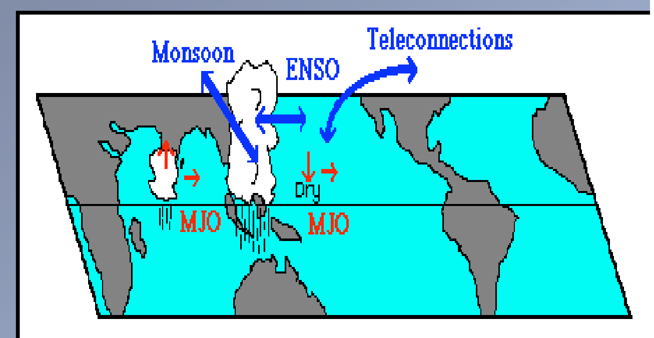
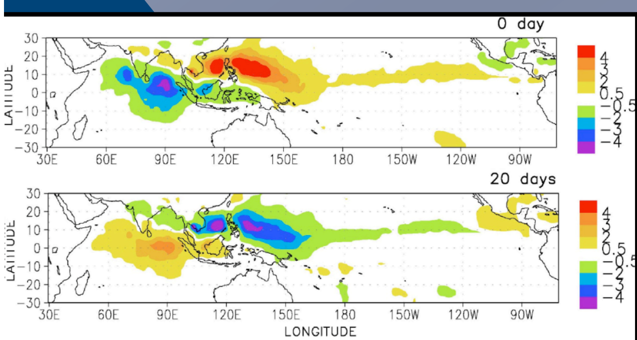
US CLIVAR MJO Working Group:
Efforts to Establish and Improve Subseasonal Predictions

D. Waliser, K. Sperber, L. Donner, J. Gottschalck, H. Hendon, W. Higgins, I. Kang, D. Kim, E. Maloney, M. Moncrieff, S. Schubert, W. Stern, F. Vitart, B. Wang, W. Wang, K. Weickmann, M. Wheeler, S. Woolnough, C. Zhang

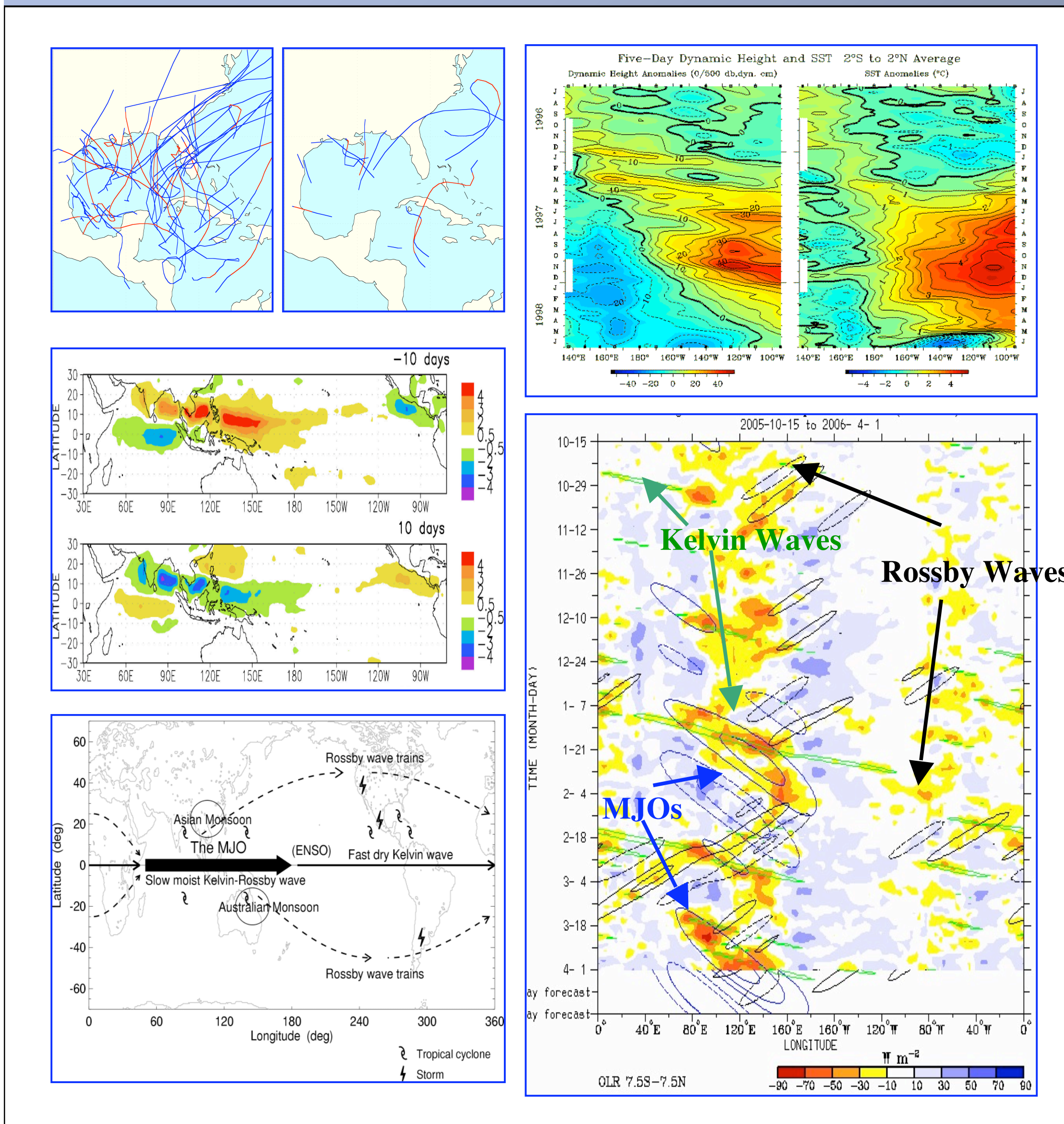


AGU, Fal 2007

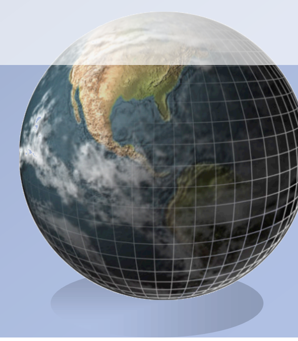


http://www.usclivar.org/Organization/MJO_WG.html

Motivation



- The MJO is the dominant form of intraseasonal variability in the Tropics.
- The MJO impacts a wide range of weather & climate phenomena.
- Our weather & climate models have a relatively poor representation of the MJO.
- Great benefit could be derived from better predictions of the MJO - Helps to fill gap between weather and seasonal predictions.



Figures: E. Maloney, PMEL/TAO, M. Wheeler, J. Lin, D. Waliser

US CLIVAR Established MJO Working Group

U.S. CLIVAR MJO Working Group

last updated July 3, 2007

Name	Affiliation	Term
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Mitch Moncrief	NCAR	
Sigfried Schubert	NASA GSFC	
Ken Sperber (co-chair)	Lawrence Livermore	
Bin Wang	University of Hawaii	
Wanqui Wang	NOAA NCEP	
Klaus Weickmann	NOAA CDC	
Duane Waliser (co-chair)	JPL/Caltech	
Chidong Zhang	University of Miami - RSMAS	
Additional Contributing Scientists		
John Gottschalck	NOAA - NCEP	
Harry Hendon	BMRC	
Wayne Higgins	NOAA-NCEP	
Daehyun Kim/In-Sik Kang	Seoul National University	
Frederic Vitart	ECMWF	
Matt Wheeler	BMRC	
Steve Woolnough	Univ. Reading	

MEETINGS | DOCUMENTS | REFERENCES | LINKS

MJO & Weather-Climate | MJO Simulation Diagnostics

Terms of Reference

- Develop a set of diagnostics to be used for assessing MJO simulation fidelity and forecast skill.
- Develop and coordinate model simulation and prediction experiments, in conjunction with model-data comparisons, which are designed to better understand the MJO and improve our model representations and forecasts of the MJO.
- Raise awareness of the potential utility of subseasonal and MJO forecasts in the context of the seamless suite of predictions.
- Help to coordinate MJO-related activities between national and international agencies and associated programmatic activities.
- Provide guidance to US CLIVAR and Interagency Group (IAG) on where additional modeling, analysis or observational resources are needed.

International participation is facilitated/ supported by International CLIVAR

Goals/Progress: Summary

1) Develop MJO WG Web Site. Done.
   Diagnostics Link, Meeting & Telecon Updates, Theme Pages
2) Diagnostics for Asessing Model Simulations of the MJO. Tracking Progress has Been Difficult.
   Done. Journal Article Forthcoming. (WG - Lead)
3) Diagnostics Application to Models. Analysis and Journal Article Underway - (D. Kim and WG Lead).
4) Prediction Targets and Metrics for MJO Forecasts. Designed, Now Being Implemented. BAMS-like Article Planned.
5) Workshop/Experimentation Planning. Done - November 2007, Irvine, CA.

