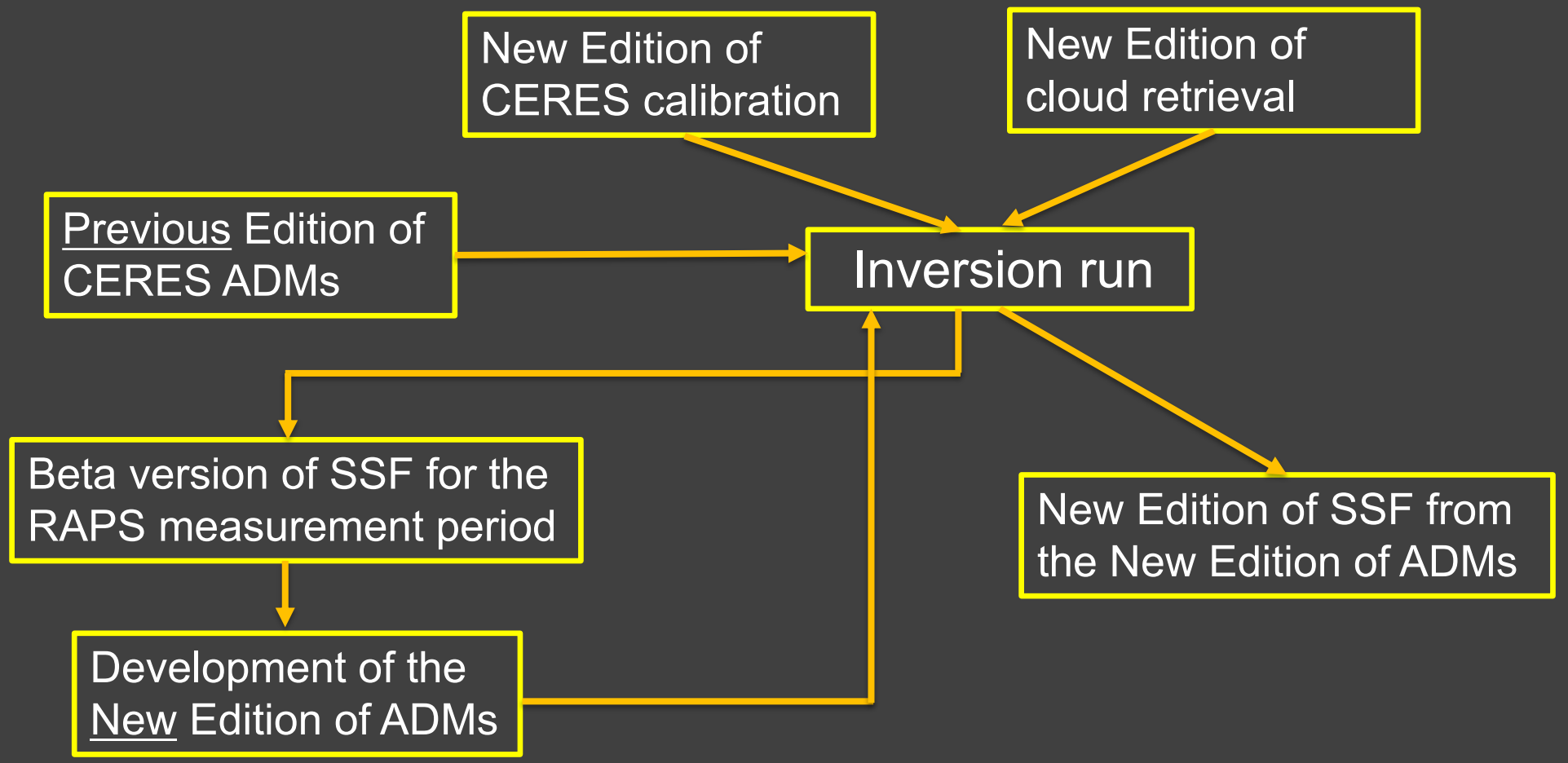








CERES SSF data processing steps



*SSF: Single Satellite Footprint TOA/Surface fluxes and clouds

ADM sensitivity to cross track (XT) data

1st ADMs: developed only using Aqua RAPS data (2002-2005)

2nd ADMs: developed using Aqua RAPS + XT data (2002-2005) → Ed4 ADMs

3rd ADMs: developed using Aqua RAPS + XT data (2002-2007)

1. Are cross track data important for ADM development? →Examine the flux difference derived using the 1st ADMs and the 2nd ADMs
2. If so, what is the sensitivity to the amount of cross track data used? → Examine the flux difference derived using the 3rd ADMs and the 2nd ADMs

ADMs are sensitive to the inclusion of cross track data with the RAPS data

- 1st ADMs - 2nd ADMs

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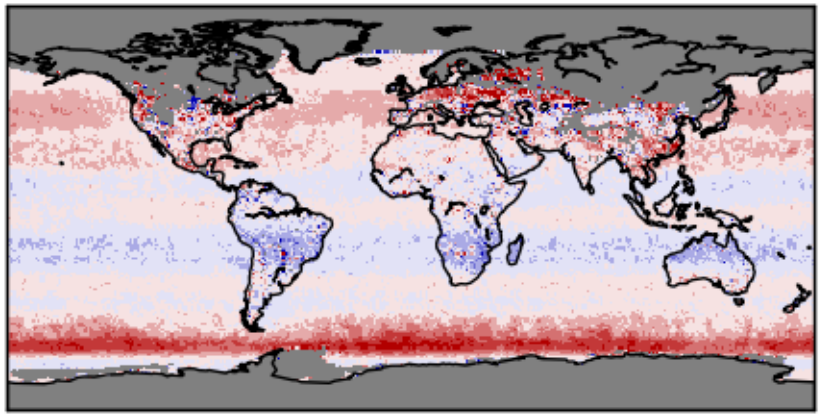

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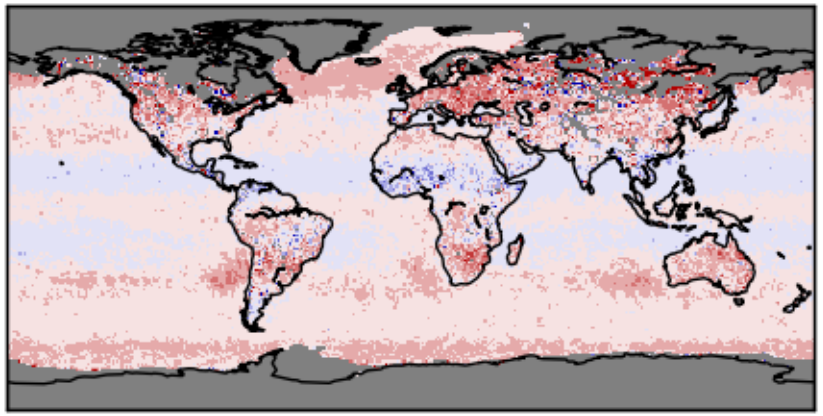

