International Standard 5878

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Reference atmospheres for aerospace use

Atmosphères de référence pour l'application aérospatiale

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Foreword

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The number bodies of the following countries expressed disapproval of the document on technical grounds:

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Reference atmospheres for aerospace use

1 Scope and field of application

This International Standard presents information on the seasonal, latitudinal, longitudinal and day-to-day variability of atmospheric properties at levels between the surface and 80 km.

2 Basis

The systematic (latitudinal and seasonal) variation of atmospheric properties is shown for altitudes up to 80 km by a family of models, comprising the following 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.

a) 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.

b) 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.

c) The air is assumed to be a perfect gas, free from moisture and dust.

d) The molar mass of dry air, $M = 28{,}964\ 420$ kg · kmol^{-1}, is assumed to be constant at altitudes up to 80 km. The specific gas constant of dry air R, is equal to 287,052 87 J · K^{-1} · kg^{-1} (table 1).

e) 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 1 — Main values used for the calculation of the reference atmospheres

Symbol	Value	SI units of measurement
g_n	9,806 65	m · s^{-2}
M	28,964 420	kg · kmol^{-1}
N_A	602,257 × 10^{24}	kmol^{-1}
R^*	8 314,32	J · K^{-1} · kmol^{-1} or kg · m^2 · s^{-2} · K^{-1} · kmol^{-1}
R	287,052 87	J · K^{-1} · kg^{-1} or m^2 · K^{-1} · s^{-2}

2.1 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 2533, "Standard Atmosphere", 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, and the values of the acceleration of free fall at sea level for latitudes other than 45° were obtained from Lambert's equation[1], in which gravity varies with latitude φ:

$$g_{0\varphi} = 9{,}806\ 16\ (1 - 0{,}002\ 637\ 3 \cos 2\varphi + 0{,}000\ 005\ 9 \cos^2 2\varphi)\ [\mathrm{m \cdot s^{-2}}]$$

Values from this relationship, along with surface temperatures and pressures, are given in table 2. For 45° N, values of $g_{0\varphi}$ and r_φ are taken from ISO 2533.

2.2 The hydrostatic equation and the perfect gas law

Being static with respect to the earth, the atmosphere is subject to gravitational forces. The conditions of air in static equilibrium are specified by the hydrostatic equation, which relates air pressure p, density ϱ, acceleration of free fall g and geometric altitude h as follows:

$$-\mathrm{d}p = \varrho\, g\, \mathrm{d}h \qquad \ldots (1)$$

The perfect gas law relates air pressure to density and temperature as follows:

$$p = \frac{\varrho R^* T}{M} \qquad \ldots (2)$$

At the altitudes of interest, $\frac{R^*}{M}$ = constant = R; hence

$$p = \varrho R T \qquad \ldots (3)$$

2.3 Geopotential and geometric altitudes; acceleration of free fall

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

Any point having coordinates x, y, z may be characterized by a single value of the geopotential $\Phi(x, y, z)$. The surface defined by the equation $\Phi\ (x, y, z)$ = constant has the same geopotential at all points and is called a geopotential surface. When moving along an external normal from any point on the surface Φ_1, to an infinitely close point on a second surface where the geopotential is $\Phi_2 = \Phi_1 + \mathrm{d}\Phi$, the work performed in shifting a unit mass from the first surface to the second will be

$$\mathrm{d}\Phi = g(h)\mathrm{d}h \qquad \ldots (4)$$

hence

$$\Phi = \int_0^h g(h)\mathrm{d}h \qquad \ldots (5)$$

By dividing the geopotential Φ by the standard acceleration of free fall g_n, a quantity H with a dimension of length is obtained, where

$$H = \frac{\Phi}{g_\mathrm{n}} = \frac{1}{g_\mathrm{n}} \int_0^h g(h)\mathrm{d}h \qquad \ldots (6)$$

Expressed in metres, the value H is numerically equal to the geopotential altitude, which in meteorology is measured in so-called standard geopotential metres; hence this value is called the geopotential altitude. Mean sea level is taken as a reference for both geopotential and geometric altitudes.

From equation (6) it can be seen that in order to relate geopotential and geometric altitude it is necessary first to find a relation between the acceleration of free fall g, and the geometric altitude h.