MJO Weather Climate Interactions

- ENSO
- Hurricanes
- Australian Monsoon
- High Latitude Weather
- Ocean Chlorophyll
- Global Benefits and Hazards
- African Rainfall
- MJO and Atmospheric Composition: Total Column Ozone
- Atmospheric Angular Momentum and Length of Da

MEETINGS

Relevant Science Meetings and Workshops

- Workshop on the Organization and Maintenance of Tropical Convection and the Madden Julian Oscillation 13-17 March 2006 (Trieste, Italy)
- Diagnosing, Modeling and Forecasting Subseasonal Atmospheric Variability, AGU, 23-25 May 2006(Balitmore, MD)
- Tropical Convection and The Weather Climate Interface 10-14 July 2006 (NCAR - Boulder, CO)
- MJO WG meeting 24-25 July 2006 (Breckenridge, CO - prior to the U.S. CLIVAR Summit)
- Posting of initial version of MJO simulation metrics 7 February 2007
- 3rd WGNE Workshop on Systematic Errors in Climate and NWP Models 12-16 Feb 2007 (San Francisco, CA)
  - Presentation from the workshop (pdf)
- CLIVAR Asian-Australian Monsoon Panel (AAMP) Meeting 19-21 February 2007 (Honolulu, HI)
  - MJO Metrics presented and Collaborations with MJOWG discussed
- NSF STC CMMAP Meeting (Kauai, Hawaii)
  - Metrics presented and Collaborations with MJOWG discussed (pdf)
- Celebrating the Monsoon 24-28 July 2007 (Centre for Atmospheric & Oceanic Sciences Indian Institute of Science - Bangalore)

Working Group Meetings/Teleconferences

- Teleconference Agenda (pdf) and Minutes (pdf) from 3 May 2006
- Teleconference Agenda (pdf), Minutes (pdf) and Attachment 1 (pdf) from 31 May 2006
- Teleconferece Minutes (pdf) and Attachment (pdf) from 27 June 2006
- Teleconference Minutes (pdf) from 18 July 2006
- MJO Metrics (26 July 2006) (pdf)
- 1st MJO WG Meeting (July 2006) at the U.S. CLIVAR Summit
  - Climate Weather Interface presentation by A. Ray(pdf)
  - Experimental Global Tropics Benefits/Hazards Assessment presentation by W. Higgins(pdf)
  - MJO Simulation Metrics - Summary to Date (pdf)
  - Summary presentation of WG Activities at US CLIVAR Summit (pdf)
- Teleconference Agenda (pdf), MInutes (pdf) and Draft Metric Calculations (pdf) from 16 October 2006
- Teleconference Minutes (pdf), Attachment (ppt) and Draft Metric Website from 29 November 2006
- Teleconference Minutes (pdf) from 19 March 2007

Web Site Resources

Theme Pages & WG Activities

MJO Weather-Climate Theme Pages

The U.S. contribution to

Climate Variability and Predictability

MJO Weather-Climate Interactions

The MJO and Hurricanes:

Could MJO Predictions Help Forecast Periods of Enhanced Hurricane Activity?

Motivation

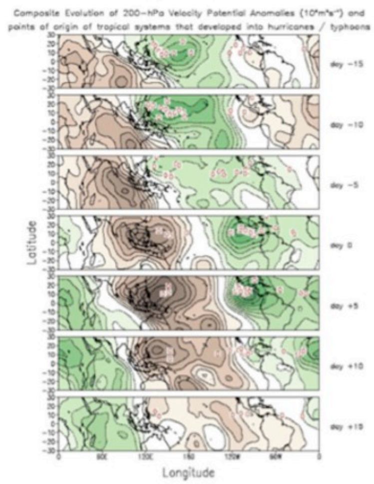
The MJO produces a strong modulation of tropical cyclone activity in many regions of the tropics, including the Atlantic Ocean, Gulf of Mexico, and east Pacific Ocean. The MJO is associated with variations in sea surface temperature, organized precipitation, low-level winds, vertical wind shear, and atmospheric humidity and temperature, important factors in tropical cyclone formation and maintenance. Forecasts of the MJO at 2-3 week lead times might aid in forecasting periods of enhanced tropical cyclone formation.

Research Summary

Tropical cyclogenesis preferentially occurs during certain phases of the MJO. Figure 1 shows the composite eastward propagation of Northern Hemisphere summer velocity potential and tropical cyclone genesis locations associated with the MJO during 1979-1997 (adapted from Higgins and Shi [2001]). Green areas indicate anomalous upper level divergence, where precipitation is enhanced and tropical cyclogenesis preferentially occurs. Brown areas indicate anomalous upper level convergence, where precipitation and tropical cyclogenesis are suppressed. One notable feature is the enhancement of tropical cyclogenesis in the Americas during periods of enhanced upper level divergence and enhanced precipitation (e.g. Day 0 and Day +5 of Figure 1). For example, an analysis during 1949-1997 indicates that the MJO strongly modulates Gulf of Mexico and Caribbean Sea hurricanes and tropical storms (Figure 2, adapted from Maloney and Hartmann 2000). Gulf of Mexico and Caribbean Sea hurricanes are four times more likely to occur when the MJO is producing enhanced precipitation and divergent upper level winds than when precipitation is suppressed and upper level winds are convergent. The modulation of major hurricanes (Categories 3-5) by the MJO is even more pronounced. Similarly, when the divergent (convergent) phase of the MJO is located over the Indian or west Pacific Ocean, typhoon activity in increased (decreased).

Example: MJO & Hurricanes by Eric Maloney

Figure 1.



Adapted from Higgins and Shi (2001)

Figure 2.

Maloney and Hartmann (2000)

Implications

Given the evidence that the MJO is predictable with 2-3 week lead-times, periods of enhanced or suppressed hurricane activity may be predicted at similar lead times. Such knowledge would have implications for public safety, energy production, recreation/tourism, among other interests.

Future Work

Two avenues of further investigation include: 1) understanding how the MJO modulates hurricane activity, and 2) determining whether 2-3 week predictions of the MJO can be used to predict periods of enhanced tropical cyclone activity.

Selected References

- Bessafi, M., and M. C. Wheeler. 2006: Modulation of south Indian Ocean tropical cyclones by the Madden–Julian Oscillation and convectively coupled equatorial waves. *Mon. Wea. Rev.*, **134**, 638–656.
- Hall, J. D., A. J. Matthews and D. J. Karoly. 2001: The Modulation of tropical cyclone activity in the Australian region by the Madden–Julian oscillation. *Mon. Wea. Rev.*, **129**, 2970–2982.
- Higgins, W and W. Shi, 2001: Intercomparison of the principal modes of interannual and intraseasonal variability of the North American monsoon system. *J. Climate*, **14**, 403-417.
- Liebmann, B., H. H. Hendon, and J. D. Glick, 1994: The relationship between tropical cyclones of the western Pacific and Indian Oceans and the Madden-Julian oscillation. *J. Meteor. Soc. Japan*, **72**, 401-411.
- Maloney, E. D., and D. L. Hartmann, 2000: Modulation of hurricane activity in the Gulf of Mexico by the Madden-Julian Oscillation. *Science*, **287**, 2002-2004
- Mo, K. C., 2000: The association between intraseasonal oscillations and tropical storms in the Atlantic basin.

Web Site Diagnostics

U.S. CLIVAR MJO Working Group

last updated July 3, 2007

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Chidong Zhang	University of Miami - RSMAS	
Additional Contributing Scientists		
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MJO & Weather-Climate | MJO Simulation Diagnostics

Link to Diagnostics

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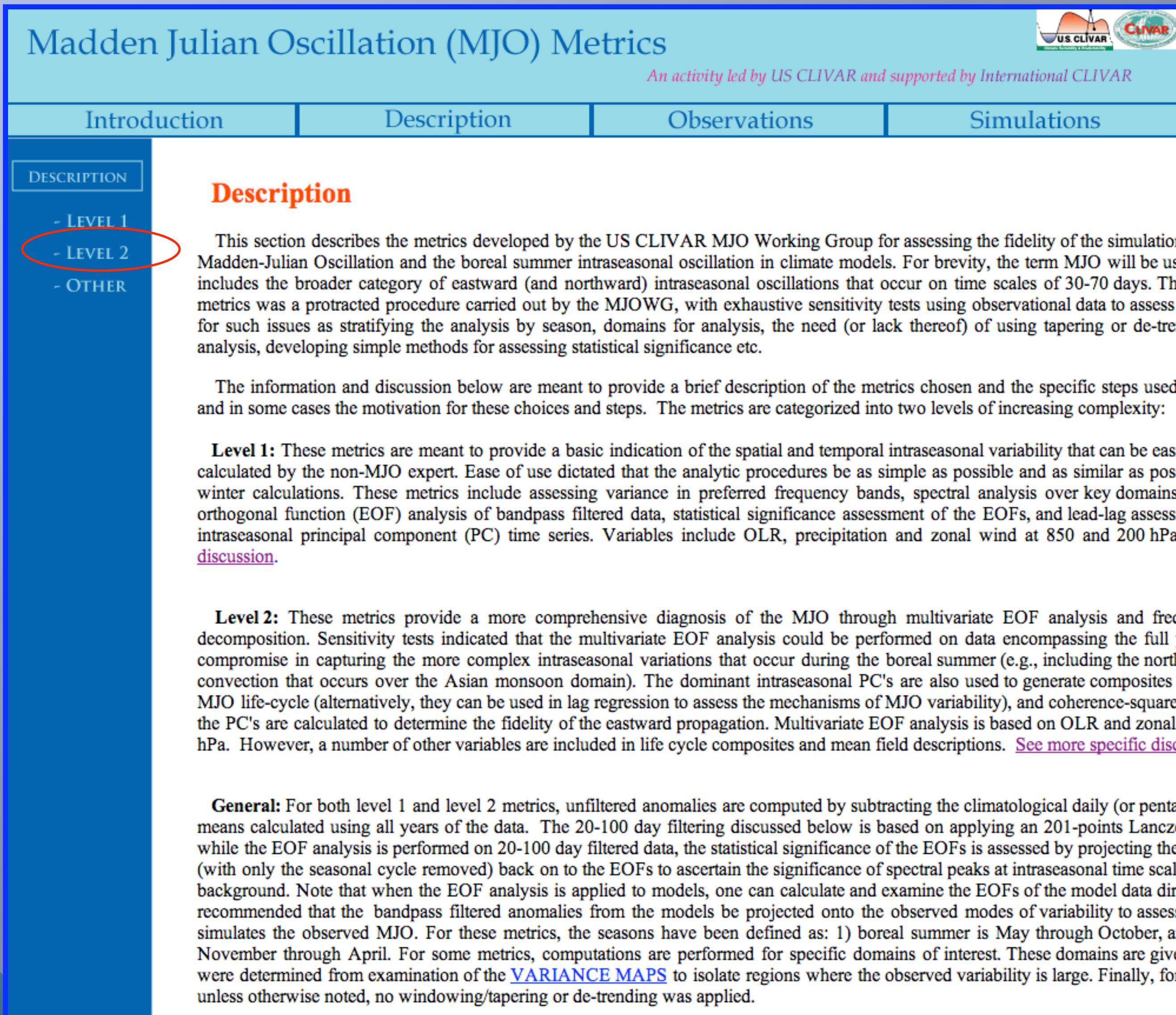
MJO Diagnostics

