The evolving hydrological cycle of the summer monsoon season over Northeast India

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1. Background

The South Asian summer monsoon is characterized by -

1. Off equatorial heat source.
2. Seasonal reversal of wind coupled to a seasonal reversal of rainfall.
3. Northward propagation of ITCZ.
4. Deep baroclinic vertical structure.
5. Abrupt 'Onset'.

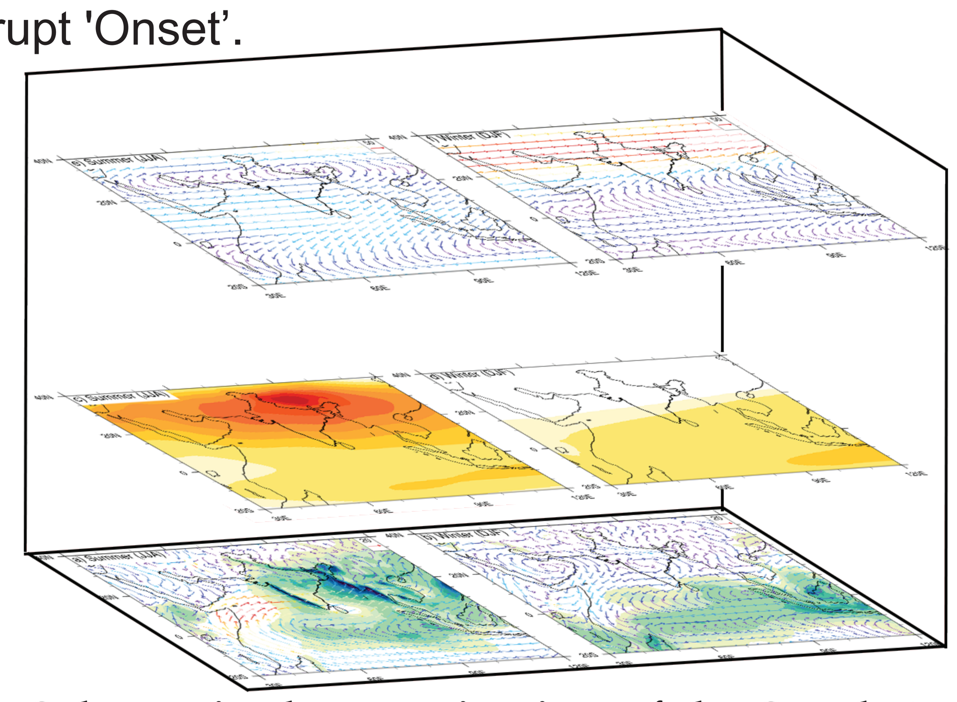

Fig. 1: Schematic characterization of the South Asian Monsoon: a, b) Rainfall with Wind at 850 hPa, c, d) Tropospheric temperature (TT), and e, f) Wind at 200 hPa for Summer (JJAS, left) and Winter (DJF, right) respectively.

Onset Mechanism

Tropospheric heating
↓
Cross equatorial flow
↓
Moisture convergence
↓
Formation of clouds
↓
Off equatorial heat source
↓
ITCZ intensification
→ Abrupt *'Onset'*

2. Introduction

1.The Northeast of India (NEI) displays an amplified annual rainfall cycle, exceeding that of Central India (CI), where the mean rainfall in May is approximately double that of June in CI.

2. We consider May rainfall over NEI to be 'pre-monsoon' as it comes in spells of persistent 'synoptic-scale' rainfall for 3–7 days.

