Understanding the impact of the Quasi-Biennial Oscillation on the subseasonal variability of the Indian monsoon

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Outline of the Talk

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2. **Data And Methodology**
3. **Results**
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1. Introduction

QBO – ISM (Indian Summer Monsoon)

Claud and Terray (2007)	**15 hPa proceeding winter WQBO leads** • **Weaker monsoon circulation at the beginning of the ISM** • **Stronger monsoon circulation at the ending of the ISM**
Giorgetta et al. 1999	**WQBO favours strong monsoon in General Circulation Model experiments (defined at 50 hPa)**
Jinggao Hu et al. 2024	**EQBO at 50 hPa corresponds to colder and higher tropopause and hence vigorous convection over India.**

The present study examines the simultaneous relationship between EOF defined QBO and ISM on seasonal and subseasonal scales.

2. Data & Methodology

QBO-TEJ Significantly Correlated

DATA

1988 to 2023

ERA5 : u-wind (0.25° X 0.25°)

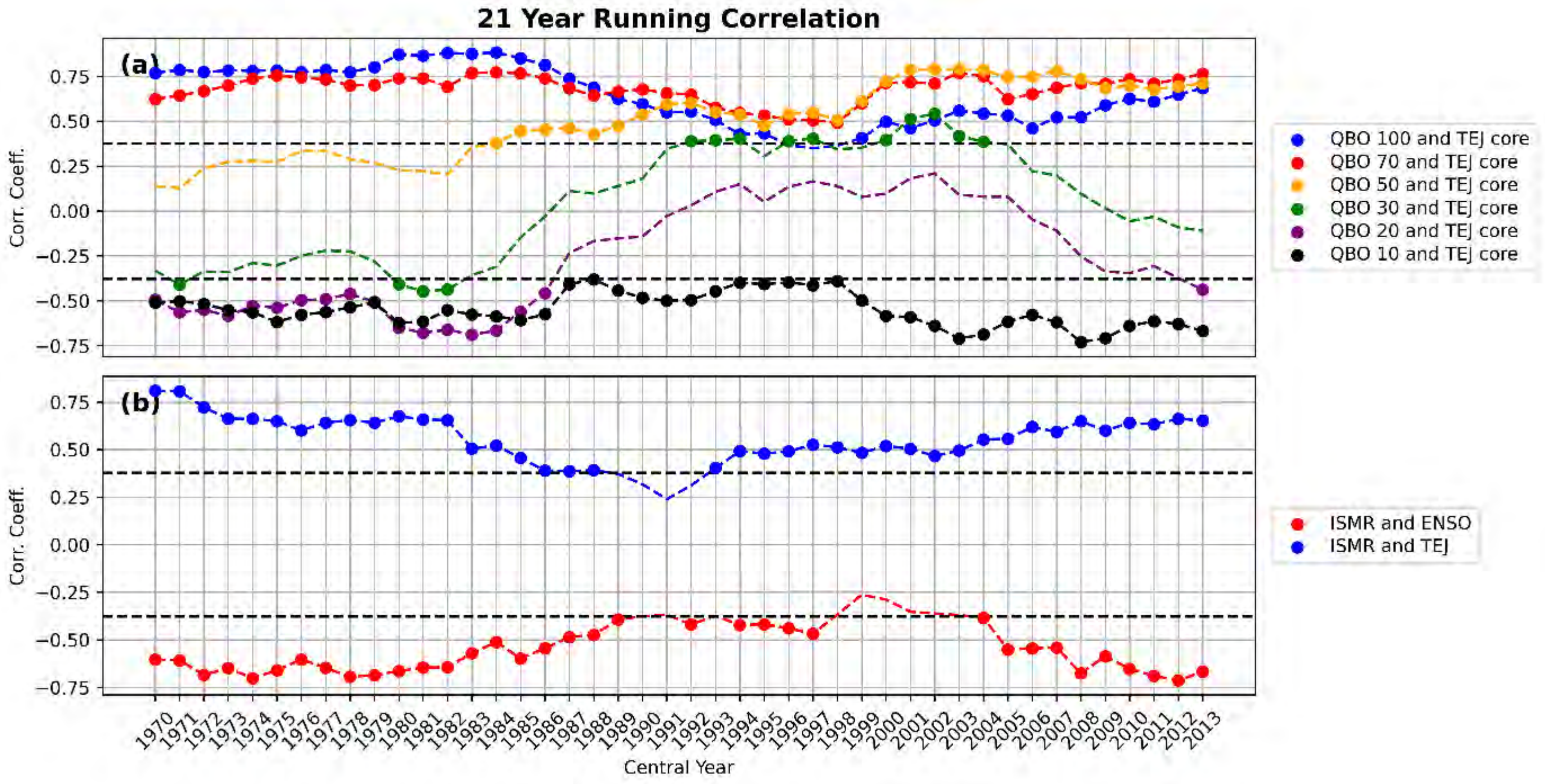
IMD: Rainfall (0.25° X 0.25°)

NCEP : OLR Data (2.5° X 2.5°)

NOAA: ENSO Index

1996 to 2023

GPCP: Precipitation (0.5° X 0.5°)



Correlation Analysis

10 hPa QBO -ve Corelated

70 hPa QBO +ve Correlated

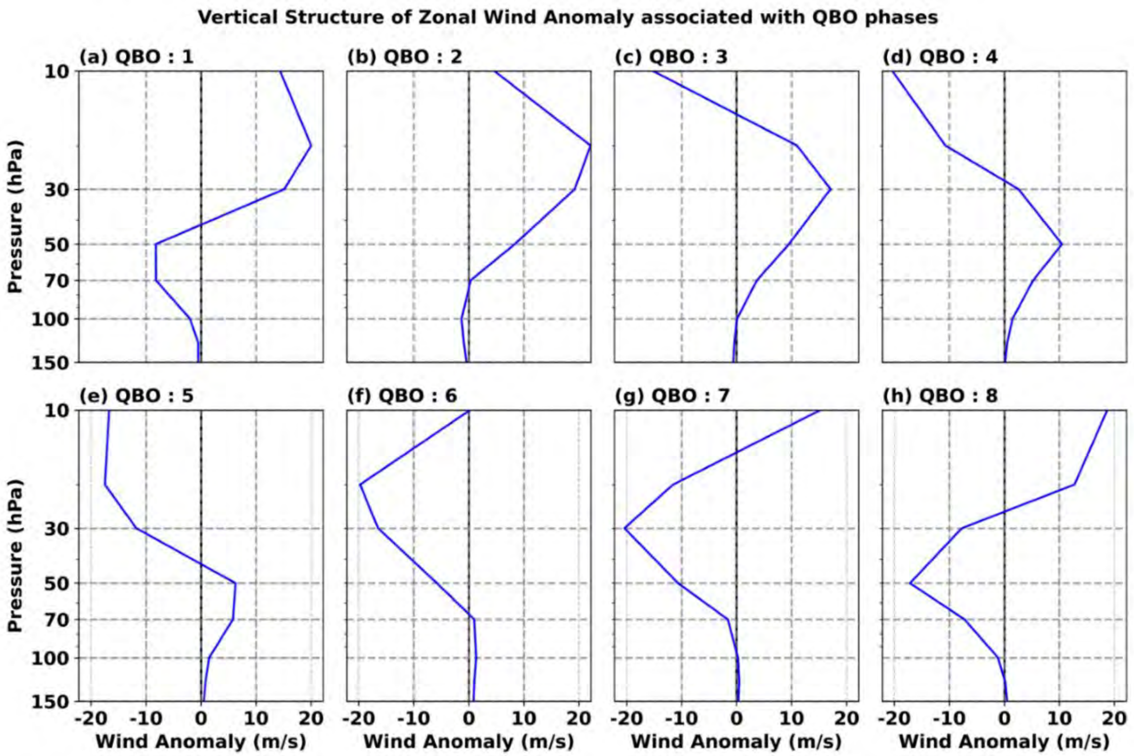
100 hPa QBO +ve Correlated

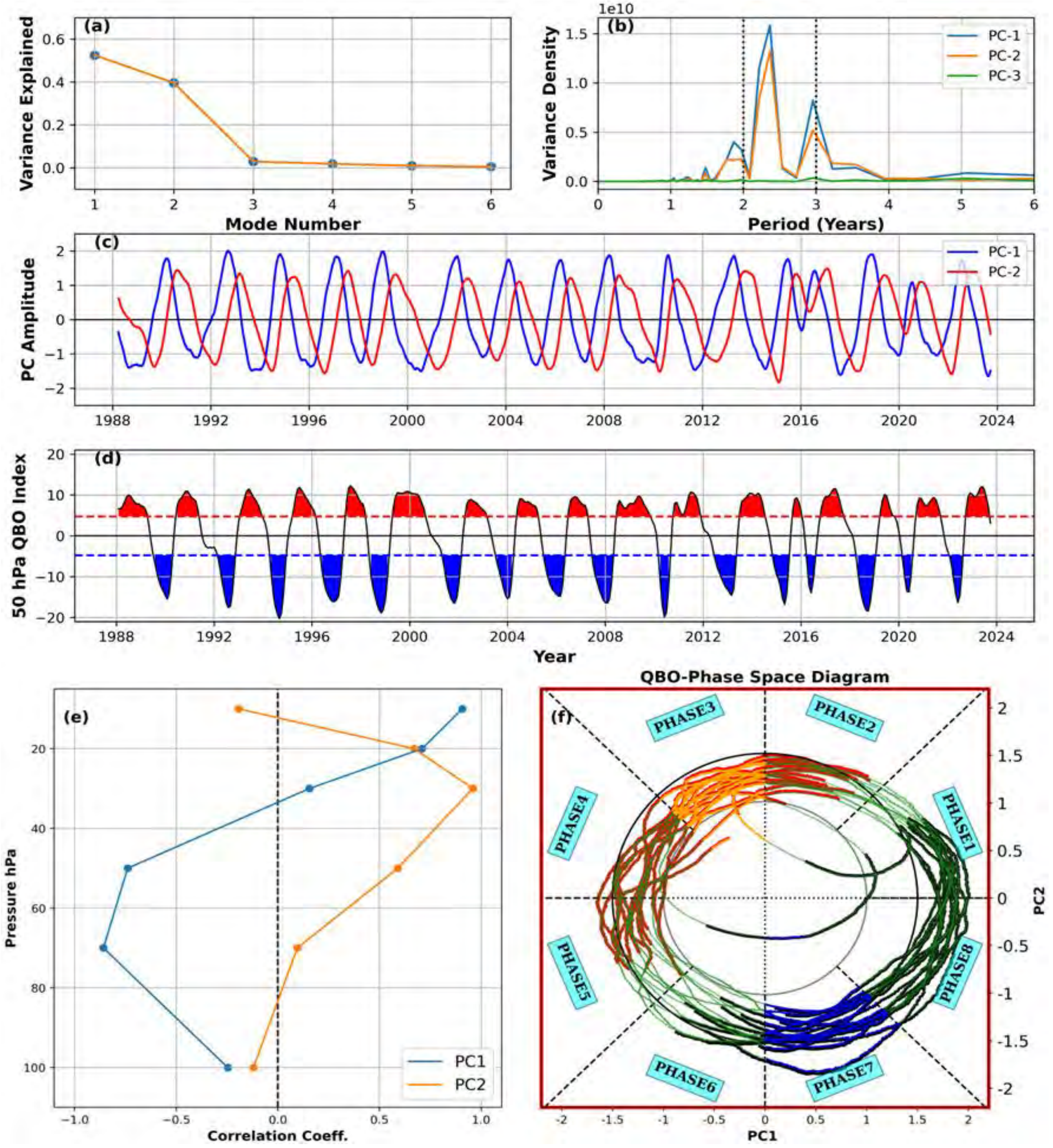
Tropical Easterly Jet (TEJ) core region (35°E-105°E, 2°N-17°N)

From the statistical analysis the QBO influences ISM through the TEJ which is semipermanent the ISM.

2. Data & Methodology

Identifying the QBO





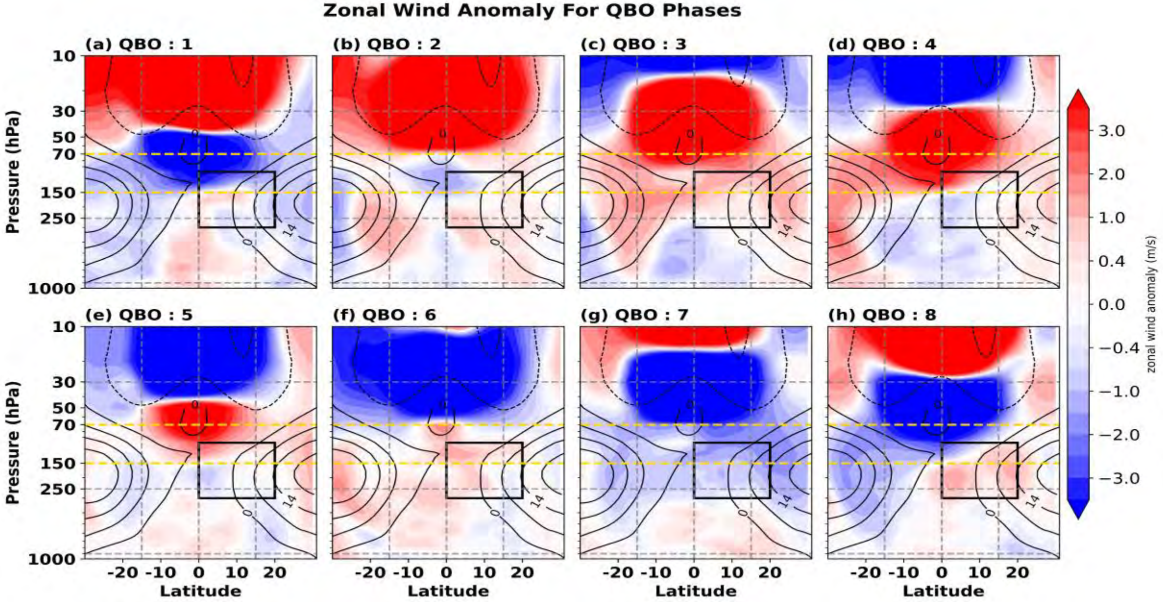
Depending on 20 hPa to 70 hPa zonal wind direction:

