ATM S 442/504: Atmospheric Motions II

DARGAN M. W. FRIERSON
UNIVERSITY OF WASHINGTON, DEPARTMENT OF ATMOSPHERIC SCIENCES

MAR 5-10, 2014
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 ($^\circ$Cm s$^{-1}$) for Northern Hemisphere winter.
Eddy Momentum Fluxes


**Figure 10.6** Observed northward eddy momentum flux distribution (m² s⁻²) for Northern Hemisphere winter.
Isentropic Circulation

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

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

Ferrel cell has disappeared!

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 $20 \times 10^9$ 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.
Eliassen-Palm Flux Divergence

- EP flux divergence

Figure 10.9  Eliassen–Palm flux divergence divided by the standard density $\rho_o$ 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.
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

Warm pool especially warm & strong Walker circulation in La Niña

[W.S. Kessler, NOAA/PMEL]
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!
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:

OCT 1 1992
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: