Forcing of the Ocean: tides, winds, and heating

Tides

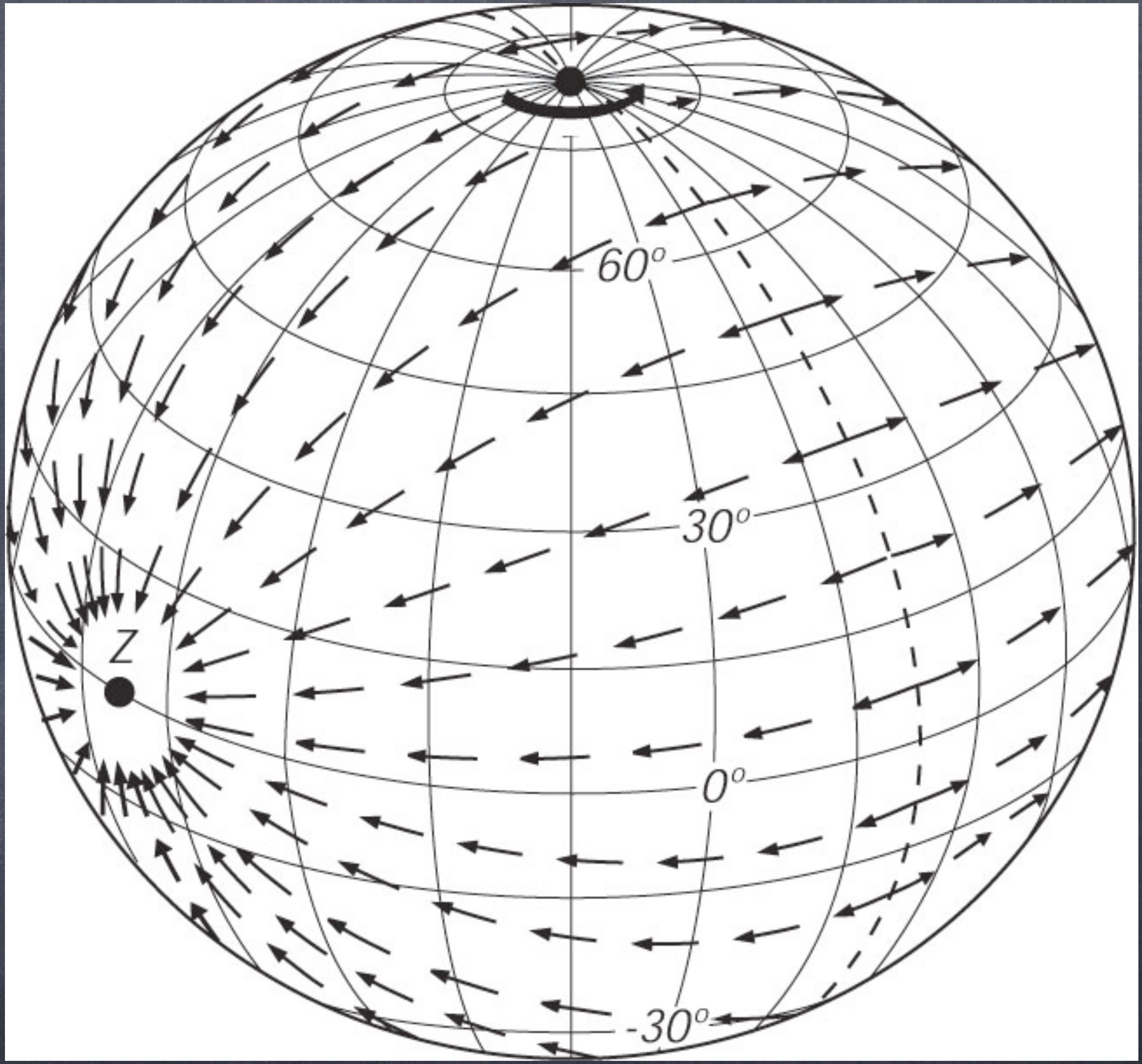
- Result from the gravitational forces of the moon and the sun
- For the Earth-moon-sun system there is a balance of gravitational forces very close to the center of the Earth.
- At any point on the Earth's surface there is a slight imbalance, giving a tide generating potential.
- The horizontal component of the tide generating potential gives TWO tidal bulges.

Tides

-There are two places of high tide at any one time. These regions are planar with the moon.

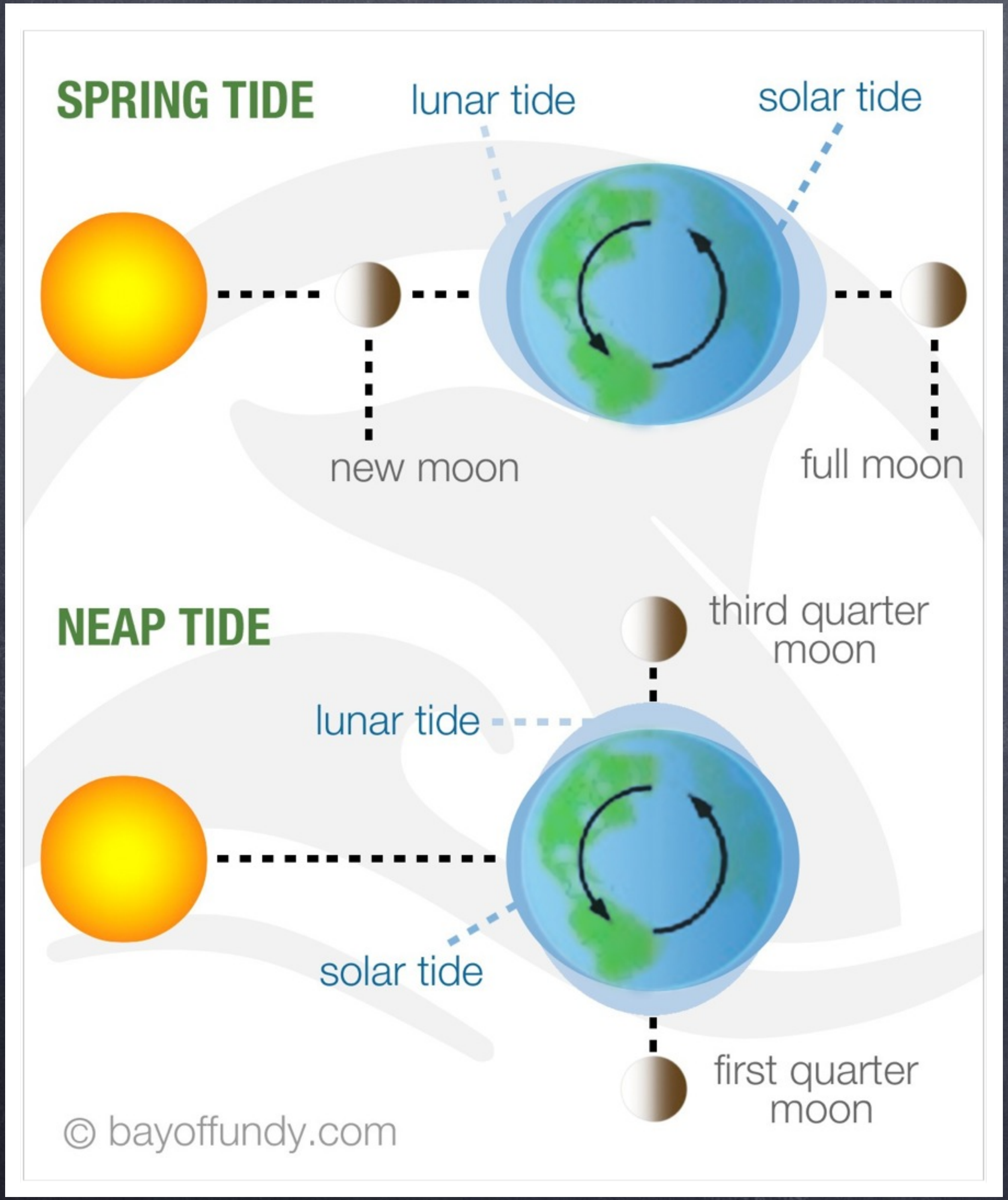
-Earth rotates once per day, so have 2 high tides per day.

-Forcing is semi-diurnal



The horizontal component of the tidal force on Earth when the tide-generating body is above the Equator at Z. From Dietrich, et al. (1980).