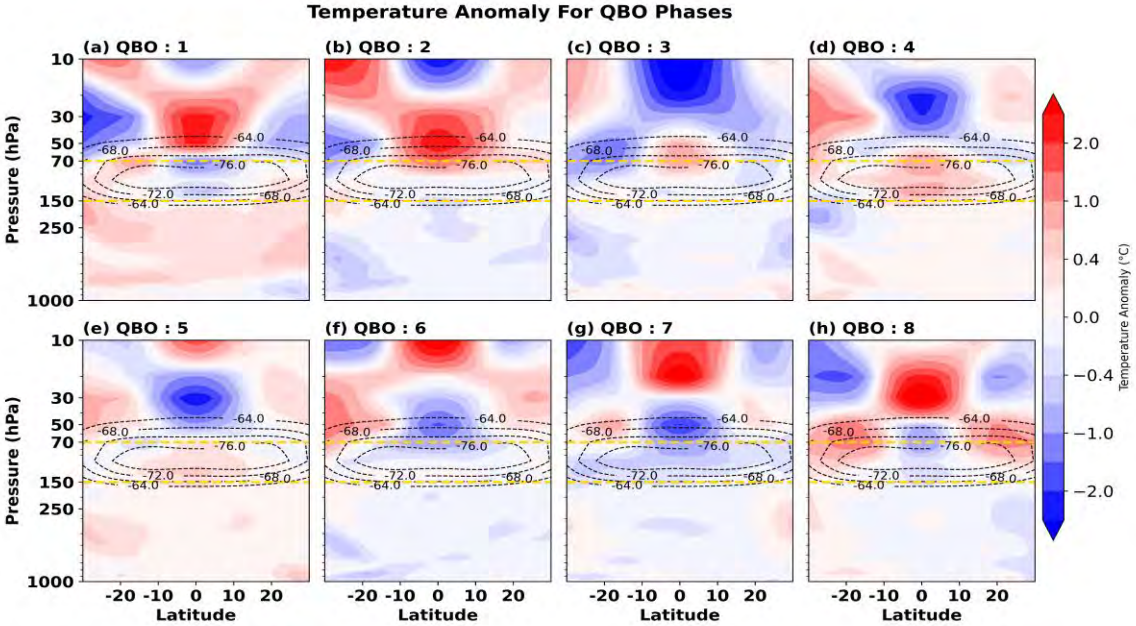
- QBO 7: EQBO
- QBO 3: WQBO

- Leading Two PC's explains 92% viability and same periodicity as QBO
- Simultaneous max. correlation Coefficient:
  70 hPa and PC1 = -0.86
  30 hPa and PC2 = 0.96

