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Achievement of a short term three dimensional electron density mapping of the ionosphere in the European sector: Comparisons with the IRI model for quiet-moderate geomagnetic-ionospheric conditions

M. Pietrella

Istituto Nazionale di Geofisica e Vulcanologia, via di Vigna Murata 605, 00143 Rome, Italy

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Abstract

In this paper will be described the procedure followed for the achievement of a short term three dimensional (3-D) electron density mapping of the ionosphere in the European area.

It consists of three main steps: (1) *foF2* and *M(3000)F2* short-term forecasts, ($foF2_{STF}$) and ($M3000F2_{STF}$), are calculated at 12 ionospheric observatories scattered in the European area; (2) the values of $foF2_{STF}$ and $M3000F2_{STF}$ on a grid of equi-spaced points, ($foF2_{STF,\ GP}$) and ($M3000F2_{STF,\ GP}$), are calculated by means of an appropriate interpolation algorithm by using the $foF2_{STF}$ and $M3000F2_{STF}$ data; (3) $foF2_{STF,\ GP}$ and $M3000F2_{STF,\ GP}$ data ingestion into the *IRI* model is employed to produce a short term 3-D electron density mapping (***ST-3D-M***) of the ionosphere.

The electron density profiles provided by the ***ST-3D-M*** and *IRI* models, were compared with the electron density profiles autoscaled by the Automatic Real-Time Ionogram Scaler with True-height (ARTIST) system, which are here considered as the truth profiles. The results of these comparisons, shown for a certain number of epochs during quiet-moderate geomagnetic-ionospheric conditions, in the truth-sites of Athens (38°.0′N, 23°.5′E), Chilton (51°.5′N, −0°.6′W), Dourbes (50°.1′ N, 4°.6′E), Pruhonice (50°.0′N, 14°.6′E), Rome (41°.9′N, 12°.5′E), and Tortosa (40°.8′N, 0°.5′E), indicate that the ***ST-3D-M*** as forecasting tool can be considered generally reliable.

Keywords: Modelling and forecasting; *foF2* and *M(3000)F2*; Electron density; Profile; Geomagnetic activity; Interpolation

1. Introduction

Nowadays the climatological behaviour of the ionosphere can be satisfactorily predicted thanks to the long term prediction models, regional and global, developed in the last two decades (Bradley, 1999; Hanbaba, 1999; Zolesi et al., 1993, 1996; De Franceschi et al., 2000; Bilitza, 2001; Bilitza and Reinisch, 2008; Radicella, 2009). The long term predictions of the main ionospheric parameters, such as the critical frequency of the F2 layer (*foF2*) and the obliquity factor for a distance of 3000 km (*M*(*3000*)*F2*), have reached a high level of accuracy. At present, the challenge is the real time specification of the ionosphere (nowcasting), i.e. the achievement of more and more reliable real time predictions of *foF2* and *M*(*3000*)*F2*, as well as other ionospheric parameters, especially during ionospheric storm events. For this purpose, in the recent past many nowcasting models have been developed (Araujo-Pradere et al., 2002; Zolesi et al., 2004; Tsagouri et al., 2005; Pietrella and Perrone, 2005; Pietrella et al.,

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E-mail address: marco.pietrella@ingv.it

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2009); they rely on the measurements of *foF2* and *M*(*3000*)*F2* provided from the automatic scaling of ionograms which is carried out by particular software (Reinisch and Huang, 1983; Pezzopane and Scotto, 2005, 2007) installed on the current digisondes.

The predictions of ionospheric characteristics such as *foF2*, *M*(*3000*)*F2*, the lowest usable frequency (LUF), and maximum usable frequency (MUF), are of great importance for many uses. The main applications aim to support the best possible planning of a HF sky-wave telecommunication system which is affected by the variability of the ionosphere (Stamper et al., 2004): *foF2* long term prediction and nowcasting maps, can be used for the choice of frequencies to be used in Near Vertical Incidence Sky-wave conditions (NVIS), when the ionosphere is quiet or under disturbed ionospheric conditions (Pietrella, 2015); good guidelines in choosing the optimal frequencies to be used for a long-distance point-to-point radio link, can be provided to HF operators consulting both the *foF2* and *M*(*3000*)*F2* prediction maps in order to get MUF predictions in a relatively large area (Zolesi and Cander, 2014); LUF and MUF predictions and skip distance maps can be employed respectively to establish the range of operative frequencies for all the hours of the day, for a given distance and month, and to know the minimum distance for which it is possible to establish a radio communication link (Zolesi and Cander, 2014); three-dimensional (3-D) electron density mappings predicted in real time can be considered as the ionospheric environment by any ray-tracing technique to calculate the 3-D HF ionospheric propagation and hence to simulate oblique ionograms relative to a given radio link (Settimi et al., 2013, 2015).

