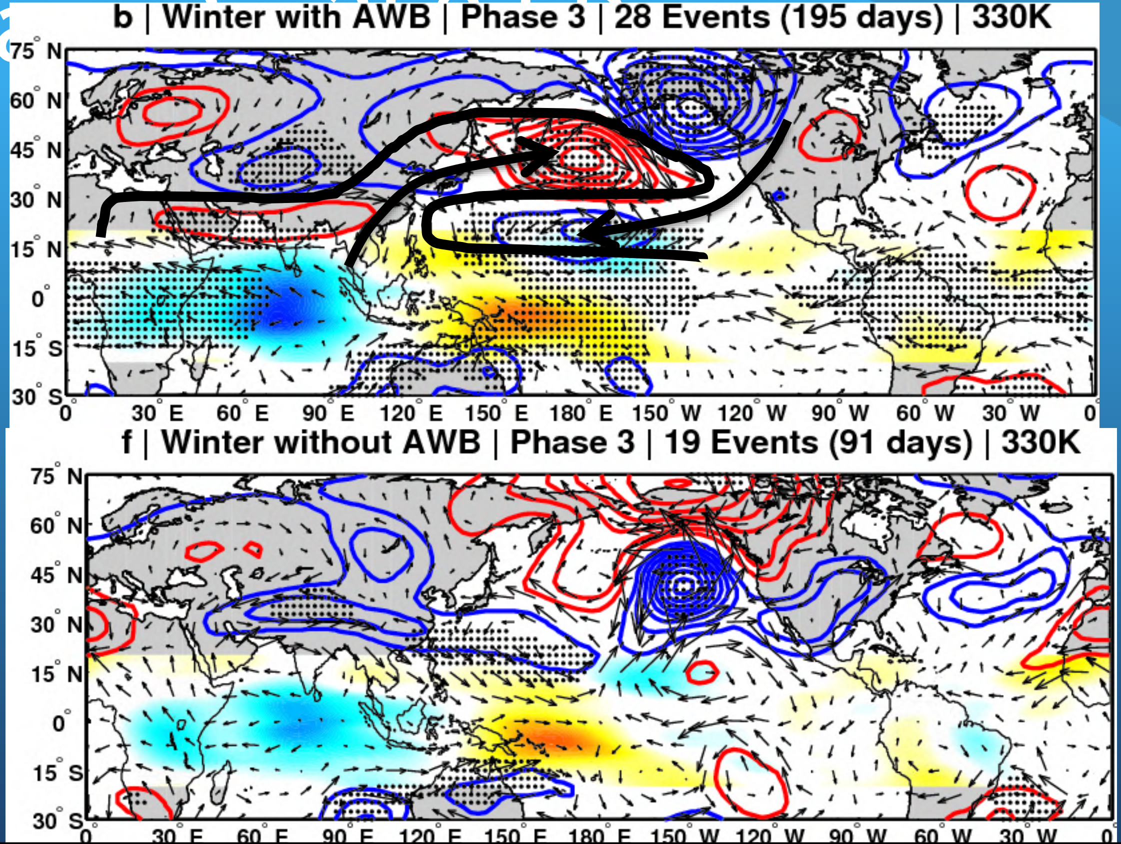
The MJO and Extratropical Wave Breaking

- Focus Northern Winter
- Identify continuously active events from the RMM index from phase 2 forward > Amp 0.5
- Identify those events that include central Pacific wave breaking phase 3
- Compare progression of events with wave breaking to events without
  - MacRitchie and Roundy (2016)

From MacRitchie and Roundy (2016, QJRMS)

Pha

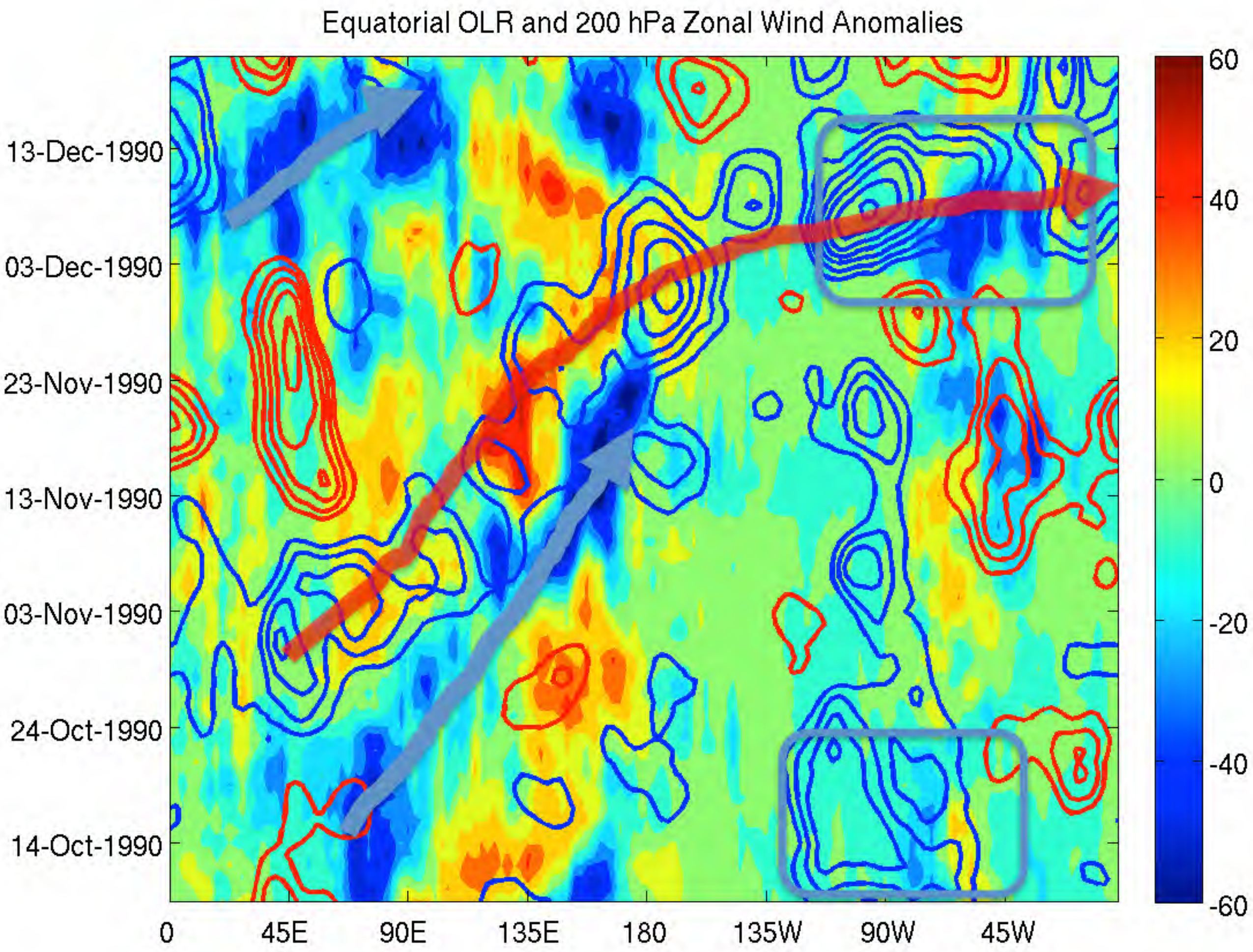
RMM Amp:
1.85



RMM Amp:
1.27

Positive Height Anomalies (15 m):
Negative Height Anomalies (15 m):

OLR Anomalies: + -

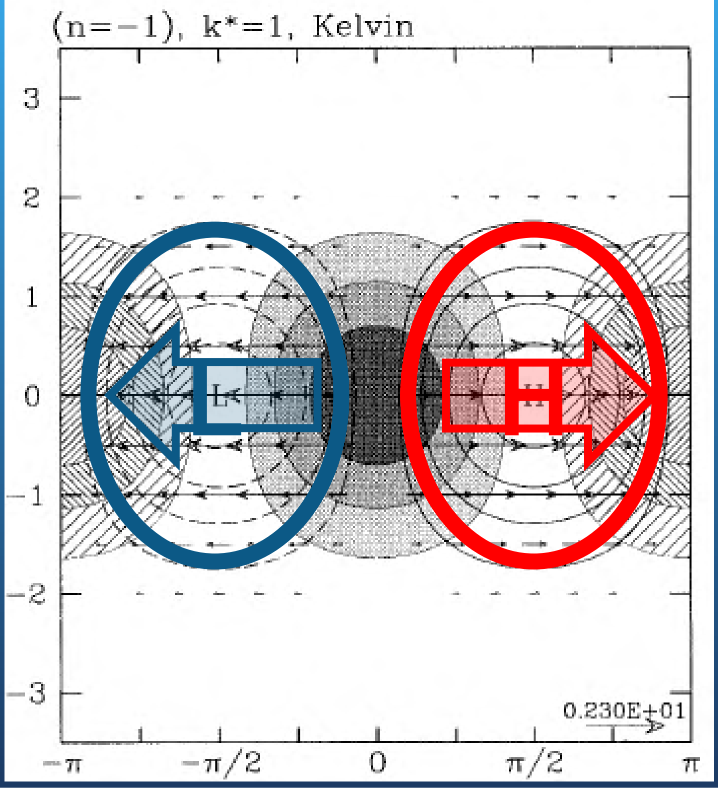


Equatorial OLR and 200 hPa Zonal Wind Anomalies
13-Dec-1990
03-Dec-1990
23-Nov-1990
13-Nov-1990
03-Nov-1990
24-Oct-1990
14-Oct-1990
0
45E
90E
135E
180
135W
90W
45W
60
40
20
0
-20
-40
-60

Roundy 2015

Theoretical Kelvin Wave Structure

Horizontal Structure



$$\frac{\partial u}{\partial t} = -g\frac{\partial \Phi}{\partial x}$$

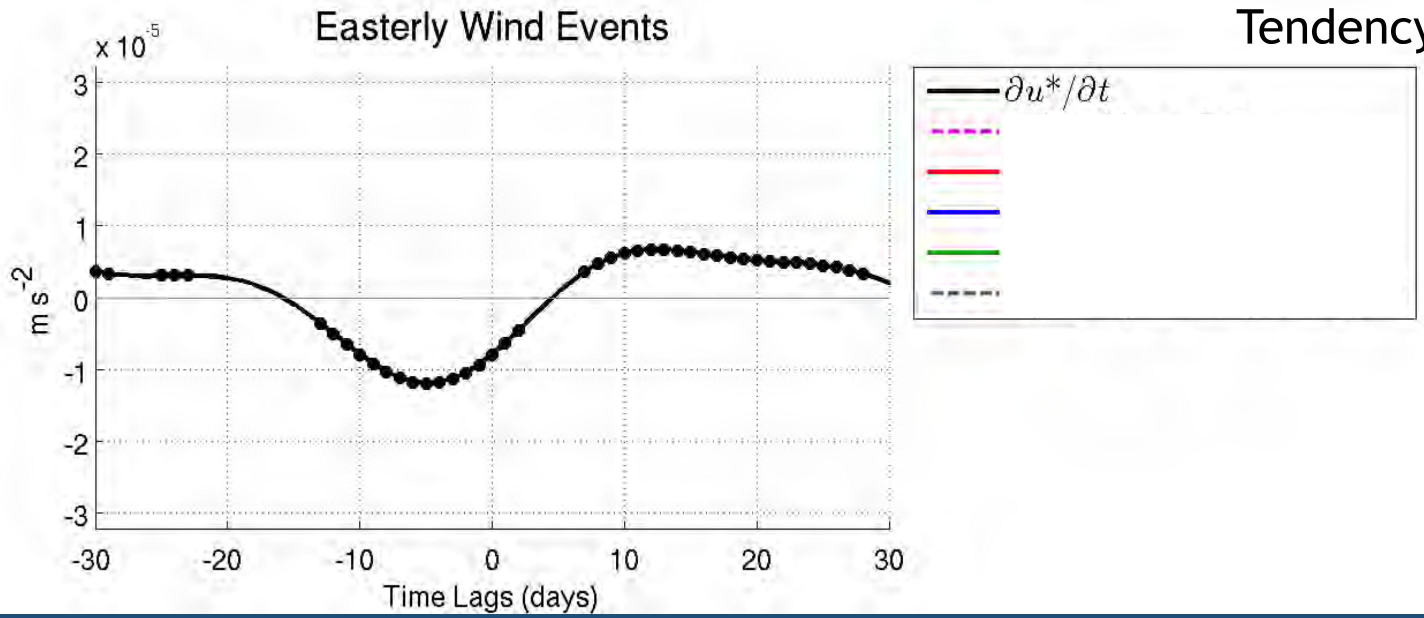
: Zonal Momentum Equation

Circumnavigating MJO Circulation: Zonal Momentum Budget at 200 hPa

$$\frac{\partial u}{\partial t} = -\vec{v} \cdot \nabla u - g\frac{\partial \Phi}{\partial x} + fv + X$$

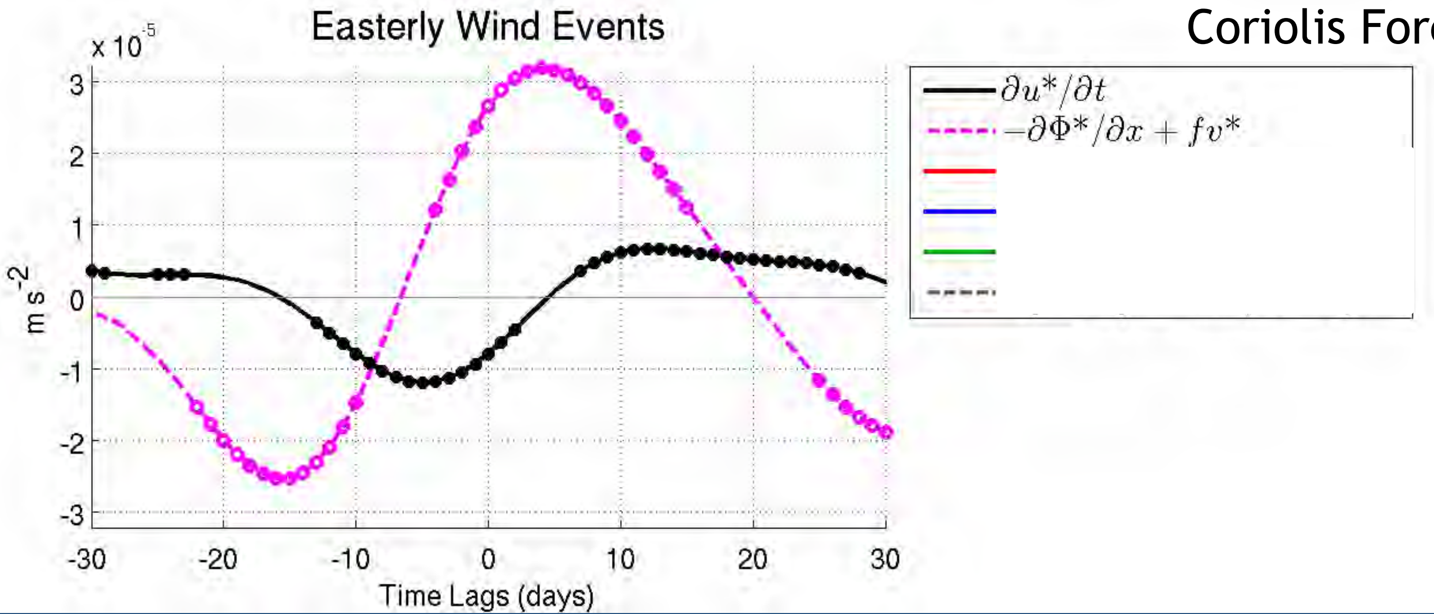
10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

Intraseasonal Zonal Wind Tendency



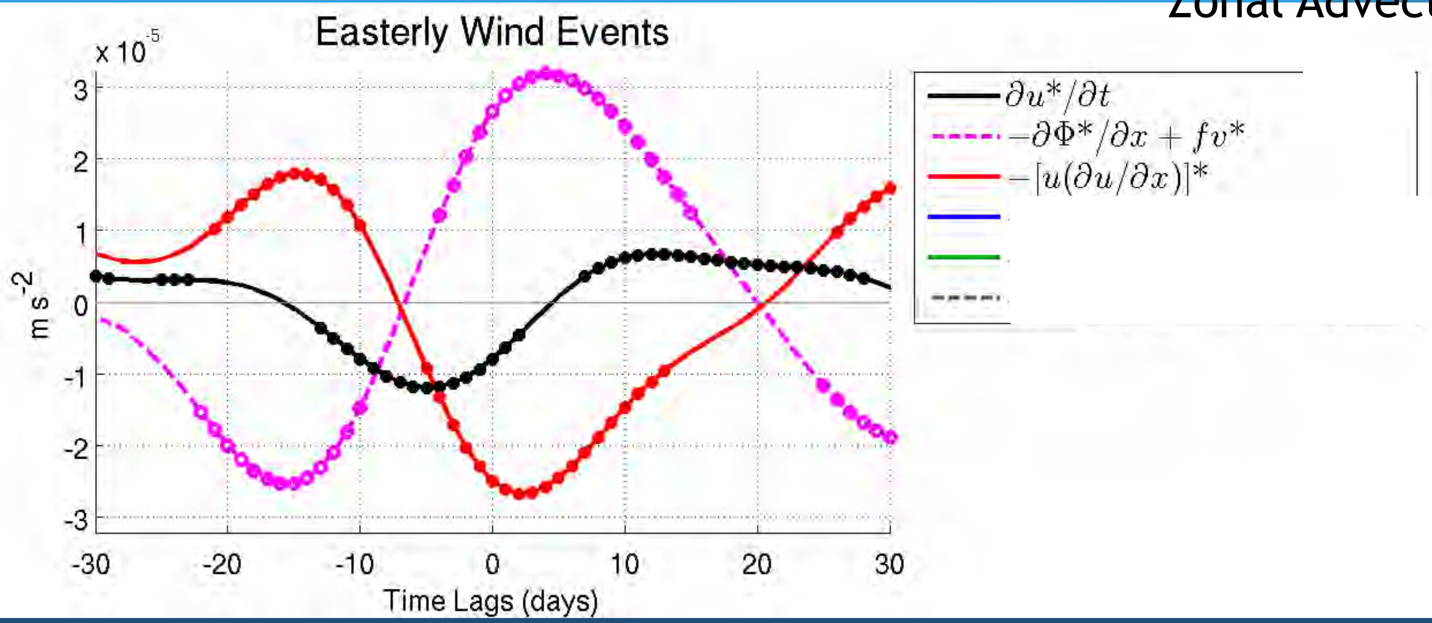
10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

