ATM S 442/504: Atmospheric Motions II

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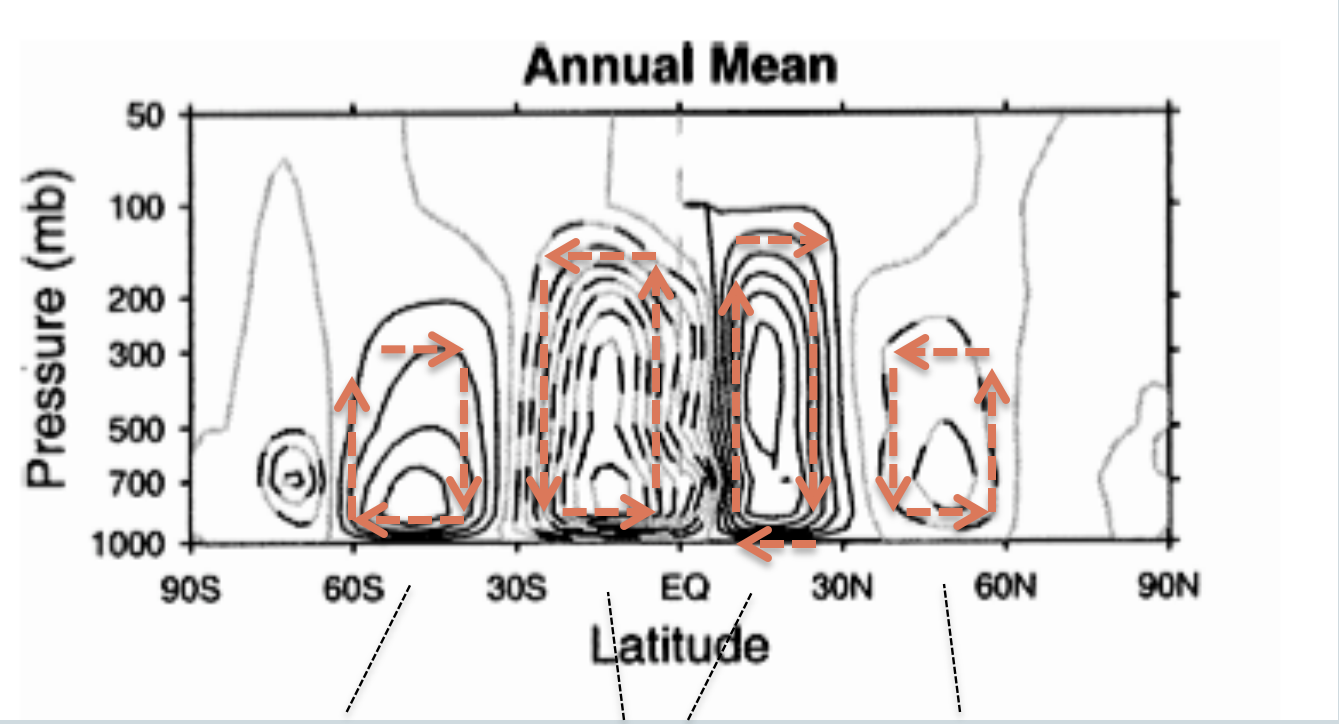
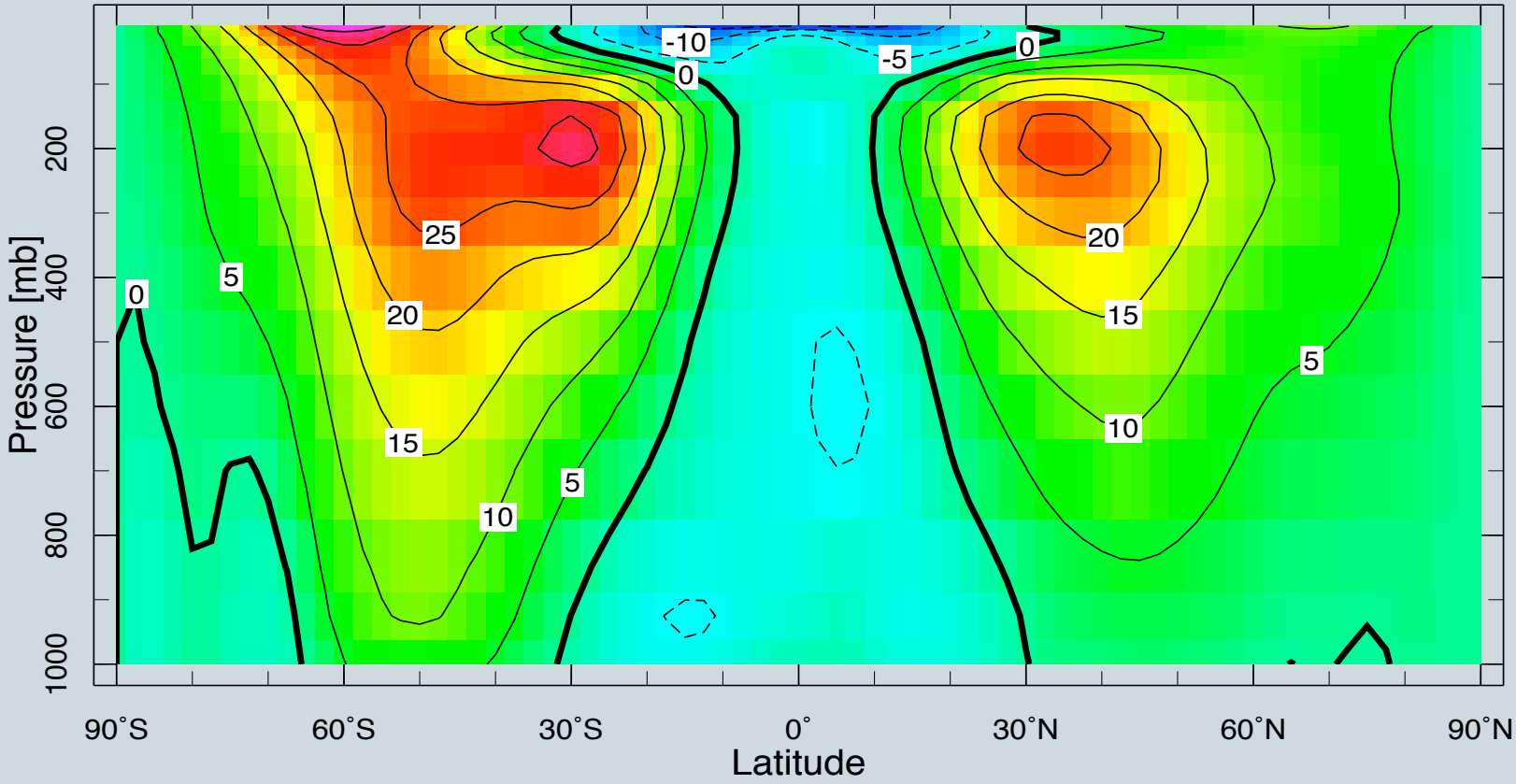
Hadley/Ferrel cell observations

- NCEP reanalysis (Dima and Wallace 2003):



Zonal Averaged Zonal Winds



Zonally averaged zonal winds from NCEP reanalysis

Eddy Heat Fluxes

- In DJF. **Poleward** over storm tracks

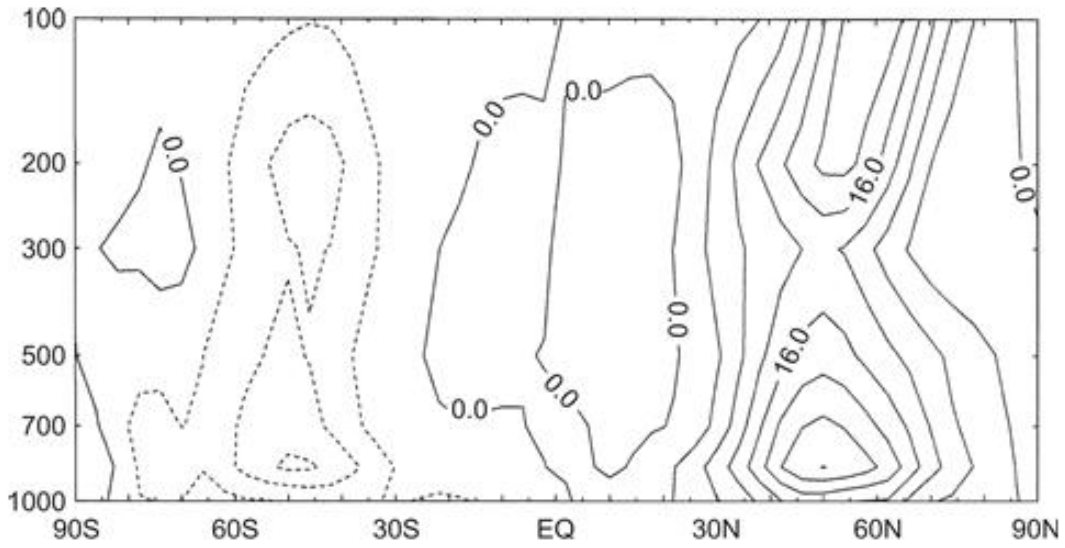


Figure 10.3 Observed northward eddy heat flux distribution (°Cm s^{-1}) for Northern Hemisphere winter.

