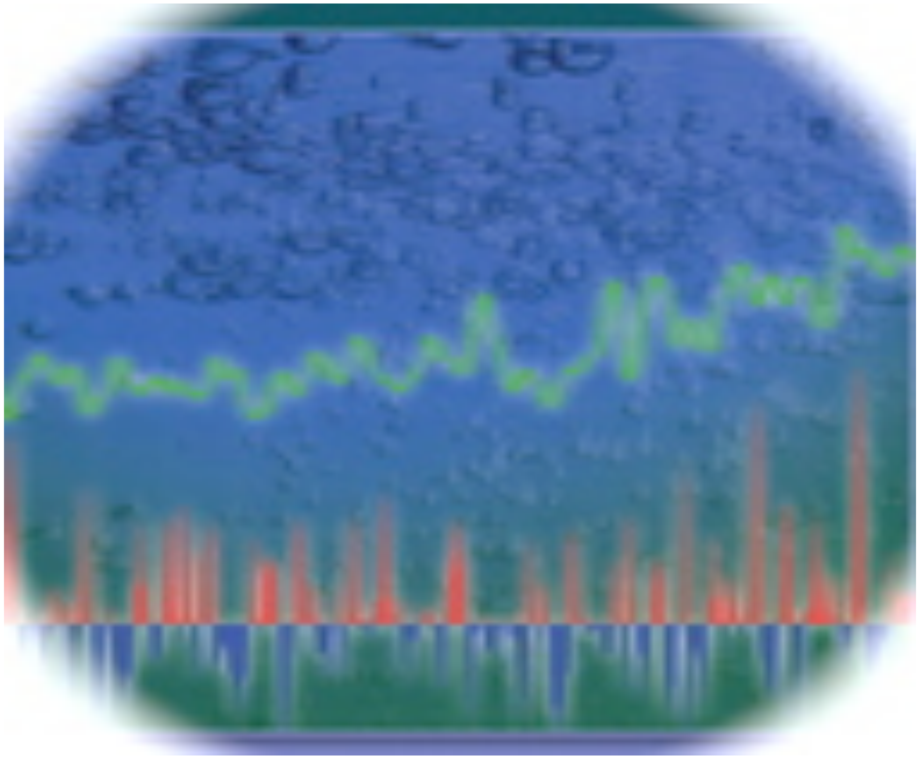
Climate Dynamics: Why Does Climate Vary?

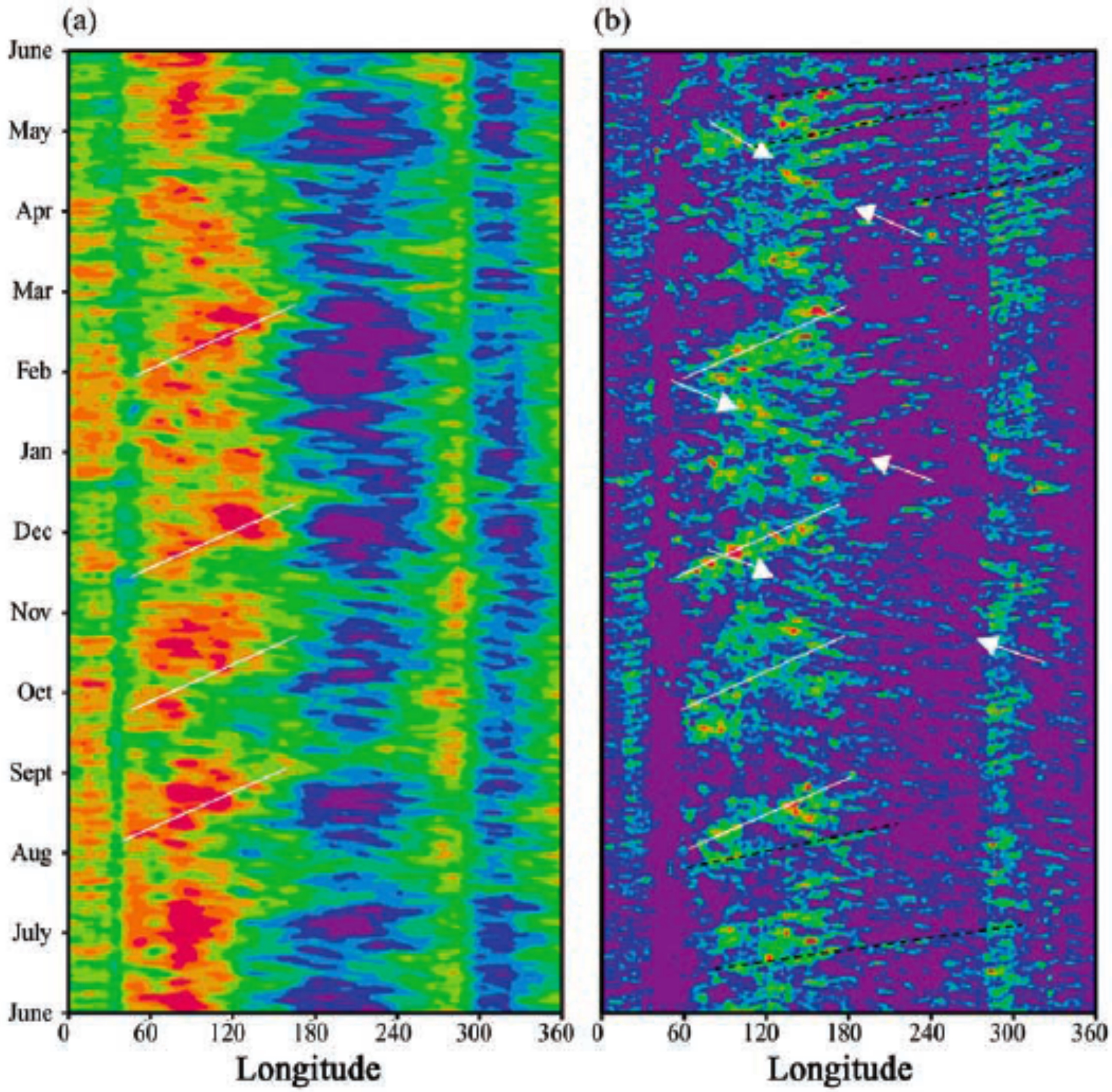


The Madden-Julian Oscillation: Organization of Weather Events Over the Warm Oceans

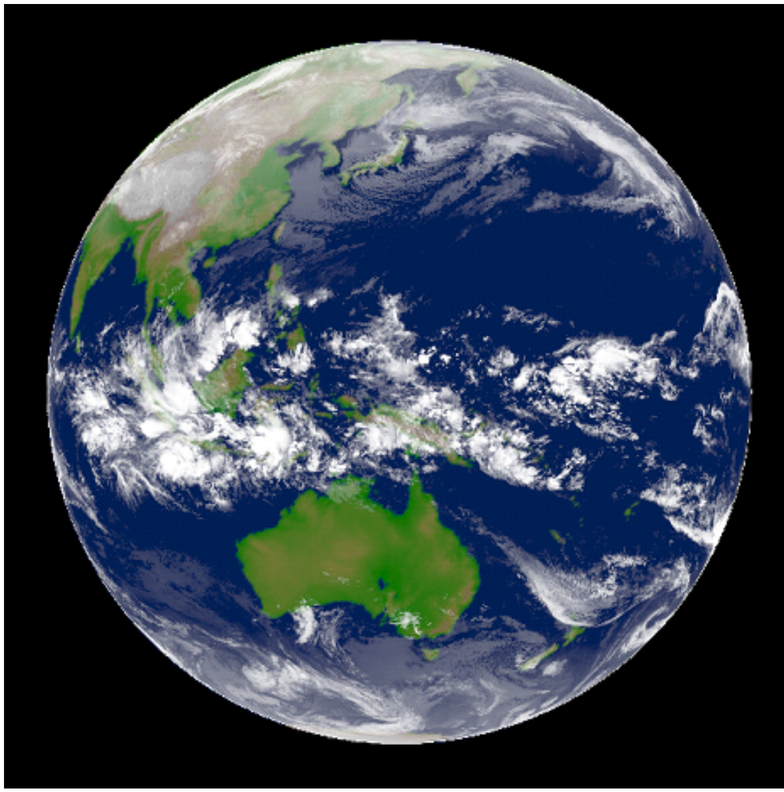
http://www.esrl.noaa.gov/psd/people/dezheng.sun/lectures/ATOC7500.html

