External forcing from the atmosphere

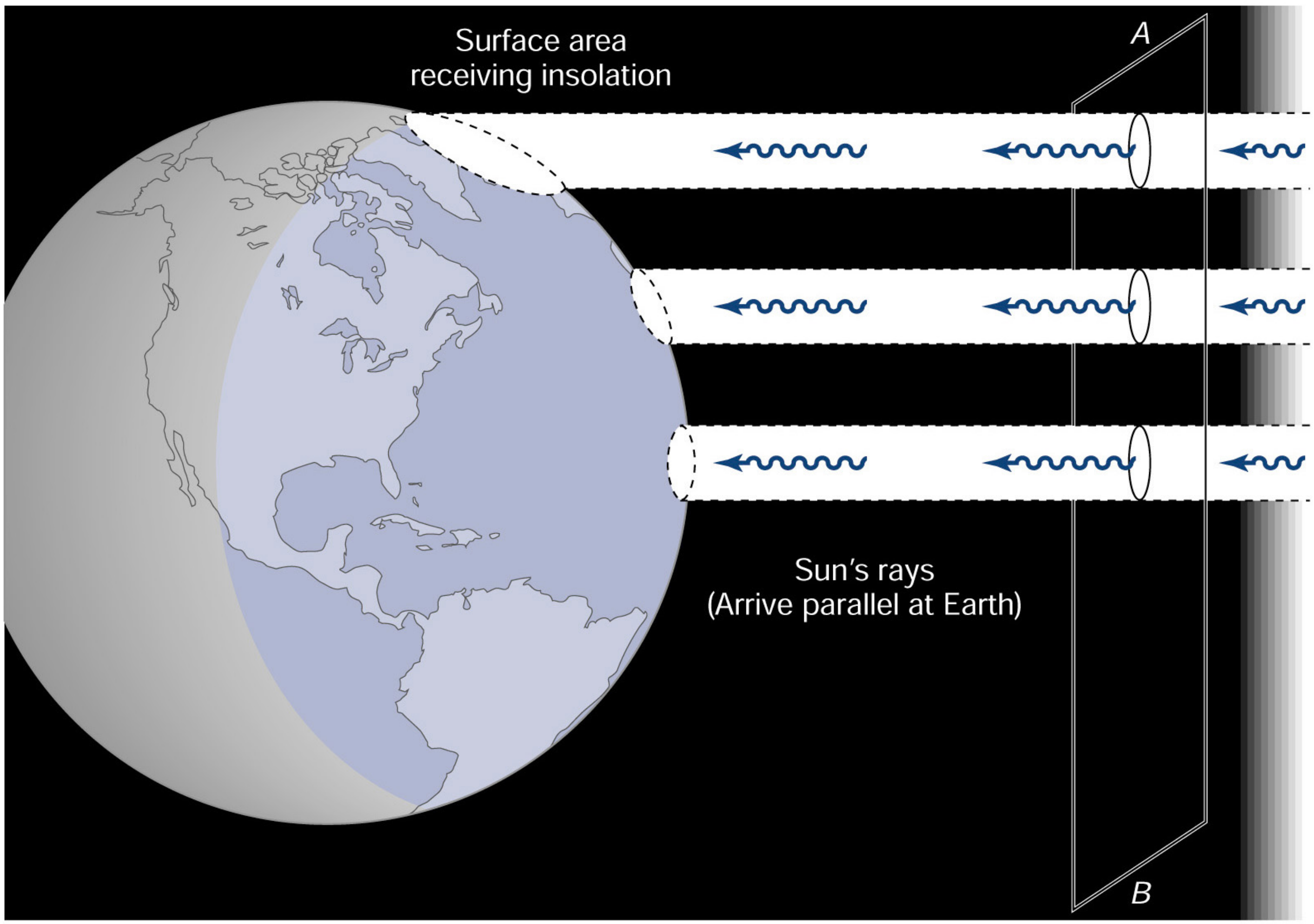
L. Talley, SIO 210 CSP Fall, 2016

Heating and cooling
Evaporation/precipitation and runoff
Wind stress

- Reading:
- Review DPO Ch. 5.3, 5.4
- DPO Chapter 5.7 (buoyancy flux), 5.8 (wind patterns)

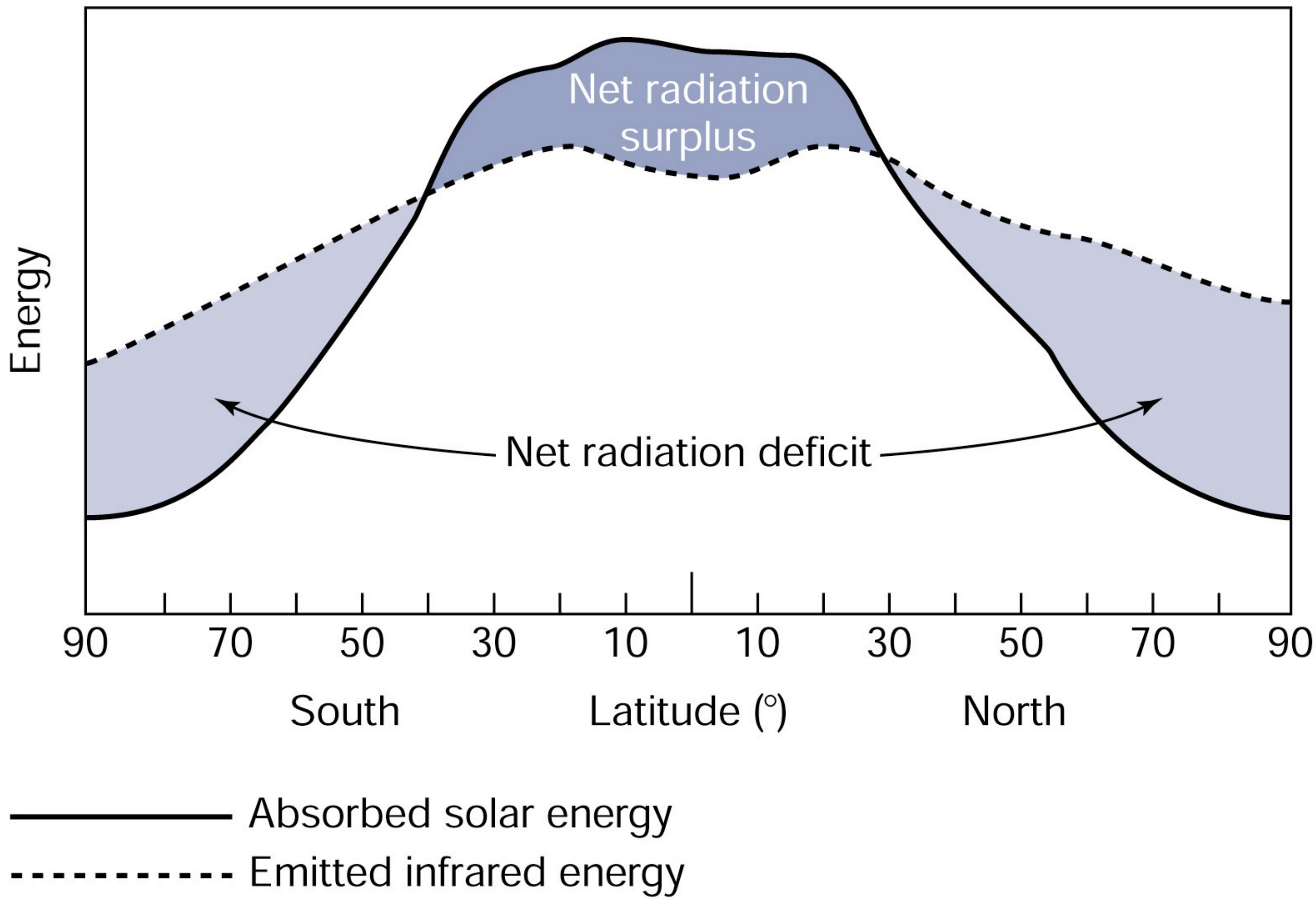
Global scale forcing: Solar radiation

More radiation reaches tropics than high latitudes, hence more heating in tropics than in high latitudes



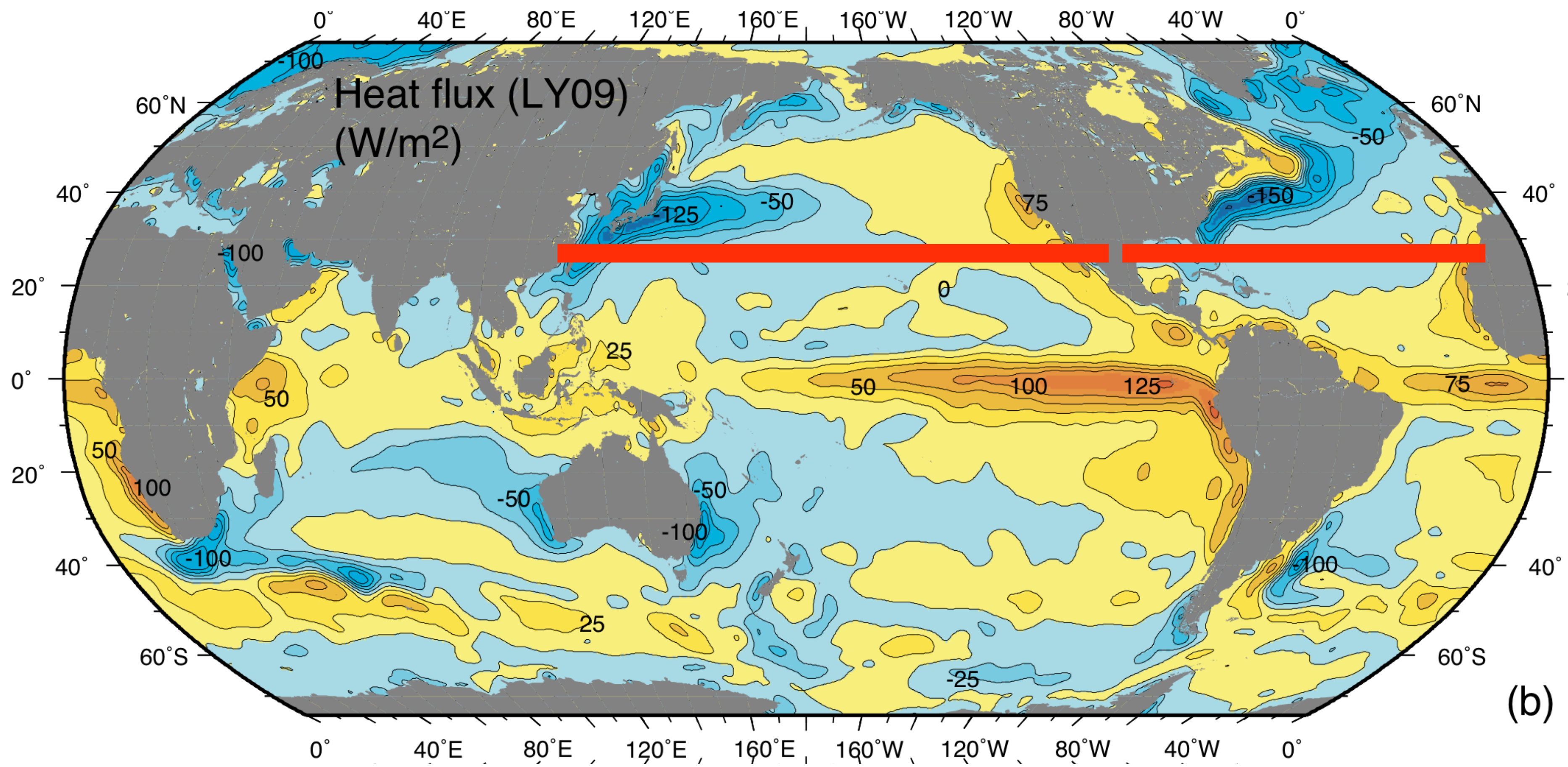
Kump, Kasting, Crane (2004) textbook

Global radiation balance - reasonable climate at mid to high latitudes because of winds (and ocean currents) that move heat



