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Introduction

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For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 5878

Reference atmospheres for aerospace use — Temperature profiles, wind characteristics and humidity models

ICS: 49.020

ISO/TC 20/SC 6

Secretariat: **GOST R**

Voting begins on:
2025-10-29

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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.

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

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

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, SC 6, *Standard atmosphere*.

This second edition of ISO 5878 cancels and replaces [ISO 5878:1982](#), [ISO 5878:1982/Add 1:1983](#) and [ISO 5878:1982/Add 2:1983](#).

The major changes from the first edition are:

- all content from [ISO 5878:1982/Add 1:1983](#) has been incorporated, namely the wind model and its data tables;
- all content from [ISO 5878:1982/Add 2:1983](#) has been incorporated, namely the humidity model and its data tables;
- calculations in this document have been updated to use the latest edition of [ISO/WD 2533](#);
- all figures have been re-plotted in vector format to the accurate specifications of the models;
- all data tables have been moved to the annexes.

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

Introduction

0.1 General

Understanding atmospheric characteristics is fundamental to numerous scientific and engineering endeavors, particularly in aerospace, meteorology, and environmental sciences. The atmosphere's complex behavior presents challenges for vehicle design, weather prediction, pollution transport modeling, and aviation operations.

The need for standardized atmospheric models has grown with the advancement of aerospace technology and increasing concerns about climate change. These models must balance accuracy with usability, providing sufficient detail while remaining accessible to non-specialists.

This document presents three key aspects of atmospheric behavior:

- Temperature and density profiles, which affect vehicle performance, aerodynamic heating, and structural loads
- Moisture content, which impacts visibility, icing conditions, and radio wave propagation
- Wind patterns, which influence flight planning, fuel consumption, and transport of atmospheric constituents

These properties vary significantly with altitude, latitude, season, and geographic location, interacting to form a complete picture of atmospheric behavior necessary for modern applications.

The publication of this document as the second edition marks the 43rd anniversary of the reference atmospheres for aerospace use, first published in 1982 and extended twice in 1983 to cover wind and humidity data.

0.2 Temperature and density variations of the atmosphere

The characterization of atmospheric temperature and density variations represents one of the most fundamental aspects of atmospheric modeling. The approach taken in this document employs a family of reference models that capture the systematic variations across different latitudinal bands, from tropical (15°) to Arctic (80° N) regions. These models are constructed from extensive observational data collected through various measurement techniques including radiosondes, meteorological rockets, and other specialized atmospheric sensing systems.

The reference atmospheres account for both the regular patterns and special phenomena that occur in different regions. In tropical areas, they capture the relatively stable annual conditions and characteristic features like the trade wind inversion. In middle latitudes, they describe the significant seasonal variations in temperature and density profiles. The models give particular attention to Arctic and sub-Arctic regions, where sudden stratospheric warmings and other unique phenomena can produce dramatic changes in atmospheric structure.

These models are founded on fundamental physical principles, including the hydrostatic equation and perfect gas law, with careful consideration given to variations in gravity with latitude and altitude through geopotential calculations. They provide not just mean conditions but also statistical distributions of observed values, giving users insight into the variability they might encounter in real-world applications. This comprehensive approach allows for realistic engineering design criteria while maintaining scientific accuracy.

0.3 Wind characteristics

The wind patterns in Earth's atmosphere emerge from complex interactions between thermal gradients, pressure systems, surface conditions, and planetary rotation. These interactions create distinctive flow patterns that vary systematically with latitude, altitude, and season, while also exhibiting significant local and temporal variations. Understanding these patterns is crucial for applications ranging from aircraft route planning to pollution dispersion modeling.

The meridional distribution of winds reveals a complex structure of atmospheric circulation. In tropical latitudes, easterly components dominate the lower and middle troposphere, while subtropical regions feature strong westerly flows and jet streams at 10km to 13km altitude. Temperate latitudes exhibit wave-like westerly flows associated with mobile cyclone systems, and the stratosphere demonstrates dramatic seasonal reversals in wind direction. This structure is further complicated by variations in wind speed and direction with altitude, creating wind shear patterns that are particularly significant for aviation and atmospheric transport.

While detailed wind data is available from various meteorological organizations, including the World Meteorological Organization (WMO) and national weather services, the sheer volume and complexity of this information can be overwhelming for practical applications. This document presents wind characteristics in a simplified yet comprehensive format, averaging data over major regions while retaining essential features of the atmospheric circulation patterns. This approach makes the information more accessible to users who require wind data for specific applications but may not have extensive meteorological expertise.

0.4 Moisture content

Atmospheric moisture, though a minor constituent by mass, plays a disproportionately large role in atmospheric processes and human activities. The maximum water content of approximately 4% by mass belies its crucial influence on weather patterns, climate systems, and aviation operations. Understanding moisture distribution and variation is essential for applications ranging from aircraft design to weather forecasting and climate modeling.

Water exists in all three phases within the atmosphere — vapor, liquid, and solid — each with distinct implications for various applications. Water vapor, the primary focus of this document, affects air density, radio wave propagation, and atmospheric stability. Liquid water in clouds and fog impacts visibility and aircraft operations, while solid forms create icing hazards and affect precipitation patterns. The vertical distribution of moisture is particularly significant, with the majority concentrated in the lower atmosphere — 60% within the first 2km and 99% below 10km .

The quantification of atmospheric moisture through multiple measures — humidity mixing ratio, vapor pressure, and dew-point temperature — provides users with flexible options for different applications. These complementary measures allow for direct use in engineering calculations, meteorological analyses, and practical operations. The data presented focuses on the lowest 10km of the atmosphere, where reliable radiosonde measurements are available and where moisture content has the most significant practical implications.

Reference atmospheres for aerospace use — Temperature profiles, wind characteristics and humidity models

1 Scope

This document presents comprehensive information on atmospheric properties and their variations from Earth's surface up to 80km , encompassing:

- seasonal, latitudinal, and longitudinal variability of temperature, pressure, and density;
- spatial distribution of wind characteristics;
- humidity values up to 10km above sea level, based on reliable radiosonde data.

The data and models are intended for use in aerospace design (such as aircraft performance evaluation), operational planning (such as air route planning), and atmospheric transport studies (such as atmospheric contaminant transport assessment).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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/WD 2533,

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org>

3.1

ISO standard atmosphere

ISA

standard atmosphere defined by ISO 2533, which specifies the average characteristics of the Earth's atmosphere at mean sea level and at various altitudes

[SOURCE: [ISO/WD 2533](https://www.iso.org/obp)]

4 Atmosphere

4.1 Basis

4.1.1 General

The systematic (latitudinal and seasonal) variation of atmospheric properties is shown for altitudes up to 80km by a family of models, comprising the following reference atmospheres in [Table 1](#).

Table 1 — Reference atmospheres

Title	Latitude	Time of year
Tropical	15°	Annual average
Sub-tropical	30° N	June-July and December-January
Mid-latitude	45° N	June-July and December-January
Sub-Arctic	60° N	June-July and December-January Cold and warm stratospheric-mesospheric regimes for December-January
Arctic	80° N	Same as sub-Arctic

Some special considerations employed in the development of this family of reference atmospheres are listed below:

- With the exception of the 15° latitude model, the reference atmospheres are considered applicable to the northern hemisphere only. However, it is believed that they closely approximate mid-latitude conditions in the southern hemisphere.
- The models are defined by temperature-altitude profiles in which the vertical gradients of temperature are constant with respect to geopotential altitude within each of a number of layers.
- The air is assumed to be a perfect gas, free from moisture and dust.
- The molar mass of dry air, $M = 28\,964\,420\text{kgkmol}^{-1}$, is assumed to be constant at altitudes up to 80km. The specific gas constant of dry air R , is equal to $28\,705\,287\text{JK}^{-1}\text{kg}^{-1}$ ([Table 2](#)).
- Characteristics such as the trade inversion in the tropics and the winter surface inversion in Arctic and sub-Arctic regions are included in the models.

Table 2 — Main values used for the calculation of the reference atmospheres

Symbol	Value	Unit of measurement	Description
g_n	9,806 65	ms^{-2}	standard acceleration of free fall
M	28,964 42	kgkmol^{-1}	molar mass of dry air at sea level
N_A	0,000 000 000 000 000 000 000 060 221 407 6	mol^{-1}	Avogadro constant
R^*	8 314,32	$\text{JK}^{-1}\text{kmol}^{-1}$ or $\text{kgm}^2\text{s}^{-2}\text{K}^{-1}\text{kmol}^{-1}$	universal gas constant
R	287,052 87	$\text{JK}^{-1}\text{kg}^{-1}$ or $\text{m}^2\text{K}^{-1}\text{s}^{-2}$	specific gas constant

4.1.2 Basic principles

The numerical values for the various thermodynamic and physical quantities used in the computations of atmospheric properties are the same as those used for [ISO/WD 2533](#), with two exceptions:

- surface conditions for each for the reference atmospheres are based on sea-level values of temperature, pressure and density for the appropriate season and latitude
- values of the acceleration of free fall at sea level for latitudes other than 45° were obtained from Lambert's equation ([Formula \(1\)](#), from [\[19\]](#)) in which gravity varies with latitude φ .

$$g_{0\varphi} = 9,806\,16(1 - 0,002\,637\,3 \cos 2\varphi + 0,000\,005\,9 \cos^2 2\varphi)[\text{ms}^{-2}] \quad (1)$$

where

$g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms^{-2});

φ is the latitude, expressed in degrees ($^{\circ}$).

Values from this relationship, along with surface temperatures and pressures, are given in [Table A.1](#). For 45° N, values of $g_{0\varphi}$ and r_{φ} are taken from [ISO/WD 2533](#).

4.1.3 The hydrostatic equation and the perfect gas law

NOTE This subclause is given identically in [ISO/WD 2533.4.2](#). It is provided here for convenience and completeness.

Being static with respect to the earth, the atmosphere is subject to gravity. The conditions of air static equilibrium are determined by the equation of the static atmosphere which relates air pressure p , density ρ , acceleration of free fall g and altitude h described by [Formula \(2\)](#).

$$-dp = \rho g dh \quad (2)$$

where

p is the air pressure, expressed in pascals (Pa);

ρ is the air density, expressed in kilograms per cubic metre (kgm^{-3});

g is the acceleration of free fall, expressed in metres per second squared (ms^{-2});

h is the geometric altitude, expressed in metres (m).

The perfect gas law relates air pressure to density and temperature is described by [Formula \(3\)](#).

$$p = \frac{\rho R^* T}{M} \quad (3)$$

where

p is the air pressure, expressed in pascals (Pa);

ρ is the air density, expressed in kilograms per cubic metre (kgm^{-3});

R^* is the universal gas constant, expressed in joules per kelvin per kilomole ($\text{JK}^{-1}\text{kmol}^{-1}$);

T is the temperature in kelvins (K);

M is the air molar mass, expressed in kilograms per kilomole (kg kmol^{-1}).

At the altitudes considered in this document, $\frac{R^*}{M} = \text{constant} = R$. The relationship is hence simplified to [Formula \(4\)](#).

$$p = \rho RT \quad (4)$$

where

p is the air pressure;

T is the temperature in kelvins;

M is the air molar mass;

R is the specific gas constant.

4.1.4 Geopotential and geometric altitudes; acceleration of free fall

NOTE 1 The first part of this subclause is given identically in [ISO/WD 2533, 4.3](#). It is provided here for convenience and completeness.

In considering pressure distribution in the atmosphere it is convenient to introduce the gravity potential or geopotential Φ , which characterizes the potential energy of an air particle at a given point.

Any point with x, y, z co-ordinates may be characterized by a single value of gravity potential $\Phi(x, y, z)$ in it.