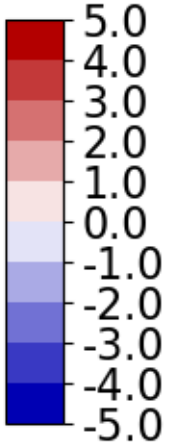

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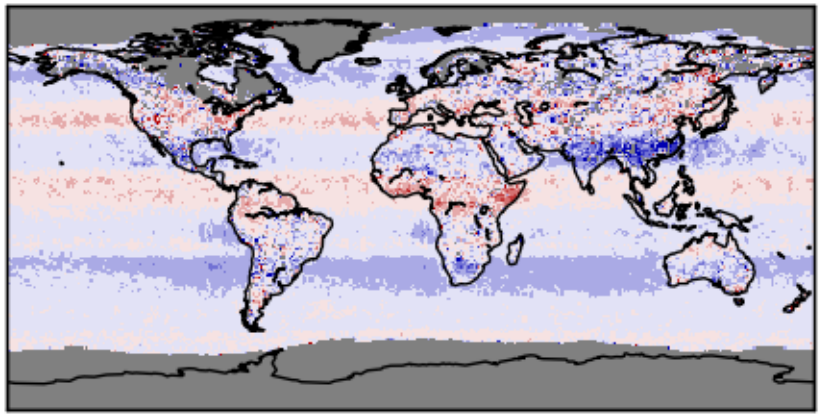
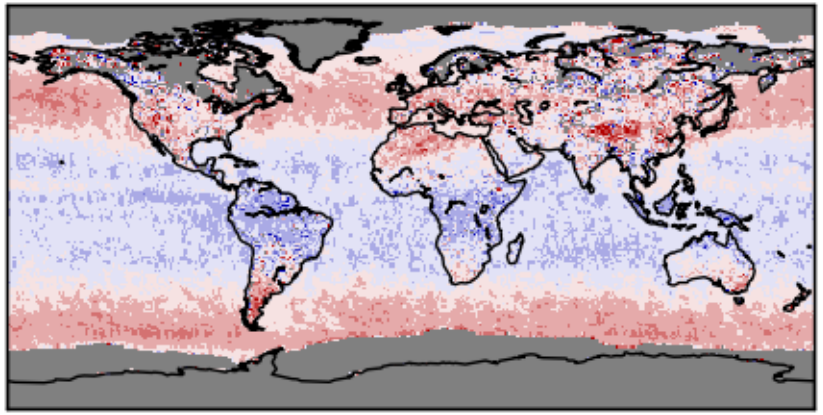
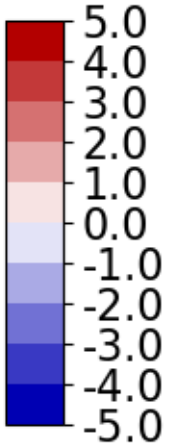


