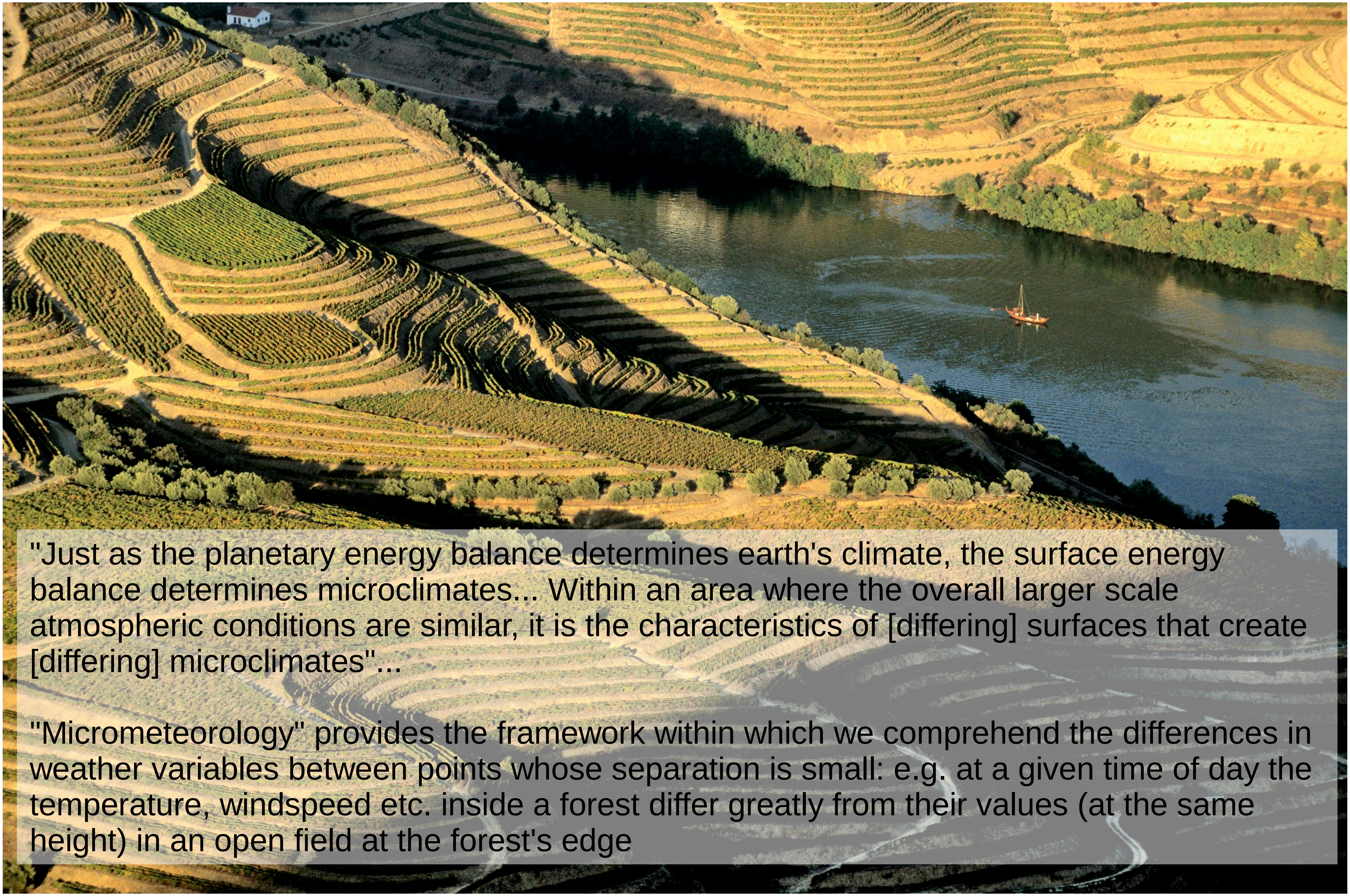
Ch6. Energy balance (ctd). Surface radiation and energy budgets

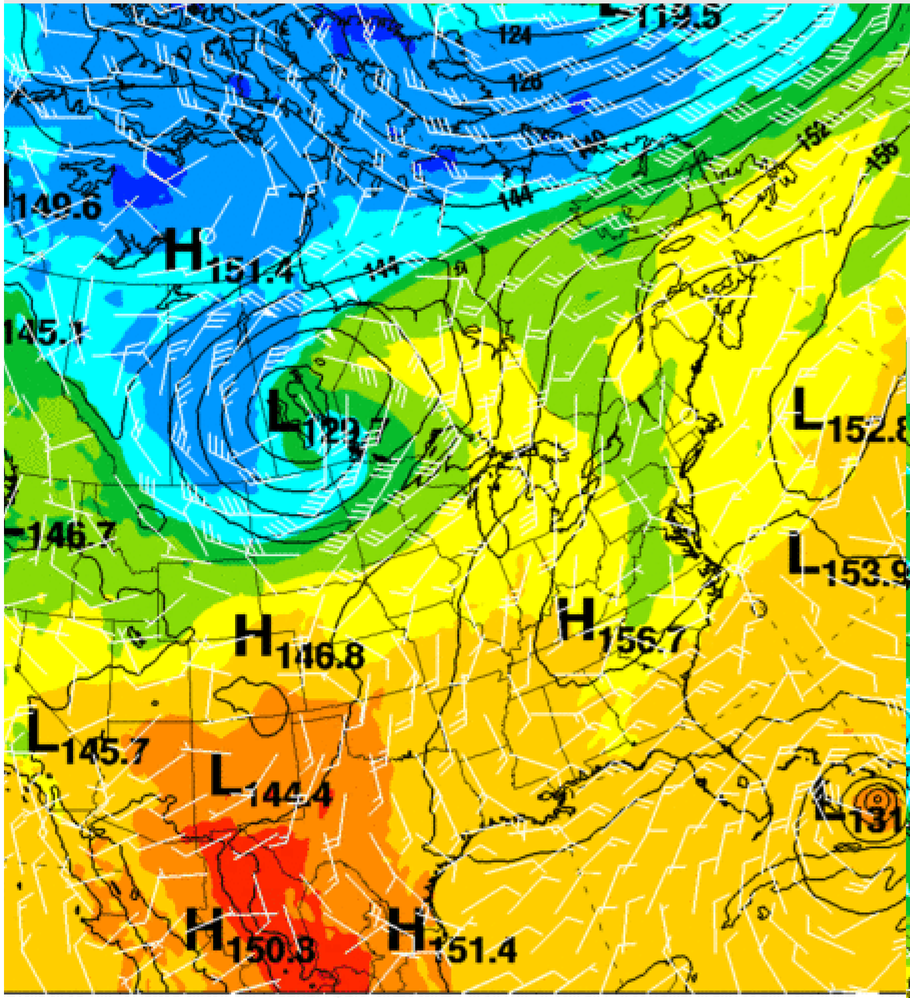


"Just as the planetary energy balance determines earth's climate, the surface energy balance determines microclimates... Within an area where the overall larger scale atmospheric conditions are similar, it is the characteristics of [differing] surfaces that create [differing] microclimates"...

"Micrometeorology" provides the framework within which we comprehend the differences in weather variables between points whose separation is small: e.g. at a given time of day the temperature, windspeed etc. inside a forest differ greatly from their values (at the same height) in an open field at the forest's edge

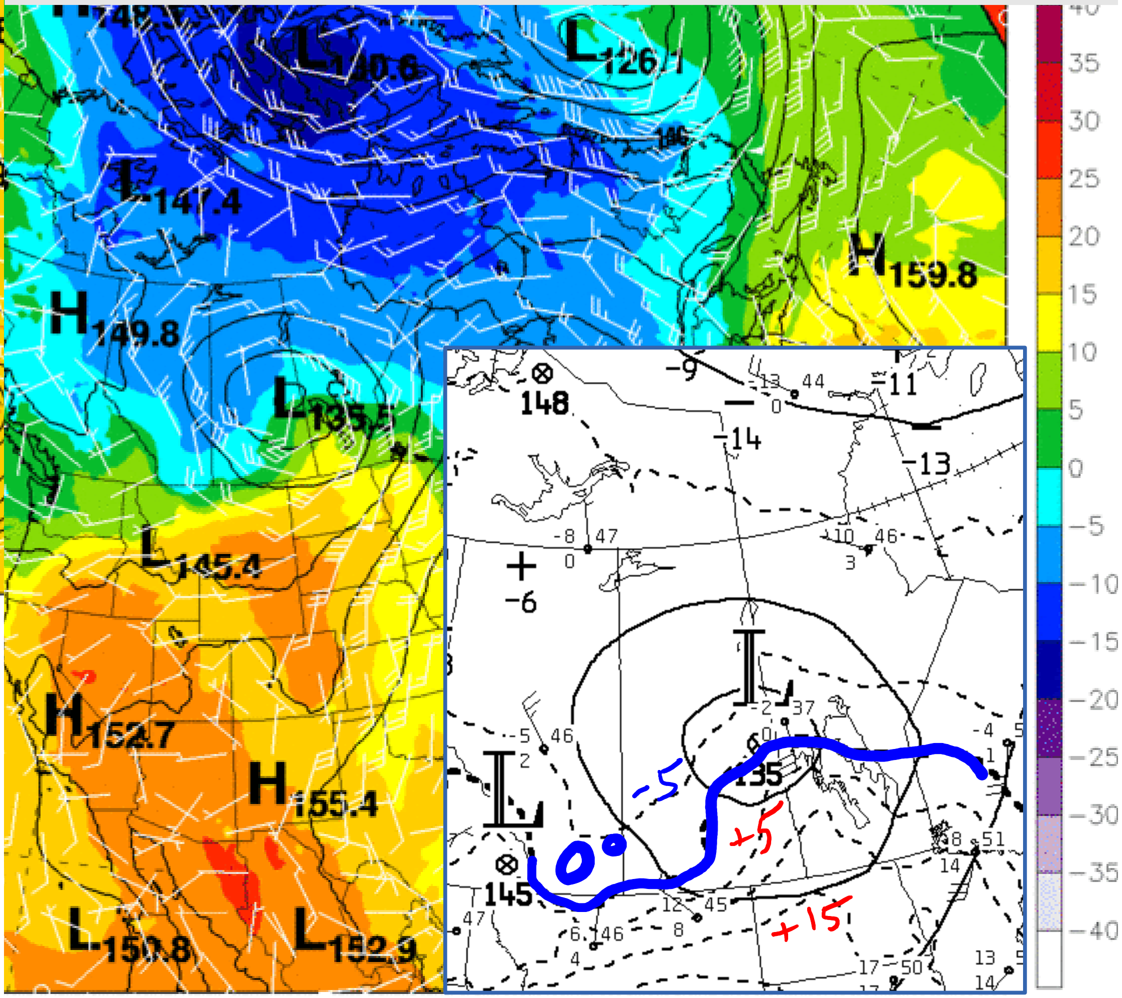
What is behind our transition (these past few days) away from summer-like weather?

CMC 850 hPa analysis, 00Z Thurs 6 Oct.



http://meteocentre.com/models/models/ – these colour charts represent the temperature field by colour shading, as opposed to the isotherms of the inset black-and-white chart.

