The Abdus Salam International Centre for Theoretical Physics

An Introduction to the Circulation of the Tropics

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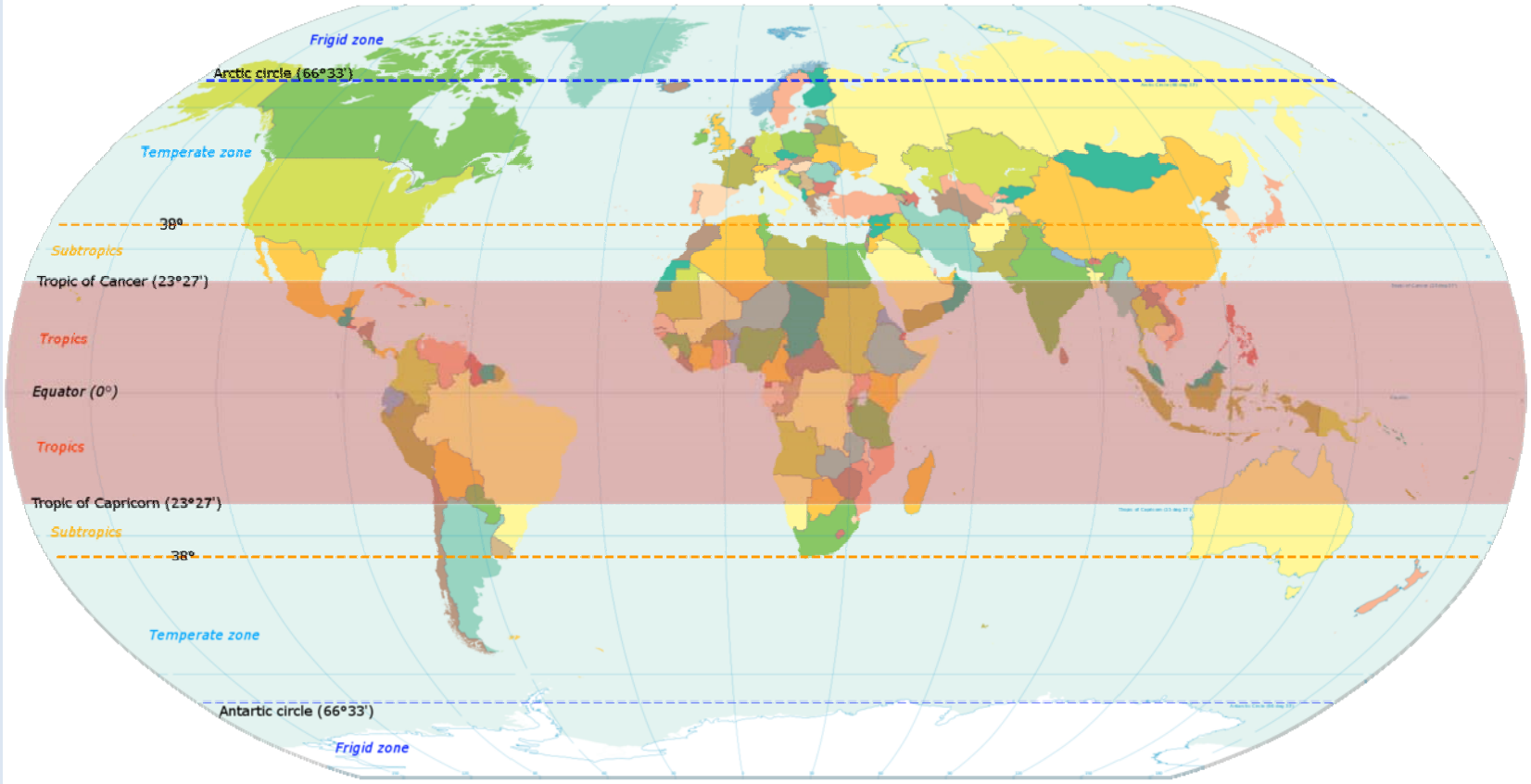
Outline

- Overview
- The observed climatology
- Why is tropical dynamics different from the mid-latitudes dynamics?
- What controls the tropical circulation?
- The Hadley circulation
- Tropical disturbances
- QBO

Geographical location



http://en.wikipedia.org/wiki/File:World_map_indicating_tropics_and_subtropics.png

The Observed Climatology

Air temperature at 2 meters above the ground

Sea level pressure

Near surface wind

Upper level wind

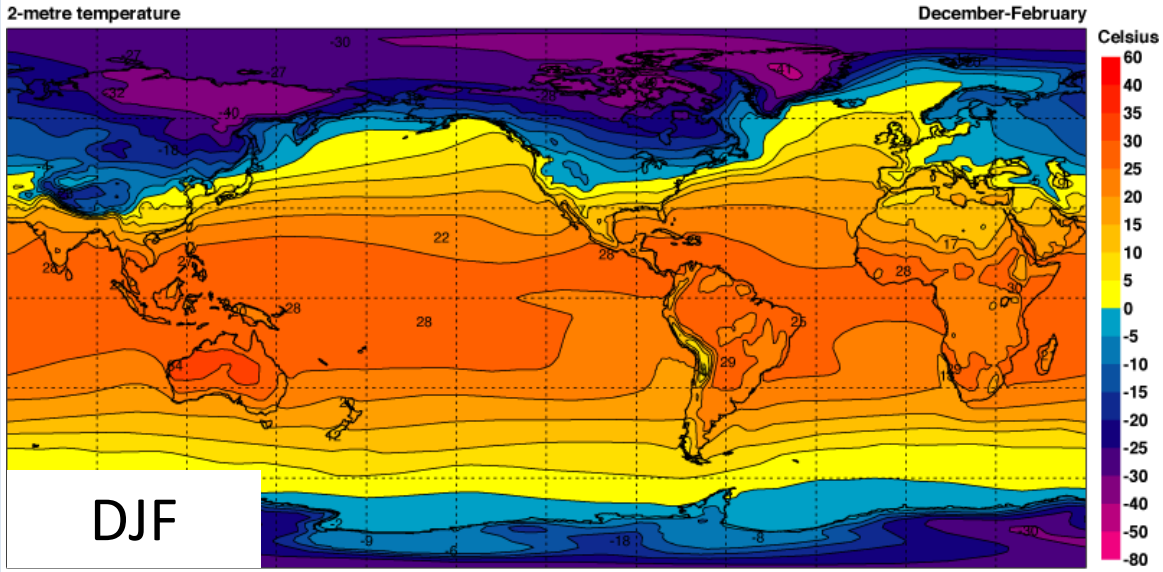
Water vapor

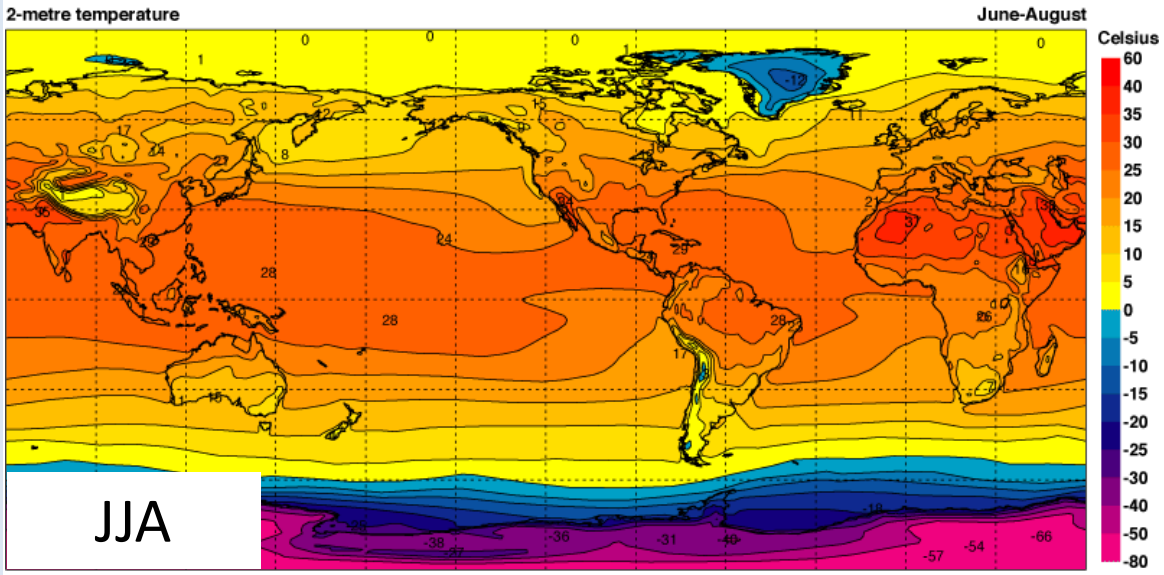
Cloud cover

Precipitation

Intertropical Convergence Zone (ITCZ)

2m Temperature





Ocean ~ 300K (28°C)

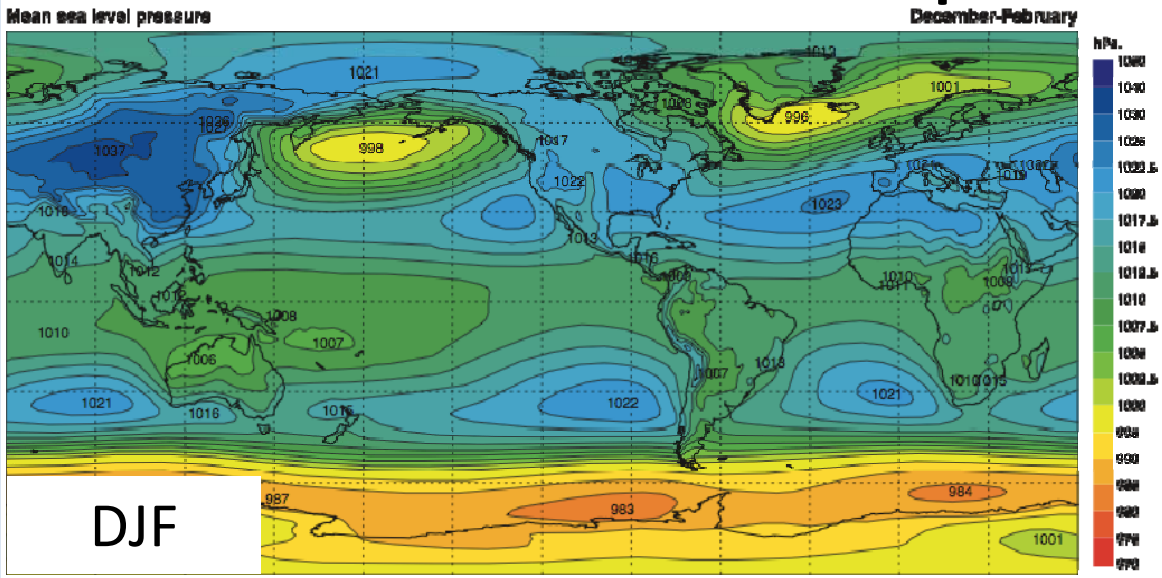
Land ~ 305K (32°C)