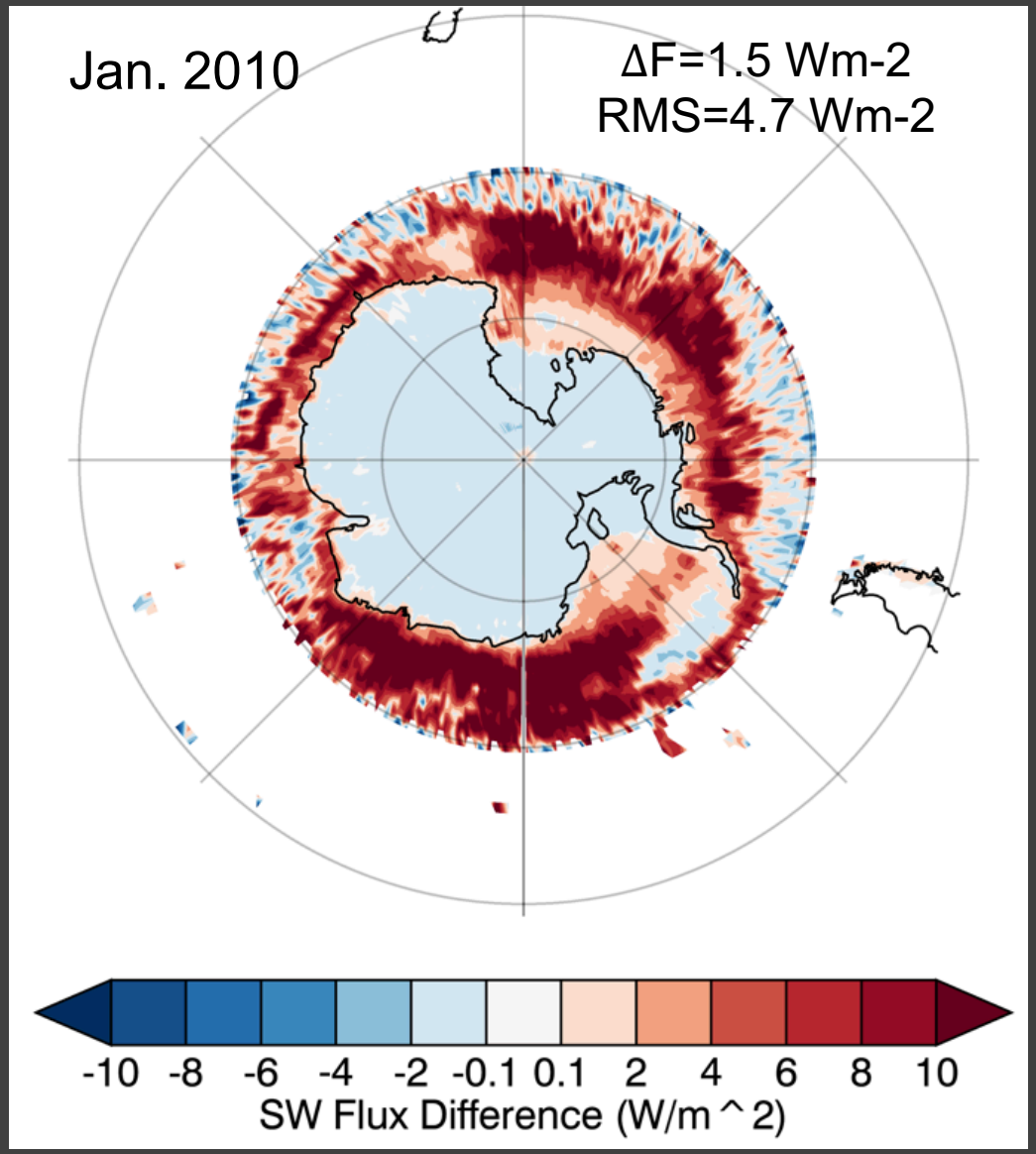
201010

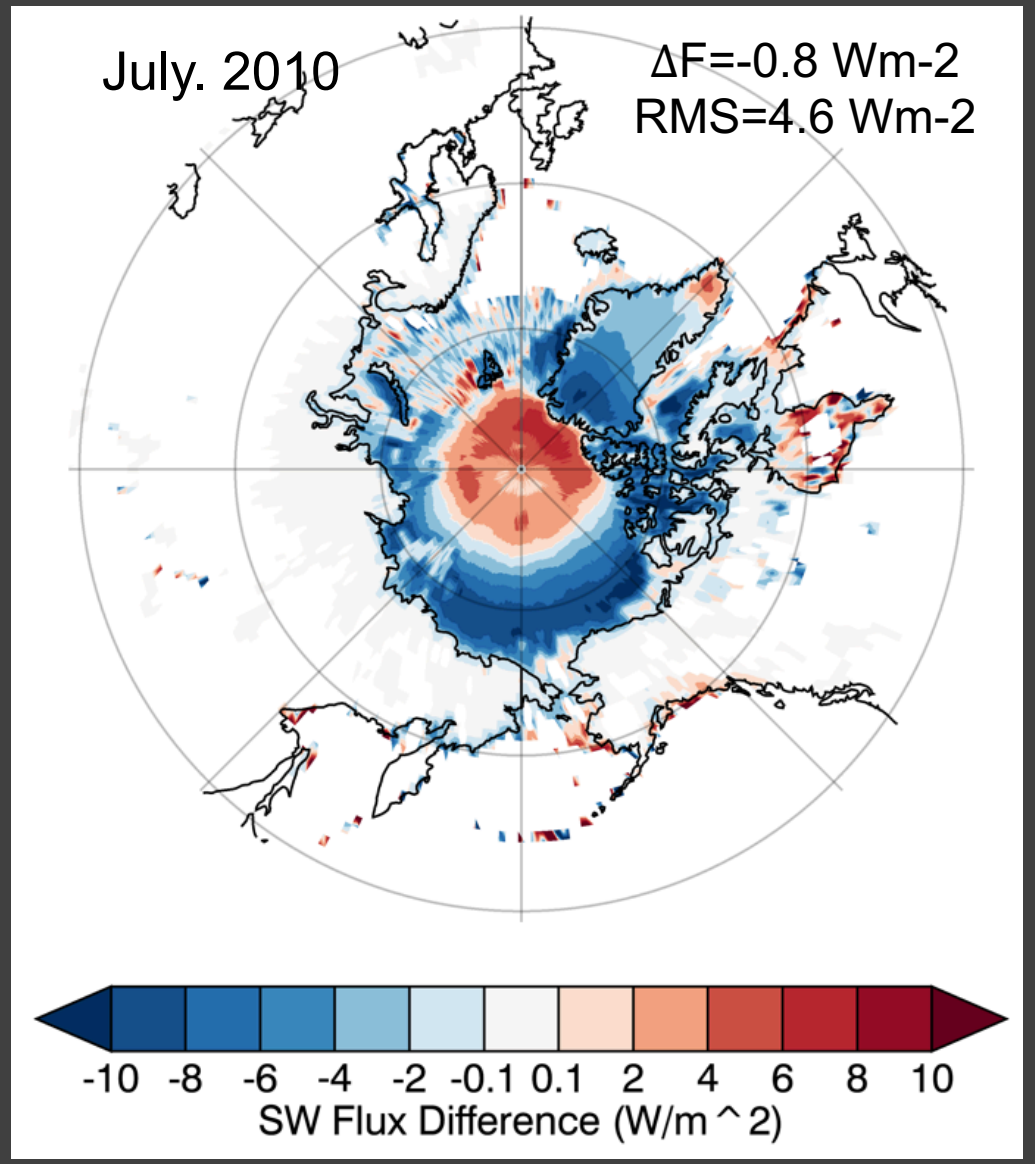




	ΔF (W/m2)	RMSE (W/m2)
Jan	0.33	1.4
Apr	0.40	1.3
Jul	-0.31	1.2
Oct	0.06	1.2

ADMs are sensitive to the inclusion of cross track data with the RAPS data





ADMs sensitivity to more cross track data

- 3rd ADMs – 2nd ADMs

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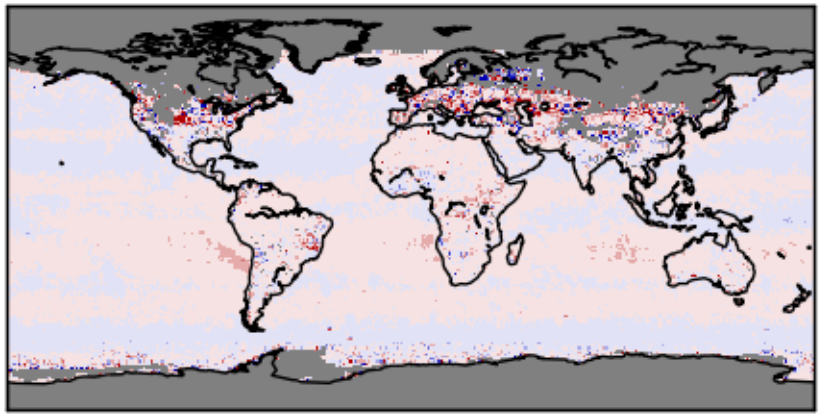

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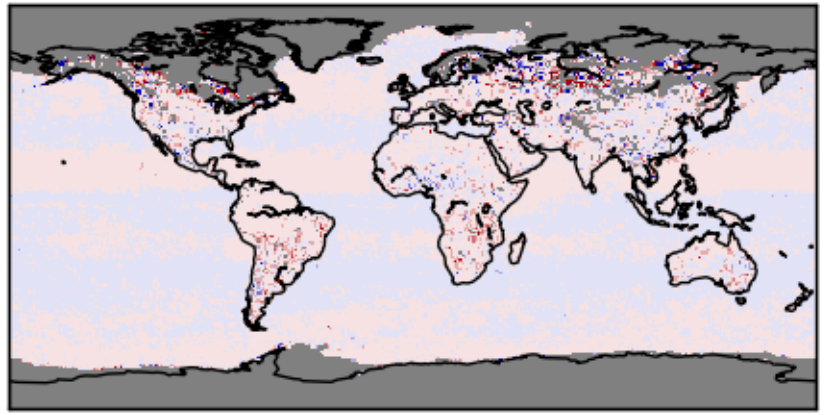

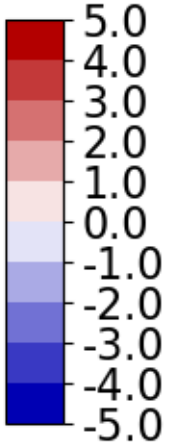

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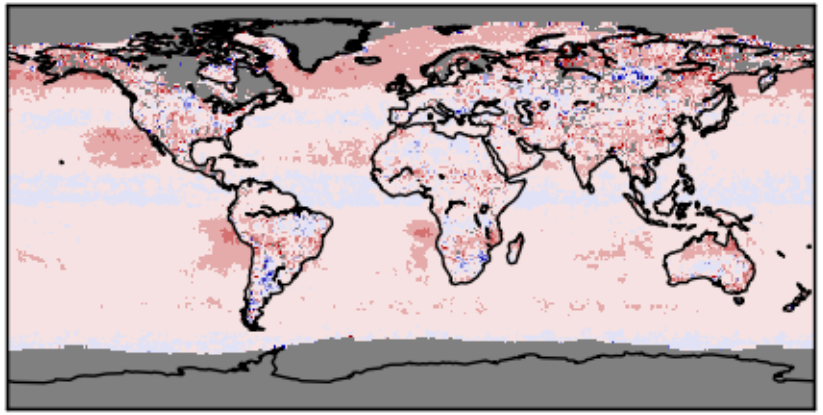

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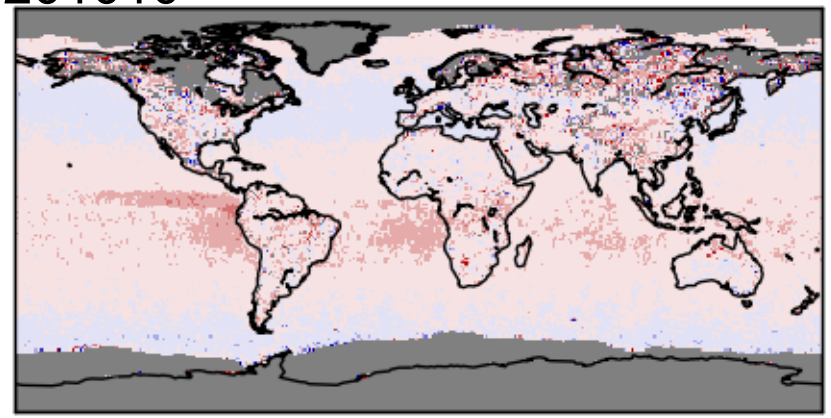
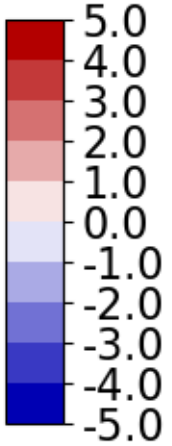
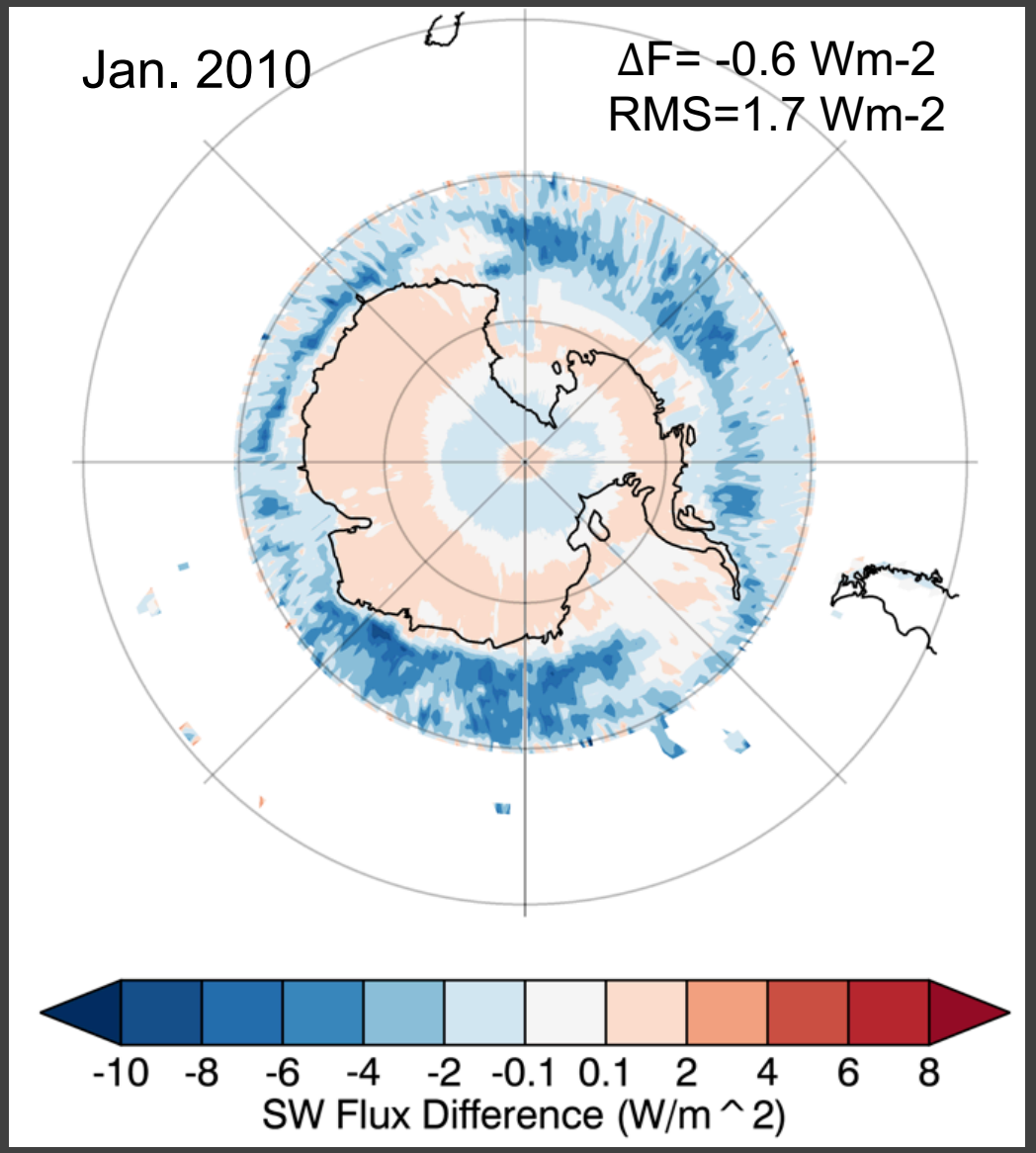
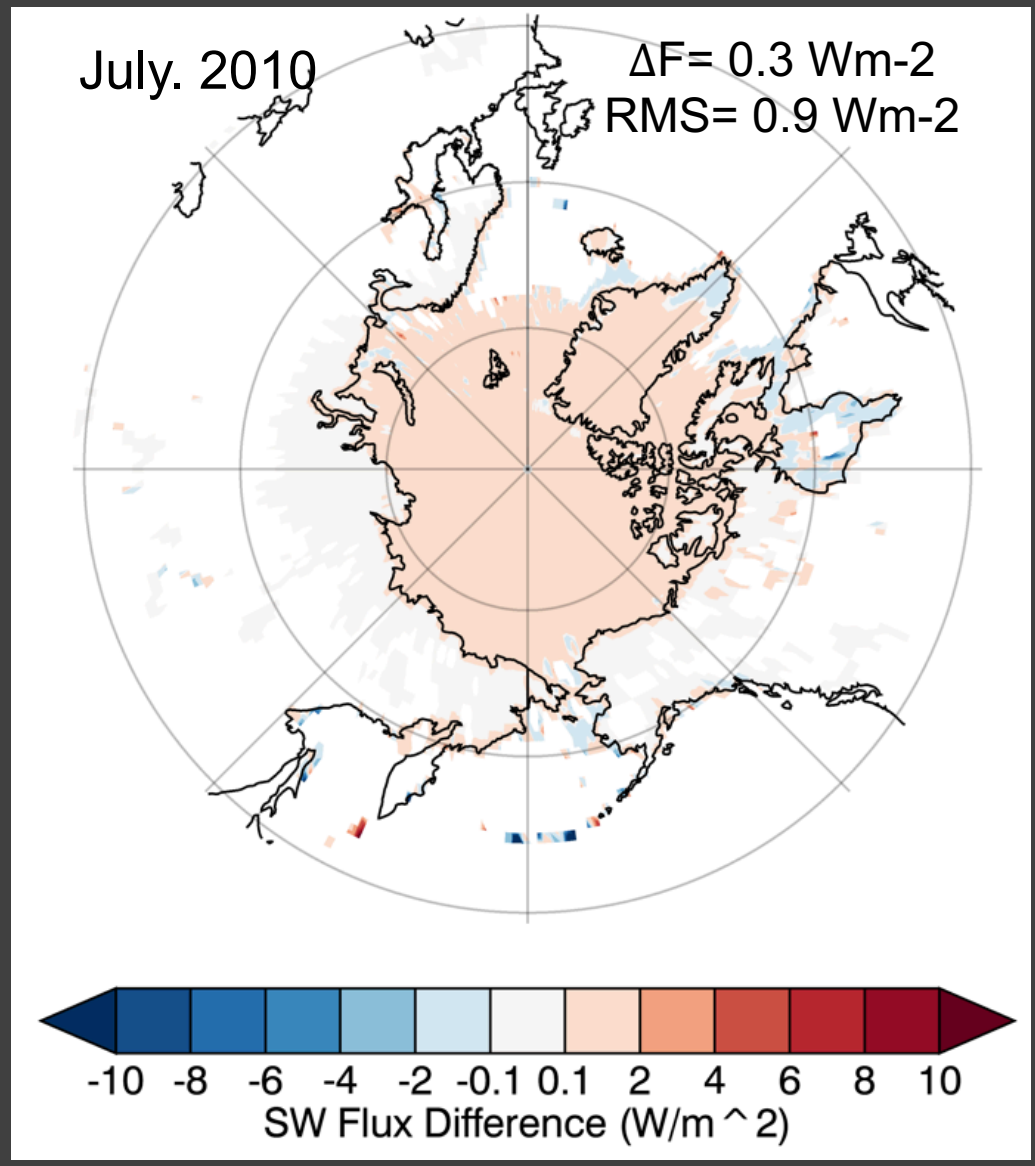




	ΔF (W/m2)	RMS (W/m2)
Jan	0.14	0.9
Apr	0.08	1.3
Jul	0.53	0.9
Oct	0.40	0.9

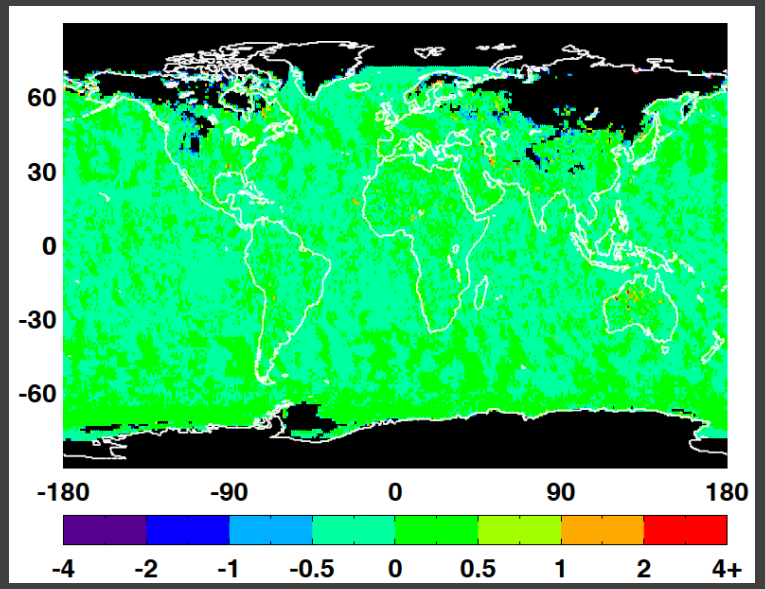
ADMs sensitivity to more cross track data