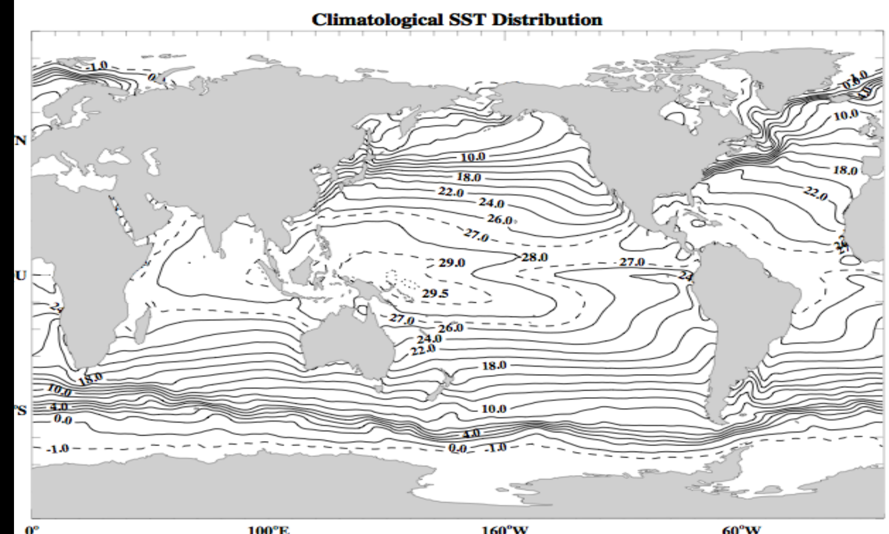
Madden-Julian Oscillation

Winds and Precipitation



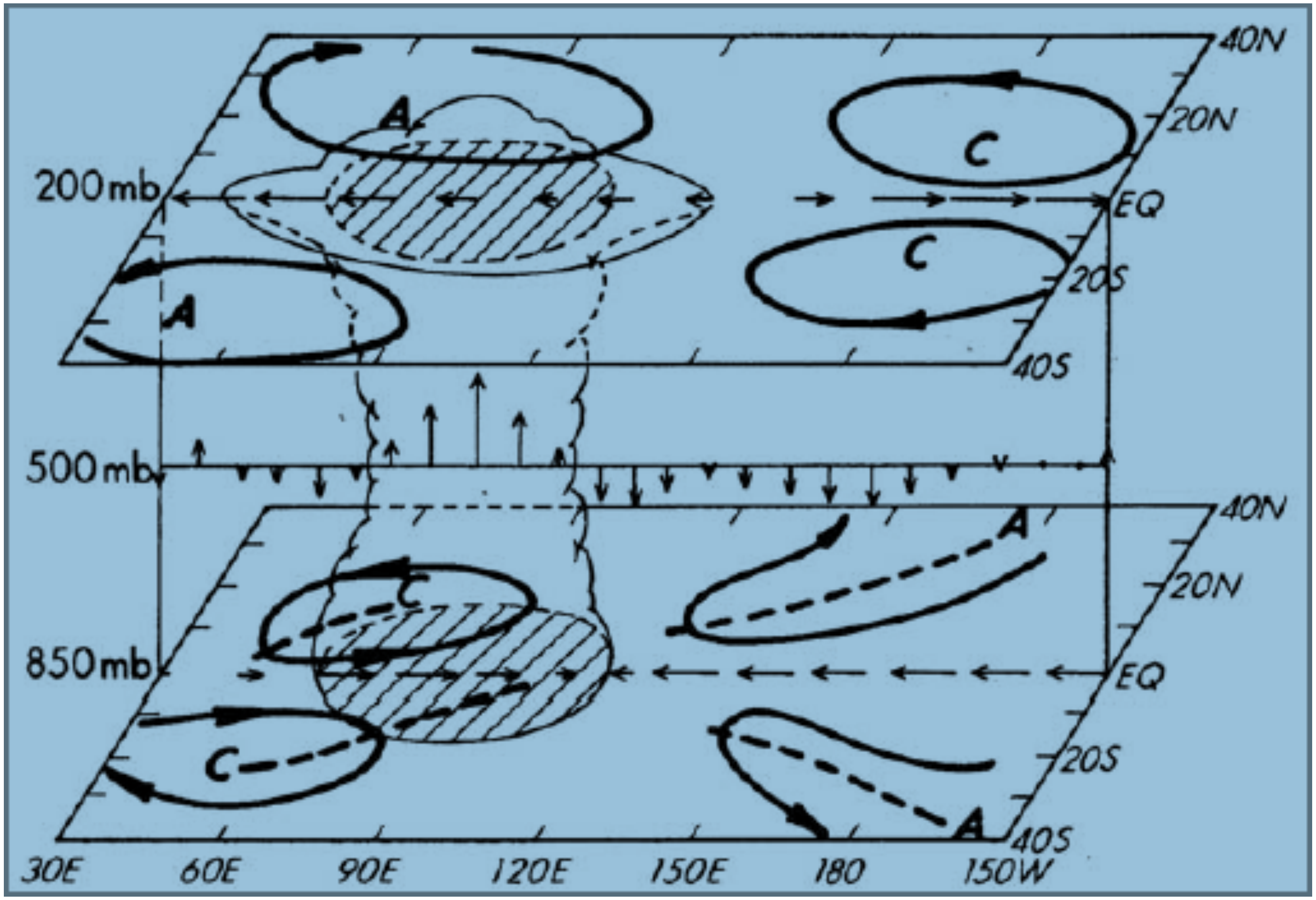
Deep Convection Over Warm Oceans





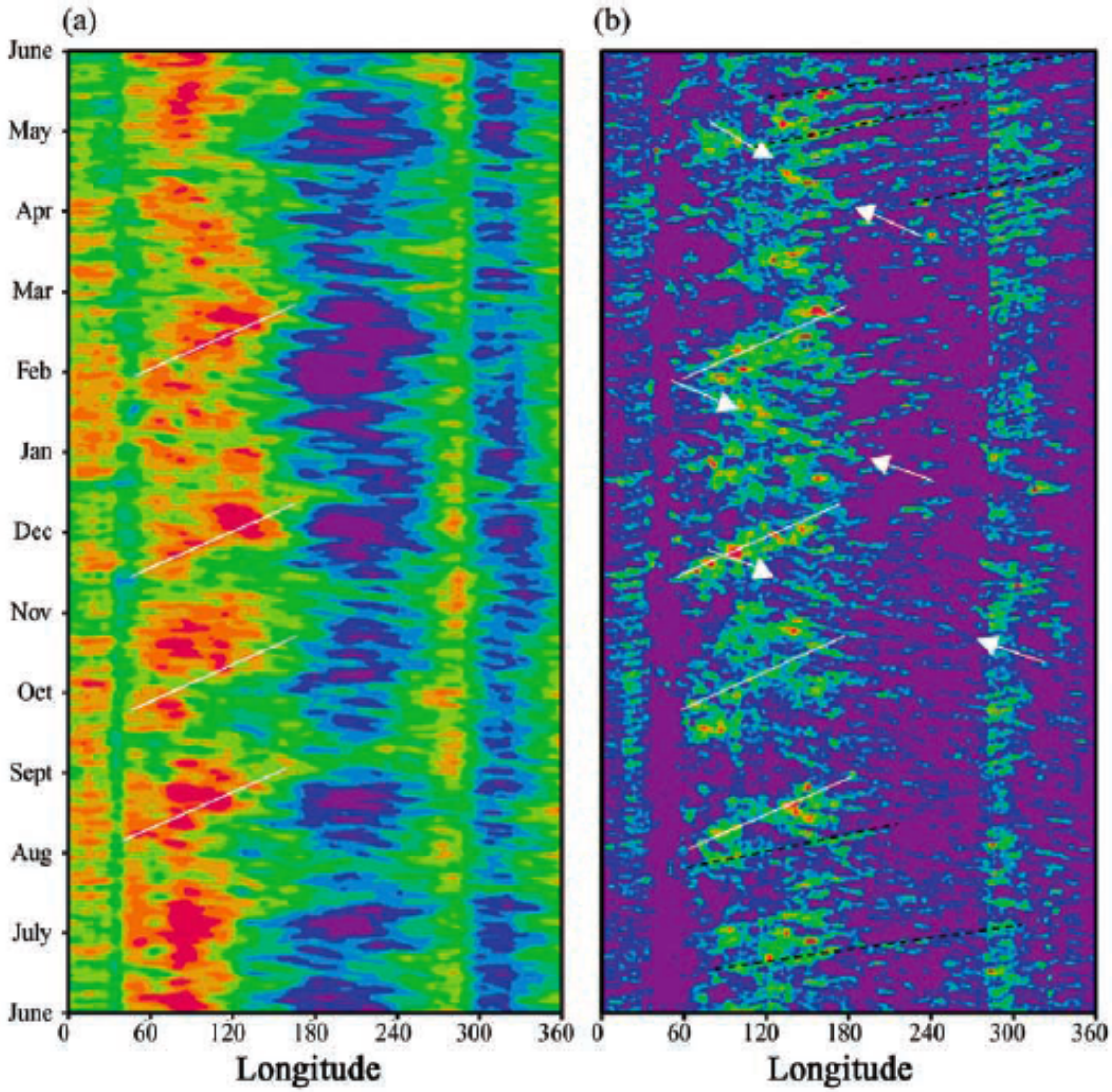
Madden-Julian Oscillation

A Three-D Schematic View

