Fueling the 2020-2023 La Niña - The Role of Cross-timescale Interference between the Indian Ocean Dipole and the Madden-Julian Oscillation

Laurel DiSera

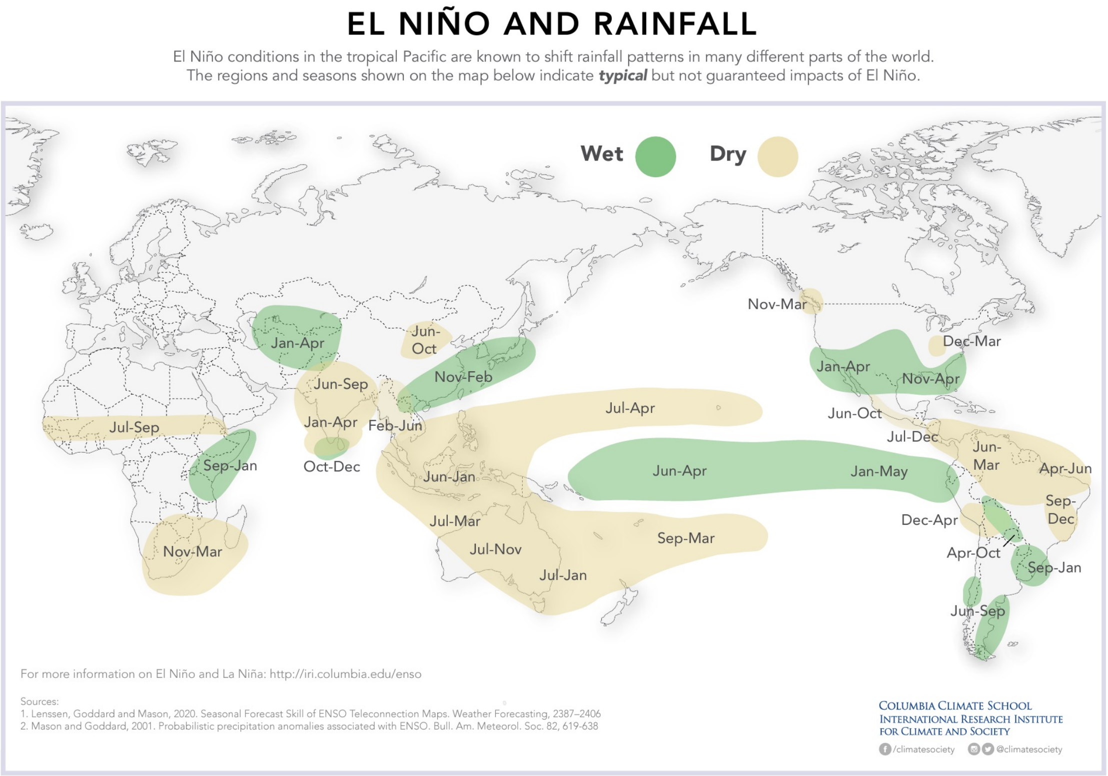
ICTP Seminar: Feb 10, 2026

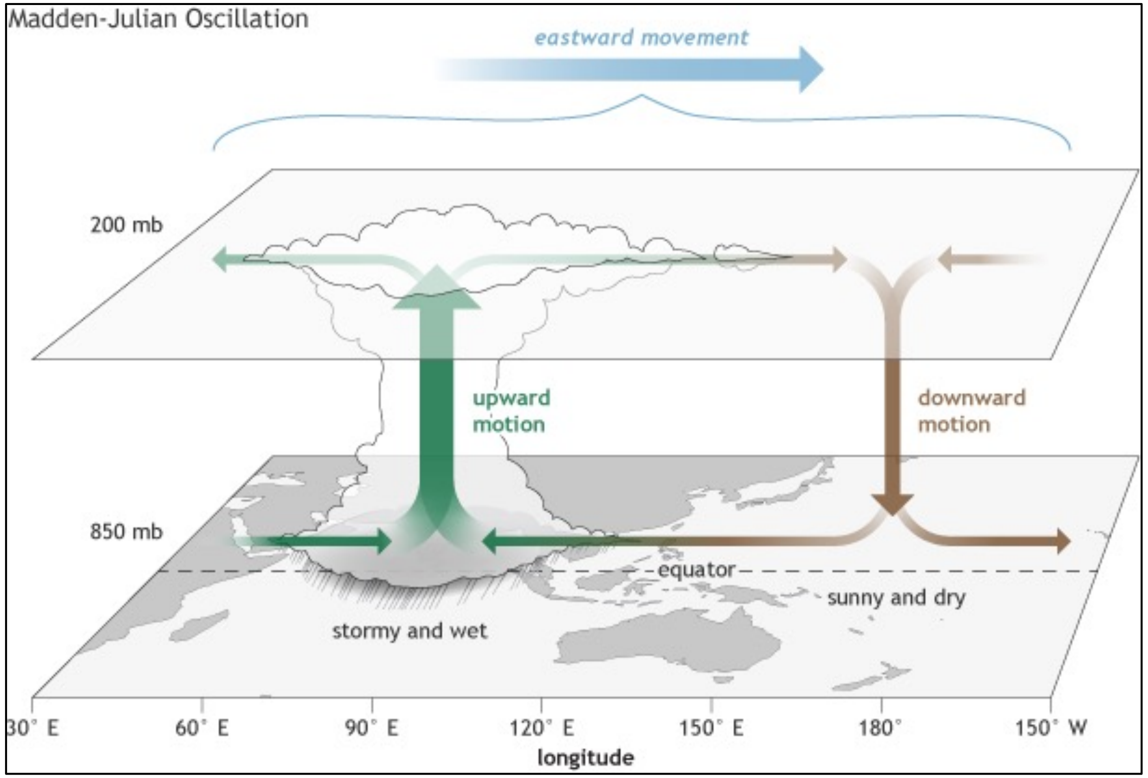
Collaborators: Ángel Muñoz & Eric Maloney

International Research Institute for Climate and Society
Earth Institute | Columbia University
Colorado State University
BSC

What is cross-timescale interference??

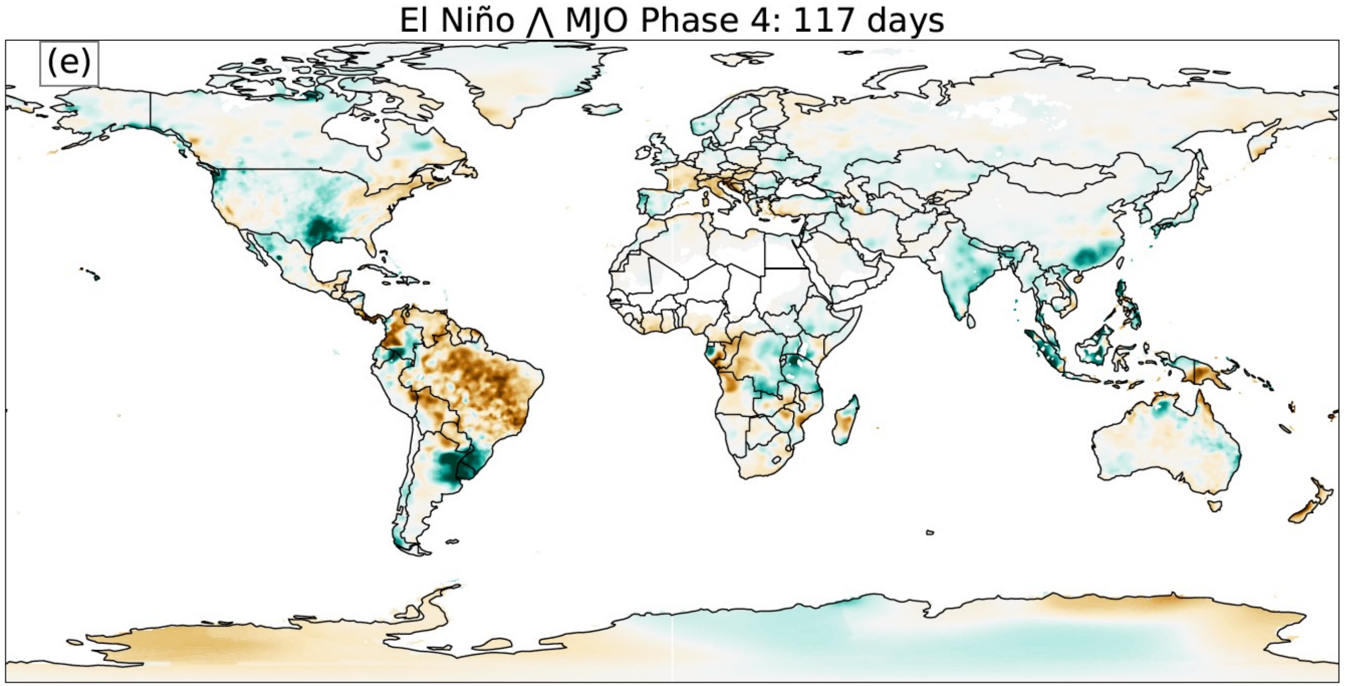
- The linear or non-linear interactions between climate drivers, acting at different or the same timescales (Muñoz et al., 2015, 2016)





Types of cross-timescale interference:

1) Coordinated Interaction/Interference



Hellzapoppin' (1941)
Frances "Mickey" Jones and William Downes

Types of cross-timescale interference:

1) Coordinated Interaction/Interference

Hellzapoppin' (1941)
Frances "Mickey" Jones and William Downes

2) Isolated Interference

Types of cross-timescale interference:

1) Coordinated Interaction/Interference

Hellzapoppin' (1941)
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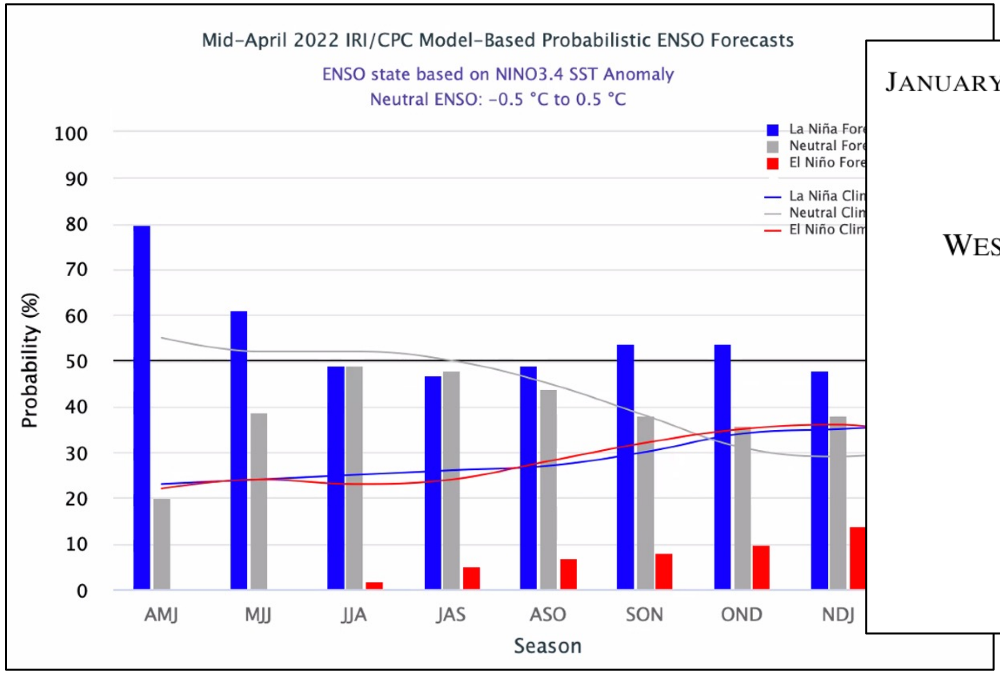
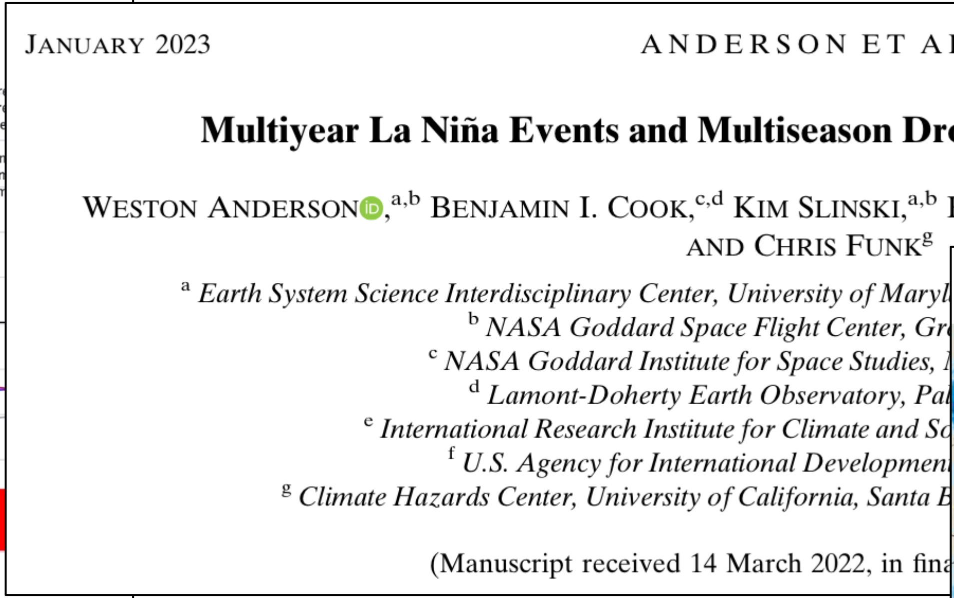
2) Isolated Interference



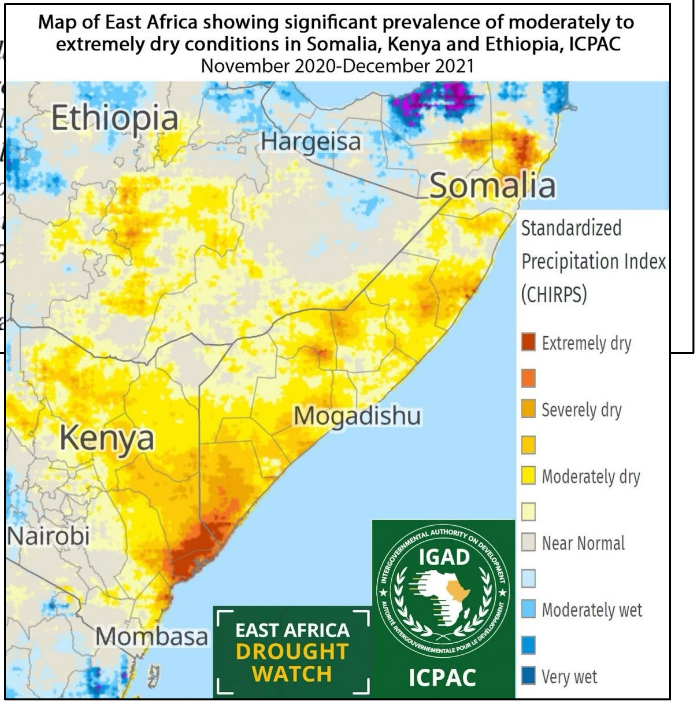

January 2023 ANDERSON ET AL. 119

Multiyear La Niña Events and Multiseason Drought in the Horn of Africa

Weston Anderson,[a,b] Benjamin I. Cook,[c,d] Kim Slinski,[a,b] Kevin Schwarzwald,[e] Amy McNally,[b,f] and Chris Funk[g]

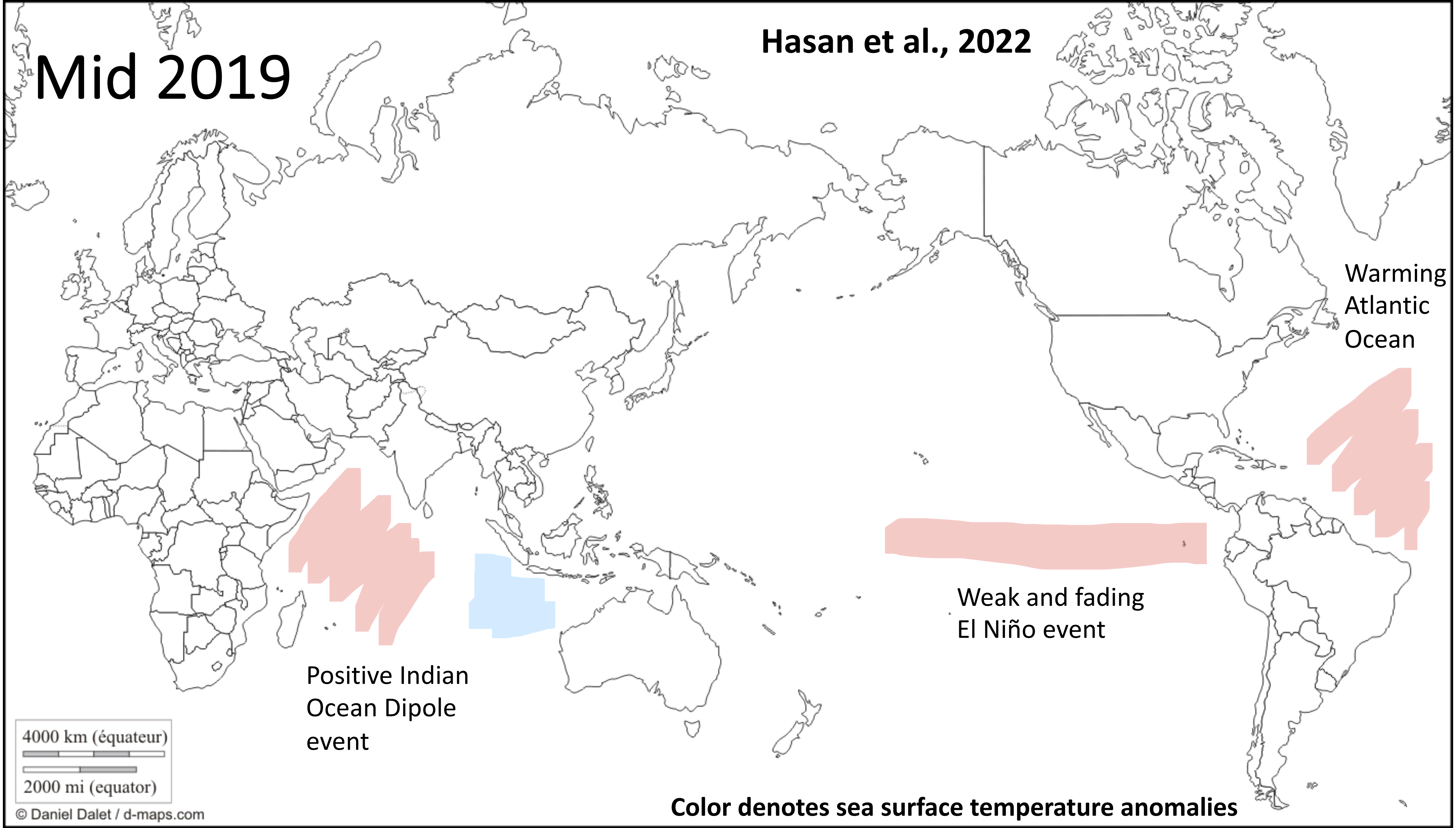
[a] *Earth System Science Interdisciplinary Center, University of Maryl*
[b] *NASA Goddard Space Flight Center, Gr*
[c] *NASA Goddard Institute for Space Studies,*
[d] *Lamont-Doherty Earth Observatory, Pal*
[e] *International Research Institute for Climate and Sc*
[f] *U.S. Agency for International Developmen*
[g] *Climate Hazards Center, University of California, Santa B*

