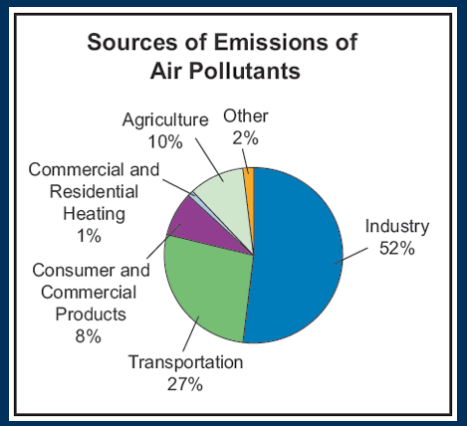
GGS 319
Part 1: Air Pollution Fundamentals

- ✓ The atmosphere and its components
- ✓ ***How air pollutants are categorized***
- ✓ ***The source/cycle of air pollutants***
- ✓ How pollution affects health and welfare
- ✓ Clean air acts
- ✓ Air quality management & standards







Aerosols

- ✓ Aerosols (micron or submicron sized particles) are produced both
  - ✓ naturally (e.g., wind-blown sea salt and dust) and
  - ✓ by human activities, such as the combustion of fossil fuels and biomass burning
- ✓ Over the past few decades international concern has grown about anthropogenic climate change
  - ✓ The main source of uncertainty in projected temperature rises are uncertainties in future emissions of greenhouse gases and uncertainty in the sensitivity of the climate system, due to climate feedbacks
- ✓ Another source of considerable uncertainty in global warming scenarios is the impact of tropospheric aerosols on the climate

Aerosols

- ✓ Aerosols are also a respiratory health hazard at the high concentrations found in urban environments
- ✓ They scatter and absorb visible radiation, limiting visibility
- ✓ They provide sites for surface chemistry and condensed-phase chemistry to take place in the atmosphere

Terminology

- Aerosol – a dispersion of solid and liquid particles suspended in gas (air).
  note: "aerosol" is defined as the dispersion of both particles and gas, but in common practice it is used to refer to the particles only!

- Primary aerosol – atmospheric particles that are emitted or injected directly into the atmosphere.
- Secondary aerosol – atmospheric particles that are created by in situ aggregation or nucleation from gas phase molecules (gas to particle conversion).

Either type may be natural or anthropogenic or both

How much aerosol is there? typically ~10's of ug/m^3

Global Particle Production

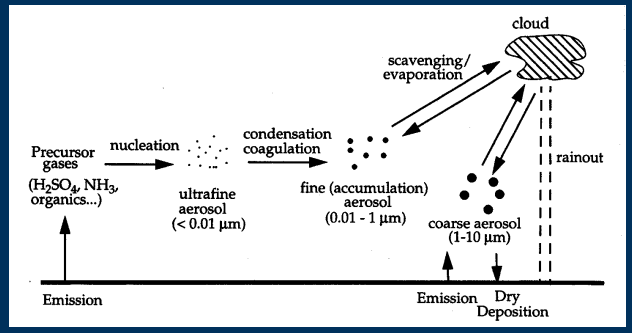
(1 tertagram (Tg) = 10^{12} g = 10^{9} kg)

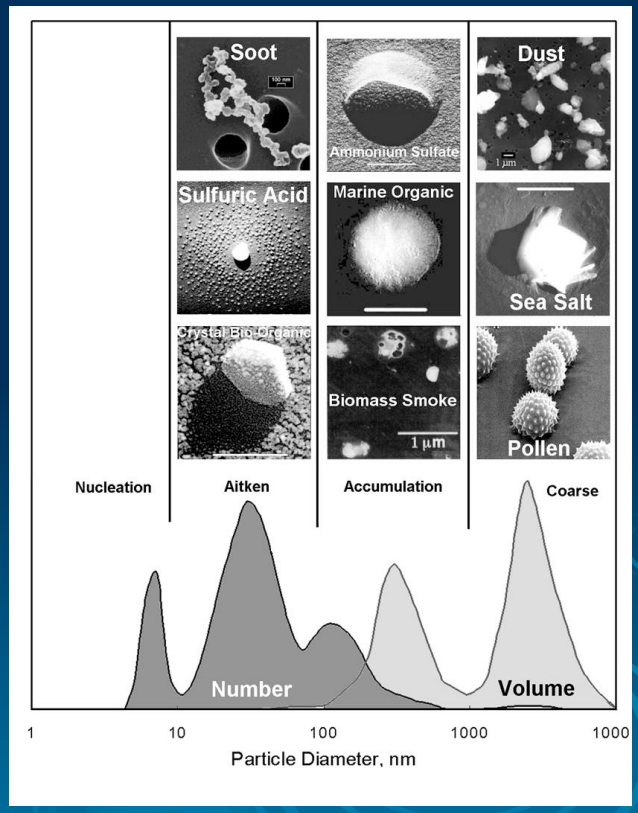
Source	Estimate Flux (Tg/yr)	Particle Size Category
Primary		
Soil dust (mineral aerosol)	1000-3000	Mainly coarse
Sea salt	1000-10000	Coarse
Volcanic dust	2-10000	Coarse
Biological debris	26-80	Coarse
Secondary		
Sulfates from biogenic gases	80-150	Fine
Sulfates from volcanic SO2	5-60	Fine
Organic matter from biogenic VOC	40-200	Fine
Nitrates from NOx	15-50	Fine and coarse
Total Natural	**2200-23500**	**Best estimate 3100**
Anthropogenic		
Primary		
Industrial dust etc. (except soot)	40-130	Fine and coarse
Soot	5-20	Mainly fine
Secondary		
Sulfates from SO2	170-250	Fine
Biomass burning	60-150	Fine
Nitrates from NOx	25-65	Mainly coarse
Organics from anthropogenic VOC	5-25	Fine
Total anthropogenic	**300-650**	**Best estimate 450**
Total	**2500-24000**	**Best estimate 3600**

Aerosol

- ✓ Atmospheric aerosols originate
  - ✓ from the condensation of gases and
  - ✓ from the action of the wind on the Earth's surface
- ✓ Fine aerosol particles (less than 0.001 μm in radius) originate almost exclusively from condensation of precursor gases
- ✓ Large particles have mechanical source (i.e., wind)

- ✓Nucleation mode < 0.01 μm
- ✓Aitken mode 0.01-0.1 μm
- ✓Accumulation mode 0.1-1 μm
- ✓Coarse mode >1 μm

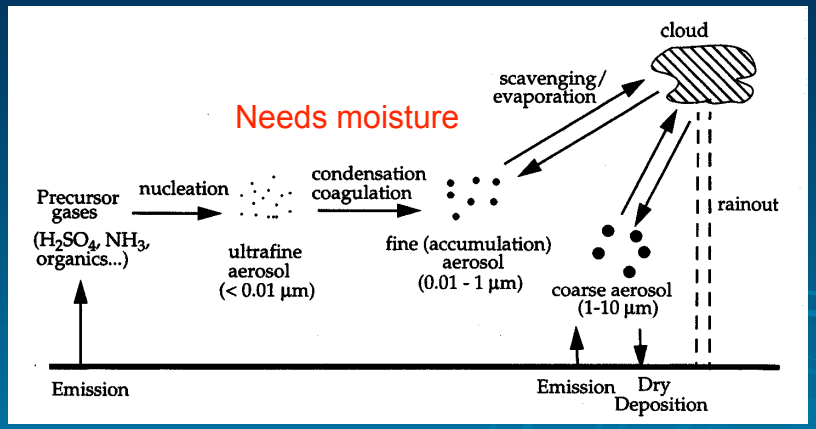




1 nm = 0.001 μm

Sources & Sinks of Aerosols

- ✓ A key precursor gas is sulfuric acid (H_2SO_4), which is produced in the atmosphere by oxidation of sulfur dioxide (SO_2) emitted from fossil fuel combustion, volcanoes and other sources
- ✓ Sulfuric acid condenses under all atmospheric conditions to form aqueous particles
- ✓ They can be further modified by NH3 and organic carbons
- ✓ Mechanical actions (winds) emits sea salt, dust, and vegetation debris (coarse particles, 1-10 mm in radius)



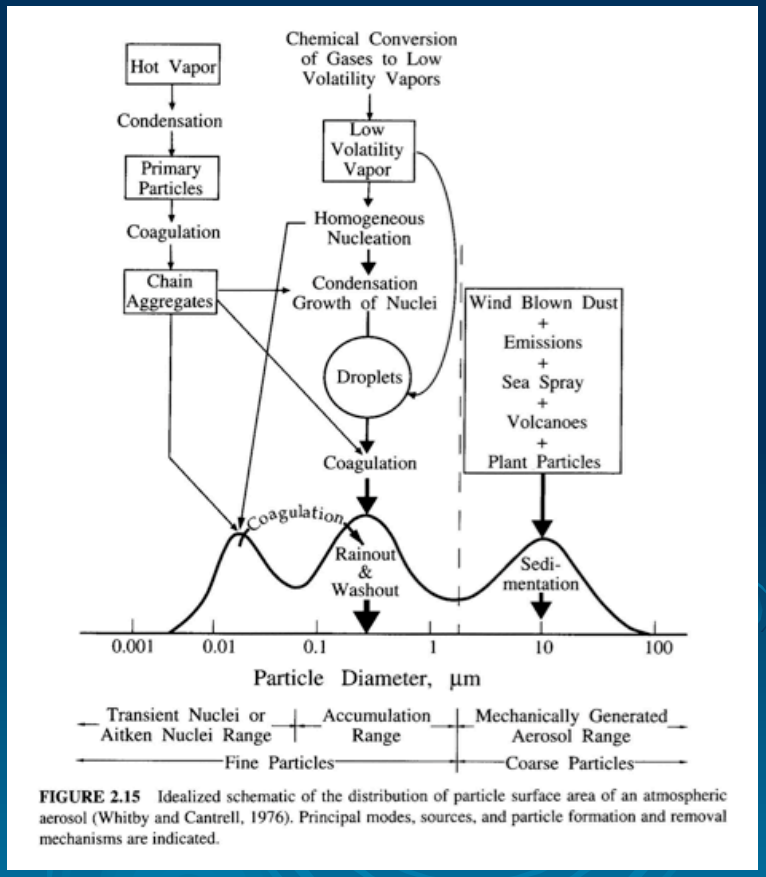
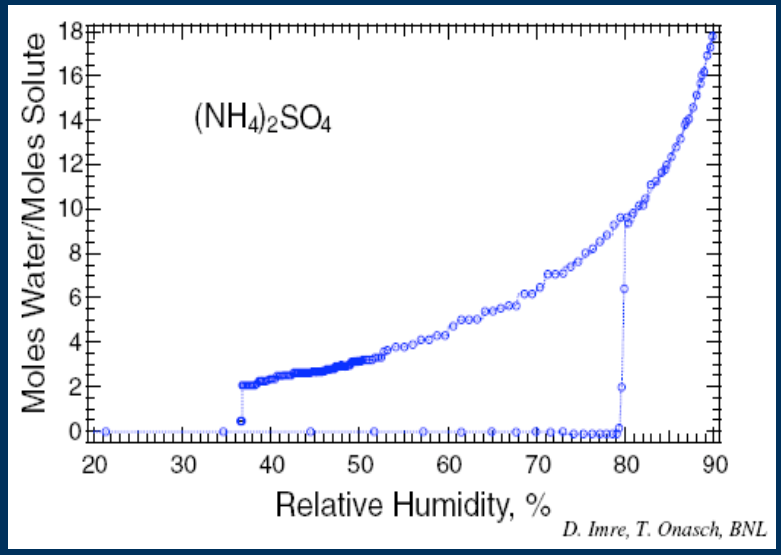
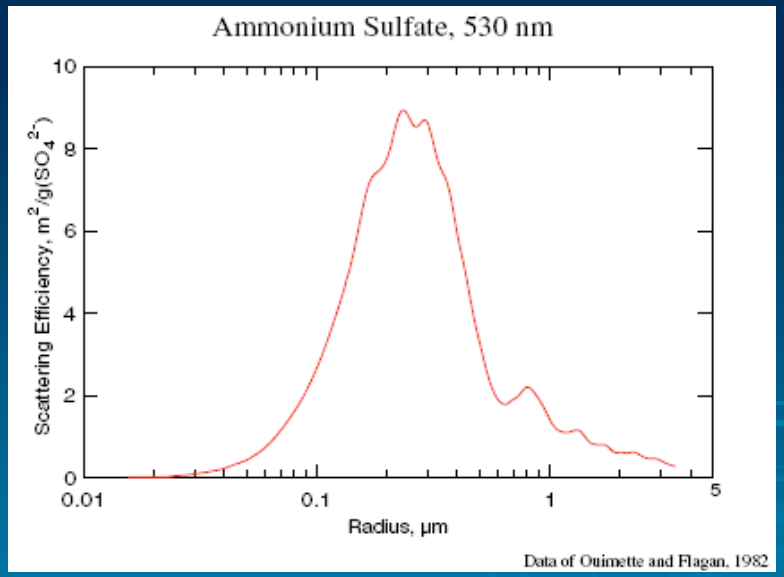


FIGURE 2.15 Idealized schematic of the distribution of particle surface area of an atmospheric aerosol (Whitby and Cantrell, 1976). Principal modes, sources, and particle formation and removal mechanisms are indicated.

Humidity and aerosol size...

- ✓ Hygroscopic aerosols grow/shrink with Relative Humidity (RH)
- ✓ Liquid solution does not yield a solid particle until 20-30% RH level





- ✓ In turn, aerosol size strongly affects light scattering cross-section

Removal Process (Gravitational Settling)

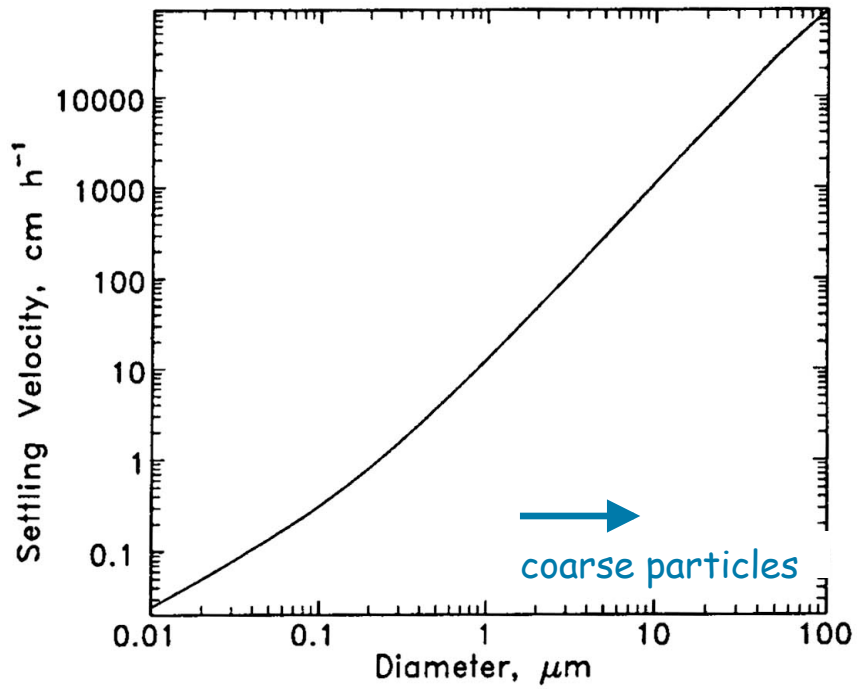


FIGURE 8.6 Settling velocity of particles in air at 298 K as a function of their diameter.

- ✓ Settling is important to coarse mode particles
- ✓ Large aerosol particle would have a lifetime of a few days
- ✓ 10 μm particle → 1000 cm hr^{-1} (240 m/day)
- ✓ 1 μm particle → 10 cm hr^{-1}

Diffusion/Coagulation

Brownian diffusion: motion caused by random collisions with surrounding gas molecules

You can estimate the distance a particle will diffuse in a given time from the equation:

$$\text{distance(cm)} = \sqrt{Dt}$$

where *D* is the diffusion coefficient

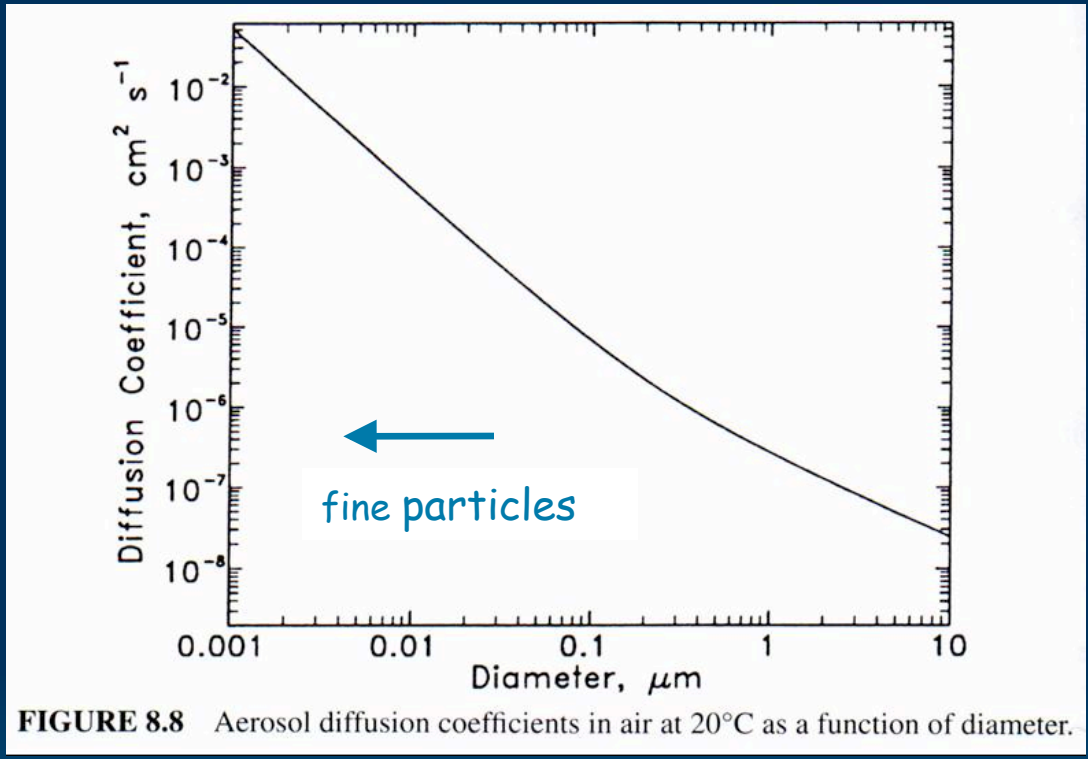


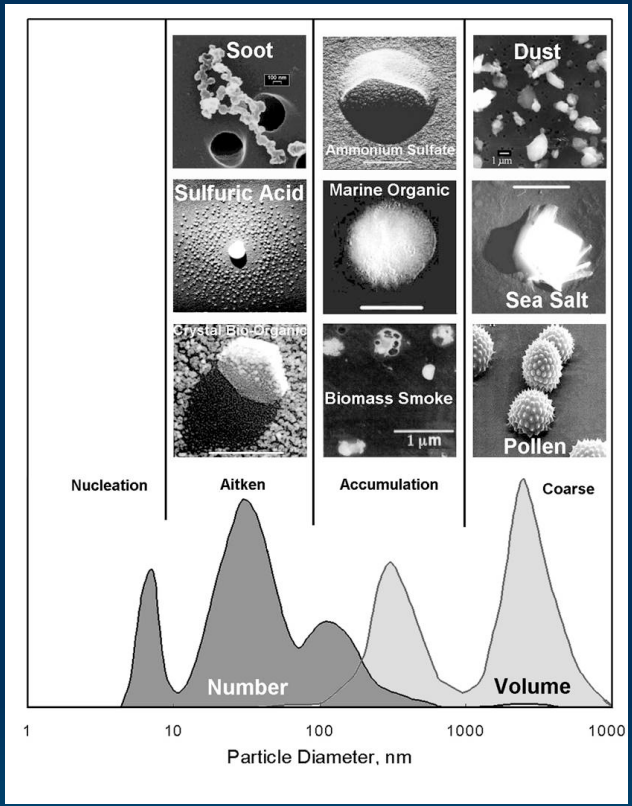
FIGURE 8.8 Aerosol diffusion coefficients in air at 20°C as a function of diameter.

Diameter (μm)	Distance diffused in 1 s (cm)
.001	0.2
.01	0.02
.1	.002
1	.0004
10	.0001

e.g., smoke particles in air

- ✓ Diffusion is important for small particles
- ✓ Diffusion increases with temperature
- ✓ Large particles are dominated by gravity

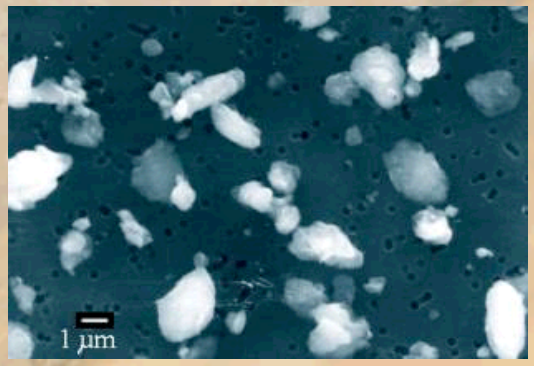
Lifetimes



- ✓ Nucleation mode <0.01 μm (**minutes to hours**)
- ✓ Aitken mode – 0.01-0.1 μm (**hours to days**) diffusion
- ✓ Accumulation mode – 0.1-1 μm (**weeks**)
- ✓ Coarse mode - >1 μm (**hours to days**) deposition

Mineral Dust

Dust (mineral aerosols)
- diameter size: 2-300 μm
- main material: sand, silt, clay
- includes essential trace metals such as Fe
- consists of insoluble and soluble fractions



Organic aerosols - burning

soot – "elemental carbon"

- formed in flames
- little spectral dependence
- carbon-only

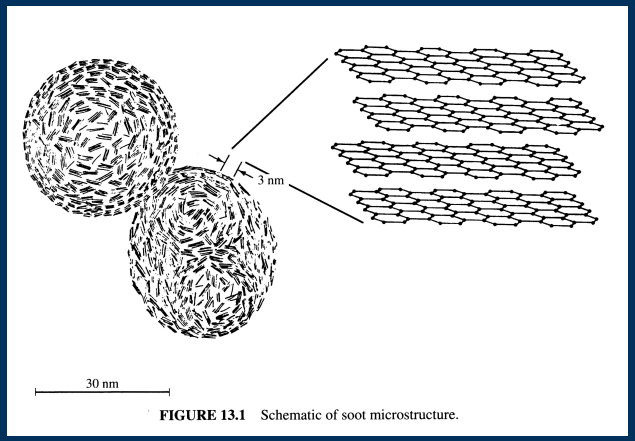


FIGURE 13.1 Schematic of soot microstructure.