The surface defined by the equation [Formula \(5\)](#) is of the same potential in all points and is called an isopotential or geopotential surface.

$$\Phi(x, y, z) = \text{constant} \quad (5)$$

When moving along an external normal from any point on the surface Φ_1 , to the infinitely close point where the value of the potential is $\Phi_2 = \Phi_1 + d\Phi$ the work performed for shifting a unit mass from the first surface to the second one will be [Formula \(6\)](#).

$$d\Phi = g(h)dh \quad (6)$$

where

Φ is the geopotential, expressed in joules per kilogram (J kg^{-1});

$g(h)$ is the acceleration of free fall at the geometric altitude h , expressed in metres per second squared (ms^{-2});

h is the geometric altitude, expressed in metres (m).

The geopotential Φ is defined as in [Formula \(7\)](#).

$$\Phi = \int_0^h g(h)dh \quad (7)$$

where

Φ is the geopotential, expressed in joules per kilogram (J kg^{-1});

$g(h)$ is the acceleration of free fall at the geometric altitude h , expressed in metres per second squared (ms^{-2});

h is the geometric altitude, expressed in metres (m).

By dividing the geopotential Φ by the standard acceleration of free fall g_n , one obtains the value of a length dimension which, symbolized as H , is called geopotential altitude. It is as defined in [Formula \(8\)](#).

$$H = \frac{\Phi}{g_n} = \frac{1}{g_n} \int_0^h g(h) dh \quad (8)$$

where

H is the geopotential altitude, expressed in metres (m);

Φ is the geopotential, expressed in joules per kilogram (Jkg^{-1});

g_n is the standard acceleration of free fall at mean sea level, expressed in metres per second squared (ms^{-2});

$g(h)$ is the acceleration of free fall at the geometric altitude h , expressed in metres per second squared (ms^{-2});

h is the geometric altitude, expressed in metres (m).

Expressed in metres, the value H is numerically equal to the geopotential altitude, which in meteorology is measured in so-called standard geopotential metres¹; hence, this value will be called geopotential altitude. The mean sea level is taken as a reference for readings for both geopotential and geometrical altitudes.

From [Formula \(8\)](#) it can be seen that, in order to relate geopotential and geometric altitudes, it is necessary first to find a relation between acceleration of free fall g and geometric altitude h .

NOTE 2 The following second part of this subclause is given not described in [ISO/WD 2533](#).

Gravity is the vector sum of the gravitational attraction and the centrifugal force induced by the earth's rotation; it is therefore a complicated function of latitude and the radial distance from the centre of the earth, and the expression for the acceleration of free fall is generally awkward and impractical. However, allowance can be made for the centrifugal forces, with sufficient accuracy for these reference atmospheres, by using a fictitious or nominal value of the earth's radius, r_φ , at each latitude. The acceleration of free fall $g_\varphi(h)$ may be found for each height and latitude by use of r_φ , with Newton's law of gravitation as shown in [Formula \(9\)](#).

$$g_\varphi(h) = g_{0\varphi} \left(\frac{r_\varphi}{r_\varphi + h} \right)^2 \quad (9)$$

where

r_φ is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m);

$g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms^{-2}).

Integration of [Formula \(8\)](#), after substituting for $g_\varphi(h)$ from [Formula \(9\)](#), gives the relationship between geopotential and geometric altitudes in [Formula \(10\)](#) and [Formula \(11\)](#).

¹ The standard geopotential metre (m') which is equal to $9,806\,65\text{m}^2\text{s}^{-2}$ has been adopted by the World Meteorological Organization (see Technical Regulations, WMO, No. 49, vol. I, ed. 1971 Appendix C) and from the 1st July 1972 replaces the geopotential metre formerly in use. Its value was $1\text{gpm} = 9,8\text{m}^2\text{s}^{-2}$.

$$H = \frac{r_\varphi h}{r_\varphi + h} \cdot \frac{g_{0\varphi}}{g_n} \quad (10)$$

where

- H is the geopotential altitude, expressed in metres (m);
- h is the geometric altitude, expressed in metres (m);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²);
- g_n is the standard acceleration of free fall at mean sea level, expressed in metres per second squared (ms⁻²);
- r_φ is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m).

$$h = \frac{r_\varphi H}{\frac{g_{0\varphi}}{g_n} r_\varphi - H} \quad (11)$$

where

- H is the geopotential altitude, expressed in metres (m);
- h is the geometric altitude, expressed in metres (m);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²);
- g_n is the standard acceleration of free fall at mean sea level, expressed in metres per second squared (ms⁻²);
- r_φ is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m).

The radius r_φ is a fictitious quantity, the meaning of which may be explained in the following way: gravity, being the vector sum of the gravitational attraction and the centrifugal force induced by the earth's rotation, has a certain potential, the geopotential. This potential may be replaced by the potential of a non-rotating homogeneous sphere in such a way that the gravitational attraction at the surface of the sphere is equal to that at the earth's surface both in magnitude and direction.

This condition is satisfied if the partial derivatives of g_φ , with respect to h for $h = 0$ in [Formula \(9\)](#) and in the more precise [Formula \(12\)](#) from reference [\[19\]](#) are equal.

$$g_\varphi(h) = g_{0\varphi} - (3,085\,462 \times 10^{-6} + 2,27 \times 10^{-9} \cos 2\varphi)h + (7,254 \times 10^{-13} + 1,0 \times 10^{-15} \cos 2\varphi)h^2 - (1,517 \times 10^{-19} + 6,0 \times 10^{-22} \cos 2\varphi)h^3 \quad (12)$$

where

- h is the geometric height, expressed in metres (m);
- g is the acceleration of free fall, expressed in metres per second squared (ms⁻²);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²);
- φ is the latitude, expressed in degrees (°);
- r_φ is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m).

The partial derivatives of g_φ , with respect to h for $h = 0$ are, from [Formula \(12\)](#), and described in [Formula \(13\)](#).

$$\left(\frac{\partial h_{\varphi}}{\partial h}\right)_{h=0} = -3,085\,462 \times 10^{-6} - 2,27 \times 10^{-9} \cos 2\varphi \quad (13)$$

where

- h is the geometric height, expressed in metres (m);
- g is the acceleration of free fall, expressed in metres per second squared (ms⁻²);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²);
- φ is the latitude, expressed in degrees (°);
- r_{φ} is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m).

And, together from [Formula \(9\)](#), we obtain [Formula \(14\)](#).

$$\left(\frac{\partial g_{\varphi}}{\partial h}\right)_{h=0} = -\frac{2g_{0\varphi}}{r_{\varphi}} \quad (14)$$

where

- h is the geometric height, expressed in metres (m);
- g is the acceleration of free fall, expressed in metres per second squared (ms⁻²);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²);
- φ is the latitude, expressed in degrees (°);
- r_{φ} is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m).

Equating the right-hand sides of [Formula \(13\)](#) and [Formula \(14\)](#), we have [Formula \(15\)](#).

$$r_{\varphi} = g_{0\varphi} \frac{2}{3,085\,462 \times 10^{-6} + 2,27 \times 10^{-9} \cos 2\varphi} \quad (15)$$

where

- h is the geometric height, expressed in metres (m);
- g is the acceleration of free fall, expressed in metres per second squared (ms⁻²);
- r_{φ} is the nominal radius of the earth at a specific latitude, taken from [Table A.1](#), expressed in metres (m);
- $g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ , expressed in metres per second squared (ms⁻²).

The values of r_{φ} , for the latitudes of the reference atmospheres are given in [Table A.1](#).

4.2 Atmospheric models to 80km altitude

4.2.1 General

The reference atmospheres are defined by the vertical temperature profiles for each latitude and season (see [4.1.1 b](#)).

Vertical pressure and density distributions were calculated from the temperature-altitude profiles using the hydrostatic [4.1.3, Formula \(2\)](#) and the perfect gas law [4.1.3, Formula \(4\)](#) from [4.1](#) and the appropriate mean sea-level values of pressure.

Temperature and other properties of the reference atmospheres are given in [Clause A.3](#). Brief descriptions of seasonal, latitudinal, longitudinal and day-to-day variations of temperature and density are included in [4.3](#).

4.2.2 Annual model for 15° latitude

A mean annual atmosphere was adopted for 15° latitude as available observations indicate that the seasonal variability of vertical profiles of temperature in the tropics is relatively small.

A mean annual temperature Profile ([Figure 1](#)) is based on observations taken at:

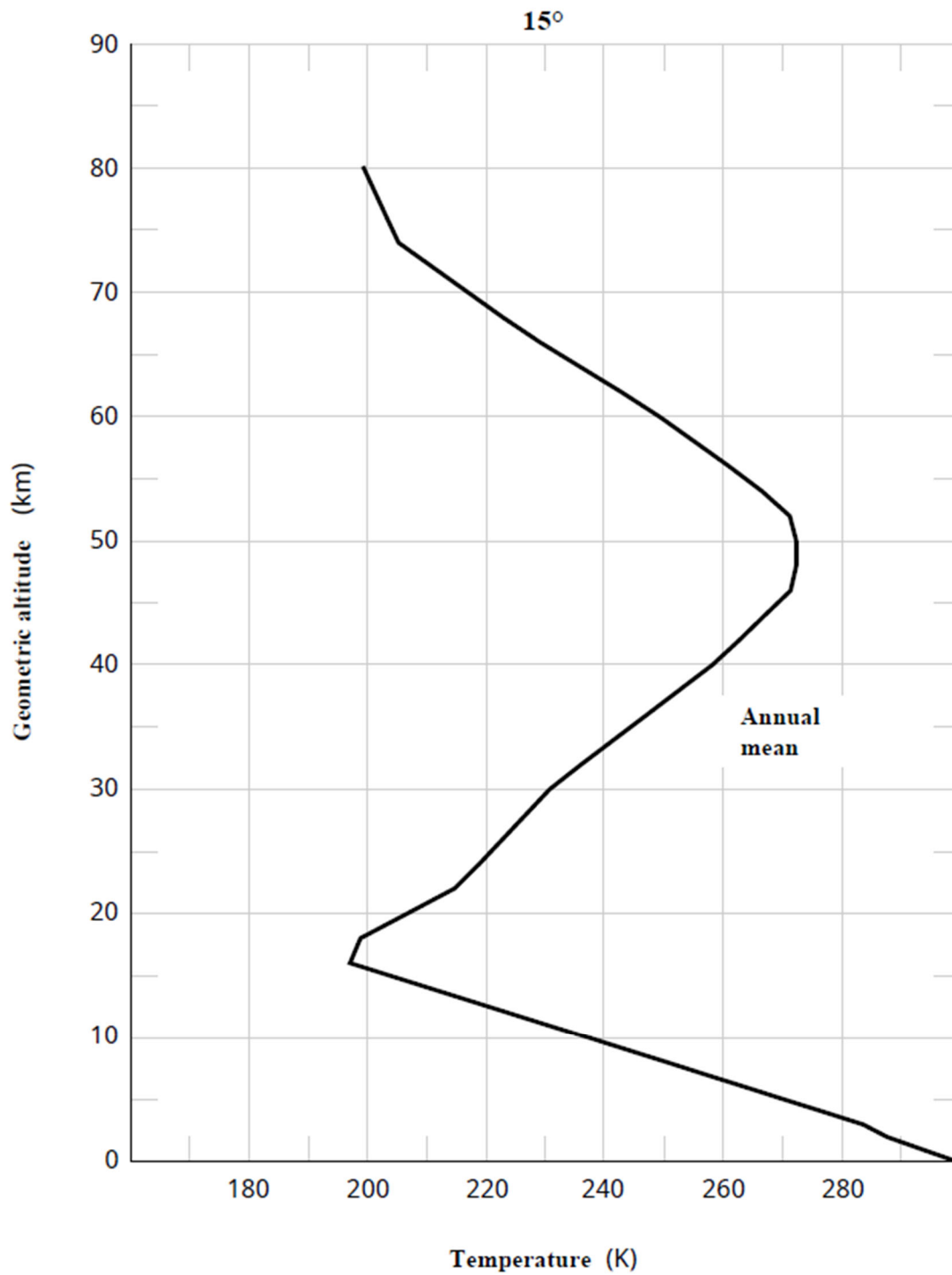
- Ascension (8° S, 14° W)
- Natal (6° S, 35° W)
- Ft. Sherman (9° N, 80° W)
- Kwajalein (9° N, 168° E)
- Antigua (17° N, 62° W)
- Guam (14° , 145° E)
- Grand Turk (21° N, 71° W) and
- research vessels Voeikov and Shokalsky (20° S).

Features typical of the thermal structure of the tropical atmosphere are shown in [Figure 1](#) and in [Table A.2](#).

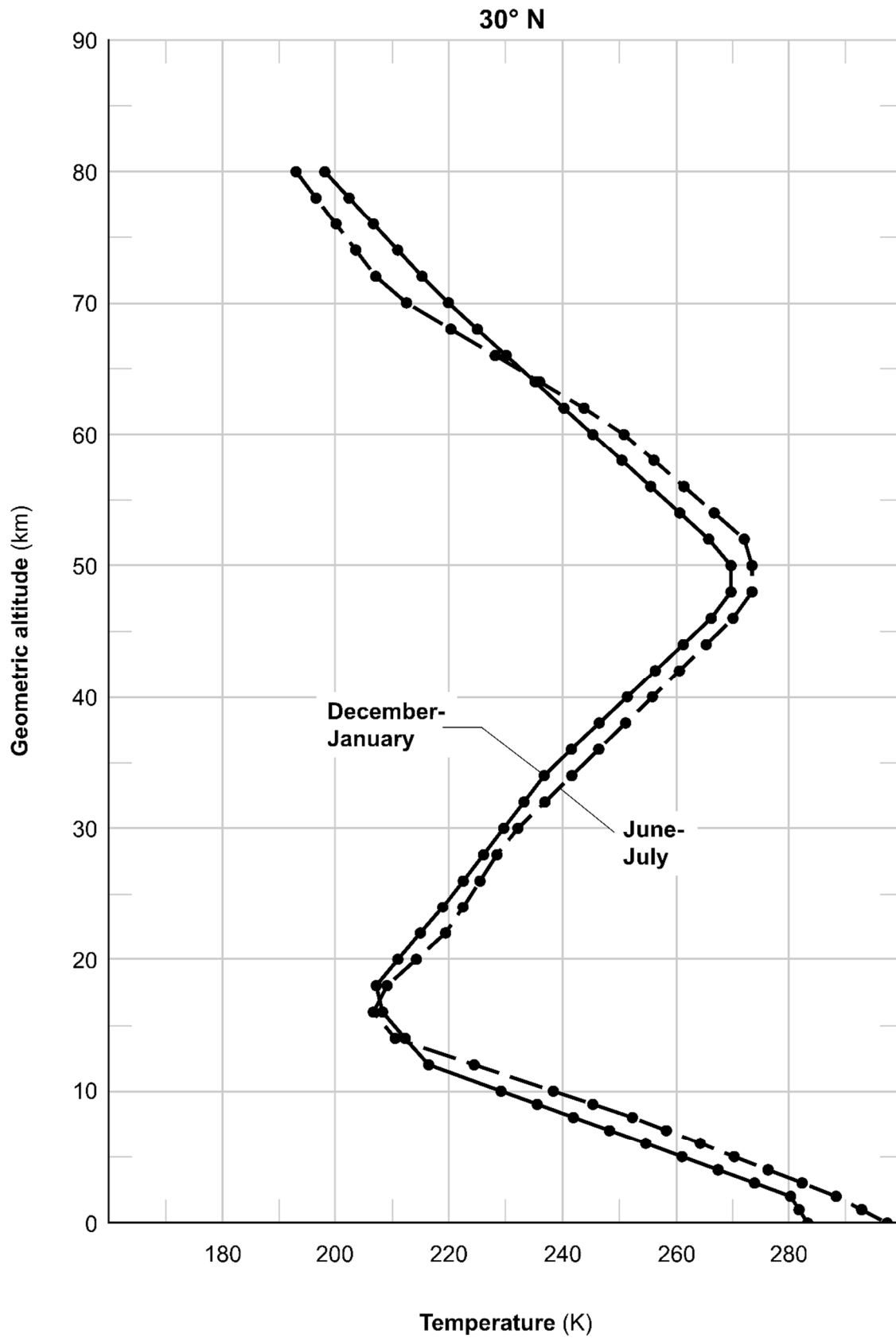
EXAMPLE Routine averaging of monthly temperature-altitude data indicates an isothermal layer about 2km thick from 16km to 18km .

An examination of daily observations, however, reveals a sharp inversion at the tropopause. The sharp inversion, a feature typical of the tropical atmosphere, has been retained and appears at 16,5km , the mean annual altitude of the tropopause at 15° latitude.

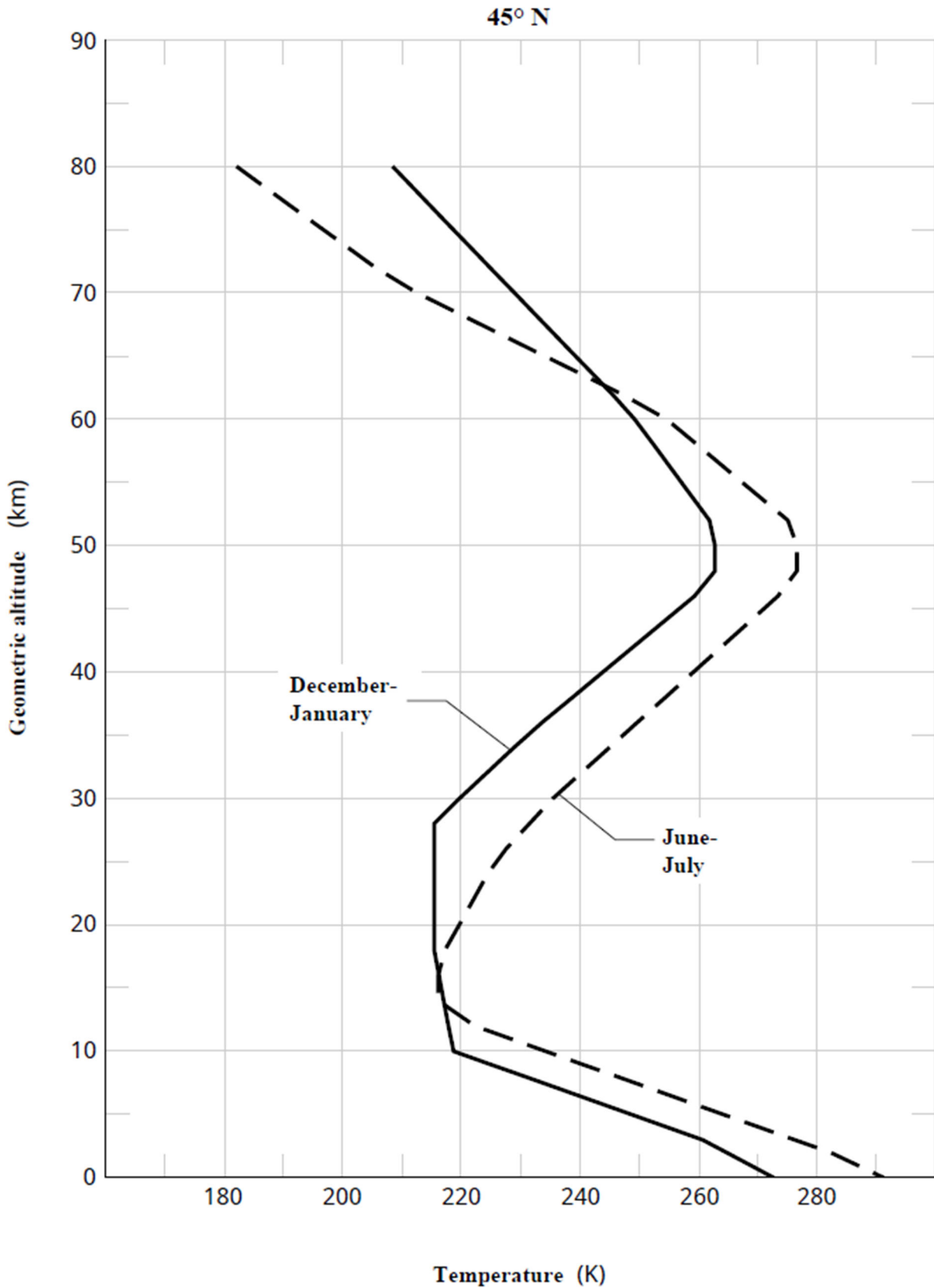
The average altitude and magnitude of the trade wind inversion, a characteristic of the temperature structure between 2km and 3km , over tropical ocean areas, have also been included in the 15° latitude temperature-altitude profile.



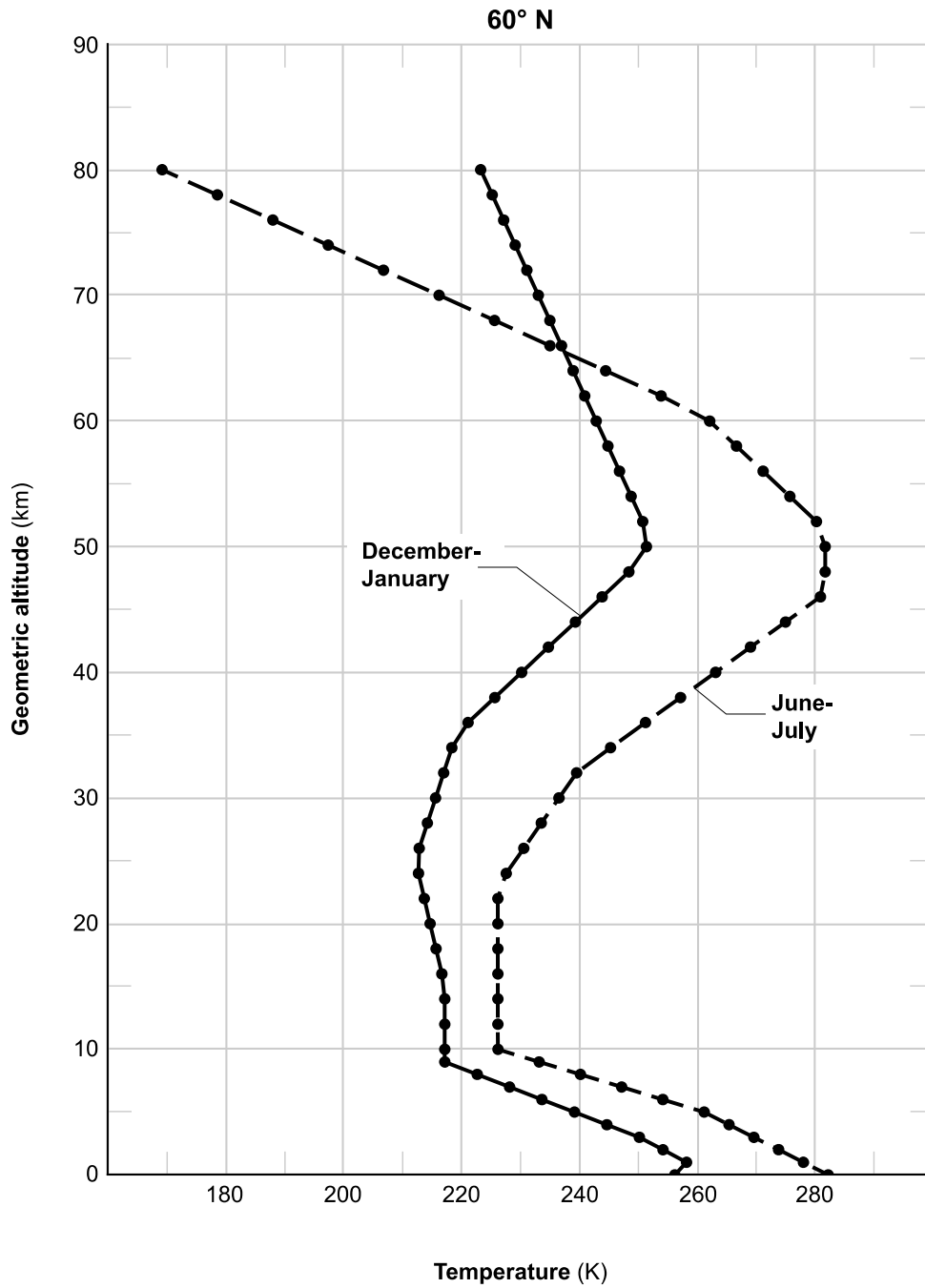
a) Temperature-altitude profiles for the mean annual atmosphere for 15° N latitude



