Mesoscale signature associated with extreme rainfall events over India in the IITM Global High resolution Forecast Model (IITM HGFM) (GMD, 2025)

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Geoscientific Model Development
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EGU

Model evaluation paper

Indian Institute of Tropical Meteorology (IITM) High-Resolution Global Forecast Model version 1: an attempt to resolve monsoon prediction deadlock

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Abstract. The prediction of Indian monsoon rainfall variability, affecting a country with a population of billions, remained one of the major challenges of the numerical weather prediction community. While in recent years, there has been a significant improvement in the prediction of the synoptic-scale transients associated with the monsoon circulation, the intricacies of rainfall variability remained a challenge. Here, an attempt is made to develop a global model using a dynamic core of a cubic octahedral grid that provides a higher resolution of 6.5 km over the global tropics. This high-resolution model has been developed to resolve the monsoon convection. Reforecasts with the Indian Institute of Tropical Meteorology (IITM) High-Resolution Global Forecast Model (HGFM) have been run daily from June through September 2022. HGFM has a wavenumber truncation of 1534 in the cubic octahedral grid. The monsoon events have been predicted with a 10 d lead time. HGFM is compared to the operational Global Forecast System (GFS) T1534. While HGFM provides skills comparable to GFS, it shows better skills for higher precipitation thresholds. This model is currently being run in experimental mode and will be made operational.

1 Introduction

In spite of significant improvement in numerical weather prediction skill in the last decades (Bechtold et al., 2008; Magnusson and Kallen, 2013; Hoffman et al., 2018), predictions of tropical rainfall variability remain a challenge (Westra et al., 2014; Prakash et al., 2016). Stephens et al. (2010) demonstrated that the models predict too many rainy days in the tropics, which are in the lighter rain category. The challenges of tropical rainfall variability have also been demonstrated by Watson et al. (2017). The vagaries of the Indian monsoon every year affect the lifestyle of billions of people and affect the economy of the Indian subcontinent, modulating its gross domestic product (GDP) (Gadgil and Gadgil, 2006). It is, therefore, of the utmost importance to improve the weather prediction skill in general and extreme precipitation event prediction in particular. With the increase in computing power, the resolution of numerical weather prediction models has been increasing, and global models with a resolution of 1–7 km have become a reality (Majewski et al., 2002; Satoh et al., 2005; Miura et al., 2007; Staniforth and Thuburn, 2012; Li et al., 2015; Satoh et al., 2019; Wedi et al., 2020). The higher resolution of numerical weather prediction (NWP) models has been found to produce realistic rainfall variability across various scales, in-

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A Milestone Accomplishment by MoES IITM GoI

The model is freely accessible from GMD.

A first of it's kind from India

Geosci. Model Dev., 18, 1879–1894, https://doi.org/10.5194/gmd-18-1879-2025, 2025

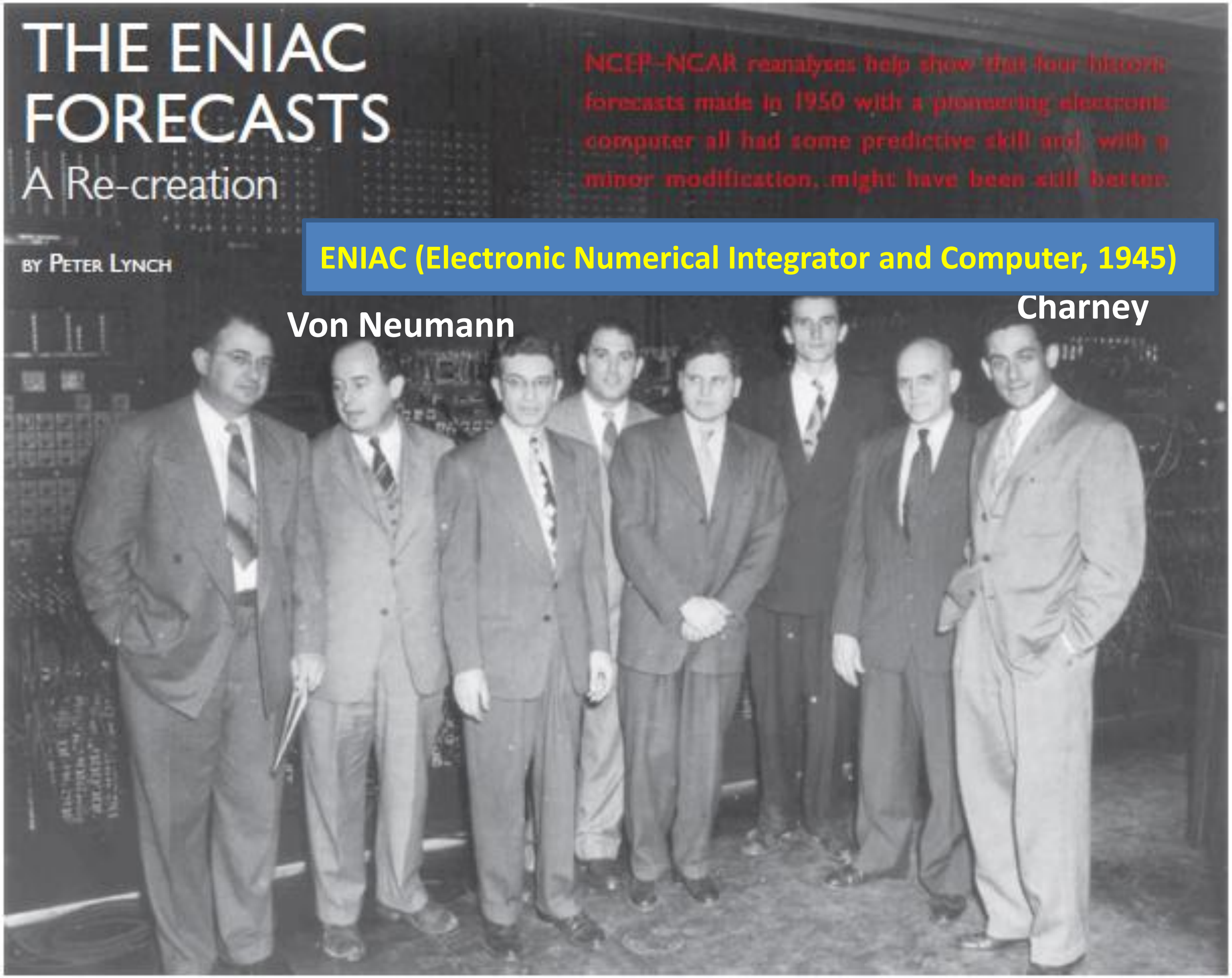
Reading UK, 2018

https://gmd.copernicus.org/articles/18/1879/2025/

Outline

- The gap in extreme Precipitation forecast
- Role of Model physics in NWP and extreme precipitation forecast
- A new IITM Global high-resolution model (km-scale~ 6.5 km over global tropics)
- Mesoscale feature in IITM HGFM
- Summary

Numerical modeling of the atmosphere: In retrospect



Lynch, 2008, BAMS

Visitors and some participants in the 1950 ENIAC computations. (left to right) Harry Wexler, John von Neumann, M. H. Frankel, Jerome Namias, John Freeman, Ragnar Fjørtoft, Francis Reichelderfer, and Jule Charney. (Provided by MIT Museum.)

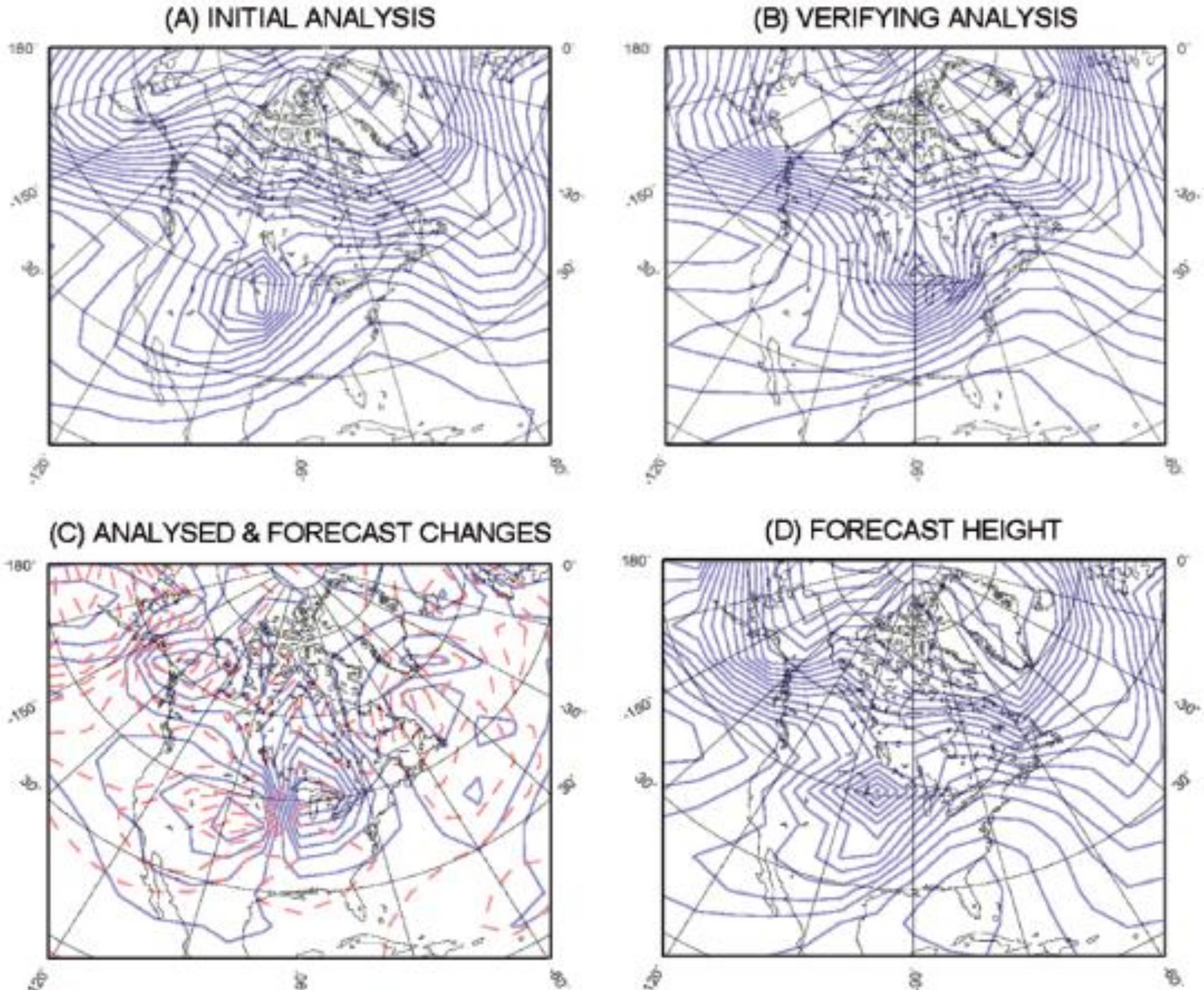
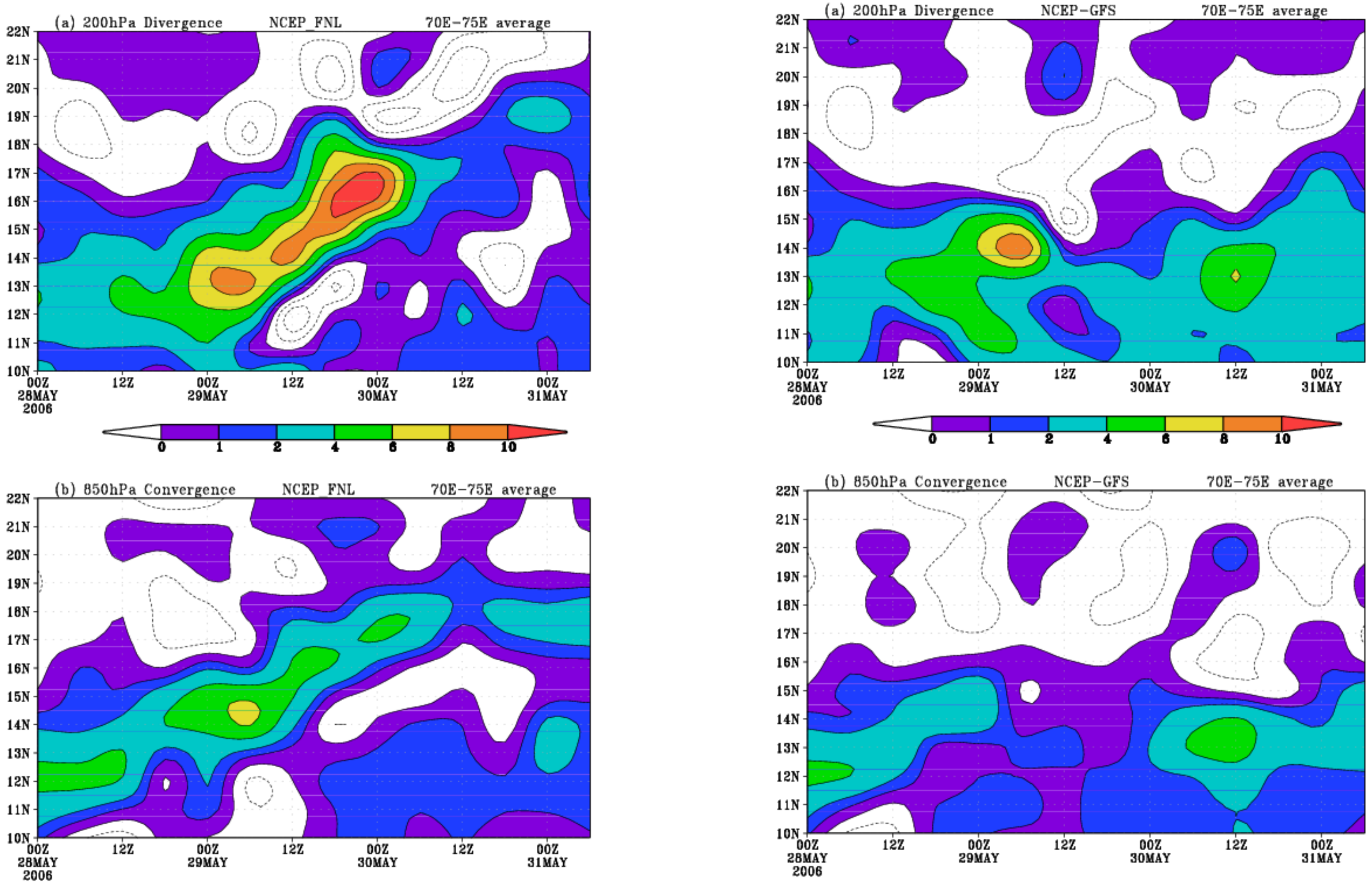


Fig. 4. Reconstructed forecast for 5 Jan 1949: (a) analysis of 500-hPa geopotential height (thick lines) for 0300 UTC 5 Jan, (b) analysis for 0300 UTC 6 Jan, (c) observed change (solid) and forecast change (dashed), and (d) forecast height valid at 0300 UTC 6 Jan. Height contour interval is 50 m.

The spatial and temporal structure of the sub daily movement of convergence zones associated with onset of monsoon 2006 is revealed based on the higher resolution NCEP GFS analyses and forecasts (28-31 May 2006)

Taraphdar et al. 2009

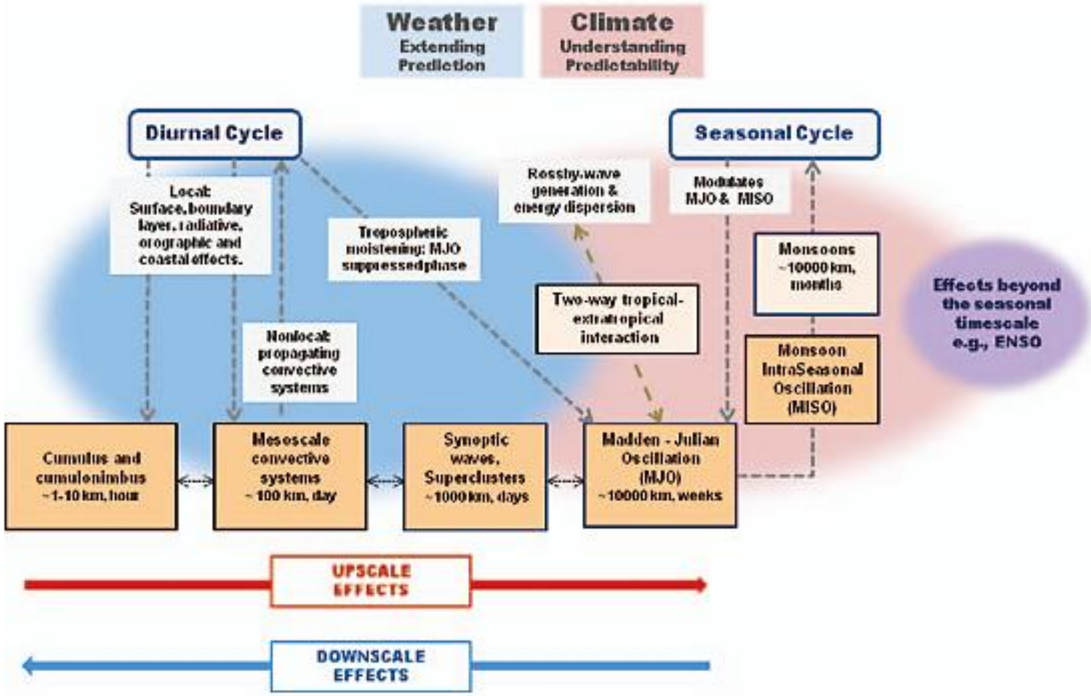
ANALYSES | FORECASTS

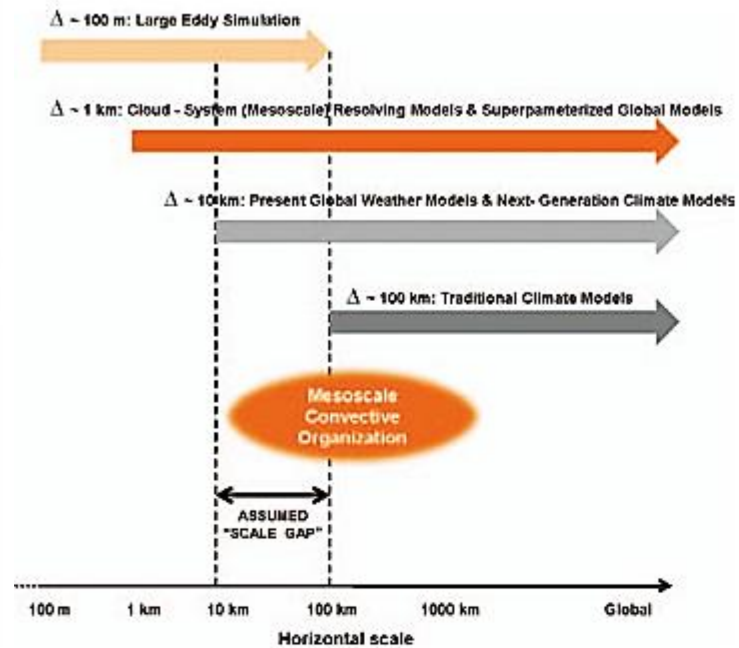


Poor representation of vertical advection of zonal wind in the middle atmosphere leads to misrepresentation of convective processes and thus deteriorates the forecast beyond 24 hour

Moncrieff et al, 2012, BAMS

Scientific Basis of the study





The organized systems exhibit hierarchical coherence: (i) mesoscale systems consist of families of cumulonimbus; (ii) cumulonimbus and MCS are embedded in synoptic waves; and (iii) the MJO/MISO is an envelope of cumulonimbus, MCS, and superclusters.
The upscale effects of convective organization are not represented in traditional climate models.
The mean atmospheric state exerts a strong downscale control on convective structure, frequency, and variability. Mesoscale convective organization bridges the scale gap assumed in traditional convective parameterization.