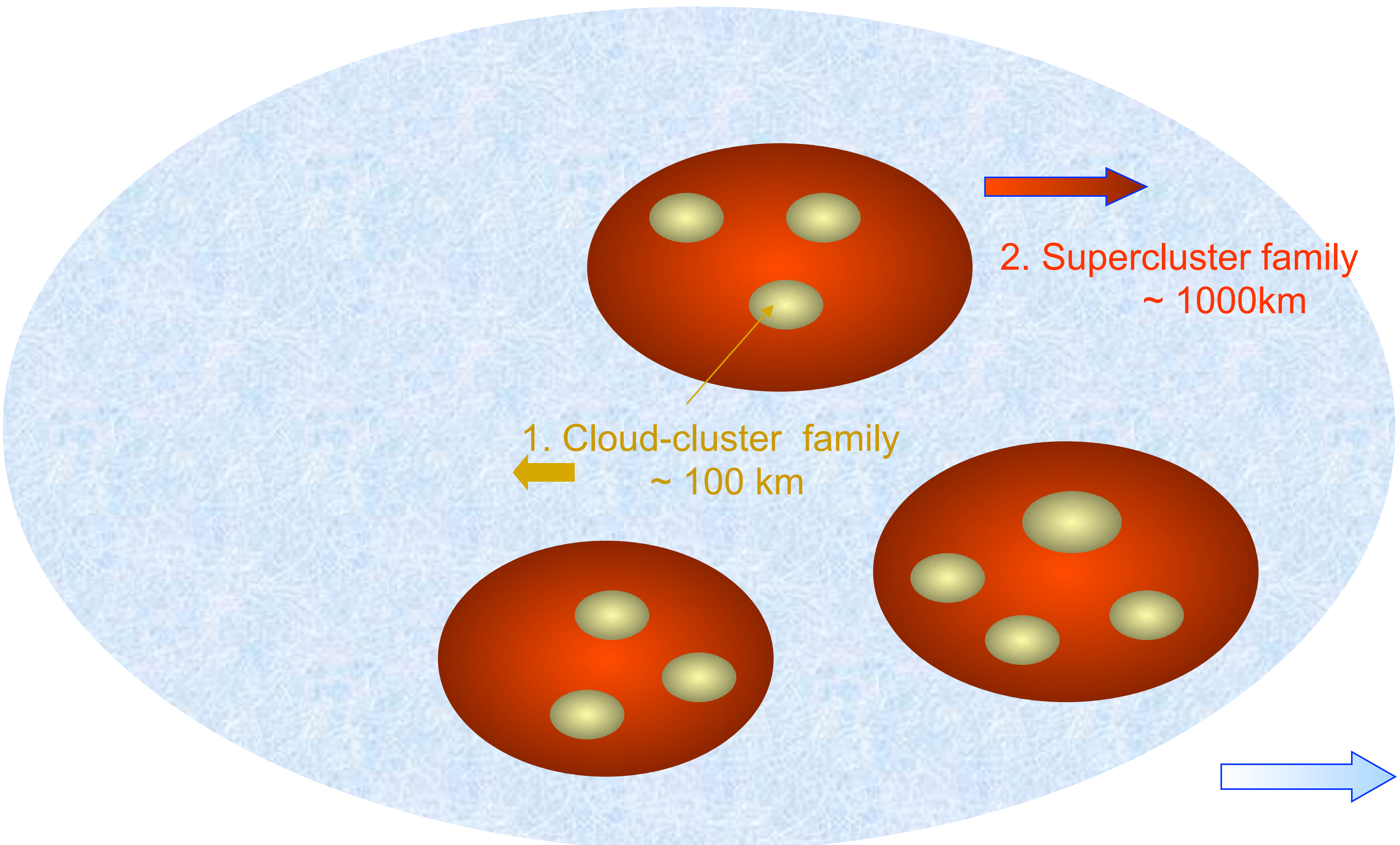


Madden-Julian Oscillation

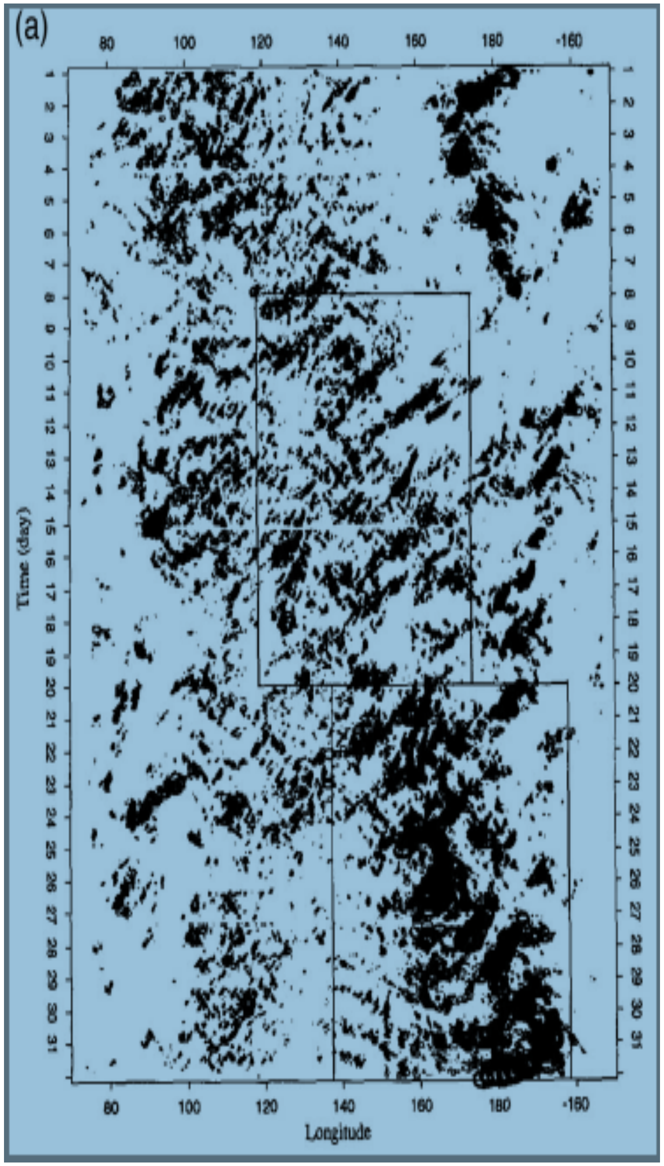
Winds and Precipitation

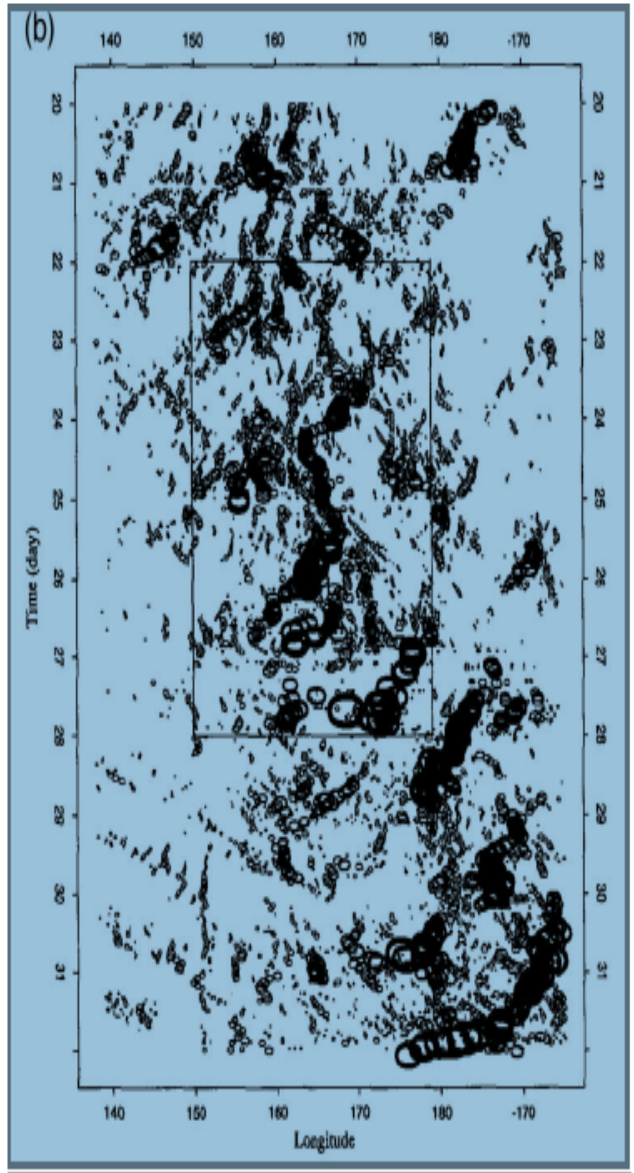


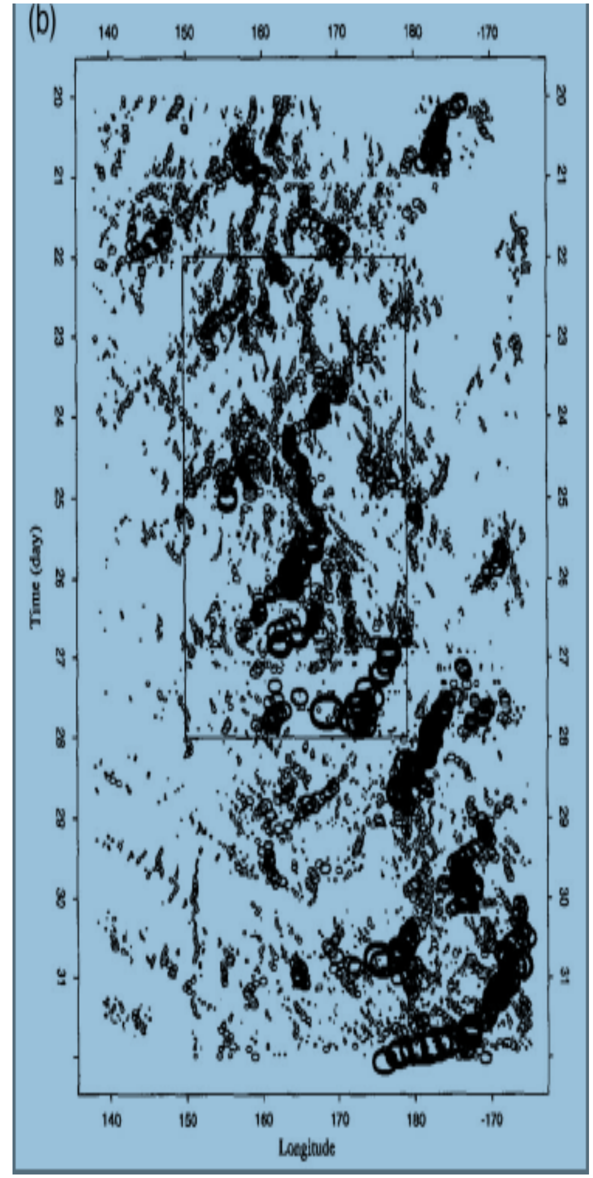
The MJO: hierarchical convective organization



