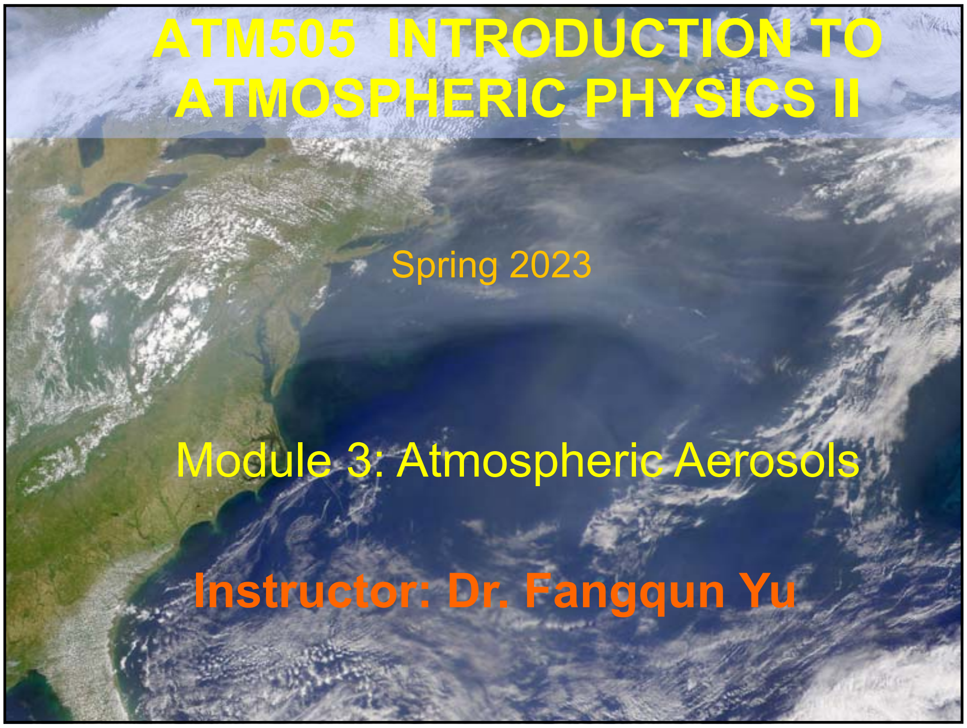

MODULE 3: Atmospheric Aerosols

The importance of aerosols in the atmosphere arises from their links to aerosol-cloud-radiation-precipitation interactions – and thus climate forcing and the hydrological cycle – as well as role in atmospheric chemistry and air quality – and therefore public health and morbidity. This brief introduction to the field will introduce students to the following important topics:

Lecture 1: Introduction and Aerosol Characterization

Lecture 2: Particle Microphysics Overview and Thermodynamics

Lecture 3: New Particle Formation -- HW3 out

Lecture 4: Aerosol Growth, Coagulation, and Deposition

Lecture 5: Environmental and Climatic Impacts of Atmospheric Aerosols

-- HW3 due

Reading Materials/Text Book:

(1) Read materials will be specified in the slides/handouts.

(2) No textbook is required but the following textbook is helpful for more in-depth understanding for some contents:

Atmospheric Chemistry and Physics: From Air Pollution to Climate Change
By Seinfeld & Pandis, 1998, 2006, or 2016.

Office Hour:

4:20 - 5:00 pm each day after class (ETEC 333)
or by appointment (fyu@albany.edu)

MODULE 4: Atmospheric Aerosols

Lecture 1: Introduction and Aerosol Characterization

I. What are AEROSOLS?

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Web Images Groups News Froogle Local more »

define:Aerosol [Search] Advanced Search Preferences

Definitions of **Aerosol** on the Web:

- a system of colloidal particles dispersed in a gas, such as smoke or fog.
  www.pnl.gov/atmos_sciences/Cdw/Glossary.html
- tiny solid or liquid particles suspended in the atmosphere
  whyfiles.larc.nasa.gov/text/kids/Problem_Board/problems/light/glossary.html
- a suspension of liquid or solid particles in air.
  www.ieainstitute.com/IndoorAirQuality/knowledge-base/iaq-glossary.htm
- An aerosol is a collection of very small particles suspended in air. The particles can be liquid (mist) or solid (dust or fume). The term aerosol is also commonly used for a pressurized container (aerosol can) which is designed to release a fine spray of a material such as paint.
  ccinfoweb.ccohs.ca/help/msds/msdstermse.html

Definition: Aerosols are suspended particulate matter (liquid or solid) – suspended in a fluid. In terms of atmospheric aerosols, this fluid is air.