Pressure Gradient Force and Coriolis Force



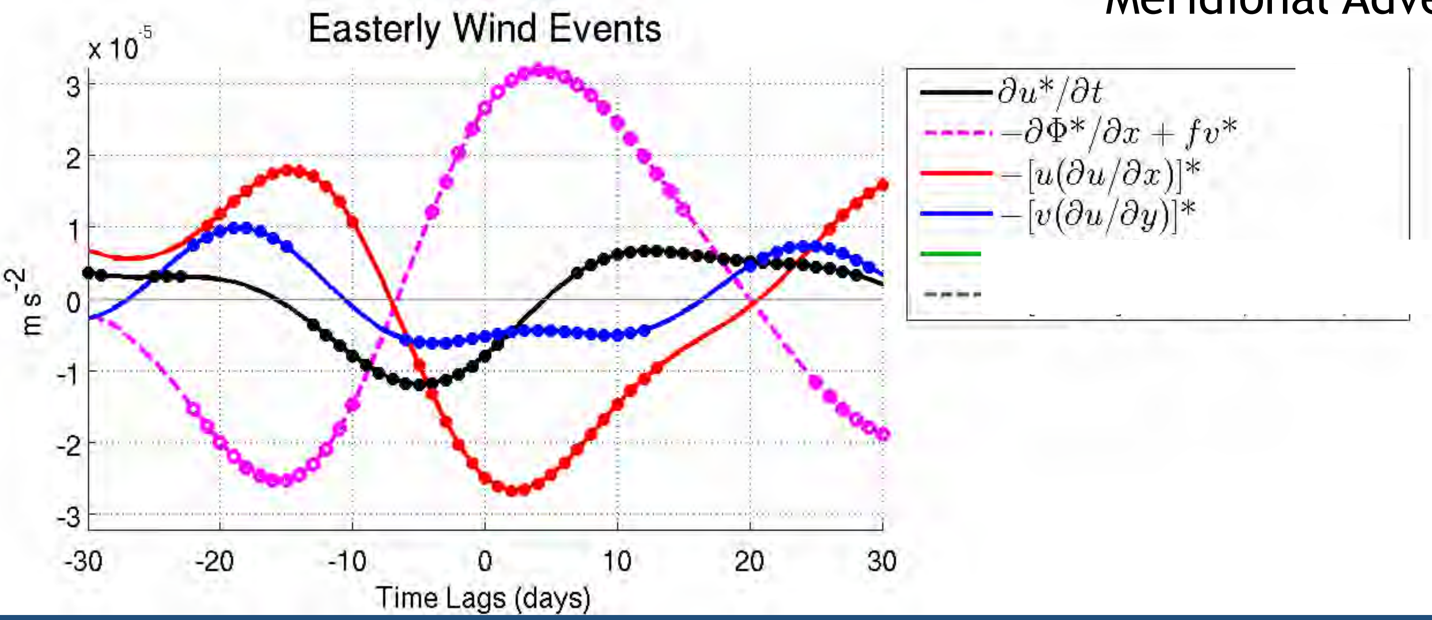
10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

Zonal Advection



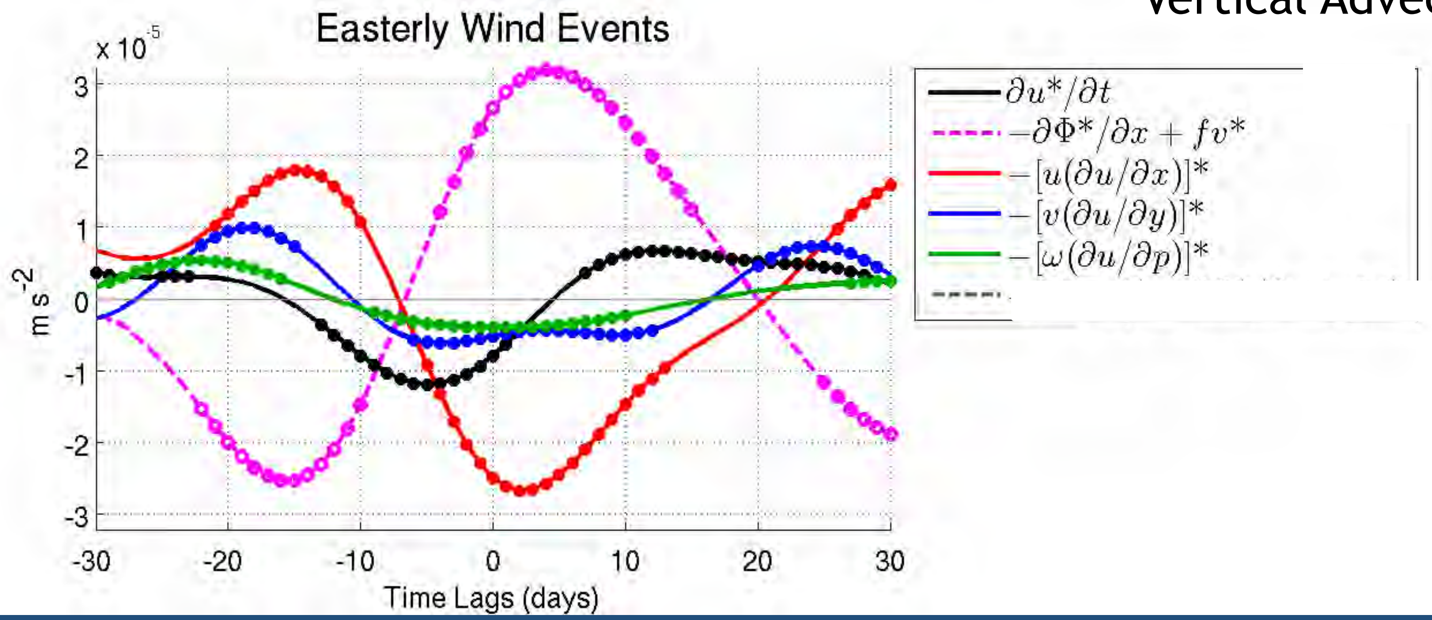
10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

Meridional Advection



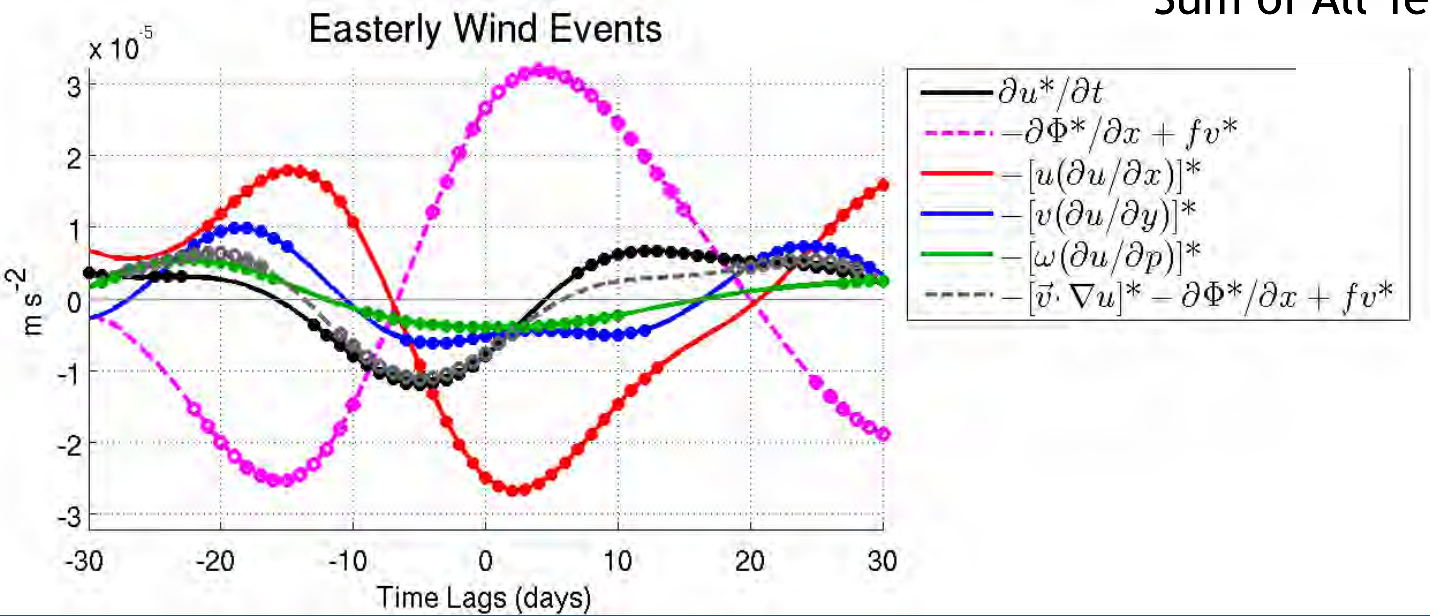
10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

Vertical Advection



10°S-5°N, 110°W-80°W Averaged *u* Budget Terms

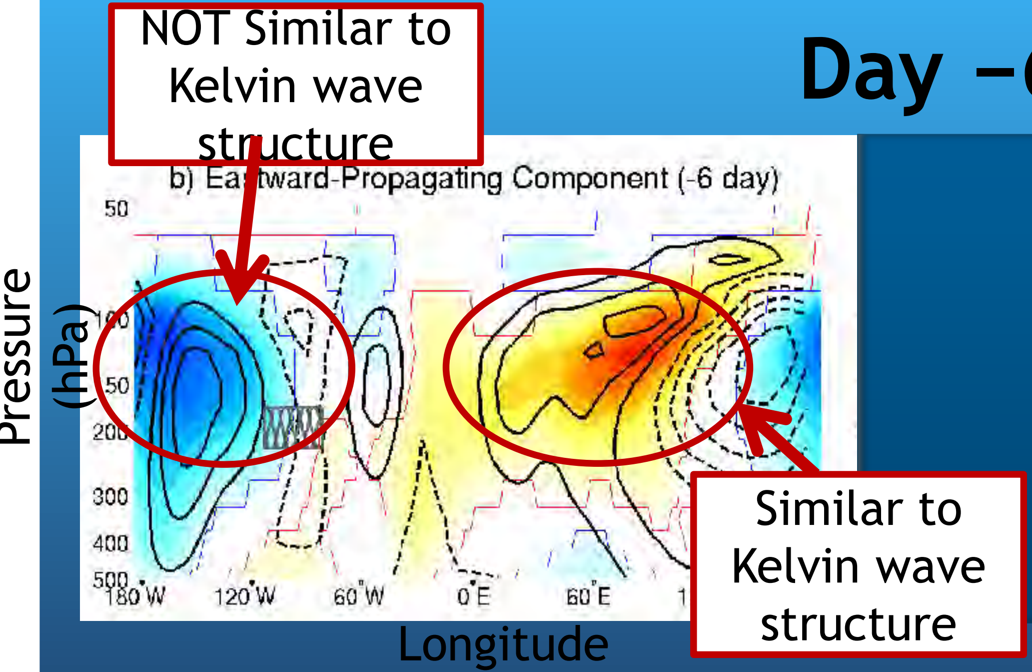
Sum of All Terms



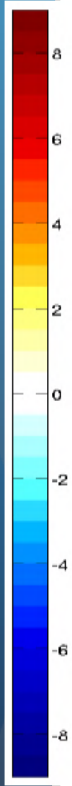
Sakaeda and Roundy (2015, 2016a,b,c)

10°S-10°N Averaged Longitude-Pressure Cross Sections

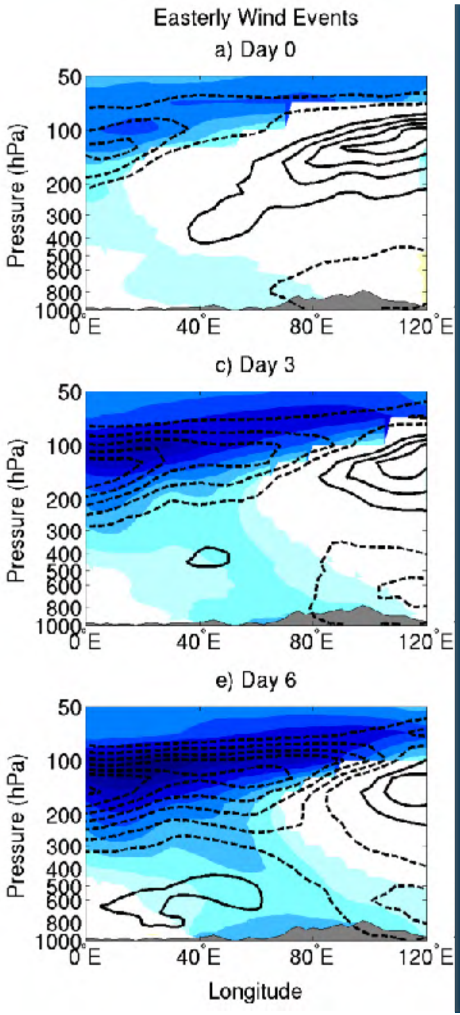
Day −6



Sakaeda and Roundy (2015)



Shading: intraseasonal zonal wind anomaly
Black contour: intraseasonal geopotential height anomaly at 2 m interval



Sakaeda and Roundy (2015)

Interaction with the extratropics may be associated with

- Changes in amplitude and spatial distribution of MJO convection
- Changes in the phase speed of MJO convection and associated global circulation anomalies

Three evidence pathways:

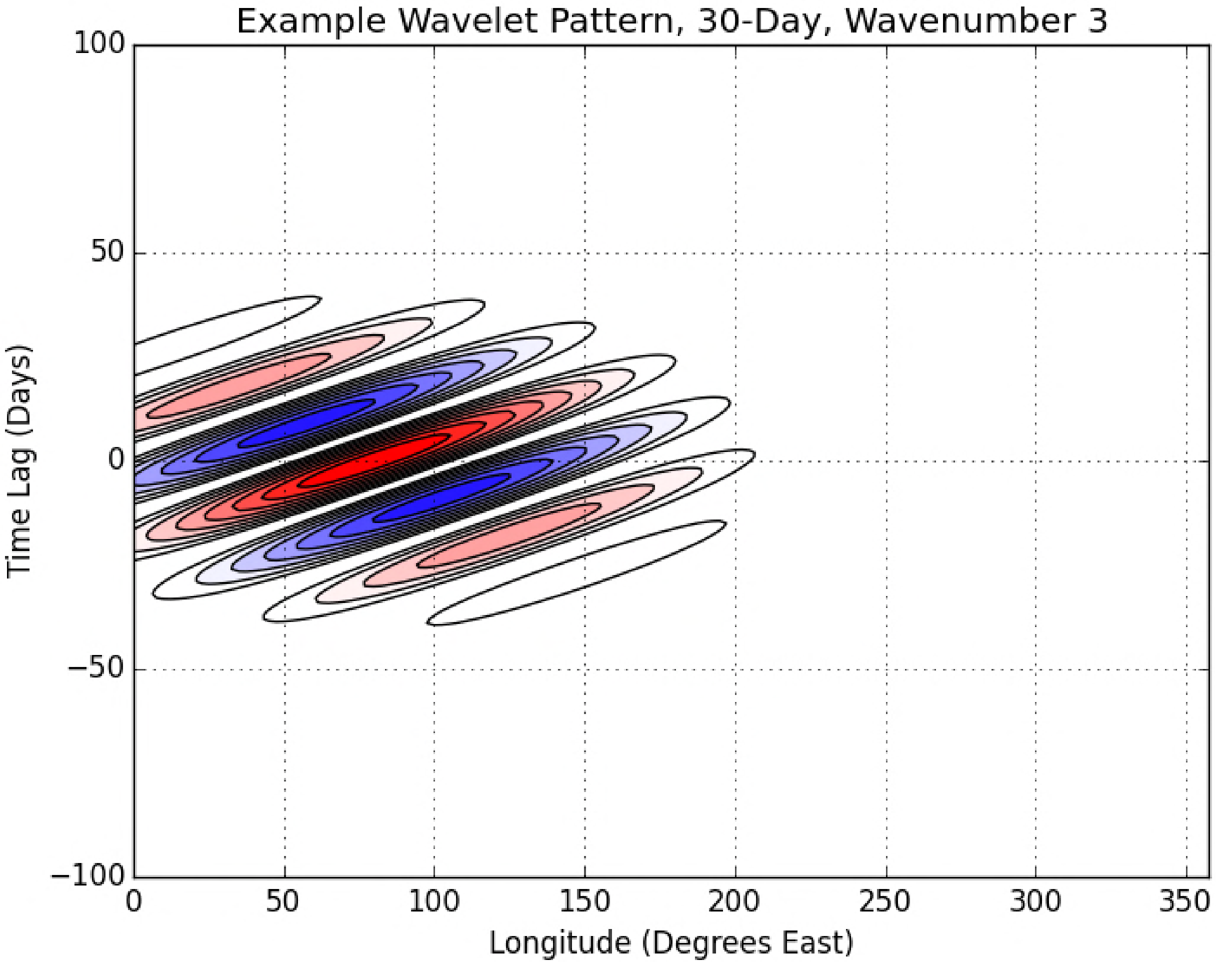
- Regress fields of data against OLR data filtered by wavelet analysis for specific phase speeds,
- Modified regression against the RMM index, and
- Simple case analysis