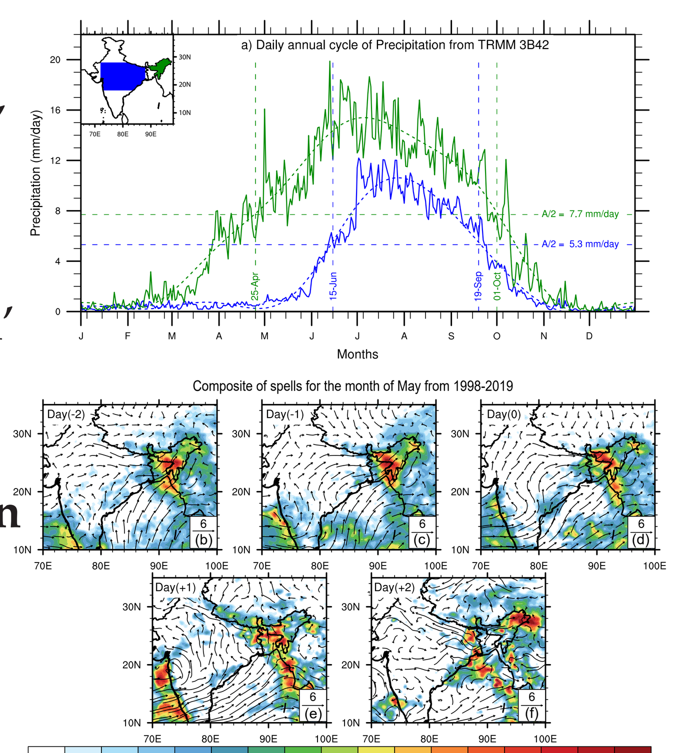

Fig. 2: Annual cycle and composites of May Precipitation and Wind anomaly at 850 hPa. a) The box average climatological annual cycle (solid line) of daily precipitation (TRMM 3B42) are computed from 1998 to 2019, along with its smoothed cycle (dashed line, mean + 3 harmonics) over CI (blue) and NEI (green).
b-f) Composites of spells (persistent of 3 days or more precipitation above 1 s.d.) for the month of May along with wind anomaly for same spell days based on index computed as area-averaged precipitation over NEI from 1998 to 2019.

3. Objectives

1. This study aims to objectively define the 'Onset date (OD),' 'Withdrawal date (WD),' and 'Length of Rainy Season (LRS)' of summer monsoon over NEI.

2. To understand NEI monsoon dynamics via CMIP6 simulations, aiding in improved preparedness for hydrological disasters.

4. Methodology

The TT and ΔTT are computed as follows:

$$TT_{air}(lat,lon,time) = \sum_{lev=600}^{lev=200} T_{air}(lat,lon,time,lev) \quad (1)$$

$$\Delta TT_{AI}(time) = \sum_{lon=40E}^{lon=100E}\sum_{lat=5N}^{lat=35N} TT(lat,lon,time) - \sum_{lon=40E}^{lon=100E}\sum_{lat=15S}^{lat=5N} TT(lat,lon,time) \quad (2)$$

$$\Delta TT_{CI}(time) = \sum_{lon=40E}^{lon=89E}\sum_{lat=5N}^{lat=35N} TT(lat,lon,time) - \sum_{lon=40E}^{lon=100E}\sum_{lat=15S}^{lat=5N} TT(lat,lon,time) \quad (3)$$

$$\Delta TT_{NEI}(time) = \sum_{lon=89E}^{lon=100E}\sum_{lat=5N}^{lat=35N} TT(lat,lon,time) - \sum_{lon=40E}^{lon=100E}\sum_{lat=15S}^{lat=5N} TT(lat,lon,time) \quad (4)$$

Where TT_{air} is the air temperature.

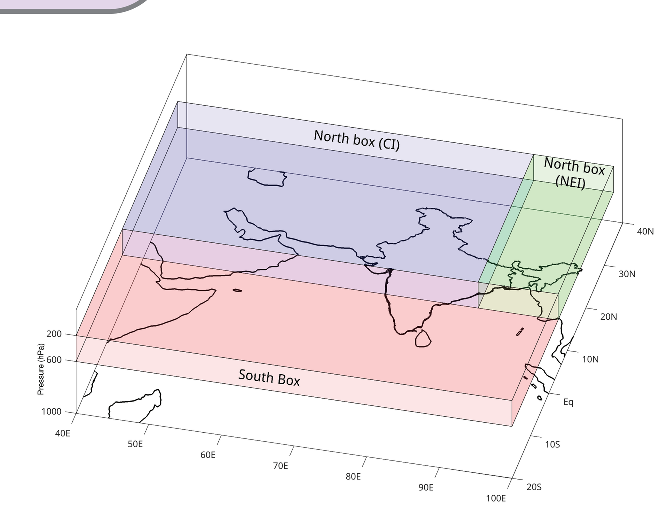

Fig.3: Schematic Tropospheric Temperature (TT).

5. Results

5a: 'Onset', 'Withdrawal', and 'LRS'

From reanalysis:
1. Climatologically (1976–2015), the 'onset' takes place on 14th May and 'withdrawal' takes place on 14th October making the LRS be 154 days over NEI based on NCEP-v3 data (Fig. 4a).

From CMIP6:
2. The models underestimate ΔTT, leading to an underestimated LRS of 144 days compared to the observed 154 days over NEI.
3. However, it reproduce the observed east-west asymmetry in LRS, with a longer rainy season over NEI than CI (Fig. 4a, b).