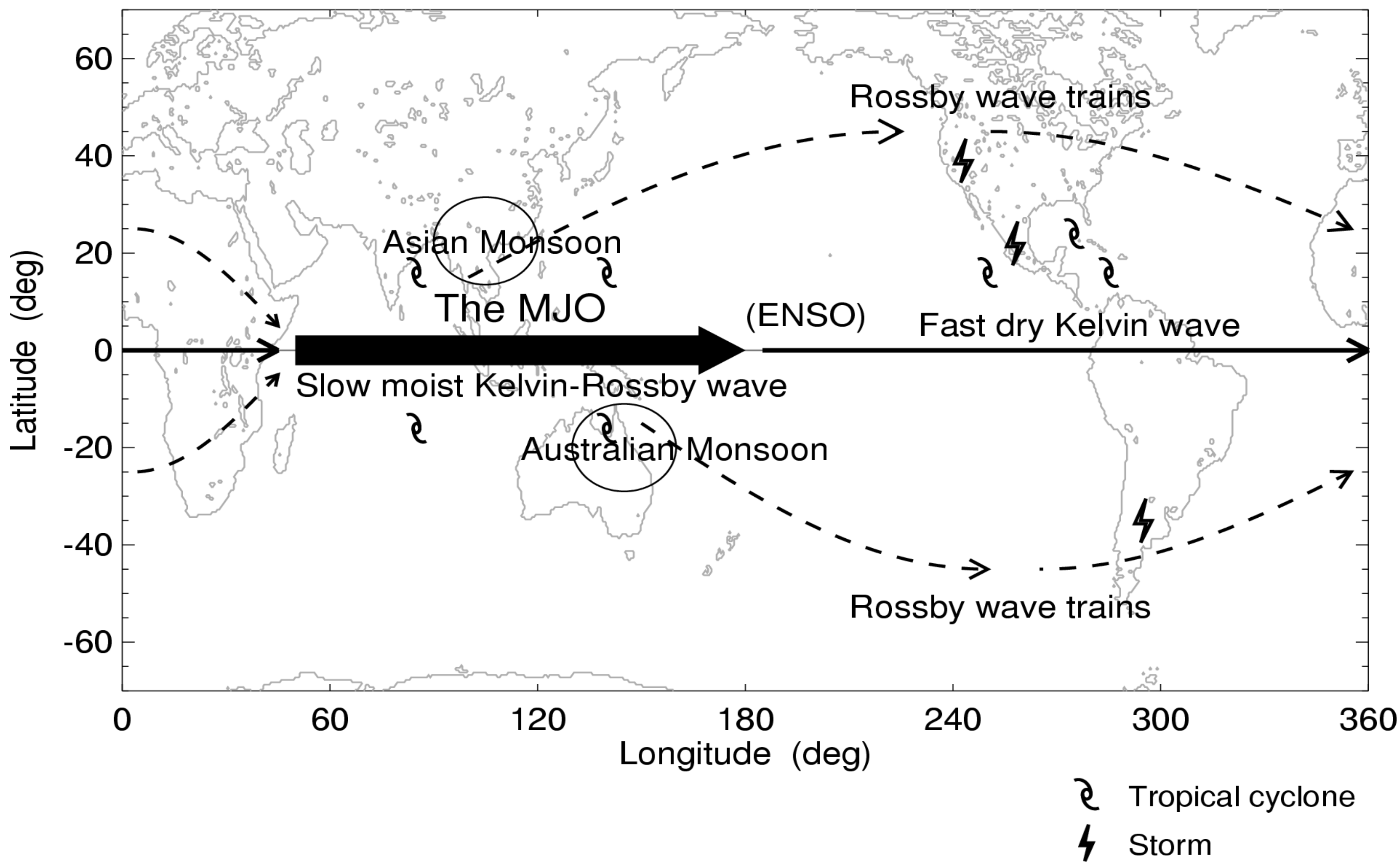
MJO: Multi-scales and Self-similarity





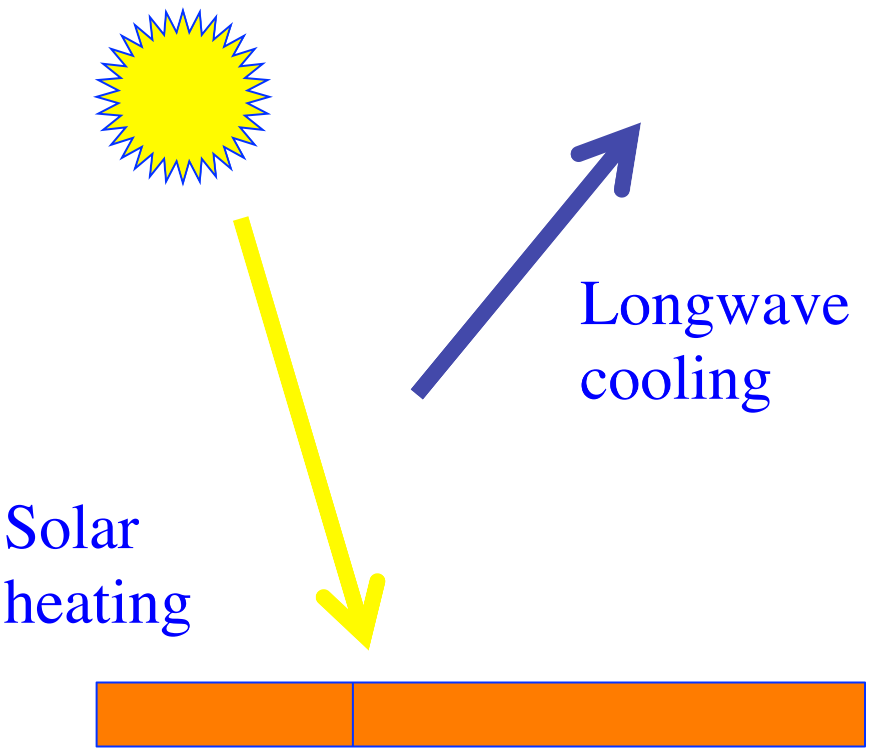


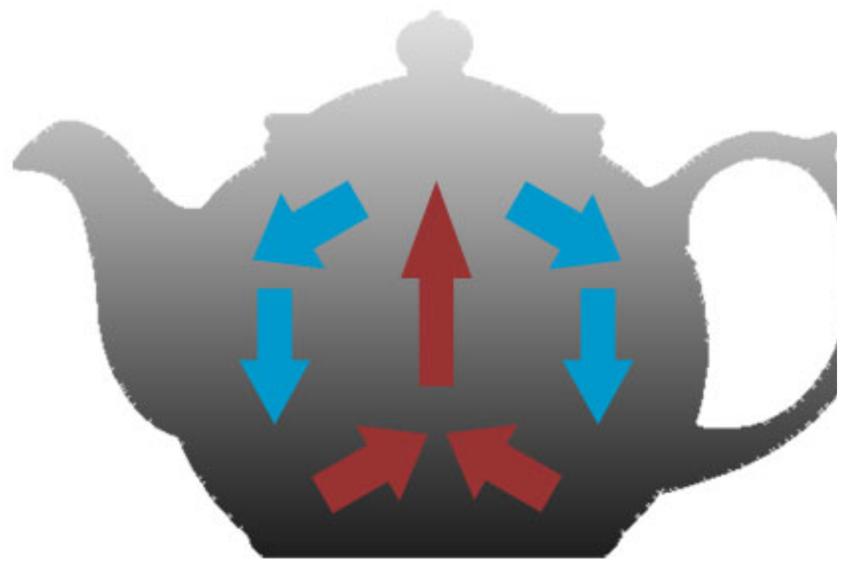
MJO: Global Climatic Impact



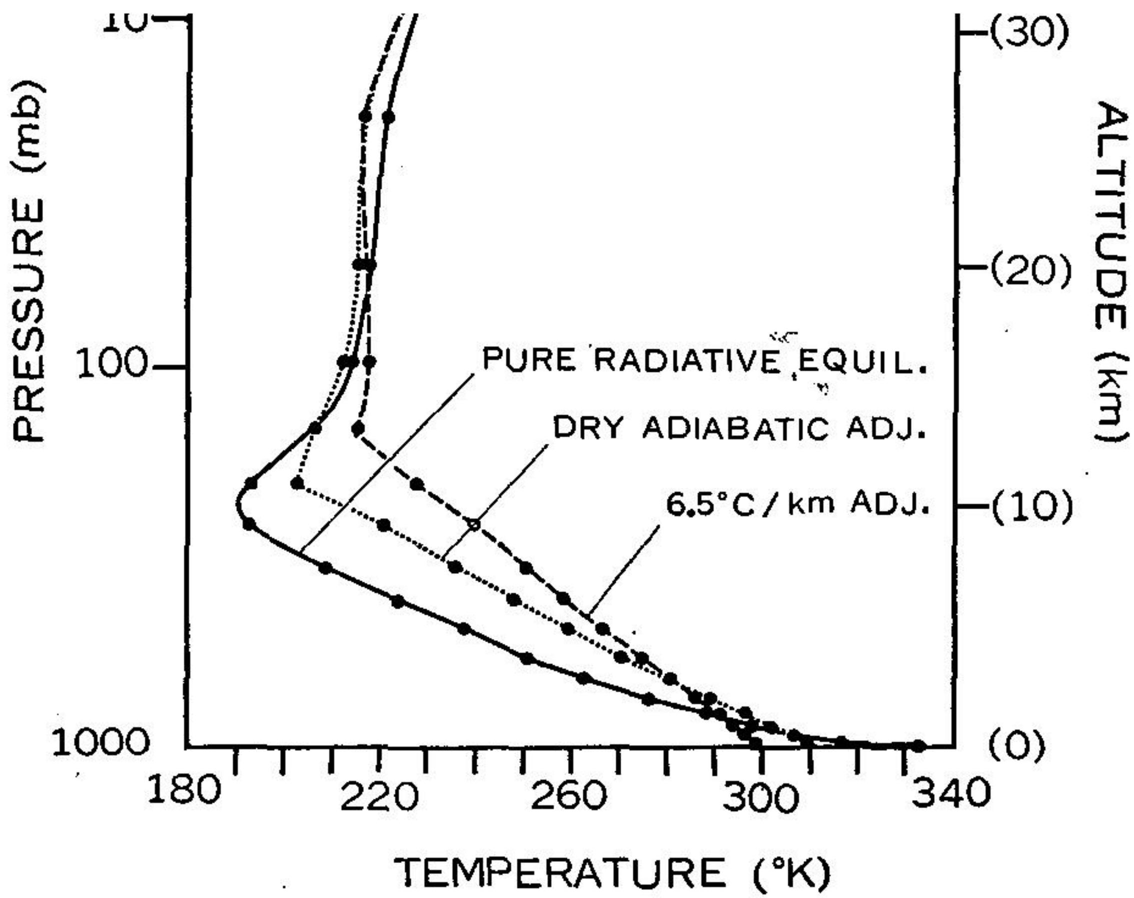
Courtesy of Jialin Lin (NOAA CDC, private communication)

Why does the tropical atmosphere convect?