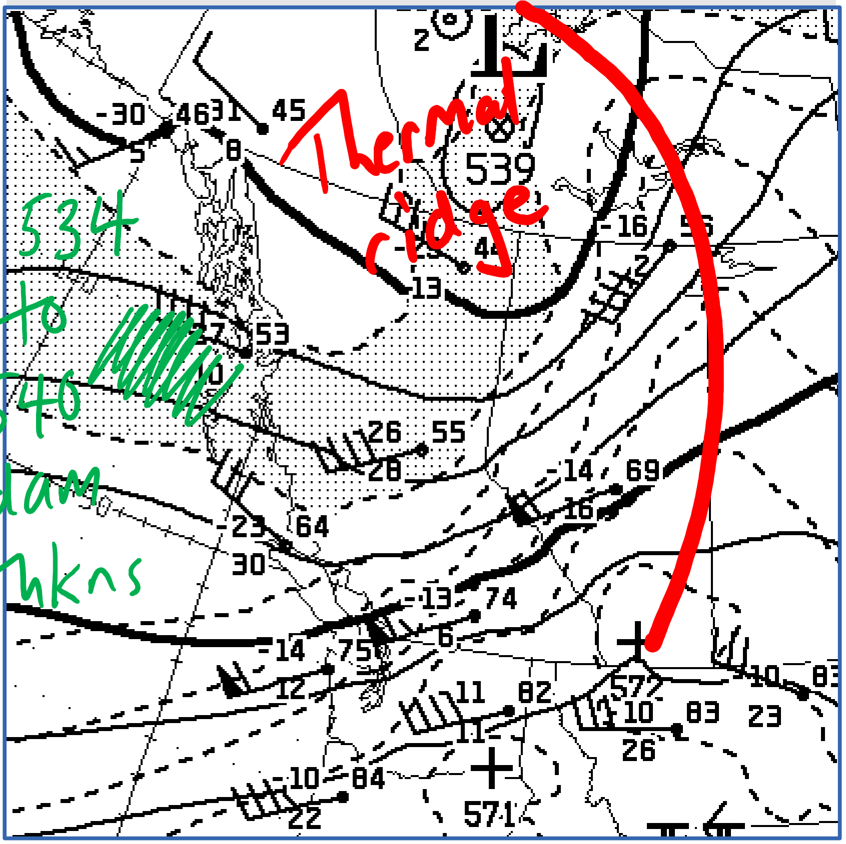
CMC 850 hPa analysis, 00Z Mon. 10 Oct., 2016



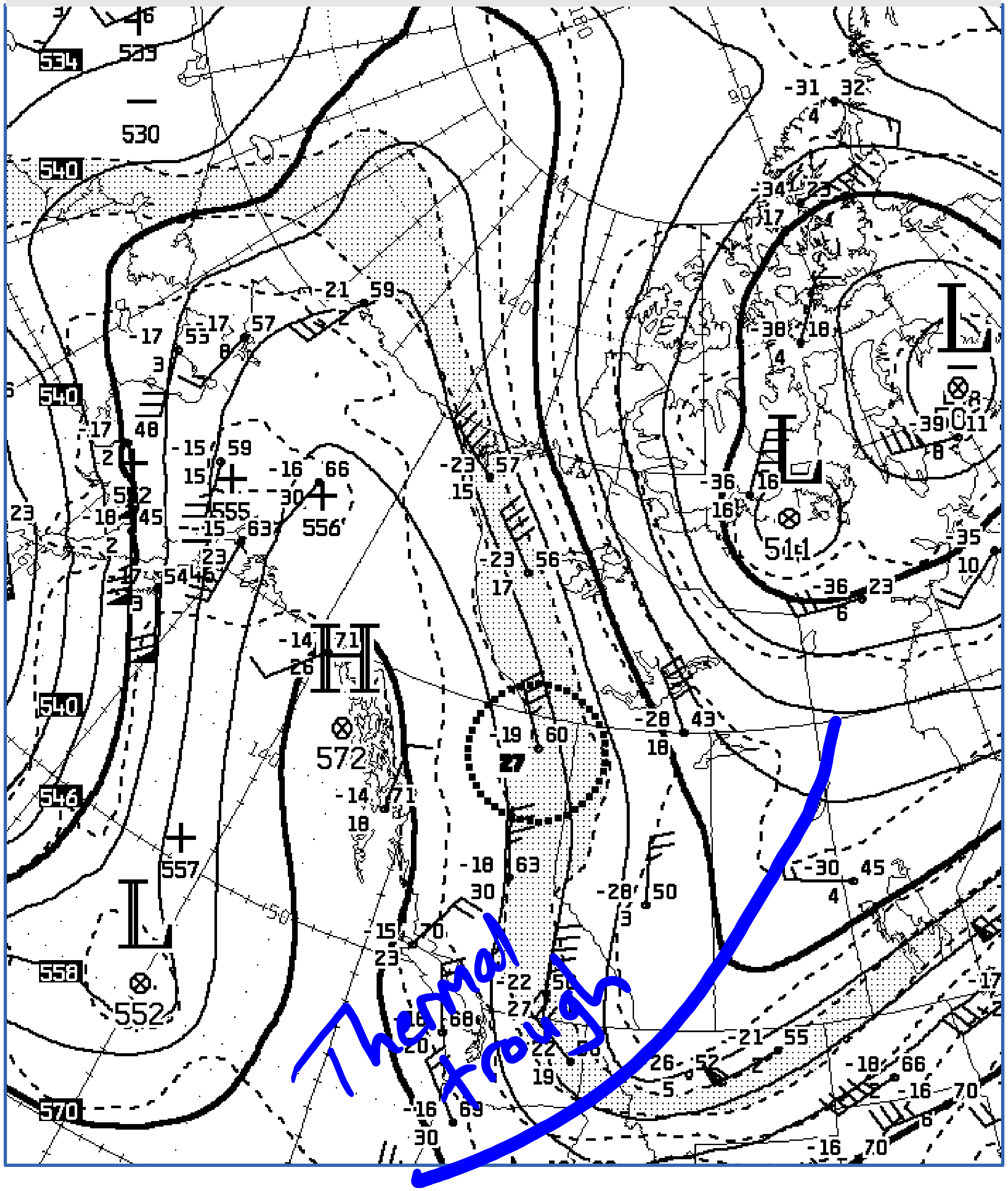
- low wrapping cold air southward on its western flank

What is behind our transition (these past few days) away from summer-like weather?

CMC 500 hPa analysis, 12Z Tues.27Sept



CMC 500 hPa analysis, 12Z Tues. 11 Oct., 2016



- switch in direction of the flow aloft – air advecting over Alberta from the far north
- change in thickness from last week to this is about 528-558=-30 dam (equiv. to 15^{o}C cooling)

Sec 6.6 Surface Energy Balance – symbols for surface radiation & energy fluxes**

Radiative fluxes at the surface

$K\downarrow, K\uparrow, L\downarrow, L\uparrow$

Net shortwave flux

diffuse + beam

$K^* = K\downarrow - K\uparrow = (1-\alpha)K\downarrow$

non-negative

$\alpha = K_\uparrow / K_\downarrow$

Net longwave flux

$L^* = L\downarrow - L\uparrow$

Net radiation

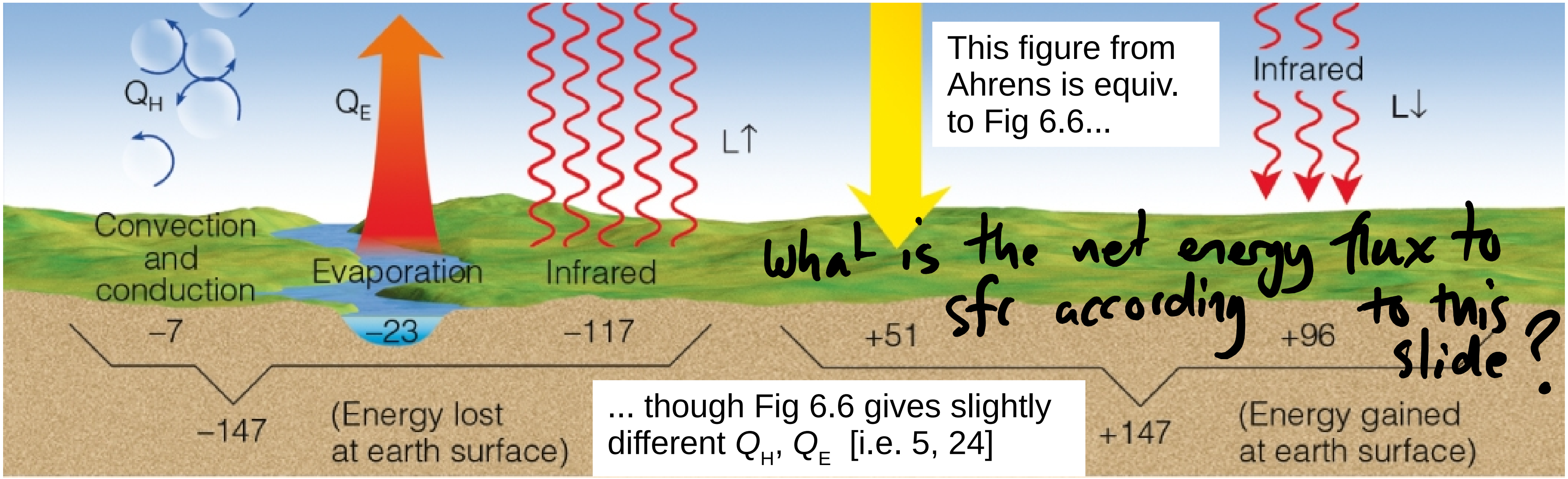
$Q^* = K^* + L^*$

Sensible & latent heat fluxes

Q_H and Q_E } convective

either sign

** Measured on horizontal surface; typical units W m $^{-2}$; also J m $^{-2}$ or J yr $^{-1}$



This figure from Ahrens is equiv. to Fig 6.6...

... though Fig 6.6 gives slightly different Q_H, Q_E [i.e. 5, 24]

what is the net energy flux to sfc according to this slide?

In the normal convention:

