# Cloud microphysics

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# Overview of cloud physics lecture

- Atmospheric thermodynamics
  - gas laws, hydrostatic equation
  - 1st law of thermodynamics
  - moisture parameters
  - adiabatic / pseudoadiabatic processes
  - stability criteria / cloud formation
- Microphysics of warm clouds
  - nucleation of water vapor by condensation
  - growth of cloud droplets in warm clouds (condensation, fall speed of droplets, collection, coalescence)
  - formation of rain
- Microphysics of cold clouds
  - homogeneous nucleation
  - heterogeneous nucleation
  - contact nucleation
  - crystal growth (from water phase, riming, aggregation)
  - formation of precipitation
- Observation of cloud microphysical properties
- Parameterization of clouds in climate and NWP models

# Energy increase due to formation of droplet

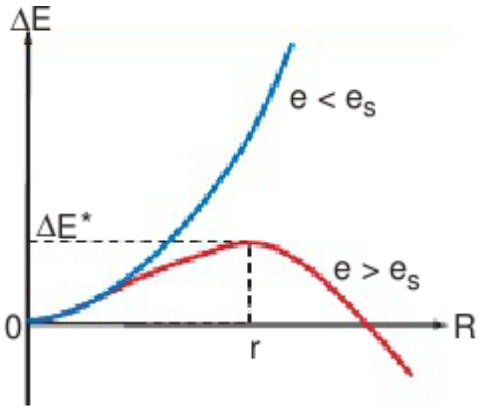



**Fig. 6.1** Increase $\Delta E$ in the energy of a system due to the formation of a water droplet of radius $R$ from water vapor with pressure $e$; $e_s$ is the saturation vapor pressure with respect to a plane surface of water at the temperature of the system.

Figure from Wallace and Hobbs

- blue curve: subsaturated conditions, formation of droplets not possible
- red curve: supersaturated conditions, droplets grow above radius r