General Strategy & Description


Madden Julian Oscillation (MJO) Metrics

US CLIVAR CLIVAR

An activity led by US CLIVAR and supported by International CLIVAR

Introduction | Description | Observations | Simulations

DESCRIPTION
- LEVEL 1
- LEVEL 2
- OTHER

Description

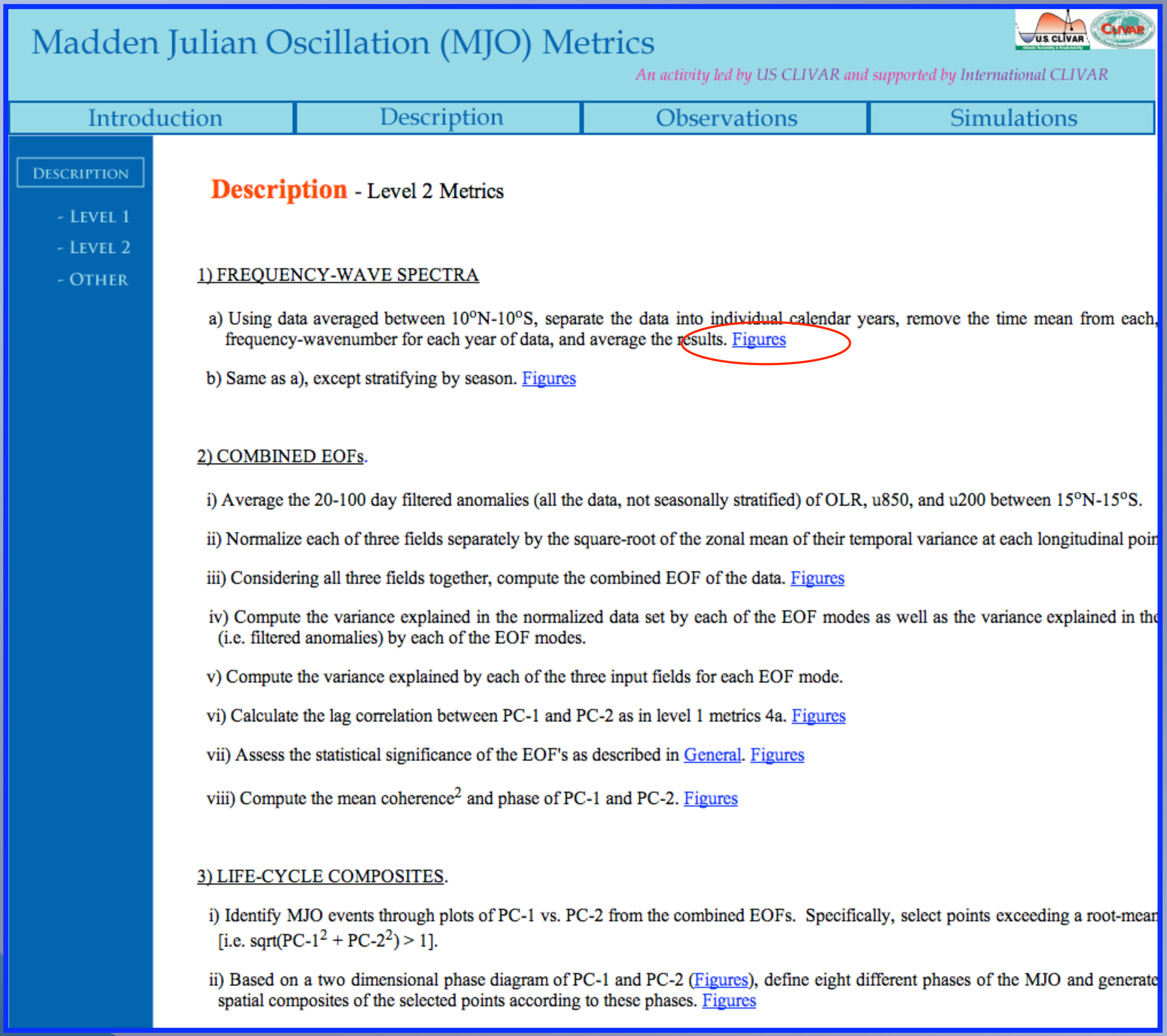
This section describes the metrics developed by the US CLIVAR MJO Working Group for assessing the fidelity of the simulatio Madden-Julian Oscillation and the boreal summer intraseasonal oscillation in climate models. For brevity, the term MJO will be us includes the broader category of eastward (and northward) intraseasonal oscillations that occur on time scales of 30-70 days. Th metrics was a protracted procedure carried out by the MJOWG, with exhaustive sensitivity tests using observational data to assess for such issues as stratifying the analysis by season, domains for analysis, the need (or lack thereof) of using tapering or de-tre analysis, developing simple methods for assessing statistical significance etc.

The information and discussion below are meant to provide a brief description of the metrics chosen and the specific steps used and in some cases the motivation for these choices and steps. The metrics are categorized into two levels of increasing complexity:

Level 1: These metrics are meant to provide a basic indication of the spatial and temporal intraseasonal variability that can be easi calculated by the non-MJO expert. Ease of use dictated that the analytic procedures be as simple as possible and as similar as poss winter calculations. These metrics include assessing variance in preferred frequency bands, spectral analysis over key domains orthogonal function (EOF) analysis of bandpass filtered data, statistical significance assessment of the EOFs, and lead-lag assess intraseasonal principal component (PC) time series. Variables include OLR, precipitation and zonal wind at 850 and 200 hPa discussion.

Level 2: These metrics provide a more comprehensive diagnosis of the MJO through multivariate EOF analysis and fre decomposition. Sensitivity tests indicated that the multivariate EOF analysis could be performed on data encompassing the full compromise in capturing the more complex intraseasonal variations that occur during the boreal summer (e.g., including the nort convection that occurs over the Asian monsoon domain). The dominant intraseasonal PC's are also used to generate composites MJO life-cycle (alternatively, they can be used in lag regression to assess the mechanisms of MJO variability), and coherence-square the PC's are calculated to determine the fidelity of the eastward propagation. Multivariate EOF analysis is based on OLR and zonal hPa. However, a number of other variables are included in life cycle composites and mean field descriptions. See more specific disc

General: For both level 1 and level 2 metrics, unfiltered anomalies are computed by subtracting the climatological daily (or penta means calculated using all years of the data. The 20-100 day filtering discussed below is based on applying an 201-points Lancz while the EOF analysis is performed on 20-100 day filtered data, the statistical significance of the EOFs is assessed by projecting the (with only the seasonal cycle removed) back on to the EOFs to ascertain the significance of spectral peaks at intraseasonal time scal background. Note that when the EOF analysis is applied to models, one can calculate and examine the EOFs of the model data dir recommended that the bandpass filtered anomalies from the models be projected onto the observed modes of variability to assess simulates the observed MJO. For these metrics, the seasons have been defined as: 1) boreal summer is May through October, a November through April. For some metrics, computations are performed for specific domains of interest. These domains are give were determined from examination of the VARIANCE MAPS to isolate regions where the observed variability is large. Finally, fo unless otherwise noted, no windowing/tapering or de-trending was applied.