Example of aerosols or particles in the atmosphere:

How many different types you can think of?

Dust Storm

Dust storm over the red sea.

Dust storm over Denver, Colorado. (Source: worldgeography.com)

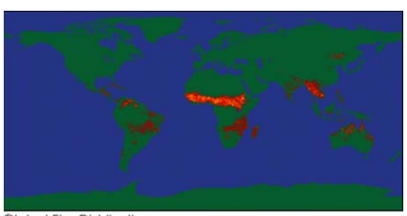
Sea Spray

Sea Salt (Giant CCN)

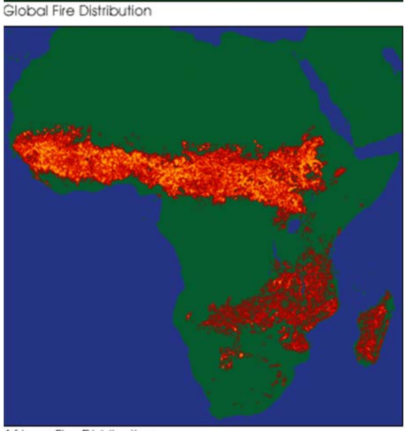
Microorganisms

Geo-engineering

Biomass Burning



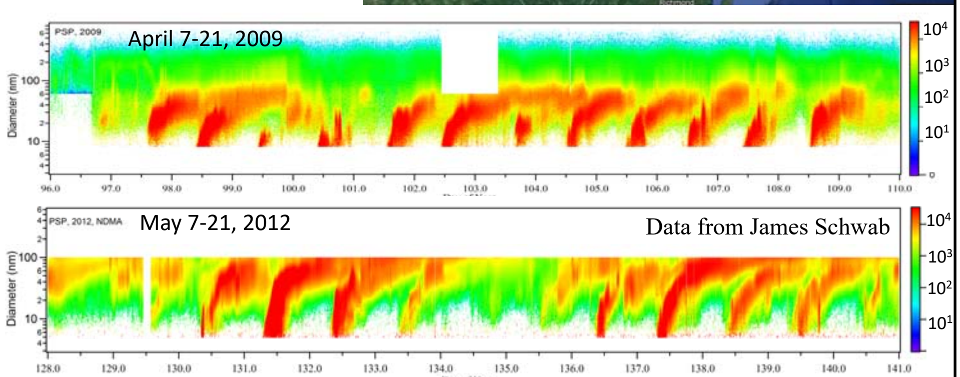
Global Fire Distribution



African Fire Distribution

Anthropogenic Emissions

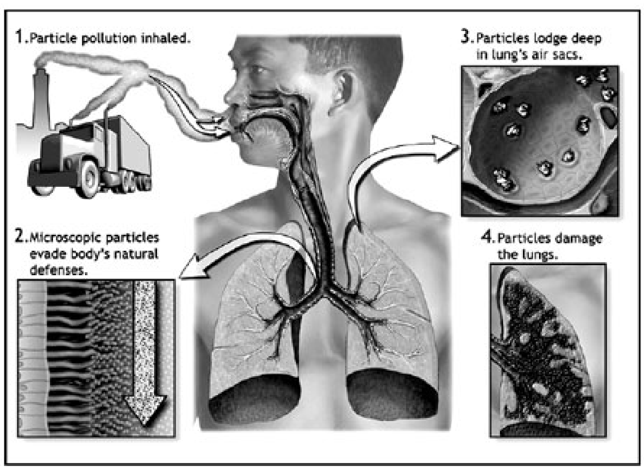
New particle formation (NPF) in the atmosphere



II. Importance of atmospheric aerosols

1. Particles and health
2. Effects of aerosols on radiation, cloud, climate and weather

1. Particles and health impact



Because of its very small size, particle pollution gets right through the nasal passage, past the trachea and deep into the lungs. The smallest of the particles can even enter the bloodstream via the lungs.

Air Pollution Linked to 1.2 Million Premature Deaths in China in 2010

Aly Song/Reuters

Shanghai in January. Researchers said the toll from China's pollution meant the loss of 25 million healthy years in 2010.