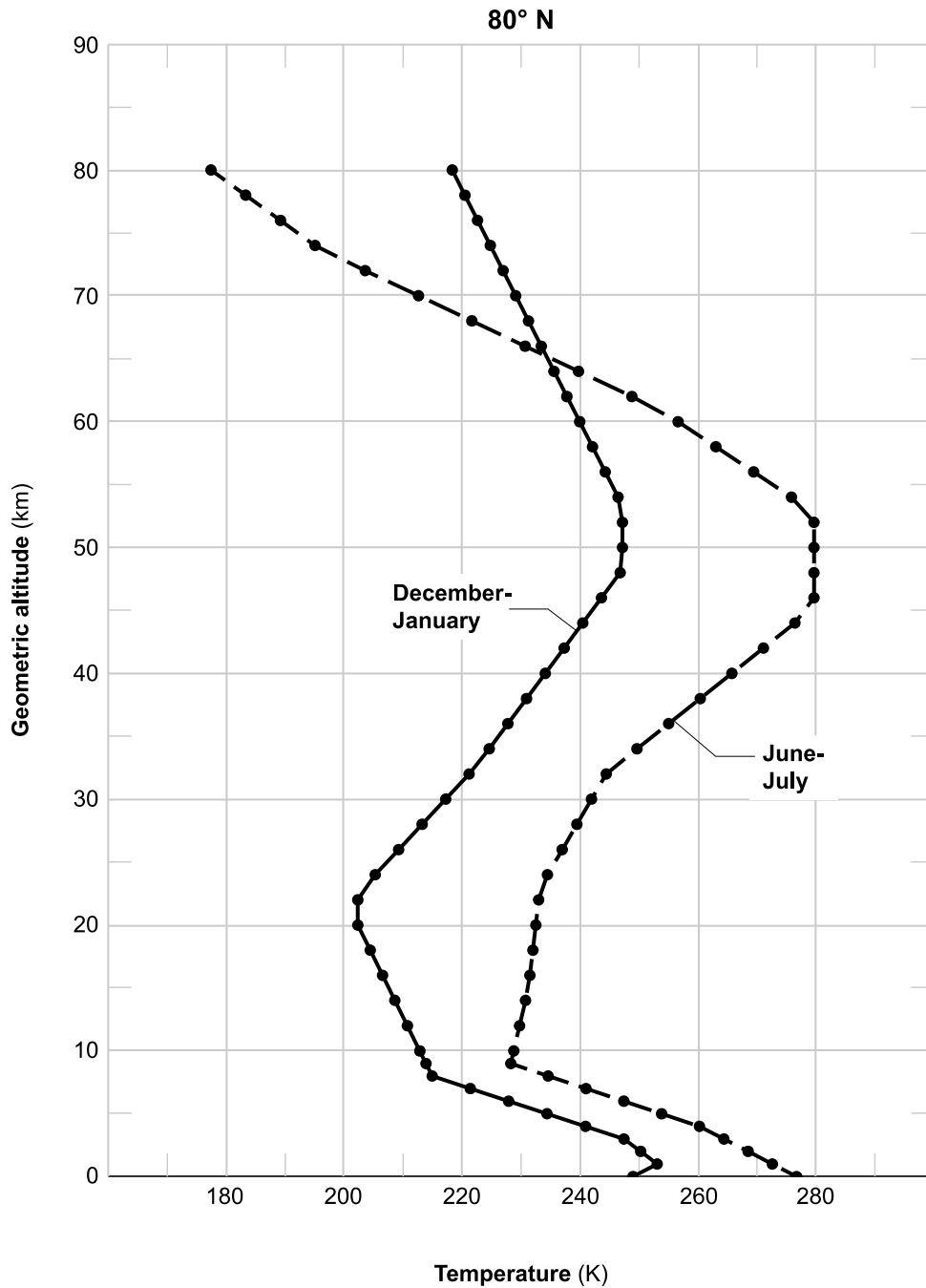
b) Temperature-altitude profiles for the mean December-January and June-July atmospheres for 30° N latitude



c) Temperature-altitude profiles for the mean December-January and June-July atmospheres for 45° N latitude



d) Temperature-altitude profiles for the mean December-January and June-July atmospheres for 60° N latitude



e) Temperature-altitude profiles for the mean December-January and June-July atmospheres for 80° N latitude

Figure 1 — Temperature-altitude profiles for the mean annual atmosphere for 15° latitude and for mean December-January and June-July atmospheres for 30° N, 45° N, 60° N and 80° N

4.2.3 Seasonal models for 30° N, 45° N, 60° N and 80° N

Temperature-altitude profiles for the mean December-January and June-July atmospheres for 30° N, 45° N, 60° N and 80° N are presented in [Figure 1](#) and [Clause A.4](#).

They are based on the temperature-altitude cross-sections in [Figure 2](#). The temperature distributions shown in [Figure 2](#) for levels below 30km were derived from routine radiosonde observations.

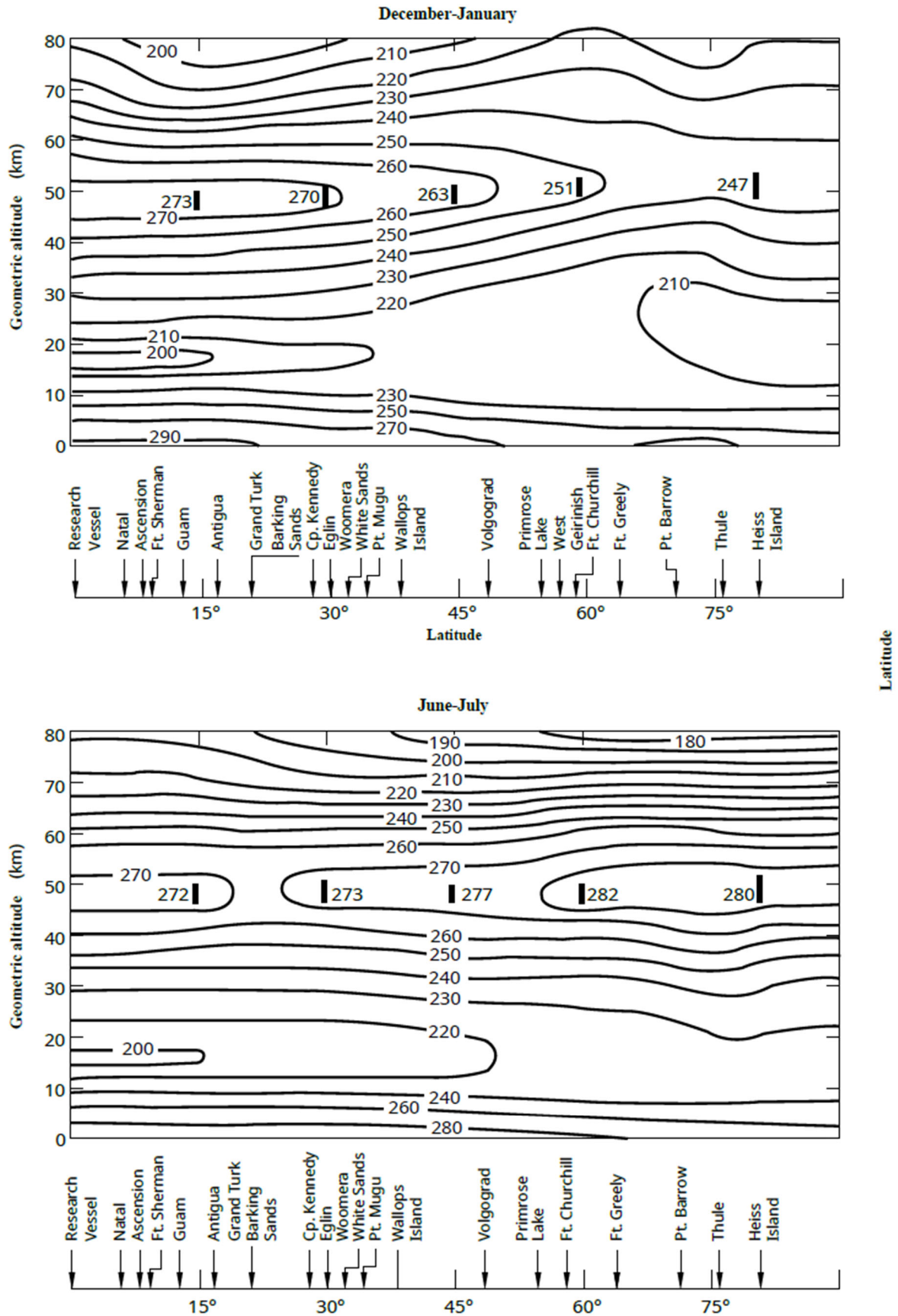


Figure 2 — Temperature-altitude cross-sections for December-January and June-July

Mean northern hemisphere values were computed at various latitudes from available summaries [17] by giving equal weight to observed and interpolated temperature data at each 10° of longitude (spatial averaging across longitudes). The initial pressures (sea-level values for each atmosphere) were obtained from monthly normal sea-level charts [6][42] of the northern hemisphere.

