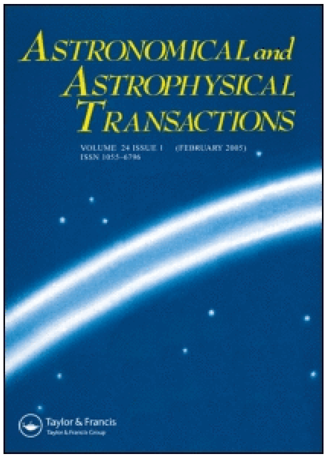

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INTERNATIONAL STANDARD MODEL OF THE EARTH'S INOSPHERE AND PLASMASPHERE

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The standard plasmasphere–ionosphere model of the International Standardization Organization is aimed at providing the distributions of the electron density, total electron content, temperature and effective collision frequency of electrons at altitudes of 65–20 000 km (or to the plasmapause) over the Earth, geodetic latitudes of 80 N to 80 S, any longitude, day of the year, and indices of solar and geomagnetic activity. It includes the International Reference Ionosphere developed by the Union Radio-Scientifique Internationale and the Committee on Space Research, and the Russian standard model of the ionosphere. Two modes of operation are envisaged: the climatological monthly average prediction and dynamic short-term forecast of space weather parameters. The reliability of results is improved on input of pre-history of observable solar and geophysical parameters. The software of the standard model is available via the Internet.

Keywords: Ionosphere, plasmasphere, model.

After more than 30 years of successful international cooperation on the joint project of the Union Radio-Scientifique Internationale and the Comittee on Space Research (COSPAR) on the International Reference Ionosphere (IRI) (Bilitza *et al.*, 1993) the International Standardization Organization (ISO) has planned to establish the Earth's standard plasmasphere–ionosphere model (SPIM) (Gulyaeva *et al.*, 2002a,b) aimed at providing the distributions of the electron density, total electron content, temperature and effective collision frequency of electrons in the Earth's ionosphere and plasmasphere in the height range 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 the year, and wide ranges of the solar and magnetic activity indices. Modern state of the art in modelling and forecasting of the space environment is presented in a unique plasmasphere–ionosphere model useful for improved communication with navigational GPS, GLONASS and Galileo satellites transmitting radio signals from altitudes of 20 000 km over the Earth to the ground receivers.

For a model to be set up as a standard for users, a number of requirements should be considered such as the best-produced results, ease of use, availability of the source model, compatibility with application software, adoption by model-developing community, relation to

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other standards, and drawbacks of the model. To this end the ionosphere part of the SPIM is presented by the IRI electron density N_e below 1000 km, which is extended with the plasmasphere option of the Russian standard model of the ionosphere (SMI) to 20 000 km (Chasovitin *et al.*, 1998). The total electron content (TEC) is integrated along the electron density height profile $N_e(h)$. The COSPAR reference atmosphere model (CIRA) is used for the neutral temperature (Hedin, 1986). The effective collision frequency N_u is calculated from the electron density N_e and temperature T_e using neutral atmosphere parameters obtained from the formulae of gas kinetic theory. The international geomagnetic reference field is used to produce SPIM driving parameters including the modified dip latitude (Rawer, 1963), corrected magnetic latitudes and longitudes (Hakura, 1965) and Comité Consultatif International des Radiocommunications (CCIR) (1986) standard maps of the F2 layer peak parameters.

Two regimes of operation are allowed for the ISO standard. The monthly average predictions of N_e, T_e, and TEC are driven by the solar activity indices: sunspot numbers R_z or solar radio flux $F_{10.7}$. The dynamic short-term operation includes storm-time update of the ionosphere and plasmasphere parameters driven by geomagnetic a_p and k_p indices (De Franceschi *et al.*, 2001; Fuller-Rowell *et al.*, 2001). The output of the full electron density profile up to the plasmapause is optional. However, in any case a series of standard output parameters are provided by the SPIM including the year, the day, the Universal and local times, the solar zenith angle, the sunspot number, the solar radio flux, the geomagnetic K_{pm} and A_{pi} indices, the geodetic and geomagnetic coordinates, the modified dip latitude, the F_2-layer critical frequency f_{oF_2} and peak height h_{mF_2}, the peak electron density, N_{mF_2}, the electron density N_{es} at the upper boundary of the ionosphere ($h_s = 1000$ km), the plasmapause altitude h_{pl} and electron density N_{epl}, the electron content for the bottom part of ionosphere, $\mathrm{EC_{bot}}$ (below h_{mF_2}), the electron content for the topside ionosphere $\mathrm{EC_{top}}$ (between h_{mF_2} and h_s), the plasmaspheric electron content $\mathrm{EC_{pl}}$, and the TEC through the ionosphere and plasmasphere. The scheme of the input–output parameters and the modes of operation of the ISO standard are presented in Figure 1.

