Chapter 6. Energy balance.

Energy in – Energy Out = Change in stored energy

or

Rate of energy addition – Rate of energy subtraction = Rate of change of stored energy

- numeric values in the radiative and energy "budgets" we cover today constitute climatological values (annual-global averages) and correspond to "steady state"
- we start with a gross planetary energy budget that assumes steady state – and reveals the strong stabilizing feedback that keeps earth's temperature in equilibrium with the sun
- we'll progress to short-term (say, 30 min) local surface energy budget

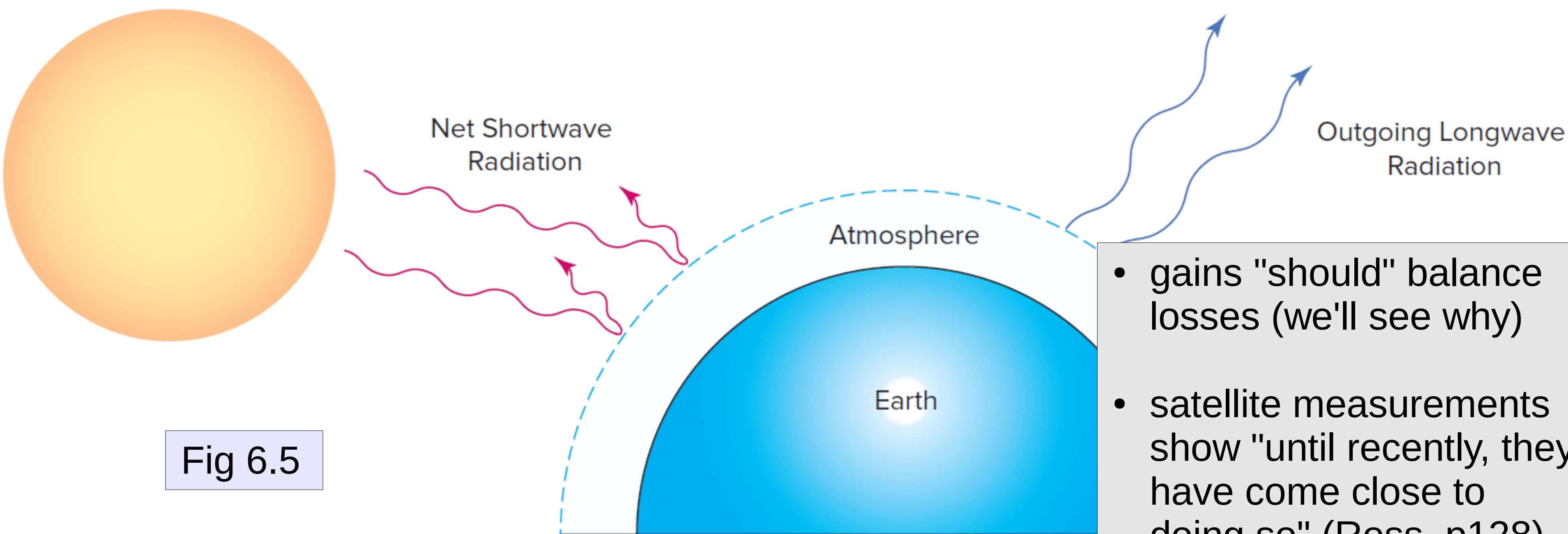


Fig 6.5

- gains "should" balance losses (we'll see why)
- satellite measurements show "until recently, they have come close to doing so" (Ross, p128)

$$\frac{d\,T_E}{dt} \propto \underbrace{(1-\alpha)}_{\text{absorbtivity}}\ S_0\ \pi r_E^2 - 4\pi r_E^2\ \sigma T_E^4\ \ [W]$$

IN: $(1-\alpha)\,S_0\,\pi r_E^2$ OUT: $4\pi r_E^2\,\sigma T_E^4$

α planetary albedo (shortwave reflectivity)

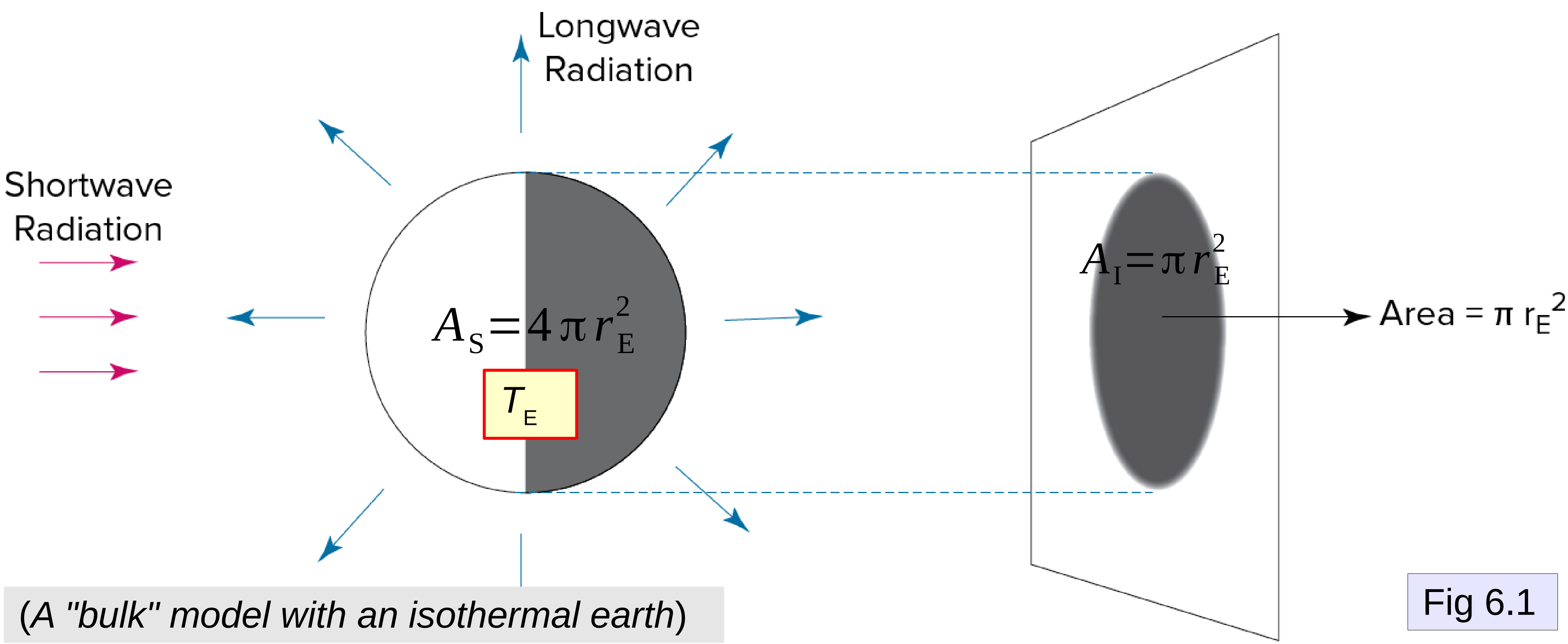
Net solar radiation $= (1-\alpha)\,S_0\,\pi r_E^2$