# Kelvin equation

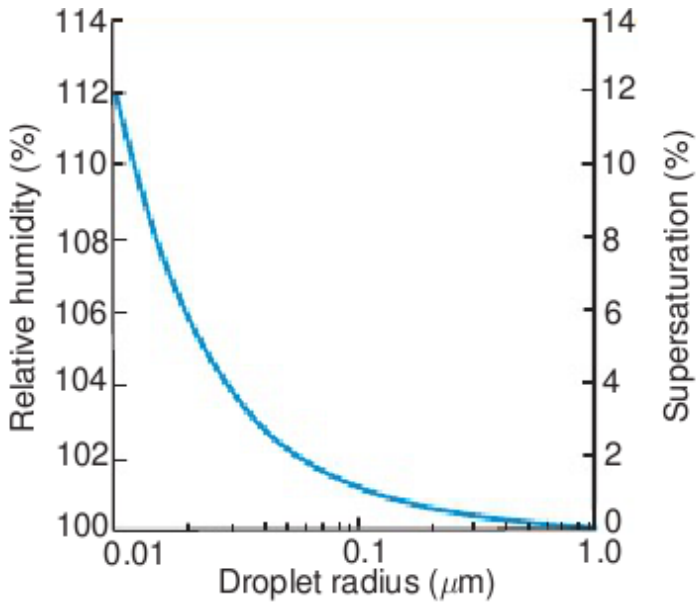


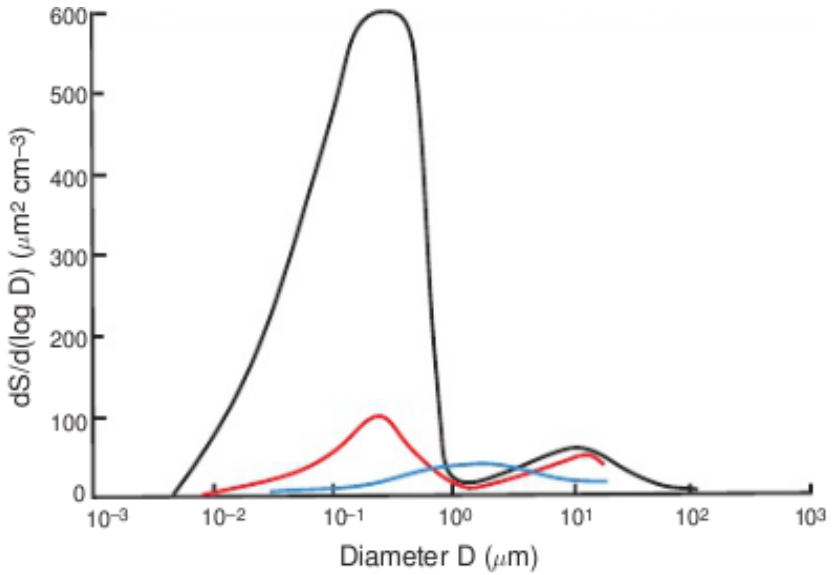

**Fig. 6.2** The relative humidity and supersaturation (both with respect to a plane surface of water) at which pure water droplets are in (unstable) equilibrium at 5 °C.

Figure from Wallace and Hobbs

## Kelvin equation

$$r = \frac{2\sigma}{nkT \ln \frac{e}{e_s}}$$

# Atmospheric aerosols




| Desig-nation | Aitken nuclei | Large particles | Giant particles |
|---|---|---|---|
| Sources | Combustion; Gas-to-particle conversions; Coagulation of Aitken nuclei; Cloud droplet evaporation | Fly ash, sea-salt, pollens | Windblown dusts; Giant particles from industries |
| Sinks | Coagulation; Capture by cloud particles | Precipitation scavenging; Dry fallout | |
| Resi-dence time | Less than an hour in polluted air or in clouds | Days to weeks | Hours to days; Minutes to hours |

**Fig. 5.11** Schematic curves of particle surface area distributions for urban polluted air (black line), continental air (red line), and marine air (blue line). Shown below the curves are the principal sources and sinks of atmospheric particles and estimates of their mean residence times in the troposphere. [Adapted from *Atmos. Environ.* **9**, W. G. N. Slinn, Atmospheric aerosol particles in surface-level air, 763, copyright (1975), with permission from Elsevier.]

# Köhler curves

$$\frac{e}{e_s} = \left(\exp \frac{2\sigma'}{n'kTr}\right)\left(1 + \frac{imM_w}{M_s\left(\frac{4}{3}\pi r^3\rho' - m\right)}\right)^{-1}$$

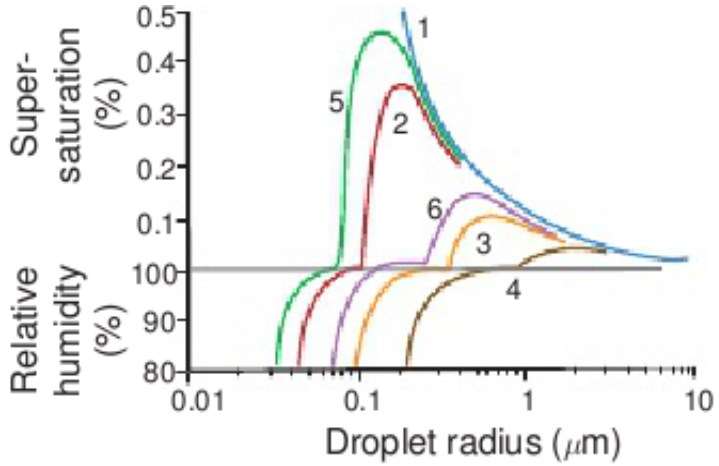



**Fig. 6.3** Variations of the relative humidity and supersaturation adjacent to droplets of (1) pure water (blue) and adjacent to solution droplets containing the following fixed masses of salt: (2) $10^{-19}$ kg of NaCl, (3) $10^{-18}$ kg of NaCl, (4) $10^{-17}$ kg of NaCl, (5) $10^{-19}$ kg of $(NH_4)_2SO_4$, and (6) $10^{-18}$ kg of $(NH_4)_2SO_4$. Note the discontinuity in the ordinate at 100% relative humidity. [Adapted from H. R. Pruppacher, "The role

