APPLICATION OF THE PLASMASPHERE–IONOSPHERE MODEL FOR SHORT-TERM FORECASTING OF TOTAL ELECTRON CONTENT

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ABSTRACT

Standard Plasmasphere–Ionosphere Model (SPIM) is under development for the International Standardization Organization. It is based on merging of the International Reference Ionosphere, IRI, below 1000 km and the plasmasphere option of the Russian Standard Model of Ionosphere, SMI, up to 20,000 km. This model driven by input files allows ingestion of routine magnetic indices updated every 3 hrs via Internet. Special subroutine of SPIM code provides forecast of magnetic activity 3 hours in advance. Artificial critical frequency of the F2 layer, f_{art}, is produced using the quiet reference GPS-TEC median for 27 days preceding given day. As a result, accuracy of the ionosphere–plasmasphere TEC forecasting is improved by 2-3 times as compared with CCIR prediction.

1. INTRODUCTION

The ionosonde network of stations played a primary role in the ionosphere research during the 20th century [1]. In particular, the empirical electron density profiles of the International Reference Ionosphere [2] and the Russian Standard Model of Ionosphere, SMI [3] are fitted to the F2 layer peak electron density and height based on the CCIR maps [4] produced from the ionosonde observations. The ionosonde foF2 critical frequency and other parameters are provided on-line via the Internet site of the Ionospheric Despatch Centre in Europe (http://www.cbk.waw.pl/) [5].

The International Standard Plasmasphere–Ionosphere Model, SPIM, in the framework of Project of the International Standardization Organization, ISO [6], preserves fitting of electron density profile to the F2 layer peak electron density and height including IRI ionosphere model below 1000 km and the plasmasphere option of SMI above 1000 km. ISO–SPIM Project is aimed to provide distribution of density, temperature and effective collision frequency of electrons in the Earth's ionosphere and plasmasphere at the height interval from 65 km to 20,000 km (or to the plasmapause if it is greater than 20,000 km) at any longitude, geodetic latitudes from 80°N to 80°S, for any time of day, day of year, wide range of the solar and magnetic activity indices.

Nowadays we witness transition to advanced modeling and forecasting of space weather in the ionosphere and plasmasphere based on the total electron content (TEC) observations measured with signal transmissions from the Global Positioning System (GPS). The European and Russian networks of GPS receivers are three times denser than the ionosonde network at the same area (see, e.g., http://igscb.jpl.nasa.gov/; http://gpsras.ru:80/). Information on GPS-TEC combined with SPIM 3-D electron density profile interpolation serves as a valuable tool for investigating global and regional ionospheric structures. By learning how to predict TEC values in advance, researchers may also be able to set up early warning procedures that give enough time to protect valuable communications satellites from the space weather impact. Thus, advanced modeling and forecasting of the total electron content (TEC) through the ionosphere and plasmasphere is one of the goals of the ISO modeling efforts.

Two kinds of forecasting procedures (model-based and data-based approaches) are combined below to provide an improved forecast of TEC with the standard plasmasphere-ionosphere model, SPIM, updated with the past history of GPS-TEC observations [6] including the storm-time update of the F2 layer critical frequency [7] and the time-weighted accumulation of geomagnetic indices [8, 9].

2. SPIM-CCIR PREDICTION OF TEC

TEC is the number of electrons in a column of one metre-squared cross-section along a path through the ionosphere and plasmasphere. Combined ionosphere and plasmasphere model provides total electron content integrated from the bottom of the ionosphere to the plasmapause from a model distribution of ionization under quiet and disturbed magnetic activity conditions.

The F2 layer peak electron density NmF2 (proportional to the ionosonde-measured critical frequency foF2) is updated during the magnetic storm using Storm-subroutine [7]. The Storm-procedure is driven by Api indices integrated from the original 3-hrs ap indices for 39 hrs preceding given time. With input of ap data file for integrated Api-indices, the instantaneous ap-indices are converted by SPIM to kp-indices using conventional relations between ap and kp values.

