Aerosols

12.340 Global Warming Science
April 3, 2012
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Reading: IPCC 2007 2.4
(www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-4.html)

Today's Class

- What are aerosols? Where are they from?

- Why should we care about aerosols?

- How do aerosols affect radiation?

- How do we measure aerosol?

- Optical depth (τ_{aero}) and direct radiative effect (DRE)

- How much aerosol is there? How much is anthropogenic? (soot and lead)

- Best estimates of the anthropogenic direct effect

What are Aerosols?

Table : Terminology Relating to Atmospheric Particles

Aerosols, aerocolloids, aerodisperse systems	Tiny particles dispersed in gases
Dusts	Suspensions of solid particles produced by mechanical disintegration of material such as crushing, grinding, and blasting. $D_p > 1$ μm.
Fog	A loose term applied to visible aerosols in which the dispersed phase is liquid. Usually, a dispersion of water or ice, close to the ground.
Fume	The solid particles generated by condensation from the vapor state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation. Often the material involved is noxious. $D_p < 1$ μm.
Hazes	An aerosol that impedes vision and may consist of combination of water droplets, pollutants and dust. $D_p > 1$ μm.
Mists	Liquid, usually water in the form of particles suspended in the atmosphere at or near the surface of the Earth; small water droplets floating or falling, approaching the form of rain, and sometimes distinguished from fog as being more transparent or as having particles perceptibly moving downward. $D_p > 1$ μm.
Particle	An aerosol particle may consist of a single continuous unit of solid or liquid containing many molecules held together by intermolecular forces and primarily larger than molecular dimensions (> 0.001 μm). A particle may also be considered to consist of two or more such unit structures held together by interparticle adhesive forces such that it behaves as a single unit in suspension or upon deposit.
Smog	A term derived from smoke and fog, applied to extensive contamination by aerosols. Now sometimes used loosely for any contamination of the air.
Smoke	Small gas-borne particles resulting from incomplete combustion, consisting predominantly of carbon and other combustible material, and present in sufficient quantity to be observable independently of the presence of other solids. $D_p \geq 0.01$ μm.
Soot	Agglomerations of particles of carbon impregnated with "tar," formed in the incomplete combustion of carbonaceous material.

Image by MIT OpenCourseWare.

Seinfeld and Pandis, Atmospheric Chemistry and Physics

Where do aerosols come from?

From ‘new particle formation’ (normally sub-micrometer) and mechanical processes (normally super-micrometer)

Particles evolve by interaction with each other and the gas phase

Ultimate removal by gravity, deposition and clouds (precipitation)

Seinfeld and Pandis, Atmospheric Chemistry and Physics

New Particle Formation

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Combustion

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Sea Salt

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Fig. 8-12: Four stages in the production of sea salt particles by the bubble-burst mechanism. (a) Film cap protrudes from the ocean surface and begins to thin. (b) Flow down the sides of the cavity thins the film which eventually ruptures into many small fragments. (c) Unstable jet breaks into few drops. (d) Tiny salt particles remain as drops evaporate; new bubble is formed. (From Day, 1965, with changes.)

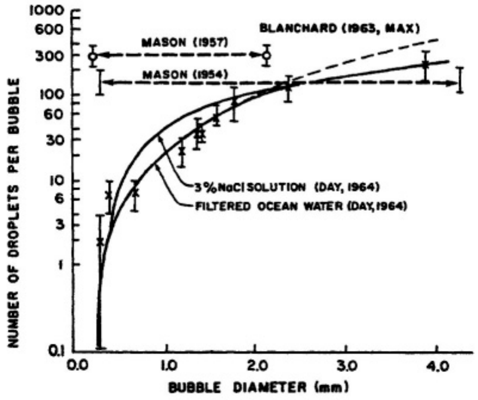

Fig. 8-13: Mean number of droplets resulting from the disintegration of an air bubble cap in salt water as a function of equivalent diameter of the air bubble. (From Day, 1964; by courtesy of *Quart. J. Roy. Meteor. Soc.*).

Mineral Dust

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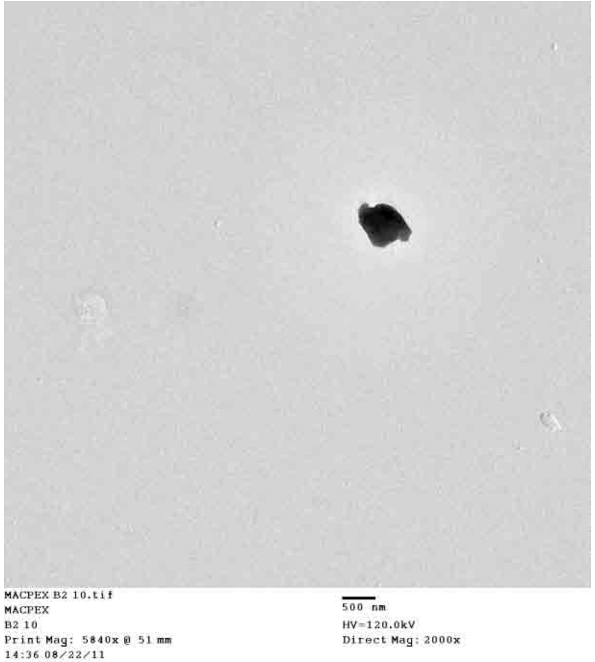
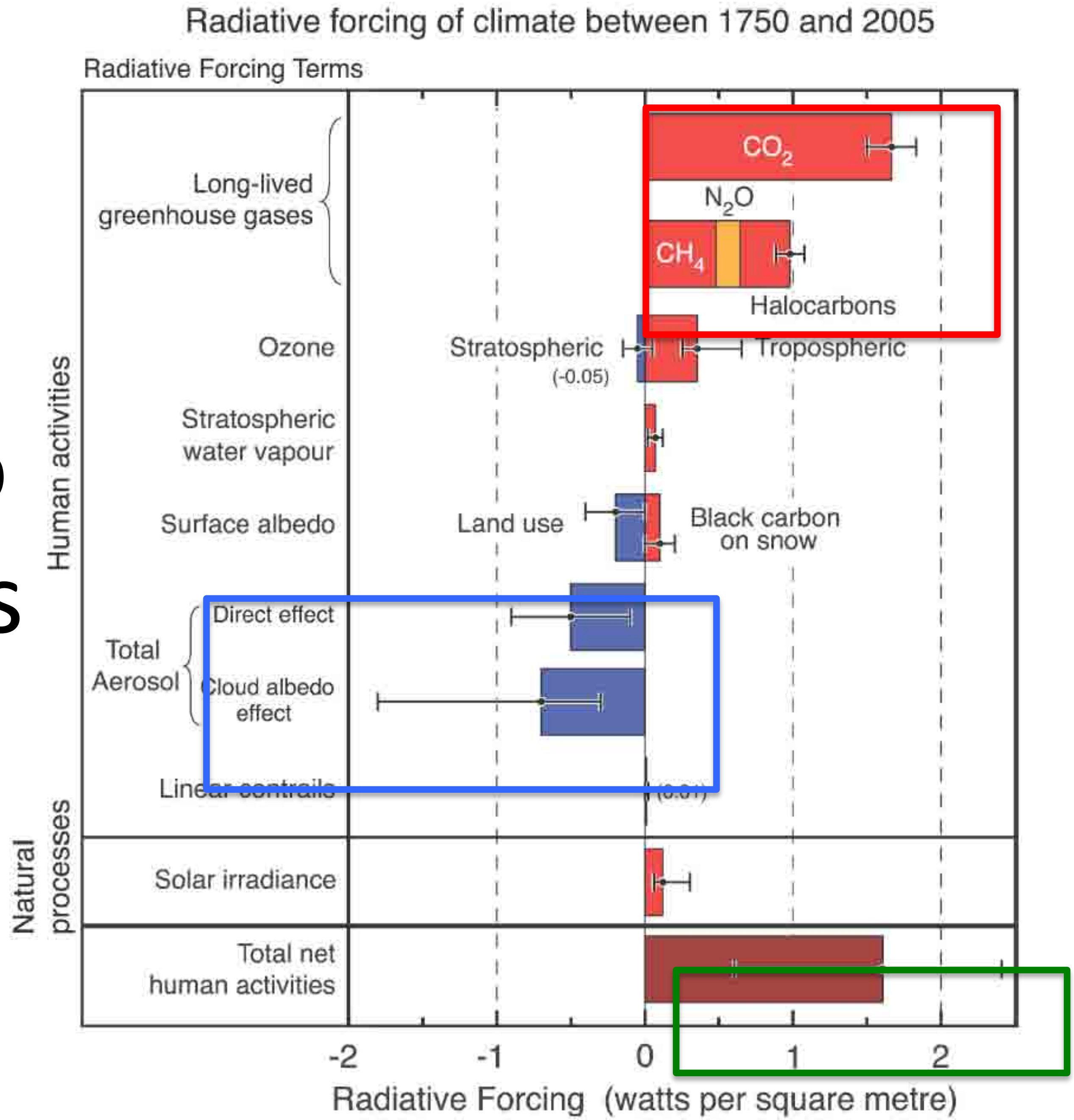


Fig. 8-11: Range of wind speed and grain size in which saltation of quartz grains can occur in the atmosphere. (From Owen, 1964; by permission of Cambridge University Press.)

Who Cares ?



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Who Cares ? (Part 2)

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Murphy et al. JGR 2009

Why Care ? : Beyond Climate

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'The Great Smog' – London, 1952

Combination of meteorology (cold air / increase heating and temperature inversion)

Particles reached 14,000 $\mu g/m^3$ (280 current US standard average and 93 times peak allowable)

Visibility < 1 m (!)

4000 deaths within 2 weeks, 10000 estimated total

http://en.wikipedia.org/wiki/Great_Smog

Radiative Balance 1

Seinfeld and Pandis, Atmospheric Chemistry and Physics

Radiative Balance 2

Seinfeld and Pandis, Atmospheric Chemistry and Physics

Aerosol Measurement : From the Ground and Aircraft

Most measurement involves collection and off-line analysis (see Prof. Prinn's 'Experimental Atmospheric Chemistry' if interested)

On-line instruments include those that measure light scattering to determine absorption, scattering, size

