Exploring the Longwave Radiative Effects of Dust Aerosols

How significant is it?

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Outline

✔ Motivation
✔ Field experiments
✔ Optical properties of dust
✔ Methodology
✔ Longwave Radiative Effects
✔ Summary
Motivation – Big Picture

- **Aerosol radiative effects are uncertain in climate models**
  - Dust is the most dominant aerosol by mass (Textor et al. 2006)
  - Shortwave behavior of dust is better constrained
  - Longwave effects of dust are not well known due to uncertainties in their optical properties
  - Climate models generally do not include the Longwave effects; Recent works suggest Longwave effects are important
Here I focus on 2 field experiments to study the radiative effects of dust:

- Sal Island (Cape Verde)
- 16.73° N, 22.93° W
- Sea-Level
- Sept 2006

NAMMA 2006 (Zipser et al. 2006)

Mineral dust streaming off the African Continent mixed with clouds during active dust period of the field campaign.

Results published in Hansell et al. (2010)
NASA SMARTLabs at Cape Verde

(Instrumentation)

Balloon soundings

Trailers arrived on Sal Island

On-site team

Scanning microwave radiometer

Aerosol & trace gases

Active/Passive Radiation sensors

Surface-sensing Measurements for Atmospheric Radiative Transfer
Chemical, Optical & Microphysical Measurements of In-Situ Troposphere

http://smartlabs.gsfc.nasa.gov
AMY2008
(Lau et al. 2008; Li et al. 2011)

- Zhangye (desert)
- 39.0°N; 101°W
- 1.5 km ASL
- April-June 2008

Circles mark location of Zhangye and NASA SMARTlabs instruments

Ge et al. 2010

MODIS L1B RGB image 3 May 2008

Dust Parameter (D* - Hansell et al. 2007)
NASA SMARTLabs at Zhangye China
(Instrumentation)

Air inlet to aerosol &
gas measurements

Shortwave/longwave broadband
radiometers

Sun-photometer

Sky imager

Solar tracker

Microwave radiometer

CHINA²-AMY08: Cloud, Humidity Interacting Natural/
Anthropogenic Aerosols in AMY-2008 (Asian Monsoon Years)
Spectral Interferometry

- Passive, fully automated, ground-based interferometer
  - Measures downward emissions
- Micheleson Series MR100 (Bomem)
- 2 detectors:
  - InSb: $3.3\,\mu m \leq \lambda \leq 5.5\,\mu m$
  - MCT: $5.5\,\mu m \leq \lambda \leq 19\,\mu m$
- 2 Blackbody references
  - Ambient /Hot (60°C)
- Scene mirror optics assembly
- Temporal frequency: $\approx 10\text{min} (\text{BB} + \text{scene} + \text{BB})$
- 1 cm$^{-1}$ spectral resolution
Giovanni allows for rapid assessment of regional aerosol conditions.

Deep Blue averaged AOT from (30 April –6 May 2008) at Zhangye during AMY.

MISR averaged AOT from (6–8 Sept 2006) at Cape Verde during NAMMA.
Dust Physicochemical Properties: Optical Model

SEM image provided by Dr. J.S. Reid
Dust model parameterizations

Hemispherical fluxes $F_{\uparrow \downarrow} (\lambda, \text{xyz}, t)$
Radiances $L (\lambda, \text{xyz}, \theta, t)$

RTM

Observed radiances and fluxes

Optical depth
$\tau(\lambda, \text{xyz}, t)$

Single-scattering albedo
$\omega = \beta_s / \beta_e (\lambda, \text{xyz}, t)$

Phase function
$P(\lambda, \text{xyz}, \theta_i, \theta_j, t)$

Dust layer thickness
Dust layer height
Vertical distribution

Size distribution
$N(r) = f(\text{xyz}, t)$

Refractive index
$m = n - ik$ ; $m = f(\lambda, \text{xyz}, t)$

Shape distribution
$F(\text{ar}) = f(\text{xyz}, t)$

$\chi^2 = \sum_{i=a}^{b} [\ln(\Delta B T_{\text{calc}}^i (\tau, a_e, T, \nu)) - \ln(\Delta B T_{\text{aeri}}^i (T, \nu))]^2$
Local measurements: model constraints

