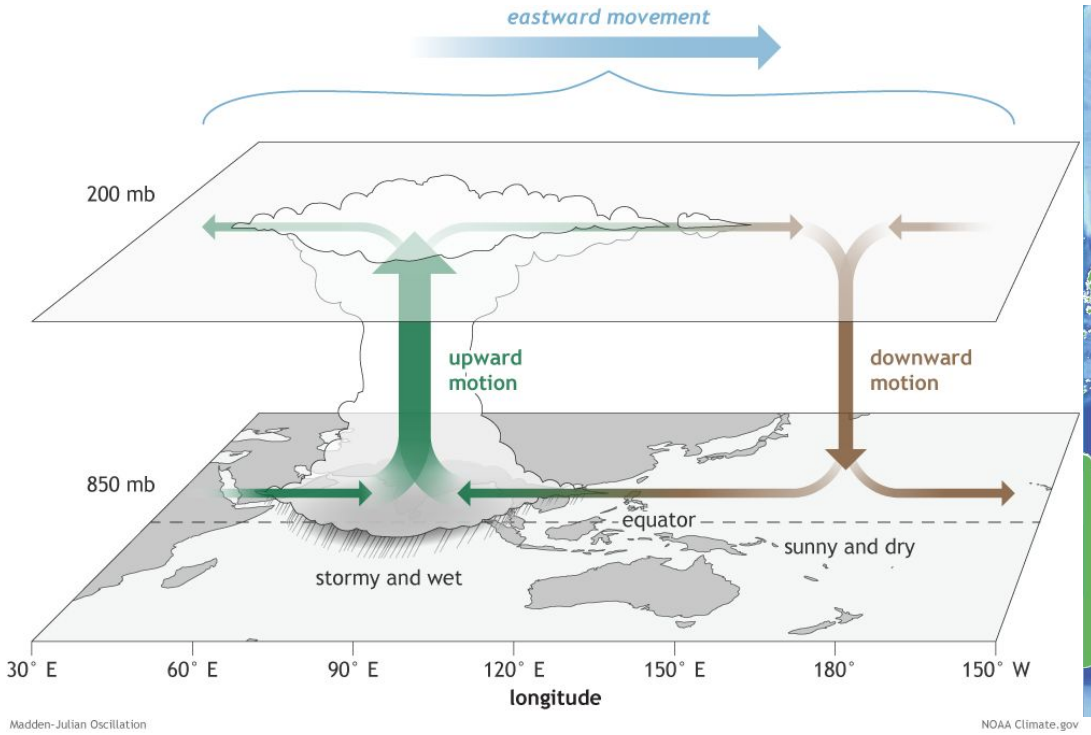
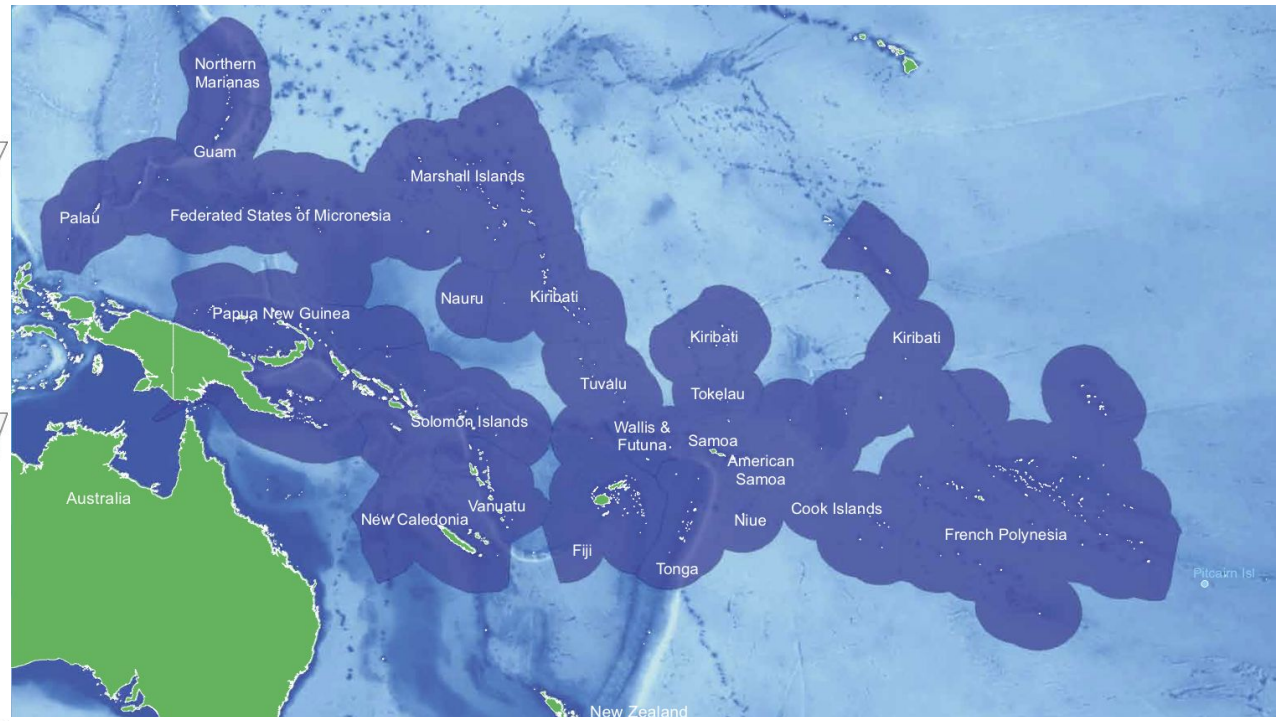
Madden-Julian Oscillation
: Impacts on the Pacific Island Region





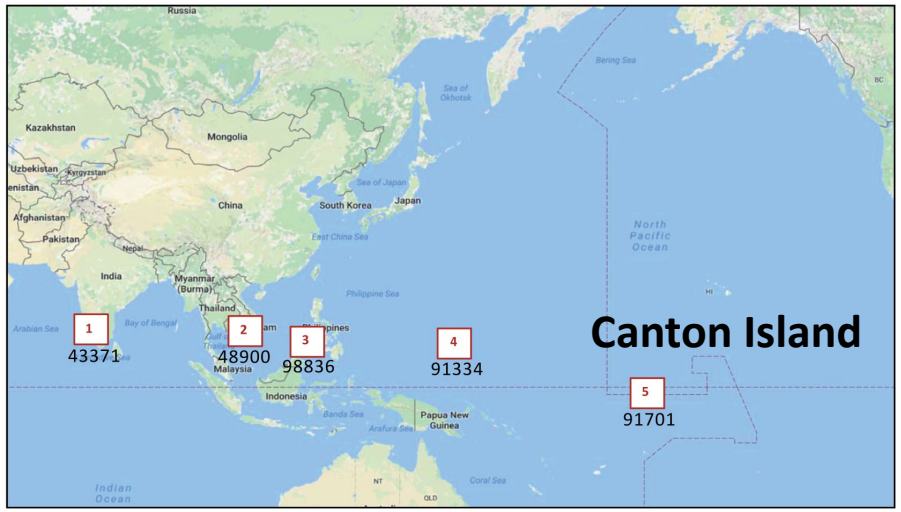
Daehyun Kim

Seoul National University

June 11, 2024

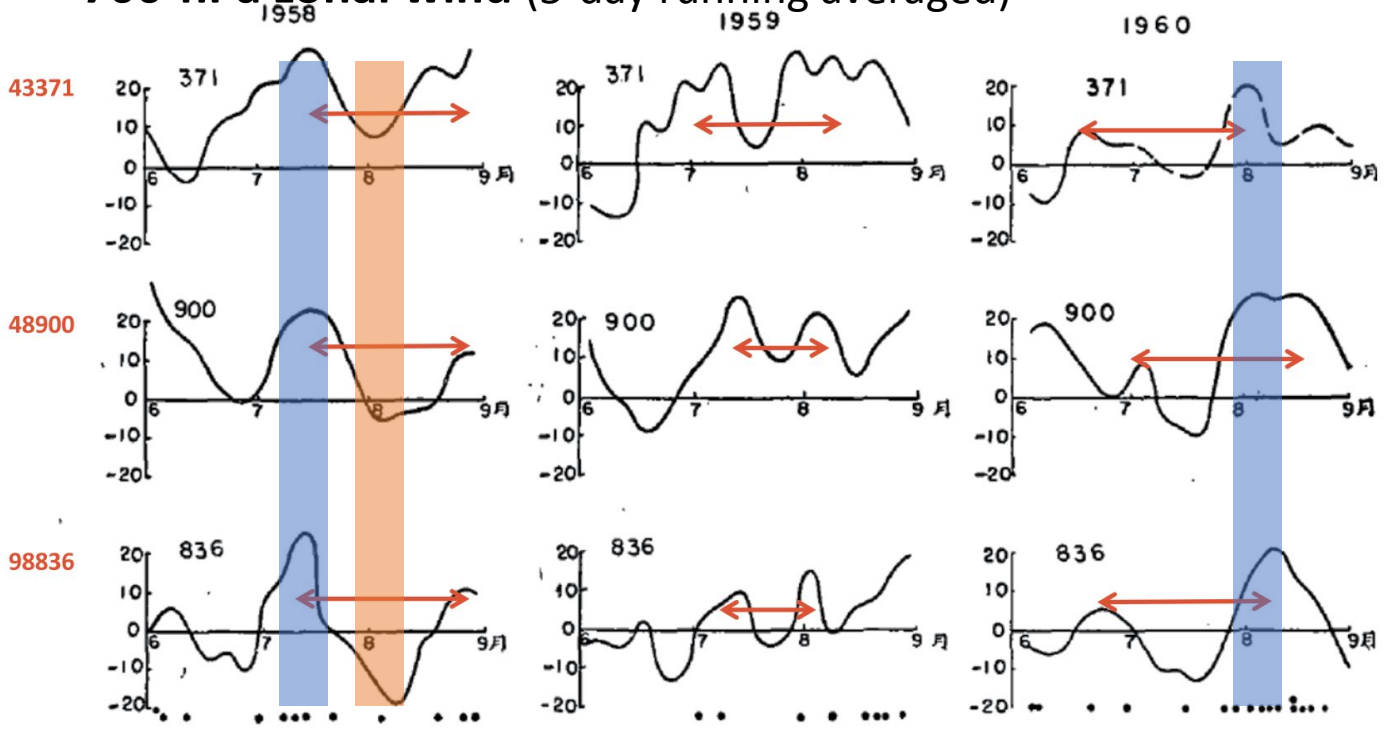
About 60 years ago...

Xie, Y.-B., S.-J. Chen, I.-L. Zhang, and Y.-L. Hung, 1963: A preliminarily statistic and synoptic study about the basic currents over southeastern Asia and the initiation of typhoon (in Chinese). *Acta Meteor. Sin.*, **33**, 206–217.



"There was a quasi-periodical oscillation of strength and position of the basic zonal flow with a period longer than one month."

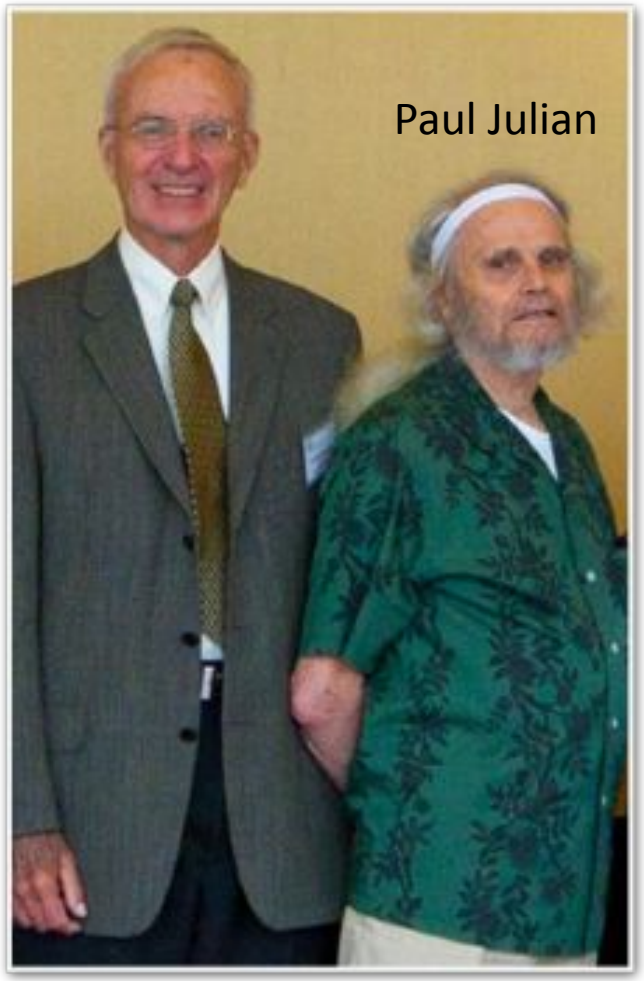
700-hPa zonal wind (5-day running averaged)



Xie et al. 1963; Li et al. 2018

Madden and Julian's amazing story

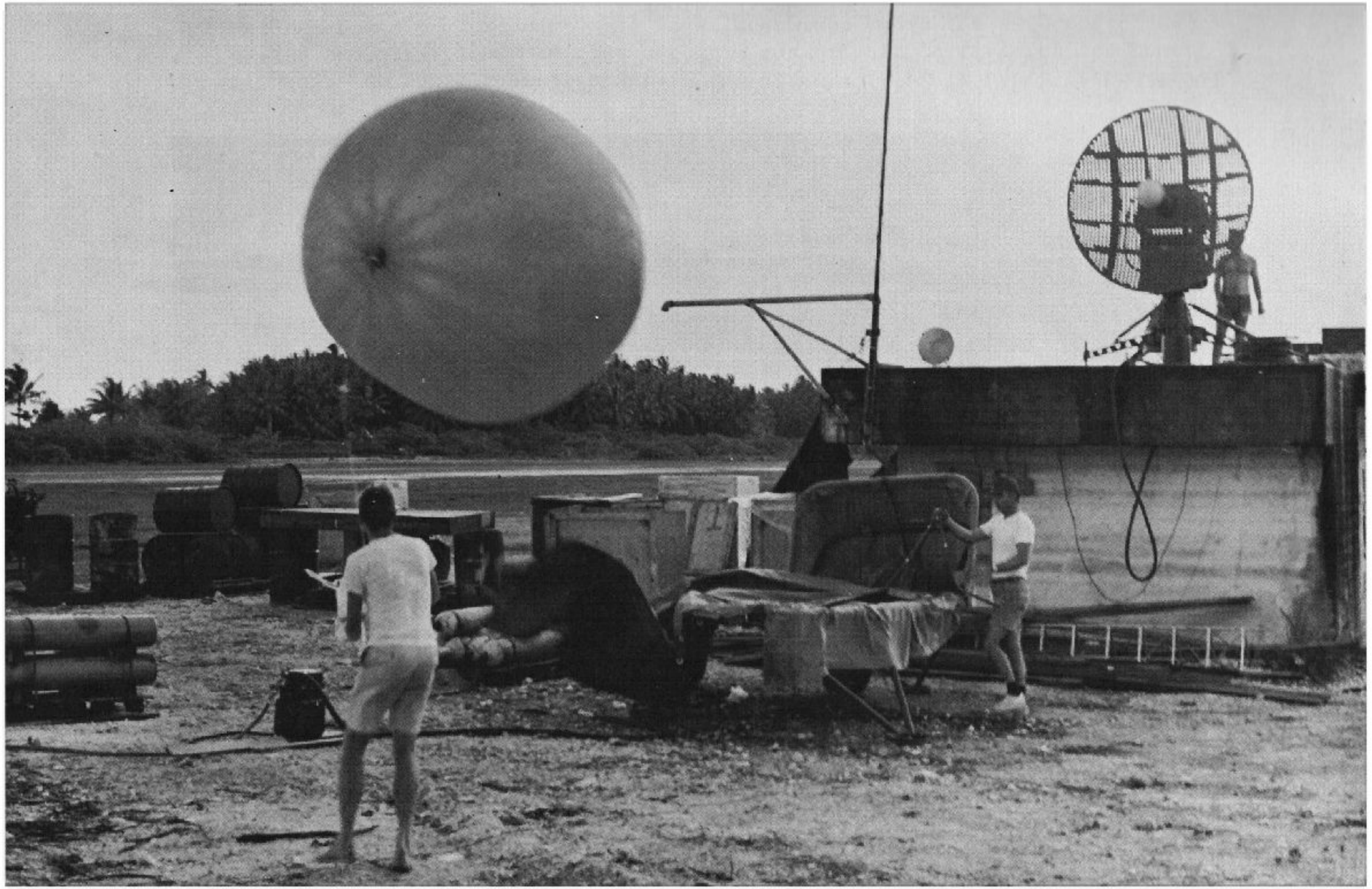
Ronald Madden



https://en.wikipedia.org/wiki/International_Geophysical_Year

International Geophysics Year (1957-58) Radiosonde observations expanded

1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

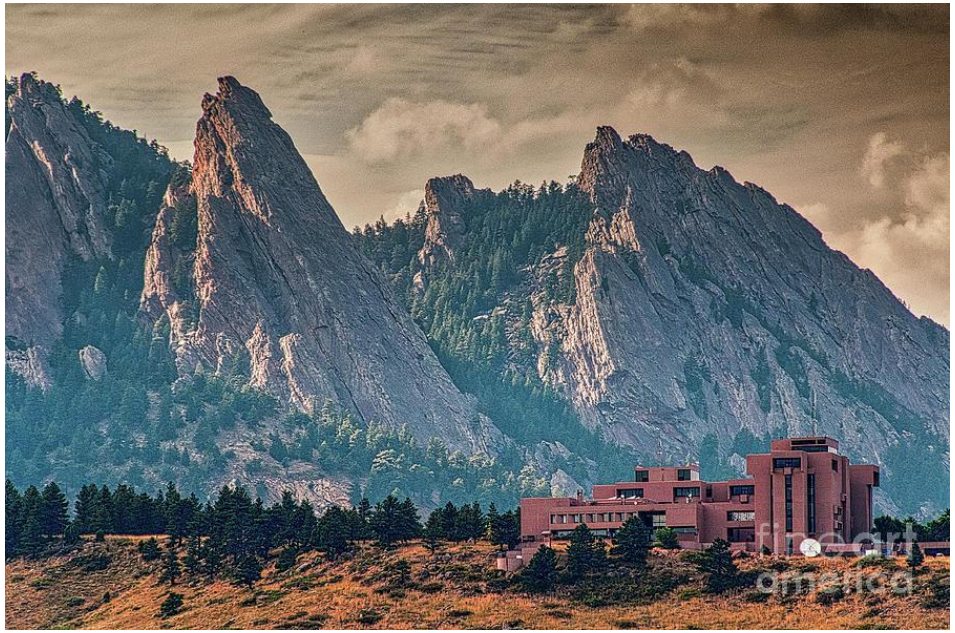


Radiosonde launch site,
Palmyra, 1967,
from R. A. Madden

National Center for Atmospheric Sciences (1960)

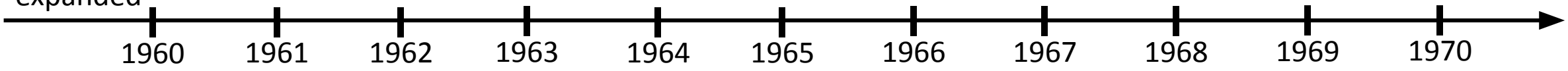
CDC 6600 (1964)

FFT algorithm (1965)



World's fastest computer at that time
Performance: 3 x 10^6 FLOPS
(*best as of today: 10^{18}FLOPS)
Memory: 982 KB
Price: $2M
(*current value: ~$22M)

International Geophysics Year (1957-58) Radiosonde observations expanded



National Center for Atmospheric Sciences (1960)

CDC 6600 (1964)

FFT algorithm (1965) "Big Data" spectral analysis made possible

Discovery of QBO (1961) Enhance research interest in tropical meteorology

Matsuno (1966) Equatorially trapped waves

MRGW (1967) Kelvin wave (1968) Discovered through spectral analysis

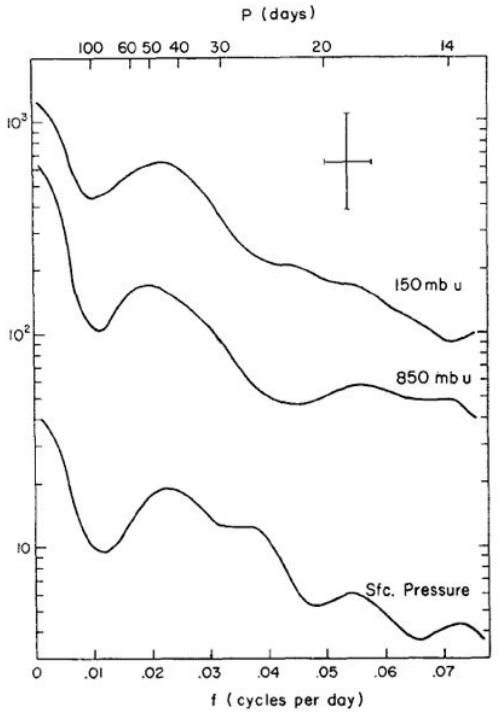
International Geophysics Year (1957-58) Radiosonde observations expanded

1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

National Center for Atmospheric Sciences (1960)

CDC 6600 (1964)

FFT algorithm (1965) "Big Data" spectral analysis made possible



Madden and Julian analyzed 10-year data from Canton Island (1970)

Discovery of QBO (1961) Enhance research interest in tropical meteorology

Matsuno (1966) Equatorially trapped waves

MRGW (1967) Kelvin wave (1968) Discovered through spectral analysis

International Geophysics Year (1957-58) Radiosonde observations expanded

Madden joined NCAR (1967)

Madden met Julian (1968)

Madden and Julian analyzed 50-day data (1969)

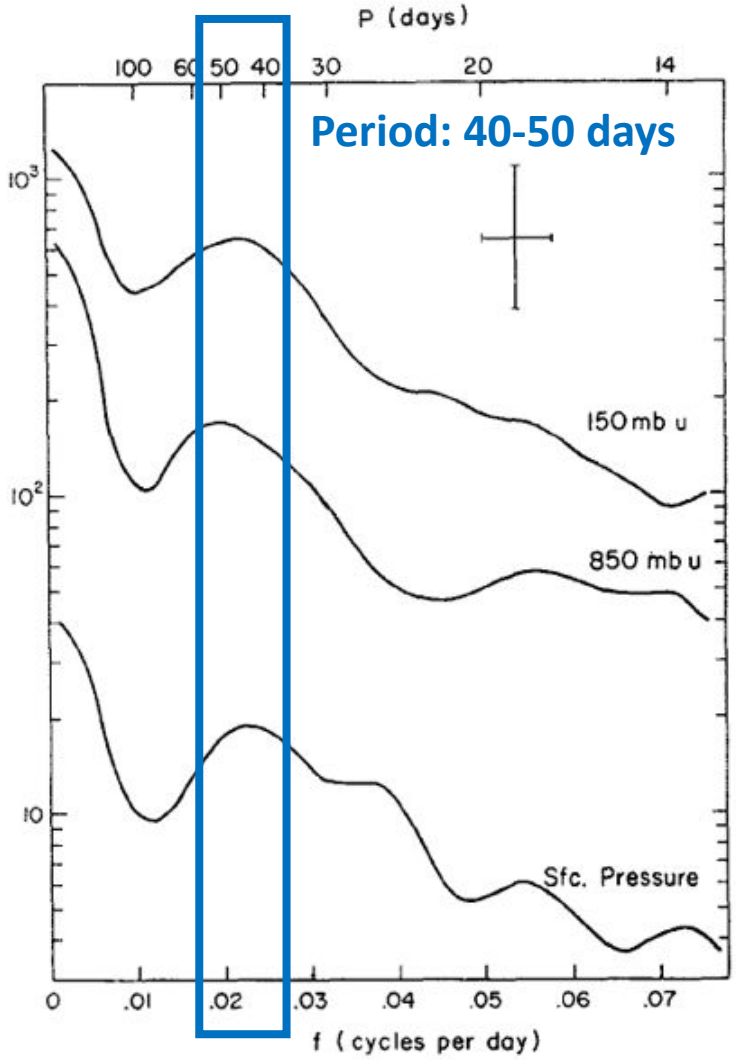
Madden attended a conference at Honolulu (1970)

1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970

Unexpected result

Power spectrum of zonal winds and surface pressure

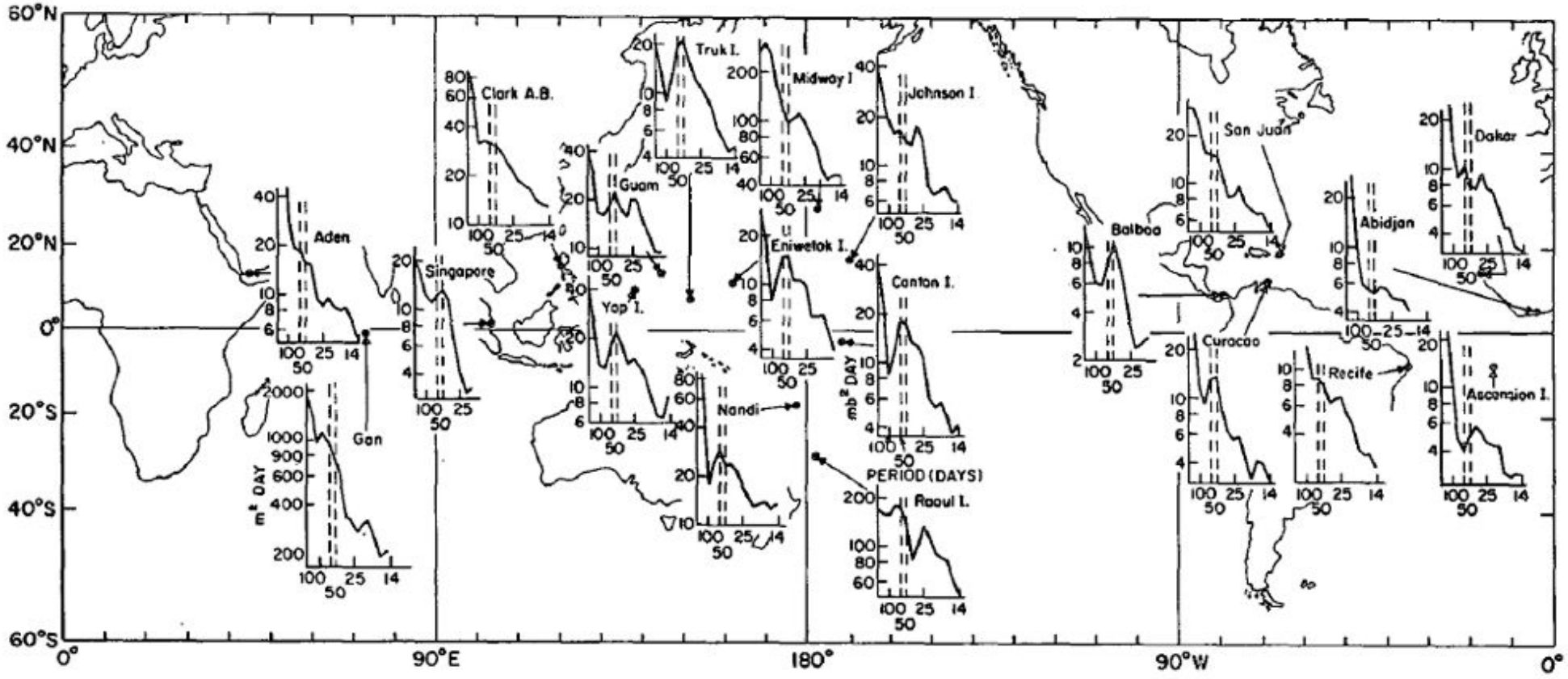
10-year daily data from
Canton Island (3°S, 172°W)



Madden and Julian 1971

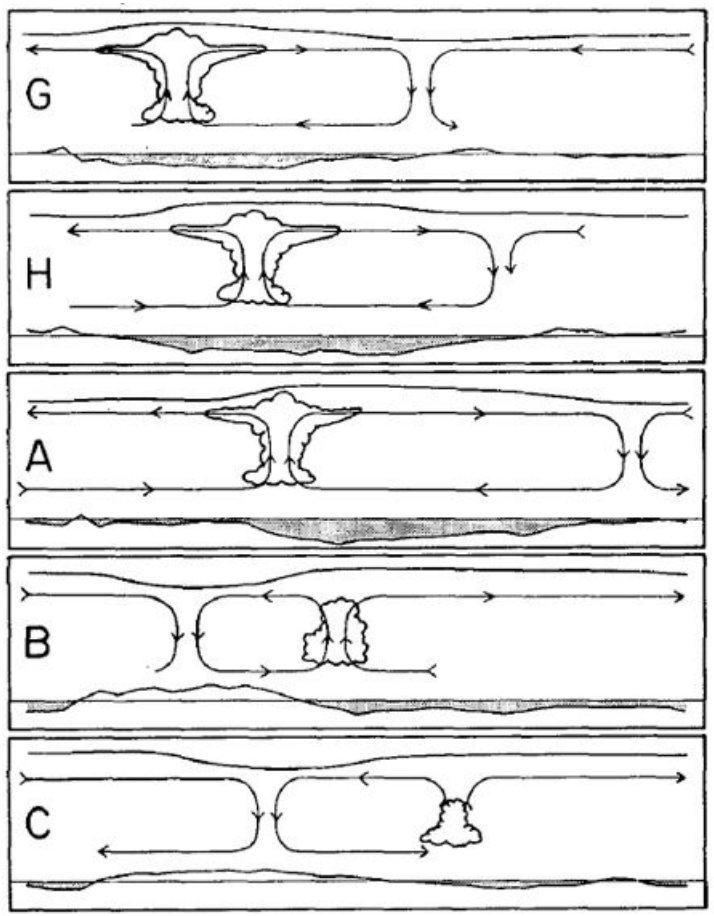
Further exploration

Power spectrum of surface pressure from (just) 20 stations



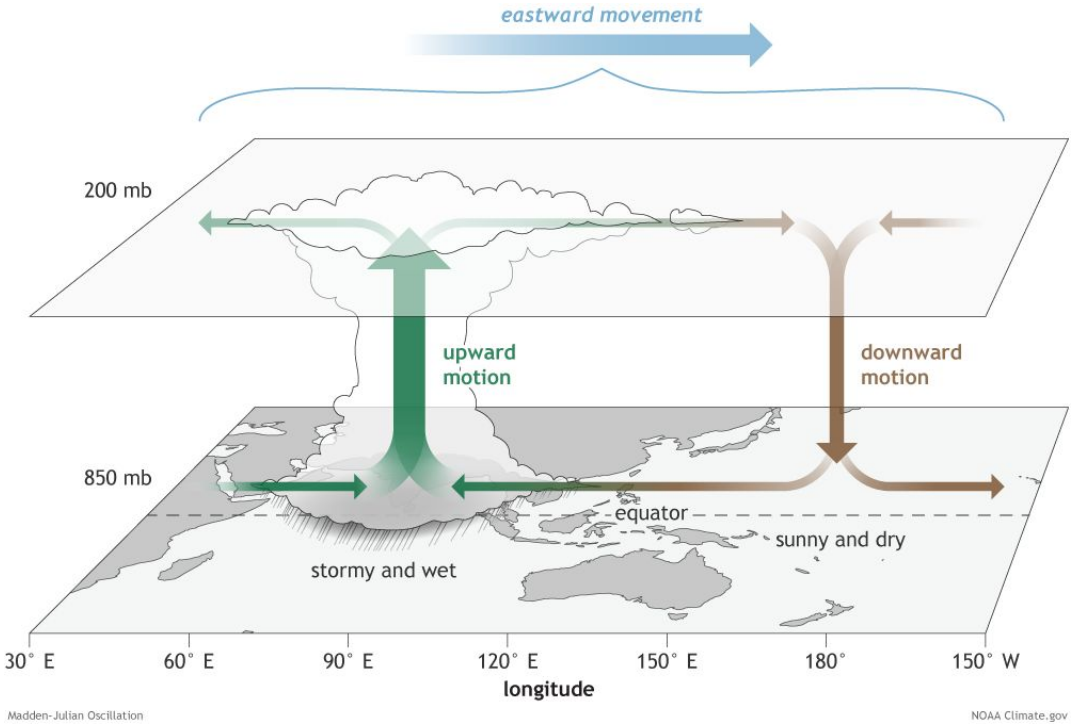
Madden and Julian 1972

Discovery of the Madden-Julian Oscillation



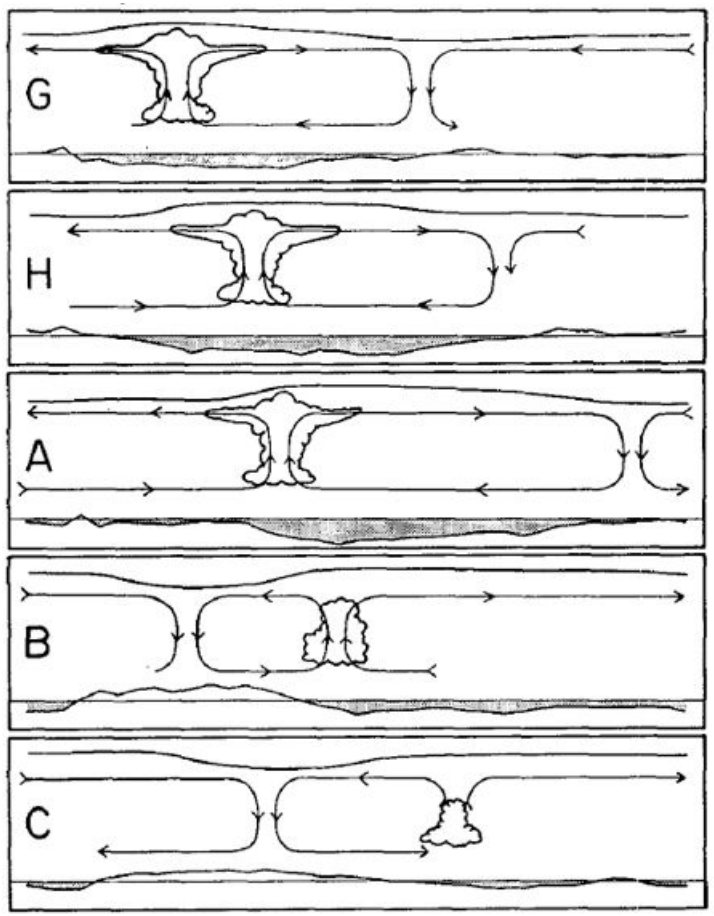
Indian Ocean **Maritime Continent** **West Pacific**

