Optical Properties of Mineral Dust Aerosol in the Thermal Infrared

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Research Goals

• Measure atmospheric radiance in the spectral range 800–1200 cm\(^{-1}\) (8–12 µm) during SAMUM-2

• Set-up a simulation environment (PIRATES) capable to compute thermal infrared (TIR) atmospheric radiation in the presence of aerosols

• Identify a microphysical aerosol model suited to reproduce the measured radiation at bottom/top of the atmosphere (BOA/TOA) with special attention to refractive index and particle shape

The SAharan Mineral dUst ExperiMent (SAMUM-2)
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- LIDAR (IfT, LMU, DLR)
- In-situ size distributions (DLR, TU Darmstadt)
- Sample analysis (TU Darmstadt)
- Radiosonde measurements (IfT)
- Radiation Measurements (Uni Leipzig, LMU, DLR)
TOA Radiative Effect of Mixed Smoke / Dust Aerosol

• Investigate influence of a thin mixed layer on TIR remote sensing applications

• Example: IASI sea surface temperature (SST) product for 25 Jan 2008

www.ghrsst.org
Vertical Aerosol Distribution on 25 Jan 2008
Measurements Entering the Simulation

- **FA_151**: 16:57 UTC, 2.0 km
- **FA_154**: 15:44 UTC, 3.6 km
- **L04**: 15:43 UTC, 3.8 km
- **L07**: 16:48 UTC, 3.7 km
- **L08**: 16:58 UTC, 2.1 km
- **FA_150**: 16:48 UTC, 3.7 km
- **1122**: 11:33 UTC
- **1443**:

Locations:
- **San Tiago**
- **Maio**
- **Praia**
- **Brava**
- **Fogo**
Comparison of Simulation and IASI Measurements

- Simulation w/o aerosols
- SST: 295 K
- Deviations in ozone band (1000 – 1080 cm\(^{-1}\)) due to profile mismatch
- Good agreement, so aerosols can be ignored?
Comparison of Simulation and IASI Measurements

- Simulation with aerosols
- Aerosol absorbs terrestrial radiation
- Simulation underestimates upwelling radiation
Comparison of Simulation and IASI Measurements

- SST: 296 K (1 K increase)
- Better fit between simulation and measurement
- O’Caroll et al. (2012) report bias of IASI SST compared to in-situ measurements
- Aerosol has to be taken into account for accuracy better 1 K
BOA Radiative Effect of Mineral Dust Aerosol

- Investigate influence of a low pure dust layer on BOA radiance
- Investigate influence of particle shape and refractive index
Vertical Aerosol Distribution on 29 January 2008

- Lin. part. depolarization ratio
- Height above ground level [km]
- Part. extinction coeff. [km⁻¹]
- Diameter [μm]

11% dust (L09)
10% dust (L10)
3% dust (Dust Phase 3)
52%
50%
43%
40%
37%
54%
Measurements Entering the Simulation

- **L09**
  - 20:34 UTC
  - 0.8 km

- **L10**
  - 20:39 UTC
  - 0.6 km

- **22:07 UTC**
The Spectral Signature of Mineral Dust

- FTIR measurements from 2024 UTC to 2105 UTC
- Mineral composition from samples collected on 25 Jan (similar source regions)
- Internal mixture of spherical particles
- Agreement not bad, but outside uncertainties
The Spectral Signature of Mineral Dust

![Graph showing the spectral signature of mineral dust with two lines: one for simulation without aerosols and one for measurement. The x-axis represents wavenumber in cm\(^{-1}\), and the y-axis represents radiance in mW/(m\(^2\) sr cm\(^{-1}\)).]
The Spectral Signature of Mineral Dust
The Spectral Signature of Mineral Dust

signature [mW/(m² sr cm⁻¹)]

wavenumber [cm⁻¹]
Internal Mixtures of Spherical Particles

- No internal dust model matches measured signature over the entire TIR window
• No external dust model matches measured signature over the entire TIR window
Influence of Non-Spherical Particles

• Oblate spheroids with large aspect ratios (1:5) as suggested by Kleiber et al. (2009) based on laboratory studies

• T-Matrix does not converge for entire size distribution

• Use spheroids for $0.01 < x < 4$, and spheres otherwise

• Sensitivity studies suggest, that the replacement of spheroids with spheres does not significantly alter the results (estimated error $< 0.2 \text{ mW} / (\text{m}^2 \text{ sr cm}^{-1})$)

External Mixture of Oblate Spheroids (AR 1:5)
Influence of Non-Spherical Particles

- Much better fit than spherical particles, although simulated aspect ratios do not match laboratory analysis

- Remaining deviations around 1100 cm\(^{-1}\) due to sulfates, quartz, orthoclase and illite

- Possible explanations
  - Illite might require larger aspect ratios (1:18), which cannot be simulated for the given size distribution (T-Matrix method diverges)
  - Sulfates might be modelled inappropriately by ammonium sulfate and gypsum since sea salt aging might result in peak shifts for other sulfates
  - Sodium sulfates have needle like shape with aspect ratio 1:10, but were modelled as spheres (or spheroids with aspect ratio 6:1)
  - Spheroids might be inadequate as well, e.g. due to missing surface roughness
Optimization of Mineral Composition and Particle Number Density

• Simulate dust signature for pure components (pure quartz, pure kaolinite …) with spheroidal model particles used before

• Size distribution from in-situ measurements

• Decompose measured spectrum into linear combination of pure signatures with least-squares fit (neglects interactions between individual components)

• Simulate aerosol signature of mixture assuming composition obtained from fit for verification purposes
External Mixture of Oblate Spheroids (AR 1:5)
Optimization of Mineral Composition and Particle Number Density

- Fitted microphysics does not match measured (laboratory) composition:

<table>
<thead>
<tr>
<th>Material</th>
<th>Fitted number concentration [%]</th>
<th>Measured number concentration [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illite</td>
<td>52</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>11</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Sea Salt</td>
<td>15</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

- Fitted microphysics similar to results obtained by Boer (2010) for airborne FTIR (ARIES) measurements close to Sal in September 2000

- Dust model neither suited for retrieval of dust composition nor concentration
Summary

• Measured spectral signature of mineral dust/biomass burning aerosol mix in the TIR window (800 – 1200 cm$^{-1}$) including uncertainties

• Confirmed a distinct spectral signature at BOA and TOA and estimated the impact on remote sensing applications (e.g. SST retrieval)

• Oblate spheroidal model particles are much better suited than spherical particles to model mineral dust aerosols, unless optical depth is small

• Model based on spheroids not accurate enough to retrieve dust load/composition

• Further simulation studies with different shapes required