Goals for today: continue Ch 5 – Atmospheric Moisture

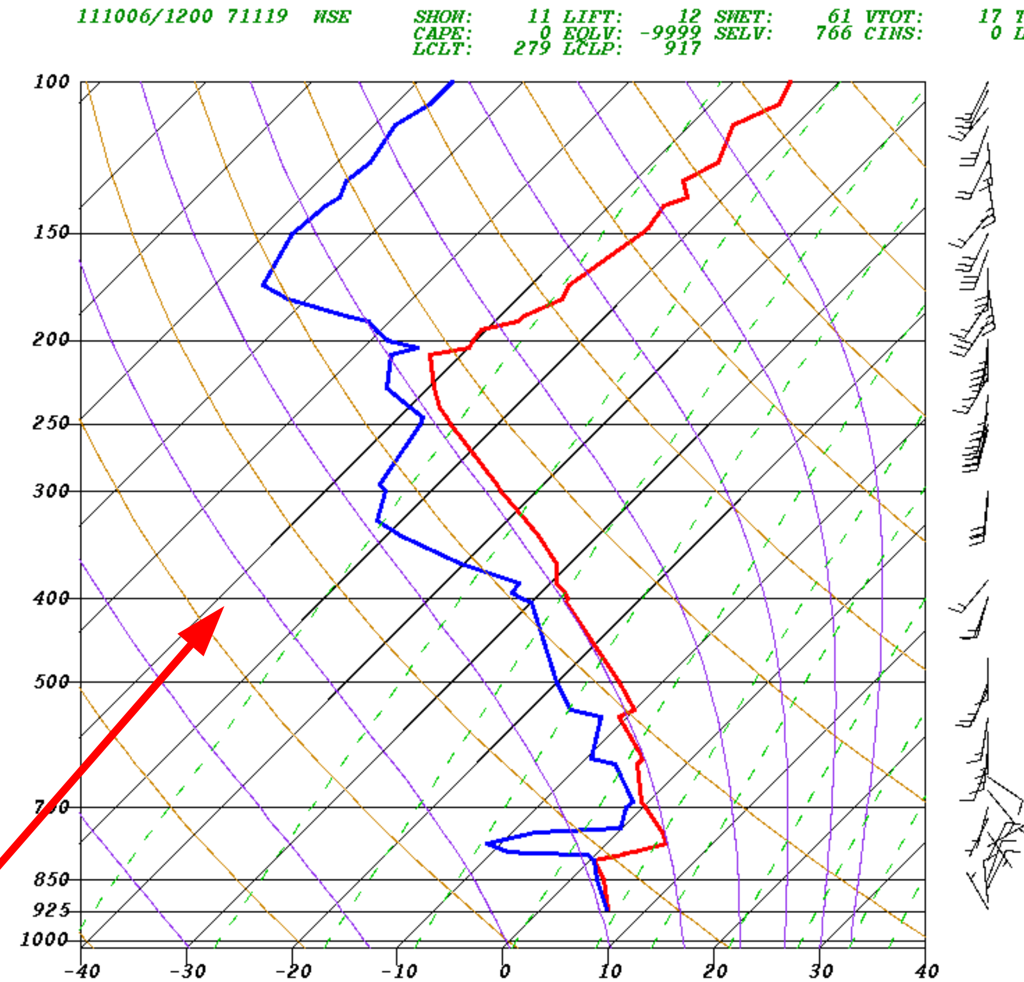
7 Oct., 2011

Ch.5 sets the stage to understand cloud formation. We need to understand how air parcels may cool to their dewpoint (saturate) merely due to their vertical motion – and how condensation may in turn influence their vertical motion

• we will today learn to distinguish the “environmental lapse rate” (ELR) from two “benchmark” lapse rates, the DALR and SALR

• on the way we learn about “adiabatic processes”

• and we have a first look at the “skew T – log p” diagram, a particular form of the thermodynamic chart (more commonly used than the Stuve diagram)



Thurs. morning sounding: a saturated layer of air on ground has mixed adiabatically and come to equilibrium such that its temperature decays with increasing height at the saturated adiabatic lapse rate – explained below

