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Comparative study of foF2 measurements with IRI-2007 model predictions during extended solar minimum

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Abstract

The unusually deep and extended solar minimum of cycle 23/24 made it very difficult to predict the solar indices 1 or 2 years into the future. Most of the predictions were proven wrong by the actual observed indices. IRI gets its solar, magnetic, and ionospheric indices from an indices file that is updated twice a year. In recent years, due to the unusual solar minimum, predictions had to be corrected downward with every new indices update. In this paper we analyse how much the uncertainties in the predictability of solar activity indices affect the IRI outcome and how the IRI values calculated with predicted and observed indices compared to the actual measurements. Monthly median values of F2 layer critical frequency (foF2) derived from the ionosonde measurements at the mid-latitude ionospheric station Juliusruh were compared with the International Reference Ionosphere (IRI-2007) model predictions. The analysis found that IRI provides reliable results that compare well with actual measurements, when the definite (observed and adjusted) indices of solar activity are used, while IRI values based on earlier predictions of these indices noticeably overestimated the measurements during the solar minimum. One of the principal objectives of this paper is to direct attention of IRI users to update their solar activity indices files regularly. Use of an older index file can lead to serious IRI overestimations of F-region electron density during the recent extended solar minimum.

Keywords: Ionosphere; F2 region critical frequency; International Reference Ionosphere; Solar cycle dependence

1. Introduction

The solar minimum of cycle 23/24 began around March 2006 and many predictions of the start and size of solar cycle 24 were given thereafter (e.g. see review in Pesnell, 2008). In 2007, the solar cycle 24 Prediction Panel anticipated that the solar minimum marking the onset of cycle 24 would occur in March 2008 (±6 months). This date was then corrected to August 2008. In the next update, users were informed that the solar minimum would occur in December 2008 (http://www.swpc.noaa.gov/SolarCycle/SC24/index.html). The minimum was in fact reached in the middle of 2009 and thus exceeded the earliest prediction by more than 2 years. This unusually deep and extended solar minimum makes corrections to the predicted values of solar cycle progression. With every update, the predicted values of sunspot numbers were decreased. Currently, the cycle continues to fall below predictions and is exhibiting 50% lower sunspot activity than predicted in May 2009. Fig. 1 illustrates the changes in the predictions of the 12-month-running mean of the global ionospheric IG index (IG12). Indicated by a thick line is the definitive IG12

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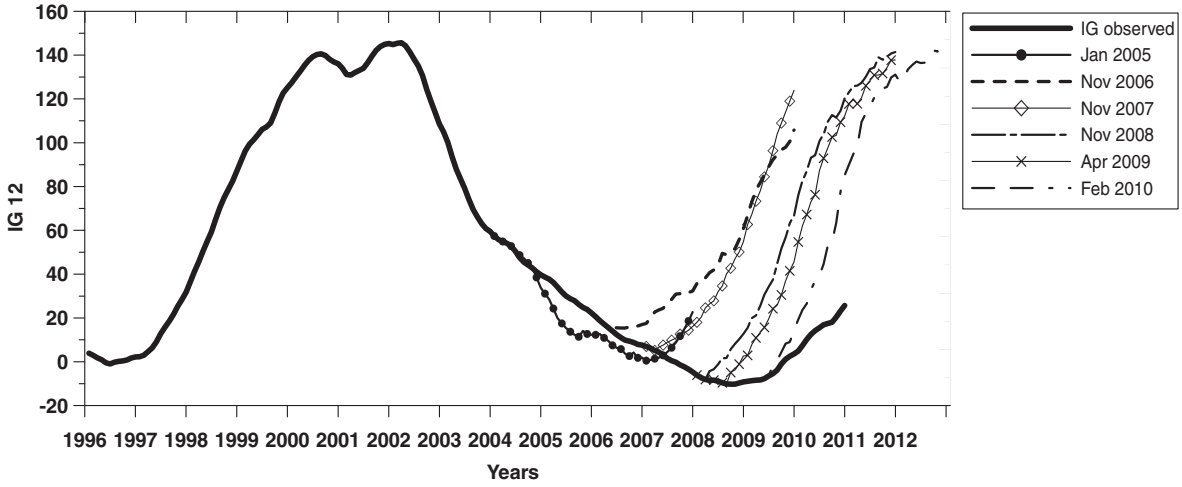

