Summer Monsoon 2023: Influence of deviant El Niño and mid-latitude circulation

Jasti S. Chowdary[1]

Email: jasti@tropmet.res.in

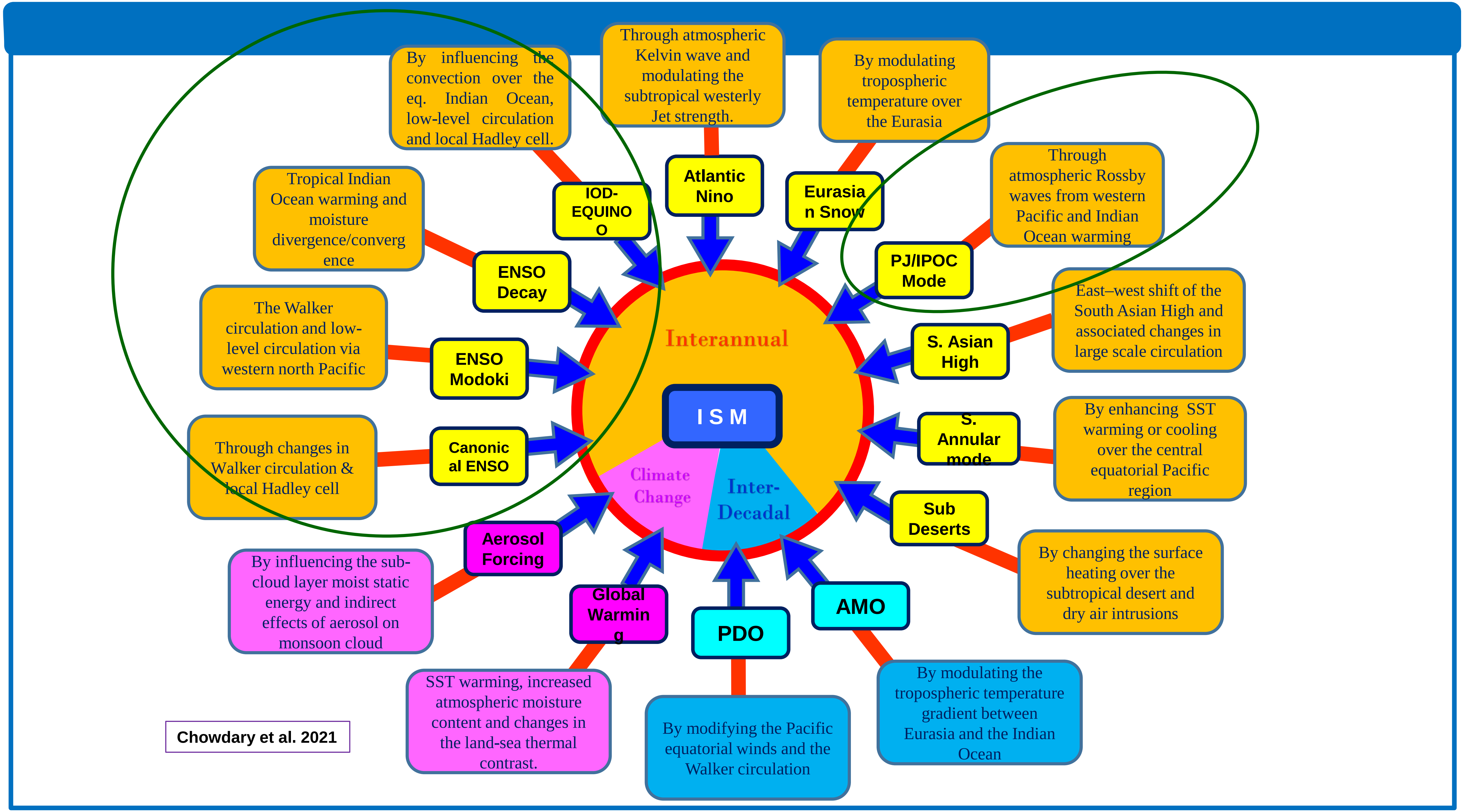
N. Mahendra[1], C. Nagaraju[1], S. Renuka[1], Anant Parekh[2], C. Gnanaseelan[2]

[1] **Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, Maharashtra, India**

Department of Earth and Atmospheric Sciences, National Institute of Technology, Rourkela – 769008, India.

Indian Summer Monsoon 2023

- **Historically, El Niño events have consistently signalled below-average monsoon rainfall in India excluding 1997.**
- **Despite 2023 being an El Niño year, India experienced normal monsoon seasonal rainfall (-6% of the Long Period Average: LPA) with above-average rainfall (+13% of LPA) during July and September but unadorned deficit rainfall in August (-36% of LPA).**
- **Thus, the complex relationship of El Niño with the Indian summer monsoon rainfall (ISMR) is apparently evident during summer 2023.**
- **Monthly rainfall variations starkly challenge conventional hypotheses, necessity for a profound understanding of the dynamics behind them.**
- **Here attempt is made to understand the complexity of ENSO interplay with regional climatic factors, particularly failure of the 2023 August monsoon rainfall focusing the mid-latitudes circulation and IOD.**

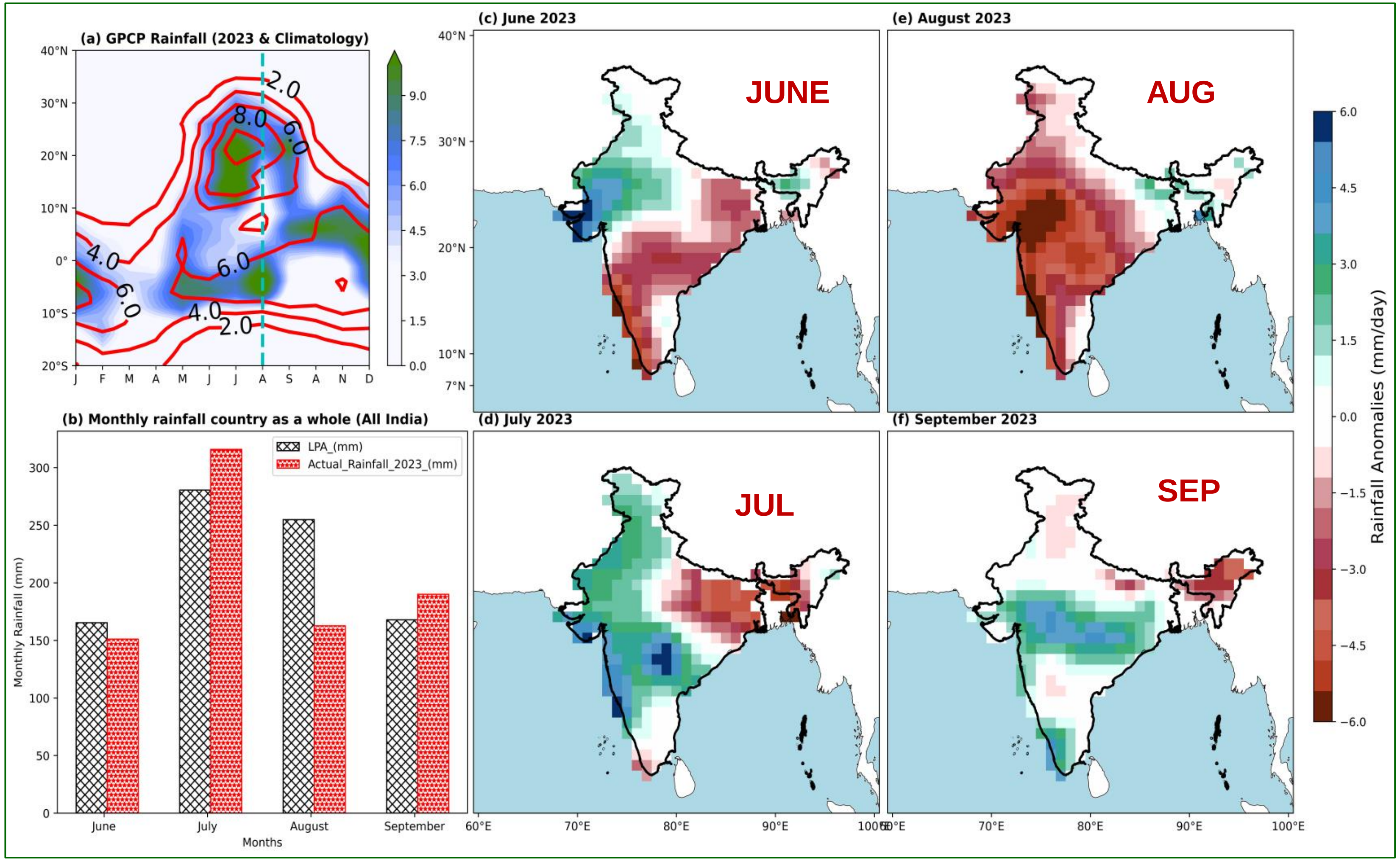


By influencing the convection over the eq. Indian Ocean, low-level circulation and local Hadley cell.
Through atmospheric Kelvin wave and modulating the subtropical westerly Jet strength.
By modulating tropospheric temperature over the Eurasia
Through atmospheric Rossby waves from western Pacific and Indian Ocean warming
Tropical Indian Ocean warming and moisture divergence/convergence
IOD-EQUINOO
Atlantic Nino
Eurasian Snow
PJ/IPOC Mode
ENSO Decay
The Walker circulation and low-level circulation via western north Pacific
ENSO Modoki
Interannual
East–west shift of the South Asian High and associated changes in large scale circulation
S. Asian High
I S M
By enhancing SST warming or cooling over the central equatorial Pacific region
S. Annular mode
Through changes in Walker circulation & local Hadley cell
Canonical ENSO
Climate Change
Inter-Decadal
Sub Deserts
Aerosol Forcing
By changing the surface heating over the subtropical desert and dry air intrusions
By influencing the sub-cloud layer moist static energy and indirect effects of aerosol on monsoon cloud
Global Warming
PDO
AMO
SST warming, increased atmospheric moisture content and changes in the land-sea thermal contrast.
By modifying the Pacific equatorial winds and the Walker circulation
By modulating the tropospheric temperature gradient between Eurasia and the Indian Ocean
Chowdary et al. 2021

Data and Methodology

- **In this study, reanalysis datasets are used from 1981 to the present, such as the National Oceanic and Atmospheric Administration (NOAA) high resolution (0.25° x 0.25°) Optimum Interpolation Sea Surface Temperature V2.1 (OISST-V2.1: Huang et al. 2021).**
- **Precipitation data was obtained from the Global Precipitation Climatology Project (GPCP) V2.3 (Adler et al. 2003).**
- **The remaining meteorological variables, such as winds (u, v, and w), relative humidity, specific humidity, and geopotential height, were taken from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) Reanalysis (https://psl.noaa.gov; Kalnay et al. 1996).**
- **Vertically Integrated Moisture Flux Transport (VIMFT) and Vertically Integrated Moisture Flux Convergence (VIMFC).**
- **We also calculate the barotropic (Rossby) potential vorticity (Holton 2007).**

Monthly rainfall anomalies spatial distribution summer 2023



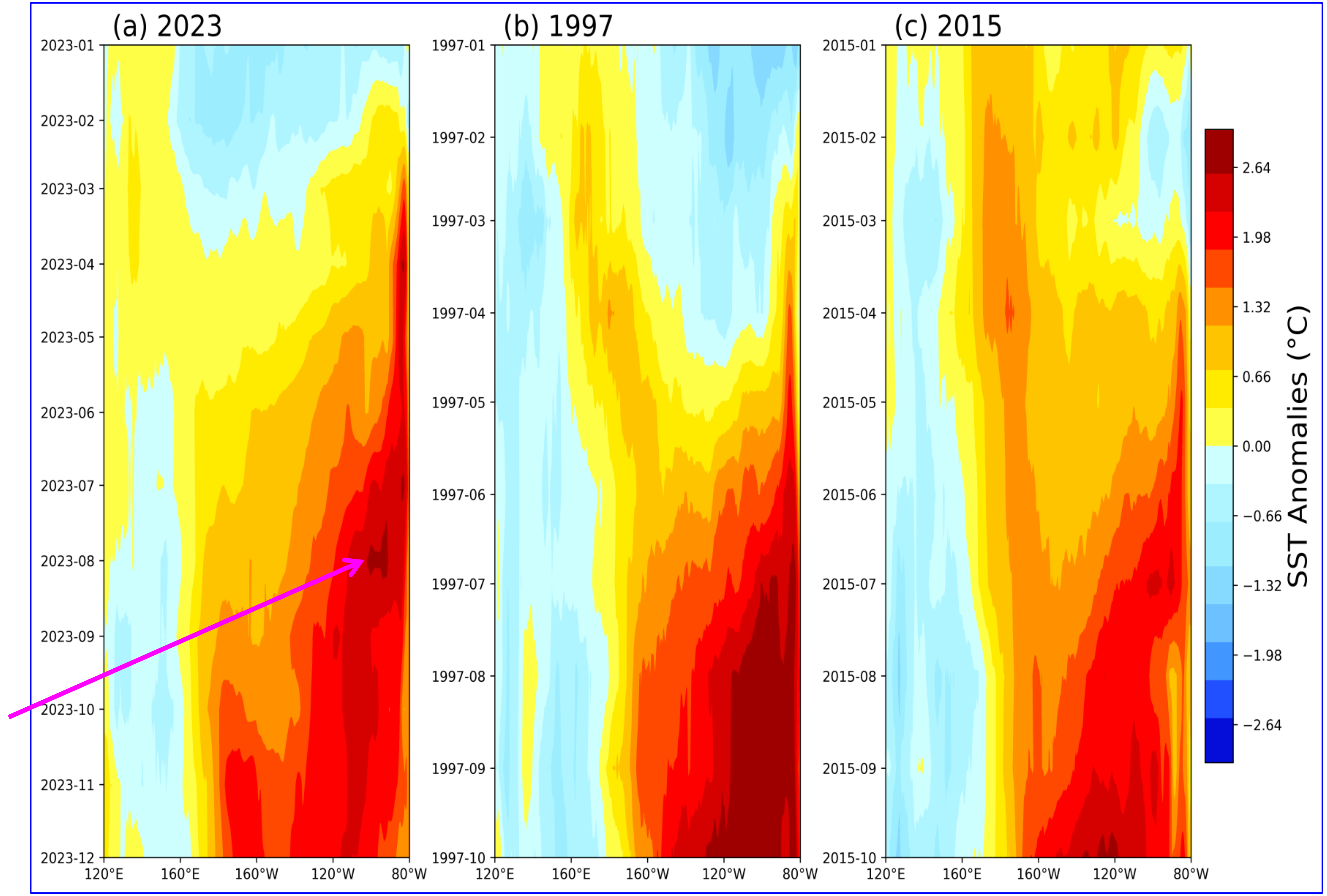
- August, in contrast to July, saw large negative rainfall anomalies across the entire country except for a few pockets in the northeast.

Latitude-time cross-section depicting precipitation in 2023 shaded (mm/day) overlaid with climatology contours spanning the period of 1980 - 2023, averaged over the longitude range of 70°E to 90°E (a).

Monthly cumulative rainfall for the entire country during June to September 2023 is illustrated by red hatched bars, contrasted against the LPA represented by black hatched bars (b).

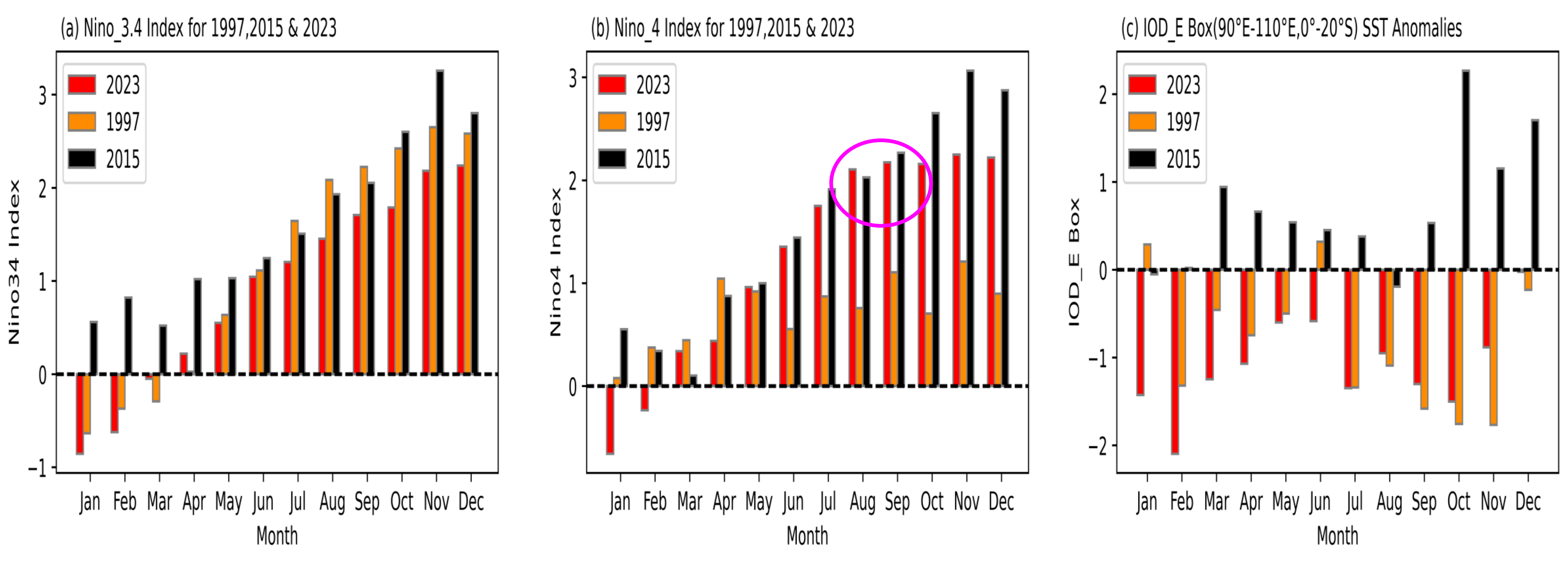
Panels (c to f) exhibit the distinctive JJAS (June to September) rainfall anomalies for 2023, providing a comprehensive view of the deviations from the mean.

