INTERNATIONAL STANDARD

ISO 16457

First edition
2014-04-15

Corrected version
2014-06-15

Space systems — Space environment (natural and artificial) — The Earth's ionosphere model: international reference ionosphere (IRI) model and extensions to the plasmasphere

Systèmes spatiaux — Environnement spatial (naturel et artificiel) — Guidage sur le modèle de l'ionosphère internationale de référence (IRI) et extensions à la plasmasphère

Reference number
ISO 16457:2014(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards 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 take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This first edition of ISO 16457 cancels and replaces ISO/TS 16457:2009, which has been technically revised.

This corrected version of ISO 16457:2014 incorporates the following correction.

In the Foreword, the following sentence has been added regarding the revision:

This first edition of ISO 16457 cancels and replaces ISO/TS 16457:2009, which has been technically revised.

Introduction

Guided by the knowledge gained from empirical data analysis, this International Standard provides guidelines for specifying the global distribution of electron density, electron temperature, ion temperature, ion composition, and total electron content through the Earth's ionosphere and plasmasphere. The model recommended for the representation of these parameters in the ionosphere is the international reference ionosphere (IRI).

IRI is an international project[1)] 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 1960s to produce an empirical standard model of the ionosphere based on all available data sources. The IRI Working Group consists of more than 50 international experts representing different countries and different measurement techniques and modelling communities. The group meets annually to discuss improvements and additions to the model. As a result of these activities, several steadily improved editions of the model have been released (see References [1], [2], [3], [5], [6], [18], [19], [20], and [53]).

For a given location over the globe, time, and date, IRI describes the monthly averages of electron density, electron temperature, ion temperature, and the percentage of O^+, H^+, He^+, N^+, NO^+, O_2^+, and Cluster ions in the altitude range from 50 km to 1 500 km. In addition, IRI provides the electron content by numerically integrating over the electron density height profile within user-provided integral boundaries. IRI is a climatological model describing monthly average conditions. The major data sources for building the IRI model are the worldwide network of ionosondes, the powerful incoherent scatter radars, the topside sounders, and *in situ* instruments flown on several satellites and rockets. This International Standard also presents several empirical and semi-empirical models that can be used to extend the IRI model to plasmasphere altitudes.

One advantage of the empirical approach is that it solely depends on measurements and not on the evolving theoretical understanding of the processes that determine the electron and ion densities and temperatures in the Earth's ionosphere. A physical model can help to find the best mathematical functions to represent variations of these parameters with altitude, latitude, longitude, time of day, day of year, and solar and magnetic activity.

IRI is recommended for international use by COSPAR and URSI. The IRI model is updated and improved as new data and new sub-models become available. This International Standard provides a common framework of the International Standard of the Earth's ionosphere and plasmasphere for the potential users.

1) The homepage of the IRI project is at http://irimodel.org/. The IRI homepage provides access to the IRI FORTRAN computer code and an interactive system for computing and plotting IRI parameters online A special PC Windows version of IRI-2001 with multiple plotting options is available from the University of Massachusetts Lowell at http://umlcar.uml.edu/IRI-2001/[16]. The IRI-Plas code including IRI extension to the plasmasphere is available at http://ftp.izmiran.ru/pub/izmiran/SPIM/.

Space systems — Space environment (natural and artificial) — The Earth’s ionosphere model: international reference ionosphere (IRI) model and extensions to the plasmasphere

1 Scope

This International Standard provides guidance to potential users for the specification of the global distribution of ionosphere densities and temperatures, as well as the total content of electrons in the height interval from 50 km to 1 500 km. It includes and explains 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 activity conditions.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
ionosphere
region of the Earth’s atmosphere in the height interval from 50 km to 1 500 km containing weakly ionized cold plasma

2.2
plasmasphere
torus of cold, relatively dense (>10 cm^{-3}) plasma of mostly H^+ in the inner magnetosphere, which is trapped on the Earth’s magnetic field lines and co-rotates with the Earth

Note 1 to entry: Cold plasma is considered to have an energy of between a few electronvolts and a few dozen electronvolts.

2.3
plasmapause
outward boundary of the plasmasphere located at between two and six earth radii from the centre of the Earth and 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

Note 1 to entry: The L-shell is a parameter describing a particular set of planetary magnetic field lines, often describing the set of magnetic field lines which cross the Earth’s magnetic equator at a number of Earth-radii equal to the L-value, e.g. “L = 2” describes the set of the Earth’s magnetic field lines which cross the Earth’s magnetic equator two earth radii from the centre of the Earth.

2.4
solar activity
series of processes occurring in the sun’s atmosphere which affect the interplanetary space and the Earth

Note 1 to entry: The level of solar activity is characterized by indices.

