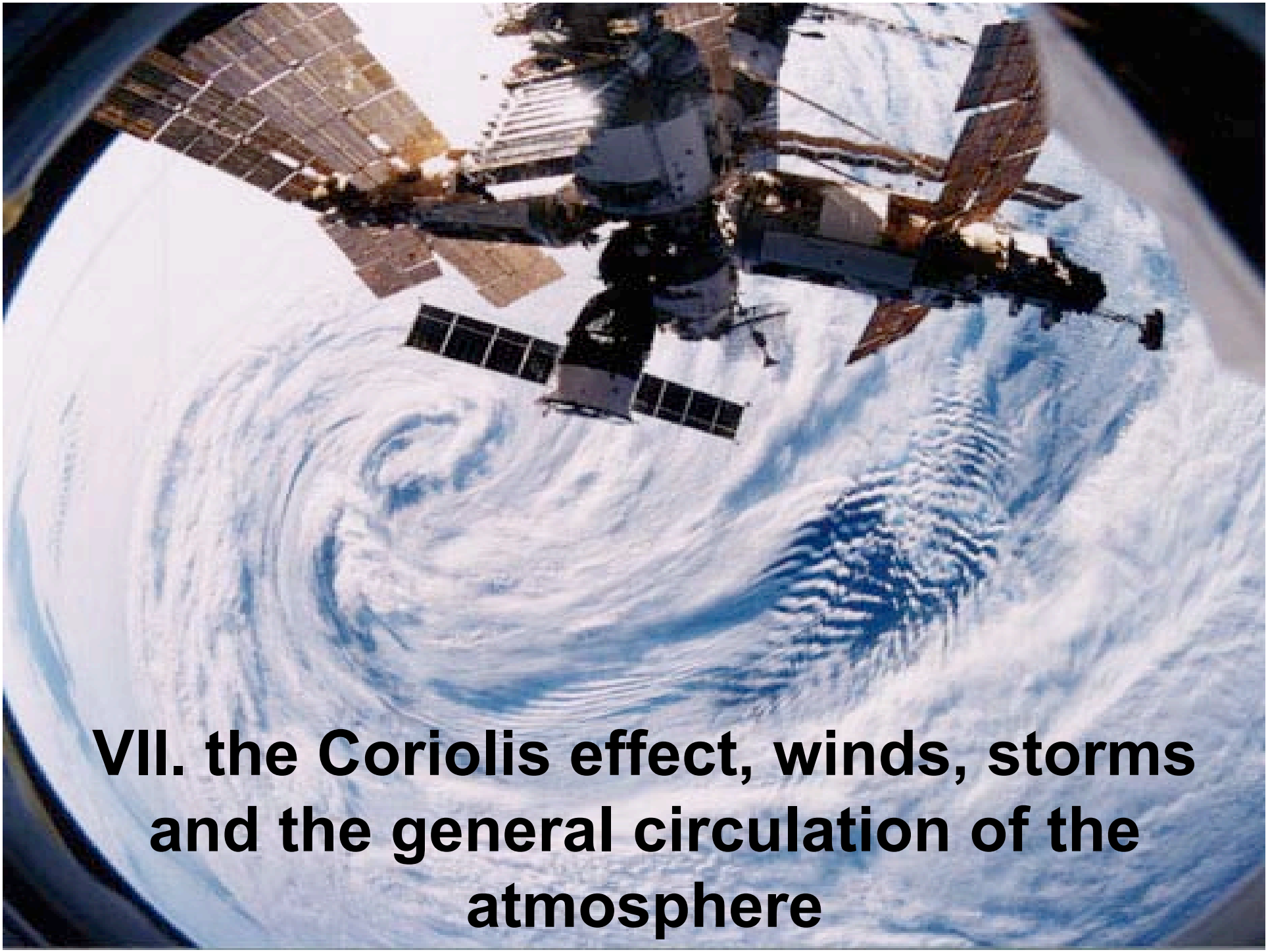
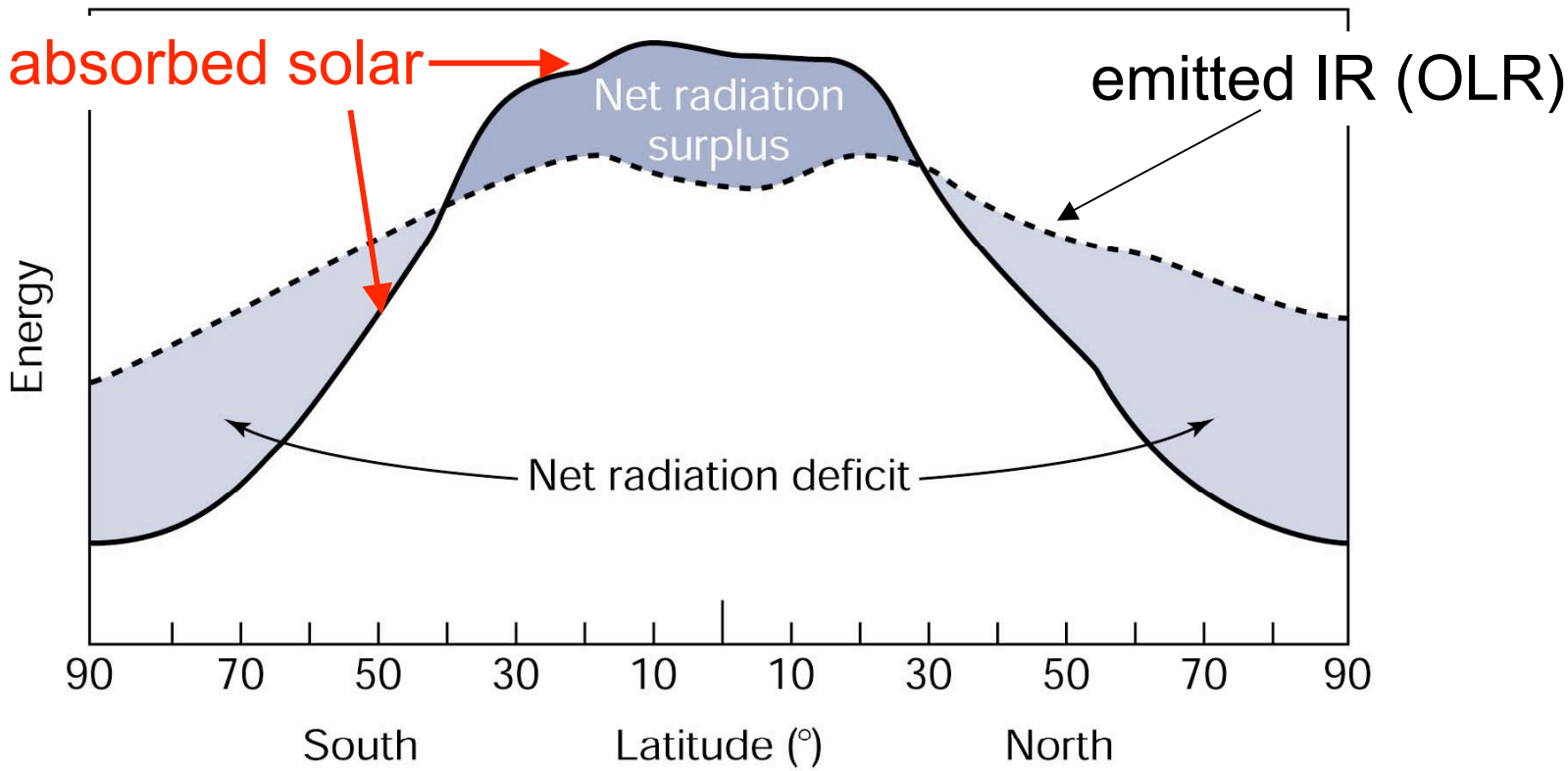


VII. the Coriolis effect, winds, storms and the general circulation of the atmosphere

clicker question



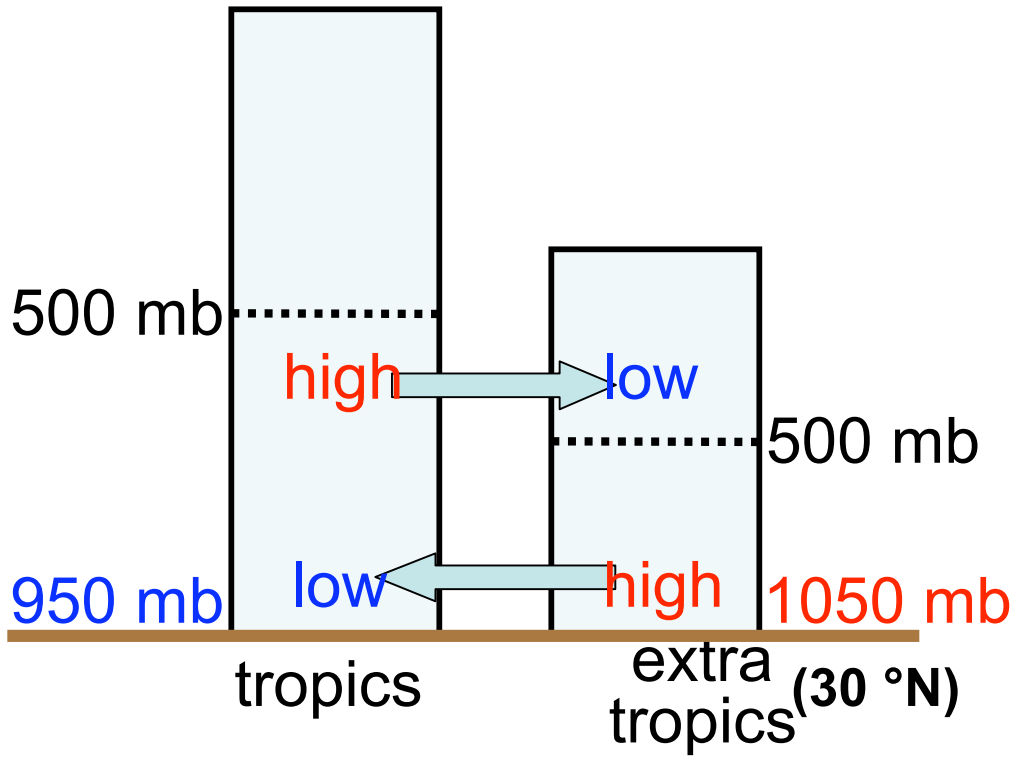
The local imbalances of received and emitted radiation (above) mean that:
a) the poles will cool forever, b) the tropics will heat up forever, c) both a & b, d) there must be a poleward transport of heat, e) there must be an equatorward transport of heat

clicker question

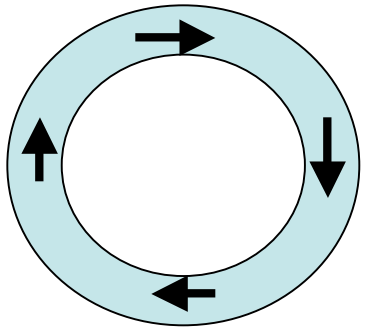
heating at the surface leads to:

a) expansion of air, b) buoyancy, c) convection, d) gradients of pressure, e) all of the above

review (from last week)



northern limb Hadley cell

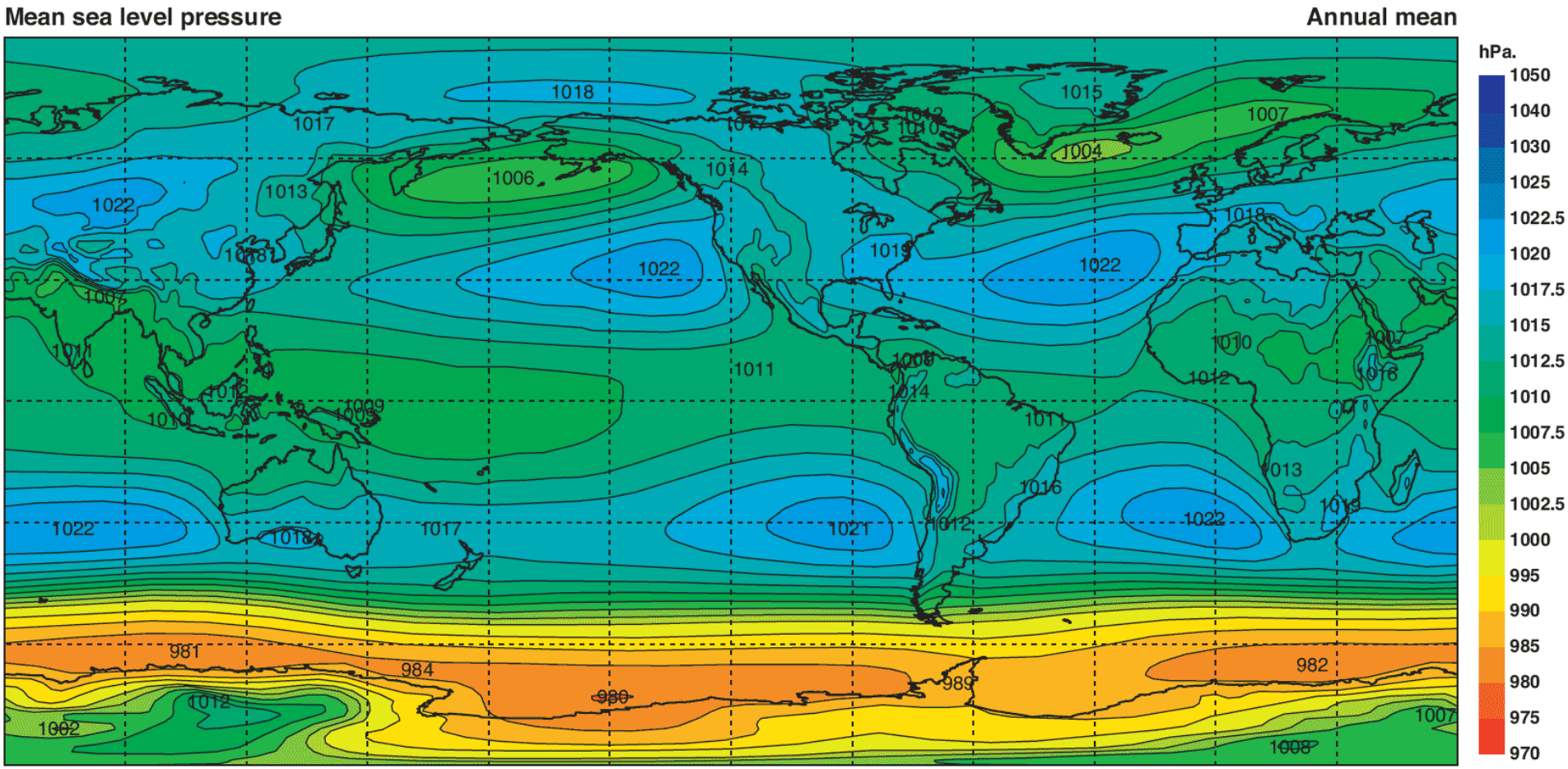


the horizontal movements of air can be satisfied by buoyancy driven vertical movements, comprising a circulation cell, such as the Hadley cell

review (from last week)

