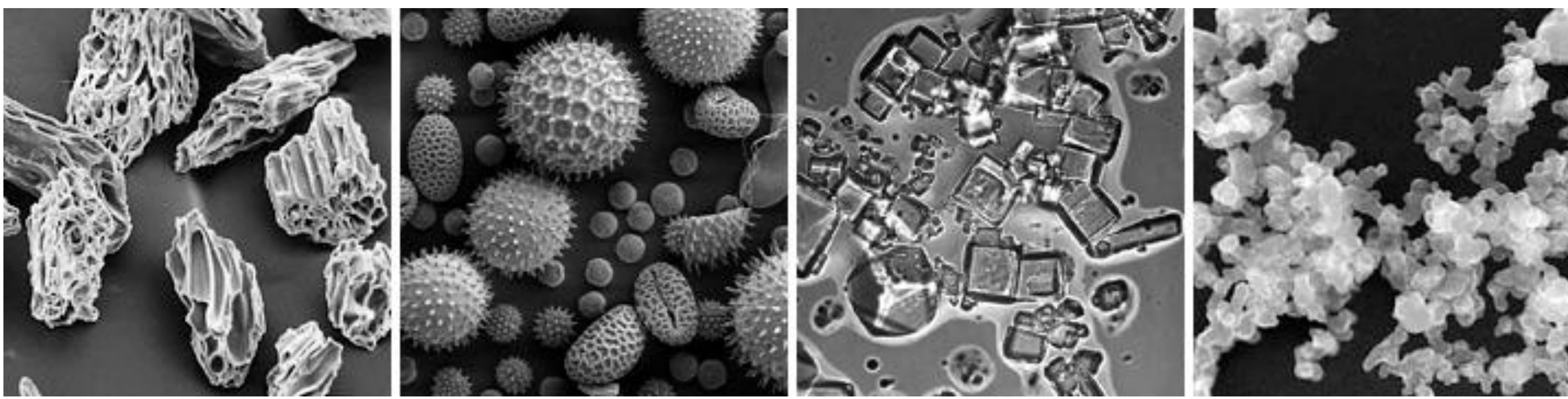
Experimental Atmospheric Chemistry (12.335/12.835)

Section 3, Lecture 1: Aerosols and Clouds

Karin Ardon-Dryer & Sarvesh Garimella

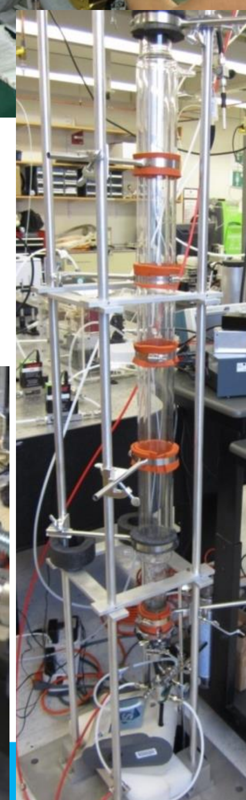
Thursday, Nov 6, 2014



http://earthobservatory.nasa.gov/Features/Aerosols/ Image courtesy of NASA.

A Little About Myself…

Image courtesy of NASA.



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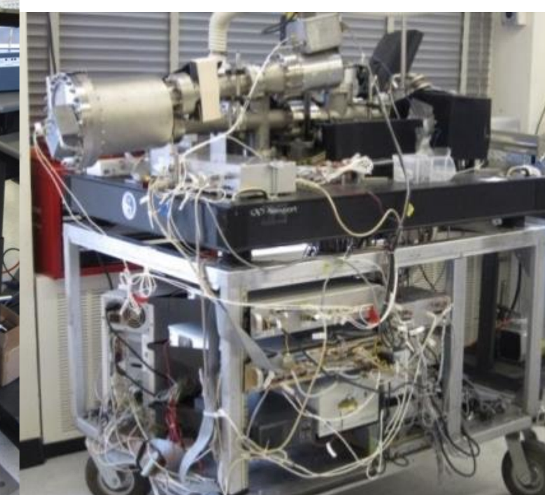


Today

1. Our schedule

2. The standard stuff (what you can expect from us, what we expect from you)

3. Definitions

4. Why you should care about aerosols and clouds : radiative effects, health, precipitation

5. Where do aerosols come from?

The Next 6 Weeks

Month	Date	Day	Topic	Where
Oct	6	Thu	Lecture 1 : Aerosols	517
Nov	13	Thu	Lab 1: Aerosols	1311
Nov	18	Tue	Lecture 2: Clouds	517
Nov	20	Thu	Lab 2: Clouds	1311
Nov	25	Tue	Lecture 3 : Atmospheric Particles and Clouds	517
Dec	2	Tue	Lab 3: The Atmosphere	1311
Dec	4	Thu	Lecture 4 : Odds & Ends + "Feedback"	517
Dec	9	Tue	Aerosol/Cloud Presentations	517
Dec	12	Fri	Reports Due (by 9am)	Online or -1413

Who We Are

Dr. Karin Ardon-Dryer

Communication Resources
Jane Connor

Teaching Assistant:
Sarvesh Garimella

Section Overview

(what you should expect from us)

This section will provide tools for understanding:

(1) Basic physics and chemistry of aerosols and cloud droplets

(2) The interaction of particles with water vapor including phase changes and droplet formation

(3) Basic operations of common measurements techniques including CPC, DMA, OPS and CCN (acronyms defined next time!). Keep in mind this you'll be working with ~$200,000 of equipment: take a moment to consider care and the opportunity!

Important Textbooks physically and ' e-vailable'*

1. ***Physics and chemistry of clouds ****
Dennis Lamb, Johannes Verlinde.
Shelf Location Hayden Library - Stacks | QC921.6.D95 L36 2011
Published Cambridge ; New York : Cambridge University Press, 2011.
ISBN 9780521899109 (hardback)

2. ***Microphysics of clouds and precipitation, 2nd Edition ****
Hans R. Pruppacher and James D. Klett.
Shelf Location Hayden Library - Stacks | QC921.5.P78 1997
Published Dordrecht ; Boston : Kluwer Academic Publishers, 1997.
ISBN 0792342119 (alk. paper)

3. ***Atmospheric chemistry and physics : from air pollution to climate change, 2nd Edition ****
John H. Seinfeld, Spyros N. Pandis.
Shelf Location Barker Library - Reserve Stacks | QC879.6.S45 2006
Published Hoboken, N.J. : Wiley, c2006.
ISBN 0471720178 (cloth)

4. ***A short course in cloud physics, 3rd Edition***
R.R. Rogers and M.K. Yau
Shelf Location Hayden Library - Stacks | QC921.5.R63 1989
Published Oxford ; New York : Pergamon Press, 1989.
ISBN 0080348645

Grading

(what I expect from you)

Lab reports

This lab report is due at 9am December 12 (few days *after* the presentations are completed). Send to me via email or bring it to my office. Late policy in effect per ‘Grading Policy’.

Presentations and Participation

Presentations will be submitted to Sarvesh via email before the start of the December 9 class. Students are expected to show up for *all* presentations regardless of if you are presenting. During each presentation you will be expected to participate by asking questions of your peers. You will also return a feedback report on the presentations the next day of class.

Laboratory Work

Students are expected to show up for all laboratory experiments. *You will also have possession of a DustTrak for a one week period.*

Special Circumstances

The penalties described in the ‘Grading Policy’ can be forgiven under special circumstances (for example, personal reasons, health reasons, etc.) if the student provides documentation from Student Services, a doctor or another reputable source.

I expect reports / presentations to be individual efforts. Collaboration is acceptable but copies and plagiarism will NOT be tolerated

Today

1. Our schedule
2. The standard stuff (what you can expect from us, what we expect from you)
3. Definitions
4. Why you should care about aerosols and clouds : radiative effects, health, precipitation
5. Where do aerosols come from?

