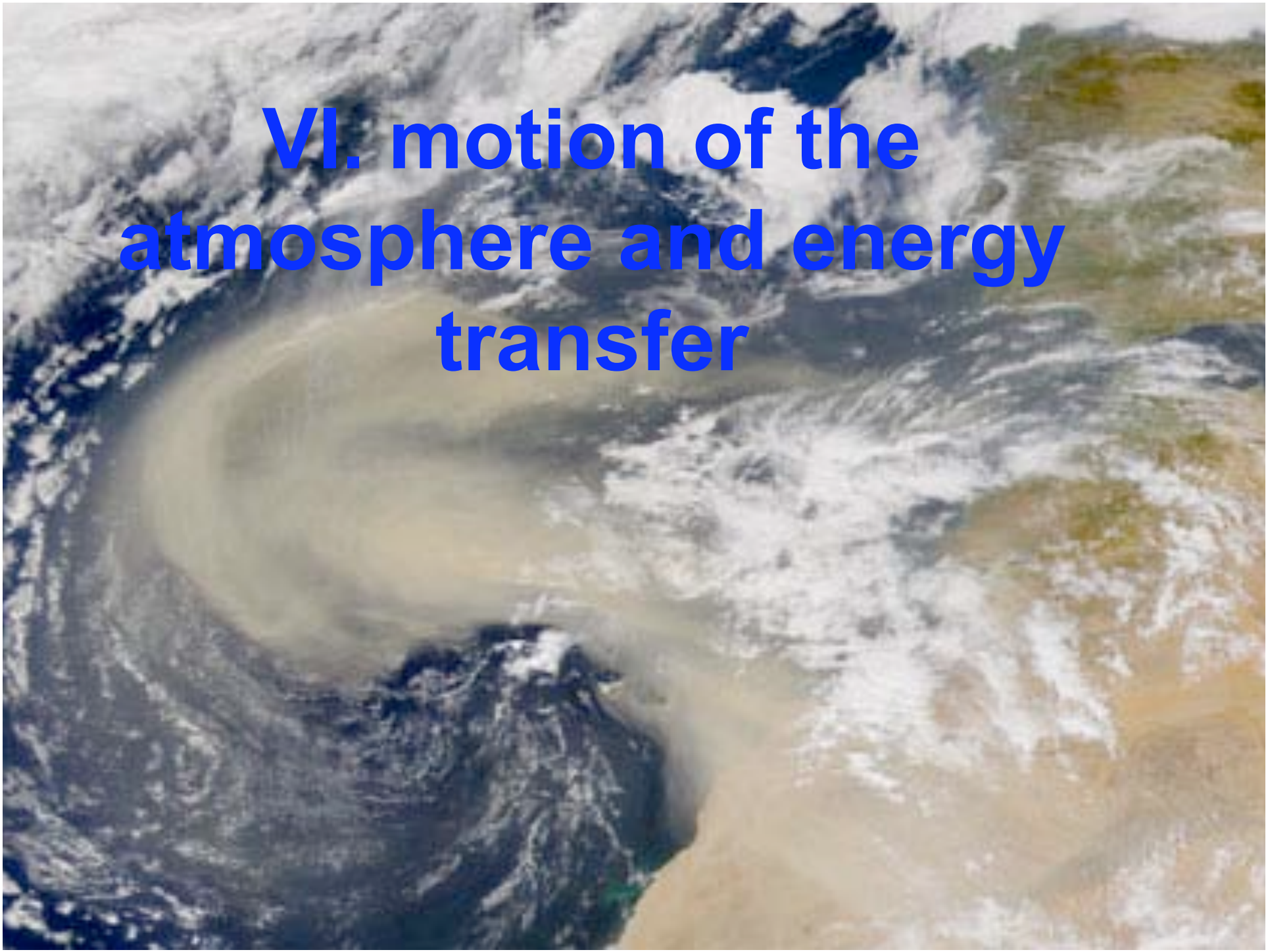
VI. motion of the atmosphere and energy transfer



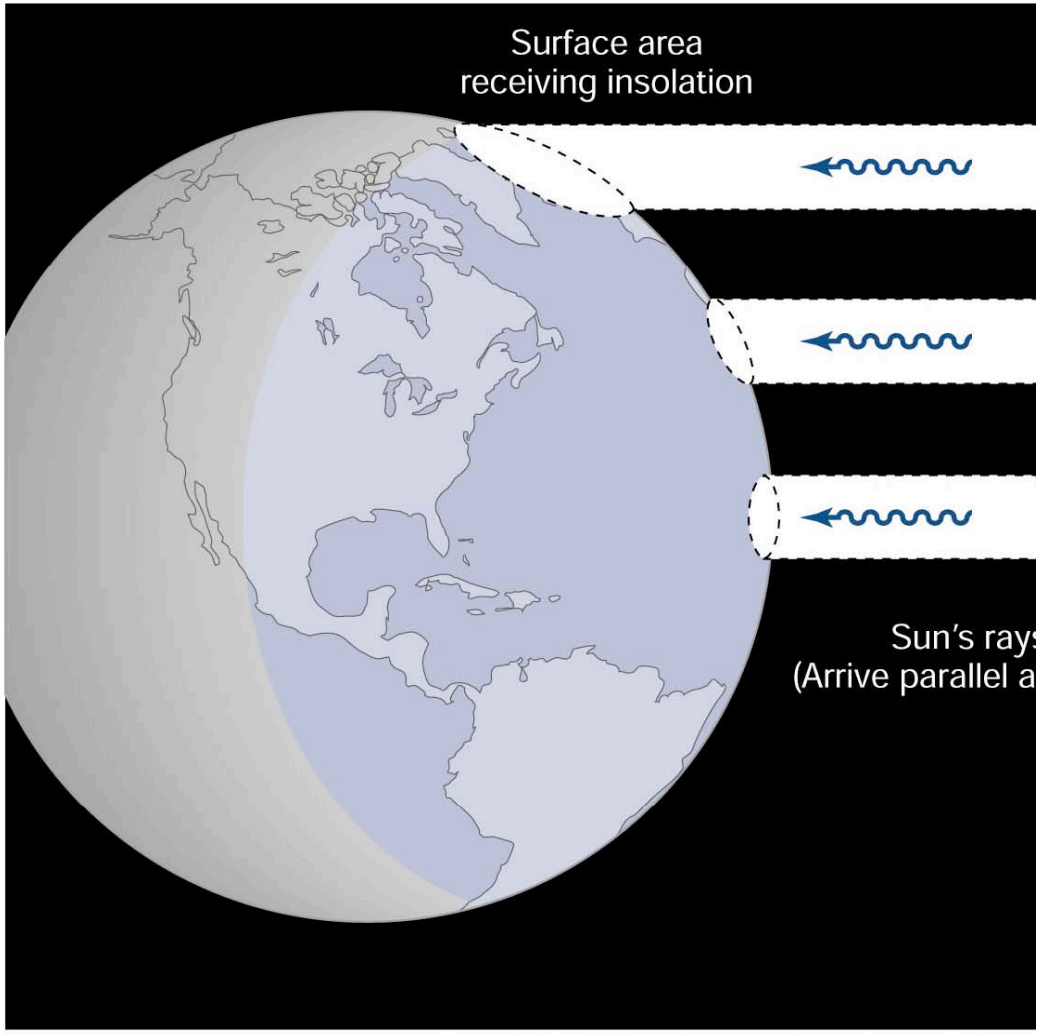
what drives the atmospheric circulation?

earlier we learned that the Earth is in radiative balance (i.e. incoming solar radiation = outgoing long wave radiation)

but is this true everywhere?

No! let's see... (and begin by recalling an old clicker question)

old clicker question:
why are the poles colder than the tropics?



