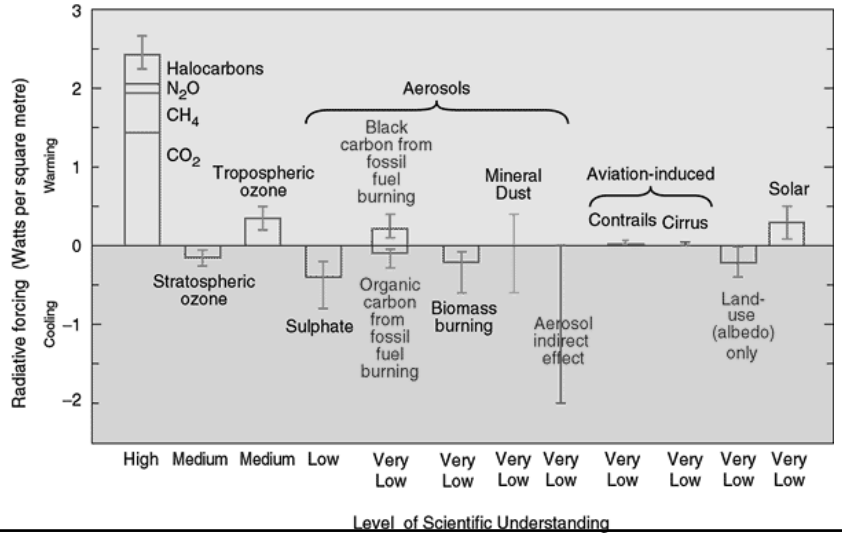
GE510 Physical Principles of the Envt

Aerosols: Their Direct and Indirect Effects on Climate

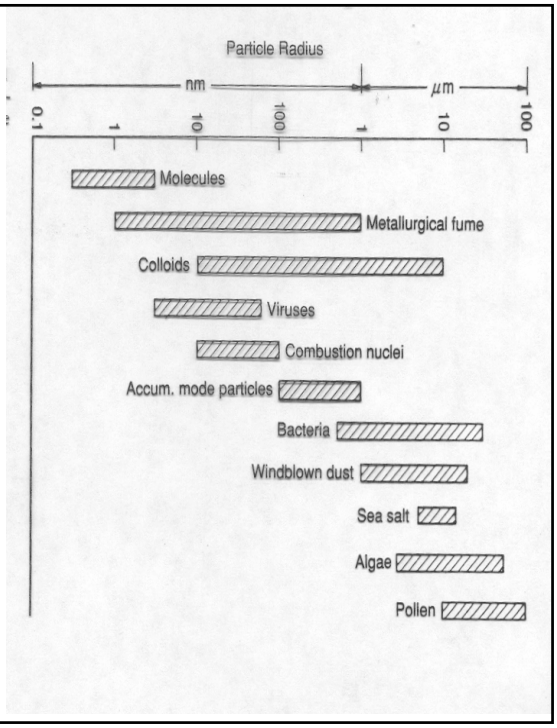
The global mean radiative forcing of the climate system for the year 2000, relative to 1750



1. What are aerosols?
2. Types of aerosols
3. How do they effect climate?

Aerosols: stable solid or liquid particles suspended in air.

Size ranges over many orders of magnitude, from nm to 10s of um typically.



Aerosol Properties: Residence Time

Mean residence time: days in troposphere, weeks to months in stratosphere.

Thus, spatially variable and traceable to ground source.

Smallest particles (<.01um) coalesce, largest particles (>10um) fall back to ground, longest lived aerosols are in the 0.1 – 1.0 um range. (thermal energy > grav. Pot. energy)

