Climate Variability and Data Assimilation Research

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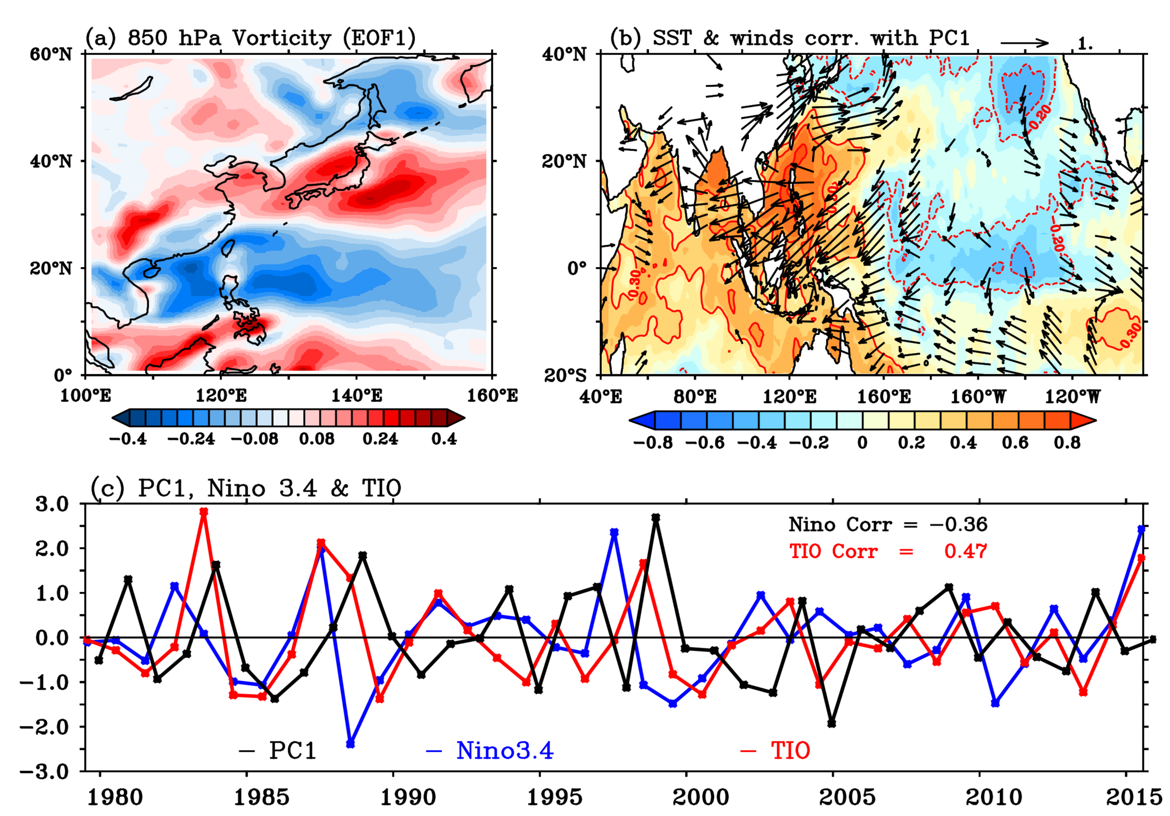