"brown carbon":

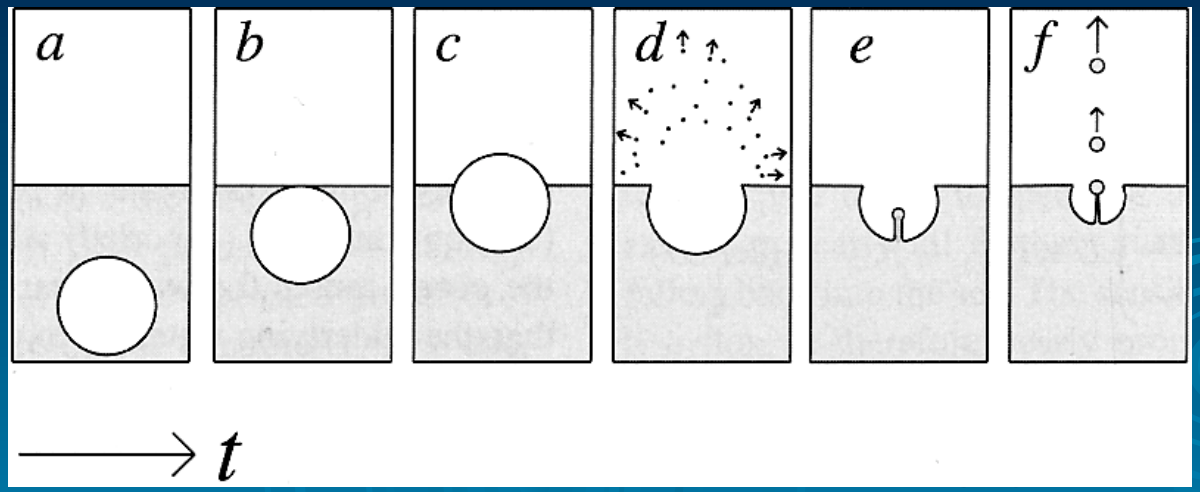
- sugars
- alcohols
- aromatics
- di/tri acids
- ketoacids
- hydroxyacids

Seasalt aerosols...

wind→ bubbles→ spray

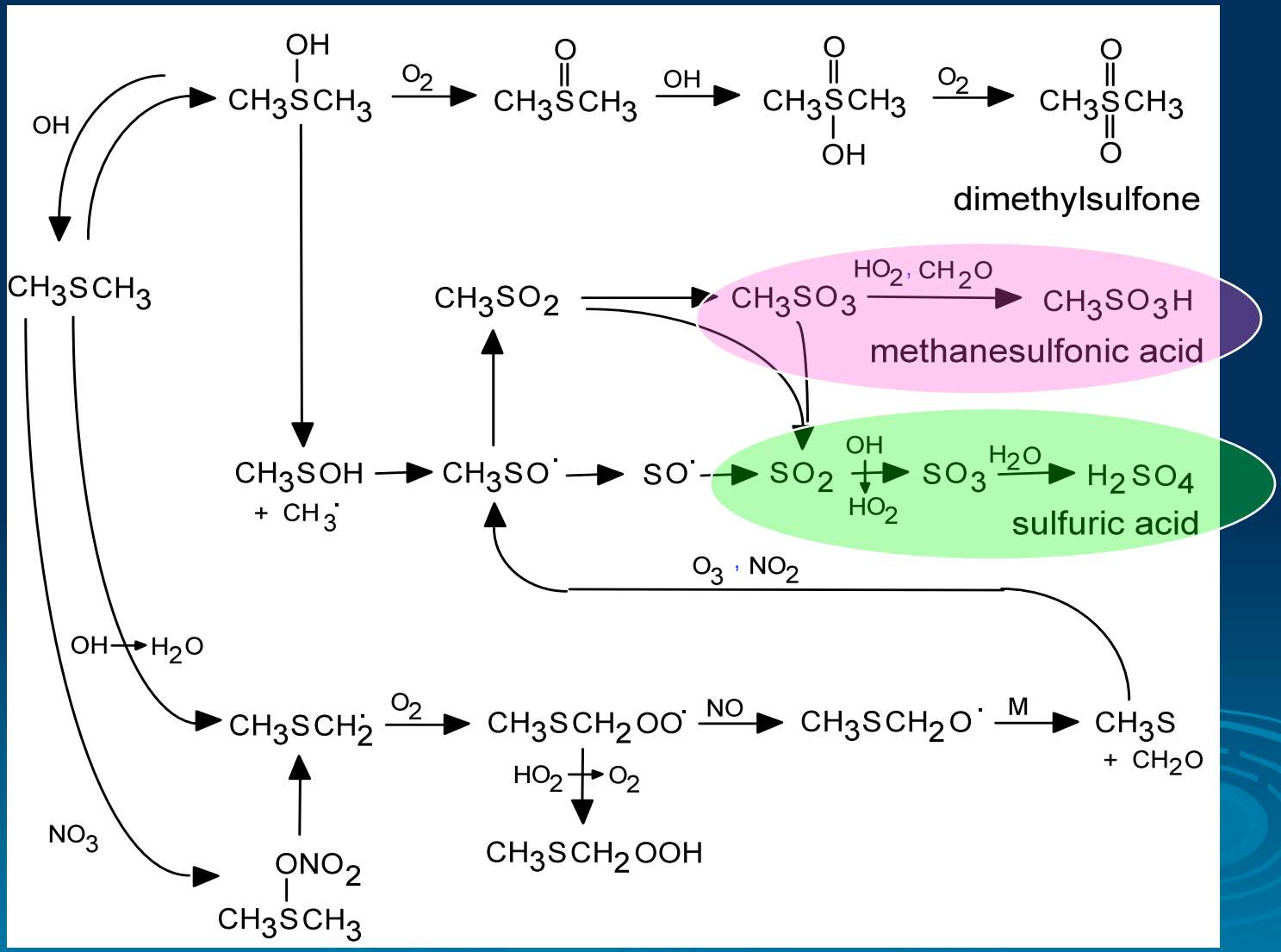


seasalt production via bubble bursting...

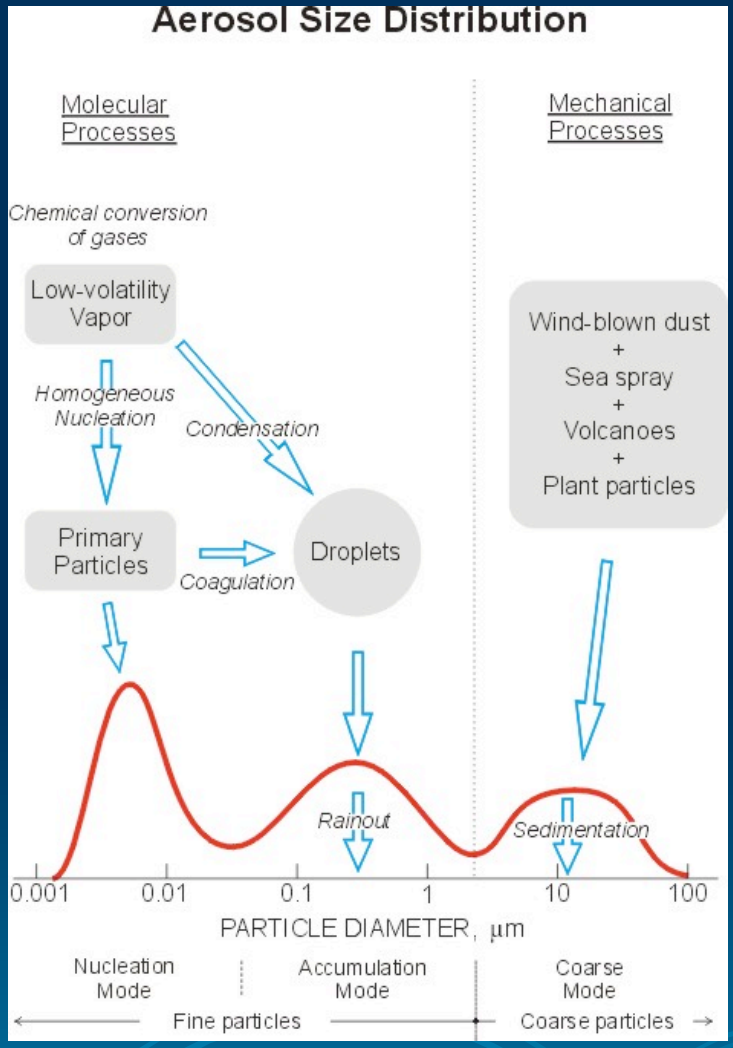


The sulfur story

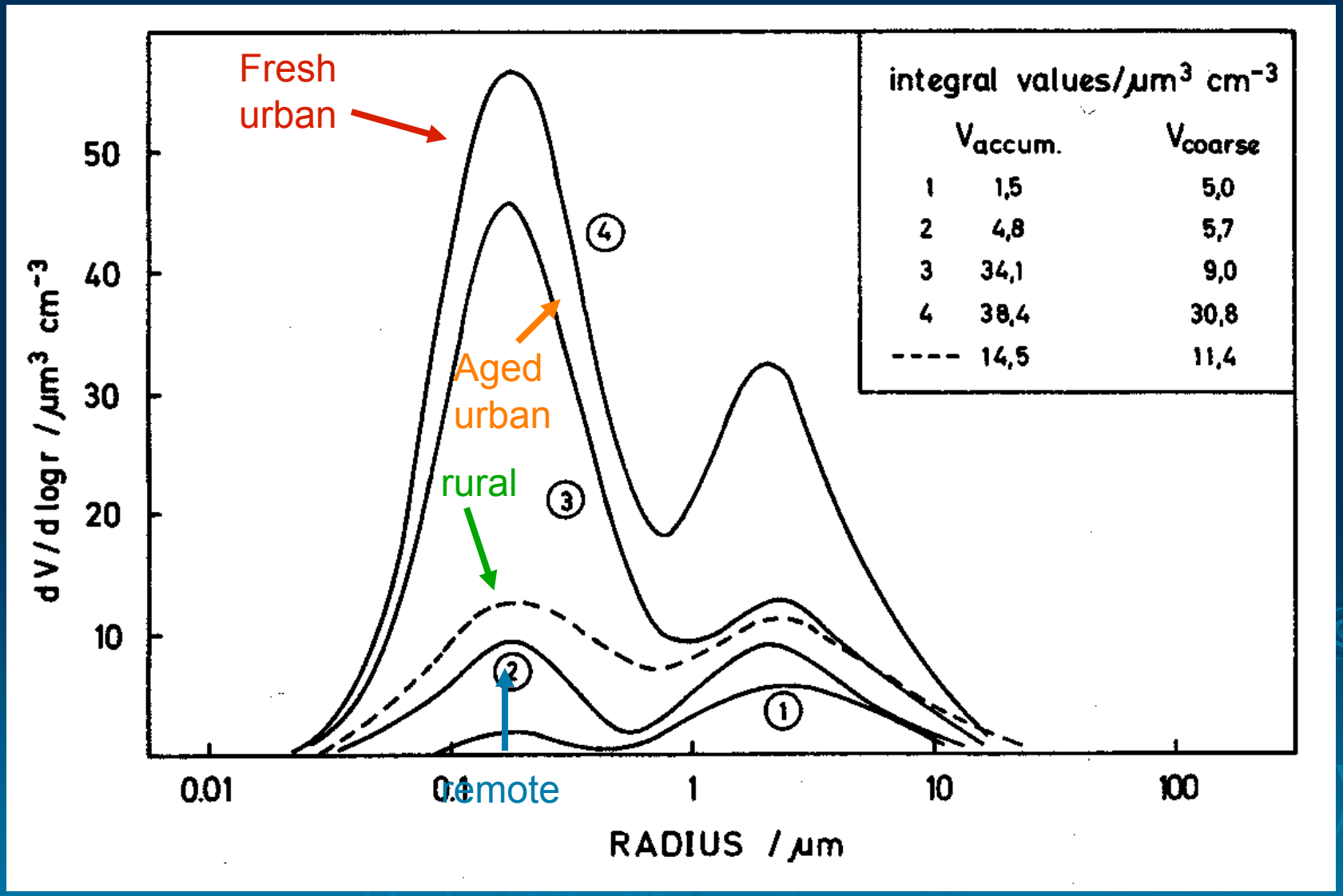
- emissions: fossil fuel SO_2, volcanic SO_2, oceanic DMS
- DMS oxidation … gas phase … complex!



Sources & Sinks of Aerosols

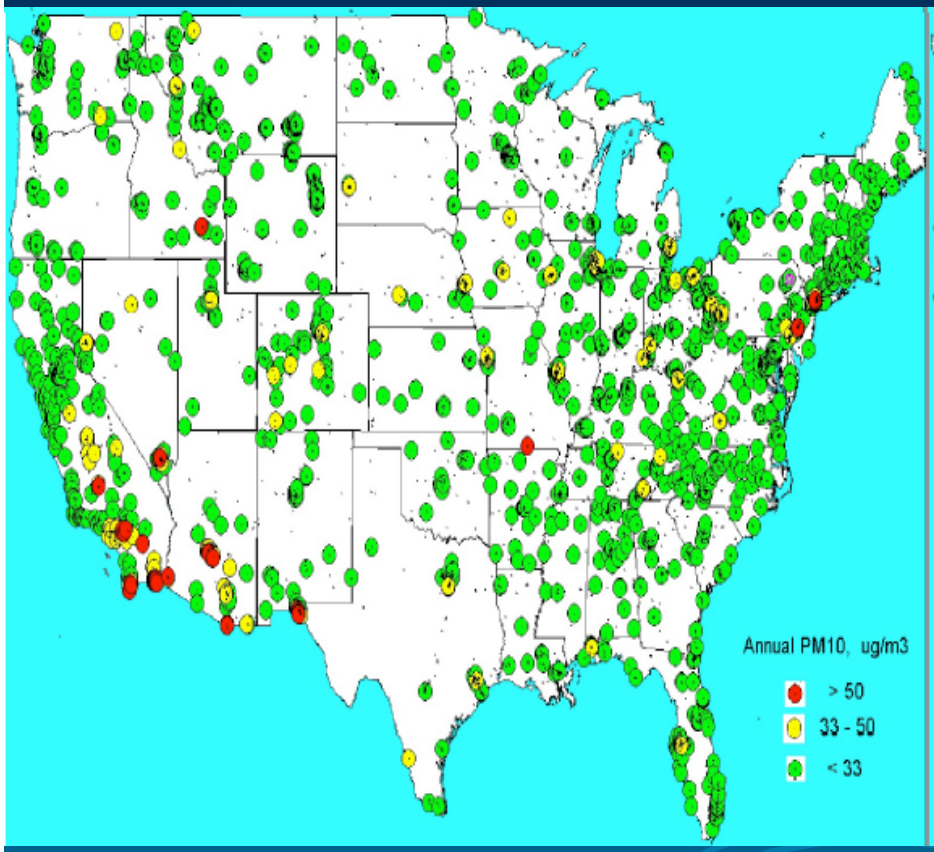


TYPICAL U.S. AEROSOL SIZE DISTRIBUTIONS

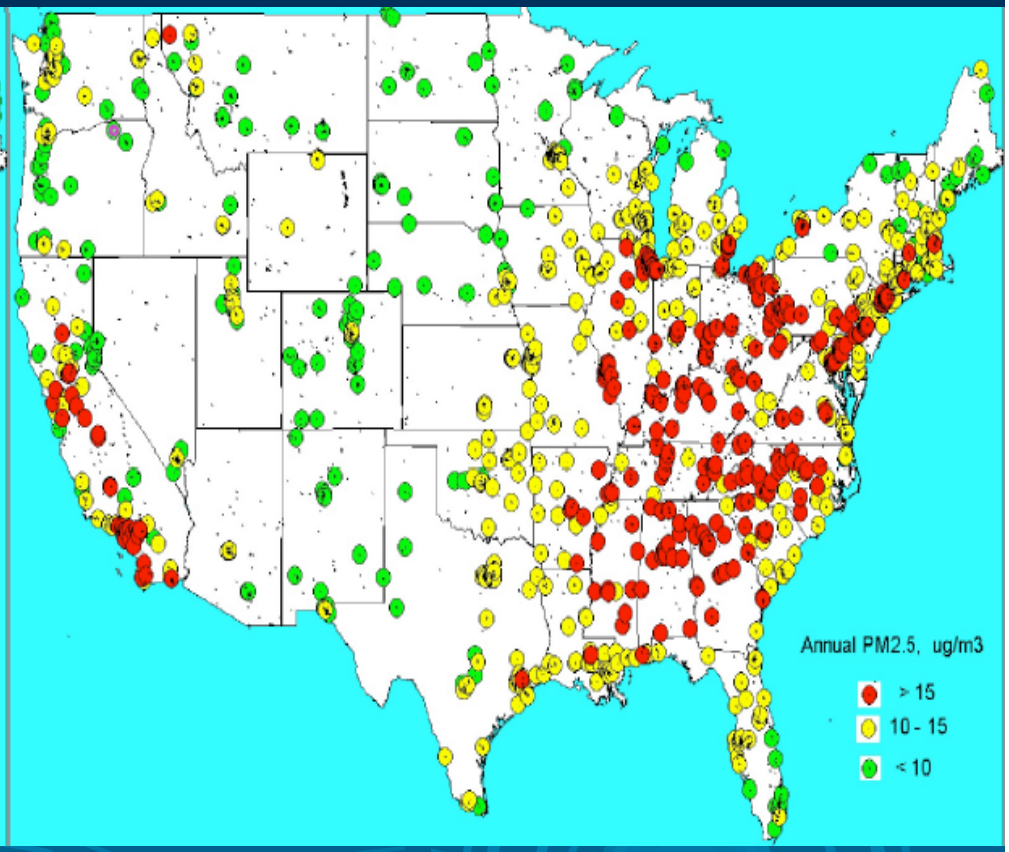


ANNUAL MEAN PARTICULATE MATTER (PM) CONCENTRATIONS AT U.S. SITES, 1995-2000

PM10 (particles > 10 μm)



PM2.5 (particles > 2.5 μm)



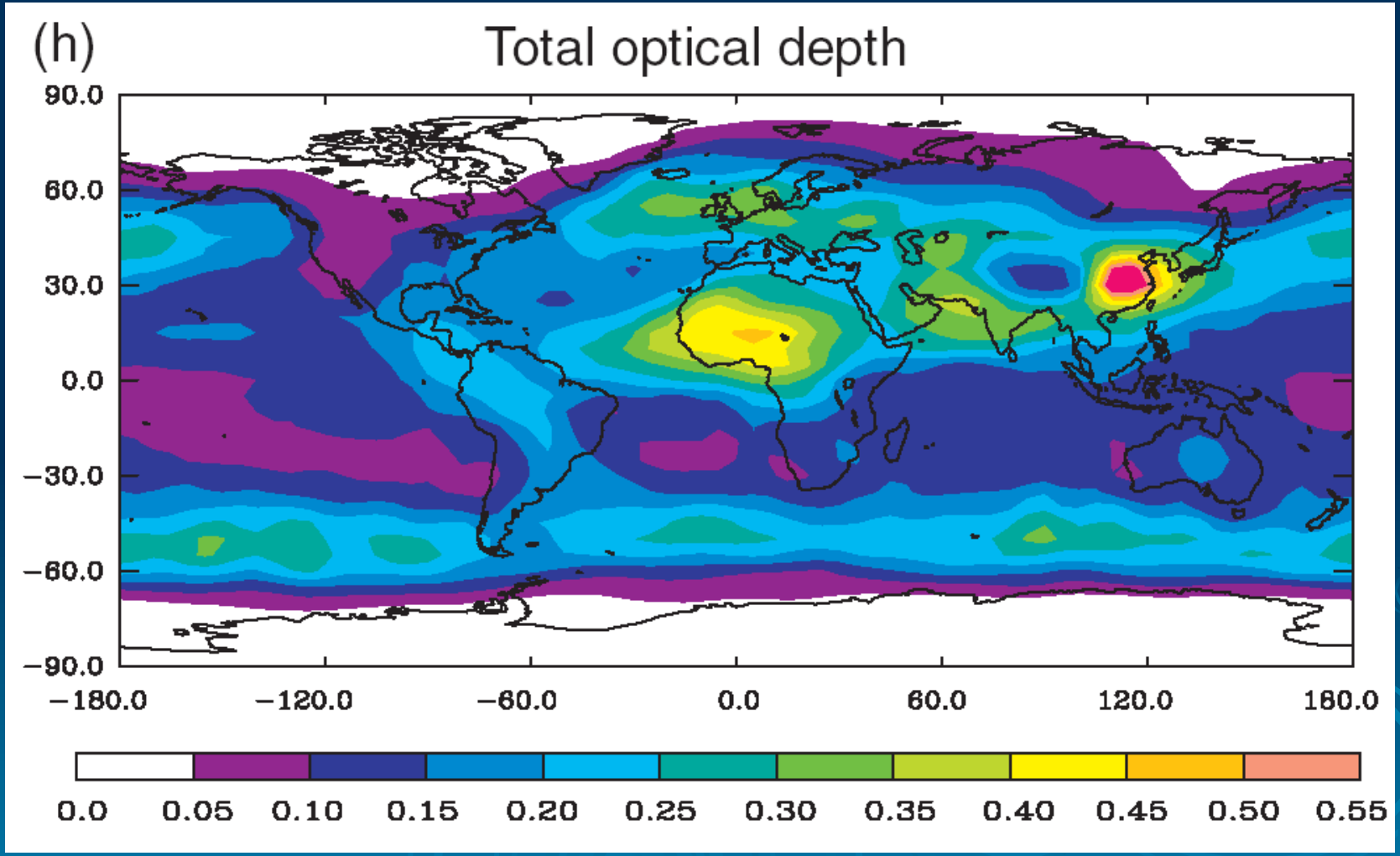
Red circles indicate violations of national air quality standard:

50 μg m^{-3} for PM10

15 μg m^{-3} for PM2.5

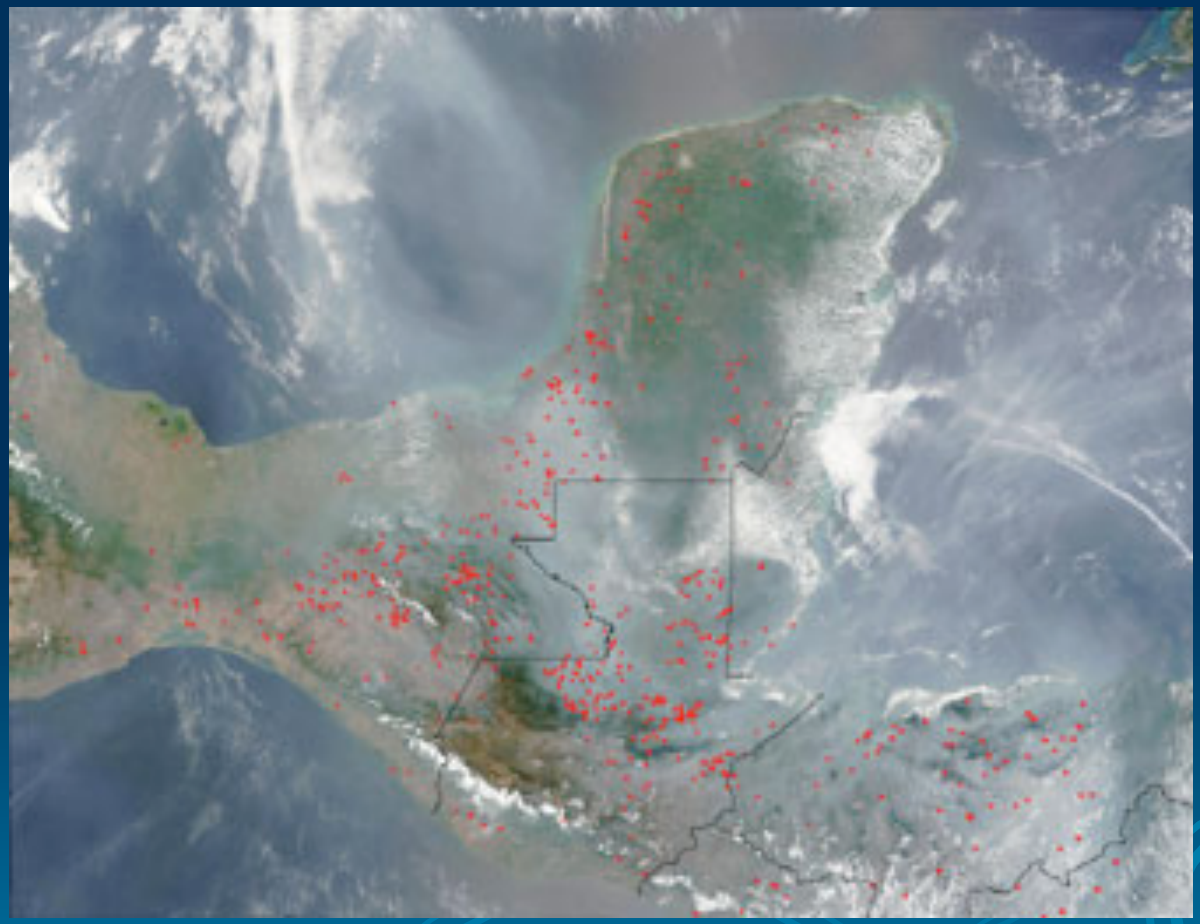
AEROSOL OPTICAL DEPTH (GLOBAL MODEL)

Annual mean



AEROSOL OBSERVATIONS FROM SPACE

Biomass fire haze in central America



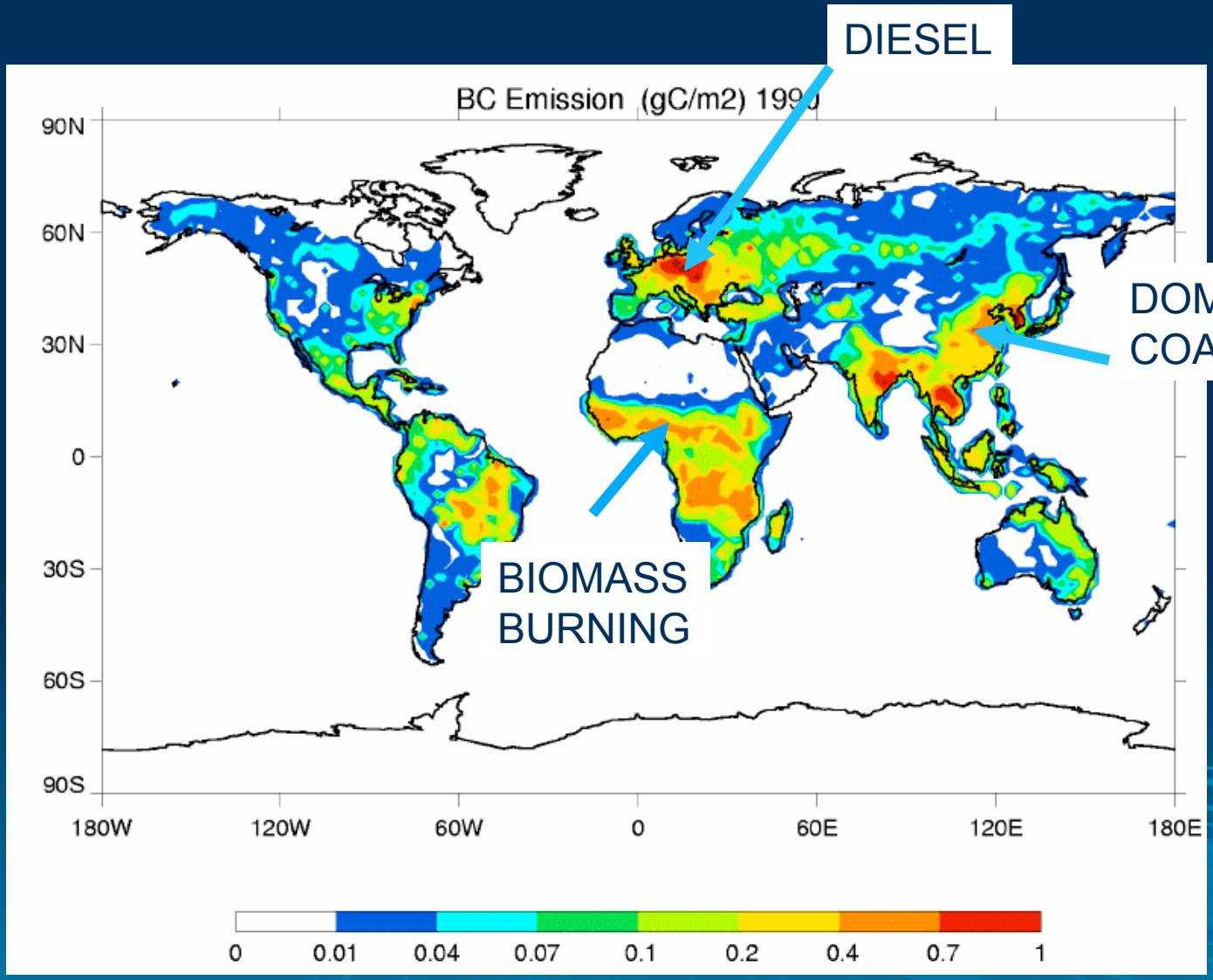
Fire locations in red

Modis.gsfc.nasa.gov

AEROSOL OBSERVATIONS FROM SPACE



BLACK CARBON EMISSIONS



EPA REGIONAL HAZE RULE: FEDERAL CLASS I AREAS TO RETURN TO "NATURAL" VISIBILITY LEVELS BY 2064

…will require essentially total elimination of anthropogenic aerosols!



clean day



moderately polluted day

Acadia National Park

http://www.hazecam.net/

Aerosol Perturbation to Climate (Earth's Albedo)

- When radiation strikes an object, there are usually three different results
  - First, some of the energy is absorbed by the object and increase its temperature
  - Second, substances such as water and air are transparent to certain wavelengths of radiation. Such materials simply transmit this energy. Radiation that is transmitted does not contribute energy to the object.
  - Third, reflection and scattering are responsible for redirecting incoming solar radiation.
- In summary, radiation may be absorbed, transmitted, or redirected (reflected or scattered).

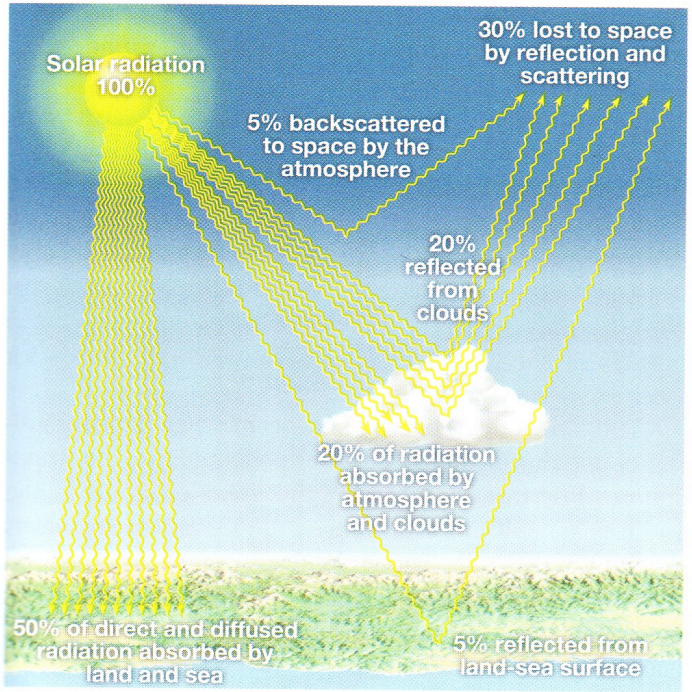


FIGURE 2-13 Average distribution of incoming solar radiation by percentage. More solar energy is absorbed by Earth's surface than by the atmosphere. Consequently, the air is not heated directly by the Sun, but is heated indirectly from Earth's surface.

Aerosol Perturbation to Climate (Earth's Albedo)

- Reflection is the process whereby light bounces back from an abject at the same angle at which it encounters a surface and with the same intensity.
- By contrast, scattering produces a larger number of weaker rays, traveling in different directions.
- The fraction of radiation that is reflected by a surface is called its albedo which various place to place and object to object.
- The albedo for Earth as a whole (planetary albedo) is 30 % (20 percent by clouds, 5 percent by Earth's surface and 5 percent by atmosphere).

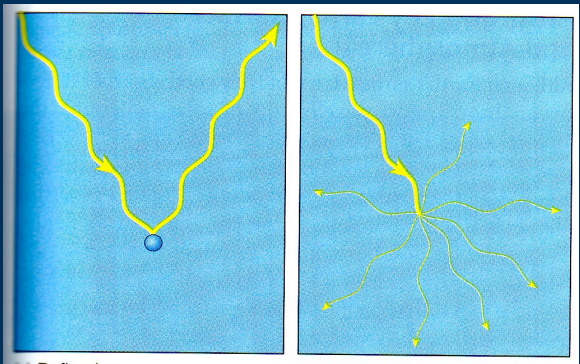
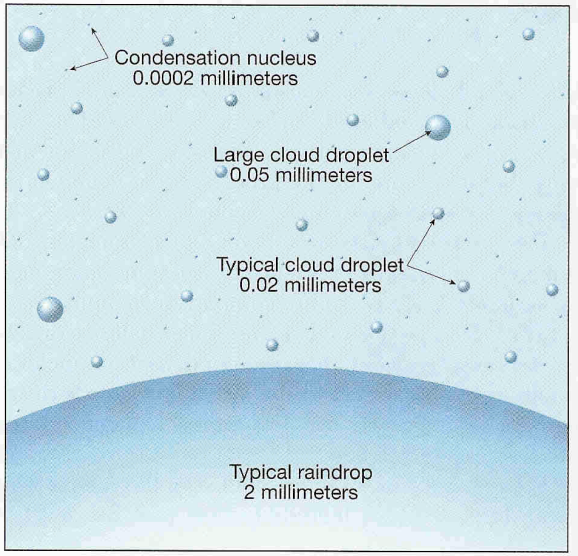


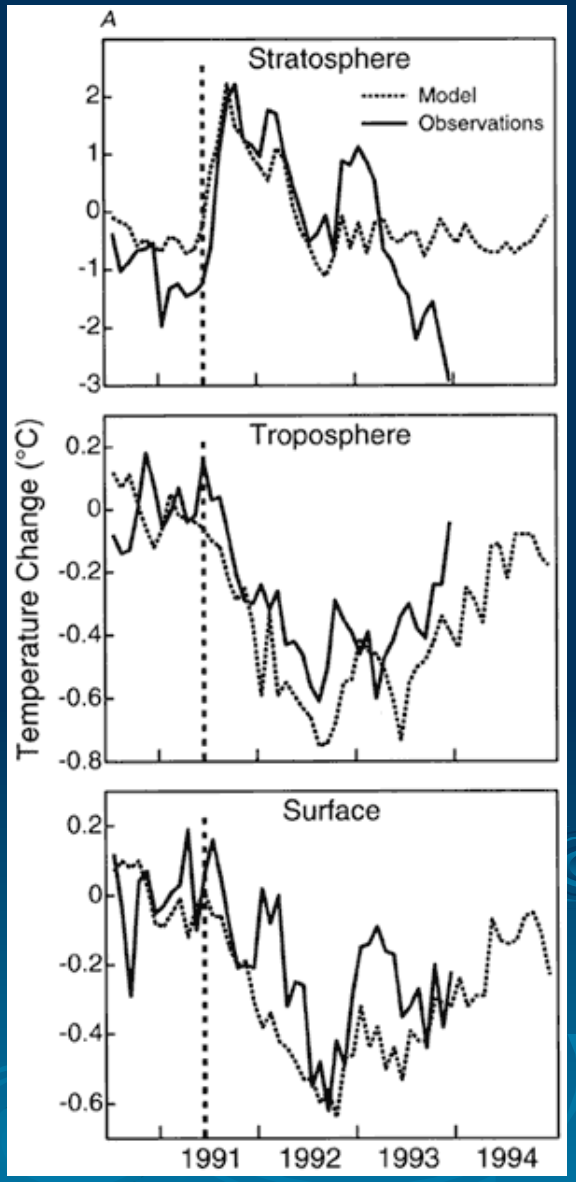
FIGURE 2-14 Reflection and scattering. (a) Reflected light bounces back from a surface at the same angle at which it strikes that surface and with the same intensity. (b) When a beam of light is scattered, it results in a larger number of weaker rays, traveling in all different directions. Usually more energy is scattered in the forward direction than is backscattered.

FIGURE 5-13 Comparative diameters of particles involved in condensation and precipitation processes.

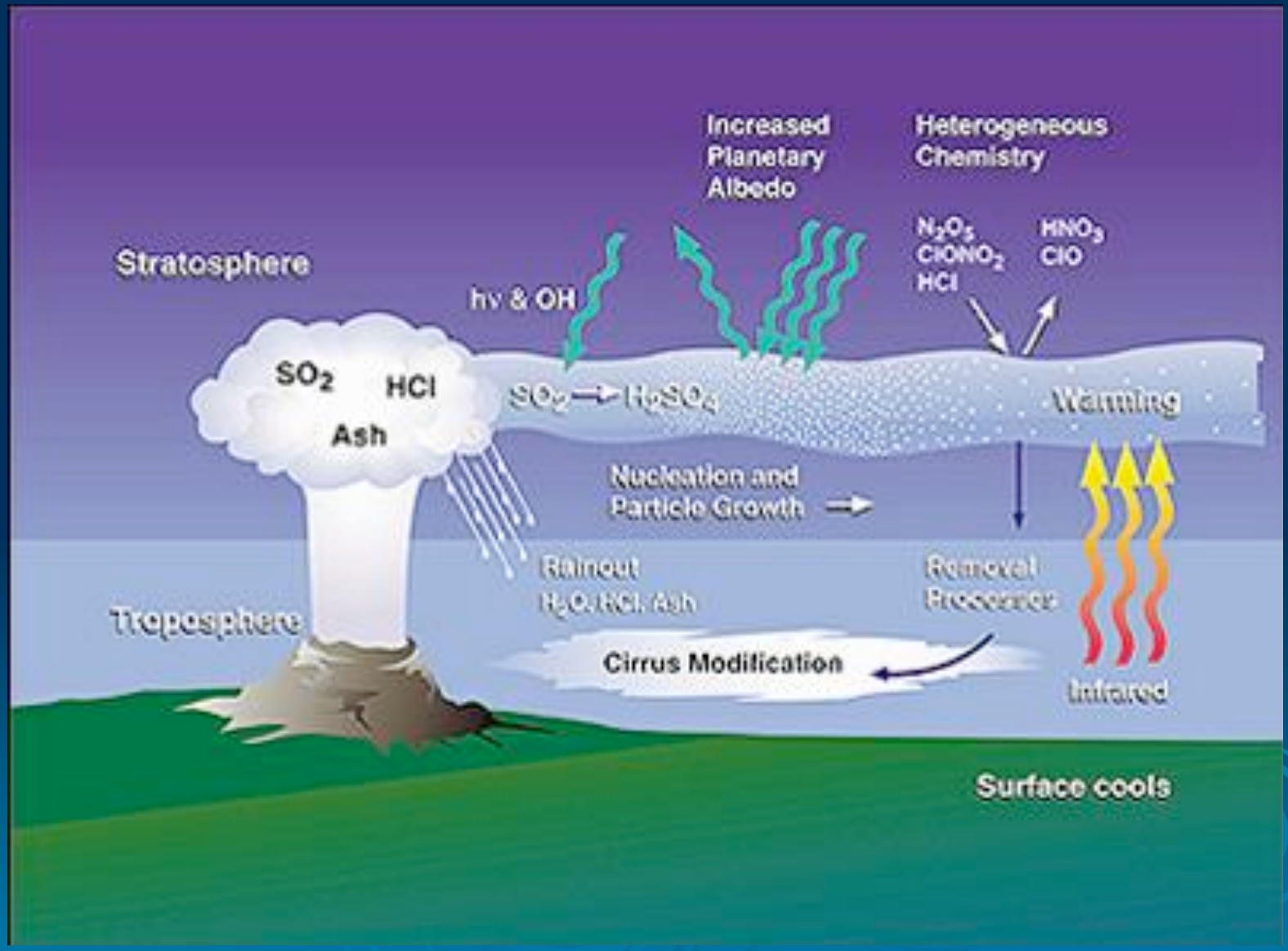


Aerosol Perturbation to Climate (Earth's Albedo)

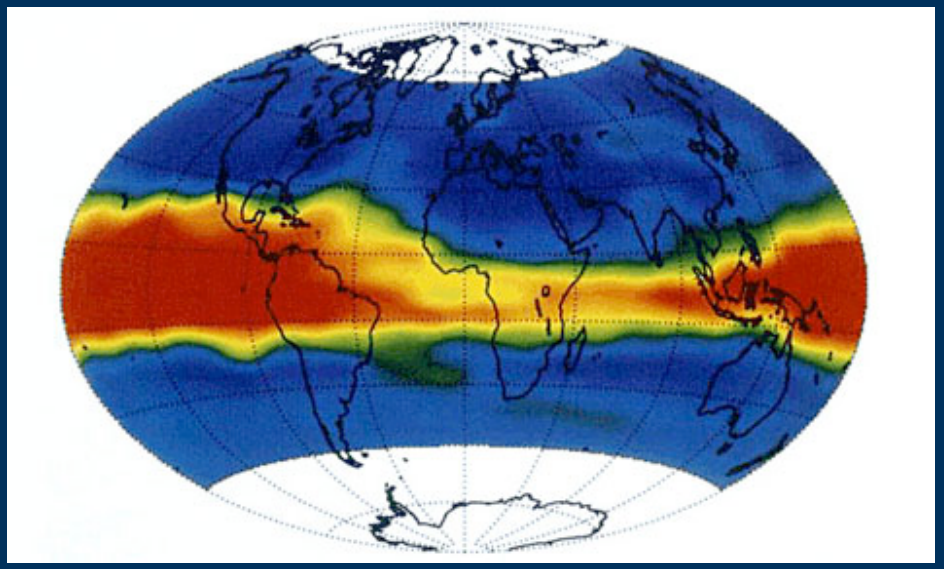
- Scattering of solar radiation by aerosols increases the Earth's albedo because a fraction of scattered light is reflected back to space
- This results in cooling of the Earth's surface
- For example, Mt. Pinatubo eruption in 1991 inject large amounts of aerosol into the stratosphere
- This followed by noticeable decreases in mean surface temperatures for the following 2 years



