African Dust and Its Deposition into Tropical Atlantic Ocean: Satellites vs. GEOS Model

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Acknowledgement:

Paul Ginoux, Alexei Lyapustin, Dong Huang, Ali Omar, Dave Winker, Lorraine Remer, Robert Levy, Ralph Kahn, Olga Kalashnikova, Laurent Crepeau, Virginie Capelle, Alain Chedin

The 17th AeroCom Workshop, October 15-19, 2018
Motivation

- Dust deposition is crucial for understanding the dust impacts on ocean biogeochemical cycle and climate change.

Current Status

- Observations are scarce & over short periods, esp. in remote oceans.
- Model simulations are very uncertain:
  - Most of dust processes are highly parameterized without adequate obs. constraints, e.g., scavenging, emissions.
  - Data assimilation, being widely used to constrain aerosol loading in the atmosphere (AOD), does not constrain the dust deposition.
Objectives

- Explore the use of satellite routine measurements to estimate:
  - dust deposition (DD) into tropical Atlantic Ocean
  - loss frequency (LF) of dust (i.e., *how efficient dust is removed*)

- Compare satellite-based estimates with GEOS simulations to understand:
  - *How large is the difference in dust deposition?*
  - *How do processes, e.g., transport/removal vs. dust emissions, contribute to the observation-model agreement or discrepancy in the dust deposition?*
Estimation of Dust Deposition from Satellites

1. Aerosol extinction/backscatter profile from CALIOP

2. Dust extinction profile

3. Profile of Dust Mass Concentration

Dust particles are large in size and non-spherical in shape, so large depolarization ratio.

4. Dust Mass Flux

\[ F = \int m(z)u(z)dz \]

MEE = 0.37 → 0.60 m²/g

5. “Mass Balance” Dust deposition

DOD derived from MODIS, MISR, IASI is distributed using the CALIOP dust extinction profile

MERRA-2 Reanalysis wind

- 2007-2016 data
- Seasonal basis
- 5°x2° resolution

No leak from top

meridional

zonal
GEOS Dust Simulations

- Huisheng Bian
- GOCART dust module \((0.2 \sim 20 \mu m)\)
- MERRA-2 meteorology
- 1°x1° horizontal resolution
- 72 vertical layers

Miami: OBS/GEOS = 1.71

Barbados: OBS/GEOS = 1.18
Dust Deposition: Satellites vs GEOS [1]

representing surface-based climatology \( (34 = 23 \text{ ocean} + 11 \text{ land}) \)

- historic data at 23 sites \( (16 \text{ ocean} + 7 \text{ land}) \) (widely used in model evaluation, e.g., Albani et al., 2014)
  - 5 DUSTTRAFFIC ocean moorings along ~12N (Korte et al., 2017; dust = total - biogenic)
  - 2 sediment traps around 20N (Fries et al., 2017)
  - 3 Sahelian Dust Transit (AMMA) sites (LAND ONLY) (Marticorena et al., 2016)
  - 1 site in Mbour (W. Africa margin) (Skonieczny et al., 2013)

Over land: \( \text{OBS} = 5 \times \text{GEOS} \)
Dust Deposition: Satellites vs GEOS [2]

CALIOP

MODIS

MISR

IASI

GEOS

DJF

MAM

JJA

SON
MEE = 0.37 m²/g

MEE = 0.37 \rightarrow 0.60 m²/g

MEE = 0.60 m²/g

In MAM, model’s interannual variability is much smaller than satellites.
What We Have Learned:
The GEOS model simulations of dust deposition into tropical Atlantic Ocean fall within the range of those derived from CALIOP, MODIS, MISR, and IASI observations.

Next Steps:
We examine how two dust processes, i.e., (1) transport/removal, and (2) emissions, contribute to the dust deposition estimates.