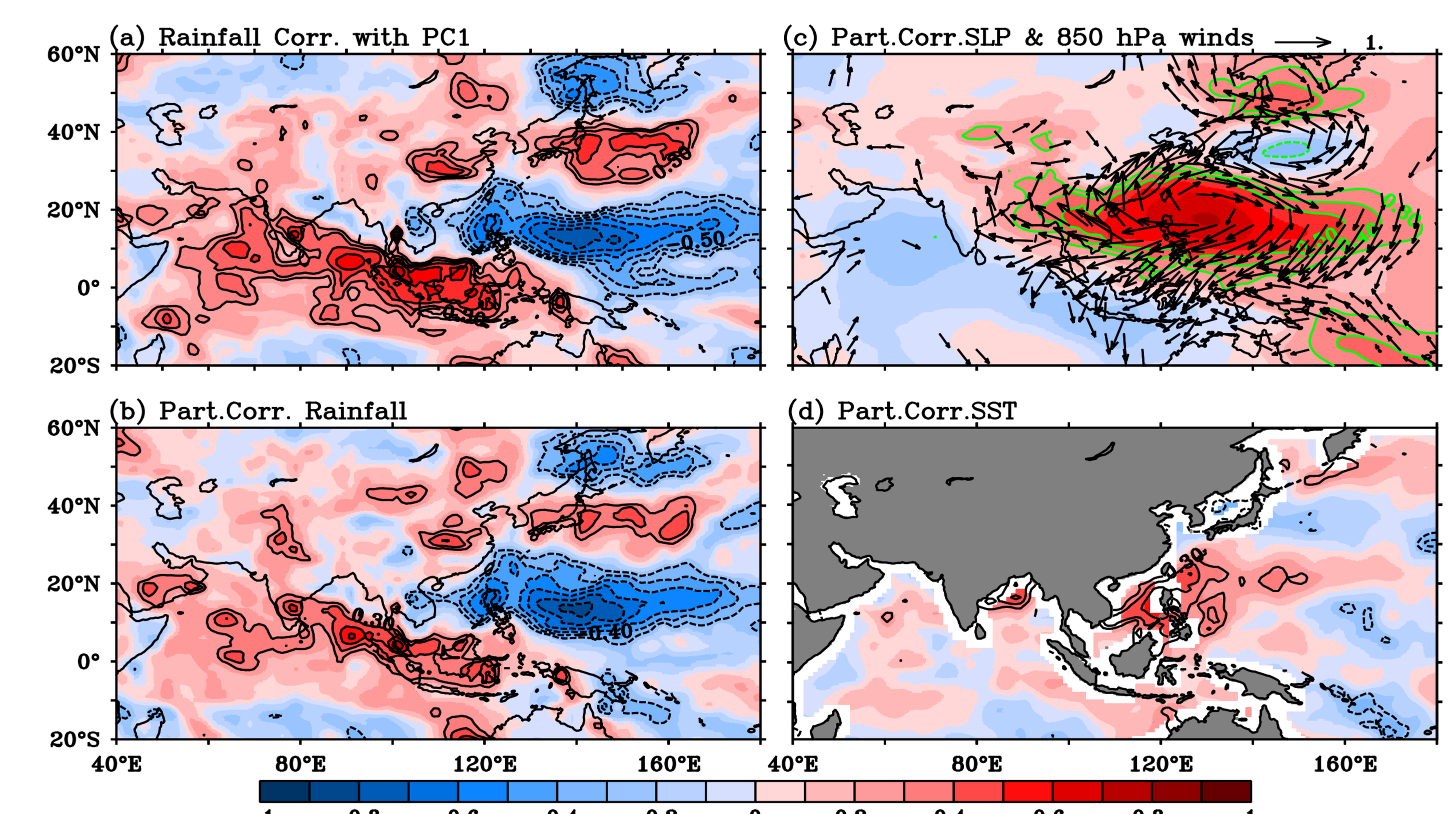
Impact of the Pacific-Japan Pattern on Indian summer monsoon rainfall