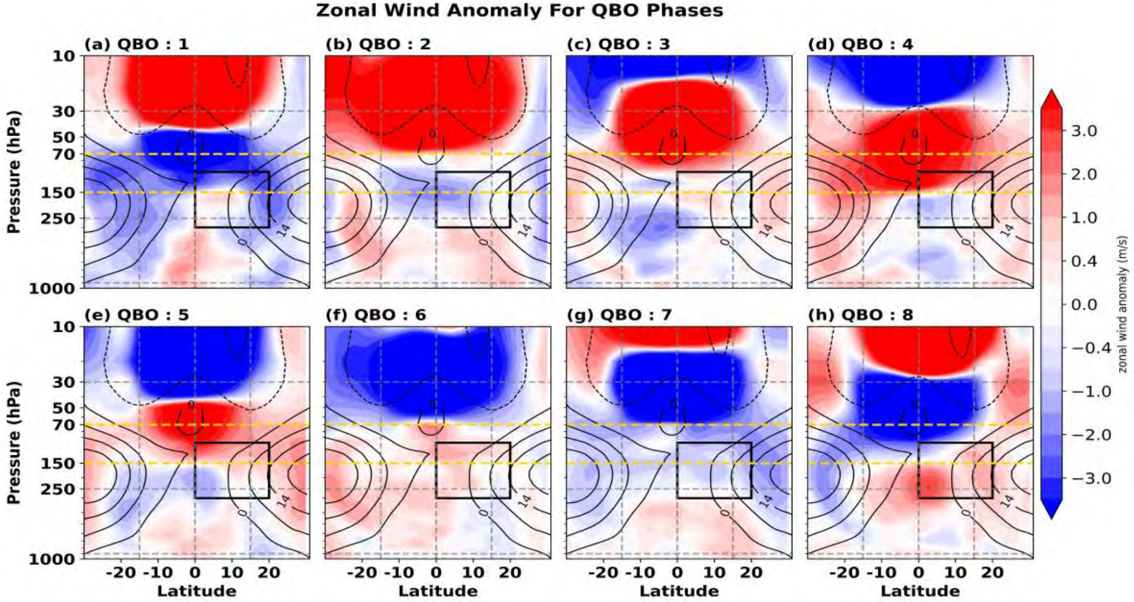
3 Result

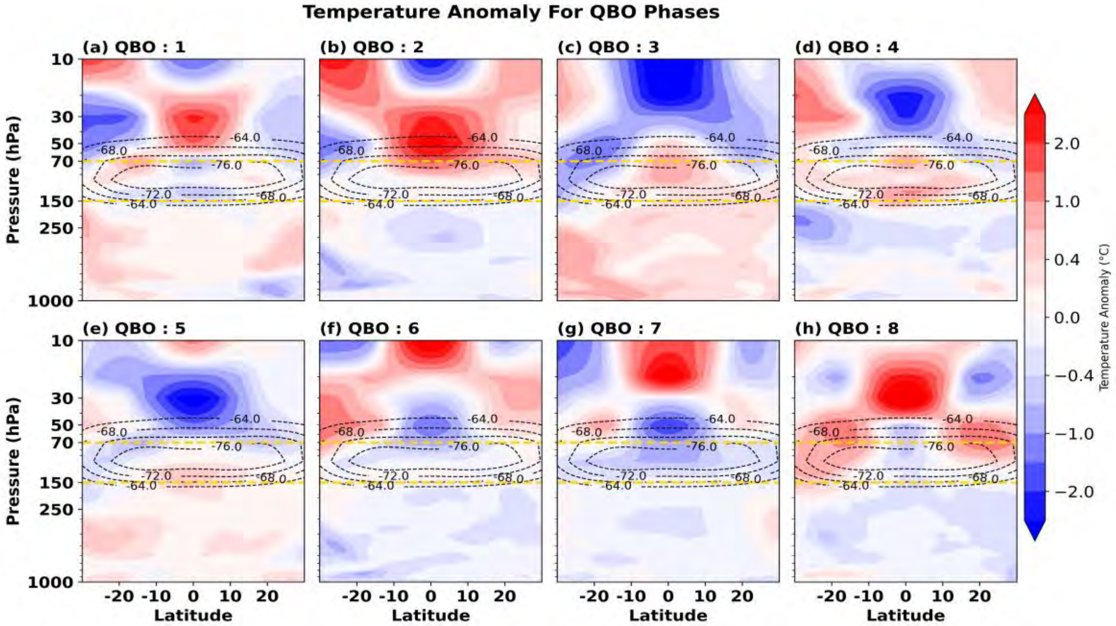
All Cases



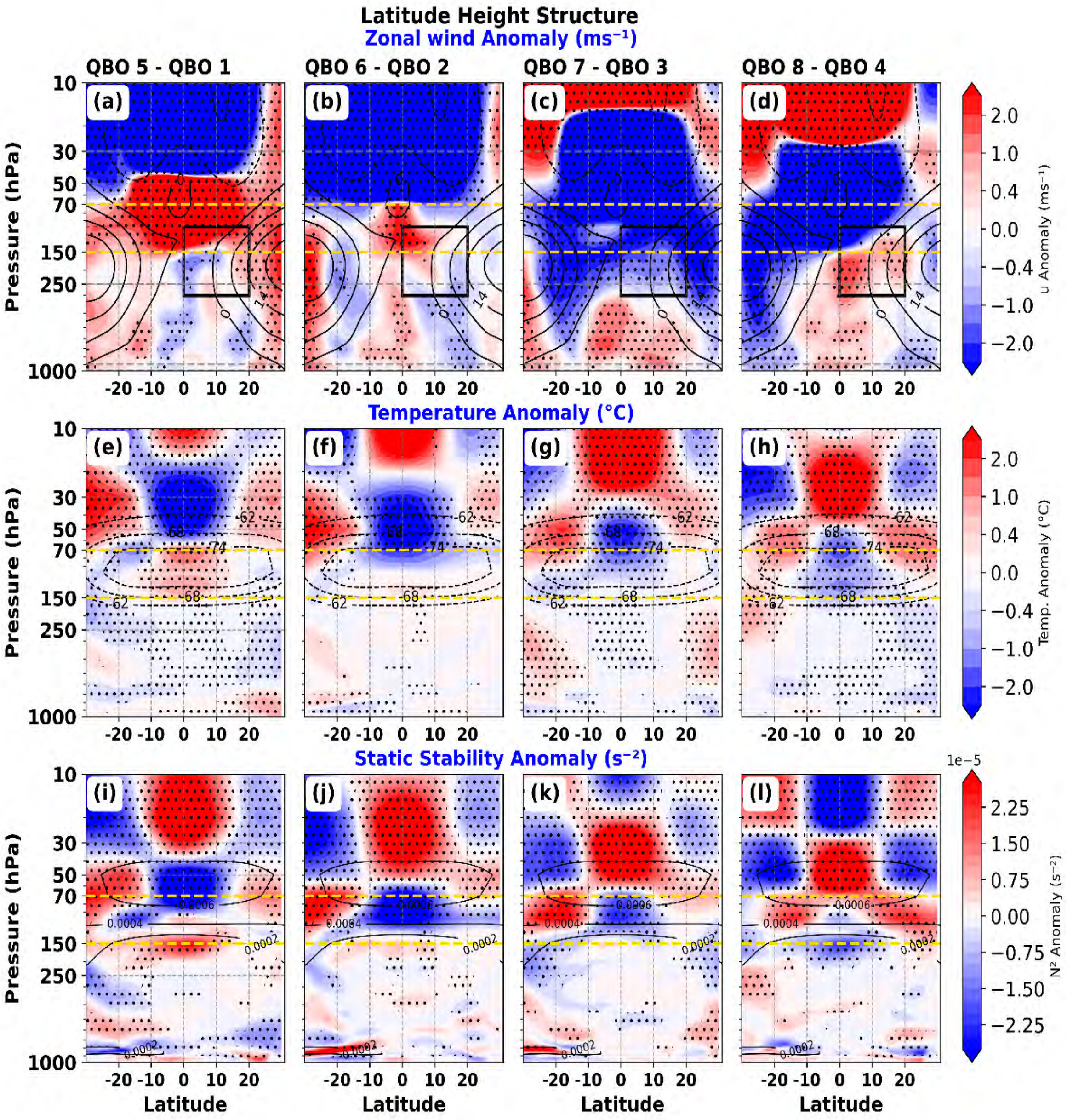


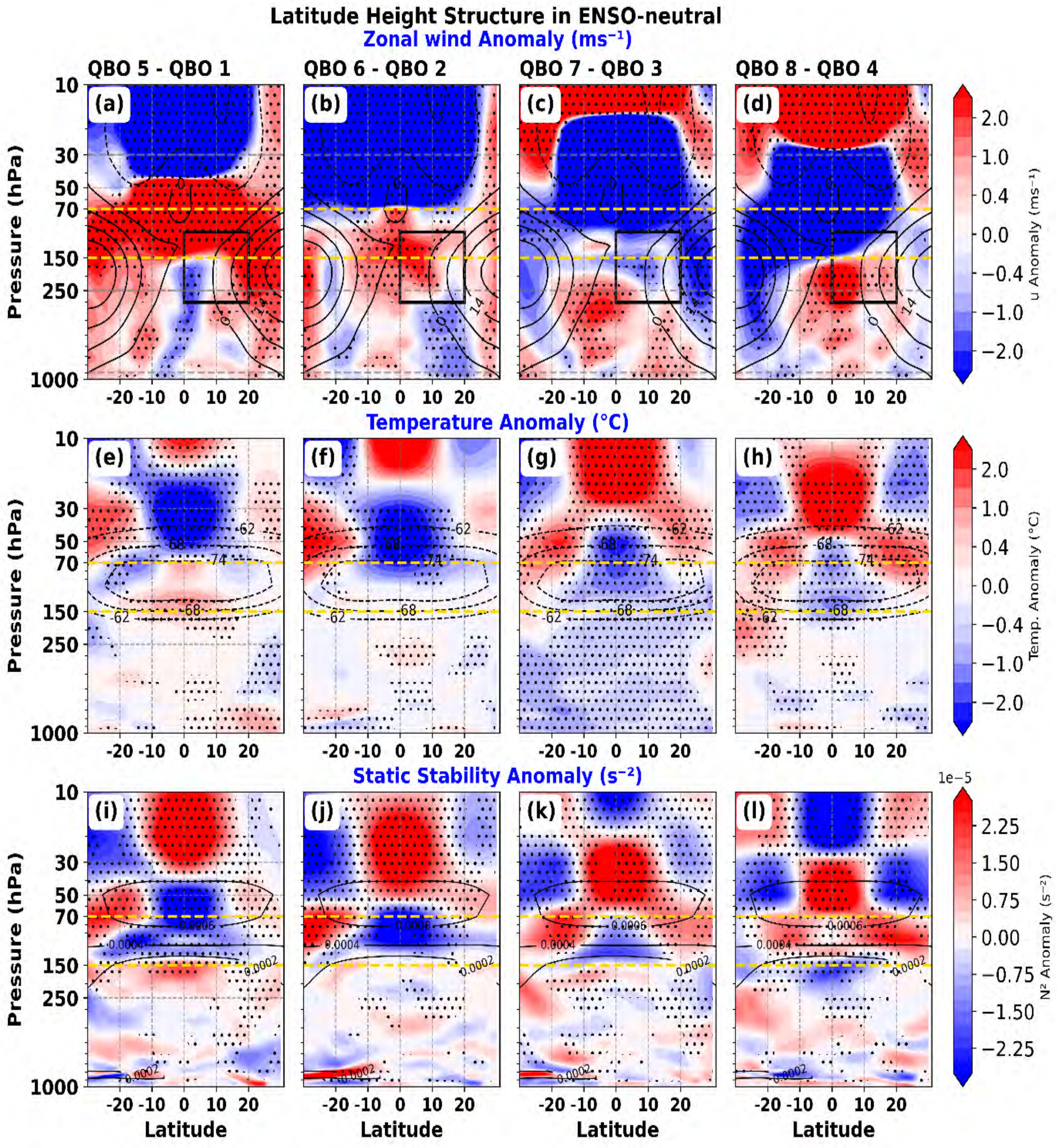
Neutral Cases



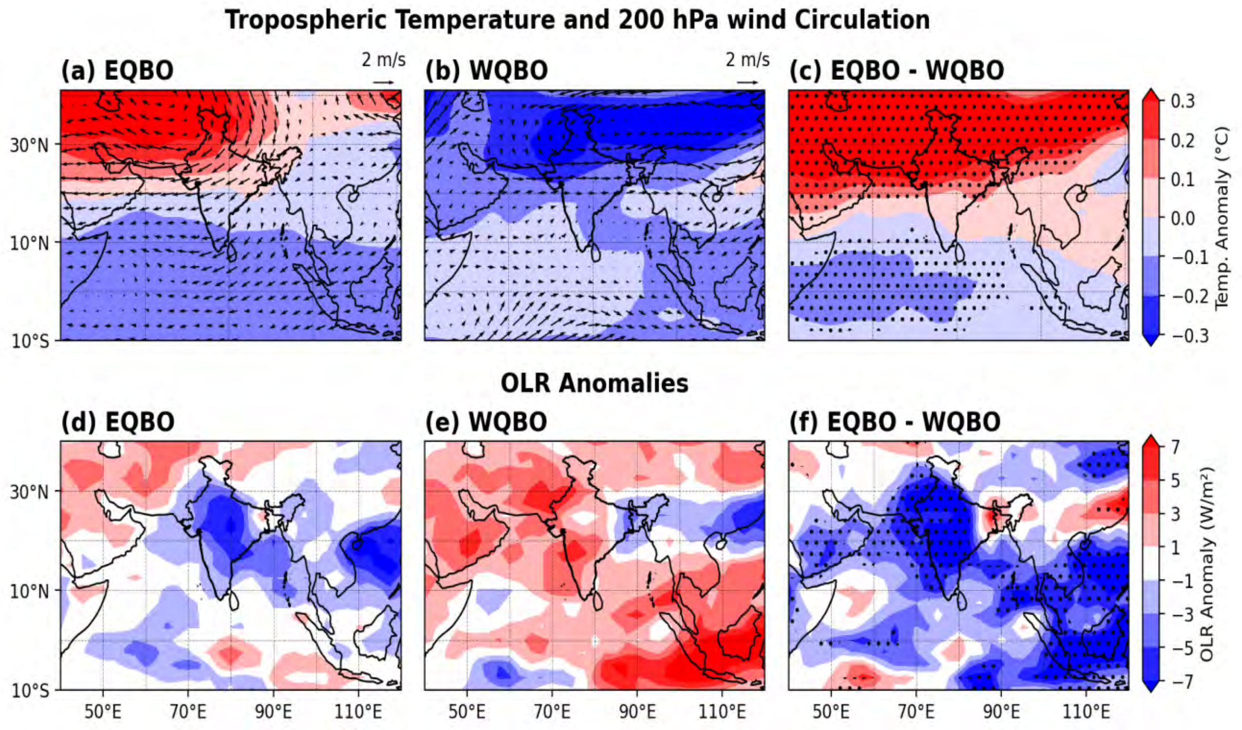


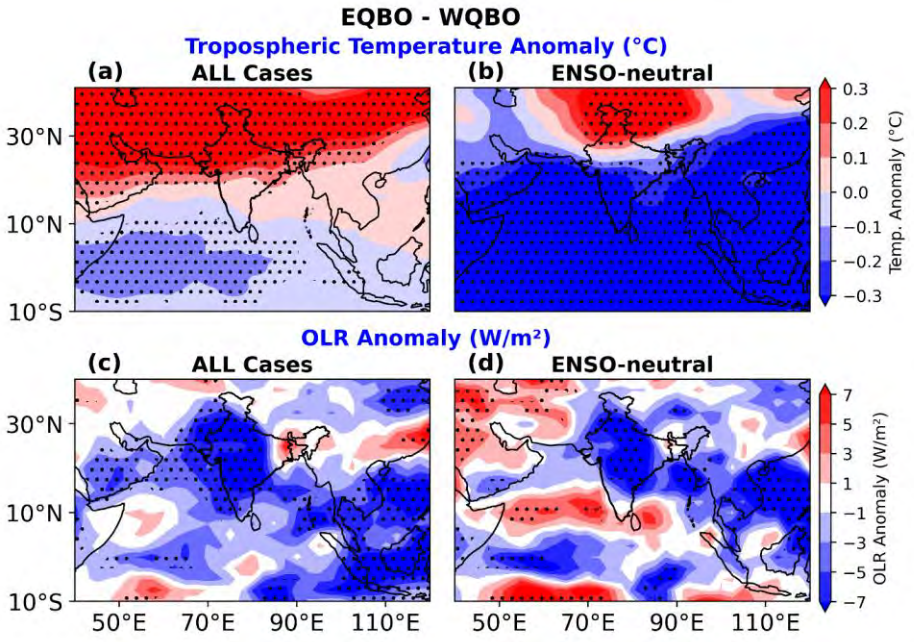