Table 2 — Acceleration of free fall at sea level $g_{0\varphi}$, nominal earth's radius r_φ from [1] and sea-level temperature and pressure for each latitudinal and seasonal model

Latitude φ	Acceleration of free fall $g_{0\varphi}$, $\mathrm{m \cdot s^{-2}}$	Nominal earth's radius r_φ, km	Temperature T, K		Pressure p, kPa, mbar	
			December-January	June-July	December-January	June-July
15°	9,783 81	6 337,84	299,650	299,650	1,013 250 × 10³	1,013 250 × 10³
30° N	9,793 24	6 345,65	283,150	297,150	1,020 500	1,014 000
45° N	9,806 65	6 356,77	272,650	291,150	1,018 000	1,013 500
60° N	9,819 11	6 367,10	256,150	282,150	1,013 000	1,010 200
80° N	9,830 51	6 376,56	248,950	276,650	1,013 800	1,012 000

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:

$$g_\varphi(h) = g_{0\varphi}\left(\frac{r_\varphi}{r_\varphi + h}\right)^2 \qquad \ldots (7)$$

where

r_φ is the nominal radius of the earth at a specific latitude and is taken from table 2;

$g_{0\varphi}$ is the acceleration of free fall at sea level for latitude φ.

Integration of equation (6), after substituting for $g_\varphi(h)$ from equation (7), gives the following relationship between geopotential and geometric altitudes:

$$H = \frac{r_\varphi h}{r_\varphi + h} \cdot \frac{g_{0\varphi}}{g_n} \qquad \ldots (8)$$

$$h = \frac{r_\varphi H}{\dfrac{g_{0\varphi}}{g_n} r_\varphi - H} \qquad \ldots (9)$$

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 equation (7) and in the more precise equation (10) from reference [1] are equal.

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

where h is expressed in metres and g in metres per second squared.

The partial derivatives of g_φ with respect to h for $h = 0$ are, from equation (10):

$$\left(\frac{\partial g_\varphi}{\partial h}\right)_{h=0} = -3{,}085\,462 \times 10^{-6} - 2{,}27 \times 10^{-9} \cos 2\varphi \qquad \ldots (11)$$

and, from equation (7):

$$\left(\frac{\partial g_\varphi}{\partial h}\right)_{h=0} = -\frac{2\, g_{0\varphi}}{r_\varphi} \qquad \ldots (12)$$

Equating the right-hand sides of (11) and (12), we have

$$r_\varphi = g_{0\varphi} \frac{2}{3{,}085\,462 \times 10^{-6} + 2{,}27 \times 10^{-9} \cos 2\varphi} \qquad \ldots (13)$$

where r_φ is expressed in metres and $g_{o\varphi}$ in metres per second squared.

The values of r_φ for the latitudes of the reference atmospheres are given in table 2.

3 Atmospheric models to 80 km altitude

The reference atmospheres are defined by the vertical temperature profiles for each latitude and season [see clause 2, paragraph b)]. Vertical pressure and density distributions were calculated from the temperature-altitude profiles using the hydrostatic equation (1) and the perfect gas law (3) from clause 2 and the appropriate mean sea-level values of pressure. Tables 3-15 of the temperature and other properties of the reference atmospheres are given in clause 6. Brief descriptions of seasonal, latitudinal, longitudinal and day-to-day variations of temperature and density are included in clause 4.

3.1 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 Voyeikov and Shokalsky (20° S).

Features typical of the thermal structure of the tropical atmosphere are shown in figure 1 and in table 3. For example, routine averaging of monthly temperature-altitude data indicates as isothermal layer about 2 km thick from 16 to 18 km. 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 16,5 km, 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 2 and 3 km, over tropical ocean areas, have also been included in the 15° latitude temperature-altitude profile.

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

Temperature-altitude profiles for the mean December-January and June-July atmospheres for 30, 45, 60 and 80° N are presented in figure 1 and table 16. They are based on the temperature-altitude cross-sections in figure 2. The temperature distributions shown in figure 2 for levels below

30 km were derived from routine radiosonde observations. Mean northern hemisphere values were computed at various latitudes from available summaries [2] by giving equal weight to observed and interpolated temperature data at each 10 degrees of longitude. The initial pressures (sea-level values for each atmosphere) were obtained from monthly normal sea-level charts [3, 4] of the northern hemisphere.

