TECHNICAL REPORT

ISO/TR 11225

First edition
2012-10-15

Space environment (natural and artificial) — Guide to reference and standard atmosphere models

Environnement spatial (naturel et artificiel) — Guide pour les modèles d'atmosphère standard et de référence

Reference number
ISO/TR 11225:2012(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO/TR 11225 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Since the mid 19th century there has been considerable effort devoted to the development of standards and reference atmosphere models. The first “Standard Atmospheres” were established by international agreement in the 1920s. Later some countries, notably the United States, also developed and published Standard Atmospheres. The term *reference atmospheres* is generally used to identify atmosphere models for specific geographical locations or globally.

The proliferation of atmospheric models and the lack of documentation have hindered general knowledge of their availability as well as information on their relative strengths, weaknesses, and limitations. The intent of this guide is to compile in one reference practical information about some of the known historical and available atmospheric models-those which describe the physical properties and chemical composition of the atmosphere as a function of altitude. The inclusion in this Guide of information on the various reference and standard atmosphere models is not meant to imply endorsement by ISO of the respective model. Also, inputs provided on the models were based on the information available at the time the entry was originally prepared.

The included Earth and other planetary models are those intended for general purpose or aerospace applications. The information provided, while deemed current at time of inclusion in the summary write-ups, may or may not still be current at the time of this version of the Guide is published. Therefore, the reader should further research the information before making decisions on usage of the model(s) of interest. The models extend to heights ranging from as low as the surface to as high as 4000 km. Models describing exclusively low altitude phenomena are not included. Possible examples of the latter are particulate aerosols or pollutants in the boundary layer and cloud properties as a function of altitude in the troposphere. Dynamical models such as the Earth Troposphere-Stratosphere General Circulation Models (GCM), the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM), and research reports on measurements made by satellite, aircraft, and ground systems of the atmosphere are also not included in this Technical Report.

Space environment (natural and artificial) — Guide to reference and standard atmosphere models

1 Scope

This Technical Report provides guidelines for selected reference and standard atmospheric models for use in engineering design or scientific research. It describes the content of the models, uncertainties and limitations, technical basis, databases from which the models are formed, publication references, and sources of computer code where available for over seventy (70) Earth and planetary atmospheric models, for altitudes from surface to 4000 kilometers, which are generally recognized in the aerospace sciences. This standard is intended to assist aircraft and space vehicle designers and developers, geophysicists, meteorologists, and climatologists in understanding available models, comparing sources of data, and interpreting engineering and scientific results based on different atmospheric models.

This Technical Report summarizes the principal features of the models to the extent the information is available:

- Model content
- Model uncertainties and limitations
- Basis of the model
- Publication references
- Dates of development, authors and sponsors
- Model codes and sources

The models are listed in the table of contents according to whether they are primarily global, middle atmosphere, thermosphere, range, or regional (i.e., applying only to a specific geographic location). This division is admittedly somewhat arbitrary because many of the models embody elements of several of the categories listed.

With few exceptions, there is no information on standard deviations from the mean values or frequencies of occurrence of the variables described by these models. This lack of information prohibits quantitative assessments of uncertainties, and is a serious deficiency in nearly all reference and standard atmospheric models.

Recommendations for models to include in subsequent revisions will be welcomed.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5878:1982, *Reference atmospheres for aerospace use*

ISO 5878:1982/Add 1:1983, *Reference atmospheres for aerospace use — Addendum 1: Wind supplement*

ISO 5878:1982/Add 2:1983, *Reference atmospheres for aerospace use — Addendum 2: Air humidity in the Northern Hemisphere*

ISO 5878:1982/Amd 1:1990, *Reference atmospheres for aerospace use — Amendment 1*

3 Terms and definitions

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

3.1
reference atmospheres
vertical temperature profiles for each latitude and season; atmosphere models for specific geographical locations or globally

3.2
mean sea level
reference point for both geopotential and geometric altitudes

3.3
geopotential altitude
point in atmosphere expressed in terms of its potential energy per unit mass (geopotential) at this altitude relative to sea level

4 COSPAR International Reference Atmosphere (CIRA), 1986

4.1 Model content

The COSPAR International Reference Atmosphere (CIRA) provides empirical models of atmospheric temperature and density from 0 km to 2000 km as recommended by the Committee on Space Research (COSPAR). Since the early sixties, different editions of CIRA have been published: CIRA 1961, CIRA 1965, CIRA 1972, and CIRA 1986.