$$Q^* = K^* + L^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow}$$

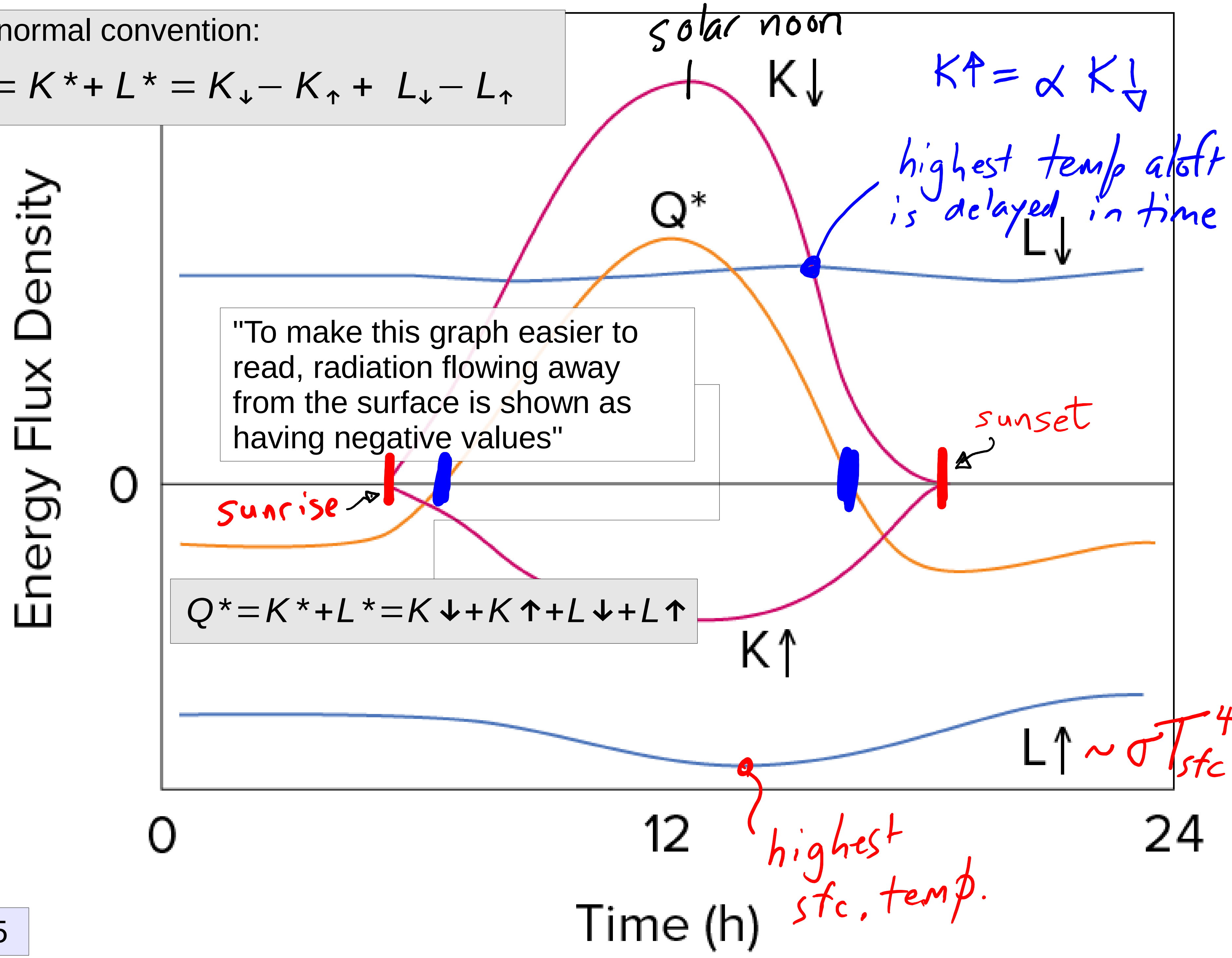


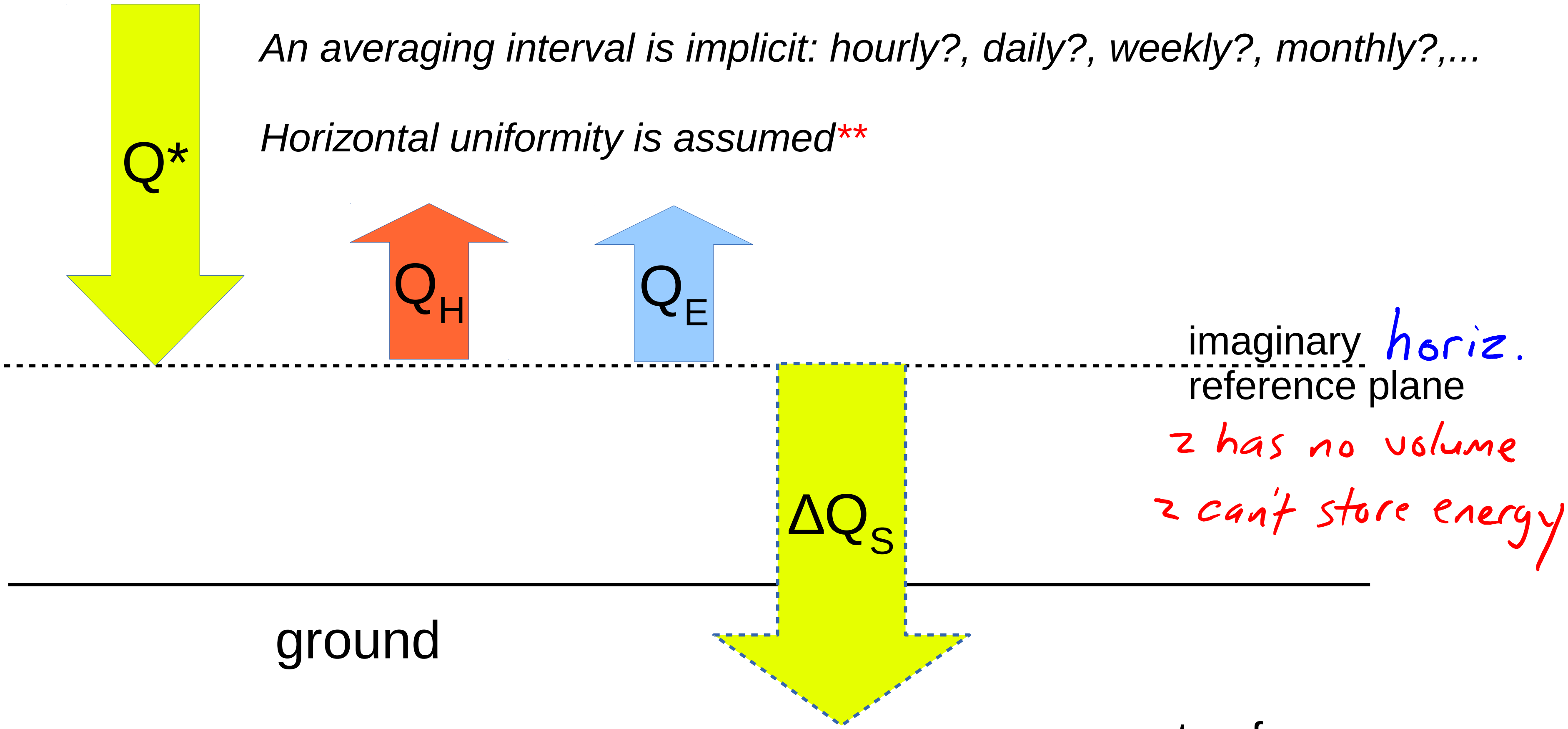
Fig 6.15

Sec 6.6.2 The surface energy balance/budget (in W m $^{-2}$ or J m $^{-2}$ or J yr $^{-1}$)

Orientation of arrows defines direction when the named flux is positive ("sign convention"). Numeric value of each can have either sign.

An averaging interval is implicit: hourly?, daily?, weekly?, monthly?,...

*Horizontal uniformity is assumed***



Eq 6.12

$$Q^* = Q_H + Q_E + \Delta Q_S$$

rate of energy *storage* in plants, buildings, soil etc. (alternate name Q_G)

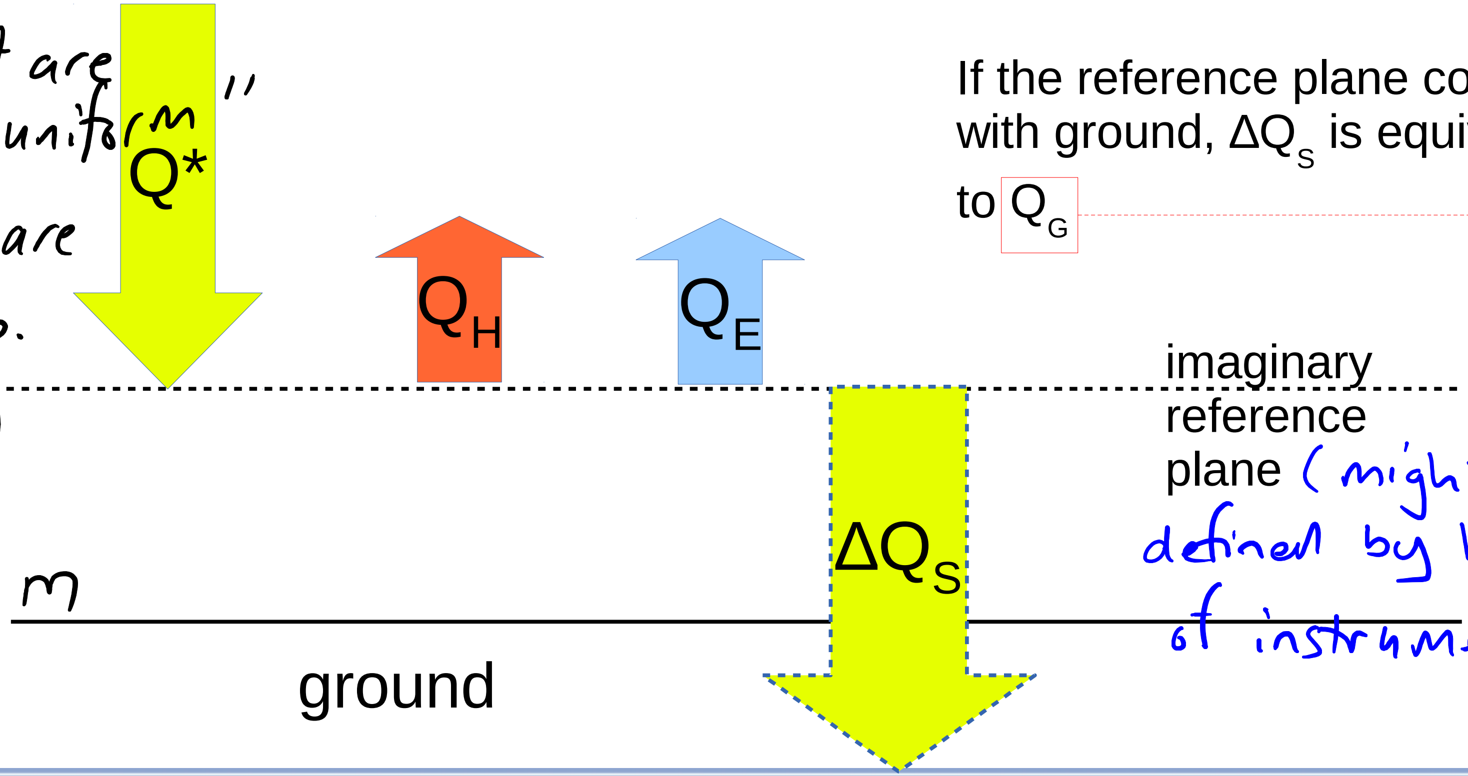
**a symmetry assumption: no need to account for horiz. flows of energy (no "advection")

Sec 6.6.2 The surface energy balance/budget (in W m $^{-2}$ or J m $^{-2}$ or J yr $^{-1}$)

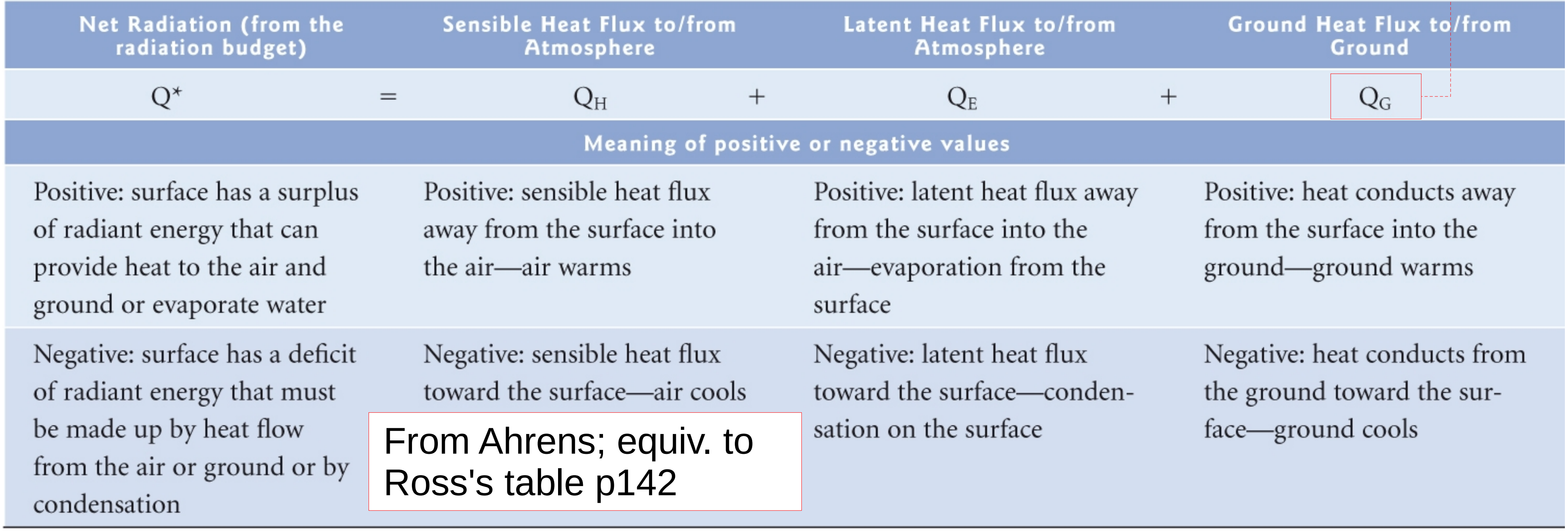
At sites that are "horizontally uniform" these fluxes are roughly indep. of height in the lowest roughly 50 m