The temperature field between 30 and 50 km is based on meteorological rocket measurements taken at locations shown in table 17. 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 50 km. Consequently the thermistor data are used only for altitudes up to 50 km. The temperature distributions between 50 and 80 km are based primarily on grenade, falling sphere and pressure gauge experiments taken at locations shown in table 18.

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 distributions are nearly normal. Dates of observation for the southern hemisphere were adjusted by six months to conform to northern hemisphere seasons.

3.3 Cold and warm stratospheric and mesospheric regimes for 60 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 35 km temperatures, for example, have a range of roughly 75 K in winter compared with 20 K in summer. Consequently, mean monthly or seasonal atmospheric models for the winter months are of limited value for specifiyng 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 and 80° N in December and January are shown in figure 3 and table 19. The profiles for the warm and cold models at 60° N were constructed from temperatures derived from radiosonde, rocketsonde 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 45 km is within ± 2 K of 267 K, 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 45 km at 60° N is within ± 2 K of 223 K, and that at 80° N is within ± 2 K of 232 K. The temperature of 223 K is equalled or exceeded in 98, 95, and 93% of the observations at West Geirinish, Ft. Churchill and Ft. Greely respectively, and 232 K is exceeded in 80% of the observations from Heiss Island (223 K is equalled or exceeded 90% of the time at Heiss Island).

Individual temperature soundings taken at Ft. Churchill, Ft. Greely, West Geirinish and Heiss Island which satisfied the temperature requirements for a particular model at 45 km were averaged together to obtain a mean temperature-altitude profile between 8 and 80 km. Mean seasonal conditions were assumed below 9 km as the vertical temperature profiles that emerged at these levels were not significantly different from those for the mean seasonal conditions at 60 and 80° N. Locations and dates of soundings used in the construction of the warm and cold models are given in table 20. Due to the sparsity of data above 30 km in Arctic and sub-Arctic regions, the frequencies of occurrence of the warm and cold models at the various locations are *rough estimates.*

4 Temporal and spatial variations

4.1 Seasonal and latitudinal variations

Maximum and minimum mean monthly temperatures between the surface and 80 km 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, 45, 60 and 80° N (table 21) 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 80 km.

The maximum and minimum mean seasonal densities and pressures between the surface and 80 km, however, normally occur in the June-July and December-January periods respectively between latitudes 30 and 80° N (table 22).

At locations between 30 and 80° N, maximum mean monthly temperatures at levels below 25 km 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 60 – 65 km, 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, 45, 60 and 80° N in figure 4 as percentage departures from the ISO standard densities. The maximum mean monthly densities at levels between 10 and 80 km and latitudes 30 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 8 km 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 65 and 75 km, and the variability is greatest at high latitudes.

4.2 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[13].

At latitudes between 60 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 to 20 K at levels between 20 and 35 km, and mean monthly densities change by 15 to 20% at levels between 40 and 60 km[14]. 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 80 km during the northern hemisphere winter[15].

5 Frequency distributions of observed temperatures and densities

The distributions of observed temperatures and densities around median*) values for December-January and June-July for 30, 45, 60 and 80° N and annual medians at 15° are shown in tables 21 and 22 respectively, for levels up to 80 km. Medians and high and low values which are equalled or exceeded in 1, 10 and 20% of cases are given at 5 km altitude increments. Densities are given as percentage departures from the ISO standard densities. Distributions for levels below 30 km are based on radiosonde observations taken in the northern hemisphere, and those above on meteorological and experimental rocket observations from locations shown in tables 17 and 18.

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

*) The median is the percentile of 50%.

6 Tables of properties of the reference atmospheres

NOTE — A one- or two-digit number preceded by a plus of minus sign following each of pressure and density indicates the power of ten by which that entry should be multiplied.

