Process oriented diagnostics of monsoon sub-seasonal variability in NCUM global and regional models

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Abstract

Aim of this study is to assess the fidelity of National Center for Medium Range Weather Prediction Unified model's (NCUM) global (12km) and regional (4km) versions in representing the monsoon sub-seasonal variability over Indian region by applying the process-oriented diagnostics. Moisture budget analysis is performed on the model's forecast fields for a typical extended monsoon break event occurred during July 2019. The exercise is repeated by using the fifth generation of ECMWF atmospheric reanalysis (ERA5) and the relative roles of the budget terms are quantified. We also tested the budget diagnostics onto the newly generated Indian Monsoon Data Assimilation and Analysis (IMDAA) product. The results obtained here are consistent with our understanding that moisture advection acts a leading term in inducing the break conditions over central Indian and adjoining oceanic regions. Specifically, dry air advection from the northwest regions strongly dries the atmospheric column nearly 7-10 days before and the peak dry phase over Indian subcontinent. Movement of this dryness, with time, towards central India and Arabian Sea is consistent with anomalous total precipitable water content seen from satellite observations. Preliminary results are encouraging and one of the direct implications of this work is that the lead times obtained in the moisture budget assessment can be used for understanding and improvement of the model forecasts.

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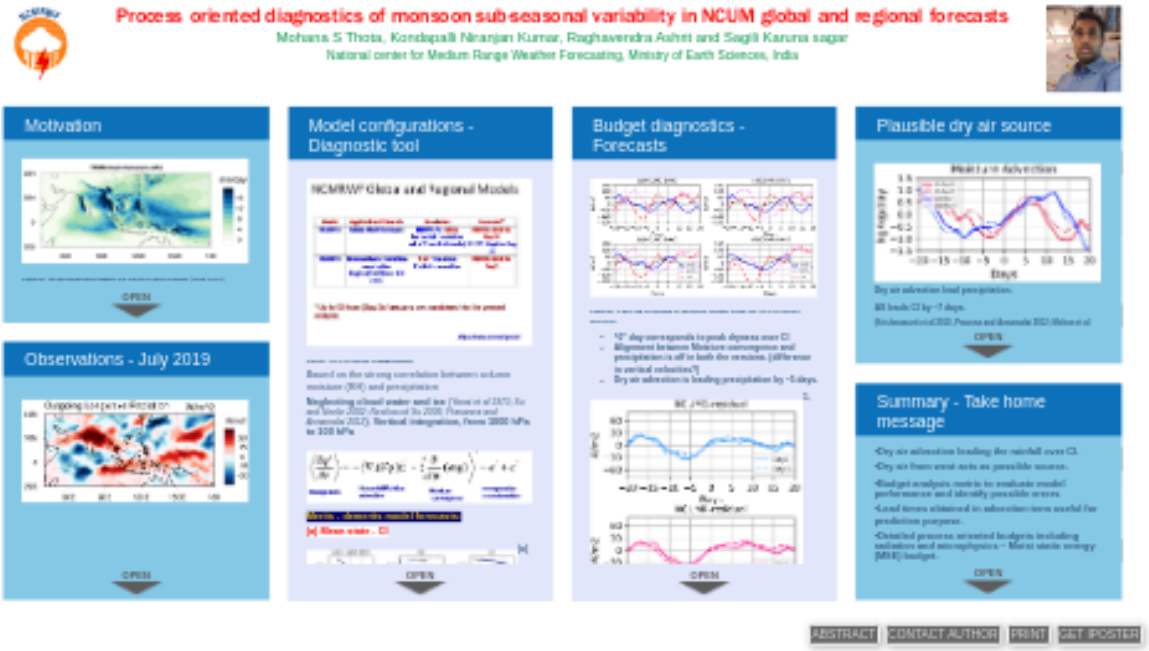

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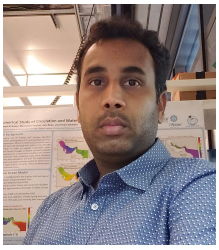

