

Global Pollution as a Climate Forcing

Aerosols Effects on Climate

Definitions: Aerosol Definitions and Terminology Are Not Universal

Terminology

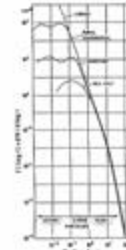
- Aerosol = stable suspension solid or liquid particle or both in air ... & condensed phase material and air that it resides with
- Hydrosol = stable suspension of acid particles in water

Definitions (Particles suspended in air: $.003 \mu\text{m} < D < 10 \mu\text{m}$)

- below $0.1 \mu\text{m}$ = Aitken nuclei
- $0.1 - 1.0 \mu\text{m}$ = large particle
- $> 1 \mu\text{m}$ = giant particle

or alternately ...

- coarse > 1 micrometer
- fine < 1 micrometer



Air Pollution: definition

A situation in which substances that result from anthropogenic effects are present at concentrations sufficiently high above their normal ambient level to produce a measurable effect on humans, animals, vegetation, or materials

Aerosol and Climate

Aerosols have 2 main effects on climate:

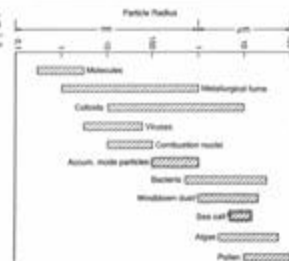
- Direct - Radiative Forcing
- Indirect - Modification of cloud optical properties and lifetime

Aerosol, Human Health and Environmental Impacts

- Aerosol have an effect on human health (e.g., asthma,cancer)
- Aerosol affect the environment
- Reducing aerosol effect has potential for reducing health and climate problems at the same time

There is a Wide Range of Aerosol Sizes

Figure 8.1 Range of equivalent diameters for some types of aerosol and biological particles. The purpose of this diagram is to illustrate the wide range of sizes.



- Not really spherical
- equivalent radius=radius of a sphere that experience same resistance to motion as the non-spherical

Two types of Aerosols

- Tropospheric aerosols (natural and anthropogenic)
- Stratospheric aerosols (natural, limited anthropogenic)

Aerosol Historical Growth

- Aerosol loading and radiative influence have increased over industrial period
- First recognized type of air pollution high concentration of sulfur compounds (SO₂ and sulfates) and aerosols resulting from combustion of coal and high sulfur containing fuels
- Anthropogenic sulfate aerosol radiative forcing is negative = Cooling effect
- Large uncertainty in magnitude of forcing
- Effect of anthropogenic aerosols may help explain difference between observation and climate model computations

Aerosol Life Time

Aerosol Life Cycle



Aerosols Properties

Full description of aerosols requires

- Concentration
- Size
- Chemical composition
- Phase
- Morphology

Sources of Aerosols are both Primary and Secondary:
Primary (Direct) are Emitted from the Surface

BROAD CATEGORIES: BOTH TYPES

- water soluble inorganic salts
- water-insoluble minerals of crustal origin
- organic compounds
- ...both water soluble and insoluble

PRIMARY (Direct)

- Oceans (sea-salt)
- Soil Dust
- VOC... bubble bursting processes, incomplete fuel combustion
- Biomass burning
- Terrestrial material (volcanic debris)
- Extraterrestrial dust
...interplanetary dust, polar regions, zodiacal light, small effect?