Volcanic Aerosol Layer



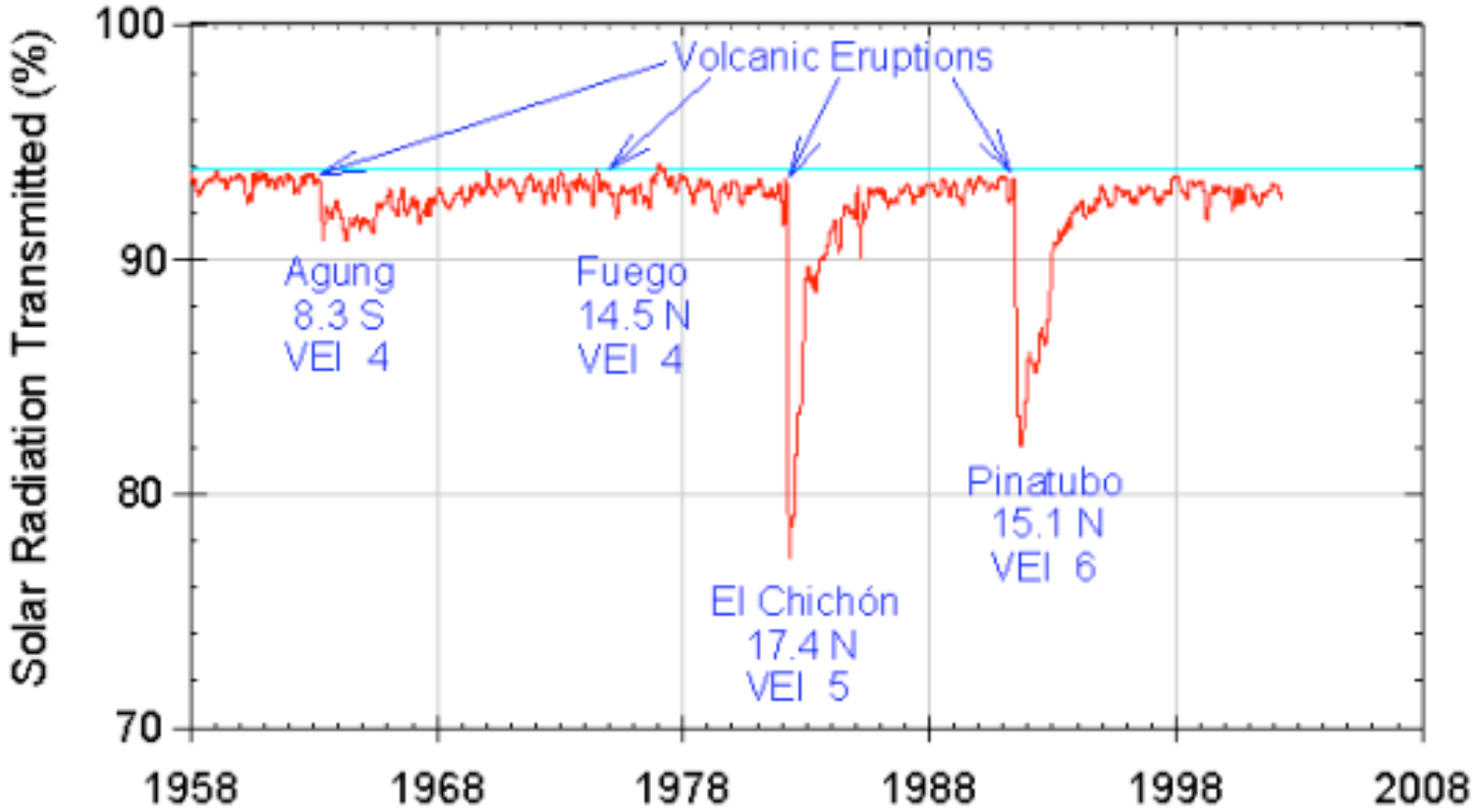
Mt. Pinatubo Aerosol Layer
June 14 - July 26, 1991



SAGE II Satellite Project - NASA

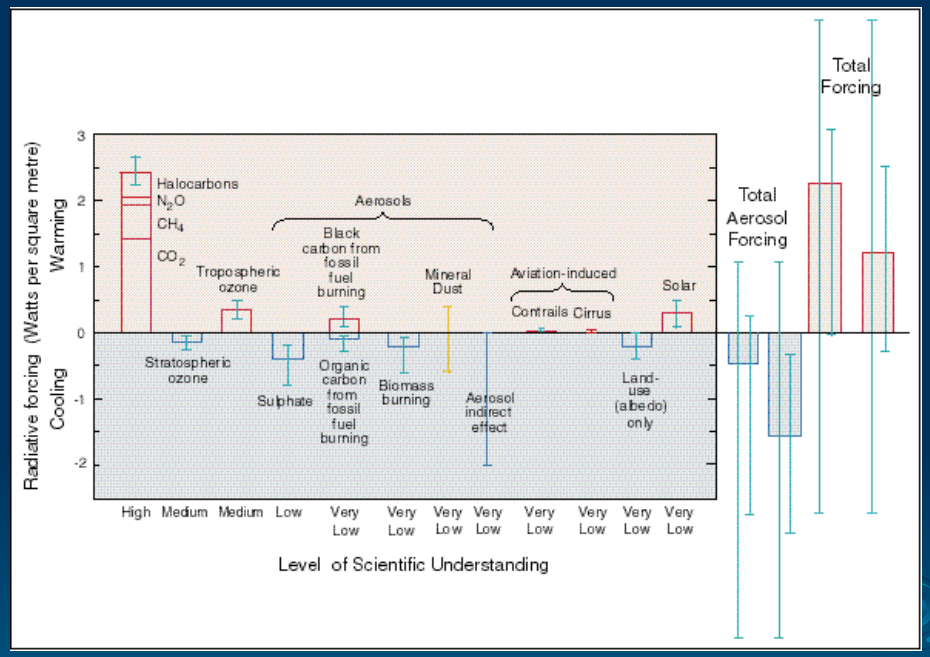


Mauna Loa Observatory Atmospheric Transmission



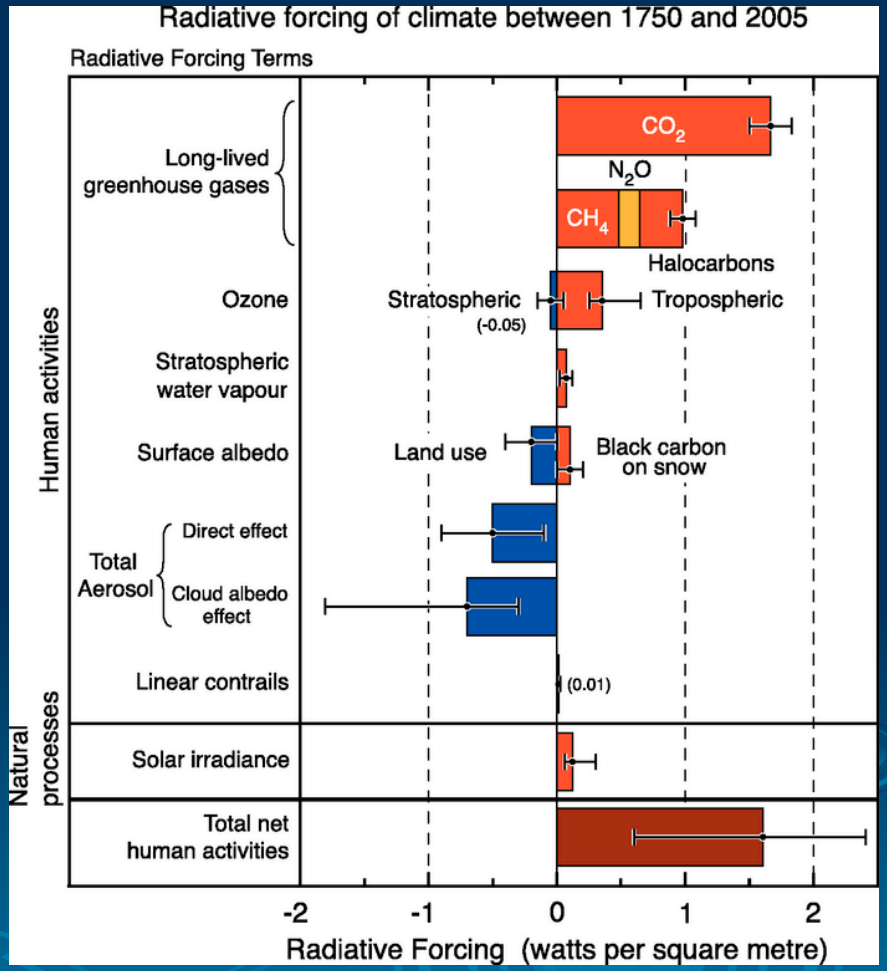
Perturbation to Climate (Radiative Forcing)

- ✓ Mainly negative impact of aerosols offsets warming impact of greenhouse gases
- ✓ Large uncertainty for aerosol effects (IPCC, 2007)
- ✓ The radiative forcing from well-mixed greenhouse gases (e.g., CO2, CH4, N2O) is well understood because their spectral absorption cross-sections and atmospheric concentrations are accurately known



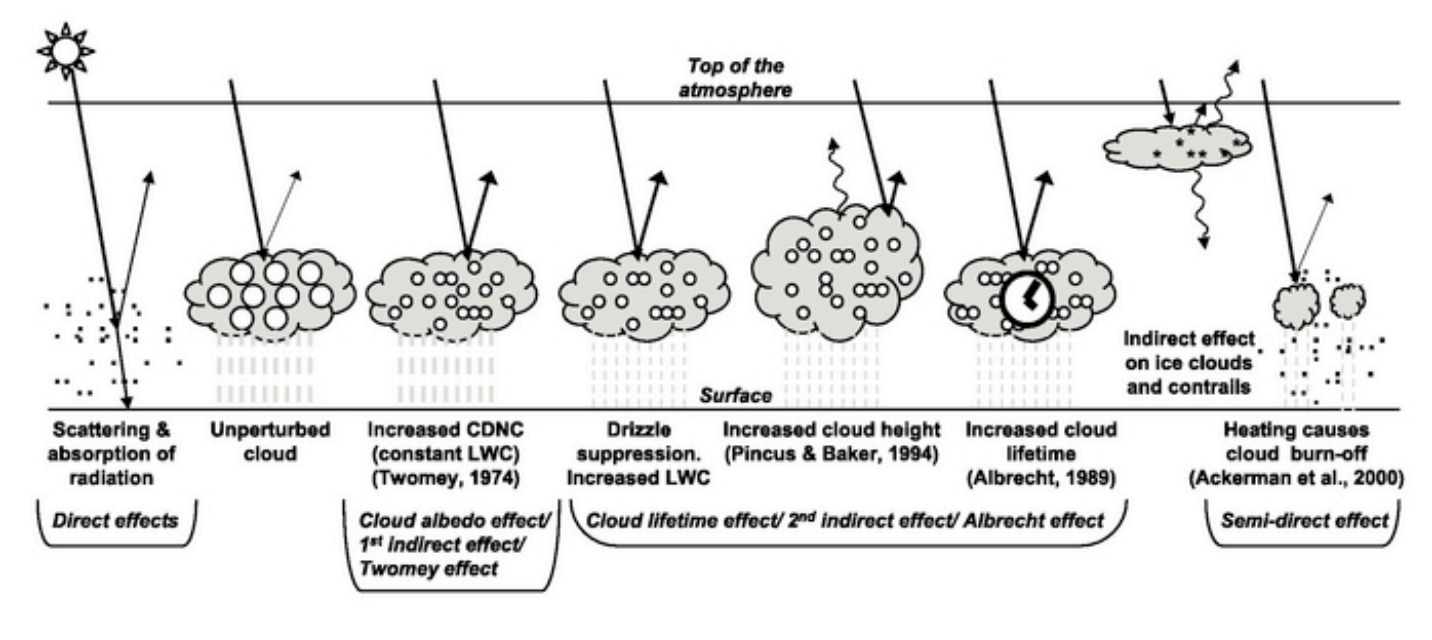
Radiative Forcing

- ✓ However, the influence of tropospheric aerosols (black carbon, sea salt, sulfates, dust) on climate is poorly understood at present largely due to:
  - ✓ the complexity of their physical, chemical, and optical properties
  - ✓ their variability in space & time
  - ✓ their interactions with clouds
- ✓ Provides valuable research opportunity in aerosol-radiation-cloud-precipitation interactions



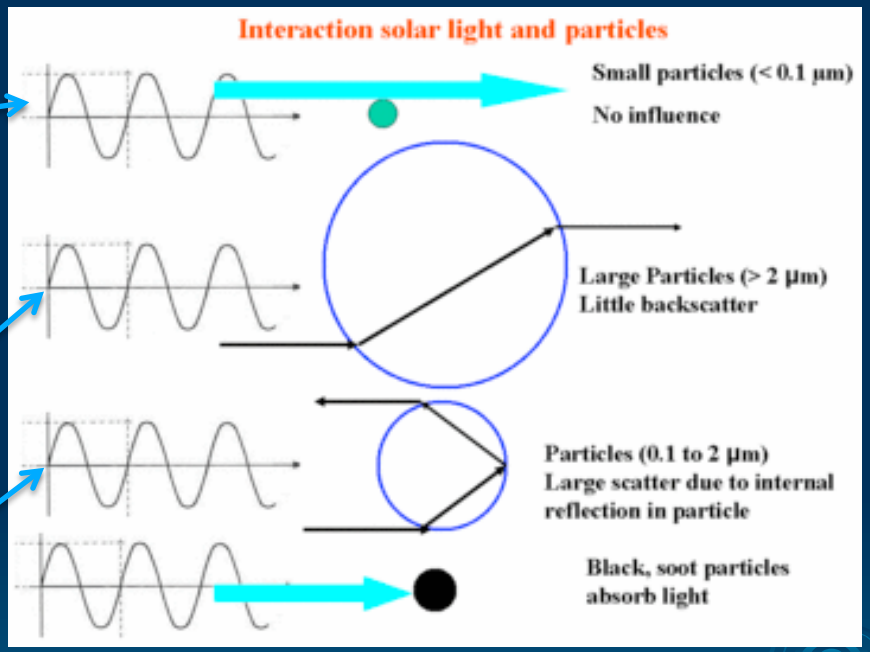
Aerosol-Radiation-Cloud-Precipitation Interactions

- ✓ It is uncertain whether aerosols have an overall negative/ positive radiative forcing, though it is most likely negative (IPCC, 2007)
- ✓ Aerosols have several effects on climate
  - ✓ Direct effect, Semi-Direct effect, Indirect effect



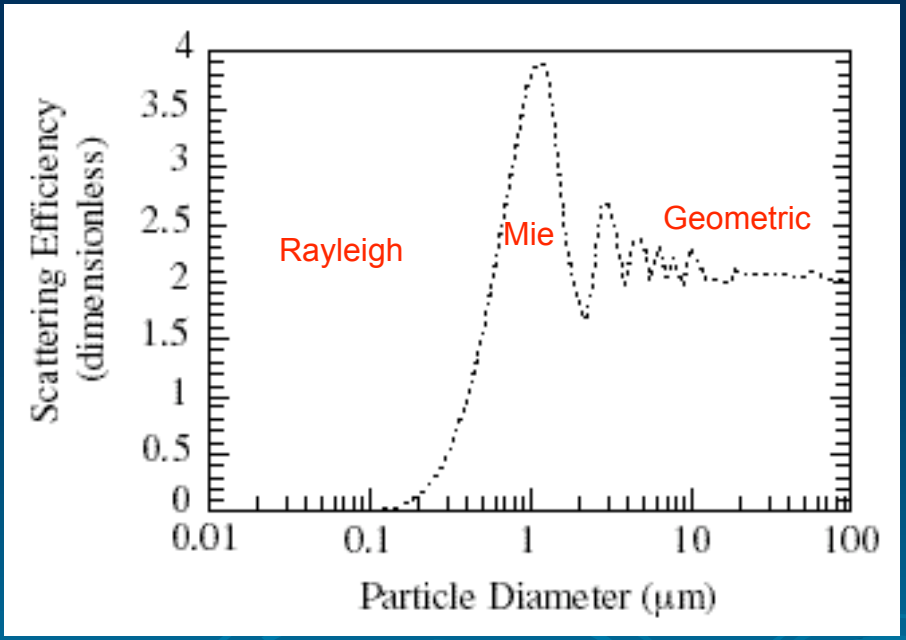
Aerosol Direct Effect

- ✓ Aerosols interact directly with radiation either through scattering or absorption
  - ✓ Rayleigh scattering: particles are smaller than the wavelength of incident light (<0.1 mm for visible)
  - ✓ Geometric scattering: particles are large compared to the wavelength
  - ✓ Mie scattering: particles are about the same size as the wavelength



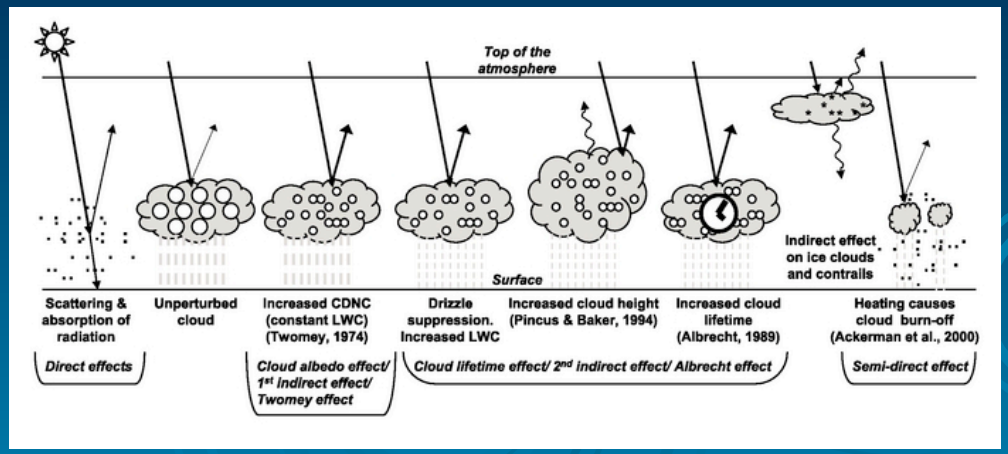
Aerosol Direct Effect

✓ Most aerosol constituents are non-absorbing and lead to a negative radiative forcing by scattering shortwave radiation back to space (the direct effect)



Aerosol Semi-Direct Effect

- ✓ Aerosols that are highly absorbing of solar radiation, such as black carbon, may reduce cloud cover and liquid water content by heating the cloud and the environment within which the cloud forms
- ✓ This is known as the semi-direct effect
- ✓ The semi-direct aerosol effect may have a significant warming impact on climate by "burning off" low clouds that scatter solar radiation back to space, but little impact on outgoing longwave radiation



Aerosol Semi-Direct Effect

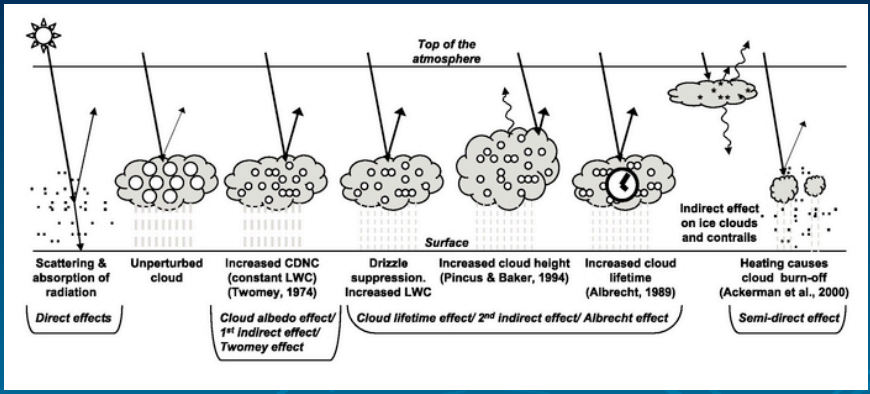
- ✓ The semi-direct effect of absorbing aerosols (black carbon) produced by human activity may have a significant impact on climate change
- ✓ However, local forcings depend highly on cloud conditions and the distribution of absorbing aerosols
- ✓ At present, the semi-direct effect is poorly understood, and it is unclear how important it is in comparison to the direct and indirect effects
- ✓ The warming of the semi-direct effect may offset the cooling of the direct and indirect effects, but more research needs to be done

Aerosol Indirect Effects

- ✓ Aerosols have an indirect effect on climate by altering the microphysical and radiative properties of clouds
- ✓ The two major aerosol effects on clouds are the Twomey or first aerosol indirect effect and the Lifetime or second aerosol indirect effect
- ✓ There are other effects which operate mostly on mixed-phase clouds (thermodynamic, riming, glaciation effects)

Aerosol First Indirect Effect

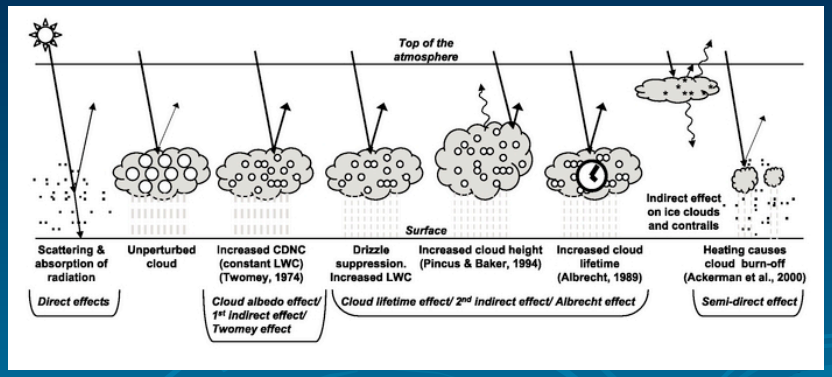
- ✓ The albedo, first indirect effect or Twomey effect, is the result of the ability of some aerosols to act as cloud condensation nuclei (CCNs) (Twomey 1977)
- ✓ With the increased number of CCNs in a cloud, more cloud droplets form, but they are smaller in size (compete against same amount of moisture with larger number of CCNs)
- ✓ This makes a cloud brighter in appearance, and will reflect more incoming solar radiation away from the Earth's surface than a "clean" cloud, resulting in cooling



Twomey, S.A., 1977: The influence of pollution on the shortwave albedo of clouds. J. Atmos. Sci., 34, 1149–1152.