2.5
ionospheric storm
storm lasting about a day, documented by depressions and/or enhancements of the ionospheric electron density during various phases of the storm

Note 1 to entry: Ionospheric storms are the ultimate result of solar flares or coronal mass ejections, which produce large variations in the particle and electromagnetic radiation that hit Earth's magnetosphere and ionosphere, as well as large-scale changes in the global neutral wind, composition, and temperature.

2.6
sunspot number
R, alternatively called Ri or Rz, is a daily index of sunspot activity defined as R=k(10g+s) where s is the number of individual spots, g is the number of sunspot groups, and k is an observatory factor

2.7
R12
12-month running mean of monthly sunspot number

2.8
kp index
kp
planetary three-hour index of geomagnetic activity characterizing the disturbance in the Earth's magnetic field over three-hour universal time (UT) intervals

Note 1 to entry: The index scale is uneven quasi-logarithmic and expressed in numbers from 0 to 9.

2.9
ap index
ap
three-hour UT amplitude index of geomagnetic variation equivalent to kp

Note 1 to entry: It is expressed in 1 nT to 400 nT.

2.10
total electron content
TEC
integral number of electrons in the column from a lower altitude boundary to an upper boundary

Note 1 to entry: Typically the integral is taken from the lower boundary of the ionosphere (65 km during daytime and 80 km during night time) to the plasmapause.

Note 2 to entry: It is expressed in units of 10^{16} electrons m^{-2} (TECU).

2.11
Ionosphere global index
IG
ionosphere-effective sunspot number[56] that is obtained by adjusting the CCIR maps[7] to global ionosonde measurements of the F2 plasma critical frequency foF2

2.12
IG12
12-month running mean of monthly ionosphere-effective sunspot number

3 Abbreviated terms

IRI international reference ionosphere

ELF extremely low frequency (less than 3 kHz)

VLF very low frequency (3 kHz to 30 kHz)

LF low frequency (30 kHz to 300 kHz)

MF medium frequency (300 kHz to 3 MHz)

HF high frequency (3 MHz to 30 MHz)

VHF very high frequency (30 MHz to 300 MHz)

UHF ultra high frequency (300 MHz to 3 000 MHz)

4 General considerations

This model for the representation of the ionospheric and plasmaspheric plasma parameters is important to a wide spectrum of applications. Electromagnetic waves travelling 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. Applications can be found in the disciplines of altimetry, radio astronomy, satellite communication, navigation and orbit determination.

Radio signals, transmitted by modern communication and navigation systems can be heavily disturbed by space weather hazards. Thus, severe temporal and spatial changes of the electron density in the ionosphere and plasmasphere can significantly degrade the signal quality of various radio systems which even can lead to a complete loss of the signal. Model-based products providing specific space weather information, in particular now- and forecast of the ionospheric state, serve for improvement of the accuracy and reliability of impacted communication and navigation systems.

For high frequency 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. High frequency communication remains of great importance in many remote locations of the globe. The model helps to estimate the effect of charged particles on technical devices in the Earth's environment and defines the ionosphere-plasmasphere operational environment for existing and future systems of radio communication, radio navigation, and other relevant radio technologies in the medium and high frequency ranges.

5 Applicability

There are a multitude of operational usages for ionospheric models, of which the most important are outlined in this clause. Operators of certain navigational satellite systems such as GPS (USA), GLONASS (Russia), BeiDou (China), and GALILEO (Europe)[2)] require ionospheric predictions to mitigate losses of navigation signal phase and/or amplitude lock, as well as to maintain accurate orbit determination for all its satellites. Users of global navigation satellite systems need precise ionospheric models to increase the accuracy and to reduce the precise positioning convergence time.[57][58] Radio and television operators using MF, HF, VHF, UHF satellite, or ground stations require ionospheric parameters for efficient communications and for reducing interferences. Space weather forecasters have a great need for accurate ionospheric models to support their customers with reliable and up to the minute space weather information. Ionospheric models are also used in the aeronautical and space system industries

2) GPS: Global Positioning System; GLONASS: Global Orbiting Navigation Satellite System; GALILEO: European Global Satellite Navigation System; BeiDou: BeiDou Navigation Satellite System.

and by governmental agencies performing spacecraft design studies. Here the models help to estimate surface charging, sensor interference, and satellite anomaly conditions.

Users also apply ionospheric models to mitigate problems with HF communications, HF direction finding, radar clutter, and disruption to ELF/VLF communications with underwater vehicles. Insurance companies estimating the cost of protecting human health in space and satellites make use of ionospheric models. Scientists using remote sensing measurement techniques in astronomy, biology, geology, geophysics, and seismology require parameter estimates for compensating the effects of the ionosphere on their observations. An ionospheric model might be also used to evaluate tomographic, radio occultation, and other similar techniques, by providing the ground-truth background model for test runs. Amateur radio operators, as well as students and teachers in space research and applications, also use ionosphere parameters. This International Standard might be also applied for ray-path calculations to assess the performance of a particular ground-based or space-borne systems. Monthly medians of ionospheric parameters are useful for HF circuit and service planning, while maps for individual days and hours aid frequency management and retrospective studies.

