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A Comparative Study on Wet Atmospheric Profiles Using KOMPSAT-5 and COSMIC Radio Occultation Data over Indian Region

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A comparative assessment of wet atmospheric profiles is conducted using data from the Korea Multi-Purpose Satellite-5 (KOMPSAT-5) and the Constellation Observing System for Meteorology, Ionosphere, and Climate(COSMIC) radio occultation (RO) to validate the KOMPSAT-5 profiles over the Indian region. KOMPSAT-5 and COSMIC wet atmospheric profiles for the year 2019 are compared, providing 29 overlapping locations that satisfy the spatial and temporal matching criteria of a 3° grid and a 3-hour window, respectively, from the surface up to 40 km altitude. The results show that the mean differences in pressure, temperature, vapour pressure, and refractivity are 0.16 hPa, 0.17 °C, -0.03 hPa, and -0.097, respectively. A relatively large temperature mean difference of nearly 3 °C is found over sea surface locations in the southern Indian region and at a location in western India. In contrast, the mean pressure difference is observed to be around 2 hPa at a location in eastern India. Vertically averaged mean differences and root mean square errors (RMSEs) for different altitude intervals from the surface to 20 km are also calculated and discussed in detail. These show greater variations in pressure, vapour pressure, and refractivity at lower altitudes, while temperature differences are more pronounced at higher altitudes. Validation of KOMPSAT-5 temperature and pressure profiles with radiosonde observations is also carried out, showing mean errors of less than 1 °C and 1 hPa, respectively. From the analysis, it is concluded that KOMPSAT-5 profiles closely match both COSMIC and radiosonde profiles and can be reliably used along with other RO datasets for various atmospheric studies over this region.

Keywords: Radio Occultation, Atmospheric profiles, COSMIC, KOMPSAT-5

1 Introduction

Radio Occultation (RO) is a modern atmospheric sounding technique in which signal bending angle information is used to estimate atmospheric pressure, temperature, and water vapour. Navigation satellites orbit the Earth at an altitude of approximately 20,000 km above the surface, continuously transmitting radio signals. These signals are affected by electron density in the ionosphere and by temperature, pressure, and water vapour in the troposphere. In the RO method, Low-Earth Orbit (LEO) satellites measure the phase of Global Positioning System (GPS) signals as they rise or set relative to the GPS satellites. From this phase information, the Doppler-shifted frequency is computed, which is then used to derive the bending angles of the radio waves. Atmospheric refractivity is retrieved using these bending angles. This refractivity depends on ionospheric electron density as well as atmospheric temperature, pressure, and water vapour. Various LEO satellites equipped with GPS receivers are operational and provide global RO data. COSMIC, CHAMP, SAC-C, and KOMPSAT-5 are some of the satellite missions that offer continuous RO observations worldwide. The retrieved data and derived products from these satellites are regularly compared and validated at both regional and global levels using other remote-sensing satellite products and in-situ measurements.

Various studies have been performed to evaluate the quality of RO datasets retrieved from different missions like COSMIC, CHAMP SAC-C. RO datasets have been validated using radiosonde observations at different locations and found very close to each other. Kuo *et al*. described the inversion process and evaluated the accuracy of refractivity soundings of the CHAMP and SAC-C satellites and compared them with radiosonde data and showed that RO soundings have smaller observational errors of refractivity[1]. He *et al*. and Zhang *et al*. investigated the COSMIC temperature profiles with radiosonde datasets and found that both datasets are in good agreement[2,3]. Sun *et al*. compared the radiosonde and COSMIC atmospheric profiles to quantify the error

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characteristics of 12 radiosonde types and to determine the effects of imperfect temporal and spatial collocation on comparison statistics[4]. Wang *et al*. assessed the COSMIC RO product using global radiosonde data with matching criteria that the radio occultation event should be within 100 km of the radiosonde station and take the 1-hour time window[5].Santhi *et al*. presented the global morphology of stability indices using COSMIC RO satellite measurements[6]. They have used ground-based GPS radiosonde observations for validation. Xu *et al*. assessed the accuracy of COSMIC RO observations with radiosonde observations over China[7]. They compared the COSMIC retrieved profiles with radiosonde profiles from 120 stations and found a mean bias of -0.10 °K, 0.69 hPa, and -0.01 hPa in temperature, pressure, and vapour pressure respectively.

Different reanalysis products and satellite datasets are also used to validate RO profiles. The results from different studies show that RO-derived profiles are very close to the reference datasets. Rocken *et al*. analysed and validated the GPS/MET data in a neutral atmosphere with NCEP/ECMWF profiles[8]. Kishore *et al*. validated the COSMIC RO temperature datasets with the NCEP, and JRA-25 reanalysis datasets and with datasetsfrom United Kingdom Met Office (MetO)[9]. They found that NCEP data sets have better resemblance with COSMIC datasets. Lin *et al*. studied the GPS RO profiles under cloudy and clear sky conditions and compared them NCEP and ECMWF reanalysis data[10]. Das and Pan validated the level 2 global temperature data in the stratosphere with SABER/TIMED and MLS/Auraand showed that COSMIC atmPrf" data are of good quality and provide a reliable large number of profiles at greater temporal and spatial resolutions[11].Shangguan *et al*. validated the COSMIC water vapour data in the upper troposphere and lower stratosphere (UTLS) using MERRA and ERA-Interim reanalysis data[12].

