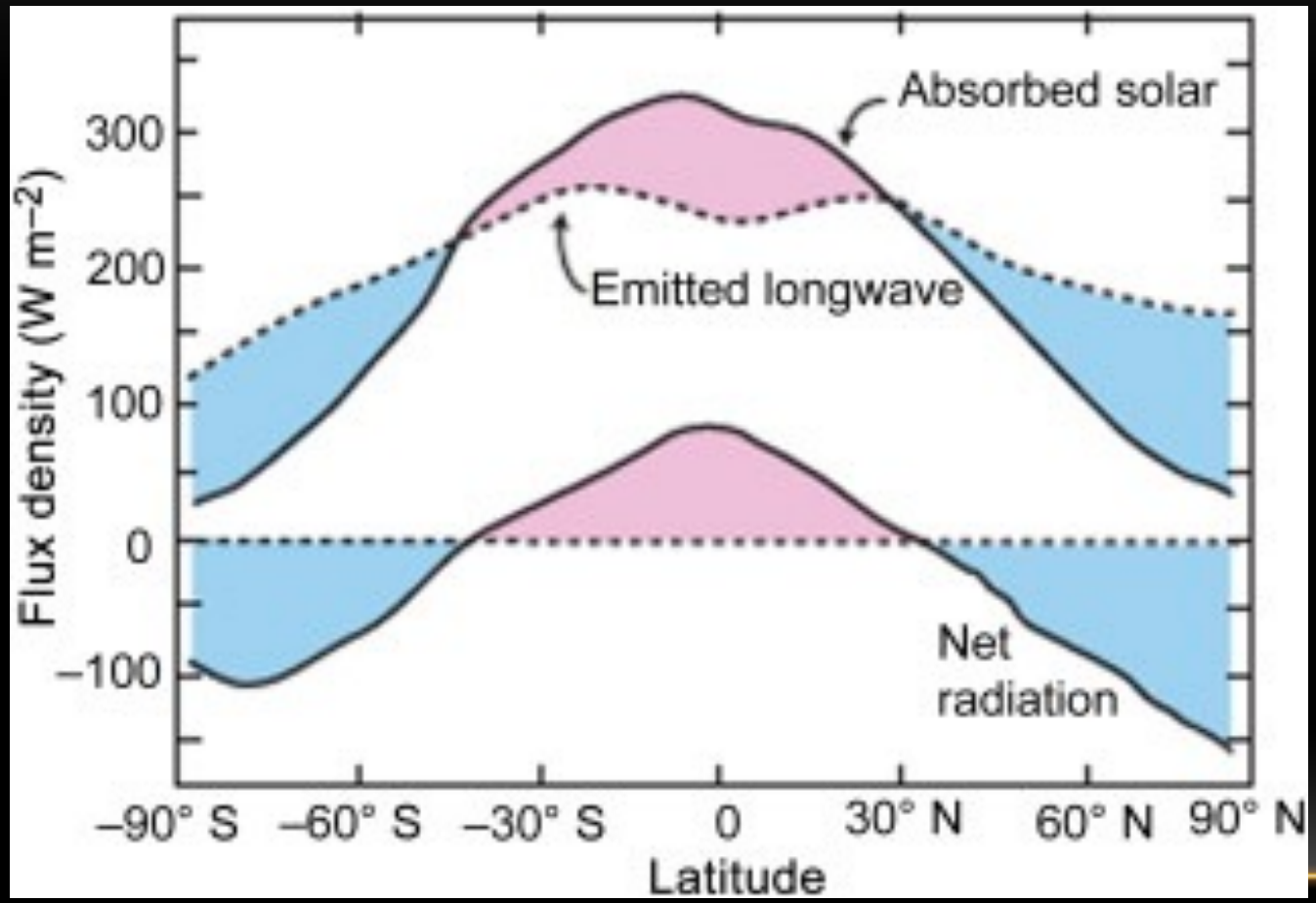
Atmospheric General Circulation

Outline

- The zonally symmetric circulation (i.e., the zonal mean circulation, in the latitude-height plane)
  - The Hadley circulation
  - ITCZ
  - Jet streams and storm tracks
- The zonally asymmetric circulation
  - The Walker circulation
  - Monsoons
  - Stationary eddies
- High-frequency eddies (very brief)

Latitudinal variations of SW and LW radiation



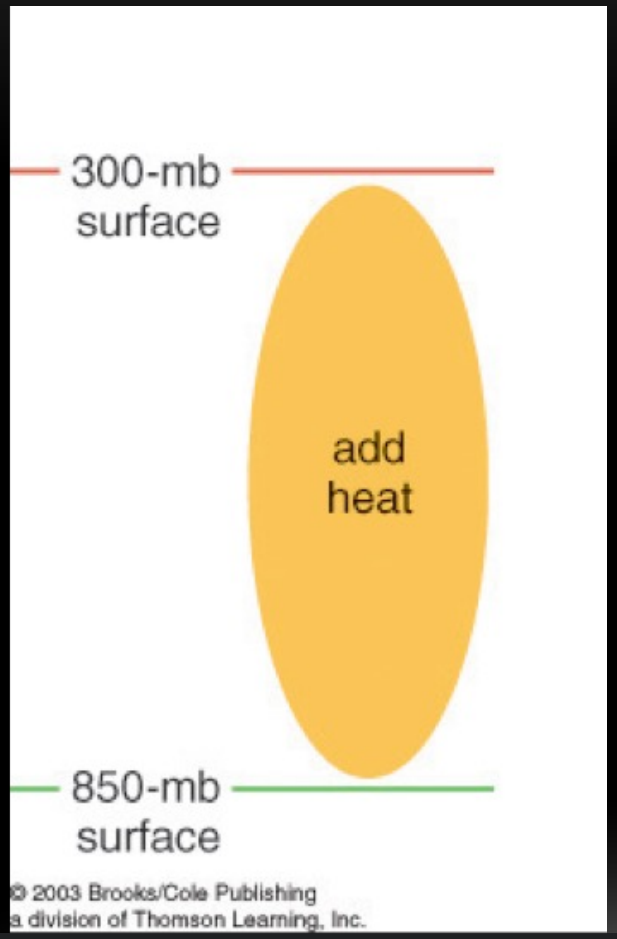
- A strong latitudinal dependency of the net solar flux exists due to the spherical shape of the earth.
- The earth receives more radiation than it emits to space in the tropics.
- Poleward of ~38 degrees, the earth emits more radiation than it receives.
- The Arctic serves as the northern hemisphere “heat sink” for the global climate system.

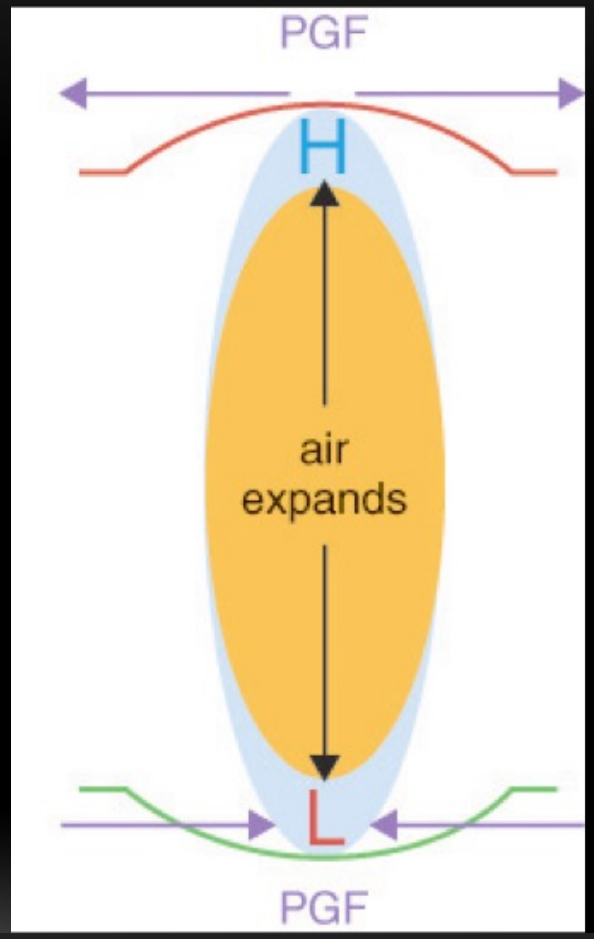
Zonally averaged components of the annual mean absorbed solar flux, emitted thermal infrared flux (or OLR), and net radiative flux at the top of the atmosphere (originally presented by Vonder Haar and Suomi (1971), Stephens *et al.* (1981), and more recently by Hartmann (1994).

Hydrostatic Balance

What upper-level and low-level pressure anomalies would you expect when a column warms up?

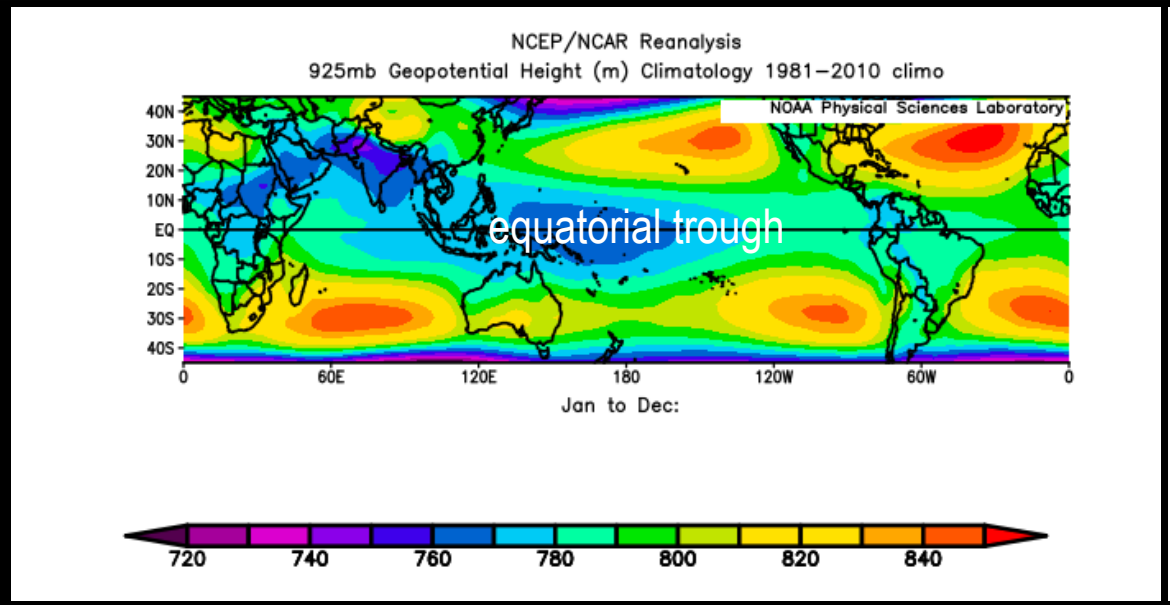
Pause and Think

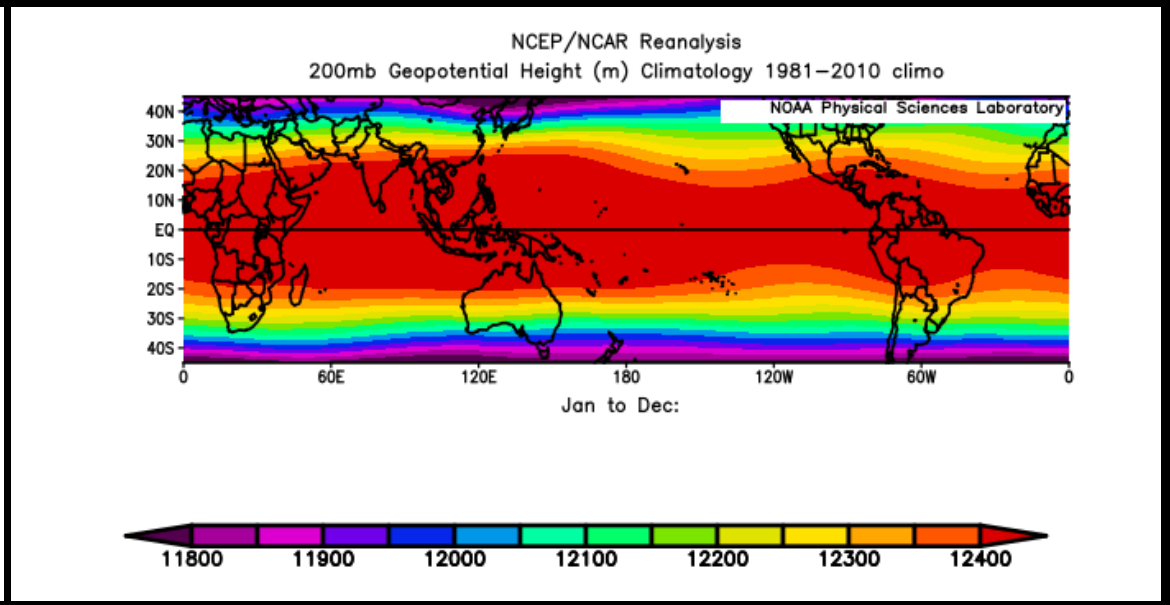




- Hydrostatic considerations requires that the surface (upper tropospheric) pressure decrease (increase) in the warm column, although horizontal pressure gradient in the tropics is generally not as large as in midlatitudes

