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# Topside ionospheric scale height analysis and modelling based on radio occultation measurements

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**Abstract**

The knowledge of the scale height in the topside ionosphere region remains rather poor due to the insufficient observations carried so far. To advance this knowledge, presented here is a new method of retrieving the topside ionospheric scale height based on radio occultation observations onboard low-earth-orbiting satellites. The scale height, well known for its dependence on the temperatures and masses of the ionospheric constituents, understandably experiences large spatial and temporal variability. With the help of the CHAMP satellite's occultation experiment, analysed is the scale height behaviour with respect to solar and geomagnetic activity, local time, season, longitude and latitude. The expected strong dependence on temperature has been confirmed; however, it has been found that this dependence is not straightforward but more complex and clearly affected by other factors. For example, while the daytime scale height values increase at higher solar activity, the night-time values do not show such a trend. The seasonal dependence proved to be strong with summer-time values significantly higher than winter-time numbers. Also, there is no common pattern for the diurnal variations: sometimes daytime values are higher, sometimes the night-time values dominate; large differences are detected from season to season and from latitude to latitude. Generally, the scale increases at higher latitudes, although a few differences do exist. No major longitudinal and hemispheric differences have been detected so far. Based on the accumulated data, a first attempt has been made to empirically simulate the scale height value at 425 km altitude; as input parameters, the model respects the local time, latitude, and season. The scale height model can be implemented into the electron density profile retrieval procedure by delivering an improved initial guess.


*Keywords:* Ionosphere; Radio occultation; Scale height; Empirical modelling

## 1. Introduction

One of the most important characteristics of the ionosphere–plasmasphere system is the plasma scale height. The plasma scale height has the dimension of length and is defined (Davies, 1990; Hargreaves, 1992) as $H_P = kT_P/m_i g$, where $m_i$ is the ion mass, $T_P = T_i + T_e$ is the plasma temperature, $T_i$ and $T_e$—ion and electron temperatures, $k$—the Boltzmann constant ($1.380658 \times 10^{-23}$ J/deg). Actually, the scale height is a critical property of any atmosphere and can be defined for each ion or neutral constituent (Van Zandt, 1967). In practice, the vertical scale height can be approximately deduced

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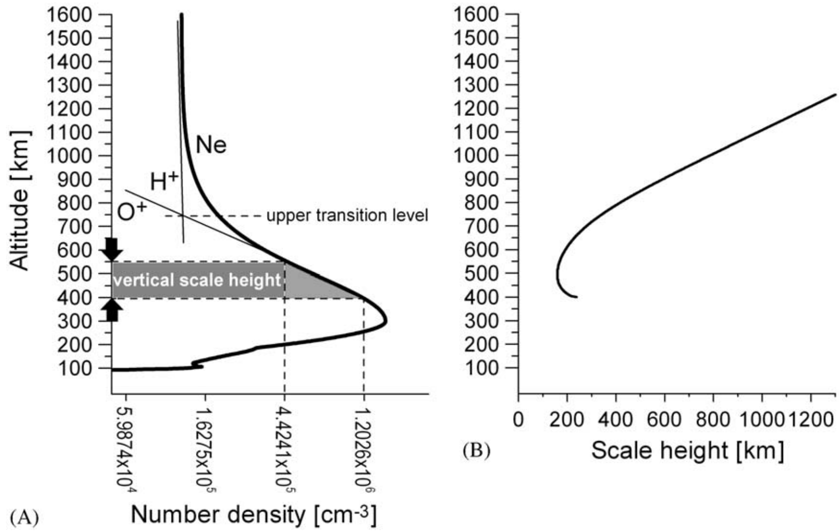


Fig. 1. Schematic view of the $O^+$, $H^+$, and Ne vertical profiles (Panel A) and the derivation of the vertical plasma scale height. Notice the altitudinal variation of the topside plasma scale height (Panel B).

(Fig. 1A) as the vertical distance in which the concentration changes by a factor of an exponent ($e \approx 2.718281828$). Since the plasma temperature varies with altitude, it is obvious that the plasma scale height varies as well (Fig. 1B). Also, the value of the plasma scale height indicates the gradient of the electron density; for instance, in the topside ionosphere region—the region situated immediately above the height ($h_mF_2$) of the ionospheric F2 peak electron density—the steeper the electron density profile, the larger is the scale height. Because many ionospheric phenomena leave their signatures on the scale height, a study of the scale height behaviour can provide valuable information on the vertical distribution of ionisation, and can thus be capable of answering many open questions in the ionospheric physics, particularly those related to ionosphere composition and dynamics (Hanson and Ortenburger, 1961; Horwitz et al., 1990; Rawer, 1993). The knowledge of the scale height value is of particular importance in several scientific and technical applications. For many years, simple ionospheric profilers, such as the Exponential, Chapman, and Epstein layers (Banks and Kockarts, 1973; Rawer, 1988; Stankov, 2002b), have been used to model the topside ionosphere, e.g. in the International Reference Ionosphere (IRI) empirical model (Bilitza, 2001). Also, in the software for inversion of ionograms in modern digital ionosondes, the Epstein formulae are applied to complement the deduced bottom-side electron profile with a topside profile (Reinisch, 1996; Reinisch and Huang, 2001). However, because the topside scale height is unknown, it is assumed that the scale height above the F2 peak equals the scale height just below the peak; this is a strong assumption which is not always correct. There are also density reconstruction techniques which could significantly benefit from the knowledge of the topside ionospheric scale height, at least as a source of an educated initial guess (Jakowski et al., 2002b; Heise et al., 2002; Stankov et al., 2003a).

The bottom-side scale height is relatively well known and easy to deduce thanks to the ground ionosonde measurements and the dense network of such ionosondes. The scale height in the plasmasphere is also relatively easy to calculate because it is changing slowly with altitude (due to the small gradient in the plasma temperature) and increasing number of in-situ measurements (both on plasma density and temperature). The plasma scale height in the topside ionosphere—from $h_mF_2$ up to the $O^+$–$H^+$ ion transition level, where the plasmasphere starts, is most difficult to obtain. The abundant ground ionosonde measurements are not helpful at all because they sound the bottom-side ionosphere up to $h_mF_2$. Besides, the temperature changes in the topside ionosphere are large and vary widely with local time (LT), season and latitudes which lead to large variations in the scale height too.

There are several techniques which have been used for gathering information on the topside