The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1956-24

Targeted Training Activity: Seasonal Predictability in Tropical Regions to be followed by Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon

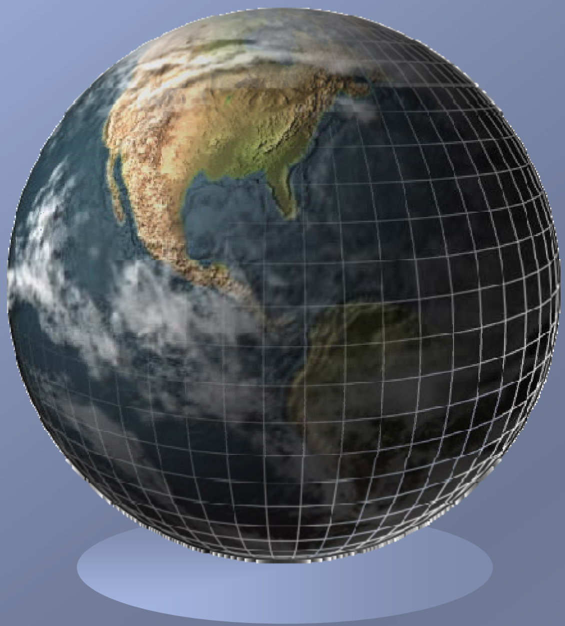
4 - 15 August 2008

Intraseasonal variability: MJO Working Group progress and YOTC plans. Part II

WALISER Duane Edward

Jet Propulsion Laboratory, Department of Physics
California Institute of Technology, CALTECH
4800 Oak Grove Drive
Pasadena CA 91109
U.S.A

Intraseasonal Variability and Predictability: *An Overview of the Madden-Julian Oscillation*



The Asian Monsoon System:
Predictability of Change and Variability
Advanced Institute, 2-12 January 2008
Honolulu, HI

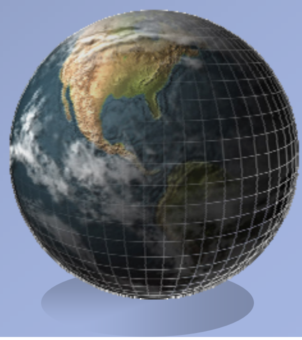
Duane Waliser
Jet Propulsion Laboratory/Caltech

Lecture Outline

- Observed Structure & Variability
- Weather/Climate Impacts and Interactions
- Theory/Physical Processes
- GCM Simulations
- Predictability and Prediction

Resources & Further Reading

- Madden, R. A., and P. R. Julian (1994), Observations of the 40-50-Day Tropical Oscillation - A Review, *Monthly Weather Review*, **122**, 814-837.
- Lau, W. K. M., and D. E. Waliser (Eds.) (2005), *Intraseasonal Variability of the Atmosphere-Ocean Climate System*, 474 pp., Springer, Heidelberg, Germany.
- Zhang, C. (2005), The Madden Julian Oscillation, *Reviews of Geophysics*, **43**, RG2003, doi:10.1029/2004RG000158.
- Waliser, D. E. (2006), Intraseasonal Variability, in *The Asian Monsoon*, edited by B. Wang, 844 pp, Springer, Heidelberg, Germany.
- U.S. CLIVAR MJO Working Group
  http://www.usclivar.org/Organization/MJO_WG.html
- MJO life cycle webcast--http://www.meted.ucar.edu/climate/mjo/

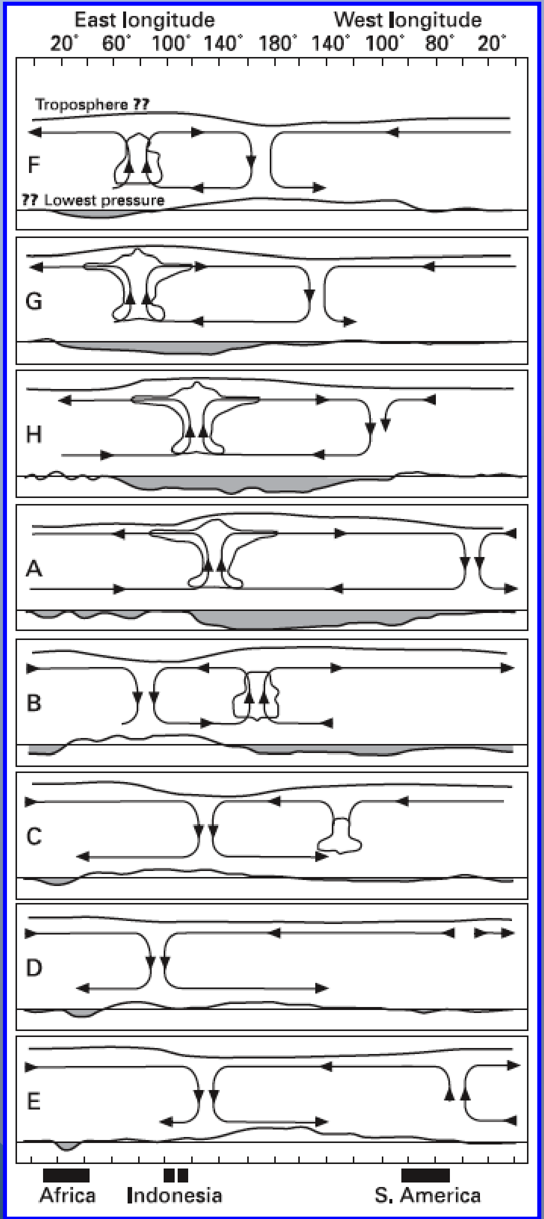


Observed Structure & Variability

Basics of MJO

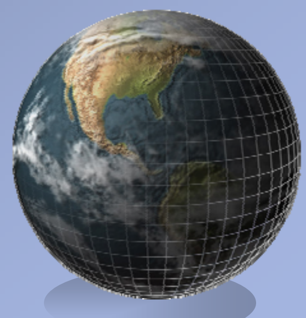
Madden-Julian Oscillation

(a.k.a. Intraseasonal, 40-50, 30-60 Day Oscillation)



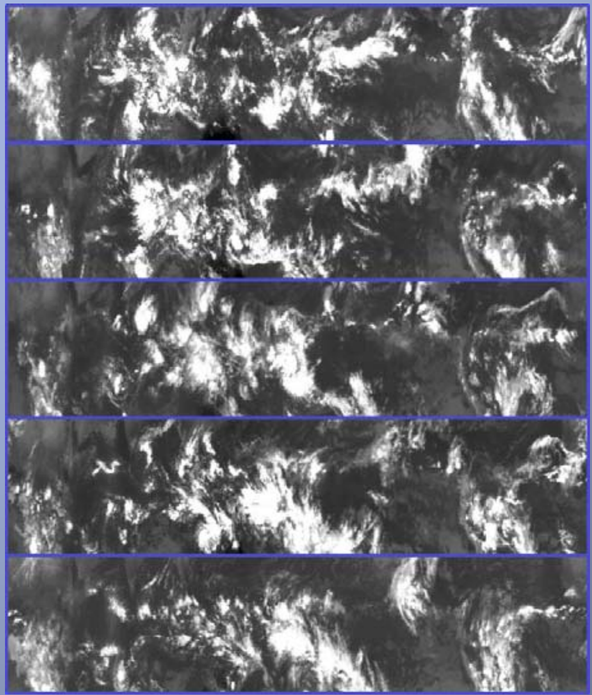
Madden & Julian, 1972

- Intraseasonal Time Scale: ~40-60 days
- Planetary-Scale: Zonal Wavenumbers 1-3
- Baroclinic Wind Structure
- Eastward Propagation
  - ✓E. Hem: ~5 m/s, Surf.+Conv.+Circ. Interactions
  - ✓W. Hem: ~ > 10 m/s, ~Free Tropospheric Wave
- Tendency to be Equatorially Trapped
- Strong Seasonal Dependence:
  - ✓ NH Winter: Eastward Propagation
  - ✓ NH Summer: ~Northeast Propagation
- Significant Interannual Variability
- Potential Role of Ocean/SST Feedback
- Convection Has Multi-Scale Structure
- Significant Remote and Extra-Tropical Impacts

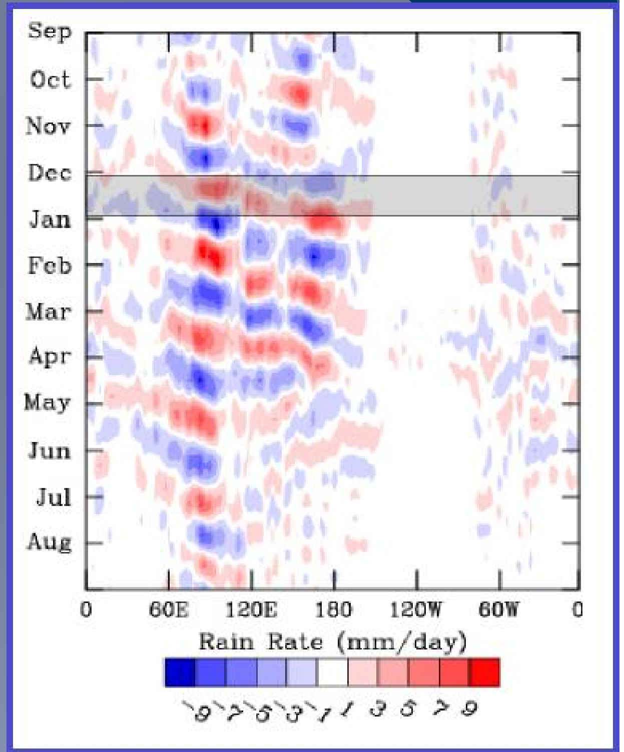


Madden-Julian Oscillation

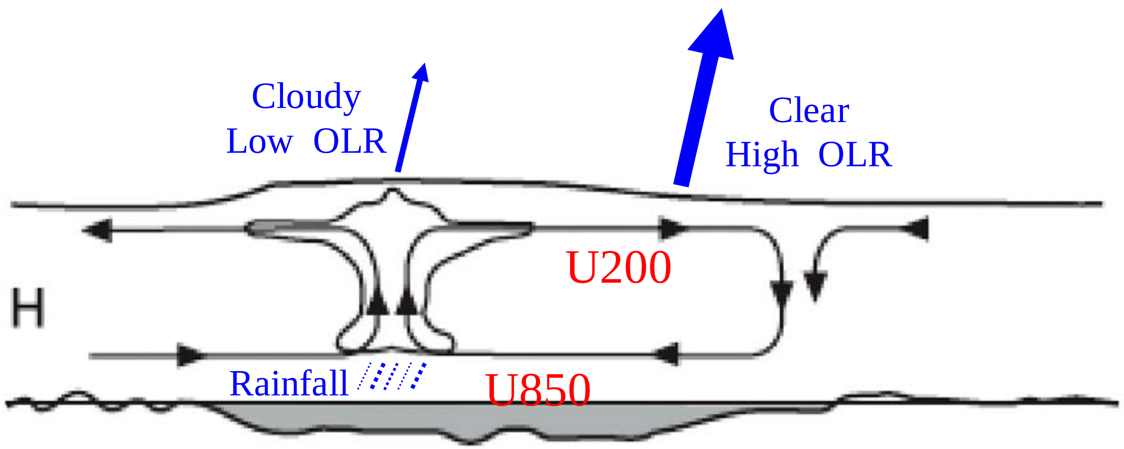
(a.k.a. Intraseasonal, 40-50, 30-60 Day Oscillation)

