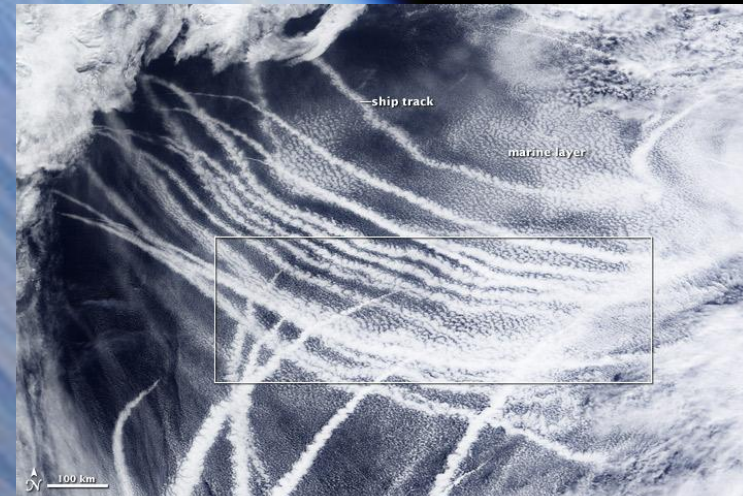
Aerosols and climate: the big climate impact of small particles



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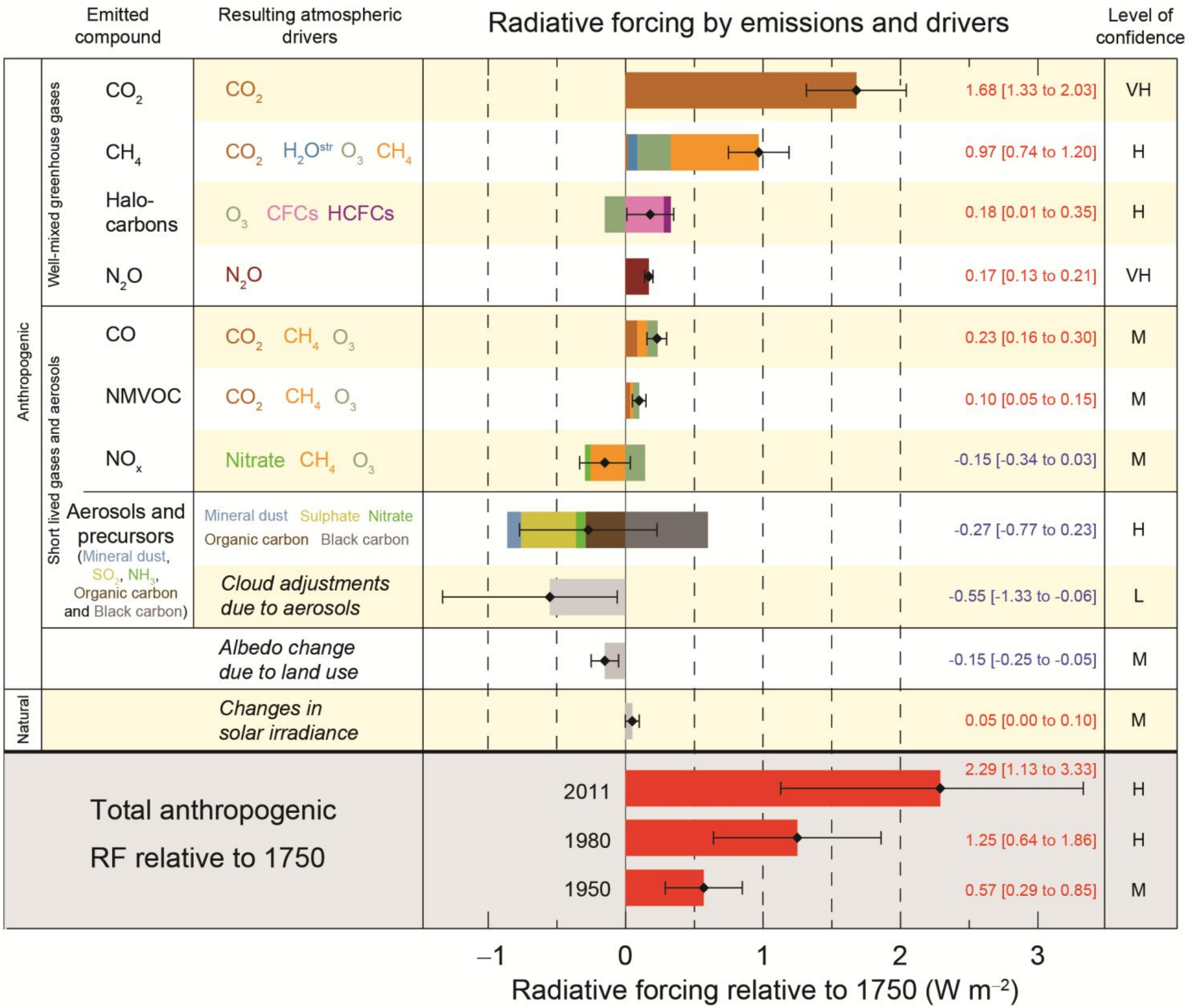
CSI – July 19, 2016

Western United States (nasa.gov)

Outline

- Introduction to aerosol – climate interactions
- Direct forcing & aerosol optical properties
- Cloud droplet nucleation
  - Aerosol size measurements & arctic observations

Global Average Climate Forcing Estimates



Taken From: IPCC, 5th Assessment Report, 2013

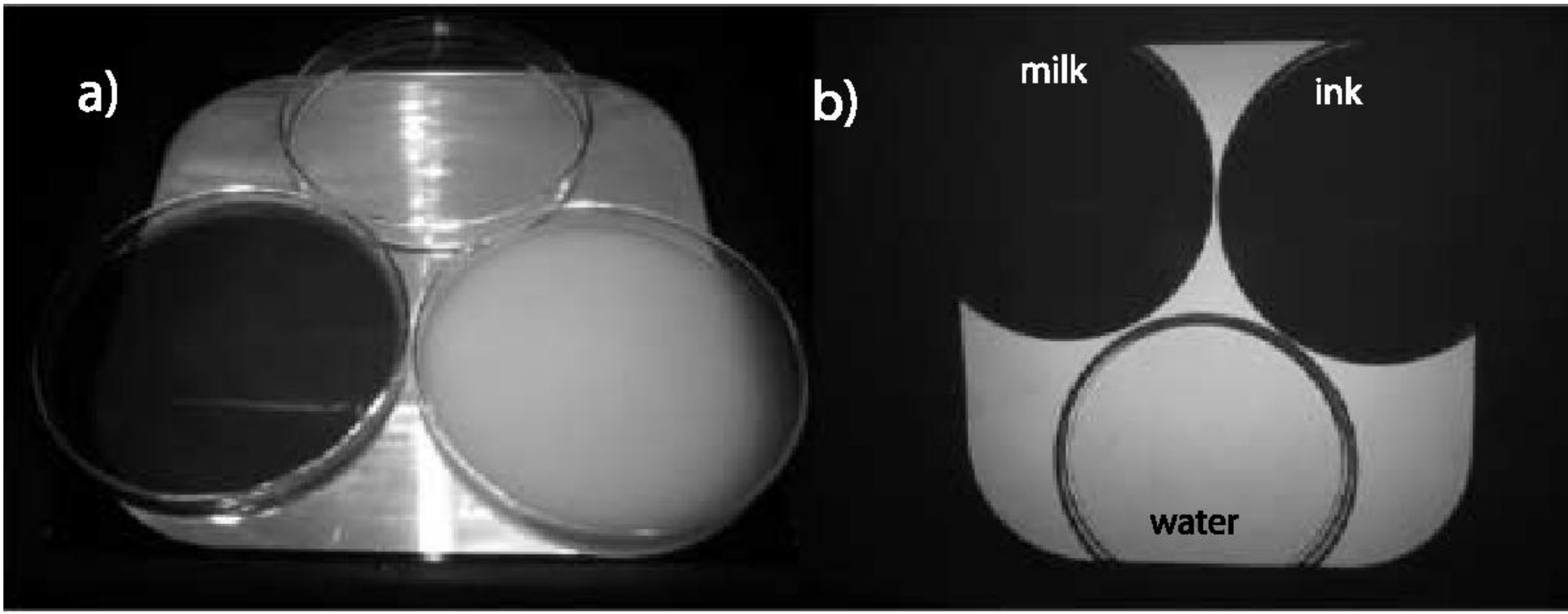
Mount Ruapehu, New Zealand (Photograph ©2007 New Zealand GeoNet)

