Oceanic influence on Large-Scale Atmospheric Convection during co-occurring La Niña and negative IOD events

Supriya Ovhal[1,2], Mujumdar M[1]*, Swapna P[1], Sreenivas P[3], Sandeep N[1], M. Ravichandran[4]

[1]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences (MoES), Pune 411008, India [2] Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, 411007, India[3] University of Hyderabad, Telangana 500046, India [4]Ministry of Earth Sciences (MoES), New Delhi, India

[1]supriyaovhal@gmail.com

Abstract No :Th-4.31

Introduction

The interaction between the ocean and atmosphere plays a crucial role in shaping Earth's climate system. Among the key drivers of climate variability, the relationship between Sea Surface Temperature (SST) and atmospheric circulation patterns significantly influences regional weather phenomena, particularly the Indian Summer Monsoon Rainfall (ISMR). While the impact of El Niño and positive Indian Ocean Dipole (IOD) on ISMR is well-documented, the combined influence of La Niña and negative IOD (nIOD) remains less understood. This study aims to explore the co-occurrence of La Niña and nIOD, particularly in years like 2010 and 2022, to assess their impact on ISMR variability, large-scale circulation anomalies, and oceanic subsurface feedback. Through an analysis spanning 1979–2022, this research seeks to enhance the understanding of ocean-atmosphere coupling and its implications for South Asian monsoon dynamics.

Data and Methodology

Data: This study utilizes rainfall data from the Climatic Research Unit (1901–2022), Outgoing Longwave Radiation (OLR) from NOAA (1979–2022), and oceanic and atmospheric parameters from HadISST and ERA5 (1979–2022). Additionally, we analyze CMIP6 simulations, including PI-control (200 years) and historical (1950–2014) data from IITM-ESM.

Methodology: Monthly datasets are detrended and regridded to 1°×1° resolution. We define Ocean Niño Index (ONI) and Dipole Mode Index (DMI) for identifying La Niña and nIOD events, validated using NOAA and BOM records. A Student's t-test is applied for statistical significance.

Results and Discussions

La Niña and negative IOD (nIOD) events were identified when ONI and DMI indices exceeded one standard deviation during JJAS. Analysis of 2010 and 2022, strong La Niña-nIOD co-occurring years, revealed significant SST anomalies, with cooling in the central and eastern Pacific and warming over the eastern Indian Ocean (EIO) and northwestern Arabian Sea (NWAS). enhanced convection (low OLR) was observed over EIO and NWAS, distinguishing these years from pure La Niña events. Atmospheric circulation analysis showed strong easterly winds extending from the Pacific into the Indian Ocean, converging with westerlies from nIOD over EIO, creating two moisture convergence zones (EIO and NWAS). The westward shift of the Western Pacific Subtropical High (WPSH) intensified monsoonal circulation and rainfall over northwest India and Pakistan. Subsurface ocean analysis indicated deep thermocline anomalies in EIO and NWAS, enhancing SST warming and convection. Negative wind stress curl and Ekman pumping supported downwelling in NWAS, further sustaining convection. IITM-ESM model simulations closely matched observed patterns, confirming the role of subsurface oceanic conditions in sustaining atmospheric convection and rainfall.