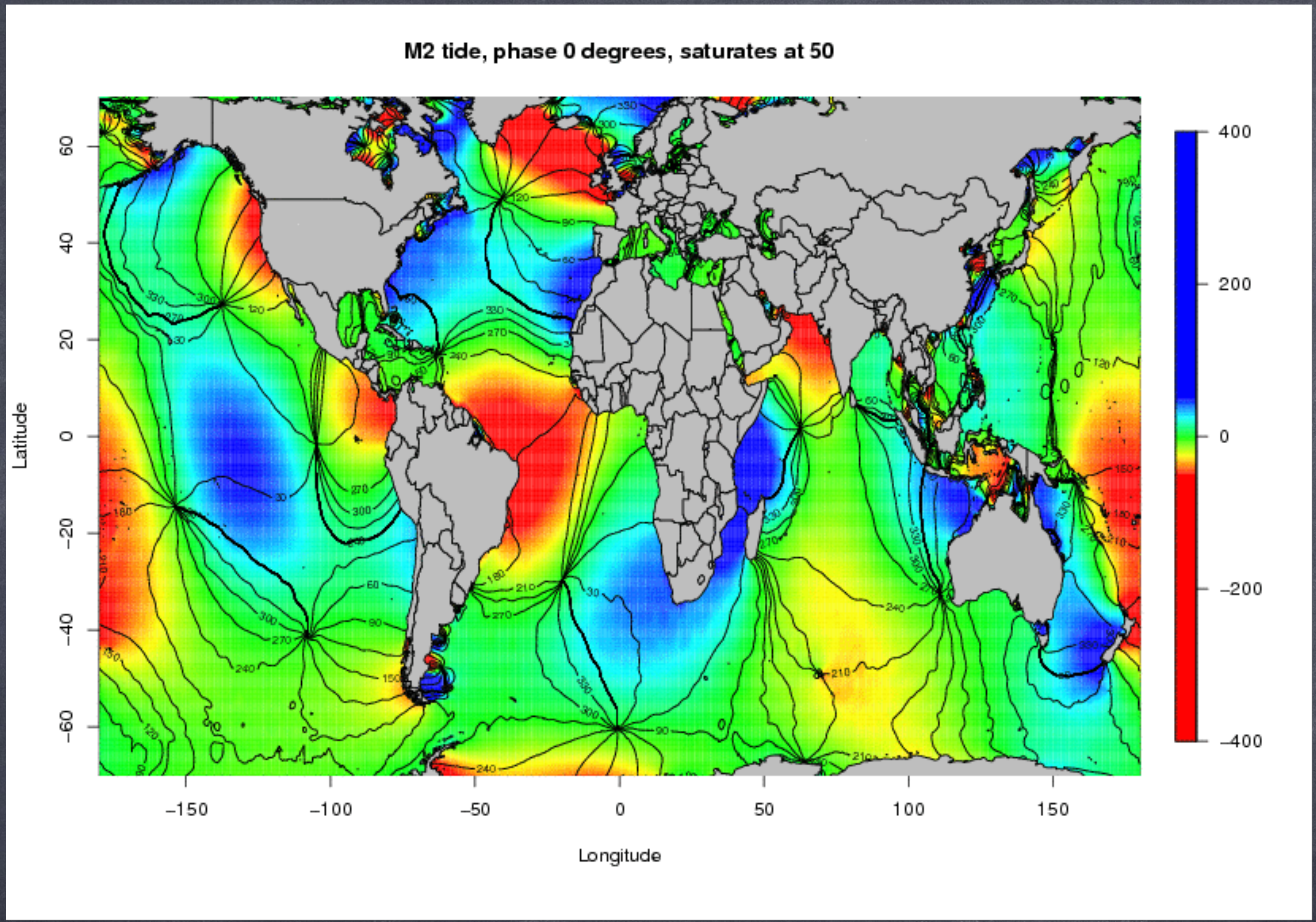
Spring-Neap cycle



"Beating" of lunar M_2 tide and solar S_2 tide leads to "spring" tides and "neap" tides

Tides are dynamic

- Tidal "bulges" travel at the surface of the Earth as "shallow-water waves" of maximum speed 230 m s^{-1} which is less than 448 m s^{-1} predicted by celestial mechanics
- Bottom drag causes the dynamic tides to lag the equilibrium tides by several hours
- Shapes of ocean basin prevent the tidal bulges from circumnavigating the globe (except in the Southern Ocean)
- lateral ocean movements are subject to Coriolis force



Animation **of M2 tidal constituent** (0-400 mm) from Tim Jupp. Cotidal lines indicating phase every 30 degrees originate at amphidromic points where the tidal range is zero.

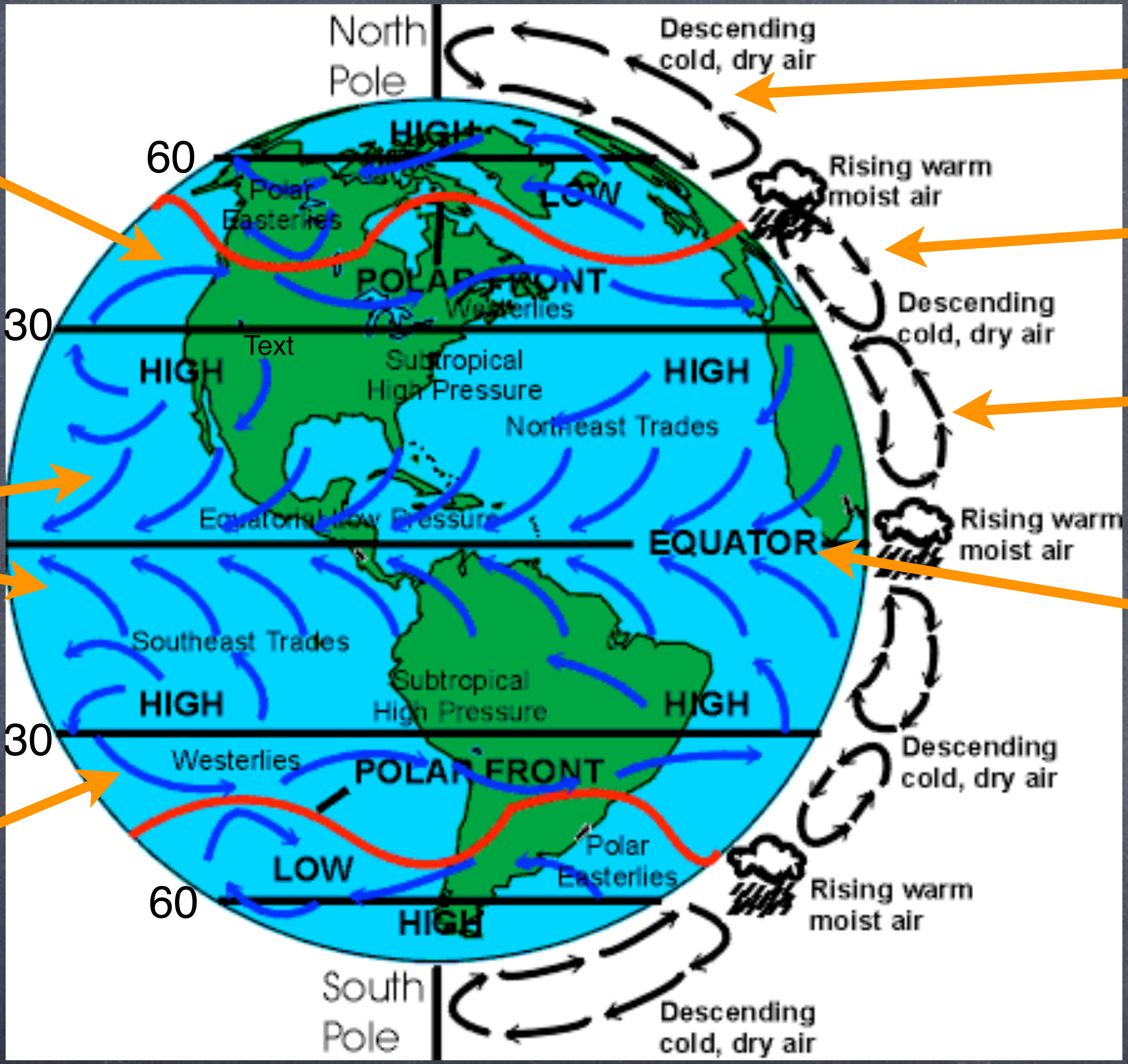
http://empslocal.ex.ac.uk/people/staff/tej202/tideomatic/ani_World_M2.gif

Global mean wind system

westerlies

trade winds

westerlies



Polar cell

Ferrel cell

Hadley cell

ITCZ: Intertropical Convergence Zone

Circulation is deflected by Earth's rotation

Air circulation driven by uneven heating by ocean (and land)