Longwave emission $= 4\pi r_E^2\,\sigma T_E^4$

M_E [kg] mass of earth
C_E [$J\,kg^{-1}K^{-1}$] specific heat capac.
$(M_E C_E)\,dT_E/dt = \ldots$

4%

Strong stabilizing feedback – if T_E were to drop by 1%, longwave loss would drop by ??%?
Then T_E would recover. It's in this sense that global gains & losses "should" (p128) balance



(A "bulk" model with an isothermal earth)

Fig 6.1

- assuming steady state, $\dfrac{dT_E}{dt} = 0$ so that $T_E = \left[\dfrac{S_0}{4\sigma}(1-\alpha)\right]^{1/4}$
- α taken as 0.3 gives T_E = -18°C (255 K)
- which is 33 K too cold relative to observed global mean annual sfc temp
- selective absorption & emission by GHG in atmos. raises surface temperature

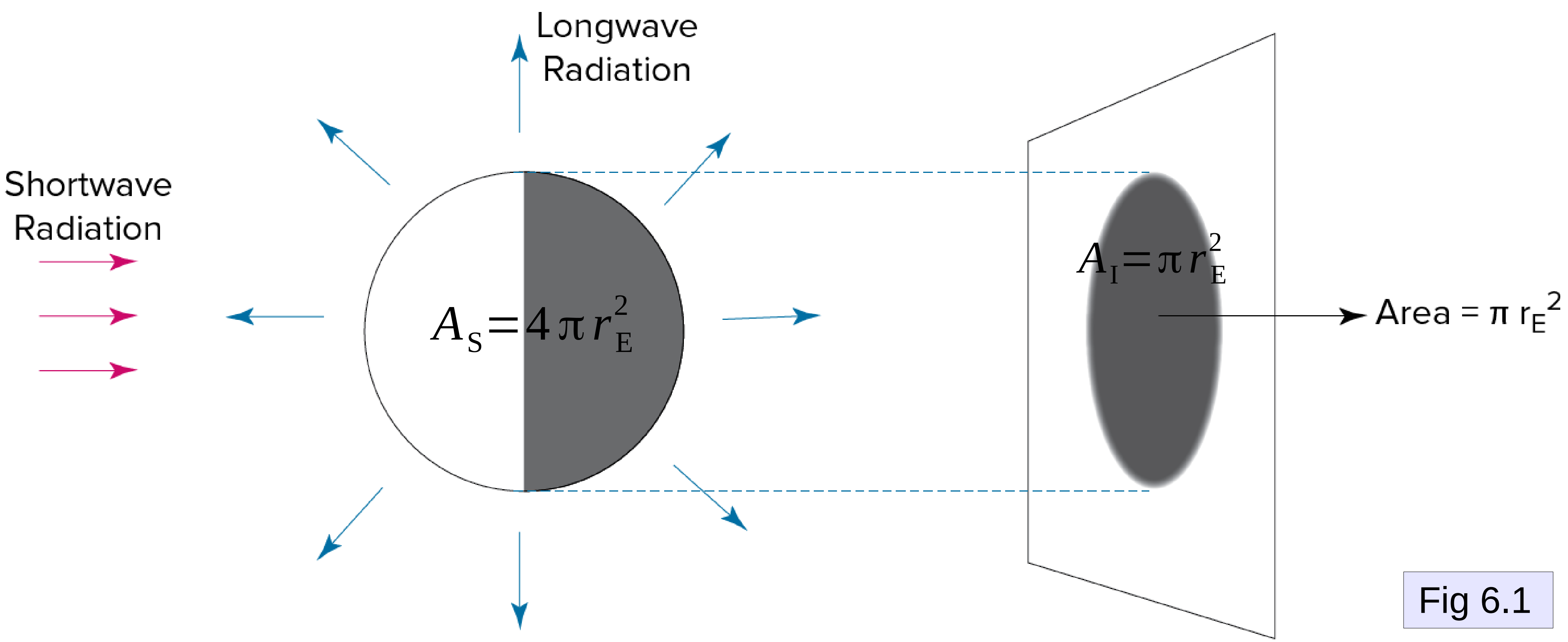
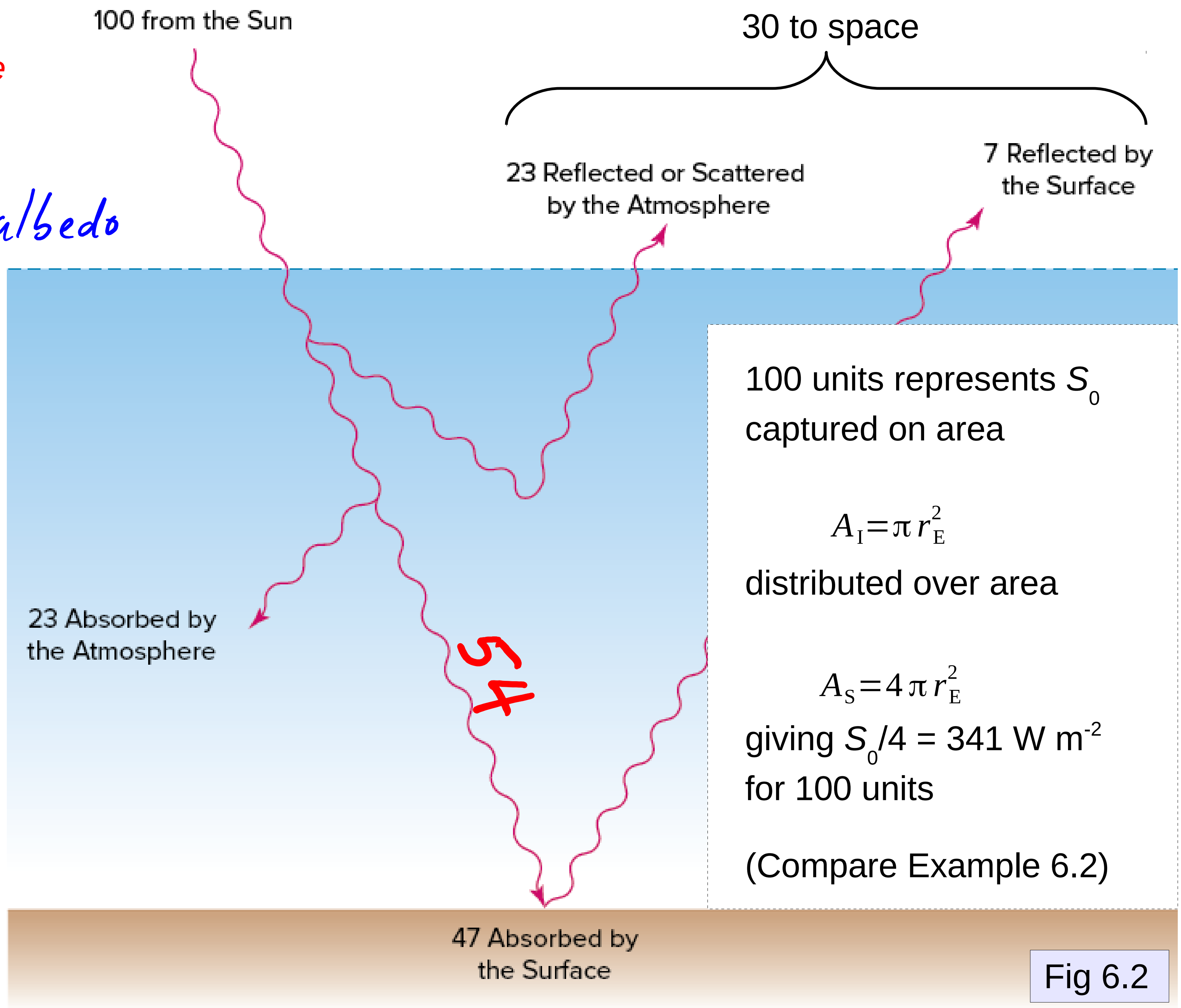


Fig 6.1

Not expected to remember these numbers

Planetary albedo ~ 0.3 ("α")



100 units represents S_0 captured on area

$$A_I = \pi r_E^2$$

distributed over area

$$A_S = 4\pi r_E^2$$

giving $S_0/4 = 341\ \mathrm{W\,m^{-2}}$ for 100 units

(Compare Example 6.2)

Fig 6.2

- recall 1 unit represents 3.41 W m^{-2} , how many units does earth's sfc emit? If we adopt a mean annual T_{sfc} = 15.9°C and assume surface emissivity is 1,

$$E = \sigma\,(273.15 + 15.9)^4$$
$$= 395.8\ \mathrm{W\,m^{-2}} = 116.07\ \text{units}$$

- surface receives less longwave than it emits because it is warmer than the atmosphere

- according to *these numbers*, the 70 units of longwave radiant energy lost to space exactly balance the 70 units of shortwave radiant energy retained by the planet