EQBO-WQBO Latitude-height profile of longitudinally averaged (60°E – 80°E) anomalies





EQBO, WQBO and Indian Seasonal Mean Monsoon





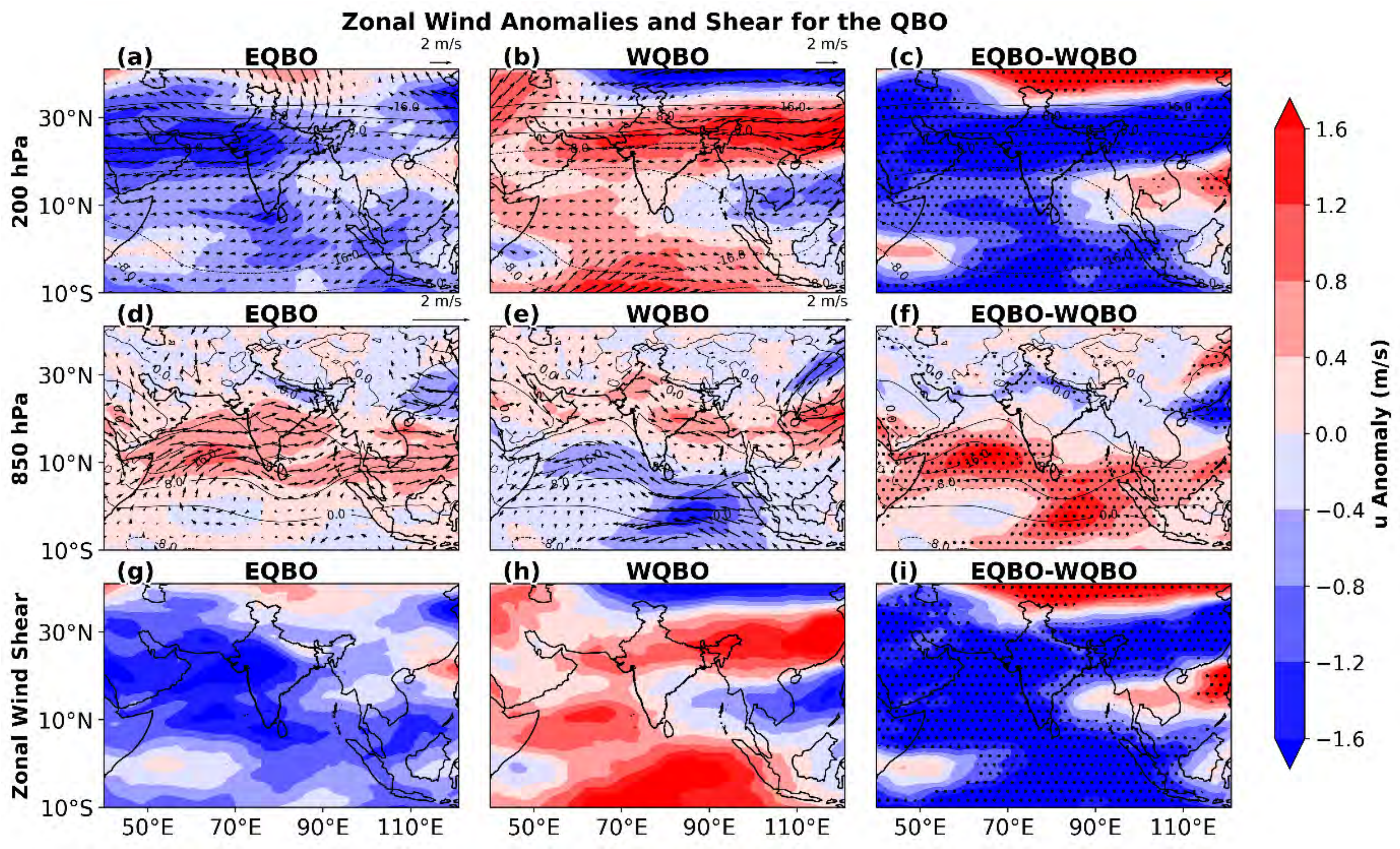
Tropospheric temperature (TT, avg. 200 hPa - 600 hPa)

- In EQBO : TT anomalously warmer in the northern latitudes (above 20°N), compared to the southern latitudes
 (20°S-10°N)