IR spectra

MPL profiles

PM10 mass concentrations

Particle size spectra

Hansell et al. 2012
Optical constants of common terrestrial minerals in the thermal IR (imaginary term)

Large variability in absorptive peaks are evident in the single-scattering properties below

Dust composition plays large role in LW applications
Absorption in the IR bands

Spectral envelope of mass extinction efficiencies of dust versus composition, shape, and size

Key optical parameters in thermal IR

Hansell et al. 2011
Jeong et al. [2008]
<table>
<thead>
<tr>
<th>Current study</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz (41%)</td>
<td>Gray (1963), Drumond (1935), Spitzer &amp; Kleinman (1961), Philipp (1985), Longtin et al. 1988</td>
</tr>
<tr>
<td>Plagioclase (17%)</td>
<td>J.R. Aronson and P.F.Strong [1975] - LW</td>
</tr>
<tr>
<td>K-Feldspar (9%)</td>
<td>Pollack et al. [1973] - SW</td>
</tr>
<tr>
<td>Calcite (10%)</td>
<td>Long et al. [1993] - LW</td>
</tr>
<tr>
<td>Mica (12%)</td>
<td>Aronson and Strong [1975] - Muscovite (LW)</td>
</tr>
<tr>
<td>Chlorite (10%)</td>
<td>Mooney and Knacke [1985] - LW</td>
</tr>
<tr>
<td>Amphibole (1%)</td>
<td>Thomas et al. [2009] - SW</td>
</tr>
<tr>
<td>Dolomite (0)</td>
<td>No data available</td>
</tr>
<tr>
<td>Gypsum (0)</td>
<td>N/A</td>
</tr>
<tr>
<td>Total – 100%</td>
<td>Total – 100%</td>
</tr>
</tbody>
</table>

Adapted from Jeong et al. 2008

Table from Hansell et al. 2012

**Zhangye**
- In-situ mineralogical measurements at Zhangye
- Birefringence properties

**Cape Verde**
- Transported Saharan dust at Cape Verde
- Clay, illite, kaolinite, and quartz traces
- IOR: local AERONET climatology, Volz (1973) and D’Almeida (1991)
- Birefringence properties

**Mineral composition – optical constants**
Dust Models

- Complex refractive indices
  - Real
  - Imaginary
- Zhangye
- Cape Verde

Hansell et al. 2012

Asymmetry parameter $\langle \cos(\Theta) \rangle$

- Zhangye
- Cape Verde

SSA ($\pi$)

Wavelength (microns)
Hematite mixture (~1%) SSA↓ ~ 5-10%

Larger scatter
Larger absorption

Hansell et al. 2012
Energy Transfer in dusty atmosphere

\[ DARE = (I_{\text{all-sky}} \downarrow - I_{\text{all-sky}} \uparrow) - (I_{\text{clear-sky}} \downarrow - I_{\text{clear-sky}} \uparrow) \]
Methodology

- **Broadband RTM**
  - **AERIPLUS + sounding profiles**

- **DRELW**
  - **Dust optical model**

- **Radiance correction spectrum**

- **AERI LW spectrum**

- **Cloud screen (BT11 μm-BT10 μm)**

- **AOT retrieval (Scaled to visible)**

- **LW radiometer PIR**

- **Broadband RTM**

- **DRE\text{LW}**

- **AERONET**
  - **AERIPLUS + sounding profiles**
  - **Dust optical model**

Hansell et al. 2012
Average visible AOT (0.55 µm) ~0.53 ± 0.32.
Daytime/nighttime loading is comparable

Hansell et al. 2012
Instantaneous Surface DARE

- **Zhangye DARE**: ~2-20 Wm\(^{-2}\)
- **Cape Verde DARE**: ~2-10 Wm\(^{-2}\)

DARE (Zhangye) ~ 2X larger than that at Cape Verde!

