tion: Laboratory Models of. **Convective Cloud Systems Modelling**. **Coupled Ocean–Atmosphere Models**. **Mesoscale Meteorology:** Models. **Numerical Models:** Methods. **Predictability and Chaos**. **Weather Prediction:** Adaptive Observations; Data Assimilation; Ensemble Prediction; Regional Prediction Models; Seasonal and Interannual Weather Prediction.

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STANDARD ATMOSPHERE

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Introduction

A ‘standard atmosphere’ is a vertical description of atmospheric temperature, pressure, and density that is usually established by international agreement and taken to be representative of the Earth’s atmosphere. The first ‘standard atmospheres’ established by international agreement were developed in the 1920s primarily for the purposes of pressure altimeter calibrations and aircraft performance calculations. Later, some countries, notably the United States, also developed and published ‘standard atmospheres’. The term ‘reference atmosphere’ is used to identify vertical descriptions of the atmosphere for specific geograp-

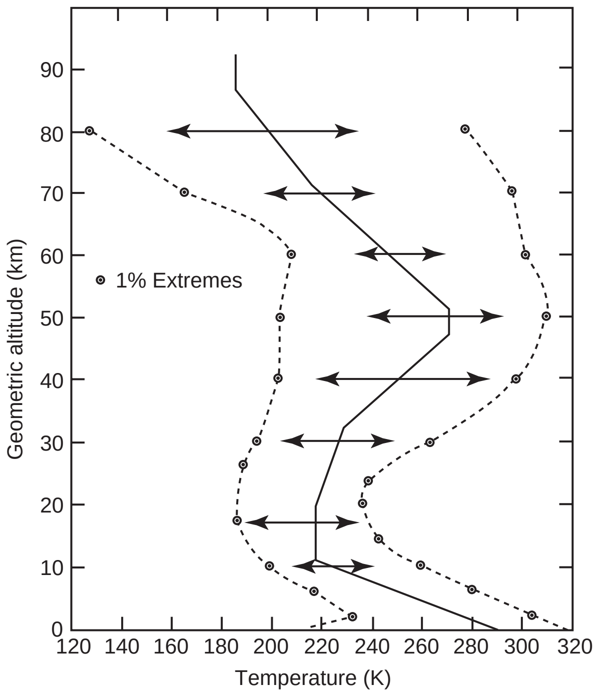

Figure 1 Range of systematic variability of temperature around the US Standard Atmosphere, 1976. (From Sissenwine *et al.* (1976).)

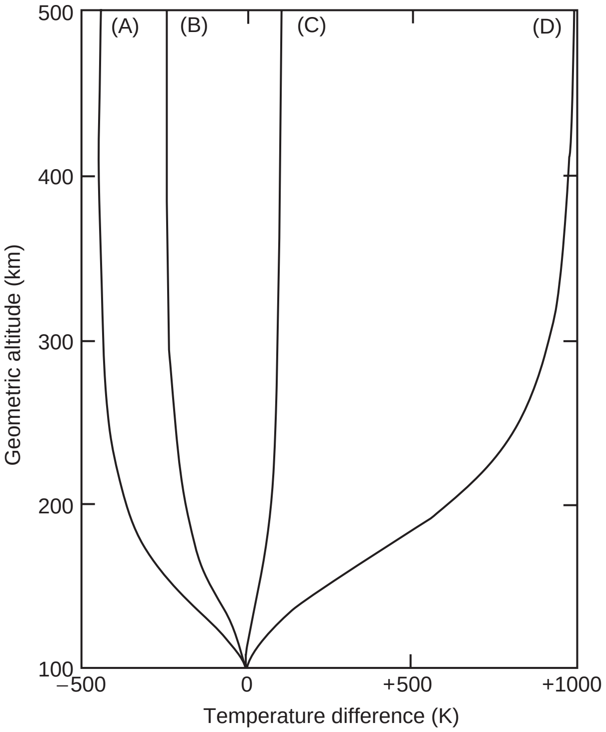

Figure 2 Departures of the temperature–altitude profiles from that of the US Standard Atmosphere, 1976, for various degrees of solar activity. (From Sissenwine *et al.* (1976).)