Long-Term Annual Mean H925 and H200



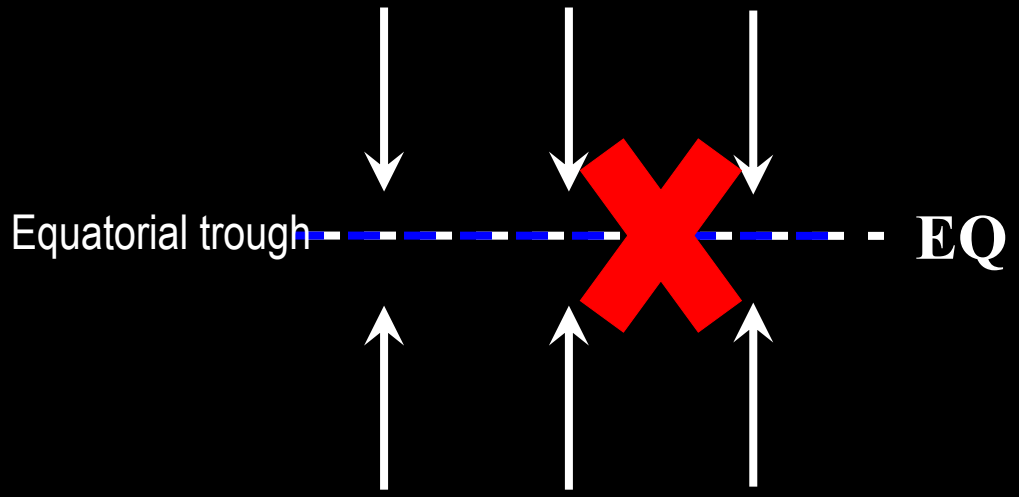


Plots created from https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl

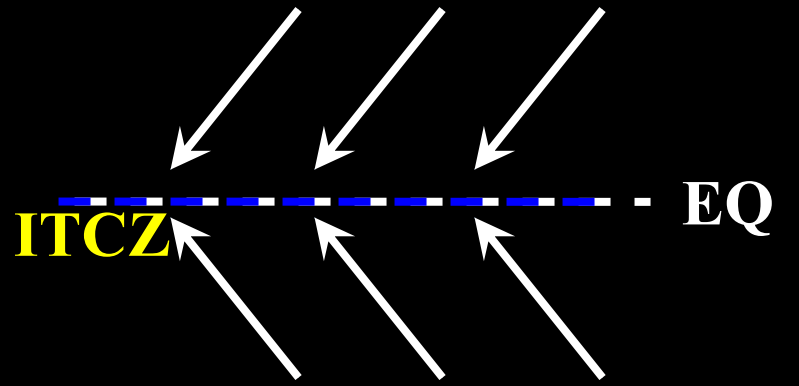
Low-level Wind

Pause and Think

Do we see low-level wind blowing straight towards the equator?



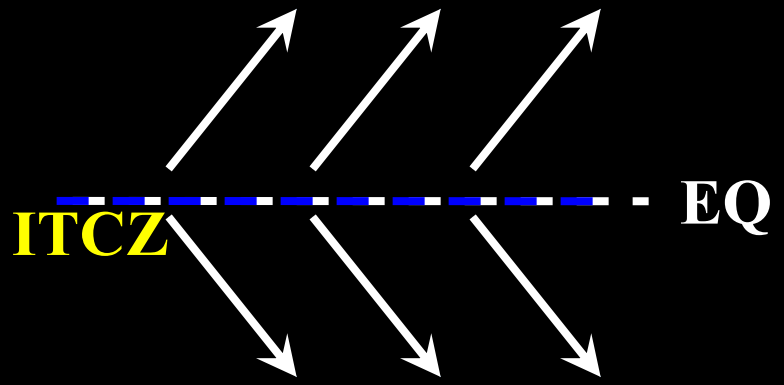
Low-level wind turns westward due to the Coriolis force (i.e., trade wind)



The trade winds converge from both hemispheres toward the equator. The ascent region with clouds is called the *Inter-Tropical Convergence Zone* (ITCZ).