Figure from Wallace and Hobbs

# Köhler curves

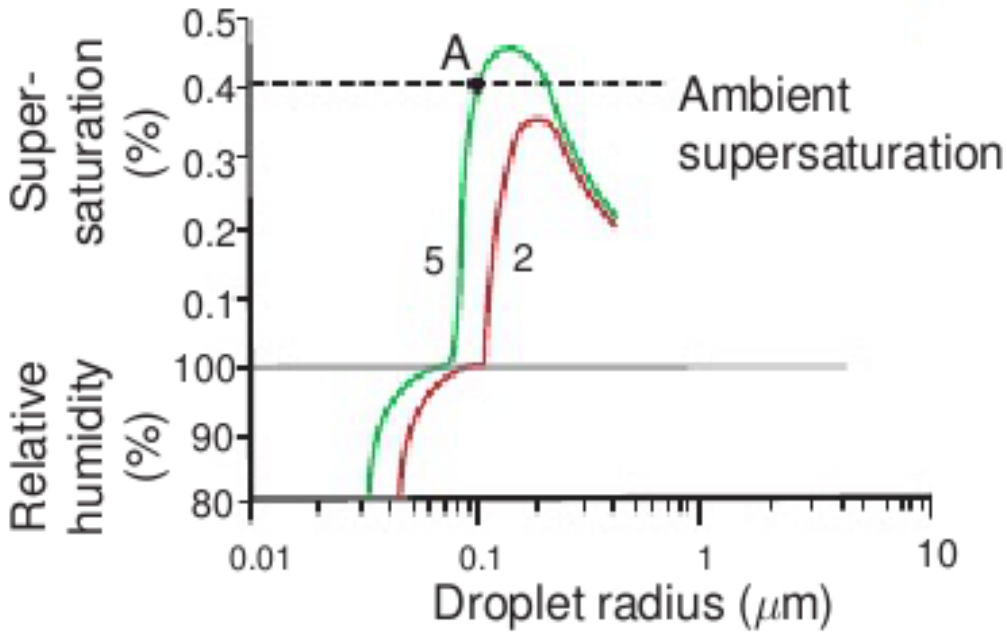



**Fig. 6.4** Köhler curves 2 and 5 from Fig. 6.3. Curve 2 is for a solution droplet containing $10^{-19}$ kg of NaCl, and curve 5 is for a solution droplet containing $10^{-19}$ kg of $(NH_4)_2SO_4$. The dashed line is an assumed ambient supersaturation discussed in the text.

# Cloud condensation nuclei

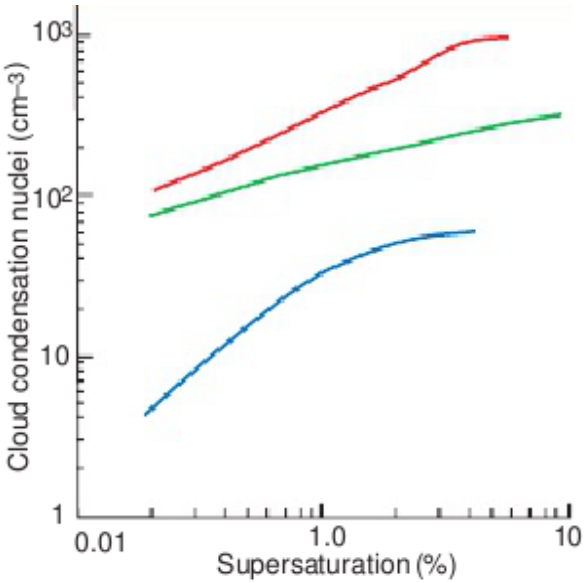



**Fig. 6.5** Cloud condensation nucleus spectra in the boundary layer from measurements near the Azores in a polluted continental air mass (brown line), in Florida in a marine air mass (green line), and in clean air in the Arctic (blue line). [Data from J. G. Hudson and S. S. Yun, "Cloud condensation nuclei spectra and polluted and clean clouds over the Indian Ocean," *J. Geophys. Res.* **107**(D19), 8022, doi:10.1029/2001JD000829, 2002. Copyright 2002 American Geophysical Union. Reproduced/modified by permission of American Geophysical Union.]

Figure from Wallace and Hobbs

- no systematic latitudinal or seasonal variations have been found so far
- near Earth's surface: continental air masses contain larger concentrations of CCN than marine air masses
- soil and dust $\Rightarrow$ not the dominant source
- forest fire, engine emission $\Rightarrow$ efficient CCNs
- not yet clear, which are the dominant sources for cloud formation

# Organic aerosols as CCN

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Review

## Atmospheric organic and bio-aerosols as cloud condensation nuclei (CCN): A review

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**Abstract**

Organic substances have been recognized as active cloud condensation and ice formation nuclei for several decades. In some regions of the world, these organic compounds (OC) consist predominantly of suspended matter mass, which can have local (e.g. toxicity, health hazards) and global (e.g. climate change) impacts. However, due to the complexity of their chemical nature, the significance of organic molecules in driving physical and chemical atmospheric processes is still very uncertain and poorly understood. The aim of this review paper is to assess the current state of knowledge regarding the role of organic aerosols (including bioaerosols) as cloud condensation nuclei (CCN), as well as to compare the existing theoretical and experimental data. It seems that classical Kohler theory does not adequately describe the hygroscopic behaviour of predominantly identified organic CCN such as pure dicarboxylic acid particles. Factors such as surface tension, impurities, volatility, morphology, contact angle, deliquescence, and the oxidation process should be considered in the theoretical prediction of the CCN ability of OC and the interpretation of experimental results. Major identified constituents of organic CCN, their main sources and their CCN properties will be herein reviewed. We will also discuss areas of uncertainty and expose key issues deserving of future research.

