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Atmospheric Temperature Profiles of the Northern Hemisphere

A Compendium of Data

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This book is dedicated to Kuey “Buck” Yee, Fung Wa “Sylvia” Yee, and Paul Mun Yee

Preface

The atmospheric temperature profiles is a series of models that define values for atmospheric temperature, density, pressure and other properties from the surface up to 10 km, representing most of the troposphere region of the atmosphere. Historically, the first model of the standard atmosphere, based on an existing international standard, was published in 1958 by the U.S. Committee on Extension to the Standard Atmosphere, and was updated in 1962, 1966, and 1976. The "Standard Atmosphere" is a hypothetical vertical representation of atmospheric properties which is intended to correspond to an average year-round, mid-latitude idealized earth atmosphere. Typical usages include altimeter calibrations, ballistic trajectories, and aircraft design and performance calculations. It is widely recognized that actual conditions may vary considerably from this standard. This reference book represents a substantial update of the standard atmosphere models that covers the four seasons (Winter, Spring, Summer, and Fall) for different latitudinal zones (5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 85°) in the troposphere. In all the models, the air is assumed to be dry and to obey the perfect gas law and hydrostatic equation, which relate temperature, pressure and density with geopotential altitude. Other derived quantities as a function of altitude for the model atmospheres include the speed of sound, the coefficient of dynamic viscosity, the coefficient of kinematic viscosity, and the thermal conductivity.

Acknowledgements

"My initiation in atmospheric sciences began at White Sands Missile Range, New Mexico in the Atmospheric Sciences Laboratory. Dr. Willis L. Webb, who had written a book about stratospheric rocketsonde measure- ments, was the director of the Satellite Meteorology Division. The laboratory had just acquired one of the first Geostationary Satellite Stations (GOES) in the world and for the very first time we were able to see the entire planet as one picture. It was truly inspirational. I am very grateful to Dr. Thomas H. VonderHaar at Colorado State University, who allowed me to pursue advance studies in the atmospheric sciences at CSU and introduced me to the world of satellite meteorology and Dr. Edward Measure at the Army Research Laboratory, who introduced me to ground based microwave temperature profiling and neural networks. The authors would also like to acknowledge the dedication of research organizations and academic institutions that are providing a wealth of meteorological data sets to the public which we have taken full advantage.

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Contents

List of Figures

1 Basis of the Tables

For more than three decades, the US Standard Atmosphere has been used by researchers and professionals in many areas of aeronautics and atmospheric sciences. It is an idealized, all season average temperature profile of the earth's atmosphere. But today's modern day sophisticated global applications require more extensive representations of the mean temperature profile. This book is a global augmentation of the climatological tropospheric temperature profiles in the Northern Hemisphere for different latitude belts and seasons. There are 72 mean temperature profile tables from the surface up to 10 km in height that represent the four seasons of the year for different latitudinal belts (5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 85°). The model is based on a neural network algorithm that uses archived radiosonde data, retrieved temperature profiles from remote sensors, and the solar insolation at the top of the earth's atmosphere. It is the most comprehensive book of mean seasonal tropospheric temperature profiles to date. It will be an indispensable reference to the aeronautic and meteorological industries worldwide as well as an easy-to-use guide for climatologists, research meteorologists, aeronautic engineers, educators and aviators.

1.1 Background

The original U.S. Standard Atmosphere relied heavily on radiosonde observations but current atmospheric temperature measurements include global satellite remote sensing retrievals (Kidder and Vonder Haar 1995), ground-based temperature profilers microwave radiometers (Westwater et al. 1999; Hogg et al. 1983), RASS Radar Acoustic Sounding Systems (Frankel et al. 1977), lidar (Lenschow 1986), and rocketsondes (Webb 1966). Table 1.1 is a brief outline of meteorological instruments that can measure lower and upper atmospheric temperature profiles.

Table 1.1 Temperature profiling instrumentations

Summary of temperature profiling instrumentations			
Met sensor	Meteorological measurement	Measurement method	Range
Microwave radiometer	Temperature	Ground-based, remote sensing, continuous sampling (minutes)	Near surface to 10 km, vertical
Rocketsonde	Temperature, pressure, relative humidity, winds	Rocket point measurements, continuous sampling (minutes, seconds)	As high as 1,000 km depending on the boosters

(continued)

Y.P. Yee et al., *Atmospheric Temperature Profiles of the Northern Hemisphere: A Compendium of Data*, Springer Atmospheric Sciences, DOI 10.1007/978-94-007-4029-7_1,

Table 1.1 (continued)