Special subroutine developed for ap-to-kp conversion produces also forecast of the Kpm-index 3 hours in advance. To reveal effect of delay of the plasma response to magnetic storm, special Kpm forecasting procedure using geomagnetic indices for the times *before* any given time has been proposed [8, 9]. It is based on 3-h ap, kp, or aa indices accumulated during 12 hrs before any given time, and ranked by decreasing order in order to put the greatest weight on maximum value of original indices. This procedure is applied by SPIM code to preliminary 3h ak indices updated every 3 hrs at Internet page of SEC, NOAA, Boulder, CO, USA.

Example is presented in Figure 1c for the magnetic storm at low solar activity (7 to 9 April, 1995) where constant kp-index during successive 3 hrs is shown by solid line and results of Kpm forecast 3 hrs in advance are shown by squares. Integrated Api indices (crosses) are produced as required for the F2 layer critical frequency storm-time updating [7] with their maximum delayed by few hours regarding peaks of Kp and Kpm indices.

The F2 layer critical frequency foF2 and GPS-TEC data for different latitudinal zones are used for the present study (Figures 1 and 2). The 1st iteration of SPIM yields CCIR prediction of the quiet monthly-mean F2 layer critical frequency, fcF2, independent of the magnetic activity indices. Results of the 1st iteration are shown in Figures 1 and 2 by triangles (CCIR). The ionosonde observed foF2 values (Figure 1b) and GPS-derived TEC (Figures 1a and 2a,b,c) are shown for a comparison (circles). Difference between observed TEC and model prediction is given as the root-mean-square (r.m.s.) error, in TECU [10^{16} , m^{-2}].

TEC variation through the ionosphere and plasmasphere produced with input of observed foF2 can differ from GPS-observed TEC due to different response of the plasmasphere and ionosphere to magnetic storm. Besides, SPIM-TEC forecast with input of the F2 layer critical frequency would depend on the ionosonde observations or forecast of foF2 which are not available for the most locations of GPS receivers. To overcome shortage of relevant ionosonde foF2 input, the procedure for TEC forecast updated with the past GPS-TEC data has been developed recently [6]. Since only the past history of GPS observations is necessary for SPIM update, the GPS-TEC data delayed by 1-2 days on-line via the IGS network present relevant data source for TEC forecasting.

3. UPDATE OF TEC FORECAST WITH PAST GPS OBSERVATIONS

To estimate a degree of TEC or NmF2 disturbance one needs quiet reference value of each parameter. A ‘sliding reference’ median of TEC and NmF2 (or foF2) is defined as the time-corresponding median of 27 days preceding any given day of observation. We assume that the period of 27 days corresponding to the solar rotation yields median values that might be valid also on the 28th day. Thus, for the forecasting purposes, one has median values for one day in advance as distinct from the monthly medians available only after the month has passed.

Solid lines in Figure 1a,b show 27-days quiet reference median of TEC and foF2 at Moscow under low solar activity which are close to CCIR predictions but differ significantly from the observed values. Different response of TEC and foF2 to magnetic storm has been pointed out for the high solar activity [6] which is also seen in Figure 1 fot the solar minimum. In particular, during the storm offset on 7 April, 1995 (curve Kp in Figure 1c) TEC values are enhanced (positive phase of the plasmasphere storm, Figure 1a) while peak electron density is depressed regarding the median of foF2 (Figure 1b).

Within the proposed scheme the GPS-TEC background median is used to calculate quiet F2 layer critical frequency one day in advance for the 2nd iteration of SPIM code. The ratio of the peak electron densities for the 1st and 2nd iterations of SPIM is assumed to be equal to the TEC ratio:

$$NqF2 / NcF2 = TECq / TECc \qquad (1)$$

Here NcF2 and TECc are obtained with SPIM-CCIR predictions, TECq is 27-days GPS-derived TEC median yielding forecast of the quiet reference TEC one day in advance. Result of Eq.1 is the peak plasma density, NqF2, providing forecast of quiet reference F2 layer critical frequency:

$$fqF2 = (NqF2 / 1.24^{10})^{1/2} \qquad (2)$$

The 2nd iteration of SPIM with input of fqF2 (Eqs.1,2) includes storm-time updating of the F2 layer critical frequency based on forecasting of magnetic kp, ap indices 3 hrs in advance. After the 2nd run of SPIM code, an updated artificial critical frequency f_{art} is obtained (Figure 1b, stars) providing SPIM forecast of TEC (Figures 1a and 2a,b,c, stars). Though an artificial F2 layer critical frequency differs from the ionosonde observations, TEC(f_{art}) forecast is very close to the instantaneous GPS-TEC observations improved by 2-3 times as compared with the 1st iteration of CCIR-TEC prediction (see r.m.s. values in legends to Figures 1-2).