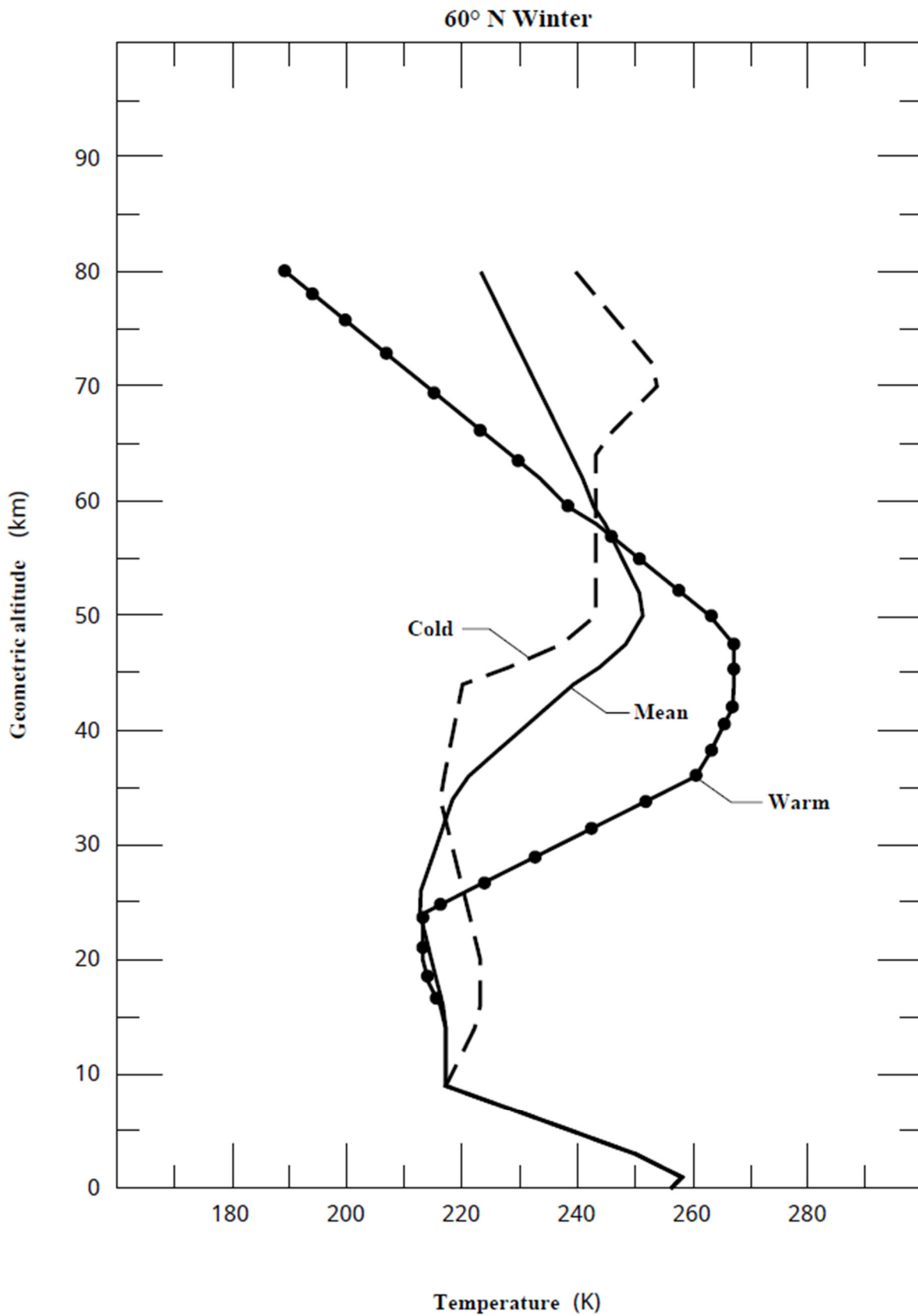
The temperature field between 30km and 50km is based on meteorological rocket measurements taken at locations shown in [Table A.19](#). Instrumentation consists primarily of parachute-borne telemetering sets with temperature-sensing elements (bead thermistors or resistance wires). Thermistor measurements are subject to large corrections and uncertainties above 50km. Consequently the thermistor data are used only for altitudes up to 50km. The temperature distributions between 50km and 80km are based primarily on grenade, falling sphere and pressure gauge experiments taken at locations shown in [Table A.20](#).

For temporal averaging of temperature observations, median rather than mean values are used since bimodal distributions of temperature occur at high latitudes in winter in the upper stratosphere and mesosphere. At other times and locations, distributions are nearly normal and the choice of median versus mean has minimal impact. Dates of observation for the southern hemisphere were adjusted by six months to conform to northern hemisphere seasons.

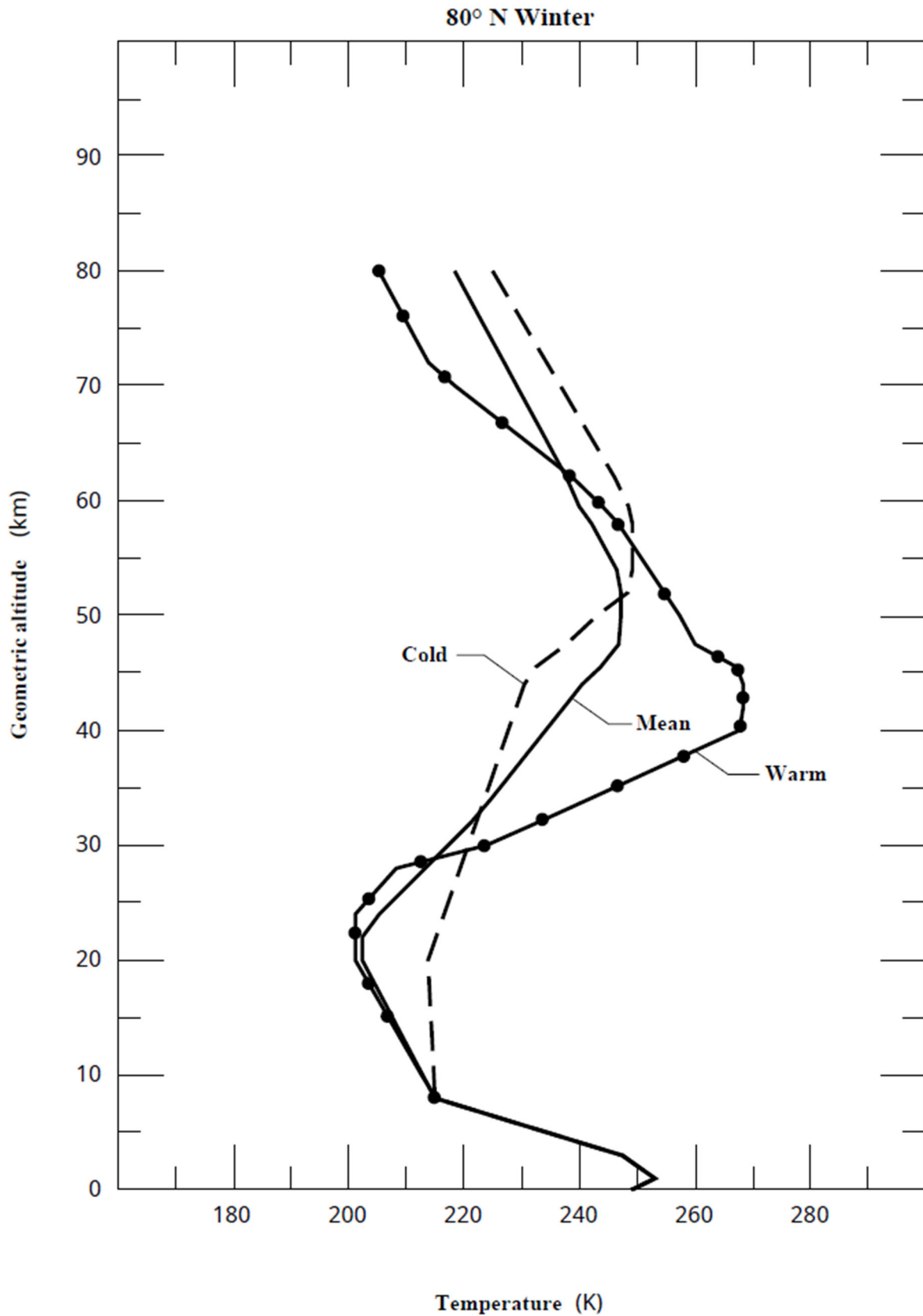
4.2.4 Cold and warm stratospheric and mesospheric regimes for 60° N and 80° N in December-January

In Arctic and sub-Arctic regions, sudden warmings and coolings of the winter stratosphere and mesosphere produce large changes in the vertical structure of the atmosphere. The magnitude and altitude of maximum temperature change during major warmings and coolings vary considerably. Some of the largest changes have been observed in the upper stratosphere. The winter temperature distributions in this region are bimodal and temperatures are normally much lower or much higher than the seasonal mean. Observed 35km temperatures, for example, have a range of roughly 75K in winter compared with 20K in summer. Consequently, mean monthly or seasonal atmospheric models for the winter months are of limited value for specifying the temperature in Arctic and sub-Arctic regions as the day-to-day variations in temperature at many levels in the stratosphere are as great as or greater than seasonal or latitudinal changes.

Vertical temperature profiles representative of the cold and warm stratospheric regimes that occur at 60° N and 80° N in December and January are shown in [Figure 3](#) and [Clause A.6](#).



a) Temperature-altitude profile for warm and cold for December-January atmospheres at 60° N



b) Temperature-altitude profile for warm and cold for December-January atmospheres at 80° N

Figure 3 — Temperature-altitude profiles for warm and cold for December-January atmospheres at 60° N and 80° N

The profiles for the warm and cold models at 60° N and 80° N were constructed from temperatures derived from radiosonde, rocket-sonde and grenade observations taken at:

- Ft. Greely, Alaska (64° N, 146° W)
- Ft. Churchill, Canada (59° N, 94° W) and
- West Geirinish, Scotland (57° N, 7° W).

The 80° N models are based on observations taken at:

- Heiss Island (81° N, 58° E).

The warm regimes are arbitrarily defined as periods when the observed temperature at 45km is within $\pm 2\text{K}$ of 267K, a value which is equalled or exceeded in 1%, 5%, 20% and 30% of the observations at Ft. Greely, Ft. Churchill, West Geirinish and Heiss Island, respectively.

The cold regimes are defined as periods when the observed temperature at 45km at 60° N is within $\pm 2\text{K}$ of 223K, and that at 80° N is within $\pm 2\text{K}$ of 232K. The temperature of 223K is equalled or exceeded in 98%, 95%, and 93% of the observations at West Geirinish, Ft. Churchill and Ft. Greely respectively, and 232K is exceeded in 80% of the observations from Heiss Island (223K is equalled or exceeded 90% of the time at Heiss Island).

NOTE The definitions of warm and cold regimes in this model differ from their counterparts defined in the Sudden Stratospheric Warming (SSW) literature [\[48\]](#).

Individual temperature soundings taken at Ft. Churchill, Ft. Greely, West Geirinish and Heiss Island which satisfied the temperature requirements for a particular model at 45km were averaged together to obtain a mean temperature-altitude profile between 8km and 80km. Mean seasonal conditions were assumed below 9km as the vertical temperature profiles that emerged at these levels were not significantly different from those for the mean seasonal conditions at 60° N and 80° N.

Locations and dates of soundings used in the construction of the warm and cold models are given in [Clause A.7](#). Due to the sparsity of data above 30km in Arctic and sub-Arctic regions, the frequencies of occurrence of the warm and cold models at the various locations are *rough estimates*.

4.3 Temporal and spatial variations

4.3.1 Seasonal and latitudinal variations

Maximum and minimum mean monthly temperatures between the surface and 80km do not occur at all latitudes and levels in the same month or season. Consequently, the tabulated temperatures for the December-January and June-July reference atmospheres for 30° N, 45° N, 60° N and 80° N ([Table A.25](#)) do not represent extreme seasonal temperatures at all altitudes. Nevertheless, they do provide a good indication of the magnitude of the seasonal and latitudinal temperature variability that can be expected at levels between the surface and 80km.

The maximum and minimum mean seasonal densities and pressures between the surface and 80km, however, normally occur in the June-July and December-January periods respectively between latitudes 30° N and 80° N ([Table A.26](#)).