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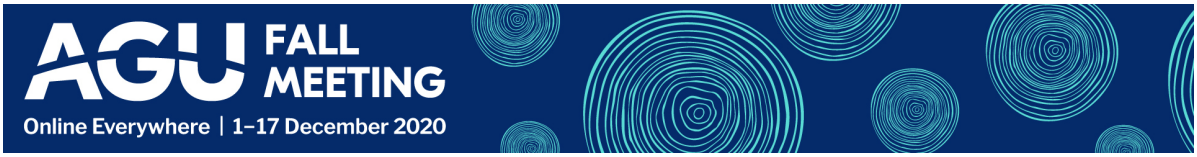


MOTIVATION

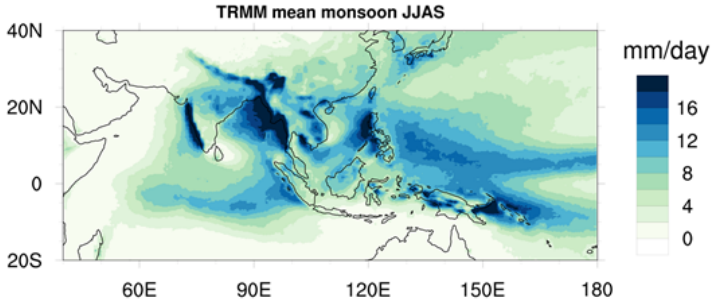


Figure1: Mean monsoon rainfall fro TRMM observations (1998-2015)

Mean monsoon rainfall (June to September) exhibits multiple rainfall maxima (heat sources). Mutual interaction of these multiple heat sources dictates mean and intraseasonal variability.

In any given season rainfall is not coherent, fluctuates between enhanced (Active)and suppressed (Break) convection.

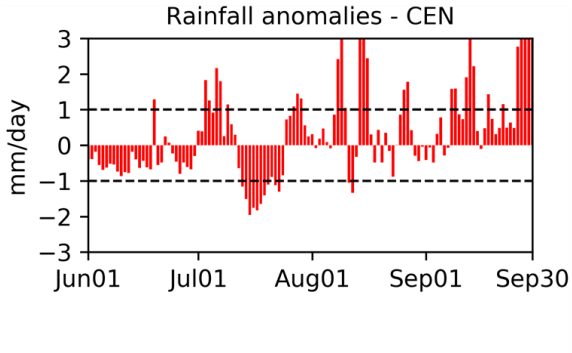
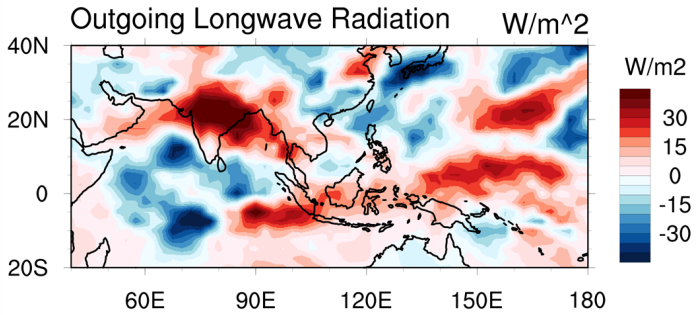


Figure2: Area averaged standerdized rainfall time series over central India(21-27N,72-85E, CEN) during summer monsoon 2019 from IMD gridded observations

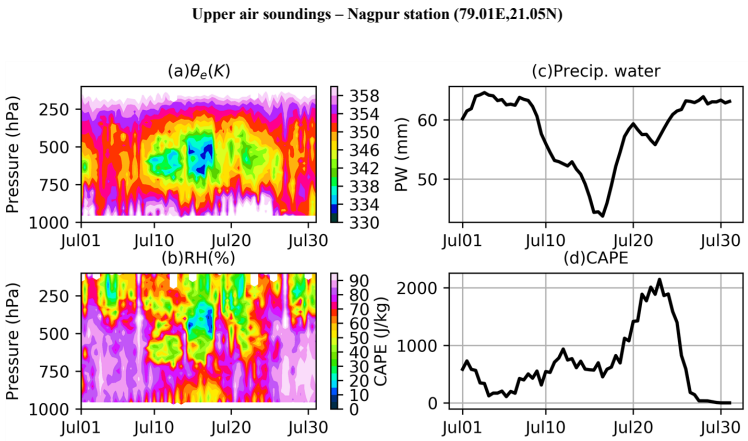
Standerdized rainfall anomalies during monsoon 2019 exhibits a break phase ~10days.