lec13.odp
JDWilson vers 6 Oct. 2011

Condensation nuclei

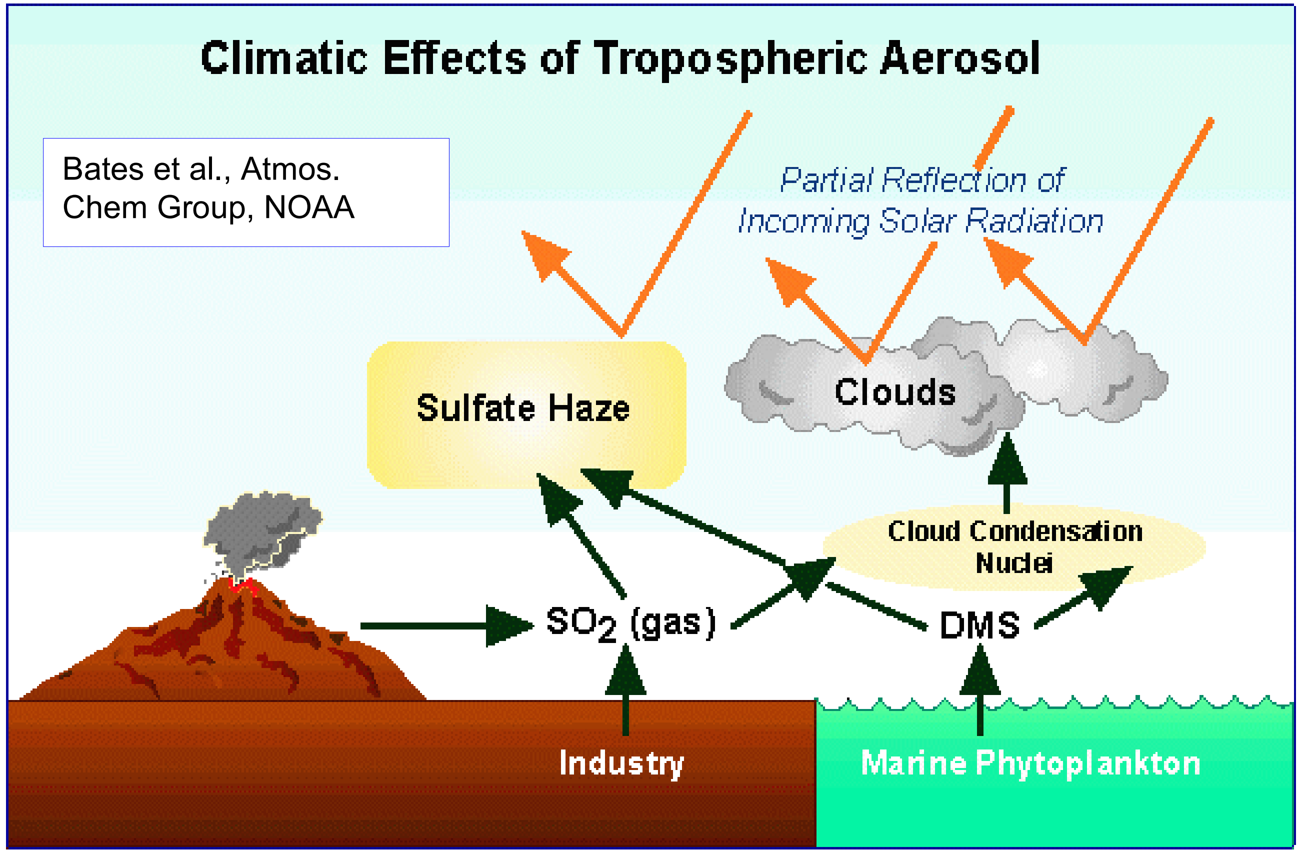
• Homogeneous nucleation requires high level of supersaturation and so seldom if ever occurs in the atmosphere

• Heterogeneous nucleation is the process of vapour condensation or deposition onto particles, which thereby function as "condensation nuclei" – permitting accumulation of liquid or solid water at RH values near or below 100%

Airborne CN counter

• Condensation nuclei may be soluble, in which case the solute effect lowers the equilibrium v.p. around the droplet

• Or, if insoluble – their size alone facilitating condensation (the gentle curvature of their surface moderating the curvature effect)



• Natural condensation nuclei include (e.g.) eroded soil, salt spray, conversion of naturally sourced gases (e.g. dimethyl sulphide "DMS" from ocean plankton)

• Artificial (anthropogenic) condensation nuclei result from conversion of pollutant gases (e.g. sulphur dioxide SO_2) to particulates

• Concentration of condensation nuclei over continents decreases with increasing height, but is generally greater than over oceans

Ice nuclei, and supercooled water droplets

What happens when "saturation occurs" (i.e. relative humidity near 100% or above) at temperatures below the freezing point?

"If saturation occurs at temperatures between about -4°C and 0°C, the surplus water invariably condenses to form supercooled water…" (p148)

… formation of ice crystals at temperatures that are not far colder than 0°C requires presence of ice nuclei

… which in most cases have a crystal structure resembling that of ice

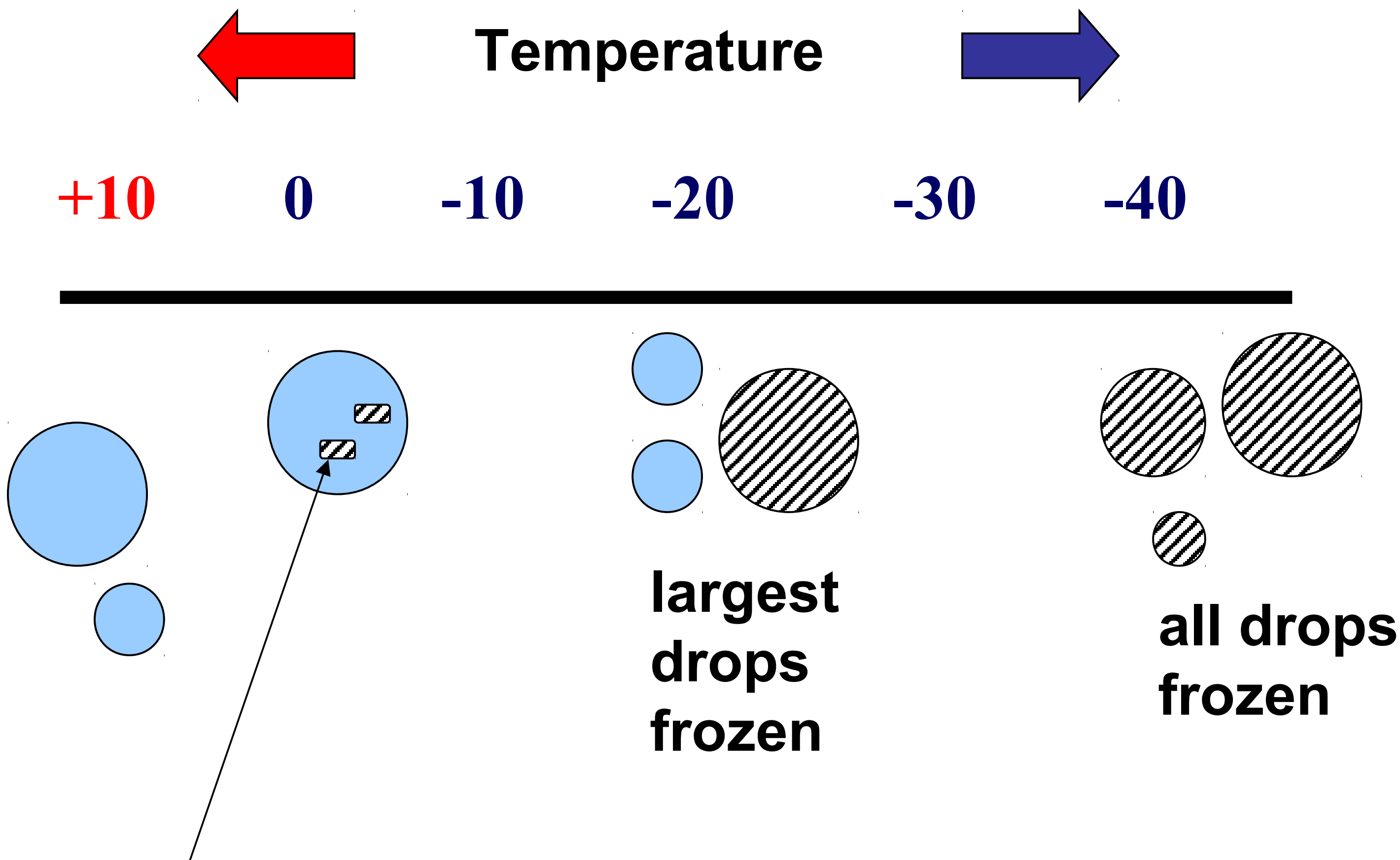
… and so (unlike condensation nuclei) are generally rare in the atmosphere