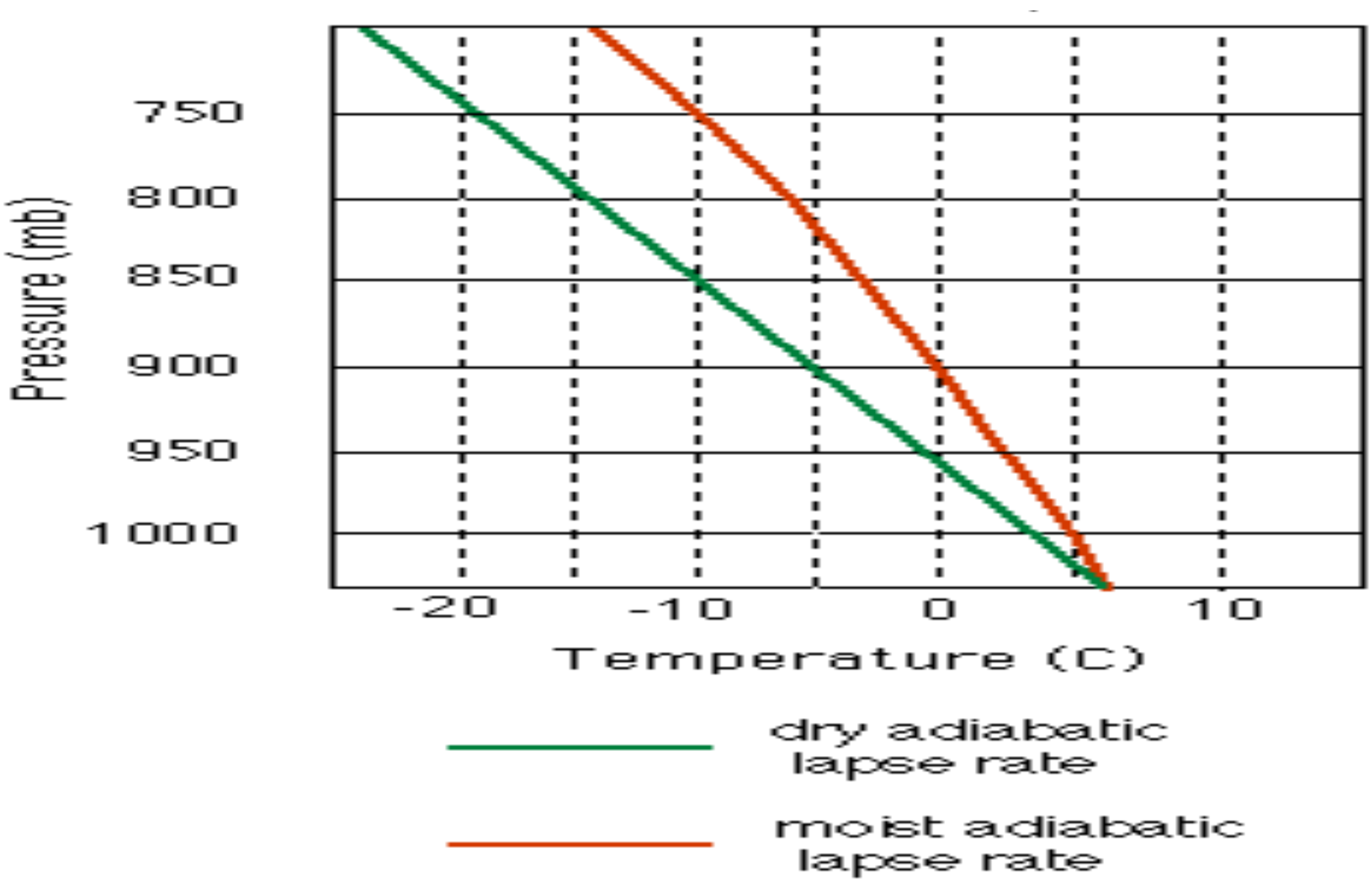




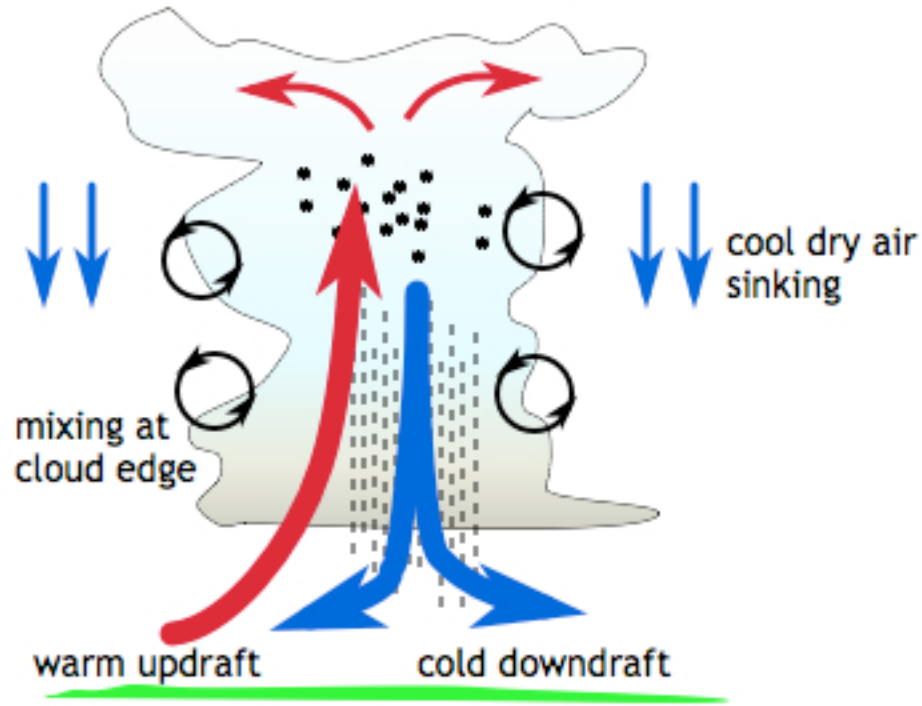
Radiative Equilibrium /Radiaitve-Convective Equilibrium



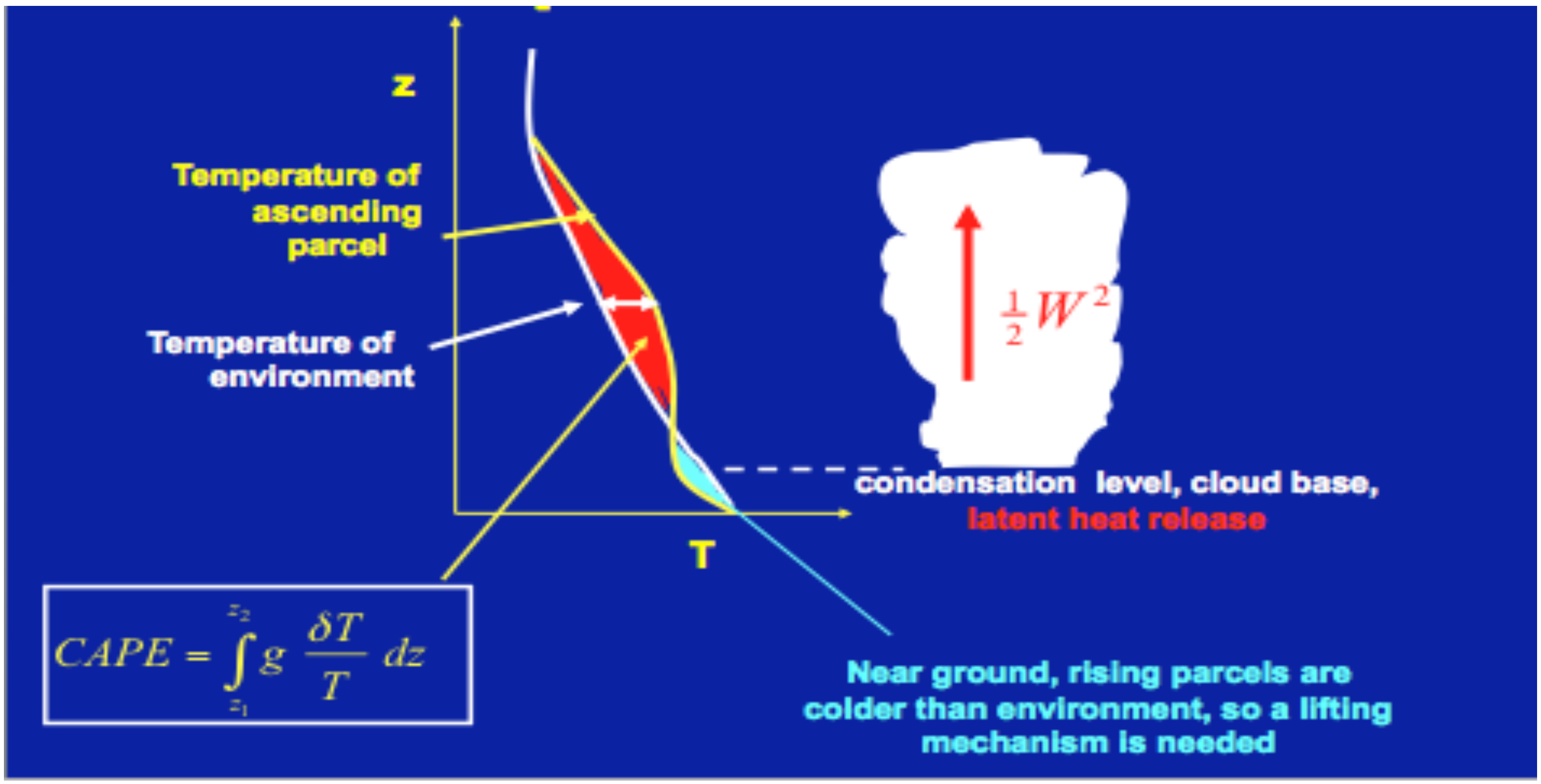
Dry and Moist Adiabatic Lapse Rate



Atmospheric Convection



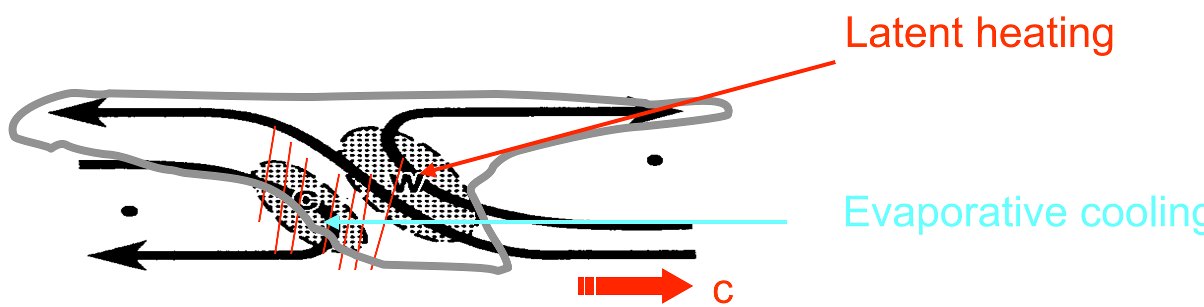
The Dynamics of Updrafts



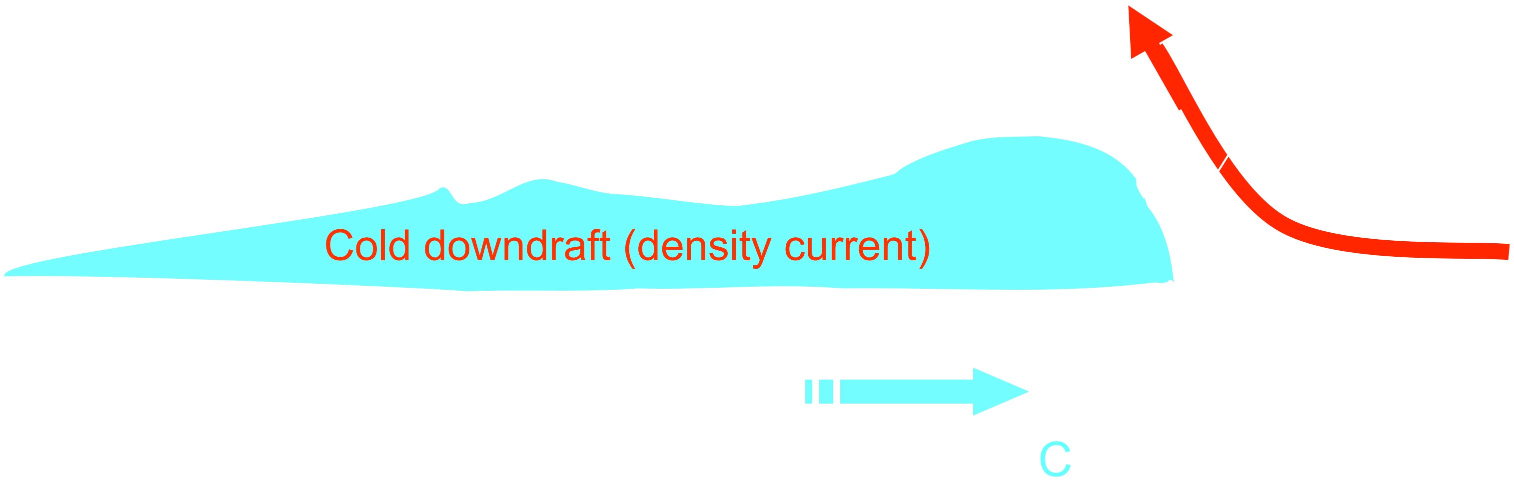
The Dynamics of Downdrafts

- **Rain evaporates, cools and descends driving evaporative downdrafts**

- **Particularly efficient when the updrafts <u>tilt backwards</u> overlying the downdrafts -- then rain falls into downdrafts which are maintained by evaporative cooling** …



