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NeQuick topside formulation over Nicosia

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Abstract

Using topside electron density measurements recorded by different techniques over Nicosia, Cyprus (geographical coordinates: 35.14ºN, 33.2ºE) we investigate the behaviour of a topside electron density formulation of the NeQuick model with an extension recently proposed, called NeQuick-corr. The selected topside electron density dataset employed in this study is primarily based on Radio Occultation (RO) topside electron density profiles on board low Earth orbit (LEO) satellites from the COSMIC/FORMOSAT-3 mission. The results are also examined based on in-situ Langmuir probe data on board European Space Agency (ESA) Swarm satellites, in the vicinity Nicosia. Our investigation demonstrates that a measurable NeQuick topside representation improvement can be achieved in the topside F region near the peak, if a key parameter (g), that regulates the altitudinal scale height variation, is adjusted to a value of 0.15 (compared to a currently adopted value of 0.125).

1 Introduction

In the absence of satellite topside sounders which would be the ideal method to investigate topside ionosphere electron density profiles, Langmuir probes and Radio occultation (RO) measurements on board low Earth orbit (LEO) satellites are the most widely used space-based techniques currently employed to perform this task. This task is quite essential as the topside ionosphere (the ionospheric region between the peak height of F2 layer and the upper transition height) encapsulates a significant percentage of the total electron content (TEC). In this way, these techniques complement ionosondes because they can only probe up to the peak height of F2 layer.

NeQuick is a semi-empirical climatological model that describes spatial and temporal variations of the ionospheric electron density at a given time and location [1,2]. The NeQuick topside formulation has been adopted as one of three options to model the electron density in the topside ionosphere in the frames of the International Ionosphere Model (IRI) -2016 [3].

The NeQuick topside model is based on an Epstein function (as shown in equation 1). The electron density profile (Ne (h)) is defined as a function of *hm*F2, *Nm*F2 and effective scale height (Hm) as follows:

$$\mathrm{Ne}\,(h) = 4.Nm\mathrm{F2}.\ \frac{exp\left(\frac{h-hmF2}{Hm}\right)}{\left(1+exp\left(\frac{h-hmF2}{Hm}\right)\right)^2} \tag{1}$$

$$\mathrm{Hm} = \mathrm{H_0}\left[1+\frac{r\cdot g(h-hmF2)}{r\cdot H_0+g\cdot(h-hmF2)}\right] \tag{2}$$

The scale height in the NeQuick topside formulation is described by three parameters, scale height at the peak (H_0), a parameter (r) which restricts the scale height at higher altitudes and the altitude gradient of the scale height (g). A value of r =100 and g =0.125 is adopted in NeQuick topside formulation.

An improvement in the NeQuick topside formulation (NeQuick-corr) was recently proposed [4]. This NeQuick-corr topside formulation is based on H_0 grids as a function of *hm*F2 and *fo*F2, derived from electron density values measured by Langmuir probes on-board Swarm satellites (A,B and C), generated by applying the IRI-UP (Update) method [5].

Pignalberi et al., have recently underlined the significance of parameters r and g in the topside scale height variation near the F2-layer peak (up to about 800 km) [6]. They have shown that the topside scale height exhibits a linear dependence on the peak-relative altitude (h-*hm*F2), where g is the slope and H_0 is the intercept, as follows:

$$\mathrm{H}\,(h) \simeq \mathrm{H_0} + g \times (h-hm\mathrm{F2}) \tag{3}$$

In this study, we exploit topside electron density profiles from collocated (within 1º of the peak electron density coordinates) and simultaneous (within 15 min time difference) COSMIC RO-Digisonde profile pairs over Nicosia and using and NeQuick-corr topside model electron density estimates we demonstrate that a value of g=0.15 achieves the best topside electron density representation, over Cyprus. We also attempt to compare the proposed and existing g value (g=0.125) using SWARM A and C values over the Nicosia.

2 Data

The COSMIC/FORMOSAT-3 (Constellation Observing System for Meteorology, Ionosphere, and Climate and Formosa Satellite) was a very successful 6-satellite mission that recently reached the end of its lifetime. It has produced more than 4 million electron density profiles by exploiting dual frequency phase measurements from GPS radio occultation (RO) receivers installed on each of the six satellites [7]. The occultation path can extend to thousands of kilometres in the horizontal direction, which gives rise to high horizontal electron density gradients. Therefore to minimize uncertainties as much as possible ground-based techniques such as ionosonde and ISR stations have been used in validation studies to examine criteria that ensure that topside RO profile accuracy is maintained.