Precipitation & Water Cycles

Extinction of radiation

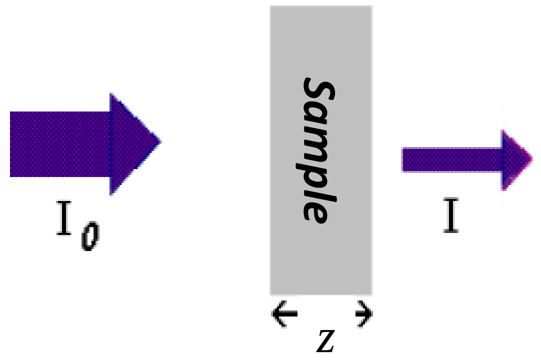
Scattering from milk, ink, and water on an overhead projector

Transmission through milk, ink, and water projected onto a screen



Beer-Lambert Law

The Beer-Lambert law describes the attenuation of light as it passes through a medium.



$$\frac{I(z)}{I_0} = e^{-b_{ext} z}$$

$$b_{ext} = b_{scat} + b_{abs}$$

The extinction coefficient, b_{ext} is the some of the scattering and absorption coefficients, b_{scat} and b_{abs}. All have units of (m^{-1}).

For milk $b_{ext} \approx b_{scat}$, and for ink $b_{ext} \approx b_{abs}$, and for water $b_{ext} \approx 0$.

Often single scattering albedo (SSA) is used as metric to indicate the importance of scattering versus absorption:

$$SSA = \frac{b_{scat}}{b_{ext}} = \frac{b_{scat}}{b_{scat} + b_{abs}}$$

Quiz! Clouds and soot…

Based on their appearance what you estimate is the value of SSA and the spectral dependence of b_{ext} for

- a cloud

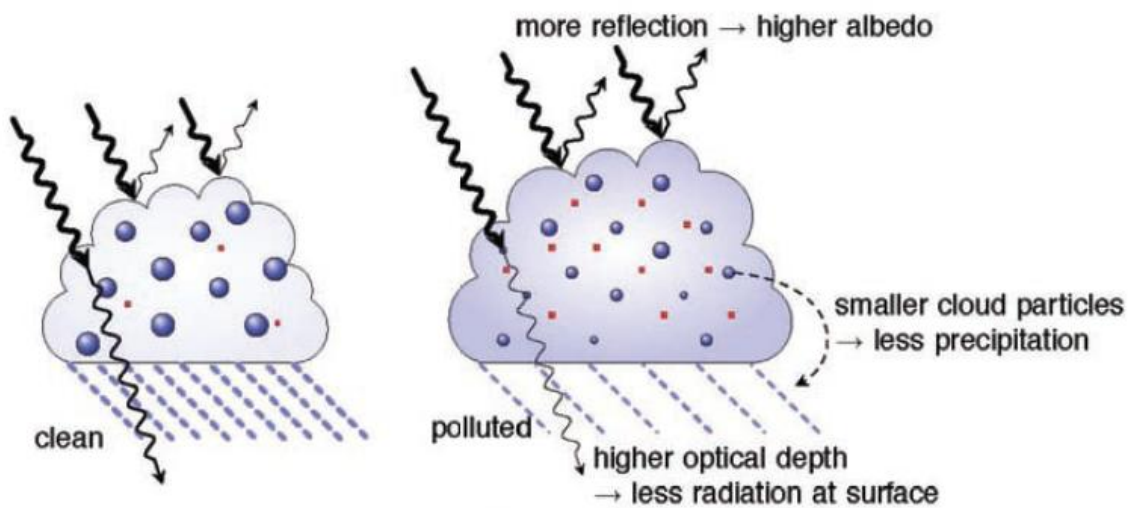
SSA $\approx$1, weak spectral dependence since color is white

- diesel exhaust fumes

Low SSA, weak spectral dependence since color is neutral

Effect	Cloud Types Affected	Process	Sign of Change in TOA Radiation	Potential Magnitude	Scientific Understanding
Cloud albedo effect	All clouds	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Negative	Medium	Low
Cloud lifetime effect	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby presumably prolonging cloud lifetime	Negative	Medium	Very low
Semi-direct effect	All clouds	Absorption of solar radiation by absorbing aerosols affects static stability and the surface energy budget, and may lead to an evaporation of cloud particles	Positive or negative	Small	Very low
Glaciation indirect effect	Mixed-phase clouds	An increase in IN increases the precipitation efficiency	Positive	Medium	Very low
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets delay freezing causing super-cooled clouds to extend to colder temperatures	Positive or negative	Medium	Very low

Cloud albedo and lifetime effect (negative radiative effect for warm clouds at TOA; less precipitation and less solar radiation at the surface)



IPCC

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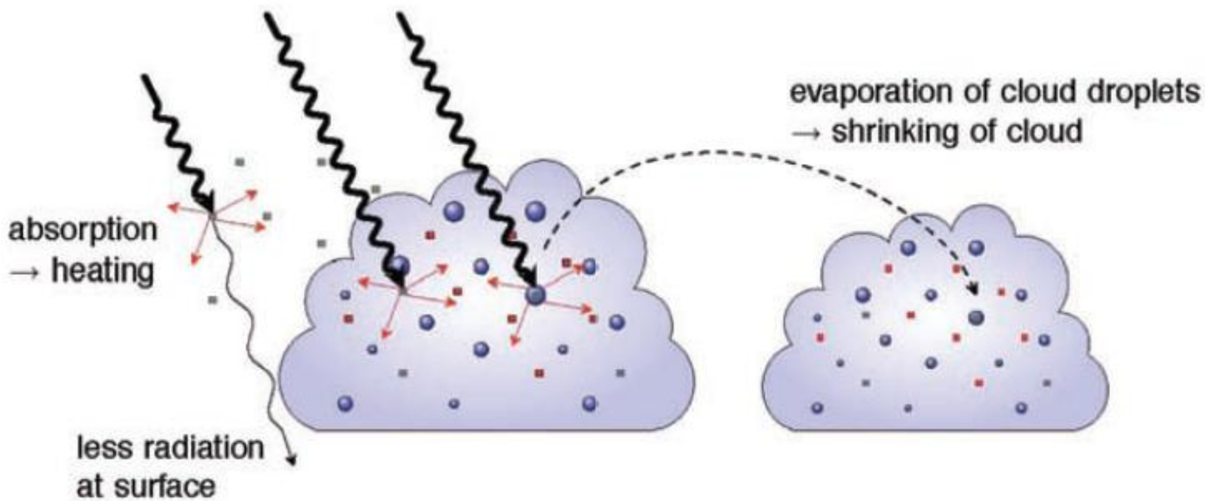
Semi-direct effect (positive radiative effect at TOA for soot inside clouds, negative for soot above clouds)