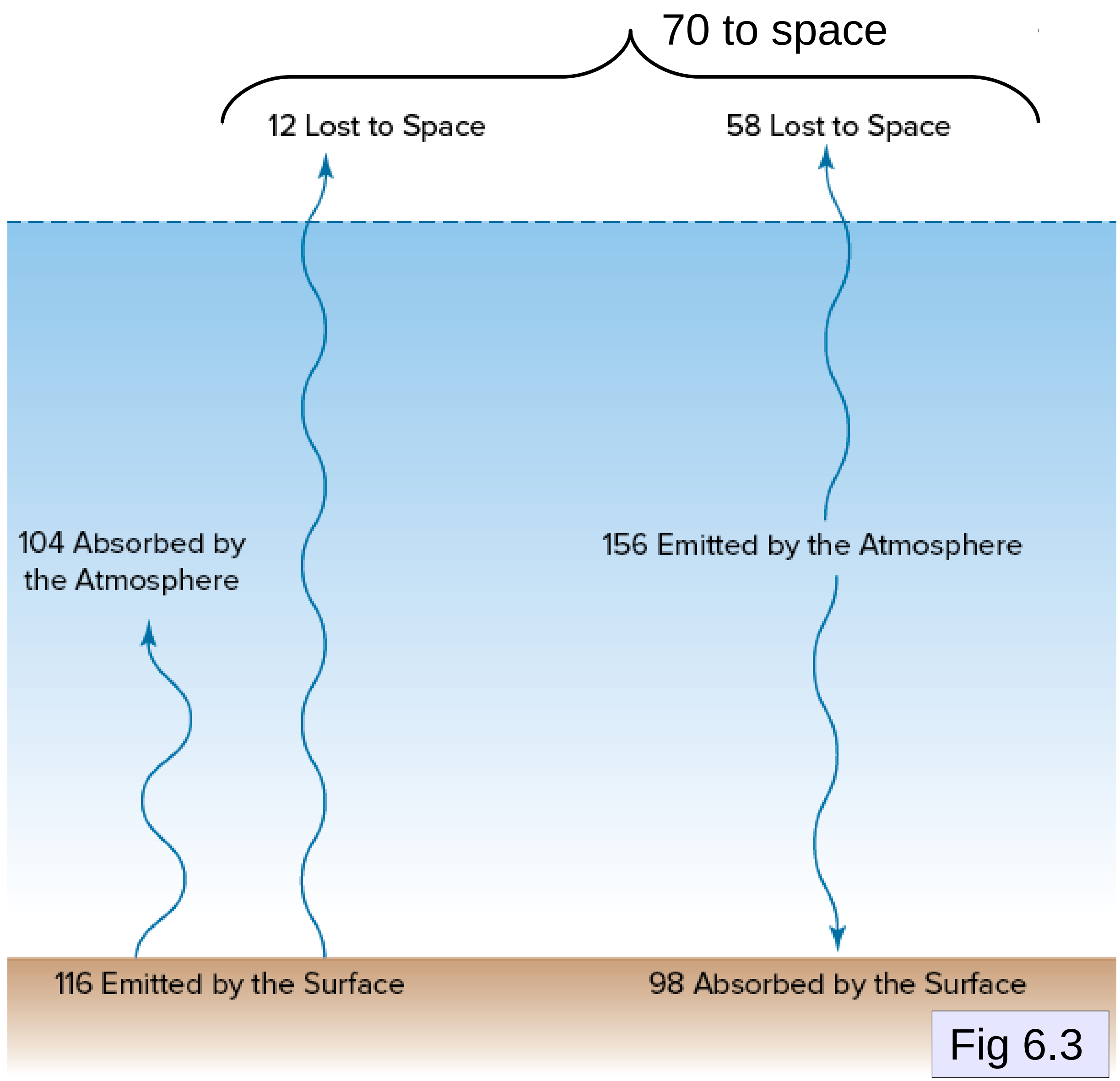


Fig 6.3

- 1 unit represents 3.41 W m^{-2}
- therefore mean sensible heat flux density Q_H = 17.1 W m^{-2}
- Q_E = 81.8 W m^{-2}