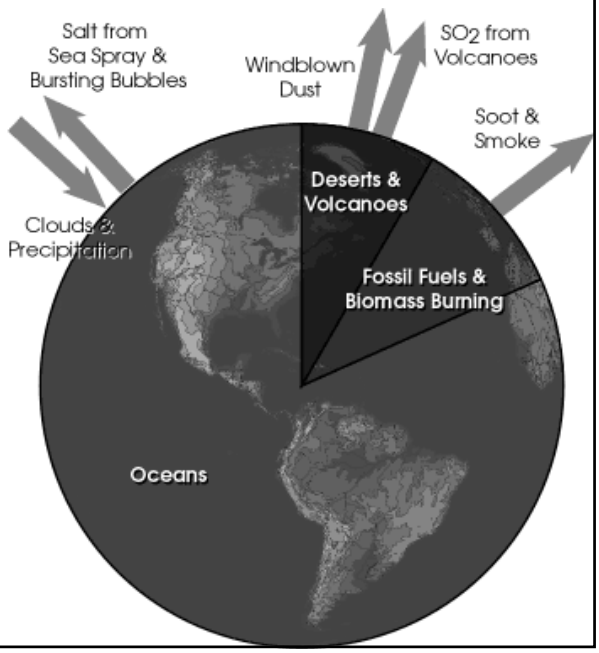
Plumes tend toward intermediate aerosol size distributions over time

2. Types of aerosols & distribution

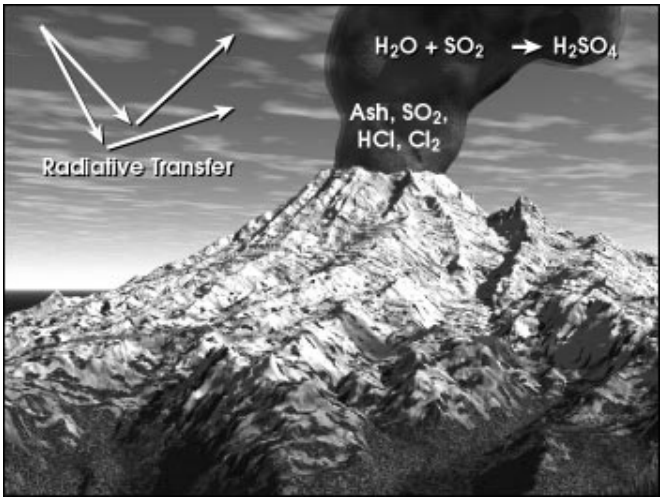
- **Sulfates (natural and anthropogenic)**
- **Nitrates**
- **Dust (soils and industrial)**
- **Sea salt**
- **Carbonaceous (organic and soot)**
- **Biogenic (largely plant debris, pollen, spores, etc)**

2. Types of aerosols & distribution

About 10% of all aerosols emitted by humans. Most others come from oceans (salt, sulfates)



Volcanoes play a special role because they inject directly into the stratosphere



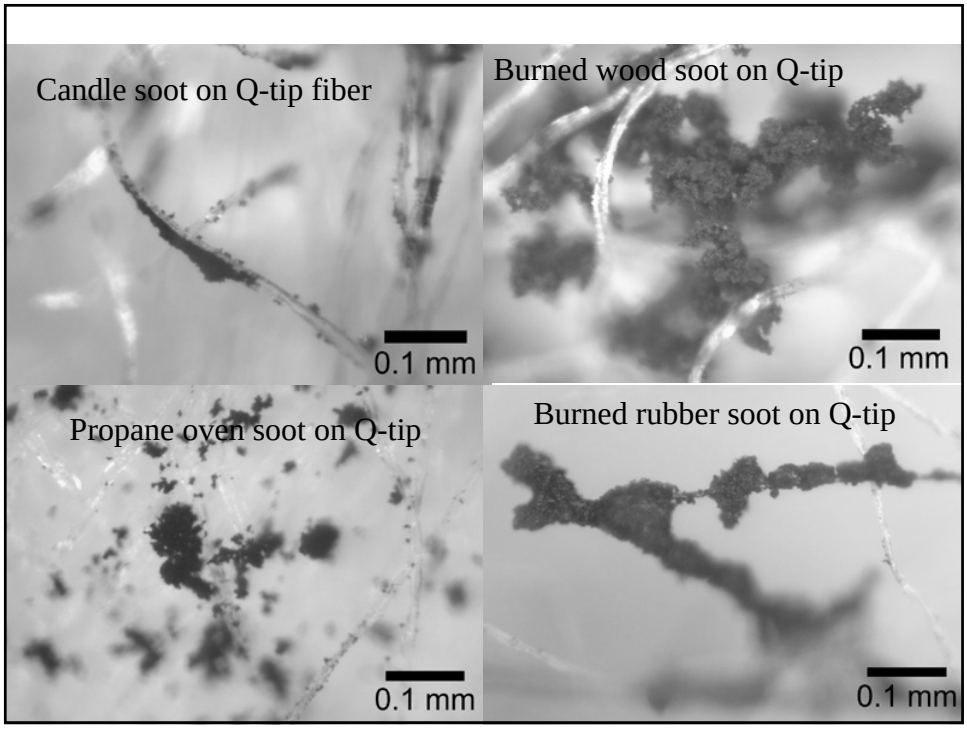
Sulfate Aerosols and the Gaia Hypothesis:

