

MJO Evolution as Revealed by Multivariate Principal Oscillation Analysis

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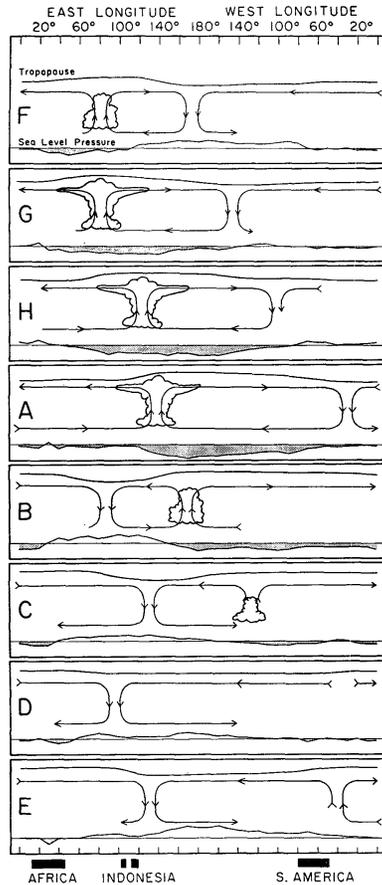
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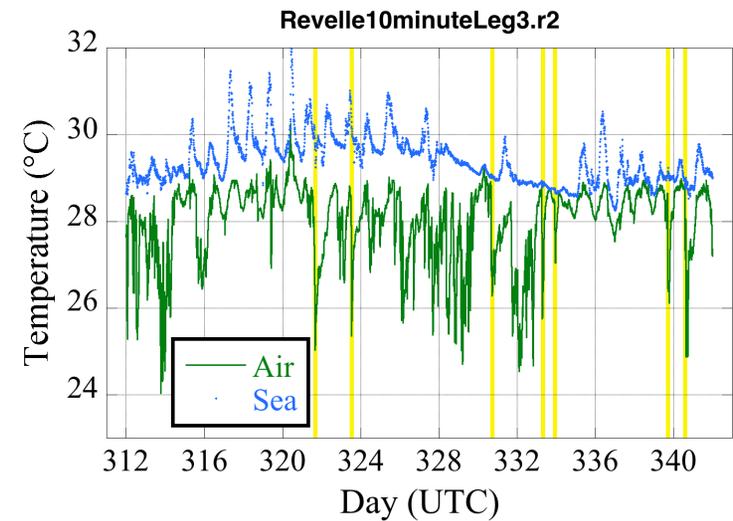
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The Conundrum:



MJO



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 $2.5^\circ \times 2.5^\circ$ 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 σ_{PCI}
- 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

