INTERNATIONAL STANDARD

ISO 16457

Second edition
2022-02

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

Environnement spatial (naturel et artificiel) — Modèle de l'ionosphère de la Terre — Modèle de l'ionosphère internationale de référence (IRI) et extensions à la plasmasphère

Reference number
ISO 16457:2022(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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 of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 16457:2014), which has been technically revised.

The main changes are as follows:

— adding a description of the newly developed real-time IRI (Clause 9);

— replacing one of the plasmaspheric extension models (GPID) that is no longer available with the option to extrapolate the standard IRI to plasmaspheric altitudes;

— providing more detail and newer references for the IMAGE/RPI and IZMIRAN plasmaspheric extensions of IRI.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to identify a set of management guidelines for dealing with space systems engineering activities and is intended to define the minimum existing processes on the subject seeking to reach an international agreement on the topic.

Guided by the knowledge gained from empirical data analysis, this document 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 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 60 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 [18],[19],[20],[5],[6],[1],[2],[3],[53],[72],[73]. The homepage of the IRI project at http://irimodel.org/ provides access to the computer code (FORTRAN) of the latest version of the model and to earlier versions and to links to several related sites that use IRI for various applications.

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 document 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 document provides a common framework of the international standard of the Earth's ionosphere and plasmasphere for the potential users.

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

1 Scope

This document 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.

A brief introduction to ionospheric and plasmaspheric physics is given in Annex A. Annex B provides an overview over physical models, because they are important for understanding and modelling the physical processes that produce the ionospheric plasma.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
ionosphere
region of the Earth's atmosphere in the height interval from 50 km to 1 500 km containing weakly ionized cold plasma

3.2
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.

3.3
plasmapause
outward boundary of the *plasmasphere* (3.2) 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.

3.4
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.

3.5
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* (3.1), as well as large-scale changes in the global neutral wind, composition and temperature.

3.6
sunspot number
R
daily index of sunspot activity defined as $k(10\,g + s)$ where s is the number of individual spots, g is the number of sunspot groups, and k is an observatory factor

Note 1 to entry: R is alternatively called Ri or Rz or SSN.

Note 2 to entry: R12 is 12-month running mean of monthly sunspot number.

Note 3 to entry: In 2014 the calculation scheme for the officially distributed sunspot number was changed[68] with the result that the new sunspot number (SSN2) is about a factor of 1,45 larger than the old one (SSN1).

3.7
F10.7
solar radio flux at 10,7 cm wavelength measured at the ground daily at noon

Note 1 to entry: Besides this 'observed' F10.7 index there is also an 'adjusted' F10.7 index that is adjusted to 1AU. Often used averages are the 81-day (3 solar rotations) running mean and the 12-month running mean.

3.8
Lyman-α index
solar activity (3.4) index based on daily measured solar emission at 121,6 nm (H Lyman-α line)

3.9
MGII index
solar activity (3.4) index based on core-to-wing ratio of the magnesium ion h and k lines at 279,56 nm and 280,27 nm

3.10
Kp index
planetary three-hour index of geomagnetic activity characterizing the disturbance in the Earth's magnetic field over three-hour universal time (UT) intervals[87]

Note 1 to entry: The index scale is uneven quasi-logarithmic and assigned to successive 3 h UT intervals giving eight values per UT day, and ranges in 28 steps from 0 (quiet) to 9 (disturbed).

3.11
ap index
three-hour UT amplitude index of geomagnetic variation equivalent to the *Kp index* (3.10)

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

3.12
total electron content
TEC
integral number of electrons in the unitary area 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* (3.1) to the *plasmapause* (3.3)

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

3.13
TECg
TEC-based global index
global ionospheric index based on GNSS-derived TEC-noon measurements at the network of IGS stations

Note 1 to entry: See References [70] and [82] for more information on IGS stations.

3.14
GEC
global electron content
integral of *TEC* (3.12) over the whole globe based on GNSS-derived TEC measurements

3.15
IG
ionosphere global index
ionosphere-effective *sunspot number* (3.6)[56] that is obtained by adjusting the CCIR maps[7] to global ionosonde measurements of the F2 plasma critical frequency foF2

Note 1 to entry: IG12 is 12-month running mean of monthly ionosphere-effective sunspot number.

Note 2 to entry: See Reference [56] for the ionosphere-effective sunspot number and Reference [7] for the CCIR maps.

4 Abbreviated terms

ELF	extremely low frequency (less than 3 kHz)
BeiDou	BeiDou Navigation Satellite System
GALILEO	European Global Satellite Navigation System
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System (e.g. GPS, GLONASS, GALILEO and others)
GPS	Global Positioning System
HF	high frequency (3 MHz to 30 MHz)
IRI	international reference ionosphere
LF	low frequency (30 kHz to 300 kHz)
MF	medium frequency (300 kHz to 3 MHz)
UHF	ultra high frequency (300 MHz to 3 000 MHz)
VHF	very high frequency (30 MHz to 300 MHz)
VLF	very low frequency (3 kHz to 30 kHz)

5 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 fore-cast 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.

6 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)[1)] 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 LF, 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 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 can 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 document may be also applied for ray-path calculations to assess the performance of a particular ground-based or space-borne system. 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.

7 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], IRI-2000[3], IRI-2007[53],[54], IRI-2012[71],[72] and IRI-2016[73]. The latest version of the model is available from http://irimodel.org.

IRI-related research efforts and applications of the IRI model are presented and discussed during annual IRI workshops[1)], 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 Research[2)]. Reviews of IRI and other ionospheric models can be found in References [4], [51], [52] and [54].

8 Model content and inputs

The IRI model uses a modular approach combining sub-models for the different parameters in different altitude and/or time 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 (NRL-MSISE-00[38]) for the neutral temperature;

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

— International geomagnetic reference field (IGRF) model of the International Association of Geomagnetism and Aeronomy (IAGA) for the magnetic coordinates (https://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;

— F10.7, the daily index and 81-day and 12-month running mean;

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

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

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 one to two years into the future. For ap index, the values start from January 1960 and include no predictions.

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), the E peak height, and the bottomside thickness and shape parameters B0 and B1. 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.

1) 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.

2) A list of IRI issues of Advances in Space Research is available at http://irimodel.org/docs/asr_list.html.

