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Vertical electron density and topside effective scale height (H_T) variations over the Indian equatorial and low latitude stations

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Abstract. Understanding the vertical electron density profile, which is the altitudinal variation of ionospheric electron density distribution is an important aspect for the ionospheric investigations. In this paper, the bottom-side electron density profiles derived from ground based ionosonde data and the ROCSAT-1 in-situ electron density data were used to determine the estimates of the topside electron density profiles using α-Chapman function over an equatorial station Trivandrum (8.47° N, 76.91° E) and a low latitude station Waltair (17.7° N, 83.3° E) in the Indian region. The reconstructed electron density profiles are compared with IRI (2007) model derived vertical electron density profiles which resulted in significant deviations between the two different profiles. Both the reconstructed electron density profiles and the IRI model derived profiles are integrated independently to derive the Total Electron Content (TEC) values which are compared with GPS derived TEC values. TEC values derived from the reconstructed electron density profiles give better estimates with the GPS-TEC compared to those of IRI model derived TEC values. Compared to the GPS-TEC, the IRI model is underestimating the TEC values during day-time and is overestimating during night-time at both the stations. The percentage deviations of IRI derived TEC from GPS-TEC are larger compared to those between reconstructed profile derived TEC and GPS-TEC.

F2-layer peak electron density, peak height and electron density at ROCSAT altitudes (≈600 km) are used to derive the effective scale heights (H_T) of the topside ionosphere during the period from July 2003 to June 2004. The diurnal and seasonal variations of H_T and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities are presented in this paper. The diurnal variation of the effective scale height (H_T) shows peak values around noon hours with higher values during day-time and lower values during night-time both at Trivandrum and Waltair. The $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities at both the places also have shown a clear diurnal variation with a negative peak around 04:00 LT and maximum during day-time hours. The higher and lower values of H_T seem to be associated with positive and negative phases of the $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities, respectively.

Keywords. Ionosphere (Electric fields and currents; Equatorial ionosphere; Plasma temperature and density)

1 Introduction

Knowledge on the spatial distribution of electron number densities or concentrations (N_e) in the ionosphere is very important for the estimation and correction of propagation delays in Global Navigation Satellite System (GNSS) particularly during space-weather effects such as ionospheric storm conditions. The traditional ground-based vertical incidence ionosonde measurements are sufficient for the precise determination of the bottom-side electron density profile. However, the ground-based ionosonde measurements alone are inadequate in delivering information about the topside electron density profile (above *hm*F2). The topside electron density can be derived from the Incoherent Scatter radar (ISR) measurements or space-borne topside sounder measurements. Observations from these topside experiments are very sparse (Reinisch and Huang, 2001) and therefore it is difficult to define a well established morphology of the topside electron density profile using these experiments. One possible way to reconstruct the topside electron density profile is to make use of the analytical functions. During the past few decades, many mathematical functions such as the Chapman, exponential, parabolic and Epstein functions have been used to describe the ionospheric height profiles (Booker, 1977; Rawer et al., 1985; Di Giovanni and Radicella, 1990;

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Bilitza, 2001; Reinisch and Huang, 2001; Stankov et al., 2003; Reinisch et al., 2004; Bilitza et al., 2006).

The simple and analytic Chapman layer representation is generally used as a convenient mathematical basis to fit the electron density profiles (Wright, 1960; Fox, 1994). Therefore the topside electron density distributions are often represented with an α-Chapman function as

$$N(h) = Nm\mathrm{F2} \cdot \exp\left[\frac{1}{2}(1 - z - e^{-z})\right] \tag{1}$$

$$z = \frac{(h - hm\mathrm{F2})}{H_\mathrm{T}} \tag{2}$$

where, NmF2 and hmF2 are the density and height at the F2-layer peak respectively. The bottom side electron density profile derived from ionograms gives NmF2 and hmF2. H_T is the scale height, which is an unknown parameter. An important and inherent parameter for the mathematical functions that largely determine the shape of the electron density profile is the ionospheric scale height (Huang and Reinisch, 2001; Stankov et al., 2003; Belehaki et al., 2006). The ionospheric scale height measures the shape of the electron density profile, indicates the gradient of electron density, and intrinsically connects to ionospheric dynamics, plasma temperature and compositions. The dynamics in the topside ionosphere is dominated by plasma diffusion, in which the thermal structure, the ion composition, field-aligned fluxes, and ion-neutral drag motions are caused by neutral winds. The movement of the ionosphere due to neutral winds may be an important cause for the variations in the topside ionosphere and consequently the scale height and the profile shapes of the topside ionosphere are modified. However, the knowledge of the behavior of the ionospheric scale height remains insufficient, especially in the topside ionosphere.

Reinisch and Huang (2001) and Huang and Reinisch (2001) introduced a new technique (R-H method) to extrapolate the topside ionosphere based on the information from ground based ionograms. They approximated the scale height (H_m) around the F2-layer peak height (hmF2) by an α-Chapman function and assumed that the scale height above the F2-layer peak is constant with height (i.e. $H_\mathrm{m}(h > hm\mathrm{F2}) \approx H_\mathrm{m}(hm\mathrm{F2})$). This method, because of its simplicity and with the availability of modern digisondes with automatic scaling algorithms, facilitates to derive the total vertical electron density profiles in real-time. A constant scale height in the topside Chapman profile can describe the profile to a few hundred km above hmF2. Reinisch and Huang (2001) have shown that $H(h)$ varies only slowly with height near hmF2 when the bottom side profiles are represented by vary-Chap functions. Independent of time of day and season, the scale height showed a maximum at F1 layer heights and then leveled off to almost constant values near hmF2. A rapid increase in $H(h)$ is expected near the transition height, while at the exospheric altitudes, the scale height is expected to become essentially constant. Rama Rao et al. (1996) have studied the vertical electron density distribution over an Indian low latitude station, Waltair using ionosonde data assuming the topside effective scale height as $H_\mathrm{T} = 1.6\,H_\mathrm{m}$. However, the R-H method does not include any additional parameter from the topside ionosphere and hence likely to cause errors in reproducing the topside plasma distribution, particularly in the equatorial latitudes, due to the assumption of constant scale height above F2-peak height (Reinisch et al., 2004; Tulasi Ram et al., 2009). Later, Reinisch et al. (2007) have shown the best representation of the topside profile up to plasmaspheric heights is obtained by using a Chapman function with continuously varying scale height. Recently, Tulasi Ram et al. (2009) have derived the topside effective scale height (H_T) using the topside in-situ ion density measurements from ROCSAT-1 in conjunction with bottom side digisonde observations over an equatorial location, Jicamarca and subsequently studies the diurnal, seasonal and solar activity variations of H_T. The reconstructed electron density profiles using H_T found to exhibit excellent agreement with the Jicamarca ISR electron density profiles (Tulasi Ram et al., 2009). Therefore, a similar method is adopted to reconstruct the vertical $N_\mathrm{e}(h)$ profiles in this investigation. ROCSAT probing altitudes are between 550 and 600 km, which is just below the $\mathrm{O}^+/\mathrm{H}^+$ transition height. Hence it may be considered that the scale height calculated using ROCSAT in-situ electron density is mostly related to O^+ ions.