$= L_v E$

L_v: 2.5×10^6 J/kg

E: mass flux density $\left[\frac{kg}{m^2 s}\right]$

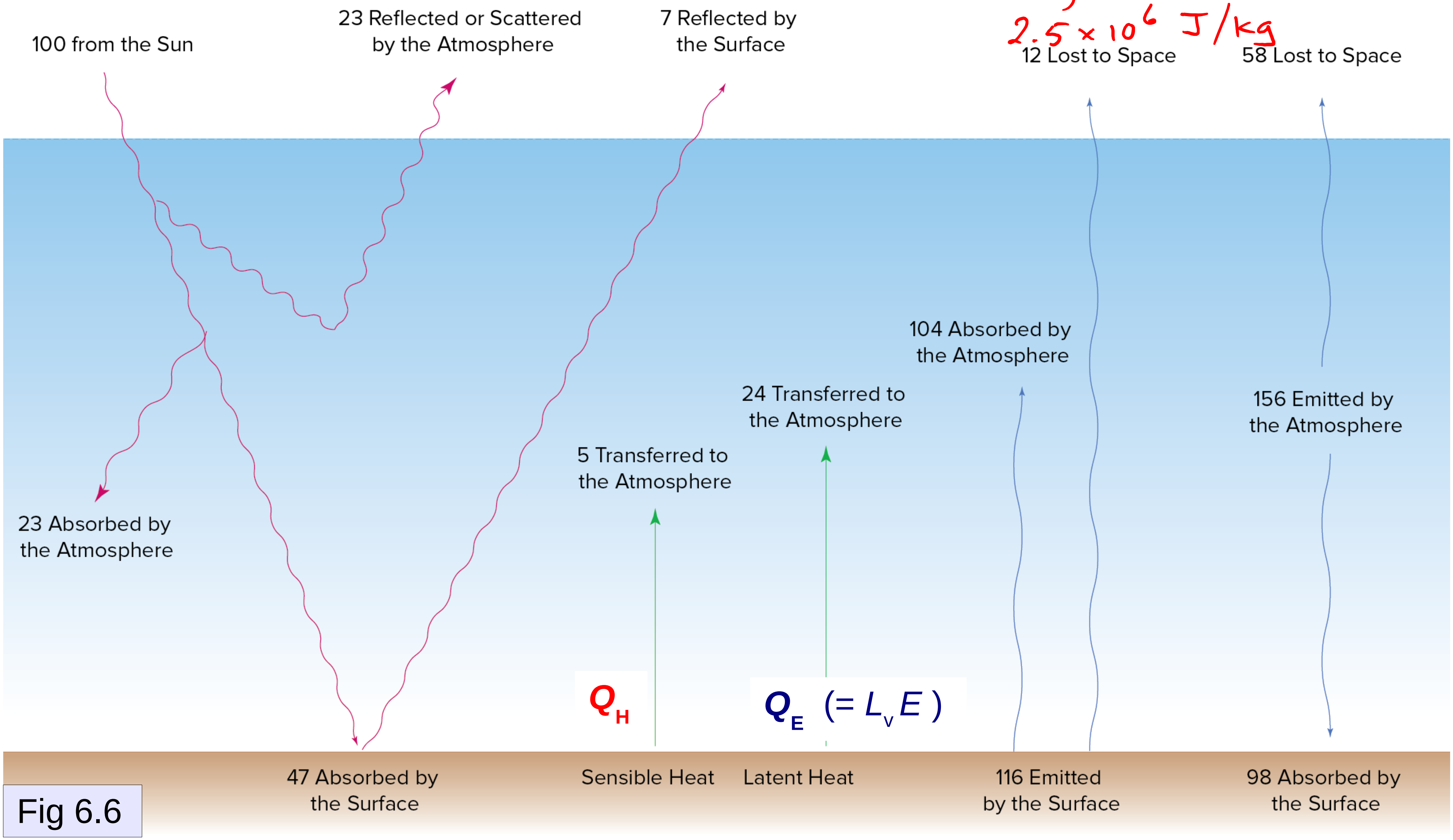


Fig 6.6

- net allwave radiative gain by surface: 54−7 + 98 − 116 = +29
- net allwave radiative gain by atmos: 23 + 104 − 156 = −29
- equilibration by non-radiative exchange (convection & conduction)

"Radiative surplus for earth's surface and a radiative deficit for the atmosphere"

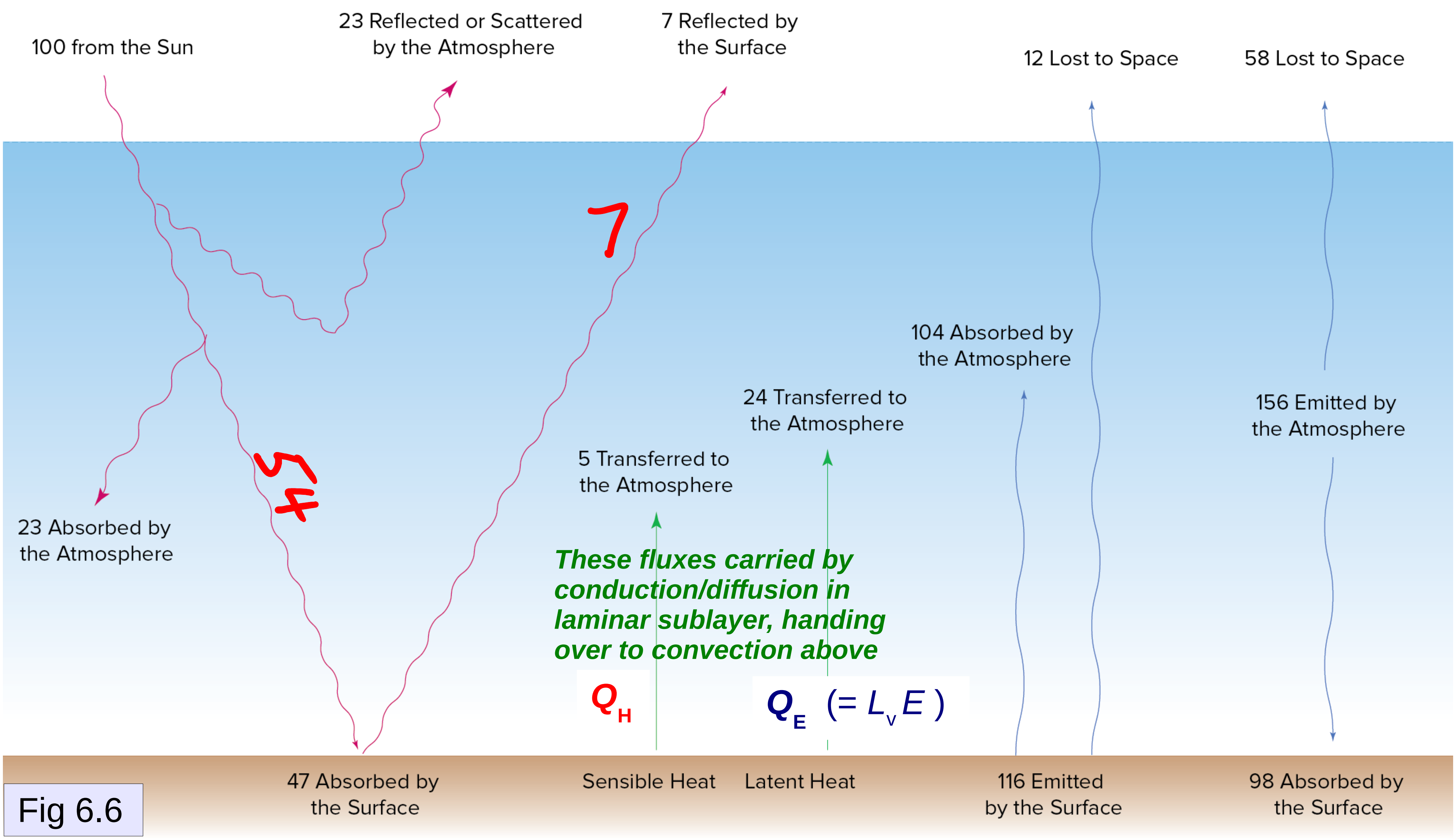


Fig 6.6

- net loss from surface in longwave: 116-98=18
- total losses from sfc: 5+24+18=47
- planetary albedo (23+7)/100=0.3
- net gain by atmos: 23+5+24+104-156=0
- net gain by planet: 100-23-7-12-58=0
- 47 absorbed by surface includes absorption within the upper ocean

