Poster
P1-4

Stochastic Forcings Associated with MJO Initiation during DYNAMO

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Introduction

The ability to forecast the Madden-Julian Oscillation (MJO) is of critical importance because of its direct and indirect influences on weather around the globe. However the medium-range weather forecasting models and the general circulation models (GCMs) on which climate simulations depend don't simulate the MJO well. The MJO is often too weak, propagates at the wrong speed, and/or has the wrong planetary scale, seasonal cycle, or dynamical-thermodynamical coupling (e.g. Slingo et al. (1996), Sperber et al. (1997), Sperber (2004)). This may be due in part to model deficiencies such as inadequate subgrid parameterizations.

While the MJO is a very large-scale phenomenon, it has regional manifestations (such as enhanced convection over a portion of the tropics) and very local roots (short-lived surface fluxes feeding and emanating from that convection). The DYNAMO field campaign was conducted from October 2011 – March 2012. Surface flux, radar, and lidar data collected during the Intensive Observing Period (IOP, October 2011 – January 2012) aboard the R/V *Revelle* captured frequent episodes in which a "cold pool" of air was laid down on the ocean surface during convective rain events (**Fig. A**). The accompanying dramatic changes in air temperature and winds led to large changes in sensible and latent heat fluxes.

Such events are sub-grid scale to global forecast models. Should those global models incorporate the effects of these subgrid events? If so, how? Stochastic forcing is one option that might be employed. **Our goal is to use both field observations and global analyses to identify the local or regional stochastic forcing required to support the onset of MJO events.**

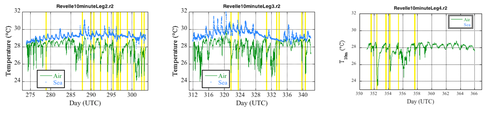

Figure A. Ten-minute air temperature at 10m and SST measured aboard the R/V *Revelle* during Leg 2 (left), Leg 3 (center), and Leg 4 (right). Yellow lines indicate possible atmospheric cold pool events.

MJO Initiation

Describing the MJO

Madden and Julian (1972), in first identifying the eponymous phenomenon, described it in terms of a travelling mass of tropical convection with associated low- and high-level zonal flow (**Fig. C**). Since then, many researchers have attempted to develop an index to summarize the "phase" of the MJO. One widely used index is the Real-time Multivariate MJO index (RMM, Wheeler and Hendon)2004)). Defined by 2 EOFs which move through positive and negative space, its 8 "phases" can be directly mapped onto that initial geographical description (**Fig. C**).

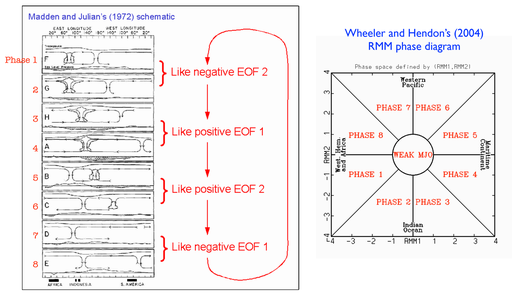

Figure C. The archetypical view of the MJO's phases (left) can be mapped fairly directly to those indicated by the RMM (right). Both images from http://cawcr.gov.au/staff/mwheeler/maproom/RMM/, with minor annotations.

Identifying "Initiation"

A recent detailed study by Straub (2013, hereafter Straub13) has shed considerable light on the variety of ways and locations "initiation" can occur. Straub13 used the daily RMM index (1979-2010) to identify two types of MJO initiation events, defined as in the table below:

Straub13's Criteria for MJO Initiation Events

	Primary	*Intensification*
(1)	No counterclockwise rotation for ≥ 7 days inside the unit circle (in mean)	Counterclockwise rotation inside the unit circle (in mean)
(2)	RMM amplitude increases to > 1.0	
(3)	RMM ≥ 1.0 for ≥ 7 days passing counterclockwise through ≥ 4 phases	

We visually applied Straub13's definition to RMM phase diagrams from the DYNAMO period, and identified 4 initiation events (see table at right). Straub13's definitions are based on the amplitude and phase changes in RMM; they do not require initiation to occur in the Africa/western Indian Ocean region (phases 1 &2). Only one of the initiation events we identified started in this region; two started near the Maritime Continent, and the fourth in the central Pacific (**Fig. D**).

