Comparison between RO and Digisonde bottomside electron density Over Cyprus

H. Haralambous*[a, b], *Mefe Moses*[c]
[a] Frederick Research Center, Nicosia, Cyprus
[b] Frederick University, Nicosia, Cyprus
[c] Department of Geomatics, Ahmadu Bello University, Zaria, 810107, Nigeria

Abstract

The objective of this study is to perform a comparison between bottomside electron density measurements from the Global Navigation Satellite System (GNSS) radio occultation (RO) FORMOSAT3/COSMIC (F3/C) constellation mission along with collocated (in space and time) electron density values from bottomside electron density profile (EDP) measurements based on manually scaled ionograms from the Cyprus Digisonde. This comparison demonstrates that there is a systematic overestimation of F3/C Ne electron density (as compared to Digisonde) in the bottomside and that the relative difference between F3/C and Cyprus Digisonde electron density increases with decreasing altitude (below the F-layer peak).

Keywords: Ionosphere, Bottomside Electron density profile, radio occultation, FORMOSAT3/COSMIC, Digisonde

1. INTRODUCTION

Atmospheric remote sensing by exploiting the GNSS radio occultation (RO) technique between GNSS and Low Earth Orbiting (LEO) satellites is an established approach that can facilitate probing of the vertical ionospheric density profile (EDP) beyond the traditional ground-based monitoring techniques such as ionosondes and GNSS receivers. The most successful radio occultation mission on the basis of the extent of the dataset assembled is the FORMOSAT3/COSMIC (F3/C), which inspired an extended array of studies based on its capability to collect >4 million Electron Density Profiles (EDPs) from 2006 to 2018. Some of these studies were carried-out by combining RO measurements coinciding in time and space with ionosondes. This approach was very powerful in the sense that it leveraged the inherent weakness of ionosondes that can only probe the bottomside EDP (below the F-layer peak) at a specific location with the superiority of the RO technique to monitor the topside EDP (beyond the F-layer peak) on a global scale (Figure 1). Based on this compromise offered by each technique, comparison studies of peak ionospheric characteristics (NmF2/hmF2) and validation of bottomside and topside ionospheric models was possible on the basis of single-station[1], multi-station[2] and global scale datasets[3]. In addition colocation studies using other instruments such as Incoherent Scatter Radar (ISR) facilitated full (bottomside-topside) EDPs validation[4]. In fact since a RO EDP is the result of two moving satellites, the actual tangent point during the RO event moves significantly in the horizontal direction on the order of several hundred km. Various studies with a local or global scope were undertaken, and established that there is a difference between Digisondes and RO plasma frequencies which is a function of the collocation distance[5]. These studies highlighted a significant overestimation of EDP peak electron density altitude (hmF2), and an underestimation of peak electron density NmF2 in addition to a notable discrepancy which varies as a function of latitude[6]. This discrepancy was explained in accordance to the assumption for spherical symmetry required for the Abel inversion (used to extract EDPs from RO data) which breaks and a result the horizontal gradient of the refractive index exists along the spherical shell should not be ignored[7]. Therefore, reliable data quality control measures have been proposed to screen inaccurate EDPs for further consideration[8].

This study presents a comparison between bottomside plasma frequency values extracted from F3/C RO EDPs and collocated bottomside (in space and time) EDPs from the Cyprus European digital ionosonde (Digisonde) that routinely probes the ionosphere in the bottomside.

There is a significant potential to establish a framework based on which GNSS radio occultation (RO) measurements on board LEO satellites can be assimilated into ionospheric mapping procedures. This is expected to improve existing bottomside ionospheric mapping and related products to facilitate improvement of the bottomside specification based on the extended capabilities of populated nanosatellite constellations under private companies such as Spire, PlanetiQ and GeoOptics. Spire (with plans to reach 10.000 daily profiles by 2024, and over 100 RO-producing satellites in the full

Tenth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2024), edited by
A. Christofe, S. Michaelides, D. Hadjimitsis, C. Danezis, K. Themistocleous, N. Kyriakides, G. Schreier,
Proc. of SPIE Vol. 13212, 132120N · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3037213

constellation) is currently under evaluation by ESA as a Third Party Mission candidate to investigate the suitability of the data for scientific and R&D activities.

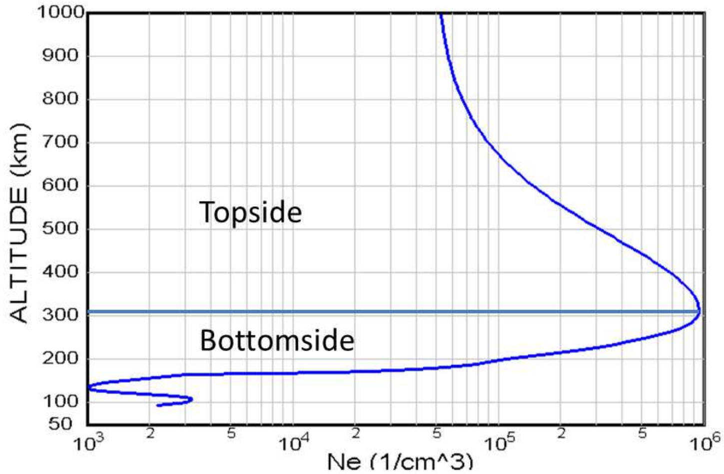

Figure 1. Typical ionospheric electron density profile.

2. DATA AND METHODOLOGY

The Digisonde EDPs are based on ionogram inversion provided by the Cyprus Digisonde at Nicosia (35^o N, 33^o E geographic; magnetic dip. 29.3^o N). The knowledge on the state of the ionosphere generated by the Cyprus Digisonde is valid only for a limited area around Cyprus therefore in order to compare with RO EDPs that, according to the nature of a RO measurement, covers a more extended geographical area, strict colocation criteria not only in time but also in space were applied. We applied a maximum acceptable time difference of 7.5 min between RO and Cyprus Digisonde EDP. For the best colocation in the bottomside we applied very strict spatial criteria ensuring that we consider the RO EDP measurement at a minimum distance from the Digisonde coordinates obtained within 2^o in latitude and longitude. The RO dataset was carefully processed to remove questionable (non-smooth) EDPs and a maximum time discrepancy of 15 min on some occasions between the Cyprus Digisonde and RO EDP was tolerated to account for ionograms that were impossible to scale due to specific ionospheric irregular conditions which are typical over European mid-latitudes especially during summer (such as spread F[9] or blanketing sporadic E[10]).

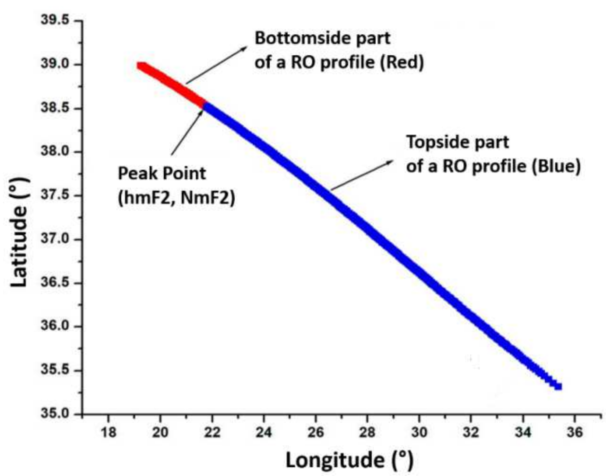

Figure 2. COSMIC RO EDP ground projection with respect to latitude and longitude around Nicosia**.**

This approach is illustrated in Figure 2. The blue dots represent the ground projection of topside measurements and the red dots the ground projection of bottomside measurements. These points typically correspond to altitudes in the range 100km<h<250km during day and 100km<h<350km during night. In this paper we focus on the red segment of the typical EDP projection which corresponds to the bottomside (i.e. below the F-layer peak). The blue dots (topside RO EDP measurements) can be as far as Athens and even further so they are not well collocated with the Cyprus Digisonde coverage area. We have restricted Digisonde EDPs to altitudes greater than 90 km since this is the approximate minimum virtual height in the ionogram traces that Digisondes capture and from which EDPs are inferred.

3. RESULTS

For each year in the interval 2009-2012, considered in this investigation, we display altitudinal plots of the relative percentage difference [(RO-Digisonde)/Digisonde] in the plasma frequency. In Figure 3 we display results for year 2009 which actually correspond to an extremely low solar activity year. In fact 2009 was a year of particular interest since extremely low solar activity was recorded for a prolonged time period. The vertical line (Relative_difference=0%) represents a convenient benchmark to compare plasma frequencies from Digisonde and RO EDPs. An immediate conclusion that stems out of these plots is a clear overestimation of RO plasma frequencies in every section of the altitudinal range. Since we are mostly interested in the bottomside ionosphere for which the Digisonde performs actual electron density measurements, we used the Digisonde dataset as the benchmark since we can assume that this is the altitude range at which Digisonde measurements are more reliable as opposed to the topside where the Digisonde dataset is based on α-Chapman profiler extrapolation (assuming a constant scale height). The F3/C overestimation in the bottomside is clearly identified in all day and night plots (with the exception of the 2009 night plot) shown in Figures 3-6. This systematic RO overestimation is particularly evident for lower plasma frequencies (at lower altitudes).

Based on the importance of the bottomside ionosphere we clearly observe that this discrepancy gradually increases as the altitude decreases below hmF2 (which is roughly designated by the area at which the count (based on the scale) maximises in all plots). For lower altitudes below hmF2 we observe that most of the plots signify even a higher overestimation of RO bottomside plasma frequencies.

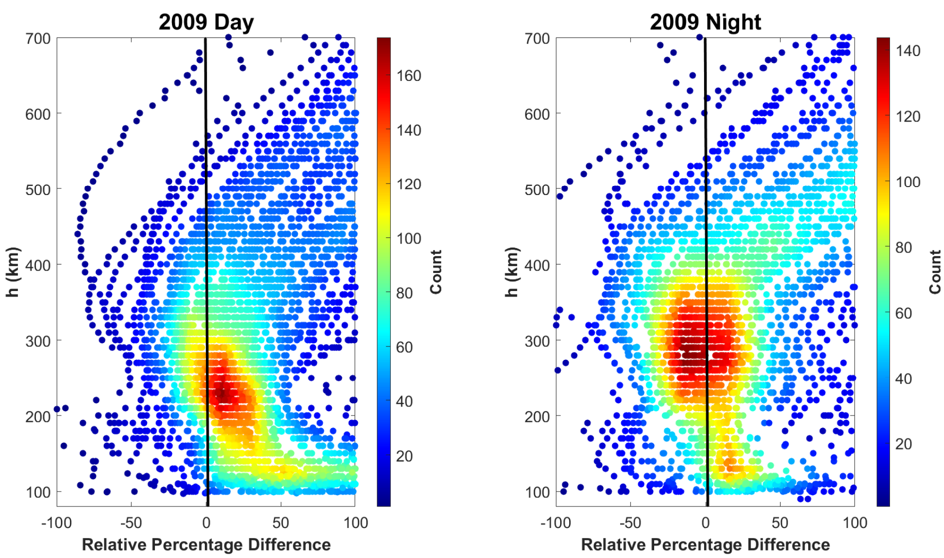

Figure 3. Relative difference of plasma frequencies from colocated Digisonde and F3/C RO EDPs over Cyprus for extreme low solar activity year 2009.

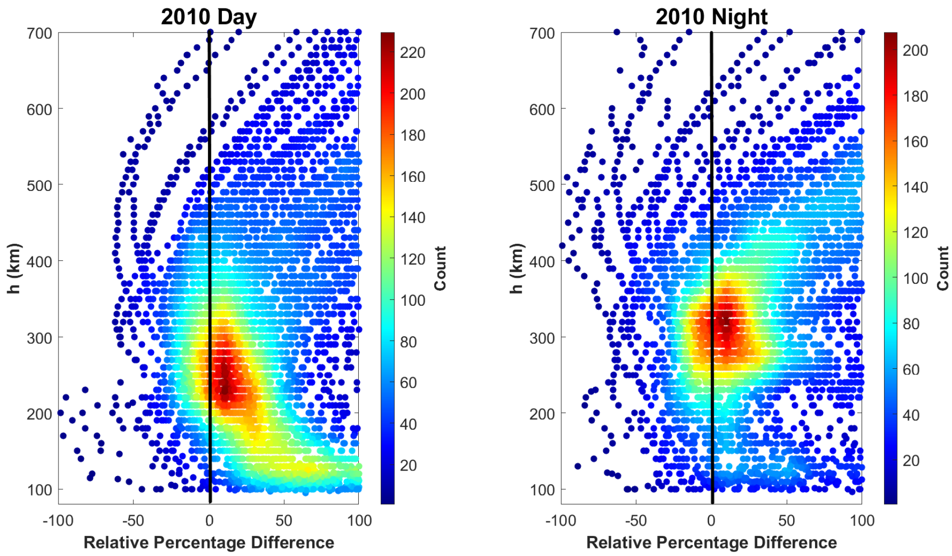

Figure 4. Relative difference of plasma frequencies from colocated Digisonde and F3/C RO EDPs over Cyprus for low solar activity year 2010.

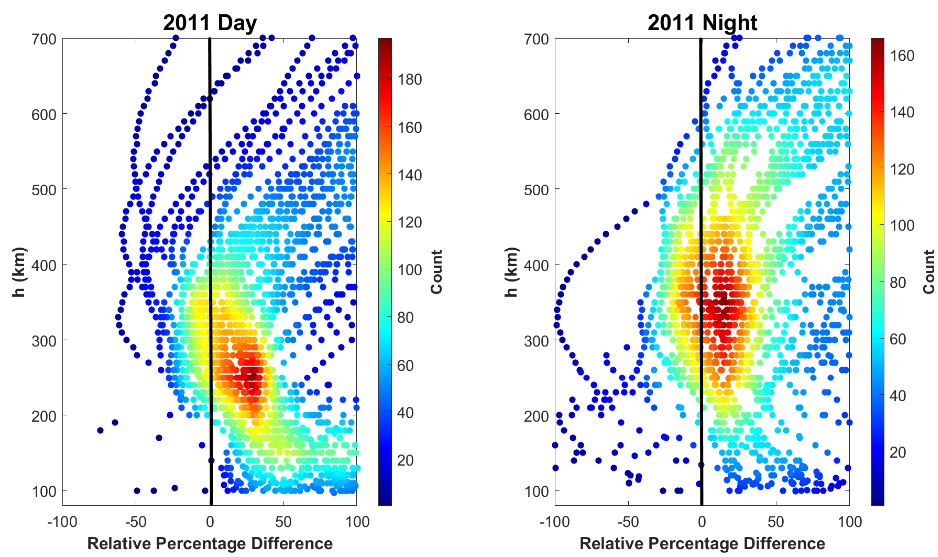

Figure 5. Relative difference of plasma frequencies from colocated Digisonde and F3/C RO EDPs over Cyprus for moderate solar activity year 2011.

For 2009-2010 years more RO EDPs were available since the F3/C mission started to generate less RO EDPs after 2011. We can also identify a gradual increase in the EDP altitude range as the solar activity increases from an extremely low level in 2009 to a moderate level in 2012 which is in line with the expected variability of EDP over Nicosia[11]. In general the agreement between RO and Digisonde in higher at night. The maximization of the discrepancy around 110-

120 km for daytime measurements is most likely attributed to sporadic E electron density which are embedded in the RO EDP but do not appear in the Digisonde EDP following the inversion of the EDP after manual scaling of Cyprus ionograms. Therefore this pronounced discrepancy is artificial and not a true feature. Despite this aspect the gradual increase of the discrepancy as a function of decreasing altitude below the peak electron density of the EDP in the bottomside is an established and undeniable finding of this comparison.

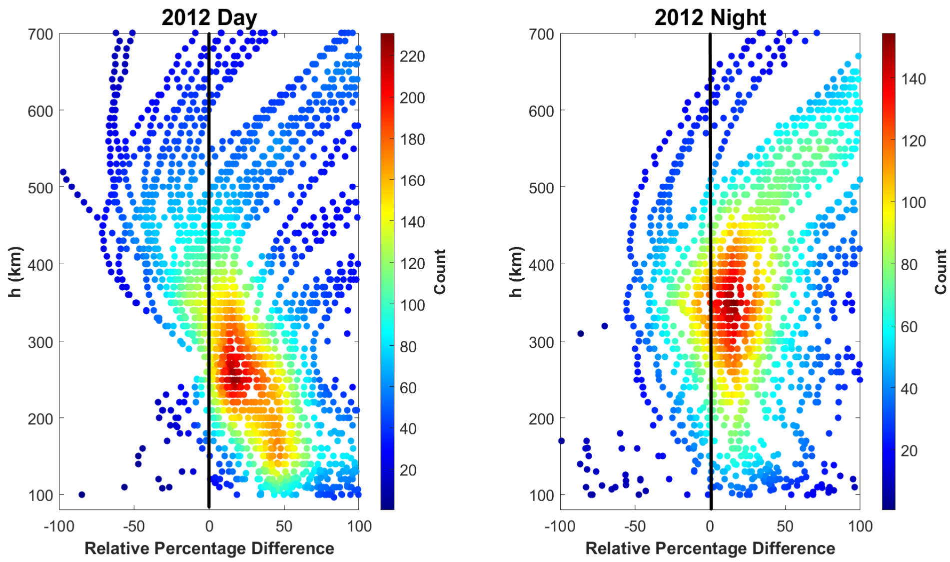

Figure 6. Relative difference of plasma frequencies from colocated Digisonde and F3/C RO EDPs over Cyprus for moderate solar activity year 2012.

4. CONCLUDING REMARKS

This study demonstrated the overestimation of bottomside F3/C plasma frequency over Cyprus with respect to Digisonde measurements that have been used as a benchmark in this comparison. From the extended investigation which encompassed extremely low (2009) to moderate (2012) solar activity levels the systematic feature of the increase of this underestimation values for lower bottomside altitudes was also manifested. The significance of the overestimation established in this study is crucial since a lot of regional and global ionospheric models are based on the fusion of RO and ionosonde data. This is particularly valid after the deployment of the F3/C mission that has generated a vast RO dataset on a global scale that was ideal for such a purpose. In fact the bottomside is particularly important since it actually defines a lot of topside ionospheric parameters. The topside is very important since over 2/3 of the Total Electron Content, which a defining ionospheric characteristic quantifying GNSS uncertainties, is mapped to the topside ionosphere. It is clear that the discrepancy between the two techniques necessitates careful data filtering before combining them on an equal basis for modeling or assimilation schemes for ionospheric nowcasting. This is the most important implication of this study and is very relevant for the near future when extended capabilities of populated nanosatellite constellations under private companies such as Spire, PlanetiQ and GeoOptics will become fully developed. In the near future a more thorough investigation will be undertaken to achieve better colocation between RO and Digisonde datasets in an attempt to analyse this discrepancy further in an effort to identify and analyse thoroughly its underlying drivers.

Acknowledgement

The authors are thankful to the CDAAC team (COSMIC Data Analysis and Archive Centre) for the FORMOSAT3/COSMIC data at their website (https://cdaac-www.-cosmic.ucar.edu/cdaac/products.html). This study was carried out under the project "International Reference Ionosphere Validation and Improvement" - IRIVIM, (Ref. No: EXCELLENCE/0421/0422) that was co-funded by the Republic of Cyprus and the European Regional Development Fund (ERDF), in the frame of the Operational Programme "ΘΑλΕΙΑ" 2021–2027 under Priority 1: "Competetive, Smart and Digital Economy" and the Specific Objective (1i): "Developing and enhancing research and innovation capacities and the uptake of advanced technologies.