(Manuscript received 14 March 2022, in fina

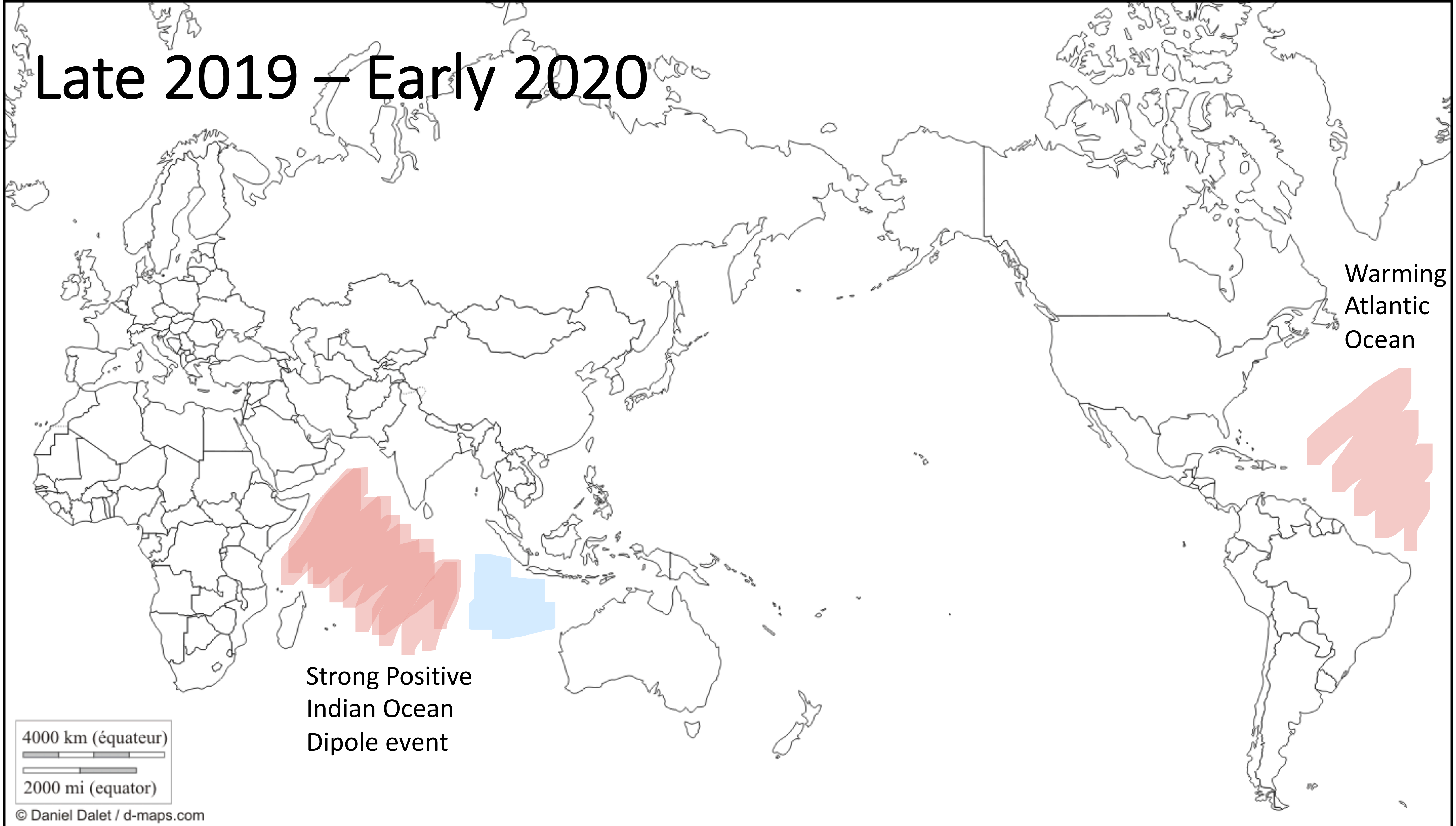


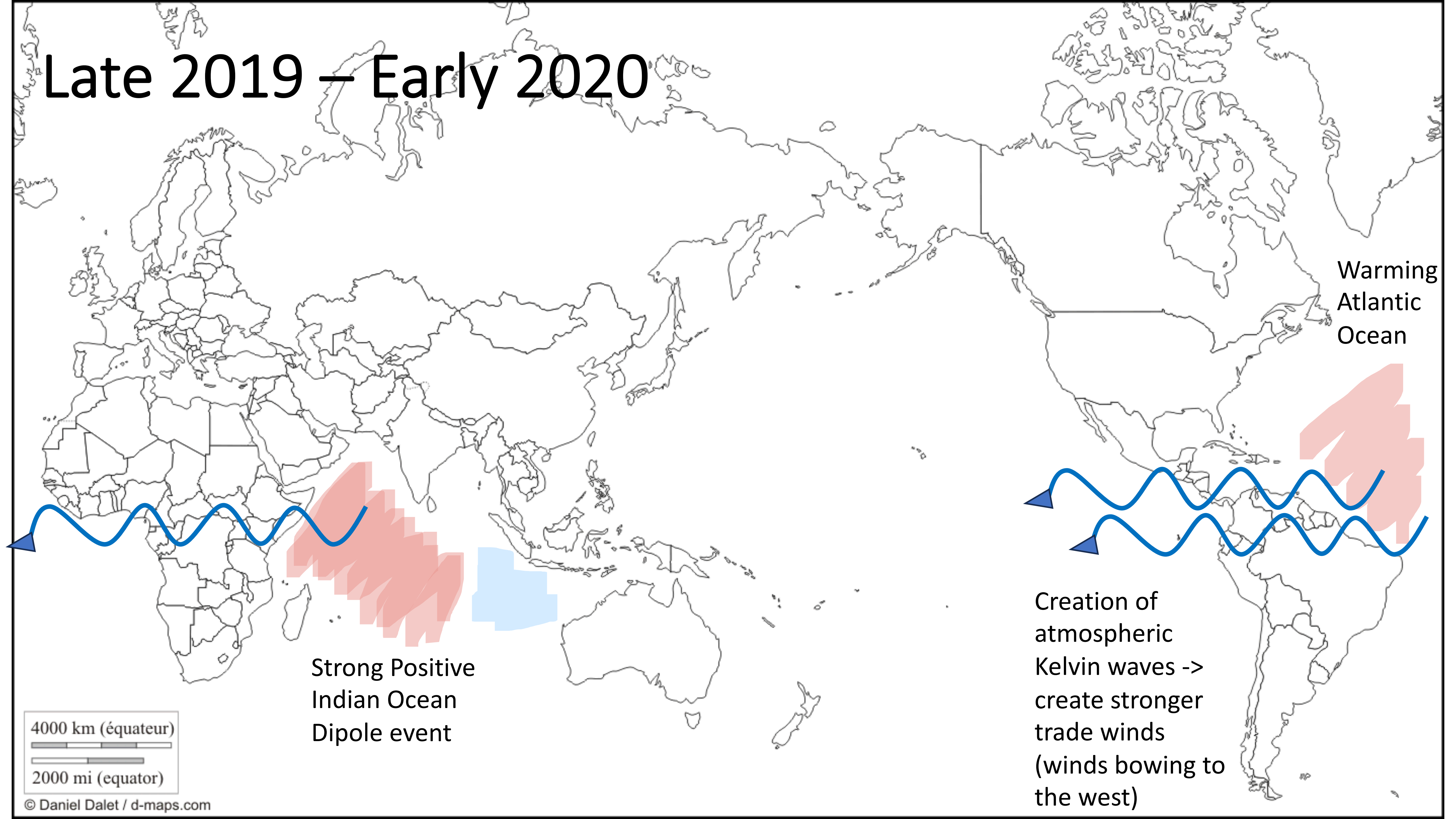
ABC10, CA

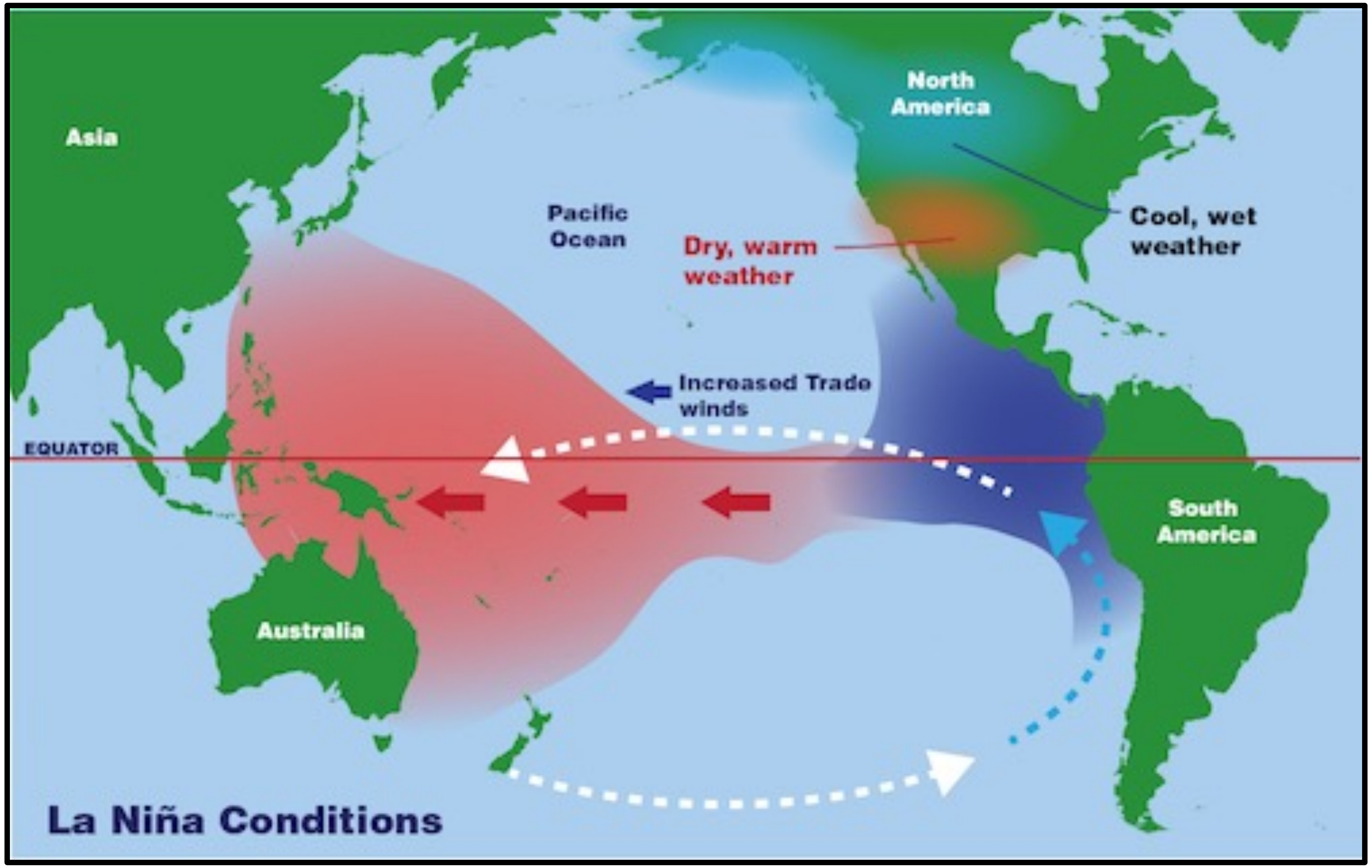
The 2020-2023 La Niña


Mid 2019
Hasan et al., 2022
Warming Atlantic Ocean
Weak and fading El Niño event
Positive Indian Ocean Dipole event
4000 km (équateur)
2000 mi (equator)
© Daniel Dalet / d-maps.com
Color denotes sea surface temperature anomalies

Late 2019 – Early 2020

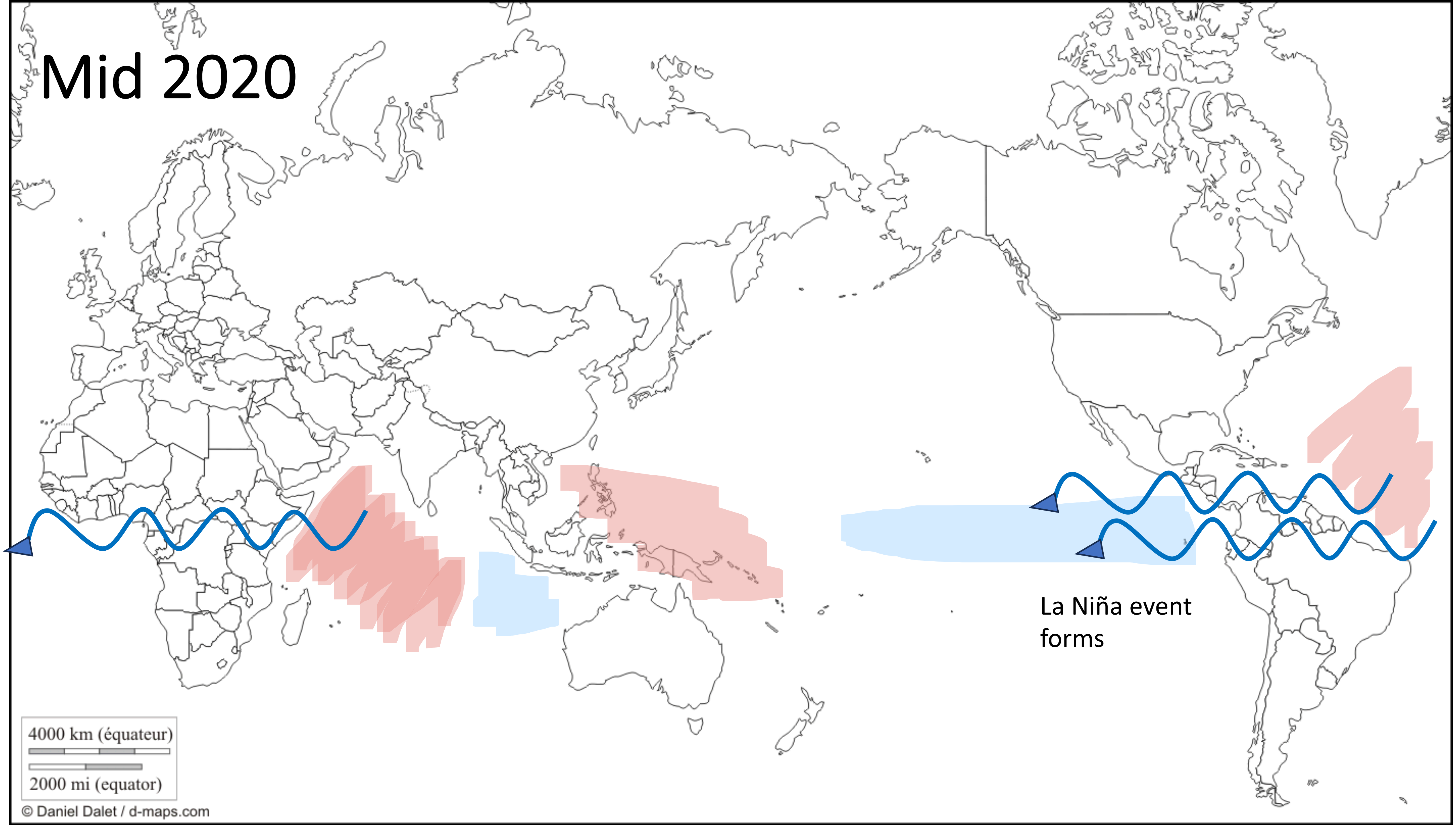



Late 2019 – Early 2020
Warming Atlantic Ocean
Strong Positive Indian Ocean Dipole event
Creation of atmospheric Kelvin waves -> create stronger trade winds (winds bowing to the west)
4000 km (équateur)
2000 mi (equator)
© Daniel Dalet / d-maps.com

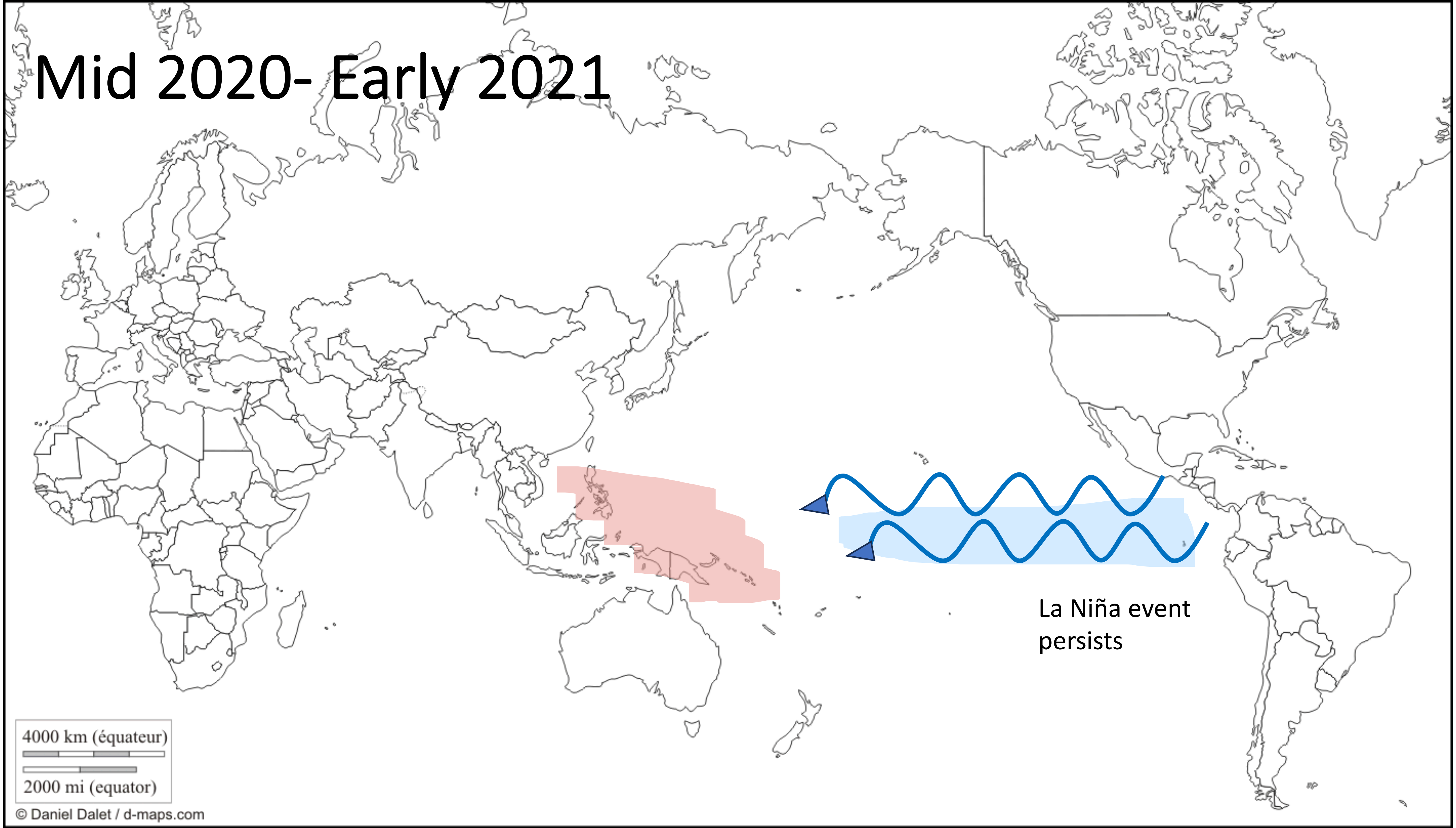

North America
Asia
Pacific Ocean
Dry, warm weather
Cool, wet weather
Increased Trade winds
EQUATOR
South America
Australia
La Niña Conditions

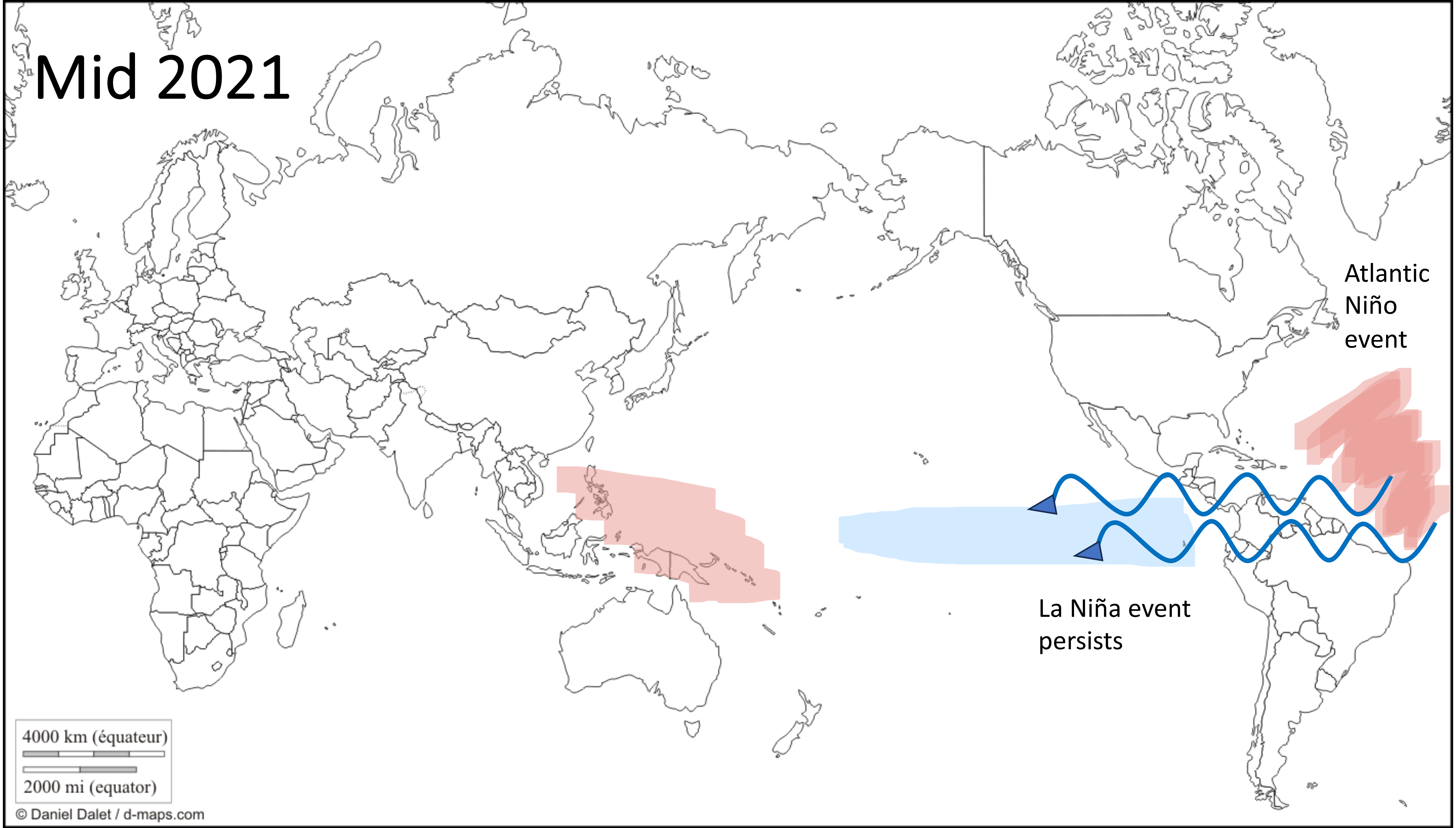
NOAA

Mid 2020


La Niña event forms
4000 km (équateur)
2000 mi (equator)
© Daniel Dalet / d-maps.com

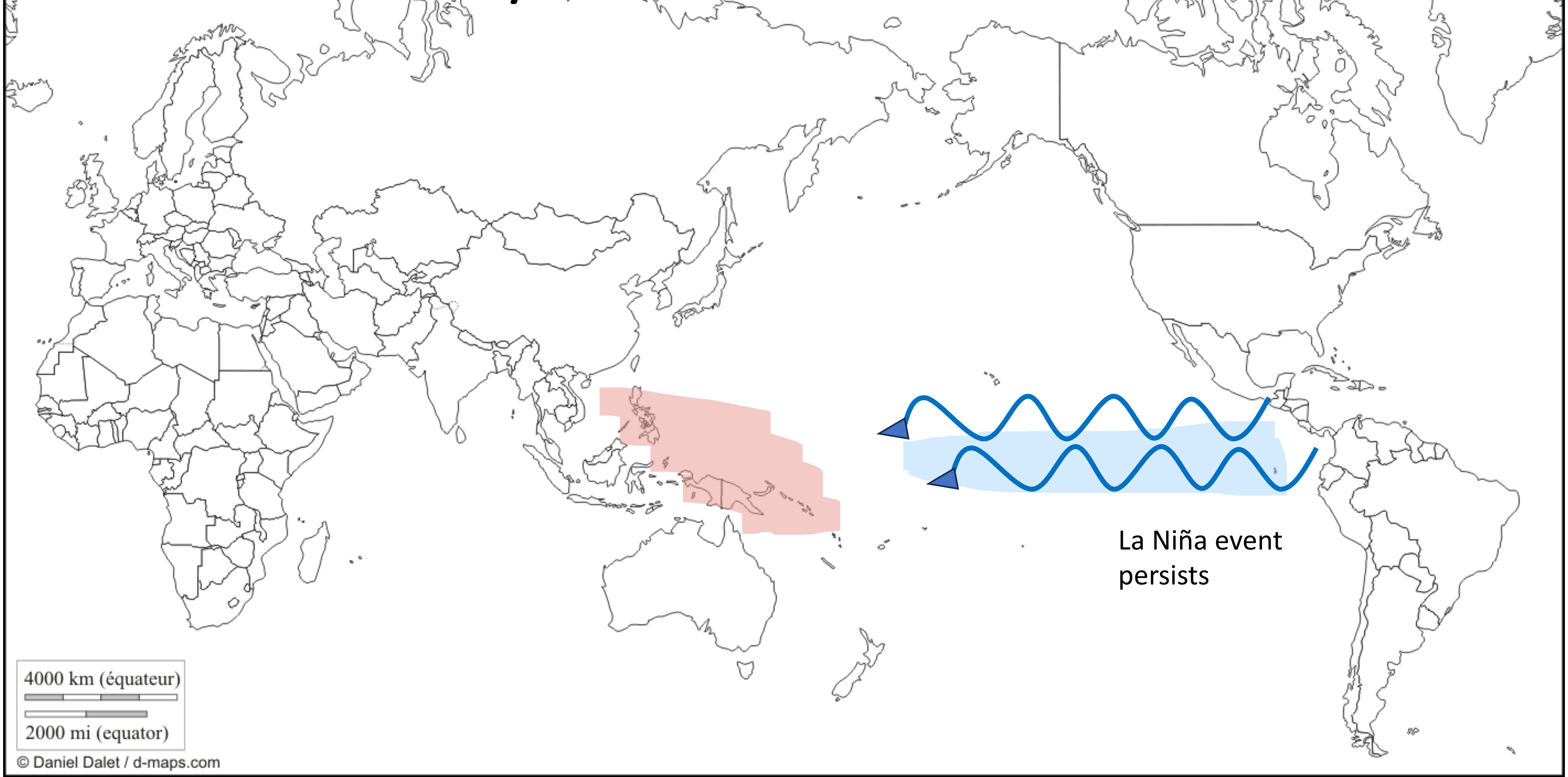
Mid 2020- Early 2021





Mid 2021
Atlantic Niño event
La Niña event persists
4000 km (équateur)
2000 mi (equator)
© Daniel Dalet / d-maps.com

Late 2021 – Early 2023



What caused the 2020-2022 LN event?

