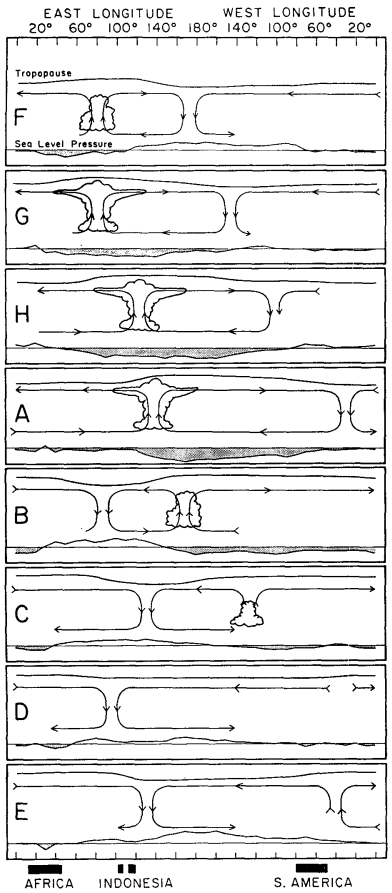
MJO Evolution as Revealed by Multivariate Principal Oscillation Analysis

Leslie M. Hartten[1, 2], Cécile Penland[2], and Rosa M. Vargas[3, 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

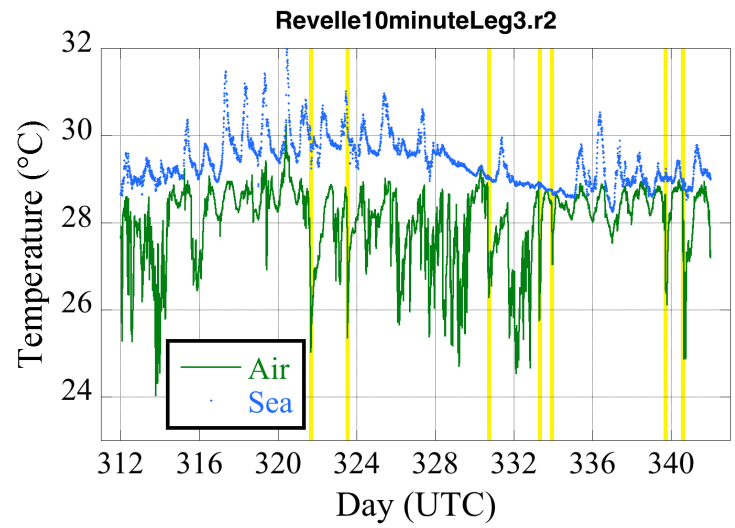
NOAA CVP 2016 Webinar Series - Understanding & Improving Prediction of Tropical Convection
25 October 2016

The Conundrum:



Madden and Julian (1972)

