

BS EN 16603-10-04:2015



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Space engineering — Space environment

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National foreword

This British Standard is the UK implementation of EN 16603-10-04:2015. It supersedes BS EN 14092:2002 which is withdrawn.

BSI, as a member of CEN, is obliged to publish EN 16603-10-04 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK committee voted against its approval as a European Standard.

The UK committee are of the opinion that parts of Clause 10 conflict with ISO 14200:2012 which has already been adopted by BSI. In particular, Clause 10 requires the use of ESA's MASTER-2005 space debris and meteoroid flux model, whereas ISO 14200:2012 does not prescribe the use of a particular flux model but sets out a process for selecting and using a model from several that are available.

Further, MASTER-2005 is a relatively old flux model that has since been superseded by MASTER-2009. The UK Committee are of the opinion that ISO 14200:2012 should be used to select a space debris/meteoroid flux model for the purpose of performing an impact risk assessment. ISO 14200:2012 can also be used in conjunction with ISO 16126:2014 which defines two different procedures for analysing impact risk.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Ingénierie spatiale - Environnement spatial

Raumfahrttechnik - Raumfahrtumweltbedingungen

This European Standard was approved by CEN on 28 December 2013.

CEN and CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN and CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN and CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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Foreword

This document (EN 16603-10-04:2015) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-10-04:2015) originates from ECSS-E-ST-10-04C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2015, and conflicting national standards shall be withdrawn at the latest by July 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document supersedes EN 14092:2002.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This standard forms part of the System Engineering branch (ECSS-E-10) of the Engineering area of the ECSS system. As such it is intended to assist in the consistent application of space environment engineering to space products through specification of required or recommended methods, data and models to the problem of ensuring best performance, problem avoidance or survivability of a product in the space environment.

The space environment can cause severe problems for space systems. Proper assessment of the potential effects is part of the system engineering process as defined in ECSS-E-ST-10. This is performed in the early phases of a mission when consideration is given to e.g. orbit selection, mass budget, thermal protection, and component selection policy. As the design of a space system is developed, further engineering iteration is normally necessary with more detailed analysis.

In this Standard, each component of the space environment is treated separately, although synergies and cross-linking of models are specified. Informative annexes are provided as explanatory background information associated with each clause.

1

Scope

This standard applies to all product types which exist or operate in space and defines the natural environment for all space regimes. It also defines general models and rules for determining the local induced environment.

Project-specific or project-class-specific acceptance criteria, analysis methods or procedures are not defined.

The natural space environment of a given item is that set of environmental conditions defined by the external physical world for the given mission (e.g. atmosphere, meteoroids and energetic particle radiation). The induced space environment is that set of environmental conditions created or modified by the presence or operation of the item and its mission (e.g. contamination, secondary radiations and spacecraft charging). The space environment also contains elements which are induced by the execution of other space activities (e.g. debris and contamination).

This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply, However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms

- [RN.1] C. Förste, F. Flechtner, R. Schmidt, R. König, U. Meyer, R. Stubenvoll, M. Rothacher, F. Barthelmes, H. Neumayer, R. Biancale, S. Bruinsma, J.-M. Lemoine, and S. Loyer, A Mean Global Gravity Field Model from the Combination of Satellite Mission and Altimetry/Gravimetry Surface Data – EIGEN-GL04C, Geophysical Research Abstracts, Vol.8, 03462, 2006
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Terms, definitions and abbreviated terms

3.1 Terms defined in other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:

contamination

environment

mission

space debris

3.2 Terms specific to the present standard

3.2.1 **Ap, Kp indices**

geomagnetic activity indices to describe fluctuations of the geomagnetic field

NOTE Values of A_p range from 0 to 400 and they are expressed in units of nT (nanotesla). K_p is essentially the logarithm of A_p .

3.2.2 **absorbed dose**

energy absorbed locally per unit mass as a result of radiation exposure which is transferred through ionization and excitation

NOTE A portion of the energy absorption can result in damage to the lattice structure of solids through displacement of atoms, and this is now commonly referred to as Non-Ionizing Energy Loss (NIEL).

3.2.3 **accommodation coefficient**

measure for the amount of energy transfer between a molecule and a surface

3.2.4 **albedo**

fraction of sunlight which is reflected off a planet

3.2.5 **atmospheric albedo neutrons**

neutrons escaping from the earth's atmosphere following generation by the interaction of cosmic rays and solar particles

NOTE Atmospheric albedo neutrons can also be produced by other planetary atmospheres and surfaces.

3.2.6 bremsstrahlung

high-energy electromagnetic radiation in the X- γ energy range emitted by charged particles slowing down by scattering of atomic nuclei

NOTE The primary particle is ultimately absorbed while the bremsstrahlung can be highly penetrating. In space, the most common source of bremsstrahlung is electron scattering.

3.2.7 contaminant

molecular and particulate matter that can affect or degrade the performance of any component when being in line of sight with that component or when residing onto that component

3.2.8 contaminant environment

molecular and particulate environment in the vicinity of and created by the presence of a spacecraft

3.2.9 current

the rate of transport of particles through a boundary

NOTE In contrast to flux, current is dependent on the direction in which the particle crosses the boundary (it is a vector integral). An isotropic omnidirectional flux, f , incident on a plane gives rise to a current of $\frac{1}{4}f$ normally in each direction across the plane. Current is often used in the discussion of radiation transport.

3.2.10 direct flux

free stream or outgassing molecules that directly impinge onto a critical surface, i.e. without prior collisions with other gas species or any other surface

3.2.11 distribution function $f(\mathbf{x}, \mathbf{v})$

function describing the particle density of a plasma in 6-D space made up of the three spatial vectors and the three velocity vectors, with units $\text{s}^3 \text{m}^{-6}$

NOTE For distributions that are spatially uniform and isotropic, it is often quoted as $f(v)$, a function of scalar velocity, with units s m^{-4} , or $f(E)$ a function of energy, with units $\text{J}^{-1}\text{m}^{-3}$. This can be converted to flux as follows:

$$Flux = \int V f(v) dv \quad (3-1)$$

or

$$Flux = \int \frac{f(E)}{m} dE \quad (3-2)$$

where

v is the scalar velocity;

E is the energy;

m is the particle mass.

3.2.12 dose

quantity of radiation delivered at a position

NOTE In its broadest sense this can include the flux of particles, but in the context of space energetic particle radiation effects, it usually refers to the energy absorbed locally per unit mass as a result of radiation exposure.

3.2.13 dose equivalent

radiation quantity normally applied to biological effects and includes scaling factors to account for the more severe effects of certain kinds of radiation

3.2.14 dust

particulates which have a direct relation to a specific solar system body and which are usually found close to the surface of this body (e.g. Lunar, Martian or Cometary dust)

3.2.15 Earth infrared

thermal radiation emitted by the Earth

NOTE It is also called outgoing long wave radiation.

3.2.16 energetic particle

particles which, in the context of space systems radiation effects, can penetrate outer surfaces of spacecraft

NOTE For electrons, this is typically above 100 keV, while for protons and other ions this is above 1 MeV. Neutrons, gamma rays and X-rays are also considered energetic particles in this context.

3.2.17 equivalent fluence

quantity which attempts to represent the damage at different energies and from different species

NOTE 1 For example: For solar cell degradation it is often taken that one 10 MeV protons is "equivalent" to 3 000 electrons of 1 MeV. This concept also occurs in consideration of Non-ionizing Energy Loss effects (NIEL).

NOTE 2 Damage coefficients are used to scale the effect caused by particles to the damage caused by a standard particle and energy.

3.2.18 exosphere

part of the Earth's atmosphere above the thermosphere for which the mean free path exceeds the scale height, and within which there are very few collisions between atoms and molecules

NOTE 1 Near the base of the exosphere atomic oxygen is normally the dominant constituent.

NOTE 2 With increasing altitude, the proportion of atomic hydrogen increases, and hydrogen normally becomes the dominant constituent above about 1 000 km. Under rather special conditions (i.e. winter polar region) He atoms can become the major constituent over a limited altitude range.

NOTE 3 A small fraction of *H* and *He* atoms can attain escape velocities within the exosphere.

3.2.19 external field

part of the measured geomagnetic field produced by sources external to the solid Earth

NOTE the external sources are mainly: electrical currents in the ionosphere, the magnetosphere and coupling currents between these regions.

3.2.20 $F_{10.7}$ flux

solar flux at a wavelength of 10.7 cm in units of 10^4 Jansky (one Jansky equals $10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}$)

3.2.21 fluence

time-integration of the flux

3.2.22 flux

amount of radiation crossing a surface per unit of time, often expressed in "integral form" as particles per unit area per unit time (e.g. electrons $\text{cm}^{-2} \text{s}^{-1}$) above a certain threshold energy

NOTE The directional flux is the differential with respect to solid angle (e.g. particles cm^{-2} steradian $^{-1} \text{s}^{-1}$) while the "differential" flux is differential with respect to energy (e.g. particles $\text{cm}^{-2} \text{ MeV}^{-1} \text{s}^{-1}$). In some cases fluxes are also treated as a differential with respect to Linear Energy Transfer (see 3.2.32).

3.2.23 free molecular flow regime

condition where the mean free path of a molecule is greater than the dimensions of the volume of interest (characteristic length)

3.2.24 geocentric solar magnetospheric coordinates (GSM)

elements of a right-handed Cartesian coordinate system (X,Y,Z) with the origin at the centre of the Earth

NOTE X points towards the Sun; Z is perpendicular to X, lying in the plane containing the X and geomagnetic dipole axes; Y points perpendicular to X and Z and points approximately towards dusk magnetic local time (MLT).

3.2.25 heterosphere

Earth's atmosphere above 105 km altitude where the neutral concentration profiles are established due to diffusive equilibrium between the species

NOTE N_2 is normally dominant below approximately 200 km, O is normally dominant from approx 200 km to approx. 600 km, He is dominant above 600 km altitude, and H dominant at very high altitudes. These conditions depend on solar and geomagnetic activity, and the situation may be quite variable at high altitudes during major geomagnetic disturbances.

3.2.26 homosphere

Earth's atmosphere below 105 km altitude where complete vertical mixing yields a near-homogeneous composition of about 78,1% N_2 , 20,9% O_2 , 0,9% Ar, and 0,1% CO_2 and trace constituents

NOTE The homopause (or turbopause) marks the ceiling of the homosphere.

3.2.27 indirect flux

molecules impinging on a critical surface, after collision with, or collision and sojourn on other surfaces

3.2.28 internal field

part of the measured geomagnetic field produced by sources internal to the solid Earth, primarily due to the time-varying dynamo operating in the outer core of the Earth

3.2.29 interplanetary magnetic field

solar coronal magnetic field carried outward by the solar wind, pervading the solar system

3.2.30 isotropic

property of a distribution of particles where the flux is constant over all directions

3.2.31 L or L shell

parameter of the geomagnetic field, often used to describe positions in near-Earth space

NOTE L or L shell has a complicated derivation based on an invariant of the motion of charged particles in the terrestrial magnetic field (see Annex E).

However, it is useful in defining plasma regimes within the magnetosphere because, for a dipole magnetic field, it is equal to the geocentric altitude in Earth-radii of the local magnetic field line where it crosses the equator.

3.2.32 linear energy transfer (LET)

rate of energy deposit from a slowing energetic particle with distance travelled in matter, the energy being imparted to the material

NOTE Normally used to describe the ionization track caused by passage of an ion. LET is material-dependent and is also a function of particle energy. For ions involved in space radiation effects, it increases with decreasing energy (it also increases at high energies, beyond the minimum ionizing energy). LET allows different ions to be considered together by simply representing the ion environment as the summation of the fluxes of all ions as functions of their LETs. This simplifies single-event upset calculation. The rate of energy loss of a particle, which also includes emitted secondary radiations, is the stopping power.

3.2.33 magnetic local time (MLT)

parameter analogous to longitude, often used to describe positions in near-Earth space

NOTE Pressure from the solar wind distorts the Earth magnetic field into a comet-like shape. This structure remains fixed with its nose towards the Sun and the tail away from it as the Earth spins within it. Hence longitude, which rotates with the Earth, is not a useful way of describing position in the magnetosphere. Instead, magnetic local time is used. This has value 0 (midnight) in the anti-sunward direction, 12 (noon) in the sunward direction and 6 (dawn) and 18 (dusk) perpendicular to the sunward/anti-sunward line. This is basically an extension of the local solar time on Earth, projected vertically upwards into space although allowance is made for the tilt of the dipole.

3.2.34 mass flow rate

mass (g) of molecular species crossing a specified plane per unit time and unit area ($\text{g cm}^{-2}\text{s}^{-1}$)

3.2.35 Maxwellian distribution

plasma distribution functions described in terms of scalar velocity, v , by the Maxwellian distribution below:

$$f(v) = 4\pi n \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} v^2 \exp \left(-\frac{v^2 m}{2kT} \right) \quad (3-3)$$

where

n is the density;

k is the Boltzmann constant;

T is the temperature.

NOTE The complete distribution is therefore described by a pair of numbers for density and temperature. This distribution is valid in thermal equilibrium. Even non-equilibrium distributions can often be usefully described by a combination of two Maxwellians.

3.2.36 meteoroids

particles in space which are of natural origin

NOTE nearly all meteoroids originate from asteroids or comets.

3.2.37 meteoroid stream

meteoroids that retain the orbit of their parent body and that can create periods of high flux

3.2.38 molecular column density (MCD)

integral of the number density (number of molecules of a particular species per unit volume) along a specified line of sight originating from a (target, critical, measuring, reference) surface

3.2.39 molecular contaminant

contaminant without observable dimensions

3.2.40 nano-Tesla

standard unit of Geomagnetism

NOTE An older unit, not widely used now, is the Gauss, which is 10^5 nT.