Summary of temperature profiling instrumentations			
Met sensor	Meteorological measurement	Measurement method	Range
Sounders on GOES satellite	Inferred temperature and winds from infrared/ microwave radiances	Satellite-based, remote sensing, geostationary, hemispheric sampling (hourly)	Top of atmosphere to surface depending on the spectral channel
Sounders on NOAA satellite	Inferred temperature and winds from infrared/ microwave radiances	Satellite-based, remote sensing, polar orbiting, 1–2 passes/day	Top of atmosphere to surface depending on the spectral channel
Radiosonde	Temperature, pressure, relative humidity, winds	Balloon-based, point measurement, 2 launches/day operationally	Ascension from surface to typically 40 km depending on wind drift
Lidar	Temperature, winds, aerosols	Molecular and aerosol scattering of light	Up to several km
RASS (Radar Acoustic Sounding System)	Temperature	Acoustic	Up to 1–2 km
Dropsondes	Temperature, Pressure, Relative Humidity, Winds	Descension from aircraft, Point measurement	From aircraft height to surface

Historical overviews of the development and modification of the Standard Atmosphere over the years is given by several authors (Champion 1995; Johnson et al. 2002; Vaughan et al. 1996)

1.2 Basic Assumptions and Formulas

1.2.1 Primary Constants

The primary constants and symbols used in a number of computations are listed in the appendix (Appendix B). The numerical values for the various thermodynamic and physical constants used in the computations of atmospheric properties are similar to those given in the U.S. Standard Atmosphere (1962, 1966, 1976). Surface pressure conditions for each of the atmospheres are based on standard conditions, i.e. 1013.25 hPa.

Accelerations due to gravity at sea level for different latitudes are calculated from Eq. 1.1 (Geodetic Reference System 1980; Li and Gotze 2001).

$$g_\phi = 9.78031846(1 + 0.0053024 \sin^2\phi - 0.0000058 \sin^2 2\phi \tag{1.1}$$

where
g is gravity at sea level as a function of latitude
φ is the latitude

1.2.2 Perfect Gas Law

For the computations that were performed to calculate the other parameters on the tables, the air is assumed to be dry and the atmosphere is assumed to be homogeneously mixed with a constant mean molecular weight M. The air will be assumed to represented by the perfect gas law where the pressure P, temperature T, and total density is in the following form:

$$P = \frac{\rho \cdot R^* \cdot T}{M} \tag{1.2}$$

where
T is temperature in Kelvin degrees
R^* is the universal gas constant
ρ is the density of air
M is the molecular weight of air.

Figure 1.1 shows density as a function of height for a typical midlatitude (45° N Latitude) winter season.

1.2.3 Altitude

The relationship between geopotential altitude and geometric altitude used in the latitudinal/ seasonal tables is approximated by Eq. 1.3 (Federal Meteorological Handbook No. 3 1997; Li and Gotze 2001).

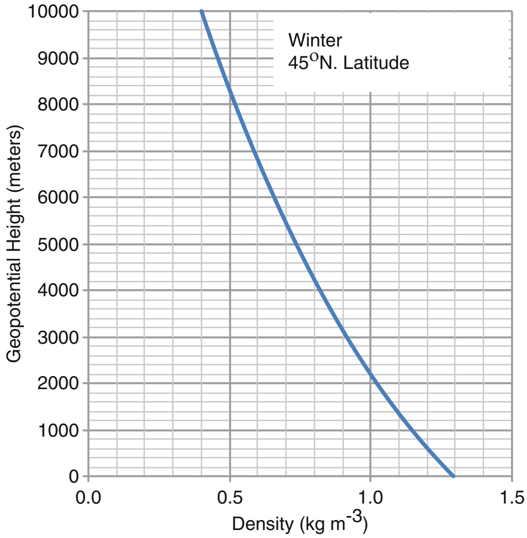

Fig. 1.1 Mean density of air as a function of geopotential height for 45° N latitude, winter case

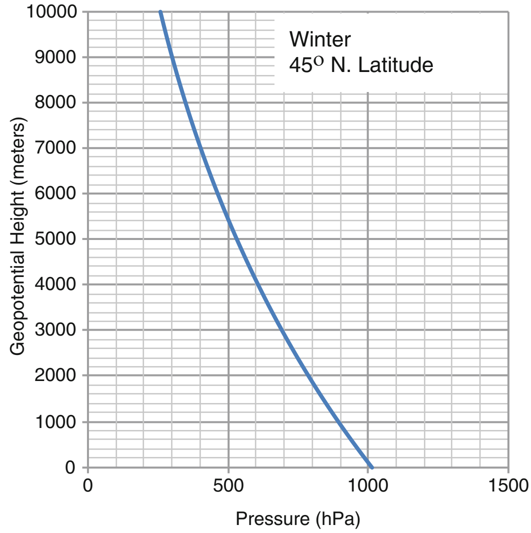

Fig. 1.2 Mean pressure as a function of geopotential height for 45° N latitude, winter case

$$Z(H,\,\phi) = (1 + 0.002644 \cdot \cos(2 \cdot \phi)) \cdot H + (1 + 0.0089 \cdot \cos(2 \cdot \phi)) \cdot \frac{H^2}{6245 \cdot km} \tag{1.3}$$

where
H is the geopotential heights
Z is the geometric heights
φ is the latitude

1.2.4 Pressure

The sea level pressure for all the model atmospheres is fixed at 1013.25 hPa as defined by the U.S. Standard Atmosphere. Pressure levels were calculated using the hypsometric equation (AMS Glossary of Meteorology 2011). For example, the mean pressure profile is depicted in Fig. 1.2 for 45° N latitude, winter case.