Global mean wind system

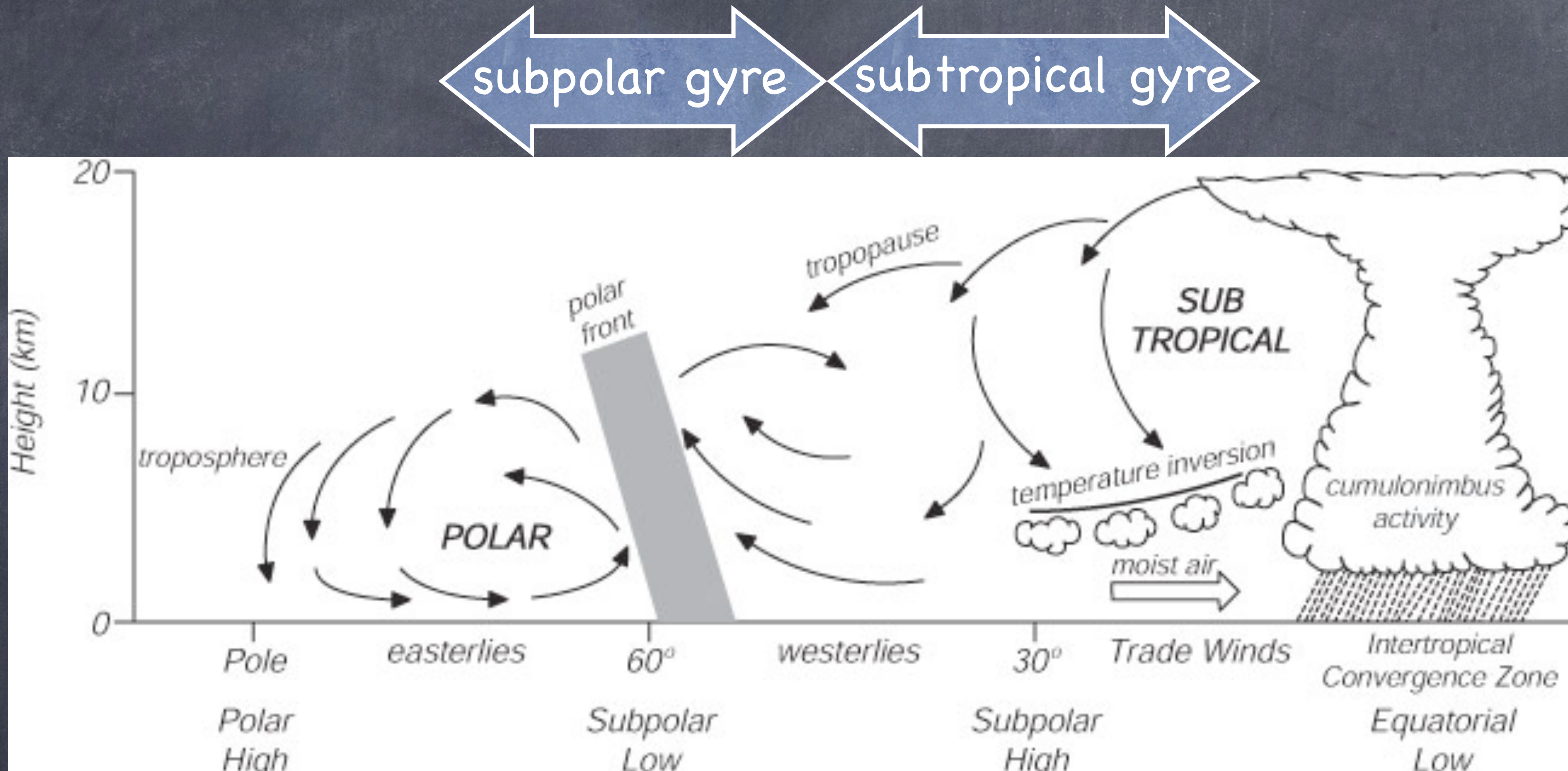
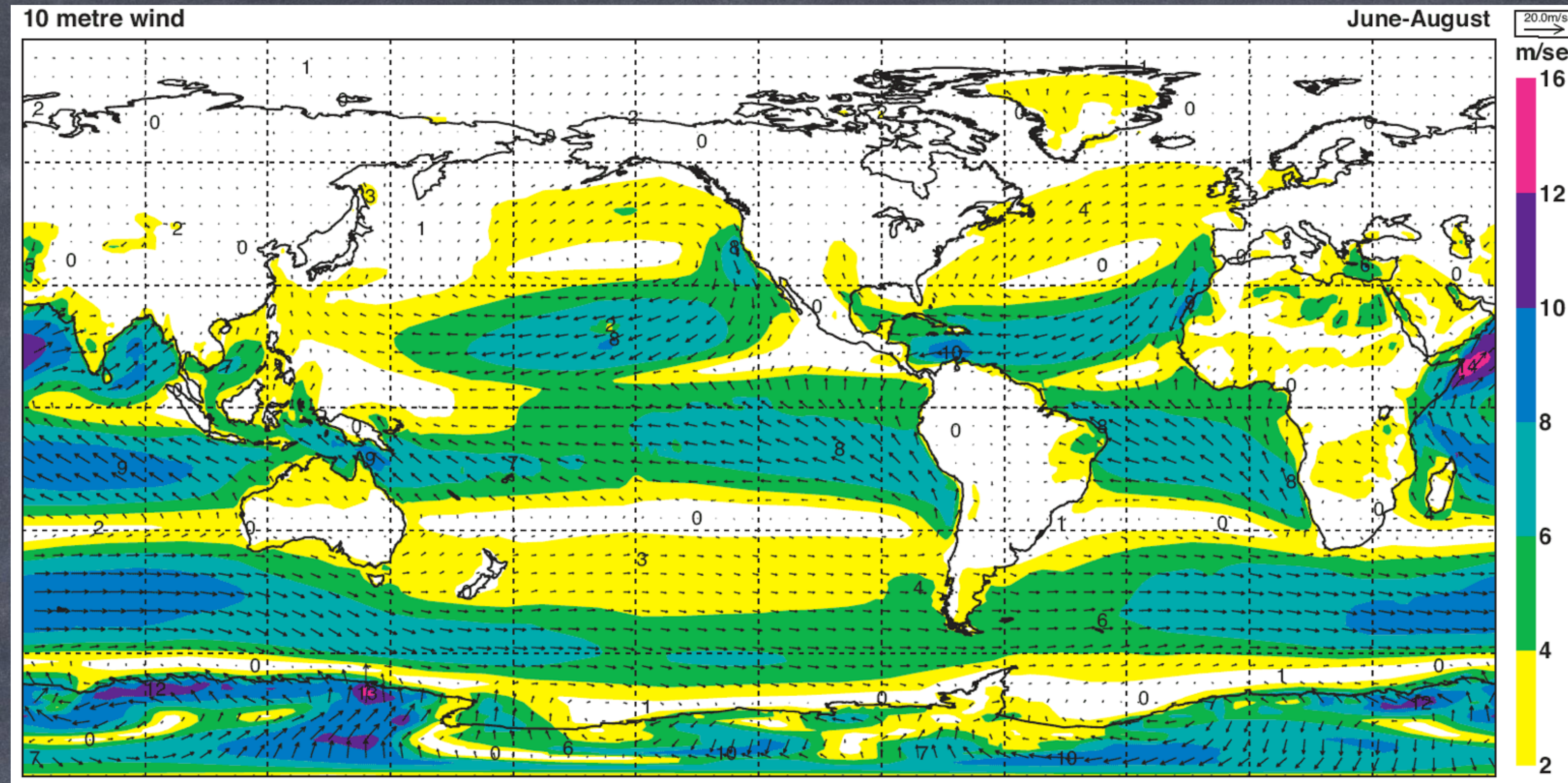
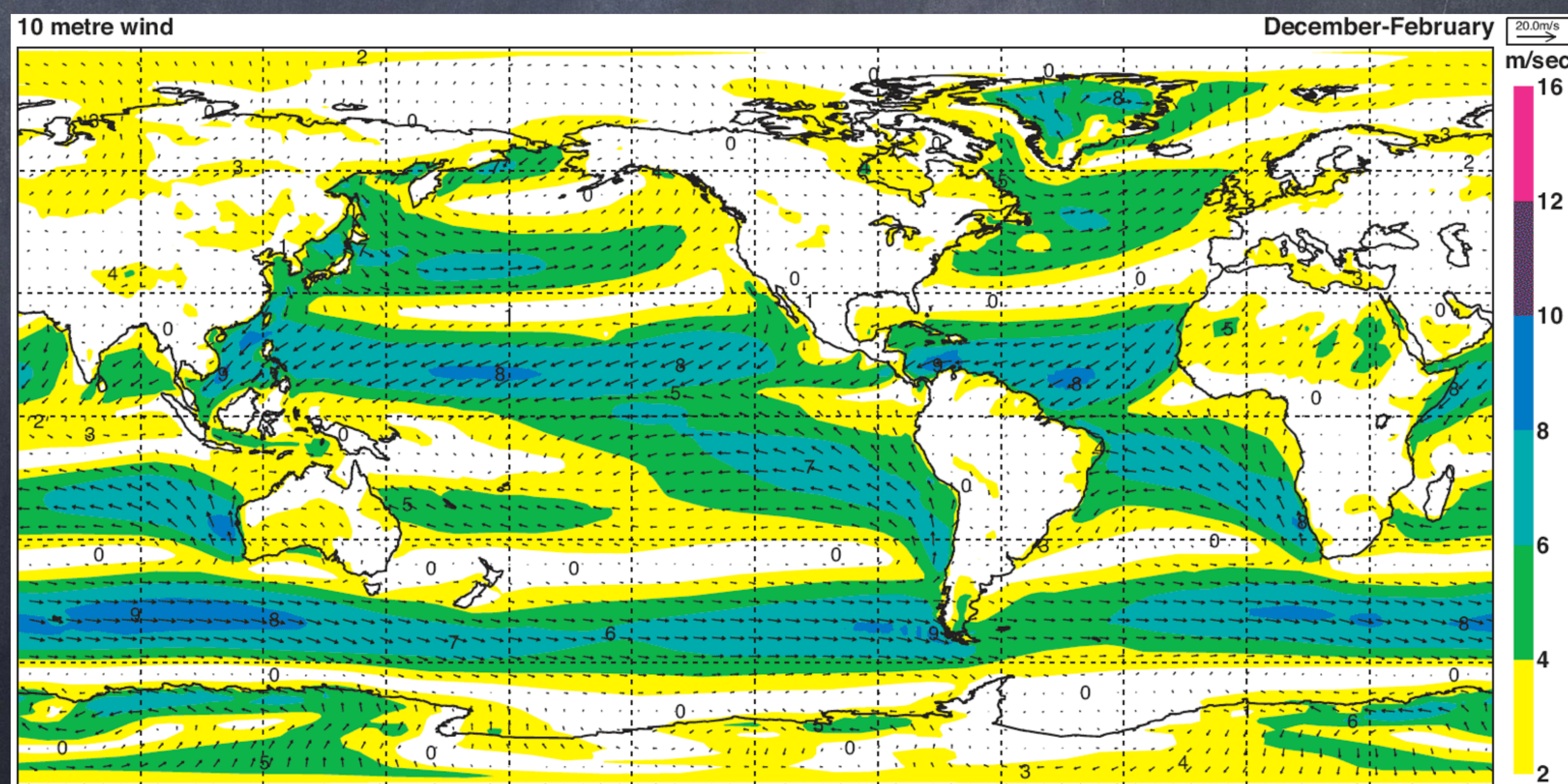


Figure 4.3(b) Simplified schematic of Earth's atmospheric circulation driven by solar heating in the tropics and cooling at high latitudes. Cross-section through the atmosphere showing the two major cells of meridional circulation. From The Open University (1989a).