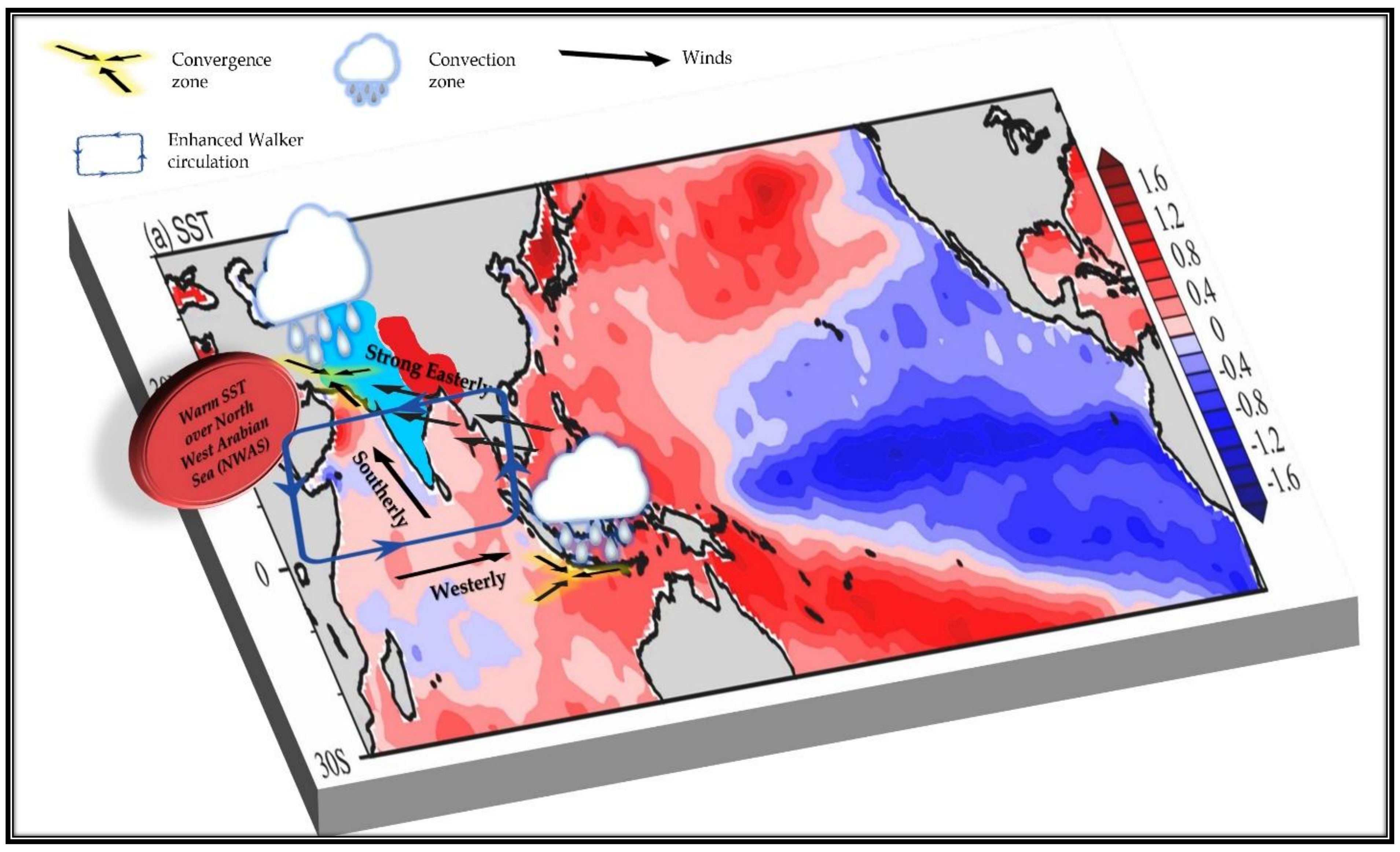

Fig 1: Graphical Abstract

observation

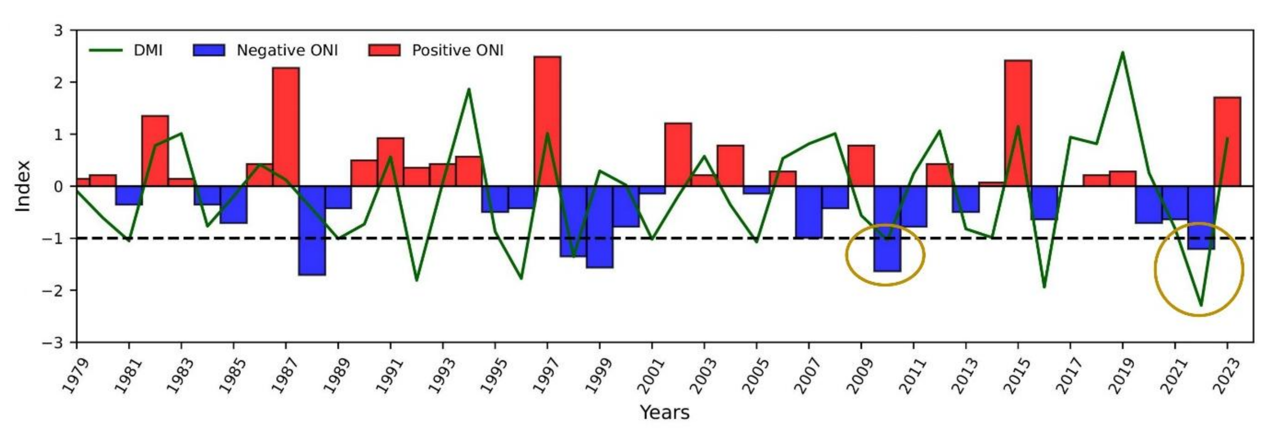

Fig 2 Time series of ONI and DMI from 1979 to 2023. Here ONI index is for JJAS and IOD index is shown for SON. Circles denotes the years with strong La Niña and nIOD