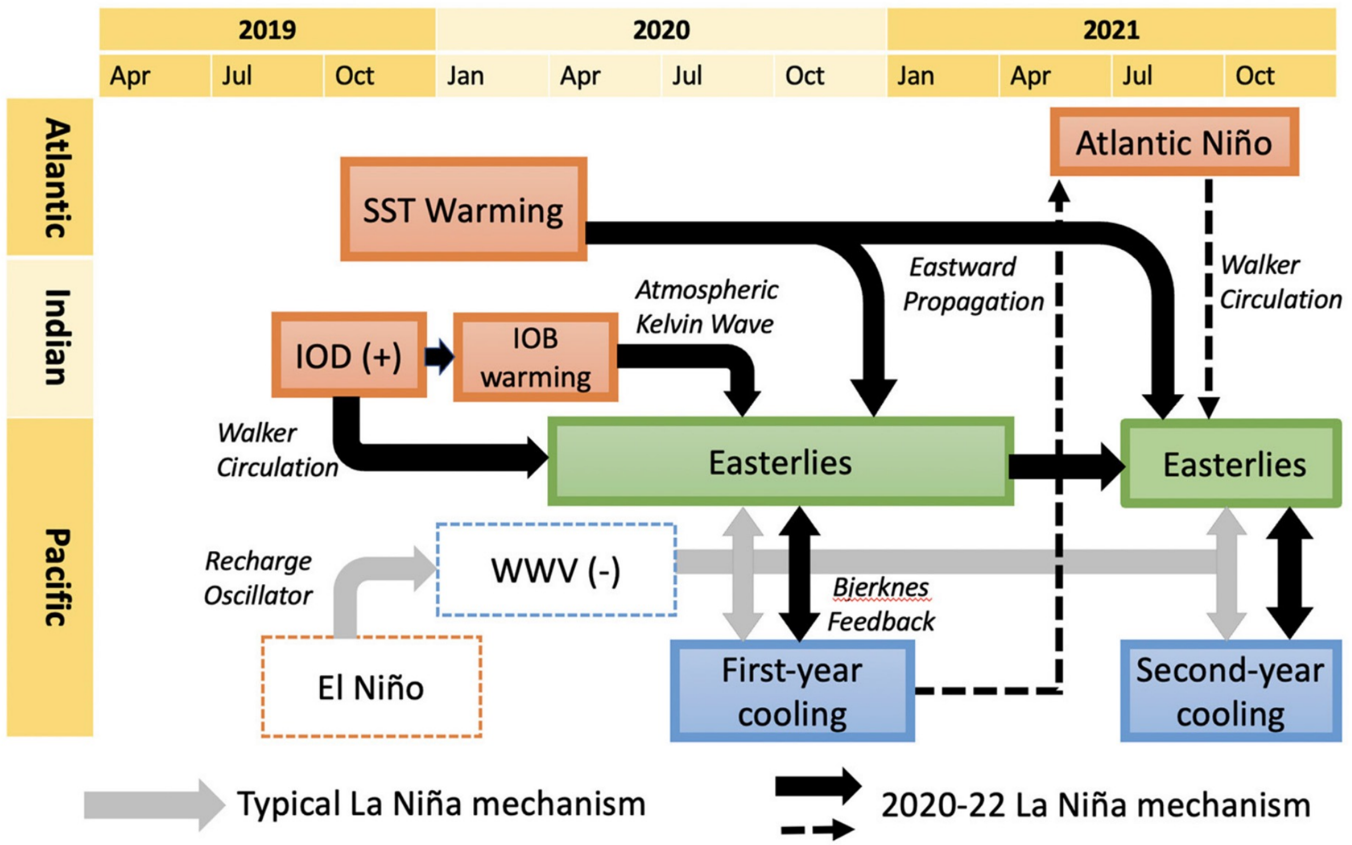
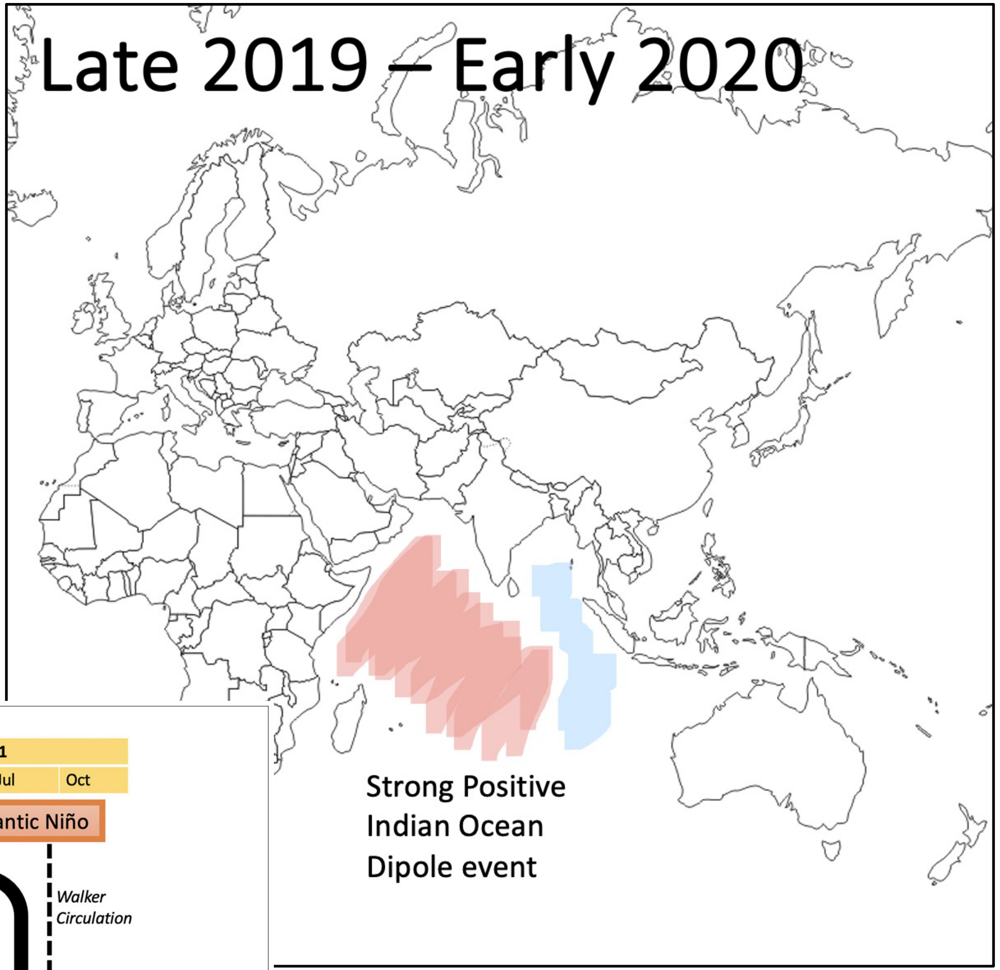


FIGURE 6
Schematic representation of the energizing and persistent processes of 2020–2022 La Niña in comparison to typical double-dip La Niña events. Solid grey arrow represents typical La Niña mechanism whereas the solid and dashed black arrow represent 2020–2022 La Niña mechanism.

Hasan et al., 2022

Research Questions

1. What caused the Indian Ocean Dipole (IOD) event to form?
2. Was cross-timescale interference involved?



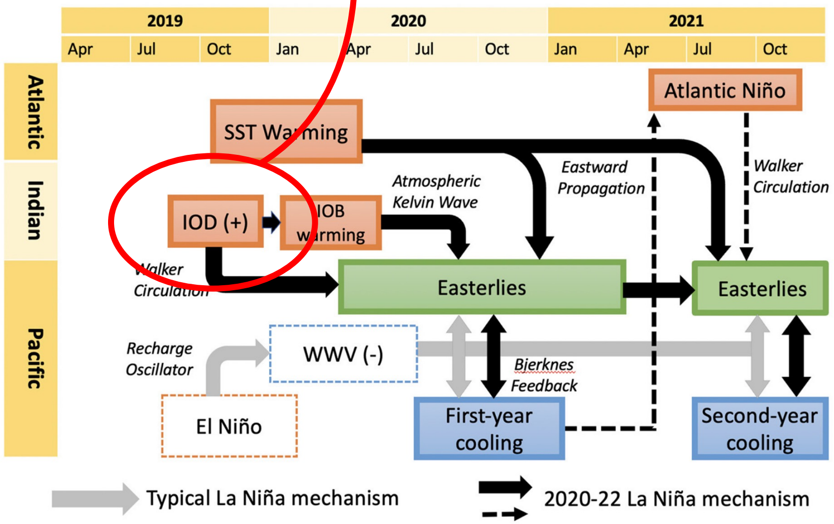
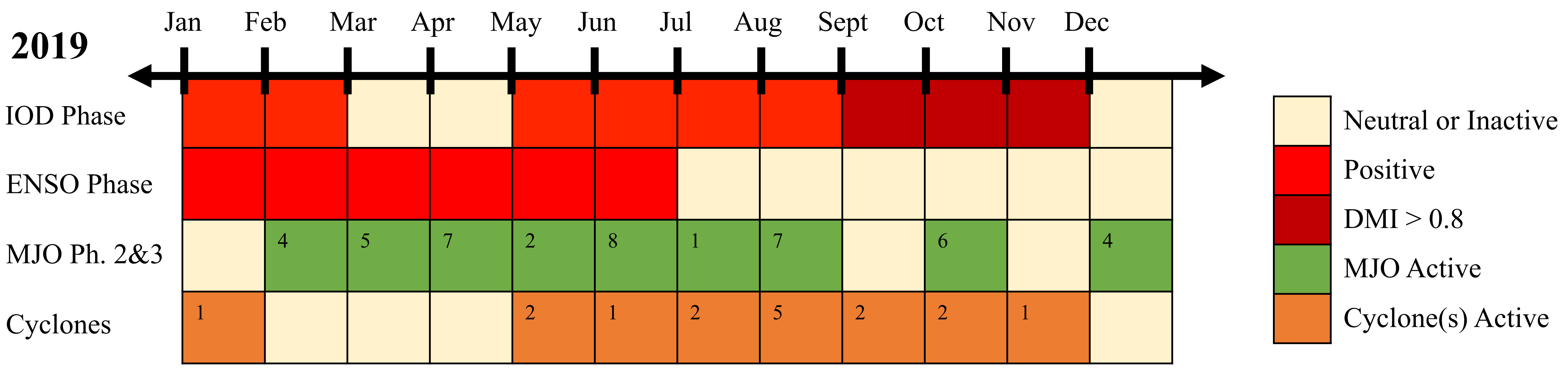


FIGURE 6
Schematic representation of the energizing and persistent processes of 2020–2022 La Niña in comparison to typical double-dip La Niña events. Solid grey arrow represents typical La Niña mechanism whereas the solid and dashed black arrow represent 2020–2022 La Niña mechanism.

Some prospects of Indian Ocean Dipole triggering/interaction:

- El Niño Southern Oscillation (e.g., Crétat et al., 2017)
- Indian Summer Monsoon (e.g., Meehl et al. 2003; Drbohlav et al. 2007; Sun et al. 2015)
- Boreal spring convection over Indonesia and the western Pacific (e.g., Kajikawa et al. 2003; Hendon 2003)
- **Madden-Julian Oscillation (MJO)**
  - Rao et al. (2008): Suppressed MJO -> Rossby wave -> strong eastward blowing low-level wind -> upwelling oceanic Kelvin waves -> shoaling the thermocline -> driving the positive IOD event
    - However, we see a convective MJO over the Indian Ocean in 2019

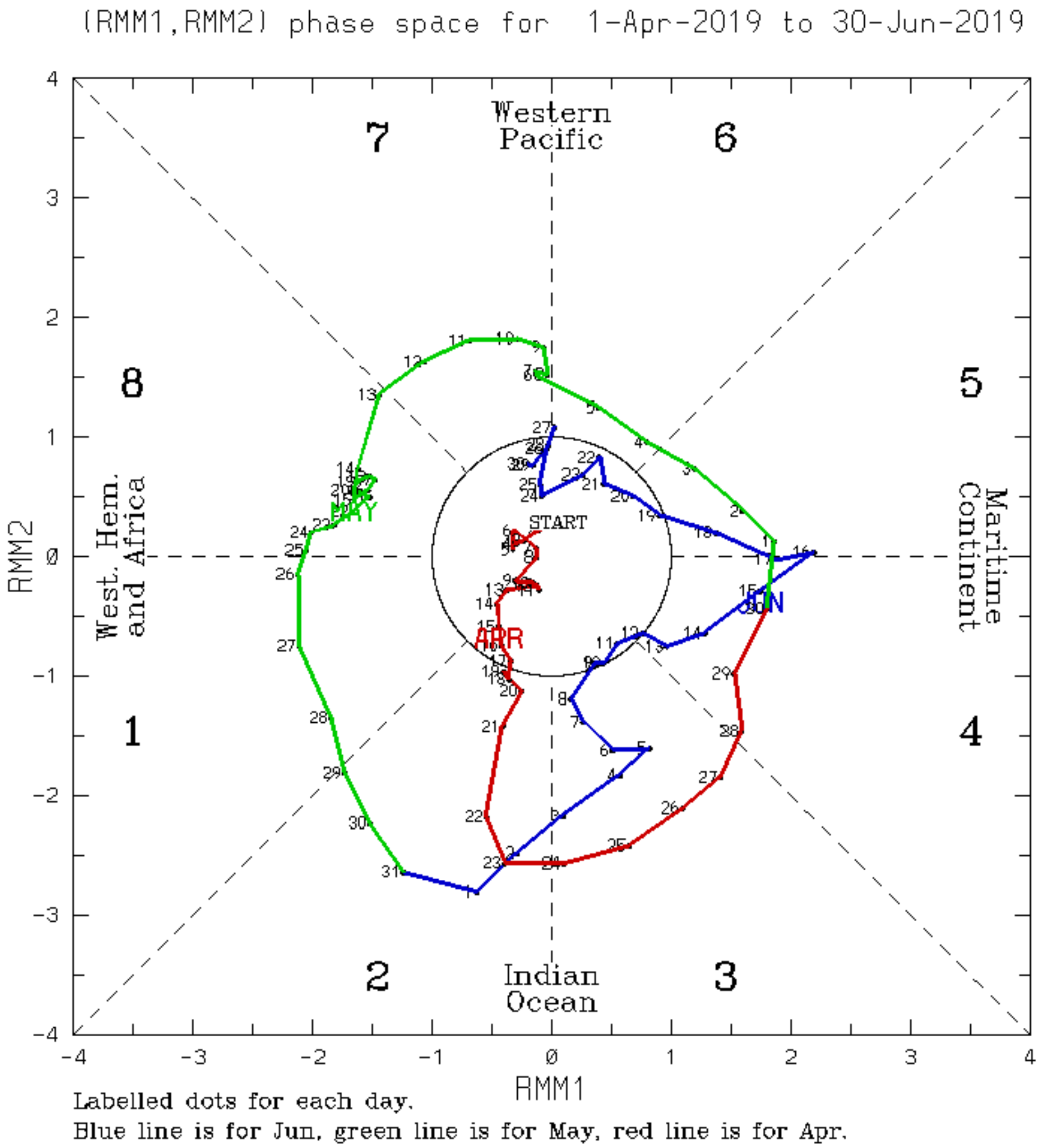
What did we see in 2019?

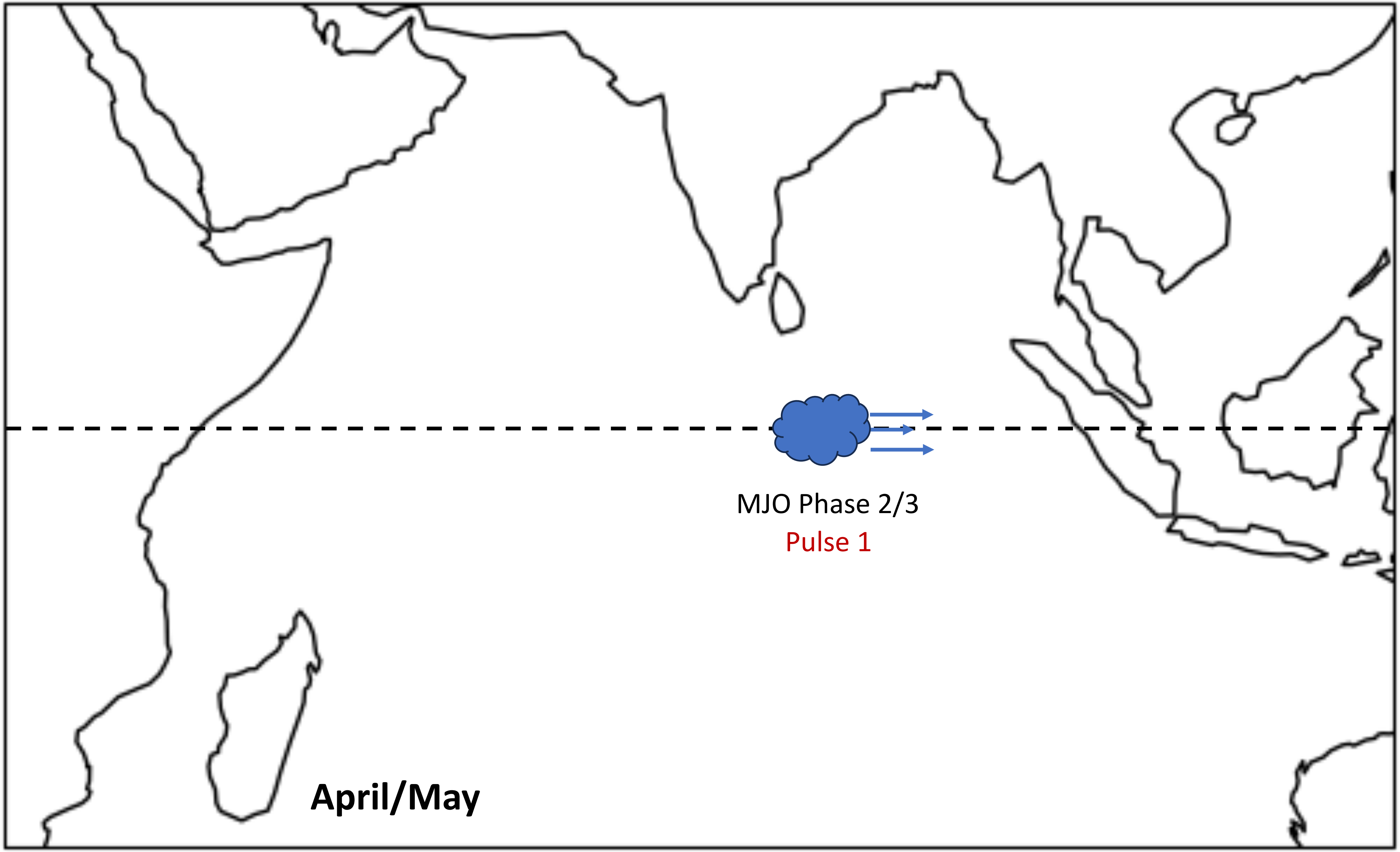


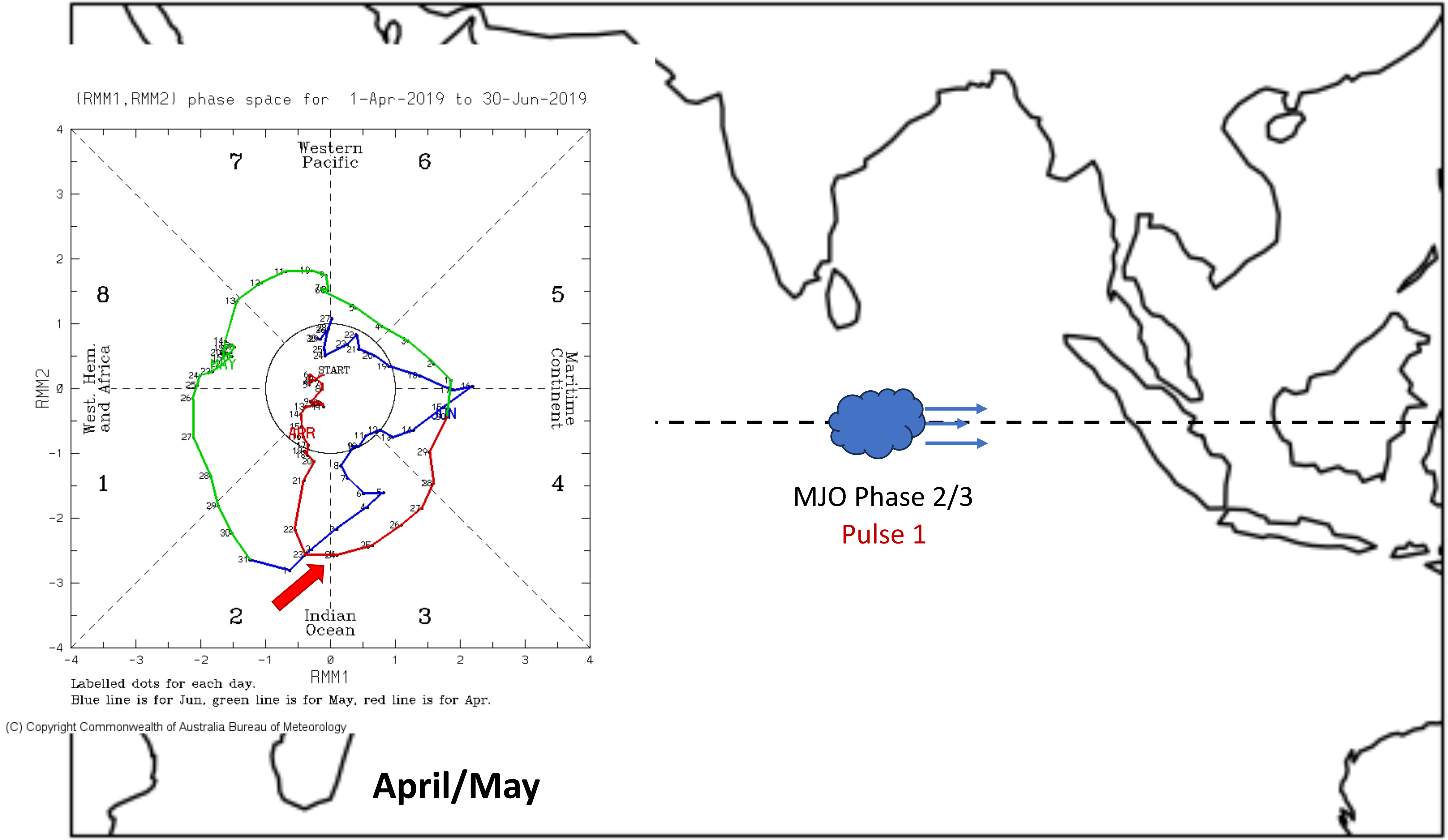
For reference:

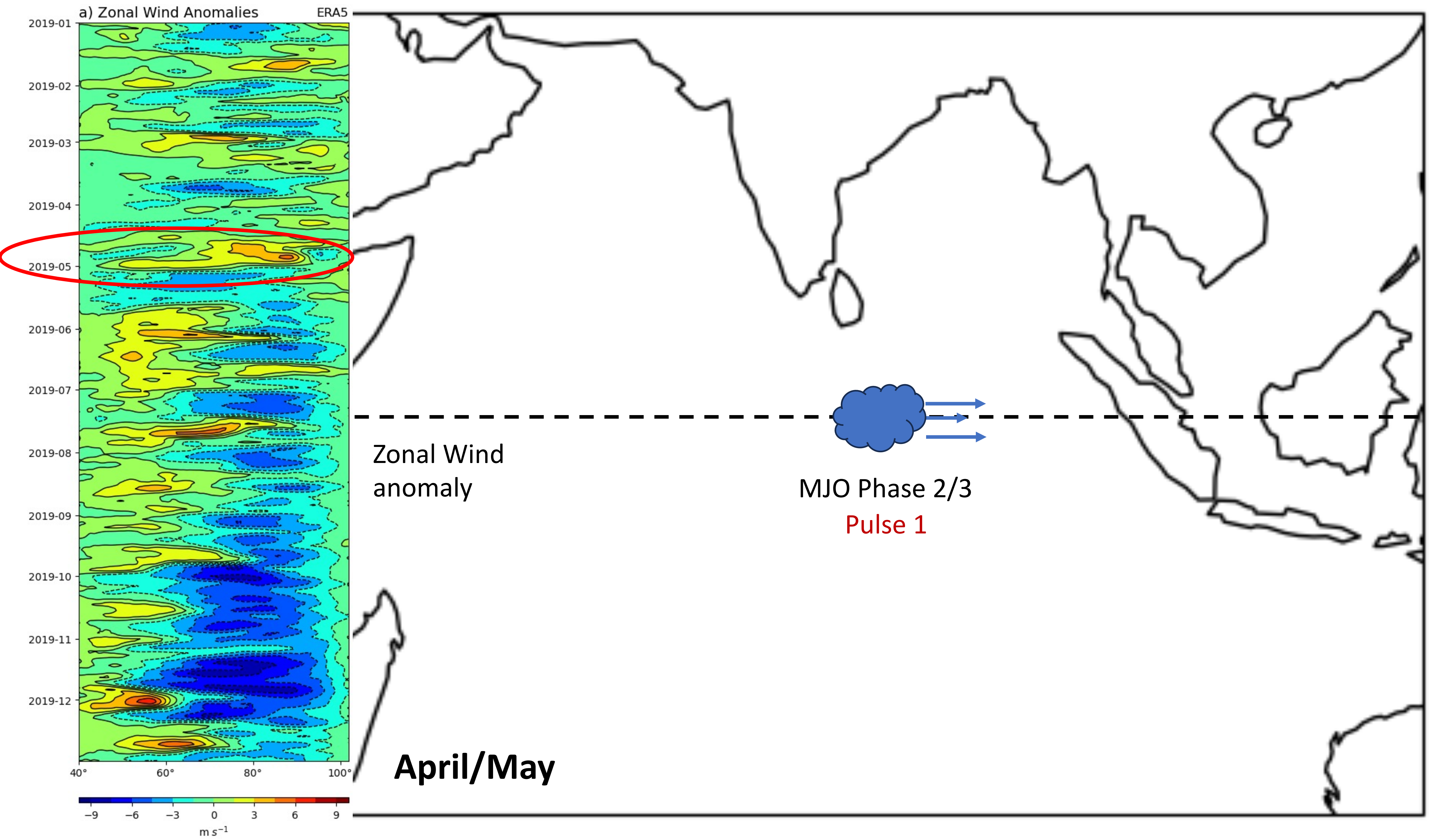
- IOD = Indian Ocean Dipole
- DMI = Dipole Mode Index (measures strength of the IOD)
- ENSO = El Niño Southern Oscillation
- MJO = Madden-Julian Oscillation

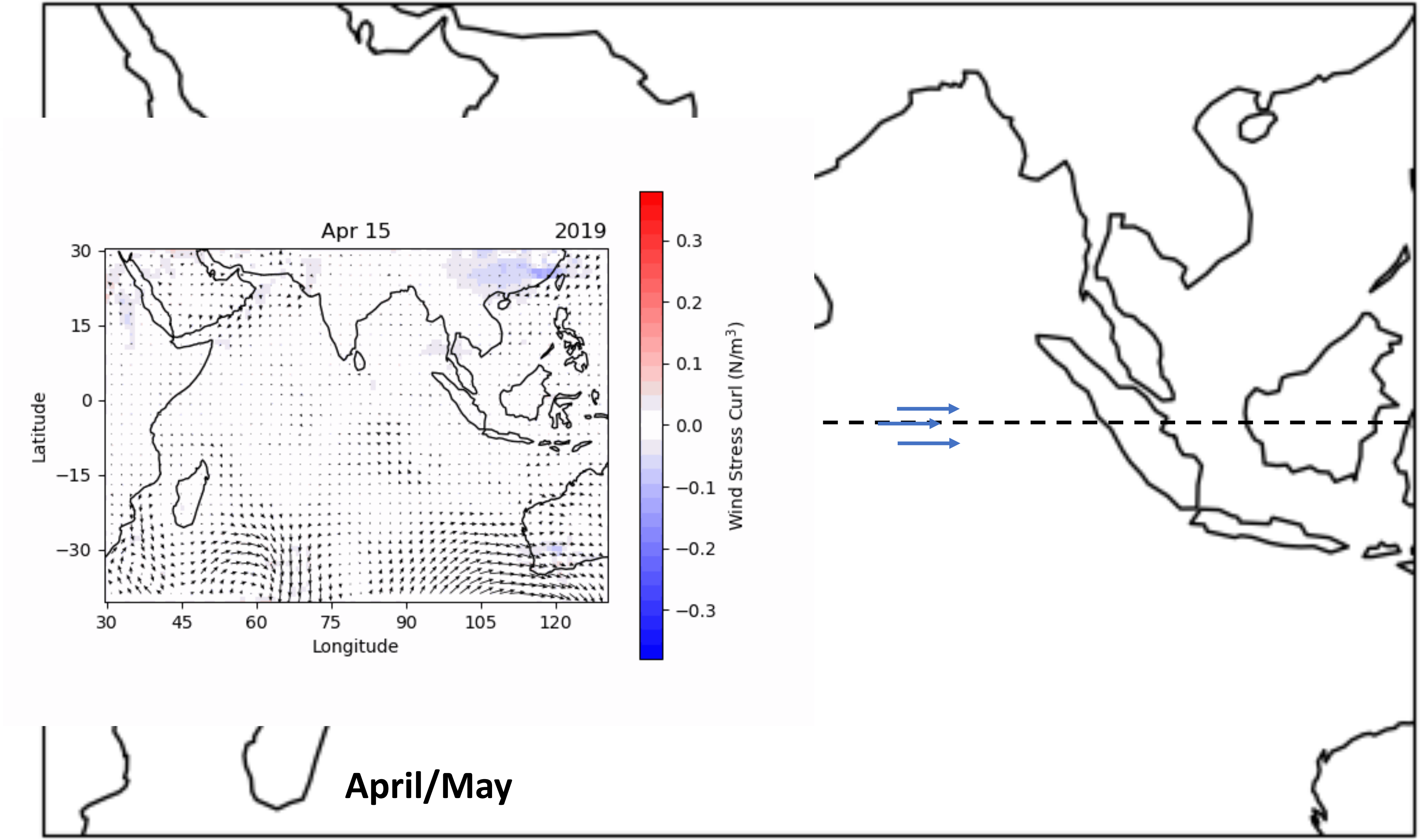
What did we see in 2019?



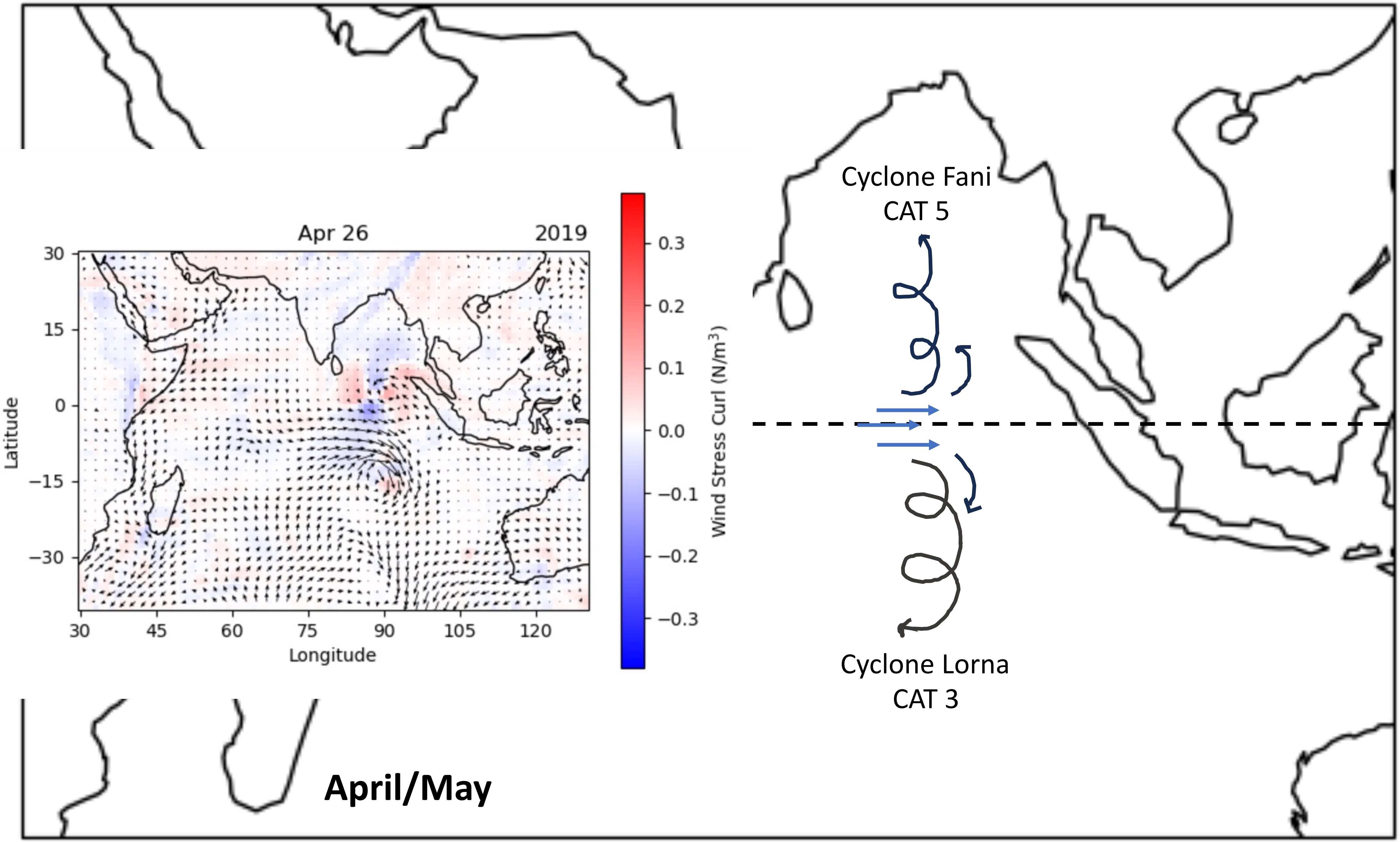

MJO Phase 2/3
Pulse 1
April/May

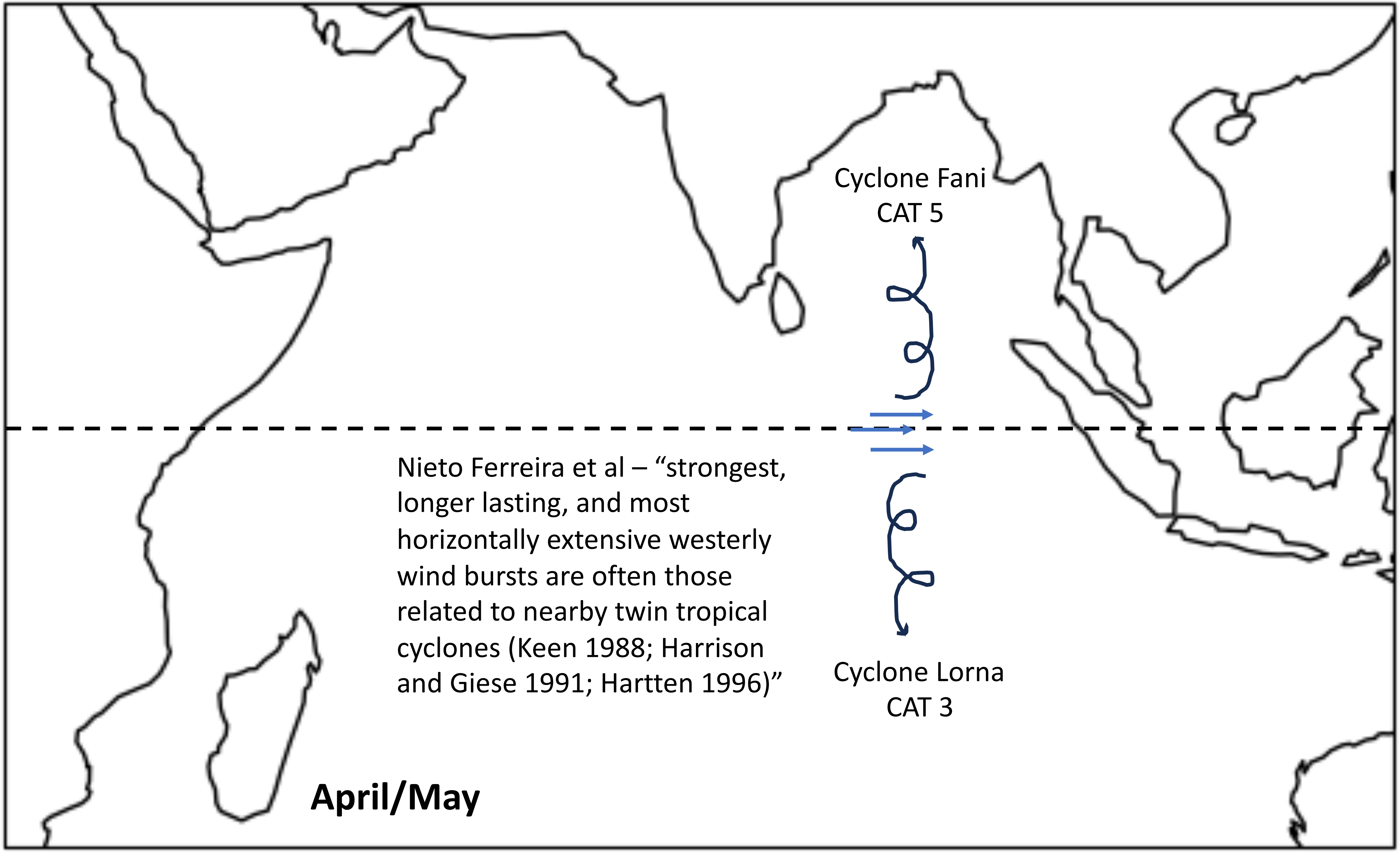

(RMM1,RMM2) phase space for 1-Apr-2019 to 30-Jun-2019
Western Pacific
Indian Ocean
West. Hem. and Africa
Maritime Continent
RMM1
RMM2
START
APR
MAY
JUN
1
2
3
4
5
6
7
8
Labelled dots for each day.
Blue line is for Jun, green line is for May, red line is for Apr.
(C) Copyright Commonwealth of Australia Bureau of Meteorology
MJO Phase 2/3
Pulse 1
April/May


a) Zonal Wind Anomalies
ERA5
2019-01
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−9
−6
−3
0
3
6
9
m s^{-1}
Zonal Wind anomaly
MJO Phase 2/3
Pulse 1
April/May

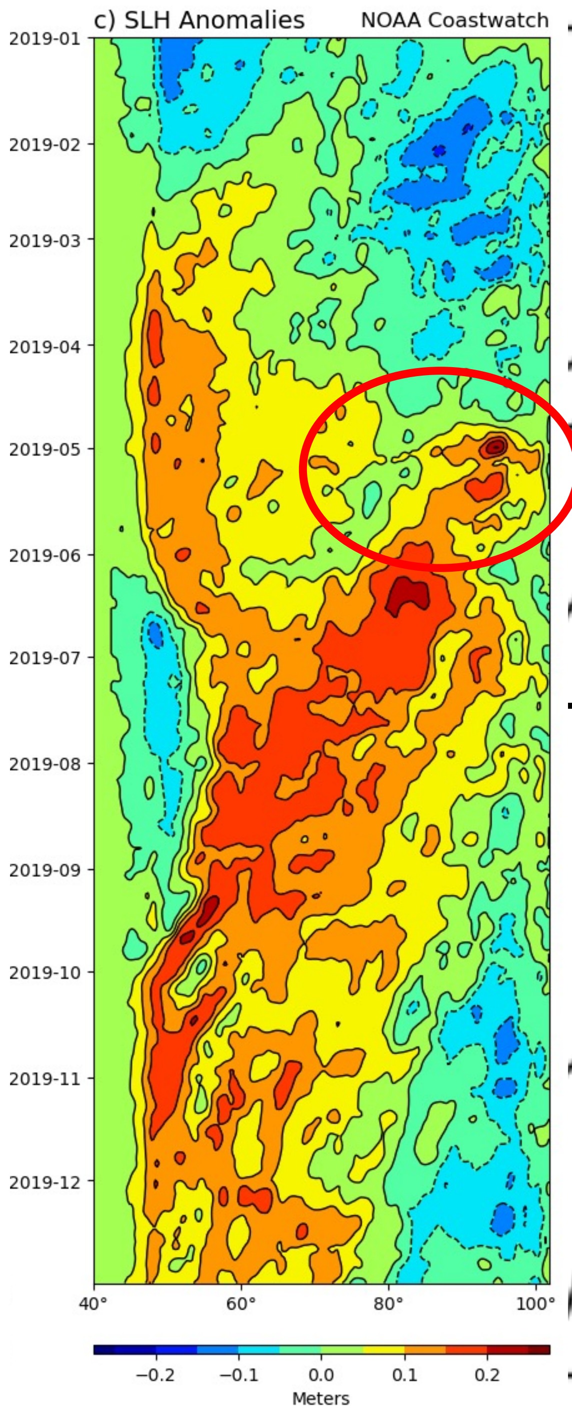

Apr 15
2019
30
15
0
−15
−30
Latitude
30
45
60
75
90
105
120
Longitude
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Wind Stress Curl (N/m³)

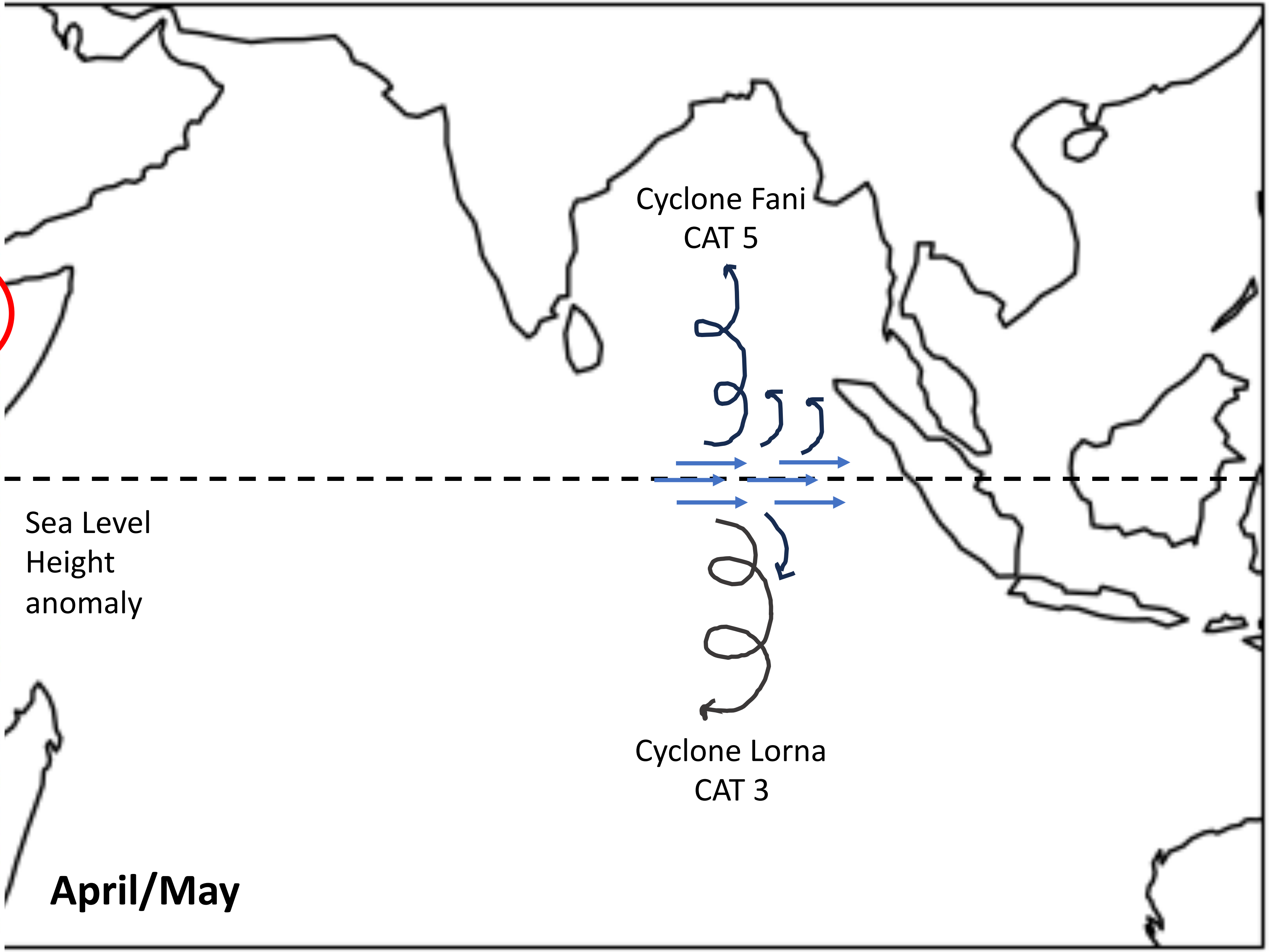
April/May


Apr 26
2019
Latitude
Longitude
Wind Stress Curl (N/m^3)
Cyclone Fani
CAT 5
Cyclone Lorna
CAT 3
April/May



Cyclone Fani
CAT 5
Nieto Ferreira et al – "strongest, longer lasting, and most horizontally extensive westerly wind bursts are often those related to nearby twin tropical cyclones (Keen 1988; Harrison and Giese 1991; Hartten 1996)"
Cyclone Lorna
CAT 3
April/May


c) SLH Anomalies
NOAA Coastwatch
2019-01
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−0.2
−0.1
0.0
0.1
0.2
Meters


Cyclone Fani
CAT 5
Sea Level
Height
anomaly
Cyclone Lorna
CAT 3

April/May

CYCLONE FANI, INDIA

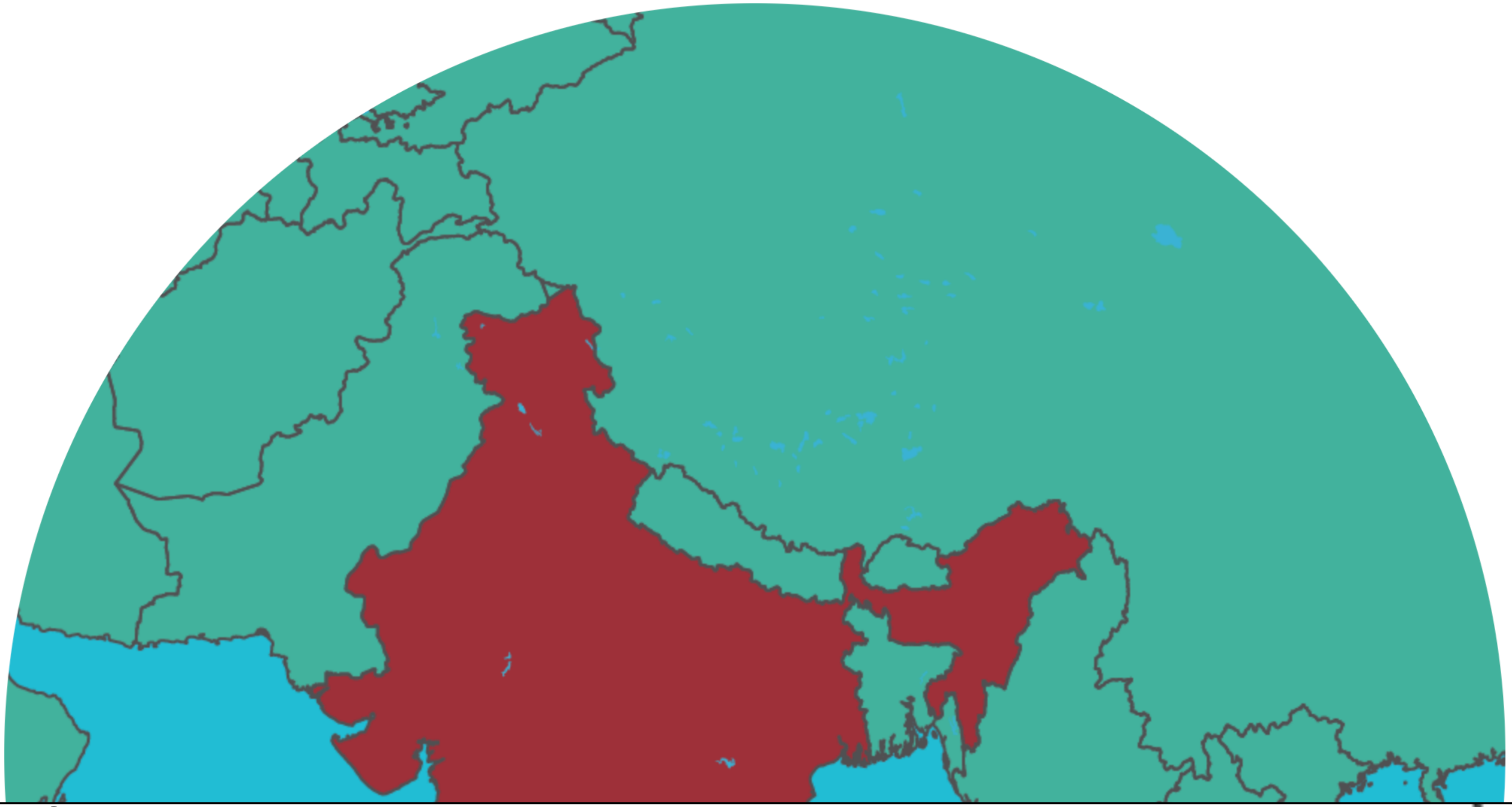
May 2019

PEOPLE HELPED

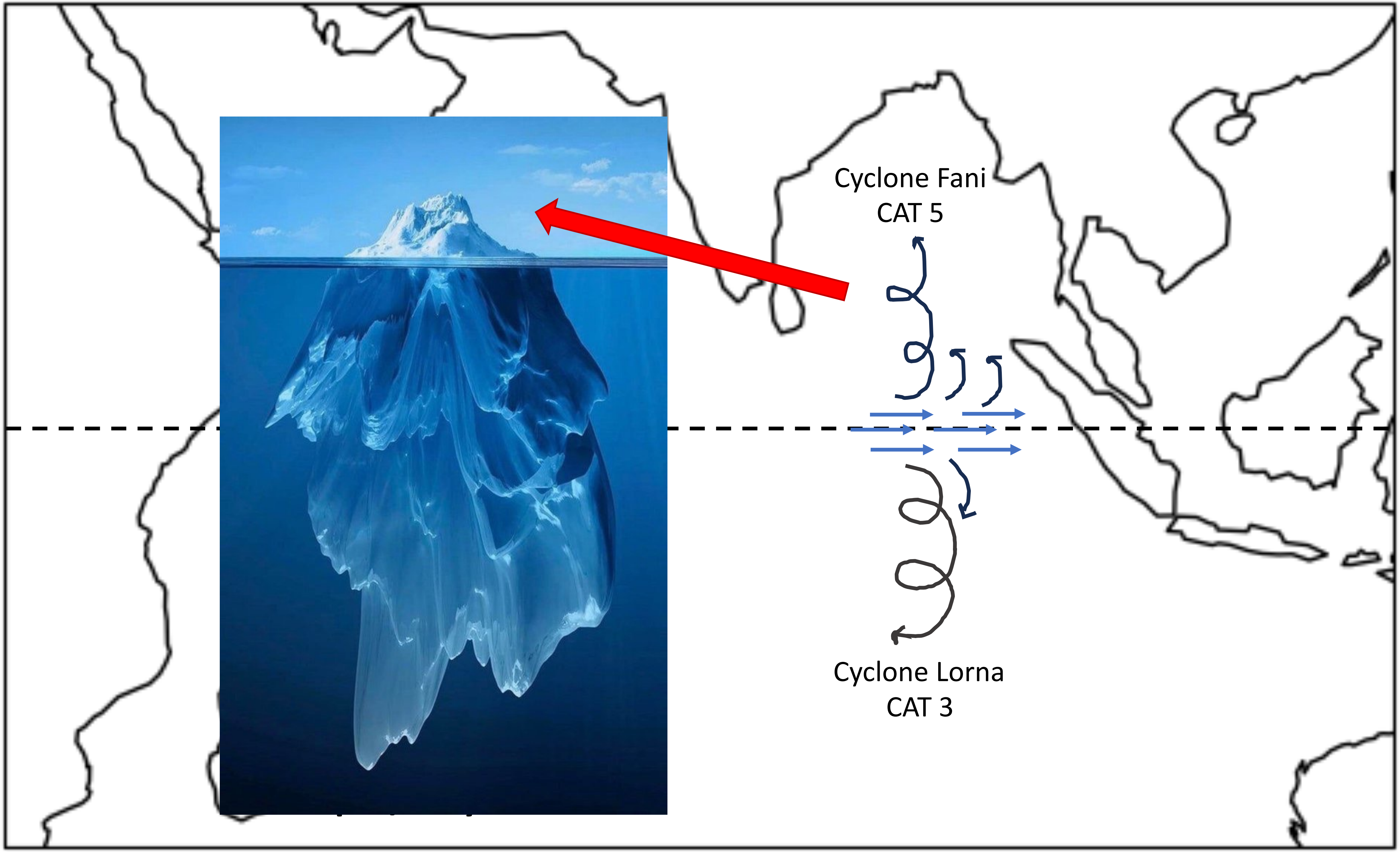
9,900 individuals (2,000 households)

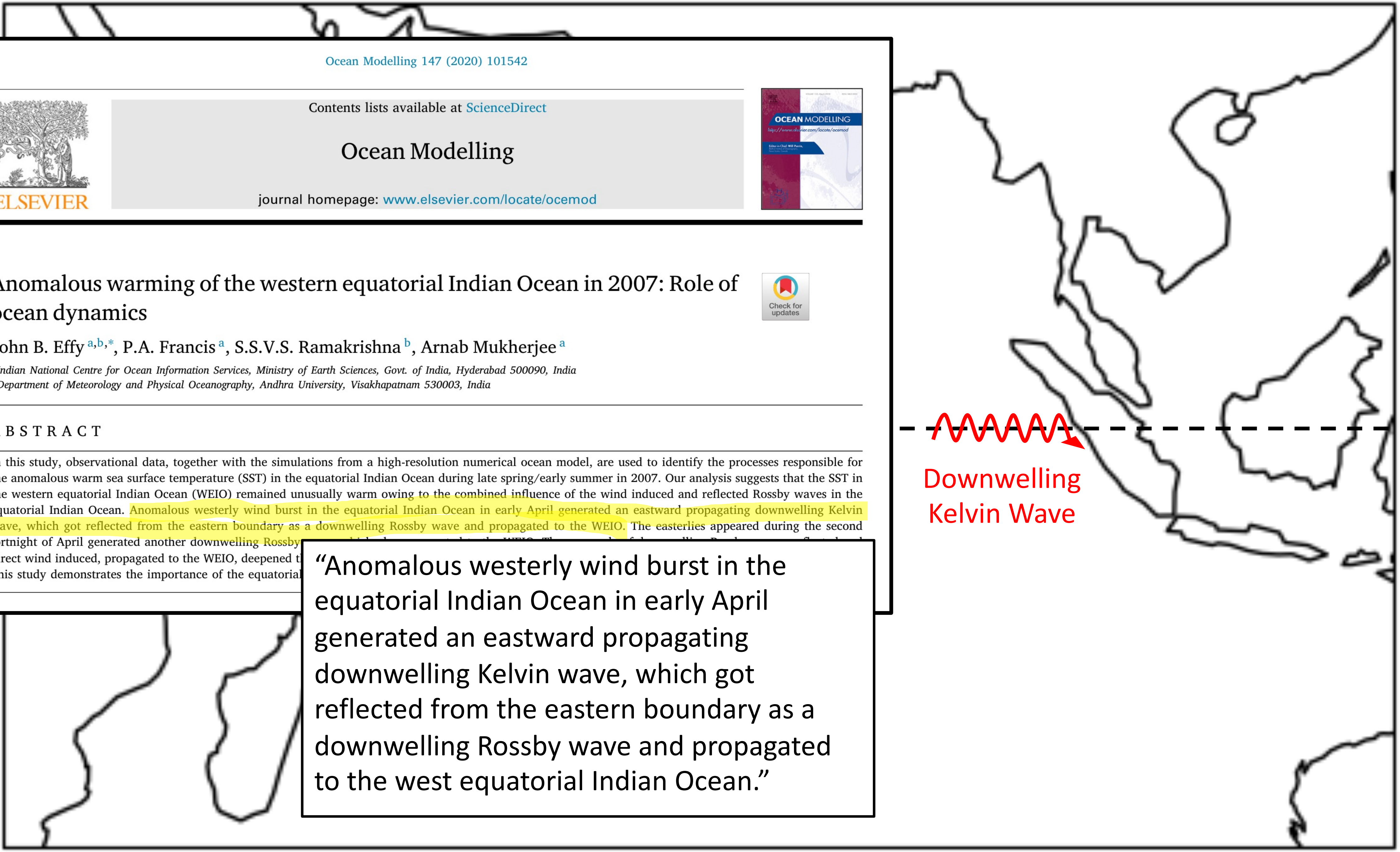
HUMANITARIAN NEEDS

Cyclone Fani, a category 4 tropical cyclone, made landfall in Odisha, India on May 3, affecting more than 15 million people across 16,000 villages. 1.5 million people were evacuated from their homes. Households in Puri district are without access to adequate food, shelter, basic protection, and clean water. The majority of houses in this district have been damaged or destroyed, leaving people at risk for the approaching monsoon season.



April/May


Cyclone Fani
CAT 5
Cyclone Lorna
CAT 3



Ocean Modelling 147 (2020) 101542

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ELSEVIER

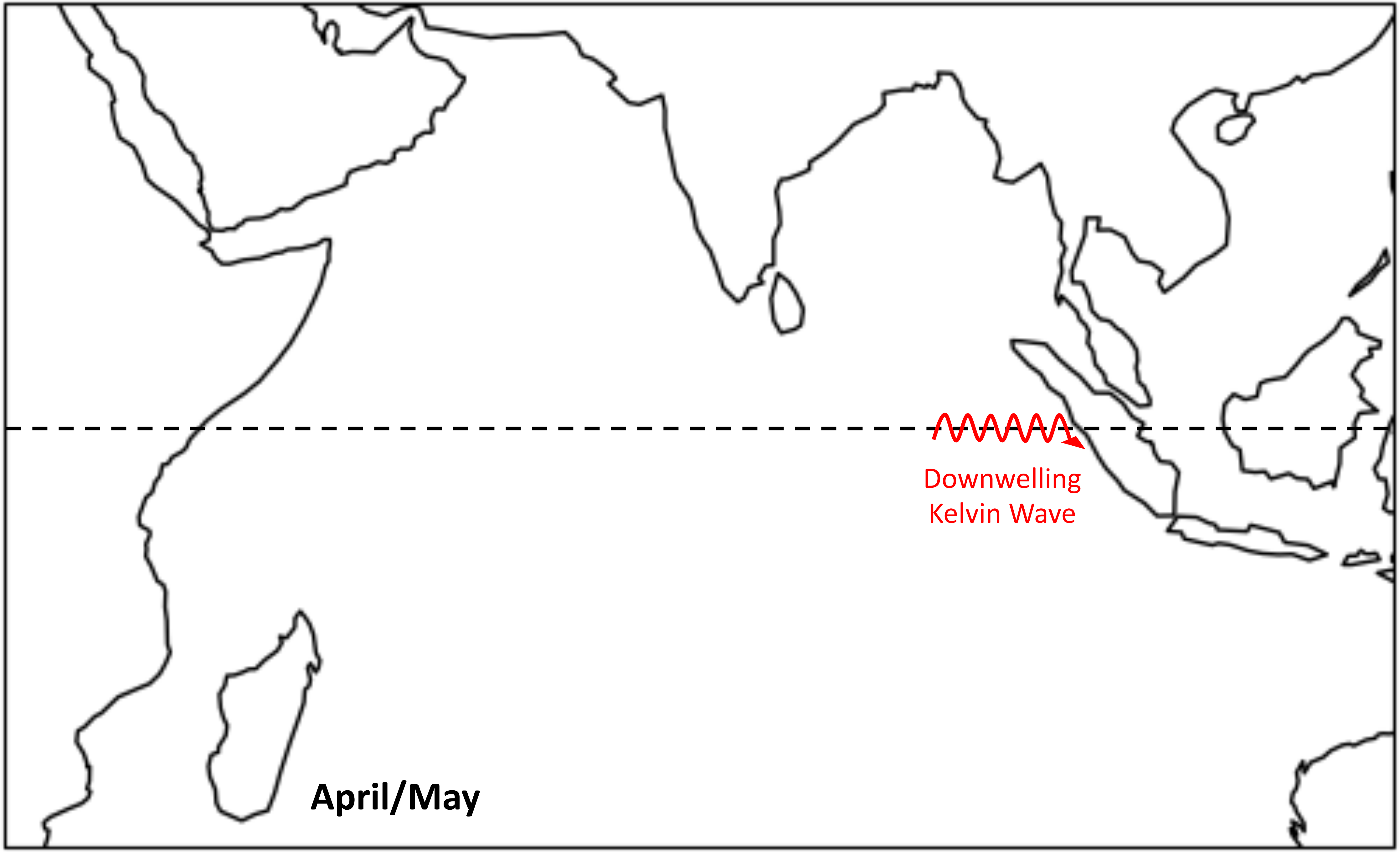
Anomalous warming of the western equatorial Indian Ocean in 2007: Role of ocean dynamics

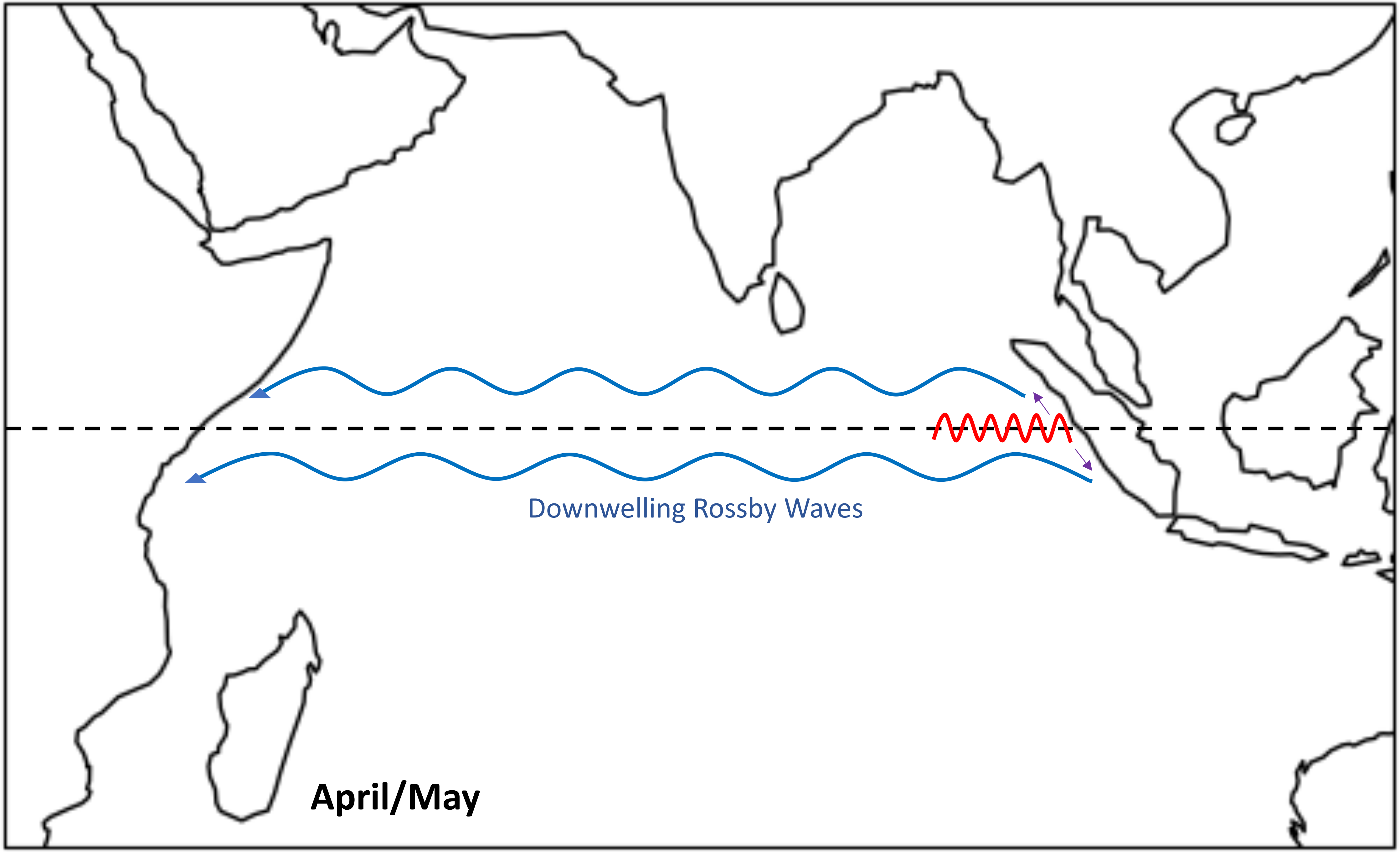
John B. Effy [a,b,*], P.A. Francis [a], S.S.V.S. Ramakrishna [b], Arnab Mukherjee [a]

[a] *Indian National Centre for Ocean Information Services, Ministry of Earth Sciences, Govt. of India, Hyderabad 500090, India*
[b] *Department of Meteorology and Physical Oceanography, Andhra University, Visakhapatnam 530003, India*

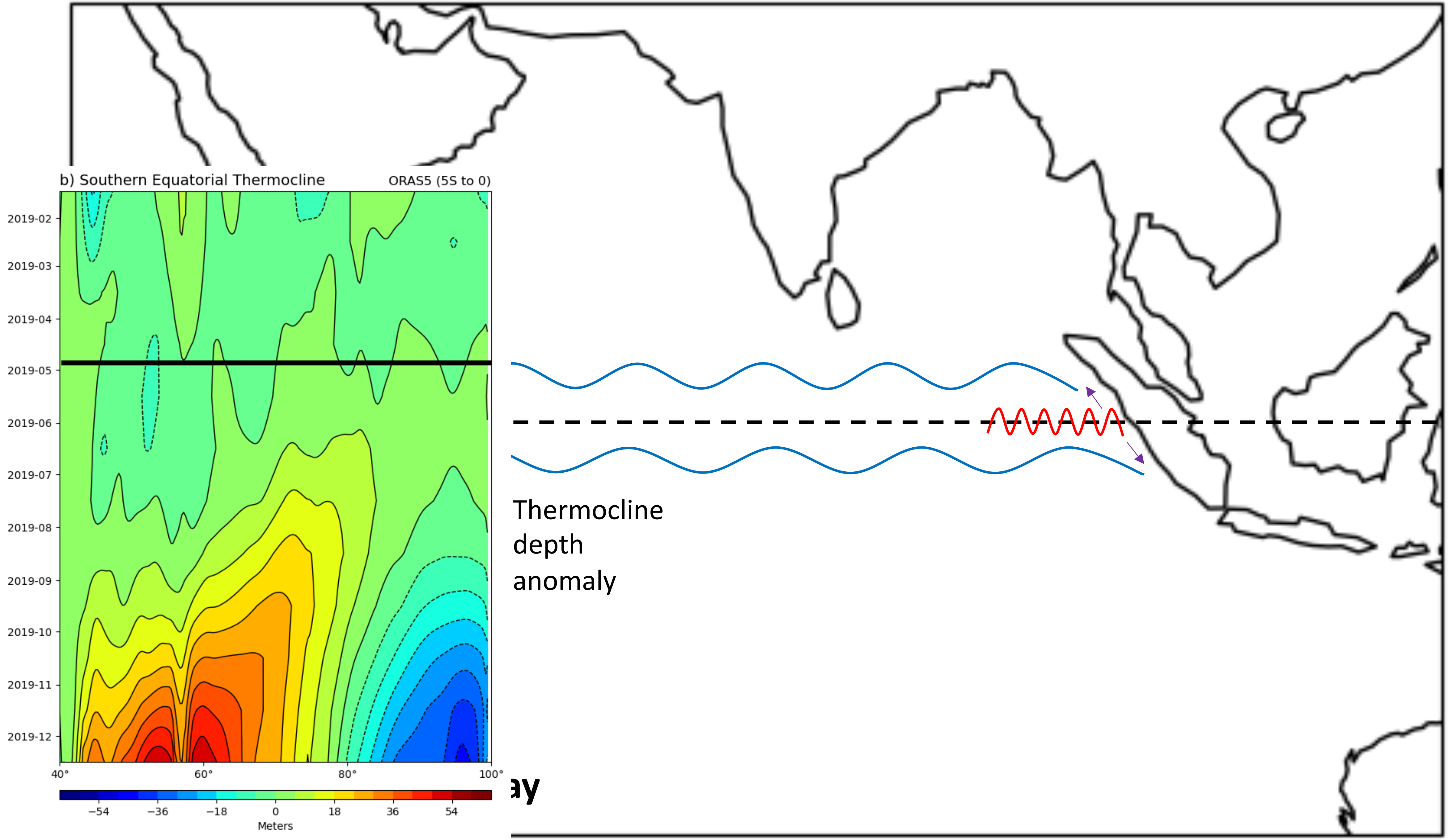
A B S T R A C T

In this study, observational data, together with the simulations from a high-resolution numerical ocean model, are used to identify the processes responsible for the anomalous warm sea surface temperature (SST) in the equatorial Indian Ocean during late spring/early summer in 2007. Our analysis suggests that the SST in the western equatorial Indian Ocean (WEIO) remained unusually warm owing to the combined influence of the wind induced and reflected Rossby waves in the equatorial Indian Ocean. Anomalous westerly wind burst in the equatorial Indian Ocean in early April generated an eastward propagating downwelling Kelvin wave, which got reflected from the eastern boundary as a downwelling Rossby wave and propagated to the WEIO. The easterlies appeared during the second fortnight of April generated another downwelling Rossby
direct wind induced, propagated to the WEIO, deepened t
This study demonstrates the importance of the equatorial