Eddy Momentum Fluxes

- In DJF. Mostly in upper troposphere. Convergence in storm tracks. Divergence out of tropics & high lats.

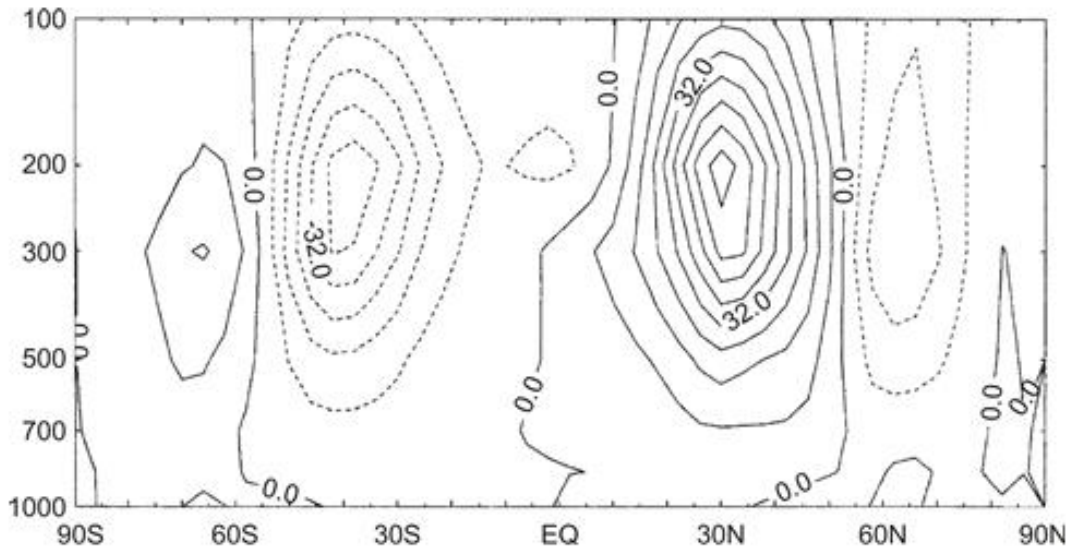


Figure 10.6 Observed northward eddy momentum flux distribution ($m^2\ s^{-2}$) for Northern Hemisphere winter.

Isentropic Circulation

- How about typical parcel trajectories?
  - Warm air goes upward, cold air goes downward within baroclinic eddies

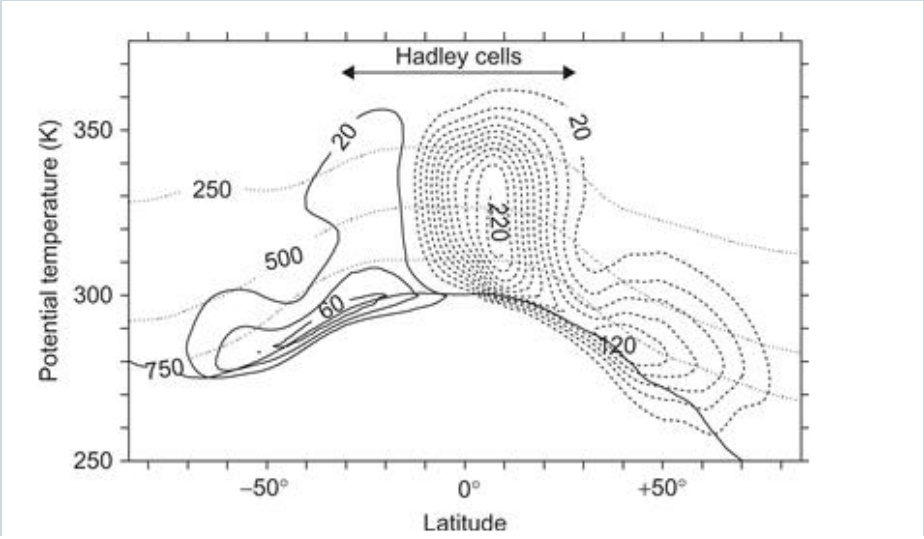


Figure 10.8 January time and zonal-mean isentropic mass flux streamfunction determined from ERA-40 reanalysis data 1980–2001). *Streamfunction contours* are shown every 20 × 10^9 kg s^{-1}, with implied clockwise circulation around negative values. *Dotted lines* show pressure surfaces and the *solid lower curve* is the median surface potential temperature.

In isentropic coordinates, there's only one cell in each hemisphere!

Ferrel cell has disappeared!

Eliassen-Palm Flux Divergence

- EP flux divergence

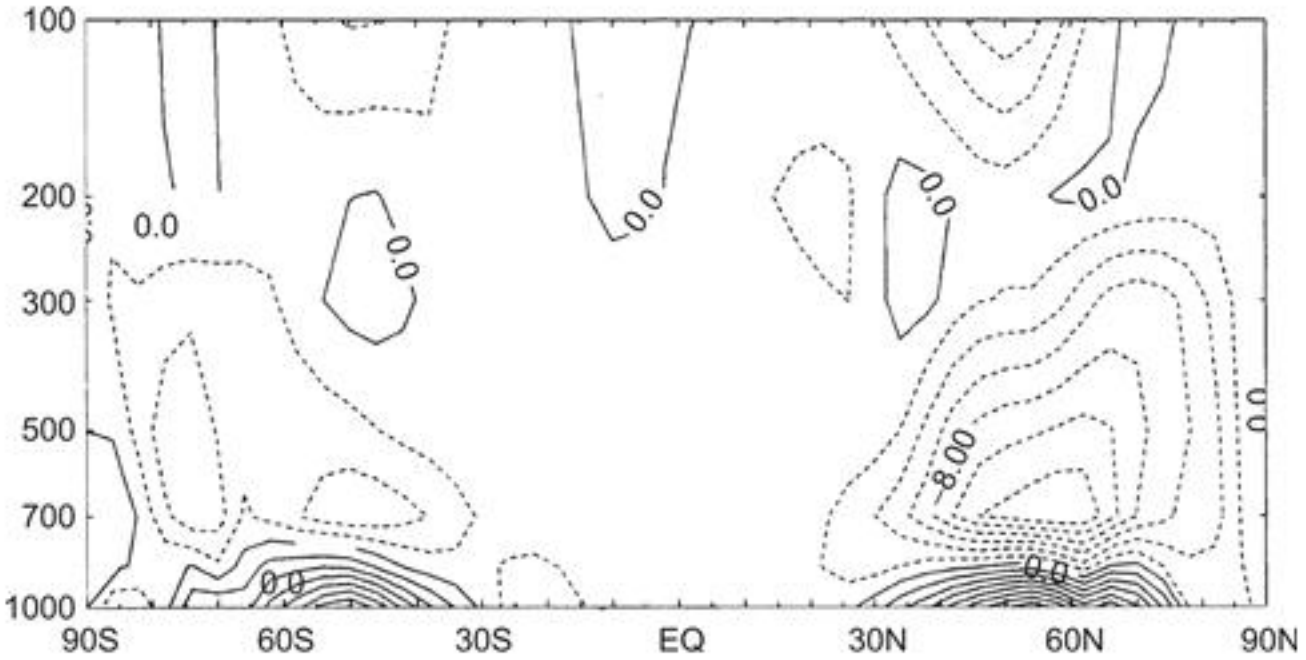


Figure 10.9 Eliassen–Palm flux divergence divided by the standard density ϱ_0 for Northern Hemisphere winter. (Units: m s^{-1} day^{-1}.)