# Organic aerosols as CCN

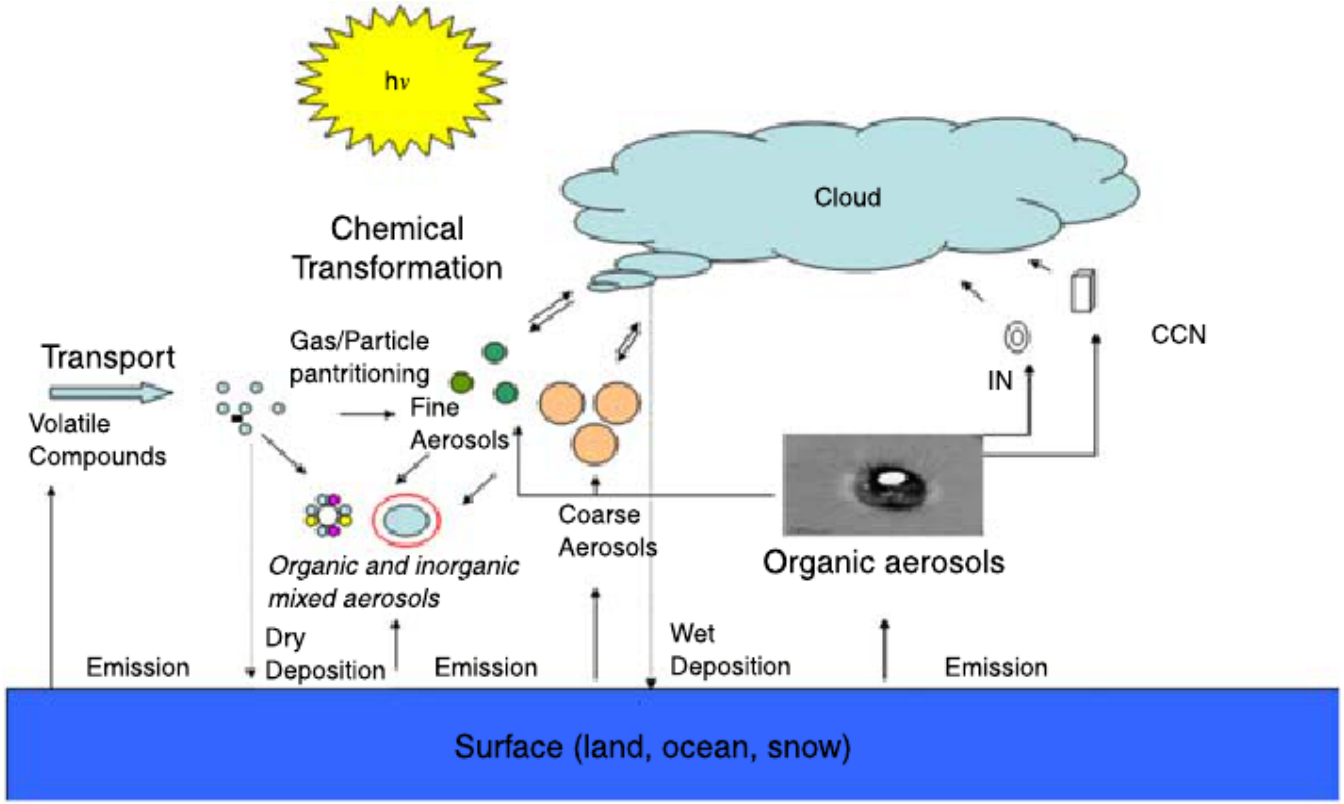
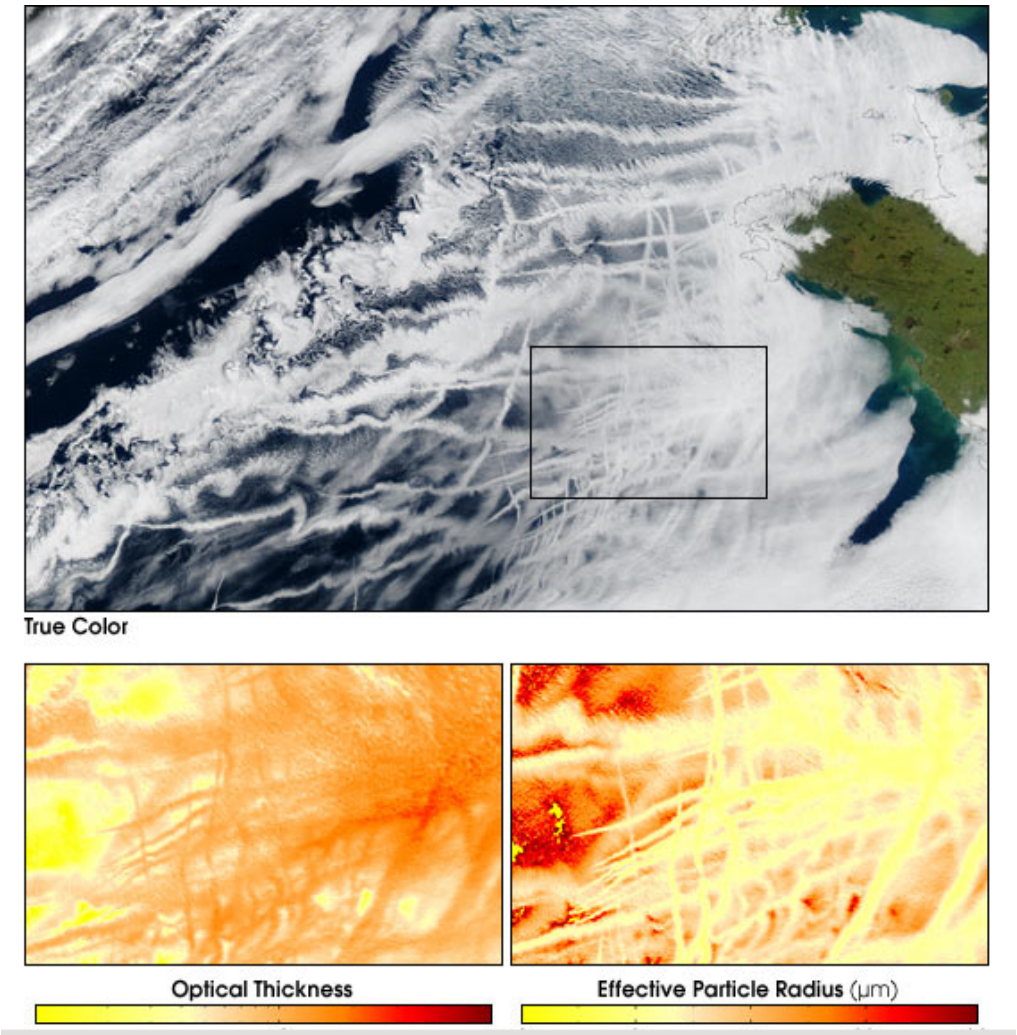



Fig. 1. The simplified schematic of organic aerosol transformation in atmosphere.

from Sun and Ariya 2005

# Ship tracks




http://earthobservatory.nasa.gov/IOTD/view.php?id=3275