Evaluation of CORDEX-CORE Simulations in Revealing the Physical Mechanisms Behind the Rainfall Extremes over the Indo-Gangetic Plains

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ABSTRACT

This study examines the Indian summer monsoon rainfall (ISMR) patterns over the agriculture based and densely populated Indo-Gangetic Plain (IGP), covering 15% of India's landmass during 1981-2005. The research reveals that 1-10mm/day of rainfall is common in this region, with higher levels in the eastern areas. Regional Climate Models (RCMs) effectively replicate the monsoon's mean precipitation patterns and reduce existing biases. The study delves into Indian Summer Monsoon (ISM) dynamics, illustrating RCMs' robust simulation of ISM features. It also identifies and analyzes extreme monsoon rainfall events in the IGP, highlighting the effectiveness of high-resolution CORDEX-CORE simulations in predicting extreme rainfall and their precursors six days in advance. This research provides crucial insights into rainfall extremes in a vulnerable region, aiding climatologists and policymakers in crafting climate change mitigation strategies.

INTRODUCTION & OBJECTIVE

The Indo-Gangetic Plain (IGP) is vital for South Asia's food security, producing over 50% of food grains for 40% of Indian population. Rapid urbanization has made the IGP prone to heavy rainfall and floods, affecting agriculture heavily reliant on the Indian Summer Monsoon Rainfall (ISMR). Recent decades have seen an increase in extreme rainfall events, exacerbated by global warming. The IGP faces more rainfall extremes while moderate rainfall decreases, leading to significant events like the 2005 Mumbai rainfall and 2018 Kerala floods. This study uses high-resolution CORDEX-CORE RCM simulations to comprehensively analyze rainfall extremes and their underlying processes in the IGP from 1981-2005 during ISM season (June to September). It emphasizes the utility of RCMs for regional assessments and addresses critical economic and agricultural challenges in a changing climate.

MATERIALS, MODEL DESCRIPTION & METHODOLOGY

- Daily gridded observation data at 0.25°× 0.25° resolution from India Meteorological Department (IMD) for 1981-2005 (Pai et al., 2014).
- **High-resolution CORDEX-CORE simulations (~25 Km) from three RCMs –** ICTP's RegCM4.7, ETH Zürich-Switzerland's COSMO-crCLIM-v1-1, and GERICS-Germany's REMO2015. All driven by common initial and boundary conditions from NOR-ESM1-M (Bentsen et al., 2013) for 1979-2005.
- **Simulation Period:** 1981-2005, with the first two years (1979-1980) as spin-up time.
- **Variables Studied:** Rainfall (PR), temperature (T), zonal (u) and meridional (v) winds, specific humidity (q), geopotential height (Zg), and water vapor path (prw) from RCM simulations and are compared with the ERA5 reanalysis (Hersbach et al., 2020).
- *Moisture transport* $(MT) = q_{850}U_{850}(u, v)$
- *Horizontal moisture flux convergence* $(HMFC) = -\left(\frac{\partial(q*u)_{850}}{\partial x} + \frac{\partial(q*v)_{850}}{\partial y}\right)$
- $Moist\ static\ energy$
- $(MSE) = C_pT + Lq + gz$

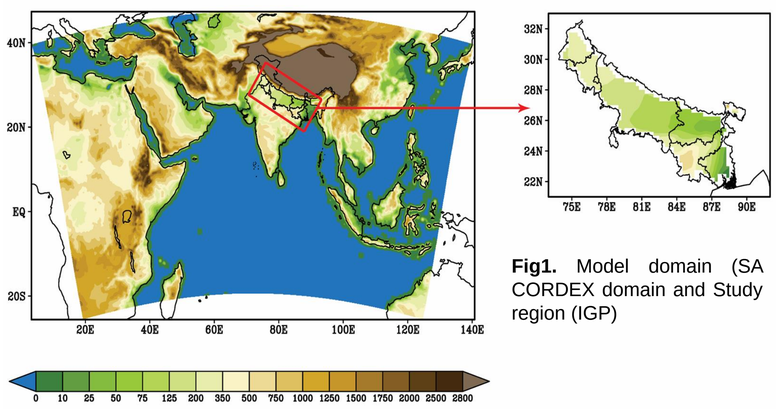


Fig1. Model domain (SA CORDEX domain and Study region (IGP)

Detailed model description

	REGCM4	COSMO	REMO2015
Institute	ICTP	CLMcom-ETH	GERICS
Version	RegCM4.7	COSMO-crCLIM-v1-1_v1	REMO2015_v1
Dynamics	Hydrostatic	Non-hydrostatic	Hydrostatic
Domain	South Asia CORDEX domain (22° S–50° N; 10° E–130° E)	South Asia CORDEX domain (22° S–50° N; 10° E–130° E)	South Asia CORDEX domain (22° S–50° N; 10° E–130° E)
Resolution	25 km	0.22º	0.22º
Vertical levels	23	57	27
PBL	Holtslag PBL (Holtslag et al. 1990)	-	Monin-Obukhov similarity theory (Louis 1979)
ICBC	NCC_Nor_ESM-1M	NCC_Nor_ESM-1M	NCC_Nor_ESM-1M
CPS	Emanuel over Land & Tiedtke over Ocean	Tiedtke (1989)	Tiedtke (1989)
Microphysics	SUBEX (Pal et al. 2000)	-	Lohmann and Roeckner (1996)
Period	1981-2005	1981-2005	1981-2005

Identification of rainfall extremes:
Days with **extreme rainfall** identified as those where **at least 20% of grid points** meet the above **95th percentile** threshold values of daily mean precipitation for the study period.

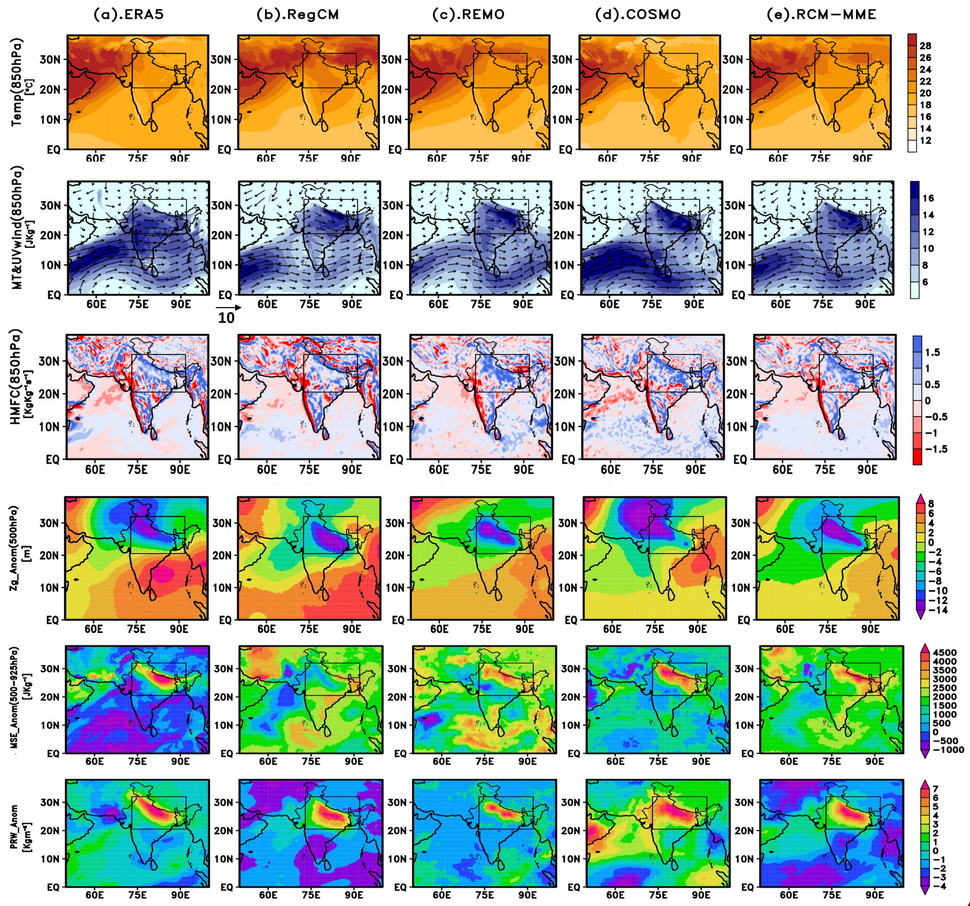
This methodology allows us to comprehensively assess the ability of RCM to capture essential climate features and investigate extreme precipitation events over the IGP region.

