ESRL Research on Aerosol Direct Radiative Forcing of Climate

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representing aerosol researchers throughout the...
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Clear-sky Aerosol Radiative Forcing over North Indian Ocean

TOA: net change in energy budget due to backscattering and absorption of solar radiation

Atmosphere: heating due to aerosol absorption of sunlight

Surface: cooling due to aerosol absorption and backscattering


average for Jan - March, 1999; 0 - 20°N; $\tau_a = 0.3$
Interactions of Aerosol Measurements and Models for Radiative Forcing

- **Measurements (Model inputs)**: aerosol source, transformation, and removal processes
- **Models**: CHEMICAL TRANSPORT MODEL
- **Model Outputs**: spatial fields of aerosol chemical and physical properties
- **Measurements (Validation)**: aerosol chemical and physical properties

**CLOSURE**
Interactions of Aerosol Measurements and Models for Radiative Forcing

**Measurements (Model inputs)**
- Aerosol source, transformation, and removal processes
- Aerosol optical properties (e.g., refractive index)

**Models**
- CHEMICAL TRANSPORT MODEL
- AEROSOL OPTICAL MODEL (e.g., Mie scattering)

**Model Outputs**
- Spatial fields of aerosol chemical and physical properties
- Spatial fields of aerosol radiative properties (e.g., optical depth)

**Measurements (Validation)**
- Aerosol chemical and physical properties
- Aerosol radiative properties

**Closure**
- Models to Measurements (Model inputs)
- Measurements to Models (Validation)
Interactions of Aerosol Measurements and Models for Radiative Forcing

Measurements (Model inputs)
- aerosol source, transformation, and removal processes
- aerosol optical properties (e.g., refractive index)

Models
- CHEMICAL TRANSPORT MODEL
- AEROSOL OPTICAL MODEL (e.g., Mie scattering)
- RADIATIVE TRANSFER MODEL

Model Outputs
- spatial fields of aerosol chemical and physical properties
- spatial fields of aerosol radiative properties (e.g., optical depth)
- spatial fields of aerosol forcing

Measurements (Validation)
- aerosol chemical and physical properties
- aerosol radiative properties
- radiative fluxes linked to aerosol column burdens

CLOSURE
Interactions of Aerosol Measurements and Models for Radiative Forcing

- Aerosol source, transformation, and removal processes
- Aerosol optical properties (e.g., refractive index)

Models
- Chemical Transport Model
- Aerosol Optical Model (e.g., Mie scattering)
- Radiative Transfer Model

Model Outputs
- Spatial fields of aerosol chemical and physical properties
- Spatial fields of aerosol radiative properties (e.g., optical depth)
- Spatial fields of aerosol forcing

Measurements (Validation)
- Aerosol chemical and physical properties
- Aerosol radiative properties
- Radiative fluxes linked to aerosol column burdens

INTEGRATED MODELING SYSTEM
Interactions of Aerosol Measurements and Models for Radiative Forcing

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Model Outputs
- spatial fields of aerosol chemical and physical properties
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Measurements (Validation)
- aerosol chemical and physical properties
- aerosol radiative properties
- radiative fluxes linked to aerosol column burdens

Climate response to aerosol forcing

CLOSURE
Interactions of Aerosol Measurements and Models for Radiative Forcing

**Measurements (Model inputs)**
- Aerosol source, transformation, and removal processes
- Aerosol optical properties (e.g., refractive index)

**Models**
- Chemical Transport Model
- Aerosol Optical Model (e.g., Mie scattering)
- Radiative Transfer Model
- Global Climate Model

**Model Outputs**
- Spatial fields of aerosol chemical and physical properties
- Spatial fields of aerosol radiative properties (e.g., optical depth)
- Spatial fields of aerosol forcing
- Climate response to aerosol forcing

**Measurements (Validation)**
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ESRL
ESRL Long-term Aerosol Network

Legend
- ★ NOAA
- ★ affiliate
- ★ future sites
Variations in Aerosol Amount and Type

A rich data set for evaluating models

1 Mm\(^{-1}\) = 1 mm\(^2\) m\(^{-3}\), extinction cross-section per cubic meter of air

Percentiles
95
75
50
25
5

Pristine Polluted

A log scale!
Variability of Radiative Forcing Efficiency

\[ \text{RFE} = \frac{\text{TOA Forcing}}{\text{Optical depth}} \]

Calculated using a simple radiative transfer model and in-situ measurements of aerosol single-scattering albedo (SSA) and backscatter fraction (BFR).

Daily averages, 1996-2005, for DOE/ARM site in Oklahoma (SGP)
Models must represent water uptake by aerosols to calculate radiative forcing. Measurements from ESRL long-term network allow evaluation of model performance for a wide range of conditions.
Chemical control of hygroscopic growth

Process studies provide predictive understanding of water uptake by aerosols. This can be parameterized in climate models and compared with results from long-term network.
In-Situ Aerosol Profiling

- **Objective:** Obtain a statistically-significant data set of vertical distribution of aerosol properties relevant to radiative forcing
- **Measurements:** emphasize aerosol scattering and absorption above a similarly instrumented surface site
- **Oklahoma:** 807 flights 2000-2007
  Illinois: 266 flights since 2006
- **Key Results**
  - aerosol properties at surface represent statistics in lower 2-km layer, which dominates forcing
  - clear seasonality seen in profiles
  - Radiative forcing efficiency fairly constant throughout lower 5km
Evaluating models with data

- Daytime measurements 2-3 times/week
- Primary measurements
  - aerosol scattering and absorption
- Derived properties
  - single-scattering albedo
  - aerosol optical depth
- AEROCOM profile comparisons
  - general agreement in aerosol extinction
  - models generally show less absorption
- Acknowledgement: R. Ferrare, NASA
Optical Closure Studies

- Over-determined set of measurements provides rigorous assessment of measurement uncertainty
- Laboratory and ambient conditions
- Upper figure: Measurement vs. Theory
- Lower figure: Measurement vs. Measurement
Aerosol optical depth over U.S.

- SURFRAD network of 7 stations
- Broadband solar irradiance shown as percent deviation from 10-year mean of 175 W m$^{-2}$
- Tick marks show standard error of mean
- Change in AOD explains less than 10% of modelled change in solar irradiance
Smoke aerosol radiative forcing in Arctic

Model parameters were constrained by observations of broadband solar irradiance, aerosol optical depth, single scattering albedo, and asymmetry parameter from the ESRL Barrow observatory.
Conclusions

• Results
  – Aerosols cool the surface and heat the atmosphere
  – Sign and magnitude of TOA forcing depends on optical depth, absorption fraction, angular scattering, and surface albedo
  – ESRL measurements of these key aerosol properties provide a rich data set for evaluating models

• Future directions
  – Improved measurements of light absorption, measure humidity dependence
  – Expand global long-term network with additional collaborators and measurements
  – Evaluate models with measurements