Gill Model

- Steady response to heating:

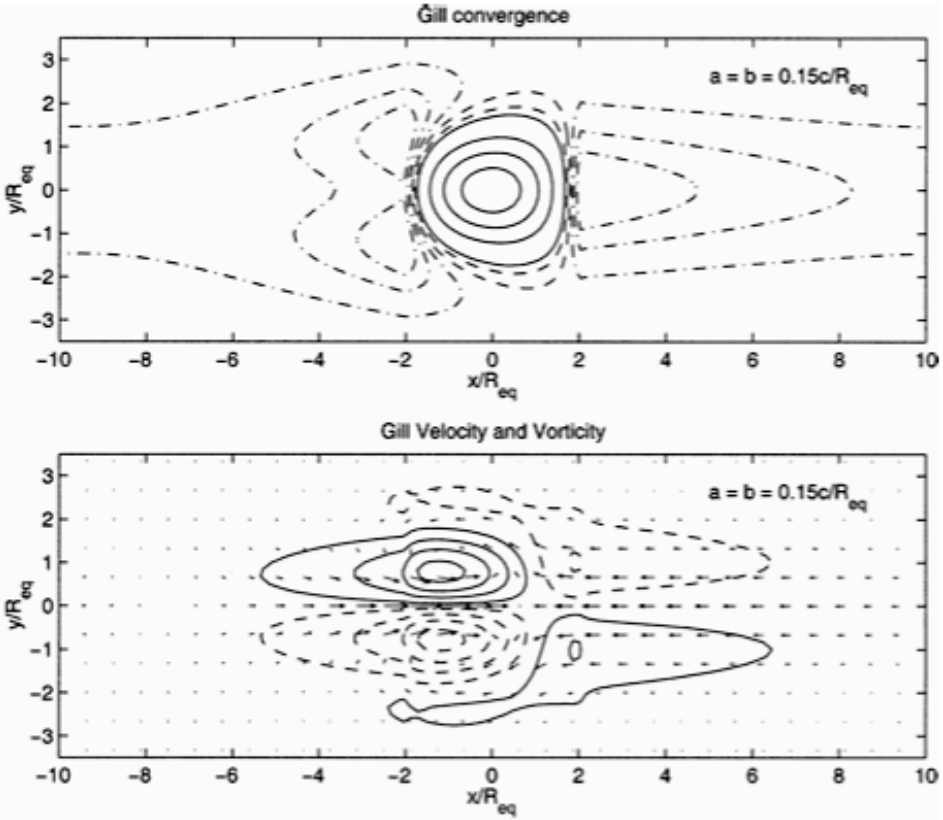


FIG. 1. Exact solution to the Gill model (no zonal compensation of mass sink) with zonally periodic boundary conditions. (top) Horizontal divergence (solid contours 0.1 to 0.9 by 0.2; dashed 0.02 and 0.06; and chain-dashed −0.1 to −0.02, by 0.04; all in units of D_0). (bottom) Velocity vectors and contours of vorticity (contour interval is $0.6D_0$, negative contours dashed). Full computational domain extends up to $|y/R_{eq}| = 10$.

Gaussian heat source in center of domain.

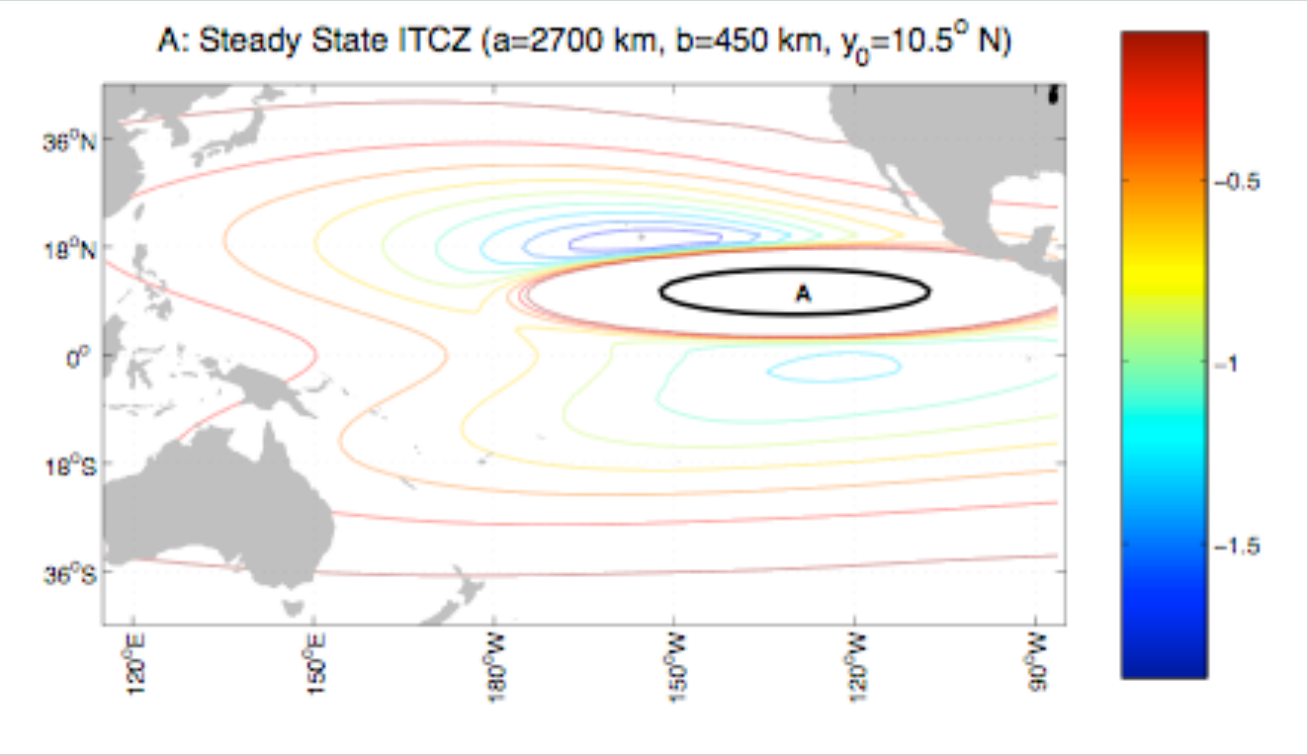
Boundary conditions are infinite in y, periodic in x

Top panel: convergence
Bottom panel: velocity vectors and vorticity

From Bretherton and Sobel 2003

Gill Model

- Also get cool asymmetric (about the equator) things:



Heating applied in region A.

Only subsidence contours are drawn (there is upward motion elsewhere).