- **(i) SCM/CRM resolves cumulus, cumulonimbus, mesoscale circulations, but the computational domain is small (~100 km) and simulations short (~1 day).**
- **(ii) Two-dimensional CSRMs in superparameterized global models permit MCS-type organization and mesoscale dynamics.**
- **(iii) High-resolution global numerical prediction models may crudely represent large MCS (superclusters). (iv) MCS, and other mesoscale dynamical systems, are absent from traditional climate models—organized convection is not parameterized.**

Issues identified as Grand challenge by WCRP: on Cloud and convection processes are as follows

WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity

White Paper on WCRP Grand Challenge #4 Sandrine Bony and Bjorn Stevens, Nov, 2012

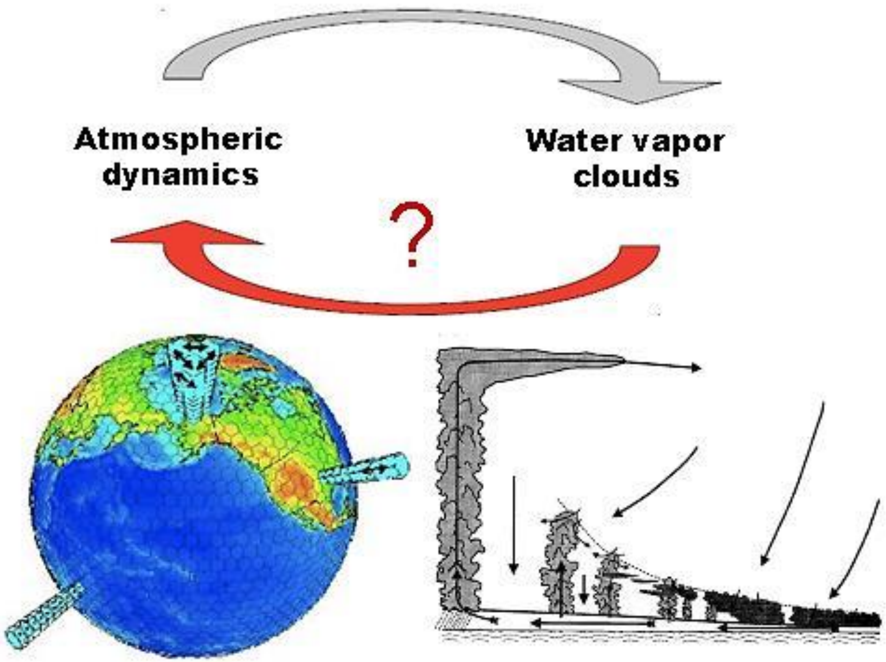
Limited understanding of clouds is the major source of uncertainty in climate sensitivity, but it also contributes substantially to persistent biases in modelled circulation systems.

As one of the main modulators of heating in the atmosphere, clouds control many other aspects of the climate system

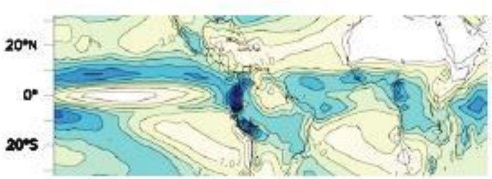
Initiative on coupling clouds to circulation (Dr. Siebesma and Frierson)

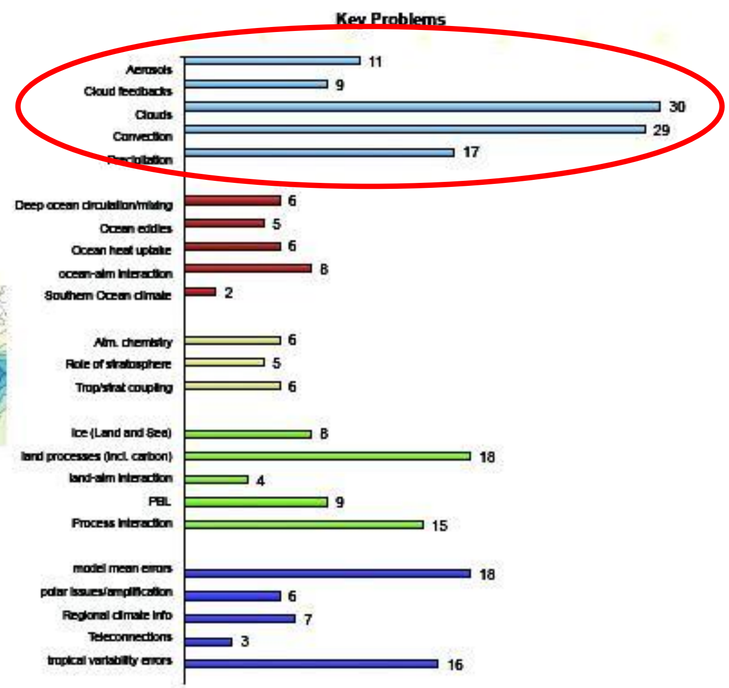
Tackle the parameterization problem through a better understanding of the interaction between cloud / convective processes and circulation system

Lessons from observations and cloud-resolving modelling over large domains; Interaction between diabatic heating and large-scale dynamics.



Source: https://www.wcrp-climate.org/gc-clouds-circulation-activities/gc4-clouds-initiatives/114-gc-clouds-inititative2





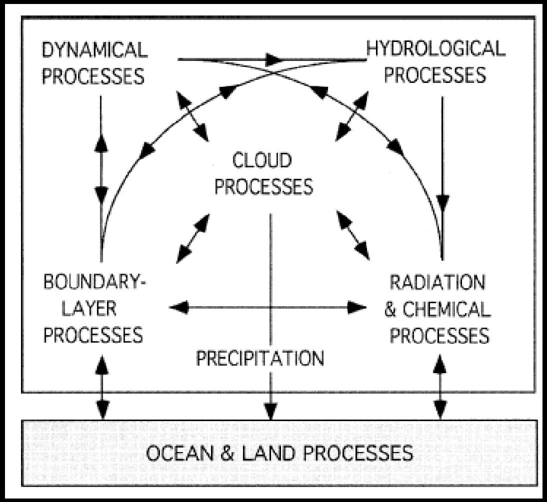
Initiative - towards more reliable models
Led by Dr. Christian Jakob (Monash Univ., Australia) & Masahiro Watanabe (Tokyo Univ., Japan)
Aim: Interpret and reduce model errors to gain confidence in projections and predictions.
Focus: Long-standing model biases (at least a few of them); Understand how model errors or shortcomings impact projections and predictions; Gain physical understanding of the climate system through model development.

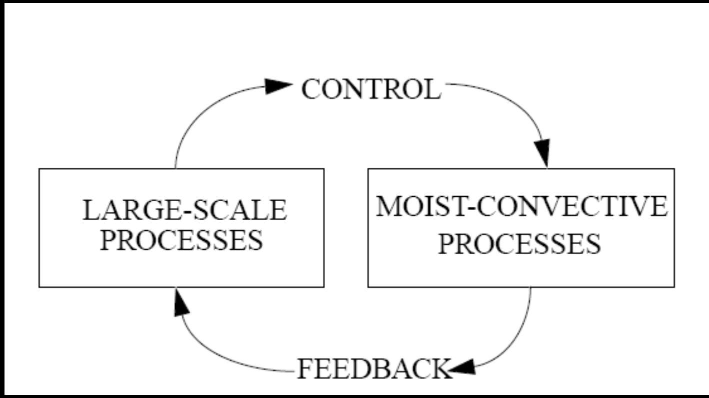
Conventional Paradigm

Issues of cumulus Parameterization

The Cumulus Parameterization Problem: Past, Present, and Future
By Akio Arakawa, JOC, 2004, Arakawa et al. 2011, Arakawa and Wu 2013, Wu and Arakawa 2014

- "Major practical and conceptual problems in the conventional approach of cumulus parameterization, includes inappropriate separations of processes and scales".





$$\sum_{j=1}^{N} K_{ij} \cdot M_{Bj} + F_i = 0$$

K_{ij} = effect of cloud j on cloud i,

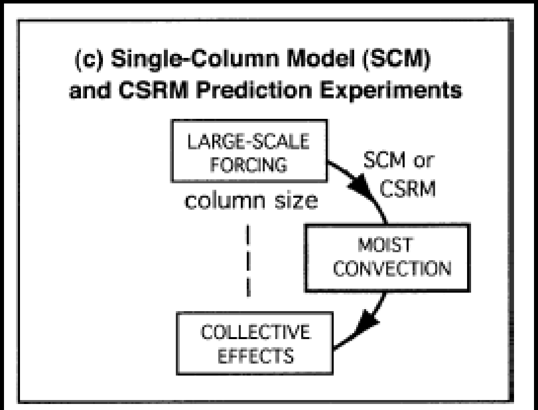
F_i = environmental forcing for

cloud i

M_{Bj} = mass flux at base of cloud j

Task of Conv. Param

To calculate the collective effects of an ensemble of convective clouds in a model column



$$Q_{1C} \equiv Q_1 - Q_R \equiv L(\bar{c} - \bar{e}) - \frac{\partial \overline{\omega' s'}}{\partial p}$$

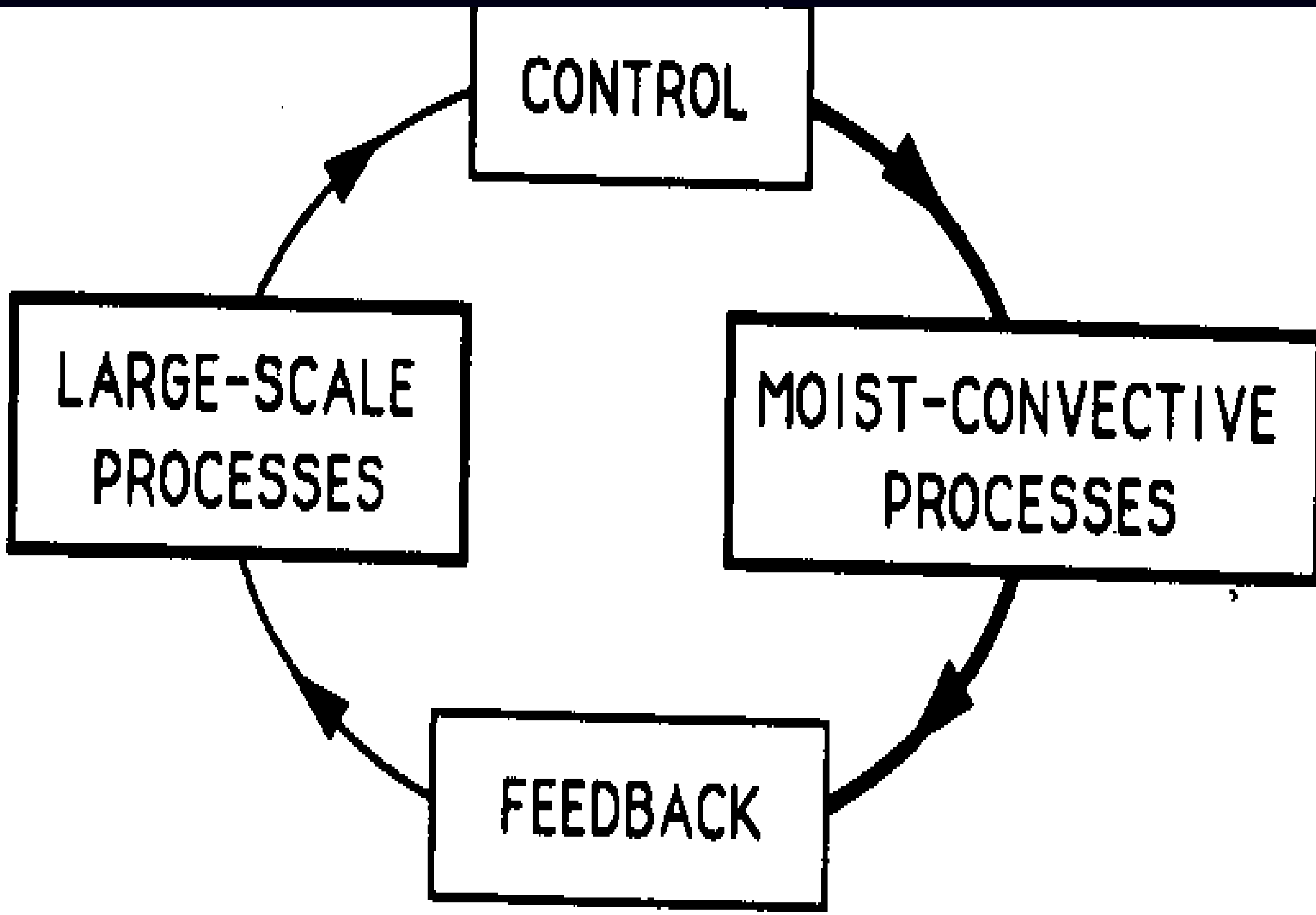


FIG. 1.1. A schematic figure showing the interaction between large-scale and moist-convective processes.

Arakawa, Met. Mono. No.46, 1993

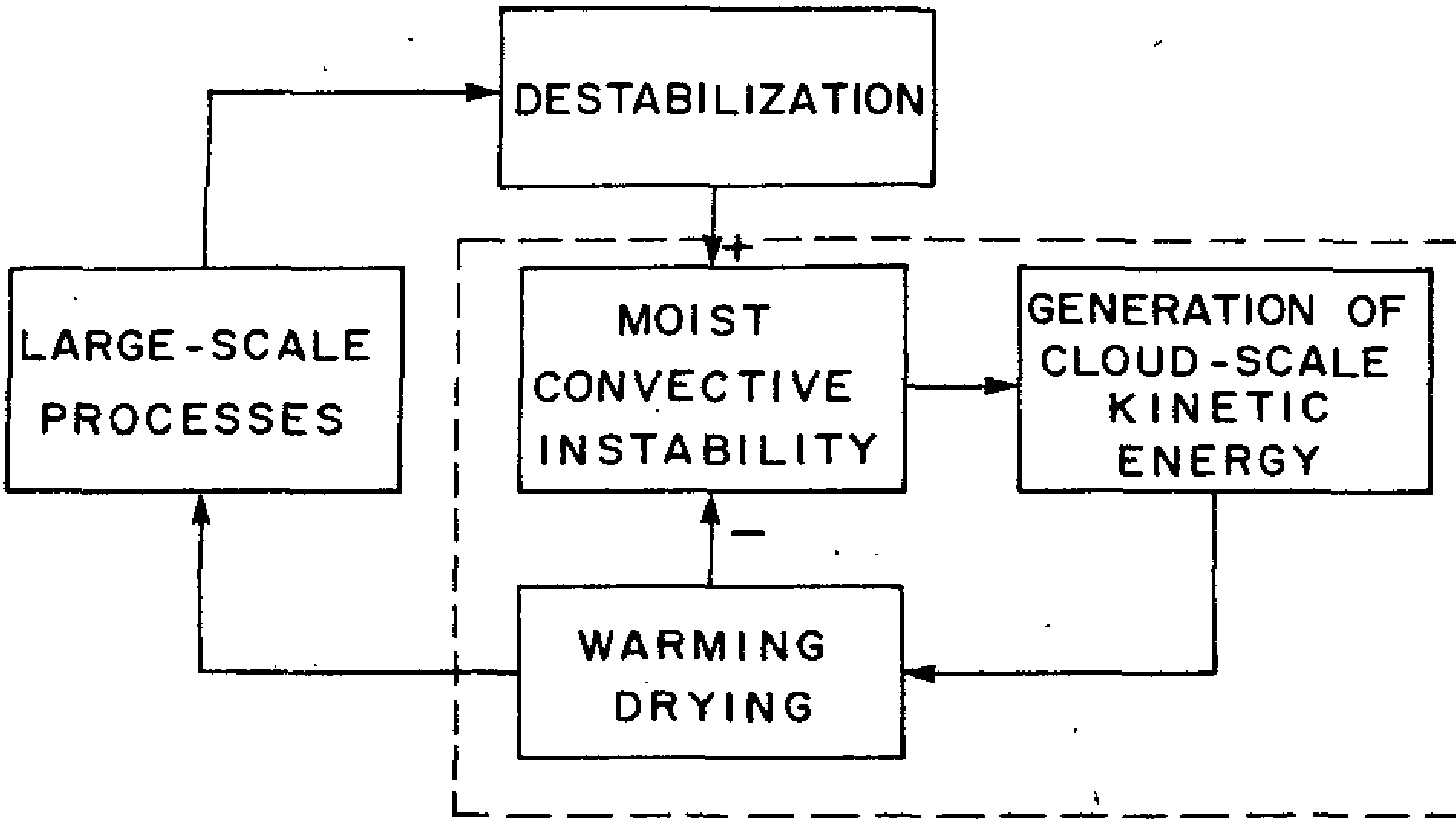


FIG. 1. A schematic diagram of the Arakawa-Schubert closure assumption. The dashed box represents the cumulus parameterization.