IPCC

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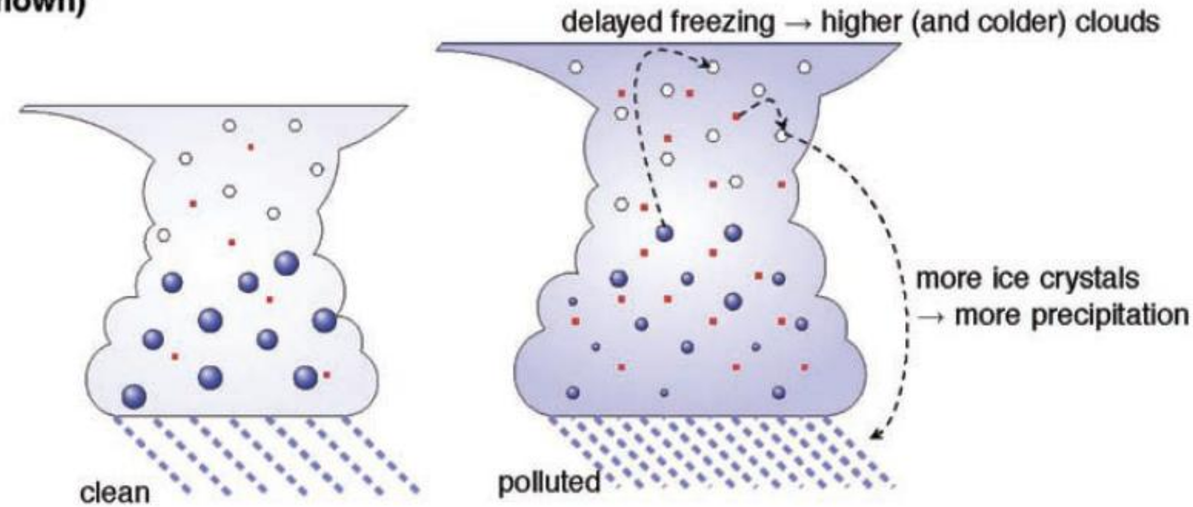
Glaciation effect (positive radiative effect at TOA and more precipitation), thermodynamic effect (sign of radiative effect and change in precipitation not yet known)



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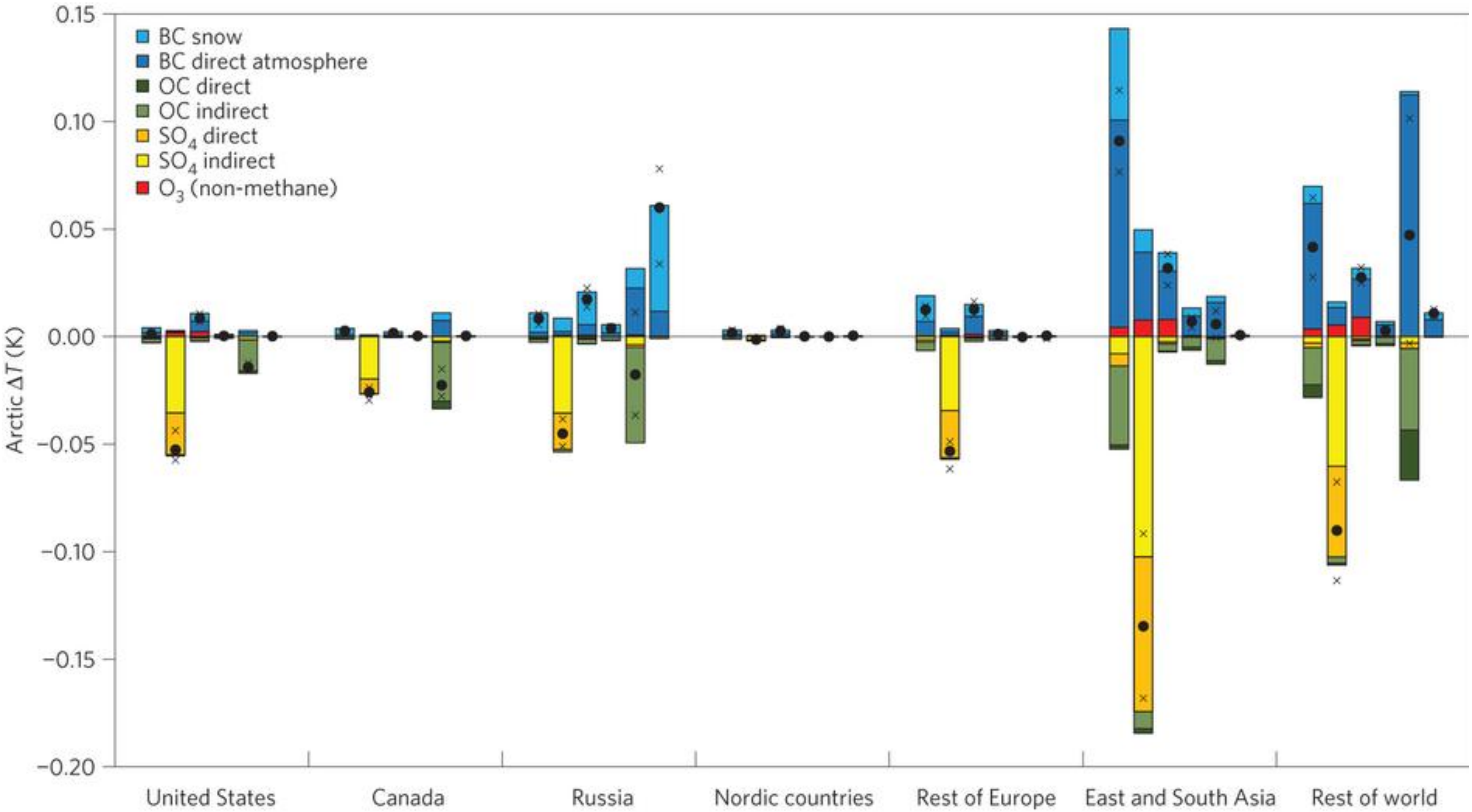
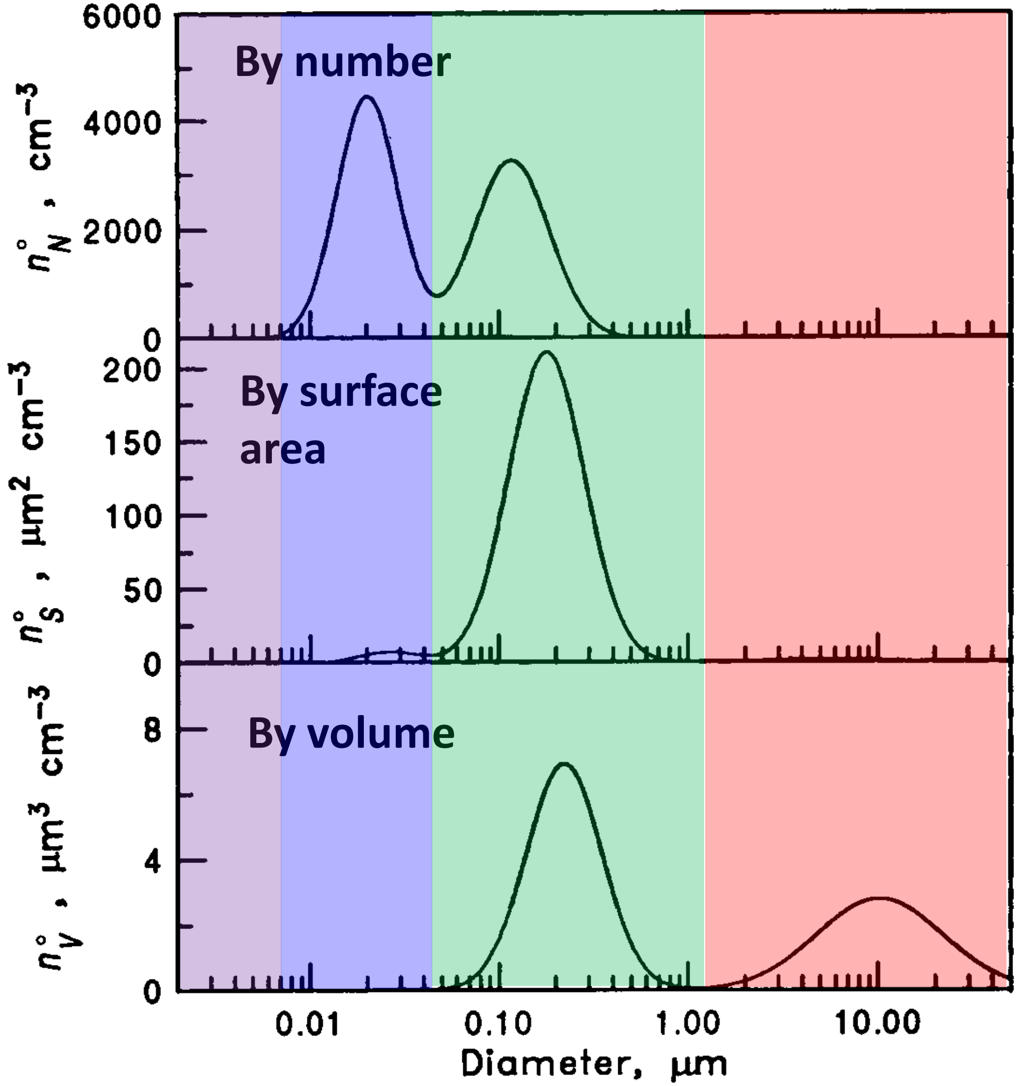
Surface temperature response to aerosols



Sand et al., *Nature Climate Change*, **2015,** *6,* 286.