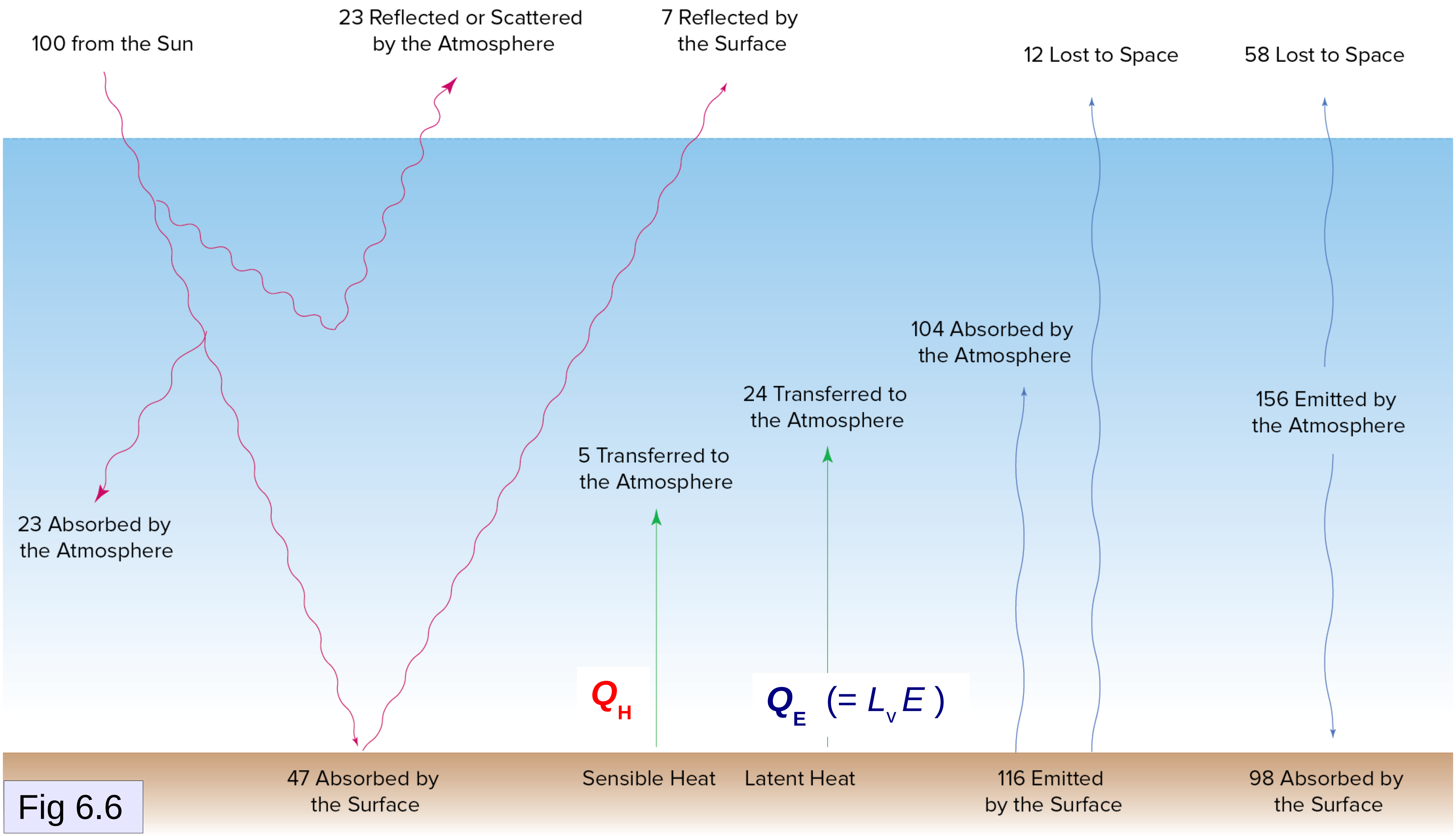


Fig 6.6

- the foregoing figures were rounded
- best satellite estimates for annual global averages:

341.3 W m^{-2} incident shortwave (100 units)

101.9 W m^{-2} reflected shortwave (29.86 units)

238.5 W m^{-2} longwave to space (69.87 units)

0.27 unit surplus (0.9 W m^{-2})

Earth system is warming as expected (feedback) – despite that, measurements indicate system is not quite in balance

