EAS270_Ch9_Condensation_A.odp
JDW, EAS U.Alberta, last mod. 27 Oct. 2016

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

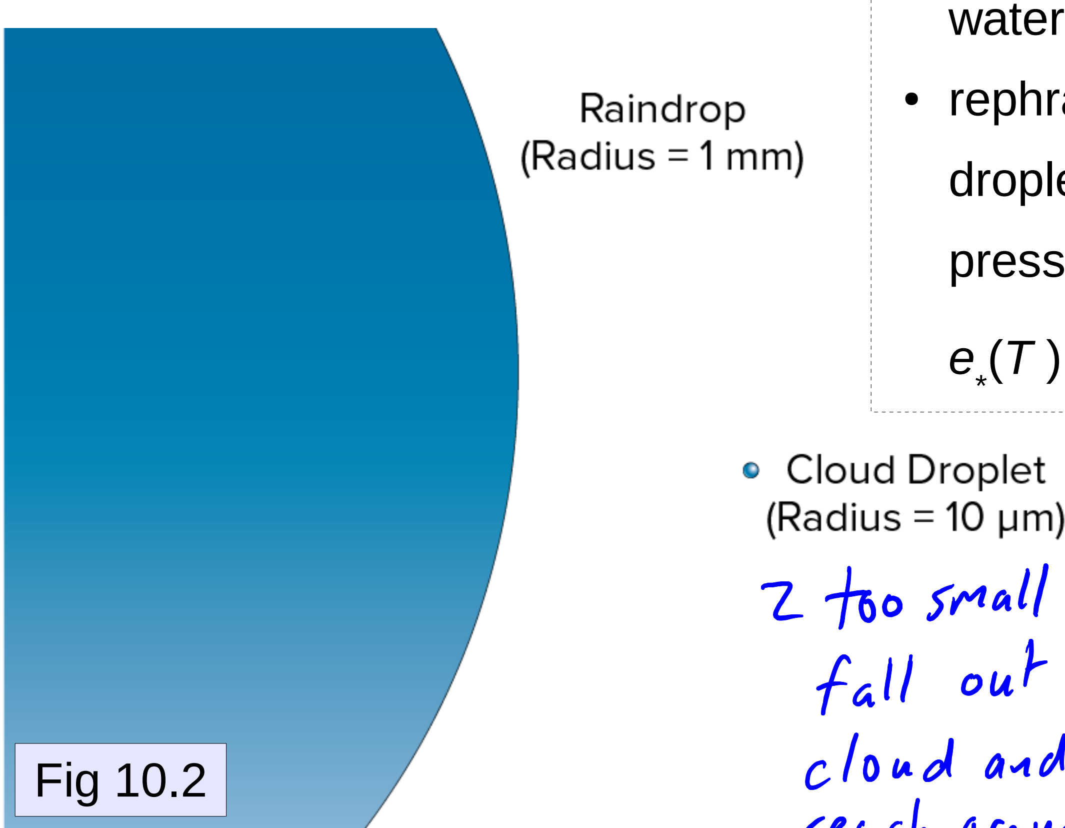


Fig 10.2

2 too small to fall out of cloud and reach ground

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

- 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!)

