MJO Evolution as Revealed by Multivariate Principal Oscillation Analysis

Leslie M. Hartten¹, ², Cécile Penland², and Rosa M. Vargas³, ⁴

¹ Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado - Boulder
² NOAA/Earth Science Research Laboratory (ESRL), Physical Sciences Division
³ Significant Opportunities in Atmospheric Research and Science (SOARS®) Program, UCAR
⁴ Dept. of Physics, University of Puerto Rico - Mayagüez

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The Conundrum:

Madden and Julian (1972)

Our Approach:

MJO = a Linear System with Stochastic Forcing

as per Newman et al. (2009, J. Climate)
Part 1 - Multivariate Principal Oscillation Analysis

Part 2 - Event Evolution
Methods – Data

• daily 2.5° × 2.5° gridded analyses, 30°S to 30°N, 1974-2013:
  - OLR, \( u_{850}, u_{200}, SLP, T_{400} \)
    (from NCEP/NCAR Reanalyses & NOAA Interpolated OLR)
  - removed longterm annual cycle & longterm mean
  - computed pentads
Methods – Analysis Technique

1) **EOF analysis with the pentad data**
   - normalized each variable set by $\sigma_{PC1}$
   - retained leading 9-24 EOFs from each variable

2) **Multivariate EOF analysis with those timeseries**
   - retained timeseries of 15 leading multivariate eigenvalues

3) **Principal Oscillation Pattern (POP) analysis**
   - with retained multivariate PCs
   - yielded 15 dynamical modes

⇒ The least-damped oscillating mode looks like the MJO
Results – An MJO-Like Mode

- 55-day period, 15-day decay time, propagates like MJO

Mode Associated with MJO: OLR contribution

Notes:
Total mode (u3) normalized to unity; period = 11 pentads; decay time = 3 pentads (not represented here)
Results – An MJO-Like Mode

• Peak power at 30-80 days
  - no Fourier filtering!

The POP analysis employed:
OLR, SLP, \( T_{400mb} \), \( u_{850mb} \), and \( u_{200mb} \)
pentads, June 1974 - December 2013, (30°S-30°N, 0.0-357.5°E)
Results – An MJO-Like Mode

- Minimally wet

![Bar chart showing contribution to modal variance for various parameters: T400, SLP, u200, u850, OLR. The x-axis represents percentage contributions ranging from 0% to 30%, and the y-axis lists the parameters.]
Part 1 - Multivariate Principal Oscillation Analysis

Part 2 - Event Evolution
## Methods – Event Selection

- event lists in Straub (2013) and from Ling et al. (2013)
  - October-April 1998-2009, start dates ±10d

<table>
<thead>
<tr>
<th></th>
<th>Lower-level wind ((u_{850}))</th>
<th>Upper-level wind ((u_{200}))</th>
<th>Convection ((\text{OLR}))</th>
<th>Precipitation ((\text{TRMM satellite}))</th>
<th>RMM*</th>
<th>Dates</th>
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*Real-time Multivariate MJO index (Wheeler and Hendon 2004)
Methods – Event Selection

- examined 8 of 12 identified events

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<td>Ling et al.</td>
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</table>
Results – November 2009 “Primary” MJO Event

• A textbook-like case of OLR evolution
Results – January 1999 “Primary” MJO Event

- Suppressed convection can be a dominant characteristic
Takeaway Points

• Isolated an MJO-like mode (without bandpass filtering)

• MJO-like mode is “minimally wet”
  - OLR contributes ~50% as much variance as other fields
  - OLR doesn’t dominate forcing

• Estimated timeseries of MJO-like mode’s stochastic forcing
  - appears unpredictable on daily timescale
  - may maintain MJO events, rather than cause them

• MJO-like mode can depict Primary, Intensifying, & non-MJO
  - Dry phase sometimes ≥ enhanced convection phase
  - Precursor patterns (Ling et al. 2013) sometimes seen
Future Work

• Stochastic forcing
  - maintaining instead of initiating events?
  - subdaily forcing?