These RO datasets have been used in various atmospheric studies. Santer et al. studied the variations in surface temperature in tropical atmospheres and their variability[13]. Ho *et al*. calibrated the lower stratosphere temperature from microwave measurements using COSMIC RO data[14]. Tsuda *et al*. analysed the vertical wave number spectrum of atmospheric gravity waves in the stratosphere by applying full spectrum inversion on COSMIC GPS radio occultation profiles[15]. Scherllin *et al*. have investigated the vertical and spatial structure of ENSO using radio occultation data within the troposphere and lower stratosphere up to 20 km[16]. Biondi *et al*. used GPS radio occultation data and studied thermal structure and conditions for the overshooting of tropical and extratropical cyclones[17]. Awange *et al*. examined the interannual variability of upper tropospheric and lower stratospheric temperature over the Ganges–Brahmaputra–Meghna (GBM) river basin using monthly averaged COSMIC radio occultation (RO) data[18].

One side, several studies are carried out using COSMIC, CHAMP, SAC-C mission's datasets, other hand very few studies are available using KOMPSAT-5 datasets and it has very limited applications. KOMPSAT-5 is developed by KARI (Korean Aerospace Research Institute) and was launched on 22 August 2011. Hwang *et al*. proposed a methodology for orbit determination for KOMPSAT-5 based on differential GPS technique[19]. Lee *et al*. simulated RO measurements from KOMPSAT-5 and retried atmospheric profiles[20]. Lee *et al*. again simulated the electron density profile for the KOMPSAT-5 radio occultation system using KROPS software[21]. KOMPSAT-5 generates the atmospheric sounding profile using AOPOD (atmospheric occultation and precision orbit determination) payload which is composed of a dual frequency GPS receiver and a laser retroreflector array (LRRA) Choi *et al*[22]. Shin *et al*. carried out a space weather study and examined the retrieval techniques for the temperature, humidity, electron density and scintillation of ionosphere[23].

On a particular day, a higher number of impact points from RO data may be required to conduct atmospheric studies or perform accurate weather forecasting. COSMIC provides an average of 400–500 distributed impact points per day across the Indian region. This number can be increased by incorporating impact points from other RO missions, thereby creating a denser observational network. Considering this, the present study evaluates the accuracy of KOMPSAT-5 RO data over the Indian region. Since COSMIC datasets are validated with radiosonde and other datasets in several studies and it is also used in various atmospheric analysis over Indian region, a comparative analysis has been carried out using temperature, pressure, vapour pressure, and refractivity profiles from the KOMPSAT-5 and COSMIC datasets. The analysis focuses on 29 geographically distributed locations across India, where initial impact points from both satellites are close to the surface and fall within a 3°×3° latitude-longitude grid and a 3-hour mistime difference. Mean difference and root mean square error (RMSE) were estimated for individual locations, combined, and along with the different altitude interval ranges to assess the accuracies. Several studies have been carried out to assess the quality of COSMIC data and its derived products and its datasets are also validated using reanalysis, and in-situ datasets, considered as reference datasets in the present study[5,12]. Radiosonde observations are also used to compare and validate the temperature and pressure profiles of KOMPSAT-5.

2 Data Description

In the RO data retrieval process, the refractivity profile at the occultation point is calculated using the phase and amplitude information. This refractivity is further used to derive profiles of temperature, pressure, vapour pressure, and the information is mainly stored in two types of files. The atm Prf files contain a moisture-free atmospheric profile, such as dry pressure, dry temperature, refractivity, bending angle, impact parameter, etc., with geometric height above mean sea level from the surface to 60 km. Similarly, wetPrf files contain the wet temperature, wet pressure, vapour pressure, and refractivity atmospheric profiles; interpolated from the atmPrf file and the global data. KOMPSAT-5 and COSMIC-2 (COSMIC) data are extracted from the University Corporation for Atmospheric Research (UCAR)'s COSMIC Data Analysis and Archive Center (CDAAC) for the study area, spread from latitudes 8° to 37° and longitudes 68° to 97° for the year 2019[24]. Pressure, temperature, vapour pressure, and refractivity data at different altitudes are taken for the analyses from both sources. Temperature and pressure profiles from radiosonde are also taken from the repository of the University of Wyoming for validation[25].

3 Methodology

In this analysis, the matching approach is adopted to check the validity of occultation data from KOMPSAT-5 and COSMIC by looking for simultaneous occultation events from KOMPSAT-5 and COSMIC within 3° latitude-longitude variability at each altitude and find 3 hours of mistime for complete available days of 2019 in the Indian Grid. The misdistance and mistime values are taken based on previous studies carried out on COSMIC and radiosonde profiles comparison (Table 1). If there is no matching, no data is taken. In case of more than one matching profile, the profile at thelowest perigee point closest to each other is taken. Data are available at different altitudes and vertical resolution is the same for KOMPSAT-5 and COSMIC satellite data. A total of 29 overlapping locations are found which have starting altitudes very near to the surface and vertically extend greater than 20 km as shown in Fig. 1. There are 200-400 altitude levels at each overlapping occultation location. The mean differences (MD) and root mean square error (RMSE) for every parameter (refractivity, temperature, pressure, and vapour pressure) are calculated and analysed between the KOMPSAT-5 and COSMIC profiles. In the current study, the biases and RMSEs between COSMIC and KOMPSAT-5 profiles in vertical means from 0 to 40 km are also estimated to assess the regional differences over the Indian region. For validation of KOPMSAT-5 profiles with radiosonde profiles, radiosonde stations are selected within the 2° of overlapping locations.