Size distributions of particles



Nucleation mode

Aitken mode

Accumulation mode

Coarse mode

Seinfeld and Pandis "Atmospheric chemistry and physics: From air pollution to climate change", *Wiley-Interscience*

Scanning Mobility Particle Sizer (SMPS)

The SMPS allows measurement of nucleation mode and Aitken mode particles

The instrument contains two devices:

- A differential mobility analyzer used to generate monodisperse aerosols
- A condensation particle counter for measuring the number concentration

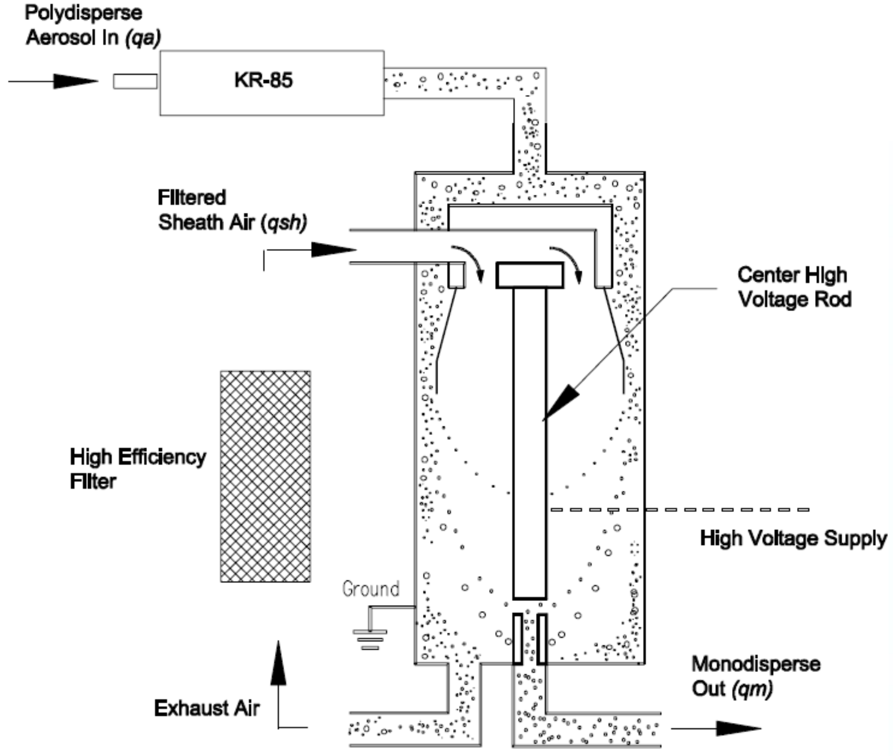
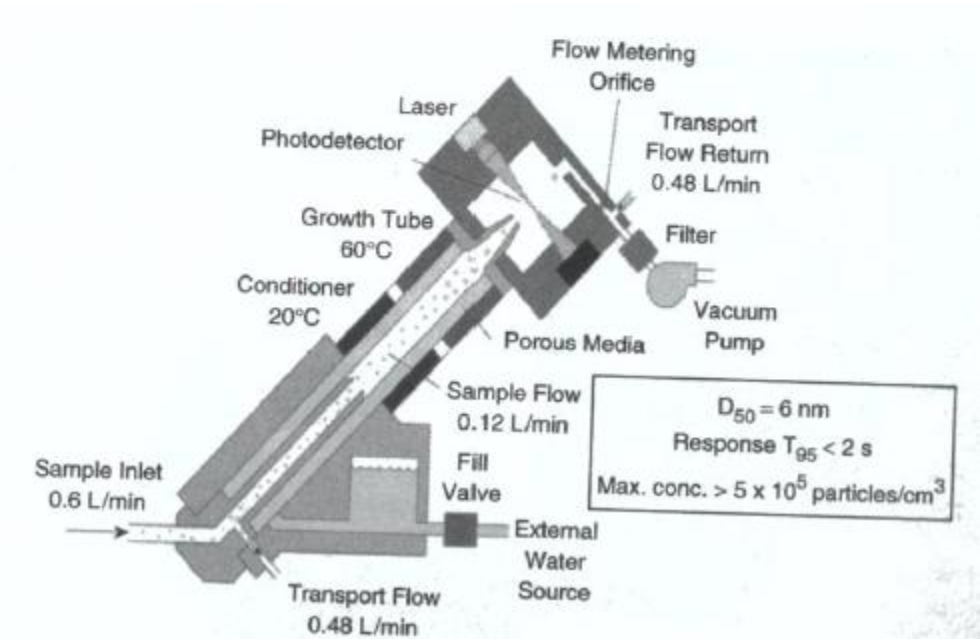


Figure B-1
DMA Column Schematic



Differential Mobility Analyser (DMA) **Condensation Particle Counter (CPC)**

Scanning Mobility Particle Sizer (SMPS)

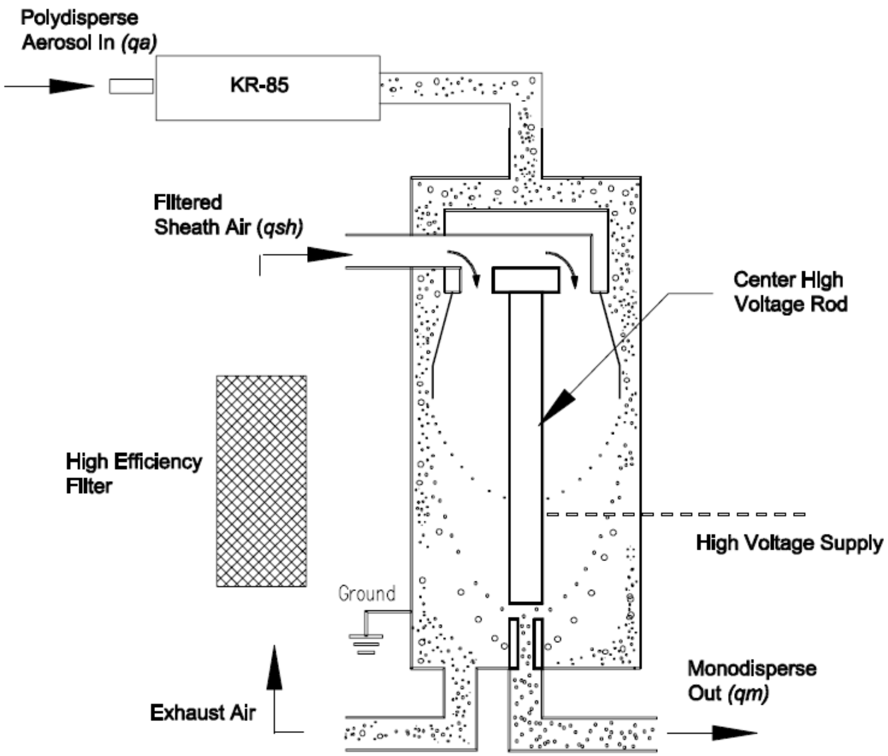
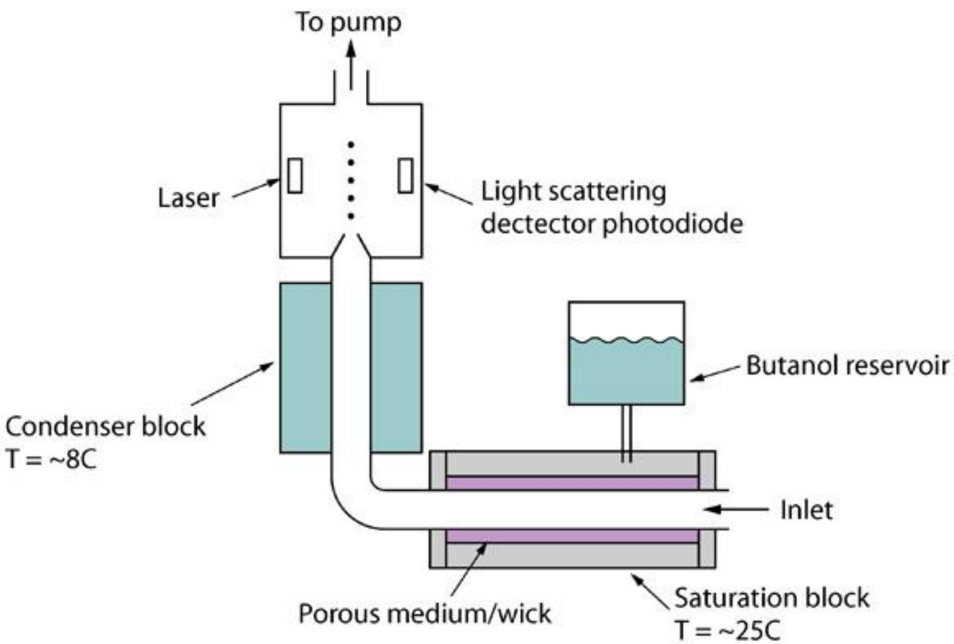


