Poster 31

Investigations of the Madden Julian Oscillation using Multivariate Principal Oscillation Analysis

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Introduction

Global models do a poor job of simulating the Madden Julian Oscillation (MJO). The research community's current focus is on better understanding the "initiation phase"; recent studies have shown that there is considerable variability in this regard. Here, we view the MJO as a fundamentally linear system which is forced stochastically. We are initially employing an event-based approach, so as not to assume similarity where it might not exist. Our ultimate goal is to determine the temporal and spatial characteristics of the stochastic forcing required to support MJO initiation.

Selecting MJO Events

While there are many methods for identifying MJO events, we have chosen to focus on three presented by Straub (2013) and one presented by Ling et al. (2013). Their key characteristics and the dates over which the authors used them to identify MJO initiation events are summarized in the table below.

	u_{850}	u_{200}	OLR	Precip†	RMM*	Dates
Straub Circulation Only	✓	✓			✓	1979-2010
Straub Full RMM	✓	✓	✓		✓	1979-2010
Straub Convection Only			✓		✓	1979-2010
Ling et al.				✓		Oct-Apr 1998-2009

† from TRMM
* Real-time Multivariate MJO index (Wheeler and Hendon 2004)

Working from event lists provided in Straub (2013) and by Zhang (2014, personal communication) we identified 12 events in October-April 1998-2009 with start dates within 10 days of each other. They spanned three types of event initiations (Primary, Intensifying, and Non-MJO) and had varying levels of agreement among the four methods. This poster focuses on the 4 events listed below.

Type(s)	Ling et al.	Straub Convection	Straub Full RMM	Straub Circulation
Non-MJO† vs. Intensifying*	2 Oct 2002		5 Oct 2002	5 Oct 2002
Non-MJO† vs. Intensifying*	17 Nov 2006		10 Nov 2006	
Intensifying*	8 Jan 2002	8 Jan 2002	12 Jan 2002	13 Jan 2002
Intensifying*	22 Apr 2003	27 Apr 2003		25 Apr 2003

† Non-MJO convection doesn't propagate out of Indian Ocean (Ling et al. 2013)
* Intensifying events "evolve from a pre-existing lower-amplitude MJO signal" in the RMM (Straub 2013)

Analysis Technique

We started with daily 2.5° × 2.5° gridded analyses, 30°S to 30°N during 1974-2013, of the following variables: u_{850}, u_{200}, SLP, T_{400}, and OLR. For each variable we removed the longterm annual cycle and the longterm mean; computed pentads; and performed an EOF analysis with the pentad data. We retained 9 to 24 eigenvalues for each variable, which we combined for a multivariate EOF analysis.

	Univariate EOF Analysis		Multivariate EOF Analysis
Field	Eigenvalues Retained	Variance Retained	Variance Retained after Combining Fields
OLR	9	23.0%	12%
u_{200}	11	41.2%	30%
u_{850}	16	45.3%	33%
T_{400}	18	58.7%	35%
SLP	24	78.3%	78%
Total	*78*	*n/a*	*n/a*

We retained 15 multivariate eigenvalues and next used them in a Principal Oscillation Pattern (POP, von Storch et al. 1988) analysis. Of the 15 resulting dynamical modes, one is MJO-like, with an 11-pentad (55-day) period, a 3-pentad (15-day) decay time, and a pattern that propagates from the Indian Ocean across the Maritime Continent to the western Pacific (**Fig. A**). The mode's power is concentrated in the 30-80 day range, with the largest peaks in the 40-60 day band (**Fig. B**).

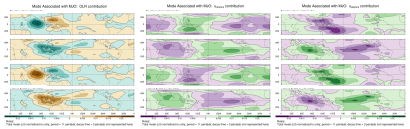

Figure A. Idealized evolution of the MJO-like dynamical mode, as seen in the contribution from OLR, u_{200}, and u_{850}. All fields are anomalies.

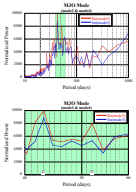

Figure B. Normalized power of the real and imaginary portions of the MJO-like mode. The 40-60 day band is shaded green in both the full range (top) and the close-up view (bottom).