Aerosol Second Indirect Effect

- ✓ The lifetime or second indirect effect is also the result of aerosols acting as cloud condensation nuclei
- ✓ In addition to making the cloud brighter, the formation of small cloud droplets inhibits precipitation (Albrecht 1989) (i.e., delayed precipitation)
- ✓ If precipitation takes longer, the amount of time that the cloud exists will be longer (i.e., increased cloud lifetime)
- ✓ This will reduce the amount of solar radiation reaching the surface

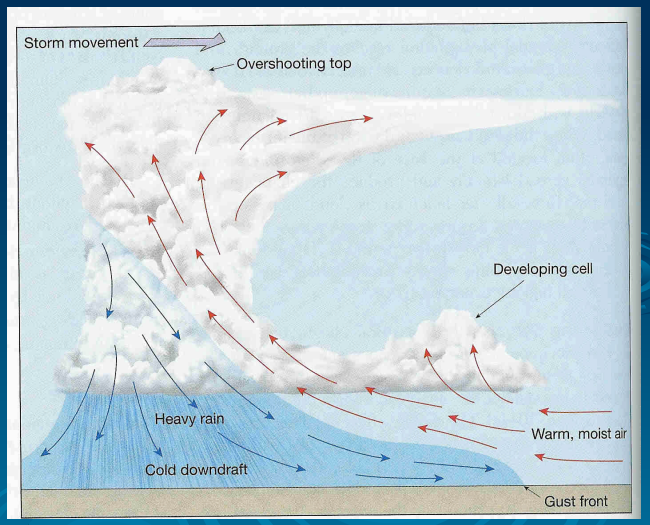


Albrecht, B., 1989: Aerosols, cloud microphysics and fractional cloudiness. Science, 245, 1227–1230.

Mixed-Phase Effects

- ✓ Mixed-phase clouds = cloud droplets + ice crystals
- ✓ The glaciation effect operates on mixed-phase clouds, where aerosols can act as ice nuclei (IN) between 0 and -35 Celsius degrees (increased IN)
- ✓ This increases precipitation efficiency, leading to shorter cloud lifetimes and more shortwave radiation at the surface
- ✓ The thermodynamic effect postulates that aerosols result in smaller cloud droplet sizes which delay the onset of freezing in convective clouds, resulting in colder temperatures but an uncertain effect on radiation



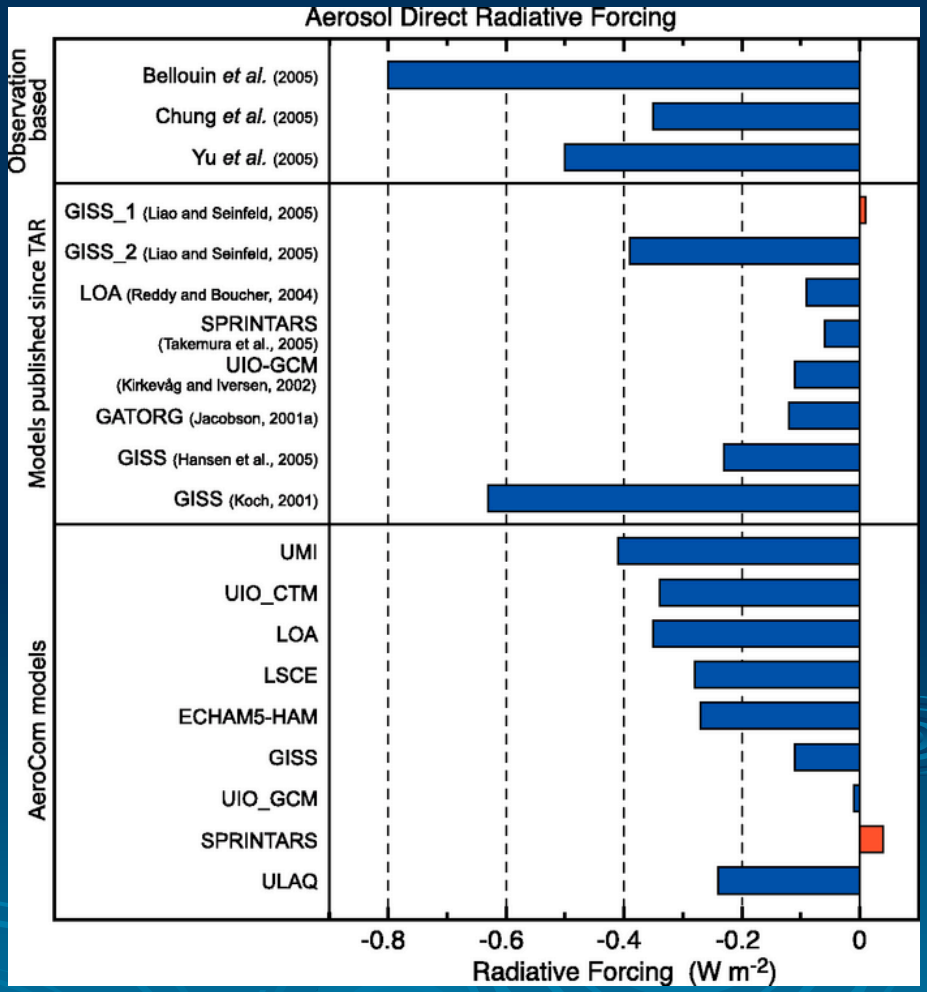


Summary of Aerosol Effects

effect	Cloud Type	Process	Sign of Change in Radiation
Cloud Albedo Effect (1st indirect effect)	All	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Surface: Negative TOA: Negative
Cloud Lifetime Effect (2nd indirect effect)	All	Smaller cloud particles decrease the precipitation efficiency thereby presumably prolonging cloud lifetime	Surface: Negative TOA: Negative
Semi-Direct Effect	All	Absorption of solar radiation by absorbing aerosols affects static stability and the surface energy budget, and may lead to an evaporation of cloud particles	Surface: Negative TOA: Positive
Glaciation Effect	Mixed Phase	An increase in IN increases the precipitation efficiency	Surface: Negative TOA: Negative
Thermodynamic Effect	Mixed Phase	Smaller cloud droplets delay freezing causing super-cooled clouds to extend to colder temperatures	Surface: Unknown TOA: Unknown

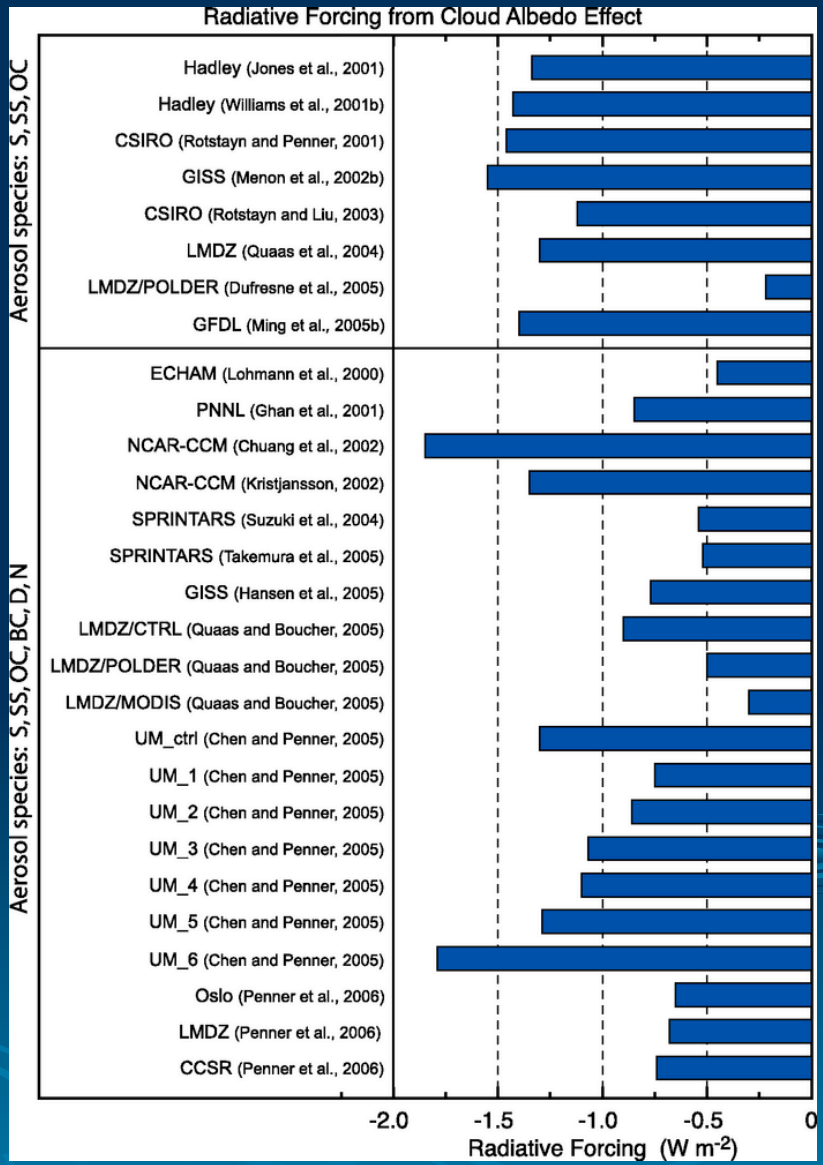
Estimates of Direct Forcing

✓ Current best estimate from IPCC between -0.2 and -0.4 W/m^2



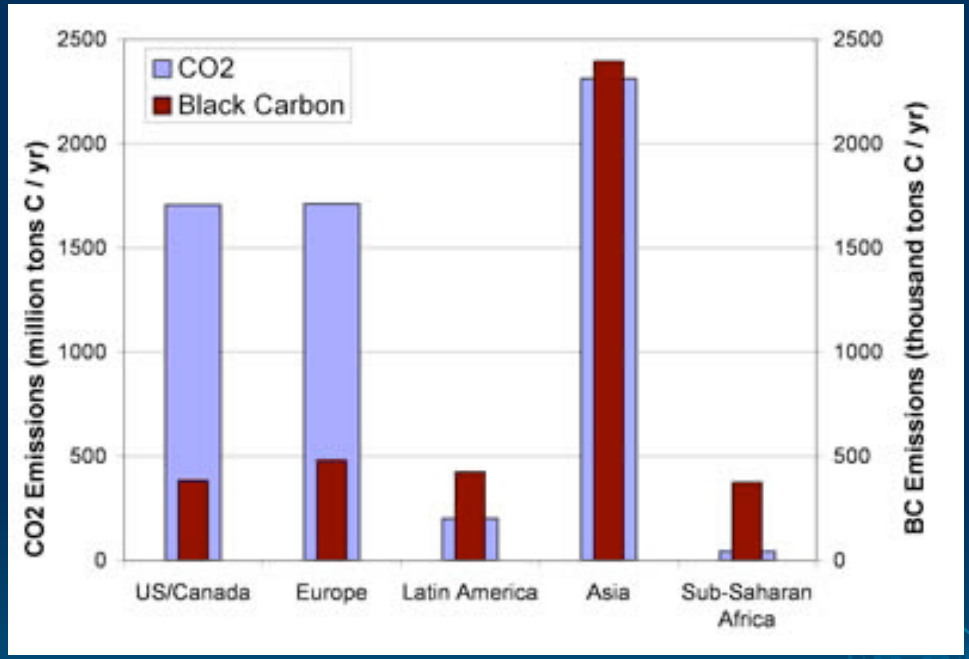
Estimates of Indirect Forcing

- ✓ IPCC Estimates vary between -0.22 and -1.85 W/m^2
- ✓ Results consistent around -1.37 W/m^2 where mainly sulphate is considered, with more spread as more species are included

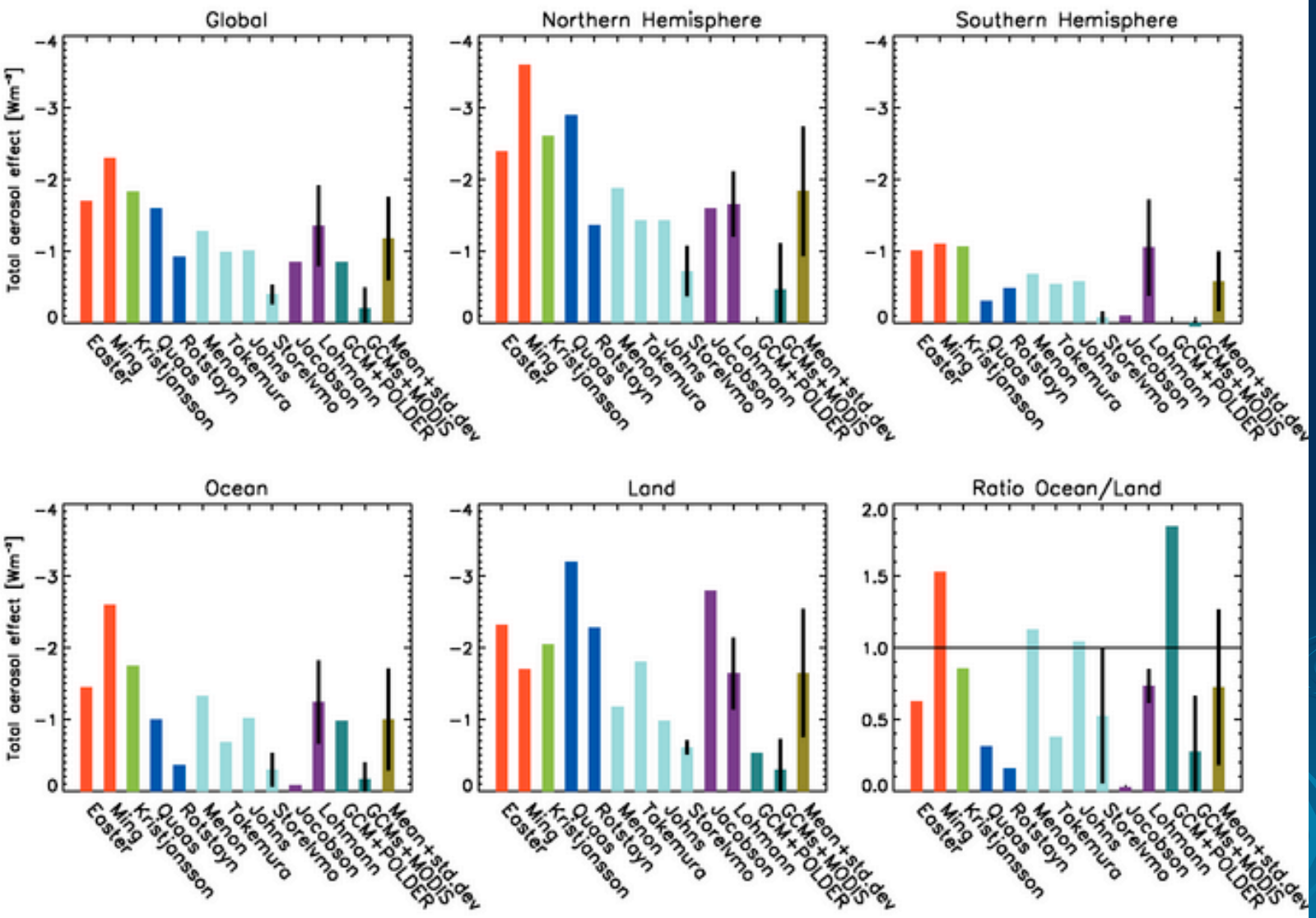


Estimates of Semi-Direct Forcing

- ✓ Estimates of semi-direct forcing are rare, making it a vital area of study
- ✓ The semi-direct effect may have a large impact on forcing, especially in areas of the developing world



Estimates of Total Forcing (TOA)



Sources of Uncertainty

- ✓ All Effects Uncertainty
  - ✓ Aerosol emission levels
    - ✓ Location of emissions
    - ✓ Amount of emissions
  - ✓ Aerosol Size distributions
  - ✓ Aerosol Optical Properties
- ✓ Direct Effect Uncertainty
  - ✓ Although optical properties of sulfate are well understood, sulfates are often found in "composite" states, either internally or externally mixed with other aerosol types, thereby changing said optical properties

Sources of Uncertainty

- Indirect Effects Uncertainty
  - Uncertainty in relationship between aerosol concentration and CCN
  - Global Climate Models (GCMs) have too coarse a resolution to accurately depict relevant updraft velocities (and therefore cloud formation and aerosol activation)
  - Inability of GCMs to produce super-cooled clouds or handle non-spherical IN shapes
- Semi-Direct Effect Uncertainty
  - Vertical position of black carbon in relation to clouds

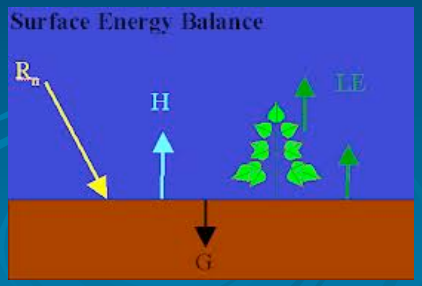
Current Science Goals

1) To assess the indirect and semi-direct aerosol effects on clouds & radiative properties (particularly on Arctic clouds).

Rationale: the indirect and semi-direct aerosol effects on climate change remain subject to a large uncertainty (cf., IPCC Assessment Report), and hence realistic future predictions of climate change requires a better understanding of the indirect aerosol effects. Particularly the Arctic region plays a very important role in our weather and climate system.

2) To assess the impact of aerosol-radiation-cloud-precipitation interactions on the surface energy balance.

Rationale: summertime Arctic sea ice has decreased dramatically in recent years. The Arctic has been projected to be ice-free during the summer within the near future (2007 IPCC Assessment Report). The role of aerosol-cloud-precipitation interactions in the loss of sea ice is not well understood.



MASON CAREER FAIR 25th

DAY 1: October 3, 11am-4pm (STEM Employers)
DAY 2: October 4, 11am-4pm (General Employers)

***Go to careers.gmu.edu and click on "Prepare for the Fair" for details/employer research!**

Sample of Science Employers Attending:

DAY 1:

- INOVA Alexandria
- ESRI
- National Geospatial-Intelligence
- SAIC
- U.S. Army Healthcare Recruiting
- U.S. Patent and Trademark Office

DAY 2:

- Center for Autism and Related Disorders, Inc.
- NASA Goddard Space Flight Center
- National Institute of Allergy and Infectious Diseases (NIH/NIAID)
- National Institutes Of Health
- Naval Research Laboratory
- U.S. Central Intelligence Agency

Aerosol Properties

Let's look at 3 kinds of properties that are important to understand about aerosols

Physical Properties

Optical Properties

These two types of properties are very closely linked in remote sensing because we infer the Physical properties from Optical measurements

Chemical Properties

Because we measure the entire column our properties represent the mean particle characteristics

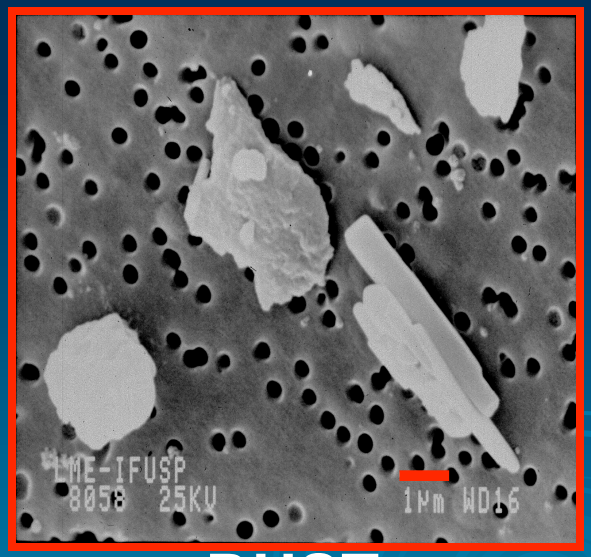
Aerosol Properties

- ✓ Aerosol Index (AI)
- ✓ Aerosol Extinction Optical Depth (AOD)
- ✓ Single Scattering Albedo (SSA)
- ✓ Aerosol Absorption Optical Depth (AAOD)

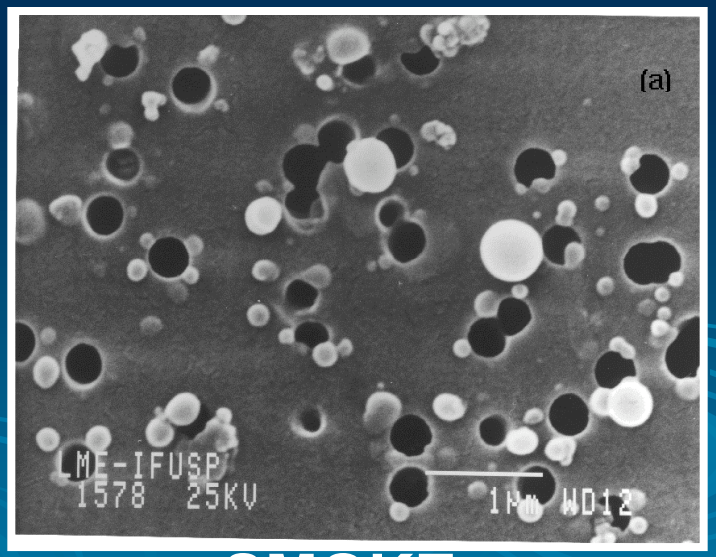
Aerosol Properties

- ✓ Aerosol Index (AI):
  - ✓ Qualitative Indicator of the presence of absorbing aerosols (e.g., smoke, desert dust, volcanic ash)
  - ✓ It is calculated using observations at two wavelengths in the range 330-390 nm.

AI > 0 for an absorbing aerosol such as (dust & smoke)
AI < 0 for a scattering aerosol and clouds (pure scattering)



DUST



SMOKE

Aerosol Properties

- Aerosol Extinction Optical Depth (AOD):
  - A measure of the aerosol capacity to extinguish radiation by scattering and absorption.
  - It is related to the total column amount of aerosol particles in the atmosphere.