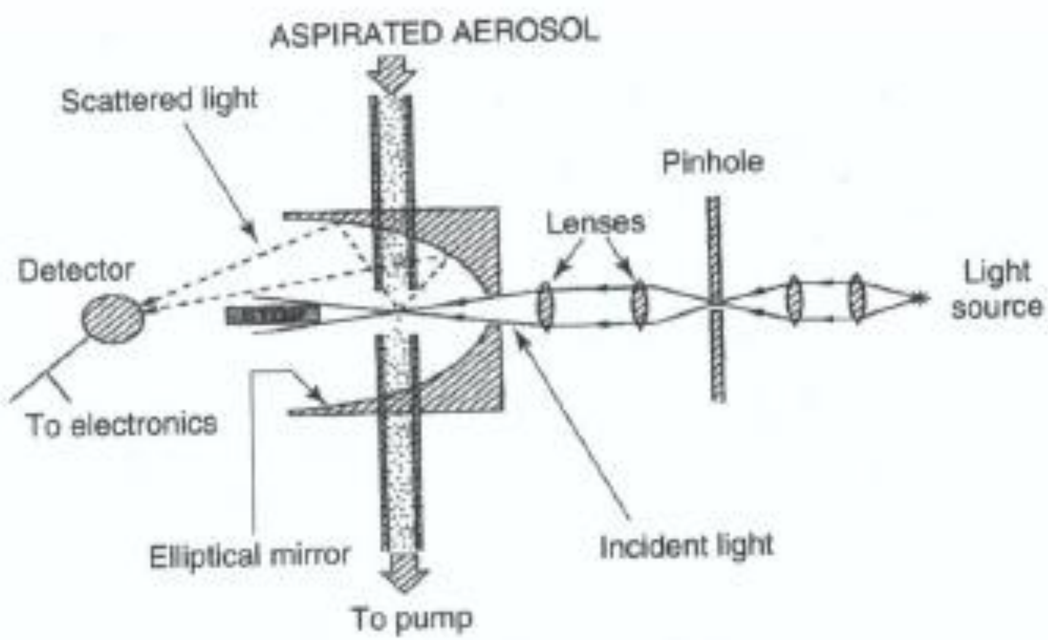
Figure B-1
DMA Column Schematic

Differential Mobilility Analyzer

- Ambient polydisperse aerosol distribution
- Radiation source is used to give aerosols known charge distribution
- In the DMA column, particle-laden air passes along the column walls
- Sheath air flowing through the center of the column is particle free
- Electrostatic potential applied between center rod and column wall
- The trajectories of the particles are a function of particle size
- Selected diameter passes through the column exit port.

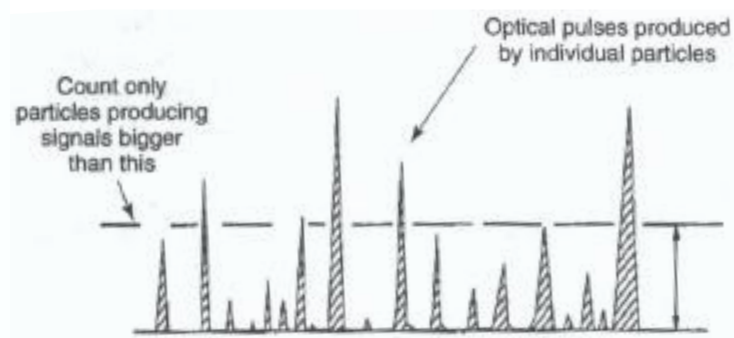
Scanning Mobility Particle Sizer (SMPS)





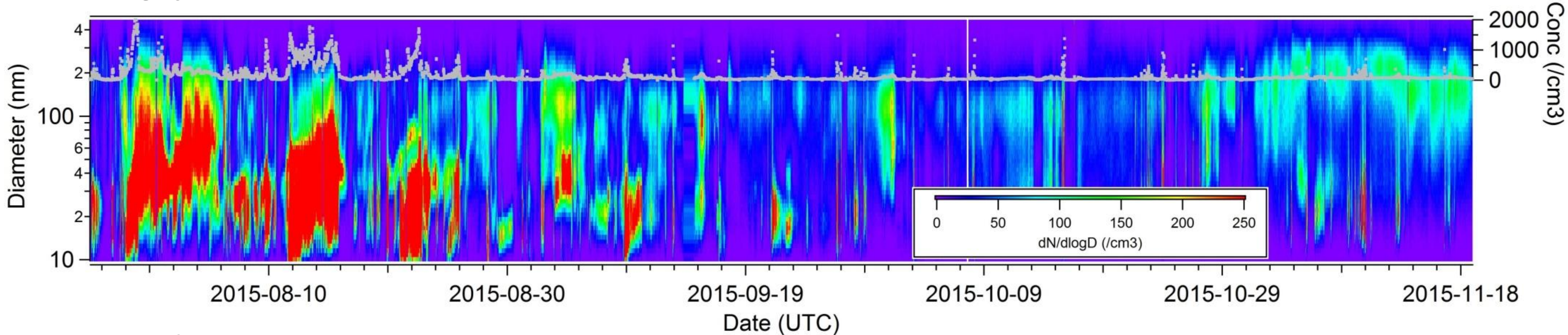
Condensation Particle Counter

- In the saturation block, the air flow is saturated in butanol
- Particles then pass to the condenser block where the air is cooled and becomes supersaturated
- The aerosols can now serve as condensation nuclei
- Light scattering is then used to count the concentration of droplets