The present paper deals with the reconstruction of vertical $N_\mathrm{e}(h)$ profiles over an equatorial station, Trivandrum (8.47° N geog. lat., 76.91° E geog. long. and 0.5° N dip. lat.) and at a low latitude station, Waltair (17.7° N geog. lat., 83.3° E geog. long. and 11.6° N dip. lat.), which is closure to the EIA crest region in the Indian sector. The reconstructed vertical electron density profiles are compared with the IRI-2007 modeled vertical $N_\mathrm{e}(h)$ profiles. Subsequently, the integrated total electron content (TEC) derived from both the reconstructed profiles and IRI-2007 profiles are compared with the TEC from ground based GPS receivers and percentage deviations are estimated. Finally, the diurnal and seasonal variations of the topside effective scale height (H_T) have been studied, for the first time, over the Indian equatorial and low latitude region and their dependence on the vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift is discussed.

2 Data and methodology

In this study, the Ionosonde (KEL) data from Trivandrum and Waltair during the period from July 2003 to June 2004 (high to moderate solar activity) are considered for the derivation of bottom side electron density profile using the true height inversion algorithm POLAN (Titheridge, 1985). The ion density and plasma drift data from Ionospheric Plasma and Electrodynamics Instrument (IPEI) on board the ROCSAT-1 satellite (http://csrsddc.csrsr.ncu.edu.tw/Welcome.html) for all the passes over Trivandrum and Waltair are considered.

ROCSAT-1 (Republic Of China SATellite-1) is Taiwan's first scientific satellite near 600 km circular orbit with 35 degrees inclination, hence provides good coverage in the low latitude regions.

The method adopted in the present paper to derive the topside electron density profile using the bottom side electron density profile and the ROCSAT in situ data is illustrated in Fig. 1. The solid line in panel (a) represents the bottom side electron density derived from ionosonde at Trivandrum at 17:30 LT on 19 March 2004. The asterisk indicate the ROCSAT-1 measured in situ electron density (5.41×10^{11} ele m^{-3}) at an altitude of 595 km and the solid circle represents the F2-layer peak electron density (NmF2 = 5.41×10^{11} ele m^{-3}) at an altitude (hmF2) of 409 km. The α-Chapman function (Eq. 1) is fitted between these two points (F2-layer peak and ROCSAT-1 altitudes) to obtain the unknown scale height H_T. In the present case shown in Fig. 1a, the unknown scale height is 63.29 km. Using this constant effective scale height (H_T), the topside electron density profile is reconstructed using Eqs. (1) and (2) from hmF2 up to 1000 km altitudes as shown in Fig. 1b.

The vertical electron density profiles for the same periods were also obtained from IRI-2007 model (http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php) and compared with the electron density profiles derived using the above method. The Total Electron Content is the integral over the vertical electron density profile $N_\mathrm{e}(h)$.

$$\mathrm{TEC} = \int_0^\infty N_\mathrm{e}(h)dh \tag{3}$$

Using the above relation, the integrated TEC values are obtained from both reconstructed as well as IRI model derived profiles up to 1000 km. The ground based GPS derived TEC values at the two stations are further used to compare with the integrated TEC values obtained from the two different electron density profiles.

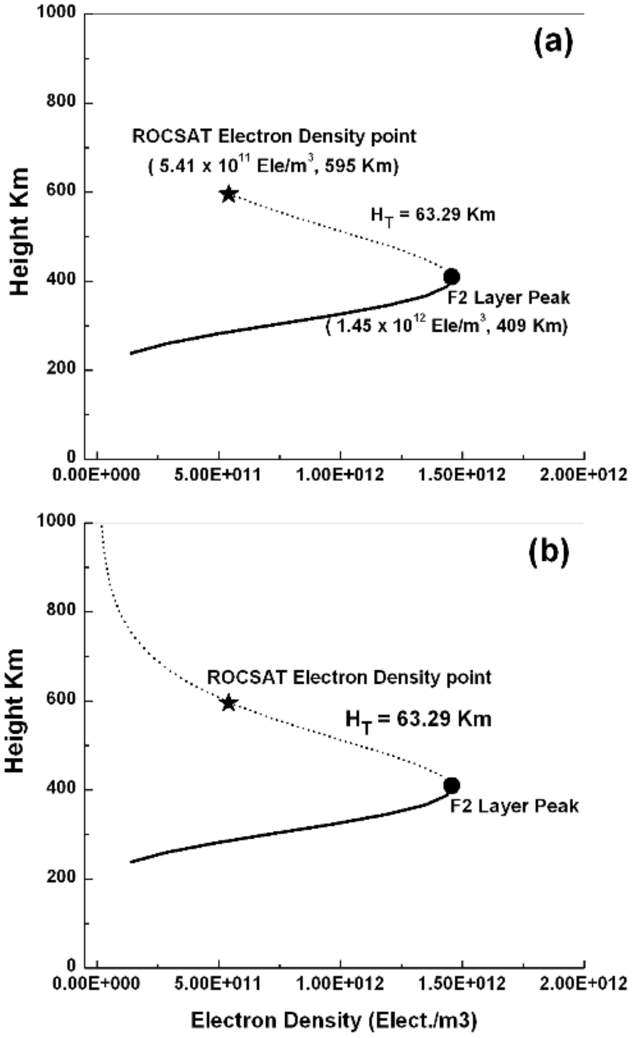

Fig. 1. **(a)** Determination of topside effective scale height (H_T) by fitting α-Chapman function between F2-layer peak and ROCSAT electron density point. **(b)** Reconstruction of topside electron density profile using above derived topside effective scale height (H_T).

3 Results and discussion

3.1 Vertical electron density profiles

Typical examples showing the vertical electron density profiles derived for an equatorial station, Trivandrum (8.47° N geog. lat., 76.91° E geog. long. and 0.5° N dip. lat.) at four different local time periods are presented in Fig. 2. The blue line represents the bottom side electron density up to the peak of the F2-layer derived from ionosonde data. ROCSAT electron density points are shown as green colored asterisk marks. Reconstructed topside profile is shown as brown colored curve. The red colored profiles are the IRI (2007) model derived vertical electron density profiles. It is seen from this figure that the IRI model derived profiles are deviating significantly from the reconstructed electron density profiles and showing distinct differences in the height as well as the peak electron density. The IRI model is overestimating the NmF2 value in case of the profile at 07:00 LT (Fig. 2a) and it is underestimating the NmF2 values in the remaining three cases. In the profile plotted for 11:30 LT (Fig. 2b), the IRI and reconstructed profiles are quiet similar below the F2-layer peak, and except in this case in all the other profiles, the IRI profiles are significantly deviating both in bottom side as well as on the topside. The integrated Total Electron Content (TEC) values are presented in the respective frames along with the simultaneous GPS observed Total Electron Content values. For the profile derived at 07:00 LT, the IRI model is overestimating the TEC value and in the remaining cases it is underestimating the TEC values when compared with GPS derived TEC. For example the profile at 11:30 LT (Fig. 2b), GPS derived TEC is 38.9 TECU whereas the IRI model is