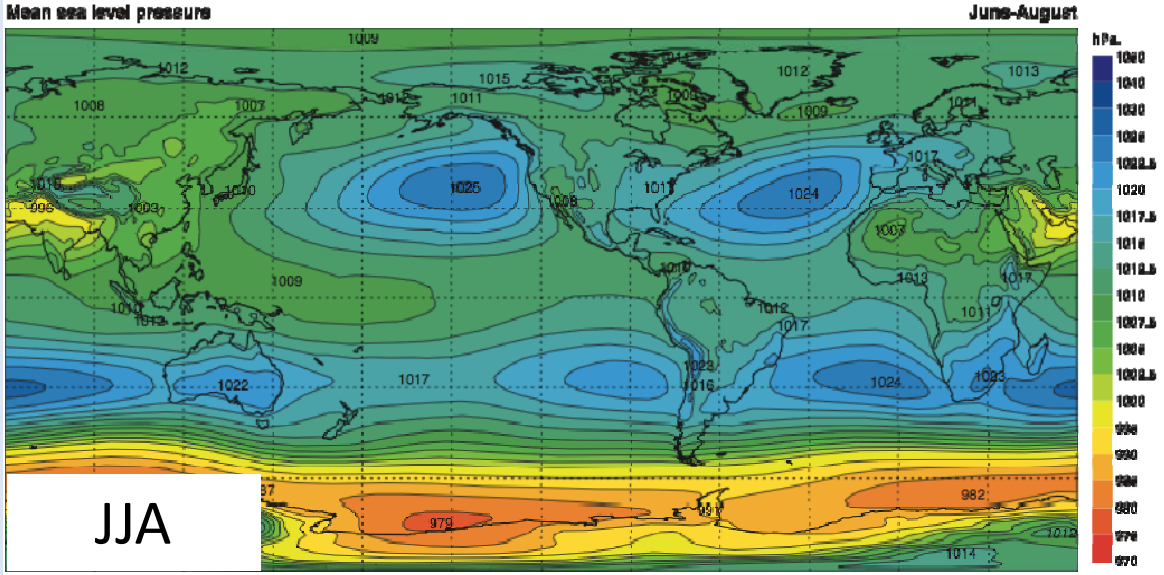
Tropics: uniform heating

Continent: large seasonal variations

http://www.ecmwf.int/research/era/ERA-40/ERA-40_Atlas

Mean sea level pressure



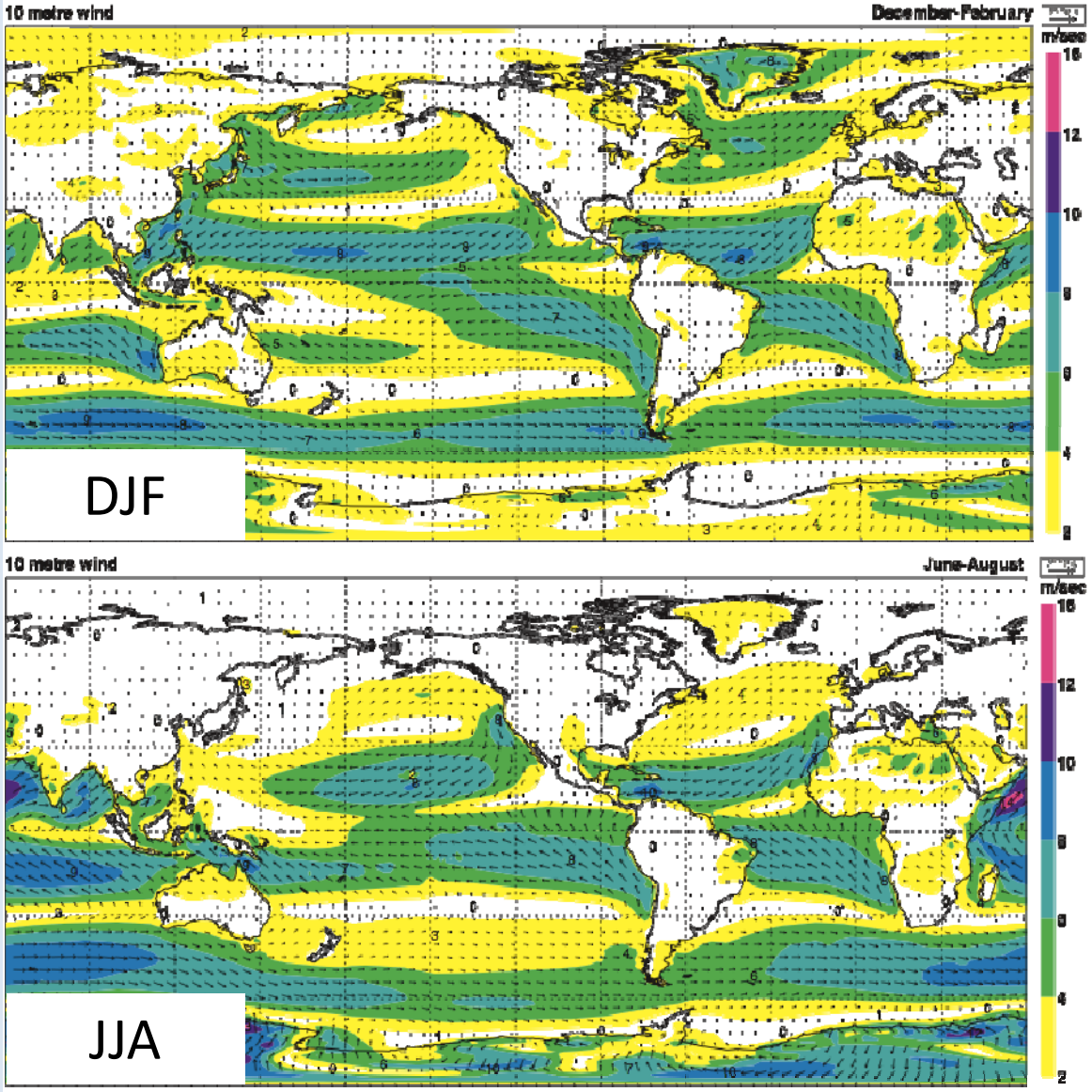


Center of low pressure

near the equator

http://www.ecmwf.int/research/era/ERA-40/ERA-40_Atlas

10m Wind



Maximum easterly flow located at 10^0N

In Atlantic and Eastern Pacific, trade-winds trough is located between 0 and 5^0N

Subtropical ridges merged with continental anticyclones

Strongest northerlies along the equator and near Africa - large pressure gradient between the winter high in the north and low pressure to the south.

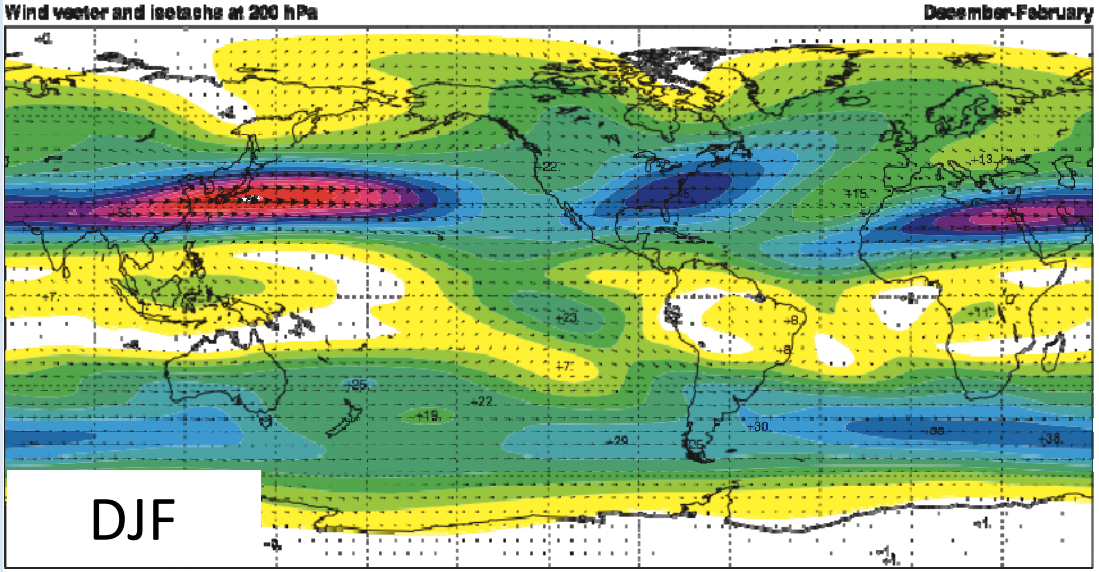
Strong tradewinds between 15^0N and 20^0N

Well established westerly flow over Arabian Sea, India, and Bay of Bengal

East African low-level jet

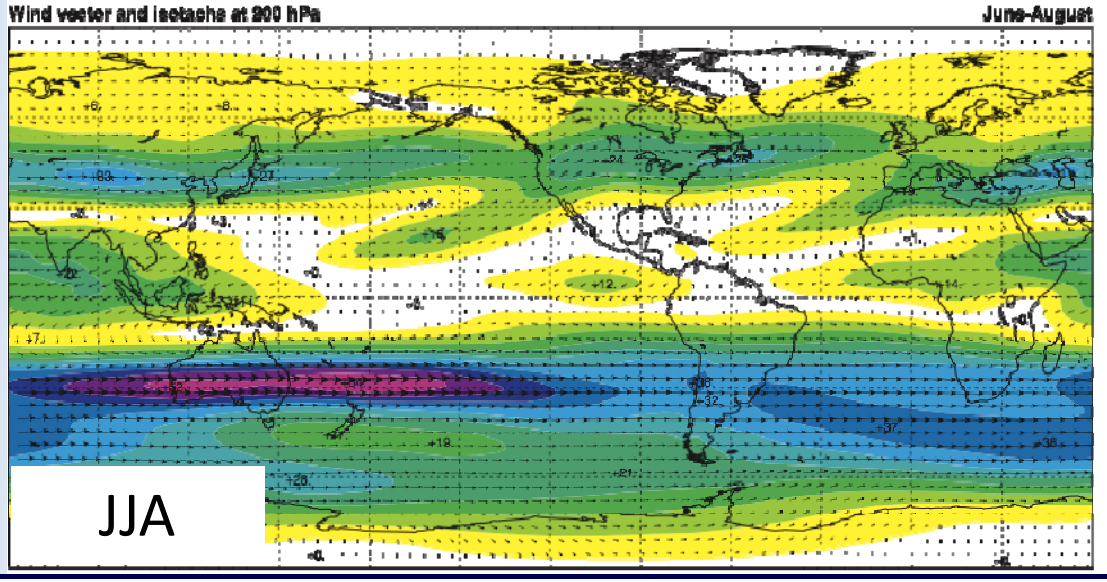
http://www.ecmwf.int/research/era/ERA-40/ERA-40_Atlas

Upper level wind



Subtropical jet streams: 3-wave pattern with maximum wind speeds over North America, Middle East and south of Japan

Eastern Pacific and Atlantic have westerly flow broken by the anticyclone over South America.