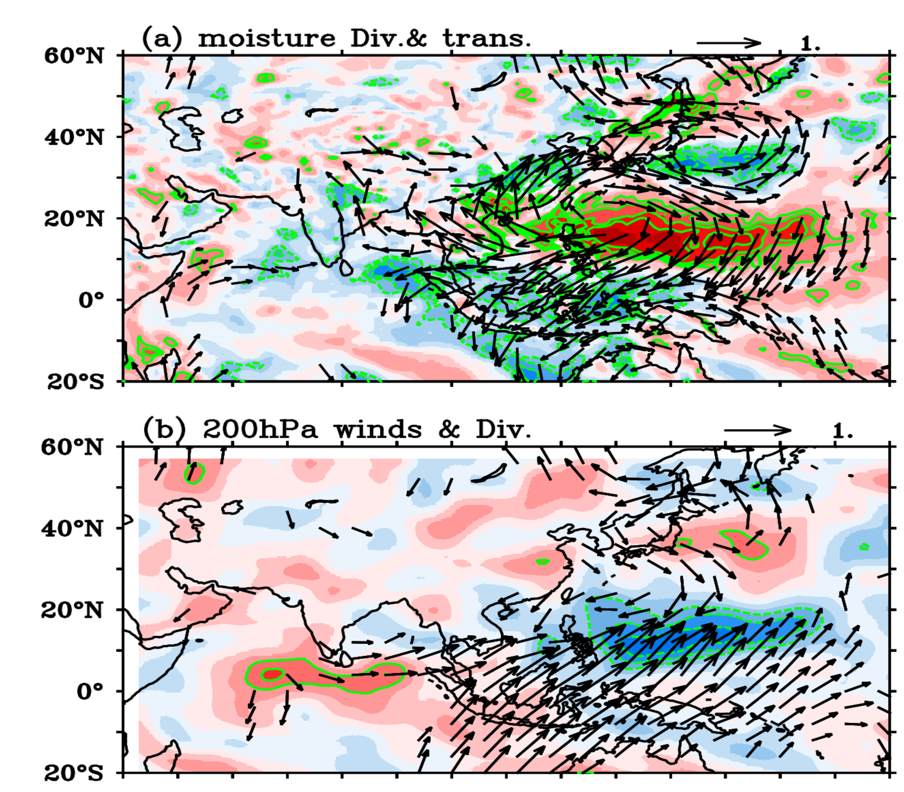
Introduction: On the interannual time scale, SST anomalies associated with the El Niño-Southern Oscillation (ENSO) are the dominant forcing for the ISM variability in spite of the uncertainty in the stability of the monsoon–ENSO teleconnections (Krishna Kumar et al. 1999, 2006; Lau and Nath 2000; Turner and Annamalai 2012). Many studies have addressed the teleconnections between ISM rainfall and ENSO. Apart from ENSO, the dominant modes in the Pacific such as the Pacific Decadal Oscillation (PDO) and Interdecadal Pacific Oscillation (IPO) have considerable impact on ISM rainfall variability at various time scales (Krishnan and Sugi 2003; Joshi and Kucharski 2016; Joseph et al. 2013; Malik et al. 2017). However, influence of the dominant mode in the low level circulation, namely the Pacific-Japan (PJ) pattern (Nitta 1987), over the western North Pacific (WNP; equator to 60ºN) on ISM rainfall is not explored. The PJ pattern features a meridional dipole structure in lower tropospheric circulation and precipitation anomalies with the tropical and midlatitude WNP lobes (Nitta 1987; Kosaka and Nakamura 2006), and provides a crucial link between the tropics and midlatitudes. The positive PJ pattern features anticyclonic (cyclonic) surface anomalies with drier and hotter (wetter and cooler) summer in the tropical (midlatitude) WNP (e.g., Huang and Sun 1992; Kubota et al. 2016). This paper discusses the impact of the Pacific-Japan (PJ) pattern on Indian summer monsoon (ISM) rainfall and its possible physical linkages through coupled and uncoupled pathways.