Some 'advanced' instruments use e.g. electro-mobility

Many aircraft instruments are an extension of these techniques

www.tsi.com

Aerosol Measurement : From Aircraft to Satellites

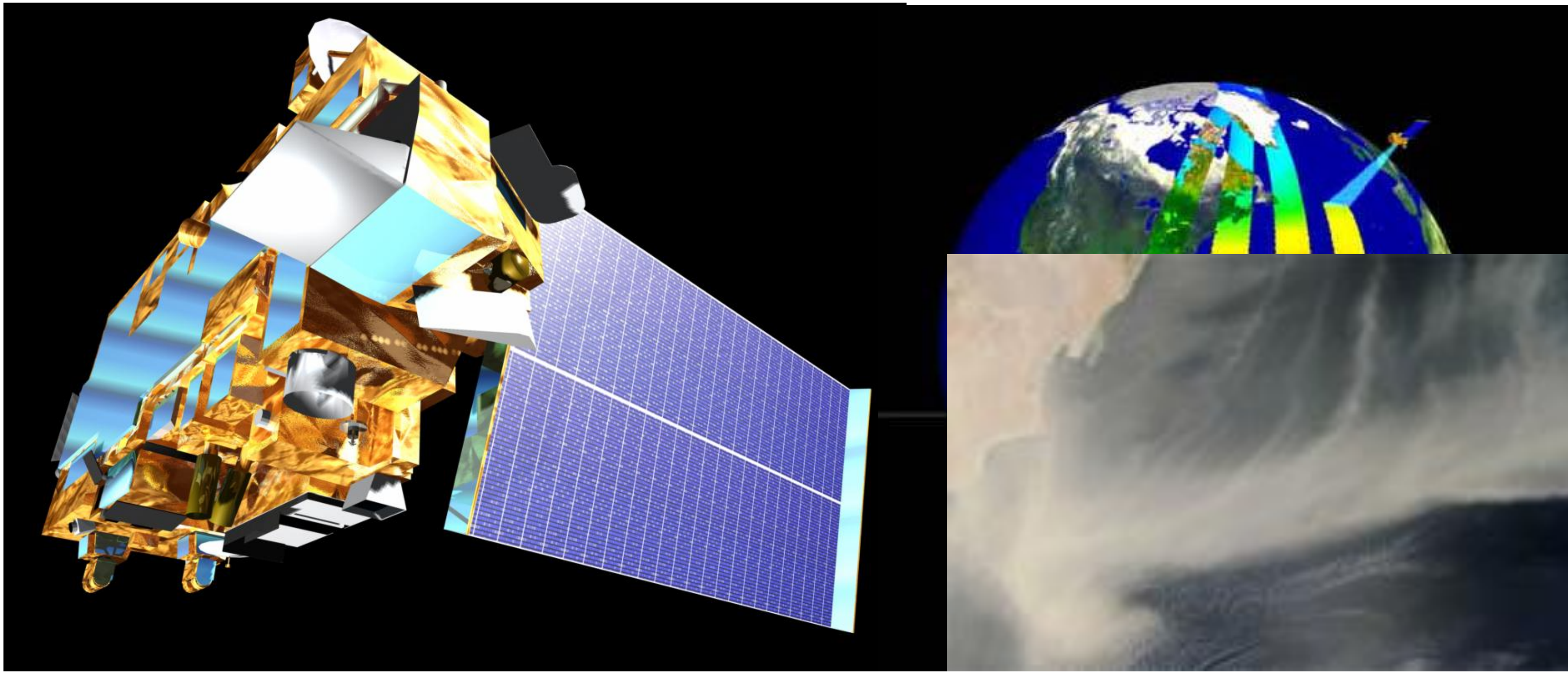


Image courtesy of NASA.

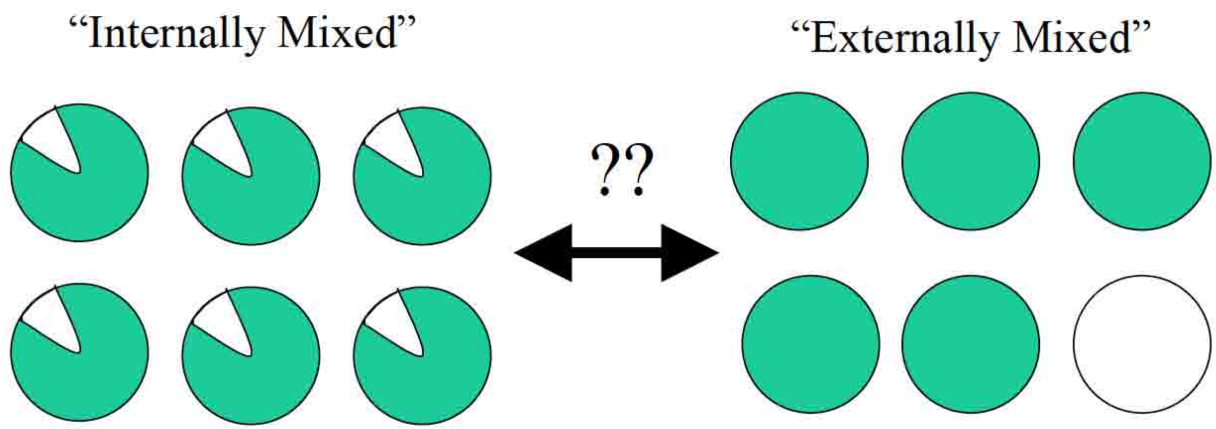
Various techniques for ‘remote sensing’ (not in situ). Among these:

LIDAR (LIght Detection And Ranging) : distance to and some other properties of aerosol and cloud. UV to many micrometers, detection via backscattering.