Aerosol Properties

- ✓ Single Scattering Albedo (SSA):
  - A measure of the fractional extinction due to scattering of incident solar radiation.
  - Varies between
    - 0 (all absorption, no scattering) and
    - 1 (all scattering, no absorption)
  - Typical variability range (0.6 to 1.0)

- ✓ Aerosol Absorption Optical Depth (AAOD):
  - The actual optical depth resulting from the absorption process.
  - It is easily calculated as

$$AAOD = AOD \times (1.0 - SSA)$$

Aerosol Properties (Aerosol Index)

- ✓ Aerosol index (AI), it is an index that detects the presence of UV-absorbing aerosols such as dust and soot.
- ✓ Quantitatively, the aerosol index (AI) is defined to be

$$AI = 100 \log_{10} \left[\frac{I_{360}^{Meas}}{I_{360}^{Calc}} \right]$$

Where

I_{360}^{Meas} = *the measured* 360 *nm radiance*

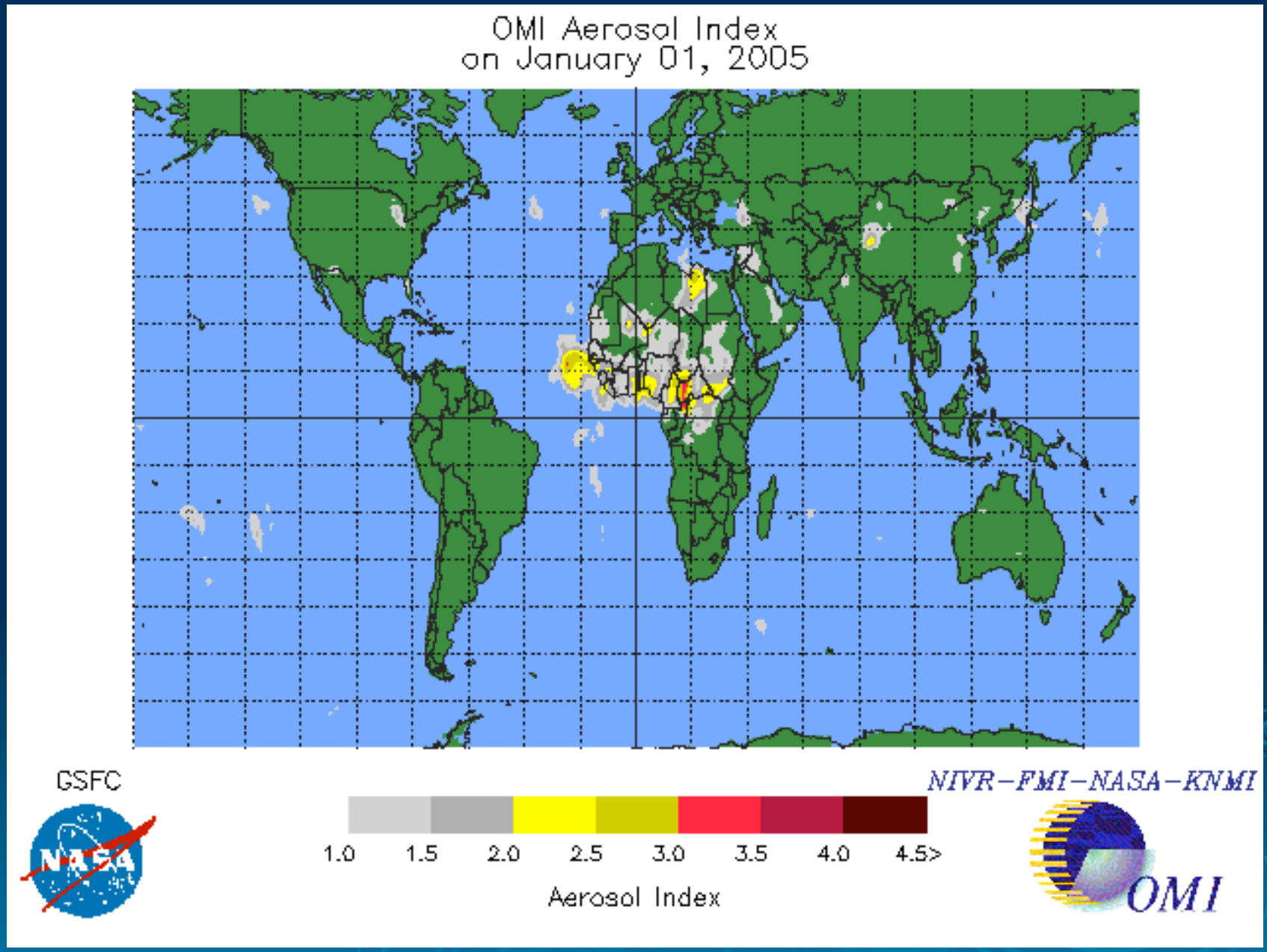
I_{360}^{Calc} = *the measured* 360 *nm radiance for a Rayleigh atmosphere*

Aerosol Properties (Aerosol Index)

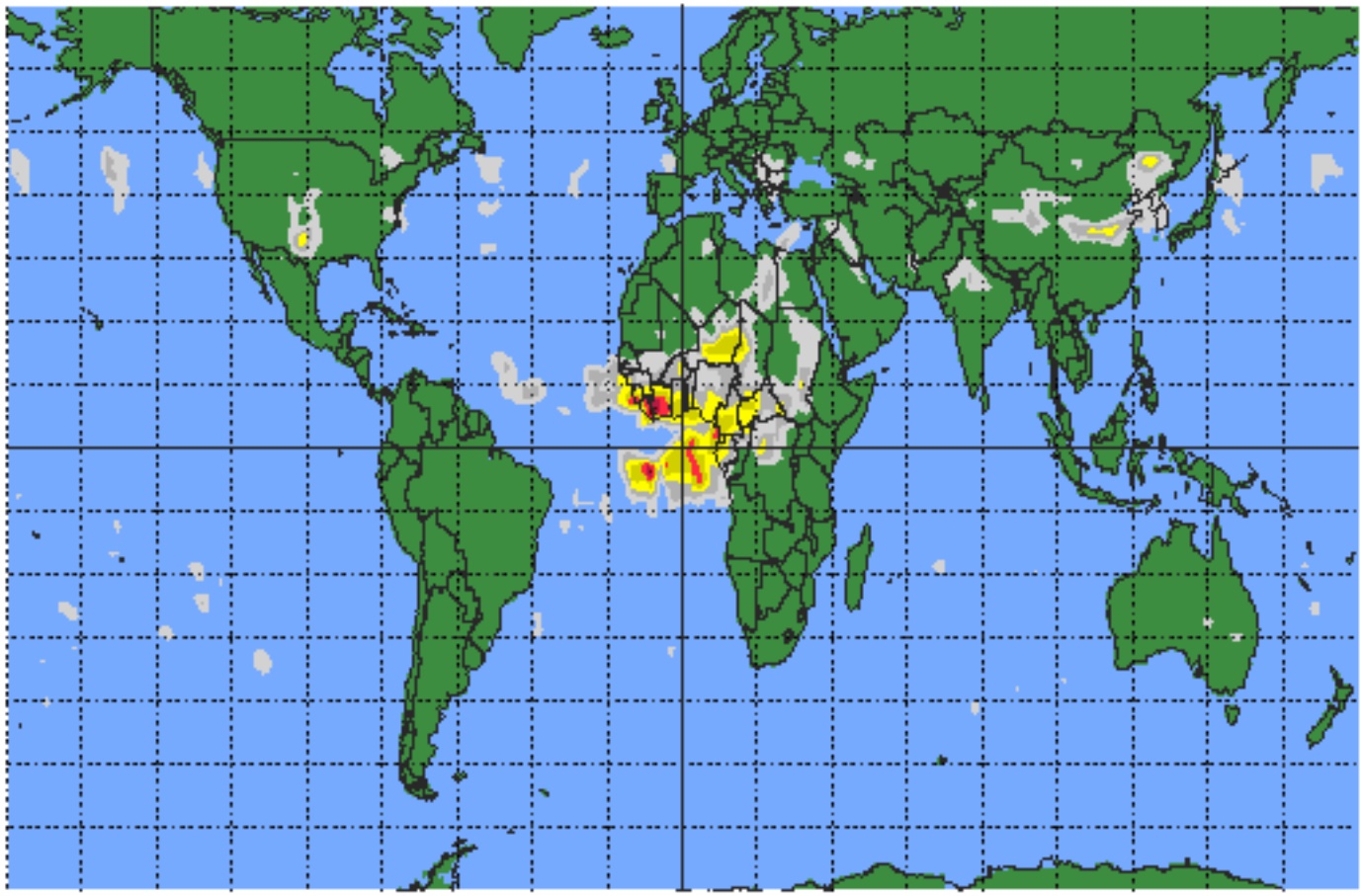
- ✓ Positive values for UV-absorbing particles: desert dust, smoke, volcanic ash
- ✓ Negative values for small size (less than 0.2 microns) non-absorbing particles. In practice, it is difficult to separate aerosol effects from other non-aerosol effects that also produce negative AI values.
- ✓ Aerosol Index yields near-zero values for clouds.
- ✓ Magnitude of positive AI depends mainly on aerosol absorption optical depth and height of aerosol layer. Also depends on aerosol microphysical properties.
- ✓ Detects absorbing aerosols over all surface types: ocean, vegetated surfaces, deserts, snow/ice, etc

Aerosol Properties (Aerosol Index)

- ✓ Detects absorbing aerosols under partial cloudiness conditions and above clouds
- ✓ Aerosol Index is insensitive to carbonaceous aerosols (smoke) below ~ 2km
- ✓ Larger sensitivity to low altitude desert aerosols (~ 0.5 km)
- ✓ Aerosol Index signal meaningful for values larger than 0.5
- ✓ Direct conversion of AI to any physically meaningful parameter is not possible because of multiple dependecies (AOD, SSA, height, etc).


OMI Aerosol Index
on January 01, 2005
GSFC
NIVR–FMI–NASA–KNMI
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5>
Aerosol Index
OMI

OMI Aerosol Index
on January 01, 2006



GSFC

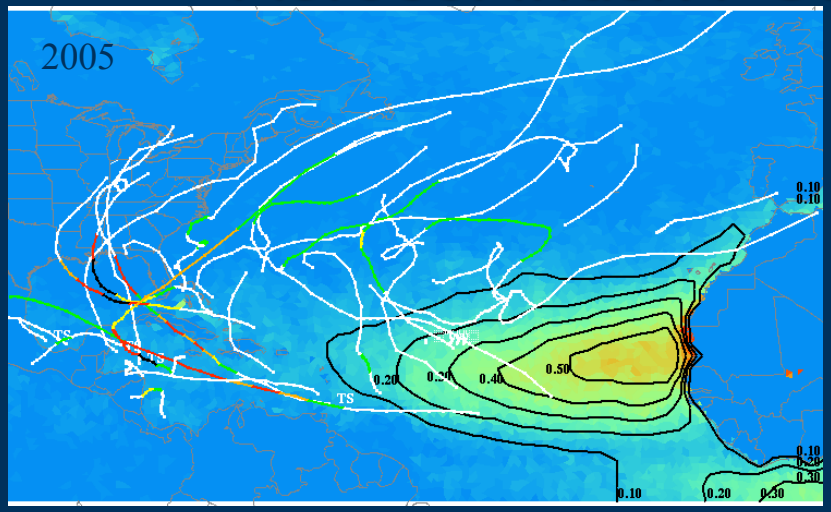
NIVR–FMI–NASA–KNMI

1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5>

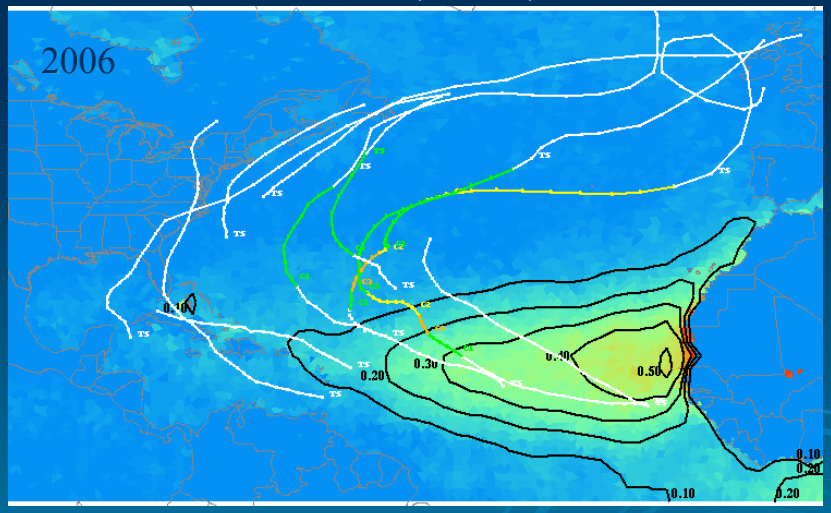
Aerosol Index

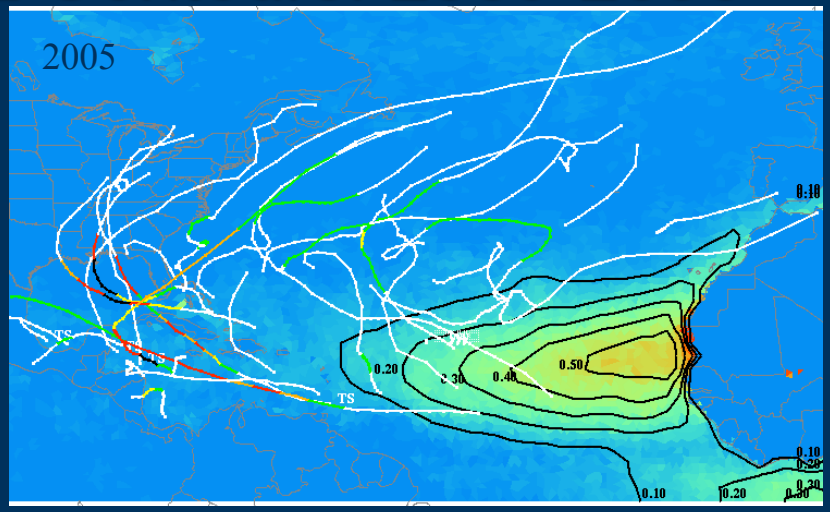
OMI

Aerosol Index POE Contours: 2005-2006

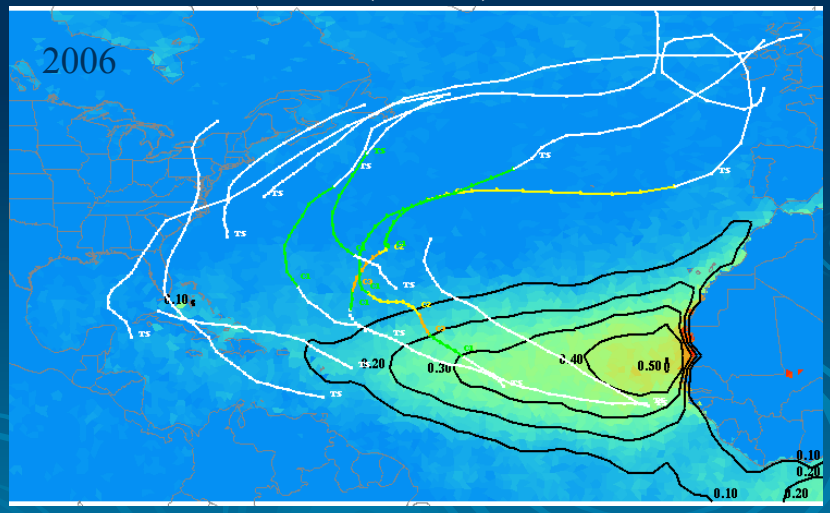


POE (AI=0.0)

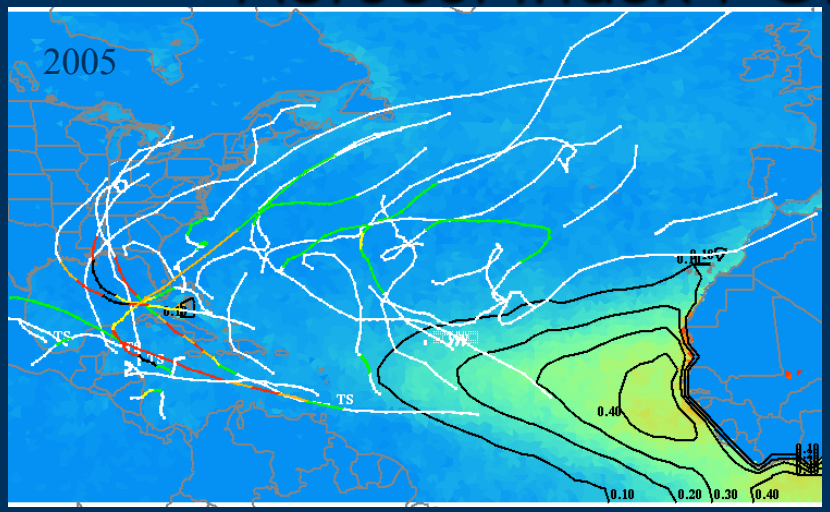




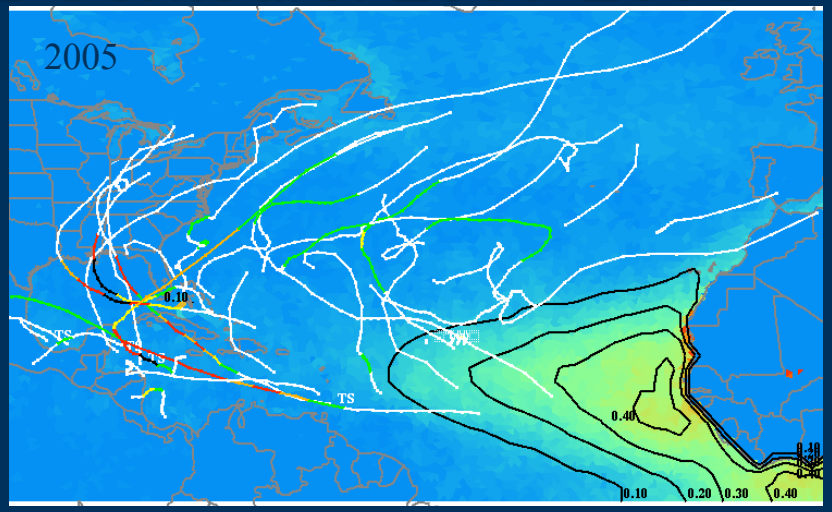
POE (AI=1.0)



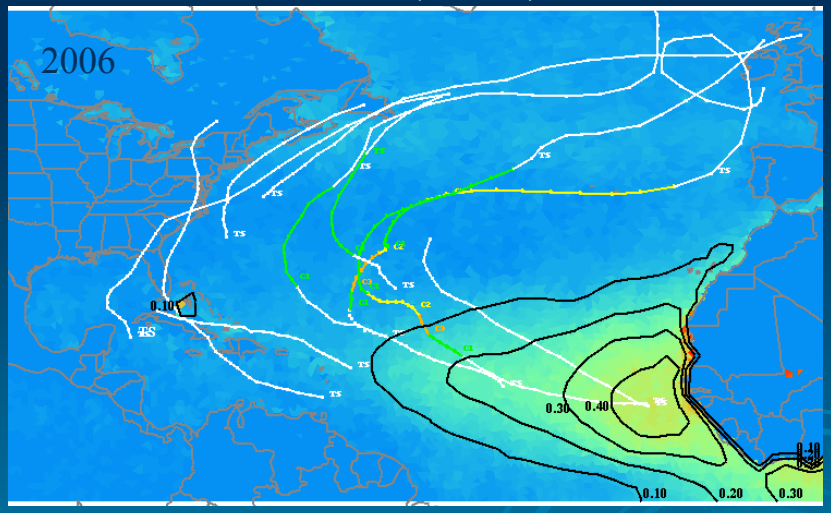
Aerosol Index POE Contours: 2005-2006

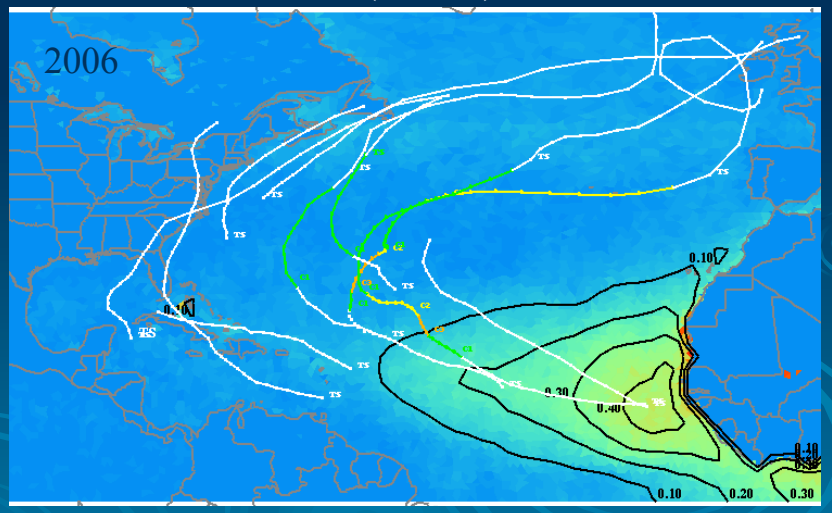


POE (AI=0.0)

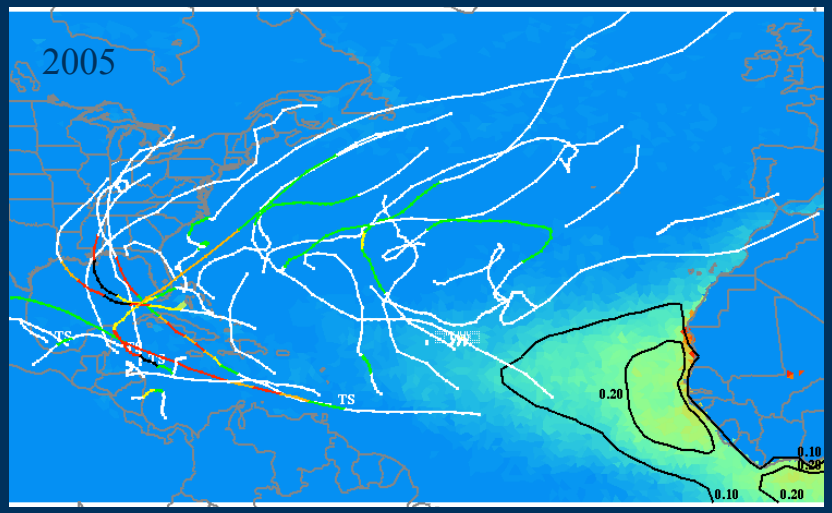


POE (AI=1.0)