Downwelling
Kelvin Wave
April/May

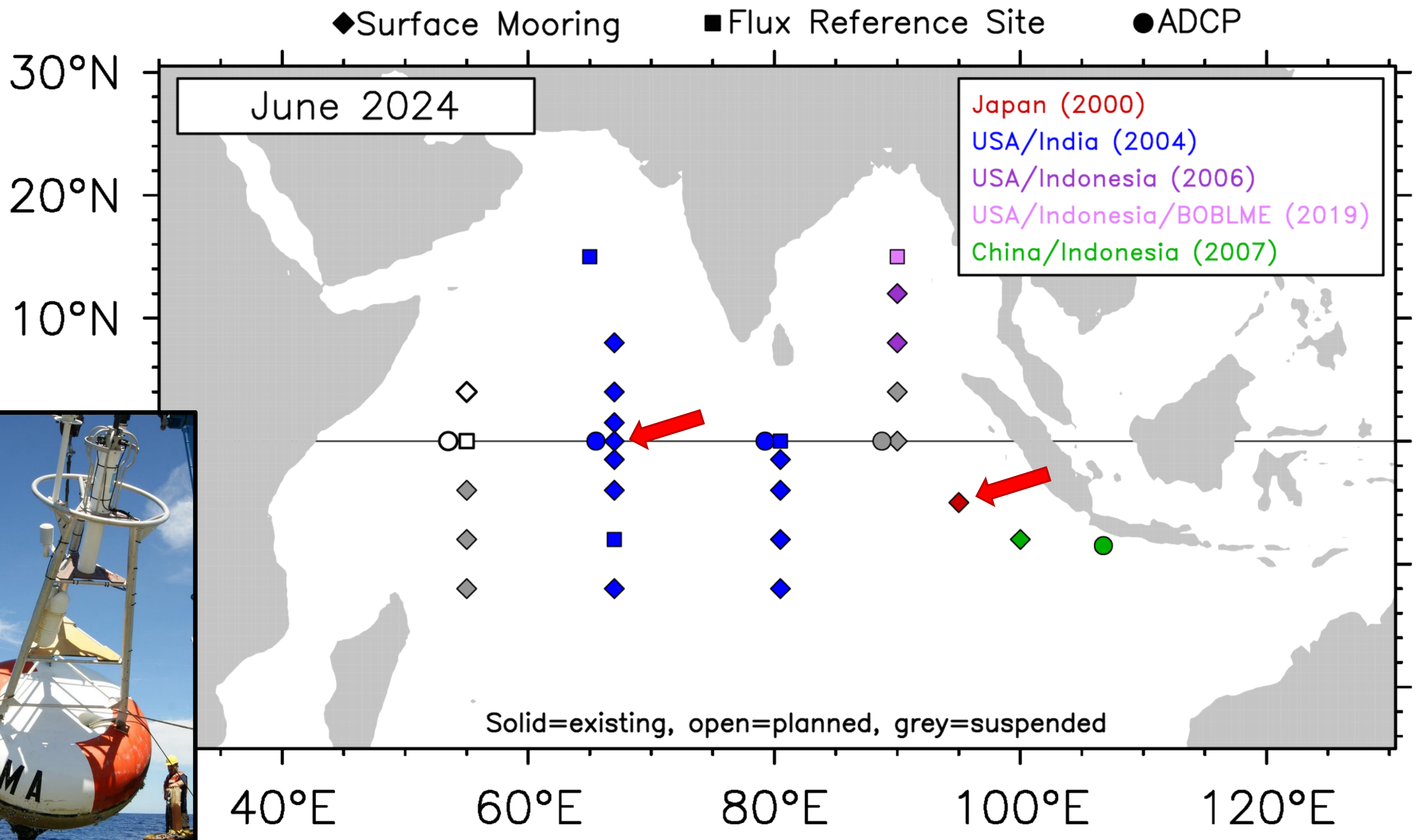


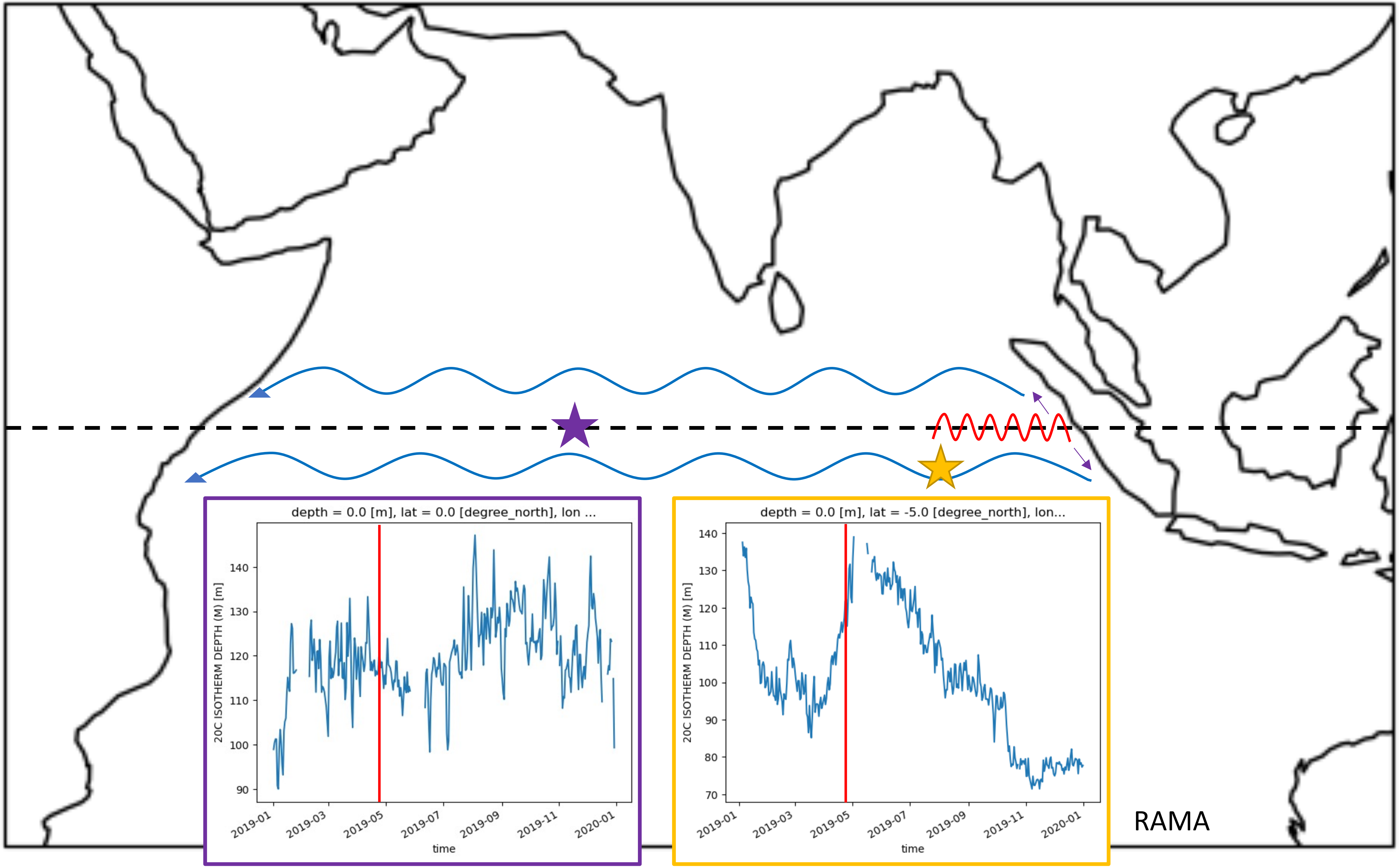
Downwelling Rossby Waves
April/May



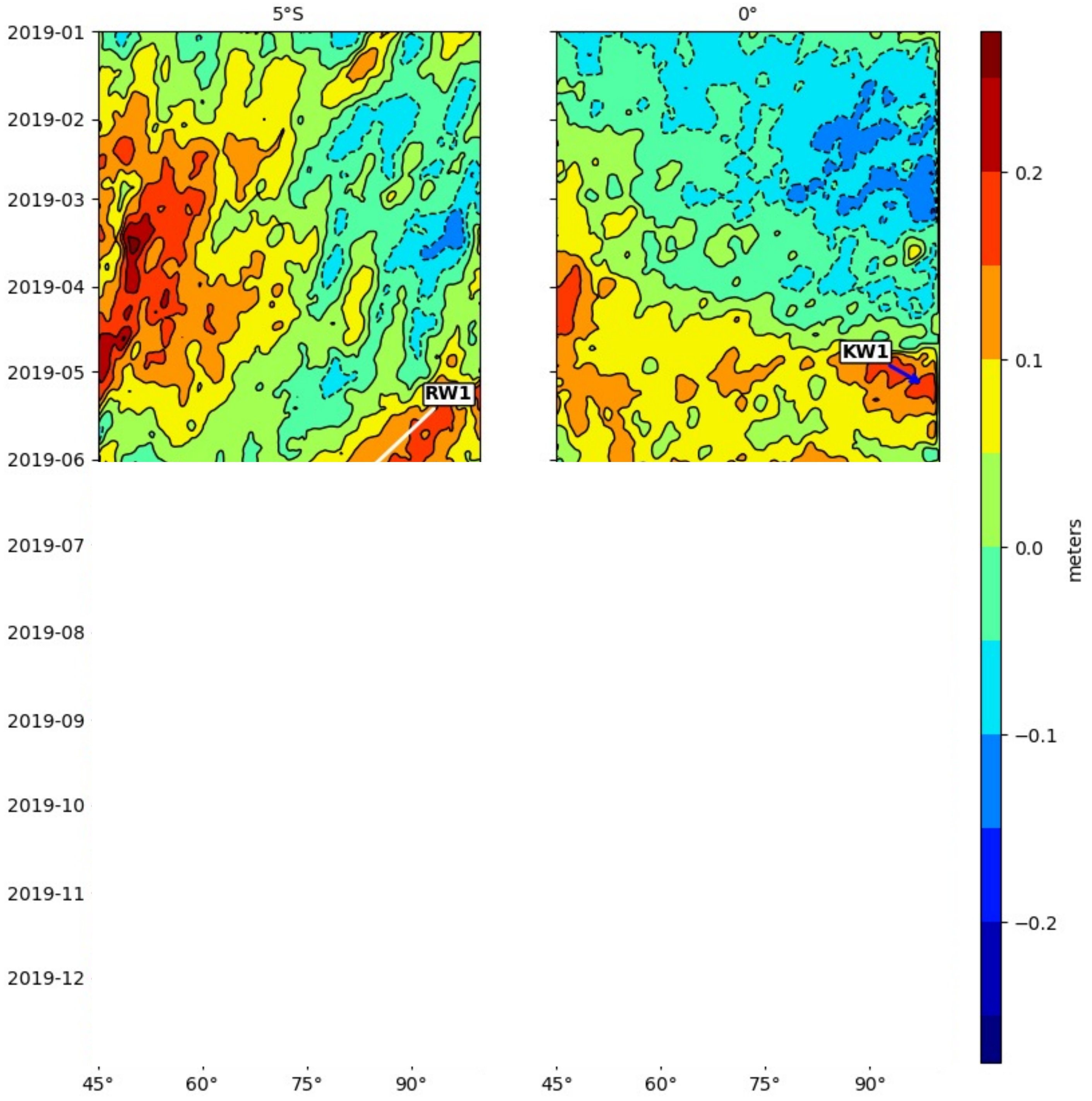
b) Southern Equatorial Thermocline
ORAS5 (5S to 0)
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−54
−36
−18
0
18
36
54
Meters
Thermocline
depth
anomaly
ay

Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (RAMA–2.0)



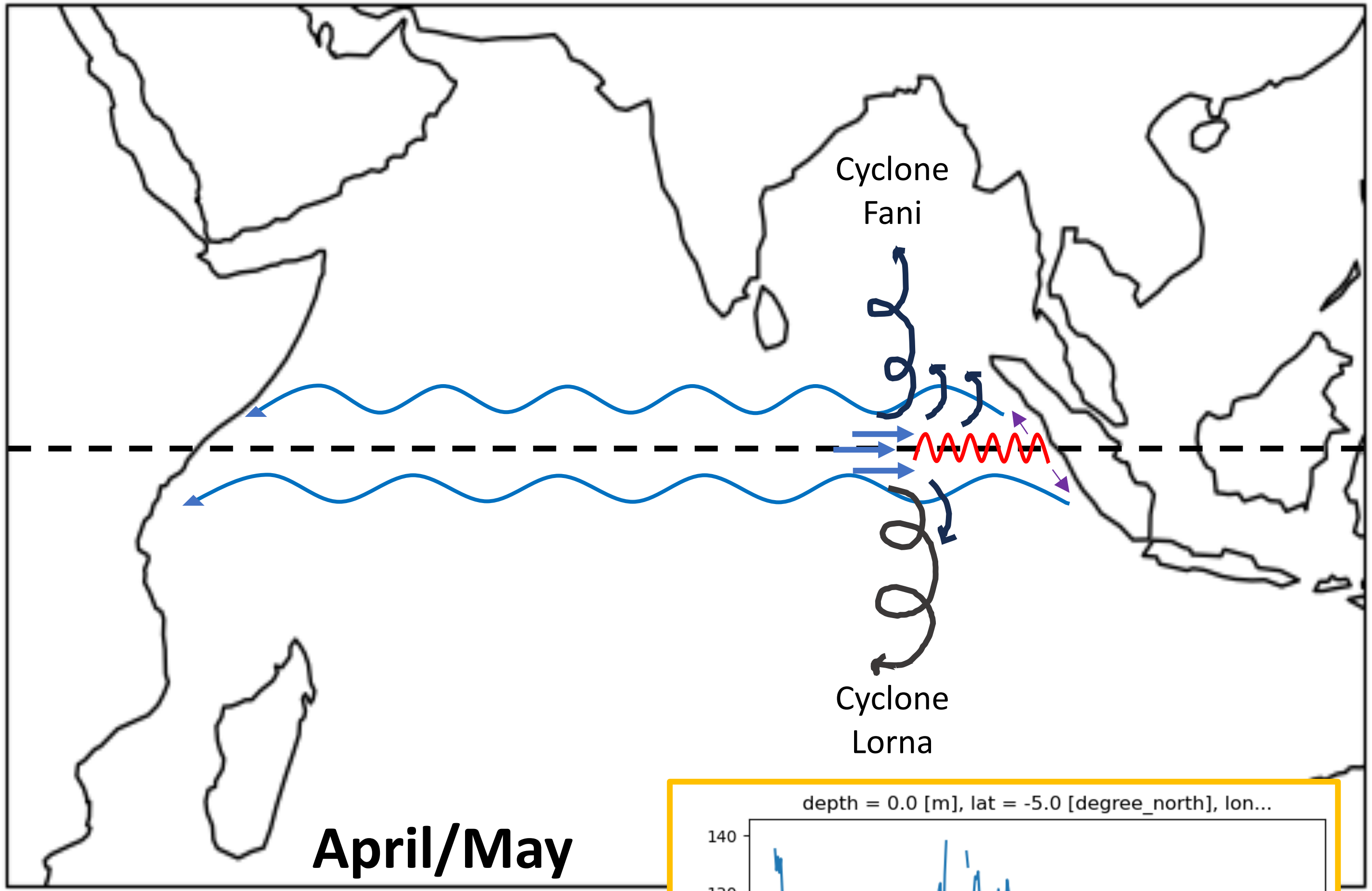

depth = 0.0 [m], lat = 0.0 [degree_north], lon ...
20C ISOTHERM DEPTH (M) [m]
90
100
110
120
130
140
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
time
depth = 0.0 [m], lat = -5.0 [degree_north], lon...
20C ISOTHERM DEPTH (M) [m]
70
80
90
100
110
120
130
140
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
time
RAMA

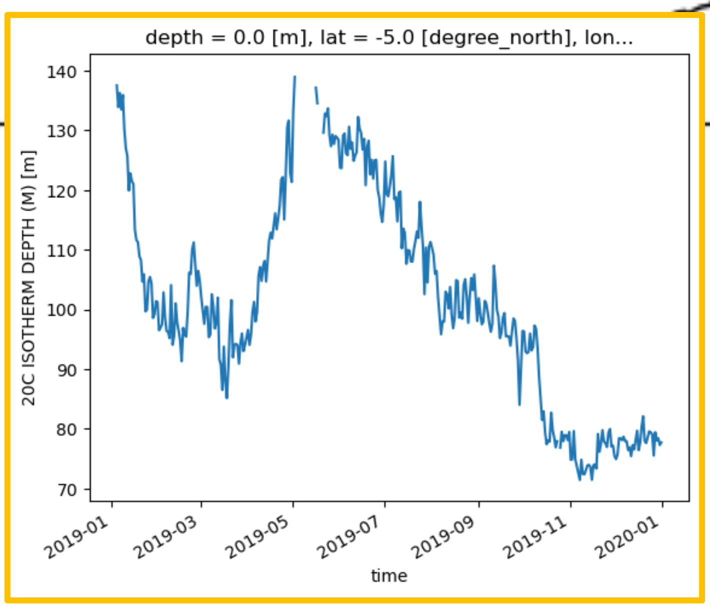
SLH Anomalies at 5S and the Equator

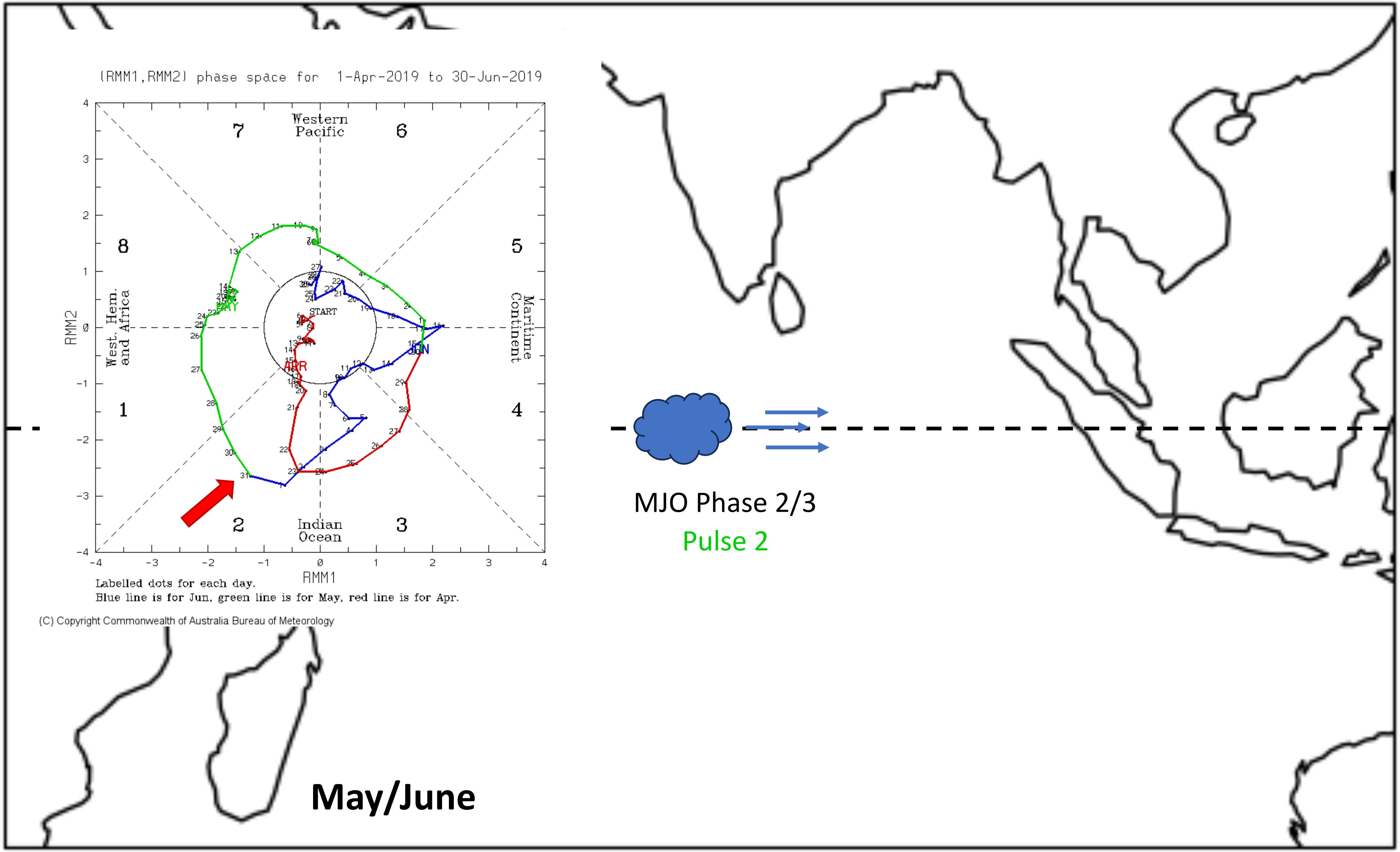


MJO Pulse 1

- Strong enough to impact local sea level height
- Not strong enough to push thermocline down all the way across the Indian Ocean
- Hypothesis – this pulse pre-conditions the system for the second MJO activity in May/June







(RMM1,RMM2) phase space for 1-Apr-2019 to 30-Jun-2019
Western Pacific
Indian Ocean
West. Hem. and Africa
Maritime Continent
RMM1
RMM2
START
APR
MAY
JUN
Labelled dots for each day.
Blue line is for Jun, green line is for May, red line is for Apr.
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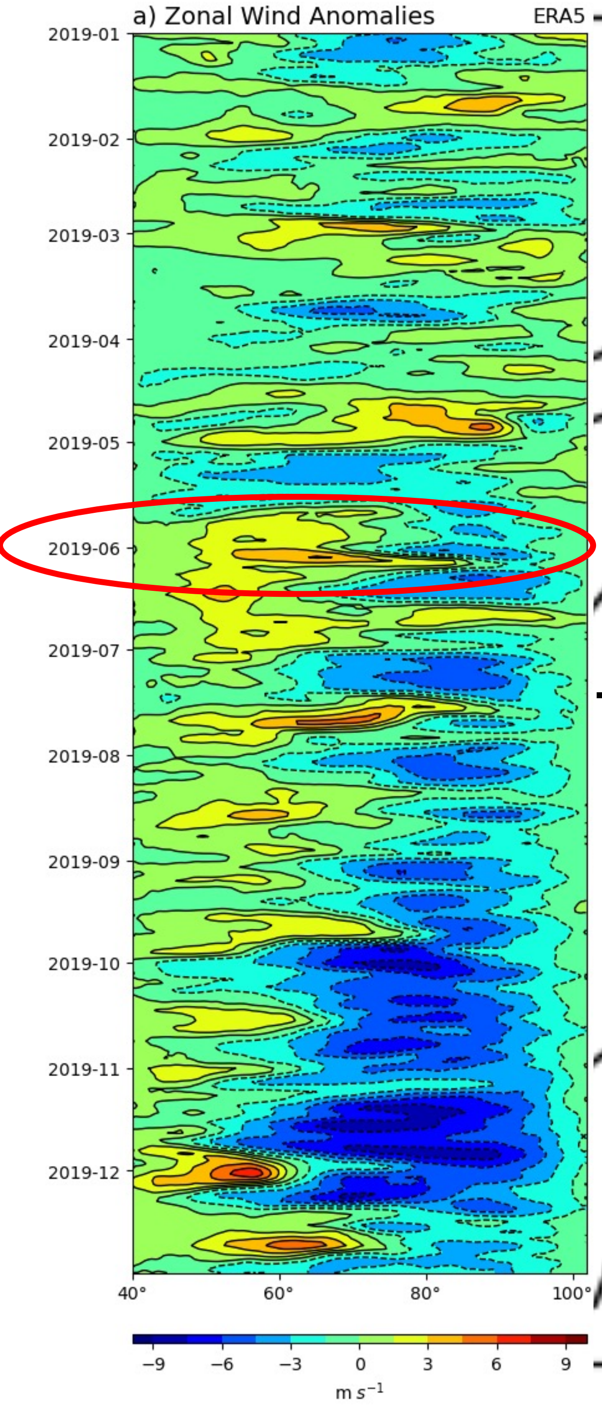
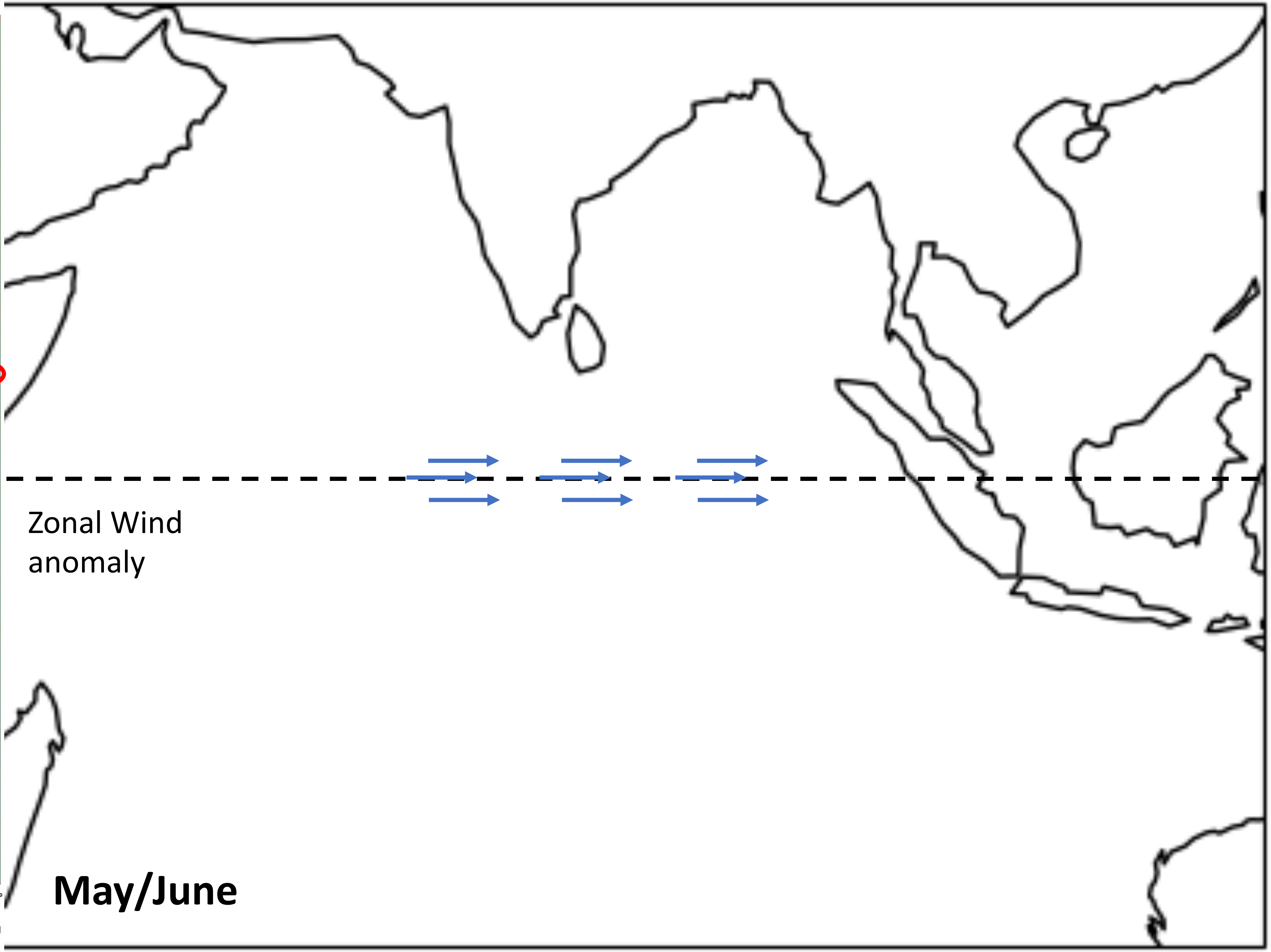
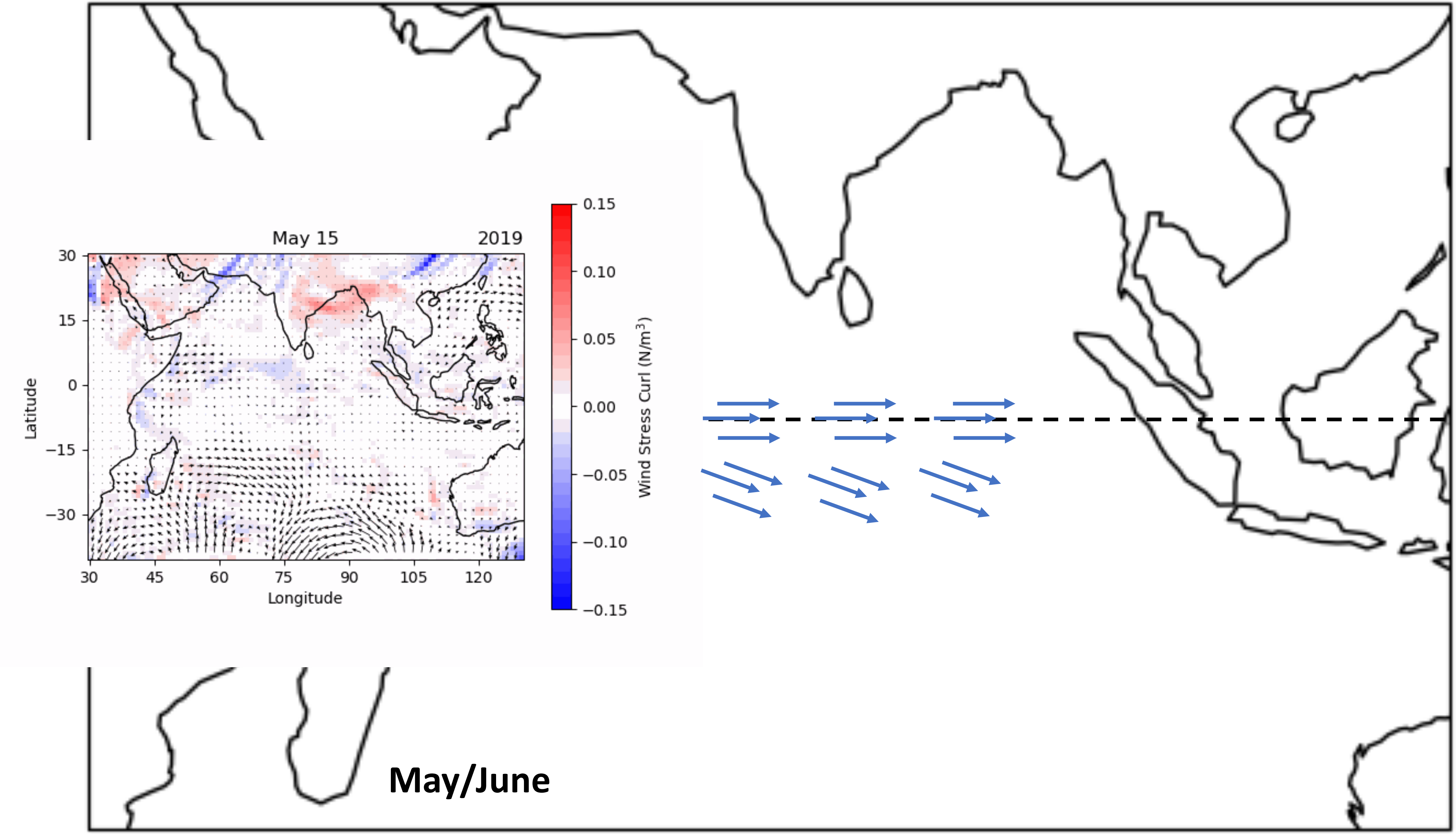
MJO Phase 2/3
Pulse 2
May/June


a) Zonal Wind Anomalies
ERA5
2019-01
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−9
−6
−3
0
3
6
9
m s−1