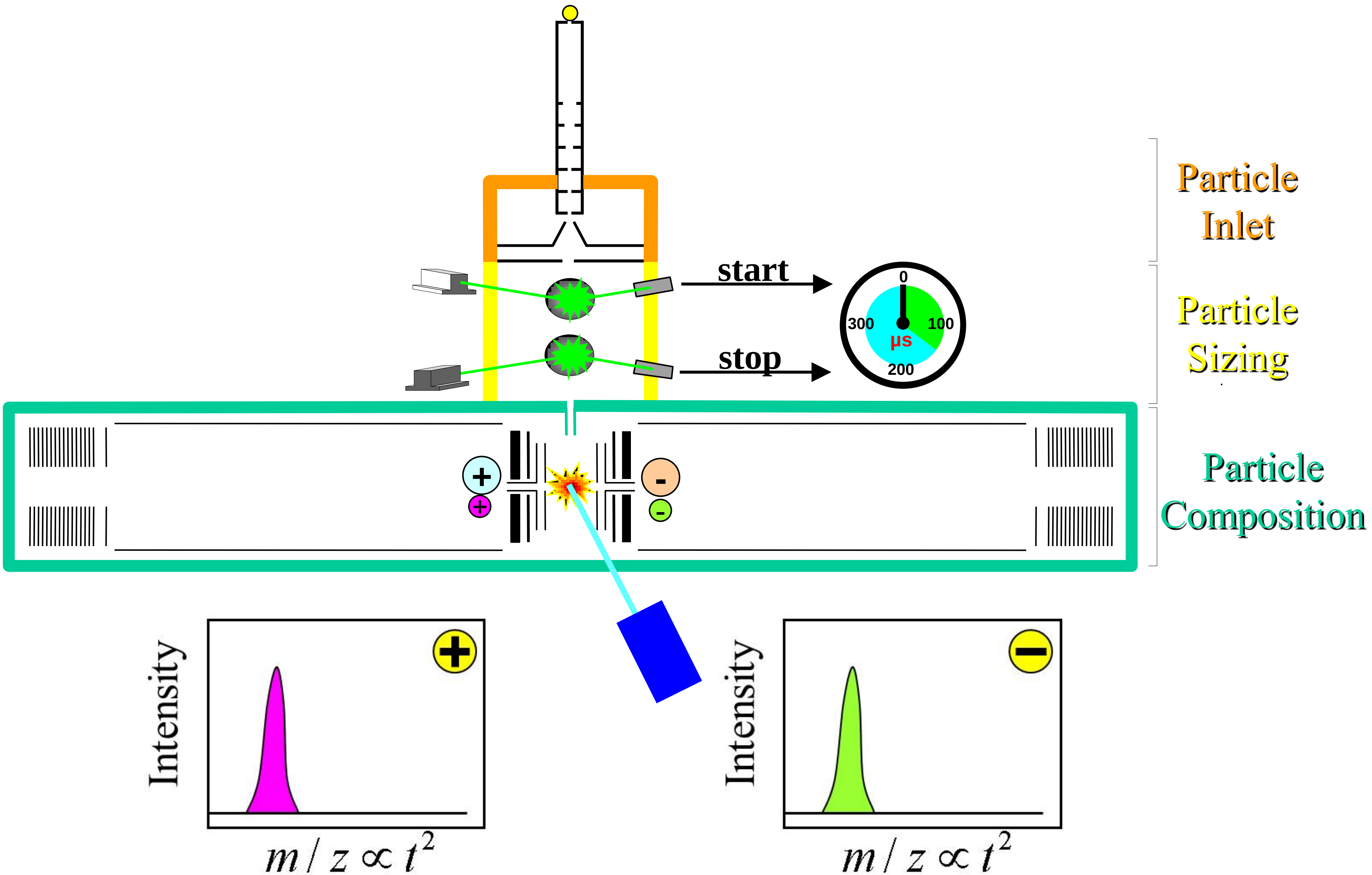
(Spectro)Radiometer - reflection or transmission properties of a material (as a function of wavelength).

http://earthobservatory.nasa.gov/Features/Terra/, http://history.nasa.gov/SP-4312/ch3.htm