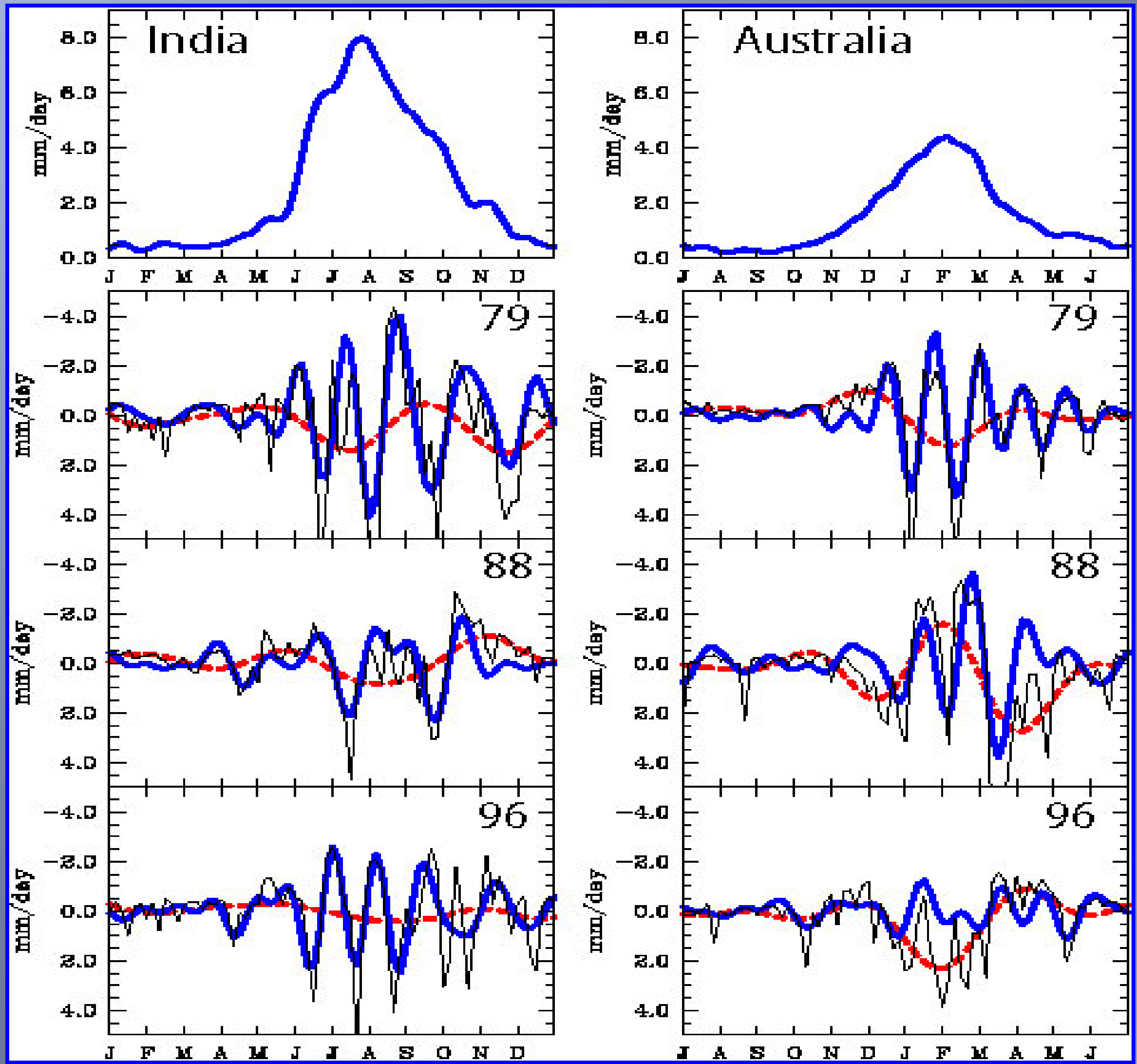


1987/88



Typical Variables Used for MJO Analysis

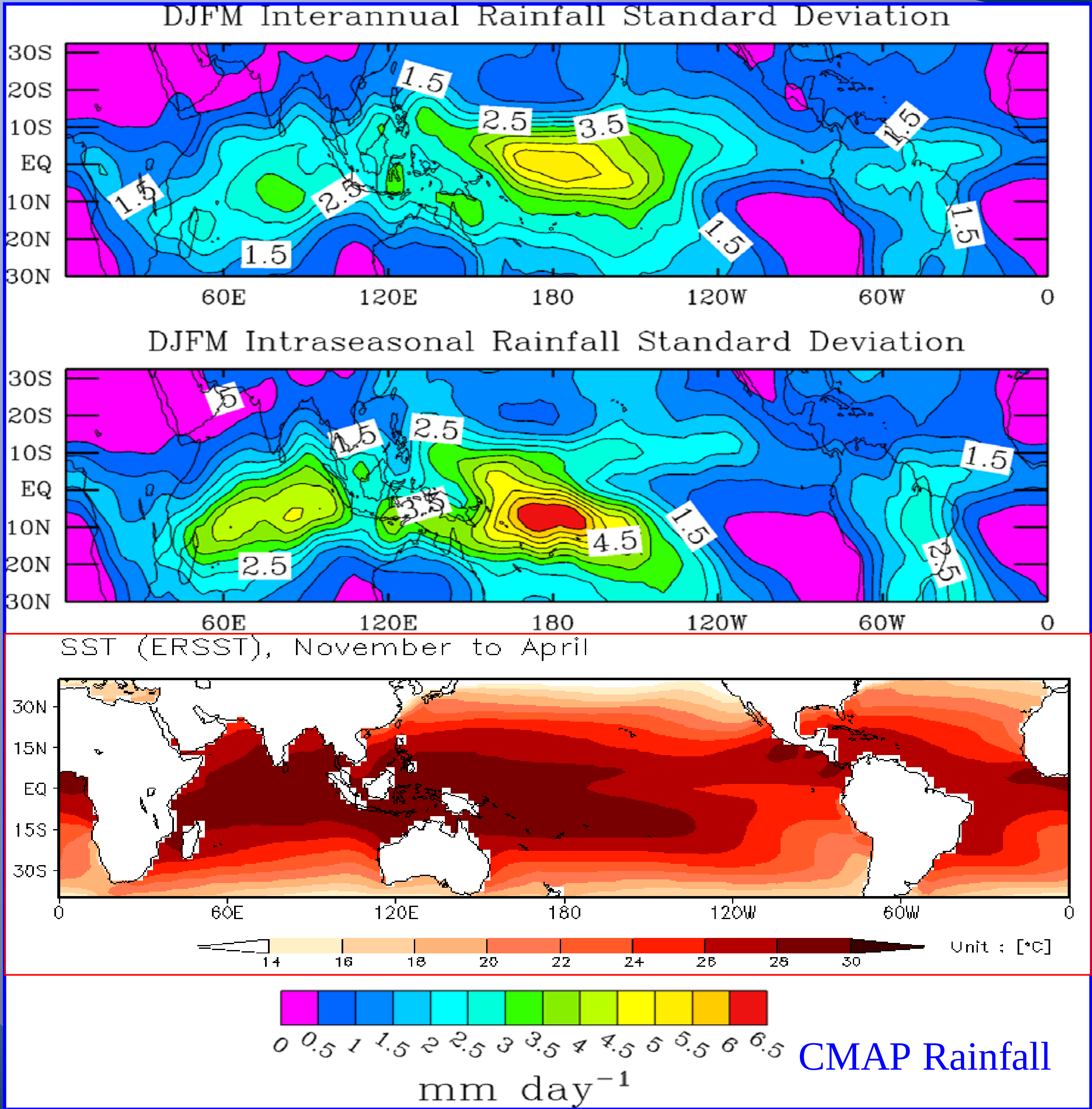




Rainfall Variability In India & Australia Sectors

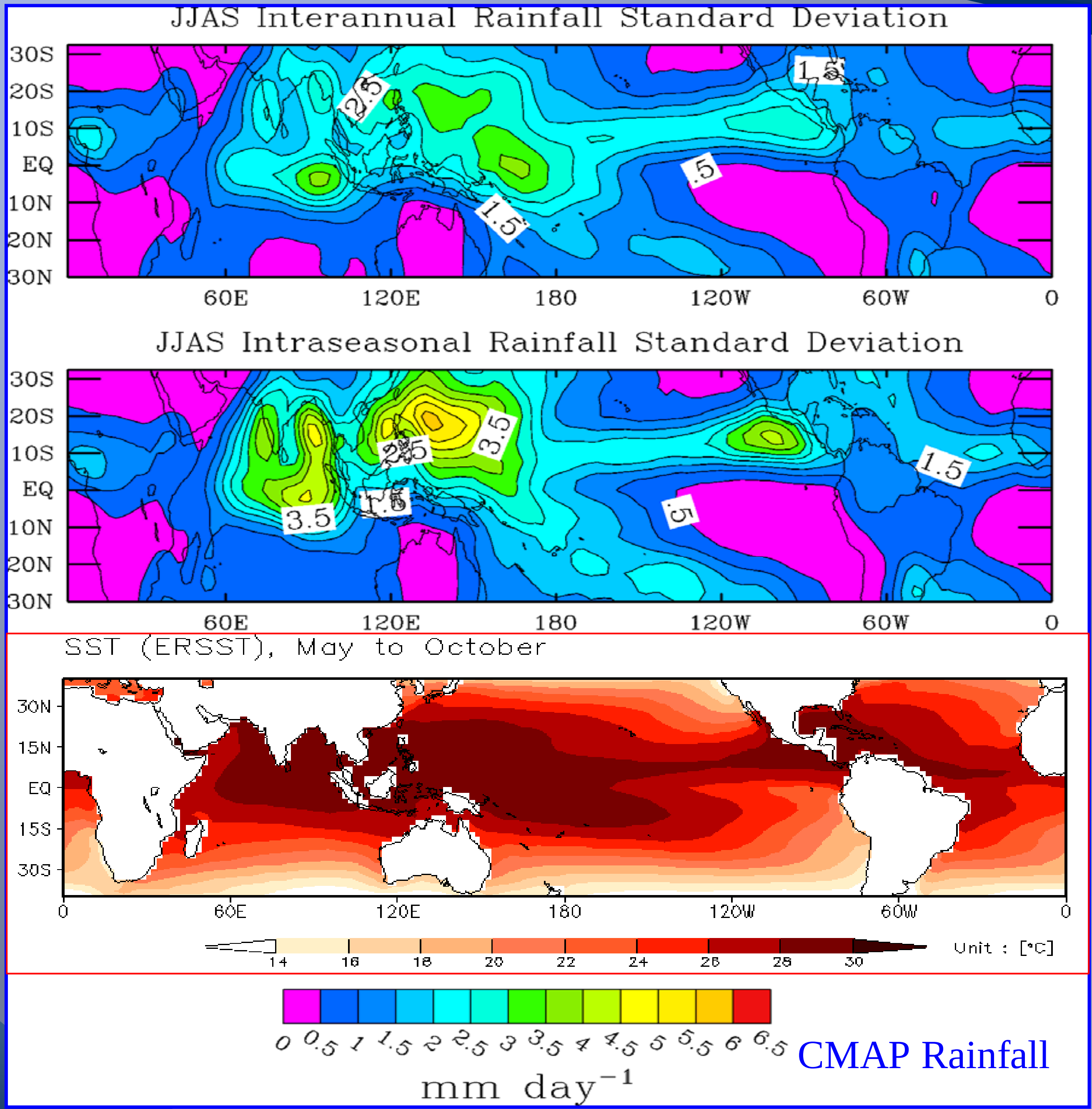
CMAP Rainfall Data

Interannual vs Intraseasonal Rainfall Variability



NH Winter

Intraseasonal : 30-90
Interannual : > 90



Interannual vs Intraseasonal Rainfall Variability

NH Summer

Intraseasonal : 30-90
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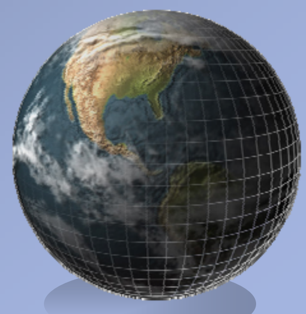
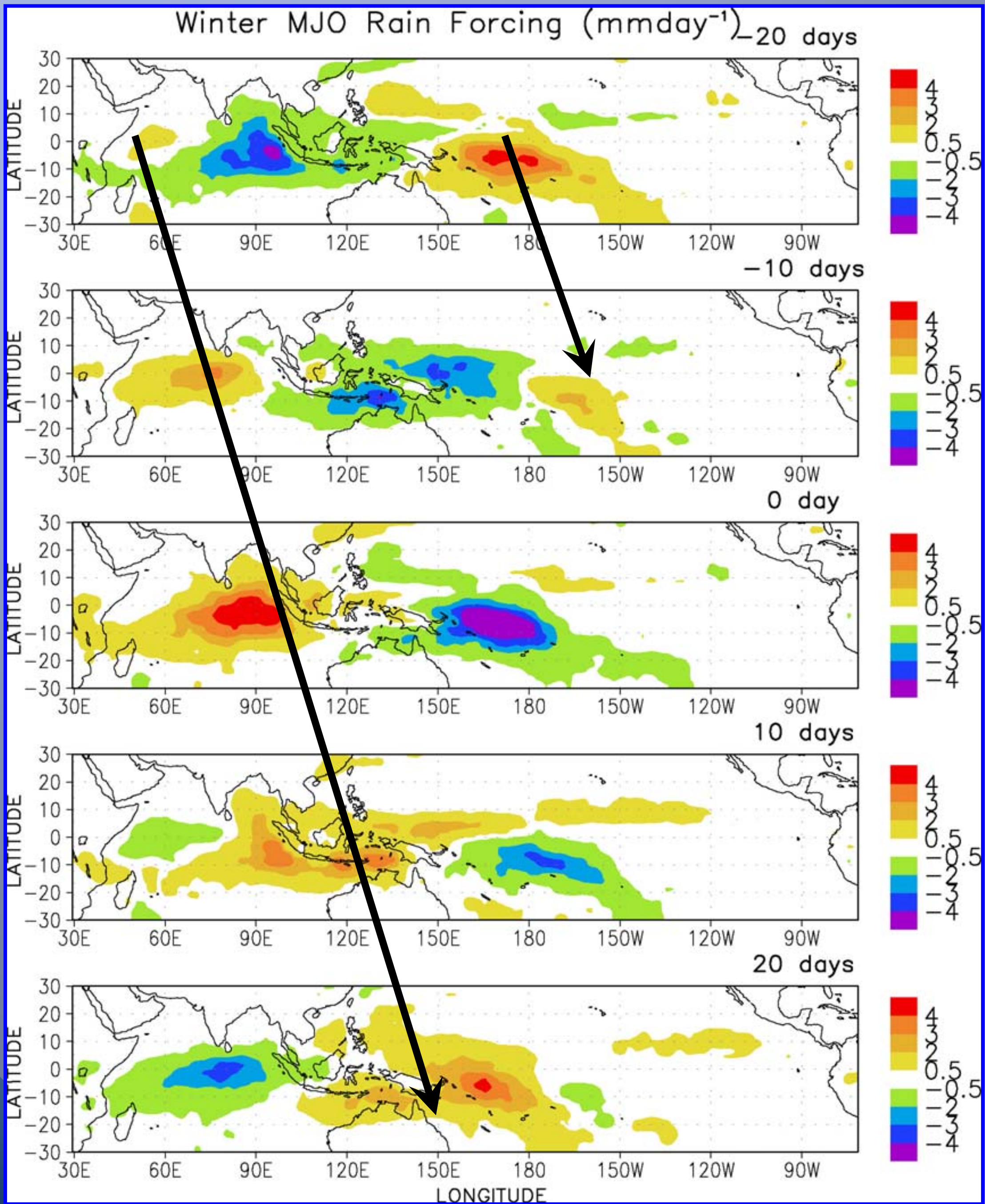
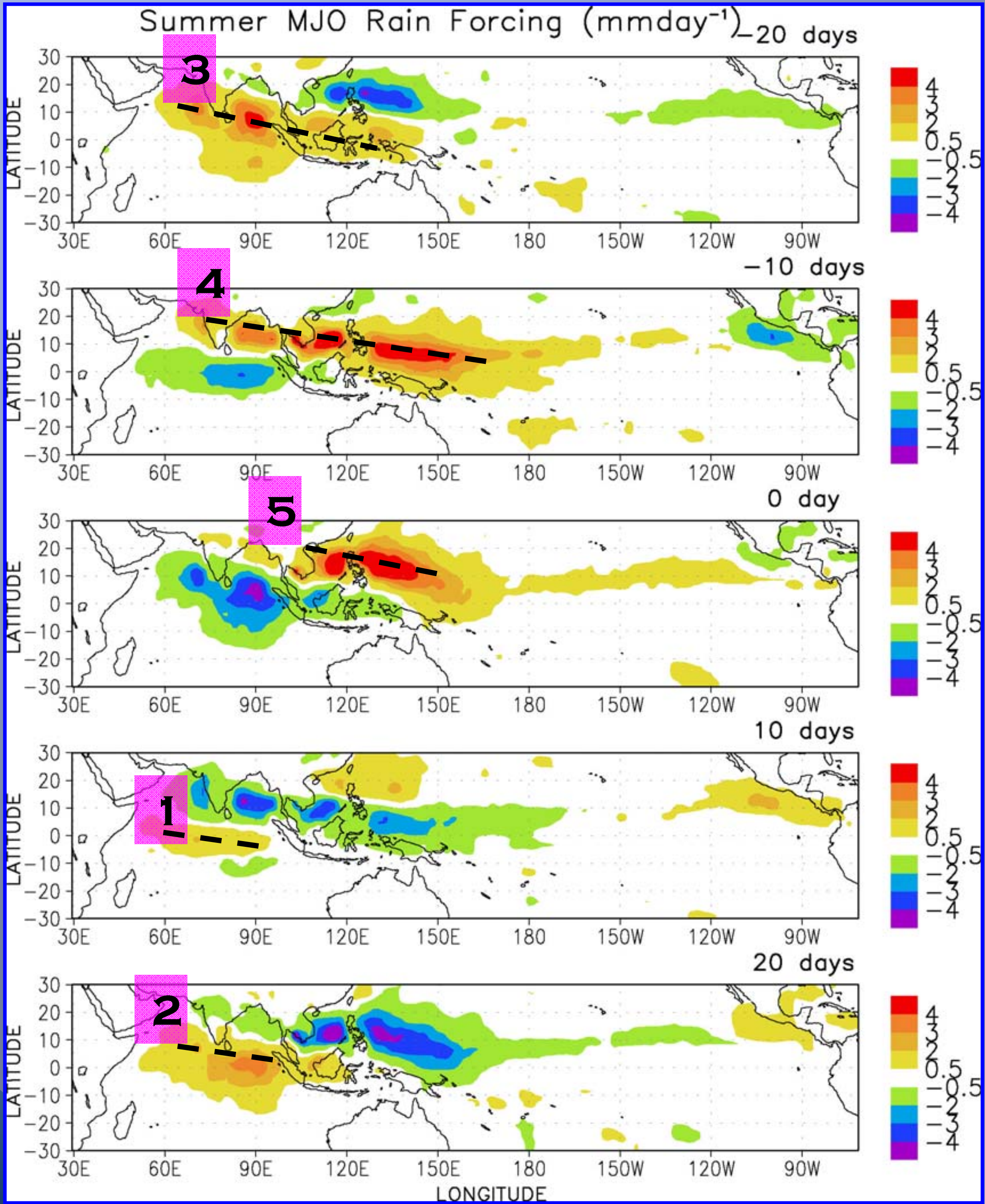




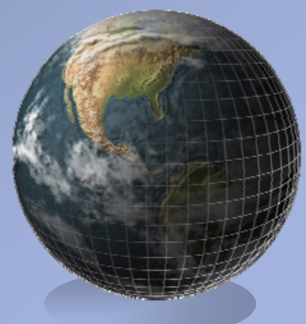
A Typical MJO in N.H. Winter

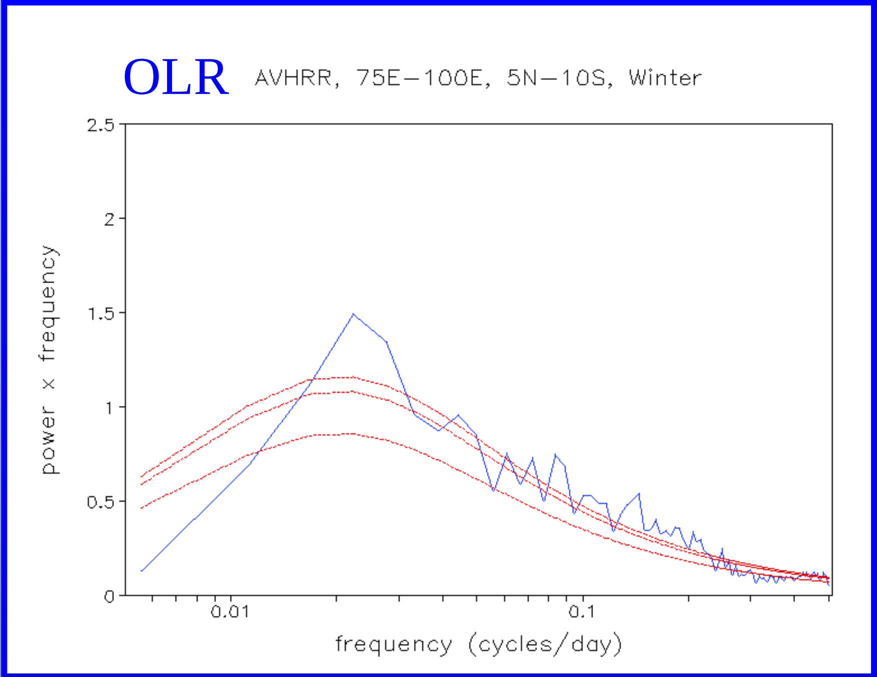
- *Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.*
- *Rainfall anomalies propagate in a eastward fashion and mainly affect the Tropical eastern hemisphere.*
- *These anomalies are accompanied by anomalies in wind, solar radiation, sea surface temperature, etc.*

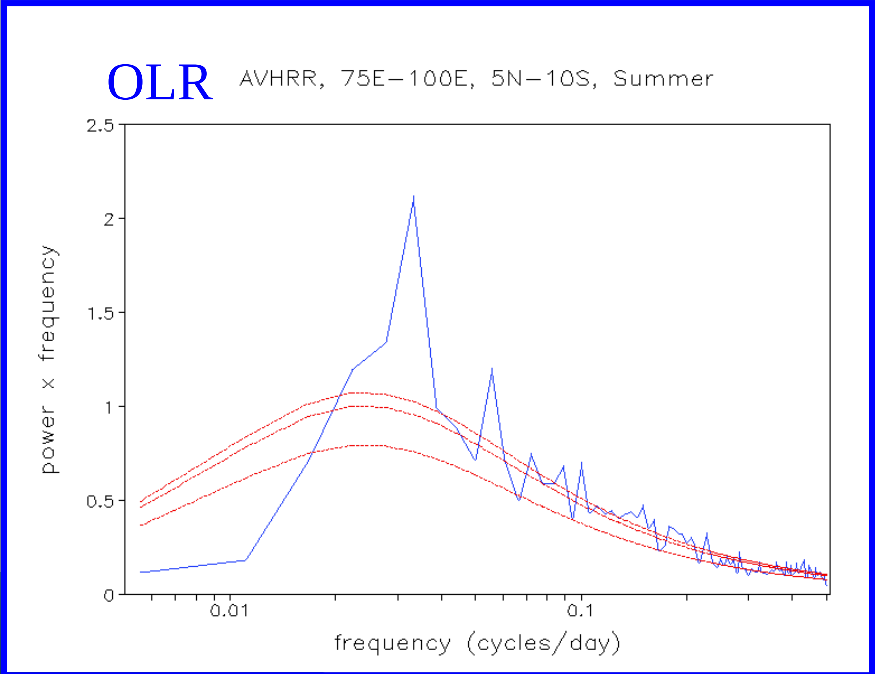


A Typical MJO in N.H. Summer

- *Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.*
- *Rainfall anomalies propagate in a* ***northeast*** *fashion and mainly affect the Tropical eastern hemisphere.*
- *These anomalies are accompanied by anomalies in wind, solar radiation, sea surface temperature, etc.*