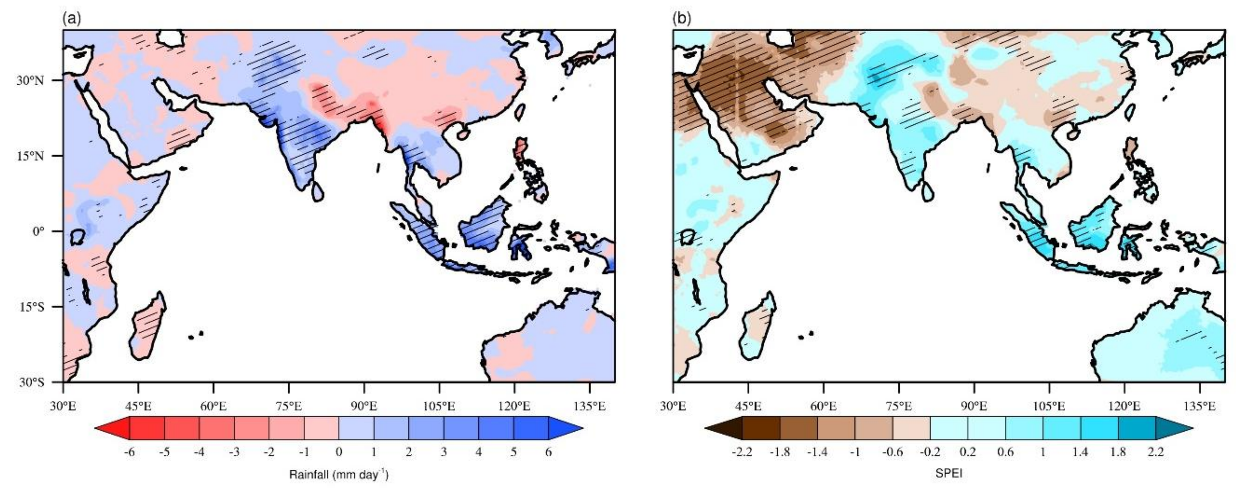

Fig 3: Anomalous (a) Rainfall (mmday^{-1}) (b) SPEI index during the summer monsoon season (JJAS) for the composite strong La Niña and negative IOD co-occurring years of 2022 and 2010. Also, the regions with statistical significance (at 90 %) are stippled.