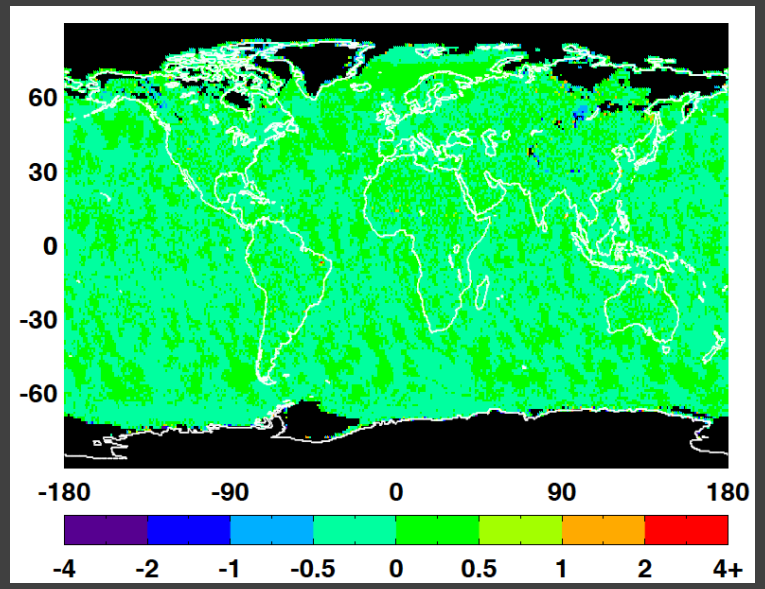


Daytime LW ADMs are not sensitive to the inclusion of cross track data: 1st ADM-2nd ADM

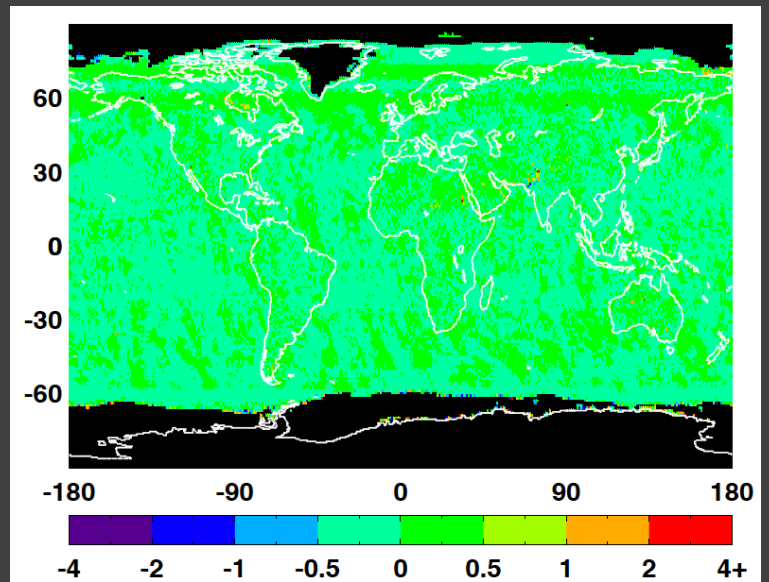
Jan 2010: Bias = -0.02 W m^{-2} RMS = 0.17 W m^{-2}



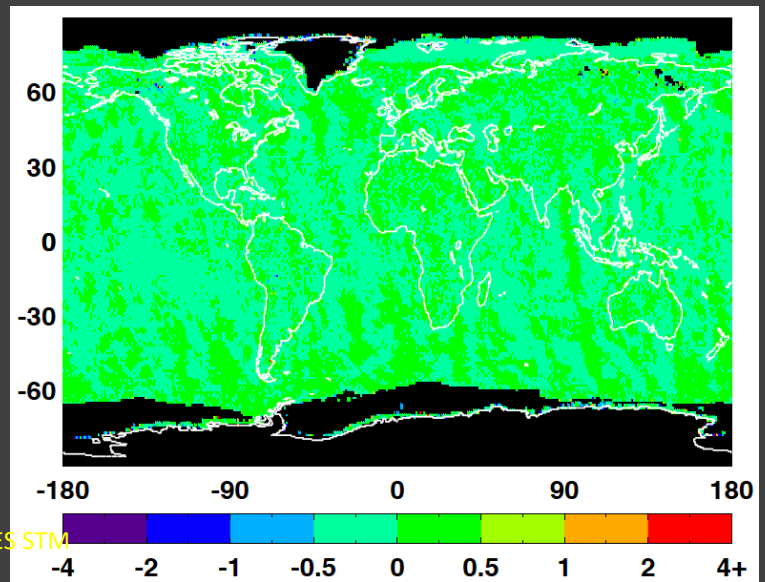
Apr 2010: Bias = -0.02 W m^{-2} RMS = 0.13 W m^{-2}



Jul 2010: Bias = -0.02 W m^{-2} RMS = 0.17 W m^{-2}

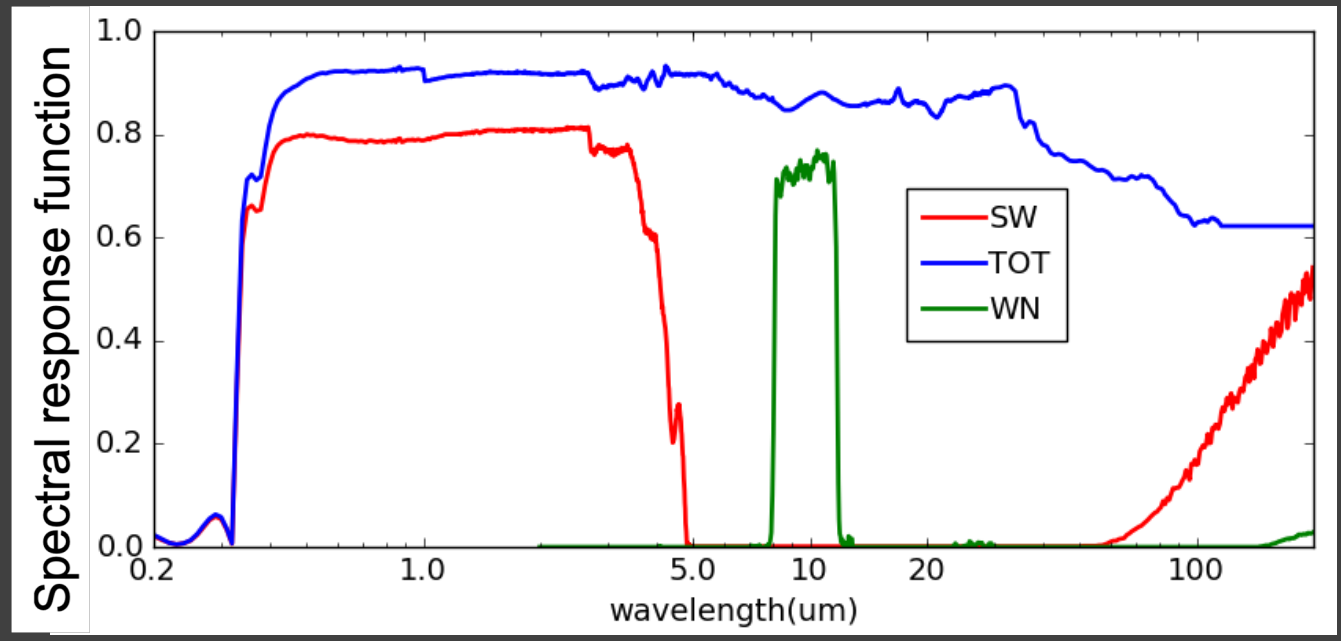


Oct 2010: Bias = -0.02 W m^{-2} RMS = 0.12 W m^{-2}



CERES unfiltering algorithm

- Filters are placed in front of the radiometers to measure the energies from the SW, WN, and total portions of the spectrum.
- These filtered radiances are dependent upon how the radiation is filtered through the instrument optics.
- A procedure is applied that corrects for the spectral response of the instrument to produce "unfiltered" radiances that represent the radiation received by the instrument prior to entering the optics.
- This procedure also separates the radiance measurements into reflected solar and emitted thermal energy category.