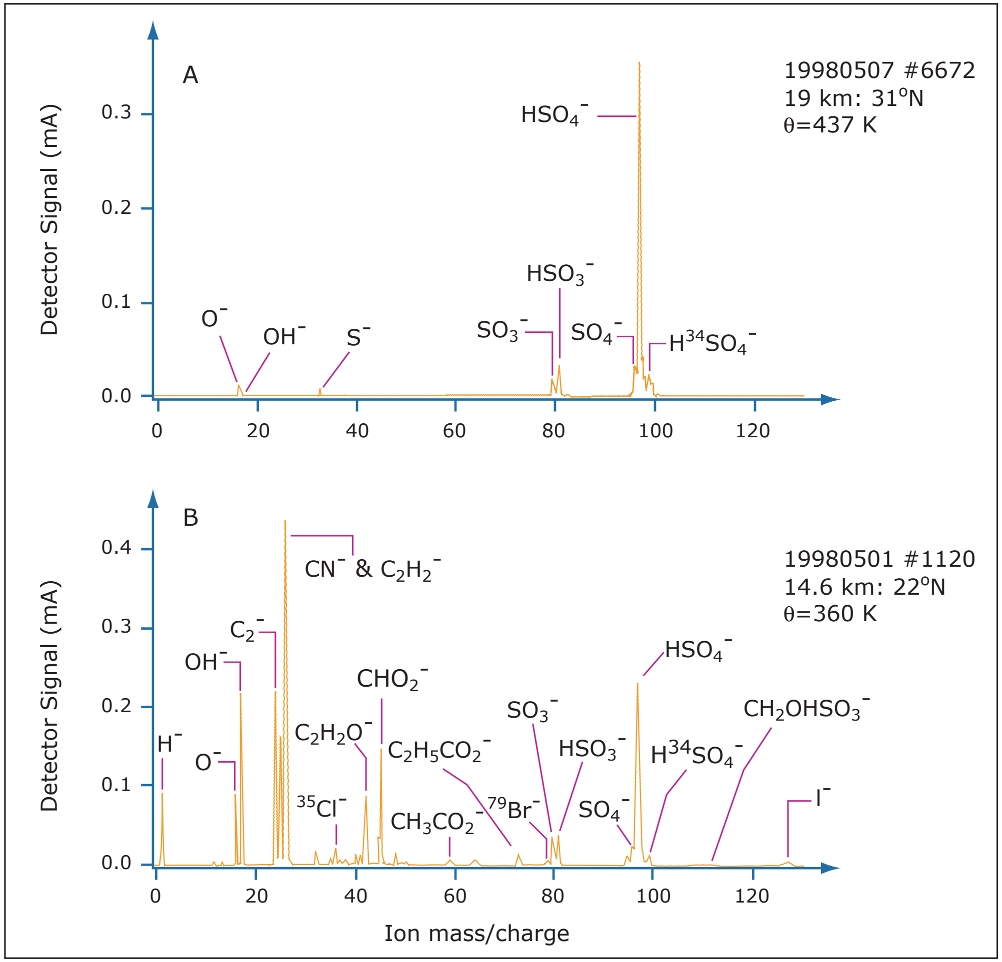
But there's a problem…

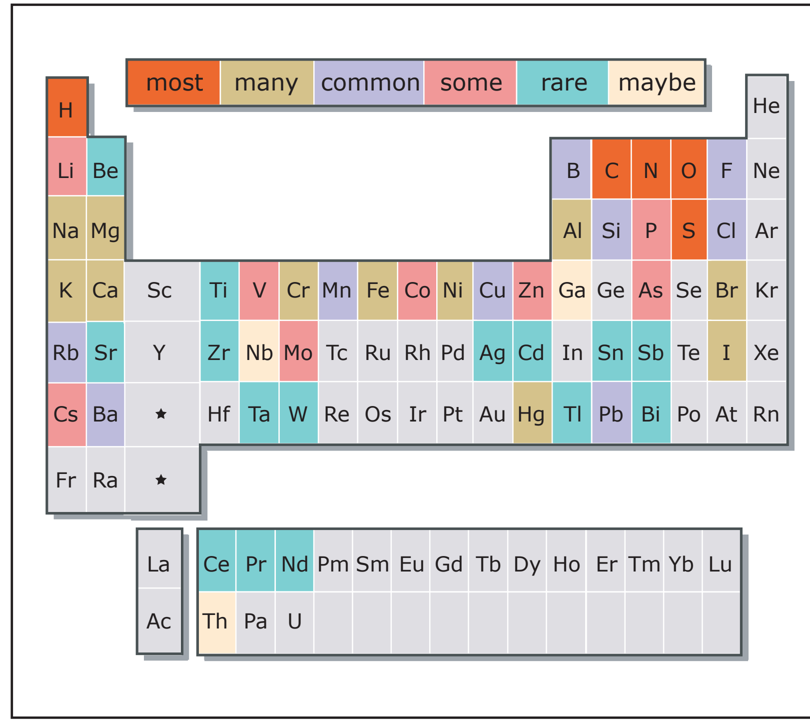


Particle Mass Spectrometry



Influential Results





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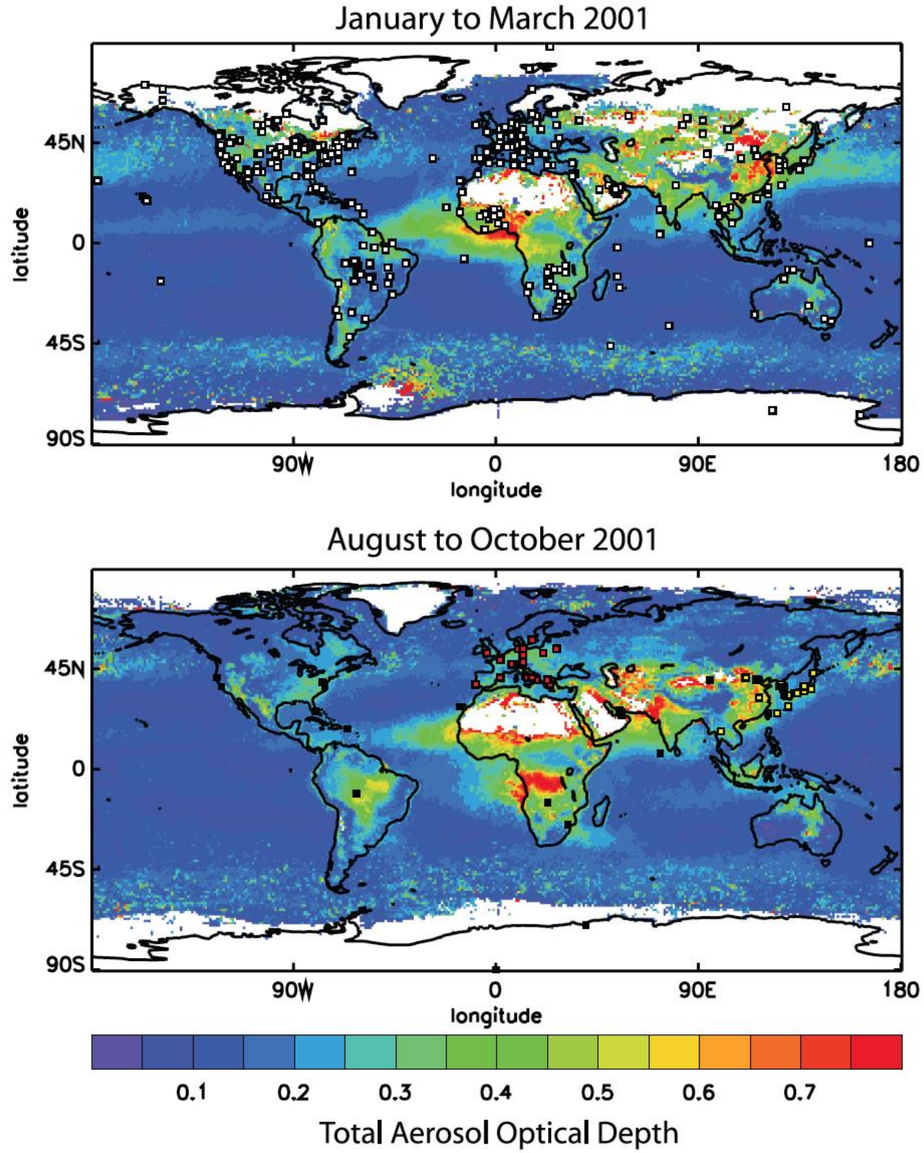
Murphy et al. Science 1998

Optical Depth ('Thickness')



(80%) (60%)