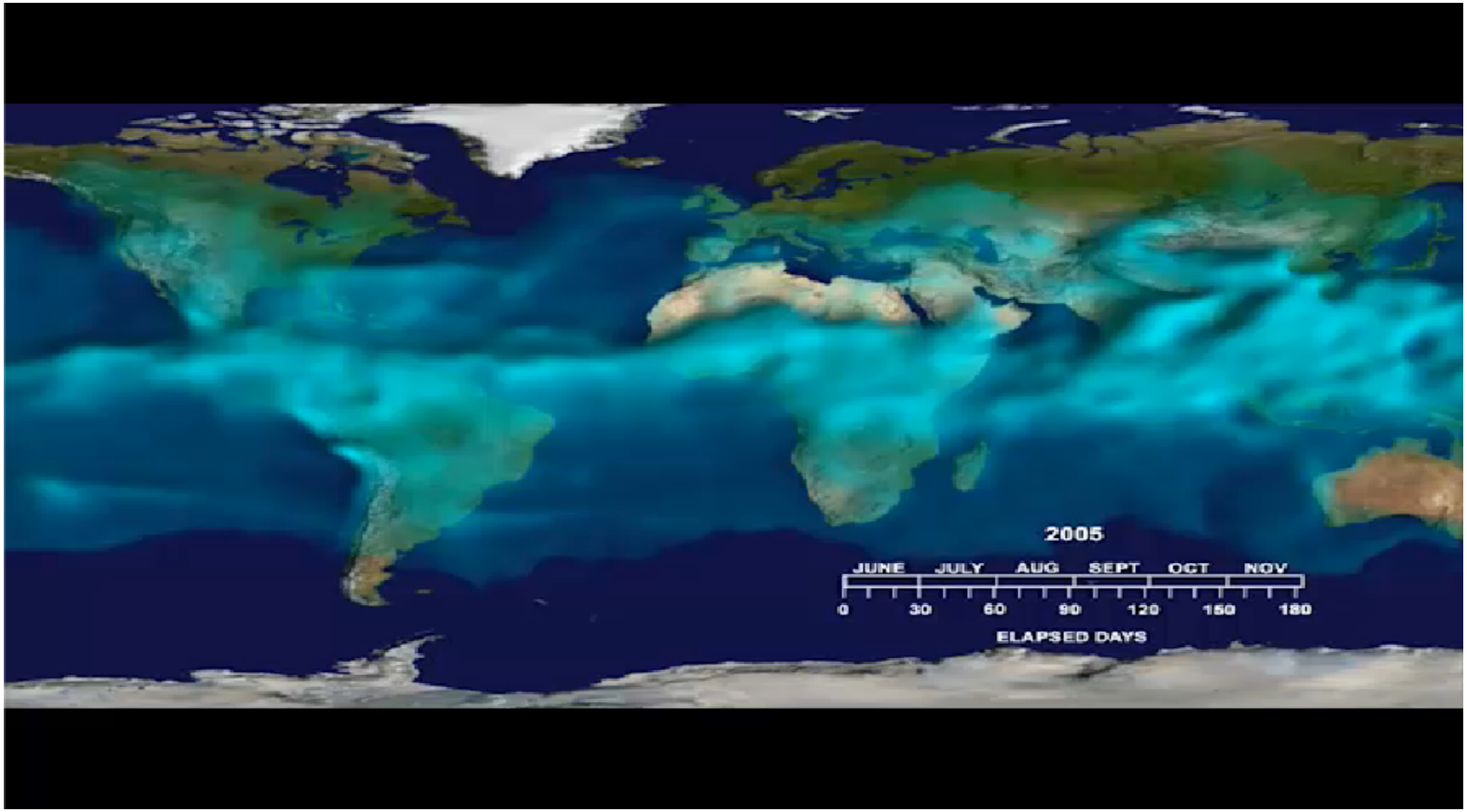


Subtropical jet stream is located near 27^0S, over and east of Australia

The tropical easterly jet extends across the Indian Ocean and Africa

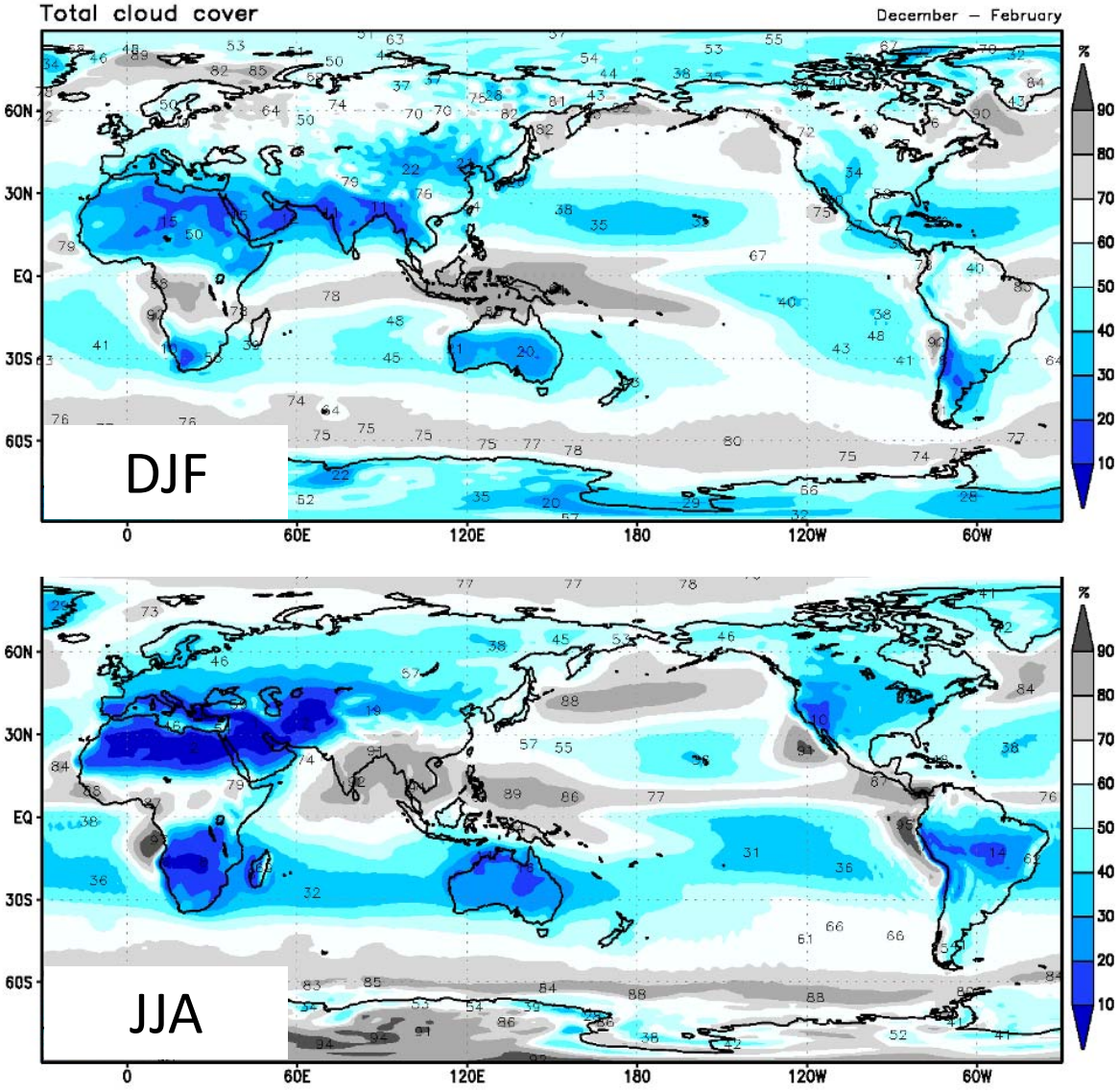
http://www.ecmwf.int/research/era/ERA-40/ERA-40_Atlas

Water Vapor



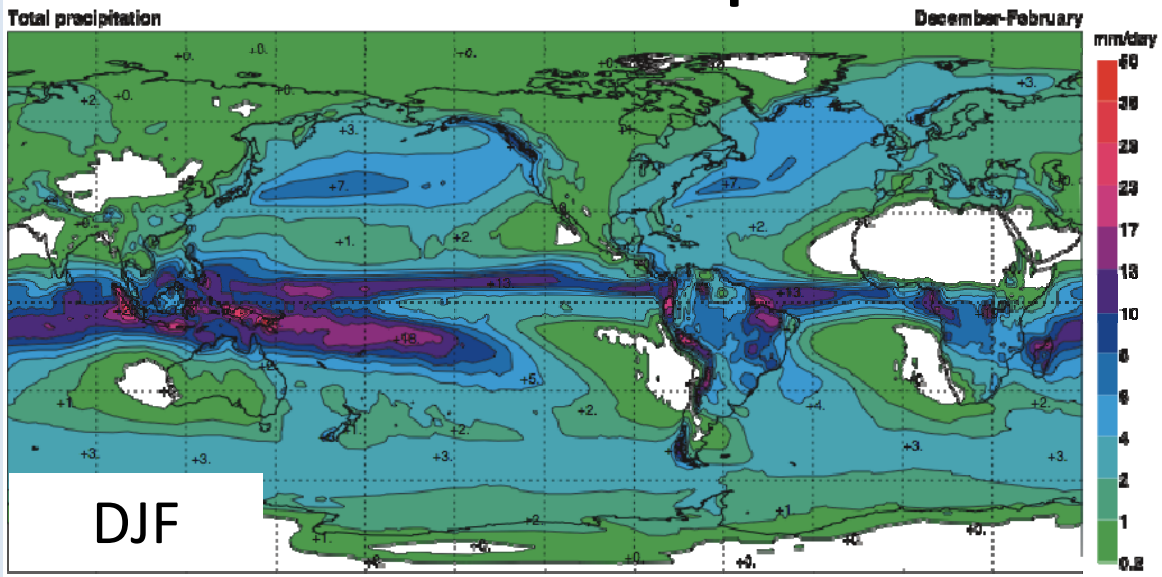
http://photojournal.jpl.nasa.gov/animation/PIA11424