Madden Julian Oscillation (MJO) Metrics

An activity led by US CLIVAR and supported by International CLIVAR

Introduction | Description | Observations | Simulations

DESCRIPTION
- LEVEL 1
- LEVEL 2
- OTHER

Description - Level 2 Metrics

1) FREQUENCY-WAVE SPECTRA

a) Using data averaged between 10°N-10°S, separate the data into individual calendar years, remove the time mean from each, frequency-wavenumber for each year of data, and average the results. Figures

b) Same as a), except stratifying by season. Figures

2) COMBINED EOFs.

i) Average the 20-100 day filtered anomalies (all the data, not seasonally stratified) of OLR, u850, and u200 between 15°N-15°S.

ii) Normalize each of three fields separately by the square-root of the zonal mean of their temporal variance at each longitudinal poin

iii) Considering all three fields together, compute the combined EOF of the data. Figures

iv) Compute the variance explained in the normalized data set by each of the EOF modes as well as the variance explained in the (i.e. filtered anomalies) by each of the EOF modes.

v) Compute the variance explained by each of the three input fields for each EOF mode.

vi) Calculate the lag correlation between PC-1 and PC-2 as in level 1 metrics 4a. Figures

vii) Assess the statistical significance of the EOF's as described in General. Figures

viii) Compute the mean coherence^2 and phase of PC-1 and PC-2. Figures

3) LIFE-CYCLE COMPOSITES.

i) Identify MJO events through plots of PC-1 vs. PC-2 from the combined EOFs. Specifically, select points exceeding a root-mean [i.e. $\mathrm{sqrt}(PC\text{-}1^2 + PC\text{-}2^2) > 1$].

ii) Based on a two dimensional phase diagram of PC-1 and PC-2 (Figures), define eight different phases of the MJO and generate spatial composites of the selected points according to these phases. Figures

MJO Diagnostics

Recipe for Calculating Diagnostics

Calculation Codes Available

Madden Julian Oscillation (MJO) Metrics

An activity led by US CLIVAR and supported by International CLIVAR

Introduction | Description | Observations | Simulations

OBSERVATIONS
- Level 1
- Level 2
- Other

Observations - Level 2 metrics figure tables

1) FREQUENCY-WAVE SPECTRA (see Description)

a) Annual data

OLR	PRCP	U200	U850	Usfc
All season sptectra (with annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1

b) Seasonally stratified data

OLR	PRCP	U200	U850	Usfc
Seasonally stratified spectra (Winter : November to April, without annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1
Seasonally stratified spectra (Summer : May to October, without annual cycle)				
AVHRR	CMAP TRMM GPCP	NCEP1 NCEP2 ERA40	NCEP1 NCEP2 ERA40	NCEP1

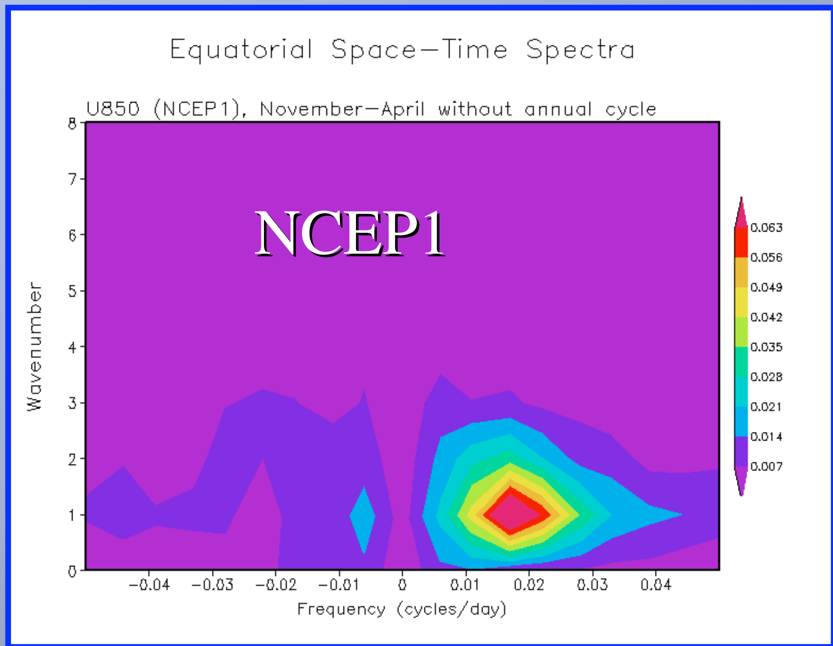
2) COMBINED EOFs (see Description)

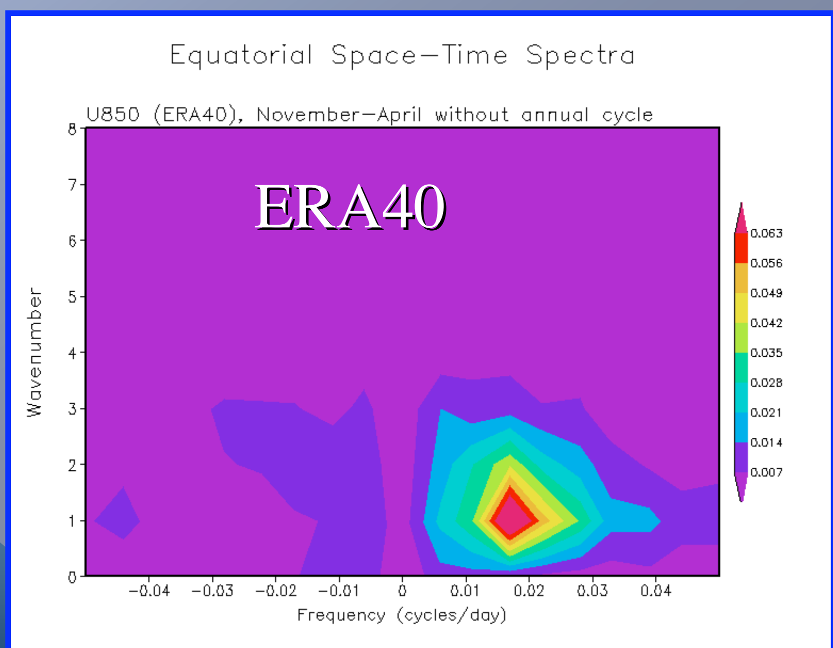
a) Combined EOFs

MJO Diagnostics

Plan To Make The Actual Map/Plot Data Available

Results to be Summarized in a Journal Article





MJO Diagnostics

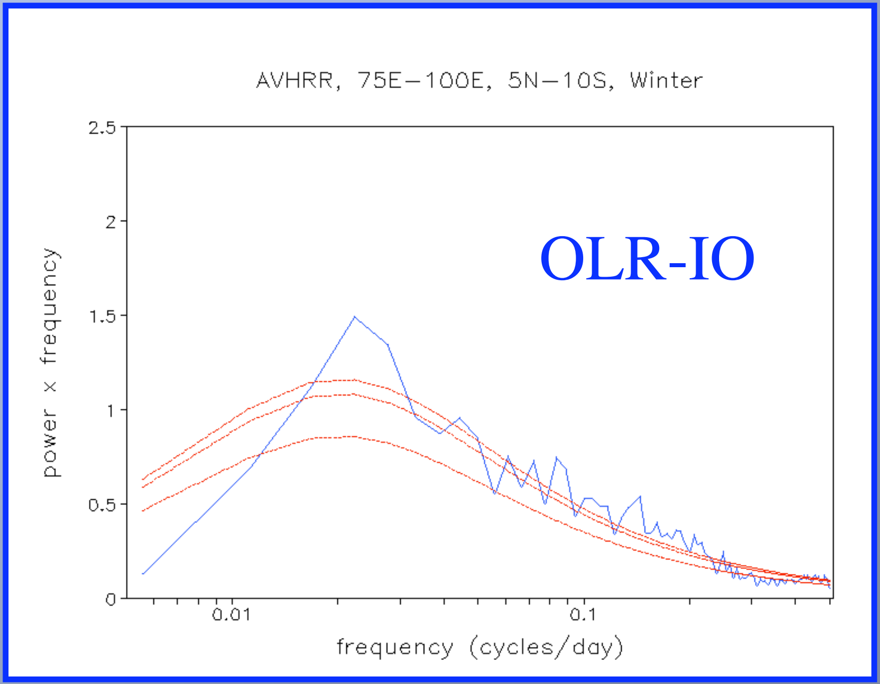
Equatorial Space-Time Spectra
U, Rain, OLR

NCEP1,
NCEP2,
& ERA40

MJO Diagnostics

Time Series Spectra U, Rain, OLR

Domains of Interest



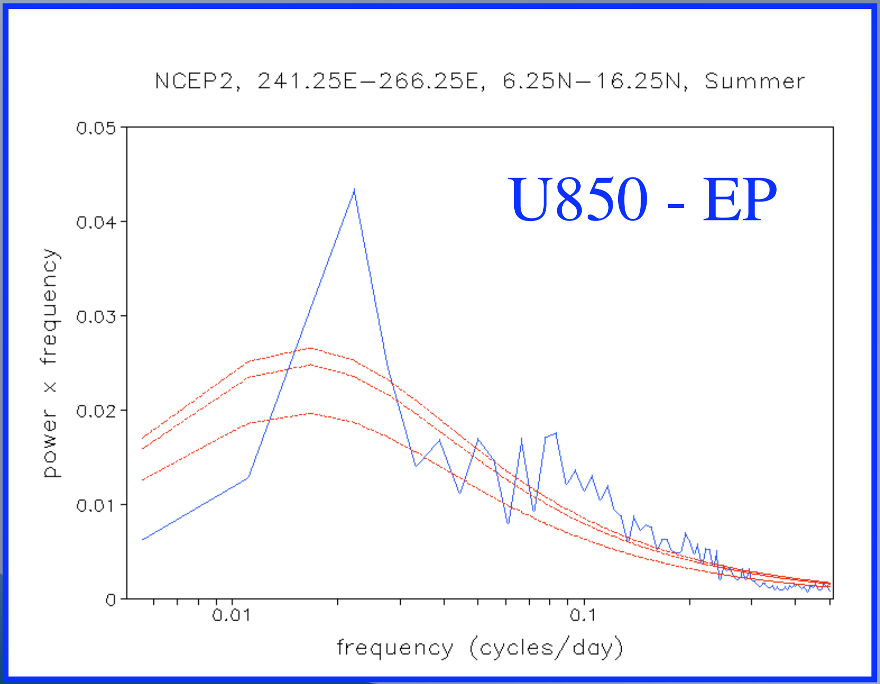
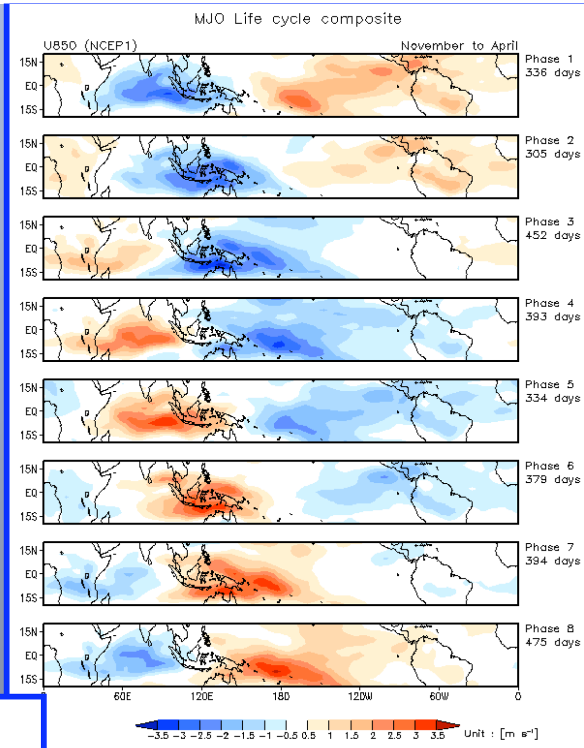


