

Evaluation of GFS T1534 hindcast precipitation skill over the Indian summer monsoon region



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1 Introduction

The Indian summer monsoon (ISM; June–September, JJAS) delivers 70–80% of India's annual rainfall and sustains rain-fed agriculture for over 700 million people. GFS T1534 (~12.5 km) is India's operational short-to-medium range forecast model. A **19-year hindcast** now allows a robust diagnosis of its systematic precipitation biases, beyond earlier 1–2 season evaluations.

2 Objectives

- a) Assess rainfall distribution, biases and variability from **diurnal to seasonal** scales
- b) Quantify biases in **extreme** (90th / 95th percentile) rainfall
- c) Evaluate categorical **forecast skill** over the ISM region

3 Model, Data & Methods

- **Model:** NCEP GFS v14.1.0, T1534 (~12.5 km), 64 hybrid σ -p levels (top 0.27 hPa), semi-Lagrangian dynamics, $\Delta t = 450$ s
- **Hindcast:** JJAS 2000–2018, daily 00 UTC runs to 10 days, 3-hourly output; initial conditions from NCMRWF hybrid 4D-Var GDAS (80-member EnKF)
- **Observation:** GPM IMERG V07 Final Run; model and IMERG regridded to 1° × 1°

Physics	Scheme in GFS T1534
Convection	Scale-aware simplified Arakawa–Schubert deep + mass-flux shallow
Microphysics	Zhao & Carr (1997); Sundqvist et al. (1989)
Gravity-wave drag	Orographic, mountain blocking and convective GWD
PBL	Hybrid eddy-diffusivity mass-flux (EDMF)
Radiation	RRTM shortwave / longwave with McICA

	Obs. yes	Obs. no
Fcst. yes	a (hit)	b (false alarm)
Fcst. no	c (miss)	d (correct neg.)

$B = (a + b) / (a + c)$
Bias score: 1 unbiased; > 1 over-forecast; < 1 under-forecast
 $ETS = (a - a_e) / (a + b + c - a_e)$, $a_e = (a + b)(a + c) / N$
 a_e : hits expected by chance; $-1/3 \leq ETS \leq 1$, 0 = no skill

