Aerosol Direct Radiative Forcing over oceans using merged MODIS/CERES analysis

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Methods

Goal: Estimates shortwave aerosol direct radiative forcing (SWARF) over oceans using combined satellite observations

Steps:

• Build new empirical aerosol ADM

• SWARF over oceans

• Diurnally averaged SWARF

• Correct for sample bias due to large CERES footprint

• Estimate Anthropogenic Aerosol Forcing
Different approaches in estimating SWARF

(1) Radiative transfer equations (e.g. Penner et al., 1992)

(2) General Circulation Models (e.g. Hansen et al)

(3) MODEL + satellite derived AOT (e.g. Chou et al., 2002)

(4) Combined Satellite observations (e.g. Christopher and Zhang, 2002; Zhang et al., 2004)

Which way to go?
Approaches from combining satellite observations

• CERES provides Top-of-Atmosphere (TOA) Shortwave (SW) and longwave (LW) observations (~20 km at nadir).

Problems:
• (1) Do not contain aerosol properties.
• (2) Cloud screening is not accurate using CERES alone.
Approaches from combining satellite observations

• MODIS data has finer spatial resolutions that can be used in detecting aerosol and cloud properties within a CERES footprint.

• Ten months of CERES SSF data were used in this study.
Angular Distribution Models (ADMs)

ADMs are needed to convert CERES measured radiances to fluxes.

**ERBE ADMs:** *Over cloud free oceans*
- Not include aerosol aerosol properties
- Not include wind speed

**TRMM ADMs:** *Over cloud free oceans*
- Include ECMWF modeled wind speed
- Use theoretical calculation to account for the effect of aerosol optical depth on TOA radiation fields

**New Terra ADM:** *Over cloud free oceans*
- Use SSM/I wind speed
- Use the fraction of small mode to total AOT ($\eta$) to distinguish aerosol types
- More coverage compared to TRMM
- MODIS: more accurate for aerosol research

Zhang, Christopher, Remer, and Kaufman, JGR, Part 1, in press
Comparison with existing ADMs

The instantaneous aerosol forcing efficiency (for $\tau_{0.55} < 0.4$) are 73.0, 63.1, and 80.5 Wm$^{-2}$ per $\tau_{0.55}$ for Terra, TRMM and ERBE ADMs respectively.

Zhang, Christopher, Remer and Kaufman, JGR, Part 1, in press
MODIS $\tau_{0.55}$ and CERES derived SWARF for NDJF

- SWARF is defined as the difference in TOA energy without ($F_{\text{clr}}$) and with ($F_{\text{aero}}$) the presence of aerosols.

- Only 99.9% clear CERES pixels were used.

- $F_{\text{clr}}$ derived using empirical regression relationship as functions of wind speed and $\theta_o$.

Zhang, Christopher, Remer and Kaufman, JGR, Part II, in press
MODIS $\tau_{0.55}$ vs. CERES derived SWARF for three seasons

The spatial and seasonal distributions of $\tau_{0.55}$ and the independently derived SWARF show a high degree of correlation.

The relationship can be estimated using the equation:

$\text{SWARF} = 0.05 - 74.6 \tau_{0.55} + 18.2 \tau_{0.55}^2 \text{ Wm}^{-2}$ (if $\tau_{0.55} < 0.8$).
SWARF over CERES cloud free oceans estimated using three different ADMs

<table>
<thead>
<tr>
<th></th>
<th>NDJF (Wm(^{-2}))</th>
<th>SPRING (Wm(^{-2}))</th>
<th>SUMMER (Wm(^{-2}))</th>
<th>10-month (Wm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERBE ADMs</td>
<td>-6.8</td>
<td>-7.5</td>
<td>-6.7</td>
<td>-7.2</td>
</tr>
<tr>
<td>TRMM ADMs</td>
<td>-5.1</td>
<td>-6.0</td>
<td>-5.2</td>
<td>-5.6</td>
</tr>
<tr>
<td>Terra ADMs</td>
<td>-6.5</td>
<td>-7.2</td>
<td>-6.3</td>
<td>-6.4±2.6</td>
</tr>
</tbody>
</table>

• The instantaneous SWARF is **-6.4±2.6 Wm\(^{-2}\)**
Estimating diurnally averaged SWARF over oceans

To convert from instantaneous to diurnally averaged SWARF, need to (1) correct for sample biases, and (2) account variations in solar zenith angle.

- The difference in MODIS and CERES cloud free sky AOT is used to correct for the sample biases due to large footprint of CERES.
- To convert from instantaneous SWARF derived at Terra overpass to 24 hour averaged SWARF, a scaling factor of 2 is used.

<table>
<thead>
<tr>
<th>Clear sky over oceans</th>
<th>W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haywood et al., 1999</td>
<td>-6.7</td>
</tr>
<tr>
<td>Boucher et al., 2000</td>
<td>-5.5</td>
</tr>
<tr>
<td>Loeb and Kato, 2002</td>
<td>-4.6</td>
</tr>
<tr>
<td>Bellouin et al., 2003</td>
<td>-5.2</td>
</tr>
<tr>
<td>Chou et al., 2002</td>
<td>-5.4</td>
</tr>
<tr>
<td>Yu et al., 2004</td>
<td>-4.6</td>
</tr>
<tr>
<td><strong>This study</strong></td>
<td><strong>-5.3±1.7</strong></td>
</tr>
</tbody>
</table>

- The uncertainties for instantaneous and diurnally averaged SWARF are 2.6 and 1.7 Wm-2 respectively.

- The diurnally averaged SWARF is **-5.3** over cloud free oceans.
Estimating anthropogenic forcing using MODIS fine mode fraction and CERES measurements is now possible because ADM as function of $\eta$ available and anthropogenic fraction can be separated using MODIS measurements (Kaufman et al., 2004, in press)

(See poster A23C-0811 this afternoon for detail)
Conclusion: Summarize and new things

• The purpose of this study is to cut down assumptions and uncertainties in SWARF studies using an empirical approach.

• New aerosol ADMs are constructed over cloud free oceans as functions of AOT MODIS and $\eta$ and ocean wind speed.

• Average over 10 month, the diurnally averaged SWARF over cloud free skies are $-5.3 \pm 1.7$ Wm$^{-2}$ respectively, this value is consistent with values reported from other studies using combination of model and satellite observations.

• Anthropogenic aerosol climate forcing can be studied using direct satellite observations since ADM’s are now available as function of $\eta$ which is a proxy for anthropogenic aerosols.