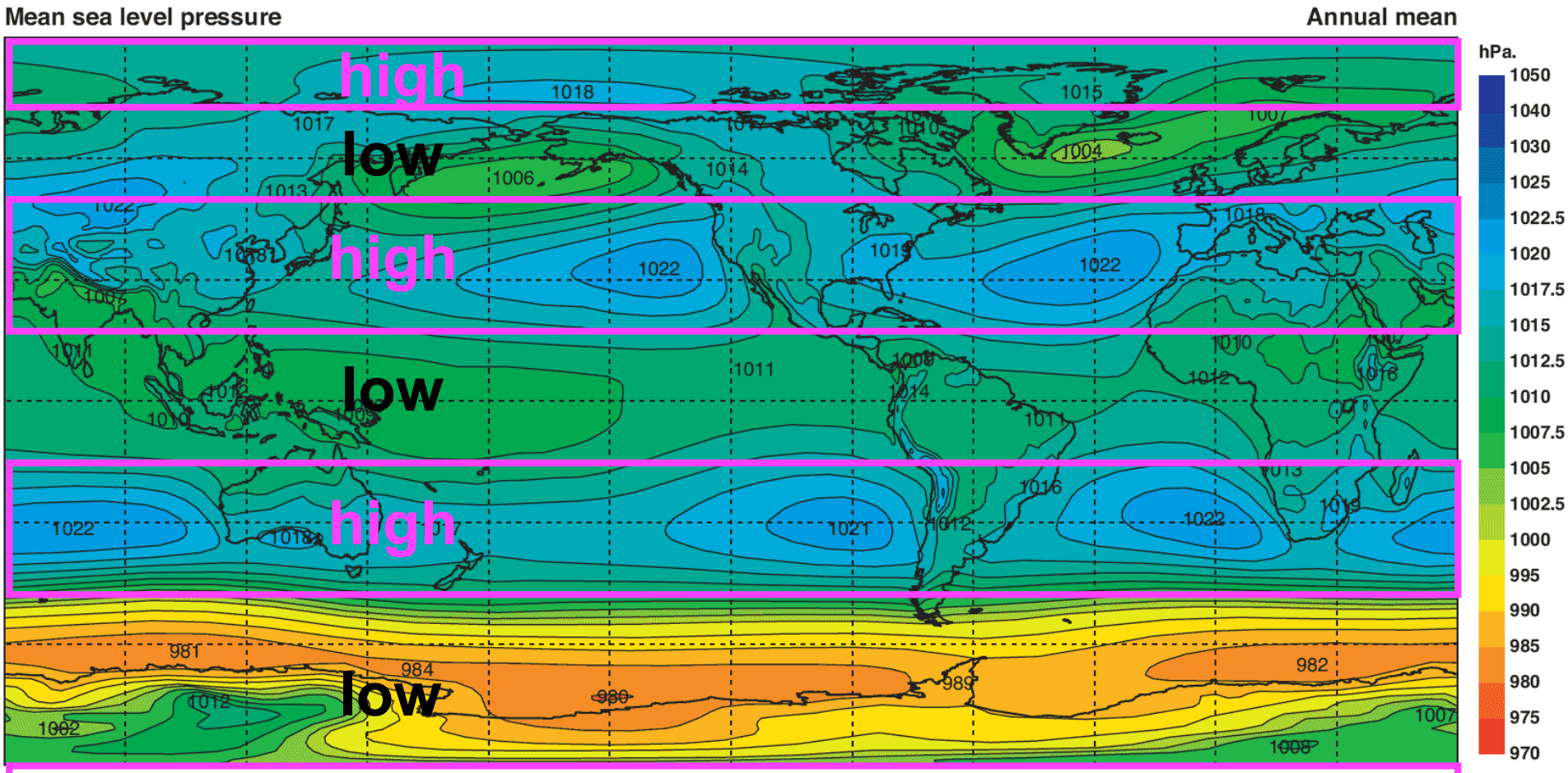
- differential heating leads to gradients of pressure
- air moves from areas of high pressure to areas of low pressure
- but does air always move in a straight line?

surface pressure



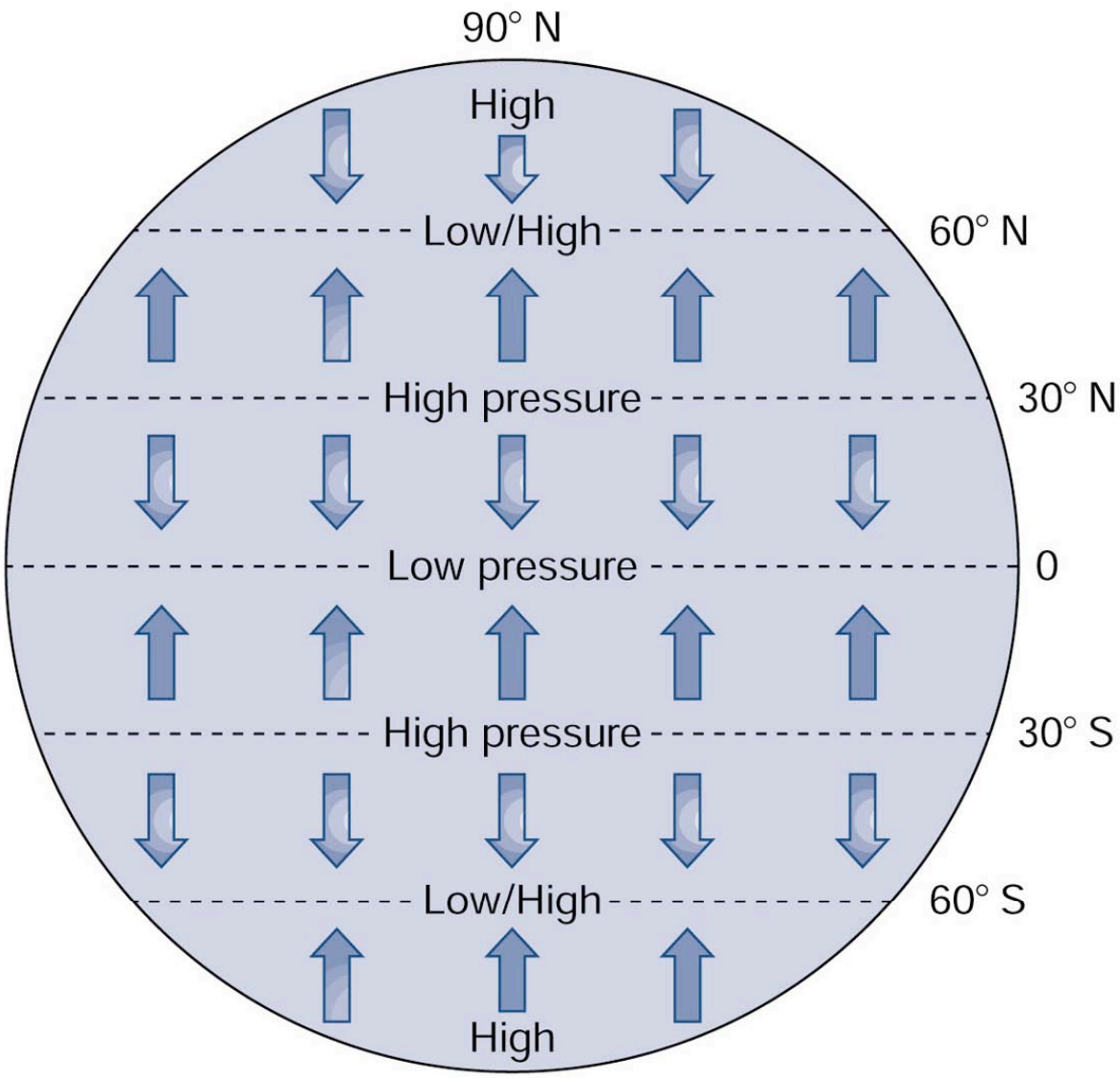
mbar

surface pressure “belts”



another **high** down under

pressure-force-only winds



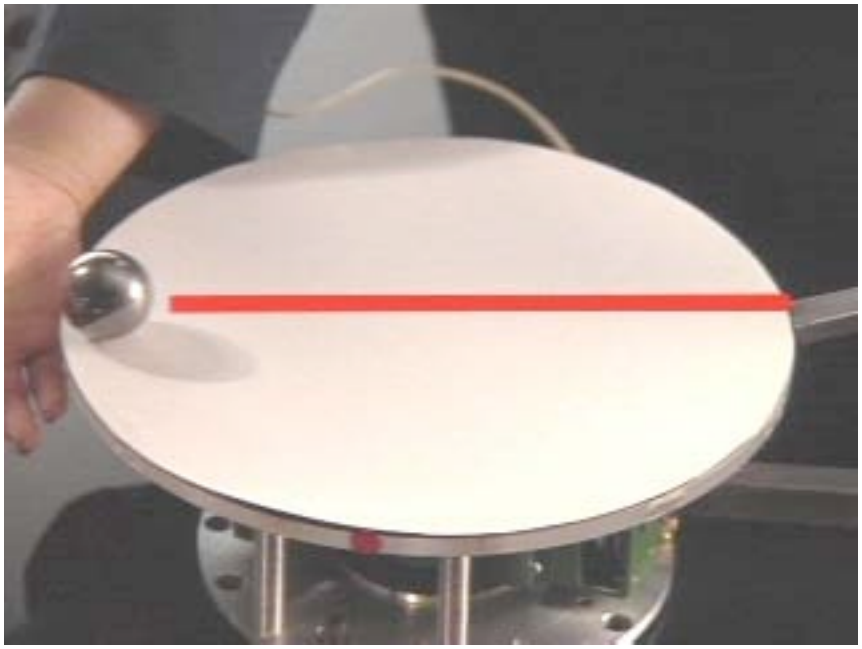
is this the observed pattern?

the Coriolis effect

- Newton says pushed objects will move in a straight line, but.....

a simple experiment

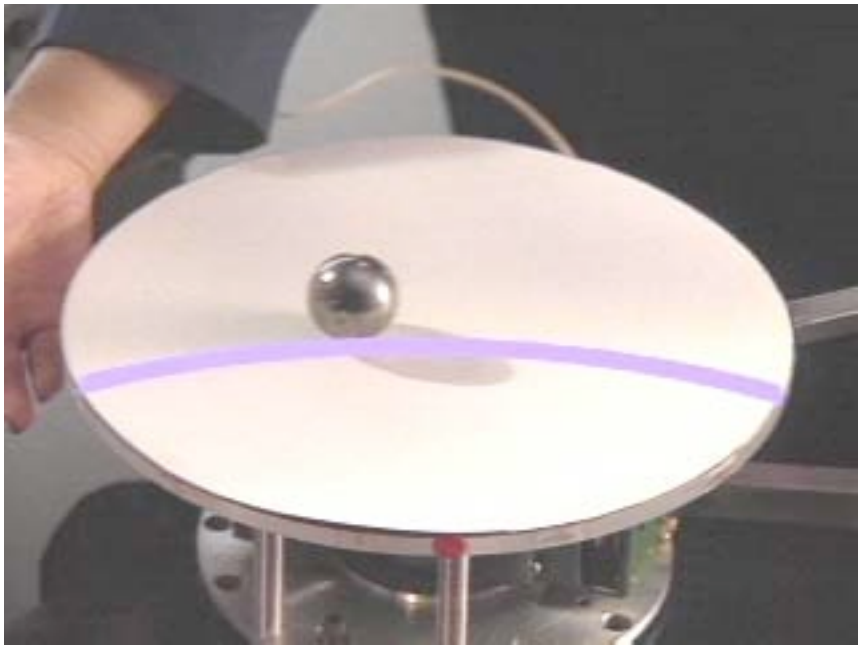
platter is stationary



Newton was right!

a simple experiment

platter now rotates!



what happened ????????
how would it look from above?

the Coriolis effect

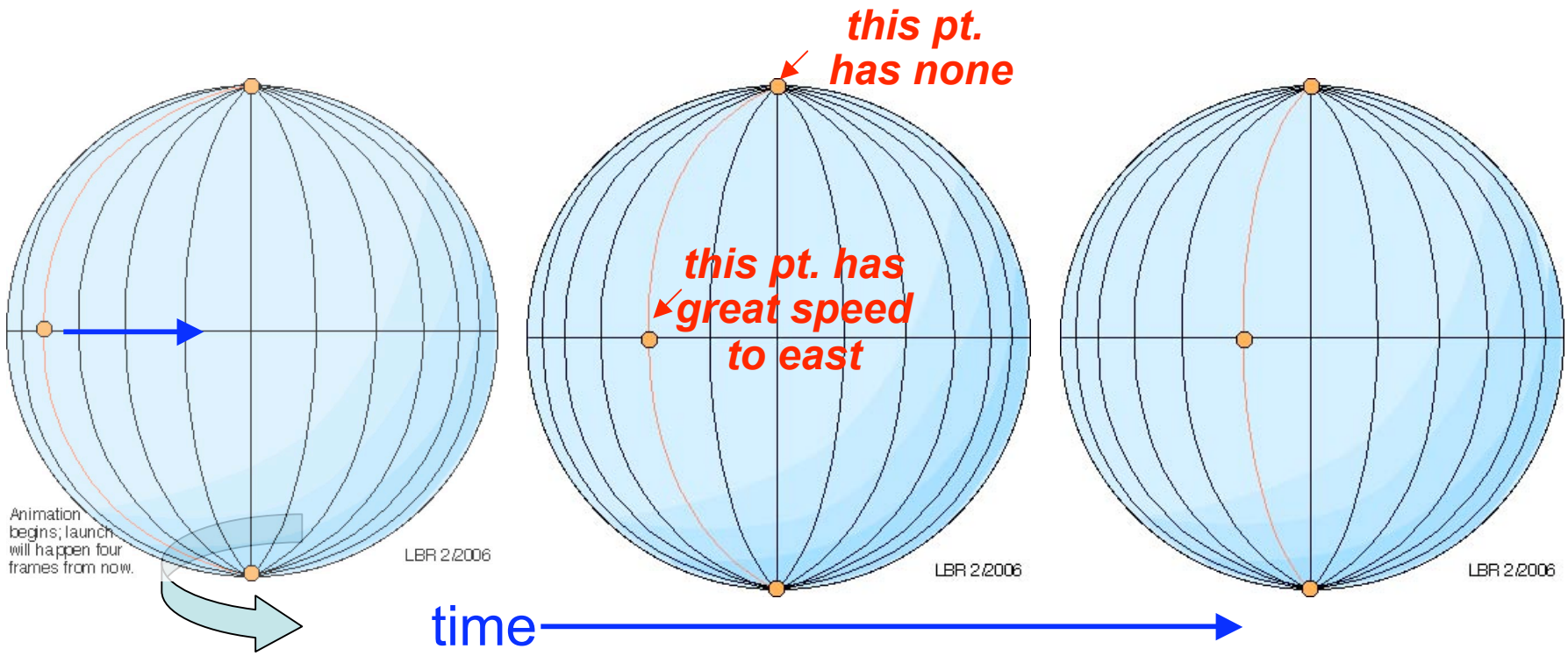
- Newton says pushed objects will move in a straight line, but.....