Both empirical source models (IRI, SMI) have been developed by statistical processing of experimental data. The models of the distributions of N_e and T_e are based on experimental data of the ground-based and space-borne ionosondes and whistler observations, the incoherent scatter, and *in-situ* rocket and satellite measurement of the ionosphere and plasmasphere parameters. The TEC measurements were not used as a data source in constructing the models; so they can serve as a tool for model testing and applications. In particular, the GPS

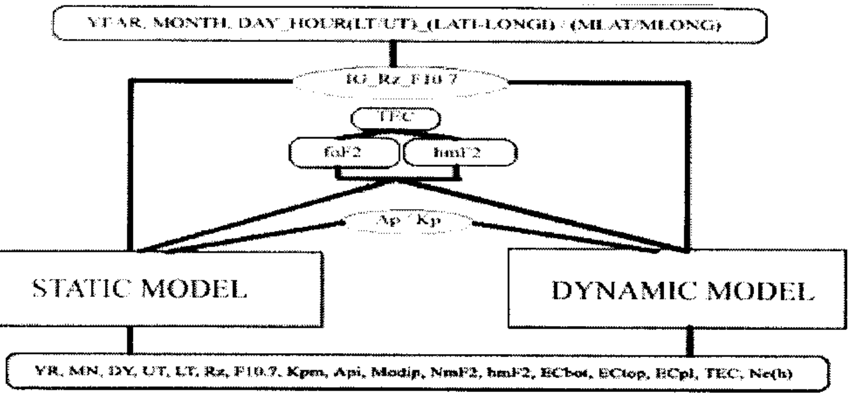

FIGURE 1 Input–output parameters of the ISO SPIM.

observations can provide unique TEC database for evaluating and updating the standard model (Gulyaeva and Jakowski, 1999).

The combined plasmasphere–ionosphere model is built to display dynamic interactions between the two media crucial for their maintenance. During quiet periods the plasmasphere is full of plasma during daytime from the ionosphere, returning it back to the ionosphere at night. The night-time sector of the plasmasphere is able to react quickly (in 2–6 h) to changes in the magnetic activity with the plasmapause moving to lower L shells and steepening with increasing activity (Chappel, 1972). This is accompanied by electron density depletion in the ionosphere propagating from high to lower latitudes. Once established on the night side, the steep density gradient co-rotates into the day side with the outer edge of the day-side bulge peeled off and convected sunwards delayed by 6–12 h by the storm offset. Both the plasmapause altitude and the density are reduced during the magnetic storm (Gallager *et al.*, 2000; Gulyaeva *et al.*, 2002b).

The SMI polar cap, the subauroral trough of ionization and the plasmasphere model are driven by the input of effective k_p indices (Chasovitin *et al.*, 1987, 1998). Chasovitin *et al.* courageously abandoned the classical way in which geophysicists normally construct models, namely in so-called 'quiet' conditions; it had been assumed that these conditions would only occasionally be abandoned. Chasovitin *et al.* however, built a model in which the disturbance activity is a leading variable. Apart from the fact that it is probably a more adequate model of the plasmasphere, they opened up at the same time a way to assess ionospheric disturbances by their plasmaspheric origin. While other plasmasphere models describe complex physical processes in the plasmasphere along the field lines (Rasmussen and Schunk, 1990; Webb and Essex, 2000), the ISO standard is based on an analytical description of the empirical electron