Dimethylsulfide production by ocean plankton may act as a global thermostat:

Higher temps: more DMS produced by plankton

More DMS leads to more cloud condensation nuclei

More clouds, less light penetration, cooler ocean waters.



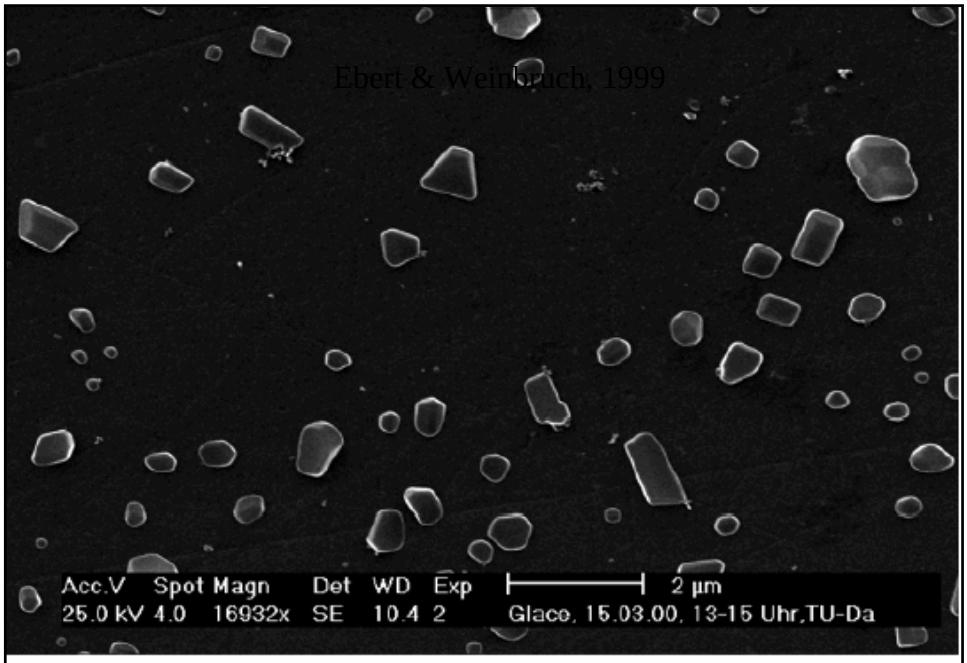


Figure 1: Secondary electron image of ammonium sulfate particles.

3. Aerosols: How do they effect climate?

Directly: scatter/reflect incoming solar radiation; less reaches earth's surface

Indirectly: modify cloud properties/amount

Both tend to have a cooling effect, but its not so simple....

3. Aerosols: How do they effect climate?
Direct effect:

Aersols directly (a) scatter/reflect and/or (b) absorb sunlight. Different aerosols have different relative scattering/absorbing properties

***Scattering* sends incoming light back to outer space – thus cooling earth's surface. Aerosol scattering increases *albedo*.**

***Absorption* also cools earth's surface, but heats up the air around the cloud**

3. Aerosols: How do they effect climate?
Direct effect:

IPCC 2001 estimates the direct albedo effect of aerosols offsets greenhouse gas warming by 25-50%!

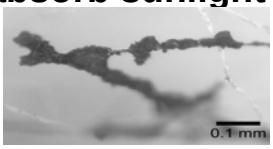
This is cause for concern, unless we want to pollute more and more to offset global warming!

3. Aerosols: How do they effect climate?

Direct effect:

However, black carbon (soot) has a special and more complex role.

They are about as ideal blackbody absorbers as possible, and so very strongly absorb sunlight (and re-radiate).