How does NCUM model forecasts represent physical processes during BSISV over India?(column integrated Moisture budget)?

OBSERVATIONS - JULY 2019



- **Suppressed convection occupied over most of the Indian sub-continent and surrounding Oceanic regions.**



- **Low moist static energy (MSE) air present around free tropospheric levels (500-700hPa).**
- **Entire tropospheric column is dry with RH as low as 15%**
- **Reflected in Column integrated water vapor – associated in large radiative cooling**
- **Quadrature relationship between moisture and energy.**

MODEL CONFIGURATIONS - DIAGNOSTIC TOOL

NCMRWF Global and Regional Models

Model	Application & Domain	Resolution	Forecasts*
NCUM-G	Global NWP Forecasts	N1024L70 (12km horizontal resolution with 70 vertical levels)	00UTC: Day0 to Day10 12UTC: Day0 to Day 10
NCUM-R	Regional high resolution over Indian Region (5-40N and 65-100E)	4 km resolution Explicit convection	00UTC: Day0 to Day3

* Up to 72-hour (Day-3) forecasts are considered for the present analysis.

https://www.ncmrwf.gov.in/

Table1: NCUM model configurations

Based on the strong correlation between column moisture (RH) and precipitation

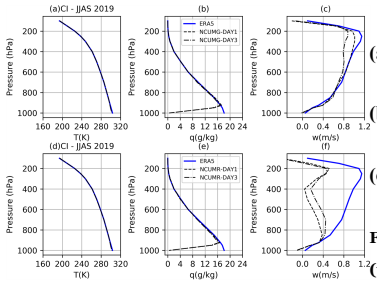
Neglecting cloud water and ice *(Yanai et al 1973; Su and Neelin 2002; Neelina nd Su 2005; Prasanna and Annamalai 2012*)**. Vertical integration, from 1000 hPa to 100 hPa**

$$\left\langle \frac{\partial q'}{\partial t} \right\rangle = -\left\langle \nabla .(Vq) \right\rangle' - \left\langle \frac{\partial}{\partial p}(\omega q) \right\rangle' - e' + c'$$

Storage term — Horizontal Moisture advection — Moisture convergence — e-evaporation c-condensation

Merits - demerits model forecasts:

(a) Mean state - CI



(a) Largest changes in moisture (q) and vertical velocity (w).

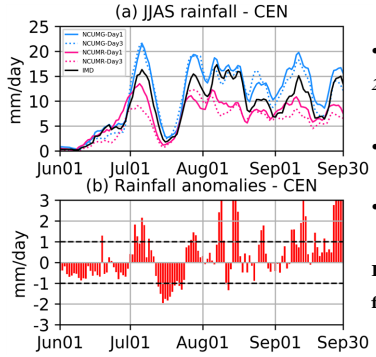
(b) Double peak in mean w in regional model forecasts.

(c) Weak ascending in the middle-upper troposphere region.

Figure3: Vertical profiles of seasonal mean T, q and w during 2019 over CI for NCUM global (upper panel) and regional (lower panel)

Short comings in *cloud micro physics*?.

(b) precipitation - variability



•Wet (Dry) bias in NCUM-Global (regional) models. (*Walters et al. 2017; Bush et. Al 2015; Levine and Martin 2018*)

•Westerly wind bias over Indian subcontinent.

•Better one-to-one agreement with observed surface rainfall.

Figure4: (a) Observed and precipitation forecast time series over CI; (b) std.rainfall anomalies from observations alone

Tendencies in rainfall forecasts during break phase are in correspondence with observed anomalies.