EAPS Earth, Atmospheric and Planetary Sciences

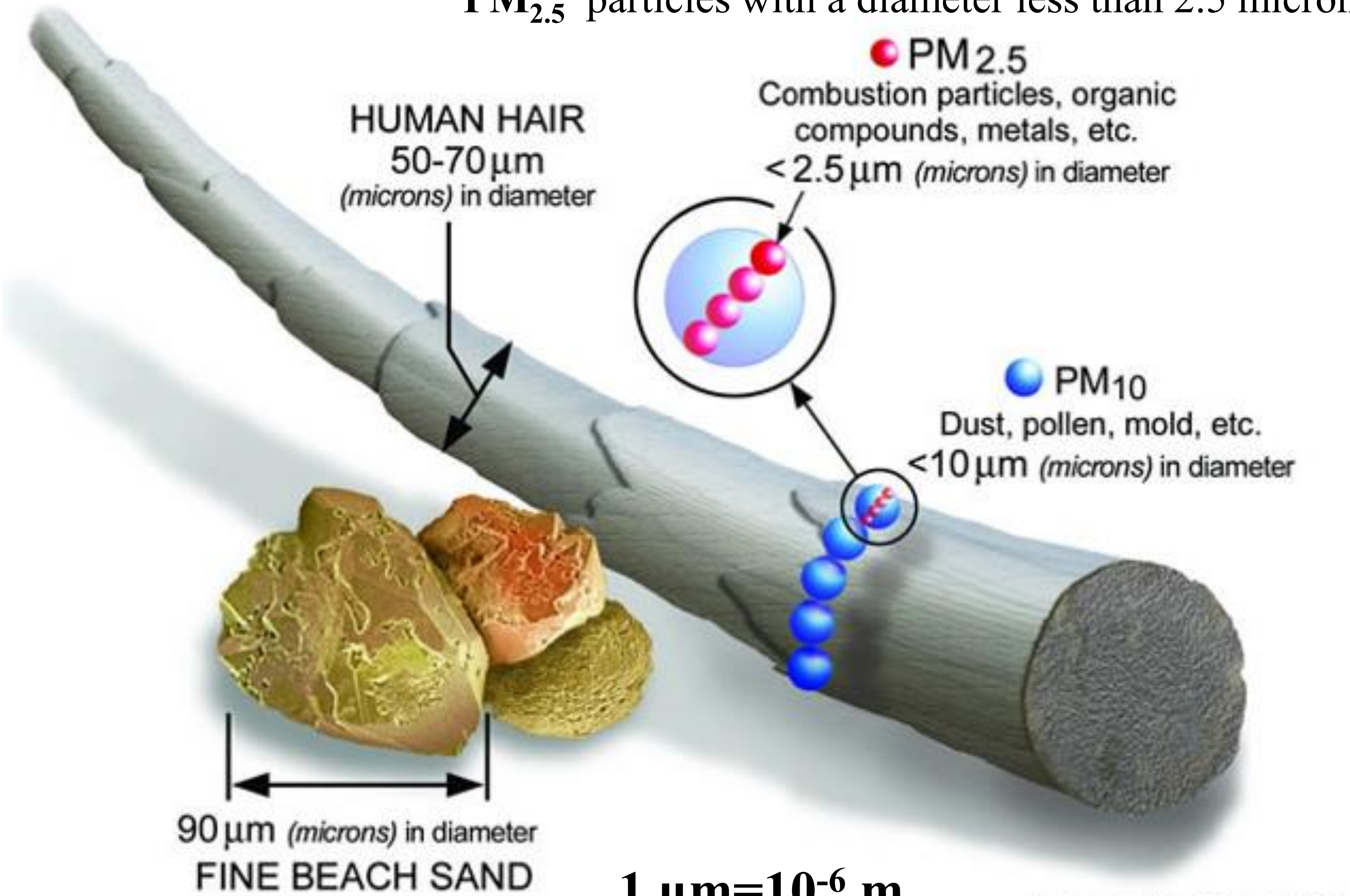
Aerosol

A colloid of fine solid particles or liquid droplets, in a gas

TABLE 1-1 Terminology Used to Describe Common Aerosol Systems

Bioaerosol	An aerosol of biological origin, including airborne suspension of viruses, pollen, bacteria, and fungal spores, and their fragments.
Cloud	A very dense or concentrated suspension of particles in air, often with a well-defined boundary at a macroscopic length scale.
Dust	Solid particles formed by crushing or other mechanical action resulting in physical disintegration of a parent material. These particles generally have irregular shapes and are larger than about 0.5 μm.
Fog or mist	Suspension of liquid droplets. These can be formed by condensation of supersaturated vapors or by nebulization, spraying, or bubbling.
Fume	Particles resulting from condensed vapor with subsequent agglomeration. Solid fume particles typically consist of complex chains of submicrometer-sized particles (usually <0.05 μm) of similar dimension. Fumes are often the result of combustion and other high temperature processes. Note that the common usage of "fume" also refers to noxious vapor components.
Haze	A visibility-reducing aerosol.
Nanoparticle	A particle in the size range of 1–100 nm.
Particle	A small, discrete object.
Particulate	An adjective indicating that the material in question has particle-like properties (e.g., particulate matter). Sometimes used incorrectly as a noun to represent particles.
Smog	An aerosol consisting of solid and liquid particles created, at least in part, by the action of sunlight on vapors. The term smog is a combination of the words "smoke" and "fog" and often refers to the entire range of such pollutants, including the gaseous constituents.
Smoke	A solid or liquid aerosol, the result of incomplete combustion or condensation of supersaturated vapor. Most smoke particles are submicrometer in size.
Spray	Droplet aerosol formed by mechanical or electrostatic breakup of a liquid.

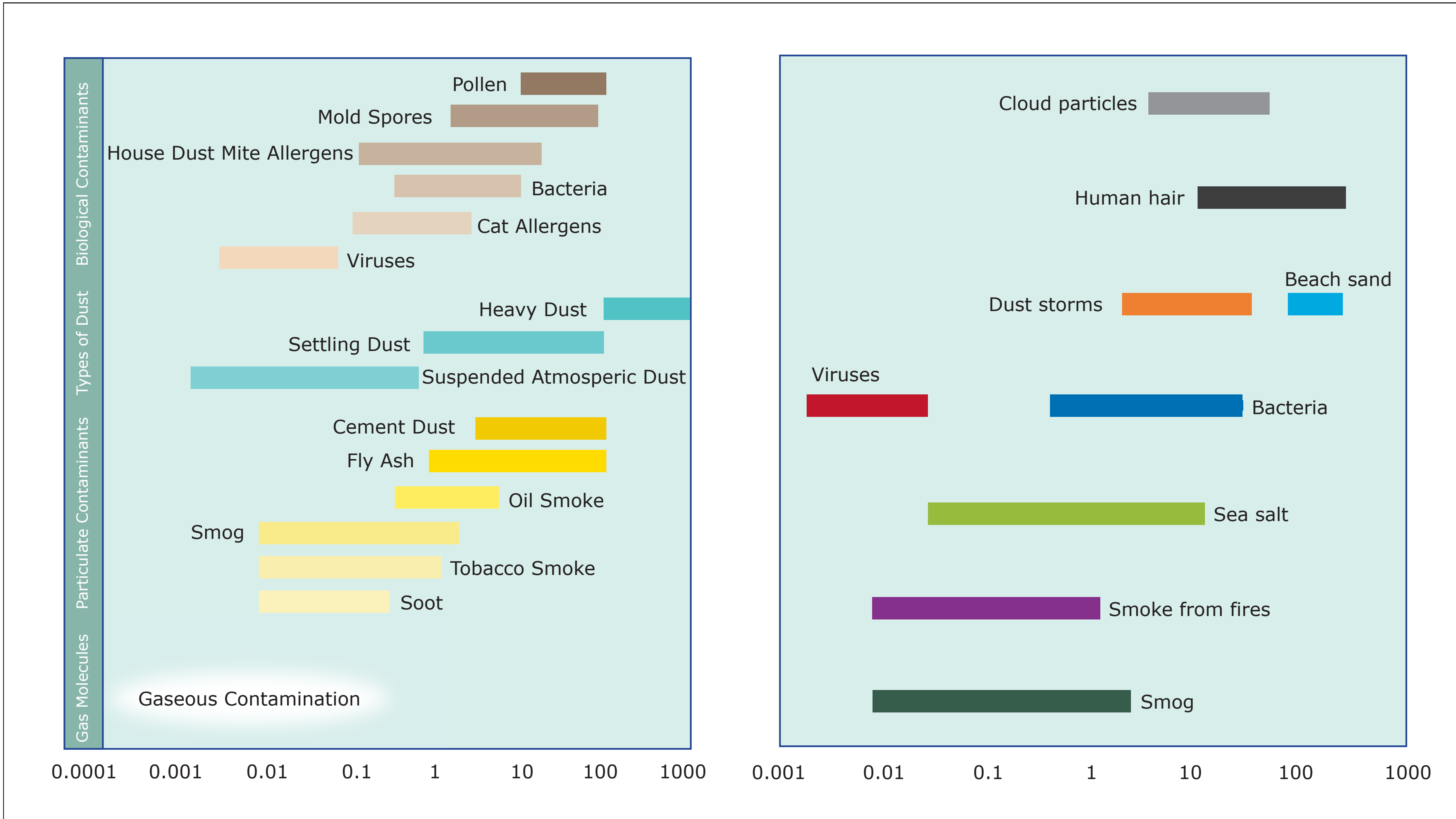
PM_{10} particles with a diameter less than 10 microns
$PM_{2.5}$ particles with a diameter less than 2.5 microns



$1\ \mu m = 10^{-6}$ m

Image courtesy of the U.S. EPA

Aerosol sizes



Sizes of Different Aerosols

Figure by MIT OpenCourseWare.

Why Study Aerosols? : Health Effects

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Please see Figure 8 on Page 829 of the PDF file: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1257642/pdf/ehp0113-000823.pdf.

From Oberdörster et al. (2005) courtesy of Eben Cross

'The Great Smog' – London, 1952

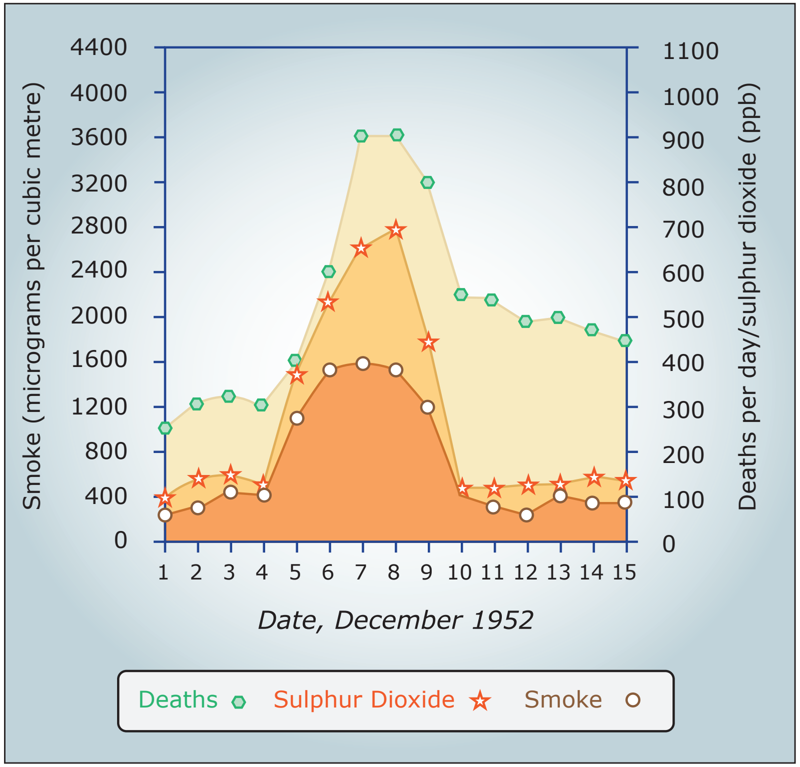


Figure by MIT OpenCourseWare.