To isolate the uncertainty associated with the transport/removal processes from that of dust emissions:

Loss Frequency (LF) \([1/day]\) = [Dust Deposition Rate] \([g/m^2/day]\) ÷ [Dust Mass Loading=DOD/MEE] \([g/m^2]\)

- less sensitive to assumed dust MEE (more accurate than dust deposition)
Compared to dust deposition, the loss frequency shows much larger satellite-model difference, with the model substantially overestimating the removal efficiency of the dust.
**Dust Loss Frequency: Satellites vs Model [2]**

Pronounced differences between the satellites and GEOS model:
- GEOS model > Satellites
- much larger in winter & fall than in spring & summer

Possible model deficiencies
- **Rainfall may be too intense**
- **Altitude of dust layer may be too low**
- Scavenging coefficient may be too high
- Settling and dry deposition may be too fast
Model’s rainfall is much more intense than GPCP
Model’s dust extinction profiles show reasonably good agreement with CALIOP observations.
How Well Does GEOS Represent Dust Emissions? [1]

- Does the model capture major dust sources?
- Are magnitudes of dust emissions biased high or low?

Over land, the comparison against surface dust deposition measurements appears to indicate a substantial underestimate of dust emissions.

- The model is mass-based.
- $DOD = \text{[Mass Loading]} \times \text{MEE}$
- It is necessary to understand potential bias in MEE.

The PSD is biased to fine particles
- Particles $>20 \mu m$ excluded
- The model MEE would be biased high.
How Well Does GEOS Represent Dust Emissions? [3]

**DSCOVR/EPIC MAIAC product** (Alexei Lyapustin)
- Deep Space Climate ObserVatoRy (L1, one million miles away)
- Earth Polychromatic Imaging Camera
- Sunrise-to-sunset, 1-2 hourly frequency, ~10km pixel resolution
- MAIAC atmos. Corr. Product (including AOD)

Large discrepancies in dust source areas are believed to be related to the temporal resolution of satellite measurements (Schepanski et al., 2009, 2012)
Conclusions

• A 10-year climatology of dust deposition into tropical Atlantic ocean was developed from CALIOP, MODIS, MISR, and IASI measurements (seasonal, 5°x2° resolution).

• The GEOS modeling of dust deposition falls within the range of satellite-based estimates.

• However, the reasonable agreement in the dust deposition is a compensation of the model’s:

  • underestimate of dust emissions, and

  • overestimate of dust removal efficiency (i.e., higher dust loss frequency, which is due largely to the model’s overestimate of rainfall rate).

Chen, C., Retrieval of desert dust and carbonaceous aerosol emissions over Africa from POLDER/PARASOL products generated by the GRASP algorithm, ACP, 18, 12551-12580, 2018.

GEOS-Chem (D = 0.2~12 um)

GEOS (D = 0.2~20 um)

Fennec Cumulative Fraction of Dust Mass as a Function of Particle Size
Does GEOS model underestimate dust concentration?

Miami: \( \text{OBS/GEOS} = 1.71 \)

Barbados: \( \text{OBS/GEOS} = 1.18 \)
GEOS-5: underestimating coarse particles, but overestimating fine particles

Fennec Cumulative Fraction of Dust Mass as a Function of Particle Size

Size distribution (SAL)

<table>
<thead>
<tr>
<th>Size Distribution</th>
<th>DU1-DU2-DU3:</th>
<th>DU4-DU5:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DU1-DU2-DU3:</td>
<td>0.2 &lt; D_e &lt; 6.0 μm</td>
<td>6.0 &lt; D_e &lt; 20 μm</td>
</tr>
</tbody>
</table>

- GEOS-5 substantially overestimates the fraction of dust < 6 μm, but underestimates the fraction of very coarse particles (> 6 μm):
  - higher dust MEE – affecting model-satellite comparisons/assimilation
  - longer transport of dust, *IF dust removals are accurately done*. But we just showed that the dust loss frequency is much larger than satellites – need to improve dust removal schemes.
Reducing Convective Scavenging Efficiency Improves GEOS & AToM Agreement

GEOS5 vs. DC-8

African Coast:
GEOS5 > DC-8 (<3km)
GEOS5 < DC-8 (>3km)

Tropical E. Pacific:
GEOS5 < DC-8

Reducing convective scavenging efficiency \(f_{\text{conv}}\) from 1.0 to 0.2 leads to much better agreement with observations in tropical E. Pacific.

Figures from Huisheng Bian
• Dust, generally large & non-spherical particles, can be separated from other types based on measurements of particle size & shape.
• A synergy of passive & active measurements can characterize dust in 3-D.