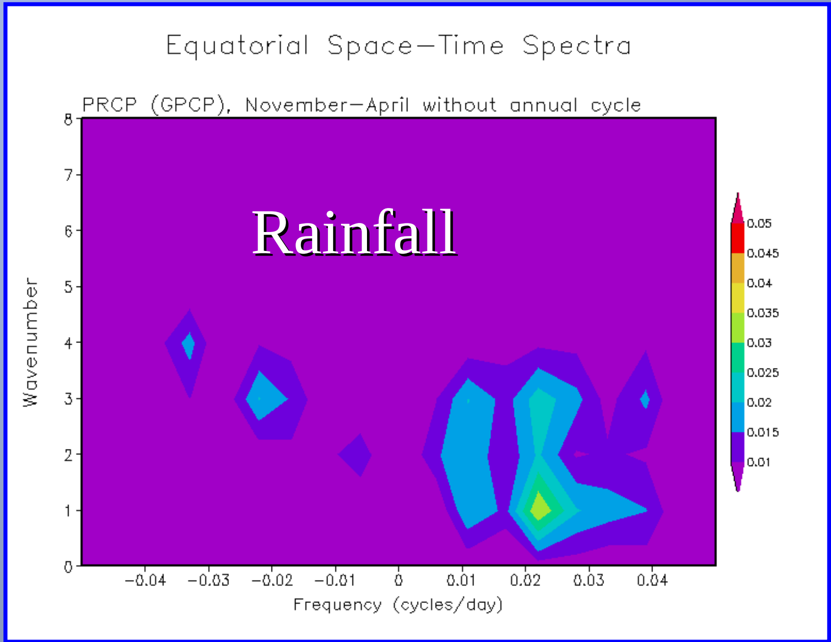


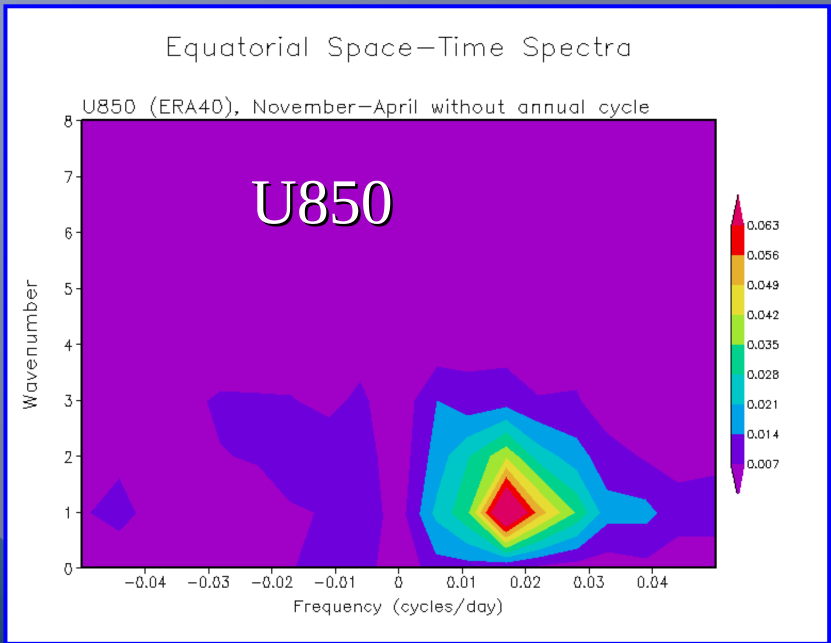
OLR Spectra Winter vs. Summer

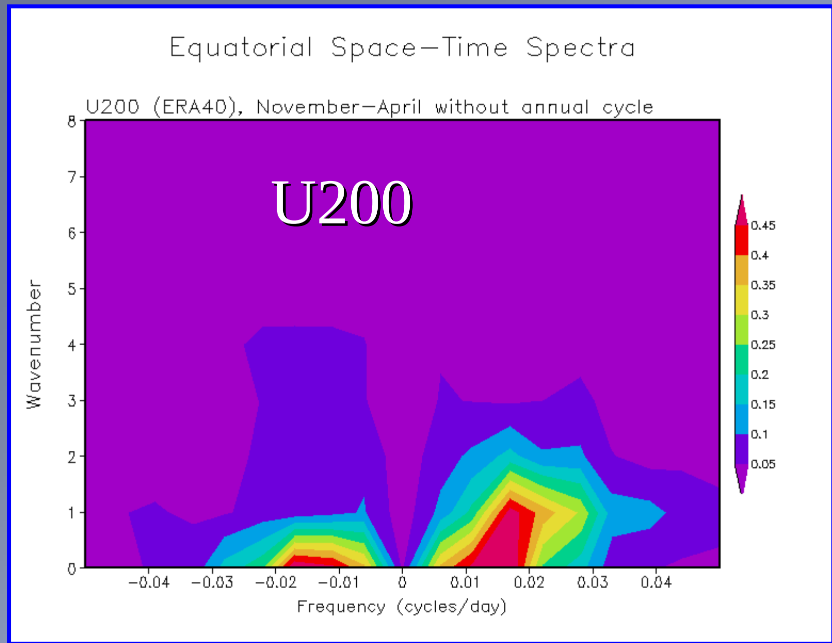
In summer the power is more Concentrated, and it occurs at a higher frequency than during winter

Wavenumber Frequency Diagrams

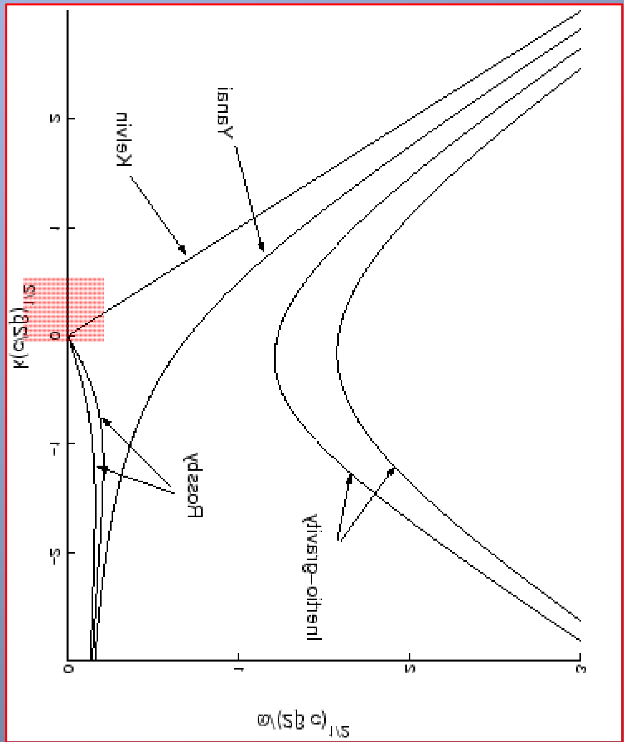
Roughly Wavenumbers 1-3 Periods 30-70 Days



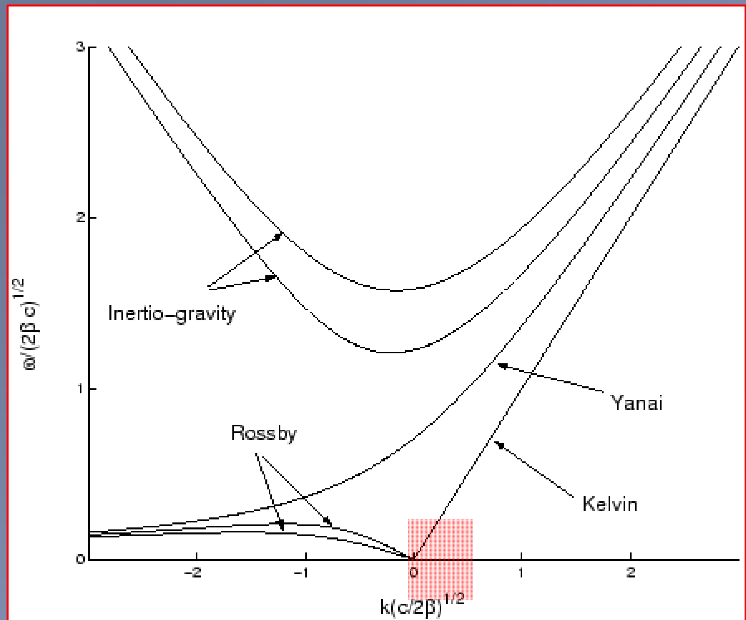




Wavenumber Frequency Diagrams

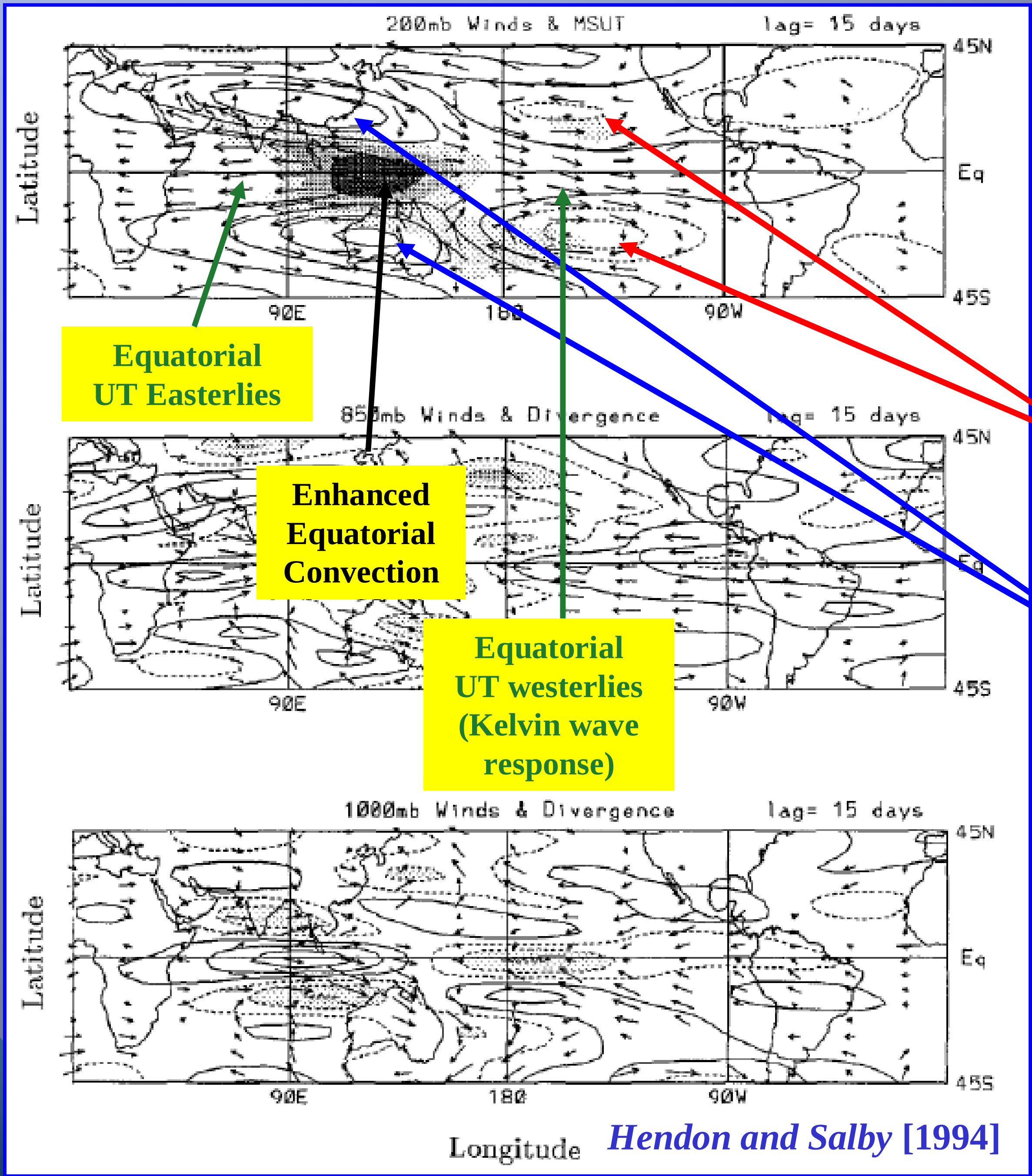


Roughly
Wavenumbers 1-3
Periods 30-70 Days

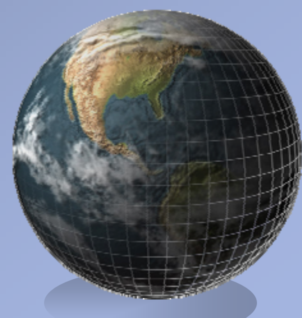


MJO Life-Cycle Composites

Vector Winds, etc.



Hendon and Salby [1994]



Coupled vs Uncoupled Modeling Studies

THEORY

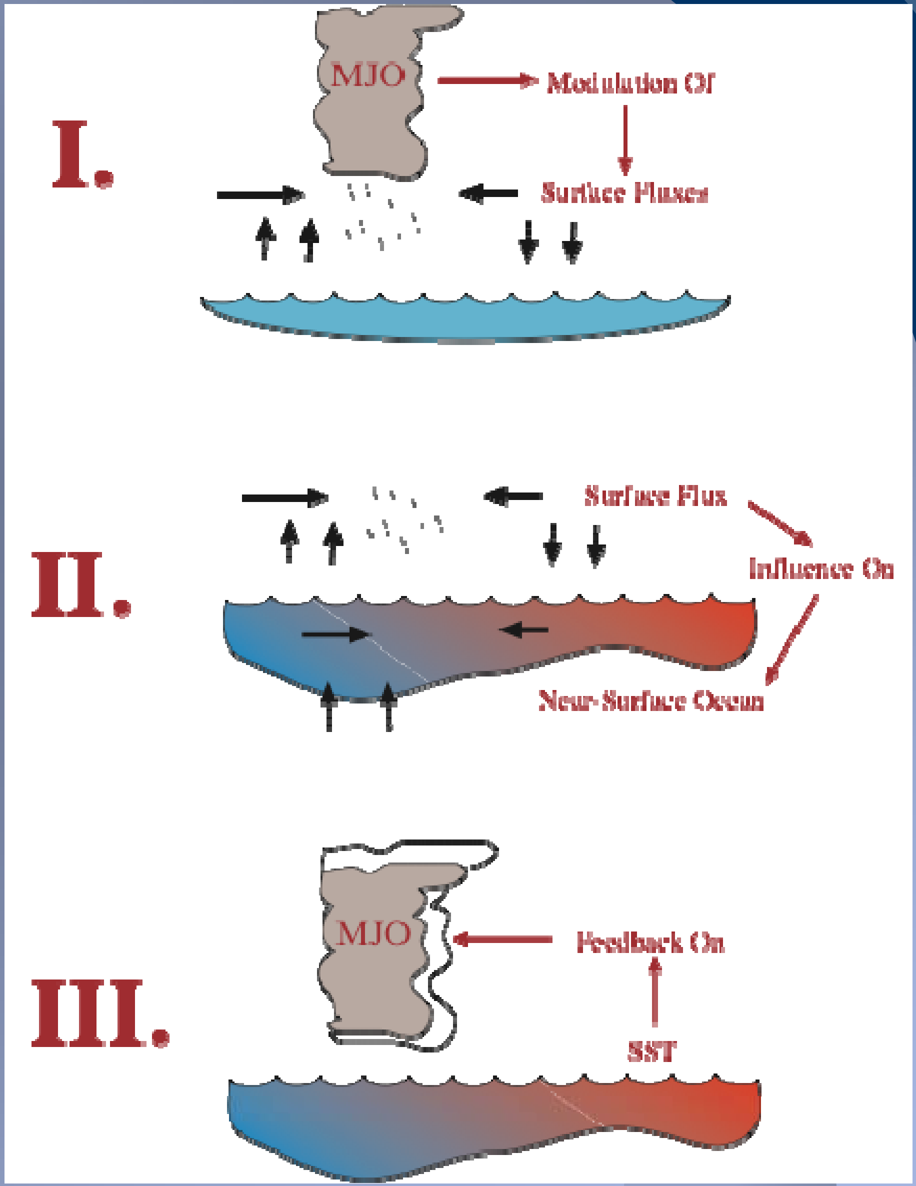
- Lau and Shen, 1988
- Hirst and Lau, 1990
- Wang and Xie, 1998
- Sobel and Gildor, 2003

MODEL

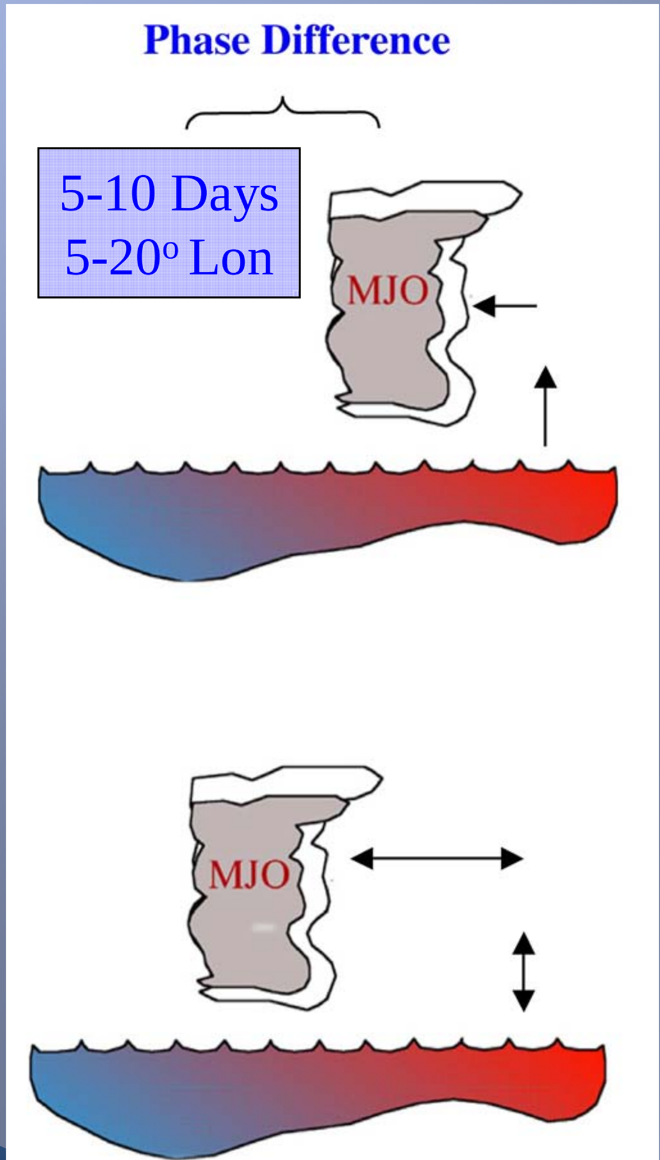
- Flatau, Flatau, Phoebus and Niiler1997
- Waliser, Lau, and Kim, 1999
- Kemball-Cook, Wang and Fu, 2002\
- Hendon, 2000
- Fu, Wang, Li and McCreary, 2003
- Inness and Slingo, 2003
- Fu and Wang, 2004
- Zheng, Waliser, Stern and Jones, 2004
- Maloney and Sobel, 2004

Generally - IMPORTANT TO COHERENCE, PHASE SPEED, *AND/OR* STRENGTH

"Coupled" or Not?