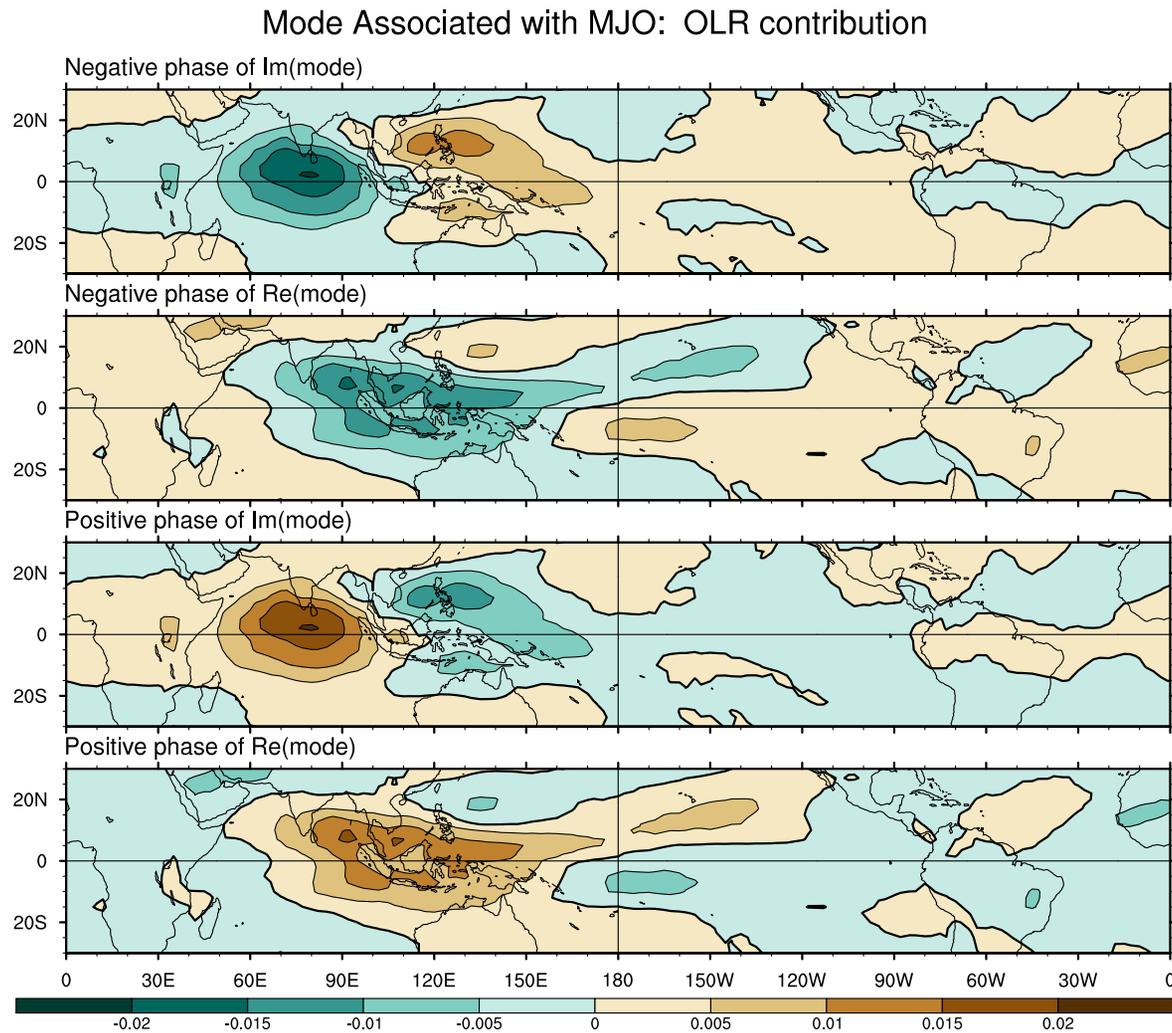
with retained multivariate PCs

- 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**

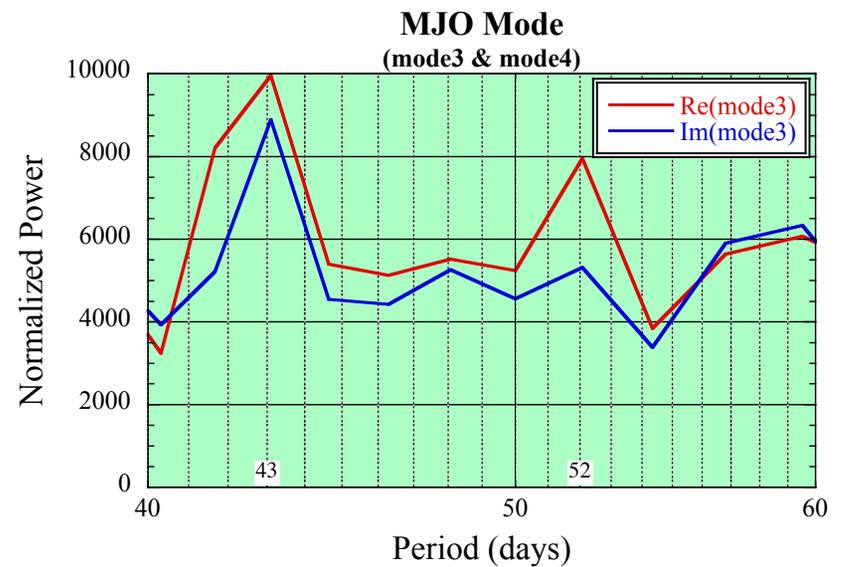
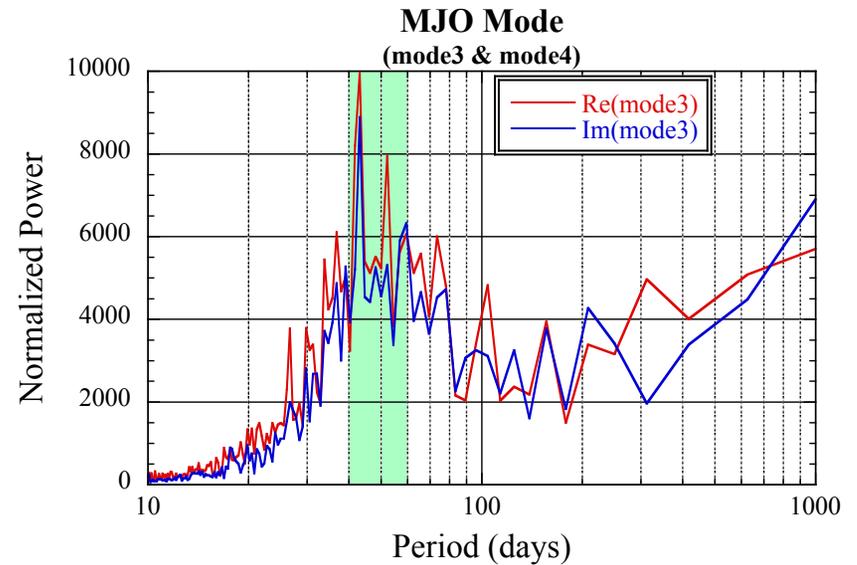