The Committee on Space Research's *CIRA 1986 Model Atmosphere* consists of three parts: Part I: Models of the Thermosphere, Part II: Models of the Middle Atmosphere, and Part III: Models of Trace constituents. Part II is similar in many respects to the *NASA/GSFC Monthly Mean Climatology of Temperature, Wind, Geopotential Height and Pressure for 0-120 km*. This model is described later in this volume. Part III (published in 1996) gives model information on ozone, water vapor, methane and nitrous oxide, nitric acid, nitrogen dioxide, carbon dioxide and halogenated hydrocarbons, nitric oxide, stratospheric aerosols, atomic oxygen, and atomic hydrogen.

Chapter 1 of Part I (ref 5.1) describes the empirical thermospheric model which is based on the *Mass Spectrometer-Incoherent Scatter (MSIS) 1986* model of Hedin (ref 5.6, 5.8). Like Hedin's model, the altitude range is 90-2000 km, however, the models presented in Part I should be used exclusively for applications above 120 km; Part II should be exclusively used below 90 km while the "merging models" contained in Part II should be used for applications between 90 and 120 km. The atmospheric parameters yielded by the model are temperature, density, and composition, but not neutral winds. A large number of representative tables, coefficients, and the FORTRAN program are listed in the appendices of this referenced volume. With the aid of the program and the coefficients, representative thermospheric parameters can be generated for all locations, Universal Time and seasons, and for a very wide range of solar and geomagnetic activity.

Chapter 2 presents theoretical thermospheric models attributed to Rees and Fuller-Rowell (ref 5.7). These models reveal the detailed interrelationships between thermospheric structure (i.e., temperature and density), chemistry, and dynamics for simplified models of solar and geomagnetic forcing. A set of initial case studies using a coupled polar ionosphere/global thermosphere model is also presented, which demonstrates the major interactions between the thermosphere and ionosphere.

Part I also contains five specialized chapters which review the major empirical contributions to our current understanding of the thermosphere. These sections discuss in situ mass spectrometer measurements of composition, temperature and winds; incoherent scatter radar measurements, satellite and ground-based measurements of thermospheric temperatures and winds, the thermospheric storm-like response to high levels of geomagnetic activities; and our understanding of the variance of solar EUV radiation.

Subsequent to publication of the CIRA 1986 model, several related developments have occurred. They include: (1) the characterization of the mean behavior of the Earth's atmosphere from 0 to 120 km altitude on the basis of the CIRA 1986 model (ref 5.4) as an annual zonal mean for 30 deg N to derive single profiles for the pressure, height, temperature, and zonal wind, and (2) a new zonal mean CIRA-1986 of temperature, zonal wind, and geopotential / geometric height as a function of altitude or pressure extending from the ground to approximately 120 km in the 80 deg S – 80 deg N latitudes (ref. 5.5).

The COSPAR committee responsible for updating the CIRA, 1986 Model met in July 2008 to address the updating of the CIRA, 1986 Model. The CIRA 2008 Model was adopted by COSPAR.

4.2 Model uncertainties and limitations

4.2.1 The quality of the database describing some observables is variable. The experimental global scale database for the lower thermosphere is still extremely limited.

4.2.2 The models are not reliable for large atmospheric disturbances. However, the causes of atmospheric variability are discussed in great detail.

Standard deviations from mean values of atmospheric parameters are not provided.

4.3 Basis of the model

As stated previously, the empirical thermosphere model is based on the MSIS-86 model of Hedin (ref. 5.7). The empirical model is complemented by theoretical models of Rees and Fuller-Rowell that show the relationships between thermospheric structure, chemistry and dynamics for simplified models of solar and geomagnetic forcing.

4.4 Databases

The principal publications which present the thermosphere database are listed in the MSIS-86 model description (ref. 5.6). Hedin (1988) also wrote a specially-commissioned section within 5.1 relating to the suitability and use of MSIS as the selected semi-empirical model for CIRA 1986-Part I.