6 Model description

The first version of the IRI model, IRI-1979, and its mathematical build-up is described in References [18], [19], and [20]. The most detailed description of the model and the mathematical formulas and methods used is given in a 155-page report about IRI-1990.[2] The next significant updates of the model were introduced with IRI-1995[5] and IRI-2000.[3] The core of the version of IRI proposed for this International Standard, IRI-2007, is described in detail in References [53] and [54].

IRI-related research efforts and applications of the IRI model are presented and discussed during annual IRI workshops3), with each workshop focusing on a specific modelling topic. Papers from these workshops have been published in dedicated issues of the journal Advances in Space Research3). Recent reviews of IRI and other ionospheric models can be found in References [4], [51], [52], and [54].

7 Model content and inputs

The IRI model uses a modular approach combining sub-models for the different parameters in different altitude regimes. Examples of such sub-models are:

— International Telecommunication Union ITU-R (former CCIR) model for the F2 layer critical frequency foF2 (directly related with the F2 peak electron density, in m^{-3}) and for the propagation factor M(3000)F2 (inversely correlated with the peak height, in km)[7]; IRI recommends use of the CCIR model above continental areas and recommends use of the URSI model[55] above ocean areas, because the URSI model produces better results than the CCIR model in these areas; Instead of the CCIR-recommended sunspot number IRI uses the global ionosphere index IG[56] because it gives better results especially at high solar activities,

— COSPAR International Reference Atmosphere (CIRA) model[14] for the neutral temperature,

— STORM model for storm-time updating of the F2 layer peak density[9], and

— International Geomagnetic Reference Field (IGRF) model of the International Association of Geomagnetism and Aeronomy (IAGA) for the magnetic coordinates (http://www.ngdc.noaa.gov/IAGA/vmod/).

The IRI model requires the following indices as input parameters:

— R12, the 12-month running mean of sunspot number R;

— IG12, the 12-month running mean of global ionosphere index IG;

3) Information about past and future workshops can be found on the IRI homepage (http://irimodel.org), which also provides access to the final report from each workshop and to a bibliography of IRI-related papers and issues of Advances in Space Research.

— ap, the 3-hourly planetary magnetic indices for the prior 33 h.

These indices can either be found automatically from the indices files that are included with the IRI software package and that are updated quarterly, or the user can provide his/her own input values for these indices. For R12 and IG12, the indices file starts from January 1958 and include indices prediction for two years ahead. For ap, the index values start from January 1960[4)].

In addition, model users have the options to use measured peak parameters to update the IRI profile, including the F2, F1, and E layer critical frequencies (or electron densities), the F2 peak height [or M(3000)F2 propagation factor], and the E peak height. In this way, real-time IRI predictions can be obtained if the real-time peak parameters are available. The total electron content (TEC) is obtained by numerical integration from the model's lower boundary (65 km during daytime and 80 km during night time) to the user-specified upper boundary.

8 Plasmasphere extension of the IRI model

8.1 General

The models described in 8.2 to 8.5 have been proposed as plasmasphere extension of the IRI model.

8.2 Global Core Plasma Model (GCPM)

GCPM-2000[10] 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 km to 600 km[5)].

8.3 Global Plasmasphere Ionosphere Density (GPID) model

The semi-empirical GPID model[23][24] includes IRI below 500 km to 600 km and extends it with theoretical plasmasphere electron density description along the field lines. Authors report on drawbacks of merging of the IRI with the plasmasphere part of GPID[6)].

8.4 IMAGE/RPI plasmasphere model

The IMAGE/RPI plasmasphere model[15] is based on radio plasma imager (RPI)[21] measurements of the electron density distribution along magnetic field lines. A plasmaspheric model is evolving for up to about four earth radii. The depletion and refilling of the plasmasphere during and after magnetic storms is described in Reference [22]. A power profile model as function of magnetic activity was developed from RPI observations for the polar cap region.[17]

8.5 IZMIRAN plasmasphere model

The IZMIRAN[7)] model[8][11][13] is an empirical model based on whistler and satellite observations. It presents global vertical analytical profiles of electron density and temperature smoothly fitted to IRI electron density profiles at an altitude of topside half peak density (400 km to 600 km for electron density and 400 km for electron temperature) 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

4) For ap, the index values currently lag a few months behind, because of the problems in obtaining and predicting this index.

5) A FORTRAN code implementation of GCPM that includes all regions except the polar cap is available from dennis.gallagher@msfc.nasa.gov.

6) The GPID model source code was written in MATLAB software but is not currently available for release.

7) IZMIRAN: Institute of Terrestrial Magnetism, Ionosphere and Radio Waves Propagation, Russian Academy of Sciences.