SW radiance unfiltering algorithm

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

$$m_u^{SWr} = a_0 + a_1 m_f^{SWr} + a_2 (m_f^{SWr})^2$$

- The filtered reflected SW radiance is the difference between filtered SW radiance and the emitted thermal portion of it:

$$m_f^{SWr} = m_f^{SW} - m_f^{SWe}$$

- The emitted thermal portion of the filtered radiance is calculated using nighttime filtered SW radiances and filtered WN radiances:

$$m_f^{SWe} = k_0 + k_1 m_f^{WN} + k_2 (m_f^{WN})^2$$

Deriving regression coefficients

- Calculate unfiltered reflected SW broadband radiances:

$$m_u^{SWr} = \int_0^\infty I_\lambda^r d\lambda$$

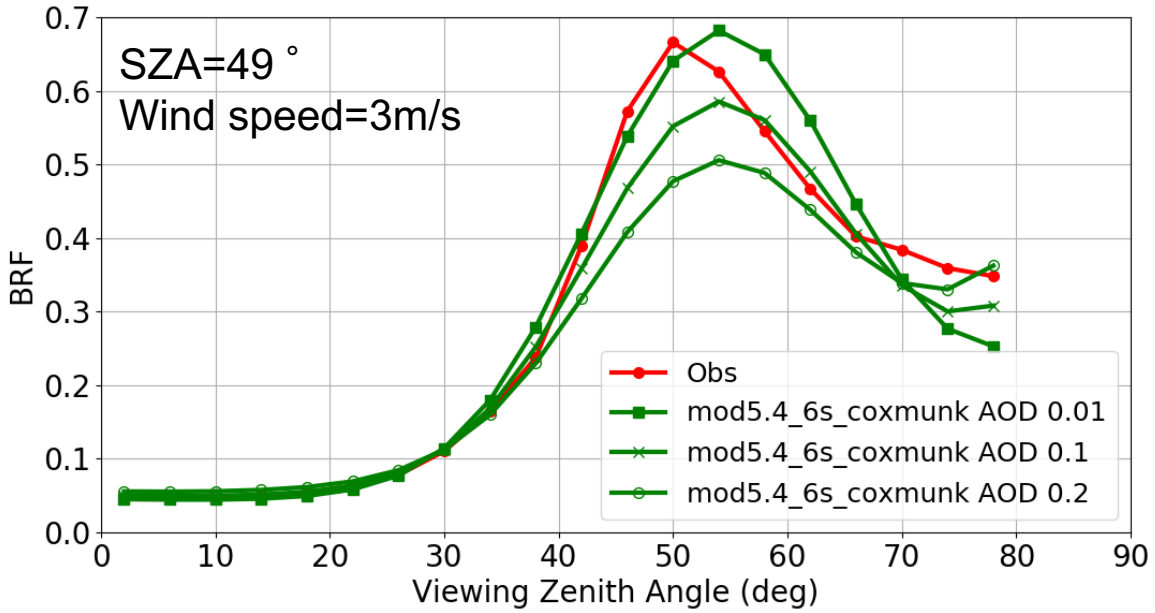
- Apply CERES spectral response functions to calculate the filtered reflected broadband radiances:

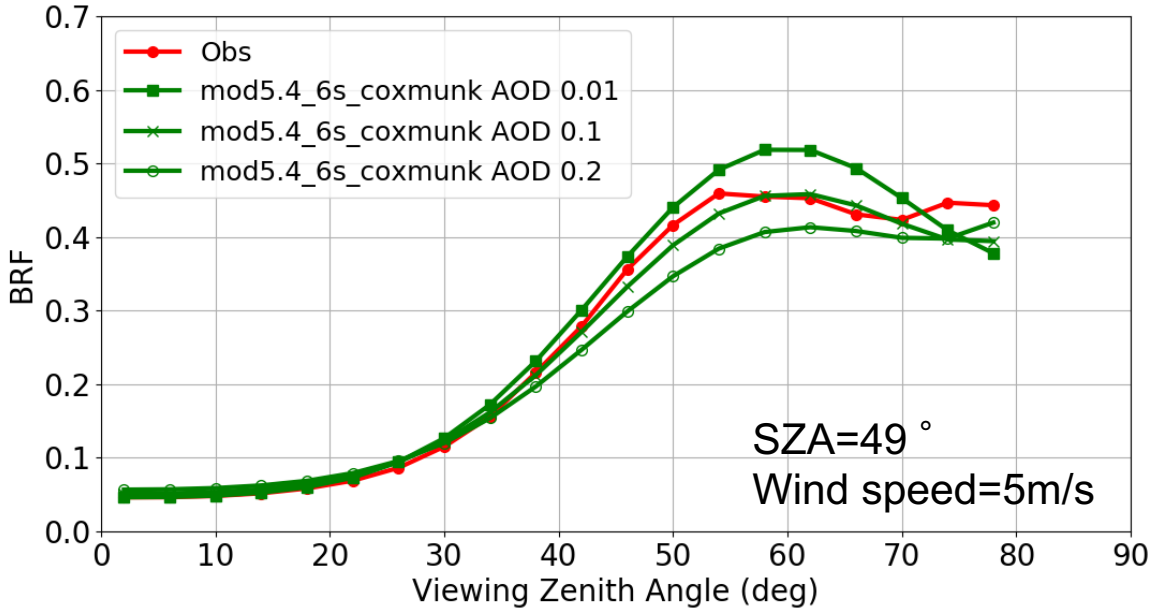
$$m_u^{SWr} = \int_0^\infty S_\lambda^{SW} I_\lambda^r d\lambda$$

- Derive the regression coefficients between unfiltered reflected SW radiance and filtered reflected SW radiances for every angular bin over typical Earth scenes:

$$m_u^{SWr} = a_0 + a_1 m_f^{SWr} + a_2 (m_f^{SWr})^2$$

MODTRAN simulation over clear ocean



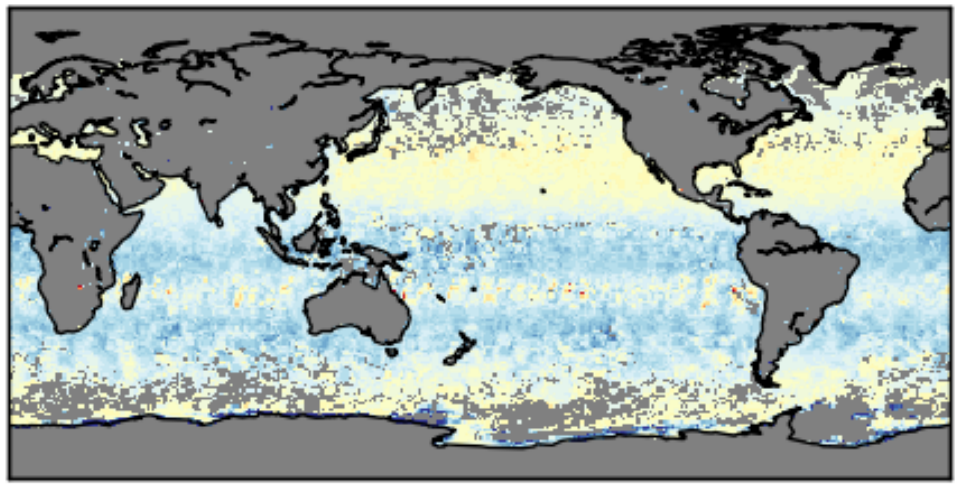


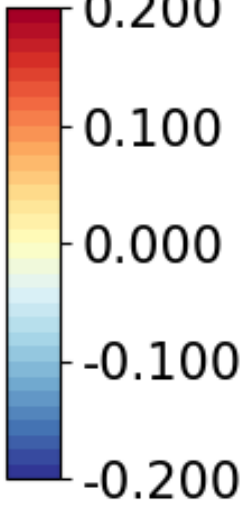
- Incorporated the CoxMunk BRDF model into the MODTRAN 5.4.
- Tropical profile, CoxMunk BRDF model with wind speed=5m/s
- Θ_0: 0, 41.4, 60, 75.5 and 85
- Θ: 0, 30, 45, 60 and 90
- Φ: 0, 7.5, 37.5, 90.0, 142.5, 172.5
- Maritime aerosol model with optical depths: 0, 0.055, 0.09, 0.16, 0.30, 0.67, 1.2
- Regression coefficients are calculated for each (Θ_0, Θ, Φ)

The impact on clear ocean unfiltering is very small

- These regression coefficients are used to derive the CERES unfiltered radiances;
- They are compared with the unfiltered radiances in the CERES Edition 4 SSF data.

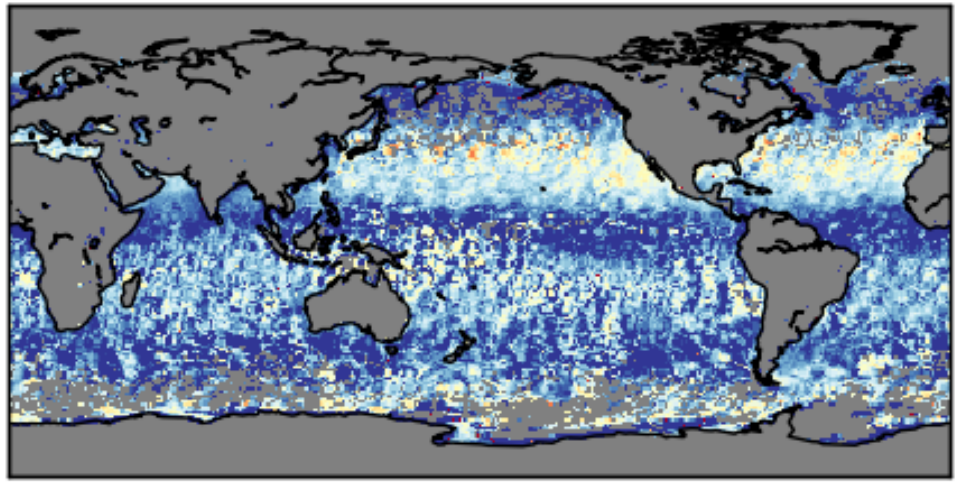
Radiance difference mean=-0.04

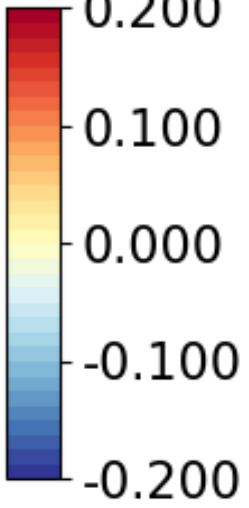




201001 FM1 Terra

Flux difference mean=-0.13





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Wind speed has very small impact on clear ocean unfiltering algorithm

Flux difference using regressions derived with wind speed of 3 m/s and 5 m/s

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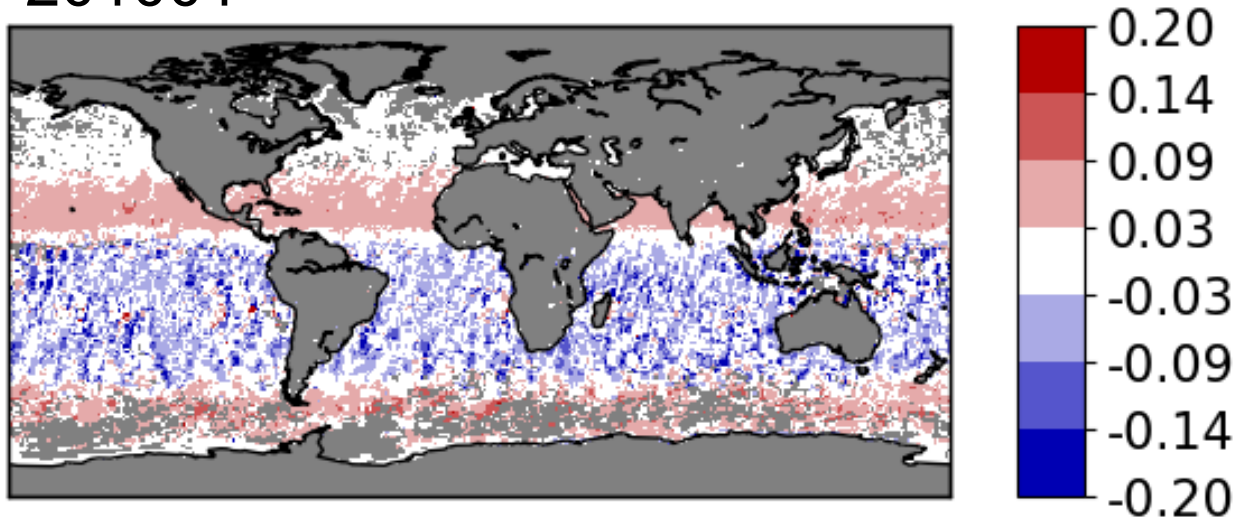

Flux difference using regressions derived with wind speed of 7 m/s and 5 m/s

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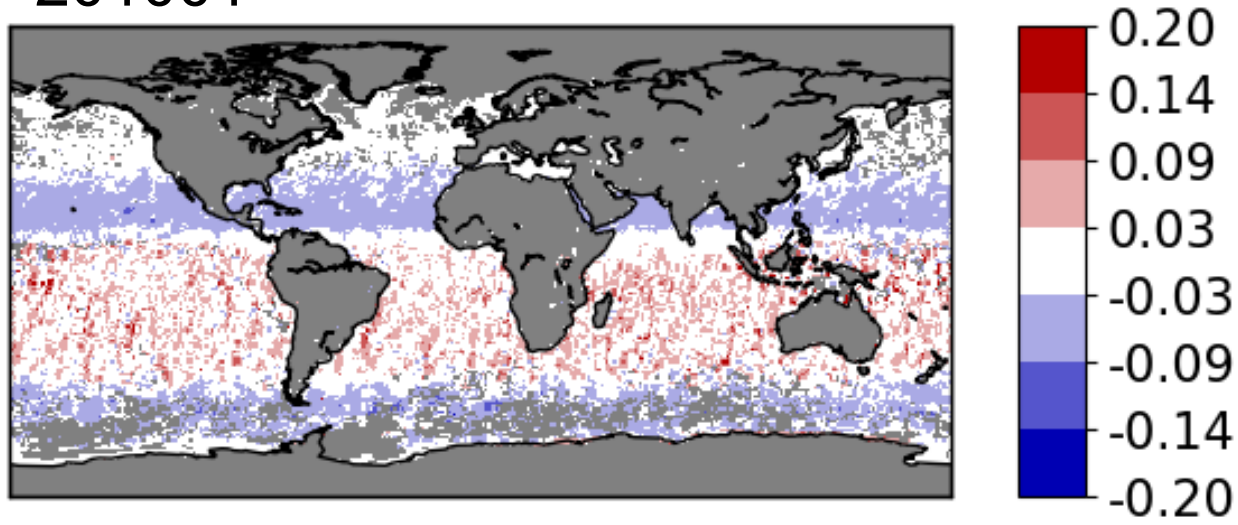
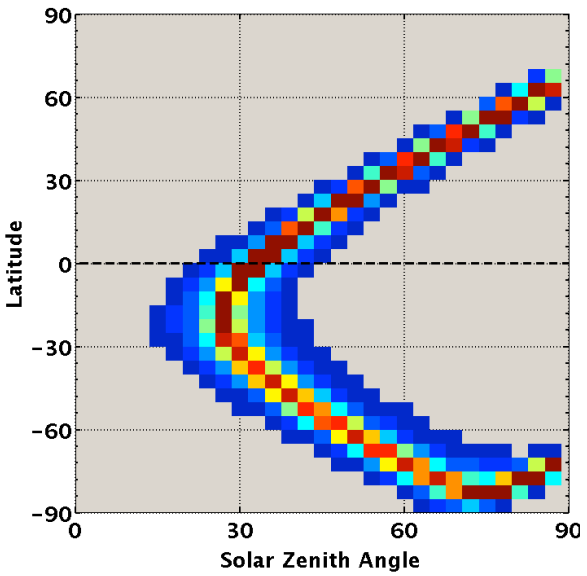