Monthly evolution of equatorial Pacific SST anomalies



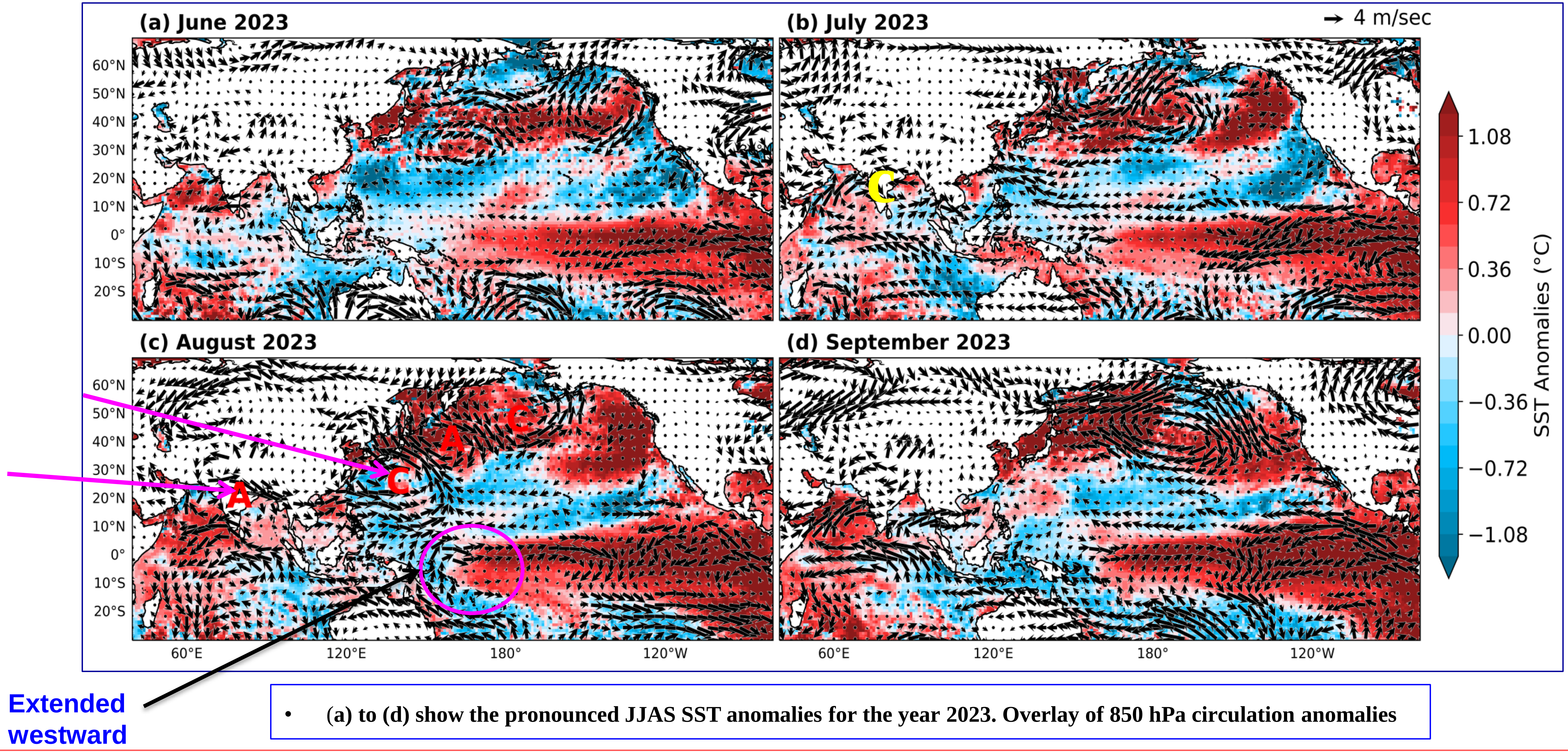
Time-longitude cross-section - robust monthly evolution of equatorial Pacific SST anomalies averaged over (5°N-5°S) during the developing phases of El Niño in 2023 (a), 1997 (b), and 2015 (c).

Nino3.4 Index , Nino4 Index and east equatorial IO SST anomalies



- **Monthly evolution of the Nino3.4 Index (a), Nino4 Index (b), and the southeast Indian Ocean SST region averaged over (90°E-110°E, 0-20°S). The distinct trends for the years 2023 (red), 1997 (orange), and 2015 (black).**

JJAS SST anomalies and 850 hPa circulation

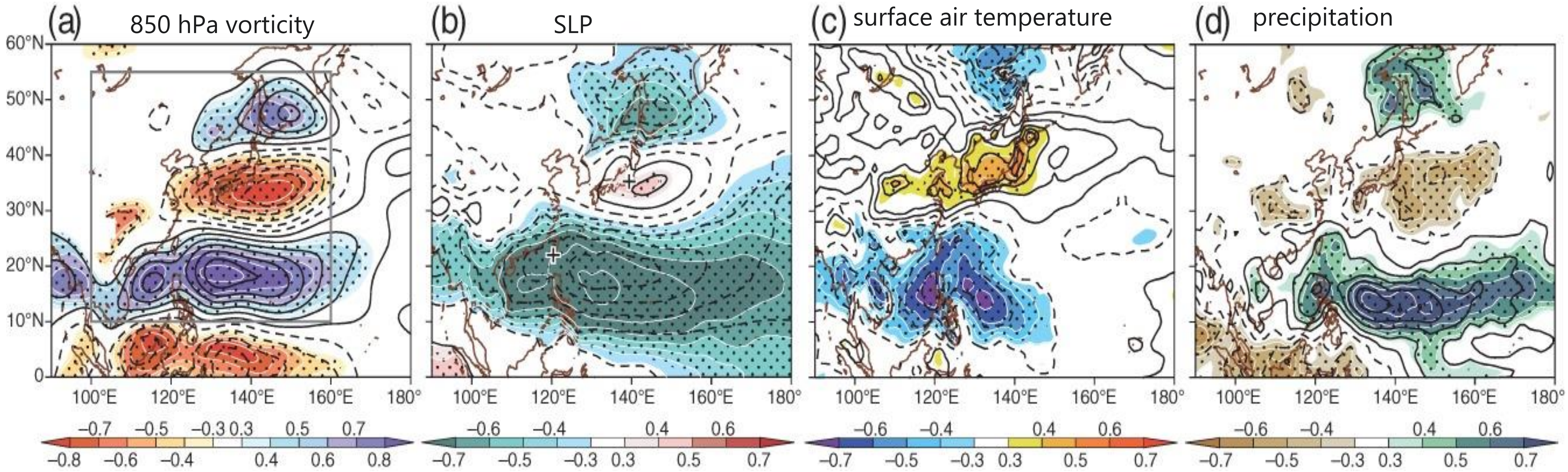


- (a) to (d) show the pronounced JJAS SST anomalies for the year 2023. Overlay of 850 hPa circulation anomalies

Anomalous cyclonic, anticyclonic and cyclonic circulations are noted along the western boundary of the northern Pacific as meridional wave response (Fig 2c) resembling a "Pacific Japan (PJ) pattern" (e.g., Yasui and Watanabe 2010; Kosaka and Nakamura 2010a; Srinivas et al. 2018; Kosaka 2021).

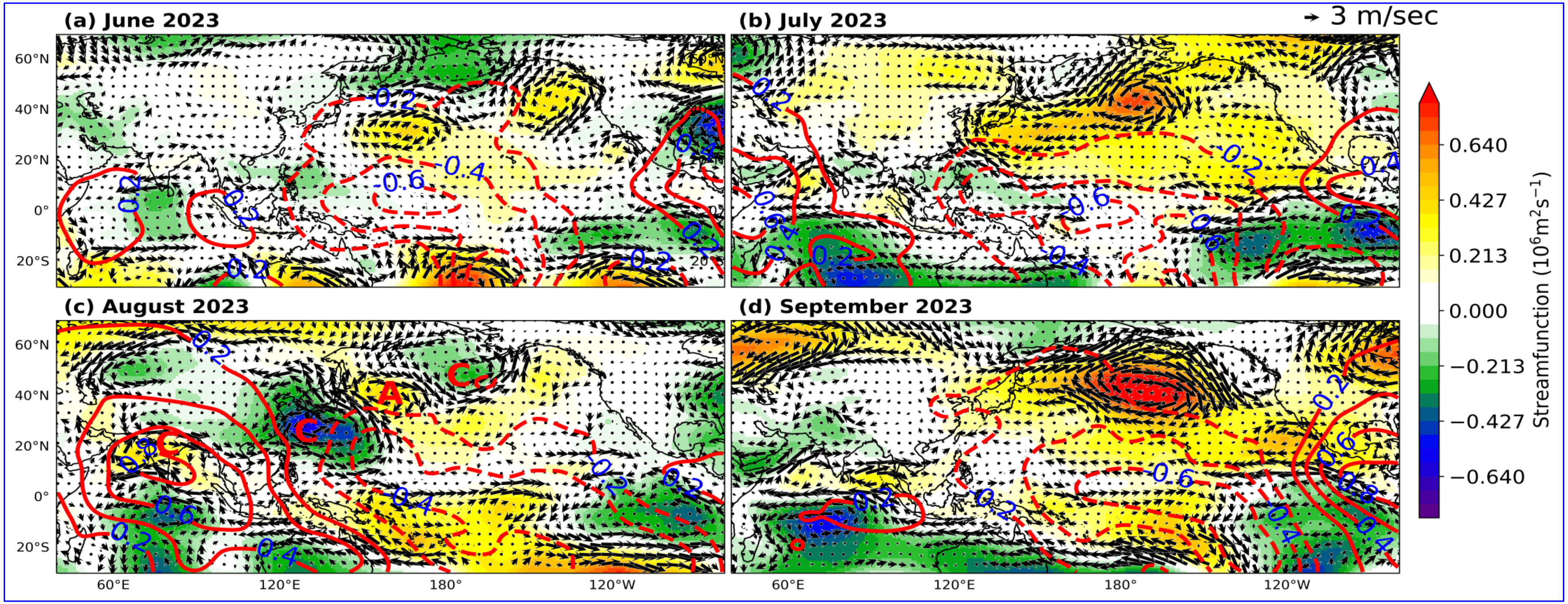
The Pacific-Japan (PJ) pattern

- **The Pacific-Japan (PJ) teleconnection pattern is a dominant pattern of interannual variability for the WNP and East Asian summer monsoons (Nitta, 1987).**
- **The PJ pattern features an anomalous dipole of lower tropospheric circulation, whose centres of action are over the Philippine Sea and the midlatitudes around Japan.**



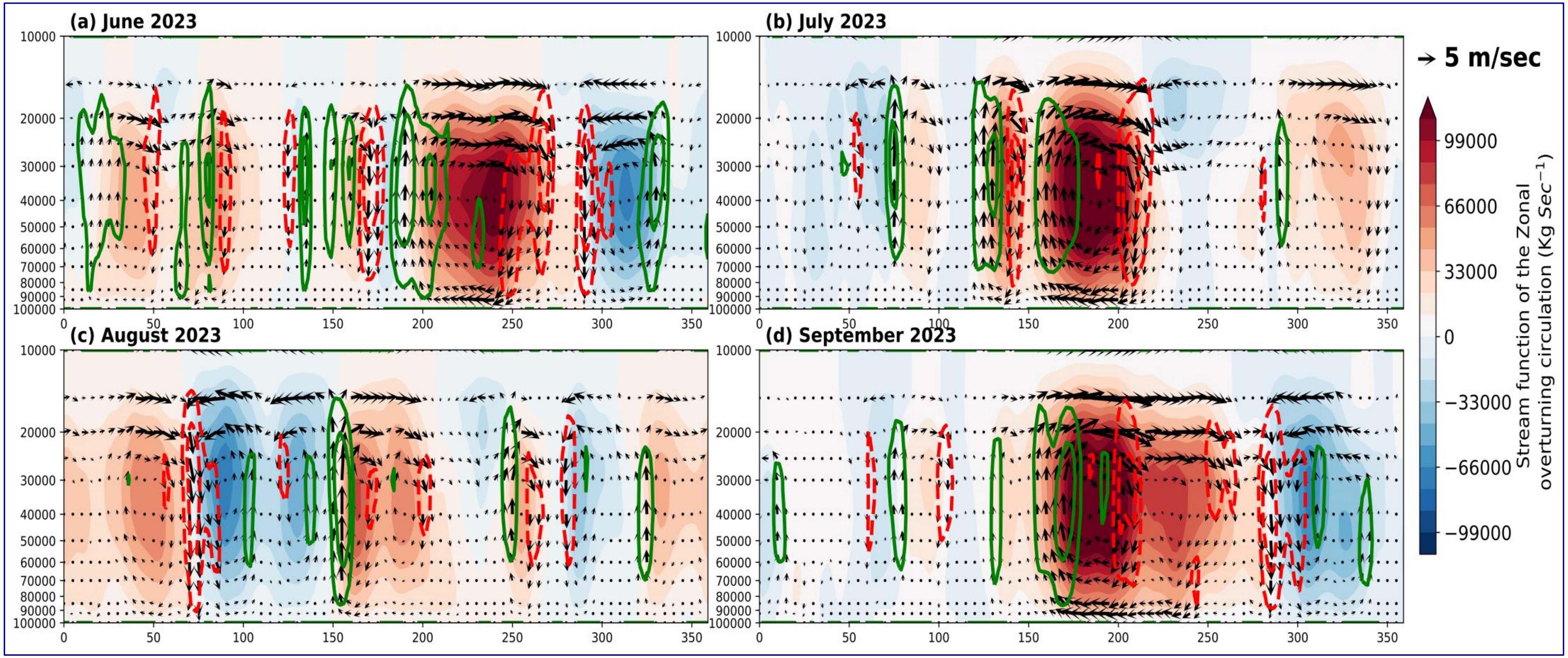
Regressed anomalies (contours) and correlations (shading) with respect to PC1 of 850 hPa vorticity over (10°–55°N, 100°–160°E) [the box in (a)] in JJA for 1979–2009 based on JRA55. (a) 850 hPa vorticity, (b) SLP, (c) surface air temperature and (d) precipitation. (a–c) JRA55 and (d) CMAP. Stippling represents confidence level >95%. **Kubota et al. 2015.**

JJAS stream function and rotational wind anomalies at 850 hPa and 200 hPa velocity potential



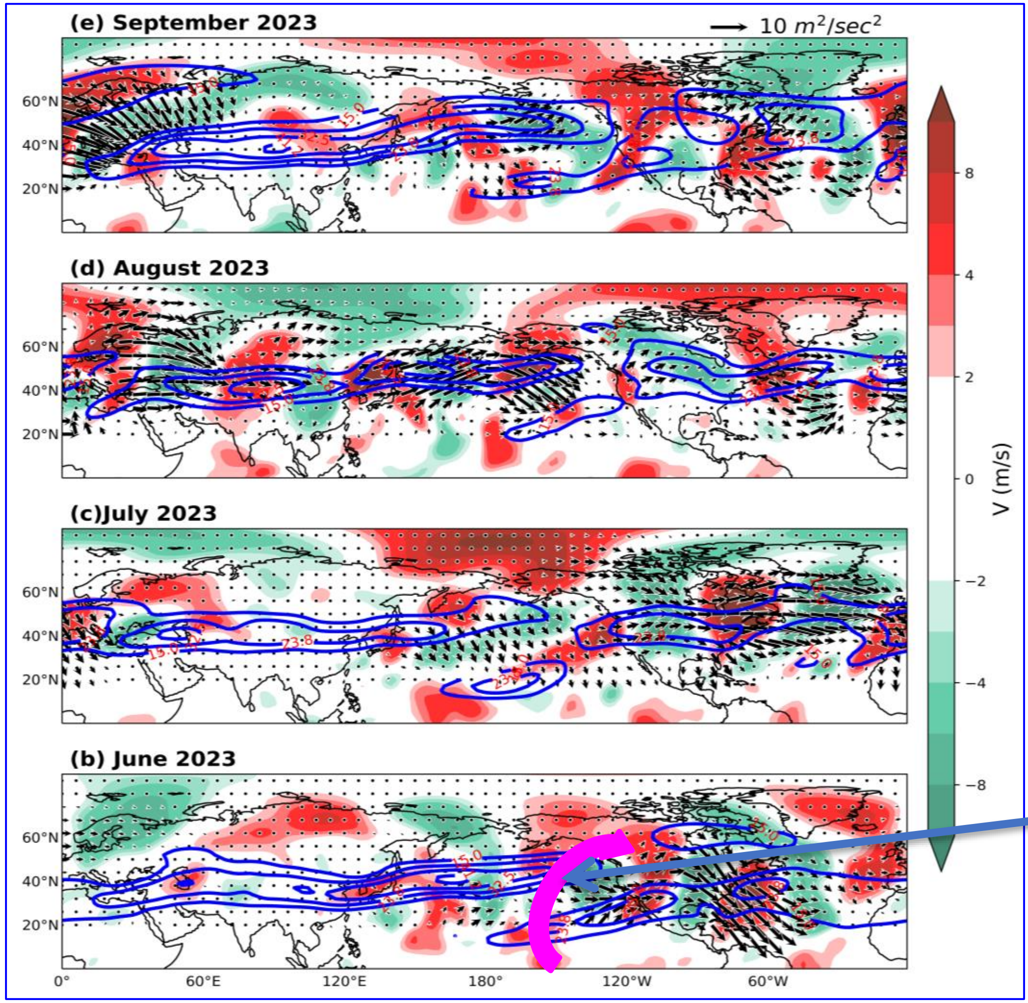
- An interesting observation in **August 2023** is the extension of anomalous westerlies from the northern flank of the anticyclone over the Indian subcontinent, making a connection with the cyclonic circulation over the WNP.
- Notably, significant deviations are observed in July and September, suggesting the influence of the IOD, namely, the absence of anomalous meridional circulation, mitigated the impact of El Niño on the monsoon.

Zonal overturning circulation averaged over 10°N- 30°N



- (a) to (d) show the pronounced JJAS streamfunction of the zonal overturning circulation (shaded) and zonal and vertical wind (vectors) anomalies and vertical velocity (contours) averaged over 10°N- 30°N for the year 2023.

