Observational Constraints
On the Global Dust Aerosol Cycle

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Model Estimates of Global Dust Emission Vary Widely

- **AEROCOM Models**
  - GISS
  - NCAR MATCH
  - GFDL MOZART
  - LSCE
  - KYU
- **Multi-year climatology:**
  - Model Mean: 1854 Tg
  - Std Dev: 1202 Tg

Modelers want to know the mass of soil particles entering the atmosphere along with its size distribution.

- Strong winds lift soil particles into the atmosphere through saltation and sandblasting.
- We have detailed physical theories of these processes and measurements from wind tunnels. (e.g. Gillette 1978, Marticorena and Bergmetti 1995, Alfaro and Gomes 2001, Grini and Zender 2002)

⇒ Attempts to apply this knowledge to global models are complicated by surface heterogeneity and the models’ large resolved spatial scale.
Emission In Global Models

• In practice, emission in global models typically increases with wind speed, and varies spatially according to the presence of dust sources. The total emitted mass and its size distribution is controlled by a factor $C(r)$ that is generally assumed independent of location.

\[ \mathcal{E} = f(u, r, x) \rightarrow C(r) S(x) f(u) \]

⇒ $C(r)$ is typically tuned to match observations (often unstated).

• Assumption: there is a ‘universal’ value of $C(r)$, such that all source regions emit with the same efficiency and size distribution for a given wind speed.

• Assumption: processes that carry dust to the measurement location are well-constrained compared to emission, so that it is appropriate to tune emission rather than the transport and removal processes to match the measurements downwind of the source.

Experiment

⇒ Tune $C(r)$ in the AEROCOM models so that each model has a minimum error with respect to a globally distributed set of observations.
⇒ If these assumptions are valid, then the range of emission among the AEROCOM models should be substantially reduced. That is, if poor knowledge and inconsistent choices of $C(r)$ are the main reasons for the disagreement among AEROCOM model emission, then tuning of $C(r)$ to match observations should reduce the estimated emission range.
GISS Model Surface Concentration at Barbados

Ratio of model to observation standard deviation $S=1.10$,

$$S^2 = \frac{\sum m_i^2}{\sum o_i^2}$$

Correlation $r=0.84$,

$$r = \frac{\sum m_i o_i}{\sqrt{\left(\sum m_i^2\right)\left(\sum o_i^2\right)}}$$

Root mean square error $E=0.60$,

$$E^2 = \frac{\sum (m_i - o_i)^2}{\sum o_i^2}$$

⇒ **Optimize:** multiply total emission by a factor $\alpha$ that minimizes the root mean square error $E$:

$$C(r) \rightarrow \alpha C(r), \ m_i \rightarrow \alpha m_i.$$  

$E = 0.54$ ($S=0.84$, $r=0.84$)

Note that total (root mean square) error is reduced, but correlation is not improved. Rescaling total emission doesn’t change the timing of the seasonal peak.

⇒ **Rescale clay and silt emission separately** (requires separate archival of clay and silt in model intercomparisons like AEROCOM).
Constrain $C(r)$ With Global Measurements

- Aerosol Optical Thickness (AOT): AERONET and MISR.
- Surface concentration from Univ. of Miami.
Global Optimization

- In a Taylor diagram, the ratio of the model and observed standard deviation is plotted on the radial axis, and the angle depends upon the correlation (Taylor, J. Geophys. Res., 2001).
- The rms error increases with distance from the blue circle on the horizontal axis.
- For each model, an arrow connects the unoptimized optimized values.
- The arrow points toward the optimized value.
- A green arrow indicates a smaller rms error after optimization; red indicates a larger rms error.
• Optimization increases the agreement of each model with the observations (by reducing the RMS error).
• But the range of emission among the AEROCOM models is not reduced.
Conclusions

• Tuning emission through $C(r)$ brings the AEROCOM models into better agreement with observations of aerosol optical thickness and surface concentration, but the range of model emission is not reduced.

• Errors and uncertainties in other processes (e.g. transport and removal) have a comparable effect upon the model dust cycle.

• Caveats:
  • Surface wind speed may vary widely among the models, creating differences in emission that can’t be corrected by adjusting $C(r)$.
  • Clay and silt emission may need to be tuned individually rather than total emission. Future intercomparison experiments should archive separate silt and clay contributions to load and AOT.

• The global rms error is a ‘skill score’ that is useful for assessing model development even in the absence of tuning.

• Soon to be publicly available as a fortran (and IDL) program.