a) the flux of radiation is smaller

b) the flux of radiation is larger

c) they are farther from the sun

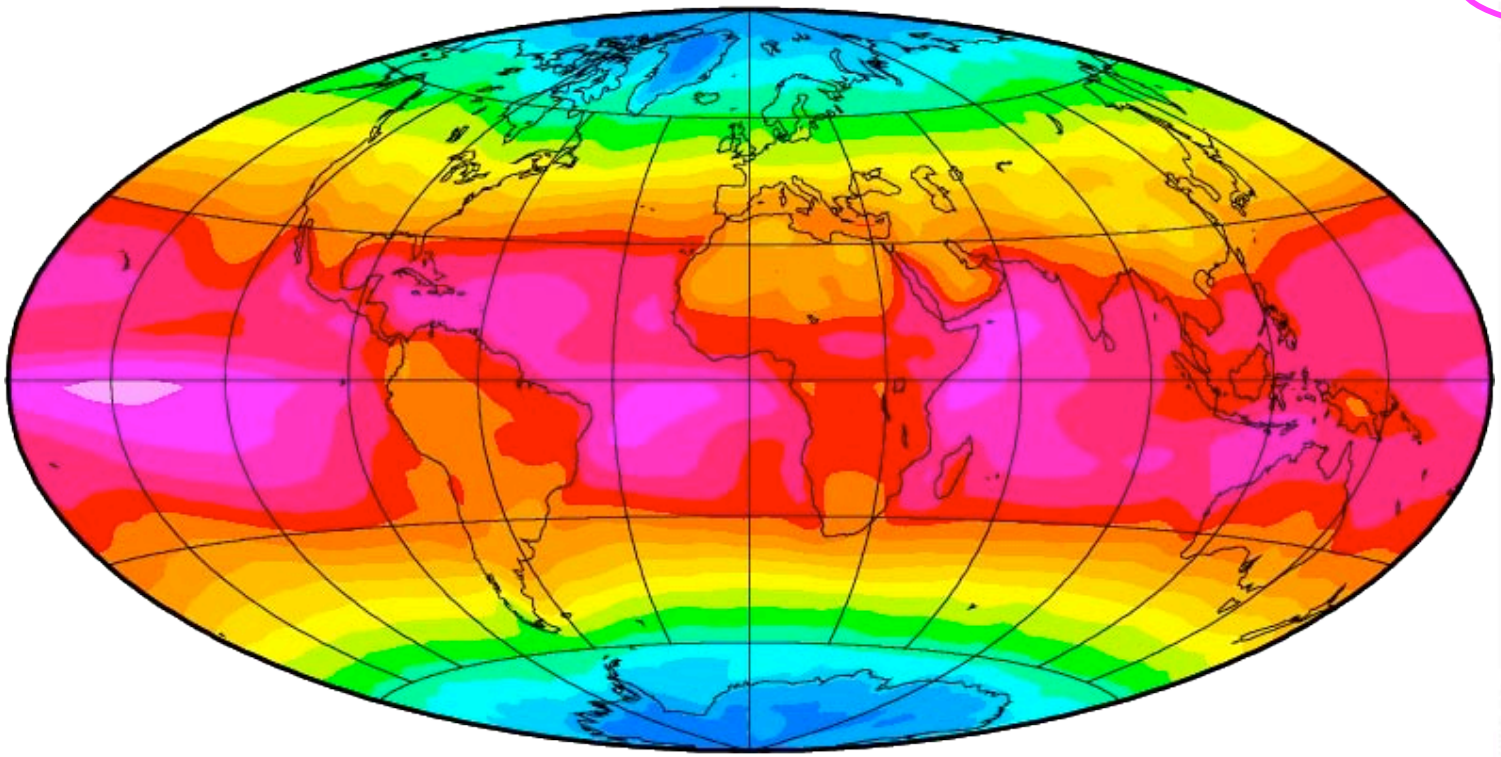
d) they are mountainous

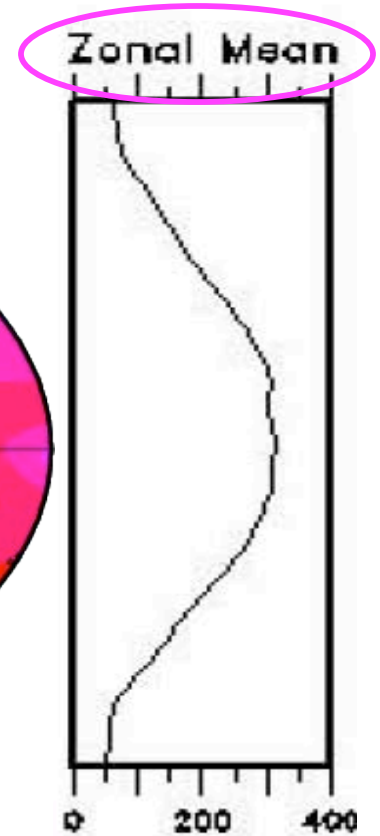
e) the atmosphere is denser

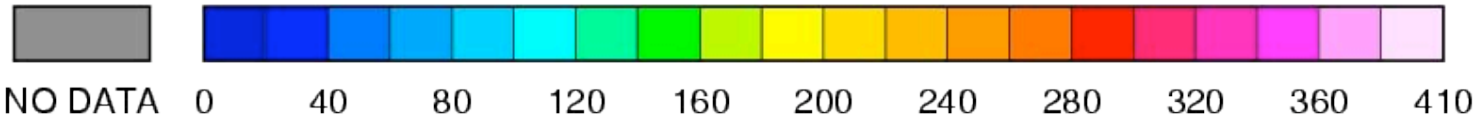
absorbed radiation

TOA annual mean incoming SW

1985-1986





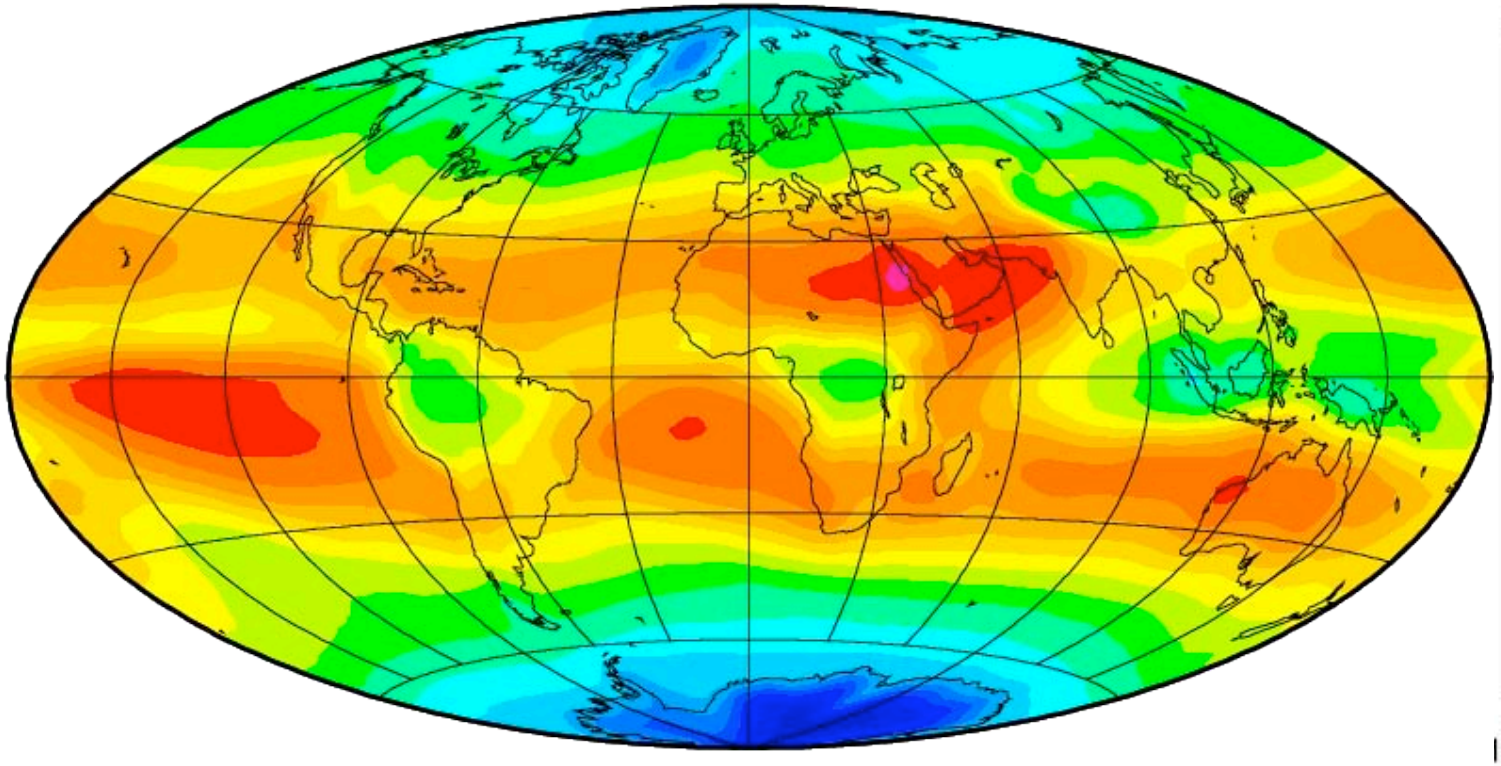


W/m**2

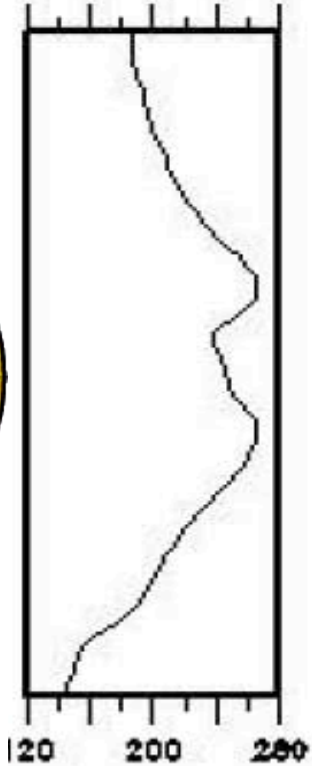
emitted radiation

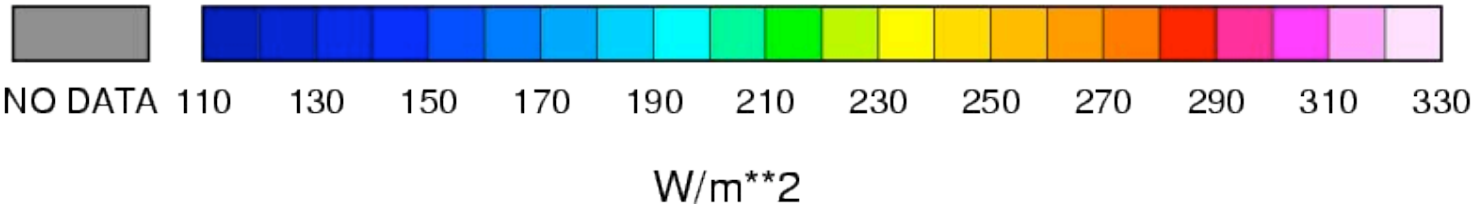
TOA annual mean OLR (Outgoing LW Radiation)

1985-1986



Zonal Mean

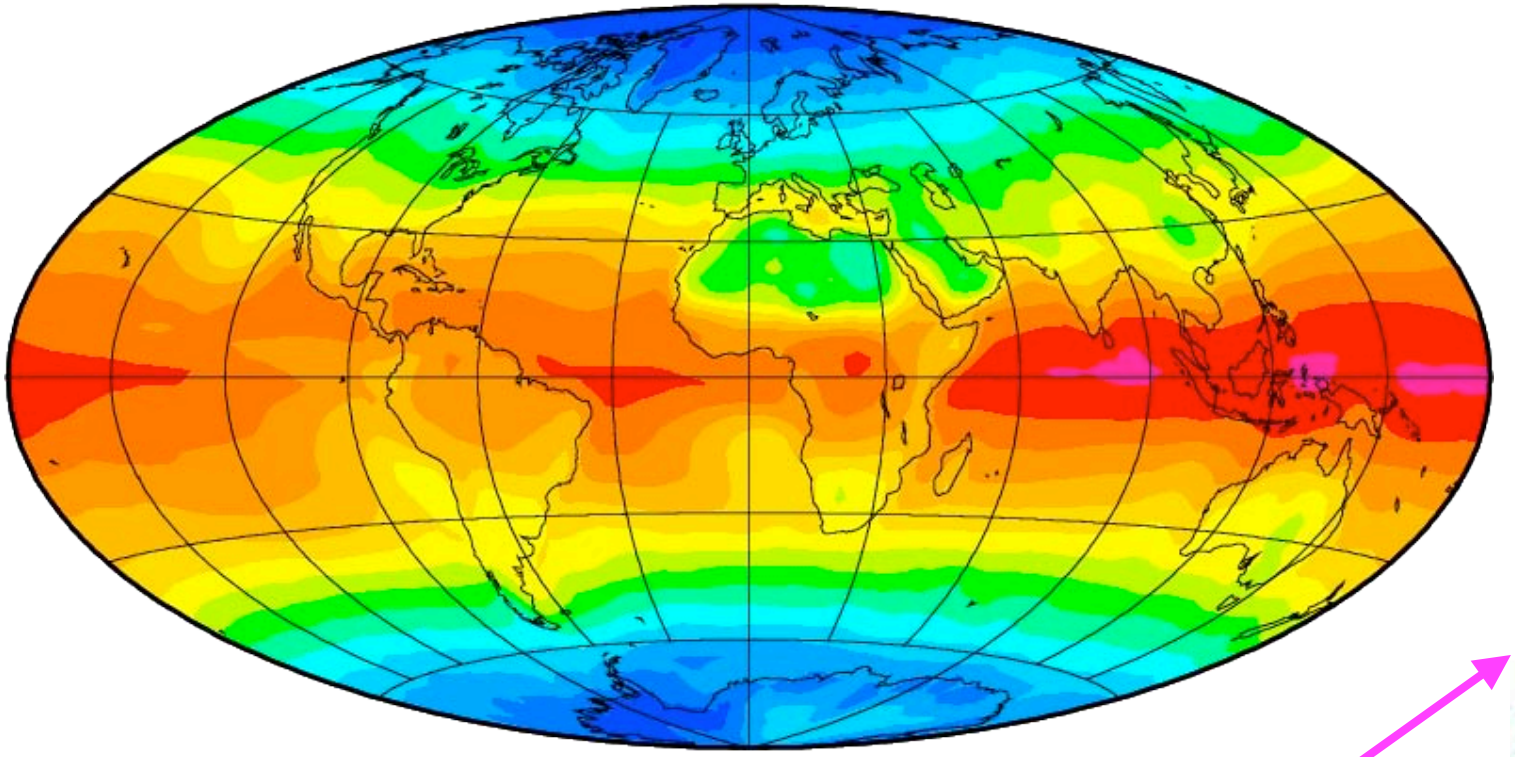




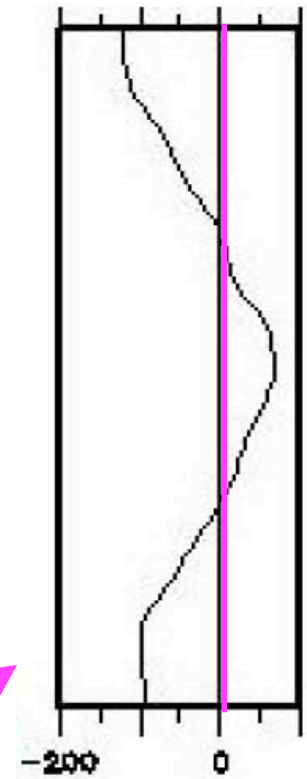
net radiation

TOA annual net radiation (incoming-emitted)

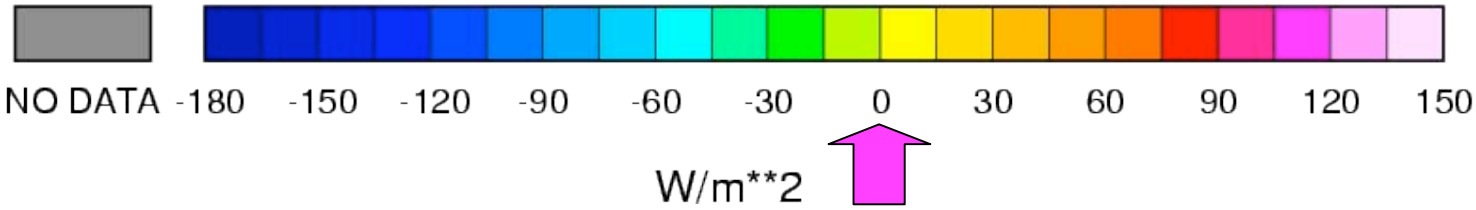
1985-1986



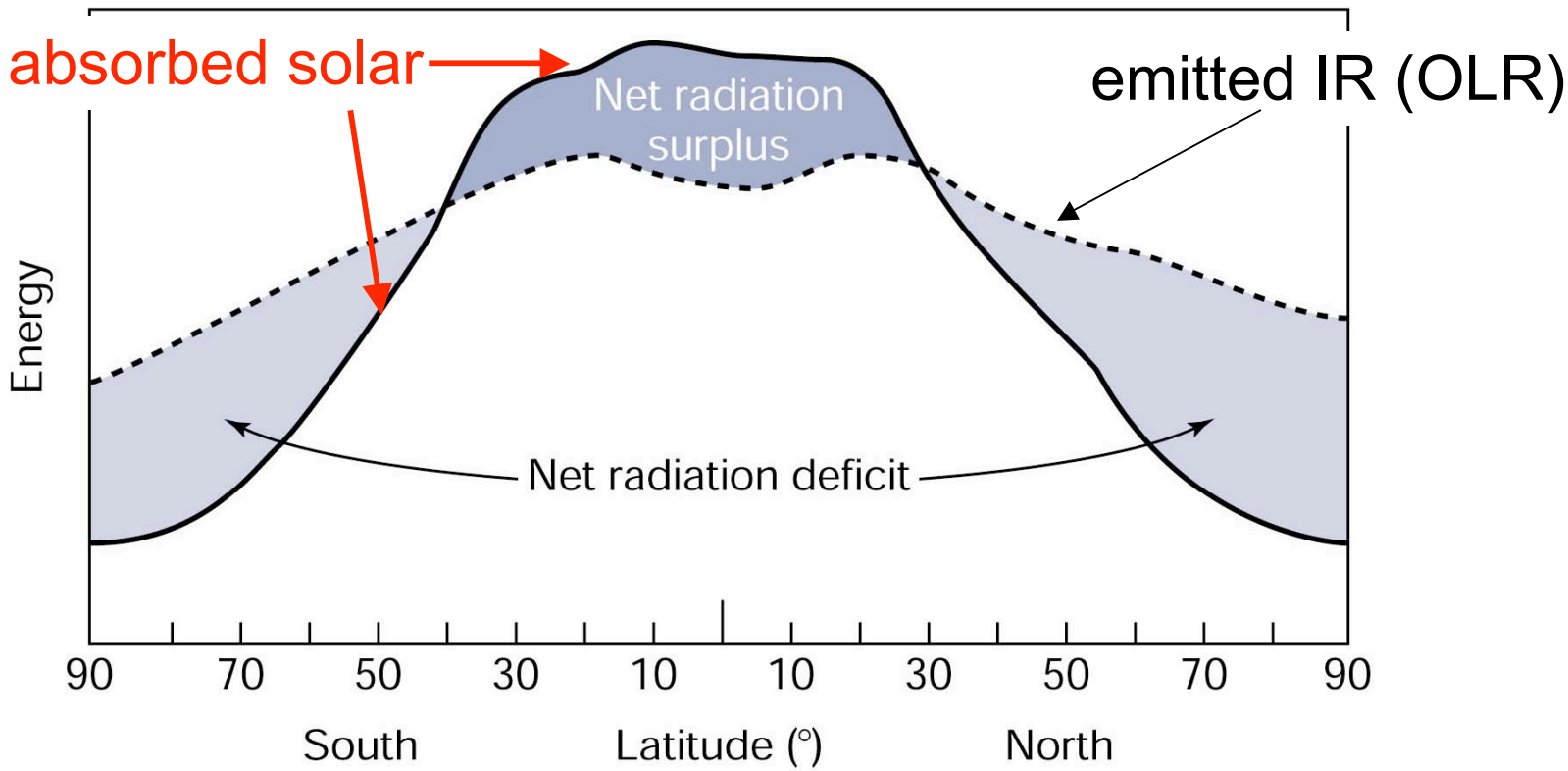
Zonal Mean difference



is radiation balanced locally?



radiation imbalance by lat.