4.5 Publication references

4.5.1 Rees, D., Editor, (1988): "COSPAR International Reference Atmosphere 1986 Part I. Thermospheric Models, "Advances in Space Research, Vol. 8, No. 5/6, Pergamon Press, Oxford and NY.

4.5.2 Rees, D., J. J. Bernett, and K. Labitzke, editors (1990): "CIRA 1986, COSPAR International Reference Atmosphere, Part II: Middle Atmosphere Models," *Advances in Space Research*, Vol. 10, No. 12, Pergamon Press, Oxford and NY.

4.5.3 Keating, G. M., editor (1996): COSPAR International Reference Atmosphere (CIRA), Part III: Trace Constituent Reference Models," *Advances in Space Research*, Vol. 18, No. 9/10, Pergamon Press, Oxford and NY.

4.5.4 Barnett, J. J. and S. Chandra (1990): "COSPAR International Reference Atmosphere Grand Mean," *Advances in Space Research,* Vol. 10, No. 12, Pergamon Press, Oxford and NY.

4.5.5 Fleming, Eric L., Sushil Chandra, J. J. Barnett, and M. Corney (1990): "Zonal Mean Temperature, Pressure, Zonal Wind, and Geopotential Height as Functions of Latitude," *Advances in Space Research,* Vol 10, No. 12, Pergamon Press, Oxford and NY.

4.5.6 Hedin, A. E. (1987): "MSIS-86 Thermospheric Model." J. Geophys. Res., Vol 92, Pages 4649-4662.

4.5.7 Rees, D., and T. J. Fuller-Rowell (1988): The CIRA Theoretical Thermosphere Model, " pages (5) 25-(5) 106, Advances in Space Research, Vol. 8, No. 5/6, Pergamon Press, Oxford and NY.

4.5.8 Hedin, A. E. (1087): The Atmospheric Model in the Region 90 to 2000 km," Pages (5) 9-(5) 25, Advances in Space Research, Vol. 8, No. 5/6, Pergamon Press, Oxford and NY.

4.5.9 Hedin, A. E., J. E. Salah, J. V. Evans, C. A. Reber, G. P. Newton, N. W. Spencer, D. C. Kayser, D. Alcayde, Pl Bauer, L. Cogger, and J. Pl McClure, (1977) "A Global Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data", MSIS 1, N2 Density and Temperature, J. Geophys. Res. 82, 2139-2147, 1977.

4.5.10 Hedin, A. E., G. A. Reber, G. P. Newton, N. W. Spencer, H. C. Brinton, H. G. Mayr, and W. E. Potter (1977): A Global Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data", MSIS 2, Composition, J. Geophys. Res., 82, 2148-2156, 1977.

4.6 Dates of development, authors, and sponsors

4.6.1 Dates:

Original model	1961
Revised model	1965
Revised model	1972
Revised model	1986
Trace constituent model	1996
Zonal mean model	1990

4.6.2 Many scientists made contributions to the three parts of the CIRA models. They are identified in references 5.1, 5.2, and 5.3.

4.6.3 Co-Sponsors: Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) and the International Union of Radio Science (URSI).

4.7 Model codes and sources

The thermosphere model is published in the form of tables and figures with a FORTRAN computer code included in an Appendix, describing the semi-empirical models of Part I, Chapter 1 (Ref 4.5.1). This program, and the program from which the results of the theoretical and numerical model results can be generated (Part I, Chapter 2) are available in computer-compatible form (tape or disk). They may also be obtained from certain electronic databases. See Reference 4.5.1 for thermosphere model, Reference 4.5.2 for middle atmosphere model, Reference 4.5.3 for trace constituent model, Reference 4.5.1 for grand mean model, and Reference 4.5.5 for new zonal mean CIRA, 1986 model.

NOTE At the time of preparation of this document, plans were being made by the COSPAR to produce an updated and revised version (CIRA08) of the COSPAR International Reference Atmosphere (CIRA), 1986. It is anticipated that the CIRA08 will be published in 2009 as a Special Issue of Advances in Space Research. Therefore, when planning to use CIRA, 1986 the availability of the new CIRA, 2008 should first be ascertained.