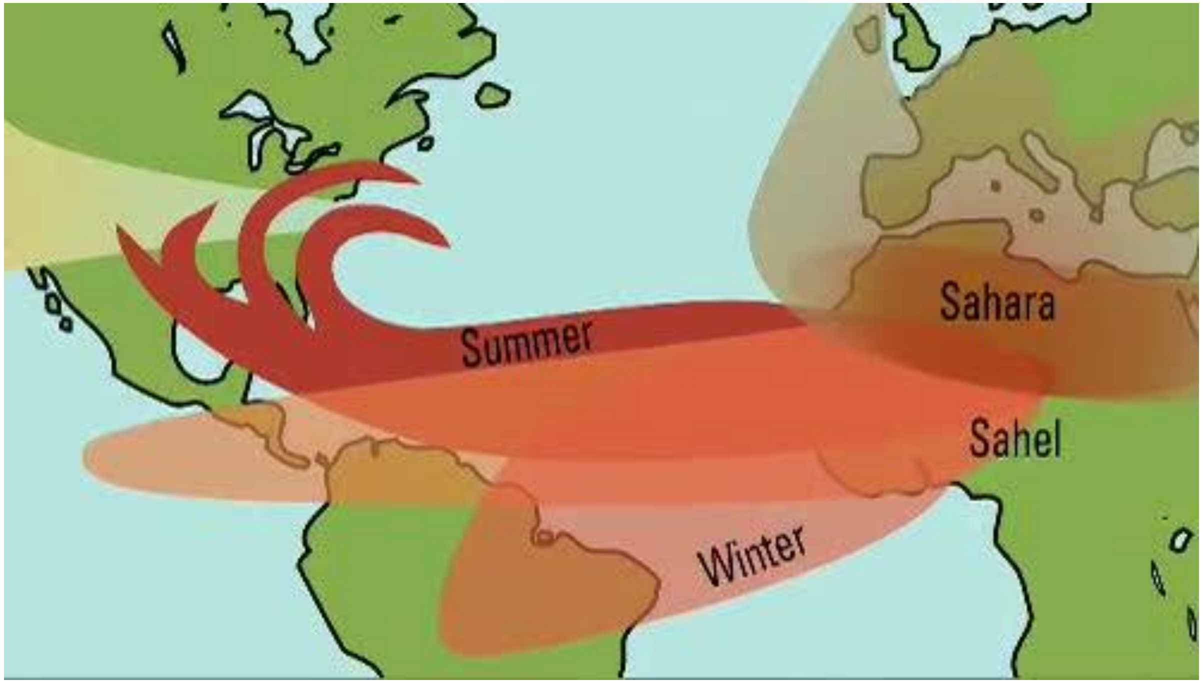
4000 deaths within 2 weeks,
12000 estimated total

- Combination of meteorology (cold air / increase heating and temperature inversion)
- Particles reached 14,000 μg/m³ (280x current US standard average and ~100x times peak allowable)
- Visibility < 1 m (!)

Why Care 2: Precipitation: Too little or too much

Dust storm approaching Stratford, Texas Dust bowl surveying in Texas
Image ID: theb1365, Historic C&GS Collection
Location: Stratford, Texas
Photo Date: April 18, 1935
Credit: NOAA George E. Marsh Album

Why Care 3: dust effect on coral reef and Amazon rainforest



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Nutrients to the rain forest
Disease for coral reef

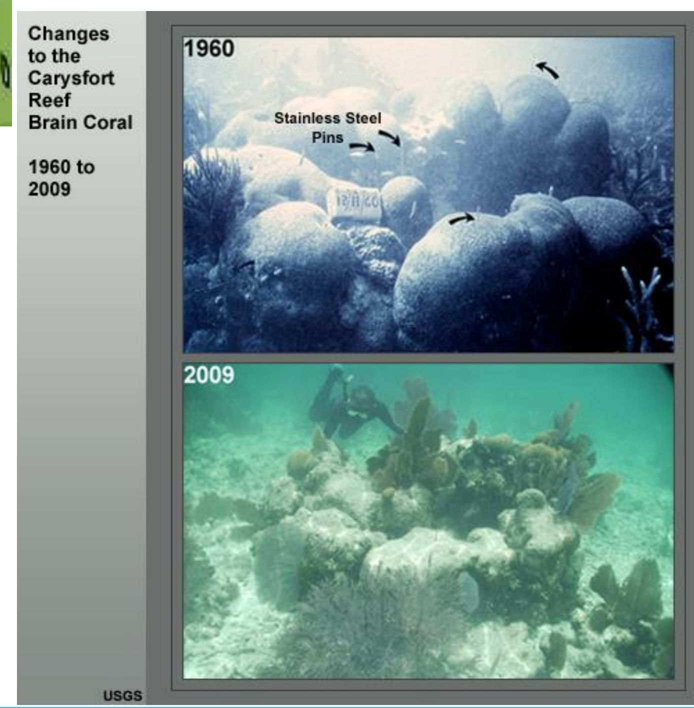


Image courtesy of USGS.

Why Study Aerosols? : Climate

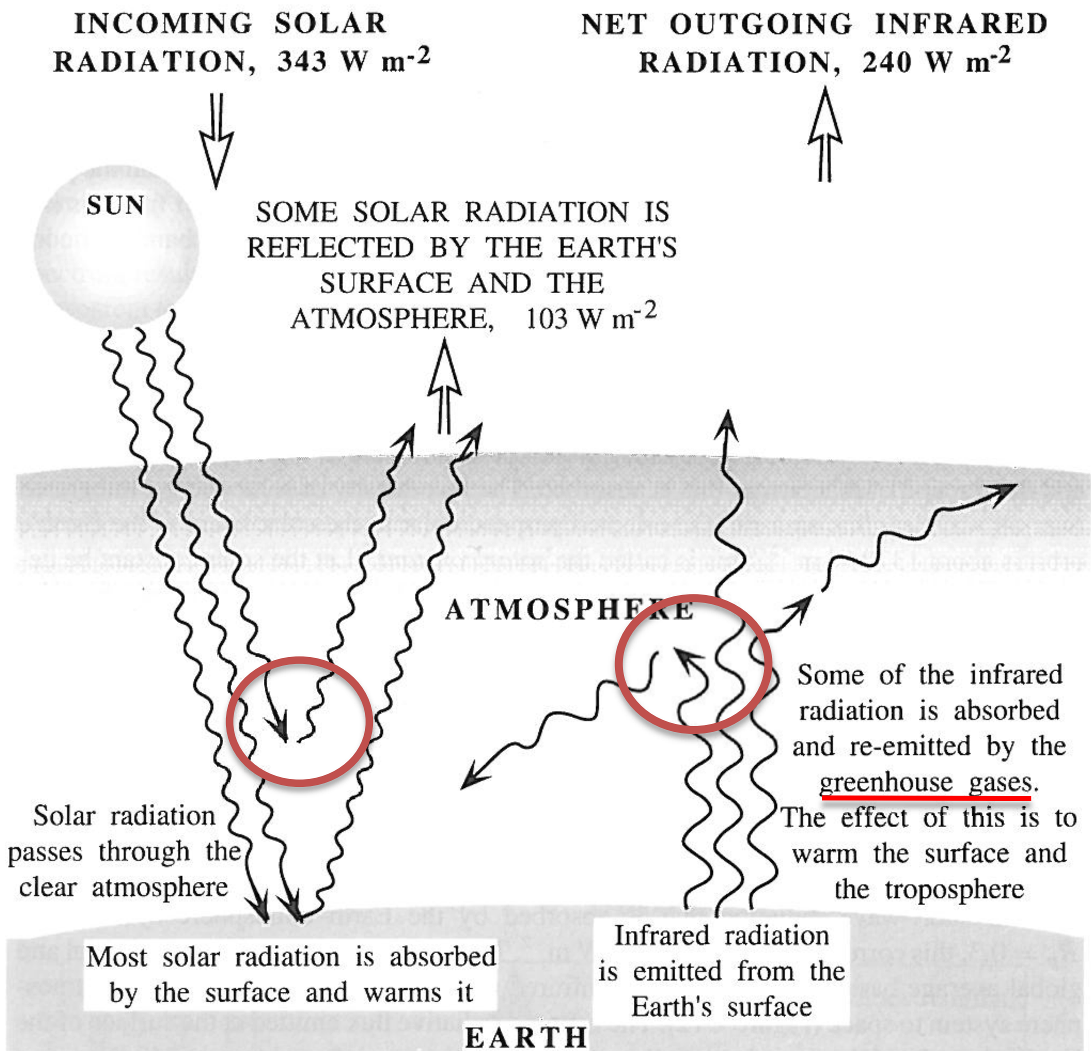
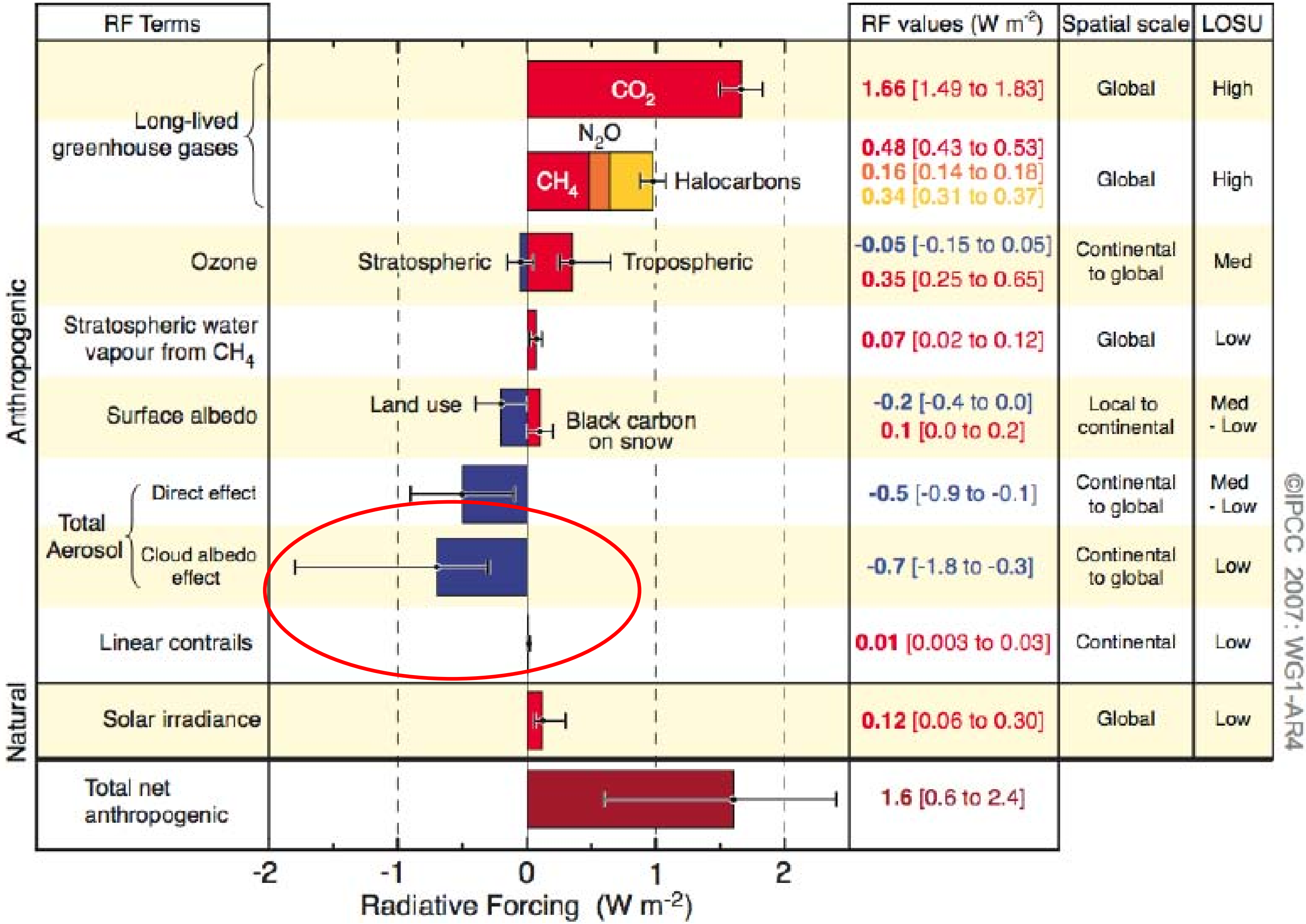