Table 1. Domains for time series power spectra metrics

	OLR	Precipitation	u_{850}	u_{200}
	Boreal Winter (November to April)			
IO	10S-5N, 75-100E	10S-5N, 75-100E	1.25°S-16.25°S, 68.75°E-96.25°E	3.75N-21.25N, 56.25E-78.75E
WP	20S-5S, 160E-185E	20S-5S, 160E-185E	1.25°N-13.75°S, 163.75°E-191.25°E	3.75N-21.25N, 123.75E-151.25E
MC	2.5S-17.5S, 115-145E	2.5S-17.5S; 115-145E		
EP				1.25N-16.25S, 256.25E-278.75E
	Boreal Summer (May to October)			
IO	10S-5N, 75-100E	10S-5N, 75-100E	21.25°N-3.75°N, 68.75°E-96.25°E	1.25°N-16.25°S, 43.75°E-71.25°E
BB	10-20N, 80-100E	10-20N, 80-100E		
WP	10-25N, 115-140E	10-25N, 115-140E	3.75°N-21.25°N, 118.75°E-146.25°E	3.75N-21.25N, 123.75E-151.25E
EP			6.25N-16.25N, 241.25E-266.25E	1.25°N-16.25°S, 238.75E-266.25E

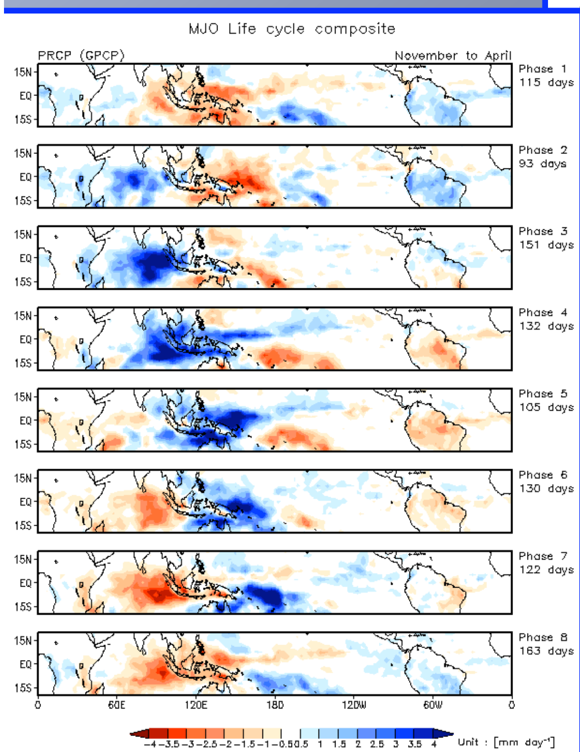
MJO Diagnostics

Life-Cycle Composites
U, Rain, OLR, SLP, SF



U850

Rainfall

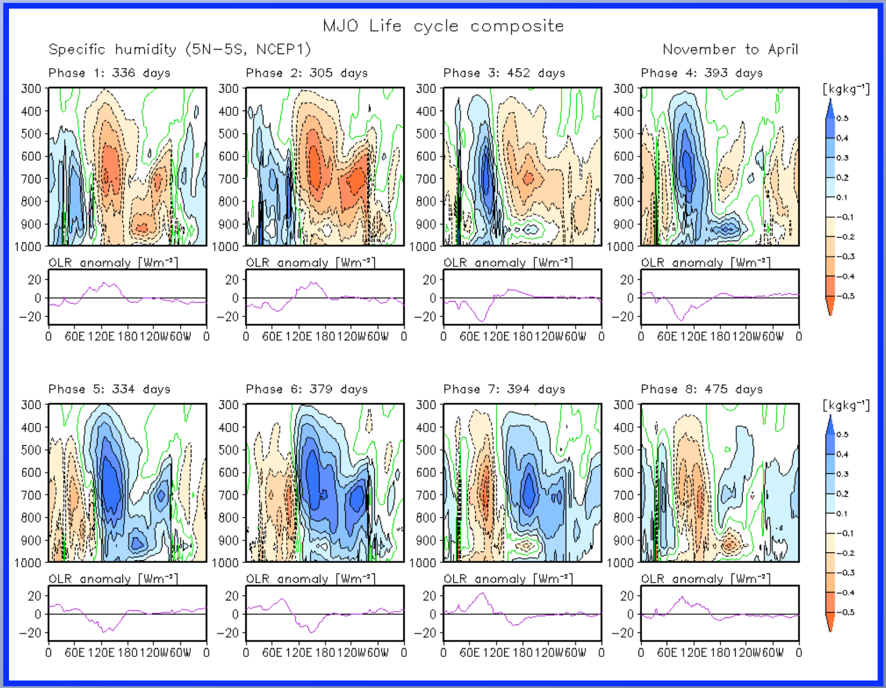


<u>Satellite Rain/Cloud</u>: AVHRR, GPCP, TRMM

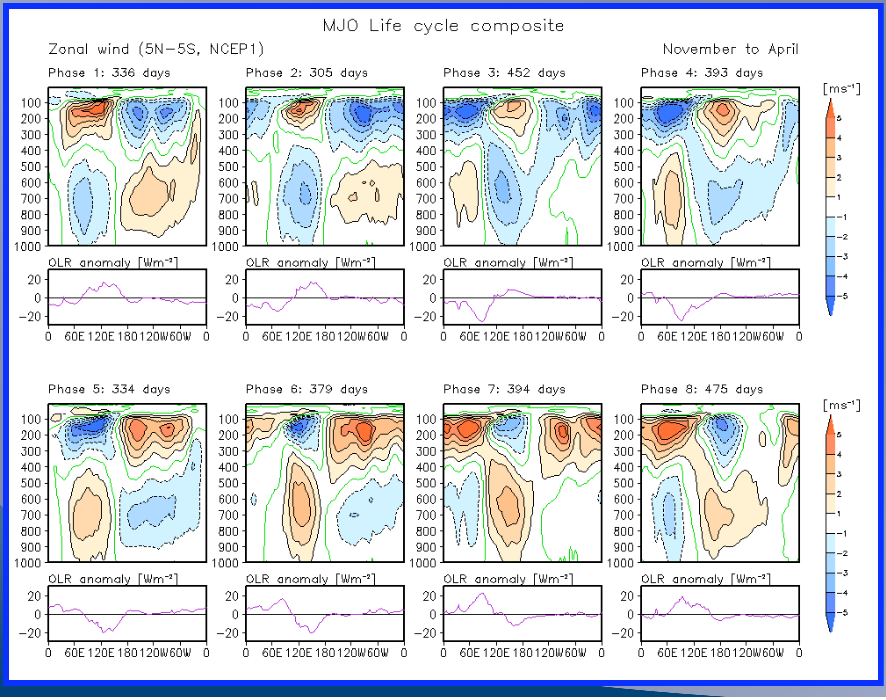
<u>Analysis Data:</u> NCEP1,NCEP2

MJO Diagnostics

Life-Cycle 3D Composites T, Q, U, W



Specific Humidity (x,p)

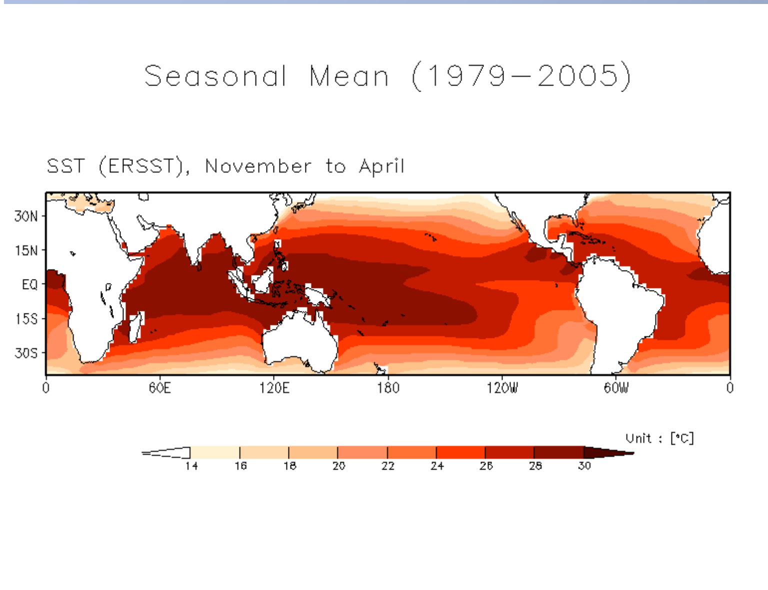


Zonal Wind (x,p)

