MJO and Other Tropical Equatorial Waves

WMO RCC Training Workshop

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NCWCP

Outline

- MJO
  - ✓ Characteristics, structure, dynamics
  - ✓ Monitoring
  - ✓ Prediction skill
  - ✓ Impacts

- Atmospheric Kelvin and Equatorial Rossby Waves
  - ✓ Overview, characteristics
  - ✓ Monitoring and Predictions

- Available Operational MJO assessments

Madden-Julian Oscillation

MJO Characteristics

- The MJO is an intraseasonal “wave“ originating in the Tropics

- The MJO results in changes in atmospheric and oceanic variables

    - Lower- and upper-level wind
    - Cloudiness and tropical rainfall
    - Sea level Pressure
    - Sea surface temperature (SST)
    - Ocean surface evaporation
    - Ocean chlorophyll

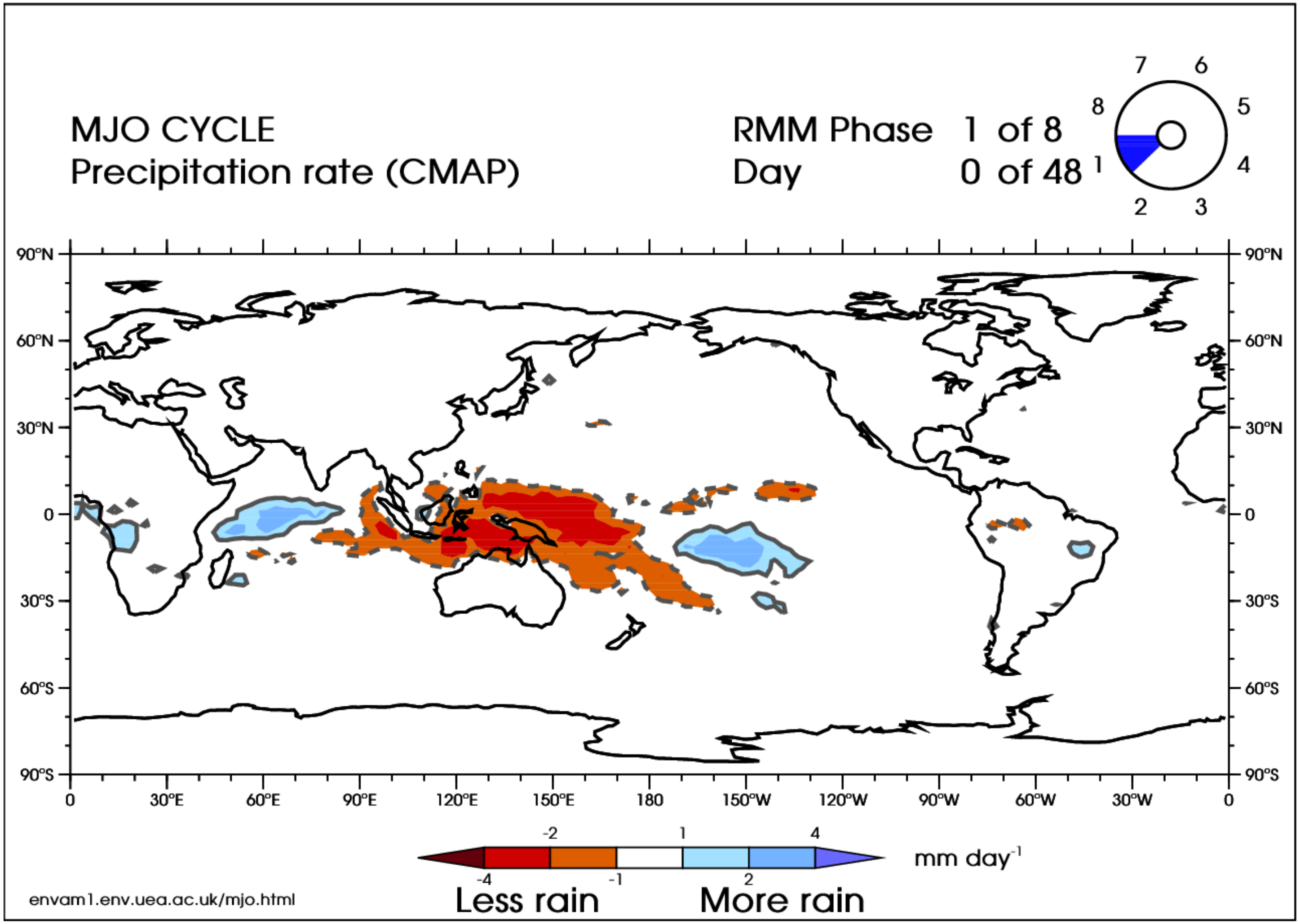
- *Typical* period of the MJO cycle is approximately 30-60 days

- Acts on a global spatial scale

- Coherent eastward propagation (EH 5 m/s and WH 15 m/s)

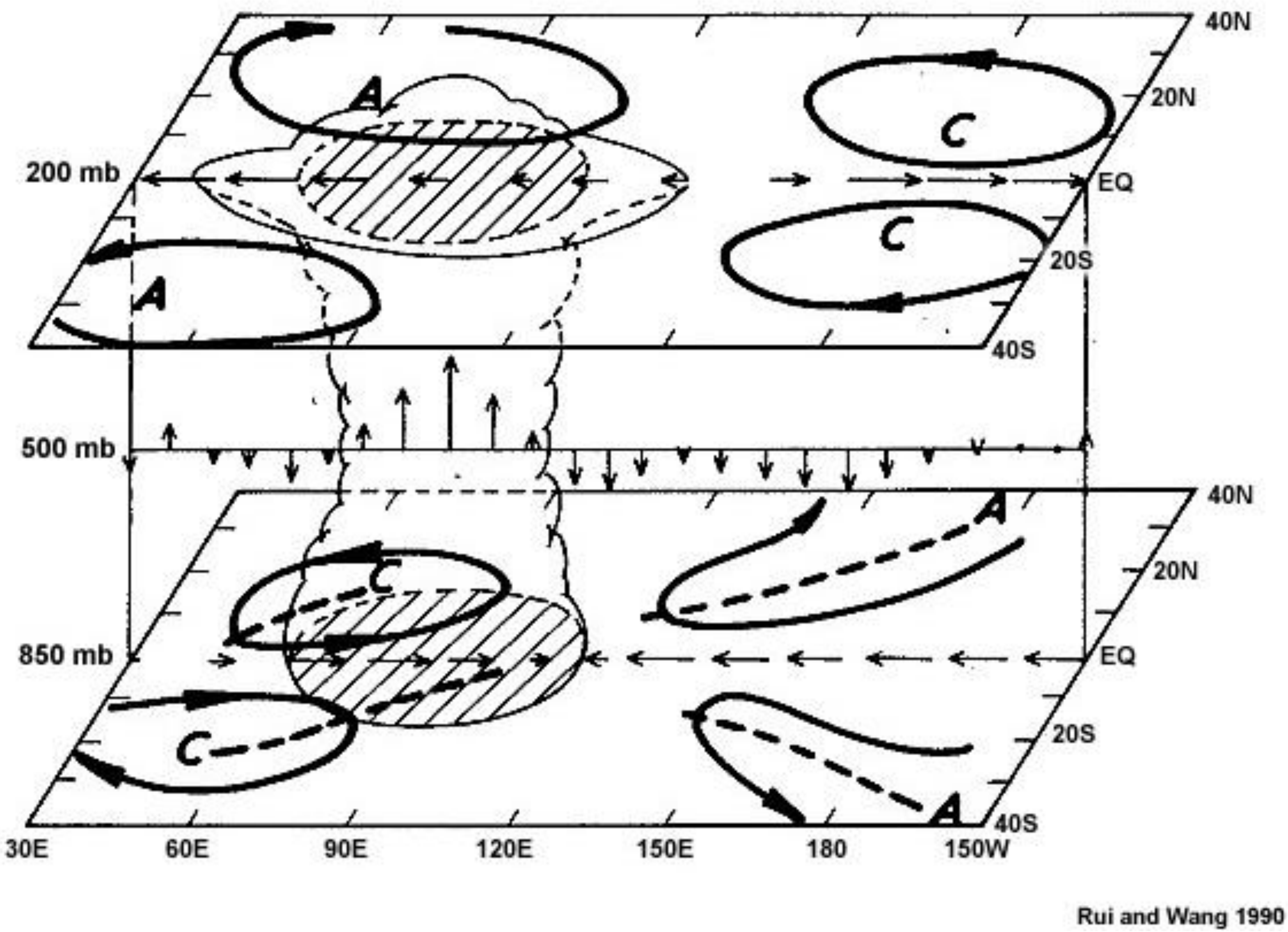
Madden and Julian, 1971; 1972; Zhang, 2005; Hendon and Salby, 1994