OLR Anomaly

- In EQBO : Significantly stronger monsoon

EQBO, WQBO and Indian Seasonal Mean Monsoon



WQBO

Anomalous Weaker

- TEJ in core region
- 200 hPa Easterlies
- 850 hPa Westerlies

EQBO

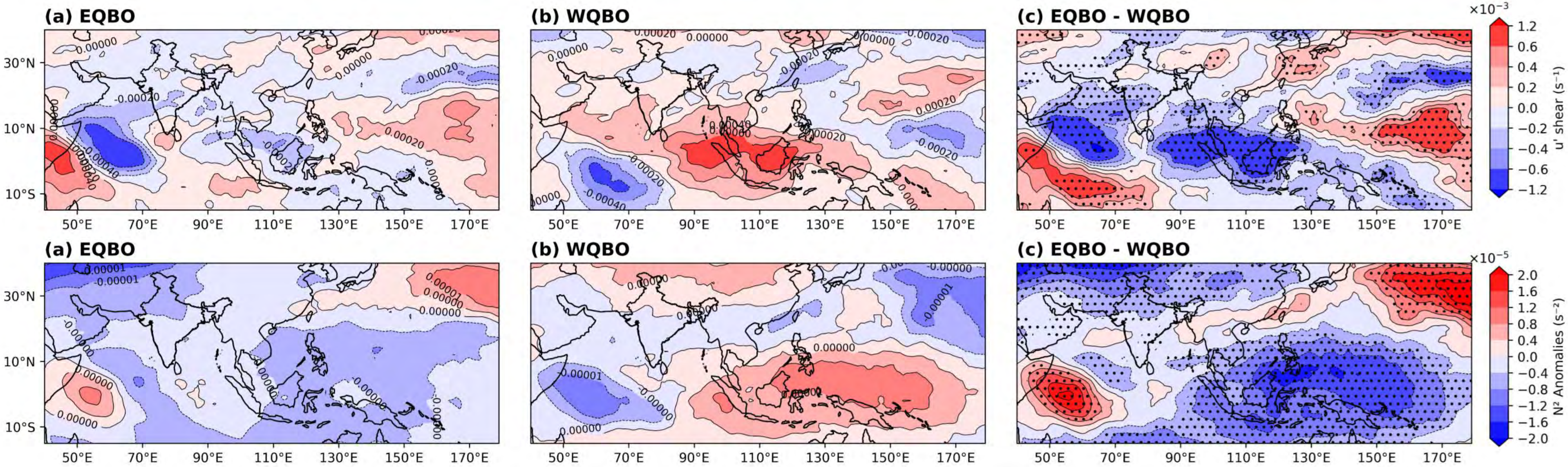
Anomalous stronger

- TEJ in core region
- 200 hPa Easterlies
- 850 hPa Westerlies

Vertical zonal wind shear (200 hPa – 850 hPa)

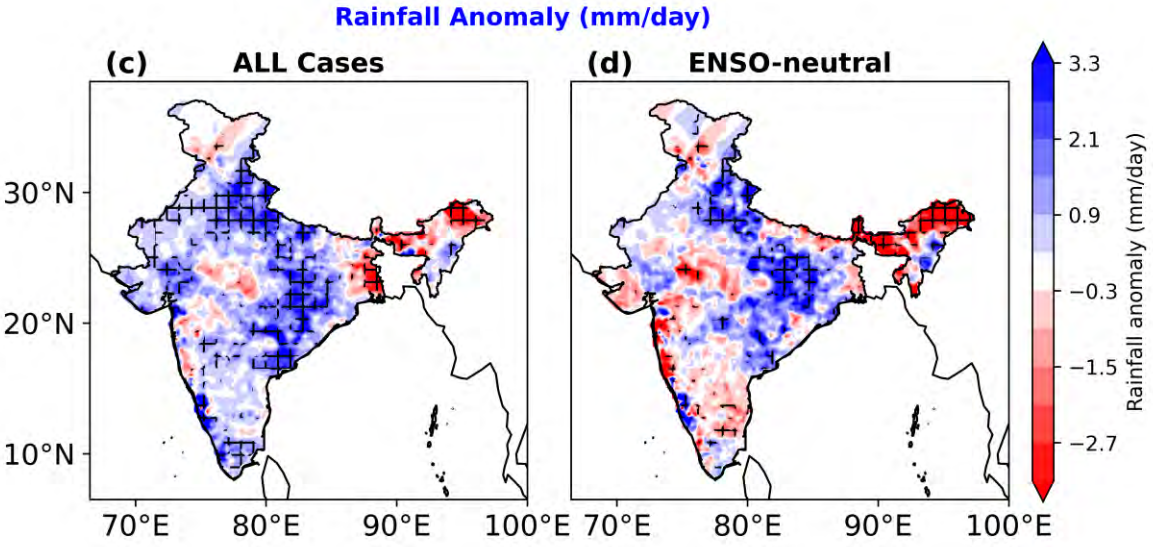
- measures the strength of Monsoon
- EQBO has anomalous strong negative shear
- Hence, Signal of stronger monsoon

Wind Shear and Static Sctability at 150 hPa

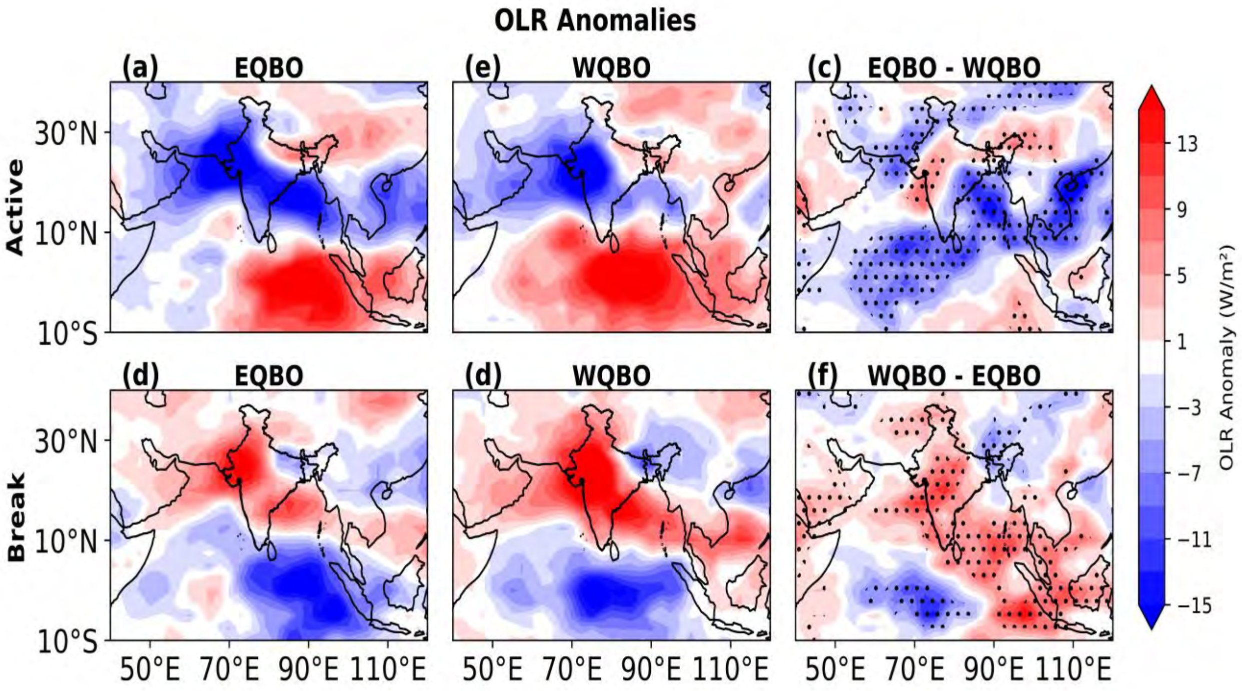


- Static Instability at 150 hPa in EQBO over Indian region supporting the increase in convection and hence precipitation over the Indian region