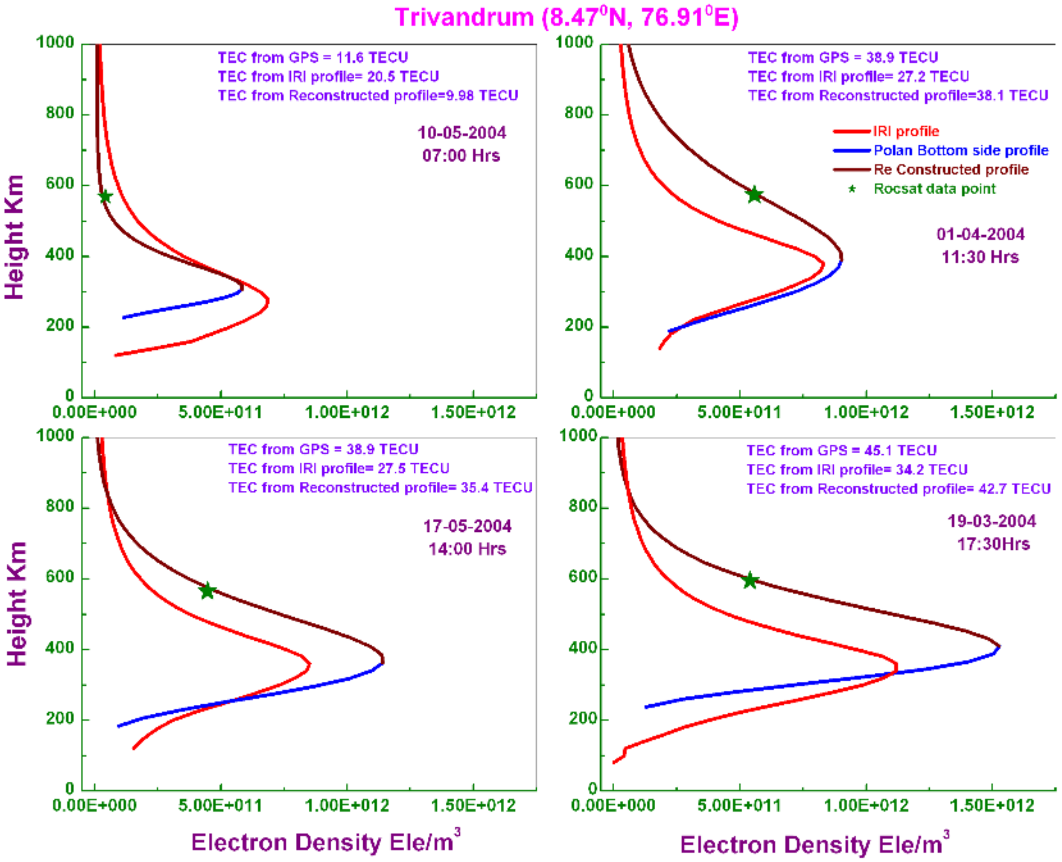

Fig. 2. Typical examples of vertical electron density profiles reconstructed over an equatorial station Trivandrum during four different time intervals. IRI model derived profiles (red lines) are also plotted for comparison.

showing 27.2 TECU. The reconstructed profile in this case gives a TEC value of 38.1 TECU which is much closer to the GPS derived value. In the remaining three cases (Fig. 2a, c and d) also the TEC measured using the reconstructed electron density profiles are closer to the GPS derived TEC compared to those of IRI derived TEC values. The slightly lower values of integrated TEC from the reconstructed profiles is mainly due to the additional contribution from the plasmaspheric electron content measured by the ground based GPS receiver.

In Fig. 3 are presented four typical vertical electron density profiles derived for a low latitude station, Waltair (17.7° N geog. lat., 83.3° E geog. long. and 11.6° N dip. lat.) at four different time periods. It is seen from these plots that the shapes of the vertical electron density profiles derived using IRI model are significantly deviating from the reconstructed profiles. IRI model is overestimating the *Nm*F2 values in the case of electron density profile derived at 11:00 LT (Fig. 3b), and is underestimating the *Nm*F2 values in the other three cases. The bottom side IRI profile at 15:00 LT (Fig. 3c) is close to that of ionosonde derived profile whereas the topside profile is deviating significantly. In the remaining two cases (Fig. 3a and d), the IRI profiles are showing significant differences in the bottom side as well as on topside compared to those of the reconstructed profiles. The TEC values in the case of the profiles derived at 15:00 LT (Fig. 3c), the GPS derived TEC is 54.7 TECU and the IRI derived TEC is 47.7 TECU where as the reconstructed profile gives TEC value of 54.6 TECU which is close to the GPS derived TEC value. In the remaining other three cases (Fig. 3a, b and d) also the IRI model derived TEC values are showing large differences while the TEC from the reconstructed profiles are comparable with those of the GPS derived TEC values.

With a view to have a better understanding on the diurnal variation of the vertical electron density distribution in the case of reconstructed profile as well as IRI model derived profiles, the ROCSAT satellite passes over Trivandrum and Waltair are obtained during all the 24 h of local time in the considered period of study. The ionograms are available for every 15 min time intervals and thus there is a possibility for a maximum time difference of about 7.5 min between the ROCSAT observation of the electron density and that of ionosonde observation. But in practice, the average time difference is observed to be 4 min. The electron density

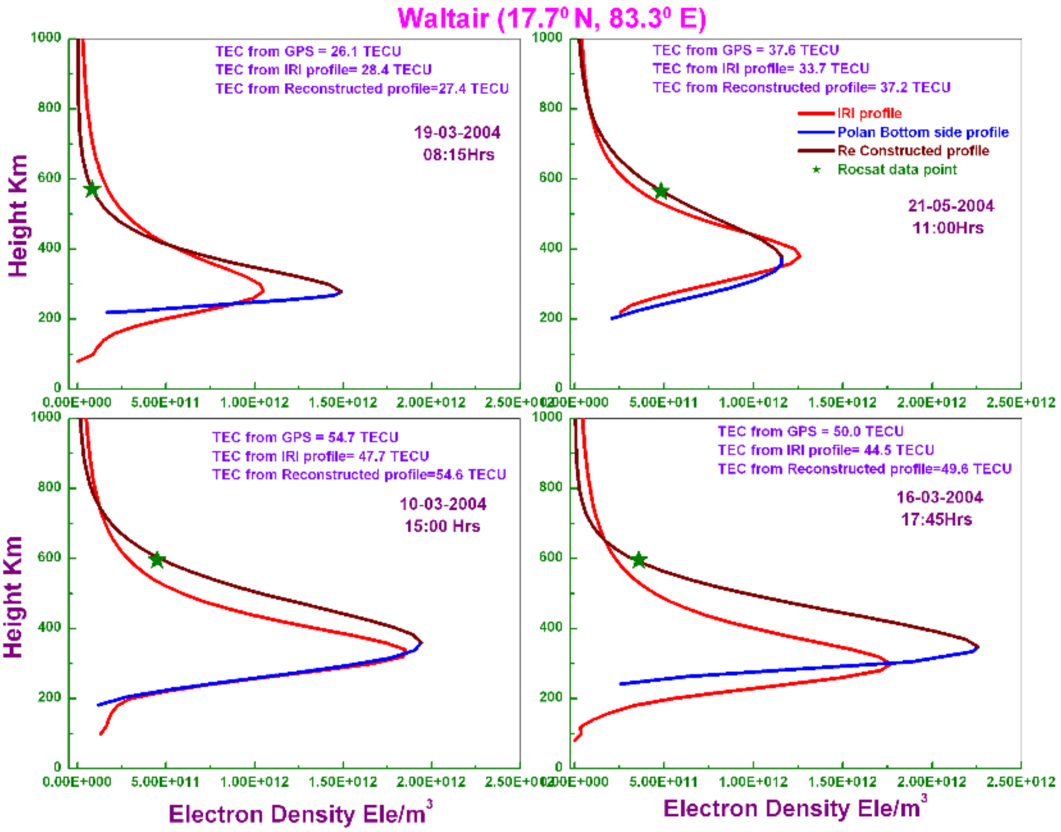

Fig. 3. Typical examples of vertical electron density profiles reconstructed over a low latitude station Waltair during four different time intervals. IRI model derived profiles (red lines) are also plotted for comparison.

profiles for all the 24 h of local time over Trivandrum are derived and presented in Fig. 4. It is seen from this figure that only for a very few hours (during 09:00 to 15:00 LT), the IRI model derived bottom side profile is comparable to that obtained from the ionosonde, however, the corresponding topside profiles are showing significant deviations from those of the reconstructed ones. No considerable similarity is observed between the reconstructed and the IRI model derived topside profiles during most of the local times. In most of the cases the IRI model is underestimating the *Nm*F2 values compared to those of the ionosonde derived values. It is observed from these plots that during 09:00 to 14:00 LT, the bottom side regions of IRI and reconstructed profiles are at the similar height range and later the reconstructed profile started drifting upward which may be due to the $\boldsymbol{E} \times \boldsymbol{B}$ drifts, while the IRI model derived profile is not showing this vertical movement and thus it differed with reconstructed profile much more in the later hours. Similarly, the vertical electron density profiles derived for all the 24 h of the local time at Waltair are presented in Fig. 5. It is also observed that the bottom side region of the IRI model derived profile compares well with that of the reconstructed profile in some cases and is differing in the rest of the cases. It is due to the variations in heights as well as the peak electron densities of the F2-layer, the IRI model is underestimating during some local times (01:00 to 06:00 LT) and overestimating during the other time intervals.

3.2 Comparison of the Total Electron Content

With a view to make a comparative study on the diurnal variation of the TEC values derived using reconstructed profile and IRI model, a plot has been made along with the GPS derived TEC for Trivandrum and Waltair respectively and is presented in Fig. 6a and b. The blue line represents the GPS derived TEC, red line represents IRI derived TEC and the green line represents TEC from reconstructed profile. ROCSAT satellite passes over Trivandrum and Waltair that are close in time and location to the ionosonde observations along with the availability of GPS-TEC data during the period from July 2003 to June 2004 are considered and the corresponding electron density profiles are reconstructed to obtain the diurnal variation of the TEC. It is readily seen from this figure that the TEC obtained from reconstructed profile is agreeing well with GPS derived TEC over Trivandrum and Waltair. The maximum difference observed between IRI derived TEC and GPS-TEC is 13.63 TECU (at 15:00 LT) where as the maximum difference

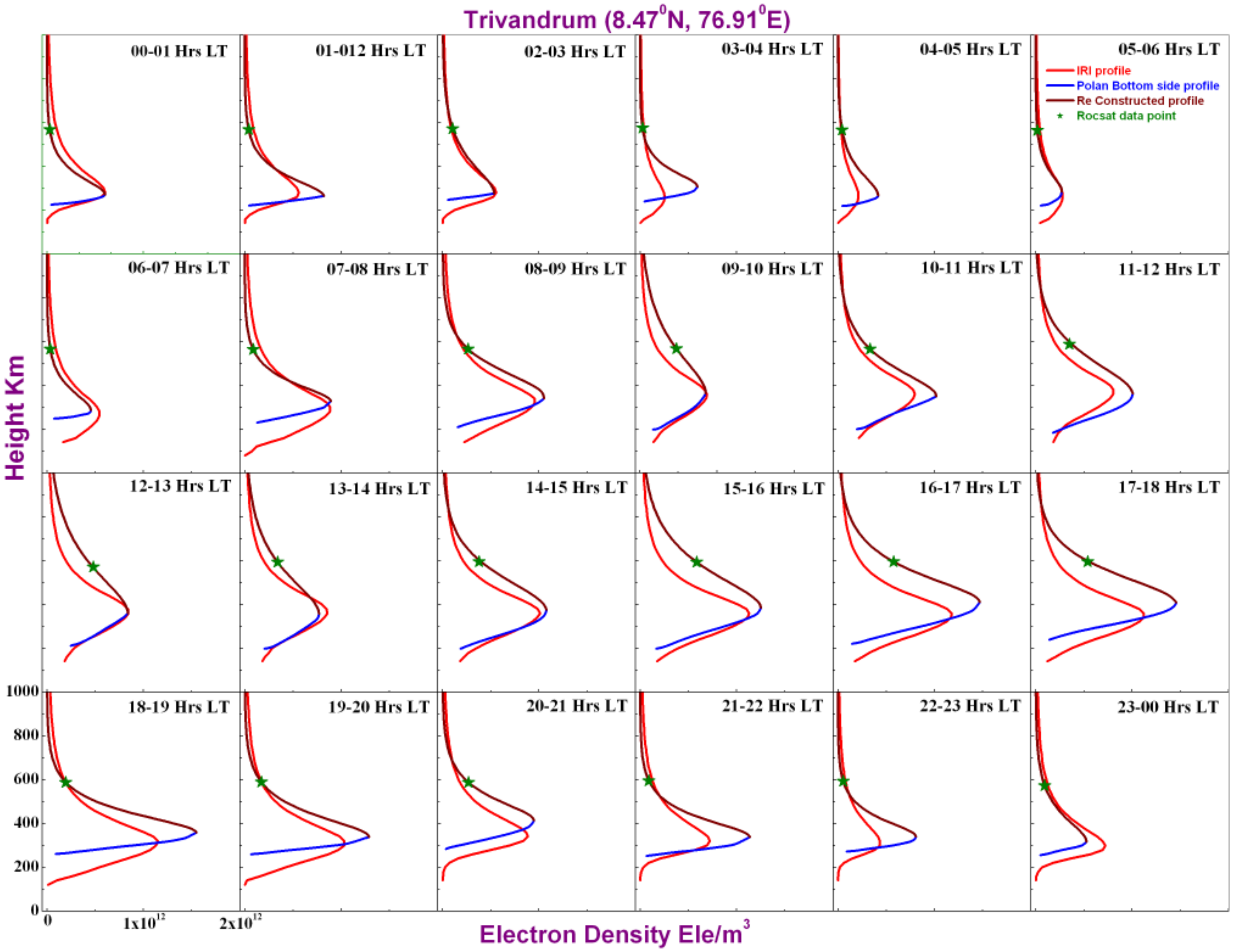

Fig. 4. Vertical electron density profiles reconstructed using ionosonde and ROCSAT data along with the simultaneous IRI model derived profiles for all the hours of the day over an equatorial station Trivandrum.

observed between TEC from reconstructed profile and GPS-TEC is 4.92 TECU (12:00 LT) over Trivandrum. At Waltair, the maximum difference observed between IRI derived TEC and GPS-TEC is 13.83 TECU (17:00 LT) where as the maximum difference observed between TEC from reconstructed profile and GPS-TEC is 5.06 TECU (17:00 LT). It is important to note from this figure that the IRI model derived TEC is underestimating with the measured GPS-TEC during day-time and overestimating during night-time at both the stations. IRI model derived TEC is obtained by considering ionosonde measured *Nm*F2 and *hm*F2 as inputs to the model and the corresponding TEC values are plotted as a purple line in Fig. 6a and b over Trivandrum and Waltair, respectively. It is seen from these figures that the IRI derived TEC values using *Nm*F2 and *hm*F2 as inputs do not show considerable difference and are very much closer to those of the IRI derived TEC values without any input parameters. Another interesting feature is the night-time enhancement (around 21:00 LT) which is observed in GPS-TEC and in the reconstructed profile derived TEC, while it is not seen in the IRI model derived TEC.

The percentage deviations in TEC from IRI model derived profile and from the reconstructed profile with GPS-TEC are plotted as histograms on either side of the zero line and are presented in Fig. 7a, b and c for Trivandrum and in Fig. 7d, e and f for Waltair. The positive values refer to the overestimation of the TEC, whereas the negative values represent the underestimation of the TEC. In general, it is observed from these figures that the percentage of deviations in TEC are more during night-time compared to those during day-time at both the stations. It is also observed that the percentages of deviations are positive during night time and negative during day time. From this observation, it is clear that the IRI model is overestimating GPS-TEC during night-time

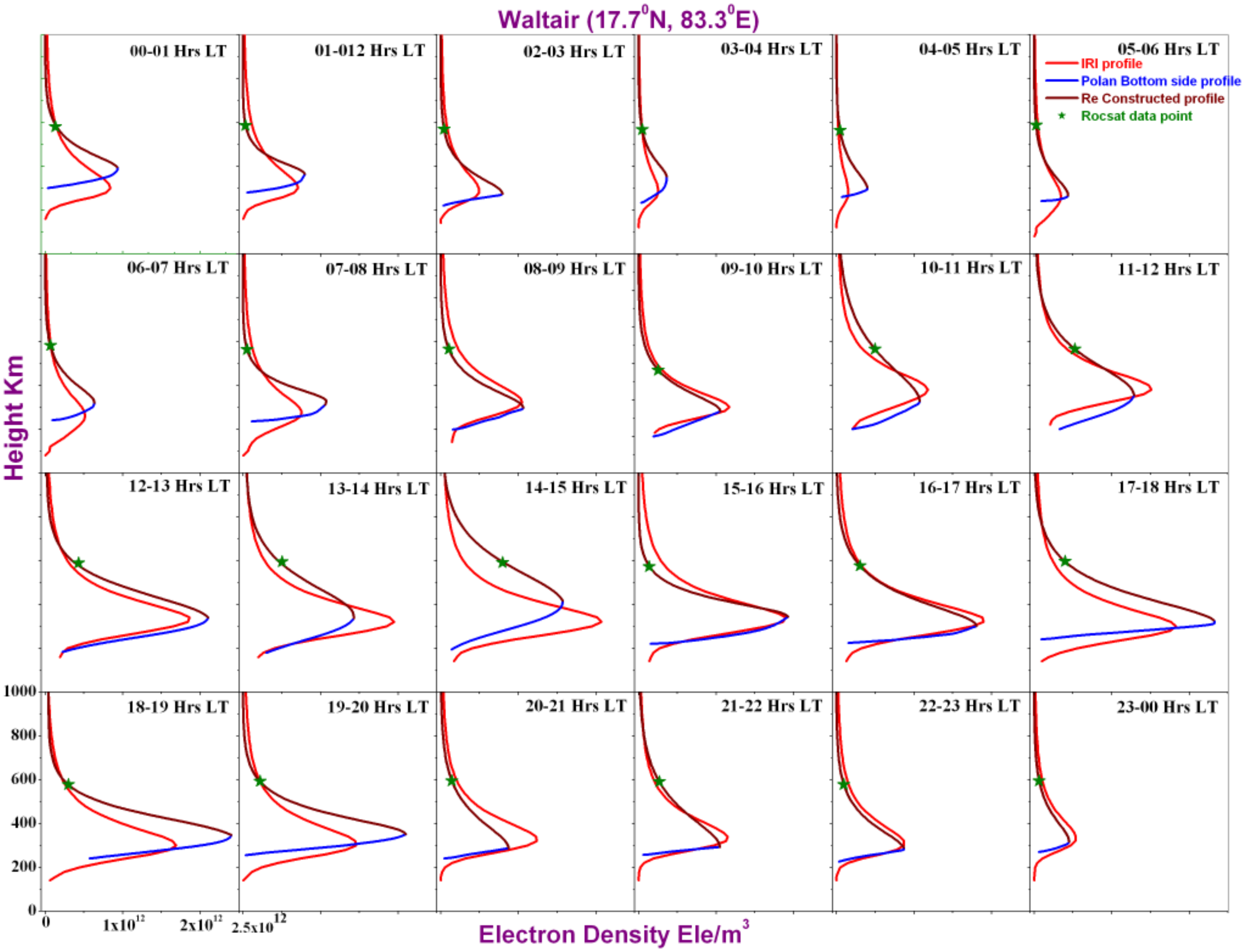

Fig. 5. Vertical electron density profiles reconstructed using ionosonde and ROCSAT data along with the simultaneous IRI model derived profiles for all the hours of the day over a low latitude station Waltair.

and underestimating GPS-TEC during day-time. The percentage of deviations between IRI model derived TEC and GPS-TEC are varying between −45 % and 60 % over Trivandrum and they are varying between −27 % and 50 % over Waltair. Whereas the percentage of deviations between reconstructed profile derived TEC and GPS-TEC are varying between −23 % and 20 % over Trivandrum and they are varying between −16 % and 16 % over Waltair. The IRI model derived TEC with *Nm*F2 and *hm*F2 as inputs also do not show significant decrease in the percentage of deviation. This reveals that the shape of the IRI derived vertical electron density profile is contributing a major input to the deviations in TEC. It should be mentioned here that the TEC values from both reconstructed profiles and IRI-2007 profiles are expected to be lower than that of GPS-TEC, as the integration is done from the bottom side to only up to 1000 km altitude, whereas, the GPS-TEC also accounts for the plasmaspheric content up to GPS altitudes (∼22 000 km) (Balan et al., 2002). However, the observed differences between the GPS-TEC and the TEC derived from IRI-2007 profiles are quite larger and in a few cases TEC from reconstructed profile is larger than that of the GPS-TEC. Several studies on the altitudinal dependence of the scale height demonstrated that the scale height varies with altitudes (Lei et al., 2004, 2005, etc.). Hence, besides the contribution from the plasmaspheric electron content, the minor differences between GPS-TEC and TEC from reconstructed profile may be arising due to the assumption that the scale height is constant while reconstructing the topside electron density profile. On the other hand, the TEC from IRI-2007 profiles overestimates during the night-time from 1900 to 02:00 LT at both Trivandrum and Waltair. These results clearly indicate that the IRI-2007 model failed to represent the true ionospheric electron density distribution in the Indian equatorial and low

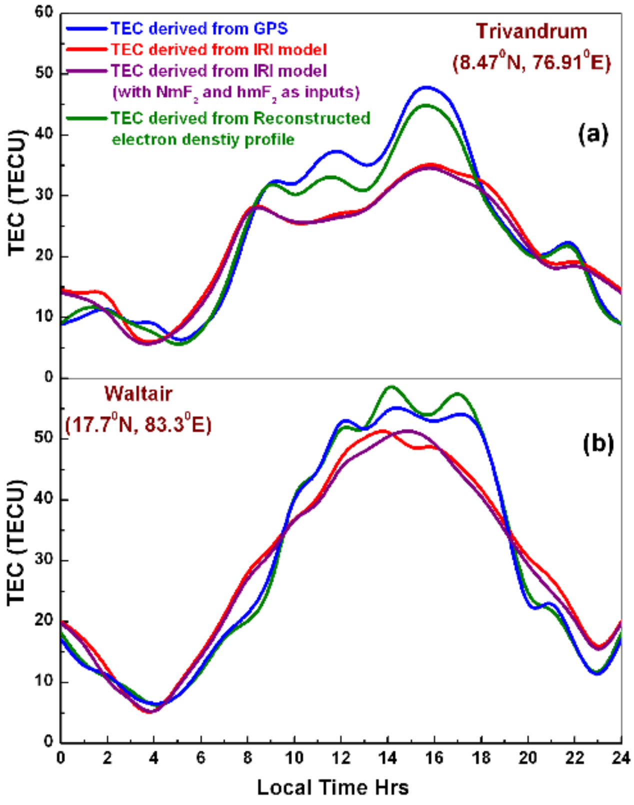

Fig. 6. Diurnal variations of TEC derived using reconstructed profile and IRI model derived TEC along with the GPS measured TEC over **(a)** Trivandrum and **(b)** Waltair.

latitude regions. Importantly, the reconstructed $N_e(h)$ profiles with the assimilation of top side in-situ ion density data with the bottom side ionsonde observations provide much better representation of electron density distribution in EIA region.

3.3 Variation of effective scale height (H_T)

According to the Chapman layer theory, the vertical electron density distribution at any given local time is controlled by the altitudinal variations in the production, loss and vertical transport of plasma. Particularly, in the dip-equatorial stations, the vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift due to the zonal electric field largely influences the vertical distribution of electron density in addition to the diffusion due to temperature and ion composition variations (Rishbeth and Garriott, 1969). The upward plasma drift induced by day-time equatorial electric fields, which induces the fountain effect playing an important role in the electron density distribution and in turn the electric field to be a possible effect to cause the variations in vertical scale height (Liu et al., 2008). In order to understand the correspondence between scale height and vertical drifts, ROCSAT satellite measured electron density vertical drifts at an altitude of ≈600 km have been considered. The seasonal mean values of effective scale height (H_T) and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities over Trivandrum along with their standard deviations as a function of local time for equinoctial (September–October 2003 and March–April 2004), summer (July–August 2003) and winter (November–February 2004) months are illustrated in Fig. 8. IRI model derived scale height values are also plotted as red colored lines for comparison. The H_T values over Trivandrum have shown a clear diurnal variation with maximum values during day-time and minimum values during night-time of all the three different seasons. The diurnal variation of H_T has shown a peak around local noon hours during three different seasons with a maximum peak value of about 130 km during equinoctial months while the night-time H_T values are varying around 40 to 60 km during all the three different seasons. A weak pre-sunrise peak in the diurnal variation of H_T is observed during equinoctial and summer months, while it is not seen during winter months.

The diurnal variations of $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities over Trivandrum for the three different seasons are presented in Fig. 8b. The $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities show a systematic diurnal variation with a sharp negative peak around 04:00 LT. Later, the drift velocity values start increasing, become positive and maximizing around noon hours. The $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities are found to vary between $-75\,\mathrm{m\,s^{-1}}$ to $45\,\mathrm{m\,s^{-1}}$. The large negative $\boldsymbol{E} \times \boldsymbol{B}$ drift value in the pre-sunrise hours indicates that the westward electric fields are stronger at 04:00 LT and becoming eastward after sunrise. After attaining a maximum during noon hours the eastward electric fields decreases becoming westward around sunset. It should be mentioned here that the measured $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities by ROCSAT-1 are at an altitude of ∼600 km which can be considered as a proxy to the $\boldsymbol{E} \times \boldsymbol{B}$ drift at F-region altitudes. However, the $\boldsymbol{E} \times \boldsymbol{B}$ drift values at F-region heights during the noontime are much higher than those measured by ROCSAT-1. The strong vertical $\boldsymbol{E} \times \boldsymbol{B}$ drifts at the equator leads to an increase in the thickness of the topside ionosphere by equatorial fountain effect and the scale height exhibits a pronounced maximum around the local noon hours. Whenever the $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities become positive i.e. the time when there is eastward electric field, the H_T values start rising rapidly and both show maximum values during day-time. It is also observed that the H_T values are staying at low level whenever the $\boldsymbol{E} \times \boldsymbol{B}$ drifts become negative i.e. at the time when the electric fields are westward. Thus, a close correspondence is observed between the diurnal variation of H_T and vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities.

In Fig. 9a are presented the diurnal variations of the effective scale height (H_T) and IRI model derived scale height over Waltair along with their standard deviations for equinox, summer and winter months. Also, the $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities over Waltair during the three different seasons are presented in Fig. 9b. Similar to that of Trivandrum, the diurnal variation of H_T over Waltair has also shown higher values during day-time and lower values during night-time hours.