"evidence indicates that the **oscillation** (in the station data) is the result of **an eastward movement of large-scale circulation cells oriented in the equatorial (zonal) plane**"



Madden and Julian 1972; climate.gov

Discovery of the Madden-Julian Oscillation

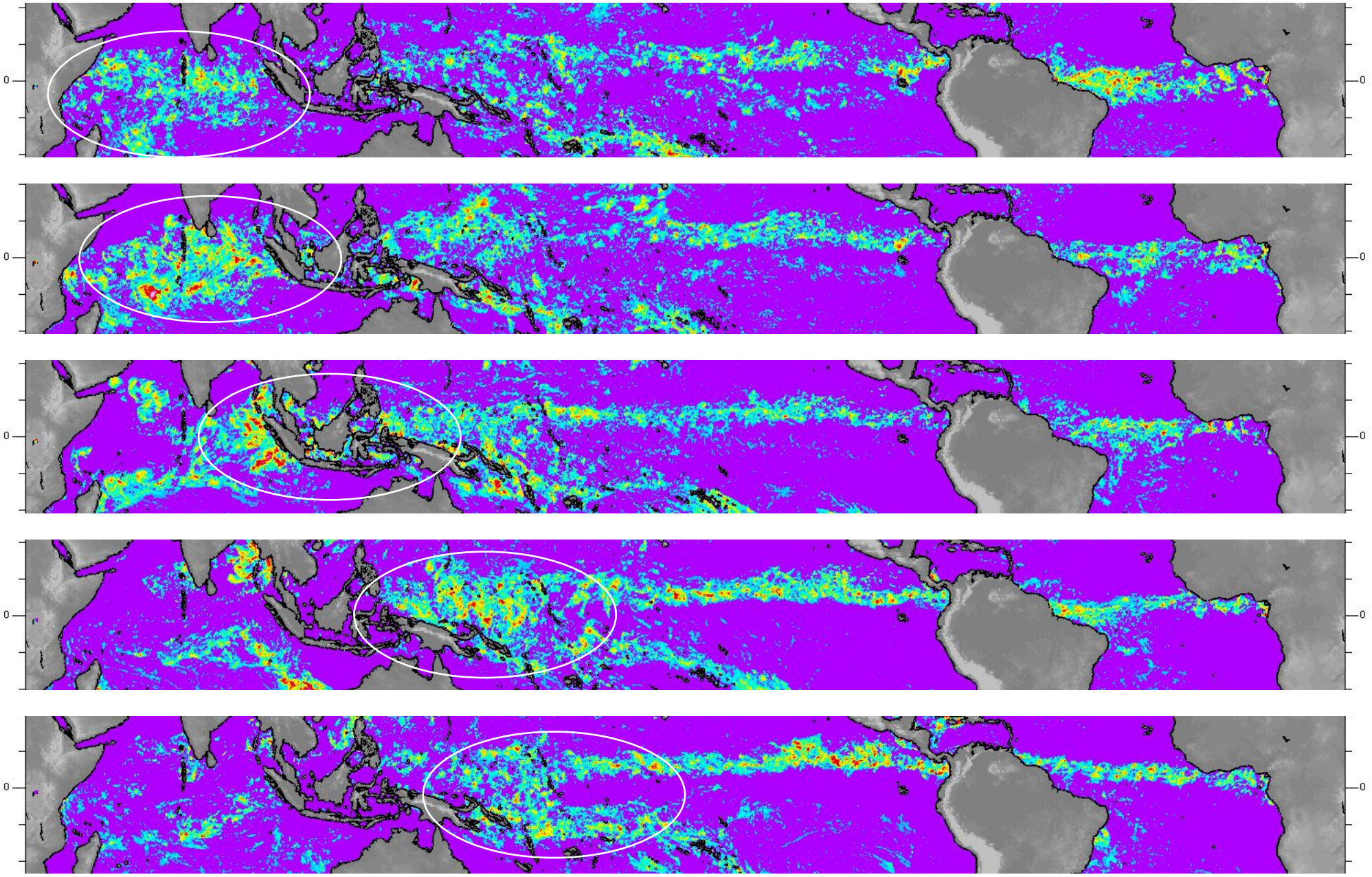


"evidence indicates that the **oscillation** (in the station data) is the result of **an eastward movement of large-scale circulation cells oriented in the equatorial (zonal) plane**"

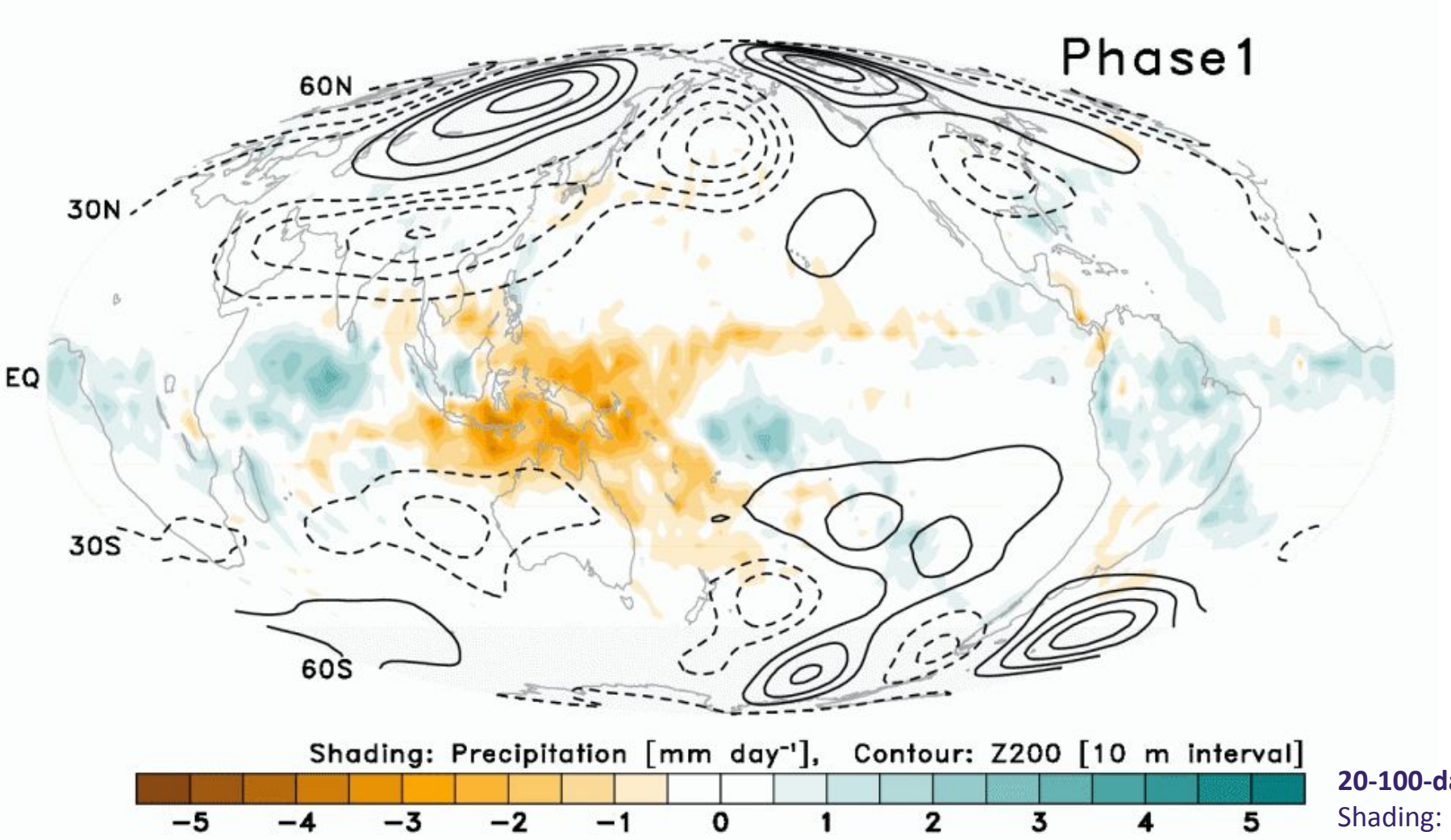
"**Satellite data** can be used to confirm if, and to learn exactly how, **convection** is associated with the disturbance."

Madden and Julian 1972; climate.gov

Satellite view of an MJO event (SSM/I Precip, April 20-May 25, 2002)



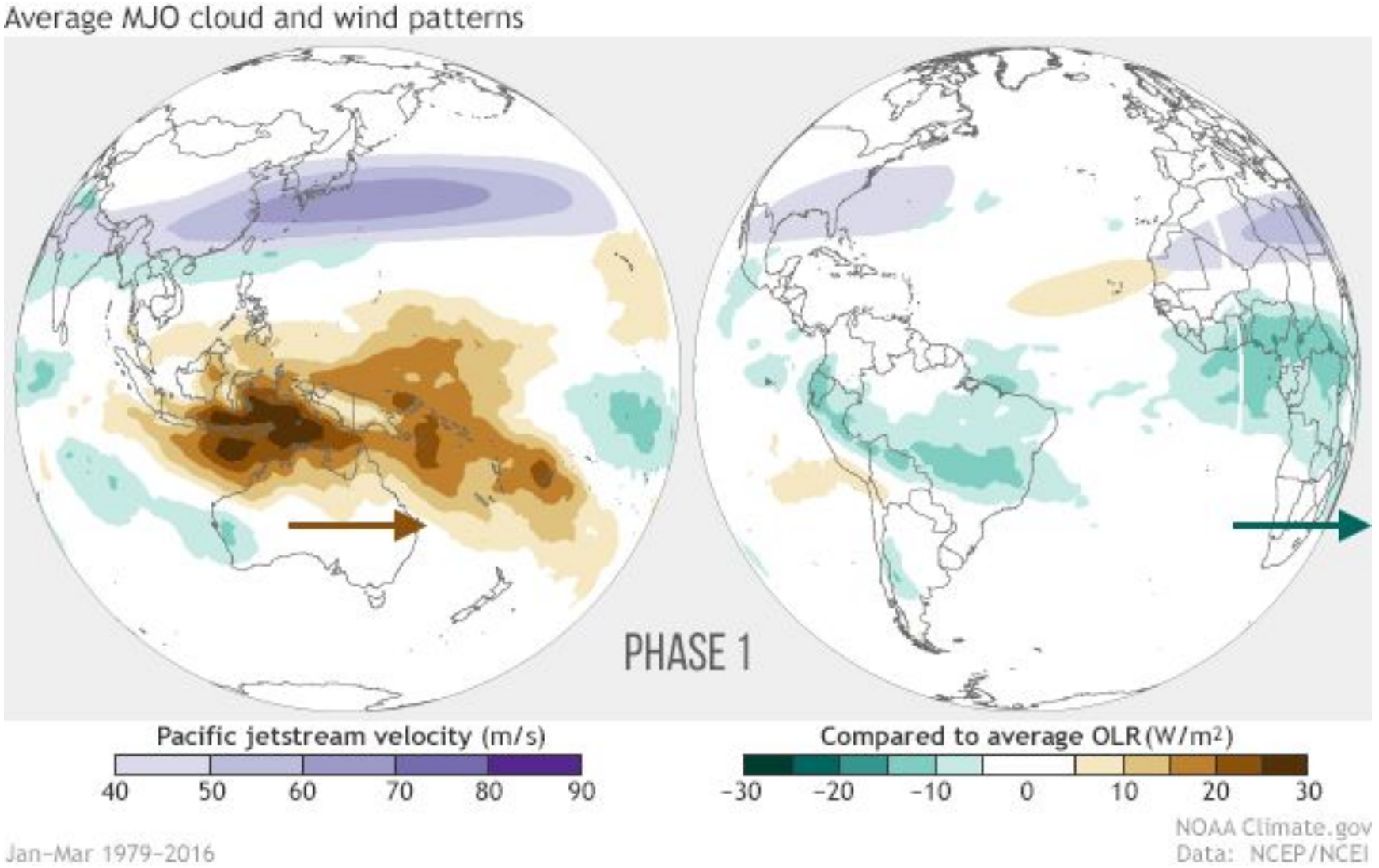
Madden-Julian Oscillation



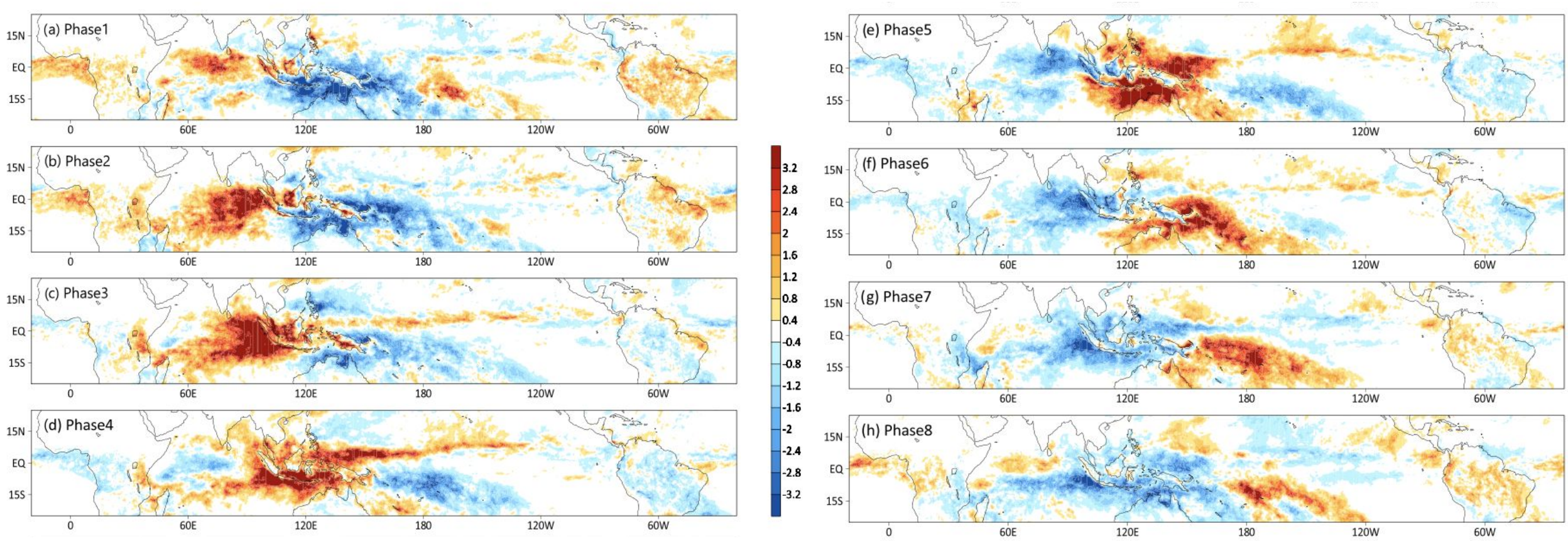
- A unique type of organized convection in the tropics
  - Planetary zonal scale (wavenumber 1-6)
  - Intraseasonal time scale (30-60 days)
  - Eastward propagation
- Modulates convection and circulation globally

20-100-day filtered variables
Shading: Precipitation
Contour: GPH200 (solid: +, dashed: -)