4 Global JJAS mean rainfall bias

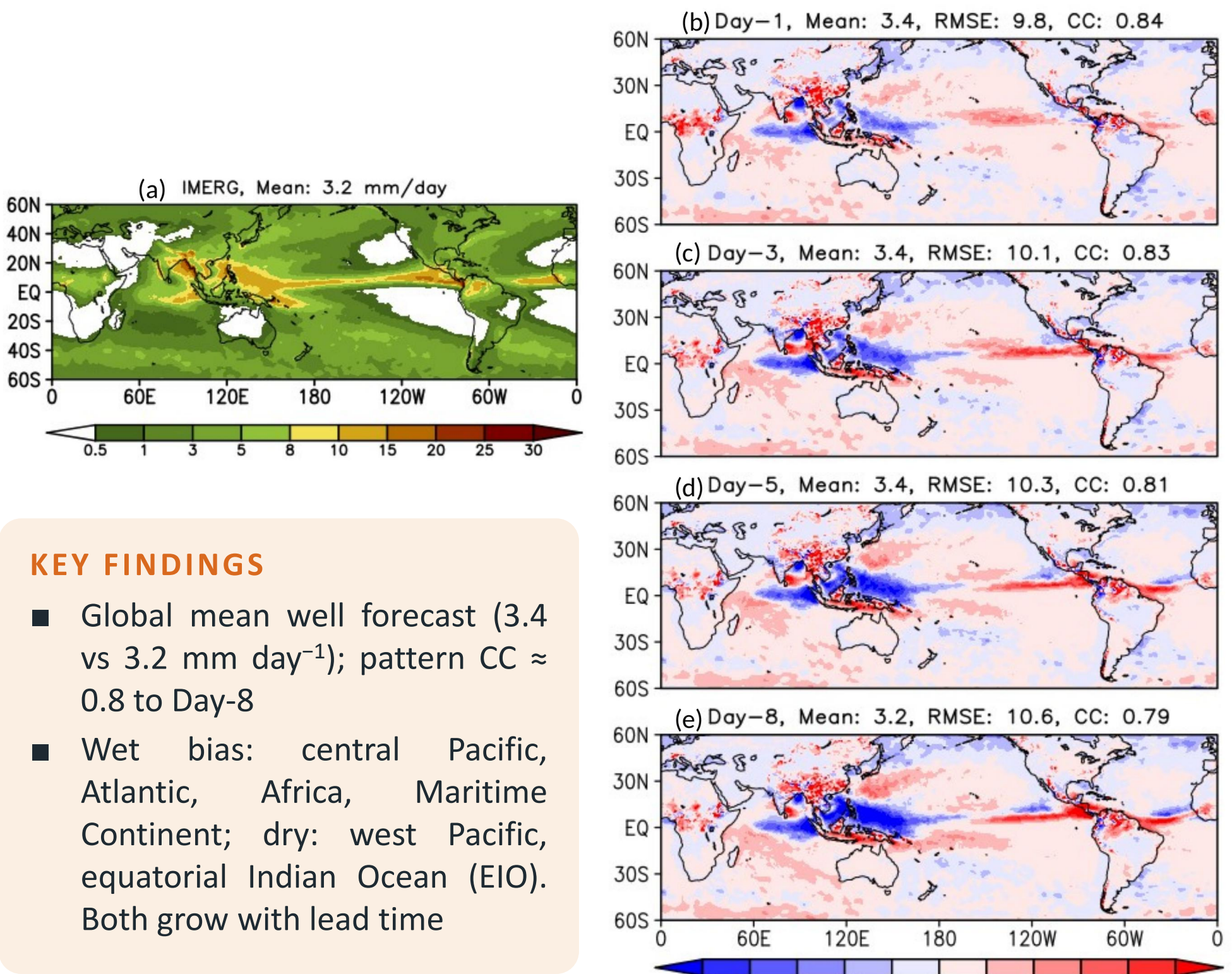


Fig. 1 (a) JJAS mean rainfall (mm day⁻¹) from IMERG, 2000–2018; (b–e) GFS T1534 bias at Day-1, -3, -5, -8 (global mean, RMSE, pattern CC in each panel).

5 Seasonal mean bias over the ISM

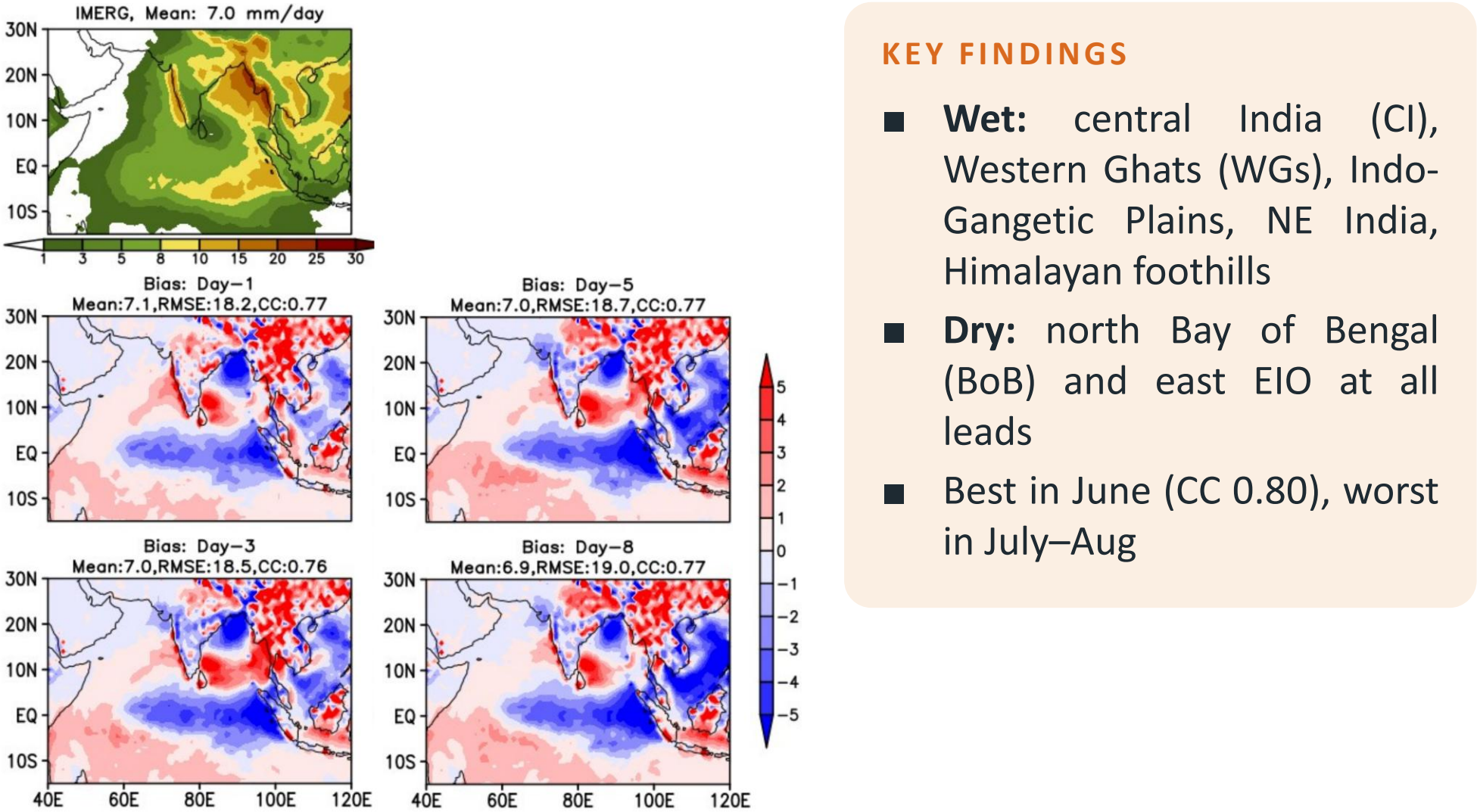


Fig. 2 (a) JJAS mean IMERG rainfall (mm day⁻¹); GFS T1534 bias at Day-1, -3, -5, -8 (domain mean, RMSE, CC in each panel). Table: Indian-landmass statistics (mm day⁻¹).