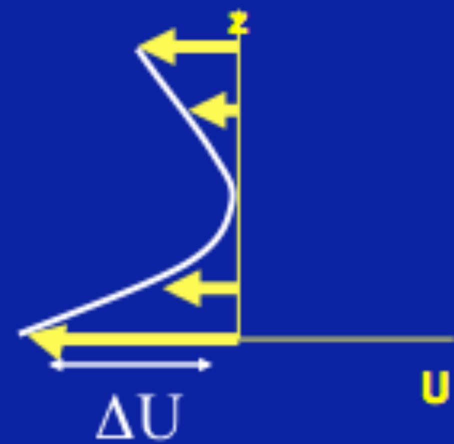
Downdraft fronts trigger cumulus convection



Organizing effects of shear

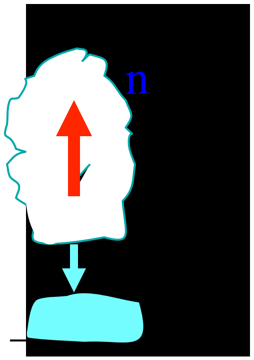
Shear: change of horizontal wind speed over a given height range

ΔU



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



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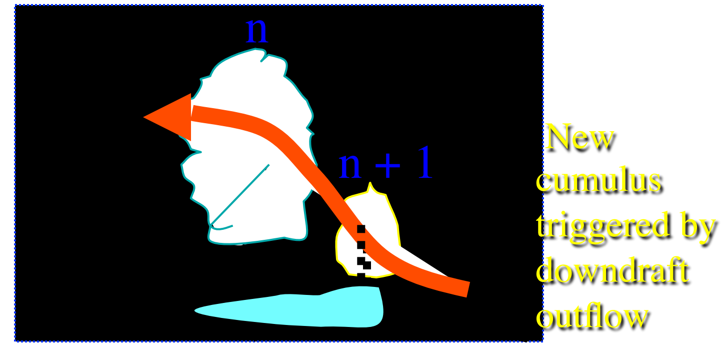
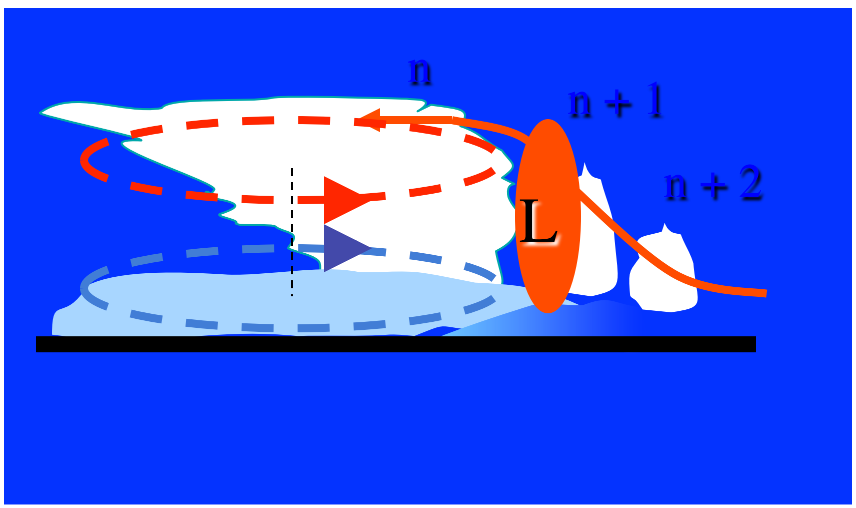
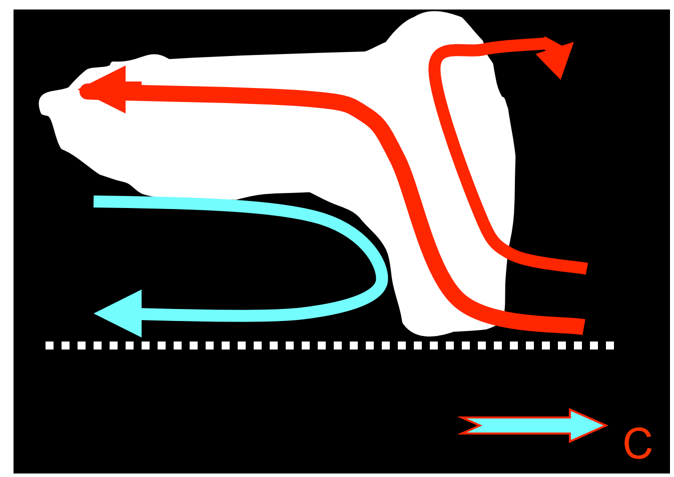


Stage 1: Onset - single cumulus

Shear

Stage 2: Family of cumulus at downdraft front



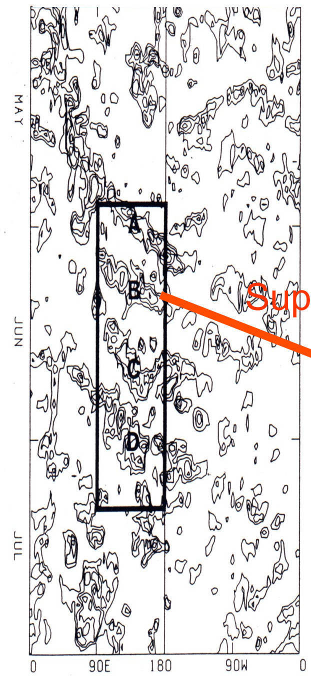


Stage 3: Mesoscale downdraft is accelerated by pressure gradient

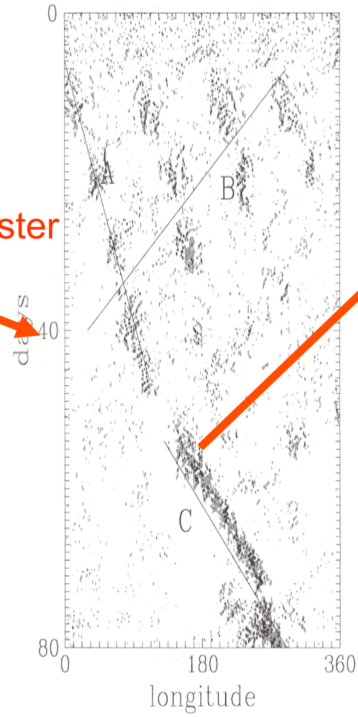
Stage 4: Mature traveling MCS

Moncrieff and Liu (2006)

MJO-like systems are produced by traveling organized convection

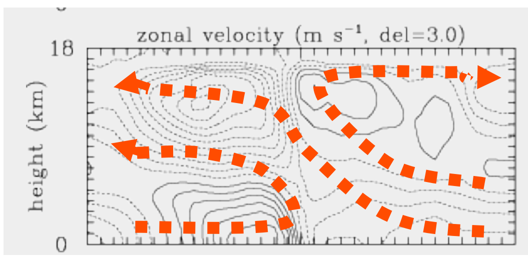


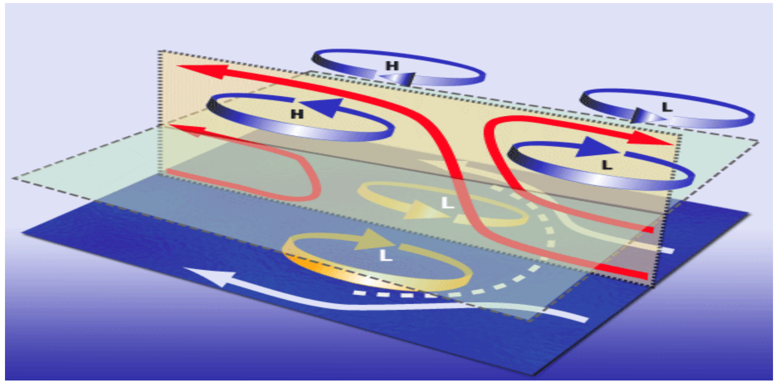
Observed
(Nakazawa 1988)



Numerical simulation
(Grabowski 2001)

Vertical structure





Dynamical model of mesoscale convective organization interlocked with MJO dynamics

Moncrieff (2004)

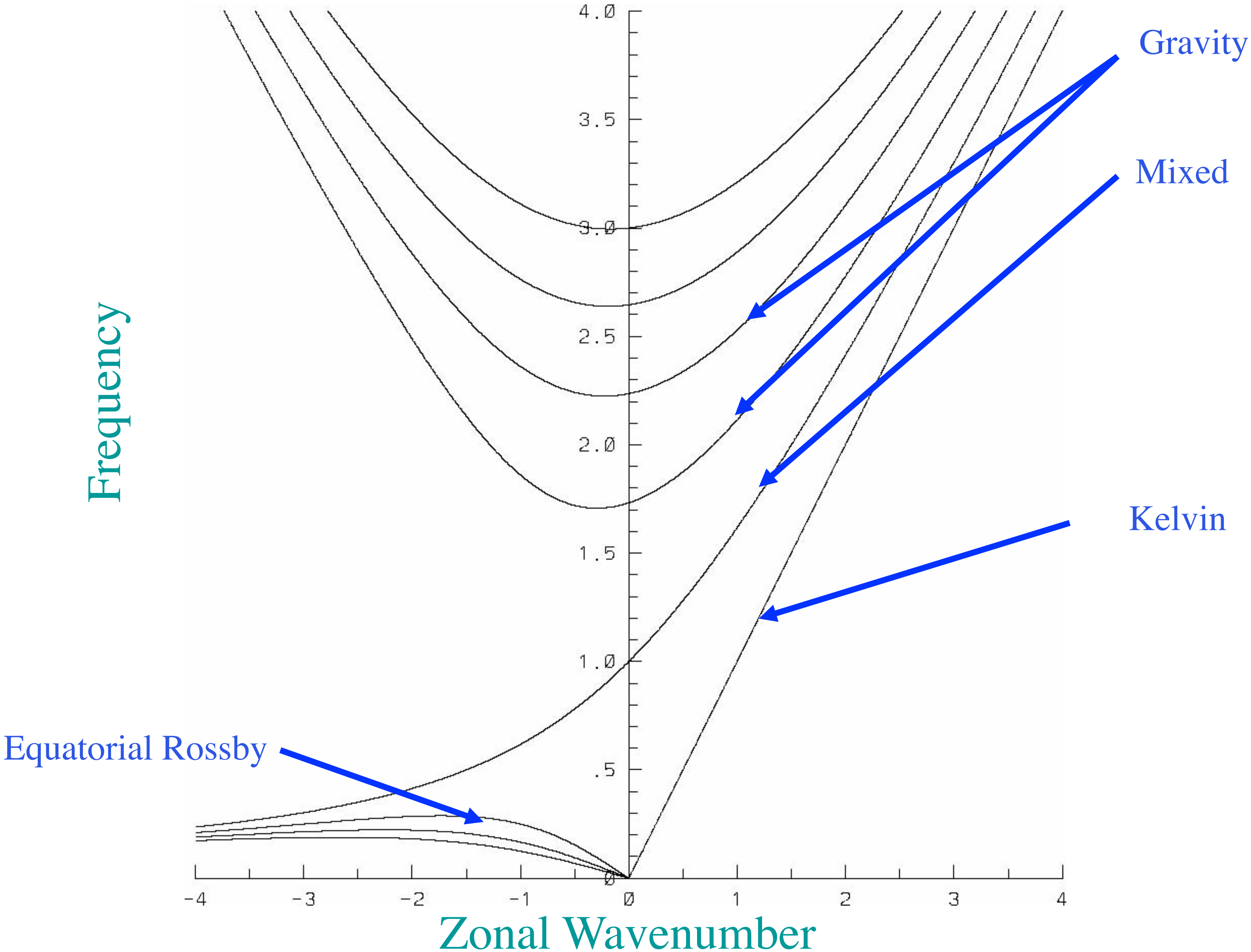
Shallow Water Equations for the Tropical Wave Dynamics