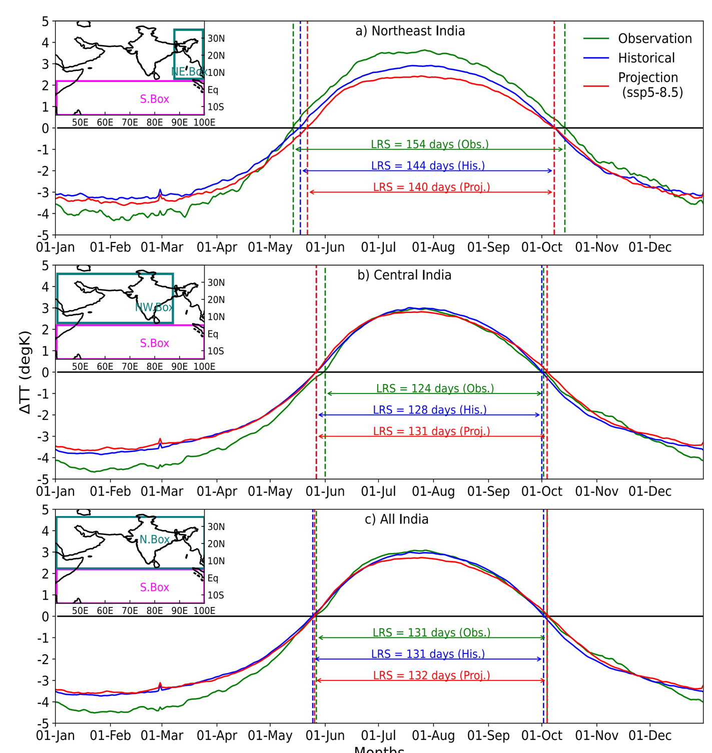

Fig. 4: Annual cycle of TT gradient (ΔTT).

5b: Inter-annual variability

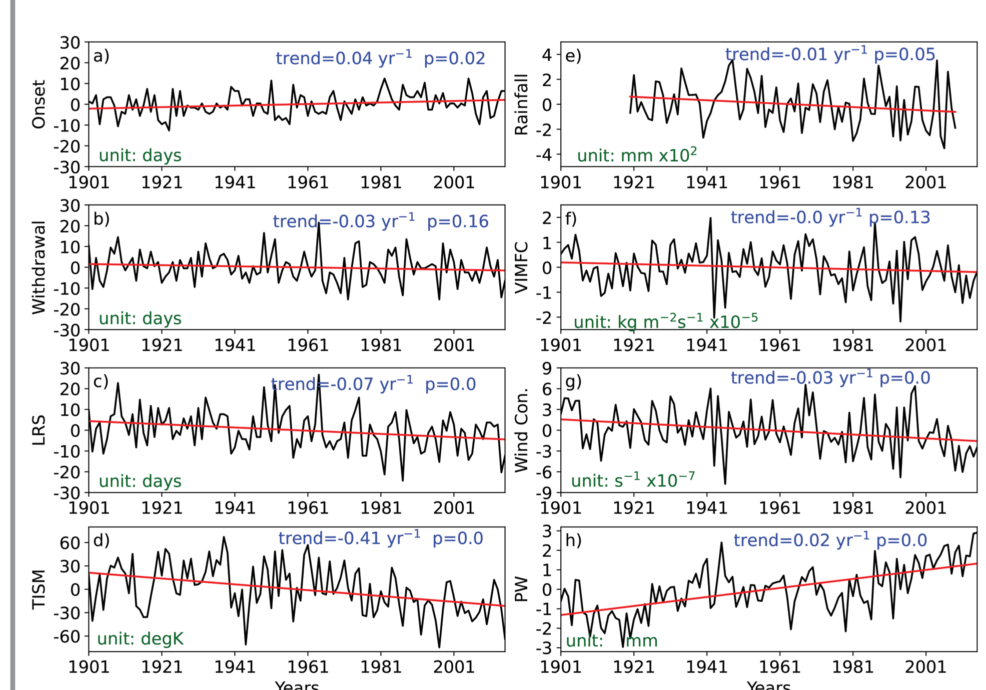

Fig. 5: Inter-annual variability and its trends over NEI from NCEPv3.