MJO Characteristics



Courtesy: Adrian Matthews, Univ. East Anglia, UK

Schematic of Three-Dimensional MJO Structure



Rainfall Composite of MJO Lifecycle

Green areas

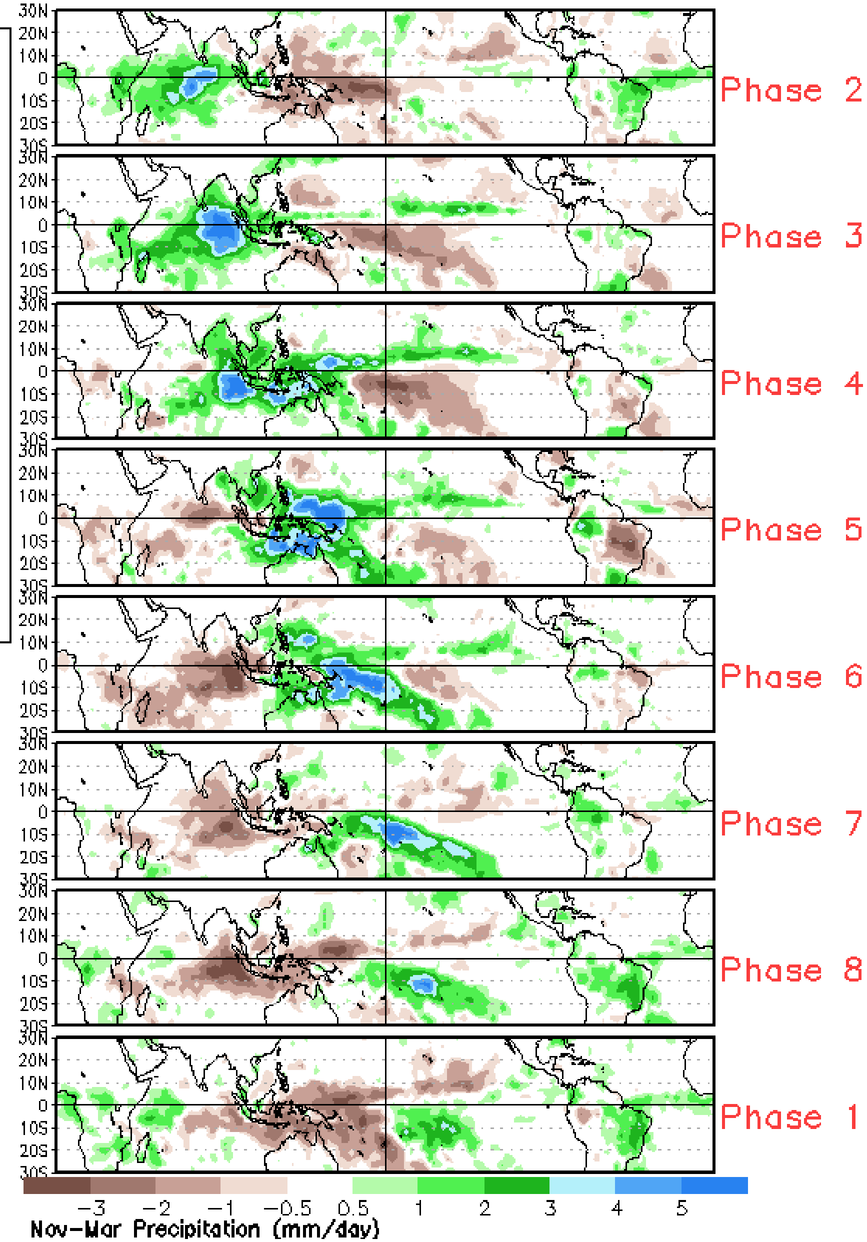
Above normal rainfall

Enhanced convective phase of MJO

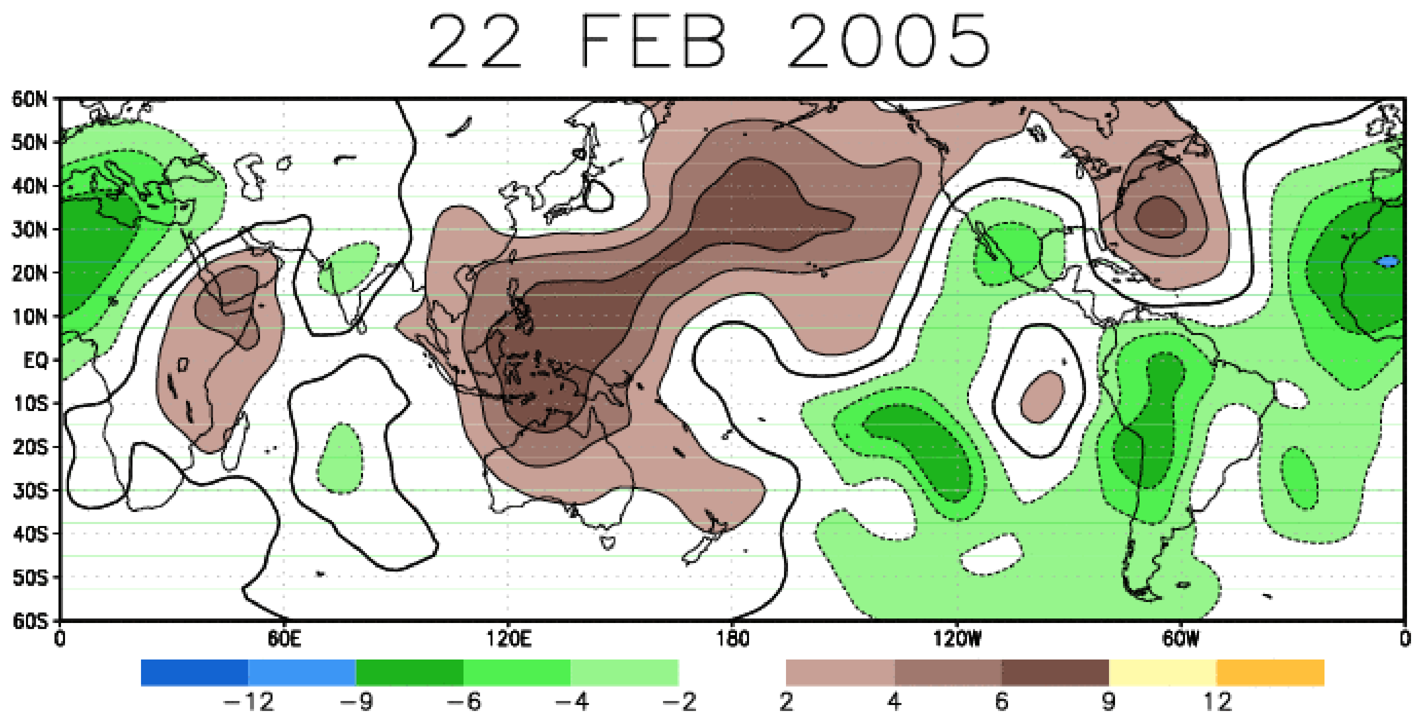
Brown areas

Below normal rainfall

Suppressed convective phase of MJO



200-hPa Velocity Potential Animation



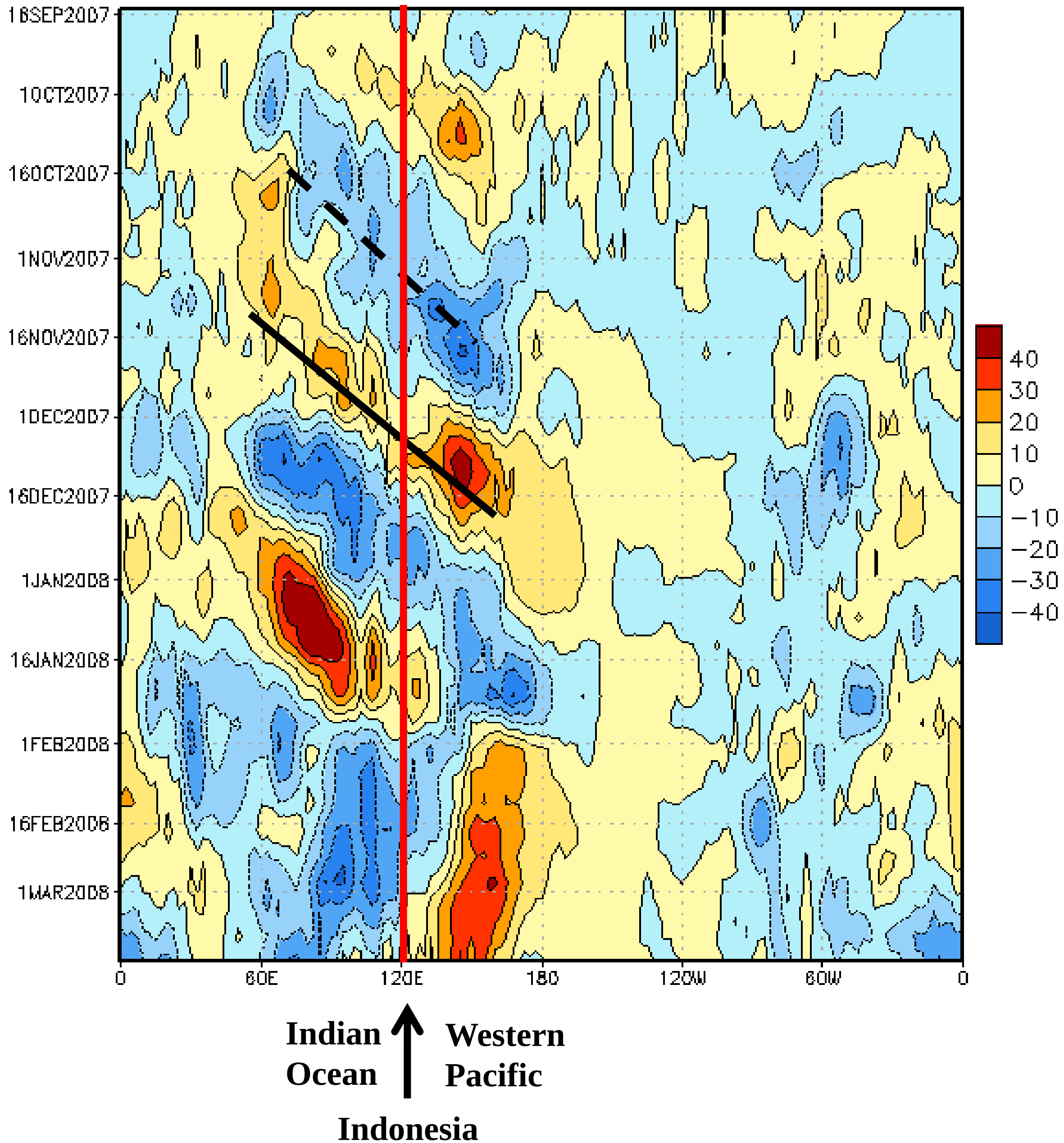
Time-Longitude Diagram – Outgoing Longwave Radiation (OLR)

5°N – 5 °S Average

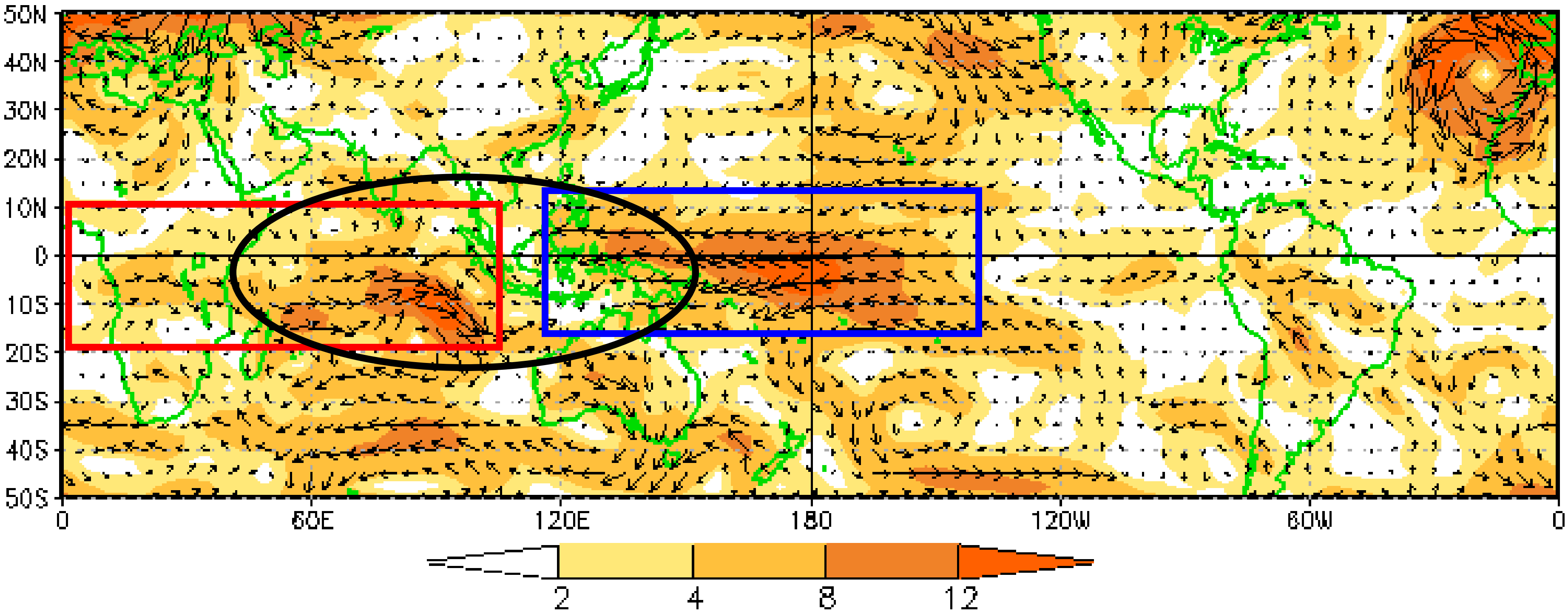
Eastward Propagation

Blue shades
Enhanced convection
Increased rainfall
Negative anomalies

Red/Yellow shades
Suppressed convection
Decreased rainfall
Positive anomalies

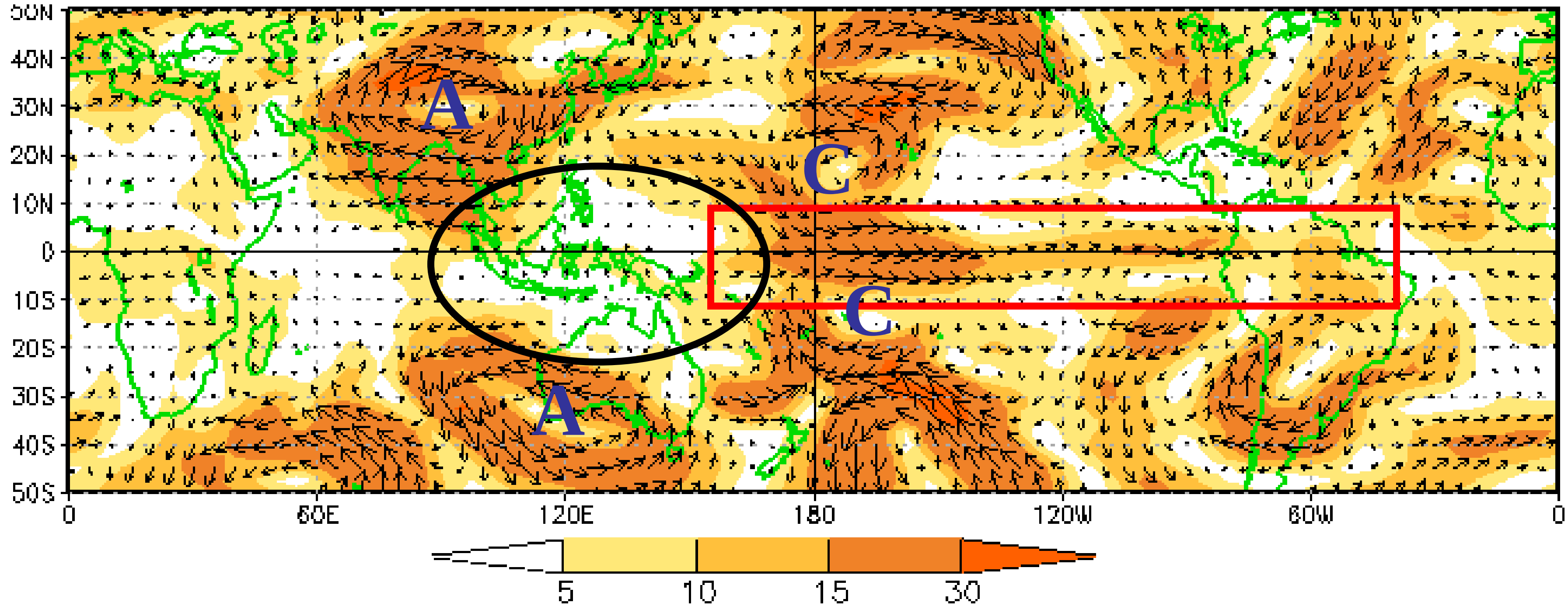


Spatial Distribution – 850-hPa Zonal Winds



- Enhanced convective phase of MJO centered over eastern Indian Ocean
- Boxes indicate enhanced westerly (red) and easterly (blue) anomalies
- Low-level convergence (black circle)

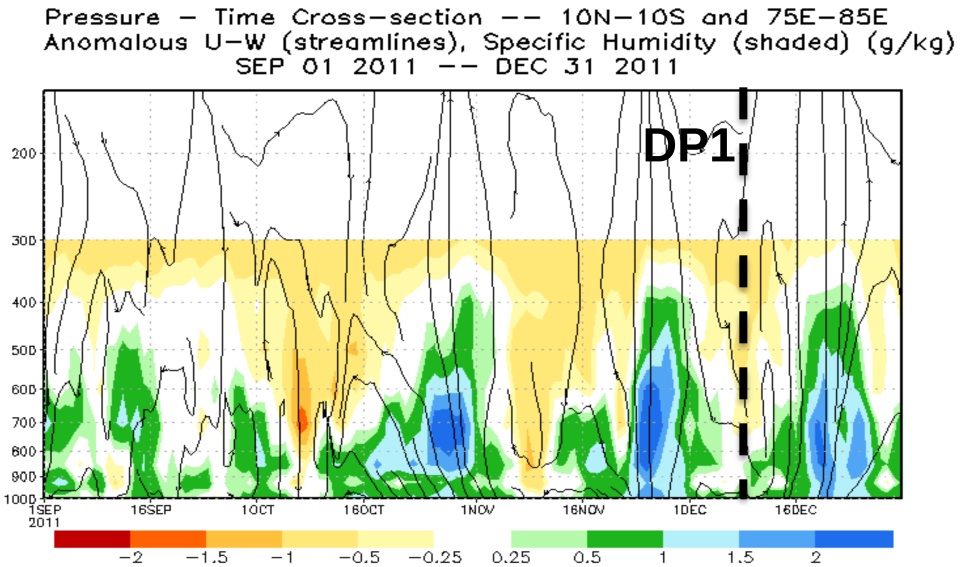
Spatial Distribution – 200-hPa Zonal Winds



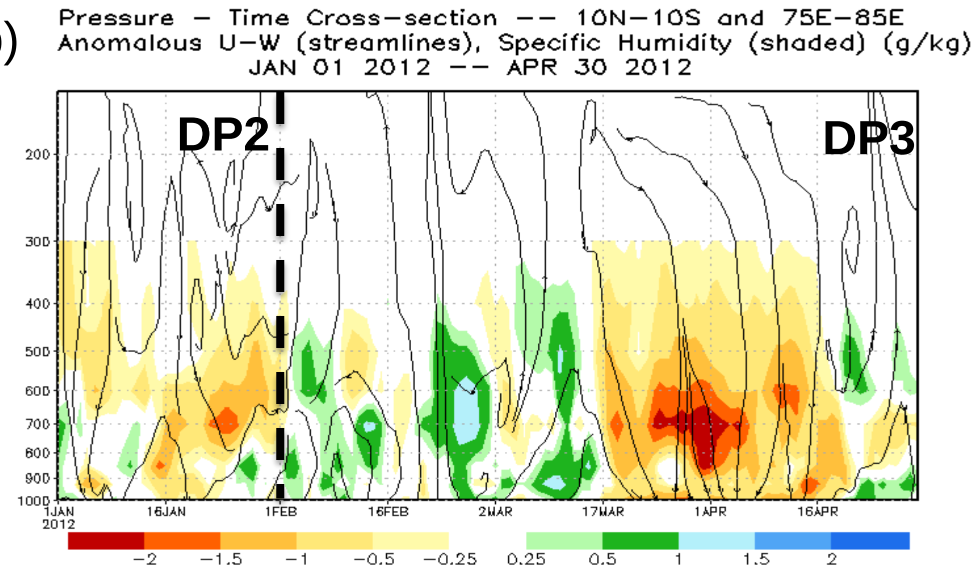
- Enhanced phase of MJO (black circle) centered across Indonesia
- Anticyclonic (A) and cyclonic (C) circulations straddling anomalous tropical convection
- Westerly anomalies over the eastern equatorial Pacific Ocean (red box)

Pressure-Time Cross Section Anomalous Specific Humidity

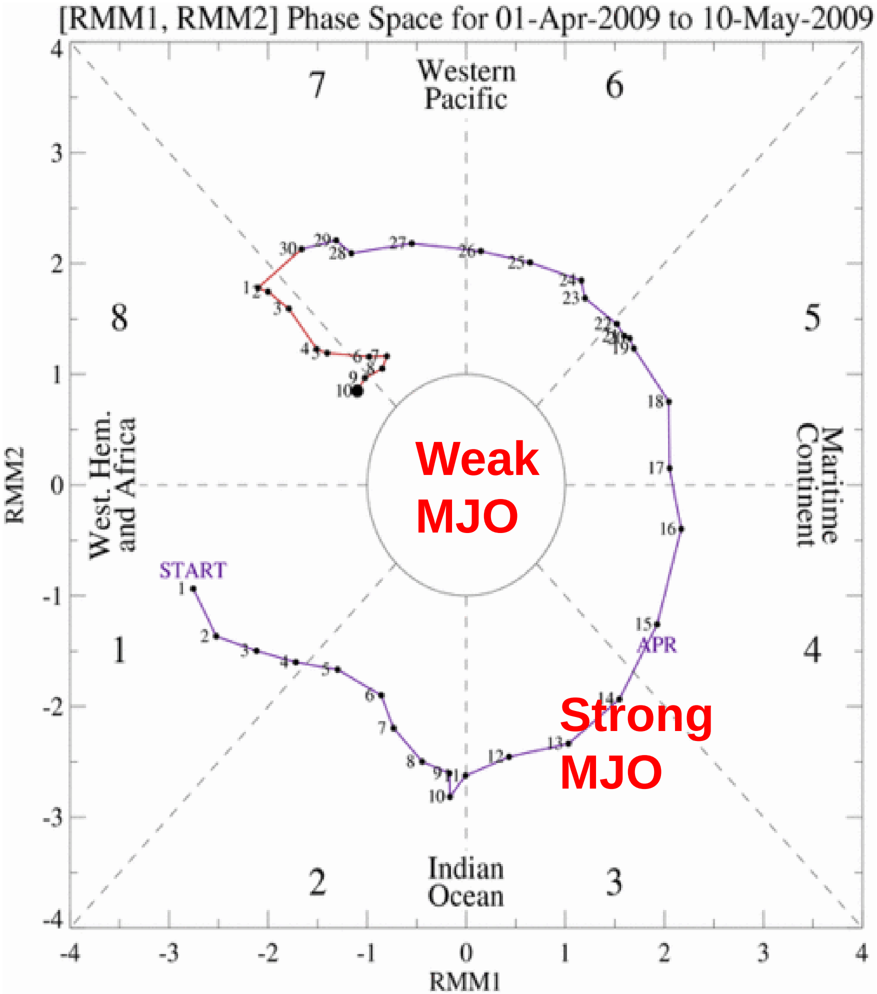
(a)