$$\frac{\partial u}{\partial t} - \beta y v + \frac{\partial \phi}{\partial x} = 0$$

$$\frac{\partial v}{\partial t} + \beta y u + \frac{\partial \phi}{\partial y} = 0$$

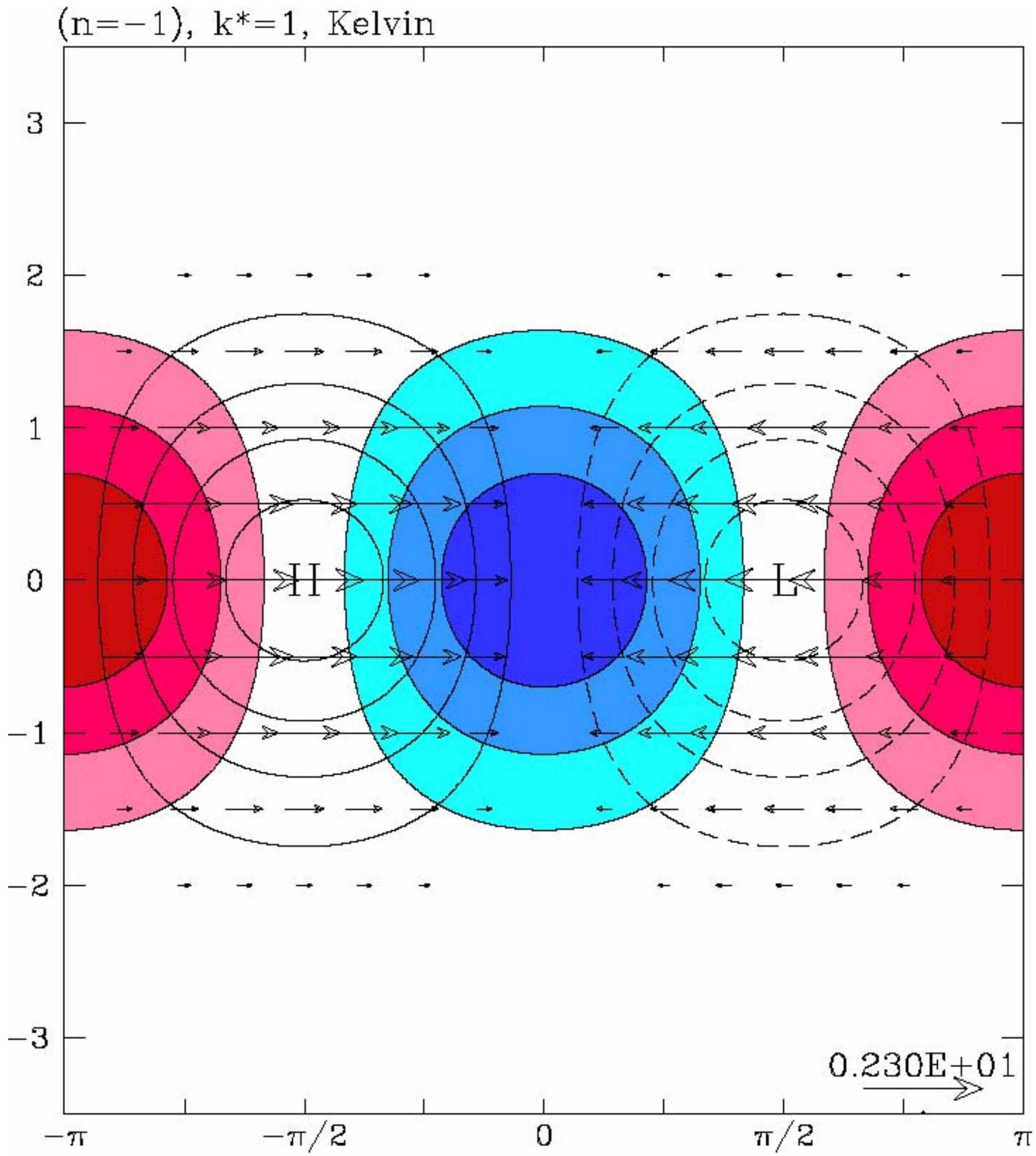
$$\frac{\partial \phi}{\partial t} + gh\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = 0$$

Theoretical Dispersion Relationships For Tropical Waves



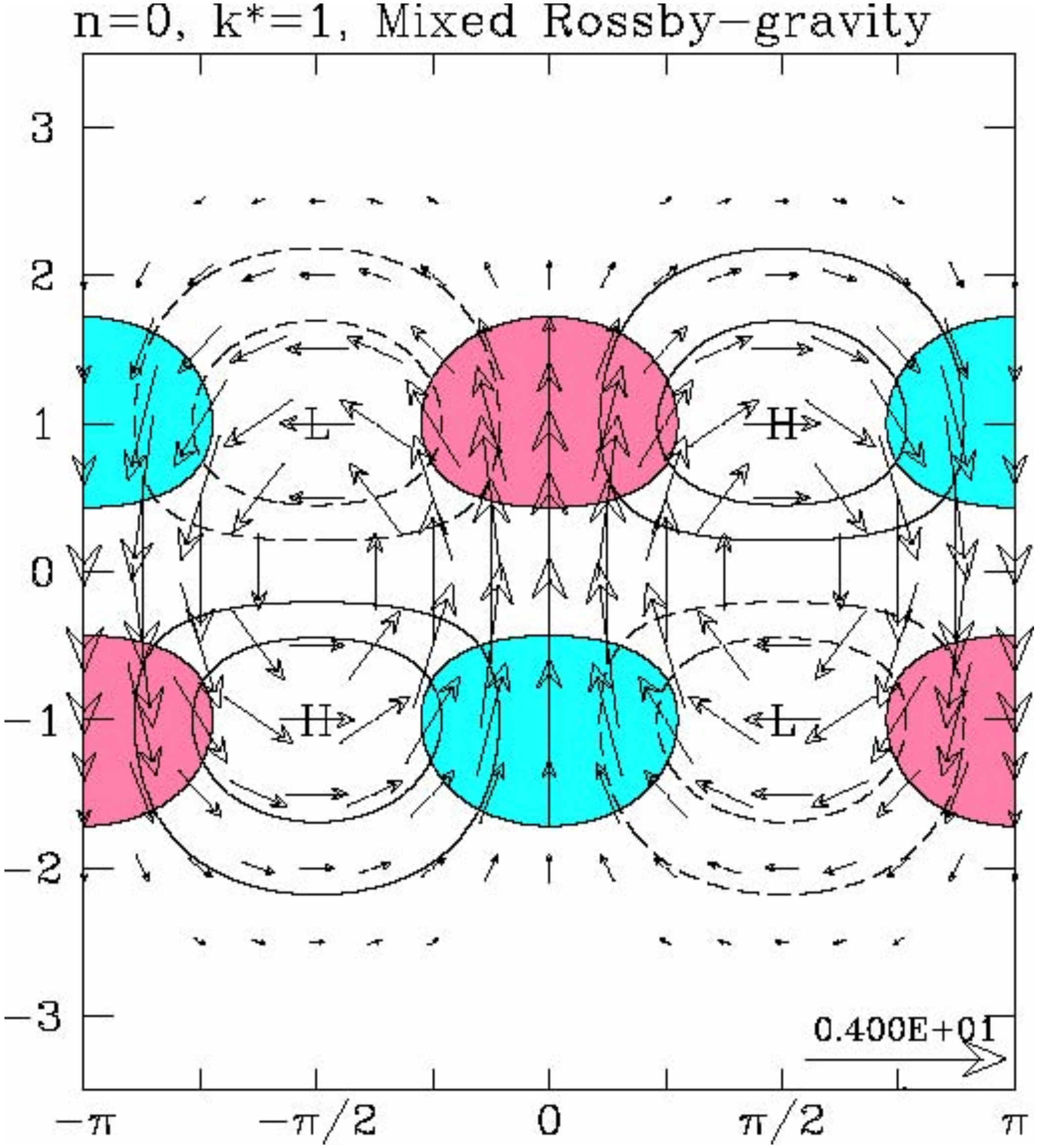
Kelvin Wave Structure

Eq.