5 COSPAR International Reference Atmosphere (CIRA), 2008

5.1 CIRA-08

The COSPAR International Reference Atmosphere (CIRA) provides empirical models of atmospheric temperature and density from 0 km to 4000 km as recommended and adopted by the Committee on Space Research (COSPAR) and by the International Union of Radio Science (URSI). Since the early sixties, several distinct editions of CIRA have been published: CIRA 1961, CIRA 1965, CIRA 1972 CIRA 1986 and most recently, CIRA-08 (or CIRA-2008), which is currently in preparation by the CIRA Working Group.

5.2 Model content

The Committee on Space Research's *CIRA 2008 Model Atmosphere* will contain the following major contributions, in terms of recommended atmospheric models for use:

For Total Mass Density above 120 km:

- Jacchia-Bowman 2008 and GRAM-07

For the Structure and Composition of the Atmosphere (ground-level upward):

- NRLMSISE-00

For Neutral Winds in the Atmosphere (all levels):

- Horizontal Wind Model-07 (HWM-07)

For Neutral Wind up to 120 km altitude:

- Global Wind Empirical Model (GWEM)

There will also be chapters discussing the current state of knowledge and application of the Solar and Geomagnetic Indices that are used to drive the new empirical models such as JB-2008; Metal Chemistry of the Mesosphere and Lower Thermosphere, and expert advice regarding the limitations of the models and the best use of the models for specific applications.

5.3 Model availability

CIRA-08 is currently in preparation, and is expected to be published in early 2009 as a Special Edition of Advances in Space Research. The recommended Models within CIRA-08 are expected to be Web based, along with guides to the best use of the Models.

5.4 Sponsors

Co-Sponsors: Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) and the International Union of Radio Science (URSI).

6 ISO reference atmospheres for aerospace use (ISO 5878:1982)

6.1 Model content

The International Organization for Standardization (ISO) *Reference Atmospheres for Aerospace Use, 1982* consists of three documents containing tables and some figures. They present information on the seasonal, latitudinal, longitudinal, and day-to-day variability of atmospheric properties at levels between the surface and 80 km.

ISO 5878:1982 contains values of temperature, pressure and density as a function of geometric and geopotential altitude up to 80 km. Specific models include: (1) an annual model for 15 deg N latitude; (2) seasonal models for 30 deg, 45 deg, 60 deg and 80 deg N latitude; (3) cold and warm stratospheric and mesospheric regimes for 60 deg and 80 deg N latitude in December and January; and (4) seasonal and latitudinal variations of temperatures and density for medium, high and low percentile values.

Addendum 2:1983 to ISO 5878:1982 contains parameters (means and standard deviations) of Northern Hemisphere observed wind distributions in January and July up to 25 km for (1) four latitude zones plus calculated values of the scalar mean wind speed and of high and low percentile values of wind speed; (2) four stations (Dakar, Kagoshima, New York and Jan Mayen) with strong winds; (3) (Ajan, Clyde, Guam, and Muharrag) with light winds; and (4) four meridians plus high and low values of wind speeds.

The Addendum contains values (mixing ratio, vapor pressure and dew point temperatures) of the Northern Hemisphere air humidity in January and July to 10 km for (1) median values at 10 deg, 30 deg, 50 deg, and 70 deg N latitude; (2) median values along 0 deg, 80 deg E and 180 deg, 80 deg W meridians; (3) percentiles (20 percent, 10 percent, 5 percent and 1 percent) in extremely dry and moist areas and seasons, and (4) mean values for four stations representative of dry and moist regions (Tammaurrasset, North Africa; Xhigawsk, East Siberia; Calcutta, India, and Turk, Pacific Islands).

6.2 Model uncertainties and limitations

6.2.1 The temperature, pressure and density models are subject to the uncertainties associated with errors (about 1 deg C) in the standard radiosonde instruments used by the various countries to measure temperature profiles to altitudes near 30 km. Meteorological Rocketsonde temperature errors are about 2 deg C in the 30 to 50 km altitude range and increase to about 8 deg C at 80 km. For the meteorological rocket measurements, the thermistor measurements of temperature are subject to large corrections and uncertainties with increasing altitude. Therefore, the measurements above 50 km were not used. Measurements above 30 km, and especially above 50 km, were very limited. The warm and cold models for 60 deg and 80 deg N latitude are based on so few measurements that they are, at best, only rough estimates. Confidence in their distribution decreases rapidly above 50 km where data are relatively sparse and instrumentation errors relatively large.

