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Evaluation and correction of the IRI2016 topside ionospheric electron density model

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Abstract

The international reference ionosphere (IRI) is the internationally recommended empirical model. The IRI2016 is now the latest version, and it includes three options for the prediction of topside electron density profiles: IRI2001, a correction of IRI2001 (IRI2001corr), and NeQuick model. In the paper, we use the Arecibo, Jicamarca, and Millstone Hill incoherent scatter radar observed topside electron density data ranging from year 2001 to 2014 to assess the prediction capabilities of these three model options. The results show that the NeQuick model outputs perform best at these areas from the point view of relative difference distribution, followed by the IRI2001corr model, and the IRI2001 option is worst. To further improve the performance of NeQuick and IRI2001corr options, the correction factors are introduced in their model formulation and are determined by the least squares estimation technique. Compared with the original models, the corrected models perform in average better, especially at low and medium solar activities.

Keywords: Topside ionospheric electron density profile; Evaluation; Correction; Least squares estimation technique

1. Introduction

The ionosphere shows significant diurnal, monthly, seasonal, solar activity and geomagnetic activity variations. Knowledge of the ionospheric electron density distribution is of critical importance for all ground and space techniques that depends on radio signals traveling through the ionosphere (Grossi, 1982).

The electrons in the topside ionosphere constitute about 70–90% of the ionospheric total electron content (TEC). However, due to the insufficient number of measured electron density profiles, it is difficult to describe a well-established morphology of the variation of the electron density in that region (Reinisch and Huang, 2001; Venkatesh et al., 2011).

Empirical models are important tools for the study of the different geospace regions from the Earth to Sun, providing the users with easy access to a synthesis of reliable measurements for specific parameters and regions (Reinisch et al., 2007).

The international reference ionosphere (IRI) is the internationally recommended empirical model. It is supported by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) and is registered by the International Standardization Organization (ISO). The IRI model describes monthly medians of the electron density, electron temperature, ion composition (O^+, H^+, N^+, He^+, O_2^+, NO^+, and $Cluster^+$), ion temperature, and ion

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drift at the non-auroral ionospheric altitude ranging from 50 to 1500 km. The model has been steadily improved with newer data and with better mathematical descriptions of ionospheric spatial and temporal variation patterns since it is released.

IRI2016 is now the latest version of the model, and there are three options available in the model for the topside electron density prediction: IRI2001, a correction of IRI2001 (IRI2001corr), and the NeQuick model. Evaluations of these model options are necessary in order to find out which of them can provide the best representation of the current ionospheric conditions. Moreover, corrections of the IRI model are still the main efforts of many researchers (e.g., Huang and Reinisch, 2001; Bilitza et al., 2006, 2011; Richards et al., 2010; Zhang et al., 2010; Galkin et al., 2012; Nsumei et al., 2012; Klenzing et al., 2013; Bilitza et al., 2014; Verhulst and Stankov, 2014; Wang et al., 2015).

Coisson et al. (2002, 2006) compared IRI and NeQuick model with ISIS 2 topside electron density profiles to identify and analyze the weak points in their topside formulation. Bilitza (2004) corrected the IRI topside electron density model using the large volume of Alouette/ISIS topside sounder data. Bilitza (2009) evaluated the two new IRI2007 options, IRI2001corr and NeQuick, with special emphasis on the uppermost topside based on the Alouette 1, 2 and ISIS 1, 2 satellites topside sounder data. They showed that overall NeQuick gives the best results, but IRI2001corr option can provide a more realistic representation of the latitudinal–altitudinal structure in the equatorial ionization anomaly region. Luhr and Xiong (2010) compared the IRI model with CHAMP and GRACE satellites in-situ electron density measurements during the solar cycle 23 minimum, and revealed that there are significant discrepancies at 400–500 km altitude. Eccles et al. (2011a, 2011b) developed a software package to assess the ionospheric models in their capability to model the ionospheric electron density profiles. The software can perform both climatological assessment and space weather assessment of the ionospheric models with a ground truth database, which has been collected, reduced, and cleaned the Arecibo Radar Observatory Incoherent Scatter Radar (ISR) observed electron density profiles spanning nearly 50 years and 4 solar cycles. Bilitza et al. (2012) showed that IRI model exhibits generally good agreement with the ionosonde measurements of the F2 peak plasma frequency throughout the whole solar cycle. Migoya-Orue et al. (2013) compared the electron density obtained by topside IRI (IRI2001corr and NeQuick options) and NeQuick models with plasma density measured by DMSP satellites for years of different solar activities. They concluded that the models present a similar behavior in general, but the IRI2001corr option overestimates electron density at high latitudes and this trend increases with solar activity.