Indian land	Mean	CC	RMSE	Std. dev.
IMERG	7.2	–	–	14.2
GFS Day-1	7.6	0.75	17.5	12.7
GFS Day-3	6.7	0.70	16.9	11.0
GFS Day-5	7.1	0.69	17.3	11.1
GFS Day-8	7.5	0.71	17.7	11.2

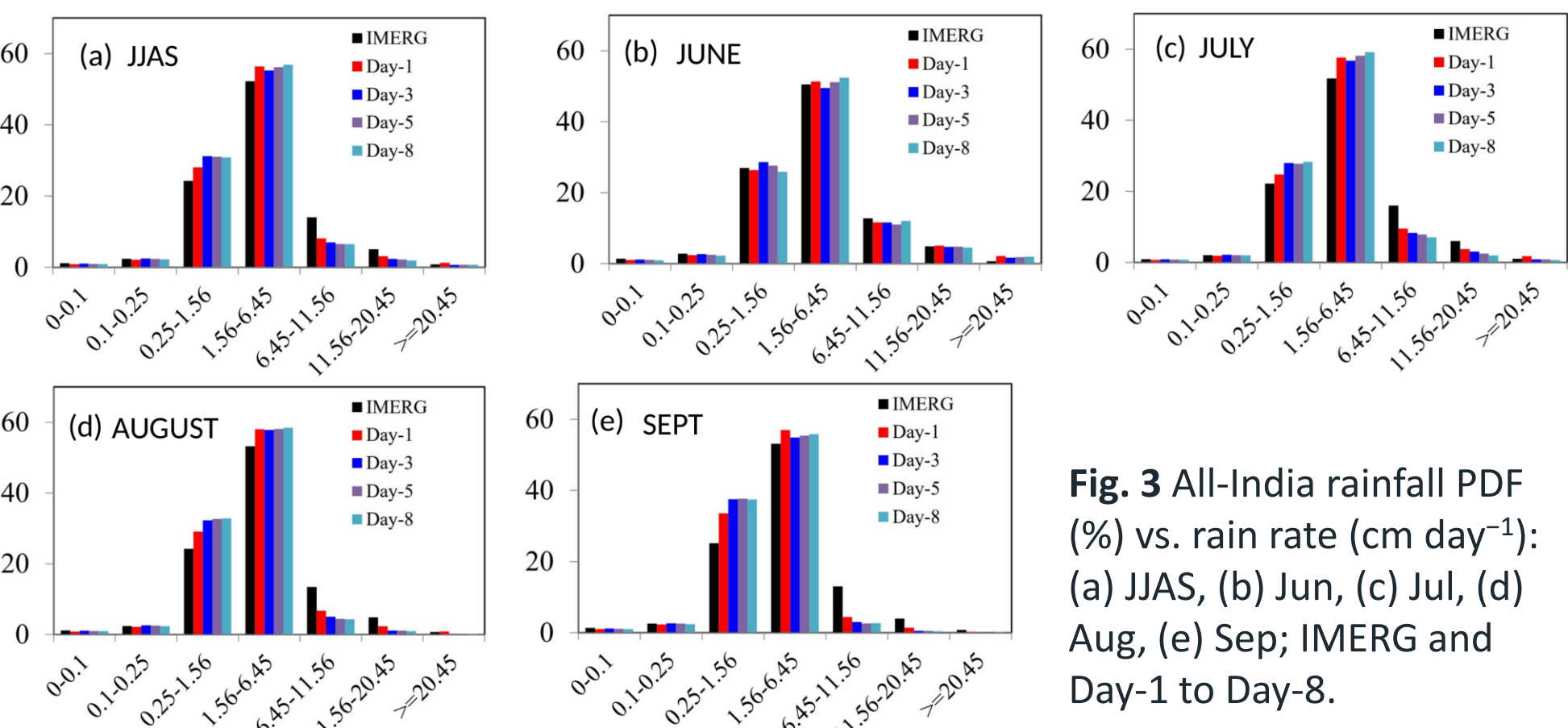
REFERENCES

Ganai M, Tirkey S, Krishna RPM et al. (2026) Evaluation of GFS T1534 hindcast precipitation skill over the Indian summer monsoon region. *Clim Dyn* 64:91
Mukhopadhyay P et al. (2019) Performance of GFS T1534 at 12.5 km over the Indian region during the 2016–2017 monsoon seasons. *J Earth Syst Sci* 128
Ganai M et al. (2021) *Atmos Res*, 10.1016/j.atmosres.2020.105185; Ganai M et al. (2024) *Clim Dyn*, 10.1007/s00382-024-07316-w
Huffman GJ et al. (2023) GPM IMERG ATBD, version 07. NASA; Wheeler M, Kiladis GN (1999) *J Atmos Sci* 56:374–399
Roebber PJ (2009) *Weather Forecasting* 24:601–608; Goswami BN, Xavier PK (2003) *Geophys Res Lett* 30:1966



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6 Rainfall probability distribution



KEY FINDINGS

- Light (0.25–1.56) and moderate (1.56–6.45 cm day⁻¹) rain **over-forecast**; heavy to very heavy (> 6.45 cm day⁻¹) **under-forecast**
- Distribution best captured in June