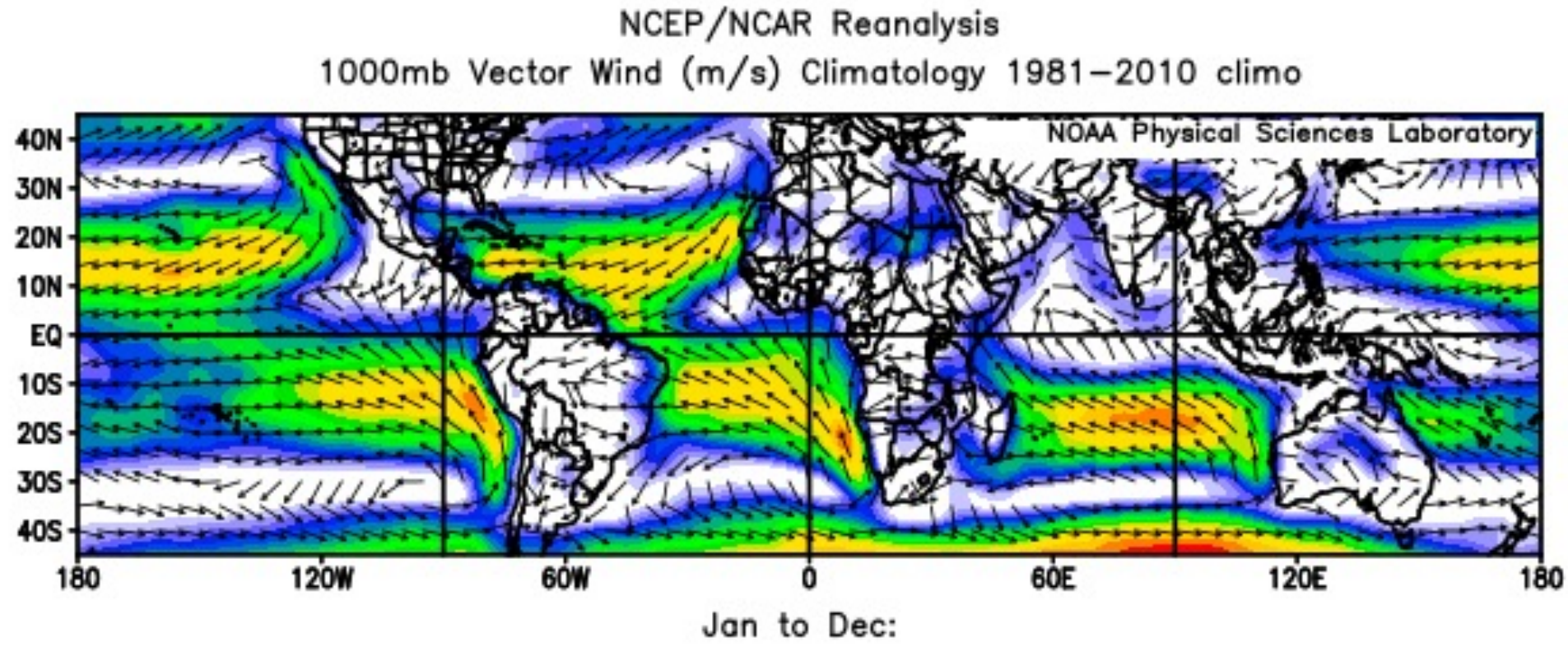
Upper-level Wind

Upper-level wind turns eastward due to the Coriolis force and contributes to the midlatitude westerly jets

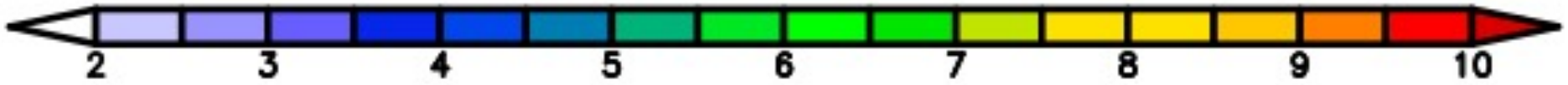


The ITCZ is characterized by upper-level divergence or poleward flow in both hemispheres.

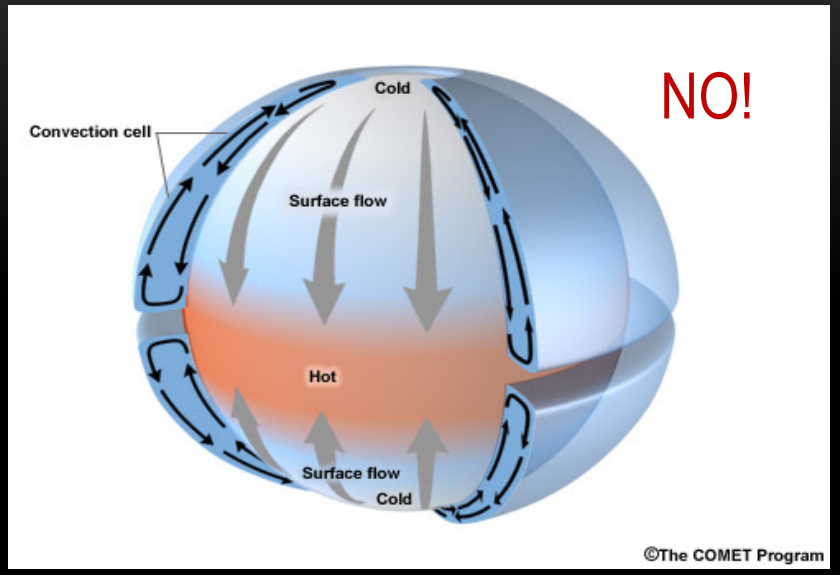
The Long-term Mean Annual Mean 1000-hPa Wind



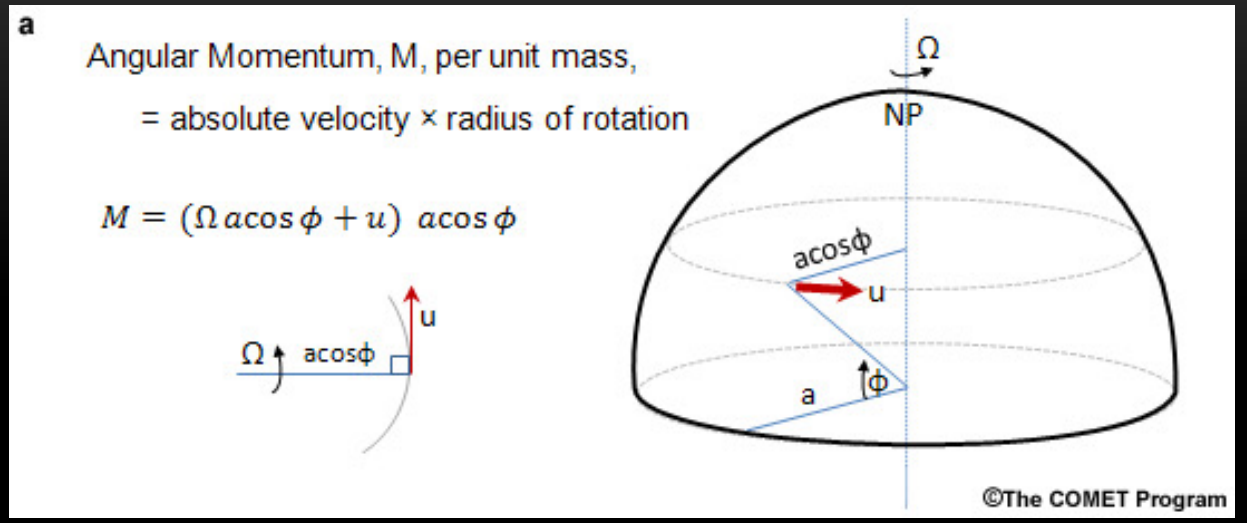
Plots created from https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl



Do we have a single-cell overturning circulation?



NO!

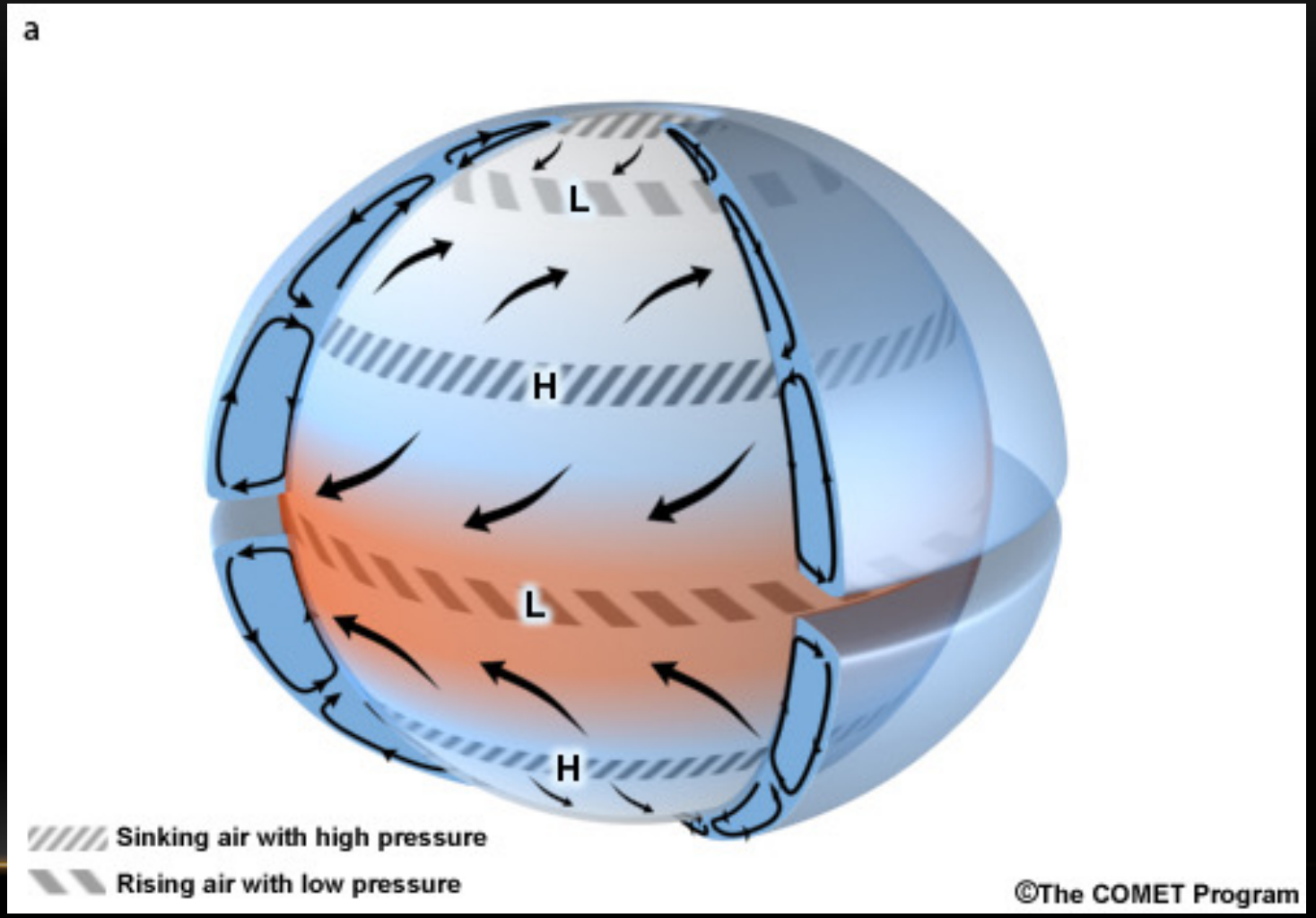


Angular momentum at various latitudes and induced relative zonal winds:

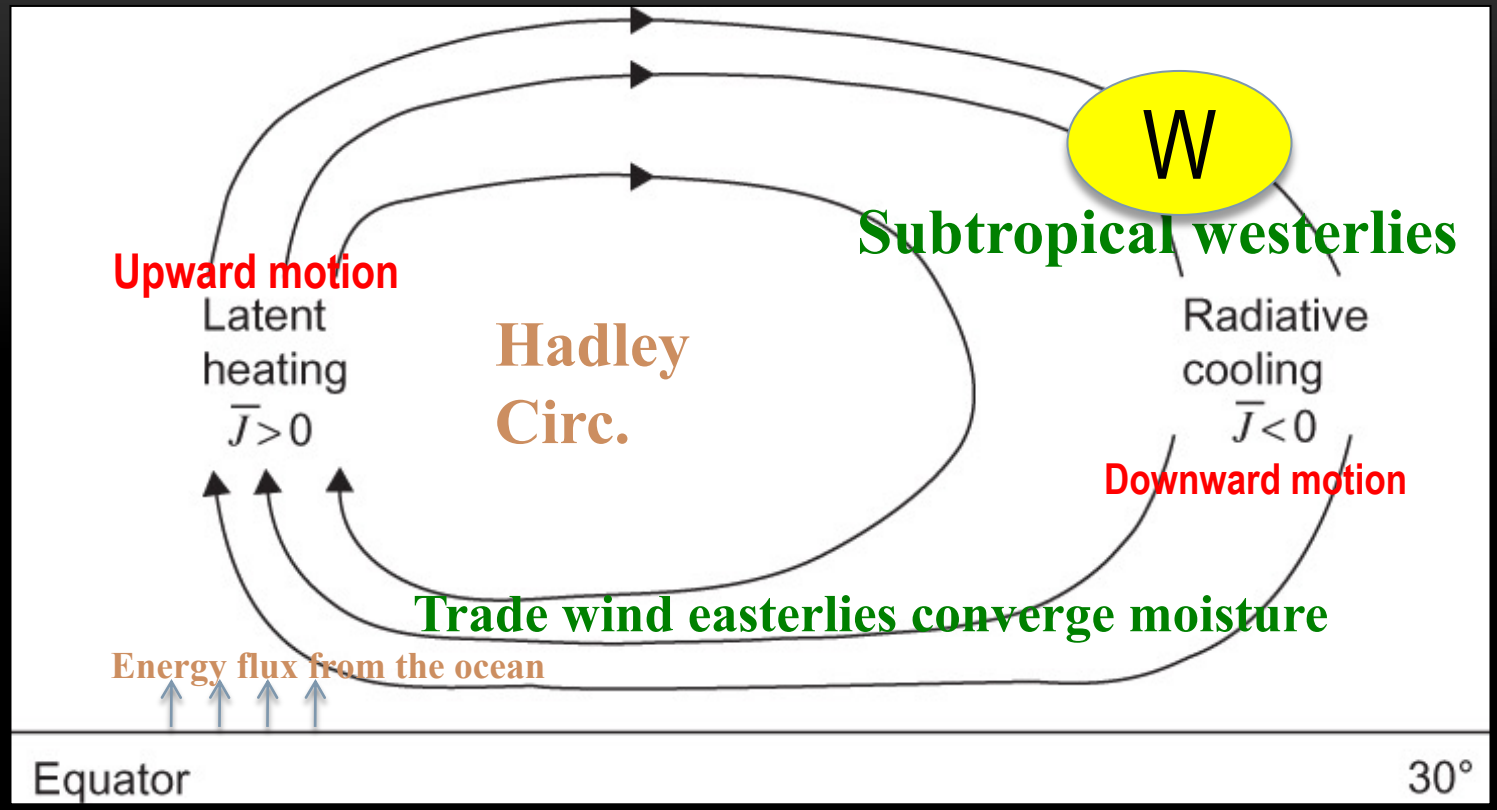
Latitude	Earth's Angular Momentum (EAM) $\times 10^9$ m^2 s^{-1}	Induced Earth-relative wind (m s^{-1})
EQ (0°)	$EAM_{EQ} = M_{EQ} = 3.0$	0
±30°	$EAM_{30°} = 2.2$	134
±45°	$EAM_{45°} = 1.5$	327 (~ speed of sound)
±60°	$EAM_{60°} = 0.4$	697
±90°	$EAM_{90°} = 0$	→ ∞ !!

Three-cell model

- Three cell circulation: Hadley + Ferrel + polar cells
- The Hadley and polar cells are thermally direct vertical circulation, and the Ferell cell is a thermally indirect circulation.



Poleward energy and momentum transport

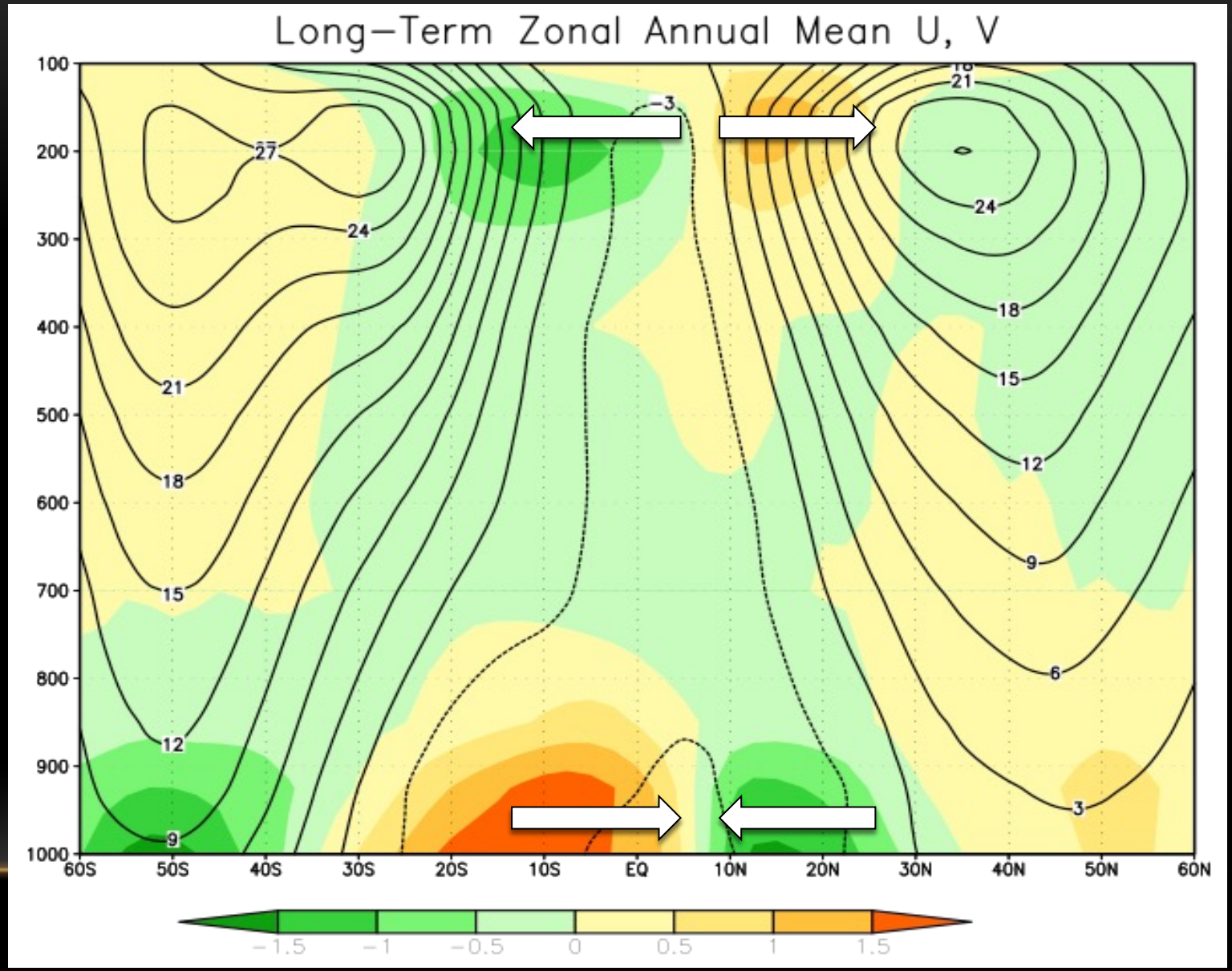


- The low-level prevailing wind is the trade wind easterlies.
- The trade winds converge toward the equator and then rise in the ITCZ (Intertropical convergence zone, collocated with the equatorial trough).
- The flow then goes poleward in the upper levels and subsides into the subtropical high-pressure zones. The poleward flow turns eastward under the Coriolis force and results in the westerly jets.
- The subtropics are characterized by relatively high surface pressure and arid climates, where evaporation exceeds precipitation and most of the world's large deserts reside.