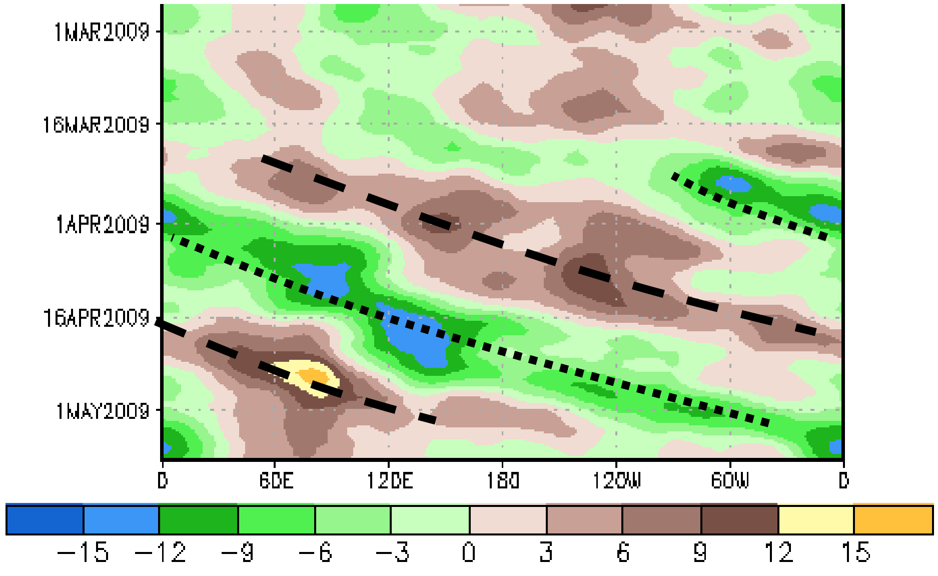
(b)



MJO Index – RMM



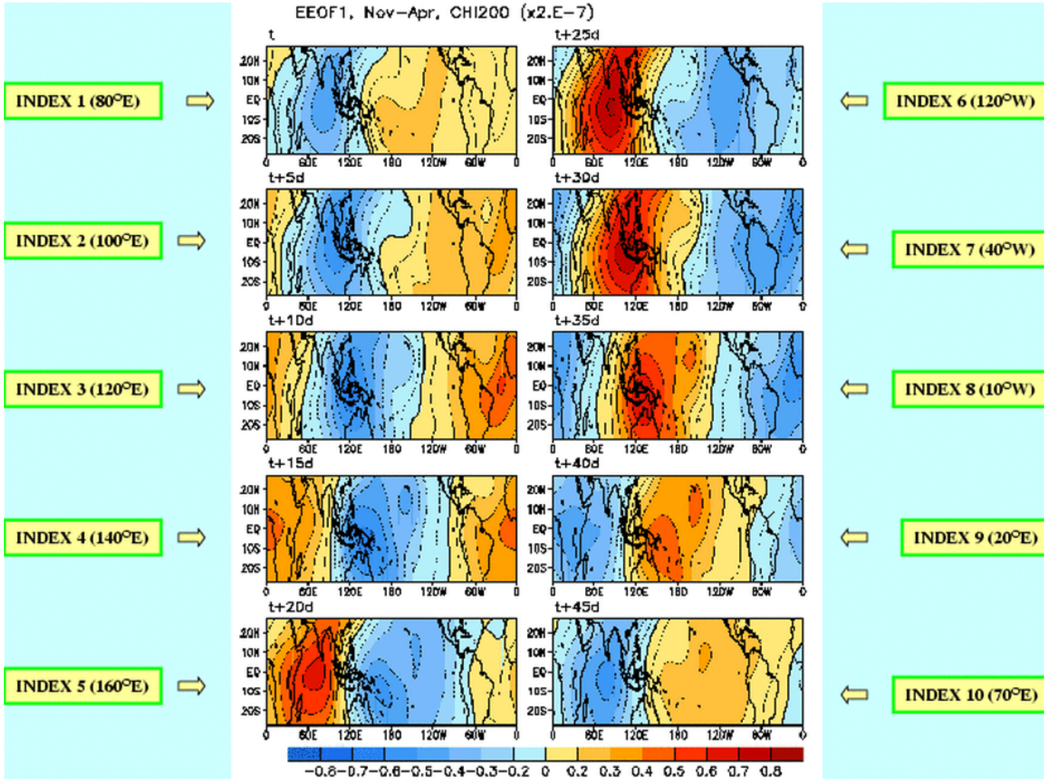
- The axes (RMM1 and RMM2) represent daily values of the PCs from two modes
- The triangular areas indicate the location of the MJO enhanced convective phase
- Counter-clockwise motion is indicative of eastward propagation. Large dot most recent day.
- Distance from center proportional to strength
- Line colors distinguish different months

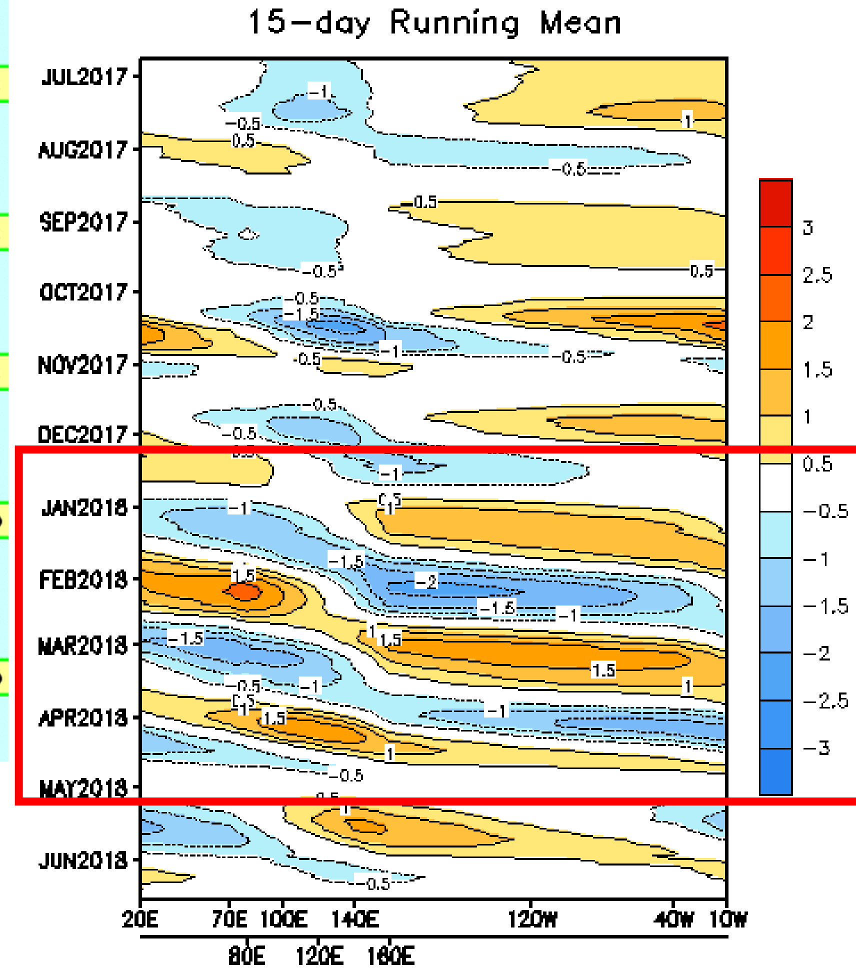


- EOF analysis (OLR, 850/200-hPa zonal winds)
- Index based on first 2 modes

Wheeler and Hendon, 2004

MJO Index – 200-hPa Velocity Potential





Xue et al. 2002

Attributes:
--Pentad velocity potential
--Extended EOF analysis
--ENSO neutral years only

Advantages:
--Velocity potential a very coherent measure of the MJO
--Temporal filtering implied with methodology

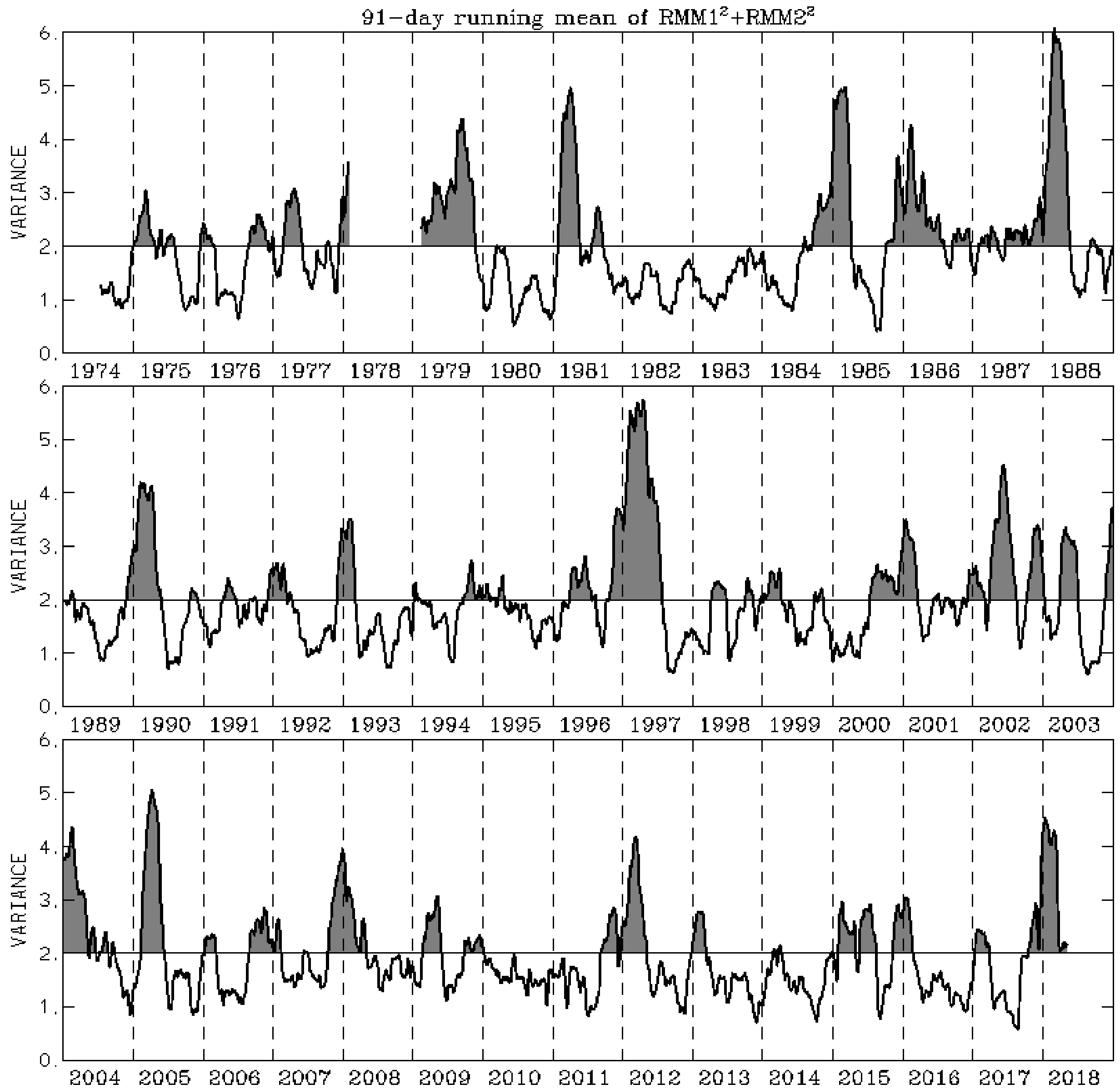
Disadvantages:
--Strong lagging index

Interannual Variability of the MJO – RMM

There is strong year to year variability in MJO activity

This interannual variability may be partly linked to the ENSO cycle

Grey areas are "active" MJO periods



Courtesy: Australia CAWCR

http://cawcr.gov.au/staff/mwheeler/maproom/RMM/ts.PCvar91drm.gif

MJO Prediction – Overview

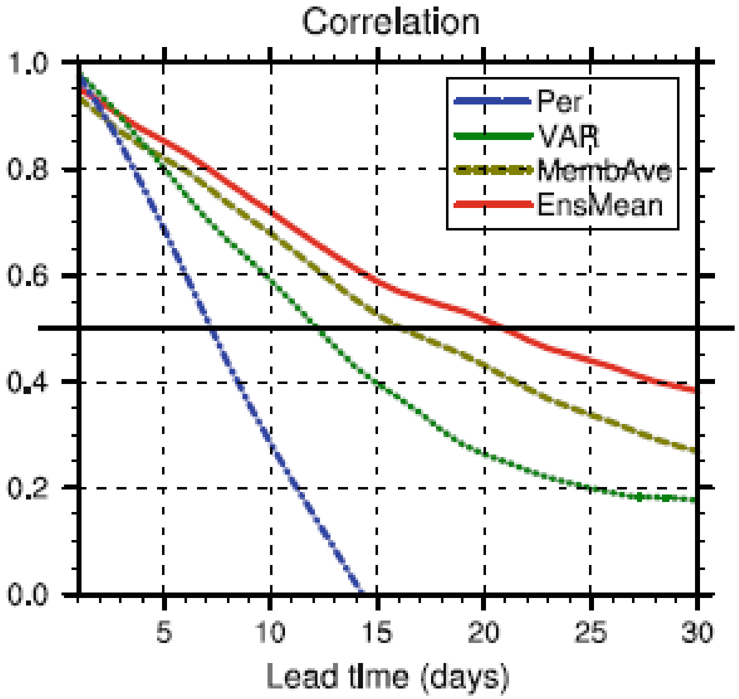
- The MJO is predictable at a forecast lead time ranging from 10-35 days depending on the forecast method and skill metric used

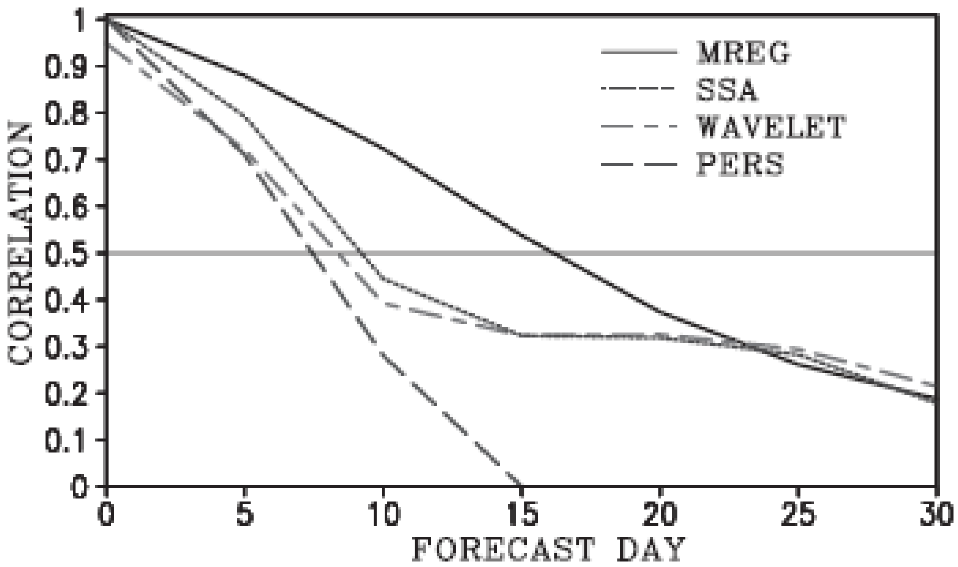
- Considerable portion of the forecast skill comes from established ongoing events

- Transitions (MJO onset/decay) remain a challenge at times, but progress has been made regarding MJO onset in part by major efforts such as the DYNAMO field campaign (2011-2012)

- Both statistical and dynamical model predictions are available

MJO Prediction – Baseline Forecast Skill





Comparison of methods:

Useful skill:

Persistence: 7 days

Simple statistical: 12 days

POAMA model: 15-20 days

Rashid et al. 2010

Other statistical MJO forecasts (MLR, Wavelet, SSA)

Useful skill:

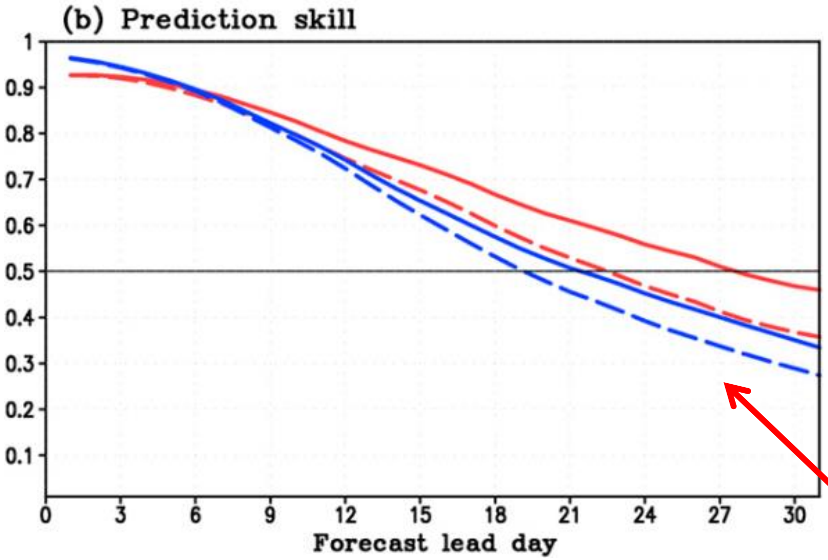
Persistence: 7 days

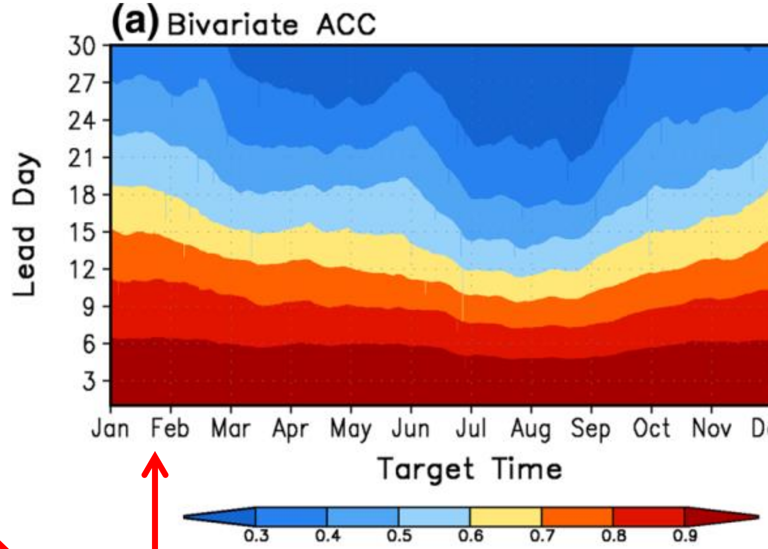
Wavelet, SSA: 10 days

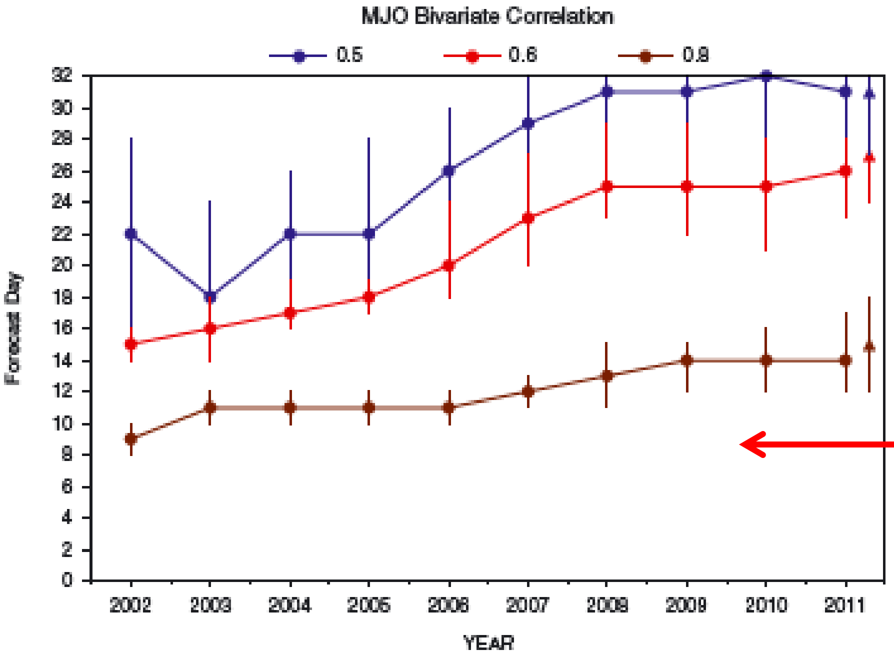
MLR: 16 days

Kang and Kim, 2010

MJO Prediction – CFS / ECMWF Forecast Skill







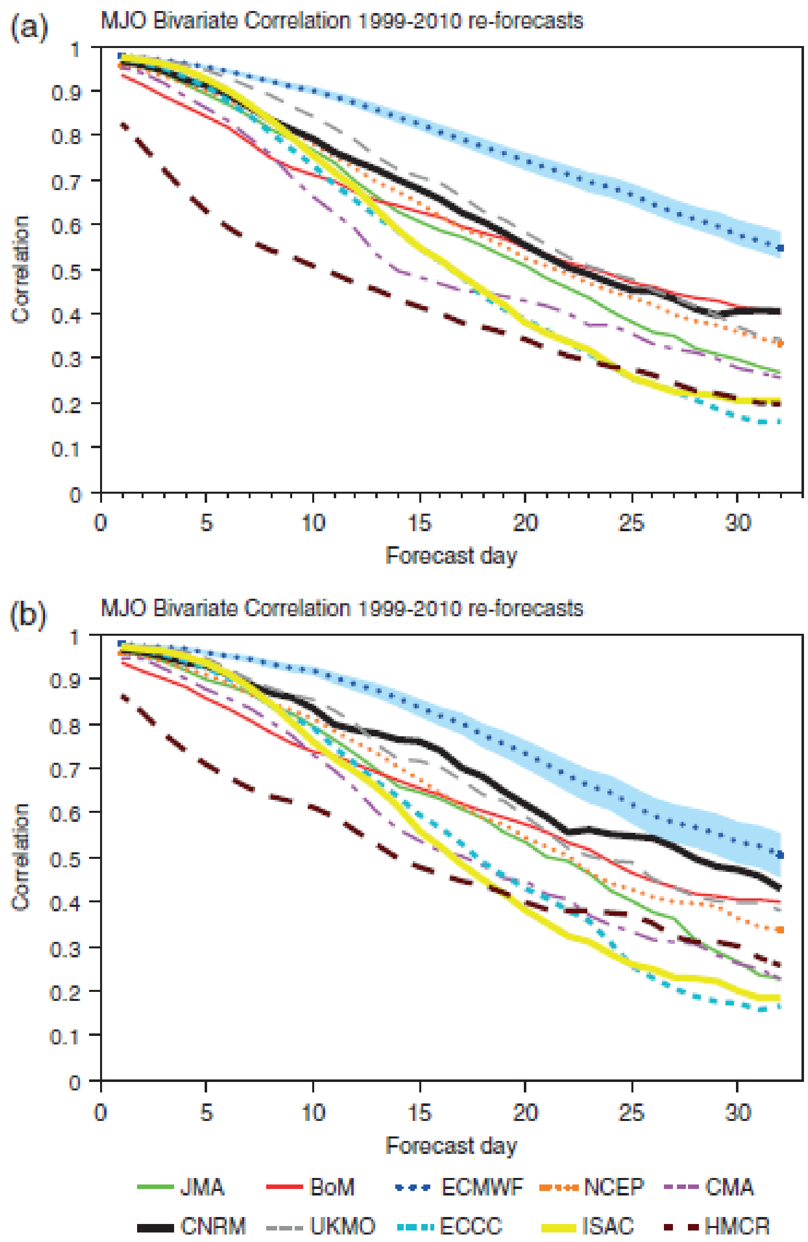
(top left) ECMWF (red) and CFS (blue) RMM bivariate correlation

(above) CFS RMM bivariate correlation as a function time of the year and forecast lead

(left) ECMWF RMM bivariate correlation change as a function of year for set given AC thresholds (*r*=0.5, *r*=0.6, *r*=0.8)

Kim et al. 2014; Wang et al. 2014; Vitart et al. 2014

MJO Prediction – S2S Models Forecast Skill

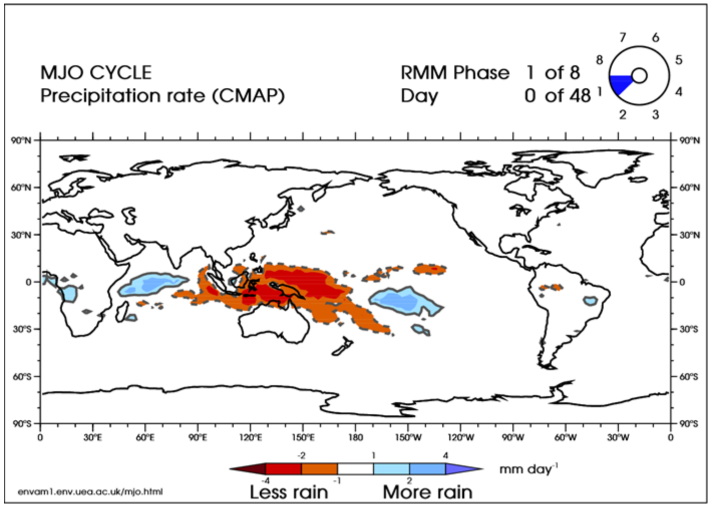


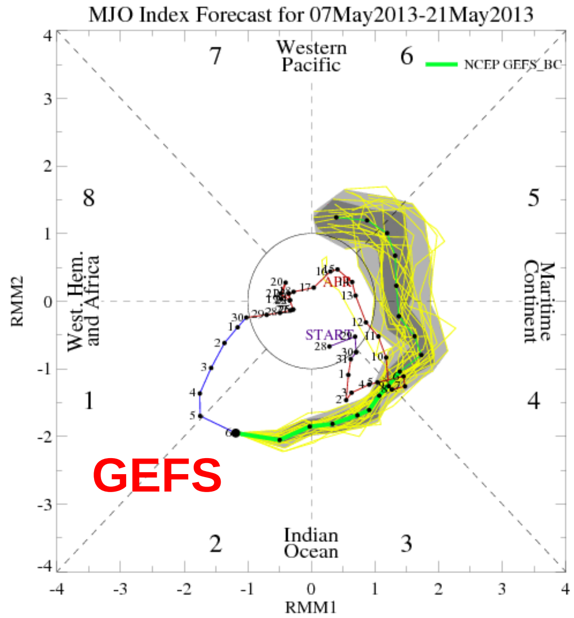
(top) RMM bivariate correlation for all seasons for the 1999-2010 overlapping reforecast period for various S2S contributing forecast models

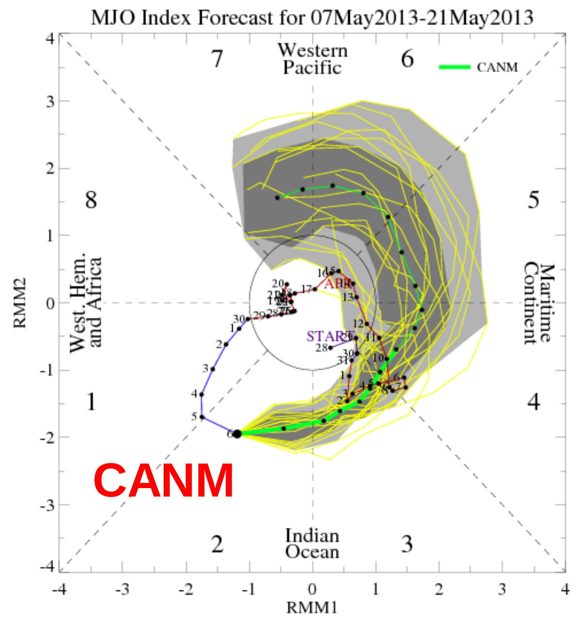
(bottom) RMM bivariate correlation for extended winter days only for same reforecast period denoted above (Dec-Mar)

Vitart et al. 2017

Operational Realtime Dynamical Model Prediction







- Application of Wheeler and Hendon (2004) MJO index methodology to dynamical model data from operational international centers
- Uniform approach for comparison and skill assessment
- Realtime forecasts

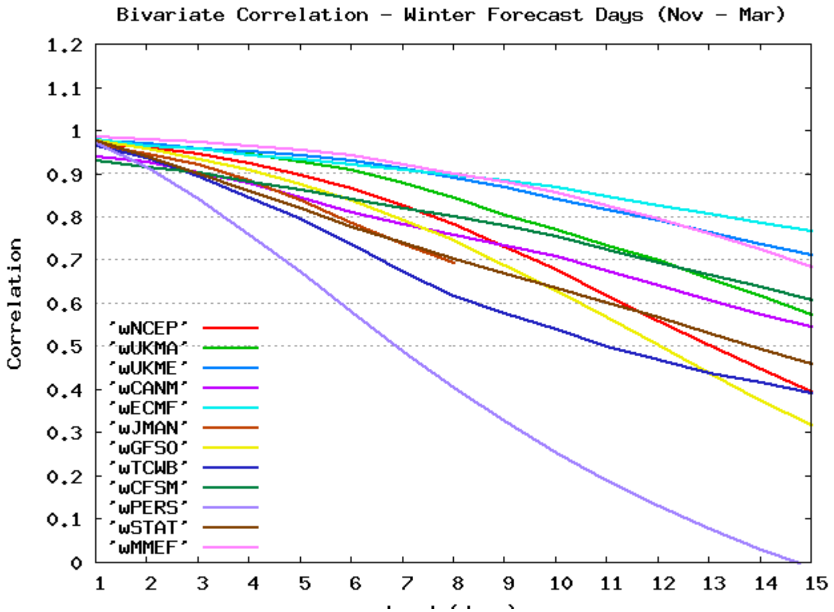
Differences in:

(1) Ensemble spread
(2) Propagation speed
(3) Amplitude

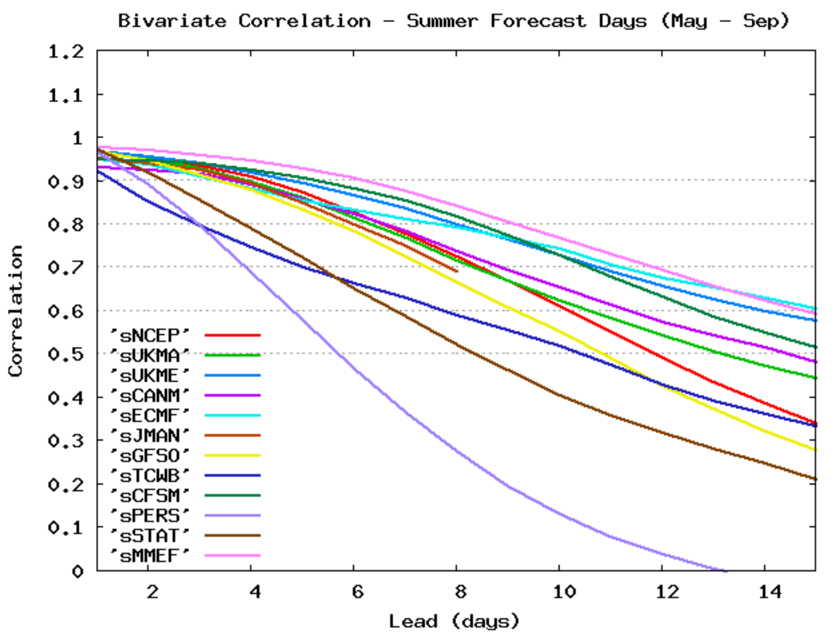
Gottschalck et al. 2010

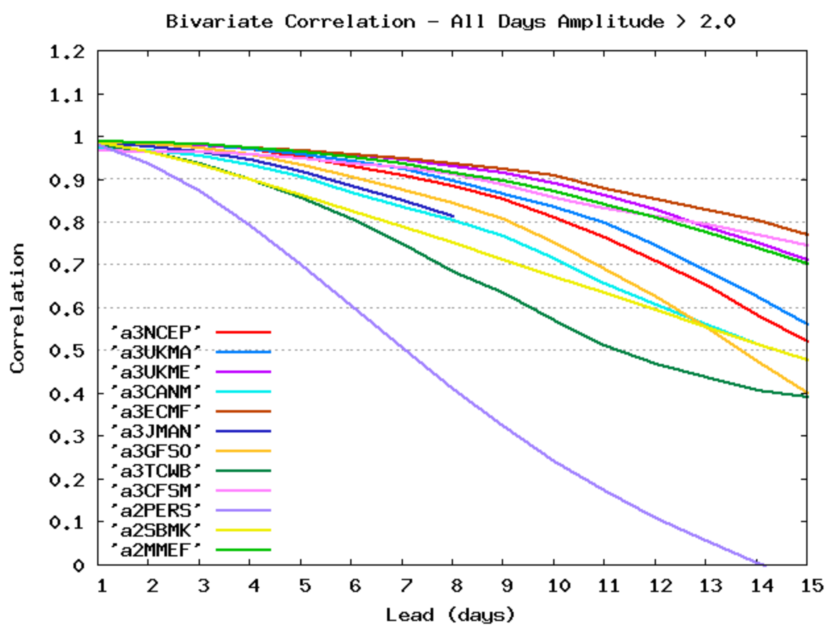
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml

MJO Prediction – Realtime Forecast Skill



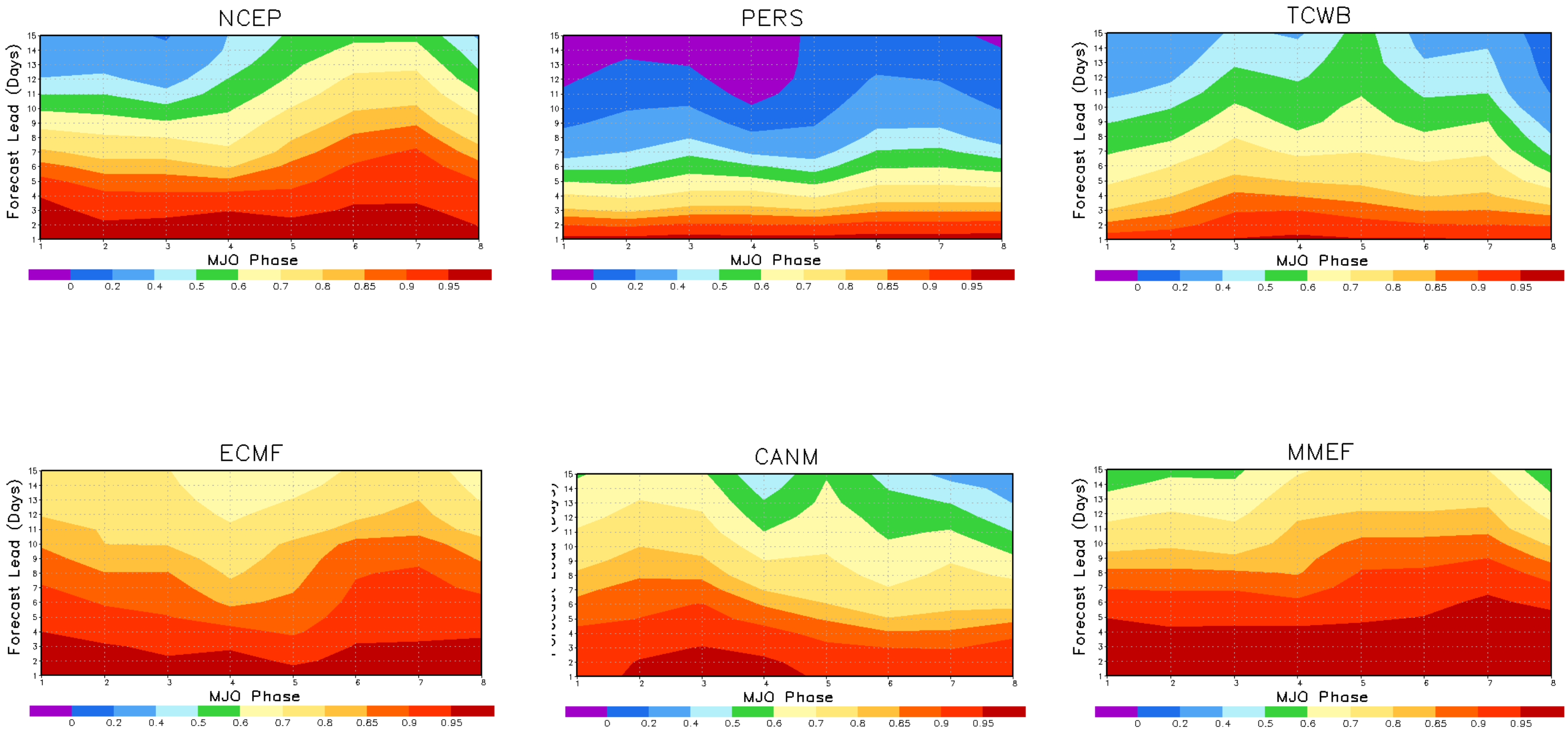
RMM bivariate correlation for:
(left top): extended winter months and
(left bottom): extended summer months
(below): Initial amplitude > 2 sigma





MJO Prediction – Realtime Forecast Skill

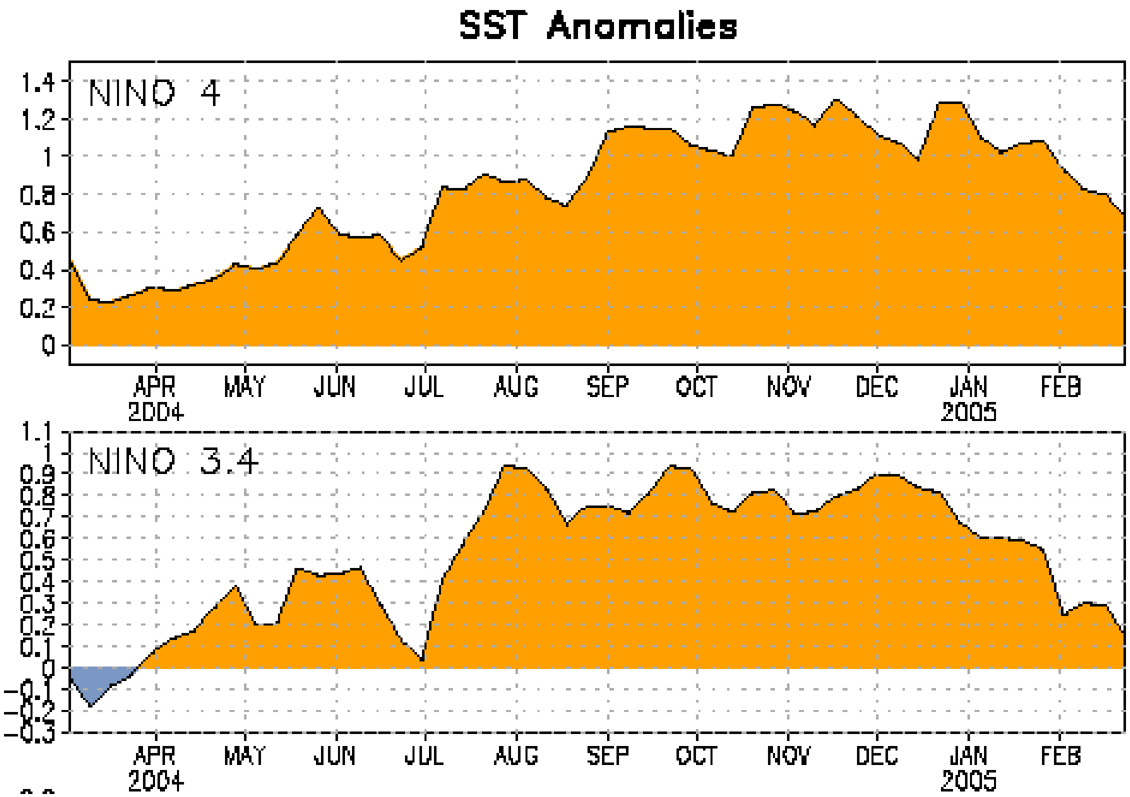
Keyed to Initial Phase   Ensemble Mean Forecasts

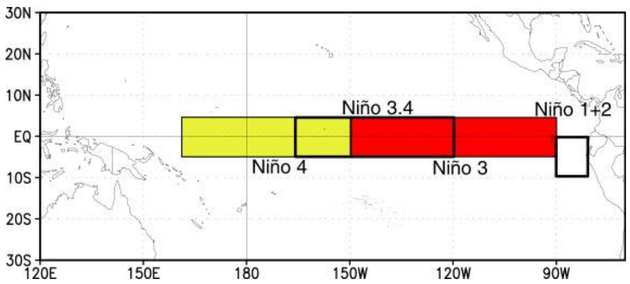


MJO Impacts – ENSO

- The MJO has been shown to modulate the intensity, timing and duration of ENSO events
- These interactions occur both at and below the ocean surface

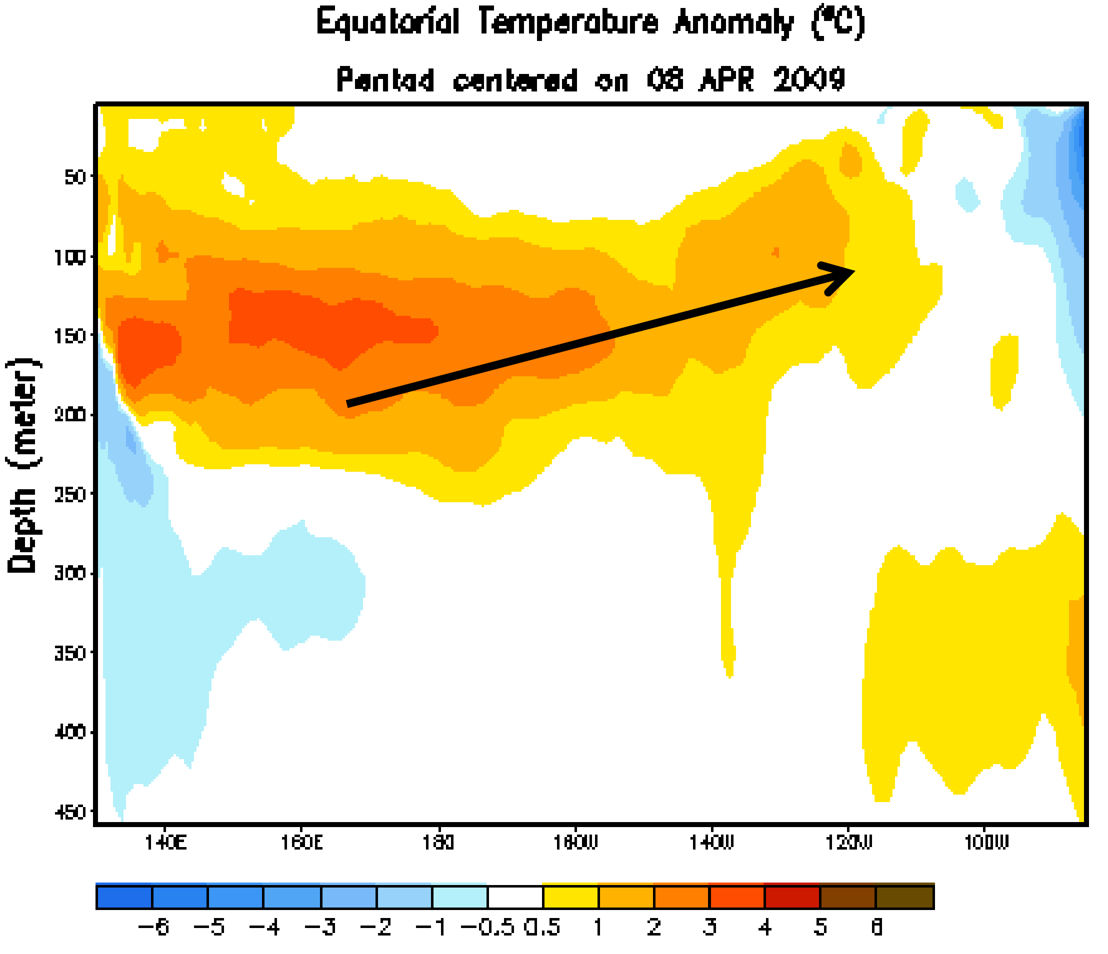
Surface: Low-level wind anomalies associated with phases of the MJO can significantly alter the pattern of SSTs in the Pacific