Table 3 — Mean annual values of characteristics at 15°

h	*H*	*T*	*t*	*p*		*ϱ*	
m	m	K	°C	hPa, mbar		$kg \cdot m^{-3}$	
0	0	299,650	26,50	1,013 250	03	1,177 987	00
1 000	998	293,665	21,52	9,032 869	02	1,071 548	00
2 000	1 995	287,682	14,53	8,033 849	02	9,728 581	−01
3 000	2 992	283,656	10,50	7,132 021	02	8,759 075	−01
4 000	3 988	276,979	5,83	6,316 301	02	7,944 263	−01
5 000	4 984	270,304	−1,15	5,577 544	02	7,188 330	−01
6 000	5 980	263,632	−9,52	4,910 097	02	6,488 298	−01
7 000	6 976	256,961	−16,19	4,308 599	02	5,841 269	−01
8 000	7 971	250,292	−22,86	3,767 974	02	5,244 434	−01
9 000	8 966	243,626	−29,52	3,283 418	02	4,695 060	−01
10 000	9 961	236,961	−36,19	2,850 398	02	4,190 503	−01
12 000	11 949	223,639	−49,51	2,122 104	02	3,305 654	−01
14 000	13 937	210,325	−62,82	1,551 827	02	2,570 343	−01
16 000	15 923	197,019	−76,13	1,112 046	02	1,966 313	−01
18 000	17 907	198,779	−74,37	7,864 157	01	1,378 225	−01
20 000	19 891	206,713	−66,44	5,629 715	01	9,487 626	−02
22 000	21 873	214,641	−58,51	4,082 017	01	6,625 209	−02
24 000	23 854	218,858	−54,59	2,987 766	01	4,755 795	−02
26 000	25 833	222,817	−50,33	2,199 570	01	3,438 964	−02
28 000	27 812	226,774	−46,38	1,628 370	01	2,501 488	−02
30 000	29 789	230,728	−42,42	1,212 014	01	1,829 974	−02
32 000	31 765	236,092	−37,06	9,075 227	00	1,339 103	−02
34 000	33 740	241,621	−31,53	6,842 101	00	9,864 886	−03
36 000	35 713	247,147	−26,00	5,192 440	00	7,319 035	−03
38 000	37 686	252,670	−20,48	3,965 297	00	5,467 150	−03
40 000	39 657	258,188	−14,96	3,046 371	00	4,110 401	−03
42 000	41 626	262,728	−10,82	2,352 931	00	3,119 903	−03
44 000	43 595	267,059	−6,09	1,825 355	00	2,381 105	−03
46 000	45 562	271,387	−1,76	1,422 088	00	1,825 475	−03
48 000	47 528	272,350	−0,80	1,111 163	00	1,421 309	−03
50 000	49 493	272,350	−0,80	8,684 371	−01	1,110 834	−03
52 000	51 457	271,254	−1,90	6,787 593	−01	8,717 218	−04
54 000	53 419	266,544	−6,61	5,289 756	−01	6,913 604	−04
56 000	55 380	261,009	−12,14	4,103 663	−01	5,477 140	−04
58 000	57 340	255,129	−18,02	3,165 824	−01	4,322 791	−04
60 000	59 299	249,253	−23,90	2,427 992	−01	3,393 472	−04
62 000	61 256	242,753	−30,40	1,850 269	−01	2,655 271	−04
64 000	63 213	235,906	−37,24	1,399 430	−01	2,066 572	−04
66 000	65 168	229,063	−44,09	1,049 963	−01	1,596 823	−04
68 000	67 121	222,786	−50,36	7,812 449	−02	1,221 626	−04
70 000	69 074	216,928	−56,22	5,767 794	−02	9,262 593	−05
72 000	71 025	211,074	−62,08	4,223 868	−02	6,971 309	−05
74 000	72 976	205,223	−67,93	3,066 854	−02	5,206 007	−05
76 000	74 925	203,225	−69,92	2,213 526	−02	3,794 413	−05
78 000	76 872	201,278	−71,87	1,592 946	−02	2,757 042	−05
80 000	78 819	199,331	−73,82	1,142 926	−02	1,997 473	−05