3.2.41 omnidirectional flux

scalar integral of the flux over all directions

NOTE This implies that no consideration is taken of the directional distribution of the particles which can be non-isotropic. The flux at a point is the number of particles crossing a sphere of unit cross-sectional surface area (i.e. of radius $1/\sqrt{\pi}$). An omnidirectional flux is not to be confused with an isotropic flux.

3.2.42 outgassing rate

mass of molecular species evolving from material per unit time and unit surface area ($\text{g cm}^{-2}\text{s}^{-1}$)

NOTE Outgassing rates can also be given in other units, such as in relative mass unit per time unit: (g s^{-1}), ($\% \text{ s}^{-1}$) or ($\% \text{ s}^{-1}\text{cm}^{-2}$).

3.2.43 particulate contaminant

solid or liquid contaminant particles

3.2.44 permanent molecular deposition (PMD)

molecular matter that permanently sticks onto a surface (non-volatile under the given circumstances) as a result of reaction with surface material, UV-irradiation or residual atmosphere induced reactions (e.g. polymerization, formation of inorganic oxides)

3.2.45 plasma

partly or wholly ionized gas whose particles exhibit collective response to magnetic and electric fields

NOTE The collective motion is brought about by the electrostatic Coulomb force between charged particles. This causes the particles to rearrange themselves to counteract electric fields within a distance of the order of the Debye length. On spatial scales larger than the Debye length plasmas are electrically neutral.

3.2.46 radiation

transfer of energy by means of a particle (including photons)

3.2.47 return flux

molecules returning to the source or a surface which is not in direct view of the incoming flux

NOTE The cause can be:

- collisions with other residual natural atmospheric species (ambient scatter) or with other identical or different contaminant species (self scatter) before reaching the critical surface;
- ionization or dissociative ionization of the molecules under radiation (e.g. UV or particles) and subsequent attraction to a charged surface

3.2.48 single-event upset (SEU), single-event effect (SEE), single-event latch-up (SEL)

effects resulting from the highly localized deposition of energy by single particles or their reaction products and where the energy deposition is sufficient to cause observable effects

3.2.49 sporadic flux

random flux with no apparent pattern

3.2.50 solar constant

electromagnetic radiation from the Sun that falls on a unit area of surface normal to the line from the Sun, per unit time, outside the atmosphere, at one astronomical unit

NOTE 1 AU = average Earth-Sun distance

3.2.51 solar flare

emission of optical, UV and X-radiation from an energetic event on the Sun

NOTE There is some controversy about the causal relationship between solar flares and the arrival of large fluxes of energetic particles at Earth. Therefore, it is more consistent to refer to the latter as Solar Energetic Particle Events (SEPEs).

3.2.52 sticking coefficient

parameter defining the probability that a molecule, colliding with a surface, stays onto that surface for a time long compared to the phenomena under investigation

NOTE It is a function of parameters such as contamination/surface material pairing, temperature, photo-polymerization, and reactive interaction with atomic oxygen.

3.2.53 surface accommodation

situation which occurs when a molecule becomes attached to a surface long enough to come into a thermal equilibrium with that surface

3.2.54 thermosphere

Earth's atmosphere between 120 km and 250 km to approximately 400 km (depending on the activity level), where temperature has an exponential increase up to a limiting value T_{∞} at the thermopause (where T_{∞} is the exospheric temperature)

3.2.55 trackable objects

objects regularly observed and catalogued by ground-based sensors of a space surveillance network (typically objects larger than about 10 cm in LEO and larger than about 1 m in GEO)

3.2.56 VCM-test

screening thermal vacuum test to determine the outgassing properties of materials

NOTE The test is described in ECSS-Q-ST-70-02 [RD.23] and ASTM-E595 [RD.24]. The test results are:

- TML - Total Mass Loss, measured ex-situ as a difference of mass before and after exposure to a vacuum under the conditions specified in the outgassing test, normally expressed in % of initial mass of material.
- CVCM - Collected Volatile Condensable Material, measured ex-situ on a collector plate after exposure (to a vacuum) under the conditions specified in the outgassing test, normally expressed in % of initial mass of material.

3.2.57 world magnetic model

revised every five years by a US-UK geomagnetic consortium, primarily for military use

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
ASTM	American Society for Testing and Materials
AE	auroral electrojet
AO	atomic oxygen
BIRA	Belgisch Instituut voor Ruimte-Aeronomie
CIRA	COSPAR International Reference Atmosphere
COSPAR	Committee on Space Research
CVCM	collected volatile condensable material
DISCOS	ESA's database and information system characterizing objects in space
DTM	density and temperature model
emf	electro-motive force
ESP Model	Emission of Solar Protons Model
GCR	galactic cosmic ray
GEO	geostationary Earth orbit
GNSS	global navigation satellite system
GRAM	global reference atmosphere model

GSM	geocentric solar magnetospheric co-ordinates
HEO	highly eccentric orbit
HWM	horizontal wind model
IAGA	International Association for Geomagnetism and Aeronomy
IASB	Institute d'Aeronomie Spatiale de Belgique
ECM	in-flight experiment for contamination monitoring
IERS	international earth rotation service
IGRF	international geomagnetic reference field
IMF	interplanetary magnetic field
JB-2006	Jacchia-Bowman semi-empirical model (2006)
LDEF	long duration exposure facility
LEO	low Earth orbit
LET	linear energy transfer
MAH	model of the high atmosphere
MASTER	meteoroid and space debris terrestrial environment reference model
MCD	molecular column density
MEO	medium (altitude) Earth orbit
MET	Marshall engineering thermosphere model
MLT	magnetic local time
MSIS	mass spectrometer and incoherent scatter
NIEL	non-ionizing energy loss
nT	nano-Tesla
PMD	permanent molecular deposition
R	sunspot number
R_c	rigidity Cut-off for geomagnetic shielding
R_E	Earth radius
RHU	radioisotope heater unit
R_j	jovian radius
r.m.s.	root-mean-square
RTG	radioisotope thermo-electric generator
SEU	single-event upset
SEE	single-event effect
SEL	single-event latch-up
SEPs	solar energetic particles
SEPE	solar energetic particle events
sfu	solar flux unit
SPE	solar particle events
SRP	solar radiation pressure

SPIDR	Space Physics Interactive Data Resource
SW	solar wind
TML	total mass loss
TD	total density model
URSI	Union Radio Science Internationale
USSA	US standard atmosphere
VBQC	vacuum balance quartz contamination
VCM	volatile condensable material
VUV	vacuum ultra violet
WMM	world magnetic model

4

Gravity

4.1 Introduction and description

4.1.1 Introduction

Any two bodies attract each other with a force that is proportional to the product of their masses, and inversely proportional to the square of the distance between them (Newton's law):

$$F = G \frac{m_1 m_2}{r^2} \quad (4-1)$$

where

F is the gravitational force

$G = (6,6726 \pm 0,0009) \times 10^{-11} \text{m}^3 \text{kg}^{-1} \text{s}^{-2}$ is the
universal gravitational constant

m_1, m_2 are the two point masses

r is the distance between the masses

The simplest case of gravitational attraction occurs between bodies that can be considered as point masses. These are bodies at a relative distance r that is sufficiently large in comparison to the sizes of the bodies to ignore the *shape* of the bodies. For two spherical bodies with a homogeneous mass distribution Newton's law is correct also at all locations above their surface ("2-body problem").