Table 2 Description of Convective and Large-scale parameterization, Convective triggers and Convective closures.
From: Pathak et al. 2019 [Precipitation Biases in CMIP5 Models over the South Asian Region]

Models	Convective precipitation	Large-scale precipitation	Convective Trigger	Convective Closure
Cloud Model Type: Spectral Cloud Ensemble				
GFDL-CM3	Relaxed Arakawa–Schubert scheme of Moorthiand Suarez [1992] with few modifications in physics from Donner *et al*. [2011]	Cloud microphysics of Rotstayn [2000] and macrophysics from Tiedtke [1993], stratiform clouds from Golaz *et al*. [2011]	Cloud work function (CWF) similar to dilute cape (DCAPE)	CAPE closure towards a threshold over a relaxation time scale
GFDL-ESM2G	Relaxed Arakawa–Schubert scheme of Moorthiand Suarez [1992] and Dunne *et al*. [2012 and 2013]	Same as GFDL-CM3	Cloud work function (CWF) similar to DCAPE	CAPE closure towards a threshold over a relaxation time scale
GFDL-ESM2M	Same as GFDL-ESM2G	Same as GFDL-CM3	Cloud work function (CWF) similar to DCAPE	CAPE closure towards a threshold over a relaxation time scale
MIROC5	Entraining plume model scheme of Chikira *et al*. [2010] similar to Gregory [2001] with some modification according Pan and Randall [1998]	Prognostic large-scale cloud scheme of Watanabe *et al*. [2009] and bulk microphysical scheme from Wilson and Ballard [1999]	CAPE	Prognostic convective kinetic energy closure similar to CAPE closure
MIROC4h	Prognostic closure Arakawa Schubert scheme from Pan and Randall [1998] and addition of relativehumidity-based suppression condition by Emori *et al*. [2001]	Prognostic cloud water scheme of Treutand Li [1991]	Relative humidity	Prognostic convective kinetic energy closure similar to CAPE closure
MIROC-ESM	Same as MIROC4h	Large-scale condensation is diagnosed based on Treut& Li (1991) and simple cloud microphysics scheme	Relative humidity	Prognostic convective kinetic energy closure similar to CAPE closure
MIROC-ESM-CHEM	Same as MIROC4h	Same as MIROC-ESM	Relative humidity	Prognostic convective kinetic energy closure similar to CAPE closure

Common issue in most CMIP model

Model Description	CFSv2 T126	CFSv2T382
Truncation	126	382
Convective Parameterization	Simplified Arakawa Schubert (Pan and Wu, 1995)	Simplified Arakawa Schubert (Pan and Wu, 1995)

The tropical atmosphere does not obey CQE on temporal scales of day and shorter (Zhang, 2003)

<u>Convective quasi-equilibrium (CQE)</u>

$$\frac{\partial CAPE}{\partial t} = \left(\frac{\partial CAPE}{\partial t}\right)_{\mathrm{largescale}} + \left(\frac{\partial CAPE}{\partial t}\right)_{\mathrm{convection}}$$

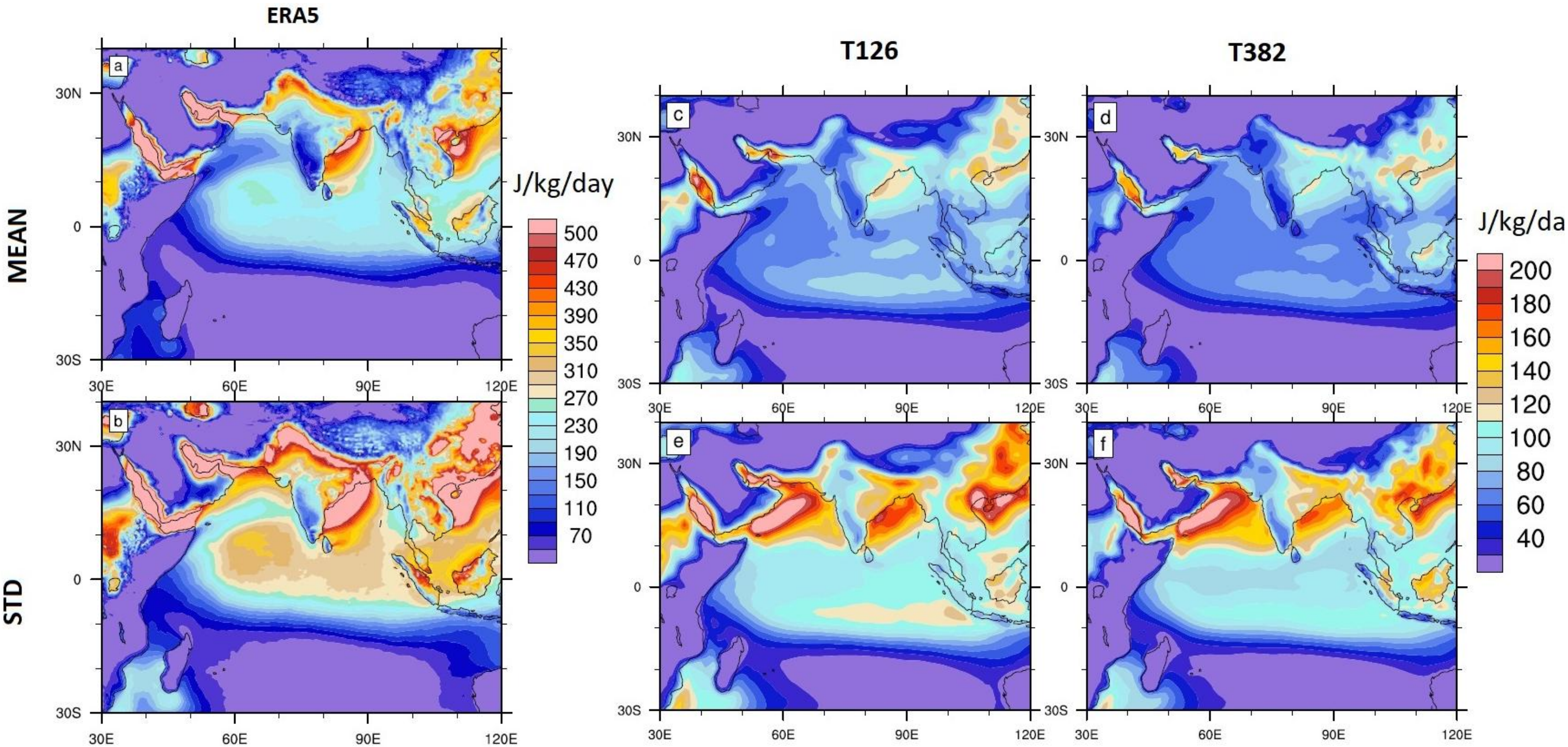
$$\left(\frac{\partial CAPE}{\partial t}\right)_{\mathrm{largescale}} \approx -\left(\frac{\partial CAPE}{\partial t}\right)_{\mathrm{convection}}$$

$$dCAPE$$

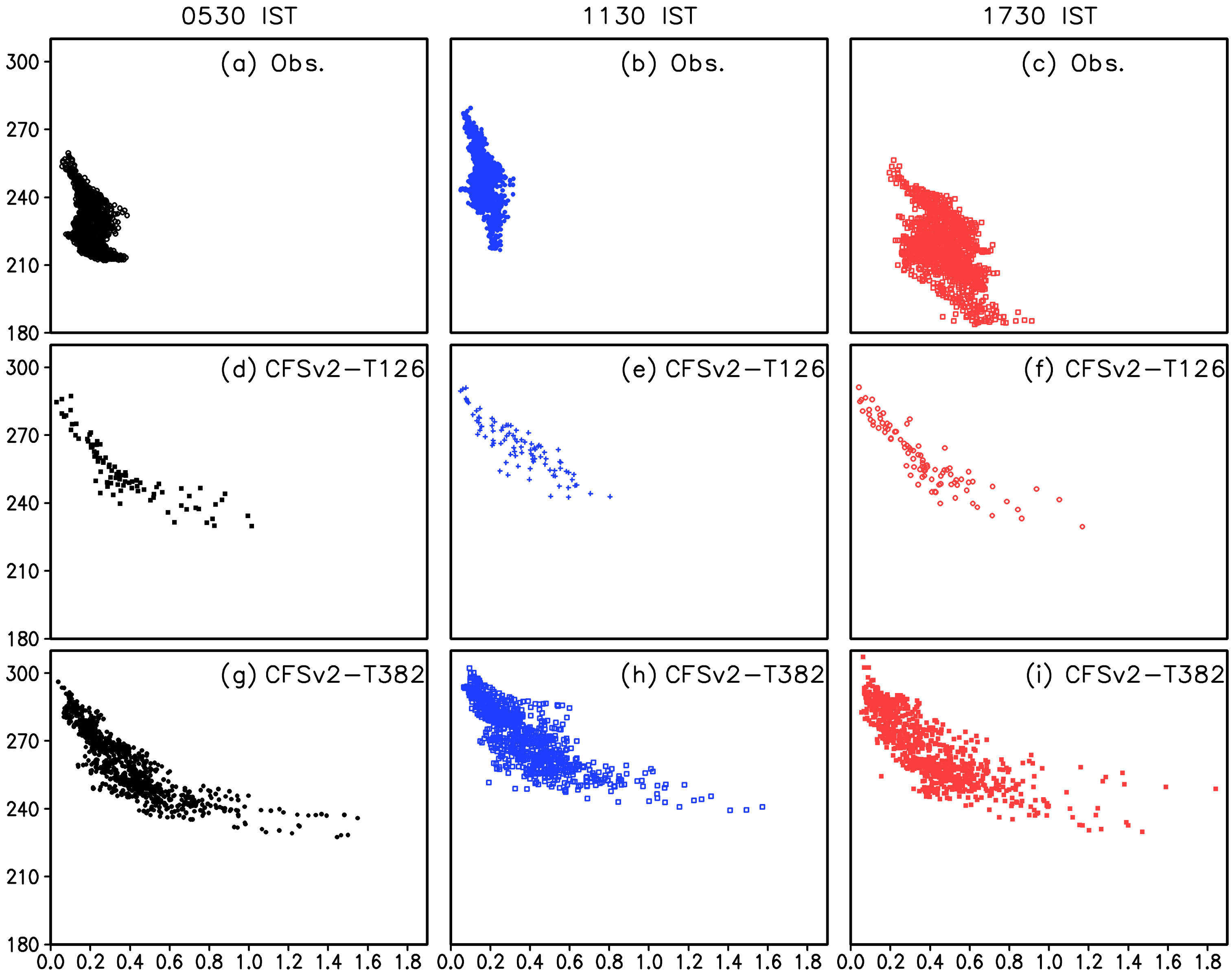
$$= CAPE(\text{ at time t} + 1) - CAPE(\text{ at time t}) \left[\frac{J}{kgday}\right]$$

Arakawa and Schubert, 1974

Convective quasi-equilibrium in CFSv2 models



Siddharth et al. GRL, 2022



Scatter plot of OLR vs rainrate

Both the model produces shallow convection throughout the day consistent with too much of lighter precipitation

Ganai et al. 2015

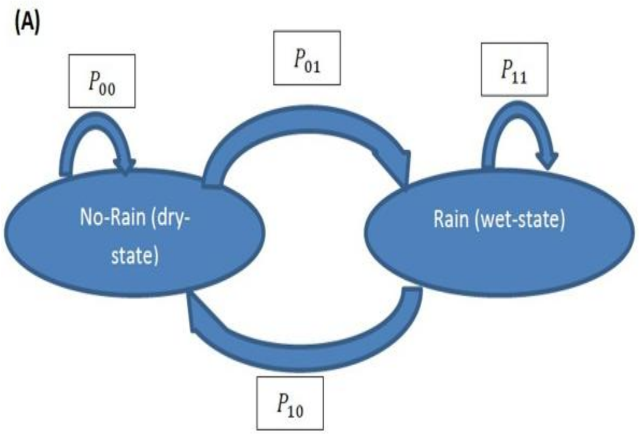
Model has the tendency to remain in wet state

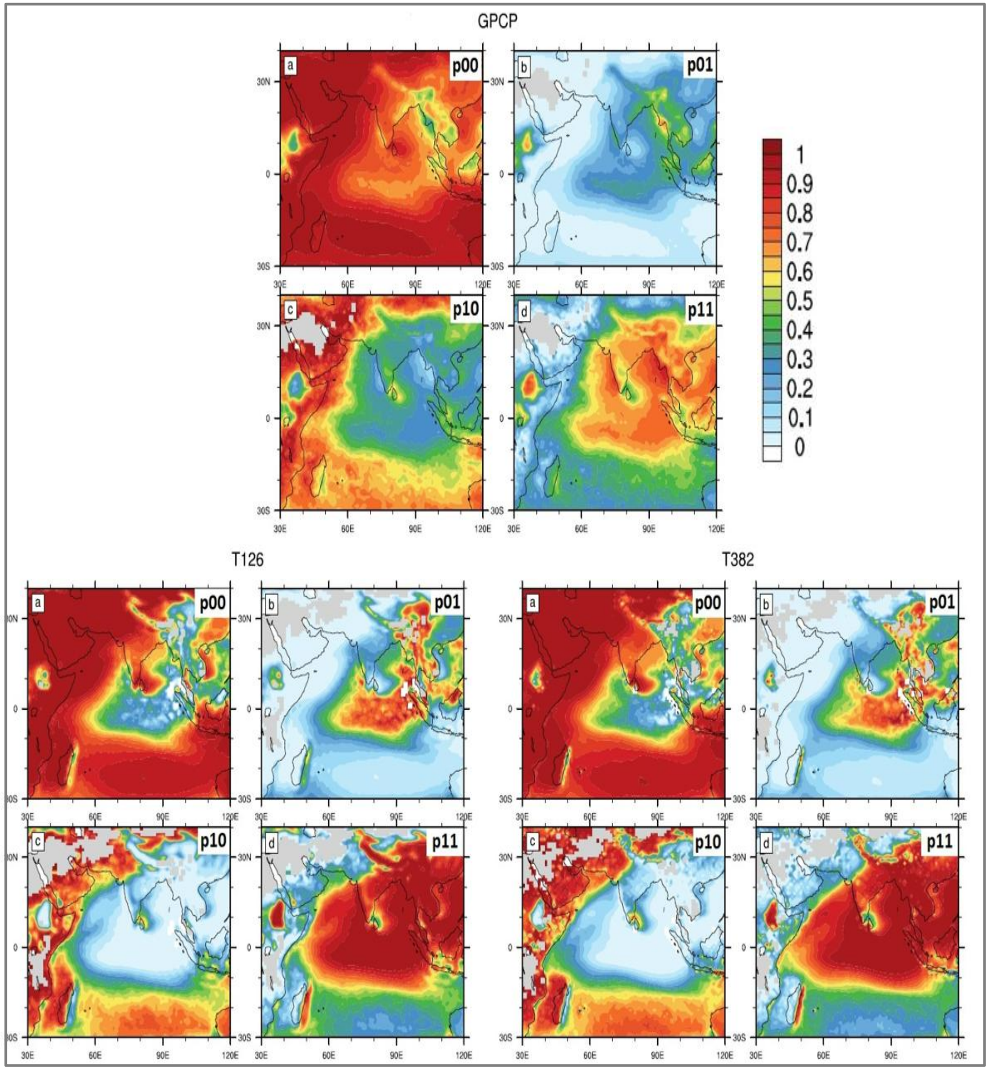
Rainfall is modelled as discrete time Markov chain

Rainy: if rain >2.5 mm/day

Transition probability

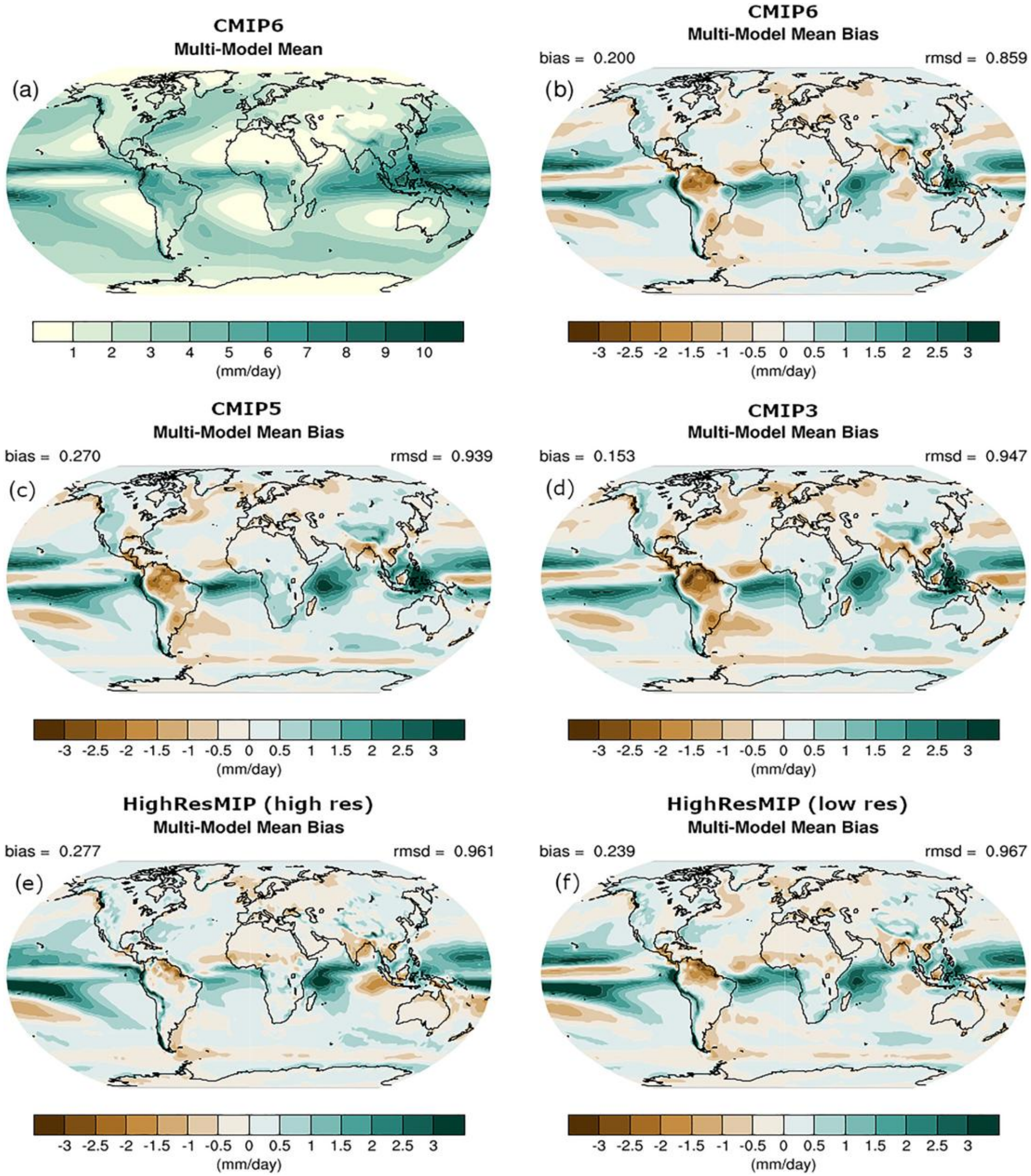
$p_{ij} = P(X_{t+1} = j \mid X_t = i)$
$\{i, j\} \in \{0,1\}$





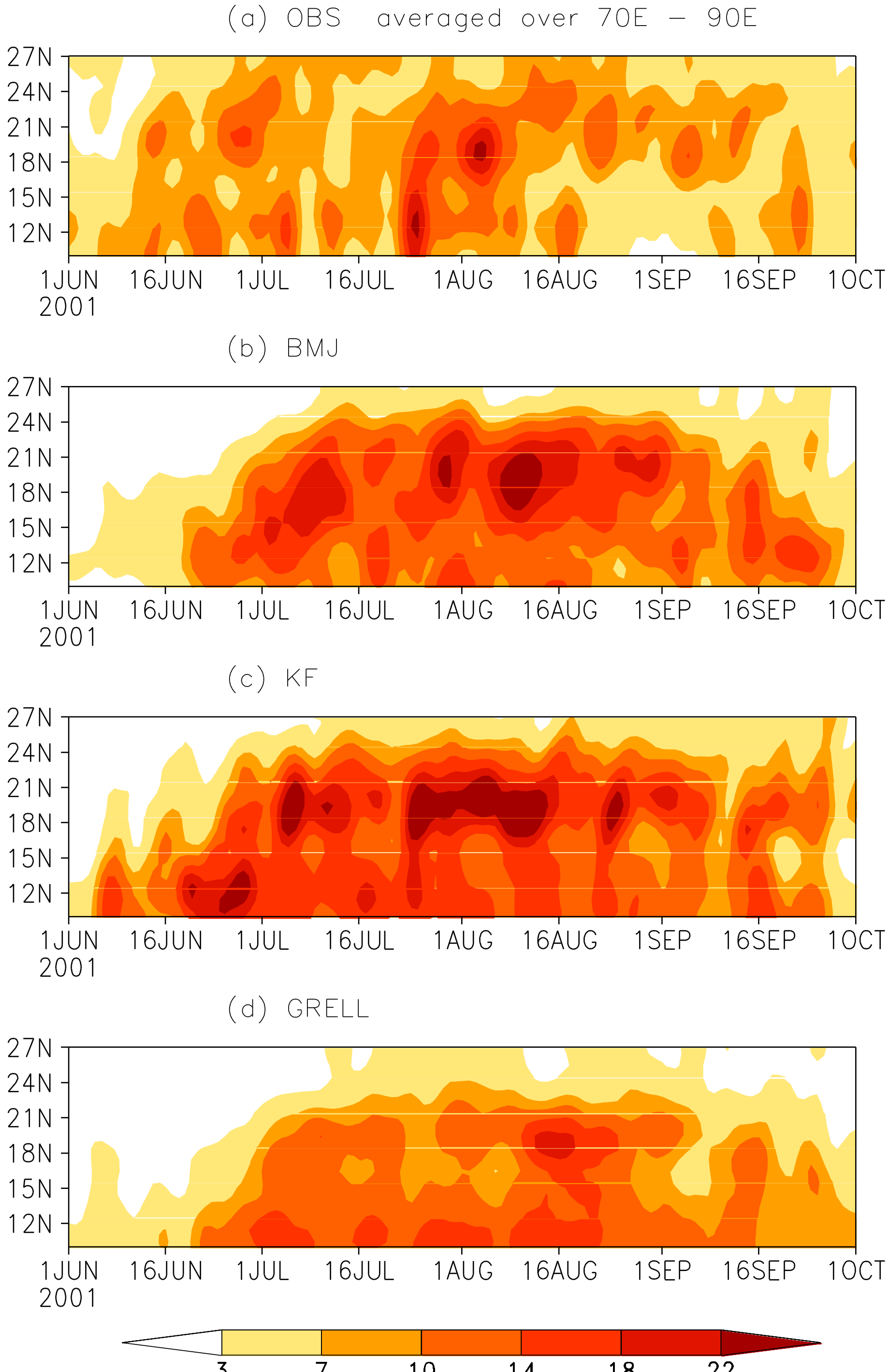
Transition probabilities

Courtesy: Siddharth et al. 2022, GRL



Annual mean precipitation rate (mm day^{-1}). Data from the Global Precipitation Climatology Project (GPCP) Version 2.3 (Adler et al., 2003) are used as a reference.