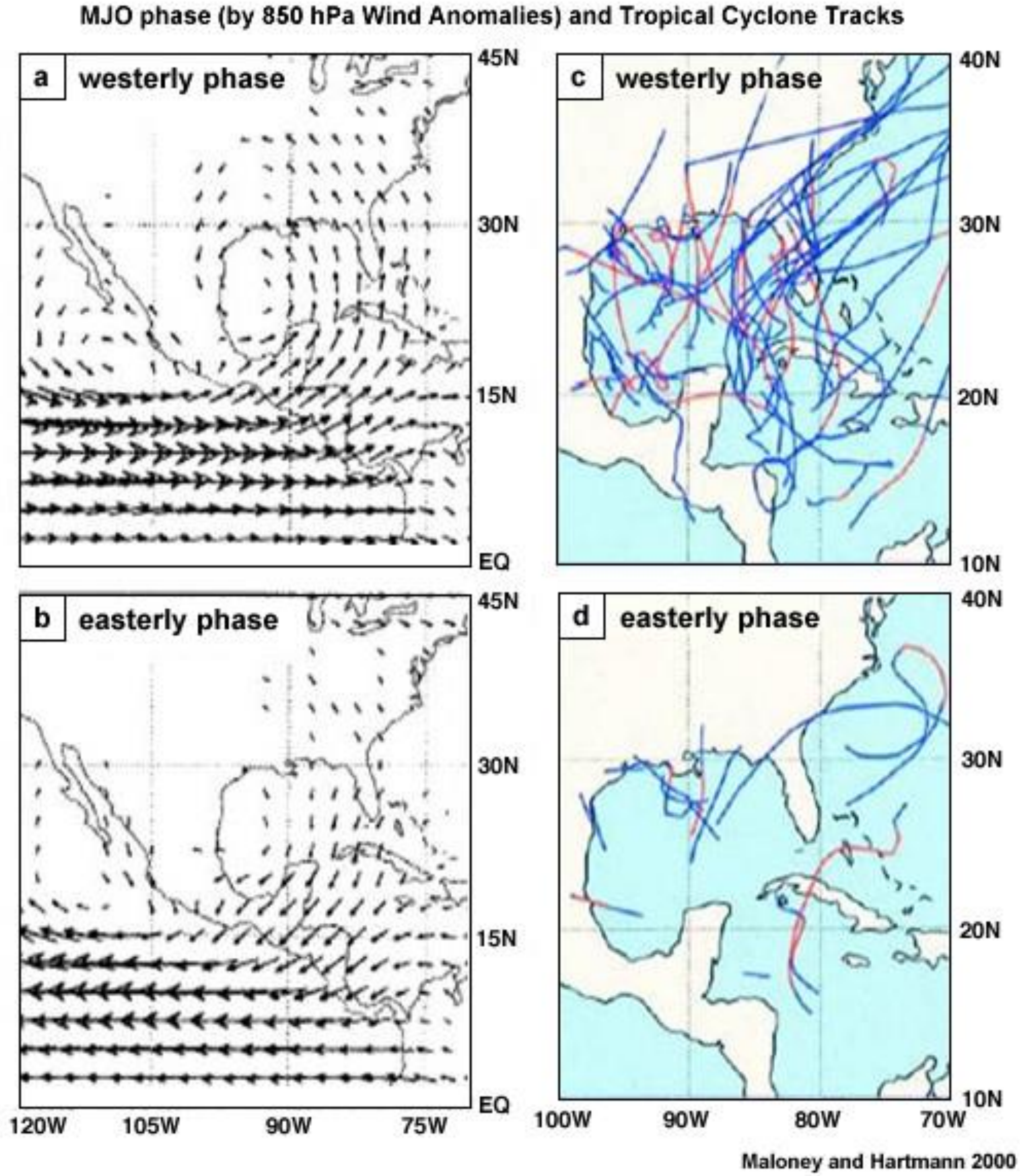


MJO Impacts – ENSO

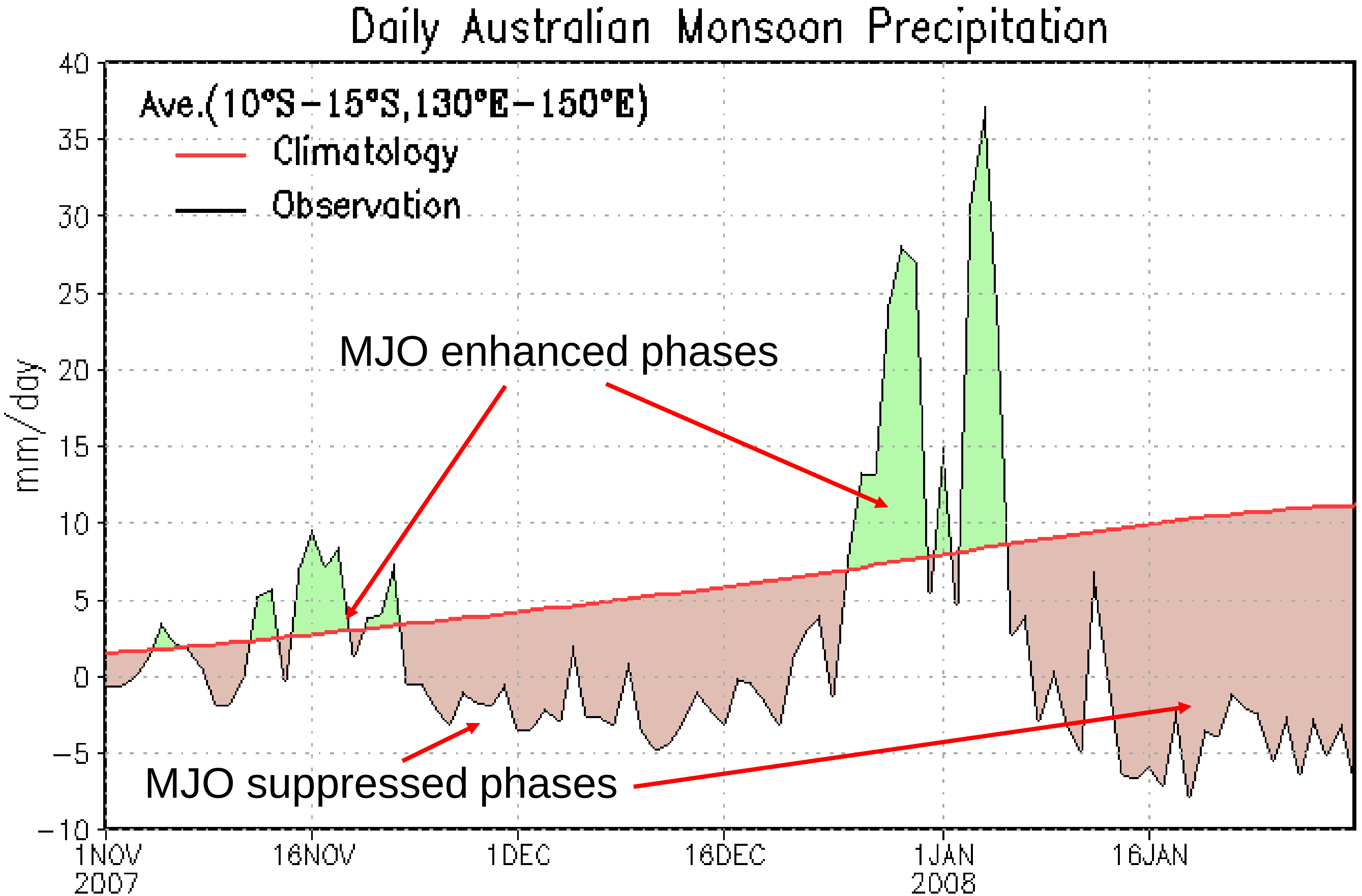
Below the Surface: Weakening of the low-level easterlies across the western-central Pacific often lead to oceanic Kelvin waves



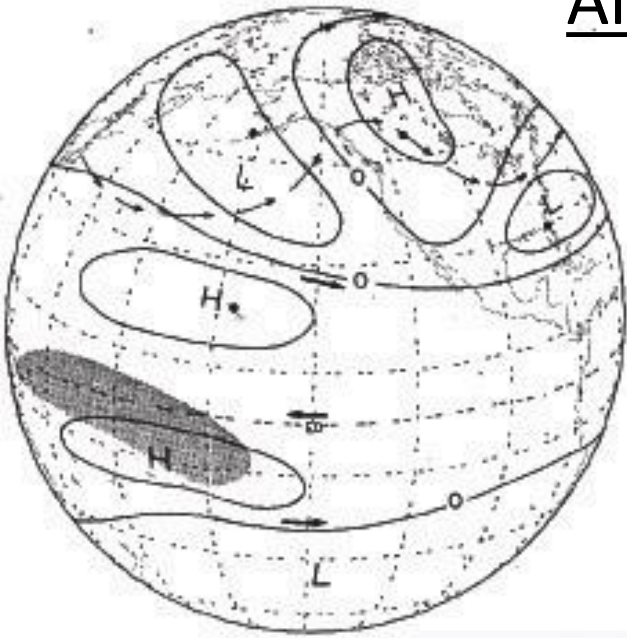
MJO Impacts – Tropical Cyclones

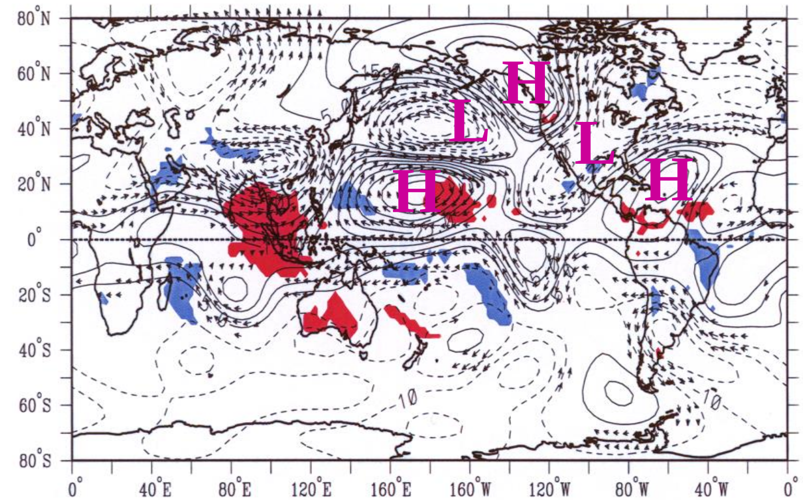


MJO Impacts – Monsoons



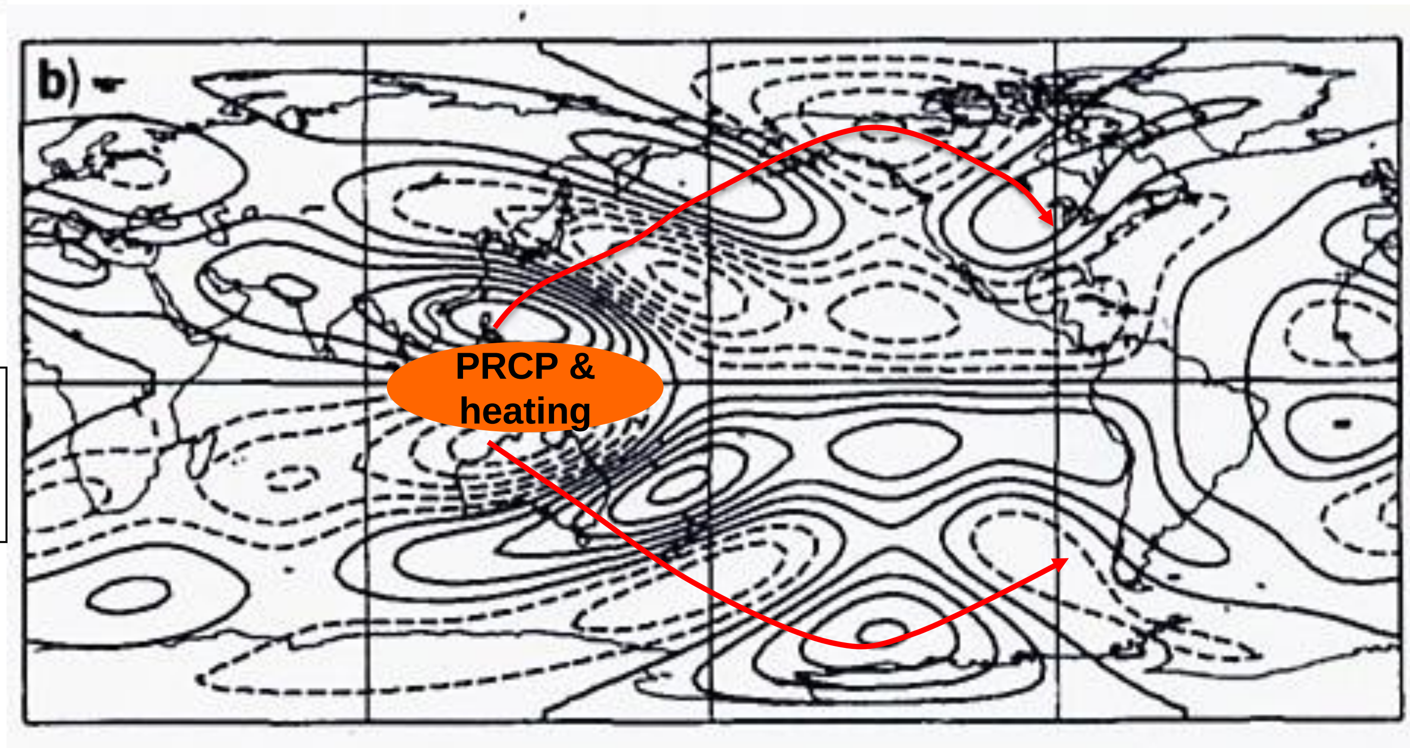
Anomalous tropical heating response





Rossby Wave Train (RWT) Response

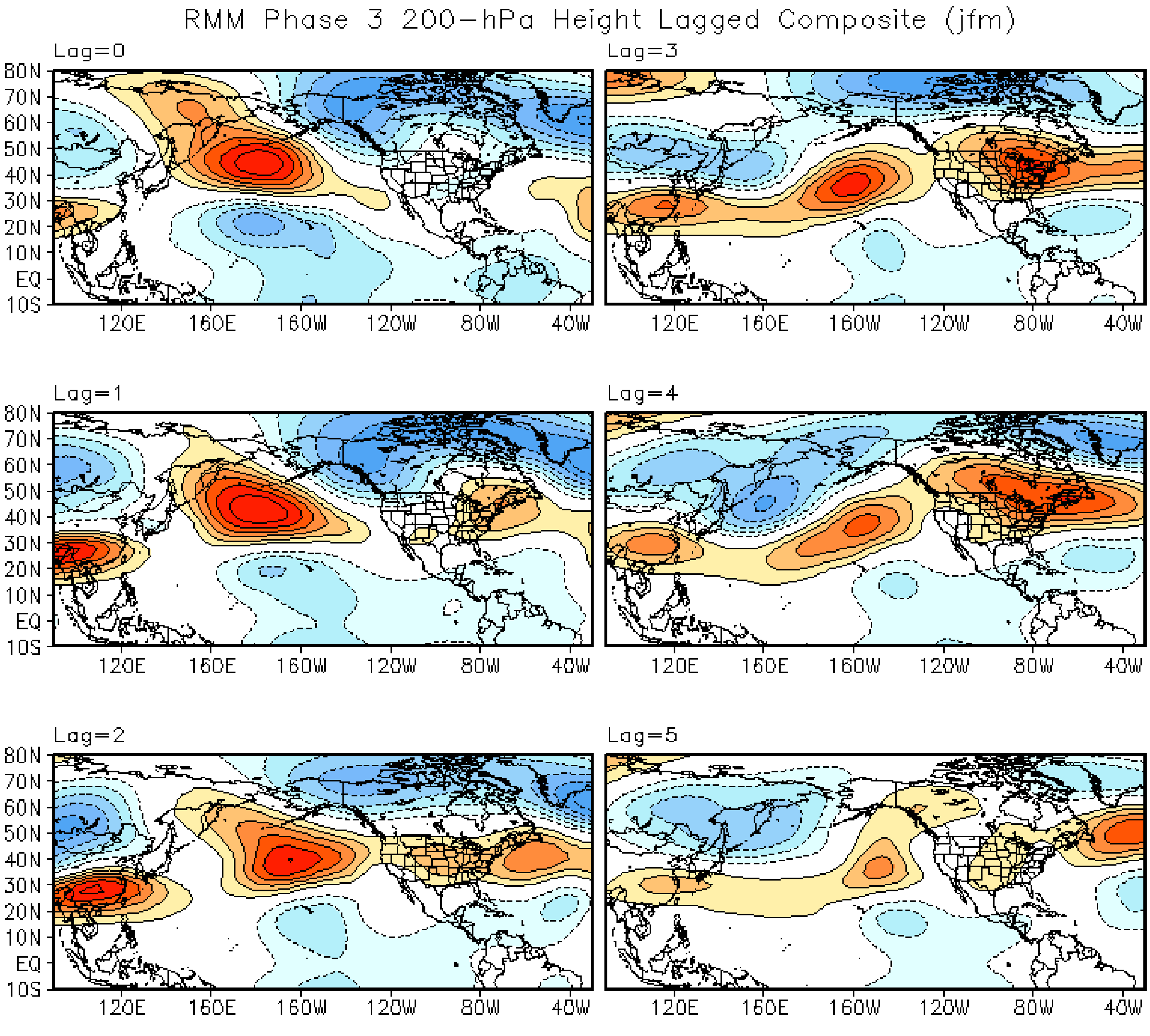
Kiladis and Weickmann, 1992; Renwick and Revell, 1999



MJO Impacts – Lagged 200-hPa Height Composites

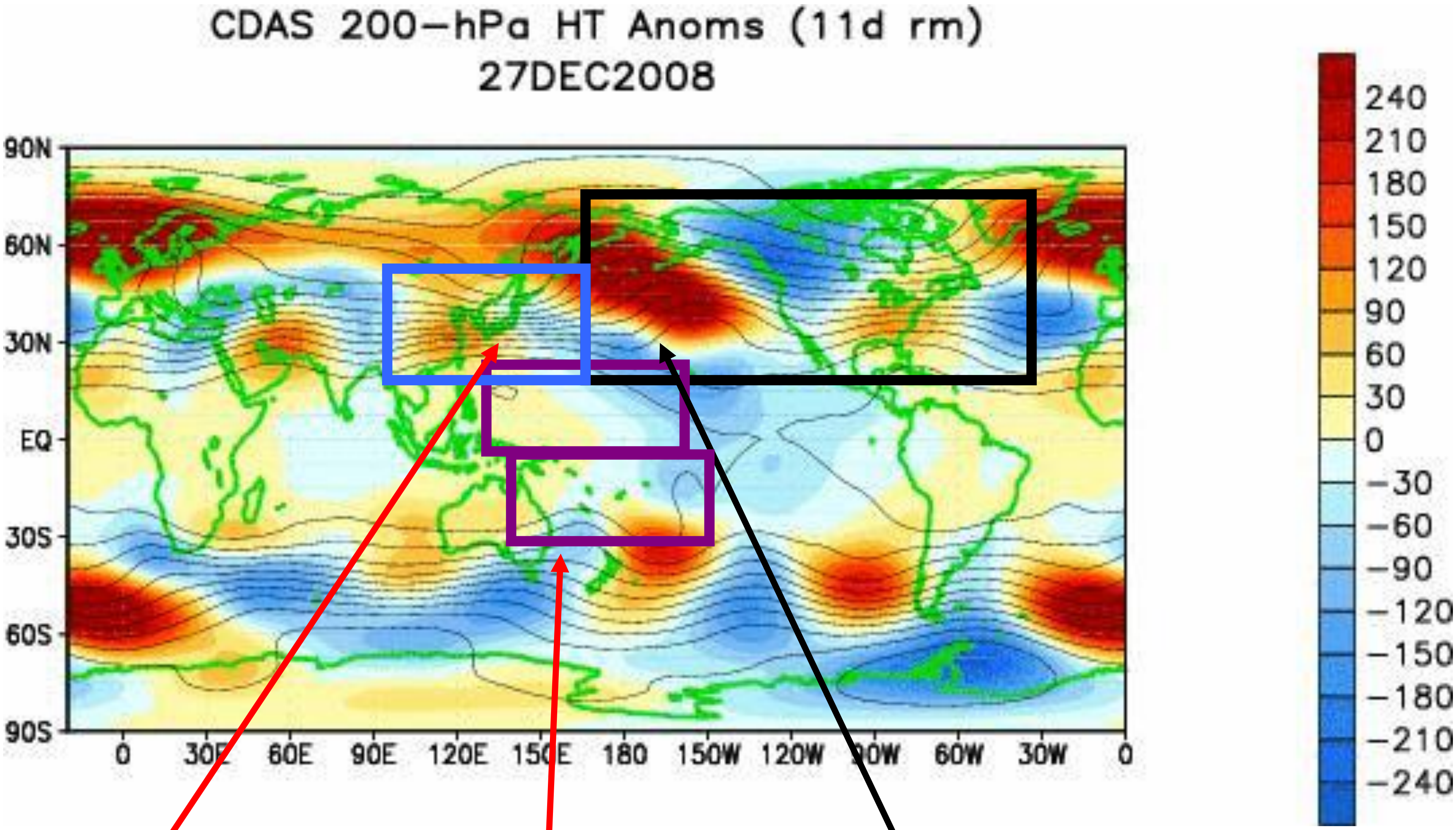
Eastern Indian Ocean enhanced Convection