Residual Circulation

- v* and w* are known as the residual circulation

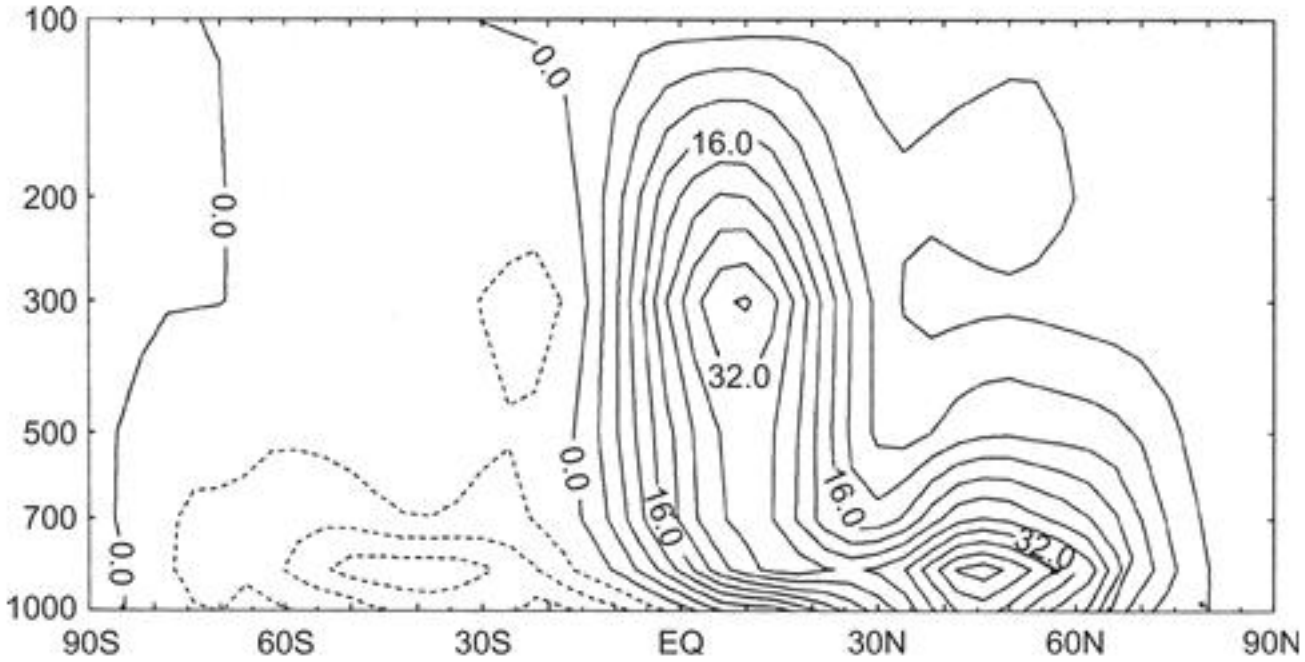
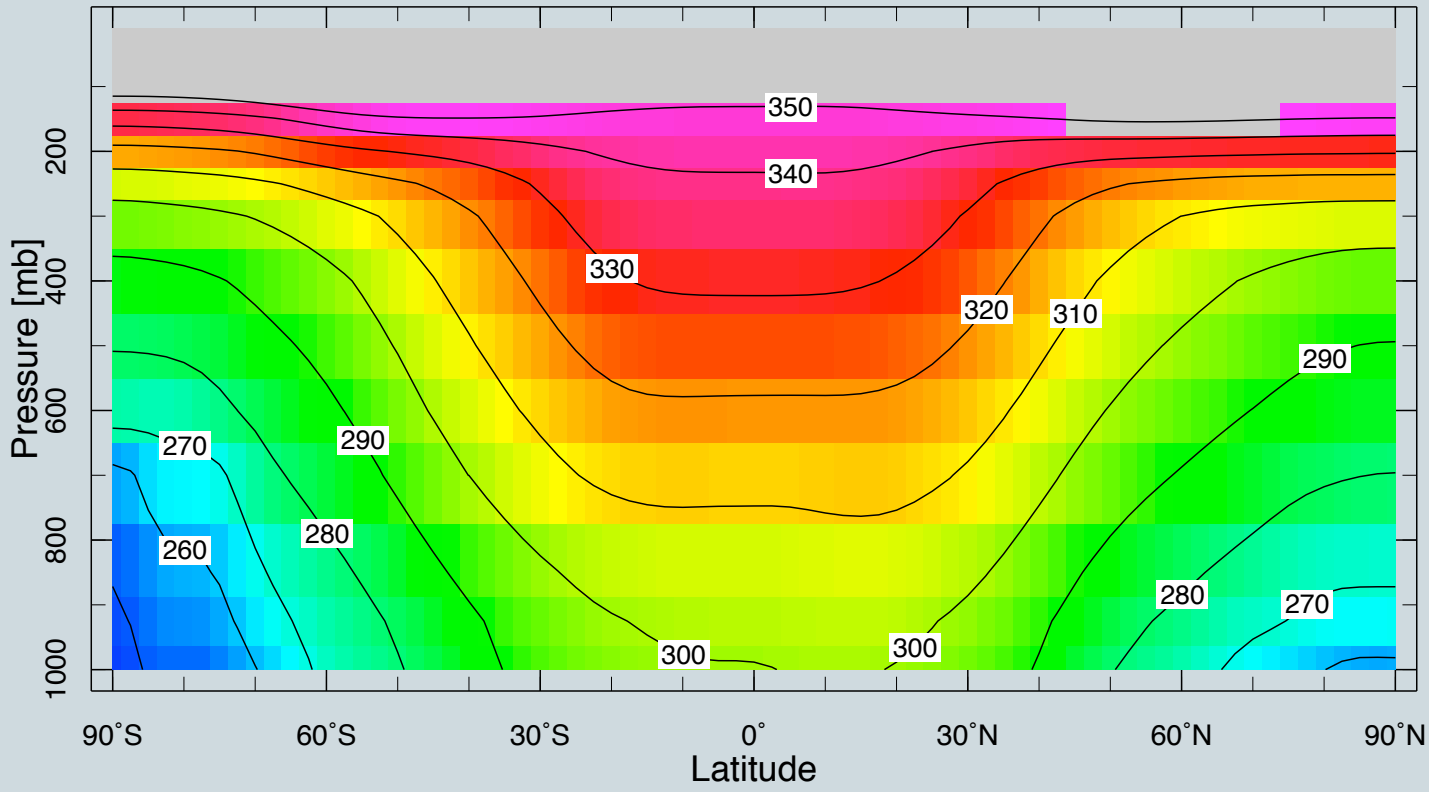


Figure 10.10 Residual mean meridional streamfunction (units: 10^2 kg m^{-1} s^{-1}) for Northern Hemisphere winter.

Tropical general circulation

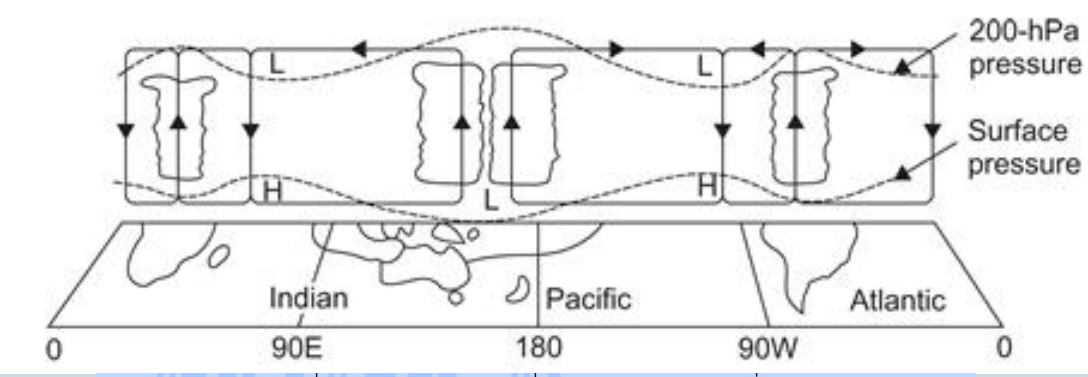
- Remarkably flat temperatures in tropical upper troposphere. Flat geopotential height too!