- 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

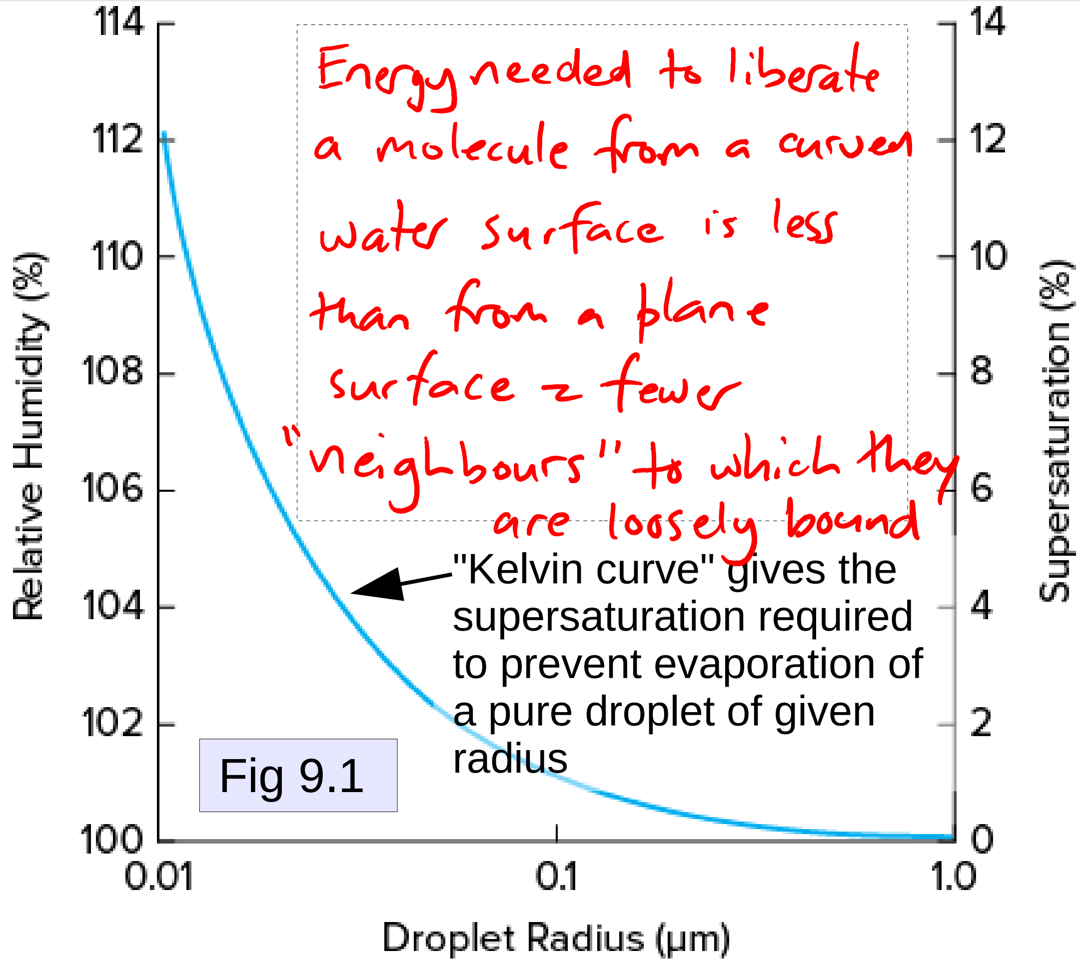


Fig 9.1