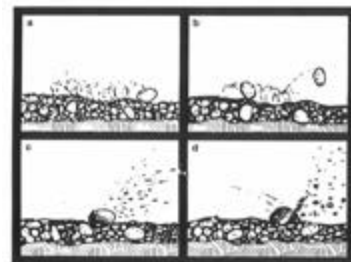
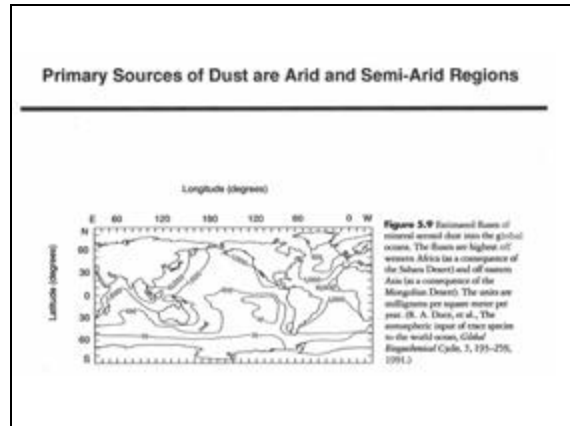
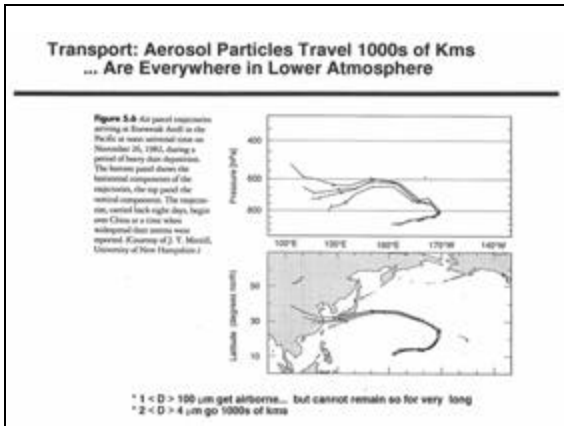


Figure 5.4 Mechanism of wind-driven aerosol particles. (a) Creeping motion of a particle moving as a consequence of a wind speed slightly greater than threshold; (b) A coarse particle lifted into the air by turbulent air fluctuations; (c) A particle collides with the surface, followed by breaking off of smaller particles that were entrained on the colliding particle's surface; (d) A particle collision followed by "glorification" of the soil. (Adapted with permission from D. Gillett, Major contributions of natural primary continental aerosols: Source mechanisms, *Annals of the New York Academy of Sciences*, 338, 348–358, Copyright 1990 by New York Academy of Sciences.)



Secondary Sources are Gas-to-Particle (GPC) Conversions

- **Where?:** Atmospheric layers in which chemical reactions take place
- **How?:** Convert natural and man-made atmospheric trace gases into solid and liquid particles
- **What gases?:**
 - sulfur...DMS (ocean), SO₂
 - ...reactive gases convert to sulfuric acid
 - ->low equilibrium vapor pressure then condenses onto cloud droplet and aerosol particle surface*
 - HCs (forests...terpenes)
 - nitrogen: NO, NO₂, HNO₃ (soil exhalation)
- **Size < 0.1 μm...** "fine" size range
 *studies show that oxidation is mediated by sunlight; i.e., processes slow in the dark

Aerosol Source Distribution

[aerosol source distributions.ppt](#)

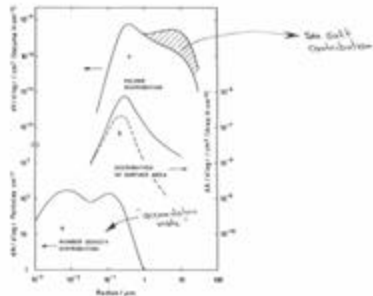
Aerosols are Removed to the Surface by Either Dry or Wet Precipitation

- **Dry deposition** is size dependent
 ...very small particles behave differently from those constrained to follow motions of atmospheric parcels in which they are embedded
- **Wet deposition**
 - interactions between gaseous molecules or airborne particles and water droplets
 - particles repeatedly exposed to raindrops with some probability of capture
 - each raindrop also has opportunity to scavenge (incorporate) particles

Transformation Processes Are Size Dependent

Type	Size (μm)	Processes	Lifetime (t)
Small	> 0.001	Coagulate into larger via Brownian Motion	few hours
Accumulation	0.1 - 1.0	CCNs, coagulation, condensation (Mie)	varies
Intermediate	.001 - 10	collision and diffusion incorporation (Mie)	~ 1 week
Large	> 10	gravitational settling	few hours

Number Density Is Dominated by Aiken (< 0.1 μm) Particles



Importance ... Total Particle Number Density is MOST Important Parameter ... Not Mass

Why is this important? BIG influence on ...