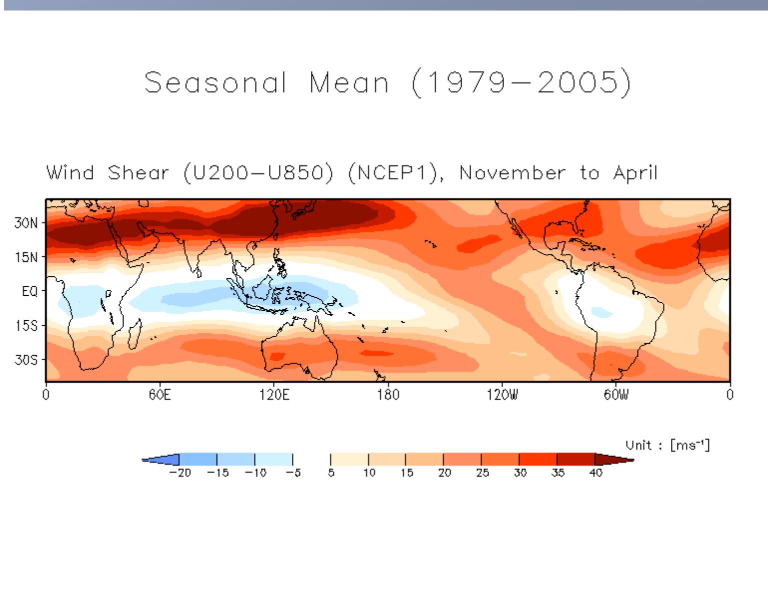
MJO Diagnostics

Important Mean State Quantities

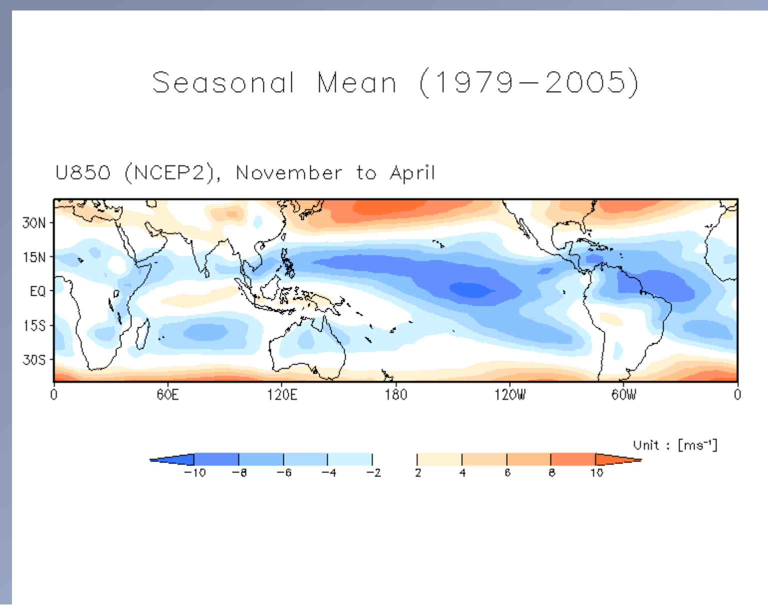
Mean SST



Mean Zonal Wind Shear



Mean 850 hPa Zonal Wind



MJO Model Diagnostics: Application to GCMs

Climate models

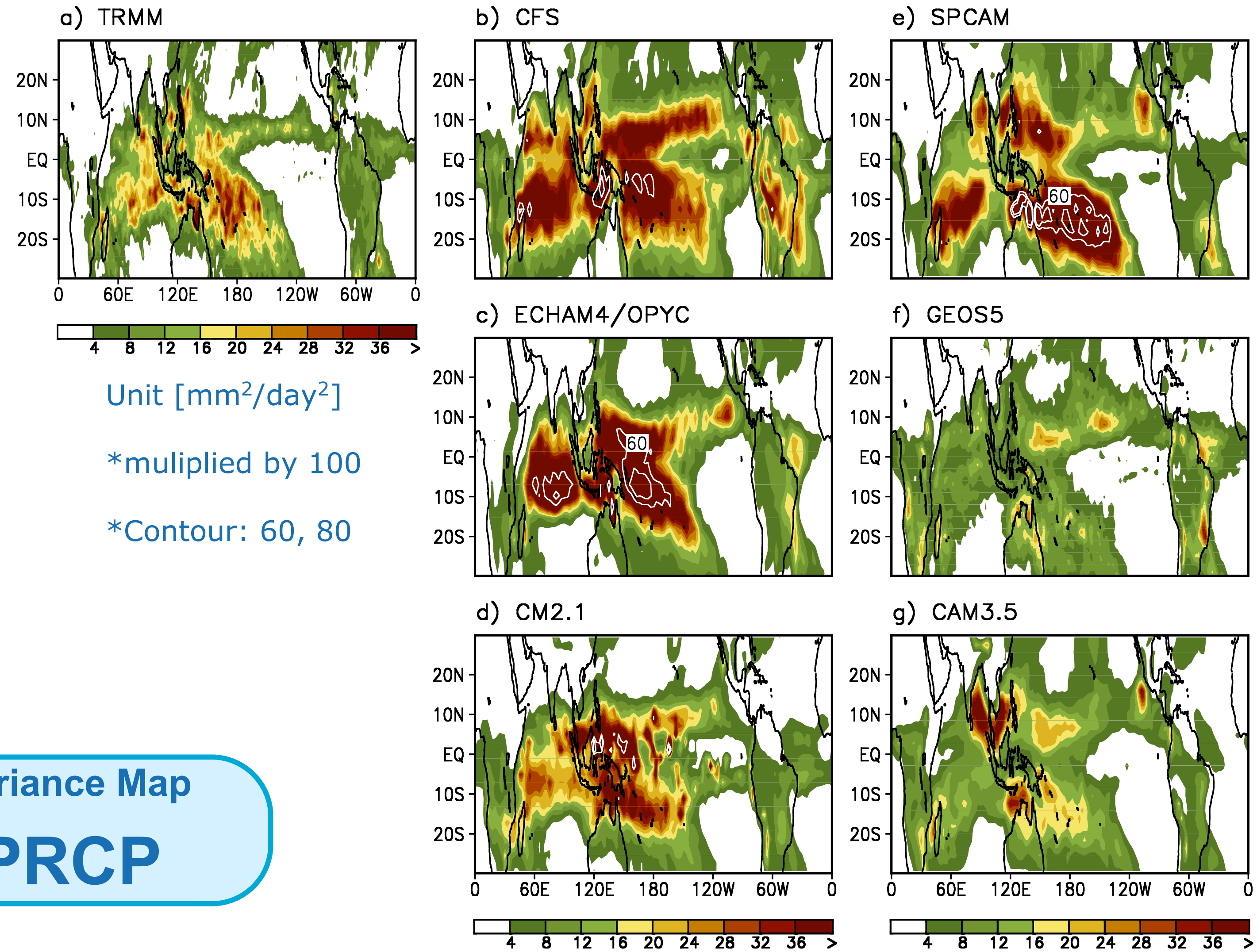
NCEP: Wanqiu Wang
PCMDI: Kenneth R. Sperber
GFDL: Bill Stern
CSU: Marat Khairoutdinov, David A. Randall
NASA/GSFC: Myong-In Lee, Max J. Suarez
CAM3.5: Richard B. Neale
SNU: In-Sik Kang

Model	Horizontal Resolution	Vertical Resolution (top level)	Cumulus parameterization	Integration	Reference
CFS - NCEP	T62(1.8°)	64 (0.2hPa)	**Mass flux** (Hong and Pan 1998)	20 years	Wang et al. (2005)
ECHAM4 /OPYC* - PCMDI	T42(2.8°)	19 (10hPa)	**Mass flux** (Tiedtke 1989, adjustment closure Nordeng 1994)	20 years	Sperber et al. (2005)
CM2.1 - GFDL	2° lat x 2.5° lon	24 (4.5hPa)	**Mass flux** (RAS; Moorthi and Suarez 1992)	20 years	Delworth et al. (2006)
SPCAM - CSU	T42(2.8°)	26 (3.5hPa)	**Superparameterization** (Khairoutdinov and Randall 2003)	19 years 01OCT1985-25SEP2005	Khairoutdinov et al. (2005)
GEOS5 - NASA	1° lat x 1.25° lon	72 (0.01hPa)	**Mass flux** (RAS; Moorthi and Suarez 1992)	12 years 01DEC1993-30NOV2005	To be documented
CAM3.5 - NCAR	1.9° lat x 2.5° lon	26 (2.2hPa)	**Mass flux** (Zhang and McFarlane 1995)	20 years 01JAN1986-31DEC2005	Neale et al. (2007)

*flux adjustment for heat and fresh water

Variance Map Diagnostics

Variance of 20-100 day filtered precipitation (Nov-Apr)



Unit [mm²/day²]