Air or aerosol transmission of VIRUS

From Pan et al., JAM, 2019

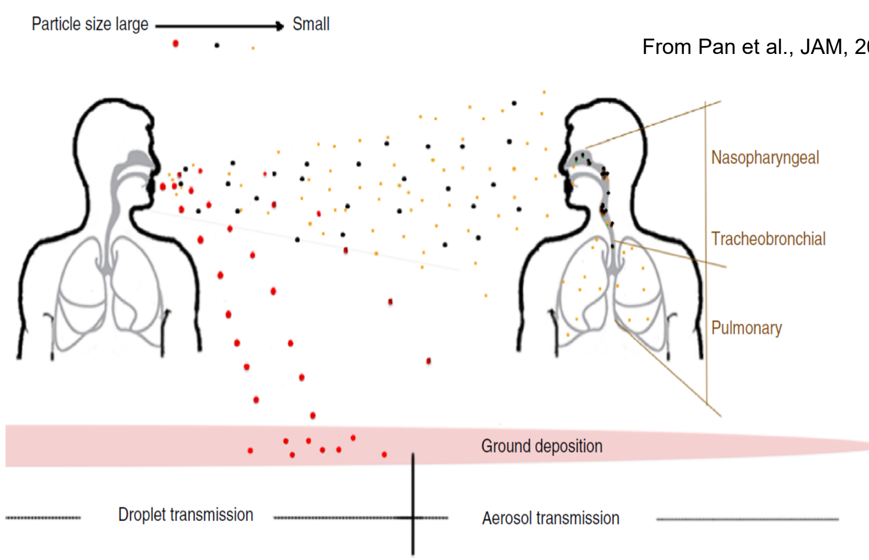
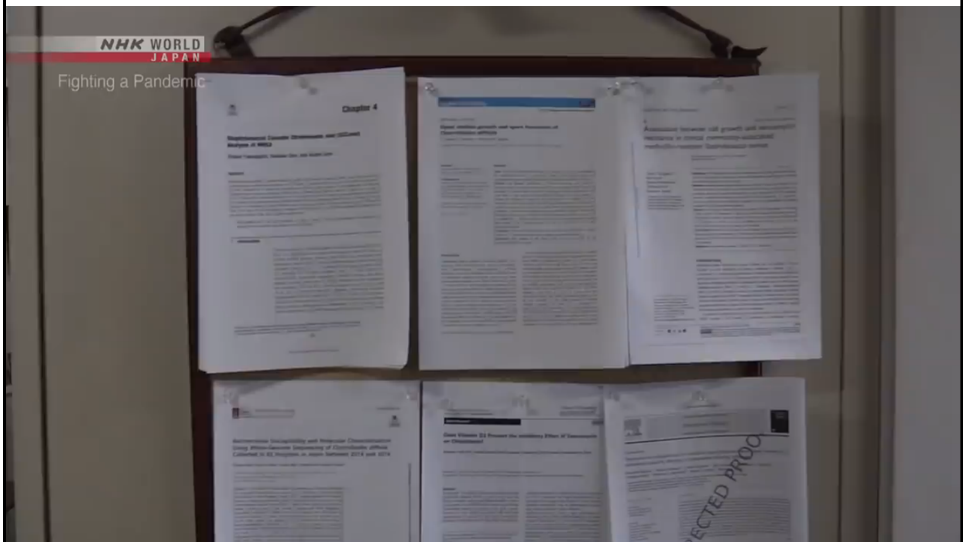


Figure 1 Comparison between droplet transmission (●) and aerosol transmission (•). Large droplets settle close to the source, while smaller aerosol particles stay aloft and can drift long distances. Once inhaled, very small particles can reach deeper to the pulmonary region while larger particles are captured in the nasopharyngeal region in the upper respiratory system. [Colour figure can be viewed at wileyonlinelibrary.com]