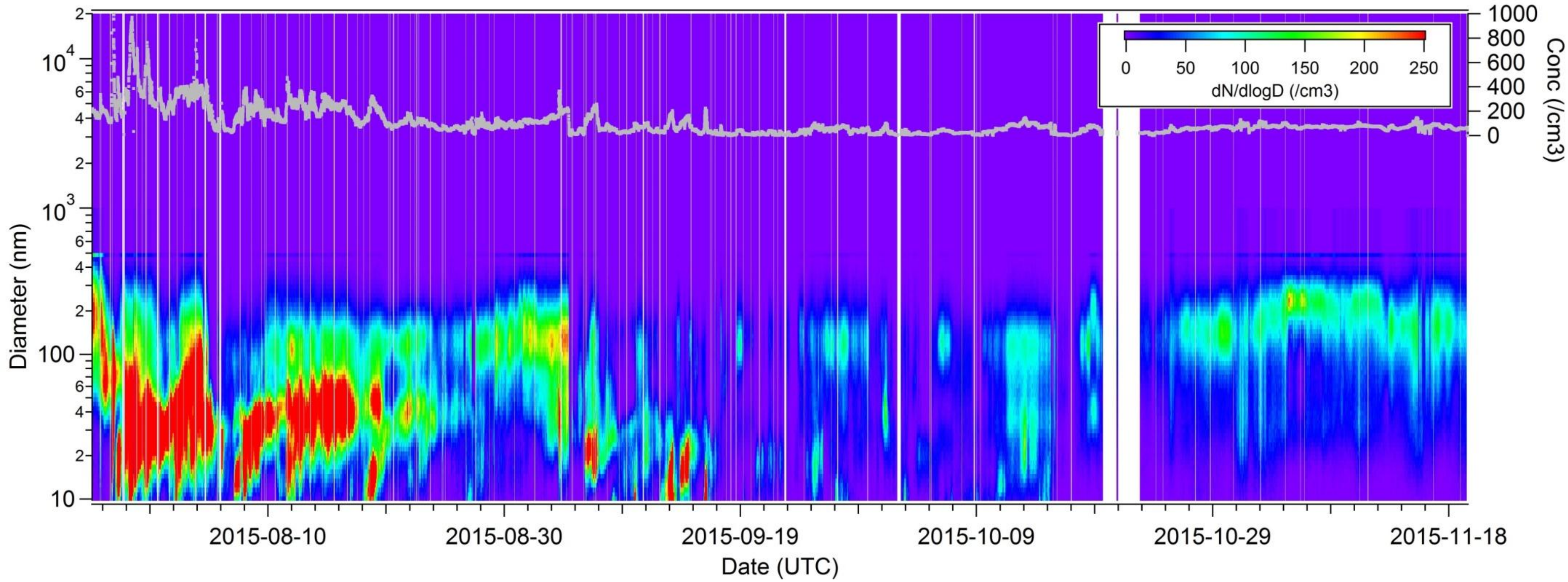


Aerosol Size Distribution

Alert

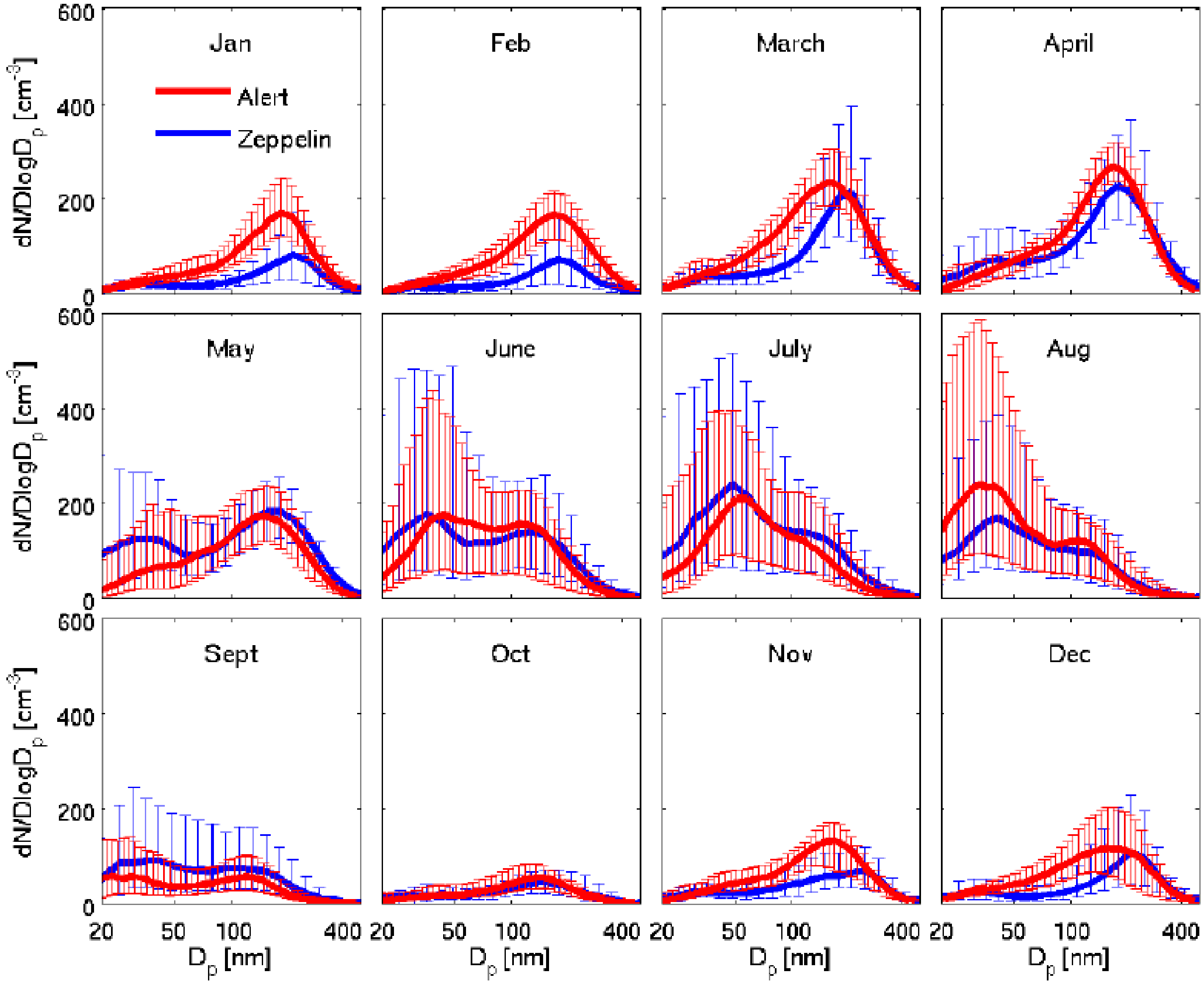


Eureka



Smaller particles will tend to have greater indirect rather than direct forcing

Size distributions of Arctic aerosol



Alert

Zeppelin

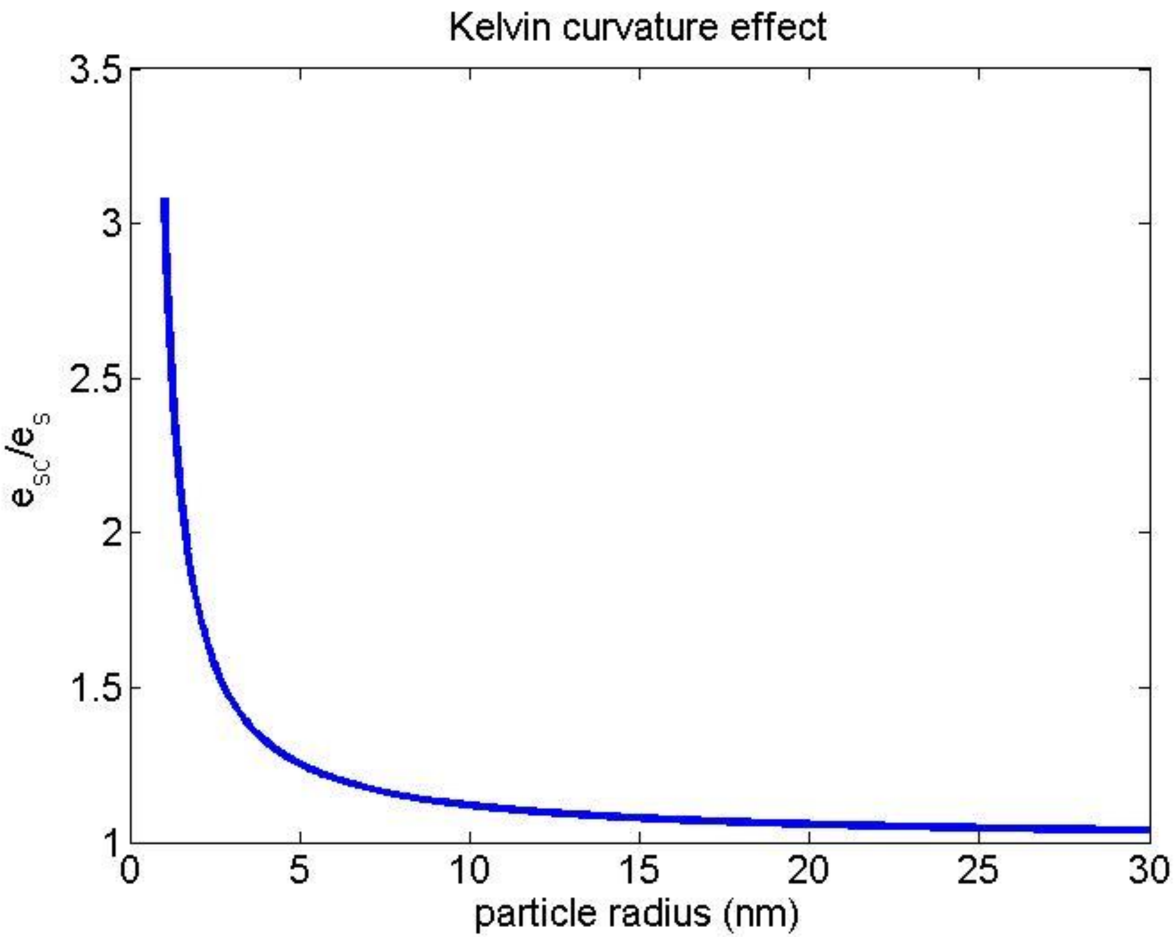
2011 - 2013

Croft et al., *Atmos. Chem. Phys. Discuss.*, 15: 129079, 2015

Cloud droplet nucleation by particles

- Process by which droplets (several microns in size) are formed from particles; also called heterogeneous nucleation
  - To what size will dry particles grow at a given atmospheric supersaturation?
  - Will the particles grow into large cloud droplets or will the particle diameters remain small (haze).