Space Time Wavelet Analysis

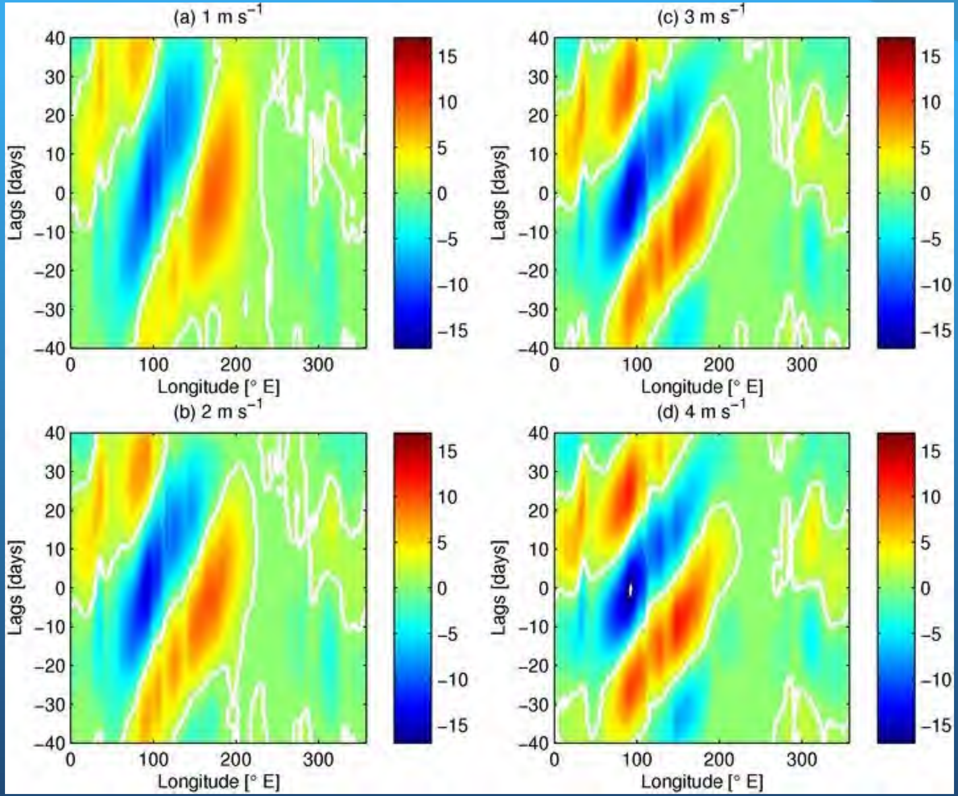
$$\psi = \frac{1}{\gamma} cos(2\pi(kx - F_C t))exp\left(\frac{-x^2}{F_{Bx}} - \frac{-t^2}{F_{Bt}}\right) \quad (1), \text{ where}$$

$$\gamma = \sum_{x=0}^{144} \sum_{t=-100}^{100} exp\left(\frac{-x^2}{F_{Bx}} + \frac{-t^2}{F_{Bt}}\right)$$

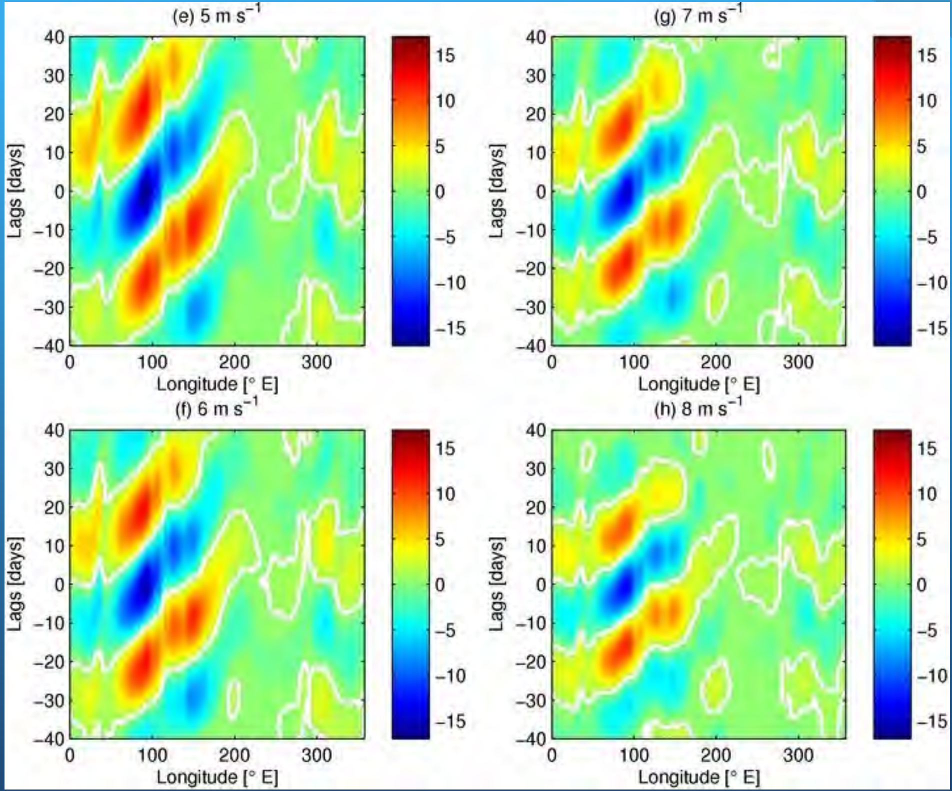
Thanks to grad students Bob Setzenfand and Kaitlyn Krzyzaniak



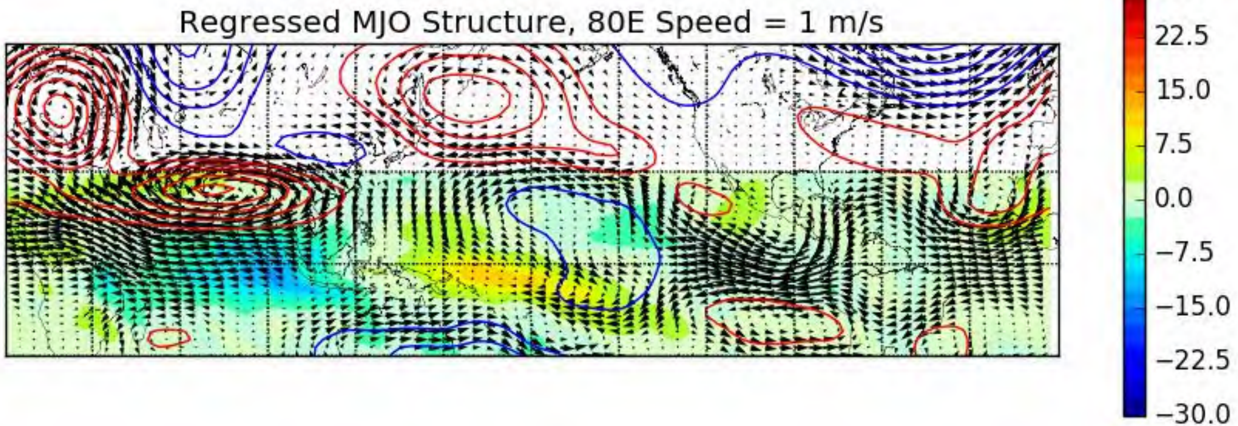
Example Wavelet Pattern, 30-Day, Wavenumber 3
100
50
0
−50
−100
Time Lag (Days)
0
50
100
150
200
250
300
350
Longitude (Degrees East)



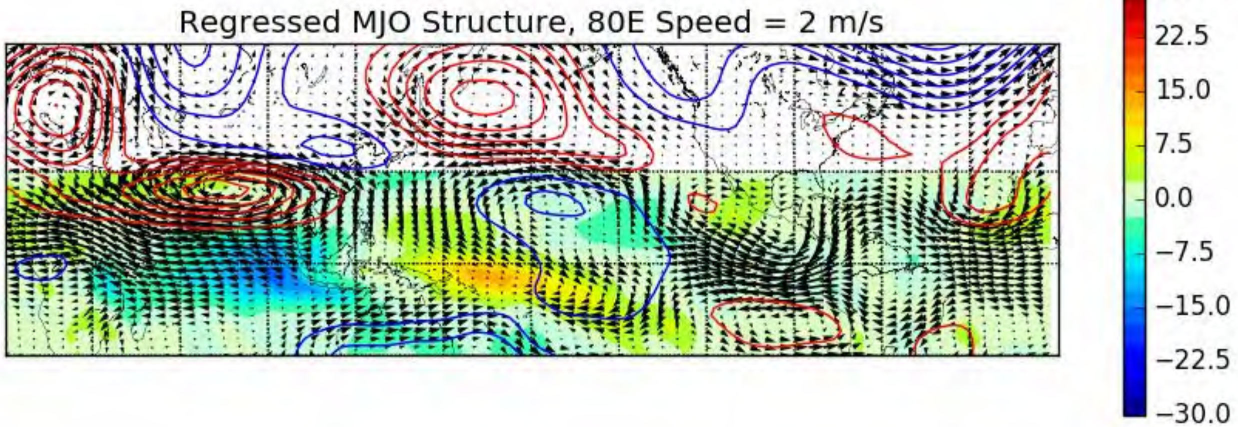
(a) 1 m s^{-1}
(b) 2 m s^{-1}
(c) 3 m s^{-1}
(d) 4 m s^{-1}
Lags [days]
Longitude [° E]


(e) 5 m s^{-1}
(g) 7 m s^{-1}
(f) 6 m s^{-1}
(h) 8 m s^{-1}
Lags [days]
Longitude [° E]