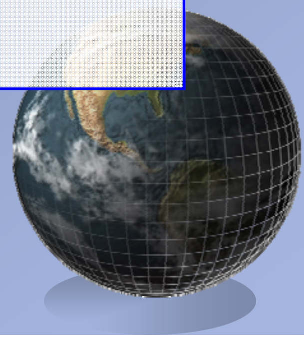


Imipact of SST coupling on MJO/ISO



Specified (CGCM) SST -> AGCM
MJO/ISO feels impact from SST - tends to move over warmest water.
One-way interaction.
Two-Tier Prediction Inadequate.

Coupled GCM
SST anomaly a product of MJO/ISO. As convection moves towards warm SST anomaly, it cools it and moves the warm anomaly eastward.
Two-way interaction.
Matches Observations.

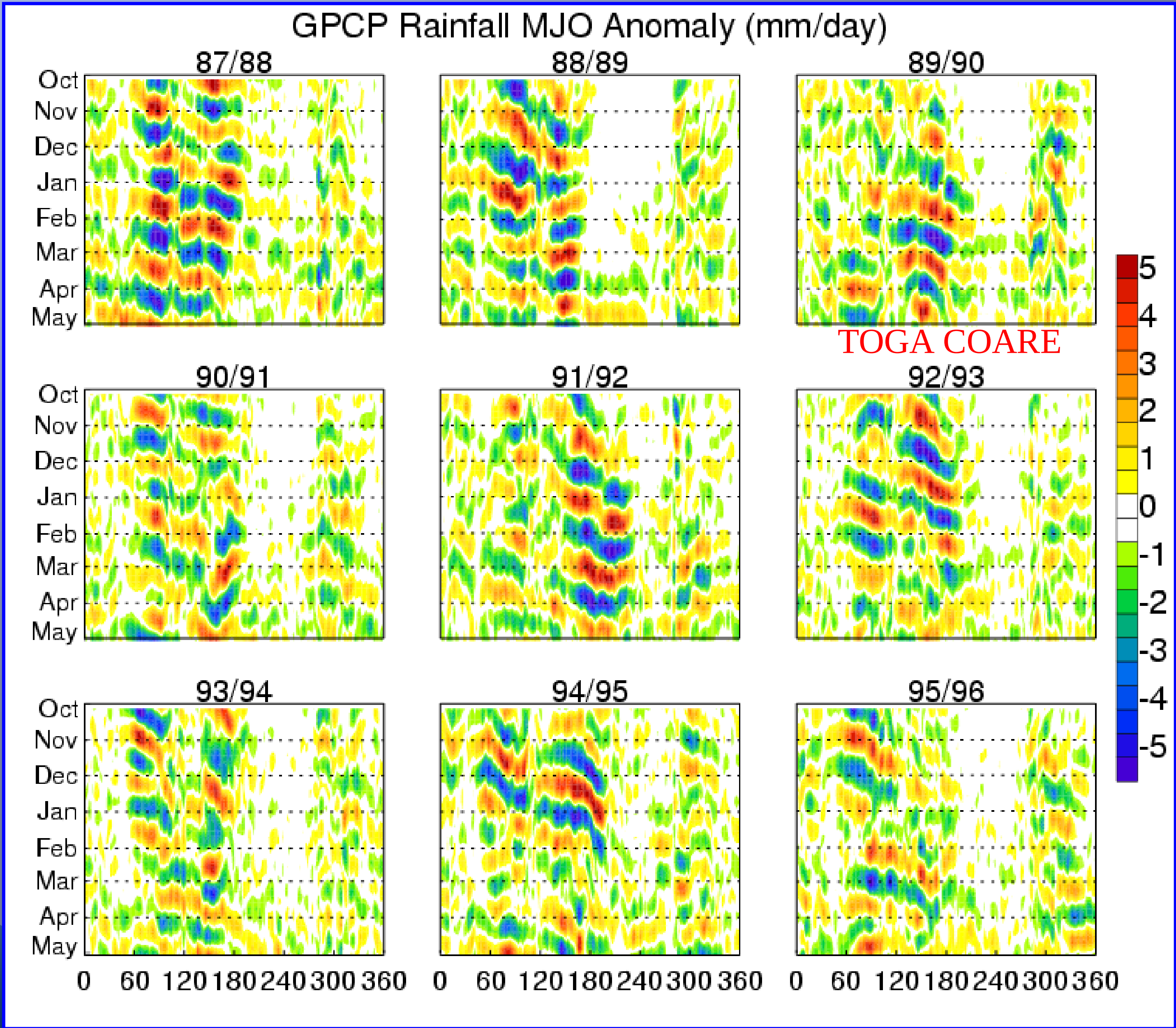


Fu and Wang, 2004; Zheng et al. 2004

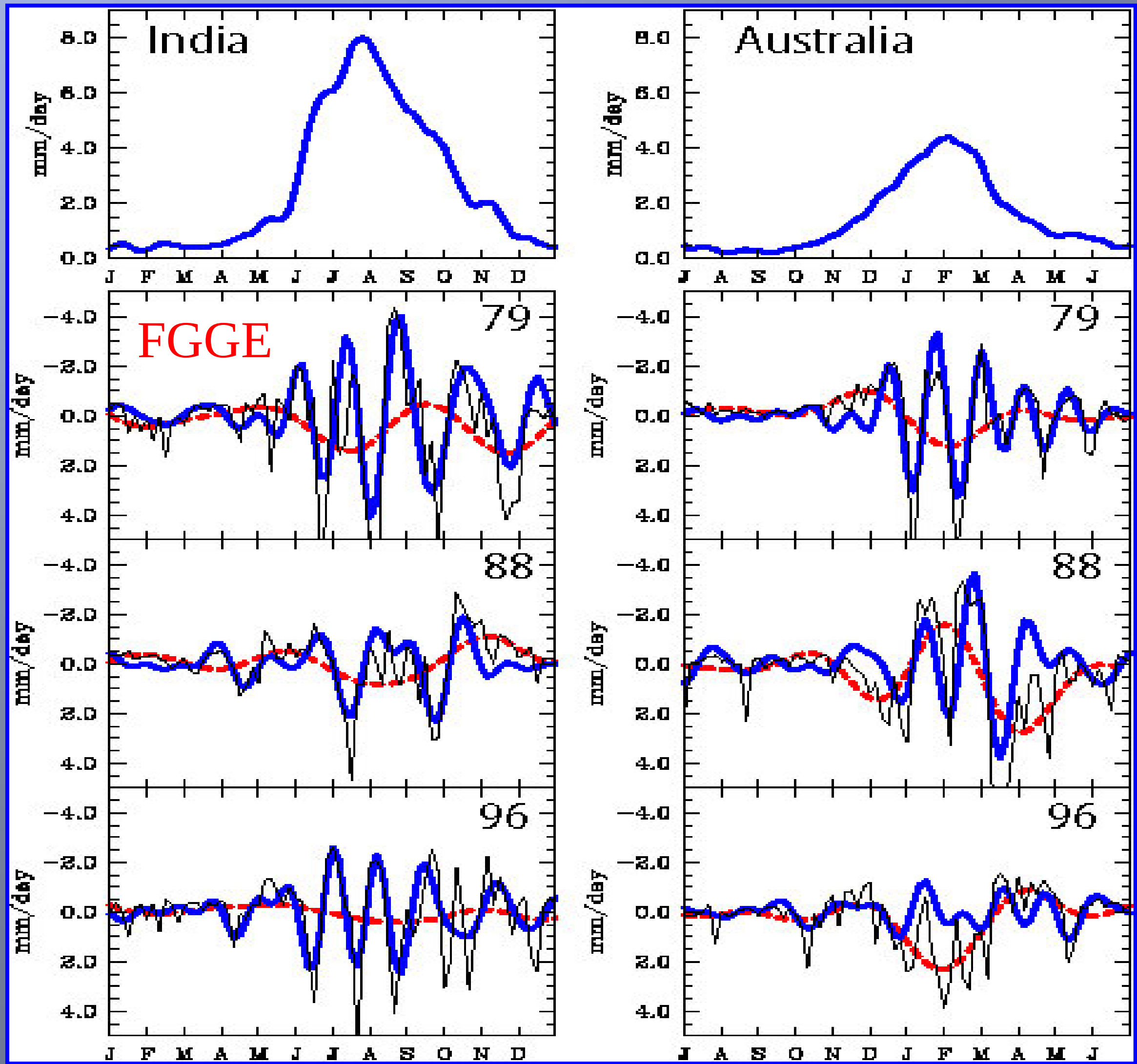
Observed Structure & Variability

Interannual Variability

Interannual Variability

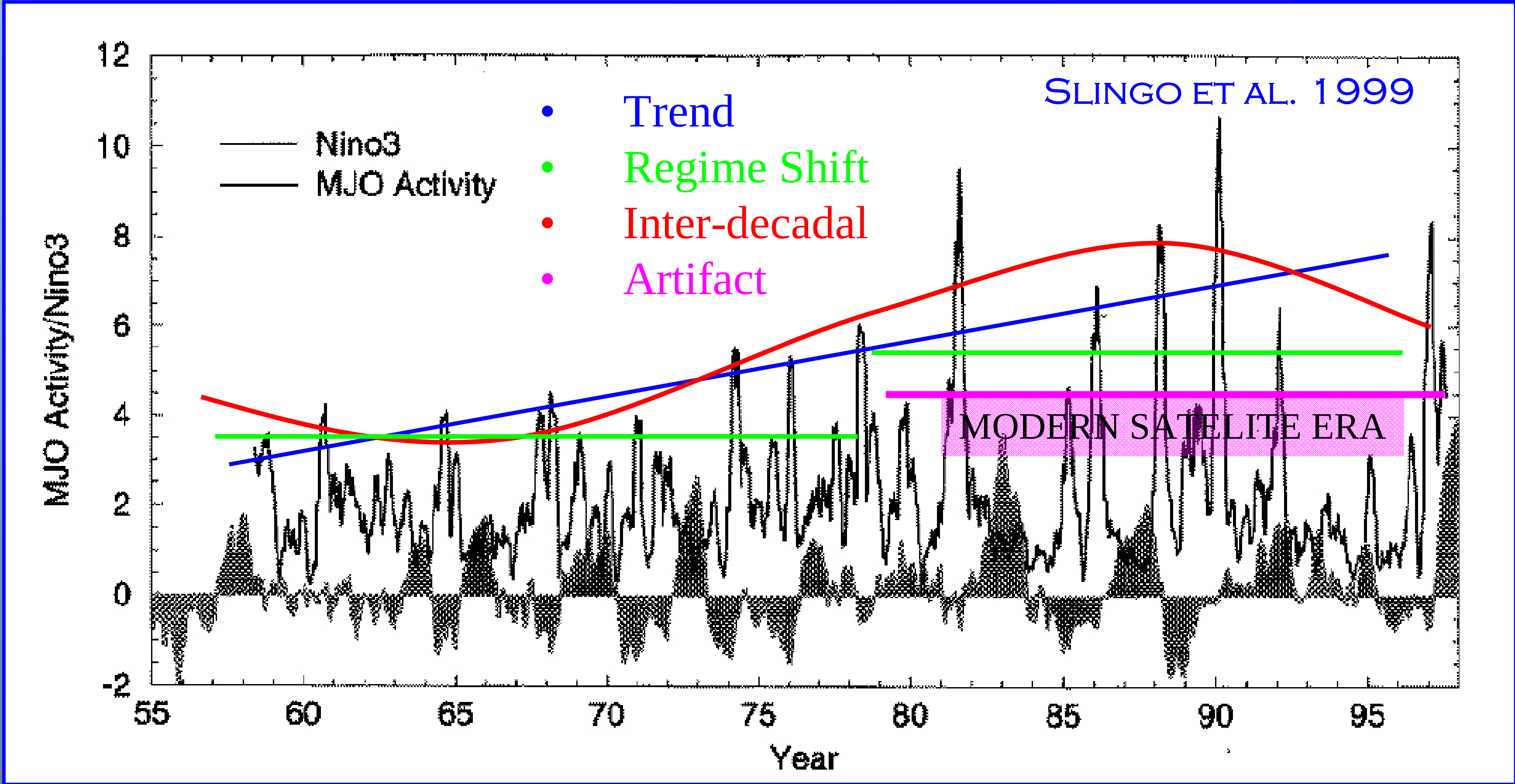


Interannual MJO Variability In India & Australia Sectors



CMAP Rainfall Data

Longer-Term Variability of MJO/ISO



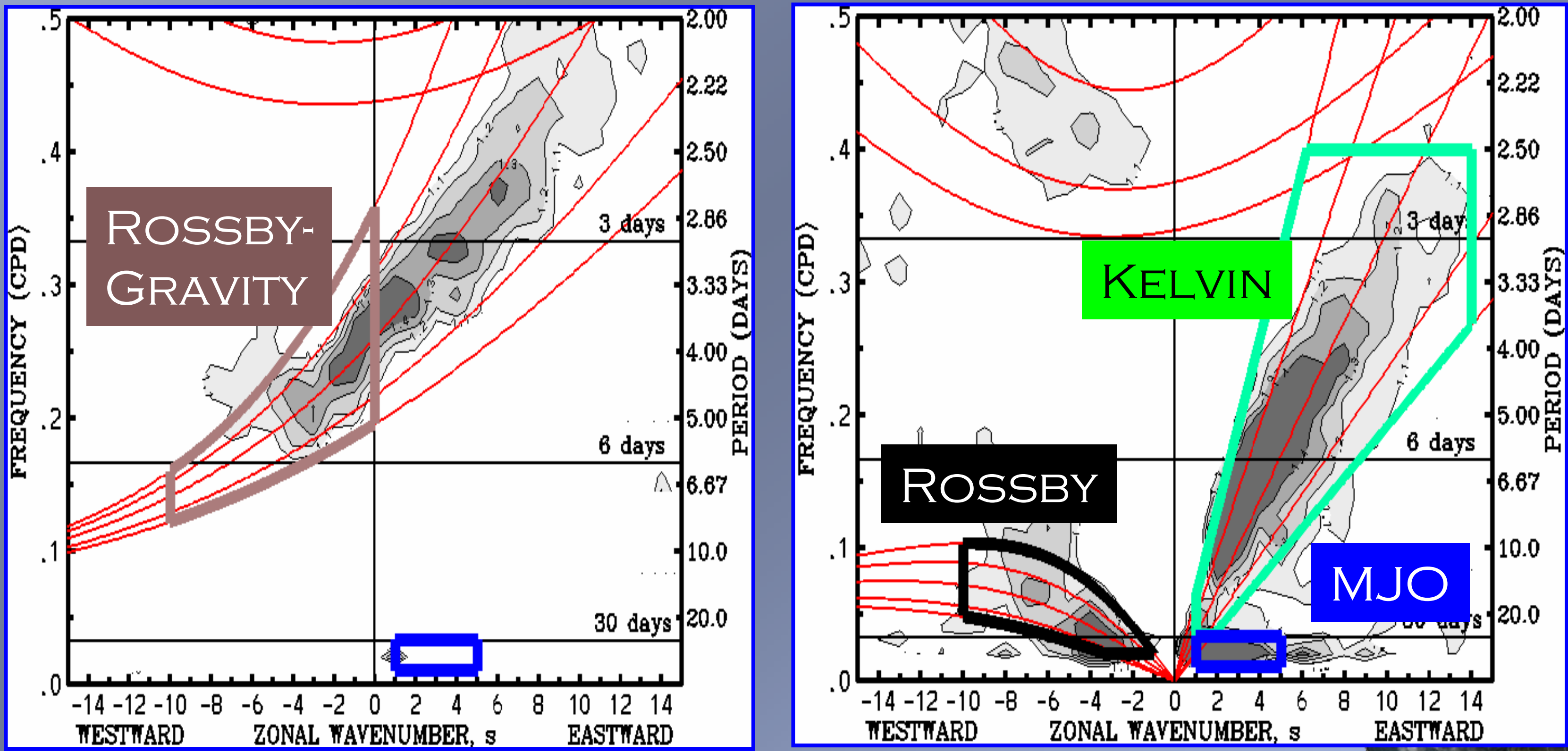
To the extent this is real, it may have ties to Indian Ocean warming: Slingo et al. 1999, Zveryaev 2002.

Observed Structure & Variability

Multi-Scale Components
&
Convectively-Coupled Waves

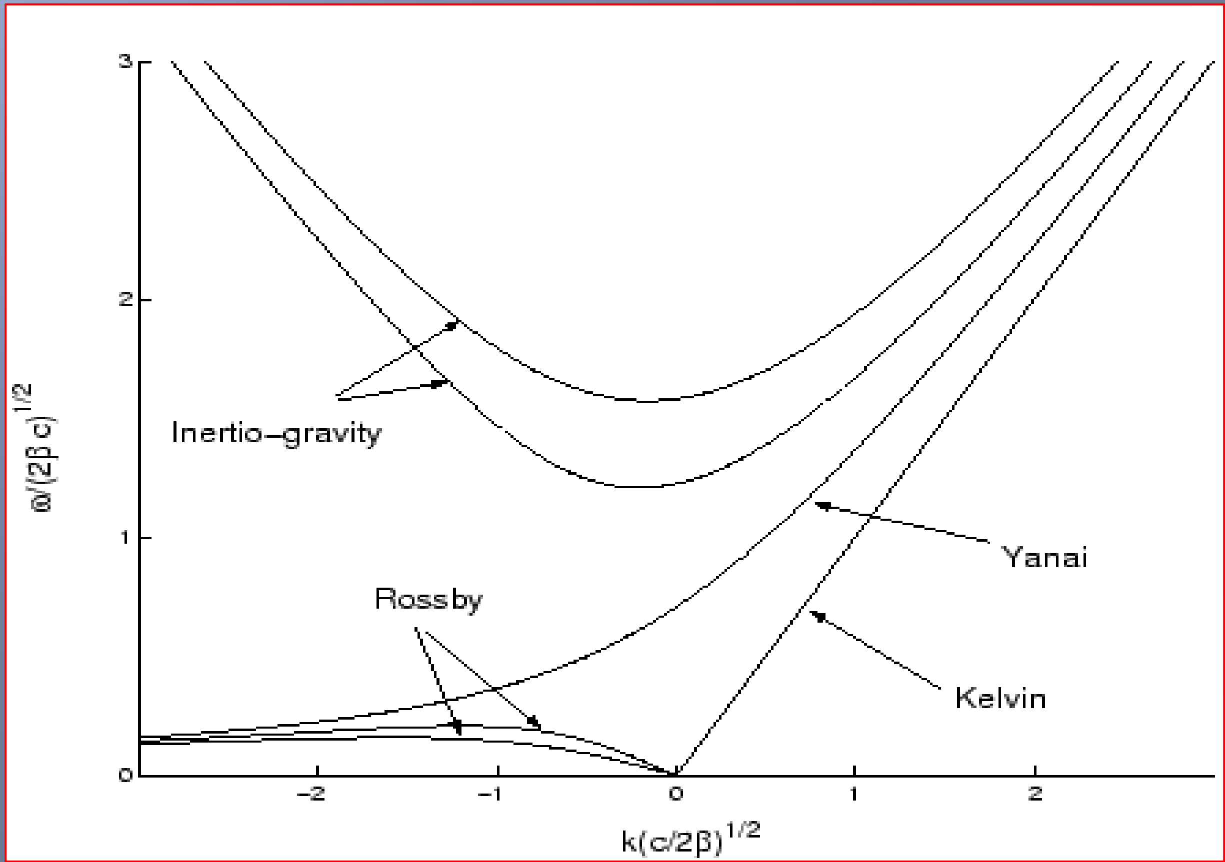
Convectively-Coupled Waves

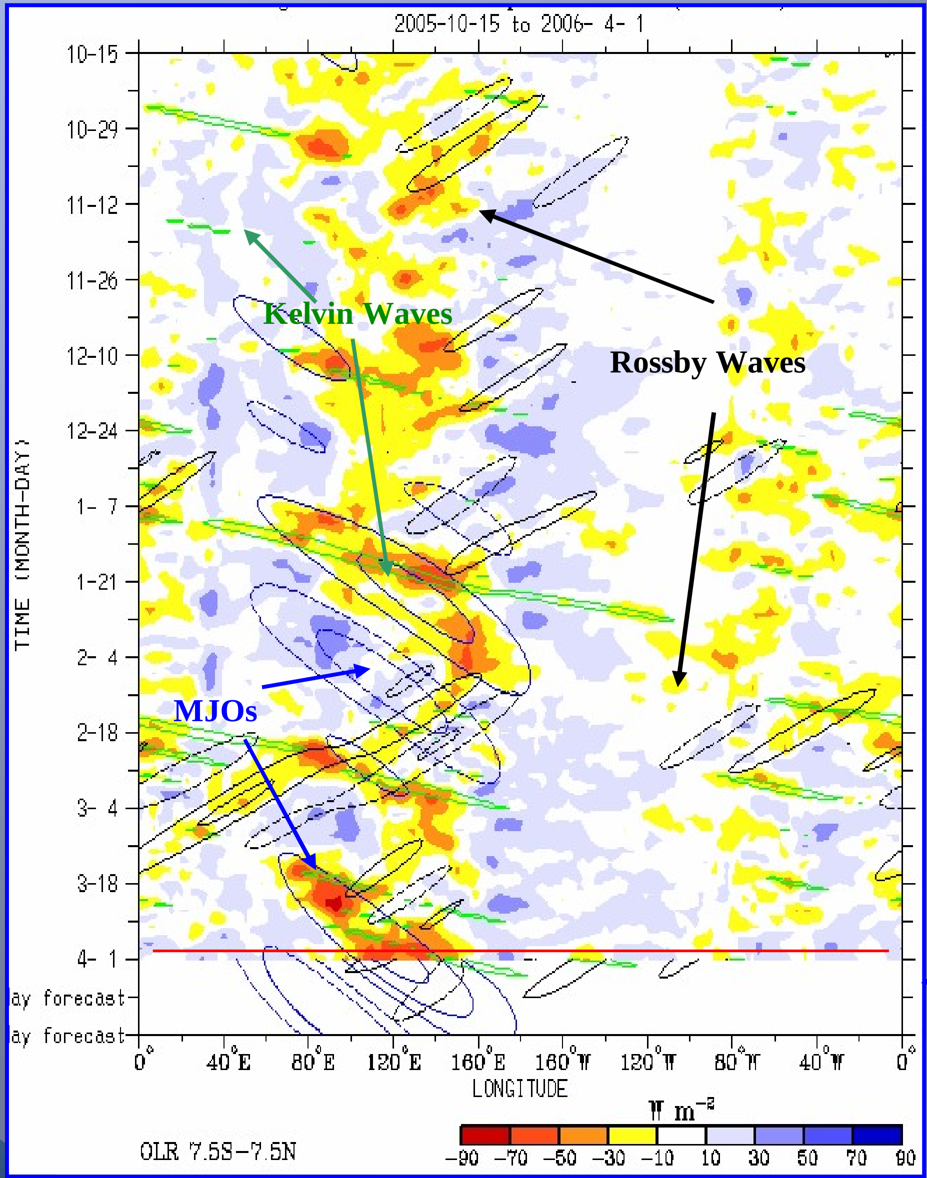
Filtering for Tropical Wave Modes



Wheeler and Weickmann 2001

Convectively-Coupled Waves





Convectively-Coupled <u>Equatorial</u> Waves

NH Winter
MJO, Kelvin, Rossby

Monitoring

Prediction

Multi-Scale Structure

How Important is This Finer Structure To The Phase Speed, Eastward Propagation, etc

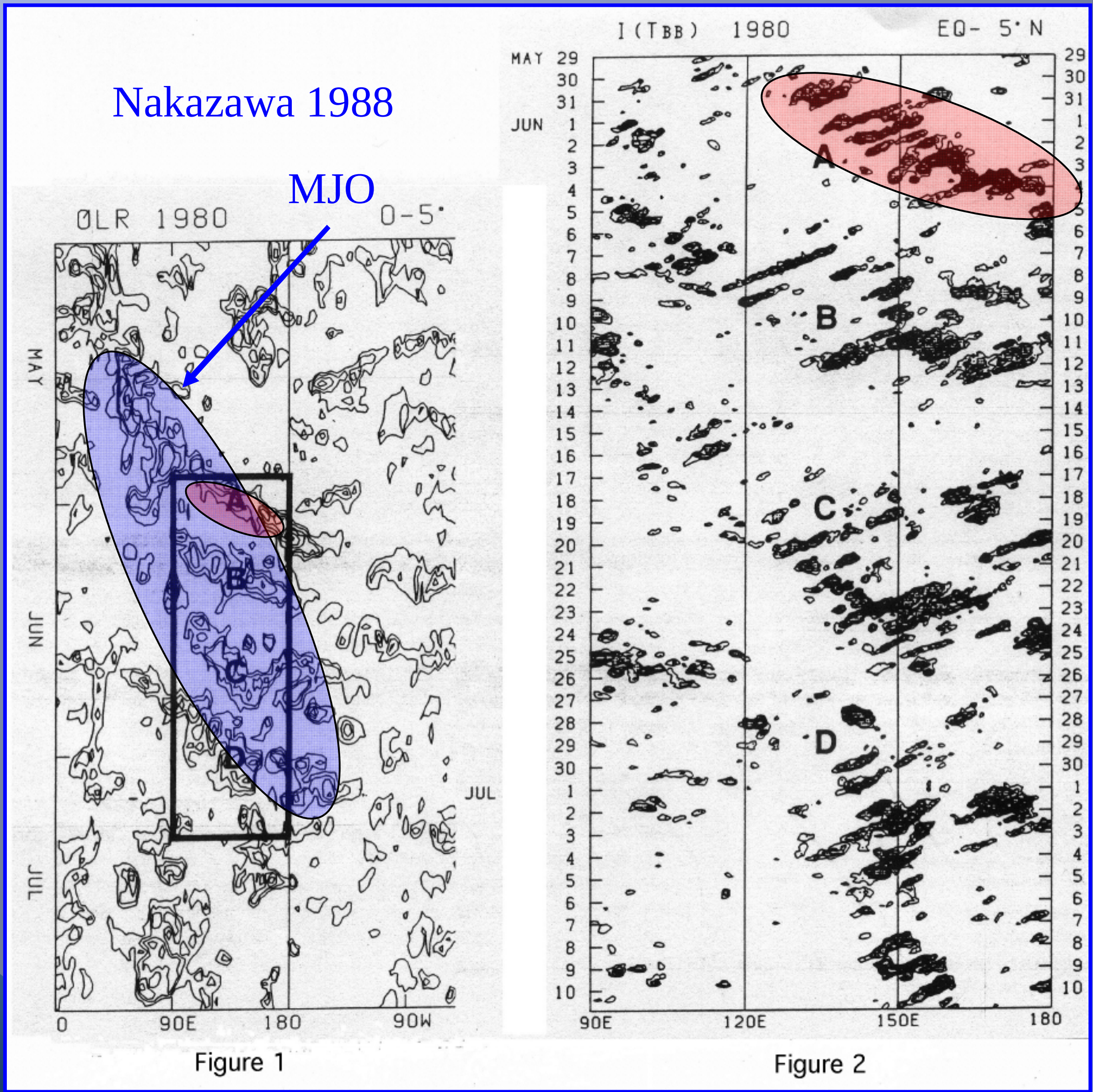
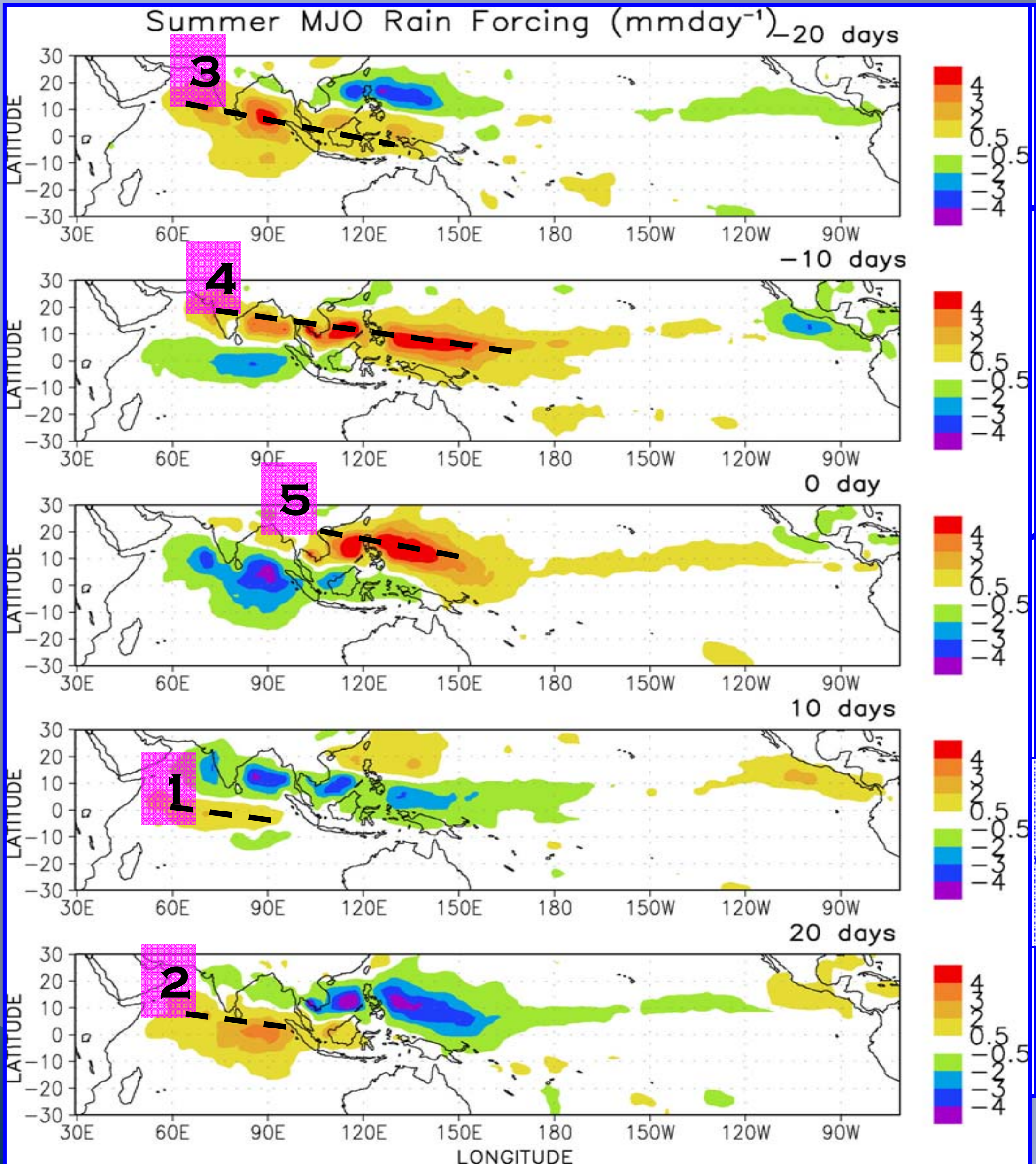


Figure 1

Figure 2

Boreal Summer Complex Propagation & Multi-Scale Organization



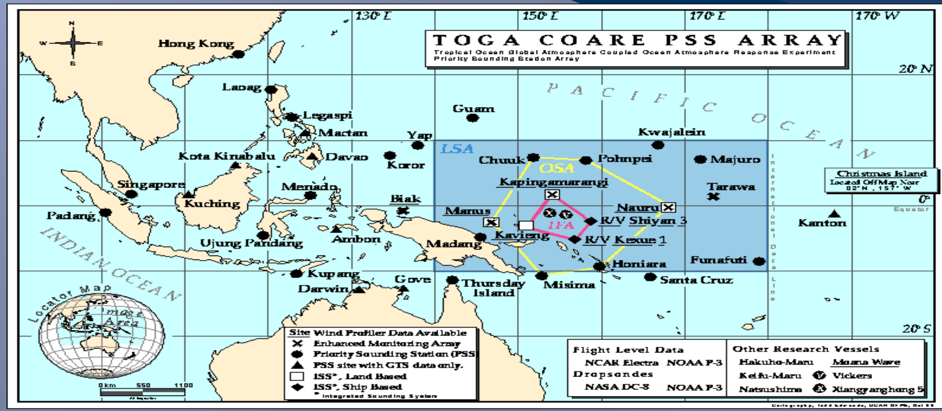
Eastward Propagating Convective Envelope ~40-50 days

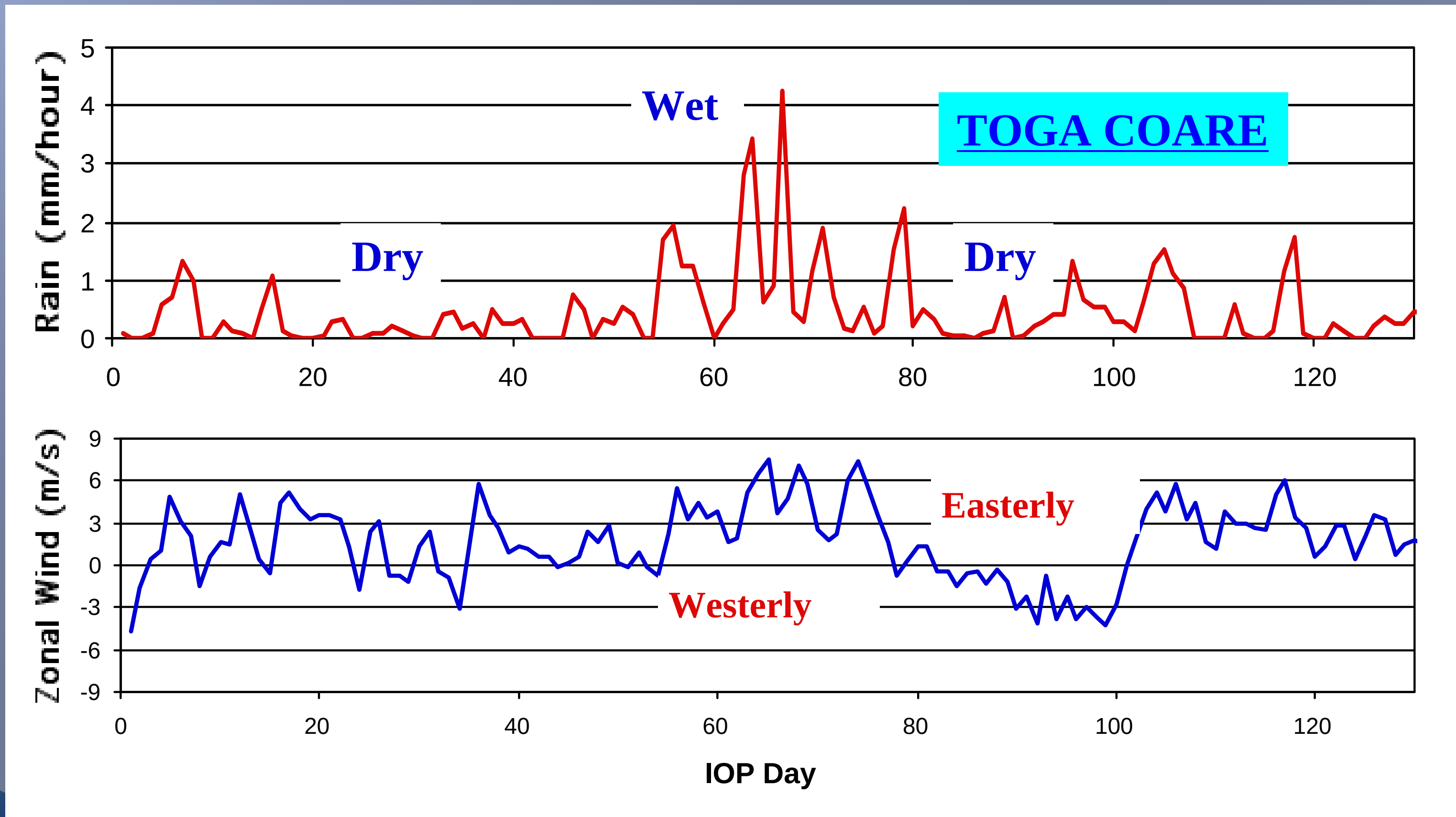
Westward Propagating Rossby-Waves ~ 10-20 day; Modulated by 40-50day

Northward Propagation Of Rossby-Wave Convection (twisting, SST, moisture feedback)