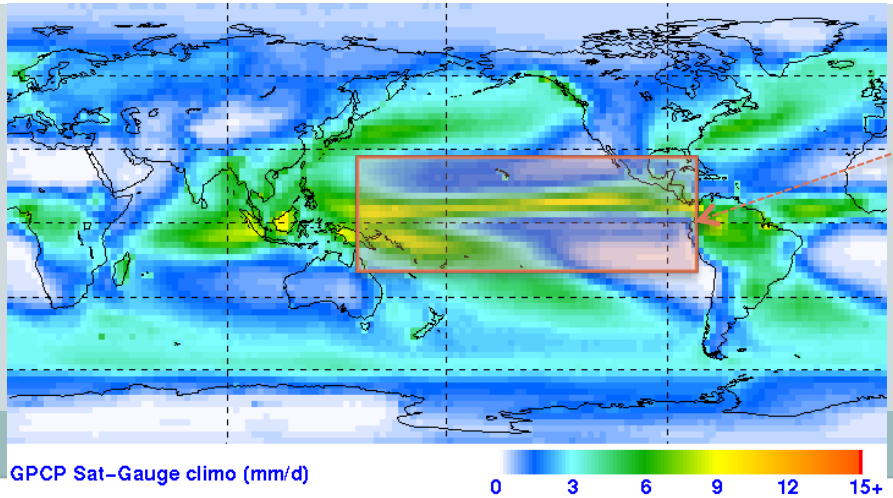


Dry static energy (similar to potential temperature) from NCEP reanalysis

The Walker Cell

- Hot air rising over the “warm pool” in the west Pacific

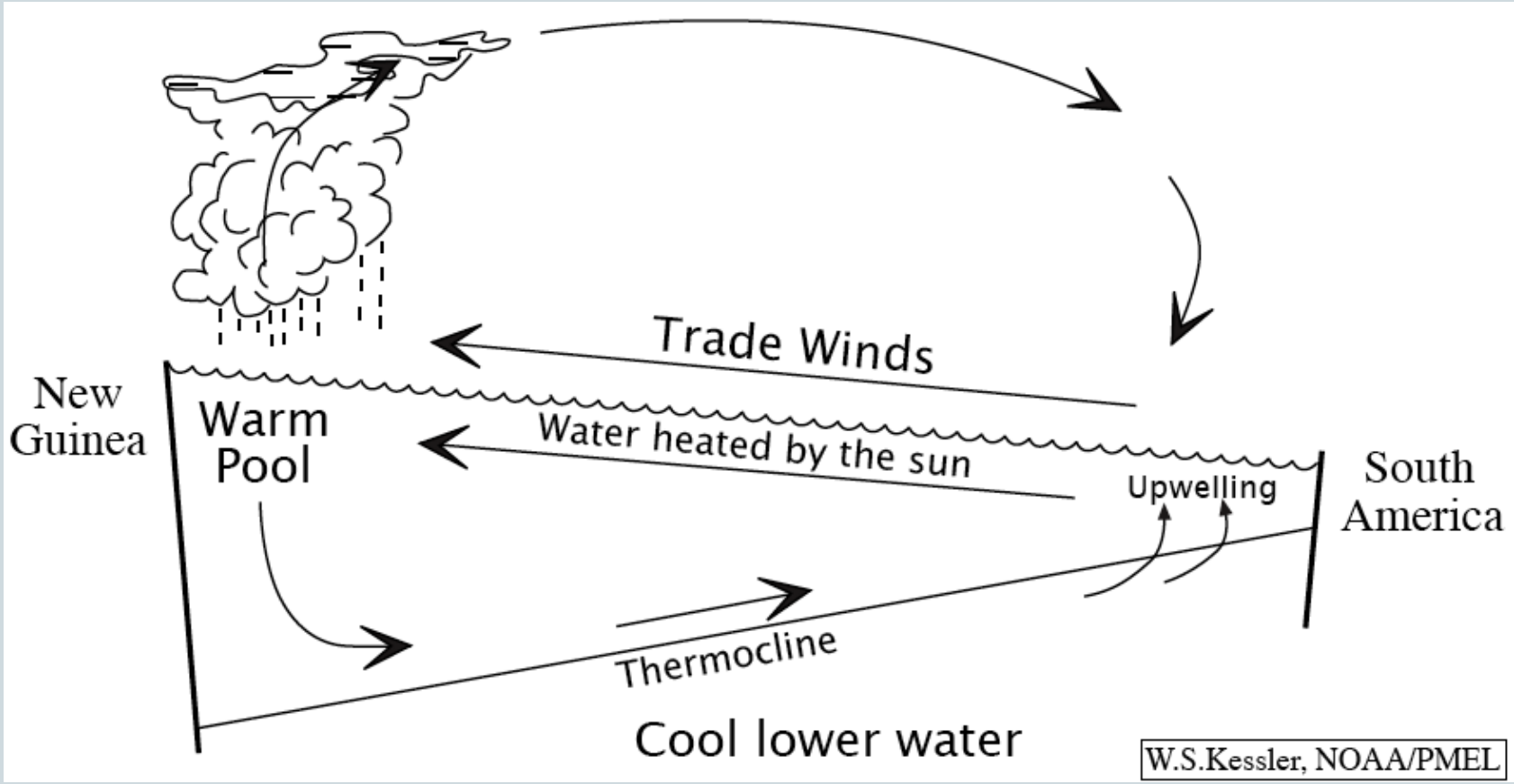




Let’s zoom into here…

El Niño/Southern Oscillation

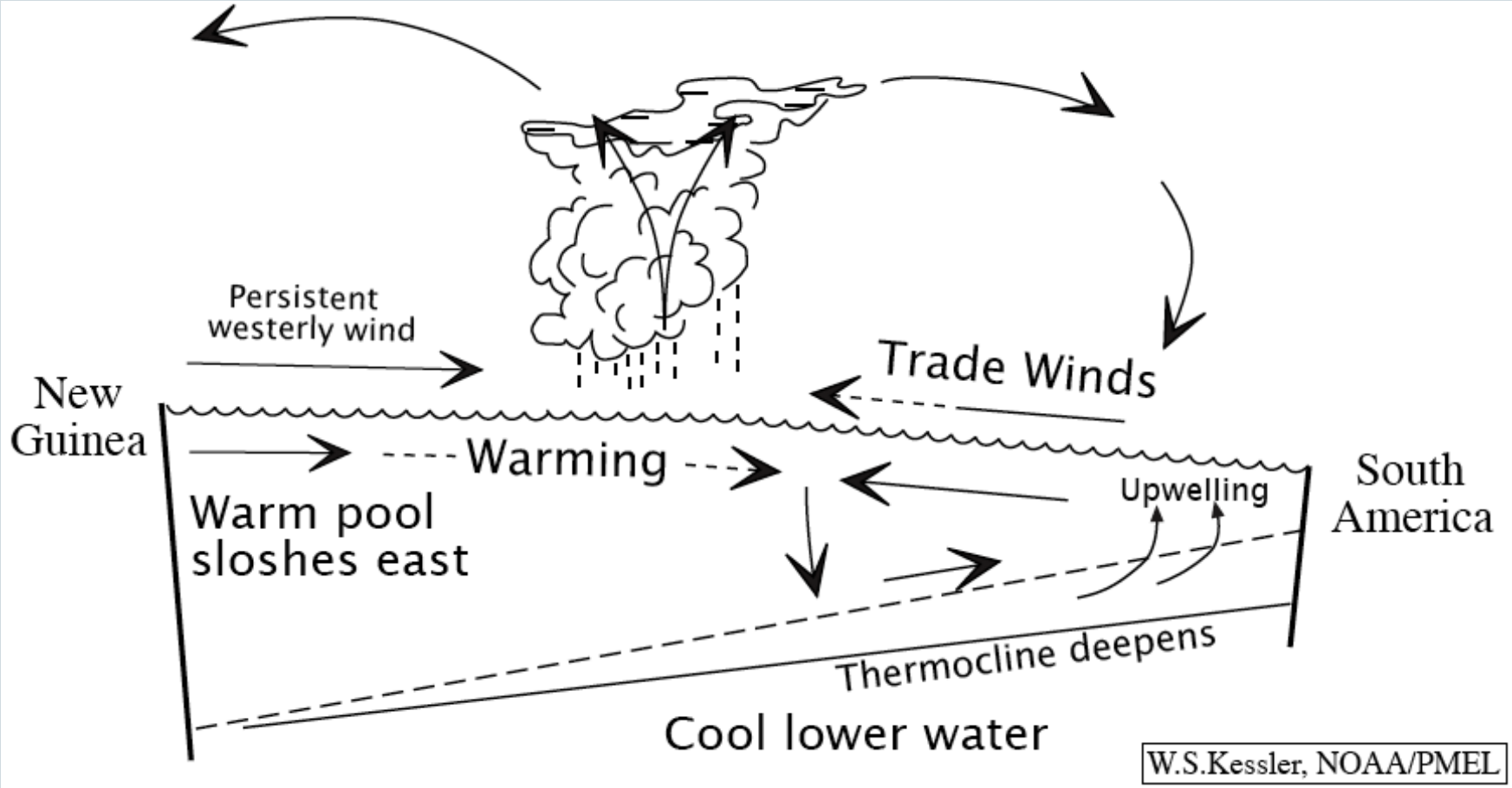
La Niña conditions: strong Walker cell



Warm pool especially warm & strong Walker circulation in La Niña

El Niño/Southern Oscillation

El Niño conditions: weak Walker cell



Warm water spreads over to the eastern Pacific

Atmospheric Kelvin Waves in a GCM

- From an ocean-covered GCM…
  - Precipitation signals go around and around and around the equator…
  - Always eastward!