Canonical MJO



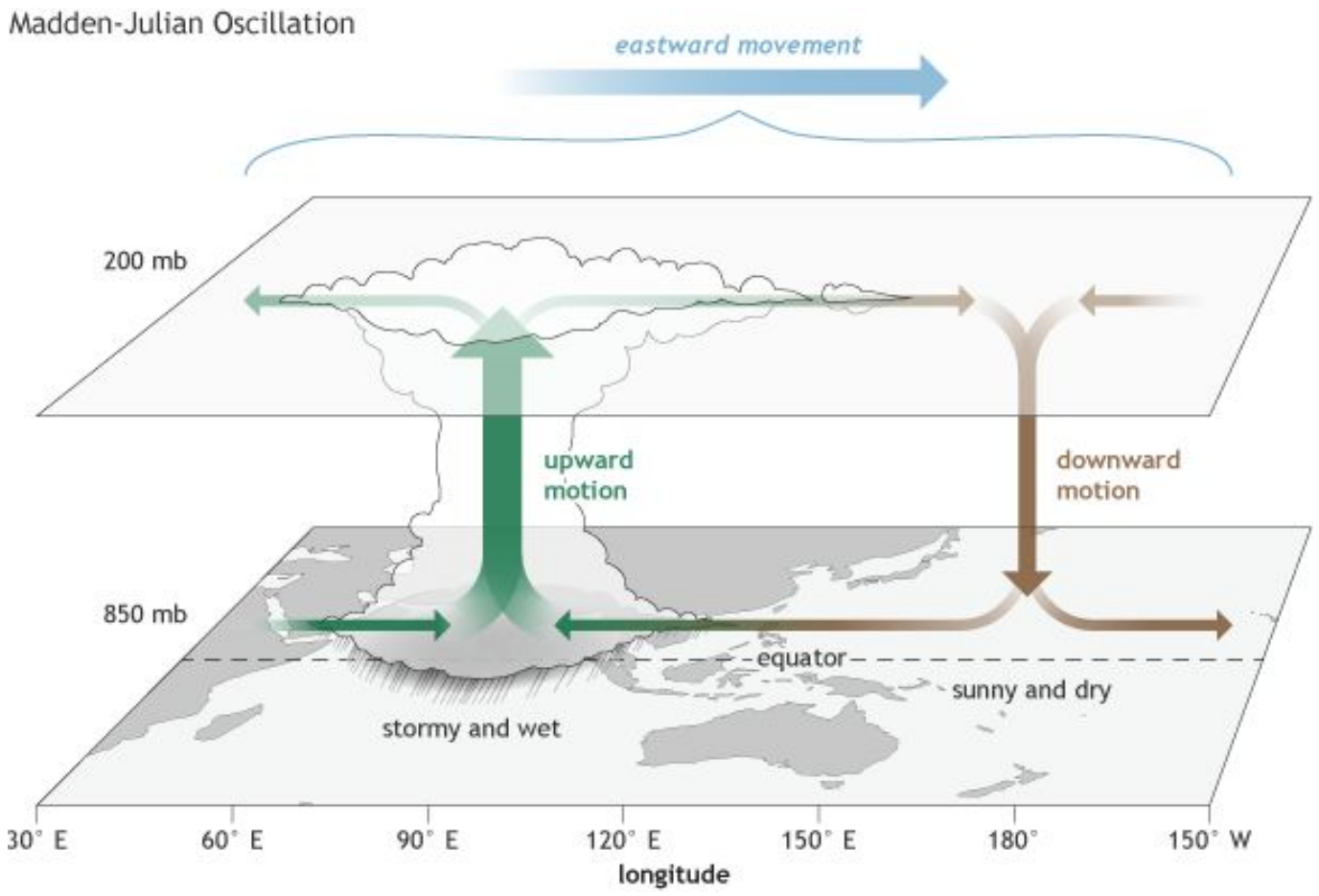
Canonical MJO

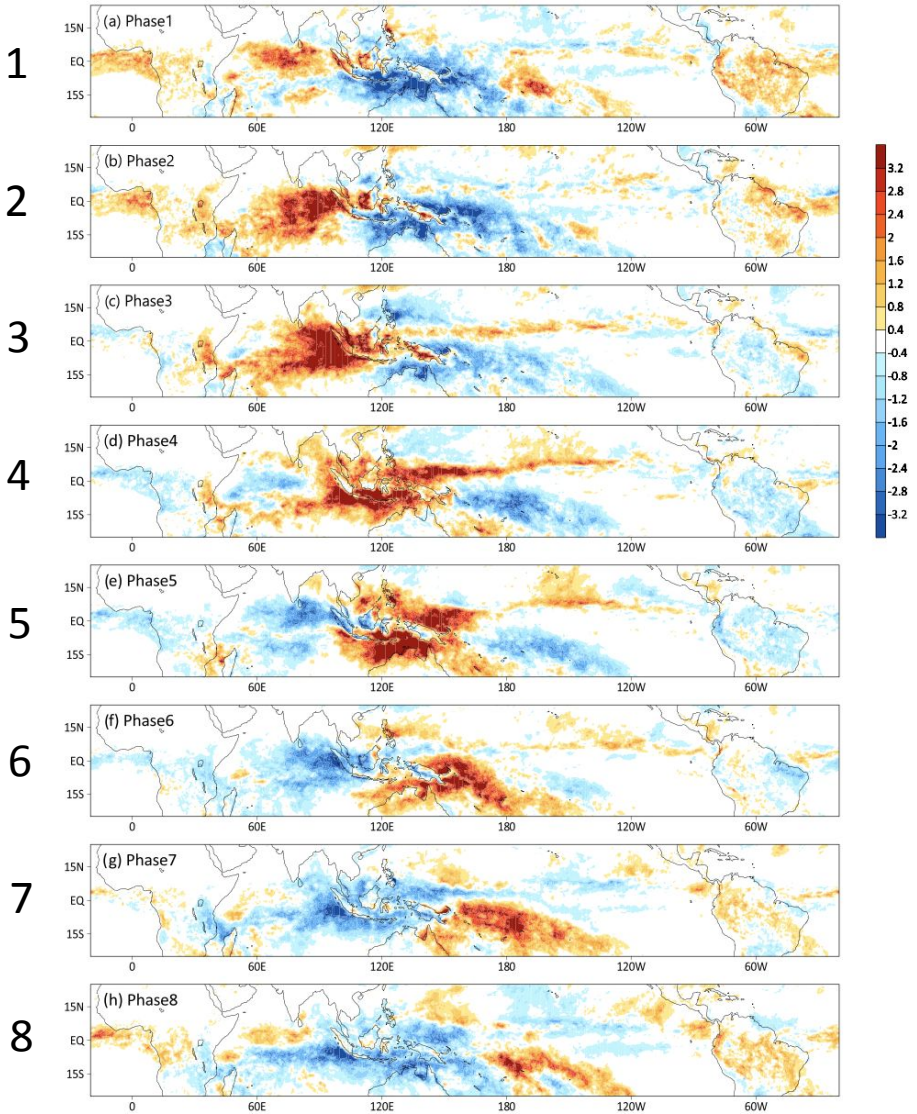


Precipitation anomalies (TRMM, mm day^{-1}) for each MJO phase

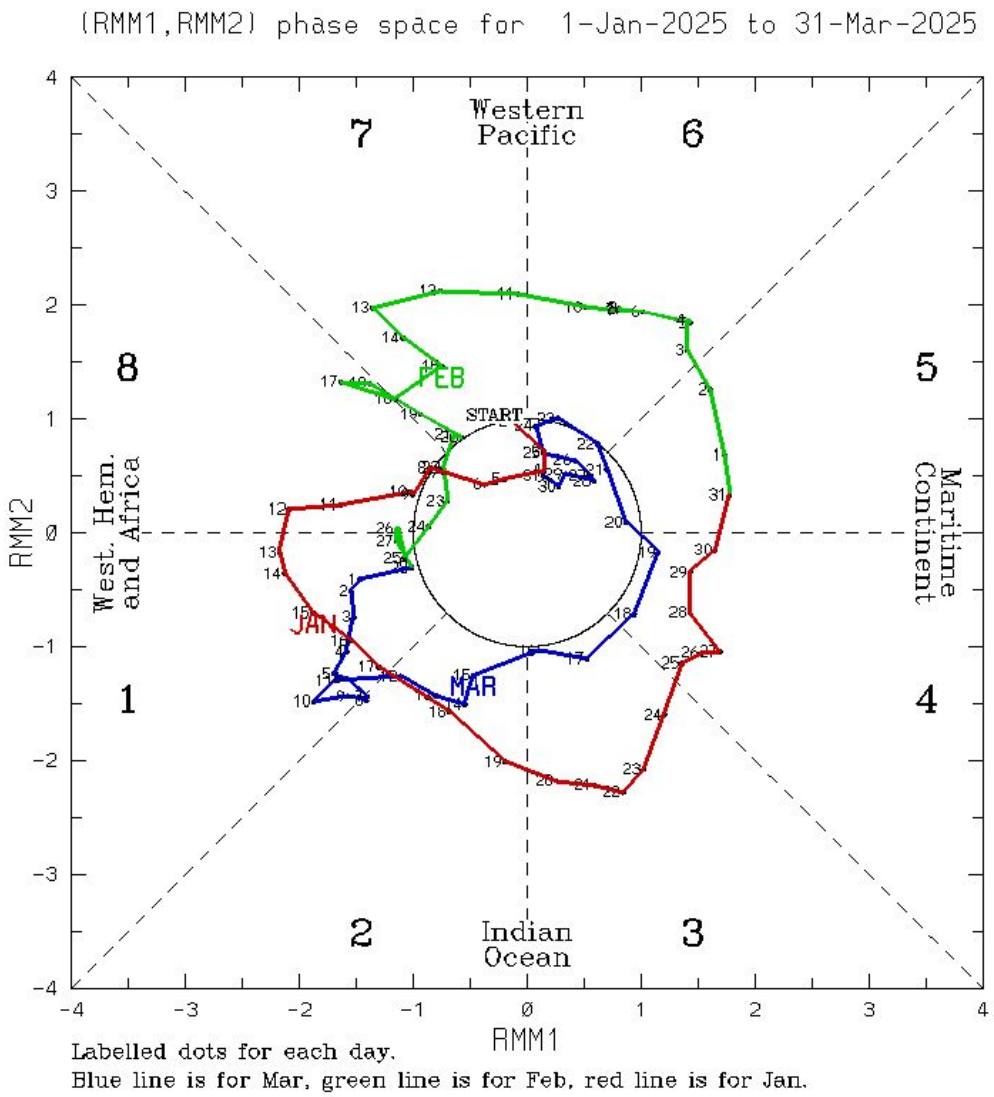
Jiang et al. 2020

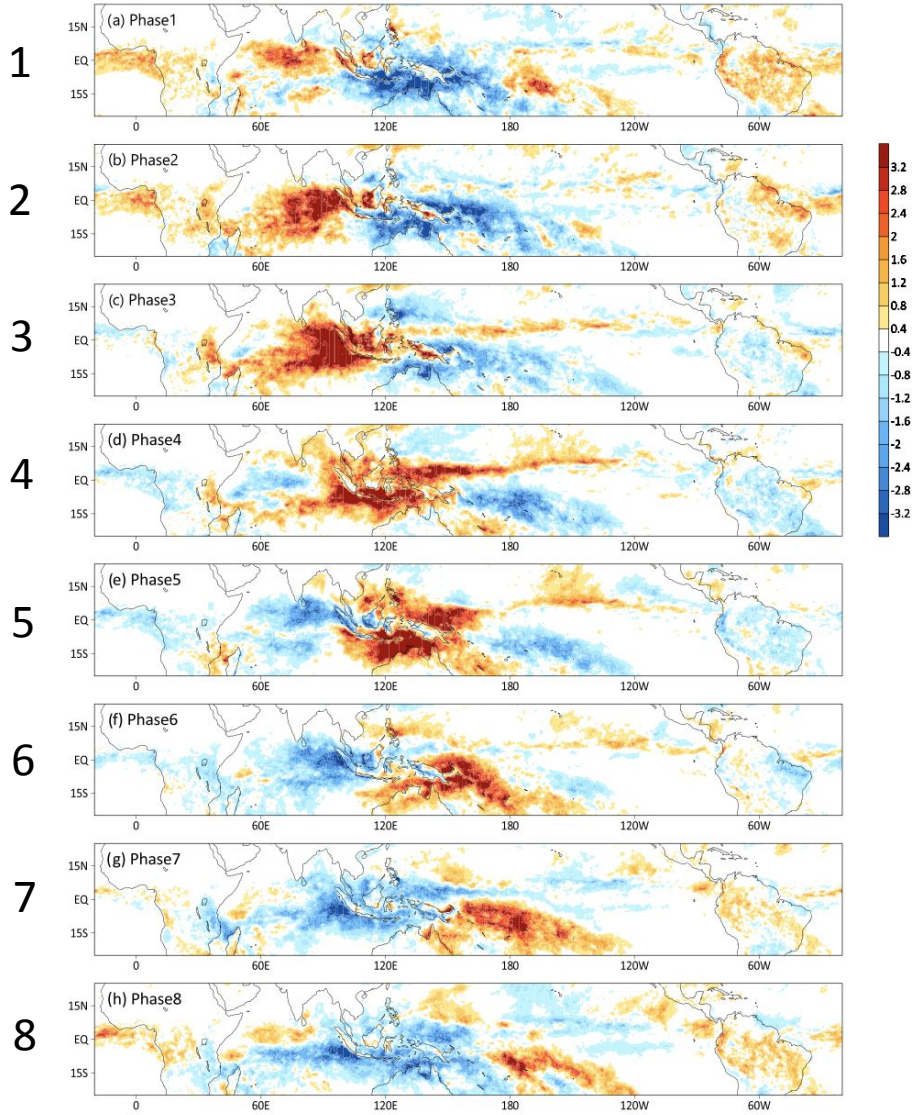
Canonical MJO



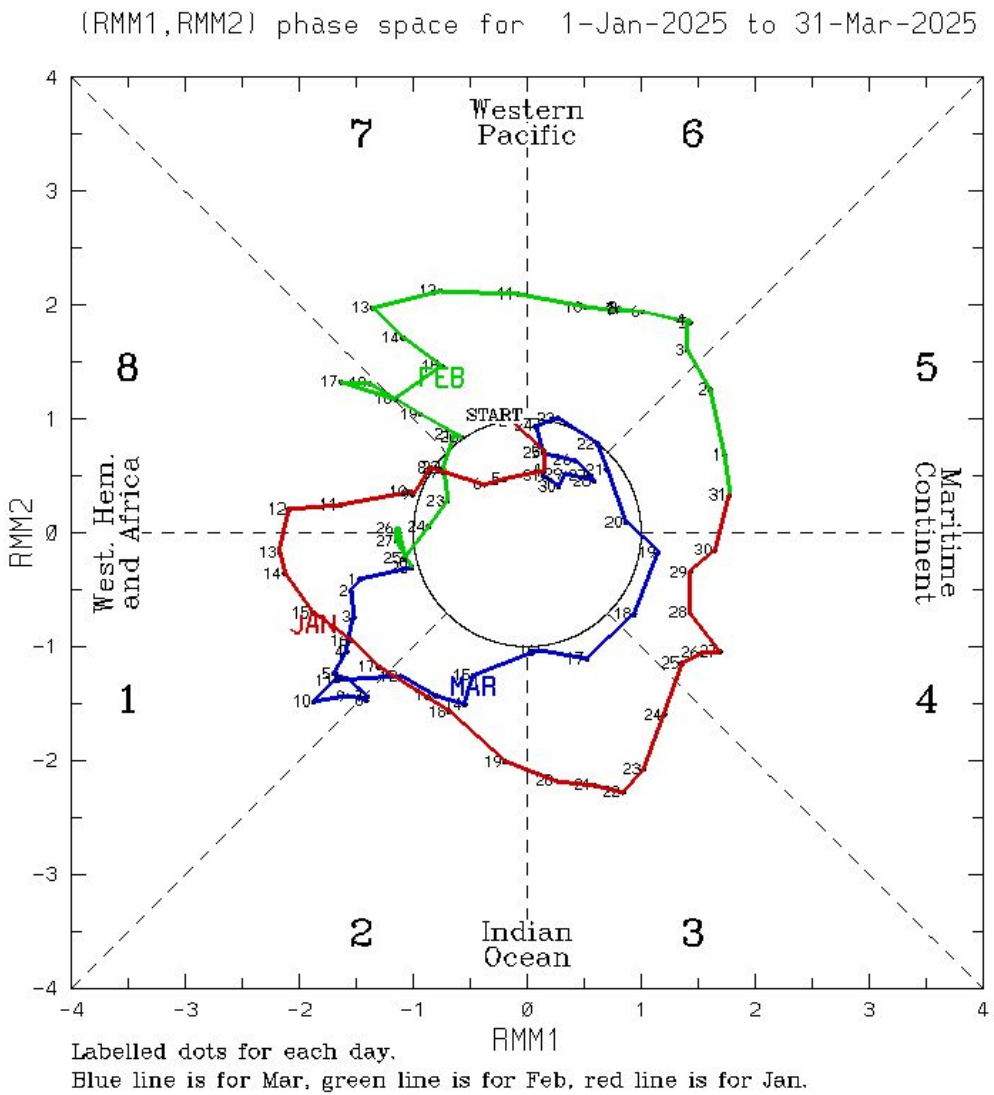


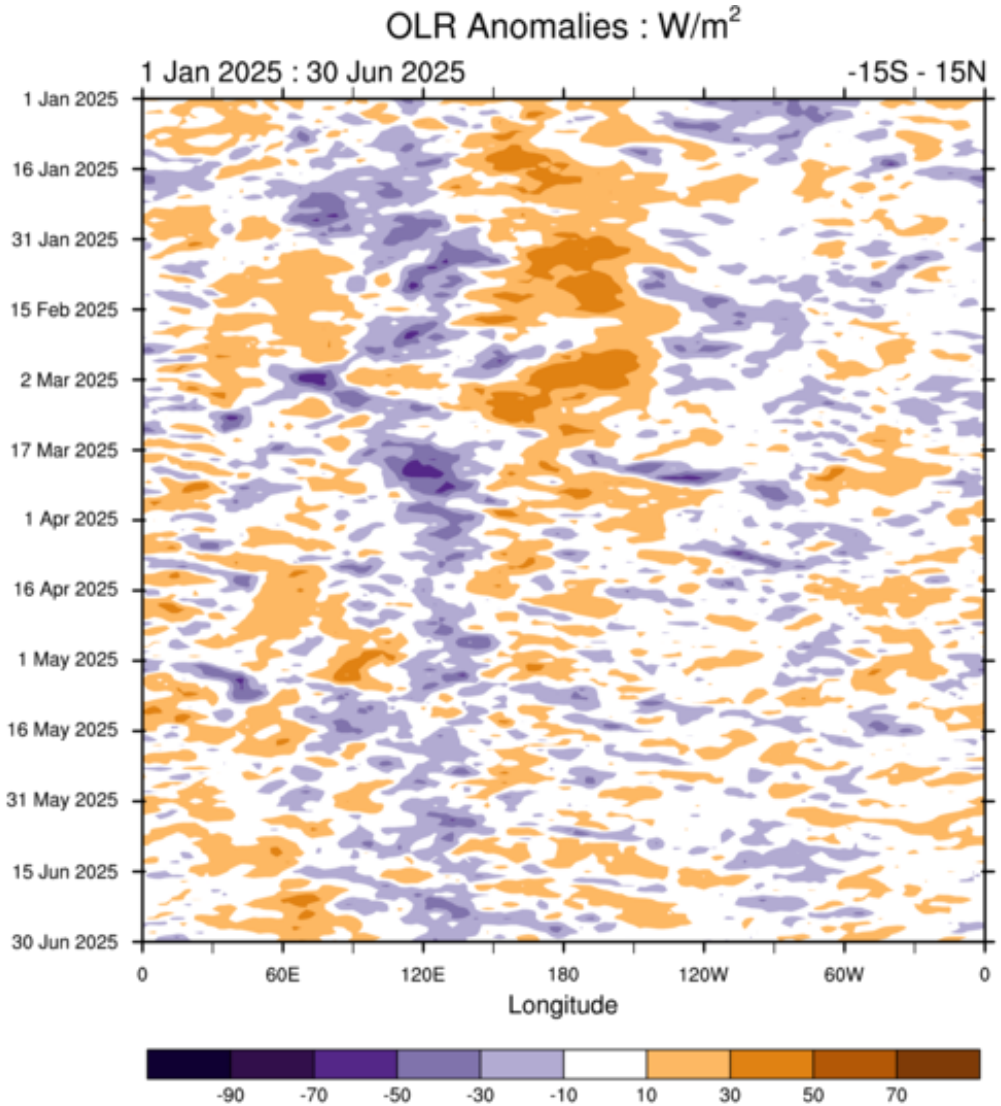
Real-time Multivariate MJO index



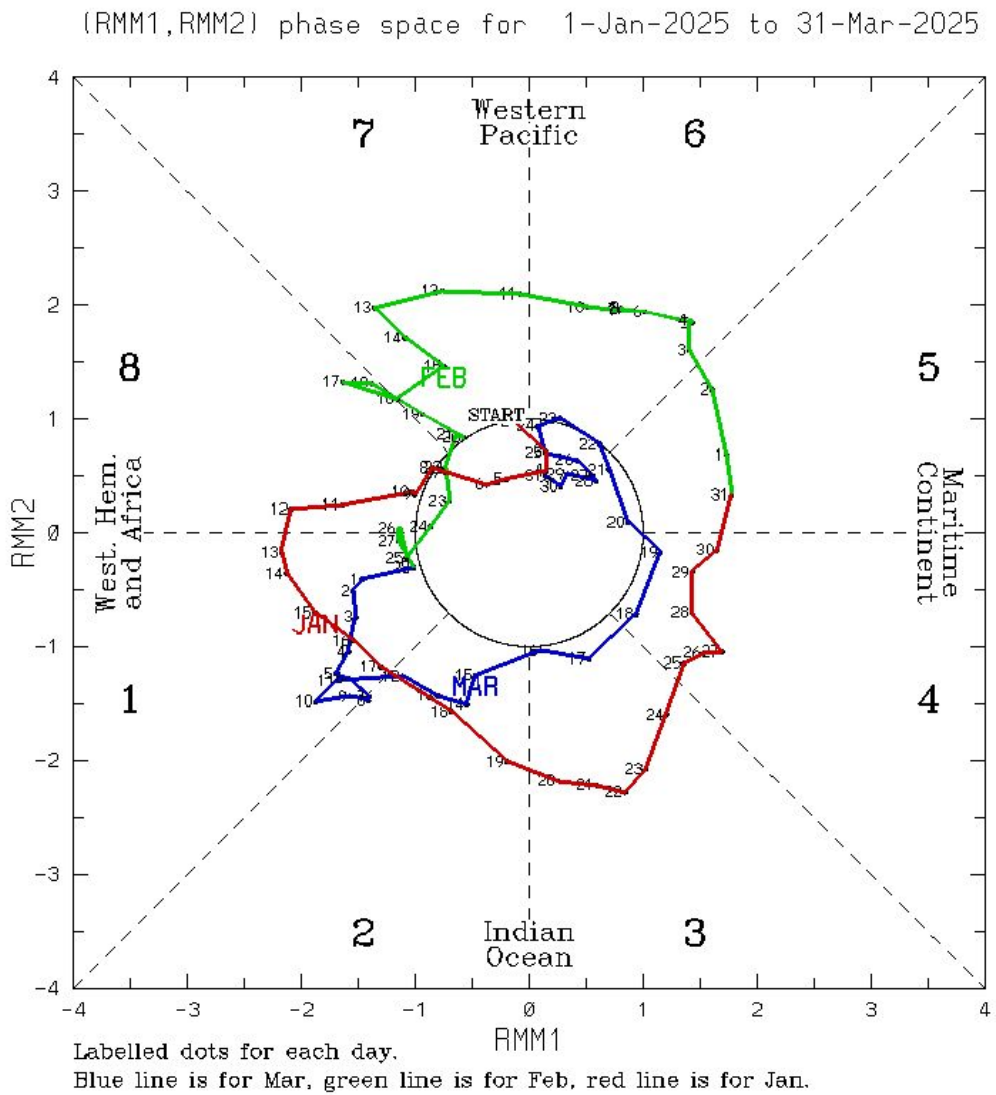


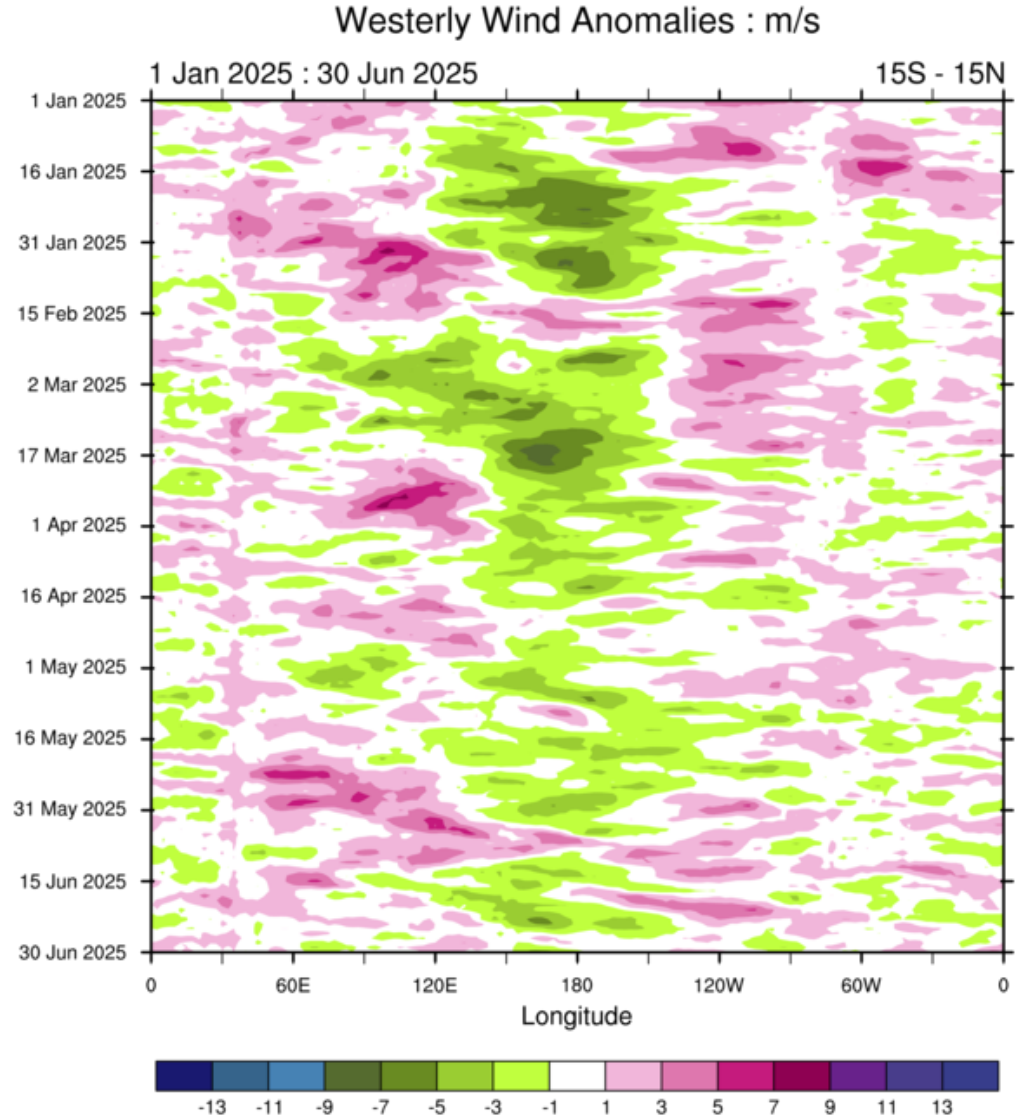
Real-time Multivariate MJO index



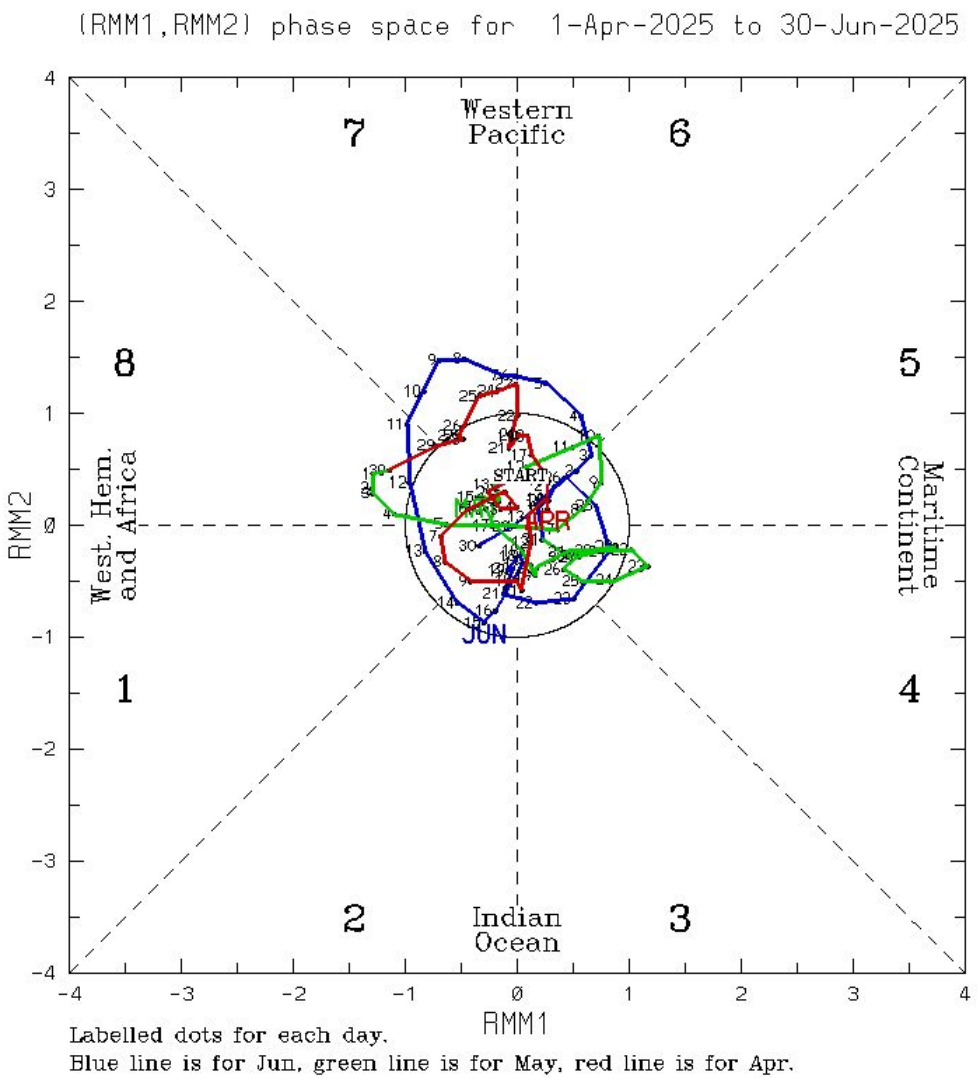


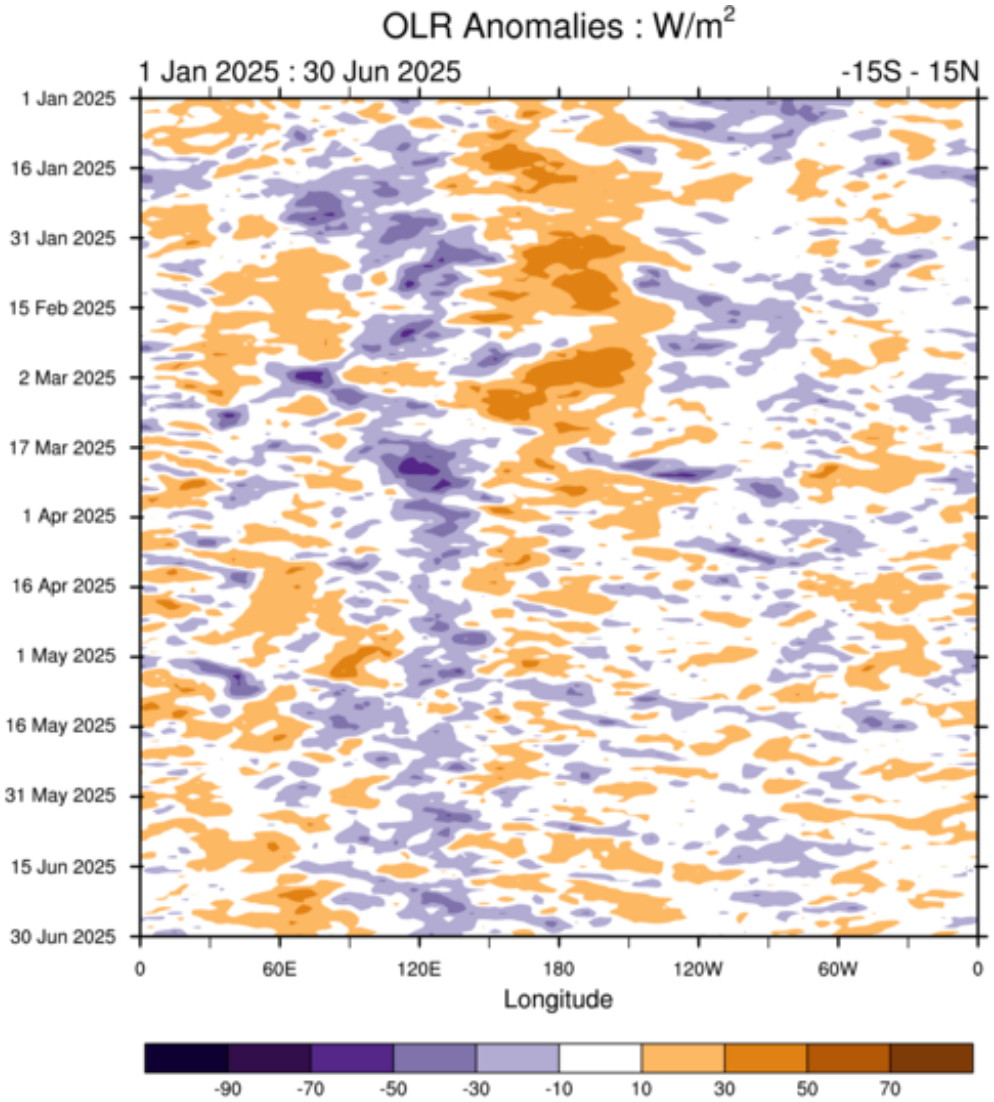
Real-time Multivariate MJO index



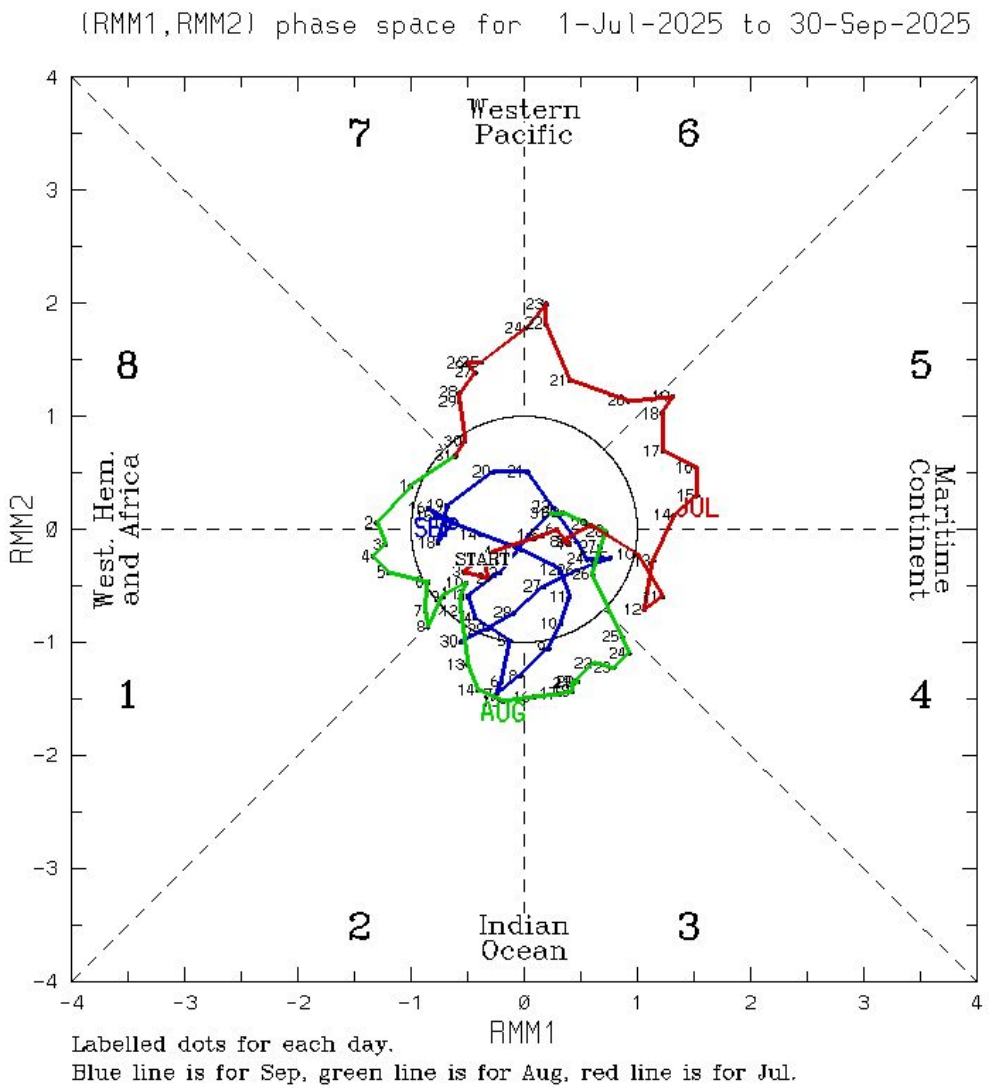


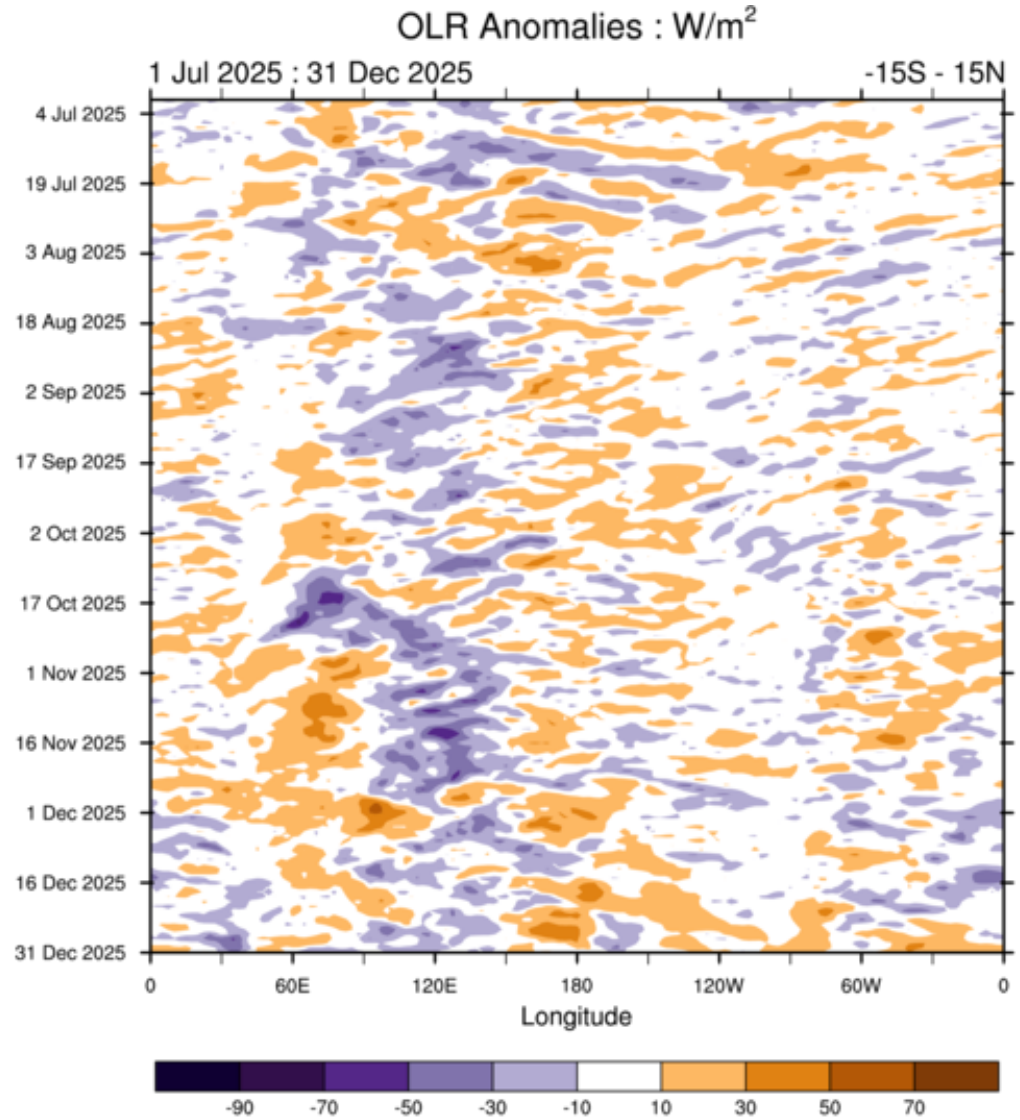
Real-time Multivariate MJO index



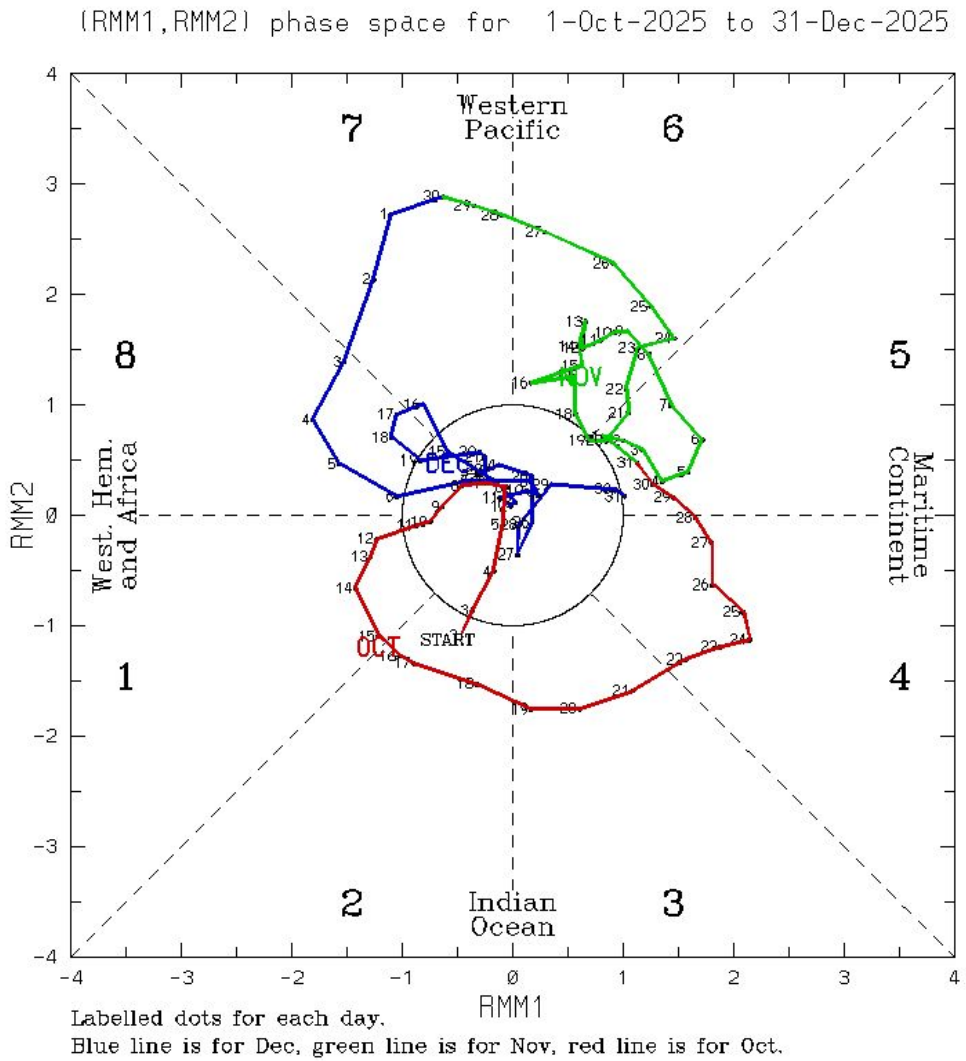


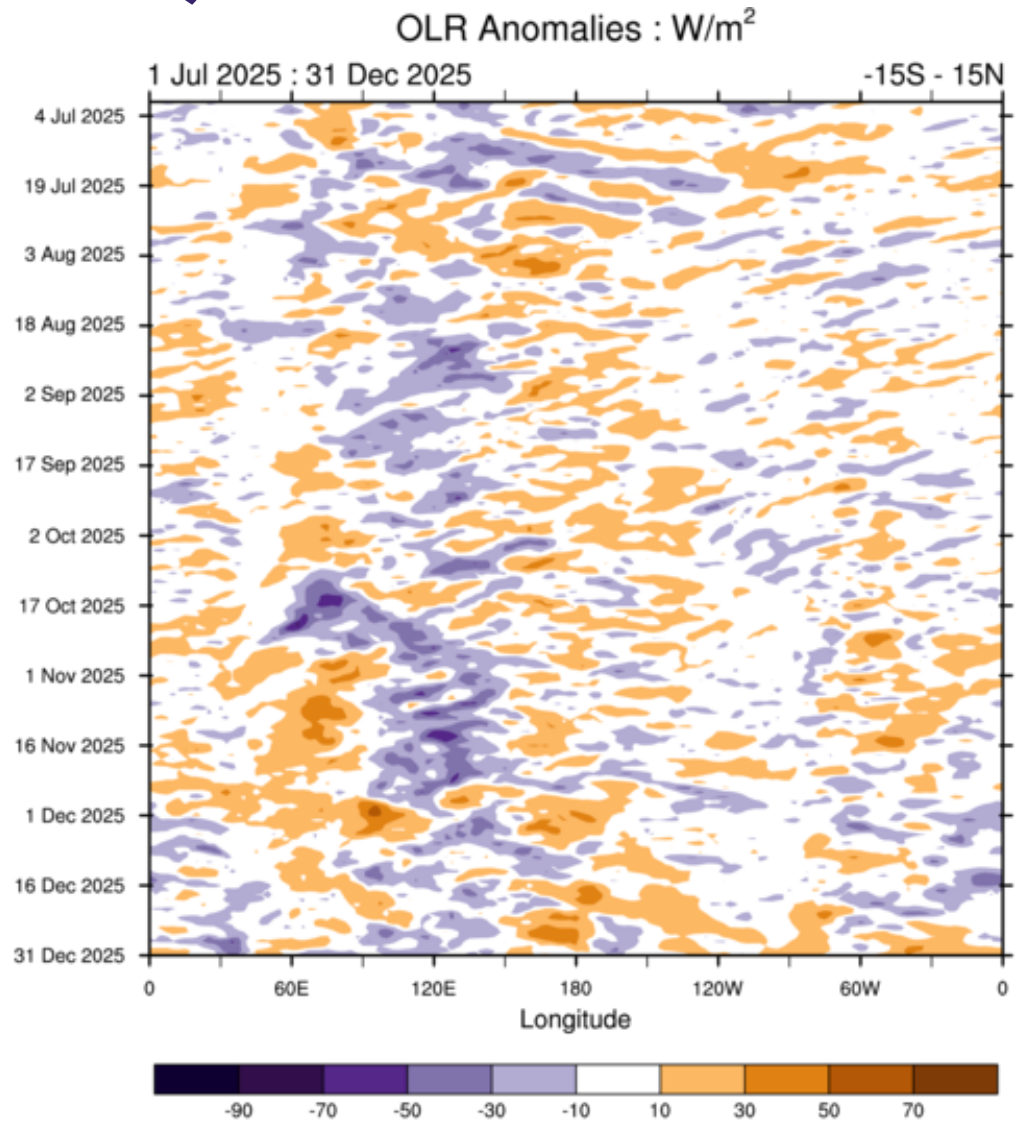
Real-time Multivariate MJO index



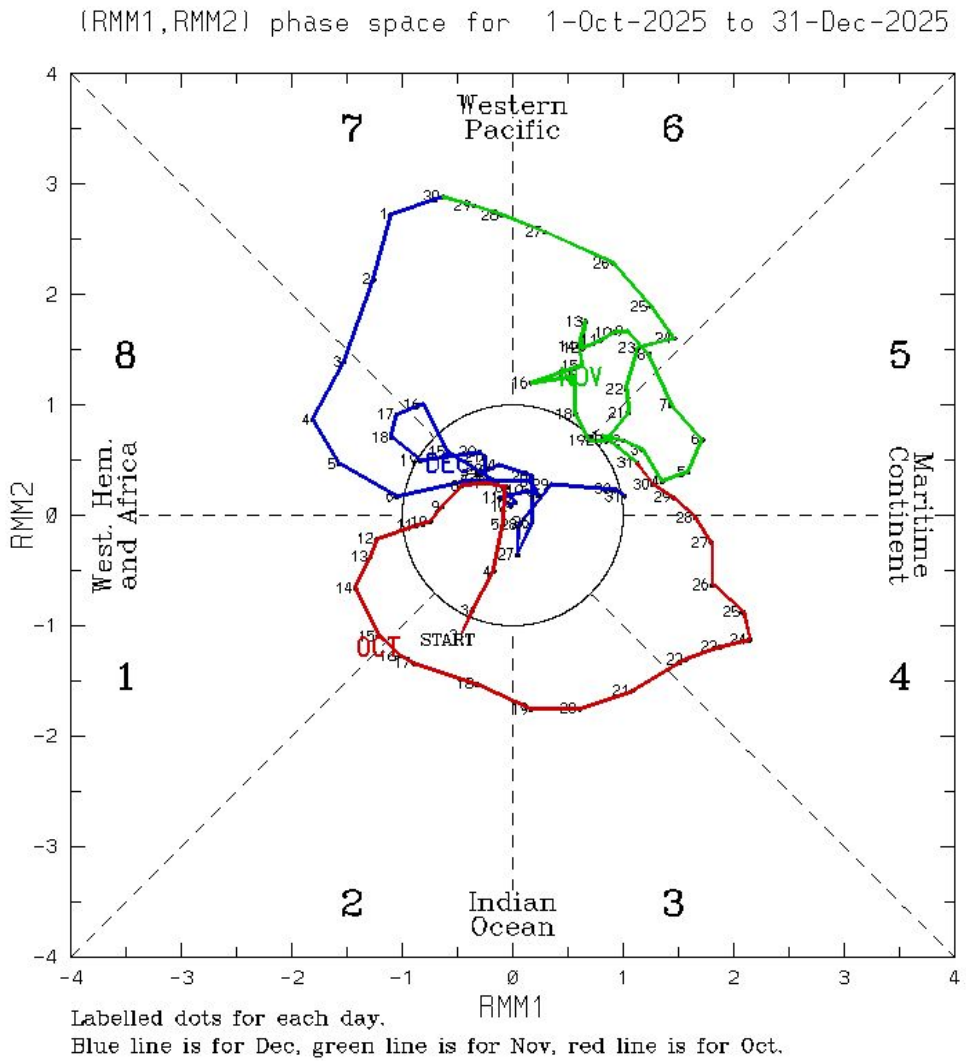


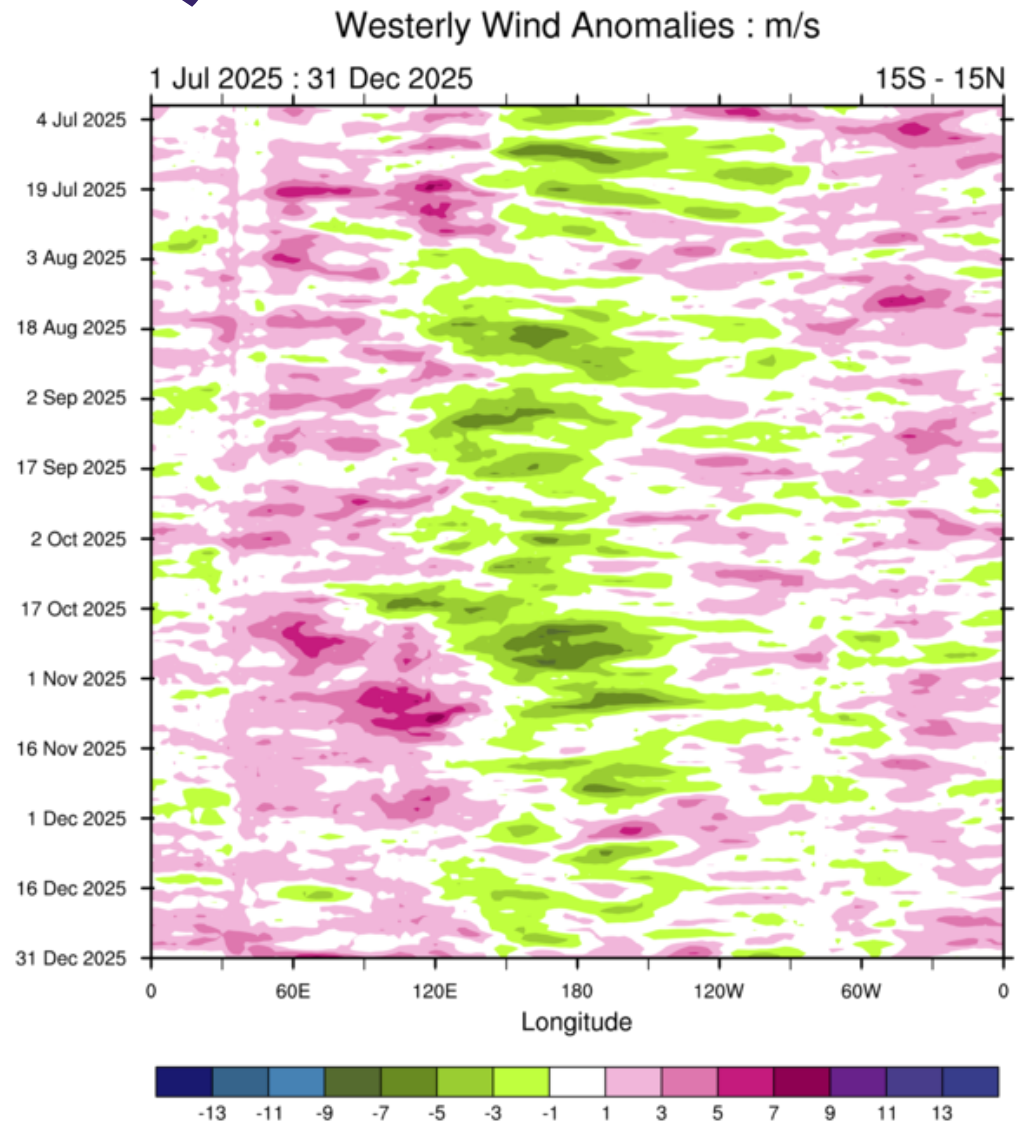
Real-time Multivariate MJO index



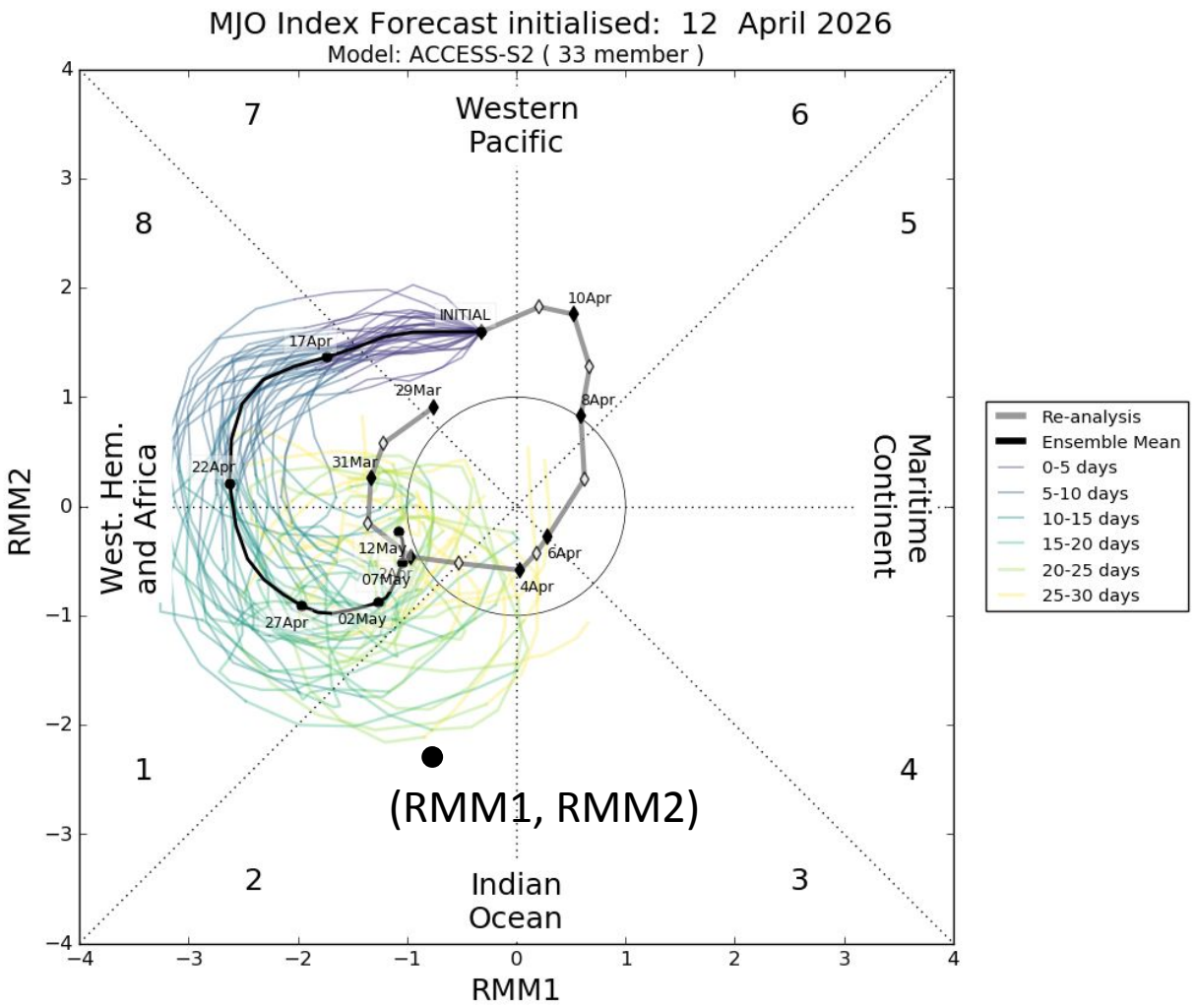


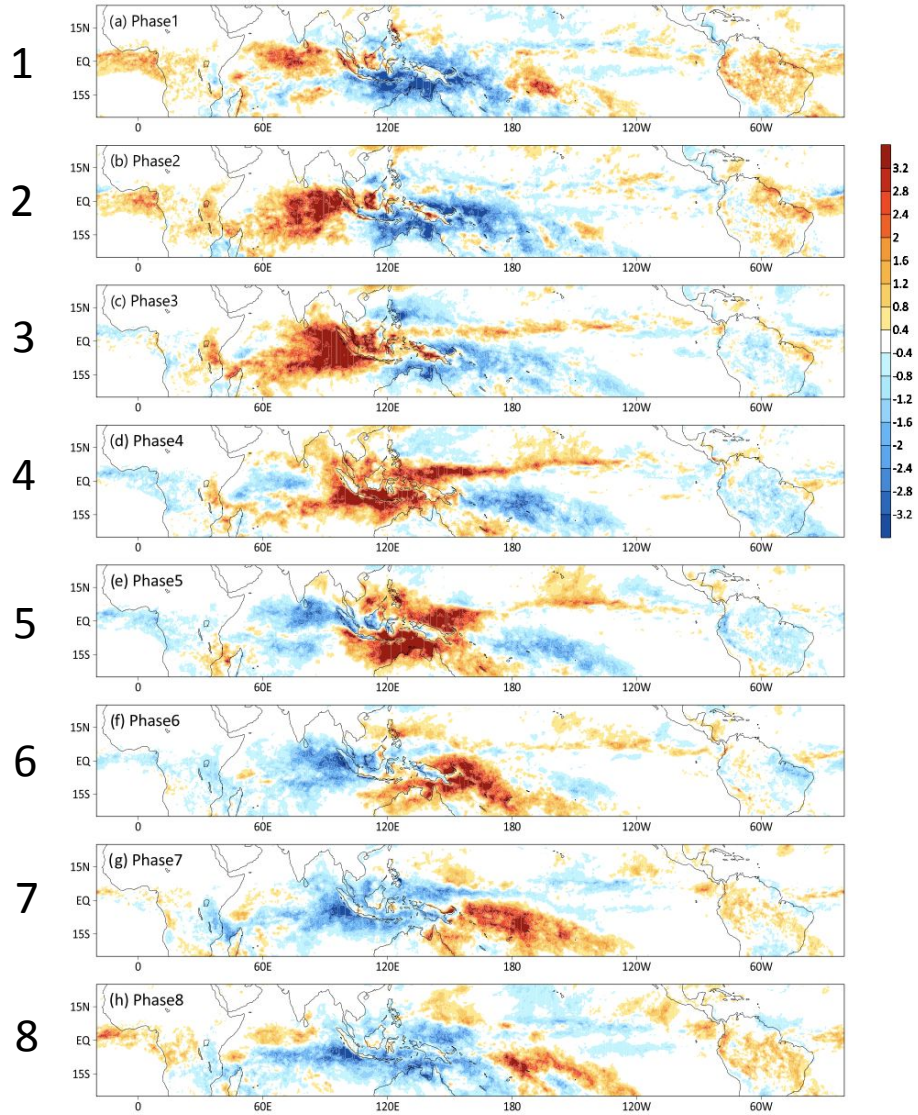
Real-time Multivariate MJO index



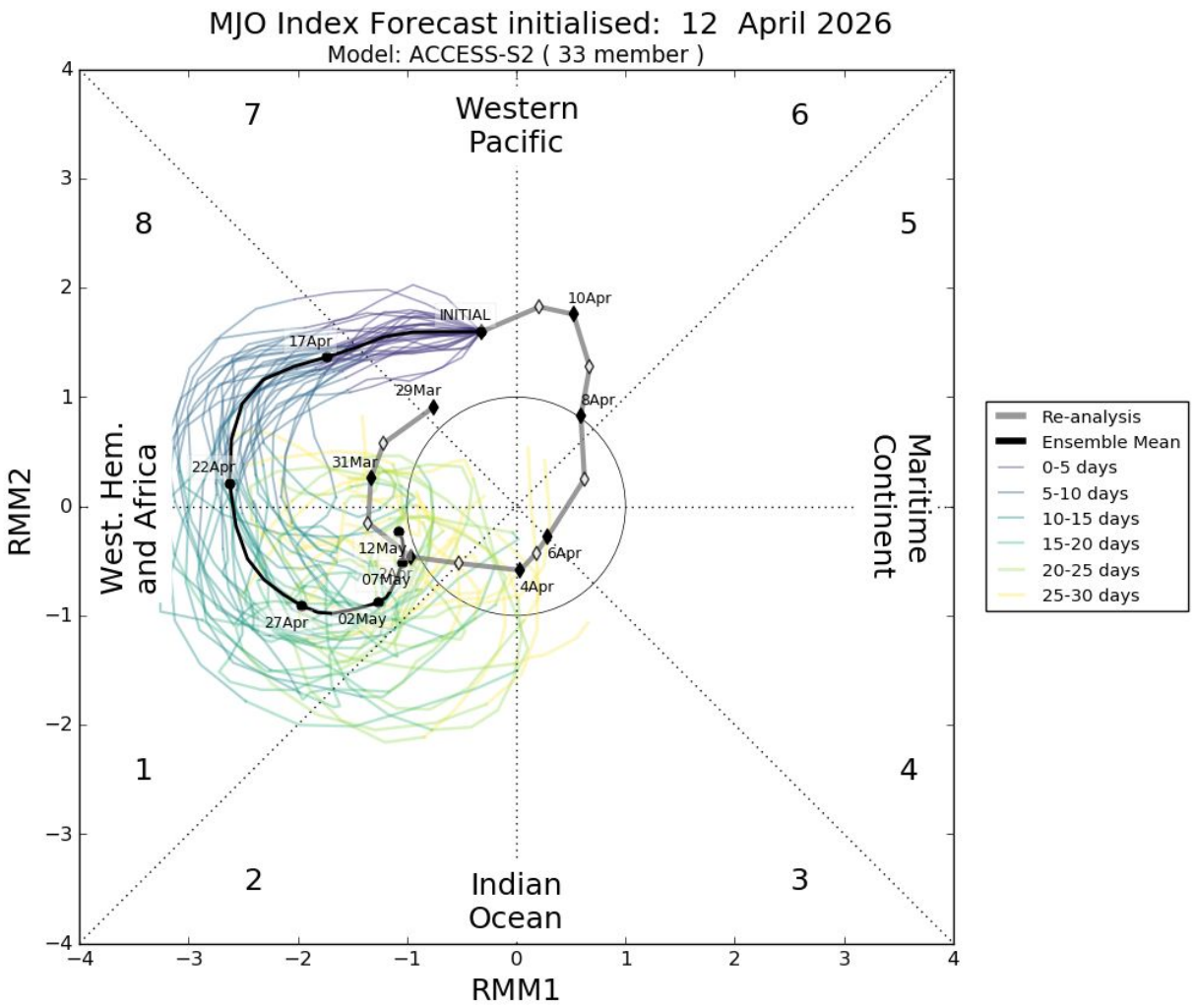


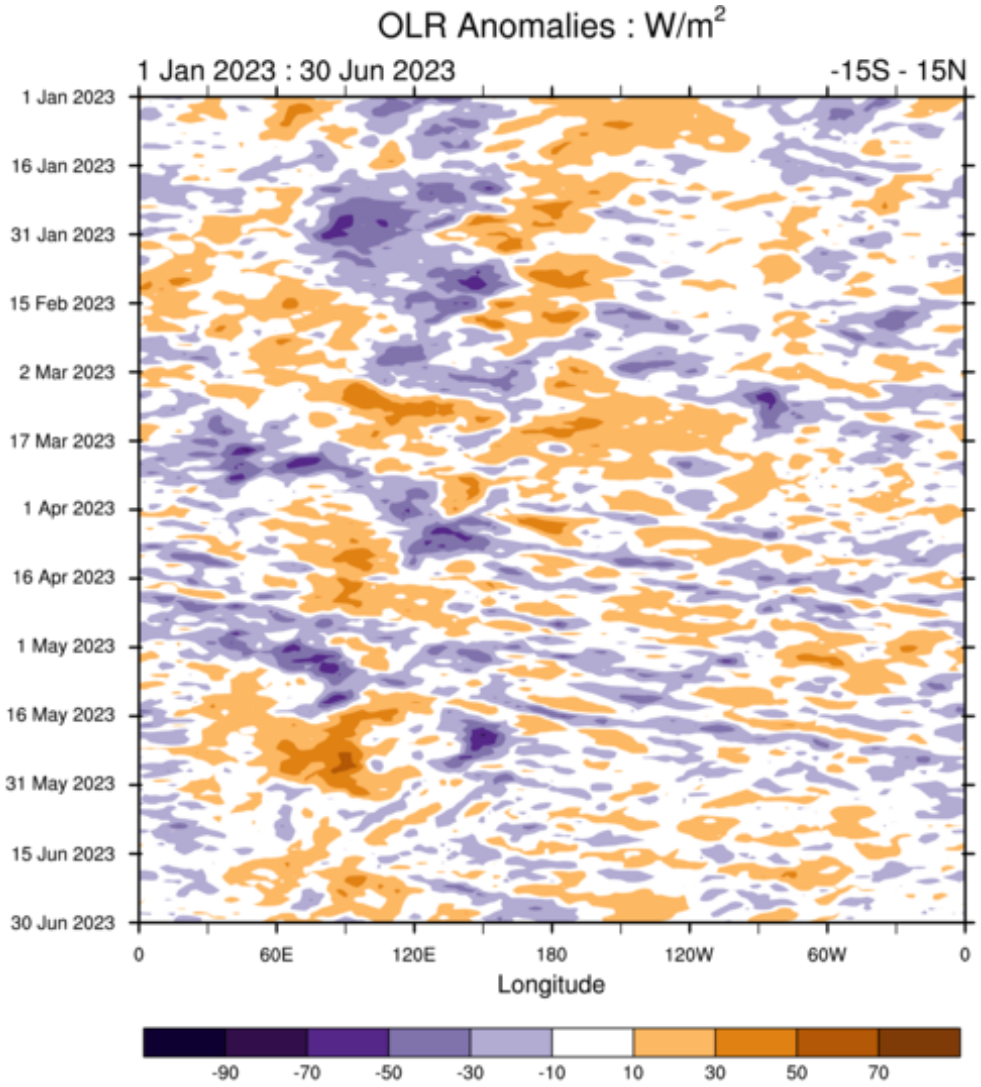
Real-time Multivariate MJO index



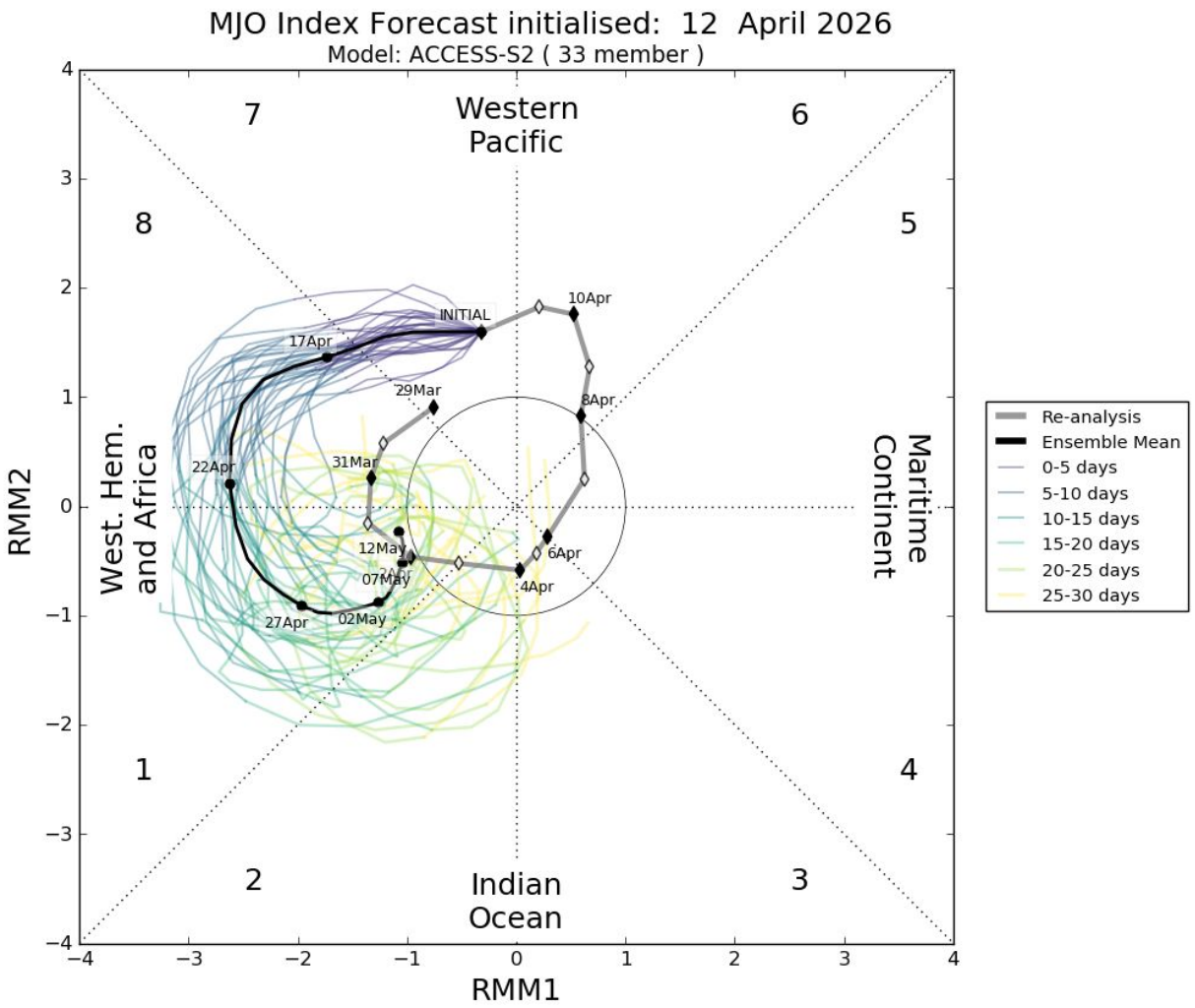


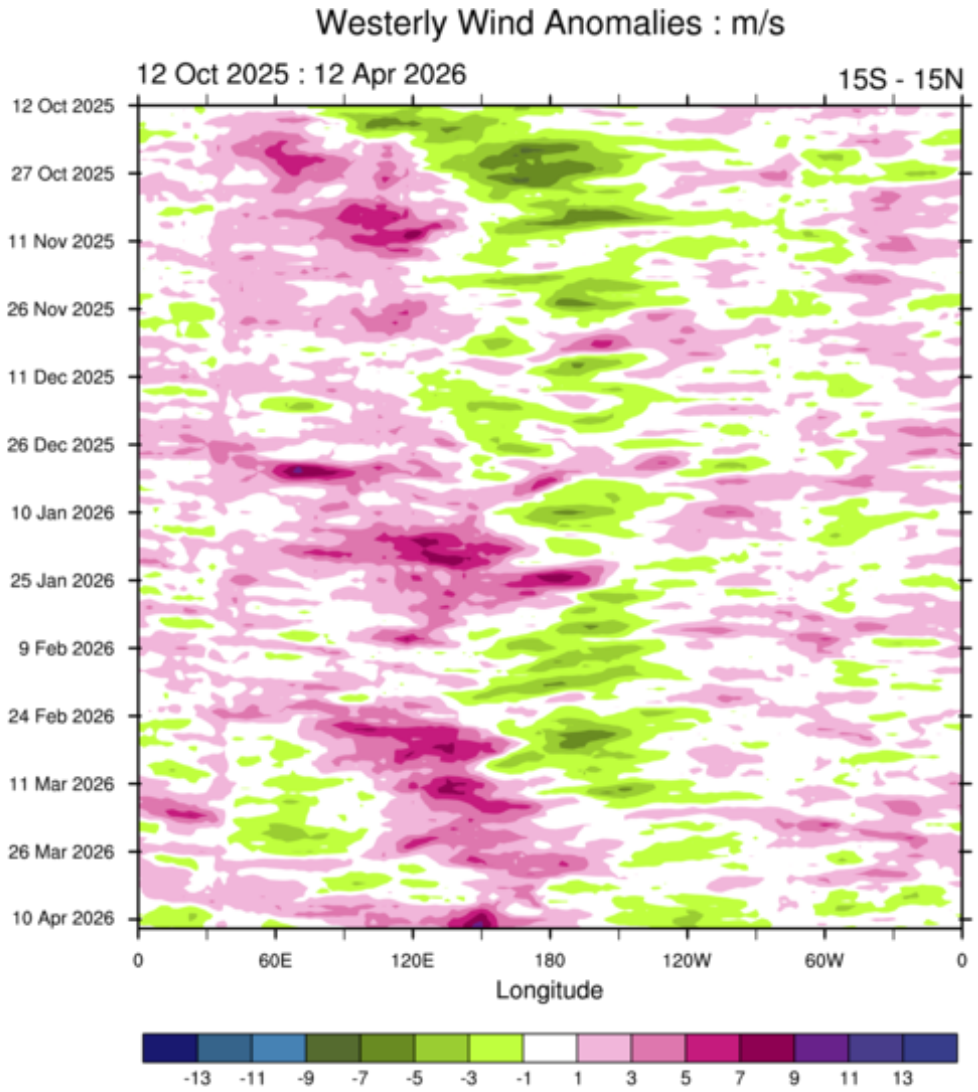
Real-time Multivariate MJO index



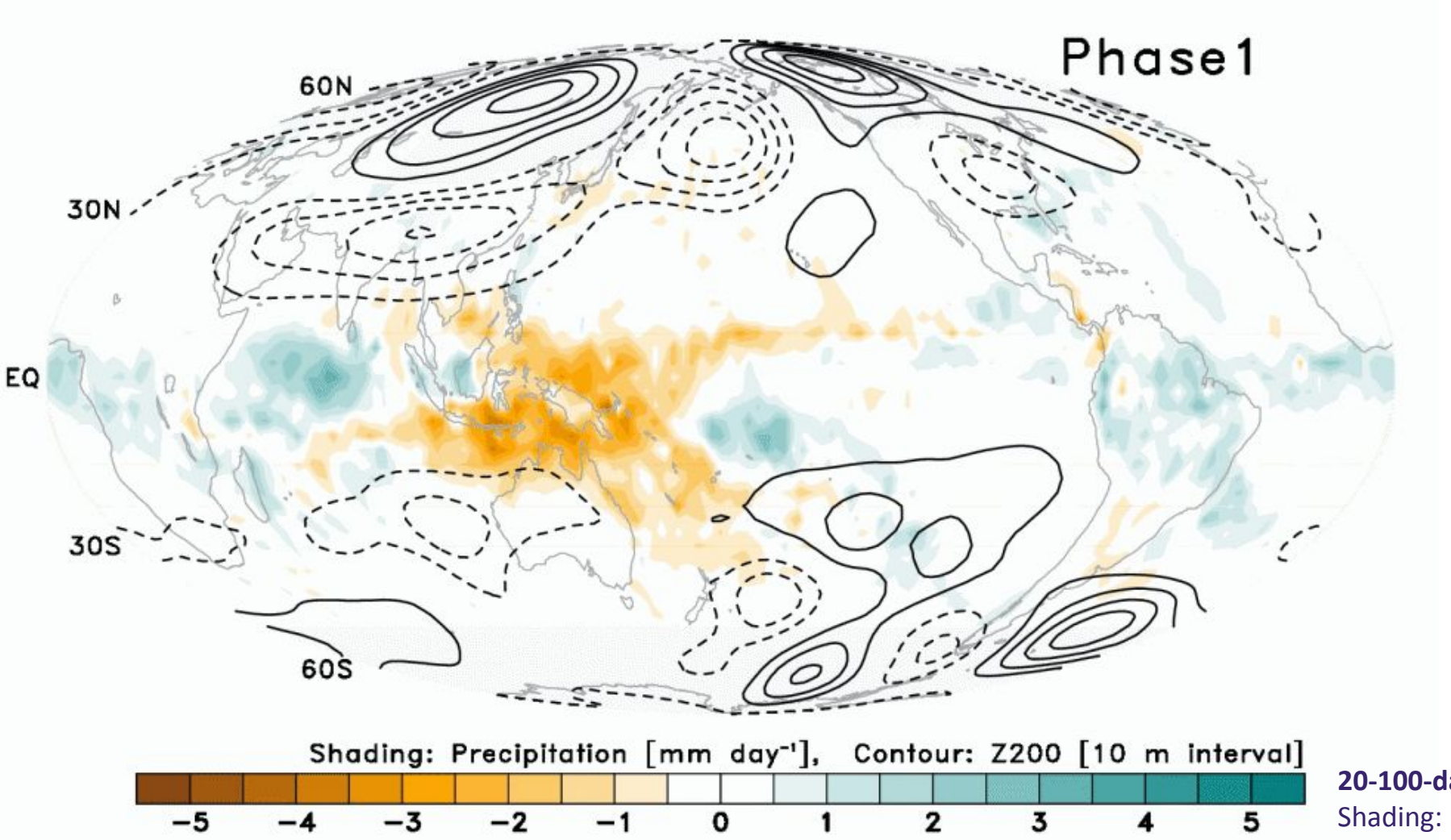


Real-time Multivariate MJO index





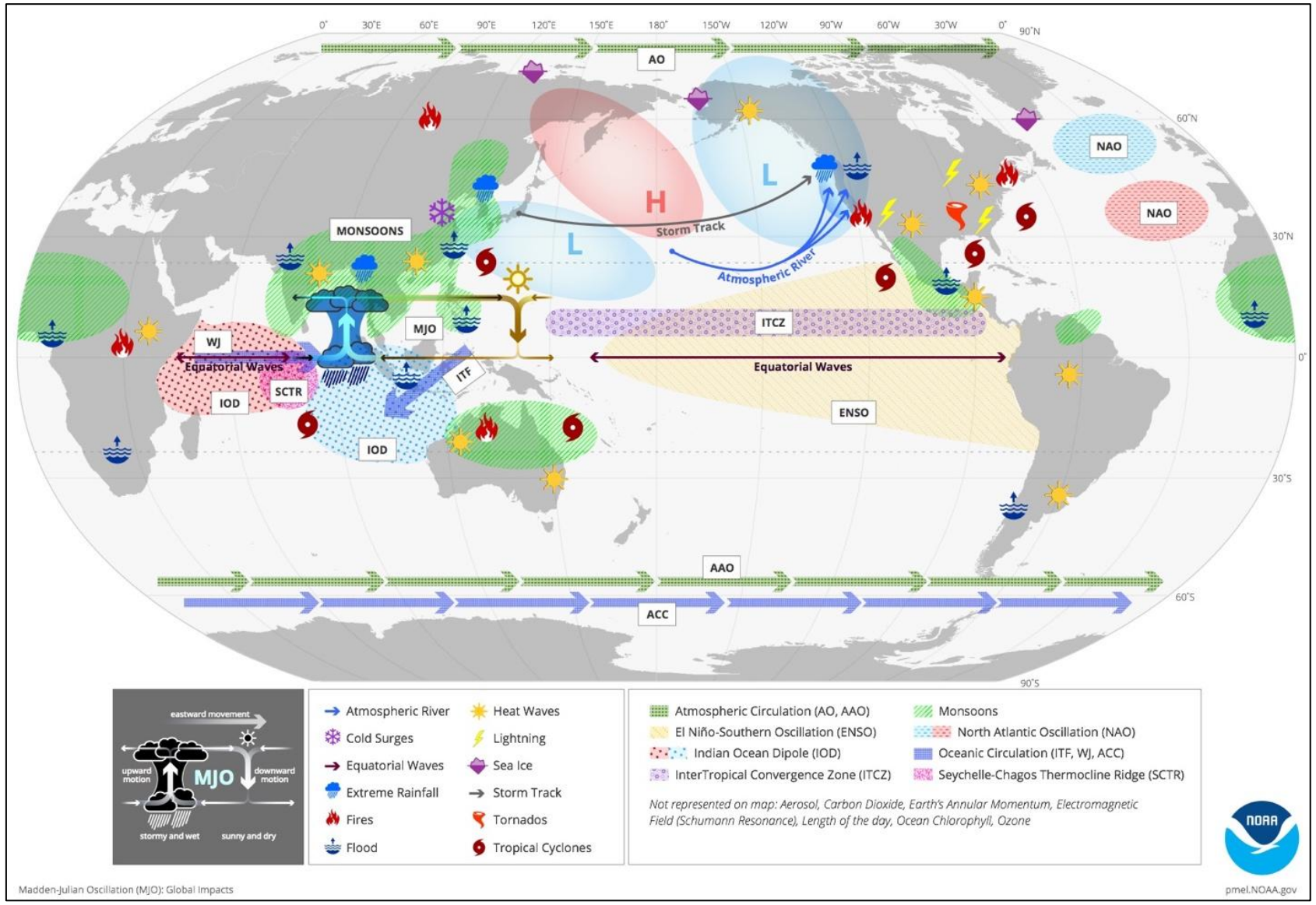
Madden-Julian Oscillation



- A unique type of organized convection in the tropics
  - Planetary zonal scale (wavenumber 1-6)
  - Intraseasonal time scale (30-60 days)
  - Eastward propagation
- Modulates convection and circulation globally

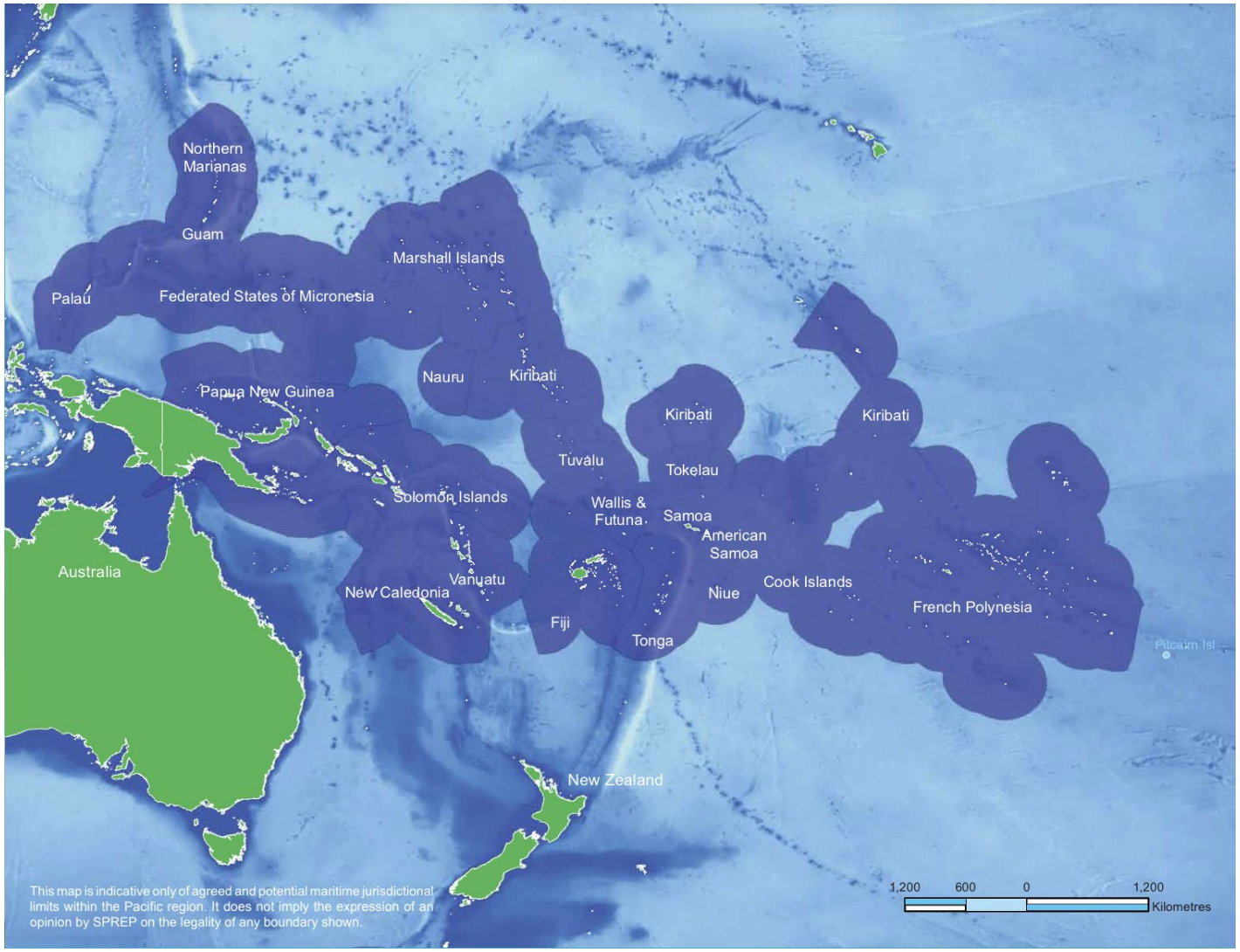
20-100-day filtered variables
Shading: Precipitation
Contour: GPH200 (solid: +, dashed: -)

Global impacts of MJO

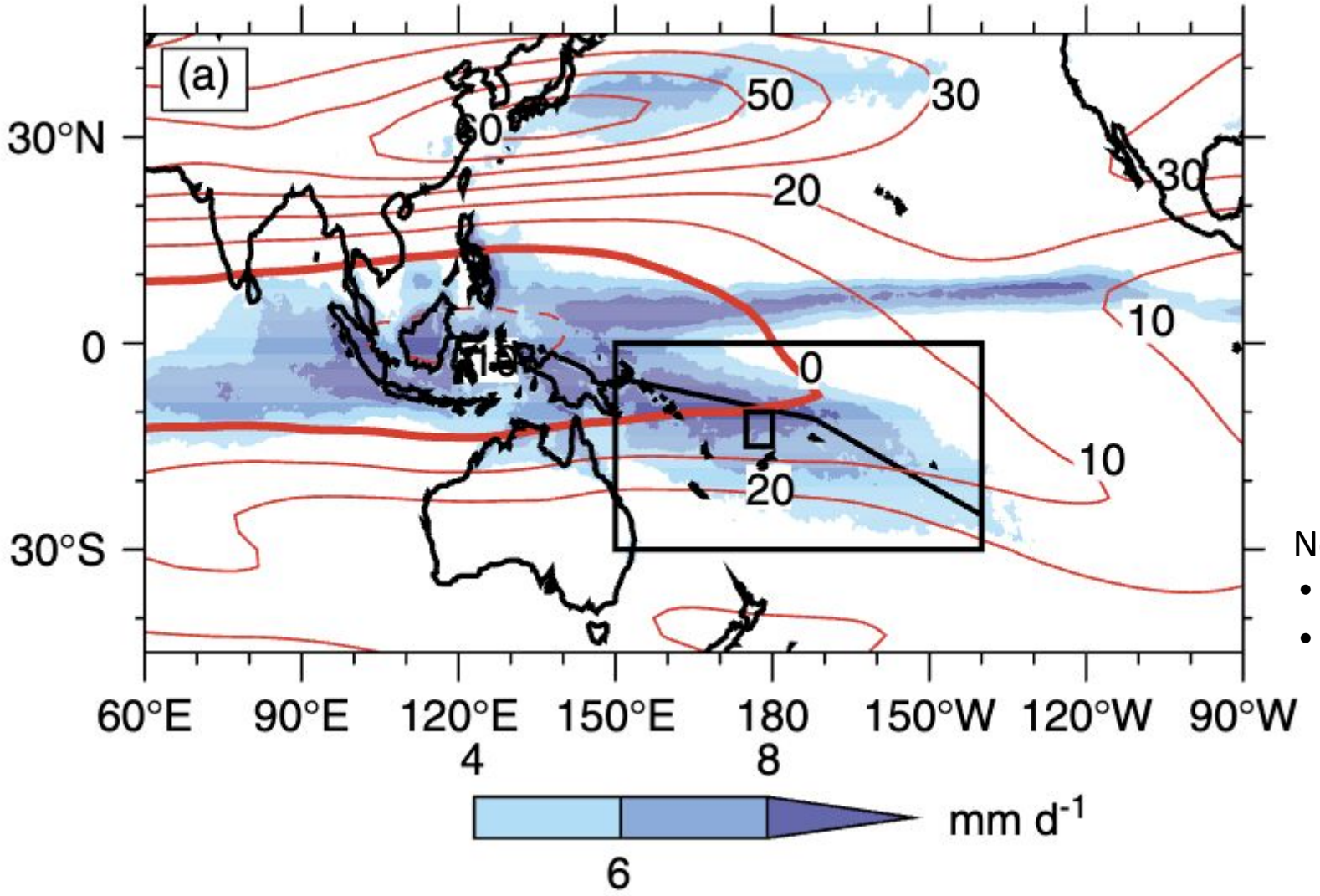


- Interacts with a wide range of Earth system phenomena, including extreme weather events such as flooding, cold surge, heat waves, and fires.