Weather & Climate Impacts

MJO & Tropical Weather Variability





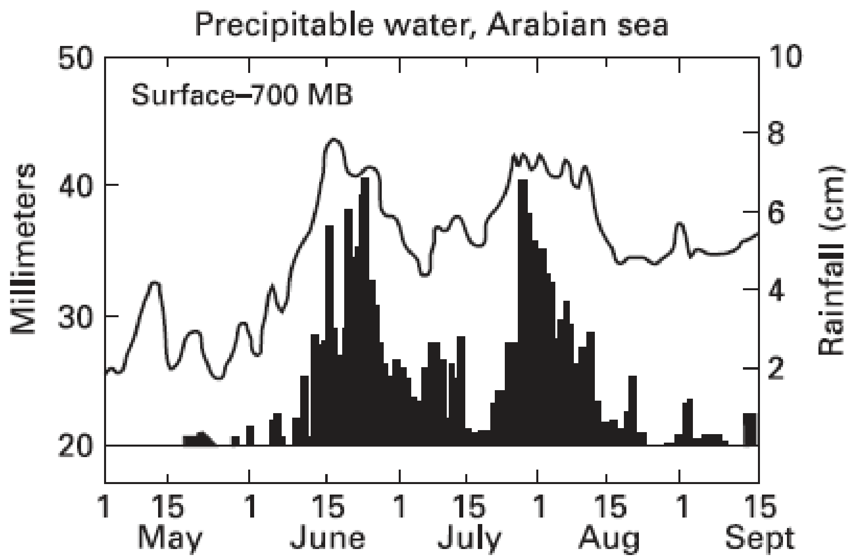
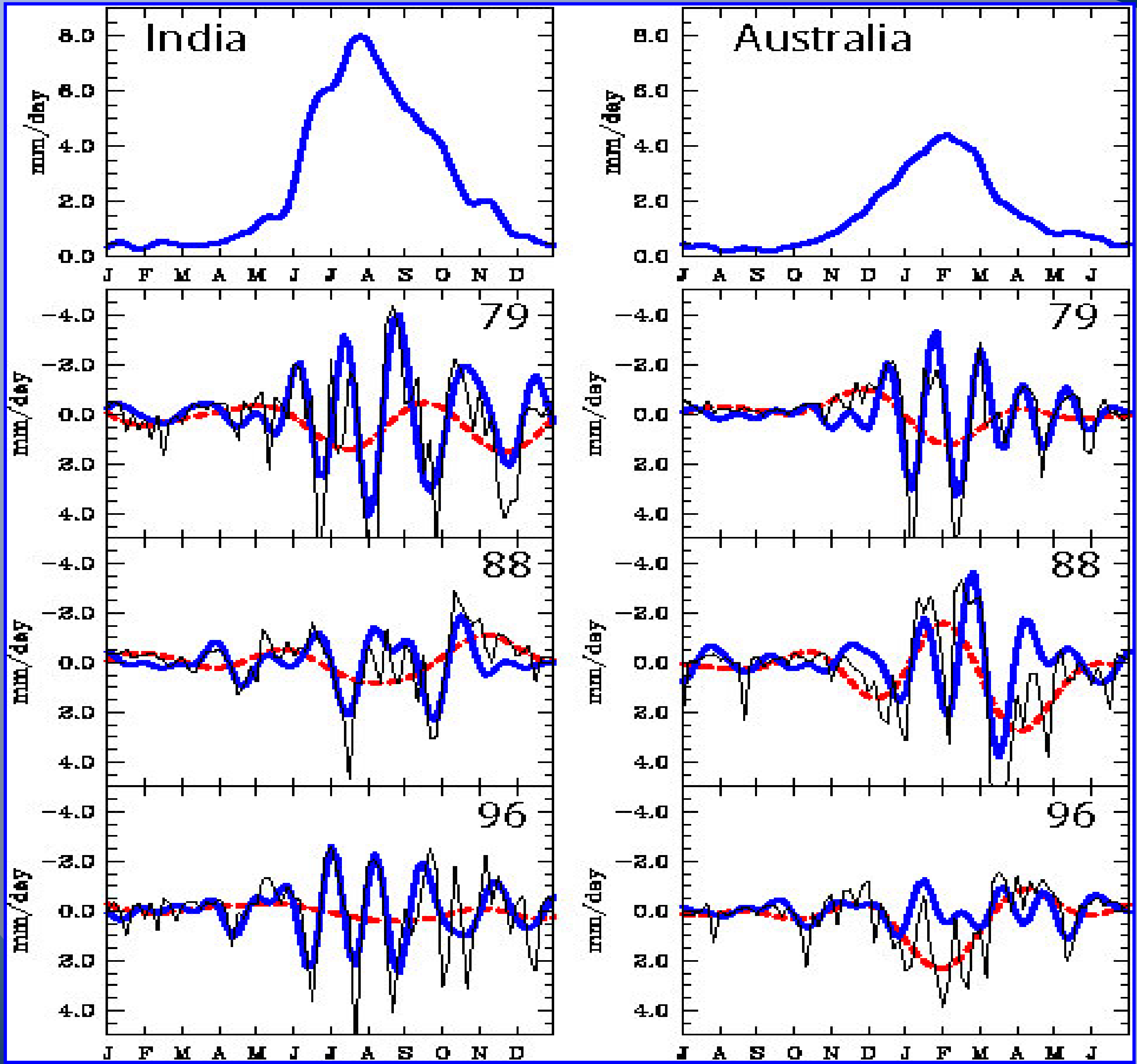


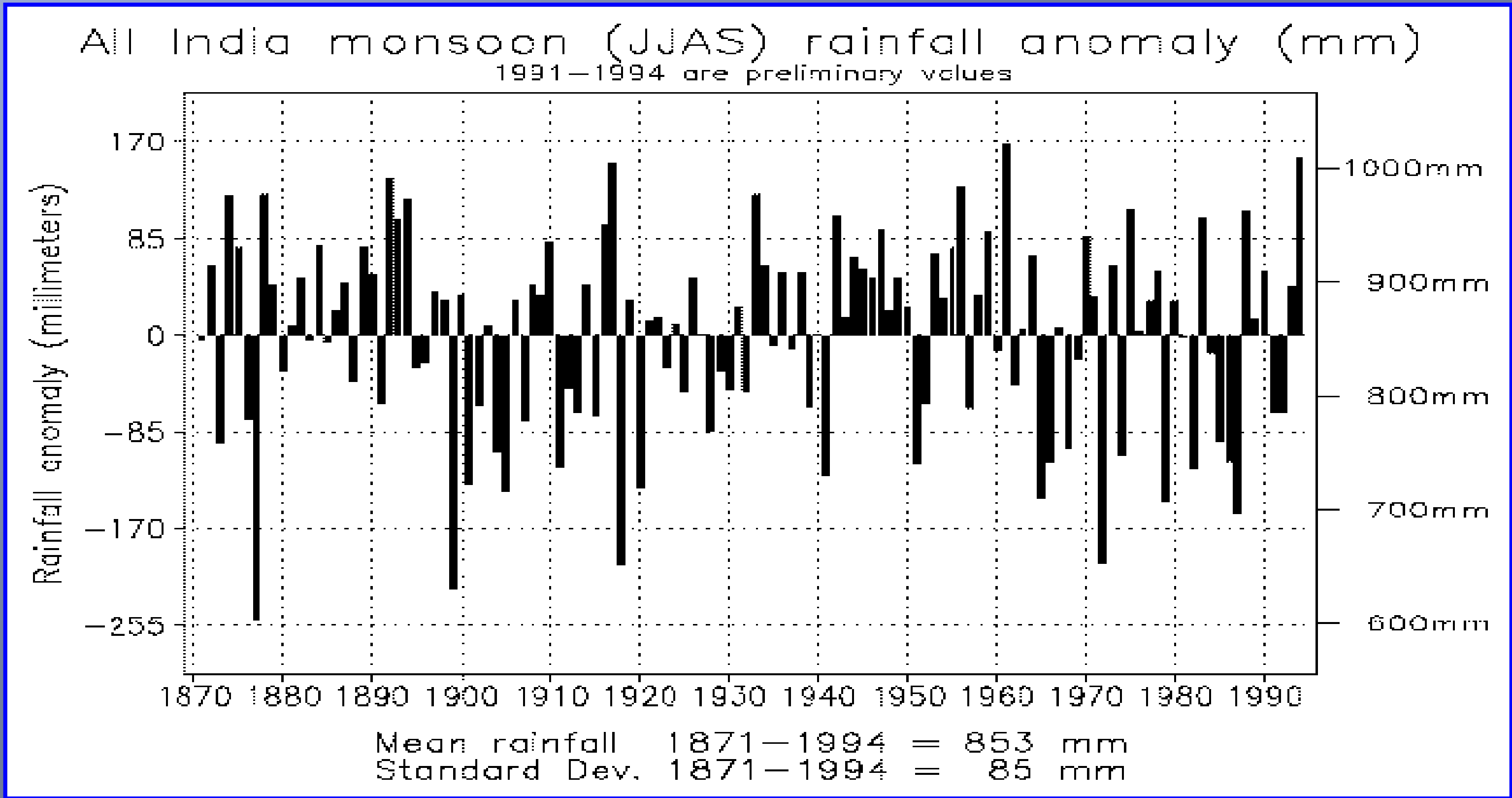
Figure 1.3. Time series of precipitable water from the surface to 700 hPa over the Arabian Sea (thin line) from TIROS-N, and the precipitation along the west coast of India during MONEX.
Adapted from Cadet (1986).

Onsets & Breaks of The Asian & Australian Summer Monsoon

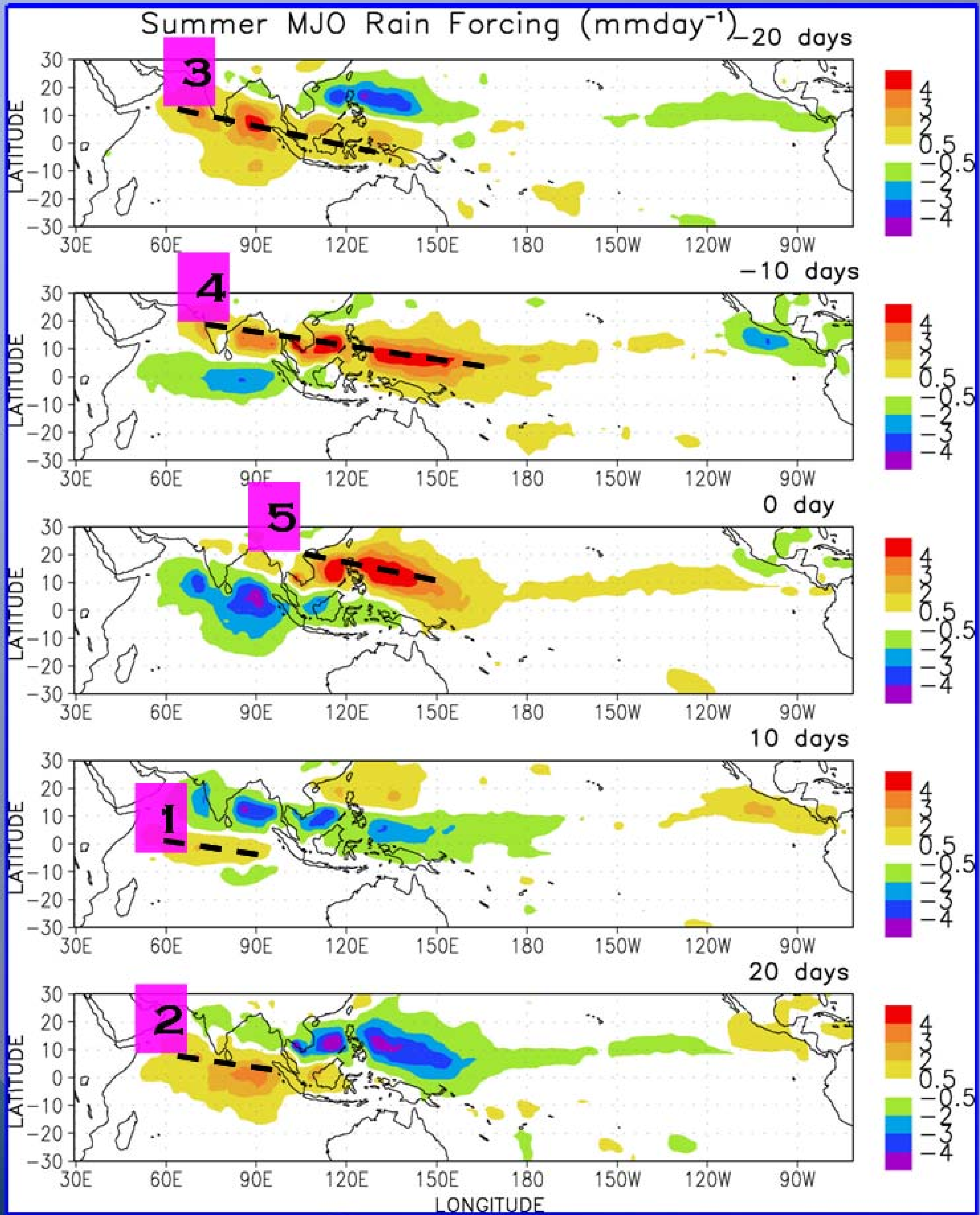

India
Australia
mm/day
8.0
6.0
4.0
2.0
0.0
J F M A M J J A S O N D
J A S O N D J F M A M J
79
88
96
-4.0
-2.0
0.0
2.0
4.0

Indian Summer Monsoon

Interannual All-India Rainfall Variability

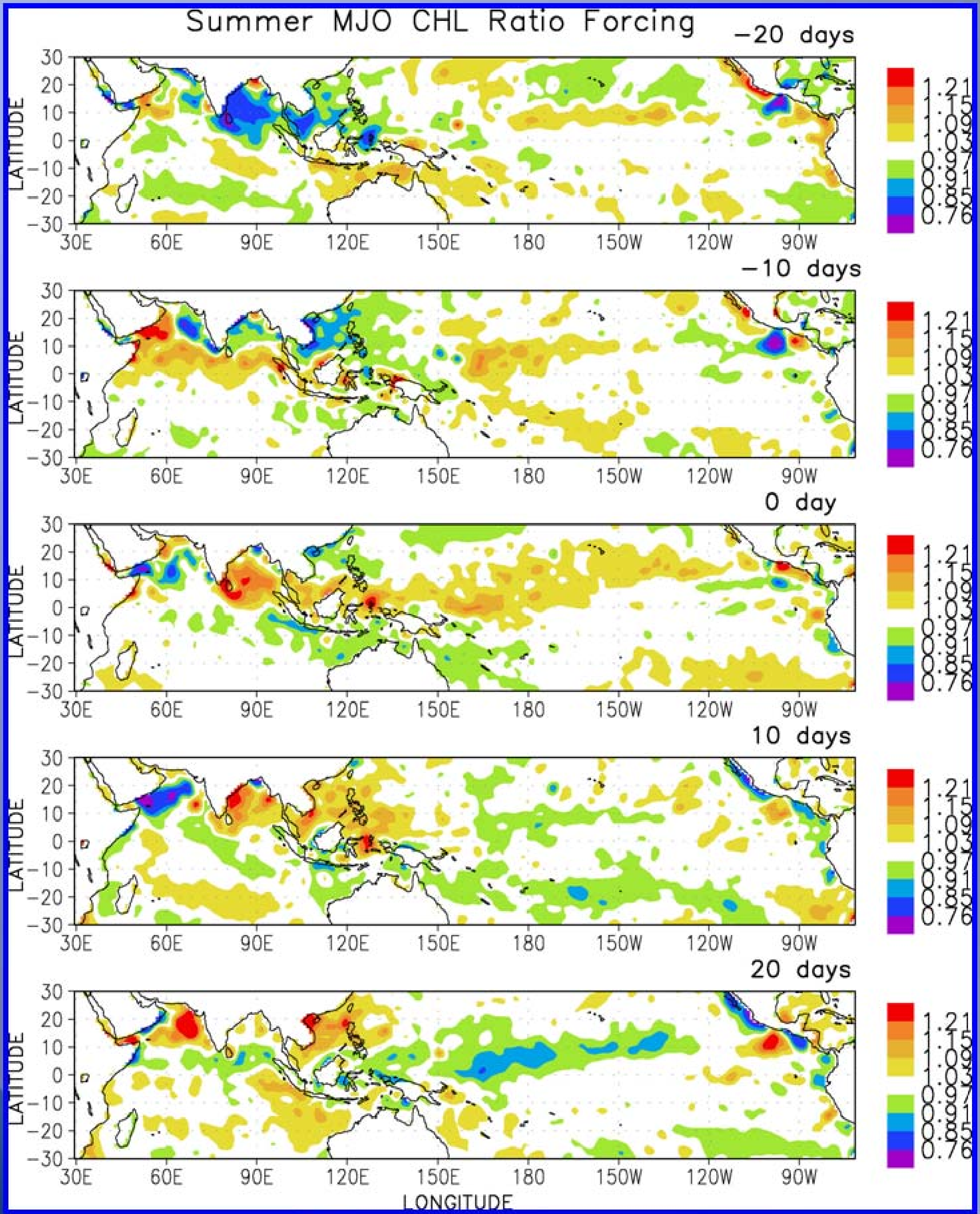


What role does MJO variability play in this?



MJO & Ocean Chlorophyll: NH Summer

- "Chl Ratio" is the value relative to the seasonal mean, thus 1.20 means a 20% increase over the typical seasonal value.
- Large-Scale systematic changes in Chlorophyll (Chl) are observed over most of the Tropical Indian and Pacific Oceans.