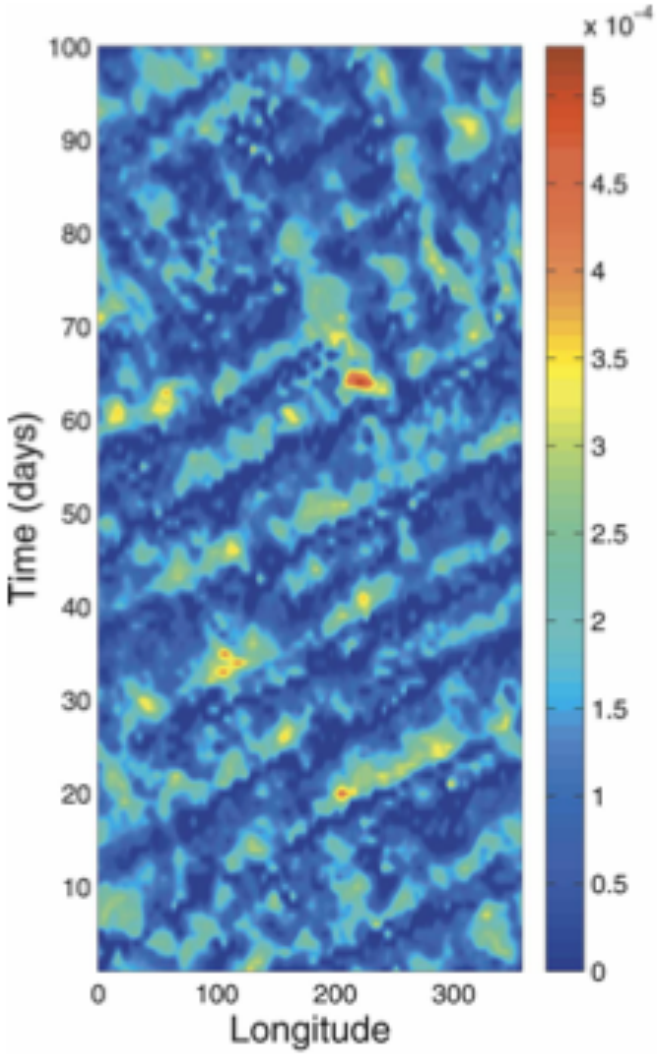
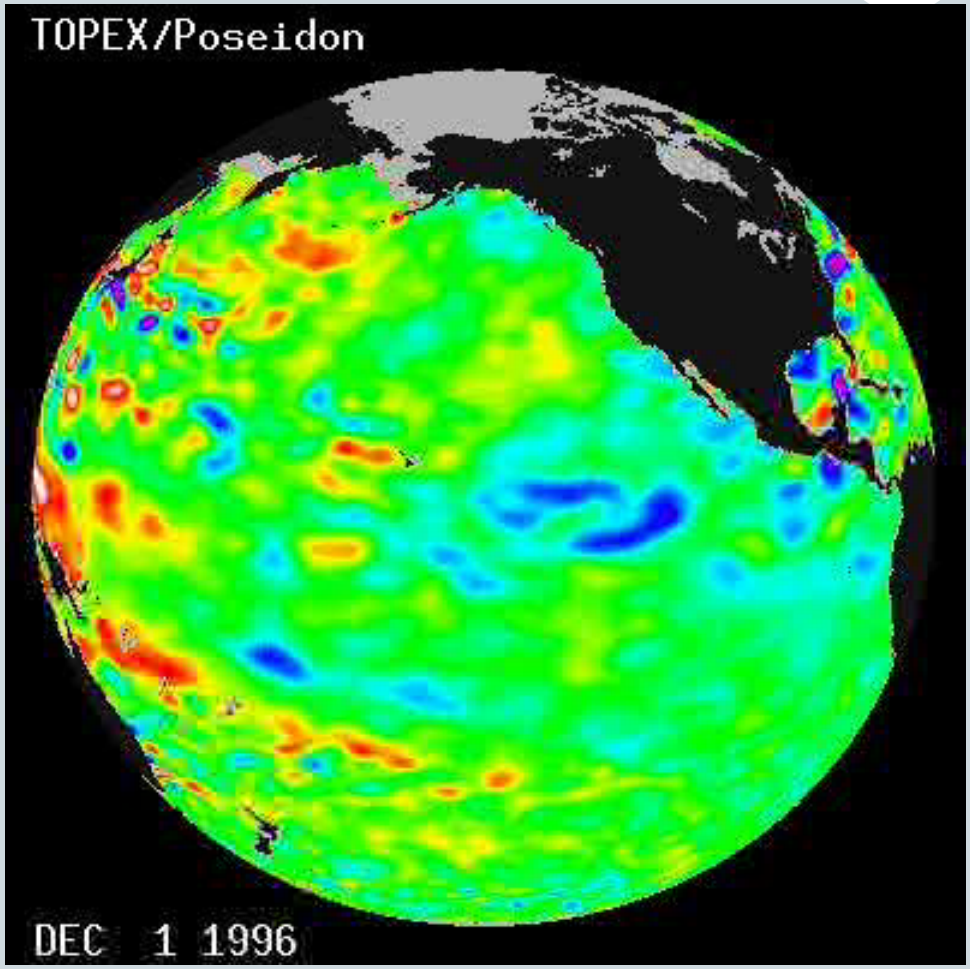


FIG. 2. Hovmöller (longitude–time) diagram of precipitation (kg m^{-2} s^{-1}) at the equator in the control case for 100 days of simulation.

El Niño Onset from Equatorial Kelvin Waves



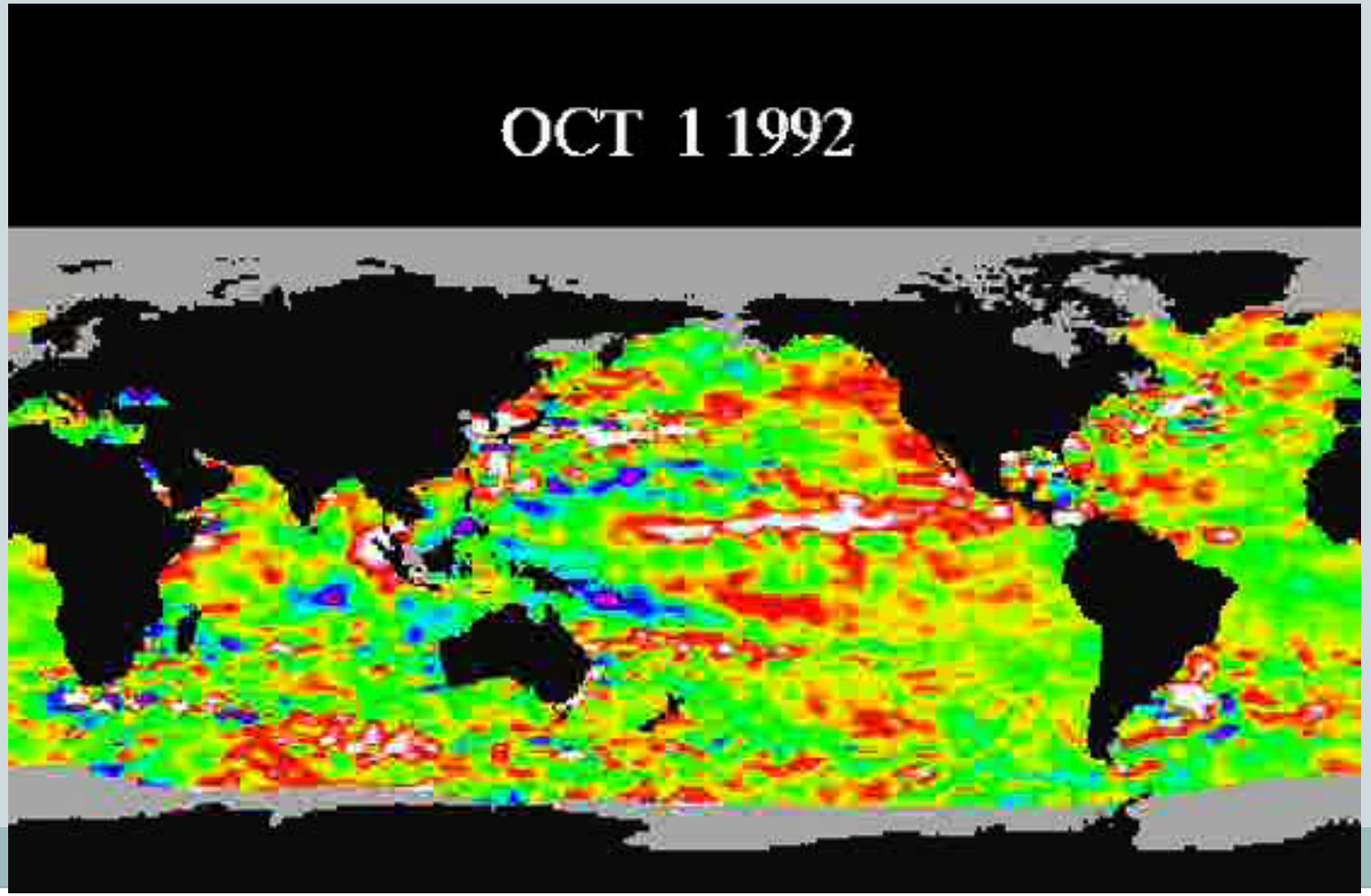
Equatorial Kelvin waves: Giant scale waves that move exactly on the equator are key for setting El Niño in motion!

Much smaller height changes than typical ocean waves (30 cm max) – but huge in scale!