MJO



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

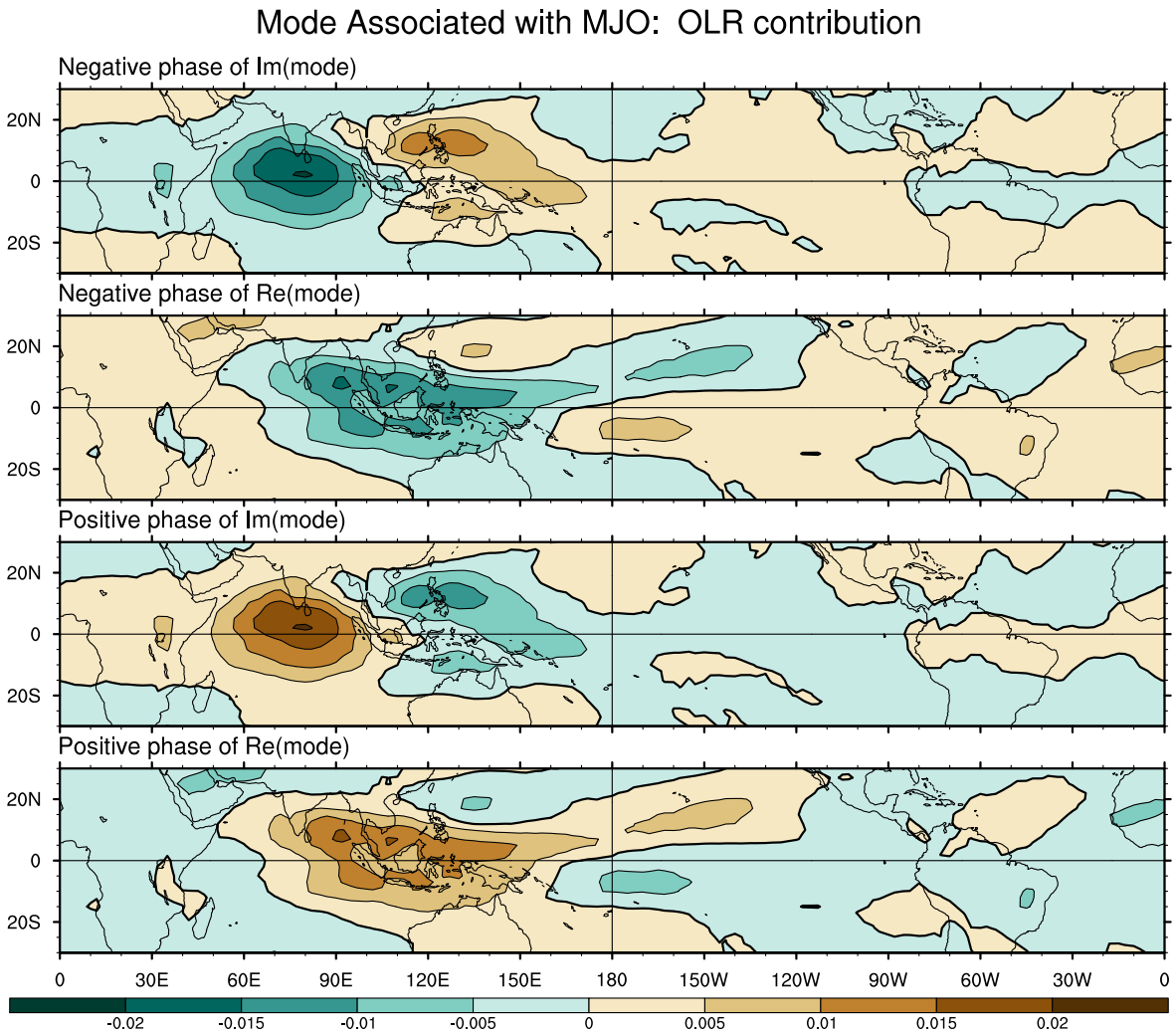
Methods – Analysis Technique

1) **EOF analysis with the pentad data**
   - normalized each set by σ_{PC1}
   - retained leading 9-24 EOFs
2) **Multivariate EOF analysis with those timeseries**
   - retained timerseries 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

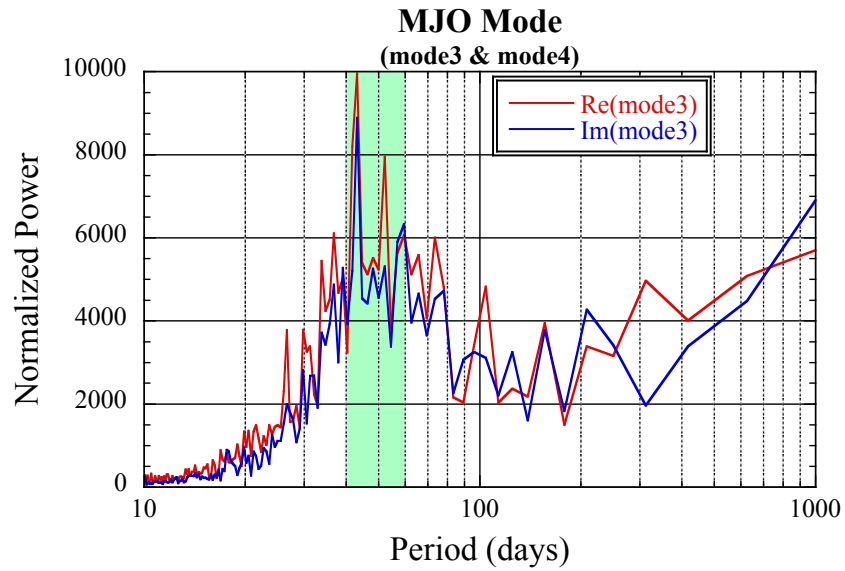
- **55-day period, 15-day decay time, propagates like MJO**