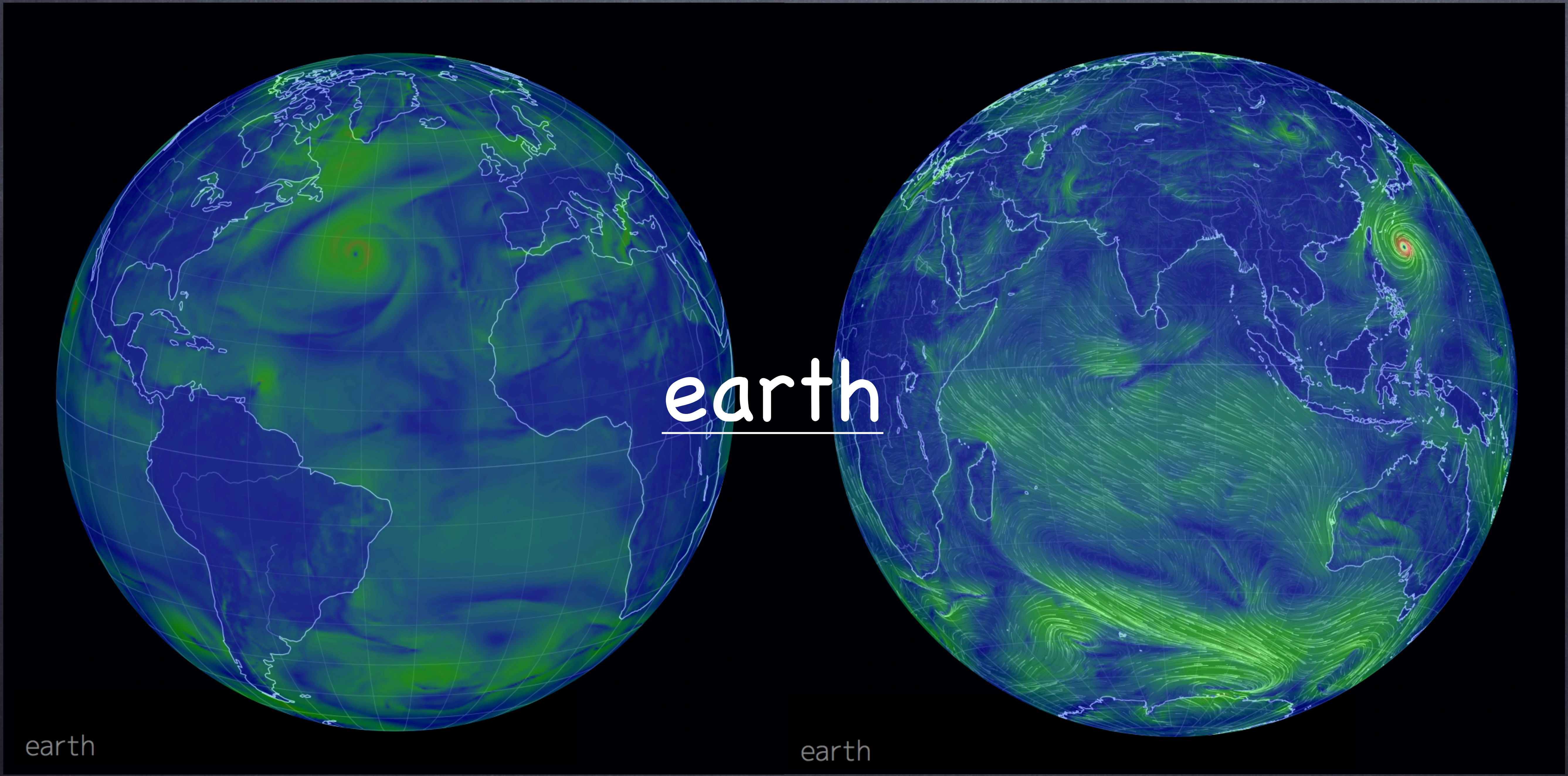
Mean 10-m winds in boreal summer (top) and winter (bottom) from ECMWF 40-year re-analysis.
(Kallberg et al, 2005).

-Stronger westerlies in winter.
-Asian monsoon affects wind direction in north Indian Ocean and NW Pacific





Winds Now!