FIGURE 1.12 Earth's overall energy balance (IPCC, 1995). Net input of solar radiation (~240 W m^{-2}) must be balanced by net output of infrared radiation. About one-third (~103 W m^{-2}) of incoming solar radiation is reflected and the remainder is mostly absorbed by the surface.

The global mean radiative forcing of the climate system



IPCC - Intergovernmental Panel on Climate Change

Why Study Aerosols? : Climate

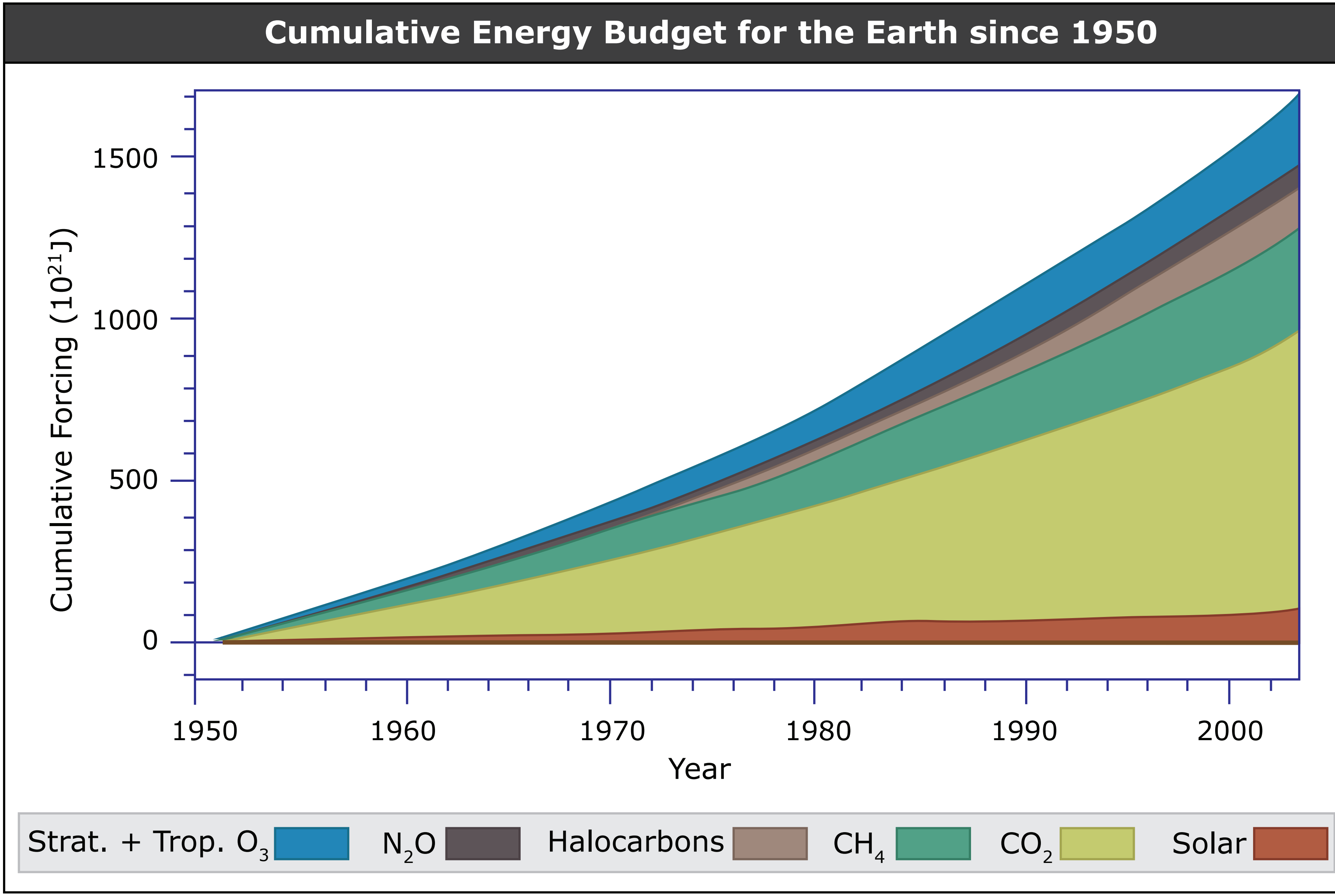
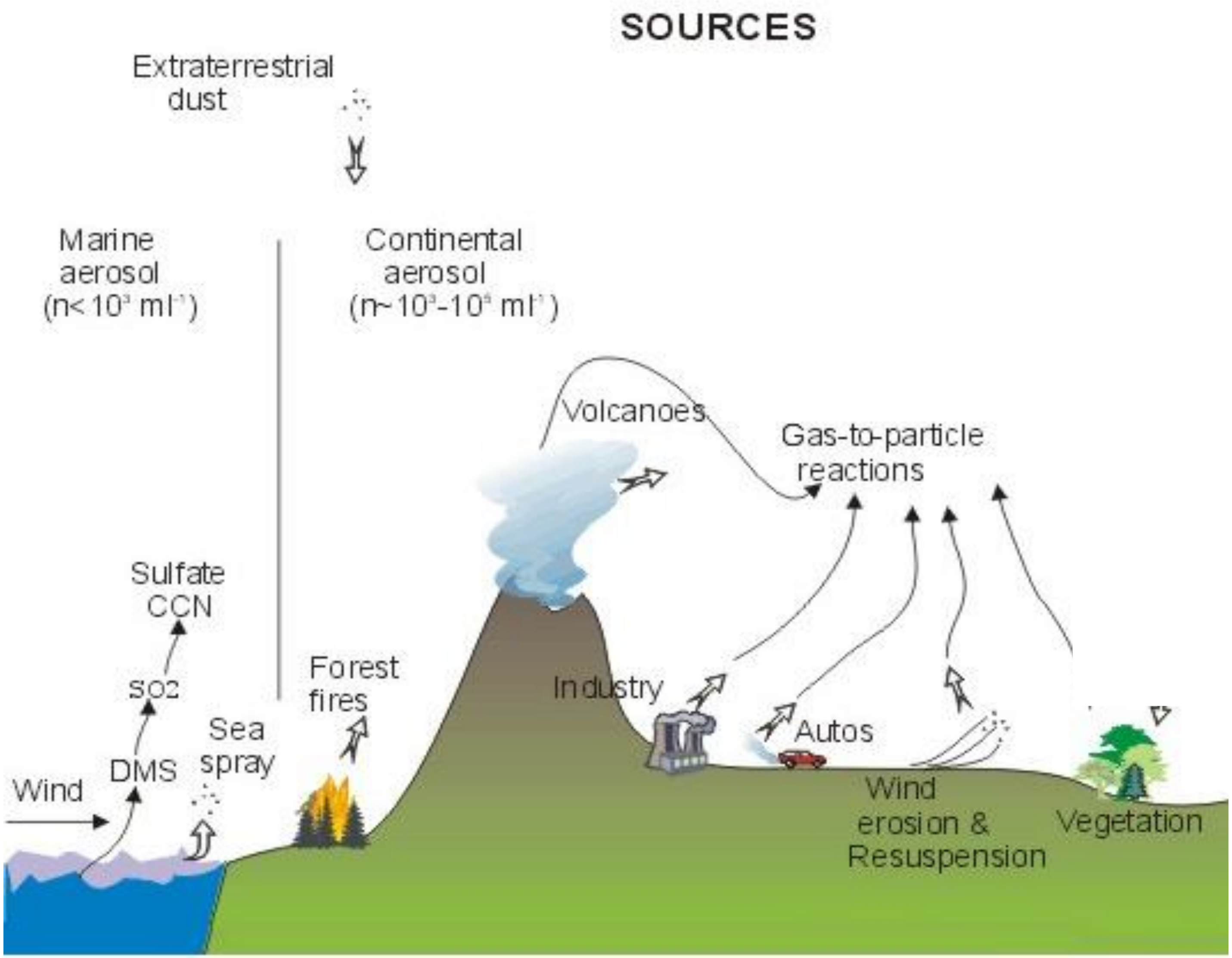


Figure by MIT OpenCourseWare.