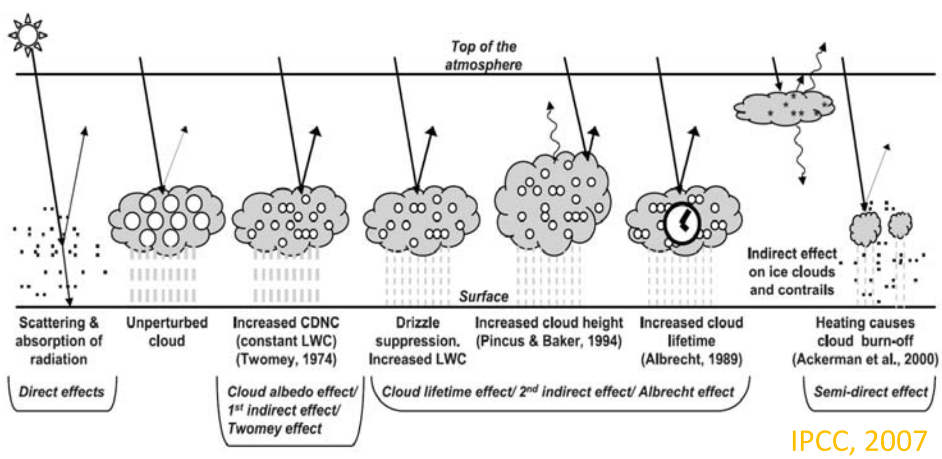
Coronavirus: New Facts about Infection Mechanisms - NHK Documentary

https://www.youtube.com/watch?v=H2azcn7MqOU



In class view: 1’58’’ – 3’00’’, 3’50’’ – 5’00”

2. Effects of aerosols on radiation, cloud, climate and weather

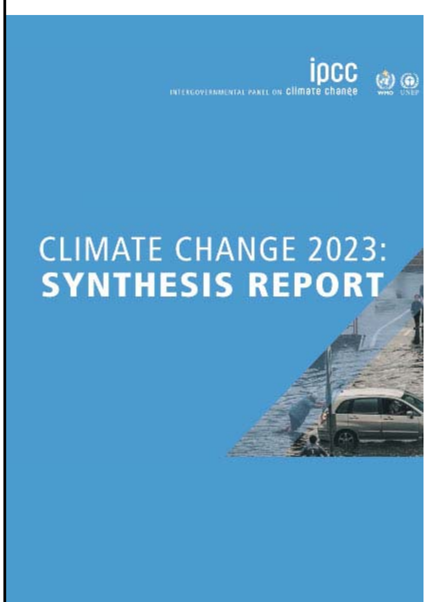


IPCC, 2007

Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

Tiny particles have outsize impact on storms

Watch PNNL video https://www.pnnl.gov/news/release.aspx?id=4489



The Washington Post
Democracy Dies in Darkness
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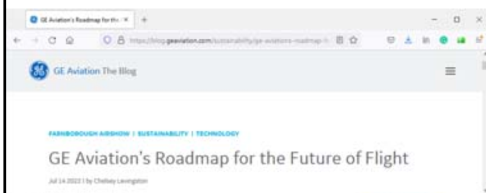
World is on brink of catastrophic warming, U.N. climate change report says

A dangerous climate threshold is near, but 'it does not mean we are doomed' if swift action is taken, scientists say

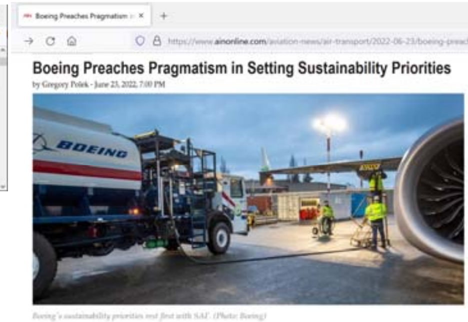
By Sarah Kaplan

Updated March 20, 2023 at 12:50 p.m. EDT | Published March 20, 2023 at 9:01 a.m. EDT

A Chinese state-owned coal-fired power plant under construction in 2017 in Huainan, Anhui province, China. (Kevin Frayer/Getty Images)



- Multiple ground and flight tests planned for the **mid-2020s**;
- Entry-into-service of a zero-emission aircraft **by 2035**;
- Net-zero carbon emissions for commercial flight **by 2050**.



Boeing chief sustainability officer Chris Raymond:

"… We have to understand how to deal with contrail formation on a hydrogen fuel cell airplane. And we're studying that."

Fig. 1 The NASA DC8 research aircraft probing contrails from the DLR A320 burning sustainable aviation fuel blends. Photo showing the DC8 chasing a contrail from the A320 burning a sustainable aviation fuel blend above Germany on 24 January 2018.

Airbus To Test Hydrogen Contr...

https://mentourpilot.com/airbus-to-test-hydrogen-con

MENTOUR PILOT

AIRBUS TO TEST HYDROGEN CONTRAILS

by Spyros Georgilidakis | Jul 22, 2022 | Airbus, Hydrogen, News, technology | 0 comments

The problem here is that it is very difficult to model the nature of contrails coming from jet engines that burn hydrogen. Finding out this information is rather urgent, as Airbus has to decide on a future direction.

