ESTIMATION OF IONOSPHERIC PROFILERS AS RECONSTRUCTION TOOLS

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ABSTRACT

Estimated and compared is the performance of several ionospheric models (Sech-squared, Exponential, Chapman) as tools for reconstruction of the topside electron density profile from total electron content, ground ionospheric soundings, and upper transition level measurements. Although the qualities and shortcomings of these models are known, they should be further investigated as parts of the reconstruction formulae based on them. The estimation of the different profilers is carried out on actual ionosonde observations and GPS-based total electron content measurements, all obtained at the Dourbes Geophysics Centre of the Royal Meteorological Institute of Belgium.

INTRODUCTION

The modern Total Electron Content (TEC) measurement technology, using signals from the Global Positioning System (GPS), provides excellent opportunities for regular monitoring of the ionosphere-plasmasphere system. Many problems can be solved successfully if knowing the TEC and its corresponding electron density distribution: estimation and correction of propagation delays in GNSS, space weather effects on telecommunications, etc.

A novel approach has been recently proposed for reconstruction of the topside electron density distribution using combined TEC and ionosonde measurements [1,2,3]. The offered reconstruction method delivers reliable information about the topside ionosphere, where ground-based soundings cannot be used. Its main idea is in the following. Measurements of foF2, foE, and M(3000)F2 are used for constructing the bottom-side electron density profile with Epstein functions. The corresponding bottom-side electron content is calculated from this profile and is then subtracted from the GPS-measured TEC in order to obtain the unknown topside electron content. Having the upper part of TEC, the corresponding electron profile is then presented as a sum of the constituent oxygen and hydrogen ion profiles. The problem is that the ion scale heights are unknown, hence the main task is to determine these scale heights. In order to solve the problem, first we have to adopt a topside model (or 'profiler'). Several ionospheric profilers are considered for the purpose: Sech-squared, Exponential, Chapman, Parabolic, etc. Knowing the profiler, a system of equations is constructed, which system fastens the available TEC and ionosonde measurements together with information about the O^+-H^+ (upper) ion transition level. The upper transition level (UTL) is determined from an empirical model [2] based on satellite in-situ measurements of the individual ion densities. In this model, the transition level is approximated by a multi-variable polynomial, providing convenience when referencing the level with respect to solar activity, season, local time, longitude and latitude. The new method is supposed to deliver better results than the standard methods of electron profiles reconstruction from digital ionosonde data and Chapman-type layers [4]. The reconstruction formula is

$$N_e(h) = N_{O+}(h_m F2)\, sech^2\left(\frac{h - h_m F2}{2.H_{O+}}\right) + N_{H+}(h_m F2)\, sech^2\left(\frac{h - h_m F2}{32.H_{O+}}\right), \quad h > h_m F2 \qquad \textbf{(1)}$$

where H_{O+} is the O^+ scale height, $sech(h) = 2 / [exp(h)+exp(-h)]$.

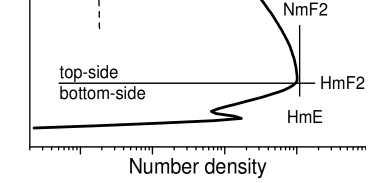

Fig.1 Density profile characteristics.

A major part of the testing procedure of this new method is to determine the most suitable ionospheric profiler for reconstruction purposes. Although the qualities and shortcomings of these simple ionosphere models are known, the models should be further investigated as ingredients of the proposed reconstruction formulae based on them. Particular attention is getting the scale height calculation in the upper ionosphere, from hmF2 up to the O^+-H^+ transition height, a region contributing a lot to the total electron content and where different profilers produce quite different results.

The purpose of this report is to present an estimation of how good the simple ionospheric models are as reconstruction instruments. Comparison is made between the different profilers and between the profiler values and satellite in-situ data. The input ionosonde and GPS TEC data are obtained at the Royal Meteorological Institute's Geophysics Centre - Dourbes (4.6°E, 50.1°N). At this center, a GPS receiver is collocated with a digital ionosonde, and TEC values are produced every 15 minutes. Measurements have been conducted regularly since 1994 and a large TEC database created for the best part of the current solar activity cycle.

ESTIMATION RESULTS AND DISCUSSION

The ionospheric profilers that are considered in this study (Sech-squared, Exponential, α-Chapman, β-Chapman, and Parabolic) may produce quite different (in shape) top-side density profiles if the peak density and scale heights are fixed. It is well demonstrated in Fig.2 for a given scale height of 100 km, maximum density of 1.0×10^5 [cm^{-3}] , and height of the peak density hmF2 = 300 km. All profiles (except the Parabolic one) asymptotically approach the exponential profile at great altitudes; the steepest profile is delivered by the α-Chapman layer.

The next step is to compare the density profiles, obtained by the analytical models, with independent measurements. Good altitude profiles of the O^+ and H^+ ion densities can be obtained from the AE-C satellite in-situ measurements carried out from 16/12/1973 to 21/3/1975 when the solar activity was low, F10.7 ≈ 85. Three seasons are considered here - winter, equinox, and summer, defined as 91 day periods centred on the 356, 81 and 264, 173 day of year respectively. Several basic profile characteristics, required as input parameters, are extracted from the averaged data – the O^+ scale height, the F2-layer density maximum and height, and the upper transition level. All night-time foE values are set to zero and at day-time foE is set to some plausible averages for the season and local time at 35° latitude. The propagation factor M(3000)F2 is obtained after fitting the satellite data with Epstein layer functions. Same scale heights were used for calculating the profiles in each season and local time conditions. The vertical ion density distributions (both observed and modelled) are given in Fig.3. Only the Sech-squared and Exponential layers are used, as the Chapman profiles repeat (in relation to the other layers) the behaviour already presented in Fig.2. The different profilers produce quite different altitude distributions in the F-region and therefore they will create significant differences in the corresponding values of the total electron content. The largest contribution to the TEC value comes from the region near the peak height and it is most important to compare the performance mainly in this region. It was shown [3] that the Sech-squared model is more suitable for describing the night-time behaviour, while the day-time behaviour is better represented by the Exponential and β-Chapman. The latter ensures a far better simulation in the region near the peak. The Sech-squared and α-Chapman layers generally overestimate the day-time values. For summer conditions, the best options are the Sech-squared layer for night-time and the Exponential profiler for day-time conditions. During equinox, the Exponential is better at day-time and Sech-squared – night-time. During winter, data are rather scarce and highly scattered which makes it difficult to draw decisive conclusions. However, the winter-time comparison results at least prove the necessity of a more detailed look on the reconstructed patterns in latitude direction.

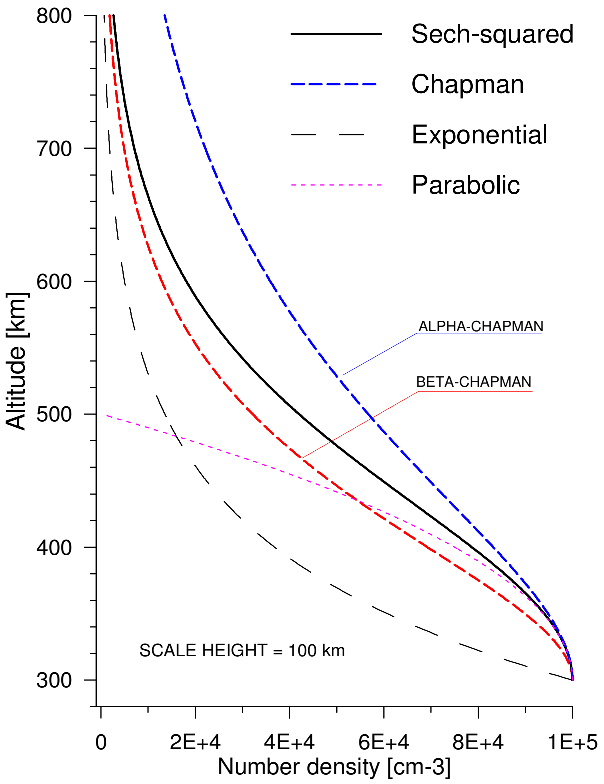

Fig.2 Comparison between vertical electron profiles obtained with analytical models and a scale height 100km.

If an electron profile is forced to pass through a given point, i.e. at a given density at a given height, then the shape of the resulting electron density profile changes. Such 'forcing', for example, is the condition imposed on the O^+ and H^+ density height profiles to cross each other at the a priori given O^+ - H^+ transition height. The 'transition-height' condition not only affects the profile shape, but also ensures the unique solution of the reconstruction problem.

The next step in the estimation procedure is to deduce the electron density profiles by using the reconstruction technique and to compare them with averaged AE-C data profiles. The results of such evaluation [3] are provided in Fig.4 for both night-time (left-hand panel) and day-time (right-hand panel) conditions and all profilers. Obviously, no single profiler is suitable for all altitudes, which comes to suggest that a composite profile should be considered. During night, the Sech-squared and Chapman-type profilers provide much better results near and slightly above the peak height, at higher altitudes the Exponential profiler becomes better, and from about 560km – the Sech-squared and Chapman profilers are again the better constructors. During day-time, the Exponential layer is the best option, except for heights around the 600km mark. Uncertainties in the evaluation procedure are introduced via possible incorrect determination of TEC and larger values of the H^+ density below the H^+ peak because of the assumption for equal heights of the O^+ and H^+ density maxima.

More measurements and studies are required for estimating the profilers under high solar activity conditions.

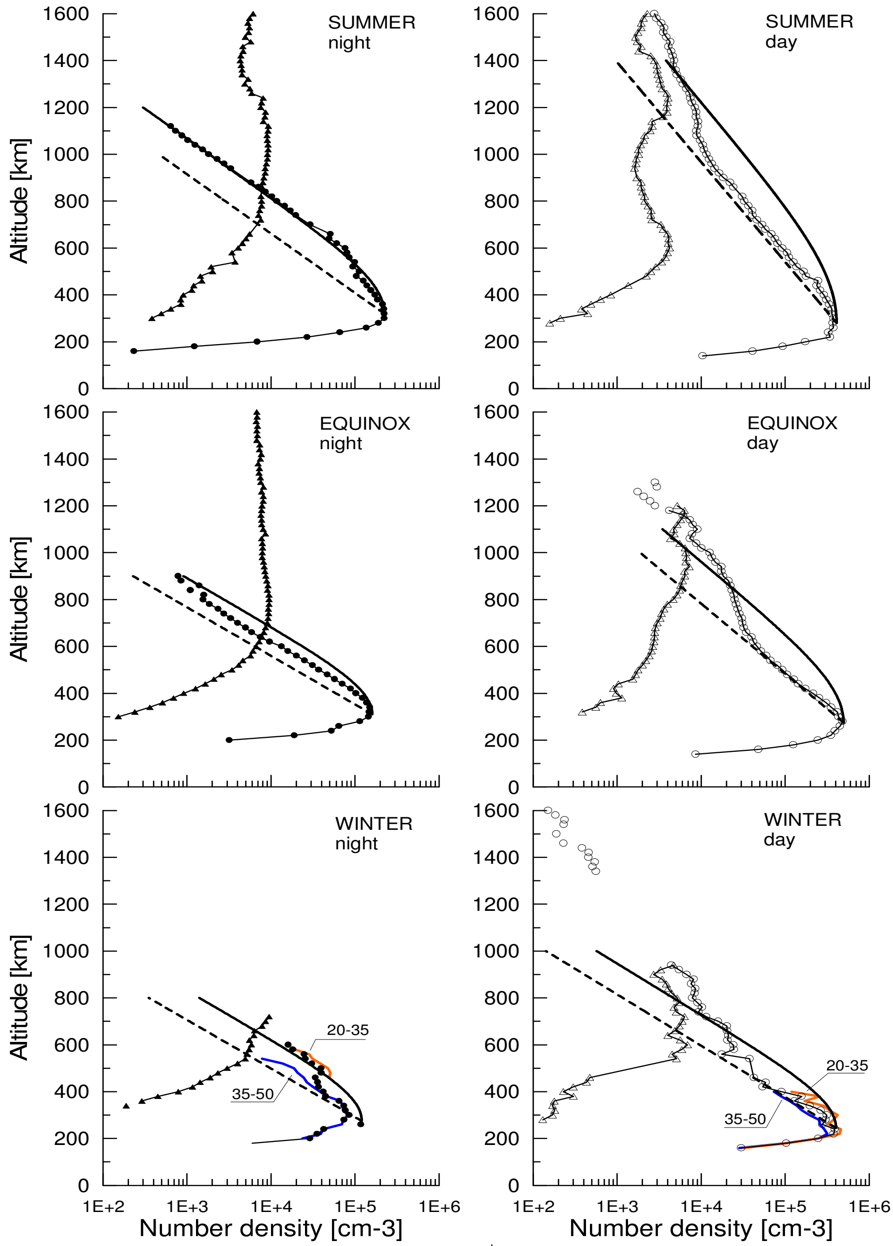

Fig.3 Sech-squared (solid line) and Exponential (dashed line) O^+ profiles compared with AE-C in-situ measurements of the O^+ (circles) and H^+ (triangles) densities from the 20-50°N geomagnetic latitude range.

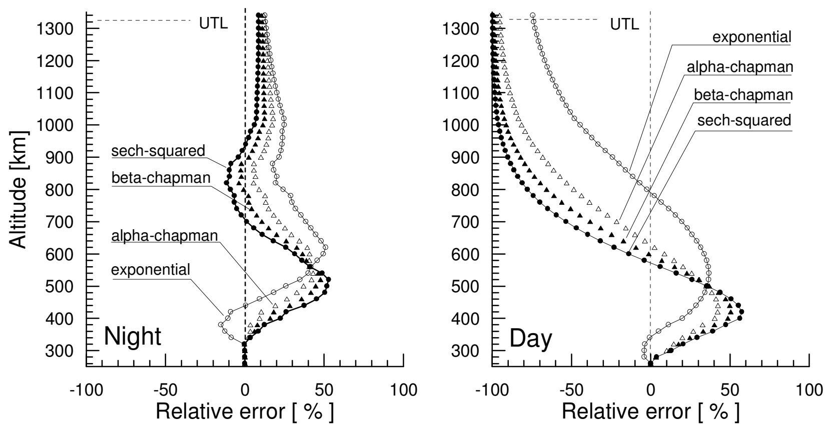

Fig.4 Reconstructed electron profiles compared with AE-C data for night-time (left) and day-time (right) conditions.

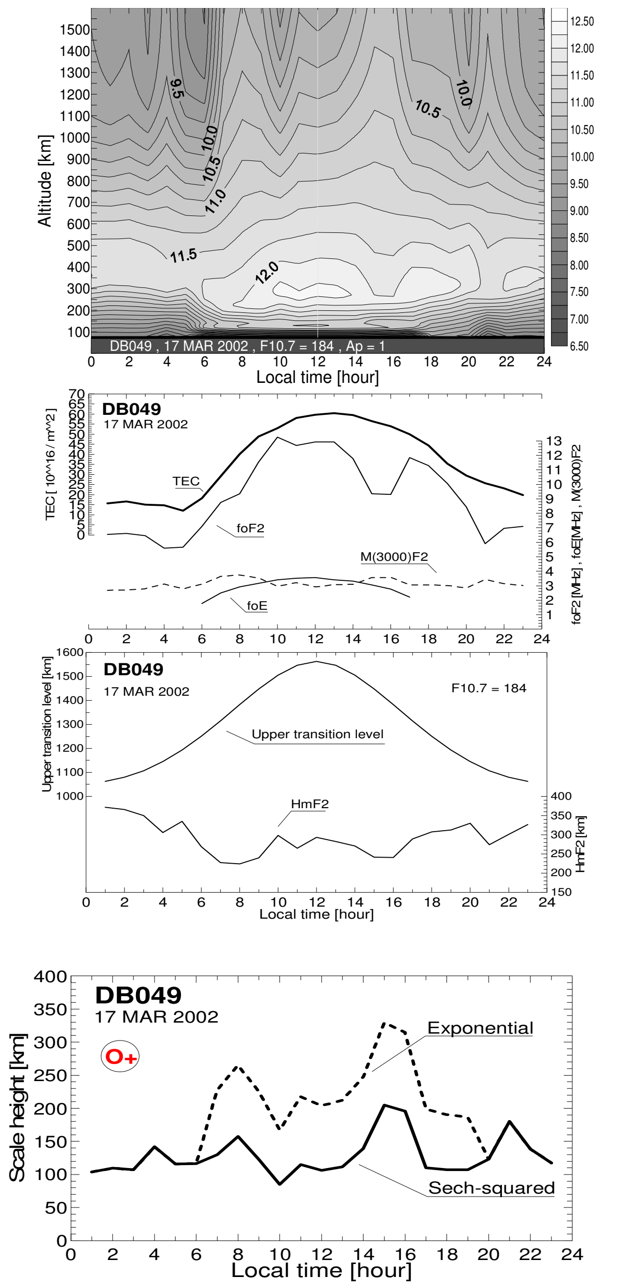

Fig.5 Profile reconstruction using Sech-squared (night-time) and Exponential (day-time) profilers: top - vertical electron density (log scale, m^{-3}), middle panels - input measurement data, bottom panel – the reconstructed oxygen ion scale height.

Considering the above estimation results, actual hourly measurement data from the RMI Geophysics Centre at Dourbes (4.6°E, 50.1°N) have been used to reconstruct the diurnal behaviour (Fig.5). In the first test, the reconstruction is carried out with Sech-squared profiler only. In the second test, the Sech-squared layer is applied for night-time conditions, while the Exponential profiler is reserved for the day-time hours, 07:00-19:00LT. Both tests reveal a high sensitivity of the reconstructed top-side electron concentration from the input parameters. While the TEC is smoothly changing during all hours, the foF2 demonstrates a sharp increase around 10:00LT and a pronounced decrease in the afternoon hours between 14:00 and 16:00LT. This leads to sharply decreased values of the slab thickness (TEC/NmF2) in the morning and a significant increase in the afternoon. In both cases the reconstruction procedure 'reacts' well according to the circumstances. However, a calculation of the scale heights (Fig.5, bottom) confirms the previous test results, i.e. that Exponential layer is preferable for day-time conditions. For example, at 10:00LT and 18:00LT, both O^+ and H^+ scale heights (deduced from Sech-squared profiler) fall below the night-time values, which is not justified considering the quiet geomagnetic conditions.

CONCLUSIONS

The basic analytical ionospheric models (Sech-squared, Exponential, and Chapman) have been evaluated as tools for electron profile reconstruction based on a recently proposed method [1,2,3]. The following conclusions have been made. The Sech-squared, Exponential, and Chapman profilers can all be successfully used in the reconstruction technique. However, no single profiler can sufficiently well represent all spatial and temporal variations. The Exponential layer is much more suitable for day-time conditions, while the other profilers (Sech-squared and Chapman) are preferable for the night and dawn/dusk time.

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