Salient features of Monsoon 2023 from NCMRWF operational model products

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Outline

- Monsoon 2023 (JJAS)
  - *Onset over Kerala: NCUM Onset Circulation Index (OCI)*
  - *Mean and anomalies - NCUM Analysis (winds, temp & RH)*
  - *Systematic errors - NCUM forecasts (winds, temp, RH & VIMT)*

- Rainfall Verification (NCUM Forecasts)
  - *Mean distribution, biases (wet/dry), rainy days etc.*
  - *Categorical verification scores*
  - *Sub-seasonal variability in JJAS Rainfall*
  - *Spectral analysis of rainfall time series (averaged over CMZ)*
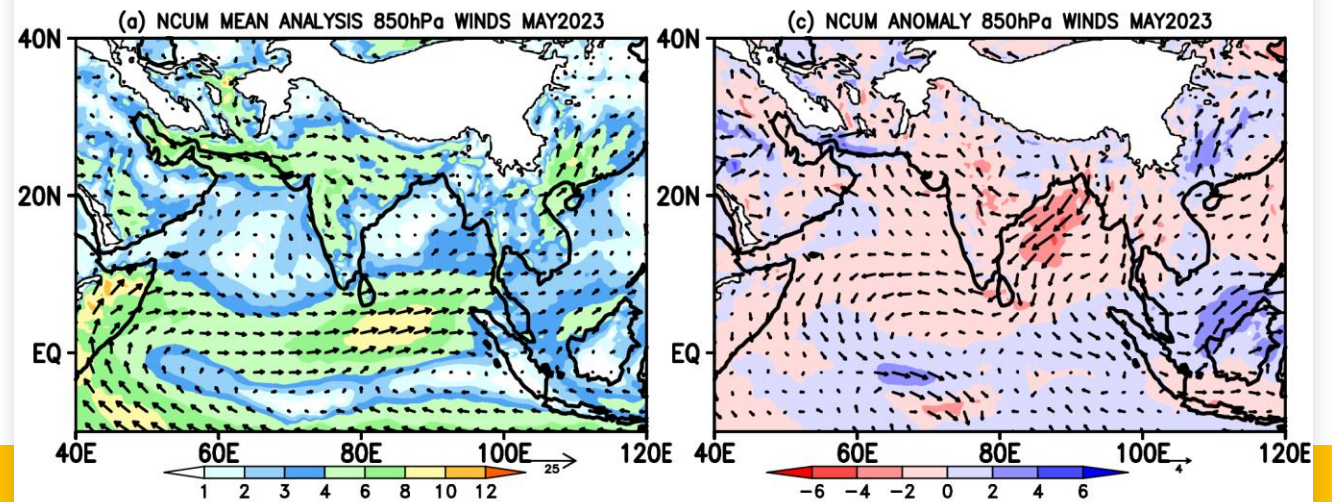 - *Process-oriented diagnostics (a new initiative)*

- Summary

Pre-Monsoon Conditions

- *Warmer temperatures across the Northwest India to southeast peninsular India.*

- *Monthly cold anomalies over NW and Central India.*

- *Anomalous easterlies over the Equatorial Indian Ocean and South Arabian Sea.*

(*Source: https://www.imdpune.gov.in/*)
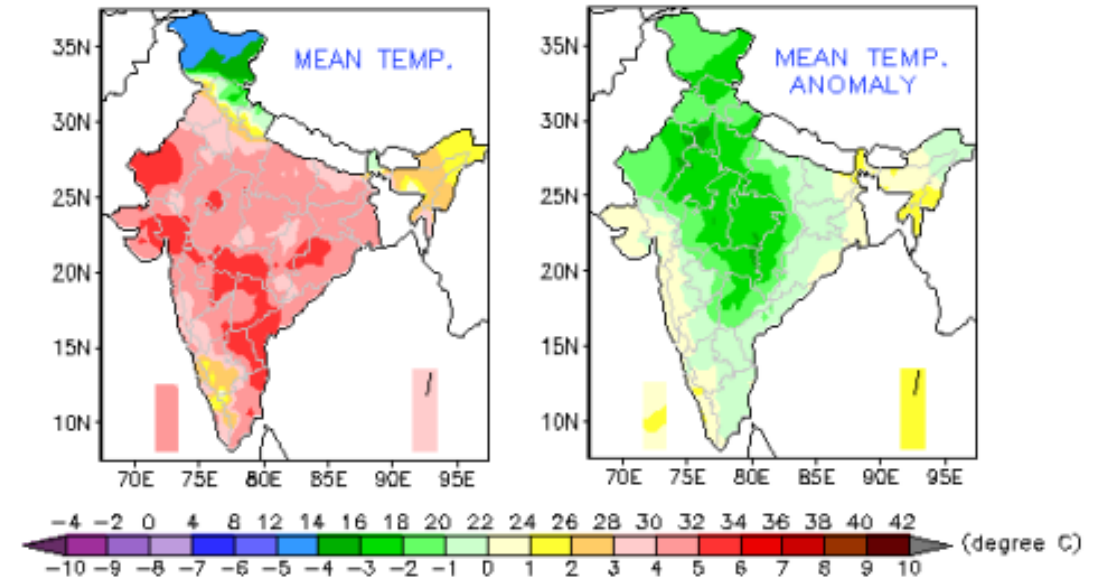
Onset

Onset Circulation Index:

850 hPa *zonal wind averaged over the Southern Arabian Sea (SAS) region i.e., 5–15N, 40–80E (Wang et al., 2009)*.

Date of Onset:

- *First day when OCI > 6.2 ms⁻¹ persists for about 6 consecutive days* — First day when OCI > $6.2\ ms^{-1}$ persists for about 6 consecutive days

- IMD declared onset on 8th June 2023 (delayed)

- NCUM model forecasts show onset on 6th June

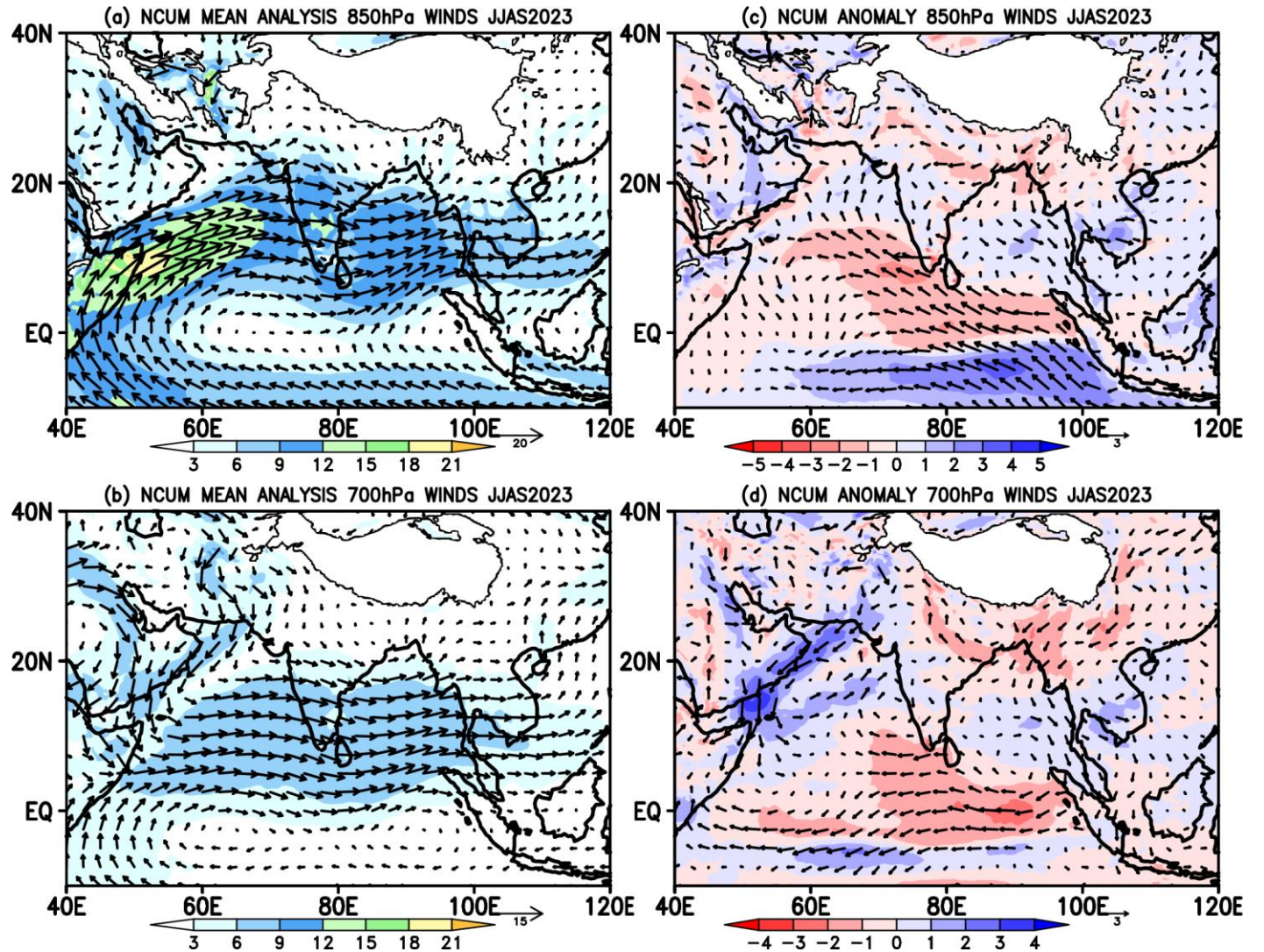Official NOAA CPC ENSO Probabilities (issued May 2023)
based on -0.5°/+0.5°C thresholds in ERSSTv5 Niño-3.4 index
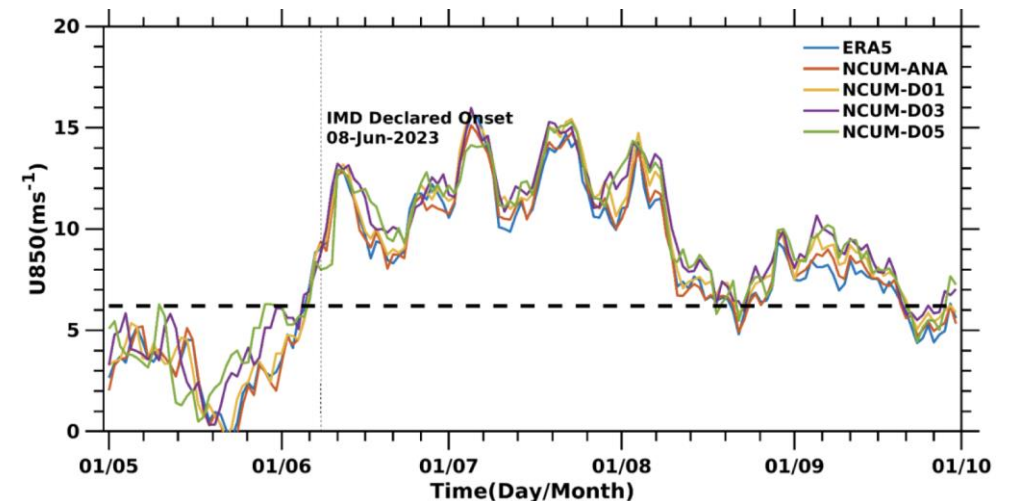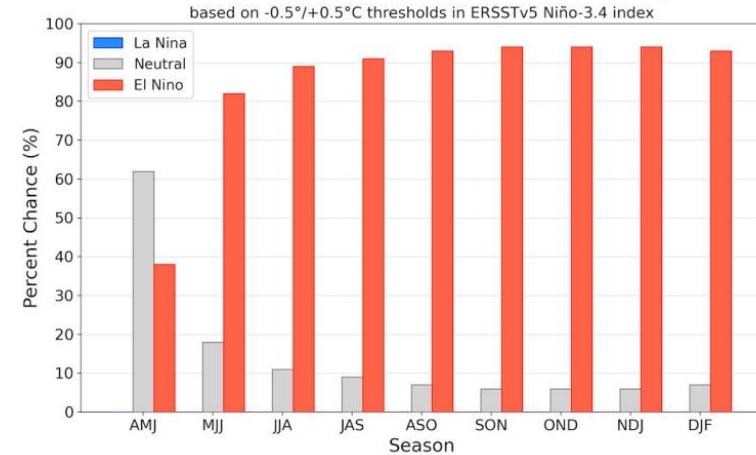
Daily Mean Rainfall Country as a whole
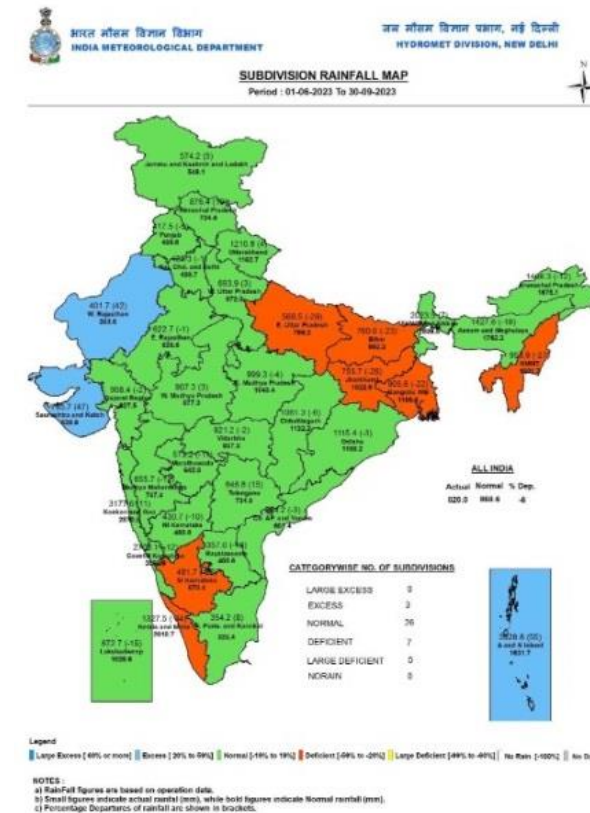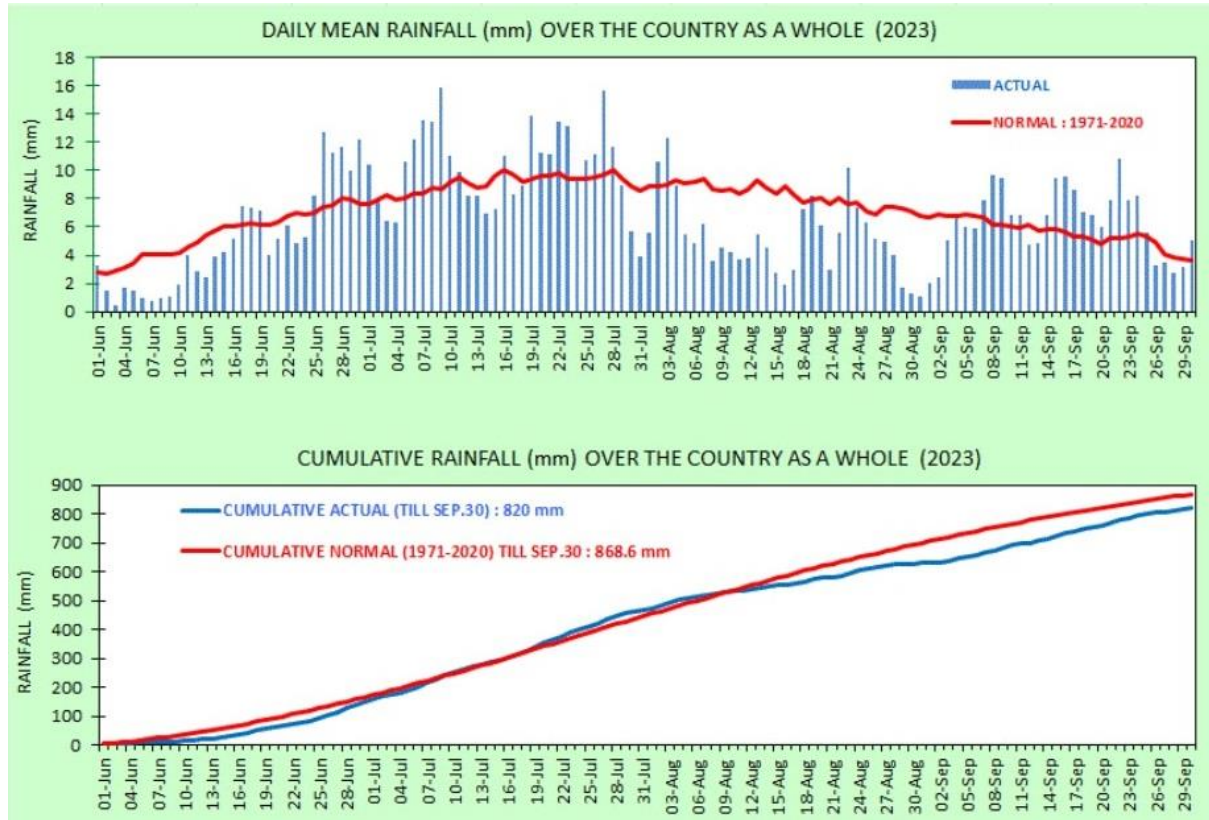
94% of LPA Normal Monsoon (source: https://mausam.imd.gov.in/Forecast/marquee_data/Endofseasonreport_2023_30_9_2023.pdf)

Analysis Mean and anomalies JJAS 2023

Anomalies against ERA-5 (1979-2018) Climatology

(a) NCUM MEAN ANALYSIS 850hPa WINDS JJAS2023
(c) NCUM ANOMALY 850hPa WINDS JJAS2023
(b) NCUM MEAN ANALYSIS 700hPa WINDS JJAS2023
(d) NCUM ANOMALY 700hPa WINDS JJAS2023

- *Anomalous easterlies over southern parts of AS and the Equatorial Indian Ocean indicate weaker than normal westerly flow.*
- *Depth of anomalous easterlies is seen up to 700 hPa level.*

200hPa winds

Analysis
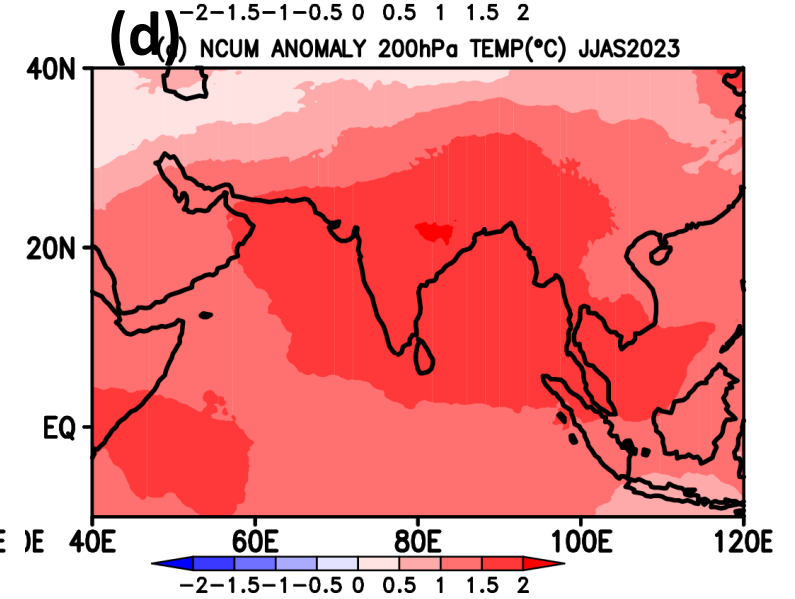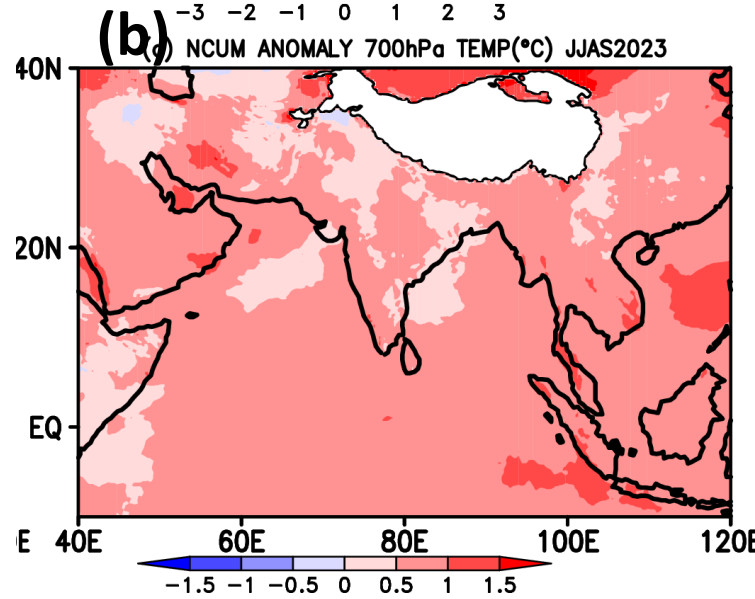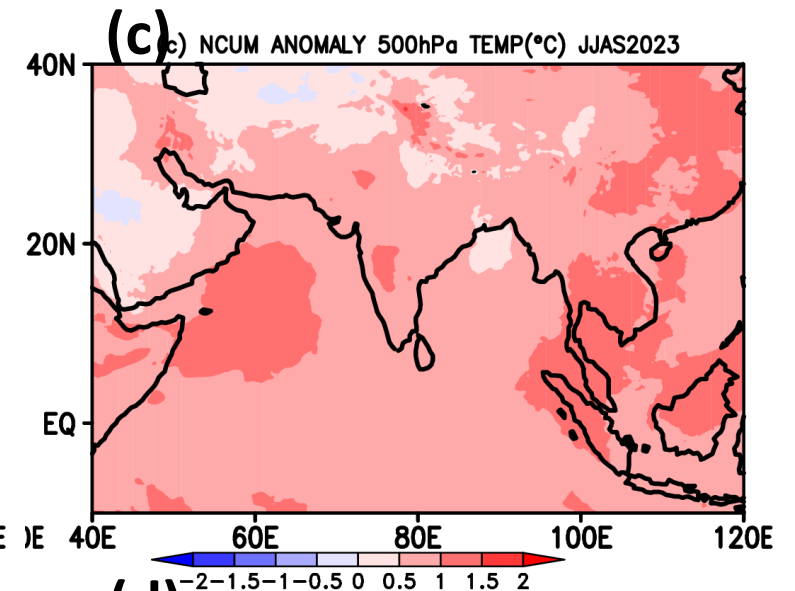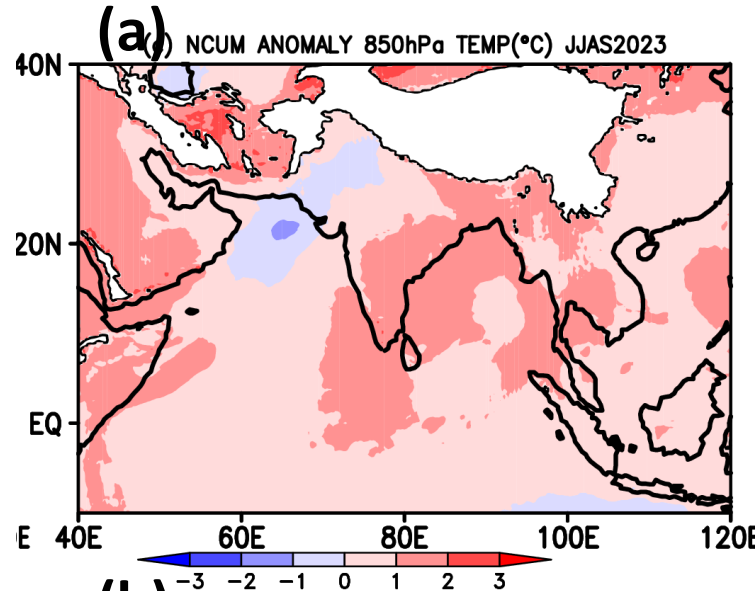Mean and
anomalies
JJAS 2023

Anomalies against ERA-5 (1979-2018) Climatology

(b) NCUM MEAN ANALYSIS 200hPa WINDS JJAS2023

(d) NCUM ANOMALY 200hPa WINDS JJAS2023
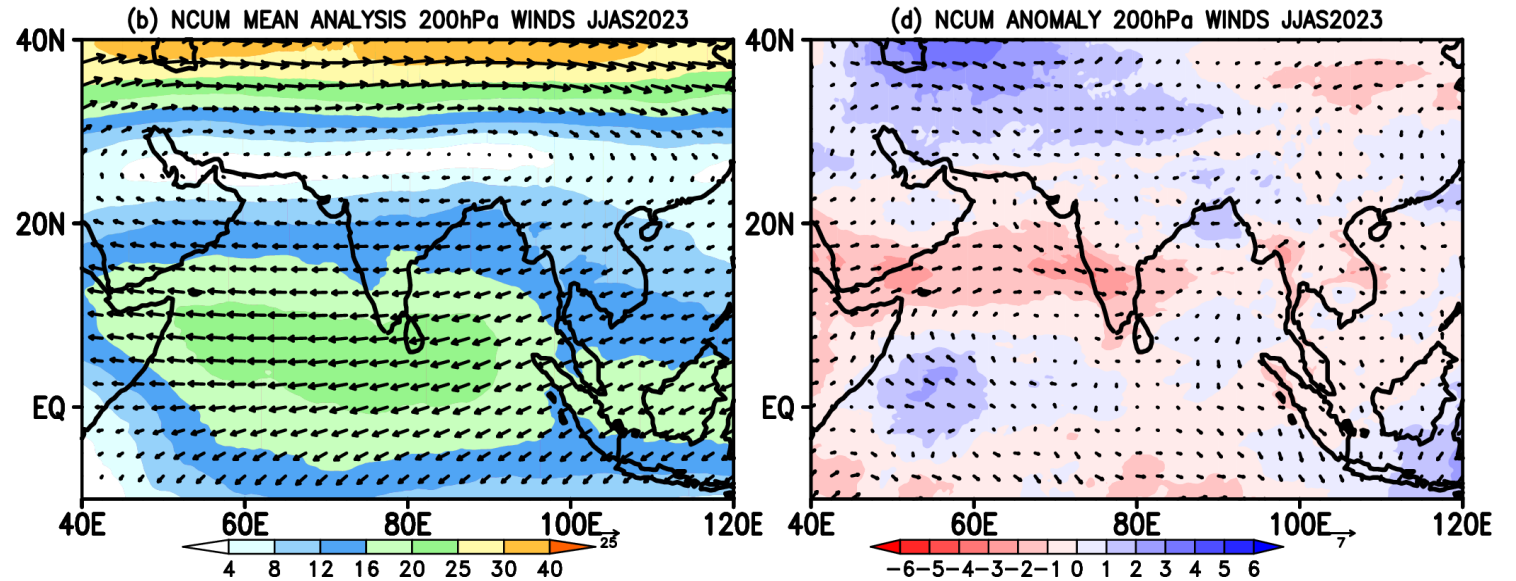
Anomalous westerlies at 200 hPa level - reduction in the TEJ in NCUM

Temperature anomalies JJAS 2023

*Anomalies against ERA-5 (1979-2018) Climatology*

(a) NCUM ANOMALY 850hPa TEMP(°C) JJAS2023

(b) NCUM ANOMALY 700hPa TEMP(°C) JJAS2023

(c) NCUM ANOMALY 500hPa TEMP(°C) JJAS2023

(d) NCUM ANOMALY 200hPa TEMP(°C) JJAS2023

Upper levels are warmer than lower– increasing column stability.
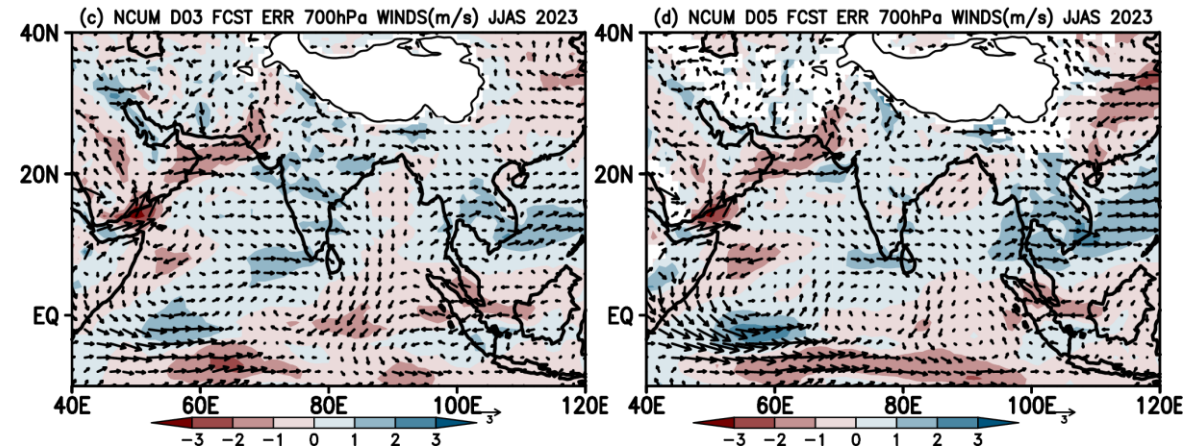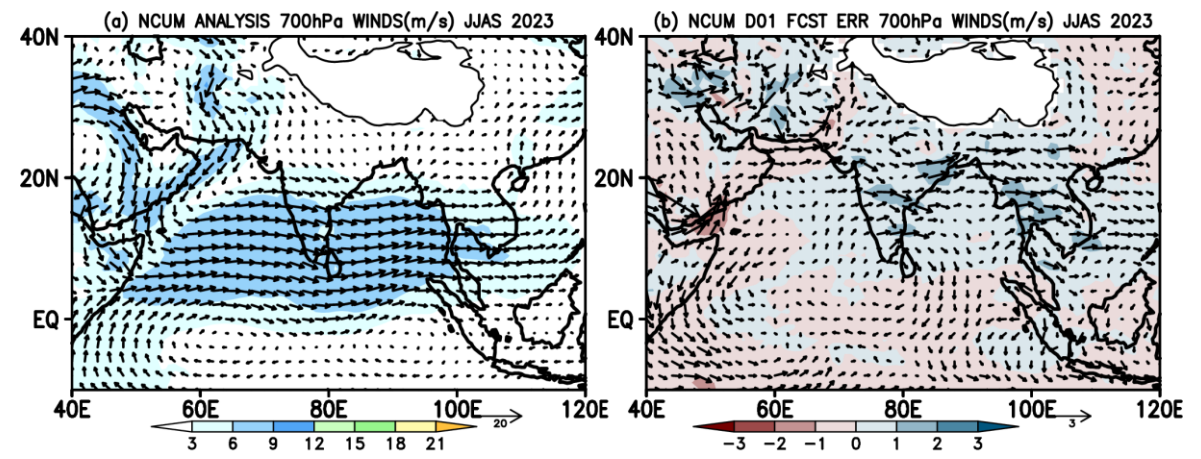
Systematic Errors in NCUM Forecasts

- **Strong westerly bias over Arabian Sea, India and Bay of Bengal**
- **Magnitude of bias increasing with lead time**
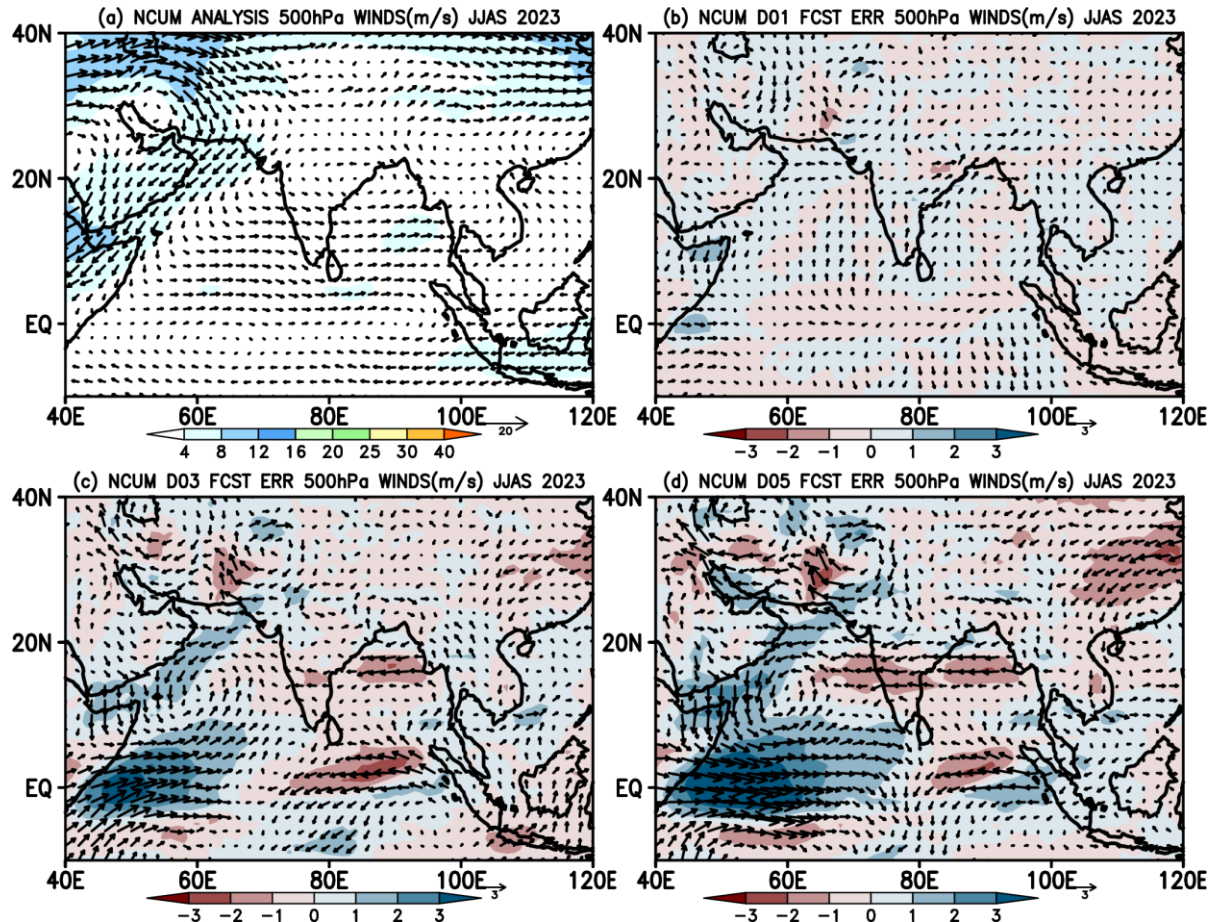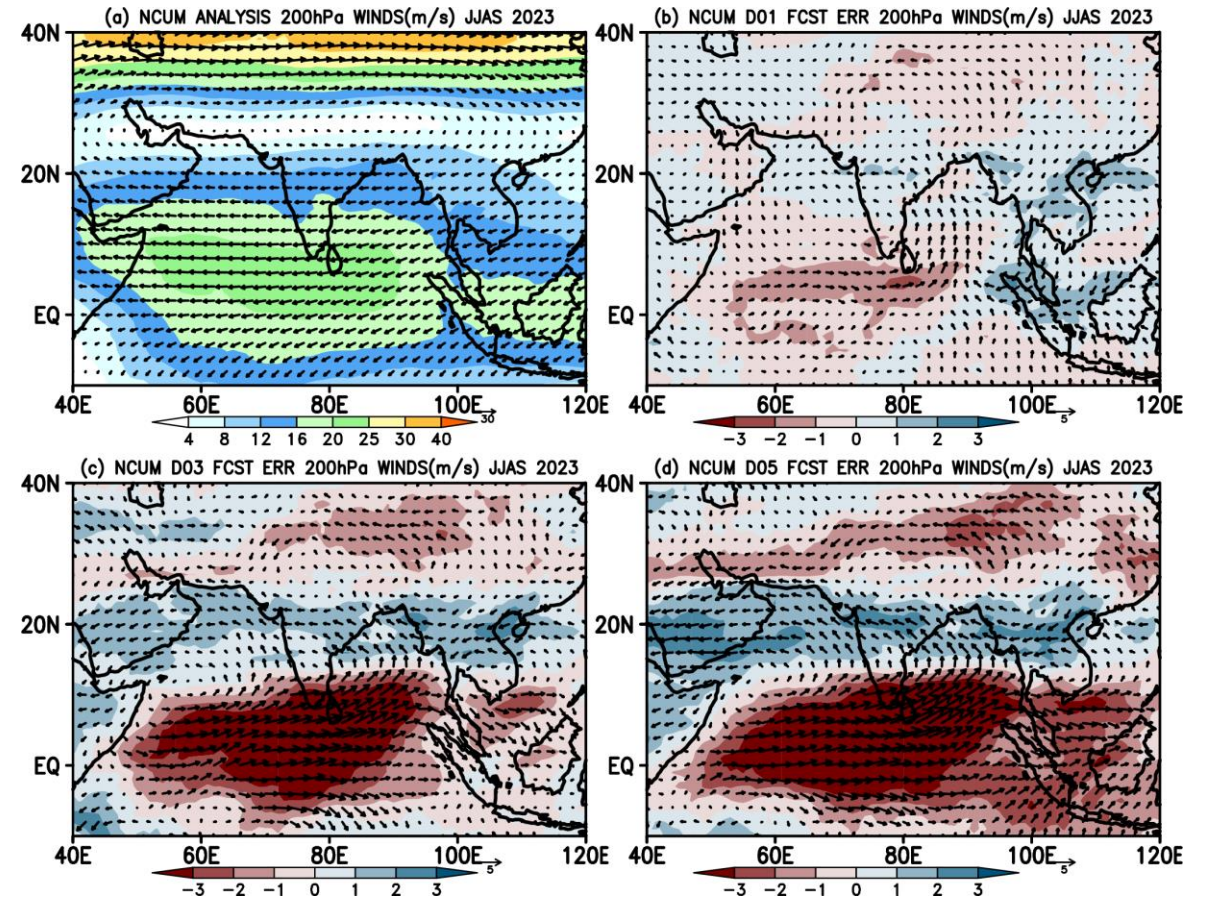
850hPa
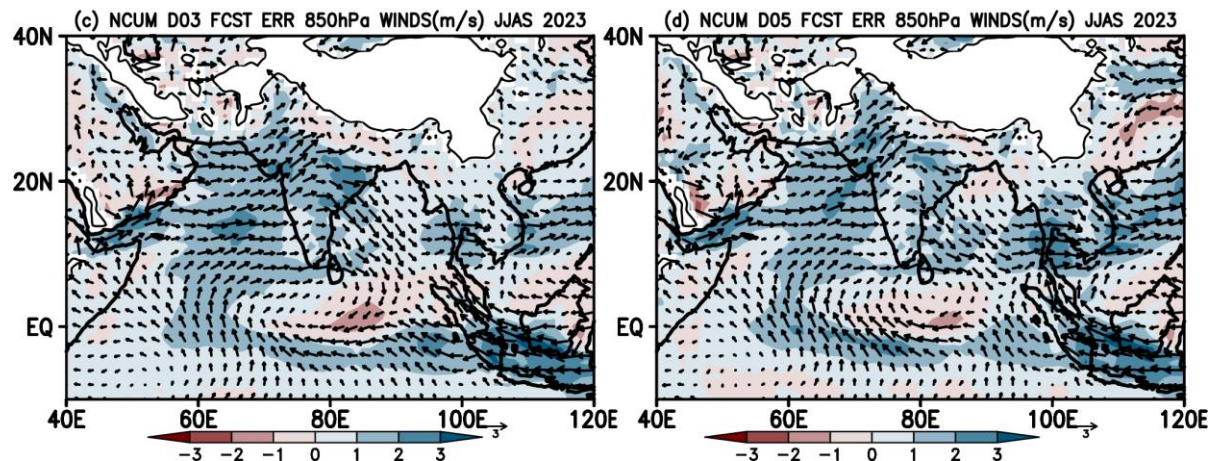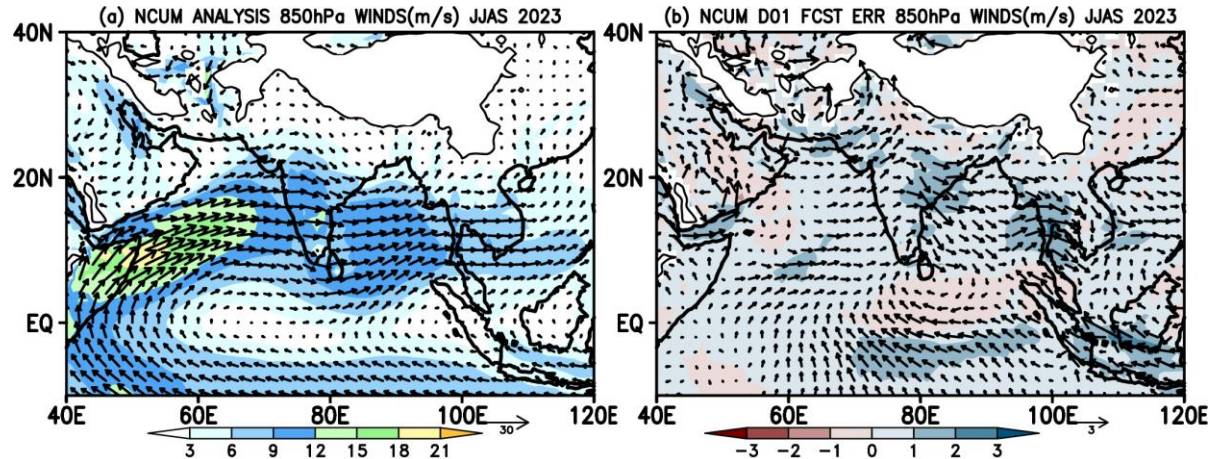
700hPa

Systematic Errors in NCUM Forecasts

- **A cyclonic circulation is noticed in the systematic bias over the eastern Arabian Sea from Day-3 onwards**
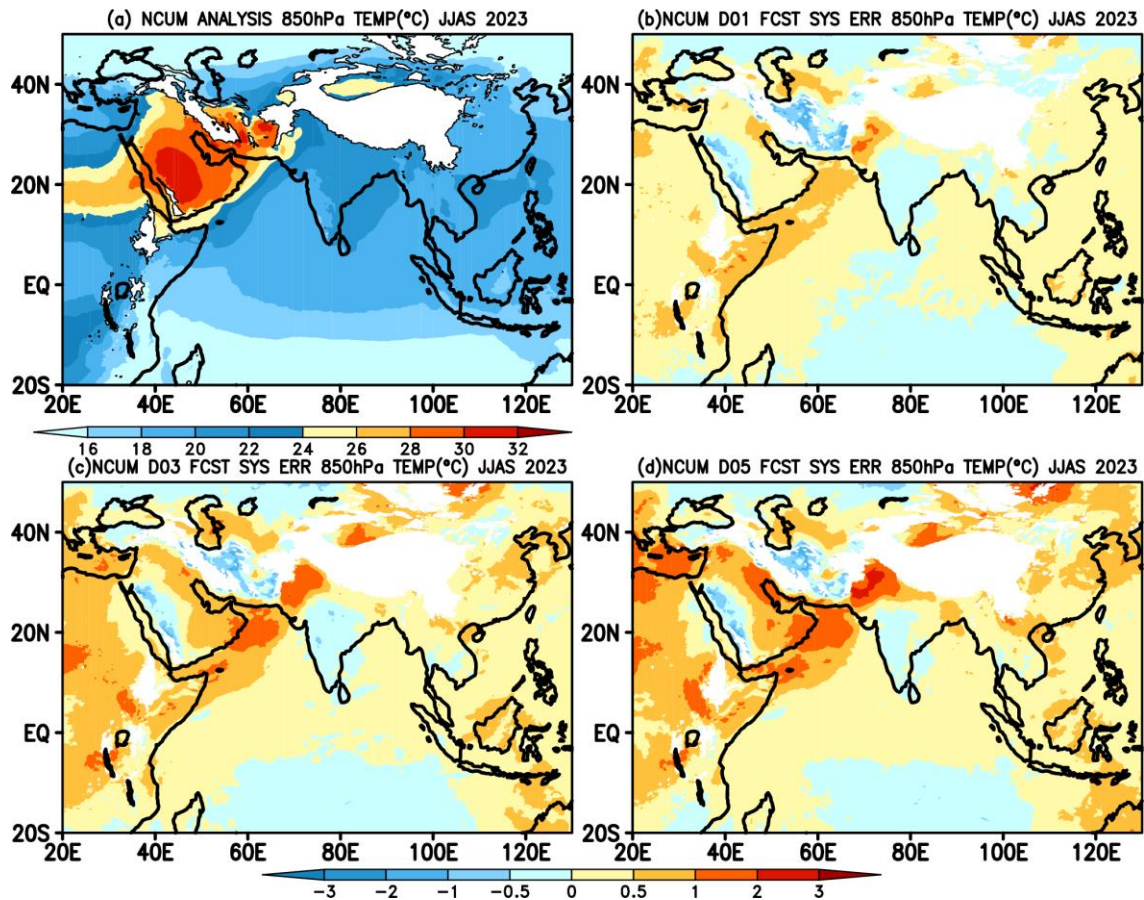- **Weaker TEJ with magnitude increasing with lead times**
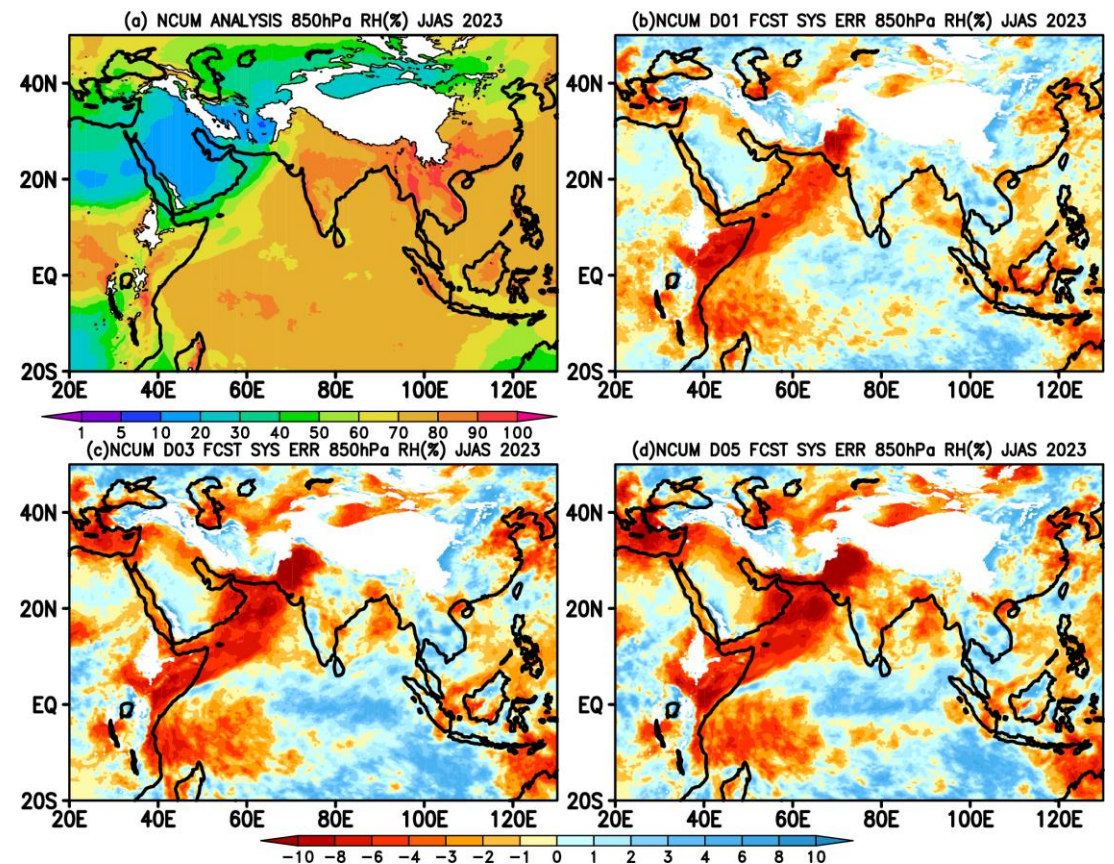
500hPa 200hPa

Systematic Errors in NCUM Forecasts

- **Warm bias in the lower troposphere at 850 hPa & IG plains monsoon trough region shows warm bias**

- **Dry bias in the lower troposphere with bias increasing with lead time.**
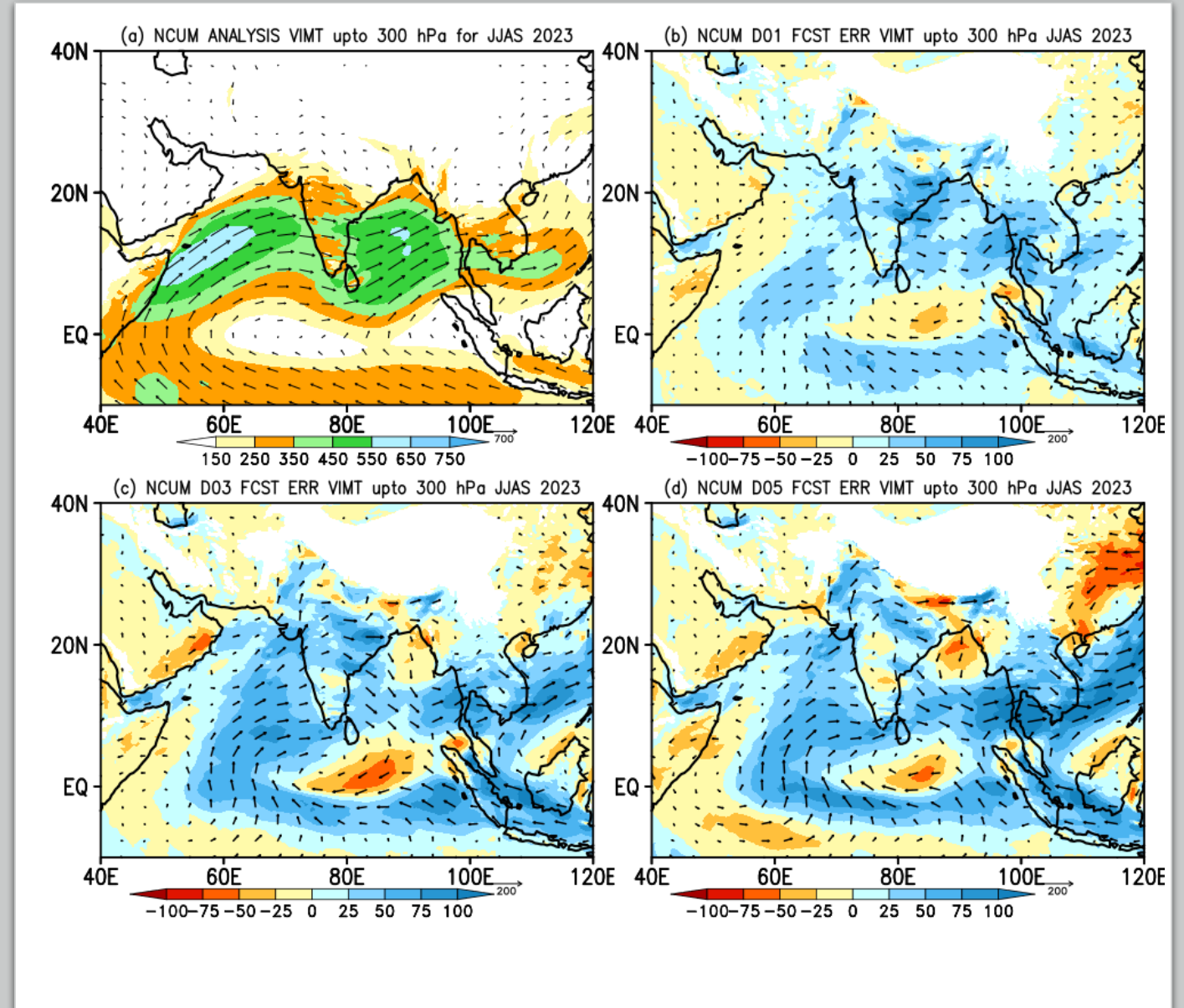
Temperature@850hPa

RH@850hPa

Vertically Integrated Moisture Transport

- Mean Analysis VIMT and systematic Mean analysis & errors in the Day-1, Day-3, and Day-5 NCUM forecasts

- VIMT (Surface – 300 hPa) Strong positive bias increasing with lead time

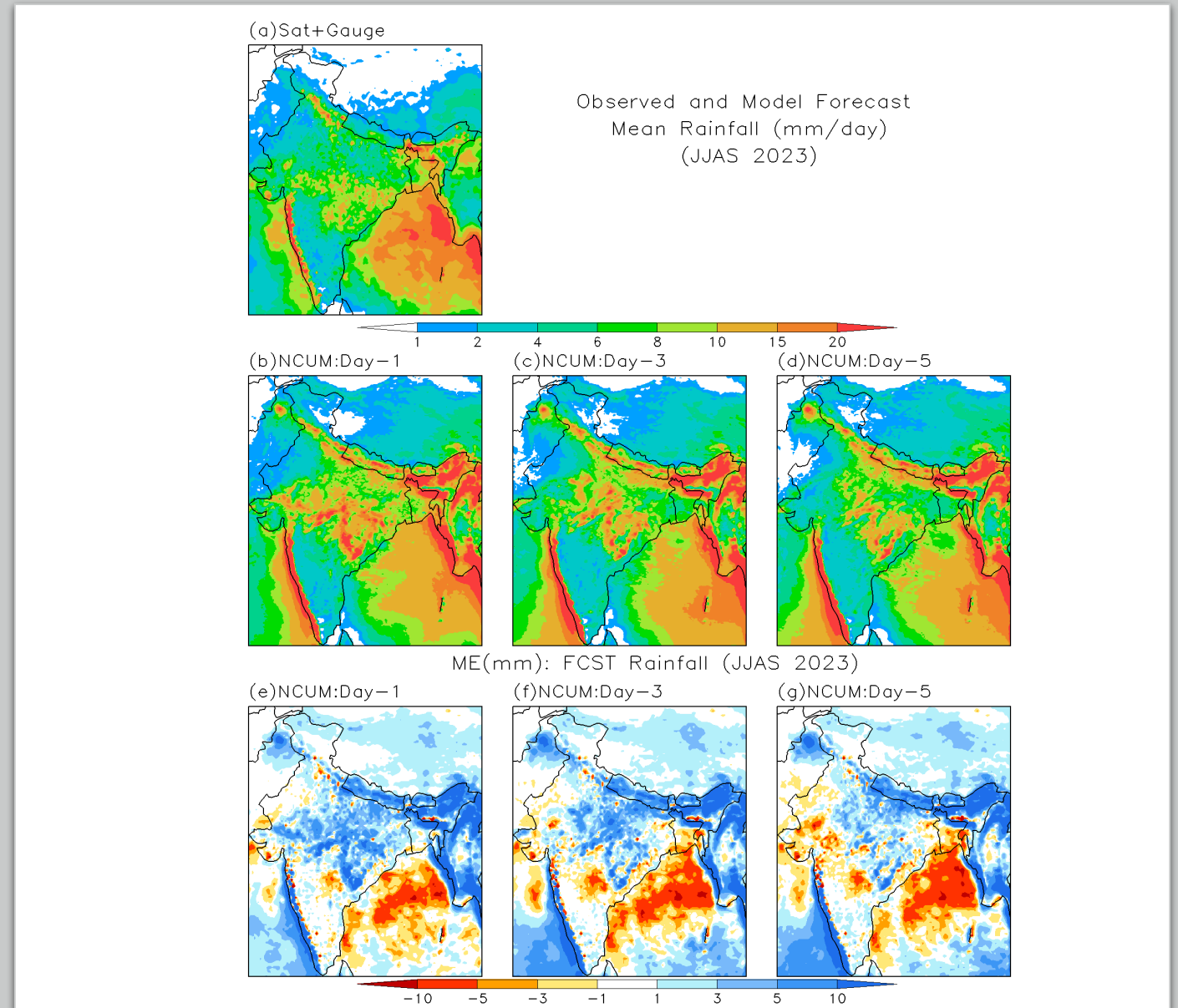- Wind bias strong enough to offset the impact of dry bias

Rainfall verification

- General wet bias (blues)

*The west coast, CMZ, NE India and Himalayas*

- General dry bias over

*BoB NW India and parts of peninsula (rains shadow region)*

Frequency of Rainy Days

- *Excessive number of rainy days in the forecasts all over India*
- *Higher moderate rain counts over west coast and NE India*
- *Dry over peninsula; lower counts*
- *Irrespective of rainfall category NCUM overestimates the rainy days.*
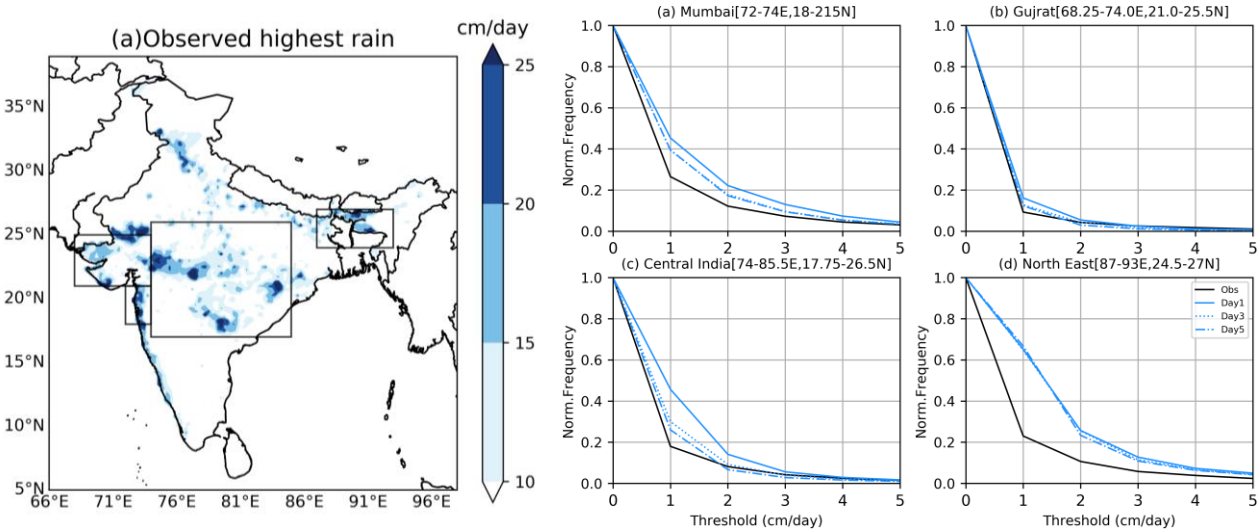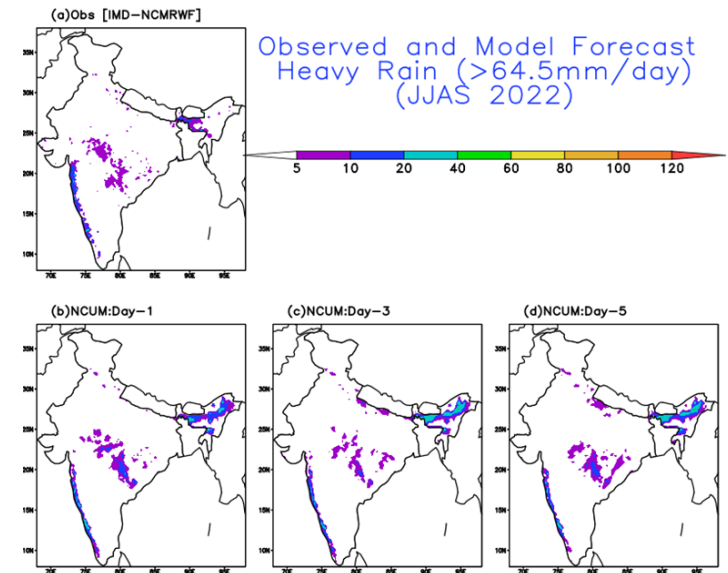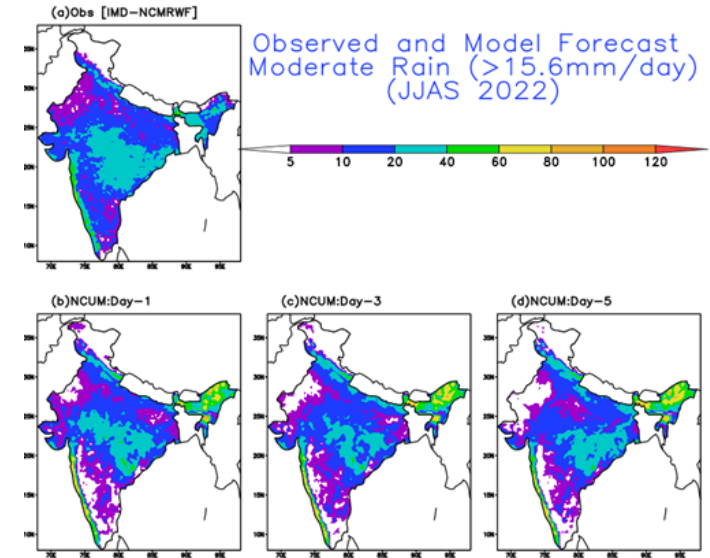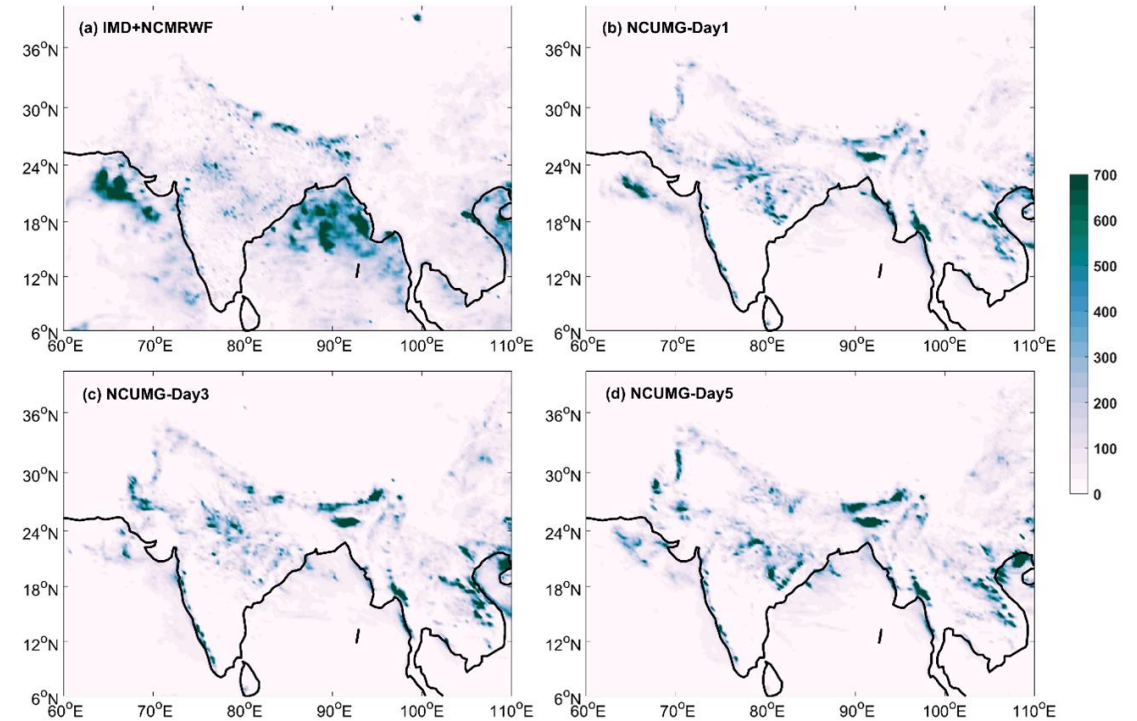
Subseasonal Variability