Also important are the short time forecasting models (Cander et al., 1998; Muhtarov and Kutiev, 1999; Stanislawska and Zbyszynski, 2002; Oyeyemi et al., 2005; Pietrella and Perrone, 2008; Strangeways et al., 2009; Pietrella, 2012, 2013, 2014), which provide predictions of *foF2* and *M*(*3000*)*F2* a few hours in advance. Their importance is also relevant to the fact that in particular circumstances, the short time forecasting models are the only ones that can be employed. For example, in case of very disturbed ionosphere, the automatic interpretation of *foF2* and *M*(*3000*)*F2* can be completely wrong; this means that the nowcasting models could rely on misleading measurements thus providing unreliable results.

Moreover the short term forecasting models are the ones that can provide predictions when the real time data provided by the digisondes, for some reason are not anymore available for a long time, e.g. due to a malfunction of the digisonde itself; in this case the absence of real time measurements prohibits the use of nowcasting models. If the malfunction of the digisonde occurs under geomagnetic or ionospheric storm events, neither the long term prediction models can be applied being completely unreliable in case of disturbed ionosphere. Therefore it might be worthwhile to continue in the development of algorithms which are able to offer more and more trustworthy short term forecasts, more than ever in case of strongly disturbed ionosphere. In the light of these considerations can be also important to develop a method to get a short term three dimensional (3-D) imaging of the ionosphere through the short term forecasting of electron density profiles on a relatively large area. To this regard, there already exist many models that after assimilating real time observations, are able to provide a comprehensive 3-D specification of the ionosphere (Angling and Khattatov, 2006; Thompson et al., 2006; Decker and McNamara, 2007; McNamara et al., 2007, 2008, 2010, 2011; Shim et al., 2011). More recently, Pezzopane et al. (2011, 2013), have developed a procedure which calculates an updated 3-D image of the ionosphere combining real time observations, regional grids of *foF2* and *M*(*3000*)*F2*, *IRI* model, and real time electron density profiles coming from some reference stations. Inspired by this work, a procedure in part similar to that developed by Pezzopane et al. (2011), has been carried out in order to get a short term 3-D electron density mapping (***ST-3D-M***) of the ionosphere.

In this work we will see how the employment of short term predictions of *foF2* and *M*(*3000*)*F2*, and the joint application of an appropriate interpolation algorithm (*INTERPOLATION*) with the International Reference Ionosphere (*IRI*) (Bilitza, 2001, 2015; Bilitza and Reinisch, 2008) long term prediction model, can provide a tool for obtaining the ***ST-3D-M*** of the ionosphere.

Specifically, the short-term forecasts of *foF2* and *M*(*3000*)*F2*, estimated in 12 ionospheric observatories up to three hours in advance by the *IFERM* (Pietrella, 2012) and *STFRM* (Pietrella, 2014) models respectively, are used in the *INTERPOLATION* procedure to generate, on a grid of equi-spaced points covering the European sector, the short term forecasting of *foF2* and *M*(*3000*)*F2*.

The short term predictions of *foF2* and *M*(*3000*)*F2* calculated on each grid point are then ingested into the *IRI* model to produce short term forecasted electron density profiles on each grid point which, by and large, constitute the ***ST-3D-M*** of the ionosphere.

In order to assess the reliability of ***ST-3D-M***, the electron density profiles autoscaled by the Automatic Real-Time Ionogram Scaler with True-height (ARTIST) system (Reinisch and Huang, 1983; Reinisch et al., 2005; Galkin and Reinisch, 2008), assumed as the correct electron density profiles, were compared with the electron density profiles outputted by the ***ST-3D-M*** and *IRI* models at the truth-stations of Athens (38°.0′N, 23°.5′E), Chilton (51°.5′N, -0°.6′W), Dourbes (50°.1′ N, 4°.6′E), Pruhonice (50°.0′N, 14°.6′E), Rome (41°.9′N, 12°.5′E), and Tortosa (40°.8′N, 0°.5′E), for a certain number of epochs during quiet-moderate geomagnetic-ionospheric conditions.

A detailed description to achieve the ***ST-3D-M*** of the ionosphere is presented in Section 2. Data analysis and the methodology adopted to assess the reliability of ***ST-3D-M*** are discussed in Section 3. The comparisons and results are shown in Section 4. Concluding remarks on