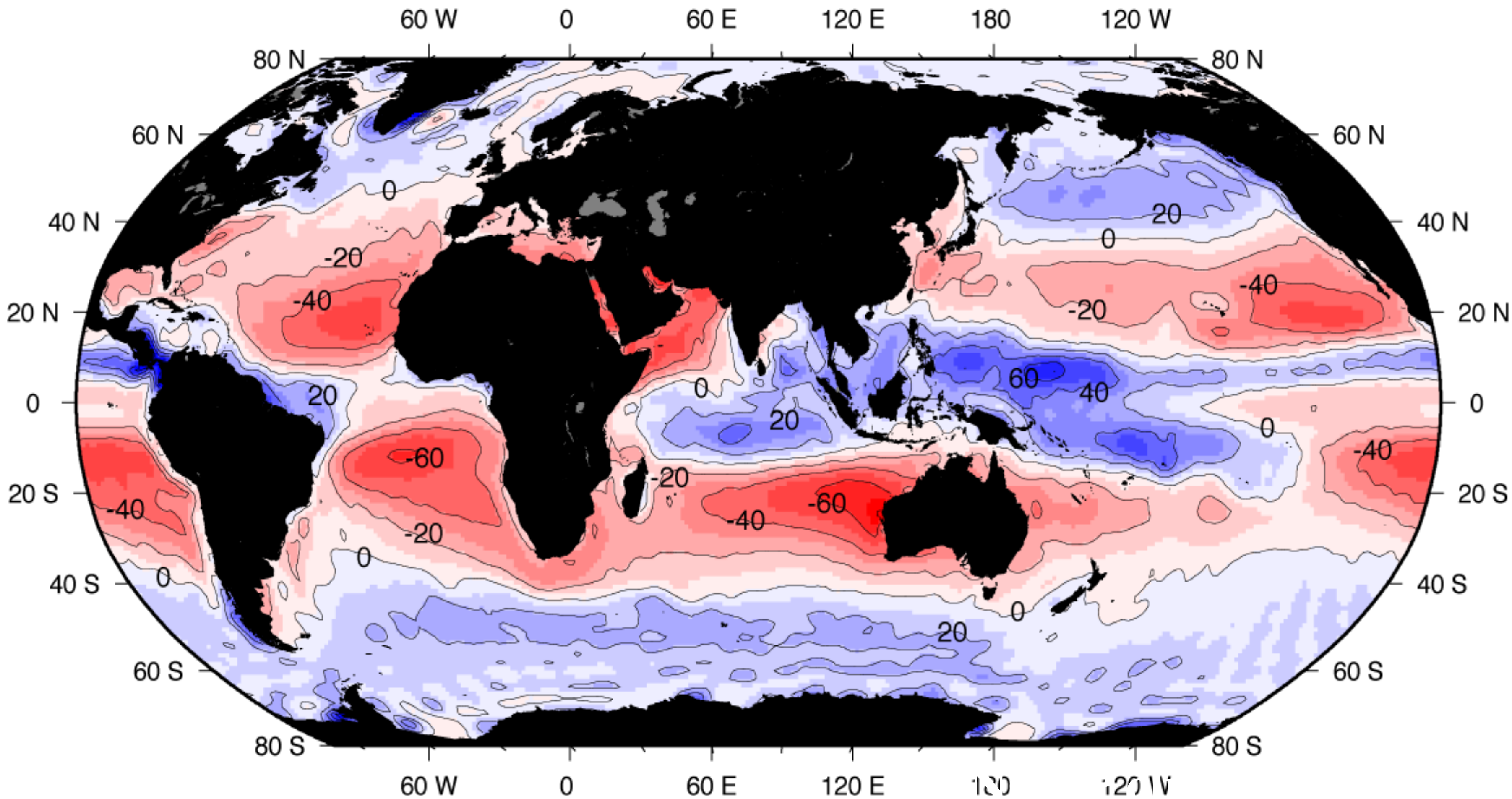
Kump, Kasting, Crane (2004) textbook

Net
Surface heat flux (W/m^2) into ocean



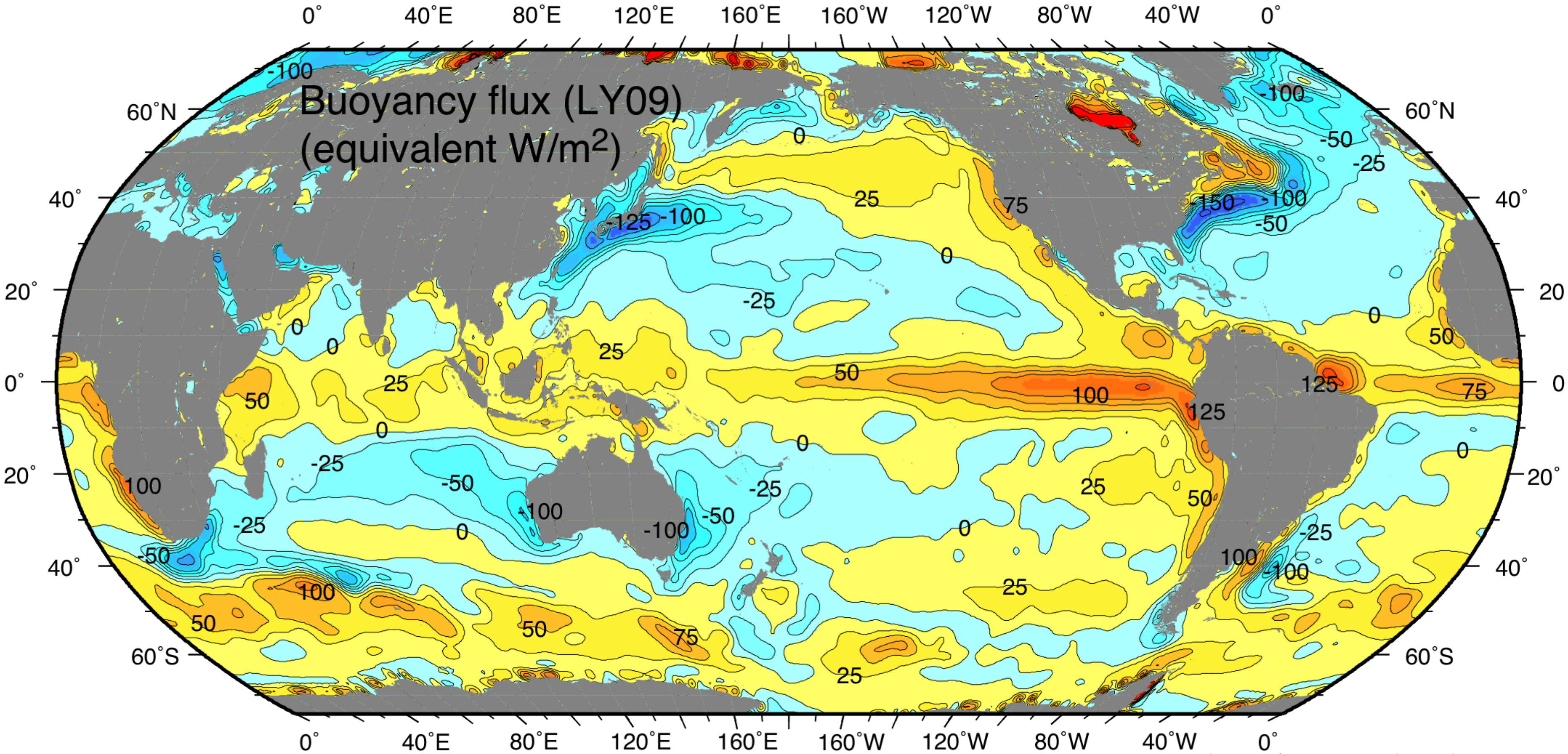
DPO Figure 5.12

Precipitation minus evaporation (runoff from land is not depicted)



Buoyancy flux

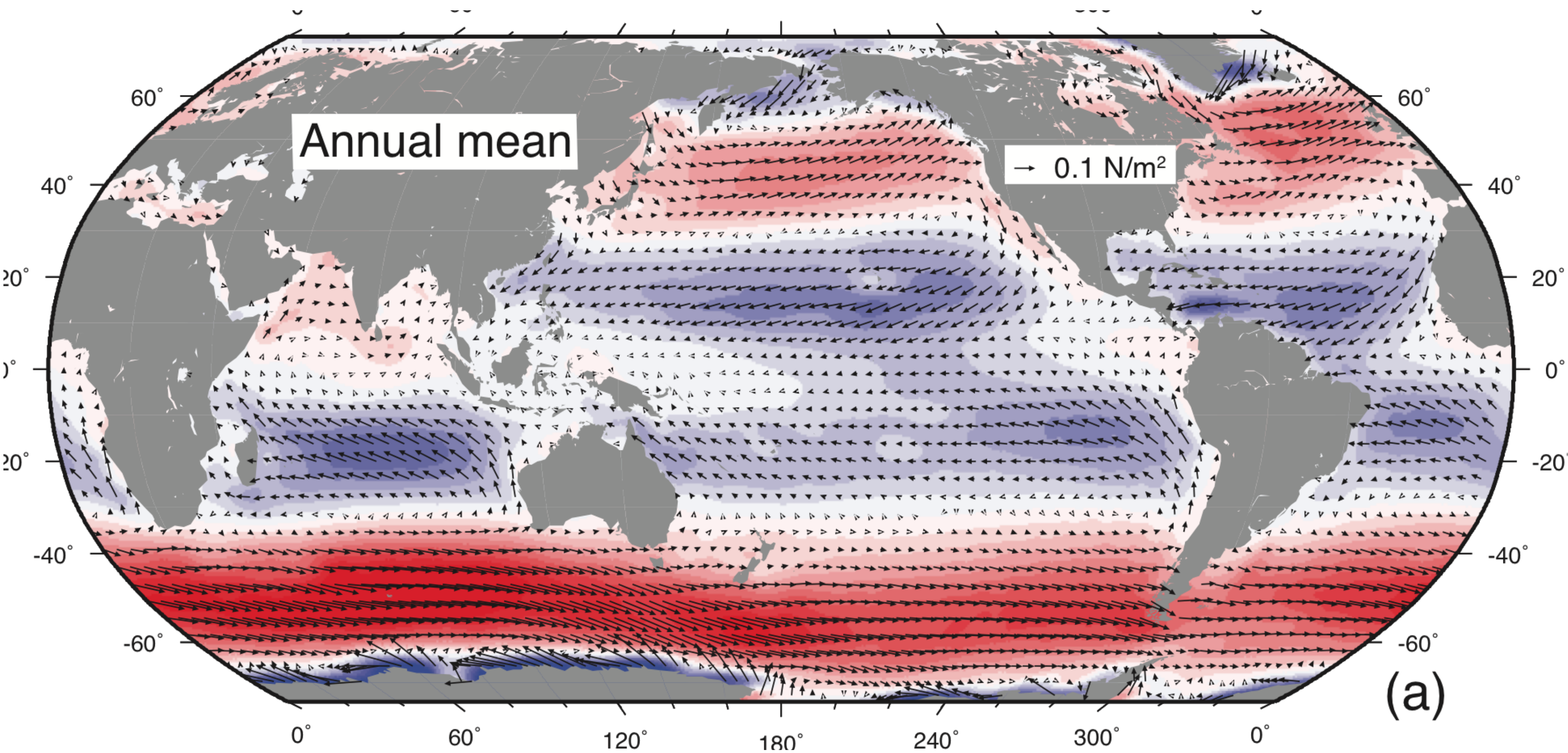
- Density is changed by buoyancy flux, which is the sum of heat and freshwater flux (changing temperature and salinity)
- Map is mostly related to heat flux, impact from E-P at high latitudes



DPO Figure 5.15

Surface wind stress (northern summer)

- Average wind speeds up to 10 m/sec (factor of 10 greater than ocean current speeds)
- Note westerlies and trades
- Monsoonal winds in Indian Ocean
- Look for monsoons in other tropical locations



DPO Fig. 5.16a

Atmospheric circulation

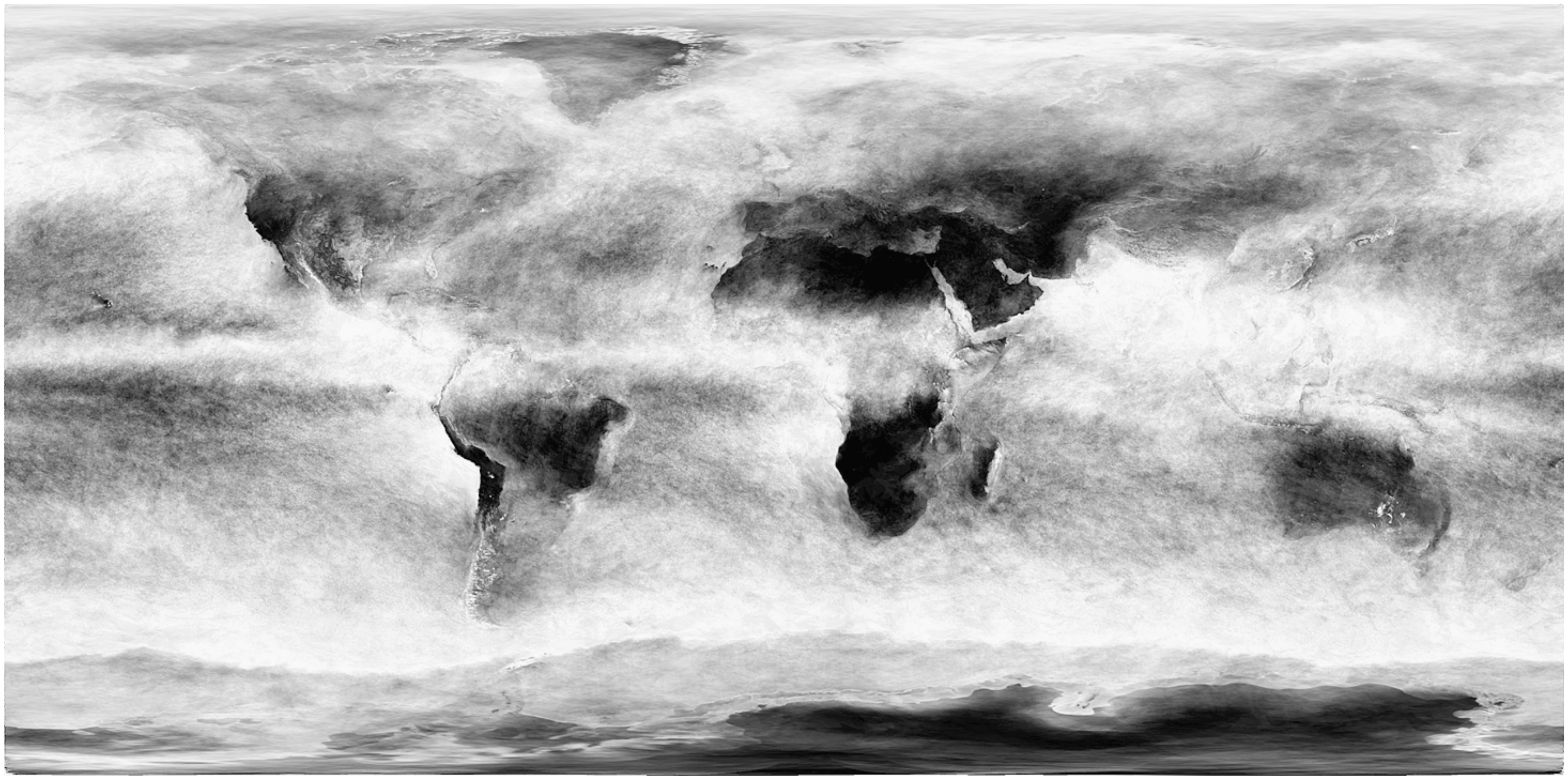
L. Talley, SIO 210 CSP Fall, 2016

- Vertical structure: troposphere, stratosphere, mesosphere, thermosphere
- Forcing: unequal distribution of solar radiation
- Direct circulation
  - Land and sea breeze
  - Monsoon
  - Equatorial: Walker circulation
- Mean large-scale wind and pressure structure
  - Hadley circulation
  - Jet Stream
  - Surface pressure
  - Surface wind stress

- Reading: Stewart Chapter 4
- Other: DPO Chapter 5.8 (for wind patterns)

Cloud cover

associated with sea level pressure
(low pressure = rising air - moist;
high pressure = sinking air – dry)

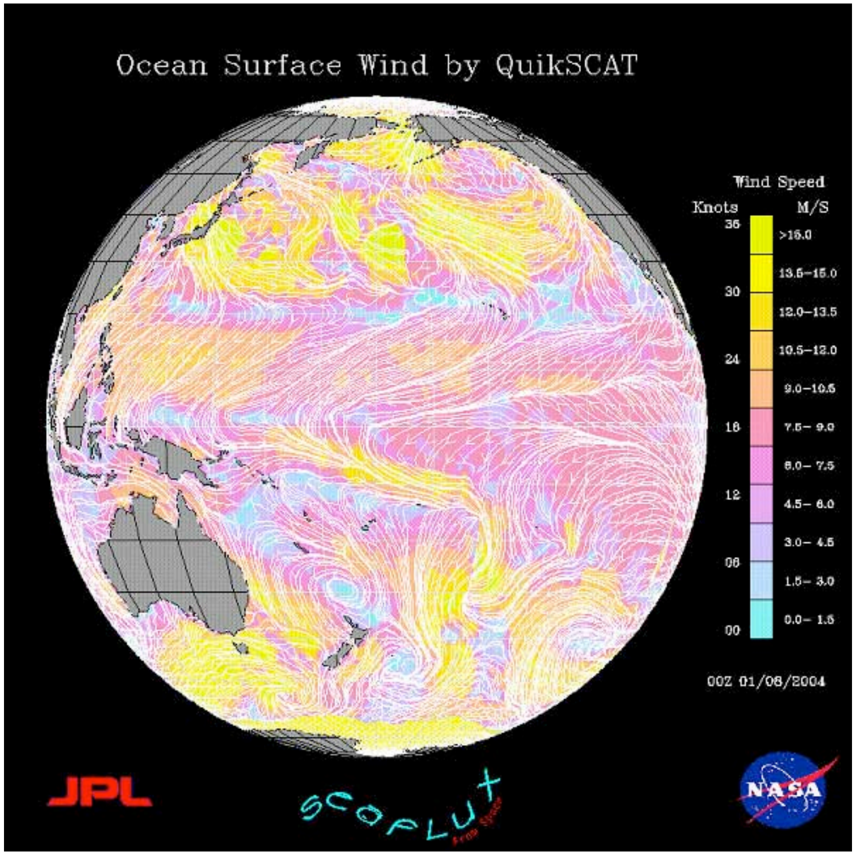


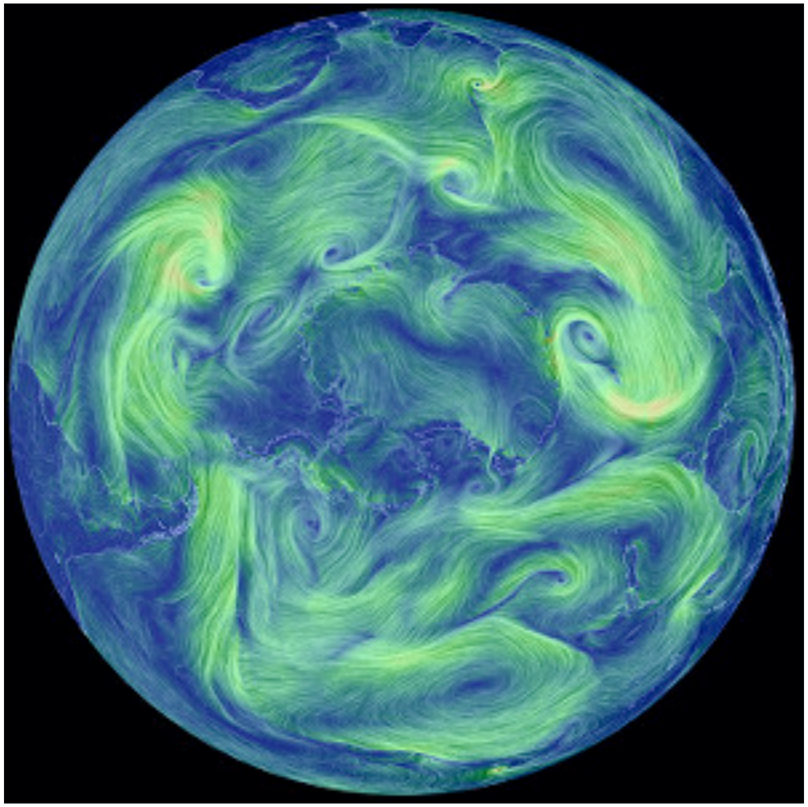
Cloud fraction (monthly average for August, 2010) from MODIS on NASA's Terra satellite. Gray scale ranges from black (no clouds) to white (totally cloudy). ***Source: From NASA Earth Observatory (2010).***

TALLEY

DPO Figure 5.8

NASA and computer wind products

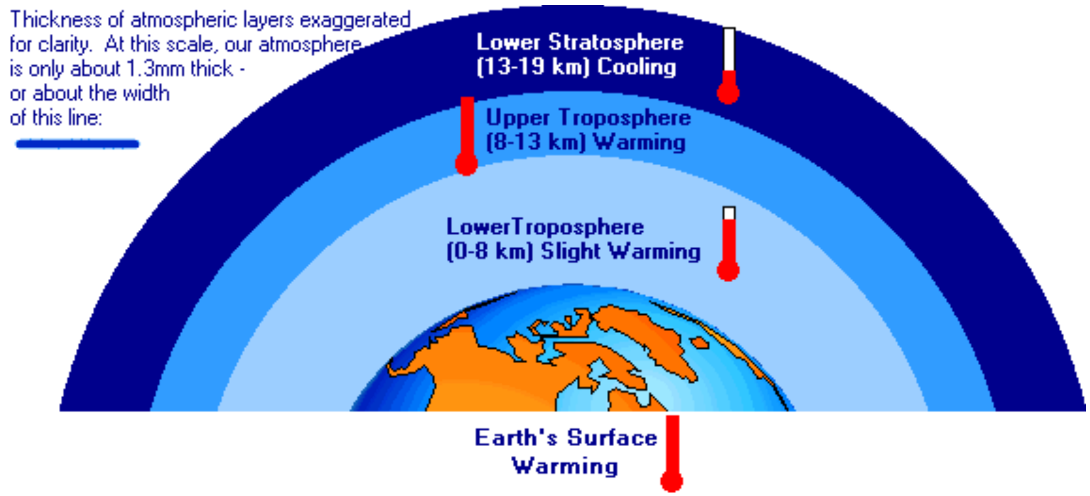




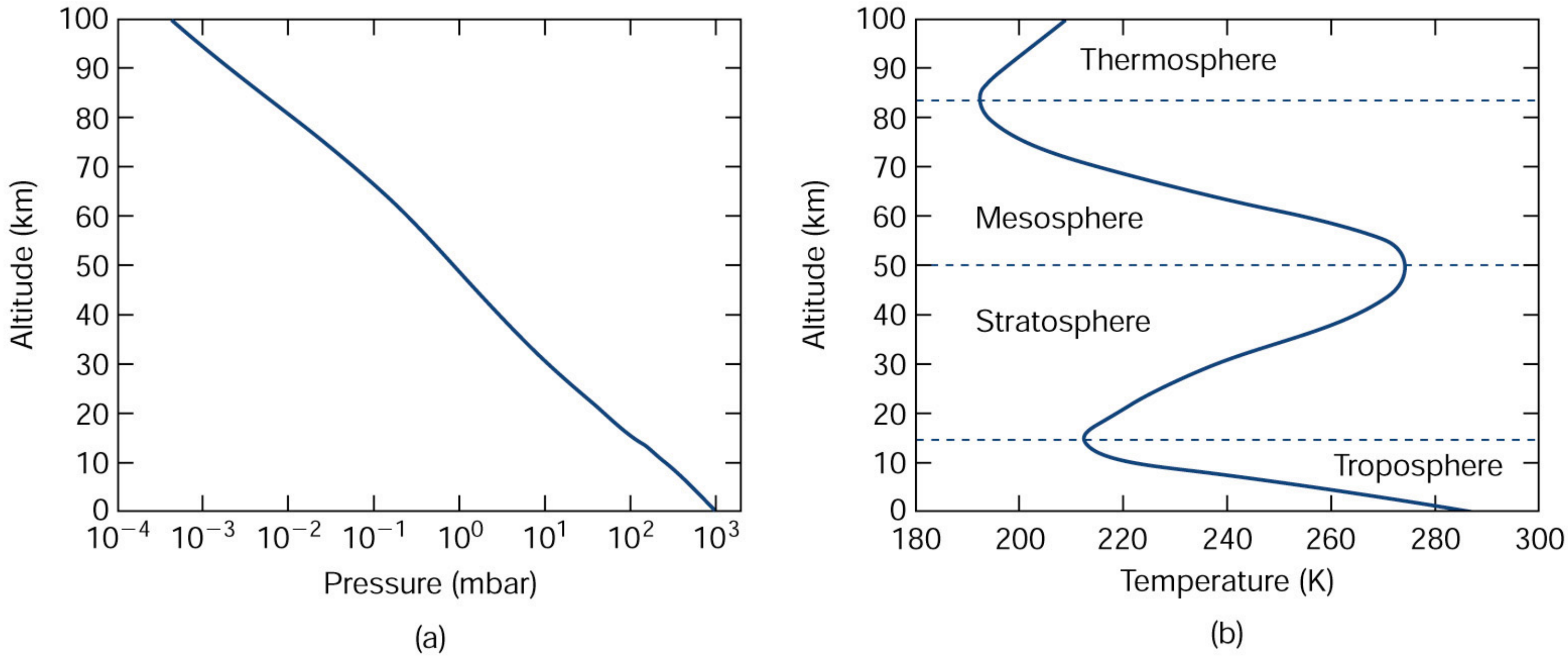
https://earth.nullschool.net/about.html

https://winds.jpl.nasa.gov/

Atmosphere structure



From NASA Science site

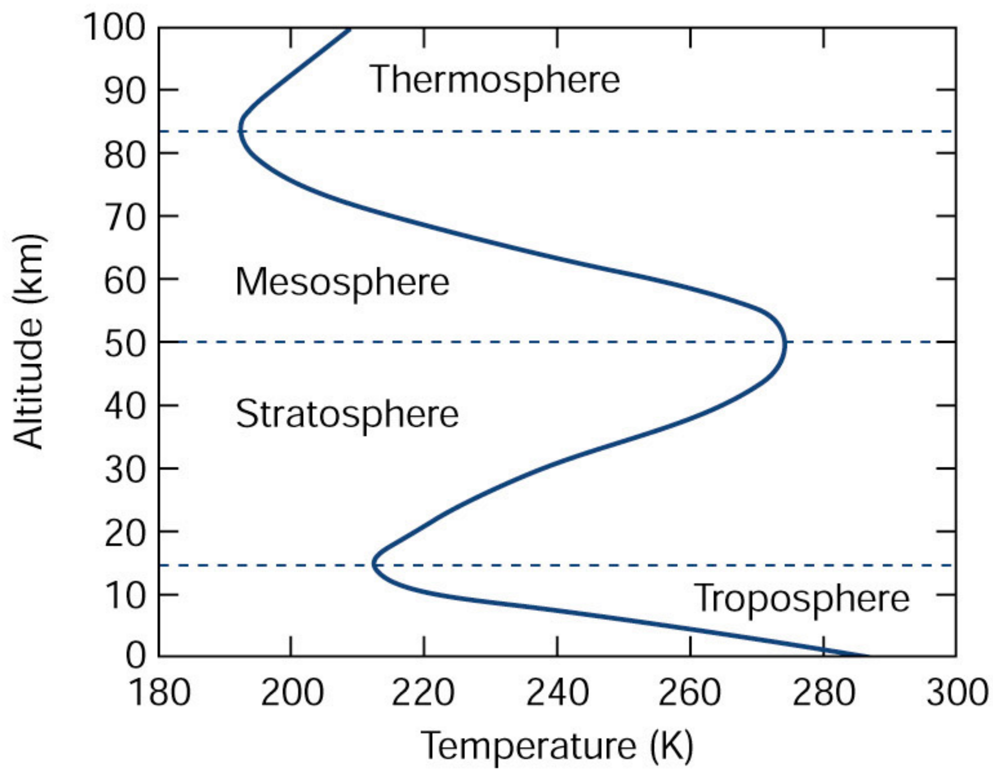


Kump, Kasting, Crane (2004) textbook

Atmospheric temperature structure

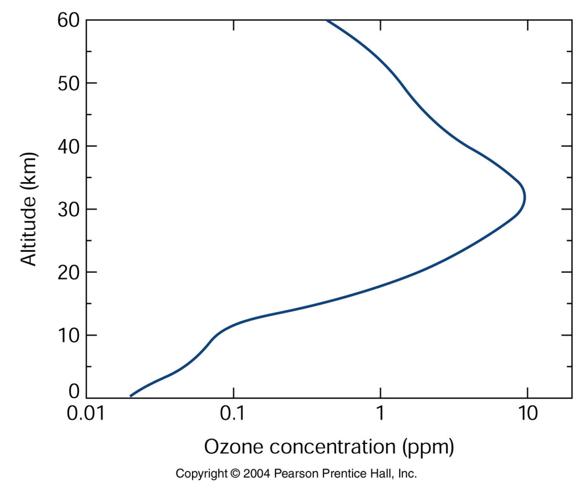
Troposphere: nearly uniform potential temperature so temperature drop with height is nearly adiabatic

Stratosphere is warmest at top: due to absorption of the sun's UV radiation. (The ozone maximum is in the middle of the stratosphere.)



(b)

Also see http://earthguide.ucsd.edu/earthguide/diagrams/atmosphere/index.html



Kump, Kasting, Crane (2004) textbook

Adiabatic lapse rate and potential temperature

Air is compressible (much more so than water). Thus the effects of compressibility on temperature are much the same as we've already learned for the ocean.

Adiabatic lapse rate Γ:

$$\Gamma_d = -(dT/dz)_{\text{dry parcel}} = g/c_p$$

where subscript d = dry, using the 1st law of thermodynamics to relate temperature and pressure change, and then using hydrostatic balance.

In dry atmosphere, adiabatic lapse rate is 9.8 °/km

In moist atmosphere, adiabatic lapse rate is 6 to 7 °/km

Potential temperature: reference level is the ground, taken as 1000 mbar.

Winds

- Winds are forced mainly by heating from the earth's surface below.
- Air rises in warmer locations.
- (As it rises, if over the ocean, it tends to carry moisture and cause precipitation.)
- Because it has much higher specific heat, water temperature varies much more weakly with given surface heat flux than does land (since dirt includes both water and lower-specific-heat air).
- With diurnal or seasonal forcing of adjacent land and sea, the sea temperature varies a little and the land temperature varies a lot This creates diurnal or seasonal reversals of locations of rising air in the atmosphere ("seabreeze" and "monsoon")
- "Direct circulation": wind (or current) blowing from high to low pressure

Direct circulation

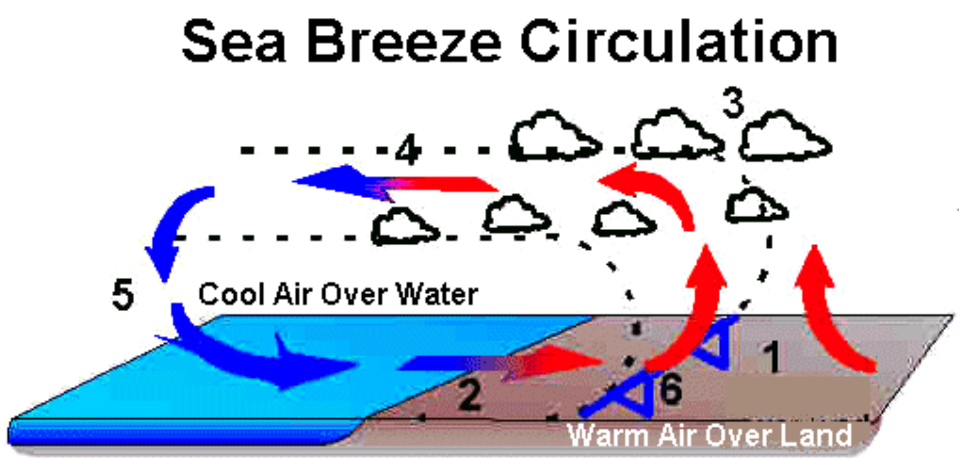
•"Direct circulation": wind (or current) blowing from high to low pressure. Rotation effects are either negligible or relatively unimportant

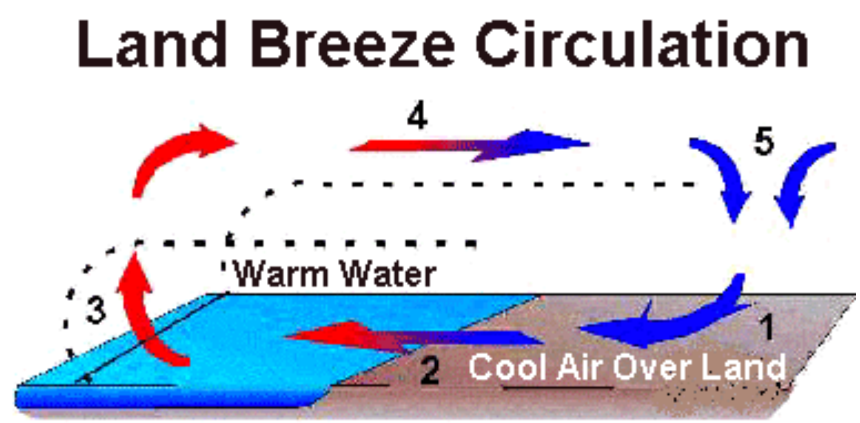
•Examples presented here:

1. Diurnal winds (sea and land breeze, driven by land-sea temperature contrast)
2. Monsoonal winds (seasonal, driven by land-sea temperature contrast in the tropics where rotation is a minor factor)
3. Walker circulation (permanent, equatorial atmospheric circulation driven by zonal SST contrast)

Wind response to differential heating: Diurnal - Land and sea breeze

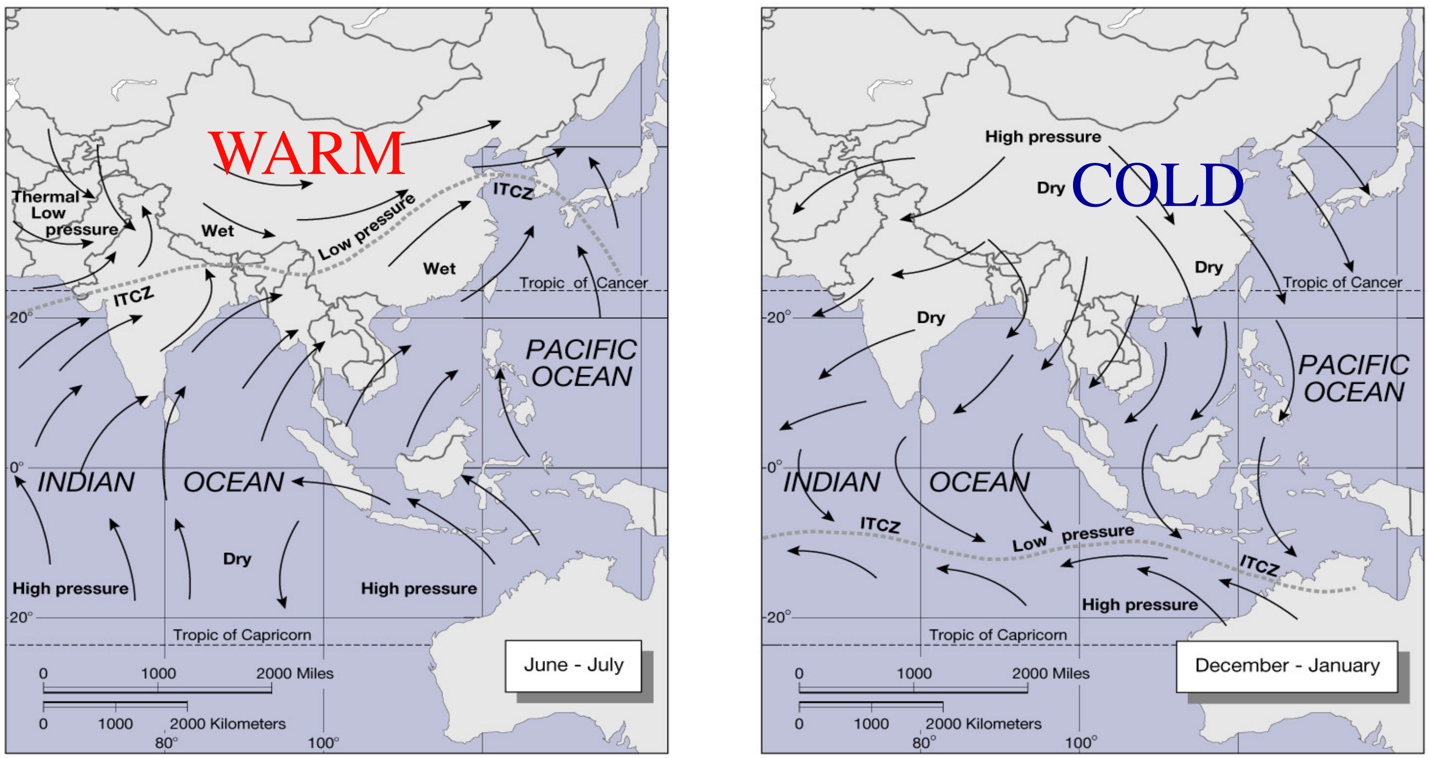
- Diurnal cycle of heating and cooling
- Land temperature extremes are much larger than ocean temperature extremes through the daily cycle (because the specific heat of water is so high compared with air and dirt)
- Hot-cold contrast creates upward convection in the air above the warm area (land in the day, ocean in the night), and sinking over the cooler area





Wind response to differential heating:
Seasonal - Monsoons

- Same idea as diurnal sea breeze: ocean seasonal temperature range is much smaller than land seasonal temperature range. Rising air over warmer area and sinking over cooler, modified by Coriolis deflection
- “Direct circulation” driven by differences in heating and cooling

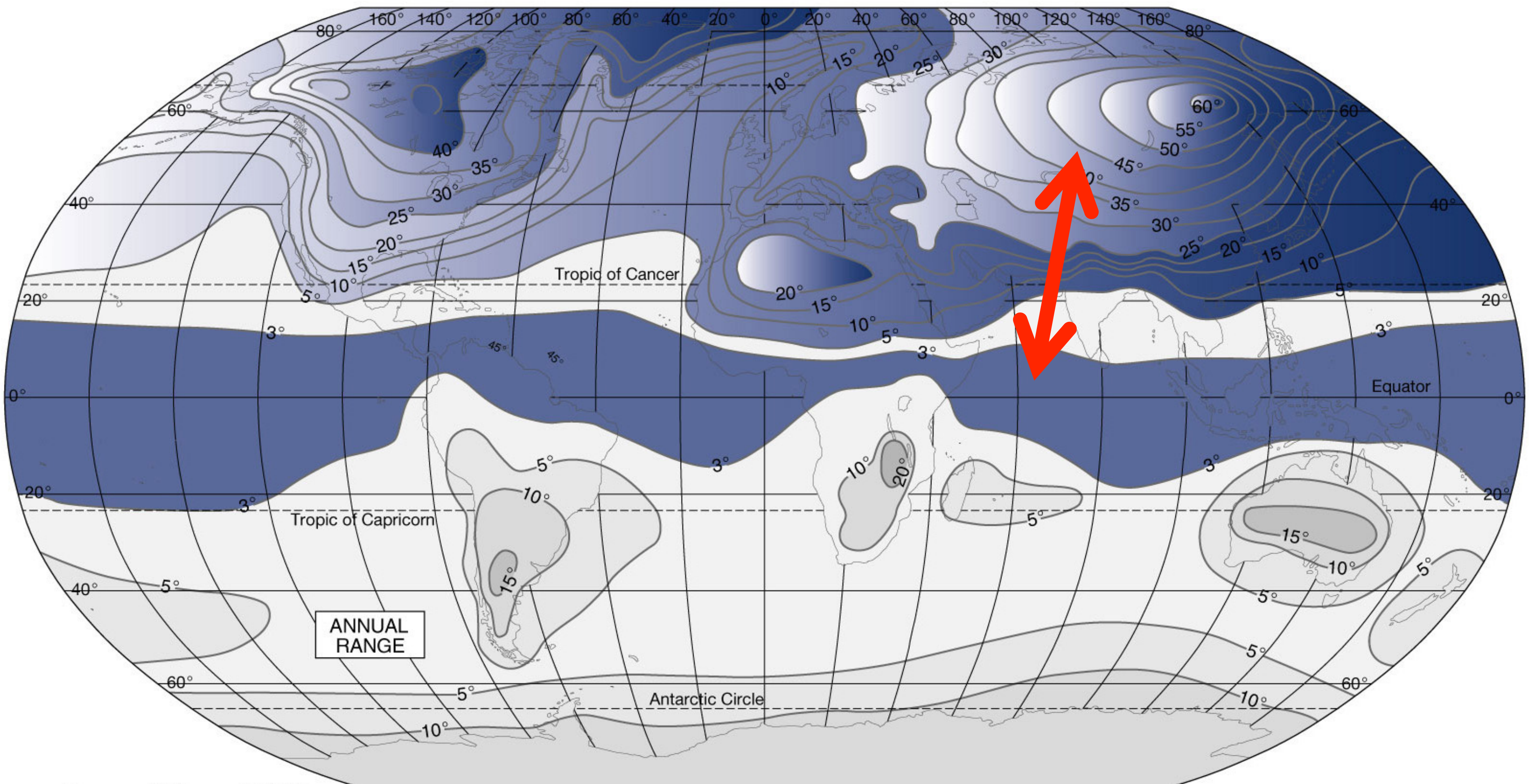


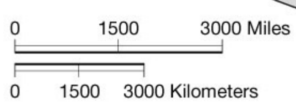
(a) (b)

Northern hemisphere summer Northern hemisphere winter

Kump, Kasting, Crane (2004) textbook

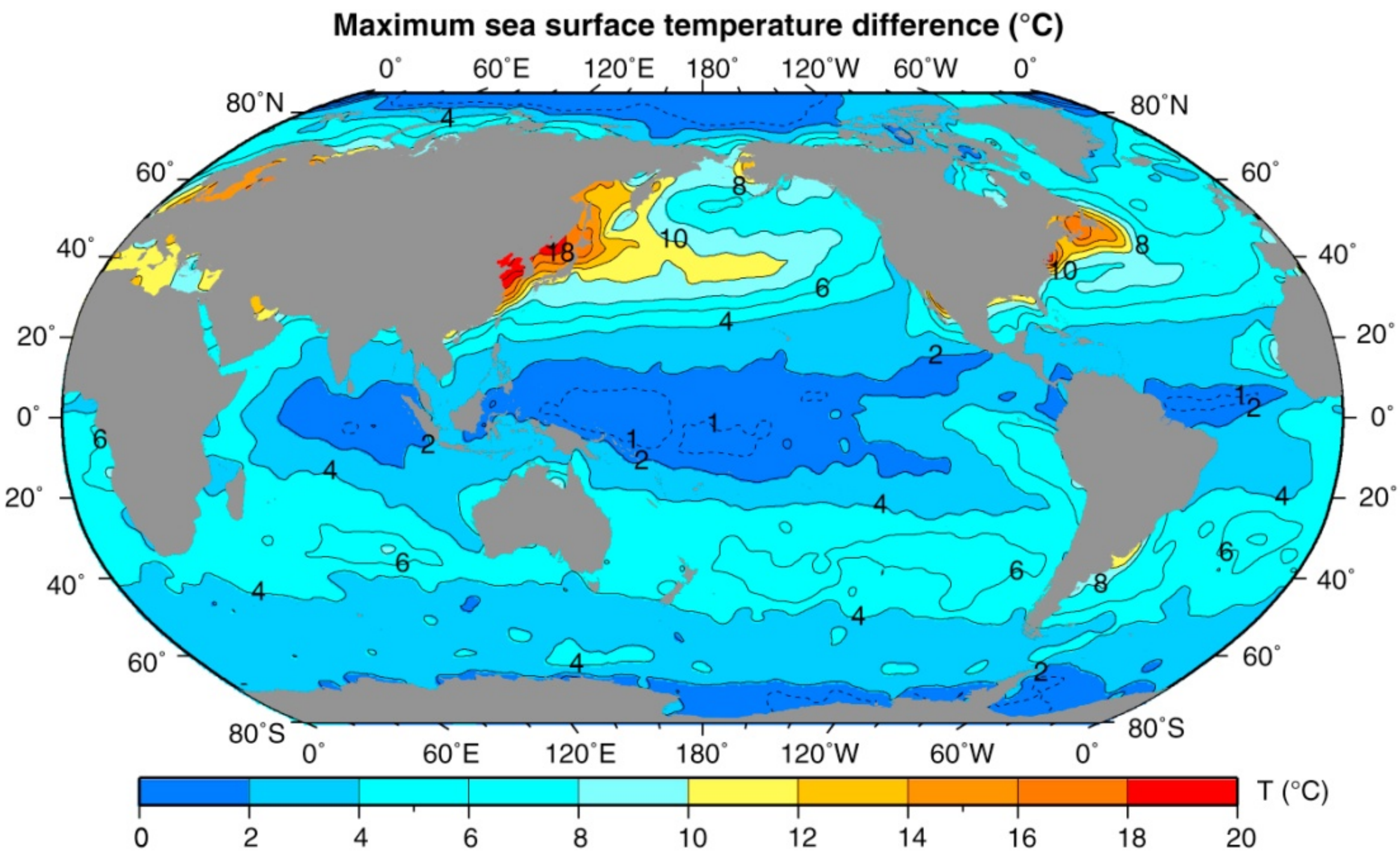
Annual range of surface temperature (°F)





F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

Kump, Kasting, Crane (2004) textbook

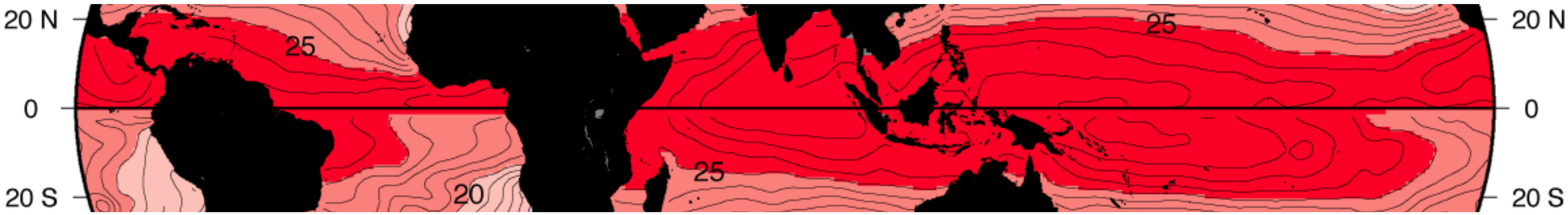


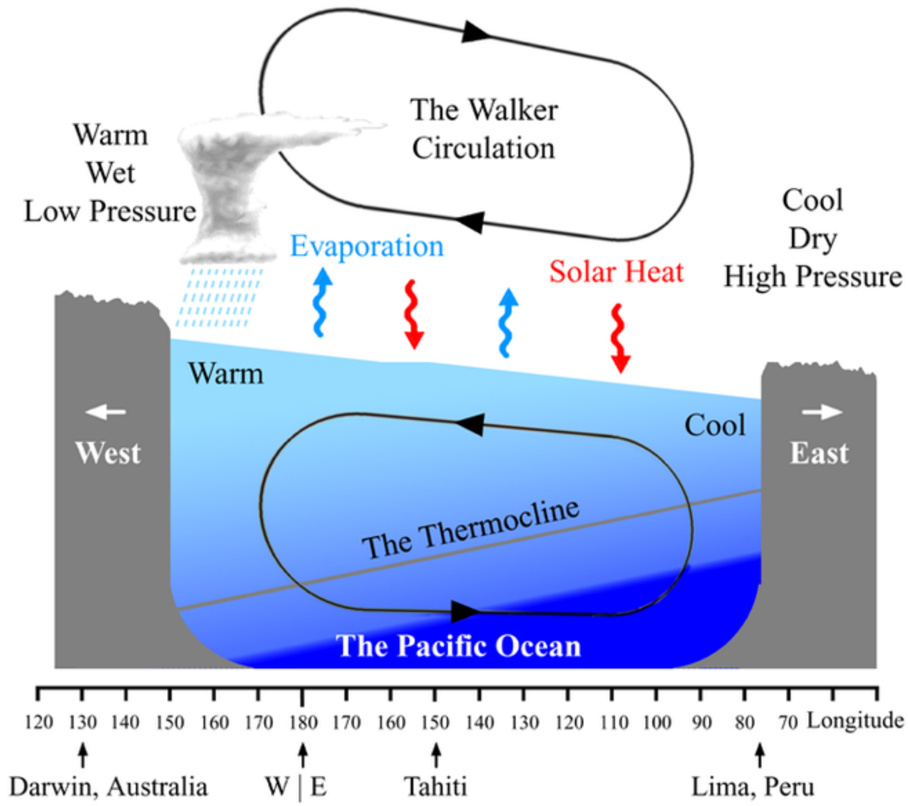
Can see that monsoon is not driven by the SST annual range in the Arabian Sea– has to be the land annual range. Monsoon: SST remains relatively constant while land temperature goes through large annual cycle.

Annual range of sea surface temperature (°C), based on monthly climatological temperatures from the World Ocean Atlas (WOA05) (NODC, 2005a, 2009).

DPO Fig. 4.9

Equatorial winds: Direct atmospheric circulation
Walker circulation: (Coriolis not important as f ~ 0)



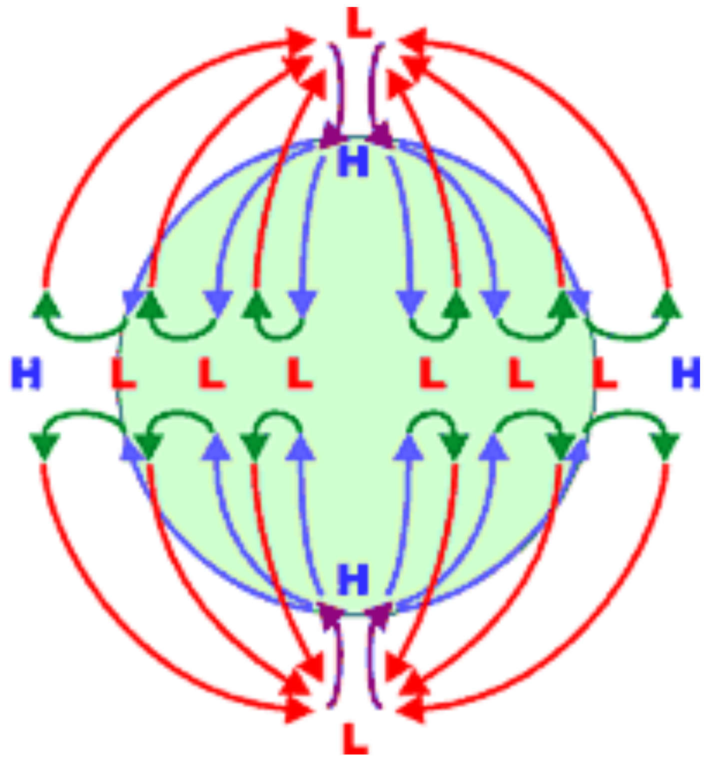


"Bjerknes feedback" between the ocean and atmosphere. Warm water causes air to rise, creates wind, that sets up currents, that causes SST contrast.

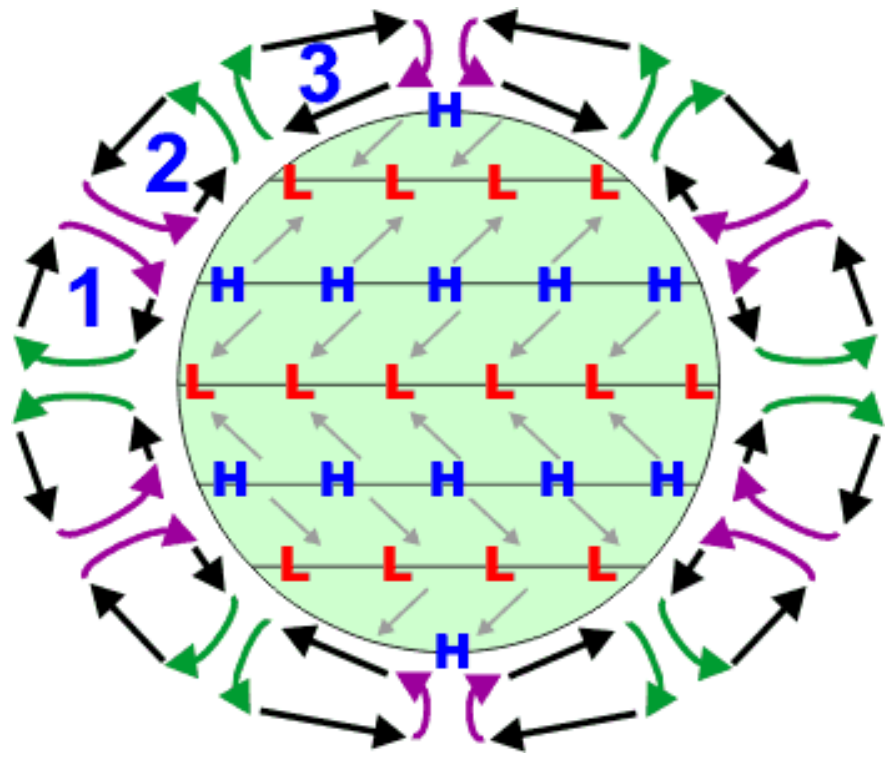
Mean large-scale wind and pressure structure

Convection and subsidence, in response to global heating and cooling

What we might expect from global heating and cooling

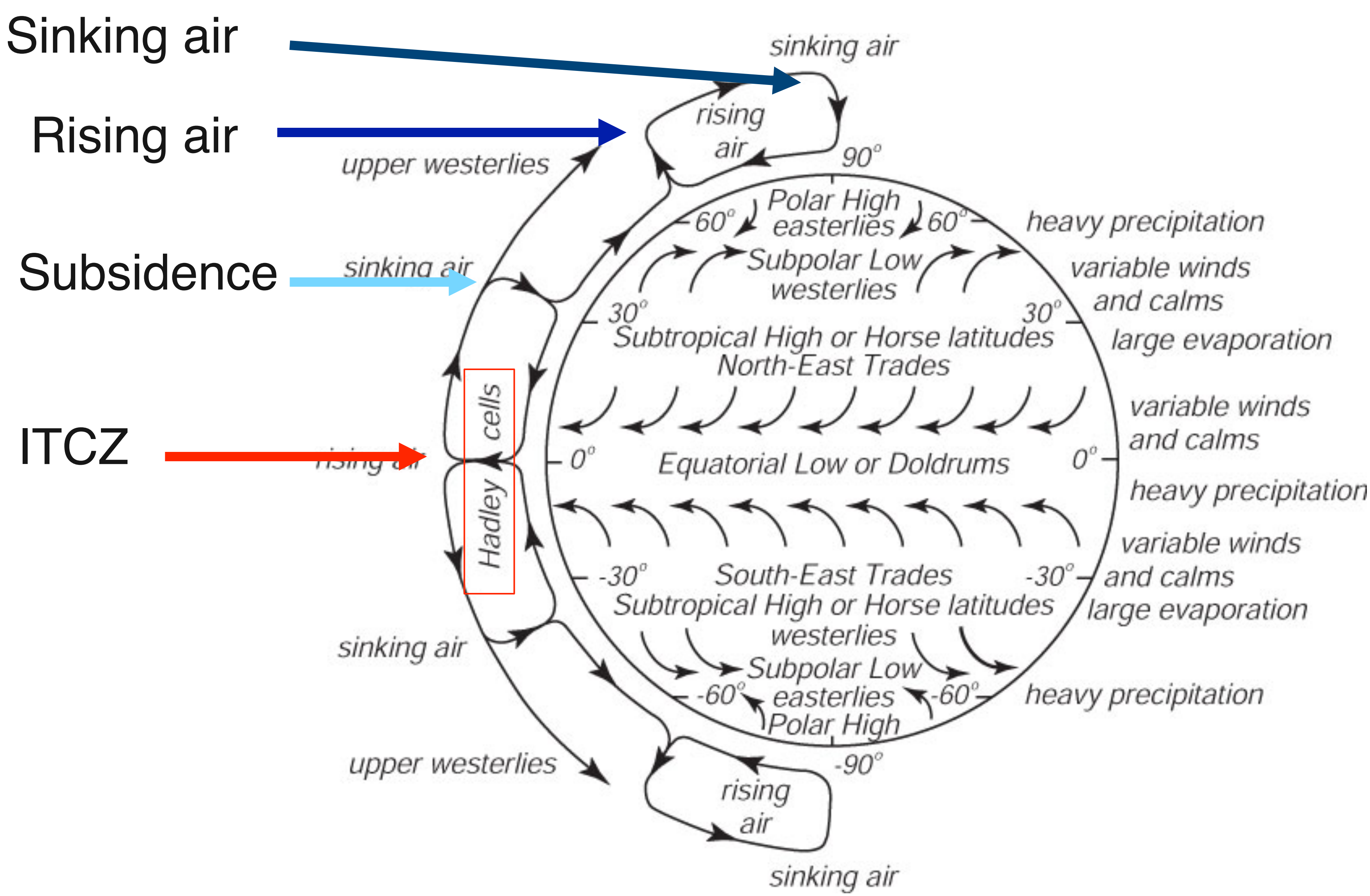


What we actually have - 3 cells - due to rotation



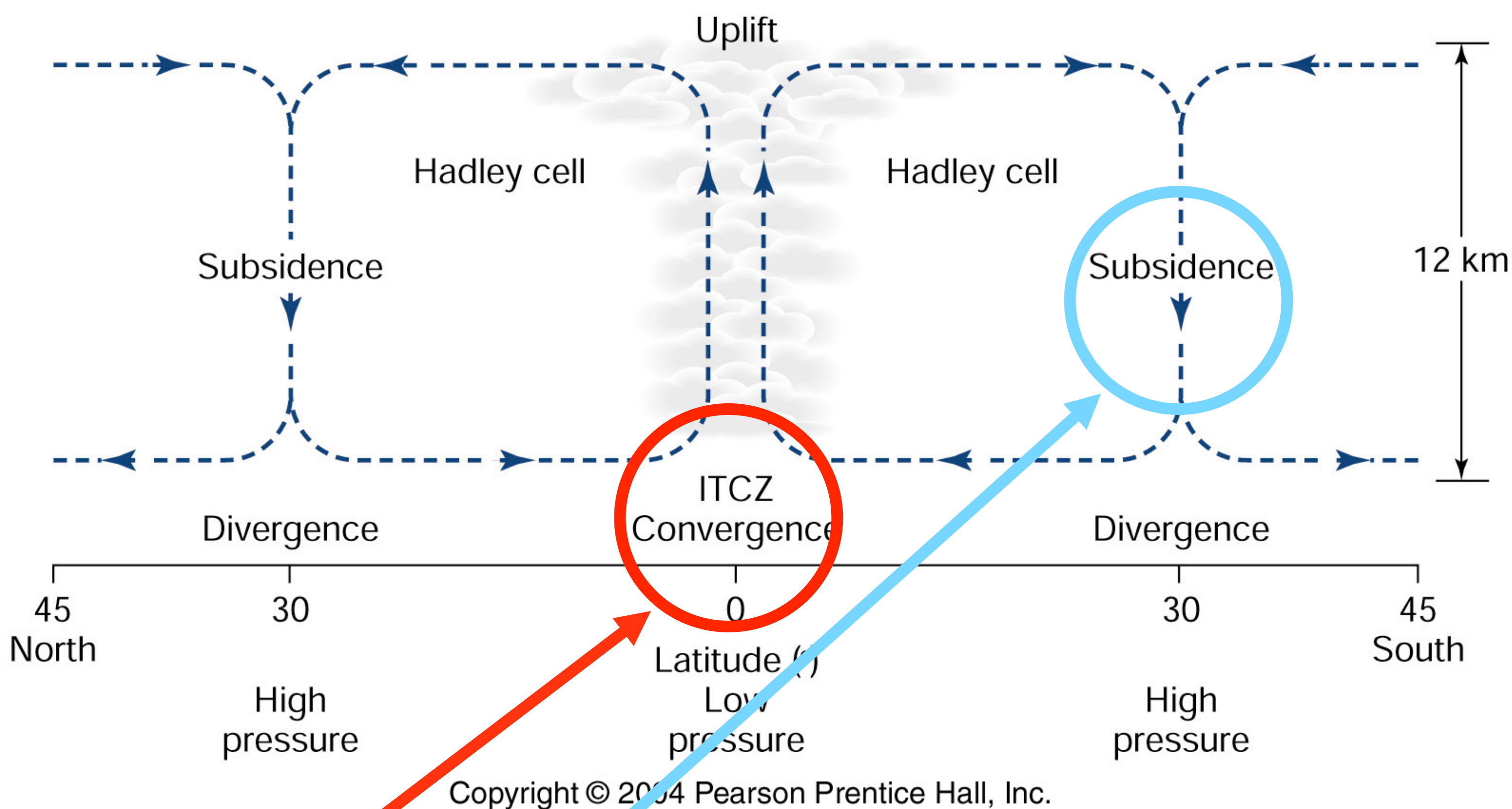
1. Hadley 2. Ferrel 3. Polar

Meridional view of global winds



Stewart Fig. 4.3

1. Hadley cell



ITCZ = Intertropical Convergence Zone

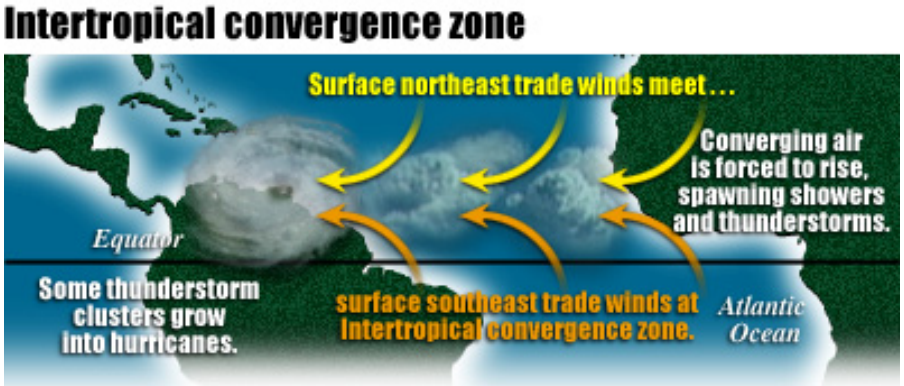
Actually not exactly on equator: seasonal variations in insolation, so ITCZ sits at maximum heating location.

ITCZ is well developed north of equator (because of land distribution).

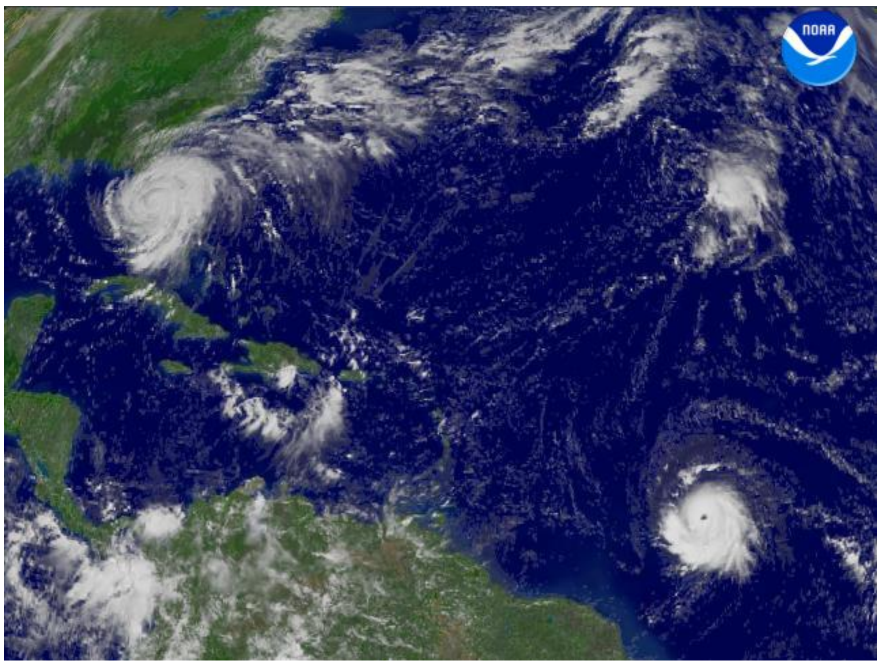
Subsidence at about 30 °N, S

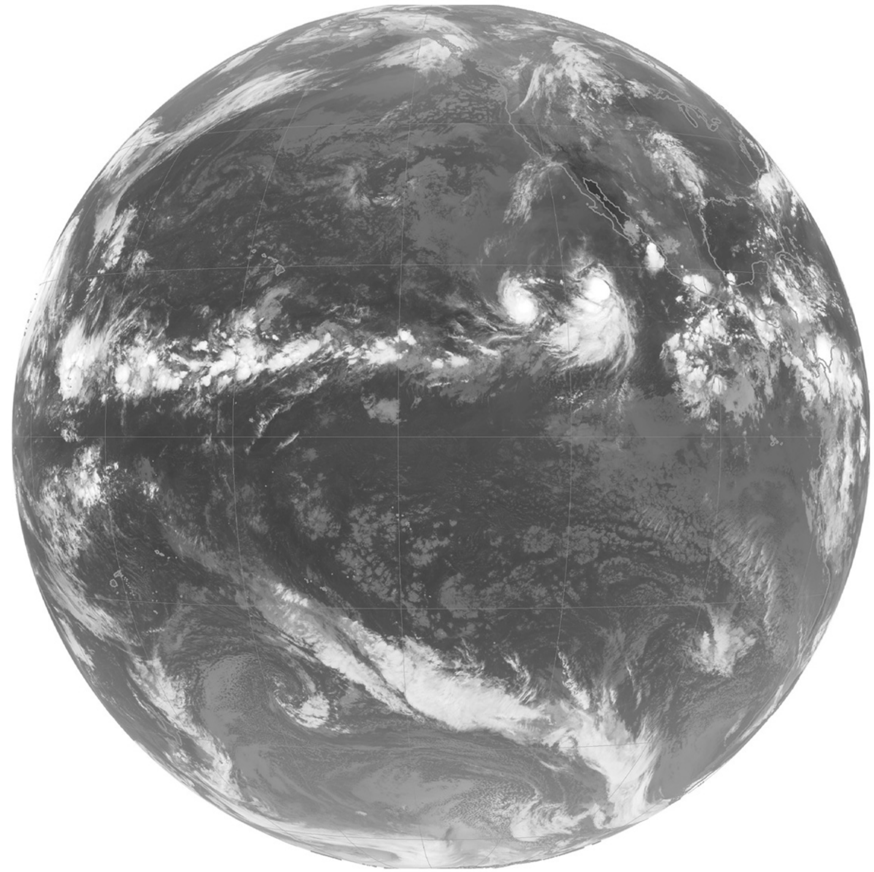
Kump, Kasting, Crane (2004) textbook

Intertropical Convergence Zone



Atlantic Ocean 9/04

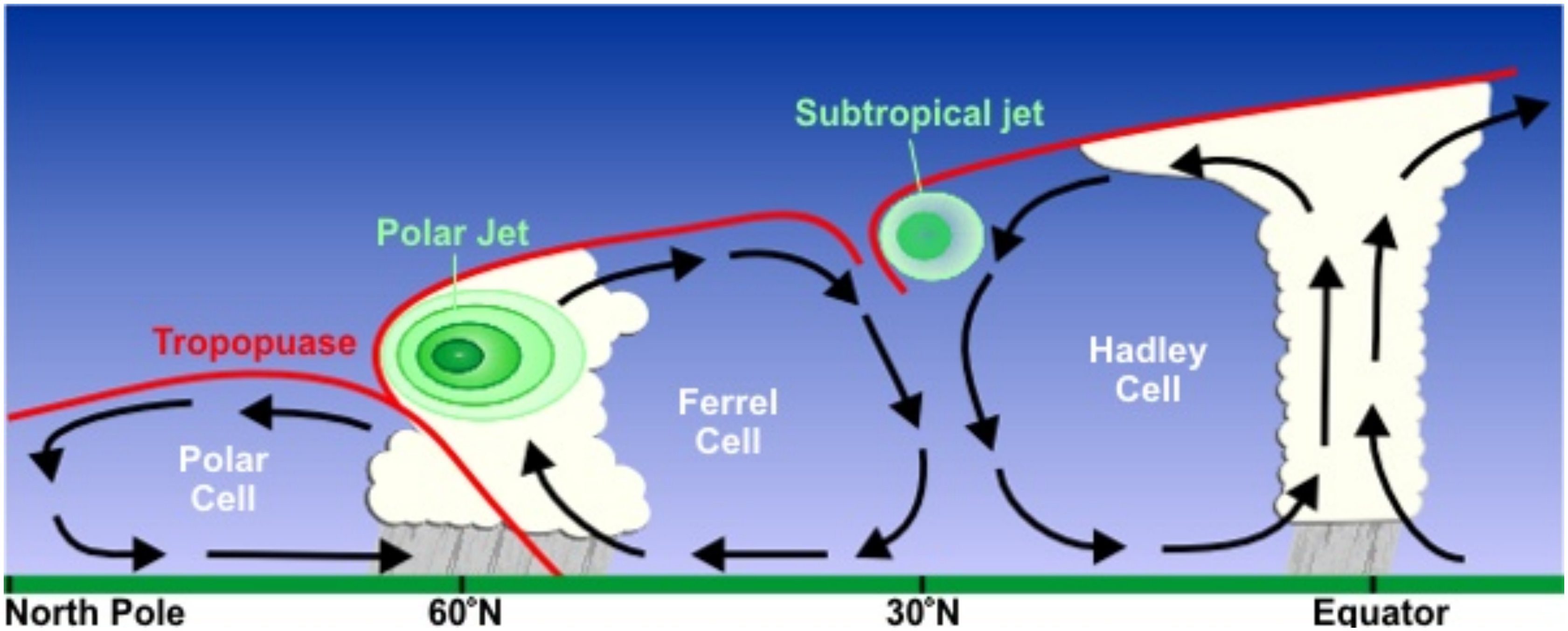




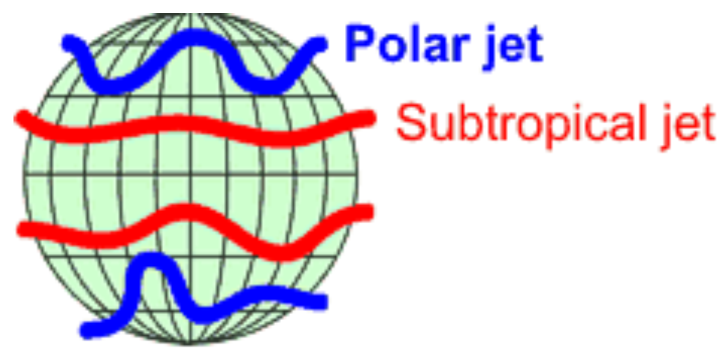
Pacific Ocean

ITCZ spawns hurricanes

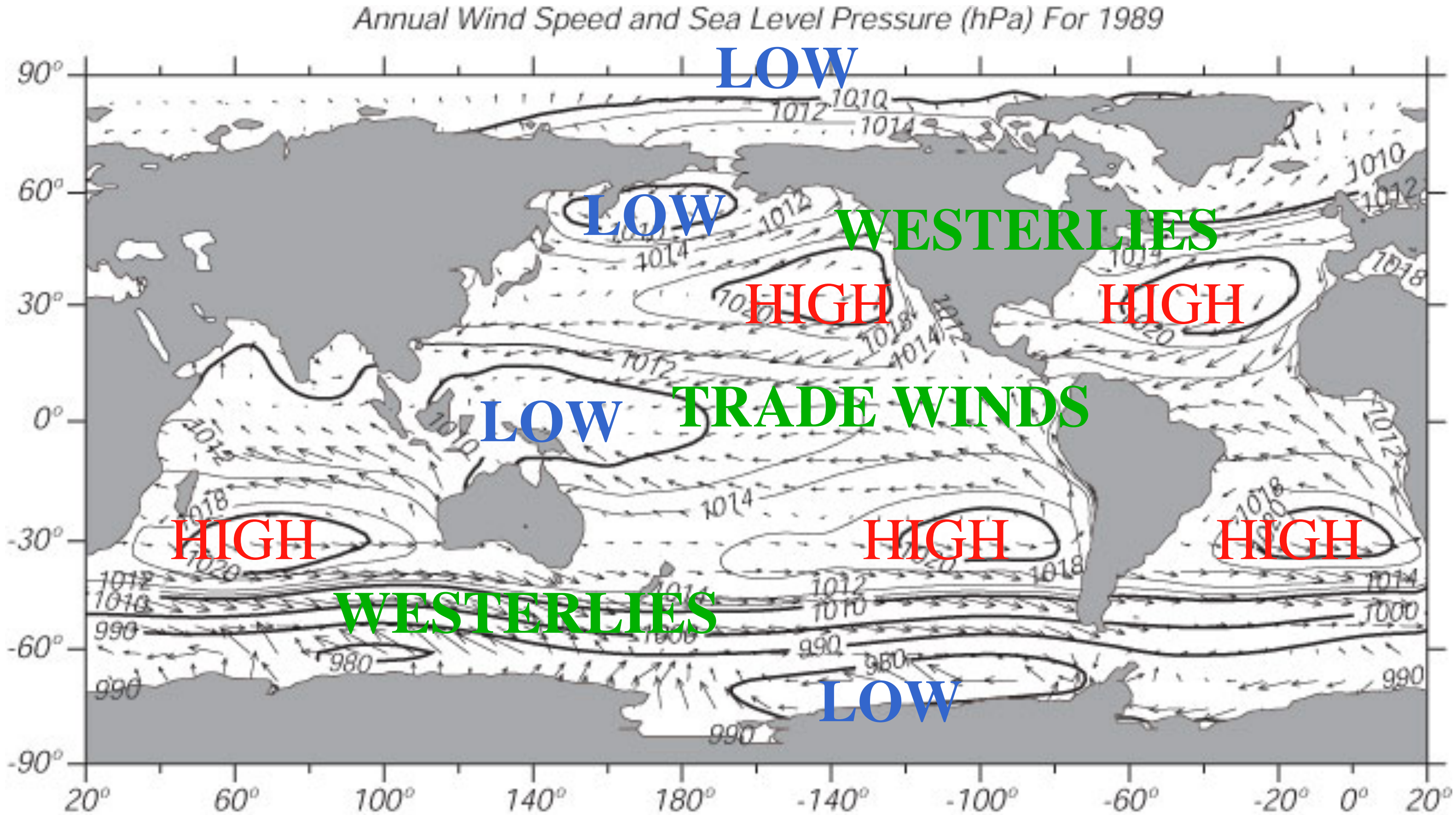
The three cells and the jet streams: Polar and Subtropical Jets



Polar easterlies   Westerlies   Trades (easterlies)



Annual mean surface winds and surface pressure



Wind stress

- Wind stress drives the ocean (waves, currents).
- Transfer of momentum from wind to ocean.
- Wind speed is measured above the sea surface. In practice measurements are at different heights. For consistency, adjust all measurements to a 10 meter height.

- Actual stress on the ocean:

$$\tau = c_D \rho u^2$$

where u is the wind speed at 10 meters, ρ is the air density 1.3 kg/m^3, and c_D is the (dimensionless) drag coefficient, which is determined empirically.

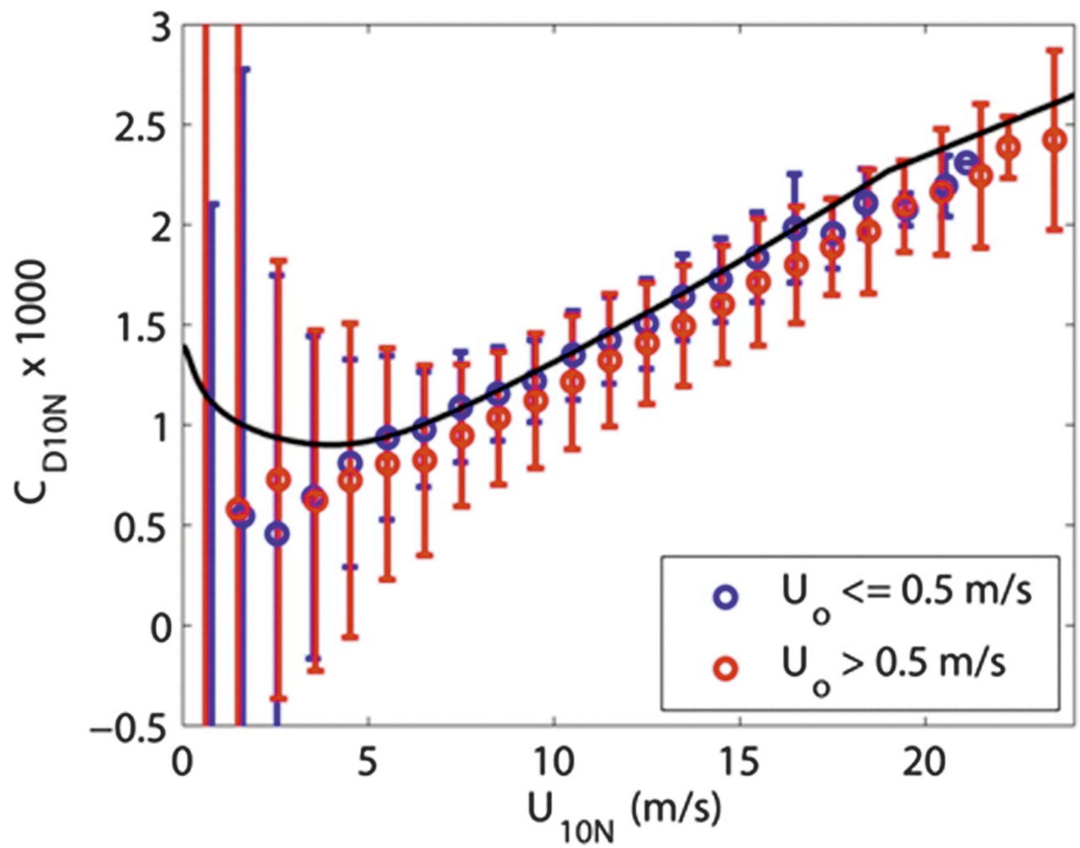
Units of wind stress: Newton/m^2

(check this using density times velocity squared)

Wind stress continued

Most recent drag coefficients "COARE 3.5" determined from direct measurements, including high wind speeds

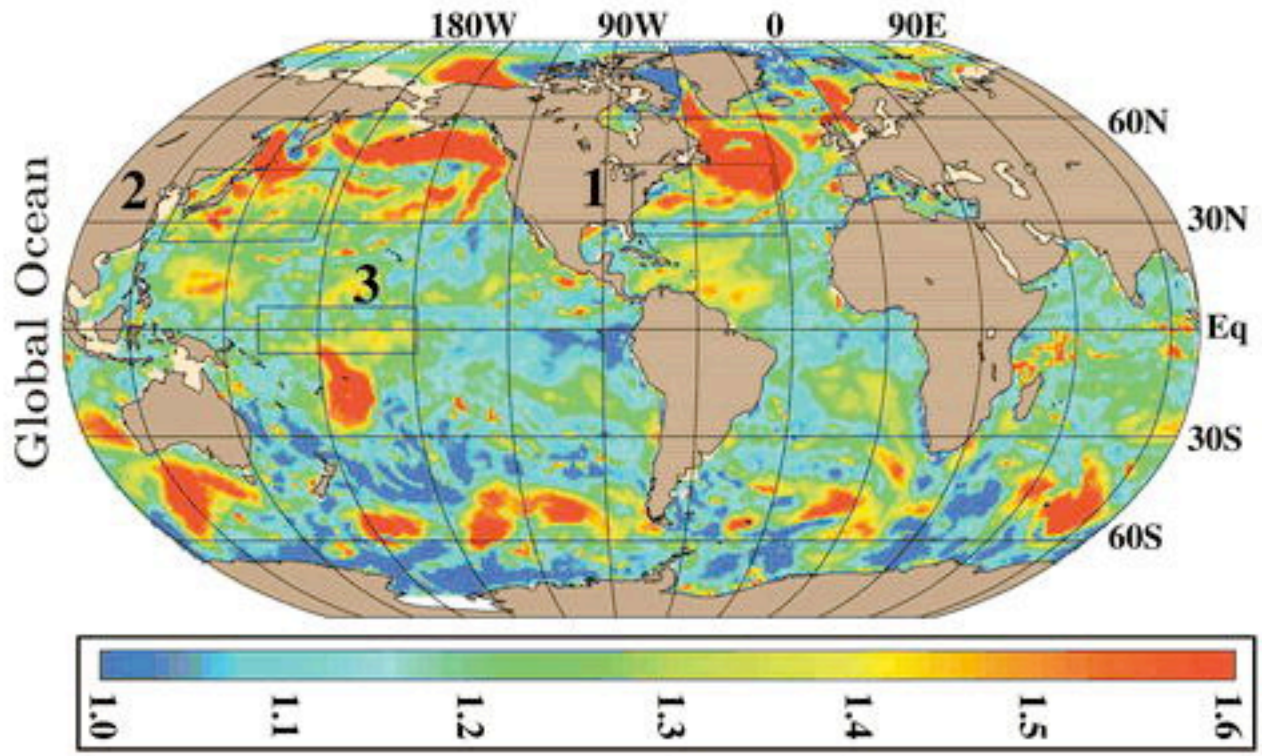
[At low wind speed c_D~ 1.1 x 10^{-3}]



Edson et al. (JPO, 2013)

(Older) COARE 3.0 algorithm, drag coefficient

(a) Drag coefficient ($C_D \times 10^3$) over the global ocean on 6 Jan 2004 (00Z)



Kara et al. (J. Clim. 2007)

Surface wind stress (northern summer)

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- Note westerlies and trades
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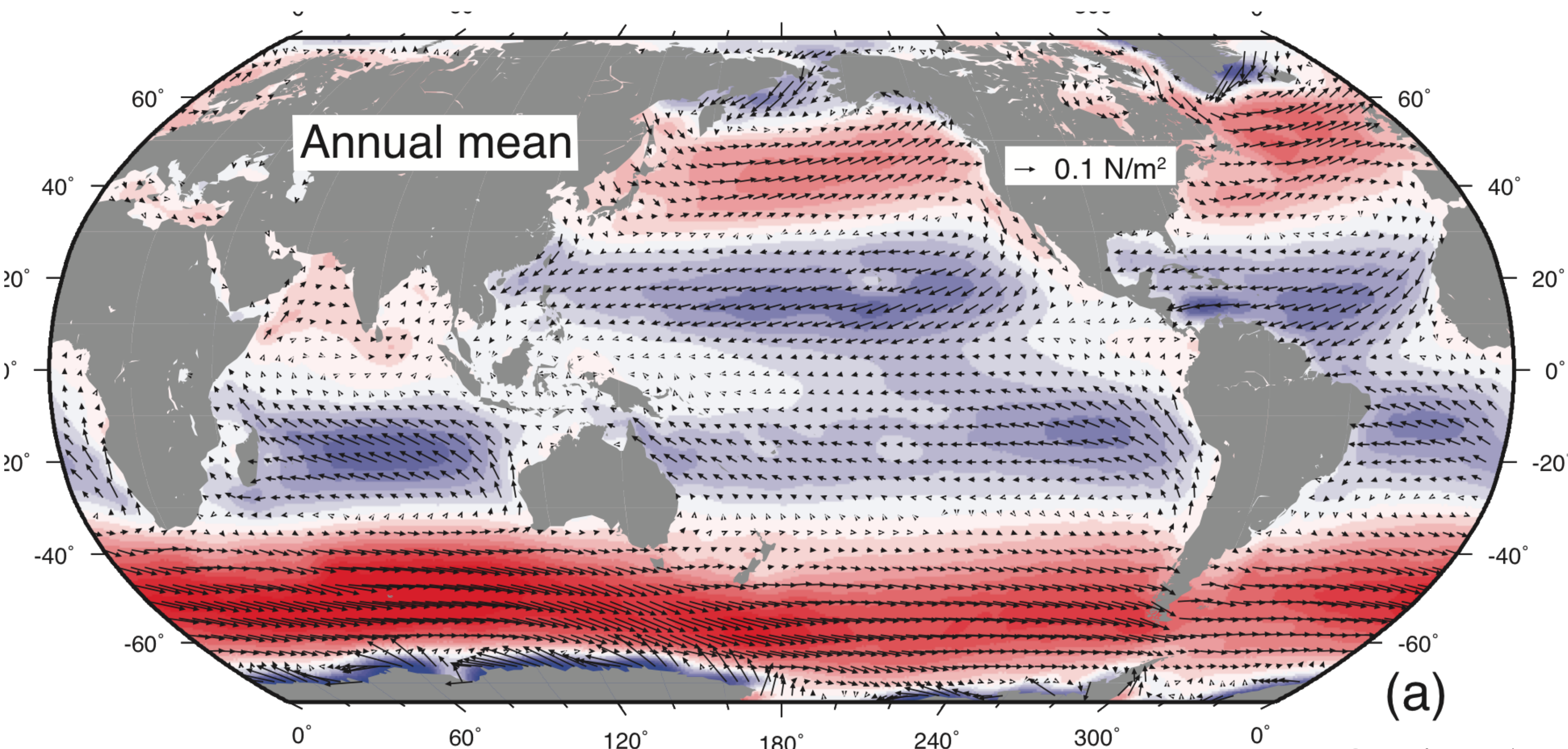
- Look for monsoons in other tropical locations



DPO Fig. 5.16a