EQBO, WQBO and Indian Seasonal to subseasonal Mean Monsoon

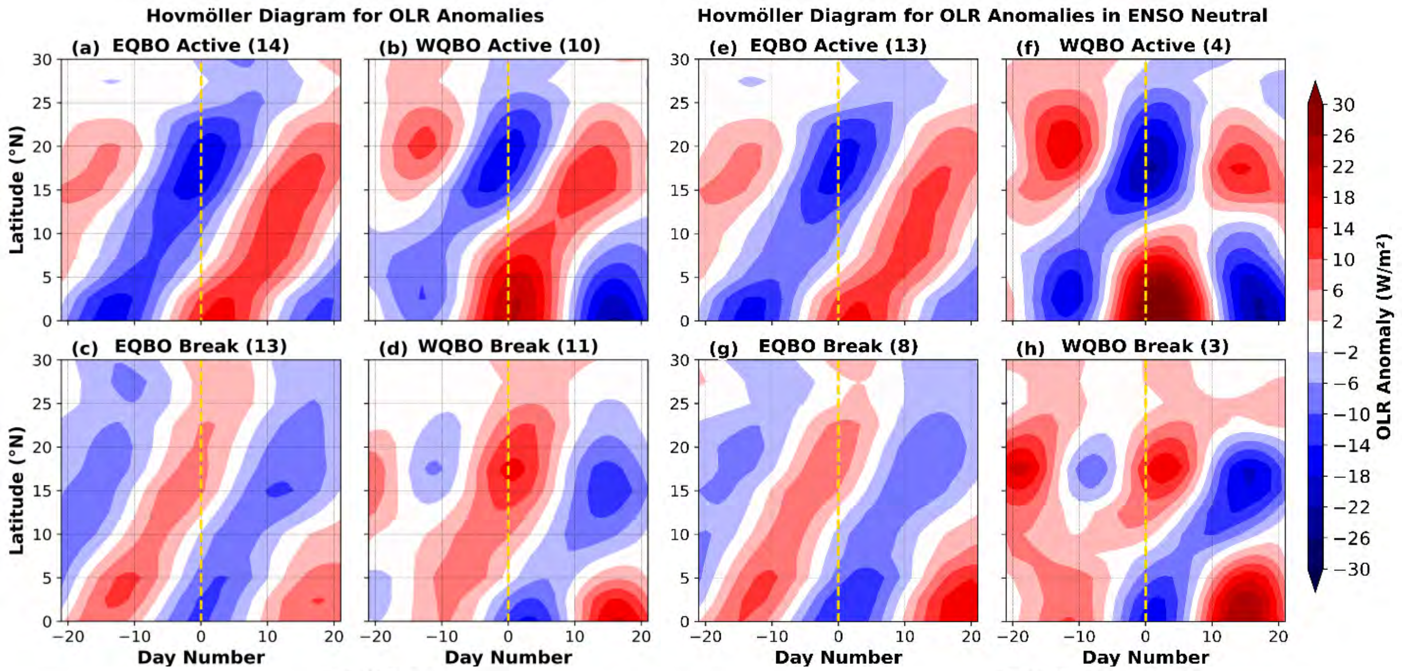


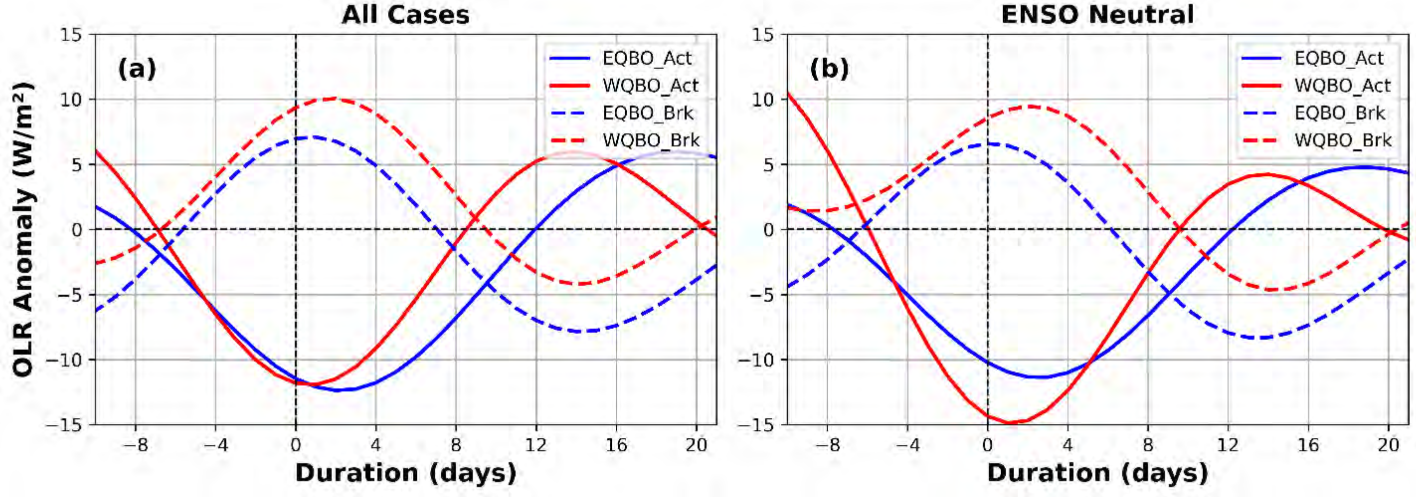
Rainfall anomaly difference 90 % significant.



OLR anomaly difference 95 % significant.

EQBO, WQBO and Active Break Spells



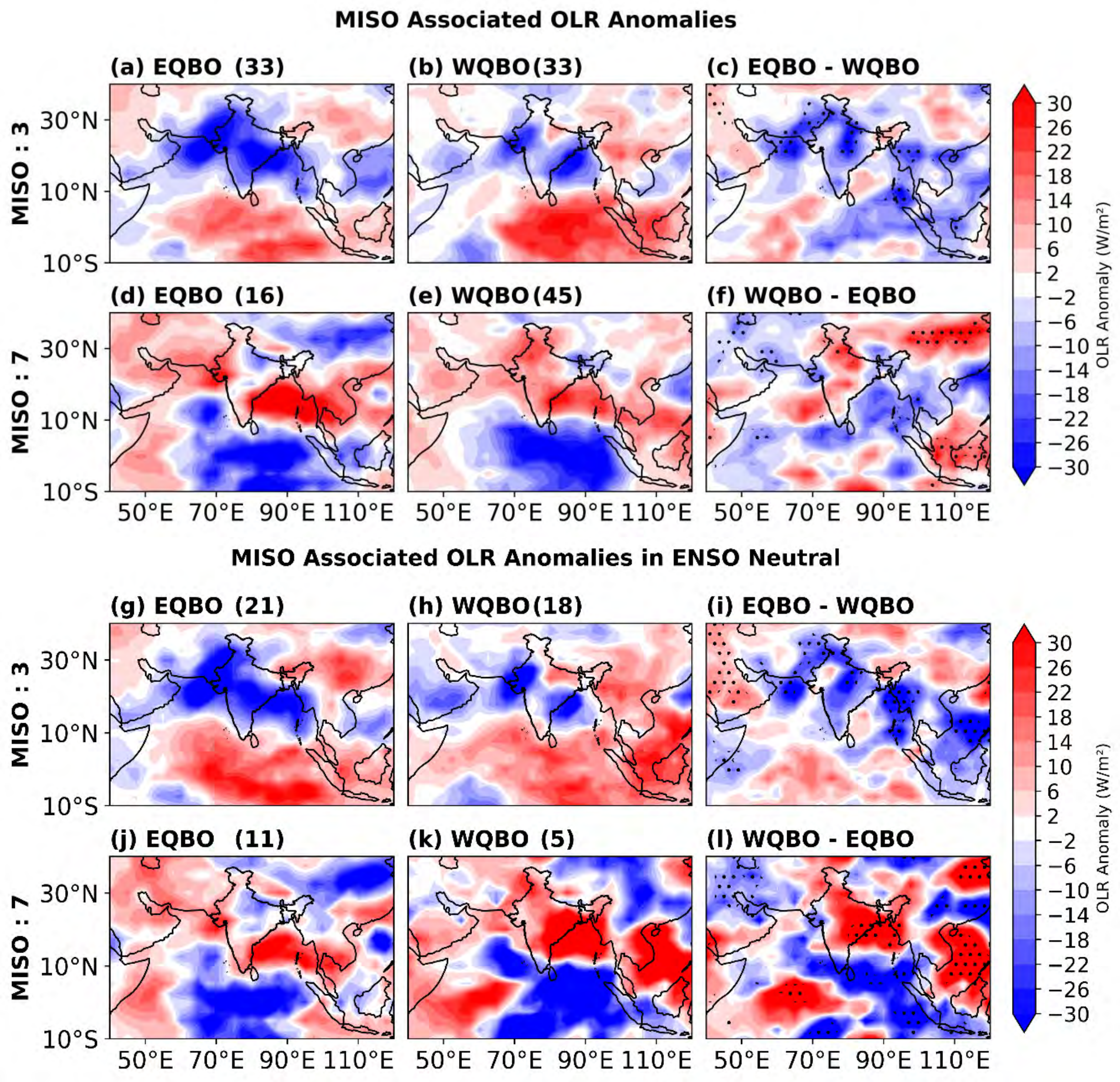


Prolonged and frequent active implies Anomalous Positive Monsoon

- In EQBO Slight Intense, longer actives and weaker, short lived breaks compared to WQBO.
- In ENSO neutral cases WQBO actives becomes more intense and short lived but breaks having no effect