… clay particles may serve as natural ice nuclei, but "no materials are effective ice nuclei at temperatures above – 4°C"

… as temperature decreases, likelihood of ice formation increases

Coexistence of liquid droplets and ice crystals

The smaller the amount of pure water, the lower the temperatures at which water freezes.

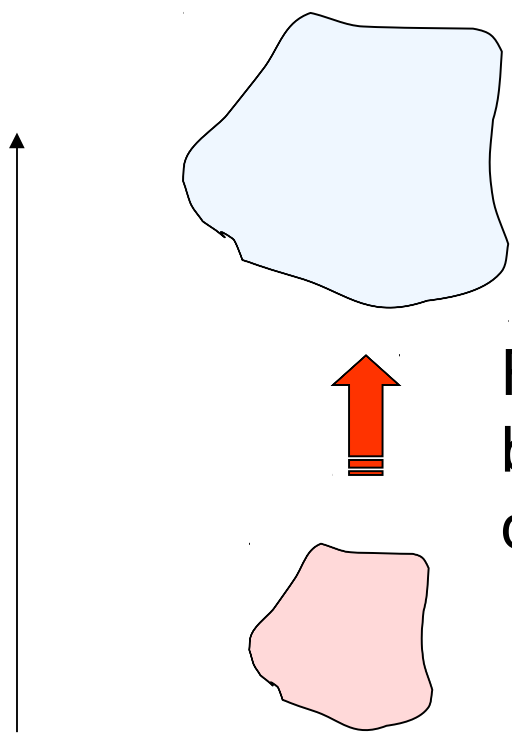


“Ice embryos”. Except at very low temperature, these tend to be destroyed by thermal agitation of the crystal lattice

Given that formation of liquid or ice droplets in the atmosphere entails achieving an RH “near” 100%, how is this achieved?