- the Coriolis effect describes the tendency of a fluid (air or water) moving across the surface of the Earth to be deflected from its straight line path

- this is not a real force (in the Newtonian sense), but apparent only from w/in the rotating Earth system

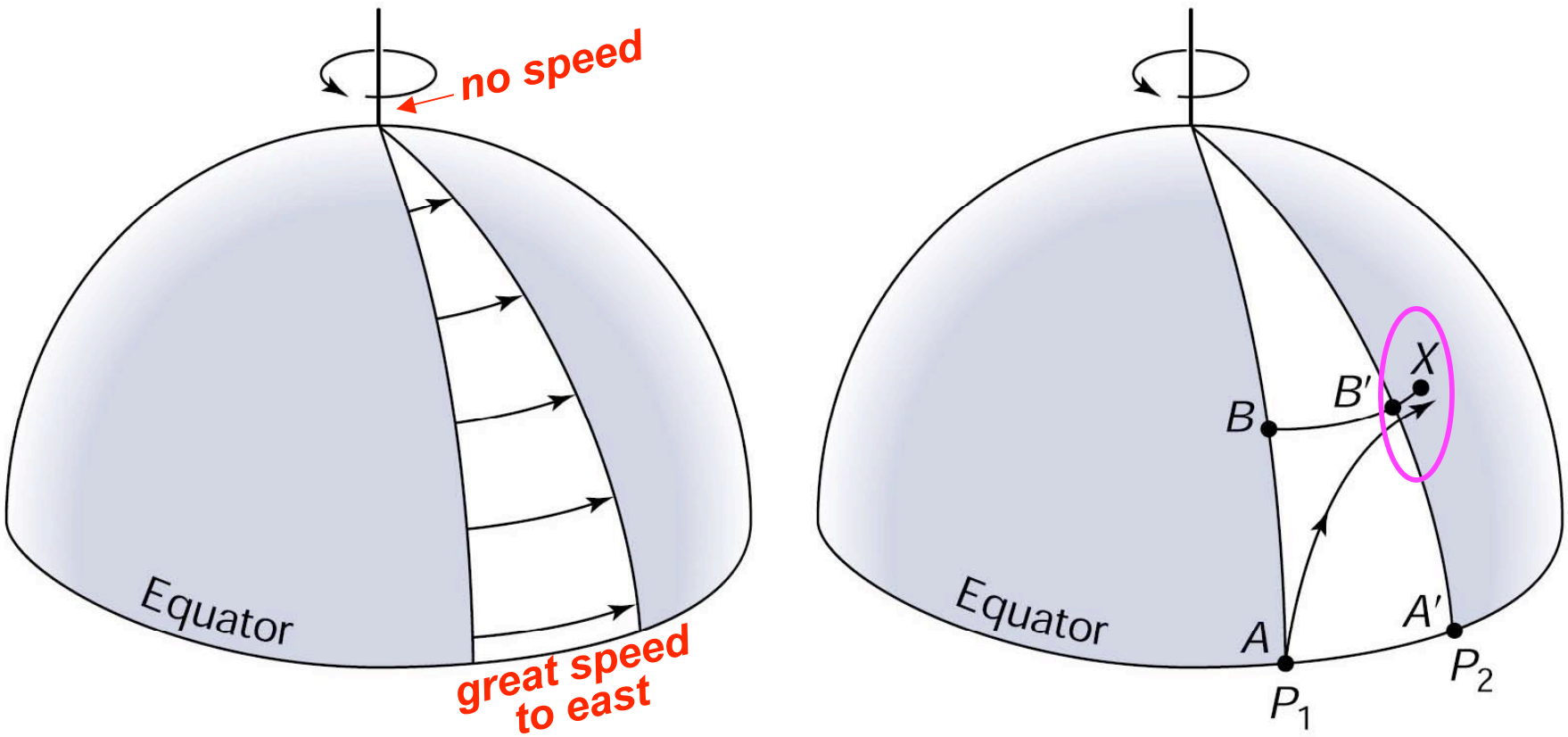
- ***let's see animation (and then derive direction of the deflection)***

consider rotating earth



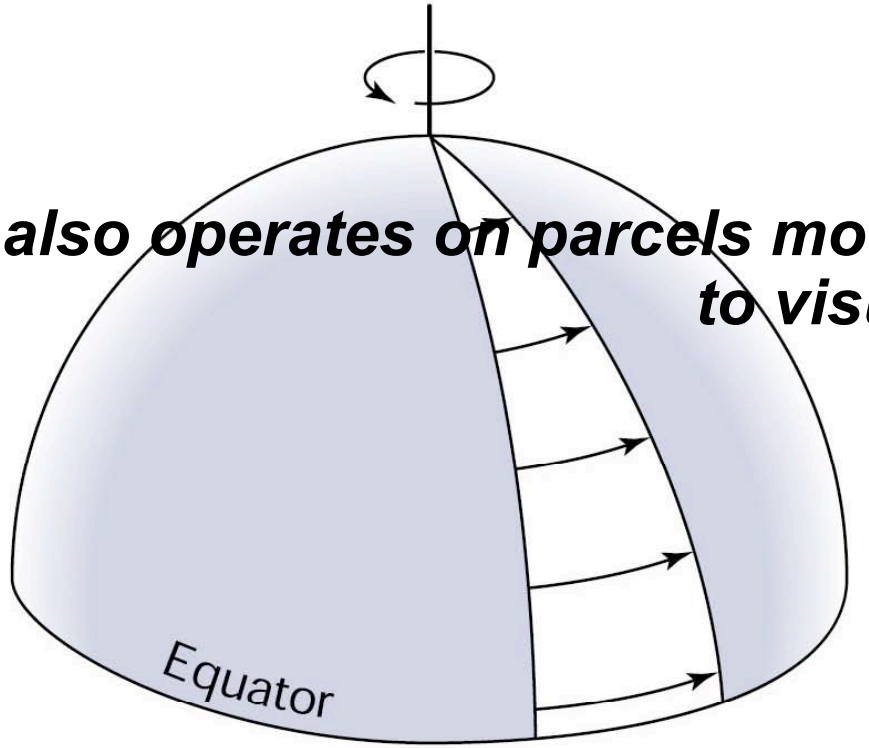
there must be a change in "speed" w/ latitude (decreasing away from the equator)

apparent deflection & speed

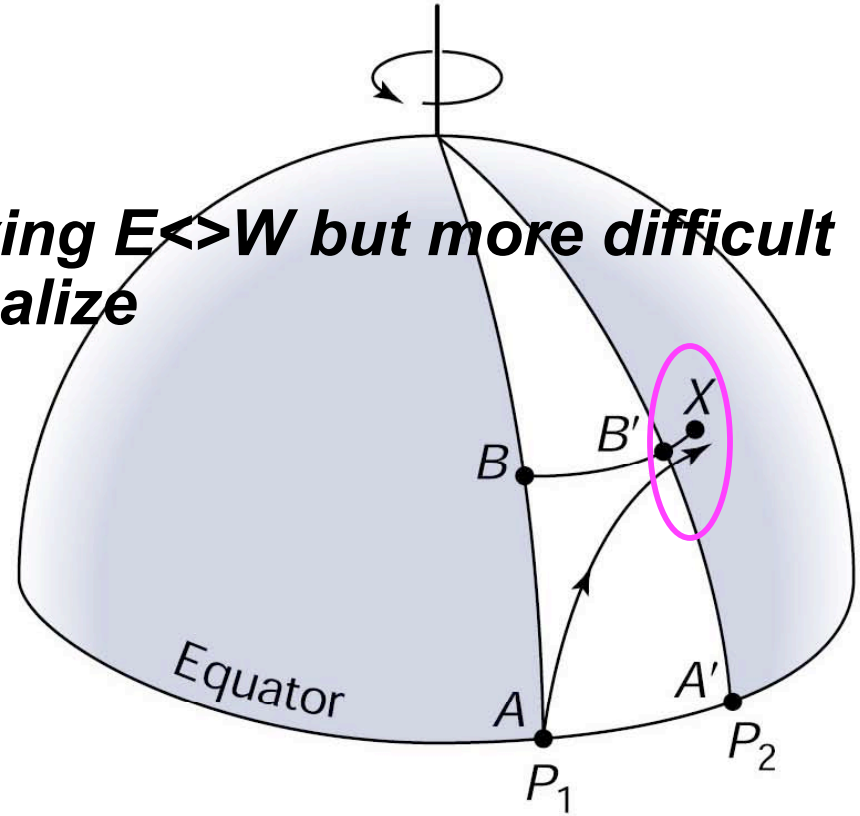


object moving northward has inherited eastward speed and overshoots target (giving impression of deflection to right and increased speed)

apparent deflection & speed

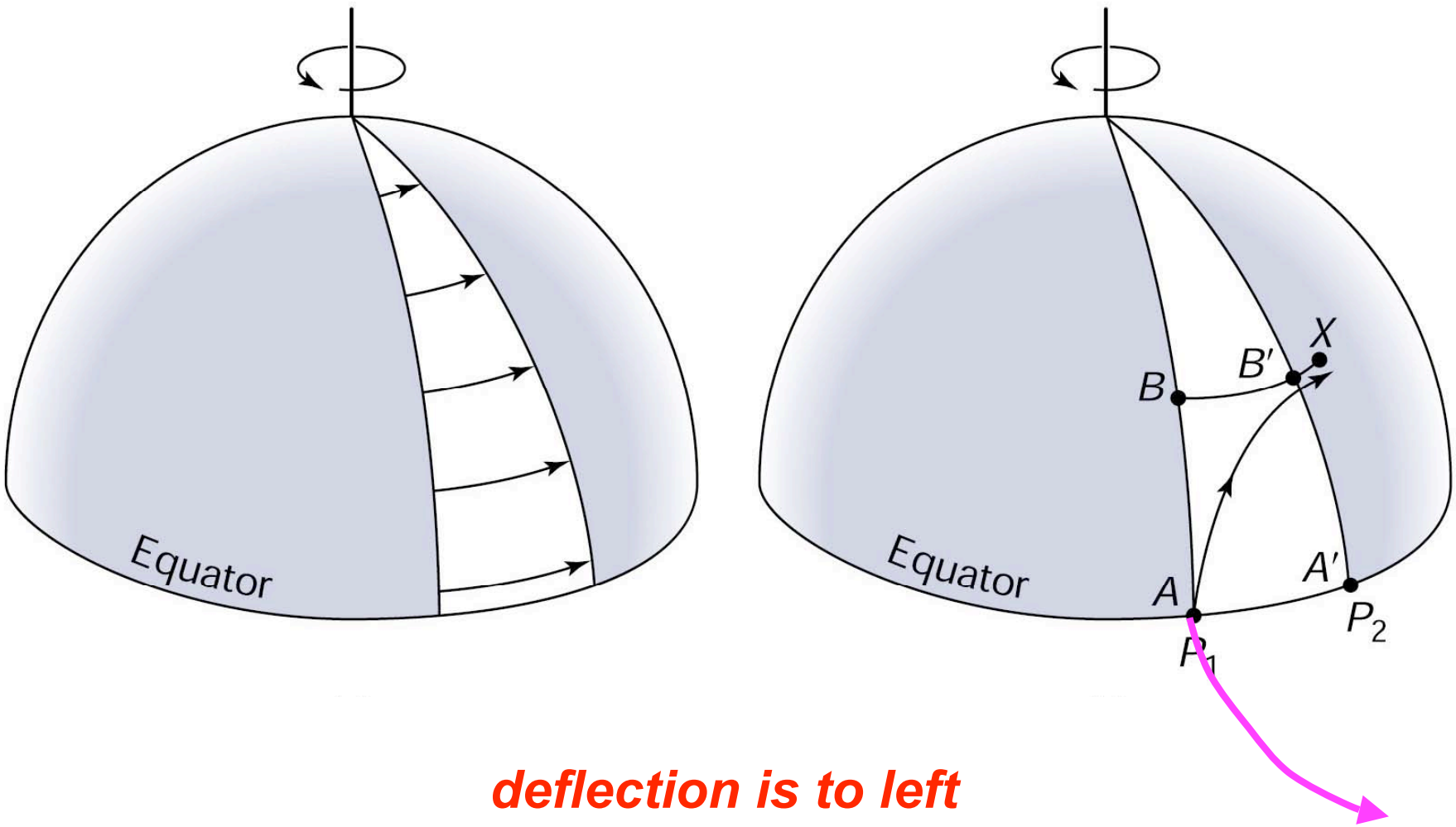


also operates on parcels moving E<>W but more difficult to visualize



object moving northward has inherited eastward speed and overshoots target (giving impression of deflection to right and increased speed)

apparent deflection & speed



deflection is to left

what happens in the Southern Hemisphere?