Table 4 — Mean values of characteristics during December-January at 30° N

h	*H*	*T*	*t*	*p*		*ϱ*	
m	m	K	°C	hPa, mbar		$kg \cdot m^{-3}$	
0	0	283,150	10,00	1,020 500	03	1,255 552	00
1 000	998	281,652	8,50	9,043 877	02	1,118 611	00
2 000	1 997	280,155	7,00	8,010 013	02	9,960 310	– 01
3 000	2 994	273,785	0,63	7,082 381	02	9,011 710	– 01
4 000	3 992	267,401	– 5,75	6,244 260	02	8,134 969	– 01
5 000	4 989	261,019	– 12,13	5,488 819	02	7,325 630	– 01
6 000	5 986	254,639	– 18,51	4,809 595	02	6,579 944	– 01
7 000	6 983	248,261	– 24,89	4,200 502	02	5,894 291	– 01
8 000	7 979	241,884	– 31,27	3,655 799	02	5,265 173	– 01
9 000	8 975	235,510	– 37,64	3,170 092	02	4,689 215	– 01
10 000	9 971	229,138	– 44,01	2,738 311	02	4,163 165	– 01
12 000	11 961	216,400	– 56,75	2,017 829	02	3,248 372	– 01
14 000	13 950	212,250	– 60,90	1,469 359	02	2,411 675	– 01
16 000	15 938	208,274	– 64,88	1,063 783	02	1,779 327	– 01
18 000	17 925	207,150	– 66,00	7,667 844	01	1,289 515	– 01
20 000	19 910	210,970	– 62,18	5,542 683	01	9,152 460	– 02
22 000	21 894	214,938	– 52,21	4,031 617	01	6,534 376	– 02
24 000	23 877	218,904	– 54,25	2,950 204	01	4,695 014	– 02
26 000	25 858	222,495	– 50,66	2,170 892	01	3,399 035	– 02
28 000	27 839	226,060	– 47,09	1,605 556	01	2,474 229	– 02
30 000	29 818	229,622	– 45,53	1,193 281	01	1,810 366	– 02
32 000	31 796	233,183	– 39,97	8,910 929	00	1,331 266	– 02
34 000	33 773	236,741	– 36,41	6,685 021	00	9,837 124	– 03
36 000	35 748	241,520	– 31,63	5,040 774	00	7,270 803	– 03
38 000	37 722	246,456	– 26,69	3,823 344	00	5,404 346	– 03
40 000	39 695	251,388	– 21,76	2,916 373	00	4,041 448	– 03
42 000	41 667	256,317	– 16,83	2,236 656	00	3,039 905	– 03
44 000	43 637	261,243	– 11,91	1,724 332	00	2,299 398	– 03
46 000	45 606	266,166	– 6,98	1,336 047	00	1,748 667	– 03
48 000	47 574	269,650	– 3,50	1,040 365	00	1,344 075	– 03
50 000	49 541	269,650	– 3,50	8,111 550	– 01	1,047 952	– 03
52 000	51 507	265,732	– 7,42	6,331 020	– 01	8,299 806	– 04
54 000	53 471	260,625	– 12,52	4,896 510	– 01	6,544 986	– 04
56 000	55 434	255,521	– 17,63	3,777 460	– 01	5,150 029	– 04
58 000	57 396	250,420	– 22,73	2,899 100	– 01	4,032 813	– 04
60 000	59 357	245,323	– 27,83	2,213 370	– 01	3,143 082	– 04
62 000	61 316	240,228	– 32,92	1,080 647	– 01	2,437 199	– 04
64 000	63 274	235,137	– 38,01	1,268 919	– 01	1,879 963	– 04
66 000	65 231	230,049	– 43,10	9,522 370	– 02	1,441 992	– 04
68 000	67 187	224,964	– 48,19	7,101 800	– 02	1,099 749	– 04
70 000	69 142	219,882	– 53,27	5,261 760	– 02	8,336 456	– 05
72 000	71 095	215,241	– 57,91	3,873 080	– 02	6,268 586	– 05
74 000	73 047	210,947	– 62,20	2,833 610	– 02	4,679 558	– 05
76 000	74 998	206,655	– 66,50	2,059 990	– 02	3,472 637	– 05
78 000	76 948	202,365	– 70,78	1,487 932	– 02	2,561 462	– 05
80 000	78 896	198,079	– 75,07	1,067 686	– 02	1,877 773	– 05