Satellite data showing ocean altimetry (sea surface height)

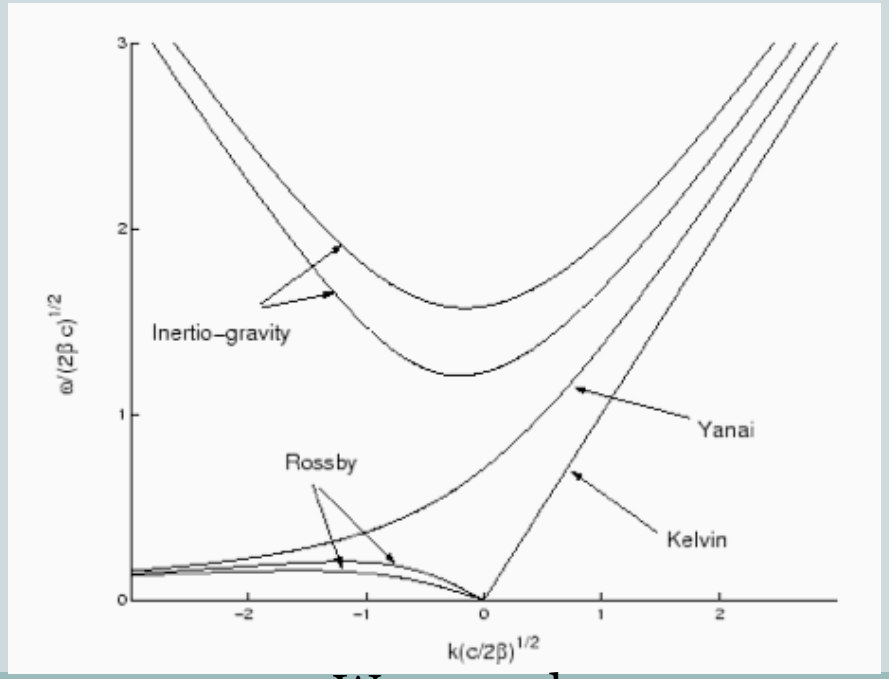
Equatorial Kelvin Waves in the Ocean

- A global picture:



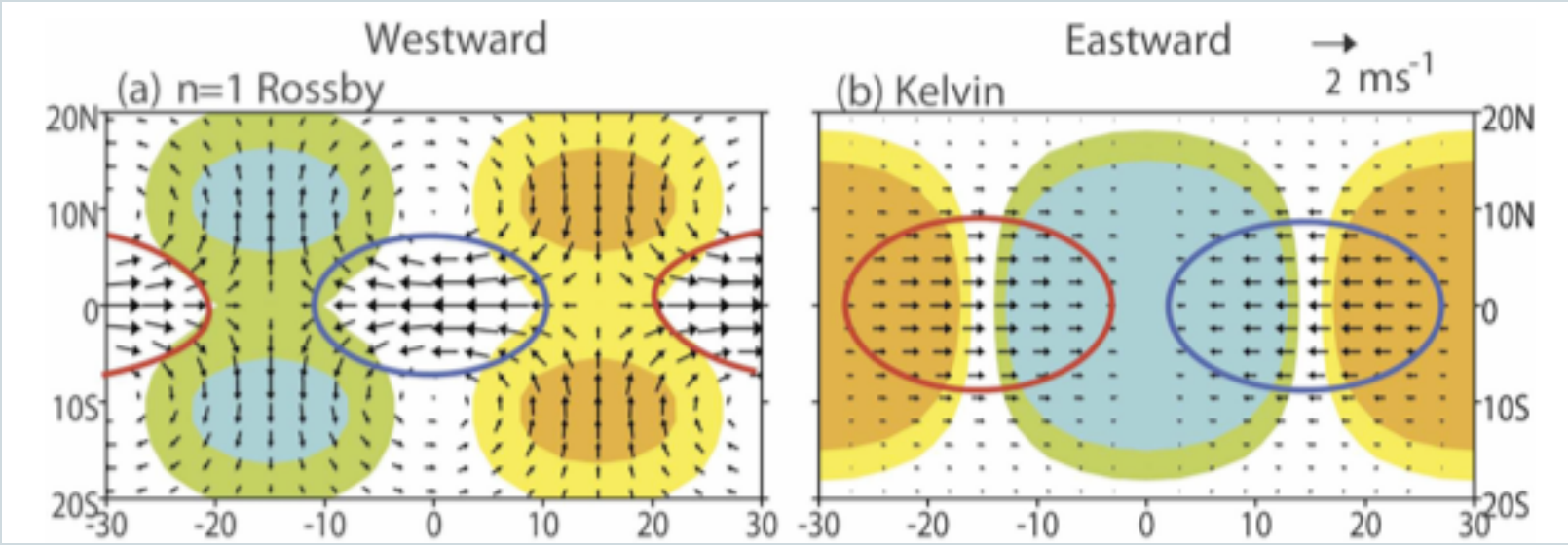
Dispersion Relations for Equatorial Waves

- System has the following: (see Section 11.4.1 for more derivation)
  - Kelvin waves (nondispersive eastward propagating waves)
  - Mixed Rossby-gravity wave (Yanai mode)
  - Equatorial Rossby waves
  - Inertia-gravity waves



Structure of Equatorial Waves

- Structures (Rossby and Kelvin):

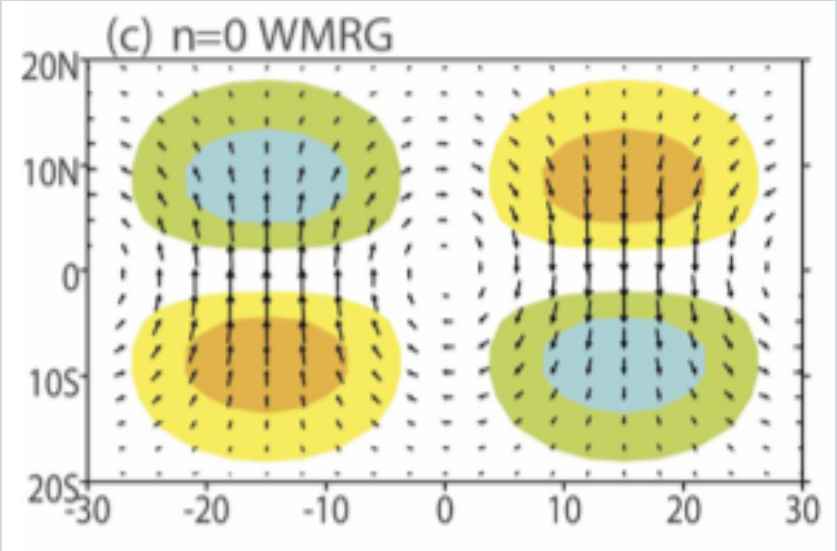


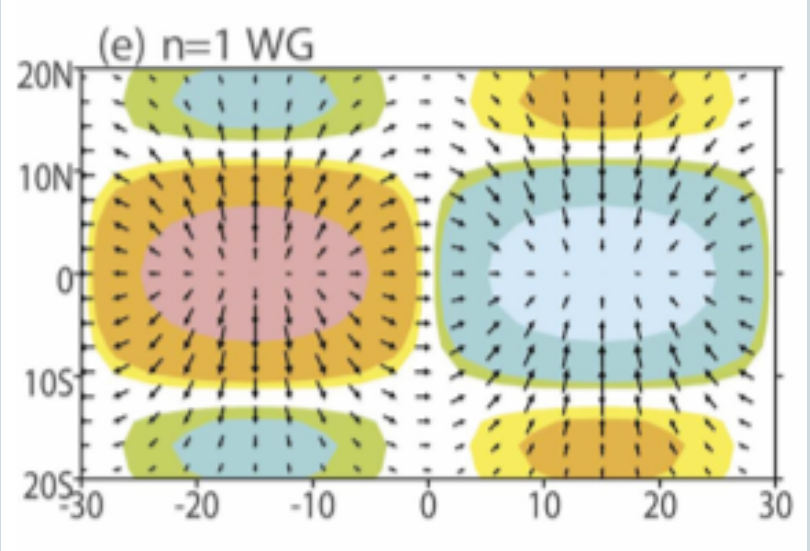
Vectors = winds
Colors = divergence contours
(ignore the ovals)

From Yang et al 2007

Structure of Equatorial Waves

- More structures (mixed Rossby gravity and WIG):