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

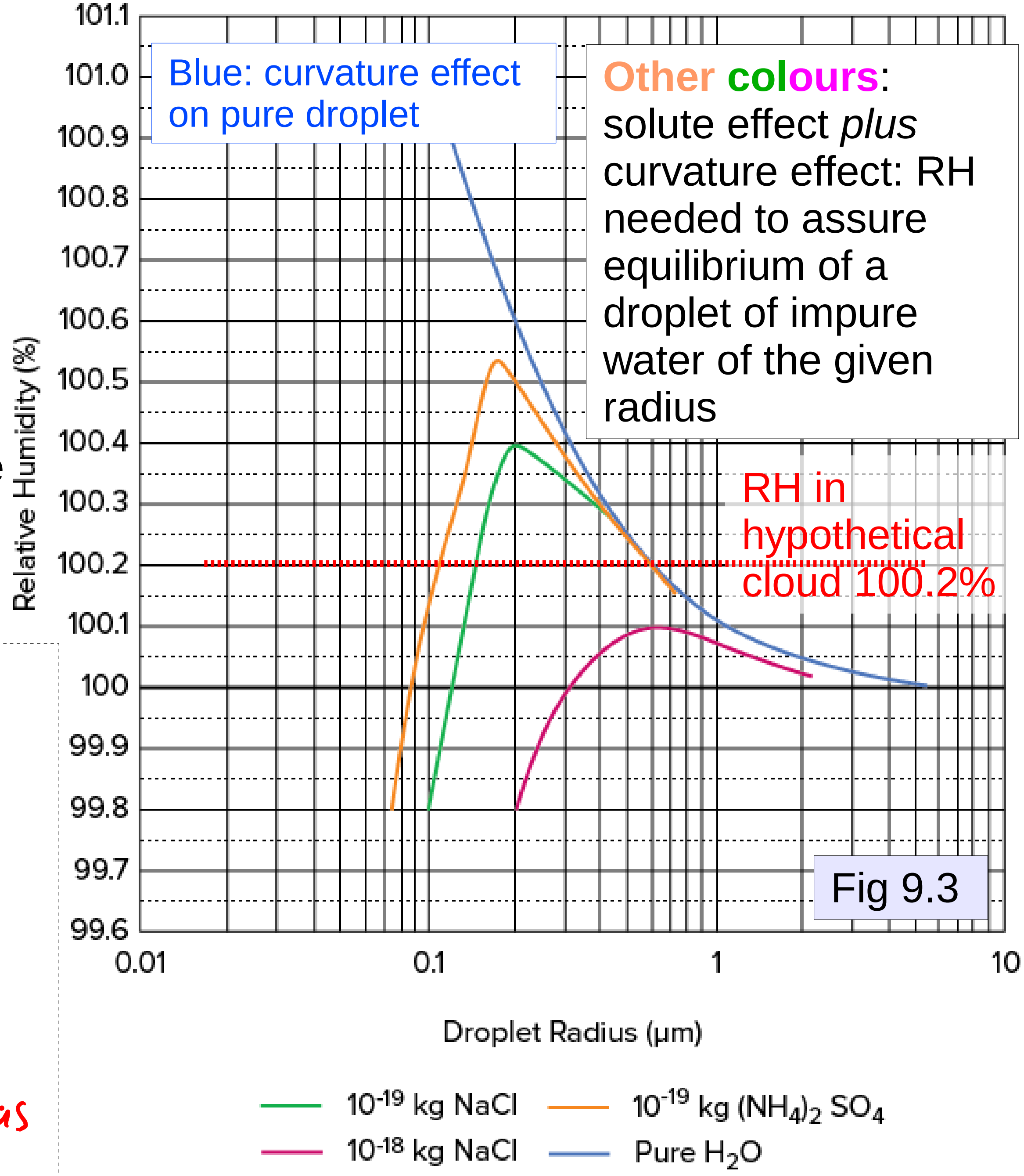
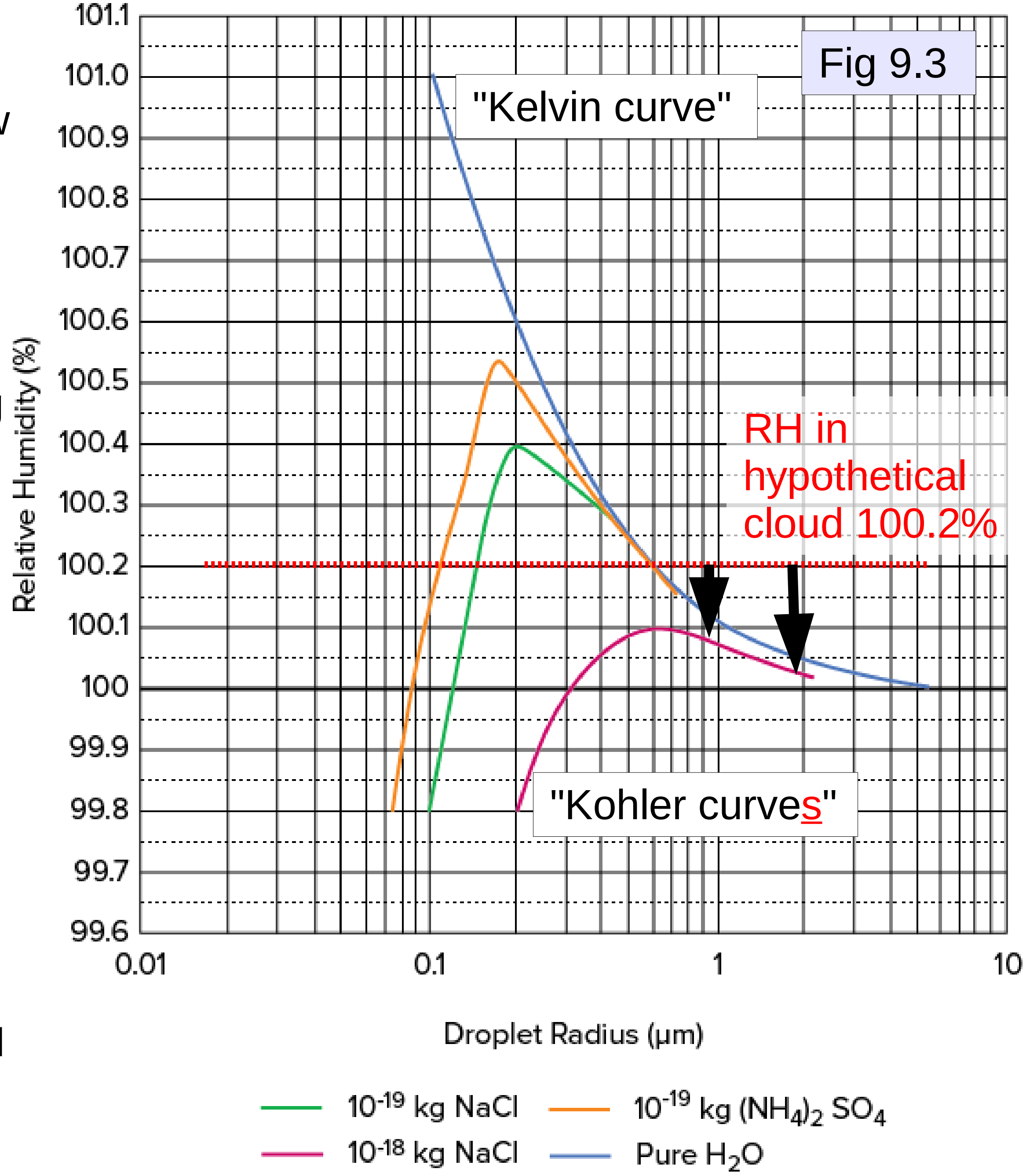