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{g}{R \cdot T_m}(z_2 - z_1) \tag{1.4}$$

where
T_m = Mean temperature (Kelvin) between atmospheric layers
g = gravitational acceleration
R = Gas constant for dry air
z_1 = Geopotential height at atmospheric level 1
z_2 = Geopotential height at atmospheric level 2
P_1 = Pressure at atmospheric level 1
P_2 = Pressure at atmospheric level 2

1.3 Derived Quantities

1.3.1 Speed of Sound

The speed of sound is calculated in the same manner as the U.S. Standard Atmosphere 1976, and is designated by C_s in the following expression:

$$C_s = \left(\frac{\gamma \cdot R^* \cdot T}{M}\right)^{1/2} \tag{1.5}$$

Where
T = temperature in Kelvin degrees
γ = the ratio of specific heat of air at constant pressure to that at constant volume = 1.40
R^* = Universal Gas Constant N-m/kmol-K = 8.3144622×10^3 which is consistent with the Boltzmann constant k and Avogados Number N
M = molecular weight of air = 28.9644 kg $kmol^{-1}$

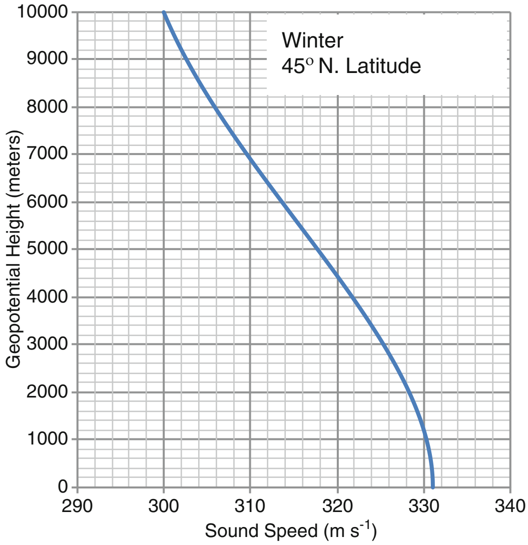

Fig. 1.3 Mean speed of sound as a function of geopotential height for 45° N latitude, winter case

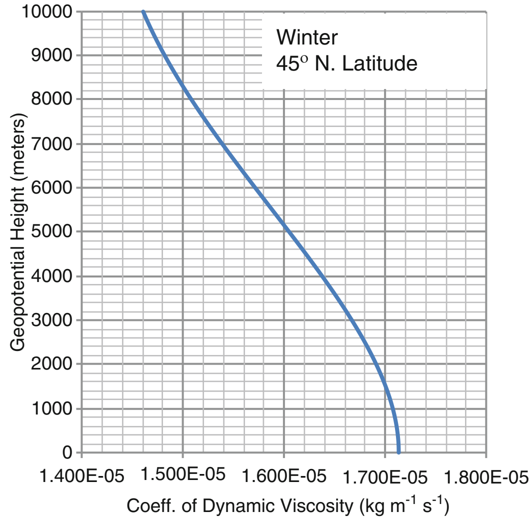

Fig. 1.4 Mean coefficient of dynamic viscosity as a function of geopotential heights for 45° N latitude, winter case

For the region of the atmosphere between surface and approximately 80 km altitude, mixing is dominant and the effect of diffusion and photochemical processes upon the molecular weight M is negligible. Therefore, the molecular weight of air can be constant at its sea level value.

A representative plot of the speed of sound with altitude is shown in Fig. 1.3 for the 45° N. Latitude winter case.

1.3.2 Dynamic Viscosity

The coefficient of dynamic viscosity μ is defined as a coefficient of internal friction in which gas regions move adjacent to each other at different velocities.

$$\mu = \frac{\beta \cdot T^{3/2}}{T + S} \tag{1.6}$$

where
T is temperature in Kelvin degrees
β is a constant = 1.458 × 10^{-6} kgs^{-1} m^{-1} $K^{-1/2}$
S is Sutherland's constant =110.4 K

This equation is not valid under very high or very low temperature conditions. Thus the equation is valid in the troposphere but breaks down at very high. Variation of dynamic viscosity with altitude is shown graphically in Fig. 1.4 for the 45° N latitude winter case.