RESULTS & ANALYSIS

Investigation of various physical processes behind the occurrence of rainfall extremes over the IGP region

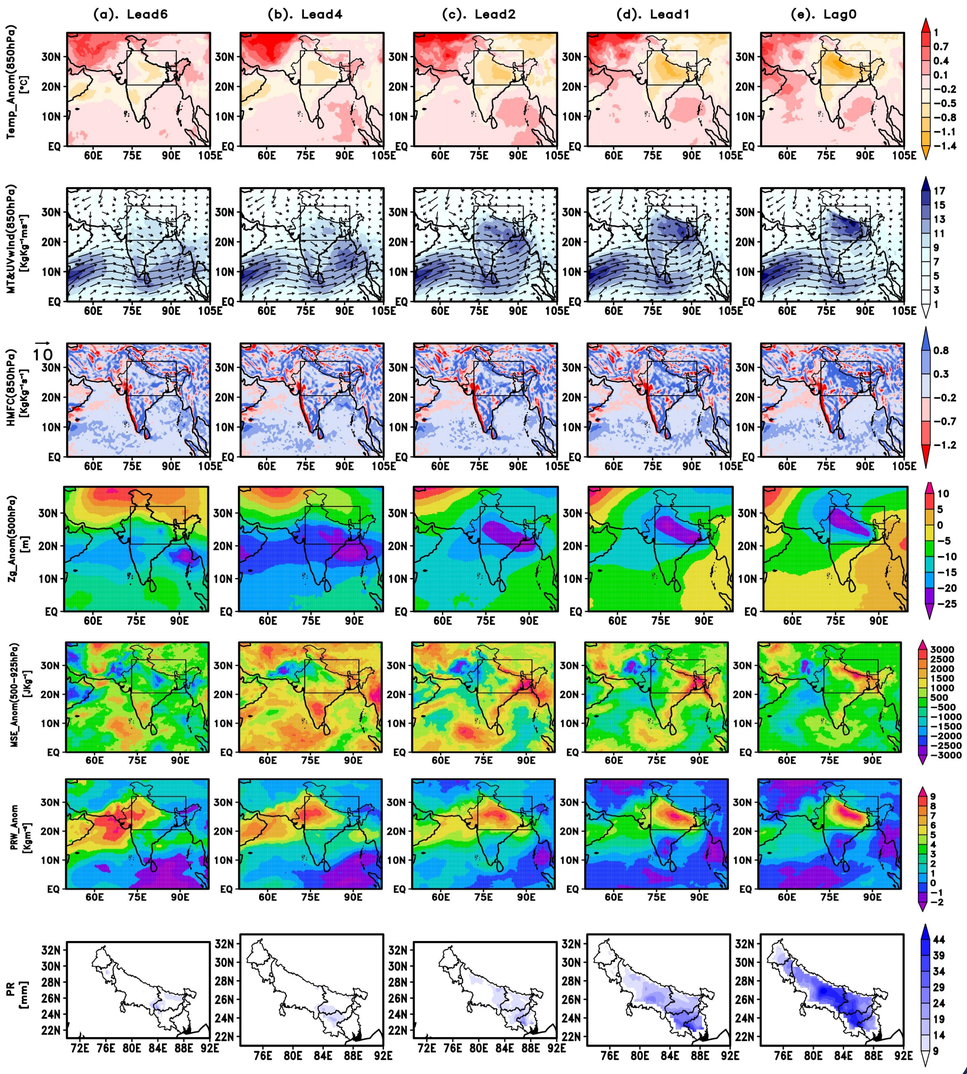
Spatial distribution of various thermodynamic/dynamic quantities on heavy rainfall days

The RCMs are able to simulate the features supporting the occurrence of heavy rainfall episodes over IGP, such as the strong cross-equatorial flow, Somali jet, availability of enormous amount of moisture and presence of monsoon trough crossing Gangetic Plains.



Evolution of rainfall extremes over the IGP region

Rainfall extremes over the IGP have been identified and their underlying mechanism analyzed, with RCMs demonstrating their ability to represent them at localized scales with their evolution up to 6 days in advance.



Terms
Temp: Temperature
MT& UV wind: Moisture transport and U-V wind
HMFC: Horizontal moisture flux convergence
Zg_Anom: Geopotential height anomaly
MSE_Anom: Moist static energy anomaly
PRW_Anom: Water vapour path
PR: Rainfall