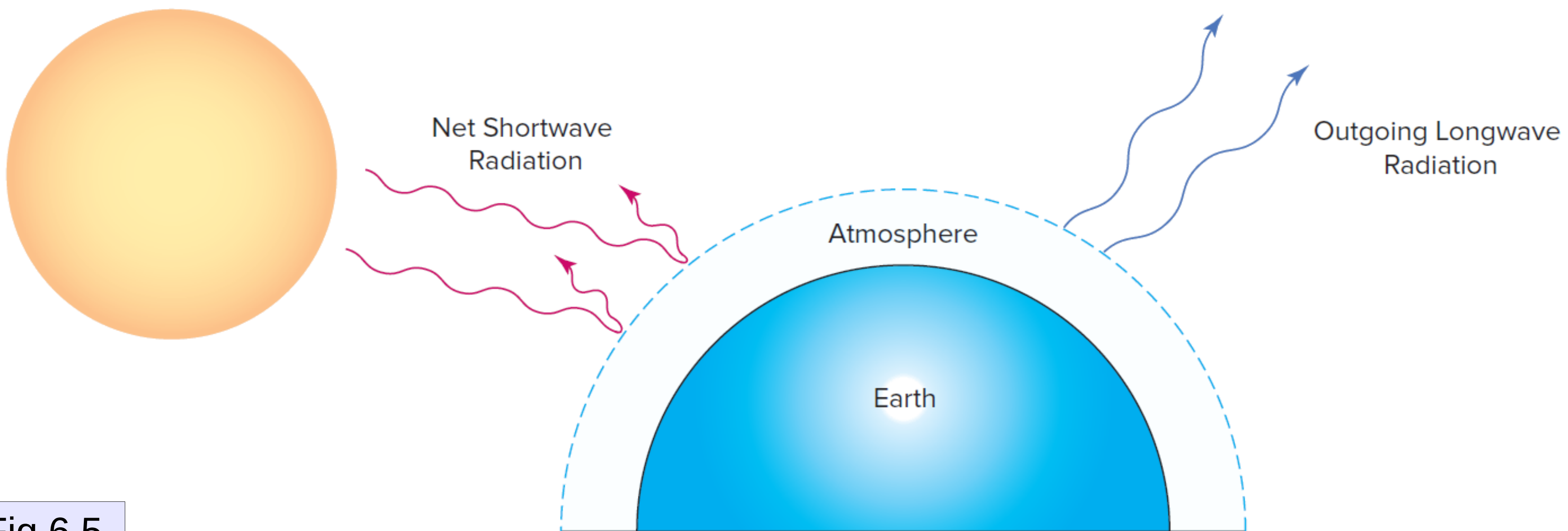


Fig 6.5

- why is there no curve for incoming longwave radiation?
- dip in L↑ in the equatorial region is due to prevalence of cloud cover

At latitudes higher than about 40° (north or south), losses exceed gains. The consequent temperature difference "drives" the general circulation of the atmosphere and oceans.

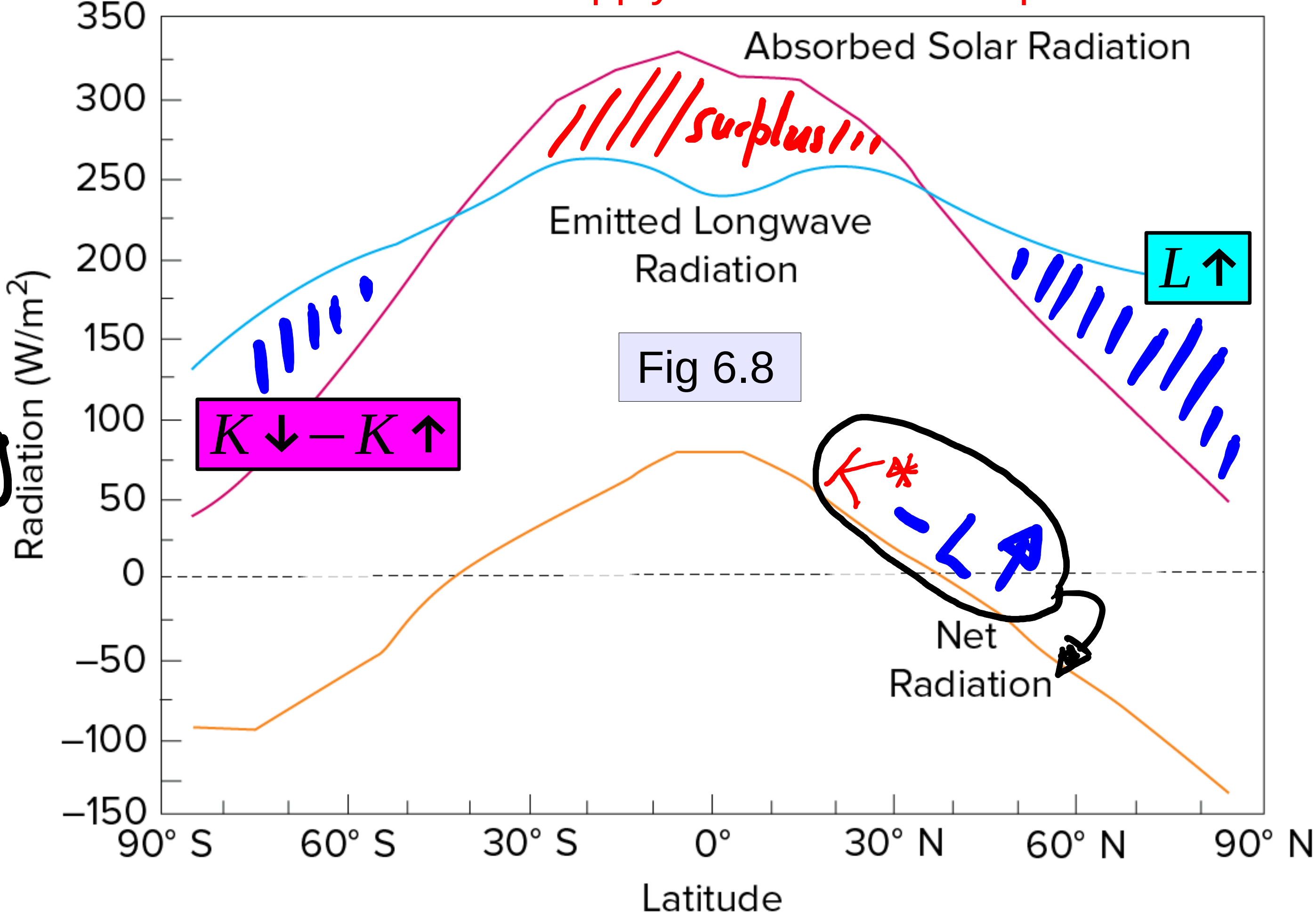
- how do we know thermal advection by atmos. & ocean largely annuls the radiative imbalance?

