Climate Dynamics: Why Does Climate Vary?

The Madden-Julian Oscillation: Organization of Weather Events Over the Warm Oceans

http://www.esrl.noaa.gov/psd/people/dezheng.sun/lectures/ATOC7500.html
Madden-Julian Oscillation

Winds and Precipitation
Deep Convection Over Warm Oceans
Madden-Julian Oscillation
A Three-D Schematic View
Madden-Julian Oscillation

Winds and Precipitation
The MJO: hierarchical convective organization

1. Cloud-cluster family
   ~ 100 km

2. Supercluster family
   ~ 1000 km
MJO: Multi-scales and Self-similarity
MJO: Global Climatic Impact

Courtesy of Jialin Lin (NOAA CDC, private communication)
Why does the tropical atmosphere convect?

Solar heating

Longwave cooling
Radiative Equilibrium / Radiative-Convective Equilibrium

![Graph showing pressure vs. temperature with different labels for pure radiative equilibrium, dry adiabatic adjustment, and 6.5°C/km adjustment.]
Dry and Moist Adiabatic Lapse Rate
Atmospheric Convection
The Dynamics of Updrafts

\[ CAPE = \int_{z_1}^{z_2} g \frac{\delta T}{T} dz \]

Temperature of ascending parcel
Temperature of environment
Condensation level, cloud base, latent heat release
Near ground, rising parcels are colder than environment, so a lifting mechanism is needed
The Dynamics of Downdrafts

• Rain evaporates, cools and descends driving evaporative downdrafts

• Particularly efficient when the updrafts tilt backwards overlying the downdrafts -- then rain falls into downdrafts which are maintained by evaporative cooling ...
Downdraft fronts trigger cumulus convection
Organizing effects of shear

Shear: change of horizontal wind speed over a given height range

\[ \Delta U \]

Shear interacts with convectively generated vorticity, tilting updrafts and downdrafts, and forming the distinctive airflow pattern characteristic of mesoscale convective systems (MCS)
Evolution of cumulus into a traveling MCS

Stage 1: Onset - single cumulus

Stage 2: Family of cumulus at downdraft front

Stage 3: Mesoscale downdraft is accelerated by pressure gradient

Stage 4: Mature traveling MCS

Moncrieff and Liu (2006)
MJO-like systems are produced by traveling organized convection

Observe (Nakazawa 1988)

Numerical simulation (Grabowski 2001)

Vertical structure

Dynamical model of mesoscale convective organization interlocked with MJO dynamics

Moncrieff (2004)
Shallow Water Equations for the Tropical Wave Dynamics

\[ \frac{\partial u}{\partial t} - \beta y v + \frac{\partial \phi}{\partial x} = 0 \]
\[ \frac{\partial v}{\partial t} + \beta y u + \frac{\partial \phi}{\partial y} = 0 \]
\[ \frac{\partial \phi}{\partial t} + gh \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = 0 \]
Theoretical Dispersion Relationships For Tropical Waves

- Kelvin
- Gravity
- Mixed
- Equatorial Rossby

Zonal Wavenumber

Frequency
Kelvin Wave Structure

\[(n = -1), \, k^* = 1, \, Kelvin\]

Wind, Pressure (contours), Divergence (color, blue negative)
Mixed Rossby-Gravity Wave Theoretical Structure

\[ n=0, k^*=1, \text{Mixed Rossby-gravity} \]

Wind, Pressure (contours), Divergence, red negative
from Wheeler and Kiladis, 1999

OLR power spectrum, 1979–2001 (Symmetric)

Westward Inertio-Gravity
Kelvin
Equatorial Rossby
Madden-Julian Oscillation

from Wheeler and Kiladis, 1999
OLR power spectrum, 1979–2001 (Antisymmetric)

from Wheeler and Kiladis, 1999
OBSERVATIONS OF KELVIN WAVES AND THE MJO

Time–longitude diagram of CLAUS Tb (2.5S–7.5N), January–April 1987

MJO (5 m s⁻¹)

Kelvin waves (15 m s⁻¹)
Homework

1. Derive the dry adiabatic lapse rate and the moist adiabatic lapse rate from the first law of thermodynamics.

2. Among the following factors, which increases the convective available potential energy of an ascending parcel originating from the surface level of the tropical atmosphere: (1) a decrease in the surface temperature, (2) a decrease in the surface humidity, (3) entraining environmental air on the way of ascending, (4) a cooling of the environmental air in the mid troposphere.

3. Adding more CO2 to the tropical atmosphere will destabilize or stabilize the tropical atmosphere? Why?
Recommended Readings For The Next Lecture

Page 1--57 in El Nino, La Nina, and the Southern Oscillation by G. H. Philander