Table 1 Summary of reference and standard atmospheres

Model (page no.)	*Geographic region*	*Altitude range (km)*	*Parameters*	*Species included*	*Temporal variation*	*Output data present*	*Principal application*
CIRA, 1972 (1)	Northern latitude Global	25 to 120, 110 to 2000	T, p, d, composition winds	N_2, O_2, O, A, He, H	Seasonal, diurnal, solar activity, magnetic activity	Tables, figures	Aerospace vehicle design and evaluation, atmospheric reference
CIRA, 1986 (3)	Global	130 to 2000	T, p, d, composition		Seasonal, solar activity, geomagnetic activity	Tables, figures, computer code	Aerospace vehicle design and evaluation, atmospheric reference
New Middle Atmosphere, 1985 (5)	Global 80° S–80° N	20 to 80	T, p, d, zonal	–	Monthly, interannual, tidal, planetary wave	Tables, figures	Aerospace vehicle design and evaluation, atmospheric reference
ISO Reference Atmosphere, 1982 (7)	Annual–15° N Seasonal–30°, 45°, 60°, 80° N Cold/warm middle atmosphere $-$60°, 80° N	0 to 80	T, p, d	Data on water vapor	Seasonal, diurnal, daily,	Tables, figures	Aerospace vehicle and aircraft design and performance studies, atmospheric reference
ISO Standard Atmosphere, 1975 (9)	45° N	-2 to 80	T, p, d, composition, sound speed, coll. freq. mfp, viscosity, spec. wt, scale ht, therm. cond.	–	–	Tables only	Aerospace vehicle design and performance studies, atmospheric reference
Monthly Mean Global Climatology, 1988 (11)	Global	0 to 120	T, p, zonal winds	–	–	Tables only	Reference Climatology, numerical model initialization, instrumental design, scientific studies

GRAM-95 (13) (Current Edition: GRAM-99)	Global coverage	0 to 2500	T, p, d, wind velocity, wind shear, composition	H_2O, N_2O, CH_4, N_2, O, He, O_3, CO, CO_2, O_2, A, H	Random perturbation, monthly	Computer code NASA–MSFC and COSMIC	Aerospace vehicle design and simulation studies, space vehicle reentry, atmosphere reference for scientific studies
US Standard, 1962 (16)	Mid-latitudes (45°)	– 5 to 700	T, p, d, composition, part. speed, coll. freq., mfp, mean mol wt, viscosity, therm. cond., sound speed	–	–	Tables, figures	Aerospace vehicle design, atmospheric reference
US Standard, 1966 Supplement (18)	Mid-latitudes with variation	– 5 to 1000	Same as USS 1962	O_2, N_2, O, He, H	Seasonal, diurnal, solar activity, magnetic activity	Tables, figures	Illustrate atmospheric variability
US Standard, 1976 (19)	Mid-latitudes (45°)	– 5 to 1000	Same as USS 1962	Some data on N_2, O_2, H, He, O	Diurnal, seasonal, solar cycle	Tables, figures	Aerospace vehicle design, atmospheric reference
International Tropical Reference Atmosphere 1987 (21)	Tropics	– 5 to 1000	T, p, d, composition, part. speed, coll. freq., mean mol. wt, viscosity, therm. cond., sound speed	N_2, O_2, O Ar, He	None	Tables, figures	Aerospace vehicle design studies, atmospheric reference
Reference Atmosphere for Indian Equatorial zone, 1985 (23)	Tropics	0 to 80	T, p, d,	–	Monthly, annual	Tables, figures	Design of aerospace vehicles, science applications
Reference Model Middle Atmosphere Southern Hemisphere 1987 (24)	South 0–70° S	20 to 80	T, p, d zonal winds	–	Monthly, latitudinal	Tables, figures	Aerospace vehicle design, atmospheric reference

Table 1 *Continued*

Model (page no.)	*Geographic region*	*Altitude range (km)*	*Parameters*	*Species included*	*Temporal variation*	*Output data present*	*Principal application*
AFGL (Phillips Laboratory) Atmospheric Constitution Profiles, 1986 (26)	Global coverage	0 to 120	Number density, aerosol properties	H_2O, CO_2, N_2O, O_3, CH_4, CO, O_2, N_2, 20 others, aerosols	None	Tables, figures, computer code	Design and performance evaluation, scientific studies
Extreme Envelope of Climate Elements 1973 (28)	60° S–90° N	0 to 80	Climatic elements: T, p, humidity, wind shear, etc.	–	Monthly	Tables, figures	Systems design
Profiles of Temperature and Density, 1984 (30)	Global except Antarctic	0 to 80	T, d	–	Monthly	Tables, figures	Systems design
Global Reference Atmosphere, 1985 (32)	Global	18 to 80	T, p, d, number density, scale ht. Wind velocity	–	Monthly	Tables, figures	Reference model for scientific studies
Earth's Upper Atmosphere Density Model (Russia), 1984 (33)	>120 km solar flux-dependent	0 to 1500	d	–	Solar flux, geomagnetic activity, daily and semi-annual effects	Tables, computer code	Aerospace vehicle design and orbital lifetimes
Jacchia J70 (34)	Mean global	90 to 2500	T, p, d, scale ht	N_2, O_2, O, Ar, He, H	Diurnal, seasonal, geomagnetic activity	Tables	Design and simulation, lifetime analysis
Jacchia J71 (35)	Mean global	90 to 2500	T, p, d, scale ht	N_2, O_2, O, Ar, He, H	Diurnal, seasonal, geomagnetic activity	Tables, some computer code	Design and simulation, lifetime analysis
Jacchia J77 (36)	Mean global	90 to 2500	T, p, d, scale ht	N_2, O_2, O, Ar, He, H	Diurnal, seasonal, geomagnetic activity	Tables, some computer code	Design and simulation, lifetime analysis
Model of Atmospheric Structure, 1987 (38)	Global	70 to 130	T, p, d	–	Monthly latitudinal, solar activity, magnetic activity	Tables	Connect Phillips Lab (AFGL) profiles of T, p to MSIS-86

NASA MSIS-86 (39) (Current Edition: NRL-MSIS-00)	Global coverage	85 to 2000	T, p, d, composition	N_2, O_2, O, He, H, Ar, N	Diurnal, semiannual, latitudinal longitudinal solar activity, magnetic activity	Computer code (NSSDC), floppy disk	General scientific and engineering studies
NASA Marshall Engineering Thermospheric Model, 1988 (41) (Current Edition: Version 2.0)	Global	90 to 2500	T, p, d, mean mol. wt, scale ht, spec. heat	N_2, O_2, O Ar, He, H	Solar activity, magnetic activity, seasonal, diurnal	Computer code (NSSDC), floppy disk	Orbital vehicle design and simulation, lifetime analysis
Range Reference Models of the Atmosphere, 1982 (43)	Specific locations (e.g., Cape Canaveral, FL; Kwajalain, MI, etc.)	0 to 70	T, p, d, wind velocity	Water vapor	Monthly, seasonal, means, monthly, parameter variations	Tables, figures	Site-related engineering analyses
Reference Atmosphere for Edwards AFB, CA, 1975 (46)	Edwards/Dryden, only	←Same as Reference Atmosphere for Patrick AFB→					
Hot and Cold Atmosphere for Edwards AFB, CA, 1975 (47)	Edwards/Dryden only	←Same as Hot and Cold Atmosphere for Kennedy Space Center→					
Hot and cold Atmosphere for Kennedy Space Center, FL, 1971 (48)	Kennedy Space Center only	0 to 90	T, p, d	–	Seasonal	Tables, figures	Engineering studies
Reference Atmosphere for Patrick AFB, FL, 1963 (49)	Cape Kennedy only	0 to 700	T, p, d, composition, mean mol. wt, sound speed, viscosity, etc.	–	–	Tables, figures	Engineering studies
Reference Atmosphere for Vandenberg AFB, CA, 1971 (50)	Point Arguello only	←Same as Reference Atmosphere for Patrick AFB→					

Table 1 *Continued*

Model (page no.)	*Geographic region*	*Altitude range (km)*	*Parameters*	*Species included*	*Temporal variation*	*Output data present*	*Principal application*
Hot and Cold Atmosphere for Vandenberg AFB, 1973 (51)	Arguello only	←Same as Hot and Cold Atmosphere for Kennedy Space Flight Center→					
Mars-GRAM, 1996 (52)	Global	0 to ∼1000	T, p, d, winds	–	Seasonal, diurnal, latitudinal longitudinal	Tables, computer code	Spacecraft design, atmospheric entry, orbital drag
Venus International Reference Atmosphere (VIRA), 1985 (53)	Global	0 to 3500	T, p, d, composition	<100 km CO_2, N_2, Ar, Ne, Kr, O_2, H_2, H_2O, SO_2, D, NH_3	<100 km latitudinal solar zenith angle, diurnal	Tables, figures	Spacecraft design, atmospheric entry, orbital drag
				>100 km CO_2, O, CO, He, N, N_2, H, O_2, D, C	>100 km solar zenith angle, decimal, latitudinal, solar activity		

Source: AIAA Guide to Reference and Standard Atmosphere Models, Vaughan *et al*. (1996).

T = kinetic temperature; p = pressure; d = mass density; mfp = mean free path; part. speed = particle speed; coll. freq. = collision frequency; mean mol. wt = mean molecular weight; therm. cond. = thermal conductivity; scale ht = scale height; spec. wt = specific weight; spec. heat = specific heat.