1.3.3 Kinematic Viscosity

Kinematic viscosity η is defined as the ratio of the dynamic viscosity of a gas to the density of that gas, ρ.

$$\eta = \frac{\mu}{\rho} \tag{1.7}$$

The variation of the kinematic viscosity with altitude for the midlatitude 45° N. Latitude winter case is shown in Fig. 1.5. Limitations of this equation are comparable to those associated with dynamic viscosity.

1.3.4 Thermal Conductivity

The empirical expression adopted for developing tabular values of the coefficient of thermal conductivitv k, for altitudes up to 86 km is as follows:

$$k = \frac{2.6502 \times 10^{-3} \cdot T^{3/2}}{T + 245.4 \times 10^{-(12/T)}} \tag{1.8}$$

where
k is the thermal conductivity in W m^{-1} K^{-1}
T is temperature in Kelvin degrees

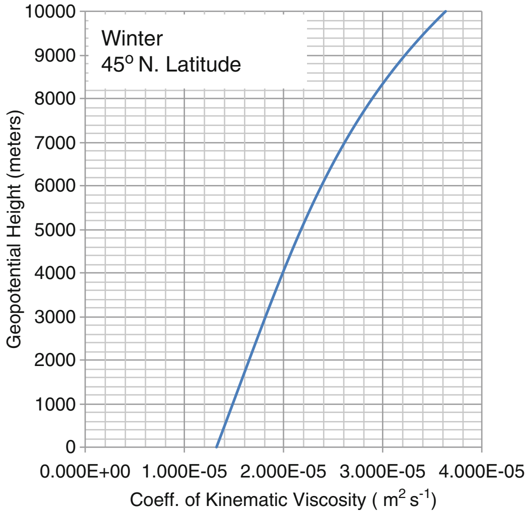

Fig. 1.5 Mean coefficient of kinematic viscosity as a function of geopotential heights for 45° N latitude, winter case

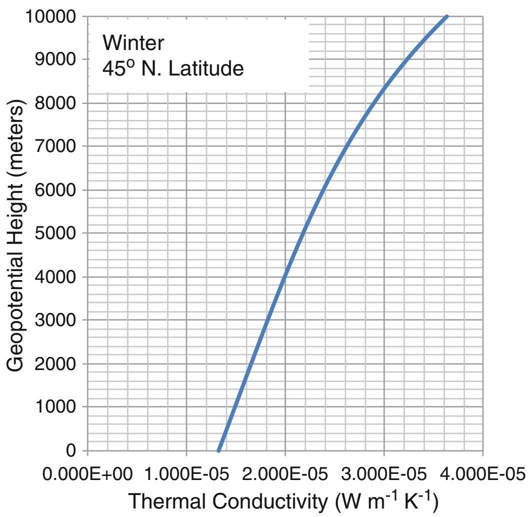

Fig. 1.6 Mean coefficient of thermal conductivity as a function of geopotential heights for 45° N latitude, winter case

This expression differs from that used in the U.S. Standard Atmosphere (1962) in that the numerical constant has been adjusted to accommodate a conversion of the related energy unit from the kilogram calories to joules.

Figure 1.6 is an example of the thermal conductivity verses the geopotential height at a particular latitude and season.

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2 Methodology for Models

2.1 Background

The temperature profile model is based on a neural network algorithm that uses archived radiosonde data, retrieved temperature profiles from remote sounders, climatological information and the solar insolation at the top of the earth's atmosphere. Neural networks have successfully been employed to retrieve temperature profiles from satellite and ground based measurements (Blackwell and Chen 2009). A neural network refers to interconnecting artificial neurons that mimic the properties of biological neurons to perform sophisticated, intelligent tasks.

Pioneer neural network research in atmospheric sciences was conducted at the former Atmospheric Sciences Laboratory in the early 1990s (Measure and Yee 1992). The research involved experimentation with neural network methods to retrieve temperature profiles from ground based microwave radiometers (Yee and Measure 1992) as well as from satellite radiance measurements. Neural networks were trained using simulated microwave radiometric measurements and archived radiosonde measurements to produce vertical profiles of temperature from the surface to approximately 10 km. Those experiments yielded errors comparable to those achieved by other sounder based methods. Neural networks are ideally suited for processing and assimilating diverse data measurements and analyzing large data sets (Yee et al. 2001).

2.2 Neural Network

The neural network architecture involves the assemble of large data sets of temperature profiles throughout the world, screening the data for incomplete data records, constructing training sets that have been segregated into latitude zones and seasons, training neural network algorithms, and evaluating performance. Previous works by the investigators (Yee and Measure 1992) have shown that a back propagation, feed forward, neural network is appropriate for these types of measurements.