MODEL EVALUATION

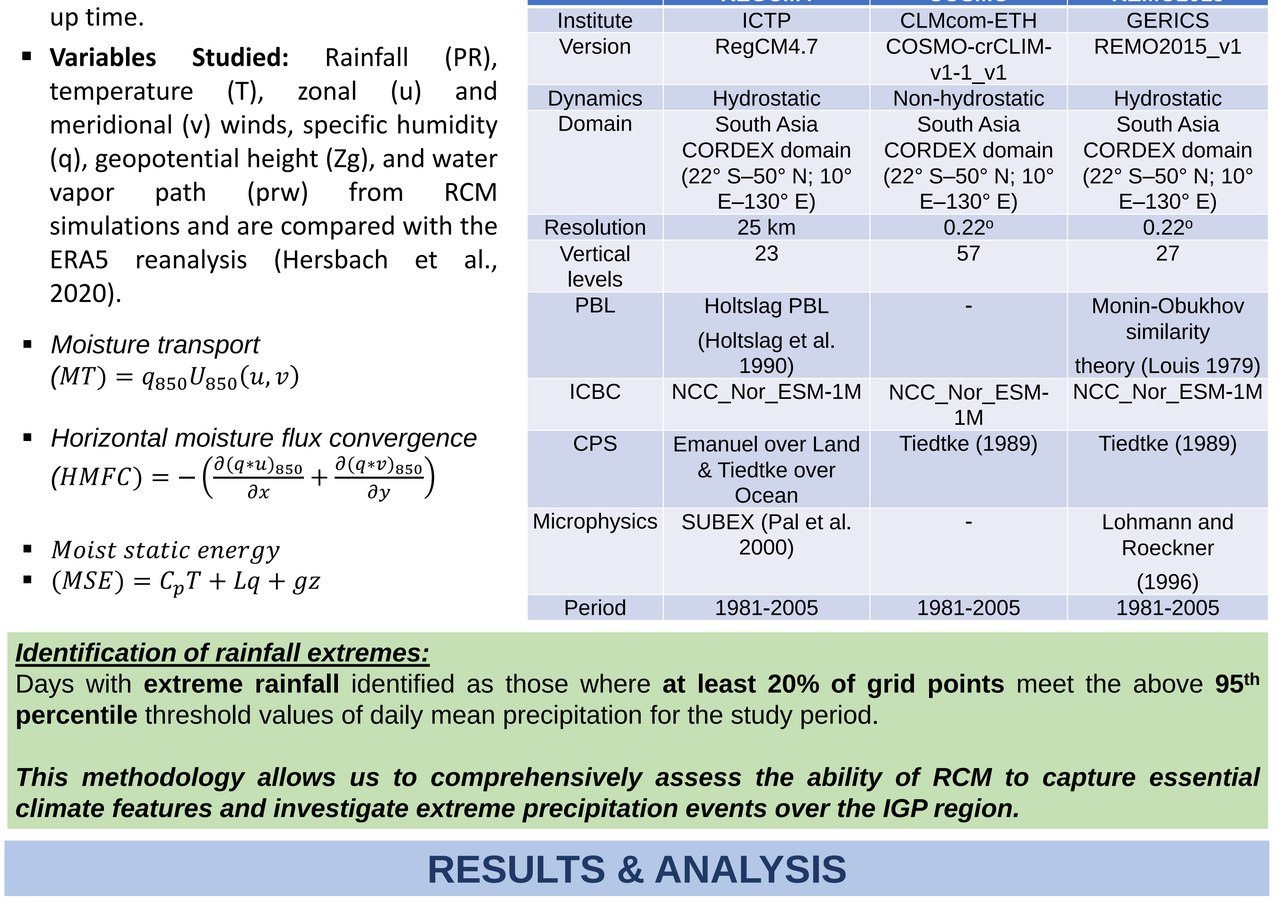


Fig3. Observed IMD's gridded data) and model simulated mean ISMR over IGP during 1981-2005

Fig4. Spatial distribution of observed and RCM simulated above mean rainfall on R95p days (composite) during ISM season over IGP region.

Fig3. Taylor's diagram for mean ISM rainfall

Fig4. Taylor's diagram for the days above 95th percentile of rainfall days

SUMMARY & CONCLUSIONS

- ✓ The study provides a first-ever detailed mechanism analysis of rainfall extremes over the IGP region
- ✓ **Effective RCMs:** COSMO and RCM-MME excelled among considered RCMs, reducing biases from parent models.
- ✓ **Validation Support:** Statistical techniques (Taylor diagrams, PDFs) confirmed RCMs' ability to reduce uncertainties from the parent GCM (Nor-ESM).
- ✓ **Successful ISM Simulation:** RCMs accurately simulated ISM features, including cross-equatorial flow, Somali jet, higher temperatures over Indo-Pak arid regions, and the monsoon trough over Gangetic Plains.
- ✓ **Extreme Rainfall Analysis:** Detailed analysis identified key parameters (HMFC, Zg500, MSE, PRW) influencing extreme rainfall. MT and HMFC at 850hPa played vital roles, with thermodynamic support from MSE buildup.
- ✓ **Policy and Research Implications:** This study provides a comprehensive analysis of rainfall extremes in a socioeconomically significant and densely populated region, offering insights for climate change adaptation and mitigation strategies, benefiting researchers and policymakers.

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