- $I = I_0 \exp[-m\tau]$
- 0.55 μm

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Direct Radiative Effect

Table 2.3. *The direct aerosol radiative effect (DRE) estimated from satellite remote sensing studies (adapted and updated from Yu et al., 2006).*

Reference	Instrument[a]	Data Analysed	Brief Description	Clear Sky DRE ($W m^{-2}$) ocean
Bellouin et al. (2005)	MODIS; TOMS; SSM/I	2002	MODIS fine and total τ_{aer} with TOMS Aerosol Index and SSM/I to discriminate dust from sea salt.	–6.8
Loeb and Manalo-Smith (2005)	CERES; MODIS	Mar 2000 to Dec 2003	CERES radiances/irradiances and angular distribution models and aerosol properties from either MODIS or from NOAA-NESDIS[b] algorithm used to estimate the direct radiative effect.	–3.8 (NESDIS) to –5.5 (MODIS)
Remer and Kaufman (2006)	MODIS	Aug 2001 to Dec 2003	Best-prescribed aerosol model fitted to MODIS data. τ_{aer} from fine-mode fraction.	–5.7 ± 0.4
Zhang et al. (2005); Christopher and Zhang (2004)	CERES; MODIS	Nov 2000 to Aug 2001	MODIS aerosol properties, CERES radiances/irradiances and angular distribution models used to estimate the direct radiative effect.	–5.3 ± 1.7
Bellouin et al. (2003)	POLDER	Nov 1996 to Jun 1997	Best-prescribed aerosol model fitted to POLDER data	–5.2
Loeb and Kato (2002)	CERES; VIRS	Jan 1998 to Aug 1998; Mar 2000.	τ_{aer} from VIRS regressed against the TOA CERES irradiance (35°N to 35°S)	–4.6 ± 1.0
Chou et al. (2002)	SeaWiFs	1998	Radiative transfer calculations with SeaWiFS τ_{aer} and prescribed optical properties	–5.4
Boucher and Tanré (2000)	POLDER	Nov 1996 to Jun 1997	Best-prescribed aerosol model fitted to POLDER data	–5 to –6
Haywood et al. (1999)	ERBE	Jul 1987 to Dec 1988	DRE diagnosed from GCM-ERBE TOA irradiances	–6.7
Mean (standard deviation)				**–5.4 (0.9)**

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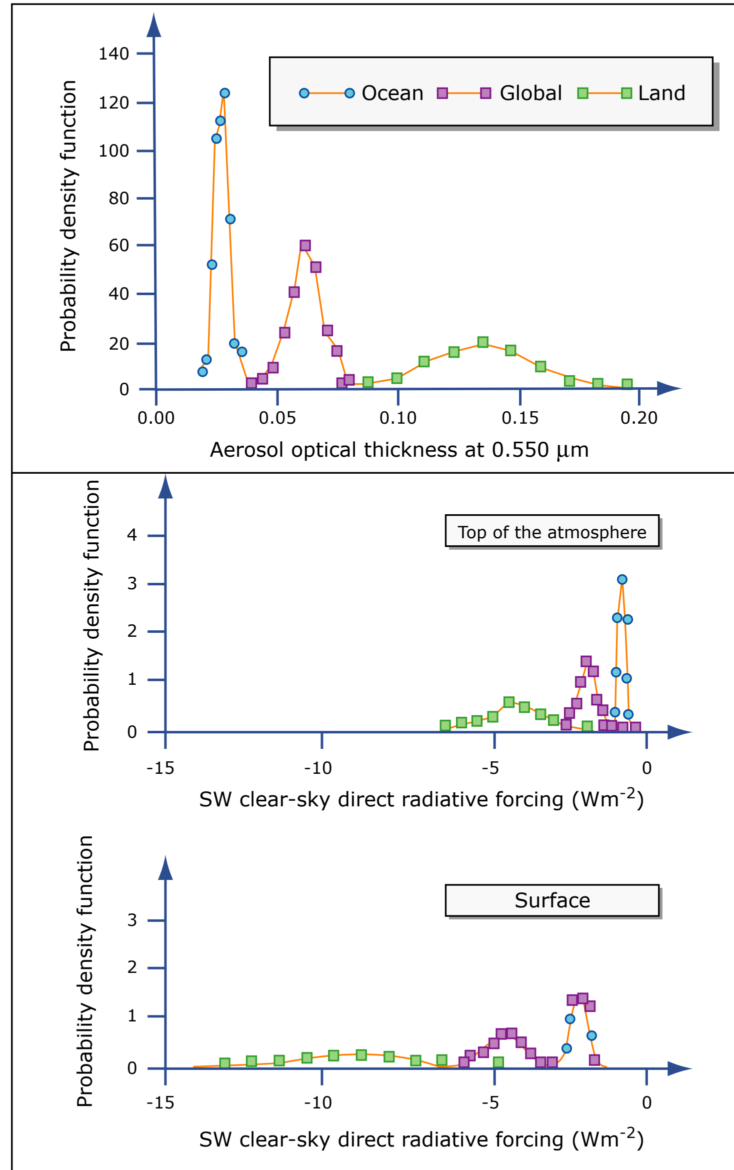