BUDGET DIAGNOSTICS - FORECASTS

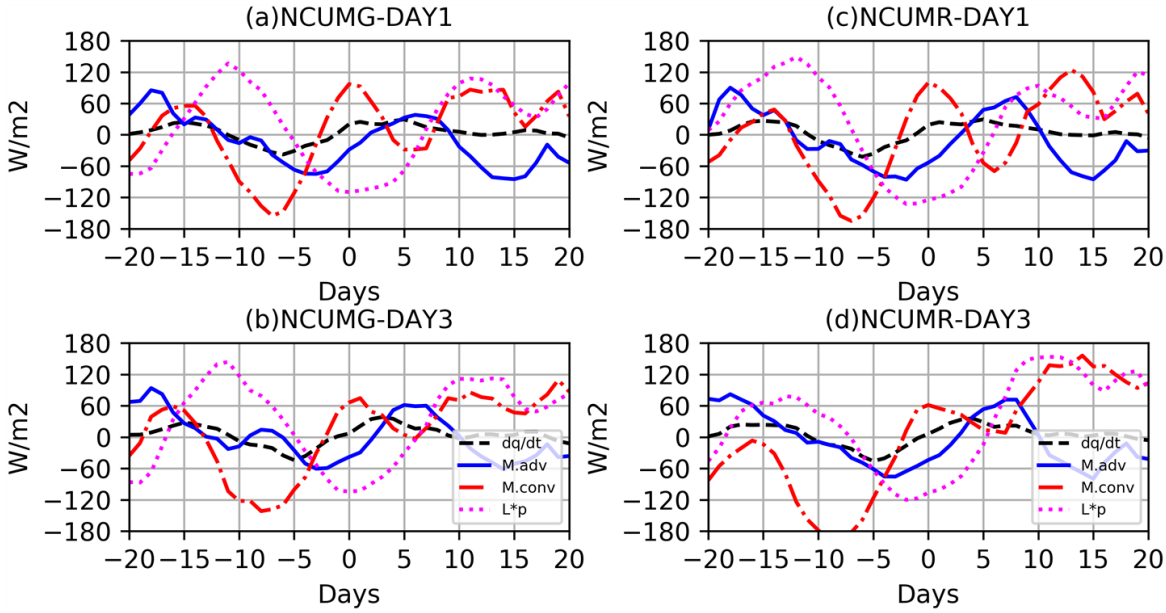
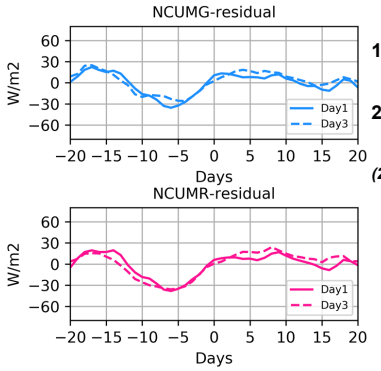


Figure5: Lead-lag evolutiom of moisture budget terms for NCUM model forecasts.

- **"0" day corresponds to peak dryness over CI**
- **Alignment between Moisture convergence and precipitation is off in both the versions. (difference in vertical velocities?)**
- **Dry air advection is leading precipitation by ~5 days.**



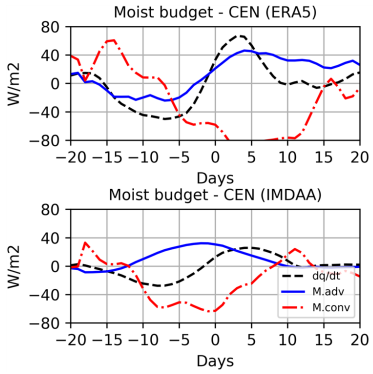
1. Residuals are as large as mosture tendency term.

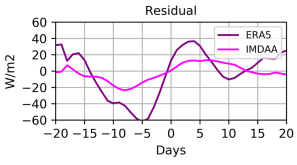
2. Indicates missing of a anomalous dry source

(28W/m^2 ~= 1mm/day)

Figure 6: Lead-lag evolution of residual terms for NCUM forecasts.