Features of the algorithm

- The model atmospheres that are produced represent mean seasonal temperature profiles with latitudinal dependence for the Northern Hemisphere troposphere.
- The parameterizations are calculated using neural network based algorithms. Training sets include archived radiosonde measurements, retrieved temperature profiles from remote sensors, climatological information and solar insolation at the top of the atmosphere.
- The calculations are applicable from sea level up to 10 km atmospheric height for the metric tables.
- The calculations are applicable from sea level up to 32,500 ft atmospheric height for the English tables.

Y.P. Yee et al., *Atmospheric Temperature Profiles of the Northern Hemisphere: A Compendium of Data*, Springer Atmospheric Sciences, DOI 10.1007/978-94-007-4029-7_2,

Preliminary case studies have shown reasonable agreement with mean NWS radiosonde temperature profile measurements at a particular locations (Yee and Yee 2011; Yee et al. 2012)

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3 Additional Information

3.1 Data Resources

Data collected through the routine operations and scientific field experiments throughout the world provided valuable data sets to perform our model development and analysis. Appendix C is a summary of the research centers and data resources that are available to us. These centers archive an enormous wealth of meteorological measurements and archived atmospheric information and in a majority of cases the data can be acquired over the Internet. The COSPAR International Reference Atmosphere (CIRA) is a data resource that provides empirical models of atmospheric temperatures and densities as recommended by the Committee on Space Research (COSPAR 1961). Several editions of CIRA have been published in the past (CIRA 1965; CIRA 1972). Fleming (1988) and Oort (1983) have compiled global climatological statistics of meteorological parameters. The archived radiosonde soundings over the world by the University of Wyoming and the National Weather Service were invaluable in compiling our temperature profile data sets.

3.2 Seasons

Latitudinal and seasonal variations of the atmosphere has been calculated for altitudes from the surface up to 10 km. For the model atmospheres that are included in this book's tables, the seasons will be representative of several months as defined by Table 3.1. The latitudinal regions include the tropics, the subtropics, the mid-latitudes, the subarctic, and the arctic. The tropics between the equator and approximately 15° N. Latitude, in general, do not have seasonal changes in its climate and therefore, the temperature profile in this latitude zone is the same (see tables).

Table 3.1 Months associated with each season

Seasons	Months
Winter	December, January, February
Spring	March, April, May
Summer	June, July, August
Fall	September, October, November

3.3 Latitudinal Land and Ocean Coverage

Temperature profiles are influenced differently over land and ocean so the user should be aware of the land and ocean coverage along latitudinal zones. Oceans cover approximately 61% of the Northern Hemisphere in contrast to the 81% coverage of the Southern Hemisphere (Sellers 1969). Table 3.2 gives the percent ocean coverage along latitude zones.

Most of the land areas in the northern hemisphere are between 40 and 70° N latitude. The lower (0–20° N) and higher latitudes (70–80° N) have over 70% ocean coverage. Between 20

Y.P. Yee et al., *Atmospheric Temperature Profiles of the Northern Hemisphere: A Compendium of Data*, Springer Atmospheric Sciences, DOI 10.1007/978-94-007-4029-7_3,

Table 3.2 Latitudinal land and ocean coverage for the northern hemisphere

Latitudinal land and ocean coverage			
	Coverage (%)		Mean
Latitude zone	Ocean	Land	elevation (m)
80–90° N	93.4	6.6	137
70–80° N	71.3	28.7	220
60–70° N	29.4	70.6	202
50–60° N	42.8	57.2	296
40–50° N	47.5	52.5	382
30–40° N	57.2	42.8	496
20–30° N	62.4	37.6	366
10–20° N	73.6	26.4	146
0–10° N	77.2	22.8	158

and 50° N latitudes the highest peaks can be found such as the Himalayas, Alps and the U.S. Rockies.

The latitudinal variation of temperature can be illustrated by satellite imagery taken by the Atmospheric Infrared Sounder (AIRS) instrument (NASA photograph). The AIRS is capable of taking highly accurate measurements of air temperature, humidity, clouds, and surface temperature over the globe (Fig. 3.1).