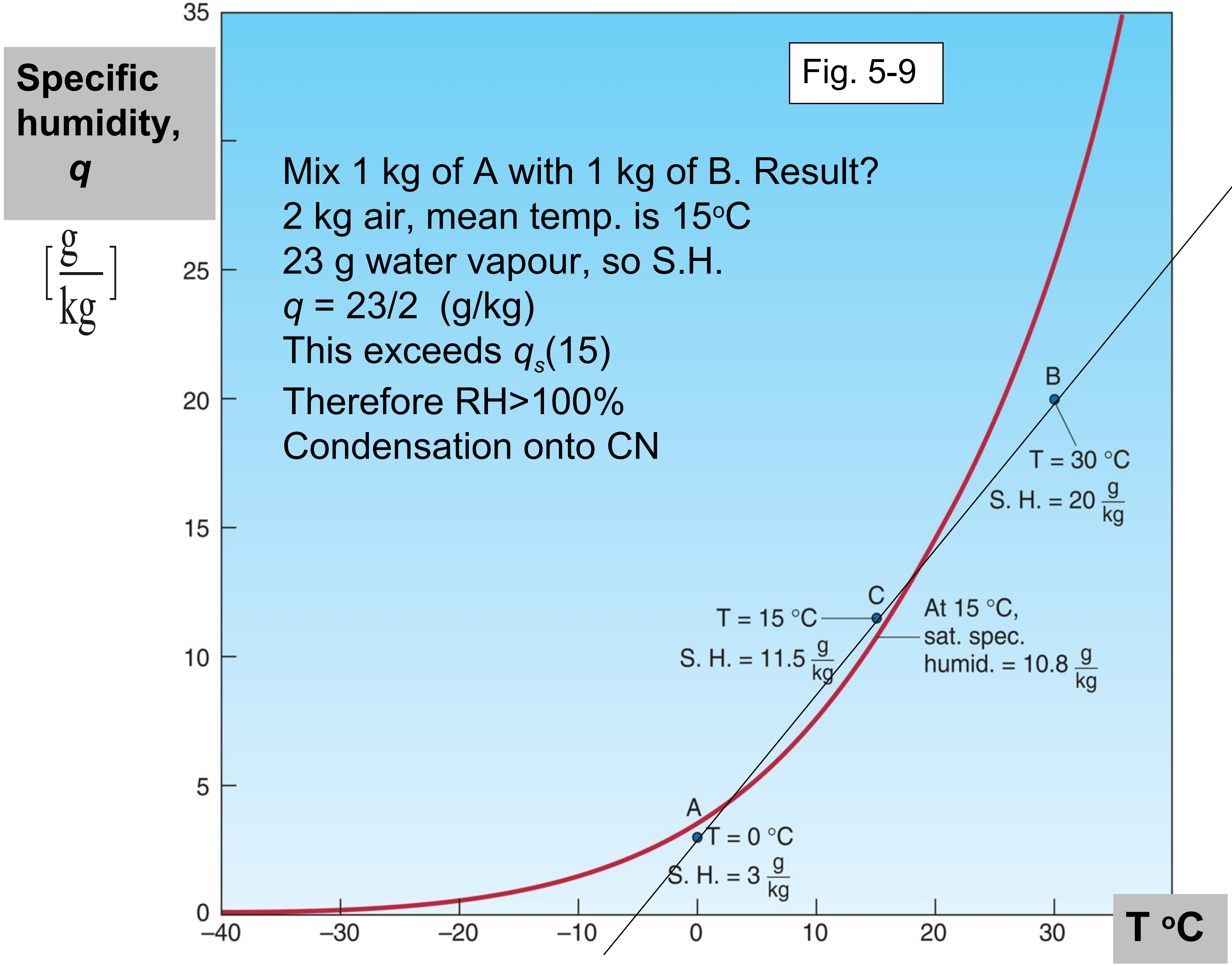
- add vapour (e.g. evaporating raindrops)
- mix cold air + warm, moist air
- lower air temperature ← most common mechanism for cloud formation

Decreasing pressure



Rising parcel expands and cools, bringing its temperature and dewpoint closer together

Saturation resulting from mixing of cold and warm, moist parcels



Given that formation of liquid or ice droplets in the atmosphere entails achieving an RH "near" 100%, how is this achieved?

- add vapour (e.g. evaporating raindrops)

- mix cold air + warm, moist air

- lower air temperature by

  - diabatic processes… heat is added or removed
  - adiabatic processes… no heat is added or removed

most common mechanism for cloud formation

Insight into “Adiabatic Process”…

“First law of thermodynamics” inter-relates small increments (that may/must occur) in the “state variables” of unit mass of the air during heat addition or removal. It may be written in two alternative forms:

ΔH (= heat added) = $p\,\Delta\alpha + c_v\,\Delta T$ ($\alpha=1/\rho$ is the “specific volume”)

Zero for adiabatic process

where ΔH is [J kg^{-1}], and c_v [J kg^{-1} K^{-1}] is the “specific heat capacity of air at constant volume” (equal to $5R/2$, R=287 the gas constant for air). If $\Delta\alpha > 0$ (expansion) then $\Delta T < 0$ (adiabatic expansion, which must occur as a parcel ascends to regions of lower pressure – work is done by the expanding gas as it “pushes” against the surround air in order to expand; and the energy corresponding to that work done is taken from internal energy, thus the parcel cools

The alternative form of the first law

$$\Delta H \text{ (= heat added)} = - \alpha \, \Delta p + c_p \, \Delta T$$

Zero for adiabatic process

where c_p is the "specific heat capacity of air at constant pressure"

$$c_p = c_v + R = 7R/2 \qquad [\mathrm{J\ kg^{-1}\ K^{-1}}]$$

If $\Delta p < 0$ (ascent) then $\Delta T < 0$

Dry Adiabatic Lapse Rate ("DALR") – a "benchmark" lapse rate

Let an unsaturated parcel ascend a distance $\Delta z > 0$ without addition or removal of heat (and without saturating). By the hydrostatic law, its pressure changes by the amount