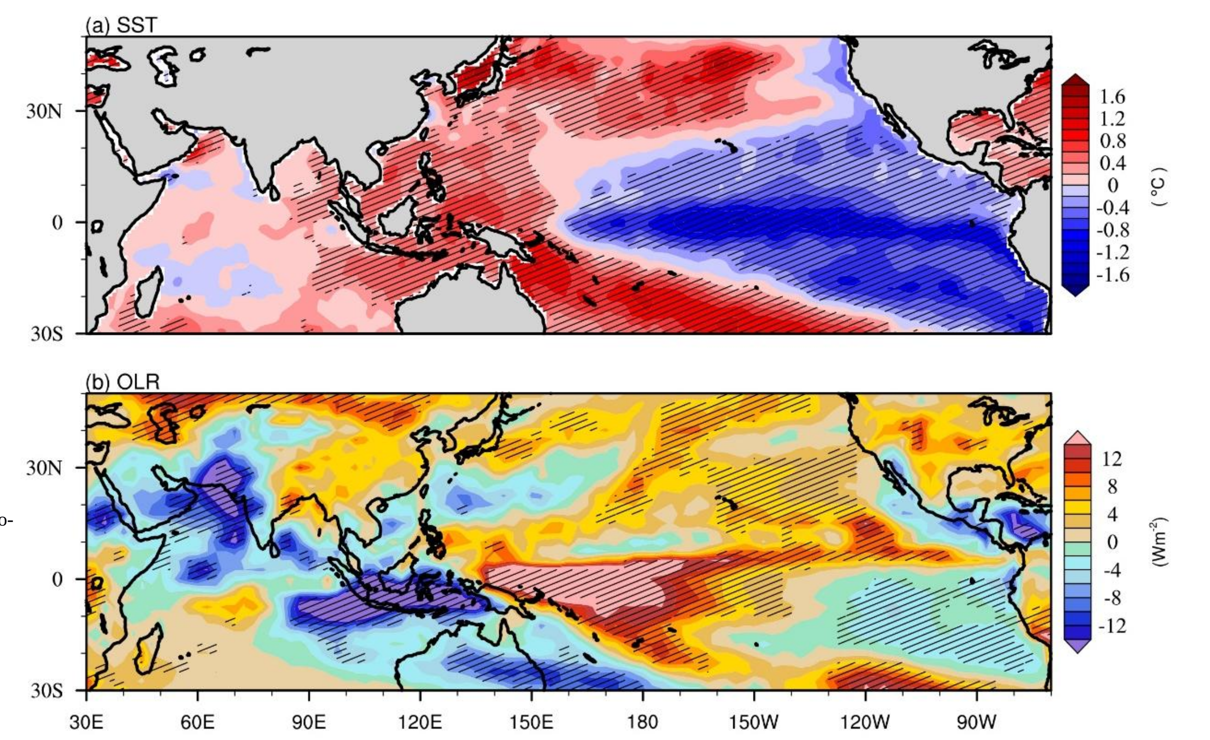

Fig 4: Spatial map showing anomalous (a) Sea surface temperature (°C) and (b) OLR (Wm^{-2}) during summer monsoon season (JJAS) of strong La Niña and nIOD co-occurring years (2010 and 2022). The regions with statistical significance (at 90 %) are stippled.

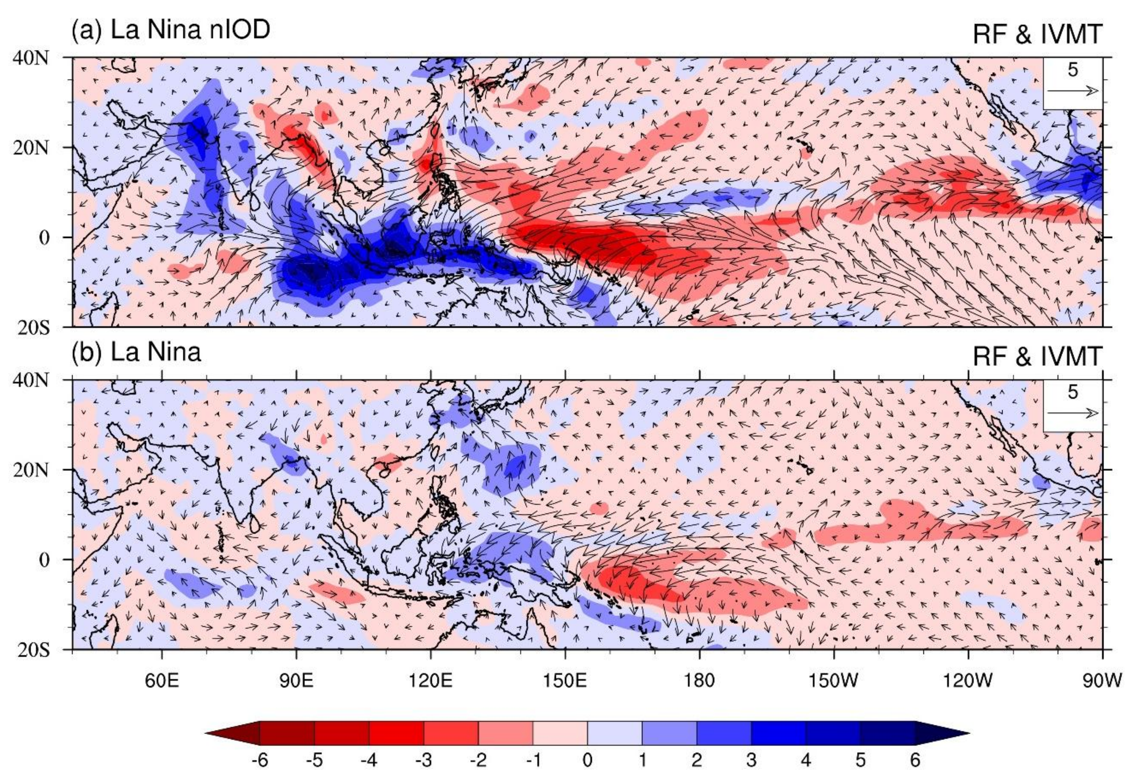

Fig 5: Spatial map showing anomalous feature during the summer monsoon season (JJAS) of co-occurring years (a) anomalies of Rainfall (shaded, mmday^{-1}) overlaid with Integrated vertical moisture transport (IVMT) (kgm^{-1}s^{-1}) wind for strong co-occurring years. (b) similar to (a) for pure La Niña years.