- The upper end of DARE is comparable to modeled and observed Cloud Radiative Effects (≥30 Wm\(^{-2}\) - e.g., *Lockwood*, 1992); Thus it is climatically significant.
Surface DARE (Efficiency)

- DARE (Zhangye) ranges from 31-35 Wm\(^{-2}\tau^{-1}\)
- DARE (Taklamakan) ranges from 18-39 Wm\(^{-2}\tau^{-1}\) (Xia et al. 2009)
- DARE (Zhangye) ~ 2X larger than that at Cape Verde

\[ y(\text{Zhangye}) = 35\tau + 1.3 \]
\[ y(\text{Cape Verde}) = 16\tau + 0.72 \]
Surface $\text{DARE}_{\text{SW}}$

- Haywood et al. 2003 estimated $\text{DARE}_{\text{SW}} = -209 \text{ Wm}^{-2}$ during SHADE field campaign (around Cape Verde).
- Diurnally averaged $\text{DARE}_{\text{SW}} \sim -38.4 \text{ Wm}^{-2}\tau^{-1}$ (Anderson et al. 2005).
- Considering meteorological and dust conditions to be comparable during both field studies (in September), the derived $\text{DARE}_{\text{LW}}$ (over ocean) from NAMMA is $\sim 42\%$ of the diurnally averaged $\text{DARE}_{\text{SW}}$ measured during SHADE.

- Level of significance tied to how well SSA can be constrained.
- LW significance (Zhangye) ranges from 51-58% of the SW effect.
- Over one half of SW cooling is compensated by LW warming.
- Larger than the 33% compensation reported by Huang et al. 2009, but very close to what was found by Xia et al. (2009) - $\sim 58\%$.
LW flux enhancement at surface is seen as a reduction in the OLR due to absorption by intervening dust layers.

TOA DARE ~ 60% larger at Zhangye

DARE ~ 20 Wm\(^{-2}\)τ\(^{-1}\)

DARE ~ 13 Wm\(^{-2}\)τ\(^{-1}\)
0.25-0.30 K/day on average, with maximum heating reaching over 1.5 K/day

*Huang et al.* [2009], using CALIPSO derived vertical distributions of dust extinction over Taklamakan Desert (July 2006), reported heating rates that varied between 1-3 K/day depending on dust load, with maximum heating reaching 5.5 K/day.
Summary Highlights

• Cape Verde: Surface $DARE_{LW}$ varied ~2-10 Wm$^{-2}$, with daytime/nighttime means of 6.9 and 8.4 Wm$^{-2}$, respectively.

• Zhangye: Conservatively, surface $DARE_{LW}$ varied about 2-20 Wm$^{-2}$, with daytime/nighttime means of ~12.0 Wm$^{-2}$. Was found to be as high as ~28 Wm$^{-2}$

• Cape Verde: $DARE_{LW}$ efficiency ~16 Wm$^{-2}\tau^{-1}$, and nearly 42% of the diurnally averaged SW values measured during SHADE

• Zhangye: $DARE_{LW}$ efficiency ~35 Wm$^{-2}\tau^{-1}$, and can be as high as 58% of the diurnally averaged observed SW values.
• Cape Verde: TOA DARE\textsubscript{LW} varied \(\sim 2 - 11\) Wm\(^{-2}\). The DARE\textsubscript{LW} efficiency at TOA is \(\sim 13\) Wm\(^{-2}\tau^{-1}\).

• Zhangye: TOA DRE\textsubscript{LW} varied \(\sim 2 - 16\) Wm\(^{-2}\). The DARE\textsubscript{LW} efficiency at TOA is \(\sim 20\) Wm\(^{-2}\tau^{-1}\).

• Certainly non-negligible, the surface DARE\textsubscript{LW} can be an important parameter for assessing regional changes in surface temperatures, moisture budgets, and being able to modulate the dynamics of the atmosphere.

• The upper end of DARE is comparable to Cloud Radiative Effects (\(\geq 30\) Wm\(^{-2}\)); Thus it is climatically significant.

• At regional scales near dust source regions, DARE in the LW is important and can leverage the impact of SW cooling.
Thank you!