Figure 1 shows the COSMIC RO profile with respect to latitude and longitude, where the red part of the profile shows the bottomside projection and blue part shows the topside profile projection. It also shows the nearest digisonde station (Nicosia station as an example). By applying a maximum separation requirement (< 1° in latitude and longitude) between a RO topside measurement and Nicosia digisonde location we could achieve sufficient colocation criteria between these two electron density profiles. The digisonde topside electron density profiles were the result of manually scaled ionograms within a time interval of less than ±15 min from the RO measurement under the additional requirement of maximum difference at the peak values (<5% difference in hmF2 and foF2), in accordance to a previous study [8]. Unrealistic RO profiles with excessive fluctuations in the topside electron density or with hmF2 values out of a realistic range [180<hmF2<450 km] were rejected. The, final dataset used was composed of 230 RO cases.

Swarm is a constellation mission by the European Space Agency (ESA). This mission comprises of three identical satellites named as A, B and C that were launched on 22 November 2013 into a near-polar orbit. Swarm A and C are flying at an altitude of around 460 km side by side with a longitudinal separation of 1.4°, while Swarm B is at around 510 km at an inclination angle of 88°. Swarm A&C and Swarm B lie on different orbital planes and their altitude and separation is changing with time. One of the instruments is the Electric field instrument (EFI), which measures the plasma density, velocity and drift in high resolution. The EFI also consists of two Langmuir probes (LP) that measure the in-situ electron density, electron temperature and electric potential from the high gain probe at a 2 Hz resolution.
Swarm topside electron density measurements over Cyprus used in this study were one minute intervals that have been averaged in the range of 34°–36° in latitude and 32°–34° in longitude. The Swarm database provides calibrated electron density at an altitude of approximately 460 km (collected by Swarm A and C). Regarding the quality of Swarm electron density (Ne), the Ne Quality flag (≤29) and the Ionospheric Plasma Irregularities (IPIR) index (<3) has been chosen as per Swarm L2 product specifications guidelines. Digisonde topside electron density values at the altitude of the Swarm satellites were extracted within 2.5 min from any Swarm A or C passage over Cyprus.

In addition, corresponding NeQuick-corr electron density values at the Swarm altitude were estimated applying the NeQuick topside option matched at the hmF2, NmF2 values measured by the digisonde. The dataset chosen for the investigation spanned from July 2014 to December 2017 and resulted in 243 values for Swarm A and Swarm C over Nicosia.

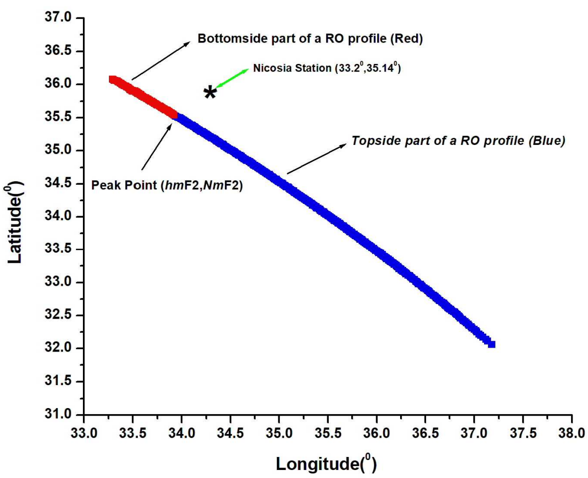

Figure 1. COSMIC RO profile ground projection variation with respect to Latitude (on y axis) and Longitude (on x-axis) and Nicosia Digisonde station location.

3 Results and Discussion

As, recently shown, the behaviour of the topside scale height in the lowest topside region (from hmF2 to about 800 km of altitude) is expected to be linear [6]. So to verify this for all RO profiles under consideration (230 profiles) the scale height was calculated using equation (3). The scale height of each profile was fitted under a linear approximation as shown in Figure 2 and subsequently the corresponding electron density profile was calculated, based on the estimated g value providing the best fit.

Figure 3 shows the histogram plot of parameter g based on the minimization of RMSE between RO and linearly fitted scale-height electron density profiles calculated according to the optimum fit. It shows that the histogram peaks at g=0.15. Themens et al., based on different datasets discussed that the NeQuick option can be improved over upper mid latitude and high latitude regions by adjusting r and g values to r =20 and g = 0.2024 [9]. Another study by Themens et al. showed that NeQuick parameterization does not adequately represent the topside thickness during solar minimum between cycles 23 and 24 [10]. Our study has demonstrated a different optimum g value that is more suitable for mid-latitude station, such as Nicosia.

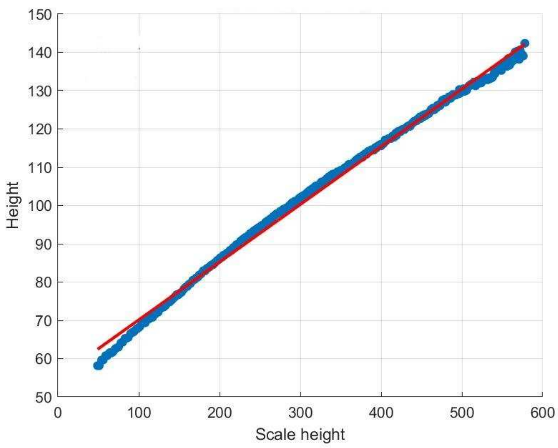

Figure 2. Topside scale height values (blue points) from the COSMIC RO measured profile shown in the top panel, and corresponding linear fit (red line).

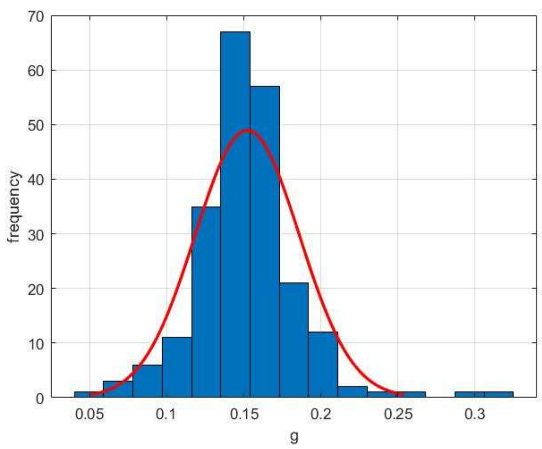

Figure 3. Histogram optimum g values for all 230 cases fitted with NeQuick-corr.

For the comparison of Swarm A&C satellite data with NeQuick-corr topside modeled data at the altitude of the Swarm in-situ electron density measurement, a relative difference has been calculated between Swarm observations and NeQuick-corr estimations as follows:

$$\text{Relative difference (RD)} = \frac{Ne_{Swarm} - Ne_{\text{NeQuick-corr}}}{Ne_{Swarm}} \quad (4)$$

Figure 4 shows the Relative difference (RD) between the Swarm A&C measured electron density and the electron density calculated from NeQuick-corr topside formulation using both proposed and currently adopted parameter g value, respectively. This graph clearly shows that for majority of observation data points RD (g=0.15) is less as compared to the RD (g=0.125).

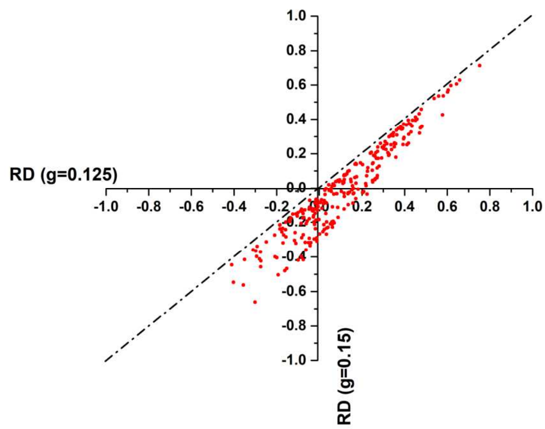

Figure 4. **S**catter plot of relative difference between SWARM and NeQuick-corr for g=0.125 (on x-axis) and SWARM and NeQuick-corr for g=0.15 (on y-axis) and also depicts the y = x line (black).

4 Conclusions

We applied a new topside formulation NeQuick-corr on a limited dataset of topside COSMIC RO observations over Nicosia. These profiles were selected based on the criterion of time coincidence and matching (within 5% at the peak RO-digisonde) of foF2 and hmF2 values. Through this selected dataset we were able to demonstrate a new value of g=0.15 (as opposed to a currently adopted value of 0.125) as the most appropriate value to ensure a superior NeQuick-corr topside representation over Nicosia, under the linear scale height variation hypothesis (up to several hundred km over hmF2). In the future we plan to perform the evaluation of this proposed g value with a more extended topside dataset [11].

5 References

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