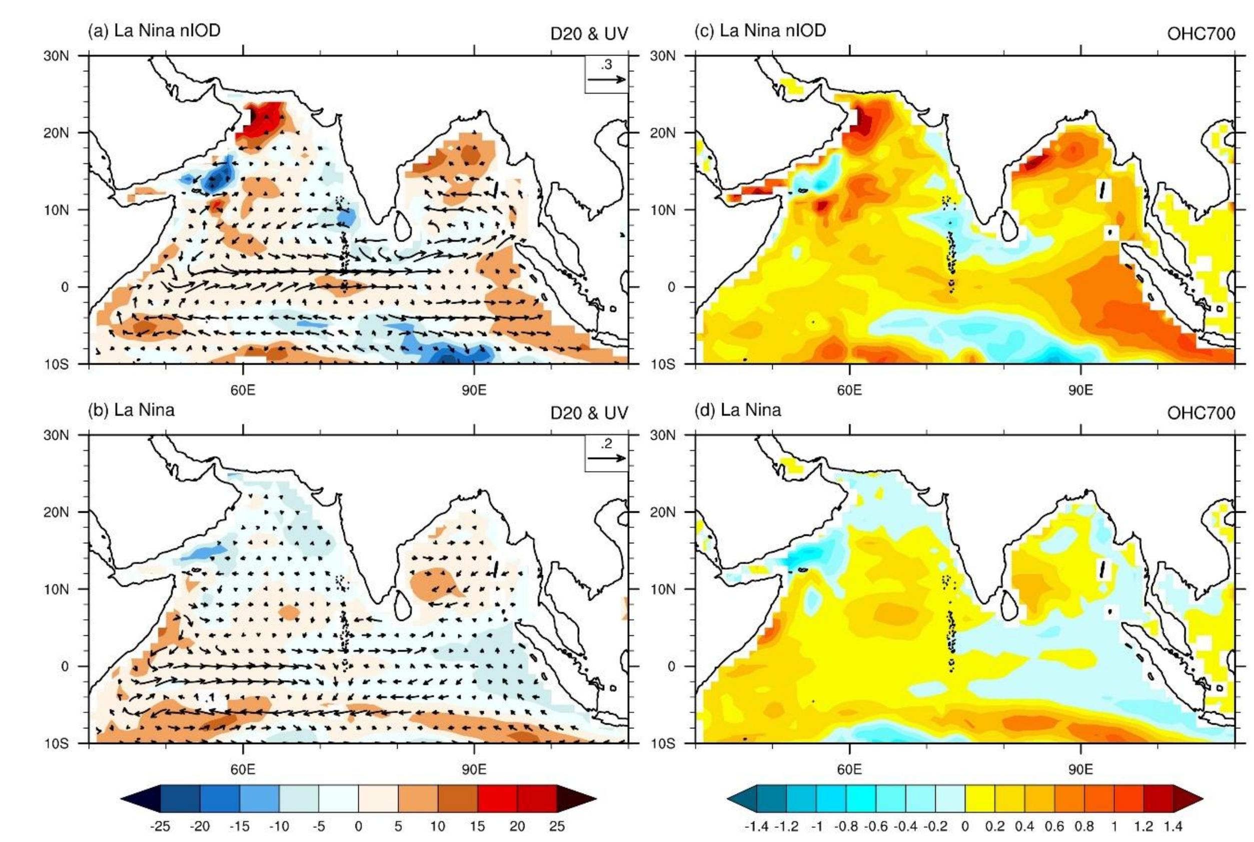

Fig 6: Spatial map showing anomalous feature during the summer monsoon season (JJAS) of co-occurring years (a) Depth at 20° Isotherm D20 (shaded)(m) overlaid with ocean currents (vectors) (ms^{-1}) at 15 m depth. (c) Ocean heat content OHC (Jm^{-2}) at 700m depth. (b) and (d) same as (a) and (c) for pure La Niña years.