Fig 9.3

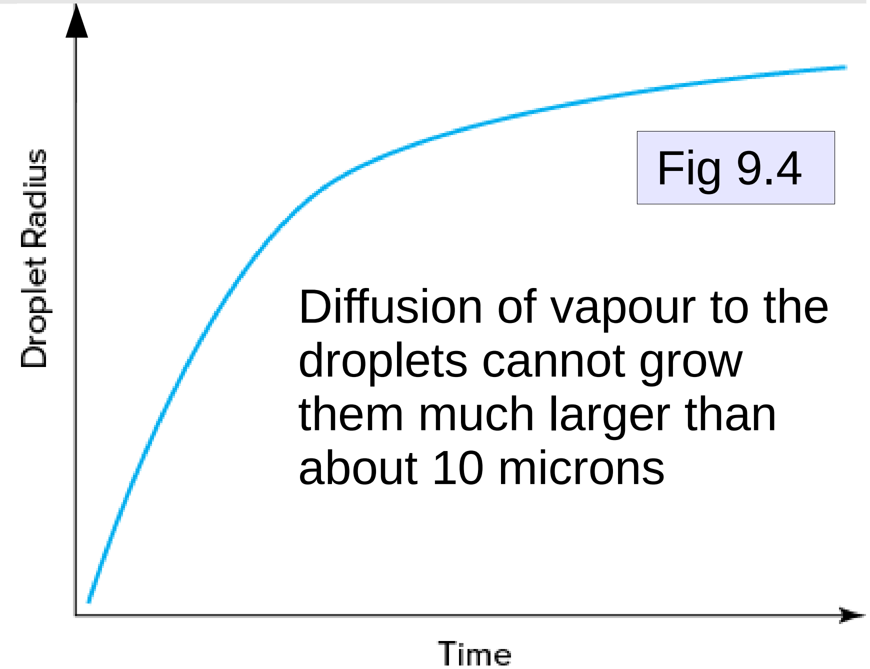
At equal temperature, the equil. v.p. over a plane surface of a solution is lower than that over a plane surface of pure water

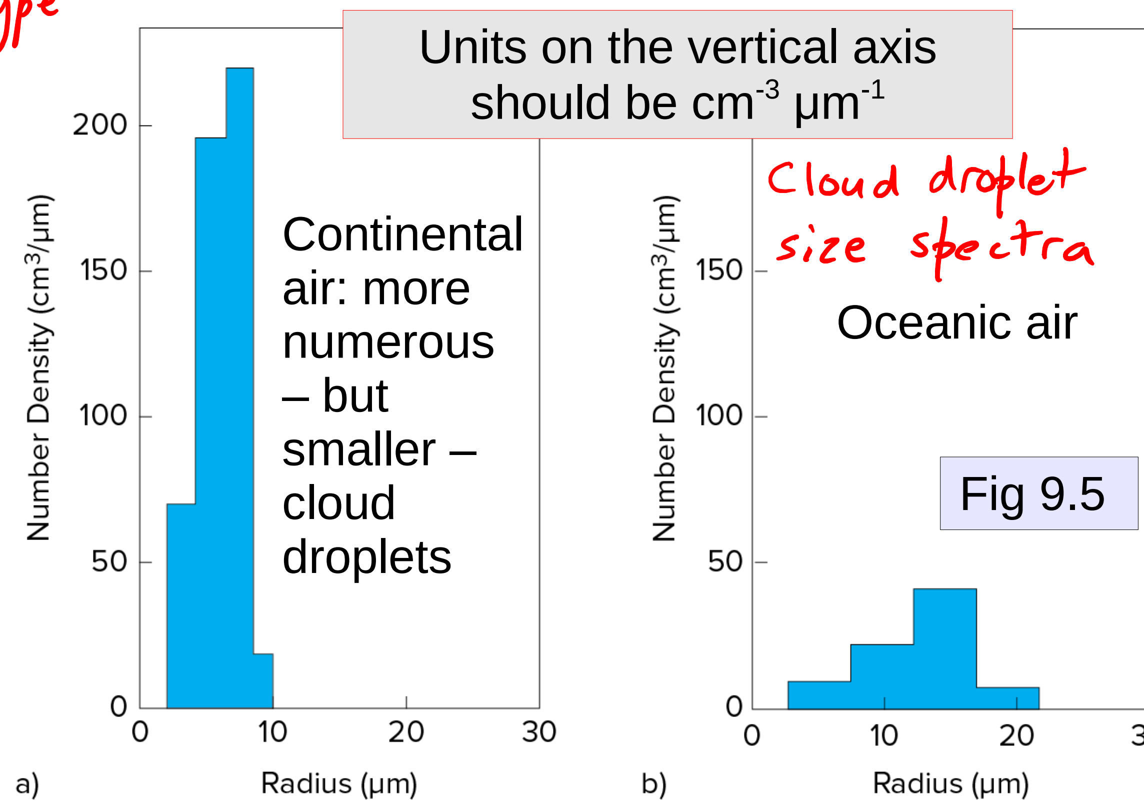
- considering the population of activated droplets (those able to grow without limit, i.e. those for which the peak of the Kohler curve lies below cloud RH), **the smaller ones grow faster than the big ones**** – tending to give the cloud a distribution of same-sized cloud droplets
- this population "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