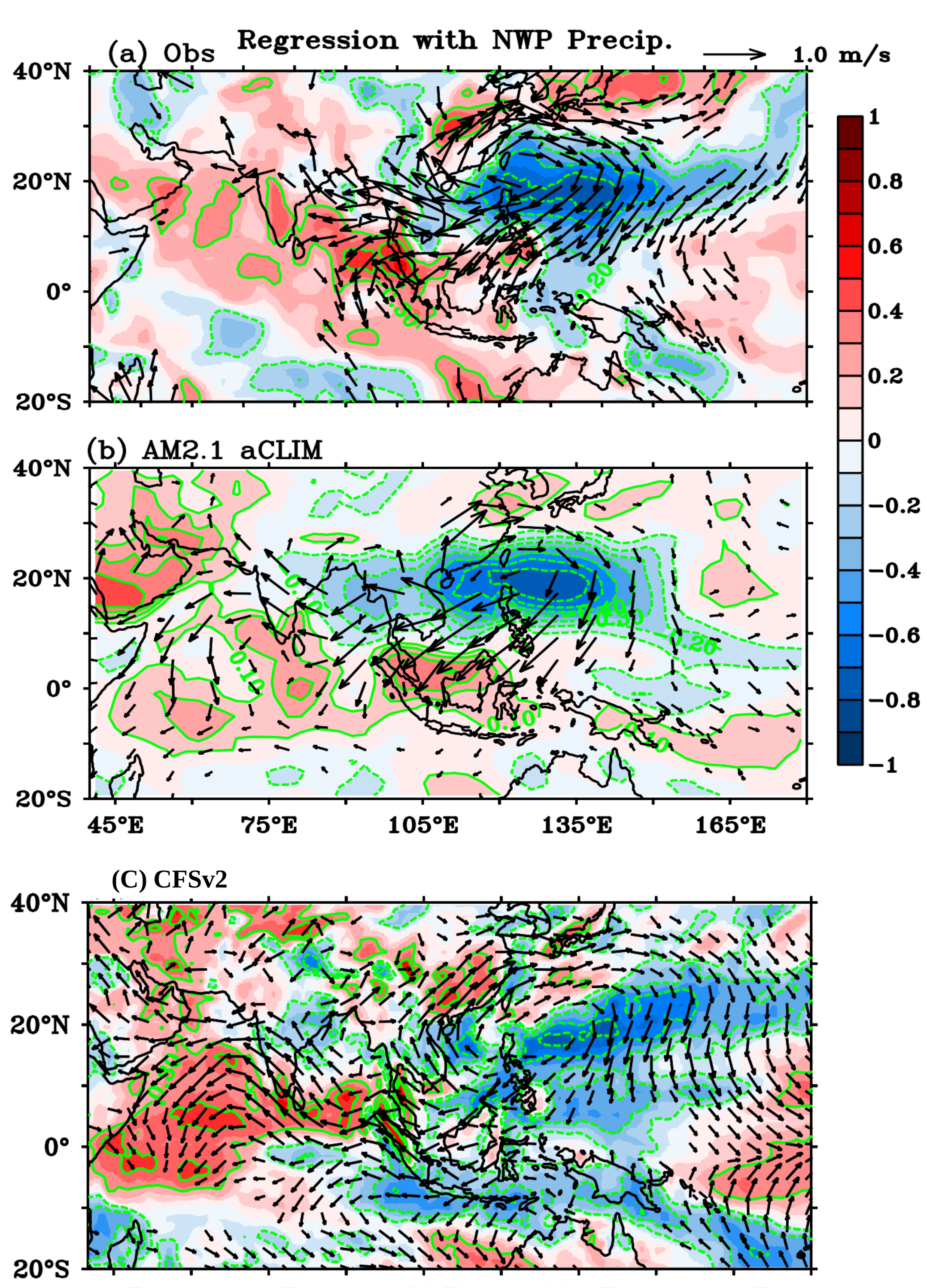
Boreal summer season (JJA): (a) EOF1 of relative vorticity at 850 hPa (dimensionalized by unit standard deviation of RV-PC1; in 10^5 s^{-1}; shaded), (b) correlation of RV-PC1 with SST (shaded) and surface wind (vectors) anomalies, and c) normalized time series of RV-PC1 (black line), SST anomalies of Niño 3.4 (blue line) and TIO (red line).