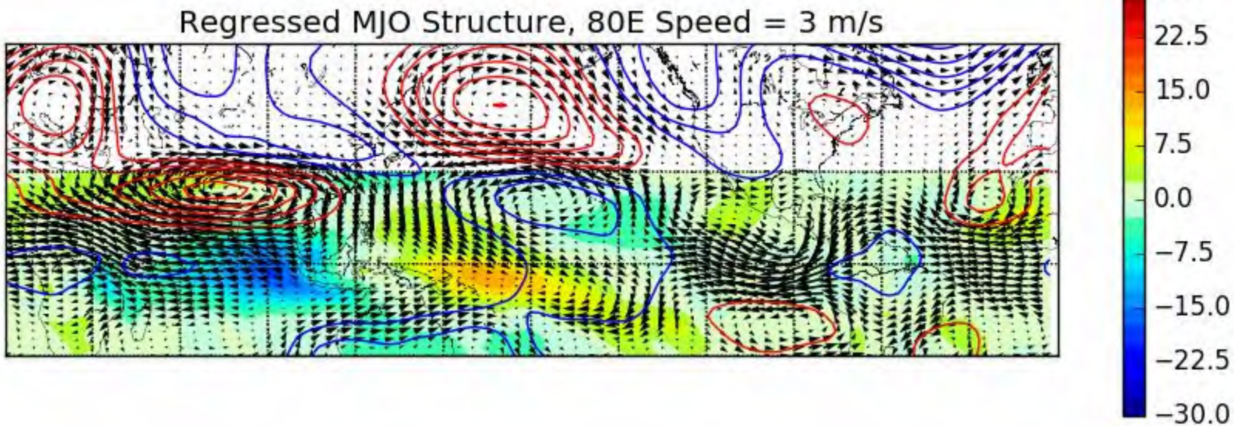
200 hPa Height Anomaly



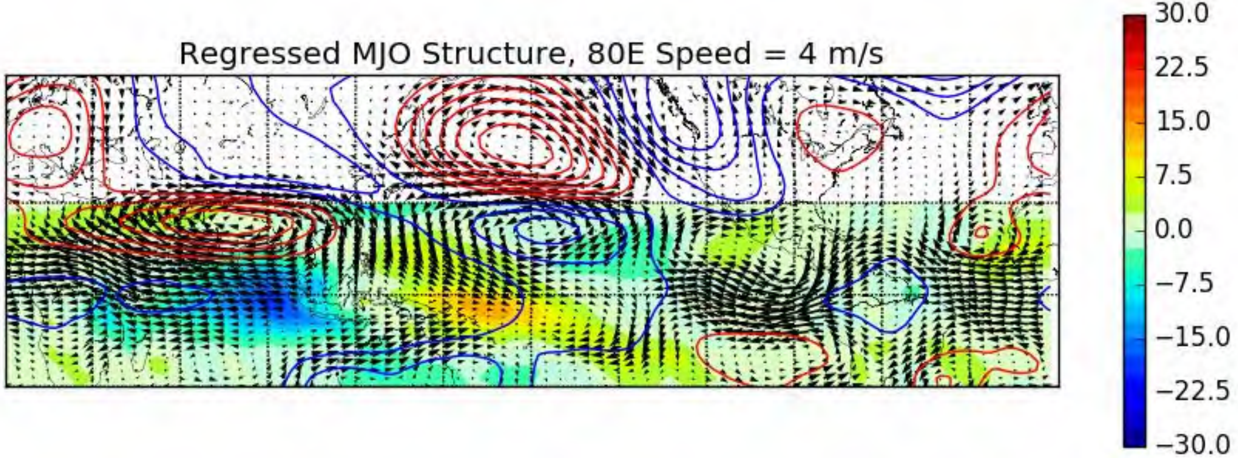
200 hPa Height Anomaly



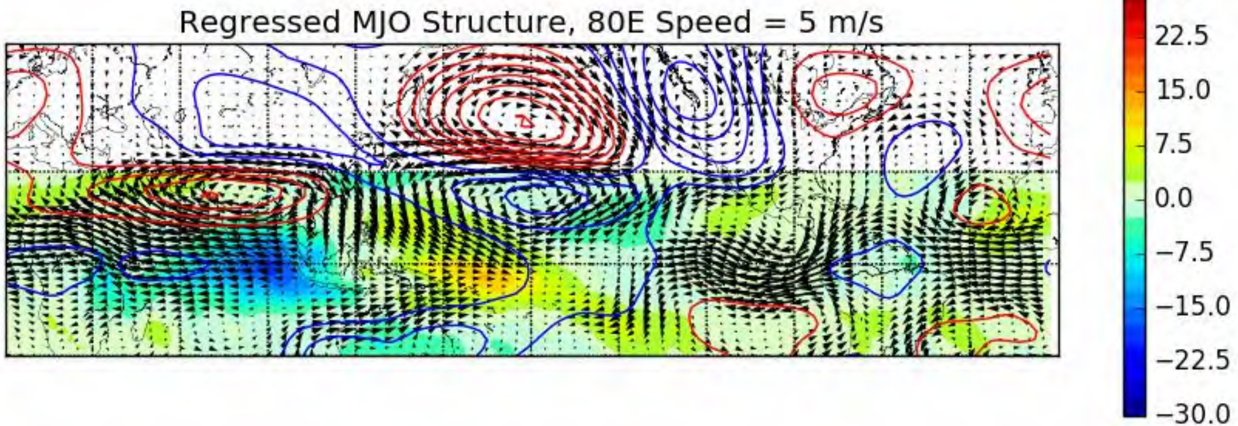
200 hPa Height Anomaly



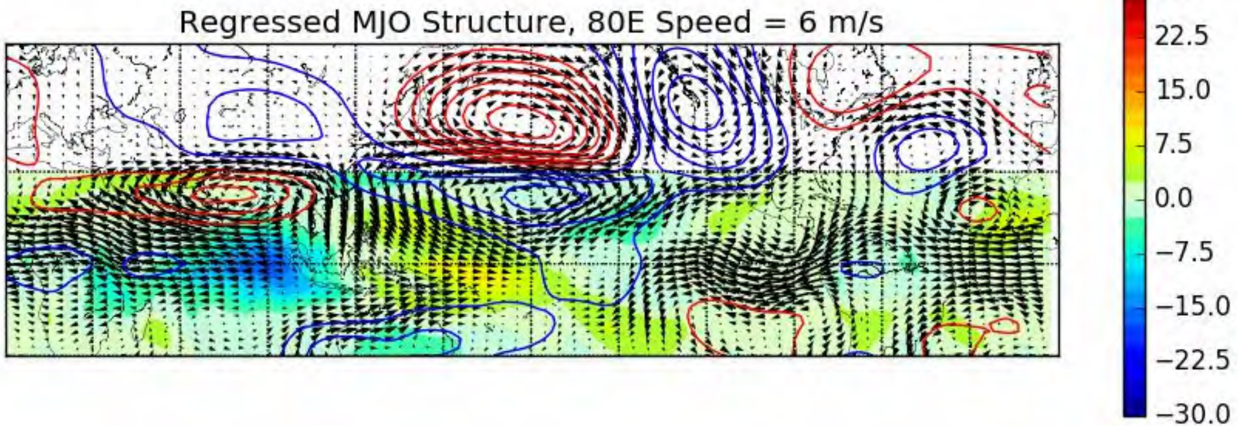
200 hPa Height Anomaly



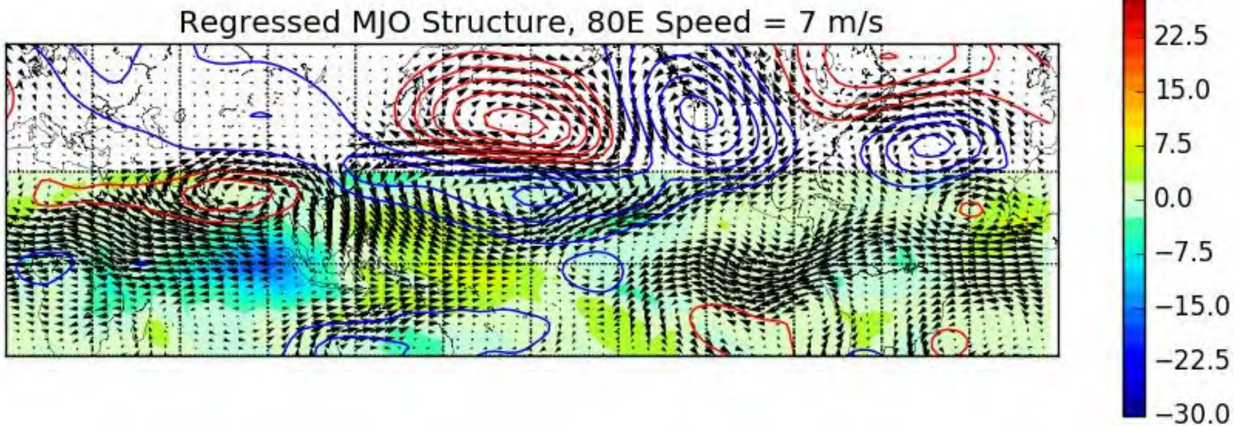
200 hPa Height Anomaly



200 hPa Height Anomaly



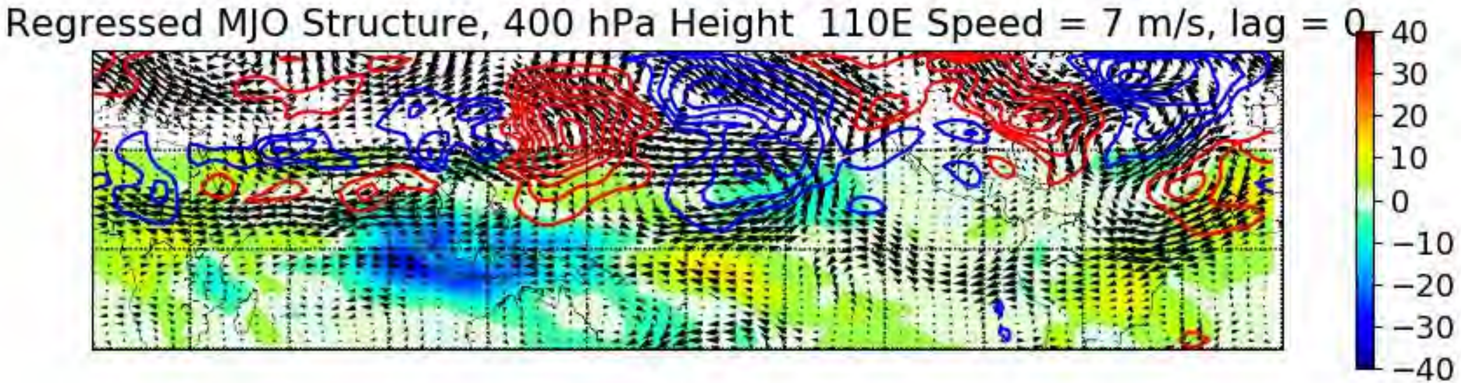
200 hPa Height Anomaly

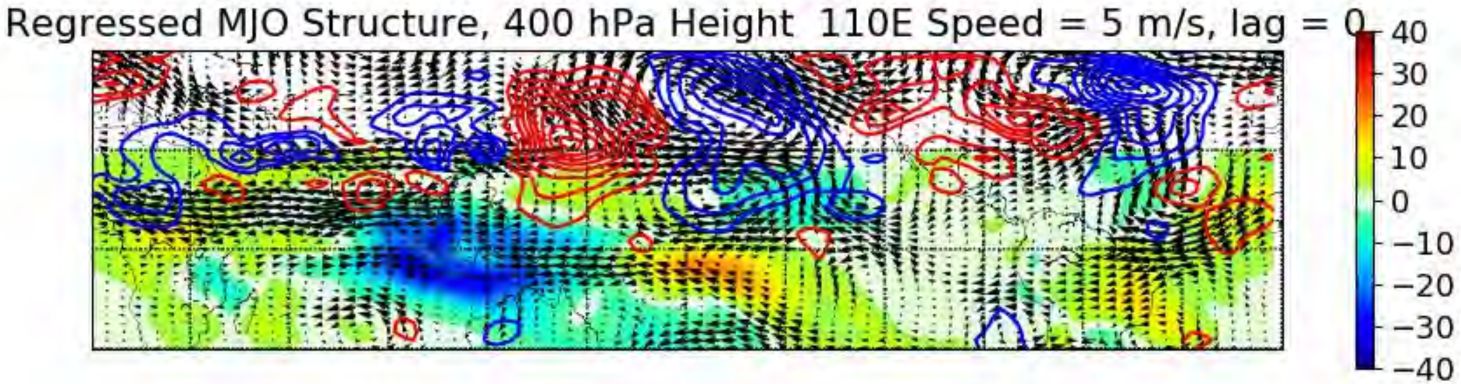


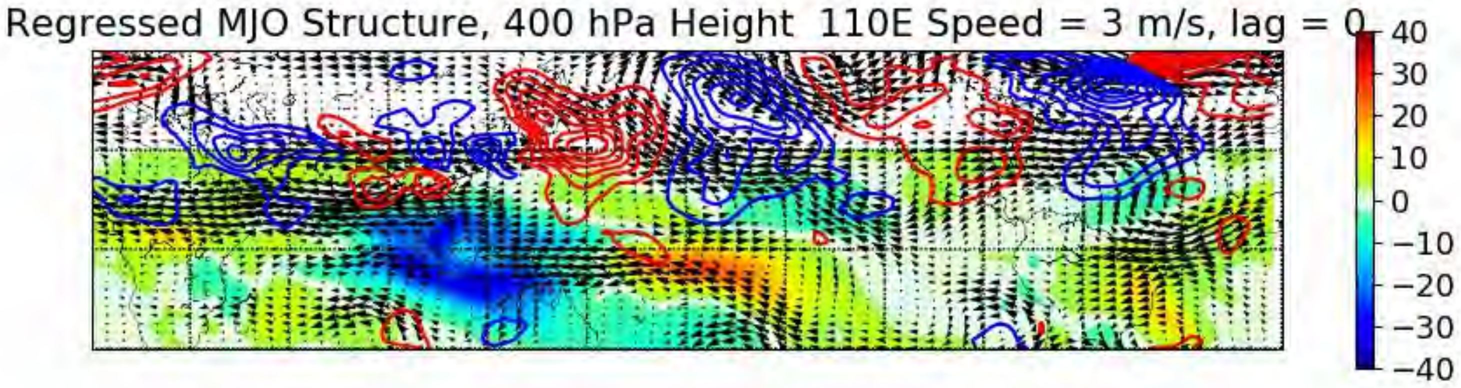
Supports conclusions of
Yadav and Straus (2017, MWR)

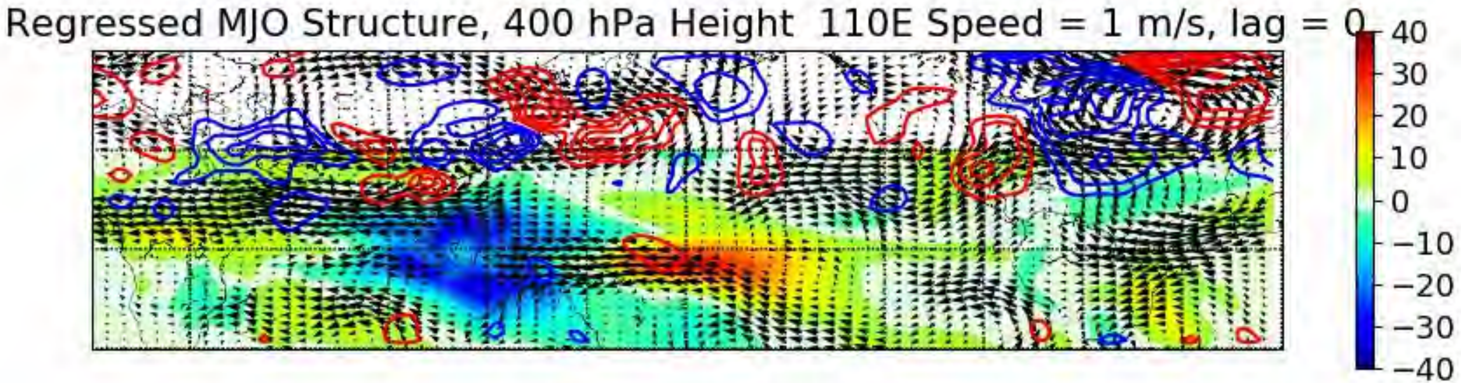
Wavelet Regression of Horizontal Advection Terms

- Regress data for horizontal advection of zonal wind against wavelet filtered MJO index at select phase speeds
- Compare magnitude of regressed anomalies with the selected phase speed


Regressed MJO Structure, 400 hPa Height 110E Speed = 7 m/s, lag = 0
40
30
20
10
0
−10
−20
−30
−40


Regressed MJO Structure, 400 hPa Height 110E Speed = 5 m/s, lag = 0
40
30
20
10
0
−10
−20
−30
−40


Regressed MJO Structure, 400 hPa Height 110E Speed = 3 m/s, lag = 0
40
30
20
10
0
−10
−20
−30
−40


Regressed MJO Structure, 400 hPa Height 110E Speed = 1 m/s, lag = 0
40
30
20
10
0
−10
−20
−30
−40

Modified linear regression against RMM index in different base states

- Algorithm similar to method of seasonally varying regression slope coefficients by Roundy (2017 QJRMS)
- Regress December through February OLR and height anomalies against RMM index for a selected RMM phase during low or high background wind at highlighted location, and check the phase speed

- Slope coefficients are the ratio of covariance between predictor RMM index and predictand to variance in the predictor
- Model the covariance and variance based on external modulating factors, on this case, low frequency background winds
- Create the slope coefficients for different background conditions in the modulating factors

$$\hat{m}_p = inv(x_p^T x_p) x_p^T y_p$$

$$x_{var} = x_p * x_p = x_p^2.$$

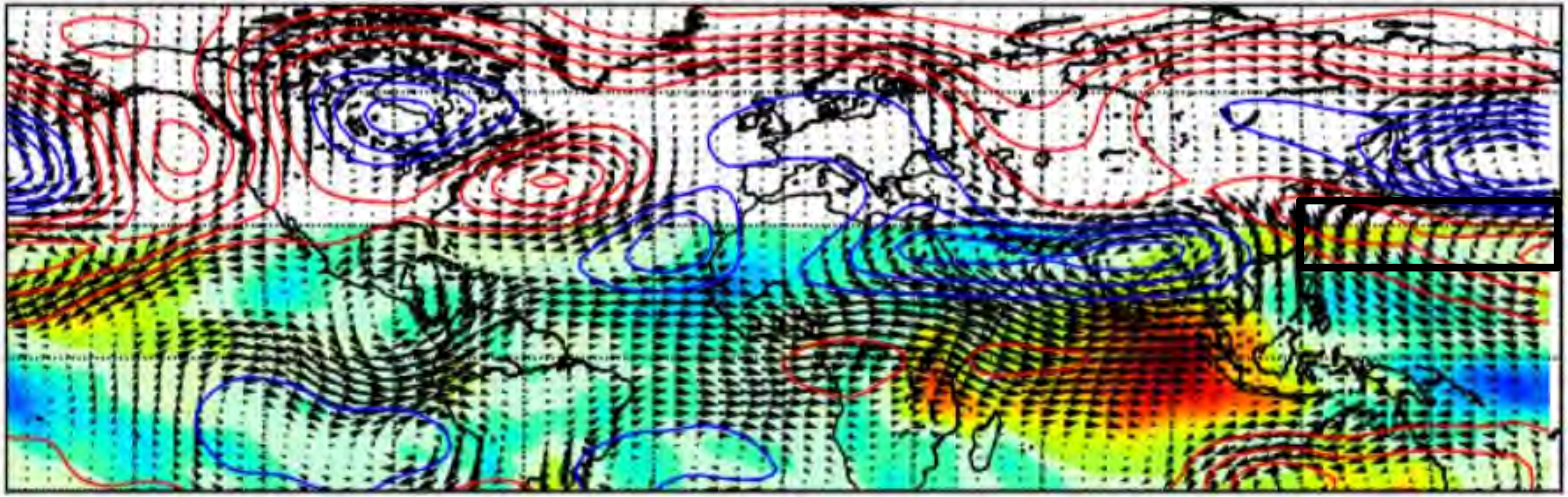
$$\hat{c}_{var} = inv(X^T X) X^T x_{var}$$

$$\text{Variance} = X\hat{c}_{var}$$

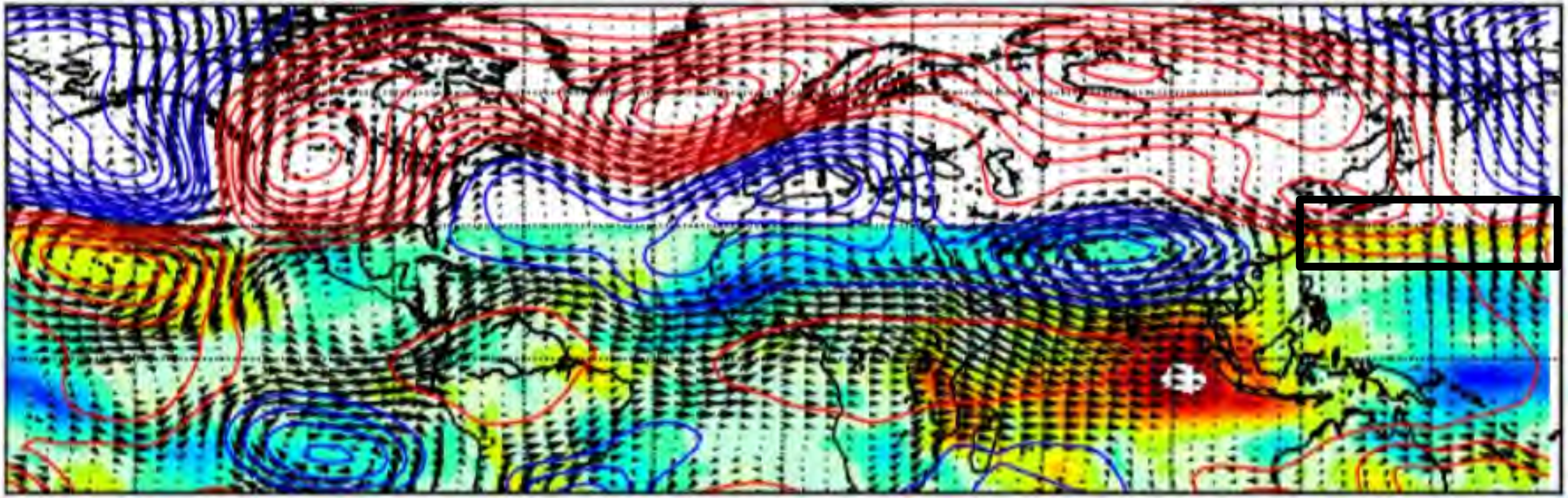
$$\hat{m}_p = \frac{\text{covariance}}{\text{variance}}$$

Roundy 2017, QJRMS

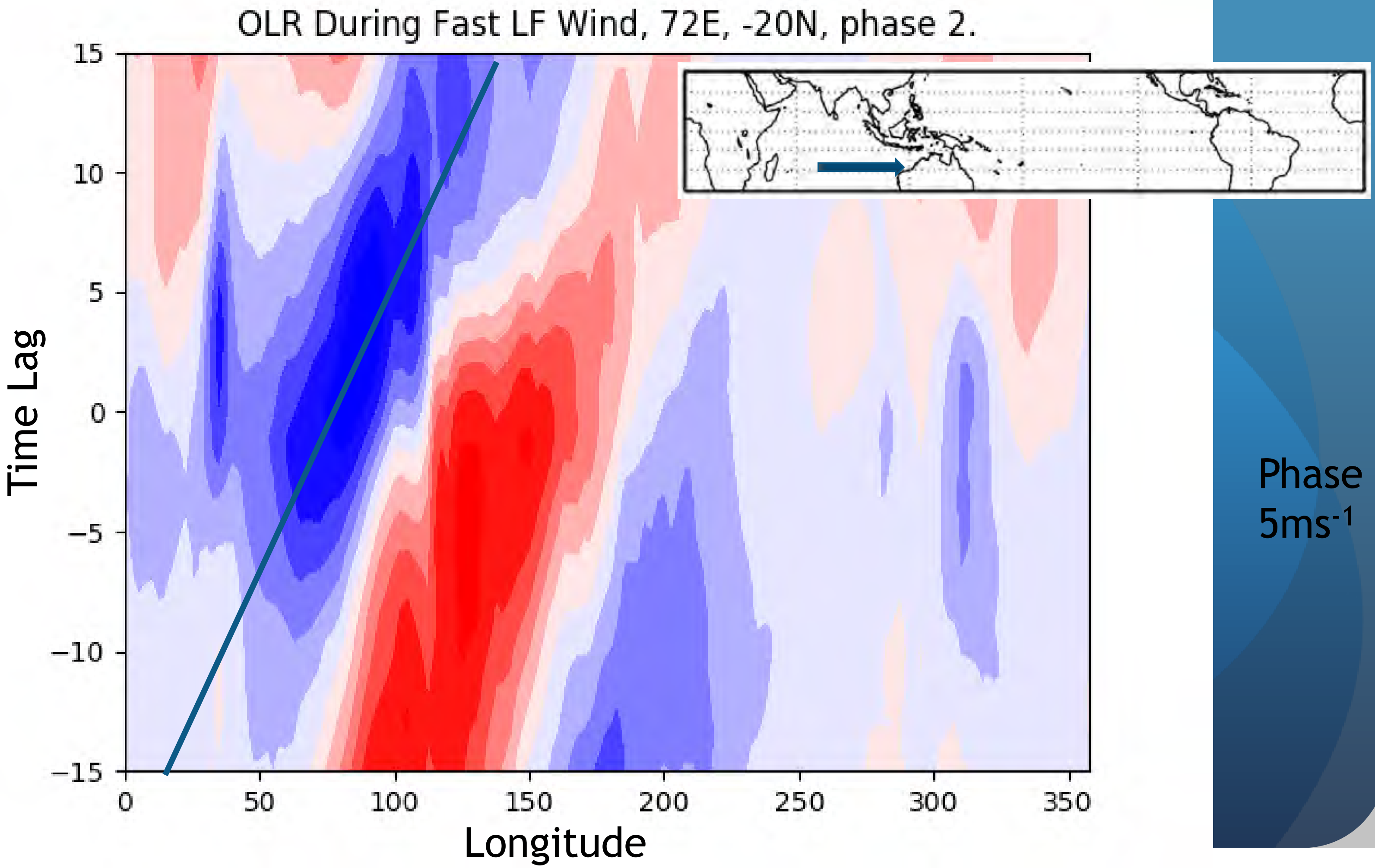
b. RMM Regression Map 200 Height (2 SDs) Phase 6 lead 5 days, 20 m/s



