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The role of altitudinal variation of scale height in determining the topside electron density profile over equatorial and low latitude sectors

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ABSTRACT

Studies on the topside electron density profile variations have gained significant importance in the recent past in view of the trans-ionospheric communication and navigation applications particularly over the equatorial and low latitude sectors. The determination of scale height to be used in analytical functions has become more important in estimating the vertical electron density profile in the topside ionosphere. The incoherent scatter radar data over an equatorial station Jicamarca and a low latitude station Arecibo during the high solar activity years 2001 and 2002 are used to estimate the altitudinal dependence of topside ionospheric scale height. These scale height values at different altitudes are used to reconstruct the topside electron density profiles to study the changes in the shape of the topside profile due to the varying scale height values. It has been observed that a closer estimates of the electron density profiles in the topside ionosphere can be derived by using scale height values around 550 km over Jicamarca and around 500 km over Arecibo. The IRI-2012 modeled electron density profiles have been derived by giving *F*-layer peak density and height as inputs and those modeled profiles are compared with ISR measured and reconstructed profiles. Further, the scale height values in the topside ionosphere are computed using the IRI-2012 modeled electron and ion temperatures around 550 km altitudes over Jicamarca and around 500 km altitude over Arecibo. The scale height values thus derived have been used to reconstruct the topside electron density profiles over Jicamarca and Arecibo, the results of which have also been discussed in this paper.

1. Introduction

The vertical electron density profile, which represents the altitudinal variation of the electron density distribution plays an important role in the estimation and correction of radio wave propagation delays in Global Navigation Satellite System (GNSS) applications, particularly over the equatorial and low latitude sectors, because of the presence of large electron density gradients with latitude as well as altitude. The traditional ground based vertical incidence ionosonde measurements provide the precise information about the bottom-side electron density profile and a good amount of ionosonde data base is available round the globe. However, to determine the topside electron density profile, these ionosonde measurements are inadequate and measurements from Incoherent Scatter Radars (ISR) or topside sounders is required, the data of which is sparse in respect of temporal and global coverage. One possible and most widely used way to reconstruct the topside electron density profiles is to make use of the analytical functions. Among the several mathematical functions such as Chapman, exponential, parabolic and Epstein functions used for the past few decades to derive the topside electron density profiles, the simple and analytical Chapman layer representation is generally used as a convenient mathematical basis to fit the electron density profiles (Wright, 1960; Fox, 1994). The α-Chapman function is described as (Hargreaves, 1979, 1992)

$$N(h) = NmF_2 \exp\left[\tfrac{1}{2}(1 - z - e^{-z})\right] \quad (1)$$

$$z = \frac{(h - hmF_2)}{H} \quad (2)$$

where, N_mF_2 and h_mF_2 are the density and height at the *F*-Layer peak respectively. While the α-Chapman function is used to determine the electron density profiles in the topside ionosphere, the scale height, H is the most important and inherent parameter

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that largely determines the shape of the electron density profile and intrinsically connects to the ionospheric dynamics, plasma temperature and composition (Huang and Reinisch, 2001; Stankov et al., 2003 and Belehaki et al., 2006). The scale height information in the topside ionosphere is very much essential to derive the complete vertical electron density profile using the bottom-side ionosonde measurements. However, the knowledge on the behavior of the ionospheric scale height remains inadequate because of the lack of sufficient measurements in the topside ionosphere compared to those in the bottom side ionosphere.

Reinisch and Huang (2001) introduced a new technique (R–H method) to extrapolate the topside ionospheric electron density based on the information from ground based ionograms by approximating the scale height (H_m) around the F_2-layer peak height (hmF_2) using an α-Chapman function and assumed that the scale height above the F_2-layer peak is independent of height (i.e., $H_m(h > hmF_2) \approx H_m(hmF_2)$). Topside sounder measurements have been used by several researchers in developing different models to reconstruct the topside ionosphere and plasmasphere (Depuev and Pulinets 2001; Depuev et al., 2001; Pulinets et al., 2002; Depuev and Pulinets, 2004; Marinov et al., 2004; Kutiev et al., 2006). Comparative studies of electron density profiles and TEC from ISR measurements over Arecibo with different versions of IRI model revealed significant discrepancies particularly during equinoctial and summer months (Pandey et al., 1997; Sethi et al., 2001; Sethi and Pandey, 2005; Eccles et al., 2011). An assessment study has been carried out by Eccles et al. (2011) using ISR measurements over Arecibo with the IRI-2012 model reveal significant discrepancies in the model derived scale height variations. Using the incoherent scatter radar data over Jicamarca, Reinisch et al. (2004) mentioned that the R–H method is likely to exhibit errors in reproducing the topside plasma distribution particularly in the equatorial latitudes since it does not include any additional parameter from the topside ionosphere. Later, Reinisch et al. (2007) have shown that the good representation of the topside profile upto plasmaspheric heights can be obtained by using a Chapman function with continuously varying scale height. In the recent past it has also been reported that a better estimation of the topside electron density profile can be derived using the single value of scale height derived using ROCSAT satellite in-situ electron density measurements around 550 km altitude in conjunction with bottom side digisonde observations with an assumption that the scale height is independent of altitude (Tulasi Ram et al., 2009 and Venkatesh et al., 2011).