Bock, L., Lauer, A., Schlund, M., Barreiro, M., Bellouin, N., Jones, C., et al. (2020). Quantifying progress across different CMIP phases with the ESMValTool. Journal of Geophysical Research: Atmospheres, 125, e2019JD032321. https://doi.org/10.1029/2019JD032321



Time Latitude Hovmöller diagram of rainfall in JJAS 2001-2007 over Indian Region from Observation, BMJ, KF and GRELL averaged between 70^{0}E-90^{0}E, hor. Res. 15km with WRF

Mukhopadhyay et al. 2010, WAF

System used: NIMBUS Cluster

JAMES | Journal of Advances in Modeling Earth Systems*

RESEARCH ARTICLE
10.1029/2024MS004315

Key Points:

- A new convective closure is applied to Geophysical Fluid Dynamics Laboratory's CMIP6 climate models AM4 (atmosphere-only) and CM4 (ocean-atmosphere coupled)
- The diurnal cycle of precipitation is significantly improved over land
- The new closure does not significantly change many aspects of AM4 and CM4's mean state and variability aside from their diurnal precipitation cycles

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Citation:
Zhang, B., Donner, L. J., Zhao, M., & Tan, Z. (2024). Improved precipitation diurnal cycle in GFDL climate models with non-equilibrium convection. *Journal of Advances in Modeling Earth Systems*, *16*, e2024MS004315. https://doi.org/10.1029/2024MS004315

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Improved Precipitation Diurnal Cycle in GFDL Climate Models With Non-Equilibrium Convection

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Abstract Most global climate models with convective parameterization have trouble in simulating the observed diurnal cycle of convection. Maximum precipitation usually happens too early during summertime, especially over land. Observational analyses indicate that deep convection over land cannot keep pace with rapid variations in convective available potential energy, which is largely controlled by boundary-layer forcing. In this study, a new convective closure in which shallow and deep convection interact strongly, out of equilibrium, is implemented in atmosphere-only and ocean-atmosphere coupled models. The diurnal cycles of convection in both simulations are significantly improved with small changes to their mean states. The new closure shifts maximum precipitation over land later by about three hours. Compared to satellite observations, the diurnal phase biases are reduced by half. Shallow convection to some extent equilibrates rapid changes in the boundary layer at subdiurnal time scales. Relaxed quasi-equilibrium for convective available potential energy holds in significant measure as a result. Future model improvement will focus on the remaining biases in the diurnal cycle, which may be further reduced by including stochastic entrainment and cold pools.

Plain Language Summary In this study, we tackled a common challenge in general circulation models concerning the timing of intense rainfall over land during summertime. Many models tend to predict the peak of precipitation too early in the day. To address this, our study introduced a new approach to simulate convection by accounting for the role of shallow convection in stabilizing rapid changes in the atmospheric boundary layer at shorter time scales. This approach delayed maximum precipitation over land by approximately three hours. This adjustment significantly improved the simulated precipitation, aligning them

$$\left(\frac{\partial CAPE}{\partial t}\right) = \left(\frac{\partial CAPE}{\partial t}\right)_{nc,BL} + \left(\frac{\partial CAPE}{\partial t}\right)_{nc,FT} + \left(\frac{\partial CAPE}{\partial t}\right)_{deep} + \left(\frac{\partial CAPE}{\partial t}\right)_{shal} \tag{1}$$

Here, the subscript "nc" refers to all non-convective processes. "BL" refers to changes in the PBL, while changes in the overlying free troposphere are denoted by "FT." These tendencies are easily computed in a model using tendencies from the dynamical core and parameterizations for radiative transfer, surface fluxes, and sub-grid diffusion. The subscripts "deep" and "shal" refer to CAPE changes from deep and shallow convection, respectively.

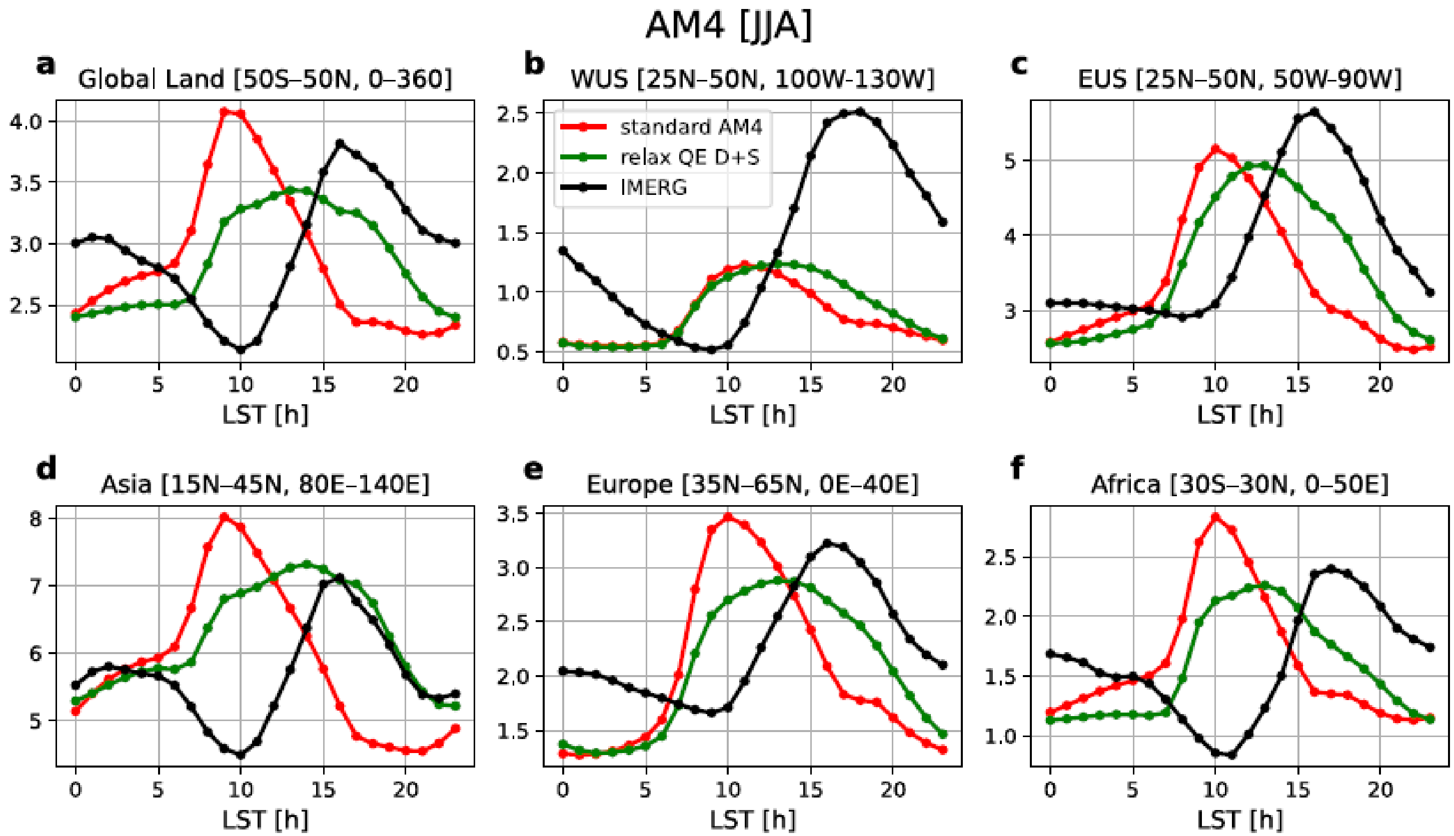
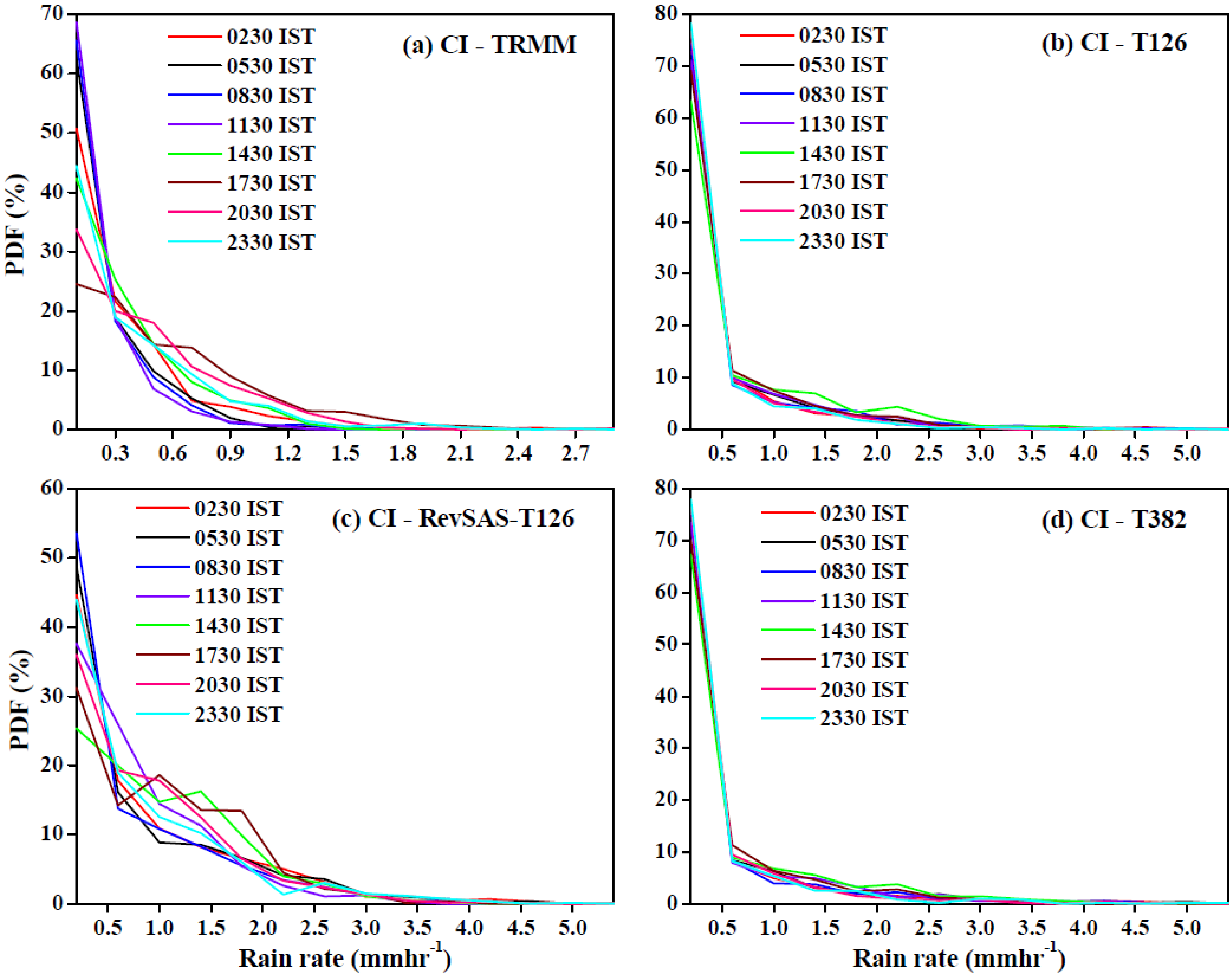


Figure 5. Domain averaged hourly land precipitation (units: mm day^{-1}) averaged from June to August for Standard AM4 (red lines), relax QE D+S (green lines), and IMERG (black lines) over (a) Global Land, (b) Western United States, (c) Eastern United States, (d) Asia, (e) Europe, and (f) Africa.



(a) CI - TRMM
(b) CI - T126
(c) CI - RevSAS-T126
(d) CI - T382
0230 IST
0530 IST
0830 IST
1130 IST
1430 IST
1730 IST
2030 IST
2330 IST
PDF (%)
Rain rate (mmhr^{-1})

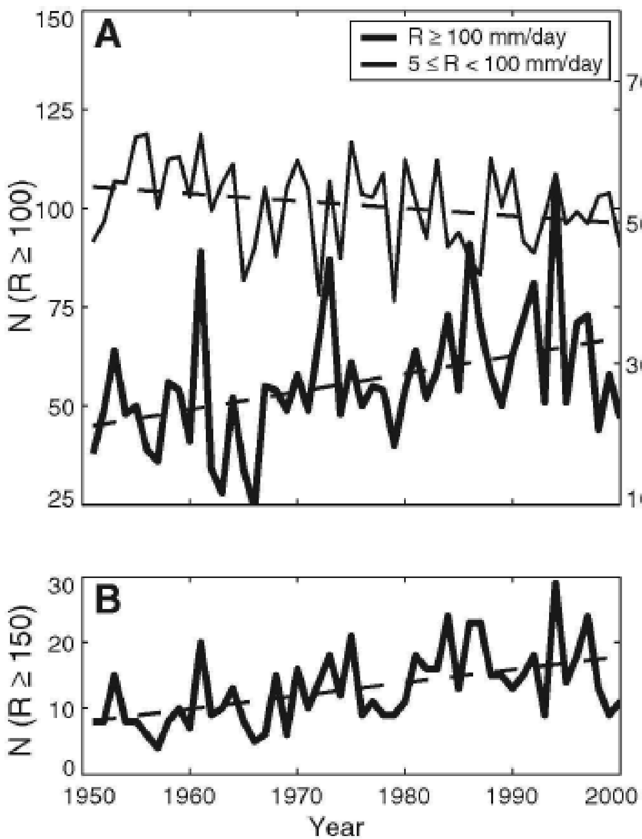
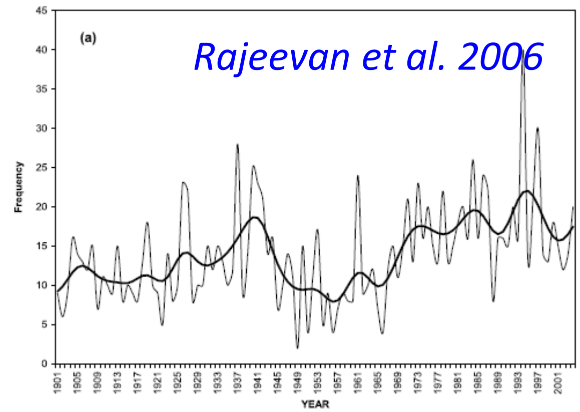
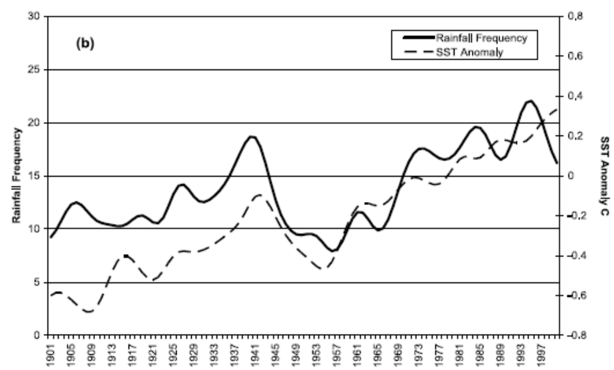


Fig. 3. Temporal variation (1951 to 2000) in the number (N) of (**A**) heavy ($R \geq 100$ mm/day, bold line) and moderate ($5 \leq R < 100$ mm/day, thin line) daily rain events and (**B**) very heavy events ($R \geq 150$ mm/day) during the summer monsoon season over CI. The statistical significance of the trends (dashed lines) was calculated as in Fig. 2.

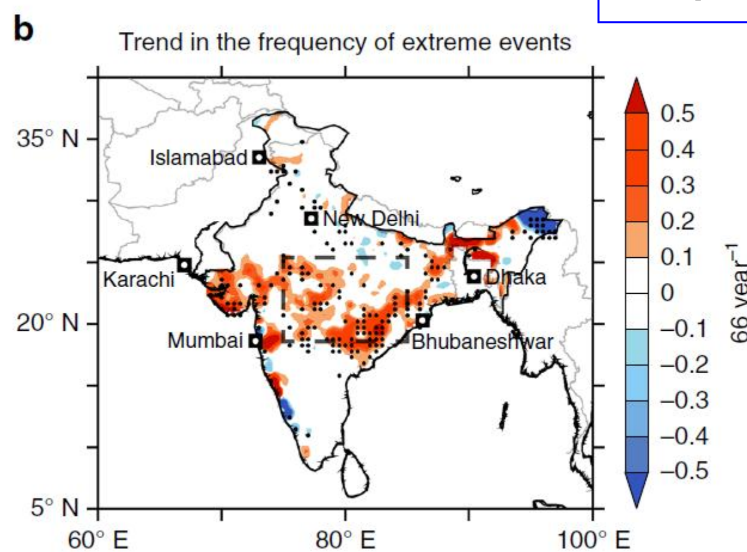
Goswami et al. 2006

Rajeevan et al. 2006





(a) Temporal variation of frequency of very heavy rainfall events (R 150 mm/day) over central India (thin solid line) and its smoothed variation (thick solid line) for the period 1901–2004. (b) Smoothed variation of frequency of very heavy rainfall events over central India and SST anomalies over the Equatorial Indian Ocean. The smoothing has been done to remove the sub-decadal fluctuations using a 13-point filter [IPCC, 2007].