Murphy et al. JGR 2009

Sources of Aerosols:



Sources of Aerosols:

Primary atmospheric aerosols are particulates that directly emitted into the atmosphere

Secondary atmospheric aerosols are particulates that formed in the atmosphere by gas-to-particles conversion processes

Type	Examples
Natural - Primary	Sea salt Soil dust Volcanic dust
Natural - Secondary	Sulfate from biogenic gases and volcanic SO_2 Nitrate from NOx Organic matter from biogenic sources
Anthropogenic -Primary	Industrial dust Soot Biomass burning
Anthropogenic -Secondary	Sulfate from SO_2 Nitrate from NOx Organic from anthropogenic sources

Origins of aerosol particles:

Aerosol	Natural (N) or Anthropogenic (A)	Annual flux (10 Tg/year)
Sea spray	N	1000-1500
Dust	N,A	100-750
Forest Fires	N,A	35-100
Volcanic	N	50 (highly variable)
Meteors	N	1
Combustion	A	50
Condensation	N,A	1500

The total annual global production of aerosol particles appears to be: 2500 – 4000 10Tg/year.

Aerosol Size Classes:

Anthropogenic
Natural

Nucleation mode: 0.001- 0.01µm

Aitkin mode: 0.01 - 0.1µm

Soot, sulfuric acid and organics

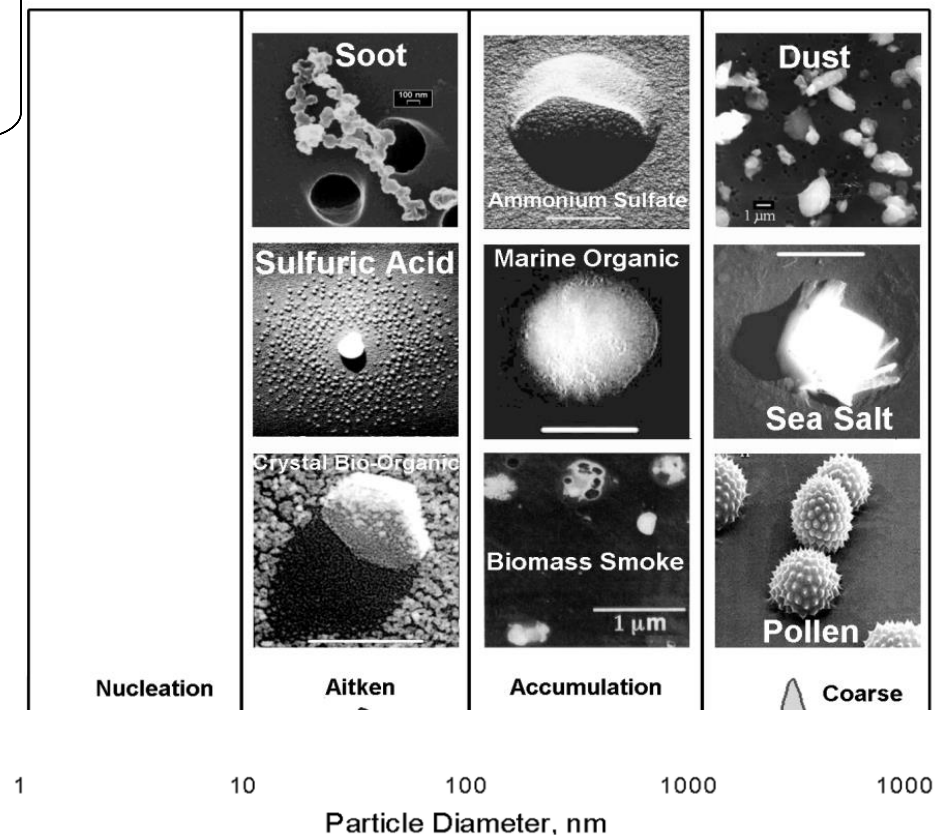
Accumulation mode: 0.1 -1µm

Ammonium sulfate and ammonium nitrate, organics and smoke from biomass burning or other fires.

Fine mode

Coarse mode: > 1µm

Mineral dust, sea salt and pollen.



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Type	Examples	Category
Natural - Primary	Sea salt Soil dust Volcanic dust	Coarse Coarse Coarse
Natural - Secondary	Sulfate from biogenic gases and volcanic SO_2 Nitrate from NOx Organic matter from biogenic sources	Fine Fine and coarse Fine
Anthropogenic -Primary	Industrial dust Soot Biomass burning	Fine and Coarse Fine Fine
Anthropogenic -Secondary	Sulfate from SO_2 Nitrate from NOx Organic from anthropogenic sources	Fine Fine Fine

Mode Sizes

TABLE: Comparison of Ambient Fine and Coarse Particles

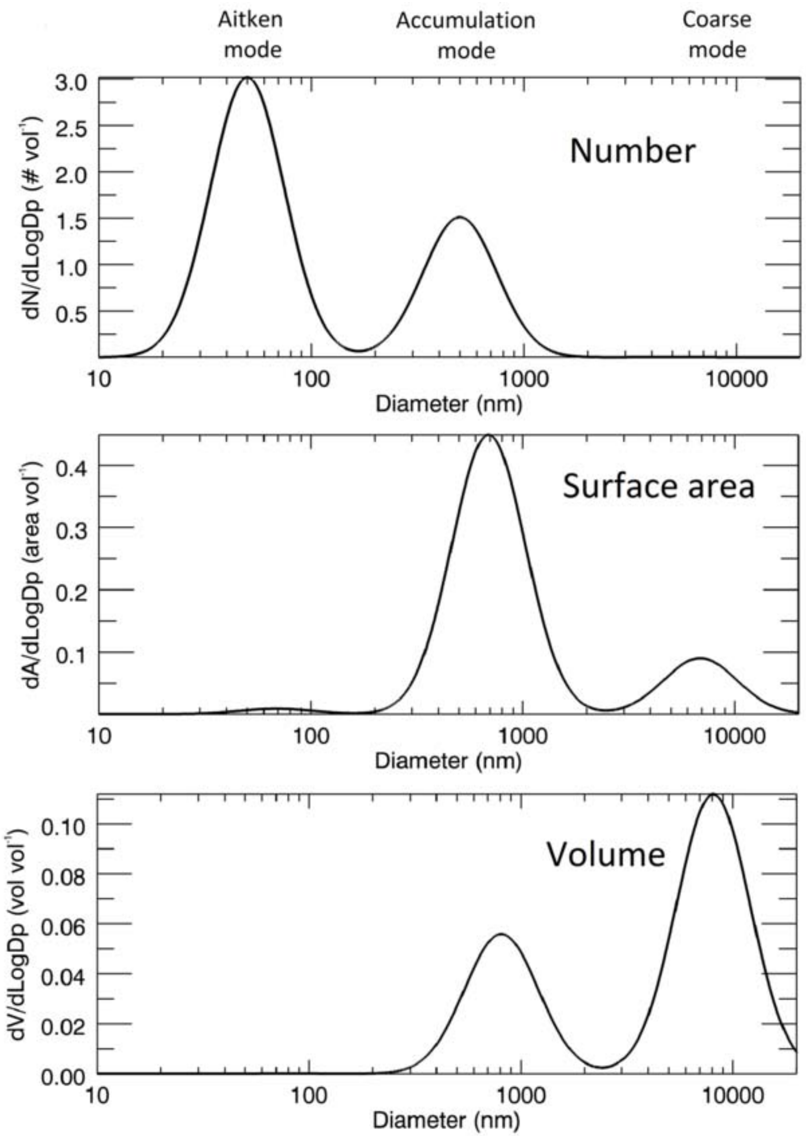
	Coarse Particles	Fine Particles
Atmospheric Lifetime	Minutes to days	Days to weeks
Composition	Resuspended dust Coal and oil fly ash Crustal element (Si, Al, Ti, Fe) oxides $CaCO_3$, NaCl Pollen, mold, spores Plant, animal debris Tire wear debris	Sulfate Nitrate Ammonium Hydrogen ion Elemental carbon (EC) Organic compounds Water Metals (Pb, Cd, V, Ni, Cu, Zn, Mn, Fe, etc.)
Formation Pathways	Mechanical Disruption Suspension of dusts	Chemical reactions Nucleation Condensation Coagulation Cloud/ Fog Processing
Solubility	Largely insoluble and non-hygroscopic	Largely soluble, hygroscopic
Sources	Resuspension of industrial dust and soil Suspension of soil (farming, mining, unpaved roads) Biological sources Construction/demolition Ocean spray	Combustion (coal, oil, gasoline, diesel, wood) Gas-to-particle conversion of NO_3, SO_3, VOCs Smelters, mills, etc.
Travel Distance	< to 10s of km	100s to 1000s of km

Figure by MIT OpenCourseWare.