REFERENCES

[1] Singh, A. K., Haralambous H., Oikonomou C., and Leontiou T., "A topside investigation over a mid-latitude digisonde station in Cyprus," Adv. Sp. Res., 67, 2, 739-748, https://doi.org/10.1016/j.asr.2020.10.009, (2021).

[2] Panda, S.K., Haralambous, H., Moses, M., Dabbakuti, J.R.K.K., Tariku, Y.A., "Ionospheric and plasmaspheric electron contents from space-time collocated digisonde," COSMIC, and GPS observations and model assessments, Acta Astronautica, 179, 619–635, https://doi.org/10.1016/j.actaastro.2020.12.005, (2021).

[3] Panda, S. K., Haralambous, H., & Kavutarapu, V. "Global Longitudinal Behavior of IRI Bottomside Profile Parameters from FORMOSAT-3/COSMIC Ionospheric Occultations," J. Geophys. Res.: Space Physics, 123, 7011– 7028. https://doi.org/10.1029/2018JA025246, (2018).

[4] Ratovsky K. G., Dmitriev A.V., Suvorova A. V., Shcherbakov A.A., Alsatkin S. S., and Oinats A.V. "Comparative study of COSMIC/FORMOSAT-3, Irkutsk incoherent scatter radar, Irkutsk Digisonde and IRI model electron density vertical profiles," Adv. Sp. Res., 60, 2, 452-460, https://doi.org/10.1016/j.asr.2016.12.026, (2017).

[5] Habarulema J.B., Katamzi Z. T., and Yizengaw E. "A simultaneous study of ionospheric parameters derived from FORMOSAT-3/COSMIC, GRACE, and CHAMP missions over middle, low, and equatorial latitudes: Comparison with ionosonde data," J. Geophys. Res., 119, 9, 7732-7744, https://doi.org/10.1002/2014JA020192, (2014).

[6] Chu Y.H., Su C.L. and Ko H.T. "A global survey of COSMIC ionospheric peak electron density and its height: A comparison with ground-based ionosonde measurements," Adv. Sp. Res., 46, 4, 431-439, https://doi.org/10.1016/j.asr.2009.10.014, (2010).

[7] Yue X., Schreiner W.S., Lei J., Sokolovskiy S.V., Rocken C., Hunt D.C. and Kuo Y.H. "Error analysis of Abel retrieved electron density profiles from radio occultation measurements," Ann. Geophys., 28, 1, 217-222, https://doi.org/10.5194/angeo-28-217-2010 (2010).

[8] Shaikh, M.M., Nava, B., Haralambous, H., "On the Use of Topside RO-Derived Electron Density for Model Validation," J. Geophys. Res.: Space Physics, 123(5), 3943–3954, https://doi.org/10.1029/2017JA025132, (2018).

[9] Paul, K.S., Haralambous, H., Oikonomou, C. and Paul, A., "Long-term aspects of nighttime spread F over a low mid-latitude European station." Advances in Space Research, 64(6), 1199-1216, https://doi.org/10.1016/j.asr.2019.06.020 (2019).

[10] Oikonomou, C., Haralambous, H., T. Leontiou, I. Tsagouri, D. Buresova, Z. Mošna, "Intermediate descending layer and sporadic E tidelike variability observed over three mid-latitude ionospheric stations" Advances in Space Research, 69(1), 96-110, https://doi.org/10.1016/j.asr.2021.08.038, (2022).

[11] Haralambous, H. and Oikonomou, C., "Comparison of peak characteristics of the F_2 ionospheric layer obtained from the Cyprus Digisonde," and IRI-2012 model during low and high solar activity period, Adv. Space Res, 56(9), 1927–1938, https://doi.org/10.1016/j.asr.2015.01.036, (2015).