7 Synoptic vs intraseasonal variance

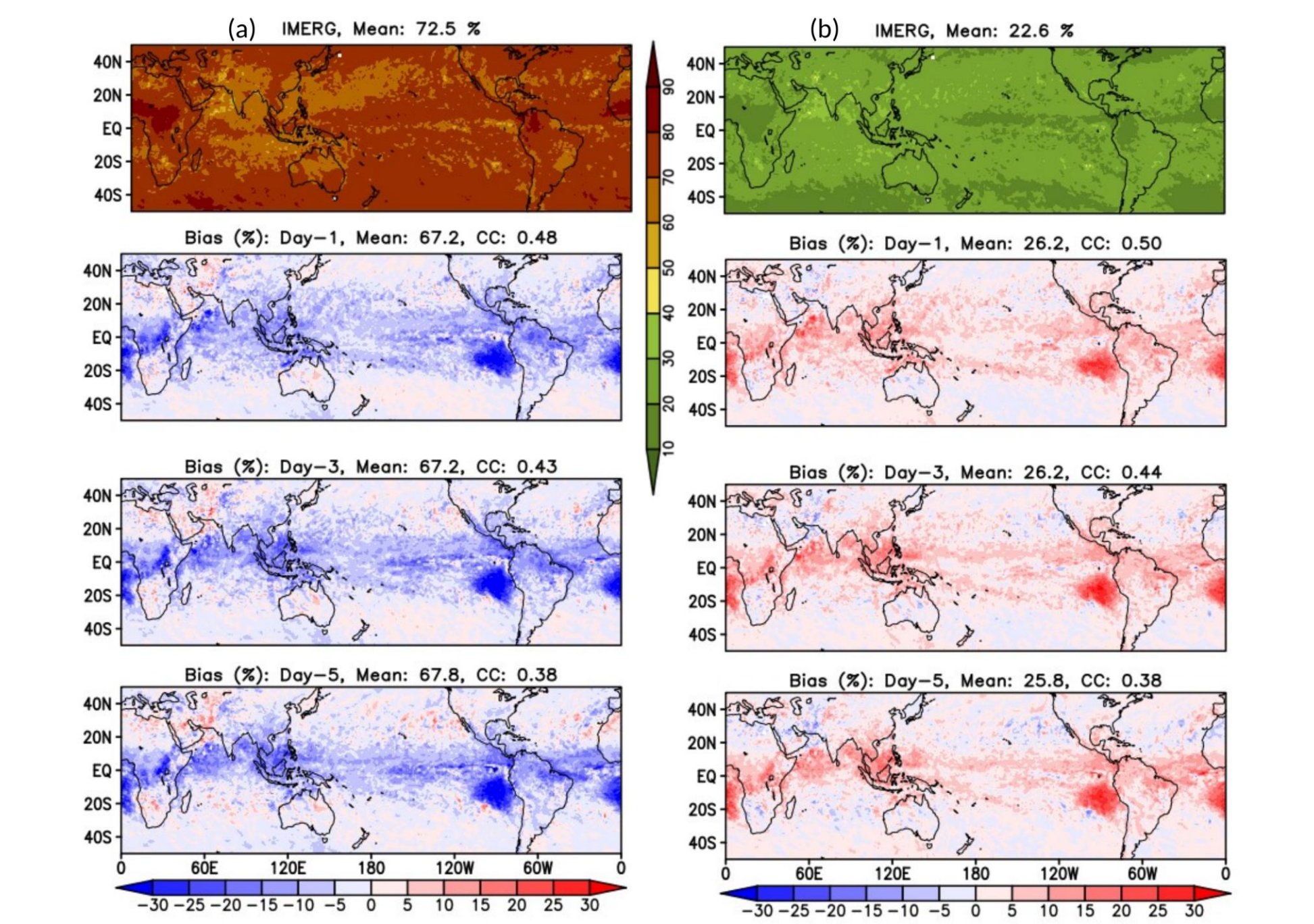


Fig. 4 Share (%) of daily rainfall variance in the (a) 2–10 day synoptic and (b) 10–90 day ISO bands: IMERG (top) and GFS bias at Day-1, -3, -5.

KEY FINDINGS

- Observed variance is synoptic-dominated (72.5% vs 22.6%)
- GFS **under-estimates synoptic** (esp. BoB, EIO) and **over-estimates ISO** variance, consistent with too-frequent convective triggering