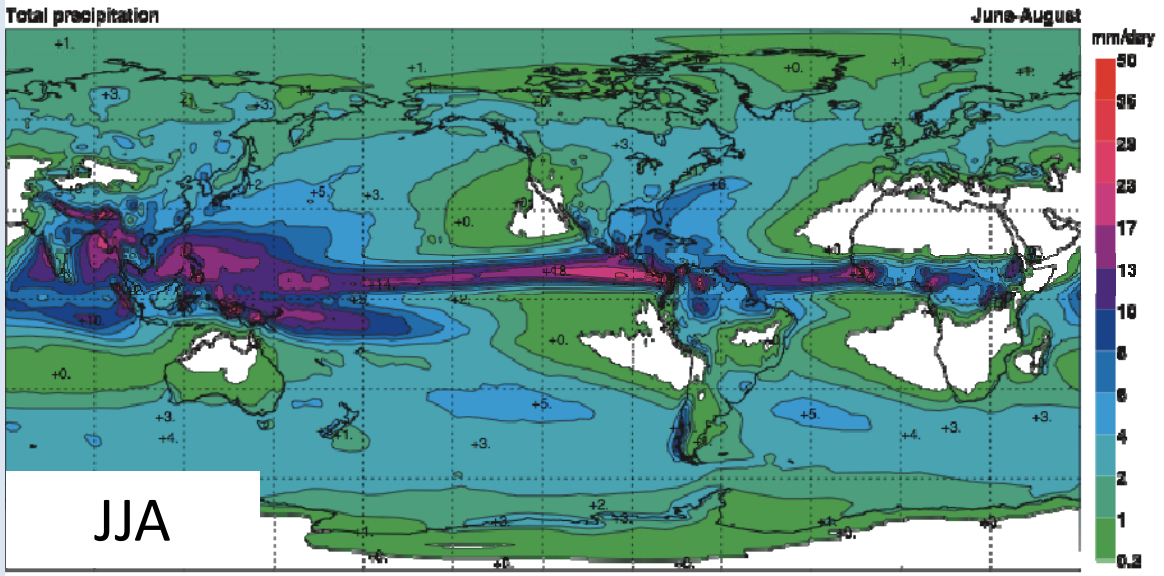
Cloud cover



http://ds.data.jma.go.jp/gmd/jra/atlas/eng/atlas-tope.htm

Precipitation





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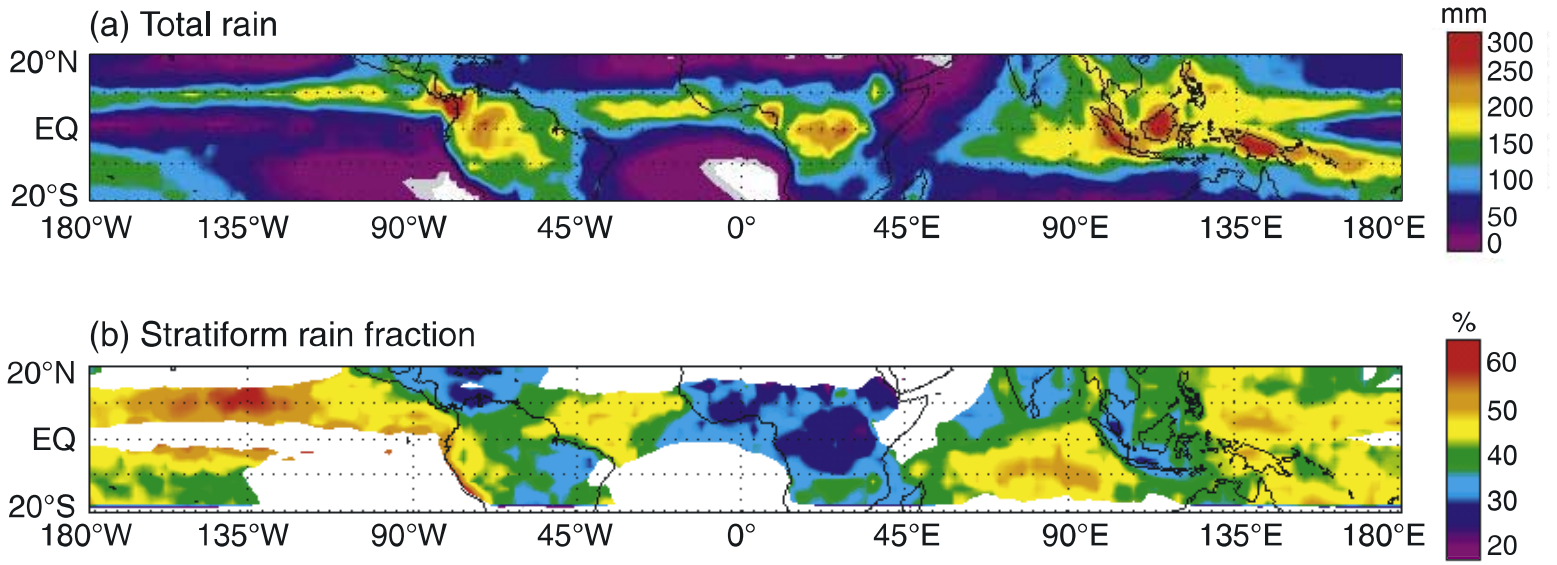
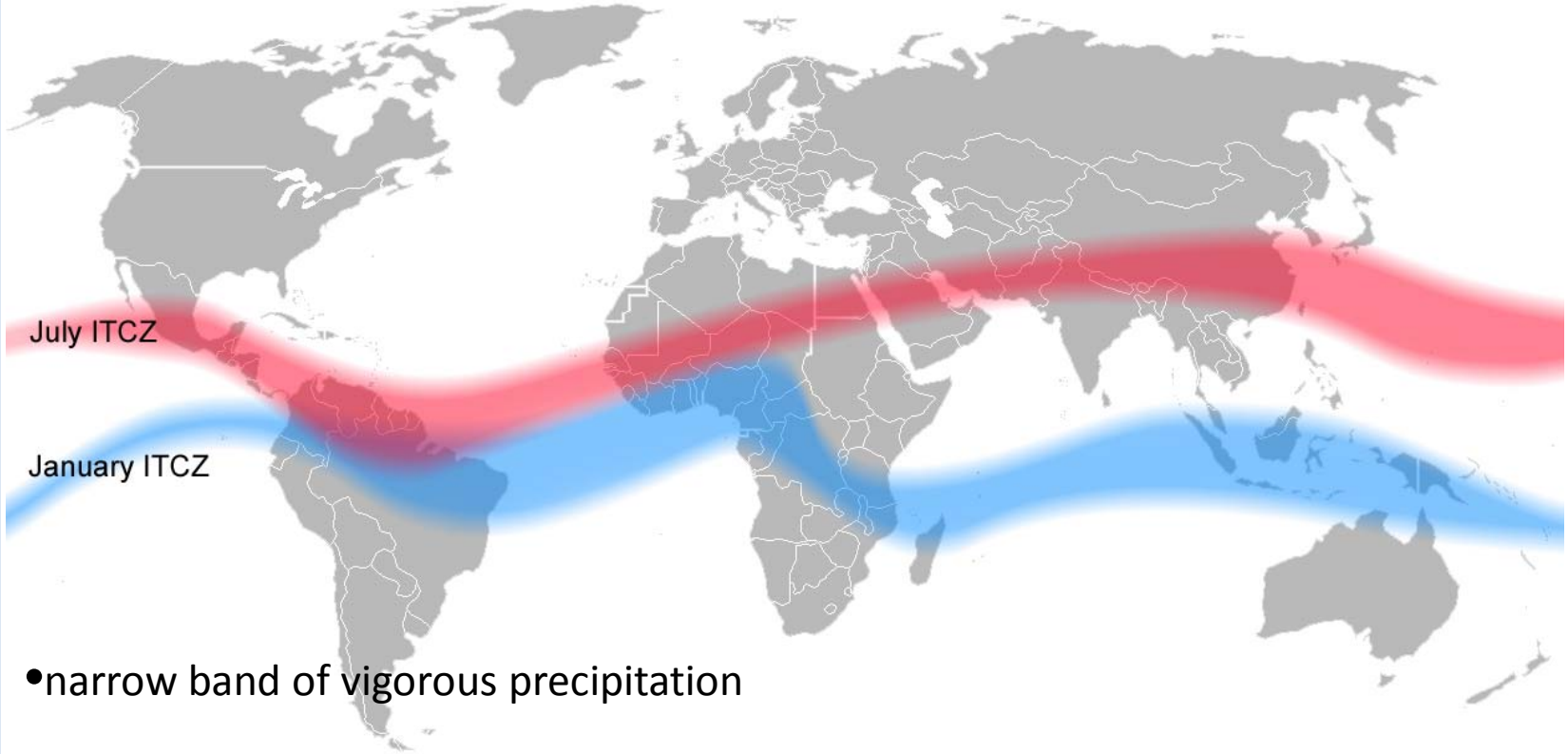
Tropical Precipitation



Schumacher and Houze, 2003

Intertropical convergence zone



- narrow band of vigorous precipitation
- generally located near the maximum sea surface temp
- the precipitation exceeds evaporation by a factor of 2
- undergoes large spatial and temporal variations

http://en.wikipedia.org/wiki/File:ITCZ_january-july.png

Why horizontal gradients are smooth?

$$\frac{D\mathbf{V}}{Dt} = -\frac{1}{\rho}\nabla p - \mathbf{k} \times f\mathbf{V}$$

Scale analysis:

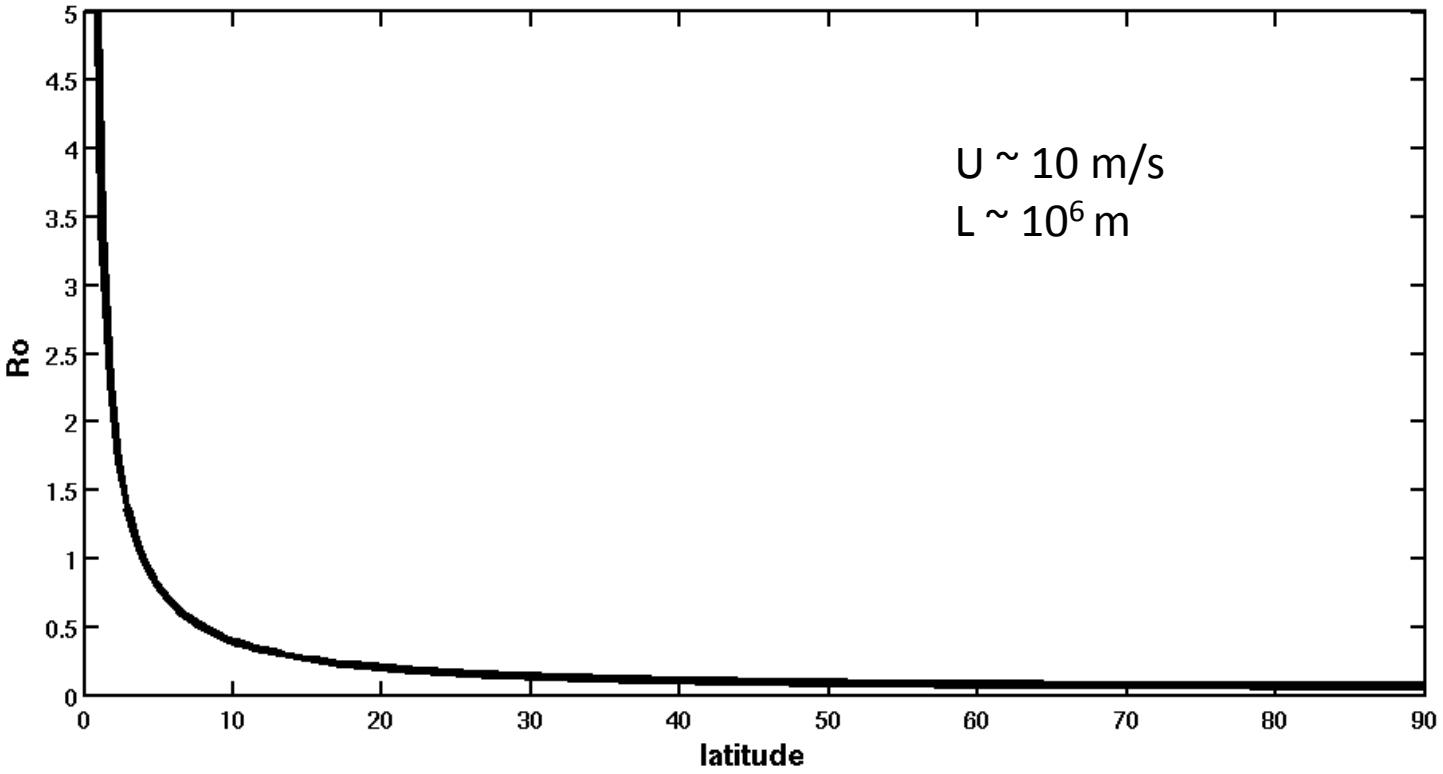
$$\frac{D\mathbf{V}}{Dt} \sim \frac{V^2}{L} \qquad f\mathbf{k} \times \mathbf{V} \sim fV \qquad \frac{1}{\rho}\nabla p \sim \frac{\delta p}{\rho_0 L}$$

