

Record-breaking unseasonal rainfall over South India in January 2021

Role of Madden–Julian Oscillations, Westerly Wind Bursts and coupled ocean–atmosphere interactions

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7×

January clim over Peninsular India:
2.52 vs 0.34 mm day⁻¹

72 yr

wettest January in the IMD record
(1951–2022); 99.3th percentile

11 days

of active MJO in Phase 3, against
a climatology of about 3

13 Jan

a rare January westerly wind
burst; U850 anomaly above +2σ

p = 0.04

rising trend in MJO-linked PIB
rainfall extremes under SSP5-8.5

1 Background

- Northeast monsoon (Oct–Dec) brings about 45% of Tamil Nadu's annual rainfall and normally withdraws by late Dec.
- In January 2021 heavy rain persisted over Peninsular India and Sri Lanka, during the 2020–22 triple-dip La Niña, but the extension worked on intraseasonal timescales.
- What drove it? Was it predictable, and will such events change with warming?

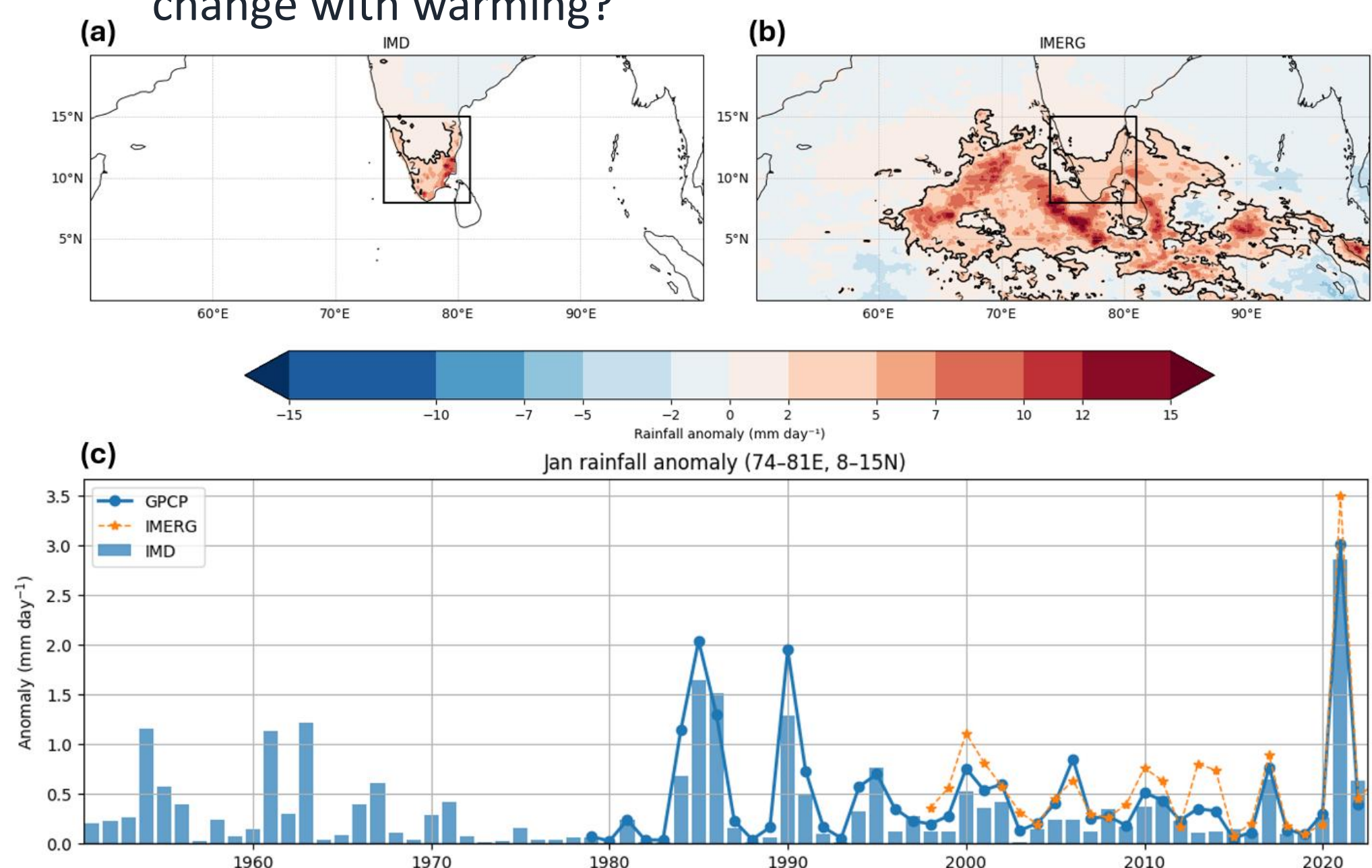


Fig. 1 Jan 2021 rainfall anomaly (mm day⁻¹) from (a) IMD and (b) IMERG; box = Peninsular India Box (PIB, 74–81°E, 8–15°N). (c) January PIB rainfall anomaly, IMD, GPCP, IMERG.