200hPa meridional wind anomalies and zonal wind – the mid-latitude wave pattern

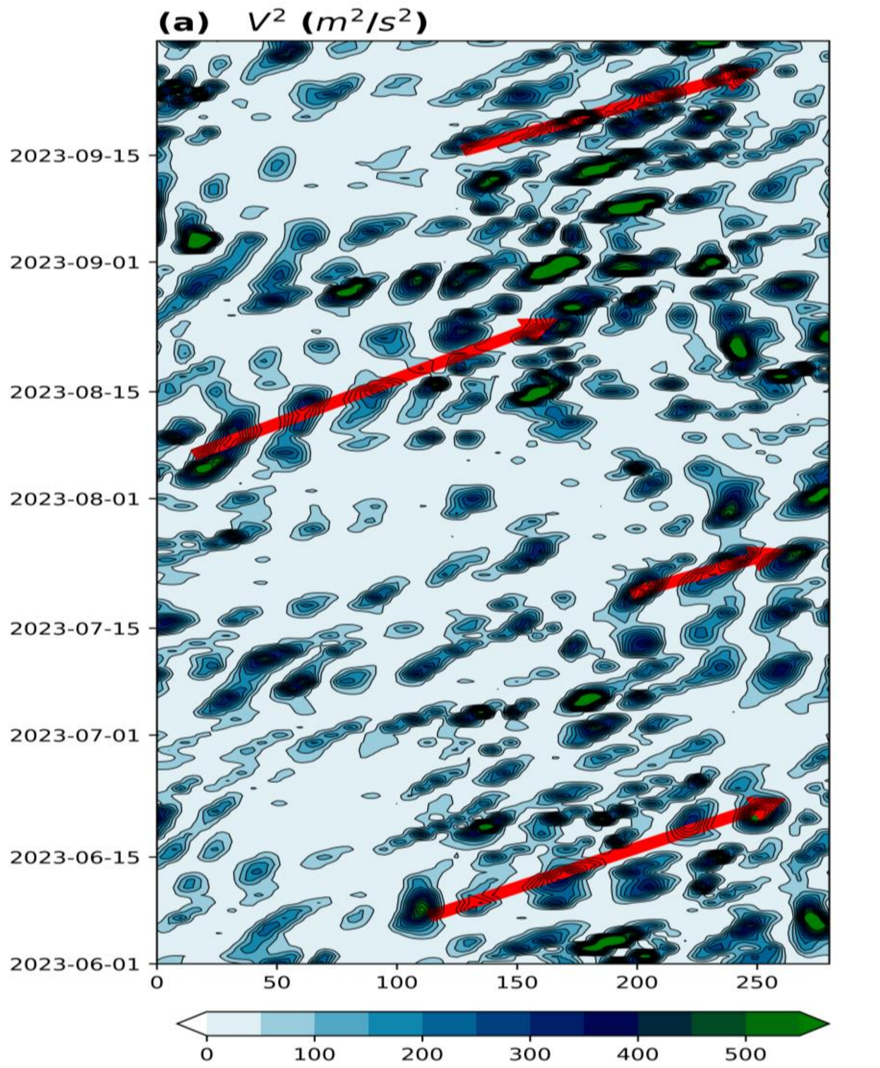


- **b-e: the wave activity flux** (m2/s2) **, meridional wind anomalies (shaded) and mean zonal wind (m/s).**

- **Figure illustrate the dynamic and spatial evolution of the mid-latitude wave pattern across the specified months.**

- **Specifically, in June, the wave pattern shows up across the northeast Pacific and north Atlantic, followed by a shift to the north Atlantic in July. By August, the wave propagation extends toward west-central Asia and the north-western Pacific, ending in September.**

- **Anomalous westerly conditions, linked with underlying warming, initiates westerly anomalies in the double jet region of the eastern north Pacific, thereby providing suitable conditions for the propagation of the tropical Pacific ENSO signal into the mid-latitudes and ultimately toward East Asia within the westerly waveguide (e.g., Webster and Holton 1982; Hoskins and Ambrizzi 1993; Wen et al. 2019).**

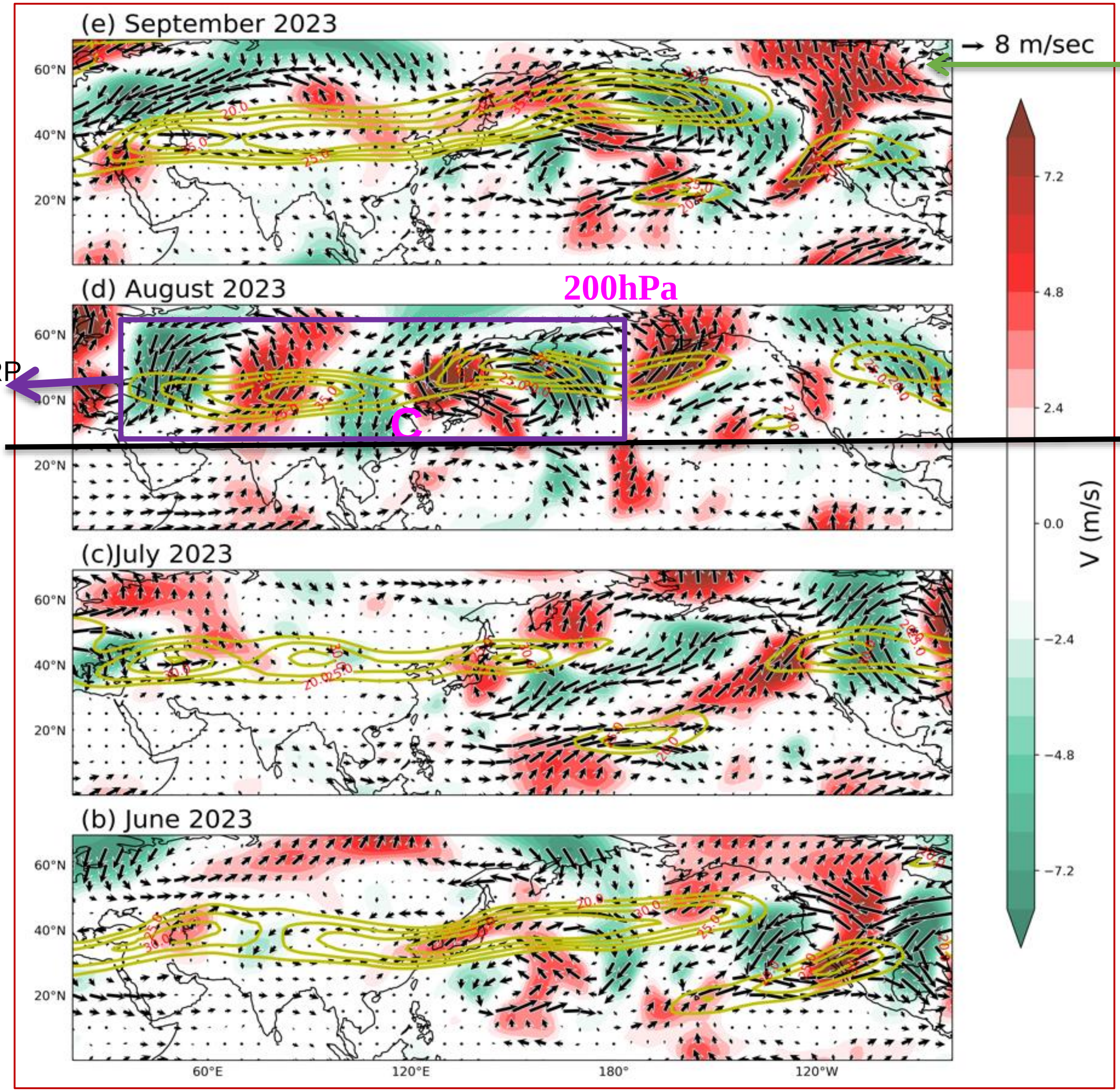


Time-longitude cross-section robust monthly evolution of 200 hPa meridional wind averaged over (30N-60N) during the developing phases of El Niño in 2023 (a).

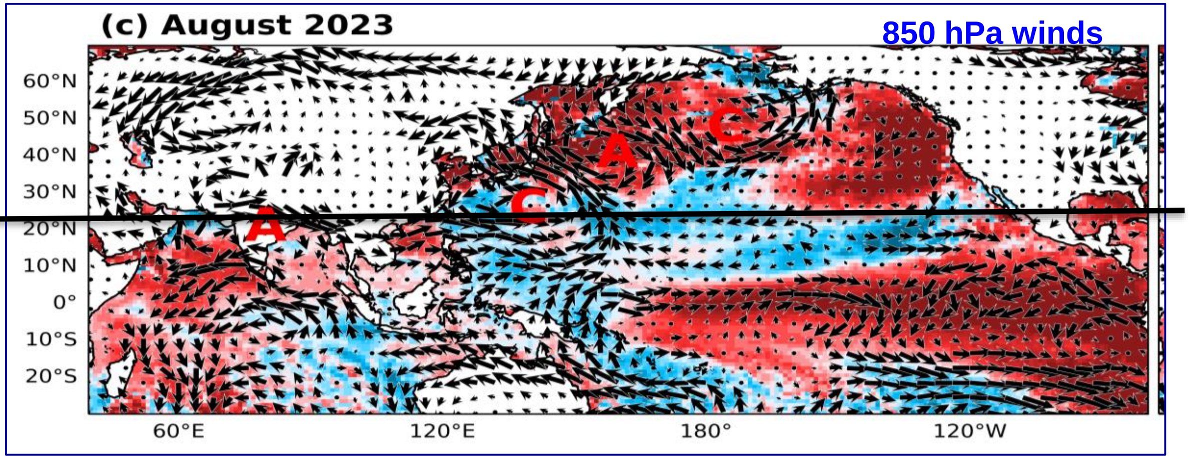
By August, the wave propagation extends toward west-central Asia and the north-western Pacific.

This results in line with Hoskins and Ambrizzi (1993) and Ambrizzi and Hoskins (1997) investigation with simple barotropic model integration under various vorticity source perturbations demonstrates the propagation of waveguides from the equatorial Pacific across the North Atlantic Ocean and even extending into the Arabian Gulf.

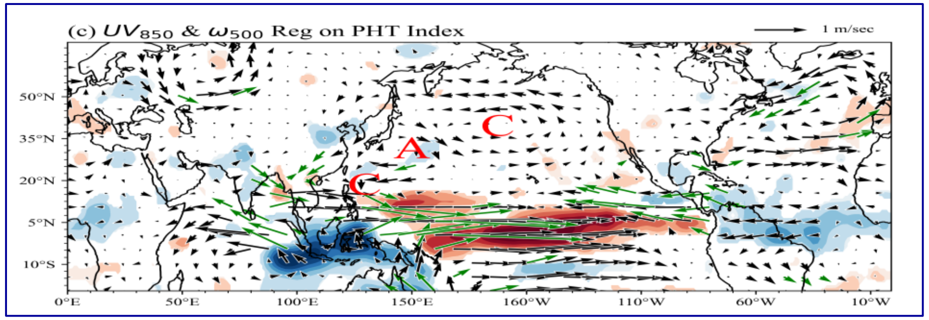
200hPa meridional wind anomalies and zonal wind



- (b) to (e) show the pronounced JJAS months 200 hPa meridional wind anomalies (shaded) and zonal wind red contours: >20 and interval of 5 m/s) for the year 2023.



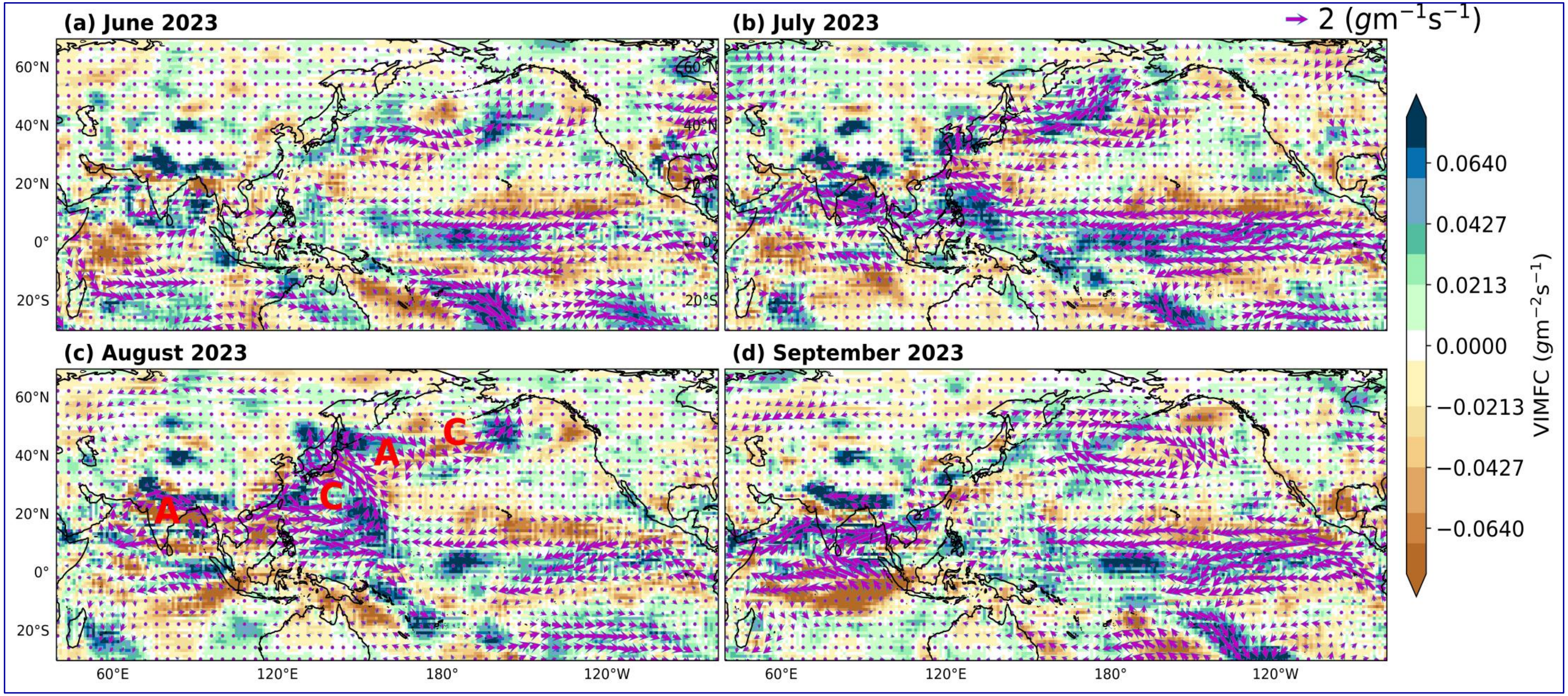
Regression of developing El Niño-induced heating indices with the 850 hPa wind anomalies



Rossby wave train response can enhance or dampen ongoing circulation patterns (Kiladis and Weickmann, 1992; Renwick and Revell, 1999).

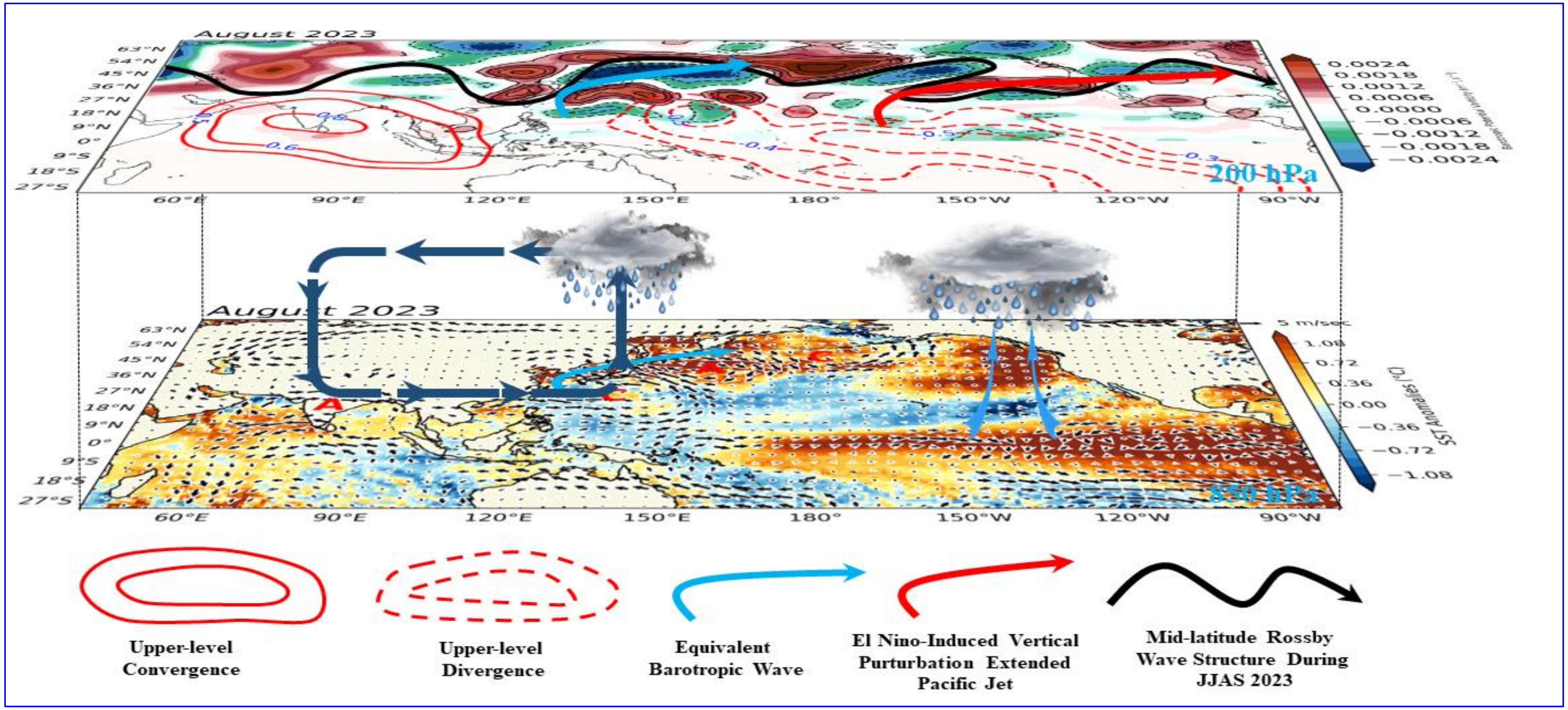
Some recent study (Takemura and Mukougawa 2020, Vibhute et al. (2023), Darshana et al. 2024) further suggests that the Silk Road pattern affects the WNP summer monsoon variability and triggers the PJ pattern.

Vertical integrated moisture flux and transport



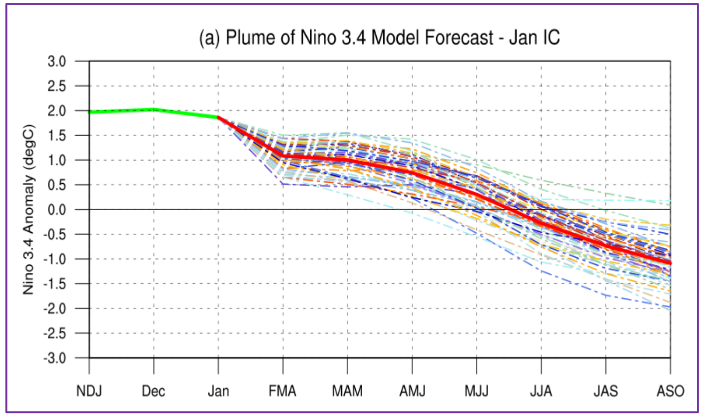
- (a) to (d) show the pronounced JJAS vertical integrated moisture flux convergence (shaded) and vertically integrated moisture flux transport (vectors) anomalies for the year 2023. Additionally, cyan coloured "C" and "A" mark cyclonic and anticyclonic patterns.