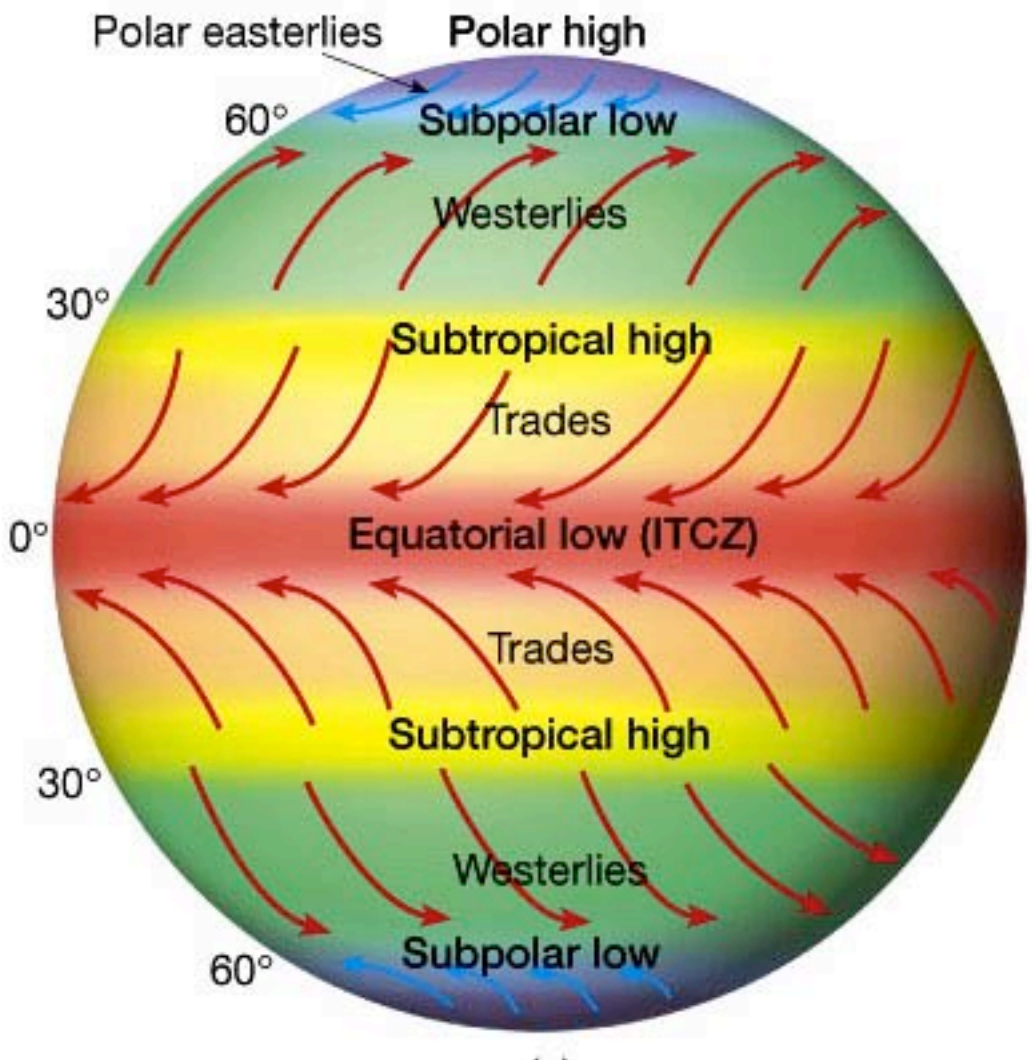
rules of thumb

- moving air (and water) is deflected to the right in the NH and to the left in the SH

- the Coriolis effect increases with the speed of the air (or water) parcel

- there is no Coriolis effect at the equator, so fluids moving E or W at the equator travel in a straight line (i.e. without deflection)

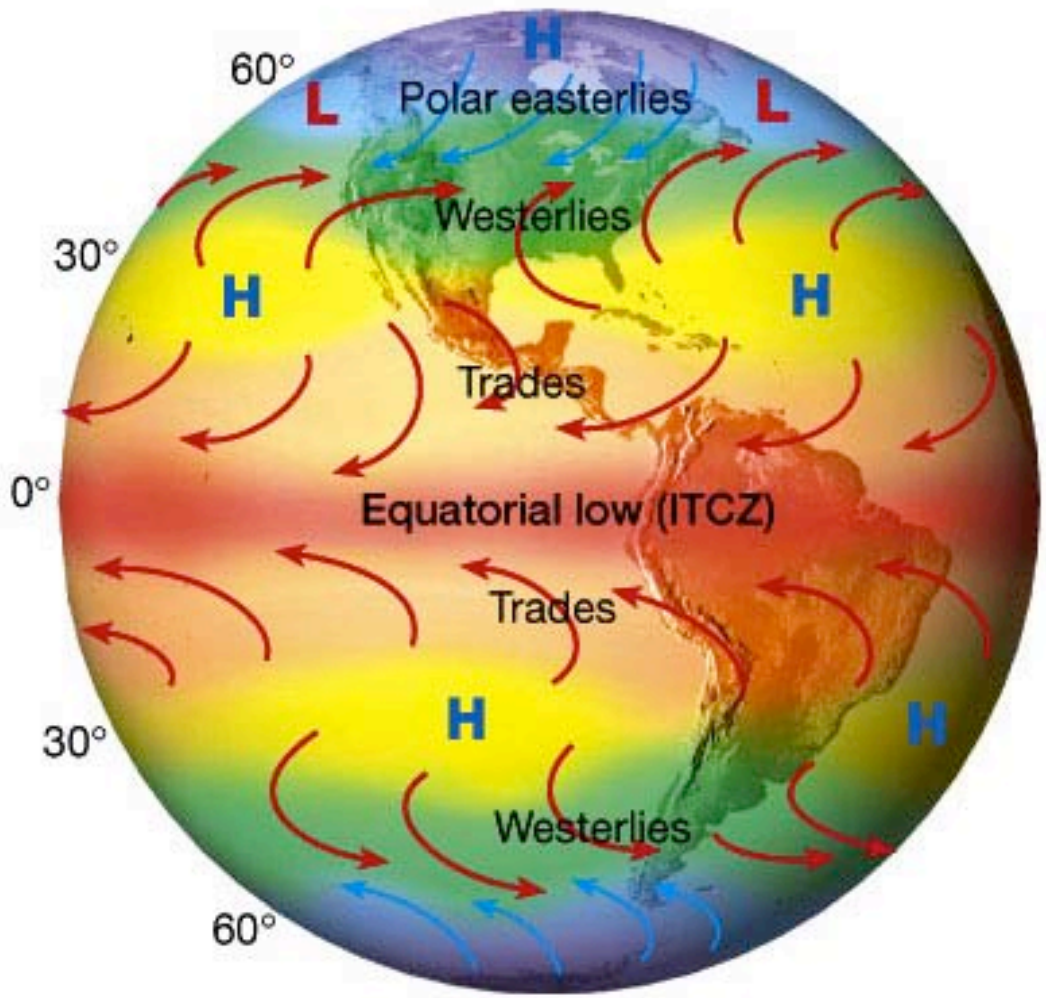
winds w/ Earth rotation



NH deflections to right

SH deflections to left

and continents....

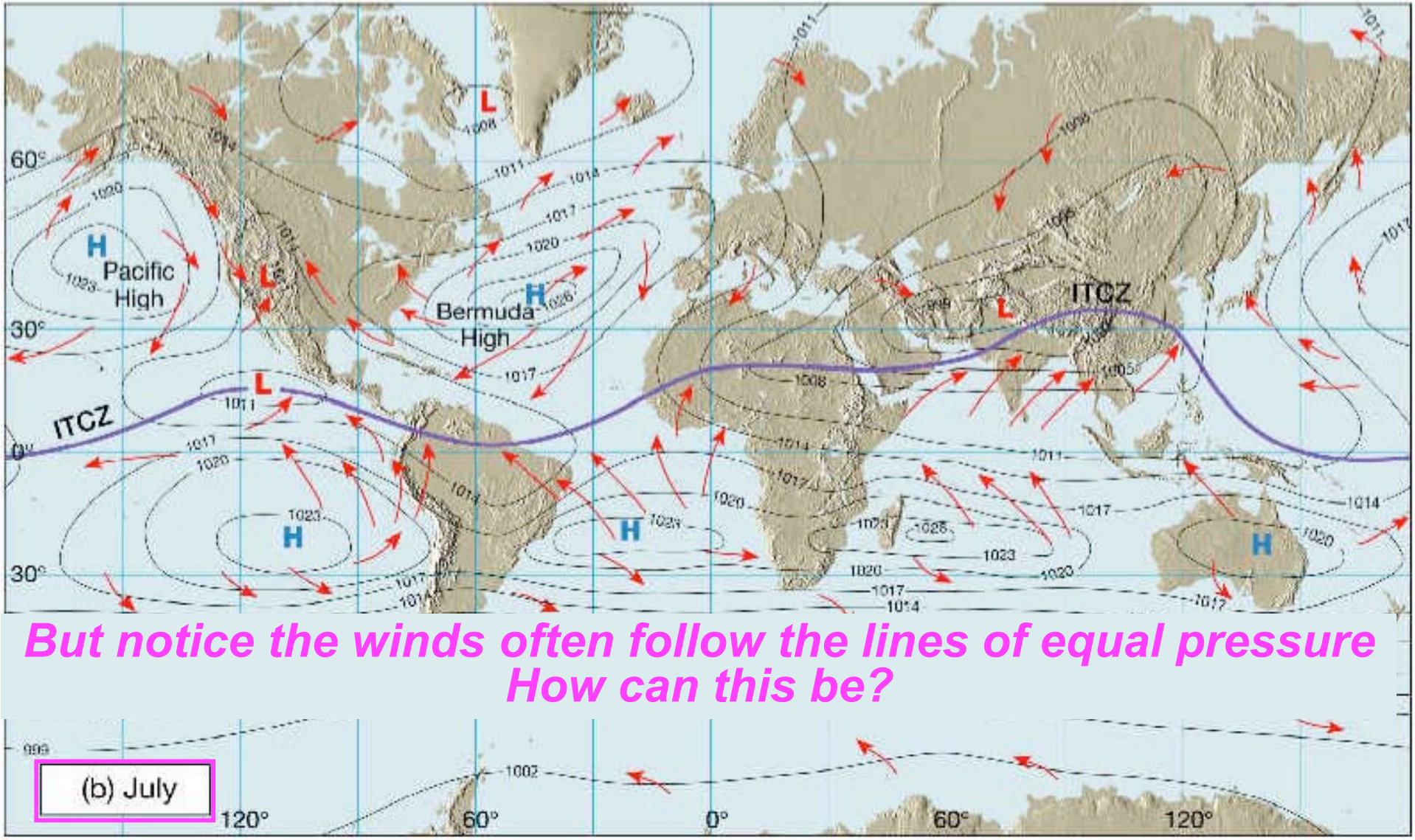


NH deflections to right

SH deflections to left

surface pressure "belts" become cells in response to differential heating of land and sea and physical barriers to flow

NH: air flows ‘round High to right



But notice the winds often follow the lines of equal pressure
How can this be?