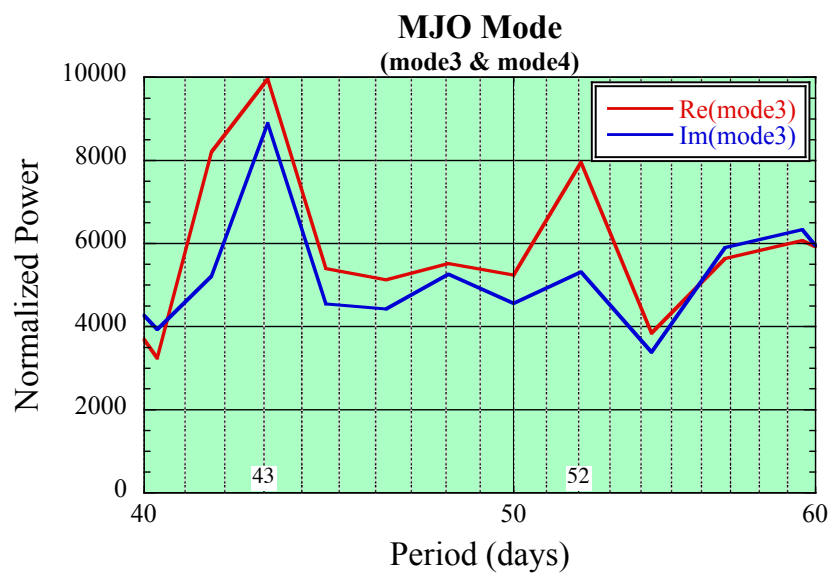


Notes:
Total mode (u3) normalized to unity; period = 11 pentads; decay time = 3 pentads (not represented here)