Properties of aerosol important to atmospheric processes:

- Number concentration
- Mass
- Size distribution
- Chemical composition
- Aerodynamic property
- Optical properties

Aerosol Size Classes:



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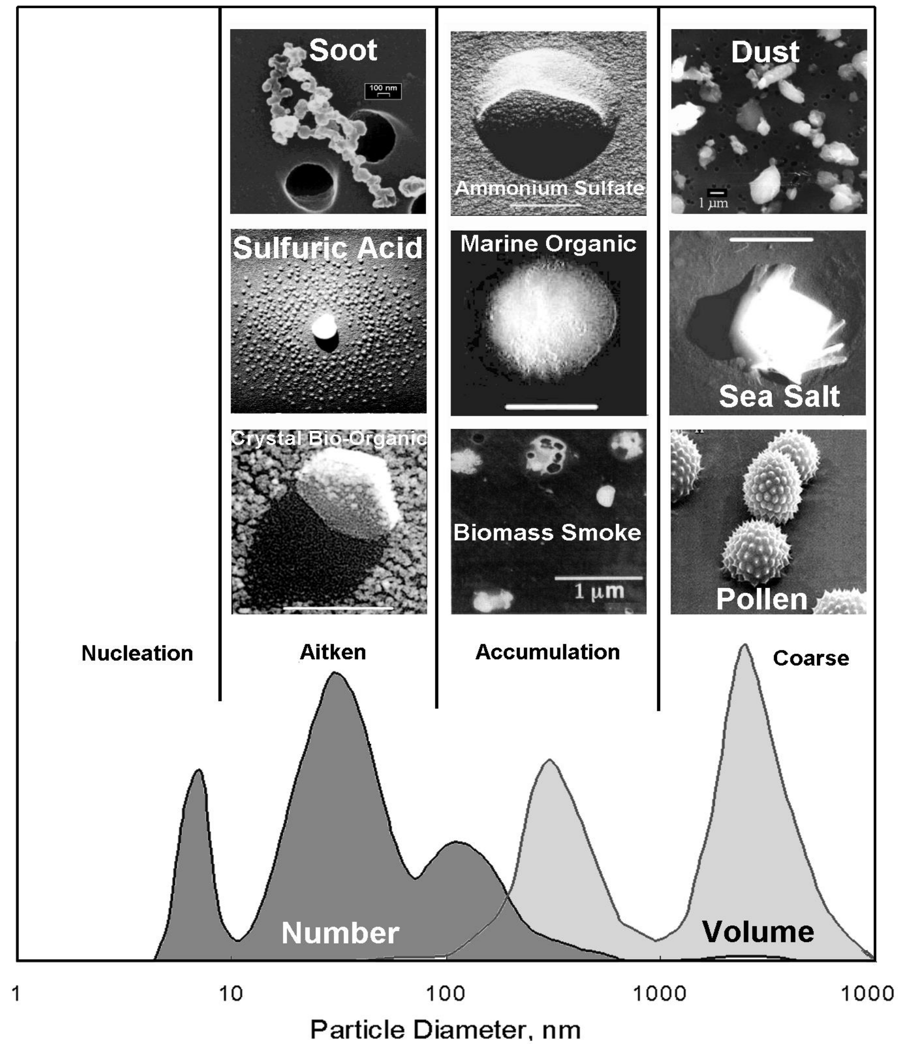

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Sea Salt - bubble burst mechanism

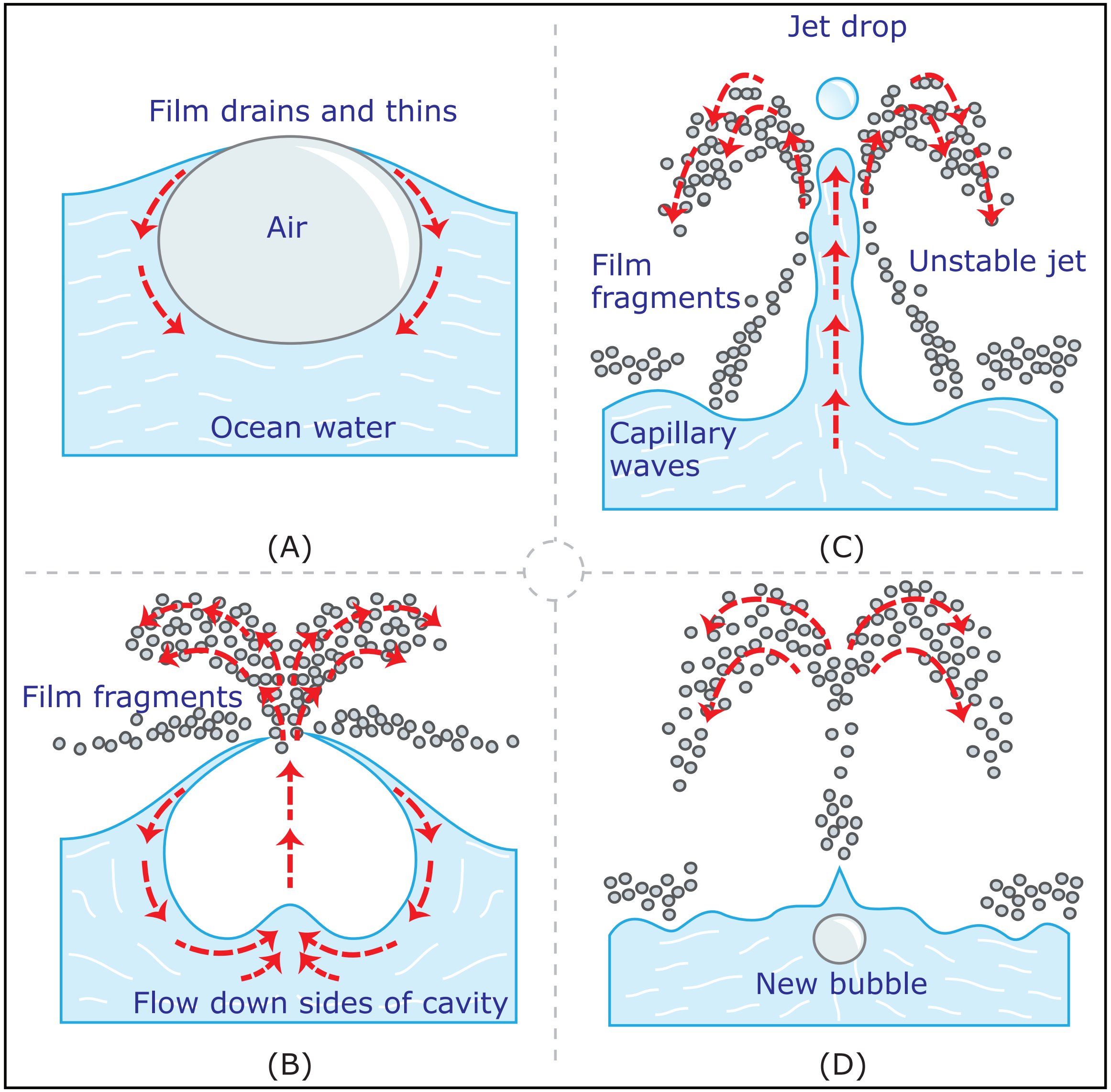


Figure by MIT OpenCourseWare.

Four stages to produce sea salt particles:

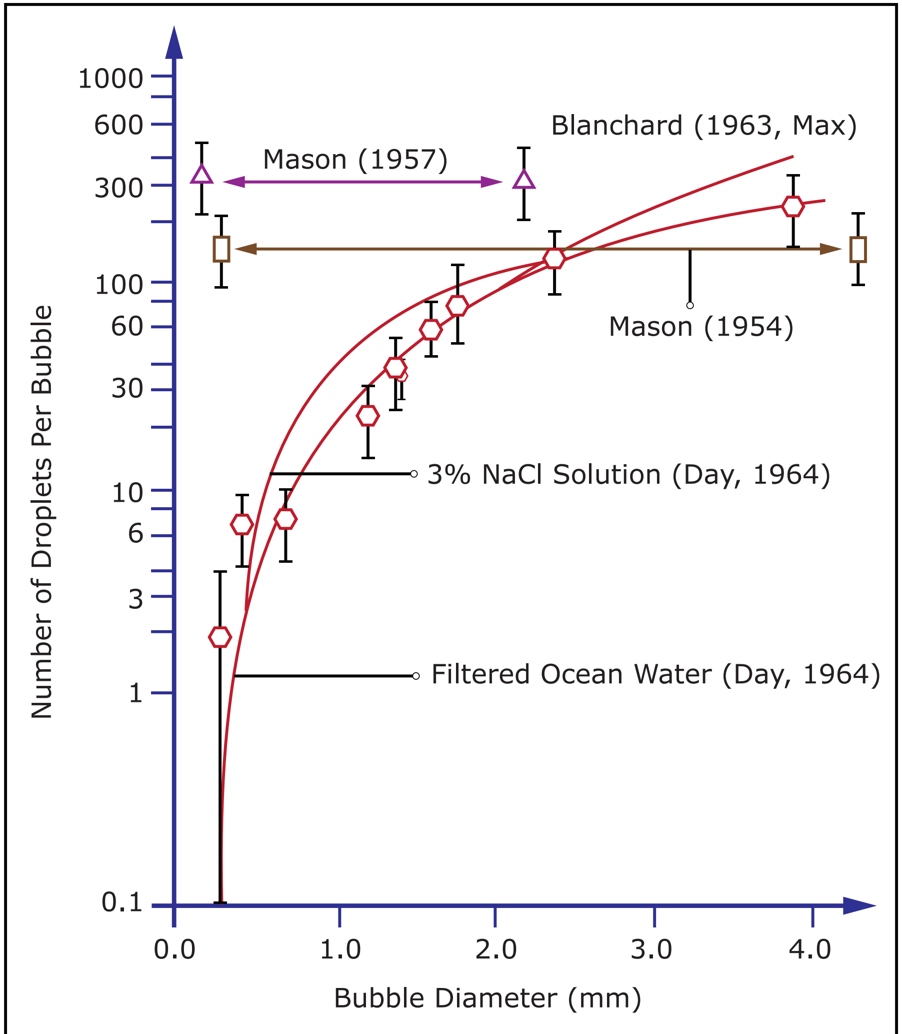
(a) First, when a bubble rises to the top of the surface, its cap becomes a very thin film.