$$\Delta p = -\rho g \Delta z$$

The first law gives us

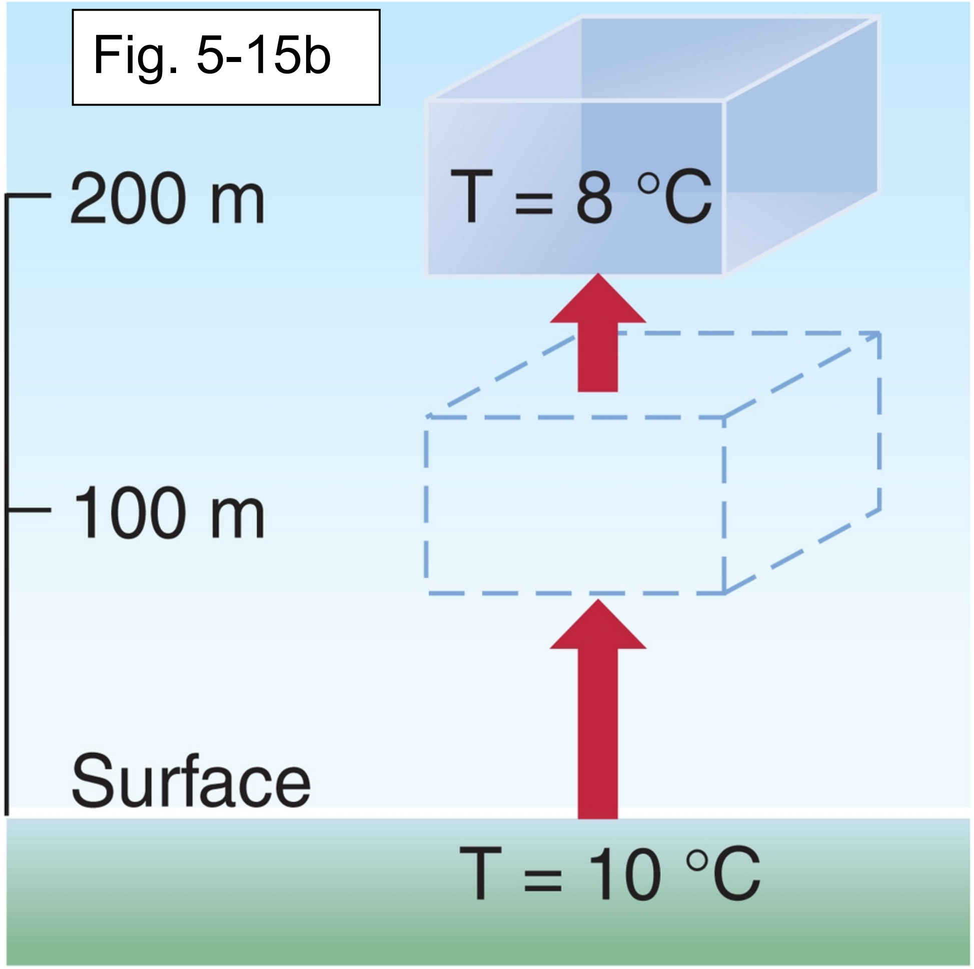
$$\Delta H = 0 = c_p \Delta T - \frac{\Delta p}{\rho}$$

Eliminating Δp , we have the **DALR**:

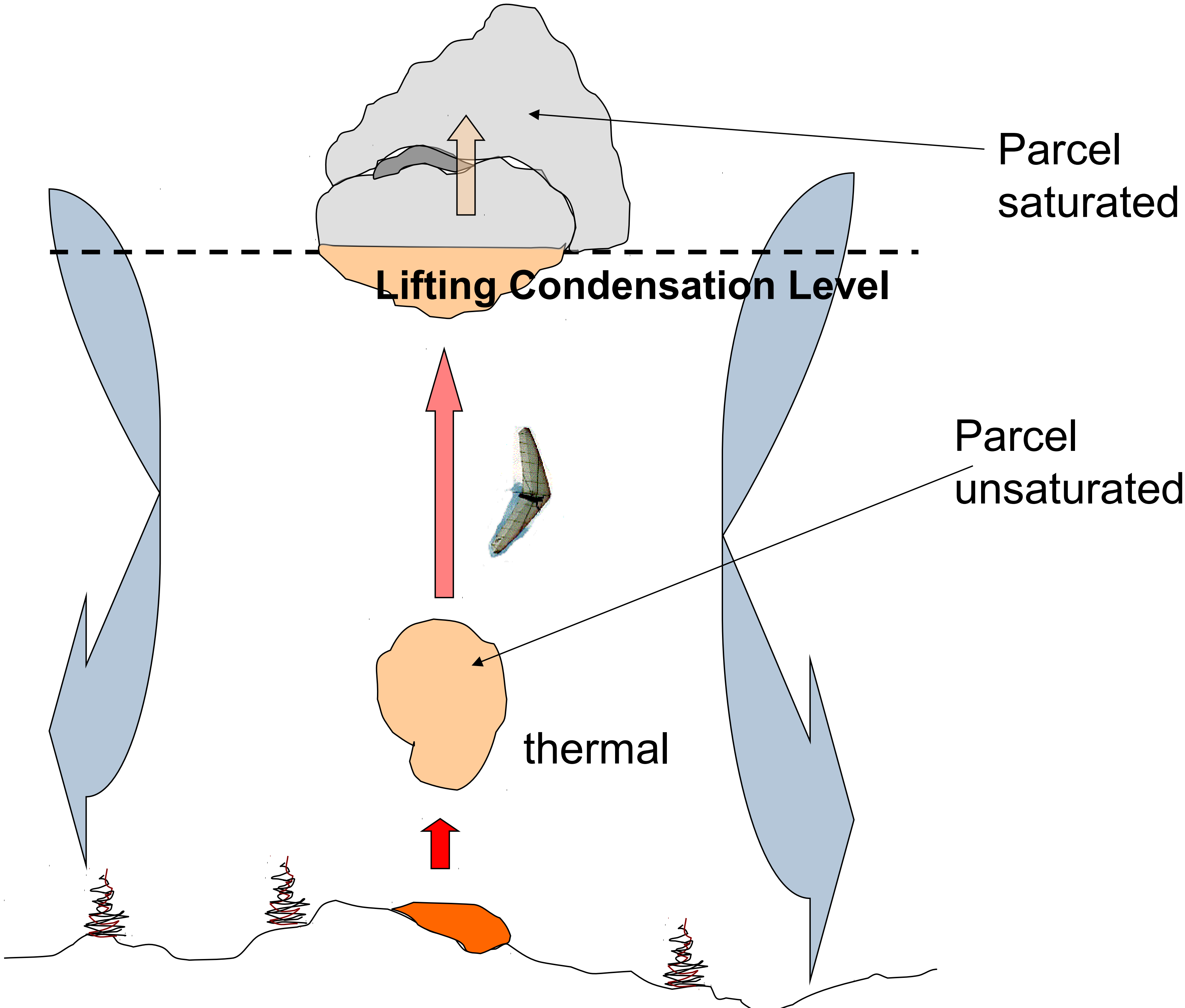
$$\frac{\Delta T}{\Delta z} = -\frac{g}{c_p} \approx -0.01 \;\mathrm{K\,m^{-1}}$$