Fig. 1. Global ionospheric index IG12 for years 1996–2010 (solid curve) and IG12 predictions issued at various times from January 2005 to February 2010.

index from 1996 to 2010. The other lines show the IG12 indices predicted at several specific dates from January 2005 to February 2010. These curves show the continued downward correction of the IG12 index starting from 2007. The cycle 23/24 minimum went lower and lasted much longer than was expected so the predictions from 2007 to 2009 overestimated the actual (definitive) indices.

The empirical International Reference Ionosphere (IRI) model (Bilitza, 2001) is actively used in a great variety of applications and research projects (e.g. McNamara, 2002; Hernandez-Pajares et al., 2002; Bilitza et al., 2008; ISRIM; SWENET portal). The IRI describes the median or average values of electron density, electron content, electron temperature and the ion composition as a function of height, location, local time and sunspot number for magnetically quiet conditions. The model takes into account daily and seasonal variations as well as the impact of solar activity on ionospheric conditions. Therefore, the IRI model results depend on the input parameters of solar activity level and the use of uncertain predicted values can lead to significant discrepancies in the IRI model outcome. The objective of this paper was to analyze how much uncertainty in the predictability of solar activity indices during this unusually deep and extended minimum of solar activity was able to affect the IRI outcome and how this variability compared to actual measurements.

2. Database

The data used for the present research were the monthly median values of the F2 layer critical frequencies (foF2) with 1 h temporal resolution. These monthly median values were calculated from the daily hourly values scaled from the ionograms recorded routinely by the DPS-4 digisonde at Juliusruh, Germany. The geographical coordinates of this mid-latitude ionospheric station are 54.6 N, 13.4 E. The ionograms were obtained from the European Digital Upper Atmosphere Server (DIAS). Since May 2005, the DIAS server (http://www.iono.noa.gr/DIAS) has been delivering such products as real-time and archive ionograms from all DIAS ionosonde stations located in Europe, and frequency plots and maps of the ionosphere over Europe based on the foF2, M(3000)F2, MUF and electron density parameters (Belehaki et al., 2005). The selected time period coverage of the ionosonde data used (from January 2007 to December 2009) is corresponded to the period of the extended solar minimum.

In order to investigate the influence of prediction values of solar activity on the IRI-derived results, we used the IRI-2007 version of the model (Bilitza and Reinisch, 2008), whose FORTRAN code is available online (ftp://nssdcftp.gsfc.nasa.gov/models/ionospheric/iri). The foF2 values were generated for each hour of the 15th (middle day) of each month of the years considered. These hourly values are taken to be representative of the ionospheric average behavior during that month. The foF2 STORM model option was turned off because this study deals with quiet geomagnetic conditions. The hourly averages obtained in this way were compared with the corresponding ones obtained from the observed foF2 values. For the input parameters of solar activity level, we used the monthly values of IG12 (a 12-month-running mean of the global ionosphere index). These values can either be found automatically from an indices file that is included with the IRI software package or the user can provide his/her own input values for this index. The file "ig_rz.dat", which contains the IG12 and Rz12 (a 12-month-running mean of the sunspot number) indices for IRI model, is updated regularly with the most recent observed and predicted indices. This file starts from January 1958 and includes indices predictions for the upcoming two years. However, the final (actual) values of IG12 and Rz12 are only available at least 6 months after the fact because the 12-month running mean is centered on the current date and needs therefore 6 months of predictions. For comparative analysis, we used the