At locations between 30° N and 80° N, maximum mean monthly temperatures at levels below 25km usually occur in June or July, and the minima in December or January. In the upper stratosphere, however, semi-annual and biennial cycles complicate the annual temperature cycle. The magnitude of the annual cycle is largest near

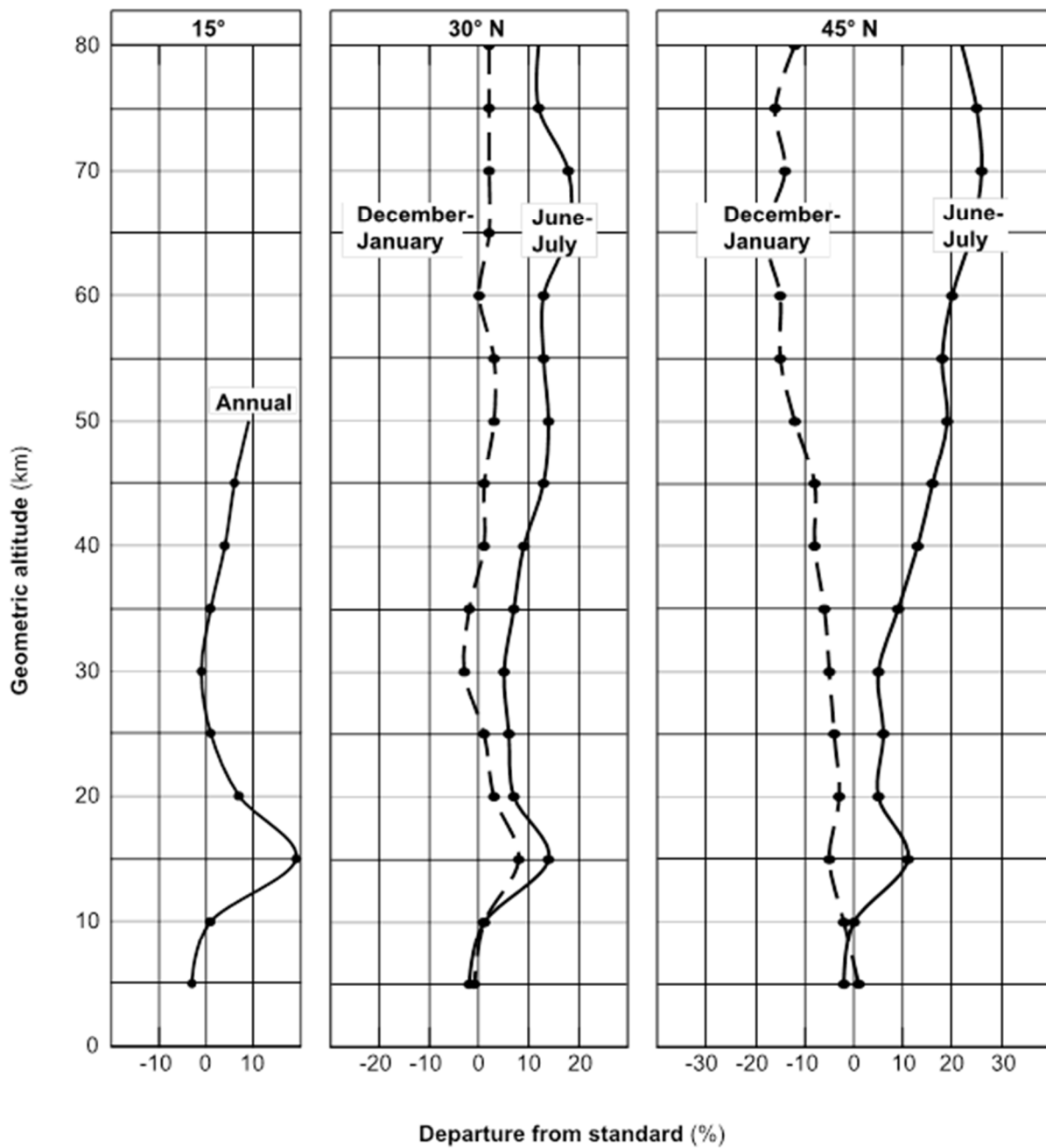
the poles, decreasing toward the equator. The semi-annual and biennial cycles are greatest near the equator, decreasing toward the poles. The phases as well as the amplitudes of these temperature oscillations change with latitude and altitude. At middle and high latitudes, the annual and semi-annual cycles tend to obscure the biennial oscillations.

Observations show that the semi-annual oscillation produces two pronounced maxima and minima within the annual stratospheric temperature cycle in tropical and sub-tropical regions. North of 25° latitude, the combined annual and semi-annual components occasionally shift the time of maximum temperature in the upper stratosphere to early June or May, and the minimum temperature to early December or November.

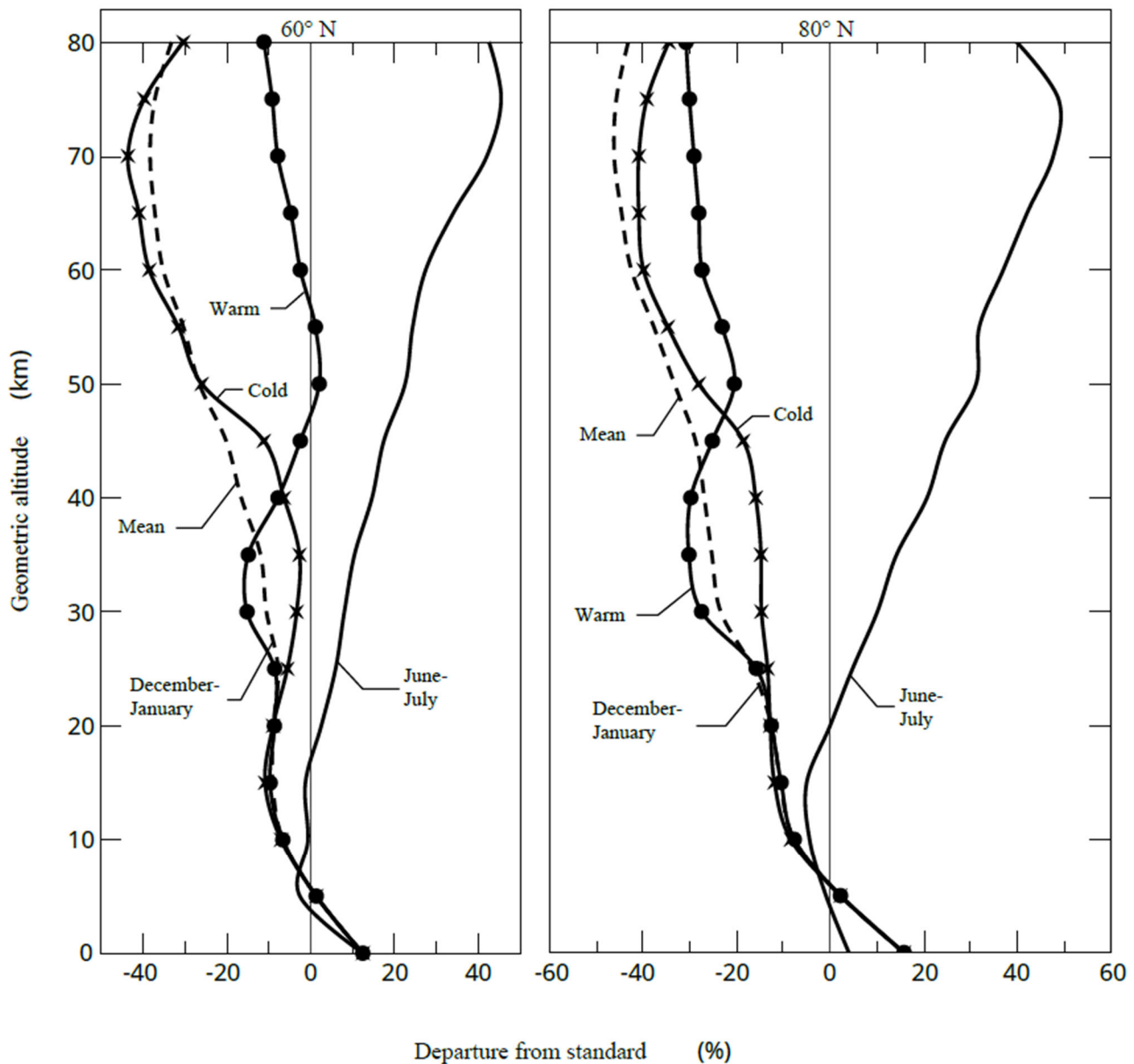
However, in cases where the maximum mean monthly stratospheric temperatures occur in May rather than June or July and the minimum in November rather than December or January, the differences between May and June and November and December values are only a few degrees. In the mesosphere, above 60km — 65km, the maximum mean monthly temperatures generally occur in December or January, and the minimum in June or July. An exception occurs at Heiss Island, where maximum temperatures are observed in late November and early December.

The vertical distribution of density is shown for the 15° latitude mean annual atmosphere and the December-January and June-July atmospheres for 30° N, 45° N, 60° N and 80° N in [Figure 4](#) as percentage departures from the ISA densities defined in [ISO/WD 2533](#). The maximum mean monthly densities at levels between 10km and 80km and latitudes 30° N to 80° N occur in June or July, and minimum values in December or January. Near the surface, pressures are usually highest in winter and lowest in summer.

The level of minimum seasonal variability of density near 8km represents the first isopycnic level where density remains relatively constant throughout the year regardless of geographic location. The levels of maximum seasonal and latitudinal variability in density and pressure are between 65km and 75km, and the variability is greatest at high latitudes.



a) Departures of reference atmosphere densities for 15° N (annual), 30° (Dec-Jan, Jun-Jul) and 45° N (Dec-Jan, Jun-Jul)



b) Departures of reference atmosphere densities for 60° N (Dec-Jan, Jun-Jul), 80° N (Dec-Jan, Jun-Jul)

Figure 4 — Departures of reference atmosphere densities (mean values from [Clause A.3](#))

4.3.2 Longitudinal variations

In summer, longitudinal variations in the structure of the atmosphere are relatively small at all latitudes compared with seasonal and latitudinal changes for levels up to 80 km. Isotherms and contour lines of constant-pressure charts in the stratosphere and mesosphere parallel the latitude circles, and the associated circulation pattern is symmetrical about the poles. During the winter season, changes with longitude remain small at low latitudes but become as important as those with latitude and season in Arctic and sub-Arctic regions [\[46\]](#).

At latitudes between 60° N and 80° N, longitudinal variations in the mean monthly altitudes of pressure surfaces in the lower mesosphere are greater than 2 500 m, mean monthly temperatures vary by 15 K to

20K at levels between 20km and 35km, and mean monthly densities change by 15% to 20% at levels between 40km and 60km [30]. These differences reflect the longitudinal asymmetry in the winter circulation pattern at high latitudes. The Aleutian anticyclone and the displacement of the polar low toward the Eurasian continent are important features of the mean monthly circulation patterns up to at least 80km during the northern hemisphere winter [29].

4.4 Frequency distributions of observed temperatures and densities

Statistical distributions of actual temperature and density observations relative to median values are provided in [Annex A](#).

NOTE The median is the percentile of 50%.

These distributions cover:

- Annual observations at 15° latitude
- December-January and June-July observations at 30° N, 45° N, 60° N and 80° N latitudes
- Altitude levels up to 80unitsml(km)

[Clause A.8](#) and [Clause A.9](#) show these distributions at 5km altitude increments, presenting:

- Median values
- High and low values exceeded in 1%, 10%, and 20% of observations

In particular,

- [Clause A.8](#) shows the median temperature and percentile temperature values;
- [Clause A.9](#) shows the median density and percentile density values as percentage departures from densities given by the ISO Standard Atmosphere model

Data sources of the observed temperature and densities vary by altitude:

- Below 30km : radiosonde observations taken in the northern hemisphere
- Above 30km : meteorological and experimental rocket observations from locations shown in [Clause A.5](#)

Data are only provided for levels up to 50km at 15° as there are insufficient observations on which to base temperature and density distributions above 50km in tropical areas. Confidence in the distributions decreases rapidly above 50km, where data are relatively sparse and instrumentation errors relatively large.

5 Wind

5.1 Introduction

A specification summarizing the characteristics of the wind is required for many practical problems, such as aircraft design, the planning and operation of air routes and airfields, estimates of the global transport of atmospheric contaminants, etc., in which the wind is one of the primary factors.

Air motions in the atmosphere occur as a result of phenomena related to air temperature and atmospheric pressure, the nature of the surface over which the air is moving, the rotation of the earth, etc. Such a complex relationship leads to large wind variations in time and space, including the seasonal variation of the general circulation of the atmosphere and the formation of disturbances on a wide range of scales from that of cyclones and anticyclones to that of small-scale turbulence.

The observed features of the wind distribution in the meridional plane are as follows:

- a) a predominantly easterly component in the airflow of the lower and middle troposphere of tropical latitudes, and in the whole of the atmosphere in equatorial latitudes;
- b) the existence of systematic meridional components in the zone 0° to 30° N — a northerly component in the lower troposphere and a southerly component in the middle troposphere;
- c) a predominantly westerly flow in sub-tropical latitudes (30° N to 40° N); the wind speed increases sharply with altitude, reaching a maximum at altitudes of 10km to 13km in the subtropical jet stream;
- d) in temperate latitudes (40° N to 60° N), a generally westerly flow having a wave-like form; jet streams with axes at altitudes of about 8km to 9km are associated with systems of mobile cyclones and are therefore more variable than the sub-tropical jet stream and much of the detail of their structure and location is lost in the averaging process;
- e) in the stratosphere, the air flow is characterized by a seasonal of monsoon-type of direction change; to the north of 30° N, westerly winds occur in winter, changing to easterly in summer, with negative wind shears (wind speed decreasing with height) prevailing in the altitude range 9km to 20km ; to the north of 60° N to 65° N, abrupt positive wind shears prevail in winter, and there is a strong westerly jet stream in the polar stratosphere.

This document is intended to provide a summary of the wind characteristics of the atmosphere, in order to present them in a form that is useful for practical applications for users who may not be specialists in meteorology. The characteristics are presented in the form of tables and diagrams, and the data are averaged over major regions.

NOTE This document is not meant to supplant the need of meteorologists for detailed information on the wind characteristics of the atmosphere, of which a huge store of climatological material is available from the World Meteorological Organization (WMO) and national meteorological services as detailed tables and atlases of the wind characteristics ([5], [22], [23]).

5.2 Methodological aspects and analysis of the data

The tables and graphs given are based on a comprehensive study and statistical analysis of wind data for the earth's surface face and eight isobaric surfaces over the northern hemisphere.

The analysis is based on a large and uniform statistical sample, the major part of which has been published [13], [15]. About two million observations from 369 aerological stations for the nine year period 1957 to 1965 were processed. In addition, statistical data from 50 further stations [17], [31] were included in the analyses. Other works [5], [22] were also used.

The following maps were compiled on the basis of the average monthly wind characteristics at the main isobaric surfaces:

- a) mean scalar wind speed, $\overline{V}_s$;
- b) mean zonal component (zonal component of the vector mean wind), $\overline{V}_x$;

- c) mean meridional component (meridional component of the vector mean wind), $\overline{V}_y$;
- d) standard deviation of the zonal component of the wind, σ_x
- e) standard deviation of the meridional component of the wind, σ_y .

The seasonal changes of the wind characteristics at the different isobaric surfaces and the effects of topography and surface roughness were taken into account in the analysis of the maps and in drawing isotachs.

The information read off at the grid points at intervals of 10° of longitude and 10° of latitude for the earth's surface and for the 850mbar , 700mbar , 500mbar , 300mbar , 200mbar , 100mbar , 50mbar and 30mbar isobaric surfaces served as a basis for the calculation of the average wind characteristics within each of the latitude zones.

Thus the mean value for a zone, $\overline{V}$, of a characteristic is given by the equation [Formula \(16\)](#).

$$\overline{V} = \frac{1}{n} \sum_{i=1}^n \overline{V}_i \quad (16)$$

where

- $\overline{V}$ is the mean value of the characteristic for the zone, expressed in metres per second (ms⁻¹);
- $\overline{V}_i$ is the monthly mean value of the characteristic at the i -th grid point, expressed in metres per second (ms⁻¹);
- V_i is the value of the characteristic at the i -th grid point, expressed in metres per second (ms⁻¹);
- n is the number of grid points within the region of averaging for each latitude circle, $n = 36$.

Then the corresponding standard deviation, σ , is given the equation [Formula \(17\)](#).

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n \sigma_i^2 + \frac{1}{n} \sum_{i=1}^n (\overline{V}_i - \overline{V})^2} \quad (17)$$

where

- σ is the standard deviation of the characteristic for the zone, expressed in metres per second (ms⁻¹);
- σ_i is the standard deviation at the i -th grid point;
- $\overline{V}$ is the mean value of the characteristic for the zone, expressed in metres per second (ms⁻¹);
- $\overline{V}_i$ is the monthly mean value of the characteristic at the i -th grid point, expressed in metres per second (ms⁻¹);
- V_i is the value of the characteristic at the i -th grid point, expressed in metres per second (ms⁻¹);
- n is the number of grid points within the region of averaging for each latitude circle, $n = 36$.

For each isobaric surface, the mean values of the zonal and meridional components of the wind and the values of the scalar mean wind speed were calculated from [Formula \(16\)](#), and the standard deviations of the components from [Formula \(17\)](#). Each of the wind characteristics was plotted as a function of the geopotential altitude H , using the mean value of H for each isobaric surface. The values interpolated from these plots for the required values of H were used in constructing the tables in [Annex B](#).

5.3 Wind models

Taking into account the features of the atmospheric circulation over the northern hemisphere, namely the presence of long waves within certain latitude zones and the existence of jet streams in certain locations, the wind fields may be represented by the following models:

- a) For latitude zones; in addition, within each latitude zone data derived from actual observations are given for two selected stations, one with very strong winds and the other with very light winds ([Tables B.1 to B.3](#); [Figure 5](#)).
- b) For meridional cross-sections ([Tables B.4 and B.5](#); [Figure 6](#)) supplement the models and illustrate the global circulation over the northern hemisphere.

Specifically, models are presented for the following latitude zones and meridians:

tropical zone	0° N — 20° N. This is the zone of the trade-wind circulation and easterly jet streams in the near-equatorial upper troposphere and stratosphere.
sub-tropical zone	20° N — 40° N. This is the zone of the strong westerly sub-tropical jet stream (at altitudes of 10km to 13km).
temperate zone	40° N — 60° N. This is the zone of strong cyclonic activity and maximum horizontal turbulent exchange.
polar zone	60° N — 80° N. This is the zone of the polar night stratospheric westerly jet stream of winter.
meridional cross-section along 140° E	This illustrates the circulation near the east Asian coastline of the Pacific Ocean, where the sub-tropical jet stream reaches its maximum intensity.
meridional cross-section along 80° E	This illustrates the circulation over the Siberian anticyclone in winter, the jet streams over Tibet, the monsoon circulation over India and the easterly jet stream over the northern parts of the Indian Ocean.
meridional cross-section along 20° E	The meridian crosses eastern Europe and central Africa, and the cross-section is characteristic of the area of cyclonic activity over Europe and the Mediterranean and of the subtropical jet stream over northern Africa.
meridional cross-section along 80° W	The meridian crosses the eastern regions of North America and the Caribbean Sea, and the profile illustrates the jet streams over the western Atlantic.

The values of the quantities describing the wind fields, obtained for the altitude range 0km to 25km from actual observations and by estimation using the circular normal distribution, are presented for the above models for January and July.

The following quantities were obtained from the actual observations:

- mean zonal component of the wind, $\overline{V_x}$, and mean meridional component of the wind, $\overline{V_y}$;
- vector mean wind, $\vec{V_r}$, magnitude of the vector mean wind, V_r , and direction of the vector mean wind, θ ; the scalar mean wind speed, $\overline{V_s}$;
- standard deviation of the vector mean wind, σ_r ;
- maximum wind speed observed once in ten years, $v_{\max}$.

The speeds equalled or exceeded on 1% , 10% , 20% , 80% , 90% and 99% of occasions were calculated using the circular normal distribution. The scalar mean wind speed, $\bar{V}_s$ for each zone was both obtained from the actual observations, $\bar{V}_{sa}$ and calculated using the law of circular normal distribution, $\bar{V}_{sc}$.

For four meridional sections the mean speed $\bar{V}_s$ is given only based on actual observations — $\bar{V}_{sa}$.

5.4 Calculation of wind characteristics by use of the circular normal distribution

Wind is a vector. In a sample of a large number of winds observed over a long period of time, each individual vector is a stochastic, or random, value, and for estimating wind distributions, probability theory may be used.

The symbols used for the calculation of wind characteristics are summarized in [Table 3](#).

Table 3 — Wind characteristics symbols

Symbol	Description
$\bar{V}_x$	Mean zonal component of the wind
$\bar{V}_y$	Mean meridional component of the wind
$\vec{V}_r$	Vector mean wind
V_r	Magnitude of the vector mean wind
θ	Direction of the vector mean wind
$\bar{V}_s$	Scalar mean wind speed
σ_r	Standard deviation of the vector mean wind
σ_x	Standard deviation of the zonal component of the wind
σ_y	Standard deviation of the meridional component of the wind
v	Wind speed
$v_{\max}$	Maximum wind speed observed once in ten years
$\bar{V}_{sa}$	Scalar mean wind speed obtained from actual observations
$\bar{V}_{sc}$	Scalar mean wind speed calculated using the circular normal distribution

For the calculation of the characteristics, the circular normal distribution may be used, the probability density, $f(v)$, being given by the equation in [Formula \(18\)](#).

$$f(v) = \frac{2v}{\sigma_r^2} - \frac{v^2 + \bar{V}_r^2}{\sigma_r^2} \times I_0 \left(\frac{2v\bar{V}_r}{\sigma_r^2} \right) \quad (18)$$

where

$f(v)$ is the probability density function for wind characteristics, expressed in inverse metres per second ($\text{units ml(m/s)}^{-1}$);

v is the wind speed, expressed in metres per second (ms^{-1});

$\bar{V}_r$ is the magnitude of the vector mean wind, expressed in metres per second (ms^{-1});

σ_r is the standard deviation of the vector mean wind, expressed in metres per second (ms^{-1});

$I_0(x)$ is the zero-order Bessel function of imaginary argument.

The circular normal distribution law may be regarded as valid for the four latitude zones, since $\sigma_x = \sigma_y = \sigma_r/\sqrt{2}$, taking into account that $\sigma_r = \sqrt{\sigma_x^2 + \sigma_y^2}$, with an accuracy acceptable for most practical purposes.

In addition, for calculating the mean characteristics for latitude zones above 20° N, where $\bar{V}_y$ does not exceed 6% of $\bar{V}_x$, and the absolute value is not more than 1ms^{-1} , it is assumed that $\bar{V}_y = 0$, so that $\bar{V}_r = |\bar{V}_r| = |\bar{V}_x|$.

This allows the basic parameters of the distribution for zones 20° N — 40° N, 40° N — 60° N and 60° N — 80° N to be determined by $\bar{V}_x$ and σ_r only.

The values of wind speed which are likely to be equalled or exceeded on 1%, 10%, 20%, 80%, 90% and 99% of occasions may be estimated from [Formula \(18\)](#). The expected scalar mean speed, $\bar{V}_{sc}$, is given by [Formula \(19\)](#) (mathematical expectation).

$$\bar{V}_{sc} = \int_0^{\infty} f(v) V dv \quad (19)$$

where

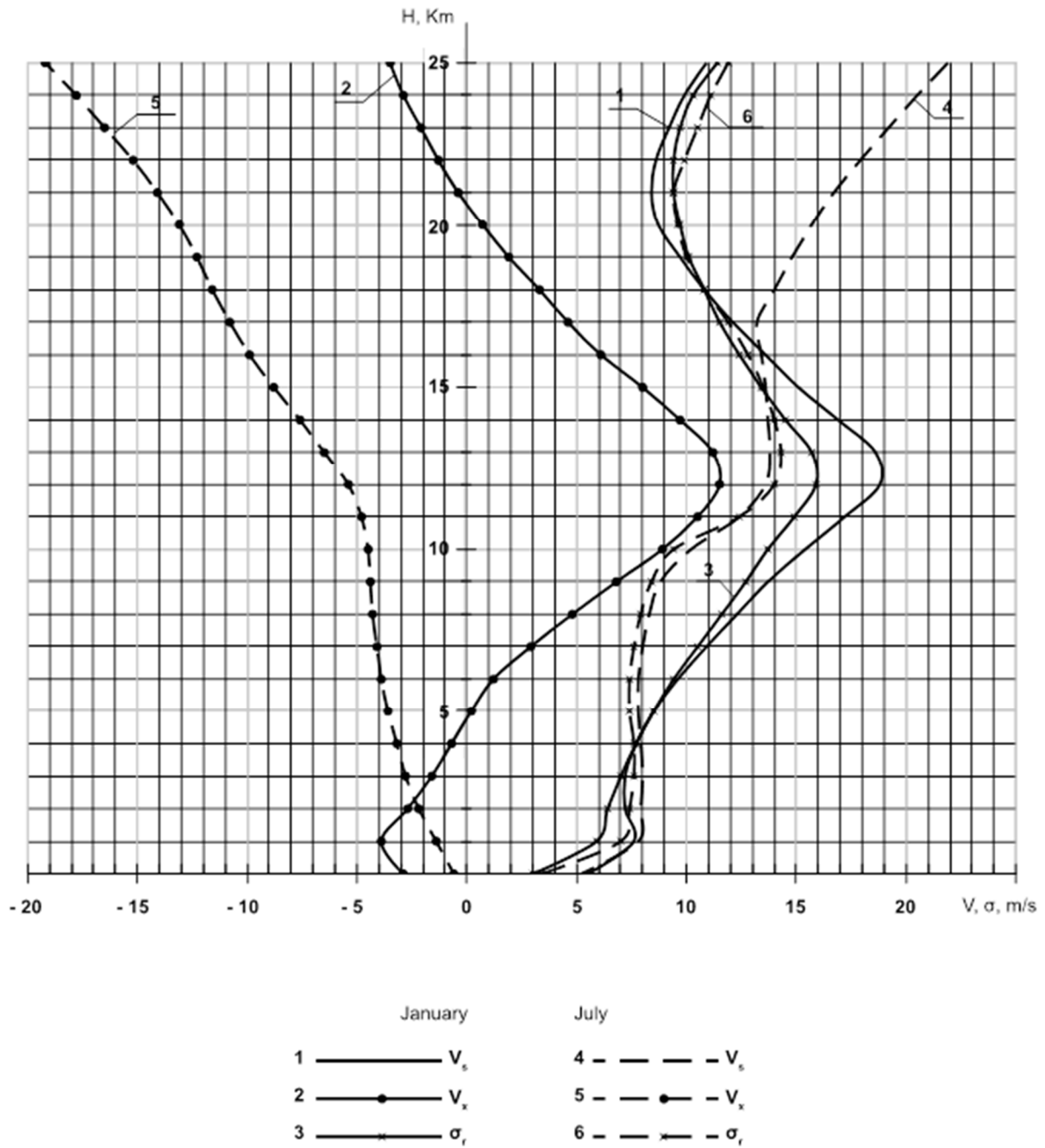
$\bar{V}_{sc}$ is the scalar mean wind speed calculated using the circular normal distribution, expressed in metres per second (ms^{-1});

$f(v)$ is the probability density function, expressed in inverse metres per second ($\text{units ml}(\text{m/s})^{-1}$);

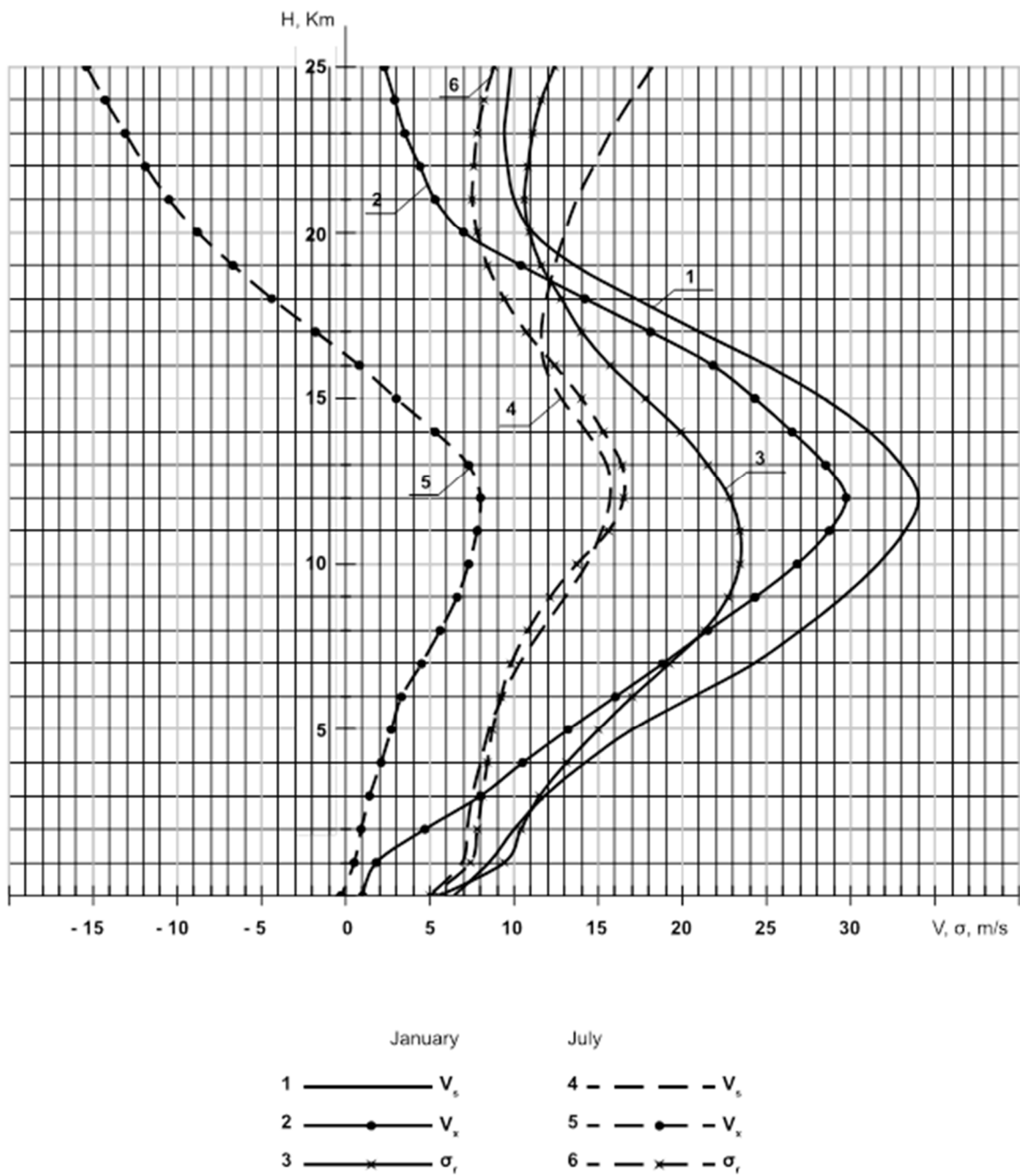
V is the characteristic of the zone, expressed in metres per second (ms^{-1});

v is the wind speed, expressed in metres per second (ms^{-1}).

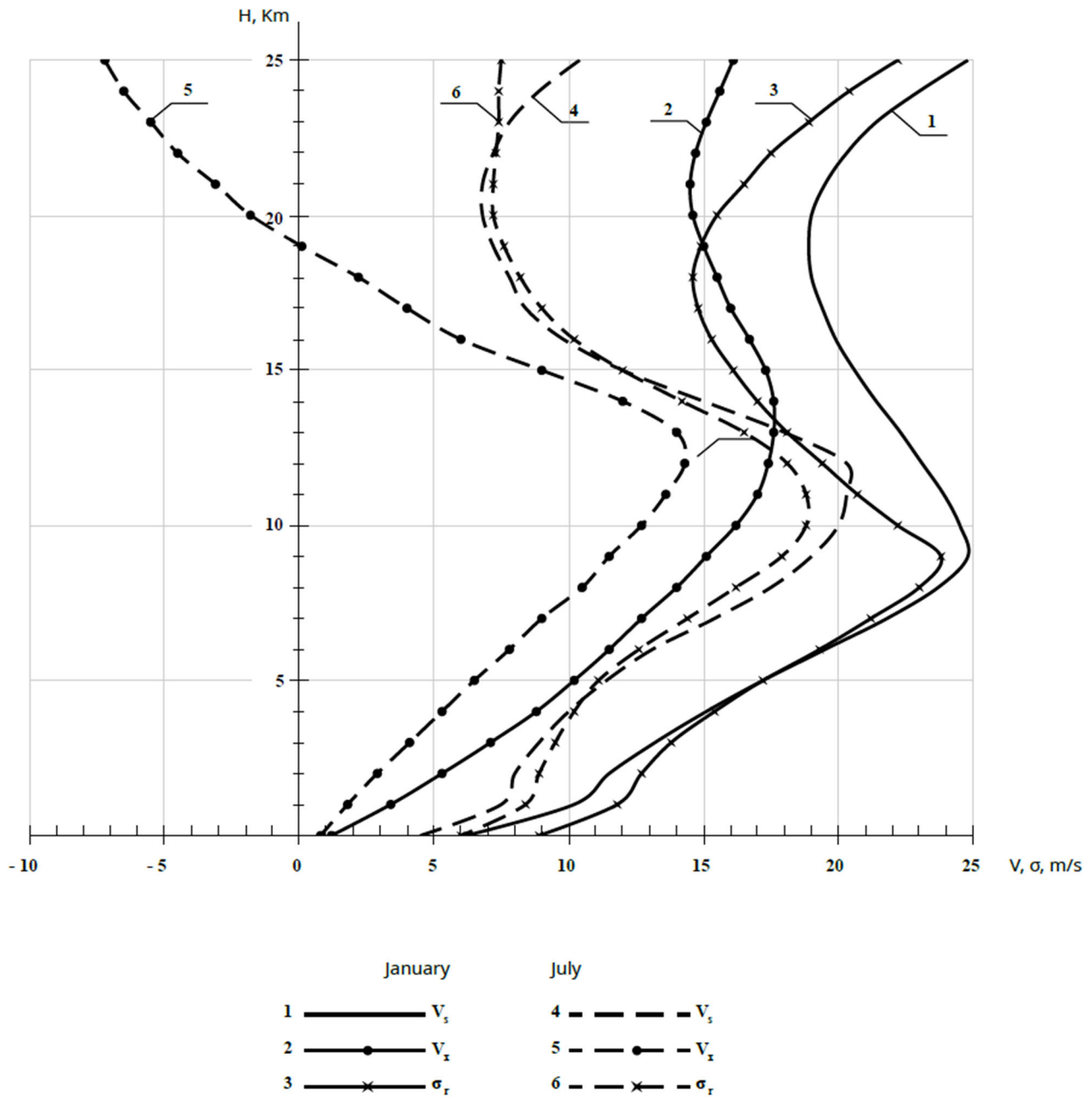
The analysis of the scalar mean speed derived from observations, and calculated from the circular normal distribution for each zone confirms that the circular normal distribution may be used to calculate the values of wind speed with an accuracy sufficient for most practical purposes.



a) Mean profiles of the wind characteristics for the latitude zone $0^\circ - 20^\circ \text{ N}$



b) Mean profiles of the wind characteristics for the latitude zone 20° N - 40° N



c) Mean profiles of the wind characteristics for the latitude zone 40° N - 60° N