$$\frac{(\delta p)_{tropics}}{\rho_0} \sim V^2 \qquad f_{midlat} V \sim \frac{(\delta p)_{midlat}}{\rho_0 L}$$

$$\frac{(\delta p)_{tropics}}{(\delta p)_{midlat}} \sim \frac{V}{f_{midlat} L} \equiv Ro_{midlat}$$

Charney, 1963

Rossby Number



U ~ 10 m/s

L ~ 10^6 m

$$\frac{(\delta p)_{tropics}}{(\delta p)_{midlat}} \sim \frac{V}{f_{midlat} L} \equiv Ro_{midlat}$$

Charney, 1963

What controls the tropical circulation

Earth's radiation budget

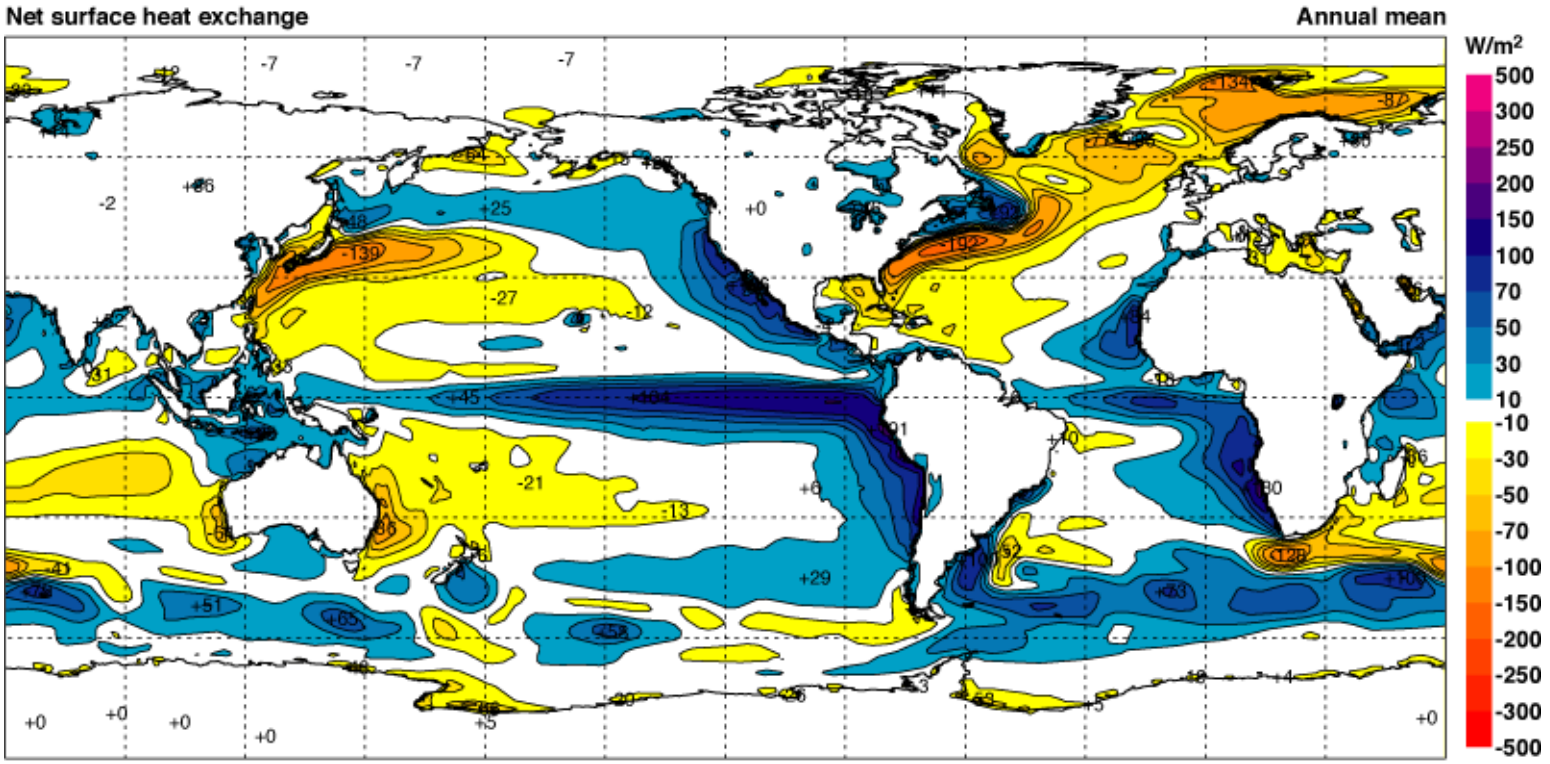
Land/Sea distribution

Sea surface temperature

Small-scale turbulence

Interaction with the midlatitude flow

Earth's Radiation budget



$$R = (Q + q)(1 - a) - I$$

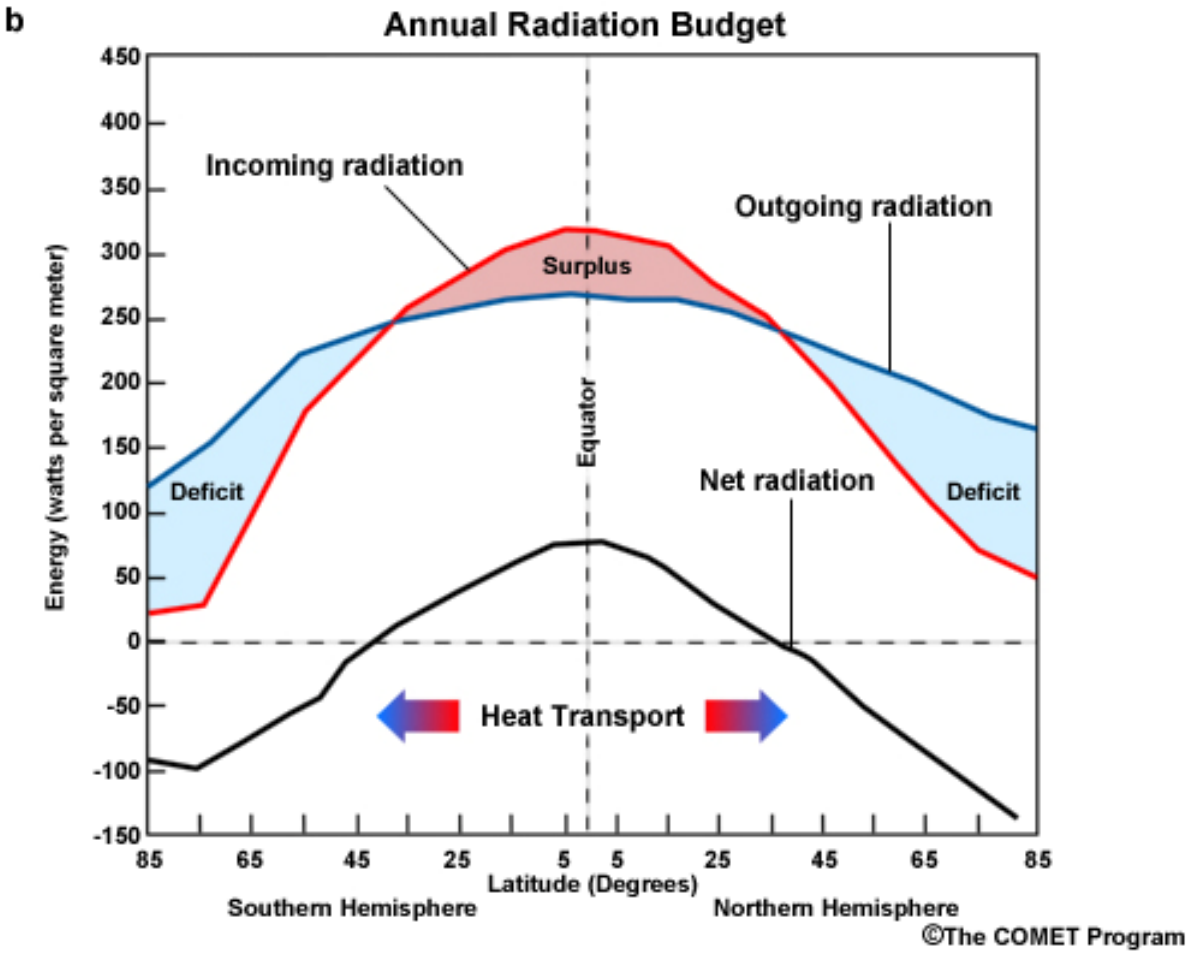
direct and indirect solar radiation

surface albedo

outgoing radiation

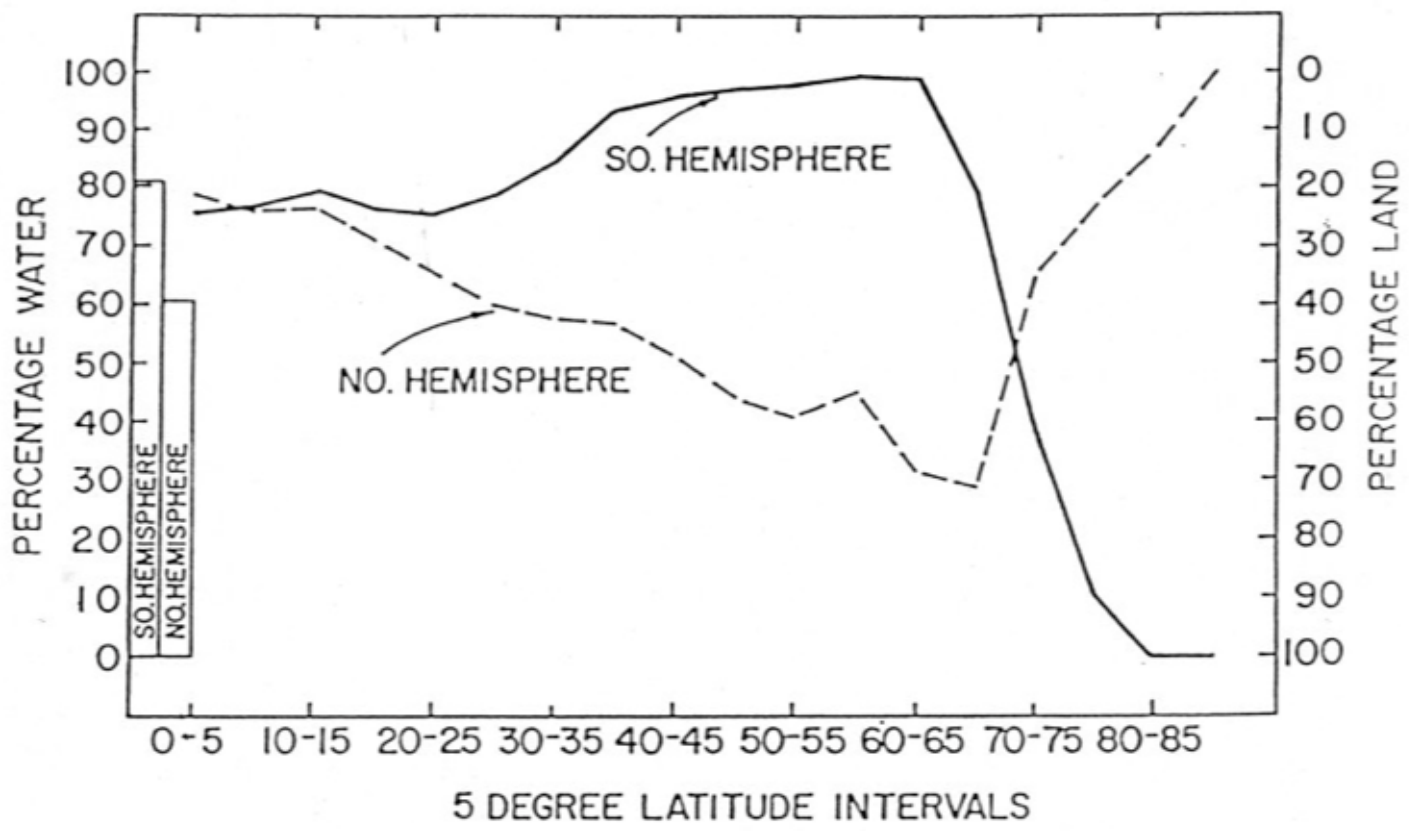
http://en.wikipedia.org/wiki/File:ITCZ_january-july.png

Global Energy Flows



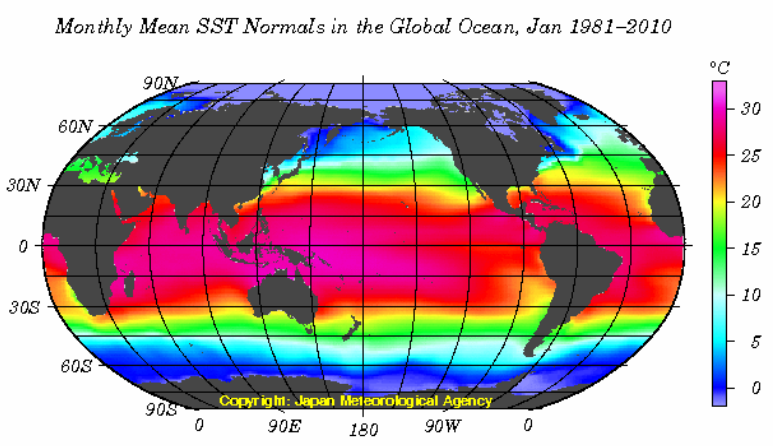
R = sensible + latent + potential + kinetic + storage + horizontal advection