CIRA: COSPAR (Committee on Space Research) International Reference Atmosphere; ISO: International Organisation for Standardization; GRAM: Global Reference Atmosphere Model; AFGL: Air Force Geophysics Laboratory; NASA: National Aeronautics and Space Agency; MSIS: Mass Spectrometer and Incoherent Scatter; NRL: Naval Research Laboratory.

hical locations or globally. These were developed by organizations for specific applications, especially as the aerospace industry began to mature after World War II. The term 'standard atmosphere' has in recent years also been used by national and international organizations to describe vertical descriptions of atmospheric trace constituents, the ionosphere, aerosols, ozone, atomic oxygen, winds, water vapor, planetary atmospheres, and so on.

A standard unit of atmospheric pressure is defined as that pressure exerted by a 760 millimeter, (or 29.22 inch) column of mercury at standard gravity at 45.5425° N latitude and sea level ($9.80665\ \mathrm{m\,s^{-2}}$) at a temperature of 0°C (32°F). The recommended unit for meteorological use is 1013.25 hectopascals (1 hPa = 1 mb). Standard temperature is used in physics to indicate a temperature of 0°C (32°F), the ice point, and a pressure of one standard atmosphere (1013.25 hPa). In meteorology, the term standard temperature has no generally accepted meaning, except that it may refer to the temperature at zero pressure-altitude in the standard atmosphere (15°C) with a density of $1.2250\ \mathrm{g\,m^{-3}}$. The standard sea-level values of temperature, pressure, and density that have been used for decades are temperature of 288.15 K, 15°C, or 59°F; pressure of 1013.25 mb, 760 mm Hg, or 29.22 inches Hg; and density of $1225.00\ \mathrm{g\,m^{-3}}$ or $0.076474\ \mathrm{lb\,ft^{-3}}$.

In 1925 the US National Advisory Committee for Aeronautics (NACA) Standard Atmosphere (or US Standard Atmosphere) was published. In 1952 the International Civil Aeronautical Organization (ICAO) produced the ICAO Standard Atmosphere, and in 1964 an extension to 32 km. Subsequently there have been a succession of 'Standard and Reference Atmospheres', some extending to altitudes above 1000 km, produced by the US Committee on Extension to the Standard Atmosphere (COESA), Committee on Space Research (COSPAR), Comitet Standartov (USSR), International Standardization Organization (ISO), US Air Force Research and Development Command (ARDC), US Range Commanders Council (RCC), and US National Aeronautics and Space Administration (NASA), plus others.

In 1975 the International Standards Organization published a Standard Atmosphere for altitudes from -2 to 50 km that is identical to the ICAO Standard Atmosphere from -2 to 32 km. Subsequently the ISO published in 1982 a family of five Reference Atmospheres for Aerospace Use for altitudes up to 80 km and latitudes of 15°, 30°, 45°, 60°, and 80° N.

Figure 1 provides an illustration of the temperature–height profiles to 100 km of the COESA US Standard Atmosphere, 1976, and the lowest and highest mean monthly temperatures obtained for any location between the Equator and Pole. The portion of the US Standard Atmosphere up to 32 km is identical with the ICAO Standard Atmosphere, 1964, and below 50 km with the ISO Standard Atmosphere, 1973.

For altitudes above approximately 100 km, significant variations in the temperature, and thus density, occur due to solar and geomagnetic activity over the period of a solar cycle. Variations in the temperature–height profiles for various degrees of solar and geomagnetic activity are presented in **Figure 2**. Profile (A) gives the lowest temperature expected at solar cycle minimum; profile (B) represents average conditions at solar cycle minimum; (C) represents average conditions at a typical solar cycle maximum; and (D) gives the highest temperatures to be expected during a period of exceptionally high solar and geomagnetic activity.

Currently some of the most commonly used Standard and Reference Atmospheres include:

ICAO Standard Atmosphere, 1952/1964
ISO Standard Atmosphere, 1973
US Standard Atmosphere, 1976
COSPAR International Reference Atmosphere (CIRA), 1986
NASA Global Reference Atmosphere Model (GRAM), 1999

In 1996 the American Institute of Aeronautics and Astronautics (AIAA) published a *Guide to Reference and Standard Atmosphere Models*. This document provides information on the principal features for a number of global, regional, middle atmosphere, thermosphere, test range, and planetary atmosphere models. Summary information on these reference and standard atmosphere models is given in the **Table 1**.

See also

Evolution of Earth's Atmosphere. **Static Stability**.

Further Reading

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