The mean difference and RMSE between both the datasets are studied for comparison[26].
Deviation is estimated using following equation

$$\Delta x_i = x_i^1 - x_i^2 , where\ i = 1,2,3, \dots , n \qquad ...(1)$$

Table 1 — Data matching method for COSMIC and KOMPSAT profiles

Authors	Mistime (Hour)	Misdistance (km.)
He *et al*. (2009)	2	300
Sun *et al.* (2010)	6	250
Zhang *et al*. (2011)	3	300
Wang *et. al*. (2013)	1	100
Guirong *et. al*. (2017)	2	300

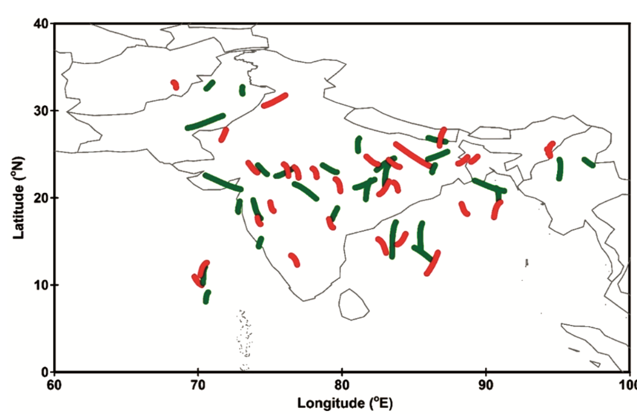

Fig. 1 — Occultation points of COSMIC (red) and KOMPSAT-5 (green) over Indian region

TheMD is given by

$$MD_{\Delta x} = \frac{1}{n}\sum_{i=1}^{n}\left(x_{i}^{1} - x_{i}^{2}\right) \quad ...(2)$$

And the RMSE is calculated using

$$RMSE_{\Delta x} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{i}^{1} - x_{i}^{2})^{2}} \quad ...(3)$$

where the superscript 1 and 2 indicate KOMPSAT-5 and COSMIC or radiosondedatasets respectively. The subscript i expresses the serial number of the altitude. $n$represents the number of altitudes. The mean difference and RMSE in individual comparisons are averaged over all altitudes to evaluate the differences between both profiles.

A statistical comparison is used to calculate the vertical profiles of MD and RMSE data that match corresponding to criteria defined below:

$$MD_{i,\Delta x} = \frac{1}{m}\sum_{j=1}^{m}\left(x_{i,j}^{1} - x_{i,j}^{2}\right) \quad ...(4)$$

$$RMSE_{i,\Delta x} = \sqrt{\frac{1}{m}\sum_{j=1}^{m}(x_{i,j}^{1} - x_{i,j}^{2})^{2}} \quad ...(5)$$

where j is the serial number of the data (there are m matching data in all).

4 Results and Discussion

An analysis is performed to validate KOMPSAT-5 RO datasets with COSMIC datasets and radiosonde observations over the Indian region. RMSE and mean difference were estimated at different altitude intervals for pressure, temperature, refractivity and vapour pressure profiles. The obtained results are discussed here in detail.

4.1 Comparison with COSMIC Datasets

4.1.1 Refractivity Profiles

The vertically averaged refractivity mean differences between KOMPSAT-5 and COSMIC observations are presented in Fig. 2. Positive mean differences are observed at 12 out of 29 locations (41%), of which 11 locations have values ranging between 0 and 1. Negative biases are observed at 17 locations (59%), with 15 of these showing mean difference values between -1 and 0. This indicates that the refractivity values from both datasets are generally close to each other. The minimum refractivity difference of -1.3 is observed at a location in western India, while the maximum difference of 1.43 occurs at a location in central India. The average refractivity bias across all locations is estimated to be -0.097. Root Mean Square Errors (RMSEs) are also computed to quantify the average magnitude of error between the KOMPSAT-5 and COSMIC refractivity profiles. Among the 29 locations, 6 (20.7%) show an RMSE of less than 1, while 9 locations (31%) have RMSE values between 1 and 2. The average RMSE is estimated to be 2.2. The minimum RMSE of 0.38 is found in the southern part of the country, while the maximum RMSE of 6.55 occurs in the western region. Refractivity is primarily influenced by atmospheric water vapour, which decreases with altitude. Therefore, greater differences are expected in the lower atmosphere. RMSEs at different altitude levels are presented in Fig. 3. From the figure, it is evident that RMSE values are higher up to the 5 km altitude range. In the central part of the country, RMSEs are relatively higher compared to other regions. A statistical test was performed to assess whether the differences in means are significant. The p-value was found to be close to zero at the 99% confidence level in all cases, indicating that the differences between the mean values are statistically significant.

4.1.2 Pressure Profiles

The mean pressure differences between the two satellite profiles are estimated for all locations. As shown in Fig. 4, 26 out of 29 locations (~90%) exhibit differences within the range of -1 hPa to 1 hPa. The maximum pressure difference of 2.2 hPa is observed at a location in eastern India, while the minimum difference of -1.3 hPa is found at a location in southeastern India. The average pressure difference across the Indian region is 0.16 hPa. Regarding the RMSE, 19 locations (65.5%) show values less than