± 10%

If the reference plane coincides with ground, ΔQ_S is equivalent to Q_G



(might be defined by height of instruments)

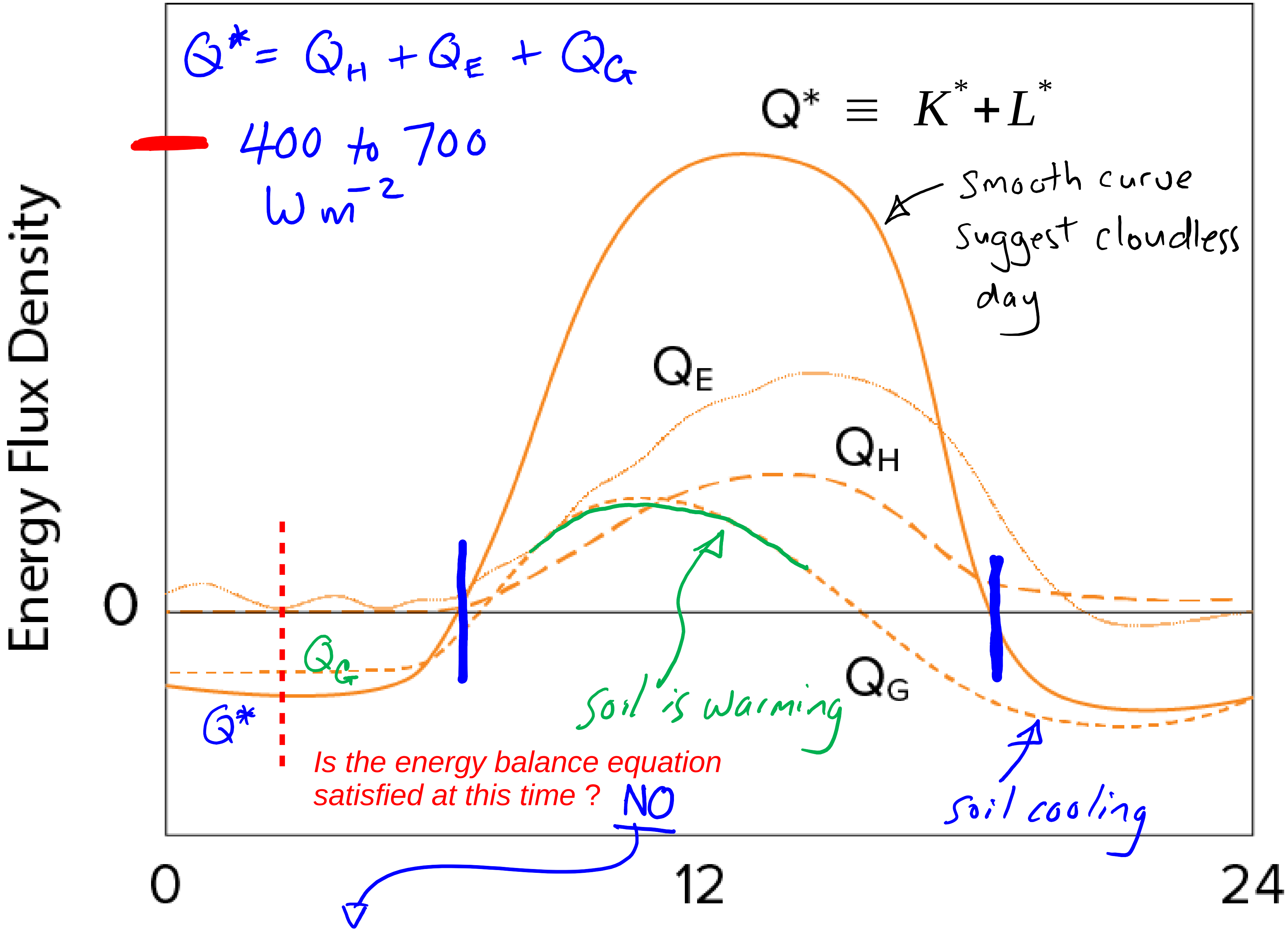


Net Radiation (from the radiation budget)	Sensible Heat Flux to/from Atmosphere	Latent Heat Flux to/from Atmosphere	Ground Heat Flux to/from Ground
Q^* =	Q_H +	Q_E +	Q_G
Meaning of positive or negative values			
Positive: surface has a surplus of radiant energy that can provide heat to the air and ground or evaporate water	Positive: sensible heat flux away from the surface into the air—air warms	Positive: latent heat flux away from the surface into the air—evaporation from the surface	Positive: heat conducts away from the surface into the ground—ground warms
Negative: surface has a deficit of radiant energy that must be made up by heat flow from the air or ground or by condensation	Negative: sensible heat flux toward the surface—air cools	Negative: latent heat flux toward the surface—condensation on the surface	Negative: heat conducts from the ground toward the surface—ground cools

From Ahrens; equiv. to Ross's table p142

$Q^* = Q_H + Q_E + Q_G$

$$Q^* \equiv K^* + L^*$$



400 to 700 $W m^{-2}$

Smooth curve suggest cloudless day

Soil is warming

soil cooling

Is the energy balance equation satisfied at this time ? NO

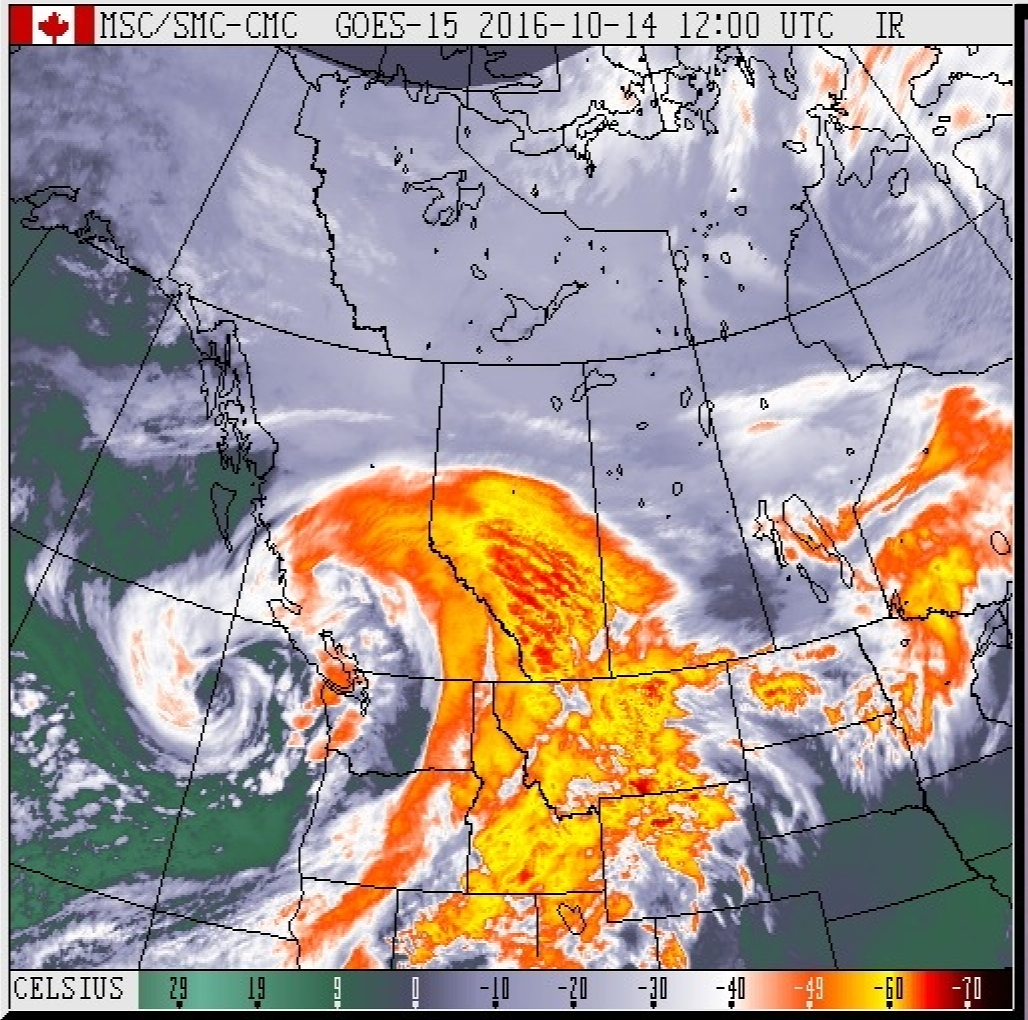
$Q_H + Q_E = 0$ BUT
$Q^* \neq Q_G$

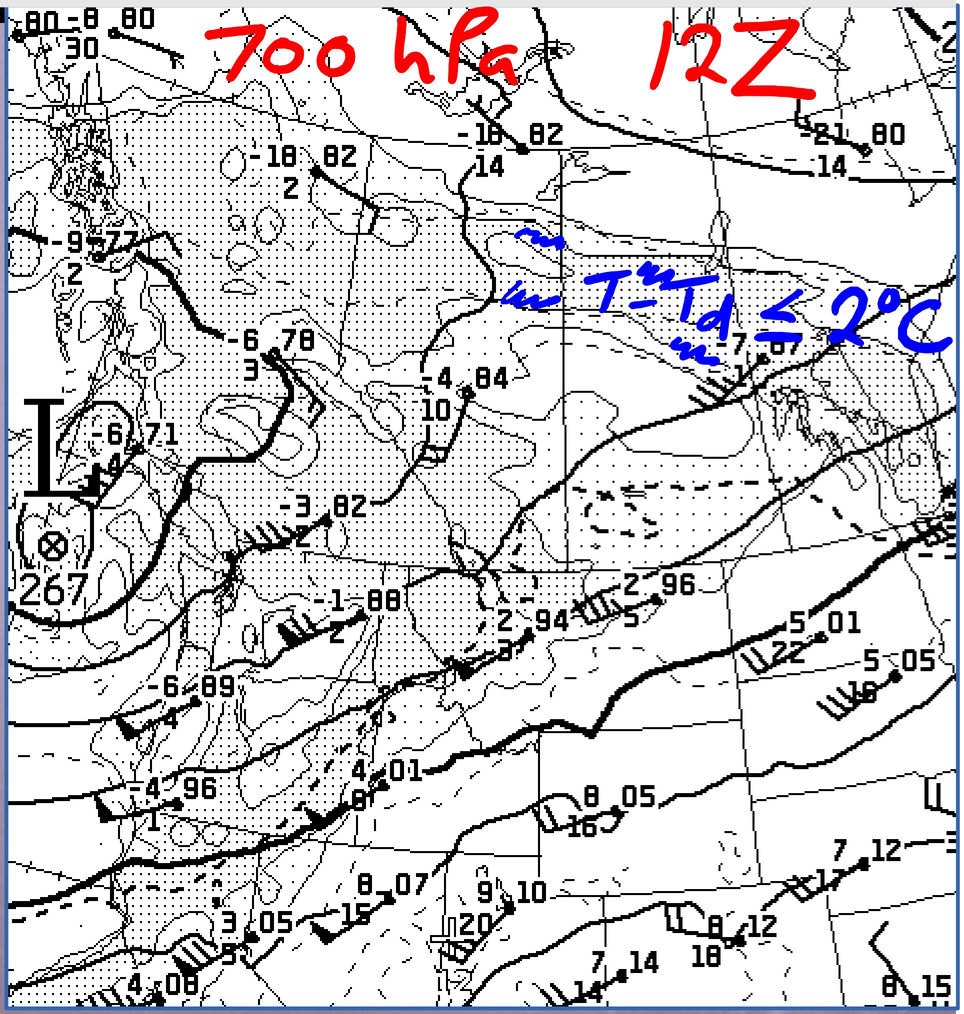
Time (h)

Fig 6.19

STOPPED HERE
WED 12 OCT.

