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Towards better description of solar activity variation in the International Reference Ionosphere topside ion composition model

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Abstract

We present a revision of the ion composition model that is included in the International Reference Ionosphere (IRI) as the TTS-03 option. We employed a better description of the solar activity variation based on the assumption that the dependence of the logarithm of absolute densities of the individual ion species (H^+, O^+, He^+ and N^+) on the F10.7 index is linear. Unlike the TTS-03 model using the relative ion densities, the revised model employs absolute ion densities measured by the Atmosphere Explorer C&E and Intercosmos-24 satellites. Results of the revised ion composition model are presented, with special emphasis on the upper transition height (H_T) during low solar activity. Equatorial H_T produced by the model for a very low solar activity is ∼800 km at daytime (14 h LT) and ∼520 km at nighttime (2 h LT). These values are closer to H_T observed by the Coupled Ion-Neutral Dynamics Investigations (CINDI) on the Communications/Navigation Outage Forecasting System (C/NOFS) satellite in the years 2008 and 2009 (minimum solar activity of the 23rd solar cycle) than the IRI-2007 and IRI-2012 options for the ion composition. A comparison of the options for the ion composition with the Sheffield University Plasmasphere-Ionosphere Model (SUPIM) is also shown.

Keywords: Ion composition; Topside ionosphere; Solar activity; Empirical model; International Reference Ionosphere

1. Introduction

The International Reference Ionosphere (IRI) is an empirical standard model of the ionosphere and the topside ionosphere based on available and reliable data sources specifying electron density, ion composition, electron temperature, ion temperature, and several additional parameters in the altitude range from 60 to 2000 km (Bilitza and Reinisch, 2008; Bilitza et al., 2011; Bilitza et al., 2014). The IRI model since its first release (IRI-75) (Rawer et al., 1975) has been employed in numerous studies. The first versions of the IRI model were focused on parameters characterizing the F2 peak – electron density at its maximum and its height. Later on, models of other parameters were progressively included in IRI. One of these parameters is also ion composition (i.e. densities of most important major and minor ions). The latest version of the IRI model includes two options for the ion composition for the topside region. The older version is based on the work of Danilov and Yaichnikov (1985) using a compilation of Russian rocket measurements including high-altitude rockets that cover topside altitudes. The model gives the percentage of O^+, H^+, He^+, and N^+. A newer topside version was developed by Třísková et al. (2003) (TTS-03)

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and is included in IRI as the recommended option since IRI-2007. This newer model takes advantage of better global coverage provided by satellite ion mass spectrometer measurements (Intercosmos-24, AE-C, AE-E) and uses the invdip latitude coordinate that is close to the magnetic inclination (dip) near the magnetic equator and closer to invariant latitude at higher latitudes (Truhlík et al., 2001). The TTS-03 model has helped in studies like propagation of radio waves close to the Lower Hybrid Resonation (LHR) (Chum et al., 2009). The knowledge of ion composition is also important for calibration of the Langmuir probes (Klenzing and Rowland, 2012) and understanding of transport of ions in the magnetosphere etc. (e.g. Nosé et al., 2009; Denton et al., 2012).

Using new Coupled Ion-Neutral Dynamics Investigations (CINDI) on the Communications/Navigation Outage Forecasting System (C/NOFS) data it was found that the IRI predicted values of ion composition did not fully reflect the extremely low solar activity conditions during the years 2008 and 2009 (Heelis et al., 2009; Klenzing et al., 2011).

We present a revised ion composition model originally included in IRI as the TTS-03 option. We employed a better description of the solar activity variation based on the assumption that the dependence of logarithm of absolute densities (H^+, O^+, He^+ and N^+) on the F10.7 index is linear (Truhlík et al., 2005). For compatibility with the TTS-03 model, the revised model produces relative densities which are calculated as fractions of densities of individual ion species normalized in sum to 100%.

2. Database

We used a revised data base (Table 1) from Třísková et al. (2003). This data base comprises data from three satellites – Atmosphere Explorer (AE) C and E and Intercosmos-24 (IK-24) The revision of the model is based on improvement of the data processing program, data averaging procedure, efficiency of exclusion of data errors and better assigning of orbital and geophysical parameters. As a result we enlarged the dataset of the AE measurement in our data base (approximately about factor 2). Thus, the data coverage in the local time vs. latitude grid for solar minimum was improved.

To investigate the solar activity variation of the ion composition we also used the newly available CINDI C/NOFS data. The C/NOFS satellite was launched on April 16, 2008 on an elliptical low inclinated orbit (inclination 13°) with perigee 405 km and apogee 853 km. Among several experiments it carried the CINDI Ion Velocity Meter (IVM)/Retarding Potential Analyzer (RPA) instrument which allows to obtain total ion density, densities of major ions (O^+, H^+, He^+), and drifts. The data used in this study are from the interval August 2008 – December 2012 and were obtained from http://cindispace.utdallas.edu.

3. Solar activity variation of ion composition

The revised model employs an improved dependence of ion densities on the solar activity. A linear dependence of logarithm of absolute densities of individual ion species (H^+, O^+, He^+ and N^+) on the F10.7 index was presented in (Truhlík et al., 2005). More recently Borgohain and Bhuyan, 2010 showed similar dependence for major ions (H^+, O^+, He^+) using data from RPA onboard the Indian SROSS satellite.

Figs. 1 and 2 show data (O^+ and H^+ densities) from C/NOFS, AE and IK-24 (Table 1) vs. solar activity (for day, night and two altitude ranges) from a wide interval of solar activity, where the PF10.7 index (e.g. Richards et al., 1994) ranges from 65 to more than 200. In spite of the fact that for the low solar activity interval ($65 < PF10.7 < 90$) the number of AE measurements is much less than the number of C/NOFS data points, the values from all three experiments are showing a good consistency. In the first approximation the linear function describes satisfactorily the dependence on solar activity. This means that the AE mass spectrometer ion composition data are generally in agreement with the C/NOFS ion composition measurements for equivalent solar activity conditions (the same PF10.7 index). Nevertheless, there is some difference between the fits using the C/NOFS and AE data. This difference can help to estimate the difference of the upper transition height if C/NOFS data or AE data are used. We consider AE densities linearly extrapolated from Fig. 1 and 2 to the values of $PF10.7 = 65$.

Fig. 3 shows an estimation of the difference of the upper transition height determined from both linear fits from Figs. 1 and 2 for the lowest solar activity considered ($PF10.7 = 65$) and daytime. Altitude profiles of O^+ and H^+ densities in the altitude interval from 550 to 750 km can be approximated by a linear dependence, since the gradient in both densities in this small altitude interval does not change too much. The difference can be estimated as about 50 km. It can be caused by the differences in solar minima during AE and during C/NOFS measurement probably due to nonlinear relation between the EUV and 10.7 cm fluxes (e.g. Balan et al., 1993) or/and due to different accuracy of both techniques/experiments employed.

Table 1
Description of data used.

Solar activity	Mean F10.7	Satellite	Altitude (km)	Inclination (km)	Time period	Ion mass spectrometer (type)
Maximum	200	IK-24	500–2500	83	Nov 1989–May 1991	Bennett
Minimum	85	AE-C	350–1150	68	Dec 1973–Nov 1974	Bennett + magnetic
Minimum	75	AE-E	350–1150	20	Dec 1975–Oct 1976	Bennett + magnetic