In the present study, the incoherent scatter radar (ISR) measurements from an equatorial station, Jicamarca and a low latitude station, Arecibo are used to identify the altitude of the scale height above the F-layer peak, using which, closer estimates of the topside electron density profile can be derived particularly over the equatorial and low latitude sectors. This could be useful in obtaining the preliminary estimates of the vertical electron density profiles using the bottom side measurements such as those from ionosonde. Further, the electron density profiles derived from the most popular International Reference Ionospheric (IRI) model are used for a comparison between the experimental and model derived profiles. The IRI is an empirical model that describes the variations of ionospheric parameters such as electron and ion density, ion composition, temperatures, Total Electron Content (TEC) and vertical ion drift. The IRI model has been continuously updated (Bilitza, 1990, 2003; Bilitza and Reinisch 2008) using different datasets available over the globe. The latest available version IRI-2012 (Bilitza et al., 2014) is used in the present study for comparison between experimental and model derived electron density profiles and the corresponding results are discussed.

2. Data and method of analysis

The vertical electron density profiles derived using the incoherent scatter radar data over an equatorial station Jicamarca (11.9°S Geog., 77.3°W Geog., 1.42°S Geomag.) and a low latitude station Arecibo (18.3°N Geog., 66.7°W Geog., 28.6°N Geomag.) (http://cedar.openmadrigal.org/) during the high solar activity period 2001–2002 (mean $Rz = 107$) are used in the present study. The α-Chapman function described in Eqs. ((1) and 2) is fitted between the F-layer peak and an electron density point at a particular altitude above the F-layer peak to derive the ionospheric scale height at the corresponding altitude. The scale height thus derived is used to compute the topside electron density profiles and it is termed as the reconstructed profile. The method mentioned above used for deriving the scale height and reconstructing the topside electron density profiles is similar to that reported earlier by Tulasi Ram et al. (2009) and Venkatesh et al., (2011). Using the ISR data in the bottom side and ROCSAT electron density measurements in the topside ionosphere, Tulasi Ram et al., (2009) reconstructed the topside profiles and validated with the ISR measured profiles. The scale height values at different altitudes in the topside ionosphere are computed in the above mentioned process using the ISR measurements. The topside profiles are reconstructed using scale heights from different altitudes to understand the effect of altitudinal variations of scale height on the shape of the topside electron density profiles. Further, the IRI-2012 modeled (http://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.html) vertical electron density profiles are derived by providing the F-Layer peak density and height values as inputs for the model. While running the IRI-2012 model, the default recommended options “ABT-2009” for bottom side thickness, “NeQuick” for topside electron density profile are considered. The results between the experimental, reconstructed and IRI-2012 model derived profiles over the two locations during different time intervals and different seasons are studied and discussed.

3. Results

3.1. Altitudinal variations of topside ionospheric scale height

With a view to study the scale height dependence with altitude above the F-layer peak, the ISR electron density measurements at different altitudes in the topside ionosphere are used to derive the corresponding scale height values. In Fig. 1 are presented the altitudinal variations of scale height derived at 0000, 0600, 1200 and 1800 h LT during three different days representing equinox, winter and summer months over the considered locations, Jicamarca and Arecibo. The three panels in the top row represent the variations of the scale height over Jicamarca while the other three panels in the bottom row represent the variations of the scale height over Arecibo during three different days of equinox, winter and summer months. It is seen from this figure that, in general the scale height above the F-layer peak increases with altitude at the two different locations with higher values during day-time hours compared to those during night-time hours. The scale height varies from 30 to 110 km over Jicamarca while it is found to vary between 30 and 90 km over Arecibo during the three different seasons. It has also been reported earlier that the topside scale height vary significantly with local time, season and latitude (Liu et al., 2007, 2008 and Lee and Reinisch 2008). The altitudinal variations of scale height show strong positive gradients during day-time hours over the equatorial station, Jicamarca compared to that over the low latitude station, Arecibo. The observations from Fig. 1 clearly indicate that the scale height above the F-layer peak increases with altitude and the shape of the topside electron density profile could exhibit significant variations while fitting