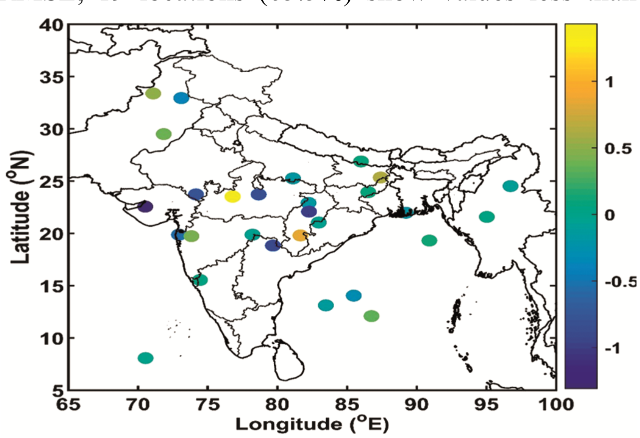

Fig. 2 — The refractivity mean differences (%) for initial to final altitudes

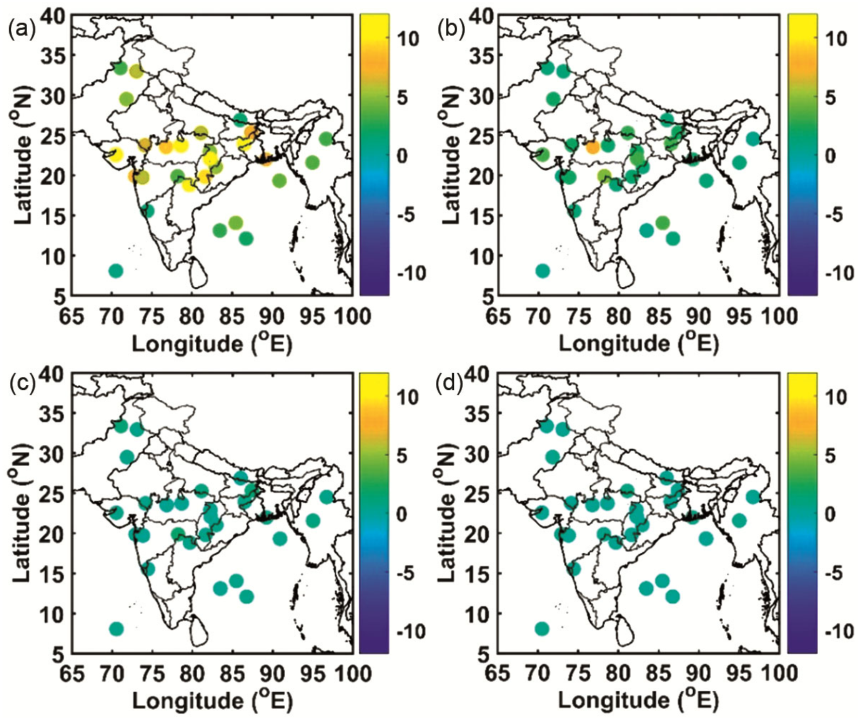

Fig. 3 — The refractivity RMSEs (%) for different altitudes (a) H < 5 km (top left) (b) 5 km <= H < 10 km (top right) (c) 10 km <= H < 15 km (bottom left) (d) 15 km <= H < 20 km (bottom right)

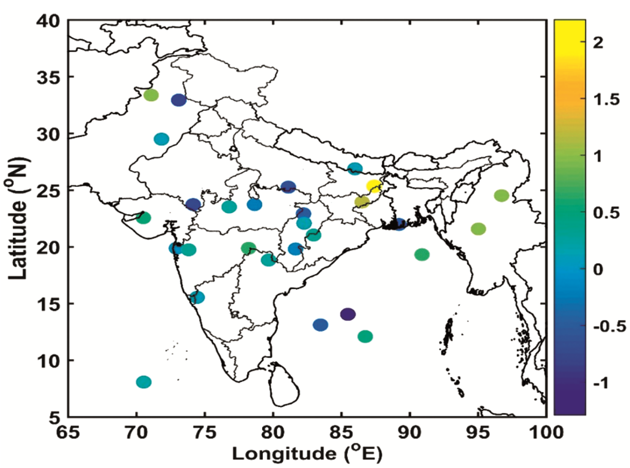

Fig. 4 — The pressure mean differences (hPa) for initial to final altitudes

1 hPa, while 7 locations (24%) fall within the range of 1 to 2 hPa. The highest RMSE of 3.22 hPa occurs at the same eastern Indian location where the maximum mean pressure difference is also recorded. Vertical RMSEs between COSMIC and KOMPSAT-5 pressure profiles are estimated for different altitude levels and are presented in Fig. 5. The results indicate that RMSE values are higher, close to 5 hPain the lower atmospheric layer (0–5 km altitude) and decrease to nearly zero at higher altitudes.A statistical test confirms that the mean pressure differences between the two datasets are significant at the 0.05 significance level.

4.1.3 Temperature Profiles

Fig. 6 represents the temperature mean differences. It can be seen that all the temperature differences vary between −2.16 °C and 3.36 °C. Out of 29 locations, 19 locations (65.5%) have differences between -1°C to 1°C. The minimum temperaturedifference of-2.16 °C occurs at a point in eastern India, and the maximum temperature difference of 3.36°Coccurs at a location in the south.The average temperature difference in India is 0.17 °C.Thereare 18 points (62%) with an RMSE of less than 2 °C, and 11 locations (38%) with an RMSE of more than 2 ºC. The minimum temperature RMSE is 0.9 °C, the maximum is 5.3 °C, and the average temperature RMSE is 2.24 °C.The temperature RMSE is minimal at lower altitudes and it is increasing with increasing altitudes except for a few cases where almost similar values are observed. The vertical profile of temperature RMSE at different altitudesis represented in Fig. 7. In this case, also, a statistical test was performed which shows that the mean differences in temperature values are significant at 0.05 significance level.