6.2.2 The rawinsonde observations of wind velocity have uncertainties of about 5 percent of the vector wind for 0.6 km mean layers. For tracking angles within 6 deg of the horizontal, which occurs under strong jet stream conditions, the wind velocities are unreliable. According to the authors, their analysis of the scalar mean speed derived from observations, and calculated from the circular normal distribution may be used to calculate the values of wind speed with an accuracy sufficient for most practical purposes.

6.2.3 Reasonably reliable radiosonde measurements of humidity are available up to 10 km above sea level. Relative error varies with temperature from about 5 percent at +40 deg C to 15 percent at -40 deg C and are unreliable below -40 deg C. The tabulated humidity values above 8 km should be regarded as approximate because the quantity of data is insufficient.

6.2.4 Other model limitations due to the analytical and statistical fractions used as well as sample sizes are discussed in the text of the documents. The reference atmospheres are considered applicable to the Northern hemisphere only.

6.3 Basis of the model

The numerical values of the various thermodynamic and physical parameters used in the comparisons of atmospheric properties are the same as those used in the ISO 2533:1975, *Standard Atmosphere*, with the exception of surface conditions and the acceleration of gravity. Mean sea level is taken as the reference for both geopotential and geometric altitudes. The reference atmospheres are defined by the vertical temperature profiles for each latitude and season. The vertical gradients of temperature are constant with respect to geopotential altitude within each of a number of layers. Air is assumed to be a perfect gas, free from moisture or dust. The reference atmosphere upper stratosphere and mesosphere temperature observations for the southern hemisphere were phase adjusted by six months to conform to Northern hemisphere seasons.

The wind parameters are based on observations and use of the circular normal distribution functions, which the authors consider acceptable for most practical purposes.

The humidity parameters are based on relative humidity and temperature measurements from radiosonde observations. The humidity-mixing ratio is used as the main humidity characteristic.

6.4 Databases

The vertical pressure and density distributions were calculated from the temperature-altitude profiles using the hydrostatic equation, the perfect gas law and appropriate mean sea-level values of pressure. The temperature distributions for levels below 30 km were derived from routine radiosonde observations from the 1955-1966 time period as contained in Monthly Climatic Data of the World by the World Meteorological Organization. The temperature field between 30 and 50 km is based on meteorological rocket measurements (bead thermistor or resistance wires) made at 17 locations primarily during the 1964-1970 time period. The temperature distributions between 50 and 80 km are based primarily on grenade, falling sphere, and pressure gauge experiments made at 12 locations during the 1957-1971 time period.

The values of the quantities describing the wind fields were obtained for the altitude range 0 to 25 km from actual observations made by balloon borne instruments and by estimation using the circular normal distribution. The measurements were primarily in the 1950 to 1970 time period.

The values of humidity were derived from radiosonde measurements for the altitude range 0 to 25 km. These measurements were also made primarily during the 1950 to 1970 time period.

6.5 Publication references

6.5.1 ISO 5878:1982, *Reference Atmospheres for Aerospace Use,* Technical Committee ISO/TC 20, Aircraft and Space Vehicles.

6.5.2 ISO 5878:1982 / Addendum 1:1983, *Reference Atmospheres, Addendum 1: Wind Supplement,* Technical Committee ISO TC 20, Aircraft and Space Vehicles.

6.5.3 ISO 5878:1982 / Addendum 2:1983, *Reference Atmospheres for Aerospace Use, Addendum 2: Air Humidity in the Northern Hemisphere,* Technical Committee ISO/TC 20, Aircraft and Space Vehicles.

6.5.4 ISO 5878:1982/ Amendment 1:1990, Reference Atmospheres for Aerospace Use, Amendment 1, Technical Committee ISO/TC, Aircraft and Space Vehicles.