Results – An MJO-Like Mode

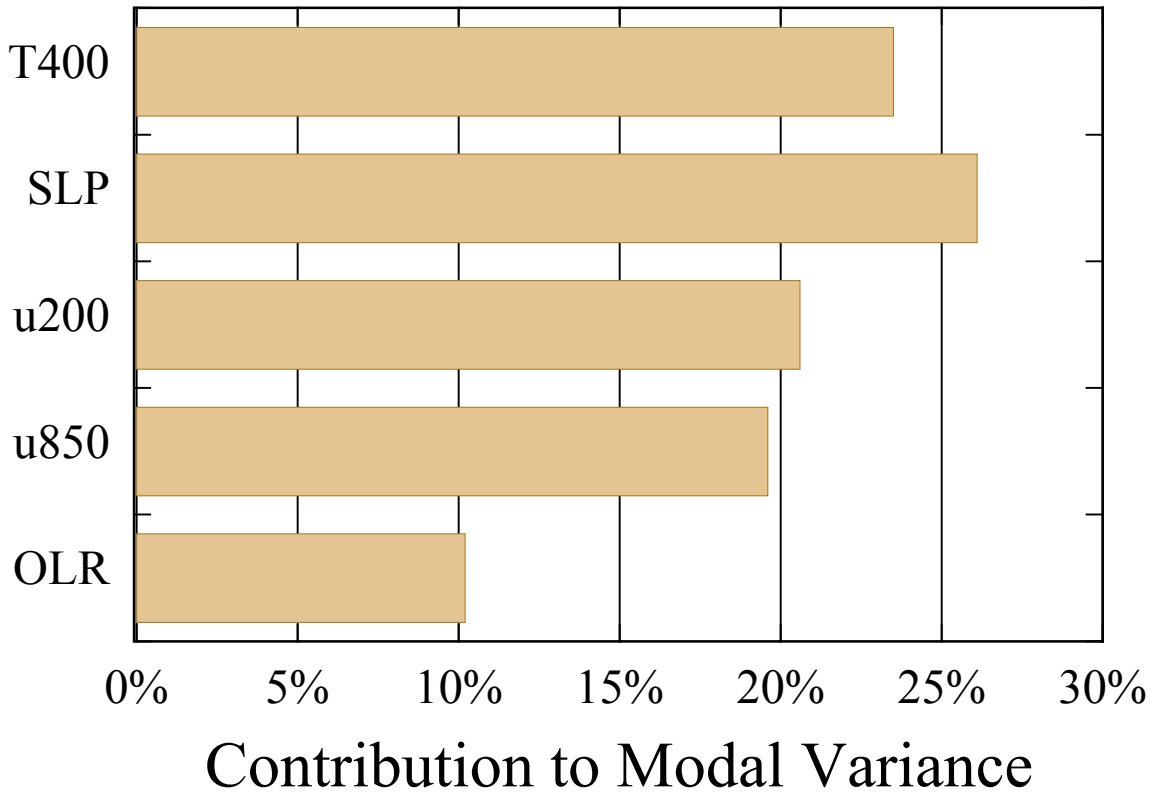
- **Peak power at 30-80 days**
  - no Fourier filtering!





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 ±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)