• Midlatitude effects

• Examine other dynamical modes
  - “Missing” enhanced convection (Jan 1999 event)?
Acknowledgements

• Chidong Zhang (U. Miami) provided us with an event list from Ling et al. (2013).
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“A linear Markov process driven by Gaussian white noise”

\[
\frac{dX(t)}{dt} = LX(t) + \xi(t)
\]

- \(X(t)\) contains 5-day mean gridded analyses
- \(L\) is estimated from \(X(t)\) using Linear Inverse Modeling (not shown)
- \(x(t)\) contains daily gridded analyses
- \(\xi(t)\) can be estimated from \(x(t)\) and \(L\)

\[
\xi(t) \approx \frac{x(t + \delta) - x(t - \delta)}{2\delta} - LX(t)
\]

see Penland and Sardeshmukh (1995, J. Climate) and Newman et al. (2009, J. Climate)
Stochastic Forcing Fields

- Field in geographical space in terms of modal patterns $u_\alpha$ and amplitudes $z_\alpha$:

$$x_i(t) = \sum_{\alpha} u_{i\alpha} z_\alpha(t)$$

- Evolution equations for $z_\alpha^r$ and $z_\alpha^i$:

$$\frac{d z_\alpha^r}{dt} = (\beta^r_\alpha z_\alpha^r - \beta^i_\alpha z_\alpha^i) + \xi_\alpha^r$$

$$\frac{d z_\alpha^i}{dt} = (\beta^i_\alpha z_\alpha^r + \beta^r_\alpha z_\alpha^i) + \xi_\alpha^i$$
### EOF Analyses

<table>
<thead>
<tr>
<th>Field</th>
<th>Univariate EOF Analysis</th>
<th>Multivariate EOF Analysis</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Eigenvalues Retained</td>
<td>Variance Retained</td>
</tr>
<tr>
<td>$u_{850}$</td>
<td>16</td>
<td>45.3%</td>
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<tr>
<td>$u_{200}$</td>
<td>11</td>
<td>41.2%</td>
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<tr>
<td>$T_{400}$</td>
<td>18</td>
<td>58.7%</td>
</tr>
<tr>
<td>SLP</td>
<td>24</td>
<td>78.3%</td>
</tr>
<tr>
<td>OLR</td>
<td>9</td>
<td>23.0%</td>
</tr>
<tr>
<td>Total</td>
<td>78</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Results – An MJO-Like Mode

- 55-day period, 15-day decay time, propagates like MJO

**OLR**

**u200**

**u850**
Results – An MJO-Like Mode

- Minimally wet

<table>
<thead>
<tr>
<th>Field</th>
<th>Contribution to Modal Variance</th>
</tr>
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<tbody>
<tr>
<td>OLR</td>
<td>10.2%</td>
</tr>
<tr>
<td>$u_{850}$</td>
<td>19.6%</td>
</tr>
<tr>
<td>$u_{200}$</td>
<td>20.6%</td>
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<tr>
<td>SLP</td>
<td>26.1%</td>
</tr>
<tr>
<td>$T_{400}$</td>
<td>23.5%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
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</table>
Methods – Event Selection

• examined 8 of 12 identified events

<table>
<thead>
<tr>
<th></th>
<th>Intensifying</th>
<th>Non-MJO</th>
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<tbody>
<tr>
<td>Straub-Circ. Only</td>
<td>P 11 Jan</td>
<td>I 10 Jan</td>
</tr>
<tr>
<td>Straub-Full</td>
<td>P 10 Jan</td>
<td>I 18 Dec</td>
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<td>Straub-Conv. Only</td>
<td>P 28 Oct</td>
<td>P 19 Dec</td>
</tr>
<tr>
<td>Ling et al.</td>
<td>P 17 Jan</td>
<td>P 30 Oct</td>
</tr>
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</table>
Results – January 2002 “Intensifying” MJO Event

- Actual evolution based on modal amplitudes ($z_\alpha$)
  - differs from theoretical & from other ID systems

$T_{400}$  

SLP  

OLR

Ling et al.

Straub Conv

Straub Full

vii  

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Results – January 2002 “Intensifying” MJO Event

• Used daily data to calculate stochastic forcing $\zeta_\alpha$
  - two-day correlation is highly insignificant

• Equations (not shown)
  - real & imaginary parts of $z_\alpha$ affect each other’s evolution
  - real (imaginary) parts of $\zeta_\alpha$ only affect real (imaginary) $z_\alpha$