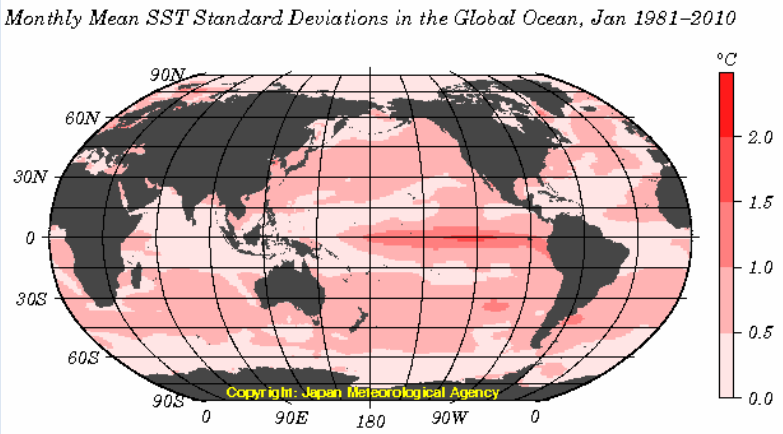
Land/Sea distribution



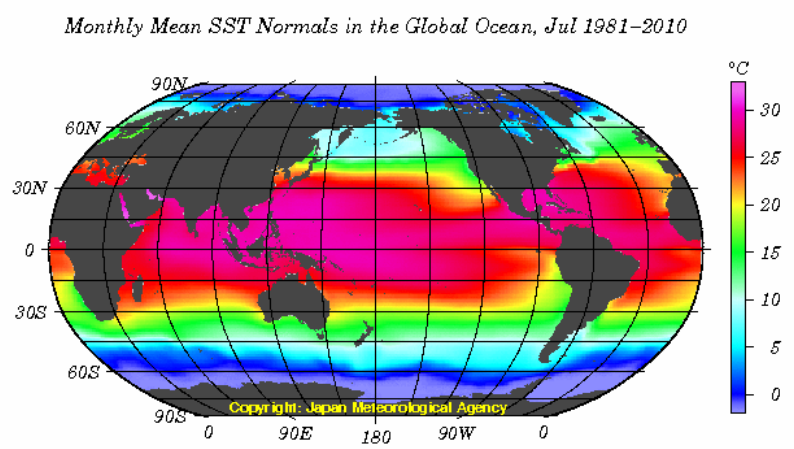
Sea Surface Temperature

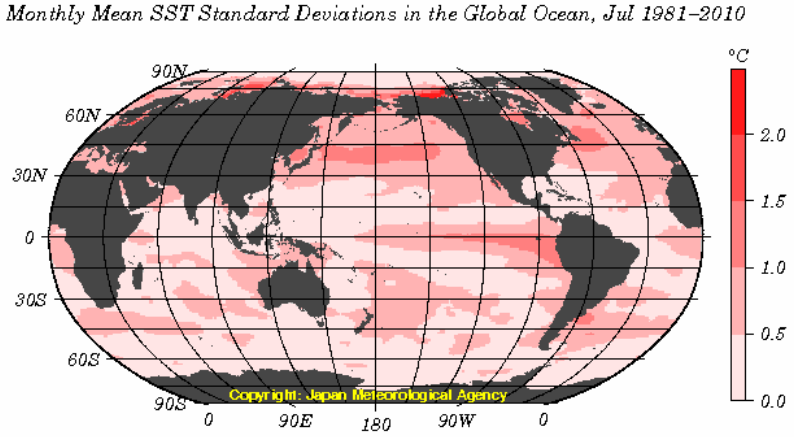
January





July

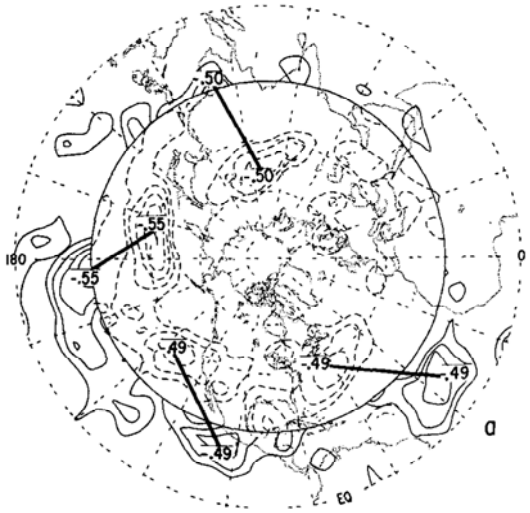




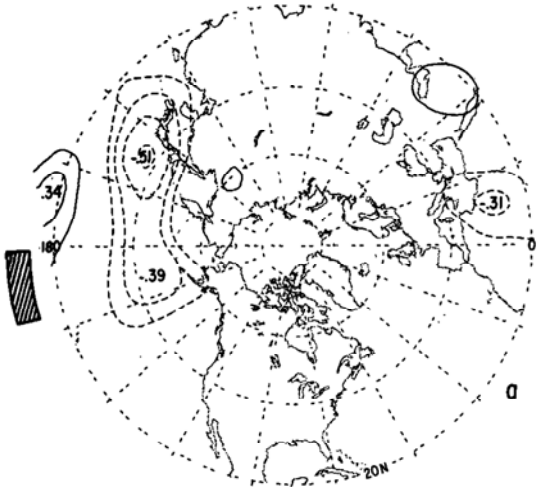
http://www.jma.go.jp

Interaction with Middle-latitudes

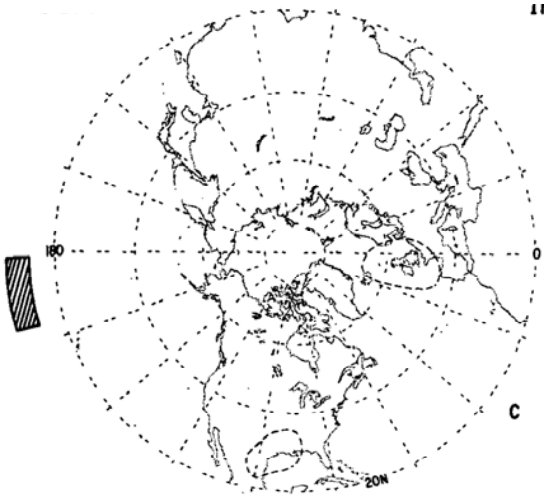
Simultaneous



HGT leads OLR

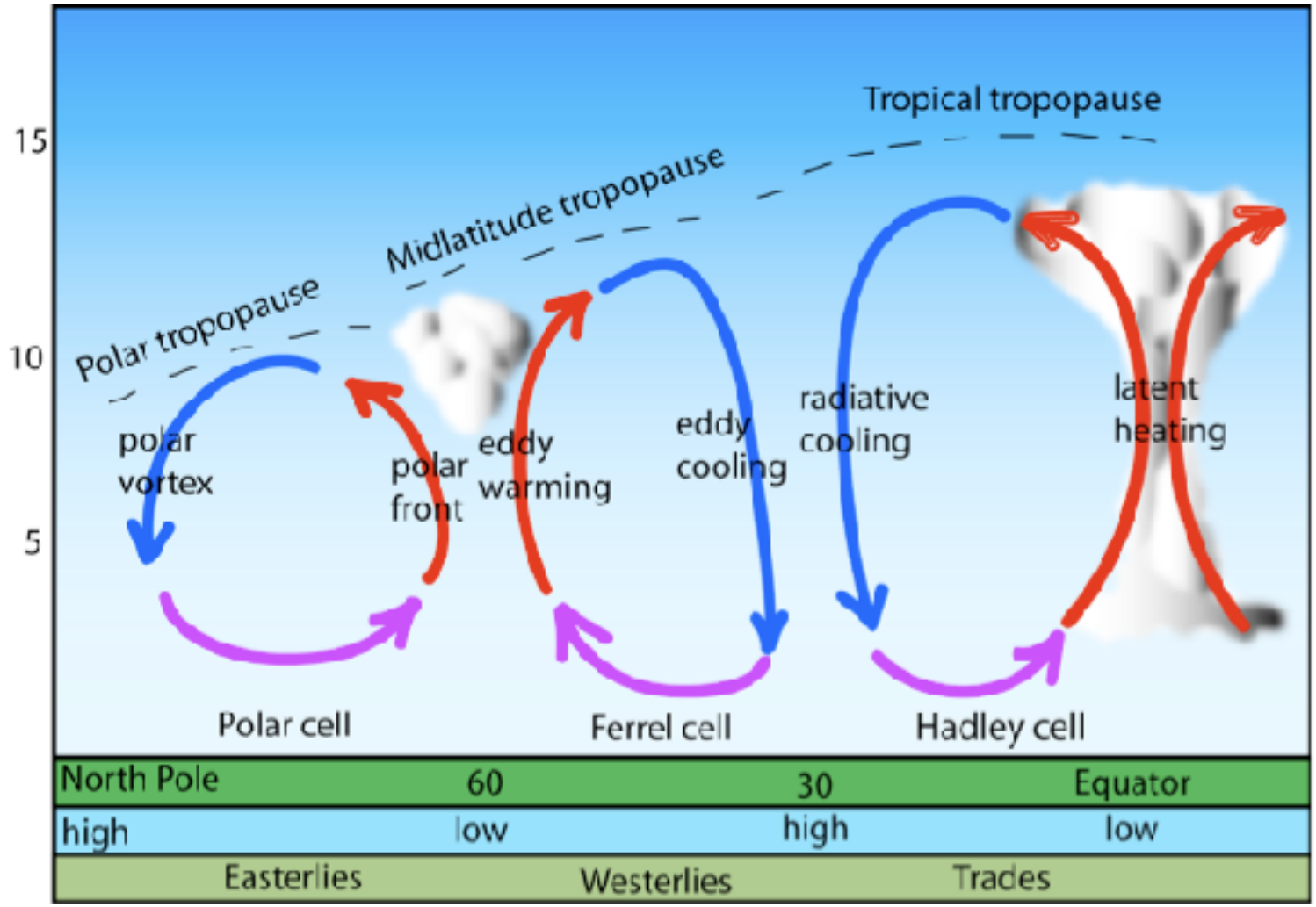


OLR leads HGT

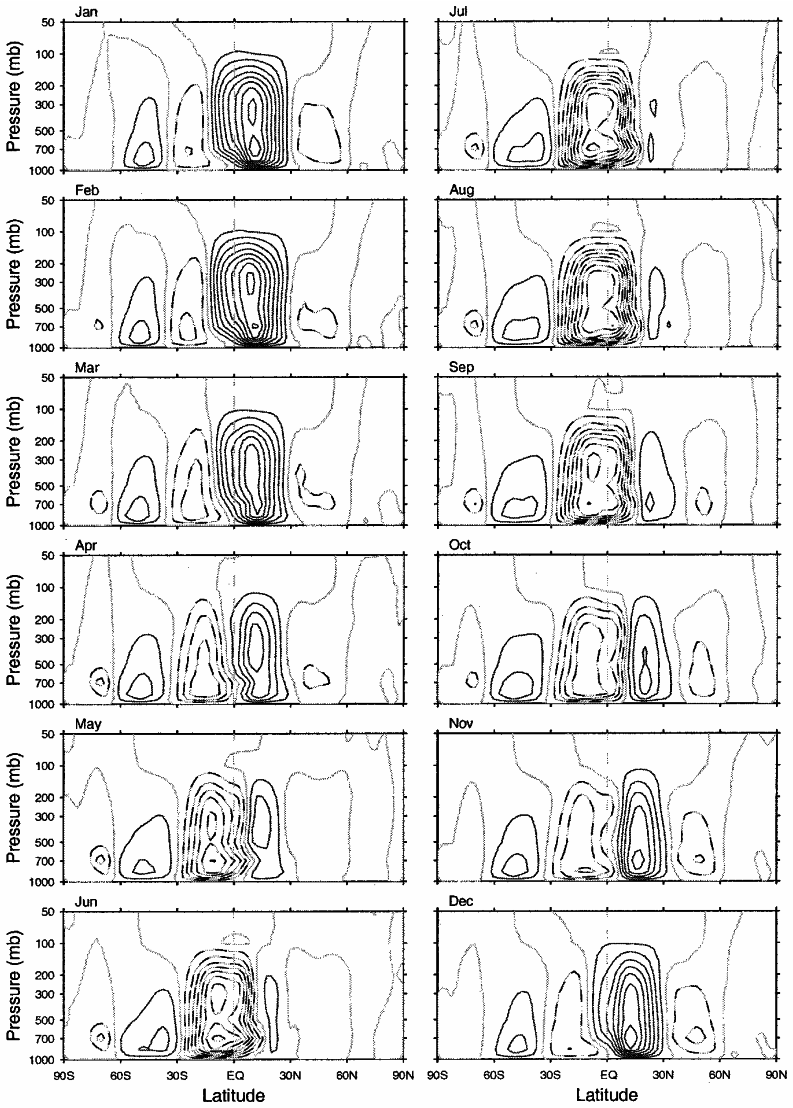


Liebmann and Hartman, 1984

The Hadley Circulation



Seasonal Variability

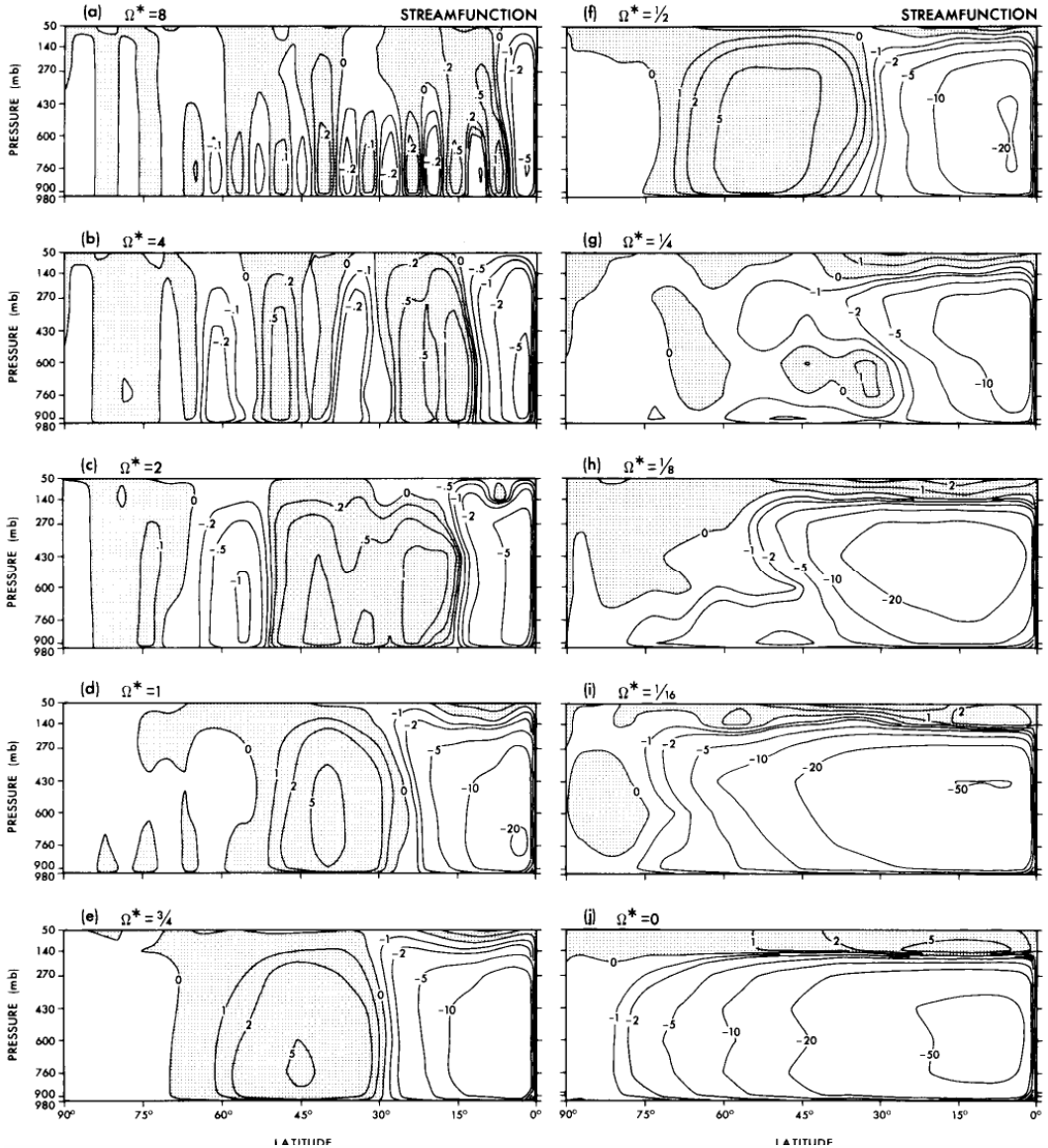


Winter Hemisphere dominated by One Hadley cell

Only in Spring and Fall there is a Hadley cell in each hemisphere

Dima and Wallace, 2008

Earth's rotation