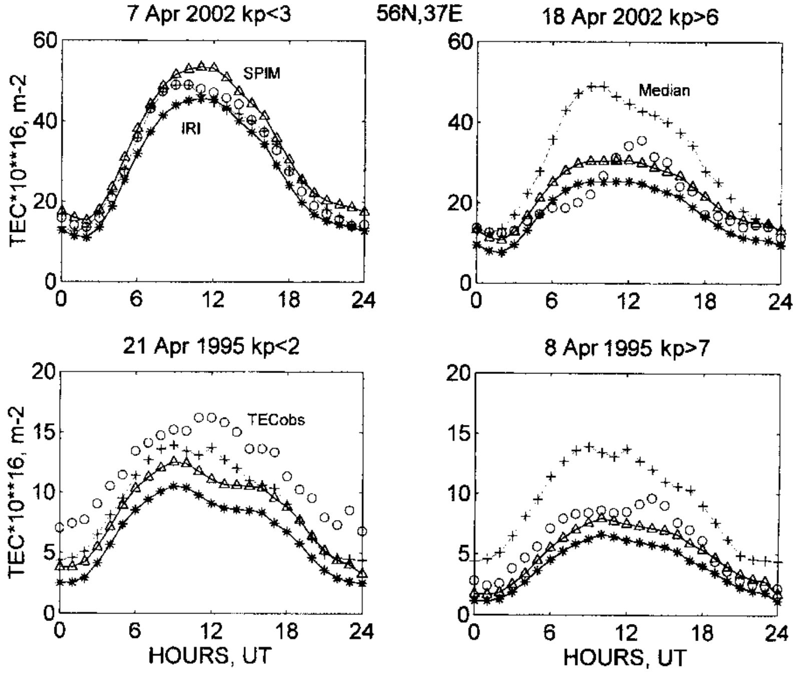

FIGURE 2 Observed instantaneous and 27 day median of GPS TEC compared with IRI TEC below 1000 km and ISO model results of TEC through the ionosphere and plasmasphere for quiet conditions ($k_p < 3$) and magnetic storm ($k_p > 6$).

density profile distribution with height from the bottom of the ionosphere to the plasmapause (Chasovitin *et al.*, 1998; Gallagher *et al.*, 2000; Gulyaeva *et al.*, 2002a).

The static and dynamic regimes of ISO model are demonstrated in Figures 2 and 3. The SPIM output is compared in Figure 2 with GPS TEC observations at Moscow for the solar minimum (1995) and the solar maximum (2002) under quite (k_{p3}) and disturbed (k_{p6}) magnetic conditions. The instantaneous observations (open circles) differ from the monthly median (crosses), particularly for ionization depletion during a magnetic storm. The ionospheric electron content calculated with IRI below 1000 km underestimates GPS TEC measurements while the SPIM results fit the observations better.

The three-dimensional interpolation of GPS TEC data for the short-term forecast of $N_e(h)$ profile and TEC in the dynamic regime of the ISO model is demonstrated in Figure 3. The first iteration of the SPIM code yields the CCIR prediction of the quiet monthly mean F_2-layer critical frequency f_{cF_2}, quiet TEC_q and $N_e(h)$ profile (solid curves) with monthly effective magnetic index $k_p = 2$. The output of the static SPIM regime allows us to estimate an effective critical frequency from GPS-derived instantaneous TEC_o or time-corresponding median for the 27 preceding days:

$$f_{\mathrm{eff}} = f_{cF_2}\left(\frac{TEC_o}{TEC_q}\right)^{1/2}.$$

Results of the second iteration with storm-time update of the F_2-layer peak electron density are shown in Figure 3 (symbols) when the SPIM code is driven by the effective F_2-layer