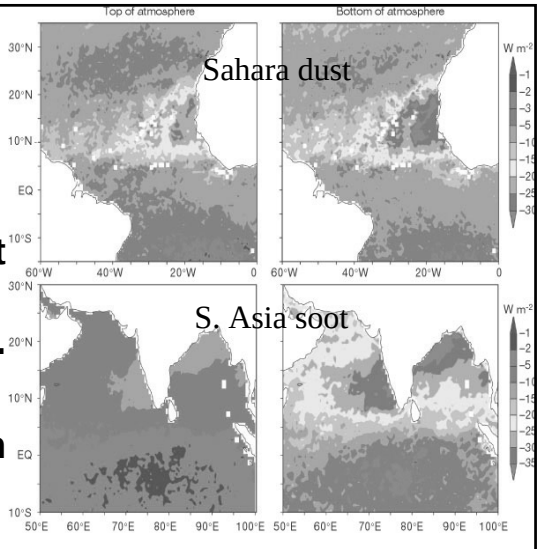
Thus, they heat the atmosphere, while cooling the earth's surface. Over Amazonia/Indian Ocean, soot reduced 15% of sunlight reaching earth's surface, while heating the lowest 2-4 km of the troposphere.

3. Aerosols: How do they effect climate?

Direct effect:

Compared to soot, dust is weakly absorbing and highly reflective.

e.g. compare Sahara Desert Dust to South and East Asia black carbon



In both cases, aerosols reduced surface illumination by 23 Wm^{-2}. But partitioned very differently. In Sahara, dust reflected 17 and absorbed 6. In S. Asia, soot reflected 10 and absorbed 13 – more than double the absorption! What is the significance of this?

3. Aerosols: How do they effect climate? Direct effect: Significance.

Heating the atmosphere above earth's surface while cooling it at the earth's surface (soot) reduces the vertical temperature gradient during daytime (because the atmosphere is usually heated from below like a pot on a stove).

This can reduce evaporation rate, cloud formation, and precipitation. Thus, soot aerosols can slow down the hydrologic cycle! This is a direct effect – we'll see later how aerosols can also promote cloud formation!

3. Aerosols: How do they effect climate? Direct effect: Significance.

Much of black carbon comes from vegetation fires and poor engine technology.

In the US, black carbon accounts for only 6% of aerosol optical thickness; in south/east asia and C. america, it accounts for 11%.

Smoldering fires produce less black carbon than hot fires. African grass fires burn hot, release more soot (12% of optical thickness) than boreal fires (5% of OT)

Weakened hydrologic cycle/less freshwater in those locations compared to US???

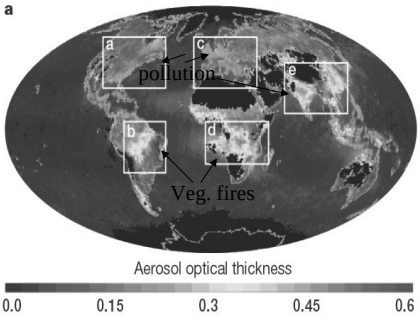
3. Aerosols: How do they effect climate?

Direct effect: Significance.

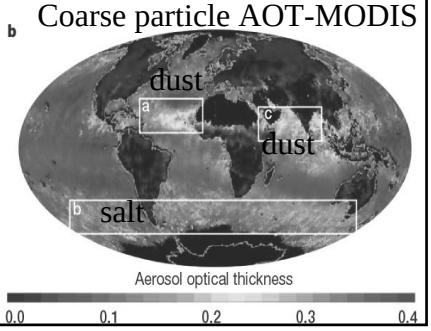
Aside: What is optical thickness (aka optical depth)?

Answer: A measure of the transparency of the atmosphere. Optical thickness of 0 means no scattering/absorption – all light gets through. Optical thickness of 1 means on average, all light is extinguished, I.e. on average each photon is scattered or absorbed once.

Fine particle AOT- MODIS



Coarse particle AOT-MODIS



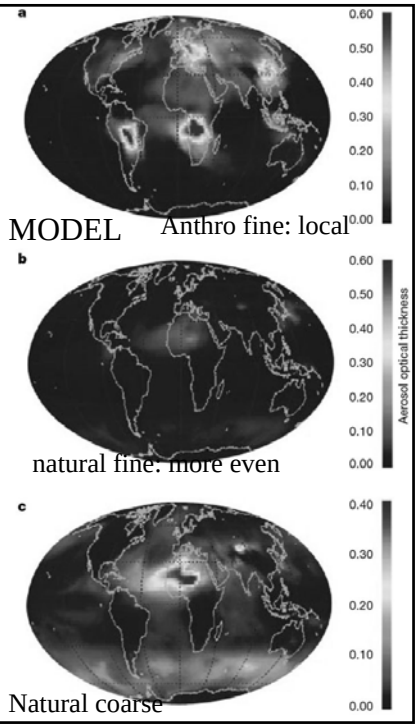
3. Aerosols: How do they effect climate?