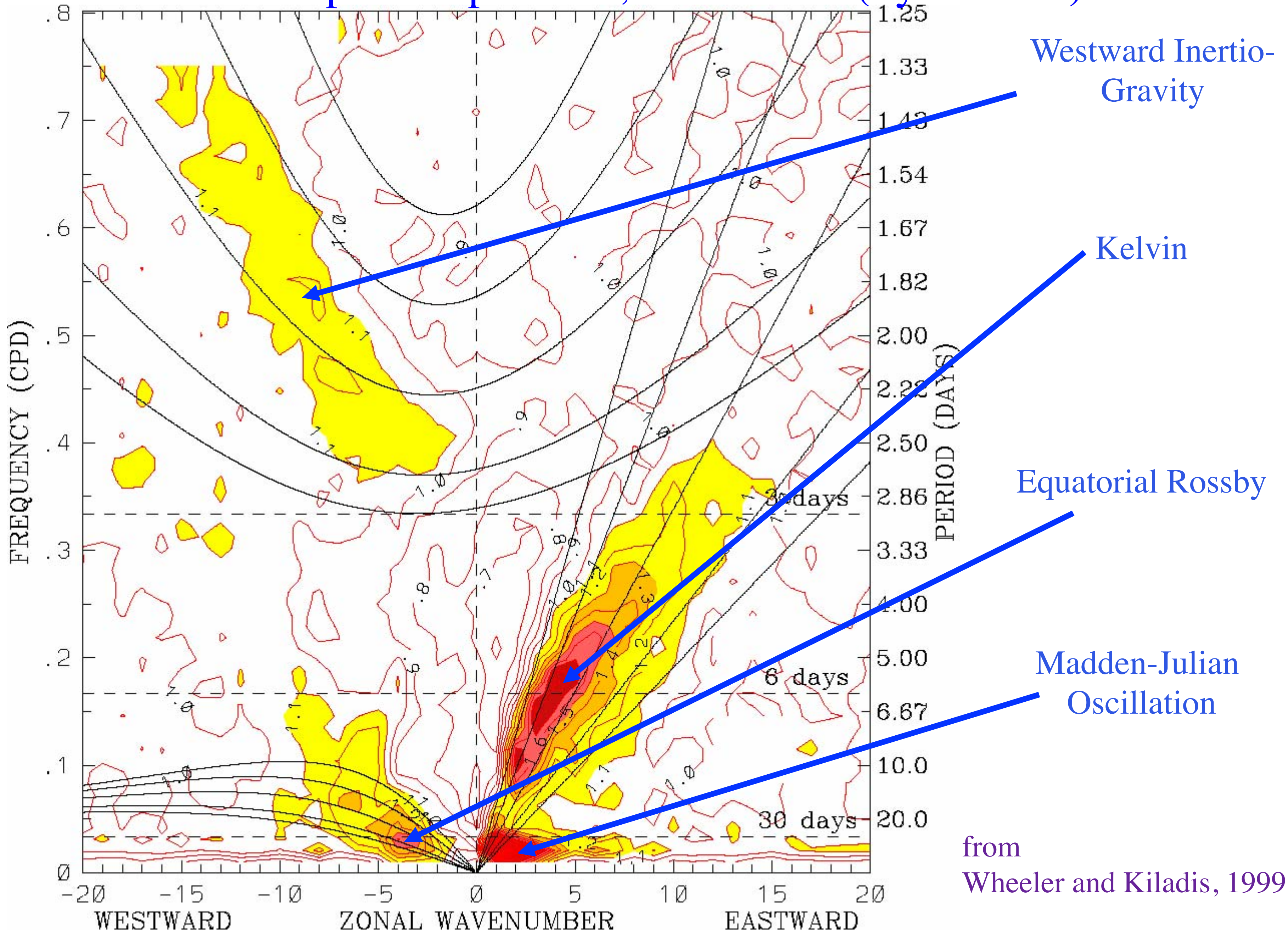
Wind, Pressure (contours),
Divergence (color, blue negative)

Mixed Rossby-Gravity Wave Theoretical Structure



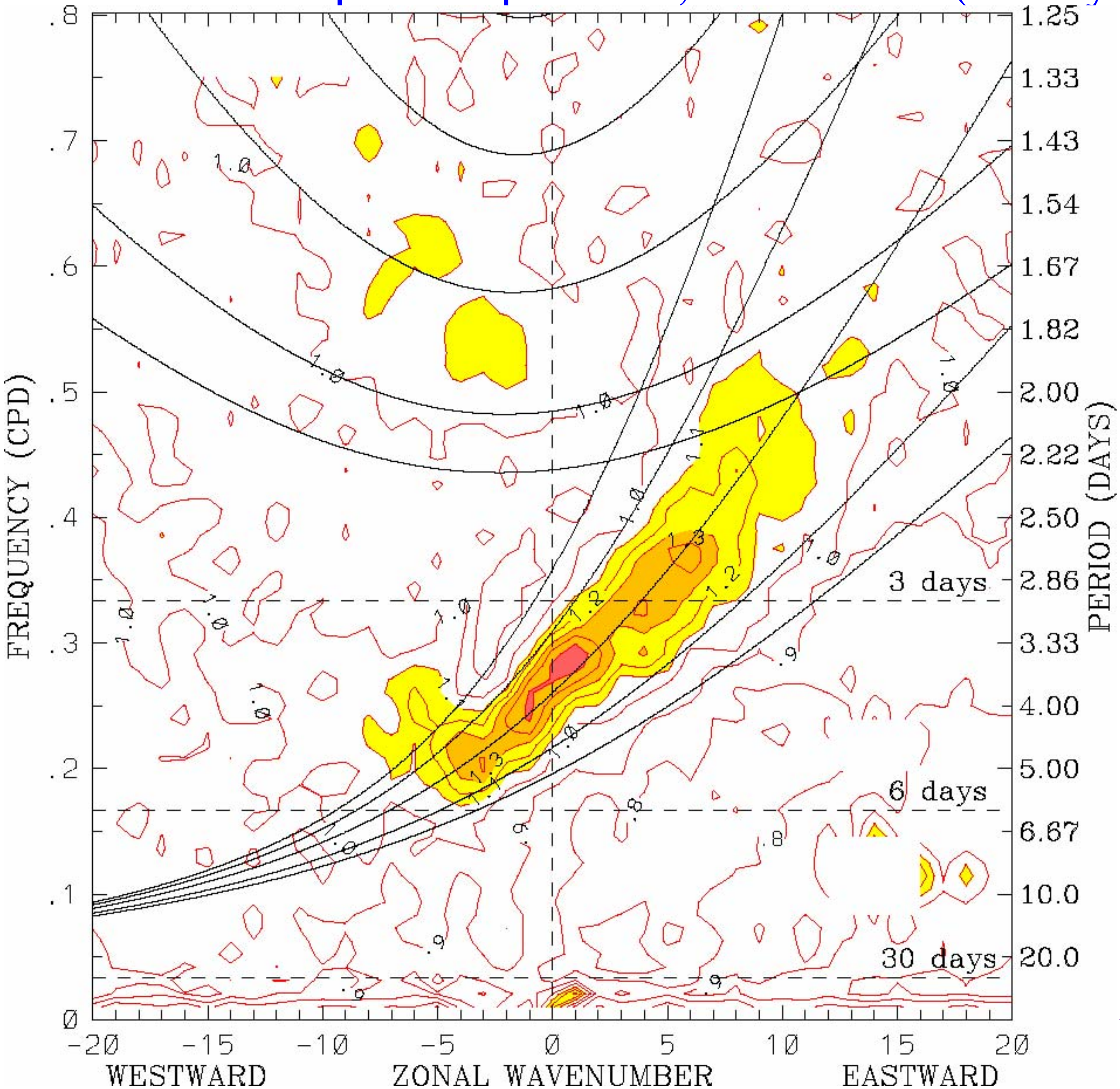
Wind, Pressure (contours),
Divergence, red negative

OLR power spectrum, 1979–2001 (Symmetric)



from
Wheeler and Kiladis, 1999

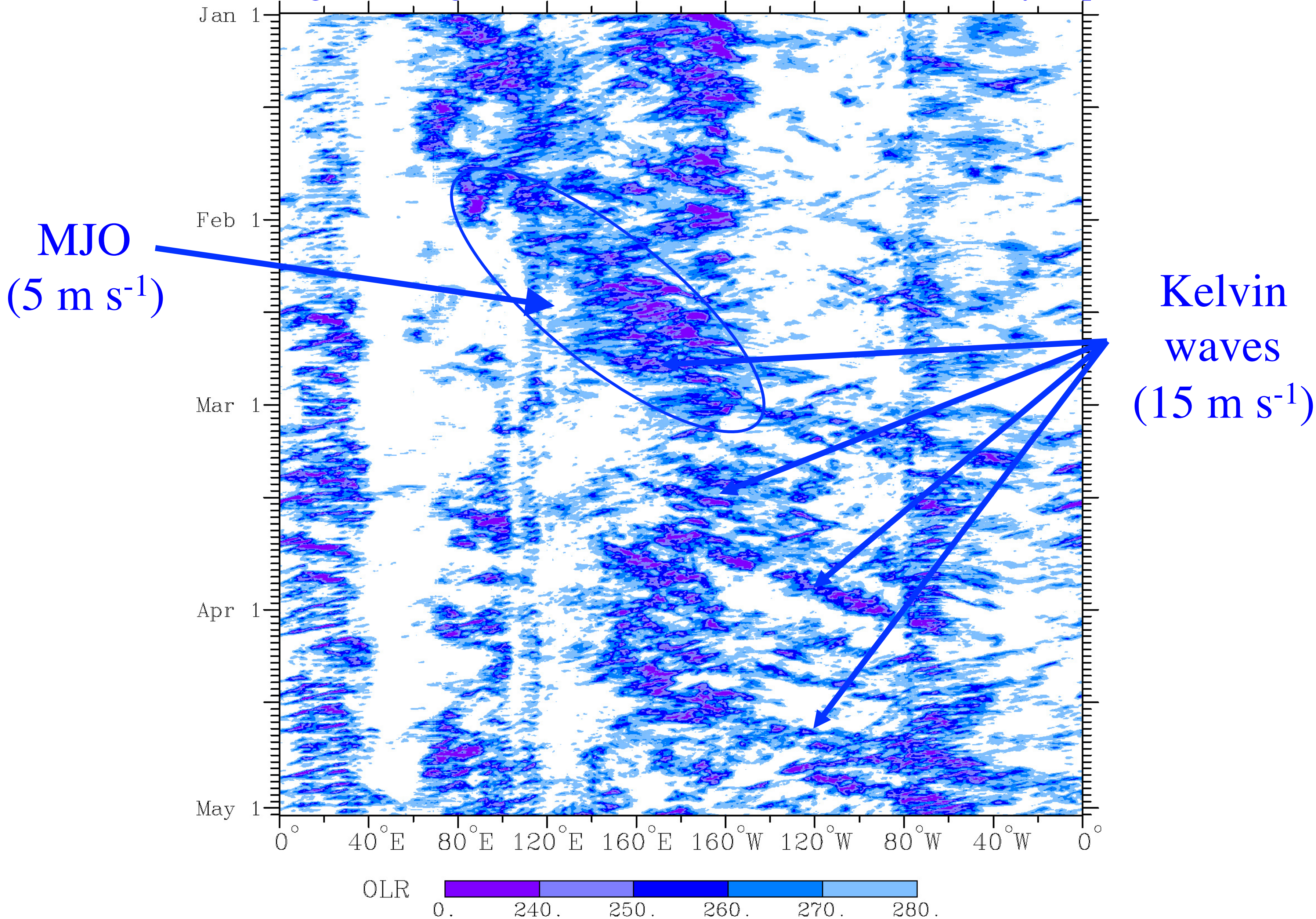
OLR power spectrum, 1979–2001 (Antisymmetric)



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



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 CO_2 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