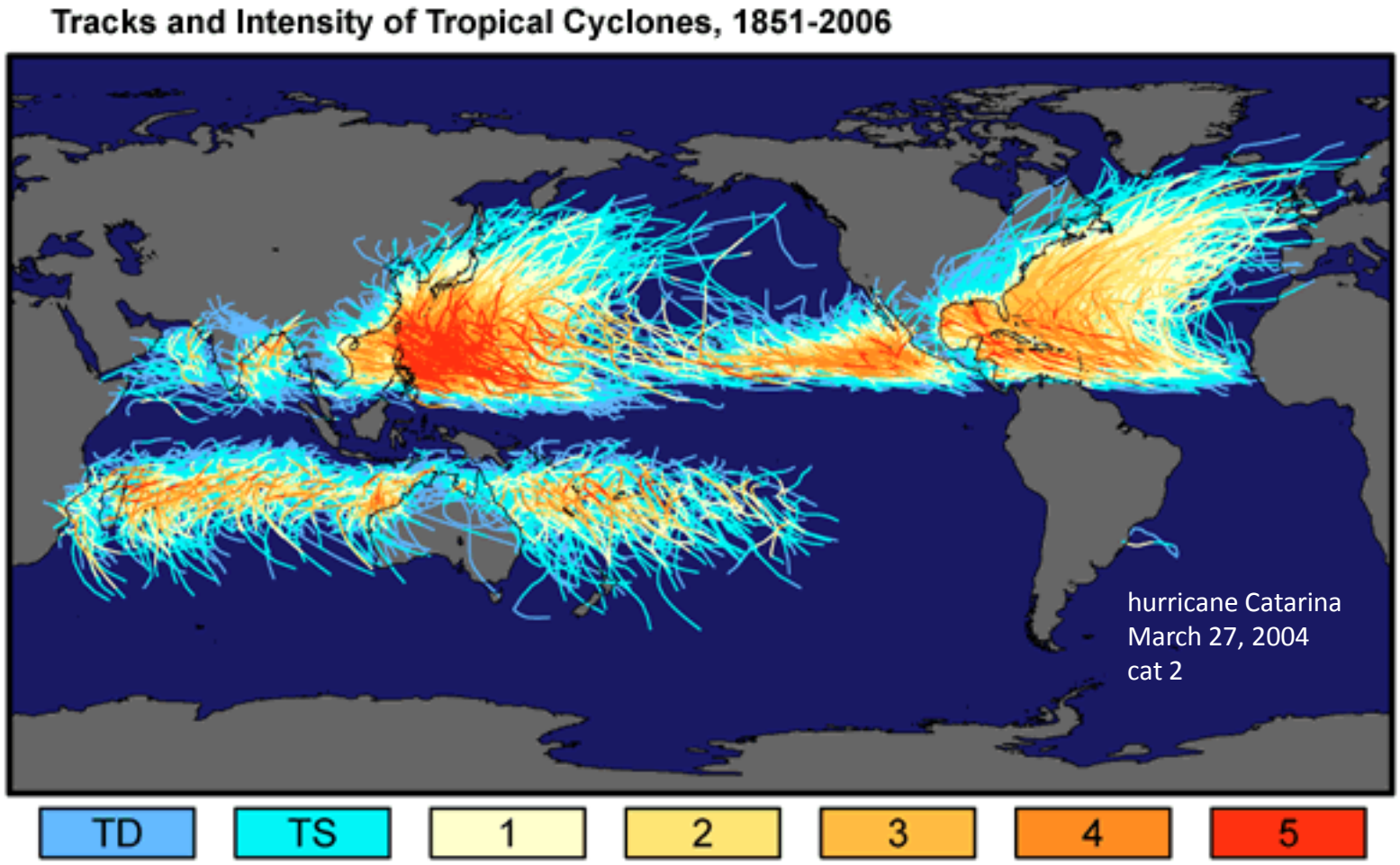
Increased Earth's rotation moves the Hadley cell closer to the equator

Decreased Earth's rotation expands the Hadley cell

No rotation yields to a hemispheric Hadley cell

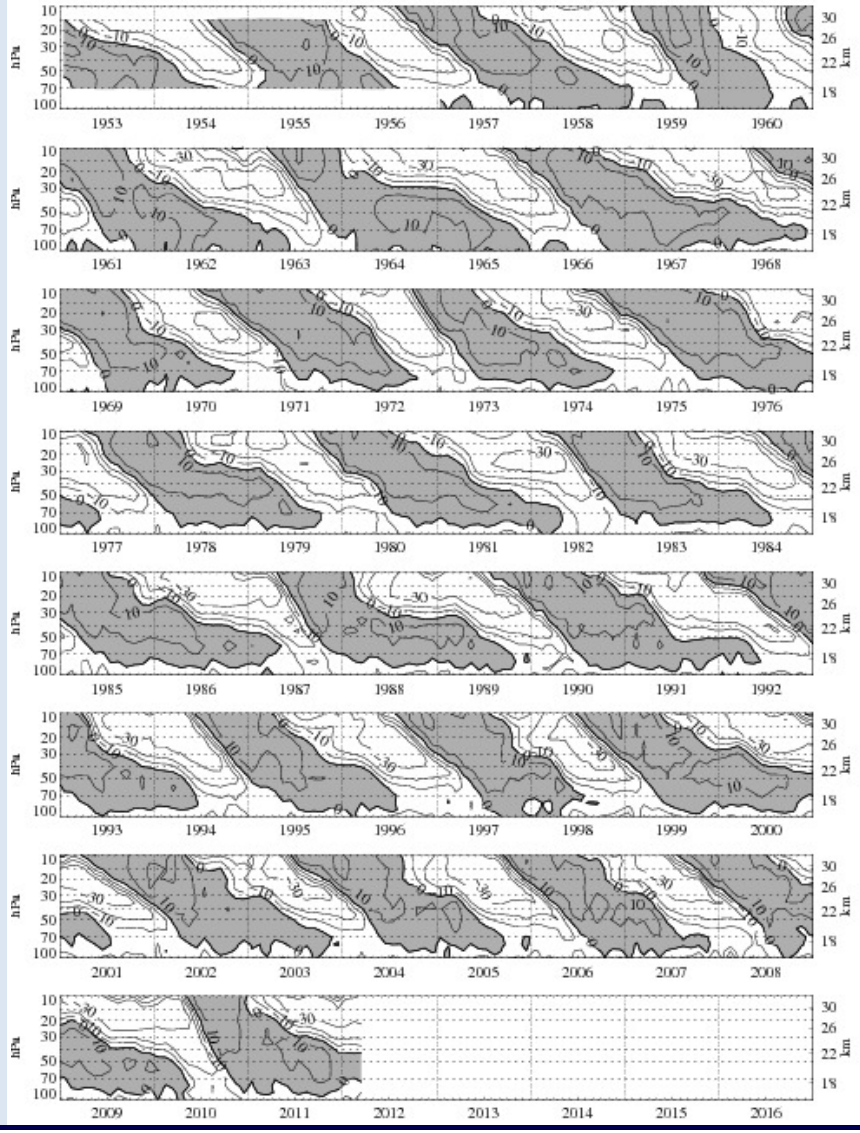
Williams, 1998

Tropical disturbances



kn	< 34	35-63	64-82	83-95	96-112	113-136	>137
mph	38	39-73	74-95	96-110	111-129	130-156	157

Stratospheric Quasi-Biennial Oscillation



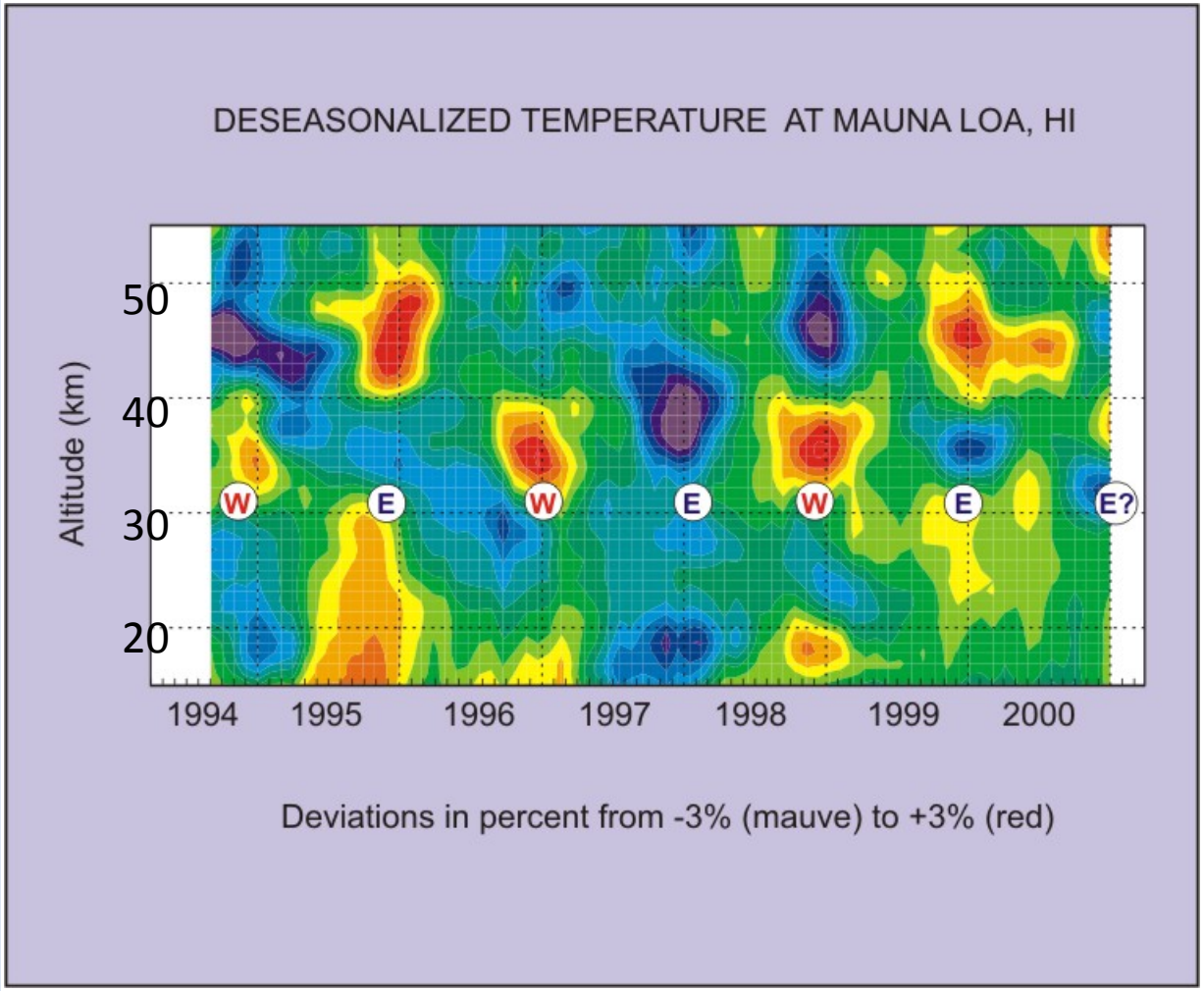
Easterlies are stronger (30-35m/s) than westerlies (15-20m/s)

Westerly winds last longer at lower levels while easterly winds last longer at higher levels

Westerlies move down faster – gradients from E-to-W transition are steeper than W-to-E

Period and amplitude vary from cycle to cycle

QBO Temperature



Max QBO temp signature 35-36km

Weak but observable signature around 45km and out of phase with that at 30km

QBO signature strongly disturbed by El Nino (cold lower stratosphere)

Seasonally synch (winter), positive anom during period of eq easterly shear, negative during periods of eq westerly shear

QBO impact

- Phase and magnitude associated with frequency of North Atlantic and western Pacific TC activity
  - Hurricanes are more frequent when the 30-hPa winds are westerlies
  - Camargo and Sobel (2010) relation robust before 1983 but not afterwards
- In the North Indian Ocean – TC numbers are larger for the easterly QBO
- Winds are significantly weaker near and south of the tropospheric jet during the easterly phase of the QBO, relative to its westerly phase.