2 Data & methods

- Rainfall:** IMD 0.25° (1951–2022), IMERG 0.1° (1998–2024), GPCP
- Atmosphere:** ERA5 winds, NOAA OLR, RMM index
- Ocean:** OISST v2.1, GODAS (D20), CMEMS sea level
- WWBs:** U10 anomaly > 5 m s⁻¹ over 10° longitude for > 4 days
- Kelvin waves:** Wheeler–Kiladis filtered OLR (k 1–14, 2.5–20 days)
- MJO tracking** from precipitation (Zhang & Ling 2017)
- Models:** IITM ERPASv1 forecasts; IITM-ESM historical and SSP5-8.5

3 Persistent deep convection

Convection began off Kerala on 4 January, covered the PIB and Sri Lanka by the 8th, and held until the 12th. Equatorial westerlies and a cyclonic gyre over the southern Bay of Bengal fed moisture into South India.

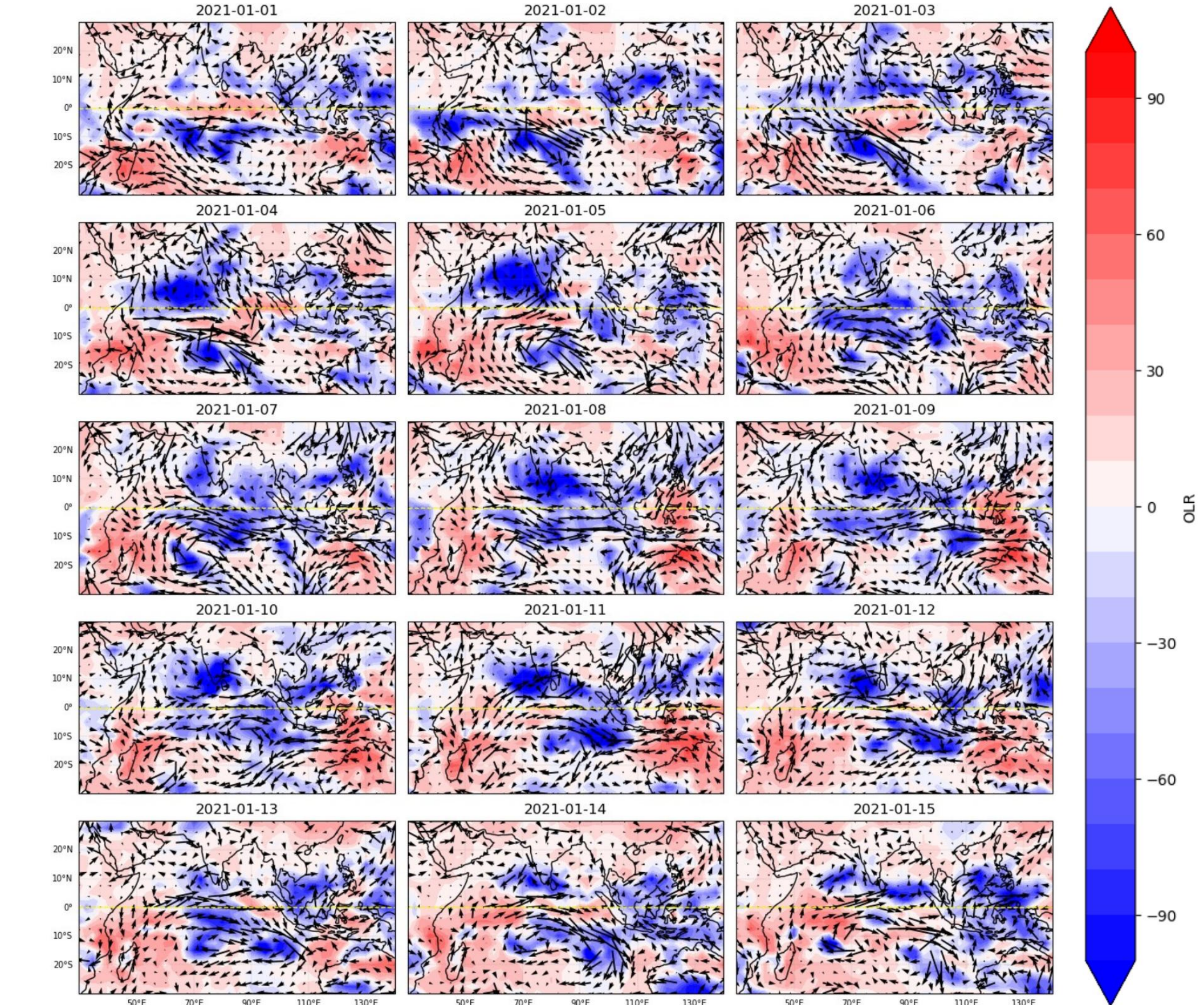


Fig. 2 Daily OLR anomalies (W m⁻², shaded) and 850 hPa wind anomalies (vectors), 1–15 January 2021.

9 A warmer future: stronger MJO-linked extremes

In IITM-ESM, peak PIB rainfall per tracked MJO event rises through 2021–2100 under SSP5-8.5 (200 events; Mann–Kendall p = 0.04). Equatorial westerlies accompany PIB crossings in every period, supporting the wind–MJO–rainfall link.

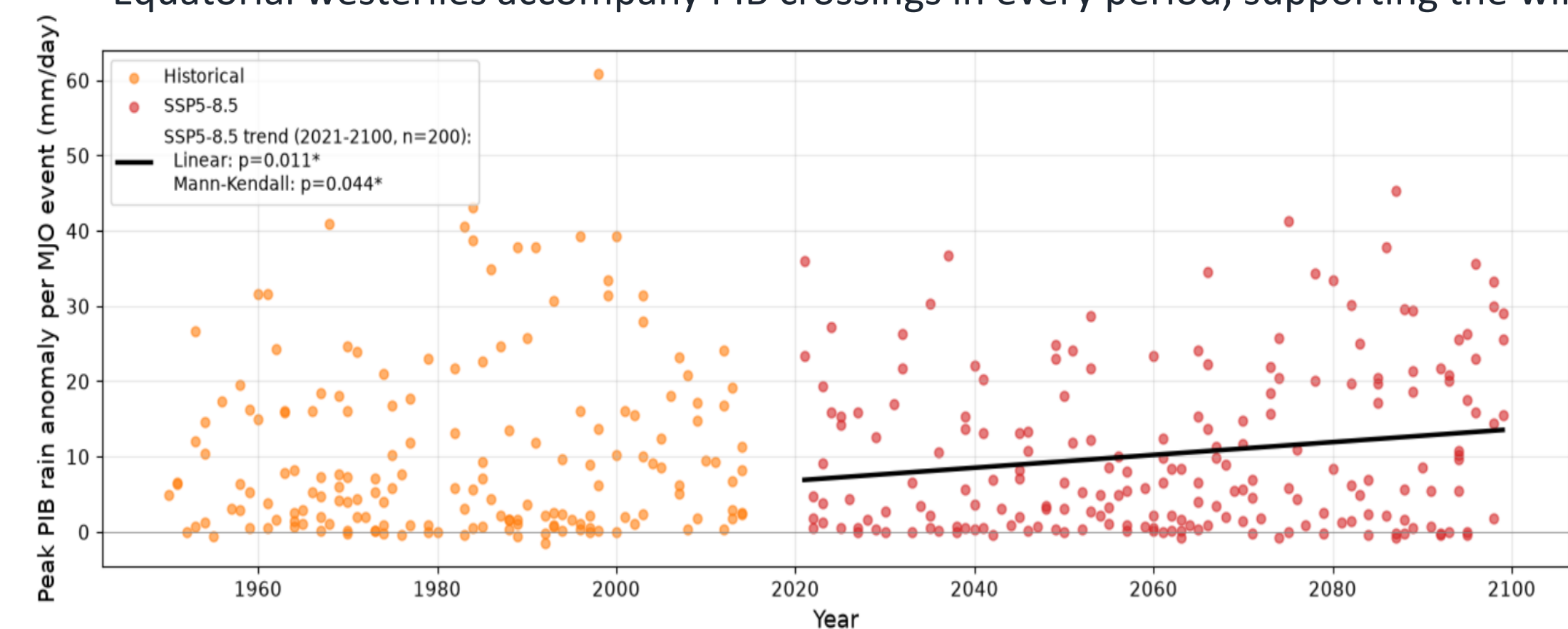


Fig. 10 Peak PIB rainfall anomaly per tracked MJO event, IITM-ESM historical and SSP5-8.5.

4 MJO Phase 3 + Kelvin waves

During the peak (5–15 January) the MJO sat in Phase 3 with amplitude above 1. Within it, convectively coupled Kelvin waves moving east at about 15 m s⁻¹ carried convection into the PIB by 8 January; two more packets followed on 10–20 January.

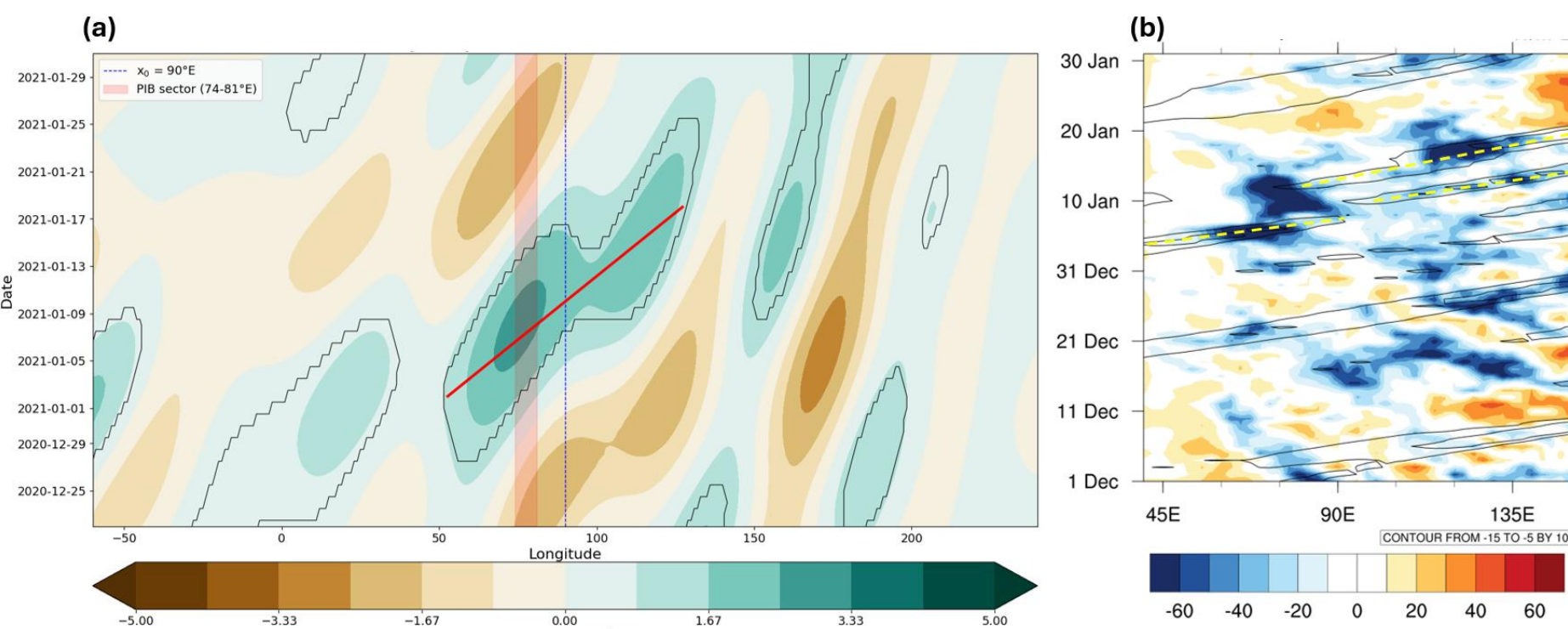


Fig. 3 (a) MJO event tracked from precipitation; (b) Kelvin-wave filtered OLR anomaly.

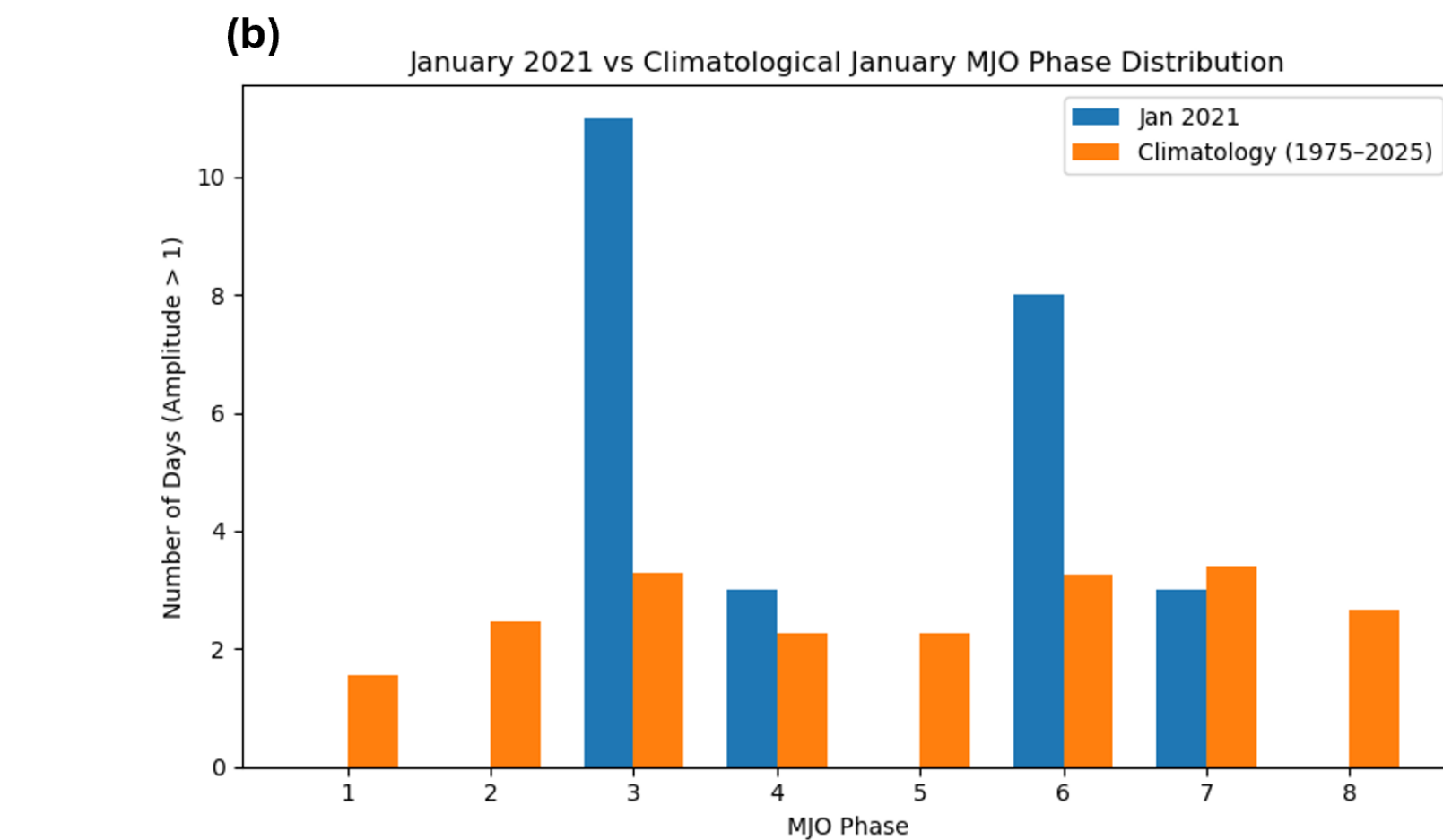


Fig. 4 Active MJO days per phase, January 2021 against climatology.

5 Moisture convergence leads rain

Two convergence pulses (6–7 and 10–11 January) each led a rainfall peak (7 and 13 January) by 1–3 days. The second sat directly over the PIB on 13 January, the day of the wind burst.

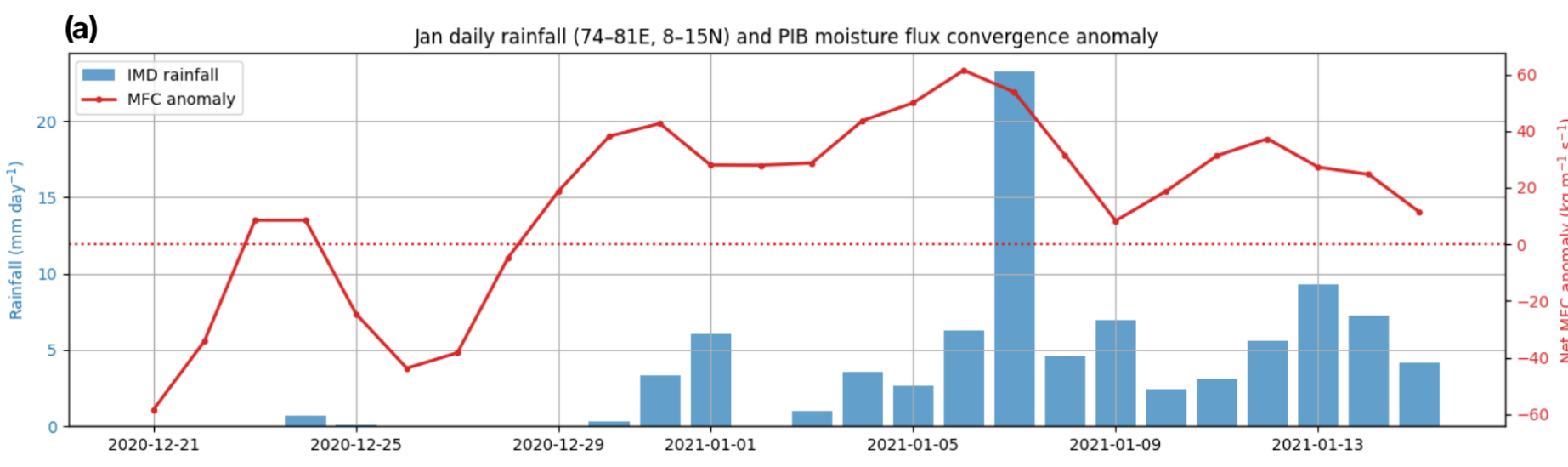


Fig. 5 Daily IMD rainfall over the PIB (bars) and net moisture flux convergence anomaly into the box (line).

6 The ocean answers back

Westerlies above 4 m s⁻¹ drove eastward currents and a downwelling Kelvin wave: the thermocline deepened and sea level rose in the eastern Indian Ocean. The warm, deep mixed layer limited SST cooling and kept convection going — a two-way coupling.

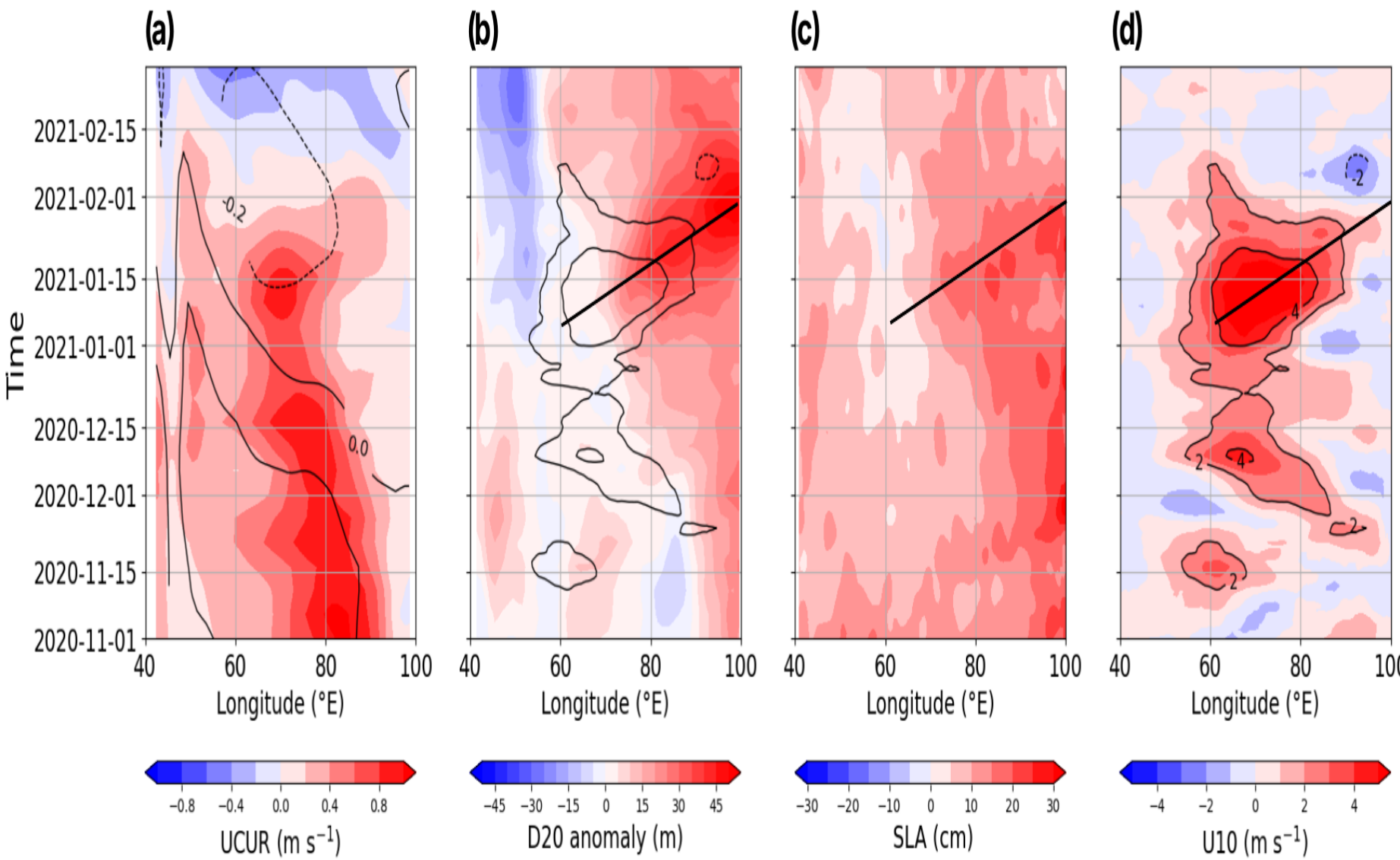


Fig. 6 Lon-time evolution of (a) 0–100 m zonal current, (b) D20 anom, (c) sea level anom, (d) U10.

7 A rare January wind burst

Indian Ocean WWBs cluster in April–May and September–November; one on 13 January is exceptional. In January 2021, U850, D20 and upper-ocean heat content over the eastern IOD pole all stand out from the record.