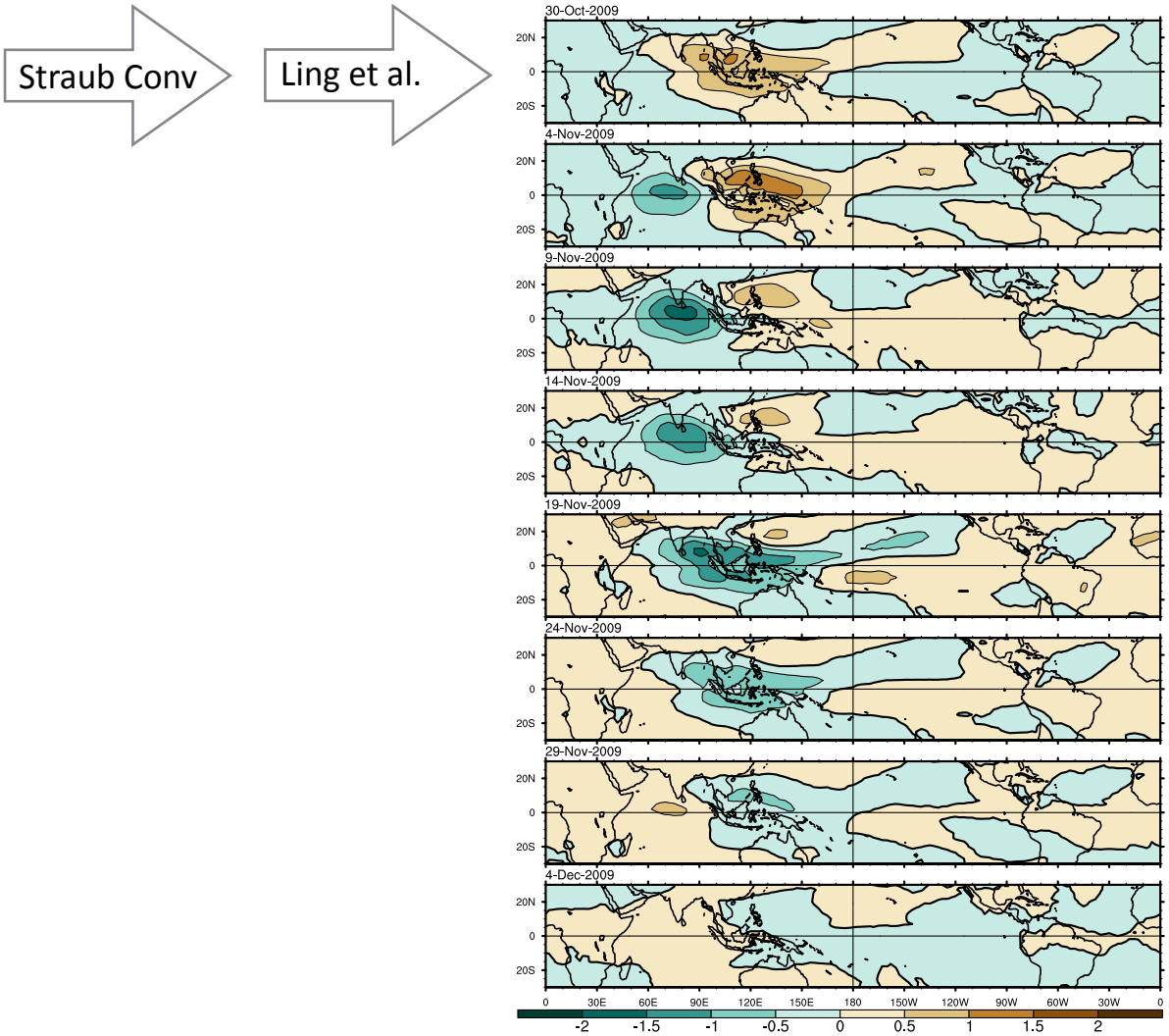
Methods – Event Selection

- **examined 8 of 12 identified events**

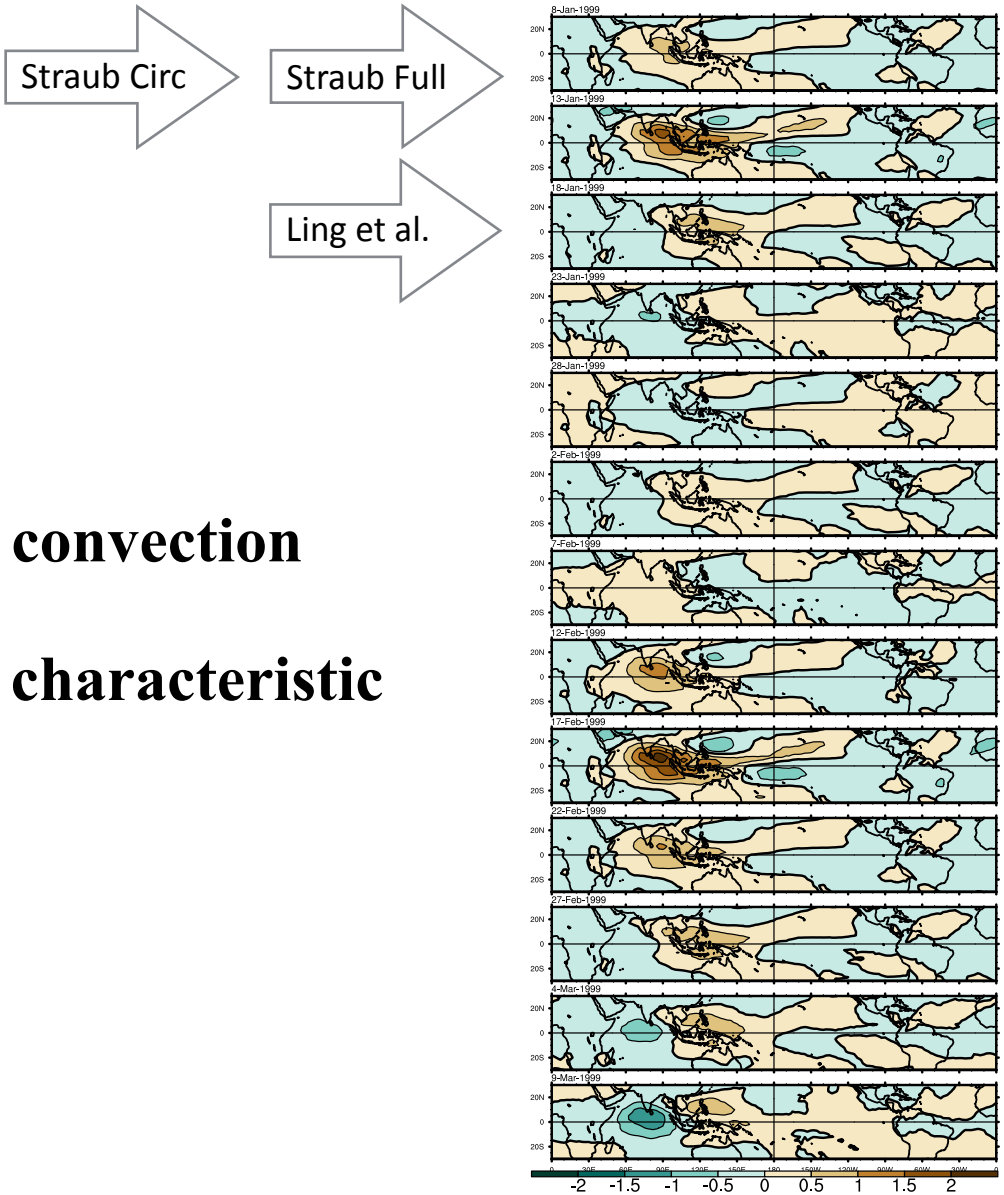
	Primary							
			Intensifying					
							Non-MJO	
	Jan 1999	Nov 2009	Jan 2006	Dec 2006	Jan 2002	Apr 2003	Oct 2002	Nov 2006
Straub-Circ. Only	✓		✓	✓	✓	✓	✓	
Straub-Full	✓			✓	✓		✓	✓
Straub-Conv. Only		✓		✓	✓	✓		
Ling et al.	✓	✓	✓	✓	✓	✓	✓	✓