Because equatorial regions are not getting runaway net shortwave warming

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

absorbtivity

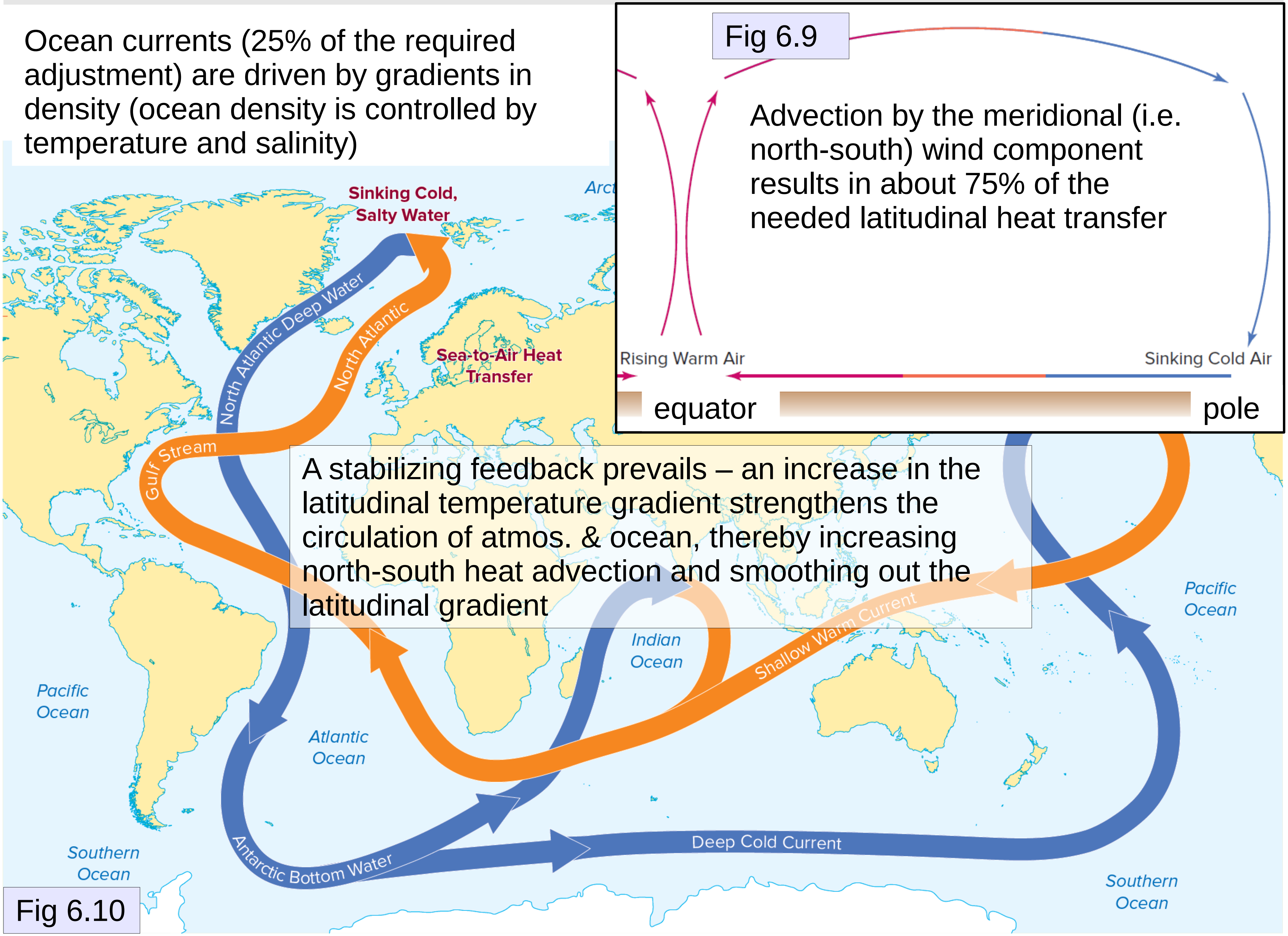
These estimates apply *above* the atmosphere



Ocean currents (25% of the required adjustment) are driven by gradients in density (ocean density is controlled by temperature and salinity)

Fig 6.9

Advection by the meridional (i.e. north-south) wind component results in about 75% of the needed latitudinal heat transfer



A stabilizing feedback prevails – an increase in the latitudinal temperature gradient strengthens the circulation of atmos. & ocean, thereby increasing north-south heat advection and smoothing out the latitudinal gradient

Fig 6.10

Topics/concepts covered

- radiative equilibrium temperature of an isothermal earth devoid of atmosphere
- global budget of solar and terrestrial radiative fluxes in earth-atmos. system
- gross global energy budget
- latitudinal trend in net radiation above the atmosphere
- resulting meridional heat transport
- when finished this material we'll move on to consider energy flows at local scale