a. RMM Regression Map 200 Height (2 SDs) Phase 6 lead 5 days, 40 m/s

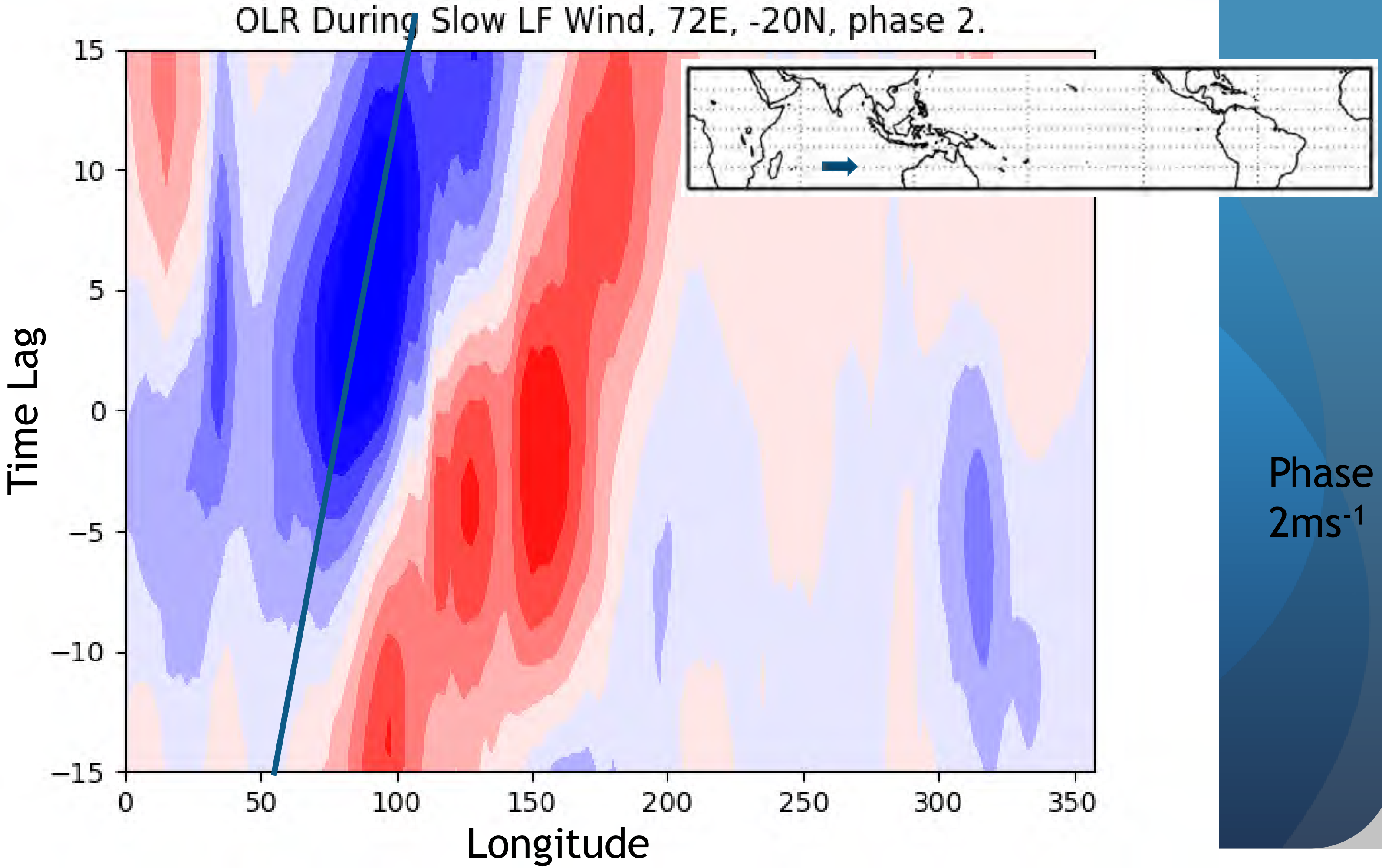


15 ms-1 Wind



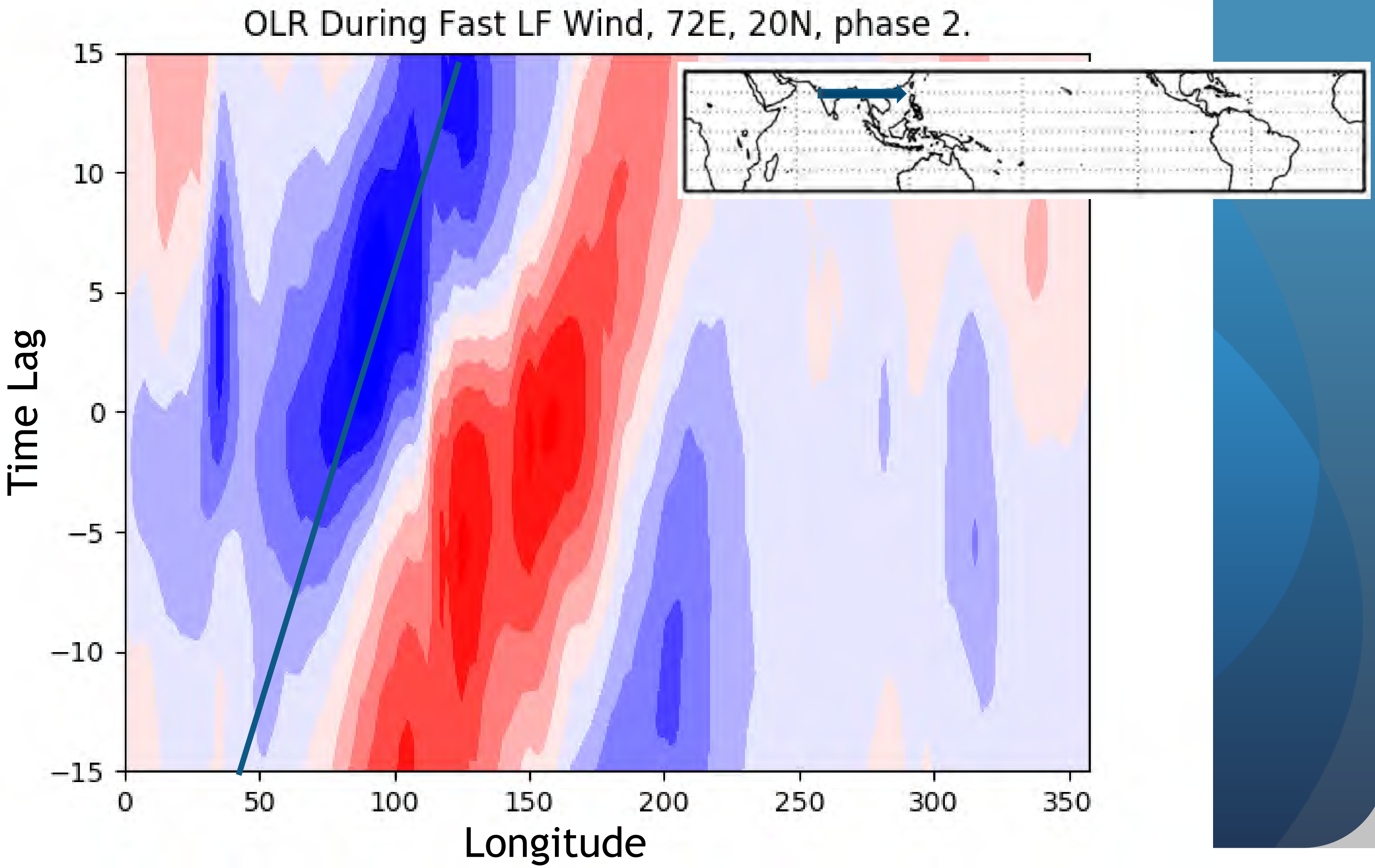
Phase
5ms-1

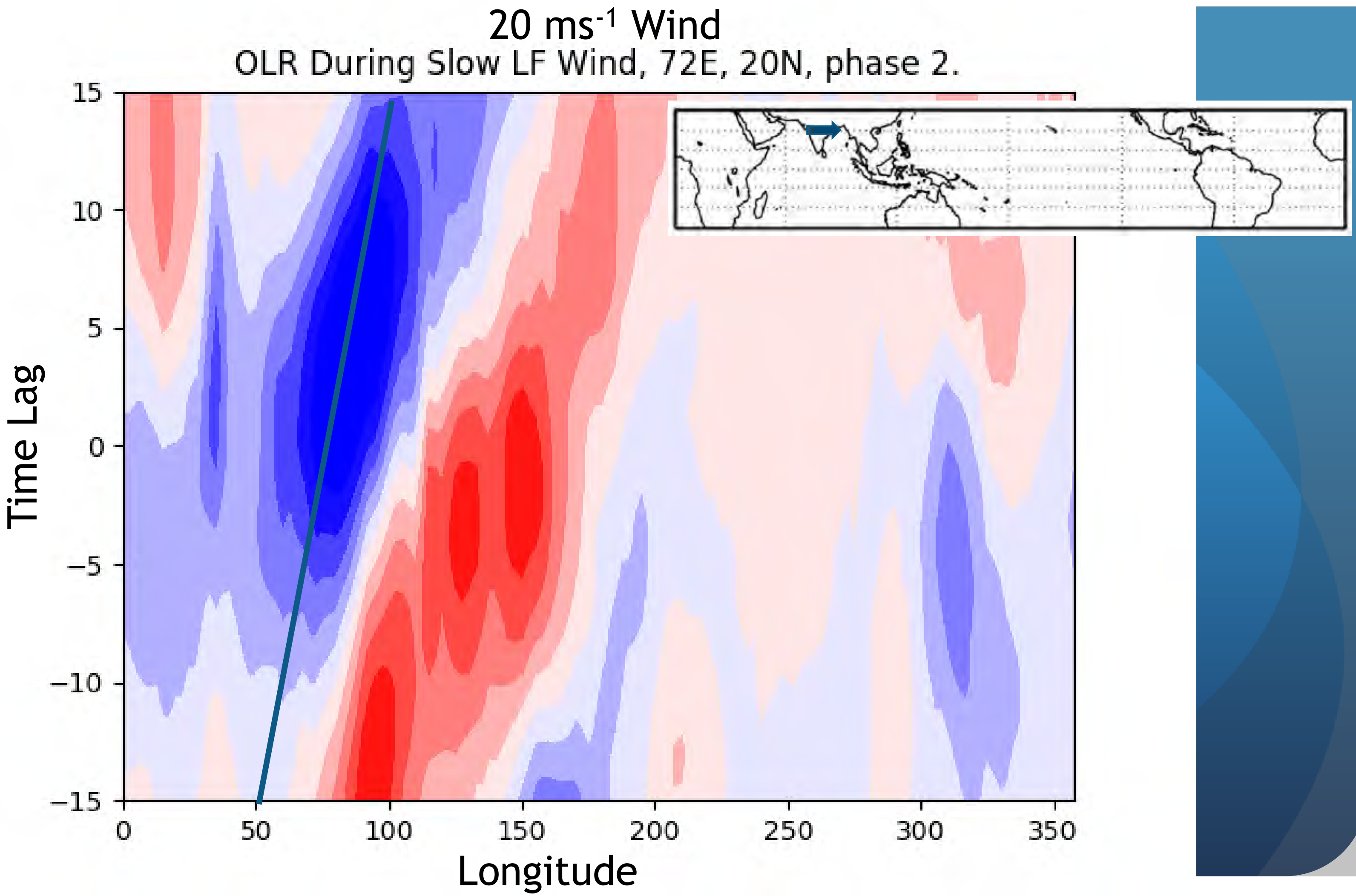
3 ms-1 Wind



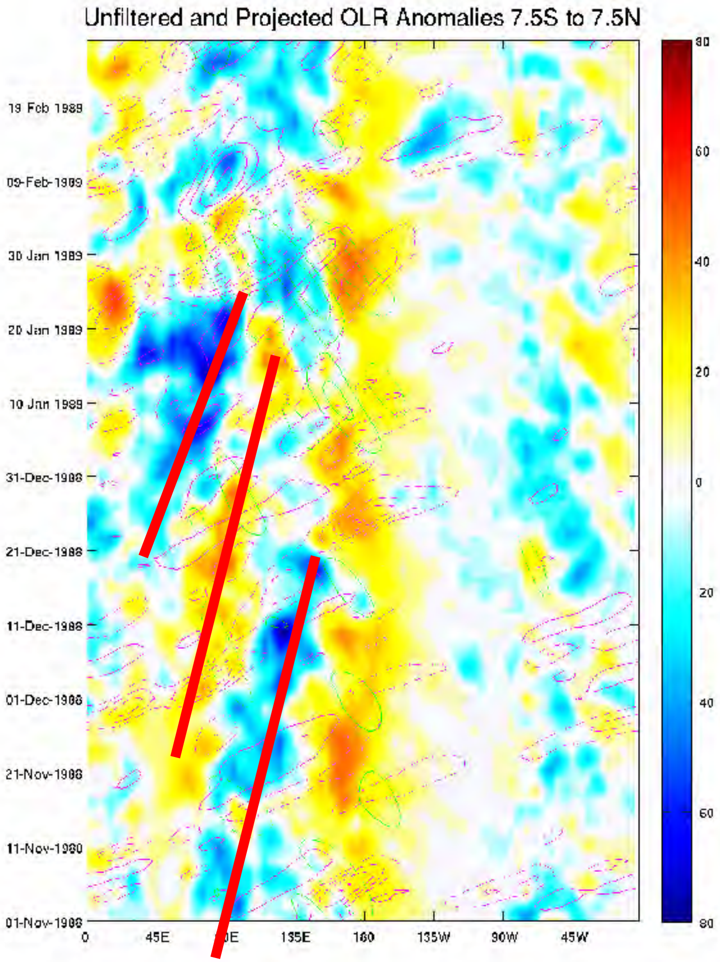
Phase 2ms-1

33 ms^{-1} Wind

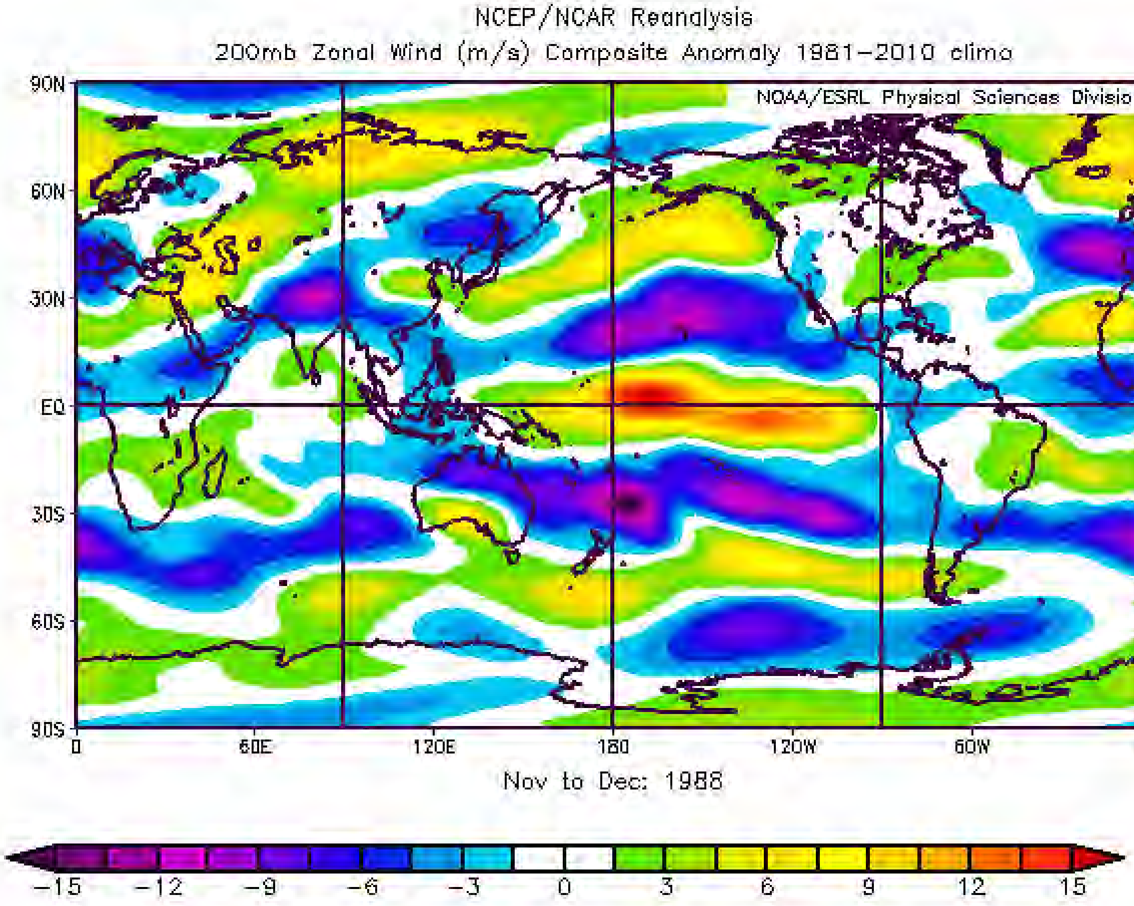

OLR During Fast LF Wind, 72E, 20N, phase 2.
Time Lag
15
10
5
0
−5
−10
−15
0
50
100
150
200
250
300
350
Longitude