- A main source of Earth system predictability on the S2S timescale

Impacts on the Pacific Island Region



South Pacific Convergence Zone

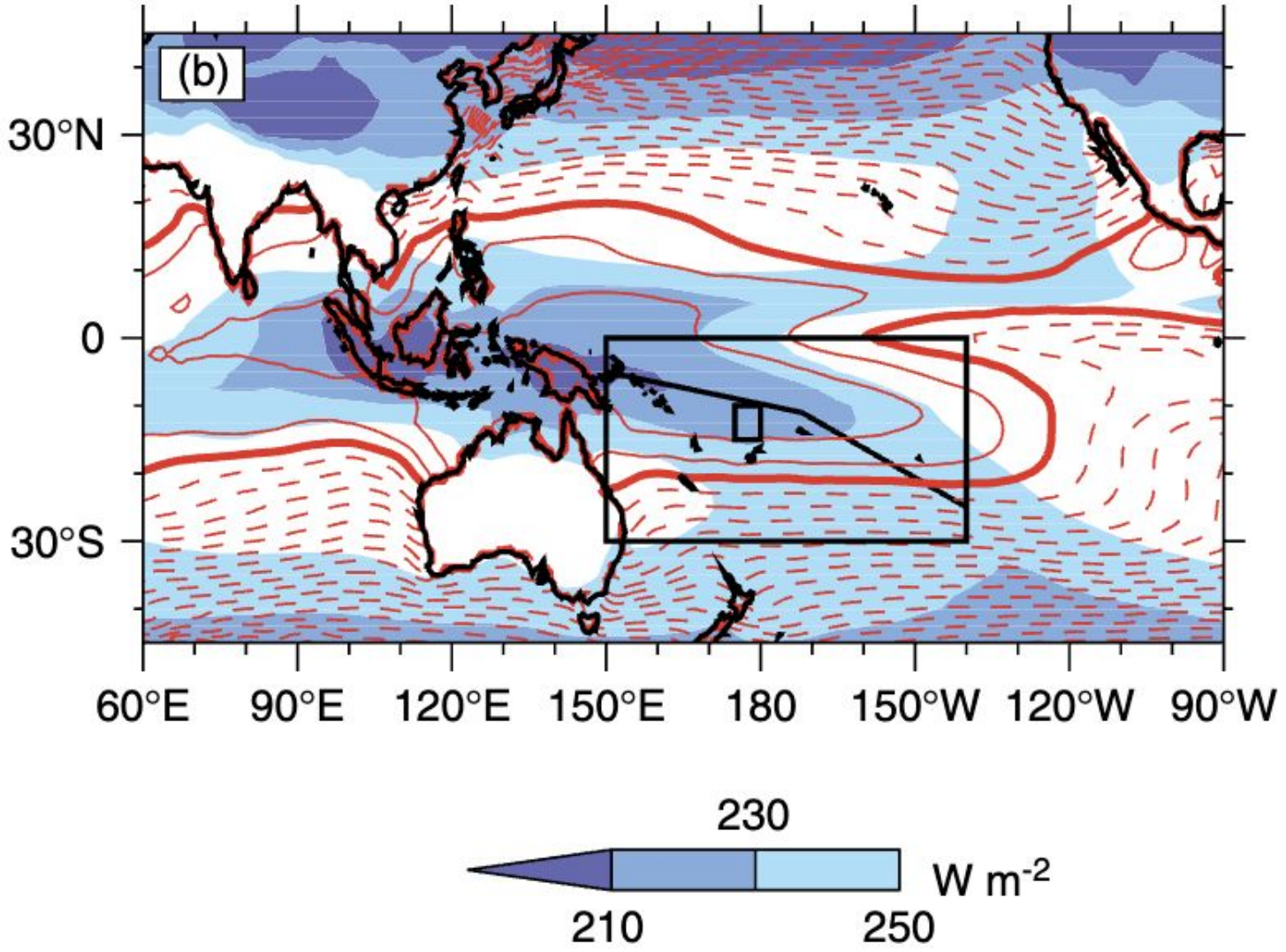


November-April mean

- Shaded: Precip
- Contours: U200

Matthews 2012

South Pacific Convergence Zone

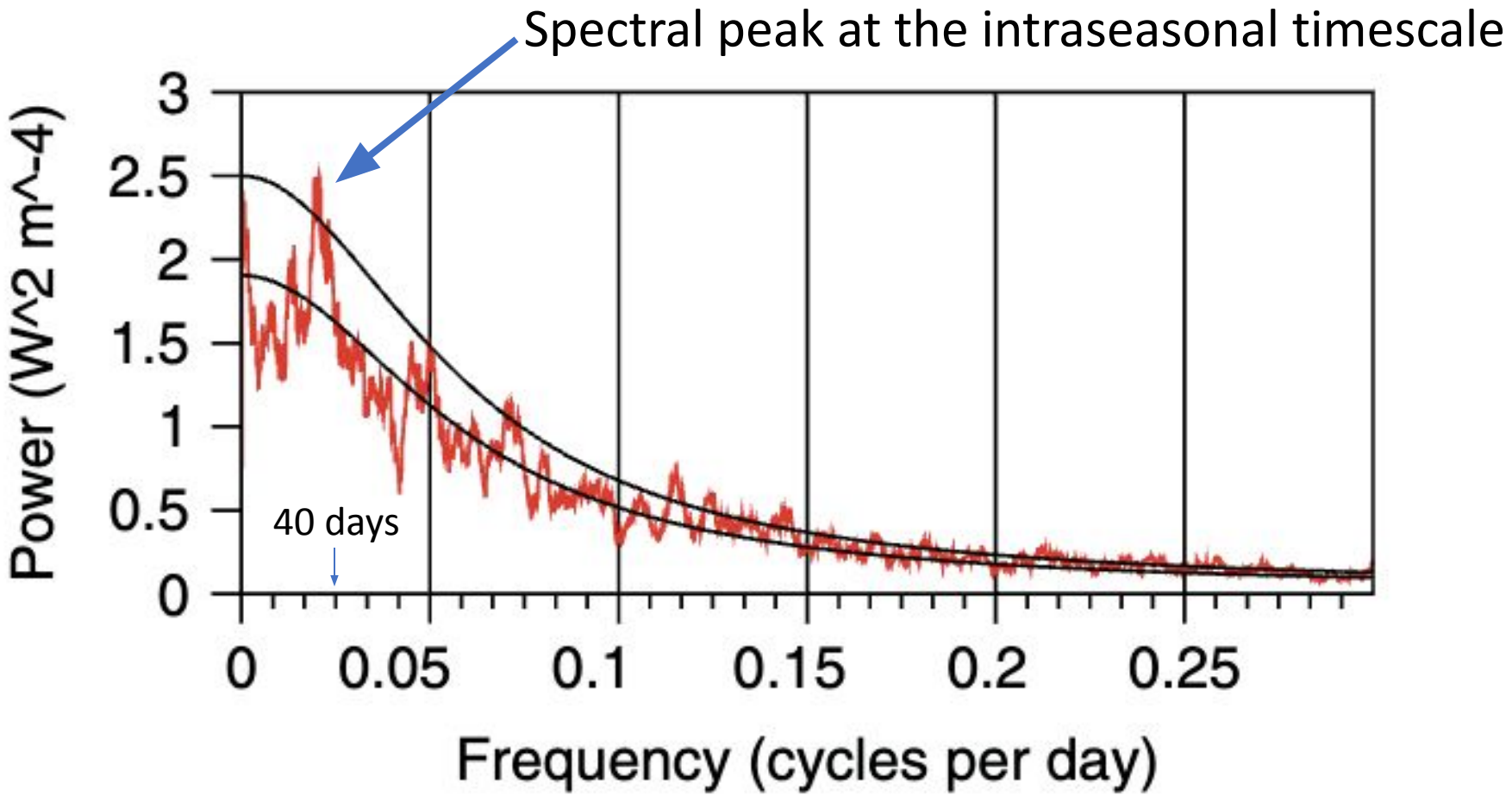


November-April mean

- Shaded: OLR
- Contours: SST

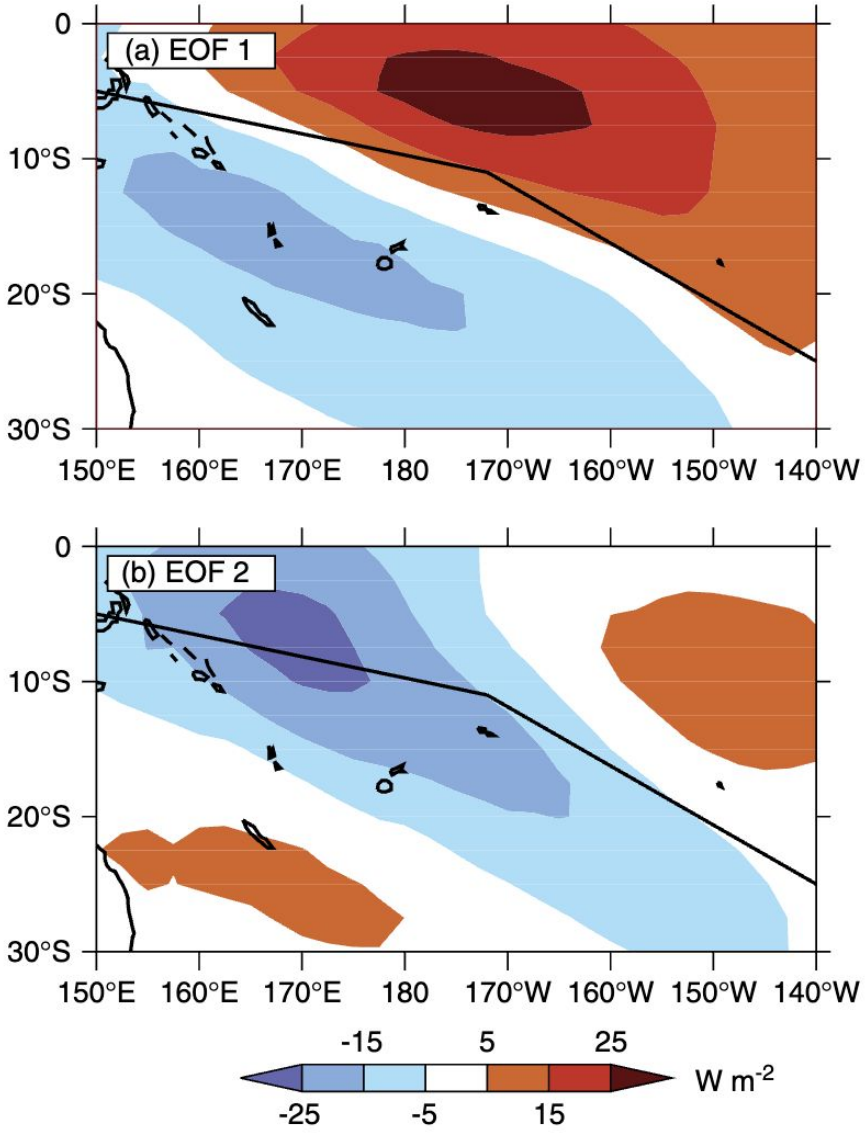
Matthews 2012

SPCZ convection variability

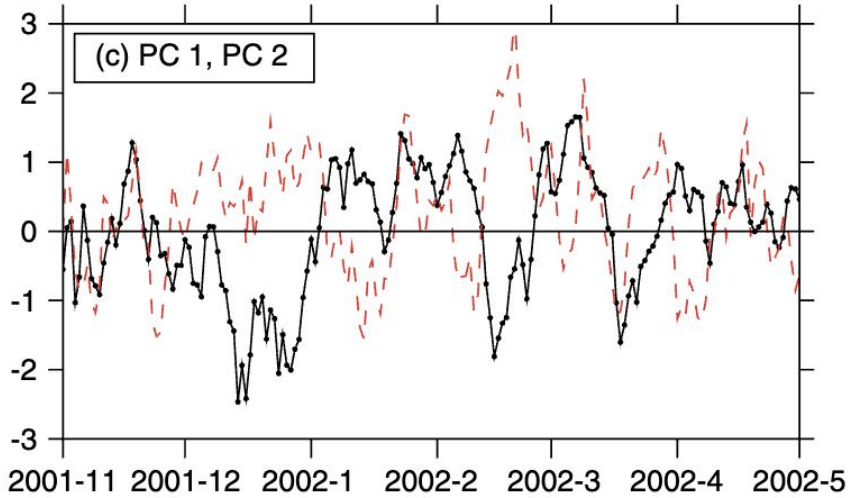


Matthews 2012

Dominant mode of SPCZ variability



Shift



Enhancement

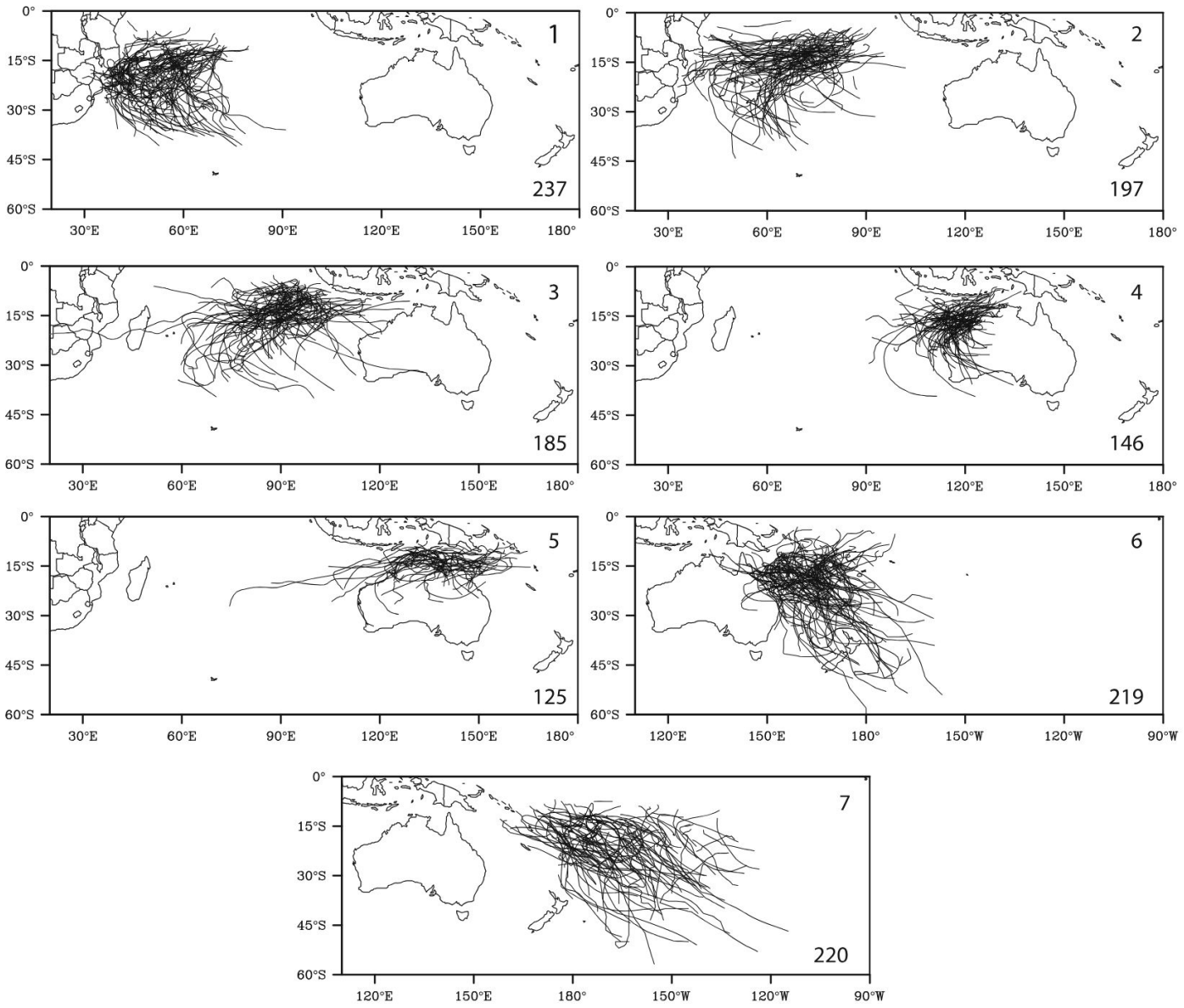
Matthews 2012

MJO's impact on SPCZ variability

	Shifted SPCZ			Enhanced SPCZ	
	N	n	$\hat{p}$(%)	n	$\hat{p}$(%)
All days	5438	171	3.1	198	3.6
No MJO	1968	64	3.2	62	3.1
MJO Phase 1 	345	2	*0.6*	14	4.1
MJO Phase 2 	428	13	3.0	7	*1.6*
MJO Phase 3 	497	19	**3.8**	12	*2.4*
MJO Phase 4 	439	19	**4.3**	12	*2.7*
MJO Phase 5 	404	22	**5.4**	19	**4.7**
MJO Phase 6 	456	17	**3.7**	28	**6.1**
MJO Phase 7 	491	9	*1.8*	33	**6.7**
MJO Phase 8 	410	6	*1.5*	11	*2.7*

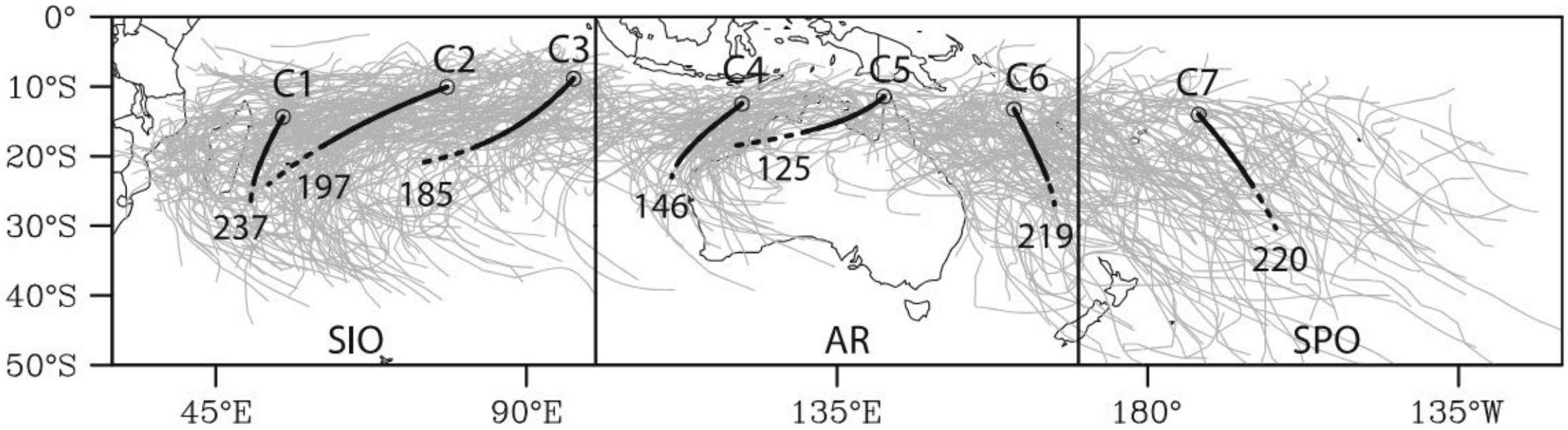
Matthews 2012

Tropical cyclone clusters



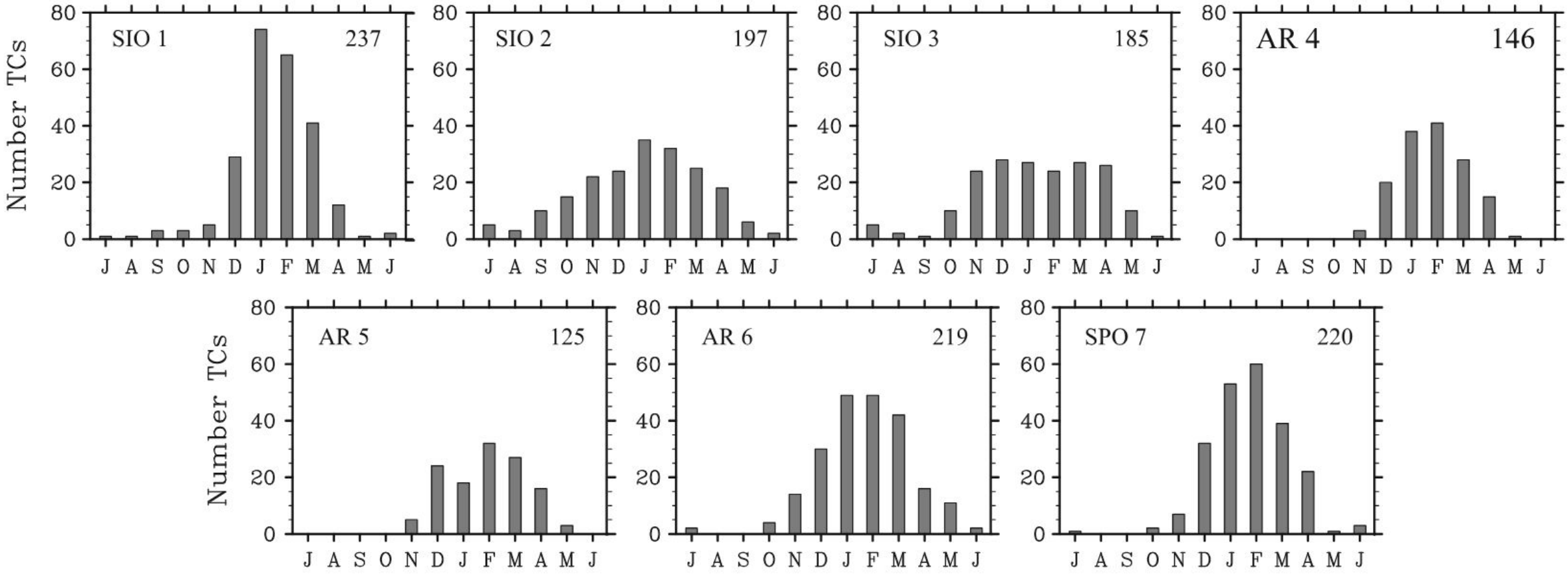
Ramsay et al. 2012

Tropical cyclone clusters



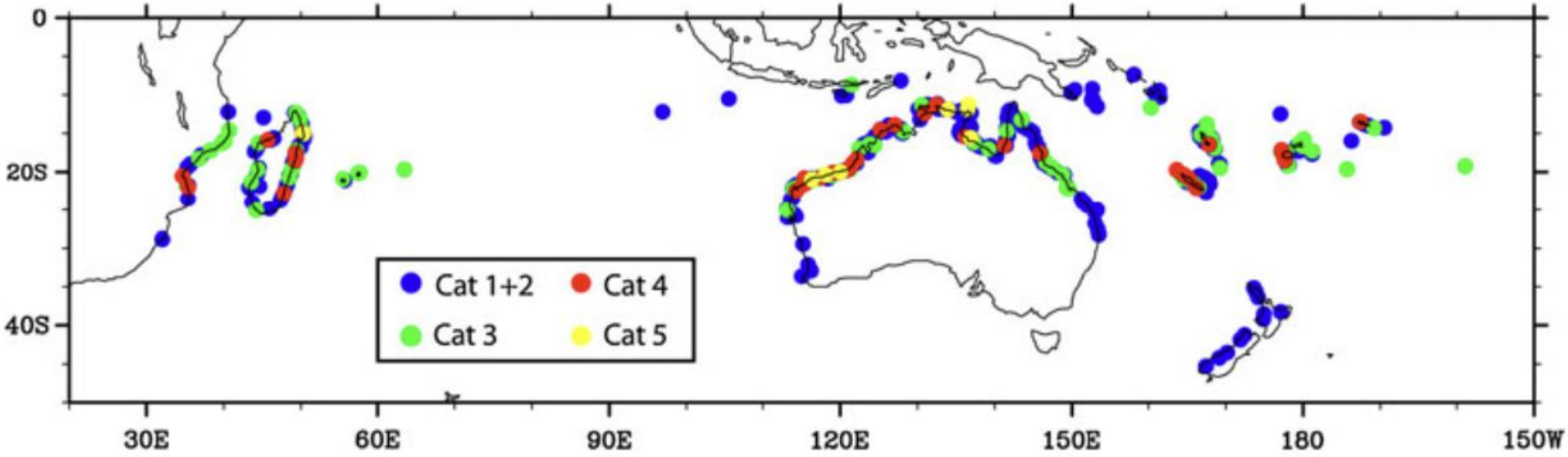
Ramsay et al. 2012

Annual cycle of TC frequency



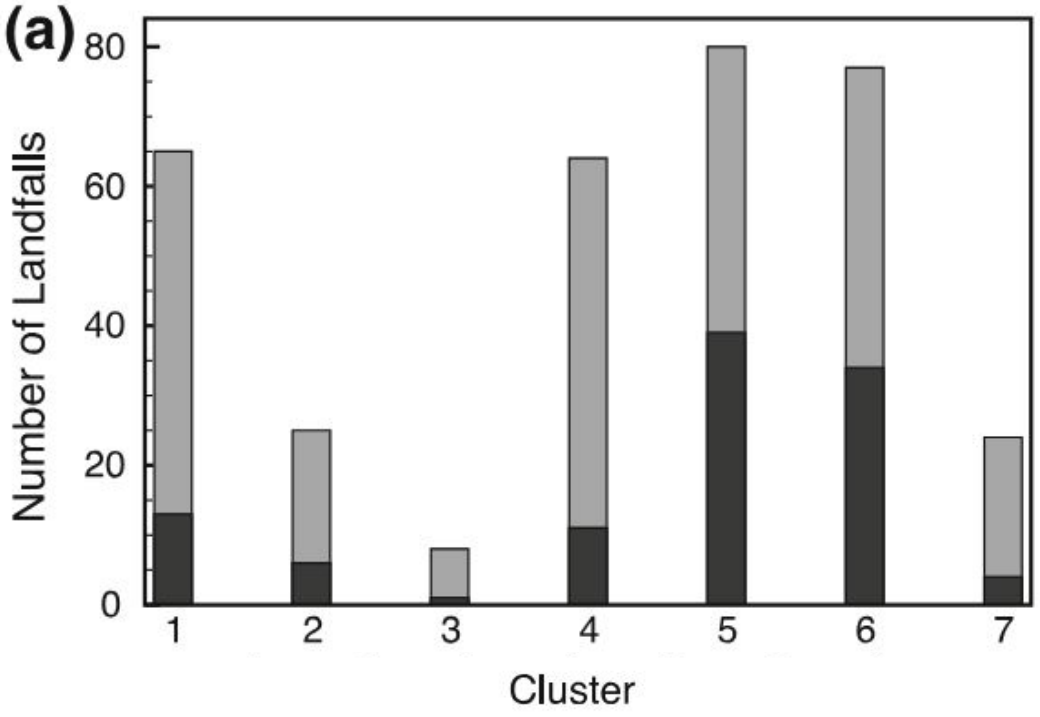
Ramsay et al. 2012

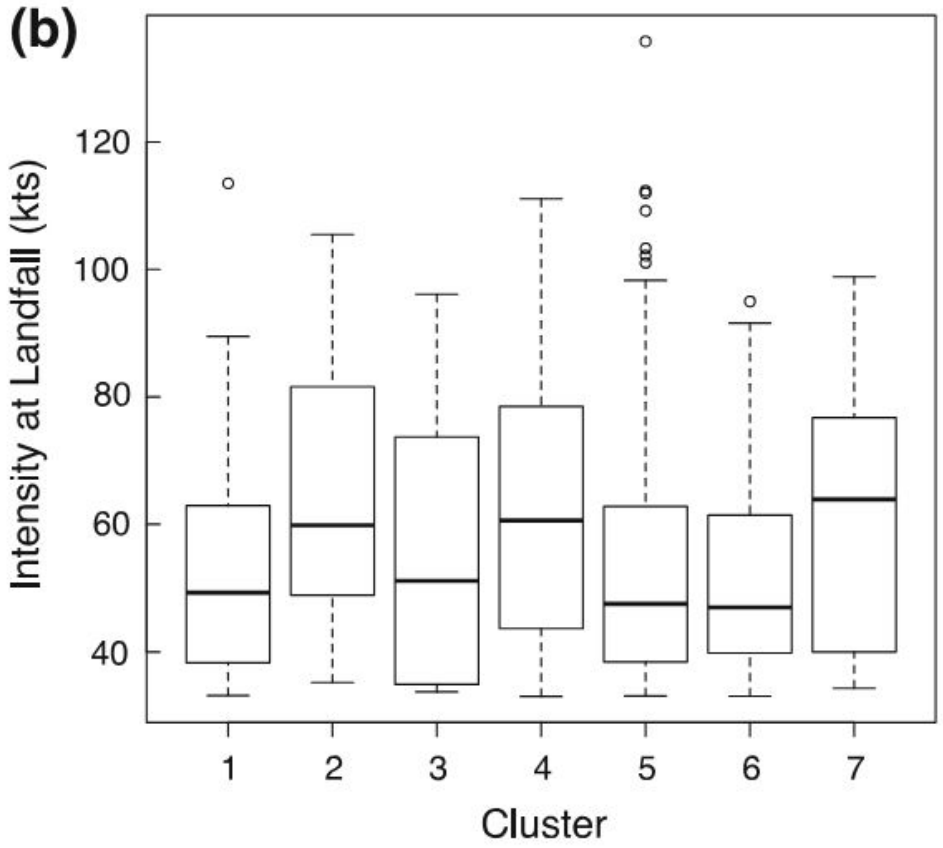
TC landfall locations



Ramsay et al. 2012

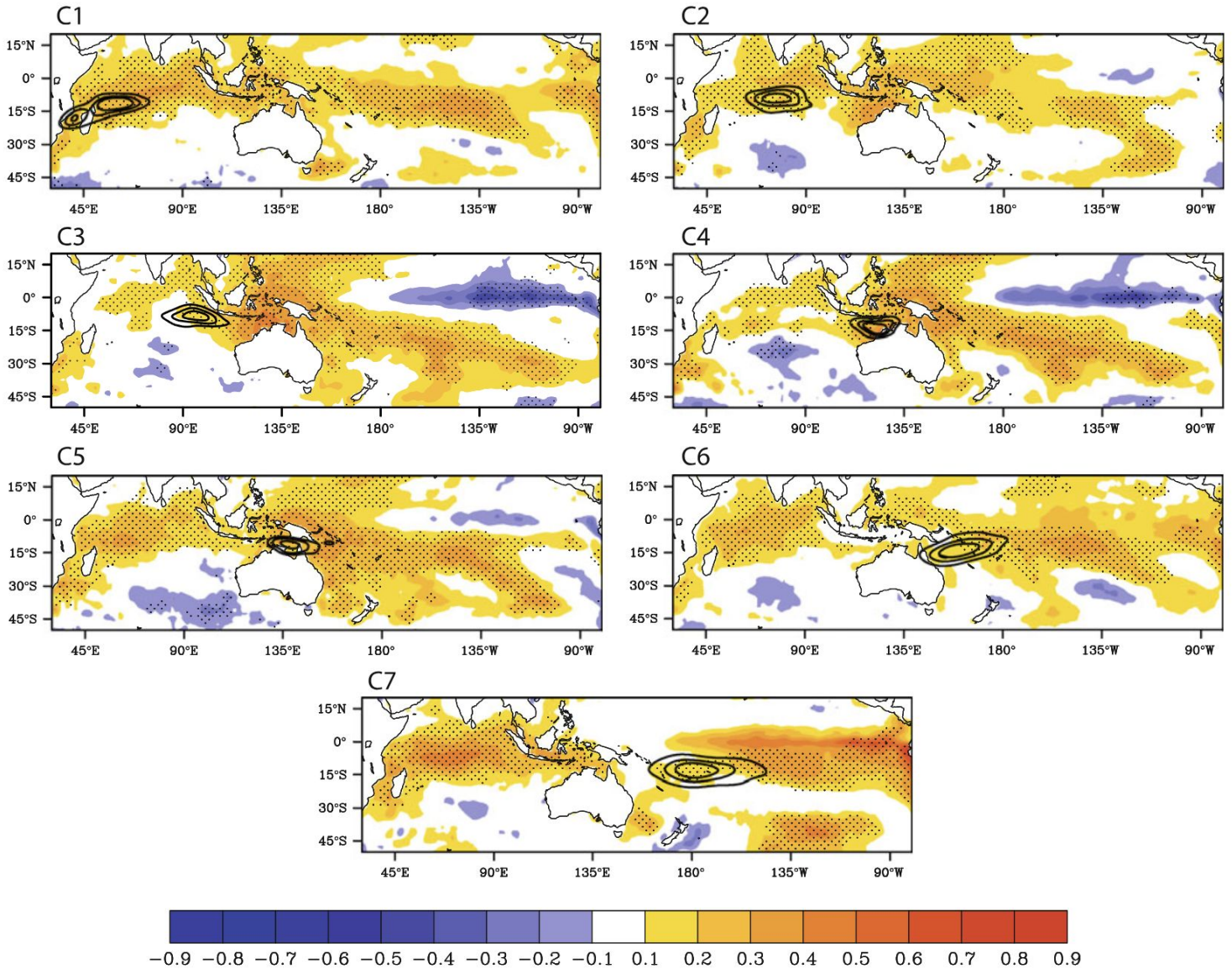
Landfalling TCs





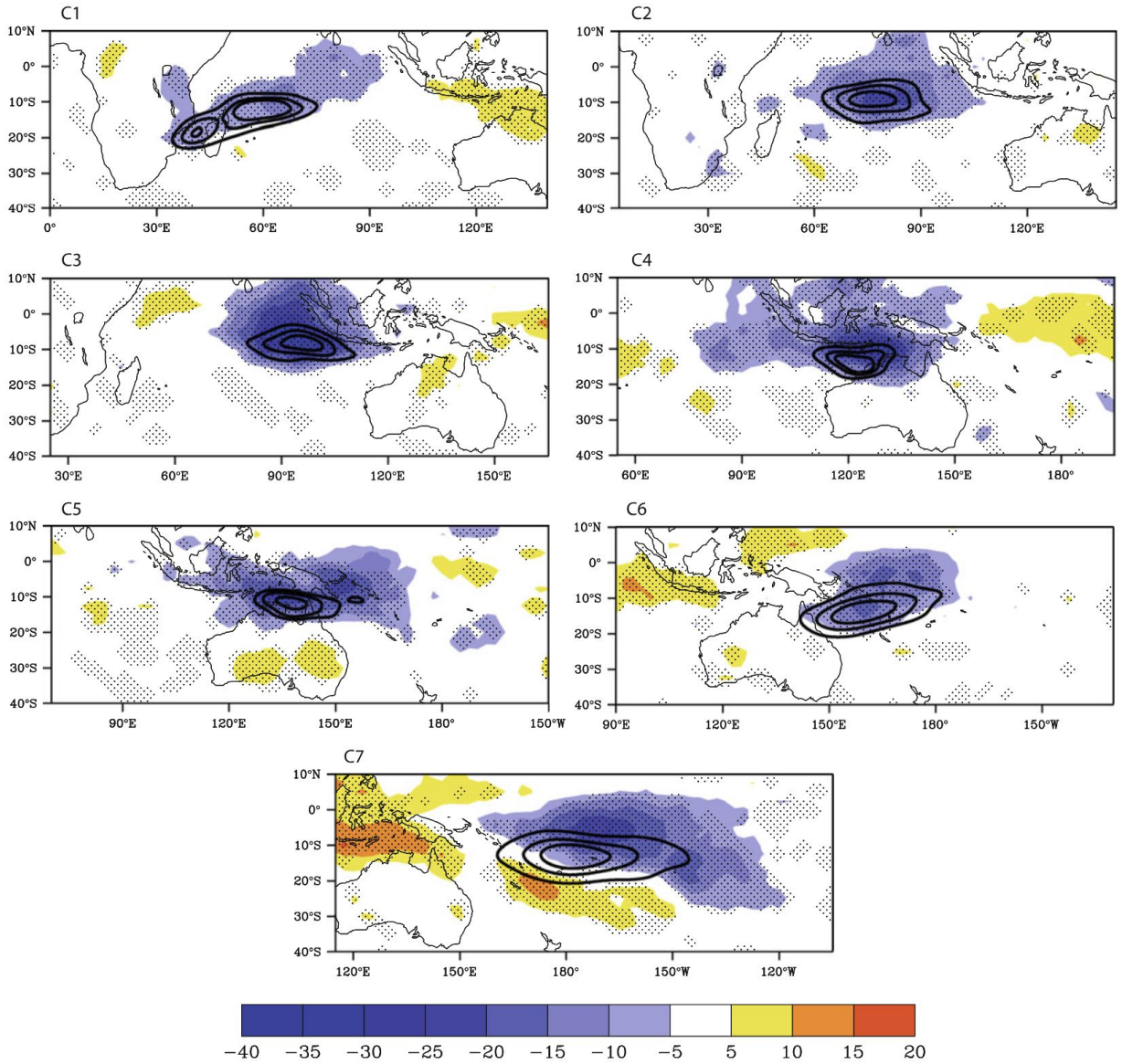
Ramsay et al. 2012

SST anomalies prior to TC genesis



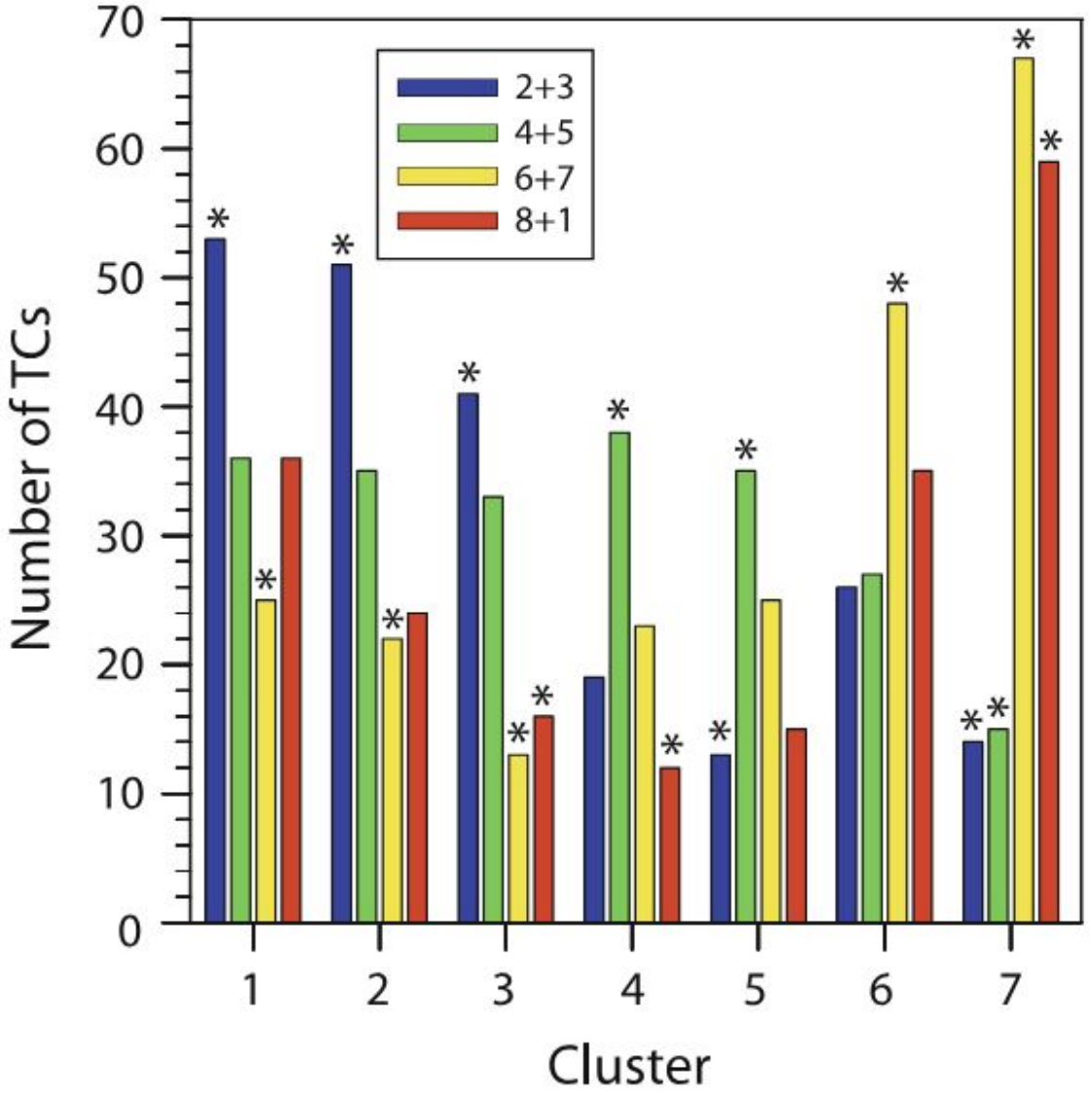
Ramsay et al. 2012

OLR anomalies prior to TC genesis



Ramsay et al. 2012

MJO's impact on TC frequency



Ramsay et al. 2012

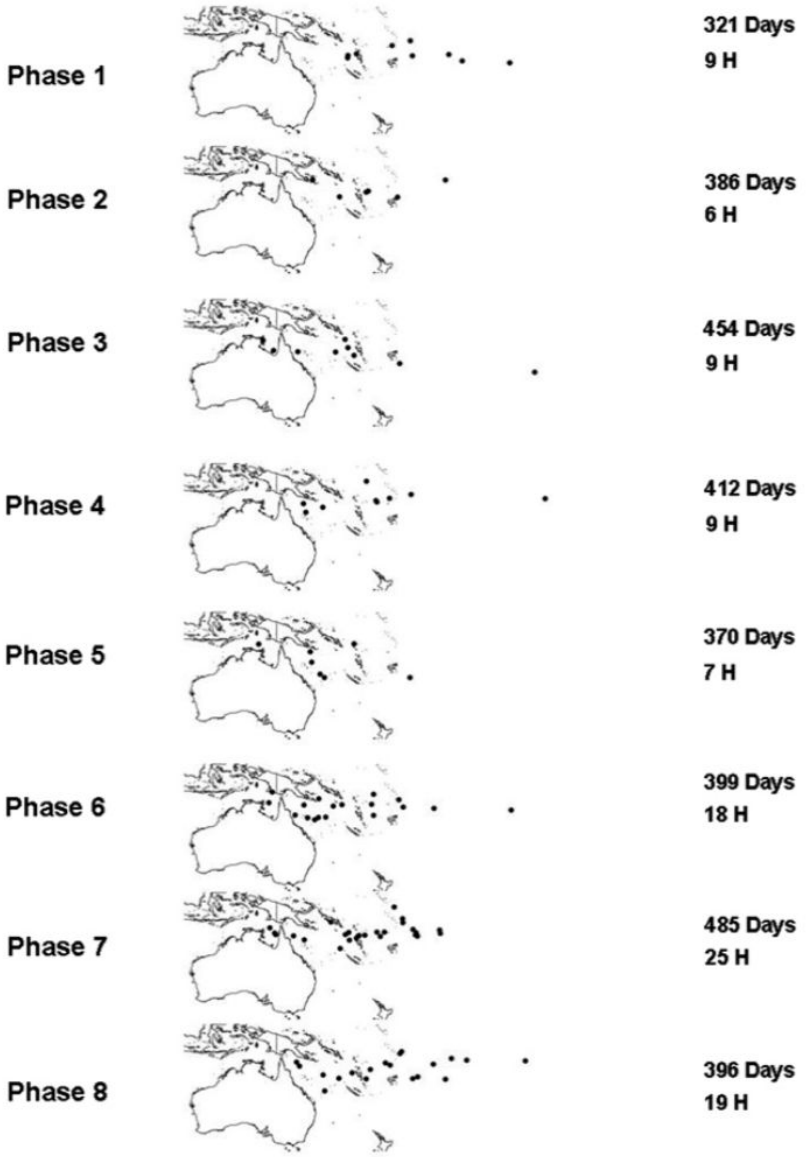
MJO's impact on TC frequency

	ALL	C1	C2	C3	C4	C5	C6	C7
Total TC count	859	151	110	119	111	87	121	160
Positive MJO	259	33	32	45	34	31	38	46
Negative MJO	37	3	5	9	2	6	7	5
Ratio Pos/ Neg	7:1	11:1	6.4:1	5:1	17:1	5.2:1	5.4:1	9.2:1

Ramsay et al. 2012

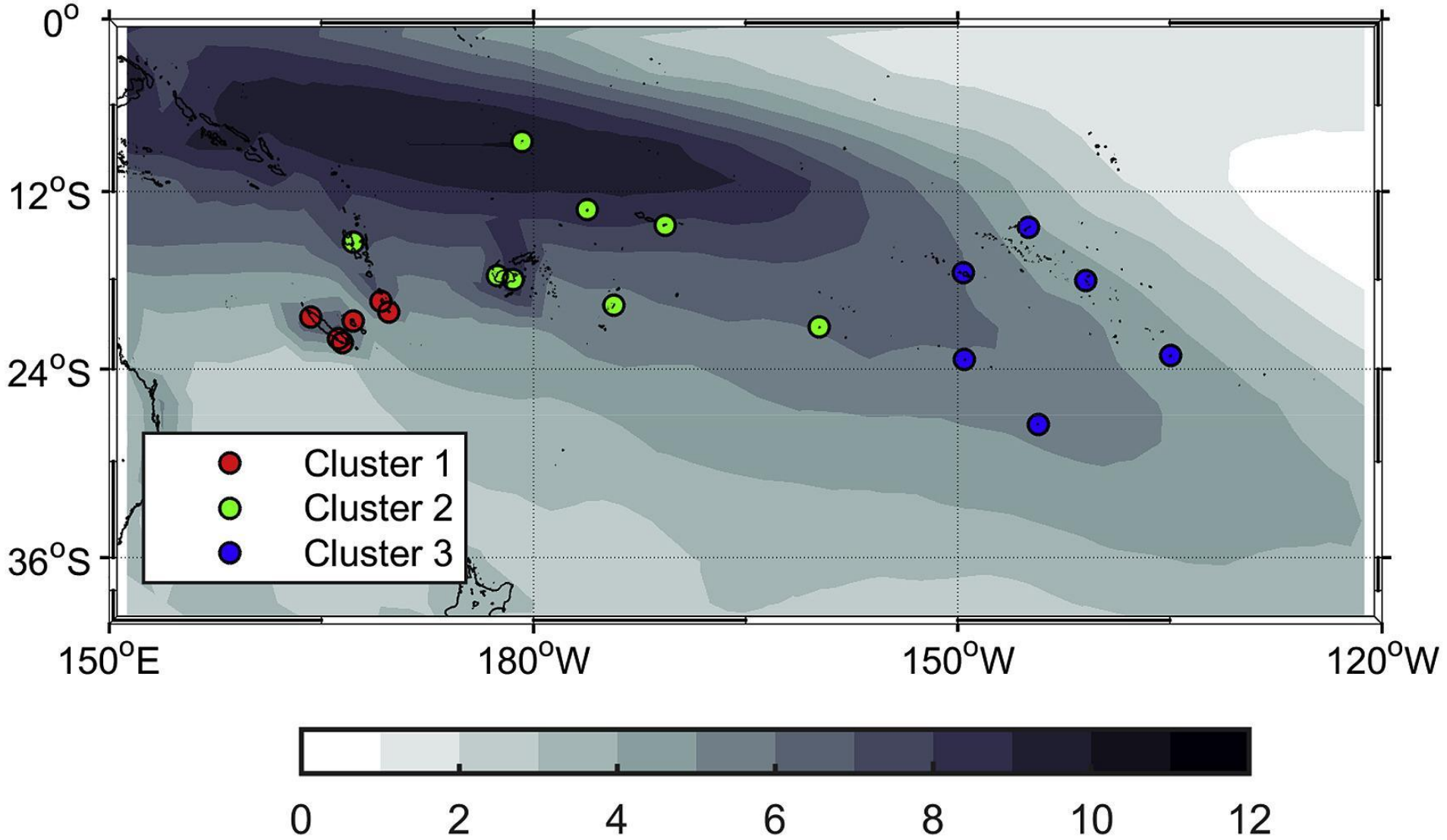
MJO's impact on TC frequency

Phase	NS	H	MH	Basinwide ACE (%)	RI 24-h periods	RI chance (%)
1	5.0	2.8	1.6	11	6.9	44
2	*3.9*	*1.6*	1.0	6	5.2	27
3	*3.5*	*2.0*	1.1	12	3.5	31
4	4.4	2.2	1.0	*6*	4.4	22
5	*4.1*	*1.9*	*0.5*	*7*	5.9	40
6	**8.5**	4.5	1.8	16	11.3	35
7	**10.3**	**5.2**	**3.1**	**22**	8.9	28
8	7.3	**4.8**	2.5	20	**13.4**	45
Phase 1–8 avg	6.0	2.9	1.6	12	7.4	34



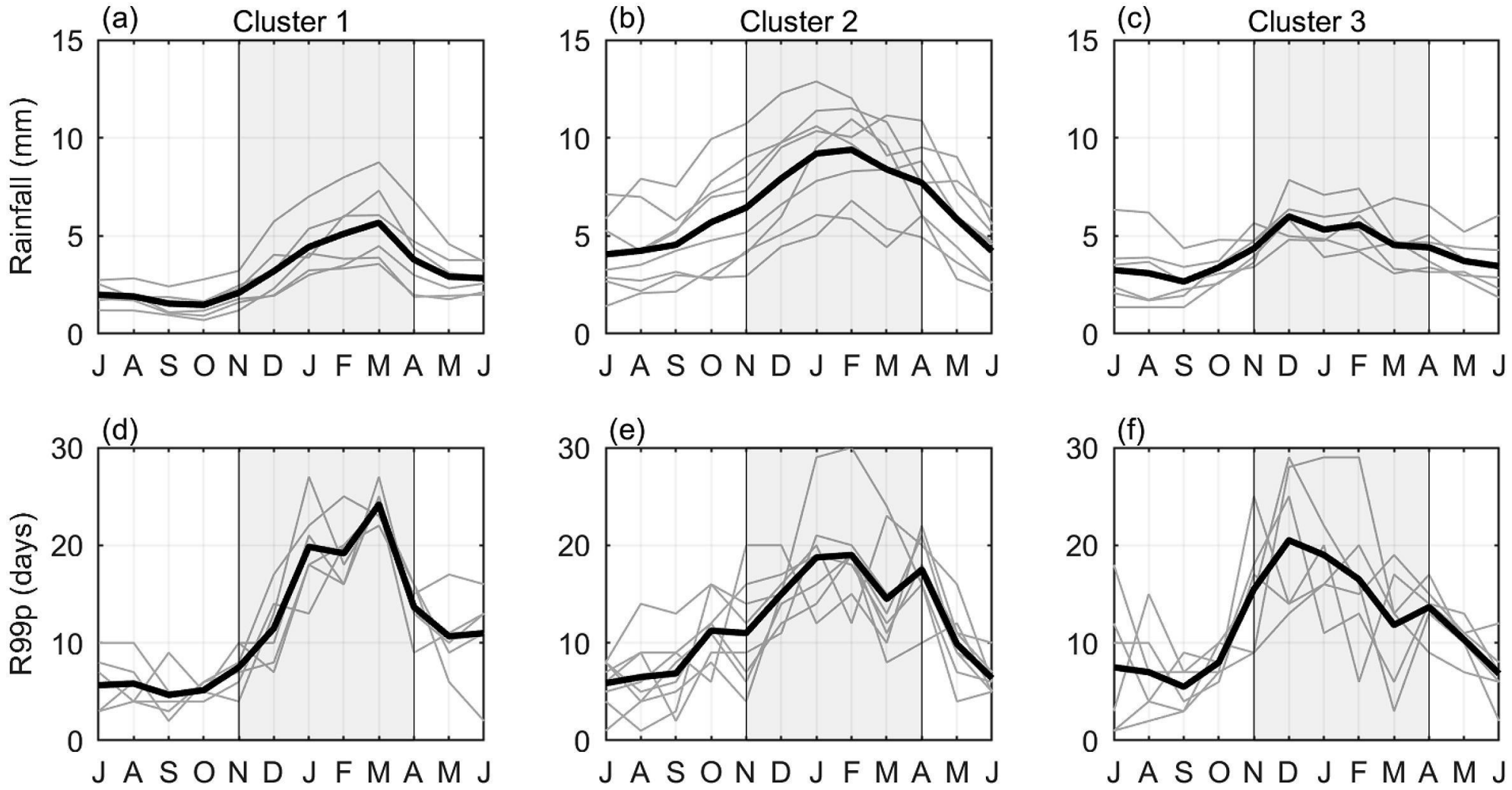
Klotzbach 2014

Extreme precipitation



Pariyar et al. 2020

Annual cycle of mean and extreme precip



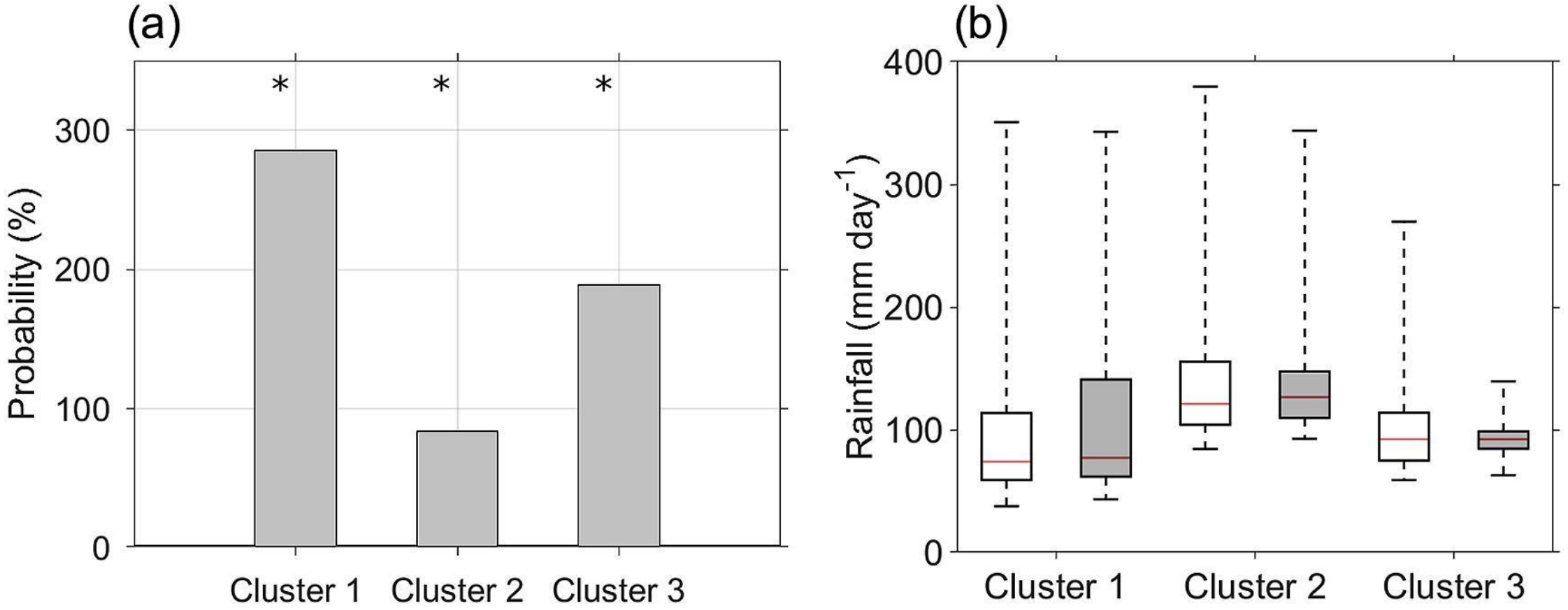
Pariyar et al. 2020

Table 1. Summary statistics of daily rainfall and rainfall extremes in November–April from 1979 to 2018.