Weather situation 14 Oct. 2016





EC 7:00 AM CDT FRI. OCT. 14 2016. FREEZING RAIN WARNING FOR SOUTH AND CENTRAL ALBERTA. SNOWFALL WARNINGS AND WINTER STORM WARNINGS FOR EAST CENTRAL ALBERTA.

DISCUSSION... AREA OF LOW PRESSURE OFF THE WEST COAST... VERY STRONG AND ZONAL UPPER FLOW ACROSS THE PRAIRIES WITH MAJOR WARM AIR ADVECTION...

SURFACE LOW DEVELOPING IN LEE OF ROCKIES IN SOUTHERN AB TODAY... NORTH OF THE LOW, HEAVY SNOW WILL DEVELOP WITH TOTAL SNOWFALL AMOUNTS OF 10 TO 15 CM IN EAST CENTRAL ALBERTA BY EVENING...

Annual surface energy budget (based on Fig. 6.6)

$$Q^* = K^* + L^* = 54 - 7 + 98 - 116$$
$$= +29$$

$$Q_H + Q_E = 29$$

This implies the storage term (heat added to/taken from the solid earth & oceans) is negligible – soils heat up in spring/summer, cool off in fall/winter... no yearly gain or loss of total energy [of earth system as a whole] and avg. temperature of the earth & atmos. remains *fairly* constant

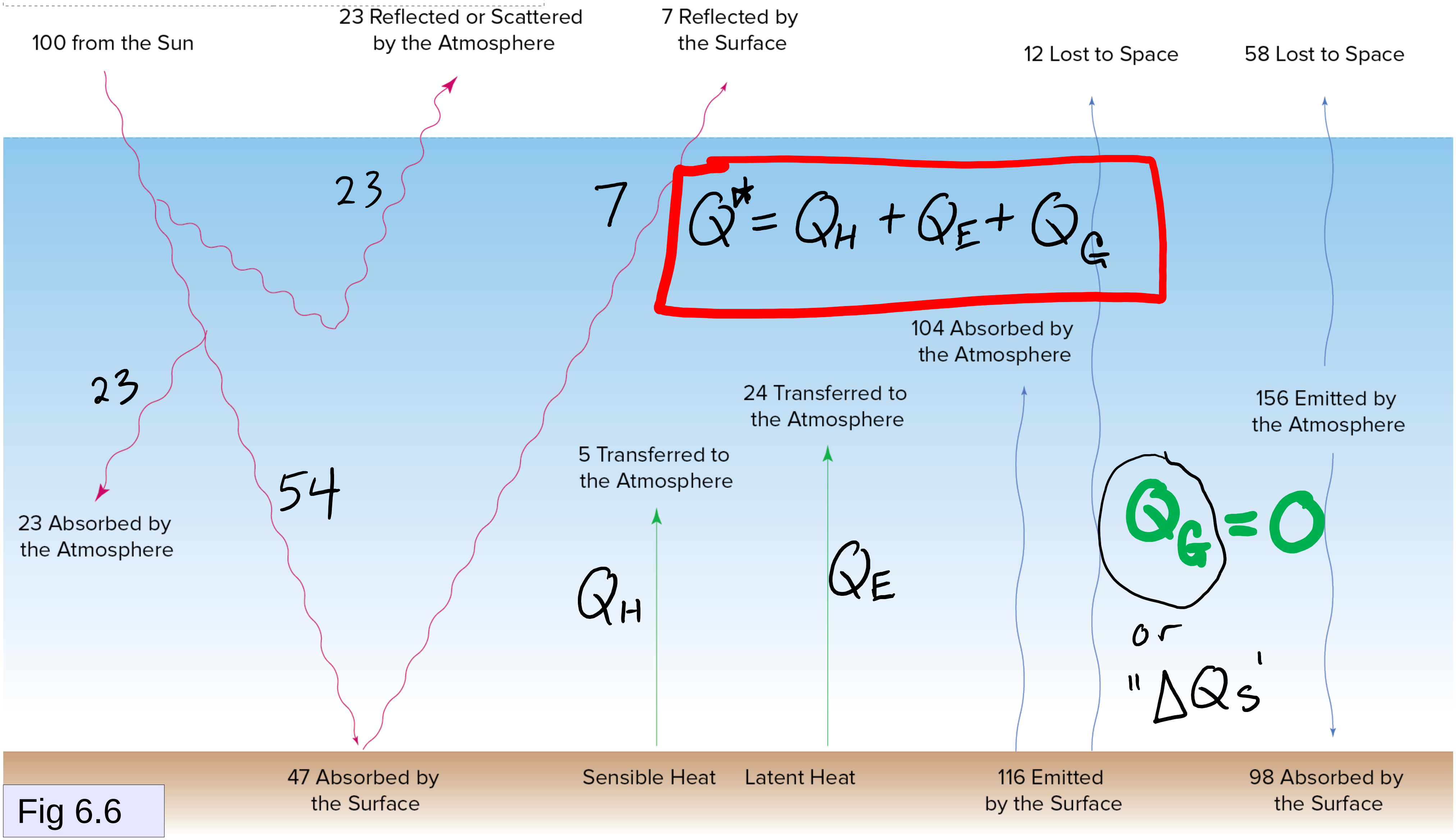


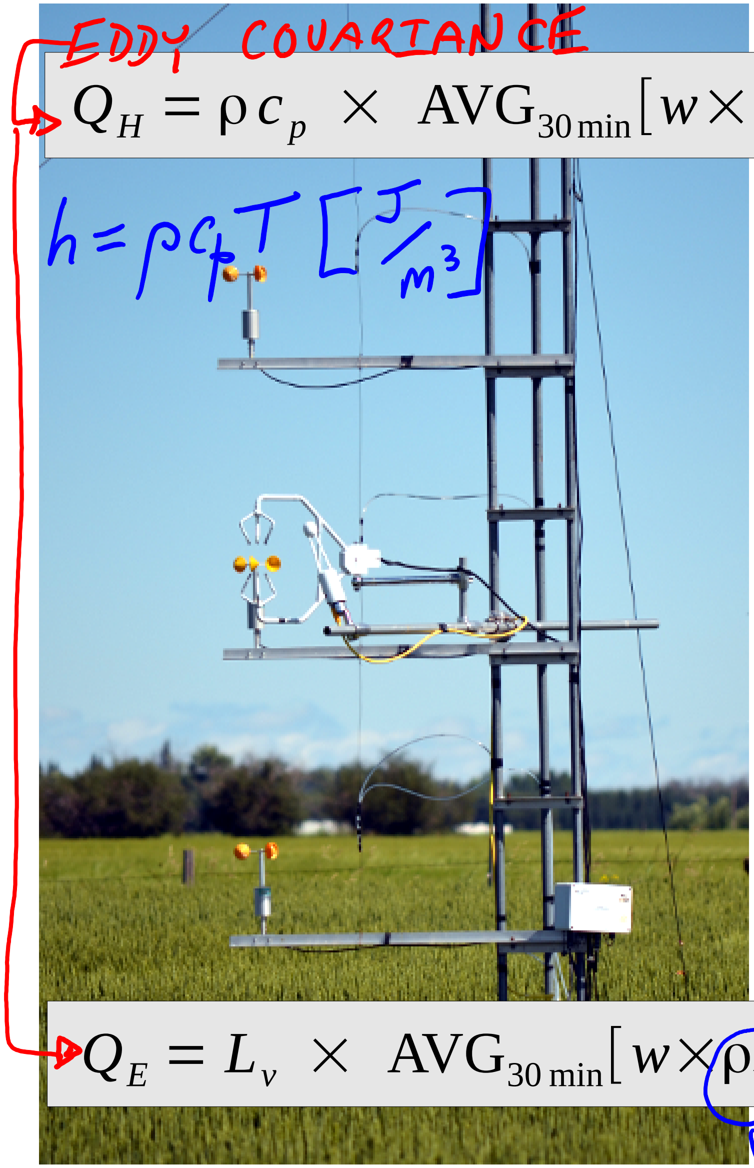
Fig 6.6

Daily surface energy budget: real example (wheat crop, St. Albert, JDW)

EDDY COVARIANCE

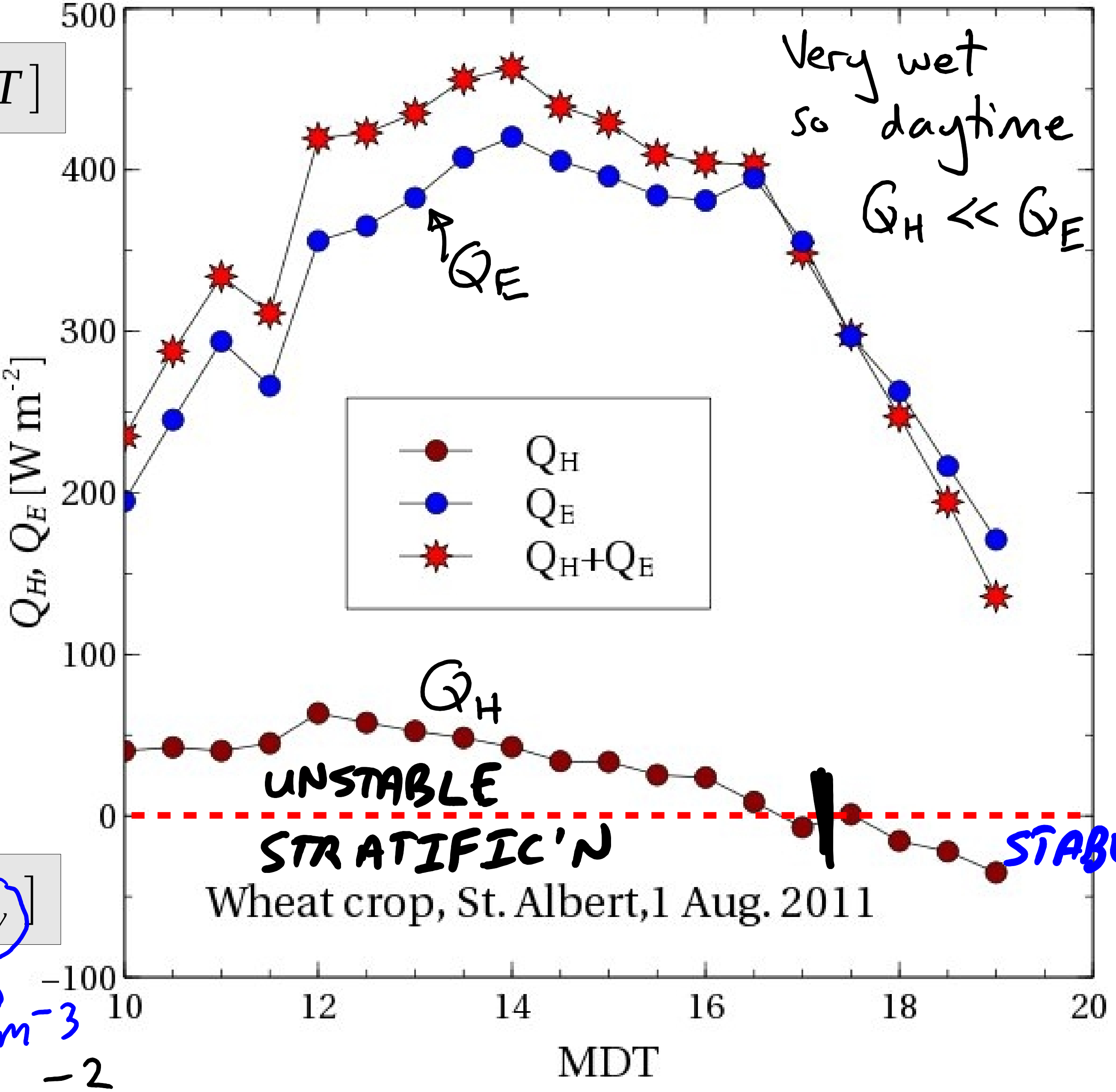
$$Q_H = \rho\, c_p \times \mathrm{AVG}_{30\,\mathrm{min}}[w \times T]$$

$h = \rho c_p T \left[\mathrm{J}/\mathrm{m}^3 \right]$



$$Q_E = L_v \times \mathrm{AVG}_{30\,\mathrm{min}}[w \times \rho_v]$$

$\mathrm{kg\,m^{-3}}$



Very wet so daytime $Q_H \ll Q_E$

Q_E

Q_H

UNSTABLE STRATIFIC'N

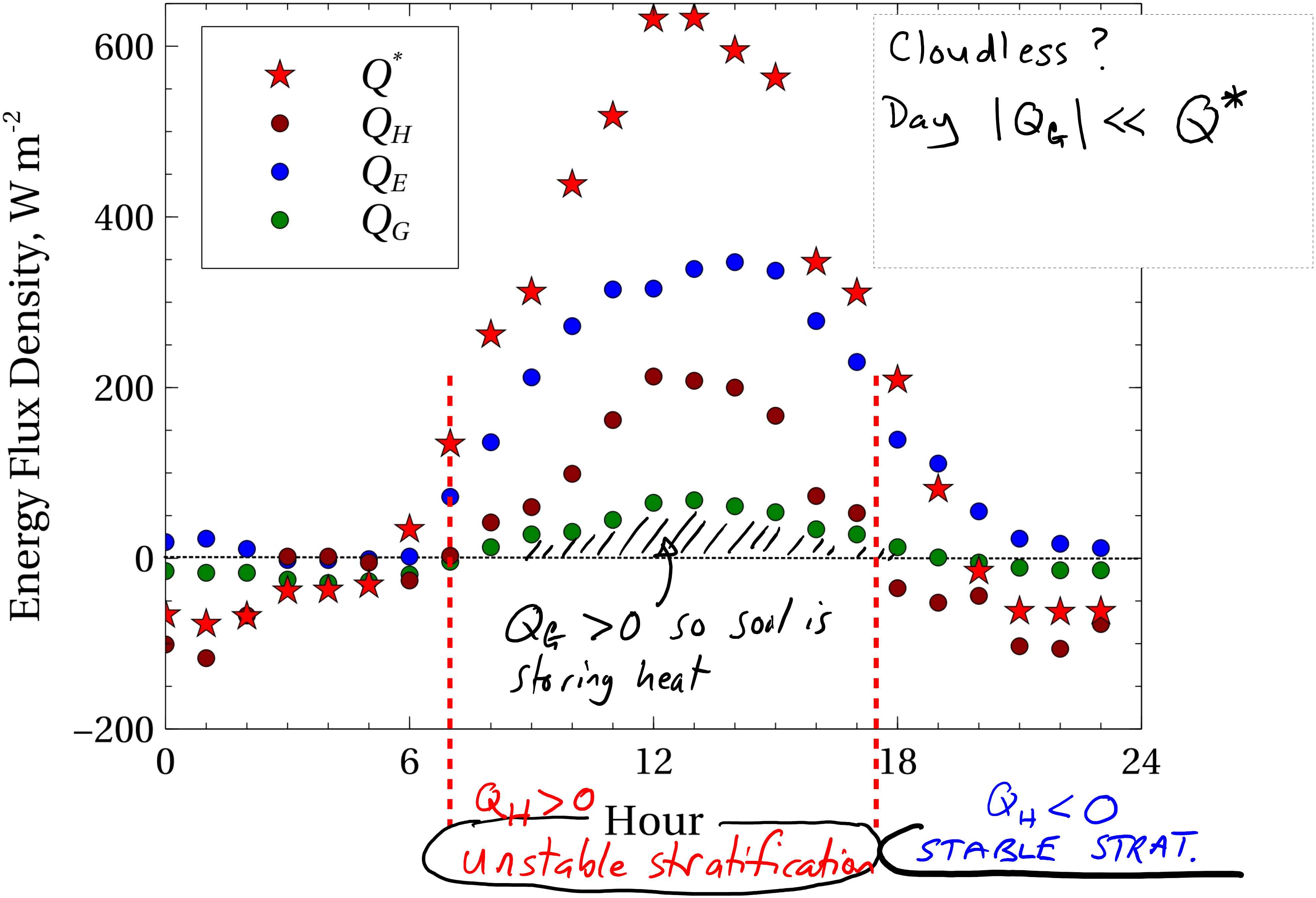
STABLE

$$[Q^*]^{\mathrm{MAX}} \gtrsim 450\ \mathrm{W\,m^{-2}}$$

Typical over crop at this latitude

Daily surface energy budget: real example (grassland, S. Alberta)

Surface energy balance over grassland 1 July 2003 (Alberta) − data courtesy L. Flanagan



Cloudless ?

Day $|Q_G| \ll Q^*$

$Q_G > 0$ so soil is storing heat

$Q_H > 0$ unstable stratification

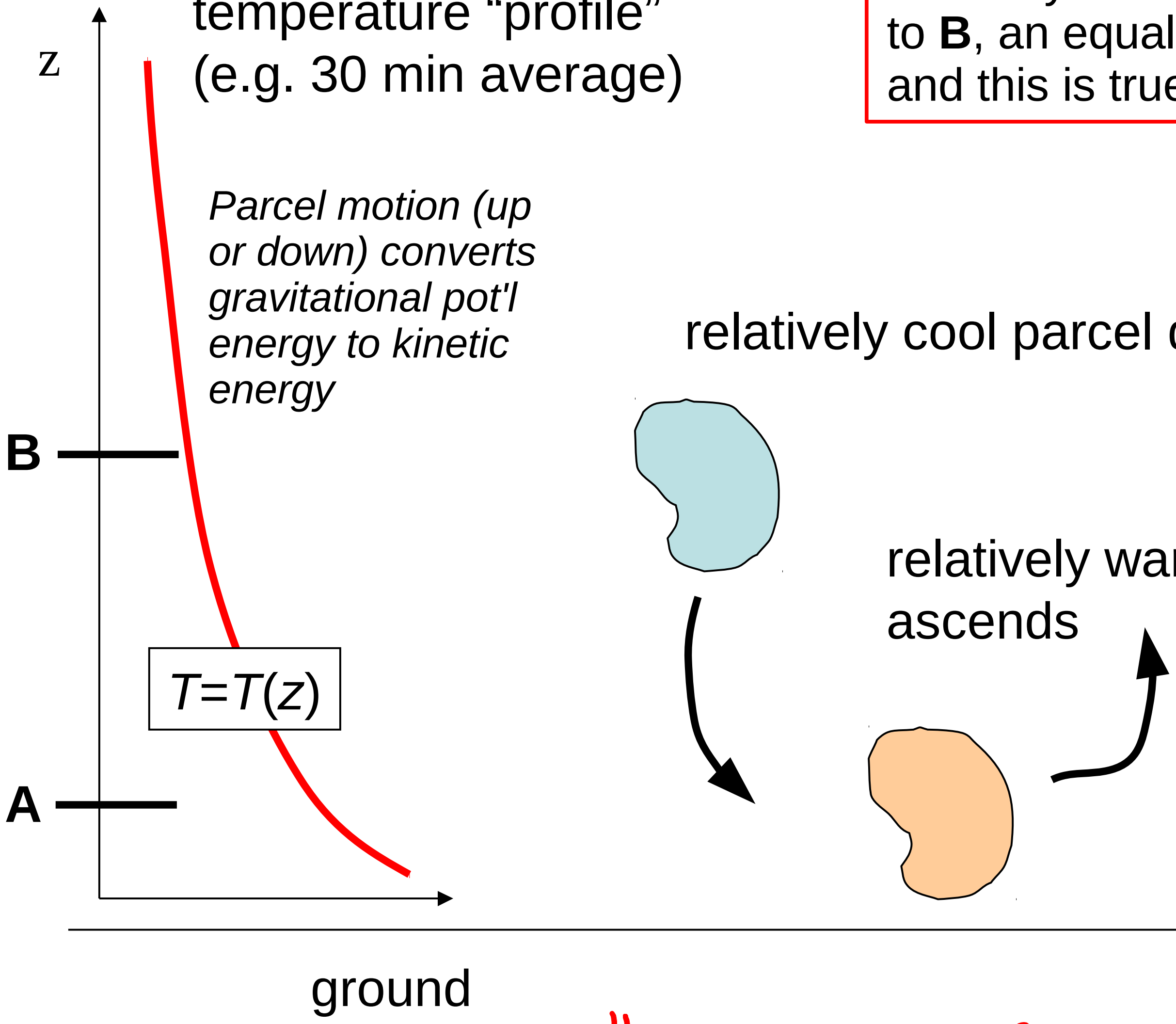
$Q_H < 0$ STABLE STRAT.