Direct effect

We can partially assess anthropogenic from natural sources of aerosols. (caveat – even individual particles can have both natural and anthro components).

Industrial processes and biomass burning typically produces fine aerosol particles stemming from 'point' sources.

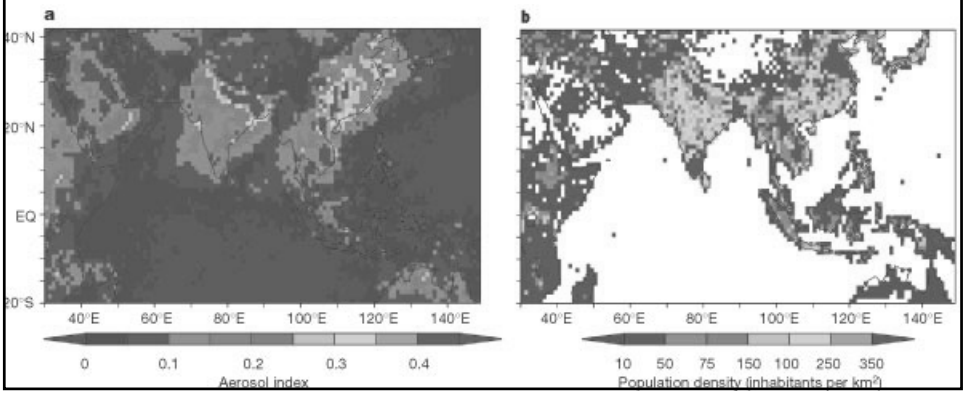
Natural processes typically produce coarse aerosols (dust, sea salt) and a much more spatially even and lower background component of fine aerosols.



3. Aerosols: How do they effect climate?
Direct effect

Fine aerosols (a), produced largely by anthropogenic activity, map fairly well to population density (b).

Feb. 1997 POLDER instrument



3. Aerosols: How do they effect climate?
Direct effect

Bottom Line:

Plumes of smoke and Industrial aerosols are largely fine aerosols (< 1 um)

Natural sources have concentrated plumes of *coarse* aerosols (> 1um) and a uniform and low distribution of fine aerosols.

In principle, we should be able to exploit these properties to find out how humans, versus nature, control aerosol climate forcing.

3. Aerosols: How do they effect climate?

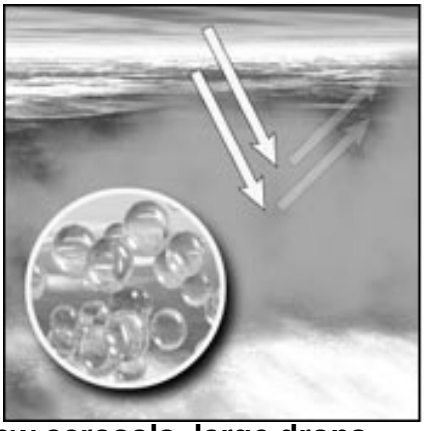
Indirect effects:

Two indirect effects:

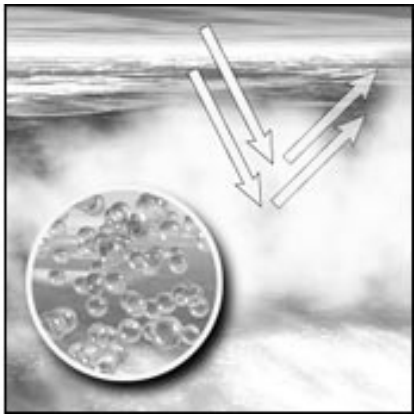
1. **Aerosols change cloud intrinsic properties (reflectance - usually increases it - cooling)**

2. **Aerosols change cloud amount, lifetime, and precipitation. – not clear whether cooling or heating results.**

Indirect effects: Aerosols tend to increase cloud albedo. This promotes surface cooling.