From Gerber, Ito and Schubert (2001)

Summary of Derivations

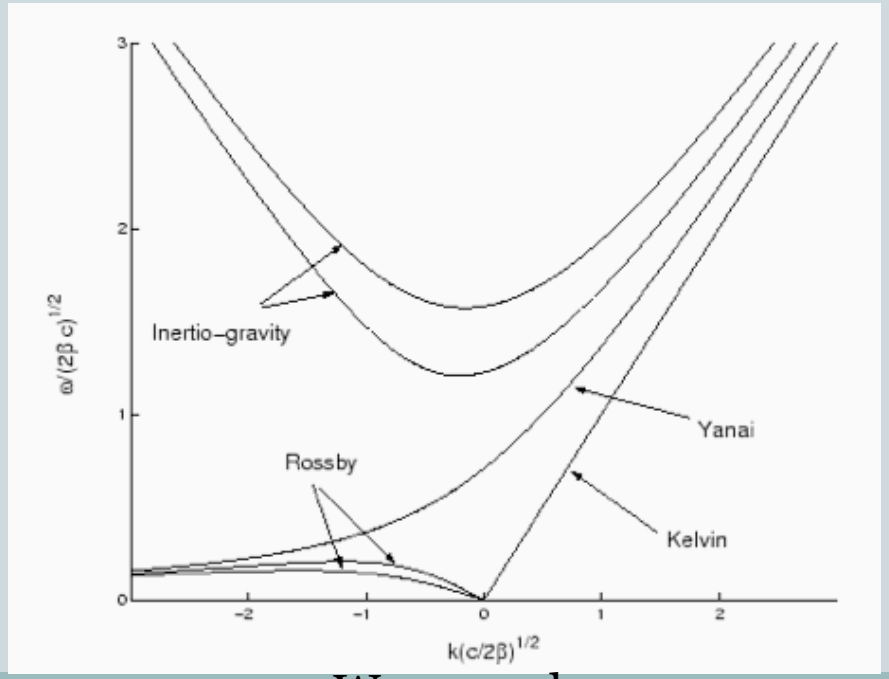
- Barotropic and first baroclinic modes
- No barotropic mode => dynamics are linear!
  - No barotropic mode + Newtonian cooling + Rayleigh friction + prescribed latent heating => “Matsuno-Gill model”
- Moisture equation for precipitation term
  - Can make condensation the only nonlinearity

The Transients

- Equatorial waves:
  - Dry and with moisture
  - Observations and models
- Start with derivations:
  - 1-D, non-rotating baroclinic modes
  - Equatorial Kelvin wave derivation

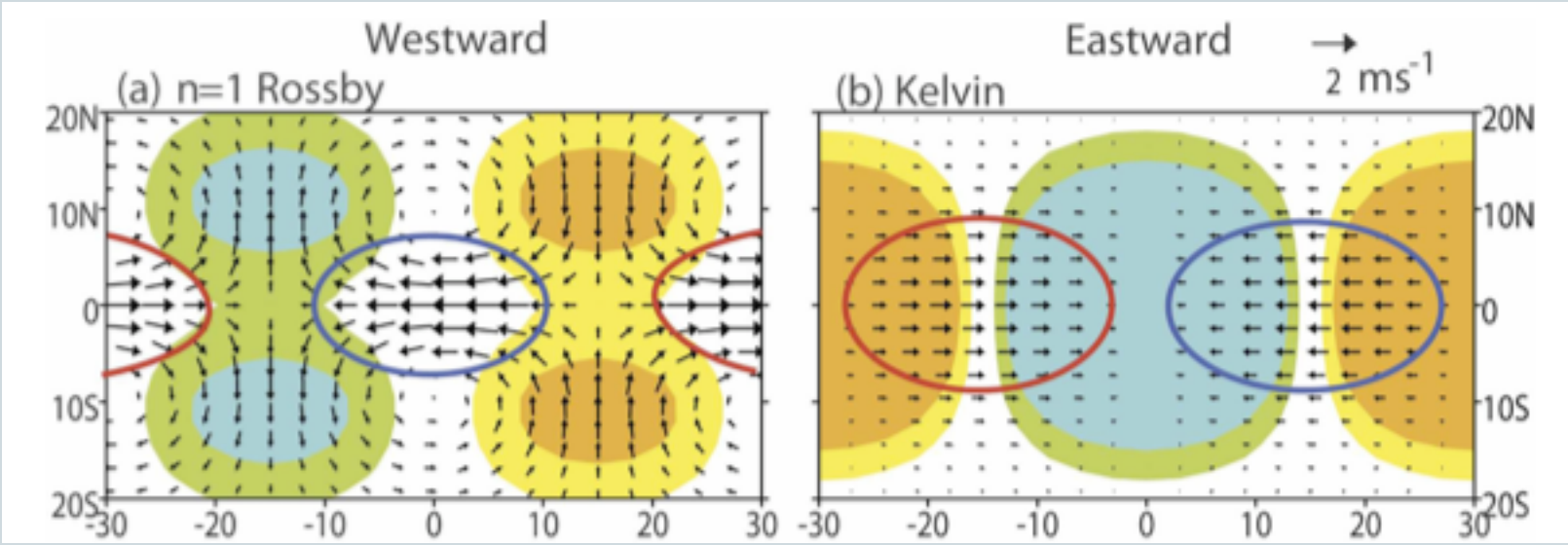
Dispersion Relations for Equatorial Waves

- System has the following: (see Majda 2003 or Gill for more details)
  - 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):