Results – November 2009 "Primary" MJO Event

- **A textbook-like case of OLR evolution**



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

- **Sub-daily forcing**

- **Midlatitude effects**

- **Examine other dynamical modes**
  - "Missing" enhanced convection (Nov 2009 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/)
- Map & plot colors from www.ColorBrewer.org by Cynthia A. Brewer (Penn State).
- Brian Bevirt & Eileen Carpenter (NCAR) and Katie McCaffrey (CIRES) offered many suggestions that improved the visual presentation of results.

- Co-Investigator Chris Fairall (NOAA/ESRL/PSD) has been a supportive presence for many years.

- Funding provided by grants from NOAA's Office of Global Programs to the NOAA/ESRL/ Physical Sciences Division.

"A linear Markov process driven by Gaussian white noise"

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

- $\underline{X}(t)$ 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
- $\underline{\xi}$(t) can be estimated from $\underline{x}(t)$ and $\underline{\underline{L}}$

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

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:**

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

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

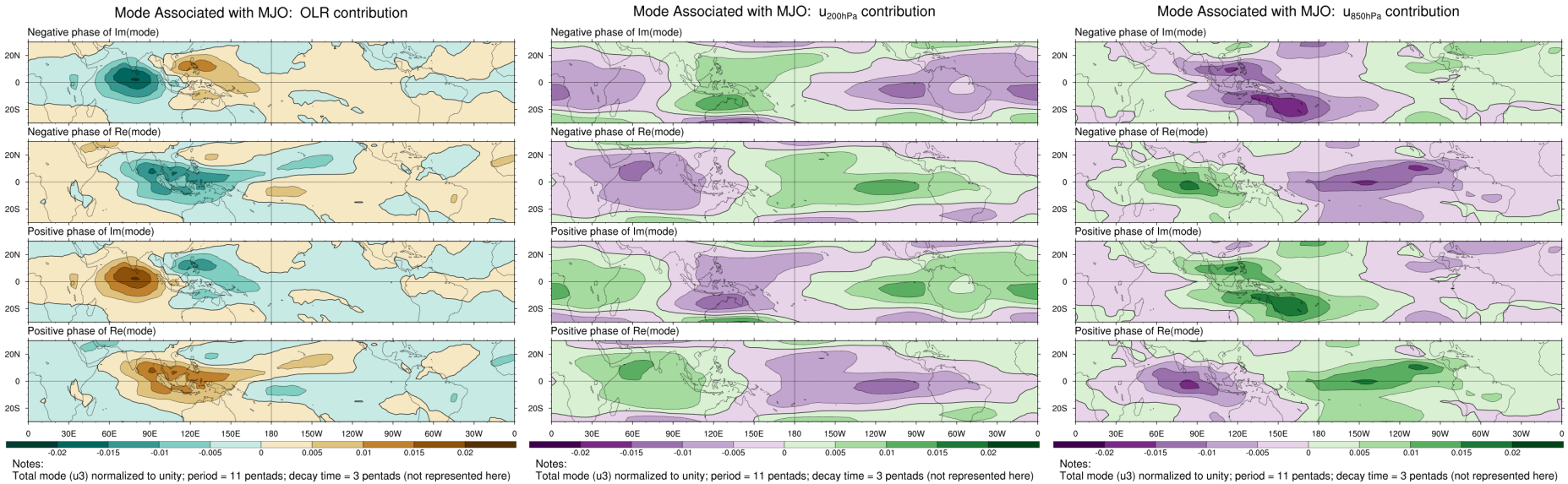
EOF Analyses

	Univariate EOF Analysis		Multivariate EOF Analysis
Field	Eigenvalues Retained	Variance Retained	Variance Retained after Combining Fields
u_{850}	16	45.3%	33%
u_{200}	11	41.2%	30%
T_{400}	18	58.7%	35%
SLP	24	78.3%	53%
OLR	9	23.0%	12%
Total	*78*	*n/a*	*n/a*

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%
Total	*100%*

Methods – Event Selection

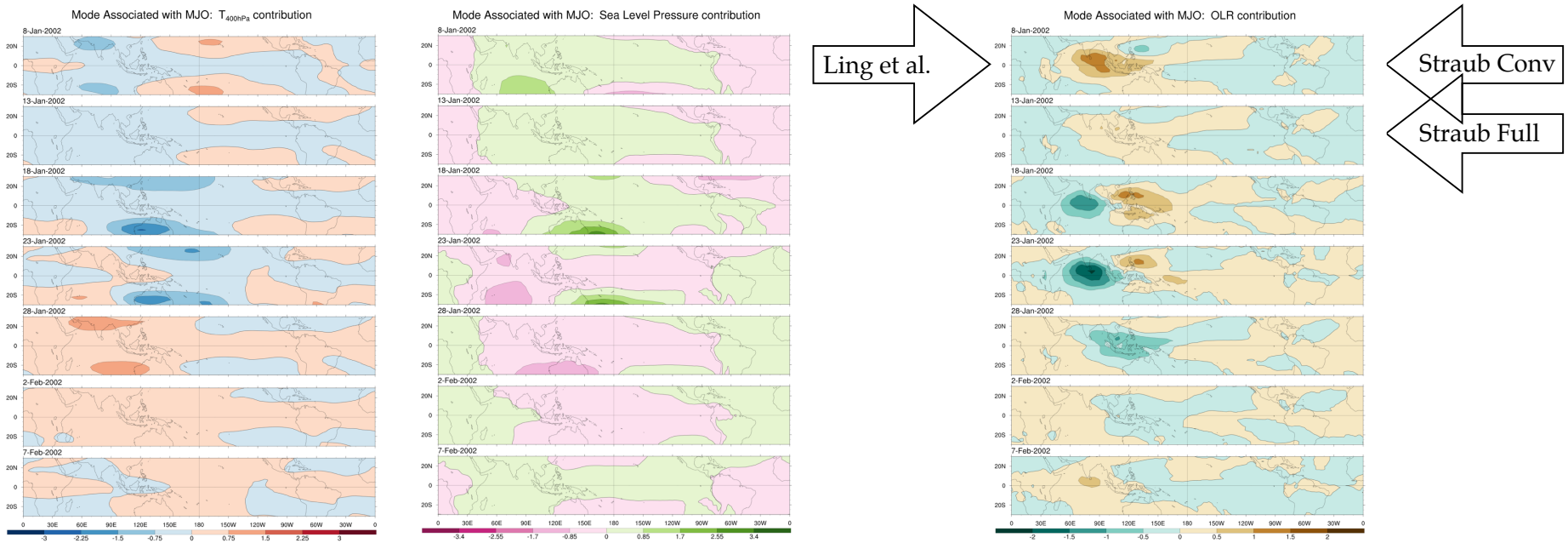
- **examined 8 of 12 identified events**