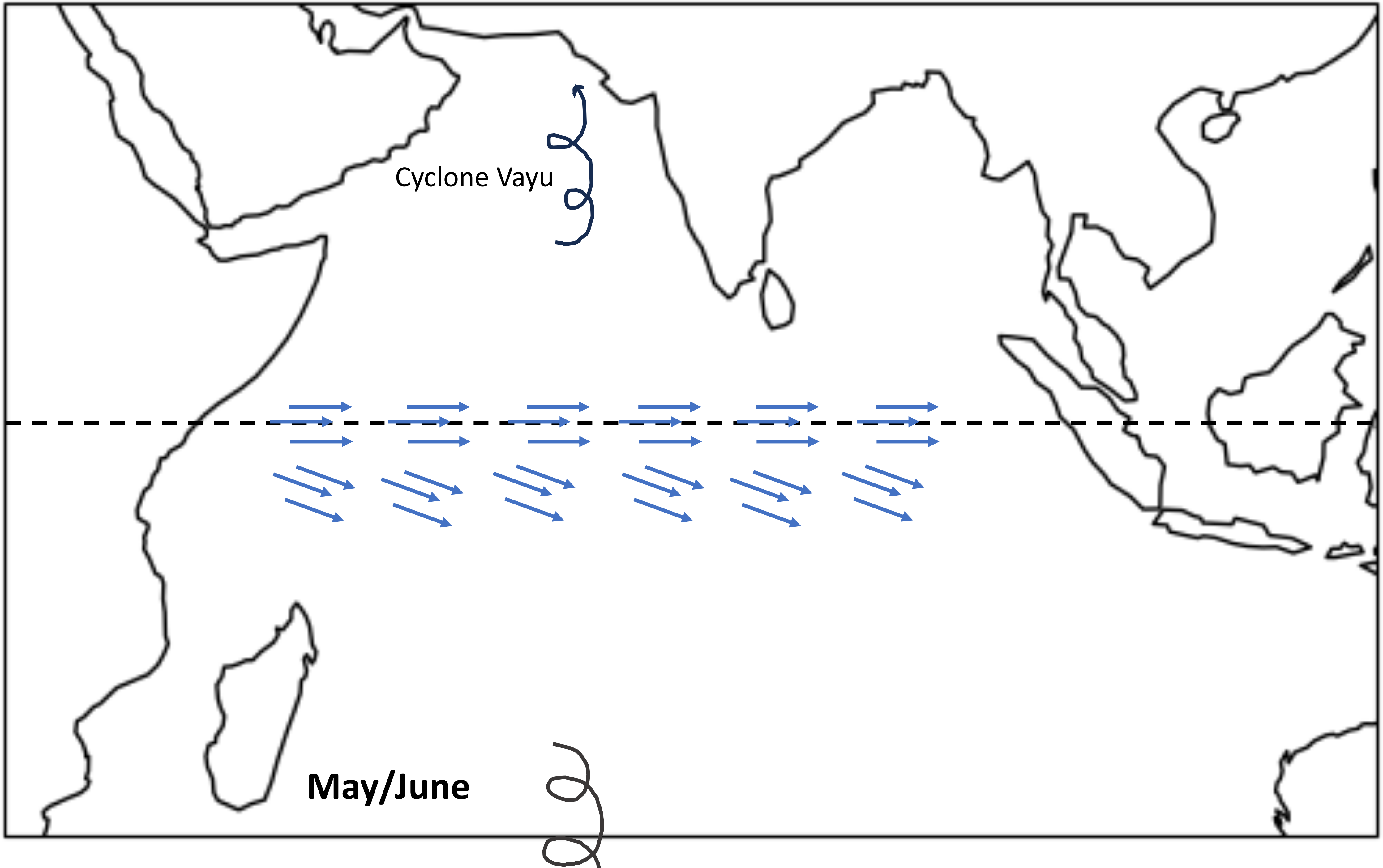

Zonal Wind
anomaly

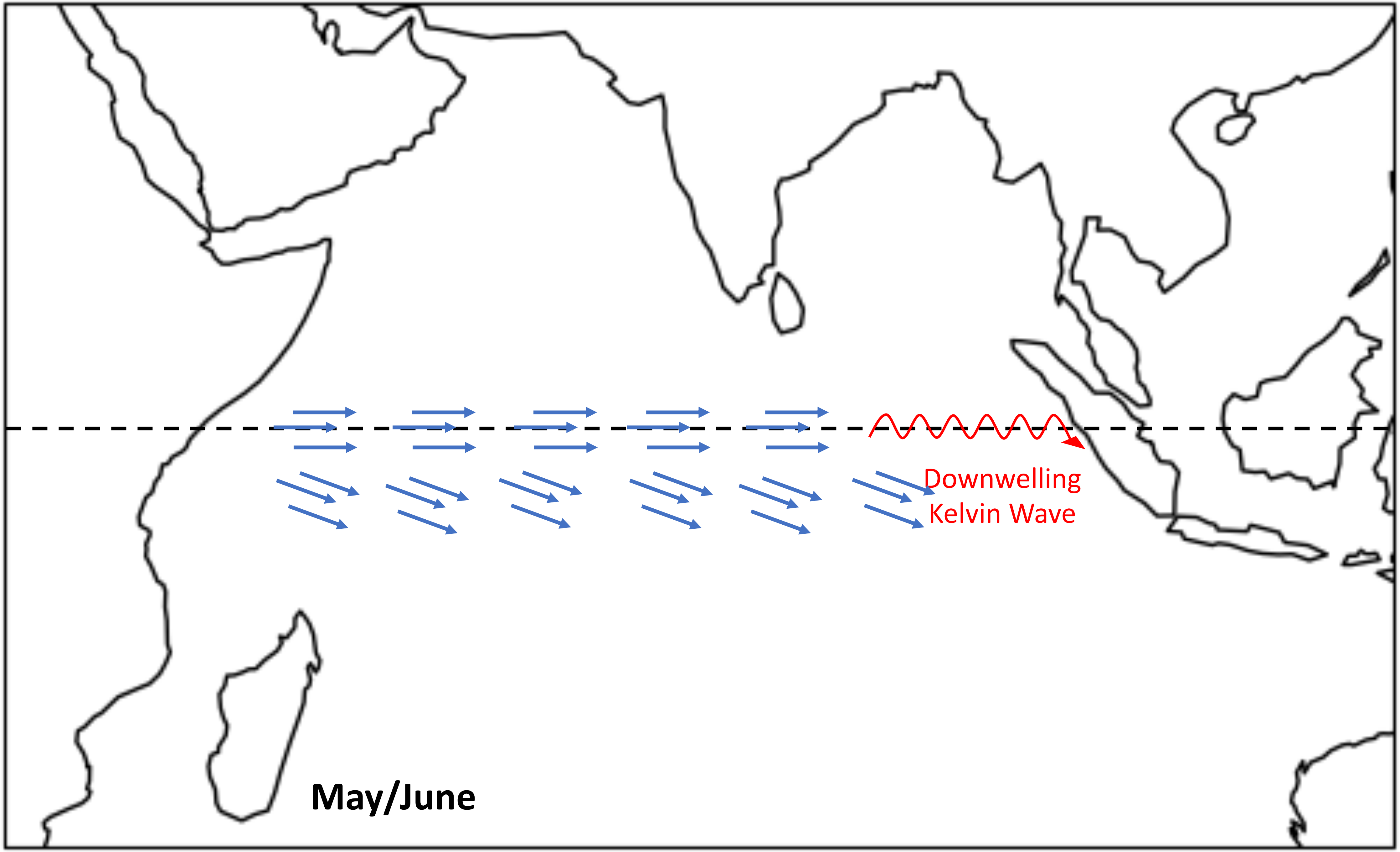
May/June

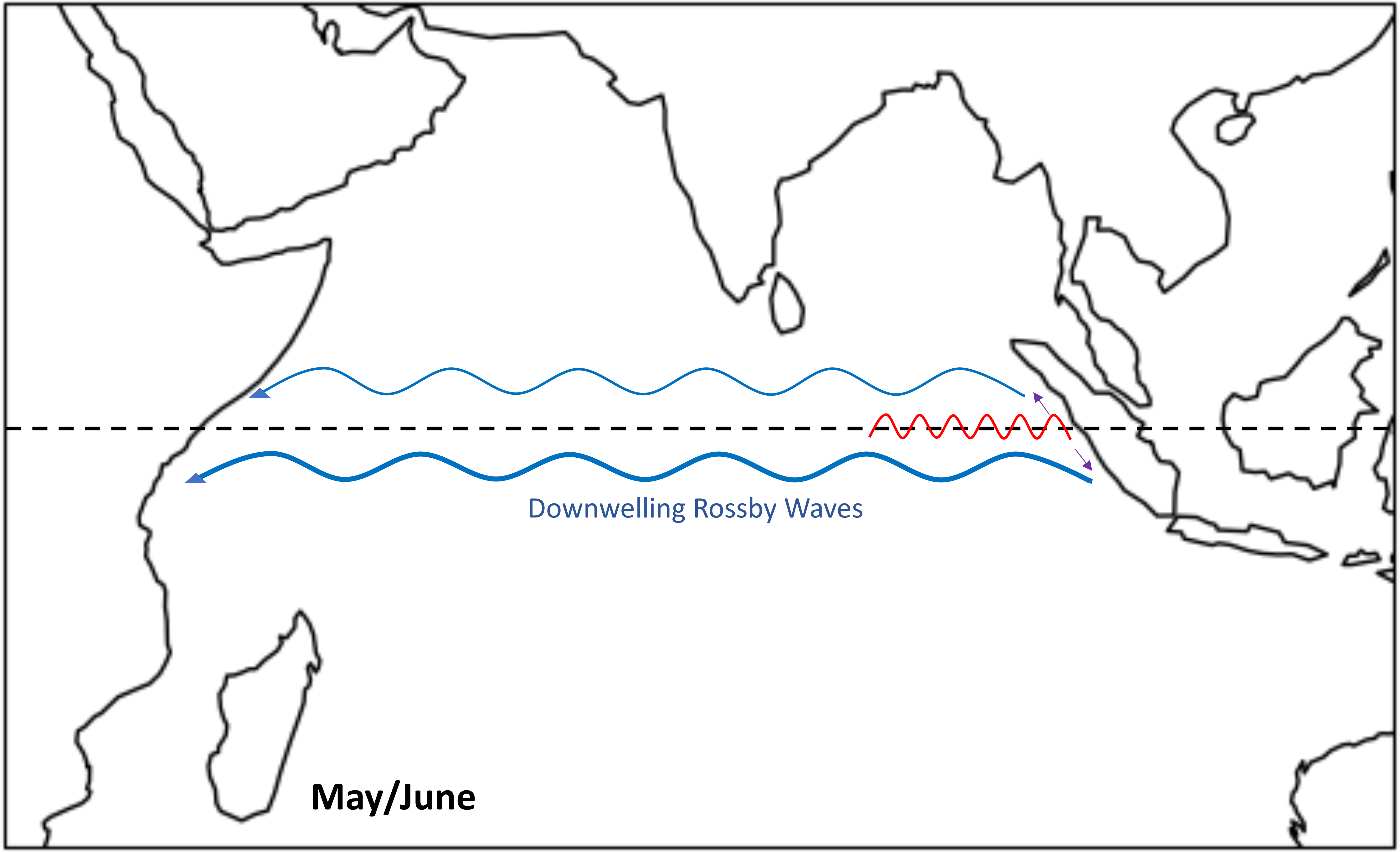


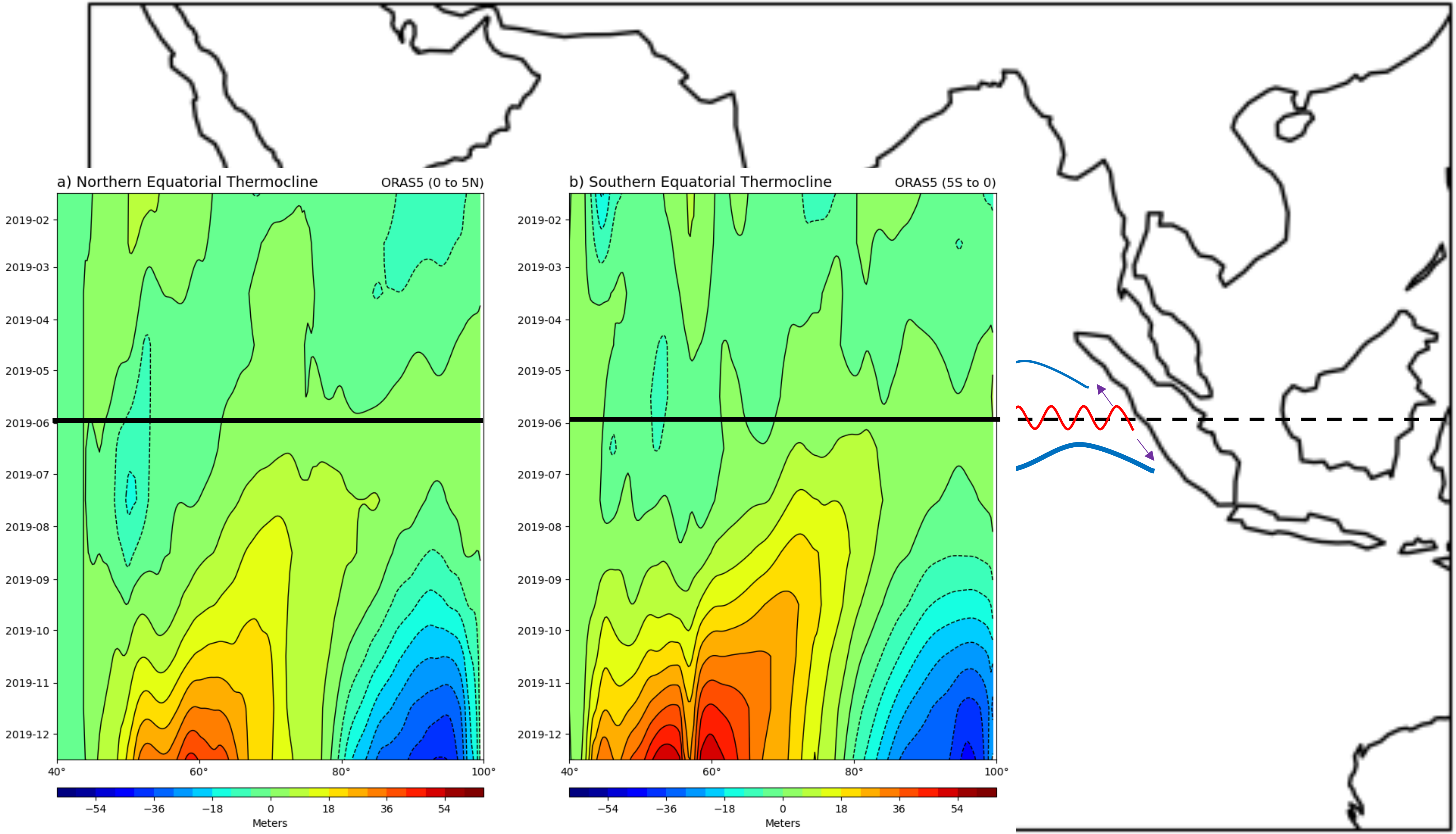
May 15
2019
30
15
0
−15
−30
Latitude
30
45
60
75
90
105
120
Longitude
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
Wind Stress Curl (N/m³)