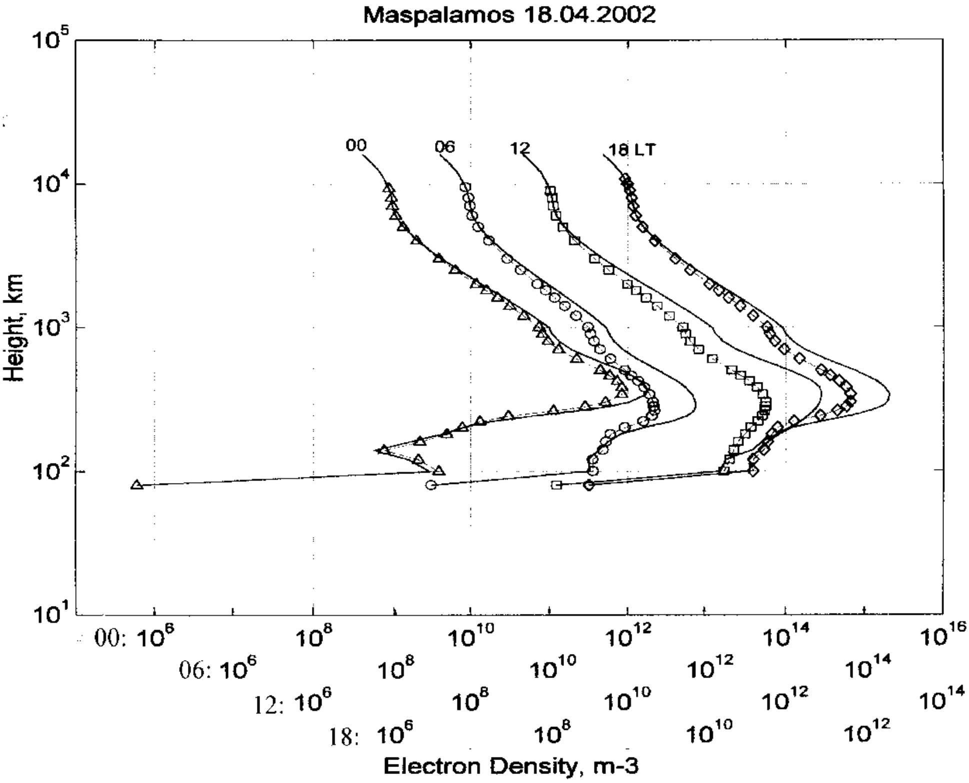

FIGURE 3 Electron density profiles for a low-latitude station (28 N, 344 E) predicted by the SPIM at high solar activity ($R_z = 100$): monthly average conditions ($k_p = 2$); ▲, ○, □, ◇, daily forecast using GPS TEC observations.

critical frequency f_{eff} and the forecast of magnetic activity is applied for 3 or 24 h in advance (Gulyaeva, 2002). The TEC-derived artificial F_2-layer critical frequency can differ from the observed f_{oF_2} owing to model shortcomings but it makes the SPIM code execution independent of input of the ionosonde-based F_2-layer peak parameters for nowcasting and forecasting purposes.

Although the IRI is widely used as a standard ionosphere model, its application alone is not sufficient to meet modern communication needs. That is why the spatial extension of the IRI above 1000 km has been made with the plasmasphere option of the Russian SMI. On the temporal scale, the storm-time updating procedure of the IRI complemented by forecast of magnetic activity 3 h in advance provides a step forward from the climatological monthly-mean IRI and SMI towards dynamic space weather forecasting capability. The package of the first issue of the ISO SPIM code is available from the Internet at ftp.izmiran.rssi.ru.

The efforts of many scientists and engineers are accumulated in the ionosphere–plasmasphere modelling results of those observations planned and made, in summarizing the observational data in analytical expressions, and in making software for modelling and predictions. These achievements combined in one ISO standard model of the Earth's ionosphere and plasmasphere are ready for further testing by experts in the field. It is hoped that the proposed model could be considered by ISO as a potential model standard.

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References

Bilitza, D., Rawer, K., Bossy, L., and Gulyaeva, T.L. (1993) *Adv. Space Res.* **13**, 3.

Chappel, C.R. (1972) *Rev. Geophys. Space Phys.* **10**, 951.

Chasovitin, Yu.K., Gulyaeva, T.L., Deminov, M.G., and Ivanova, S.E. (1998) In: COST 251TD(98)005, Rutherford Appleton Laboratory, Oxford, pp. 161–172.

Chasovitin, Yu.K., Shirochkov, A.V., Besprozvannaya, A.S., Gulyaeva, T.L., *et al.* (1987) *Adv. Space Res.* **7**, 49.

Comité Consultatif International des Radiocommunications (1986) *Atlas of Ionospheric Characteristics*, CCIR Report 340, Comité Consultatif International des Radiocommunications, Geneva.

De Franceschi, G., Gulyaeva, T.L., and Perrone, L. (2001) *Annali Geofis.* **44**, 1067.

Fuller-Rowell, T.J., Codrescu, M.V., and Araujo-Pradere, E.A. (2001) In: AGU Geophysical Monograph, Vol. 125, American Geophysical Union, Washington, DC, pp. 393–401.

Gallager, D.L., Craven, P.D., and Comfort, R.H. (2000) *J. Geophys. Res.* **105**, A18819.

Gulyaeva, T.L. (2002) *Geomagn. Aeronomy* **42**, 159.

Gulyaeva, T.L., Huang, X., and Reinisch, B.W. (2002a) *Adv. Space Res.* **29**, 825.

Gulyaeva, T.L., Huang, X., and Reinisch, B.W. (2002b) *Acta Geodaetica Geophys. Hung.* **37**, 143.

Gulyaeva, T.L., and Jakowski, N. (1999) In: *Proceedings of the COST 251 Workshop*, University of Huelva, Spain, 1999, pp. 109–118.

Hakura, Y. (1965) *Rep. Ionosphere Space Res. Labs. Japan* **19**, 121.

Hedin, A.E. (1986) *CIRA-1986 Neutral Thermosphere Model*, COSPAR, Paris.

Rasmussen, C.E., and Schunk, R.W. (1990) *J. Geophys. Res.* **95**, 6133.

Rawer, K. (1963) In: B. Landmark (ed.), *Meteorological and Astronomical Influences on Radio Wave Propagation*, Pergamon, Oxford, pp. 221–250.

Webb, P.A., and Essex, E.A. (2000) *Phys. Chem. Earth* C **25**, 301.