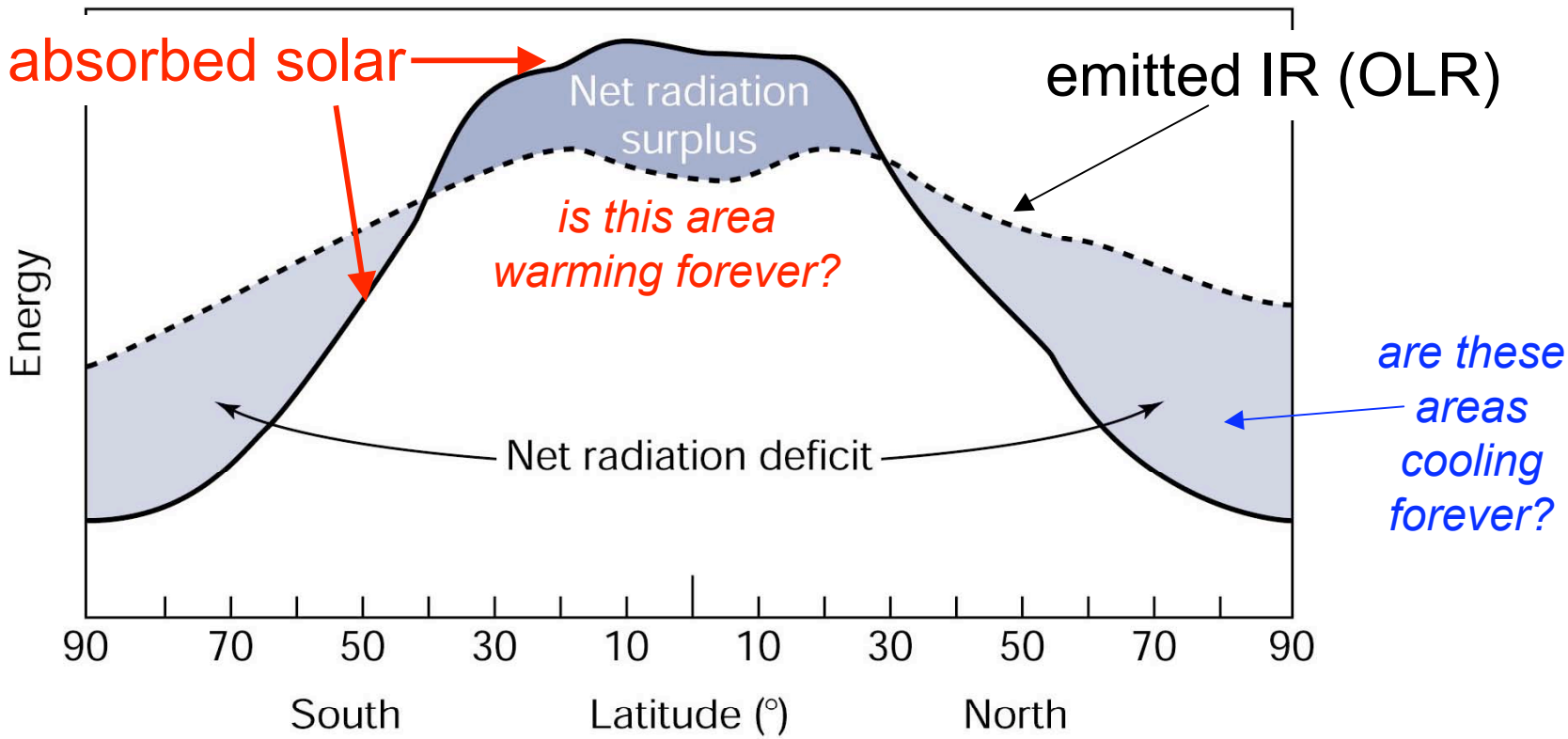


what determines the shape of the dashed profile of emitted radiation (recall $F=\sigma T^4$)?

temperature!

note: emitted infrared rad. is also called *outgoing long-wave radiation* (OLR)

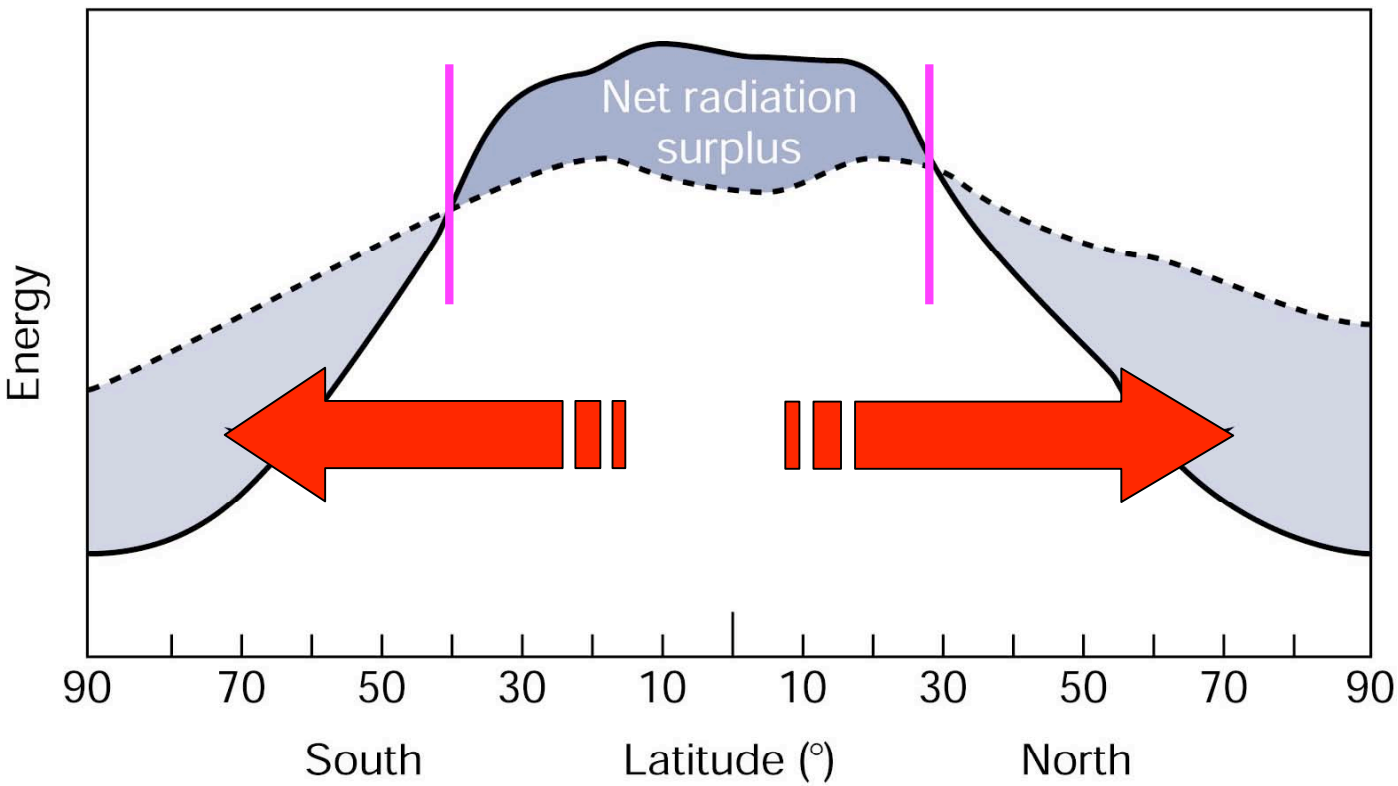
radiation imbalance by lat.



what determines the shape of the dashed profile of emitted radiation (recall $F=\sigma T^4$)?

how can the steady state profile of temperature (and OLR) be maintained against the local radiation imbalance?

radiation imbalance by lat.

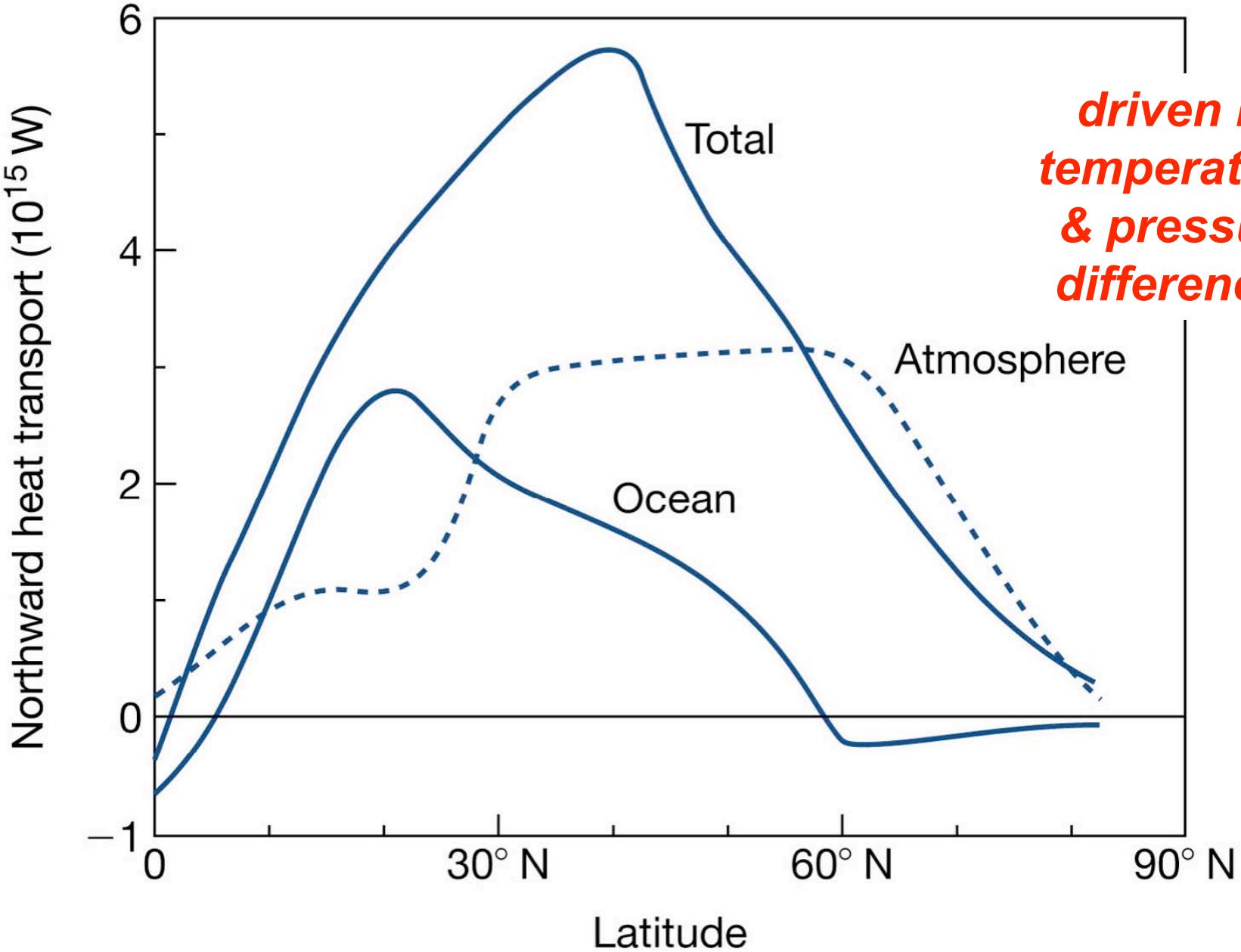


there must be <u>poleward</u> <u>transport</u> of energy!

the transport is largely from atmospheric and oceanic motions driven by gradients of heat and pressure

(we already noted that the dashed profile must reflect a gradient in temperature)

northward transport of energy (NH)



driven by temperature & pressure differences

6×10^{15} W?