Airbus To Test Hydrogen Contr...

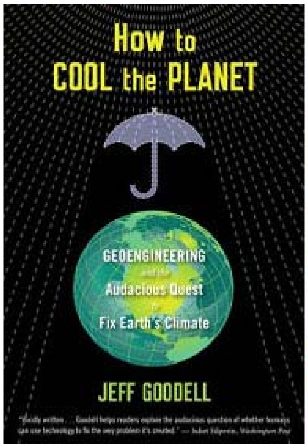
https://mentourpilot.com/airbus-to-test-hydrogen-contrails-with-gl...

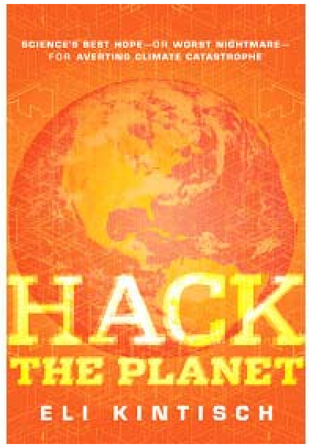
The A380 ZEROe hydrogen flightlab. Note the 5th engine. Image: Airbus

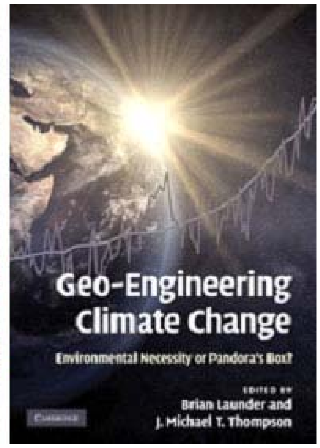
HYDROGEN AND CONTRAILS – THE AIRBUS A380 FLIGHT LAB

The problem here is that it is very difficult to model the nature of contrails coming from jet engines that burn hydrogen. Finding out this information is rather urgent, as Airbus has to decide on a future direction. **As we have seen, Airbus will fly one of its A380s as a hydrogen flight lab.** This aircraft will feature a fifth engine (GE Passport), the size we normally see on business jets.

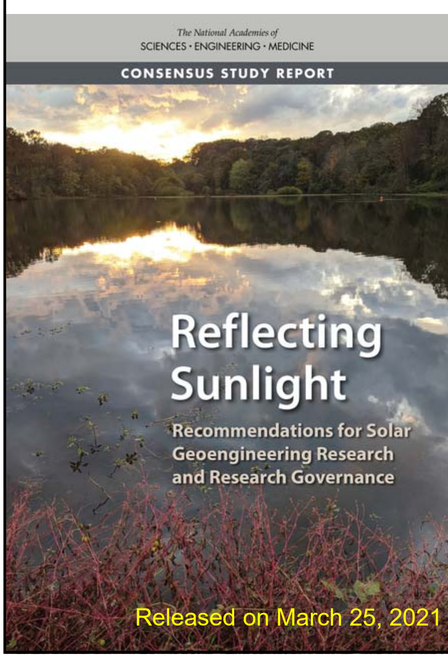
Geo-Engineering







Geo-Engineering



Released on March 25, 2021

"Given the urgency of the risks posed by climate change, the U.S. should pursue a research program for solar geoengineering — in coordination with other nations, subject to governance, and alongside a robust portfolio of climate mitigation and adaptation policies, says a new report from the National Academies of Sciences, Engineering, and Medicine. The report emphasizes that solar geoengineering is not a substitute for reducing greenhouse gas emissions."

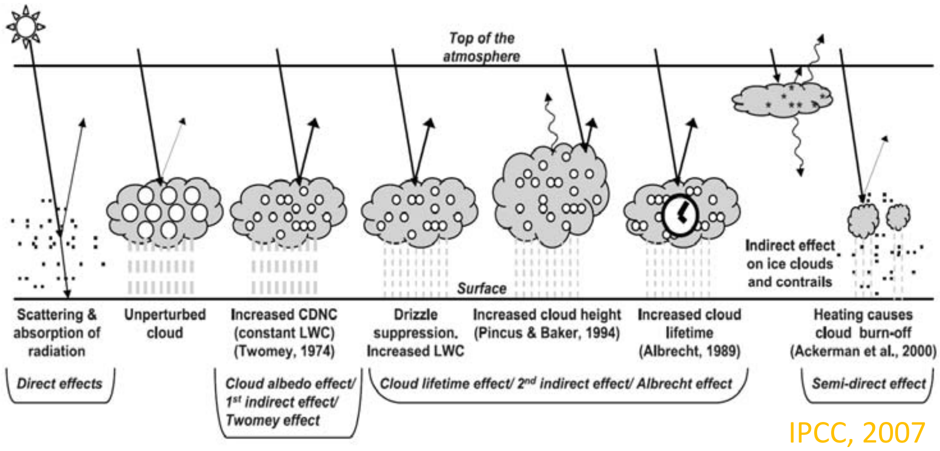
"The report says the U.S. Global Change Research Program (USGCRP) should lead the effort to establish and coordinate a solar geoengineering research program across federal agencies and scientific disciplines, with funding in the range of $100 million-$200 million over the first five years."