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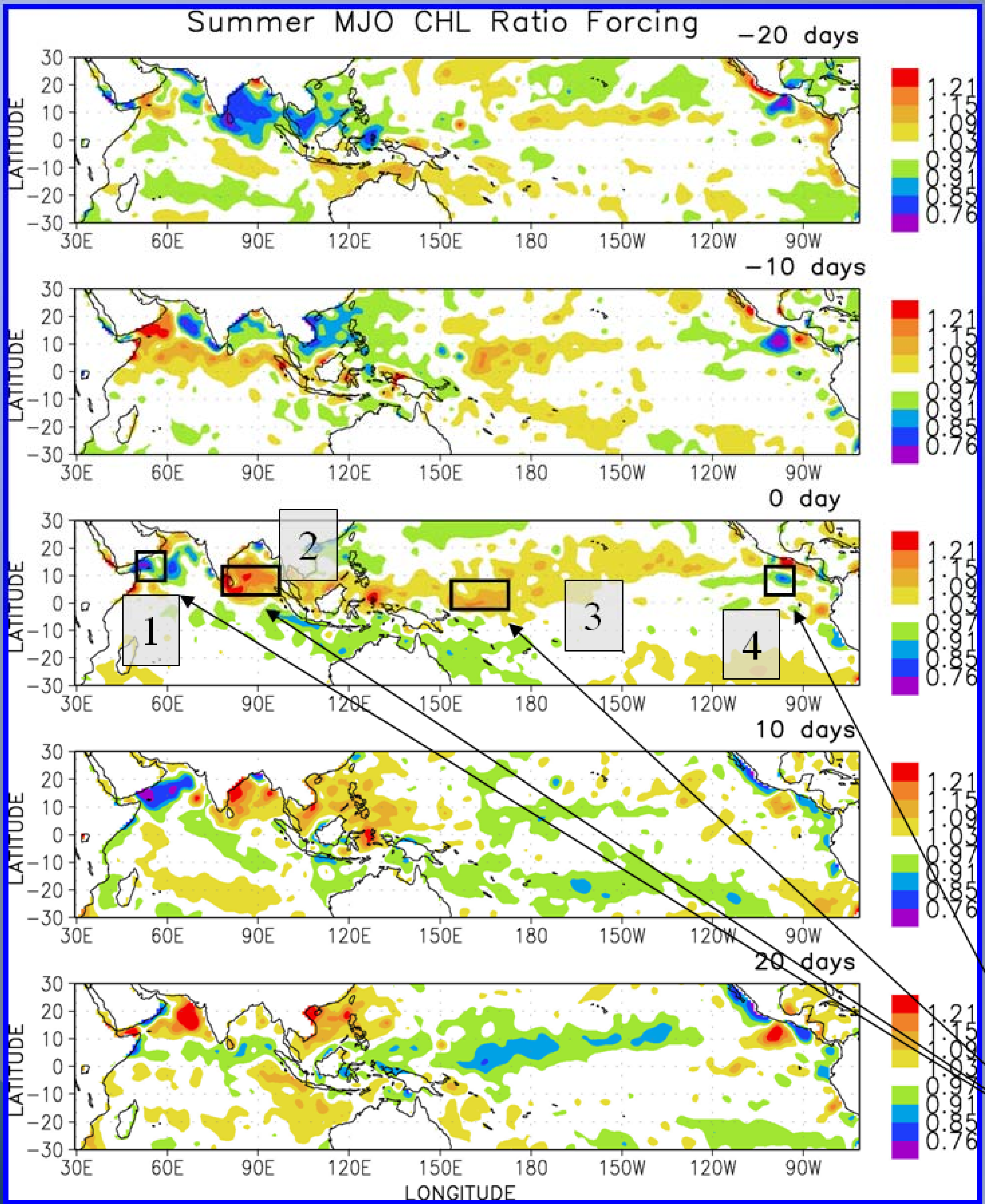

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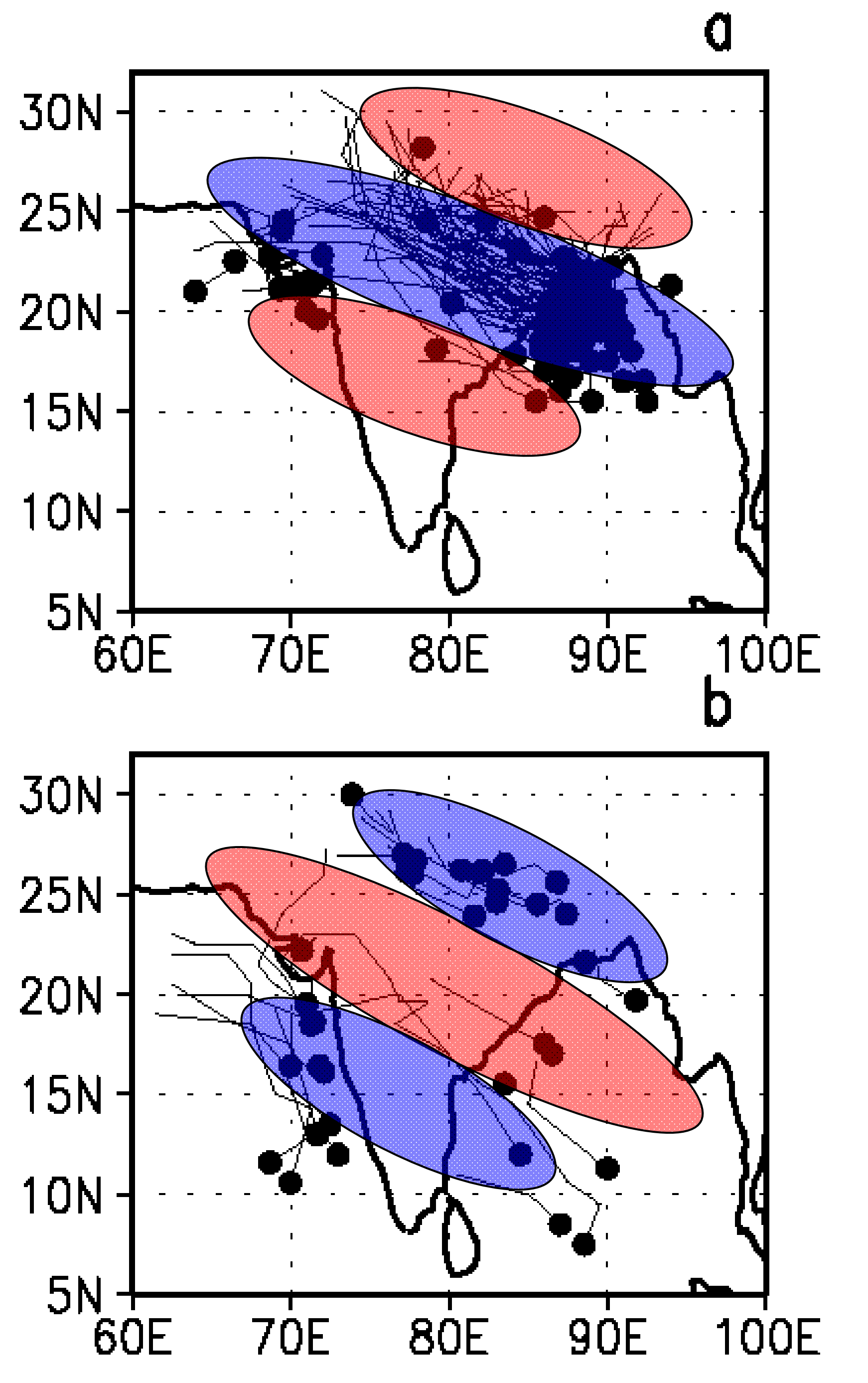
Sensitive Regions

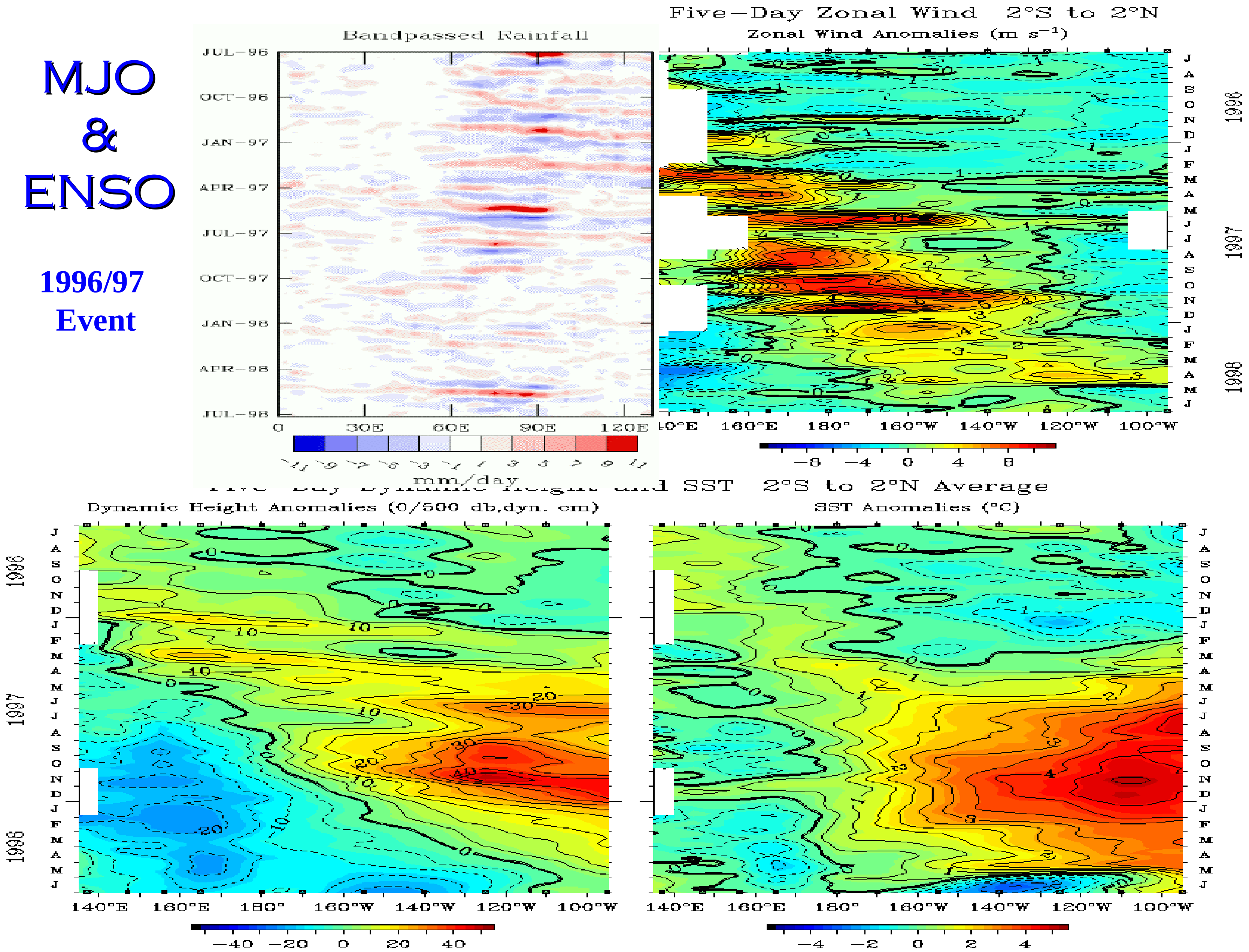


Local Synoptic Organization By ISO

Goswami et al. 2003

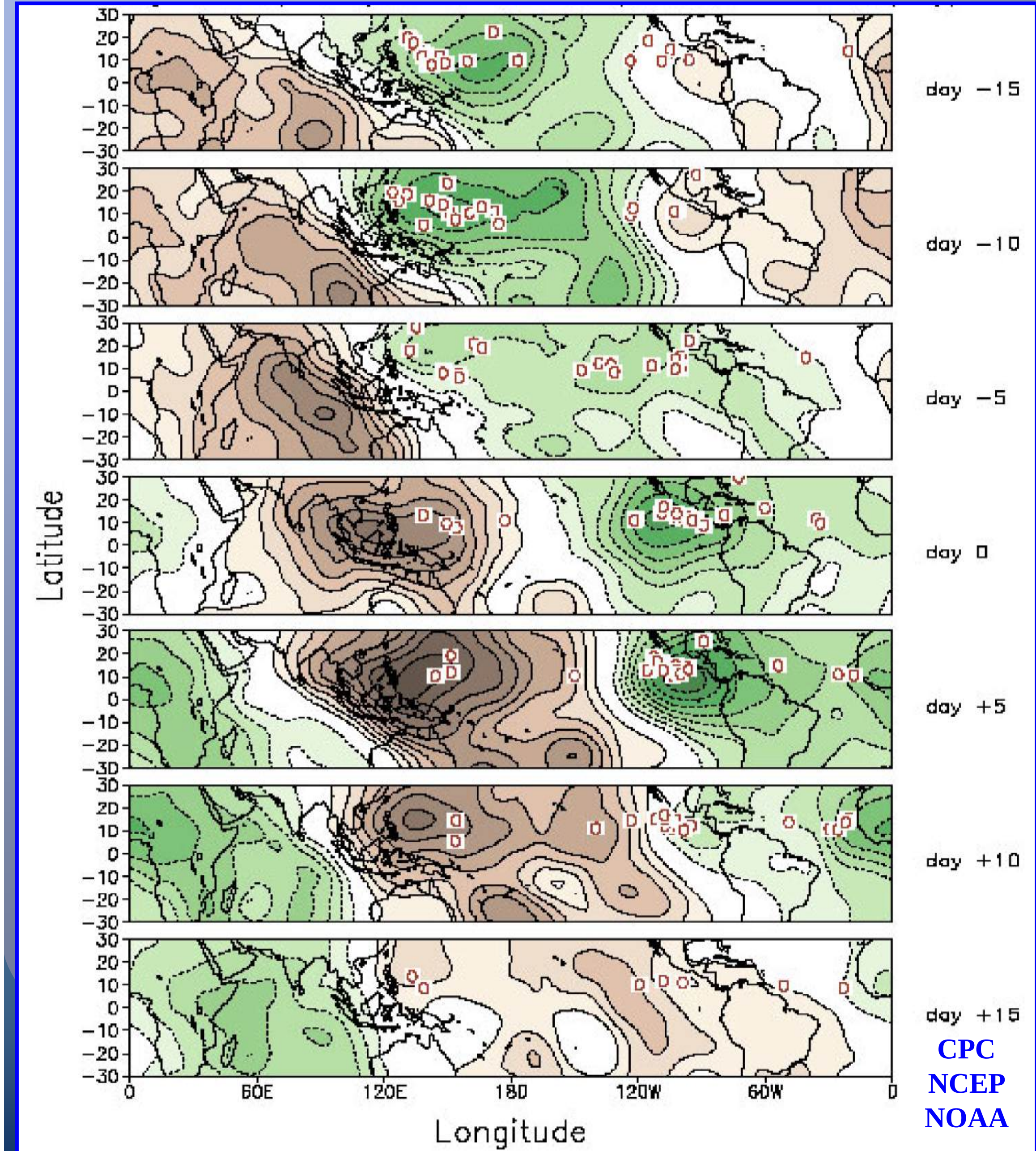
MJO & ENSO

1996/97 Event



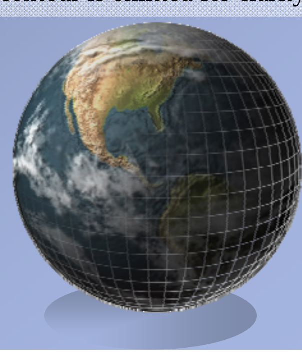
Remote Organization Of Tropical Cyclones

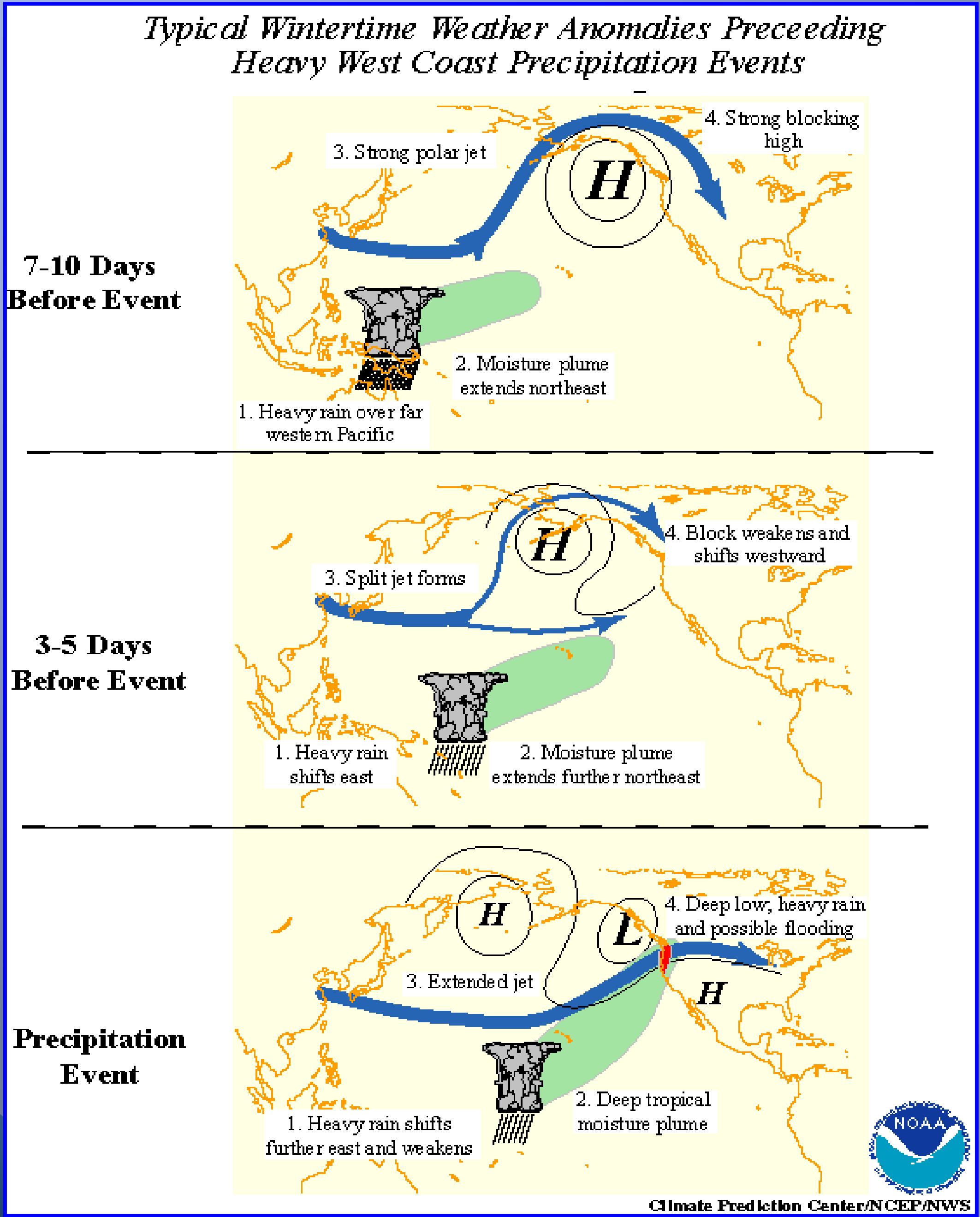
Higgins et al. 2000



CPC
NCEP
NOAA

The green (brown) shading roughly corresponds to regions where convection is favored (suppressed) as represented by 200-hPa velocity potential anomalies Composites are based on 21 events over a 35 day period. Hurricane track data is for the period JAS 1979-1997. Points of origin in each panel are for different storms. Contour interval is 0.5x106 m2 s-1, negative contours are dashed, and the zero contour is omitted for clarity.