SH: air flows ‘round High to left

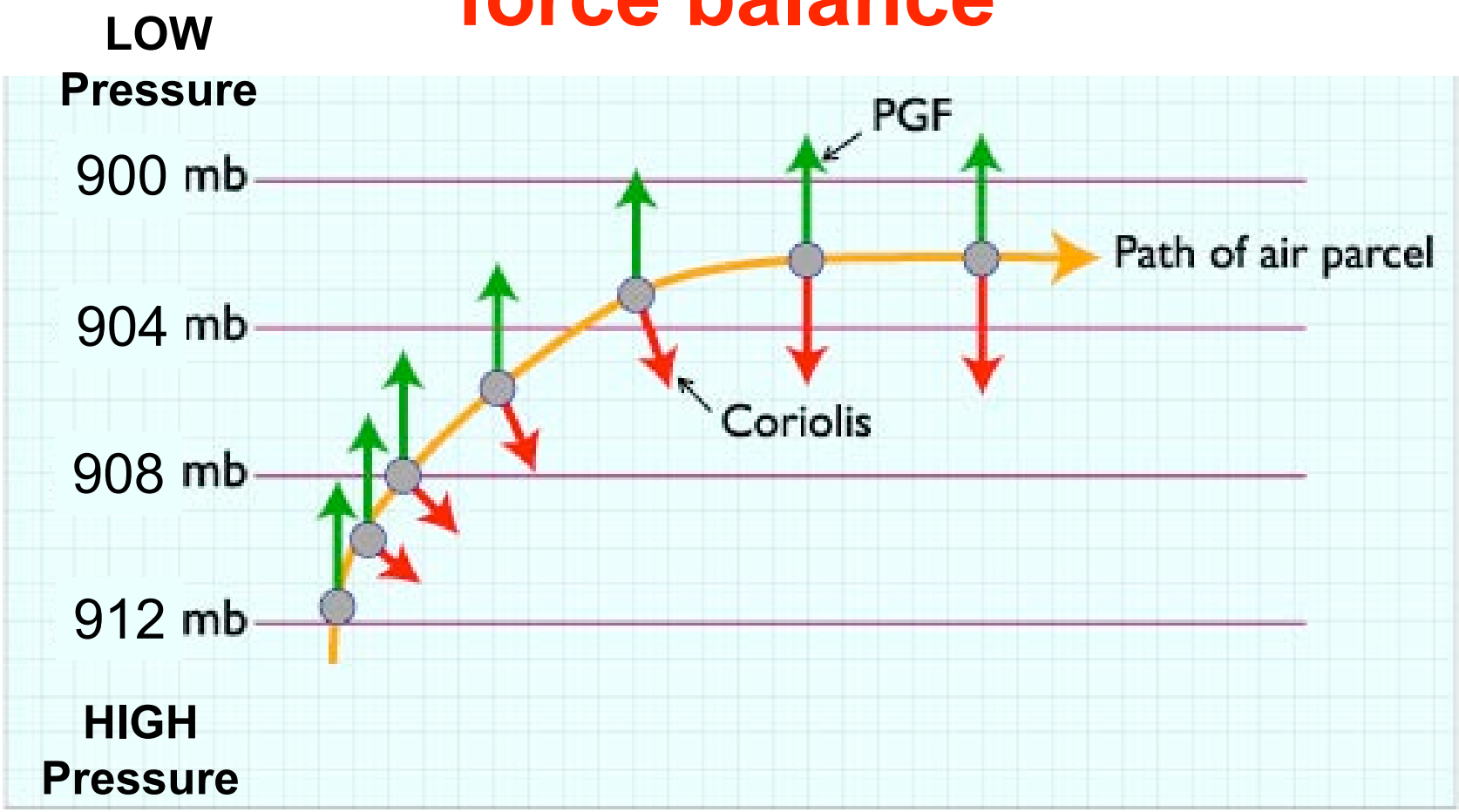
mid-latitude winds

- ***which way does the wind blow across the high plains of America?***

- ***so, we live in a westerly wind (and the wind is not always turning)…***

- ***why not?***

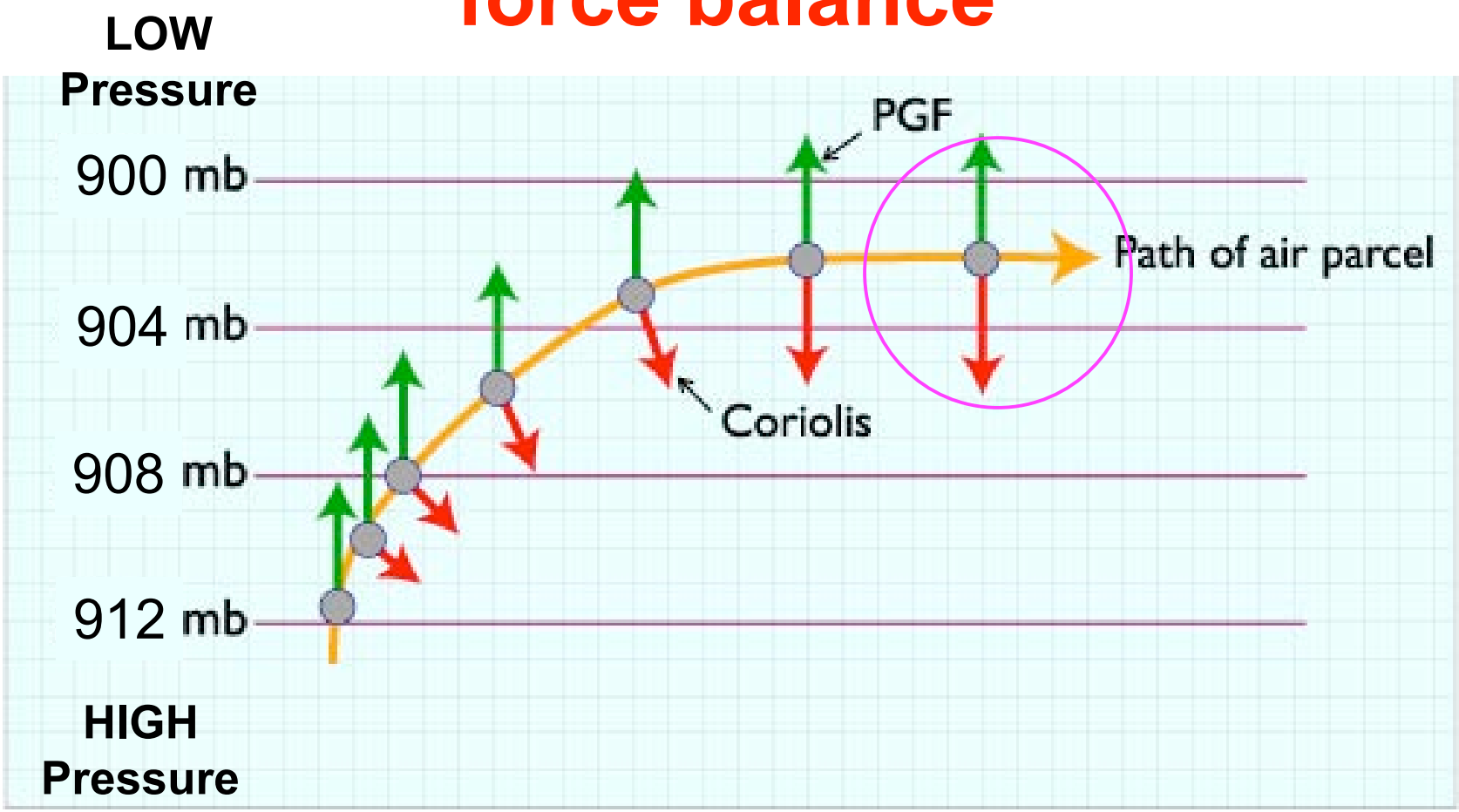
force balance



the initial motion of air is from high to low pressure, in the direction of the pressure gradient force (PGF)

the air parcel then begins to turn to the right (in the NH) in response to the coriolis effect, and….

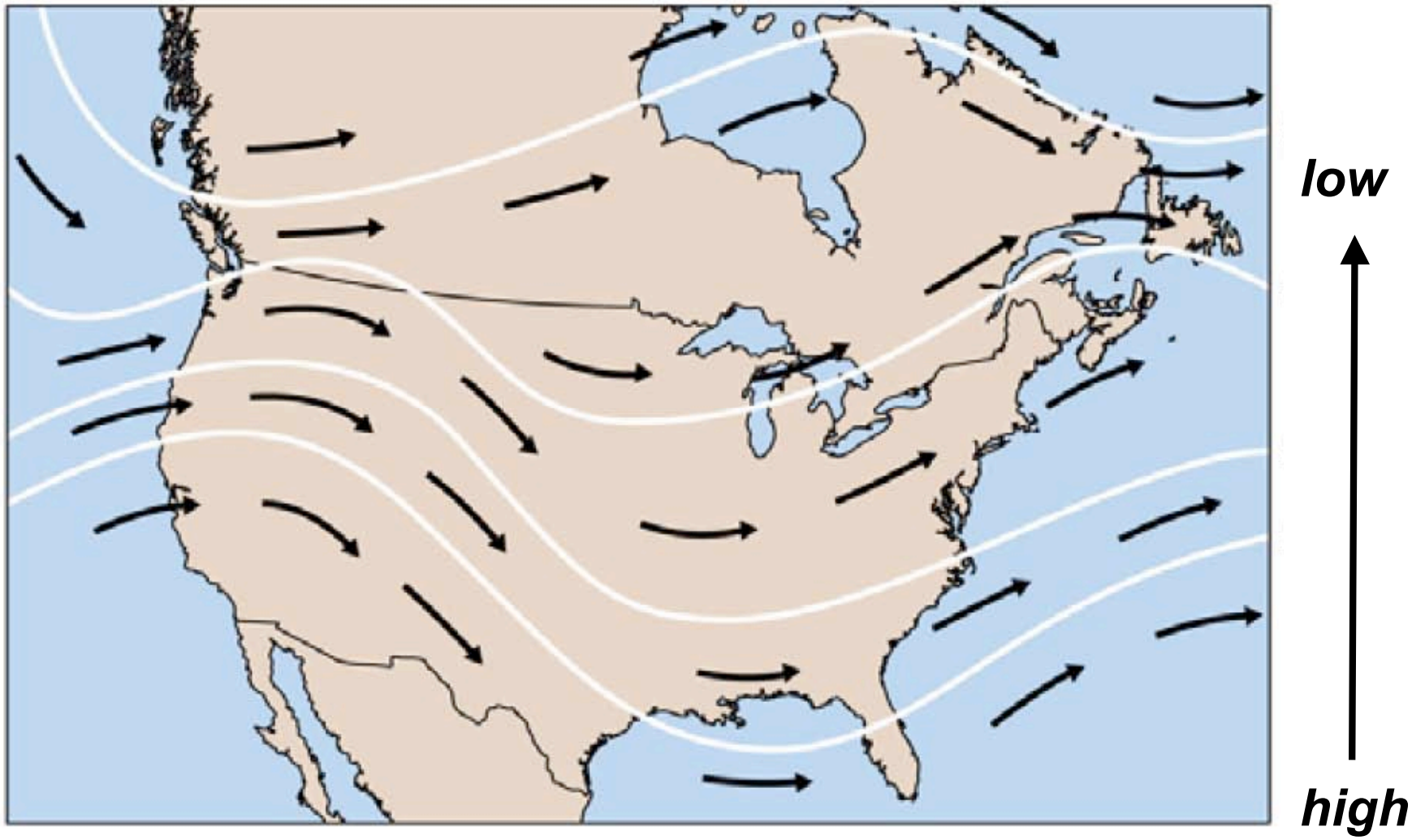
force balance



the air parcel continues to turn until the pressure gradient force and coriolis "force" are in balance

this balanced flow is called "geostrophic flow" and *follows the lines of equal pressure*….

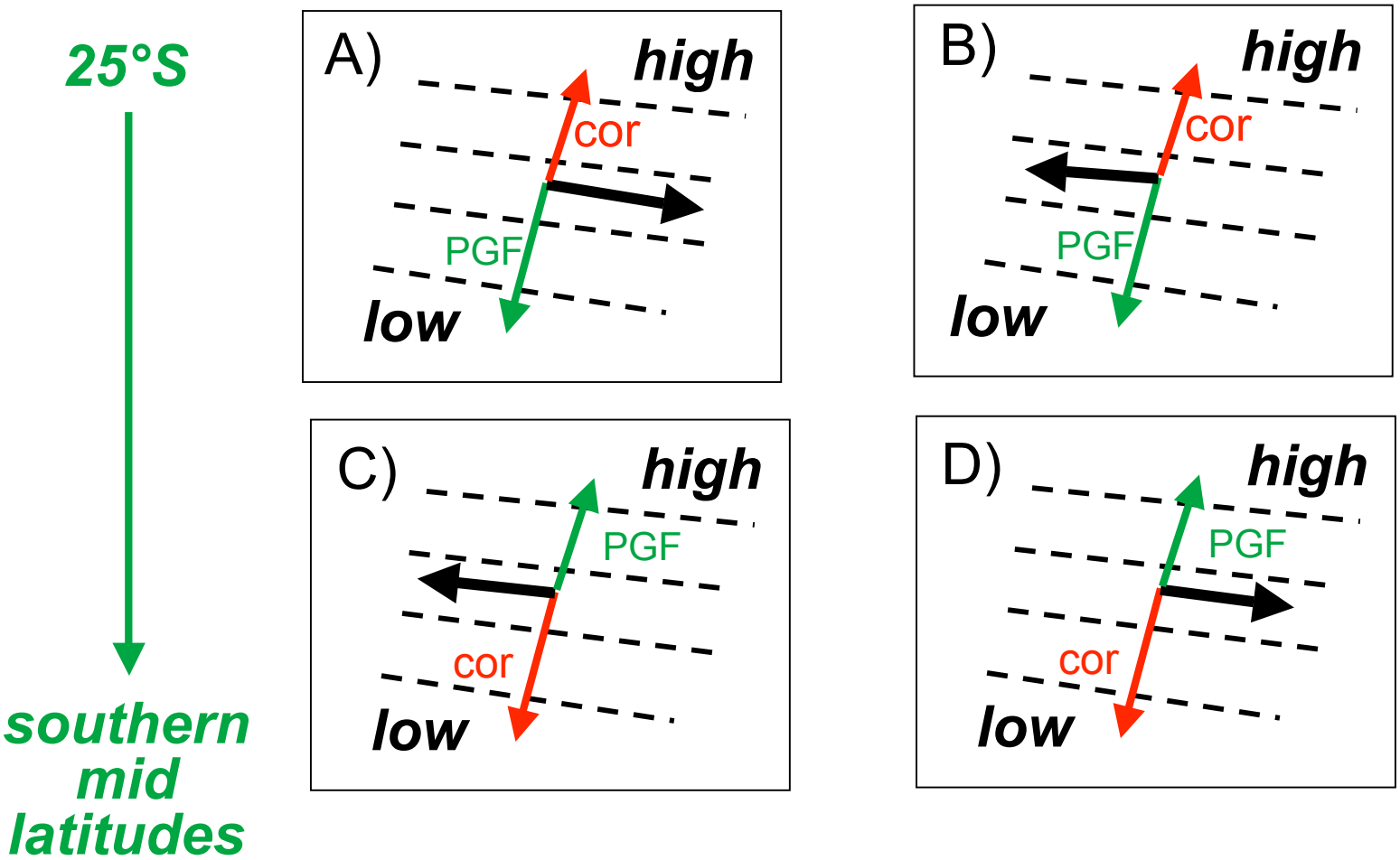
geostrophic flow



the geostrophic flow is along the lines of equal pressure
(and to the right of the pressure gradient force, i.e. westerly)