  - *Koehler theory is used to address these questions*

Cloud Nucleation : Kelvin Effect

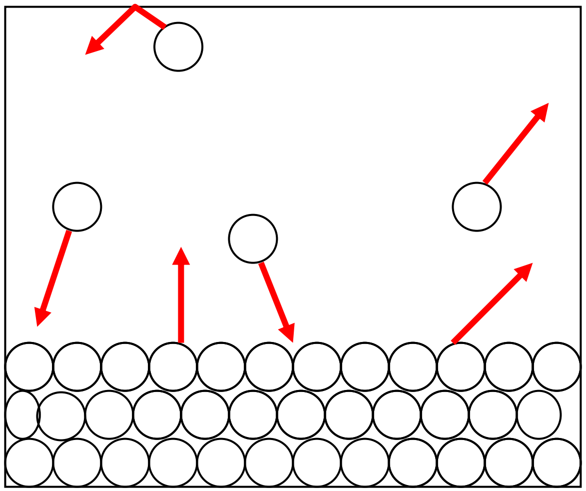


Rate of evaporation increases with curvature of droplet due to reduced H-bonding

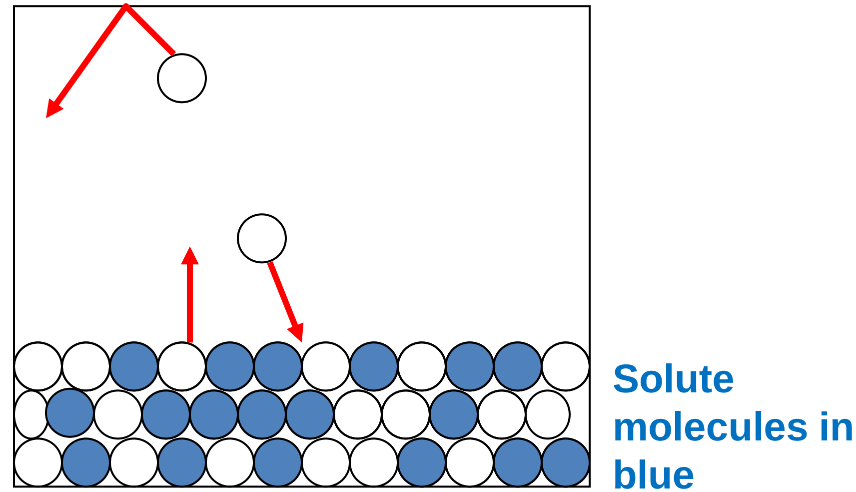
Very high saturation vapor pressures over small droplet compared to flat water surface

Raoult's Law

$$P^{o}_{H2O,SAT}$$



$$P_{H2O,SAT} = x_{H2O} P^{o}_{H2O,SAT}$$

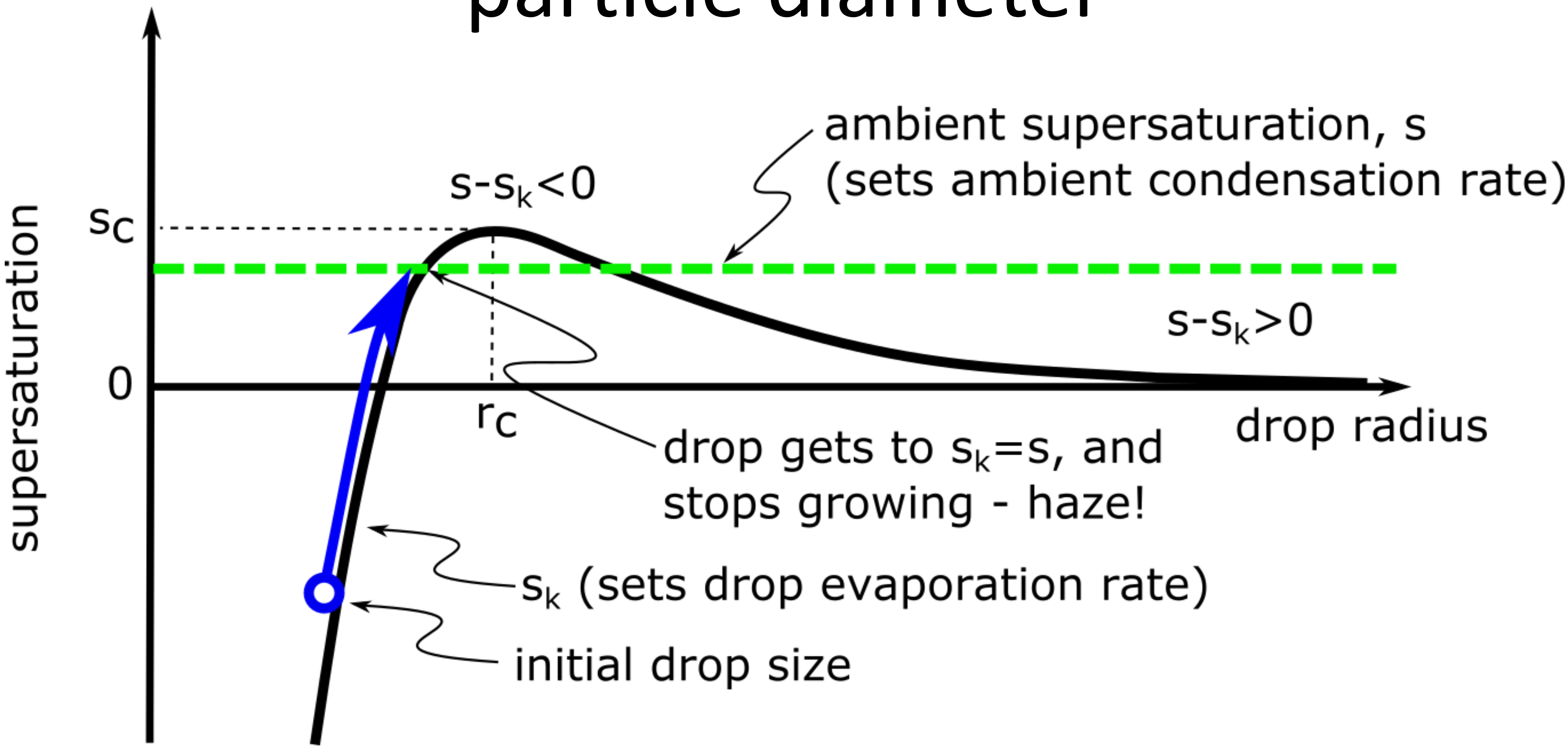


The presence of dissolved species on the surface of water reduced the speed of evaporation

- The saturation vapor pressure is proportional, $P_{H2O,\ SAT}$, is the product of the molar fraction of water and the saturation vapor pressure of pure water, $P^{\circ}_{H2O,SAT}$.

