ISO TC 20/SC 14

Date: 2005-01-20

ISO/TS 16457

ISO TC 20/SC 14/WG 4

Secretarian: ANSI

Space Environment (Natural and Artificial)– Earth's Ionosphere model: International Reference Ionosphere and Extensions to the Plasmasphere

Document type: Technical Specification
Document subtype:
Document stage: TS
Document sub-stage: 20.20
Document language: E

ISO TS 16457 was prepared by Technical Committee ISO/TC 20, *Aircraft and Space Vehicles,* Subcommittee SC 14, *Space Systems and Operations*.

Contents

Foreword

ISO (the International Organization for Standardization) is a world-wide federation of national standards organizations (ISO member bodies). The work of preparing International Standards and other ISO documents is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also are eligible to take part in the work.

When the subject in question is still under development or where for any other reason there is a future but not immediate possibility of an agreement to publish an International Standard, the technical committee or subcommittee may decide, by following the ISO procedures, that the publication of a Technical Specification would be appropriate. The reasons for publishing the Technical Specification, and an explanation of its relationship to the expected future International Standard, shall be given in the foreword. The drafts of International Standards and Technical Specifications approved by Technical Committees are sent to all the participant committees for consideration pending approval of the ISO Council.

International Technical Specifications for the "Space Environment (Natural and Artificial). *Earth's Ionosphere Model: International Reference Ionosphere (IRI) and Extensions to the Plasmasphere"* is provided for the users upon authorization by ISO/TC20 Technical Committee on Aircraft and Spacecraft, ISO/TC20/SC14 Subcommittee on Space Systems and Operations, and ISO/TC20/SC14/WG4 Working Group on Space Environment (Natural and Artificial). The International Reference Ionosphere, IRI, is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). These organizations formed a Working Group in the late sixties to produce an empirical standard model of the ionosphere based on all available data sources. Several steadily improved editions of the model have been released. For given location, time and date, IRI describes the electron density, electron temperature, ion temperature, and ion composition in the altitude range from about 50 km to about 2000 km, and also the electron content. It provides monthly averages in the non-auroral ionosphere for magnetically quiet conditions. The major data sources are the worldwide network of ionosondes, the powerful incoherent scatter radars, the topside sounders, and in situ instruments on several satellites and rockets. The IRI model and its mathematical build-up were described in detail in a WDC/NSSDC report (Bilitza, 1990) and the most recent updates were presented by Bilitza (2001). A recent review of IRI and other ionospheric models can be found in the 1999-2002 Review of Radio Science published by the International Union of Radio Science (URSI) (Bilitza, 2002).

The document will also present several models that could be used to extend the IRI model to plasmaspheric altitudes. Taking into account that

- IRI is de facto the international standard model for the ionosphere under COSPAR and URSI patronage
- IRI is a continuously evolving model which will be improved as new data become available.
- IRI is an important step towards a future International Standard for the ionosphere and plasmasphere.

the ISO / TC20 / SC14 / WG4 recommends to approve ISO Technical Specification TS 16457.

Introduction

This Technical Specification provides guidelines for specifying the global distribution of ionospheric electron density, electron temperature, ion temperature, ion composition, and total electron content. The model recommended for the representation of these parameters is the International Reference Ionosphere (IRI) a joint project of the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) (Rawer et al. 1981; Bilitza et al., 1993; Bilitza, 2001)

The remaining sections of the present document discuss the purpose and scope, potential users, computer program, input and output arrangements, and give reference data to be used with the program.

Space Environment (Natural and Artificial)– Earth's Ionosphere model: International Reference Ionosphere and Extensions to the Plasmasphere

1 Purpose and Scope

The ISO TS 16457 Technical Specification has the objective to provide potential users with a guidance on the global ionosphere model for the height distribution of density and the total content of electrons in the height interval from 65 km to 1500 km with several options for a plasmaspheric extension of the model, embracing the geographical area between latitudes of 80°S and 80°N and longitudes of 0°E to 360°E, for any time of day, any day of year and various solar and magnetic activities conditions. The present TS 16457 uses terms, notations and definitions given in Appendix A.

Technical Specification of an international model for the representation of the ionospheric and plasmaspheric plasma parameters is important to a wide spectrum of applications. Electromagnetic waves traveling through the ionized plasma at the Earth's environment experience retardation and refraction effects. A remote sensing technique relying on signals traversing the ionosphere and plasmasphere therefore needs to account for the ionosphere-plasmasphere influence in its data analysis. Examples are Altimetry, Radio Astronomy, Satellite Communication, Navigation and Orbit Determination.