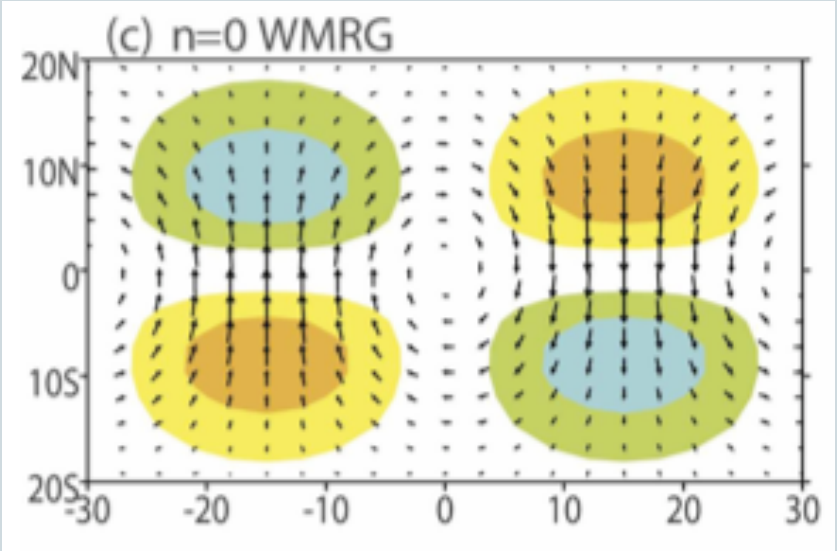


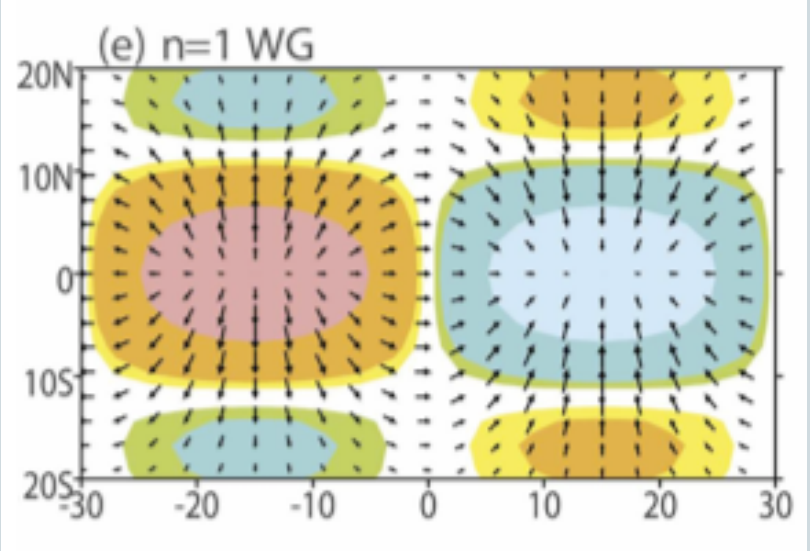
Vectors = winds
Colors = divergence contours
(ignore the ovals)

From Yang et al 2007

Structure of Equatorial Waves

- More structures (mixed Rossby gravity and WIG):





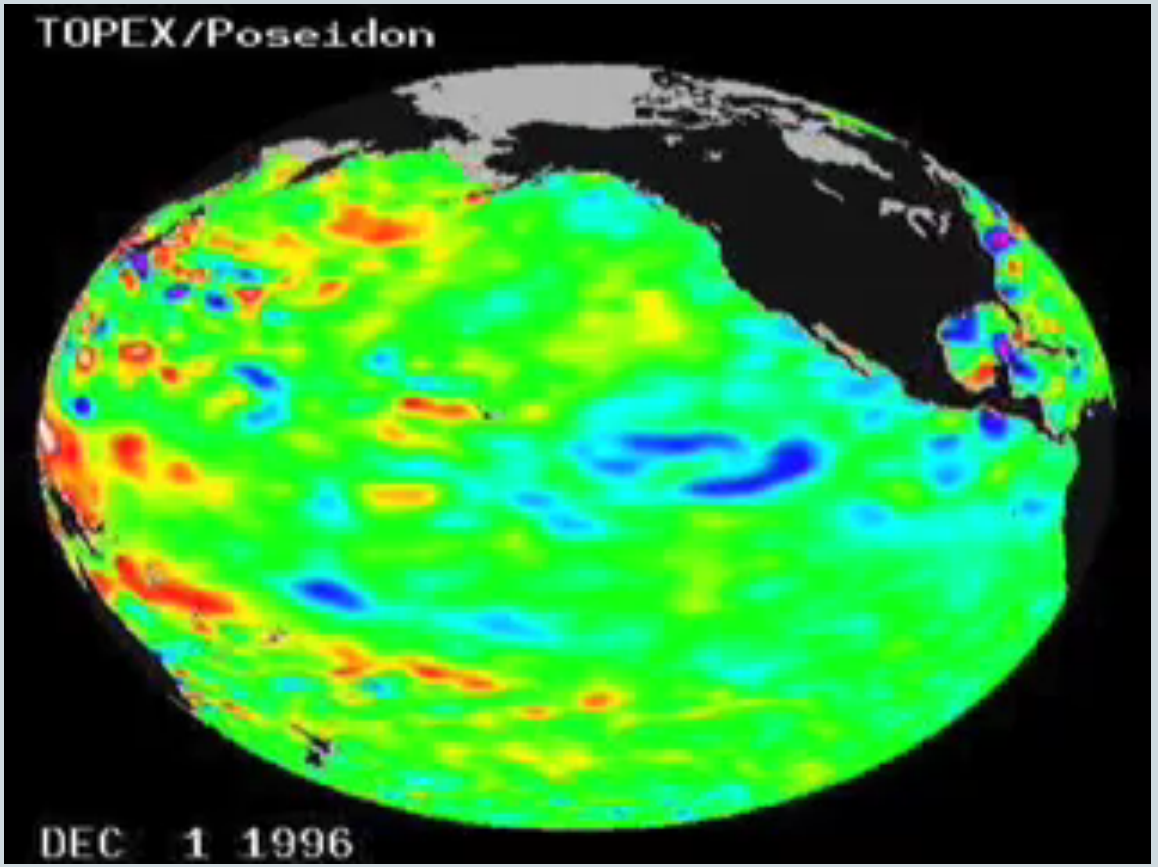
Vectors = winds
Colors = divergence contours
(ignore the ovals)