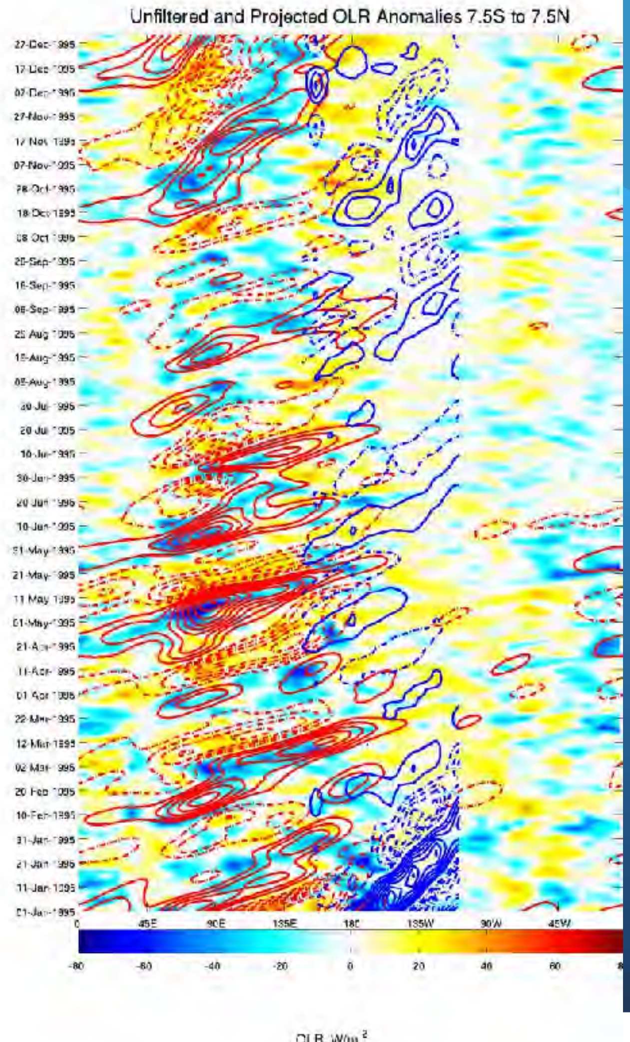
20 ms-1 Wind
OLR During Slow LF Wind, 72E, 20N, phase 2.
Time Lag
15
10
5
0
−5
−10
−15
0
50
100
150
200
250
300
350
Longitude

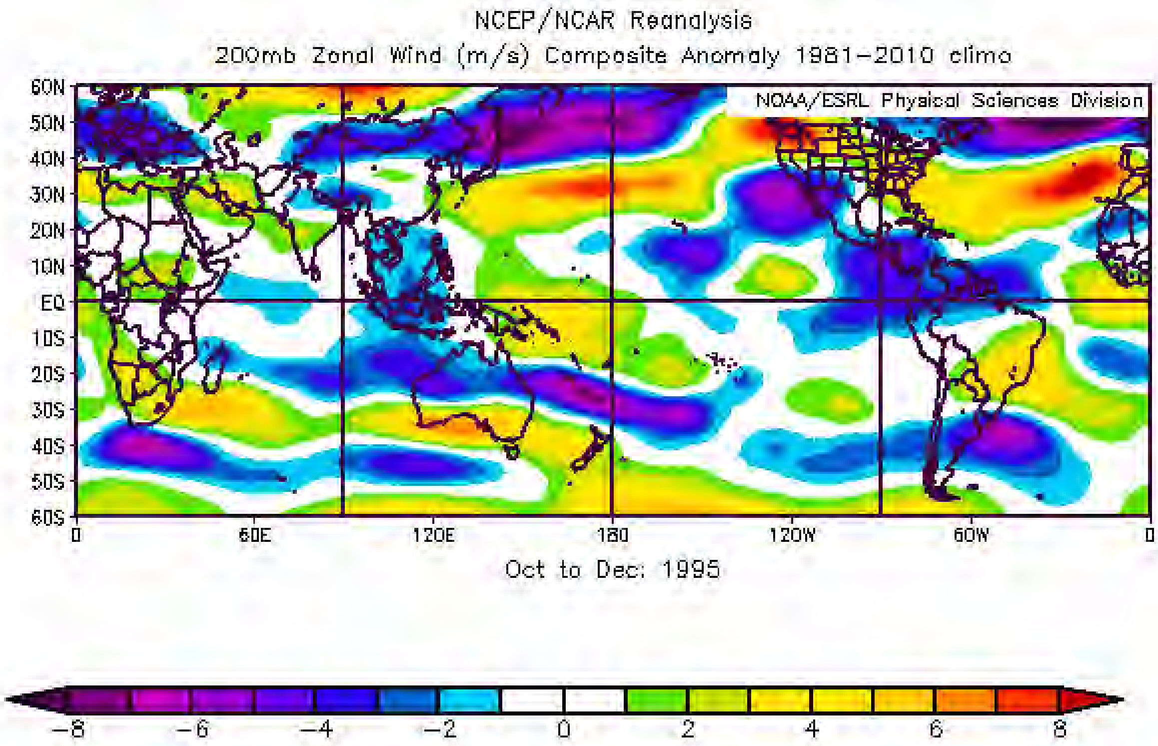


Unfiltered and Projected OLR Anomalies 7.5S to 7.5N
19 Feb 1989
09-Feb-1989
30 Jan 1989
20 Jan 1989
10 Jan 1989
31-Dec-1988
21-Dec-1988
11-Dec-1988
01-Dec-1988
21-Nov-1988
11-Nov-1988
01-Nov-1988
0
45E
135E
180
135W
90W
45W
80
60
40
20
0
20
40
60
80

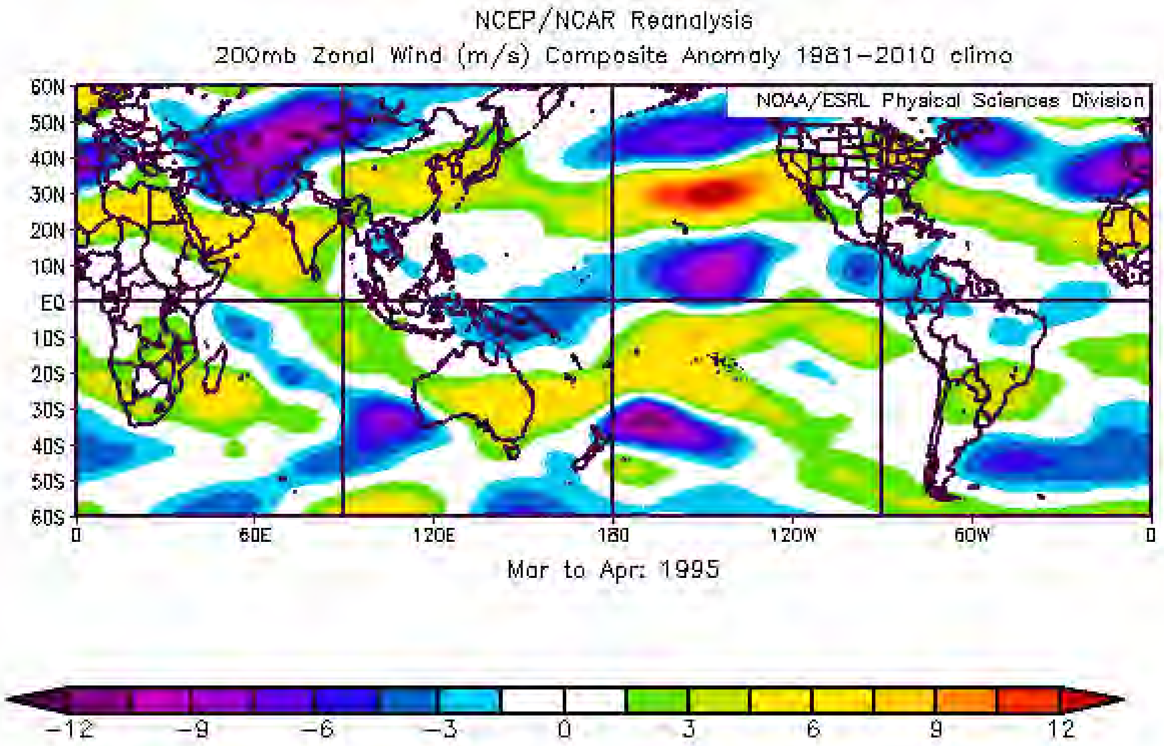


NCEP/NCAR Reanalysis
200mb Zonal Wind (m/s) Composite Anomaly 1981-2010 climo
NOAA/ESRL Physical Sciences Division
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
Nov to Dec: 1988
-15
-12
-9
-6
-3
0
3
6
9
12
15


Unfiltered and Projected OLR Anomalies 7.5S to 7.5N
0
45E
90E
135E
180
135W
90W
45W
-80
-60
-40
-20
0
20
40
60
OLR W/m^2



NCEP/NCAR Reanalysis
200mb Zonal Wind (m/s) Composite Anomaly 1981-2010 climo
NOAA/ESRL Physical Sciences Division
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
0
60E
120E
180
120W
60W
0
Oct to Dec: 1995
-8
-6
-4
-2
0
2
4
6
8

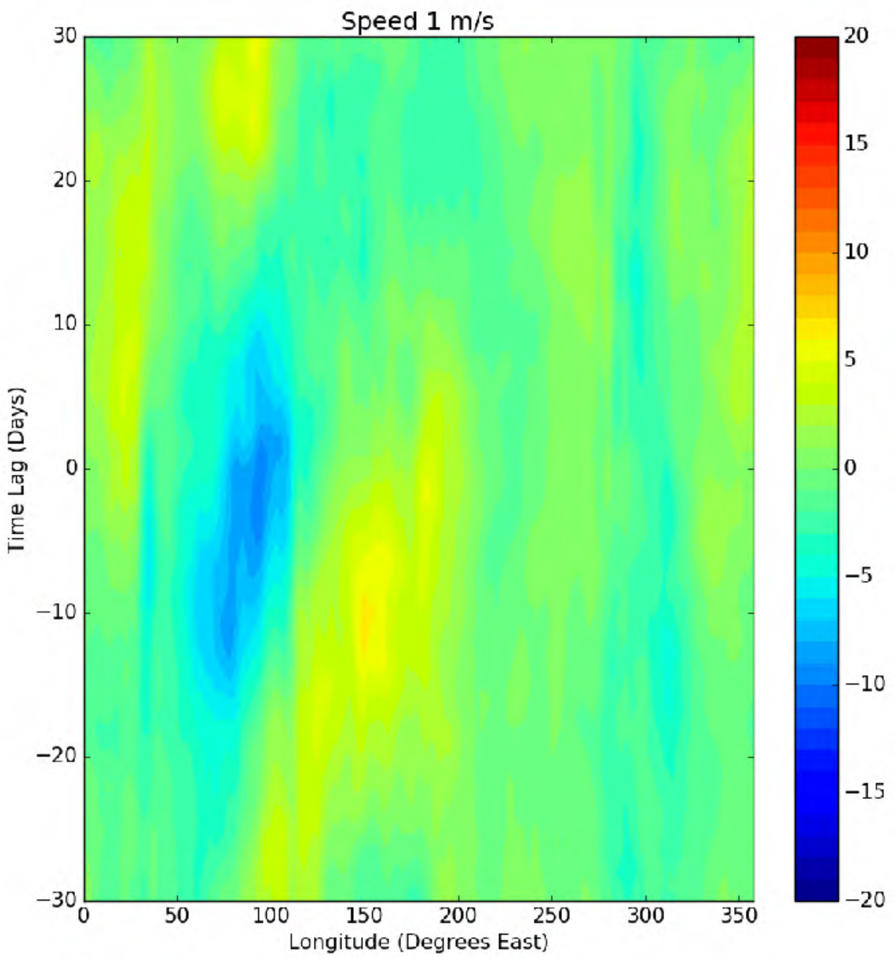

NCEP/NCAR Reanalysis
200mb Zonal Wind (m/s) Composite Anomaly 1981-2010 climo
NOAA/ESRL Physical Sciences Division
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
0
60E
120E
180
120W
60W
0
Mar to Apr: 1995
-12
-9
-6
-3
0
3
6
9
12

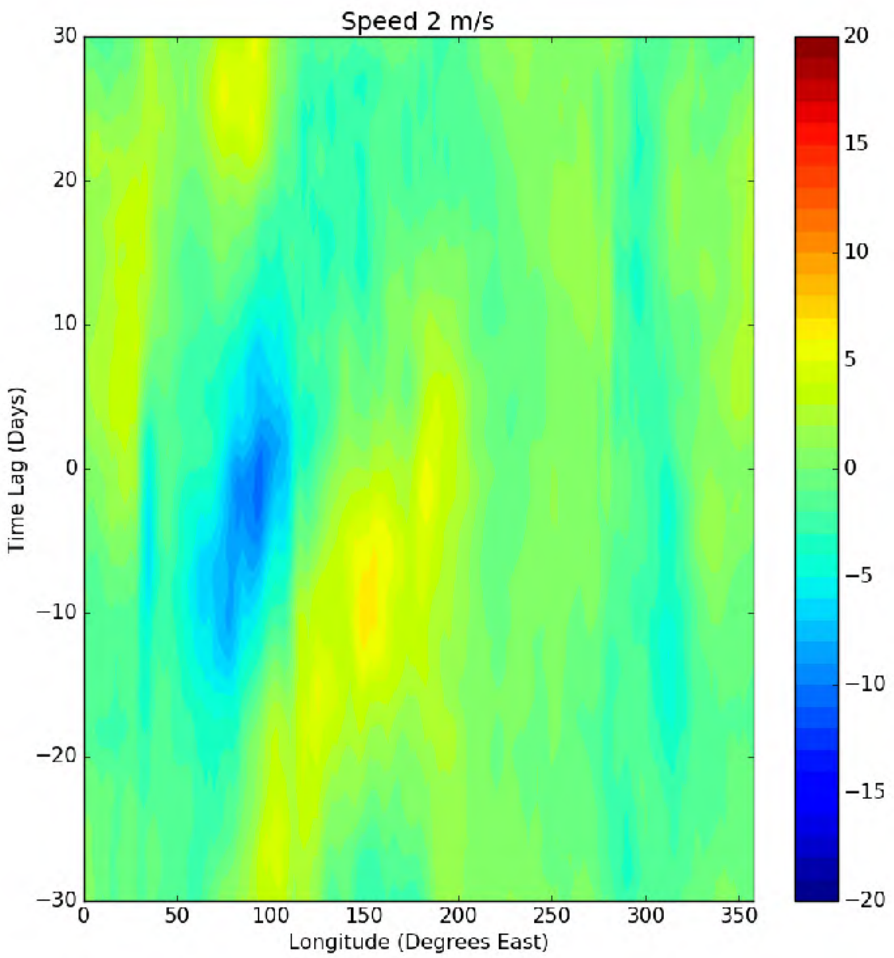
Conclusions

- MJO and Kelvin wave signals exist as parts of a continuum within a single broad spectral peak.
- MJO impact on extratropical circulation is well known
- Extratropical patterns are relevant to the propagation characteristics of the observed MJO: They are not just passive response patterns

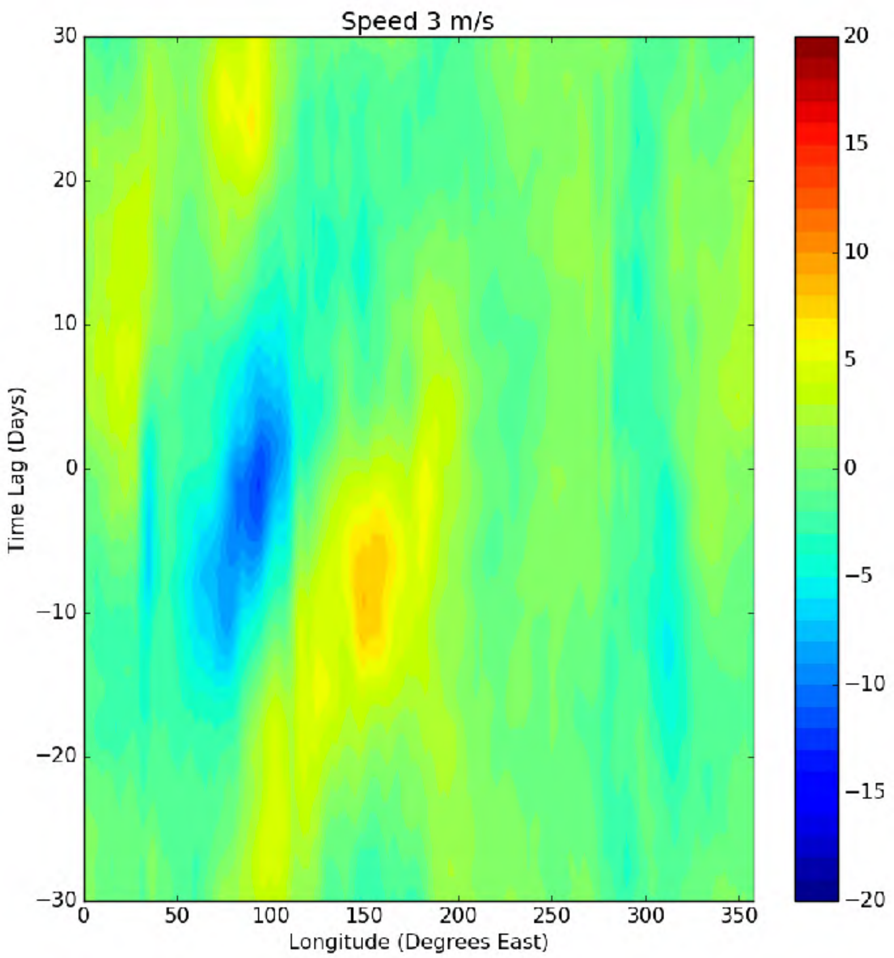
- The slowest MJO events over the Indian Ocean have cool dry air intrude over the Indian Ocean, facilitated by blocking over western Europe. Slow events have slow subtropical jet at proximate longitudes.
- The fastest Indian Ocean MJO events have more blocking over the Pacific Ocean and fast background subtropical jets at proximate latitudes.