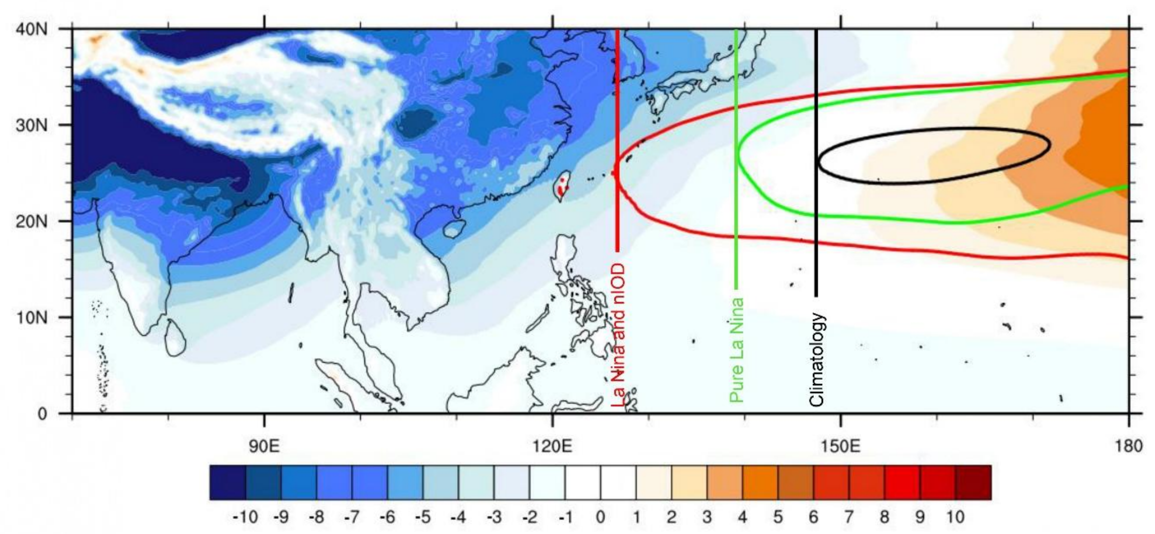

Fig 7: Spatial map showing anomalous feature during the summer monsoon season (JJAS). The shading denotes the anomalies of geopotential height (gpm) at 1,000 hPa for the period 1979–2023 overlaid with the contours climatology (black) pure La Niña years (green) and co-occurring of La Niña and nIOD years (red).

Model

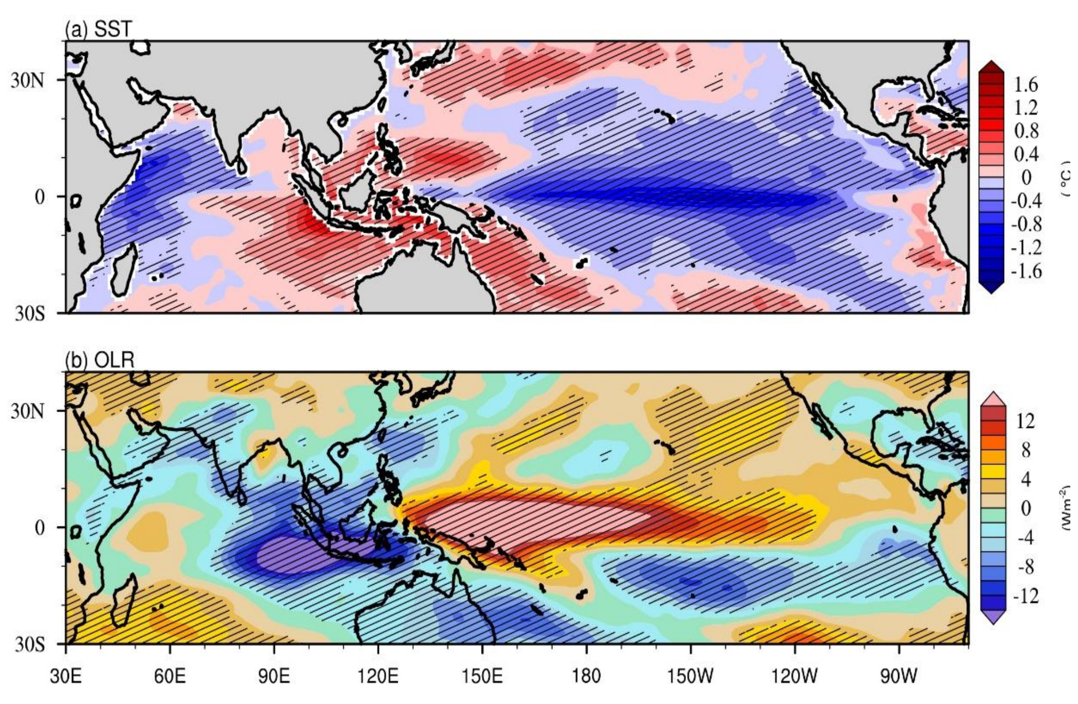

Fig 8: Spatial map showing anomalous from the PI-control simulation(a) Sea surface temperature (°C) and (b) OLR (Wm^{-2}) during summer monsoon season (JJAS) during strong La Niña and nIOD co-occurring years. The regions with statistical significance (at 90 %) are stippled.