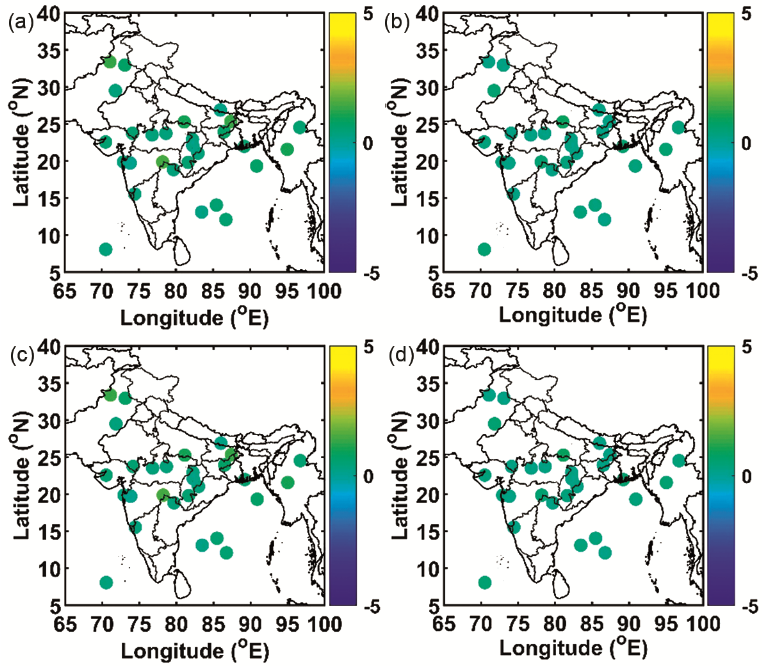

Fig. 5 — The pressure RMSEs (hPa) for different altitudes (a) H < 5 km (top left) (b) 5 km <= H < 10 km (top right) (c) 10 km <= H < 15 km (bottom left) (d) 15 km <= H < 20 km (bottom right)

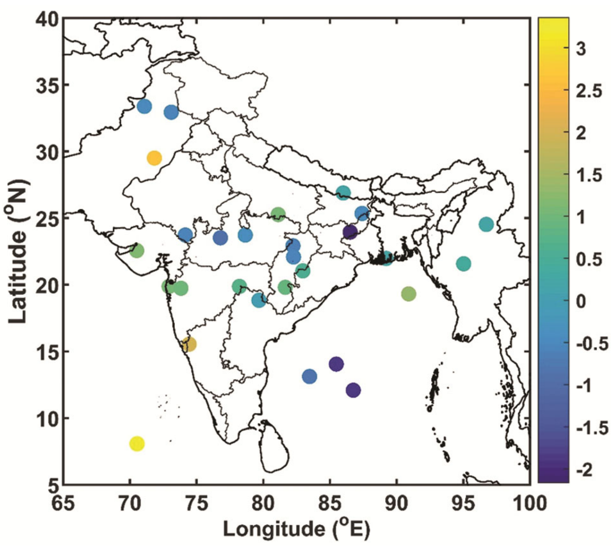

Fig. 6 — The temperature mean differences (°C) for initial to final altitudes

4.1.4 Vapour Pressure Profiles

Figure 8 presents the vertically averaged vapour pressure mean differences. The minimum difference of -0.28 hPa is observed in the western part of India, while the maximum positive difference of 0.23 hPa occurs at a location in central India. Among the 29 locations, 10 (34.5%) exhibit positive biases in the range of 0 to 1 hPa, while 19 locations (65.5%) show negative differences ranging from -1 to 0 hPa. The estimated average vapour pressure difference across all locations is -0.03 hPa. In terms of RMSE, 28 locations have values less than 1 hPa, with only one location exceeding 1 hPa. The minimum RMSE of 0.04 hPa is recorded in the southern part of the country, while the maximum RMSE of 1.4 hPa occurs in the western region. The average RMSE in vapour pressure between the KOMPSAT-5 and COSMIC datasets is estimated to be 0.43 hPa. As shown in Fig. 9, RMSE values are higher within the 0–5 km altitude range, with minimal differences observed at higher altitudes. A statistical test further confirms that the mean differences in vapour pressure profiles are significant.

4.1.5 Vertical Profiles at a Location

The inversion results for temperature, pressure, refractivity, and vapour pressure profiles from KOMPSAT-5 are found to be similar to those from COSMIC radio occultation data. Figure 10 displays these profiles for 27th October 2019, with the near-surface location at a latitude of 29.4° and a longitude of 71.4°.From the figure, it is observed that the pressure and refractivity profiles obtained from both satellites closely match. The pressure difference is around 2 hPa near the surface, gradually decreases to zero at approximately 5 km altitude, and then increases negatively, reaching -1 hPa at 10 km. This