*mulipled by 100

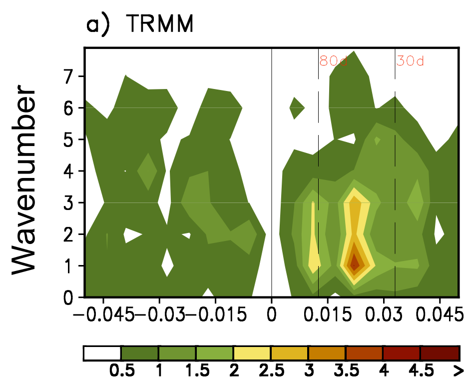
*Contour: 60, 80

Variance Map

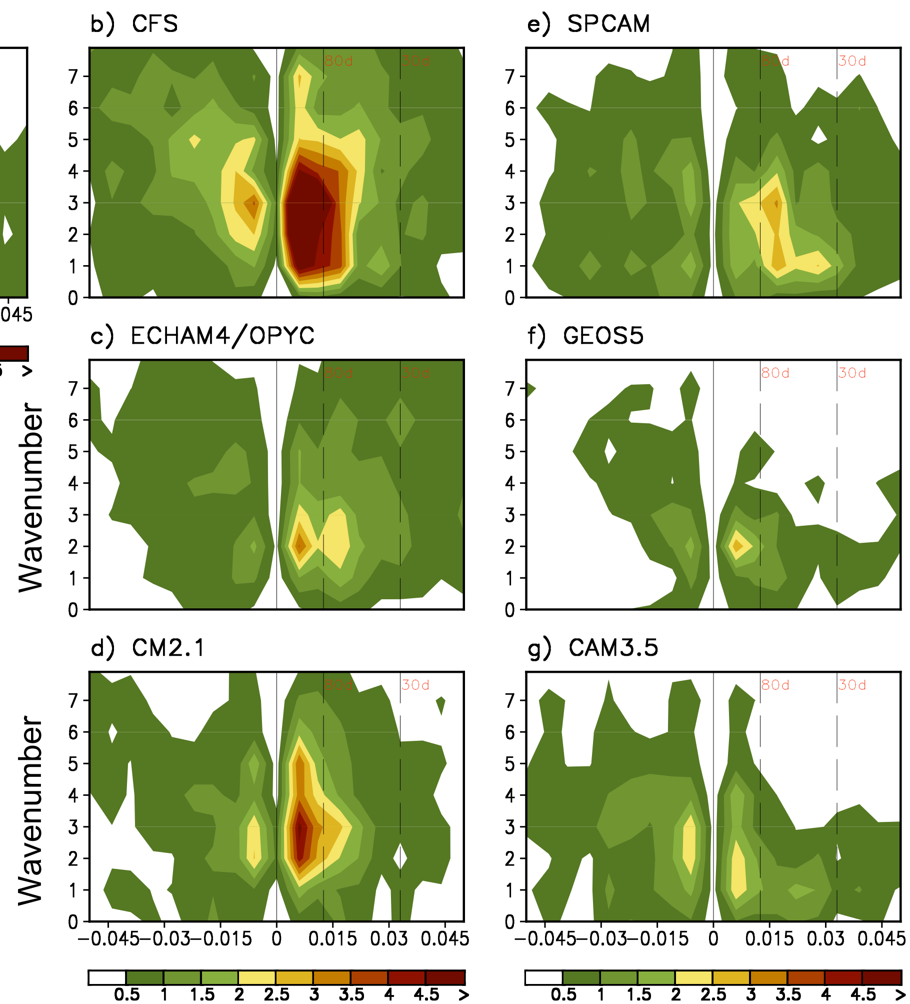
PRCP

FREQUENCY-WAVE SPECTRA DIAGNOSTICS

Equatorial space-time power spectrum (Nov-Apr)



