On the Initiation of the Madden-Julian Oscillation (MJO)

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Busan, South Korea, 18th June 2010
Background

Longitude-height Structure

Teleconnections

Time period: 30-70 days
Propagation speed: 5 m/s
First-mode baroclinic structure

Madden and Julian (1972)

Lin et al. (2006)
Motivations

• What is the mechanism of the MJO initiation?
• How different parameters affect the MJO initiation?

Proposed Mechanisms of the MJO Initiation

• Discharge-recharge mechanism (i.e. tropical internal dynamics)
• Initiation by circumnavigating waves (i.e. from previous MJO event)
• Extra-tropical influences
• Stochastic forcing
A New Approach

• Use a unique model, i.e., a Tropical Channel Model.
• Start with the full physics, and then test one factor at a time.
• Make the problem more tractable by doing sensitivity tests on the parameters (e.g., lateral boundaries), and not by testing the mechanism (e.g., extratropical forcing) directly.
• Case study
Outline

The Initiation of the MJO:
- Background and Motivations
- Model and Data
  - Tropical Channel MM5 (TMM5) : Case Study
  - Tropical Channel WRF (TWRF) : Statistics and Case Study
- Results
  - Sensitivity to the SST, Initial Conditions, Convection-Circulation Interactions and the Boundary Conditions
  - Mechanism for the Extratropical Influence
  - MJO Statistics and Cases in Climate Simulations
- Implications and Summary
Tropical Channel MM5 (TMM5) : D1 : 111 km, D2 : 37 km

data : NCEP ‘FNL’ data (1x1, 6 hourly)
moisture scheme : Simple Ice
cumulus scheme : Betts-Miller
radiation scheme : RRTM
time step: 3 minutes
model output: 3 hourly

• More than 30 tests were performed to choose the set of schemes
Choice of the MJO Events

U850 Reanalysis

- Randomly chosen with different background SSTs.
- MJO initiation is defined wrt U850.
MJO initiation is captured two months after the model initial time.
Cannot be attributed to the model initial conditions.
Control simulation uses constant SST with one domain only.
Intraseasonally varying SST is not a determining factor.

Consistent for Case 2 (November 2000 MJO event).

Stochastic Forcing with time-scale < 6 hr. from lateral boundaries do not play any role.
Role of the Moist Processes

- Moist processes are crucial for the strength & propagation, but not for the initiation.

- Consistent results by Lin et al. (2007) and Monier et al. (2009).

- Lateral boundary conditions are critical!
Sensitivity to the boundary conditions

Case 1

- Lateral boundary conditions are the only important factor.
- Are the lateral boundary conditions being forced by the MJO itself??

Case 2

- Lateral boundary conditions are the only important factor.
- Are the lateral boundary conditions being forced by the MJO itself??
• MJO is reproduced when model boundaries are further moved to 28SN and 38SN.

• Results are consistent for Case 2.

➢ Lateral boundary conditions for these two cases represent extratropical, instead of MJO, influences.
Outline

The initiation of the MJO:

- Background and Motivations
- Model and Data
- Results
  - Role of the Initial Conditions and SST: No
  - Role of the Convection-Circulation Interactions: No
  - Sensitivity to the Boundary Conditions: Yes
  - Mechanics of the Extratropical Influence
  - MJO Statistics and Cases in Climate Simulations

- Conclusions and Implications
Evidence of extratropical influences (case 1: May 2002)

- Valid at other levels (e.g., 925 hPa).
- Zonal momentum budget can quantitatively confirm this influence
Mechanics of the extratropical influences

- Lower troposphere: Zonal momentum budget

\[
\frac{\partial u'}{\partial t} = -\frac{\partial \phi'}{\partial x} + f v' - (u \frac{\partial u'}{\partial x} + u' \frac{\partial u}{\partial x}) - (v \frac{\partial u'}{\partial y} + v' \frac{\partial u}{\partial y}) - (\omega \frac{\partial u'}{\partial p} + \omega' \frac{\partial u}{\partial p}) + R'
\]

\[u = \text{zonal wind}\]
\[v = \text{meridional wind}\]
\[\omega = \text{vertical pressure velocity}\]
\[f = \text{Coriolis parameter}\]
\[\Phi = \text{geopotential}\]
\[R = \text{residual}\]
Zonal Momentum Budget (10S-10N, 40E-50E)

- Meridional advection of zonal momentum is crucial at the lower troposphere.

\[
(v \frac{\partial u'}{\partial y} + v' \frac{\partial u'}{\partial y} + v' \frac{\partial u}{\partial y})
\]

- What happens at the upper troposphere?
Mechanics of extratropical influences..