Role of (turbulent vertical) convection in local energy balance… day

(turbulent) vertical convection of (sensible) heat, or "convective heat exchange" is the mechanism of the "sensible heat flux" Q_H [W m^{-2}]

Air is effectively incompressible in the ABL: thus for every cubic metre of air that ascends from **A** to **B**, an equal volume descends from **B** to **A** – and this is true by day or by night

Daytime near-ground temperature "profile" (e.g. 30 min average)



Parcel motion (up or down) converts gravitational pot'l energy to kinetic energy

relatively cool parcel descends

relatively warm parcel ascends

Sign convention – a positive flux transports heat UP

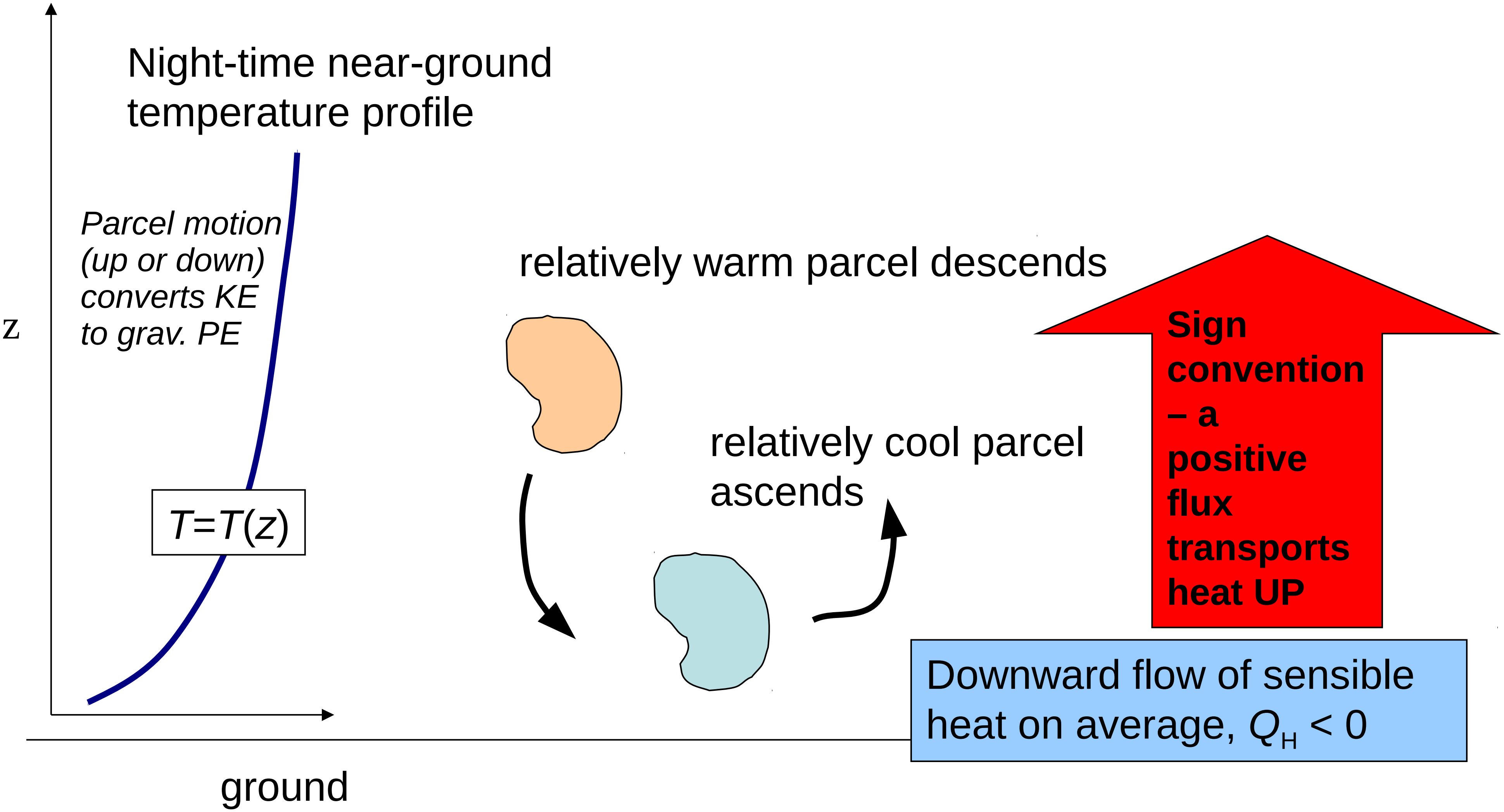
Upward flow of sensible heat on average, $Q_H > 0$

"UNSTABLE STRATIFICATION"

Role of (turbulent vertical) convection in local energy balance… night

In this case, mixing results in a downward (turbulent, convective) flow of sensible heat, i.e. $Q_E < 0$

"STABLE STRATIFICATION"



Night-time near-ground temperature profile

Parcel motion (up or down) converts KE to grav. PE

z

$T=T(z)$

ground

relatively warm parcel descends

relatively cool parcel ascends

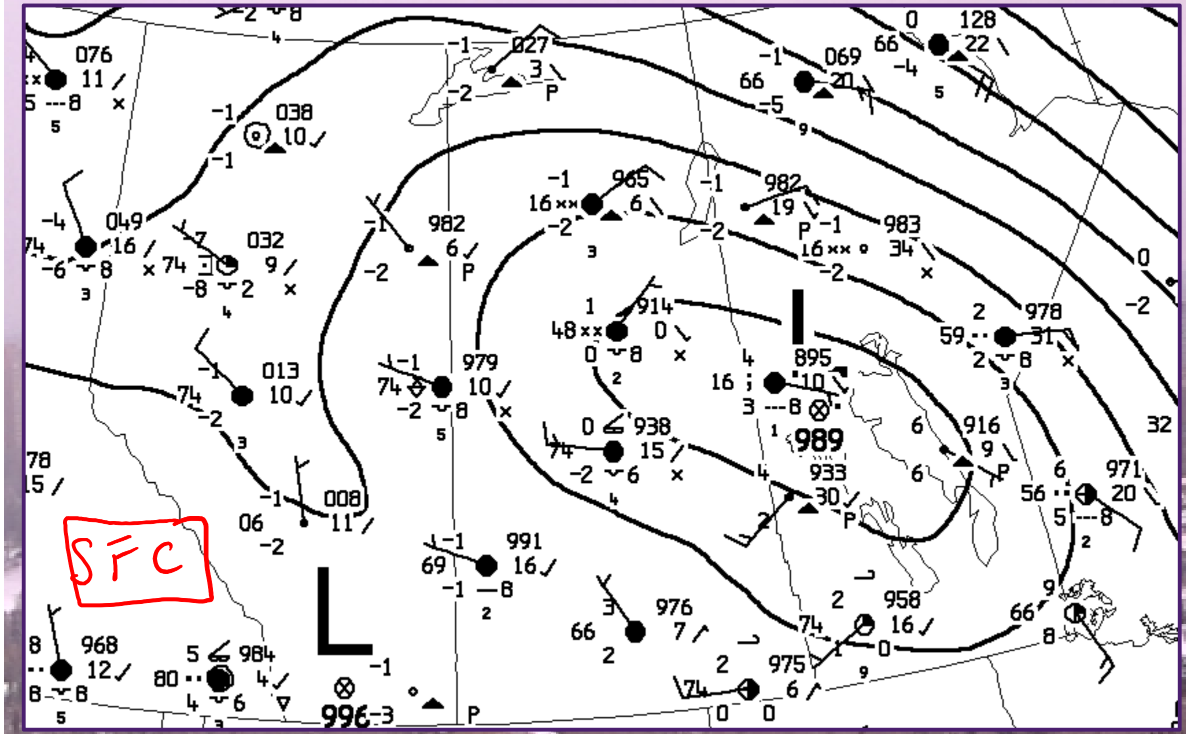
Sign convention – a positive flux transports heat UP

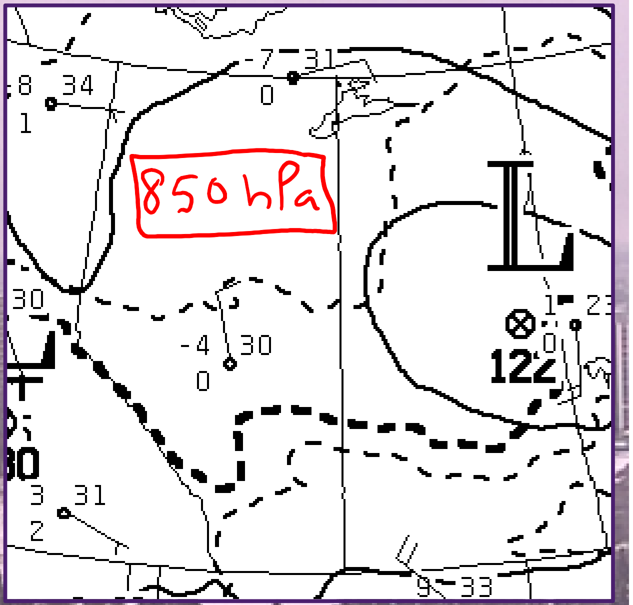
Downward flow of sensible heat on average, $Q_H < 0$

STOPPED HERE 14 OCT. 2016

Weather situation 12Z Monday 17 Oct. 2016

CMC Analyses

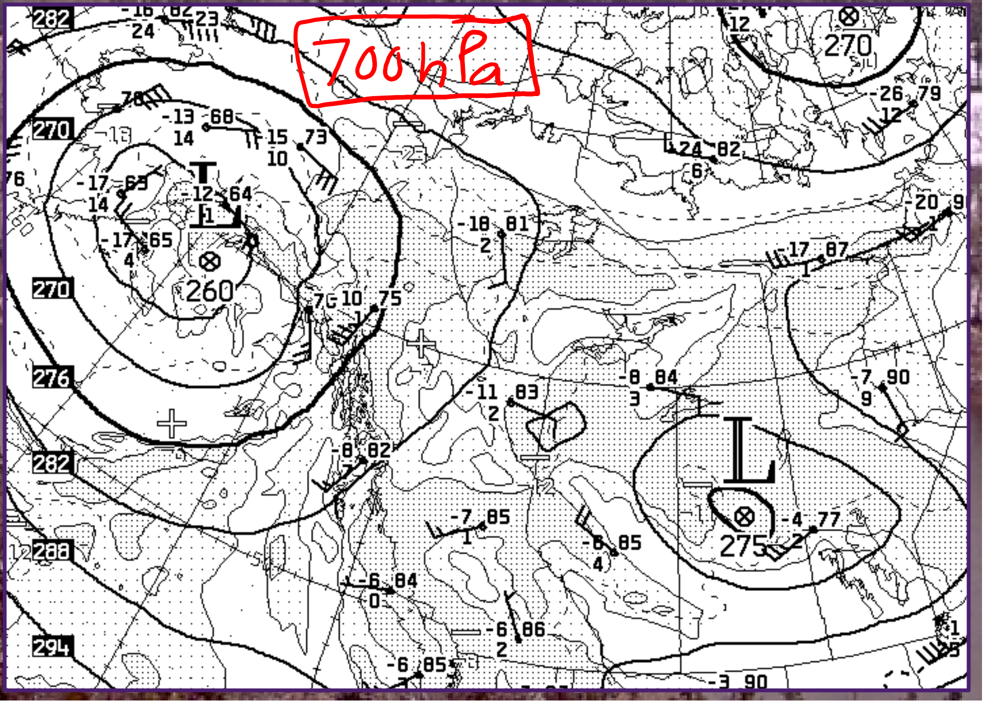




Another in a sequence of lows that have affected Alberta weather over the past few days now straddles the Sask/Manitoba border