Also third body perturbations and tidal effects are important for an accurate analysis of the gravitational interaction.

4.1.2 Gravity model formulation

Without compromising the general validity of underlying theories, all subsequent gravity model discussions are focused on the Earth. The gravity acceleration acting on a point mass, which is external to the central body, is the gradient of the potential function U of that body. The corresponding geopotential surface satisfies the so called Laplace equation:

$$\nabla^2 U = 0 \quad (4-2)$$

The corresponding perturbing acceleration can be determined from equation (4-3) by means of computationally efficient recursion algorithms (e.g. as in [RD.1]).

$$\ddot{\vec{r}} = \nabla U \quad (4-3)$$

where

$\ddot{\vec{r}}$ is the 2nd time derivative of the position vector.

The solution U of the partial differential equation (4-2) is typically written in the form of a series expansion, in terms of so-called surface spherical harmonic functions, for a location defined in spherical coordinates r, λ, φ .

$$U = \frac{GM}{r} \left\{ 1 + \sum_{l=2}^N \left(\frac{a_e}{r} \right)^l \sum_{m=0}^l [C_{lm} \cos(m\lambda) + S_{lm} \sin(m\lambda)] P_{lm}(\sin \varphi) \right\} \quad (4-4)$$

where

$GM = \mu$ is the gravity constant of the Earth (M being its mass);

$\mu = 3,98604415 \times 10^{14} \text{ m}^3\text{s}^{-2}$ for the EIGEN-GL04C model

a_e is the mean equatorial radius of the Earth;

$a_e = 6\,378\,136,460 \text{ m}$ for the EIGEN-GL04C model

r is the radial distance from centre of the Earth to satellite

N is the maximum degree of the expansion

l is the degree of a certain harmonic function

m is the order of a certain harmonic function

C_{lm}, S_{lm} are coefficients that determine amplitude and phase of a certain harmonic function

λ is the geodetic longitude of the sub-satellite point

φ is the geodetic latitude of the sub-satellite point

P_{lm} are associated Legendre functions of the first kind, of degree l and order m ; recurrence relations for these functions are available in the literature (e.g. [RD.1]).

A gravity model consists of adopted values for GM, a_e , and a set of model coefficients C_{lm}, S_{lm} . Practical implementations of gravity models, e.g. for numerical integration of a satellite orbit, are typically interested in the gravity acceleration resulting from the potential function U in (4-4). Corresponding partial derivatives of (4-4) in Cartesian coordinates of an Earth-fixed system x, y, z can be computed recursively (see [RD.1]).

The model coefficients C_{lm} , S_{lm} are typically provided in their normalized versions, according to (4-5) in order to limit their numerical range for higher degrees and orders.

$$\begin{Bmatrix} \overline{C}_{lm} \\ \overline{S}_{lm} \end{Bmatrix} = \sqrt{\frac{(l+m)!}{k(2l+1)(l-m)!}} \begin{Bmatrix} C_{lm} \\ S_{lm} \end{Bmatrix} \quad k = \begin{cases} 1 & \text{for } m = 0 \\ 2 & \text{for } m \neq 0 \end{cases} \quad (4-5)$$

The Legendre functions $P_{lm}(\sin \varphi)$ in this case are normalized by the inverse of the square root in equation (4-5).

4.1.3 Third body gravitation

When acting as a third-body perturbation, the gravitational attraction by the Sun and its planets can be modelled by means of point mass attractions. This requires knowledge on the masses and positions of the bodies, as well as some guidelines on which effects are important. In general, for orbit computations of Earth-orbiting satellites it is sufficient to include the planetary gravity due to Venus, Mars, Jupiter and Saturn; the other planets are either too small, or too far away to have any significant impact on a satellite orbit around the Earth.

4.1.4 Tidal effects

The gravity potential of a central body only represents the static part of the gravitational acceleration acting on a satellite. There are, however, additional gravity-related effects due to tides that can be important for precise applications. Several tidal effects can be distinguished (see [RD.1]):

- Solid Earth tides associated with the deformations of the Earth's body under the gravitational effects of Sun and Moon and leading to complicated variations in the geopotential coefficients.
- Ocean tides, associated with the displacements of the ocean water masses under the effect of solar and lunar tides. The water displacements in turn modify the geopotential in complicated variational patterns.
- The permanent tide, which is a non-zero constant component of the above tides which nonetheless is not considered part of the static geopotential.
- Pole tides, which are due to the centrifugal effects of polar motion, which in turn is the movement of the Earth's body axis relative to the instantaneous axis of rotation.

4.2 Requirements for model selection and application

4.2.1 General requirements for gravity models

- a. Gravity effects shall be included in all orbit determination and orbit prediction processes, and in attitude determination and prediction processes for Earth and planetary orbiters.

- b. The inclusion of different gravity sources, their associated model details, and corresponding model truncation errors shall be compliant with the requirements on orbit and/or attitude determination accuracy, and they shall be at least of the same perturbation order as considered perturbing accelerations due to non-gravitational effects.
- c. The retained accuracy level of a gravity model shall be compliant with the accuracy of the position and orientation of the central body.

NOTE Harmonic coefficients can lead to resonance effects, if they have a degree or order close to some integer multiple of the ground track repeat cycle. For orbits that are known to be repetitive, it is then recommendable to include discrete resonant harmonics of degrees that normally fall outside the truncated expansion series.

4.2.2 Selection and application of gravity models

- a. For Earth orbits the gravity model EIGEN-GLO4C given in [RN.1] shall be used.

NOTE The EIGEN-GLO4C model has a spatial resolution in latitude and longitude of $1^\circ \times 1^\circ$ (corresponding to degree $\times$ order = 360×360).

- b. Data on gravitational effects from tides and on Earth orientation parameters shall be obtained from the International Earth Rotation Service IERS given in [RN.2].
- c. For third body gravitational perturbations the Development Ephemerides data on planets (DE-405) and the Lunar Ephemerides data (LE-405), both given in [RN.3], shall be used.
- d. For planetary mass values the 2003 standards of the International Earth Rotation Services IERS, as described in IERS Technical Note 32 [RN.2], shall be used.

Geomagnetic fields

5.1 Introduction and description

5.1.1 The geomagnetic field and its sources

Within the magnetopause, the boundary between the influence of the solar wind and embedded IMF of solar origin, the near-Earth environment is strongly influenced by the geomagnetic field. The geomagnetic field is due to a variety of sources, those within the Earth, those within the ionosphere, and those within the magnetosphere.