Spectral analysis of JJAS 2023 daily rainfall averaged over the Indian region from Observed and NCUM-G forecasts
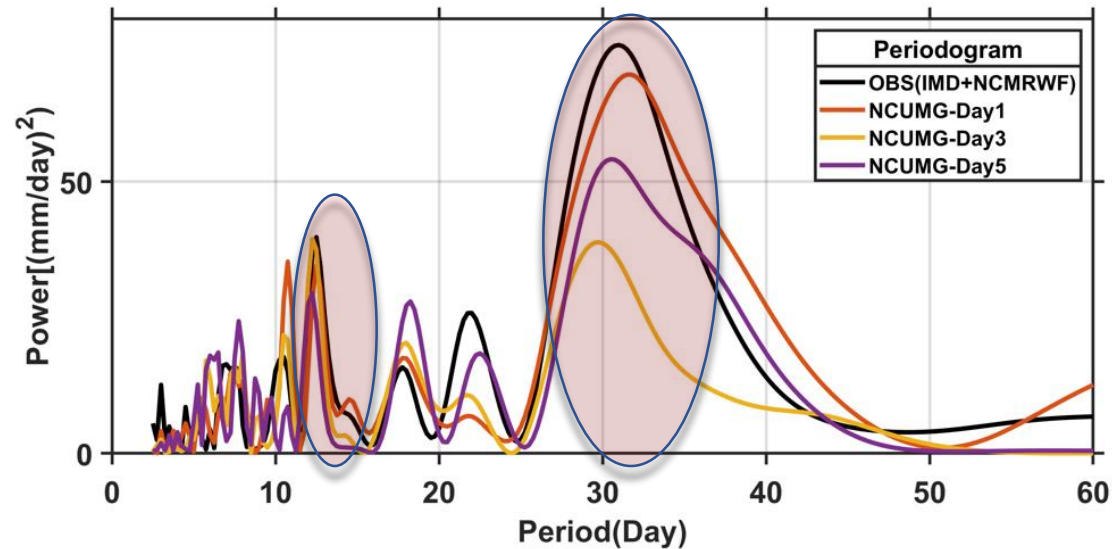
Spectral analysis of rainfall time series all over India

-Underestimation of ISO amplitudes in model forecasts with significant decrease at longer lead-times.

- *High Variance: central India and the complex Himalayan region (movement of monsoon trough and monsoon depressions)*

- *High Variance: Head BoB and west coast (topography, offshore vortices, deep convection & depressions)*

- *Forecasts overestimate the synoptic variance over the west coast CMZ and NE India.*

- *Forecasts underestimate the synoptic variance over head BoB.*

Model Skill
(*rainfall verification*)

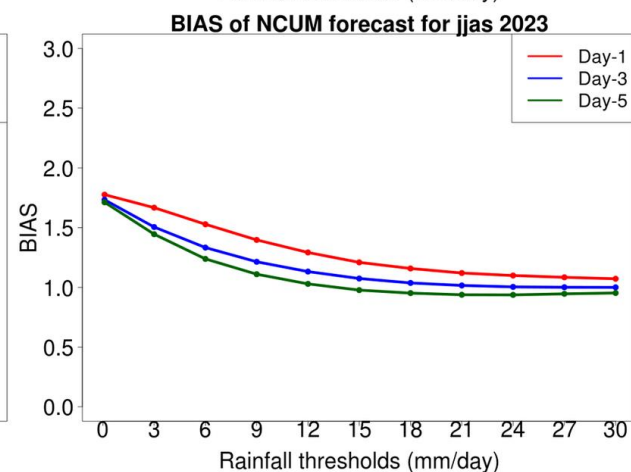Categorical (up to 12mm/day) verification suggests good (moderate) skill in Day-1 (Day-3 & Day-5) forecasts with SEDI>0.5 (6mm/day with SEDI >0.4)
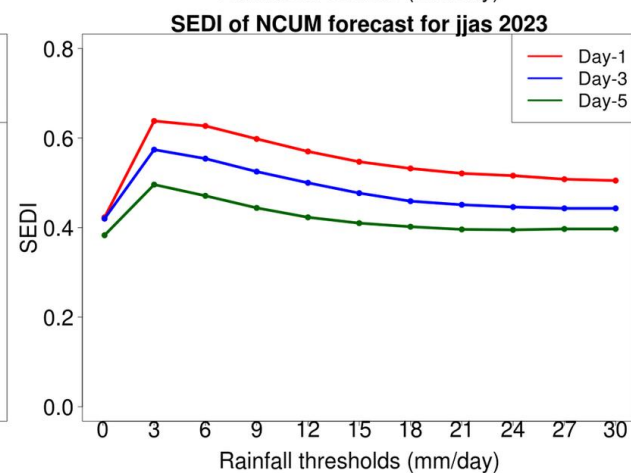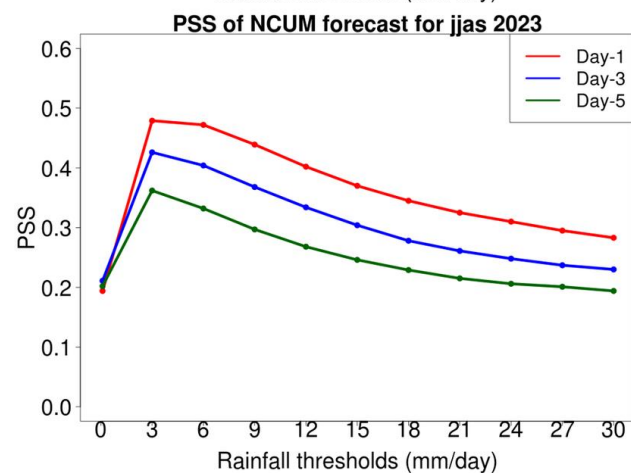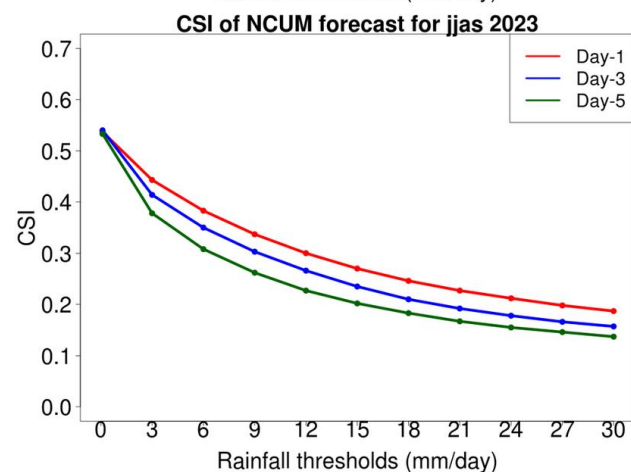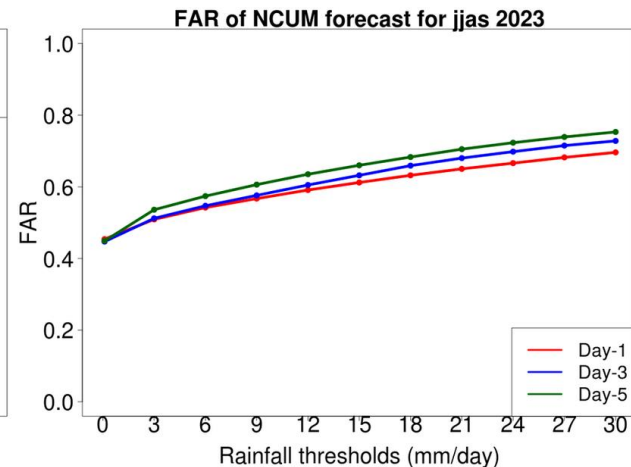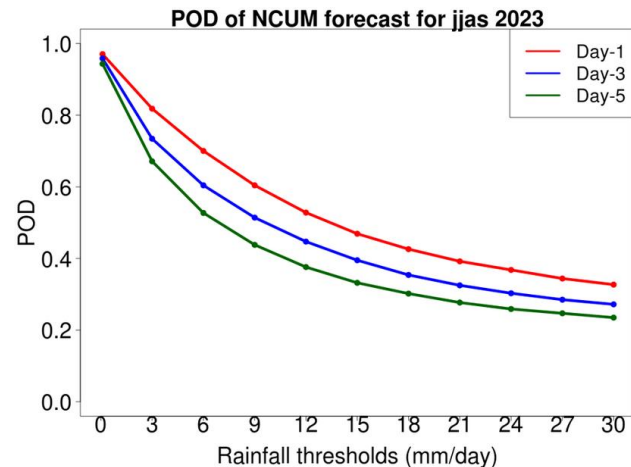
Process-oriented Diagnostics

"…..*process-oriented diagnostics* that are designed to inform parameterization improvements to address long-standing model biases" [*Maloney et al 2019*]

   (*ex. Biases in Asian monsoon region*)