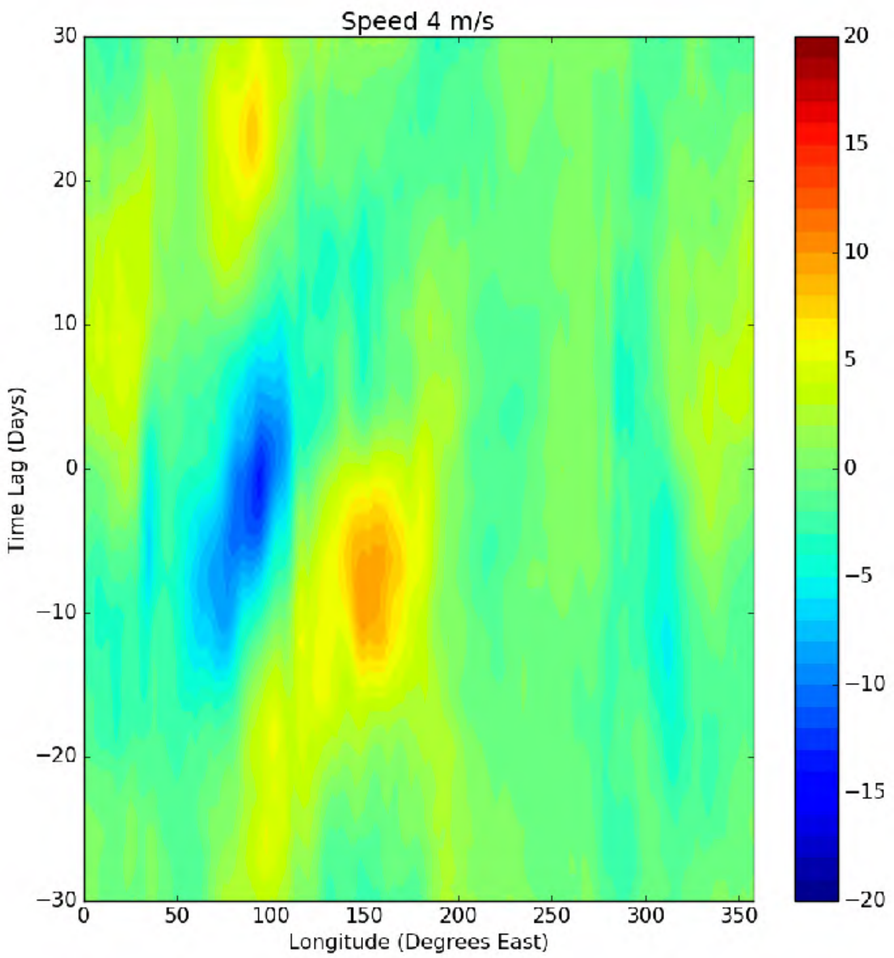
- The spectrum of observed intraseasonal variability must depend on the background state circulation.
- If models depend similarly, than getting the spectrum right must account for these effects. Concentration on convection is not enough.


Speed 1 m/s
Time Lag (Days)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
Longitude (Degrees East)
20
15
10
5
0
−5
−10
−15
−20

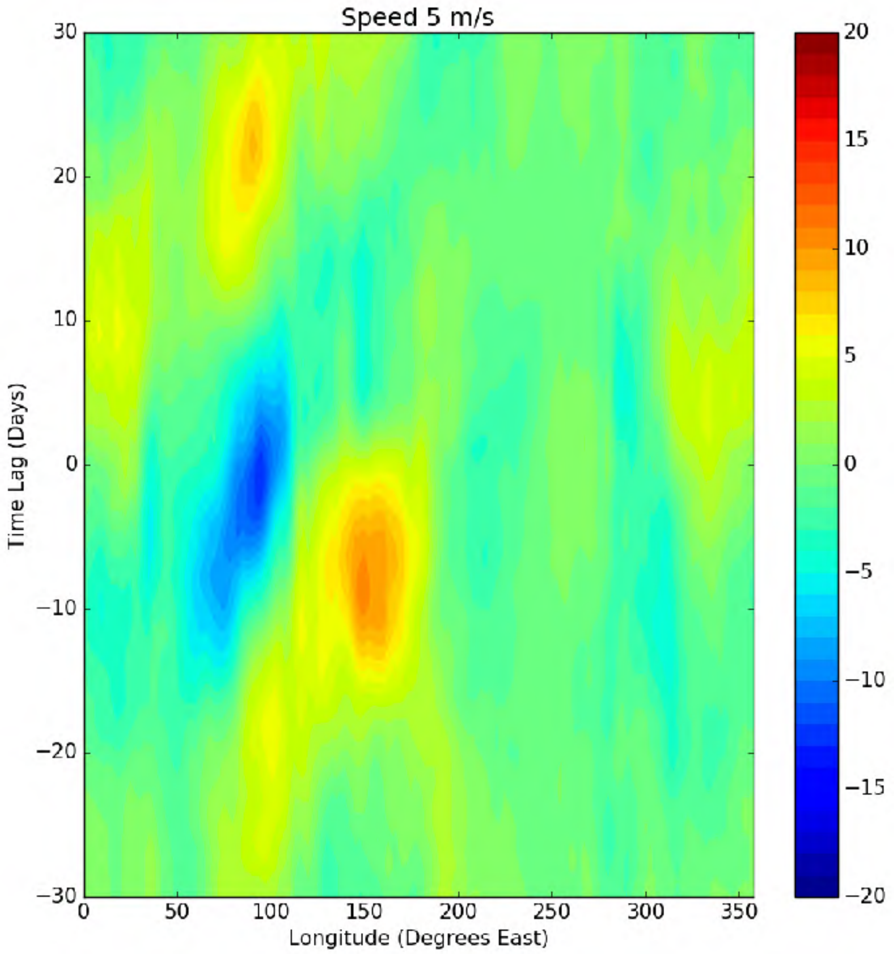


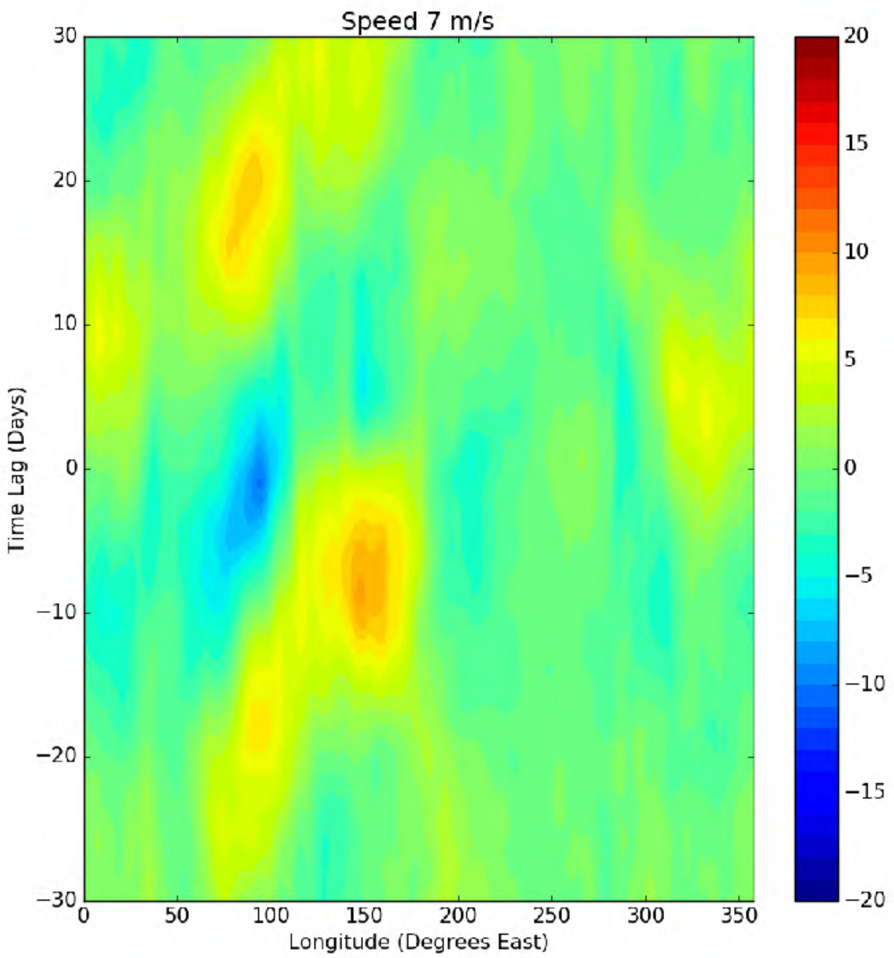
Speed 2 m/s
Time Lag (Days)
Longitude (Degrees East)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
20
15
10
5
0
−5
−10
−15
−20


Speed 3 m/s
Time Lag (Days)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
Longitude (Degrees East)
20
15
10
5
0
−5
−10
−15
−20

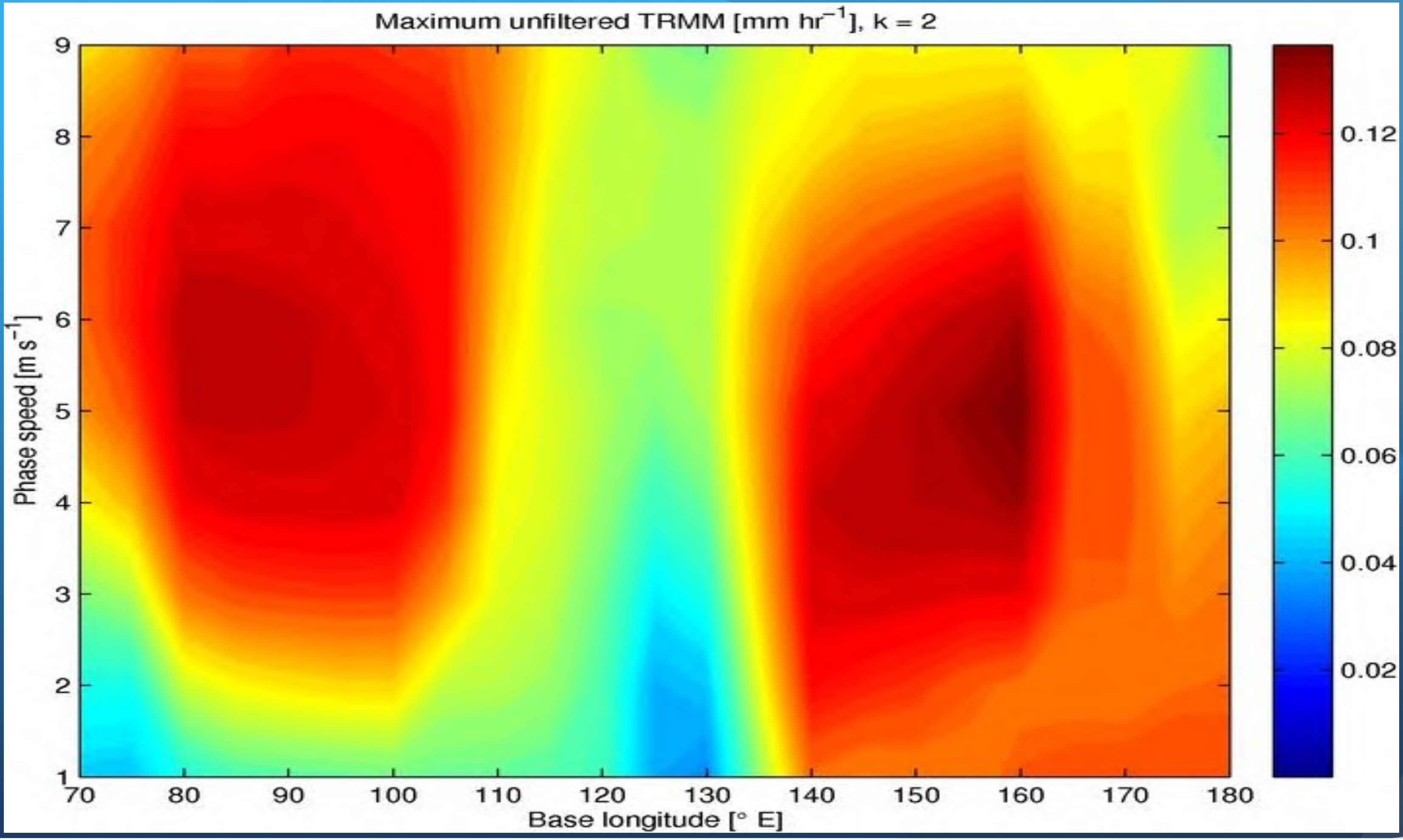


Speed 4 m/s
Time Lag (Days)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
Longitude (Degrees East)
20
15
10
5
0
−5
−10
−15
−20


Speed 5 m/s
Time Lag (Days)
Longitude (Degrees East)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
20
15
10
5
0
−5
−10
−15
−20

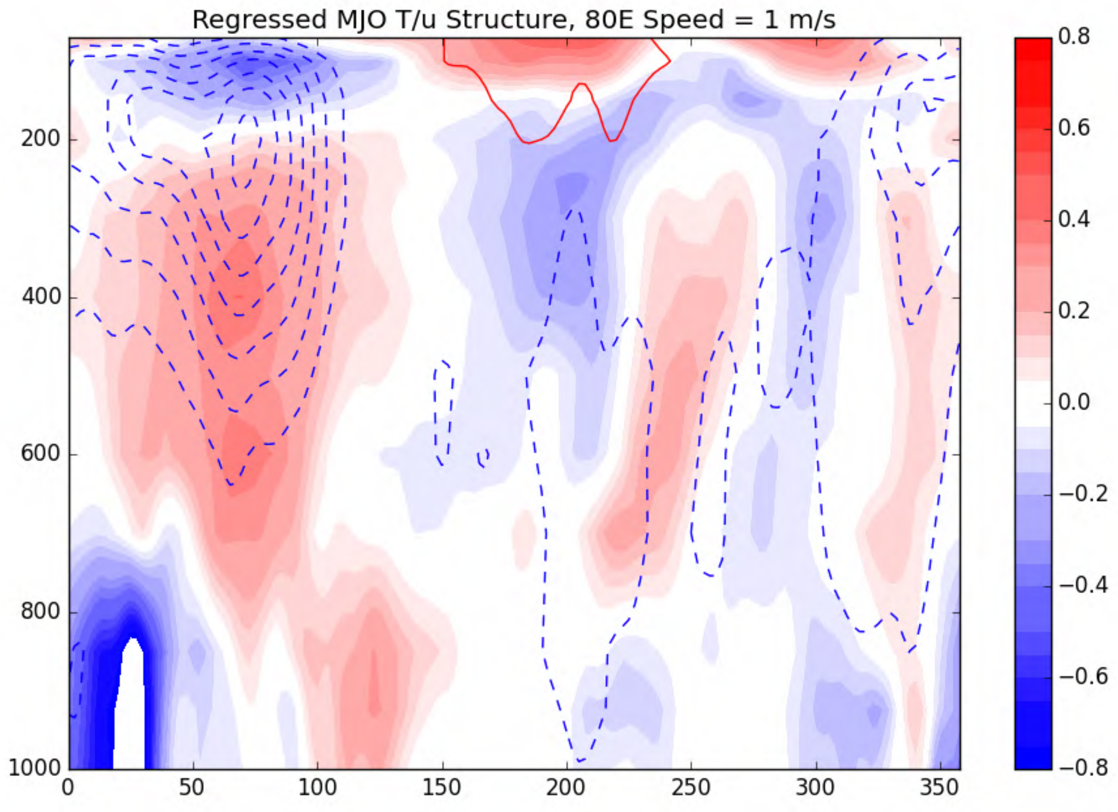


Speed 7 m/s
Time Lag (Days)
Longitude (Degrees East)
30
20
10
0
−10
−20
−30
0
50
100
150
200
250
300
350
20
15
10
5
0
−5
−10
−15
−20



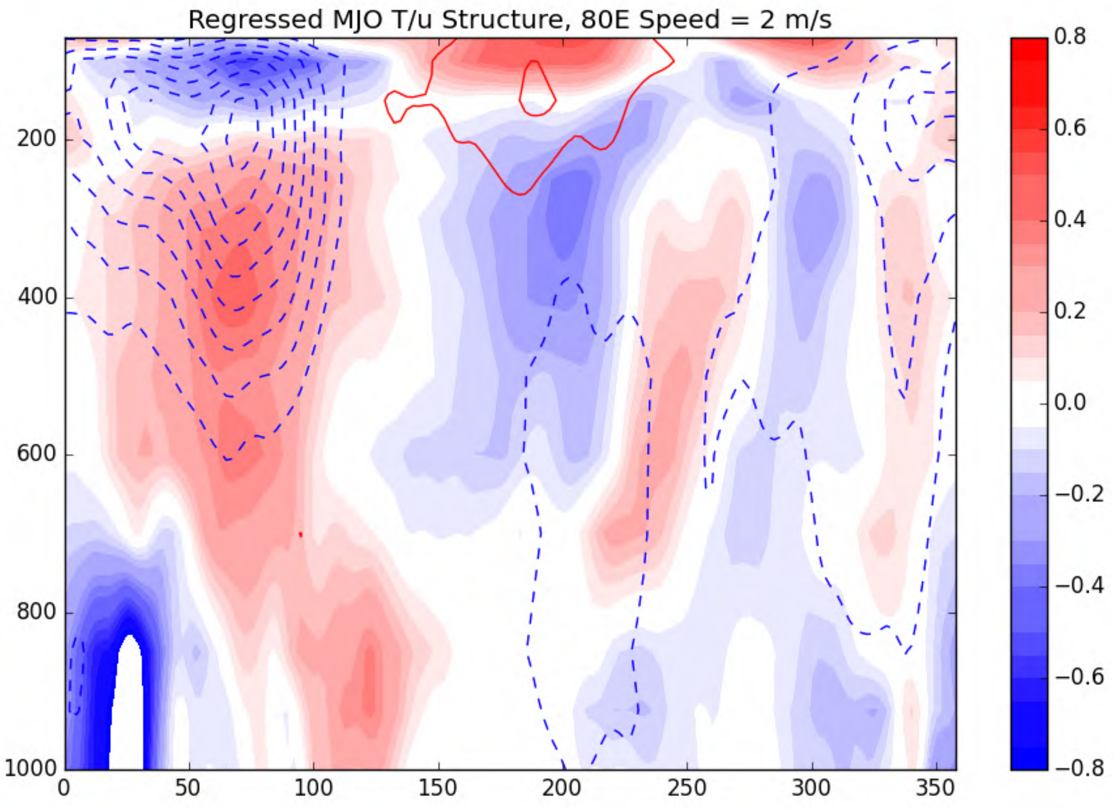
Maximum unfiltered TRMM [mm hr^-1], k = 2
Phase speed [m s^-1]
Base longitude [° E]
9
8
7
6
5
4
3
2
1
70
80
90
100
110
120
130
140
150
160
170
180
0.12
0.1
0.08
0.06
0.04
0.02