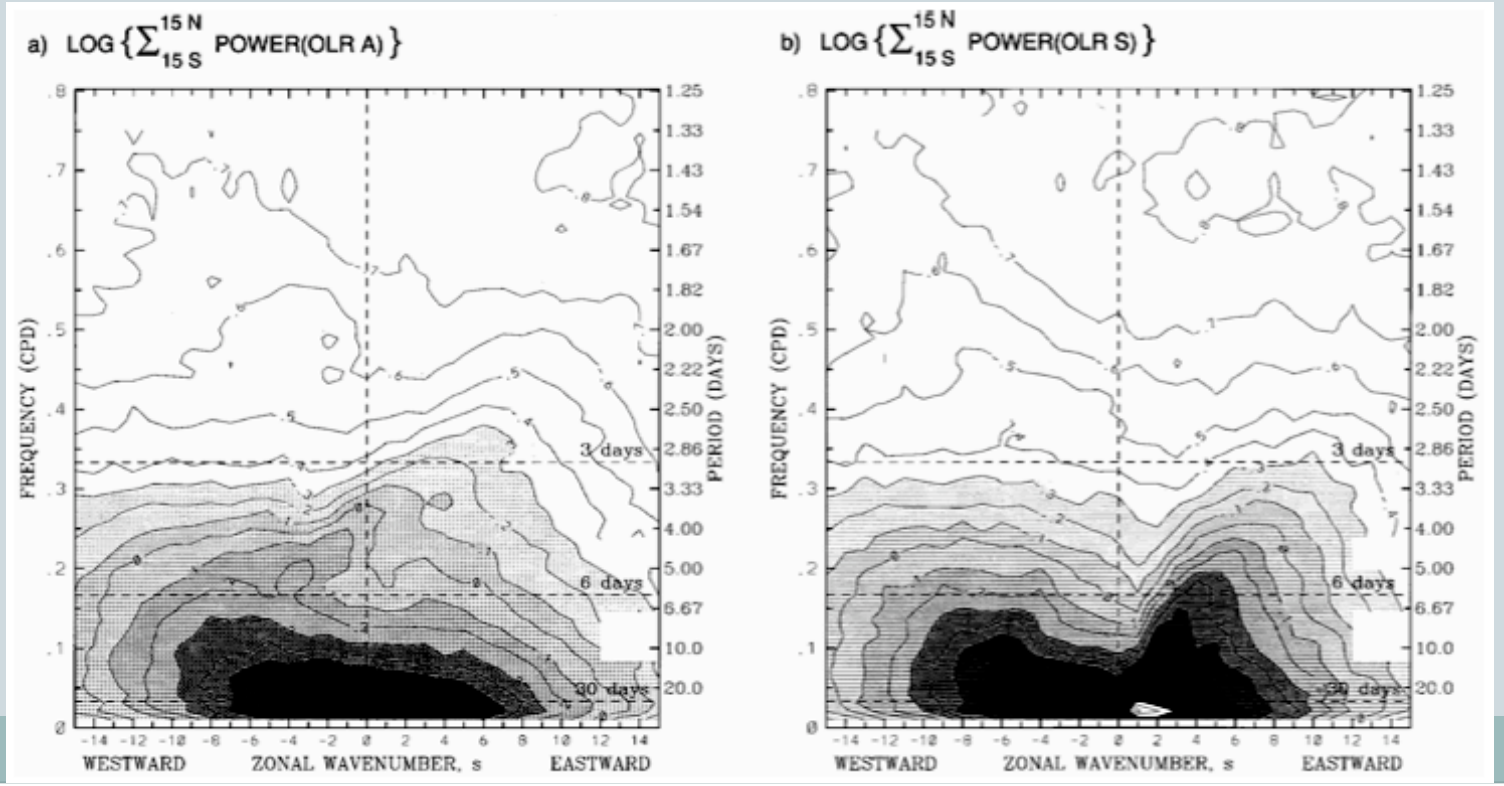


Vectors = winds
Colors = divergence contours
(ignore the ovals)

From Yang et al 2007

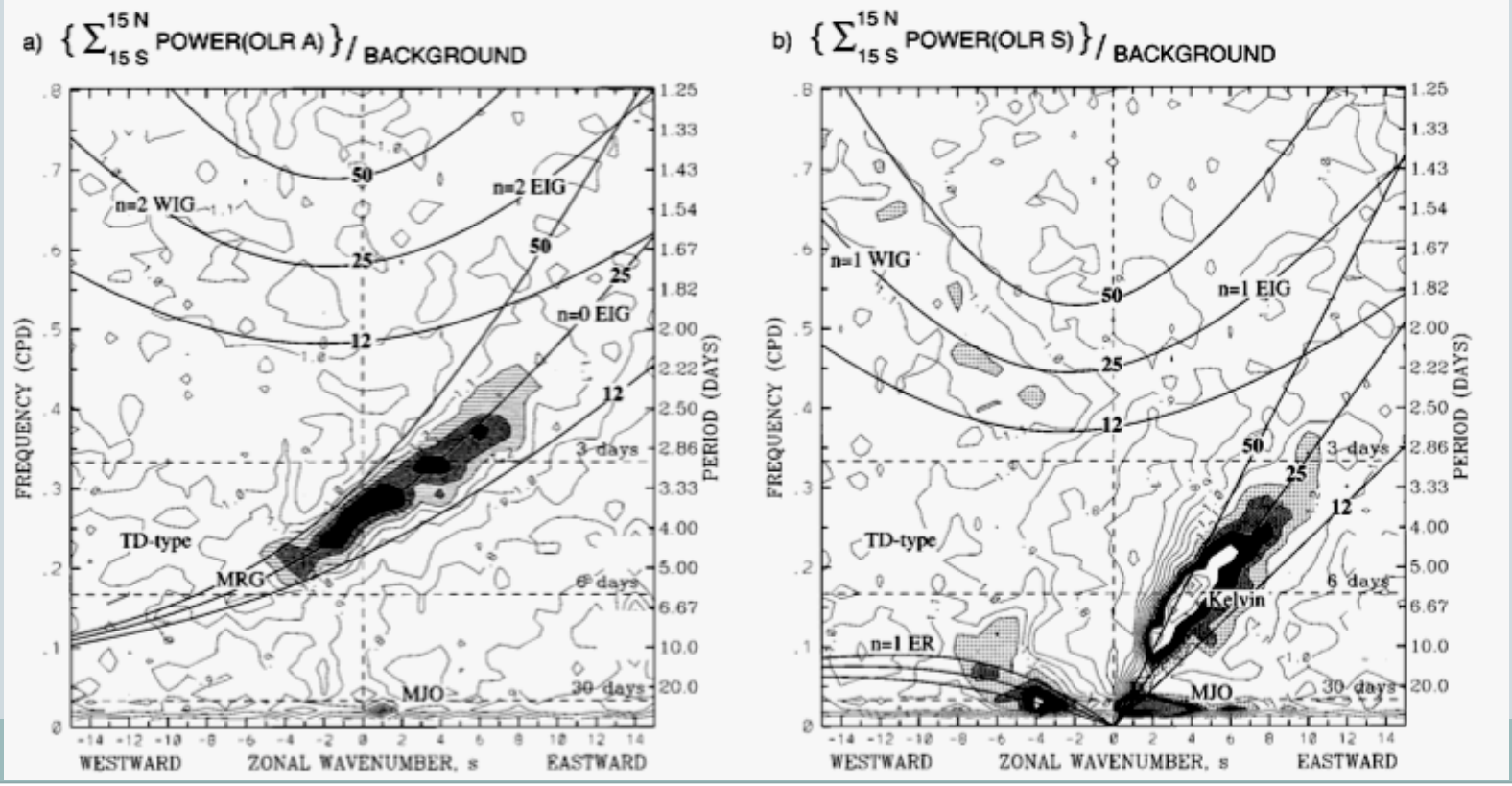
Atmospheric Obs. of Equatorial Waves

- Wheeler and Kiladis (1999) examined spectra of OLR data in the tropics:



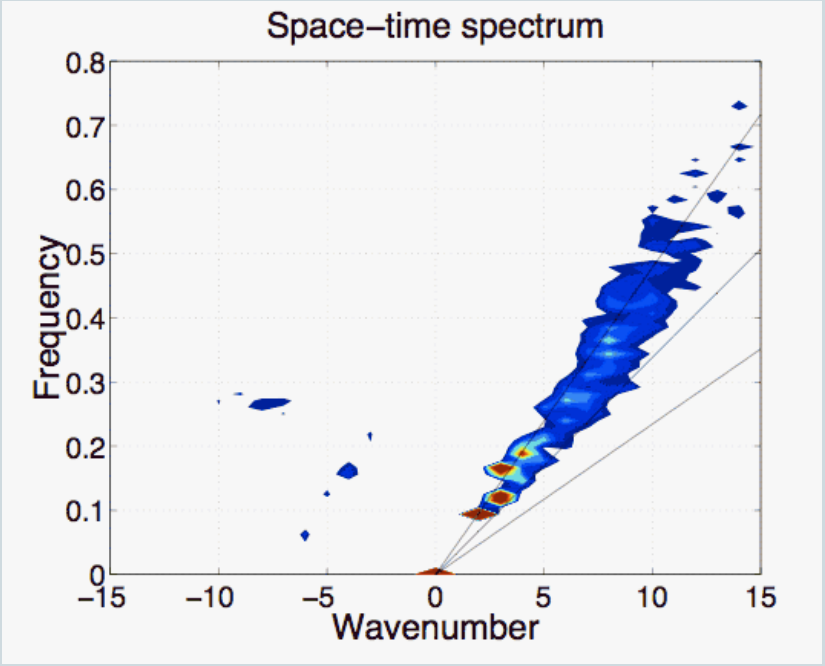
Atmospheric Obs. of Equatorial Waves

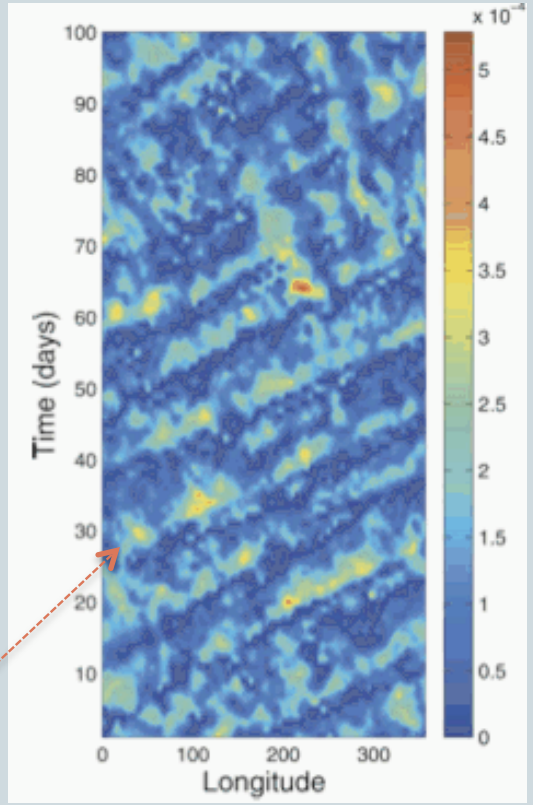
- Filter out "background spectrum":
  - Can see all different wave types! Especially Kelvin, MRG, and ER. Also, the mysterious MJO…