Upper troposphere

• Wave activities (W-vector, Takaya and Nakamura 1997) originate over the southern Indian Ocean where it grows by extracting kinetic energy from the mean flow.

April 13

W (vector); Energy conversion (shaded)
The initiation of the MJO:

- Background and Motivations
- Model and Data
- Results
  - Role of the Initial Conditions and SST: No
  - Role of the Convection-Radiation Interactions: No
  - Sensitivity to the Boundary Conditions: Yes
  - Mechanics of the Extratropical Influences
  - MJO Statistics and Cases in Climate Simulations

- Conclusions and Implications
What we know so far…

• Extratropical influences through time-varying lateral boundary conditions are important for the chosen MJO events.

• Successive MJO events (with preceding events) may be influenced by the extratropics (Matthews, 2008).

Hypotheses

1. Multi-year simulation using a tropical channel model would reproduce the two MJO events under study.

2. It would also reproduce good MJO statistics if forced by time-varying boundary conditions.

3. MJO without extratropical influences may not be captured in a multi-year simulation.

➤ Use a different model with a different set up
### Model and the Simulations

**Tropical Channel WRF or Nested Regional Climate Model**

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1DOM</td>
<td>1996-2000</td>
<td>30°S to 45°N. Covers Case 2 (Nov 2000)</td>
</tr>
<tr>
<td>1DOM_2</td>
<td>2000-2005</td>
<td>45°S to 45°N. Covers Case 1 (May 2002)</td>
</tr>
</tbody>
</table>

- **Resolution**: 36/12/4 km
- **Model output**: 3 hr
- **Moisture scheme**: WSM6
- **Cumulus scheme**: KF
- **Radiation scheme**: CAM
Testing hypothesis 1: Multi-year simulation reproducing MJO event

Case 1
May 2002

Case 2
Nov 2000

Model initial time
1 Dec 1999

Model initial time
1 Jan 1996
Testing hypothesis 2: MJO statistics in multi-year simulation

Space-Time Spectrum (10S-10N)

- MJO statistics in the NRCM not better than those in the GCMs.
Causes behind poor MJO statistics…….

Mean Precipitation (1996-2000)
Testing hypothesis 3: MJO with no extratropical influences......

Case 3
May 1997

• Several sensitivity tests were conducted.
• This MJO is reproduced when the MJO signal is already present in the initial conditions.
• Does the error growth prevent this event in the model?
In the absence of extratropical influence error in the mean state may prevent the MJO initiation.
Implications / Outcome / Recommendation

- **An alternative view for the poor MJO simulation**:
  - When the MJO signal starts in the dynamic field due to the lateral influences, a cumulus parameterization may work against it and weaken it.

- **MJO prediction**:
  - A cloud resolving domain of the tropics nested in a coarse resolution global model.

- **MJO validation**:
  - Model validation over the extratropics, and not concentrate in the tropics only.

- **Necessary and sufficient conditions for the MJO initiation**:
  - Extratropical influences in the intraseasonal time-scale may not be necessary (Gustafson and Weare 2004). Our results indicate that the lateral influences can be sufficient.
Limitations

- Only two MJO events were considered.
- Meridional extent of the model not sufficient to have a global view of the intraseasonal oscillation.
- ...............
Summary

• Time-varying lateral boundary condition was the only factor found crucial for the MJO initiation which in turn comes from the extratropics. (Ray, Zhang, Dudhia and Chen (2009), JAS, 66, 310-331).