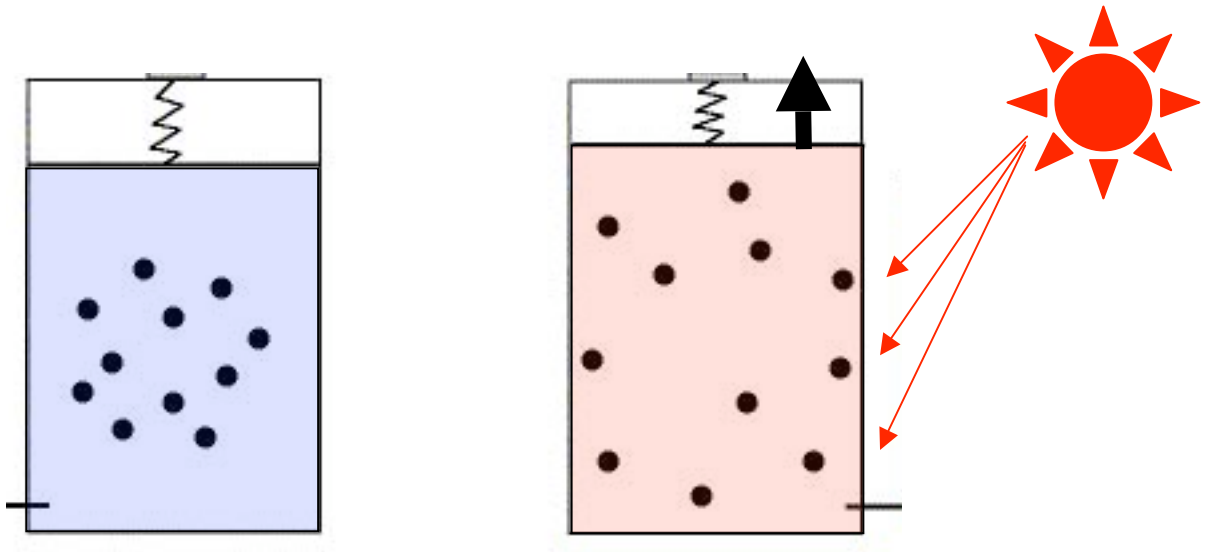
- how much is 6×10^{15} W (6 PetaWatts)?
- a Watt is an amount of energy (1 joule) per second
- a large nuclear power plant can deliver 1 GigaWatt
- 6 PW is the continuous output of 6 million large nuclear power plants
- *how is all this energy transport accomplished?*

wind and currents

- gradients of heating and pressure drive *winds and currents* in the atmosphere and ocean which carry heat poleward

- let's start by recalling the basics of heating and pressure

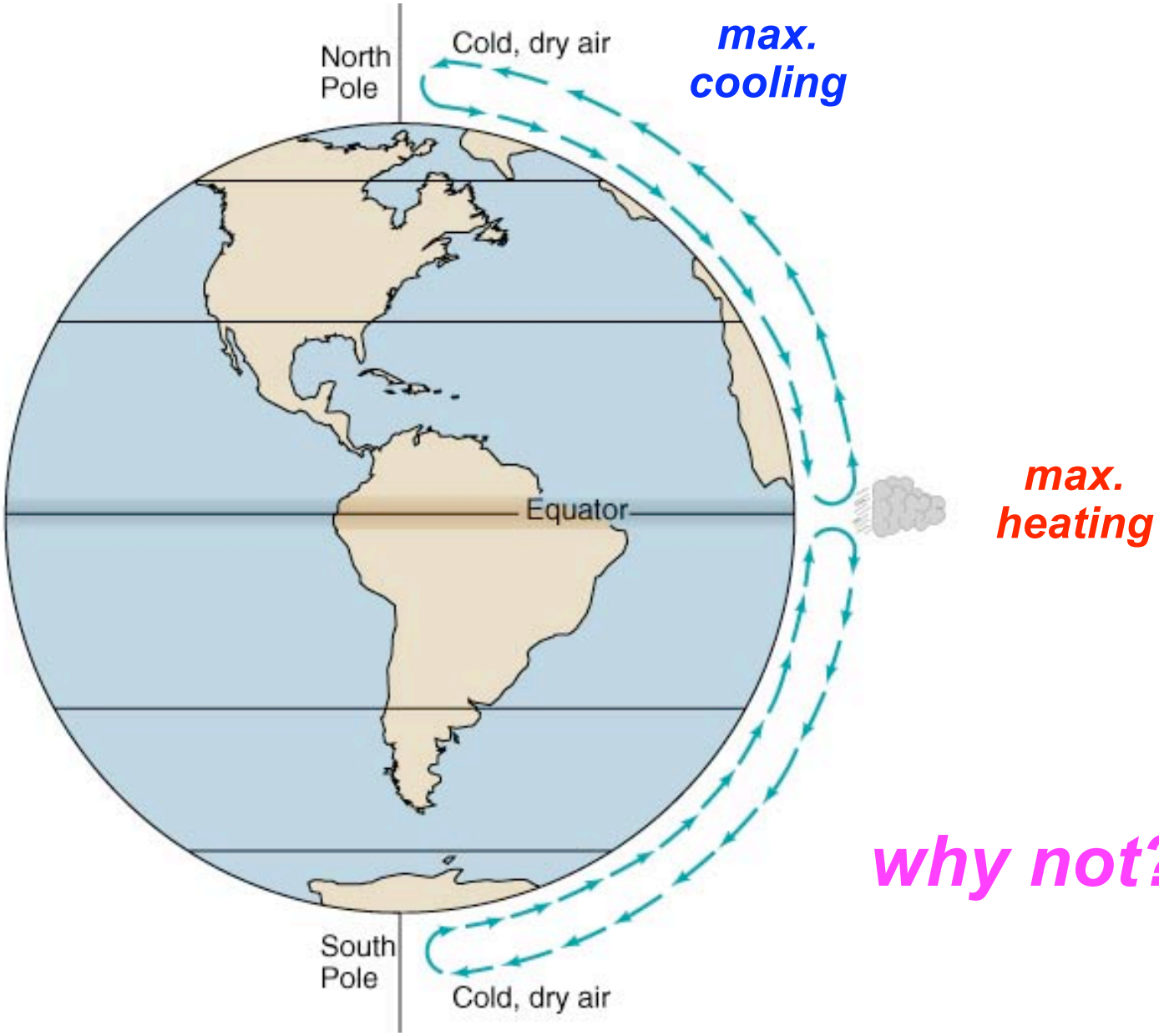
heating drives expansion



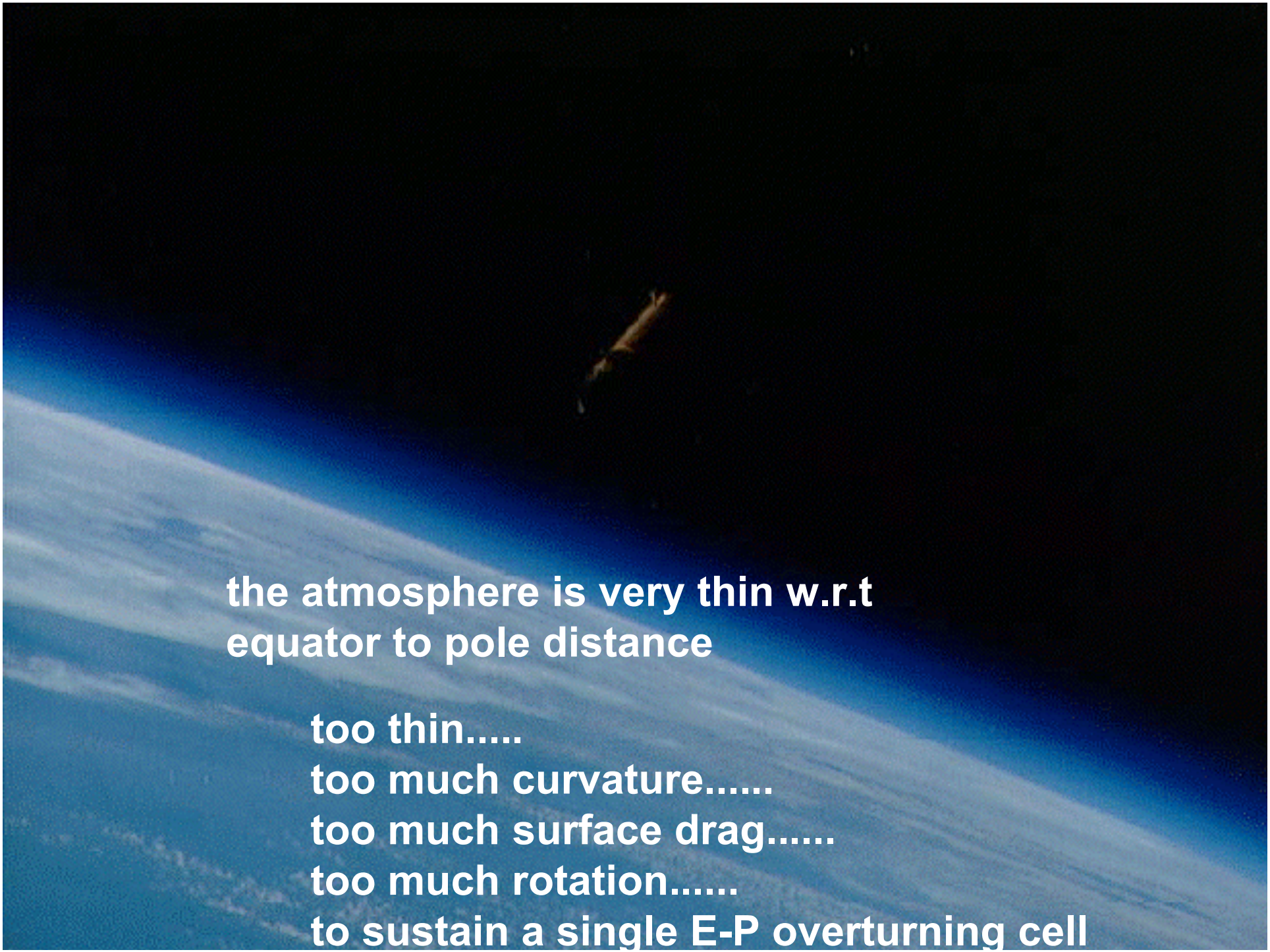
recall that heating leads to expansion, reducing density and creating <u>buoyancy</u>

conversely, cooling increases density and leads to sinking or subsidence (negative buoyancy)

so circulation looks like this?



why not?!

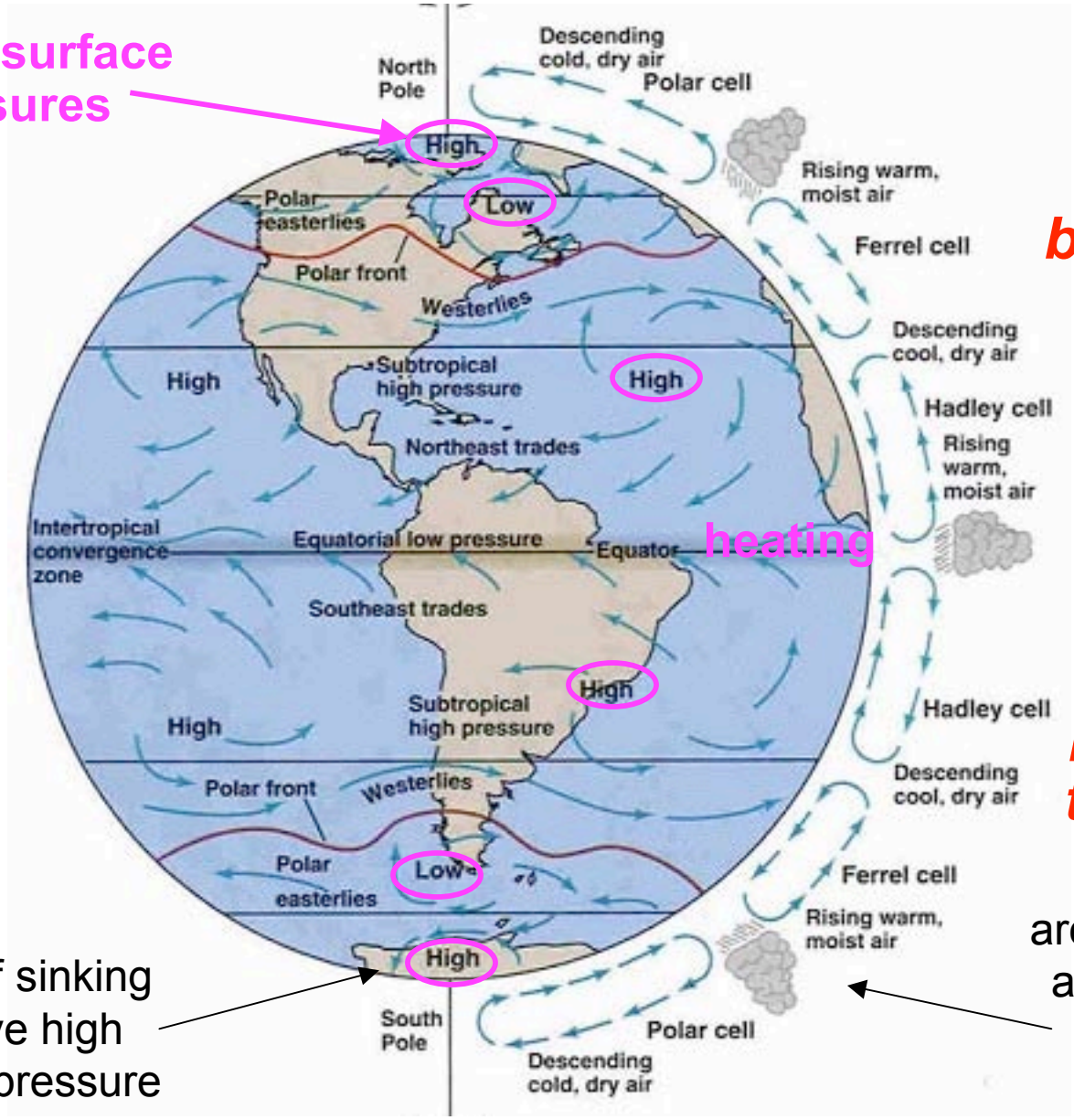


the atmosphere is very thin w.r.t
equator to pole distance

too thin.....
too much curvature.....
too much surface drag.....
too much rotation.....
to sustain a single E-P overturning cell

idealized vertical circulation

relative surface pressures



broken up in to several cells

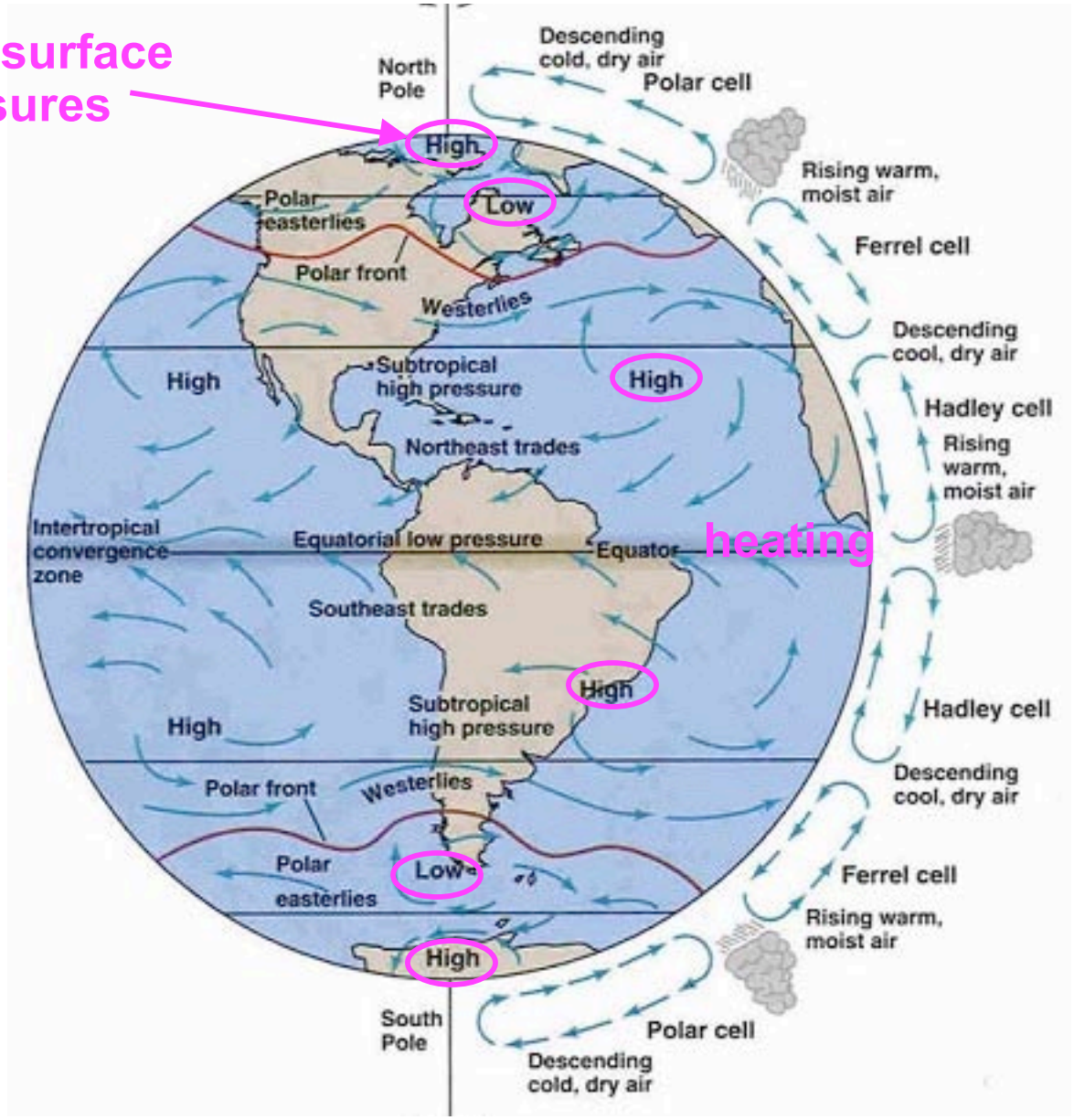
these help determine pressure patterns at the surface

areas of sinking air have high surface pressure

areas of rising air have low surface pressure

idealized vertical circulation

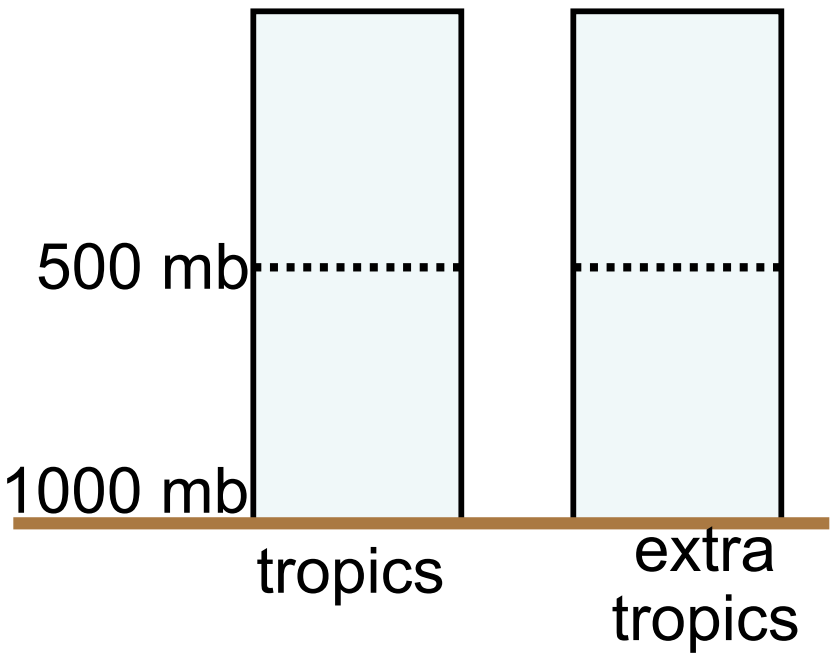
relative surface pressures



the Hadley cells are esp. robust

heating and pressure force

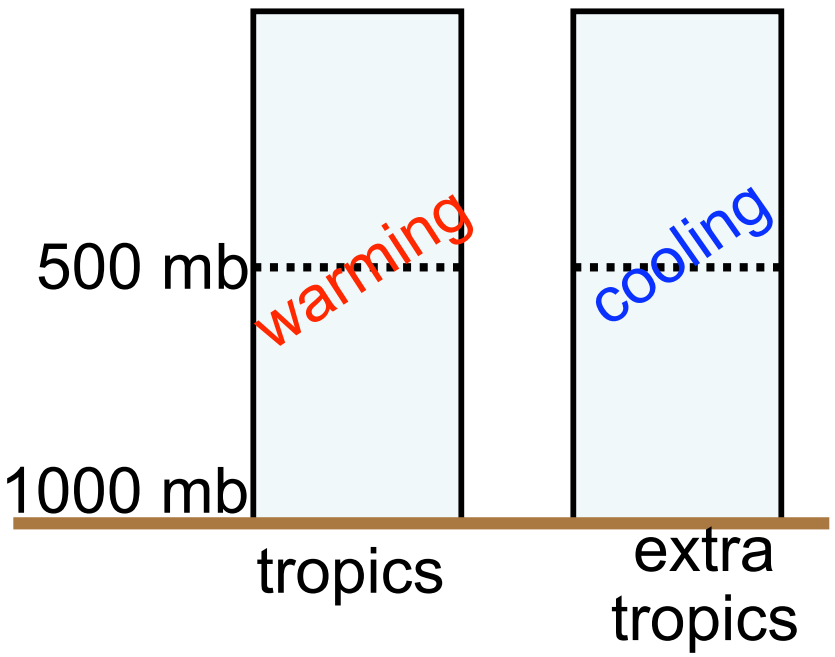
consider 2 columns of air, one warming and the other cooling



assume initially they are the same

heating and pressure force

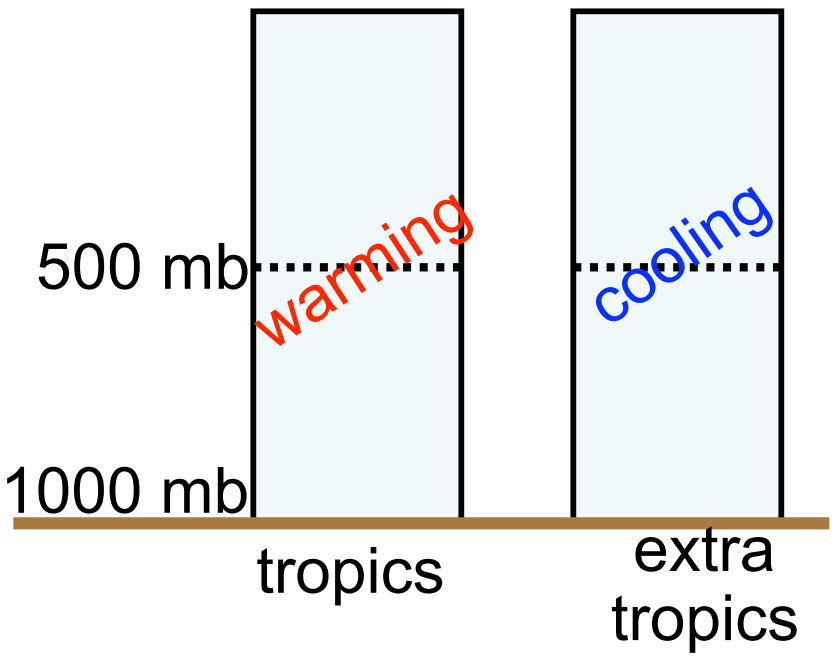
consider 2 columns of air, one warming and the other cooling

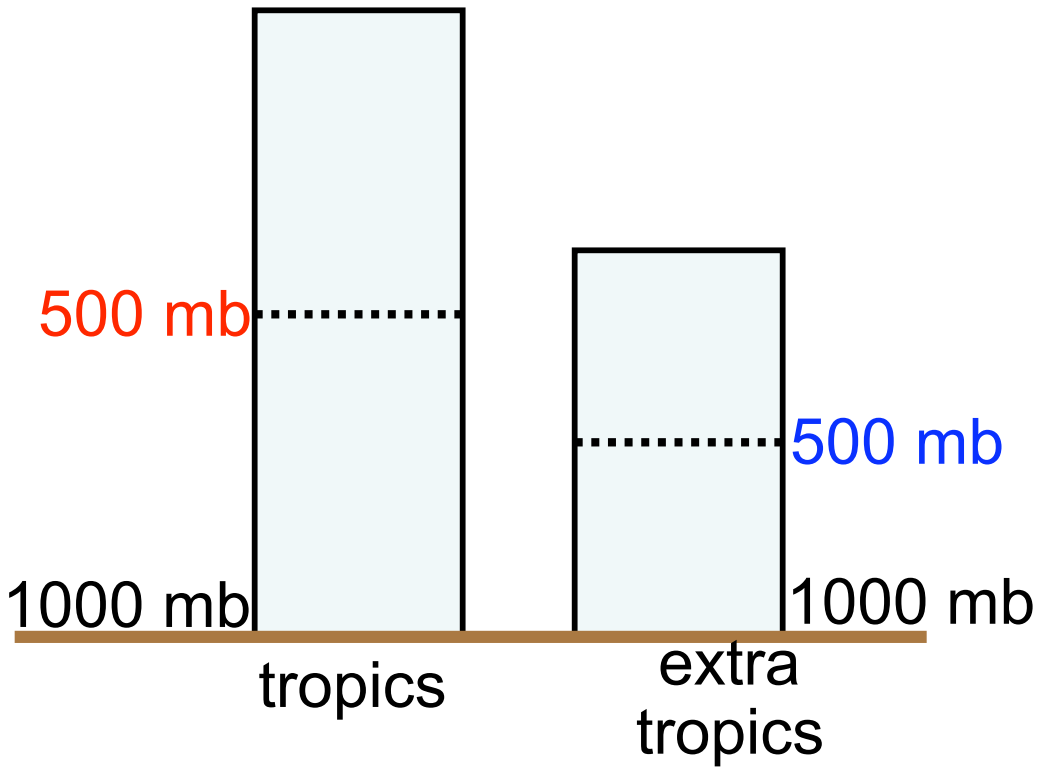


what will happen to the columns?

