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# Comparison of the observed topside ionospheric and plasmaspheric electron content derived from the COSMIC podTEC measurements with the IRI_Plas model results

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**Abstract**

In this paper, variations of the topside ionospheric and plasmaspheric electron contents (TPEC) in the altitude range of ~800 to 20,200 km are compared with the IRI_Plas model results for the low (2008) and high (2012) solar activity years using TEC data (podTEC) derived from the upward-looking precise orbit determination antenna on board COSMIC low Earth orbit (LEO) satellites tracking the GPS signals. For each year, the dataset were divided into groups according to four seasons: M-Equinox (March, April), J-Solstice (May June, July and August), S-Equinox (September, October) and D-Solstice (January, February, November, and December). Our study showed that the IRI_Plas model is able to reproduce reasonably well the main features of the observational TPEC's latitudinal, diurnal as well as seasonal variation tendency when no longitudinal difference is taken into account. However, there exist discrepancies between the observational TPEC and the model results. Except for the daytime hours in the Equinoctial seasons of the high solar activity year 2012 when the IRI_Plas model results showed an overestimation, in general, the IRI_Plas model results underestimate the observational ones, in particular at nighttime hours in the low-latitude region. When the longitudinal difference is taken into account, the comparison study showed that the longitudinal dependence effect shown in the observational TPEC's seasonal variations was not captured by the IRI_Plas model result. Moreover, the IRI_Plas model results tend to show a double-peak structure in the low-latitude region, a feature not appearing in the observational results.


*Keywords:* Total Electron Content (TEC); Topside ionosphere; Plasmasphere; COSMIC; IRI_Plas model

## 1. Introduction

Variations of the ionosphere and plasmasphere form a significant aspect of the complex subject of space weather, which has important impacts on satellite navigation and positioning, remote sensing and GPS (Global Positioning System) survey, etc. Radio signals transmitted from GPS satellite going through the ionization zone above the Earth will be refracted by the ionized components in the ionosphere and the plasmasphere, which would produce additional delay relative to the situation in vacuum and generate extra errors in satellite navigation and positioning, timing, remote sensing and telemetering. These errors have strong relation with the total electron content (TEC) along the signal's travelling path. Therefore TEC is one of the most important parameters required by many users for different modern usage purposes such as ionospheric range error correction required by geodetic community. The topside ionospheric and plasmaspheric electron content makes a large contribution to TEC. Study

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on the variations of the topside ionospheric and plasmaspheric electron content is a significant part of the space weather issues. The plasmasphere is a part of the Earth's magnetosphere and also the extension of the ionosphere. Although the electron density in the plasmasphere is much smaller than that in the ionosphere, the altitude range of the plasmasphere is much larger than that of the ionosphere. Therefore the contribution of the plasmasphere to TEC could not be ignored, especially at nighttime and during geomagnetic quiet periods when the plasmasphere has been refilled from its depletion following the geomagnetic storm. Previous studies (Yizengaw et al., 2008; Chong et al., 2013; Chen and Yao, 2015) revealed that the relative contribution of the plasmaspheric electron content to TEC exhibits a diurnal variation with minimum contribution (∼10%) during daytime and maximum (up to ∼60% to 80%) at night, depending on local times, latitudes and solar activity levels. As it is well known, the International Reference Ionosphere (IRI) model (Bilitza, 2001; Bilitza and Reinisch, 2008; Bilitza et al., 2014) is a model widely used in practice by many communities for different purposes. An increasing number of users of the ionospheric models also require information about the plasma conditions above the ionosphere in the plasmasphere. Extension of the IRI model to the plasmasphere is one of the main goals of the IRI community. A number of approaches have been proposed for extending IRI to the plasmaspheric altitudes (Gulyaeva and Bilitza, 2012). Among them is the IRI_Plas model, which is a combination of the IRI (version IRI-2001) model with the plasmasphere model developed by the Institute of Terrestrial Magnetism, Ionosphere and Radiowaves Propagation, Russian Academy of Sciences (IZMIRAN). The IRI_Plas model presents global vertical analytical profiles of electron density smoothly linked with the IRI electron density profile at altitude of one basis scale height above the F2 peak and extended towards the plasmapause up to 36,000 km (Gulyaeva and Bilitza, 2012; and references therein). Validation study on such an extended model is very important and a necessity. The huge amount accumulated data from the space-borne GPS measurements on board various satellites provides a unique opportunity to do the model validation study. Recently, Cherniak and Zakharenkova (2016) used the topside electron content values derived from the GPS measurements onboard the GOCE and TerraSAR-X satellites to validate the NeQuick2 (Nava et al., 2008) and IRI-Plas models' performance on topside electron content representation. They found that the IRI-Plas model overestimates the electron content in the 250–500 km altitude interval for low solar activity and the topside total electron content (TEC) for the 500–20,000 km altitude range during daytime local time at low and moderate solar activities. In the present study, we conducted a comparison study with the IRI_Plas model using the topside ionospheric and plasmaspheric electron content (hereafter, TPEC) data in the altitude range of ∼800 to 20,200 km, derived from the podTEC measurements of the precise orbit determination (POD) antenna on board the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) low Earth orbit (LEO) satellites tracking the GPS signals. The organization of the paper is as follows. In Section 2, we will specify the source of data we used for the present study. Then, in Section 3, we will present our comparison results with the IRI_Plas model. The last Section 4 is discussion and conclusion on our study.

## 2. Data used

The COSMIC LEO satellites were first launched in June 2006. Since then huge amount of observational data has been accumulated. The COSMIC Data Analysis and Archive Center (CDAAC, http://cosmic-io.cosmic.ucar.edu/cdaac/index.html) is a comprehensive data center responsible for data processing of the COSMIC observations. It provides registered users with diverse catalogues of COSMIC data in different processing levels, For the ionospheric study, two main kinds of product data can be used. One is the Radio Occultation (RO) measurements which provide the electron density altitude profiles up to an altitude of about 800 km (LEO satellite orbit's altitude), the other product is the 'podTEC' dataset, which archives the TEC measurement derived from the COSMIC LEO satellites' POD antennas. Each 'podTEC' dataset file contains continuous data from one GPS satellites (Pedatella and Larson, 2010). The absolute TEC along the ray path and other auxiliary data are recorded during the interval of each GPS satellites in sight. The data we used for our present study is the 'podTEC' data. For the present study, we were interested in the topside ionosphere and plasmasphere, therefore only podTEC data from rays with elevation angle greater than 30 deg have been used for our analysis.

For the present study, we selected a dataset from a low solar activity year (2008) and another dataset from a high solar activity year (2012). For each year, the dataset were divided into groups according to the following four defined seasons: M-Equinox (March, April), J-Solstice (May June, July and August), S-Equinox (September, October) and D-Solstice (January, February, November, and December).

Before we can make the comparison study of the observations with the IRI_Plas model results, we need to convert the slant podTEC to the vertical TPEC for our present study. As in Zhang et al. (2016), the method we used to derive TPEC from podTEC involves a slant-to-vertical TEC conversion technique by using a mapping function. For detailed description of the data conversion technique, the reader is referred to Zhang et al. (2016) and references therein. The mapping function depends on both the elevation angle ($\varepsilon$) and the altitude of the pierce point of the LEO-GPS ray path in the plasmasphere (*Hppt*). This means the calculated TPEC is affected by both the values of $\varepsilon$ and *Hppt*. We have made a study of the dependence of TPEC on $\varepsilon$ and *Hppt* and found that when $\varepsilon$ is large enough, the calculated TPEC is insensitive to the value of