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

The Asian Monsoon System: Predictability of Change and Variability
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Lecture Outline

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

Resources & Further Reading

- 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)

- Intraseasonal Time Scale: ~40-60 days

Typical Variables Used for MJO Analysis

- Cloudy Low OLR
- Clear High OLR

U200
Rainfall //\\
U850

Madden & Julian, 1972
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
Interannual: > 90
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.
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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
MJO Life-Cycle Composites

Vector Winds, etc.

Equatorial UT Easterlies
Enhanced Equatorial Convection
Equatorial UT westerlies (Kelvin wave response)

Subtropical UT cyclones lead EQ enhanced convection (Rossby wave response)
Subtropical UT anticyclones lag EQ enhanced convection (Rossby wave response)

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 Niiler, 1997
- 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

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

"Coupled" or Not?
**Impact of SST Coupling on MJO/ISO**

**Phase Difference**

5-10 Days
5-20° Lon

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 MJO VARIABILITY IN INDIA & AUSTRALIA SECTORS

CMAP Rainfall Data
To the extent this is real, it may have ties to Indian Ocean warming: Slingo et al. 1999, Zveraev 2002.
Observed Structure & Variability

Multi-Scale Components & Convectively-Coupled Waves
Convectively-Coupled Waves

Wheeler and Weickmann 2001
Convectively-Coupled Equatorial Waves

NH Winter
MJO, Kelvin, Rossby

Monitoring
Prediction
Multi-Scale Structure

How important is this finer structure to the phase speed, eastward propagation, etc.

Nakazawa 1988

MJO

Figure 1

Figure 2
Boreal Summer Complex Propagation & Multi-Scale Organization

1. Northward Propagation of Rossby-Wave Convection (twisting, SST, moisture feedback)
2. Eastward Propagating Convective Envelope ~40-50 days
3. Westward Propagating Rossby-Waves ~10-20 day; Modulated by 40-50 day
Weather & Climate Impacts
MJO & Tropical Weather Variability
**Onsets & Breaks of the Asian & Australian Summer Monsoon**

**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).
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.

Sensitive Regions
Local Synoptic Organization by ISO

Goswami et al. 2003
MJO & ENSO

1996/97 Event

Five-Day Zonal Wind 2°S to 2°N
Zonal Wind Anomalies (m s⁻¹)

Five-Day Dynamic Height and SST 2°S to 2°N Average
Dynamic Height Anomalies (0/600 db, dyn. cm)

Dynamic Height Anomalies (0/600 db, dyn. cm)

SST Anomalies (°C)
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.

CPC
NCEP
NOAA
Typical Wintertime Weather Anomalies Preceeding Heavy West Coast Precipitation Events

7-10 Days Before Event
1. Heavy rain over far western Pacific
2. Moisture plume extends northeast
3. Strong polar jet
4. Strong blocking high

3-5 Days Before Event
1. Heavy rain shifts east
2. Moisture plume extends further northeast
3. Split jet forms
4. Block weakens and shifts westward

Precipitation Event
1. Heavy rain shifts further east and weakens
2. Deep tropical moisture plume
3. Extended jet
4. Deep low, heavy rain and possible flooding

MJO Influence on US West Coast Rainfall

CPC
NCEP
NOAA
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 Northwest wintertime precipitation for three Phases of the Madden Julian Oscillation (MJO). Blue shading indicates increased rainfall.
Subtropical Ozone Variability
Tian et al., 2007

MOD TotO3 MJO Anom (CT, Color shading)
Contours: CMAP Rainfall MJO Anom; Solid: Pos; Dashed: Neg;
Contours starts at +/-0.5 with interval of 1 mm day

200 mb Winds & MSUT lag = 15 days

850 mb Winds & Divergence lag = 15 days

1000 mb Winds & Divergence lag = 15 days
**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 circulation, 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 simulate 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 & Climate 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....