heating and pressure force

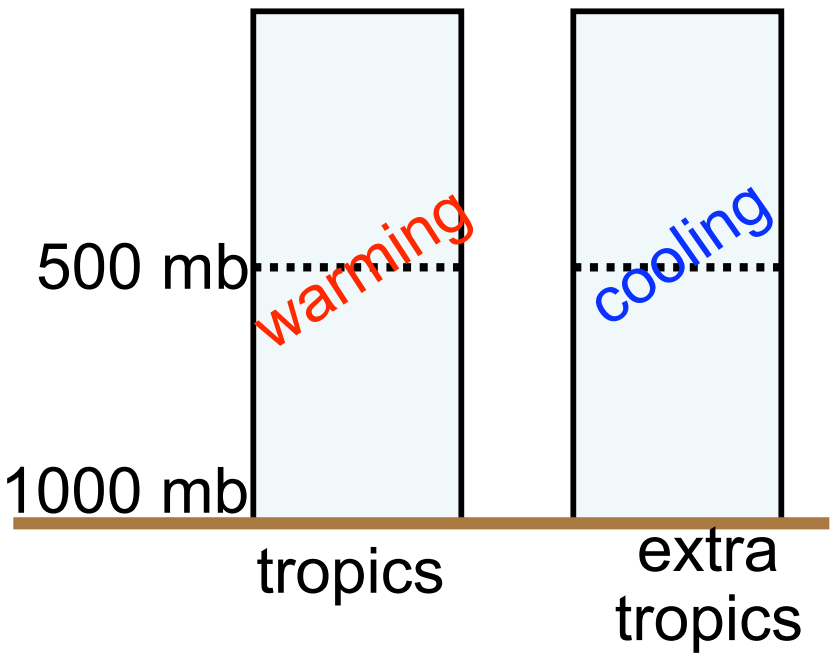
consider 2 columns of air, one warming and the other cooling

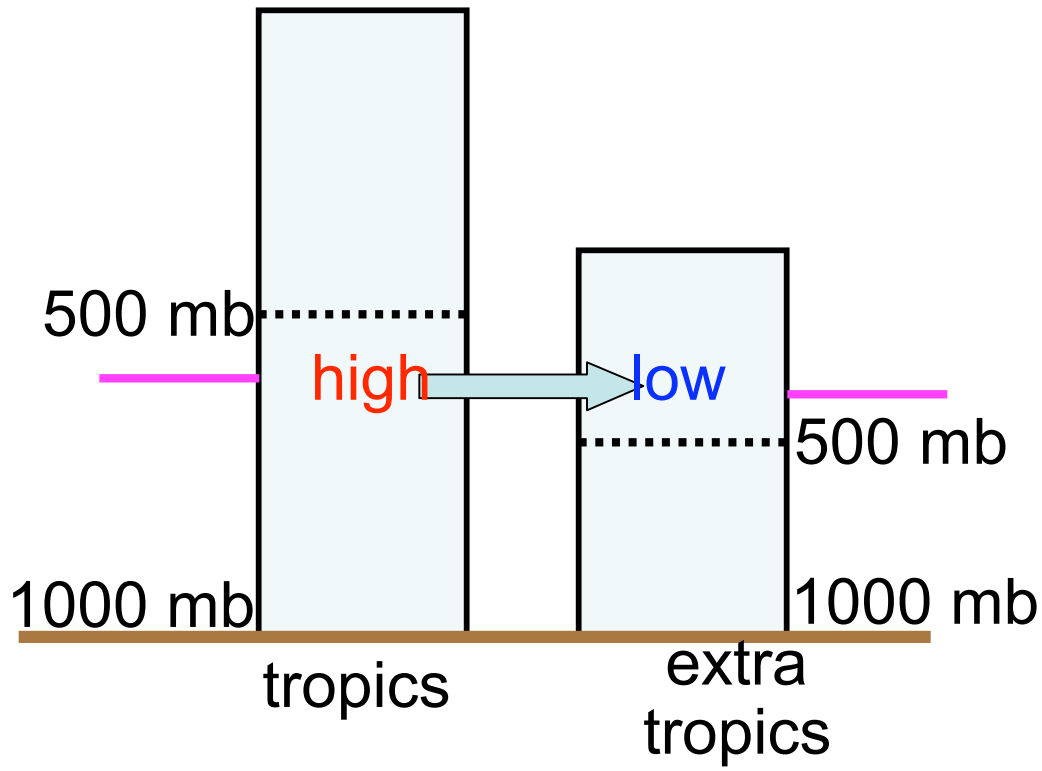




heating and pressure force

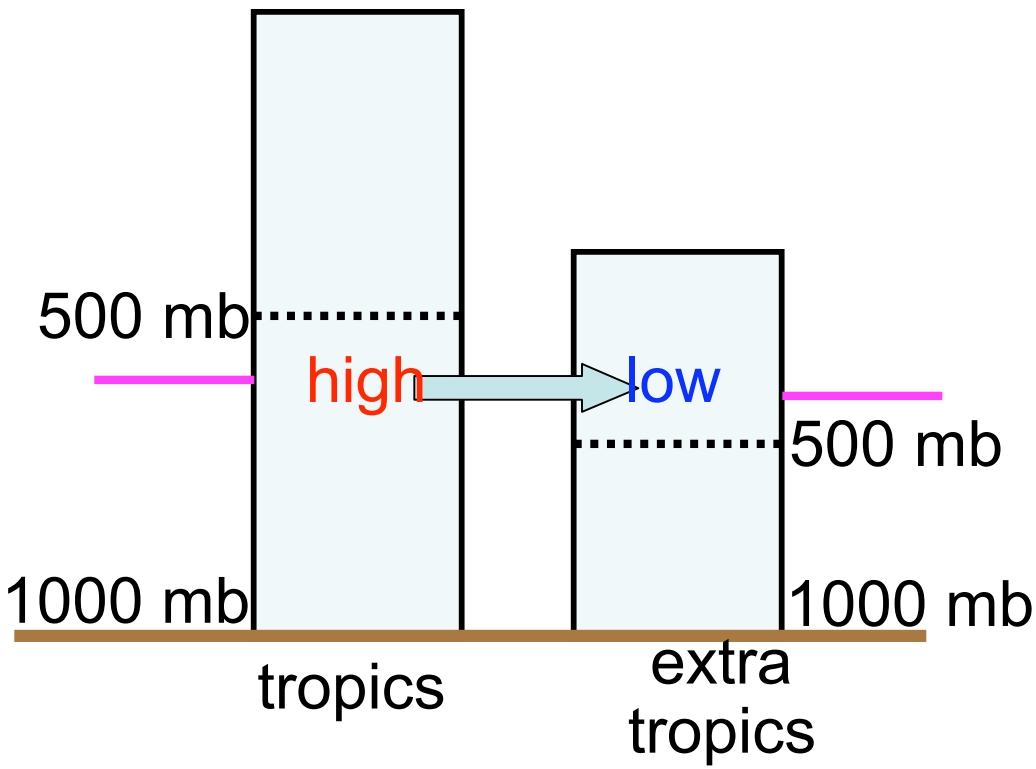
consider 2 columns of air, one warming and the other cooling





now there is a difference of pressure at a given level air flows from high to low pressure

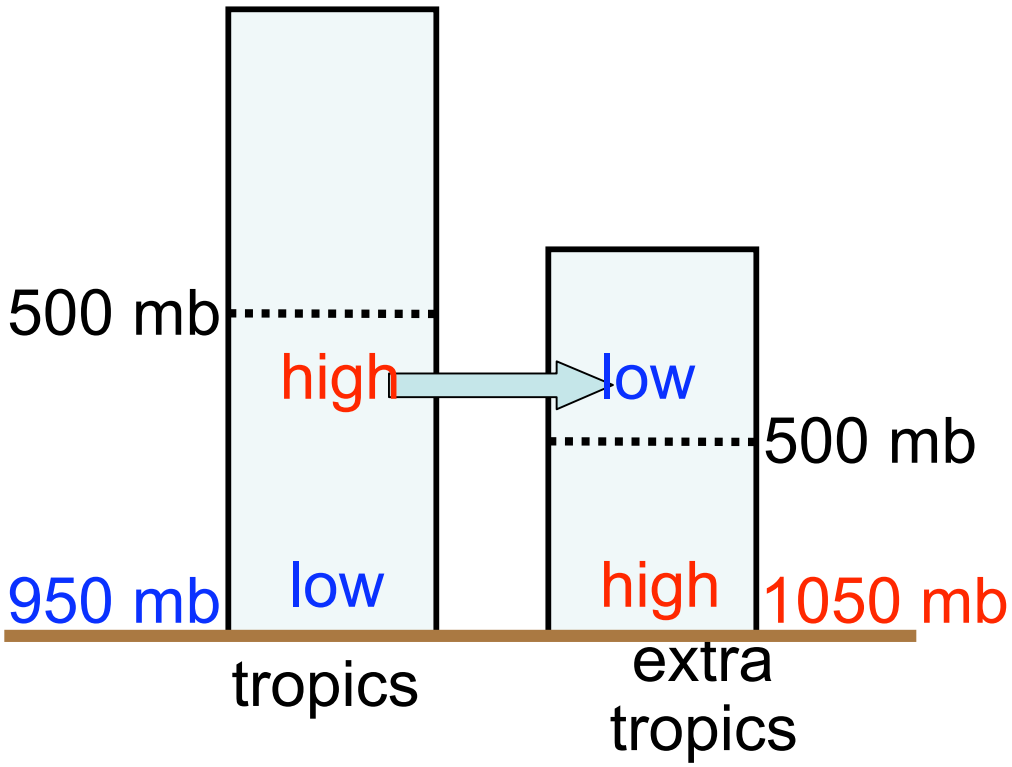
and, adjustment near the surface



what happens?:

1) air has moved out of tropics

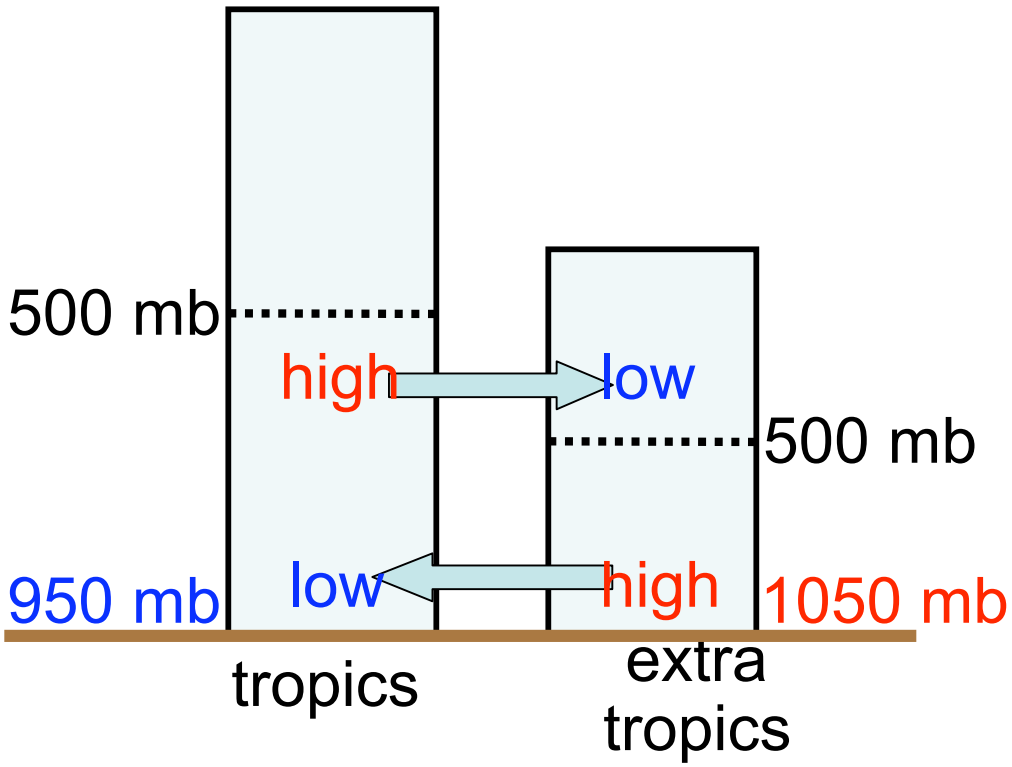
and, adjustment near the surface



what happens?:

1) ***air has moved out of tropics***
2) ***pressure is related to mass of atm. above, so tropical surface pressure decreases***

and, adjustment near the surface

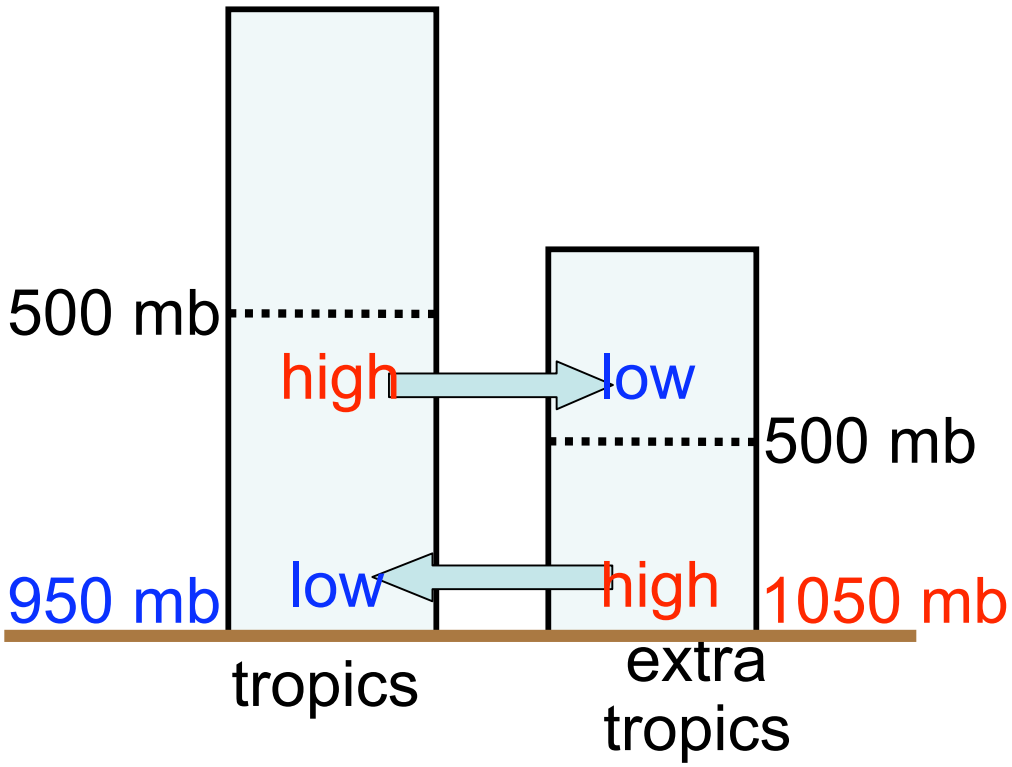


what happens?:

1) ***air has moved out of tropics***
2) ***pressure is related to mass of atm. above, so tropical surface pressure decreases***
3) ***air moves from high to low pressure at the surface***

teaching slides from Prof. D. Noone (ATOC)

and, adjustment near the surface

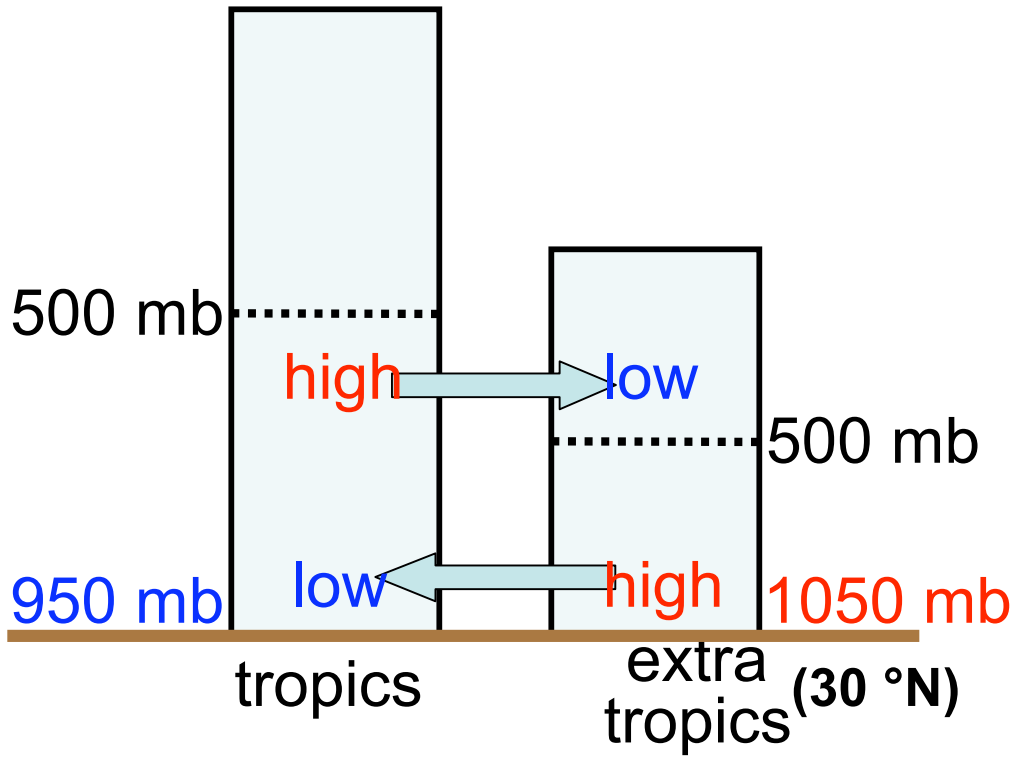


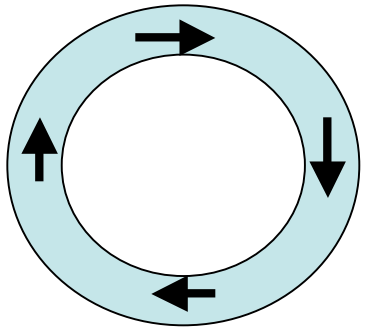
what happens?:

1) ***air has moved out of tropics***
2) ***pressure is related to mass of atm. above, so tropical surface pressure decreases***
3) ***air moves from high to low pressure at the surface***

the horizontal movements of air can be satisfied by buoyancy driven vertical movements, comprising a circulation cell

welcome (again) to the Hadley Circulation

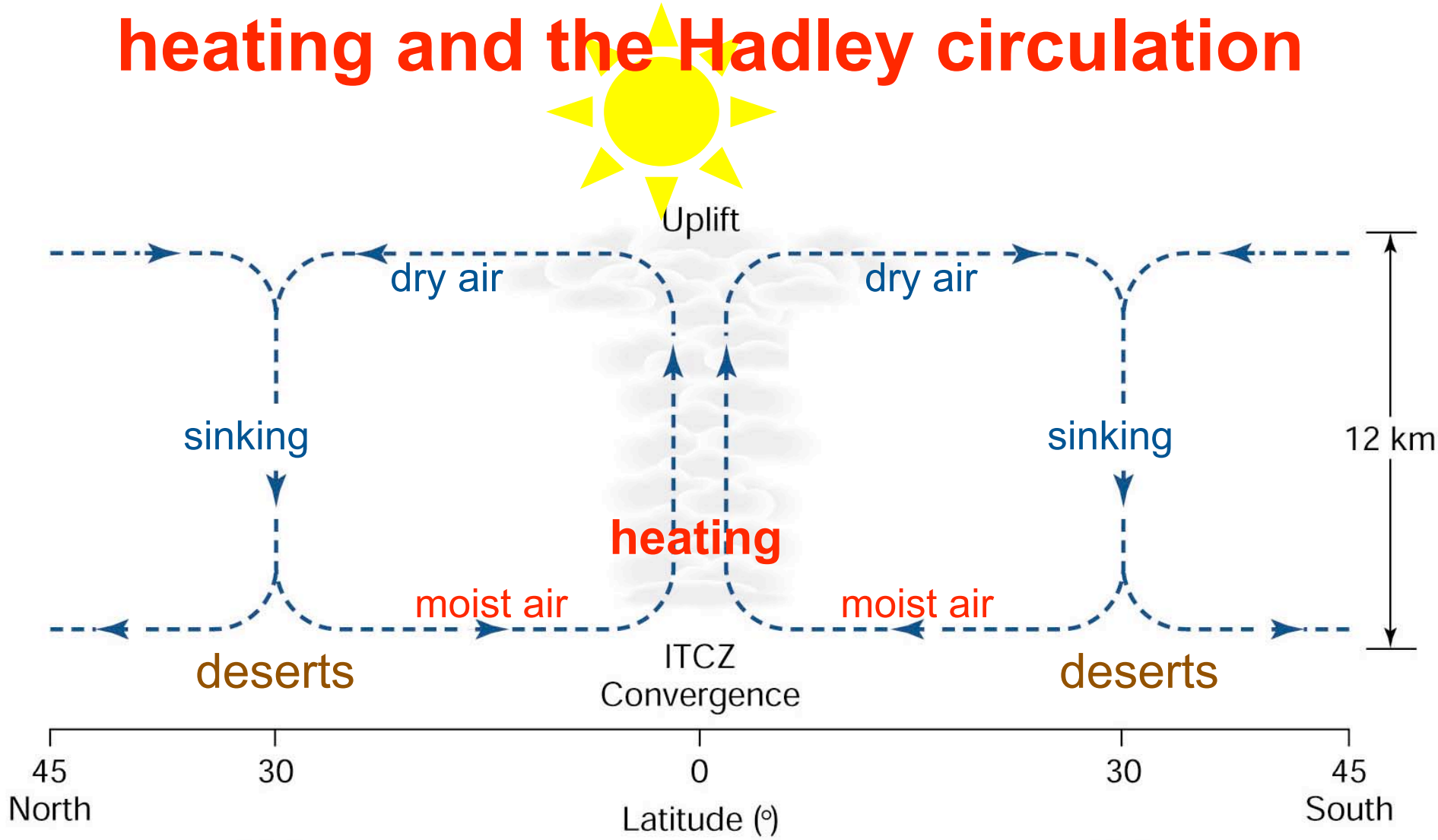




these are the forces that drive the circulation of the Hadley cells

northern limb

heating and the Hadley circulation

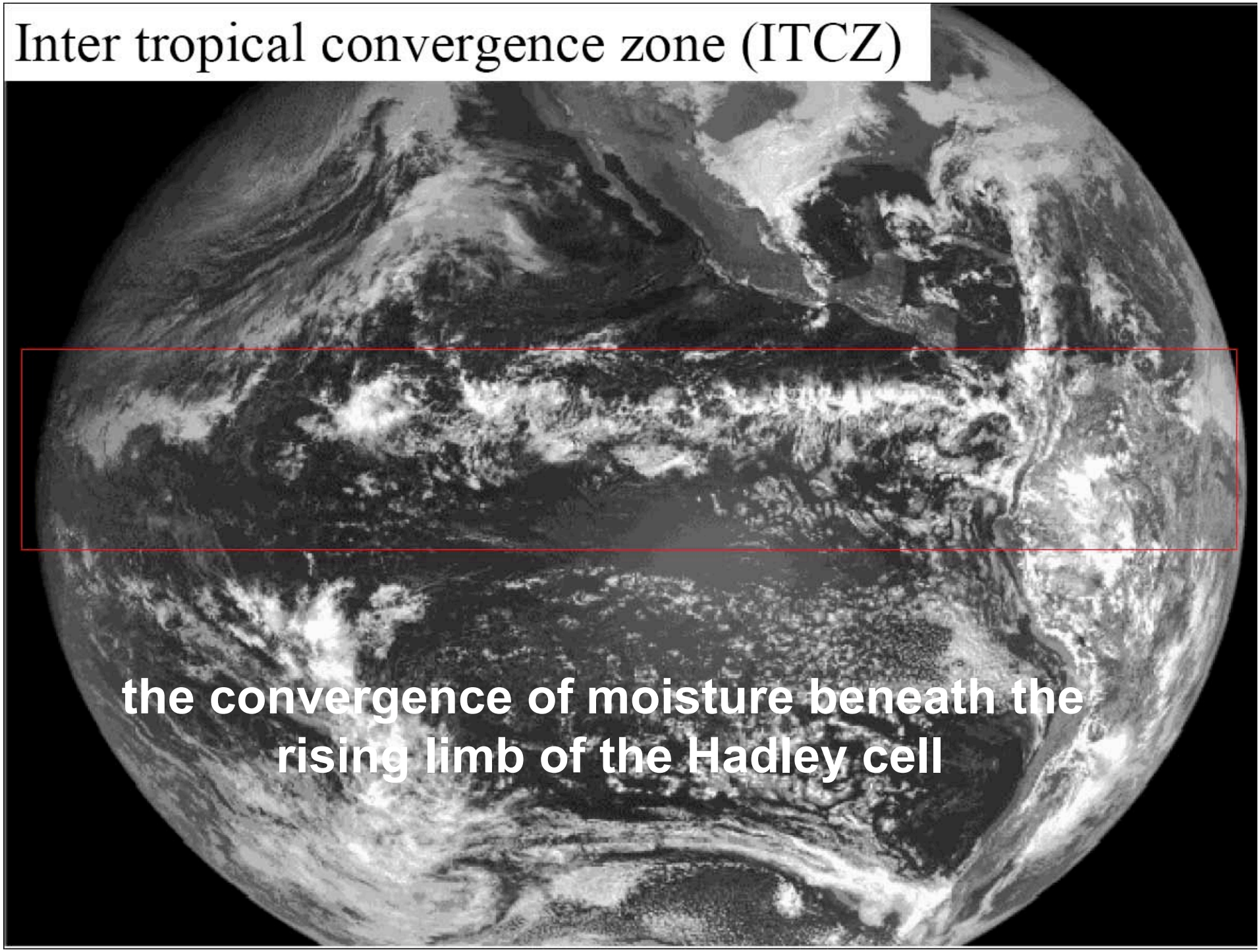


heating = expansion = buoyancy = uplift

rising air replaced by moist air converging from below

sinking air is dry *(why?, recall from last lecture)*

Inter tropical convergence zone (ITCZ)