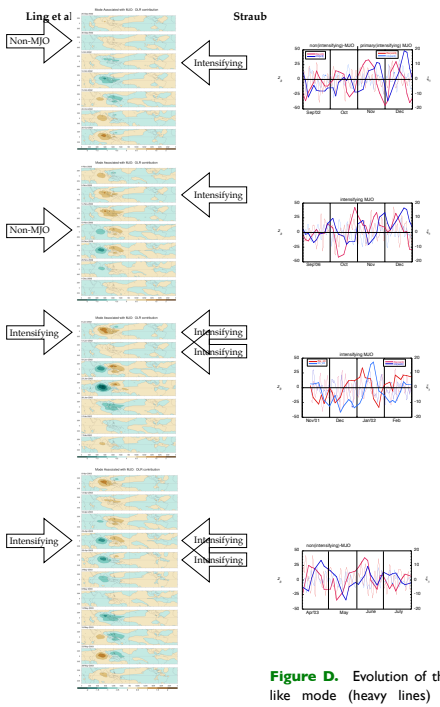

Figure C. Evolution of the OLR contribution of the MJO-like mode during the 4 events. Arrows indicate the classification types and times.

Figure D. Evolution of the MJO-like mode (heavy lines) and its stochastic forcing (light lines) during the 4 events. Real part in red; imaginary part in blue.

Evolution and Forcing of the MJO-like Mode

The actual evolution of the mode during events (**Fig. C**) differs from the theoretical to the extent that the real and imaginary amplitudes vary from perfectly in-quadrature sine waves. Our MJO-like mode picks up one "Non-MJO" event but not the other. The timing of the mode's convection sometimes differs from various estimates of "Intensifying" initiation events.

We used daily u_{850}, u_{200}, SLP, T_{400}, and OLR to calculate the stochastic forcing fields (c.f. Penland and Hartten 2014):

- Field in geographical space in terms of modal patterns $\boldsymbol{u}_\alpha$ and amplitudes z_α: $x_i = \sum_\alpha u_{i\alpha} z_\alpha(t)$
- Evolution equations for $z_\alpha{}^r$ and $z_\alpha{}^i$:

$$\frac{dz^r_\alpha}{dt} = (\beta^r_\alpha z^r_\alpha - \beta^i_\alpha z^i_\alpha) + \xi^r_\alpha \qquad \frac{dz^i_\alpha}{dt} = (\beta^r_\alpha z^i_\alpha + \beta^i_\alpha z^r_\alpha) + \xi^i_\alpha$$

The real and imaginary parts of modal amplitudes (**Fig. D**) affect each other's evolution, but the real (imaginary) part of the forcing ξ affects only the real (imaginary) modal amplitude. Unlike the modes, the real and imaginary parts of ξ do not appear in a set sequence. Extremes of ξ in some fields (e.g. OLR) look like the modes themselves; others (**Fig. E**) bear little resemblance to the modal patterns.

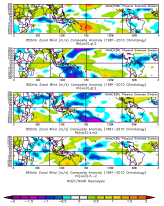

Figure E. u_{850} composited onto extremes of Re(ξ_3) and Im(ξ_3).

Takeaway Points

✦ We have isolated an MJO-like dynamical mode without bandpass filtering the underpinning data; its Fourier spectrum is naturally concentrated in the 40-60 day band.

✦ We have objectively estimated the time series this mode's stochastic forcing. Unfortunately for prediction, this forcing does indeed appear to be unpredictable on the daily timescale.

✦ It is not clear that extrema of this forcing initiate MJO events as much as they play a role in maintaining it. (c.f. **Fig. D**)

✦ We need to examine both midlatitude effects and forcing at sub-daily timescales.

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NOAA Interpolated OLR and NCEP/NCAR Reanalysis data provided by the NOAA/OAR/ESRL Physical Sciences Division, Boulder, Colorado, USA (http://www.esrl.noaa.gov/psd/). Map colors from www.ColorBrewer.org by Cynthia A. Brewer, Dept. of Geography, Penn State.

Some Key References

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