In present paper, we use the Arecibo, Jicamarca, and Millstone Hill ISR observed topside electron density profiles ranging from year 2001 to 2014 to assess the performance of these three options in the IRI2016 model, and to correct the NeQuick and IRI2001corr options to improve the model prediction capabilities.

2. Data

ISR is a very powerful ground-based remote sensing technique that can be used to measure many ionospheric quantities including electron density, electron/ion temperature, and line-of-sight ion flow velocity over the ionospheric altitude range. The physical basis of the ISR technique is Thomson scattering in which the echo is the result of the scattering of electromagnetic energy radiated

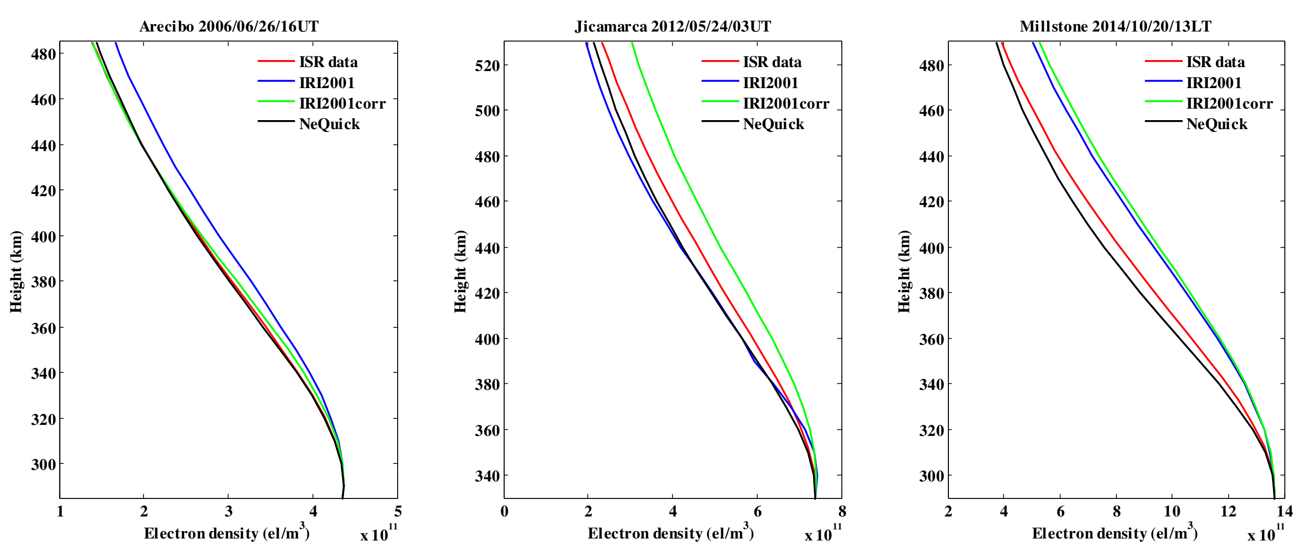

Fig. 1. Examples of the ISR measured topside electron density profiles (red line) and the corresponding model prediction values, IRI2001 (blue line), IRI2001corr (green line), and NeQuick (black line), at three ISR sites (a, Arecibo; b, Jicamarca; and c, Millstone Hill). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)