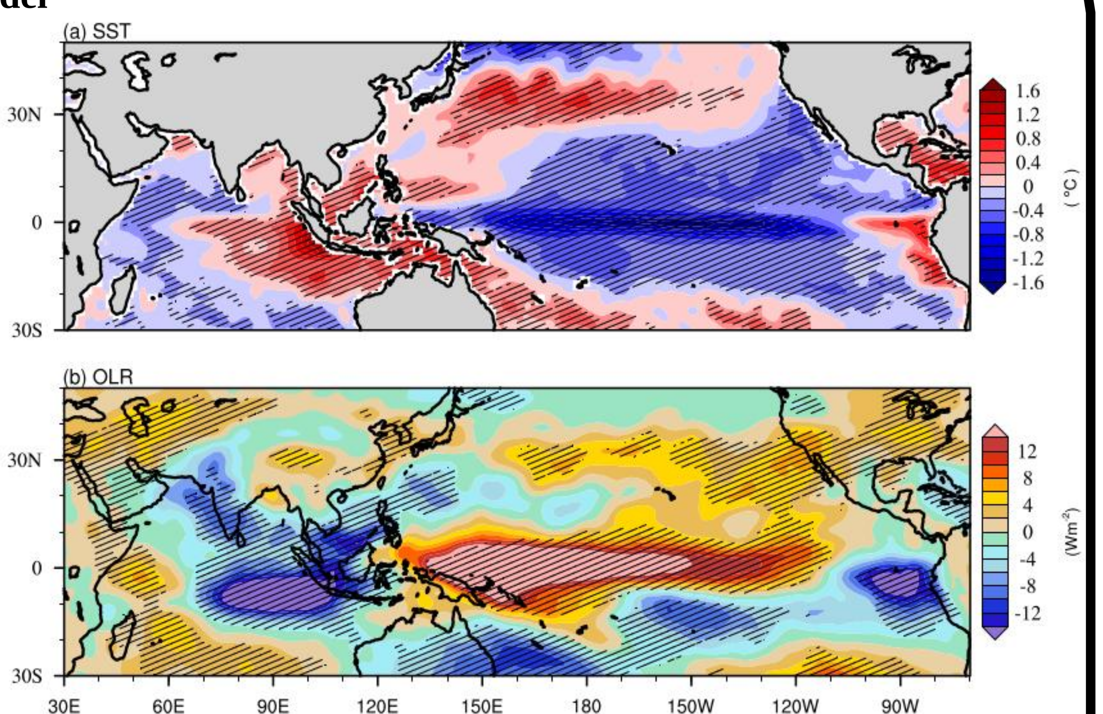

Fig 10: Spatial map showing anomalous (a) Sea surface temperature (°C) and (b) OLR (W/m^{2}) during summer monsoon season (June-September) for strong La Niña and nIOD co-occurring year from the IITM-ESM historical simulation. The regions with statistical significance (at 90 %) are stippled.

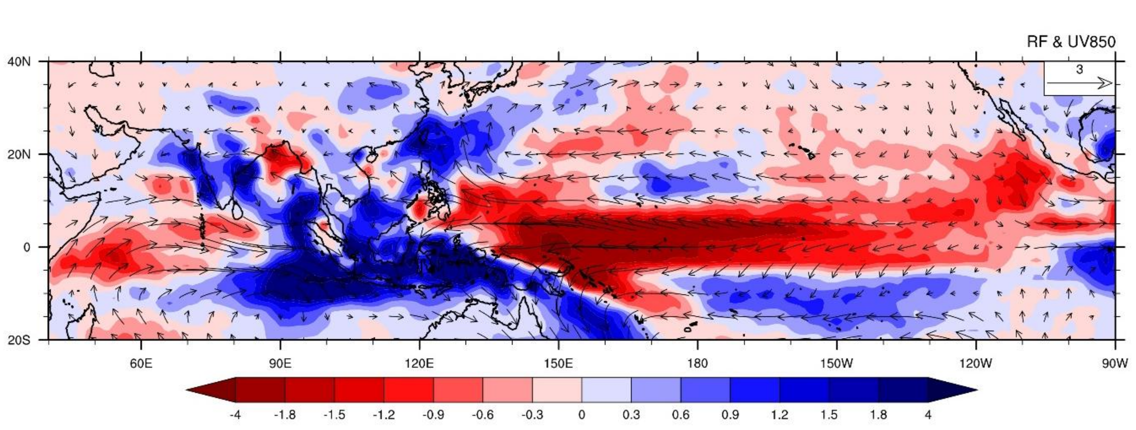

Fig 9: Spatial map showing anomalous feature during the summer monsoon season (JJAS) of co-occurring years from the PI-control simulation Rainfall (shaded, mmday^{-1}) overlaid with wind (vectors, ms^{-1}) at 850 hpa.