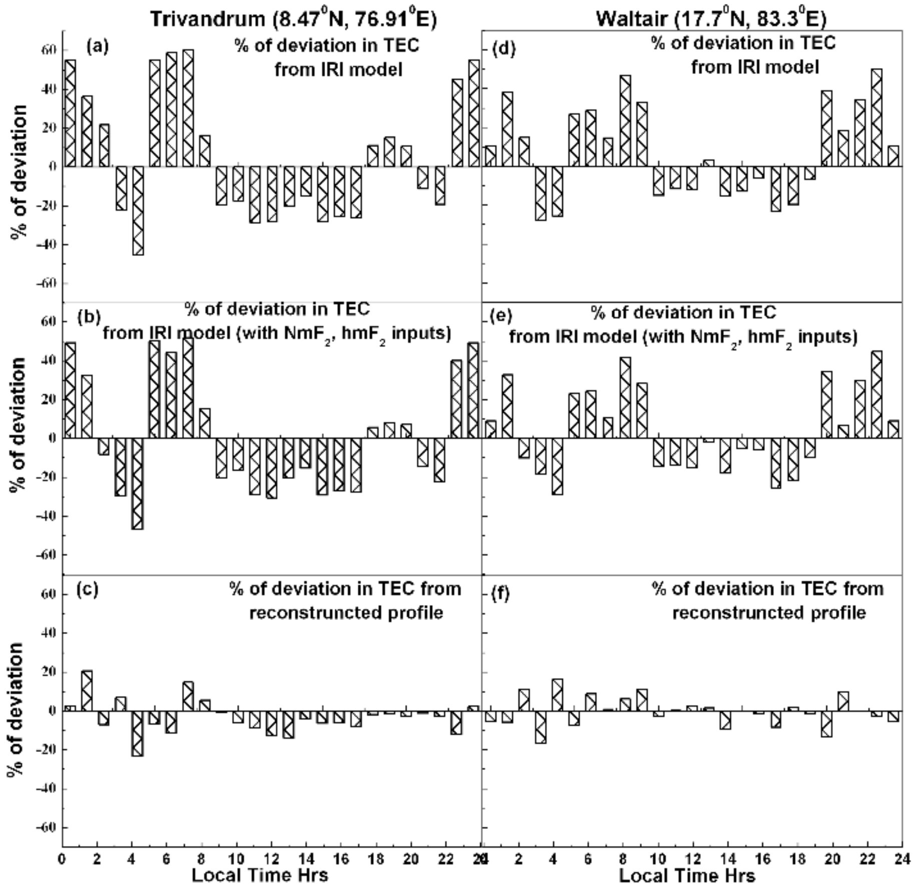

Fig. 7. Percentage deviations of IRI (2007) model derived TEC and reconstructed profile derived TEC from GPS measured TEC over Trivandrum (**a**, **b** and **c**) Percentage deviations of IRI (2007) model derived TEC and reconstructed profile derived TEC from GPS measured TEC over Waltair (**d**, **e** and **f**).

During winter months over Waltair, the diurnal variation of H_T has shown a mixed trend of variation. During equinoctial and summer months, the day maximum values of H_T are around 75 km and night-time values are varying between 40 and 60 km. The day maximum values of H_T are less at Waltair compared to those at Trivandrum during all the three different seasons, where as the night-time values of H_T are varying in the same range over the two stations during the three different seasons. Form Fig. 9b, it is observed that the diurnal variation of $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities over Waltair has shown a sharp minimum around 04:00 LT similar to that at Trivandrum and later, the $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities increased and became positive around 08:00 LT. The diurnal variations of H_T and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities are thus showing quiet similar dependence as is seen at Trivandrum. The dependence observed between H_T and $\boldsymbol{E} \times \boldsymbol{B}$ drifts shows that the vertical movement of ionization is playing a significant role on the variations of the topside scale height and thereby influencing the shape of the electron density distribution. It is observed from Figs. 8a and 9a that the IRI model derived scale height is more than the measured scale height during night-time hours and much less during day-time hours over both the stations Trivandrum and Waltair. Thus, during day-time, the lower value of the IRI scale height makes the vertical electron density profile more skewed compared to that of the real profile and the corresponding TEC becomes less which leads to underestimation of TEC. Whereas during night-time, due to the larger value of the IRI scale height, the model derived profile becomes fatty compared to the real profile and the corresponding TEC is more leading to overestimation of TEC. This result is in good agreement with the TEC comparison made in Sect. 3.2.

Lee and Reinisch (2007) studied the diurnal and seasonal variations of the scale height (H_m) at the F2 layer peak over a dip equatorial station Jicamarca and indicated that the diurnal variations of H_m generally show the greatest value at 11:00 to 12:00 LT and that these values at noon are greater in the equinoctial and winter months. Liu et al. (2008) investigated the local time, seasonal, latitudinal and longitudinal variations of Vertical Scale Height (VSH) with the COSMIC radio occultation measurements during low solar activity period (2006–2008) and reported that the VSH values are higher

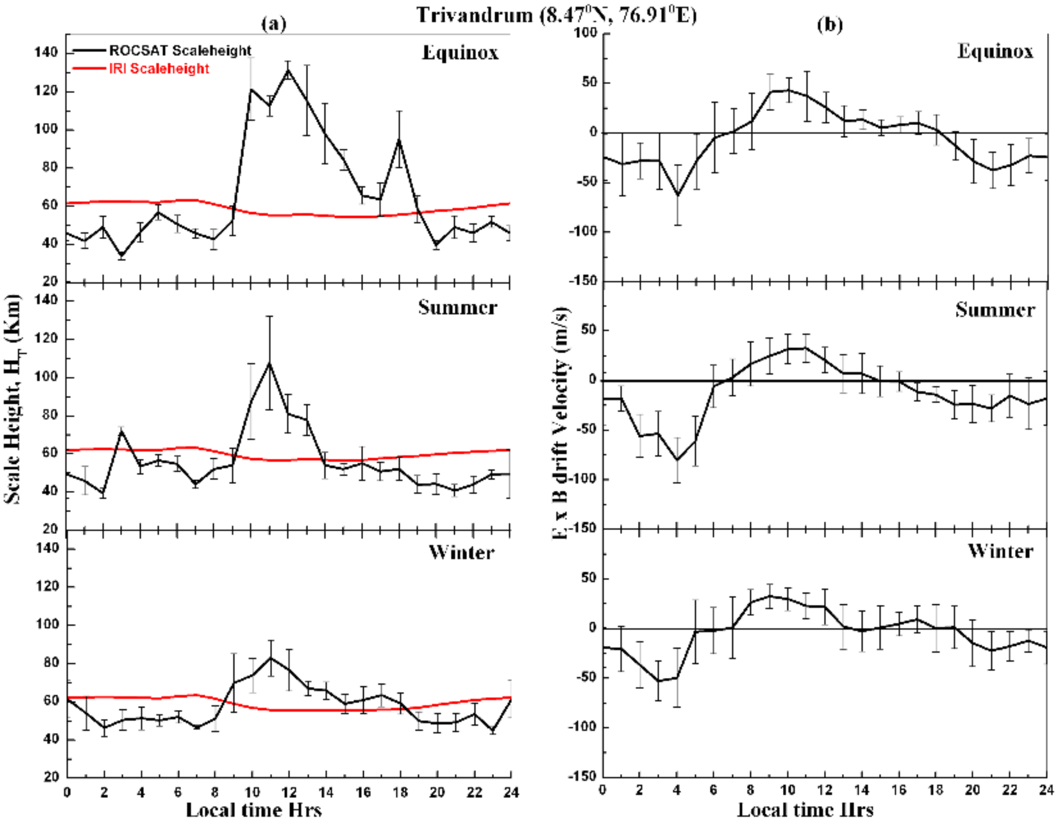

Fig. 8. The mean diurnal variations of effective scale height (H_T) and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities (measured by ROCSAT-1 satellite and IRI model (red line)) over Trivandrum during three different seasons.

during day-time, compared to those in the night-time with an outstanding peak around local noon and decreasing after noon till mid night. Similar results obtained in the present study are found to be consistent with the earlier studies mentioned above. Lei et al. (2005) investigated the diurnal variation of scale height (H_m) over a mid latitude station, Millstone Hill and their results indicate that the scale height values are lower during day-time and higher during night-time which is opposite to the observations over equatorial and low latitudes in the present study. Tulasi Ram et al. (2009) studied the diurnal, seasonal and solar activity variations of H_T using ROCSAT in-situ data over a dip-equatorial station Jicamarca during 2001–2004. In general the diurnal and seasonal variations of H_T derived over Trivandrum in the present study are similar to those obtained over Jicamarca with a pronounced peak in the noon-time hours and lower values during night-time hours. These results consistently indicate the role of $\boldsymbol{E} \times \boldsymbol{B}$ drift on the variation of topside effective scale height (H_T). However, the magnitude of H_T values at Trivandrum are lower than the H_T values at Jicamarca. This could be possibly due to the longitudinal differences in the vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift values between the Peruvian and Indian sectors.

4 Summary

The present study adopted the method for the assimilation of topside in-situ electron density data from the ROCSAT-1 satellite in conjunction with the ionosonde measurements for accurate determination of effective scale heights using an α-Chapman function and further to reconstruct the topside electron density profile over equatorial and low latitude stations in the Indian sector. A comparison between reconstructed profiles using ROCSAT data and IRI model derived profiles is made. The IRI model derived profiles show significant deviations from the reconstructed profiles both at equatorial and low latitude stations. The IRI model derived profile over Trivandrum does not show the vertical movement of the electron density profile which is observed in reconstructed profile during afternoon and evening hours. The deviations in IRI model derived electron density profiles from reconstructed profiles are observed to be more at Trivandrum compared to those at Waltair. The TEC values derived using reconstructed profiles are well correlated with GPS derived TEC values. The IRI model derived TEC is underestimating the GPS-TEC during day-time and overestimating during night-time. Significant percentage deviations are observed between IRI derived TEC and GPS-TEC, where as the TEC derived

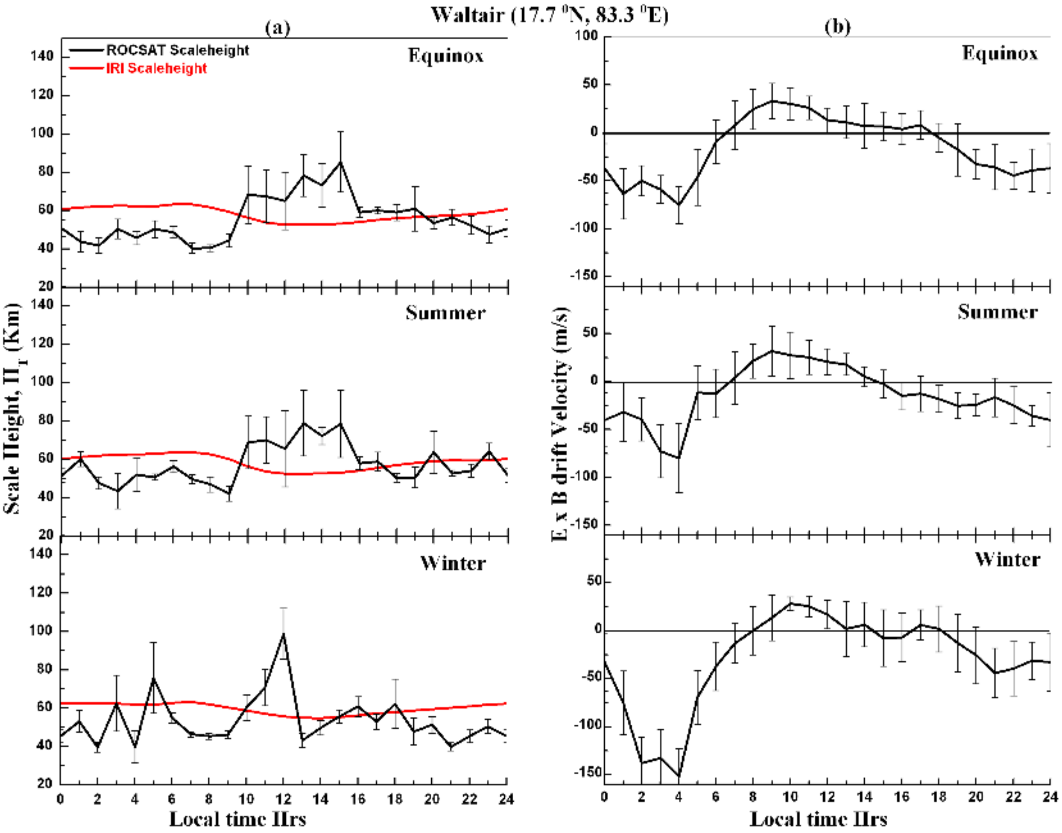

Fig. 9. The mean diurnal variations of effective scale height (H_T) and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities (measured by ROCSAT-1 satellite and IRI model (red line)) over Waltair during three different seasons.

from the reconstructed profiles exhibit good agreement with GPS-TEC.

From a study on the diurnal and seasonal variations of effective scale height H_T and $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities over Trivandrum and Waltair significant diurnal variations in the H_T values are observed with higher values during day-time and lower values during night-time. The day-time H_T values over Trivandrum are higher during equinoctial months and lower during winter months. While the H_T values over Waltair during equinox and summer are quite similar and during winter, a mixed trend of variation in the diurnal variation of H_T is observed. The $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities shows a negative peak around 04:00 LT at both the stations during three different seasons. In the diurnal variations of H_T, the higher and lower values seem to be associated with the positive and negative values of $\boldsymbol{E} \times \boldsymbol{B}$ drift velocities, respectively. Whenever the drift velocities alter from westward to eastward in the morning hours, there is a simultaneous raise in the H_T values at both the stations. The results obtained on the variations of effective scale height in the present study are in good agreement with those of the earlier studies, further confirming the dependency of H_T on the vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift.

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