(b) which eventually ruptures to form numerous mini-droplets that fly into the air.

(c) Some of these film droplets eventually evaporate to leave dry sea salt particles that may be carried up higher by winds. At the same time, the water in the remnant bubble creates a jet due to the buildup of pressure at the bottom of the bubble. As the jet rises, instability grows such that the jet breaks into a few droplets that also fly into the air.

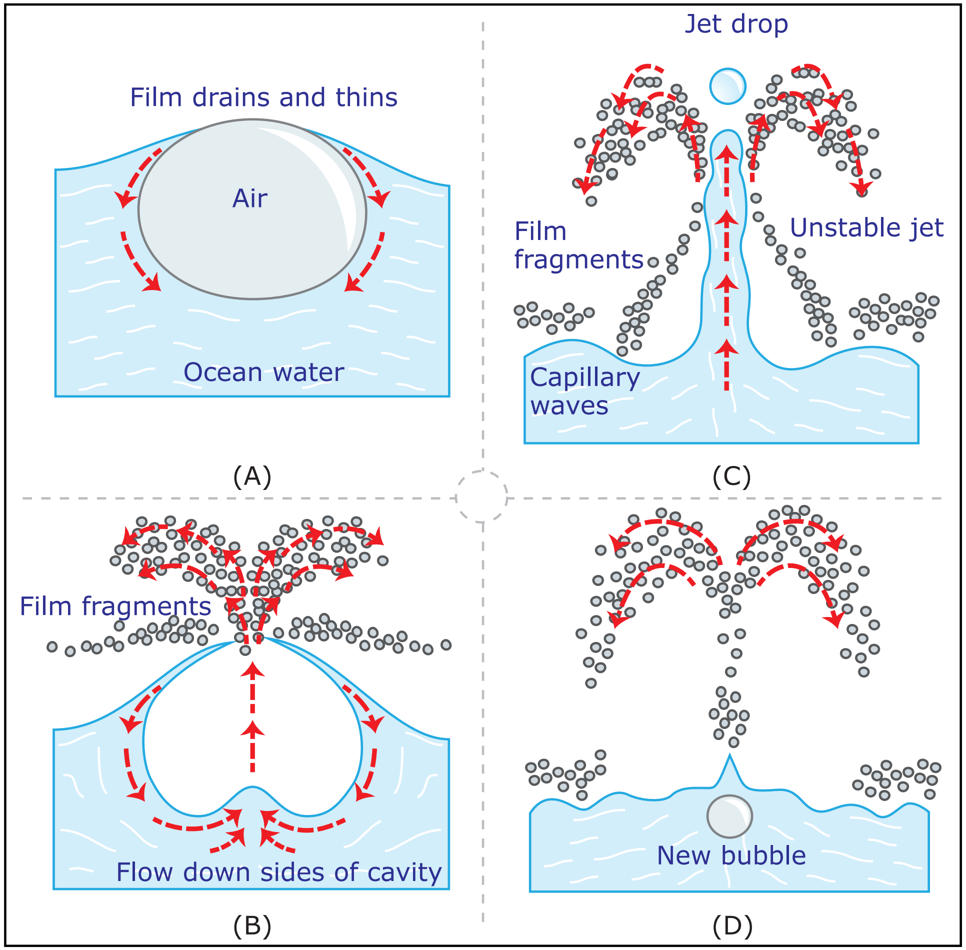
(d) These jet drops are usually larger than the film drops. Some of these droplets are then carried by winds to higher layers and evaporate to become dry sea salt particles.

Sea Salt - bubble burst mechanism



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.

Figure by MIT OpenCourseWare.



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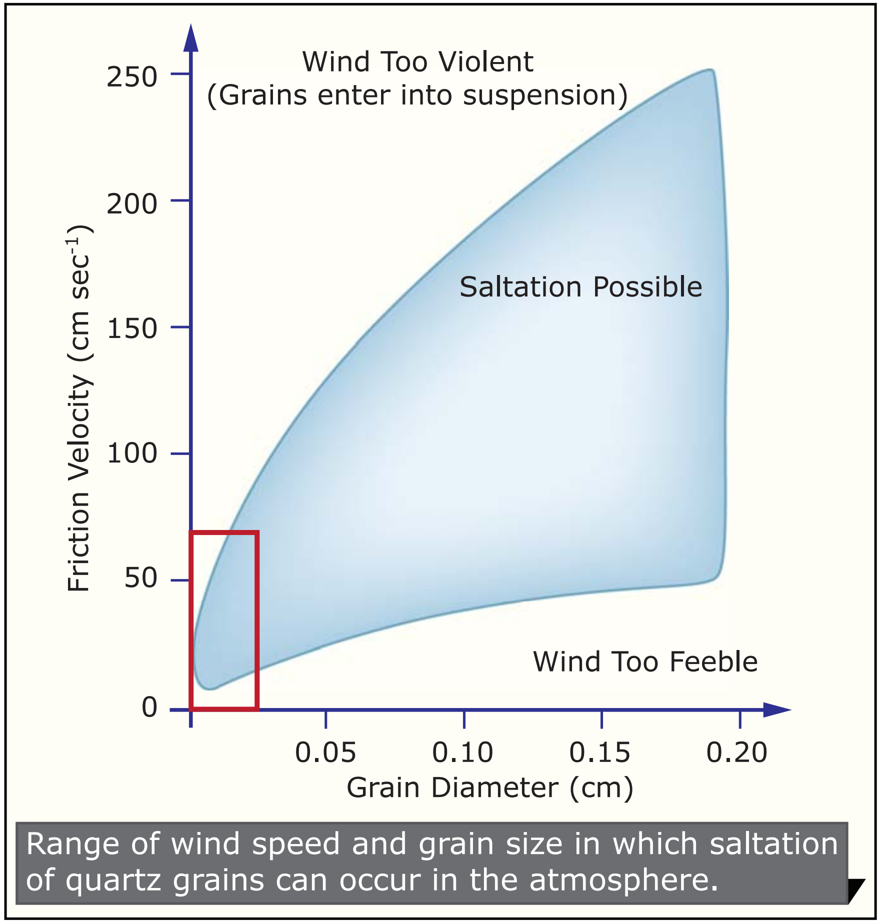

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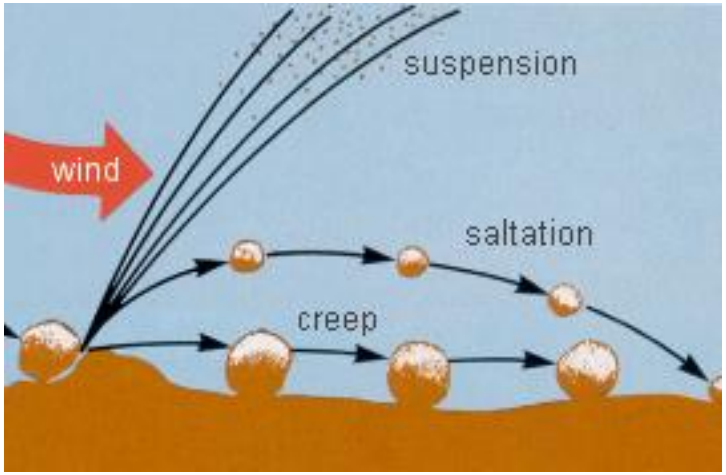

Image courtesy of NASA.
http://commons.wikimedia.org/wiki/File:Saltation-mechanics.gif

Biological Aerosol

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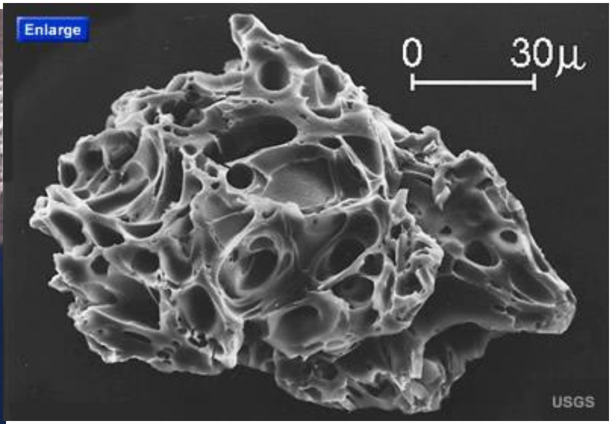
Primary Volcanic Emissions

Image courtesy of NASA.



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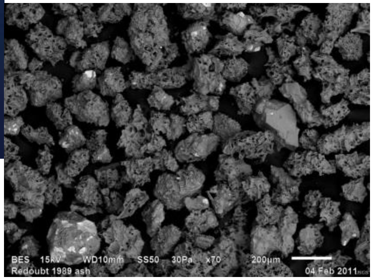

Image courtesy of USGS.

Volcanic Ash From 1989 Mt. Redoubt Eruption, Alaska

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http://www.hko.gov.hk/blog/en/archives/00000107.htm

Nitrogen oxides :

Nitric oxide (NO)

Nitrogen dioxide (NO_2)

Sulfur oxides :

Sulfur dioxide (SO_2)

Sulfur trioxide (SO_3)

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http://janison.cyriljackson.wa.edu.au/Janison/Science/Chem3A3B/WestOne/Chem3A/content/008_environmental_processes/page_08.htm

$$NO_2 + OH\cdot \dashrightarrow HNO_3$$

$$SO_2 + H_2O \dashrightarrow H_2SO_3$$
$$SO_3 + H_2O \dashrightarrow H_2SO_4$$

Nitric Acid - HNO_3

Sulfuric Acid - H_2SO_4

Acid Rain

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Sandstone portal Figure on Herten Castle in Ruhr district of Germany, Sculpted 1702.