- radiative transfer thru atmosphere
- atmospheric water cycle

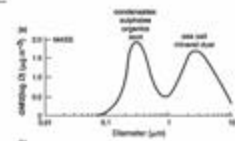


Figure 3.1: Schematic diagram showing the mass balance of the aerosol size distributions as a function of (a) mass and (b) number. The distributions have been plotted such that the area under the curve corresponds to the total mass and number concentrations respectively. Although coarse particles contribute substantially to the aerosol mass, they have a very small part of the number of aerosol particles.

Aerosol Radiative Effects

- Reflection and Absorption of Solar Radiation - Negative forcing = Cooling effect
- Absorption of Solar Radiation - Positive forcing = Warming effect

Radiative Forcing

- Radiative forcing = A change in net radiation at top of troposphere induced by a perturbation
- Shortwave influence (e.g. clouds, aerosol)
- Longwave influence (e.g. clouds, GHG)
- Affect radiation budget => - atmospheric circulation - water cycle
- Difficult to measure
- Uncertainties in computations with Climate Models

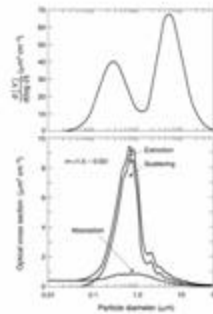


Figure 3.7: Aerosol radiative size distribution and the calculated scattering and absorption cross sections per unit aerosol volume at a wavelength of 550 nm, calculated by Covert et al. (1986), using Mie theory and an assumed refractive index of $n = 1.5 - 0.01i$. Note that the major contribution to aerosol scattering is an associated with the part of the size distribution extending most to the aerosol mass loading.

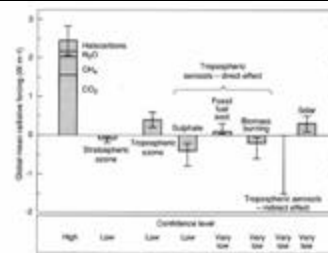


Figure 3.8: Relative of the globally and annually averaged radiative forcing for the 1.8 due to changes in concentration of greenhouse gases and aerosols that are radiative active in the greenhouse and to natural changes in water vapor that (W m⁻²) in the present day. The height of the rectangular bar indicates a mid-range estimate of the forcing, while the error bars show an estimate of the uncertainty range. Resulting on the spread of published values, our subjective confidence that the actual forcing lies within this range has been indicated by the "confidence level". The contribution of individual gases to the direct greenhouse forcing is indicated on the bar chart. The indirect greenhouse forcings associated with the distribution of atmospheric ozone and the increased concentration of tropospheric ozone are shown in the rounded and filled bar respectively. The direct contribution of individual tropospheric aerosol components are grouped into the size of their bars. The indirect aerosol effect, arising from the indirect change in cloud properties, is shown over our present understanding of the process is very limited in present and future so far representing a mid-range estimate in shown. The bar chart shows the estimate of the changes in radiative forcing due to variations in other ranges. The forcing associated with atmospheric ozone resulting from volcanic eruptions is not shown, as it is not available over the time period. Figure 3.17 shows estimates of this variation. Note that there are substantial differences in the geographical distribution of the forcing due to the well-mixed greenhouse gases (CO₂, CH₄, N₂O), and the heterogeneous and the clear in recent past aerosols, which could be an important difference in their respective global and regional climate responses can (Chapter 10). In this sense, the negative radiative forcing due to aerosols should be accounted to be regarded as an offset against the greenhouse gas forcing.