"As the air rises, it encounters lower surrounding pressures, expands, and cools" (p155)

Fig. 5-15b



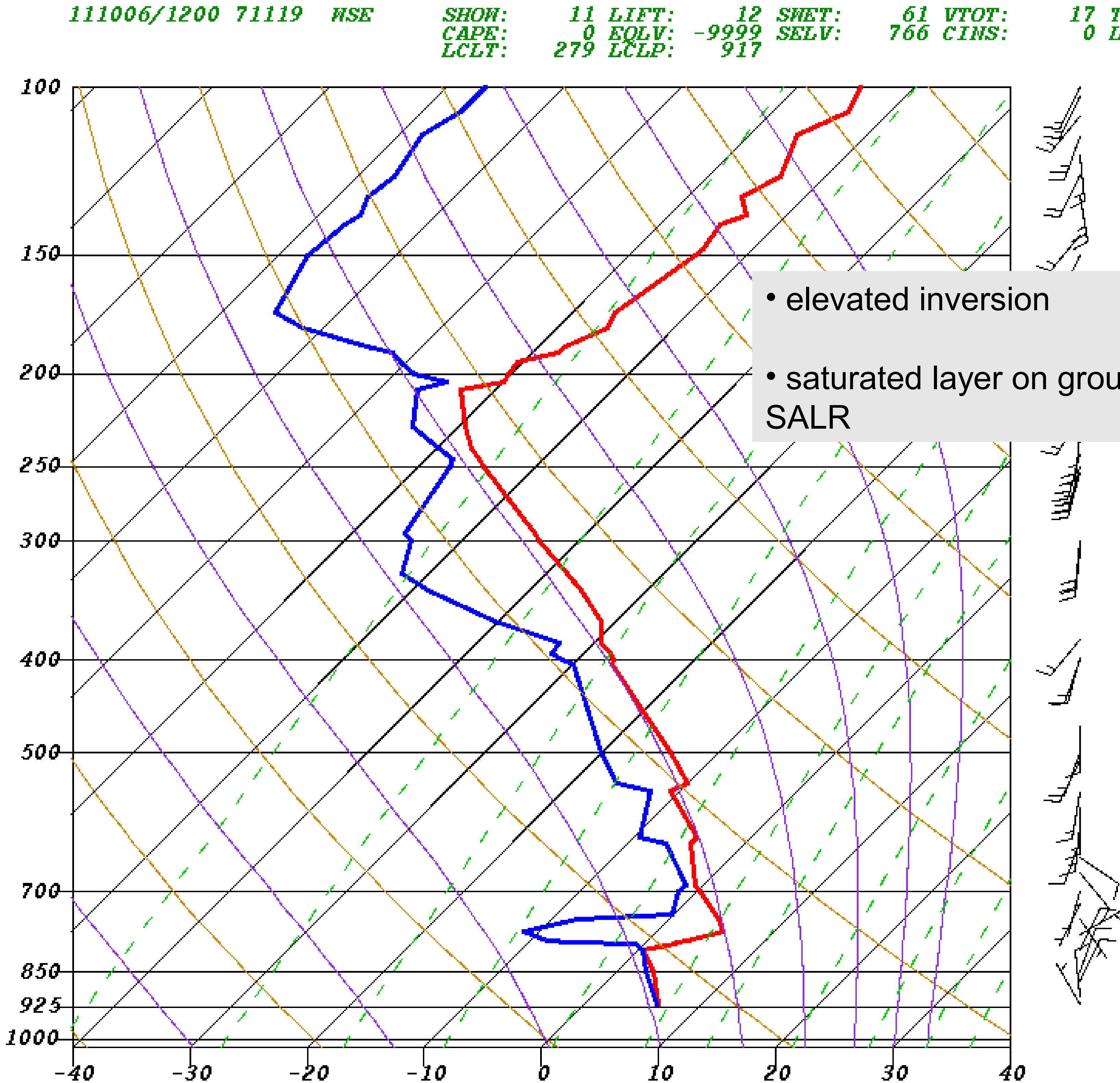
If a parcel rises high enough, expansion lowers its temperature to the dew or frost point (p155)



Saturated Adiabatic Lapse Rate ("SALR") – another "benchmark"

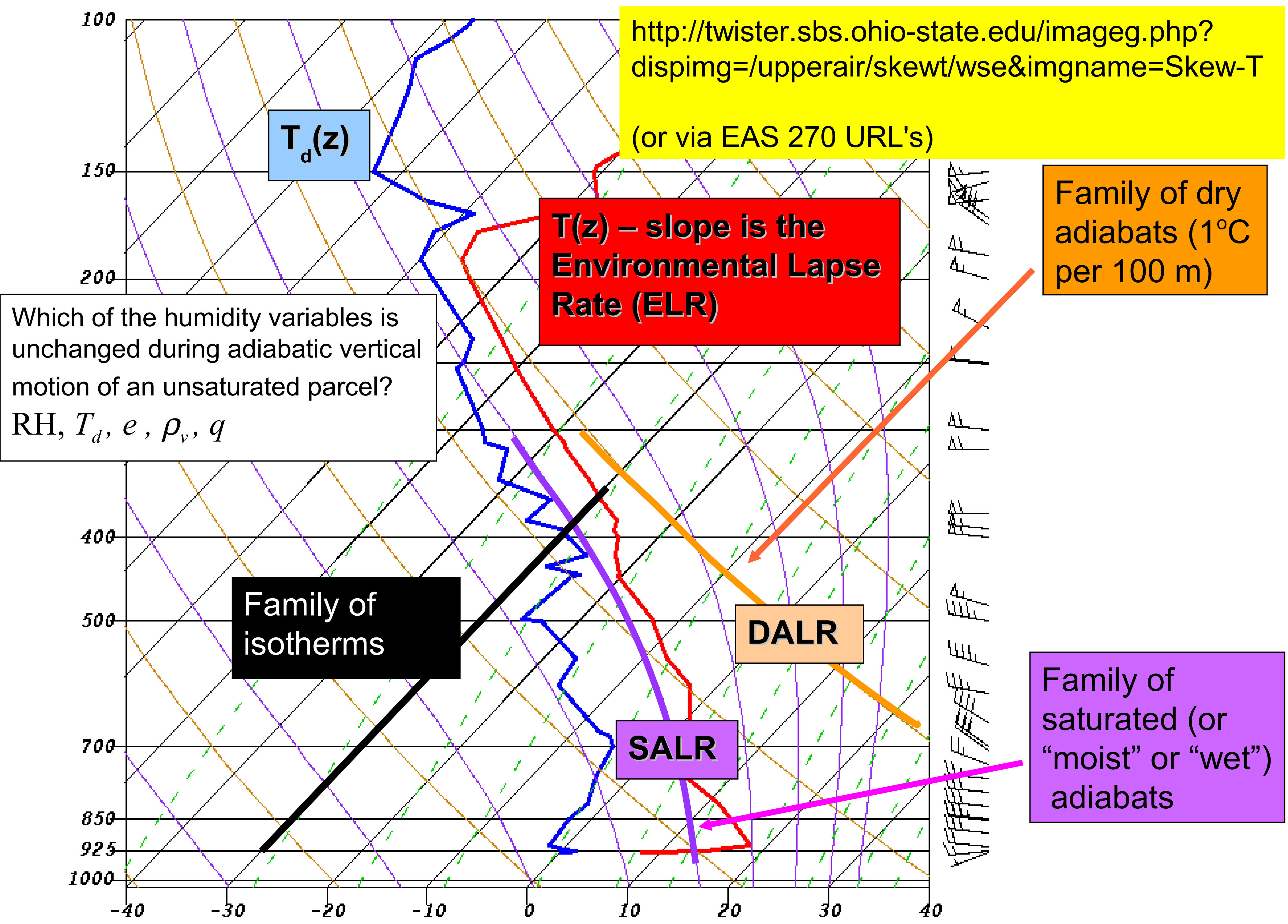
During the adiabatic ascent of a saturated parcel, the release of latent heat by condensing water vapour offsets the cooling by expansion…

The rate of cooling per metre of lifting is consequently smaller than the DALR (except high in the atmosphere where due to the colder temperature there is little vapour in the air to be condensed – see Sec. 5-4)



- elevated inversion
- saturated layer on ground, ELR equals SALR

Families of curves on the skew T/log P thermodynamic chart



• The skew-T/log-P diagram is fundamentally just a strange type of graph paper allowing to plot points (p,T) – “strange”, in that the isotherms (lines of constant T) don’t run vertically

• in the context of cloud processes and vertical motion, meteorologists are as interested in temperature lapse rates as they are in temperature itself – for which reason it is convenient to register on the thermodynamic chart these families of “benchmark curves,” whose slopes are respectively the DALR and the SALR

“Condensation or deposition can occur in the air as cloud or fog, or onto the surface as dew or frost” (p157)

Adiabatic cooling is normally the agency that produces condensation well aloft, ie. clouds

What about the types of condensate we see at/near ground, viz., dew, frost, fog…?

In these latter cases, cooling to the dew (or frost) point usually entails some heat removal, ie. “diabatic processes” (e.g. Table 5-4)

(Photo: Susan H. McGillivray)

DEW and FROST

- nocturnal radiative **ground cooling** , Q* < 0
- cold ground cools the air above, $Q_H < 0$
- temperature of ground surface cools to surface air's dewpoint ($T_{sfc}=T_d$), vapour condenses onto leaves etc. and/or water droplets form in the chilled air and deposit onto surface... **dew** (which may later cool to become frozen dew)
- if $T_{sfc}=T_d < 0^oC$, ie. below "frostpoint", delicate white crystals (hoar frost) or just "frost"
- if air temp. T(z) falls to dewpoint $T_d(z)$ in a deeper layer as opposed to right at surface, haze or fog will form

HAZE & FOG

HAZE a layer of light-scattering droplets formed by condensation onto condensation nuclei (may occur at RH<100%)

FOG a cloud, resting on/near ground, of bigger, possibly visible droplets or crystals (visibility < 1 km)

** more precisely: ground cools radiatively, and air cools by contact (convection, $Q_H < 0$) and radiation

- **FOG** Formation (process/mechanism)
- **cooling**
  - "radiation fog" due to radiational cooling** (diabatic process)
  - "advection fog," eg. warm moist air advected over a cold surface
  - "upslope fog" (adiabatic expansion -> cooling)
- **vapour addition** (evaporation-mixing fog)
  - eg. "steam fog," **cold** air moving over **warm** water