6.6 Dates of development, authors and sponsors

6.6.1 Dates: ISO 5878-1982 circulated in November 1978, published in 1982

ISO 5878-1982/Addendum 1-1983 circulated in March 1979, published in 1983

ISO 5878/1982/Addendum 2-1983 circulated in April 1982, published in 1983

6.6.2 Authors: Members of Subcommittee 6 (Standard Atmospheres) of the International Organization for Standardization, Technical Committee 20 (Aircraft and Space Vehicles).

6.6.3 Sponsors: International Organization for Standardization, Geneva, Switzerland, under the direction of Technical Committee 20 - Secretariat, Aerospace Industries Association of America, Inc., 1250 Eye Street, N.W., Washington, DC 20005.

6.7 Model codes and sources

The models are published in the form of tables and figures only. They are available from: American National Standards Institute, 25 West 43 Street, New York, NY 10036. http://www.ansi.org

NOTE At the time this document was prepared, the SC 6 "Standard Atmosphere" of Technical Committee ISO/TC20, *Aircraft and Space Vehicles* was in the process of updating and revising ISO 5878, *ISO Reference Atmospheres for Aerospace Use*. This new version of ISO 5878 was published in draft form for review April 12, 2004 as ISO/WD 213-3 “Global Reference Atmosphere for Altitude 0-120 km for Aerospace Use” based on the work by ISO/TC 20/SC 6 “Standard Atmosphere” during the period 1998–2003. It is the intent that it be published as an ISO International Standard "Global Reference Atmosphere for Altitude 0-120 km for Aerospace Use".

This planned new ISO International Standard will present a set of models of vertical profiles of zonal (for 10 degree latitudinal belts) and seasonal mean temperatures, pressures, densities, and meridian and zonal wind speeds, as well as the space and temporal variability of these parameters in terms of standard deviations, for the altitude from 0 up to 120 km. The models of atmospheric parameters will be presented in graphic and tabular form in terms of geometric and componential altitudes and nearly pole-to-pole coverage (80 degrees N–80 degrees S) of both hemispheres for four central months of the seasons—January, April, July and October. The algorithms and recommendations for the atmospheric parameters probability characteristics, which are the most useful for aviation and space practice, will also be given. ISO 213 is being developed to serve as an informational basis for international air-space practice as well as to unify the atmospheric models, which have to be used for design, production, exploitation and navigation of aircraft and space vehicles and their equipment.

Accordingly, it is recommended that those consulting this document for information on ISO 5878 investigate to see if the new ISO standard “Global Reference Atmosphere for Altitude 0-120 km for Aerospace Use” has been published by the ISO/TC 20/SC 6 “Standard Atmospheres” and obtain a copy for use in lieu of ISO 5878. At the time of the preparation of this document the Draft Standard “Global Reference Atmosphere for Altitude 0-120 km for Aerospace Use” was in a process of approval as a National Russia and Commonwealth of Independent States (CIS) Countries Standard.

7 ISO Standard Atmosphere (ISO 2533:1975)

7.1 Model content

The International Organization for Standardization (ISO) *Standard Atmosphere* consists of a document containing tables of atmospheric characteristics as functions of geometric and geopotential altitudes to 80 km. They define the ISO Standard Atmosphere for the altitudes to 50 km. The data are identical to the ICAO and WMO Standard Atmospheres to 32 km and are based on the standard atmospheres of ICAO 1964 and US Standard 1962. The authors considered these models to be the most representative when comparing current national and international standards and recommendations relative to the atmosphere based on the results of recent research. Data from this recent research have been used for calculation of the atmospheric characteristics for altitudes 50 km to 80 km that represent the ISO Interim Standard Atmosphere for this altitude range. Data in the tables are given in SI units except that temperature is also given in degrees Celsius and pressures are given in millibars and millimeters of mercury.

ISO 2544:1975 contains values of temperature, pressure, density, acceleration of gravity, speed of sound, dynamic viscosity, kinematic viscosity, thermal conductivity, pressure scale height, specific weight, air number density, mean air-particle collision frequency, and mean free path as a function of geometric and geopotential altitude up to 80 km.