• Meridional advection of zonal momentum at the lower troposphere and wave activity flux at the upper troposphere were important. (Ray and Zhang (2010), JAS, 67, 515-528).

• In the absence of dynamical connection between the MJO and extratropics, the error in the mean state could be sufficient to prevent the MJO initiation. (Ray, Zhang, Moncrieff, Dudhia, Caron, Leung, and Bruyere (2010), Clim. Dyn., DOI: 10.1007/s00382-010-0859-2).

• The MJO structures in a high-resolution nested regional climate model was explored. (Ray, Zhang, Moncrieff, and Dudhia (2010), Clim. Dyn. In preparation).
THANK YOU
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Rests are
Supplementary slides
Define an MJO index…

Method

MJO Variance (MV)
- 20-90 day and $k = 1-5$ filtering.
- SVD analysis on filtered U850 and Precipitation.
- Separate the leading SVD modes based on North et al. criteria.
- Use these leading modes to reconstruct the time series of U850 and Precipitation.
- We call these MJO U850 (U850*) ; and MJO Precip (P*).
- Variance of these two quantities are referred as the MJO variance.
Causes behind poor MJO simulation….. MJO and mean state

- Error in the mean state responsible for the poor MJO statistics.
- What happens for an MJO event with no extratropical influence?
Testing hypothesis 3: MJO with no extratropical influences

U850 (shaded) and U200 (contoured)

- Is the forecast error comparable to the climate error??
Mechanics of extratropical influences

- Upper troposphere: Wave Activity Flux (W-vector, Takaya and Nakamura 1997)

\[
W = \frac{1}{2|U|} \left[ u(\psi_x^2 - \psi \psi_{xx}) + v(\psi_x \psi_y - \psi \psi_{xy}) \right] \\
+ u(\psi_x \psi_y - \psi \psi_{xy}) + v(\psi_y^2 - \psi \psi_{yy})
\]

- Source of energy (Simmons et al. 1983)

\[
C = -\left( u'^2 - v'^2 \right) \frac{\partial \bar{u}}{\partial x} - u'v' \frac{\partial \bar{u}}{\partial y}
\]

1: contribution from anisotropy
2: contribution from zonal momentum

\[ C = \text{Conversion of kinetic energy from the mean flow to a disturbance} \]
Wave Activity Flux and its energy source
Is the forecast error comparable to the climate error??

**RMSE of U850**

- 30S - 45N
- 10S - 10N

- Consistent with Boyle et al. (2008)

- In absence of extratropical influence error in the mean state prevents the MJO initiation
## Simulations using TMM5

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Integration Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>1 Mar – 30 June</td>
<td>One domain. Varying SST.</td>
</tr>
<tr>
<td>D1+D2</td>
<td>1 Mar - 30 June</td>
<td>2 way nested, 111/37 km. Varying SST.</td>
</tr>
<tr>
<td>CS1</td>
<td>10 Apr – 10 June</td>
<td>Control simulation. Constant SST. Lateral boundaries at 21SN.</td>
</tr>
</tbody>
</table>

- More than 20 sensitivity experiments for Case 1

[Map diagram showing nested domains D1 and D2]
Testing hypothesis 1: Multi-year simulation reproducing MJO event

Case 1
May 2002

Model initial time
1 Dec 1999

Case 2
Nov 2000

Model initial time
1 Jan 1996
Intraseasonally varying SST is not a determining factor.

Stochastic Forcing with time-scale $< 6$ hr from lateral boundaries do not play any role.

Consistent for Case 2 (Nov-Dec 2000) when the SST was $1{^\circ}$C cooler than that for Case 1.
Sensitivity to the Initial Conditions

Case 1: Total 12 tests were conducted, using constant and varying SSTs. \((t = -5 \text{ day to } t = 5 \text{ day})\)

Same for Case 2.

Model Initial Condition is not a determining factor.
Zonal Momentum Budget (10S-10N, 40E-50E)

- Meridional advection of zonal momentum is crucial at the lower troposphere.

- What happens at the upper troposphere?