Spatial patterns in boreal summer: (a) correlation of RV-PC1 with rainfall (shaded and contour), (b) partial correlation of RV-PC1 with rainfall after removing the influence of Niño 3.4 and TIO indices (shaded and contour), (c) same as in (b) but for MSLP (shaded) and winds at 850 hPa (vectors) and (d) same as in (b) but for SST anomalies.



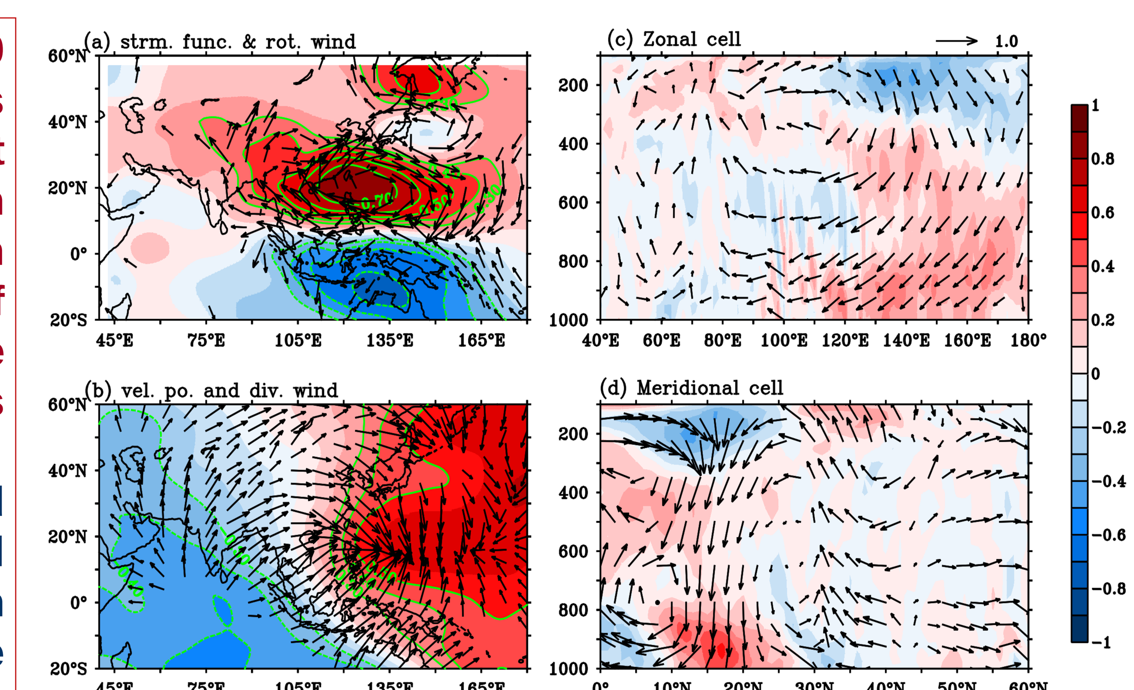
Boreal summer season (JJA): Partial correlation of RV-PC1 after removing the influence of ENSO and TIO (a) moisture transport (vectors) and moisture divergence (shaded) anomalies, and (b) 200 hPa wind (vectors) and divergence (shaded) anomalies,



(a) Partial regression of precipitation averaged over the tropical WNP region (latitude 15 – 25ºN and longitude 110 – 150E) with anomalies of precipitation (mm/day) and wind at 850 hPa (vectors; m/s) during JJA for observations, (b) same as in (a) regression in AM 2.1 climatological SST run and (c) as in (a) but for CFSv2. Vectors and contours are significant at 95% confidence level.