Notes:

Total mode (u_3) normalized to unity; period = 11 pentads; decay time = 3 pentads (not represented here)

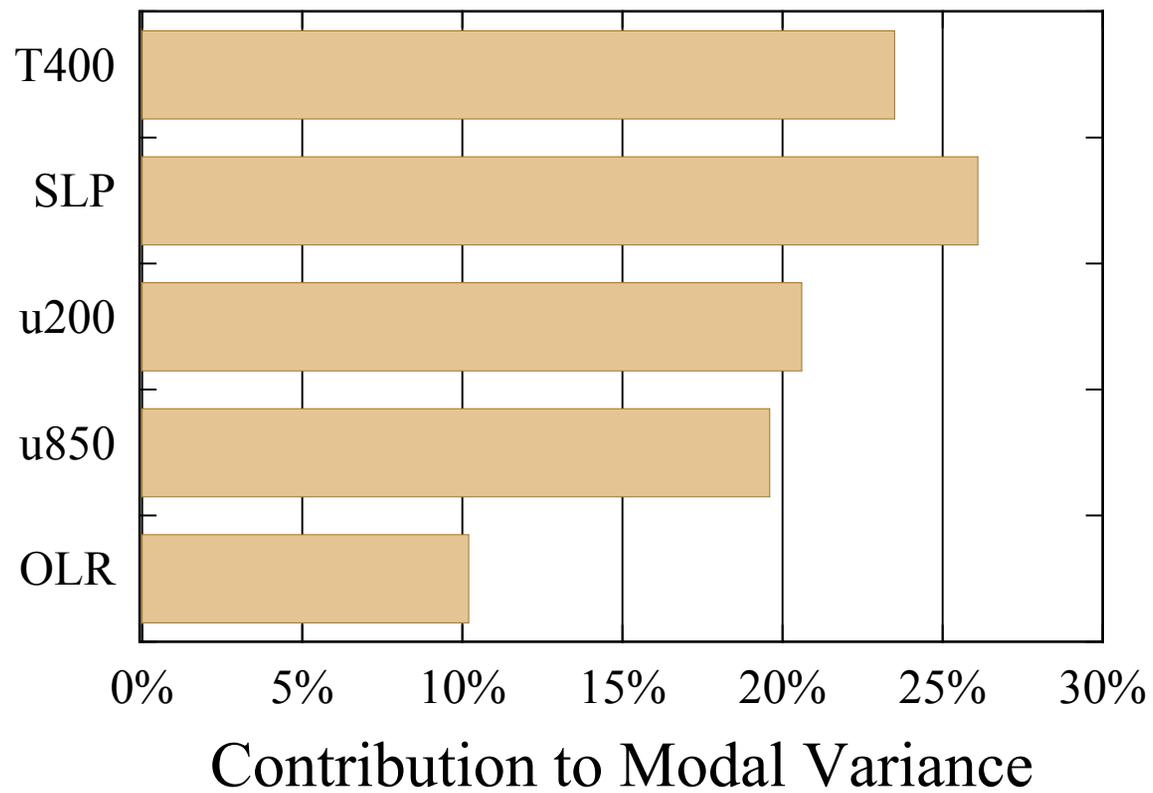
Results – An MJO-Like Mode

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



Results – An MJO-Like Mode

- **Minimally wet**



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 $\pm 10d$

	Lower-level wind (u_{850})	Upper-level wind (u_{200})	Convection (OLR)	Precipitation (TRMM satellite)	RMM*	Dates
Straub- Circ. Only	✓	✓			✓	1979 - 2010
Straub- Full	✓	✓	✓		✓	1979 - 2010
Straub- Conv. Only			✓		✓	1979 - 2010
Ling et al.				✓		Oct - Apr 1998 - 2009