For HF radio communication a good knowledge of the heights and plasma frequencies of the reflective layers of the ionosphere and the plasmasphere is critical for continuous and high quality radio reception. HF communication is still of great importance in many remote locations on our globe and for some specialized military applications. The present model software is aimed to estimate the effect of charged particles on technical devices in the Earth's environment and to define the ionosphere-plasmasphere operational conditions compatible with existing and future systems of radio communication, radio navigation and other relevant radio technologies in the ranges of medium and higher frequencies.

2 ISO Requirements

The present TS 16457 is intended to meet users requirements on
- the best produced results,
- easy to use software,
- availability of the source model,
- compatibility with application software,
- adoption by users community,
- relevance to other standards

3 Identification of Users

An early review of requirements identified the needs for model to be recommended for a range of telecommunications and scientific applications with different timescales. Maps of spatial and temporal variations of ionospheric characteristics given from vertical ionospheric soundings are seen as providing anchor points for the specification of a height profile model of electron density. Ray-path calculations can use this model to assess the performance of particular ground-based and space-borne systems. Specifically, long-term monthly median parameters are useful for HF circuit and service planning; maps for individual days and hours might potentially aid frequency management and retrospective studies. Short-term model application is needed in the interpretation of data from over-the-horizon radar and passive HF target detection systems. Total electron content (TEC) given by integrating the electron density height distribution from the ground to a spacecraft yields the ionospheric refraction and group delay at a chosen frequency on an Earth-space link.

List of potential users:

- Navigational satellites operators of GPS (U.S. Global Positioning System), GLONASS (Russian Navigational System), Galileo (European Navigational System)
- Radio and television operators (satellite's communication)
- Space weather forecasters (Medium Frequency, High Frequency, VHF & UHF systems)
- Phone communication (interference possibility)
- Aero and space industry (spacecraft design, internal/surface charging, sensor interference, satellite anomalies, loss of navigation signal phase and amplitude lock)
- Military (space communication and navigation, loss of HF communications, loss of HF direction finding, clutter in over the horizon radar, targeting, disruption to ELF/VLF communications with submarines, reduced detection of missile launch)
- Radio communication agencies (efficient communication, reduced interference)
- Insurance companies (protect satellites, human health and life)
- Mass media (broadcast of space weather forecasts)
- Scientists using remote sensing measurement techniques in astronomy, biology, geology, geophysics, seismology, etc. for compensating the effects of the ionosphere on their observations.
- Manned spacecraft's travels (planning the electromagnetic environment conditions)
- Amateur radio operators
- Students in space research and applications (course material for undergraduate education)
- And many more

4 Model Composition and Inputs

A modular system approach is used for the IRI code including subroutines for the following sub-models::

(i) COSPAR International Reference Atmosphere (CIRA) model for the neutral temperature

(ii) International Telecommunication Union ITU-R (former CCIR) model for the F2 critical frequency foF2 (directly correlated with the F2 peak electron density NmF2) and for the propagation factor M(3000)F2 (inversely correlated wit the peak height hmF2) (CCIR, 1990)

(iii) International Association of Geomagnetism and Aeronomy (IAGA) International Reference Geomagnetic Field (IGRF) 2000 Model for the magnetic coordinates

(iv) Space Environment Center (SEC) STORM model for storm-time updating of the F2 layer peak density (Fuller-Rowell et al., 2001)

The model requires the following indices as input parameters:

(1) 12-month running mean of sunspot number R12

(2) 12-month running mean of global ionospheric index IG

(3) 3-hourly planetary magnetic ap indices for the prior 39 hours

These indices can be either found automatically from an indices file that is included with the IRI software package and that is updated quarterly, or the user can provide them as input values for the computer code. For R12 and IG12 the indices file starts from January 1958 and includes indices prediction for two years ahead. For ap the index values start from January 1960 and currently lack a few month behind because of the problems in obtaining this index.

In addition model users have the options to use measured peak parameters to update the IRI profile, e.g., the F2, F1, and E critical frequencies or electron densities, the F2 peak height, and the E peak height.

The total electron content TEC is obtained by numerical integration from the model's lower boundary (65 during daytime and 80 during nighttime) to the user-specified upper boundary.

5 Computer Code and Related Websites

The homepage of the IRI project is at http://nssdc.gsfc.nasa.gov/space/model/ionos/iri.html.

The IRI program is provided as a FORTRAN computer code for use on UNIX, VAX, and PC-Windows systems. The code can be downloaded from **ftp://nssdcftp.gsfc.nasa.gov/models/ionospheric/iri/iri2001/fortran_code/**.