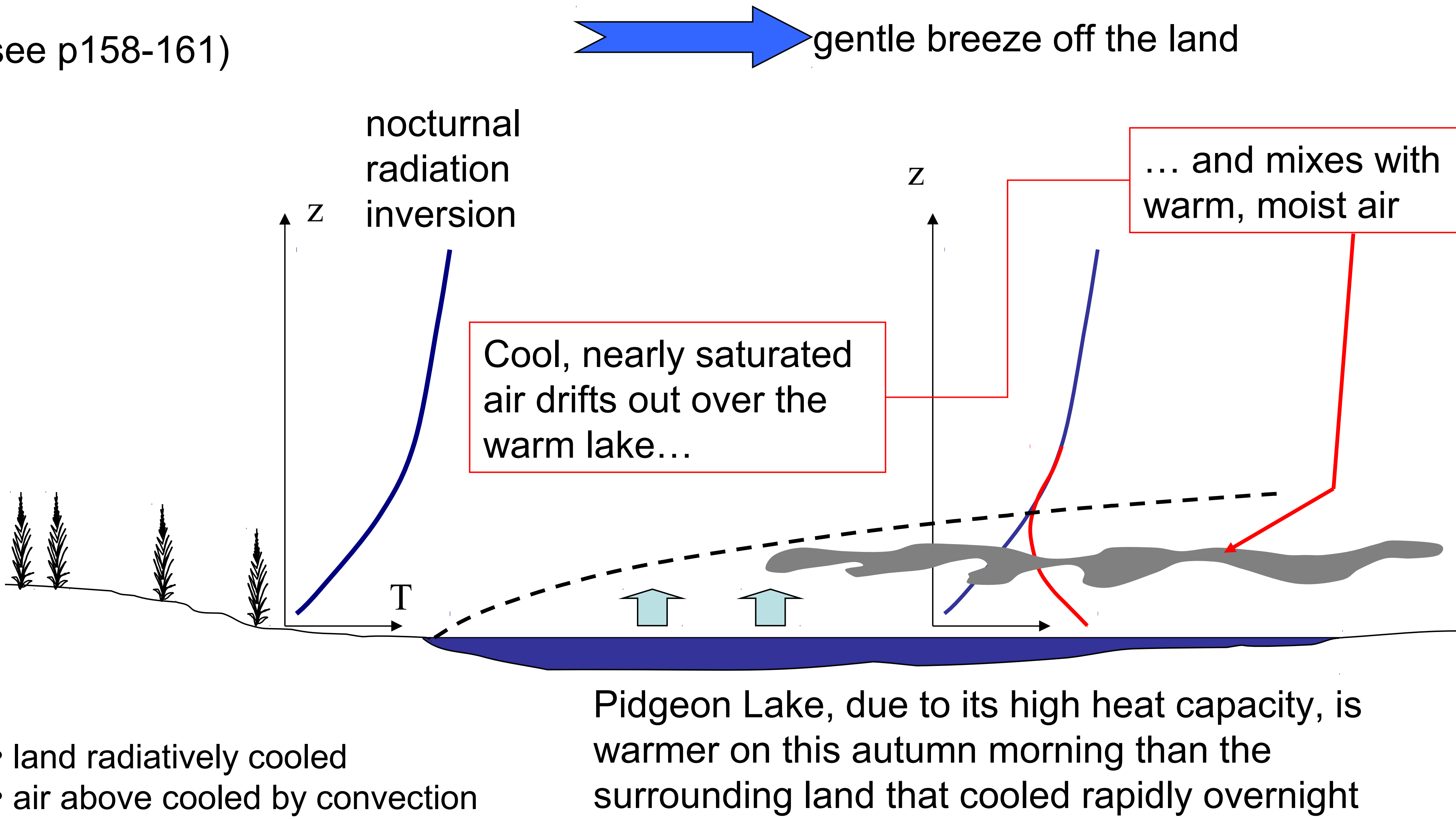
The first two paragraphs of Dickens' "Bleak House"

London. Michaelmas term lately over, and the Lord Chancellor sitting in Lincoln's Inn Hall. Implacable November weather. As much mud in the streets as if the waters had but newly retired from the face of the earth, and it would not be wonderful to meet a Megalosaurus, forty feet long or so, waddling like an elephantine lizard up Holborn Hill. Smoke lowering down from chimney-pots, making a soft black drizzle, with flakes of soot in it as big as full-grown snowflakes--gone into mourning, one might imagine, for the death of the sun. Dogs, undistinguishable in mire. Horses, scarcely better; splashed to their very blinkers. Foot passengers, jostling one another's umbrellas in a general infection of ill temper, and losing their foot-hold at street-corners, where tens of thousands of other foot passengers have been slipping and sliding since the day broke (if this day ever broke), adding new deposits to the crust upon crust of mud, sticking at those points tenaciously to the pavement, and accumulating at compound interest.

Fog everywhere. Fog up the river, where it flows among green aits and meadows; fog down the river, where it rolls defiled among the tiers of shipping and the waterside pollutions of a great (and dirty) city. Fog on the Essex marshes, fog on the Kentish heights. Fog creeping into the cabooses of collier-brigs; fog lying out on the yards and hovering in the rigging of great ships; fog drooping on the gunwales of barges and small boats. Fog in the eyes and throats of ancient Greenwich pensioners, wheezing by the firesides of their wards; fog in the stem and bowl of the afternoon pipe of the wrathful skipper, down in his close cabin; fog cruelly pinching the toes and fingers of his shivering little 'prentice boy on deck. Chance people on the bridges peeping over the parapets into a nether sky of fog, with fog all round them, as if they were up in a balloon and hanging in the misty clouds.

The possible *complexity* of a fog's formation – here a "steam fog" observed at dawn after a clear night over Pidgeon Lake, Sept./96

(see p158-161)



- land radiatively cooled
- air above cooled by convection
- then advects over lake
- and is moistened by evaporation ("mixing of cold air with warm moist air")
- reaches the dewpoint within this shallow layer indicated