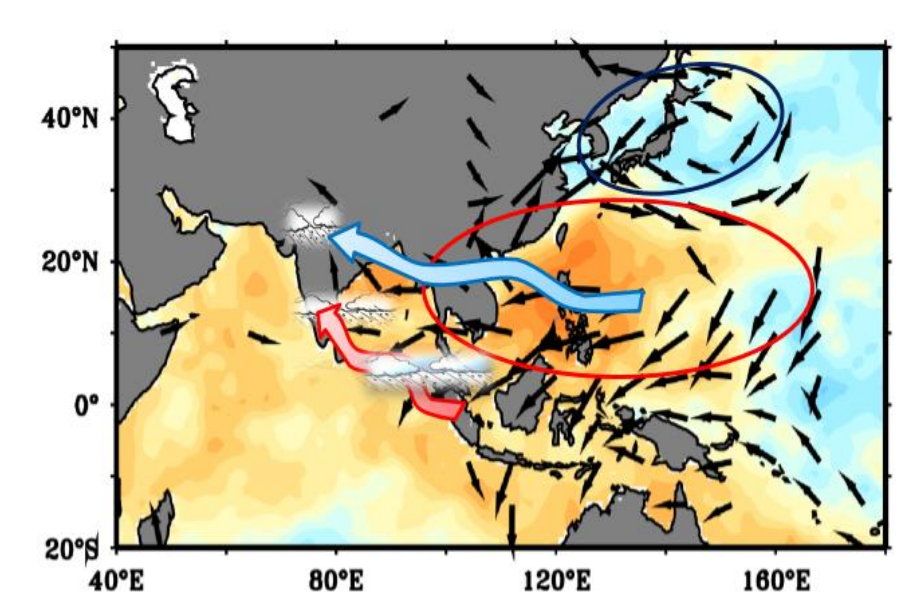
Data: Monthly atmospheric data such as wind at different pressure levels and mean sea level pressure (MSLP) for the period of 1979-2015 are obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis data set (ERA-Interim; Dee *et al.* 2011) Tropospheric temperature is defined as mean temperature between 850 and 200 hPa. Precipitation data from Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) and the latest version of Hadley Centre Sea Ice and SST (HadISST; Rayner et al. 2003) data sets are utilized in the present study.

- **The partial correlation of the PJ index (the leading PC of the 850 hPa relative vorticity over the WNP) on precipitation anomalies showed significantly positive correlation over the Maritime Continent and southern and northern parts of India. Enhanced convection in southern peninsular India is due to the response of deep convection over the Maritime continent through northwestward propagation of warm Rossby waves. Enhanced deep convection over the Maritime Continent is associated with tropical WNP anomalous anticyclone as a part of the PJ pattern.**
- **In conjugation with this, the east-west circulation (zonal and vertical) cell with ascending motion corroborated by low level convergence and upper level divergence over the Indian subcontinent and strong subsidence over WNP region indicates the influence of the PJ pattern on ISM rainfall.**
- **It is found that positive rainfall band over north India is mainly due to anomalous low level moisture convergence in the northwestern edge of westward propagating atmospheric cold Rossby wave as a response to suppressed convection over the tropical WNP region associated with the PJ pattern.**
- **The intrinsic PJ mode captured in AGCM exerts significant precipitation anomalies over the ISM region through westward extension of the tropical WNP anticyclone, in particular over southern parts of India.**
- **This highlights the importance of atmospheric pathway of the PJ influence on ISM rainfall. Furthermore, the north Indian Ocean (NIO) warming induced by easterly wind anomalies along the southern periphery of the tropical WNP-NIO anticyclone enhances the local convection, which in turn feeds back to the WNP convection anomalies. This coupled nature via inter-basin feedback between the PJ pattern and NIO are confirmed using coupled model sensitivity experiments.**