An interactive system for computing and plotting IRI parameters is accessible at
http://nssdc.gsfc.nasa.gov/space/model/models/iri.html
A bibliography of IRI-related issues of Advances in Space Research can be found at
http://nssdc.gsfc.nasa.gov/space/model/ionos/asr_list.html

6 Plasmaspheric Extension of the IRI Model

Several models have been proposed as plasmaspheric extension of the IRI model:

- The Global Core Plasma Model (GCPM-2000) of Gallagher et al. (2000) is an empirical description of thermal plasma densities in the plasmasphere, plasmapause, magnetospheric trough, and polar cap. GCPM-2000 uses the Kp index and is coupled to IRI in the transition region 500-600 km. A FORTRAN code implementation that includes all except the polar cap is available from
dennis.l.gallagher@nasa.gov.

- The semi-empirical Global Plasmasphere Ionosphere Density (GPID) model of Webb and Essex (2000) includes IRI below 500-600 km extended with theoretical plasmasphere electron density description along the field lines. Authors report on drawbacks of merging of IRI with plasmasphere part of GPID. Model source GPID code written in commercial MATLAB software is not currently available for release.

- The IZMIRAN plasmasphere model (Chasovitin et al., 1998; Gulyaeva et al., 2002) is an empirical model based on whistler and satellite observations. It presents global vertical analytical profiles of electron density smoothly fitted to IRI electron density profile at 1000 km altitude and extended towards the plasmapause (up to 36,000 km). For the smooth fitting of the two models, the shape of the IRI topside electron density profile is improved using ISIS 1, ISIS 2, and IK19 satellite inputs (Gulyaeva, 2003). The plasmasphere model depends on solar activity and magnetic activity (kp-index). Source code for this IRI ionosphere-plasmasphere version is available from the IZMIRAN web site
ftp://ftp.izmiran.rssi.ru/pub/izmiran/SPIM/.

- The IMAGE plasmaspheric model of Huang et al. (2004) is based on Radio Plasma Imager (RPI) measurements of the electron density distribution along magnetic field lines. A plasmaspheric model is evolving for up to about 4 R_E. The depletion and refilling of the plasmasphere during and after magnetic storms is described (Reinisch et al., 2004). A power profile model as function magnetic activity was developed from RPI observations for the polar cap region (Nsumei et al., 2003).

7 Accuracy of the Model

The IRI model has been built up to represent the monthly average behavior of space plasma. Efforts are underway to also include a quantitative description of the monthly variability in IRI. As variability measure either the relative standard deviation or upper/lower quartiles and deciles will be used.
The accuracy of the IRI electron density model is typically

- 50-80 % at heights from 65 km to 95 km
- 5-15 % at heights from 100 km to 200 km during daytime
- 15-30 % at heights from 100 km to 200 km during nighttime
- 15-25 % at heights from 200 km to 1000 km at low and middle dip latitudes (< 60°)
- 50-80 % at heights from 200 km to 1000 km at high dip latitudes (> 60°)

8 Summary

This ISO document TS 16457 “Earth’s Ionosphere Model: International Reference Ionosphere and Extensions to Plasmasphere” has been composed according to resolutions of ISO/TC20/SC14/WG4. The URSI/COSPAR International Reference Ionosphere is recognized by ISO and recommended to the users for the purpose and scope described above. A few example models are provided for an extension of IRI to plasmaspheric heights. The composition of the computer program allows its future improvements and modification by removing or incorporating different sub-models in the model software.

APPENDIX A. DEFINITIONS AND NOTATIONS

- Earth's ionosphere: Region of the Earth's atmosphere in the height interval from 30 to 1000 km containing partially ionized cold plasma.

- Earth's plasmasphere: Region of magnetosphere containing low energy plasma particles with energies of typically a few eV to a few 10's eV, and with densities more than 10 cm-3.

- Plasmapause: Outward boundary of the plasmasphere formed by geomagnetic field lines where the plasma density drops by a factor of 10 or more across a range of L-shells of as little as 0.1.

- Solar activity: A series of processes occurring in the Sun's atmosphere affecting the interplanetary space and the Earth; the level of solar activity is characterized by indices.

- Sunspot number, *Rz*: An international relative number of sunspots determined every day; the most commonly used index of solar activity.

- Mean smoothed sunspot number, *R12*: A 12-months-running mean monthly number of sunspots.

- Planetary 3-hour index of geomagnetic activity, *kp*: Index characterizing the disturbance in the Earth's magnetic field over 3-hours UT interval; the index is expressed in numbers from 0 to 9 (*kp* scale is uneven quasi-logarithmic).