The Earth's magnetic field is responsible for organizing the flow of ionized plasmas within most regions of the near-Earth environment. Hence, it determines the boundaries of distinct plasma regimes. The magnetic field is also used widely for attitude measurement and for important spacecraft sub-systems such as magneto-torquers.

5.1.2 The internal field

Under quiet solar and geomagnetic activity conditions, the magnetic field measured at the Earth's surface is primarily (>90%) due to a magneto-hydrodynamic dynamo, operating in the liquid outer core of the Earth. The secular (or time) variation of this field operates on a scale of months to centuries, or more, with position dependent amplitude of anywhere between zero and up to a few hundred nT year⁻¹. The core field morphology is closely dipolar, at least far from the Earth, and is inclined to the Earth's rotation axis by around 11 degrees at the present time (see Figure E-1).

Superimposed on this core field is the static magnetic field of geological sources in the lithosphere and upper mantle. Typically the field from these crustal rocks decays rapidly away from the source. For example, in low Earth orbit, the crustal signature is probably no more than about 20 nT, decaying rapidly with altitude.

Traditionally the combination of the core and crustal field is referred to as the 'main field'. The mean "main field" as measured at the Earth's surface is depicted in Figure E-1.

5.1.3 External field: ionospheric components

Currents flowing in the ionosphere induce an external magnetic field component. Sources of these currents include wind-driven motion of ionospheric plasma that produces a daily variation field known as Sq ('solar quiet'). This takes the form of two vortices, fixed north and south of the Sun-Earth line, on the dayside of the Earth, as the Earth rotates beneath. Along the geomagnetic equator an equatorial electrojet is formed, due to a high conductivity channel related to the near-horizontal field morphology. Below (or above) this electrojet the field amplitude can be enhanced by several hundred nT, within about five degrees i.e. a few hundred km of the magnetic equator.

At auroral latitudes (approximately 55-65 magnetic degrees), the auroral electrojet is formed at the open/closed field line boundary. This electrojet is fed by field-aligned currents that connect the ionosphere to the magnetospheric flanks and to the night-side tail and partial ring current sheet. The magnitude of the resulting induced fields is very dynamic and can be many hundreds of nT as observed at ground level or in low Earth orbit during periods of disturbed geomagnetic activity.

In the lower magnetosphere there are inter-hemispheric (field-aligned) currents of several nT at around 400 km altitude. Plasma 'bubbles' can also cause localised magnetic variations of a few nT to be measured by low-Earth orbit satellite altitudes. At high and polar latitudes the Earth's field is also open to the solar wind and cusp currents, also known as Region 0 currents flow.

5.1.4 External magnetic field: magnetospheric components

In the magnetosphere, there are several major current systems controlled by the interaction of the Earth's field with the solar wind. The strength of the total magnetospheric field is closely tied to solar and solar wind variations and to plasma outflow from the ionosphere. The major magnetospheric magnetic fields are a result of: magnetopause currents; cross-tail currents, and the symmetric and partial ring currents.

Magnetopause currents flow to shield the internal field from the IMF. And connect to a cross-tail current sheet that separates lobes of opposite magnetic polarity, extending hundreds of Earth radii down-wind from the Earth. An azimuthal drift of plasma (westward for ions, eastwards for electrons) around the Earth produces the symmetric ring current. The partial, or asymmetric, ring current is found on the dusk-side of the Earth and is closed via ionospheric currents. 0 provides the general morphology of model magnetospheric field lines, according to the Tsyganenko 1989 model [RD.111] showing the seasonal variation, dependent on rotation axis tilt. This figure shows a cut in the noon-midnight plane.

5.1.5 Models of the internal and external geomagnetic fields

The magnetic field is commonly modelled by expressing the field as a series of spherical harmonic terms. At the present time (2000-2010) there is much

scientific activity in the field modelling community and in source field reconstruction. This is due to several successful satellite magnetometer surveys, such as those of Ørsted and Champ.

5.1.5.1 Models of the internal field

Scientific models of the internal field now extend to around spherical harmonic degree 100, equivalent to a minimum wavelength of 400 km at the Earth's surface. However the effective amplitudes of these high degree terms decrease rapidly with increasing altitude above the Earth's surface. The core field, which dominates for degrees less than about 14 at the Earth's surface, can be readily simplified to that of a simple inclined and offset dipole or a low-degree model for spacecraft operation above a few hundred km altitude.

Although they are by no means the only recognised high quality models, the IGRF models are products of the international community of geomagnetic scientists, updated on a five-year basis, assuming a linear secular variation between updates.

The descriptive annex to this Chapter (Annex E) describes in more detail the current revision of the IGRF, and further information on other internal field models.

5.1.5.2 Models of the external field

There are a number of dynamic models of the external field. These are typically either empirical (in the sense of a simplified mathematical model fit to measured data), analytic (based on physical models of the various external current systems), or magneto-hydrodynamic (or 'general circulation models'). Of the latter type, the science is rapidly evolving and whilst, in principle, they should fully capture the details of magnetospheric processes, such models are judged not yet mature enough to serve as a reliable standard.

Of those models that are currently maintained and updated in the light of new data and new field parameterisations, the model of Tsyganenko (revised repeatedly between 1987 and 2006 [RN.31] [RD.98] [RD.99] [RD.111] [RD.112]) is well used and is empirical in nature. The model of Alexeev *et al* (2001) [RN.30] is described as an analytic model. This model is at the core of a proposed International Standards Organisation (ISO) standard external field model [RD.113].

The availability of suitable inputs to external models is a factor that affects whether they can be useful in common applications. Alexeev *et al* (2001) [RN.30] has inputs of date, time, solar wind density and velocity, and Tsyganenko 1996 [RN.31] has inputs of solar wind pressure, Dst and IMF By and Bz components. Tsyganenko 2002 to 2005 [RD.98] [RD.99] models require a more complex set of inputs.

Further discussion of these models and of their applications are dealt with in Annex E.

5.2 Requirements for model selection and application

5.2.1 The internal field

- a. IGRF 10 [RN.29] shall be used as the Internal Geomagnetic Field Model.

NOTE As a stand-alone model, the inputs required of the IGRF-10 are either position in geodetic coordinates, according to the reference 'World Geodetic Service 84' standard ellipsoid, or position in a geocentric system, with respect to the centre of the Earth and for which the reference Earth radius is 6 371,2 km. The coordinates are therefore geodetic or geocentric latitude in decimal degrees, longitude (same in both coordinate systems), altitude in km above the reference ellipsoid, or distance in km from the centre of the Earth. Time is input in decimal years, e.g. 2 007,5. It is recommended that geocentric data are used, to avoid errors or confusion in respect of the reference ellipsoid.

- b. If a different model is an inherent part of a specific space environment model, then that specific geomagnetic field model shall be used.

NOTE An example is the AE8 and AP8 radiation flux / belt models (see Clause 9)

5.2.1.2 Application

- a. For times in the past and in the future, IGRF-10 shall be used, in association with its secular variations.

