Dust Aerosol Radiative Effects from Terra and Aqua

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Outline

- Why are dust aerosols important?
- Goals of this research
- Data
- Assumptions
- Separation of AOT components
- Dust Radiative Effect
- Terra vs. Aqua differences
- Continuing Research
Importance of Dust Aerosols

- Naturally occurring dust aerosols are major contributors to the Earth-atmosphere system
  - Annual dust aerosol emissions range from 1000-3000 Tg
- Dust aerosols generally originate over desert regions such as the Sahara
  - Atmospheric transport allows dust to spread far away from its source regions
  - Uncertainty exists as to the contribution of land use change and anthropogenic aerosols to overall dust loading.
Effect of Dust Aerosols

- Over open oceans, dust aerosols increase reflectivity, reducing incoming TOA solar (shortwave) flux
  - A cooling effect

- Dust aerosols also absorb and emit outgoing longwave flux, but emit at colder temperatures than the background ocean
  - A warming effect

- Previous research indicates that SW cooling generally exceeds LW warming, but the magnitude of the LW effect is largely unknown
Goals

- Use satellite observations of aerosol optical thickness (AOT) and fine mode fraction (FMF) to determine the proportion of AOT due to dust aerosols
- Use satellite-derived TOA incoming SW and outgoing LW fluxes to determine the effect of dust AOT on the energy budget
- Compare SW and LW effects to produce a net dust radiative effect
  - Does LW warming significantly offset SW cooling?
- Since the greatest concentration of dust aerosols occurs over the Atlantic ocean, west of Africa, this research was initially restricted to that domain.
Data

- CERES Single Satellite Footprint (SSF)
  - Terra FM1, Edition 2B data files
  - CERES reports SW and LW TOA radiance at a ~20 km resolution which are converted to fluxes using ADMs (Zhang et al. 2005a)
  - Data collected for June, July, and August between 2000 and 2005
  - Spatial domain limited to tropical Atlantic (10-60°W, 0-30°N)

- MODIS
  - Reports aerosol optical thickness at 0.55 µm
  - Combined with CERES footprint data using a point spread function
    - Raw MODIS AOT available at higher resolution
Assumptions

- Only over-ocean data considered.
  - Pixels over land or near coast are removed
- Only clear-sky pixels considered
  - MODIS Cloud Fraction < 1.0 %
  - CERES Clear sky percent > 99.0 %
  - Removes ~95% of total data
- Dust Radiative Effect statistics calculated from only data where dust AOT is > 0
  - Dust AOT only valid where 0.3 ≤ FMF ≤ 0.9
Separation of AOT

- We use Kaufman et al. (2005) technique to separate observed AOT into maritime, anthropogenic, and dust components
  - Simple mathematical function

- Separates AOT components using assumed FMF characteristics of each
  - \( F_{\text{mari}} = 0.3, \ F_{\text{dust}} = 0.5, \ F_{\text{anth}} = 0.9 \)

- Assumes maritime optical thickness is a function of surface wind speed
  \[ \tau_{\text{ma}} = 0.007W + 0.02 \]
Separation of AOT

- Kaufman et al. Dust AOT Equation:

$$\tau_{du} = [\tau_{0.55}(f_{an} - f) - \tau_{ma}(f_{an} - f_{ma})]/(f_{an} - f_{du})$$

- Uncertainties and limitations:
  - Observed FMF bounded between 0.5 and 0.9
  - For low observed AOT, this equation can return a negative value for dust AOT
    - Dust AOT set equal to 0 in this case
  - Kaufman et al. estimates a 15% uncertainty in component AOT using this technique
    - Has a downstream effect on component radiative effect uncertainty
Dust AOT Map

Highest dust concentration
Calculating Radiative Effect of Dust Aerosols

- Dust Radiative Effect is calculated by subtracting SW and LW fluxes containing aerosols ($F_{aero}$) from a clear-sky, aerosol-free background ($F_{clr}$)
  - This difference is then scaled by the ratio of dust AOT to total AOT to derive the component of forcing from dust

$$DRE = \frac{\tau_{du}}{(\tau_{0.55} - \tau_{ma})} \times (F_{clr} - F_{aero})$$

