

Comprehensive Evaluation of COSMIC-2 Radio Occultation Thermodynamic Profiles over Monsoon-Dominated India

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6+ years

COSMIC-2 (C2) record
Oct 2019 – Dec 2025

43 stations

Radiosonde(RS) network in
7 climatic regions

±1–2 K

temperature difference
vs. radiosondes

$r > 0.95$

above 10 km
(T and refractivity)

$< \sim 5$ km

where refractivity & RH
uncertainty concentrates

Abstract

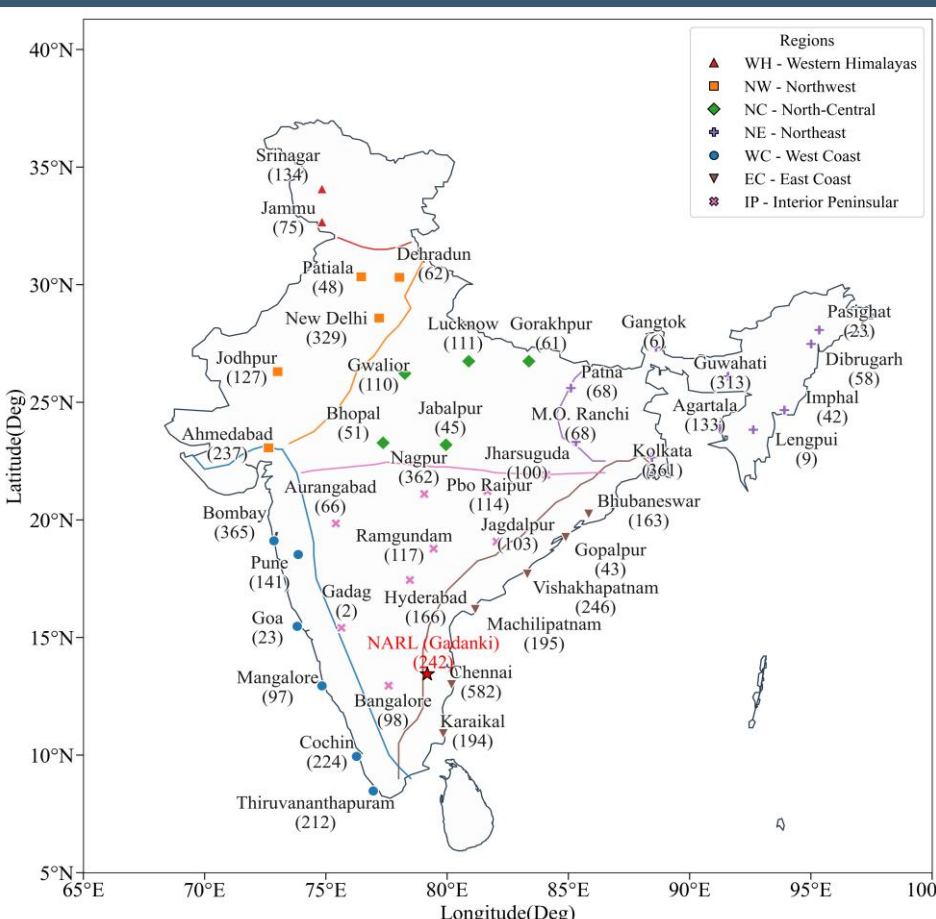
We assess the second-generation COSMIC-2 (C2) radio occultation constellation over monsoon-dominated India using radiosondes (RS) and ERA5 for October 2019 – December 2025. We combine a Gadanki case study, 43 RS stations in seven climatic regions and ERA5 maps. Temperature is the most robust variable (differences within $\pm 1-2$ K; $r > 0.95$ above ~ 10 km). Refractivity shows a systematic negative lower-tropospheric difference, and relative humidity shows the largest seasonal and regional variability below ~ 5 km, especially during the monsoon. C2 captures the broad spatial and seasonal structure of ERA5 temperature and humidity.

1 Introduction & Objectives

C2 performance in India's monsoon environment remains poorly characterised. We evaluate it at three scales:

- **Gadanki:** profile-level C2–RS evaluation of refractivity, temperature and RH
- **Regional:** seasonal C2–RS differences across seven homogeneous climatic regions
- **Spatial:** C2–ERA5 bias, RMSE and correlation at multiple pressure levels

2 Study area



3 Data & Methods

- **COSMIC-2** (CDAAC NRT Level-2): atmPrf (Abel refractivity, dry T) and wetPf2 (1D-Var T, RH)
- **Radiosondes:** NARL Gadanki (since 2006) and 43 WMO stations (Univ. Wyoming); range-based QC
- **Common grids** (0–40 km): 200 m (N, T), 100 m (RH); median + mean filters
- **Regions** WH, NW, NC, NE, WC, EC, IP
- **ERA5:** 0.25° regrid to 2.5°; T at 200–10 hPa, RH at 925–300 hPa

$$N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2}$$

P: pressure, e: water-vapour pressure (hPa);
T: temperature (K)

4 Collocation & Quality Control

Tangent point within $\pm 1^\circ$
lat/lon

With in ± 2 h of 00/12 UTC
launch

Closest pair if multiple
occultations

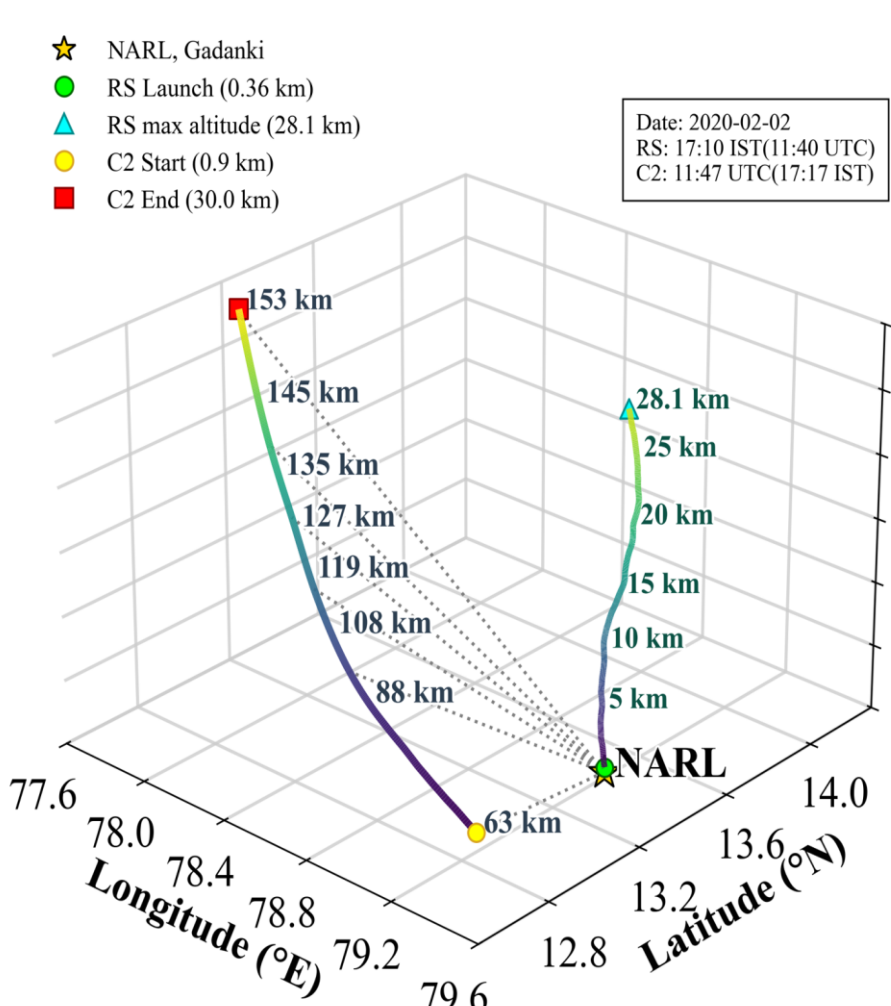
Level-wise 3σ outlier
screening

$$\Delta X(\%) = \frac{X_{C2} - X_{RS}}{X_{C2}} \times 100$$

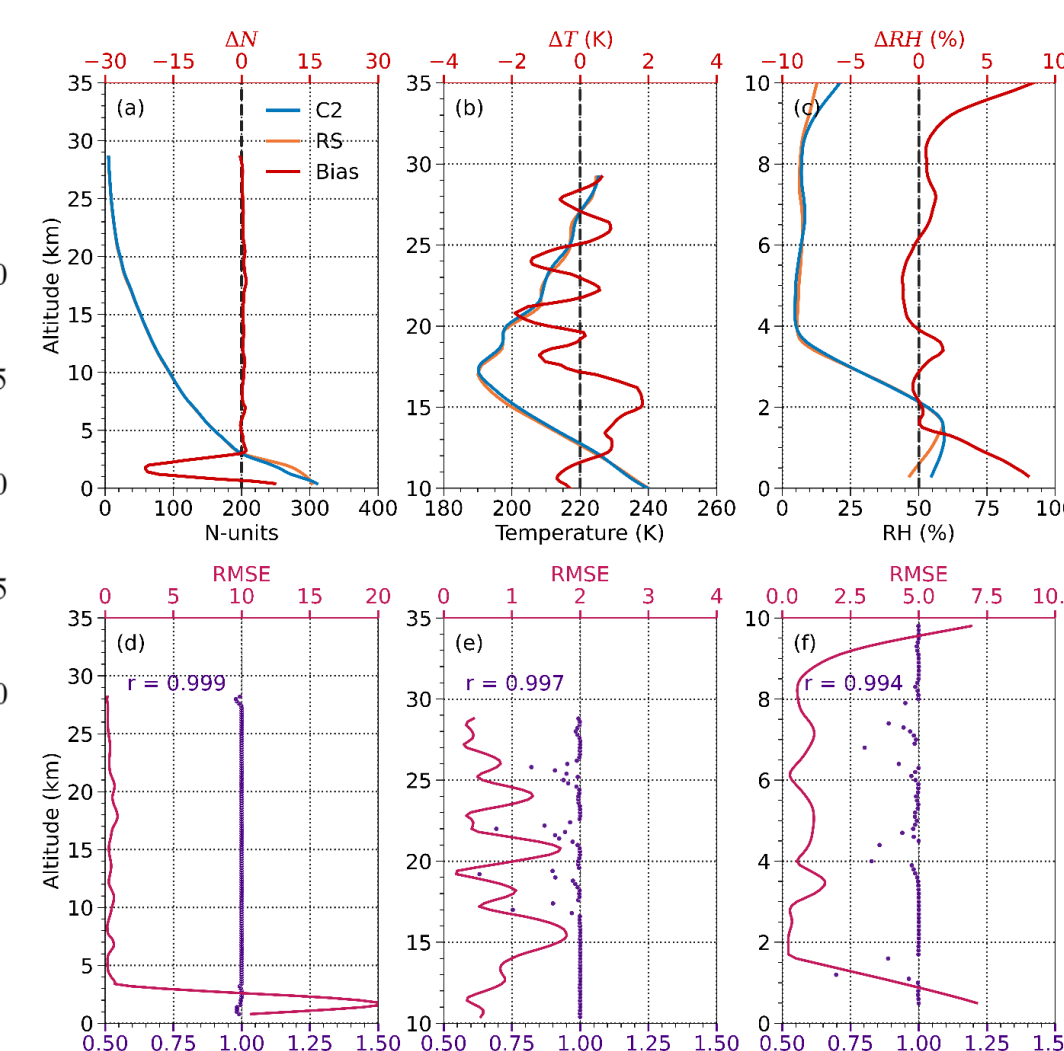
Profiles are retained only if N, T and RH all pass QC, giving one consistent sample. C2 is assimilated in ERA5, so ERA5 results are a **consistency check, not independent validation**.

5 Case Study: NARL Gadanki, 2 Feb 2020

Radiosonde flight trajectory
and cosmic occultation path.



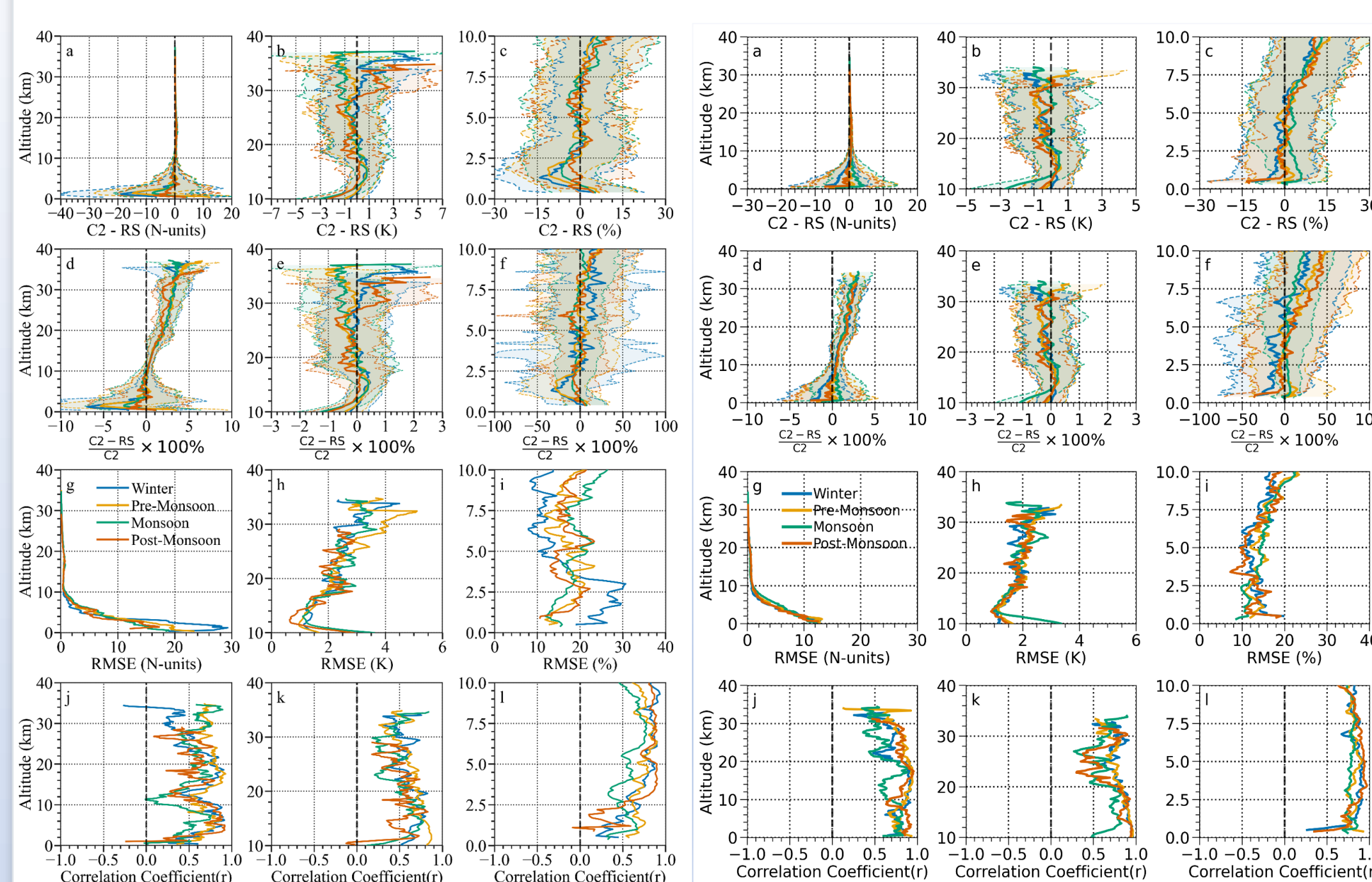
Profile comparison



- RS launched 11:40 UTC (0.36–28.1 km); C2 event 11:47 UTC (0.9–30 km): only **~7 min apart**
- Horizontal separation grows from **~63 to ~153 km** with altitude: different air volumes are sampled

6 Seasonal-COSMIC Vs Radiosonde (Gadanki & NC)

Seasonal Statistics Gadanki and North central India



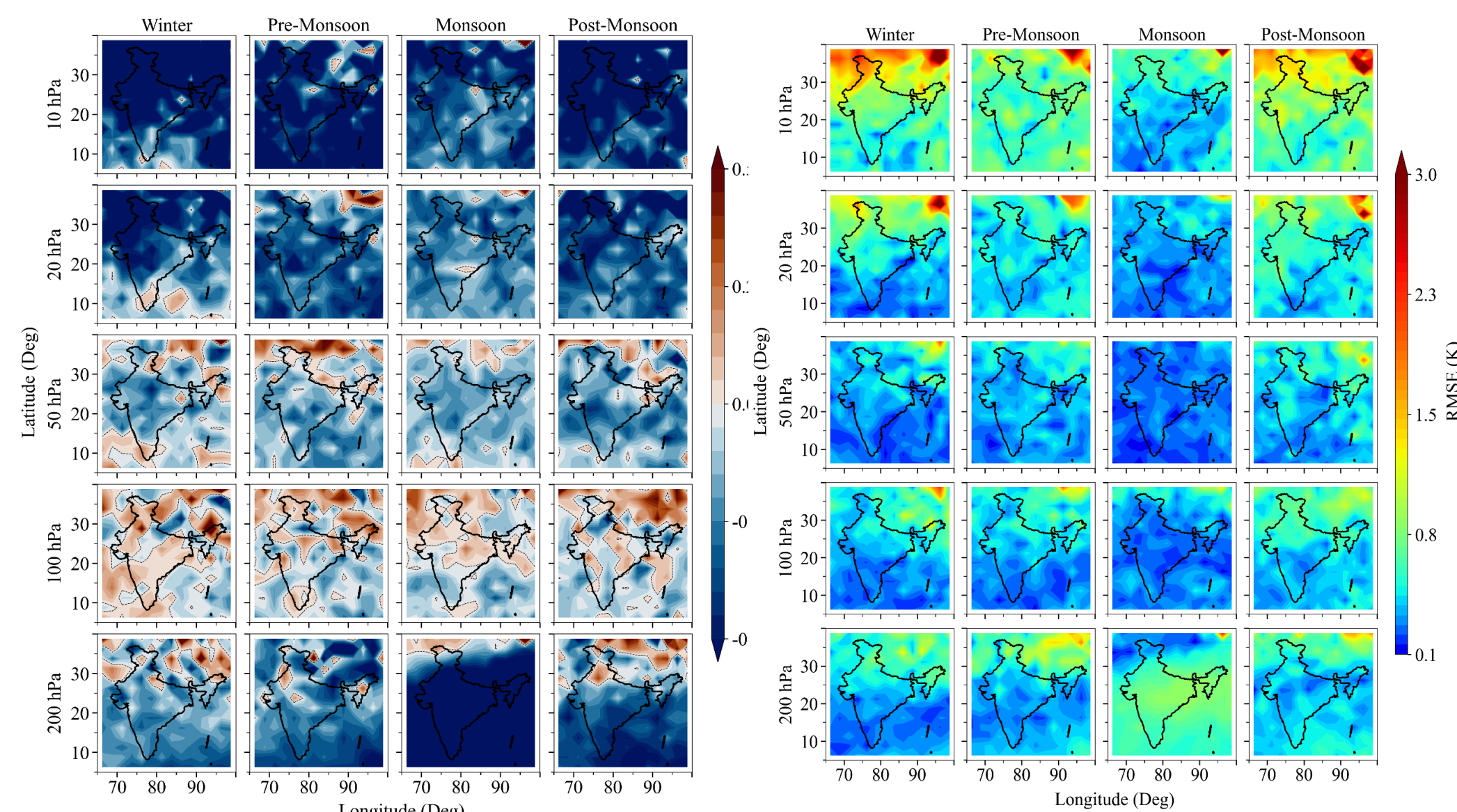
- **N:** largest differences in lowest 2–3 km, bias $\rightarrow 0$ above ~ 5 –10 km;
- **T:** within ± 1 K at 10–40 km
- **RH:** largest spread below 5 km, structure still captured

7 Seven-Region Synthesis (43 stations)

Variable	Upper levels (> 10 km)	Lower troposphere (< 5 km)
Temperature	Within $\pm 1-2$ K; $r > 0.95$; weak regional or seasonal dependence	RMSE increases towards the surface
Refractivity	Bias $\rightarrow$ close 0; fractional difference mostly within 10%	C2 lower by ~ 5 –10 N-units; $< -20\%$ and RMSE ~ 20 –30 N in monsoon
Relative humidity	Structure well captured	Bias ~ 50 to $+100\%$; RMSE up to $\sim 40\%$; $r < 0.8$; peaks in monsoon and post-monsoon

8 COSMIC2 vs. ERA5: Temperature (200–10 hPa)

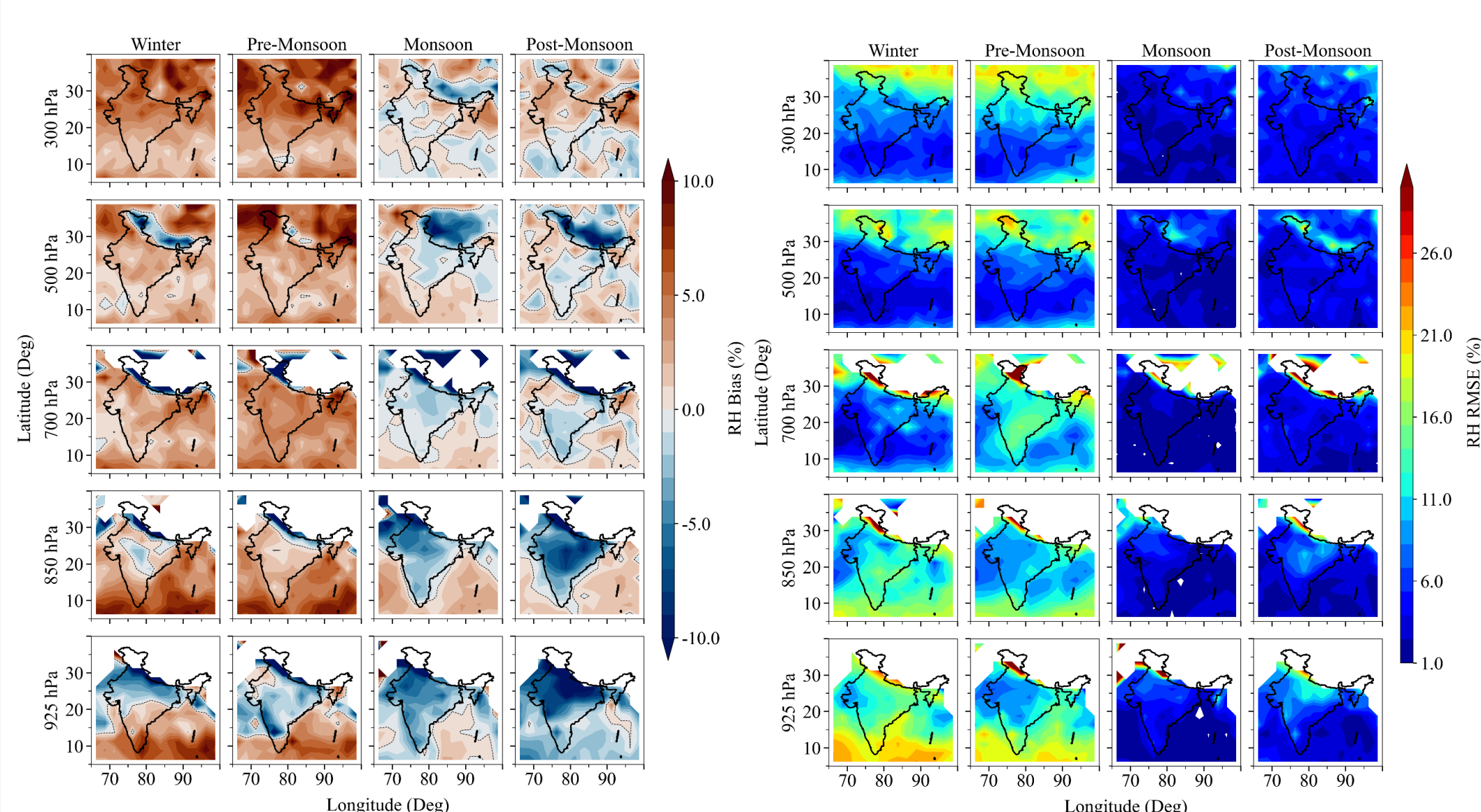
Spatial Seasonal variation-Bias & RMSE



- Differences are small (± 0.5 K colour scale); **most coherent near 50 hPa**
- More regional variability at 100–200 hPa in monsoon (deep convection, latent heating)
- More heterogeneous at 10–20 hPa (ionospheric effects, retrieval uncertainty)

9 COSMIC2 vs. ERA5: Relative Humidity (925–300 hPa)

Spatial Seasonal variation-Bias & RMSE



- Bias is most variable at **925 and 850 hPa** (boundary layer, land–sea contrast, convection)
- Bias and RMSE become more coherent at 700–500 hPa
- **Monsoon is the most challenging season**; winter shows the closest agreement

10 Conclusions

- **Gadanki:** C2 reproduces the vertical structure of refractivity, temperature and RH, best above the lower troposphere.
- **Lower-tropospheric refractivity:** C2 is systematically lower than RS near the surface, more so in the monsoon and over moisture-rich regions.
- **Temperature:** small differences across all seven regions, $r > 0.95$ above ~ 10 km, weak seasonal and regional dependence.
- **Humidity:** greatest RH variability below ~ 5 km, especially in monsoon and post-monsoon.
- **ERA5 supports the regional findings:** C2 captures the broad spatial and seasonal evolution of T and RH; largest differences are in heterogeneous lower-tropospheric environments.
- **A valuable resource for India:** consistent upper-level performance and broad coverage suit monsoon, UTLS, moisture and NWP studies; lower-troposphere use needs careful treatment of uncertainty and representativeness.

Overall: a multi-scale observational baseline for C2 over India; reliable vertically resolved information across diverse environments, with limitations concentrated in the moist, variable lower troposphere.

Graphical Abstract: How well does COSMIC-2 observe the atmosphere over India?

EVIDENCE BASE

Gadanki case study
RS vs. C2, profile level

43 RS stations

7 climatic regions, seasonal

ERA5 comparison

T 200–10 hPa · RH 925–300 hPa

PERFORMANCE vs. ALTITUDE

UTLS & free troposphere (> 10 km)
T $\pm 1-2$ K · $r > 0.95$ · refractivity bias $\rightarrow 0$

Middle troposphere (~ 5 –10 km)
Good agreement; ERA5 RH coherent at 700–500 hPa

Lower troposphere (< 5 km)
N: ~ 5 to ~ 10 N-units · RH: ~ 50 to $+100\%$, RMSE $\leq \sim 40\%$

APPLICATIONS

Suitable: NWP assimilation & UTLS
monitoring

Suitable: monsoon & tropical
atmosphere studies

Caution (boundary layer): apply QC,
representativeness checks and bias
correction

Key references: Schreiner et al. (2020) GRL 47:e2019GL086841; Anthes et al. (2008) BAMS 89:313; Kuo et al. (2005) GRL 32:L05817; Rao et al. (2009) TAO 20:59; Singh et al. (2021) JGR 126:e2021JD034935; Shao et al. (2021) TAO 32; Rieckh et al. (2018) AMT 11:3091; Hersbach et al. (2020) QJRM 146:1999.

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