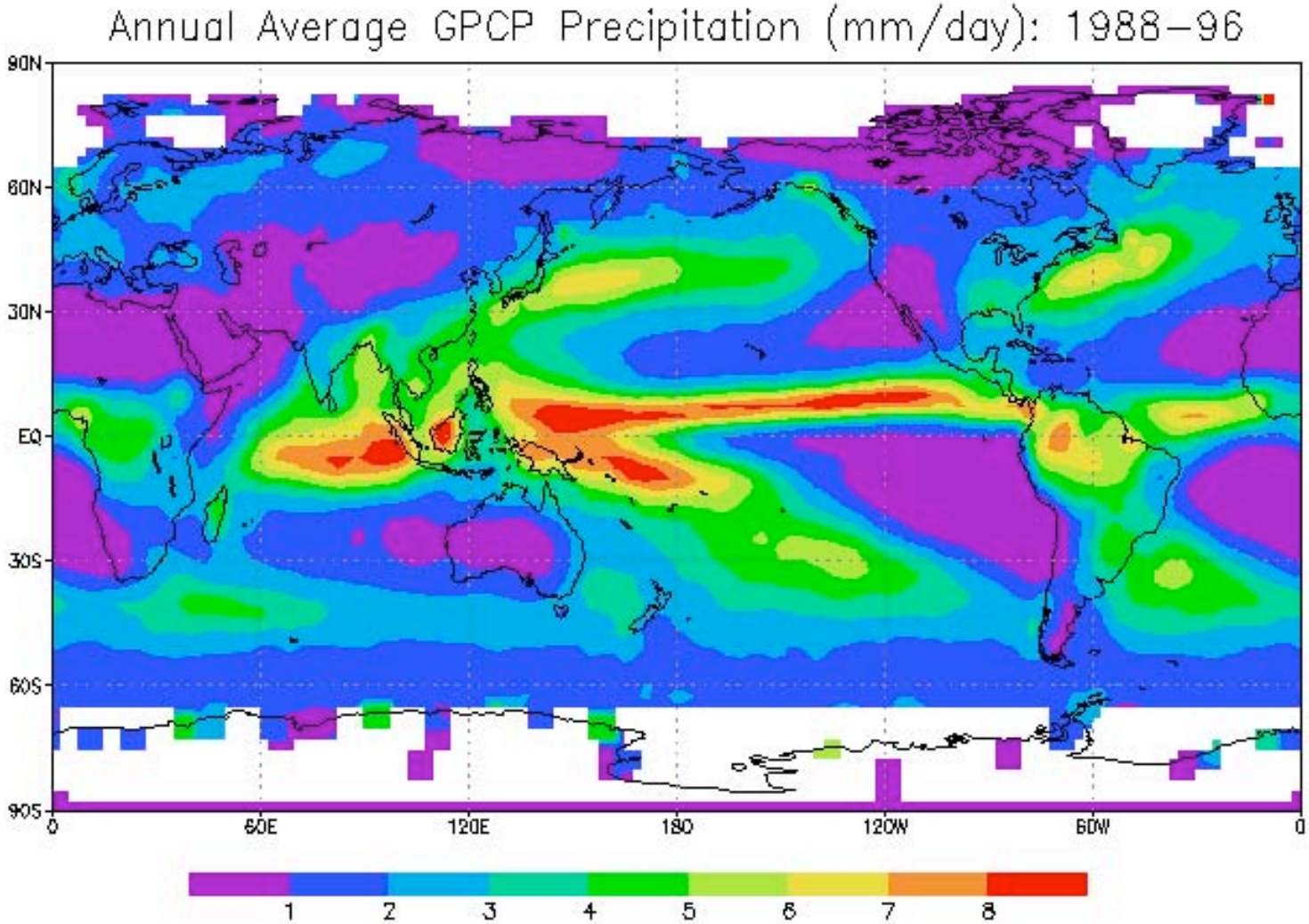


warming and the Hadley circulation

We'll talk about the seasonal migration of the ITCZ in an upcoming class on monsoon climates (as you might imagine, it simply follows the Sun or the "heating" into the summer hemisphere….) .

But, we already know enough to guess how the Hadley circulation might respond to global warming or increased "heating"…..

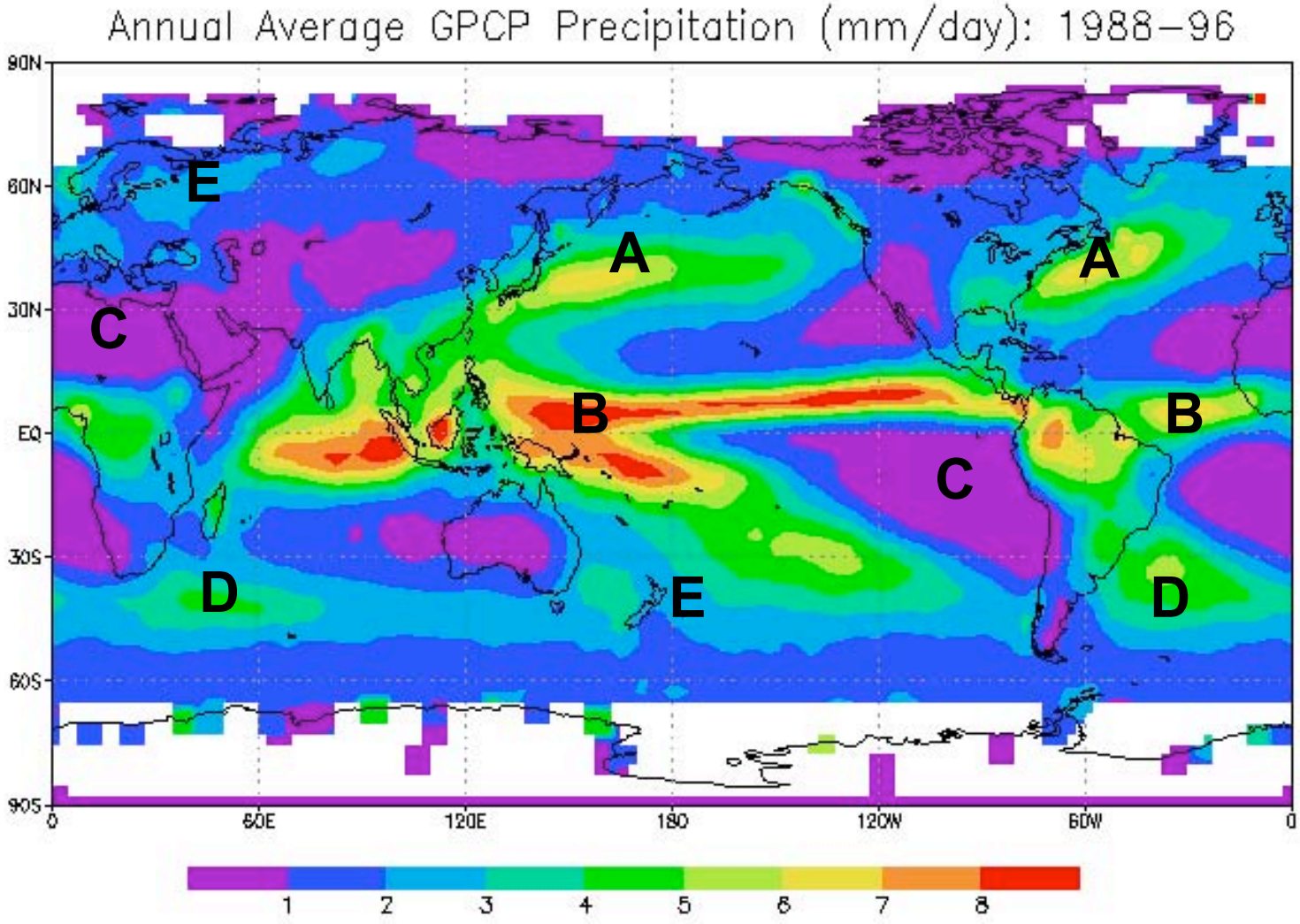
precipitation amount



scale is mm/day

where is the greatest precipitation?

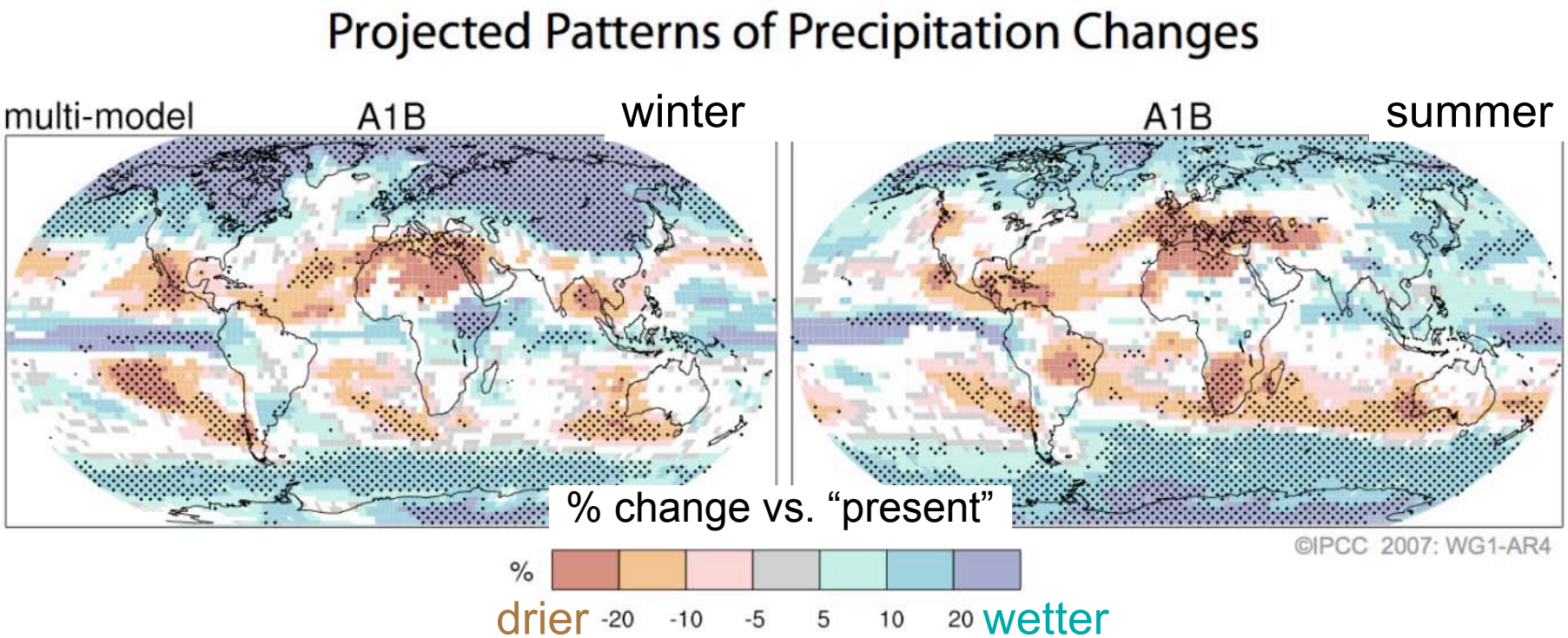
clicker question:



the areas of most active atmospheric sinking or subsidence are most likely

A), B), C), D), or E)?

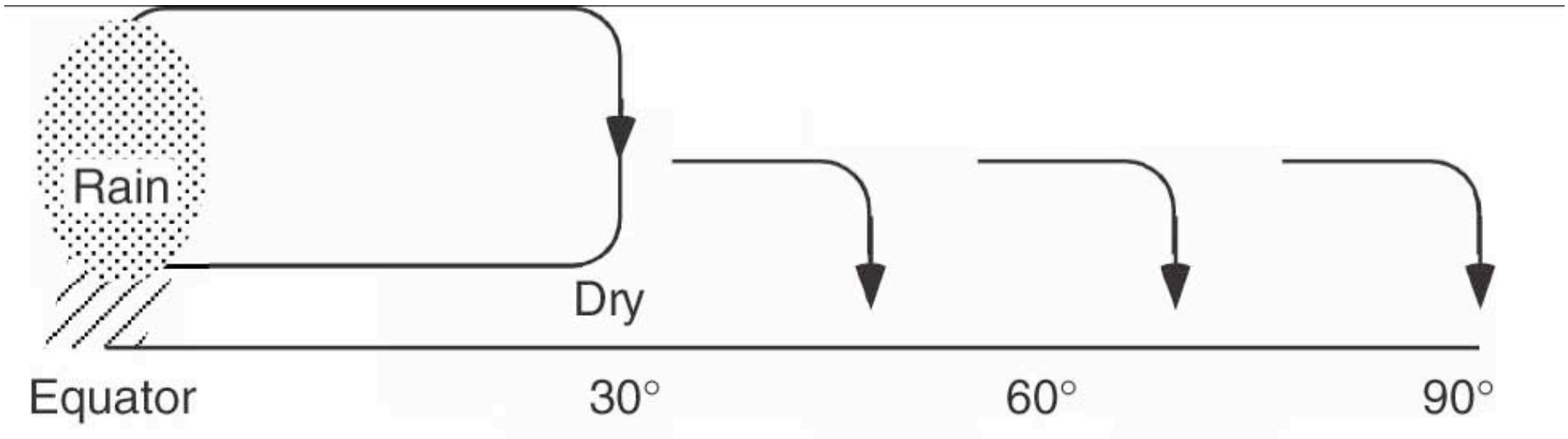
latest from IPCC



Seasonal 2090-99 projection vs. 1990-99 for average of many models. White areas are where less than 66% of models agree. Stippled areas are where more than 90% of models agree. All for same GHG scenario.

the pattern looks like that associated with the Hadley circulation but stronger

a simple mechanistic forecast



more intense heating, more convection, rainfall and flooding

more descending dry air, more & longer drought

warmer, wetter, more snowfall

why this?

Archer

summing up....

- *variations in heating lead to pressure variations*
- *heating and pressure influence buoyancy*
- *pressure variations also drive horizontal air movement (as air moves from areas of high to low pressure)*
- *the combination of vertical (buoyant) and horizontal motions allows the development of circulation cells*
- *the associated winds will determine the transport of heat and moisture*

learning goals

- explain the role of poleward energy transport in maintaining observed latitudinal temperature gradient

- explain the relationship of heating, pressure force, and air movement

- describe the circulation of the Hadley cell

next week

- the coriolis force and the general circulation of the atmosphere
- land-sea temperature contrasts
- ocean currents

- reading: Ch. 6
- Homework: posted today, due next Thurs.

key terms and concepts

- net radiation surplus or deficit
- poleward heat transport
- heating, pressure and pressure force
- heating and buoyancy
- cooling and negative buoyancy
- uplift and subsidence
- convergence (and divergence)
- circulation cells
- the Hadley circulation
- the Inter-Tropical Convergence Zone (ITCZ)