III. How to characterize aerosols?

Aerosol properties:

How many different kinds you can think of?

Aerosol properties and climate impacts

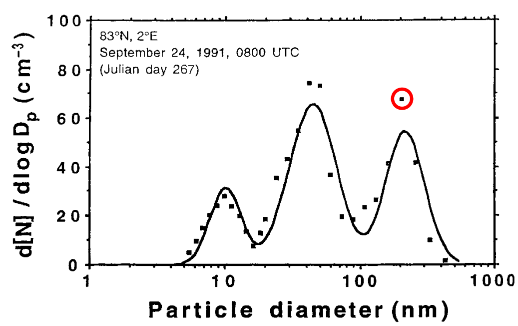


IPCC, 2007

Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

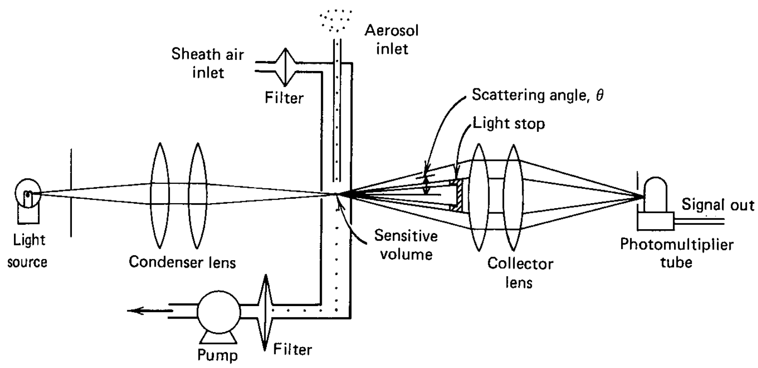
Particle Size Distributions

Example of size distribution (Number size distribution with three log-normal modes measured in the Arctic):



○ **How do we measure particle number and particle size ?**

Optical Particle Counter (OPC): ~ 100 nm to 5 μm



size limits defined by Mie scattering, which are used to interpret integrated scattered intensity.

Condensation Particle Counter

Saturate an aerosol with water or alcohol vapor

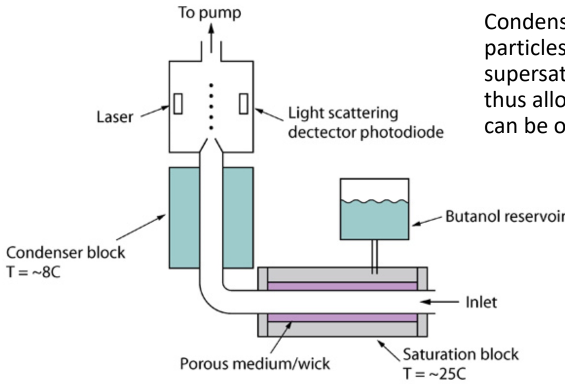
Cool by adiabatic expansion or flow through a cold tube

Nuclei will grow to ~ 10 μm

Every nuclei grows to a droplet

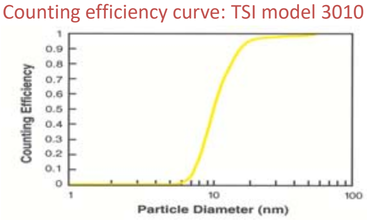
Measure the number of droplets with an e.g. single particle optical counter

Condensation Particle Counter (CPC): ~1.5 nm to 0.5 μm



Condensation Particle Counters (CPCs) detects particles by exposing them to a region that is supersaturated with vapor (usually butanol), thus allowing particles to grow to a size that can be optically detected.