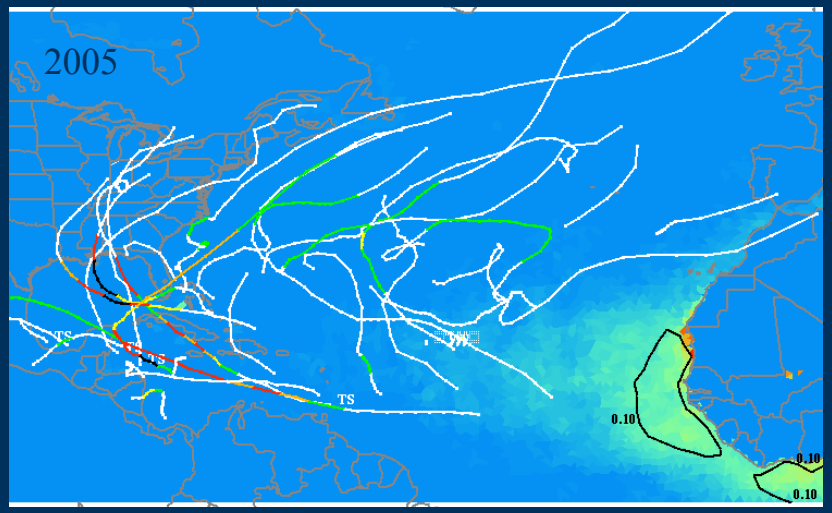




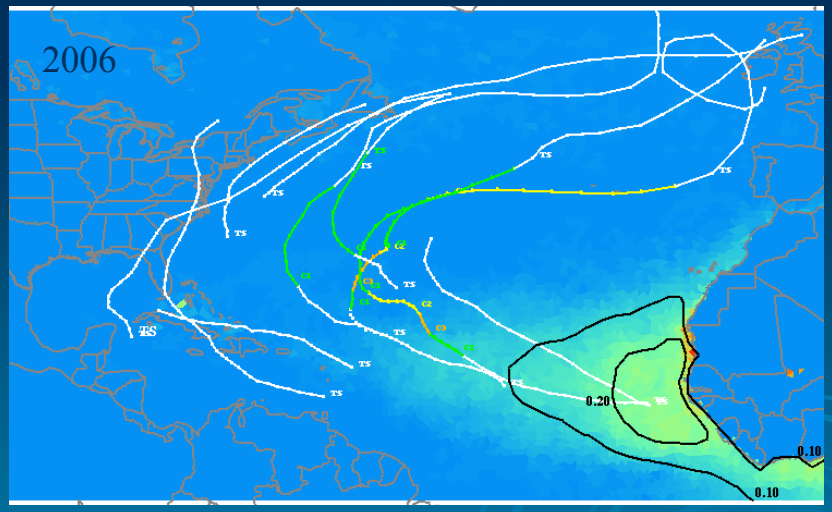
Aerosol Index POE Contours: 2005-2006

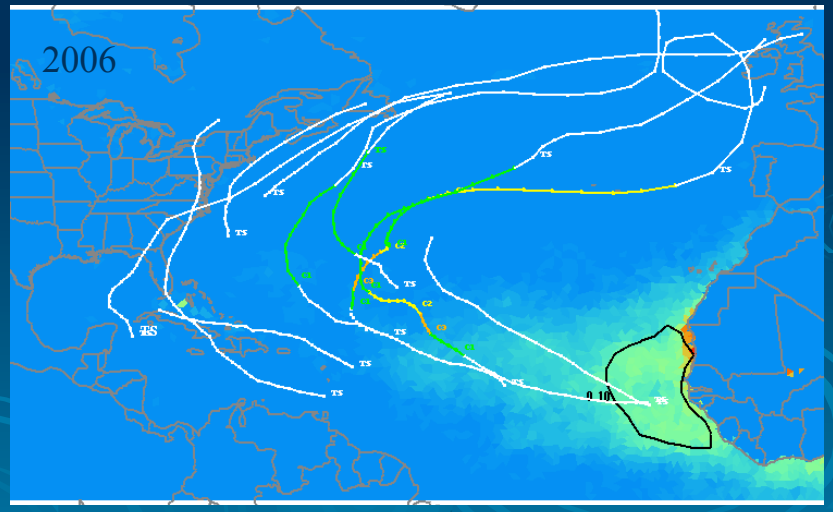


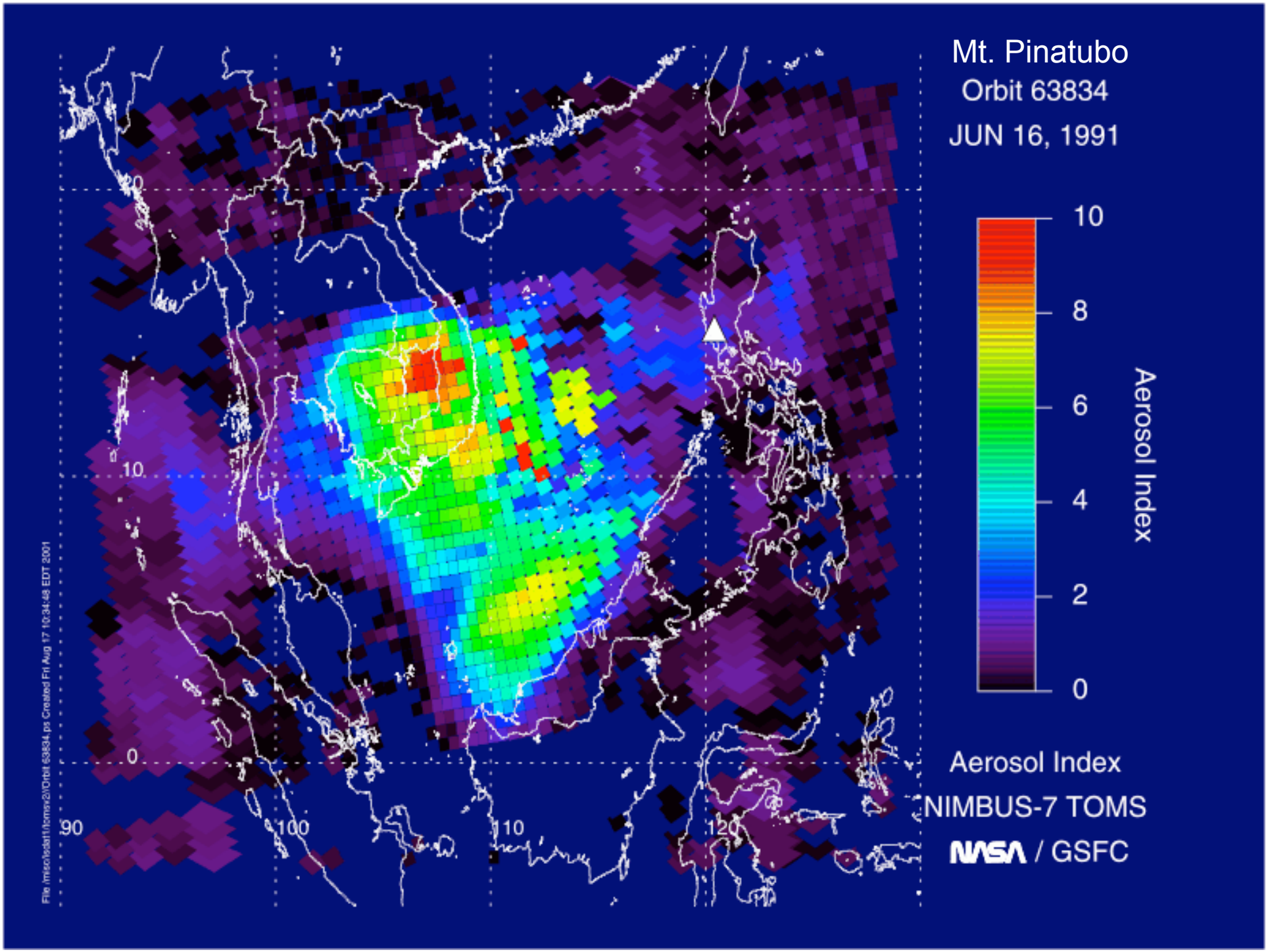
POE (AI=1.5)

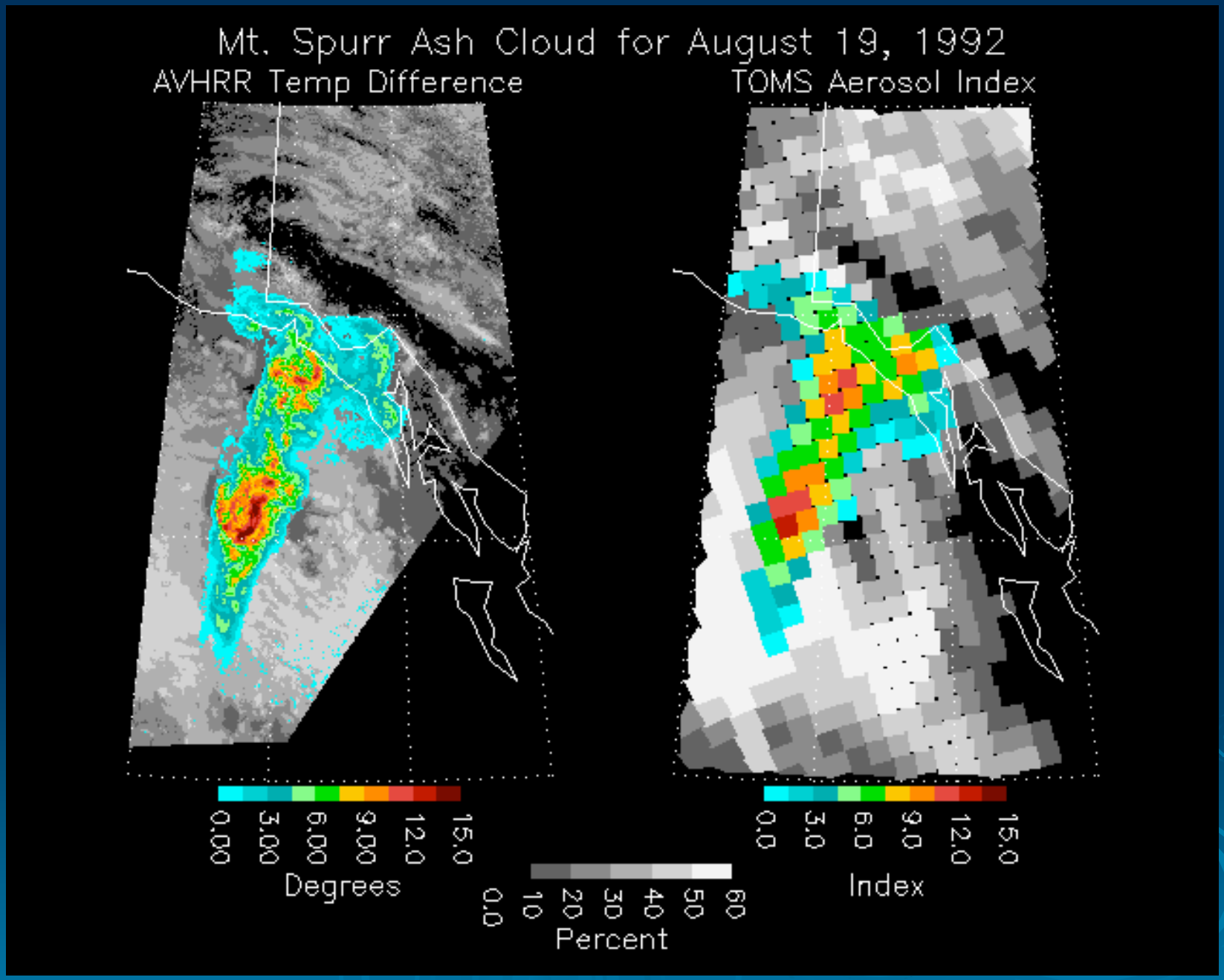


POE (AI=2.0)






Mt. Pinatubo
Orbit 63834
JUN 16, 1991
10
8
6
4
2
0
Aerosol Index
Aerosol Index
NIMBUS-7 TOMS
NASA / GSFC
10
0
90
100
110
120


Mt. Spurr Ash Cloud for August 19, 1992
AVHRR Temp Difference
TOMS Aerosol Index
0.00
3.00
6.00
9.00
12.0
15.0
Degrees
0.0
10
20
30
40
50
60
Percent
0.0
3.0
6.0
9.0
12.0
15.0
Index

Aerosol Properties (Aerosol Optical Depth)

Aerosol Amount

- AOD - Aerosol Optical Depth
- AOT - Aerosol Optical Thickness

These optical measurements of light extinction are used to represent aerosol amount in the entire column of the atmosphere.

Aerosol Properties (Aerosol Optical Depth)

- ✓ AOD is a unitless value of aerosol amount.
- ✓ Sample AOD values:

  0.02 - very clean isolated areas.
  0.2 – fairly clean urban area
  0.4 – somewhat polluted urban area
  0.6 – fairly polluted area
  1.5 – heavy biomass burning or dust event

Moderate AOD ~0.40
Near Mt. Abu, India



Heavy AOD
Mexico City

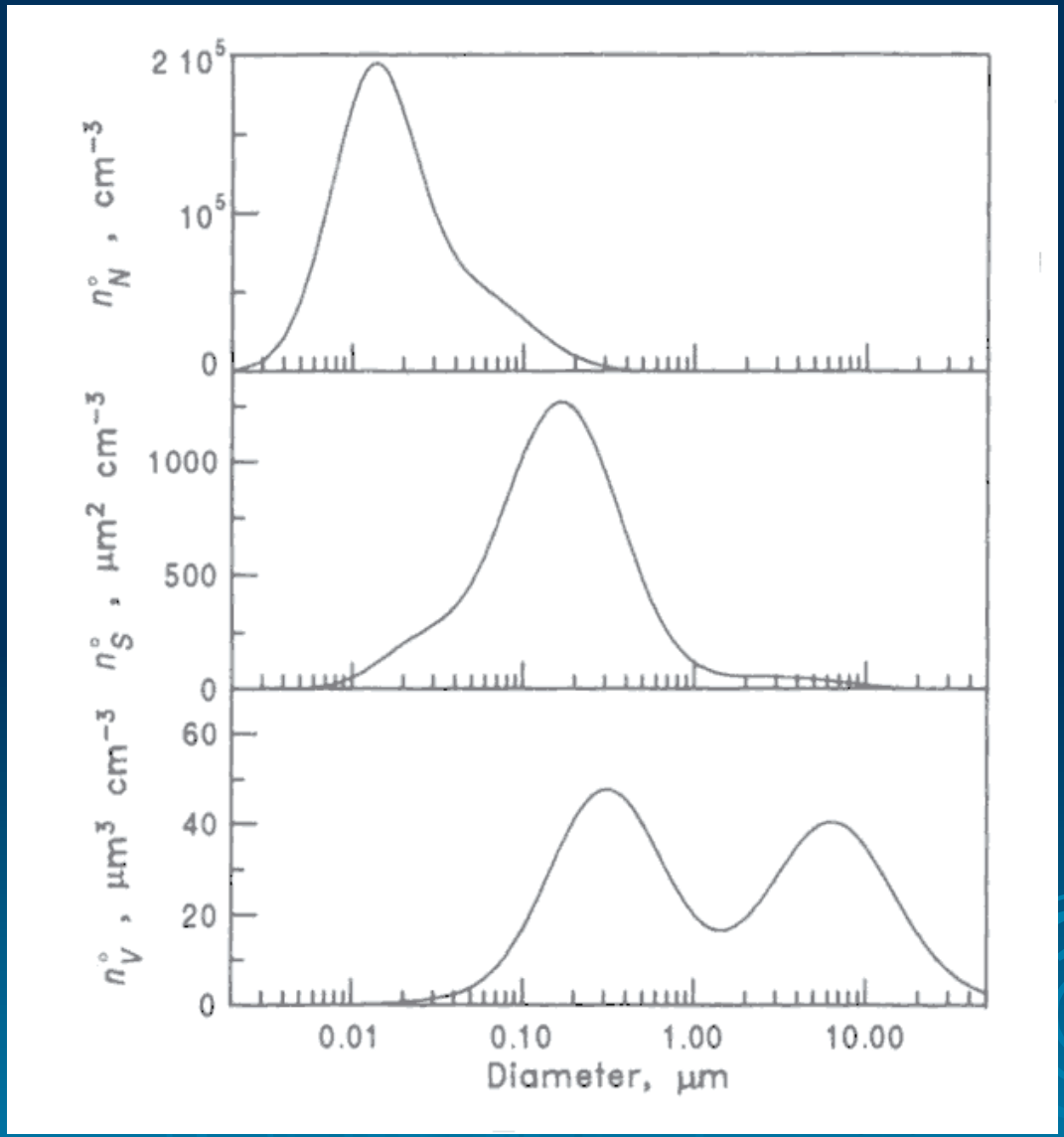


Physical Properties

Particle Size Distribution - There is an assumption, based on many years of measurements, that aerosols in the optically active size ranges are best represented as a bimodal distribution. The aerosol size distribution can be represented as a volume or number distribution.

The mode representing the small (fine mode) aerosol has a size distribution centered on radii between 0.1 and 0.25 microns.
The mode representing the large (coarse mode) aerosol has a size distribution centered on radii between 1 and 2.5 microns.

Size Distribution



Why is Size Distribution Important?

A result of a combustion process

Smoke

(Biomass Burning) > Small

Industrial Pollution

NATURAL - A result of a wind or erosion process

Sea Salt

Dust > Large

Physical Properties

- $PM_{2.5}$ - particles of less than 2.5 μm aerodynamic diameter. These can penetrate deeply into the lungs

$PM_{2.5}$ concentration at ground level is an important parameter for air quality studies.

- CCN (Cloud Condensation Nuclei) Concentration.

These are particles that act as condensation surfaces and encourage water droplet formation within clouds.

Single Scattering Albedo

Light Scattering
Light Absorption

> These quantities are difficult to separate and measure individually

Extinction = Scattering + Absorption

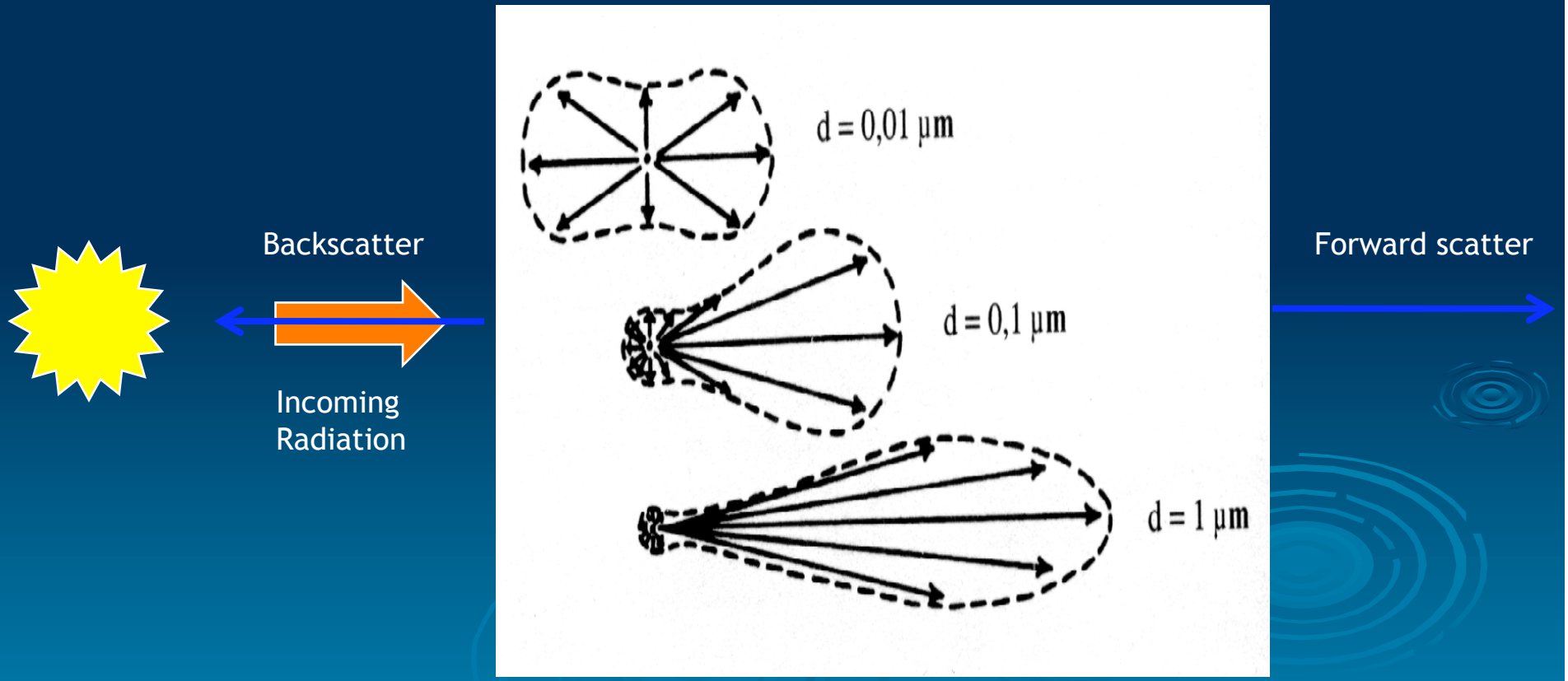
Single Scattering Albedo - a measure of how absorbing or scattering we consider the mass of aerosol particles.

$$\omega_o = \frac{\text{AOT scatter}}{\text{AOT scatter} + \text{AOT absorption}}$$

Values of .85 are considered very absorbing
Values of .95 are considered very non-absorbing