From Yang et al 2007

Equatorial Kelvin Waves in the Ocean

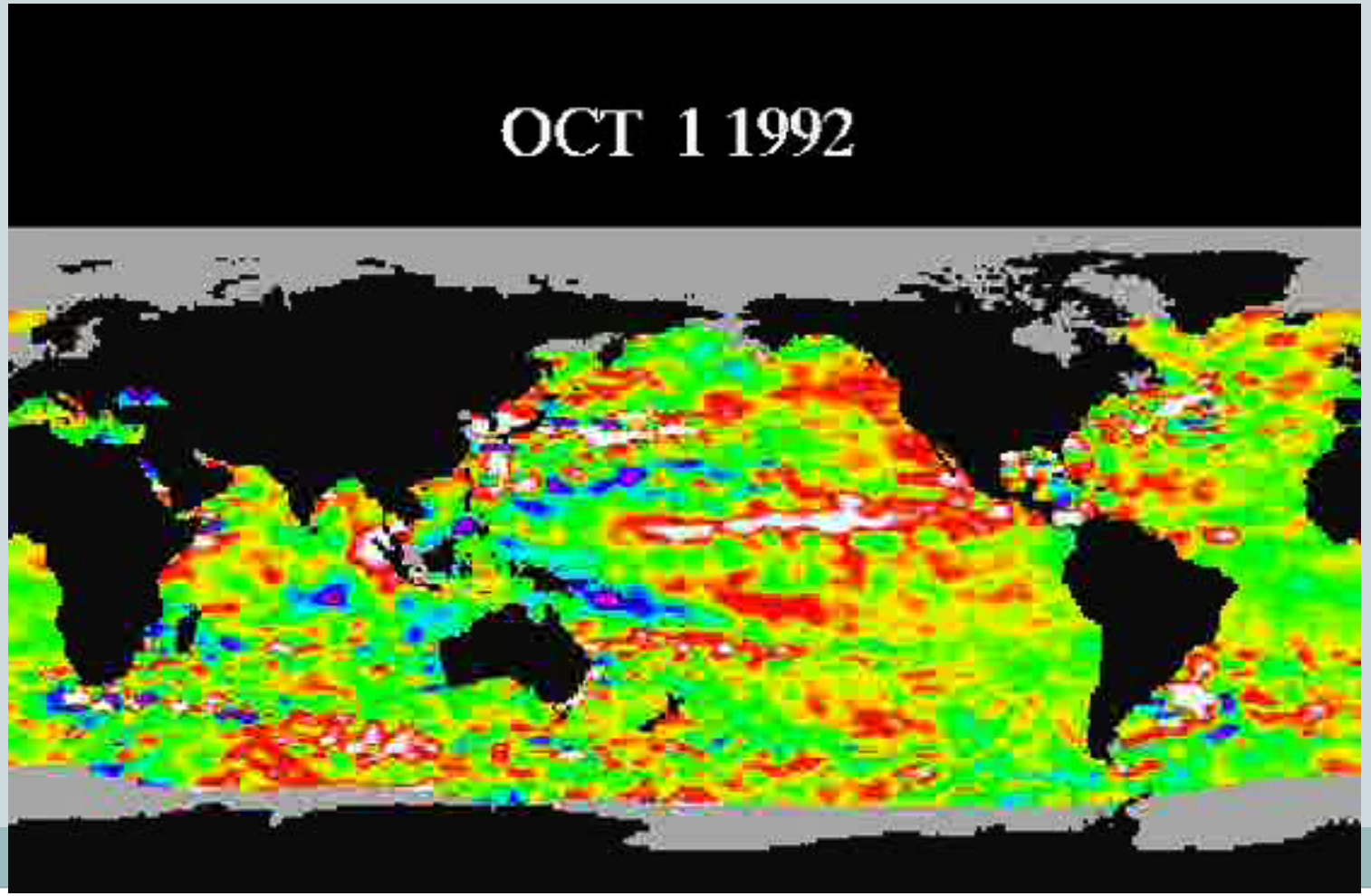
- These are seen in the ocean, and are key to El Nino dynamics

Sea surface height anomalies



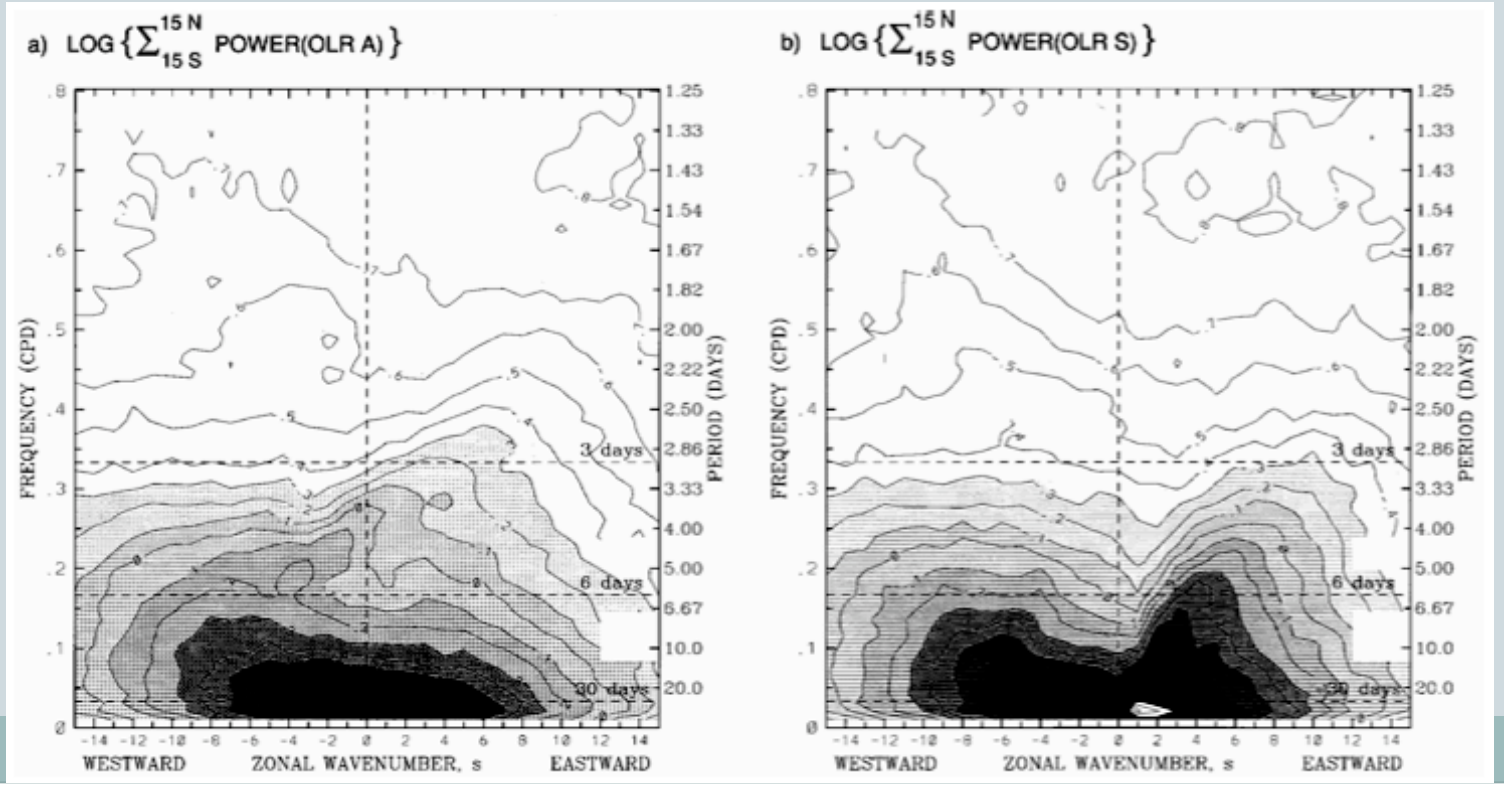
Equatorial Kelvin Waves in the Ocean

- A global picture:



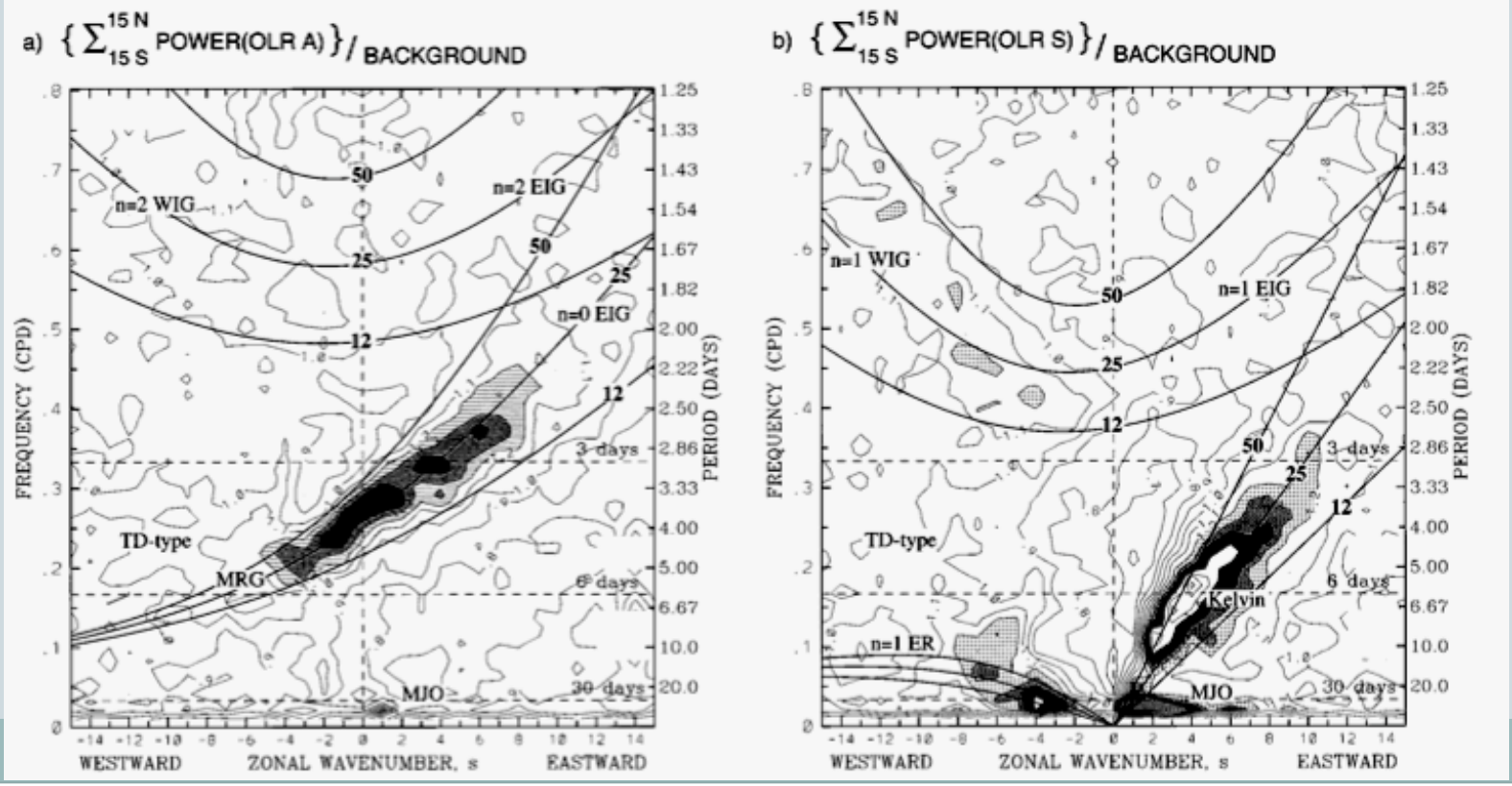
Atmospheric Obs. of Equatorial Waves

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



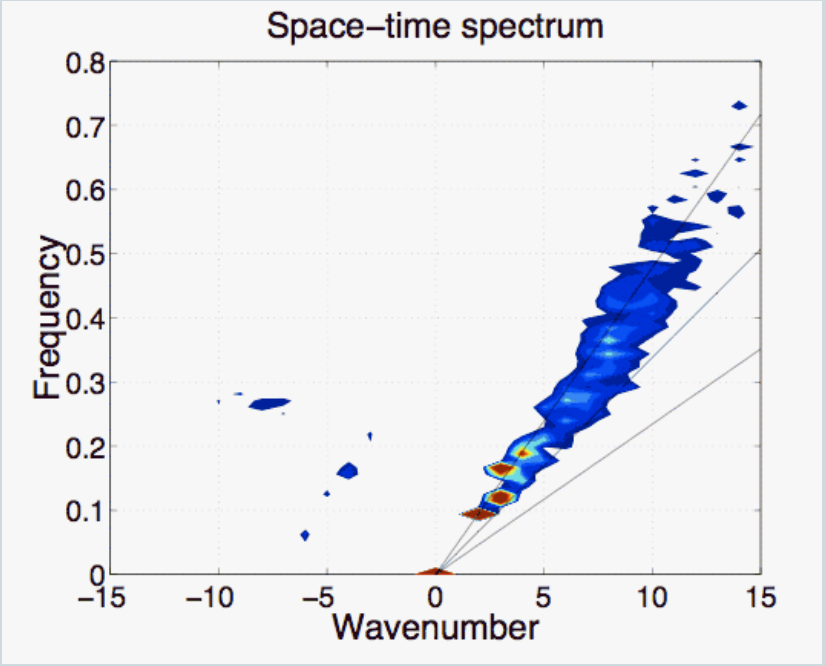
Atmospheric Obs. of Equatorial Waves

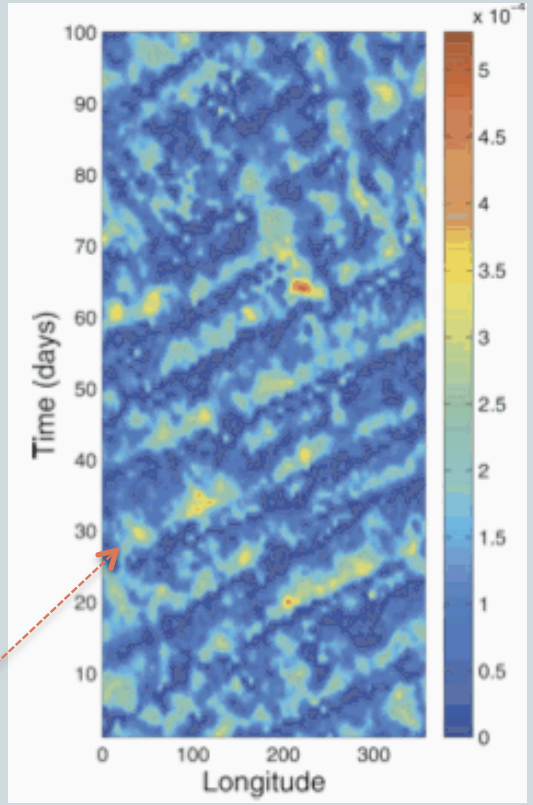
- Filter out "background spectrum":
  - Can see all different wave types! Especially Kelvin, MRG, and ER. Also, the mysterious MJO…



