Chapter 9. Condensation

Ch 9 covers:

- microscopic process leading to formation of cloud (but excluding the processes that convert cloud droplets to precipitation – Ch 10)

- lifting mechanisms to chill the air, leading to cloud

- cloud recognition/classification

- the everyday "benchmark" for relative humidity is the equilibrium vapour pressure over a flat surface of pure water $e^*$

- but cloud droplets are not flat, and not pure – they contain solute, because the water has aggregated onto pre-existing aerosol particles

- Ross: "in theory, when saturation is reached, the water vapour should condense"

- rephrasing Ross: it is tempting to think that droplets would form if (but only if) vapour pressure $e$ increased to the benchmark value $e^*(T)$ . (It isn't that simple!)

- mass droplet

\[
\frac{\text{mass droplet}}{\text{mass raindrop}} = \left[\frac{10 \mu m}{1 \text{ mm}}\right]^3 \approx 10^{-6}
\]

Fig 10.2
relative humidity in clouds rarely goes above about 101%
a considerably higher degree of supersaturation would be required to prevent evaporation of sub-micron sized water droplets
"homogeneous nucleation," i.e. formation of pure water droplets by collision and aggregation of vapour molecules, is **NOT** the mechanism for creating cloud droplets
hetereogeneous nucleation: water molecules condense onto aerosols capable of acting as cloud condensation nuclei (CCN)
to act as CCN, aerosols must be "hydrophilic" (wettable)
initial radius of wet CCN ≈ aerosol size

if water deposits onto a **wettable** aerosol with radius 0.2 μm, it **forms a film** over the surface; and can grow if RH exceeds about 100.5%

For droplet with radius ~ 1 μm, equilib. v.p. same as for plane surface
hygroscopic CCN are aerosols that dissolve in the water that deposits onto them.

- a small mass of (e.g.) salt dissolved in a droplet permits that droplet to be in equilibrium in sub-saturated air... the solute effect. Water will condense onto salt aerosols with RH as low as 70-80%.

Suppose cloud RH is 100.2%.

- $10^{-19}$ kg NaCl will grow until its radius is about 0.16 µm.
- $10^{-18}$ kg NaCl can grow without limit ("is activated") so long as RH of the air is sustained.

At equal temperature, the equil. v.p. over a plane surface of a solution is lower than that over a plane surface of pure water.
considering the population of activated droplets (those able to grow without limit, i.e. those for which the peak of the Kohler curve lies below cloud RH), the smaller ones grow faster than the big ones** – tending to give the cloud a distribution of same-sized cloud droplets

this population "competes" for water, the finite supply of which ultimately limits droplet size growth by diffusion – indeed growth of the droplets (by diffusion) tends to deplete the cloud air of water vapour

for the same size droplets, higher RH needed to grow those formed on insoluble CCN than those formed on soluble CCN

**this is not obvious; the proof is laborious
• the bigger a droplet, the slower its growth rate (*not proven*)

• so smaller droplets "catch up" with bigger

• and together, this population of droplets is soaking up vapour from the cloud air

• limiting the ultimate size of the droplets to a *nominal* 10 microns

• actual size depends on number of CCN available, and moisture supply

• given the same initial RH, an airmass with a higher count of CCN will produce more, but smaller, cloud droplets

• aerosols most favourable for cloud formation are large, wettable and highly soluble – e.g. salt aerosols from evaporated ocean spray). Continents?... dustier, but dust is not hygroscopic
"Pure water does not necessarily freeze at 0°C. In fact, temperatures must drop to about -40°C before water droplets will spontaneously freeze to form ice crystals... larger droplets will freeze at slightly warmer temperature than will smaller droplets.

"ice embryos" form spontaneously but are mostly destroyed by thermal agitation of the crystal lattice – except at very low temperature.

The smaller the volume of a sample of pure water, the lower the temperature at which it freezes.

Thus in cold clouds we have a mix of supercooled liquid droplets and frozen droplets.
- Ice crystals may form in subfreezing air on "ice nuclei" of several types.
- Particles are effective ice nuclei if their crystal structure resembles that of ice.
- More effective at lower temperatures.
- Ice nuclei generally rarer than condensation nuclei.

Due to the rarity of ice nuclei, the lower regions of a cold cloud (i.e. below about the level of the \(-40^\circ C\) isotherm) contain:

- A few ice crystals
- Many supercooled droplets, which is crucial to the precipitation process in cold clouds.

Fig 9.6
Sec 9.3 Mechanisms producing lift that can result in parcel cooling and cloud

Fig 9.7

a) buoyant forcing
b) orographic forcing
c) low level convergence due to cross-isobar winds (weather system cloud)
d) frontal lift
e) divergence aloft

often occur together
Ch 9. Forcing mechanism dictates the scale and organization of cloud

Fig 9.7

a) sporadic, randomly distributed, small scale, vertical development may be large or small

b) orographic forcing – linear organization, tied to landscape

c, e) weather system scale, long lived (cloud shield)

d) frontal lift – linear organization

Height/width (aspect ratio)

Warm Surface

Warm Air

Cold Air

Winds speeding up
Topics/concepts covered

- role of CCN; countervailing curvature and solute effects
- tendency to grow a population of equi-sized, small cloud droplets – that by virtue of their competition for water vapour are size-limited
- role of ice nuclei, and the co-existence of liquid and frozen cloud particles in cloud layers with temperatures in the range (roughly) 0°C to -40°C
- mechanisms that result in lift, potentially initiating cloud

Lenticular cloud (Figure 9.11a) caused when a stable air layer is forced to ascend as it blows over the mountains – this is termed “orographic” cloud (because it is forced by the orography, i.e. topography)