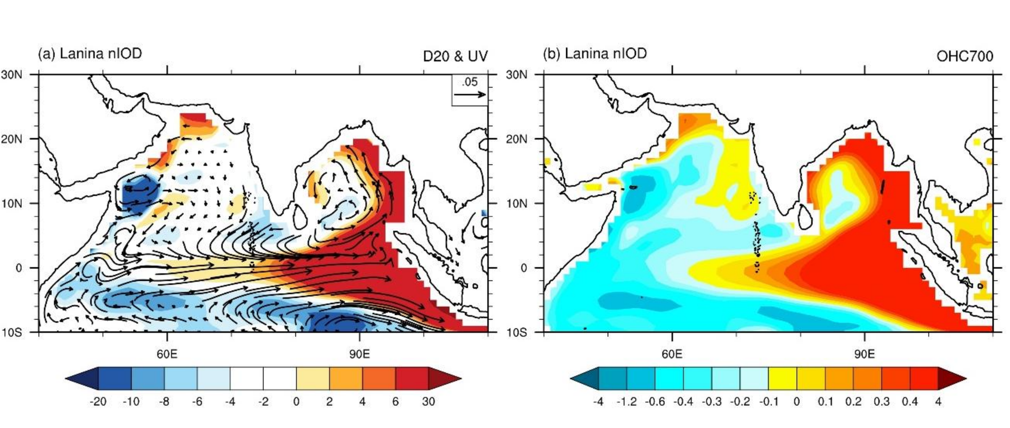

Fig 11: Anomalous feature during the summer monsoon season (JJAS) of co-occurring years values from the PI-control simulation (a) Depth at 20° Isotherm D20 (shaded)(m) overlaid with ocean currents (vectors) (ms^{-1}) at 15 m depth. (b) Ocean heat content OHC (Jm^{-2}) at 700m depth.

Summary

- **Study Focus:** Investigates the interaction between oceanic and atmospheric processes in sustaining convection over the Northern Indian Ocean, particularly the northern Arabian Sea and eastern Equatorial Indian Ocean (EIO).
- **Co-occurrence of La Niña & nIOD:** Examines the combined impact of La Niña and negative Indian Ocean Dipole (nIOD) on subsurface oceanic conditions and large-scale convection.
- **Monsoon Rainfall Patterns:**
  - Below-normal precipitation in northern, northeastern, and Indo-Gangetic plain regions of India.
  - Above-normal rainfall in southern and western India and the Indo-Pak region, especially in 2022 and 2010.
- **Oceanic & Atmospheric Mechanisms:**
  - Equatorial Winds: Strong equatorial westerly wind anomalies deepen the thermocline, warm SSTs in the eastern EIO, and enhance moisture convergence.
  - Walker Circulation: Strengthens over the Indian Ocean, leading to subsidence and moisture divergence over the western EIO.
  - Moisture Transport: Divergence in the western EIO leads to strong northward moisture transport and southerlies over the northern Arabian Sea.
  - Low-Level Winds: Westward shift of the West Pacific Subtropical High (WPSH) causes easterly winds over the Indo-Gangetic plain, converging with southerlies over the northern Arabian Sea.
  - Thermocline Deepening: Leads to SST warming in the northern Arabian Sea due to reduced upwelling, local Ekman pumping, and wind stress curl.
- **Key Findings:**
  - Oceanic subsurface conditions play a crucial role in sustaining atmospheric convection over the northern Arabian Sea and eastern EIO.
  - Model simulations (IITM-ESM) align with observations, supporting findings through a 200-year historical analysis.
- **Significance:**
  - Highlights the importance of incorporating oceanic subsurface dynamics for better monsoon forecasting and climate modeling.
  - Provides insights into summer monsoon variability and its implications for agriculture and society in South Asia.

Paper under review in MAAPS journal

Acknowledgement : This work is supported by the Indian Institute of Tropical meteorology (IITM), Pune, India.