Soot & Black Carbon (BC)

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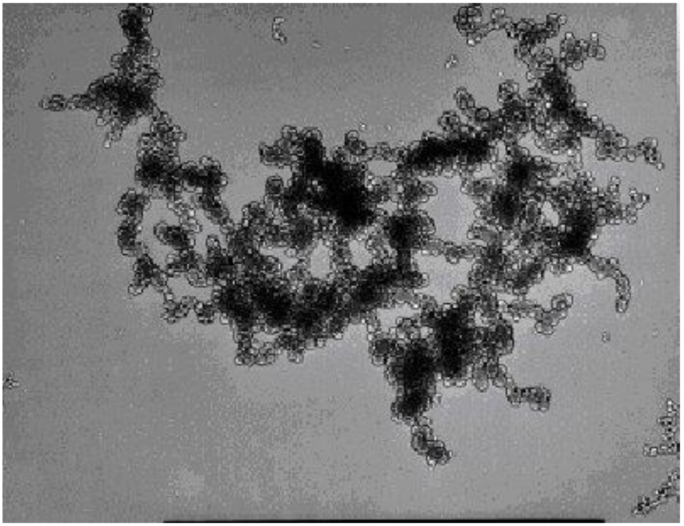

http://www.sites.mech.ubc.ca/~rogak/research/aerosol.html

Image courtesy of Steven Rogak, University of British Columbia. Used with permission.

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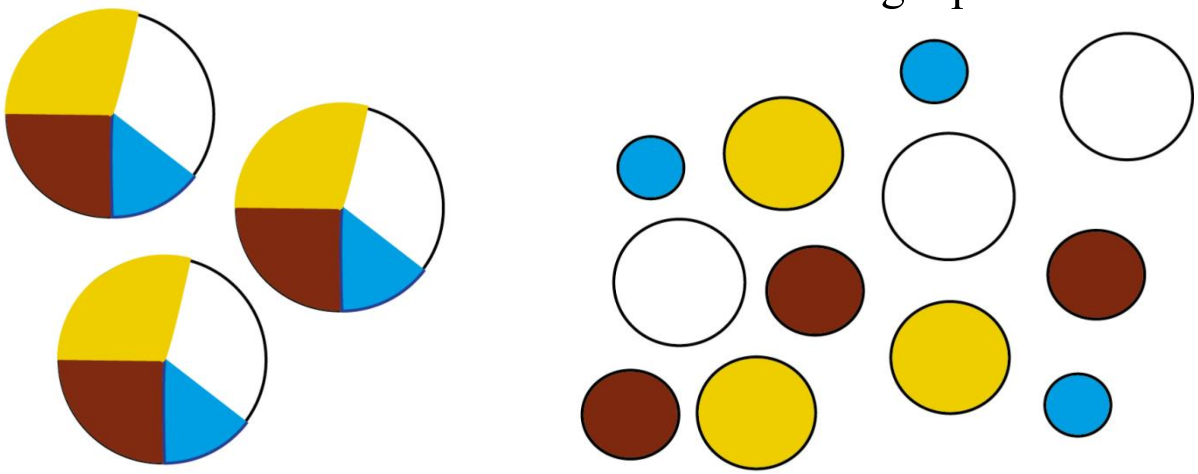
Coville et al 2011

Internally mixed aerosol Externally mixed aerosol.

(a) Multiple phases (b) Single phase



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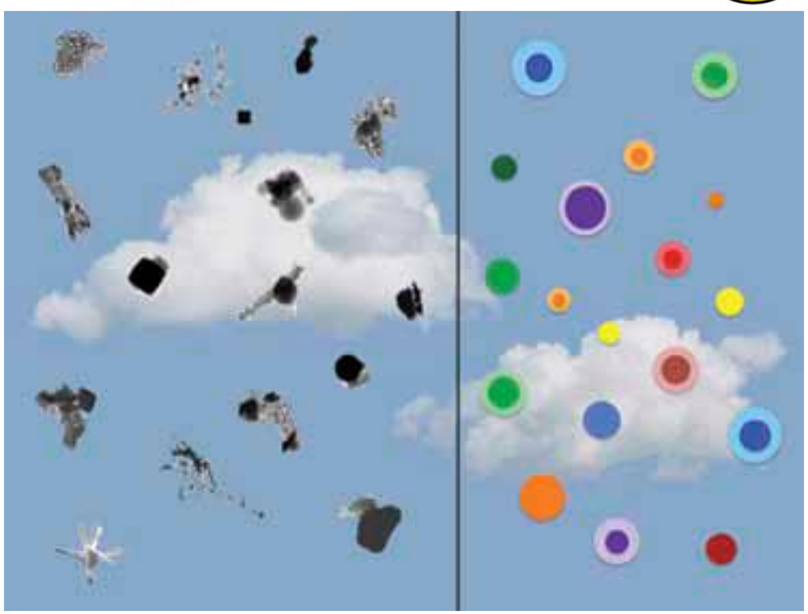
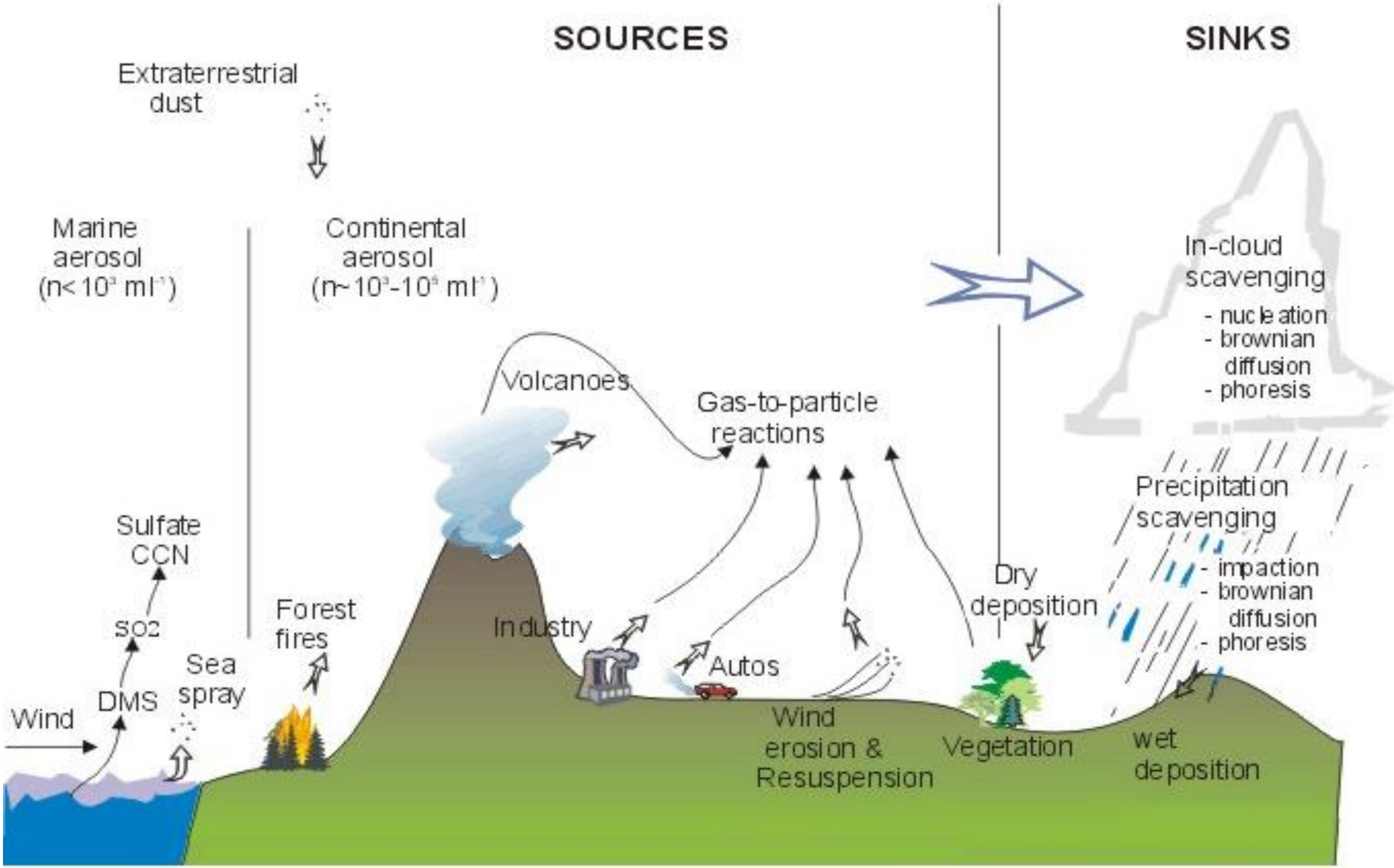


Most solid aerosol particles :

(a) not single-phase (i.e. not externally mixed)
(b) irregularly shaped rather than spherical
(c) do not have core–shell configurations

Sources and sinks of Aerosols:

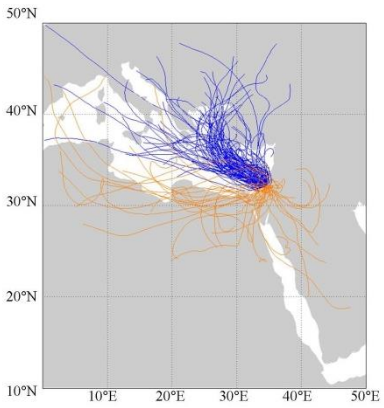


Lab 1 Objectives (Nov 13):

1. Learn how aerosol number and size are measured in the lab and field.

2. Measure aerosols during your everyday activities. When are you being exposed?

3. Long-term measurements with an eye on sources (e.g. urban, clean and maritime)
    1. Backtrajectories – where did that air come from?



Lecture 4

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Weather Modification

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Ice in clouds

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Geoengineering

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Broken Hill Dust Storm Australia