	Mean (mm)	SD (mm)	95th percentile (mm)	99th percentile (mm)
Daily rainfall				
Cluster 1	3.6	13.9	19.8	62.9
Cluster 2	7.6	19.0	39.9	89.3
Cluster 3	4.7	14.0	26.9	68.1
Daily extreme rainfall events				
Cluster 1	105.8	62.3	229.8	350.5
Cluster 2	139.7	57.9	265.7	379.5
Cluster 3	100.6	42.3	169.5	269.5

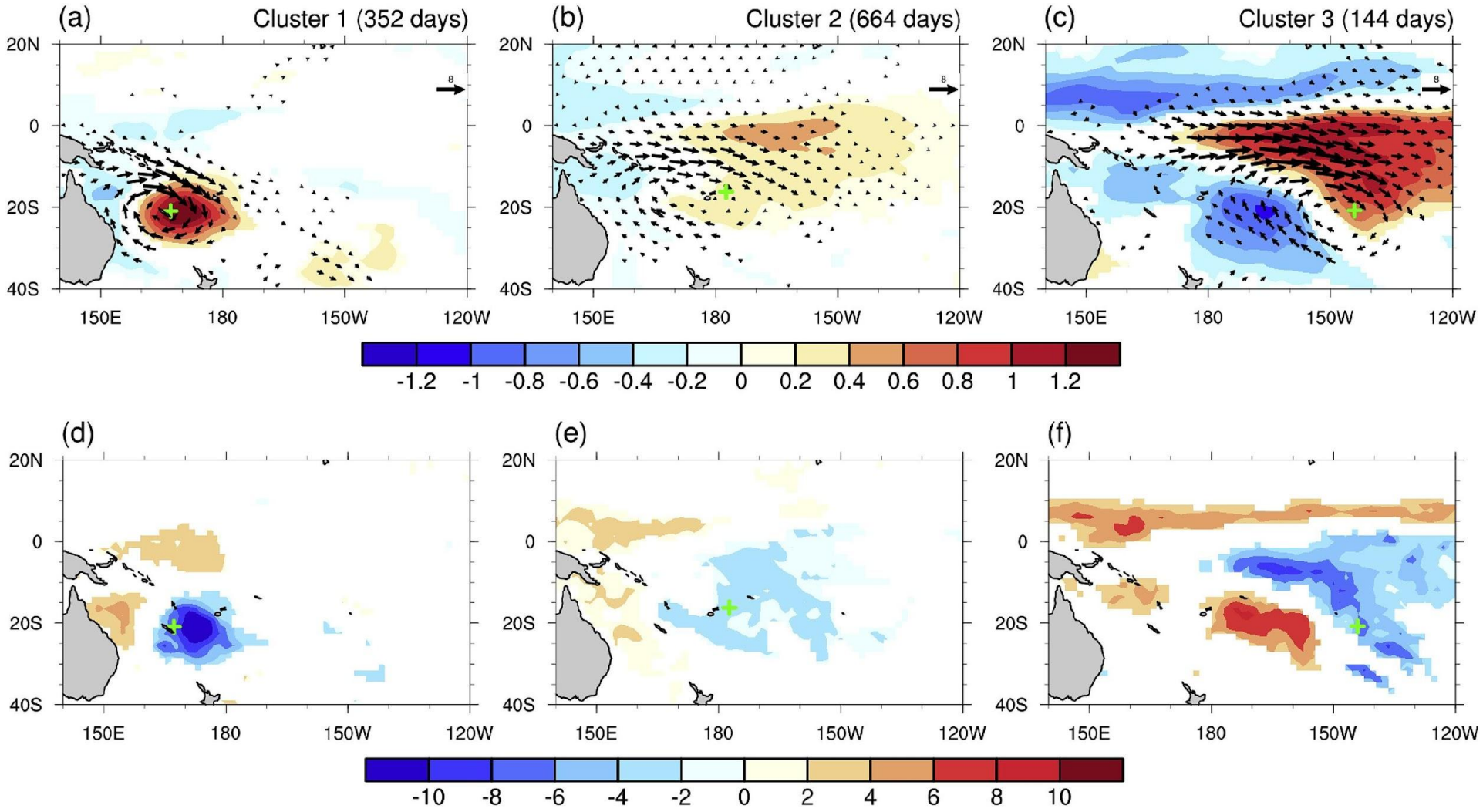
Pariyar et al. 2020

Impact of TCs on extreme precip events



Pariyar et al. 2020

Impact of TCs on extreme precip events

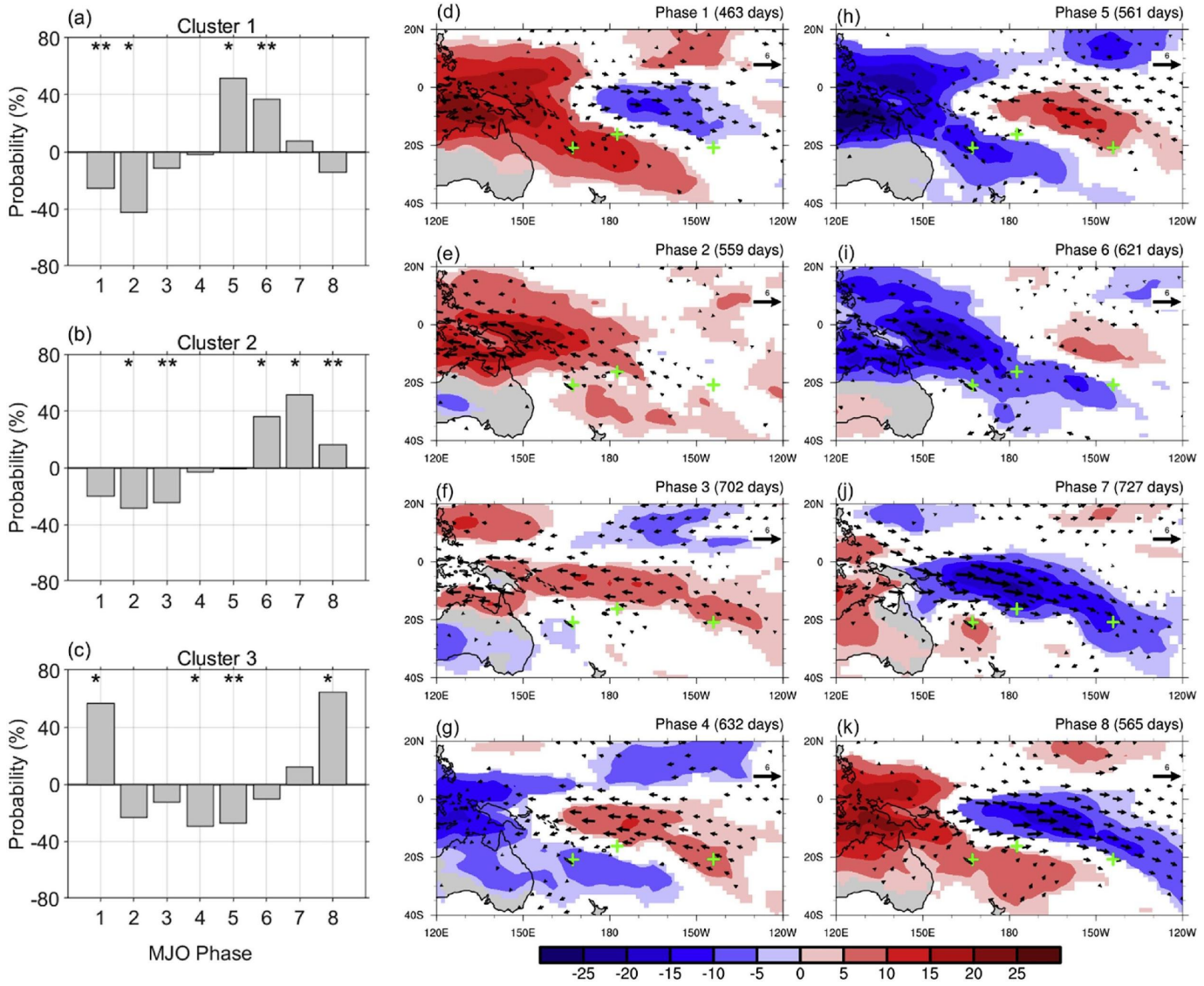


Anomaly composite
- Shaded: PW
- Vectors: U850

Anomaly composite
- Shaded: vertically-integrated moisture flux divergence

Pariyar et al. 2020

Impact of the MJO on extreme precip events

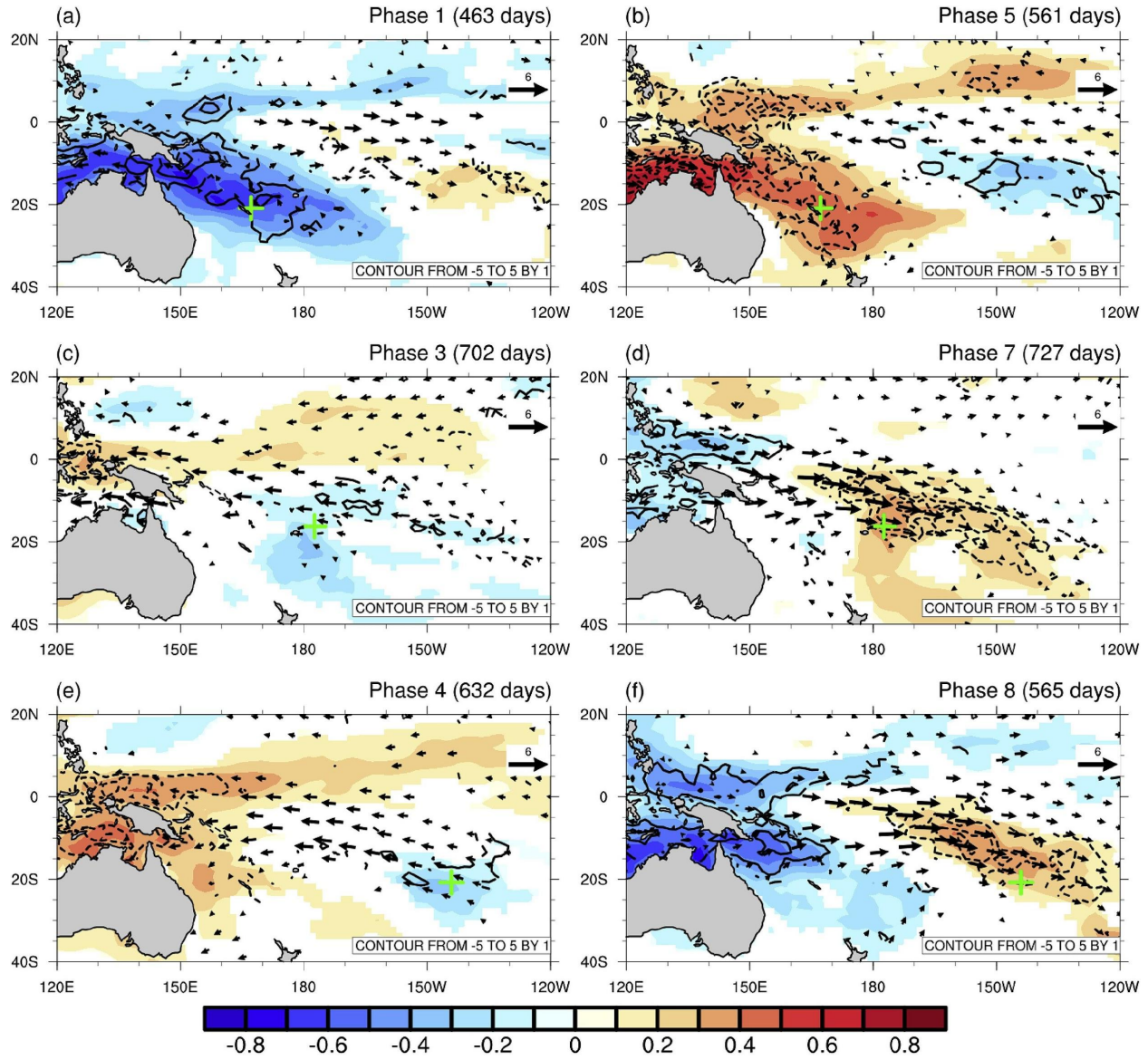


Anomaly composite

- Shaded: OLR
- Vectors: U850

Pariyar et al. 2020

Impact of the MJO

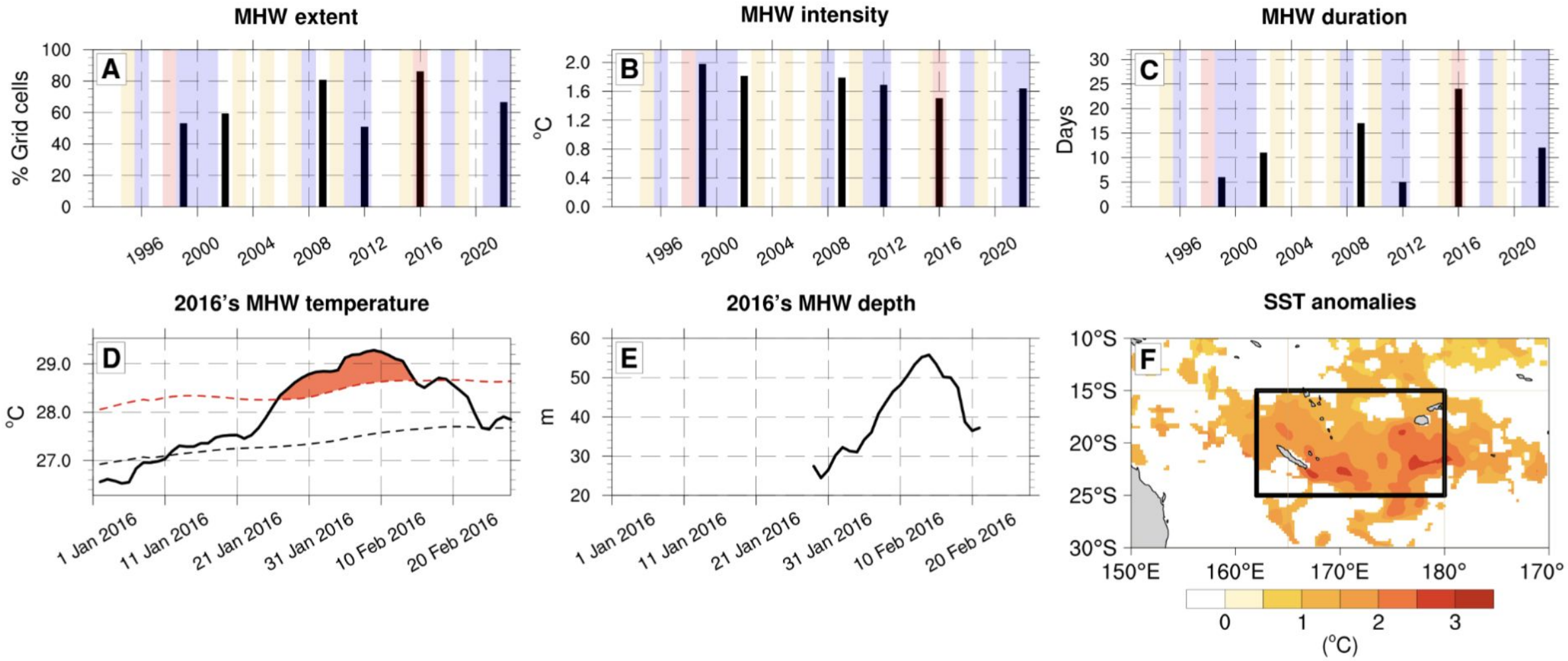


Anomaly composite

- Shaded: PW
- Vectors: U850
- Contours: vertically-integrated moisture flux divergence

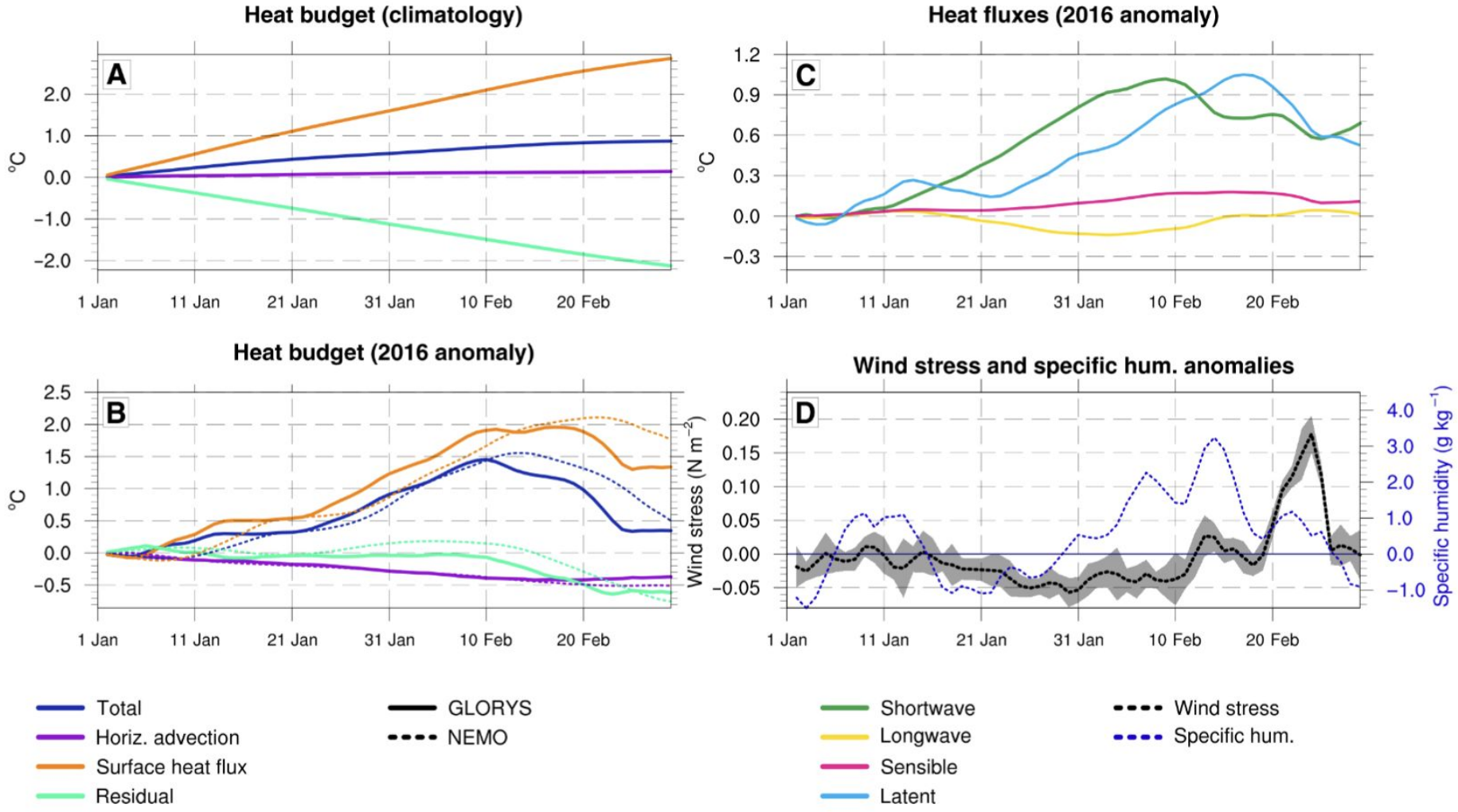
Pariyar et al. 2020

Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific



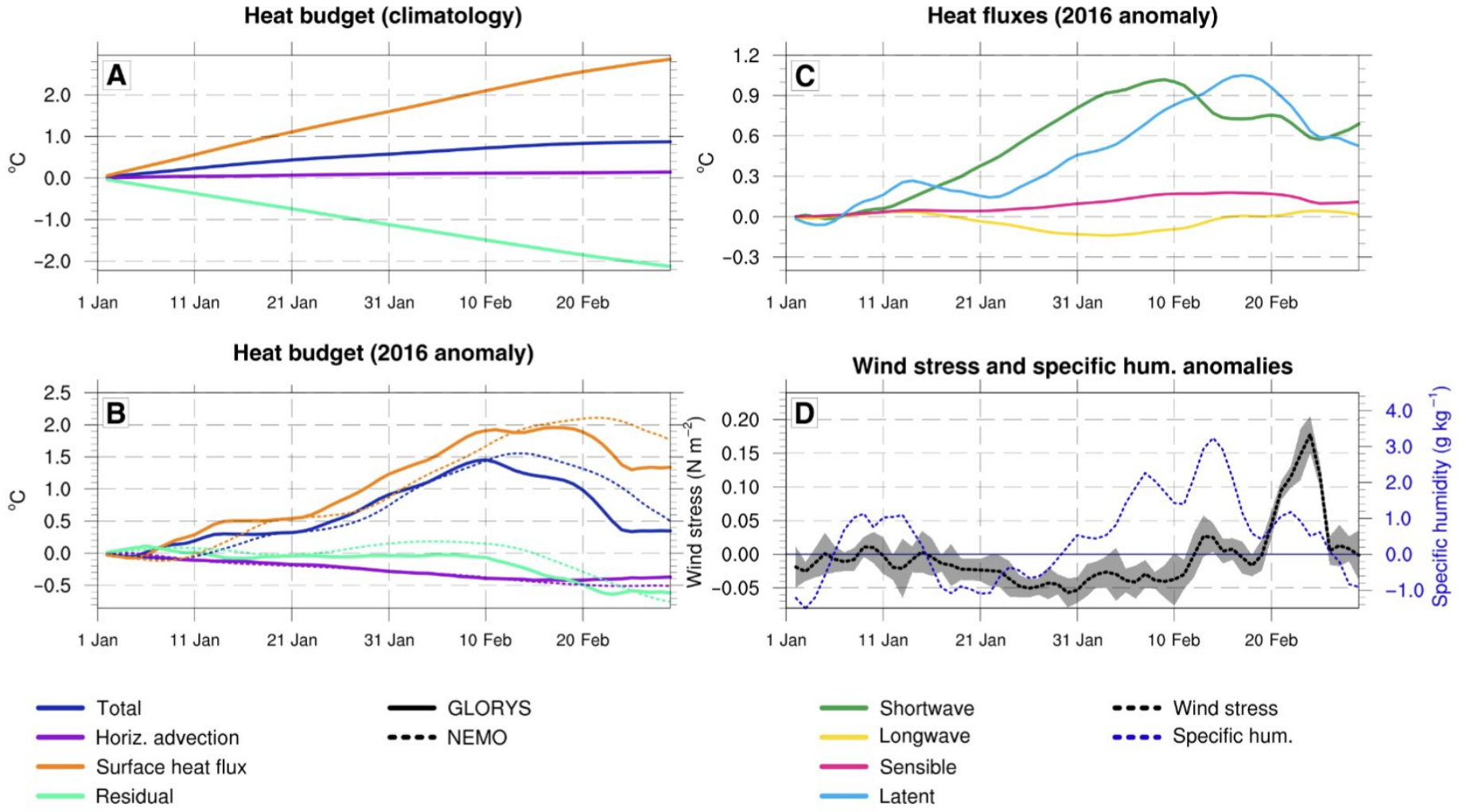
Dutheil et al. 2024

Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific



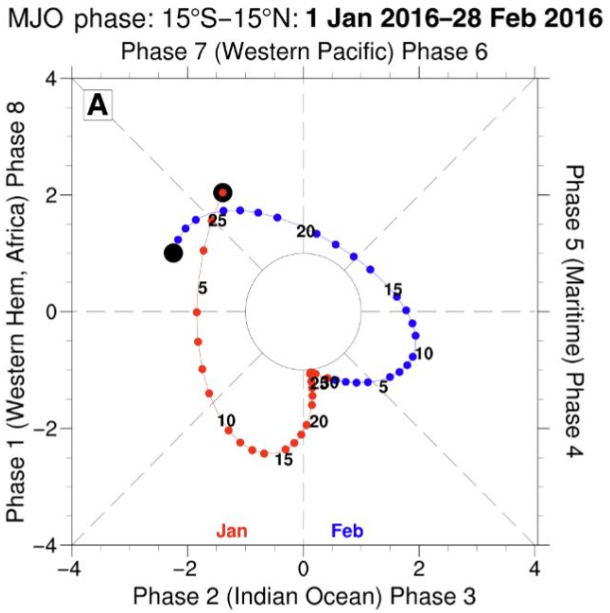
Dutheil et al. 2024

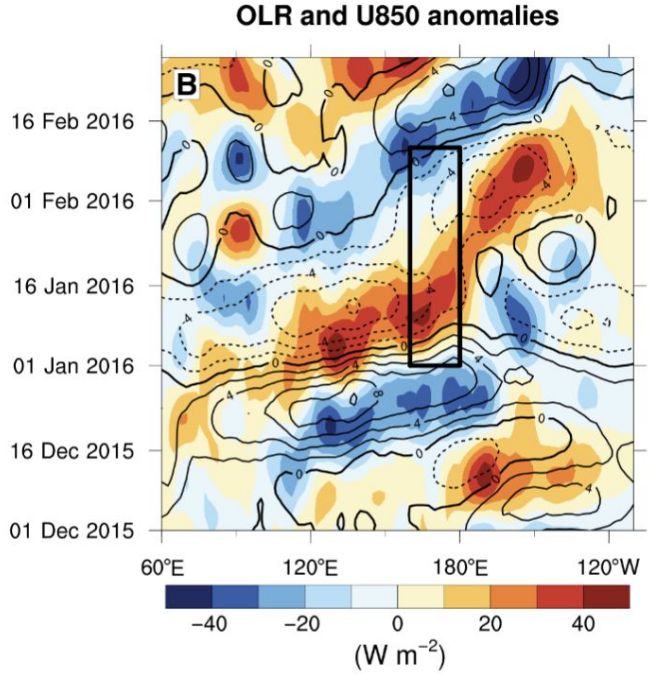
Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific

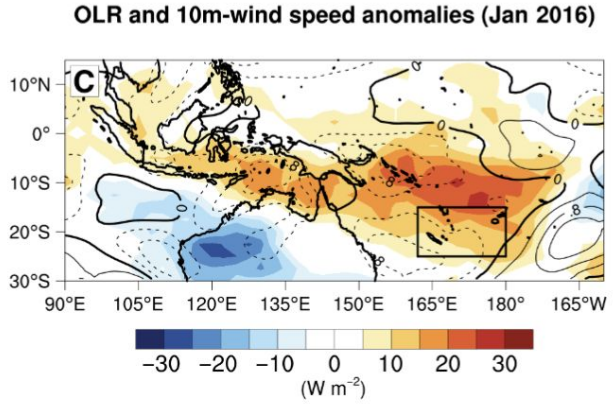


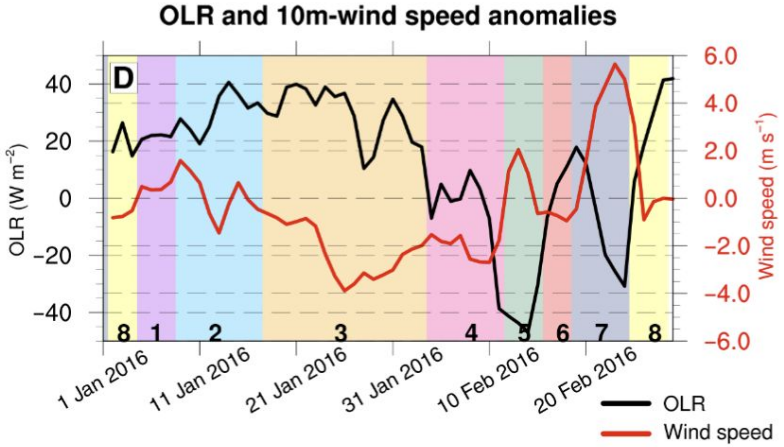
Dutheil et al. 2024

Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific



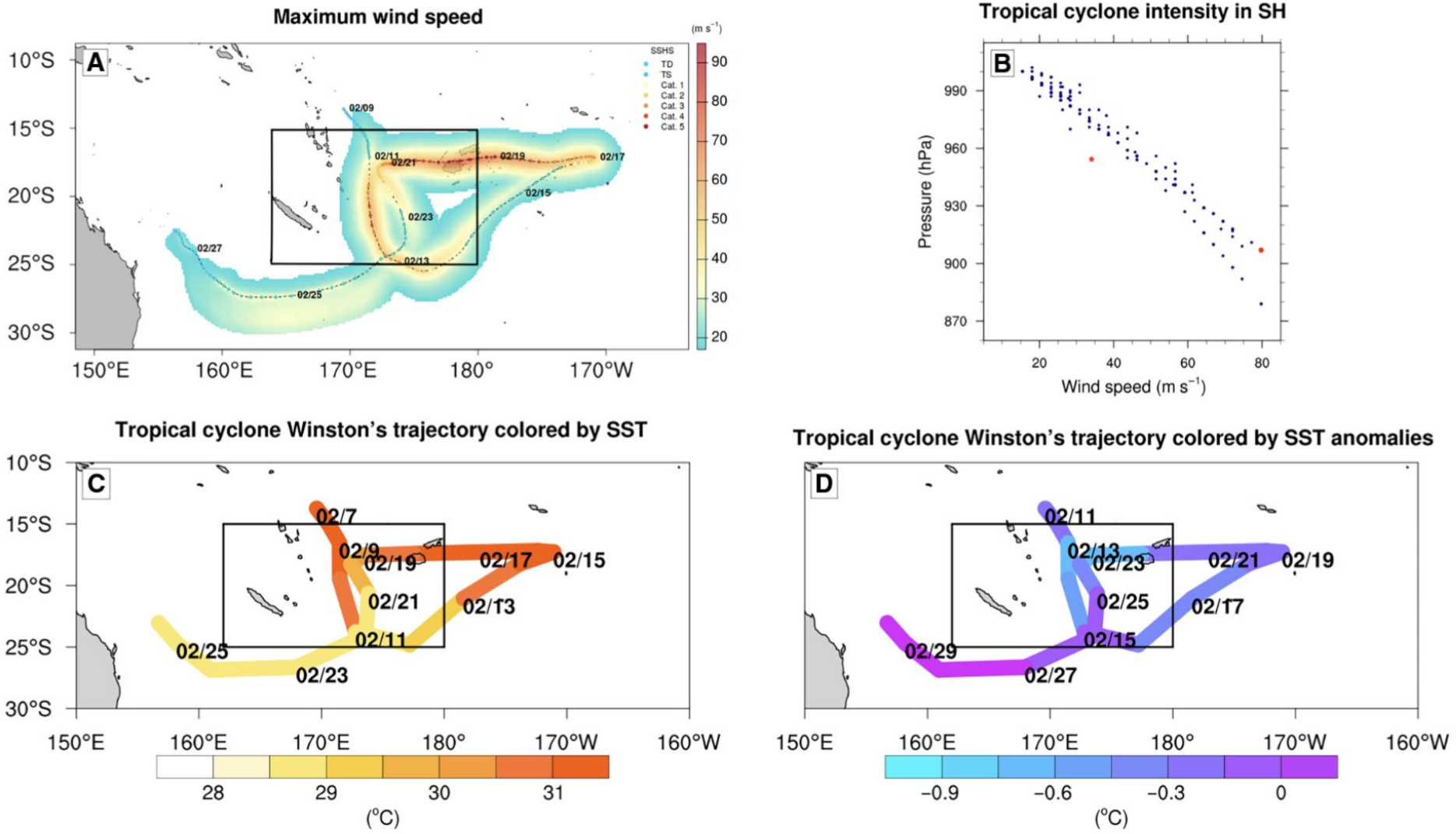






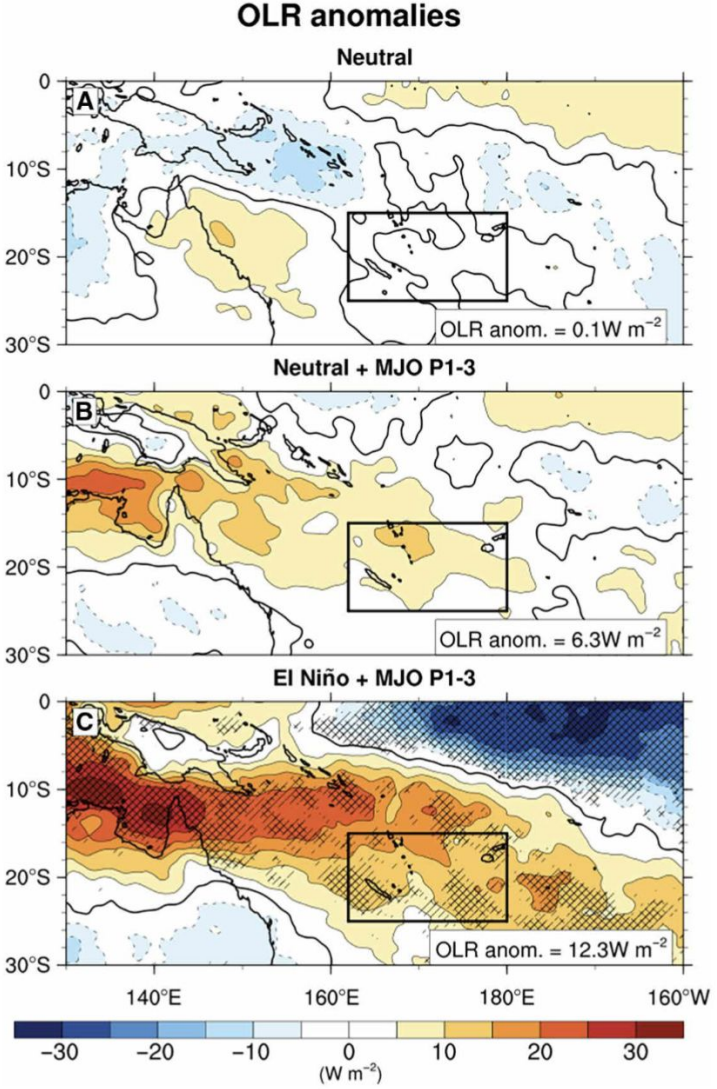
Dutheil et al. 2024

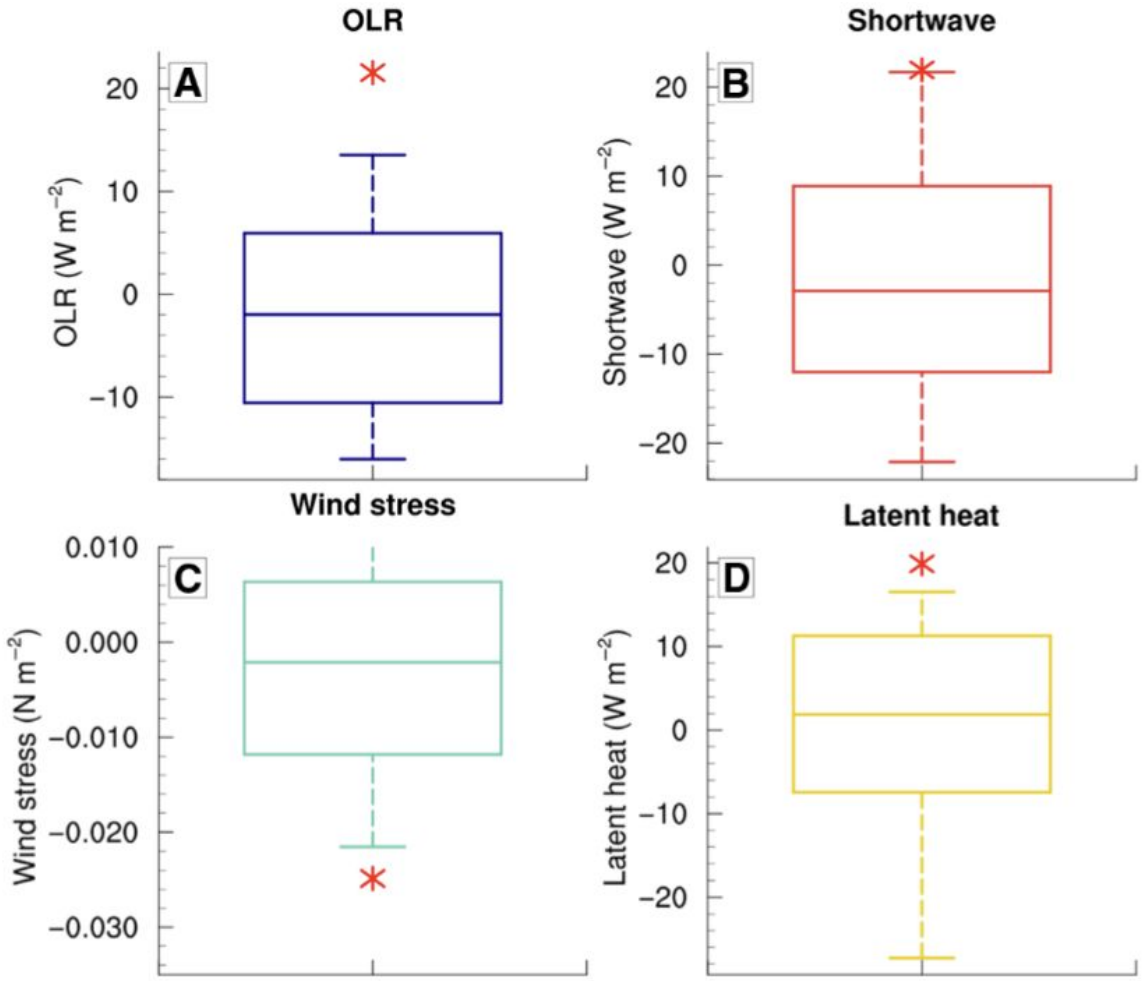
Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific



Dutheil et al. 2024

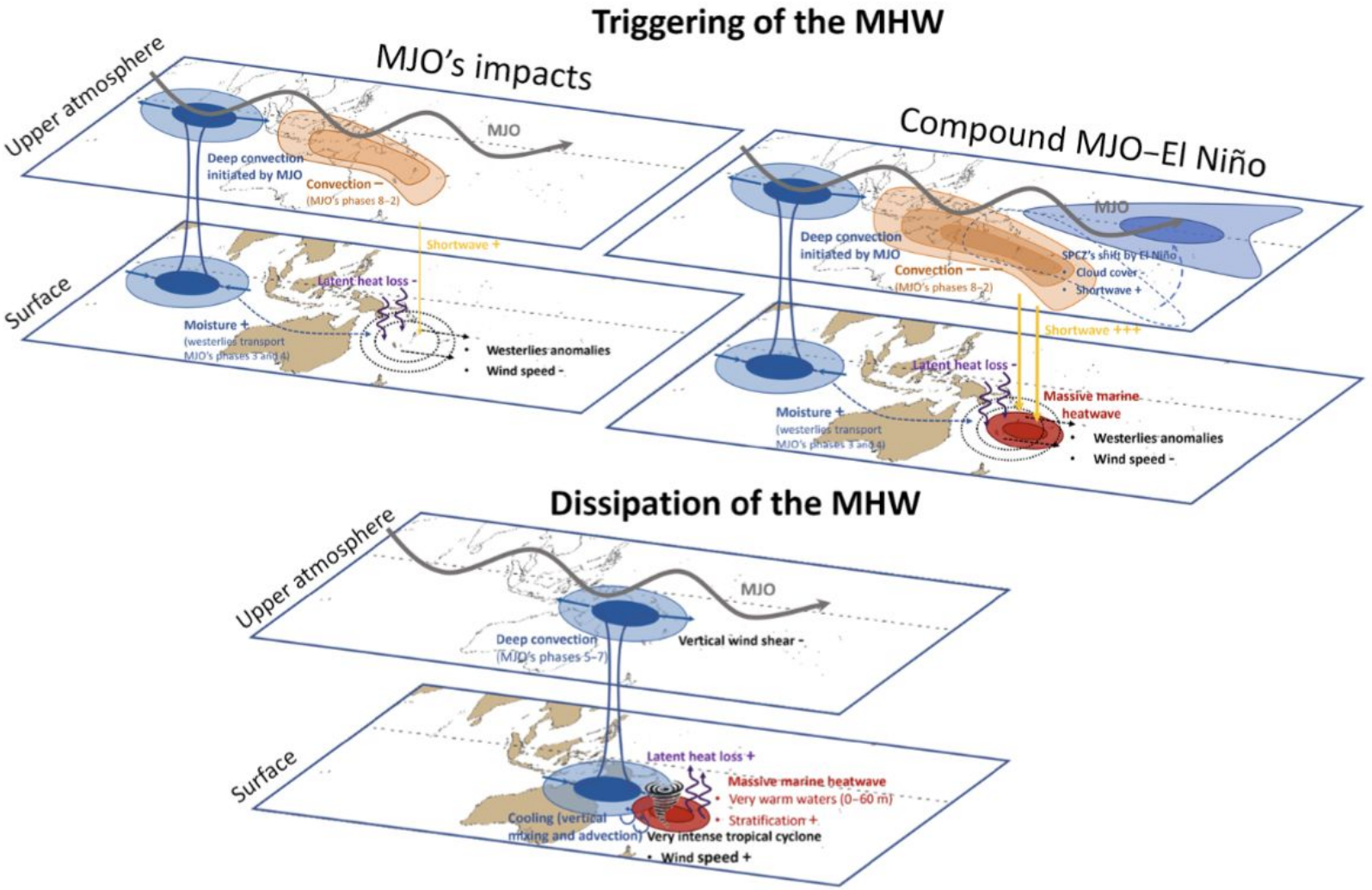
Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific





Dutheil et al. 2024

Impact of the MJO on the 2016 marine heatwave event in the southwest Pacific

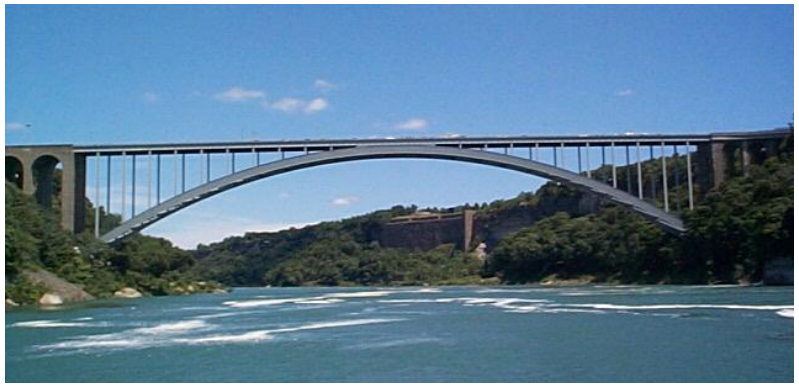


Dutheil et al. 2024

Bridging predictability gap

MJO provides the dominant source of predictability in the intraseasonal time scale

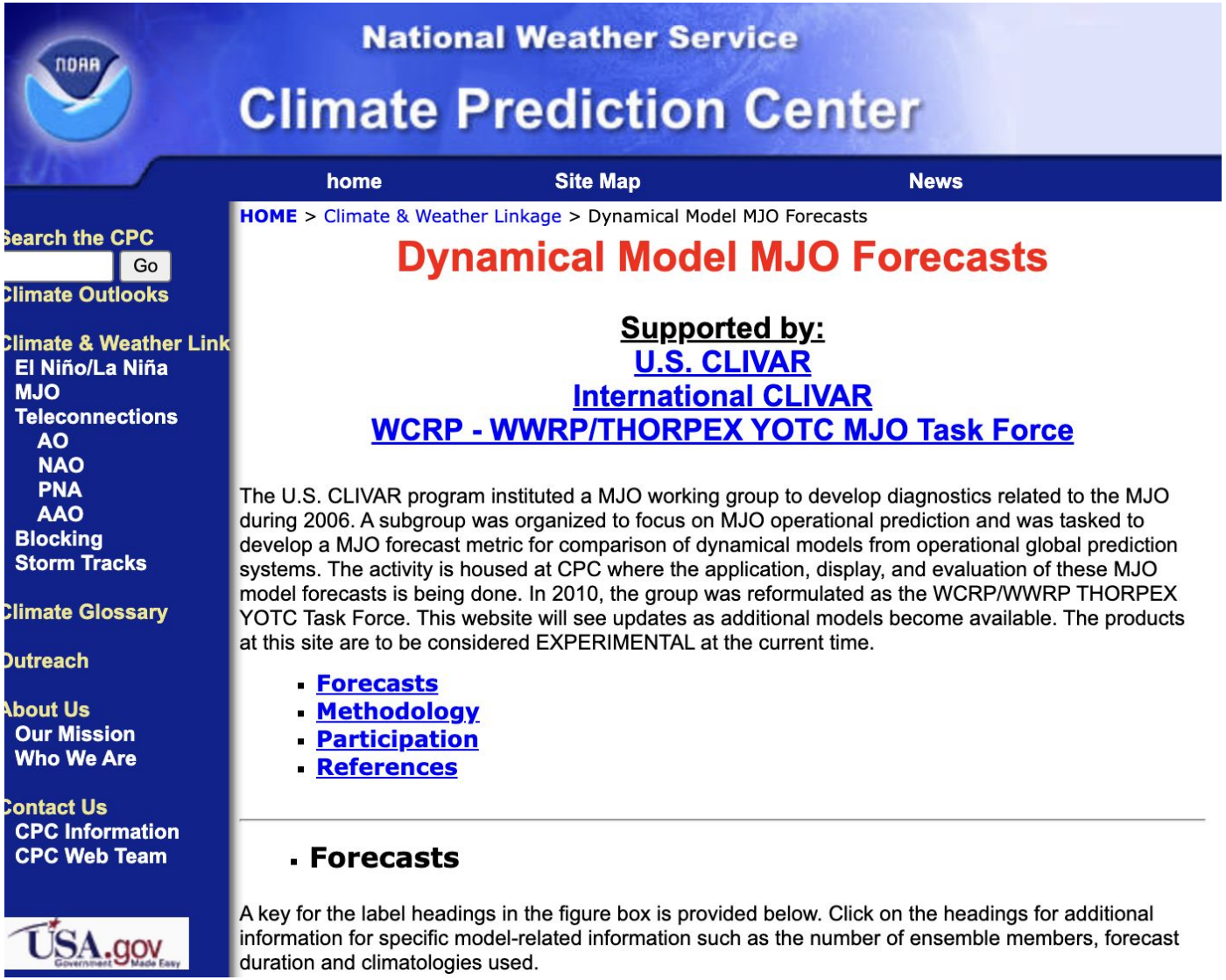
Weather forecast
(0-14 day)
- Atmospheric
initial condition



Subseasonal prediction
(2-8 weeks)
- Madden-Julian Oscillation

Seasonal prediction
(2-6 month)
- El Niño

Operational MJO forecast



National Weather Service

Climate Prediction Center

home Site Map News

Search the CPC
Go
Climate Outlooks
Climate & Weather Link
El Niño/La Niña
MJO
Teleconnections
AO
NAO
PNA
AAO
Blocking
Storm Tracks
Climate Glossary
Outreach
About Us
Our Mission
Who We Are
Contact Us
CPC Information
CPC Web Team
USA.gov

HOME > Climate & Weather Linkage > Dynamical Model MJO Forecasts

Dynamical Model MJO Forecasts

Supported by:
U.S. CLIVAR
International CLIVAR
WCRP - WWRP/THORPEX YOTC MJO Task Force

The U.S. CLIVAR program instituted a MJO working group to develop diagnostics related to the MJO during 2006. A subgroup was organized to focus on MJO operational prediction and was tasked to develop a MJO forecast metric for comparison of dynamical models from operational global prediction systems. The activity is housed at CPC where the application, display, and evaluation of these MJO model forecasts is being done. In 2010, the group was reformulated as the WCRP/WWRP THORPEX YOTC Task Force. This website will see updates as additional models become available. The products at this site are to be considered EXPERIMENTAL at the current time.

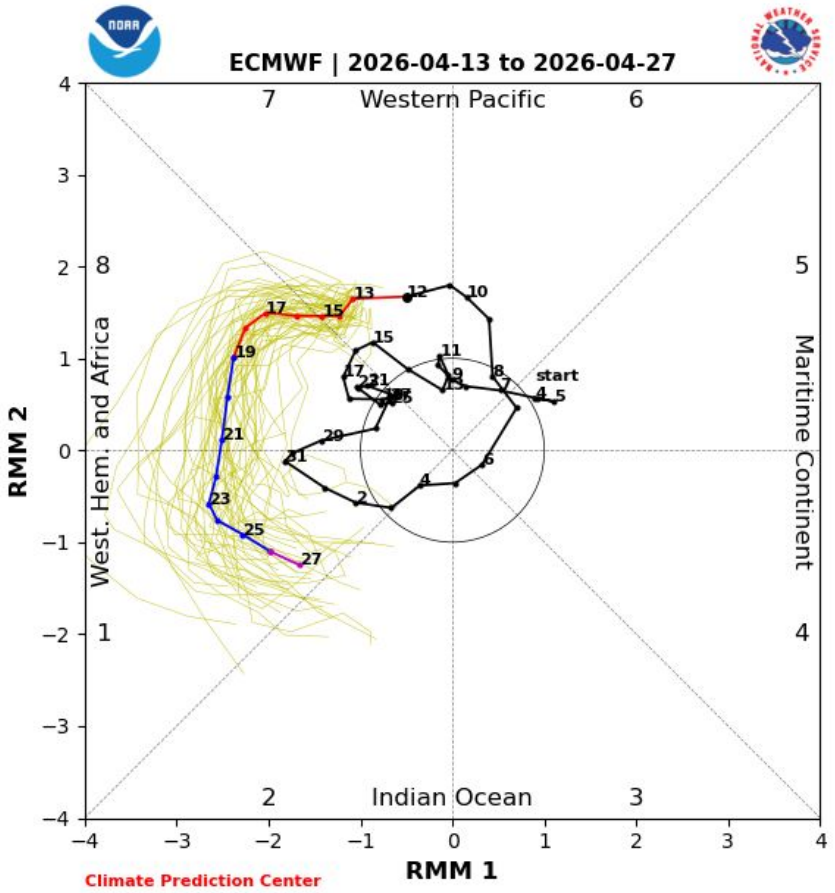
- Forecasts
- Methodology
- Participation
- References

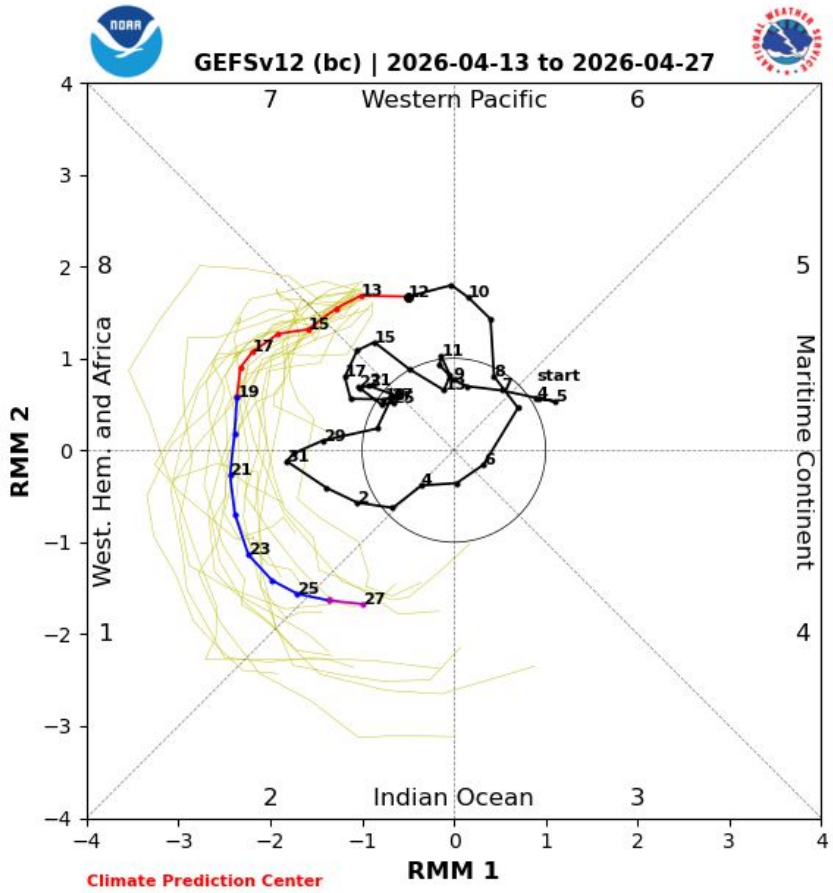
Forecasts

A key for the label headings in the figure box is provided below. Click on the headings for additional information for specific model-related information such as the number of ensemble members, forecast duration and climatologies used.

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

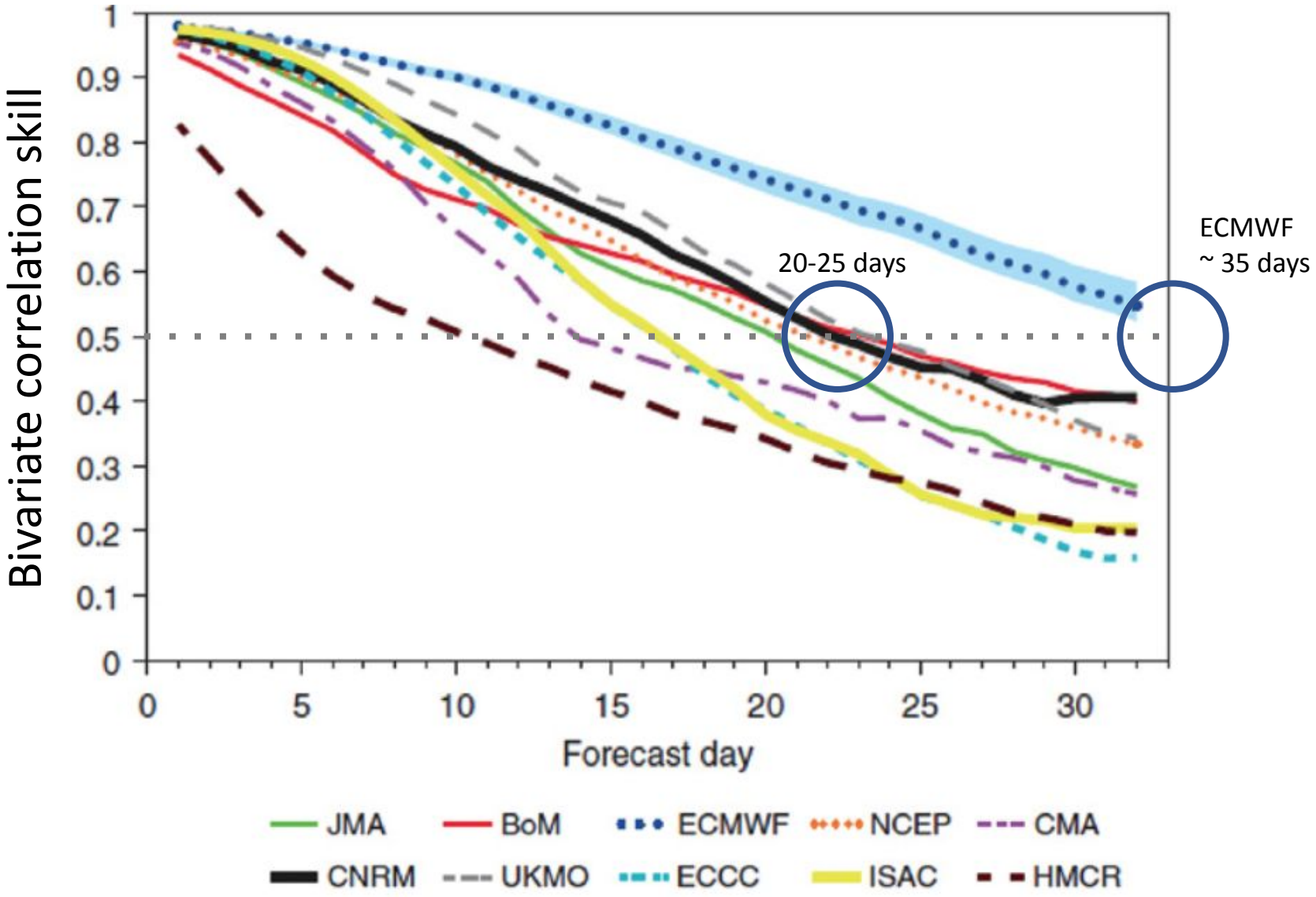
Operational MJO forecast





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

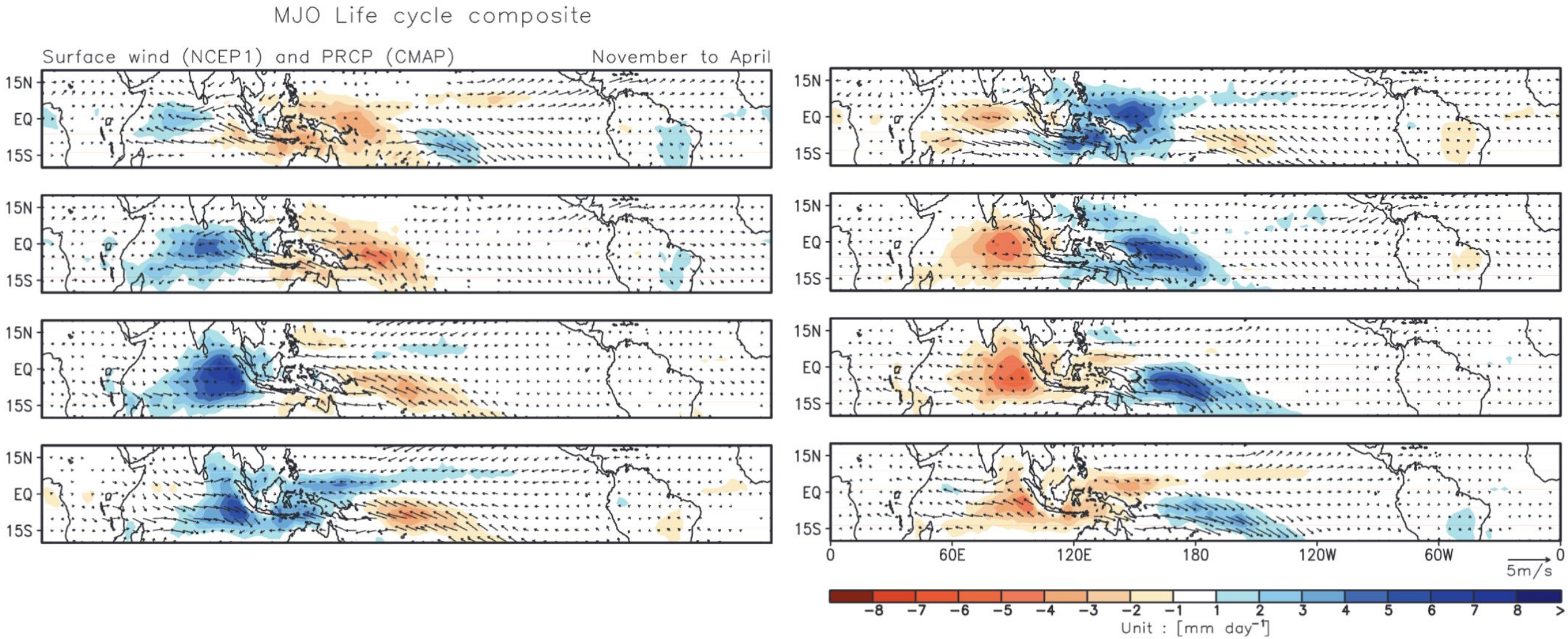
MJO prediction skill – dynamical models



Vitart et al. 2017

Summary

- The Madden-Julian oscillation (MJO) is a special type of organized convection in the tropics which is distinguished from the other convectively coupled tropical waves by its vast spatial scale, intraseasonal time scale, and slow eastward propagation.
- The MJO affects weather in the Pacific Island regions by modulating the South Pacific Convergence Zone, Tropical Cyclones, and extreme precipitation events.
- The contemporary state-of-the-art dynamical models produce skillful prediction of the Realtime Multivariate MJO (RMM) index up to 3-5 weeks.
- Operational MJO prediction combined with the statistical relationship between the MJO and weather-influencing phenomena can be used to provide the communities in the Pacific Island region with subseasonal outlook of future weather.


MJO Life cycle composite
Surface wind (NCEP1) and PRCP (CMAP)
November to April
15N
EQ
15S
0
60E
120E
180
120W
60W
0
5m/s
−8 −7 −6 −5 −4 −3 −2 −1 1 2 3 4 5 6 7 8 >
Unit : [mm day⁻¹]