Equatorial Waves in Idealized GCM

- In simplified moist GCM, Kelvin waves dominate the spectrum

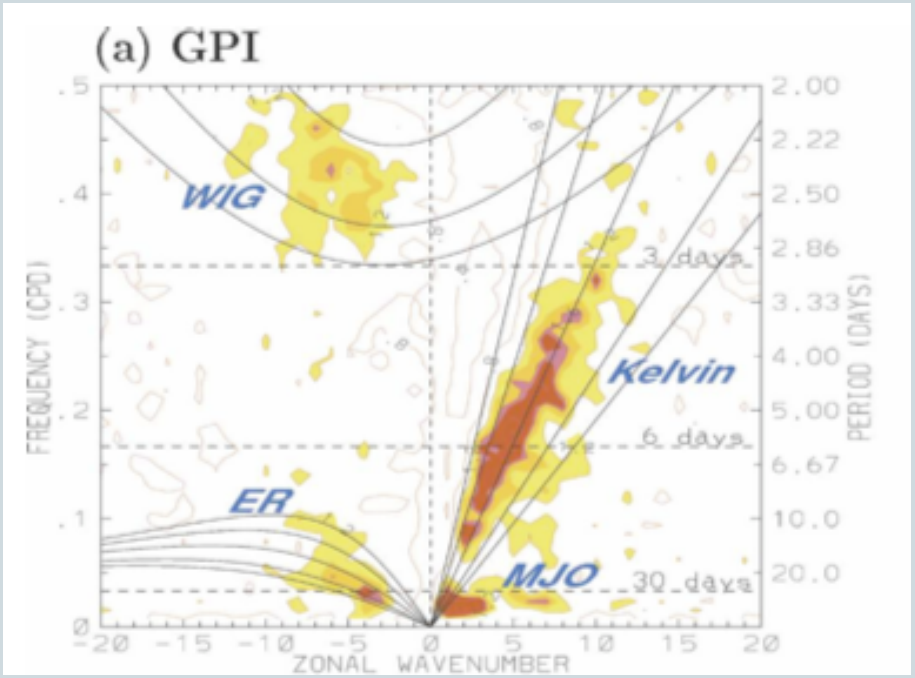


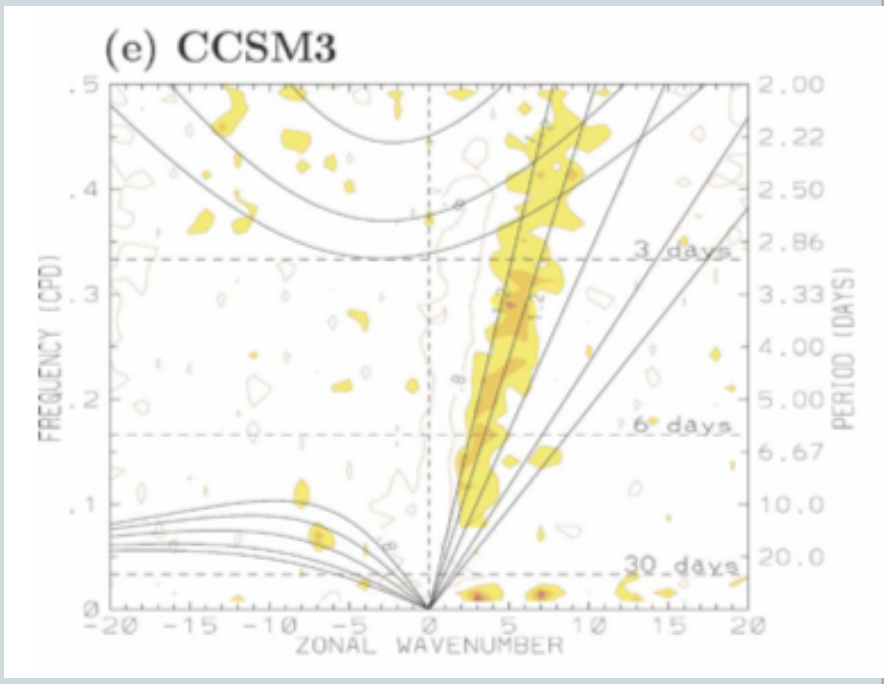


They can propagate around and around the equator multiple times!

Full GCM Waves

- Observations versus models:





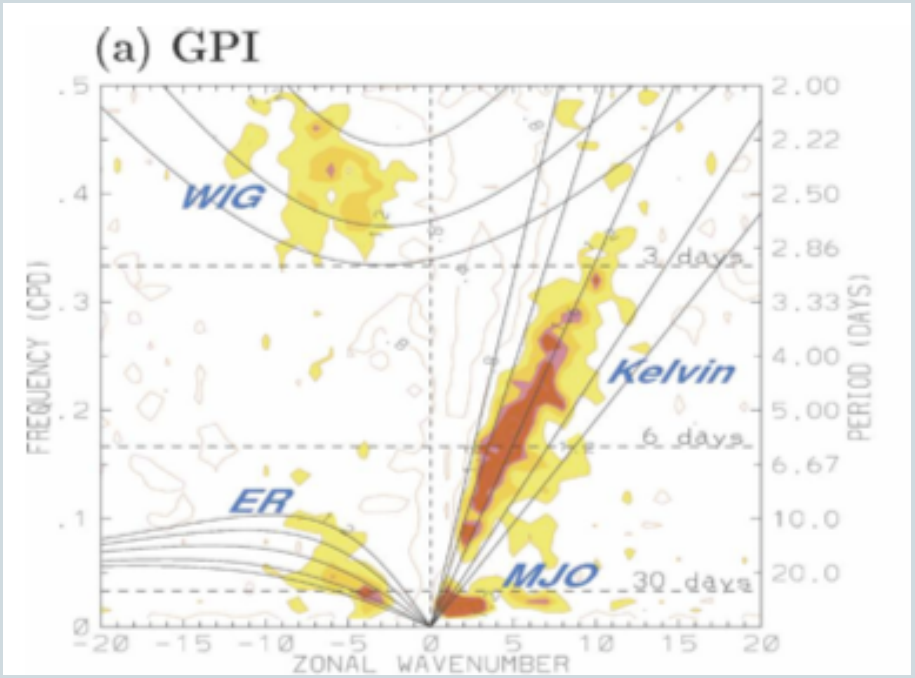
Obs

AM2

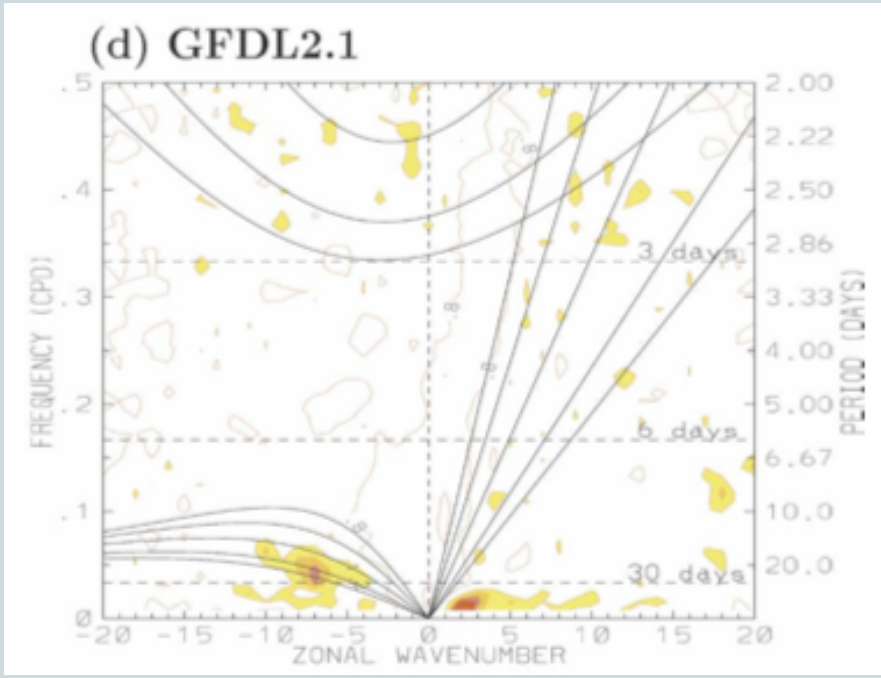
From Lin et al (2006)

Full GCM Waves

- Models are too weak, too fast



Obs



NCAR CCSM

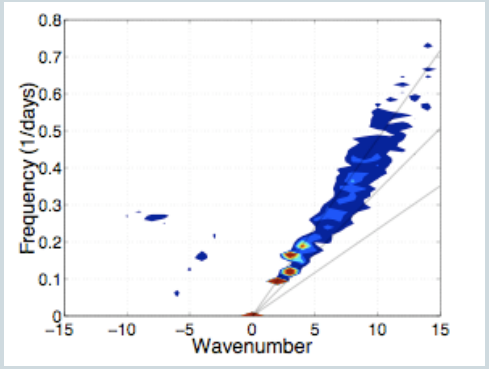
From Lin et al (2006)

Equatorial Waves

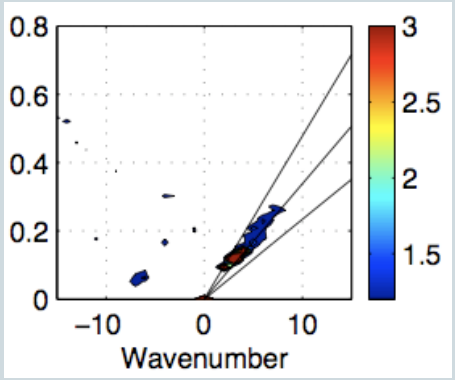
- In observations, speeds are significantly slower than predicted by the dry theory
  - Kelvin wave travels at ~15-20 m/s in obs
- Also true in simplified GCM/full GCMs:
  - Speeds are still significantly slower than predicted by the dry theory
  - Even in fastest model, only get ~30 m/s speed
- There's a simple theory for speed reduction that involves condensation
  - Derivation w/ active moisture

Convectively coupled Kelvin waves

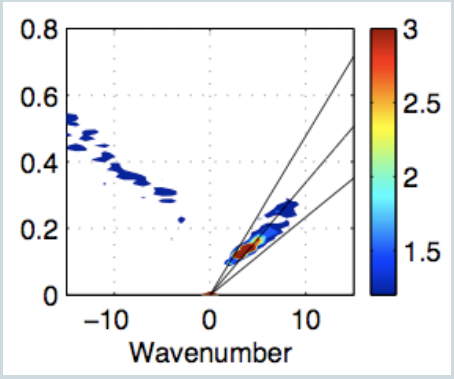
- In simplified moist GCM, GMS reduction leads to slower convectively coupled waves:



GMS = 7 K



GMS = 4.5 K



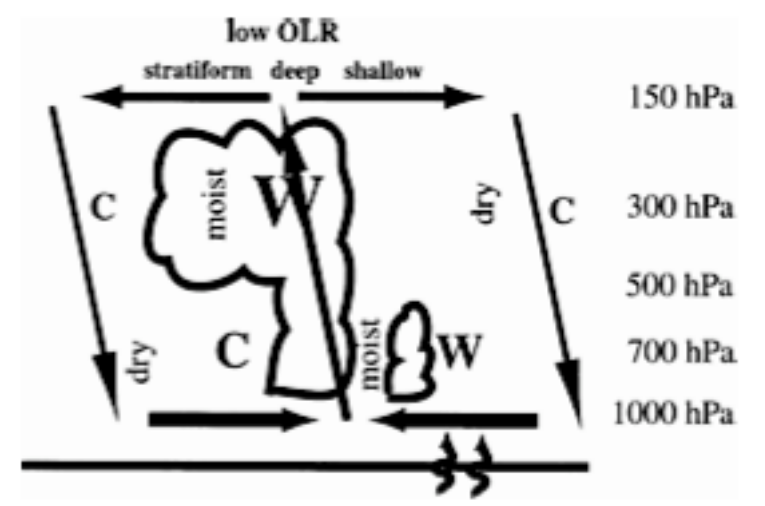
GMS = 2.5 K

Wavespeed can be tuned to essentially any value in this model

See Frierson (2007b) for more detail

Equatorial Waves

- Alternative theory for wave speed:
  - Higher vertical mode structure causes phase speed reduction



Schematic of Kelvin wave structure from Straub and Kiladis (2003)