- Geomagnetic amplitude index, *ap*: Three-hours UT amplitude index of geomagnetic variation equivalent to *kp*

- Ionospheric disturbance: Disturbance in the ionospheric layers that exceeds usual changes in mean characteristics of ionization for given geophysical conditions.

- Ionospheric storm: Continuous ionospheric disturbance.

- Density of electrons, *Ne*: Electrons number per one cubic meter, m^{-3}. Peak electron density, *NmF2*, at the peak height, *hmF2*, in the ionosphere.

- Total electron content, *TEC*: Integral number of electrons in the column from 65 km to the plasmapause, m^{-2}.

- Slab Thickness, τ: equivalent thickness of ionosphere/plasmasphere defined by ratio of TEC/NmF2.

- Medium frequencies: Radio frequencies from 300 kHz to 3000 kHz.

- High frequencies: Radio frequencies from 3000 kHz to 30 MHz.

- Corrected geomagnetic latitude, *F'*: Geomagnetic latitude calculated using the higher spherical harmonic expansion terms of geomagnetic field alongside with dipoles.

APPENDIX B BIBLIOGRAPHY

Bilitza, D., *International Reference Ionosphere 1990*, 155 pages, National Space Science Data Center, NSSDC/WDC-A-R&S 90-22, Greenbelt, Maryland, November 1990.

Bilitza D. International Reference Ionosphere 2000. *Radio Sci.*, **36**, N.2, 261-275, 2001.

Bilitza, D., Ionospheric Models for Radio Propagation Studies, in: *Review of Radio Science 1999-2002*, 625 - 679, Oxford University Press, Oxford, 2002.

Bilitza D., K. Rawer, L. Bossy, and T.L. Gulyaeva. International Reference Ionosphere - past, present, and future: I. Electron density. *Adv. Space Res.* **13**, N 3, 3–13, 1993.

CCIR Atlas of Ionospheric Characteristics. Comite Consultatif International des Radiocommunications Rept. 340, Geneva, 1990.

Chasovitin Yu.K., T.L.Gulyaeva, M.G. Deminov, S.E. Ivanova. Russian Standard Model of Ionosphere (SMI). In *COST251TD(98)005*, RAL, UK, 161-172, 1998.

Fuller-Rowell T.J., M.V. Codrescu, and E.A. Araujo-Pradere. Capturing the storm-time ionospheric response in an empirical model. *AGU Geophys. Monograph*, **125**, 393-401, 2001.

Gallagher D.L., P.D. Craven, and R.H. Comfort. Global Core Plasma model. *J. Geophys. Res*., **105**, A8, 18819-18833, 2000.

Gulyaeva T.L., X. Huang, and B.W. Reinisch, The ionosphere-plasmasphere model software for ISO, *Acta Geodaetica et Geophysica Hungarica* **37**, No. 2-3, 143-152, 2002.

Gulyaeva T.L. Variation in the half width of the topside ionosphere according to the observations by space ionosondes ISIS 1, ISIS 2, and IK 19. *Intern. J. Geomagn. and Aeronomy*, **4**, No.3, 201-207, 2003.

Huang, X., B. W. Reinisch, P. Song, P. Nsumei, J. L. Green, D. L. and Gallagher, Developing an empirical density model of the plasmasphere using IMAGE/RPI observations, Adv. Space Res., 33, 6, 829-832, 2004.

Nsumei, P.A., Huang, X., Reinisch, B.W., Song, P., Vasyliunas, V.M., Green, J.L., Fung, S.F., Benson, R.F., and Gallagher, D.L., Electron Density Distribution Over the Northern Polar Region Deduced from IMAGE/RPI Sounding, *J. Geophys. Res*., 108, A2, 2003.

Rawer K., J.V.Lincoln, and R.O.Conkright (eds.). International Reference Ionosphere – IRI 79. *Rept. UAG-82*, WDC-A for STP, NOAA, Boulder, CO, USA, 243 pp., 1981.

Reinisch, B. W., Huang, X.; Song, P.; Green, J. L.; Fung, S. F.; Vasyliunas, V. M.; Gallagher, D. L.; Sandel, B. R., Plasmaspheric mass loss and refilling as a result of a magnetic storm, *J. Geophys. Res*., 109, A1, A01202, 1-11, 2004

Webb P.A. and E.A. Essex. An ionosphere-plasmasphere global electron density model. *Phys. Chem. Earth (C)*, **25**, No.4, 301-306, 2000.