Table 5 — Mean values of characteristics during June-July at 30° N

h	*H*	*T*	*t*	*p*		*ϱ*	
m	m	K	°C	hPa, mbar		kg·m⁻³	
0	0	297,150	24,00	1,014 000	03	1,188 777	00
1 000	998	292,657	19,51	9,032 389	02	1,075 182	00
2 000	1 997	288,165	15,01	8,031 678	02	9,709 637	−01
3 000	2 994	282,183	9,03	7,126 716	02	8,798 254	−01
4 000	3 992	276,198	3,05	6,307 772	02	7,955 980	−01
5 000	4 989	270,215	−2,93	5,568 245	02	7,178 729	−01
6 000	5 986	264,233	−8,92	4,901 913	02	6,462 735	−01
7 000	6 983	258,254	−14,90	4,302 921	02	5,804 369	−01
8 000	7 979	252,276	−20,87	3,765 769	02	5,200 150	−01
9 000	8 975	245,325	−27,82	3,284 424	02	4,663 963	−01
10 000	9 971	238,356	−34,79	2,853 462	02	4,170 466	−01
12 000	11 961	224,423	−48,73	2,126 718	02	3,301 264	−01
14 000	13 950	210,499	−62,65	1,555 791	02	2,574 770	−01
16 000	15 938	206,650	−66,50	1,120 965	02	1,889 708	−01
18 000	17 925	209,054	−64,10	8,078 713	01	1,346 239	−01
20 000	19 910	214,216	−58,93	5,863 399	01	9,535 340	−02
22 000	21 894	219,374	−53,78	4,288 995	01	6,810 950	−02
24 000	23 877	222,465	−50,68	3,156 591	01	4,943 040	−02
26 000	25 858	225,438	−47,71	2,333 098	01	3,605 326	−02
28 000	27 839	228,408	−44,74	1,731 603	01	2,641 037	−02
30 000	29 818	232,113	−41,04	1,290 625	01	1,937 039	−02
32 000	31 796	236,860	−36,29	9,674 904	00	1,422 960	−02
34 000	33 773	241,604	−31,55	7,295 464	00	1,051 930	−02
36 000	35 748	246,345	−26,80	5,532 453	00	7,823 695	−03
38 000	37 722	251,083	−22,07	4,218 382	00	5,852 837	−03
40 000	39 695	255,818	−17,33	3,233 311	00	4,403 055	−03
42 000	41 667	260,550	−12,60	2,490 793	00	3,330 307	−03
44 000	43 637	265,279	−7,87	1,928 131	00	2,532 043	−03
46 000	45 606	270,006	−3,14	1,499 575	00	1,934 788	−03
48 000	47 574	273,350	0,20	1,171 338	00	1,492 798	−03
50 000	49 541	273,350	0,20	9,160 719	−01	1,167 478	−03
52 000	51 507	271,982	−1,17	7,164 314	−01	9,176 418	−04
54 000	53 471	266,678	−6,47	5,584 194	−01	7,294 768	−04
56 000	55 434	261,378	−11,77	4,331 538	−01	5,773 137	−04
58 000	57 396	256,081	−17,07	3,342 986	−01	4,547 745	−04
60 000	59 357	250,787	−22,36	2,566 539	−01	3,565 178	−04
62 000	61 316	243,785	−29,36	1,958 440	−01	2,798 599	−04
64 000	63 274	235,953	−37,20	1,481 758	−01	2,187 714	−04
66 000	65 231	228,125	−45,02	1,110 795	−01	1,696 288	−04
68 000	67 187	220,302	−52,85	8,245 235	−02	1,303 836	−04
70 000	69 142	212,484	−60,67	6,055 874	−02	9,928 629	−05
72 000	71 095	207,079	−66,07	4,402 212	−02	7,405 810	−05
74 000	73 047	203,565	−69,58	3,181 313	−02	5,444 279	−05
76 000	74 998	200,054	−73,10	2,286 524	−02	3,981 684	−05
78 000	76 948	196,544	−76,61	1,634 168	−02	2,896 502	−05
80 000	78 896	193,037	−80,11	1,161 134	−02	2,095 460	−05