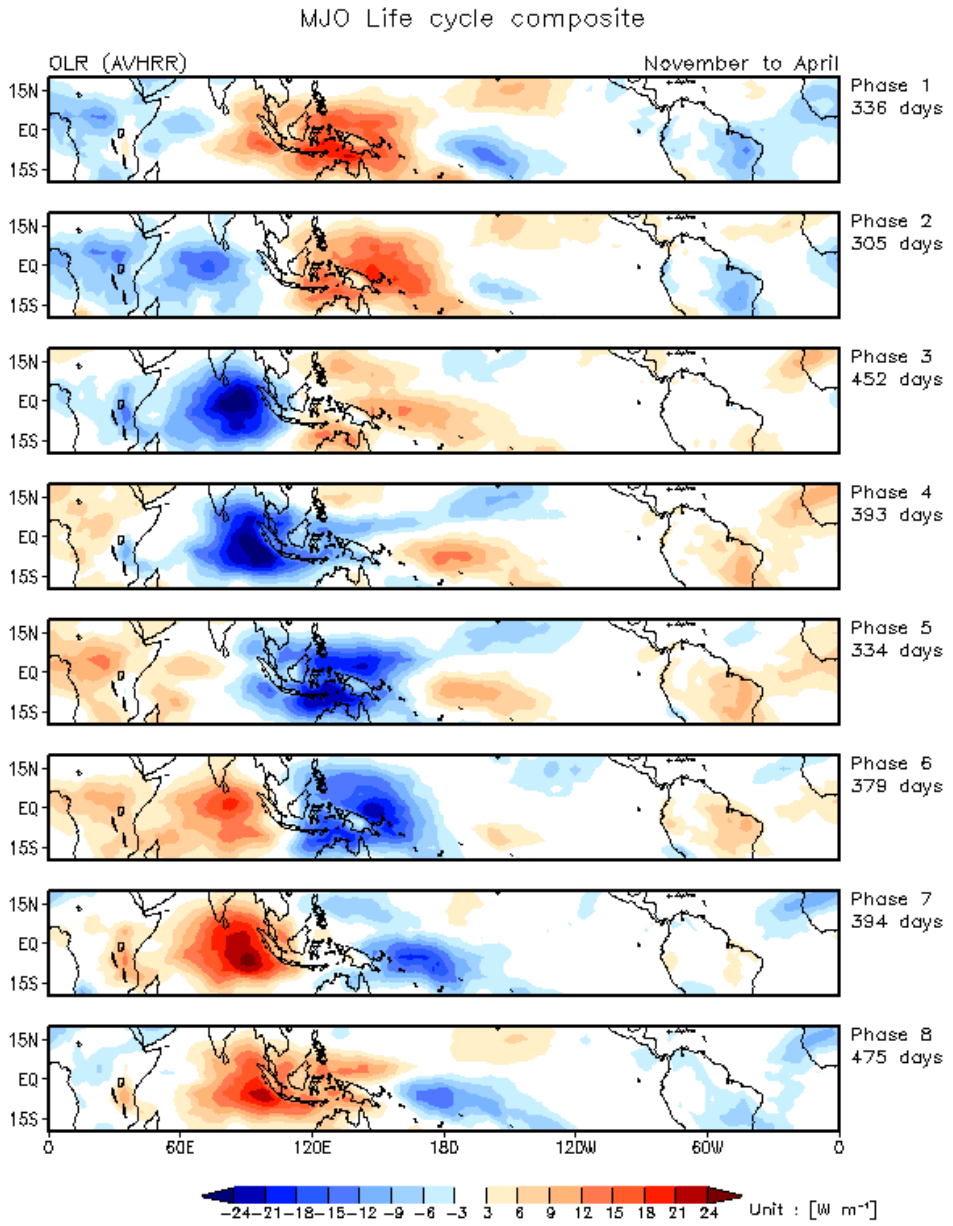
- What powers the waves?
  - Evaporation-wind feedback derivation

Madden-Julian Oscillation

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

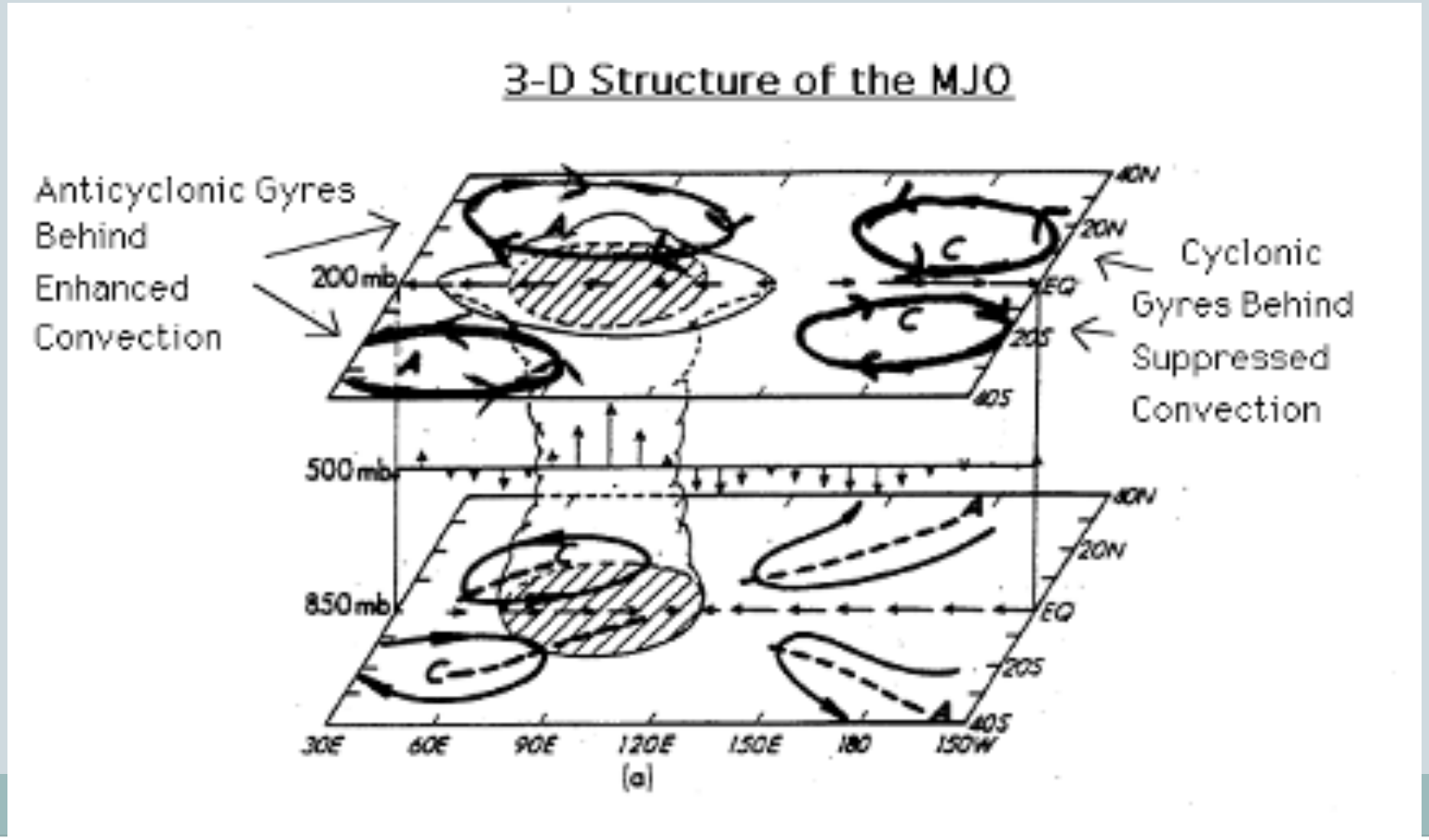
Figure is boreal winter OLR composite

From MJO diagnostics webpage



MJO Structure

- Has characteristics of Kelvin wave and Rossby wave



Movie of Indian Ocean Twin Cyclones

- Precipitable water satellite images: