

Region-Dependent Aerosol Association on Clouds and Rainfall over India during the Summer Monsoon

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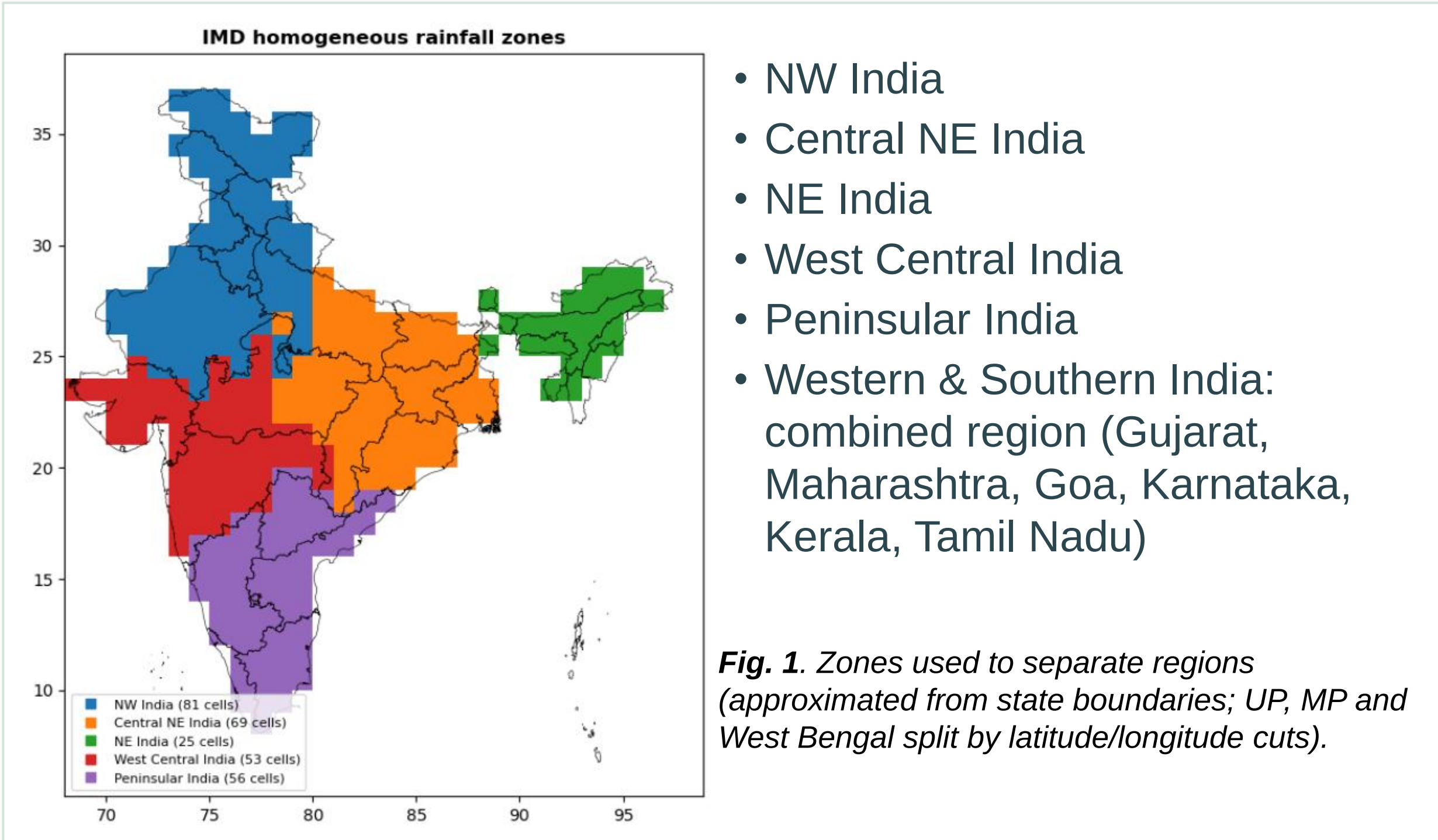


WHY THIS MATTERS

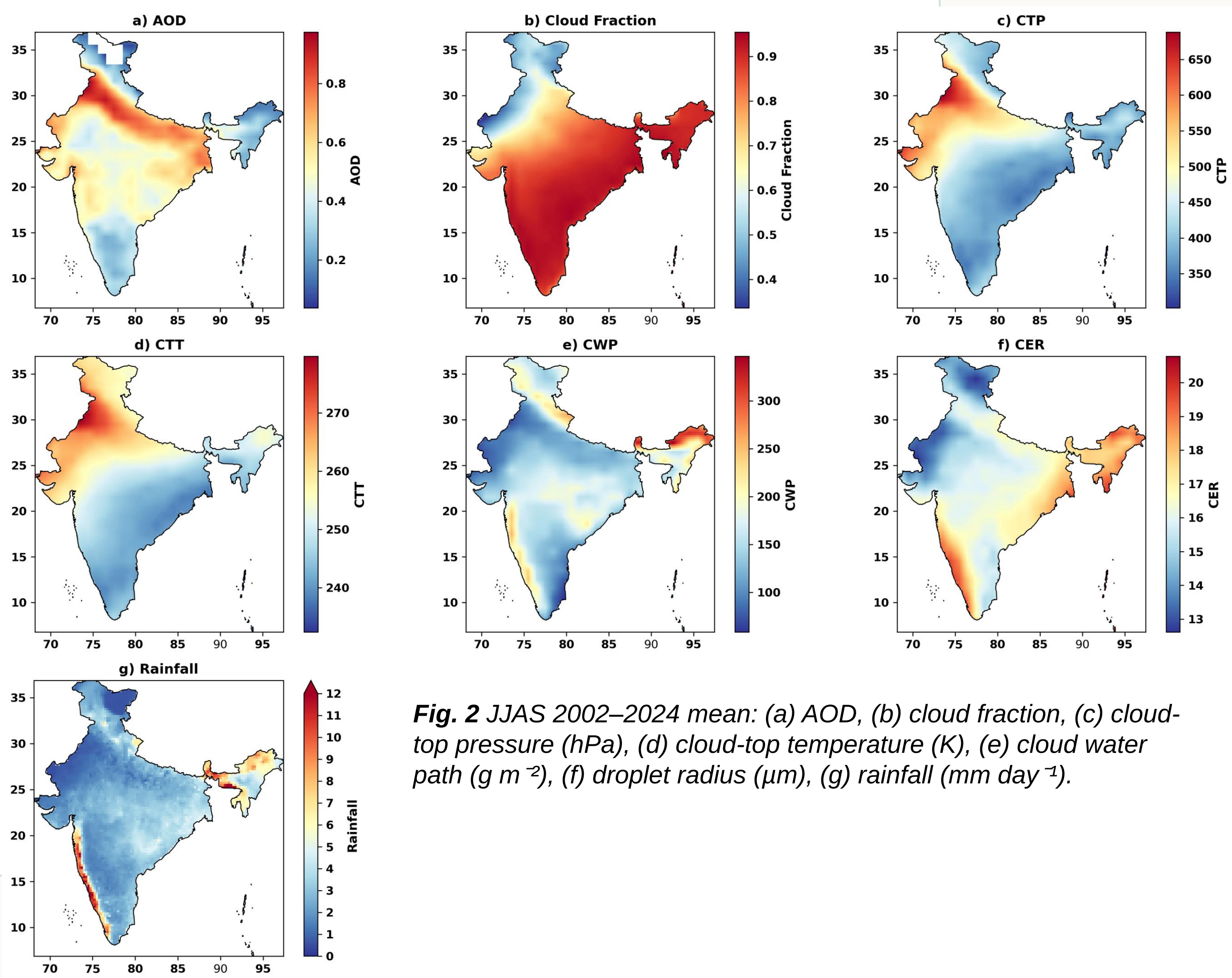
- India has some of the highest aerosol loads on Earth (Lau et al., 2006; Dey & Di Girolamo, 2010), yet their effect on monsoon clouds and rain is still debated.
- Smaller droplets can suppress rain (Twomey, 1977; Albrecht, 1989), while deeper convection can invigorate it (Rosenfeld et al., 2008; Fan et al., 2016).
- Monsoon-wide analysis finds a positive aerosol–cloud–rainfall link (Sarangi et al., 2017). Does it hold in every sub-region?

DATA & METHOD

- MODIS Aqua L3 aerosol and cloud properties (Platnick et al., 2017) + IMD gridded rainfall (Rajeevan et al., 2006; Pai et al., 2014), 1° × 1°, JJAS 2002–2024
- Mainly IMD homogenous regions and a western and southern Indian box.
- Filters: AOD ≤ 1, CTP < 850 hPa, rainfall > 0. Grid points sorted by AOD into 20 equal-sample bins; bin-median of each variable (Sarangi et al., 2017)



Clouds and rain peak where aerosol does not



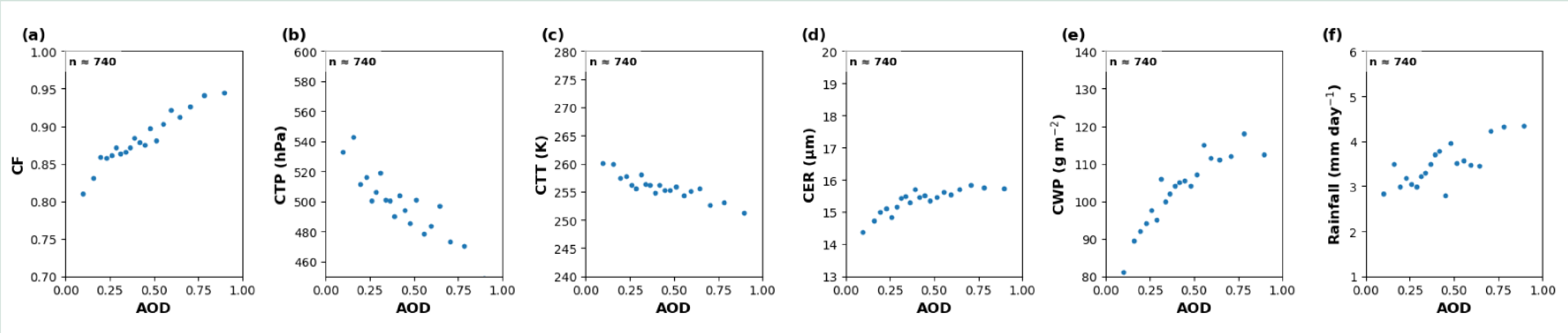
- AOD peaks over the Indo-Gangetic Plain and NW India (0.7–0.9) (Lau et al., 2006; Dey & Di Girolamo, 2010).
- Cloud fraction is highest (>0.8–0.9) over Central and South India, where cloud tops are also highest and coldest (CTP ≈ 350–450 hPa, CTT ≈ 240–250 K).
- Rainfall peaks (>8 mm/day) over the Western Ghats and NE India (Gadgil, 2003).
- This mismatch shows that large-scale monsoon dynamics, not aerosol, set the mean pattern, so aerosol effects must be read region by region.

Opposite responses: invigoration in the west–south, suppression in the north-east

WESTERN & SOUTHERN INDIA

Invigoration

- Deeper, colder clouds
- More cloud water
- Slightly larger droplets
- Rainfall rises (≈2.8 → 4.3 mm/day)
- Consistent with invigoration (Rosenfeld et al., 2008)



NORTH-EAST INDIA

Suppression

- Smaller droplets (Twomey effect; Twomey, 1977)
- Less cloud water
- No clear rainfall gain

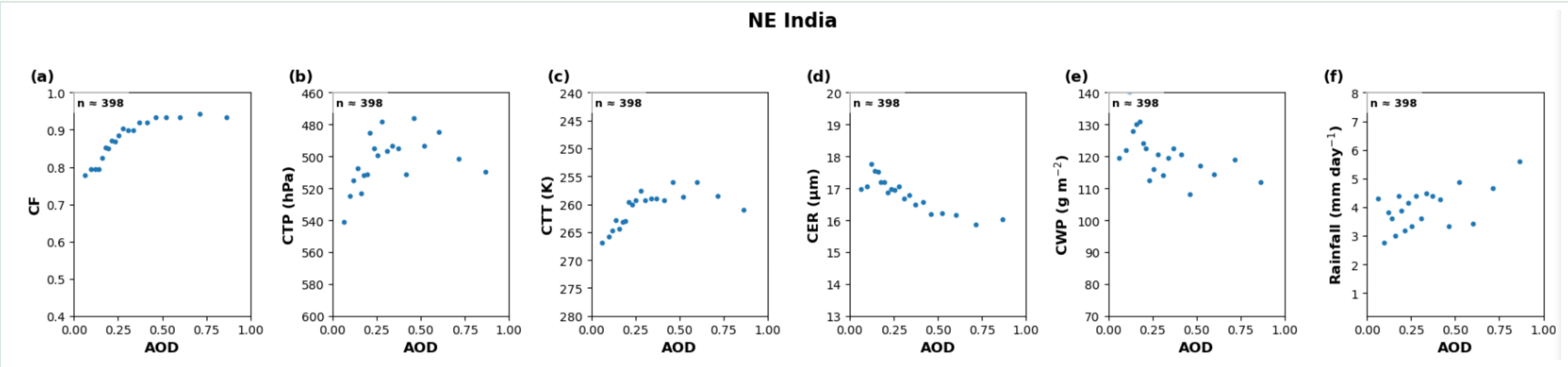


Fig. 3 & 4. Bin-median (a) cloud fraction, (b) cloud-top pressure, (c) cloud-top temperature, (d) droplet radius, (e) cloud water path and (f) rainfall versus AOD for Western & Southern India (Fig. 3, n ≈ 740) and NE India (Fig. 4, n ≈ 398).

KEY FINDINGS

- Cloud fraction increases with AOD in every zone, but cloud-depth and droplet responses differ from zone to zone.
- Rainfall rises with AOD most clearly over Western & Southern India, where clouds deepen and hold more water. Over NE India, smaller droplets and less cloud water come with no clear rain gain.

Aerosol effects on the monsoon are regional, not uniform.

Associations only: meteorology also varies with AOD. Peninsular and West Central zones show deeper clouds with little rain change; NW and Central NE show weak rainfall response. The South vs East India contrast also appears in the box-region analysis of the project report (Salva, 2026), where rainfall–AOD links were more regriding-sensitive than cloud links.

ACKNOWLEDGEMENTS

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