15°N



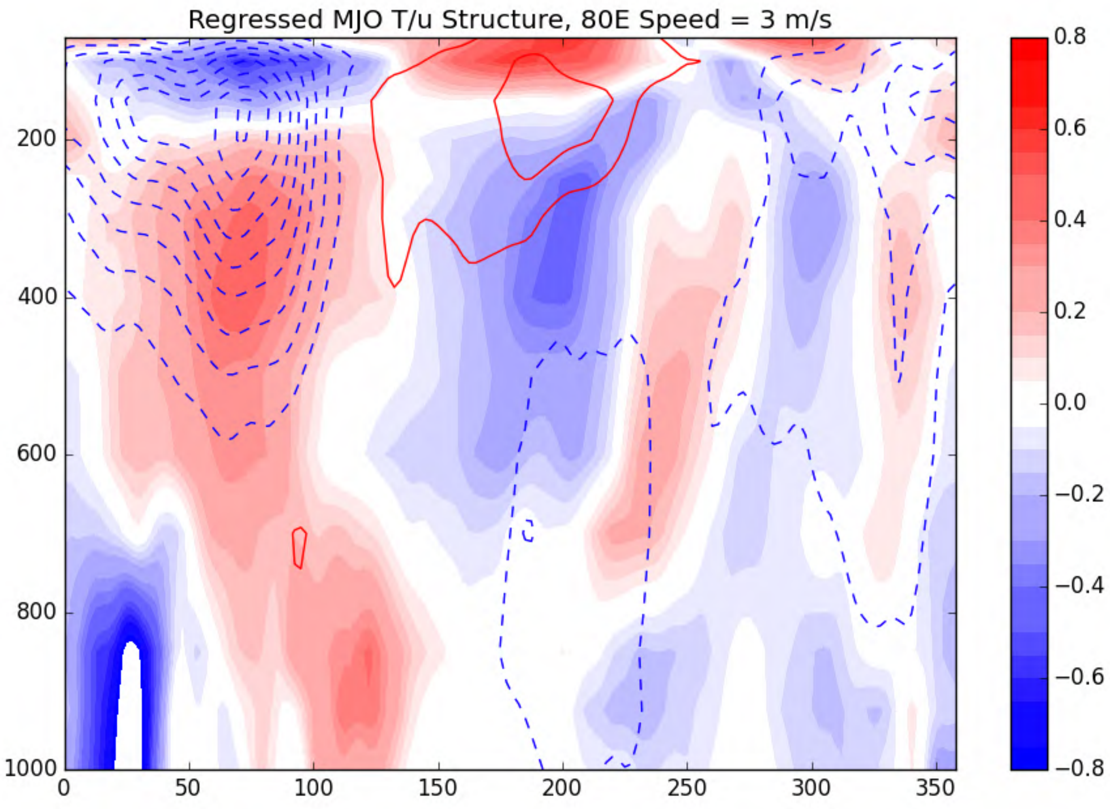
Regressed MJO T/u Structure, 80E Speed = 1 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

15°N



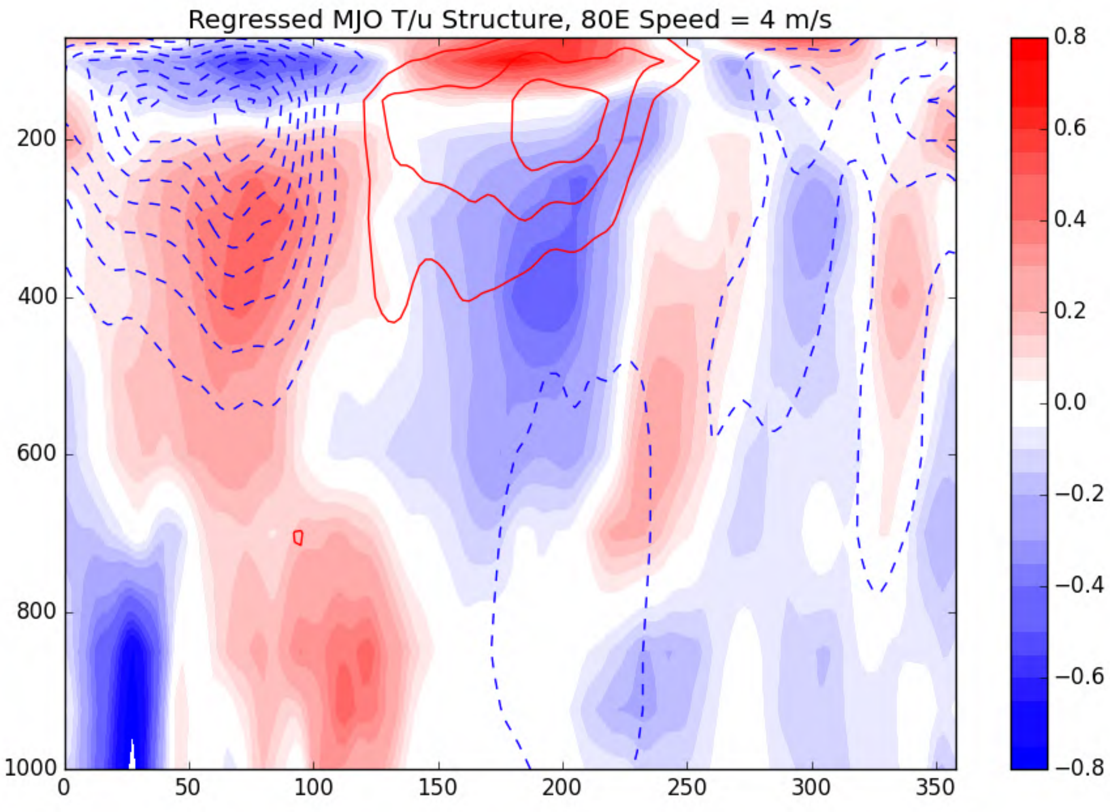
Regressed MJO T/u Structure, 80E Speed = 2 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

15°N

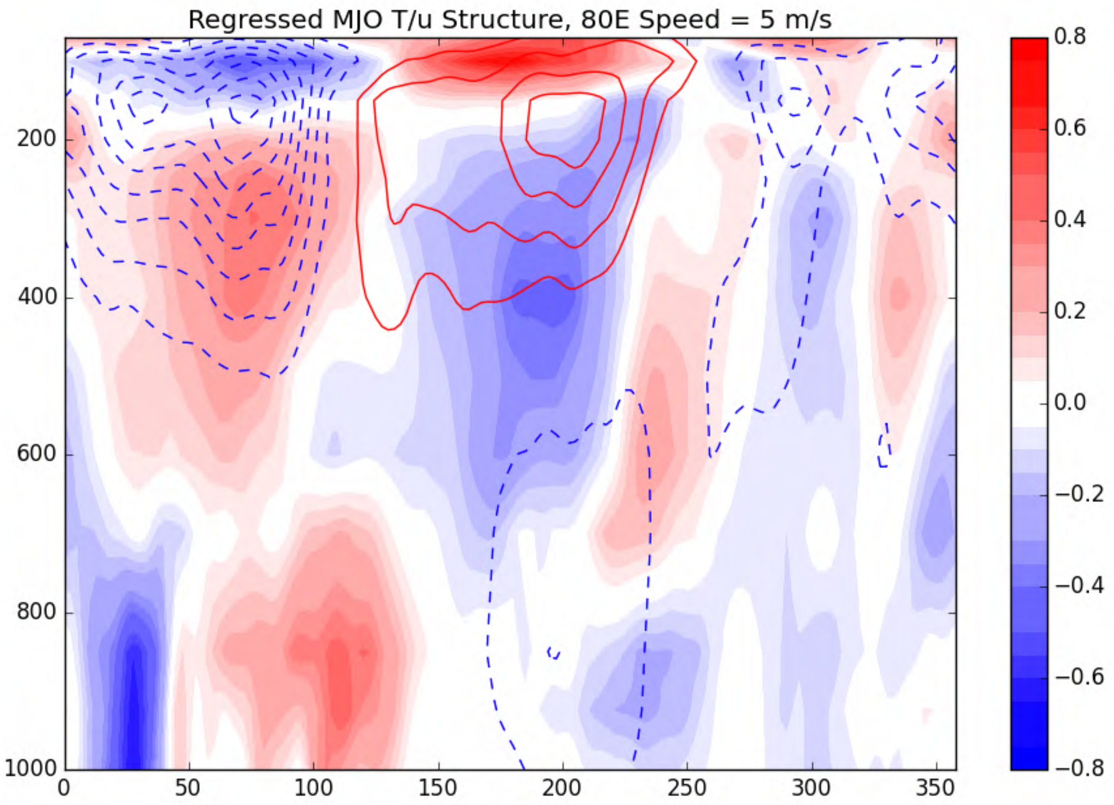


Regressed MJO T/u Structure, 80E Speed = 3 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

15°N

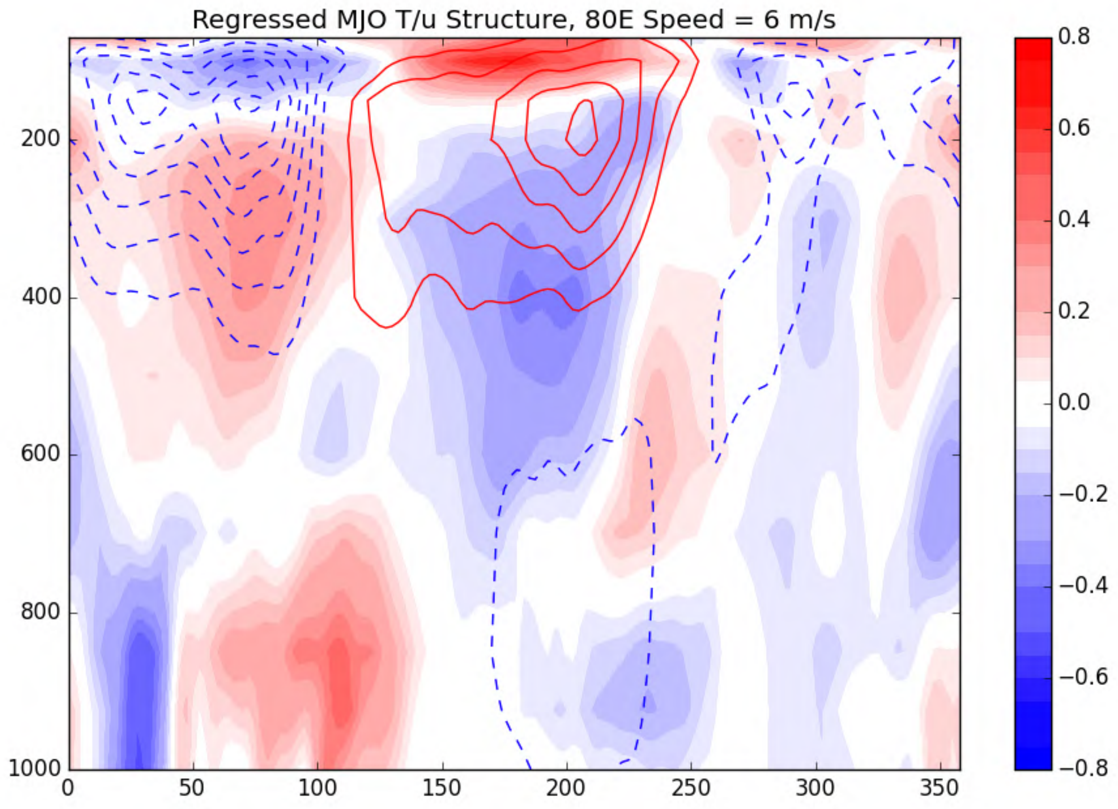


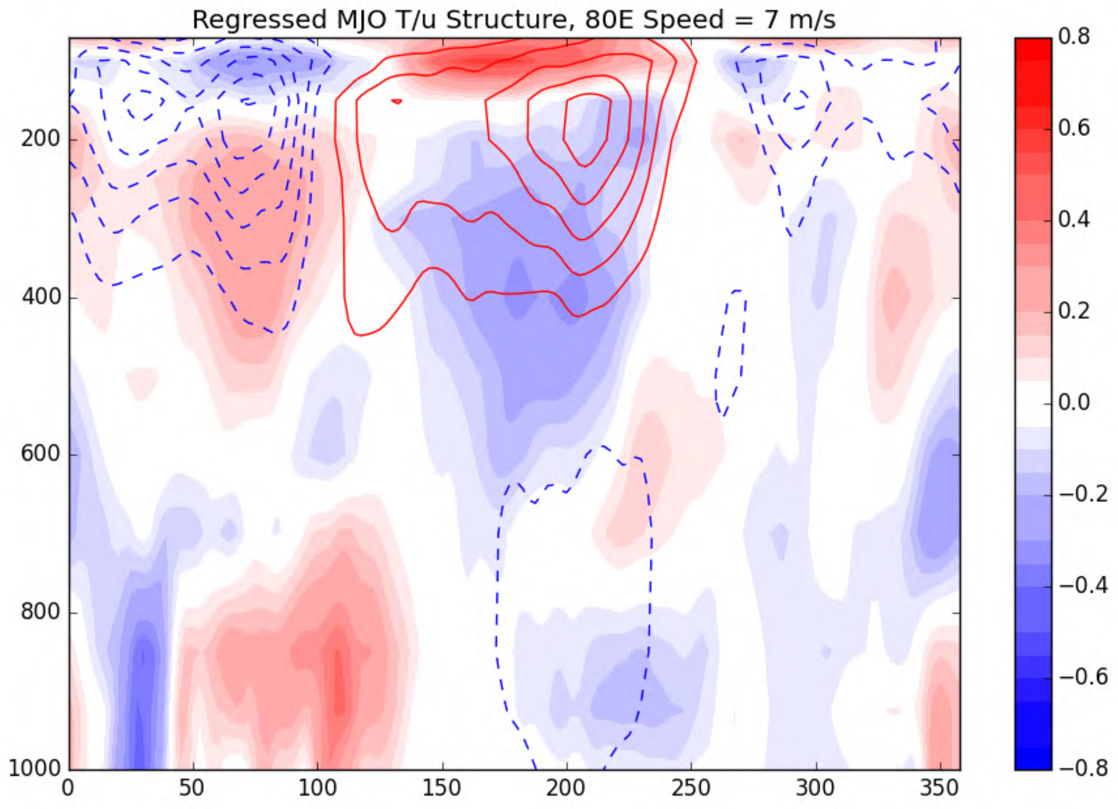
Regressed MJO T/u Structure, 80E Speed = 4 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8


Regressed MJO T/u Structure, 80E Speed = 5 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

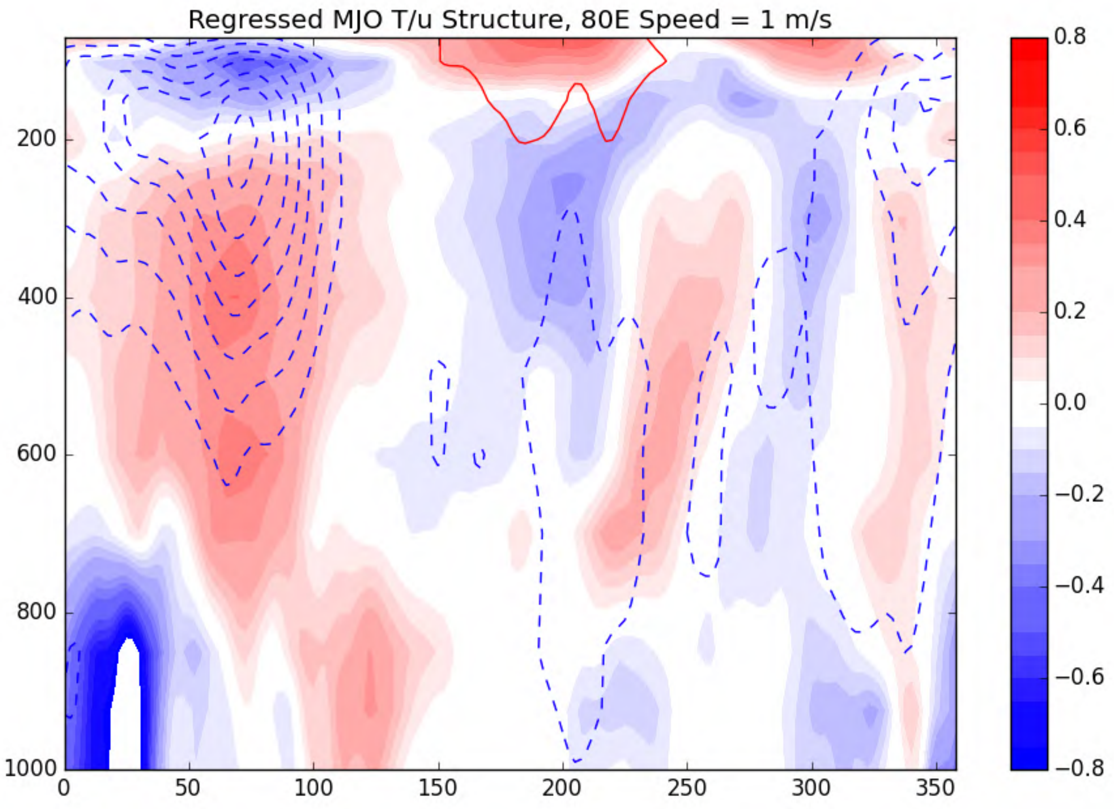
15°N

15°N


Regressed MJO T/u Structure, 80E Speed = 6 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8


Regressed MJO T/u Structure, 80E Speed = 7 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

15°N



Regressed MJO T/u Structure, 80E Speed = 1 m/s
200
400
600
800
1000
0
50
100
150
200
250
300
350
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

15°N