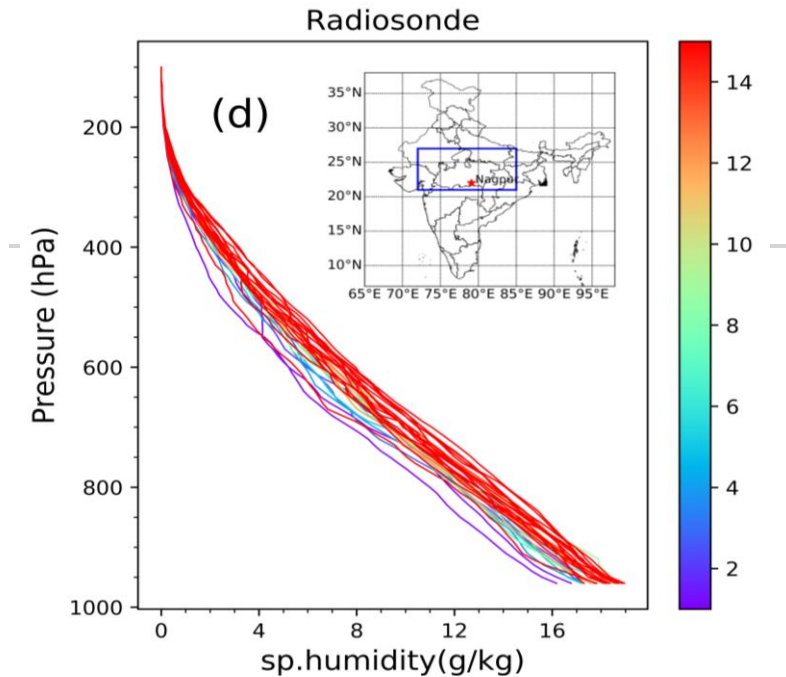*Quality and continuous radiosonde ascents (moisture and temperature) are warranted over Indian region.*

(a) Precipitation – moisture structure

CEN [18-28N, 72-85E]
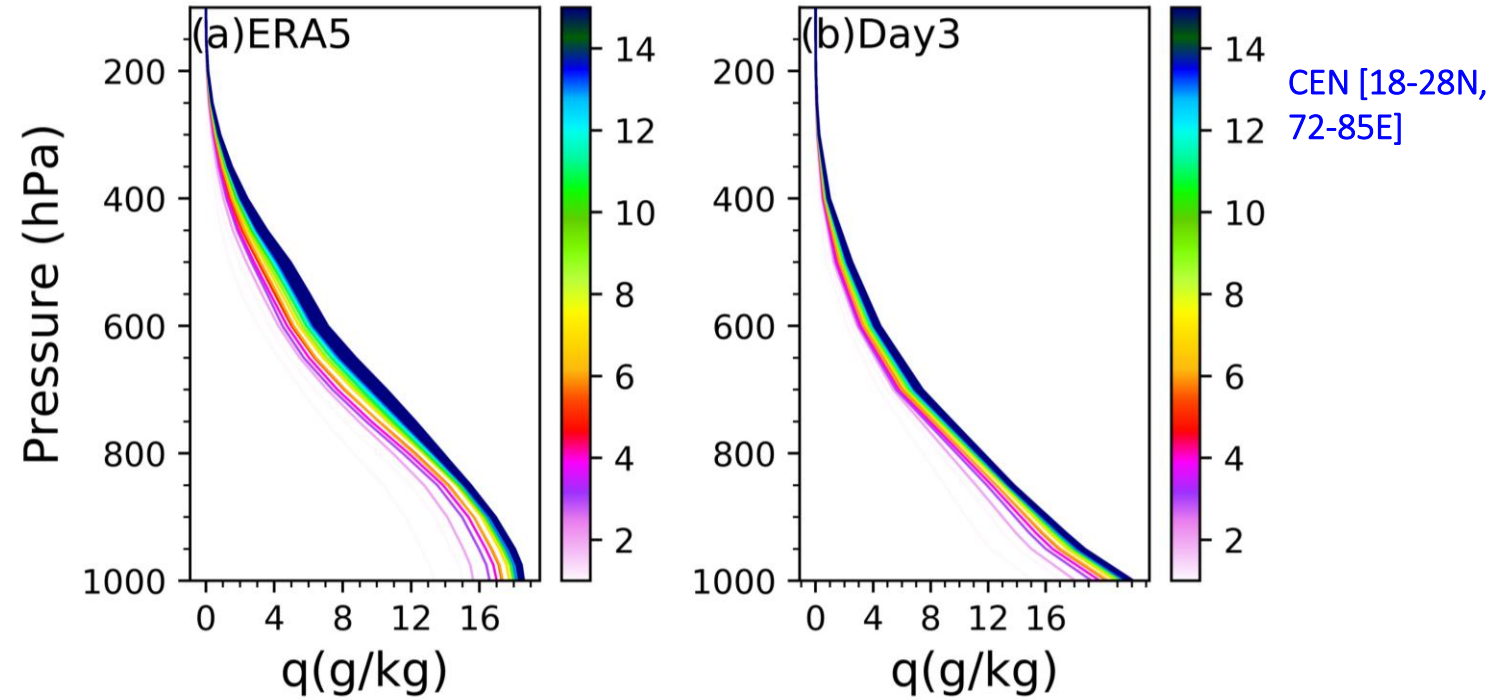
- *Deep convection is more sensitive to free tropospheric moisture [ex. Bretherton et al 2004; Sherwood et al 2004; Holloway and Neelin 2009].*

- *NCUMG - boundary layer moisture over Land regions*

- *Forecast profiles - demonstrate the weak association between convection and free tropospheric moisture.* constraint!

Process-oriented Diagnostics

- *Monotonous increase in rainfall – CWV bins (1mm).*
- *Sharp "pickup" demonstrates conditional instability leading to deep convection.*
- *At a given rainfall– NCUMG needs relatively less CWV compared to TMI observations.*
- *Entrainment! Or Shortcomings in microphysics!*

Under the CQE framework of [Arakawa and Shubert (1974)] representation of the interaction between cumulus convection and large-scale circulation requires consideration of moisture and temperature - MSE

- *The slope of Radiative heating/cooling per unit MSE is a metric to study the cloud-radiative feedback mechanism in the model.*
- *A large spread indicates the weaker feedback and vice-versa.*

Mohan et. al., (2024) Moist process in NCUM global operational forecasts during the boreal summer monsoon (revised version submitted Atmospheric Research)

(b) Column water vapor vs precipitation
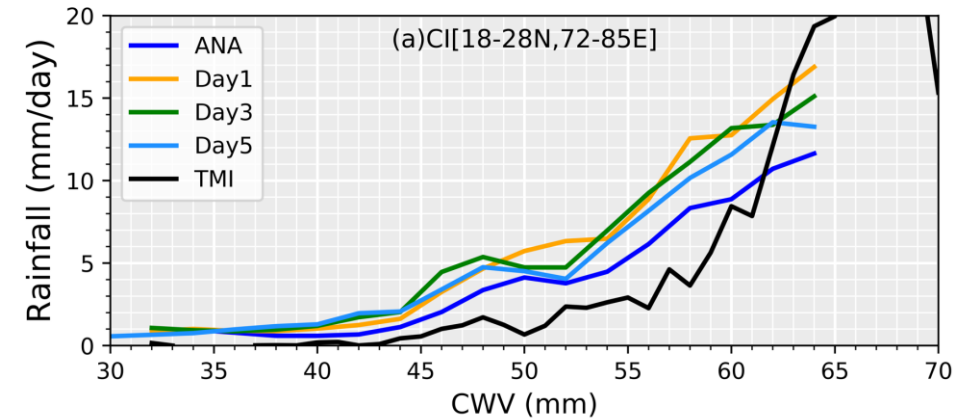
(c) Net Radiation vs MSE
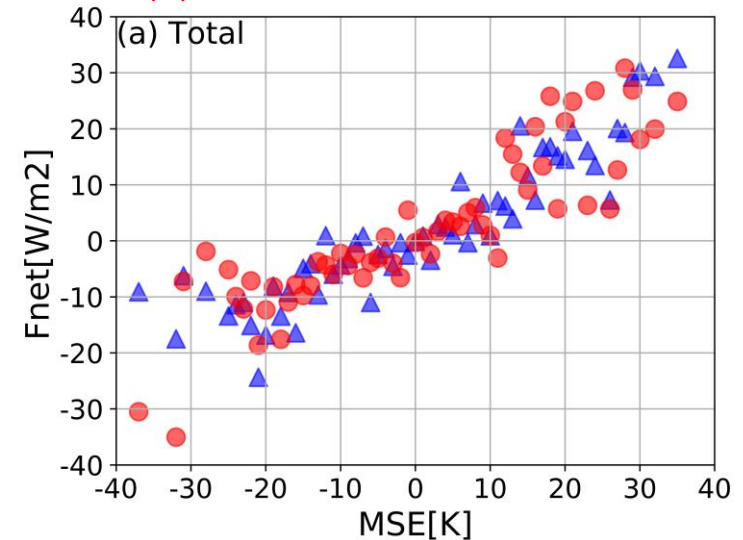
Summary

Anomalies

- Weaker than normal westerlies (JJAS) in the lower troposphere
- Warmer upper troposphere and relatively cooler temperatures lower – stable conditions over the Indian subcontinent.
- Wetter than normal RH in the lower troposphere (over the Arabian Sea & West coast)
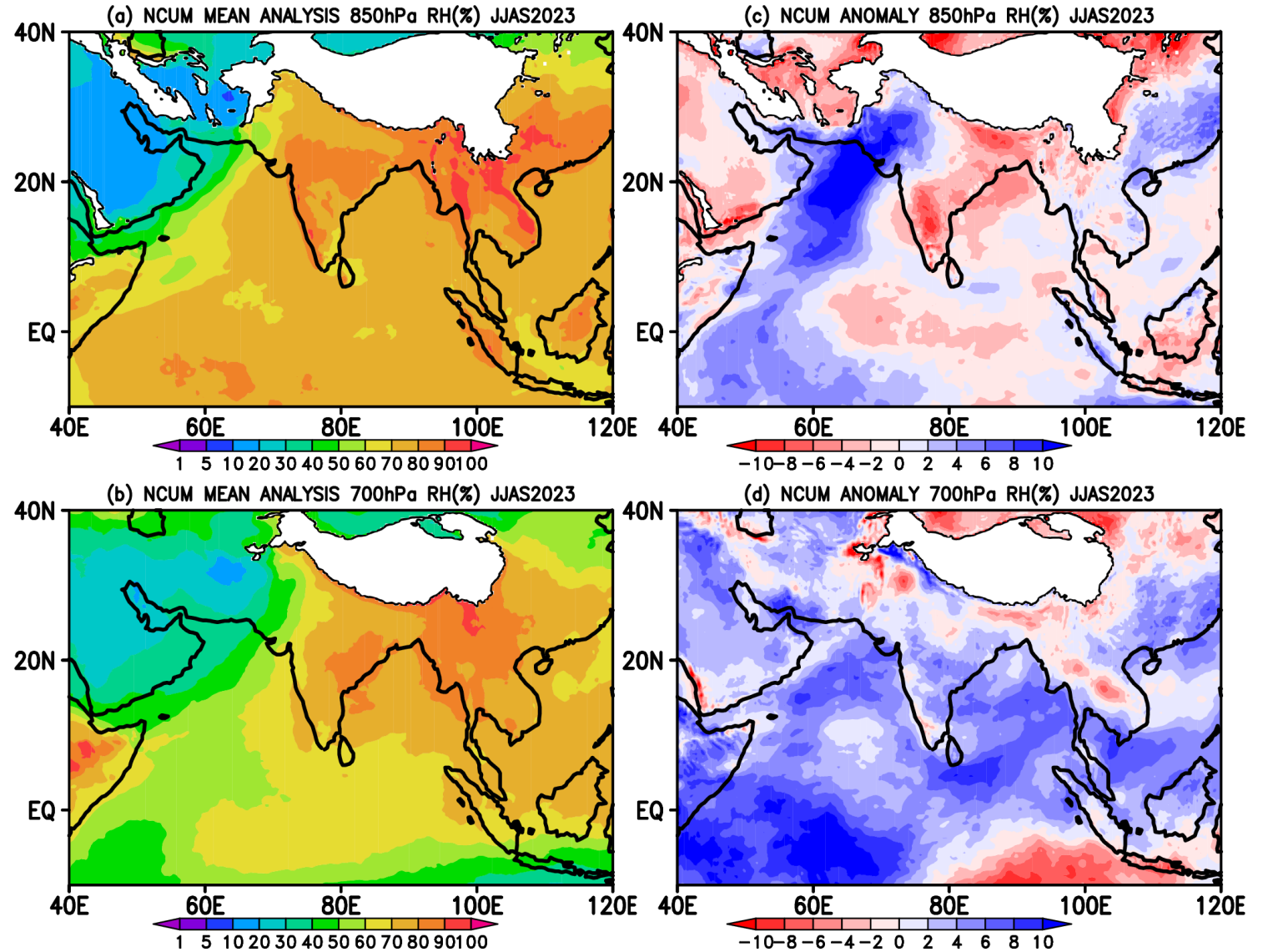
Systematic Errors

- Strong westerlies and weakened TEJ
- Dry bias over large parts of the Arabian Sea & Central India
- Enhanced moisture build-up in the forecasts.
- Underestimate the synoptic variance over BoB.
- Excess number of rainy days (irrespective of category)

Process oriented diagnostics

- Lack of free moisture sensitivity in model forecasts
- Weak conditional instability pickup over Land regions.