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

Methods – Event Selection

- examined 8 of 12 identified events

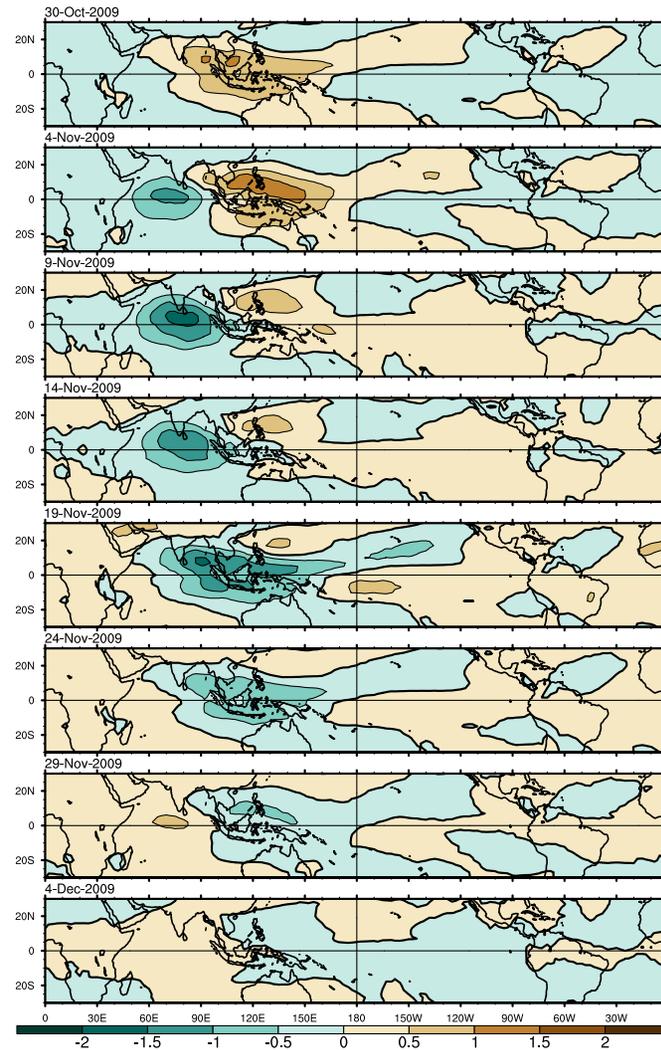
	Primary							
			Intensifying					
							Non-MJO	
	Jan 1999	Nov 2009	Jan 2006	Dec 2006	Jan 2002	Apr 2003	Oct 2002	Nov 2006
Straub-Circ. Only	✓		✓	✓	✓	✓	✓	
Straub-Full	✓			✓	✓		✓	✓
Straub-Conv. Only		✓		✓	✓	✓		
Ling et al.	✓	✓	✓	✓	✓	✓	✓	✓