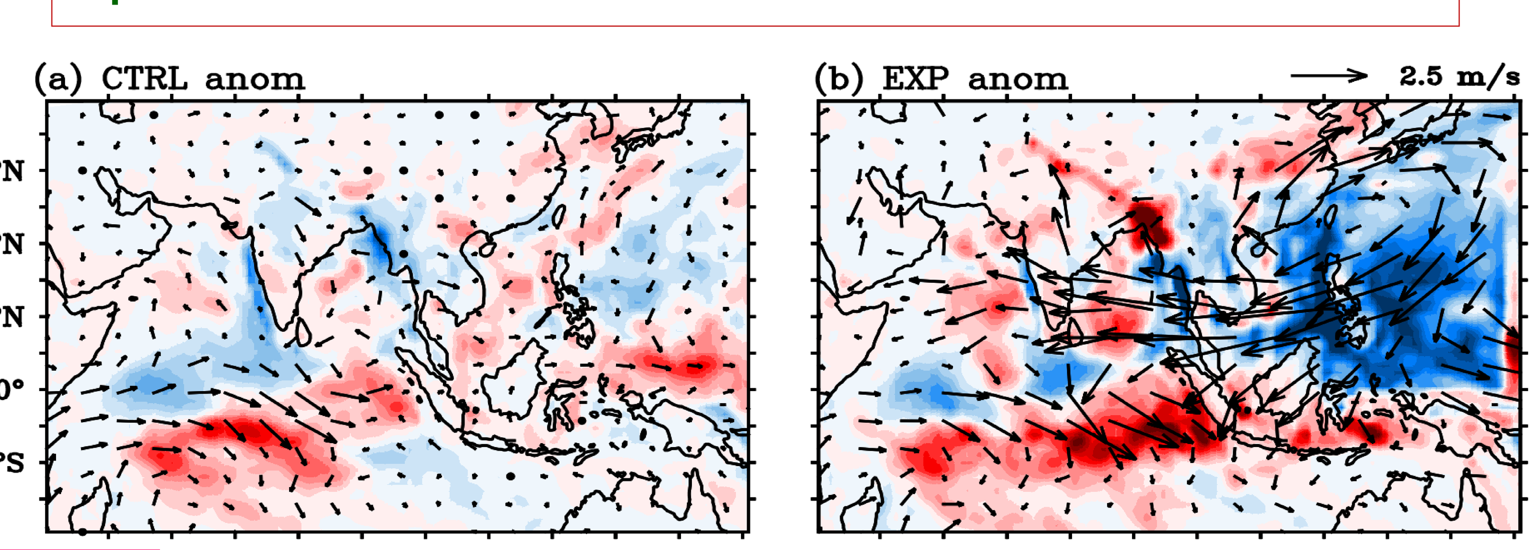


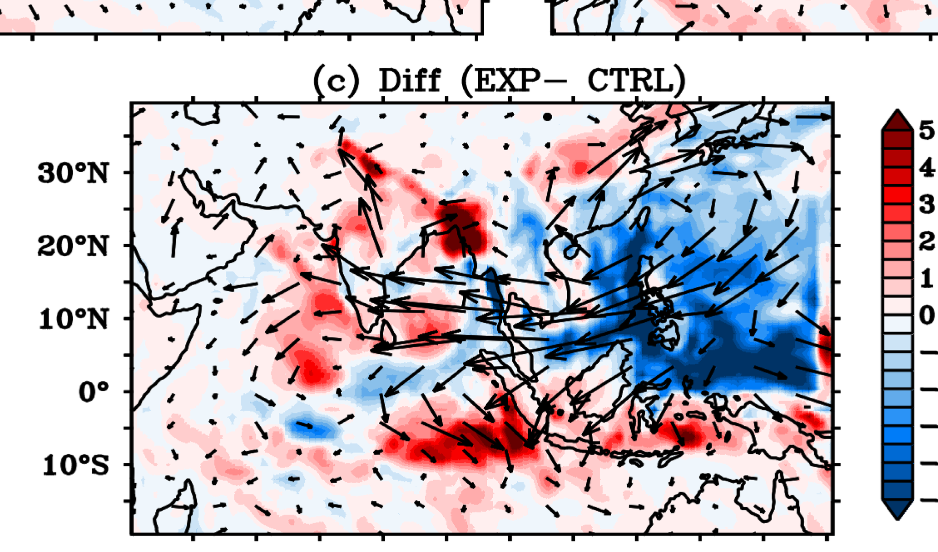
Partial correlation of RV-PC1 (a) stream function (shaded) and rotational component of winds at 850 hPa (vectors), (b) same as but for (a) velocity potential (shaded) and divergence component of winds at 200 hPa (vectors). Contours and vectors are significant at 95% confidence level. (c) same is in (a) but for zonal overturning circulation (shaded, divergence; vectors, u, w) averaged over 5 – 25ºN and (d) same as in (a) but for meridional overturning circulation (shaded, divergence; vectors, v, w) averaged over 130 - 160ºE.