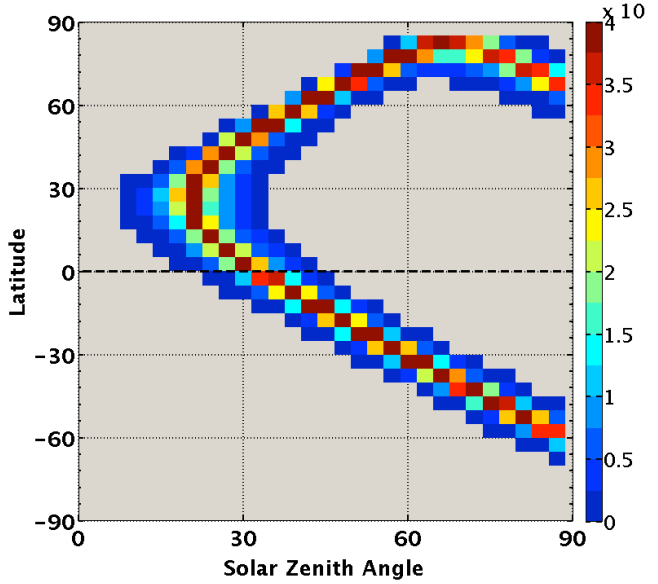
Unfiltering algorithm over clear ocean shows small sensitivity to aerosol type

- Flux difference using regressions derive with dust aerosols and maritime aerosols, both are with wind speed of 5 m/s
- Global mean difference is about 0.15 Wm-2, and difference at the grid box level is less than 0.5 Wm-2
- The zonal feature is related to solar zenith angle

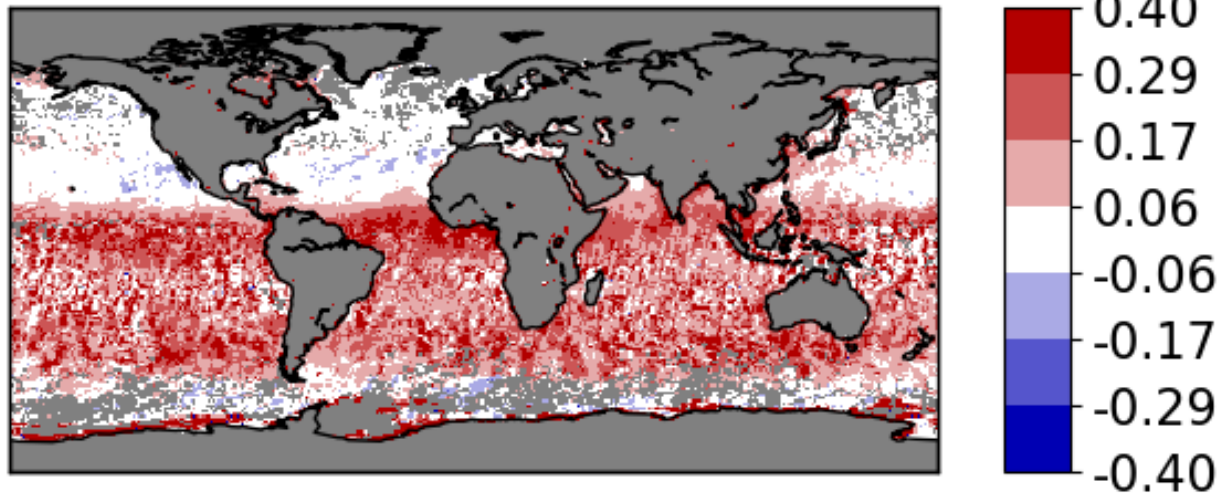
Number of observations for Jan



Number of observations for July



201001



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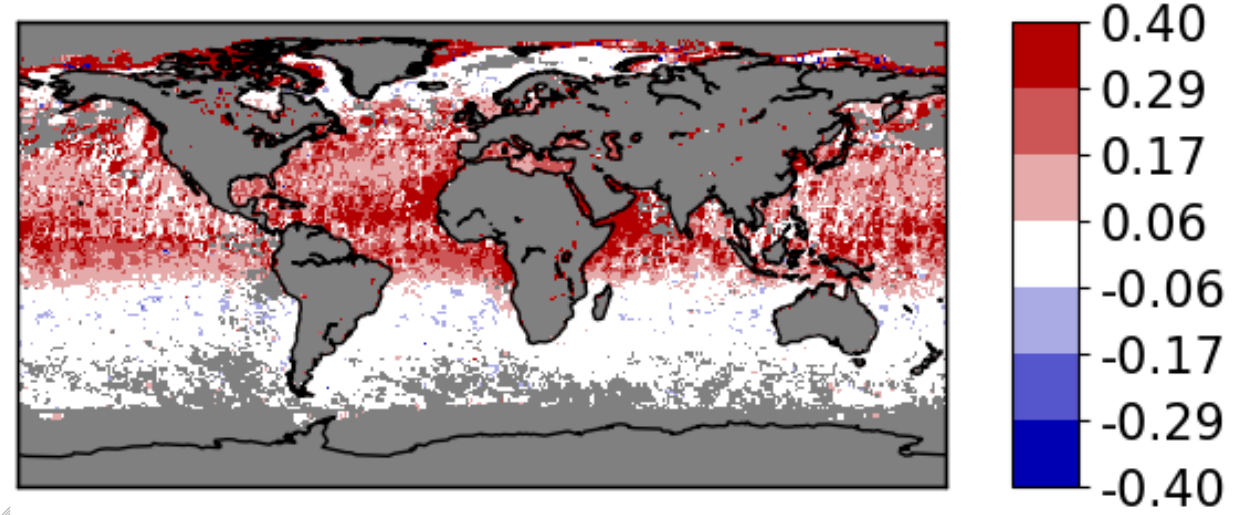

Summary

- CERES NPP started taking RAPS data on March 24, 2020
- CERES SW ADMs are sensitive to the inclusion of cross track data. It is important to include 2-3 years of cross track data in the development of ADMs. Additional cross track data have small impact.
- CERES LW ADMs are not sensitive to the inclusion of cross track data.
- CoxMunk ocean surface BRDF model was incorporated in MODTRAN 5.4.
- Derived the unfiltering regression coefficients over clear ocean using the same configuration as Loeb et al. (2001). Unfiltered radiances agree to within 0.2% using these two sets of regression coefficients.
- Clear ocean unfiltering shows small sensitive to surface wind speed and the aerosol types used, but changes in radiances are related to solar zenith angle.