NOTE 1 IGRF-10 and future versions contain revisions of models of earlier epochs.

NOTE 2 Beyond 5 years from the assumed epoch, the precision of the model is considerably reduced. IGRF-11 is expected to be issued for the epoch 2010, and can be used post 2010.

5.2.2 The external field

- a. For modelling the average characteristics of the terrestrial magnetic field and its variation according to geomagnetic and solar activity, one of the following two external magnetic field models shall be used:

- Alexeev et al 2001, [RN.30]
- Tsyganenko 1996 [RN.31]

NOTE 1 These models are suitable for assessment of the mean and range of magnetic field strength; for estimation of B and L coordinates (but not for input to radiation belt models created with different field models); and in calculation of

geomagnetic shielding of cosmic rays and solar particles.

NOTE 2 Recently, external field models have been created (e.g. Tsyganenko 2001 [RD.98], 2004 [RD.99]) that are used in research environments for dynamic modelling of field variations, e.g. substorm development. These have the capacity to represent more accurately the instantaneous magnetic field, but are not given here as standards because the definition of inputs to the models is not reasonably achievable in an engineering environment.

5.3 Tailoring guidelines

- a. While the IGRF 10 model should normally be used for internal fields, a low-fidelity dipole model (using aligned, eccentric or tilted dipoles as appropriate) may suffice for some engineering applications.
- b. For the external field, the recent Tsyganenko 2001 [RD.98] and 2004 [RD.99] models may be used instead of the reference models defined in clause 5.2.2.

NOTE Most engineering applications do not need the external-source model augmentation of these later Tsyganenko models. These are only useful for certain scientific magnetospheric missions, for instance if data on high latitude or high altitude variability of the fields with respect to local time and solar-geomagnetic activity was important.

6

Natural electromagnetic radiation and indices

6.1 Introduction and description

6.1.1 Introduction

A spacecraft in LEO receives electromagnetic radiation from three primary external sources. The largest source is the direct solar flux. The mean value of this solar flux at the mean Sun-Earth distance is called the “solar constant”. It is not really a constant but varies by about 3,4 % during each year because of the slightly elliptical orbit of the Earth about the Sun. The two others radiation sources are the fraction of the incident sunlight reflected off the planet, termed albedo, and the Earth infrared radiation.

Solar and geomagnetic activities are often described by indices. The UV radiation of the Sun, which strongly affects the Earth atmosphere, cannot be directly measured from the ground. But it was found to be strongly correlated with e.g. the sunspot number and the cm wavelength Sun radiation. For example, the widely used 10,7 cm radio flux index ($F_{10.7}$) gives an indication of the solar UV radiation output which is highly variable over a solar cycle.

Geomagnetic indices typically describe the variation of the geomagnetic field over a certain time period. They provide a measure of the disturbance of the magnetosphere which has direct consequences for the charged particle space environment, or the external component of the geomagnetic field.

Solar and geomagnetic indices are used as input for upper atmosphere and other models of the near Earth space environment. They are provided for short durations or as long time averages. Predictions for future index values are usually provided at different confidence levels and they are available for complete solar cycles. The given data are mainly average values. For detailed thermal analyses or certain special applications, more detailed data and models are required. These are outside the scope of this Standard.

6.1.2 Electromagnetic radiation and indices

6.1.2.1 Solar constant

The solar constant is defined as the radiation that falls on a unit area of surface normal to the line from the Sun, per unit time, outside the atmosphere, at one

astronomical unit (1 AU = average Earth-Sun distance). The currently measured 1-sigma standard deviation in the composite dataset is approximately $0,6 \text{ Wm}^{-2}$ and there is a long-term (yearly) smoothed solar cycle minimum to maximum relative variation about the mean value of approximately $1,4 \text{ Wm}^{-2}$ [RD.2] (largest during the period of maximum solar activity).

6.1.2.2 Solar spectrum

6.1.2.2.1 Soft X-rays or XUV (0,1 nm to 10 nm)

Usually associated with solar coronal phenomena, flares, million-degree temperatures, and atomic dissociation. The corona extends from about 21 000 km to 1 400 000 km above the photosphere. X-ray flares are responsible for enhancements in the D and E regions of the Earth's ionosphere.

6.1.2.2.2 Extreme ultraviolet or EUV (10 nm to 121 nm)

EUV has emission lines that come from the upper chromosphere (near-coronal temperatures), transition region, and lower corona. This spectral band is responsible for ionization and heating in the E and F regions of the ionosphere.

6.1.2.2.3 Ultraviolet or UV (100 nm to 400 nm)

UV solar flux is emitted primarily from the base of the sun's chromosphere layer, and has components due to active and quiet solar conditions. This band is responsible for only 1% of the total solar irradiance, but it is important because below 300 nm, it is completely absorbed by ozone and diatomic oxygen atoms in the earth's upper atmosphere.

6.1.2.2.4 Visible, optical or VIS (380 nm to 760 nm)

Visible light comes from the solar photosphere, which is only about 400 km thick, has a temperature of approximately 5 000 to 6 000 degrees Kelvin, and yet is responsible for the greatest percentage of the total solar radiation.

6.1.2.2.5 Infrared or IR (0,70 μm to 1 mm)

Solar infrared in this range is responsible for the direct heating of the Earth's lower atmosphere, through absorption by H_2O , and has an effect on minor species constituents in the Earth's mesosphere and thermosphere.

NOTE The ISO 21348 Standard on determining solar irradiances provides more details on the solar spectrum [RD.3].

6.1.2.3 Indices

6.1.2.3.1 General

Solar and geomagnetic indices are used to describe the activity levels of the Sun and the disturbance of the geomagnetic field. Most activity indices are given for short periods and as long duration averages. They are also used for long range predictions of solar activities. Many space environment models require activity index values as input parameters.

6.1.2.3.2 Solar activity indices

- **Sunspot number (R)**

The sunspot number (R , alternatively called R_i or R_z) is a daily index of sunspot activity, defined as

$$R = k(10g + s) \quad (6-1)$$

where

s is the number of individual spots,

g the number of sunspot groups, and

k is an observatory factor.

NOTE R_{12} (R_{z12}) is the 12-month running mean of the sunspot number R .

- **F10.7**

F10.7 (abbreviated F10) is the traditional solar energy proxy that is used both for NRLMSISE-00 [RN.4] and JB-2006 [RN.5] atmosphere models. It corresponds to the solar radio flux emitted by the sun at 2 800 megaHertz (10,7 cm wavelength).

NOTE The physical units of $F_{10.7}$ are $10^{-22} \text{ W m}^{-2} \text{ Hz}^{-1}$; the numerical value is used without the multiplier as is customarily done and expressed as solar flux units (sfu). In other words, a 10,7 cm radio emission of $150 \times 10^{-22} \text{ W m}^{-2} \text{ Hz}^{-1}$ is simply referred to as $F_{10.7} = 150 \text{ sfu}$.