Results – November 2009 “Primary” MJO Event

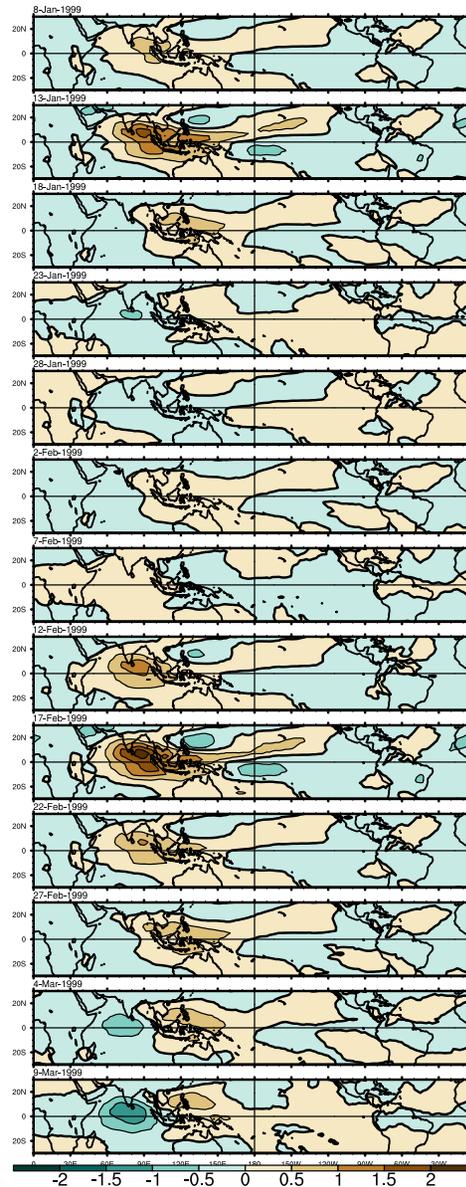
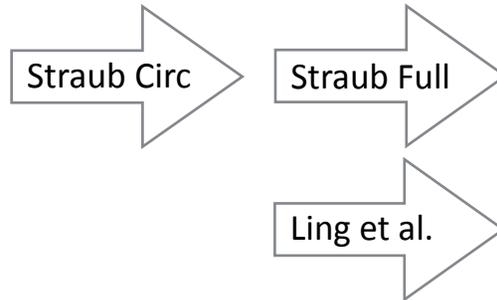
- A textbook-like case of OLR evolution

Straub Conv

Ling et al.



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 \geq 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).
- 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/](http://www.esrl.noaa.gov/psd/))
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“A linear Markov process driven by Gaussian white noise”

$$\frac{d\underline{X}(t)}{dt} = \underline{\underline{L}}\underline{X}(t) + \underline{\underline{\xi}}(t)$$

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

$$\underline{\underline{\xi}}(t) \approx \frac{\underline{x}(t + \delta) - \underline{x}(t - \delta)}{2\delta} - \underline{\underline{L}}\underline{X}(t)$$

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_α and amplitudes z_α :**

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

- **Evolution equations for z_{α}^r and z_{α}^i :**

$$\frac{dz_{\alpha}^r}{dt} = (\beta_{\alpha}^r z_{\alpha}^r - \beta_{\alpha}^i z_{\alpha}^i) + \xi_{\alpha}^r$$

$$\frac{dz_{\alpha}^i}{dt} = (\beta_{\alpha}^i z_{\alpha}^r + \beta_{\alpha}^r z_{\alpha}^i) + \xi_{\alpha}^i$$

EOF Analyses

	Univariate EOF Analysis		Multivariate EOF Analysis
Field	Eigenvalues Retained	Variance Retained	Variance Retained after Combining Fields
<i>u</i> ₈₅₀	16	45.3%	33%
<i>u</i> ₂₀₀	11	41.2%	30%
<i>T</i> ₄₀₀	18	58.7%	35%
SLP	24	78.3%	53%
OLR	9	23.0%	12%
<i>Total</i>	78	<i>n/a</i>	<i>n/a</i>