Roxy et al. 2017

npj | climate and atmospheric science

Article

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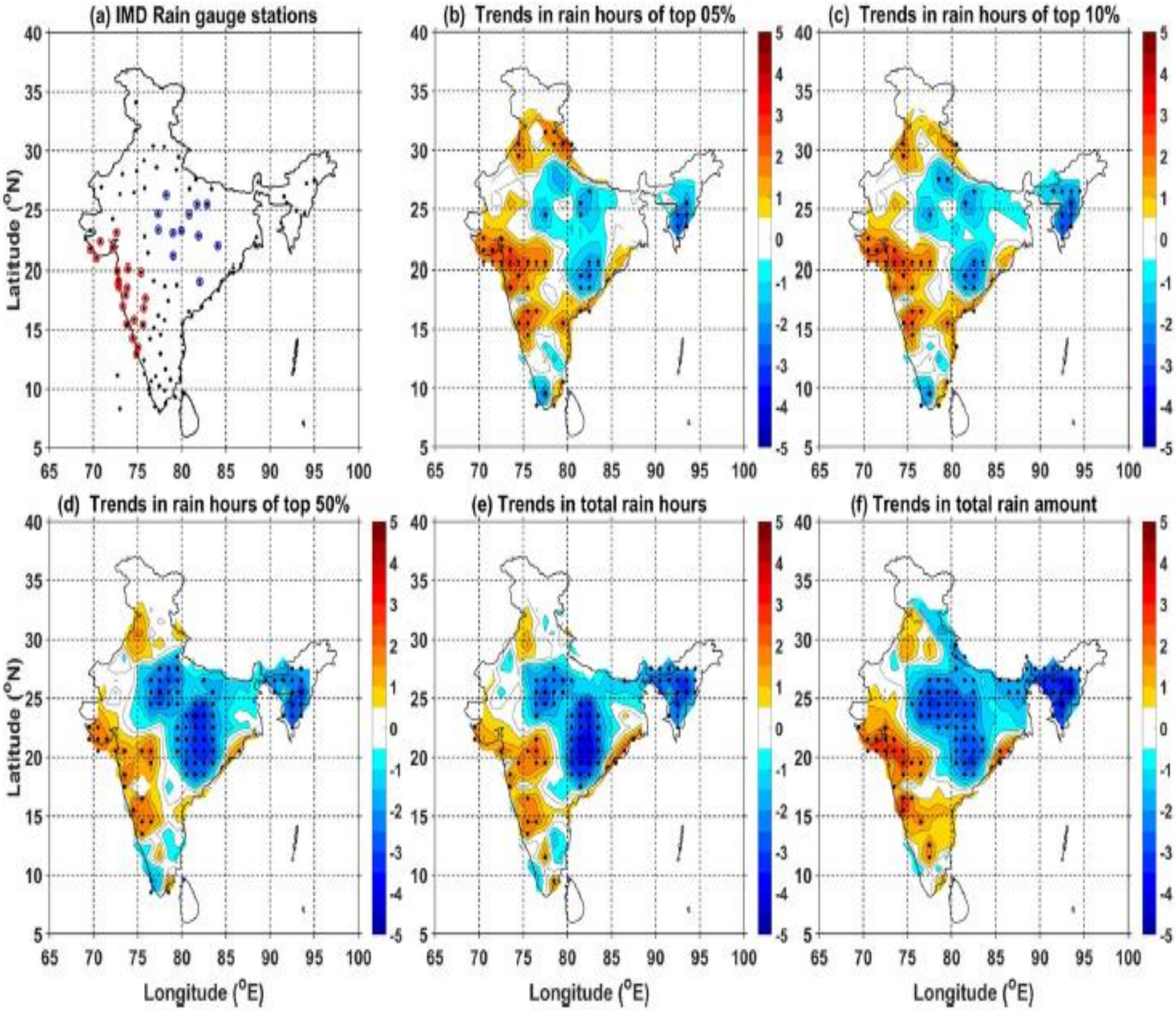
https://doi.org/10.1038/s41612-024-00885-x

Sub-daily scale rainfall extremes in India and incongruity between hourly rain gauges data and CMIP6 models

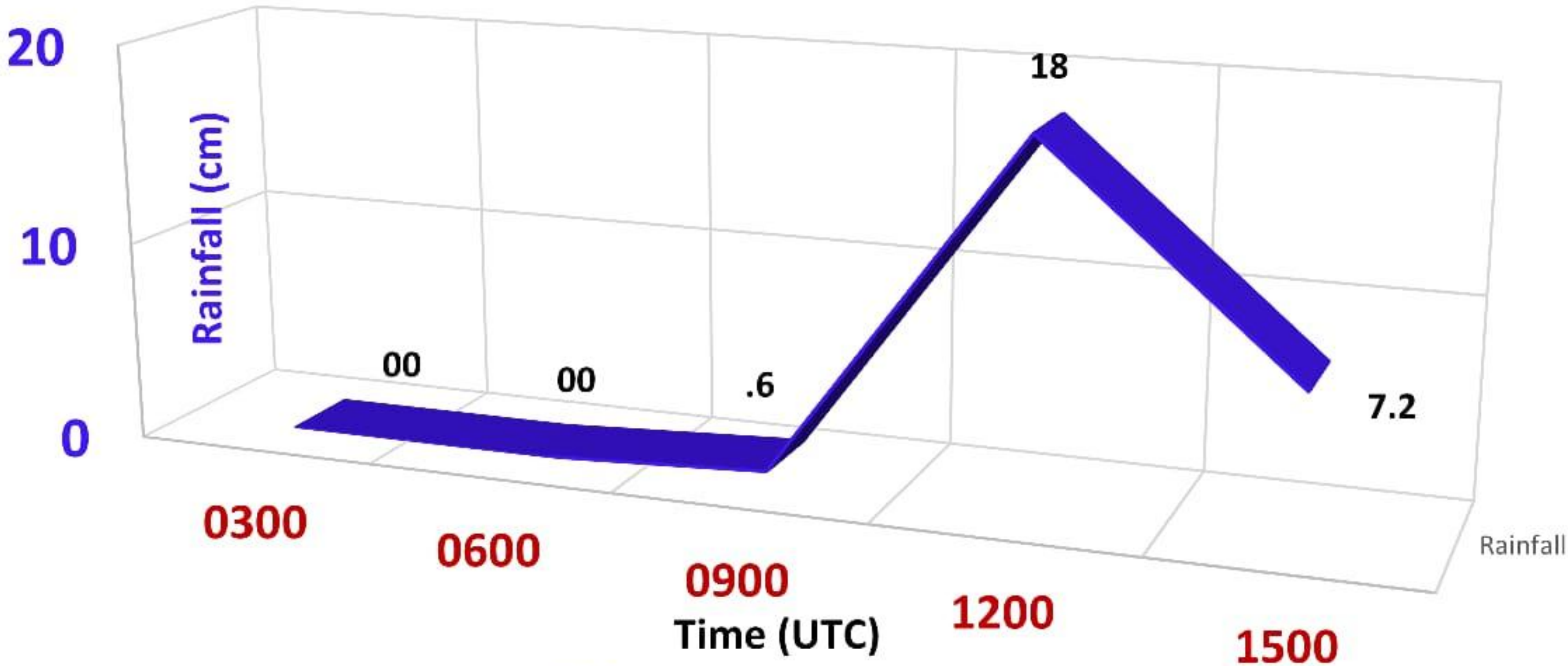
Check for updates

Kadiri Saikranthi[1,4], Basivi Radhakrishna[2,4] & Madhavan Nair Rajeevan[3]

Self-recording rain gauges hourly rainfall data from 1969 to 2010 have been utilized to identify rain events at a sub-daily scale. At the sub-daily scale, a significant decrease in the frequency of heavy rainfall events (HREs) is observed over central India and northeast India, while an increase is observed over the northern west coast of India. Frequency of short-duration HREs over central India and long duration HREs over northern west coast of India is increased in the recent decades than in earlier decades. Incongruity with the observations, CMIP6 historical and AMIP high temporal resolution models are not able to simulate the short-duration HREs and, in turn, the observed trends at a sub-daily scale over the India landmass. The inability of CMIP6 models to predict short-duration HREs suggests caution in predicting future projections of extreme precipitation at a sub-daily scale and highlights the need for further improvements in climate models.

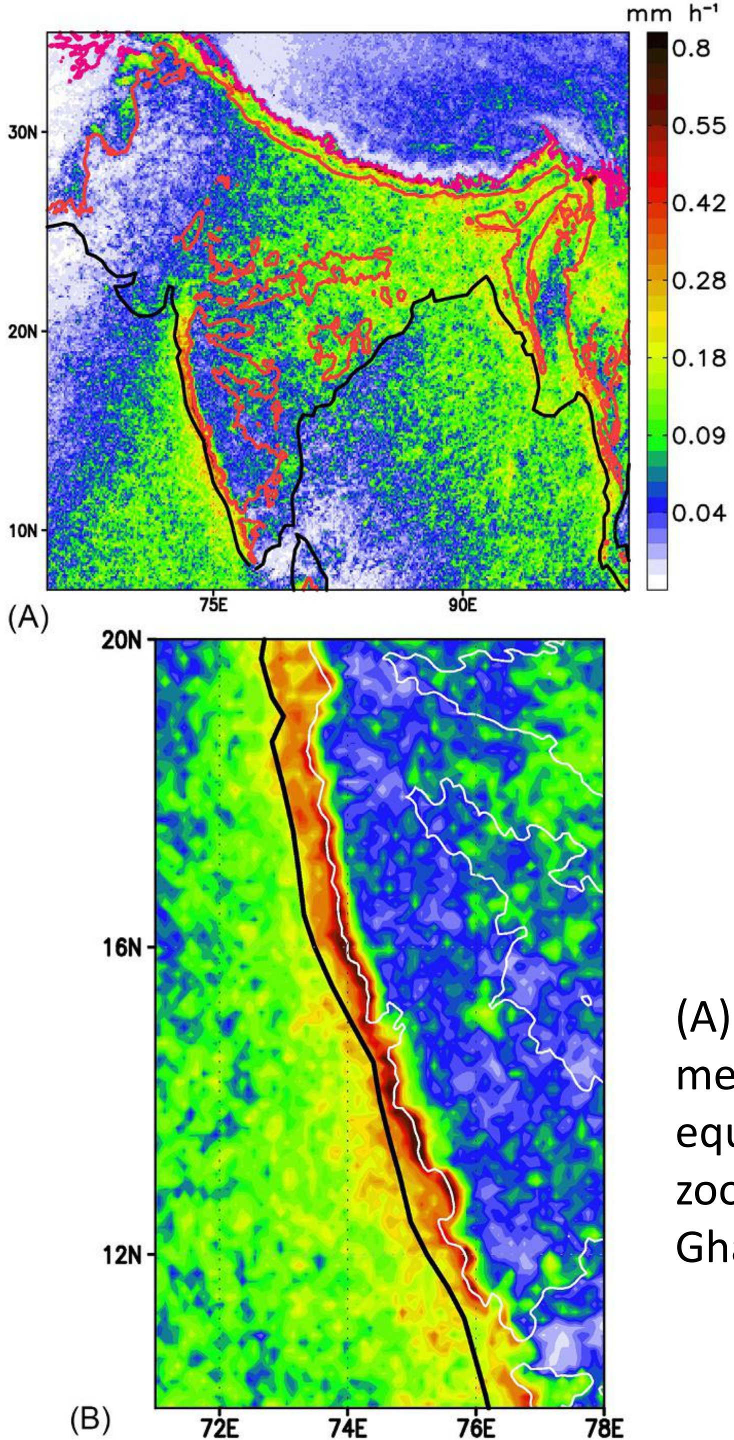


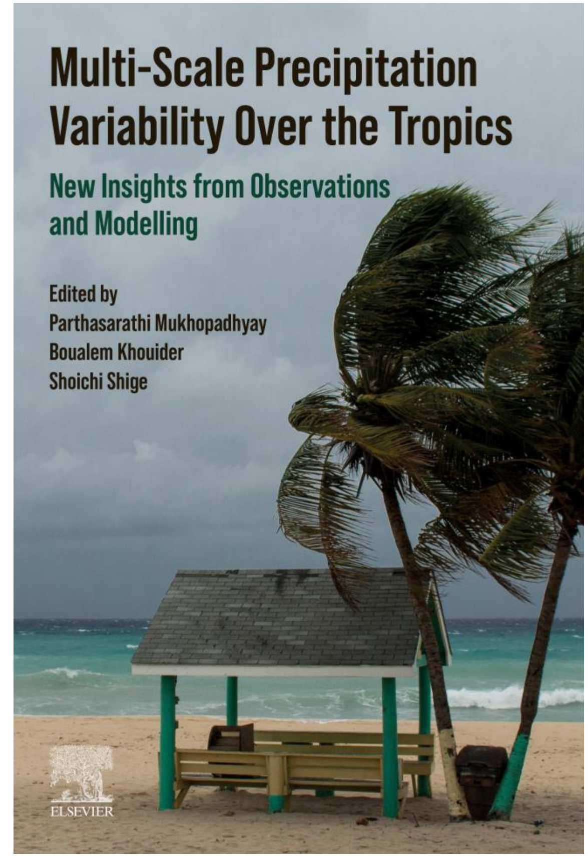
(a) IMD Rain gauge stations
(b) Trends in rain hours of top 05%
(c) Trends in rain hours of top 10%
(d) Trends in rain hours of top 50%
(e) Trends in total rain hours
(f) Trends in total rain amount
Latitude (°N)
Longitude (°E)



N.B. 3hourly Rainfall reported over Bhubaneswar city between 0300 Hrs IST to 1500 Hrs IST of 31st August, 2023

Courtesy: Dr. Umasankar, IMD

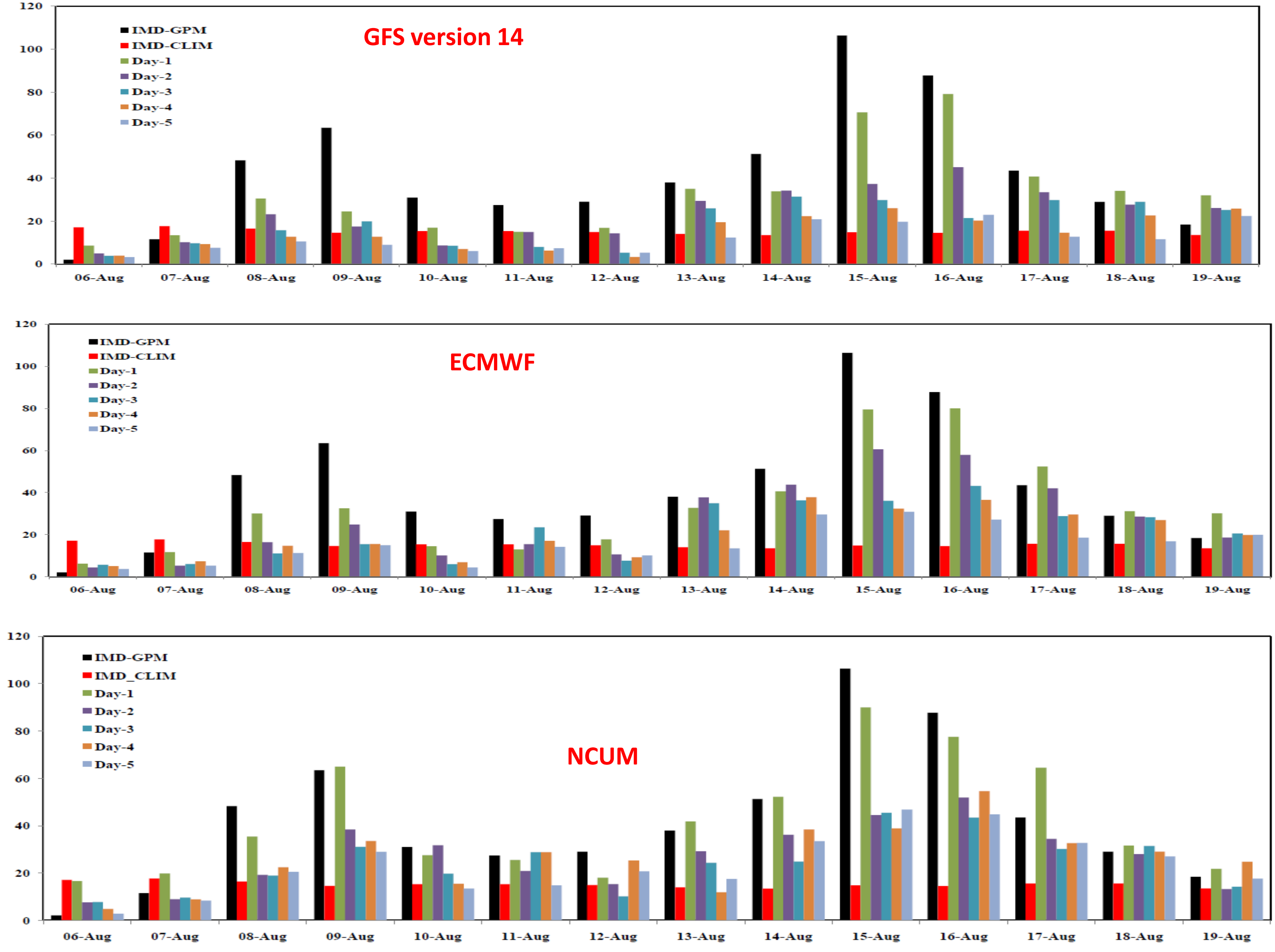




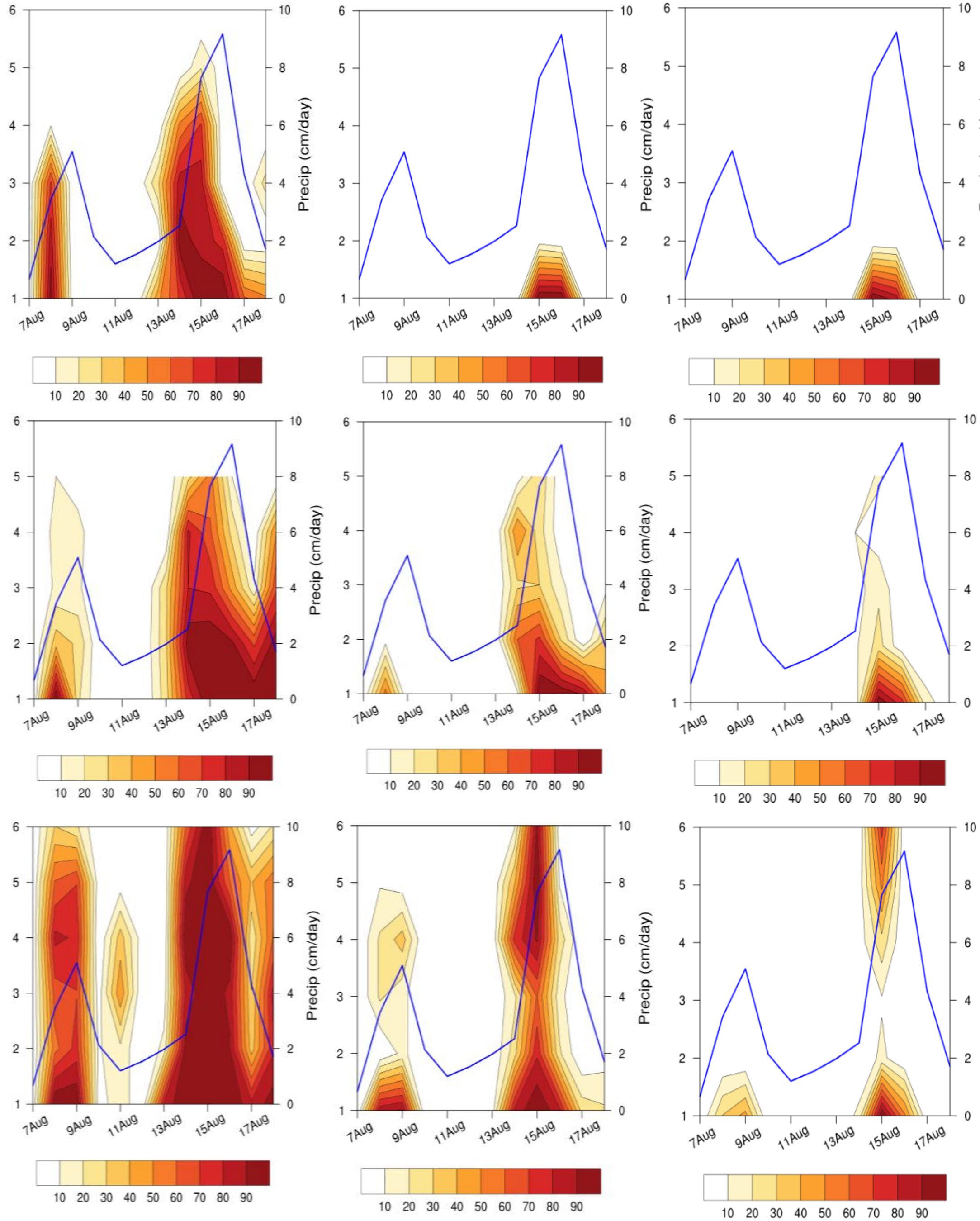
(A) Average precipitation rate (mmh^{-1}) for medium-size precipitation systems (an area-equivalent diameter 10–100km) and (B) zoomed-in view of (A) along the Western Ghats and adjoining region.