Indirect Effect of Aerosol

- Aerosols modify cloud radiative properties
- Aerosols modify cloud formation and lifetime

Aerosol and Cloud Radiative Properties

- Aerosol acting as CCN will induce production of many small cloud droplets
- Small cloud droplets will increase cloud albedo for same amount of water
- Marine stratus with cloud albedo of ~0.5 are most sensitive to anthropogenic aerosol
- Continental clouds and clouds with vertical extent are not sensitive to change in cloud droplet size
- Radiative effect of anthropogenic aerosol is negative
- Ship tracks show evidence of brightening marine stratus
- DMS emitted by phytoplankton can serve as CCN and potentially modify climate

Aerosol and Cloud Formation

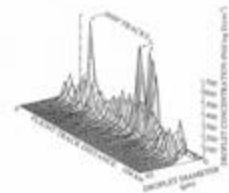
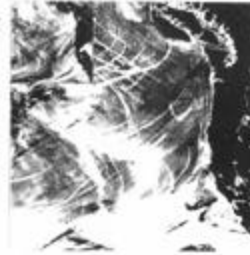
- Clean air condenses to form droplets only if supersaturated
- If particulate matter present, 100 - 102% sufficient for clouds to form
- Aerosols in right conditions act as Cloud Condensation Nuclei
- Aerosol size is a major variable in determining cloud droplet formation
- Aerosols affect precipitation - for precipitation to occur, droplets must grow to a size ~ 1000µm
- Concentration of large aerosol particles produces more precipitation
- Concentration of small aerosol particles will produce many small drops that will slow down the formation of large droplets and precipitation

Indirect Effect of Aerosols on Climate

More Aerosols → More CCN → More and smaller Droplets → Higher Albedo → Colder Climate

Example:

- Effect is evident in ship tracks visible in satellite images off Western coast of U.S. - AVHRR image
- Combustion from ships creates effluents releasing many small aerosols into the atmosphere
- Overall effect of aerosols on climate tends to be negative, but net effect is difficult to measure



Remote Sensing of Aerosol Indirect Forcing

- Ship tracks
 - AVHRR NOAA-9, 1 km
 - ship effluents act as CCNs
 - clearly visible in the 3.75 µm channel
 - increased reflectance in this channel of 15-20%
 - in situ study showed ship tracks to suppress drizzle (drizzle mode > 30 µm) to less than half and thereby increasing LWC
 - another in situ study showed an increase in droplet concentration from 30 cm⁻³ to 120 cm⁻³ and a drop size decrease from 12/15 µm to 7 µm

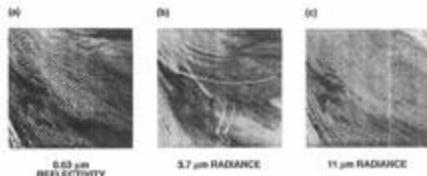
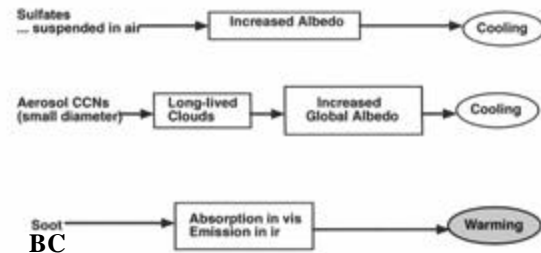


Figure 9.1.6 NOAA-9, 1 km resolution, AVHRR images of ship tracks in marine stratus cloud off the coast of California (April 5, 1997). (a) is a small channel in the reflectance of clouds in the 0.63 µm channel (b) the variability of the cloud reflectance in the channel. Same effect in the 3.75 µm channel (c) where the ship effluents increase the ship size concentrations and reduce their size, thus increasing the cloud reflectance at 3.75 µm. No effect in the 11 µm channel (d). After Coakley et al. (1997).

Summary: Aerosols Affect Climate In Different Ways



Aerosol Main Issues for Future

- Aerosols budgets not well quantified
- SO₂ comes from burning of fossil fuel (CO₂ budget well known)
- Black Carbon BC warming due to increase
 - BC mostly comes from heating and cooking
- Particles emitted by vehicles (diesel)

Black Carbon BC

- 30% comes from residential coal and biofuel
 - technology available to reduce: combustion improvement, fuel switching=>indoor air quality
- 15% exhaust (mobile 10% stationary 5%)
- 50% open burning fields
 - Changes of practices
 - Public education