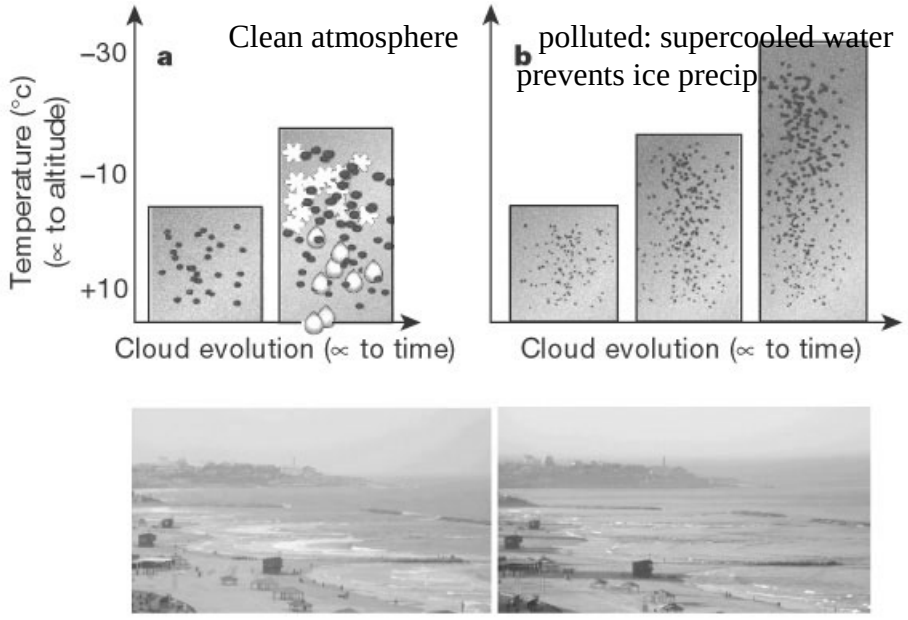


Few aerosols, large drops
Transmits light well



Many aerosols, small drops
Transmits light poorly (10%)

Fine aerosols tend to prevent precipitation…

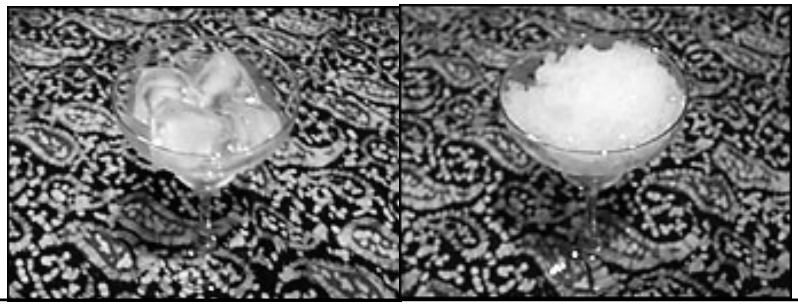


Aside:

Precipitation efficiency: The ratio of precipitation to total atmospheric moisture content.

Fine aerosols tend to decrease precipitation efficiency.

Polluted air may show 6-fold increase in # concentration of fine aersols – producing 3-5 x increase in droplet concentration, and 10-25% smaller cloud droplets (conservation of water mass – assumed for simplicity)
This increases reflection: called the "first aerosol indirect effect".



It's a bit more complicated than that though…

Twomey (1984) computed that the 1st indirect effect (as described in last slide) could completely offset global warming. We don't observe that.

It could be that only a few big aerosol particles in a polluted cloud can scavenge water, decrease reflectance, increase precipitation.

2nd Indirect Effect:

Lots of fine aerosol particles tend to increase cloud formation and cloud size instead of increasing precipitation.

Instead of droplets growing larger and ultimately raining, water vapor simply condenses onto new fine aerosols.

More clouds needed for the same amount of precip.

The global effect of this 2nd indirect effect is very uncertain.

A troubling scenerio:

"The reduction of the precipitation efficiency by anthropogenic aerosols has the potential to shift precipitation away from polluted regions. Because the continents are more polluted than the ocean, this can cause a loss of fresh water over continents, and in particular around populated regions." – Kaufman et al. 2002 Nature