Chapter 1: Mahakur, Shige, Hirose

Rainfall (mm/day) time series over Kerala during 06-19Aug, 2018 (Mukhopadhyay et al. 2021, WAF)



August 2018



GEFS

ECMWF

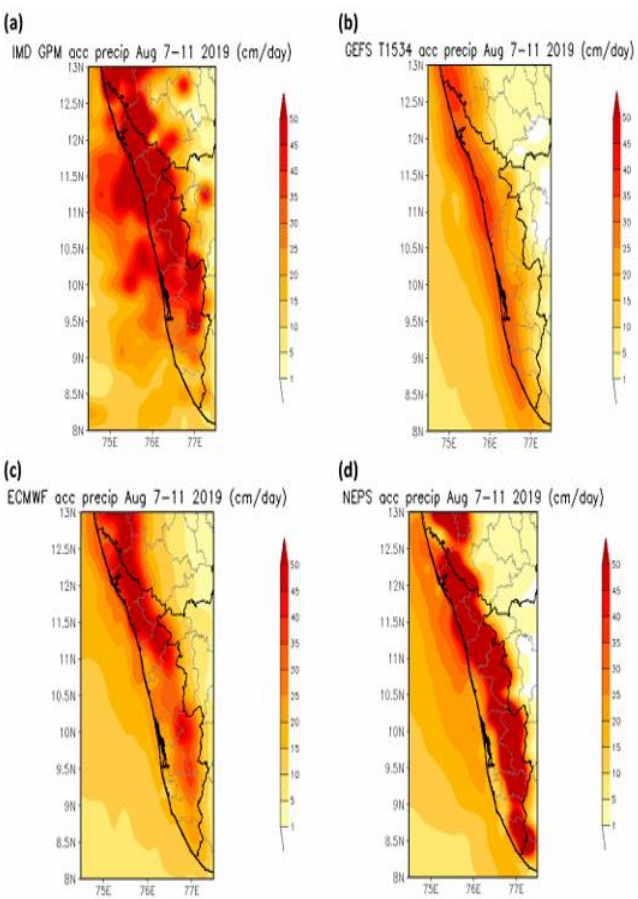
NEPS

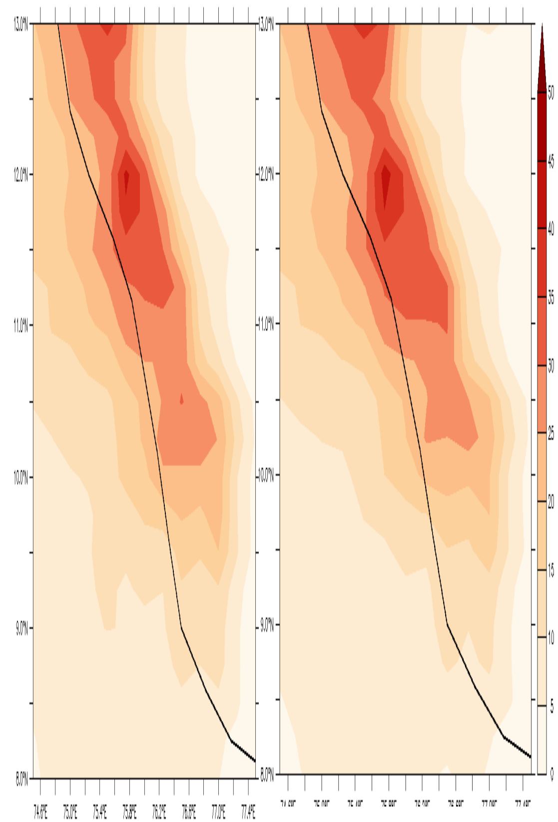
Forecast lead time diagram of the probability (%) from (a)–(c) GEFS, (d)–(f) ECMWF, and (g)–(i) NCUM forecasts for the daily accumulated rain over Kerala (9.58–11.58N, 768–77.58E) exceeding the observed daily climatology (left) plus one standard deviation (SD), (center) two SD, and (right) three SD. The thick blue line represents the IMD-GPM rainfall (cm day^{-1}) averaged for the same region for the period 6–19 Aug 2018. The shading represents probability.

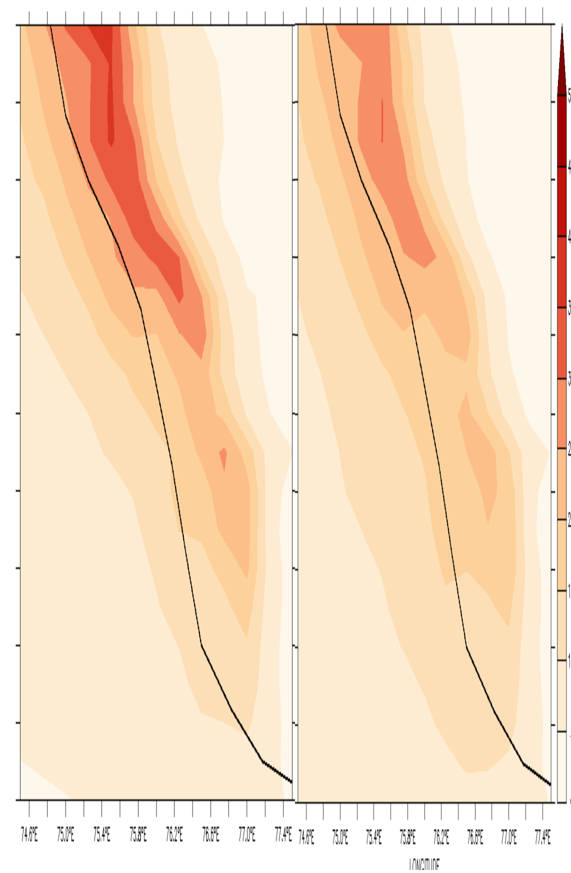
Mukhopadhyay et al. 2021, WAF

Observation, numerical models and AI models intercomparison
Forecastnet-NVIDIA, GraphCast-Google

Courtesy: Manmeet singh, Siddharth kumar et al.







Forecast initiated at 00 hours of Aug 6. (accumulated rain from Aug 7 to Aug 11)

Day 1 and day 2 forecast from Forecastnet model (accumulated rain from Aug 7 to Aug 11)

Day 1 and day 2 forecast from GraphCast model (accumulated rain from Aug 7 to Aug 11)

To do list: extreme prediction

- Location (Where the convection would trigger)
- Time (When the convection would trigger)
- Intensity (Strength of the multi-scale convection/precipitation efficiency)

AMS Journals

Article Type: Research Article

Can a 12 Km GFS model simulate the observed relationship between cloud optical properties and extreme rainfall of Indian Summer monsoon?

Tanmoy Goswami, Parthasarathi Mukhopadhyay, R Phani Murali krishna, M Rajeevan, and Subharthi Chowdhuri

Online Publication: 25 Nov 2024

DOI: https://doi.org/10.1175/WAF-D-24-0010.1

The simulation of associated cloud optical parameters is also poor at all lead times in different parts of India. The model also fails to capture the observed relationship between the frequency of extreme precipitation and deep convective clouds without showing any correlation between them at all lead times.

https://doi.org/10.5194/gmd-2024-89
Preprint. Discussion started: 7 August 2024

Geoscientific Model Development
Discussions
Open Access
EGU

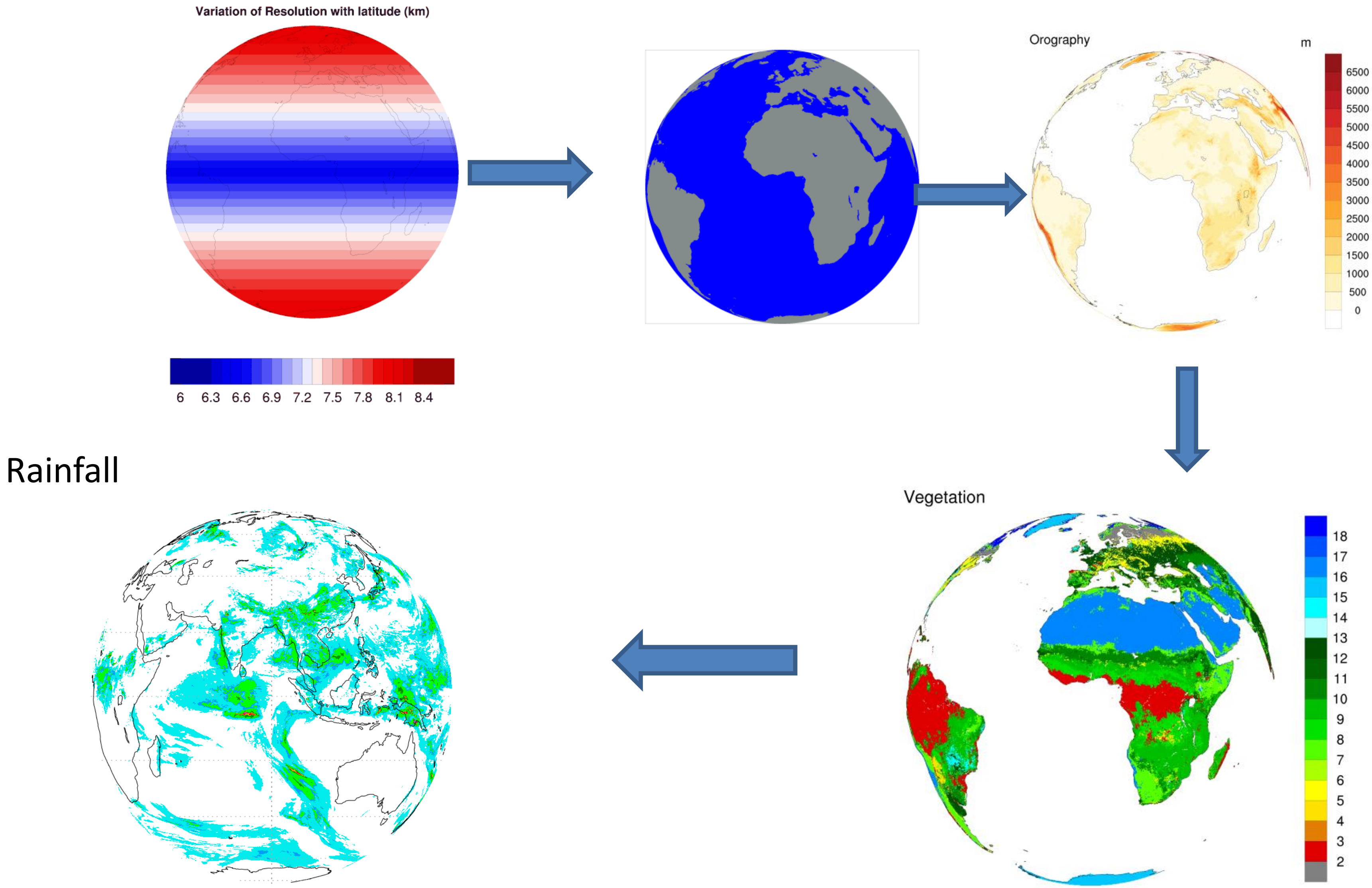
IITM High-Resolution Global Forecast Model Version 1: An attempt to resolve monsoon prediction deadlock

R. Phani Murali Krishna[1], Siddharth Kumar[1], A. Gopinathan Prajeesh[2], Peter Bechtold[3], Nils Wedi[3], Kumar Roy[4], Malay Ganai[1], B. Revanth Reddy[1], Snehlata Tirkey[1], Tanmoy Goswami[1] , Radhika Kanase[1], and Parthasarathi Mukhopadhyay[1]

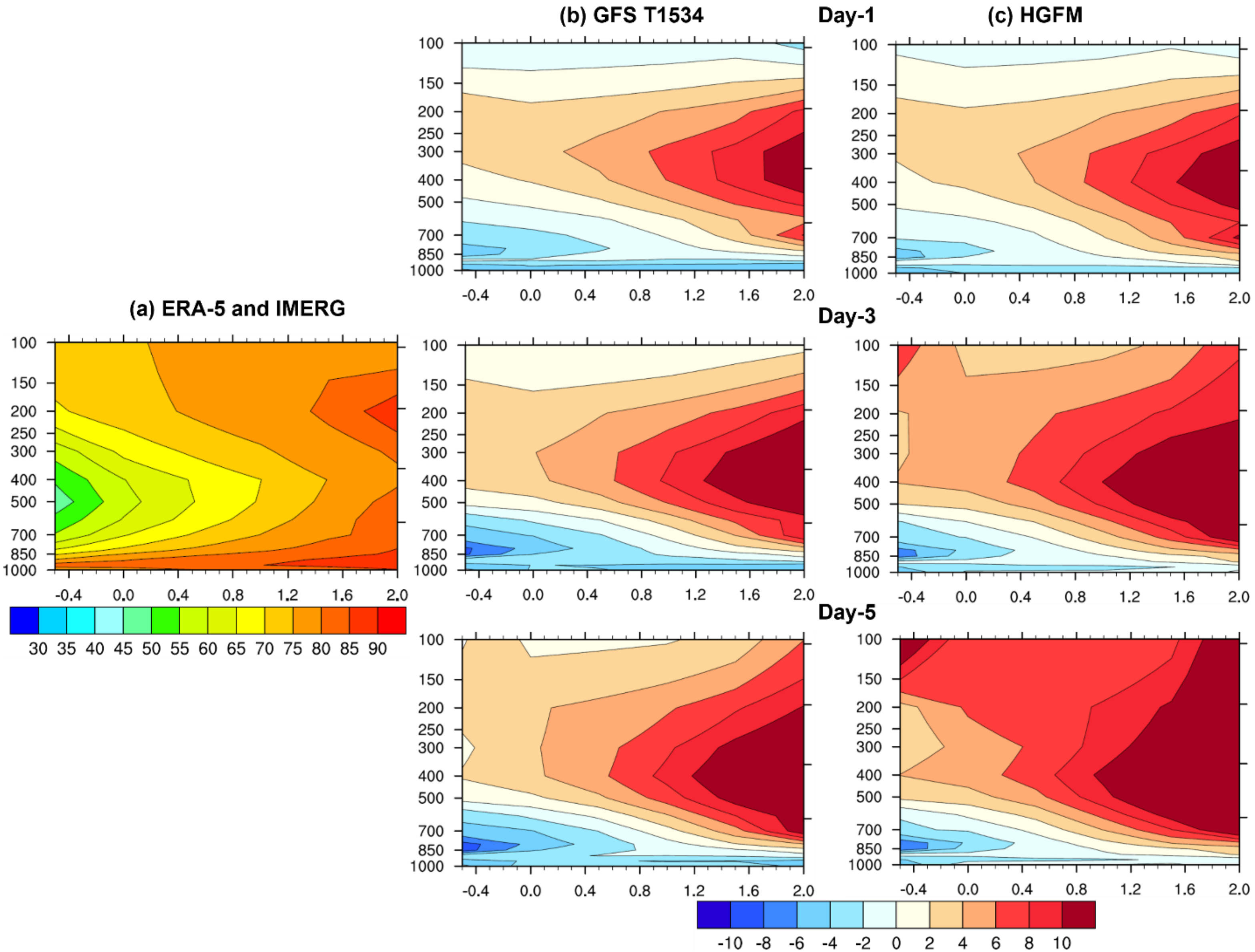
[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Dr. Homi Bhabha Road, Pune 411008, India
[2] King Abdullah University of Science and Technology, Saudi Arabia
[3] ECMWF
[4] University of Victoria, Canada

Correspondence to: Dr. P. Mukhopadhyay (mpartha@tropmet.res.in; parthasarathi64@gmail.com)

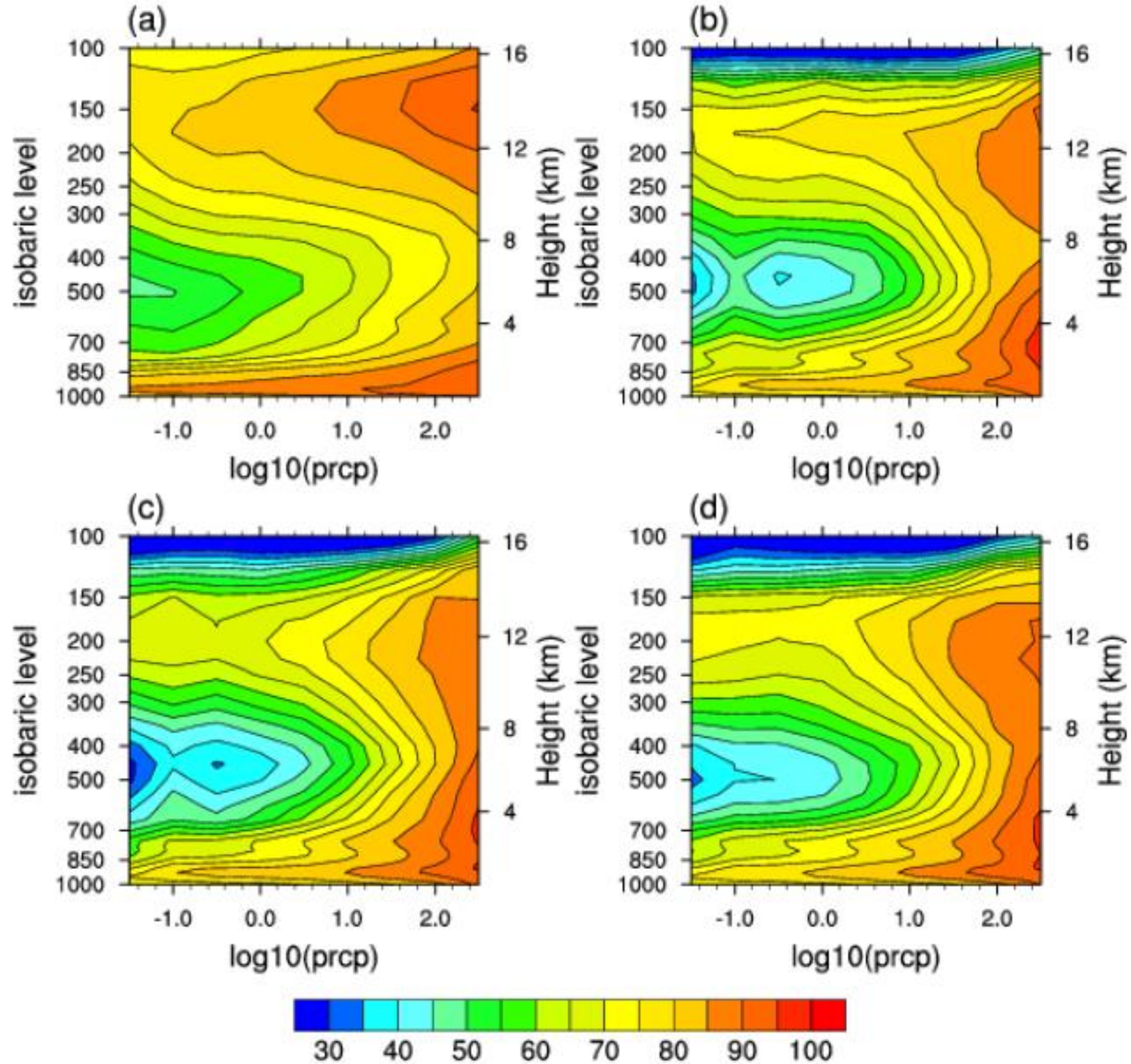
Sequence of IITM HGFM Development (gmd-2024-89)