Unit [mm²/day²]
*multiplied by 100

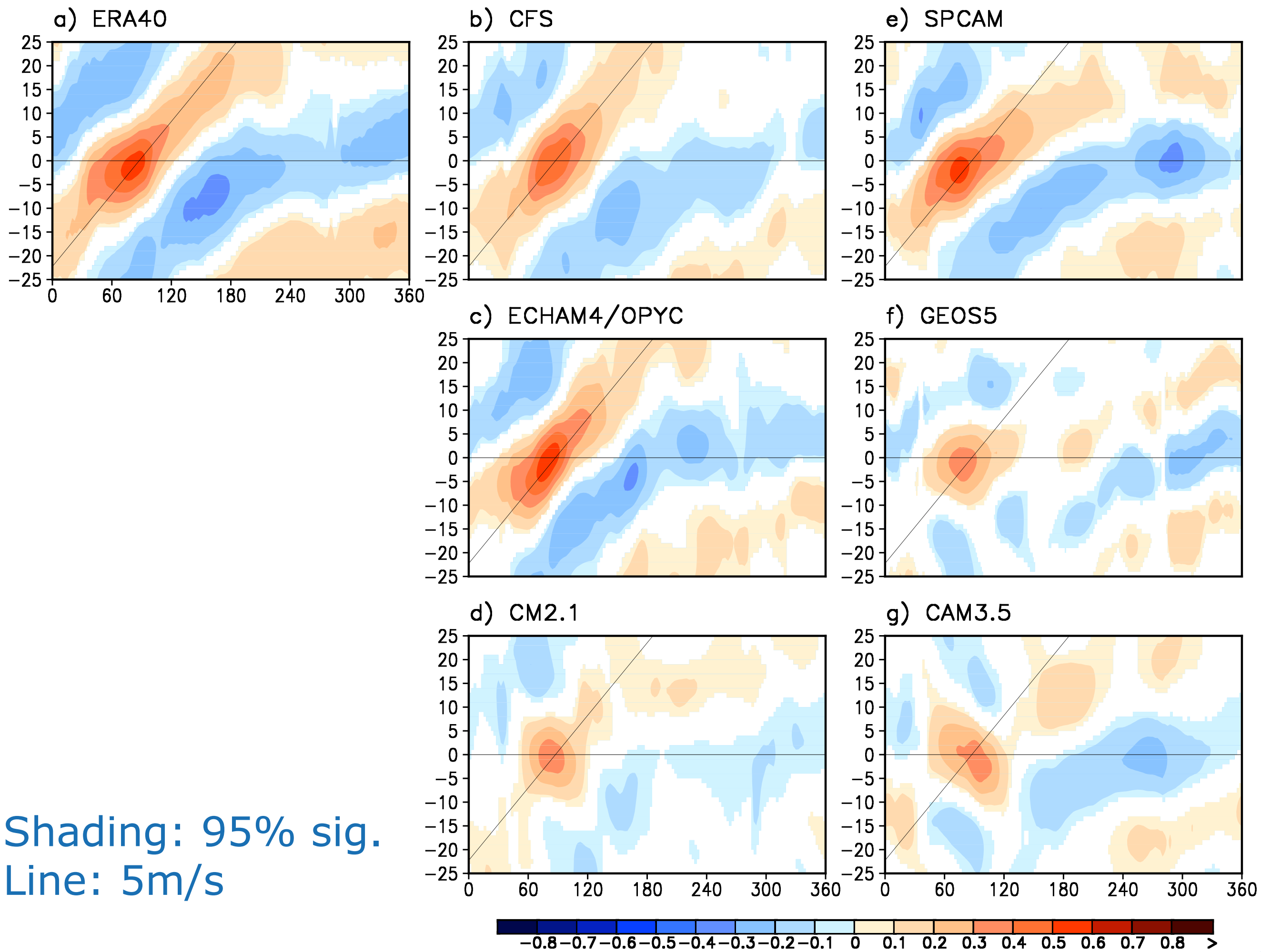


Frequency-Wave

PRCP

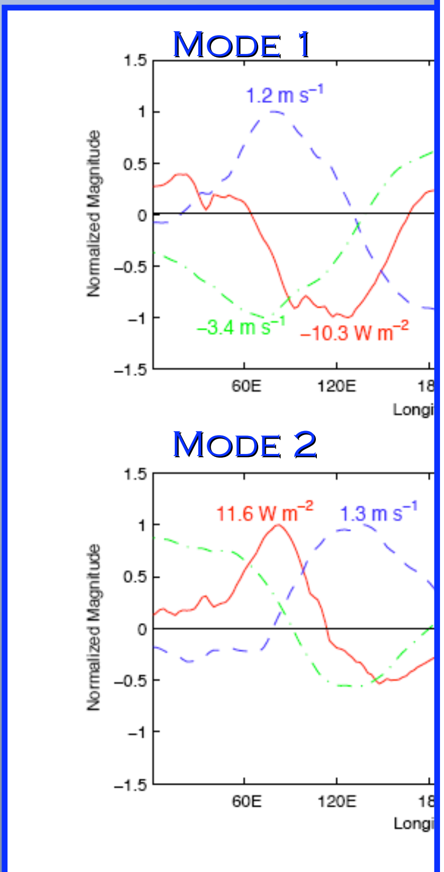
Lag - Correlation Diagnostics

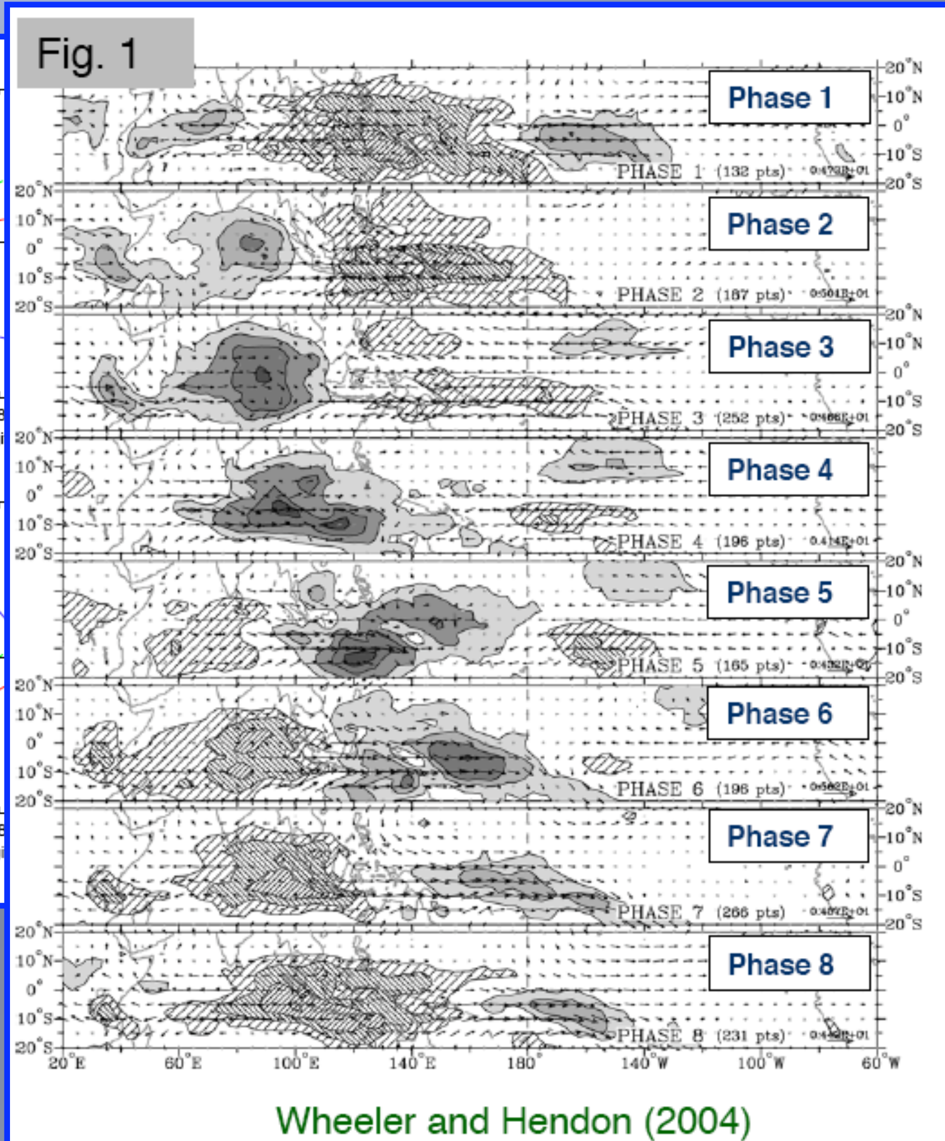
U850: Lag-correlation diagnostics (Nov-Apr)

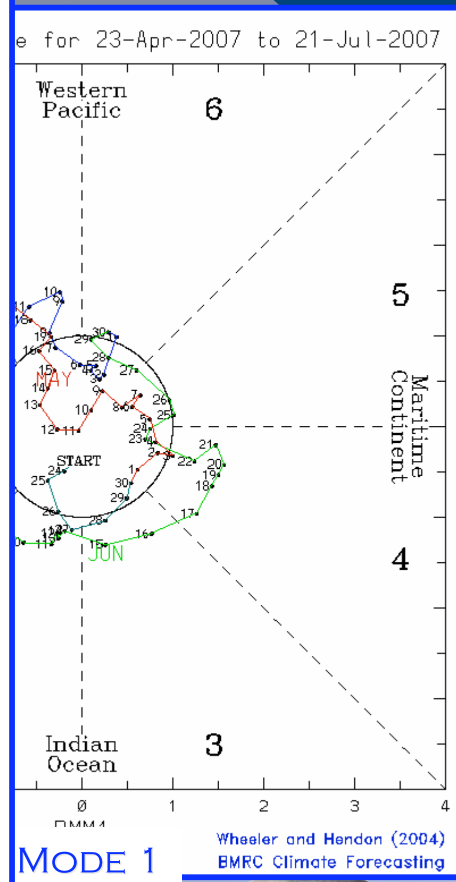


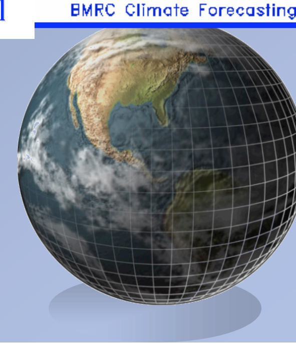
*Shading: 95% sig.
*Line: 5m/s

Developing an MJO Forecast Metric





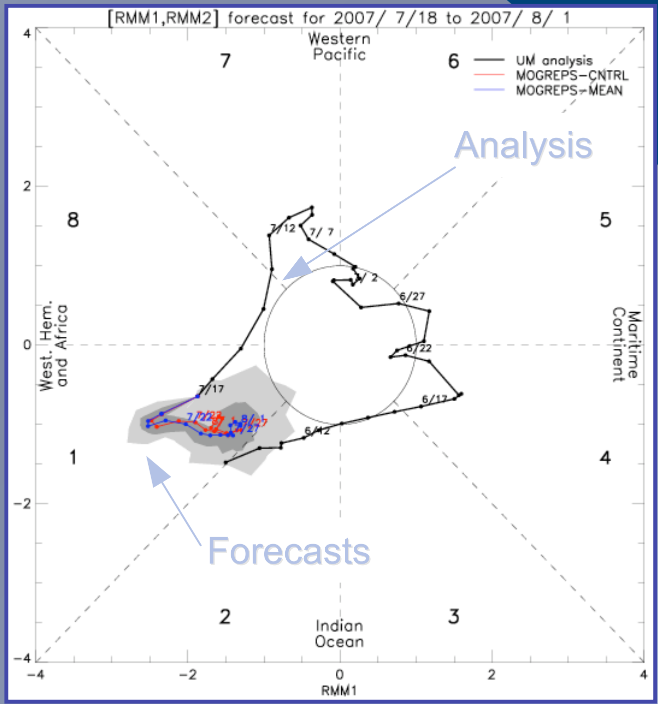




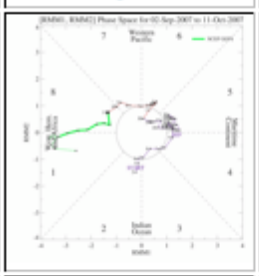
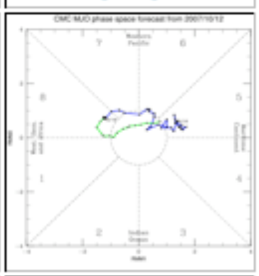
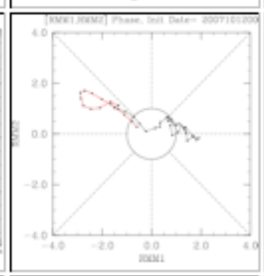
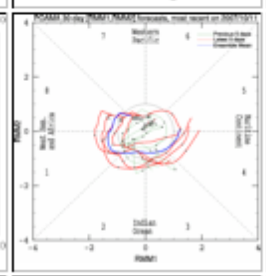
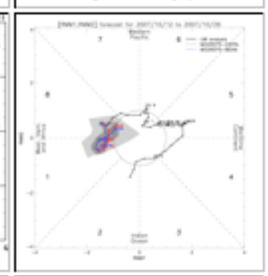
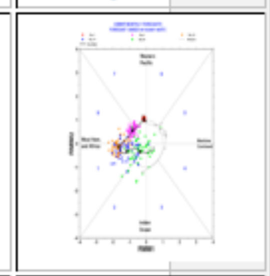
Implementing the MJO Forecast Metric Into the Operational Environment

- This metric is now in use or will be adopted by a number of operational weather forecast centers (e.g., ECMWF, US, Canada, UK, Australia).

- Use of a common forecast metric allows for:
  - ✓ quantitative forecast skill assessment.
  - ✓ targeted model improvements.
  - ✓ even friendly competition to motivate further improvements.
  - ✓ developing a multi-model ensemble forecast of the MJO.



Based on Wheeler & Hendon 2004

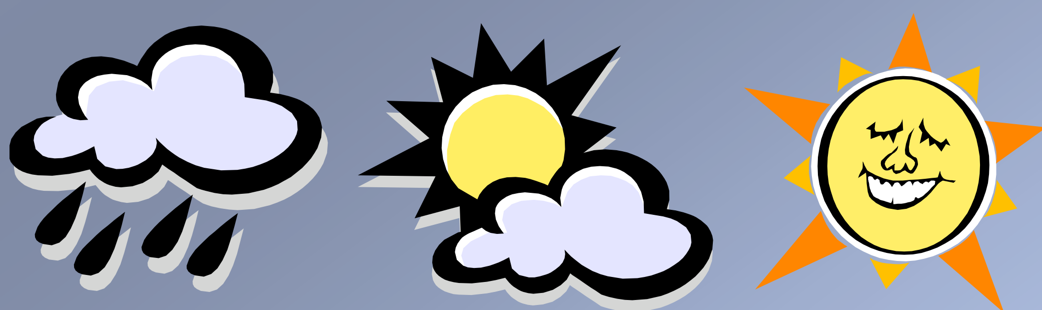
	Forecast Center					
	NCEP	CMC	PSD	BMRC	UK Met	ECMWF
All RMM plots						

http://www.cdc.noaa.gov/MJO/Forecasts/index_phase.html

While Challenges Remain……
Based on growing awareness, interest, resources & capabilities:

The outlook for MJO-Based Environmental Predictions is Continuing to Improve

Day 1-10	Day 11-20	Day 21-30



http://www.usclivar.org/Organization/MJO_WG.html