Counting efficiency curve: TSI model 3010



DMA - Differential Mobility Analyzer

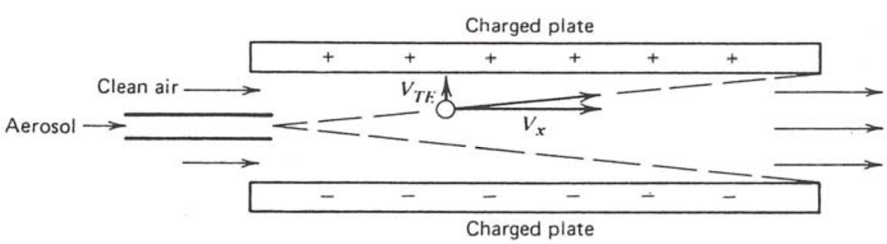


FIGURE 15.10 Diagram of a simple electrical mobility analyzer.

A charged particle will be pushed in the direction of V_{TE} by the electric field E between the two plates.

Hinds

DMA - Differential Mobility Analyzer

Stokes Drag on a particle

$F_d = 3 \pi \eta V d / Cf$

η = viscosity of air

V = transverse velocity (going from plate to plate)

d = diameter of the particle

Cf = 1 + (mean free path of particle) / d (correction factor)

Electric force on a particle with charge Q in electric field E is

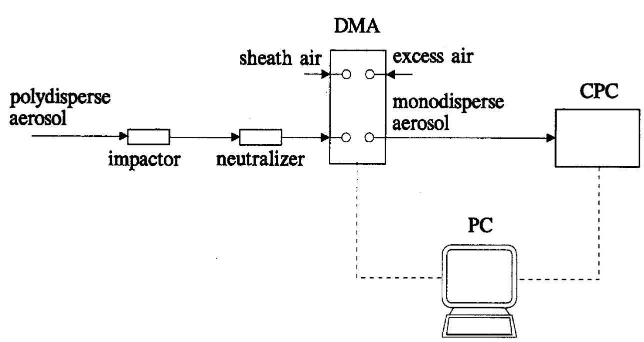
QE

Equate the two forces , solve for $V = Q E Cf / 3 \pi \eta d$

V = Q E B where B is called the Mobility

Hinds

DMA + CPC = Scanning Mobility Particle Sizer (SMPS) or Differential Mobility Particle Sizer (DMPS)

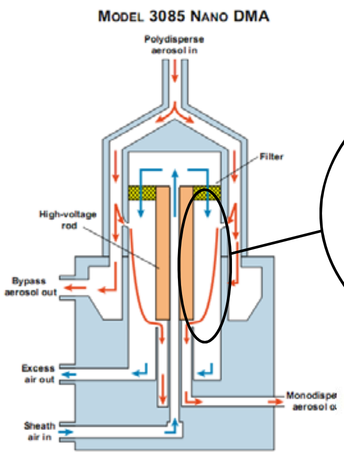


DMPS:

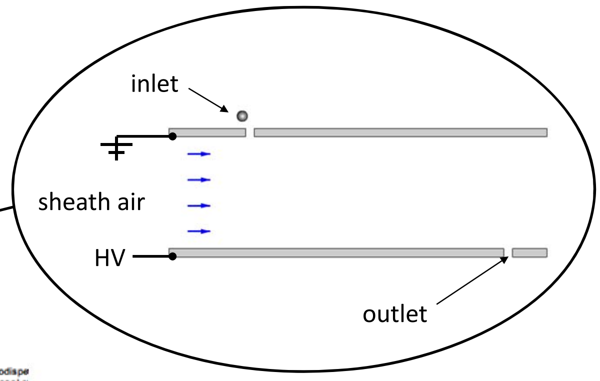
- A pre-impactor removes all particles larger than the upper diameter of the size range to be measured
- The particles are brought in the bipolar charge equilibrium in the bipolar diffusion charger.
- A computer program sets stepwise the voltage for each selected mobility bin.
- After a certain waiting time, the CPC measures the number concentration for each mobility bin.
- The result is a mobility distribution.
- The number size distribution must be calculated from the mobility distribution by a computer inversion routine.

Differential Mobility Analyzer (shown below, a "Nano DMA")

Efficiently size-selects charged particles for collection and analysis.



TSI, Inc.