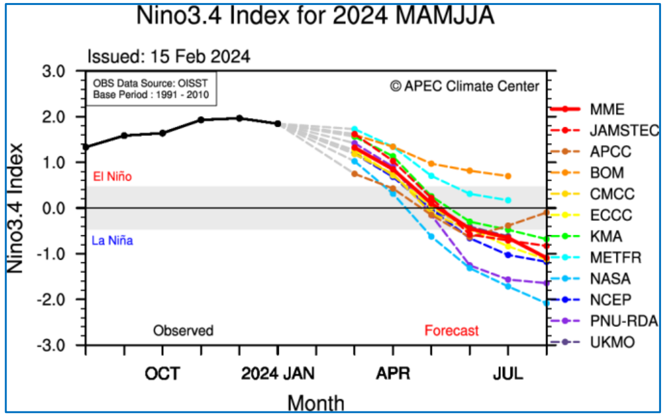
Schematic diagram explaining the in August 2023 rainfall deficit - Mahendra et al....Revised CD

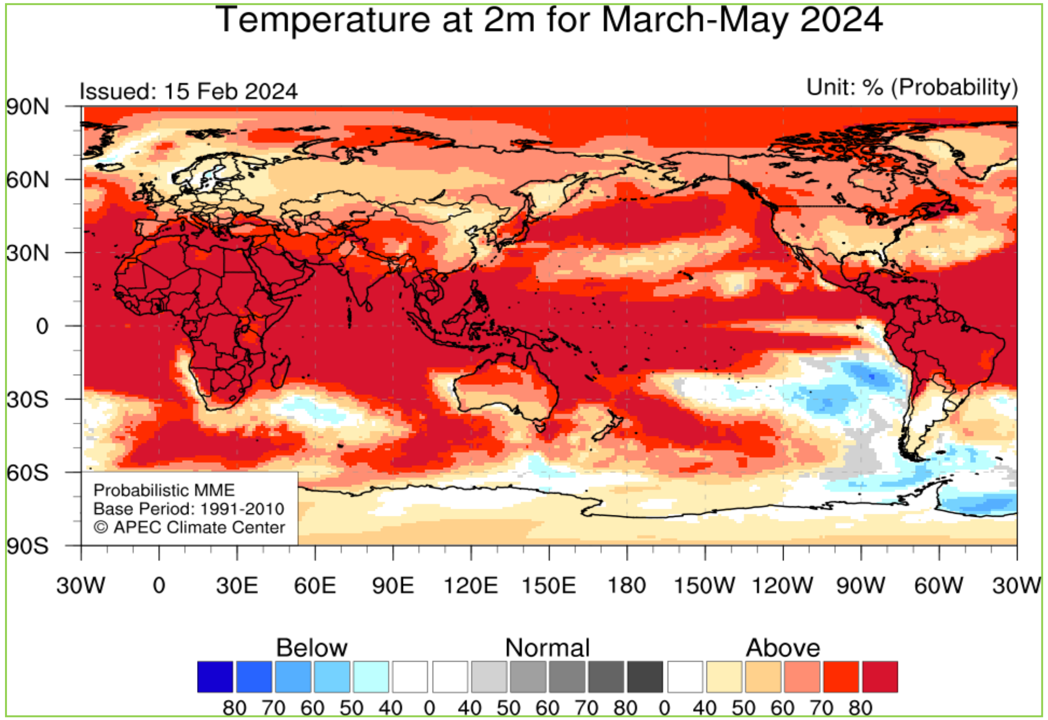


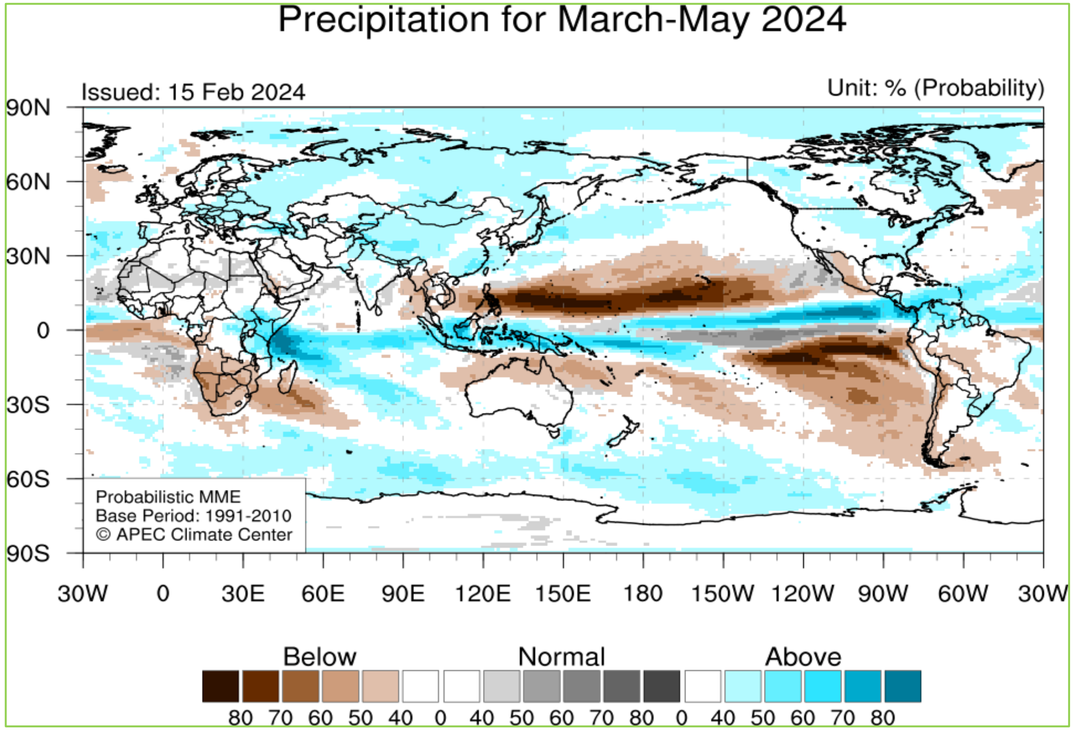
Schematic diagram explaining the in August 2023 El Niño-induced convective activity over the western tropical Pacific, generating the low and upper level equivalent barotropic wave structure propagation along the East Asia coast (as indicated by the sky-blue curve). The red curve refers to the El Niño-induced vertical perturbation over the eastern-central tropical Pacific into the subtropical jet during June, July, and September, exciting the wave propagation downstream to East Asia (as indicated by the black curve). Red colour solid and dashed contours denote the upper level convergence (positive) and divergence (divergence) velocity potential respectively.

APCC – MAM temp and rainfall prediction





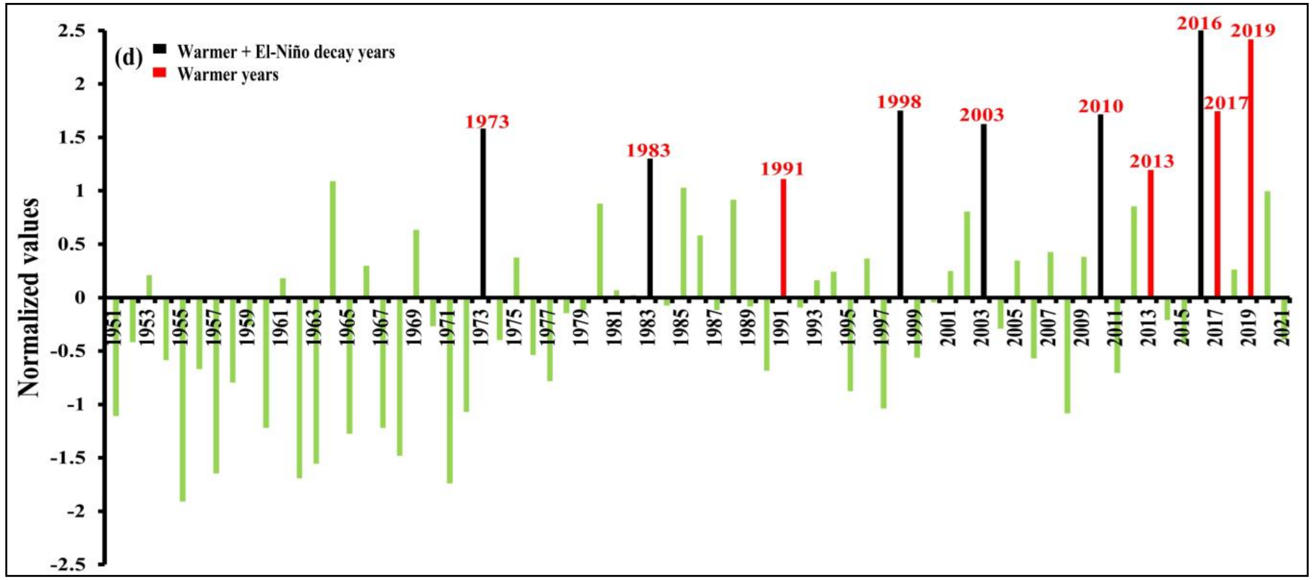




https://www.apcc21.org/prediction/global/outlook?lang=en

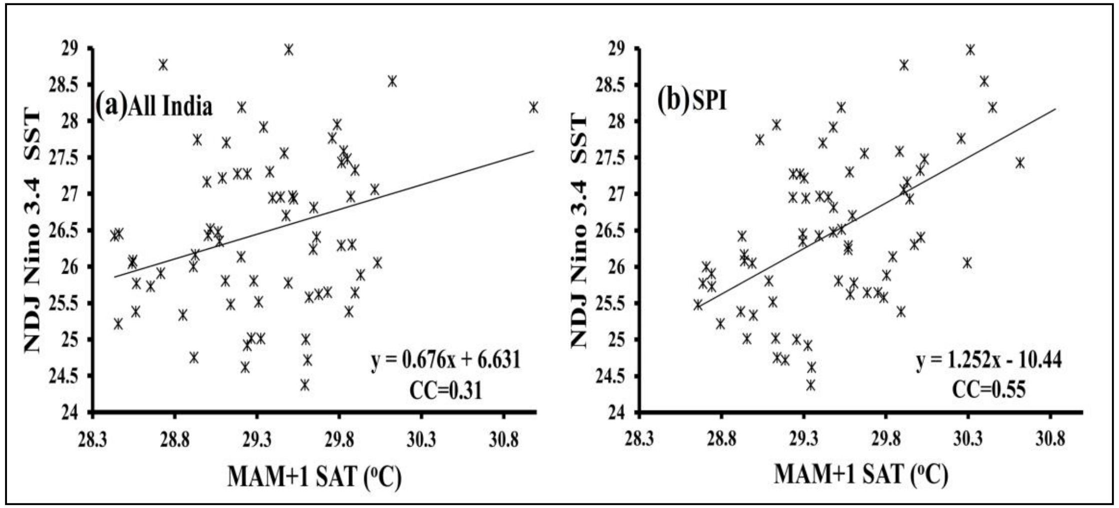
Delayed impact of El Nino – applicable for 2024 – Spring SAT over India

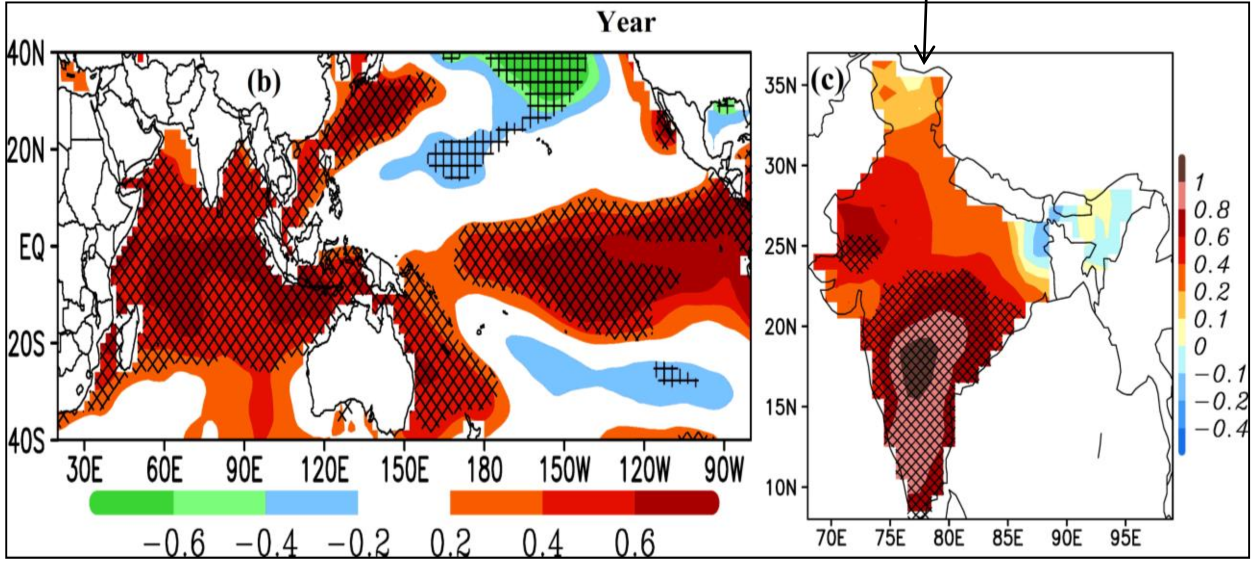
MAM –SAT time series - India



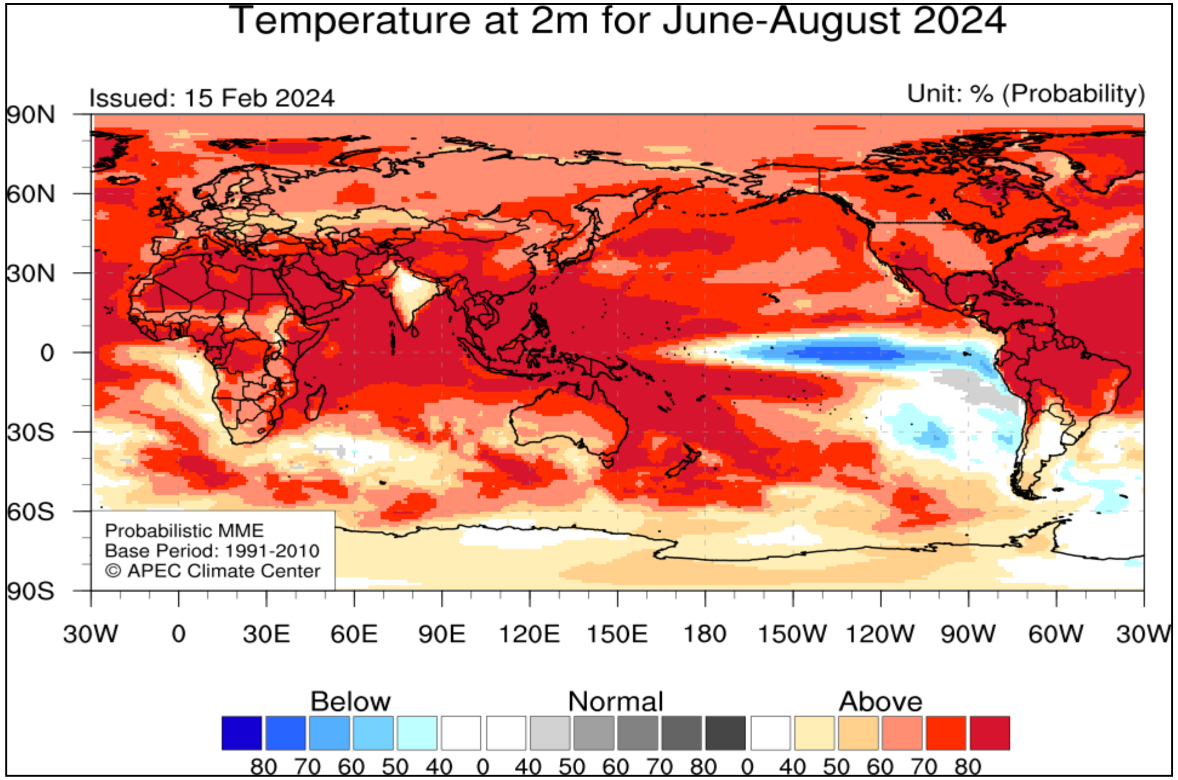
Composite of El Nino decay - Spring SAT over India.

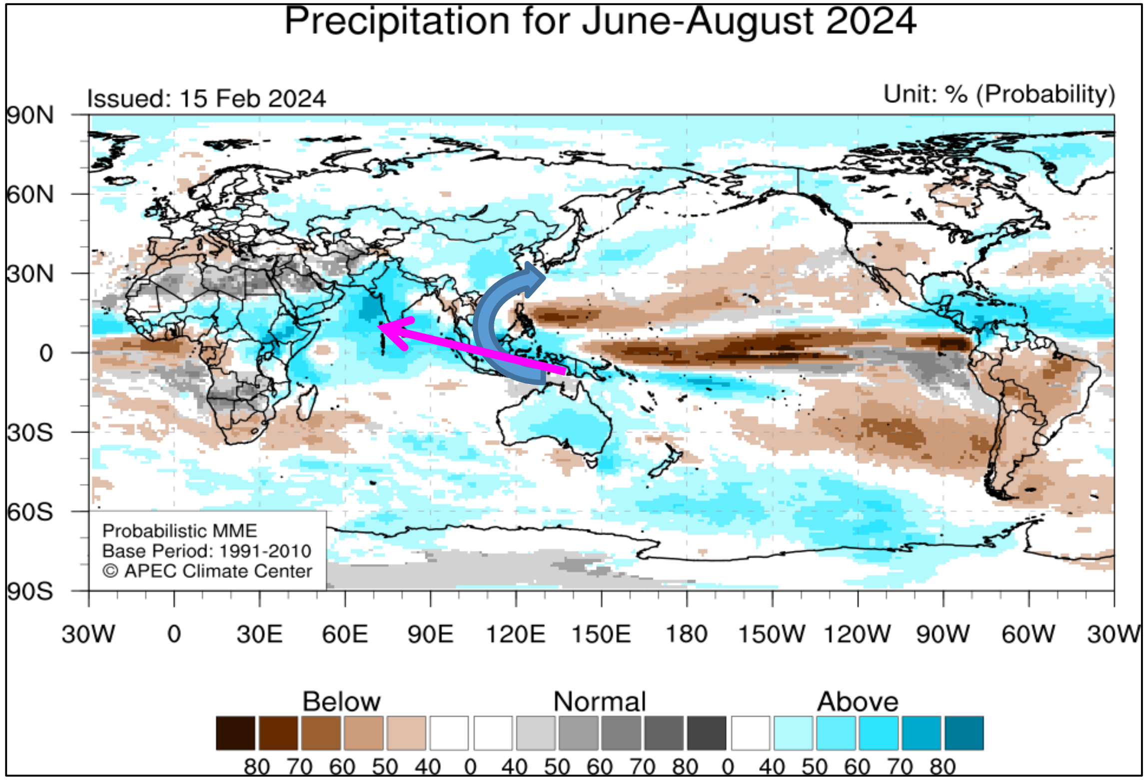
Velivelli et al 2023, CD





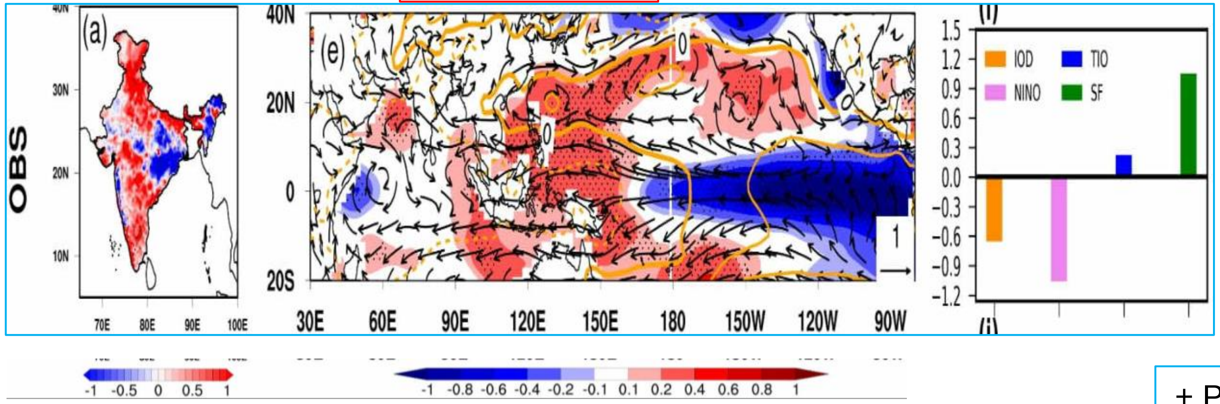
APCC – JJA temp and rainfall prediction



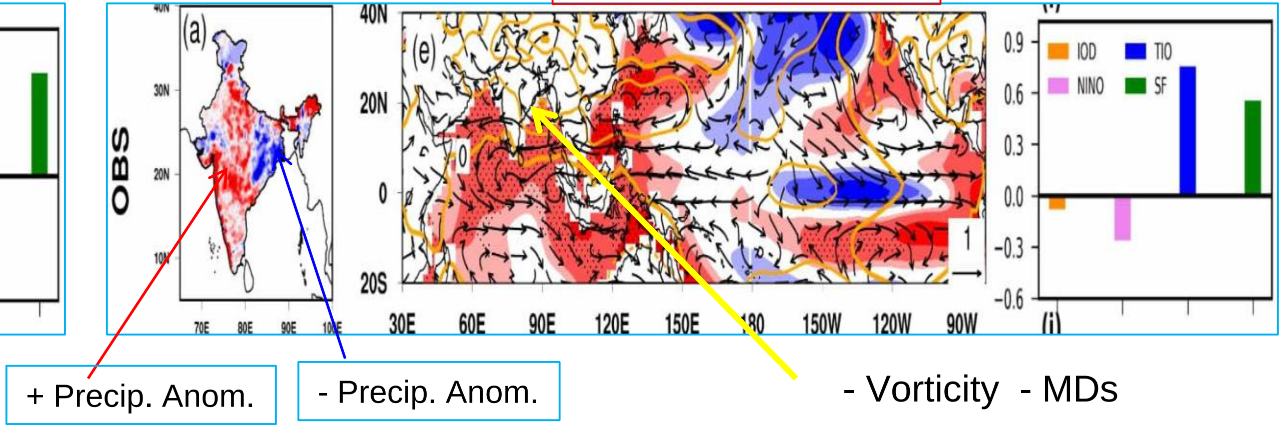


Chowdary et al. 2023

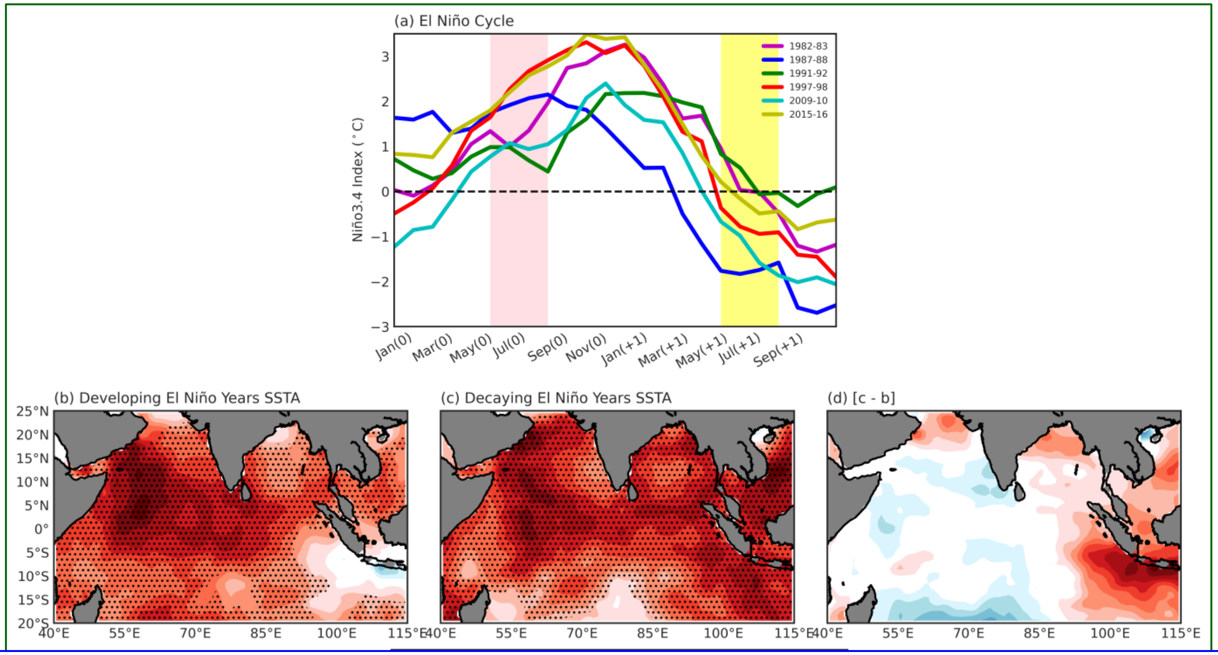
Early decay

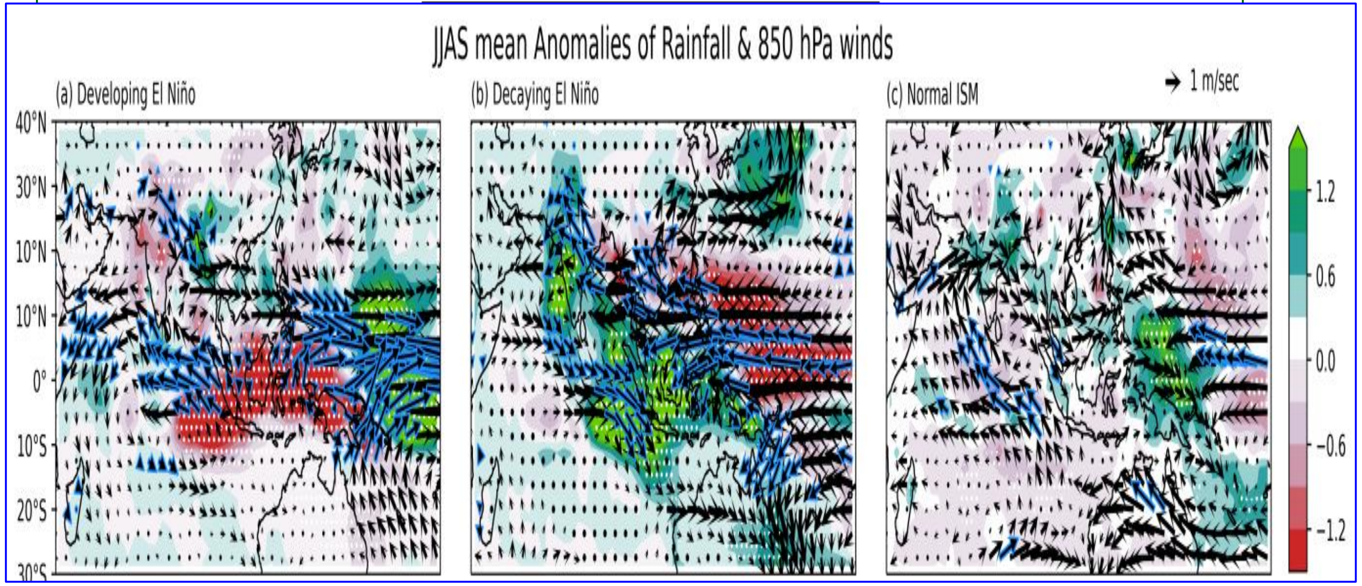


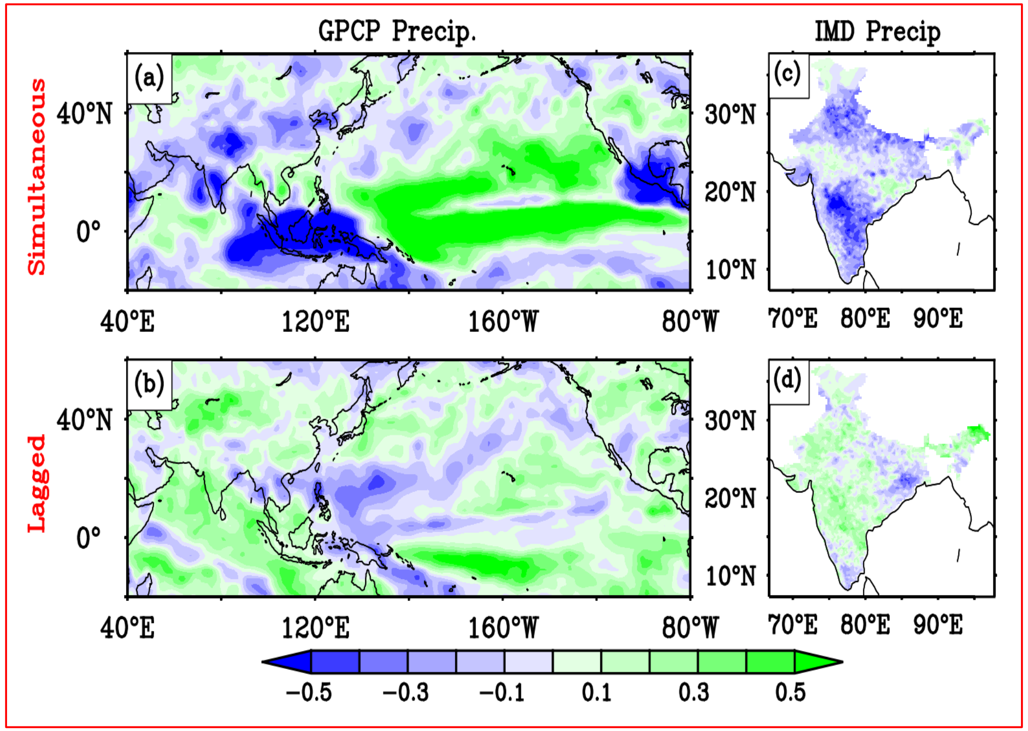
Mid summer decay



Delayed impact of El Nino – applicable for 2024 - ISM

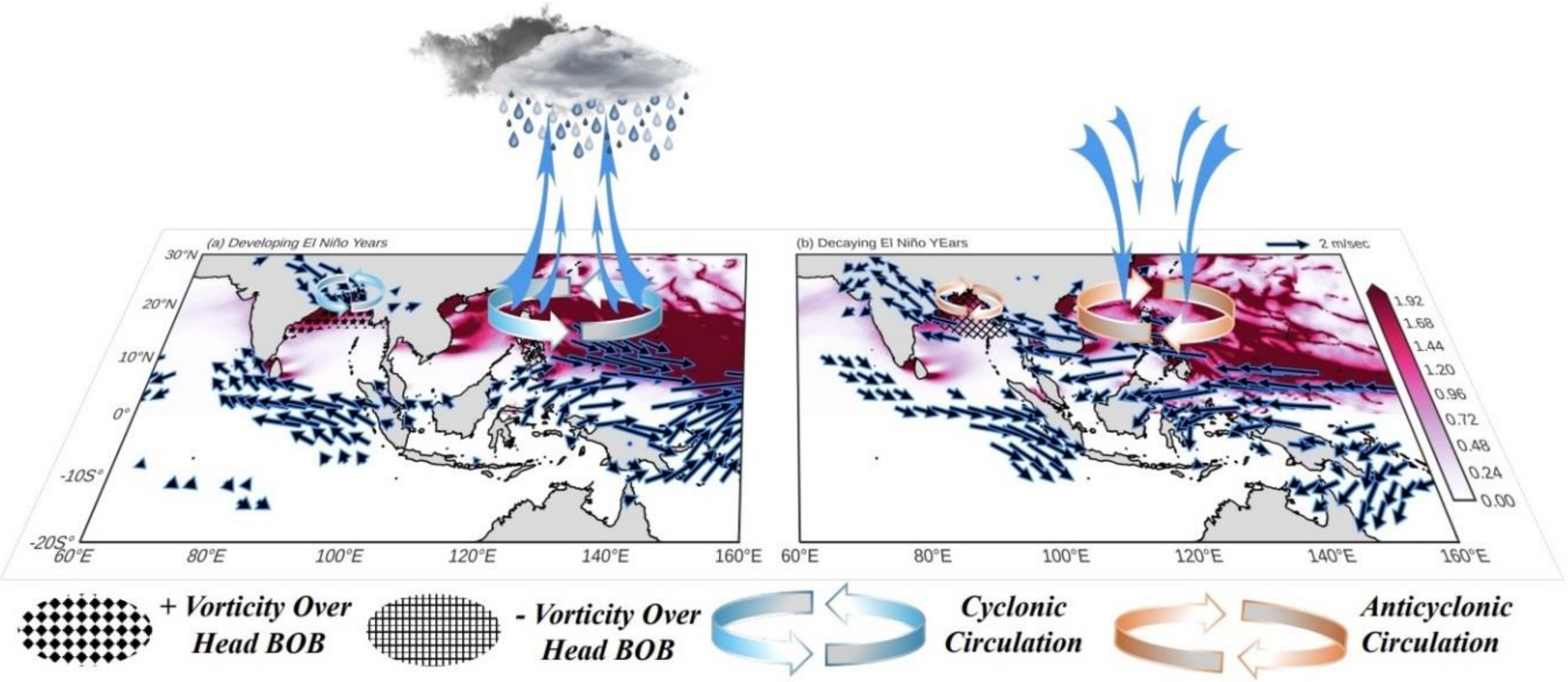






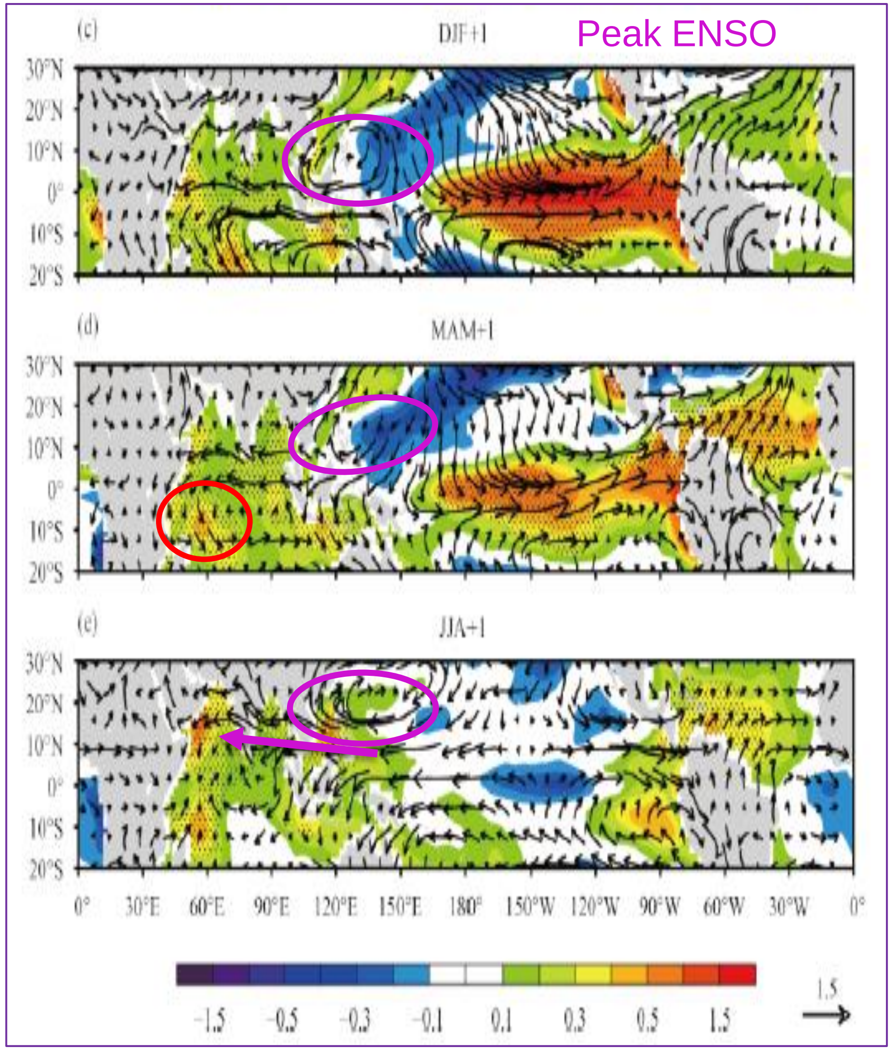
Chowdary et al.,2024 (CD) – Revised ; Darshana et al . 2024

Delayed impact of El Nino

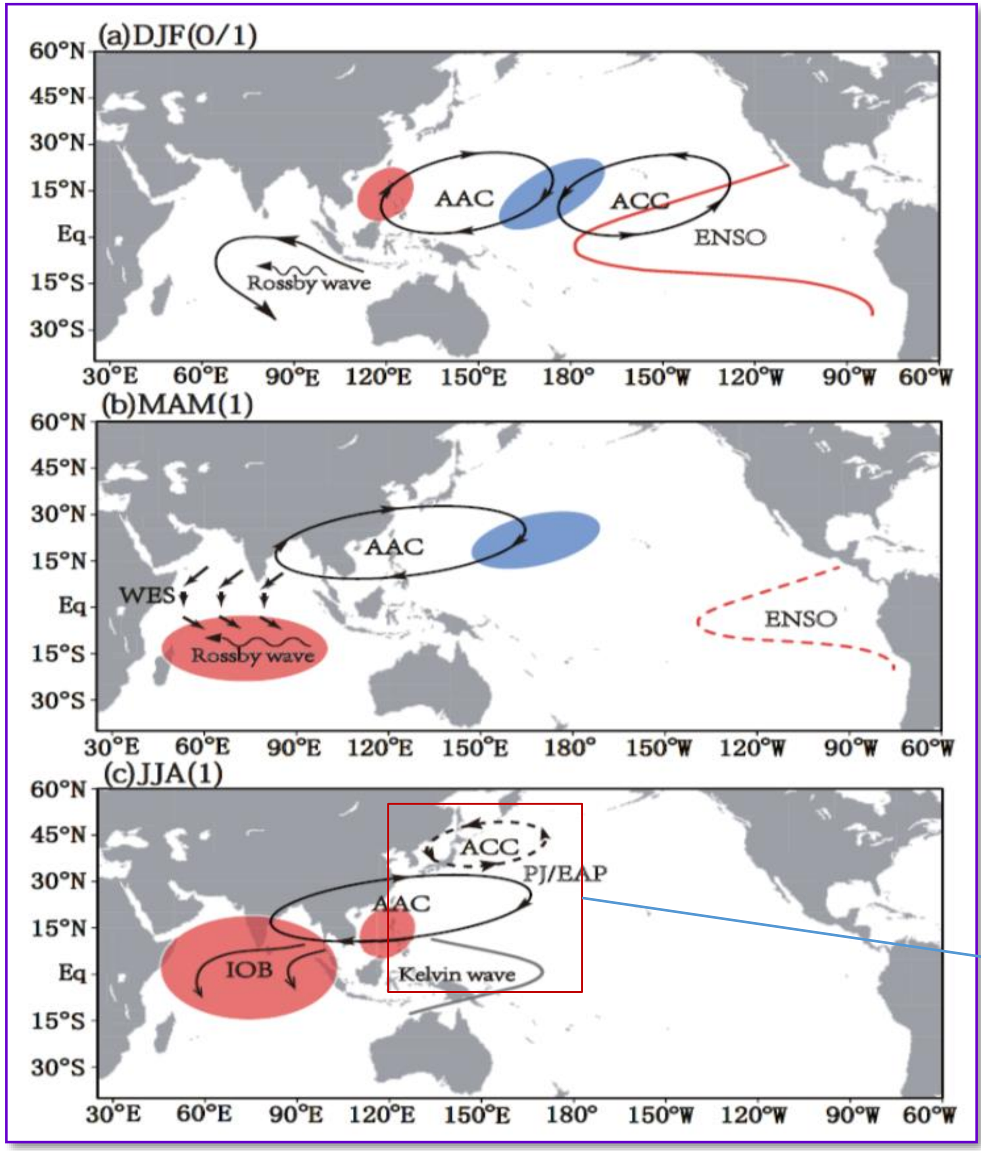


Chowdary et al . 2024,

Evolution of 1) TIO basin wide warming 2) The Western-North Pacific AC - Indo-western Pacific Ocean capacitor Mode



Anomalous SST (shaded, °C) and 850-hPa wind (m s–1) fields regressed against the Niño 3.4 index for (a) JJS0, (b) SON0, (c) DJF+1, (d) MAM+1, and (e) JJA+1 of 1980–2015 (Li et al. 2017).