https://earth.nullschool.net/

Heat fluxes

short wave long wave

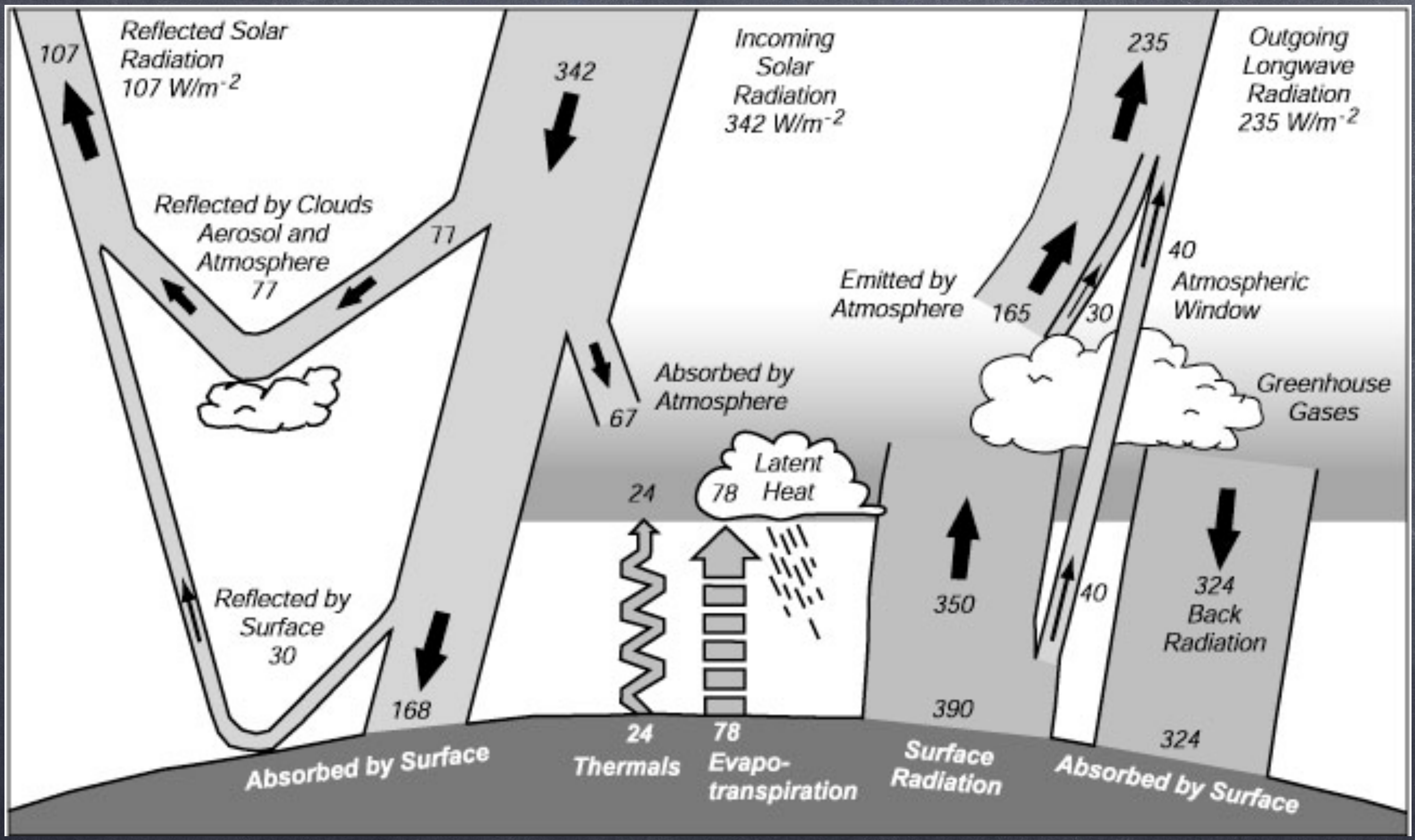
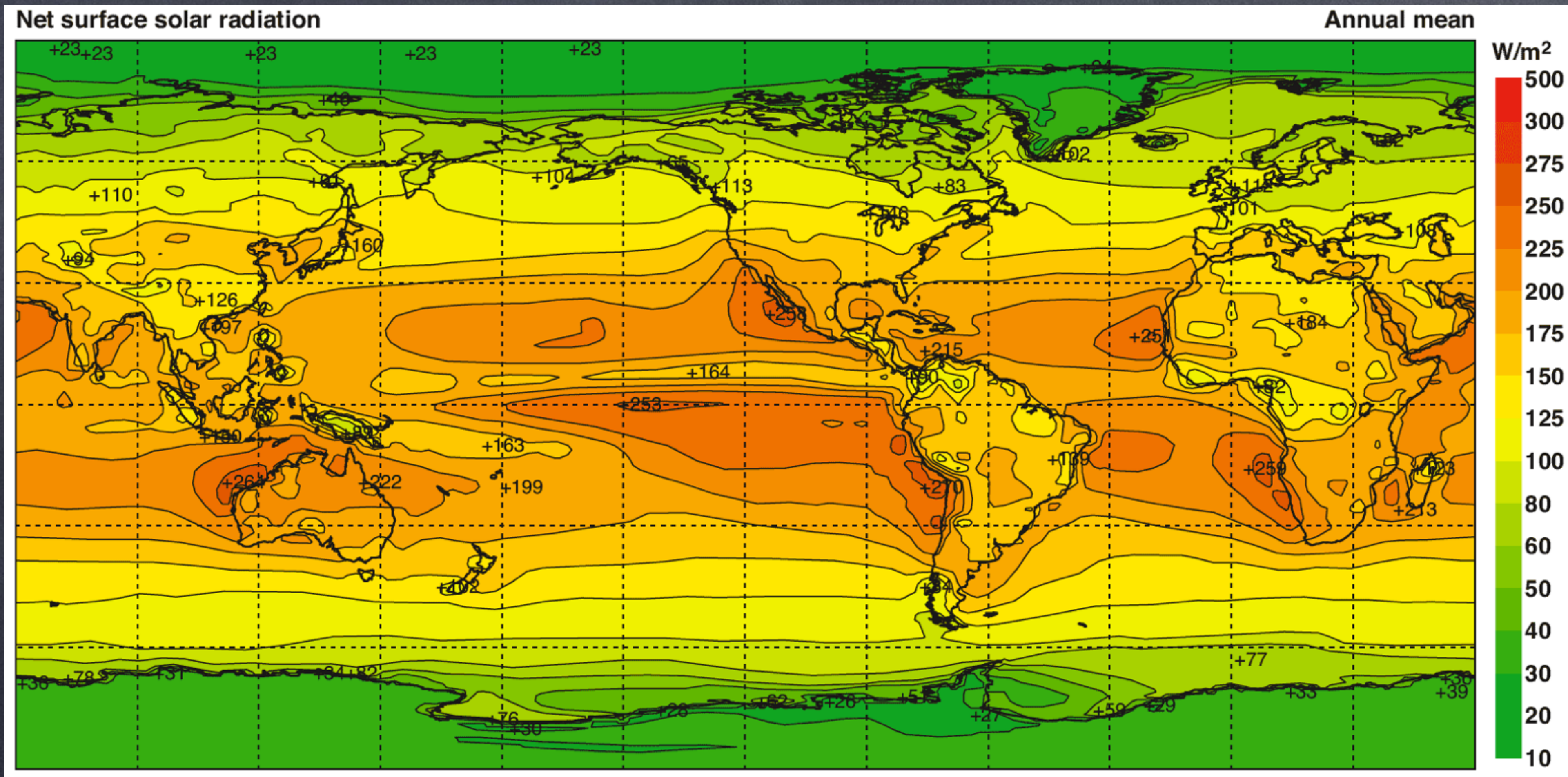
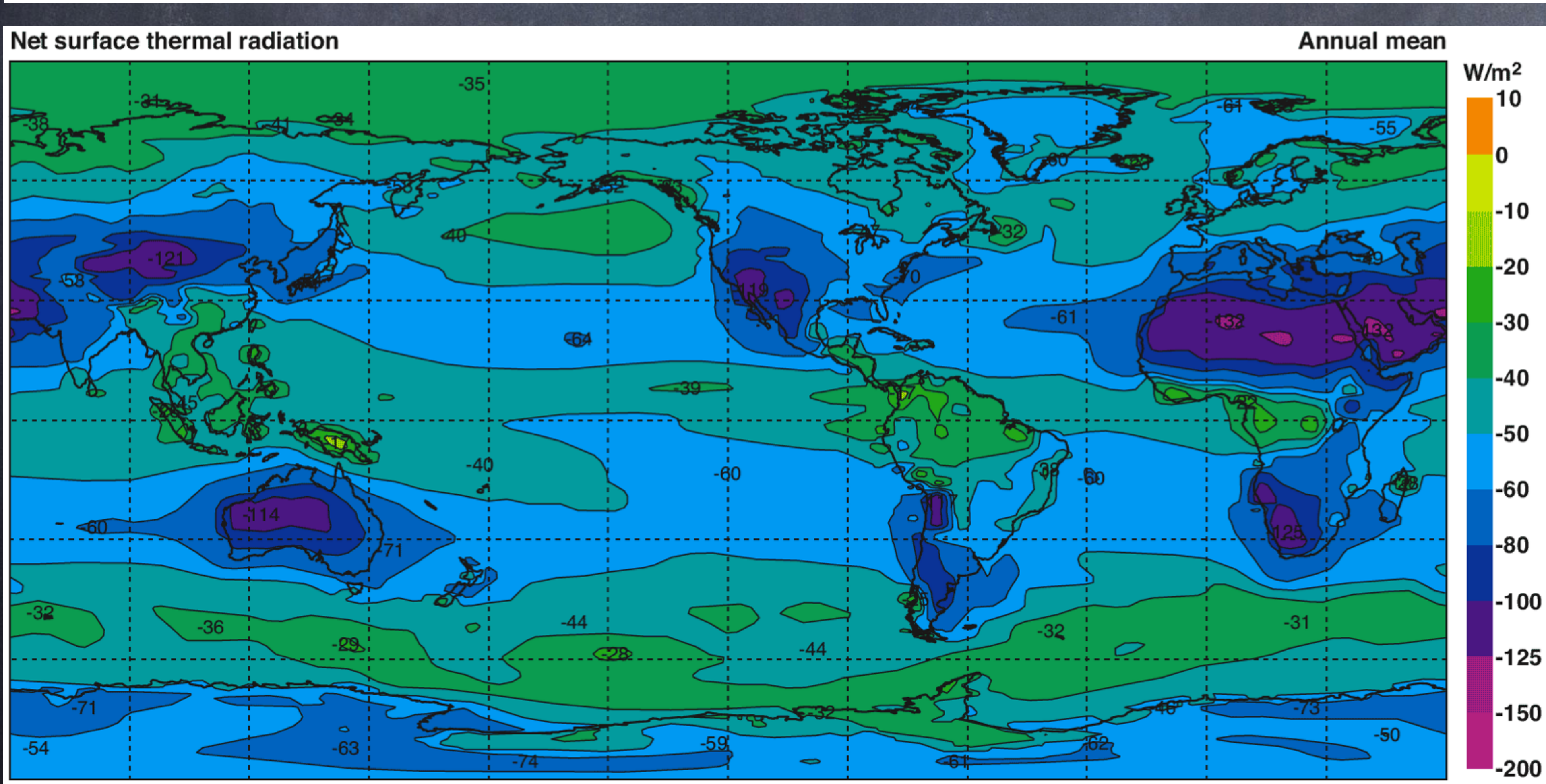


Figure 5.6 The mean annual radiation and heat balance of the Earth. From Houghton et al., (1996: 58), which used data from Kiehl and Trenberth (1996).



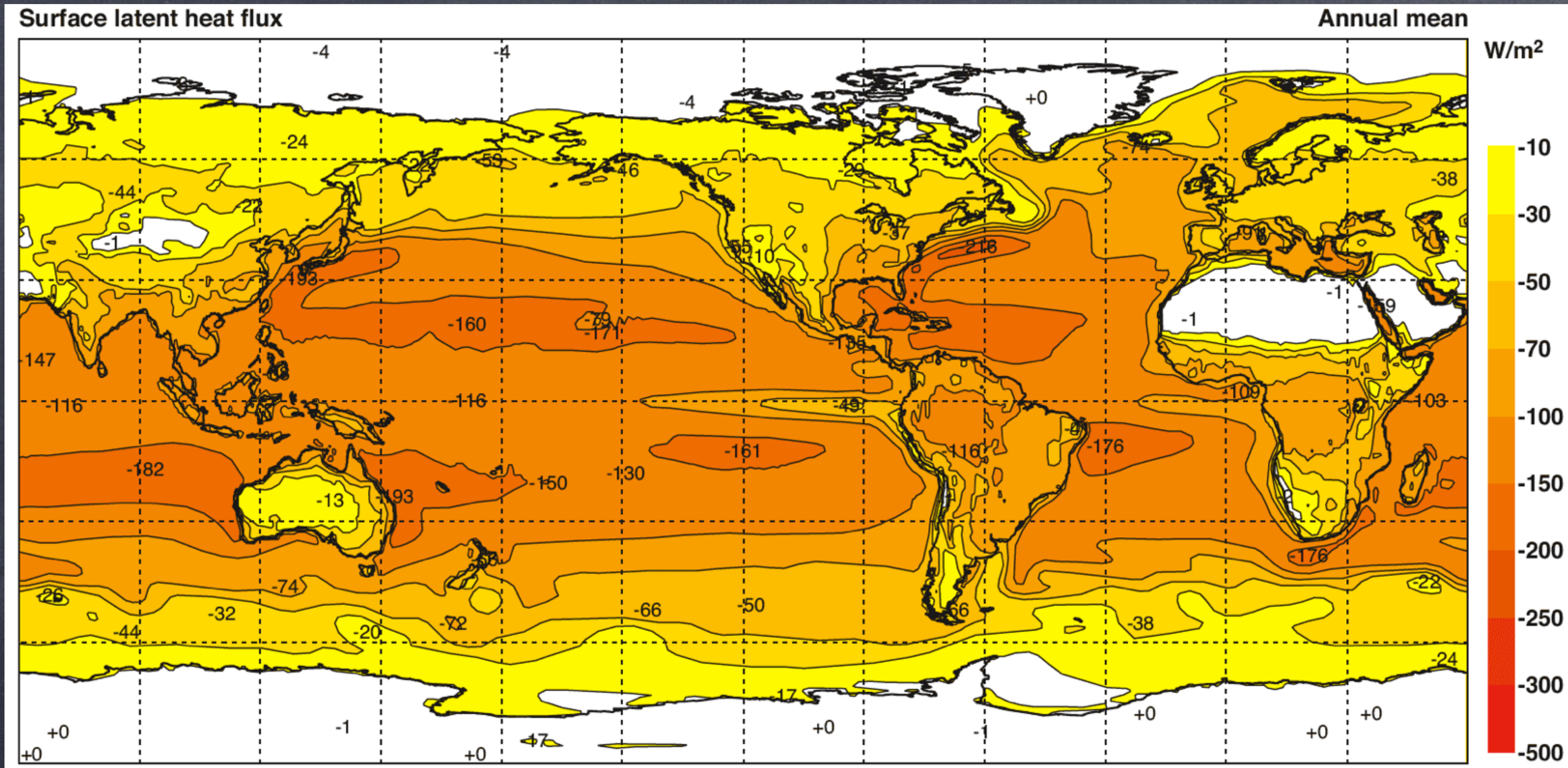


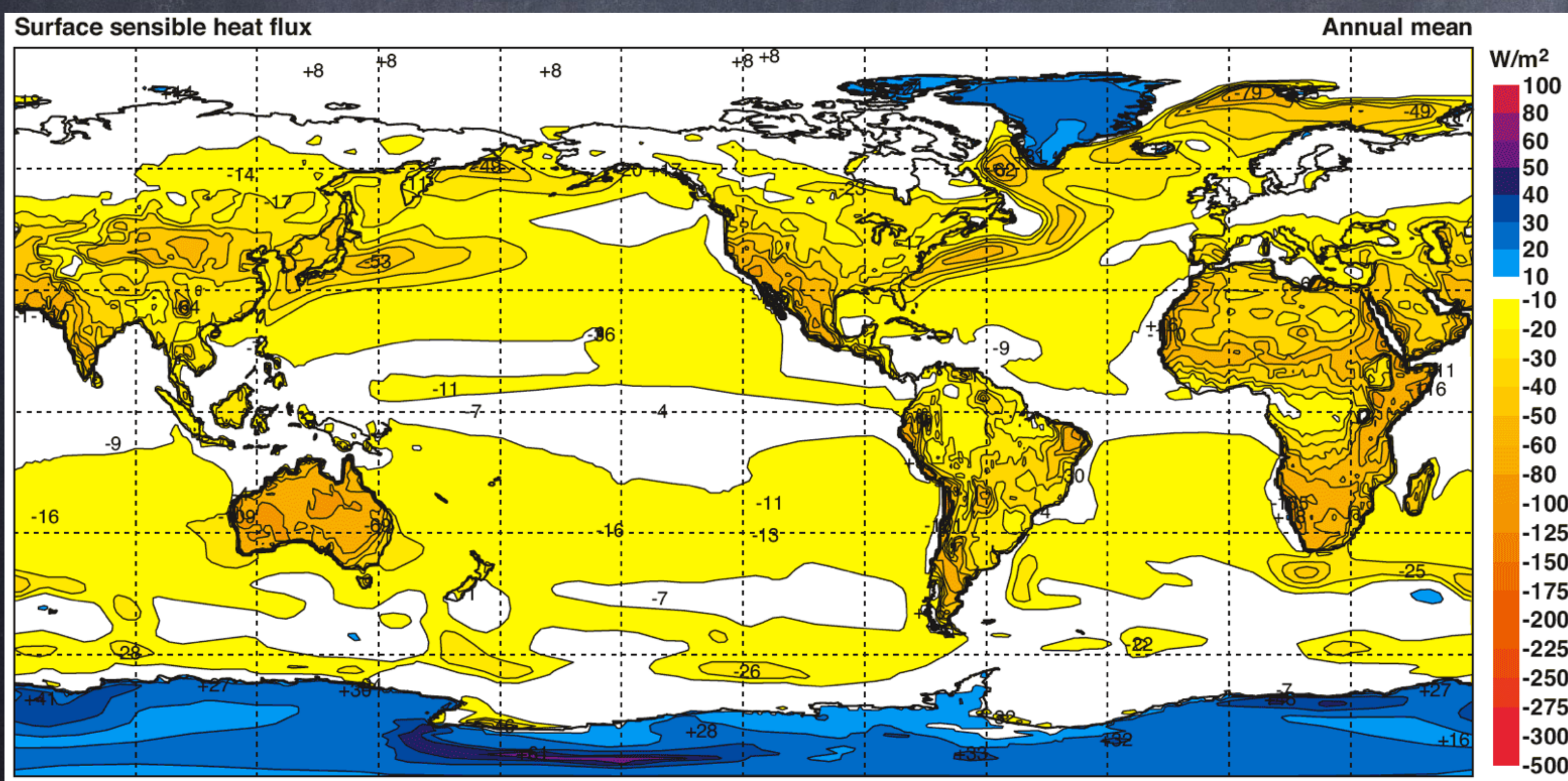
Annual-mean heat flux at surface

Top: net solar, Q_{SW} = incoming-reflected

Bottom: net infrared, Q_{LW} = greenhouse-outgoing

From the ECMWF 40-year reanalysis. Units are W m^{-2}. From Kallberg et al 2005.





Annual-mean heat flux at surface

Top: latent heat flux, Q_L

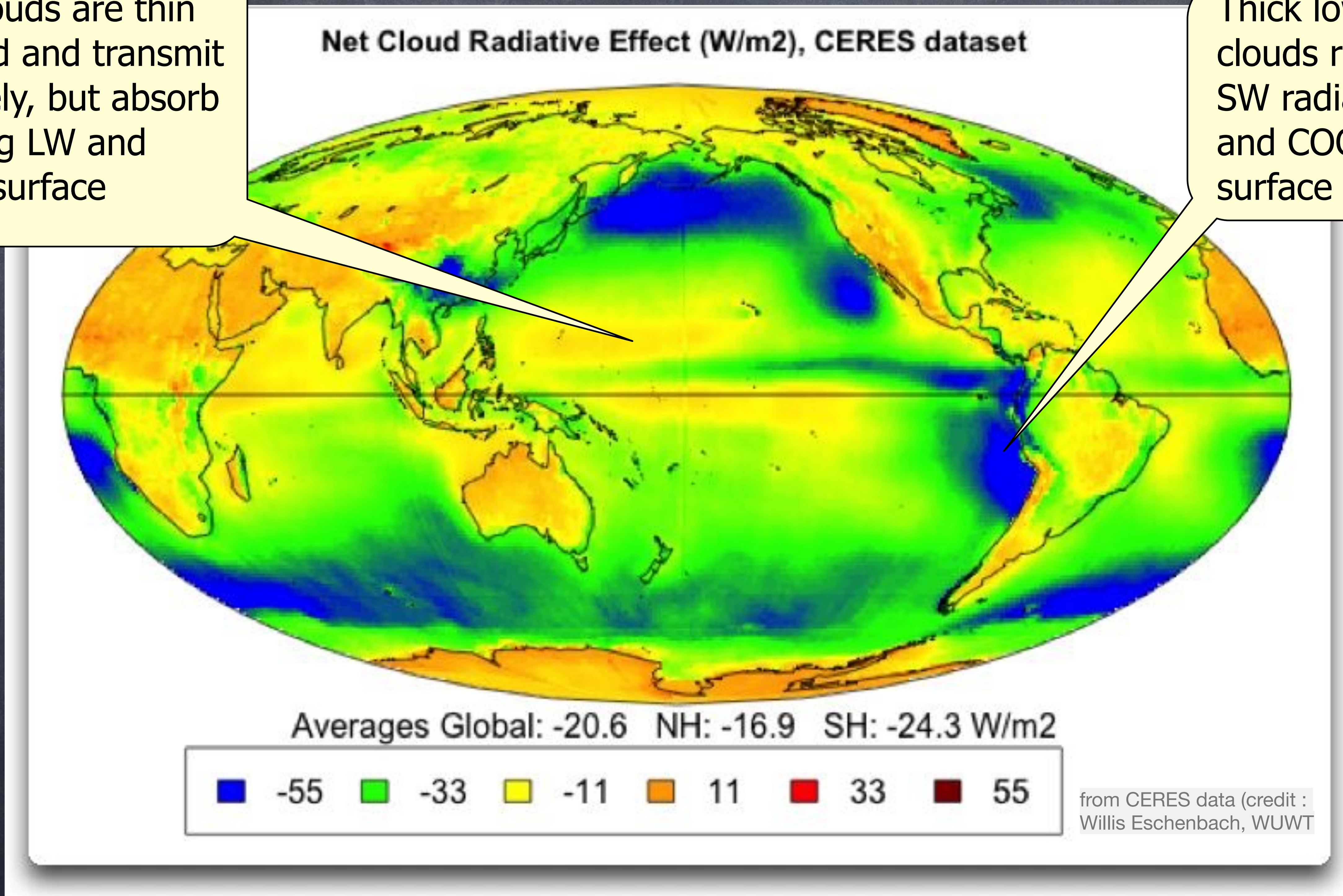
Bottom: sensible heat flux, Q_S

From the ECMWF 40-year reanalysis. Units are W m^{-2}. From Kallberg et al 2005.

Net cloud radiative effect

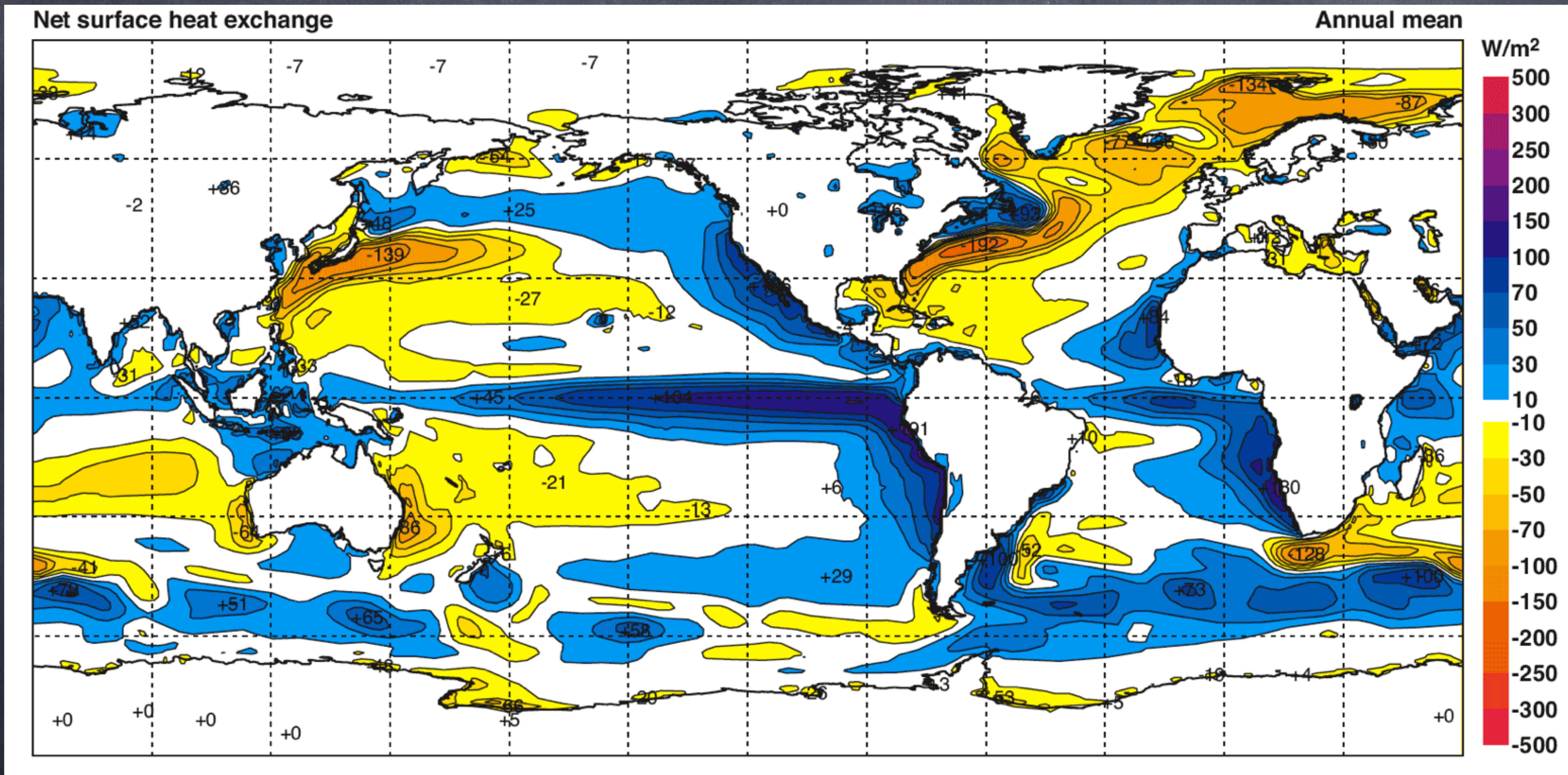
High clouds are thin and cold and transmit SW freely, but absorb outgoing LW and WARM surface

Thick low clouds reflect SW radiation and COOL surface



Clouds both reflect solar SW radiation AND absorb terrestrial LW radiation. Their net effect is currently cooling ~ 13 W/m^2, but could be changing with climate.

Net Annual-mean heat flux Q through the sea surface in W m^{-2}, calculated from the ECMWF 40-year reanalysis. From Kallberg et al 2005.



Max into ocean in tropics and upwelling regions.
Max loss from ocean over WBCs.
(Few measurements in Southern Ocean)

Heat flux through sea surface

-insolation greatest in tropics

-evaporation + LW primarily balances insolation

-sensible heat flux is smallest

-what balances total heat flux?

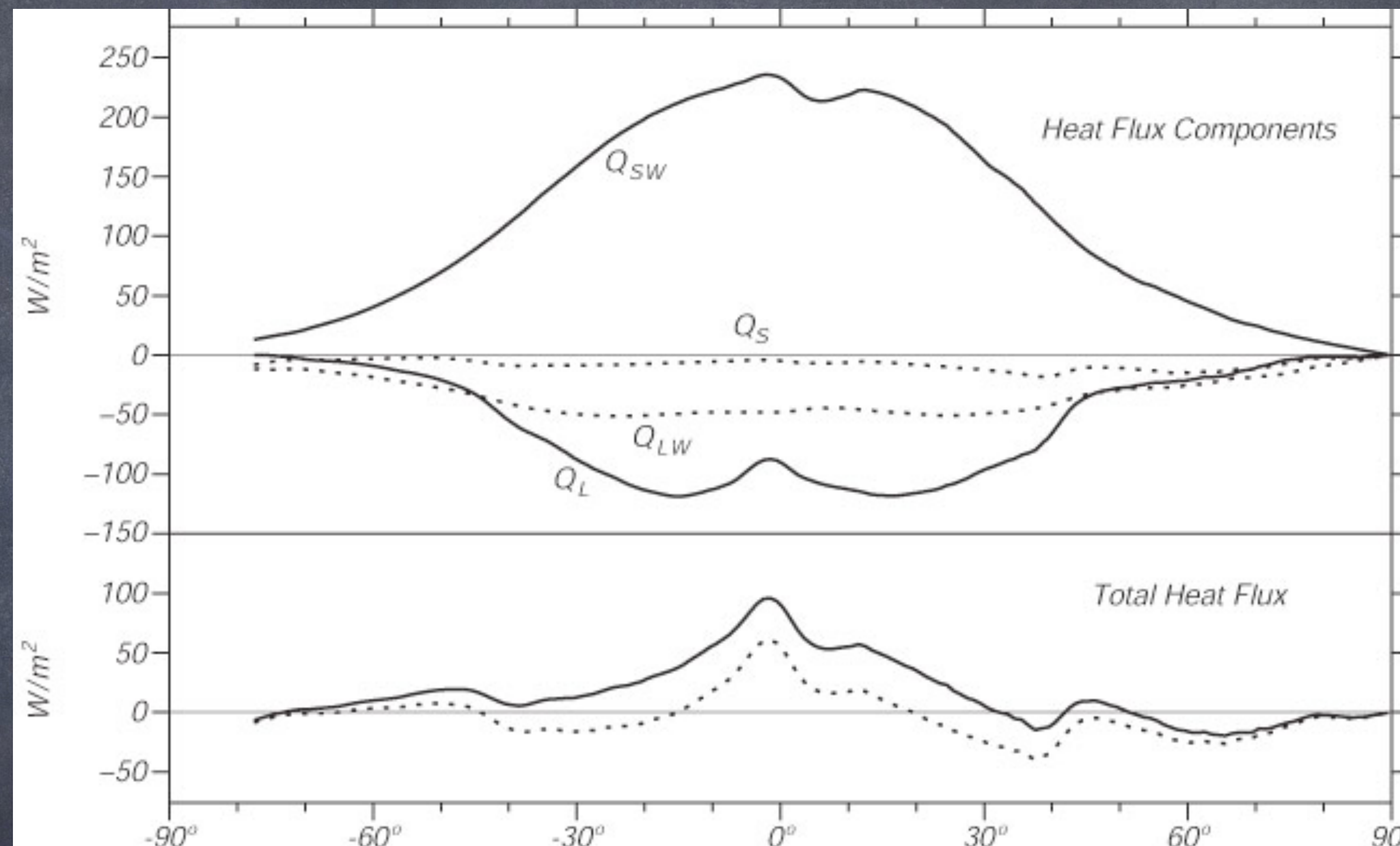
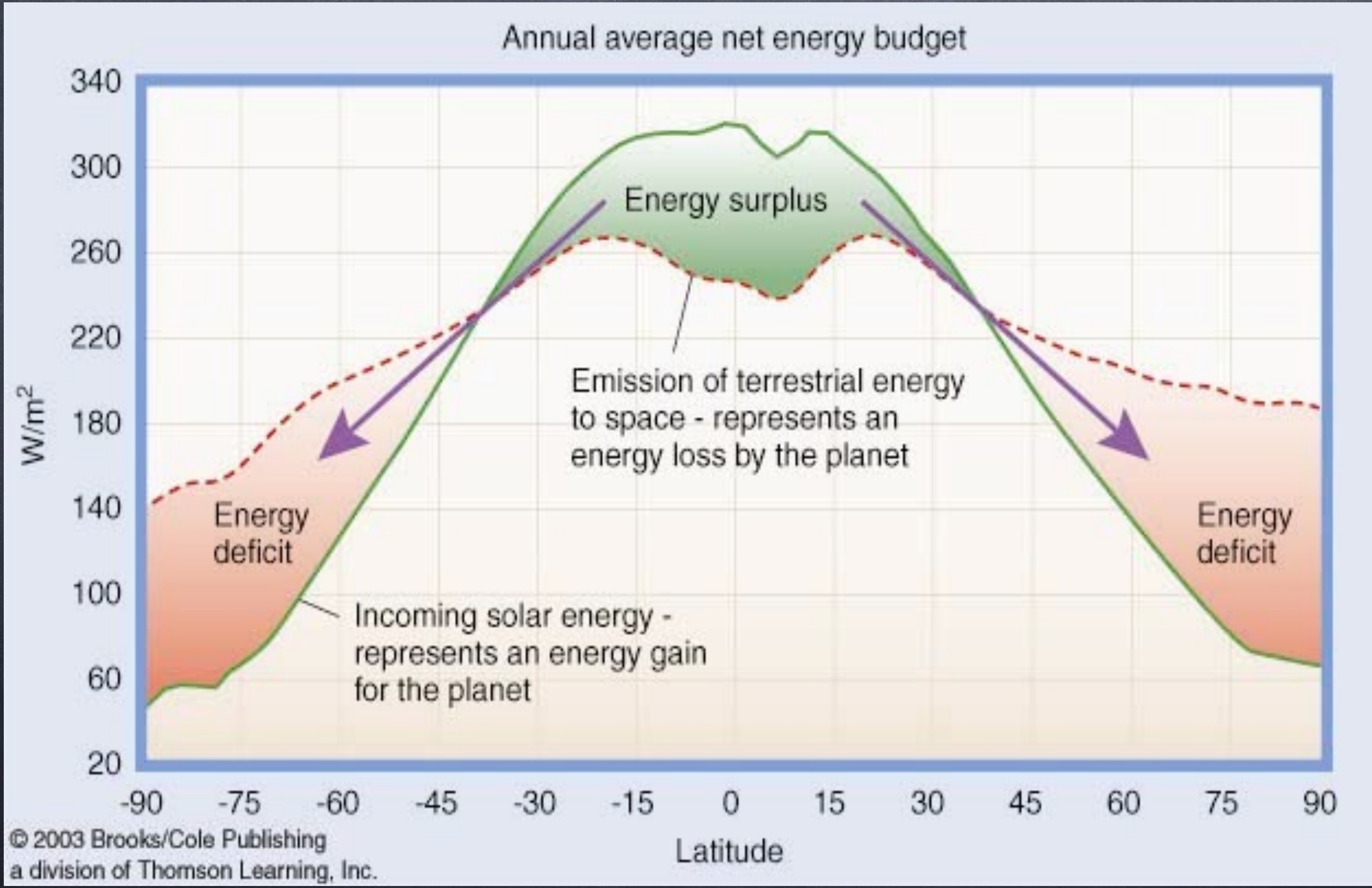
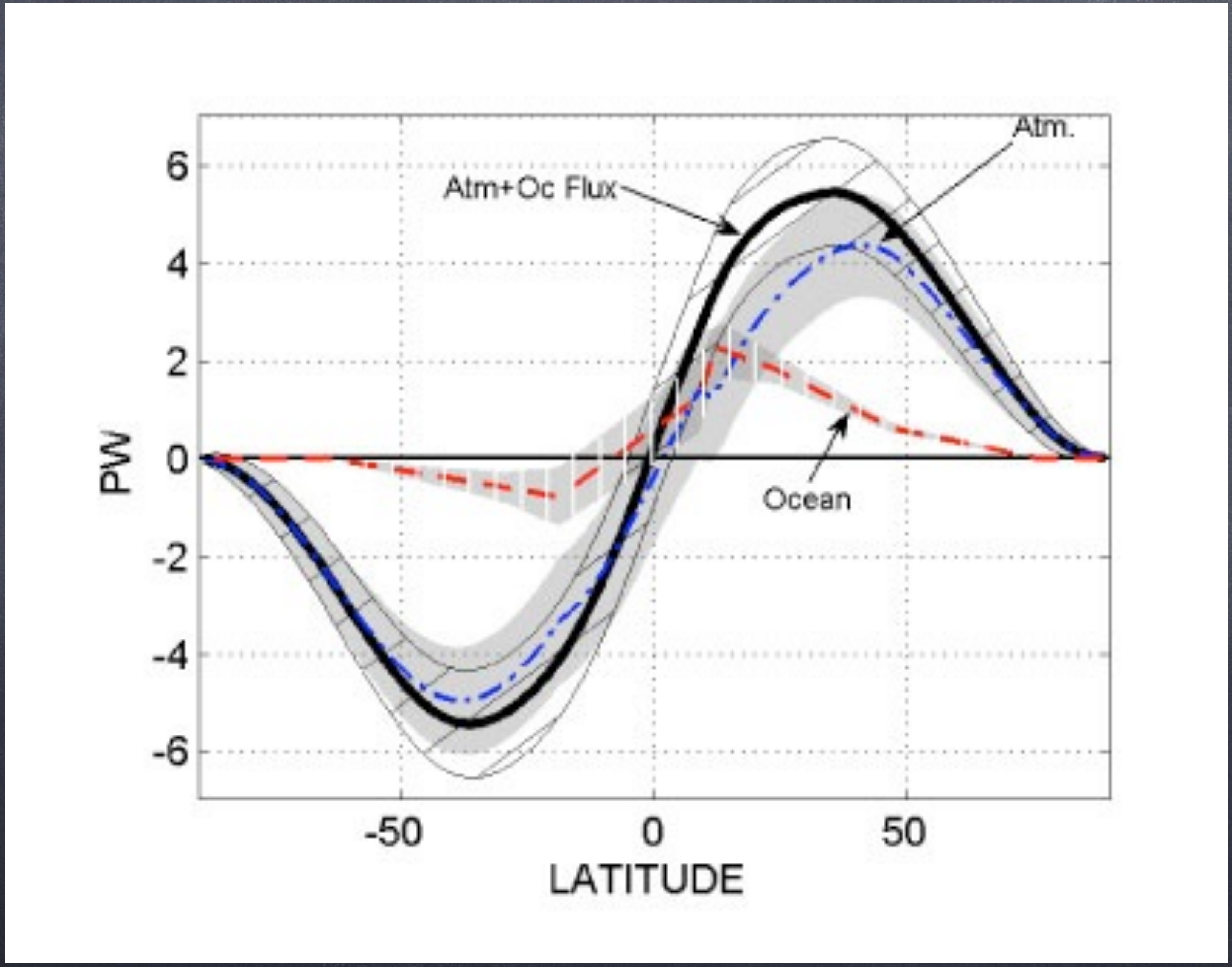


Figure 5.7 Upper: Zonal averages of heat transfer to the ocean by insolation Qsw, and loss by longwave radiation Qlw, sensible heat flux Qs, and latent heat flux Ql, calculated by DaSilva, Young, and Levitus (1995) using the COADS data set.
Lower: Net heat flux through the sea surface calculated from the data above (solid line) and net heat flux constrained to give heat and fresh-water transports by the ocean that match independent calculations of these transports.

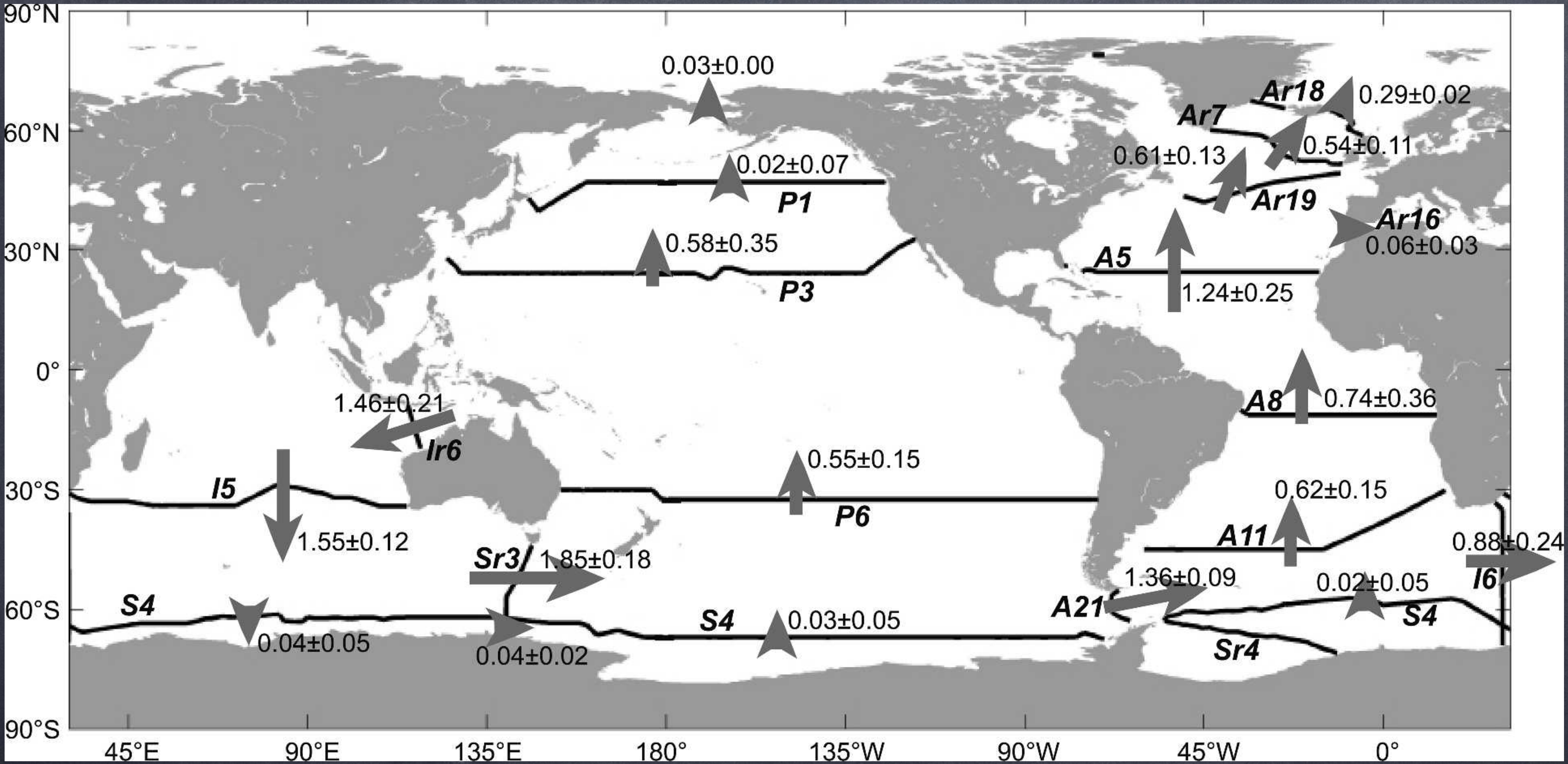
Global energy budget at top of atmosphere with latitude



Oceanic and atmospheric meridional heat flux



Meridional oceanic heat fluxes



Lumpkin and Speer (2007)