May/June

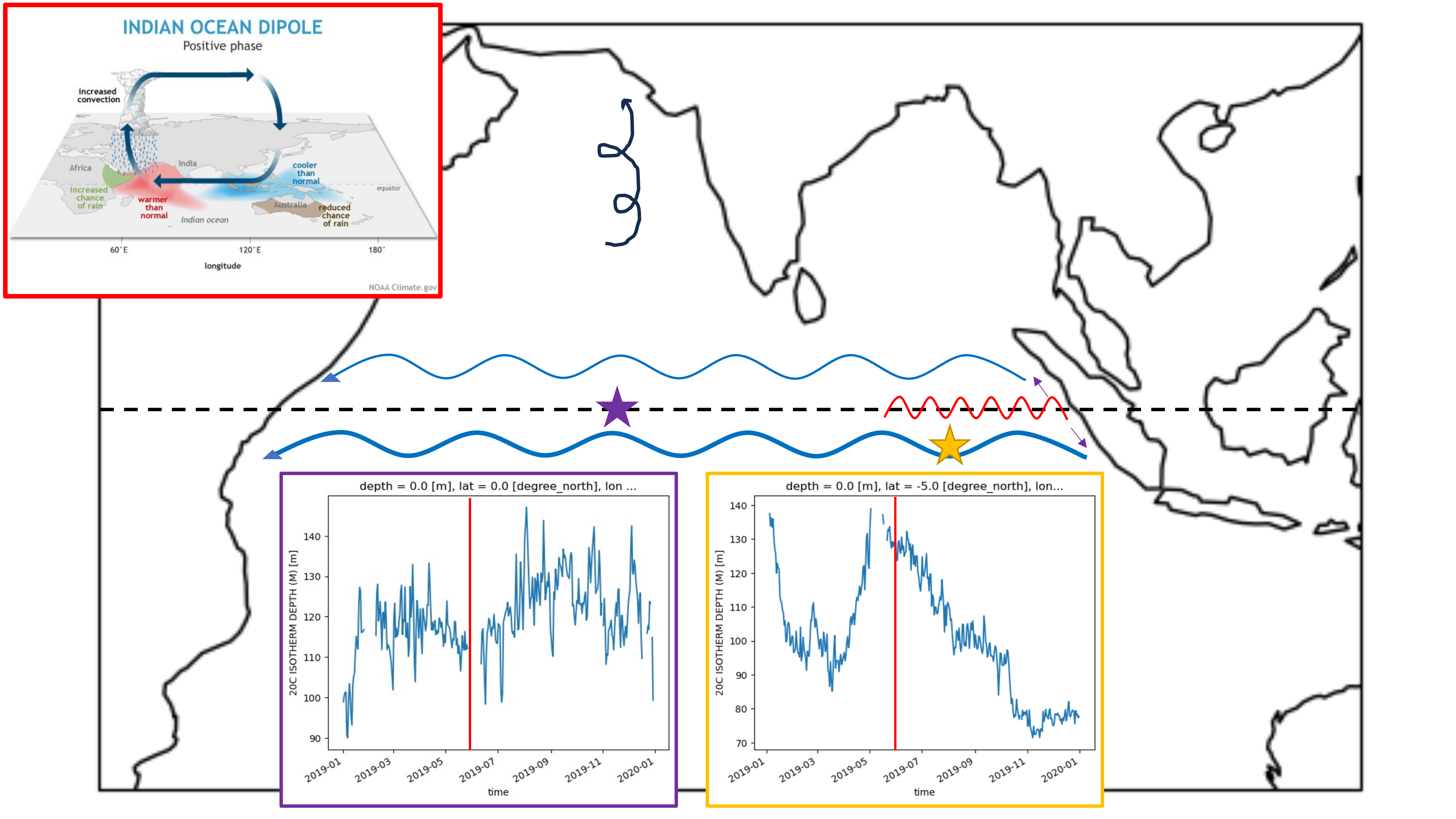

Cyclone Vayu
May/June

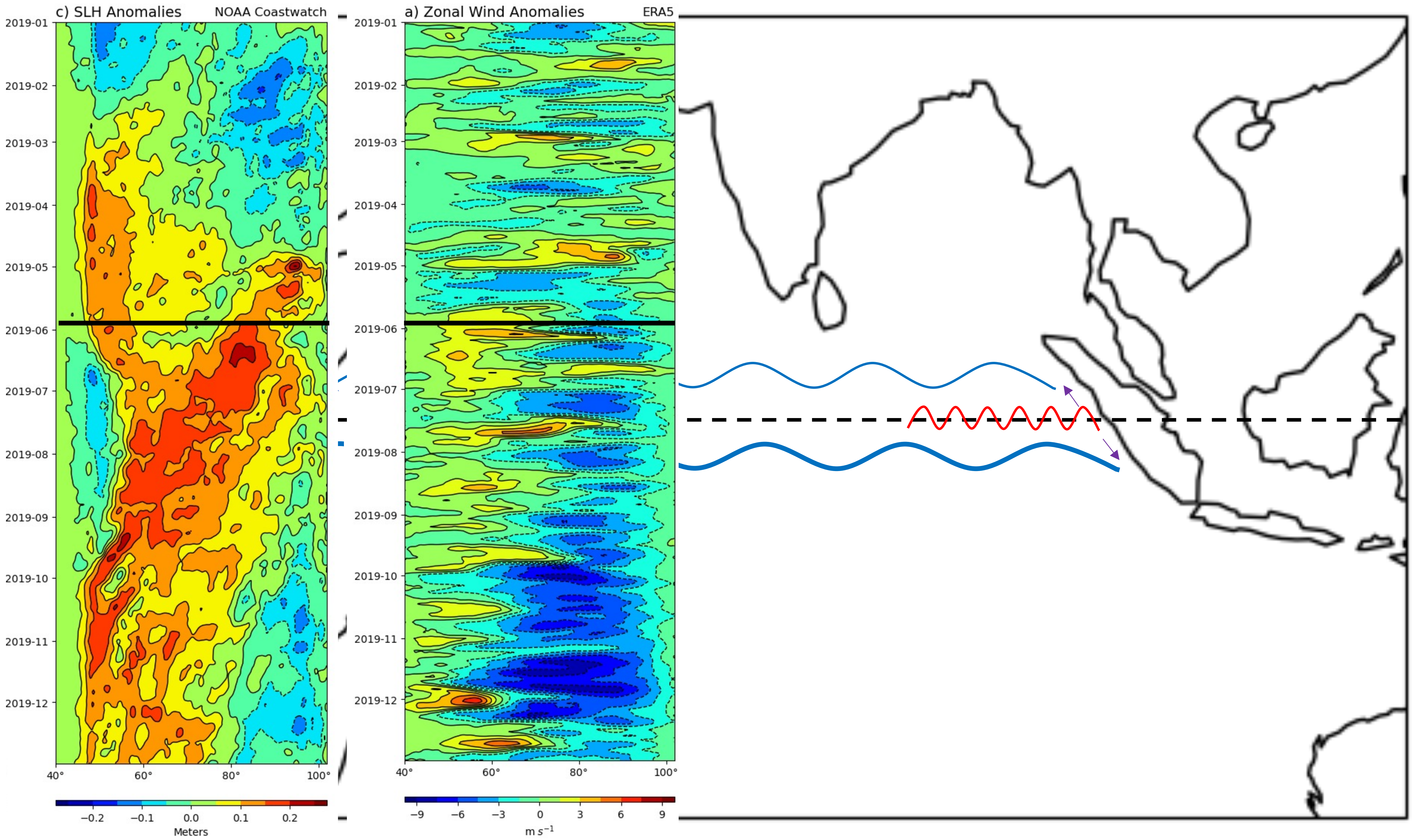

Downwelling
Kelvin Wave
May/June


Downwelling Rossby Waves
May/June

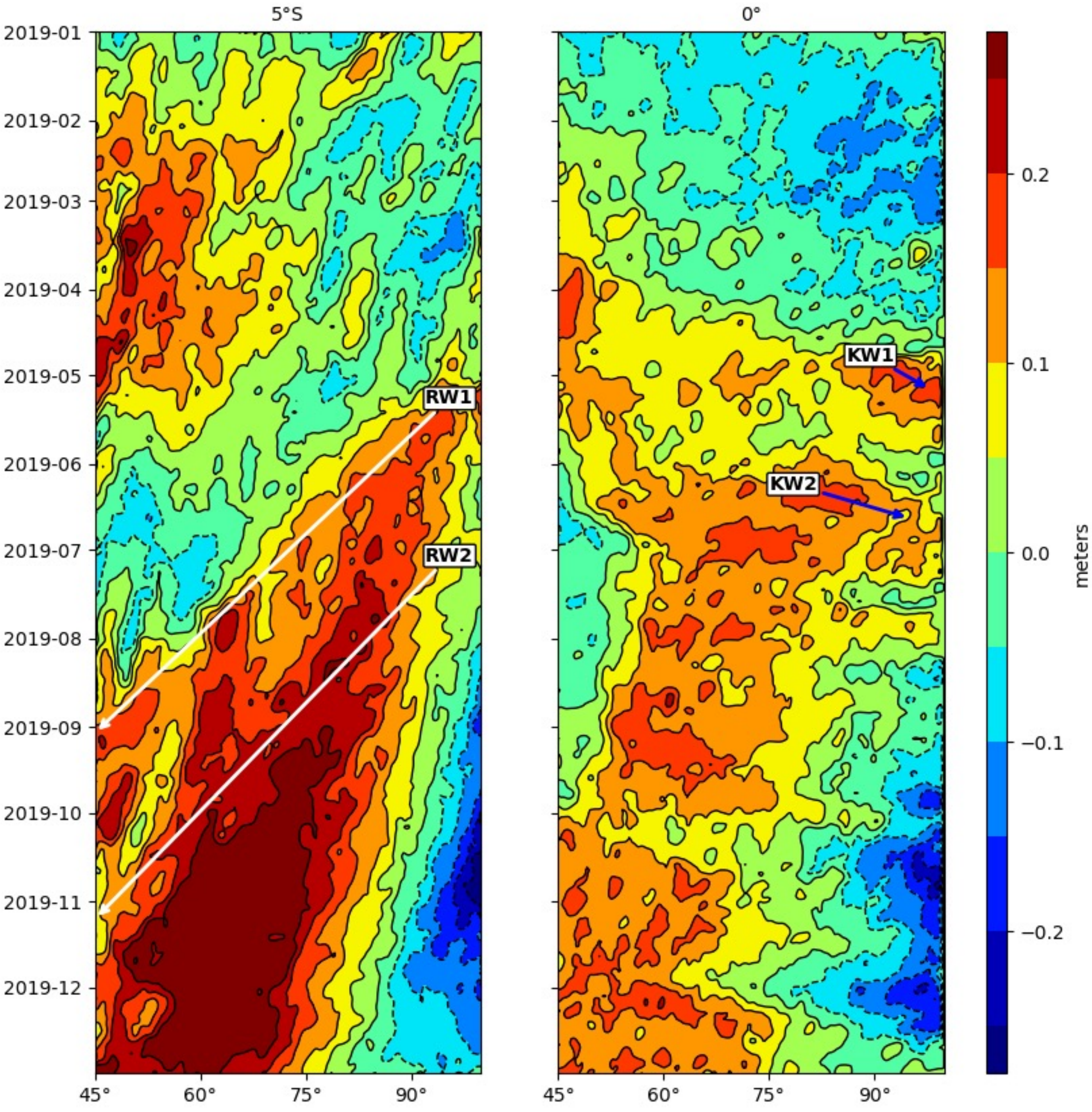


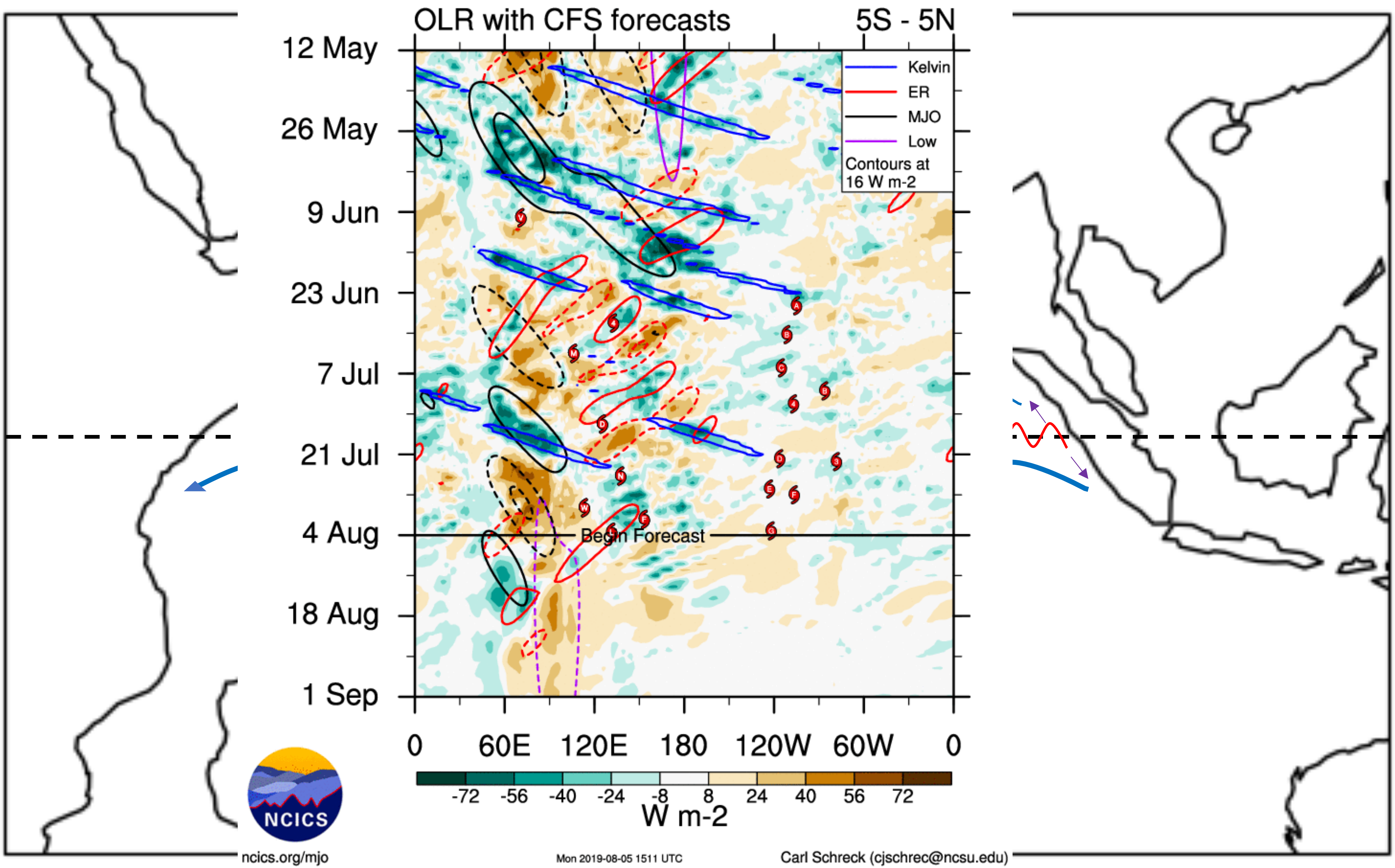
a) Northern Equatorial Thermocline
ORAS5 (0 to 5N)
b) Southern Equatorial Thermocline
ORAS5 (5S to 0)
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−54
−36
−18
0
18
36
54
Meters


INDIAN OCEAN DIPOLE
Positive phase
increased convection
Africa
India
cooler than normal
equator
increased chance of rain
warmer than normal
Indian ocean
Australia
reduced chance of rain
60°E
120°E
180°
longitude
NOAA Climate.gov
depth = 0.0 [m], lat = 0.0 [degree_north], lon ...
20C ISOTHERM DEPTH (M) [m]
140
130
120
110
100
90
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
time
depth = 0.0 [m], lat = -5.0 [degree_north], lon...
20C ISOTHERM DEPTH (M) [m]
140
130
120
110
100
90
80
70
2019-01
2019-03
2019-05
2019-07
2019-09
2019-11
2020-01
time


c) SLH Anomalies
NOAA Coastwatch
2019-01
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−0.2
−0.1
0.0
0.1
0.2
Meters
a) Zonal Wind Anomalies
ERA5
2019-01
2019-02
2019-03
2019-04
2019-05
2019-06
2019-07
2019-08
2019-09
2019-10
2019-11
2019-12
40°
60°
80°
100°
−9
−6
−3
0
3
6
9
m s^{-1}

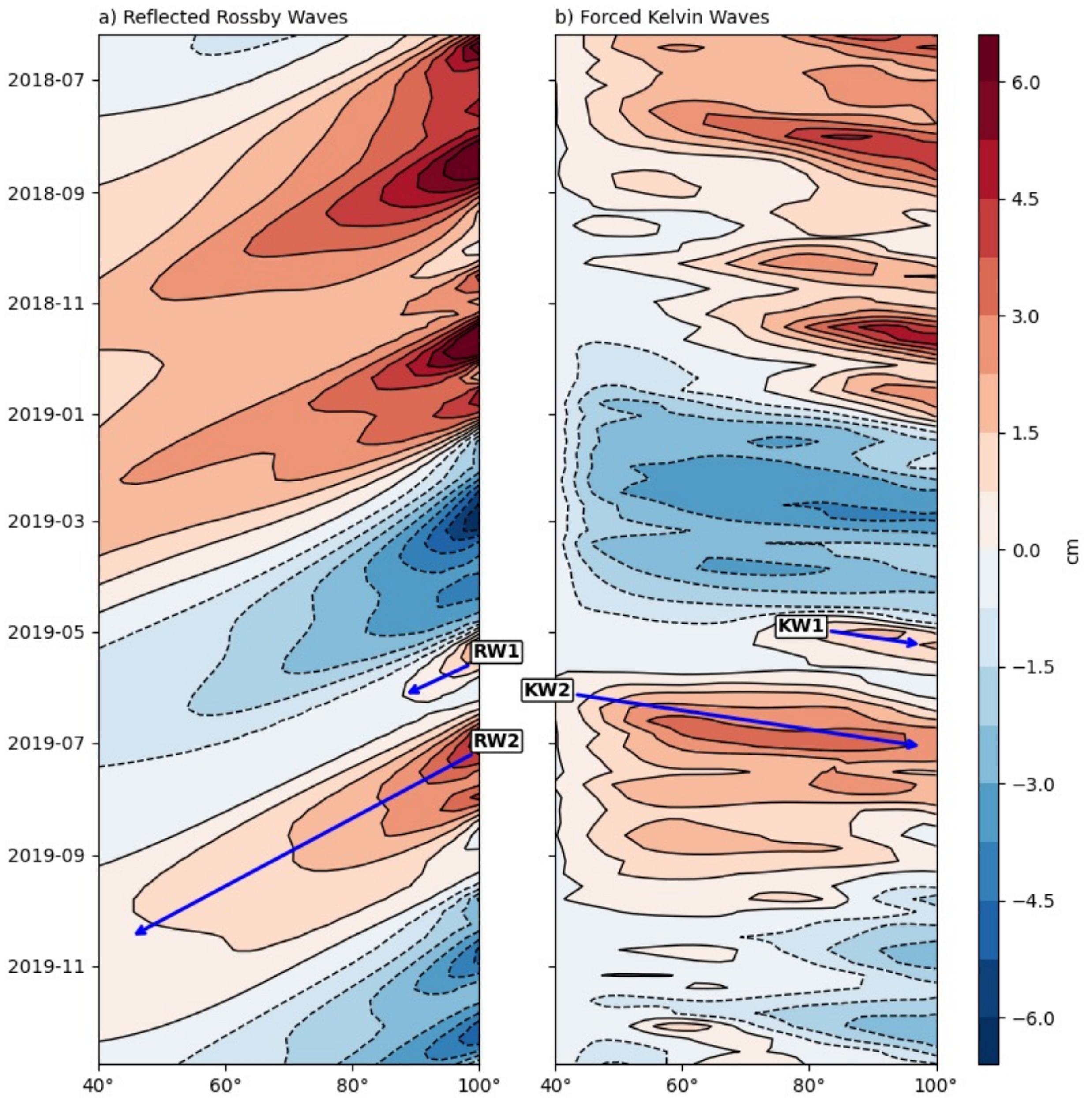
SLH Anomalies at 5S and the Equator




OLR with CFS forecasts
5S - 5N
12 May
26 May
9 Jun
23 Jun
7 Jul
21 Jul
4 Aug
18 Aug
1 Sep
Kelvin
ER
MJO
Low
Contours at 16 W m-2
Begin Forecast
0
60E
120E
180
120W
60W
0
-72
-56
-40
-24
-8
8
24
40
56
72
W m-2
NCICS
ncics.org/mjo
Mon 2019-08-05 1511 UTC
Carl Schreck (cjschrec@ncsu.edu)

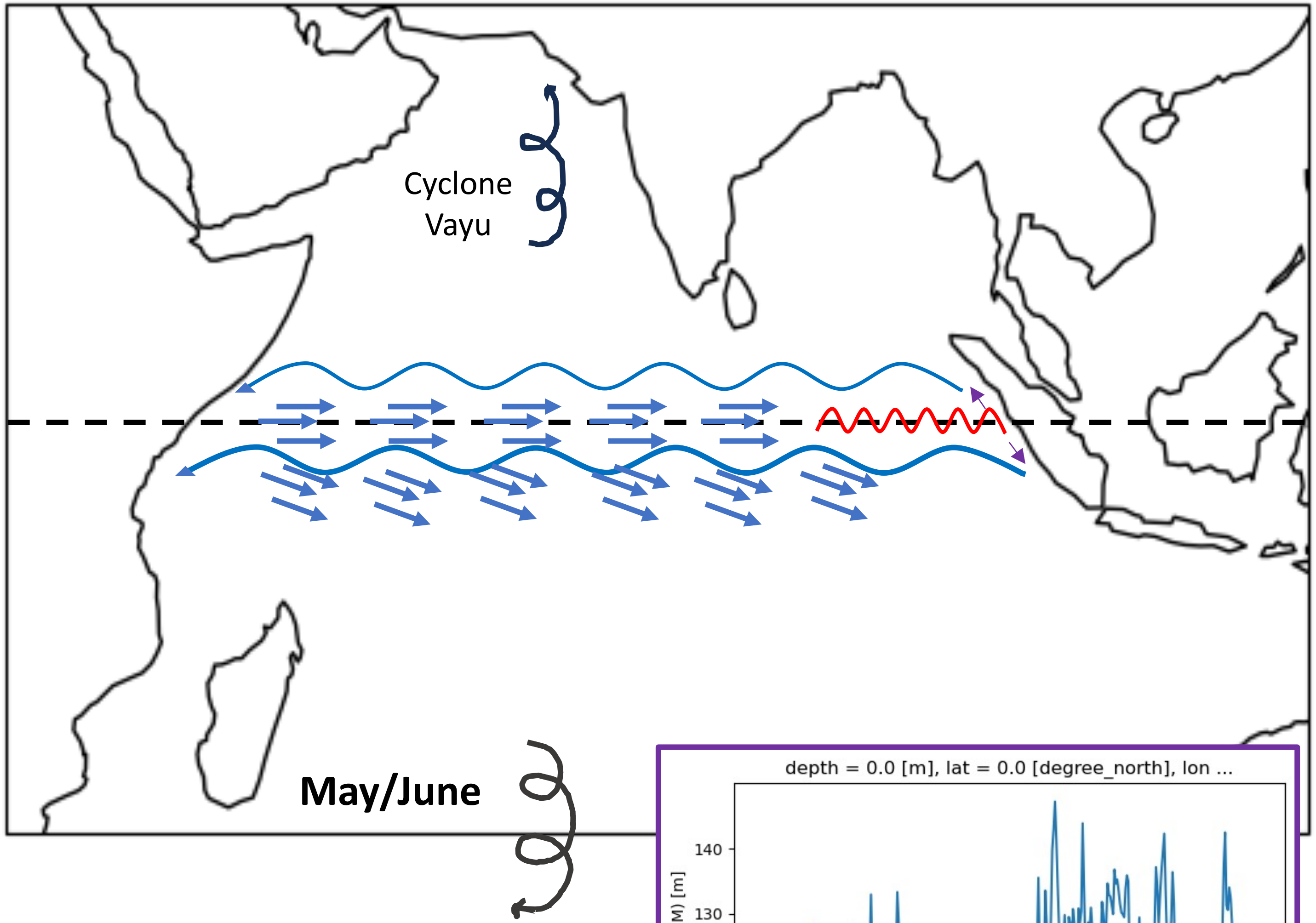
Linear Numerical Wave Model

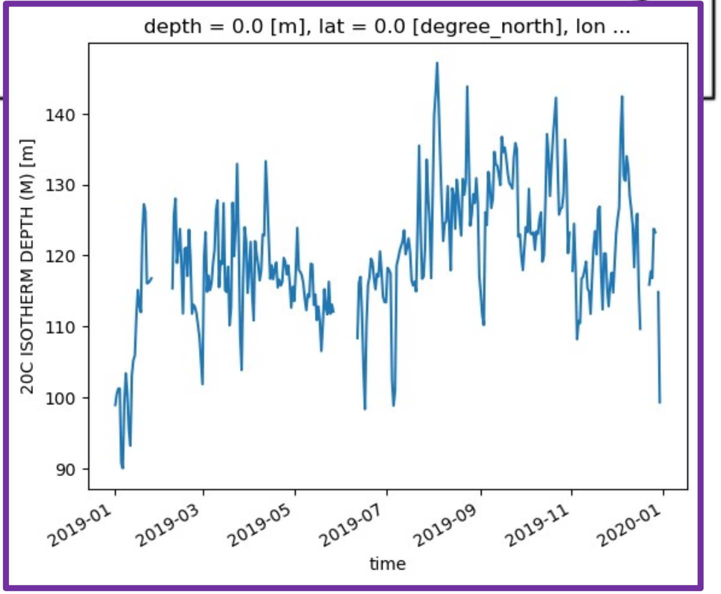
- Model described by McPhaden and Yu (1999) and Nagura and McPhaden (2010a)
- Region: 40°E-100°E and 5°S-5°N
- ERA5 12-hourly surface downward eastward stress data for the IO basin was obtained for 2017-2020

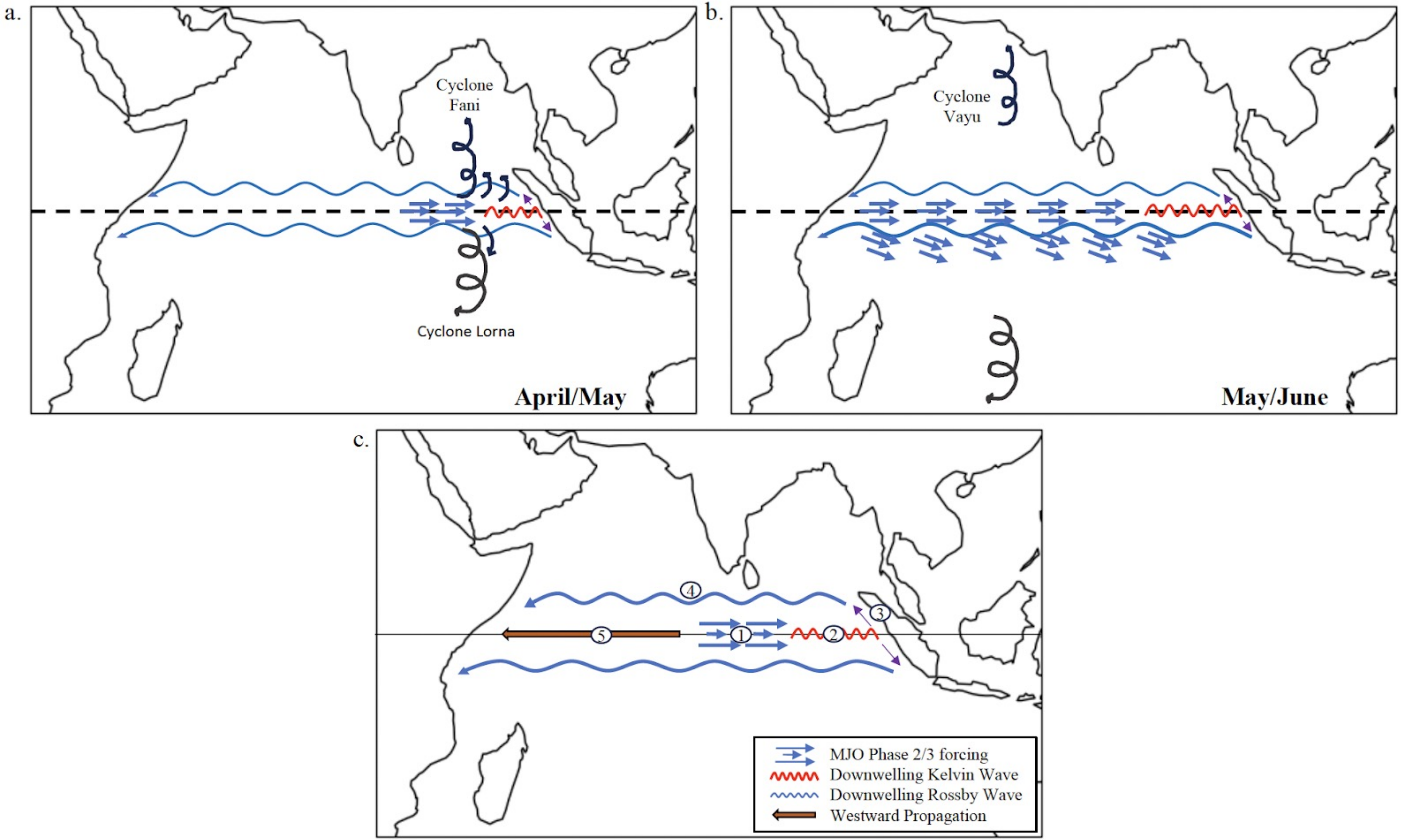


Pulse 2

- MJO interference depresses the thermocline across the Indian Ocean basin through wind forcing and wave interactions
- Continues water movement towards the west
- Hypothesis – this pulse triggers the positive IOD event







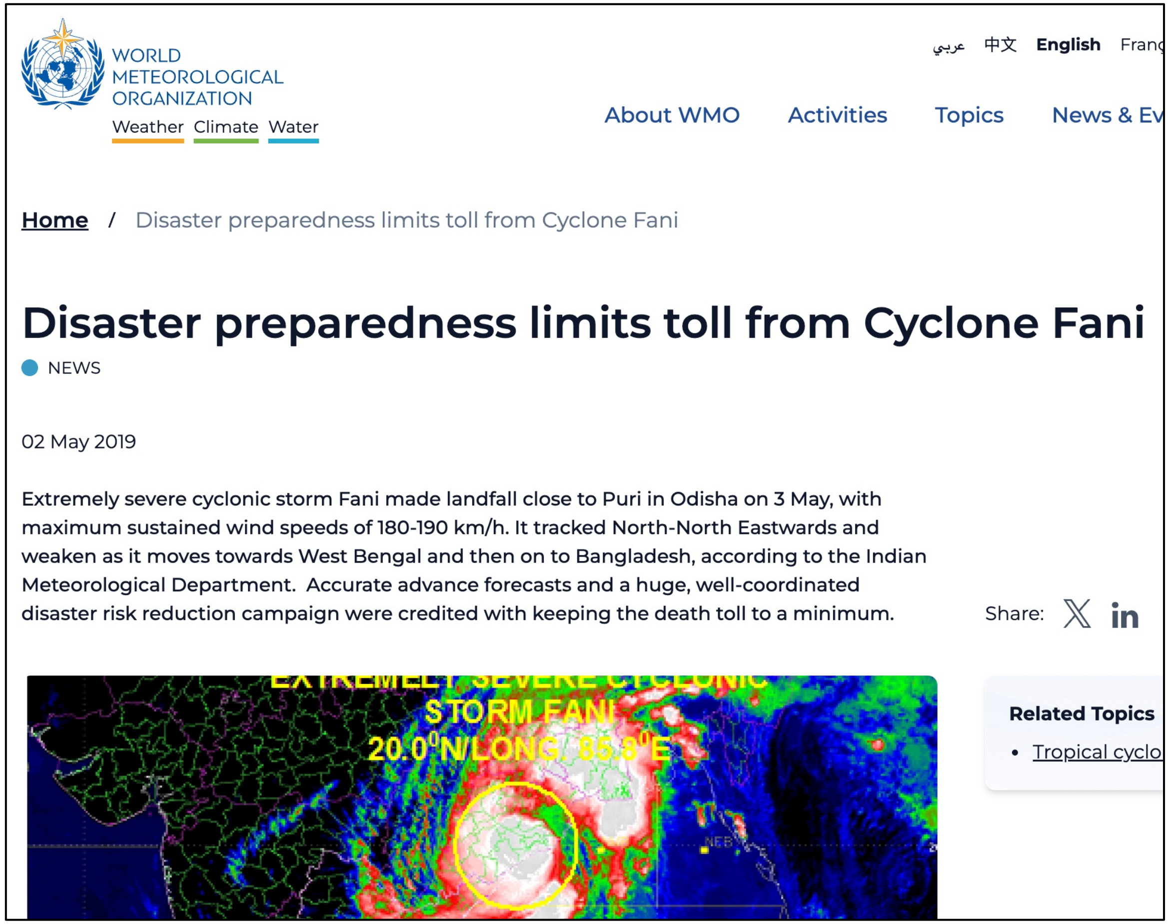
a.
Cyclone Fani
Cyclone Lorna
April/May
b.
Cyclone Vayu
May/June
c.
4
3
1
2
5
MJO Phase 2/3 forcing
Downwelling Kelvin Wave
Downwelling Rossby Wave
Westward Propagation

Conclusion

- MJO Pulse 1: preconditions the system
  - Impacts local sea level height, but not strong enough to depress thermocline across the basin
- MJO Pulse 2: utilizes the preconditioned system to trigger the +IOD event
  - Depresses thermocline across the Indian Ocean basin through wind forcing and wave interactions
- The two MJO pulses contribute to the 3 year long La Niña event
- Understanding how different modes of variability, like the IOD and the MJO interact can help us capitalize on forecasts to identify windows of opportunity, which can lead to the improvement of early warning systems and anticipatory action

Cyclone Fani – Disaster Preparedness

- Indian Prime Minister Shri Narendra Modi credited the role played by technology including satellite imagery and advanced weather forecasting techniques in minimizing loss of life.
- Fani reached a peak of the equivalent of a Category 4, with maximum sustained wind speeds of 190 – 200 km/h, gusting to 220 km/h on 2 May
- After landfall, it weakened gradually and was forecast to enter into West Bengal as a Severe Cyclonic Storm with the wind speed of 90- 100 km/h gusting to 115 km/h.
- The India Meteorological Department issued warnings for extremely heavy rainfall for affected areas in Odisha, North Andra Pradesh and West Bengal and other states. Sea conditions are “phenomenal” over the west-central Bay of Bengal and off north Andhra Pradesh coasts. Fishermen were advised not to venture out.



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Disaster preparedness limits toll from Cyclone Fani

NEWS

02 May 2019

Extremely severe cyclonic storm Fani made landfall close to Puri in Odisha on 3 May, with maximum sustained wind speeds of 180-190 km/h. It tracked North-North Eastwards and weaken as it moves towards West Bengal and then on to Bangladesh, according to the Indian Meteorological Department. Accurate advance forecasts and a huge, well-coordinated disaster risk reduction campaign were credited with keeping the death toll to a minimum.

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Thank you!

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