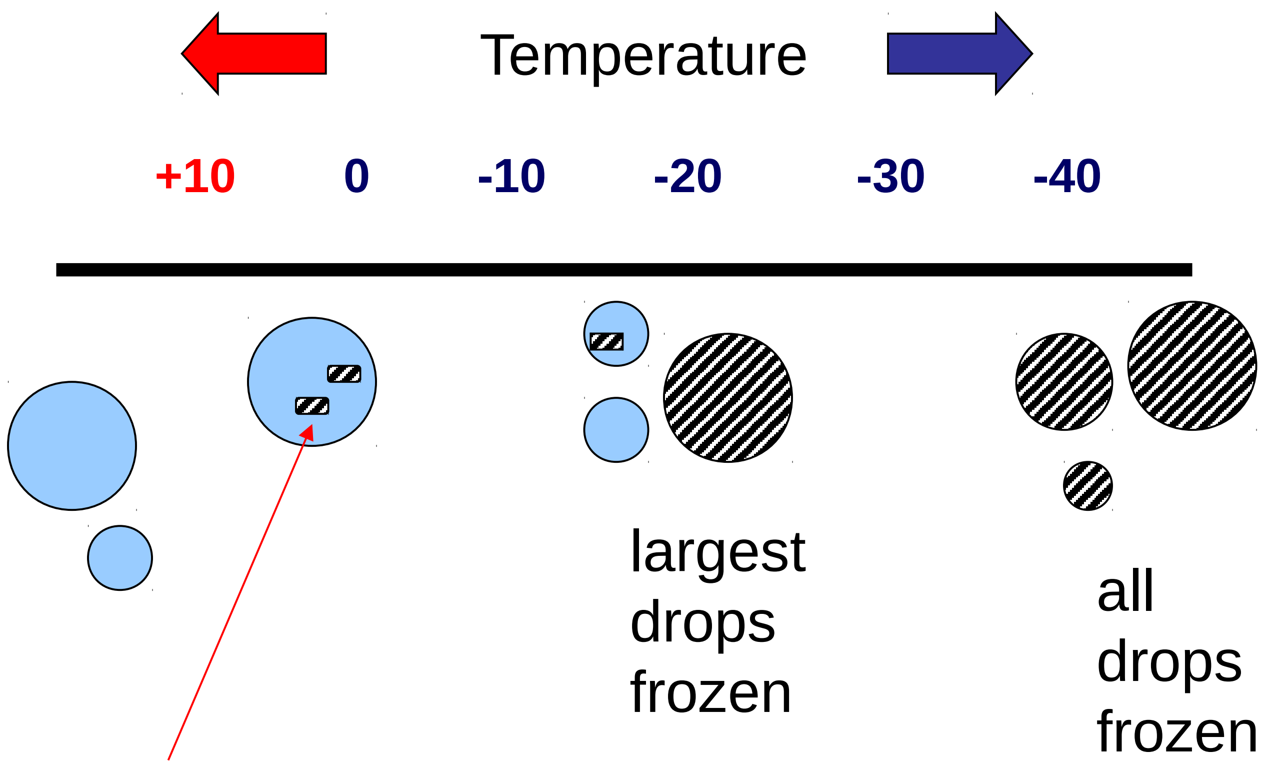
- the bigger a droplet, the slower its growth rate (*not proven*)
- so smaller droplets "catch up" with bigger
- and together, this population of droplets is soaking up vapour from the cloud air
- limiting the ultimate size of the droplets to a *nominal* 10 microns
- actual size depends on number and type 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 drpolets will spontaneously freeze to form ice crystals... larger droplets will freeze at slightly warmer temperature than will smaller droplets"