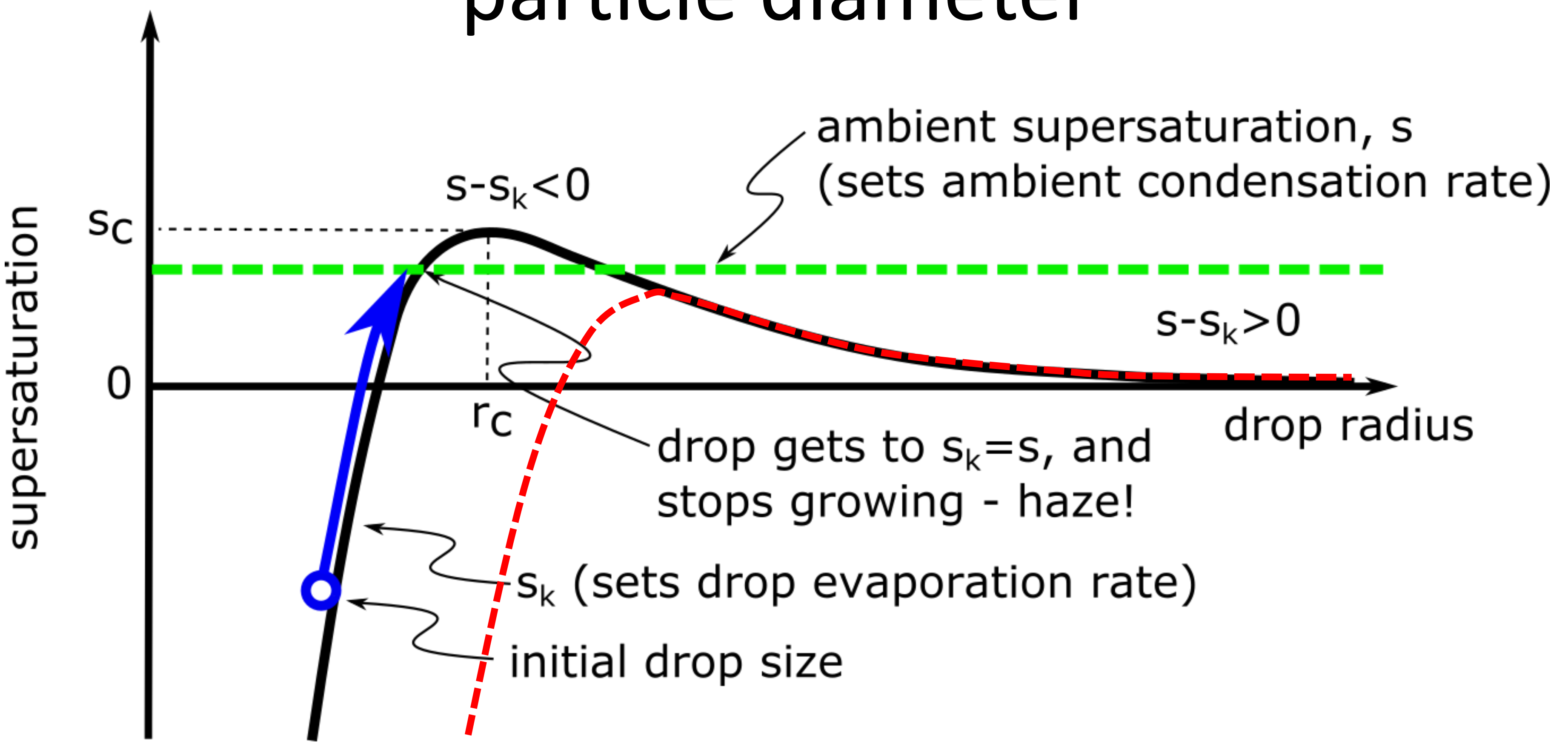
D. Jacob

Koehler Theory: Cloud nucleation and particle diameter



W. Brune

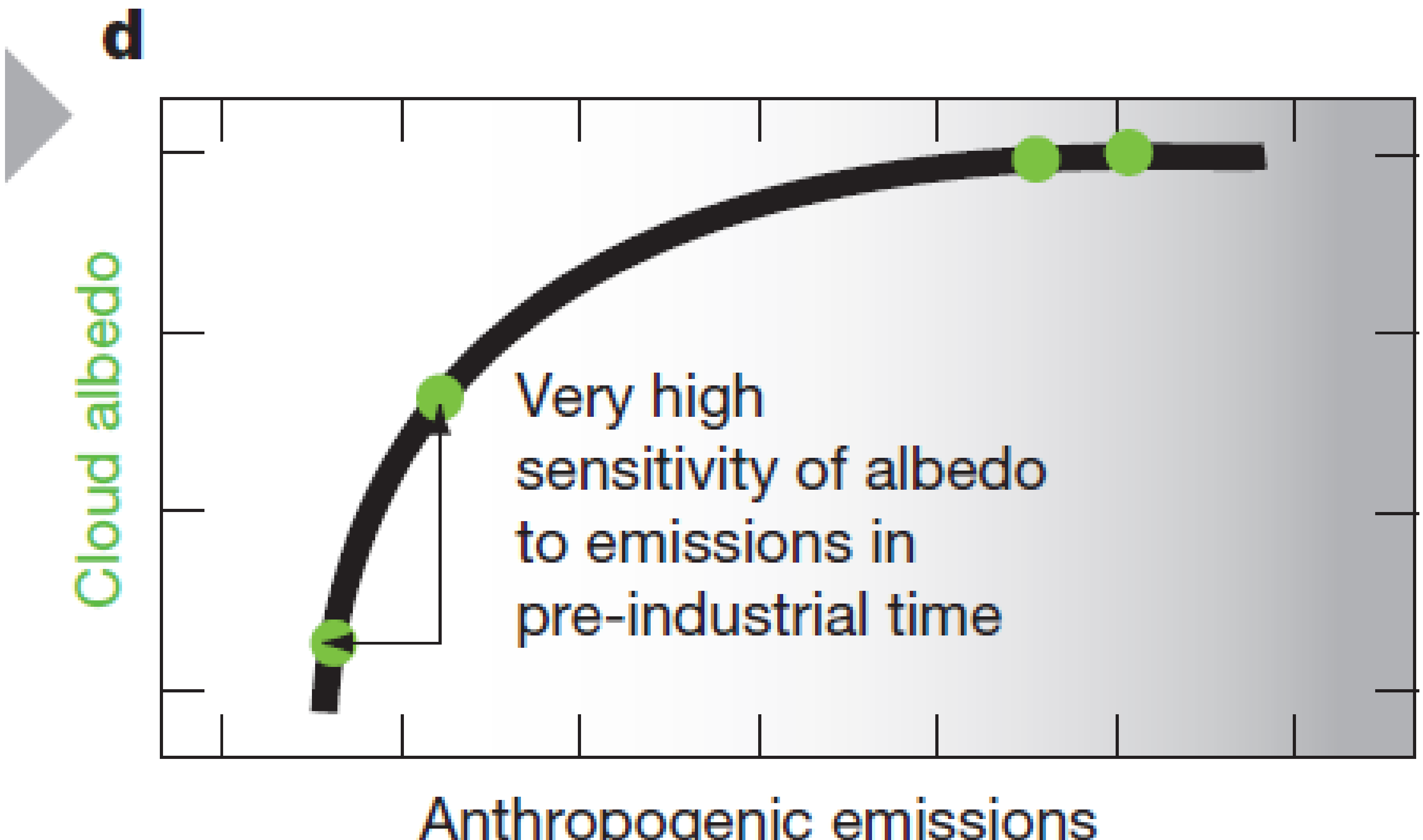
Koehler Theory: Cloud nucleation and particle diameter



Larger initial dry particle sizes will favor cloud nucleation

W. Brune

Arctic atmosphere sensitive to aerosol concentrations



Carslaw et al., *Nature*, 503:67, 2013

Questions / Discussion