Lag is 5 days



Baxter et al. 2014

MJO Impacts – Extratropical Circulation



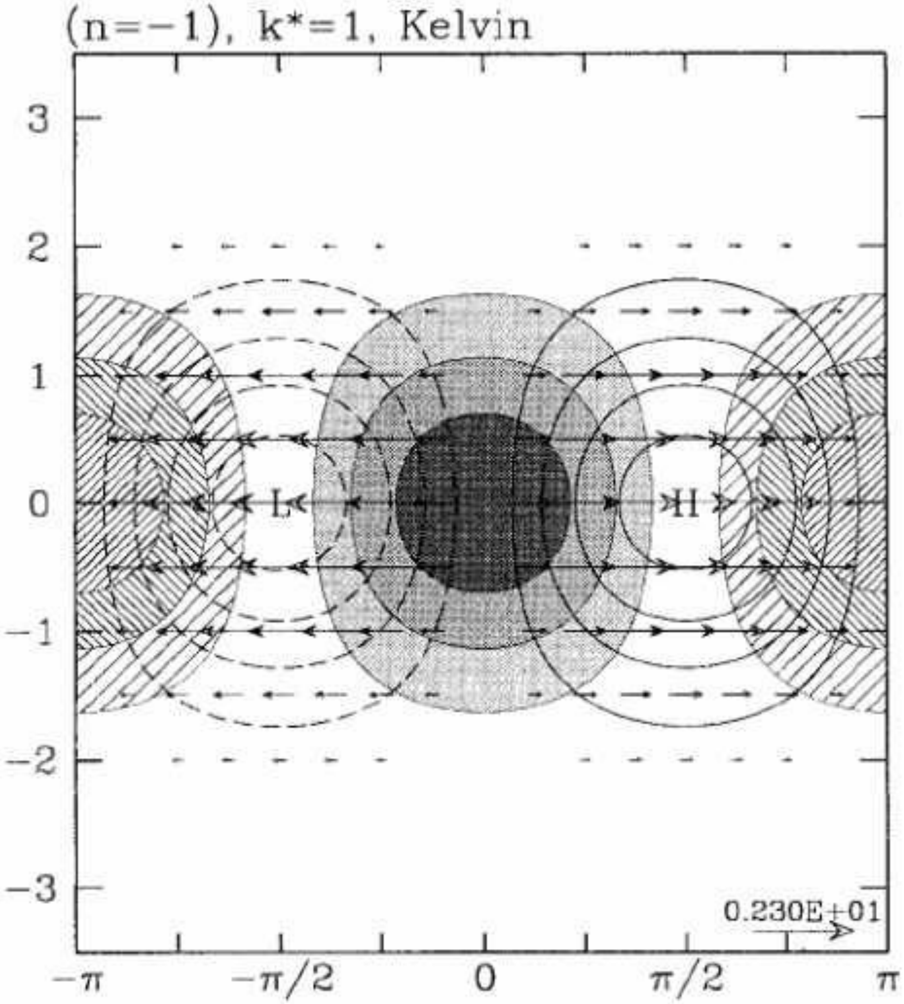
Retracted Jet
Dec 27 – Jan 2

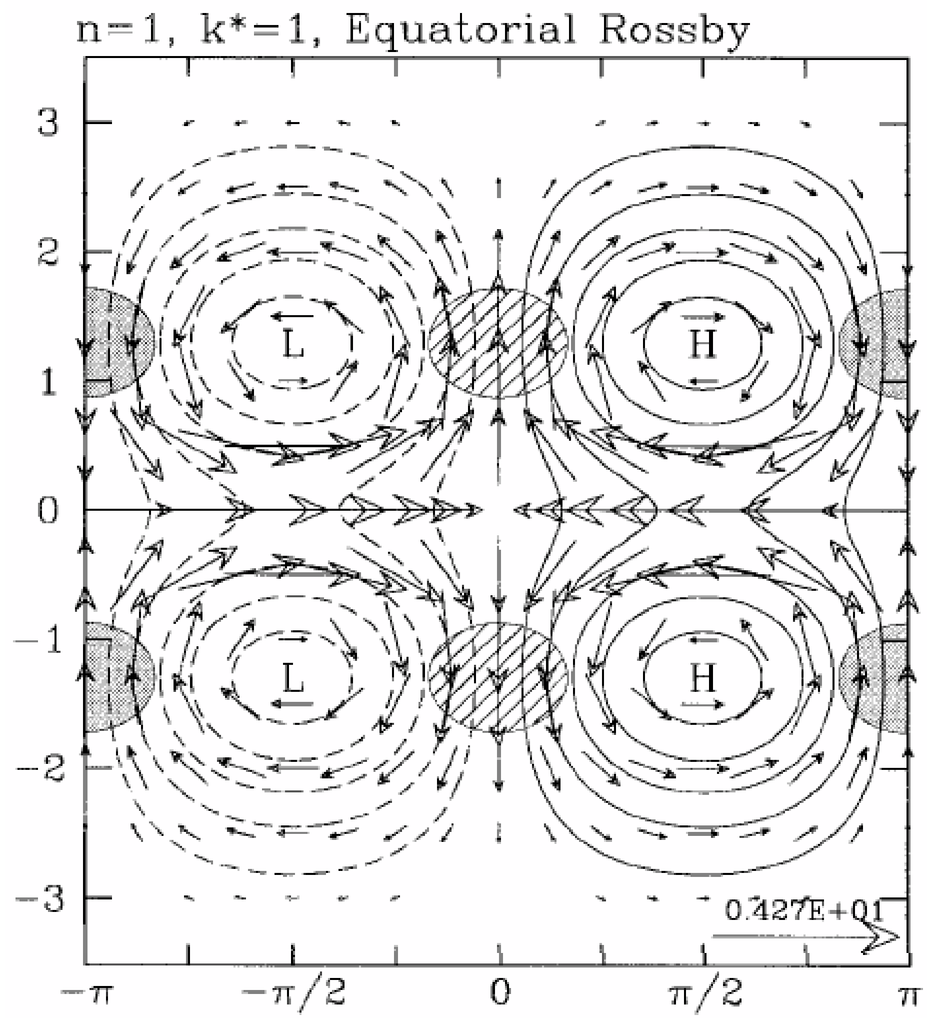
Tropical Heating
Jan 4 - 17

Jet Extension -- Jan 10 - 21
Downstream pattern modulation

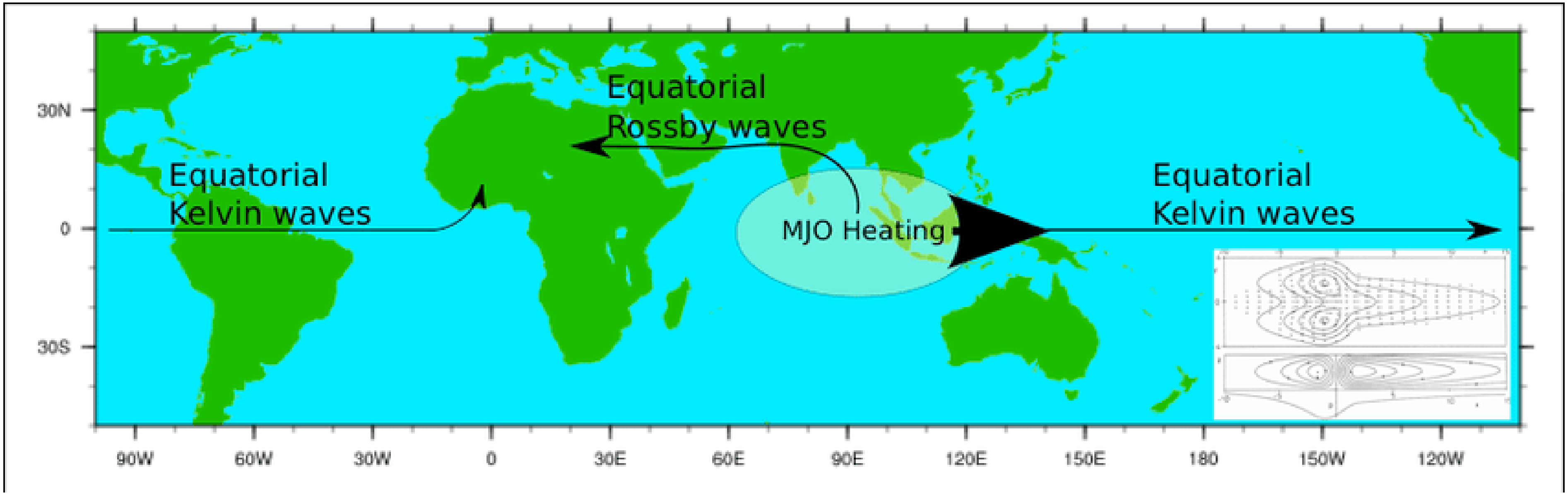
Other Equatorial Subseasonal Waves

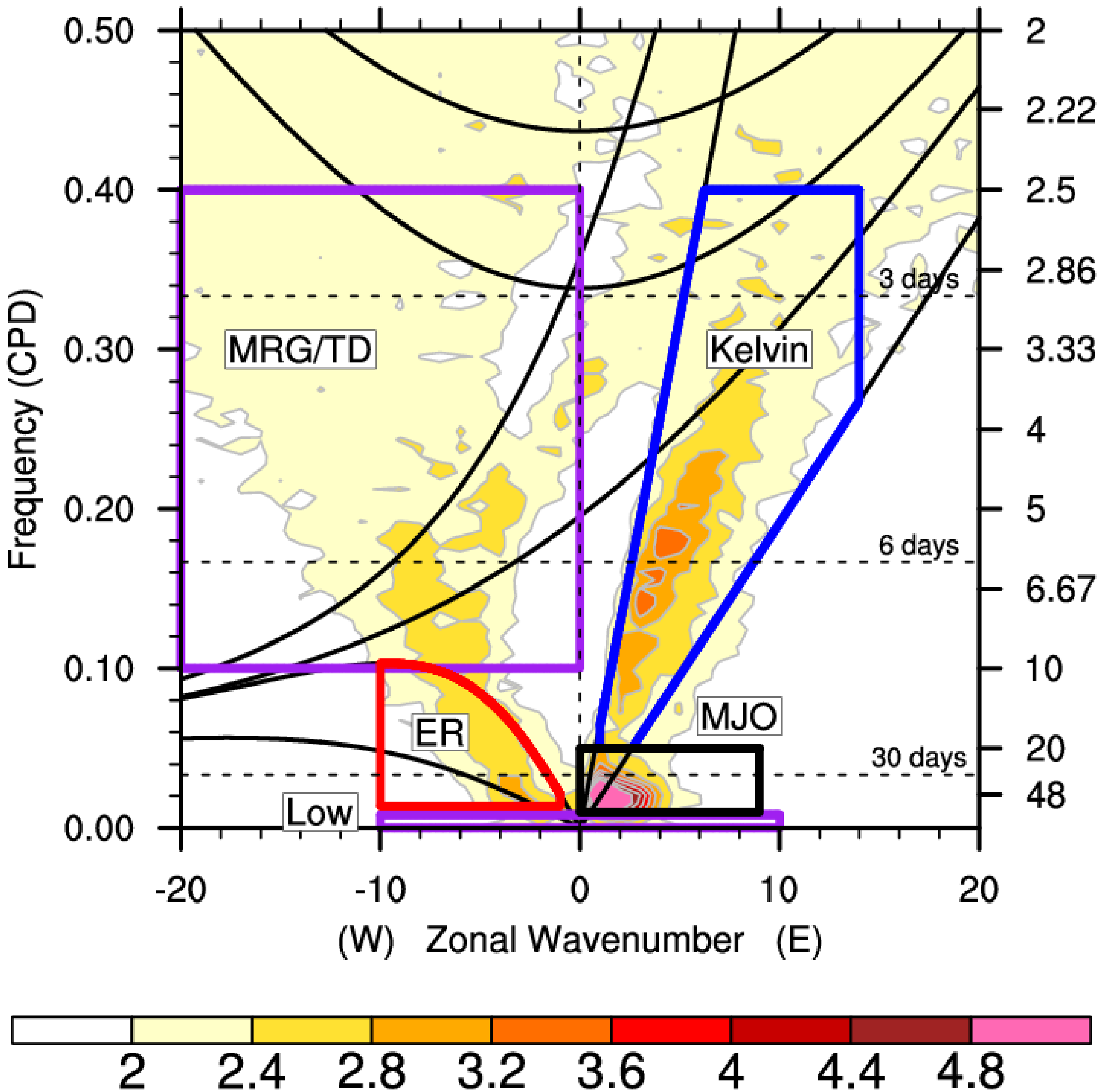
Theoretical Depictions of Kelvin/ER Waves





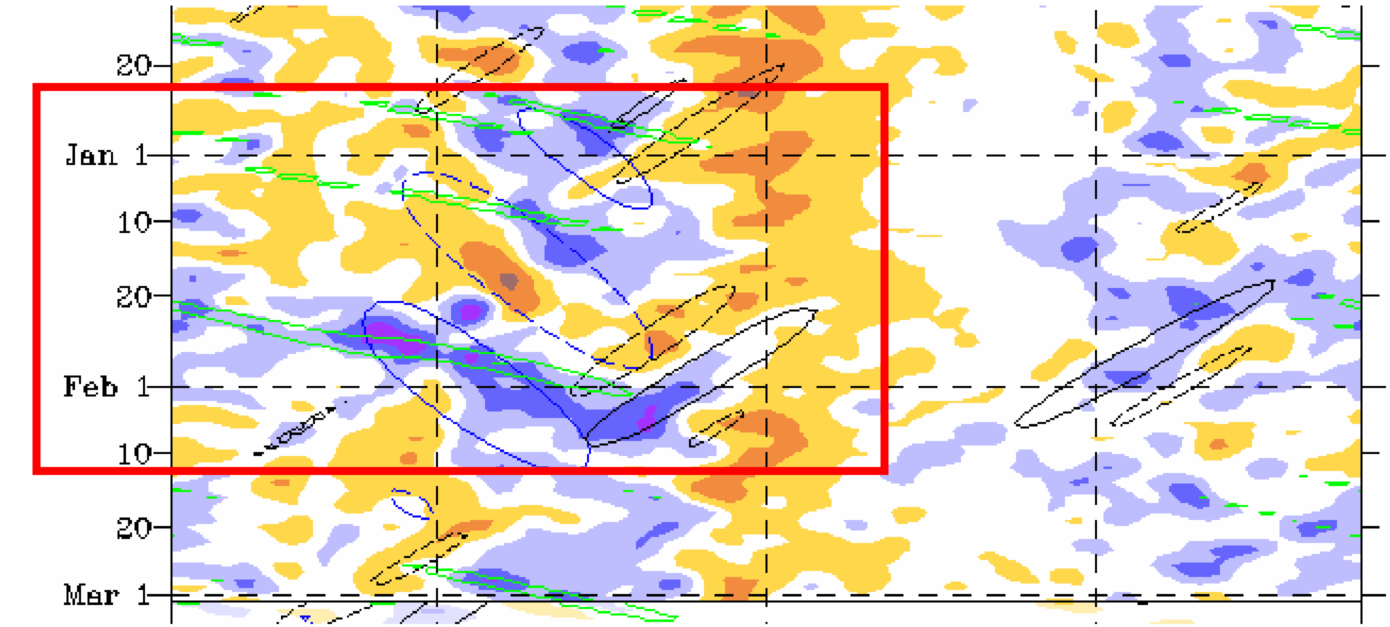
Typical MJO – KW –ER Relationships





0.50
0.40
0.30
0.20
0.10
0.00
Frequency (CPD)
2
2.22
2.5
2.86
3.33
4
5
6.67
10
20
48
3 days
6 days
30 days
MRG/TD
Kelvin
ER
MJO
Low
-20
-10
0
10
20
(W) Zonal Wavenumber (E)
2
2.4
2.8
3.2
3.6
4
4.4
4.8