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



largest drops frozen

all drops frozen

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

Thus in cold clouds we have a mix of supercooled liquid droplets and frozen droplets.

STOPPED HERE 31 OCT.

- 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

clay particles
combustion products
some bacteria
silver iodide

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

- a few ice crystals
- many supercooled droplets

which is crucial to the precip process in cold clouds.

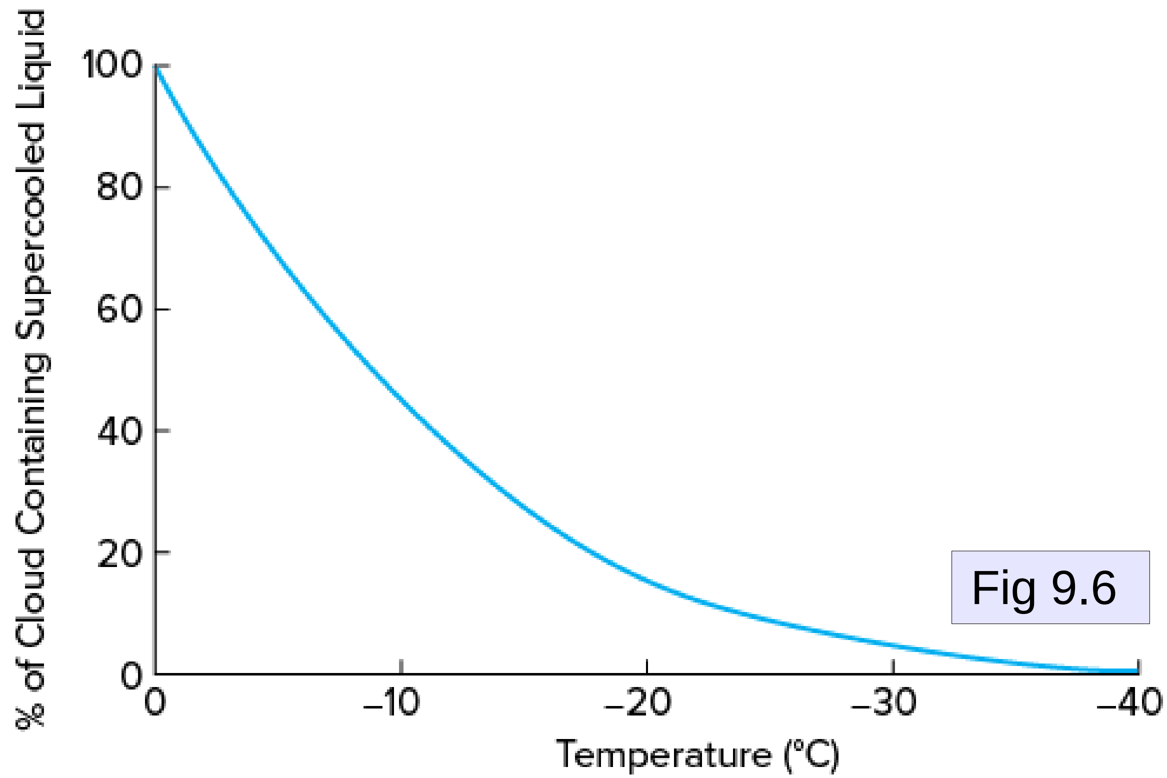


Fig 9.6

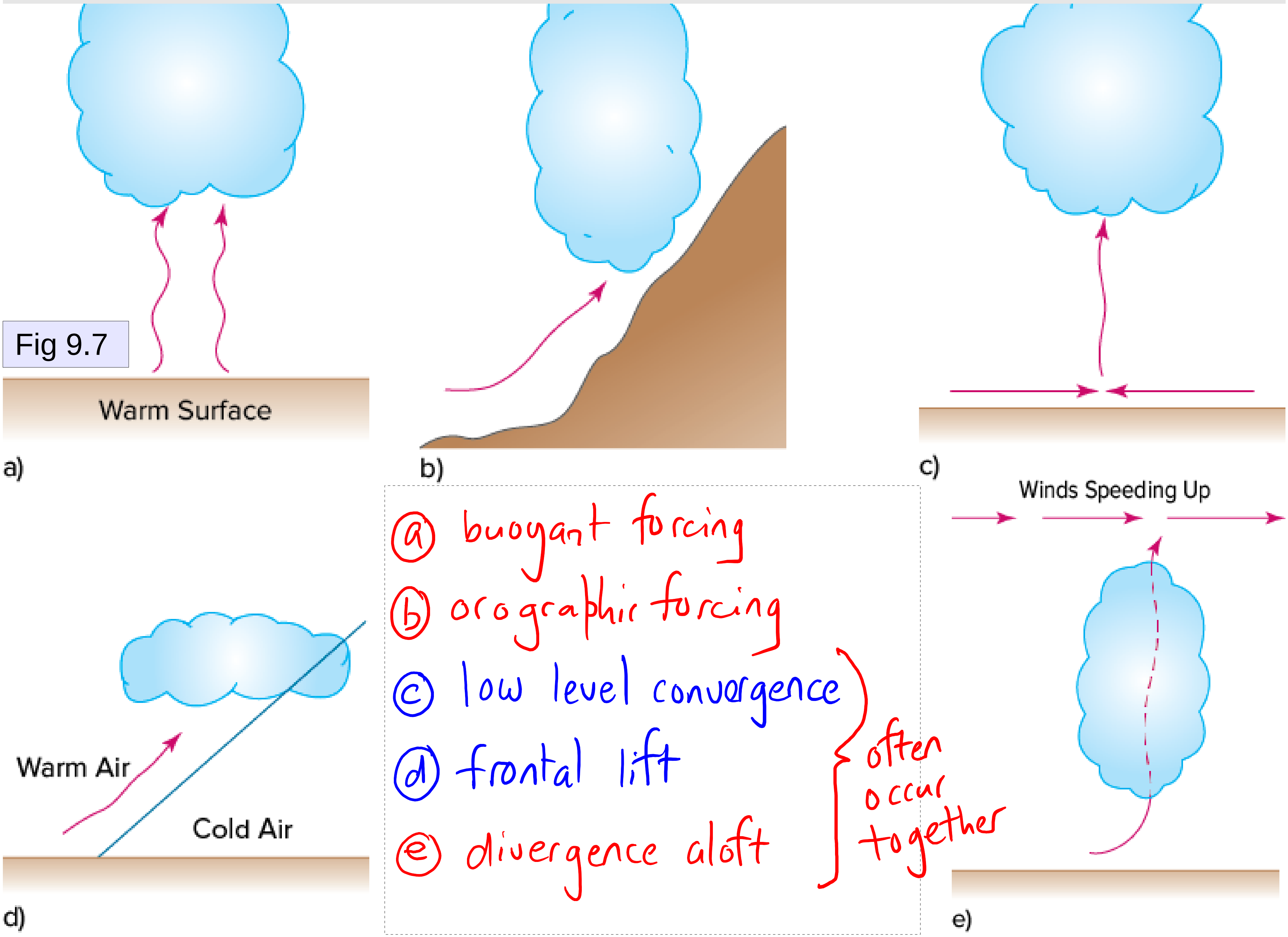


Fig 9.7

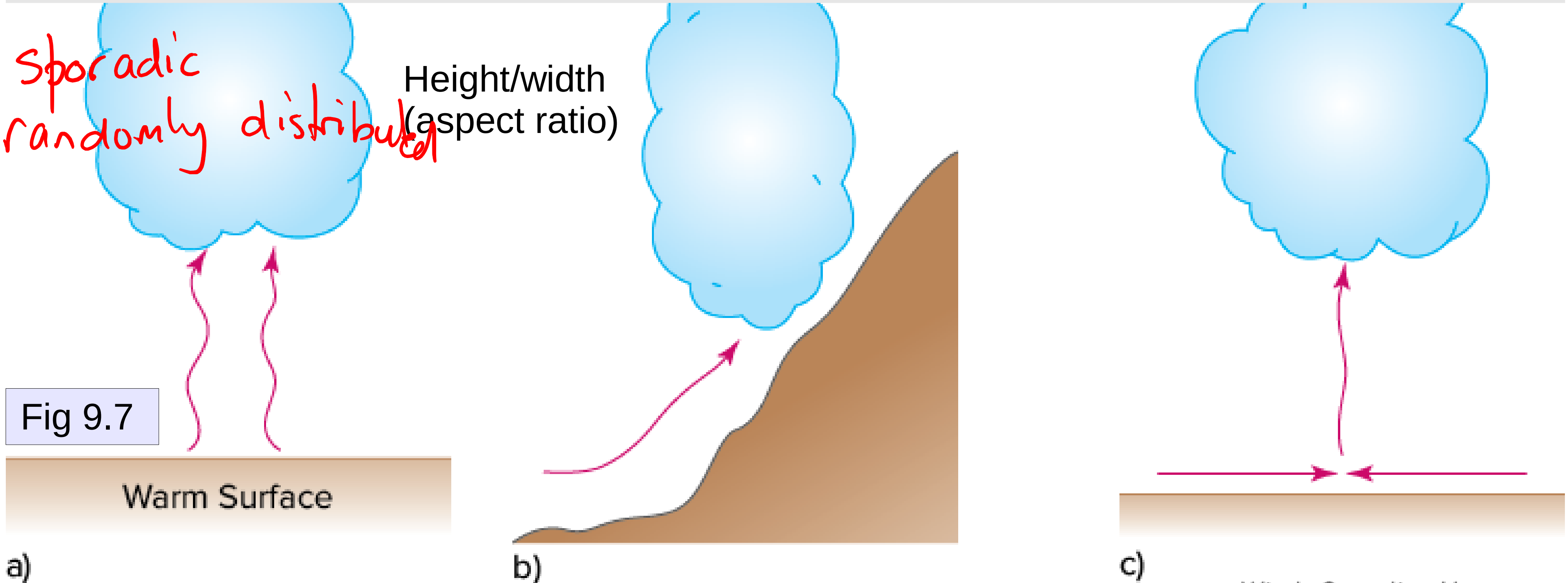
(a) buoyant forcing
(b) orographic forcing
(c) low level convergence
(d) frontal lift
(e) divergence aloft