8 Convectively coupled equatorial waves

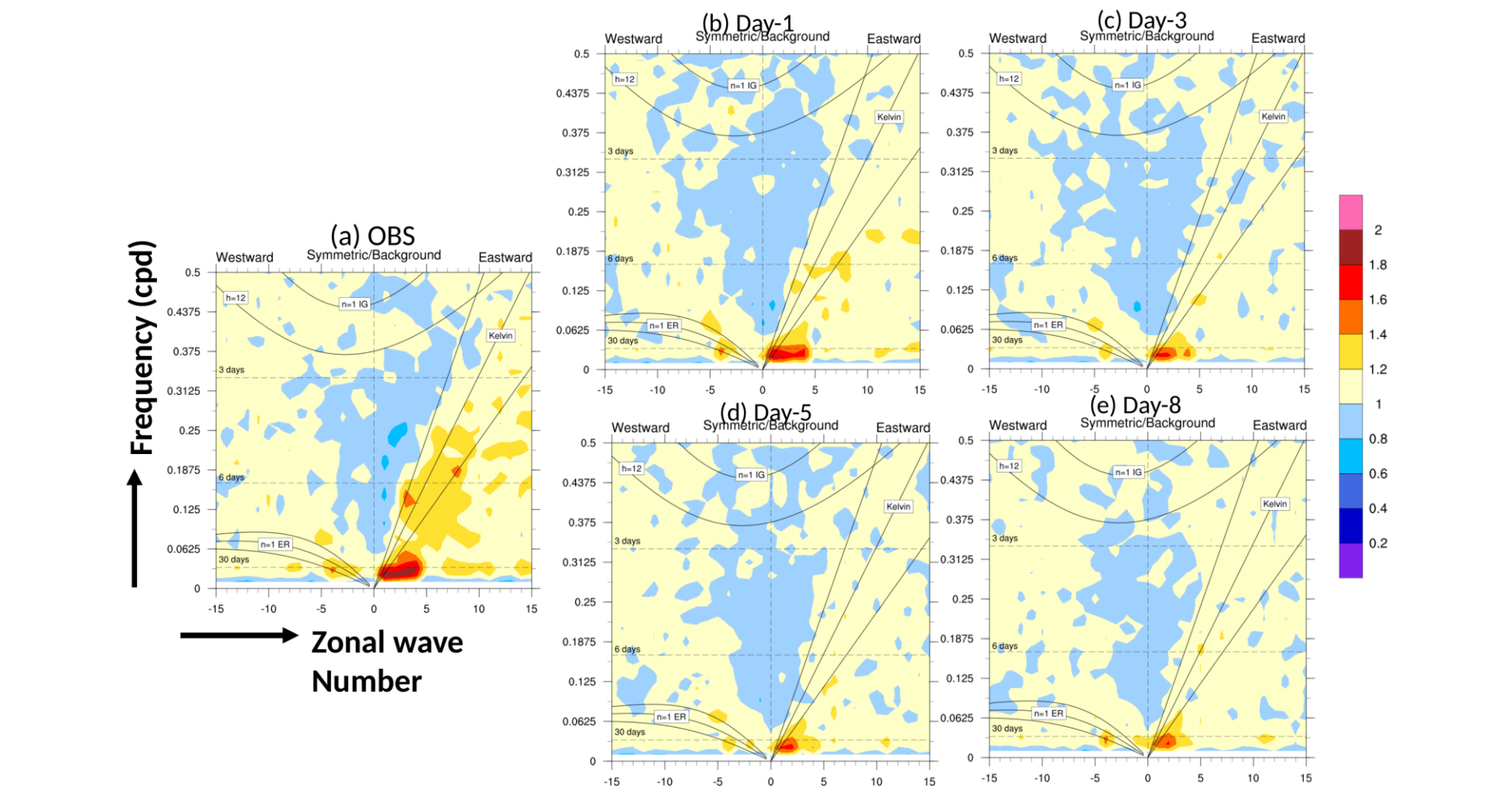


Fig. 5 Wavenumber–frequency spectra (power / background) of **symmetric** rainfall: (a) IMERG; (b–e) GFS Day-1, -3, -5, -8. Lines: dispersion curves, $h = 12, 25, 50$ m.

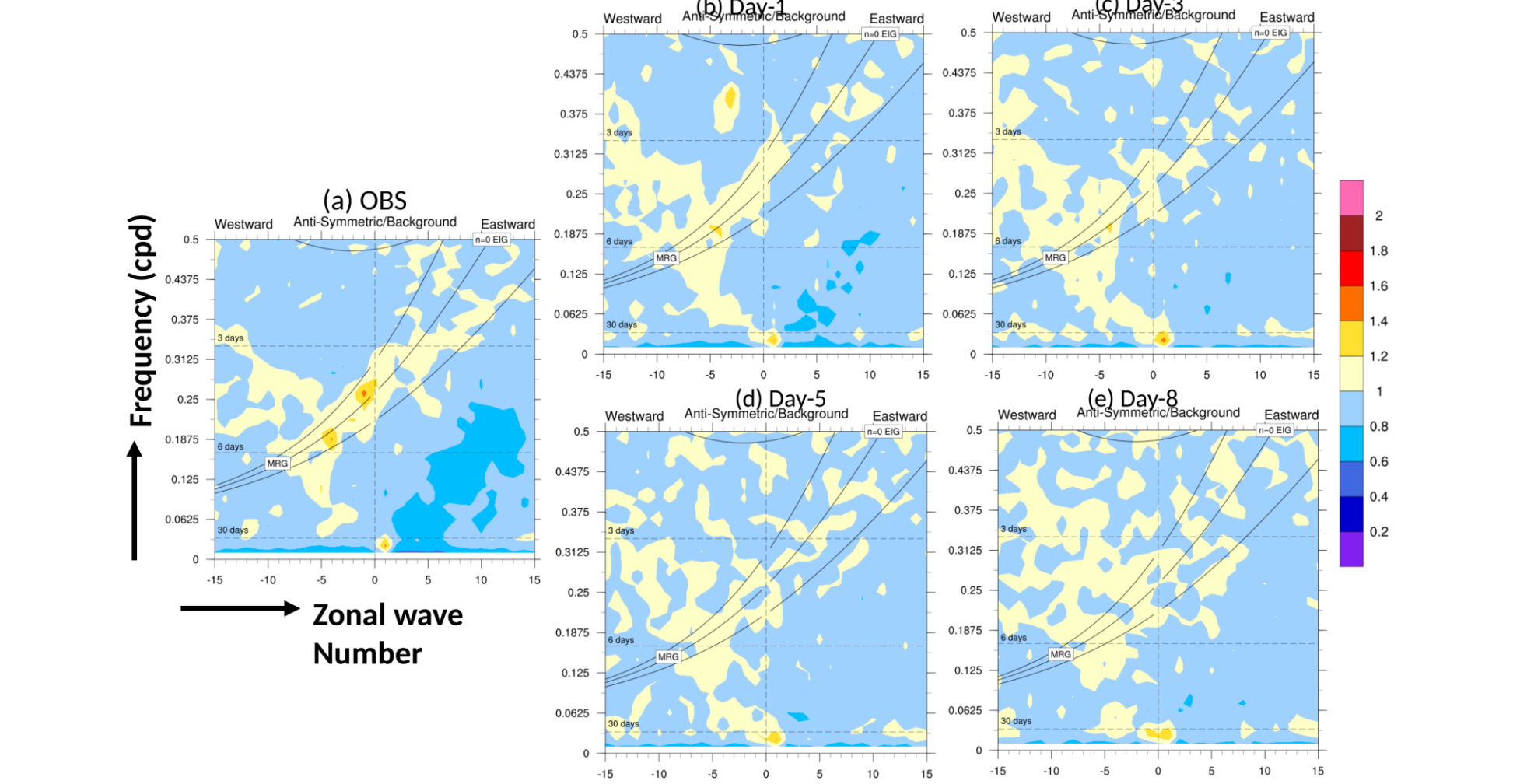


Fig. 6 As Fig. 5, for the antisymmetric component.

KEY FINDINGS

- MJO ($k = 1–4$, 30–45 d) captured but weak; Kelvin waves too weak and lost with lead time
- Mixed Rossby–gravity and inertio-gravity waves under-estimated; antisymmetric MJO well captured

9 Heavy-to-extreme rainfall

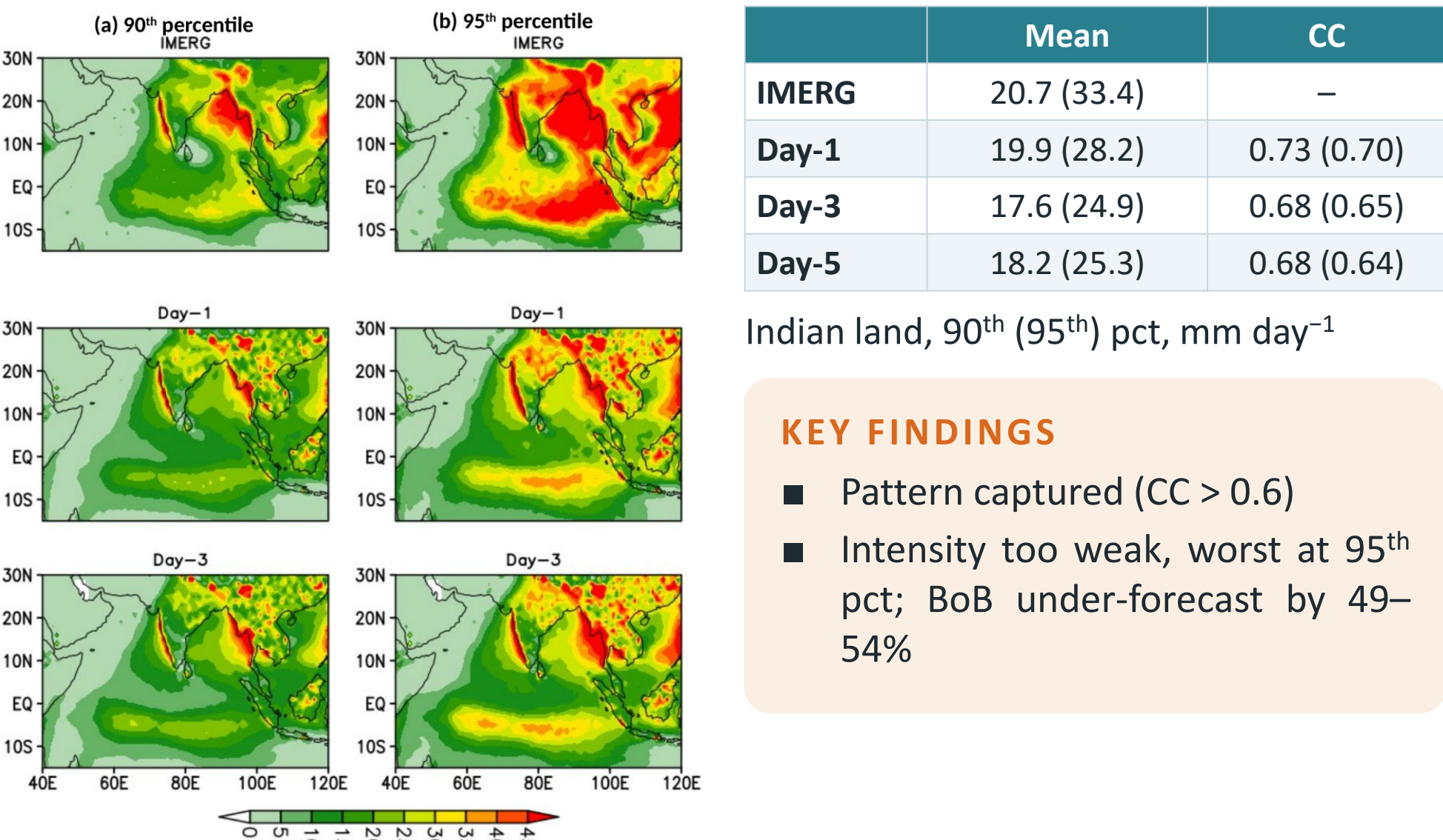
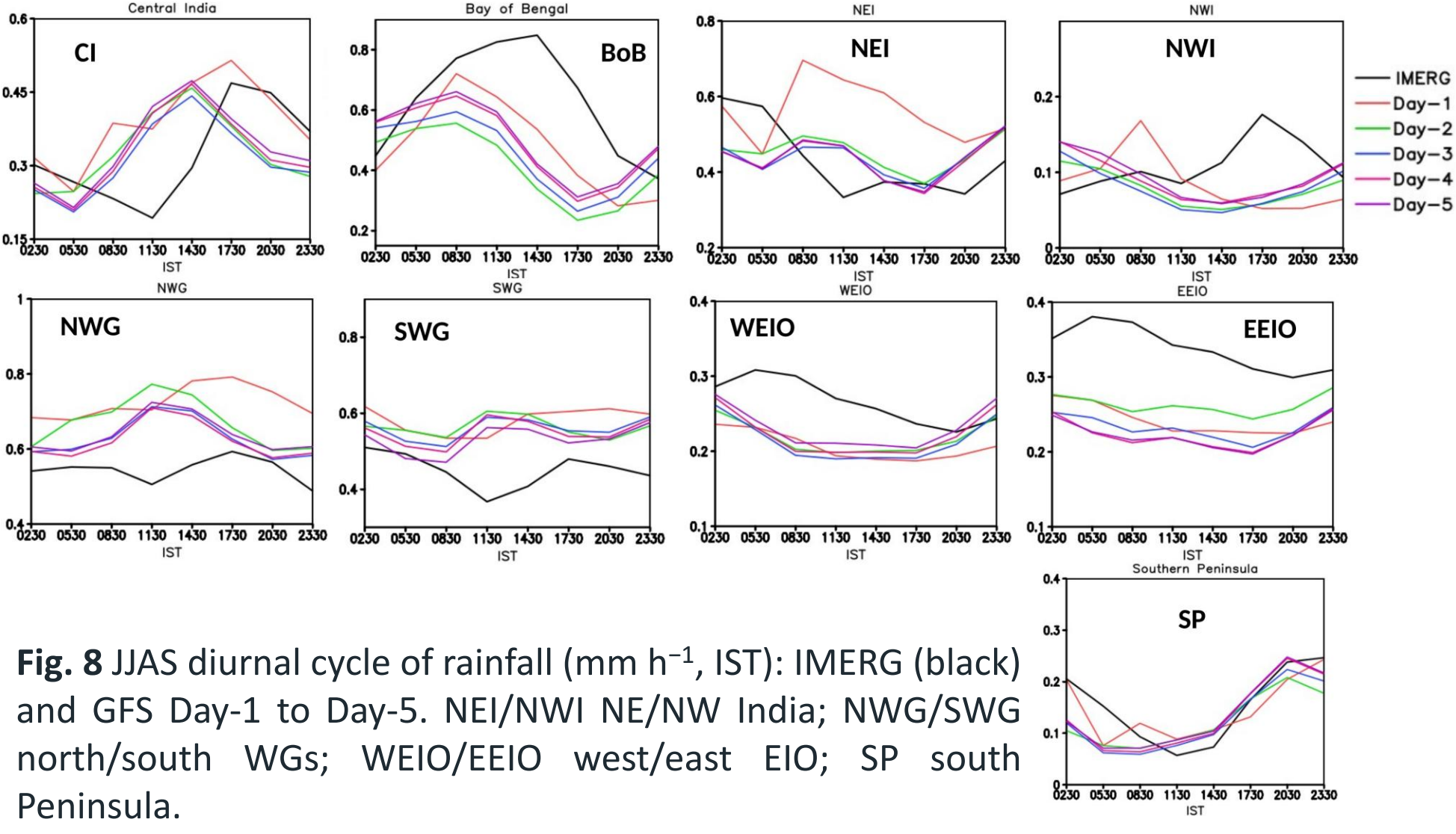


Fig. 7 (a) 90th and (b) 95th percentile JJAS rainfall (mm day⁻¹): IMERG, GFS Day-1, Day-3.