- The clear-sky, aerosol free background is derived by relating pixels where AOT < 0.2 to SW flux and deriving what the AOT=0 flux value should be.
  - No adjustment for LW (Use AOT < 0.1)
Diurnal and Sample-Bias Adjustments

- Instantaneous radiative effect numbers do not tell the whole story
- Terra only observes AOT and flux at ~10:30 local time
  - Diurnal variability not sampled
  - Use “diurnal adjustment” functions developed by Remer and Kaufman (2005)
  - Diurnal effect \( \approx \) instantaneous effect \( \div 2.0 \)
- The CERES footprint is much larger than the MODIS footprint
  - Due to clear-sky assumption, DRE is biased toward clear-sky regions
  - AOT from the MOD08 data set were used to derive MODIS-only dust AOT, which is higher than the CERES-footprint dust AOT
  - This difference (0.045) is used to adjust DRE upward
Radiative effect values include diurnal and sample bias adjustments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERES AOT</td>
<td>0.23</td>
</tr>
<tr>
<td>DUST AOT</td>
<td>0.15</td>
</tr>
<tr>
<td>SWRE (Wm(^{-2}))</td>
<td>-7.36</td>
</tr>
<tr>
<td>LWRE (Wm(^{-2}))</td>
<td>0.89</td>
</tr>
<tr>
<td>NRE (Wm(^{-2}))</td>
<td>-6.47</td>
</tr>
<tr>
<td>CLOUD FRACTION</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Uncertainty is \(~20\%\)

Spatial and temporal domains are not an exact match.

- Li et al. (2004)  -12.6
- Loeb et al. (2005) -5.99
Adjusted SWRE:
Maximum cooling corresponds to location of highest dust aerosol concentration

Adjusted LWRE:
Correlation with AOT concentration much less
Cooling along ITCZ
DRE as a Function of Dust AOT

\[ \text{SW}_{\text{eff}} = -33.8 \text{ Wm}^{-2} \tau^{-1} \]

\[ \text{LW}_{\text{eff}} = 2.3 \text{ Wm}^{-2} \tau^{-1} \]
Conclusions

- Dust aerosols have a measurable impact on both SW and LW fluxes
  - For this region, almost all NRE can be attributed to dust aerosols
- The LW warming offsets SW cooling by approximately 15%
  - A significant number
- Provides framework for global analysis
Terra vs. Aqua DRE

- CERES SSF data from Terra and Aqua satellites were compared to examine the effect of different overpass times on AOT and DRE measurements
  - 2003-2005, June, July, and August
  - FM1 and FM3 instruments used
  - Same Atlantic ocean domain as before
  - Aqua satellite overpass time is approximately 3 hours after Terra (13:30 vs. 10:30 local time)
AOT histogram

Aerosol Optical Thickness

Adjusted NET Dust Radiative Effect

<table>
<thead>
<tr>
<th></th>
<th>Terra</th>
<th>Aqua</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOT</td>
<td>0.24</td>
<td>0.22</td>
</tr>
<tr>
<td>NRE</td>
<td>-6.90</td>
<td>-7.00</td>
</tr>
</tbody>
</table>
SWRE vs. Dust AOT

SWRE - AOT relationship for Terra and Aqua is the same
Terra – Aqua Net Radiative Effect
Terra-Aqua Conclusions

- Terra AOT are slightly higher than corresponding Aqua AOT throughout this domain
  - Differences are small and randomly distributed

- Differences in adjusted net dust radiative effect are small.
  - AOT-SWRE relationship is the same
  - Sample bias adjustment is larger for Aqua
Ongoing Research

- **Global Dust**
  - Use 2000-2001 CERES SSF data for global determination of dust radiation effect
  - Also study sensitivity of FMF thresholds on component radiative effect results

- **Averaging**
  - Performing an analysis of the statistical properties and assumptions inherent reported DRE values.
References


Questions
The End

- Who am I, and why am I here?