# Thanks

850hPa & 700hPa Relative Humidity

Anomalies against ERA-5 (1979-2018)
Climatology

(a) NCUM MEAN ANALYSIS 850hPa RH(%) JJAS2023

(c) NCUM ANOMALY 850hPa RH(%) JJAS2023

(b) NCUM MEAN ANALYSIS 700hPa RH(%) JJAS2023

(d) NCUM ANOMALY 700hPa RH(%) JJAS2023

Very humid in the lower troposphere at 850 and 700 hPa over the Arabian Sea

Monthly mean winds and anomalies

DAILY MEAN RAINFALL (mm) OVER THE COUNTRY AS A WHOLE (2023)
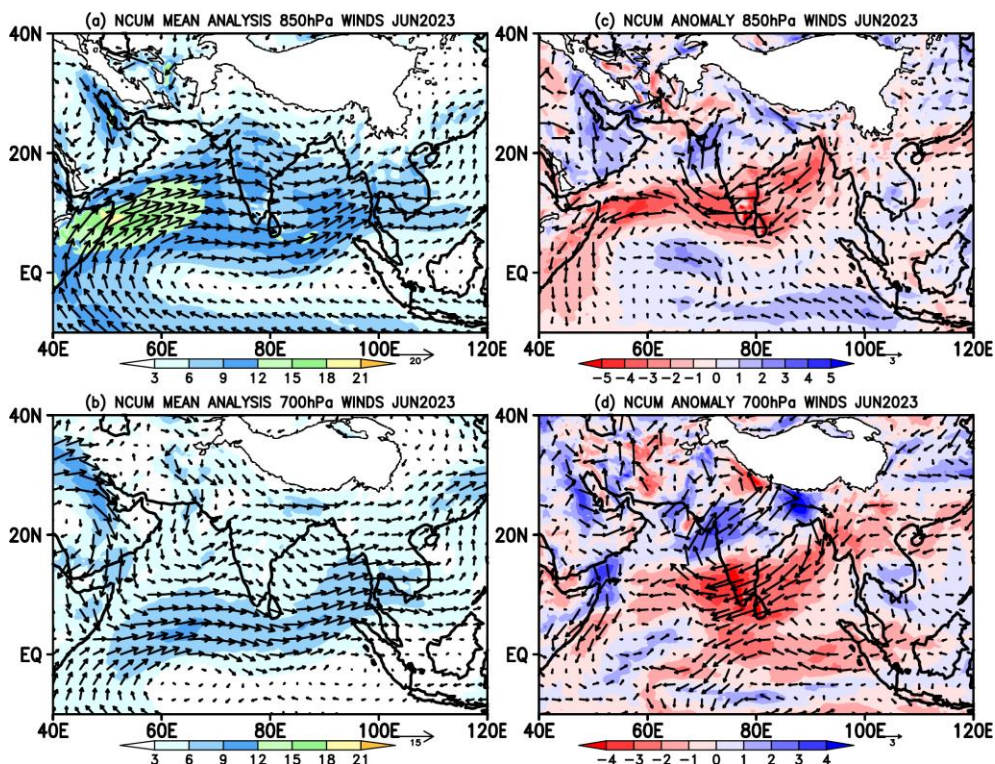
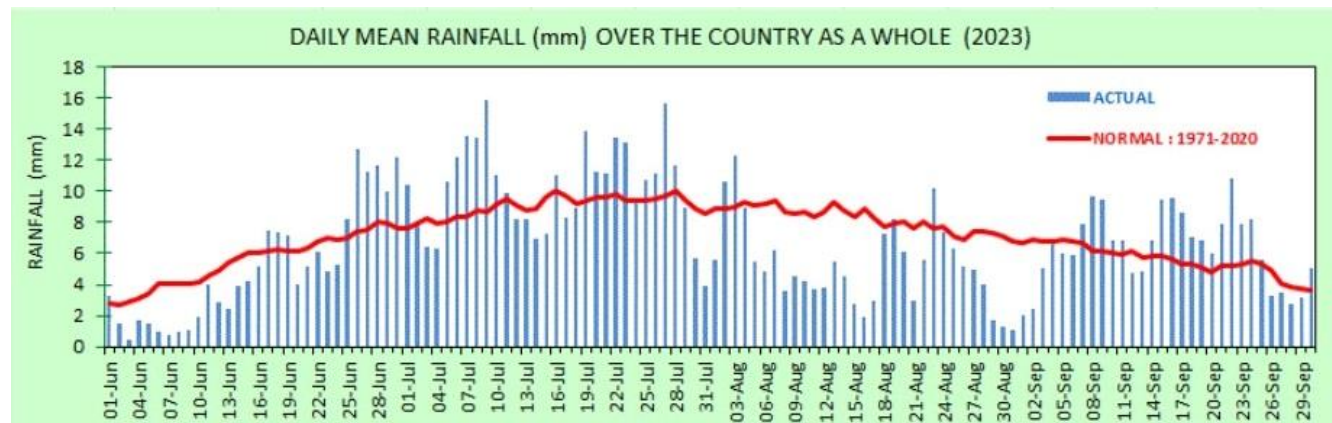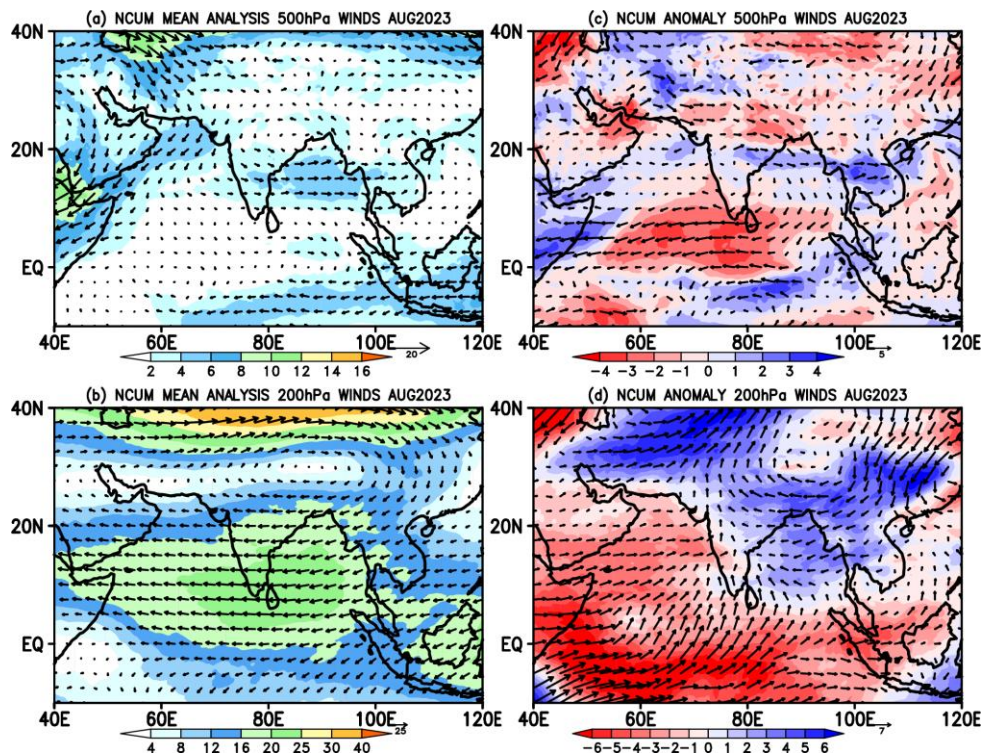*Weak cross-equatorial flow in Jun relative to Jul*
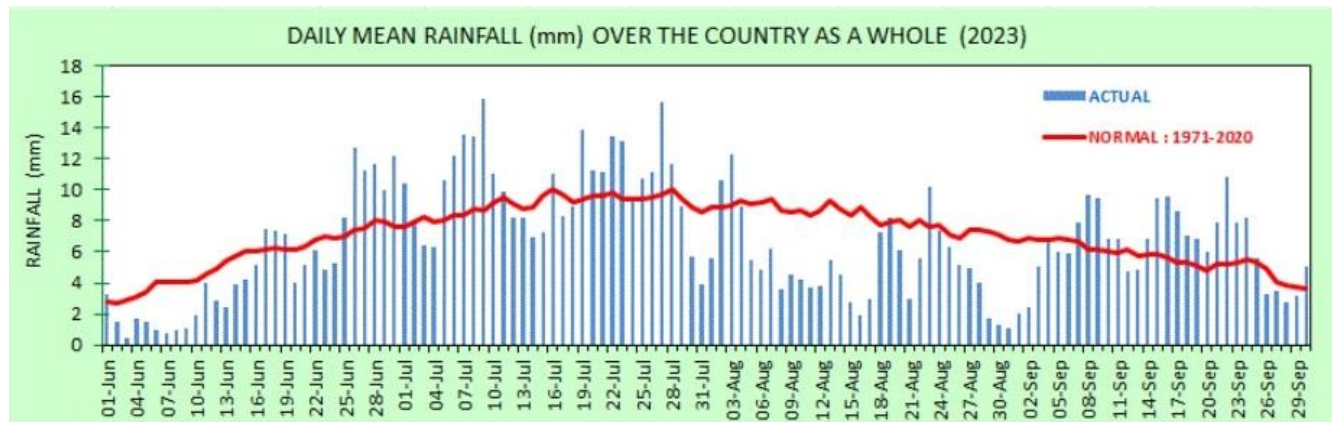
Jun 2023

Jul 2023
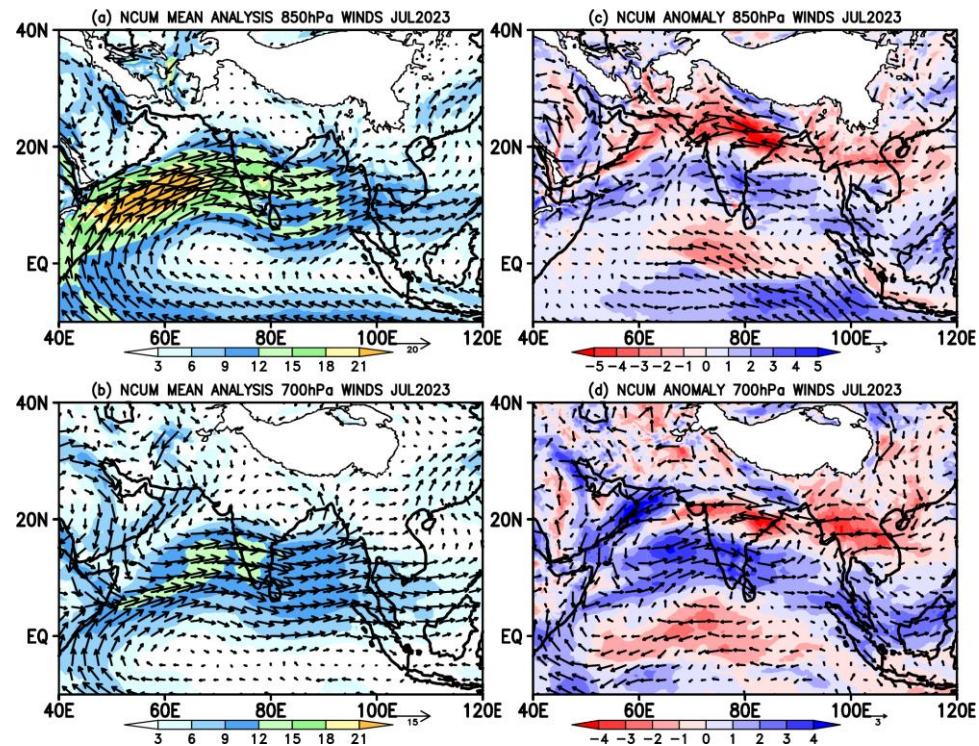
Monthly mean winds and anomalies

Aug 2023

Sep 2023

(a)CI[18-28N, 72-85E] (b)CI[18-28N, 72-85E] (c)CI[18-28N, 72-85E]