10 Diurnal cycle of precipitation



KEY FINDINGS

- CI: 1730 IST peak captured at Day-1; from Day-2 the peak is **3 h early**
- BoB: peak **6 h early** (0830 vs 1430 IST); NEI, NWI phase missed; EIO amplitude too weak

11 Forecast skill

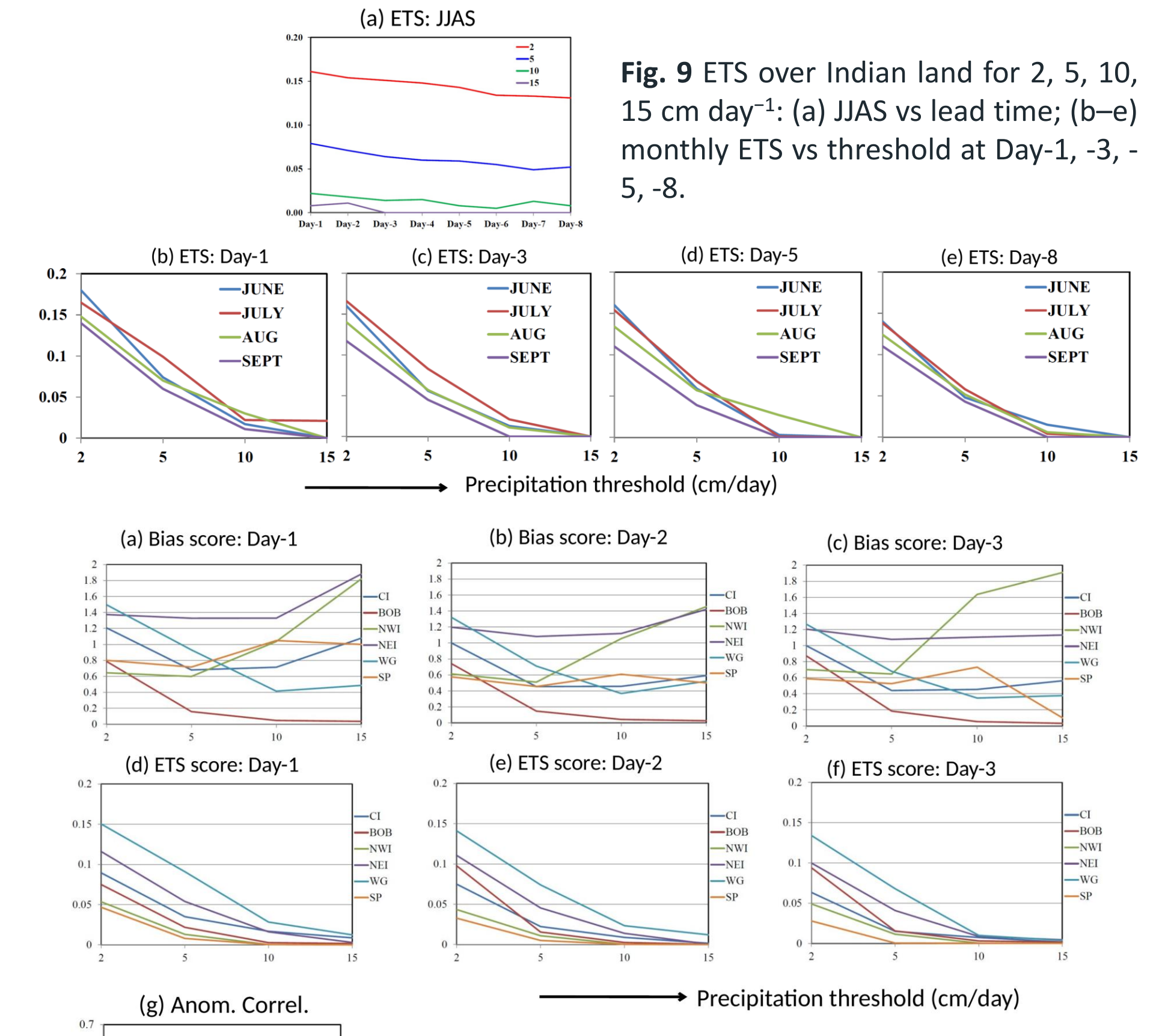


Fig. 9 ETS over Indian land for 2, 5, 10, 15 cm day⁻¹: (a) JJAS vs lead time; (b–e) monthly ETS vs threshold at Day-1, -3, -5, -8.

KEY FINDINGS

- Light-rain skill high and nearly lead-independent; extreme rain: ETS 0.005–0.02, **no skill beyond Day-3**
- Best in July–August, over CI (ACC 0.6 → 0.4) and NEI; BoB, NWI poorest

12 Conclusions

19 yr JJAS hindcast	–7.3 95 th pct bias (mm day ⁻¹)	3–6 h early diurnal peak	Day-3 skill limit, extremes
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- Persistent **dry bias over north BoB / east EIO** calls for **ocean coupling**
- Light rain too frequent, heavy rain too weak: improve **convection, microphysics, PBL**
- Synoptic variance too weak, ISO too strong; premature diurnal peak from the **convective trigger**

Operational implication: issue light-to-moderate rain with confidence; treat heavy-rain forecasts with caution and ensemble support.

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