7.2 Model uncertainties and limitations

7.2.1 The tables have been calculated assuming the air to be a perfect gas free from moisture and dust and based on conventional initial values of temperature, pressure and density.

7.2.2 The model approximates the annual nominal atmosphere for 45 degrees north latitude. As such, large variations in monthly mean or even annual mean atmospheres for the other latitudes and longitudes around the globe, relative to the values given in the ISO Standard Atmosphere, may be expected. Thus, while providing a common frame of reference for comparing engineering designs, instrumentation calibrations and processing of data, the model may exhibit significant deviations from the nominal annual, and especially monthly, profiles of atmospheric parameters for given latitude and longitude locations. These are, however, the same limitations found in the models used as a basis for the ISO Standard Atmosphere. The user should be aware of these uncertainties and limitations of the model.

7.3 Basis of the model

The numerical values in the table for altitudes to 50 km are based on the *ICAO Standard Atmosphere 1964,* the *US Standard Atmosphere, 1962,* and the *COSPAR International Reference Atmosphere, 1965 (CIRA 1965)*; results of recent research as noted in the references were used for the 50 to 80 km altitude region. For the altitudes to 32 km the tables are identical to the *ICAO Standard Atmosphere, 1964.*

7.4 Databases

Mean sea level is taken as the reference point for both the geopotential and geometric altitudes. The perfect gas law is used for the calculations that assume a well-mixed atmosphere. The temperature of each atmospheric layer is taken as a linear function of the geopotential altitude. The constants, coefficients, equations and data were selected from these references:

7.4.1 COSPAR Working Group IV. COSPAR International Reference Atmosphere, 1965 (CIRA 1965), North Holland Publishing Co., Amsterdam, 1965.

7.4.2 Comitet Standartov USSR: GOST 4401.64 "Tabblitsa Standartnoy Atmosfery," Izdatelstvo Standartov, Moskva, 1964

7.4.3 Deutscher Normenausschuss: DIN 5450 "Norm Atmosphere," 1968.

7.4.4 Doc. 7486/2. Manual of the ICAO Standard Atmosphere extended to 32 kilometers, second edition, 1964, International Civil Aviation Organization, Montreal, 1964.

7.4.5 List, R. J., editor: Smithsonian Meteorological Tables, Sixth Revised Edition, Washington, DC, 1963.

7.4.6 US Committee on Extension to the Standard Atmosphere: US Standard Atmosphere, 1962, US Government Printing Office, Washington, DC, 1962.

7.4.7 US Committee on Extension to the Standard Atmosphere: US Standard Atmosphere Supplements, 1966. US Government Printing Office, Washington, DC, 1966.

7.5 Publication references

ISO 2533:1975 "Standard Atmosphere First Edition, "Corrigendum 1, 1978, ISO, Geneva, Switzerland

7.6 Dates of development, authors and sponsors

7.6.1 Dates: Published 1975; corrected and updated 1978

7.6.2 Authors: Members of ISO TC20/SC6 (Aircraft and Space Vehicles / Standard Atmospheres)

7.6.3 Sponsors: International Organization for Standardization, Geneva, Switzerland

7.7 Model codes and sources

The model is published in the form of tables only. It is available from American National Standards Institute, 25 West 43 Street, New York, NY 10036. http://www.ansi.org

8 NASA/GSFC monthly mean global climatology of temperature, wind, geopotential height and pressure for 0–120 KM, 1988

8.1 Model content

This climatological model, the National Aeronautics and Space Administration's *NASA GSFC Monthly Mean Global Climatology of Temperature, Wind, Geopotential Height and Pressure for 0-120 km,* consists of a NASA report and a floppy diskette to be used with a PC, and contains figures and tables which present profiles of temperature, winds, and geopotential height as functions of altitude and pressure in the height range 0-120 km. These atmospheric properties, which are presented in a climatological format, are monthly mean values with nearly pole-to-pole coverage (80 deg S to 80 deg N). The model is intended for various research and analysis activities such as the numerical simulation of atmospheric properties and the design and development of satellite instruments for measuring Atmospheric parameters. The climatological data and the related text will also form the basis of the new COSPAR International Reference Atmosphere (CIRA 86) for the altitude range 0-120 km (Part II).