Table 6 — Mean values of characteristics during December-January at 45° N

h	H	T	t	p		ϱ	
m	m	K	°C	hPa, mbar		kg·m^{-3}	
0	0	272,650	− 0,50	1,018 000	03	1,300 710	00
1 000	1 000	268,651	− 4,50	8,972 965	02	1,163 553	00
2 000	1 999	264,653	− 8,50	7,894 410	02	1,039 158	00
3 000	2 999	260,656	− 12,49	6,932 257	02	9,265 002	− 01
4 000	3 997	254,665	− 18,48	6,072 291	02	8,306 561	− 01
5 000	4 996	248,674	− 24,48	5,302 482	02	7,428 269	− 01
6 000	5 994	242,684	− 30,47	4,615 185	02	6,625 005	− 01
7 000	6 992	236,696	− 36,45	4,003 243	02	5,891 946	− 01
8 000	7 990	230,710	− 42,44	3,459 967	02	5,224 480	− 01
9 000	8 987	224,726	− 48,42	2,979 117	02	4,618 188	− 01
10 000	9 984	218,744	− 54,41	2,554 879	02	4,068 852	− 01
12 000	11 977	217,859	− 55,29	1,870 175	02	2,990 506	− 01
14 000	13 969	217,062	− 56,09	1,367 674	02	2,195 008	− 01
16 000	15 960	216,266	− 56,88	9,992 378	01	1,609 602	− 01
18 000	17 949	215,470	− 57,68	7,293 541	01	1,179 204	− 01
20 000	19 937	215,450	− 57,70	5,321 437	01	8,604 398	− 02
22 000	21 924	215,450	− 57,70	3,883 336	01	6,279 089	− 02
24 000	23 910	215,450	− 57,70	2,834 438	01	4,583 091	− 02
26 000	25 894	215,450	− 57,70	2,069 257	01	3,345 847	− 02
28 000	27 877	215,450	− 57,70	1,510 942	01	2,443 089	− 02
30 000	29 859	219,726	− 53,42	1,106 675	01	1,754 596	− 02
32 000	31 840	224,281	− 48,87	8,159 176	00	1,267 334	− 02
34 000	33 819	228,834	− 44,32	6,053 611	00	9,215 780	− 03
36 000	35 797	233,623	− 39,53	4,518 989	00	6,738 512	− 03
38 000	37 774	238,763	− 34,39	3,395 100	00	4,953 632	− 03
40 000	39 750	243,900	− 29,25	2,566 753	00	3,666 157	− 03
42 000	41 724	249,033	− 24,12	1,952 186	00	2,730 876	− 03
44 000	43 698	254,164	− 18,99	1,493 329	00	2,046 823	− 03
46 000	45 670	259,291	− 13,86	1,148 646	00	1,543 253	− 03
48 000	47 640	262,750	− 10,40	8,879 803	− 01	1,177 331	− 03
50 000	49 610	262,750	− 10,40	6,873 676	− 01	9,113 484	− 04
52 000	51 578	261,825	− 11,32	5,320 918	− 01	7,079 676	− 04
54 000	53 545	258,678	− 14,47	4,110 013	− 01	5,535 059	− 04
56 000	55 511	255,532	− 17,62	3,165 179	− 01	4,315 095	− 04
58 000	57 476	252,389	− 20,76	2,430 079	− 01	3,354 193	− 04
60 000	59 439	249,248	− 23,90	1,859 846	− 01	2,599 465	− 04
62 000	61 401	245,408	− 27,74	1,418 451	− 01	2,013 559	− 04
64 000	63 362	241,290	− 31,86	1,077 094	− 01	1,555 081	− 04
66 000	65 322	237,174	− 35,98	8,141 625	− 02	1,195 864	− 04
68 000	67 280	233,061	− 40,09	6,125 179	− 02	9,155 594	− 05
70 000	69 238	228,951	− 44,20	4,585 691	− 02	6,977 505	− 05
72 000	71 194	224,843	− 48,31	3,415 810	− 02	5,292 389	− 05
74 000	73 148	220,738	− 52,41	2,531 081	− 02	3,994 538	− 05
76 000	75 102	216,636	− 56,51	1,865 337	− 02	2,999 616	− 05
78 000	77 055	212,536	− 60,61	1,366 971	− 02	2,240 608	− 05
80 000	79 006	208,438	− 64,71	9,959 045	− 03	1,664 481	− 05