Chen et al., 1998

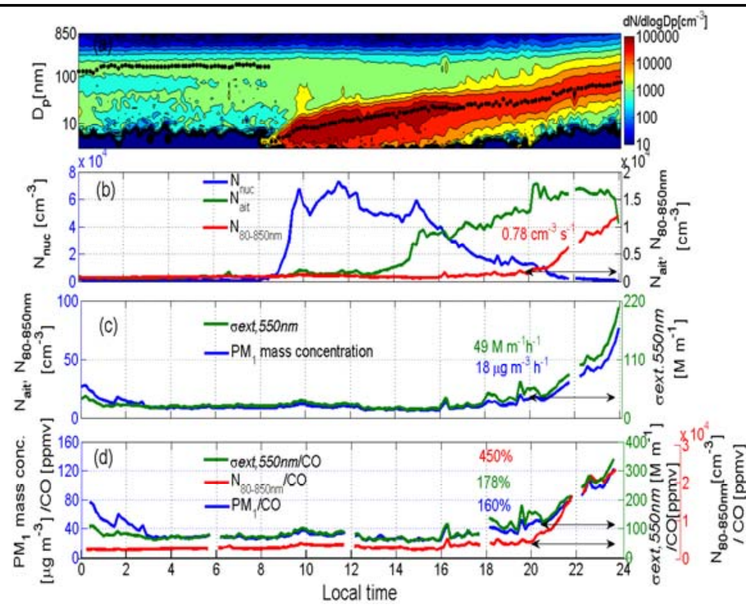
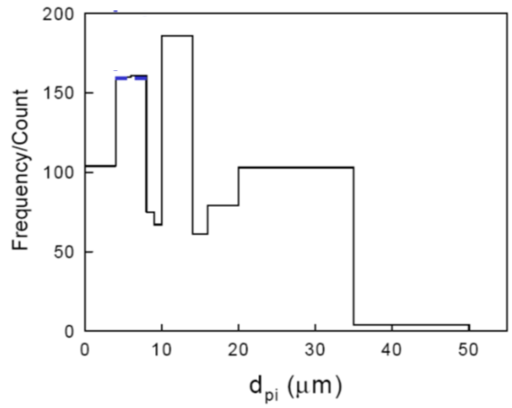


Fig. 9. The number size distribution at SDZ on 13 March 2008 and mode diameter (dots) **(a)**, evolution of the N_{nuc}, N_{ait} and $N_{80-850nm}$ respectively **(b)**, evolution of $\sigma_{ext,550nm}$, extinction coefficient at 550 nm and PM_1 mass concentration calculated from TDMPS data **(c)** and the normalized $N_{80-850nm}$, PM_1 mass concentration and $\sigma_{ext,550nm}$ by the concentration of CO. Shen et al., ACP, 2011

Histogram of frequency (count) versus particle size

Size Range (μm)	Count (#)
0-4	104
4-6	160
6-8	161
8-9	75
9-10	67
10-14	186
14-16	61
16-20	79
20-35	103
35-50	4
> 50	0
Total	1000

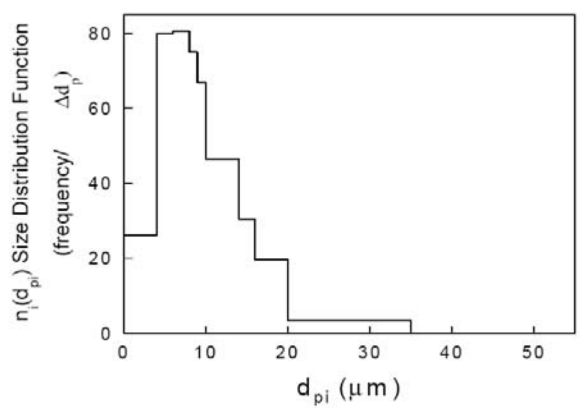


Q: Which size range has the most particles?

Q: See any problem in this approach of describing particle size distributions?

Frequency/Δd_p (distribution function) vs particle size

Size Range (μm)	Count/Δd_{pi} (#/μm)
0-4	26
4-6	80
6-8	80.5
8-9	75
9-10	67
10-14	46.5
14-16	30.5
16-20	19.25
20-35	6.87
35-50	0.27
> 50	0



$$n_i = \frac{Count_i}{\Delta d_{pi}}$$

Q: Total # of particles ?

Hands-on exercise of particle size distributions during the first part of next lecture, everyone needs to have access to excel in class

Key knowledge points of Lecture 1:

1. Atmospheric aerosols and their impacts

2. Aerosol properties and aerosol climate effects

3. Particle size distributions