$F_{10.7}$ and the sunspot number, R , are correlated. Averaged (over one month or longer) values can be converted by the following expression:

$$F_{10.7} = 63,7 + 0,728R + 8,9 \times 10^{-4} R^2 \quad (6-2)$$

- **S10.7**

S10.7 (abbreviated S10) [RD.122] is a solar energy proxy that is used for the JB-2006 atmosphere model [RN.5] It is measured by SOHO with the Solar Extreme-ultraviolet Monitor (SEM) in the 26–34 nm solar EUV range, and normalized using a mean value of $1,9955 \times 10^{10} \text{ photons cm}^{-2} \text{ s}^{-1}$. It is expressed in sfu, as $F_{10.7}$.

- **M10.7**

M10.7 (abbreviated M10) [RD.122] is a solar energy proxy that is used for JB-2006 atmosphere model. It is measured by NOAA 16 and NOAA 17 operational satellites with the Solar Backscatter Ultraviolet (SBUV) spectrometer. It is a measure of chromospheric and some photospheric solar active region activity and is expressed in sfu, as $F_{10.7}$ and $S_{10.7}$.

- **IG12**

IG12 [RD.147] is a solar activity index derived from the monthly mean noon f0F2 data available from thirteen ionospheric observations. The IG index has been confirmed as an alternative to sunspot number when

predictions of f0F2 are being prepared with the aid of the CCIR atlas of ionospheric characteristics. IG12 is used for the IRI-2007 ionospheric model.

- **Solar wind speed**

The solar wind speed is used in external magnetic field model computation. It is the outward flux of solar particles and magnetic fields from the sun. Typically, solar wind velocities are near 350 km s⁻¹.

6.1.2.3.3 Geomagnetic activity indices

Geomagnetic activity indices are used to describe fluctuations of the geomagnetic field.

- **K_p and a_p**

Most widely used planetary indices are K_p and a_p. They are based on 3-hour measurements from 13 ground stations. Values of a_p range from 0 to 400 and are expressed in units of 2 nT. K_p is essentially the logarithm of a_p, its scale is 0 to 9 expressed in thirds of a unit, e.g. 5- is 4 2/3, 5o is 5 and 5+ is 5 1/3. The conversion from K_p to a_p is given in Table 6-1 (taken from [RD.100]). A daily index, A_p, is obtained by averaging the eight values of a_p for each day. The index A_p can have values intermediate to those of a_p.

- **Dst**

Dst (Disturbance Storm Time) is a geomagnetic index used in external magnetic field model computation. It describes variations in the equatorial ring current and is derived from hourly scalings of low-latitude horizontal magnetic variation. It is expressed in nT.

- **IMF**

IMF (Interplanetary Magnetic Field) is a geomagnetic index used in external magnetic field model computation. It corresponds to the part of the Sun's magnetic field that is carried into interplanetary space by the solar wind. The three orthogonal components of the IMF are B_x, B_y and B_z. B_x and B_y are oriented parallel to the ecliptic.

The IMF is a weak field, varying in strength near the Earth from 1 to 37 nT, with an average value of about 6 nT.

6.2 Requirements

6.2.1 Electromagnetic radiation

- The values in Table 6-2 shall be used for the electromagnetic radiation.
- The solar spectrum shall be approximated by a black body curve with a characteristic temperature of 5 762 K.
- A space sink temperature of 3 K shall be used.

6.2.2 Reference index values

- a. For daily and 81 day averaged values of F10.7, S10.7 and M10.7 the values given in Table A-1 shall be used.

NOTE 1 A_p is only weakly correlated with the solar activity indices. It has a seasonal variation and is higher at the equinoxes.

NOTE 2 81 days corresponds to 3 solar rotations and 81 day averaged values are used as input for atmosphere models.

- b. For fixed index values, the numbers given in Table 6-3 for low, moderate and high solar and geomagnetic activities shall be used:
1. The long-term values are averaged values for periods longer than 27 days.
 2. The long-term values apply as well for periods of 1 week or longer.
 3. The short-term values are daily values.
- c. The temporal evolution in a_p shown in Table 6-4 shall be used to describe the worst case fluctuations during successive three-hour intervals for a total duration of 24 hours.
- d. The a_p values of Table 6-4 shall be used together with the relevant (low, moderate or high) long term averaged values of F10.7, S10.7 and M10.7 given in Table 6-3.

6.2.3 Tailoring guidelines

- a. For design purposes the “worst-case” activity values given in Table 6-3 shall be used.

NOTE These can be the high or low values, depending on the effect to be studied.

- b. All worst-case values shall be used without any additional margin.
- c. The values given in Table A-1 for a full solar cycle shall be used:
1. for applications that require a realistic sequence of index values for future predictions, for example orbital calculations using index-driven atmospheric models;
 2. for a given specific phase of the solar activity cycle.
- d. The solar cycle activity in Table A-1 of the normative annex shall be extended by repetition of the 11-year cycle.

NOTE August 2008 can be assumed as start of cycle 24 unless another estimate with a higher confidence level is released from the Solar Cycle 24 Prediction Panel (at NOAA Space Environment Center (SEC) [RD.4]).

6.3 Tables

Table 6-1: Conversion from K_p to a_p

K_p	0	0+	1-	1o	1+	2-	2o	2+	3	3o	3+	4-	4o	4+
a_p	0	2	3	4	5	6	7	9	12	15	18	22	27	32
K_p	5-	5o	5+	6-	6o	6+	7-	7o	7+	8-	8o	8+	9-	9o
a_p	39	48	56	67	80	94	111	132	154	179	207	236	300	400

Table 6-2: Electromagnetic radiation values

Solar constant at 1 AU	1 366,1 W m ⁻²
Solar energy flux at aphelion	1 321,6 W m ⁻²
Solar energy flux at perihelion	1 412,9 W m ⁻²
NOTE The solar constant, a historical term, is not constant. It varies geometrically with the Earth's distance from the sun and physically with the sun's magnetic field activity on short to long timescales, as well as with the observer's heliocentric latitude. The value of 1 366,1 W m ⁻² is the measurement community's current agreement. The currently measured 1-sigma variation of the composite dataset of space based measurements is approximately 0,6 W m ⁻² and there is a long-term (yearly) smoothed solar cycle minimum to maximum relative variation about the mean value of approximately 1,4 W m ⁻² [RD.2].	

NOTE

Table 6-3: Reference fixed index values

	Long-term (27+ days)			Short-term (daily)		
	Low	Moderate	High	Low	Moderate	High
F10.7	65	140	250	65	140	300
S10.7	60	125	220	60	125	235
M10.7	60	125	220	60	125	240
A_p	0	15	45	0	15	240
NOTE 1 The reference index values are rounded numbers from the last solar cycle 23. NOTE 2 Low, moderate or high values for A _p can occur at any time in the solar cycle. NOTE 3 For short terms, higher values than those given in this table have been measured (e.g. F10.7 = 380 over a day and a _p = 400 for 3 hours). However, present atmosphere models are not developed for such high index values and its use leads to large and unknown errors.						