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

Results – January 2002 "Intensifying" MJO Event

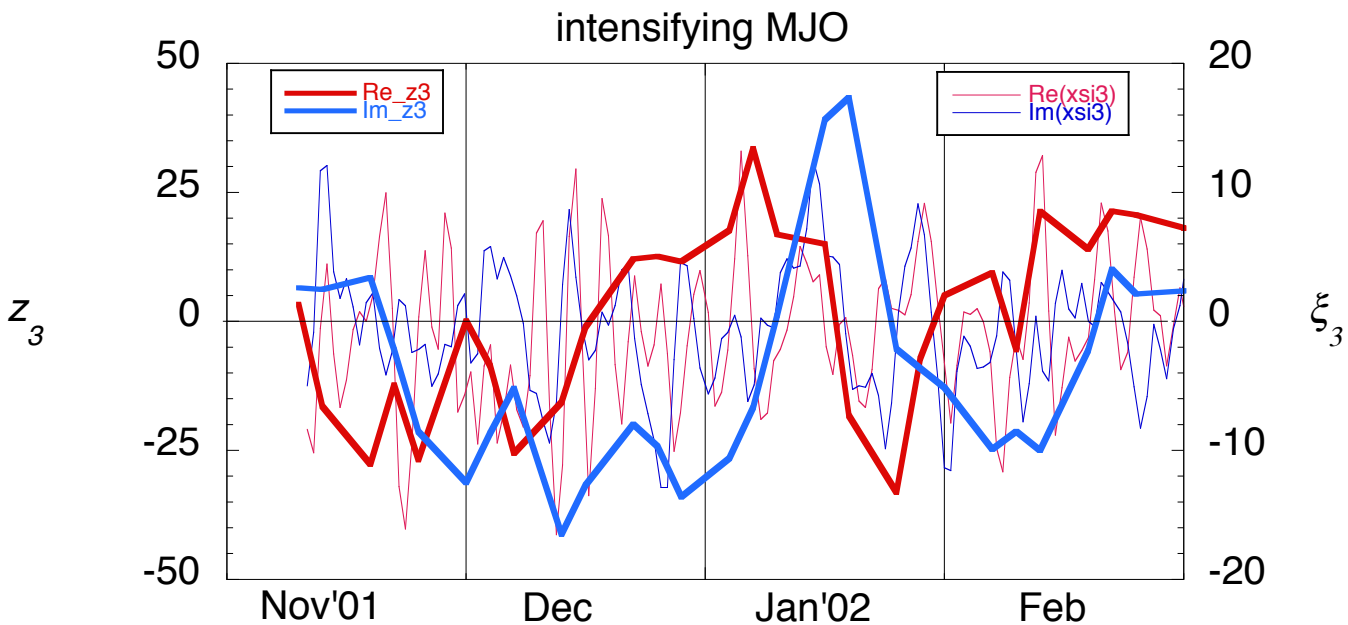
- **Actual evolution based on modal amplitudes (z_α)**
  - differs from theoretical & from other ID systems

T_{400} *SLP* OLR



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