[Link for a film on the development of the model https://youtu.be/dxacESa28bY](https://youtu.be/dxacESa28bY)

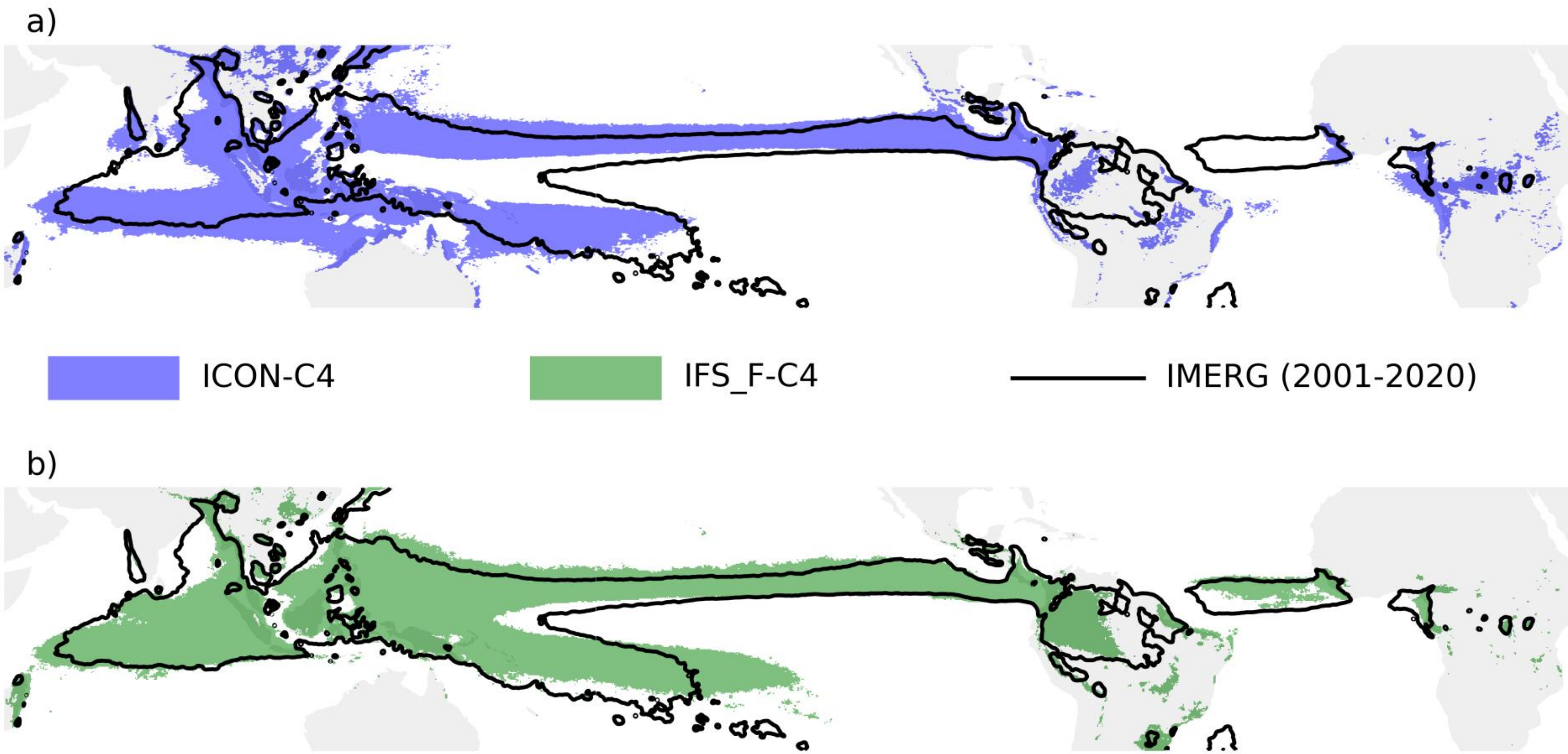


Comparison of Relative humidity (%, bias in shaded) vs rain rate (mm/day) over ISM region (60° E-100° E, 10° S-30° N) during JJAS-2022 from ERA-5 and IMERG (a) with GFS T1534 (b) and HGFM (c) during JJAS 2022 for day-1 day-3 and day-5 lead time

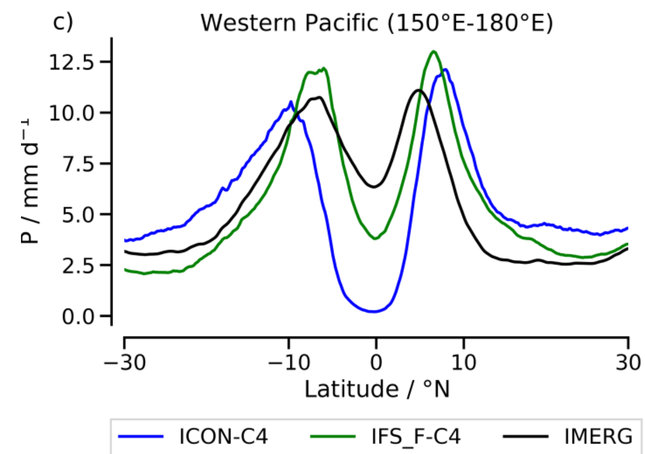


Tirkey et al. 2019

Composite of vertical profile of relative humidity (%, shaded) with respect to precipitation for MISO events for (a) Observation; (b) T62; (c) T126, and (d) T382

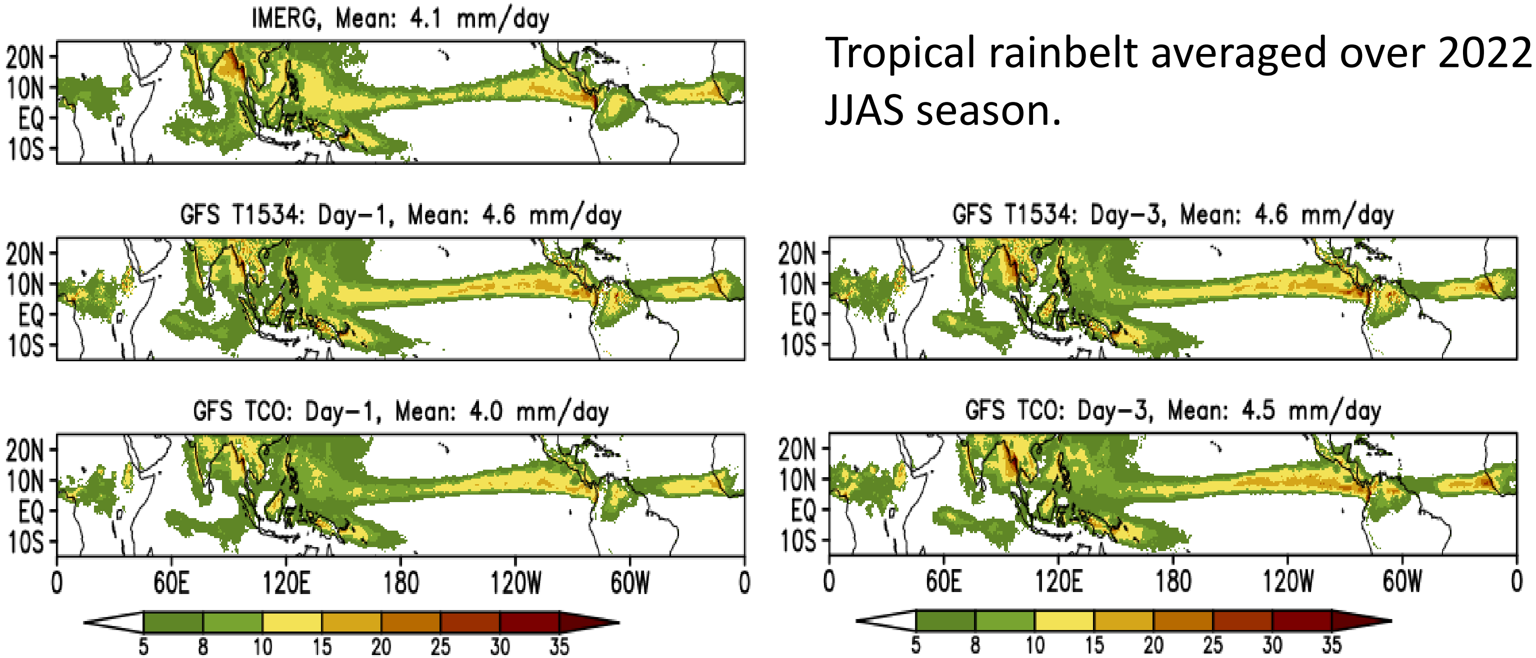


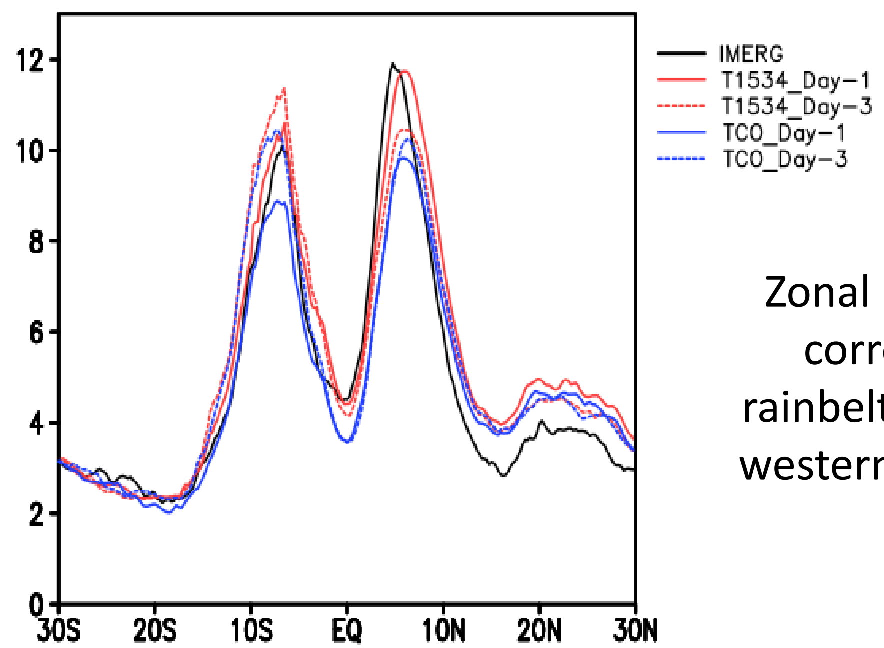
On the left, tropical rainbelt in ICON-C4 (a) and IFS_F-C4 (b) averaged over 2021 to 2025. The tropical rainbelt from IMERG
(Huffman et al., 2019) averaged over 2001 to 2020 is outlined by black contour lines. On the right, zonal mean precipitation corresponding to the rainbelts on the left averaged over the western Pacific (c).



Segura et al. 2025 https://doi.org/10.5194/egusphere-2025-509

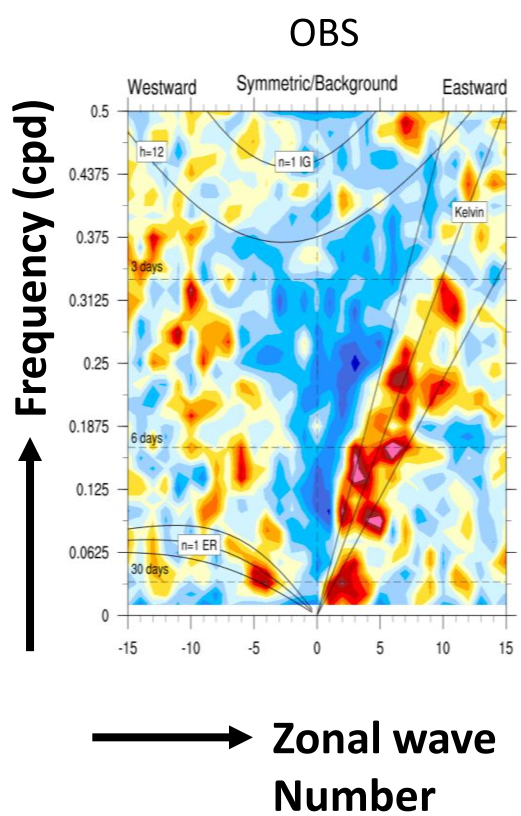
Tropical rainbelt averaged over 2022 to 2024, JJAS season.

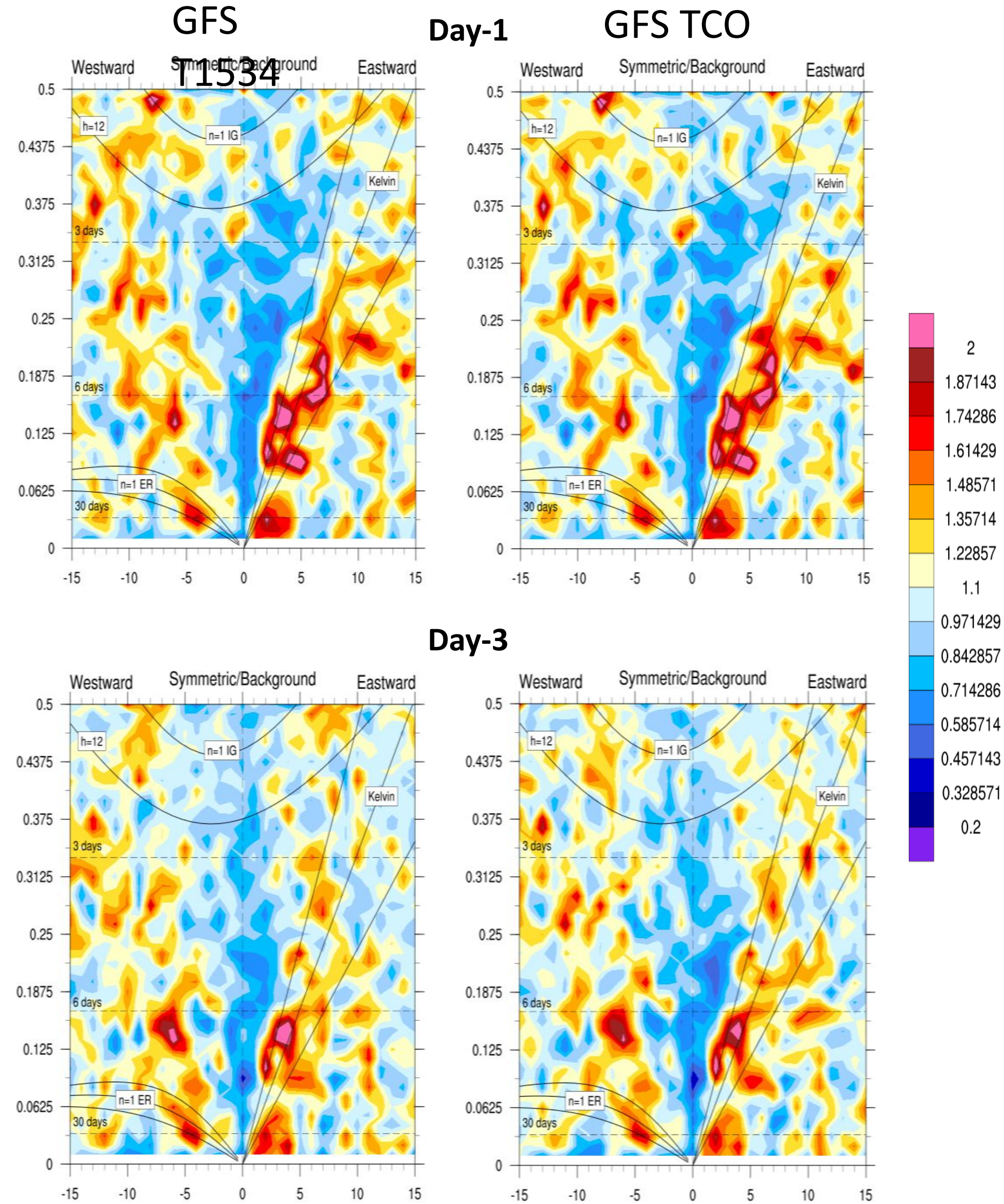




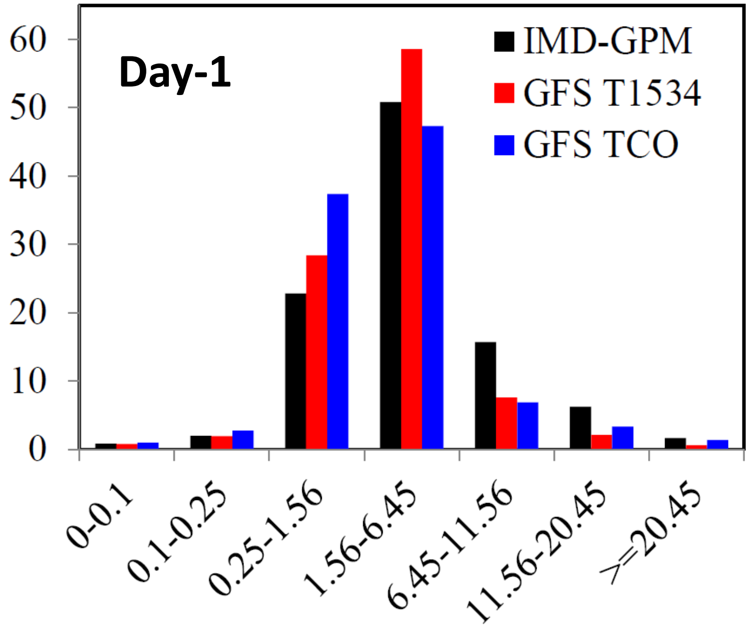
Zonal mean precipitation corresponding to the rainbelts averaged over the western Pacific (150E-180E)

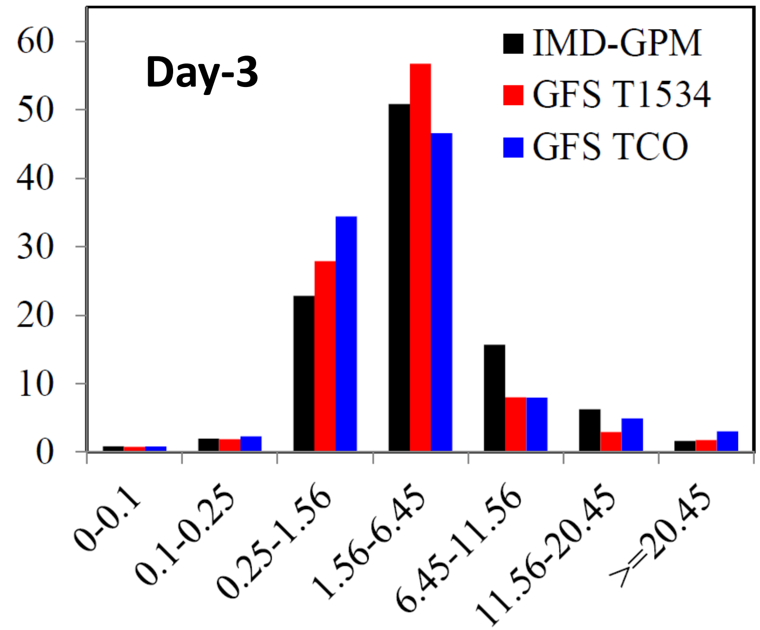
Wave number vs frequency distribution of spectral-power of OLR