The Hadley Circ. and the Subtropical Jet

Key features:

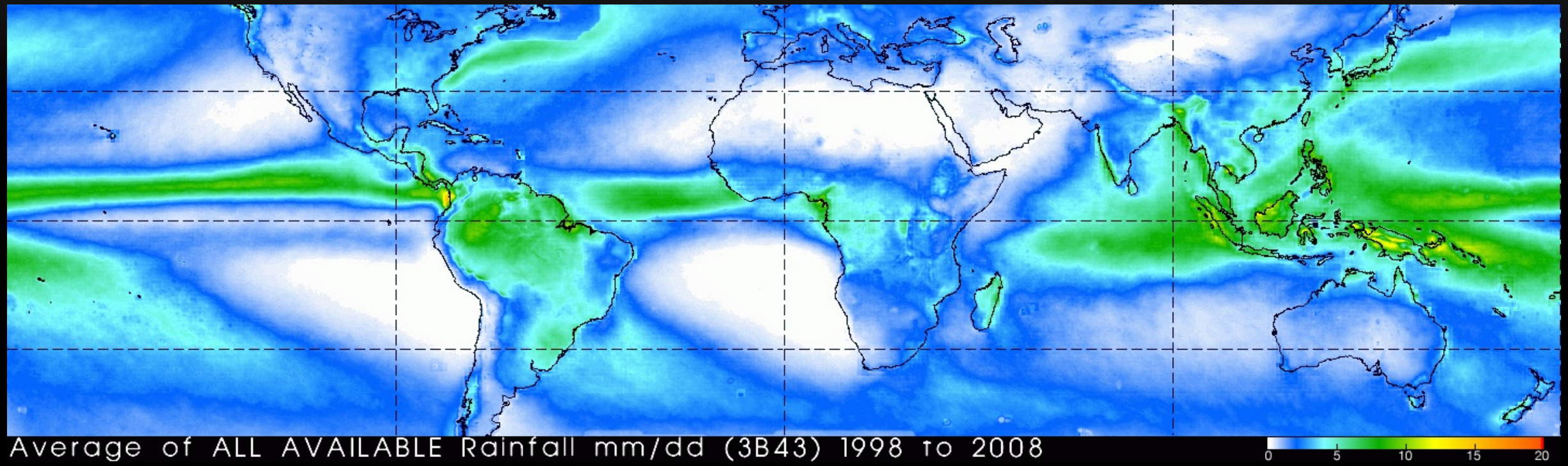
- Low-level convergence
- Upper-level divergence
- Low-level easterlies in the tropics
- Upper-level westerly jets



Legend (annual mean meridional flow from NNR2):
Shading: meridional wind V
Contours: zonal wind U

Plot produced using the NCEP/NCAR reanalysis

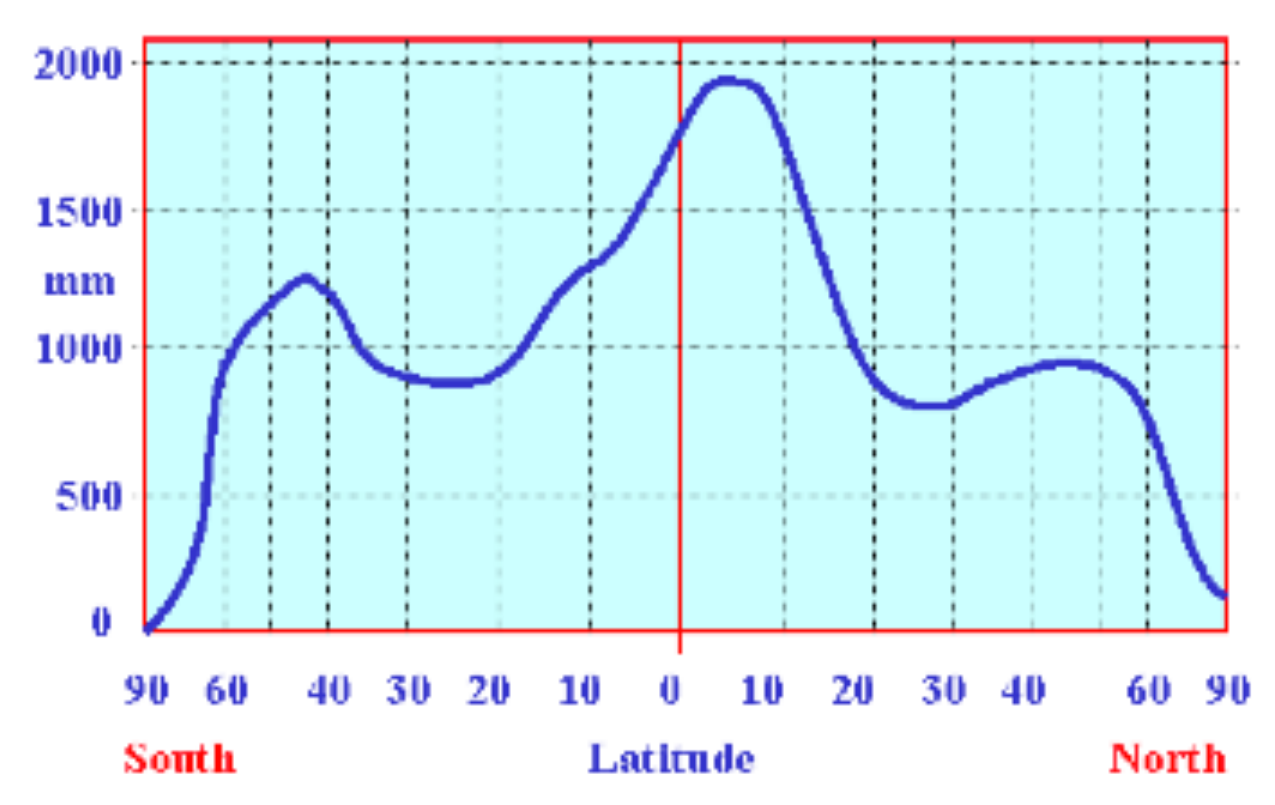
Annual Mean Precipitation (TRMM)



- *Can you identify the ascending and the descending branches of the Hadley circulation on the map?*
- Heavy rainfall occurs the tropics along the ITCZ/monsoon regions, corresponding to the ascending branch of the Hadley circulation, while the subtropics are relatively dry due to the descending motion.