4. CONCLUSION

Combined model-data approach is demonstrated for application of the standard plasmasphere-ionosphere model for the total electron content forecasting 3 hours in advance using on-line forecast of magnetic activity. The advance time of the forecast could be extended to 24 hours with daily forecast of magnetic storms [9].

Indirect mode of incorporation of the past GPS-TEC observations is proposed to update the F2 layer quiet reference critical frequency produced with CCIR maps. In particular, forecast of the quiet total electron content one day in advance is made with GPS-TEC median estimated during 27 days preceding forthcoming day. Results of the artificial critical frequency f_{art} can provide TEC forecast which is 2 – 3 times more reliable than CCIR-TEC prediction. Artificially produced F2 layer critical frequency variation may be different from the ionosonde data but TEC results fit well GPS-TEC observations.

Independent variability of the plasmasphere and ionosphere revealed by parameters of TEC and foF2 during storm-time allows TEC predictions to rely solely on the past GPS-TEC data available from IGS Internet sites. Thus the GPS receiver appears to serve as a self-sufficient instrument for the proposed forecast of the space weather in the ionosphere and plasmasphere with SPIM code. The discrepancy between artificial critical frequency f_{art} and observed foF2 suggests that SPIM electron density profile parameters can be further improved for the better consistency of TEC results with the ionosonde observations.

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5. REFERENCES

1. Wilkinson P. (ed.). Ionosonde networks and stations. *Rept. UAG-104*, NGDC, Boulder, CO, USA, 155 pp, 1995.

2. Bilitza D. International Reference Ionosphere 2000. *Radio Sci.* **36**, 261-276, 2001.

3. Chasovitin Yu.K., et al. Russian Standard Model of Ionosphere (SMI). *COST251TD*(98)005, RAL, UK, 161-172, 1998.

3. Atlas of Ionospheric Characteristics. Comite Consultatif International des Radiocommunications *Rept.* 340, Geneva, 1986.

4. Stanislawska I., et al. *Phys. Chem. Earth (C)*, Vol. 24, No.4, 355-357, 1999.

5. Gulyaeva T.L., et al. The ionosphere-plasmasphere model software for ISO. *Acta Geod. Geophys. Hung.*, Vol. 37, No. 3, 2002.

6. Gulyaeva T.L. Short-term forecasting of total electron content through the plasmasphere and ionosphere. Submitted to *J. Atmos. Solar-Terr. Phys.*, 2001.

7. Fuller-Rowell T.J., et al. Capturing the storm-time ionospheric response in an empirical model. *AGU Geophys. Monograph*, Vol. 125, 393-401, 2001.

8. De Franceschi G., et al. Forecasing of magnetic activity 3 hours in advance for ionospheric applications. *Annali di Geofisica*, Vol. 44, Nos.5-6, 2001.

9. Gulyaeva T.L. Forecast of recurrent magnetic storms one day in advance. *Geomagnetism and Aeronomy*, Vol. 44, No.2, 2002.

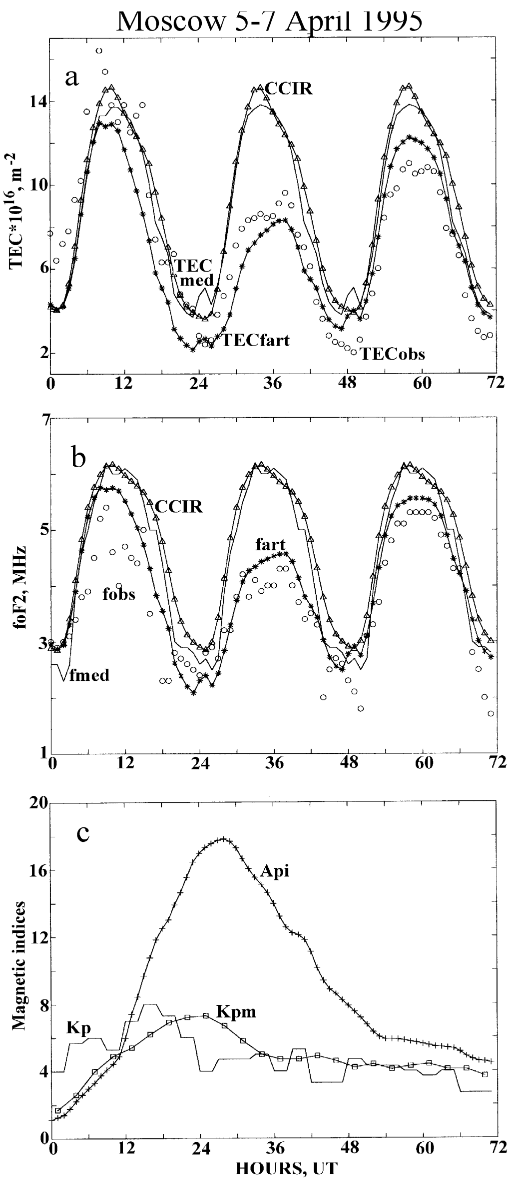

Fig. 1. Observations and forecast of TEC at Moscow (55.5N, 37.3E) for storm period 5 to 7 April, 1995, low solar activity (Rzs=30). (a) TEC-CCIR (r.m.s.=2.8), TEC-f_{art} (r.m.s.=1.8); (b) foF2, (c) magnetic indices: Kp – SEC k-index, Kpm-forecast of kp, Api/100, nT, - integrated ap-indices for foF2 storm update.

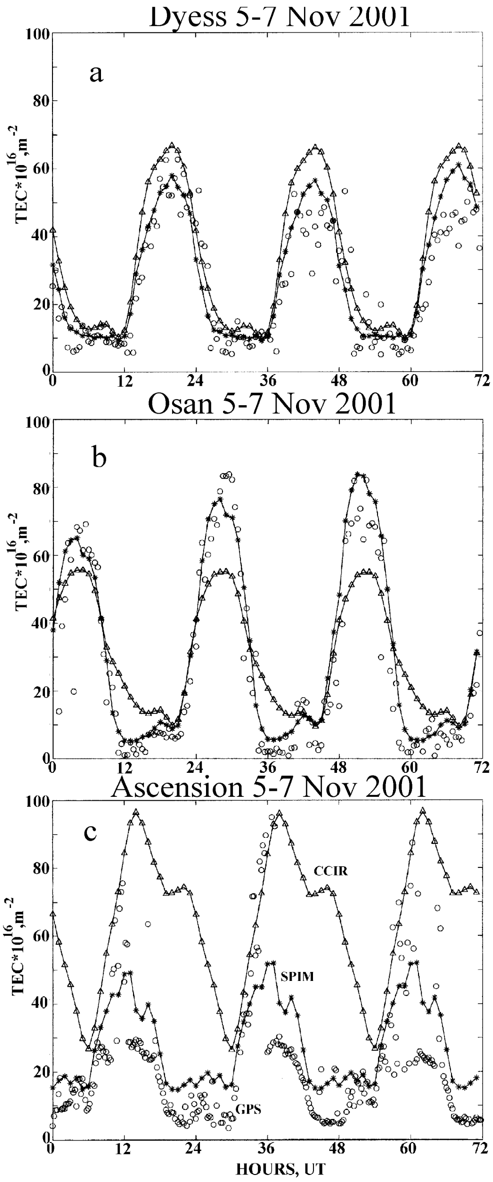

Fig. 2. GPS-TEC observations and forecast during storm on 5 – 7 November, 2001, at high solar activity (Rzs=130). (a) Dyess (32N, 260E), TEC-CCIR (r.m.s.=11.5), TEC-f_{art} (r.m.s.= 6.9); (b) Osan (37N, 127E), TEC-CCIR (r.m.s.=13.1), TEC-f_{art} (r.m.s.=8.9); (c) Ascension Is (8S, 346E), TEC-CCIR (r.m.s.=48.9), TEC-f_{art} (r.m.s.=11.1). Circles –15-min observations, triangles – CCIR prediction, stars – updated SPIM TEC-f_{art} forecast.