Equatorial Waves in Idealized GCM

- In simplified moist GCM, Kelvin waves dominate the spectrum





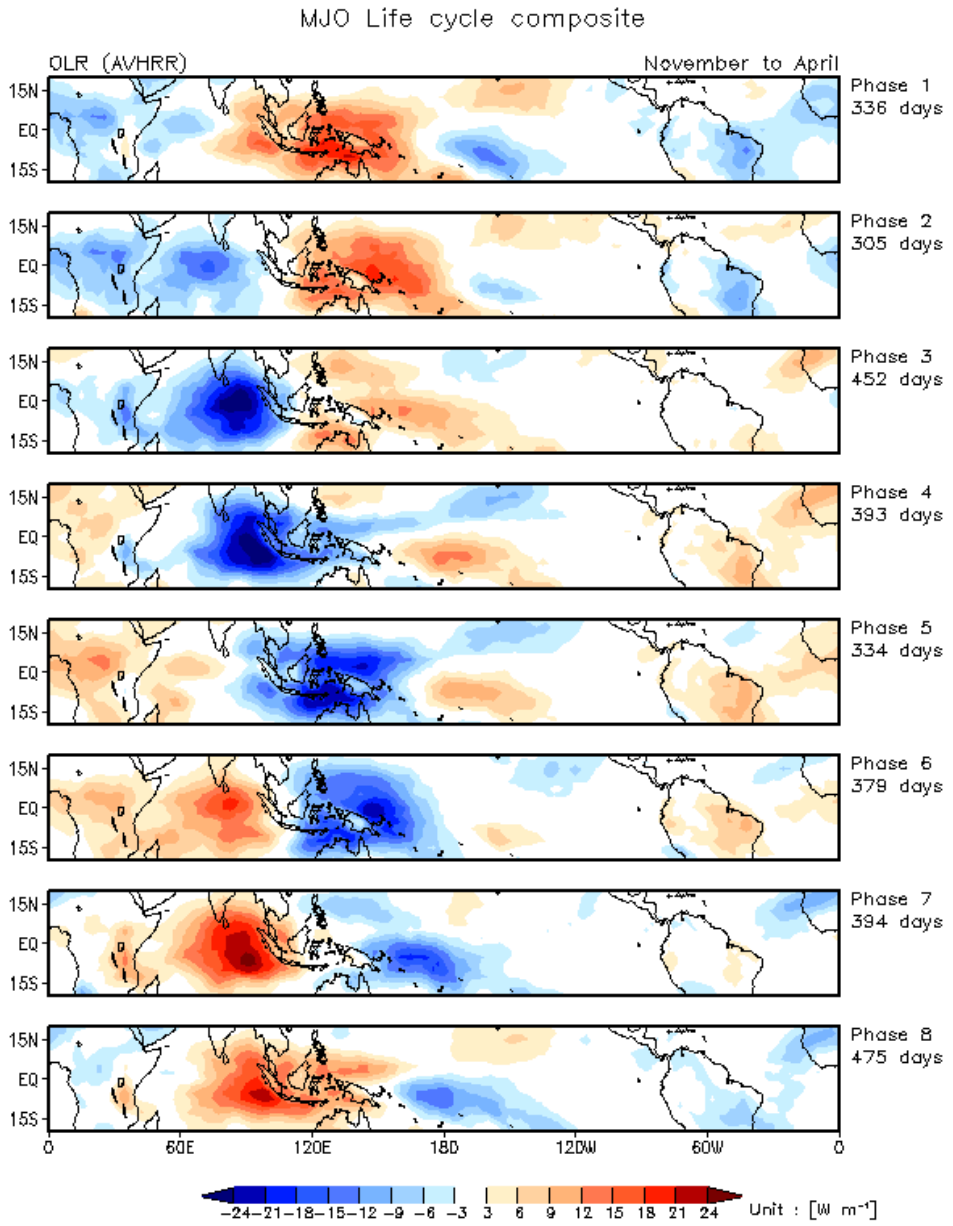
They can propagate around and around the equator multiple times!

Madden-Julian Oscillation

- 30-60 day eastward propagating envelope of enhanced/suppressed precip

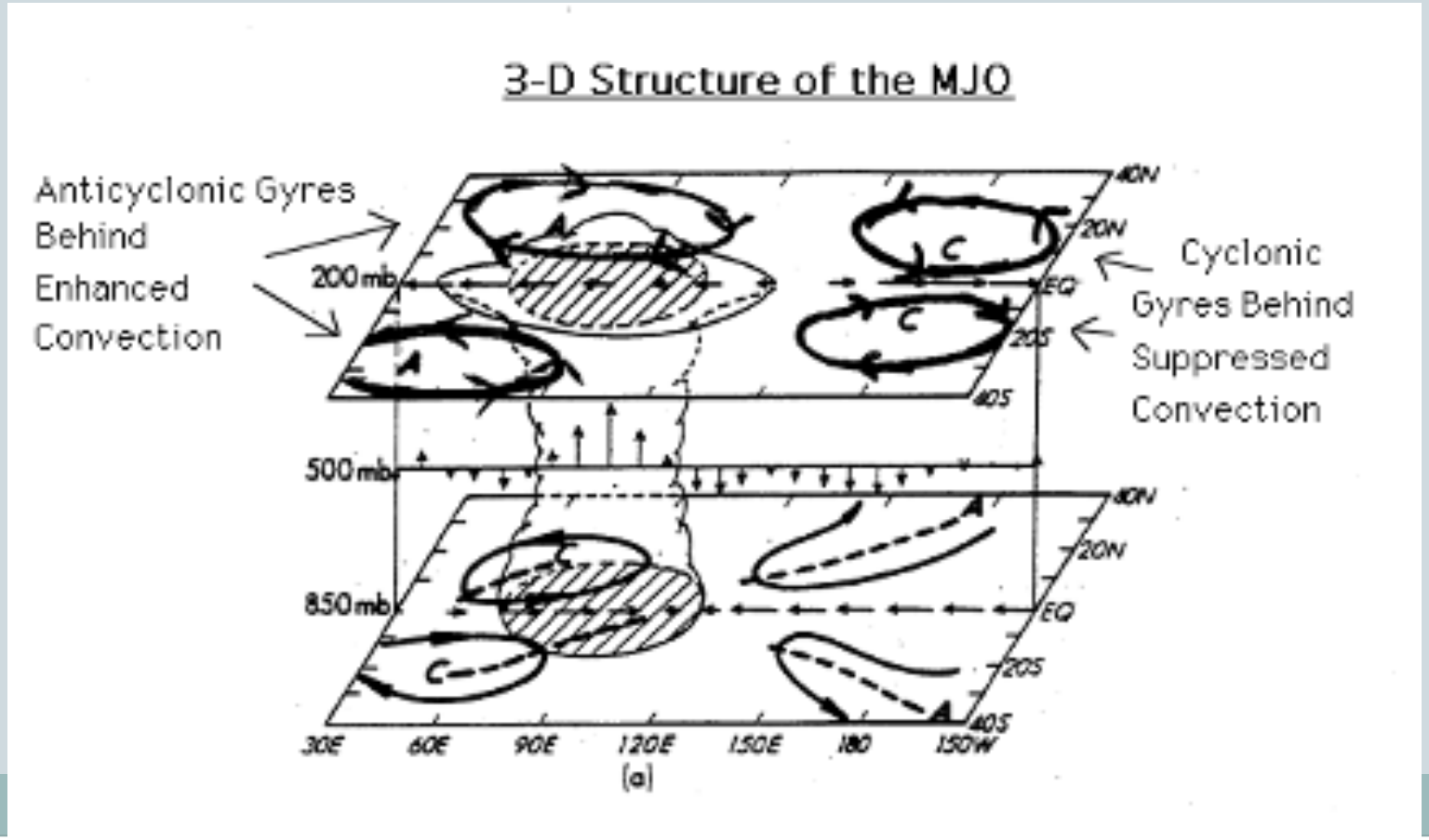
Figure is boreal winter OLR composite

From MJO diagnostics webpage



MJO Structure

- Has characteristics of Kelvin wave and Rossby wave



Movie of Indian Ocean Twin Cyclones

- Precipitable water satellite images: