AEROSOL Particles—What’s all the fuss?

- Why are they important?
- What are they?
- Where do they come from?
- How are they measured?
- What is AERONET all about?
Variations of the Earth's surface temperature for:

(a) the past 140 years

Year

1860 1880 1900 1920 1940 1960 1980 2000

GLOBAL

Data from thermometers.

(b) the past 1,000 years

Year

1000 1200 1400 1600 1800 2000

NORTHERN HEMISPHERE

Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
ATMOSPHERIC CARBON DIOXIDE IS INCREASING

Global carbon dioxide concentration and infrared radiative forcing over the last thousand years
AEROSOLS
THE “MONKEY WRENCH” OF FORCING
Radiative Forcing by Tropospheric Aerosol

Partial Reflection and Absorption of Incoming Solar Radiation

Aerosol Haze

Clouds

Organics

Dust

SO₂

Soot

Sea salt

Land Use Changes

Industrial Emissions

Biomass Burning

Ocean
GLOBAL-MEAN RADIATIVE FORCINGS (RF)
Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)

LOSU denotes level of scientific understanding.

Factor of 4 limits empirical inferences and model evaluation.
What is an AEROSOL particle?

- Liquid or solid particle suspended in the atmosphere
- Size: Typically 0.01 to 20 µm in diameter
- Composition:
  - Liquid: Water, sulfate, sea salt
  - Solid: Carbon, mineral (dust)
- Shape: Spherical to angular
- Types: Anthropogenic, Natural <biogenic>
Hair: ~100 μm
Water drop: 14 μm
Sea salt: 1 μm

Figure 1. Secondary electron images of aerosol particles: (a) silicate spheres (fly ash); (b) silicate (presumably soil material); (c) iron oxides spheres; (d) calcium sulfate; (e) carbonate; (f) sea salt; (g) biological particle; (h) carbon/sulfate mixed particles; (i) large soot agglomerate and small silicate fly ash particles (bright spheres); (j) ammonium sulfate agglomerates; (k) soot (1), ammonium sulfate (2), and carbon/sulfate mixed particles (3); (l) carbon-rich particle (C_{rest}).
Types of Particles
University of Sao Paulo – Institute of Physics

Saharan Dust in the US

Amazon: Biogenic Cluster

Flaming Smoke Smoldering

Smoke Cluster

US Urban Pollution
What are the sources of aerosol particles?

- Natural (~90%)
  - Volcanoes
  - Dust storms
  - Wildfires
  - Vegetation
  - Sea spray

- Anthropogenic (~10% but mostly in N. hemisphere)
  - Industrial emissions
  - Fossil Fuel combustion
  - Land use/land cover changes
Aerosol sources - Volcanoes

- Particles and SO$_2$ may reach the stratosphere, 22 km
- Photo chemical conversion to SO$_4$ aerosols
- Transported globally, cools the surface, direct effect
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Natural Aerosols

Marine aerosols, wind/wave generated, large particles (>1 μm), lowest 100 m, Non absorbing, restricted to oceans, conc. low
Aerosols from Biomass Burning

Flaming Phase $\Rightarrow$ oxygen starved, black carbon, absorbing

Smoldering Phase $\Rightarrow$ oxygen rich combustion, non absorbing
Dust-Natural and Anthropogenic sources
Anthropogenic: Urban Aerosols

Black Carbon (highly absorbing): diesel engines, coal

$\text{SO}_4$ (small, non absorbing): factories, power plants, gas engines
The lives of aerosols

- Dust and sea salt spray, >1 micron radius
- Sulfate, soot and smoke generated from conversion processes, <1 micron radius, potential health issues
- Mixed and transported by atmospheric winds
- Removed by precipitation and sedimentation
- Duration 5 to 14 days
- Episodic events make prediction and global impact uncertain
Why should we care about aerosols? - the ‘Direct effect’

- Climate Change
  - In the absence of clouds they have a direct cooling effect reflecting sunlight back to space
  - Magnitude depends on size, concentration, composition and surface reflectance
  - Aerosol cooling may partially offset global CO₂ warming

- Health effects
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- **Health effects**

Mediterranean coast of Turkey
Another reason we should care—the ‘Indirect’ effect: Modifies Clouds and Precipitation

- Without aerosols there would be few clouds
- Few aerosols, dark cluds & rain
- More aerosols result in more and smaller cloud drops-less rain
- More cloud drops, brighter clouds, more sun light reflected to space
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What we don’t know about aerosols?

- We don’t know to what extent aerosols affect regional and global climate
- We don’t know the relative magnitude of natural vs man-made aerosols on climate
- We don’t know where on the planet aerosols are increasing, decreasing or are unchanged
- We don’t know with certainty, if aerosols are heating or cooling the planet
- We don’t know the aerosol burden over the planet at any point in time.
Sun Photometry with GLOBE and AERONET

- A direct measurement
- Relatively simple measurement
- Highly accurate
Sun Photometry
Direct Sun Radiance

\[ T = \exp \left( -\frac{\beta l}{\cos \theta_0} \right) \]

- \( f \) = thickness of medium
- \( \beta \) = optical index of the material
- \( \theta_0 \) = solar zenith angle
- \( \tau = \beta l \) = optical thickness
- \( M = \frac{1}{\cos \theta_0} \) = air mass

\[ \frac{V}{V_0} = \exp \left( MW \right) \]

- \( V \) = voltage measured
- \( V_0 \) = voltage at TOA
- $\tau_a = \text{Aerosol Optical Thickness}$
  - $\tau = \tau_r + \tau_w + \tau_g + \tau_a$
  - $r =$ Rayleigh scattering
  - $w =$ Water vapor
  - $g =$ gaseous absorption
  - $a =$ Aerosols

- Ranges between 0.00 and $\infty$
  - 0.05 background
  - 1.00 is very polluted
  - CP = Jan. 0.1, July 0.48

- Spectral
- Value depends on size of aerosols
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- **Single Scattering Albedo**
  \[
  \tau_e = \tau_\alpha + \tau_s \\
  \omega = \frac{\tau_s}{(\tau_\alpha + \tau_s)}
  \]
  - Range 0 to 1 (absorbing to non-absorbing)
  - Mid Atlantic aerosol > 0.95
  - Flaming Phase Biomass Burning, \( \sim 0.85 \)

- \[
  V = \exp\left(-\frac{\beta l}{\cos \theta_0}\right) \\
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  \]
AERONET GSFC Calibration Facility
What Does AERONET Provide?

AOD 15 minute observations

AOD Climatology
Anmyon, S. Korea Monthly Ave. AOD 1999-2002

Size Distributions
Anmyon Island, South Korea 2001 AOD>0.4
Mean of 10 almucantars / AOD level
Spheroid Model Inversions Sky Error < 7%

Single Scattering Albedo
Anmyon Island, South Korea 2001 AOD>0.4
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2013- 400 active sites world wide but there is still a lot of territory to cover GLOBE can Help!
MAN represents an important strategic sampling initiative and ship-borne data acquisition complements island-based AERONET measurements.

Maritime Aerosol Network global coverage from October 2006 to May 2013

What are aerosols?
- Properties, composition, definition, shape, size
- Natural vs Anthropogenic

What are the source regions of aerosols?
- Relate geography and aerosol type
- People vs emissions

Why are aerosols important?
- Climate forcing
- Health
- Aesthetics
How are aerosols measured?
- Active and passive systems
- Satellite, airborne and ground-based
- Sun Photometry-Globe
Extra slides
GLOBAL ENERGY BALANCE
Global and annual average energy fluxes in watts per square meter

\[ \frac{1}{4} S_0 = 343 \]

\[ \alpha = 31\% \]

\[ 1/4 S_0 (1 - \alpha) = \sigma T^4 \]

\[ 237 \approx 254K \]

\[ 69\% = 1 - \alpha \]

\[ H_2O, CO_2, CH_4 \]

\[ 390 \approx 288K \]

\[ 296 \]

\[ 169 \]

\[ 16 \]

\[ 31 \]

\[ 90 \]

\[ 48 \]

\[ 27 \]

\[ 106 \]

\[ 27 \]

\[ 237 \]

\[ \text{Shortwave} \quad \text{Longwave} \]

\[ \text{Atmosphere} \]

\[ \text{Latent heat} \quad \text{Sensible heat} \]

Schwartz, 1996, modified from Ramanathan, 1987
GLOBAL-MEAN RADIATIVE FORCINGS (RF) BY LONG-LIVED GREENHOUSE GASES
Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
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</tr>
</tbody>
</table>

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Total radiative forcing: 2.64 ± 0.26 W m⁻²
The global mean radiative forcing of the climate system for the year 2000, relative to 1750

Source: Summary for Policymakers, IPCC, 2001
Aerosols-general characteristics

- Ubiquitous:
  - 5 to 1000 mg/m³

- Remote sensing characteristics
  - Color:  $f(\text{size and composition})$
  - Directional Scattering efficiency: $f(\text{size})$
  - Absorption: $f(\text{composition})$

- Lifetime:
  - 5 to 14 days (tropospheric)
  - Years (stratospheric)