The Pacific Japan pattern (Nitta 1987)

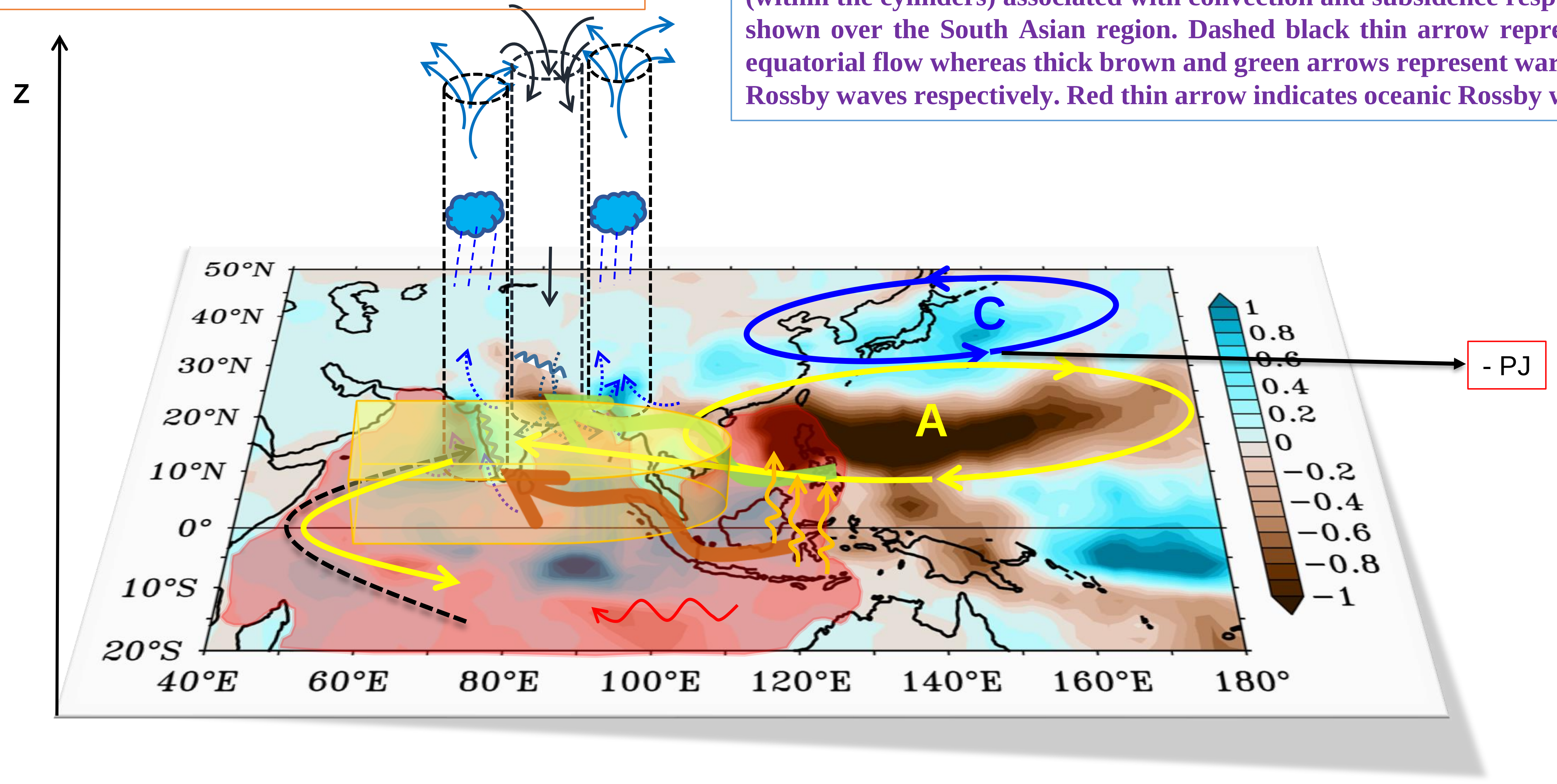
- **In decay phase of El Niño (JJA1), WNP AC keeps IO warm. In response, TIO SST feeds back and reinforces the AC via a tropospheric Kelvin wave. IPOC mode.**

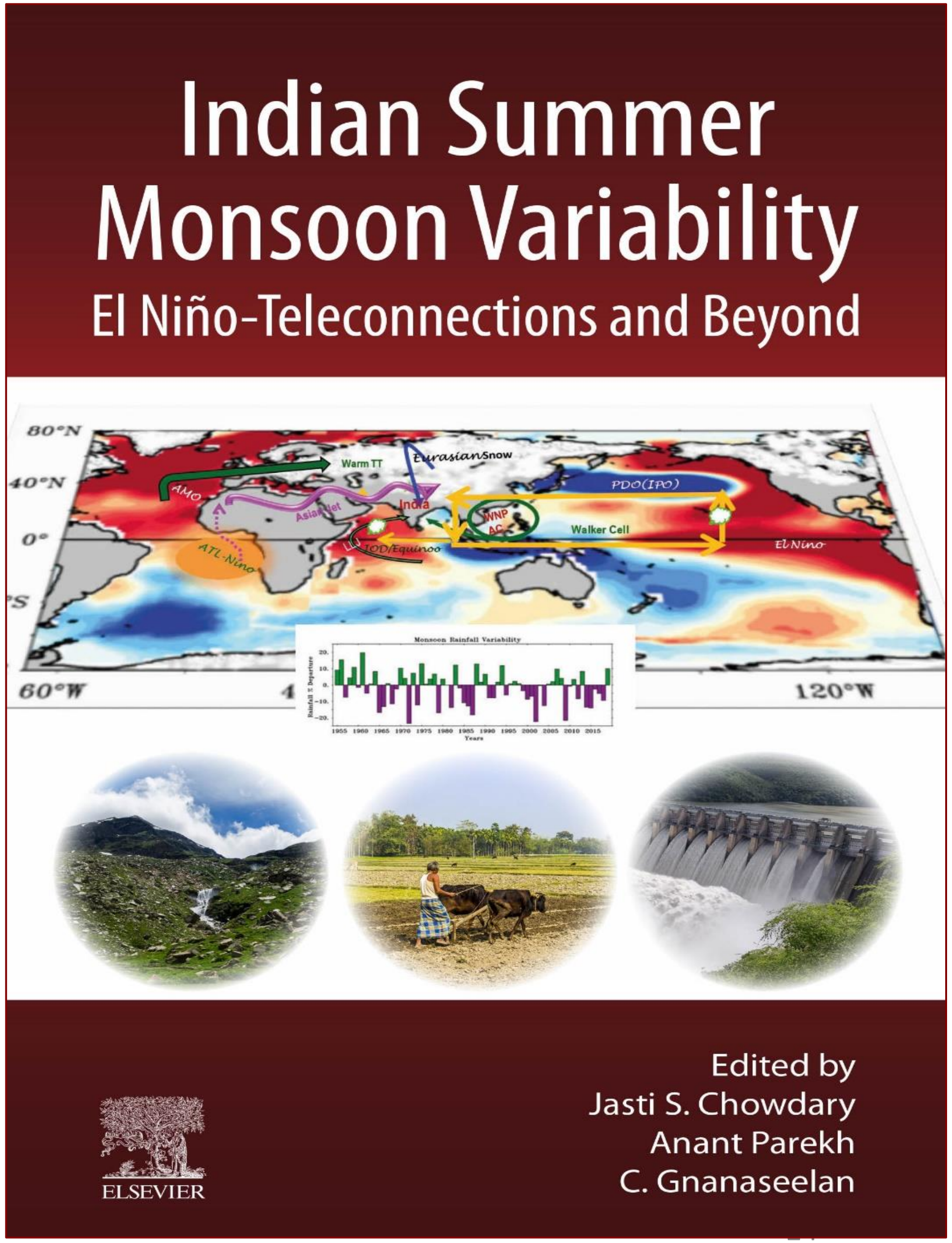
Xie, S.P., Kosaka, Y., Du, Y., Hu, K., **Chowdary, J.S**. and Huang, G., 2016. Indo-western Pacific Ocean capacitor and coherent climate anomalies in post-ENSO summer: A review. *Advances in Atmospheric Sciences*, *33*(4), pp.411-432.

Impact of the Indo-Western Pacific Ocean Capacitor mode on South Asian Summer monsoon rainfall

Chowdary et al. 2019; Darshana et al. 2020; Gnanaseean and Chowdary 2020 ; Xie et al. 2016

Schematic diagram that shows factors responsible for changes in ISM rainfall associated with the IPOC mode. Area shaded in red color represent SST warming over the TIO and SCS regions, Yellow arrows show WNP anticyclone and easterlies over Bay of Bengal (850 hPa) and blue arrows for cyclonic circulation. Low level convergence and upper level divergence and vice-versa (within the cylinders) associated with convection and subsidence respectively are shown over the South Asian region. Dashed black thin arrow represent cross-equatorial flow whereas thick brown and green arrows represent warm and cold Rossby waves respectively. Red thin arrow indicates oceanic Rossby waves.




Indian Summer
Monsoon Variability
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Anant Parekh
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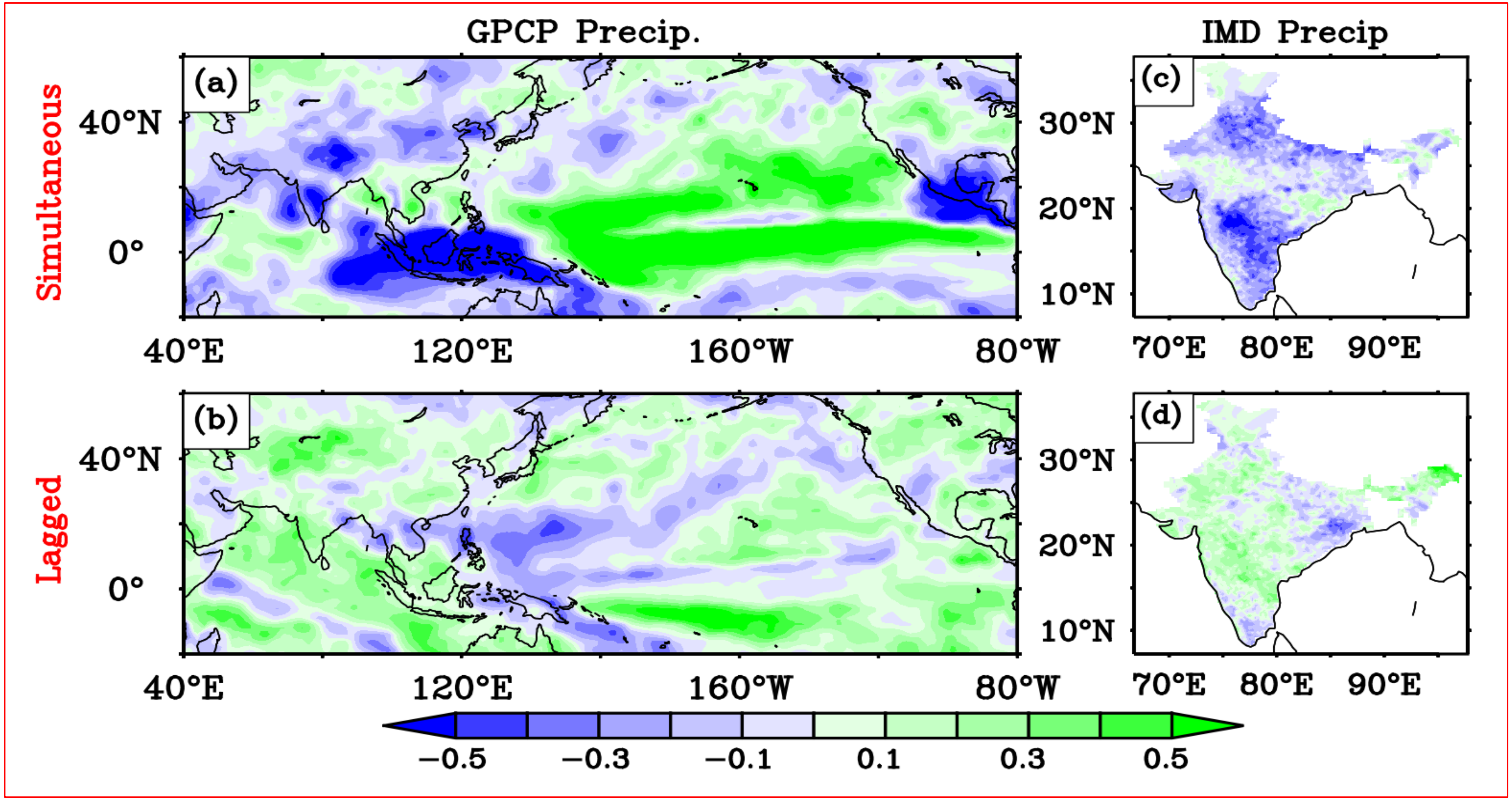
Thank you

Delayed impact of El Nino

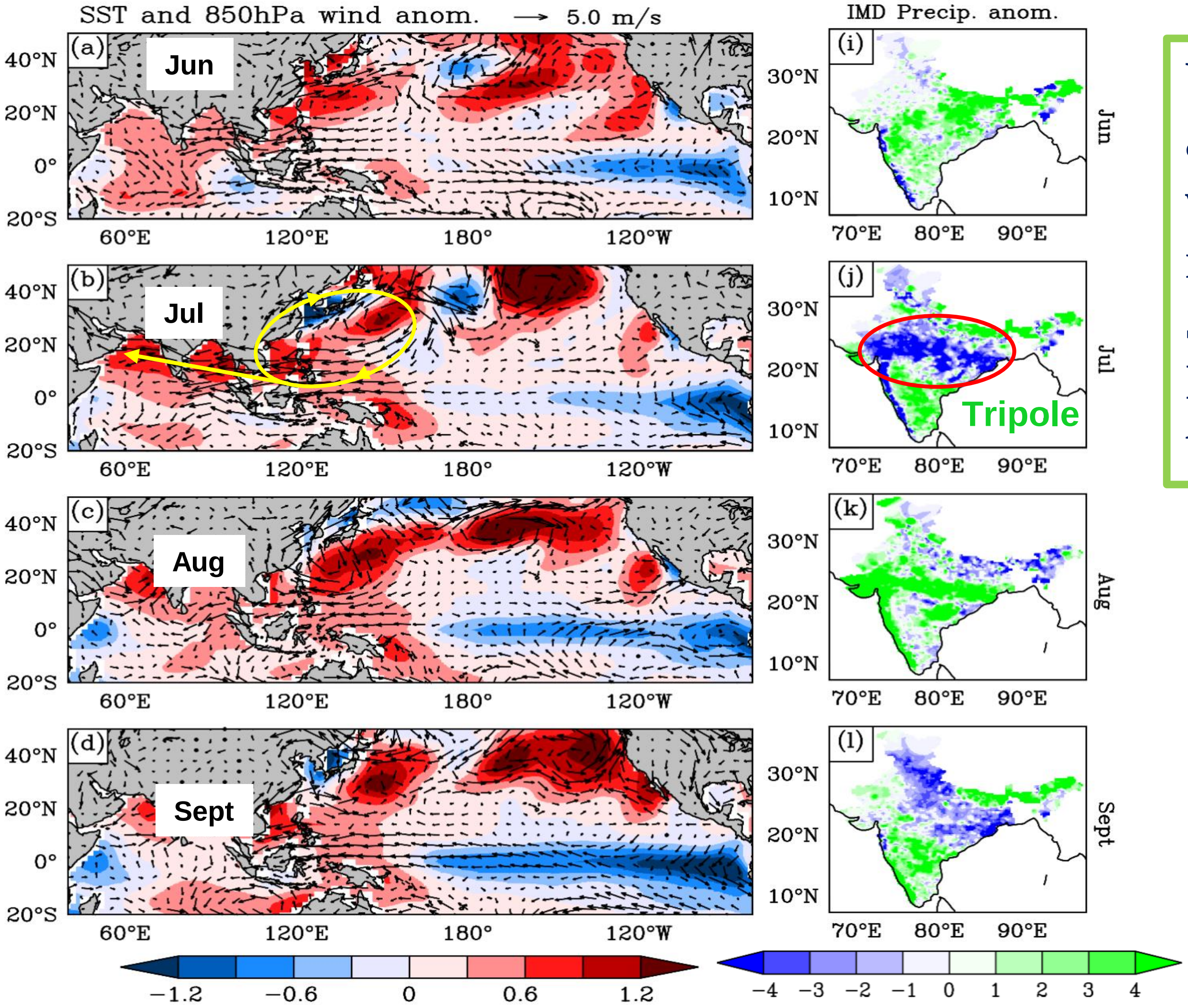


Darshana et al.,2024 (QJRMS)

IPOC mode – ISM sub-seasonal variability

Obs 2020

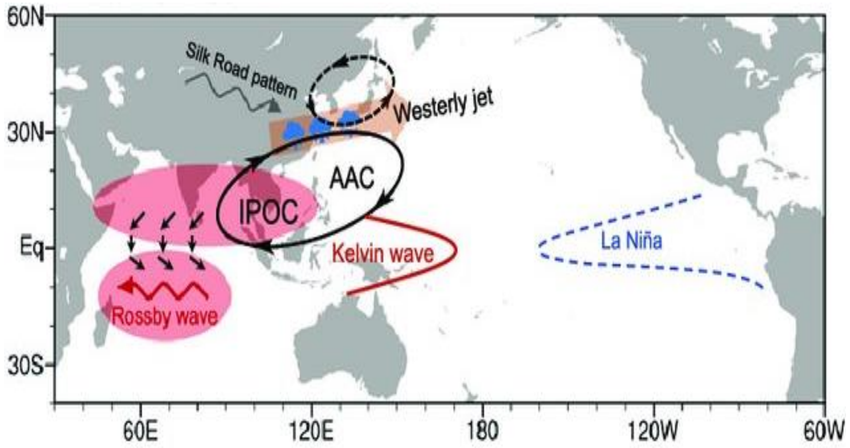
- Year 2020 is the third highest in all India seasonal rainfall (109% of its Long Period Average (LPA)) since 1990.
- The rainfall over country was 118%, **90%**, 127% and 104% of LPA during Jun, July, August and September respectively.

