From radiance to flux: angular distribution models

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

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

- 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.
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

- VZA
- backward
- forward
Comparison with Aqua biaxial scan sample distribution for 20040324

Aqua scan SZA: [20,30]  NPP scan SZA: [20,30]
Aqua scan SZA: [40,50]  NPP scan SZA: [40,50]
Aqua scan SZA: [60,70]  NPP scan SZA: [60,70]
Aqua scan SZA: [80,90]  NPP scan SZA: [80,90]
CERES SSF data processing steps

- New Edition of CERES calibration
- New Edition of cloud retrieval
- Previous Edition of CERES ADMs
- Inversion run
- Beta version of SSF for the RAPS measurement period
- Development of the New Edition of ADMs
- New Edition of SSF from the New Edition of ADMs

*SSF: Single Satellite Footprint TOA/Surface fluxes and clouds
1. Are cross track data important for ADM development?

2. If so, what is the sensitivity to the amount of cross track data used?

1\textsuperscript{st} ADMs: developed only using Aqua RAPS data (2002-2005)

2\textsuperscript{nd} ADMs: developed using Aqua RAPS + XT data (2002-2005) \(\rightarrow\) Ed4 ADMs

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

\(\rightarrow\) Examine the flux difference derived using the 1\textsuperscript{st} ADMs and the 2\textsuperscript{nd} ADMs

\(\rightarrow\) Examine the flux difference derived using the 3\textsuperscript{rd} ADMs and the 2\textsuperscript{nd} ADMs
ADMs are sensitive to the inclusion of cross track data with the RAPS data

- **1\textsuperscript{st} ADMs - 2\textsuperscript{nd} ADMs**

<table>
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<th>Date</th>
<th>ΔF (W/m²)</th>
<th>RMSE (W/m²)</th>
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<tr>
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<td>0.33</td>
<td>1.4</td>
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<tr>
<td>Apr</td>
<td>0.40</td>
<td>1.3</td>
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<tr>
<td>Jul</td>
<td>-0.31</td>
<td>1.2</td>
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<tr>
<td>Oct</td>
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ADMs are sensitive to the inclusion of cross track data with the RAPS data.

Jan. 2010

ΔF=1.5 Wm-2
RMS=4.7 Wm-2

July. 2010

ΔF=-0.8 Wm-2
RMS=4.6 Wm-2
ADMs sensitivity to more cross track data

- 3rd ADMs - 2nd ADMs

<table>
<thead>
<tr>
<th></th>
<th>∆F (W/m²)</th>
<th>RMS (W/m²)</th>
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<tr>
<td>Jul</td>
<td>0.53</td>
<td>0.9</td>
</tr>
<tr>
<td>Oct</td>
<td>0.40</td>
<td>0.9</td>
</tr>
</tbody>
</table>
ADMs sensitivity to more cross track data

Jan. 2010
\[ \Delta F = -0.6 \text{ Wm}^{-2} \]
\[ \text{RMS} = 1.7 \text{ Wm}^{-2} \]

July. 2010
\[ \Delta F = 0.3 \text{ Wm}^{-2} \]
\[ \text{RMS} = 0.9 \text{ Wm}^{-2} \]
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:

\[ m_{ul}^{SWr} = a_0 + a_1 m_f^{SWr} + a_2 (m_f^{SWr})^2 \]

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

\[ m_f^{SWr} = m_f^{SW} - m_f^{SWEP} \]

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

\[ m_f^{SWEP} = k_0 + k_1 m_f^{WN} + k_2 (m_f^{WN})^2 \]
Deriving regression coefficients

• Calculate unfiltered reflected SW broadband radiances:

\[ m_{u}^{SW r} = \int_{0}^{\infty} I^{r}_\lambda d\lambda \]

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

\[ m_{u}^{SW r} = \int_{0}^{\infty} S_{\lambda}^{SW} I^{r}_\lambda d\lambda \]

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

\[ m_{u}^{SW r} = a_0 + a_1 m_{f}^{SW r} + a_2 (m_{f}^{SW r})^2 \]
• Incorporated the CoxMunk BRDF model into the MODTRAN 5.4.
• Tropical profile, CoxMunk BRDF model with wind speed=5m/s
• $\Theta_0$: 0, 41.4, 60, 75.5 and 85
• $\Theta$: 0, 30, 45, 60 and 90
• $\Phi$: 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 $(\Theta_0, \Theta, \Phi)$
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.
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

Flux difference using regressions derived with wind speed of 7 m/s and 5 m/s
Unfiltering algorithm over clear ocean shows small sensitivity to aerosol type

- Flux difference using regressions derived 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
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.