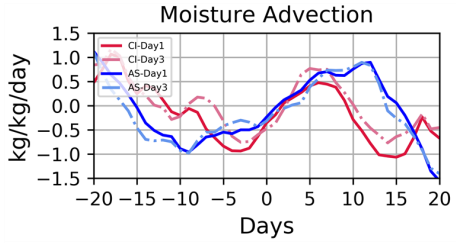
Moisture budget - Reanalysis data





- **Moisture convergence – precipitation alignment is better.**
- **Dryness leads rainfall over CI by ~7-8days in ERA5**
- **Leading nature of dryness is ~14 days in Indian Monsoon Data Assimilation and Analysis reanalysis (IMDAA) reanalysis (https://rds.ncmrwf.gov.in/).**
- **Residuals – misrepresenting "some" recharge process (need to look!)**

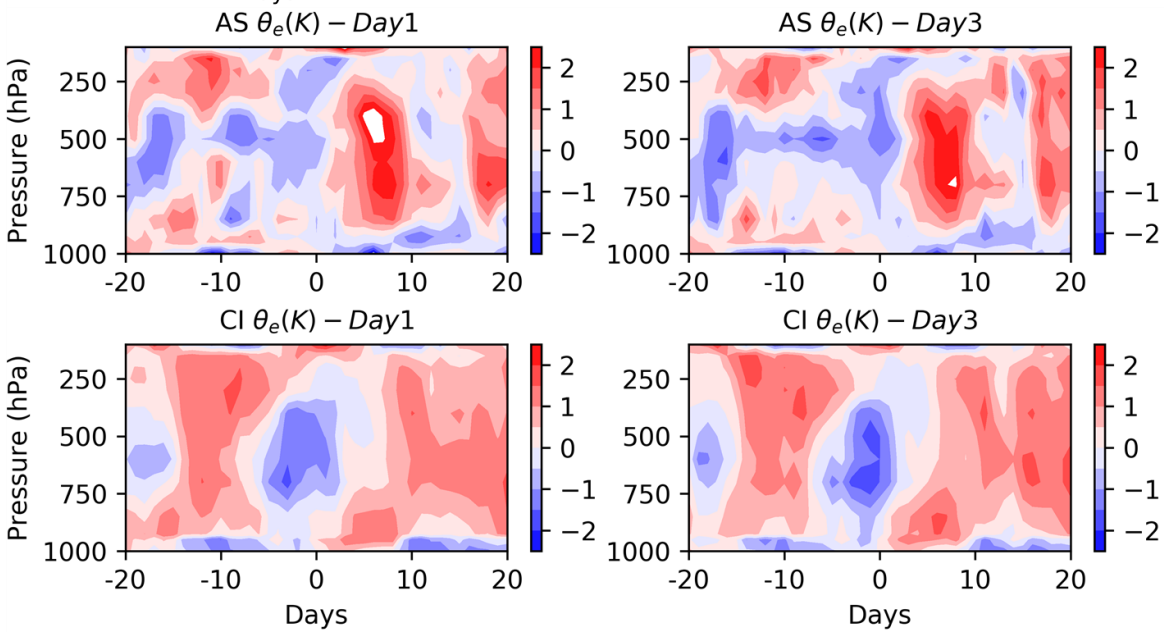
PLAUSIBLE DRY AIR SOURCE



Dry air advection lead precipitation.

AS leads CI by ~7 days.

(Krishnamurti et al 2010, Prasnna and Annamalai 2012; Mohan et al 2018)



- **Low MSE air peaking around free tropospheric levels (500-750hPa).**
- **Over AS it is much earlier than CI (possible source).**

SUMMARY - TAKE HOME MESSAGE

•Dry air advection leading the rainfall over CI.

•Dry air from west acts as possible source.

•Budget analysis metric to evaluate model performance and identify possible errors

•Lead times obtained in advection term useful for prediction purpose.

•Detailed process oriented budgets including radiation and microphysics – Moist static energy (MSE) budget.

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