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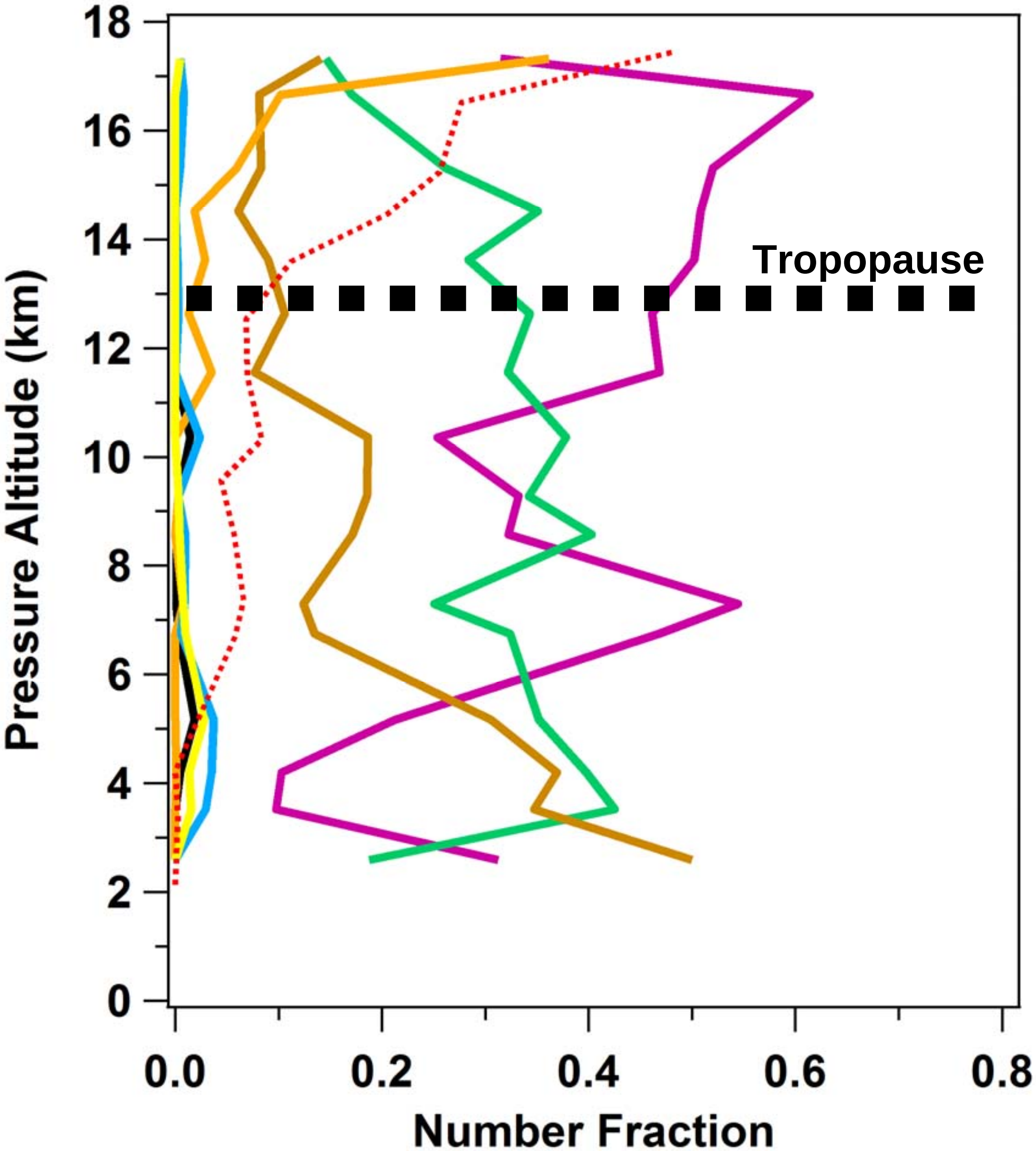
IPCC and Bellouin et al. Nature 2005

How Much Aerosol is There?

Unless otherwise specified figures from Seinfeld and Pandis

Clear Air Aerosol

Continental US, spring 2011



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- Regional **Biomass Burning**
- **Sulfate-Organic mixtures** dominate in UTLS
- **Mineral Dust**: 10-30%
- Little **Sea Salt** in UT
- **Meteoric** particles in stratosphere
- **Oil Combustion** at low alt
- **Sulfate Acidity** is high only in stratosphere

K. Froyd, unpublished

How Has Aerosol Changed?

Sulfate - fossil fuel : ~70% vs natural (biology, volcanoes) : 30%

Organic – poorly constrained, anthro. mainly from fuel combustion, ~40% of total

Black carbon – mainly from fossil fuel combustion, a minor component of natural biomass burning. A net absorber (warmer)

Biomass burning – different from above in that it is normally incomplete combustion, only from plant material. Net scattering (cooling) due to combination with organics and sulfate

Nitrate – natural but dominated by anthropogenic farming / fertilizers

Mineral dust – now 30 – 50% due to land use changes (note: sometimes not considered anthropogenic)

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Aerosol History : Soot

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Use of ice core

Melted, aerosolized by ‘month’ of material

Abundance of soot

McConnel et al. Science 2007

Aerosol History : Soot

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VA from biomass burning : what does this tell us?

Non sea salt sulfate from fossil fuels : what does this tell us?