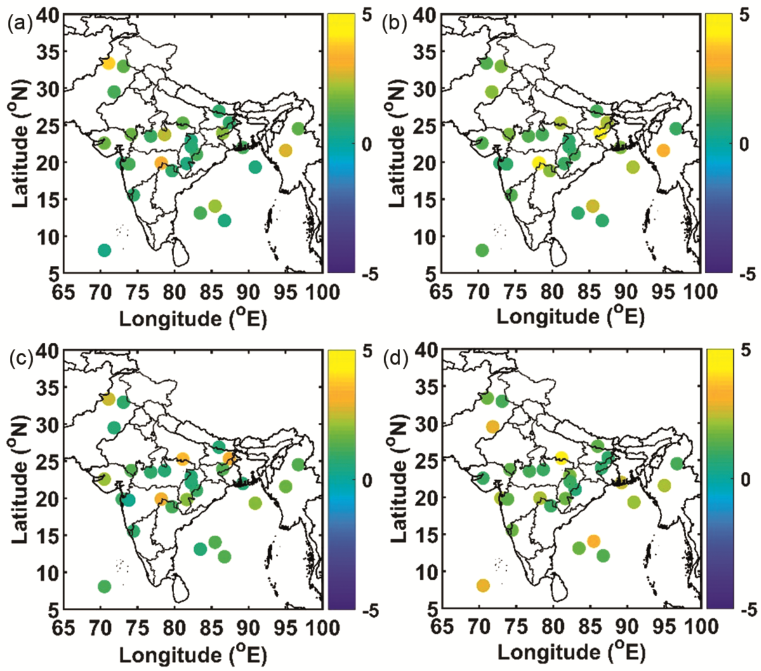

Fig. 7 — The temperature RMSEs (°C) for different altitudes (a) H < 5 km (top left) (b) 5 km <= H < 10 km (top right) (c) 10 km <= H < 15 km (bottom left) (d) 15 km <= H < 20 km (bottom right)

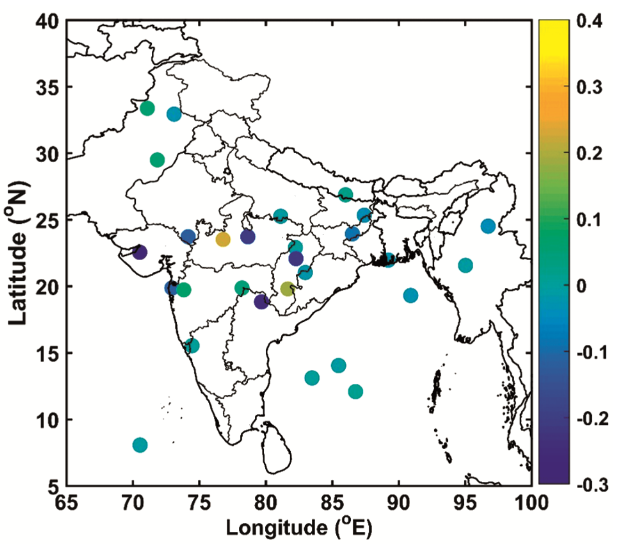

Fig. 8 — The vapour pressure mean differences (hPa) for initial to final altitudes

variation continues up to 20 km, beyond which no significant difference is observed. Similarly, for the refractivity profile, the differences remain within ±10 units, with more noticeable variation up to 5 km, stabilizing thereafter. In the temperature profile, the difference remains within 0 to 2 °C up to 10 km altitude but increases with height, reaching up to 8 °C at 40 km.The vapour pressure profile also shows differences within ±2 hPa at lower altitudes, with negligible differences at higher altitudes. Table 2 presents the mean and RMSE values for all profile differences. It can be seen that the temperature profile exhibits the highest mean difference and RMSE, while vapour pressure shows the lowest mean difference with minimal variation.

4.1.6 Average Vertical Profile Analyses

Altitude-wise mean difference and RMSE profiles for temperature, pressure, refractivity, and vapour pressure are shown in Fig. 11. The mean difference, best and worst differences, along with RMSE profiles, are presented in the figure. The differences and RMSE values for all locations are estimated at various altitudes and then averaged to obtain a single mean difference and RMSE for each altitude level. It is observed that the mean differences and RMSE values for refractivity and vapour pressure are relatively high at lower altitudes, particularly around 5 km. For pressure, both the mean difference and RMSE values fall within the range of -5 to 5 hPa, while for vapour pressure, the range is from -4 to 4 hPa. The pressure profile shows minimal variation in mean difference up to 10 km altitude. For refractivity, very minor differences are observed up to 5 km, beyond which the differences approach zero, indicating high agreement between the datasets. In the case of temperature, the mean difference remains close to

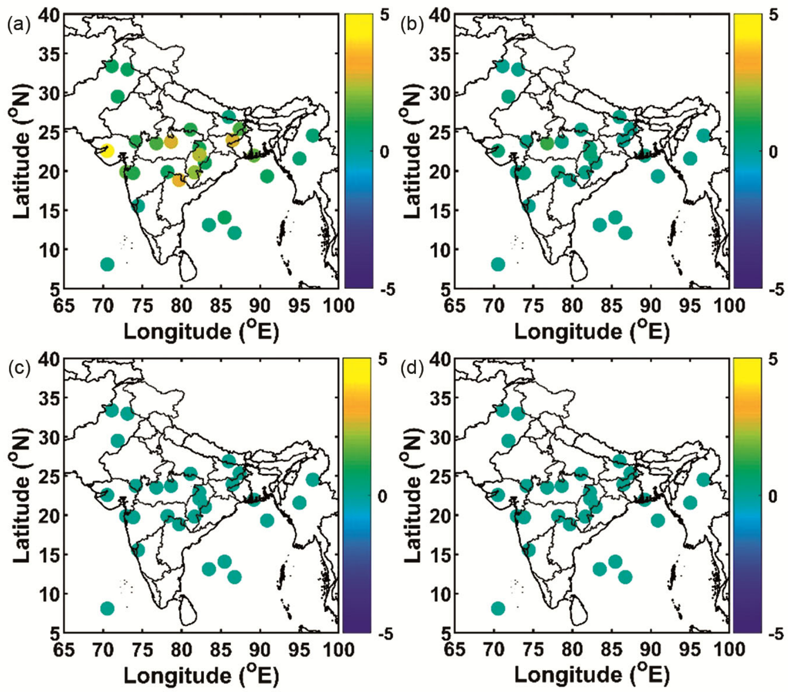

Fig. 9 — The vapour pressure RMSEs (hPa) for different altitudes (a) H < 5 km (top left) (b) 5 km <= H < 10 km (top right) (c) 10 km <= H < 15 km (bottom left) (d) 15 km <= H < 20 km (bottom right)

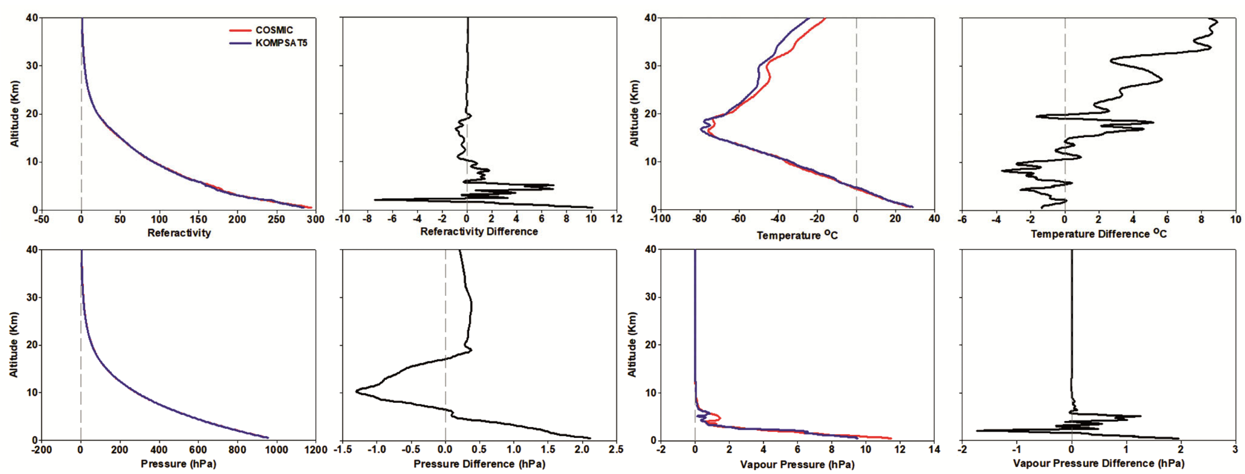

Fig. 10 — COSMIC and KOMPSAT profiles of Refractivity, Temperature, Pressure and Vapour pressure and their differences for 27 October, 2019

Table 2 — Altitude wise mean difference (MD) are RMSE for profiles of 27 October, 2019

27 October, 2019	Pressure (hPa)	Refractivity(N)	Temperature(^{0}C)	Vapour Pressure(hPa)
MD	0.112697427	0.363253440	2.626085600	0.050202234
RMSE	0.647360958	1.696795265	4.377682521	0.298004043

zero up to 30 km altitude but increases significantly above this height. The highest discrepancies for temperature are observed beyond 30 km. Alongside the mean bias and RMSE, the best and worst bias and RMSE profiles are also derived to provide a complete view of the profile variability. The mean differences and mean RMSE values for pressure, temperature, vapour pressure, and refractivity are calculated and summarized in Table 3.

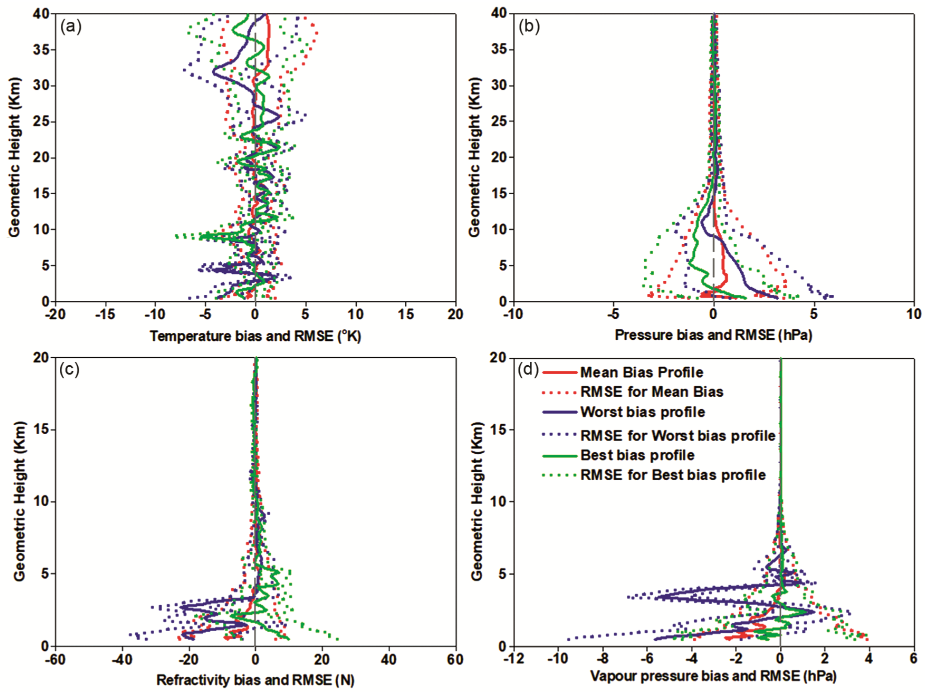

Fig. 11 — The mean (red), best (green) and worst (blue) mean difference and RMSE profiles of COSMIC retrievals compared to KOMPSAT. The solid lines indicate the biases and the dotted lines are for RMSE (a) temperature (b) pressure (c) refractivity (d) vapour pressure