OLR – Many Eastward/Westward Moving Features

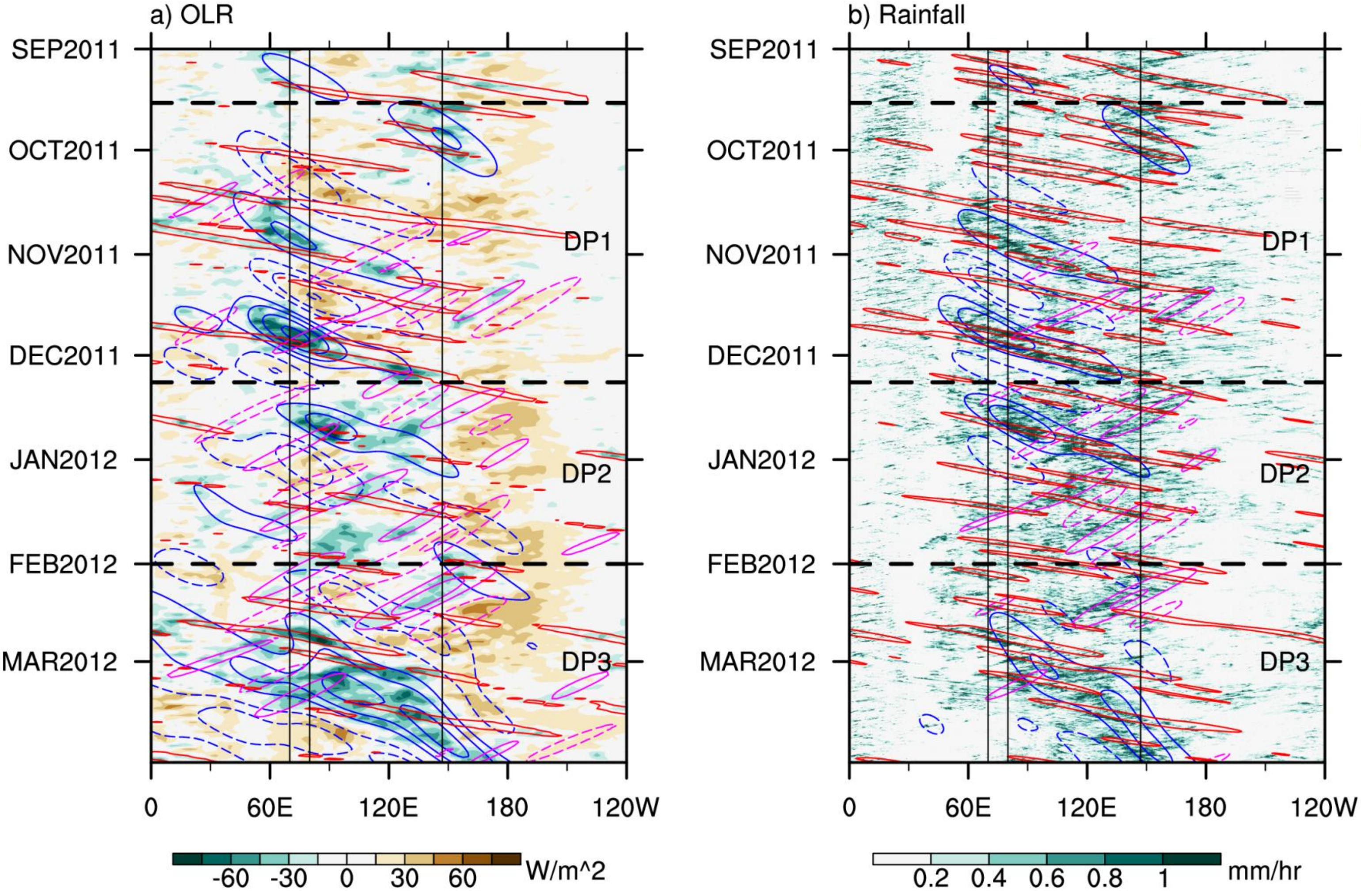


MJO enhanced phase:

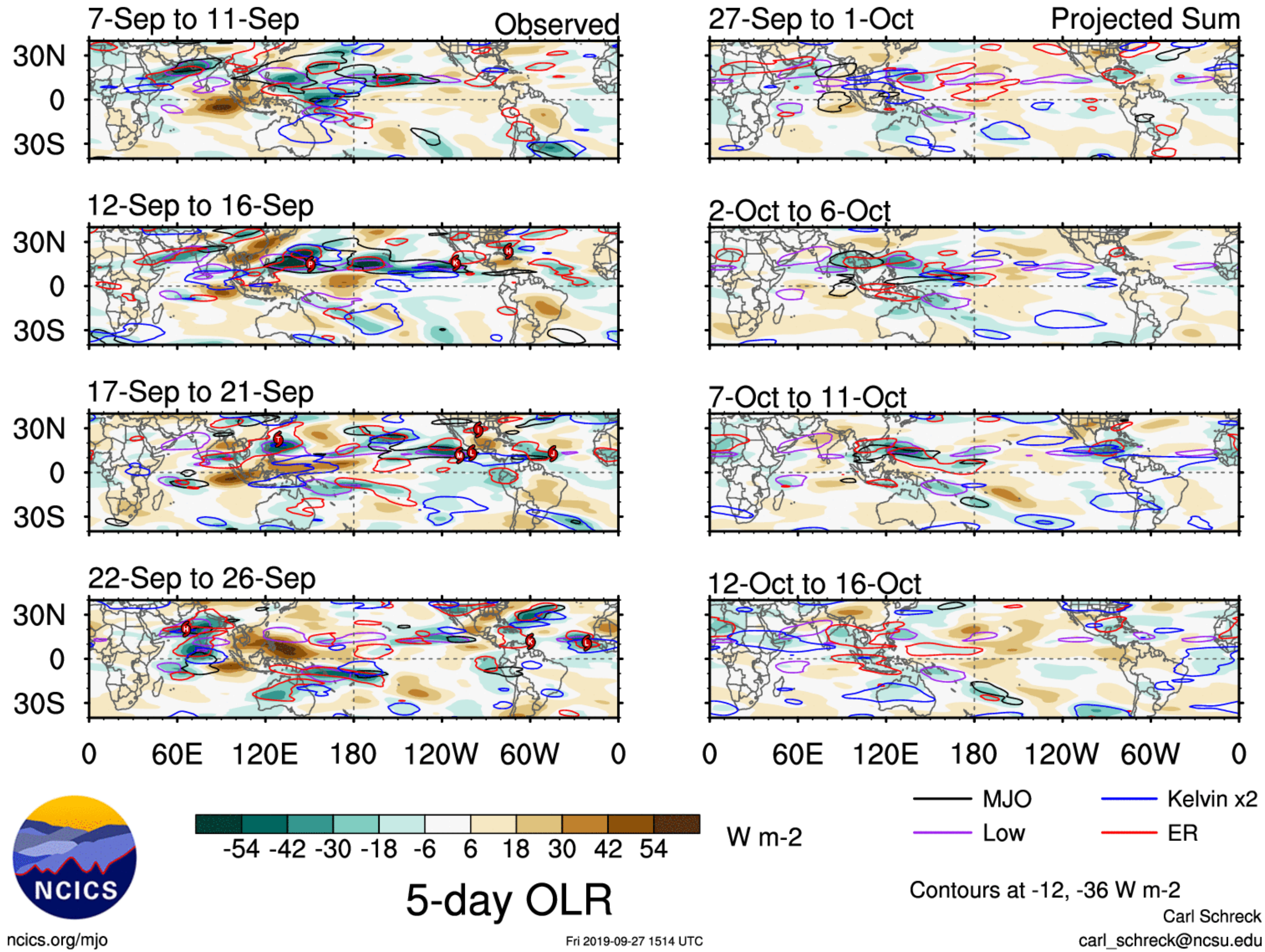
Higher-frequency coherent tropical variability is included in the MJO
Atmospheric Kelvin waves (green) and equatorial Rossby waves (black)

“Envelope” of all of these convective elements (large and small, fast or slow) is what travels eastward with time (black dashed line)

OLR and Rainfall – Other Modes



Courtesy: Carl Schreck, North Carolina Institute for Climate Studies

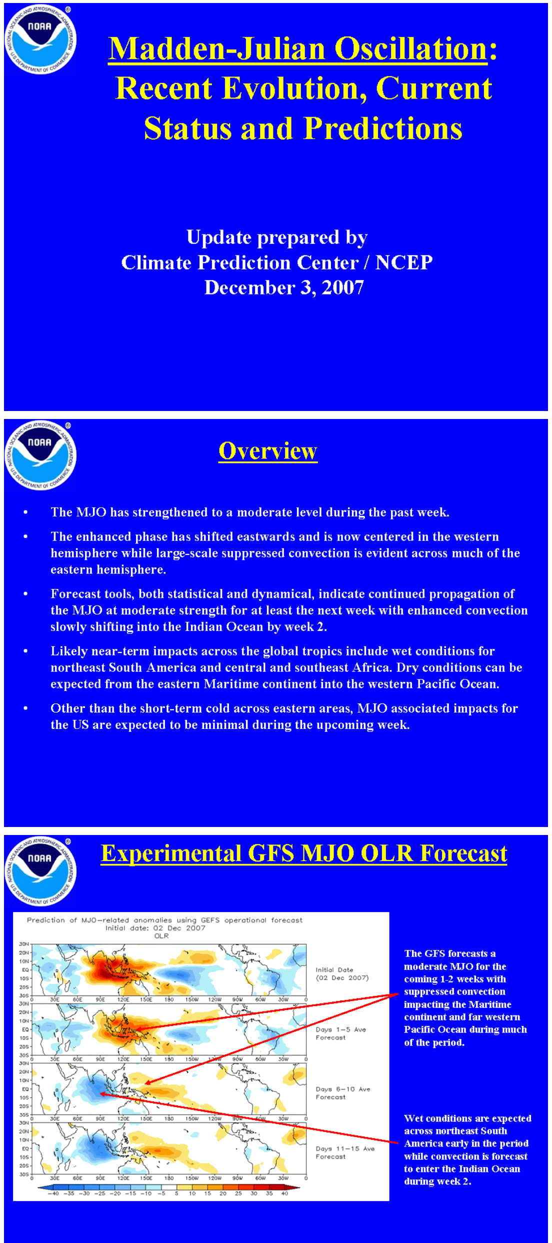


Courtesy: Carl Schreck, North Carolina Institute for Climate Studies

Available Operational Assessments

CPC MJO Weekly Update

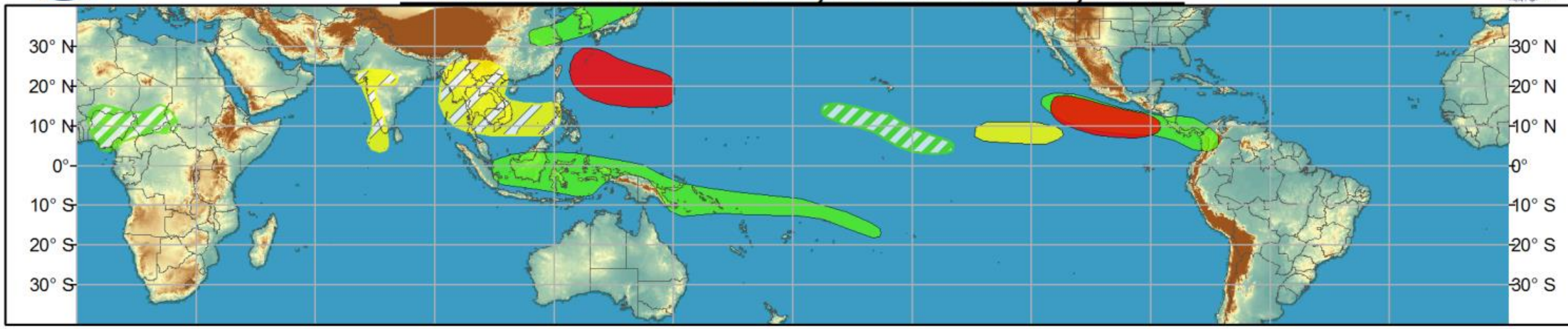
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjoupdate.pdf



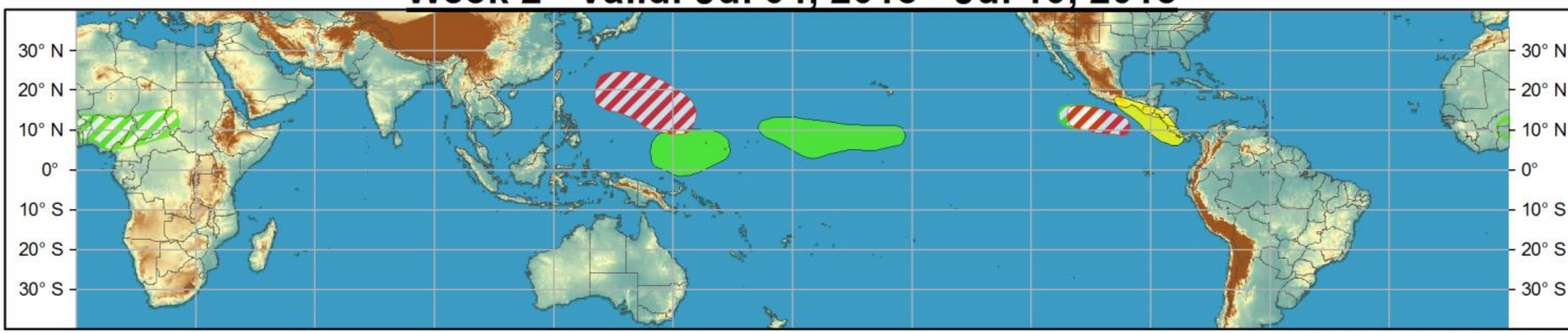
- Review of weekly changes in the MJO
- Includes some of the monitoring and prediction products described here
- Provides an assessment in compact form
- Anticipated evolution and impacts of the MJO during the next 2 weeks
- Released every Monday ~ 4 PM ET

Global Tropics Hazards and Benefits Outlook - Climate Prediction Center

Week 1 - Valid: Jun 27, 2018 - Jul 03, 2018



Week 2 - Valid: Jul 04, 2018 - Jul 10, 2018



Produced: 06/26/2018

Forecaster: Allgood

	Confidence: High	Confidence: Moderate	
Tropical Cyclone Formation			Development of a tropical cyclone (tropical depression - TD, or greater strength).
Above-average rainfall			Weekly total rainfall in the upper third of the historical range.
Below-average rainfall			Weekly total rainfall in the lower third of the historical range.
Above-normal temperatures			7-day mean temperatures in the upper third of the historical range.
Below-normal temperatures			7-day mean temperatures in the lower third of the historical range.

Product is updated once per week, except from 6/1 - 11/30 for the region from 120E to 0, 0 to 40N. The product targets broad scale conditions integrated over a 7-day period for US interests only. Consult your local responsible forecast agency.

Thank You for Your Attention

Jon.Gottschalck@noaa.gov

MJO Onset and Maintenance

- The mechanisms for MJO onset and subsequent maintenance have not been well understood

- Initiation is likely a result of complex interactions ……
  - (1) between atmosphere and ocean
  - (2) across multiple temporal and spatial scales
  - (3) across regional boundaries

No one theory completely explains the mechanisms for the period, zonal scale and eastward propagation of the MJO

Two types of theories:

Independent external forcing: Stationary intraseasonal oscillations in Asian monsoon, stochastic forcing, extratropical disturbances

Internal MJO mechanisms driven: Complex air-sea interactions initiate MJO, varying temporal / spatial scales of convection interact and organize MJO

Zhang, 2005

What is DYNAMO?

DYNAMO – *Dynamics of the Madden-Julian Oscillation (MJO)* – is a US research program for improving our understanding of MJO initiation and our capability of forecasting it.

- Experiment to better understand the mechanisms for MJO onset
- Extensive instrumentation was deployed and subsequent diagnostic and modeling research ongoing
- Sounding data was included into operational modeling centers ingest