Stream function anomalies show westward extension of tropical WNP anticyclonic anomalies and northwestward extending cyclonic anomalies from the Maritime Continent towards southern tip of India in association with the PJ pattern.



Schematic diagram that shows pathways associated with the impact of the PJ pattern on ISM rainfall. Red (blue) ellipse indicates anomalous anticyclone (cyclonic) circulation over the tropical (midlatitude) WNP and vectors represent broad low level circulation associated with PJ pattern. Thick red (blue) arrow represents westward extension of warm (cold) Rossby wave and Yellow to Red (light blue) shading indicates warm (cold) SST anomalies.





Spatial pattern of JJA precipitation (mm/day) and 850 hPa wind (m/s) anomalies for (a) CTL run in 1990, (b) EXP run and (c) their difference (EXP minus CTL).

- **To examine the atmospheric pathway that links the PJ pattern and ISM, we have used an AGCM experiment forced with observed climatology of SST (Raynolds et al. 2007) globally. The model used in this study is the Geophysical Fluid Dynamics Laboratory (GFDL) Atmospheric Model version 2.1 (AM2.1; Anderson et al. 2004) with horizontal resolution of ~200 km and 24 vertical levels. This model run is carried out with a single ensemble member for 200 years.**
- **Furthermore, a fully coupled ocean-atmosphere model, National Center for Environmental Prediction (NCEP) Climate Forecasting System version 2 (CFSv2; Saha et al. 2014) is used in this study to carry out sensitivity experiment (EXP) with the 1990 condition, which is free from both the PJ pattern and ENSO. Anomalies of precipitation and circulation for JJA in the ensemble mean of CTL are calculated with respect to 1985 – 2014 climatology.**
- **EXP is similar to CTL but tropical WNP convection is suppressed by imposing strong negative SST anomalies (varying between -1 to -2ºC) over the tropical WNP region to explore the coupled processes associated with the PJ influence on ISM. Corresponding anomalies in EXP run with respect to climatology display a PJ-like pattern in precipitation but with widespread negative values over the WNP .**

The present study shows a robust inter-basin influence of the PJ pattern. In particular, NIO SST warming due to easterly wind anomalies associated with the PJ pattern could contribute to increased rainfall in the former region including parts of the Indian subcontinent.

✓Overall, the PJ pattern arising from the inter-basin ocean-atmosphere feedback enhances the convection over some parts of the Indian subcontinent and NIO through the westward propagating Rossby waves and the changes in zonal overturning circulation around 10ºN. This suggests that the atmospheric pathway (atmospheric Rossby wave response) and coupled interaction (the PJ and NIO interaction) provide a vital clue on how the PJ influences ISM. It is also found from long period data sets (20CR and CRU) that the PJ teleconnections to ISMR is stable in time

G. Srinivas; J S. Chowdary; Yu Kosaka; C. Gnanaseelan; Anant Parekh; K.V.S.R. Prasad (2018) Influence of the Pacific-Japan Pattern on Indian summer monsoon rainfall. Journal of Climate, DOI: 10.1175/JCLI-D-17-0408.1, in Press.

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