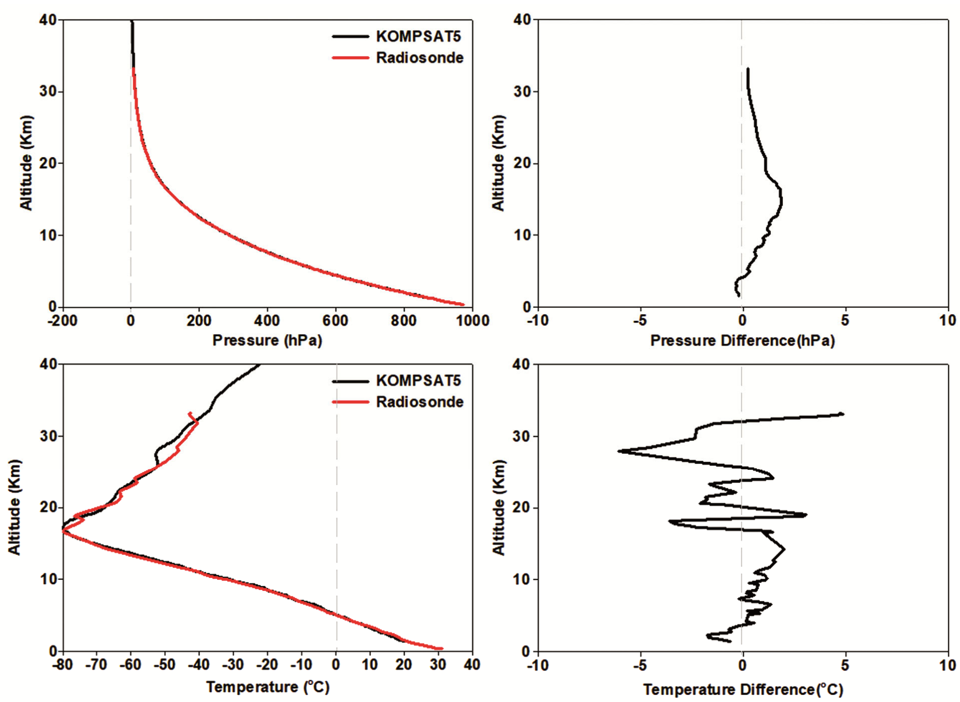

Fig. 12 — KOMPSAT and Radiosonde profiles of Pressure and Temperature and their differences for 27 October, 2019

4.2 Validation with Radiosonde Observations

The KOPMSAT-5 temperature and pressure profiles are also validated using radiosonde observations as shown in Fig. 12. The figure represents these profiles for 27 October 2019. Radiosonde stations were selected within the 2 deg. of KOMPSAT5 and COSMIC overlapping locations. From the figure it is seen that these temperature and pressure profiles from both the

Table 3 — Mean difference (MD) and RMSE for all the atmospheric profiles

Profiles	MD	RMSE
Pressure	0.158887139	0.983354091
Refractivity	-0.097338403	2.176473106
Temperature	0.167600064	2.244556485
Vapour Pressure	-0.033605022	0.427724365

sources are closely matching. Maximum pressure difference is observed 2 hPa at 15 Km. altitude. However, the difference remains within 2 h Pa at other places. From the temperature profiles, it is observed that upto 18 Km. the differnces is less than 2 °C. But at higher altitudes, these differences go upto 5 °C. These phenomenon is similar to KOMPSAT-5 and COSMIC differences. There also temperuate differences goes upto 5 °C and beyond after 20 Km and pressure differences are found around 2 hPa after 10 Km. The mean and RMS difference values for pressure are observed 0.70 hPa and 0.91 hPa respectively and for temperature these are estimated 0.03 °C and 1.82 °C respectively. This comparison shows that KOMPSAT-5 profiles match closely with radiosonde observations. Similar, observations are found for other days also.

5 Conclusion

Different studies have been conducted using various RO mission datasets across the globe. The addition of different RO mission datasets provides a greater number of observations over specific locations. However, studies utilizing data from the KOMPSAT-5 RO mission remain limited, especially over the Indian region. The present study focuses on the utilization of KOMPSAT-5 datasets over India. These datasets are retrieved and validated using COSMIC datasets and radiosonde observations. Specifically, the refractivity, temperature, pressure, and vapour pressure profiles from both satellites, spanning 0 to 40 km altitude, are compared at various locations in India for the year 2019. The vertical profiles of temperature and pressure from KOMPSAT-5 are also compared with radiosonde profiles. Results from this study show that the average temperature difference between COSMIC and KOMPSAT-5 is 0.17 °C, with a root mean square error (RMSE) of 2.24 °C. For pressure profiles, an average bias of 0.16 hPa and an RMSE of 0.98 hPa were observed. Vapour pressure differences were minimal, with an average bias of −0.03 hPa and an RMSE of 0.43 hPa. The average refractivity difference and RMSE between both satellite datasets were −0.097 and 2.2, respectively. The analysis of average vertical profiles across all study points reveals that the largest variations in refractivity, pressure, and vapour pressure occur within the lower troposphere (surface to 10 km), where atmospheric moisture and thermal gradients are typically more dynamic due to weather systems and boundary layer processes. At higher altitudes (above 10 km), these differences reduce and approach zero, indicating more stable atmospheric conditions. Conversely, for temperature profiles, slightly larger discrepancies are observed at higher altitudes, likely due to variations in radiative cooling, stratospheric dynamics, and instrumental sensitivity in the upper atmosphere. These findings demonstrate that the KOMPSAT-5 atmospheric profiles are largely consistent with those from COSMIC and radiosonde observations, confirming their scientific reliability. Thus, KOMPSAT-5 data can be effectively incorporated alongside other RO datasets for enhanced atmospheric analysis and modeling over the Indian region, particularly for studies involving vertical structure and climate variability.

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