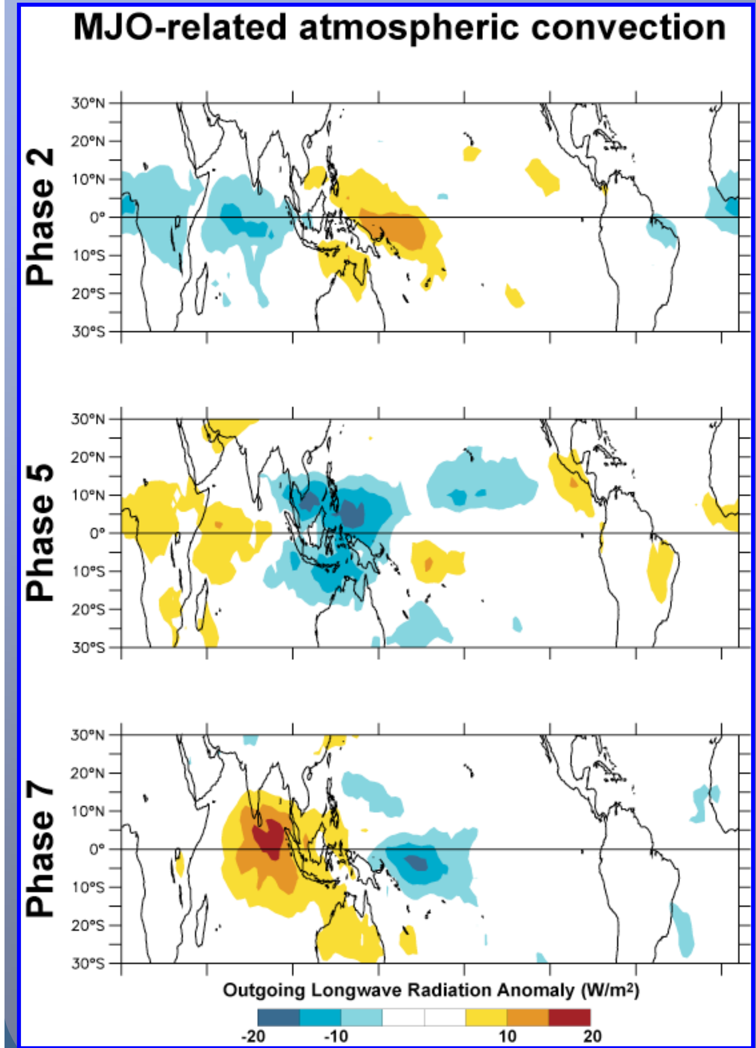


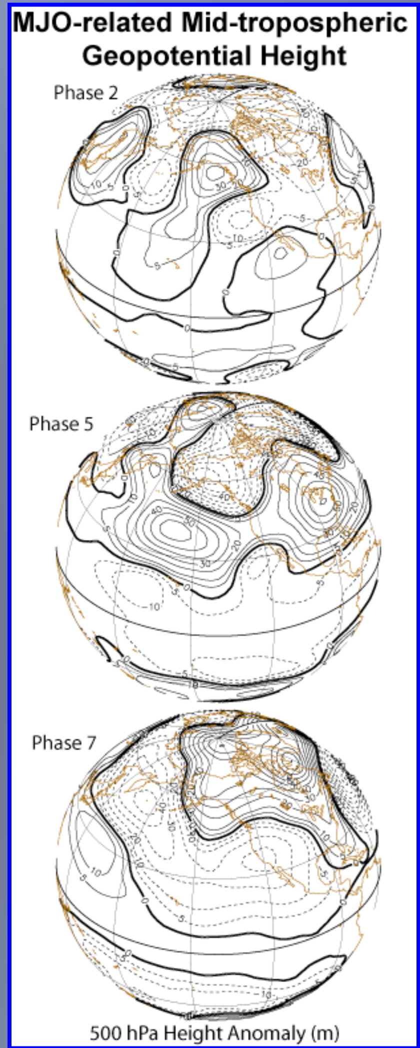
MJO Influence on US West Coast Rainfall

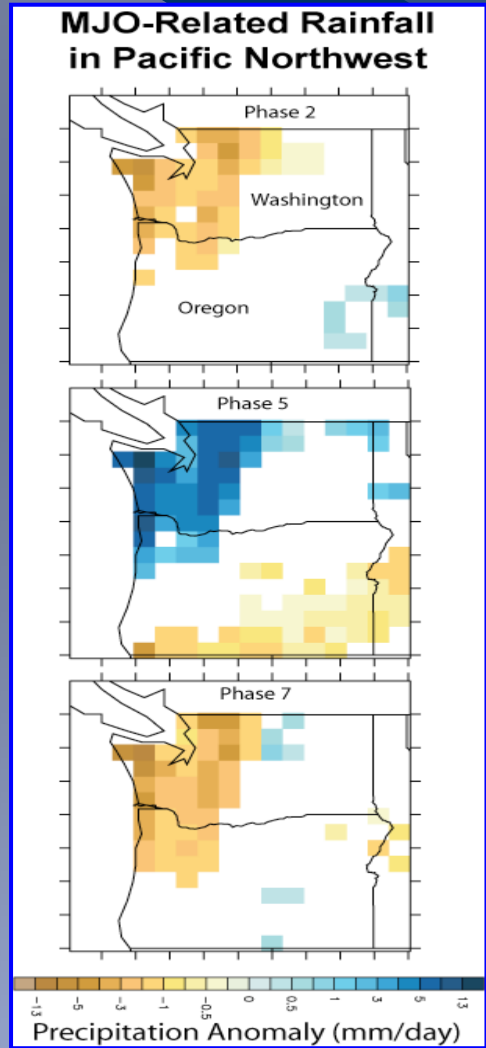
CPC
NCEP
NOAA

Extra-Tropical Weather : US West Coast

Bond and Vecchi, 2004







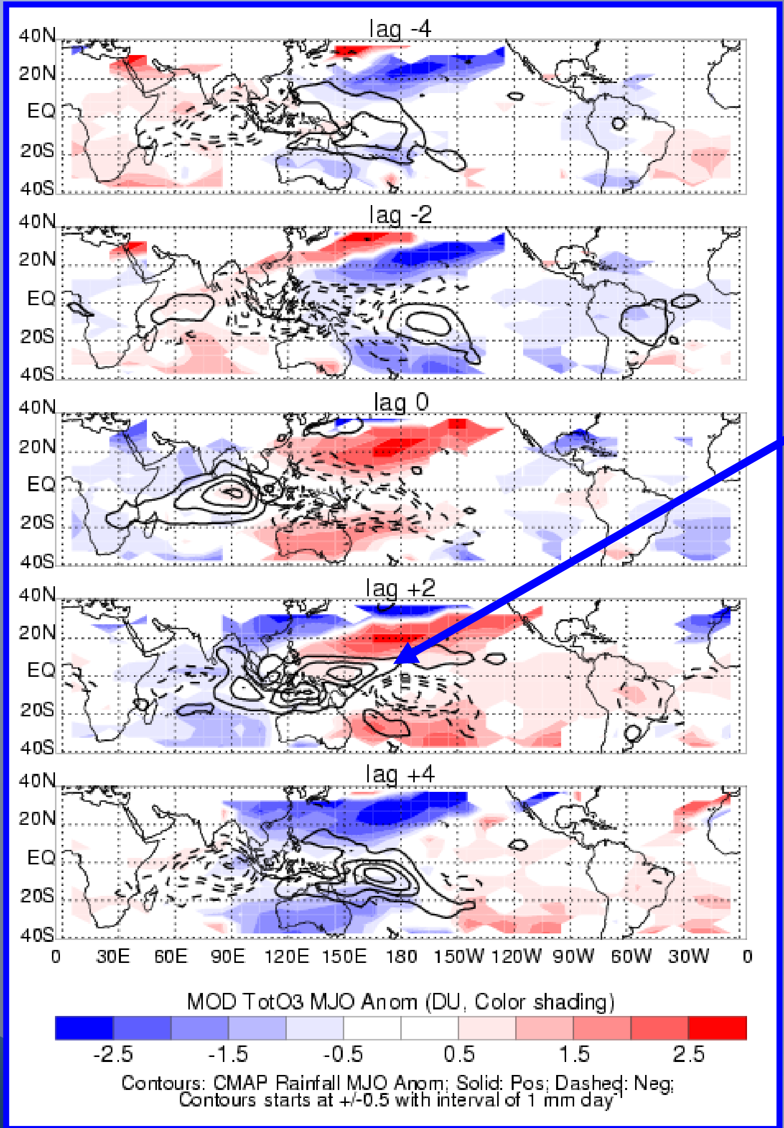
Composite tropical convection for three Phases of the Madden Julian Oscillation (MJO). Blue shading indicates increased atmospheric convection. On average each phase lasts 7 days, and these three phases span about one half of a complete MJO cycle.

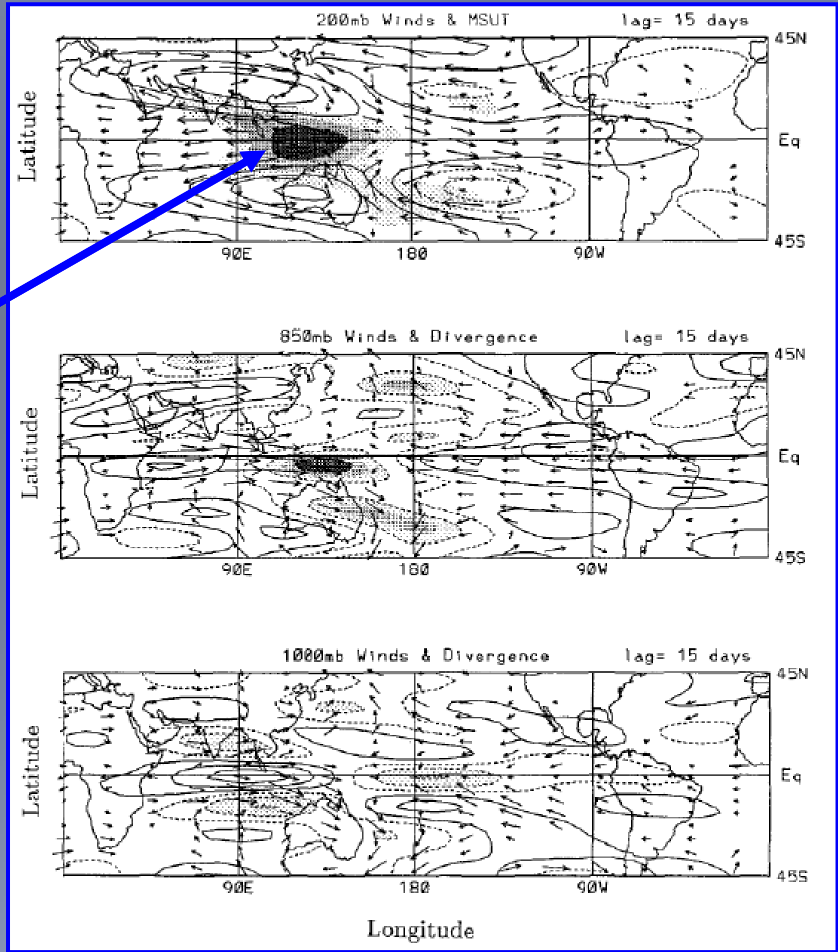
Same, except for mid-tropospheric (500 hPa) geopotential height over the Pacific/North American region during northern hemisphere winter. Solid contours indicate regions of anti-cyclonic (clockwise) circulation, dashed contours indicate regions of cyclonic (counterclockwise) circulation.

Composite Pacific Nortwest wintertime precipitation for three Phases of the Madden Julian Oscillation (MJO). Blue shading indicates increased rainfall.

Subtropical Ozone Variability

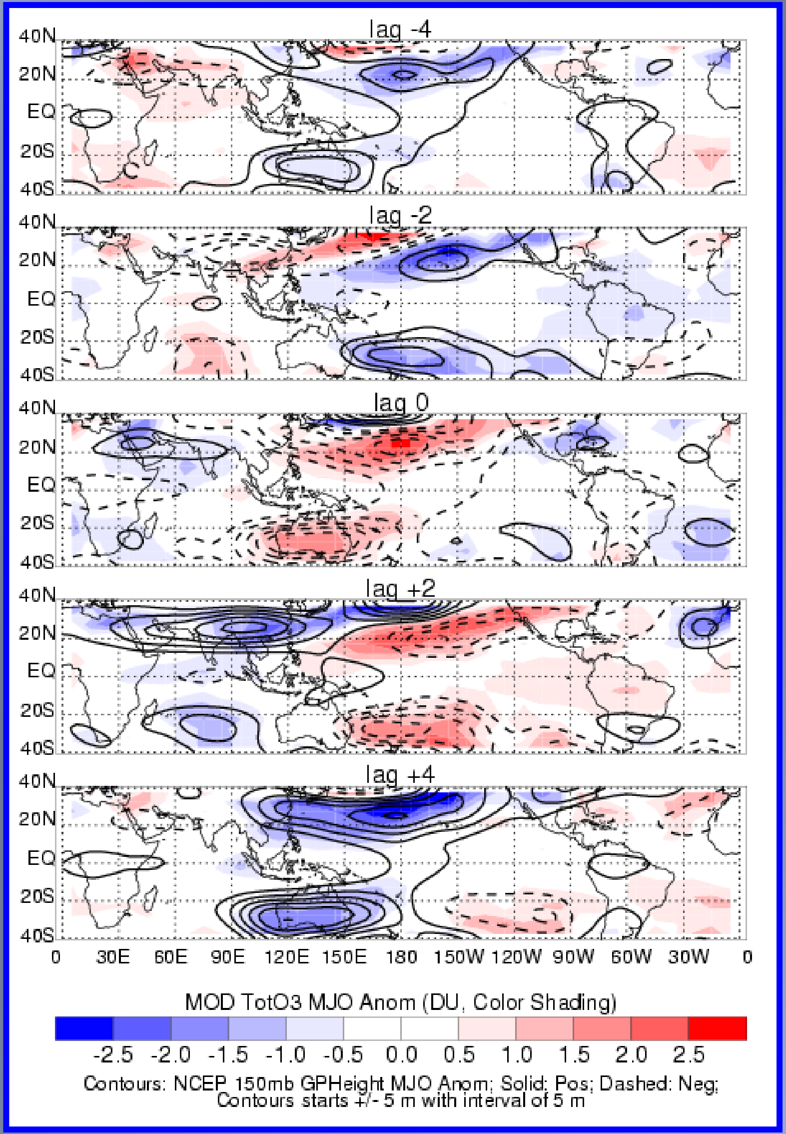
Tian et al., 2007





Subtropical Ozone Variability

Tian et al., 2007



Some Research Questions

General

- What are the crucial elements of the large-scale environment that influence the development, organization and maintenance of the MJO? What starts and MJO event? Is there a mid-latitude influence? Does one event precipitate the next? Issues of what determines the time/space scale selection and propagation speed are still not agreed upon.
- What are the characteristics and relative roles of processes occurring: i) within the large-scale circulation; ii) on the mesoscale, and iii) internally on the storm scale that influence the development, organization, and maintenance of the MJO?
- Under what circumstances and via what mechanisms is water vapor, energy, and momentum transferred across scales ranging from the mesoscale to the large (or planetary) scale? Do these translate up or down scale?
- What role does ocean coupling play? Land-atmosphere interactions appear to dampen the MJO - why?

Multi-scale Processes & CCEWs

- Do systematic relationships exist between the MJO's large-scale characteristics (e.g., propagation speed, growth/decay) and its fine-scale/multiscale convective structure (e.g., westward versus eastward-moving fine-scale components, shallow versus deep convective elements), and to what extent do models capture these relationships? Are these relationships indicative of an upscale cascade, or downscale conditioning?
- Does the convection provide an important feedback to a CCEW or is it just a by product of the adjustment? Are these really "coupled"?
- Does the characterization and connections between the circlation, diabatic heating (e.g. latent, radiative) and boundary layer processes differ in the context of the MJO and CCEW, and do numerical weather and climate models properly represent these connections?

Prediction

- What is the predictability of the MJO?
- What is the current level of prediction skill attained for the MJO by operational numerical prediction models?
- Does this skill translate to extended-range (i.e., 1-3 week) predictability of tropical rainfall?
- How might it translate into predictability for related processes, such as mid-latitude weather, tropical cyclone genesis, monsoon onset and breaks, ocean bio-chem, atmospheric composition (e.g. aerosols, ozone).
- Do research or operational models (i.e. GCMs) successfully simlate and predict the higher-frequency convectively-coupled equatorial waves?

Low-Frequency Variability

- What factors influence interannual and longer-term mjo variability (e.G,. Enso, pdo, climate change)? How much is just stochastic?
- How does interannual mjo variability influence seasonal monsoon rainfall? Is any part of this predictable?
- Does the mjo influence enso or other long-term ocean variability?
- Are MJO effects on other weather/climate processes neutral on longer time scales or do they rectify and produce a net impact?

Weather & Cilmate Impacts

- Are there any fundamental differences between boreal summer and boreal winter MJO that are important to their impacts on monsoon variability? Are the multiscale structures different and how might this effect the high-frequency variability of the monsoons? Do these seasonal differences or multi-scale / characteristic wave differences impact the predictability?
- MJO and Atmospheric Composition - very new area - many many questions.
- What oceanic and ocean-atmosphere processes combined to produce the variability observed in ocean Chl? Does this translate into an impact on fisheries?
- Interactions between the MJO & CCEWS and midlatitude flow/weather are still being discovered and disentangled....