Figure credit: Precipitation Processing System/NASA Goddard

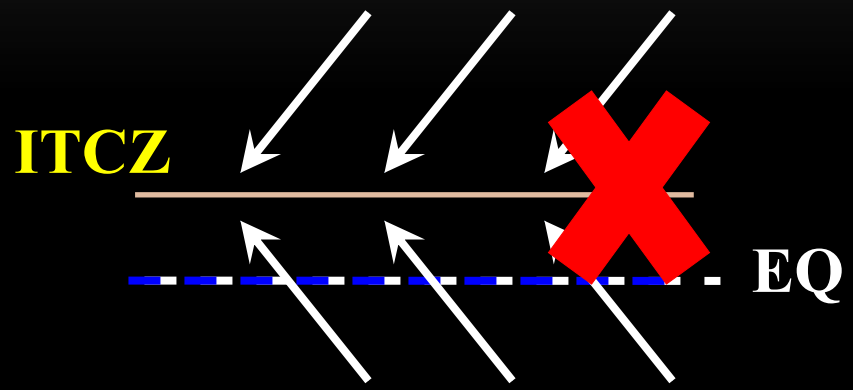
Annual Mean Precipitation as a Function of Latitude

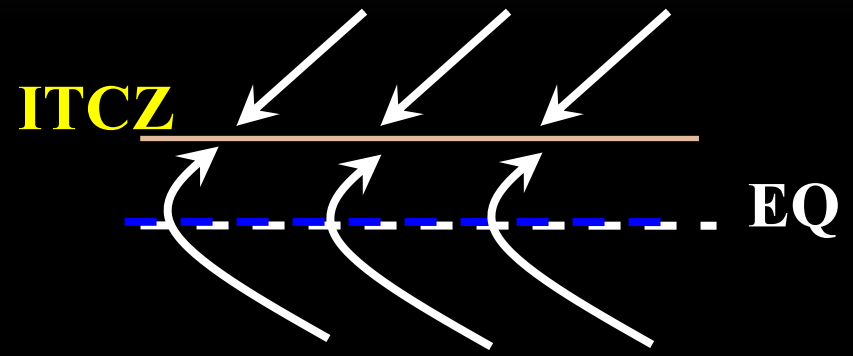


- The mean ITCZ, however, is located off the equator.
- *How does this affect the atmospheric circulation?*

Figure credit: Roger Smith from https://www.meteo.physik.uni-muenchen.de/~roger

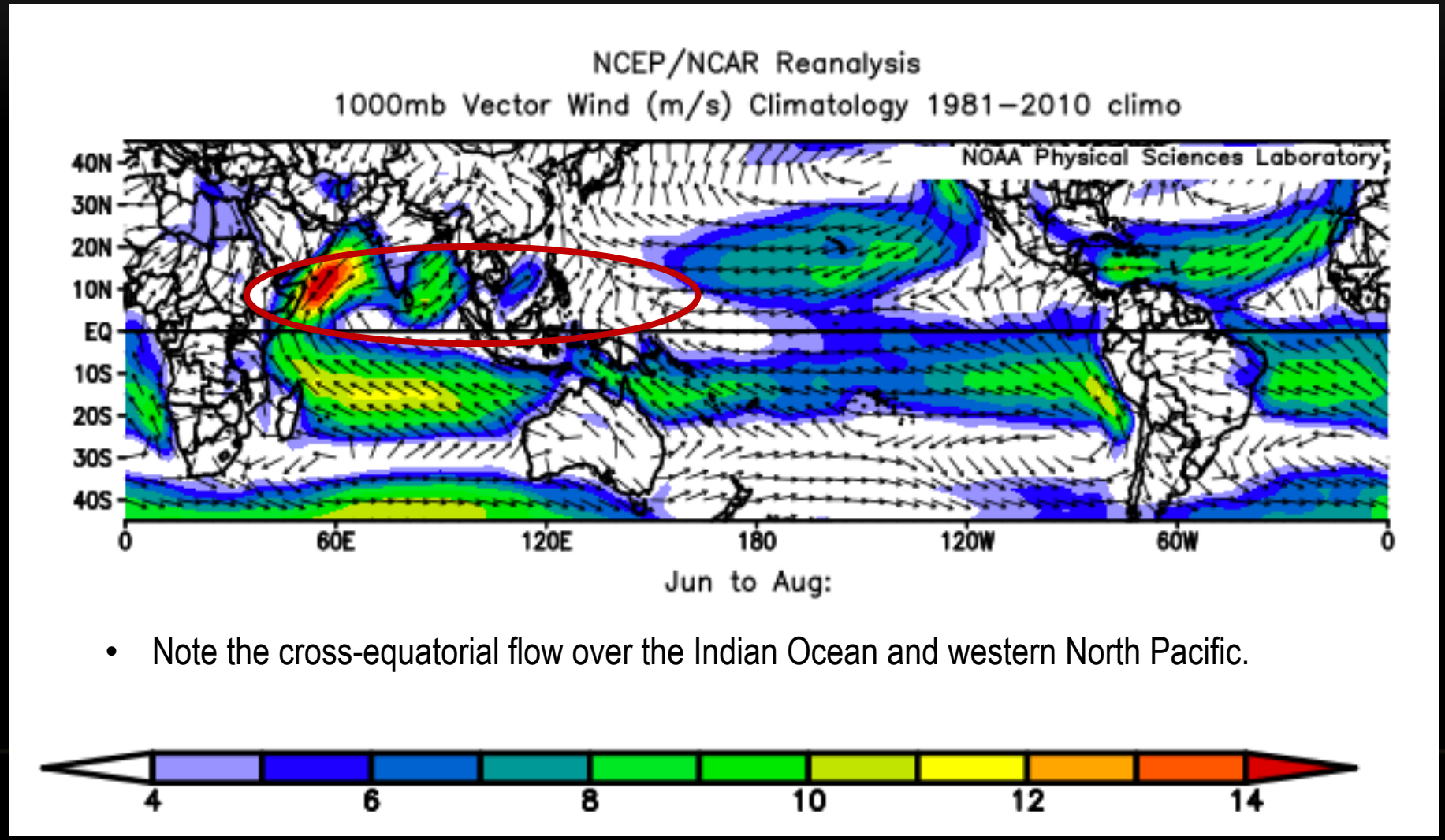
ITCZ off the Equator: which low-level flow pattern is correct?





- Note the turning of the cross-equatorial flow

The Long-term JJA Mean 1000-hPa Wind



- Note the cross-equatorial flow over the Indian Ocean and western North Pacific.

Plots created from https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl

References

- Cook, K. H., 2013: Section 2.1
- COMET: Introduction to Tropical Meteorology, Section 3.1 and 3.2 https://www.meted.ucar.edu/tropical/textbook_2nd_edition/navmenu.php?tab=4
- Understanding Assimilation Systems: How Models Create Their Initial Conditions - version 2. The source of this material is the COMET® Website at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR), sponsored in part through cooperative agreement(s) with the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC) ©1997-2010 University Corporation for Atmospheric Research. All Rights Reserved.