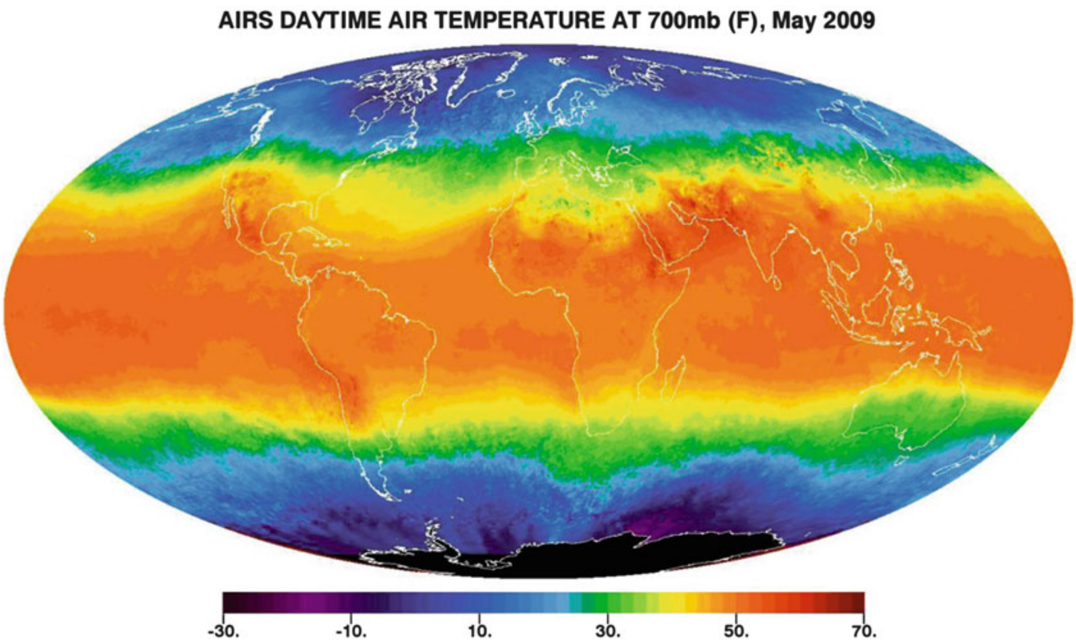

Fig. 3.1 Global temperature measurements by the Atmospheric Infrared Sounder (AIRS) instrument (Image courtesy of NASA/JPL-Caltech AIRS Project)

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Tables of Atmospheric Profiles (Metric Units)

4

4.1 Northern Hemisphere Winter Tables

Sea level to 10 km

Geopotential height (H), geometric height (Z), temperature (T), deviation from standard atmosphere temperature (t – Tstd), pressure (P), density (ρ), sound speed (C_s), coefficient of dynamic viscosity (μ), coefficient of kinematic viscosity (η), thermal conductivity (k)

Y.P. Yee et al., *Atmospheric Temperature Profiles of the Northern Hemisphere: A Compendium of Data*, Springer Atmospheric Sciences, DOI 10.1007/978-94-007-4029-7_4,