McConnel et al. Science 2007

Lead

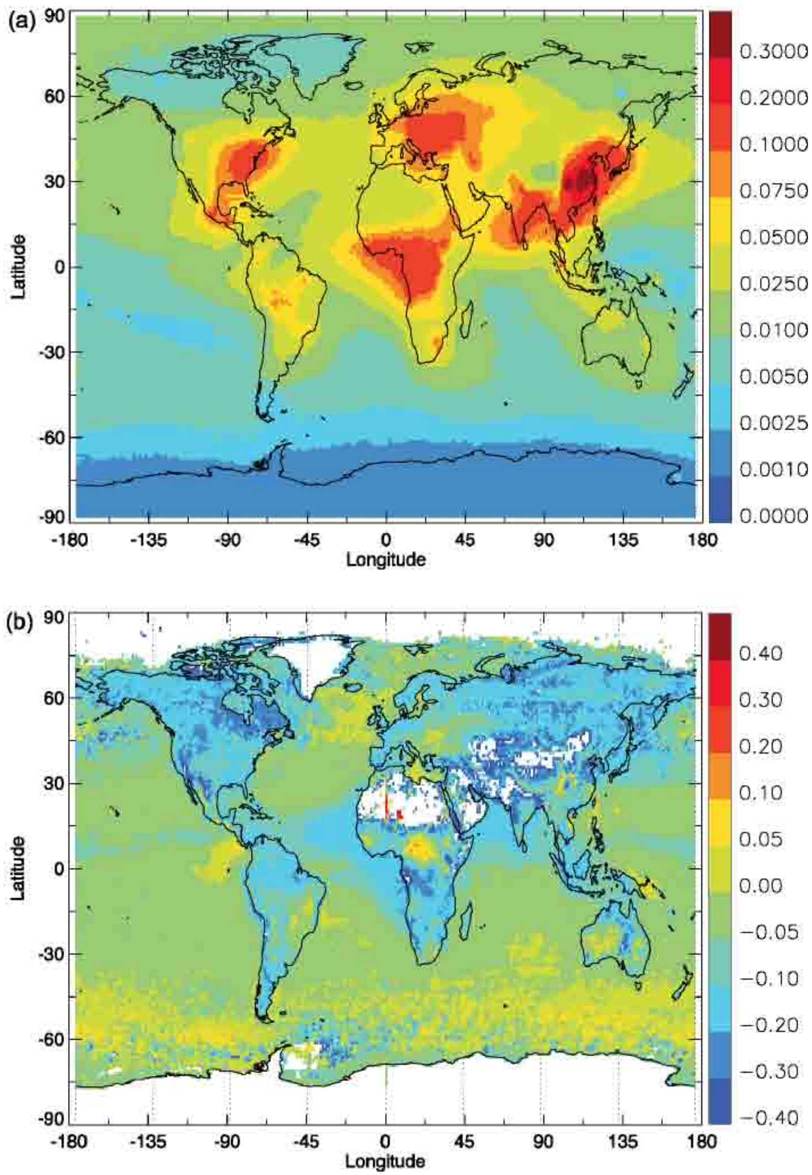
Use of peat bog cores
Abundance of anthropogenic tracers e.g. Pb

Peak at -3000 to -1600 years?

Peak at -10.5k years?

Shotyk et al. Science 1998

Decouple the Anthropogenic Effect



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Model *Anthropogenic* Aerosol Optical Depth:
From model studies, assumes a knowledge of what aerosol is natural and what is anthropogenic

Difference : Model – Satellite
How good to models do? (Answer : OK, not great)

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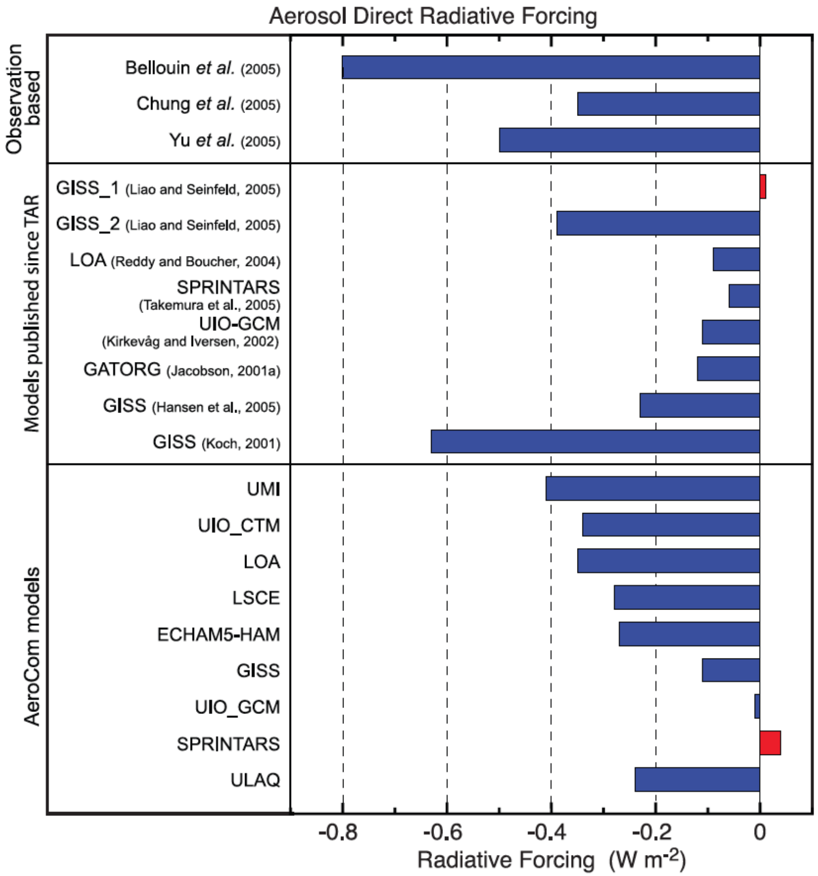
Best Estimates



Therefore, the results summarised in Table 2.6 and Figure 2.13, together with the estimates of nitrate and mineral dust RF combined with the measurement-based estimates, provide an estimate for the combined aerosol direct RF of –0.50 ± 0.40 W m^{-2}. The progress in both global modelling and ~~measurements~~ of the direct RF of aerosol leads to a medium-low level of scientific understanding (see Section 2.9, ~~Table 2.11).~~

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Observation and model based estimates of ANTHROPOGENIC aerosol direct effect (in all but two cases a cooling)

Best estimate : -0.5 W/m^2

Note greenhouse gas warming is ~+2.5 W/m^2

Unlike greenhouse gases the level of certainty is “medium-low”

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Recap

- What are aerosols? Where are they from?

- Why should we care about aerosols?

- How do aerosols affect radiation?

- How do we measure aerosol?

- Optical depth (τ_{aero}) and direct radiative effect (DRE)

- How much aerosol is there? How much is anthropogenic? (soot and lead)

- Best estimates of the anthropogenic direct effect