Table 6-4: Reference index values for variations of a_p

Time [hrs]	a_p
0	15
3	15
6	300
9	130
12	50
15	15
18	15
21	15
24	15

Neutral atmospheres

7.1 Introduction and description

7.1.1 Introduction

A good knowledge of temperature, total density, concentrations of gas constituents and pressure is important for many space missions exploiting the low-earth orbit regime (LEO), below approx. 1 000 km altitude. Aerodynamic forces on the spacecraft, due to the orbital motion of a satellite through a rarefied gas which itself can have variable high velocity winds, are important for the combination of planning satellite lifetime, for the maintenance of orbits, for sizing the necessary propulsion system, for the design of attitude control system, and for estimating the peak accelerations and torques imposed on sensitive payloads.

Surface corrosion effects due to the impact of large fluxes of atomic oxygen are assessed to predict the degradation of a wide range of sensitive coatings of spacecraft and instruments. The reactions of atomic oxygen around a spacecraft can also lead to intense “vehicle glow”.

7.1.2 Structure of the Earth's atmosphere

The Earth atmosphere can be broadly divided into three distinct regimes:

- The homosphere which comprises the regions of the troposphere (surface up to ~ 10 - 12 km altitude), the stratosphere (~ 10 - 12 km up to 50 km), and the mesosphere (~50 km up to about 90 km);
- The thermosphere which extends from about 90 km altitude to approx. 400 km (depending on solar and geomagnetic activity levels);
- The exosphere which extends from the top of the thermosphere and extends into space.

More information on these three regions can be found in Annex G.

7.1.3 Models of the Earth's atmosphere

7.1.3.1 NRLMSISE-00 model

The NRL Mass Spectrometer, Incoherent Scatter Radar Extended Model (NRLMSISE-00) model [RN.4] describes the neutral temperature and species densities in Earth's atmosphere.

It is based on a very large underlying set of supporting data from satellites, rockets and radars, with extensive temporal and spatial distribution. It has been extensively tested by the global scientific community against experimental data. The model has a flexible mathematical formulation.

It is valid for use from ground level to the exosphere.

Two indices are used in this model:

- $F10.7$ (both the daily value of the previous day and the 81-day average centred on the input day),
- A_p (daily value).

7.1.3.2 JB-2006 model

The Jacchia-Bowman 2006 (JB-2006) model [RN.5] also describes the neutral temperature and the total density in Earth's thermosphere and exosphere. Its new features, described in Annex G, lead to a better and more accurate model representation of the mean total density, compared with previous models, including the NRLMSISE-00.

It is valid for use from an altitude of 120 km to the exosphere.

Four indices are used in this model:

- $F10.7$ (both tabular value one day earlier and the 81-day average centred on the input time),
- $S10.7$ (both tabular value one day earlier and the 81-day average centred on the input time),
- $M10.7$ (both tabular value five days earlier and the 81-day average centred on the input time),
- A_p (tabular value 6,7 hours earlier).

7.1.4 Wind model of the Earth's homosphere and heterosphere

The Horizontal Wind Model (HWM) is a comprehensive empirical global model of horizontal winds in the mesosphere and thermosphere (middle and upper atmosphere). The HWM-93 model [RN.6] is based on accumulated measurements made using a variety of observational techniques, including satellite, radar, and ground-based optical remote sensing. The model is used to provide the necessary winds, accounting for time, space and geophysical variations, for many ionospheric, dynamical, and aeronautical calculations. It provides meridional (+ northward) and zonal (+ eastward) speed and covers all altitude regions.

Two indices are used in this model:

- $F10.7$ (both the daily value of the previous day and the 81-day average centred on the input day),
- A_p (daily value).

7.2 Requirements for atmosphere and wind model selection

7.2.1 Earth atmosphere

7.2.1.1 General

- a. The NRLMSISE-00 model [RN.4] shall be used for calculating both the neutral temperature, and the detailed composition of the atmosphere.
- b. The JB-2006 model [RN.5] shall be used for calculating the total atmospheric density above an altitude of 120 km.
- c. For altitudes below 120 km, NRLMSISE-00 shall be used for calculating the total air density.

NOTE This recommendation follows the advice of the CIRA Working Group, sponsored by COSPAR and URSI.

7.2.1.2 Application guidelines

- a. The NRLMSISE-00 model for species densities shall not be mixed with the JB-2006 model for total density.
- b. For worst case high results and analysis periods not exceeding 1 week high daily short-term values given in Table 6-3 shall be used as input for daily activity together with the high long-term values for the 81-day average activity.
- c. For analysis periods longer than 1 week the long term activities given in Table 6-3 shall be used as input for both, the daily and the 81-day averaged values.
- d. For analysis periods longer than 1 week and conditions specified in 6.2.3c, the daily and 81-day averaged solar activities given in Table A-1 shall be used.
- e. Short-term daily high solar activity values shall not be used together with low or moderate long-term solar activity values.

NOTE 1 Both models can only predict large scale and slow variations, on the order of 1 000 km (given by the highest harmonic component) and 3 hours. Spacecraft can encounter density variations with smaller temporal and spatial scales partly since they are in motion (for example, +100% or -50% in 30 s), and partly because smaller-scale disturbances certainly occur during periods of disturbed geomagnetic activity.

NOTE 2 Reference values for the key indices needed as inputs for the atmosphere models are given in Clause 6.

NOTE 3 The F10.7 81-day average activity can also be estimated by averaging three successive monthly predicted values.

NOTE 4 Information on density model uncertainties can be found in G.5 and in [RN.4] and [RN.5].

NOTE 5 For high activities the atmosphere models only give realistic results if high short term values are combined with high 81-day averaged values.

NOTE 6 High Ap values can be used with low, moderate or high solar activities.

7.2.2 Earth wind model

- a. The HWM-93 model [RN.6] shall be used.
- b. High daily short-term values shall be used as worst-case for the daily activity but the 81-day average activity shall not exceed the high long-term value.

NOTE 1 Reference values for the key Indices needed as inputs for the wind model are given in Clause 6.

NOTE 2 The F10.7 81-day average activity can also be estimated by averaging three successive monthly predicted values as given in Clause 6.

NOTE 3 The use of the HWM-93 model at high geomagnetic latitudes and for disturbed geomagnetic periods necessitates caution.

7.2.3 Models of the atmospheres of the planets and their satellites

- a. For the Martian Atmosphere, the European Martian Climate Data Base [RN.7] shall be used.

NOTE 1 No specific models are imposed for the other planets and their satellites.

NOTE 2 International Reference Atmospheres have been adopted for Mars (MIRA) and Venus (VIRA). There have also been major advances in the case of the atmospheres of Jupiter, Saturn, Neptune and Titan. This is a matter of ongoing work. Considerable work has also been performed for the atmosphere of Mercury.

NOTE 3 Additional information on Planetary Atmospheres is provided in Annex G.