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Comparison of the topside ionosphere scale height determined by topside sounders model and bottomside digisonde profiles

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Abstract

Topside ionospheric electron density extrapolation techniques rely on the applied profiler model with different techniques resulting in different profile shape. In all these techniques, the parameter that largely determines the shape of the profile is the scale height. Recently, an empirical model of the topside ionosphere scale height was developed, based on the vertical electron density profiles from the topside sounders onboard Alouette and ISIS satellites. The aim of this paper is to compare the scale height determined by the topside sounders model and bottomside digisonde profiles extrapolated above the maximum of the F layer. Theoretical scale height values, calculated by using the IRI plasma temperature model are also included in the comparison.

Keywords: Scale height; Electron density profile; Topside ionosphere; Topside extrapolation; Topside sounders

1. Introduction

The accurate reconstruction of the topside ionospheric electron density profile (Ne) from ground-based sounders depends on the topside profiler model applied, for example Chapman, exponential, parabolic, etc. (Davies, 1996; Stankov, 2002). This dependence is clearly demonstrated in Fig. 1 where, using the same scale height (H), the shape of the topside Ne profile is very different depending on the choice of the topside profiler (Stankov et al., 2003). On the other hand, the plasma scale height (H_p) is an inherent parameter of every model. Fig. 2 demonstrates the changes in the shape of the topside profile for different values of the scale height using the α-Chapman reconstruction profiler (left panel) and the exponential profiler (right panel). It is evident that the topside scale height is a key parameter for a realistic topside extrapolation. While the H_p along the magnetic field lines is subject to the theoretical modeling, the vertical plasma scale height (H_v) is frequently used in various practical applications. Usually H_v is the parameter in electron density (Ne) models, which is obtained by fitting the data with the respective expressions.

A new model of topside ionosphere scale height H was recently developed by Kutiev et al. (submitted for publication), based on the vertical Ne profiles obtained from topside ionosondes. The model provides the H_v as a function of month, local time, geomagnetic latitude, solar flux F107 and K_p index. To define the H_v, the O^+ scale height above the peak of the F2 layer is assumed to be represented by the lowest gradient in the measured topside Ne profile. The model data base contains 170,033 H_v values, extracted from individual Ne profiles gathered between 1962 and 1978 by the Alouette and ISIS satellites. The model describes the H_v by a multivariable polynomial consisted of Chebishev's and trigonometric base functions, which are fitted to the data in the 5-dimensional space. The H_v in

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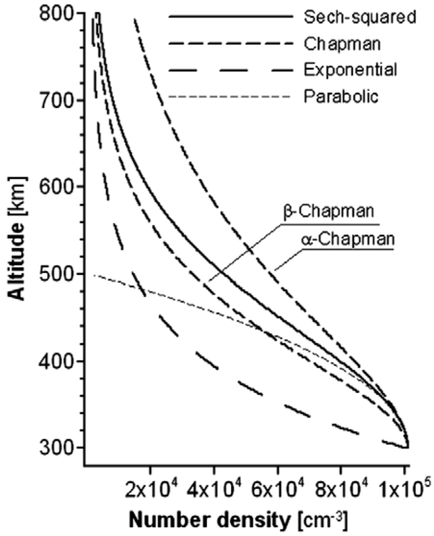

Fig. 1. The dependence of the topside profile shape for different topside profilers (after Stankov et al., 2003), for a scale height equal to 100 km.

each topside ionogram retrieved, is defined as the lowest gradient of the measured Ne profiles, obtained as a regression line fit over the data points whose gradients do not exceed the lowest gradient by 30%. The most likely H_v value is around 100 km, as 90% lie within the range 50–200 km. The longitude distribution is highly non-uniform. One-half of the data have geographic longitudes between 250° and 310°. The overall model error is 34.6 km or 23%.

This paper compares H determined by the Vertical Scale Height (VSH) model (Kutiev et al., submitted for publication) with H values derived from two different sources:

(a) Ionograms from the Athens Digisonde using the Reinisch and Huang (2001) method.
(b) Theoretical H values calculated by using the IRI plasma temperature model.

2. Ionogram derived scale height around F2 peak

Reinisch and Huang (2001) developed a new technique (hereby denoted by R–H) for calculating the vertical total electron content from Digisonde's ionograms (ITEC). They approximate the Ne profile around and above the height of the F2 layer peak (hmF2) by an α-Chapman function, with the scale height (H_m) determined at hmF2. To construct the profile above the peak, R–H assumed that the H above the F2 peak does not change and remains equal to H_m. To evaluate the vertical gradient (scale height) of the α-Chapman profile in the topside ionosphere we take a logarithm of the function, and rewrite it in the form $h(\ln(\mathrm{Ne}))$. We consider the scale height of the new profile equal to the lowest value of $\mathrm{d}h/\mathrm{d}(\ln(\mathrm{Ne}))$. The latter asymptotically tends to $2H_m$ at high altitudes, where $h \geqslant H_m$. Indeed, the scale height H in α-Chapman function represents the scale height of the neutral atmosphere, so the plasma scale height is roughly as twice large as that obtained above.

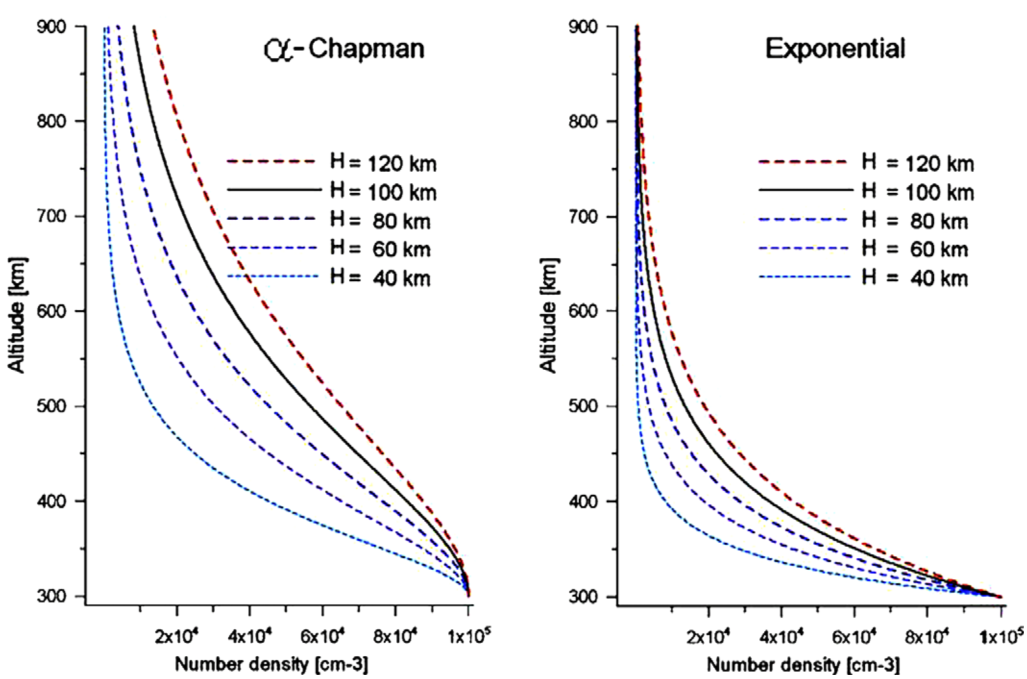

Fig. 2. The changes in the shape of the topside profile for different values of the scale height (H) using the α-Chapman reconstruction profiler (left panel) and the exponential profiler (right panel).

3. The theoretically derived scale height

The scale height is defined as the height range in which the plasma density changes by a factor of $e(\sim 2.718)$. When the topside Ne profile is controlled mainly by diffusion, the plasma scale height H_p is measured along the magnetic field lines and depends only on plasma temperature $T_p = T_e + T_i$, where T_e and T_i are the electron and ion temperatures, respectively.

$$H_p = \frac{kT_p}{m(\mathrm{O})g},$$

where the k is the Boltzmann constant, $m(\mathrm{O})$ is the oxygen mass, and g is taken equal to be 9.81 m/s^2. H_p is used in the form $H_p = 52.7 \times T_p/1000$. The vertical plasma scale height (H_v) is obtained by reducing H_p by the factor $\sin I$ (I is magnetic inclination) if we assume a horizontally stratified ionosphere. The factor $\sin I$, therefore, depends on geomagnetic latitude ($\tan I = 2\tan(\mathrm{glat})$). For Athens, magnetic inclination is $I = 55.5°$ and $H_v = 0.82H_p = 43.4T_p/1000$.

In the following analysis we evaluate the plasma scale height by using T_e (Bilitza et al., 1985) and T_i (Bilitza, 2001) provided by the IRI temperature model. The neutral atmosphere scale height Hn, used in the α-Chapman function, can be also theoretically evaluated by replacing T_p with the neutral temperature T_n. The theoretically derived scale heights are used in the comparison between VSH model and R–H scale height.

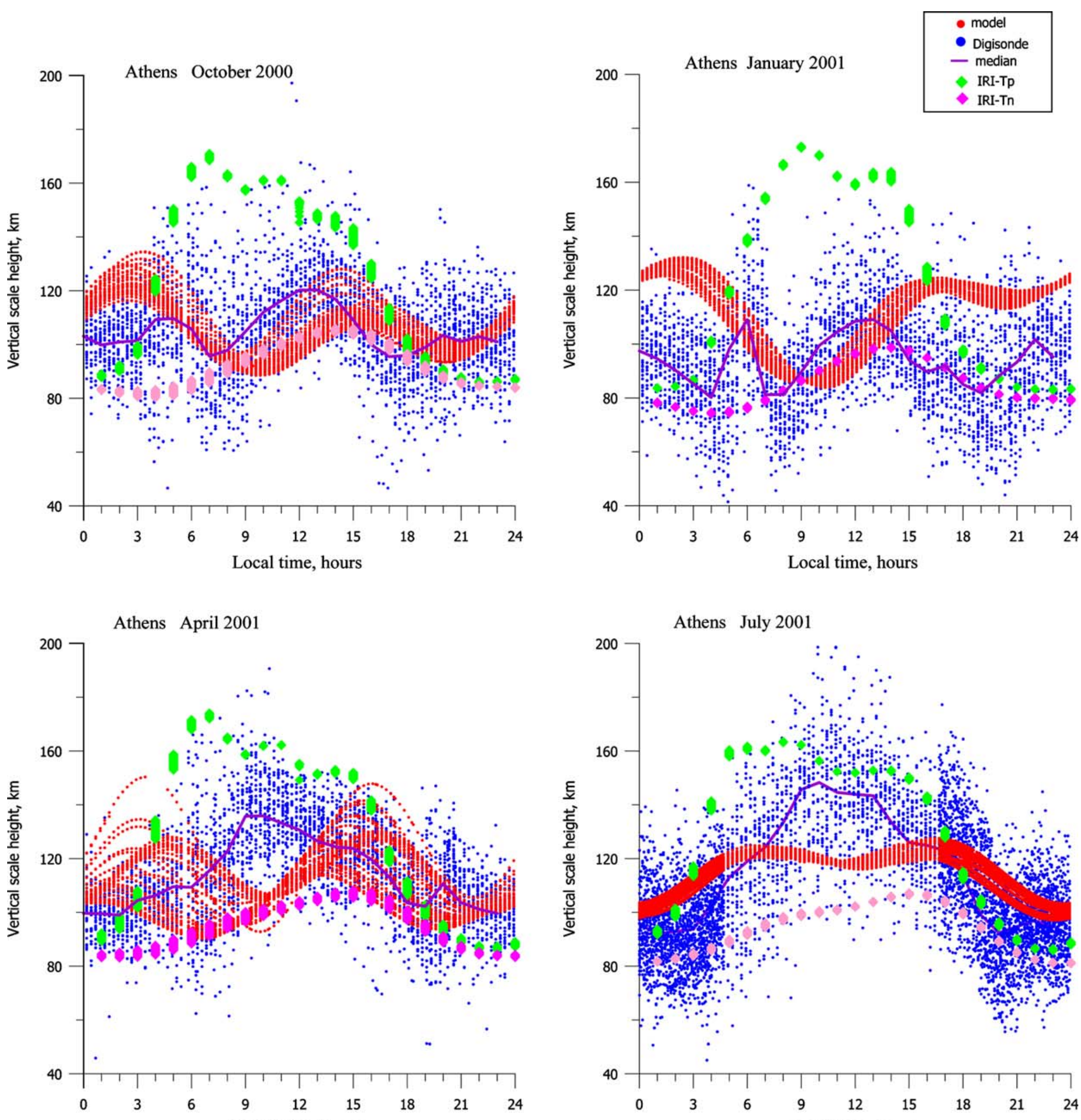

Fig. 3. Comparison between model results and scale height from Athens digisonde. Also plotted are the scale heights calculated from the neutral and plasma temperatures obtained from the IRI model, for October 2000, January 2001, April 2001 and July 2001.

4. Comparison to results

In Fig. 3 we present a comparison between the doubled R–H scale height (blue dots), provided by the Digisonde software, with their corresponding median values (purple line) and the predictions of the VSH model (red dots) for October 2000, January 2000, April 2001 and July 2001, representative of the four seasons. The green dots represent the theoretically derived H_p, while the pink dots represent the doubled Hn values. Each panel in Fig. 3 shows a scatter plot of the monthly values of the quantities considered. From the plots the following results can be concluded:

1. The magnitude of the scale height values derived from the VSH model and the R–H method are in general agreement.
2. Diurnal variation of both quantities differs from each other. H_v values show persistent post-midnight and afternoon maximums, while the R–H scale height values show a maximum around noon. The post-midnight increase in H_v is probably connected with the downward diffusion flow from the plasmasphere which maximizes at the end of the night (before sunrise) to compensate the F layer collapse, but this needs further investigation.
3. A marked increase in the scale height is expected to be observed at sunrise, during the so-called "morning T_e overshoot", as the green dots indicate. Scale height values derived with the R–H method from Athens Digisonde appear to show the morning T_e overshoot which is more prominent in January. This is expected to be strongly observed during winter, in the form of conjugate heating along the closed magnetic field lines from the opposite hemisphere. The rapid increase in the January digisonde scale heights around 0600 LT appears to show this quiet nicely.
4. Both scale height values do not follow the diurnal variation pattern of the neutral density scale height H_n, whose maximum occurs in the afternoon hours. This is expected since for the altitudes being used here $T_e > T_i > T_n$, and that is why the scale heights variations do not agree during the course of the day.

It should be noted that both models VSH and R–H are application oriented models, providing numerical values of the parameter "scale height" in various formulas for the vertical topside density profiles. Roughly (expect for the low latitudes) the output of these models can represent the theoretical scale height by dividing it with $\sin I$. The theoretically derived plasma scale heights are given in Fig. 3 just for reference. For example, they allow a reader to judge to what extent the empirically derived scale heights follow the "morning T_e overshoot". The Chapman formula uses the neutral scale height, H_n, and it is interesting to see how the extracted from the ionograms scale height follows the neutral temperature variations. Fig. 3 clearly shows that in winter the ionograms derived scale height reacts to the morning T_e increase, but also closely follows the H_n diurnal variations.

5. Summary

The different diurnal behavior of the two scale height parameters, the H_v and the R–H scale height, can be explained taking into account their different derivations. The H_v is a model-derived parameter, based on topside sounders. Therefore, its main influence comes from the topside ionosphere and the plasmasphere. On the other hand, the R–H scale height is calculated based on the bottomside parameters and is, therefore expected to exhibit a variation consistent with the thermospheric temperature.

The same conclusion was reached by Belehaki et al. (2003), when they compared the slab thickness derived by Global Positioning Systems (GPS) Total Electron Content (TEC) with the ionospheric slab thickness derived from Athens Digisonde ionospheric TEC (ITEC).

Another potential problem with the VSH model causing systematic differences in the diurnal variation comparing to the R–H scale height is the fact that large portion of the data set was collected over America and therefore, Athens' different longitude could explain some of the discrepancies between the digisonde observations and the VSH model.

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