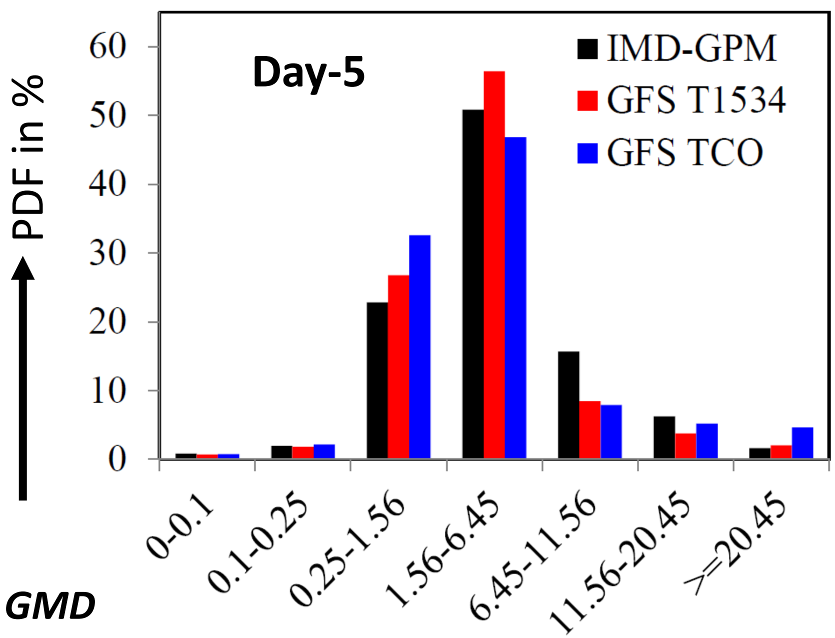




JJAS rainfall PDF over continental India during 2022





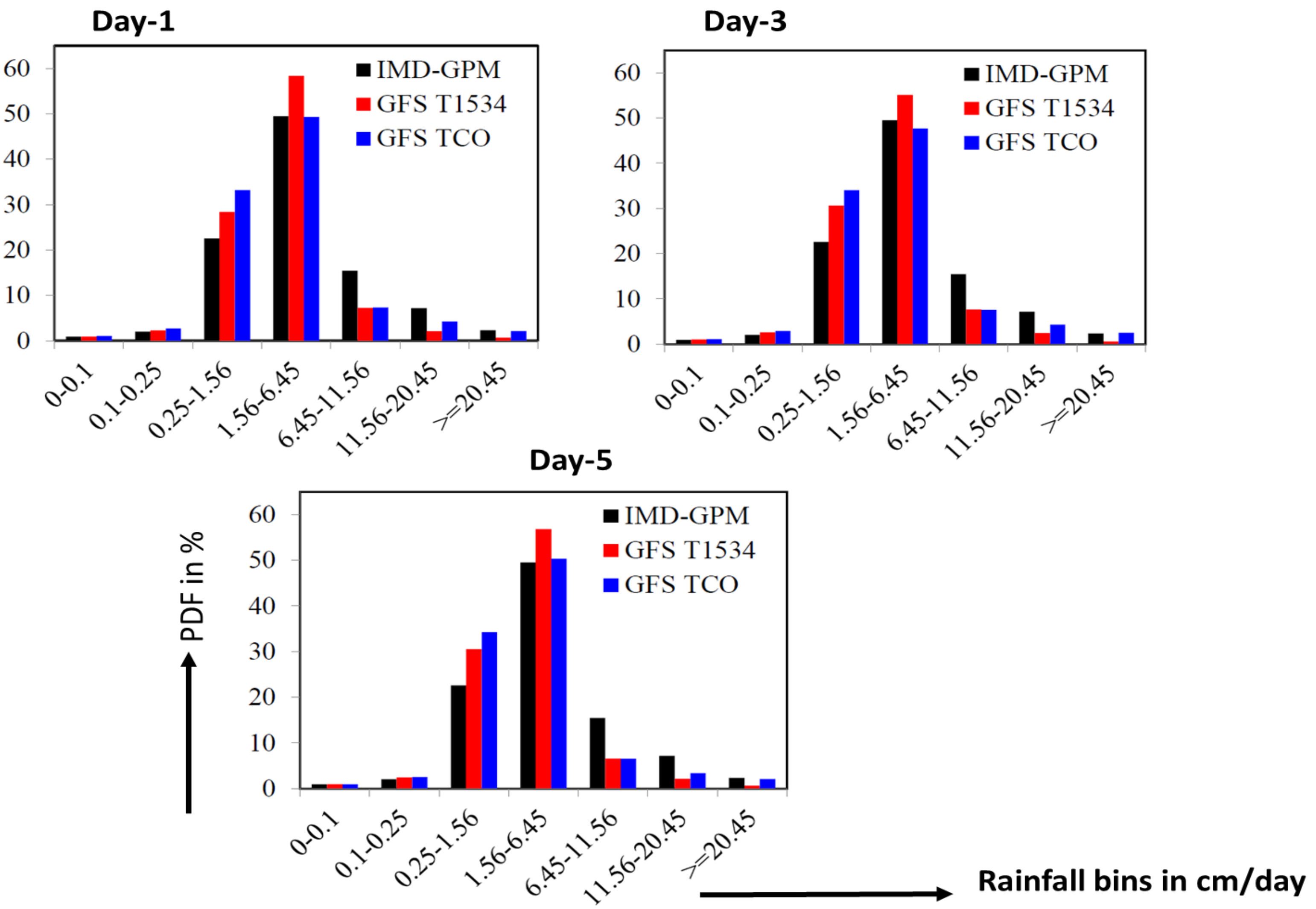


GFS TCO better captures the heavier rainfall categories

Under review in GMD

Rainfall bins in cm/day

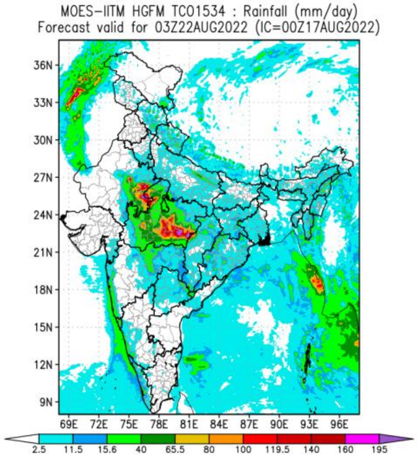
JJAS rainfall PDF over continental India during 2023

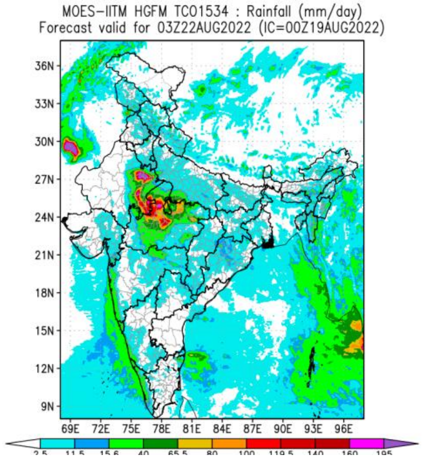


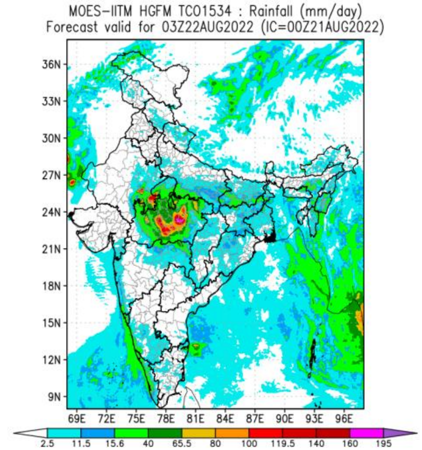
Precipitation probability distribution function (%) over the Indian landmass region during JJAS 2023 for (a) Day-1, (b) Day-3, and (c) Day-5 lead time based on IMERG (Black bar), GFS T1534 (Red bar) and HGFM (Blue bar).

Heavy rainfall event

TCO

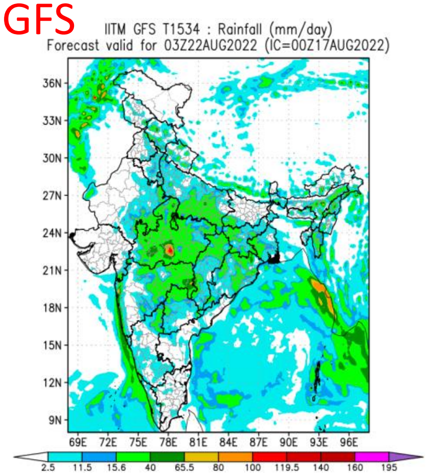


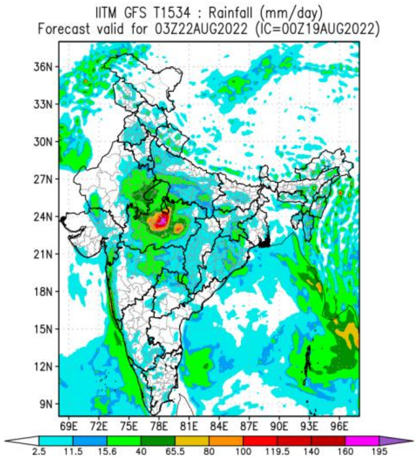


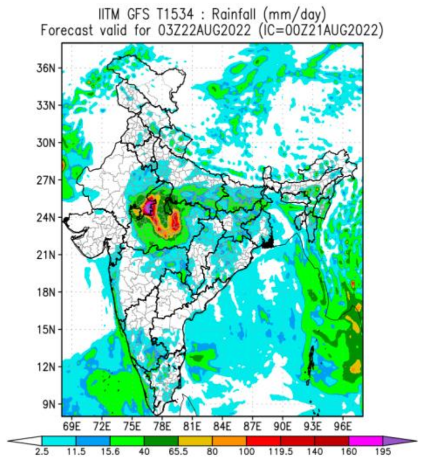


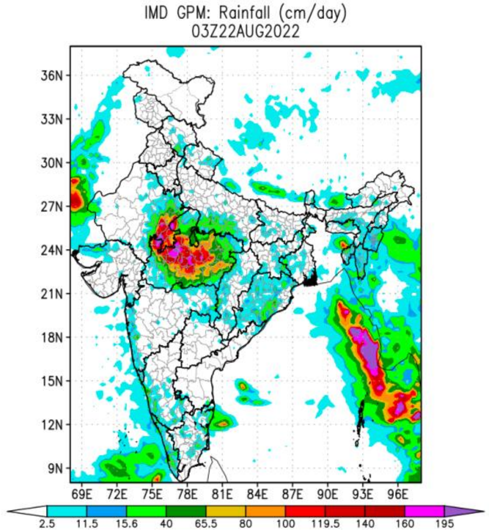
Day-5 Day-3 Day-1

GFS









22nd August 2022

ATMOSPHERIC SCIENCE

Intensification of daily tropical precipitation extremes from more organized convection

Bao et al. Sci. Adv. 2024

Jiawei Bao[1,2]*, Bjorn Stevens[1], Lukas Kluft[1], Caroline Muller[2]

Tropical precipitation extremes and their changes with surface warming are investigated using global storm resolving simulations and high-resolution observations. The simulations demonstrate that the mesoscale organization of convection, a process that cannot be physically represented by conventional global climate models, is important for the variations of tropical daily accumulated precipitation extremes. In both the simulations and observations, daily precipitation extremes increase in a more organized state, in association with larger, but less frequent, storms. Repeating the simulations for a warmer climate results in a robust increase in monthly-mean daily precipitation extremes. Higher precipitation percentiles have a greater sensitivity to convective organization, which is predicted to increase with warming. Without changes in organization, the strongest daily precipitation extremes over the tropical oceans increase at a rate close to Clausius-Clapeyron (CC) scaling. Thus, in a future warmer state with increased organization, the strongest daily precipitation extremes over oceans increase at a faster rate than CC scaling.

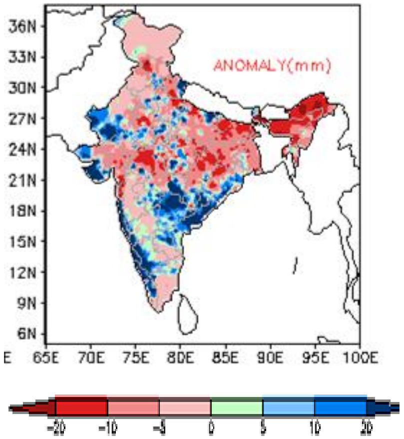
It is useful to introduce a metric of convective clustering [e.g., Tobin et al., 2012]. Many metrics based on OLR or water vapor gauge relative clustering and scenes over different surface temperature boundary conditions are difficult to compare. Here a simple organization index (Iorg) is introduced that permits one to classify a field as regular, random or clustered. To calculate the index, updraft grid cells are identified based on a threshold vertical velocity of 1 m s^{-1} at the level of 730 hPa (2680 m) [e.g., LeMone and Zipser, 1980; Robe and Emanuel, 1996; Tompkins, 2000]. The domain is recursively traced to identify adjacent updraft cells as a single updraft core entity (Figure 17). For each updraft core, the distance from its geometrical centroid to that of its nearest neighbor is calculated, accounting for the periodic boundary conditions. Updraft cores cover a small fraction of the domain [Craig, 1996; Tompkins and Craig, 1998a] and thus the impact of edge effects and merging are minimized [Weger et al., 1992]. The cumulative density function of these nearest neighbor distances is calculated (NNCDF).
(Tompkins and Semie 2017, JAMES)

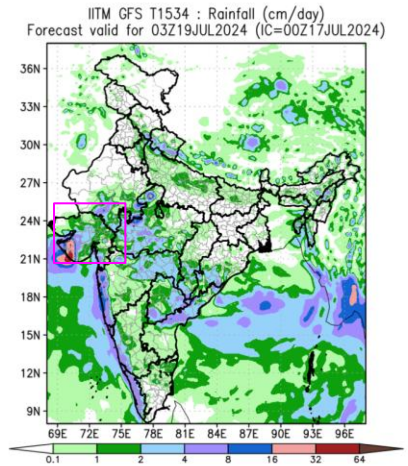
It is useful to introduce a metric of convective clustering [e.g., Tobin et al., 2012]. Many metrics based on OLR or water vapor gauge relative clustering and scenes over different surface temperature boundary conditions are difficult to compare. Here a simple organization index (Iorg) is introduced that permits one to classify a field as regular, random or clustered. To calculate the index, updraft grid cells are identified based on a threshold vertical velocity of 1 m s^{-1} at the level of 730 hPa (2680 m) [e.g., LeMone and Zipser, 1980; Robe and Emanuel, 1996; Tompkins, 2000]. The domain is recursively traced to identify adjacent updraft cells as a single updraft core entity (Figure 17). For each updraft core, the distance from its geometrical centroid to that of its nearest neighbor is calculated, accounting for the periodic boundary conditions. Updraft cores cover a small fraction of the domain [Craig, 1996; Tompkins and Craig, 1998a] and thus the impact of edge effects and merging are minimized [Weger et al., 1992]. The cumulative density function of these nearest neighbor distances is calculated (NNCDF).

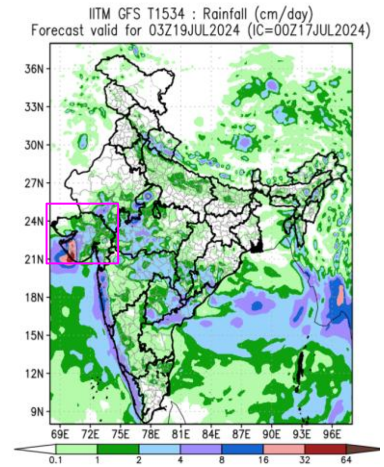
$$NNCDF_{ran} = 1 - \exp(-\lambda \pi r^2).$$

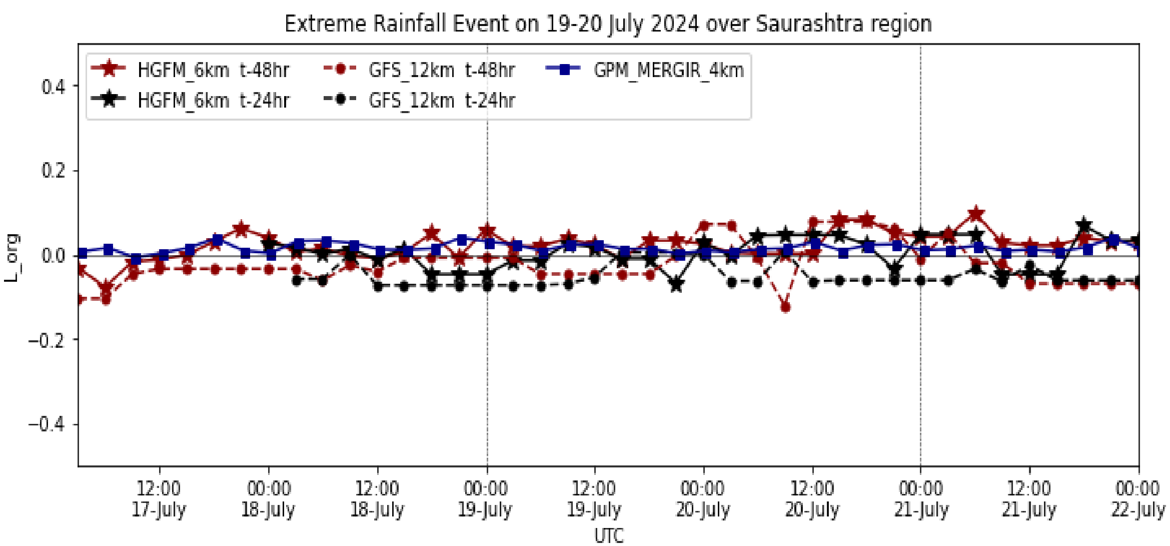
Here λ is the number of points per unit area (a normalizing factor) and r is the nearest neighbor distance. A simple index of organization (Iorg) can be derived by integrating the area under the NNCDF graph. Random convection will have Iorg=0.1, and clustered (regular) states will have values that exceed (are less than) this

19 July 2024









Comparison between 5-day model simulation with 19th June 2022 initial condition

L_org = 0 : random organization

< 0 : regular organization

> 0 : clustered organization

Concluding remarks

- A km-scale (~6 km over global tropics) model has been developed by IITM
- The model shows promise in capturing heavy rain events with longer lead. Also the cyclone forecasts have significantly improved.
- The initial results suggest the model captures organized convection relatively better than the operational GFS.
- More research and improvement needed

a) Incorporate non-equilibrium closure (improve diurnal scale). Incorporate Mesoscale closure (TCWV, Mid level RH & Vertical moisture flux) (MUETZELFELDT et al. 2025)

b) Shallow, deep or explicit approach

c) AI/ML based convective trigger (Siddharth et al. 2024 Clim. Dyn)

d) AI/ML based microphysics and radiation

e) ML based postprocessing of model forecast output

Thank You !