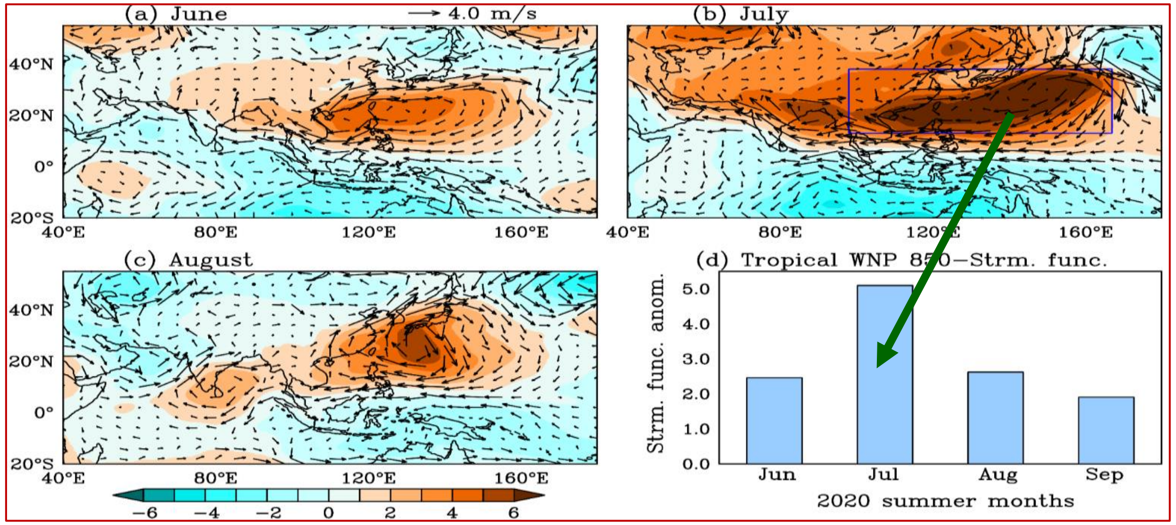


Why anomalous weak rainfall in July 2020? Is it related to IPOC !!

Zhou et al., 2021

JJA 2020

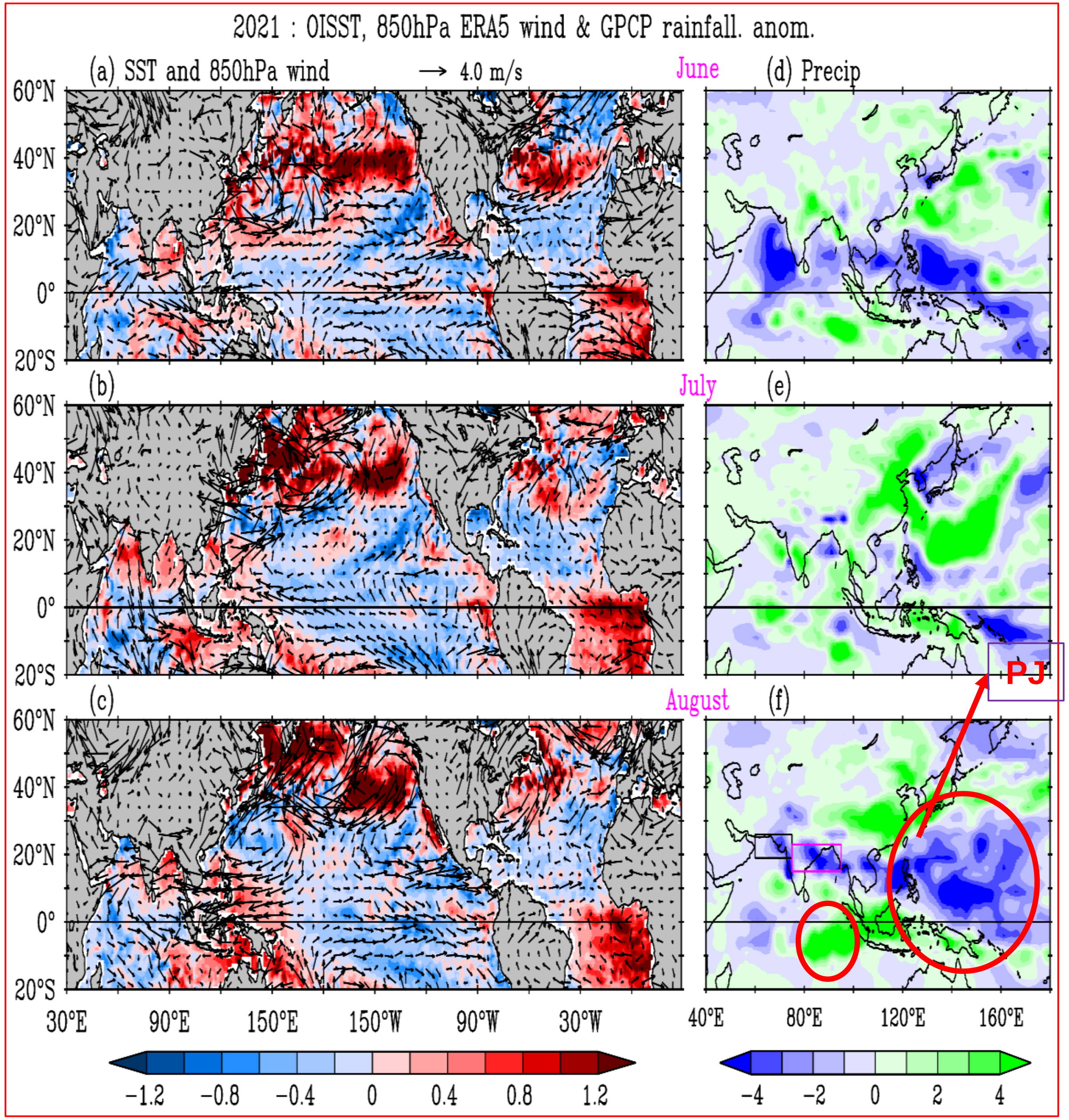


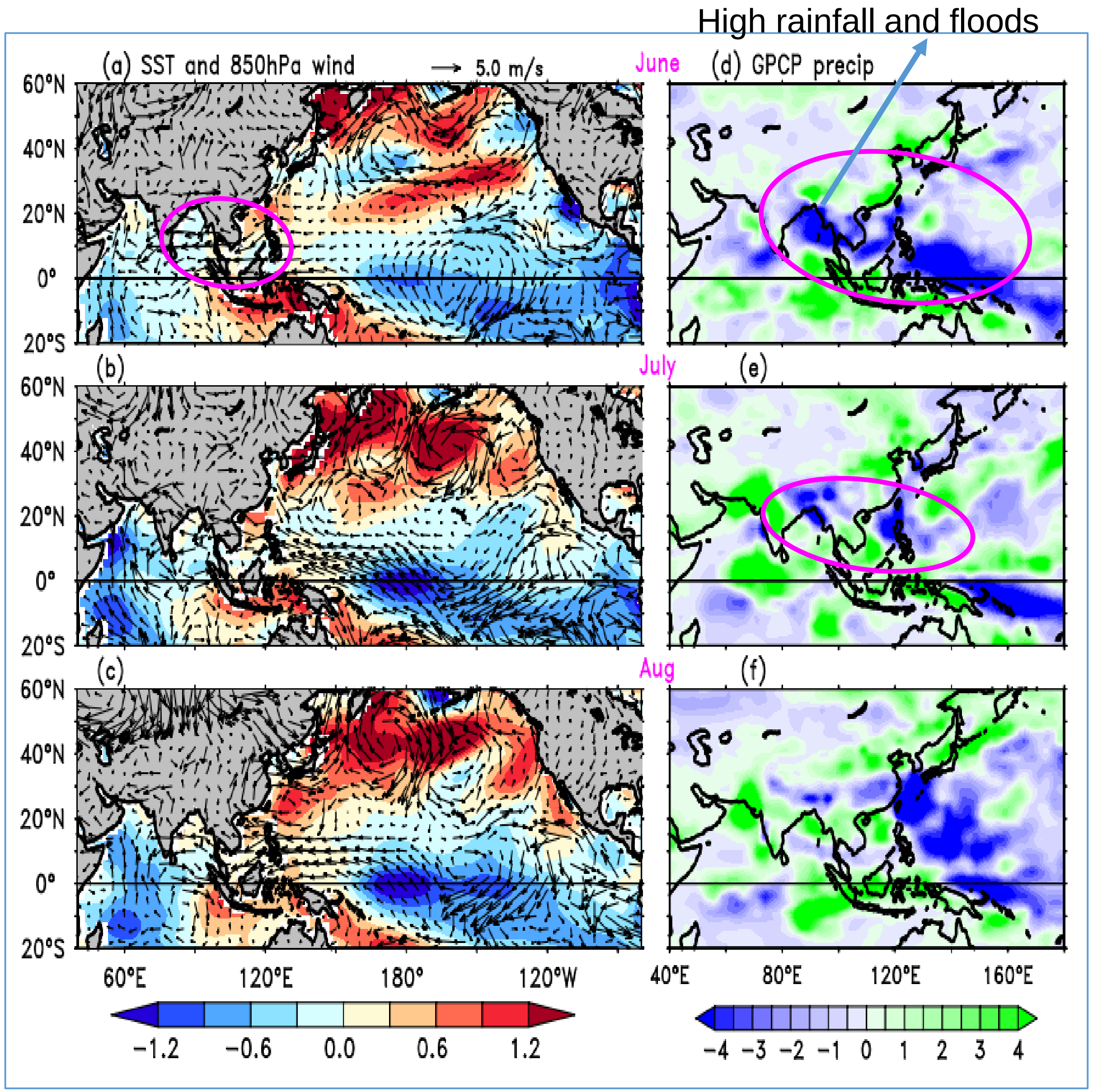


Darshana et al.,2024 (QJRMS)