Observation

Delay Onset →
Early Withdrwal → Short LRS

Decreasing TISM, VIMFC, Wind Conv. } Weaker Monsoon Season *But increasing **PW**!*

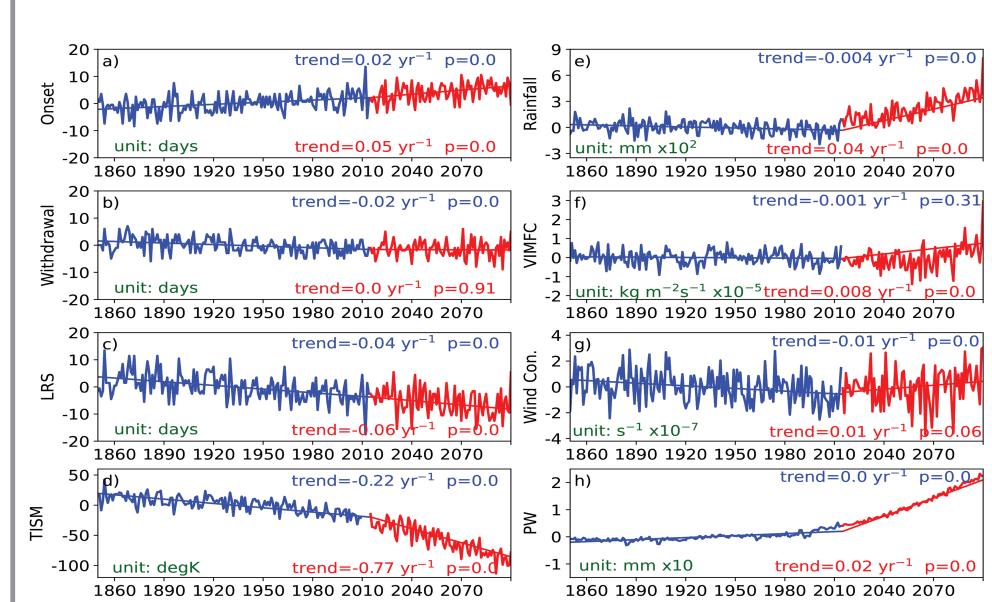

Fig. 6: Inter-annual variability and its trends over NEI from CMIP6.

Simulations

1. Historical simulation is consistent with observation.
2. However, VIMFC, Wind conv., PW, and thus Rainfall will increase in projection under SSP5-8.5 scenerio.

5c: Causes

1. The rapid rise in SST in projections explains the decreasing trend of TISM.
2. Despite the high equatorial SST weakening TISM, the abundant moisture content over NEI and the north Indian Ocean atmosphere results in a significant increase in VIMFC and leads to increased rainfall.

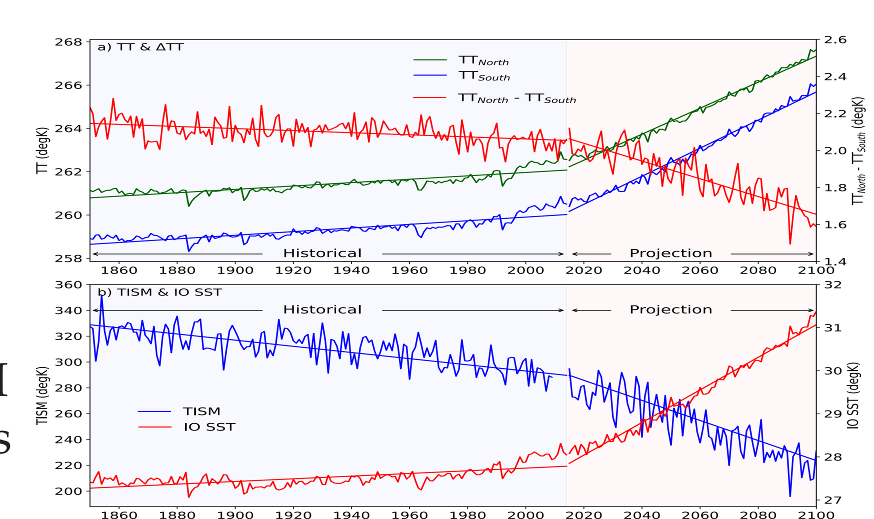

Fig 7: Strengthening of Indian Ocean (IO) SST over ΔTT from CMIP6.

6. Conclusion

1. Climatologically (CI/NEI): LRS → 124/154 days ; OD (14th May), WD (14th October).
2. The 'onset' over the NEI is not linked with ITCZ, rather linked with westward propagating quasi-biweekly oscillation and extratropical potential vorticity intrusion at upper level.
3. CMIP6: underestimate ΔTT -> underestimation of LRS by 8 days. However, the IAV aligns consistently with observations across all three regions.
4.The projected high moisture content results in: decrease -> increased rainfall.