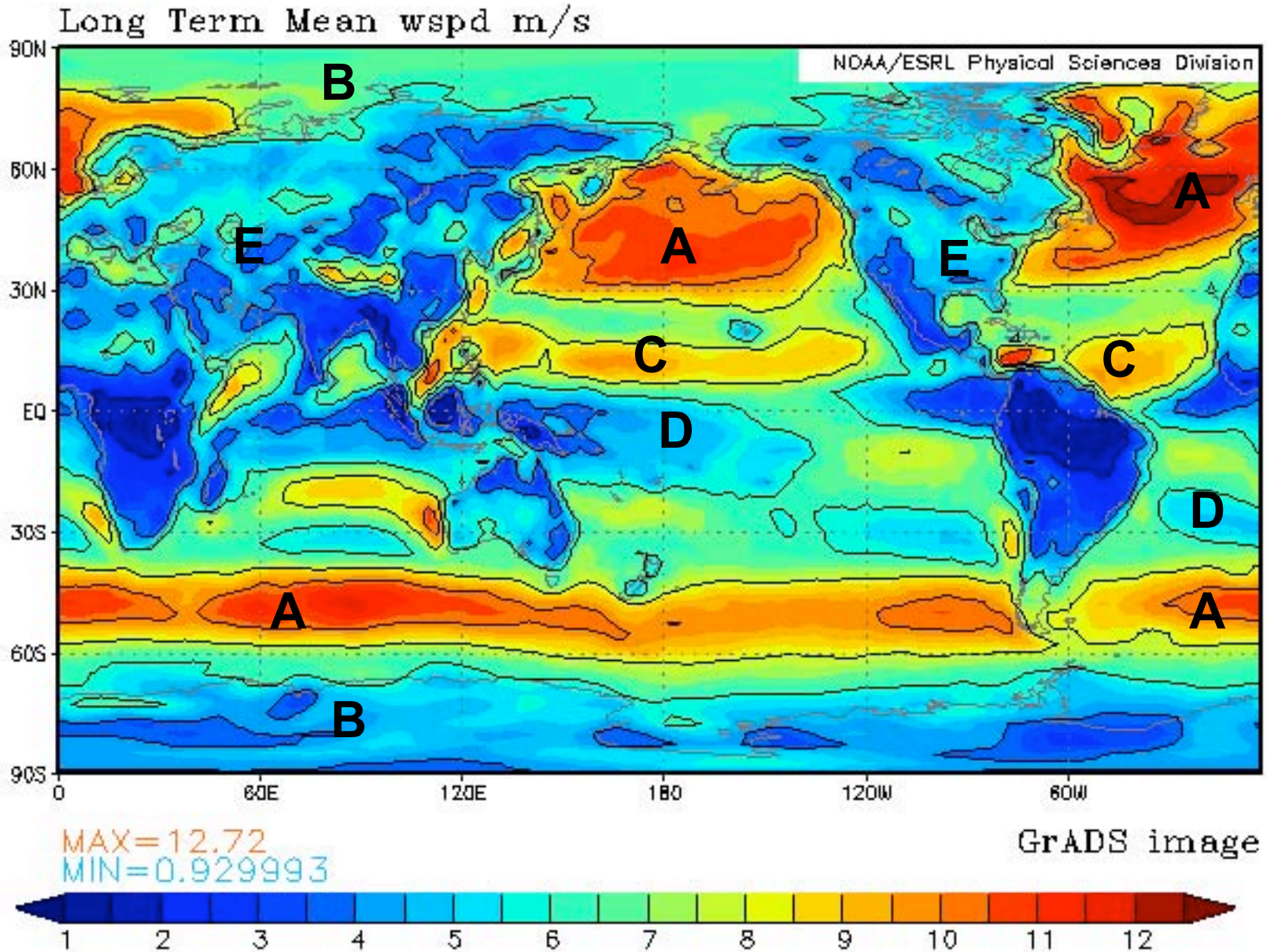
clicker question

In the Southern Hemisphere, the geostrophic wind (the bold black arrow) would best be represented by diagram….



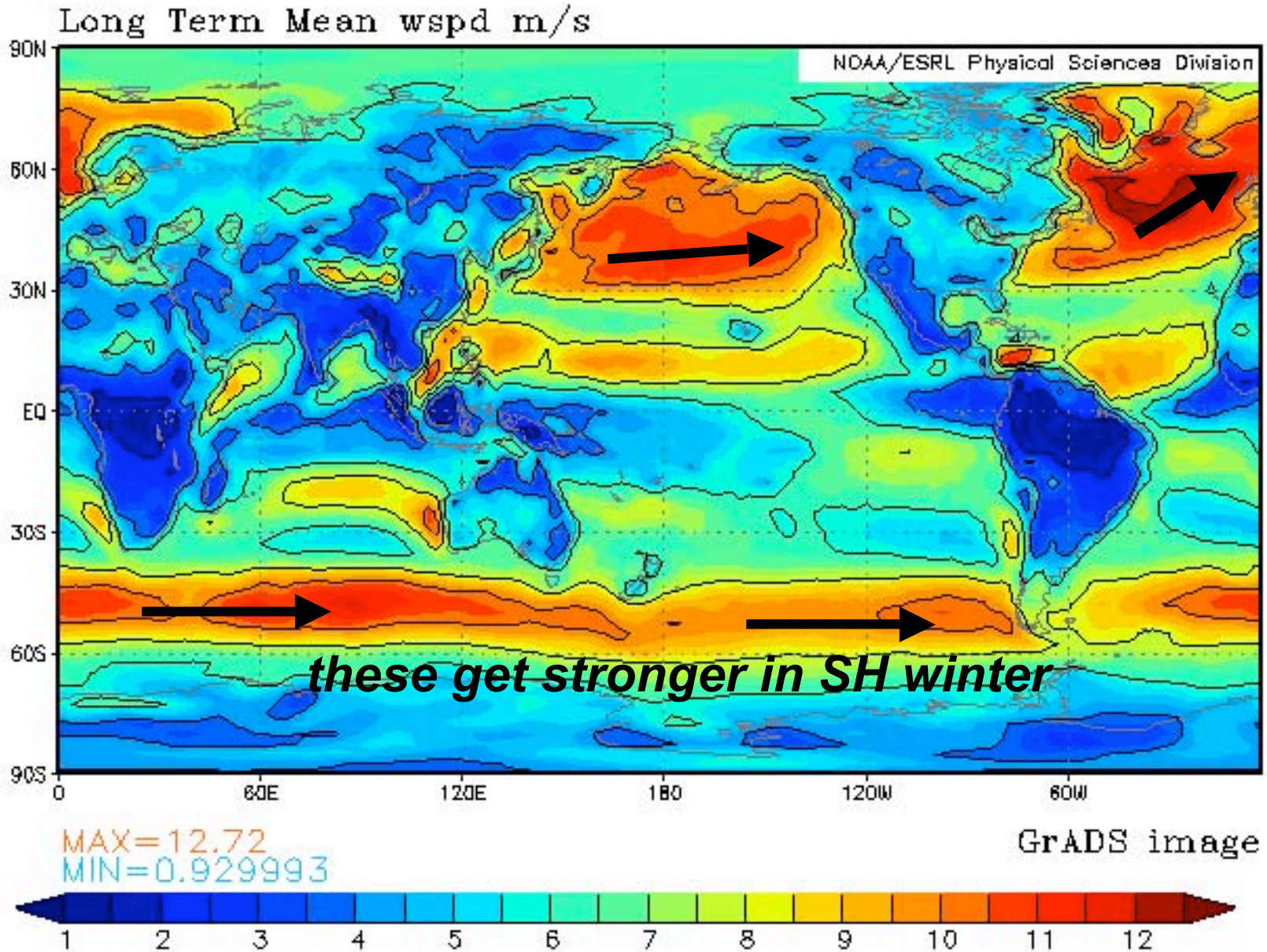
dashed lines are lines of equal pressure

global winds (Jan) clicker question:



Where are the strongest westerly winds? **A), B), C), D), or E)**

global winds (Jan)



the mid-latitudes are characterized by a strong westerly wind!

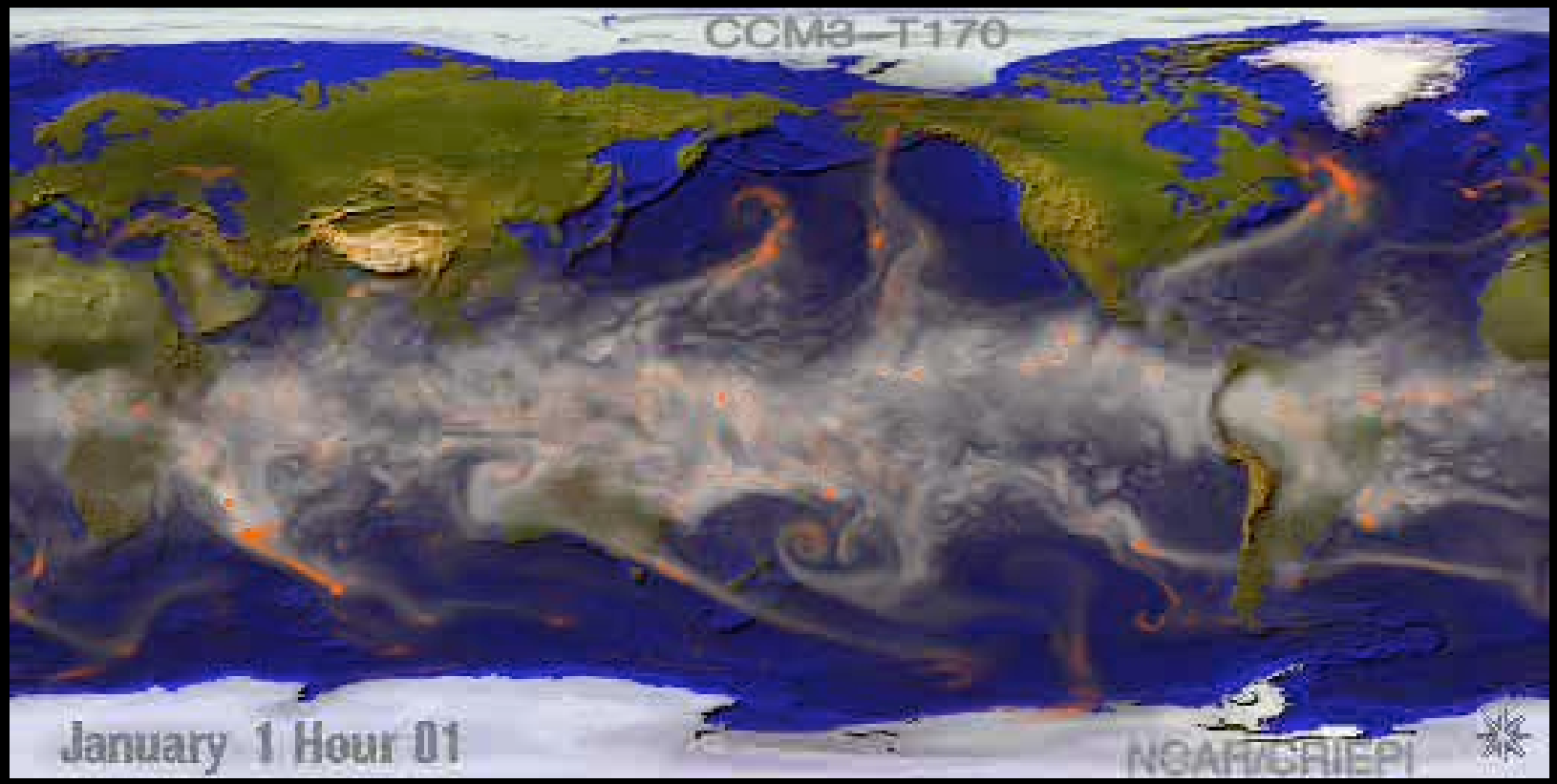
how to make weather!

- *heating in the tropics, cooling at higher latitudes*
- *the difference in heating causes a difference of pressure (i.e. a pressure gradient is formed)*
- *pressure force is balanced by Coriolis force to make westerly wind (so **no** energy is moved poleward beyond the edge of the Hadley cell…)*
- *heat and temperature continue to build up in the tropics, making the pressure force stronger*
- *finally, this can not be balanced by the Coriolis force, so the pile of air collapses (creating turbulence)*
- *since this occurs when the pressure force is stronger than the Coriolis force, we see spinning in the direction of the pressure force*
- *this is a cyclone! (we must have low pressure)*

This process carries <u>sensible</u> <u>heat</u> (i.e. temperature, or heat you can feel) and <u>latent</u> <u>heat</u> from the tropics toward the poles!

fr. D. Noone ATOC

global moisture transport

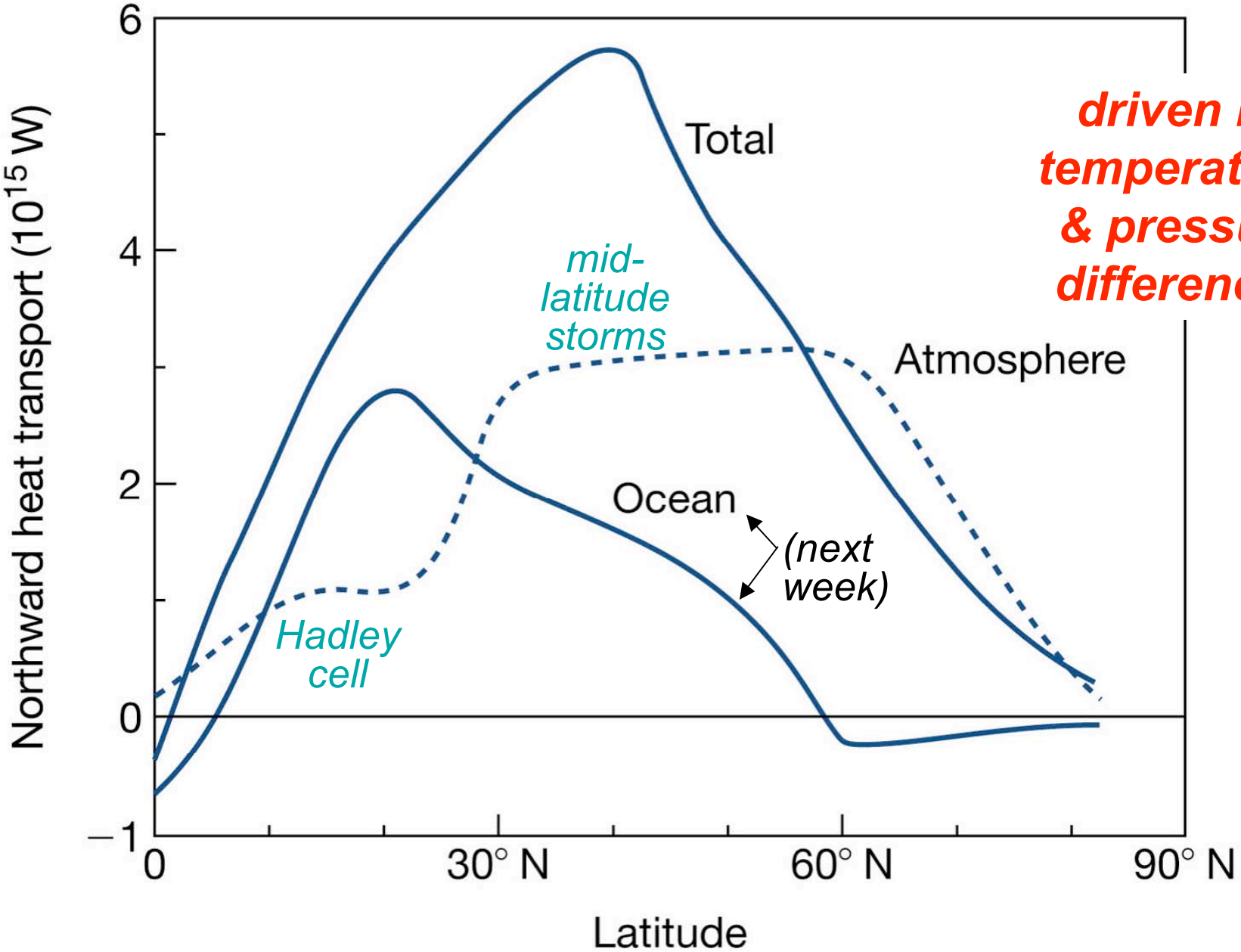


note turbulent rivers of moisture (along with sensible and latent heat) moving out of tropics to mid-latitudes

develop the circulation in animation at http://www.wereldorientatie.net/SWF/Het%20klimaat.swf