Table 4.1 5° N latitude winter (metric)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	kg m^{-3}	m s^{-1}	kg m^{-1} s^{-1}	m^2 s^{-1}	W m^{-1} K^{-1}
0	0	302.65	29.50	14.50	1,013.3	1.1663	348.7	1.859E-05	1.593E-05	2.650E-02
100	100	301.90	28.75	14.40	1,001.9	1.1561	348.3	1.855E-05	1.605E-05	2.644E-02
200	201	301.17	28.02	14.32	990.6	1.1459	347.9	1.852E-05	1.616E-05	2.638E-02
300	301	300.44	27.29	14.24	979.5	1.1357	347.5	1.848E-05	1.627E-05	2.632E-02
400	401	299.73	26.58	14.18	968.4	1.1256	347.1	1.845E-05	1.639E-05	2.627E-02
500	501	299.03	25.88	14.13	957.5	1.1154	346.7	1.841E-05	1.651E-05	2.621E-02
600	602	298.34	25.19	14.09	946.6	1.1053	346.3	1.838E-05	1.663E-05	2.616E-02
700	702	297.66	24.51	14.06	935.8	1.0953	345.9	1.835E-05	1.675E-05	2.611E-02
800	802	296.99	23.84	14.04	925.2	1.0852	345.5	1.832E-05	1.688E-05	2.606E-02
900	902	296.33	23.18	14.03	914.6	1.0752	345.1	1.829E-05	1.701E-05	2.600E-02
1,000	1,003	295.68	22.53	14.03	904.2	1.0653	344.7	1.825E-05	1.714E-05	2.595E-02
1,100	1,103	295.03	21.88	14.03	893.8	1.0554	344.3	1.822E-05	1.727E-05	2.590E-02
1,200	1,203	294.39	21.24	14.04	883.5	1.0455	344.0	1.819E-05	1.740E-05	2.585E-02
1,300	1,304	293.76	20.61	14.06	873.3	1.0357	343.6	1.816E-05	1.754E-05	2.580E-02
1,400	1,404	293.14	19.99	14.09	863.3	1.0259	343.2	1.813E-05	1.768E-05	2.575E-02
1,500	1,504	292.52	19.37	14.12	853.3	1.0162	342.9	1.810E-05	1.782E-05	2.571E-02
1,600	1,605	291.91	18.76	14.16	843.4	1.0065	342.5	1.807E-05	1.796E-05	2.566E-02
1,700	1,705	291.30	18.15	14.20	833.6	0.9969	342.1	1.805E-05	1.810E-05	2.561E-02
1,800	1,805	290.70	17.55	14.25	823.9	0.9874	341.8	1.802E-05	1.825E-05	2.556E-02
1,900	1,906	290.10	16.95	14.30	814.3	0.9779	341.4	1.799E-05	1.839E-05	2.552E-02
2,000	2,006	289.50	16.35	14.35	804.8	0.9684	341.1	1.796E-05	1.854E-05	2.547E-02
2,100	2,106	288.91	15.76	14.41	795.4	0.9591	340.7	1.793E-05	1.870E-05	2.542E-02
2,200	2,207	288.32	15.17	14.47	786.0	0.9497	340.4	1.790E-05	1.885E-05	2.538E-02
2,300	2,307	287.74	14.59	14.54	776.8	0.9405	340.1	1.787E-05	1.900E-05	2.533E-02
2,400	2,407	287.16	14.01	14.61	767.7	0.9313	339.7	1.785E-05	1.916E-05	2.528E-02
2,500	2,508	286.58	13.43	14.68	758.6	0.9222	339.4	1.782E-05	1.932E-05	2.524E-02
2,600	2,608	286.00	12.85	14.75	749.6	0.9131	339.0	1.779E-05	1.948E-05	2.519E-02
2,700	2,708	285.42	12.27	14.82	740.8	0.9041	338.7	1.776E-05	1.965E-05	2.515E-02
2,800	2,809	284.84	11.69	14.89	732.0	0.8952	338.3	1.773E-05	1.981E-05	2.510E-02
2,900	2,909	284.27	11.12	14.97	723.3	0.8864	338.0	1.771E-05	1.998E-05	2.506E-02
3,000	3,009	283.69	10.54	15.04	714.6	0.8776	337.7	1.768E-05	2.014E-05	2.501E-02
3,100	3,110	283.12	9.97	15.12	706.1	0.8689	337.3	1.765E-05	2.031E-05	2.497E-02
3,200	3,210	282.55	9.40	15.20	697.7	0.8602	337.0	1.762E-05	2.049E-05	2.492E-02
3,300	3,310	281.97	8.82	15.27	689.3	0.8516	336.6	1.759E-05	2.066E-05	2.487E-02
3,400	3,411	281.39	8.24	15.34	681.0	0.8431	336.3	1.757E-05	2.083E-05	2.483E-02
3,500	3,511	280.82	7.67	15.42	672.8	0.8347	335.9	1.754E-05	2.101E-05	2.478E-02
3,600	3,611	280.24	7.09	15.49	664.7	0.8263	335.6	1.751E-05	2.119E-05	2.474E-02
3,700	3,712	279.66	6.51	15.56	656.7	0.8180	335.2	1.748E-05	2.137E-05	2.469E-02
3,800	3,812	279.08	5.93	15.63	648.7	0.8098	334.9	1.745E-05	2.155E-05	2.465E-02
3,900	3,913	278.50	5.35	15.70	640.9	0.8016	334.5	1.742E-05	2.174E-05	2.460E-02
4,000	4,013	277.92	4.77	15.77	633.1	0.7936	334.2	1.740E-05	2.192E-05	2.455E-02
4,100	4,113	277.33	4.18	15.83	625.4	0.7856	333.8	1.737E-05	2.211E-05	2.451E-02
4,200	4,214	276.74	3.59	15.89	617.7	0.7776	333.5	1.734E-05	2.230E-05	2.446E-02
4,300	4,314	276.15	3.00	15.95	610.2	0.7697	333.1	1.731E-05	2.249E-05	2.441E-02
4,400	4,415	275.56	2.41	16.01	602.7	0.7619	332.8	1.728E-05	2.268E-05	2.436E-02
4,500	4,515	274.96	1.81	16.06	595.3	0.7542	332.4	1.725E-05	2.287E-05	2.432E-02
4,600	4,615	274.36	1.21	16.11	588.0	0.7466	332.0	1.722E-05	2.307E-05	2.427E-02
4,700	4,716	273.76	0.61	16.16	580.7	0.7390	331.7	1.719E-05	2.326E-05	2.422E-02
4,800	4,816	273.15	0.00	16.20	573.5	0.7315	331.3	1.716E-05	2.346E-05	2.417E-02
4,900	4,917	272.54	−0.61	16.24	566.4	0.7240	330.9	1.713E-05	2.366E-05	2.412E-02

(continued)