August – 2021 – PJ and ISM

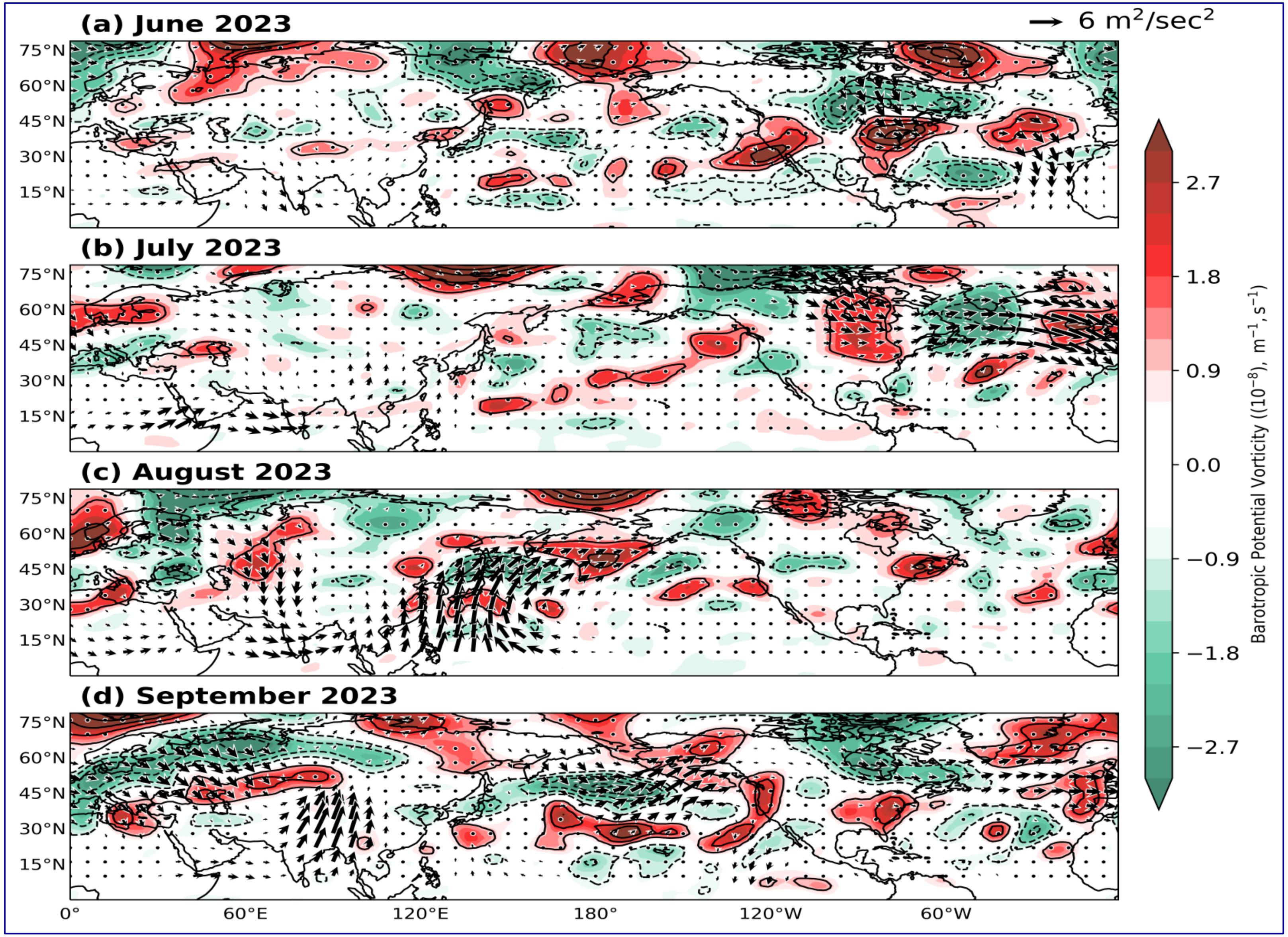
June – 2022 – PJ and ISM





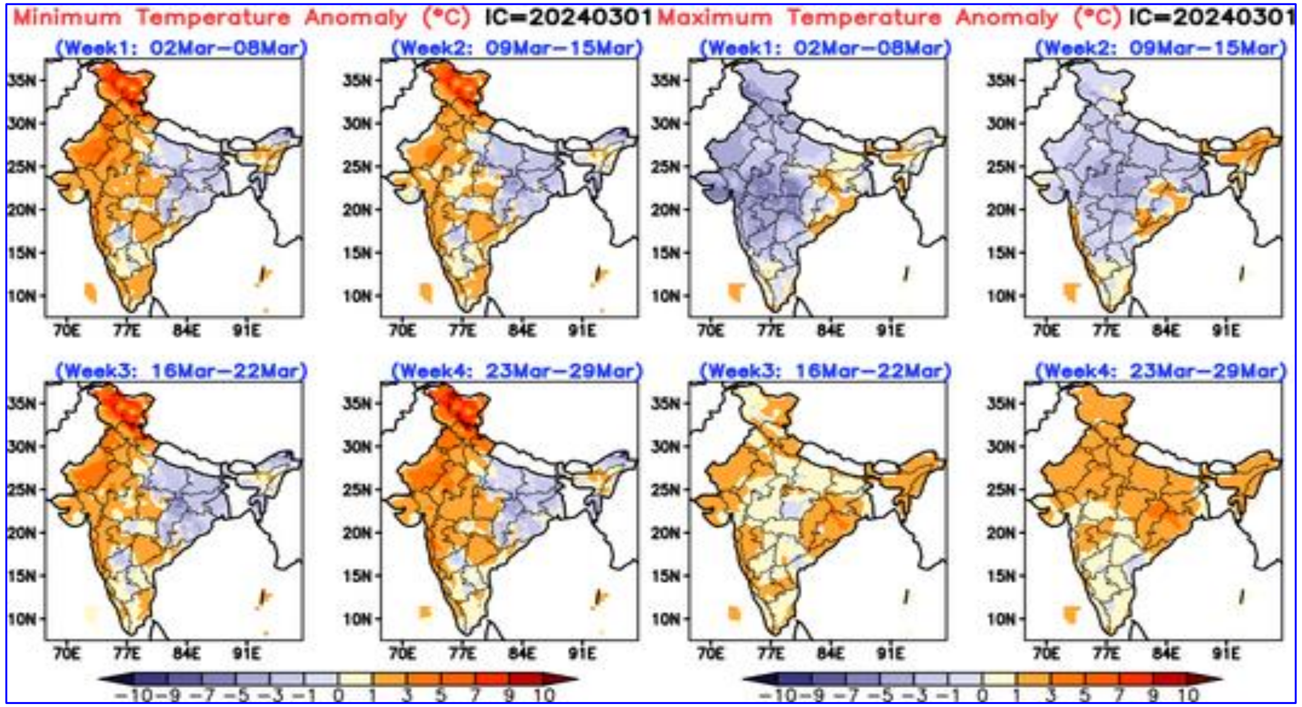
Vibhute et al. 2023, AR

200 hPa barotropic potential vorticity

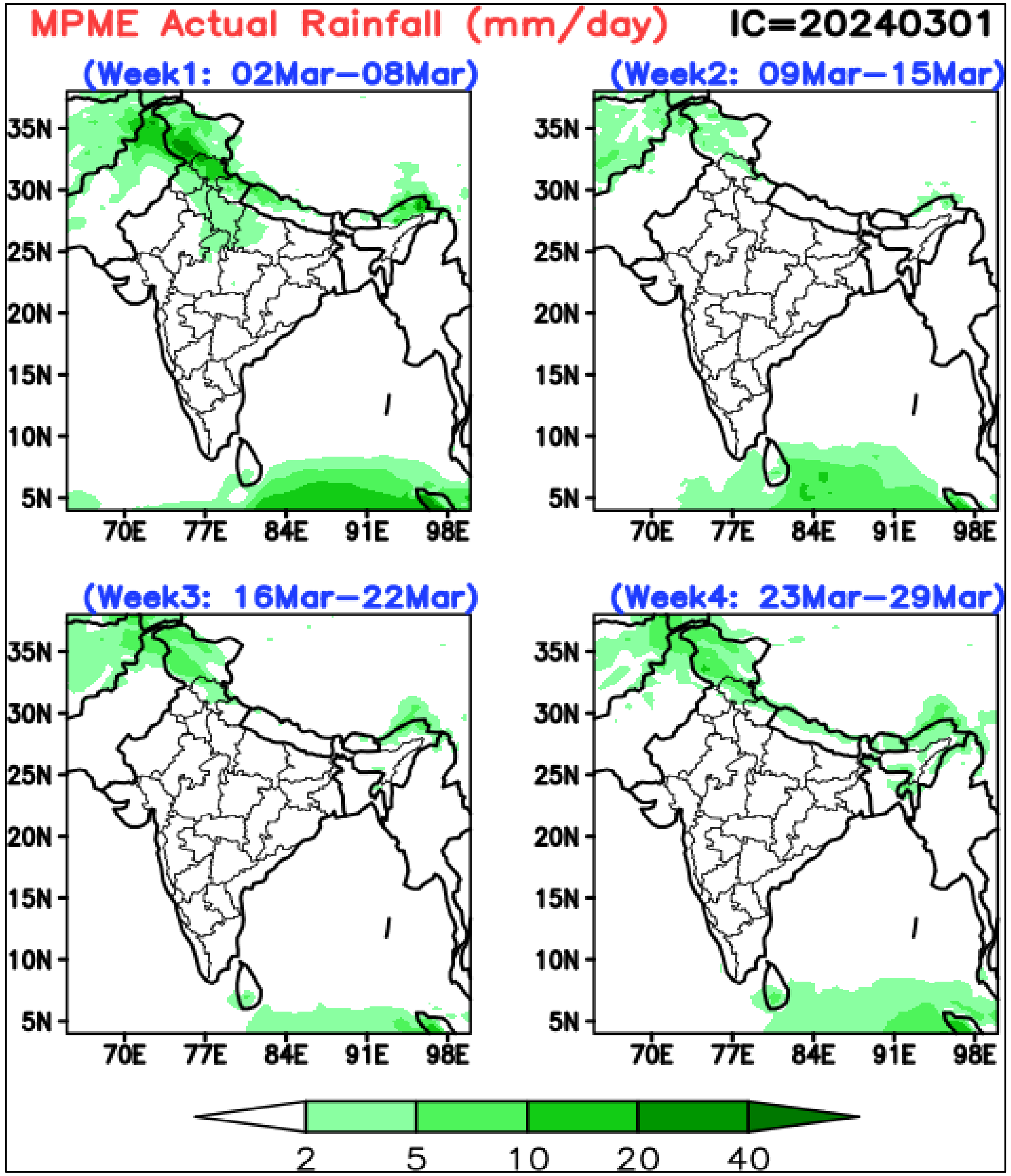


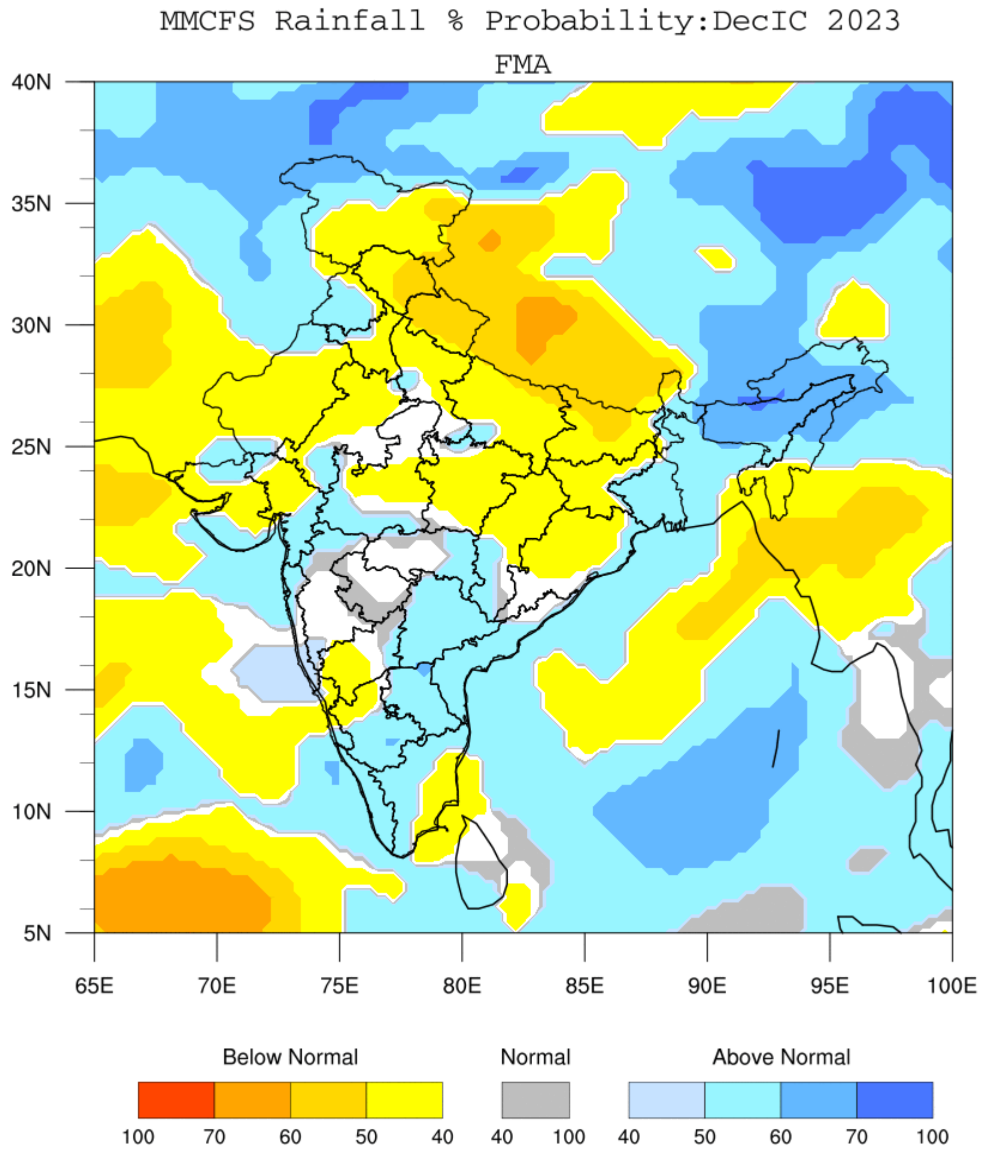
- (a) to (d) show the pronounced JJAS months 200 hPa barotropic potential vorticity, shaded with contours for the year 2023.

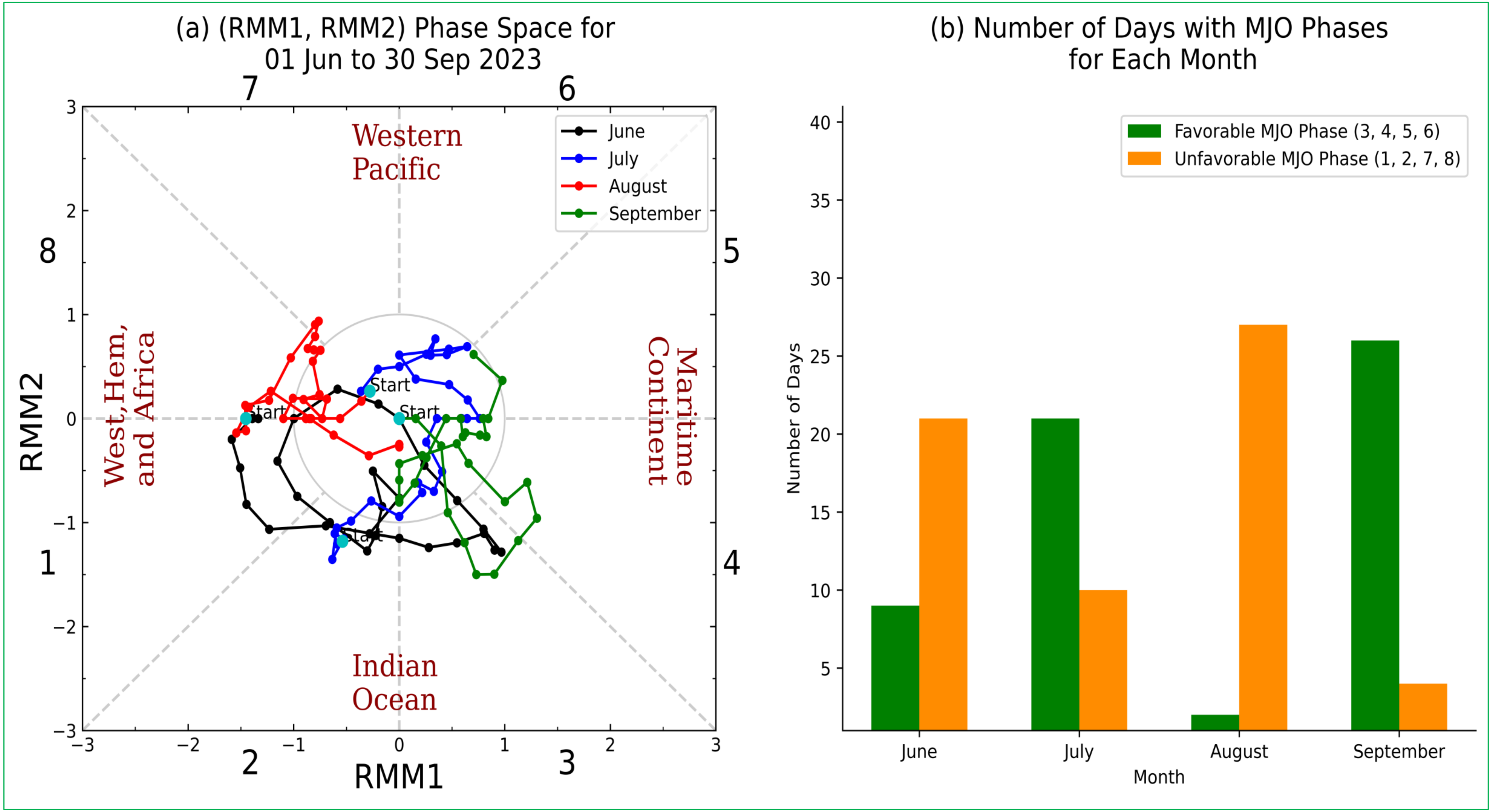
IITM

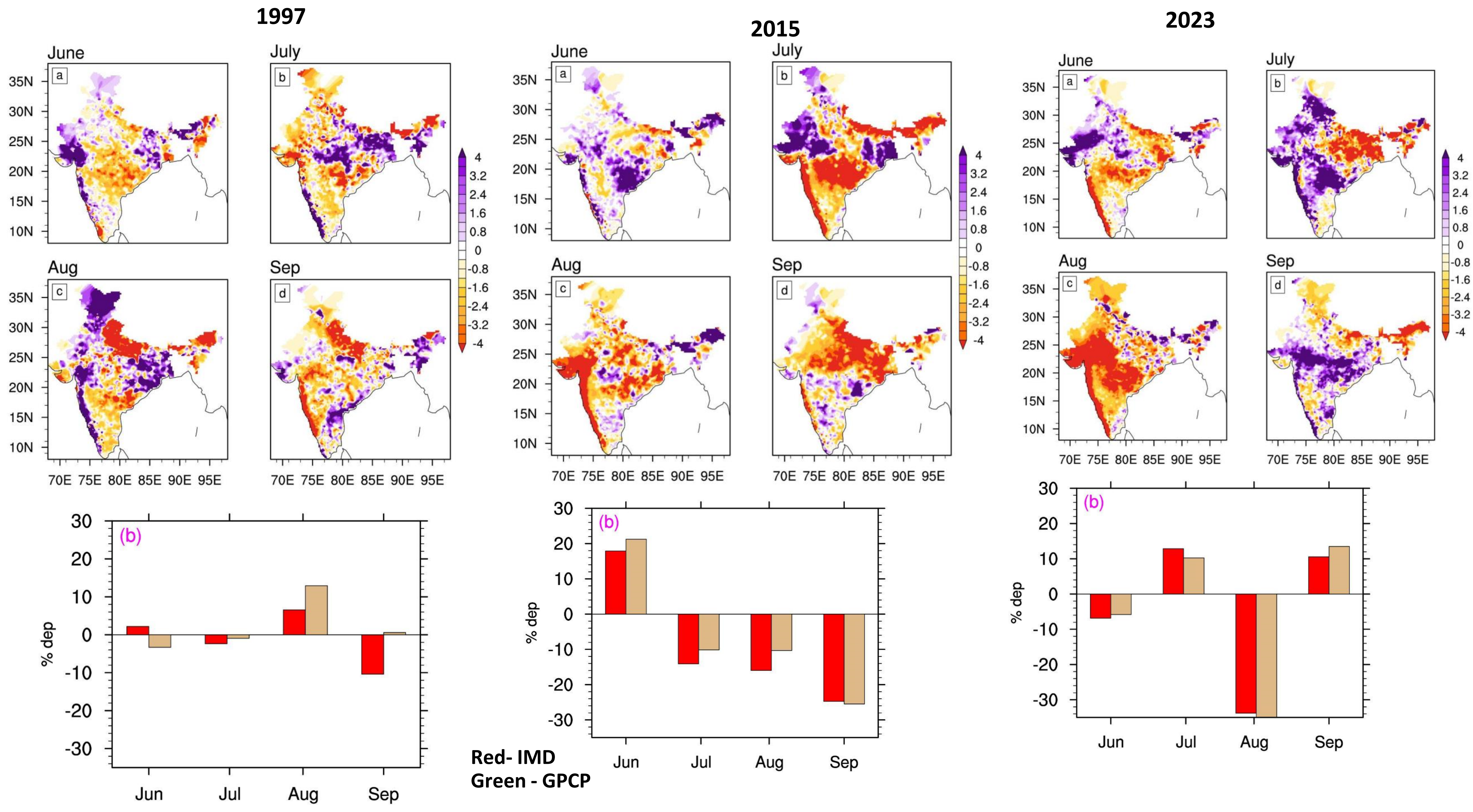


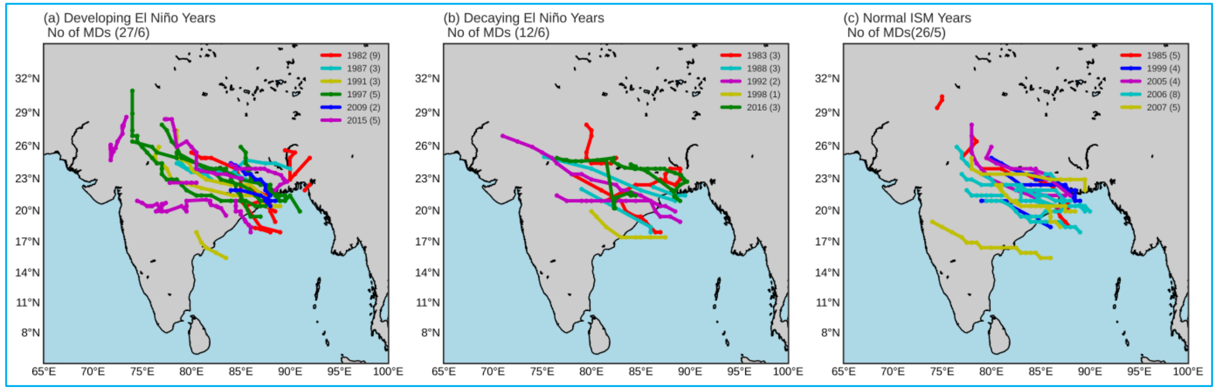
Minimum Temperature Anomaly (°C) IC=20240301
Maximum Temperature Anomaly (°C) IC=20240301
(Week1: 02Mar–08Mar)
(Week2: 09Mar–15Mar)
(Week3: 16Mar–22Mar)
(Week4: 23Mar–29Mar)
35N 30N 25N 20N 15N 10N
70E 77E 84E 91E
−10 −9 −7 −5 −3 −1 0 1 3 5 7 9 10

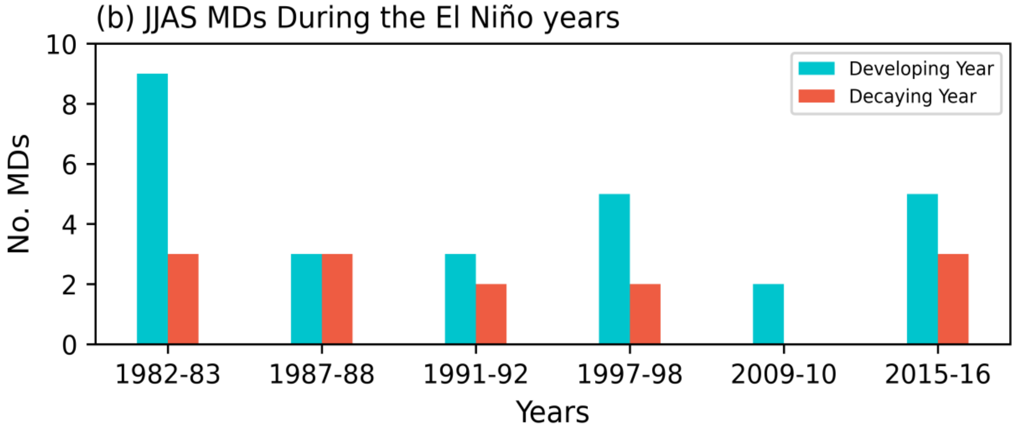

MPME Actual Rainfall (mm/day) IC=20240301
(Week1: 02Mar–08Mar)
(Week2: 09Mar–15Mar)
(Week3: 16Mar–22Mar)
(Week4: 23Mar–29Mar)
35N 30N 25N 20N 15N 10N 5N
70E 77E 84E 91E 98E
2 5 10 20 40


MMCFS Rainfall % Probability:DecIC 2023
FMA
40N 35N 30N 25N 20N 15N 10N 5N
65E 70E 75E 80E 85E 90E 95E 100E
Below Normal
Normal
Above Normal
100 70 60 50 40
40 100
40 50 60 70 100


(a) (RMM1, RMM2) Phase Space for
01 Jun to 30 Sep 2023
Western
Pacific
West.Hem,
and Africa
Maritime
Continent
Indian
Ocean
June
July
August
September
Start
RMM1
RMM2
(b) Number of Days with MJO Phases
for Each Month
Favorable MJO Phase (3, 4, 5, 6)
Unfavorable MJO Phase (1, 2, 7, 8)
Number of Days
June
July
August
September
Month


1997
2015
2023
June
July
Aug
Sep
a
b
c
d
35N
30N
25N
20N
15N
10N
70E 75E 80E 85E 90E 95E
4
3.2
2.4
1.6
0.8
0
-0.8
-1.6
-2.4
-3.2
-4
(b)
% dep
30
20
10
0
-10
-20
-30
Jun
Jul
Aug
Sep
Red- IMD
Green - GPCP


(a) Developing El Niño Years
No of MDs (27/6)
1982 (9)
1987 (3)
1991 (3)
1997 (5)
2009 (2)
2015 (5)
(b) Decaying El Niño Years
No of MDs (12/6)
1983 (3)
1988 (3)
1992 (2)
1998 (1)
2016 (3)
(c) Normal ISM Years
No of MDs(26/5)
1985 (5)
1999 (4)
2005 (4)
2006 (8)
2007 (5)


(b) JJAS MDs During the El Niño years
Developing Year
Decaying Year
No. MDs
Years
1982-83
1987-88
1991-92
1997-98
2009-10
2015-16