Note how it depicts heat leaving Hadley cell (as we just described)…

recall transport of energy (NH)



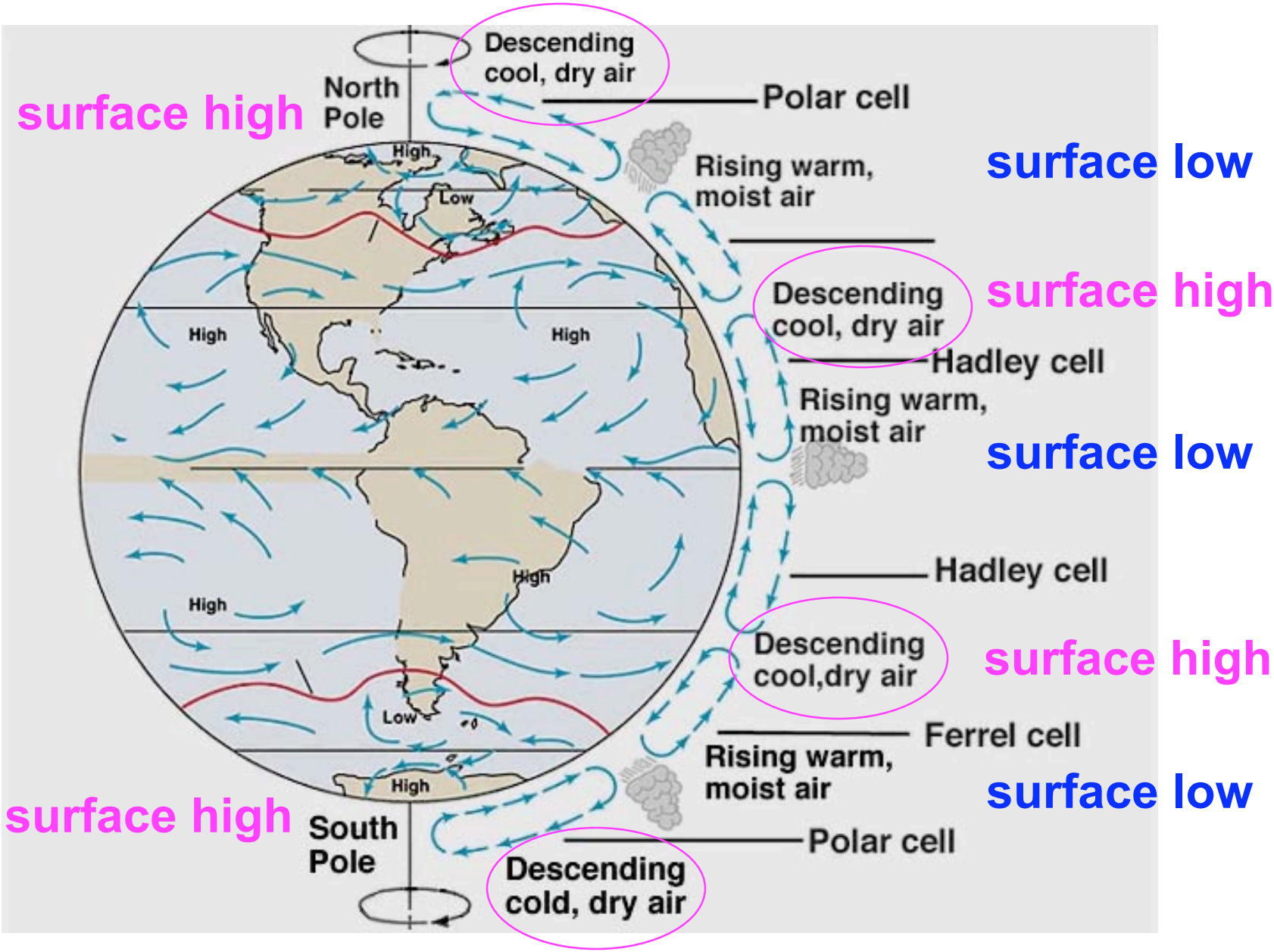
driven by temperature & pressure differences

regional climates

- regional climates are controlled by the general wind direction and the general rising and sinking of air

- i.e., by the “general circulation of the atmosphere”

surface press. v. vertical motions

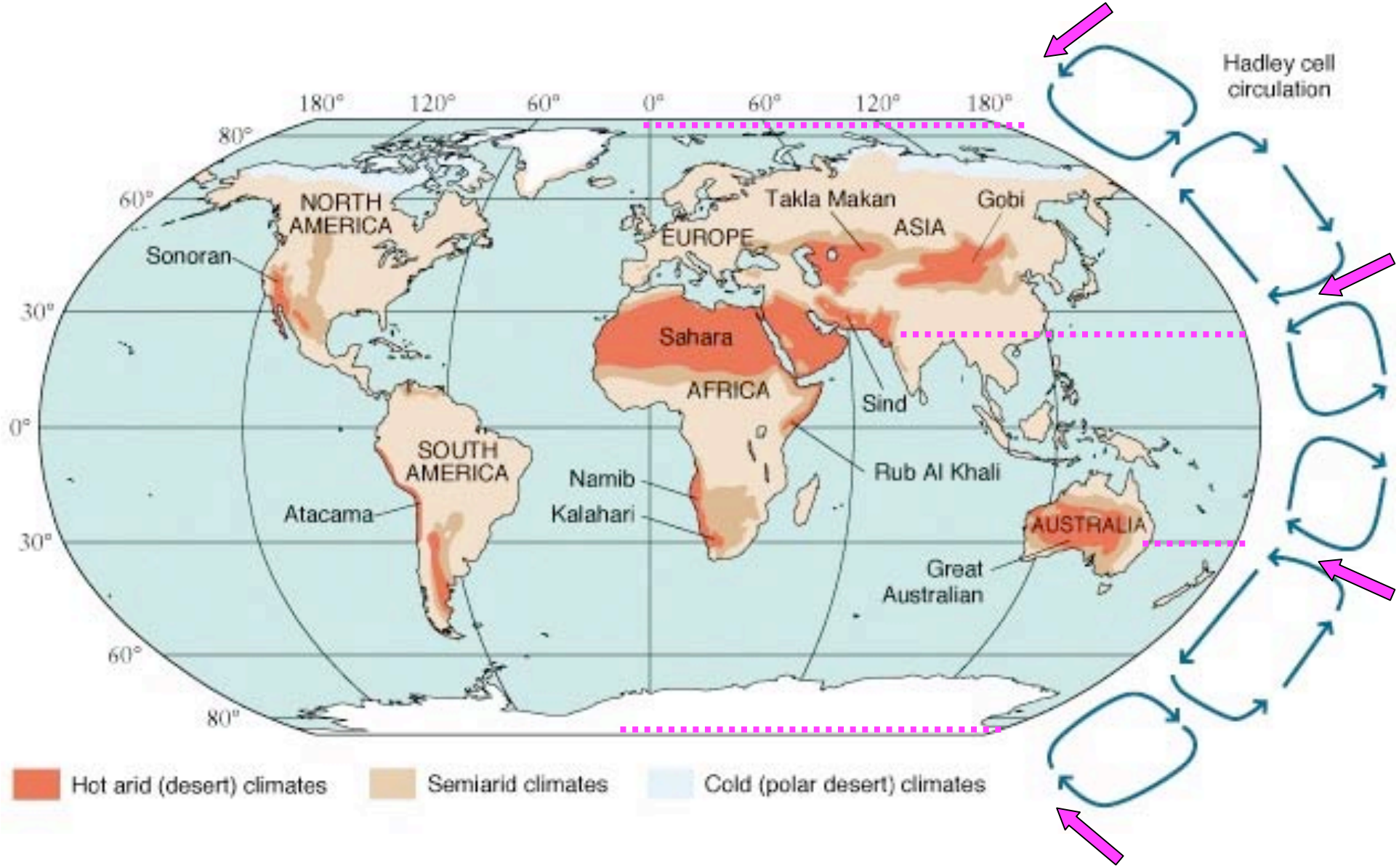


recall

- areas of subsiding or sinking air are characterized by dryness or aridity

- areas of converging air (and moisture) are generally wetter, with greater precipitation

arid regions (& subsidence)



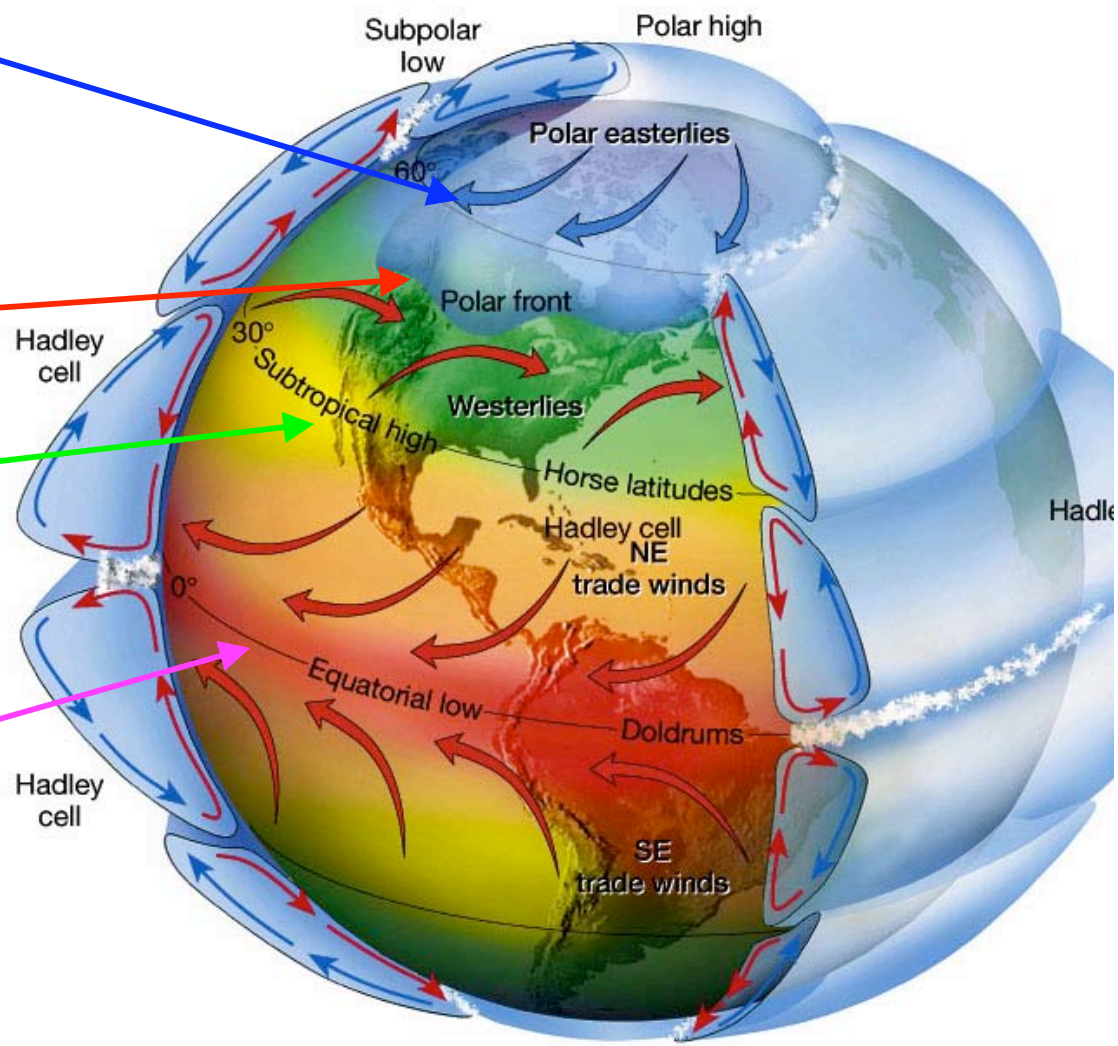
climate zones & surface winds

Polar regions – high pressure, surface divergence, descent, snow fall due to mid-latitude storms moving poleward, weak easterly wind.