OLR anomalies averaged over central India (18°-28°N; 65°-88°E)

EQBO, WQBO and MISO Phases



	MISO- 3	MISO- 7
Associated with	Active	Break
Intensity	Slightly intense	Slightly weak
Number of occurrence	Higher	Less

The results are consistent with ENSO Neutral Cases

4 Summary

- To consider the continuous vertical structure of QBO with alternating patterns of zonal wind and temperature varying with height, the EOF of equatorial (10°S-10°N) zonal wind between 100 – 10 hPa has been used.

Seasonal	**Stronger Monsoon**	**Weaker Monsoon**
	EQBO	**WQBO**
TEJ Core region	Stronger	Weaker
Tropopause	Colder	Warmer
Static Stability	Instable	Stable
200 hPa Easterlies	Stronger	Weaker
850 hPa Wesetrlies	Stronger	Weaker
Vertical Shear	Stronger	Weaker
Tropospheric Temperature N-S Gradient	Warmer in northern latitudes compared to southern	Colder in Northern latitudes and hence no N-S gradient

- Slight intense longer actives and weaker shorter breaks in EQBO compared to WQBO
- Stronger MISO phase 3 in EQBO
- This is true in ENSO neutral cases

Thank You

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ORIGINAL ARTICLE

Role of Quasi-Biennial Oscillation in modulating subseasonal to seasonal variability of Indian Summer Monsoon

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Abstract
The Quasi-Biennial Oscillation (QBO) influences the static stability and wind shear over the equatorial upper-tropospheric regions and lower-stratospheric regions, and hence the convections of underlying areas. This study evaluates the concurrent relationship between QBO phases and the Indian Summer Monsoon (ISM). QBO is identified by the Empirical Orthogonal Function analysis of equatorial zonal wind bounded by 10°S-10°N over 100−10 hPa. Since the QBO affects the tropical troposphere, it is hypothesised that QBO can influence ISM through upper-level wind circulation, particularly the tropical easterly jet (TEJ). The easterly phase of QBO (EQBO) is associated with strong easterlies (westerlies) at 200 hPa (850 hPa), enhancing vertical zonal wind shear, strengthening the TEJ, and increasing upper-level divergence and lower-level convection—favourable conditions for a strong ISM. On the contrary, the westerly phase of QBO (WQBO) exhibits opposite features, signifying weak monsoon conditions. Temperature and static stability anomalies further support these findings. The QBO effect extends to the monsoon intraseasonal variability as well. The active spells are more persistent and spatially extended during EQBO, while break spells are shorter and weaker. Contrarily, the breaks are of higher amplitude and long-lived during WQBO. The robustness of these relationships is confirmed by ENSO-neutral cases, highlighting the independent role of QBO in modulating the subseasonal to seasonal variability of ISM. These findings emphasize the potential of incorporating QBO signals into monsoon prediction frameworks, aiding in the differentiation of QBO and ENSO-driven influences.

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Relationship between Changes in Vertical Shear with Height and Horizontal Changes in Static Stability

Deriving the relationship between changes in vertical shear of zonal winds and stability begins with the thermal wind equation for an equatorial beta-plane [Eq. (A1)], where u is the zonal wind speed ($\mathrm{m\,s^{-1}}$), z is height, R is the dry air gas constant ($287\,\mathrm{J\,kg^{-1}\,K^{-1}}$), β is the change in Coriolis with latitude, H is the atmospheric scale height (m), T is the temperature (K), and y is meridional position (m). This equation has been used in numerous studies relating QBO-driven zonal wind and temperature variations (e.g., Baldwin et al. 2001):

$$\frac{\partial u}{\partial z} = \frac{-R}{\beta H}\frac{\partial^2 T}{\partial y^2}. \tag{A1}$$

Taking the derivative of Eq. (A1) with respect to height z, expanding the partial derivatives with product and quotient rules, and consolidating the meridional curvature ($\partial^2/\partial y^2$) terms restates the thermal wind balance as Eq. (A2):

$$\frac{\partial^2 u}{\partial z^2} = -\frac{1}{\beta}\frac{\partial^2}{\partial y^2}\left[\frac{R}{H}\left(\frac{\partial T}{\partial z} - \frac{T}{H}\frac{\partial H}{\partial z}\right)\right]. \tag{A2}$$

In Eq. (A2), R/c_p (where c_p is the specific heat capacity of dry air with respect to constant pressure, $\mathrm{J\,kg^{-1}\,K^{-1}}$) can be substituted for $-\partial H/\partial z$ [Eq. (A8)] by first solving the scale height relationship [Eq. (A3)] for z to yield Eq. (A4):

$$P = P_o e^{-z/H} \tag{A3}$$

$$(H)\ln\left(\frac{P}{P_o}\right) = -z. \tag{A4}$$

Expressing the hypsometric equation [Eq. (A5)] in terms of height z at pressure P by letting $z_2 = z$, $z_1 = 0$, $P_2 = P$, and $P_1 = P_o$ yields Eq. (A6) as follows:

$$z_2 - z_1 = \frac{RT}{g}\ln\left(\frac{P_1}{P_2}\right), \tag{A5}$$

$$z = \frac{RT}{g}\ln\left(\frac{P_o}{P}\right). \tag{A6}$$

Substituting Eq. (A6) into Eq. (A4), taking the derivative with respect to height z, and substituting the atmospheric lapse rate equation [Eq. (A7)] links the change in scale height H with altitude z to the quotient of the dry air gas constant R and specific heat capacity at constant pressure [c_p; Eq. (A8)]:

$$\frac{g}{c_p} = -\frac{\partial T}{\partial z}, \tag{A7}$$

$$\frac{\partial H}{\partial z} = \frac{-R}{c_p}. \tag{A8}$$

Substituting Eq. (A8) into Eq. (A2) restates the thermal wind balance as in Eq. (A9):

$$\frac{\partial^2 u}{\partial z^2} = -\frac{1}{\beta}\frac{\partial^2}{\partial y^2}\left[\frac{R}{H}\left(\frac{\partial T}{\partial z} + \frac{RT}{c_p H}\right)\right]. \tag{A9}$$

$$N^2 = \frac{R}{H}\left(\frac{\partial T}{\partial z} + \frac{RT}{c_p H}\right), \tag{A10}$$

$$\frac{\partial^2 u}{\partial z^2} = -\frac{1}{\beta}\frac{\partial^2 N^2}{\partial y^2}. \tag{A11}$$

QBO phase	Active phase		Break phase		Total no. of QBO days
	No. of spells	Median period	No. of spells	Median period	
QBO-1	10 (2)	8 (8)	10 (2)	5 (6)	512 (197)
QBO-2	13 (10)	8 (7)	12 (7)	7.5 (8)	529 (316)
QBO-3	9 (4)	8 (10)	11 (3)	9 (8)	613 (254)
QBO-4	11 (5)	7 (5)	12 (7)	6 (6)	556 (264)
QBO-5	11 (7)	7 (7)	18 (8)	7 (8)	696 (341)
QBO-6	9 (7)	7 (6)	8 (7)	8 (8)	383 (332)
QBO-7	14 (13)	7 (7)	13 (8)	6 (6)	668 (533)
QBO-8	10 (6)	6 (7.5)	9 (6)	5 (6)	426 (233)