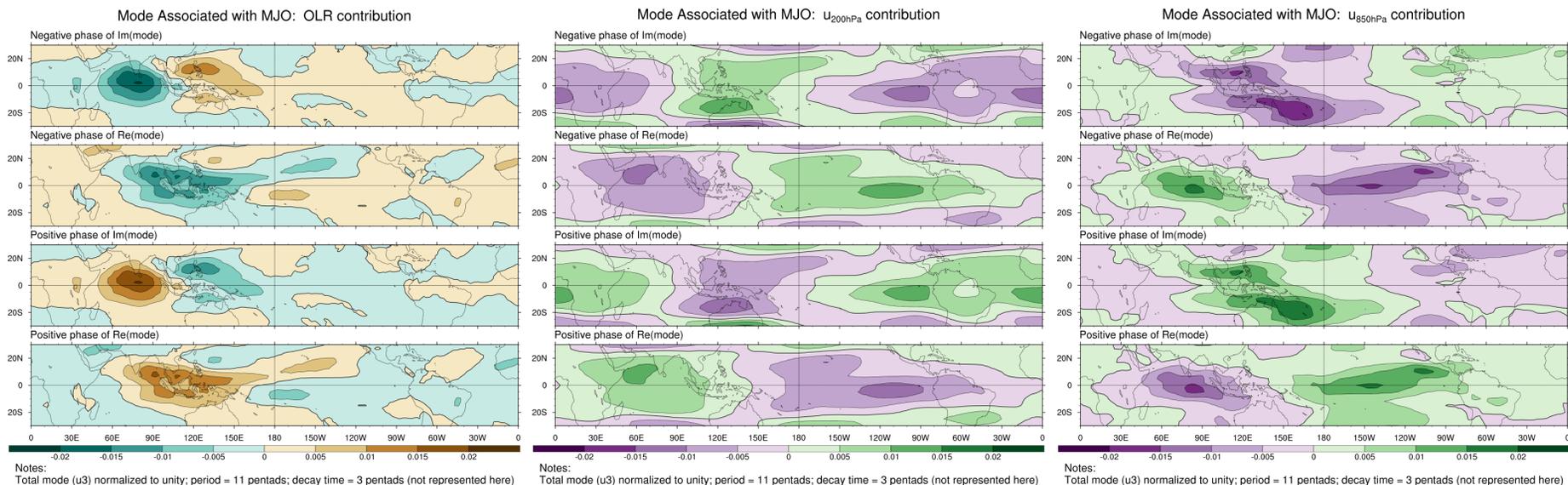
Results – An MJO-Like Mode

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

OLR

u_{200}

u_{850}



Results – An MJO-Like Mode

- **Minimally wet**

Field	Contribution to Modal Variance
OLR	10.2%
u_{850}	19.6%
u_{200}	20.6%
SLP	26.1%
T_{400}	23.5%
<i>Total</i>	<i>100%</i>

Methods – Event Selection

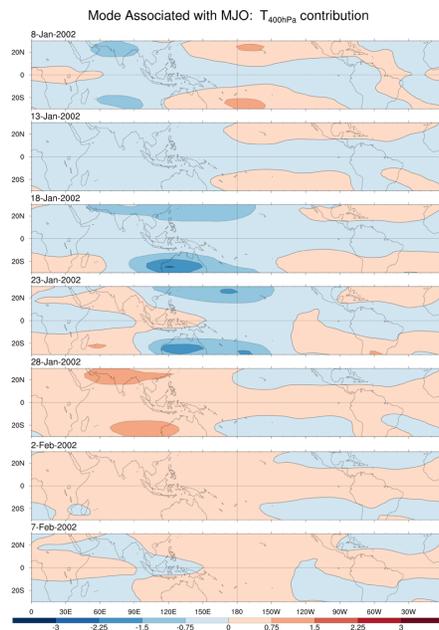
- examined 8 of 12 identified events

	Primary			Intensifying				Non-MJO	
	Jan 1999	Nov 2009	Jan 2006	Dec 2006	Jan 2002	Apr 2003	Oct 2002	Nov 2006	
Straub-Circ. Only	P <i>11 Jan</i>		I <i>10 Jan</i>	I <i>18 Dec</i>	I <i>13 Jan</i>	I <i>25 Apr</i>	I <i>5 Oct</i>		
Straub-Full	P <i>10 Jan</i>			I <i>18 Dec</i>	I <i>12 Jan</i>		I <i>5 Oct</i>	I <i>10 Nov</i>	
Straub-Conv. Only		P <i>28 Oct</i>		P <i>19 Dec</i>	I <i>8 Jan</i>	I <i>27 Apr</i>			
Ling et al.	P <i>17 Jan</i>	P <i>30 Oct</i>	P <i>9 Jan</i>	P <i>15 Dec</i>	I <i>8 Jan</i>	I <i>22 Apr</i>	N <i>2 Oct</i>	N <i>17 Nov</i>	

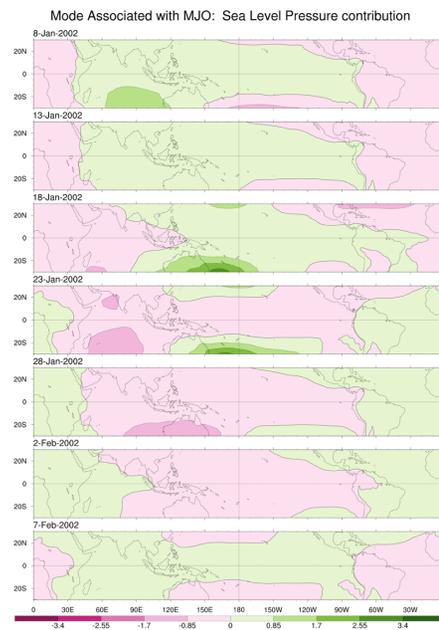
Results – January 2002 “Intensifying” MJO Event