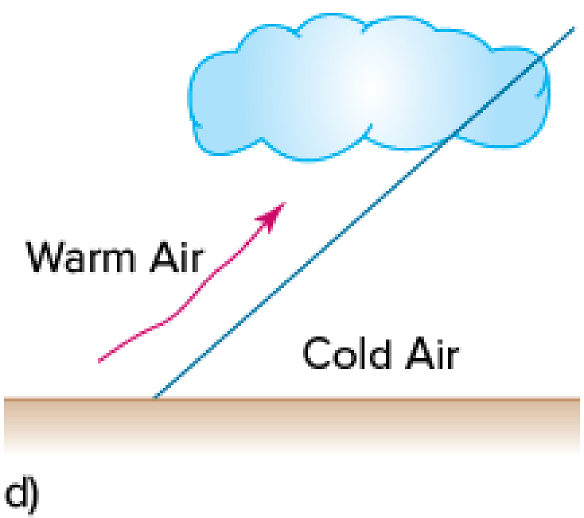
} often occur together

sporadic
randomly distributed

Height/width
(aspect ratio)

Fig 9.7

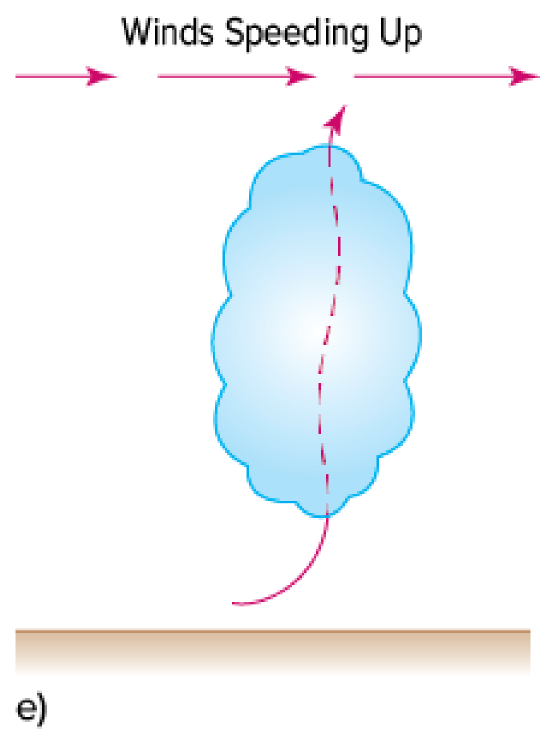




ⓐ vert. development depends on ELR (small scale)

ⓑ tied to topography

(c, e) weather system scale



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^{o}C to -40^{o}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)