Mid-latitudes – low pressure systems, surface convergence, ascent, rain associated with cold fronts, very strong westerly wind

Extra tropics – descending air, high pressure, surface divergence, few clouds low rainfall, almost no wind
(deserts, arid regions, the "doldrums")

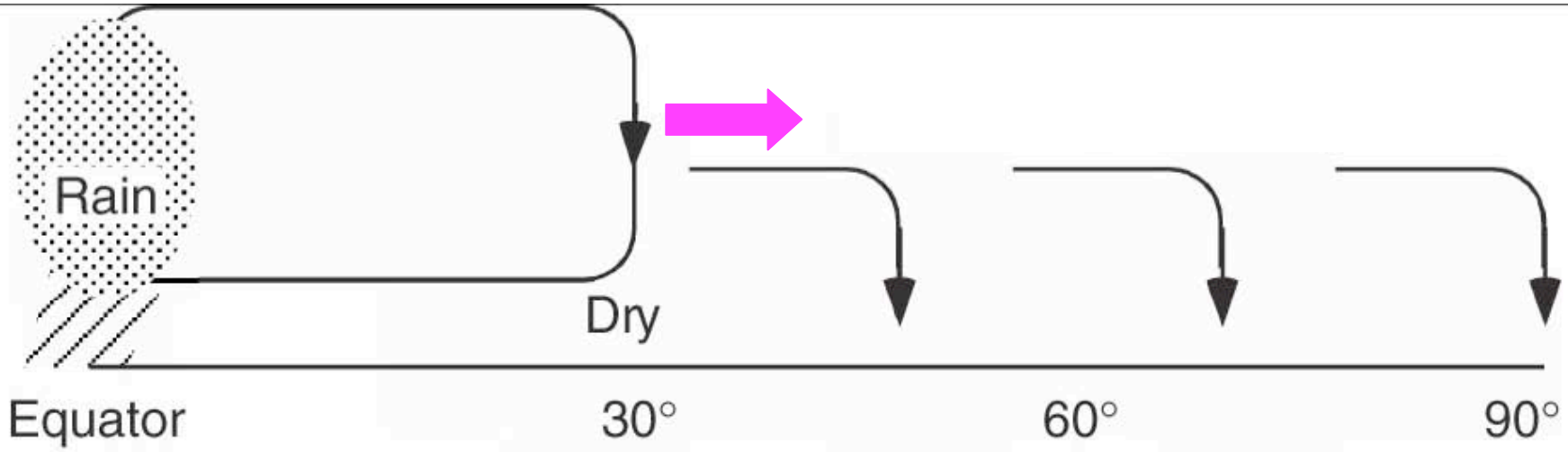
ITCZ – ascending air, low pressure, surface convergence, lots of clouds and rain fall, easterly winds
(lush rainforests, monsoons)



overview slide from Prof. D. Noone ATOC

a simple mechanistic forecast

(in response to heating due to greenhouse warming)



fewer but bigger storms?

more intense heating, more convection, rainfall and flooding

more descending dry air, more & longer drought

warmer, wetter, more snowfall

Archer

Feature

Text Size

NASA Finds Stronger Storms Change Heat and Rainfall Worldwide **03.09.06**

Studies have shown that over the last 40 years, a warming climate has been accompanied by fewer rain- and snow-producing storms in mid-latitudes around the world, but the storms that are happening are a little stronger with more precipitation. A new analysis of global satellite data suggests that these storm changes are affecting strongly the Earth's water cycle and air temperatures and creating contrasting cooling and warming effects in the atmosphere.

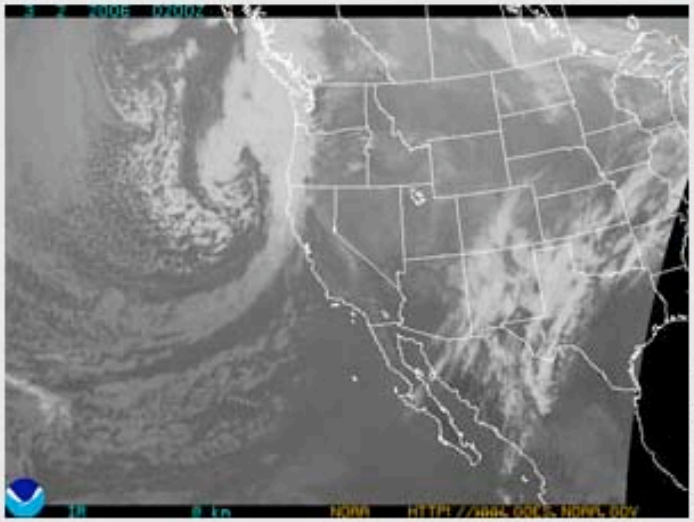


Image to left: Comma-shaped storm systems in the mid-latitude regions, like the one shown here on the Pacific Northwest coast, produce our everyday weather but also determine the radiation, heat, and water budgets of those regions. This image was taken from the Geostationary Operational Environmental Satellite, Thurs. March 2, 2006. Click on image to enlarge. Credit: NOAA

The mid-latitudes extend from the subtropics (approximately 30° N and S) to the Arctic Circle (66° 30" N) and the Antarctic Circle (66° 30" S) and include pieces of all of the continents with the exception of Antarctica.

George Tselioudis and William B. Rossow, both scientists at NASA's Goddard Institute for Space Studies (GISS) and Columbia University, New York, authored the study that appears in the January issue of the American Geophysical Union's journal, Geophysical Research Letters.

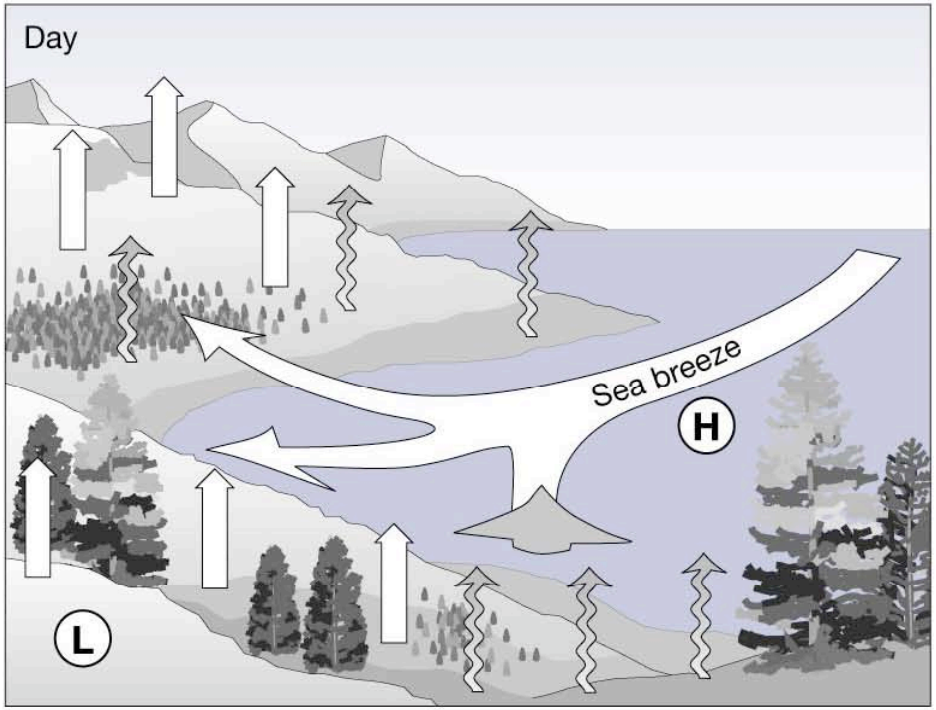
land-sea contrasts

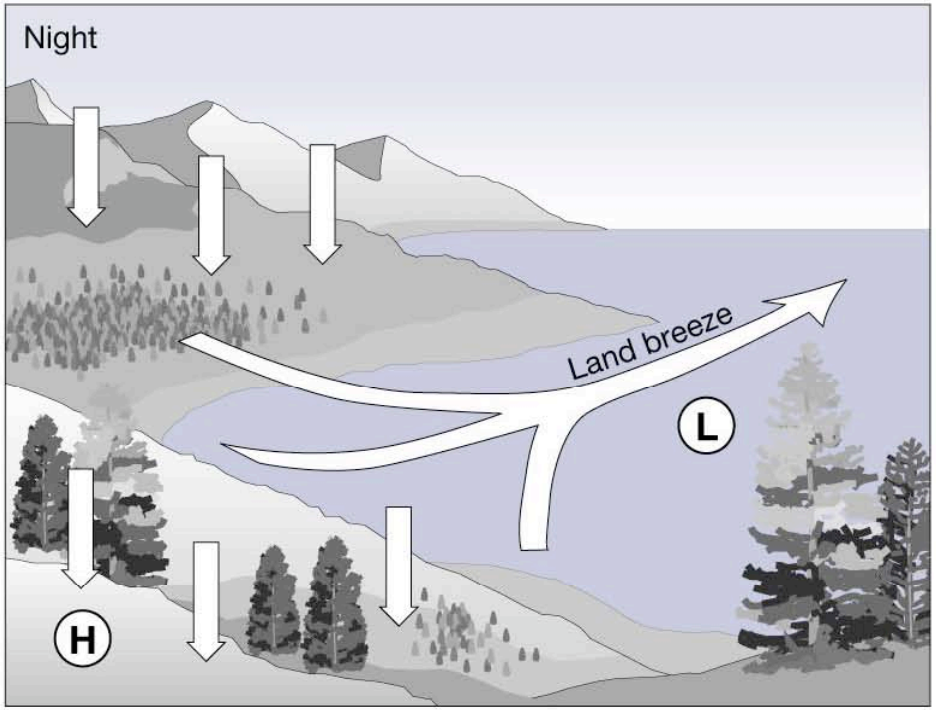
- recall horizontal motions of air arise from differential heating leading to gradients of pressure

- differential heating also creates vertical motions due to changes in buoyancy

- *what happens during the daily cycle of heating along the coast?*

daily land-sea contrast





land heats up faster for same energy input (from Sun) than does water, i.e. it has a much higher <u>heat capacity</u>

this leads to differential heating and assoc. movement of air (since land temp. can change quickly and ocean temp. does not)

heat capacity

- the rate of change of temperature as heat (energy) is added to a material

- a high heat capacity (like that of water) is associated with a small rate of temperature change as heat is added (and thus a greater heat storage)

clicker question:

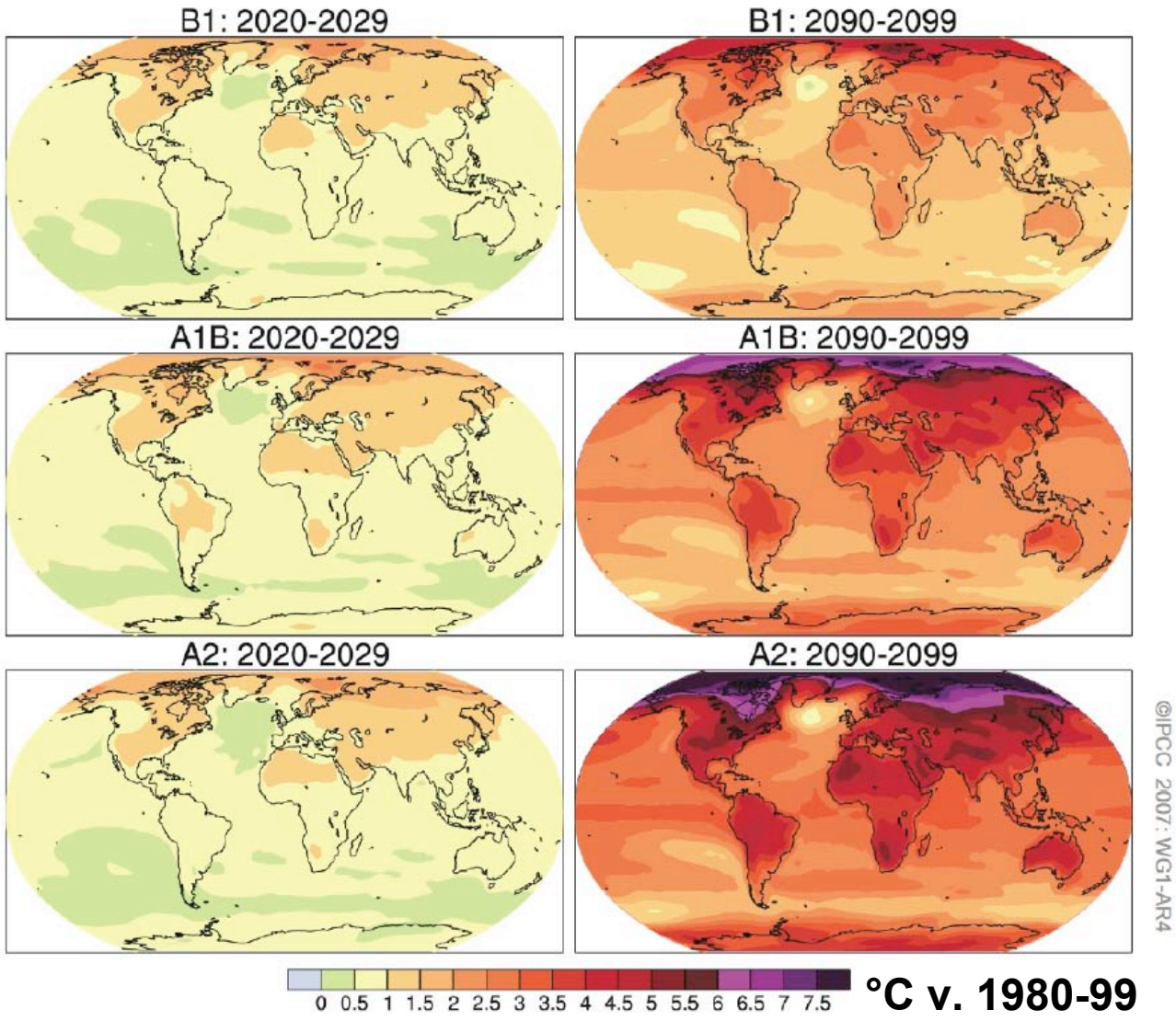
Since water has a high heat capacity, on timescales of years to decades, would you expect greenhouse warming to lead to:

a) more warming over the ocean than land areas

b) more warming over land areas than the ocean

c) the same amount of warming everywhere

latest from IPCC



multi-model decadal average temperature change projections for 2020-9 and 2090-9 for three different GHG growth scenarios

learning goals

- explain the roles of pressure force, the Coriolis effect and force balance in determining wind direction
- be able to predict the direction of the balanced or geostrophic wind flow with respect to the orientation of lines of equal pressure (and the pressure force)
- explain the influence of the general circulation on regional climate patterns (in terms of wind direction and speed, storminess, and rising or sinking of air)
- explain land - sea contrasts of heating
- define and make use of the concept of heat capacity (for ex., in predicting future patterns of warming)

key terms and concepts

- Heating and buoyancy
- pressure force
- Coriolis effect or “force”
- geostrophic or balanced flow
- heat capacity
- IPCC (Intergovernmental Panel on Climate Change) at http://www.ipcc.ch/