Single Scattering Albedo

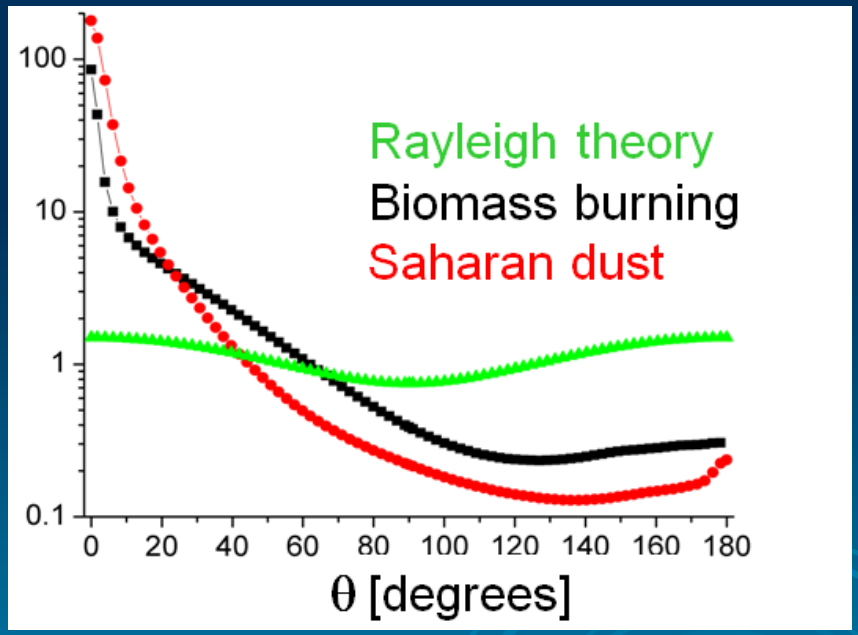
The directional light scattering due to the aerosol particles

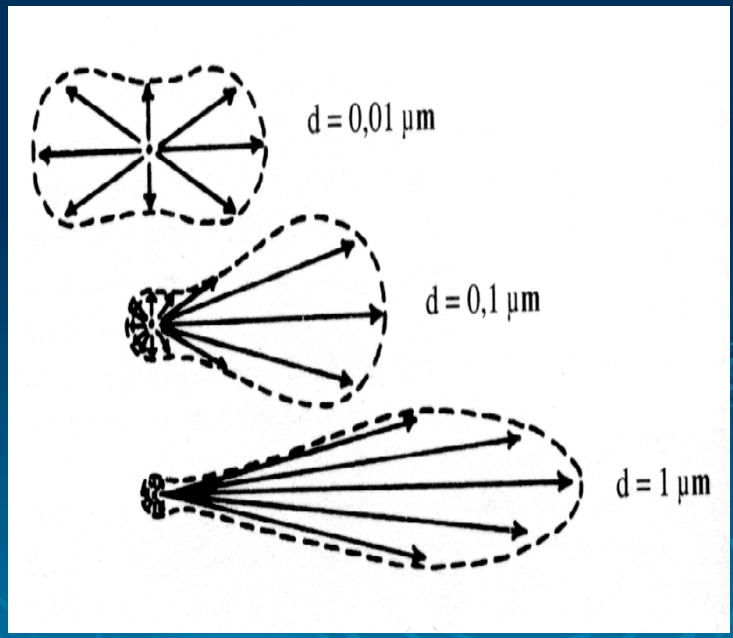


Single Scattering Albedo

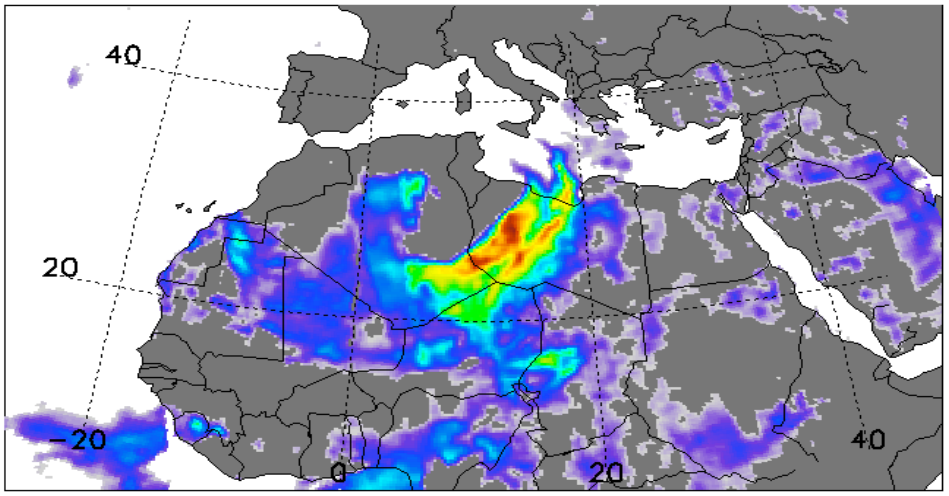
The scattering phase function:

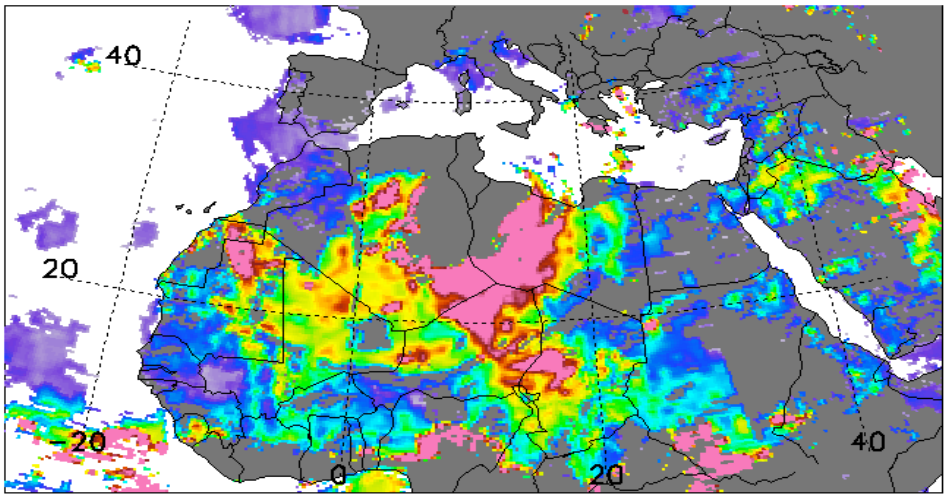
- relative angular distribution of scattered light
- heavily depends on the size and shape of aerosol particles





OMI Retrieved Dust Properties (March 9-2007)



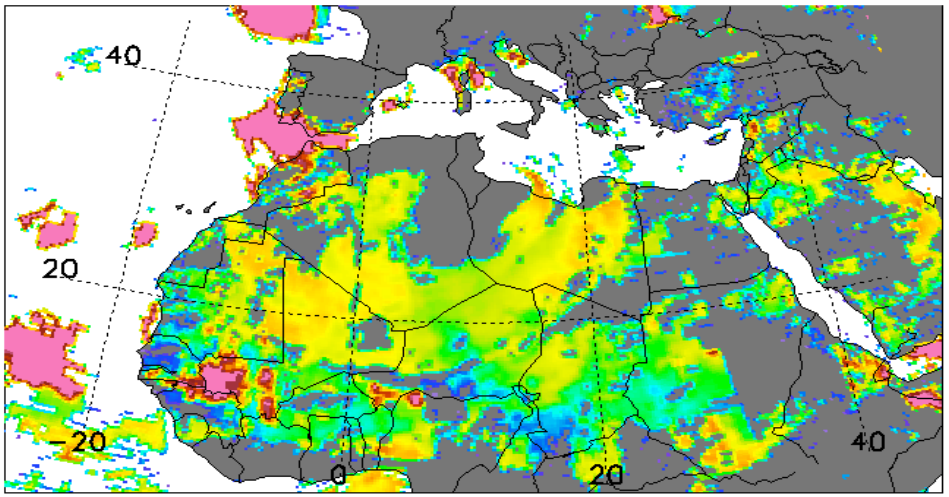


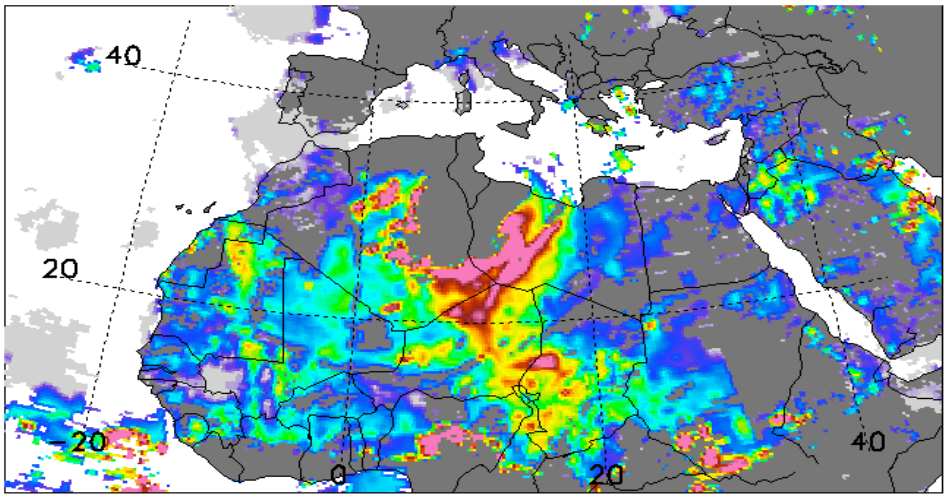
Aerosol Index

1.0 2.5 4.0 5.5

Aerosol Optical Depth

0.0 0.4 0.8 1.2 1.6 2.0





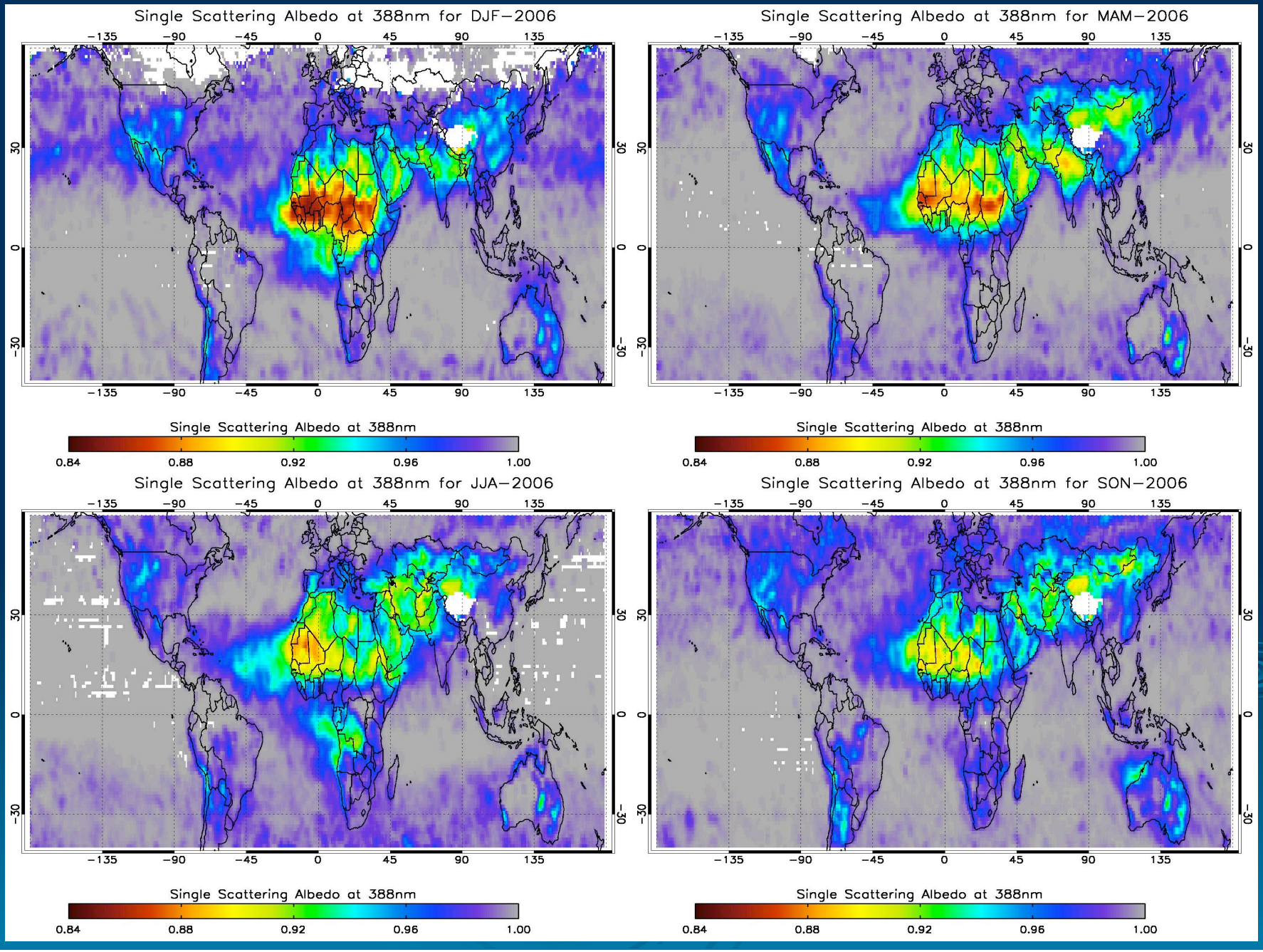
Single Scattering Albedo

0.75 0.80 0.85 0.90 0.95 1.00

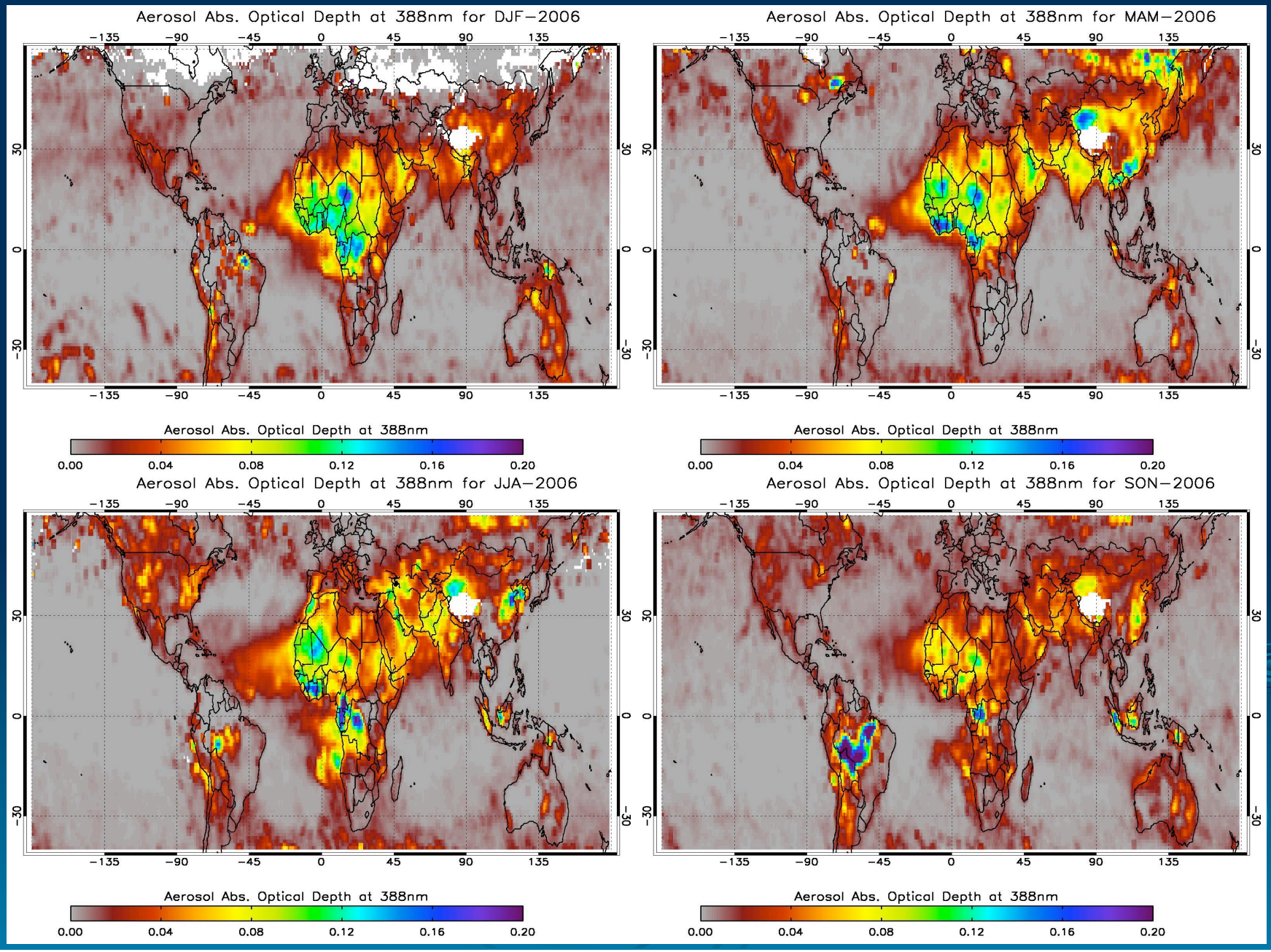
Aerosol Abs. Optical Depth

0.0 0.1 0.2 0.3

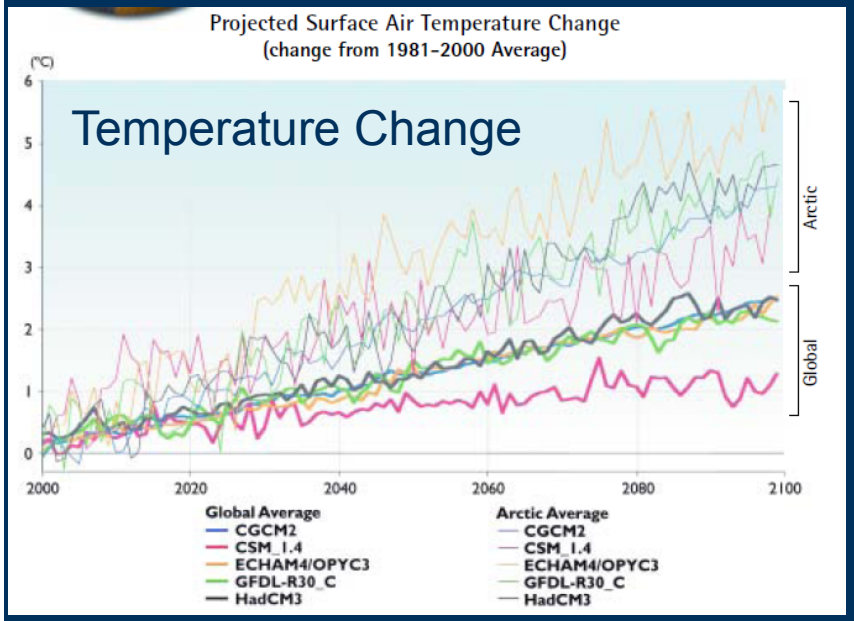
Single Scattering Albedo Global Climatology



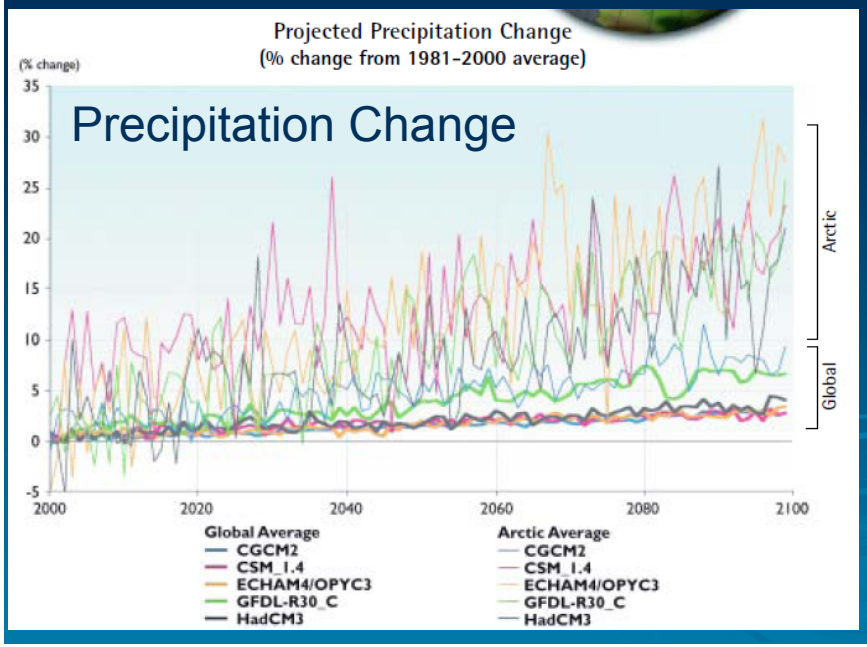
Global Climatology Aerosol Absorption Optical Depth



Aerosol Effects



At latitudes poleward of 40° in winter, positive correlations between Temperature and Precipitation dominate as the water-holding capacity of the atmosphere limits precipitation amounts in cold conditions and warm air advection in cyclonic storms is accompanied by precipitation (IPCC Fourth Assessment Report: Climate Change 2007)



Projected Changes in Arctic Precipitation

Global warming will lead to increased evaporation and in turn to increased precipitation (this is already occurring). Over the Arctic as a whole, annual total precipitation is projected to increase by roughly 20% by the end of this century, with most of the increase coming as rain. During the summer, precipitation over northern North America and Chukotka, Russia is projected to increase, while summer rainfall in Scandinavia is projected to decrease. During winter, precipitation for virtually all land areas (except southern Greenland) is projected to increase. The increase in arctic precipitation is projected to be most concentrated over coastal regions and in the winter and autumn; increases during these seasons are projected to exceed 30%.

ICIA (Arctic Climate Impact Assessment)

Summary

- ✓ Aerosols are one of the most important and certainly the most visible aspects of air pollution.
- ✓ The effects span the areas of health (1% increase in mortality per 10 μg m^{-3}); acid rain, visibility degradation, radiation, photochemistry, cloud microphysics changes (and thus climate changes), and the Antarctic ozone hole.