- **Actual evolution based on modal amplitudes (z_α)**
 - differs from theoretical & from other ID systems

T_{400}

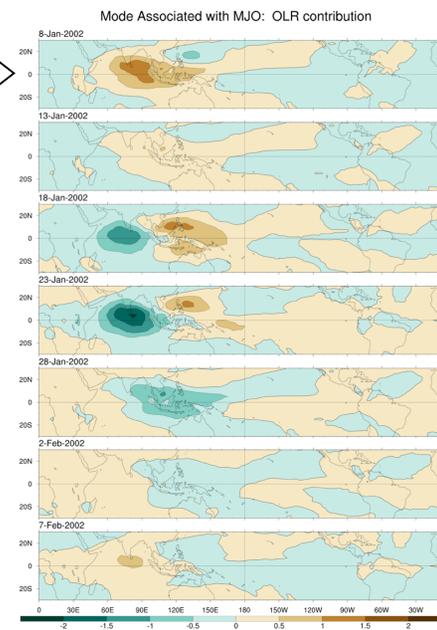


SLP



Ling et al.

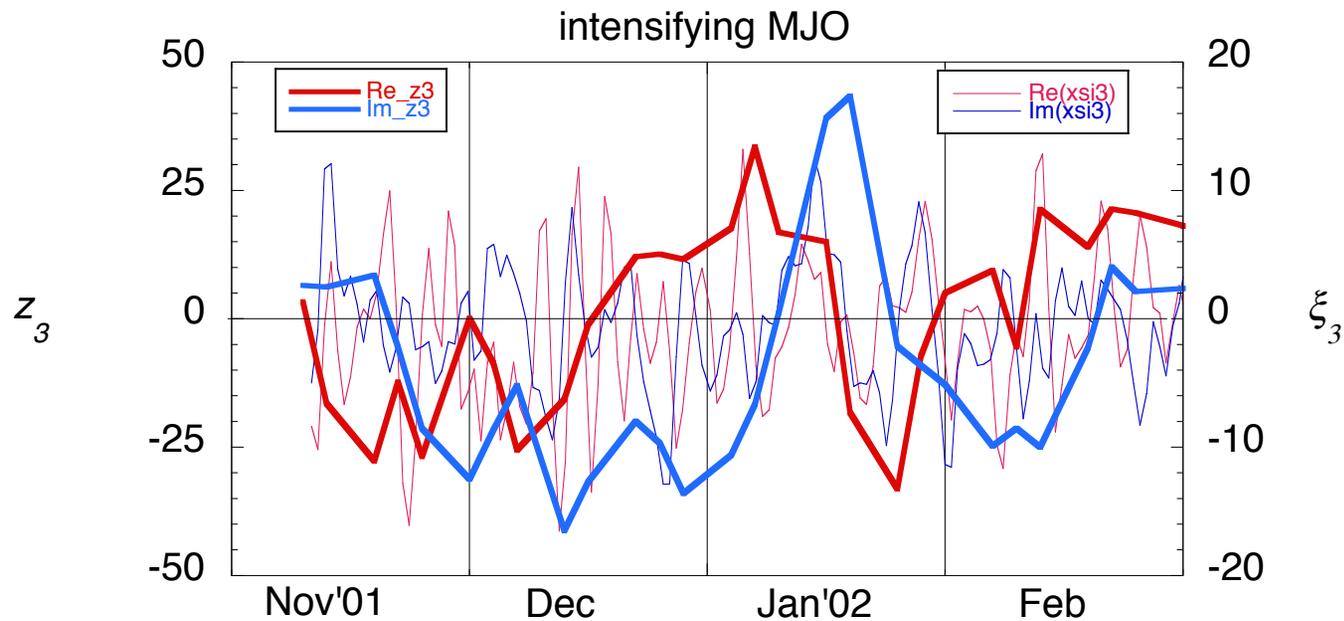
OLR



Straub Conv
Straub Full

Results – January 2002 “Intensifying” MJO Event

- **Used daily data to calculate stochastic forcing ξ_α**
 - two-day correlation is highly insignificant



- **Equations (not shown)**
 - real & imaginary parts of z_α affect each other's evolution
 - real (imaginary) parts of ξ_α only affect real (imaginary) z_α