850 hPa chart suggests weak cooling to occur over the short term

SSW upper flow continues to inject moist air over the prairies



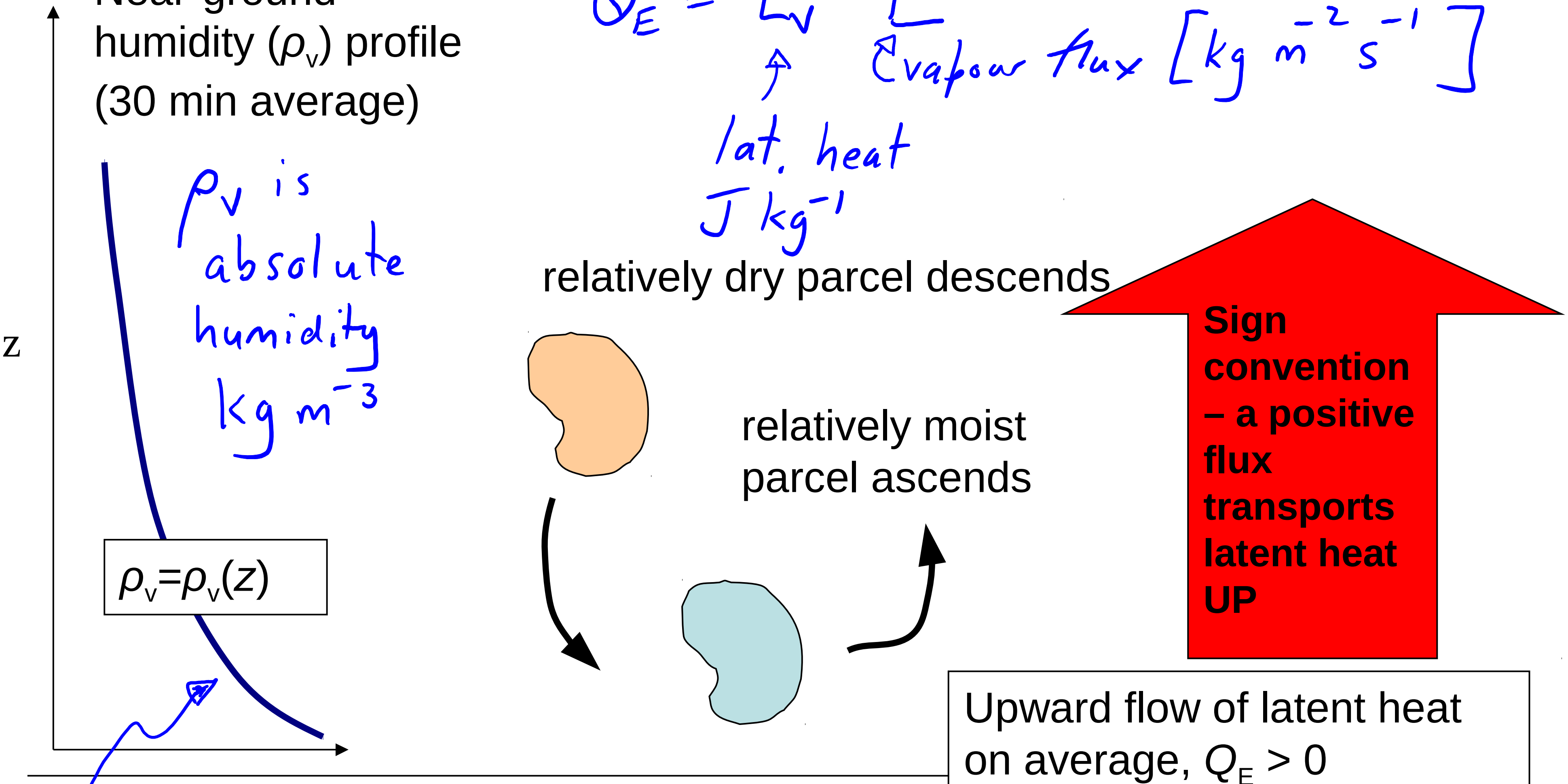
Role of turbulent convection of latent heat in local energy balance…

Vertical convection of vapour implies a “latent heat flux” Q_E [W m^{-2}] , because every kg of vapour added to the atmosphere carries with it a quantity of “hidden heat” equal to the “latent heat of vapourization,” i.e. (at 20°C) 2.5 x 10^6 Joules

$$Q_E = L_v \; E$$

lat. heat $J \, kg^{-1}$

vapour flux $[kg \, m^{-2} \, s^{-1}]$



Near-ground humidity (ρ_v) profile (30 min average)

ρ_v is absolute humidity $kg \, m^{-3}$

$\rho_v = \rho_v(z)$

relatively dry parcel descends

relatively moist parcel ascends

Sign convention – a positive flux transports latent heat UP

Upward flow of latent heat on average, $Q_E > 0$

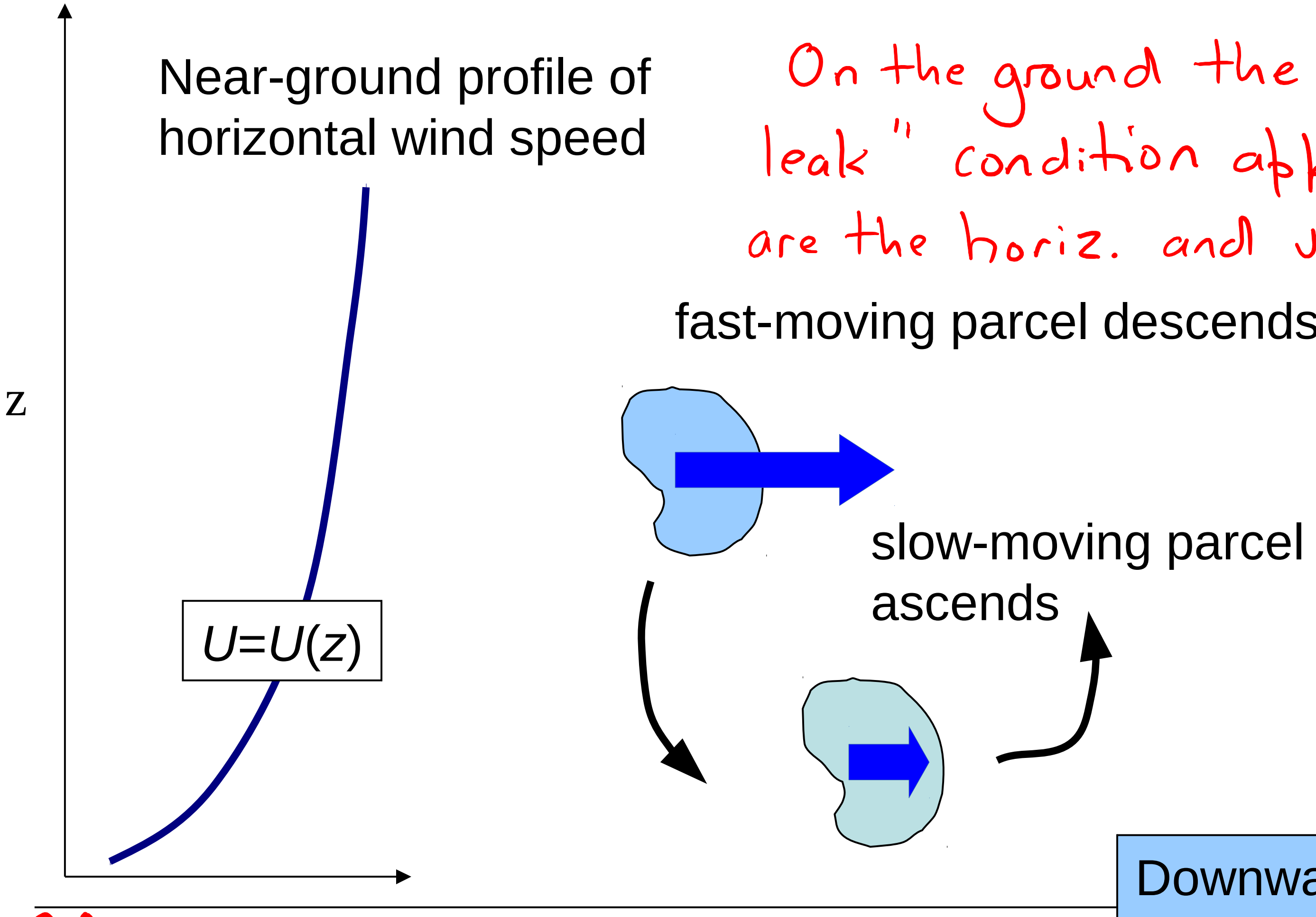
ground

assuming the ground is moist such that evapotranspiration occurs

Turbulent vertical convective transport ("mixing") of horizontal momentum

Because horiz. wind speed near ground increases with increasing height, mixing results in downward (turbulent, convective) transfer of momentum

$\rho(u,v) = \vec{M}$ mtm/vol



Near-ground profile of horizontal wind speed

z

$U=U(z)$

fast-moving parcel descends

slow-moving parcel ascends

ground

no slip condition

On the ground the "no slip, no leak" condition applies: if (U, w) are the horiz. and vertical wind speeds then at $z=0$

$U = w = 0$

no slip

no leak

Downward flow of horizontal momentum on average

DEW & FROST

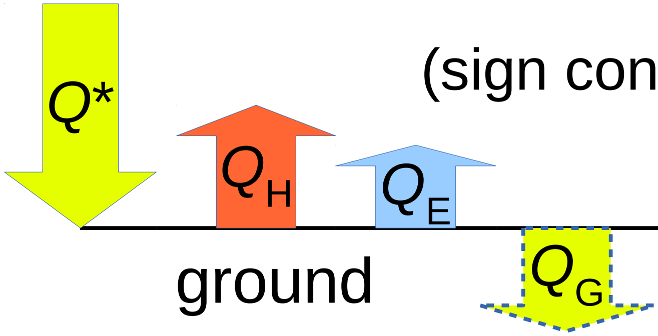
$K^* = 0$

More likely on clear nights without too much wind to mix down warmer air from aloft

Equiv. to Fig 7.12

- nocturnal radiative **surface cooling** , $L^* < 0$
- cold surfaces cool air in contact by conduction
- wind exchanges cold air from the laminar boundary layer with warmer air aloft, deepening the layer that loses heat
- $$Q^* = L^* = Q_H + Q_E + Q_G < 0$$

(each term liable to be negative)



(sign convention)

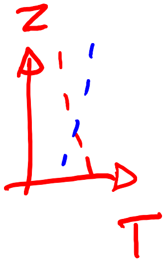
- surface cools to surface air's dewpoint ($T_{sfc} = T_d$), vapour condenses onto leaves etc. and/or water droplets form in the chilled air and deposit onto surface... **dew** (which may later cool to become frozen dew)

Sec 6.6.3 Contrast surface climates (ocean and desert, same latitude and time)

$$\boxed{Q^* = Q_H + Q_E + \Delta Q_S}$$

OCEAN

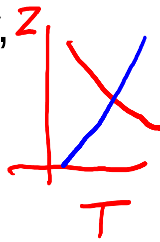
- solar radiation penetrates ocean, low albedo α , high K^* [$=(1-\alpha)$ K↓]
- ocean surface cool, low $L\uparrow$
- moist lower atmosphere, high $L\downarrow$
- high Q^*
- ocean turbulence mixes energy gain/loss through depth – small surface temperature response to radiant energy suplus/deficit
- freely available water to evaporate, so Q_H small compared to Q_E – therefore stratification is moderate



- small diurnal range in temperature

DESERT

- high albedo, reducing K^* [$=(1-\alpha)$ K↓]
- hot surface, meaning high $L\uparrow$ [$\approx \sigma T^4$]
- dry air, meaning low $L\downarrow$
- Q^* not as large as over the ocean
- sand a poor conductor, meaning large surface temperature response to radiant energy surplus/deficit (Q^*)
- no water, so Q_E=0. Thus $|Q_H|$ is a large proportion of the net radiation – therefore **strongly unstable** stratification by day, **strongly stable** stratification by night



- large diurnal range in temperature
- desert winds strong by day, light at night (stratification controls downward mixing of momentum)

Topics/concepts covered

- symbols and conventions for the radiation and energy budgets
- understanding the daily cycle in energy budget components
- dependency of the local energy balance on particulars of the surface
- daily cycle in the energy balance differs from place to place, from day to day, from season to season
- must be represented by weather & climate models
- radiation and energy budgets may be studied locally, or on a regional or global scale
- mechanism for Q_H, Q_E is turbulent convective transport (these are often named "eddy fluxes")
- understanding "radiative frost" by way of the surface energy budget