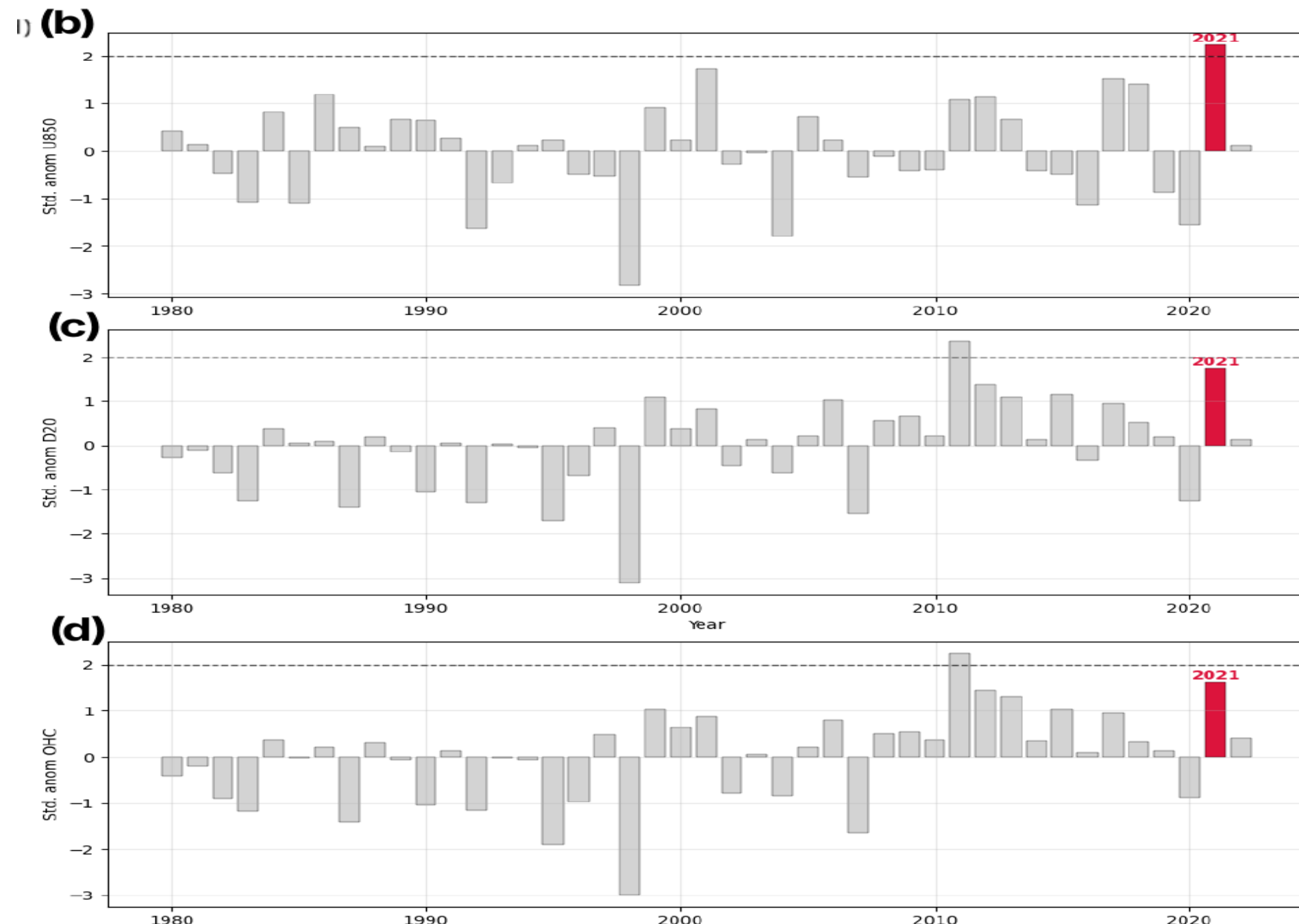


Fig. 7 (b–d) standardised U850, D20 and OHC anomalies, eastern IOD pole; 2021 highlighted.

8 Was it predictable?

IITM ERPASv1 captured the wet spell and the MJO's eastward march with useful lead time, though the MJO was slow and weak at long leads.

Eq. wind skill has an ACC of about 0.8 at short lead

At 9–16 days, the burst's peak was underestimated (about 4 against 6 m s⁻¹), as was rainfall magnitude.

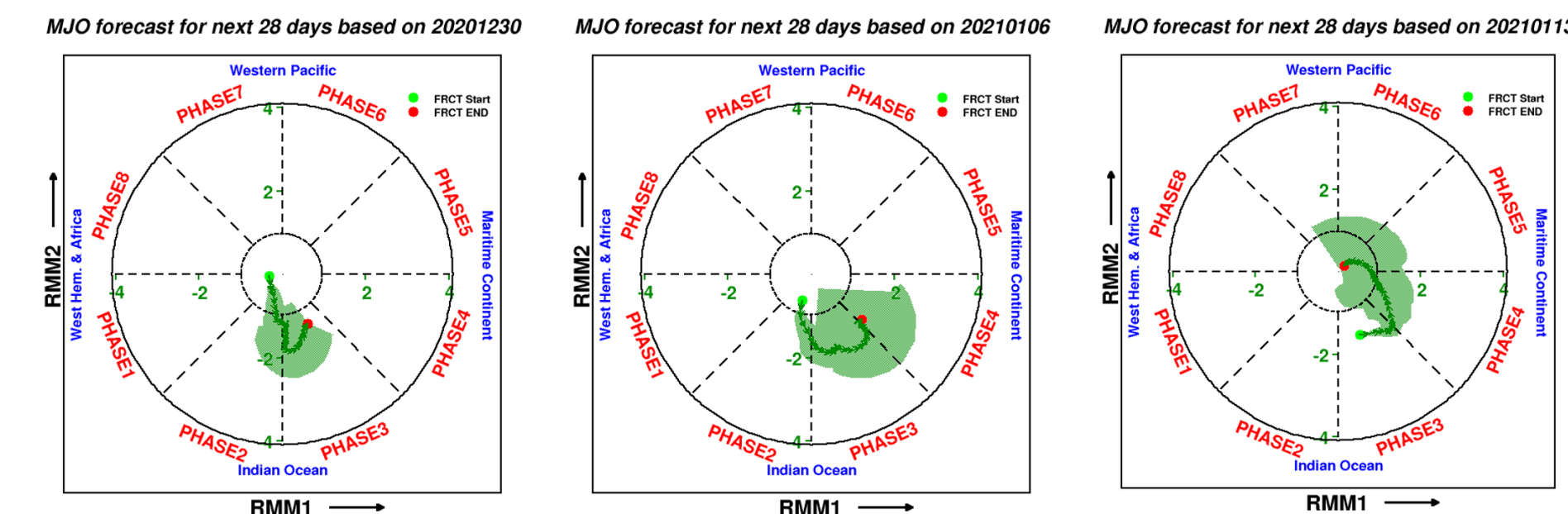


Fig. 8 ERPASv1 MJO forecasts initialised 30 Dec 2020, 6 Jan and 13 Jan 2021.

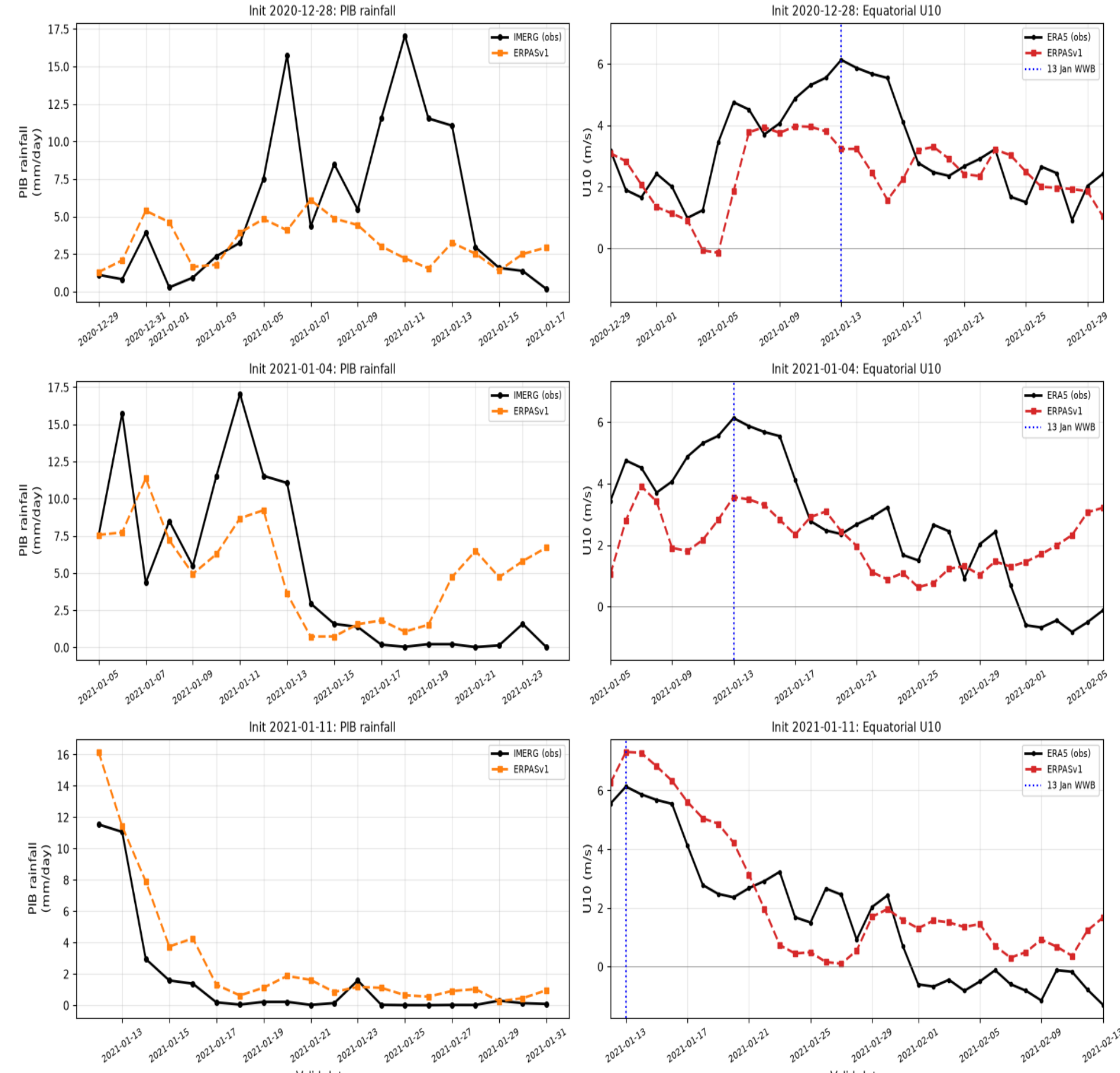


Fig. 9 PIB rainfall (left) and equatorial U10 (right): ERPASv1 forecasts against observations for three initializations.

Conclusions

- Record January 2021 rain came from MJO Phase 3, embedded Kelvin waves, and a rare wind burst acting together.
- A downwelling oceanic Kelvin wave deepened the thermocline and warmed the upper ocean, sustaining convection.
- The convection then moved east, bringing floods and landslides to Indonesia and the Philippines.
- Subseasonal forecasts caught the event with useful lead; wind was predicted better than rainfall.
- Such MJO-linked extremes are projected to intensify with warming: monitor the MJO, equatorial winds and ocean preconditioning.