MJO Initiation Events during DYNAMO (preliminary)

Type	*Start Date*	*Start Phase*
Intensification	25 Sept. 2011	5
Intensification	1 November 2011	3
Intensification	18 November 2011	1
Primary	20 January 2012	4

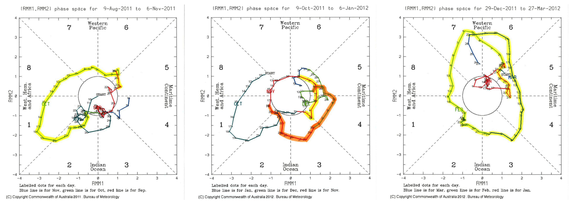

Figure D. RMM phase diagrams from DYNAMO, with MJO initiation events and their subsequent propagation highlighted. Original images from NCAR/EOL's Field Catalog at http://catalog.eol.ucar.edu/dynamo/ops/bom_mjo_monitoring.

Some Key References

Penland, C.P., and L.M. Hartten, 2014: Stochastic forcing of north tropical Atlantic sea surface temperatures by the North Atlantic Oscillation. *Geophys. Res. Lett.*, in press. doi: 10.1002/2014GL059252

Penland, C., and P. D. Sardeshmukh, 1995: The optimal growth of tropical sea-surface temperature anomalies. *J. Climate*, **8**, 1999-2024.

Straub, K.H., 2013: MJO initiation in the real-time multivariate MJO Index. *J. Climate*, **26**, 1130–1151.

Wheeler, M.C., and H.H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.*, **132**, 1917–1932.

DYNAMO (Dynamics of the Madden-Julian Oscillation)

DYNAMO's field phase focused on the central equatorial Indian Ocean (**Fig. B**). The R/V *Revelle* collected data on 5 legs; during the 3 which occurred during the IOP, it was mostly on station at (0°N, 80°E), serving as a "corner" of two quadrilateral sonde arrays. Instrumentation included a suite of surface meteorology and turbulent flux instruments operated by Oregon State University and NOAA/ESRL/PSD.

Figure B. Map showing the locations of the 6 primary DYNAMO stations (4 on land plus 2 ships) and their relationship to the DYNAMO Sounding Network. Figure courtesy of C. Zhang, U. Miami/RSMAS.

Linear Inverse Modelling // Stochastic Forcing

Our plan is to use Linear Inverse Modeling (LIM) to study the stochastic forcing associated with MJO initiation. However, the preparatory stages also give us information about RMM. We applied LIM to the pair RMM1 and RMM2, 1979-2013; this lets us know if RMM is describing something that is really an oscillation. The process, described fully in Penland and Sardeshmukh (1995), can be summarized using

$$\frac{d}{dt}\begin{pmatrix}\text{RMM1}\\ \text{RMM2}\end{pmatrix} = \begin{pmatrix}L_{11} & L_{12}\\ L_{21} & L_{22}\end{pmatrix}\begin{pmatrix}\text{RMM1}\\ \text{RMM2}\end{pmatrix} + \begin{pmatrix}\xi_1\\ \xi_2\end{pmatrix}$$

After getting **L** from statistics we estimate the white noise forcing ξ.

The analysis yielded two complex-conjugate eigenmodes having a period of 50.6 days and a decay time of 17.8 days. No linear combination of these modes can yield non-modal growth; all predictable growth comes from positive slopes of the very slightly underdamped sinusoids. In other words, RMM has no aperiodic, non-normal growth.

When we projected onto the adjoints of these modes, the real part turned out to be equivalent to RMM1 and the imaginary part to ±RMM2. This tells us that the LIM process doesn't "mix up" the two components.

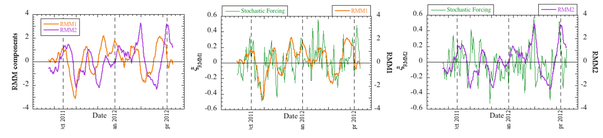

Figure E. Timeseries of RMM1 and RMM2 (left), and of each components with its associated ξ (center and right) during the DYNAMO IOP.

We used these results to estimate the stochastic forcing time series, ξ, during the DYNAMO IOP (**Fig. E**; see Penland and Hartten (2014) for methodology.) **Figure F** compares the component of ξ representing stochastic forcing of OLR at 80°E (c.f. **Fig. B**) with surface latent heat flux measured during DYNAMO before and after MJO initiation events. These graphs suggest that positive OLR forcing precedes MJO onset by a week or two, and that this signal may be accompanied by in-phase perturbations of latent heat. However, these results are preliminary and require more intense analysis.

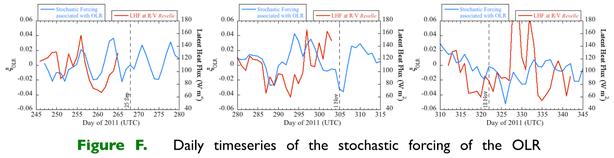

Figure F. Daily timeseries of the stochastic forcing of the OLR component of RMM and of the R/V *Revelle* latent heat flux during 3 of the MJO initiation events during DYNAMO.

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