Table 4.1 (continued)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	kg m^{-3}	m s^{-1}	kg m^{-1} s^{-1}	m^2 s^{-1}	W m^{-1} K^{-1}
5,000	5,017	271.93	−1.22	16.28	559.4	0.7166	330.6	1.710E-05	2.386E-05	2.408E-02
5,100	5,117	271.31	−1.84	16.31	552.4	0.7093	330.2	1.707E-05	2.406E-05	2.403E-02
5,200	5,218	270.69	−2.46	16.34	545.5	0.7021	329.8	1.704E-05	2.427E-05	2.398E-02
5,300	5,318	270.07	−3.08	16.37	538.7	0.6949	329.4	1.701E-05	2.448E-05	2.393E-02
5,400	5,419	269.44	−3.71	16.39	532.0	0.6878	329.1	1.698E-05	2.468E-05	2.388E-02
5,500	5,519	268.81	−4.34	16.41	525.3	0.6807	328.7	1.695E-05	2.489E-05	2.383E-02
5,600	5,620	268.17	−4.98	16.42	518.7	0.6738	328.3	1.691E-05	2.510E-05	2.377E-02
5,700	5,720	267.53	−5.62	16.43	512.1	0.6669	327.9	1.688E-05	2.531E-05	2.372E-02
5,800	5,821	266.89	−6.26	16.44	505.6	0.6600	327.5	1.685E-05	2.553E-05	2.367E-02
5,900	5,921	266.24	−6.91	16.44	499.2	0.6532	327.1	1.682E-05	2.574E-05	2.362E-02
6,000	6,021	265.59	−7.56	16.44	492.9	0.6465	326.7	1.678E-05	2.596E-05	2.357E-02
6,100	6,122	264.94	−8.21	16.44	486.6	0.6398	326.3	1.675E-05	2.618E-05	2.351E-02
6,200	6,222	264.28	−8.87	16.43	480.4	0.6333	325.9	1.672E-05	2.640E-05	2.346E-02
6,300	6,323	263.61	−9.54	16.41	474.2	0.6267	325.5	1.668E-05	2.662E-05	2.341E-02
6,400	6,423	262.95	−10.20	16.40	468.2	0.6202	325.1	1.665E-05	2.685E-05	2.335E-02
6,500	6,524	262.28	−10.87	16.38	462.1	0.6138	324.7	1.662E-05	2.707E-05	2.330E-02
6,600	6,624	261.60	−11.55	16.35	456.2	0.6075	324.2	1.658E-05	2.730E-05	2.324E-02
6,700	6,725	260.92	−12.23	16.32	450.3	0.6012	323.8	1.655E-05	2.753E-05	2.319E-02
6,800	6,825	260.24	−12.91	16.29	444.4	0.5949	323.4	1.651E-05	2.776E-05	2.313E-02
6,900	6,926	259.56	−13.59	16.26	438.7	0.5888	323.0	1.648E-05	2.799E-05	2.308E-02
7,000	7,026	258.87	−14.28	16.22	432.9	0.5826	322.5	1.644E-05	2.822E-05	2.302E-02
7,100	7,127	258.17	−14.98	16.17	427.3	0.5766	322.1	1.641E-05	2.846E-05	2.297E-02
7,200	7,227	257.48	−15.67	16.13	421.7	0.5706	321.7	1.637E-05	2.870E-05	2.291E-02
7,300	7,328	256.78	−16.37	16.08	416.2	0.5646	321.2	1.634E-05	2.894E-05	2.285E-02
7,400	7,428	256.07	−17.08	16.02	410.7	0.5587	320.8	1.630E-05	2.918E-05	2.280E-02
7,500	7,529	255.37	−17.78	15.97	405.3	0.5528	320.4	1.627E-05	2.942E-05	2.274E-02
7,600	7,629	254.66	−18.49	15.91	399.9	0.5470	319.9	1.623E-05	2.967E-05	2.268E-02
7,700	7,730	253.95	−19.20	15.85	394.6	0.5413	319.5	1.619E-05	2.992E-05	2.262E-02
7,800	7,830	253.24	−19.91	15.79	389.3	0.5356	319.0	1.616E-05	3.017E-05	2.257E-02
7,900	7,931	252.52	−20.63	15.72	384.1	0.5299	318.6	1.612E-05	3.042E-05	2.251E-02
8,000	8,031	251.80	−21.35	15.65	379.0	0.5243	318.1	1.608E-05	3.068E-05	2.245E-02
8,100	8,132	251.08	−22.07	15.58	373.9	0.5188	317.7	1.605E-05	3.093E-05	2.239E-02
8,200	8,232	250.36	−22.79	15.51	368.9	0.5133	317.2	1.601E-05	3.119E-05	2.233E-02
8,300	8,333	249.64	−23.51	15.44	363.9	0.5078	316.7	1.597E-05	3.145E-05	2.227E-02
8,400	8,433	248.92	−24.23	15.37	359.0	0.5024	316.3	1.594E-05	3.172E-05	2.221E-02
8,500	8,534	248.19	−24.96	15.29	354.1	0.4970	315.8	1.590E-05	3.199E-05	2.215E-02
8,600	8,634	247.46	−25.69	15.21	349.3	0.4917	315.4	1.586E-05	3.226E-05	2.209E-02
8,700	8,735	246.74	−26.41	15.14	344.5	0.4864	314.9	1.582E-05	3.253E-05	2.204E-02
8,800	8,835	246.01	−27.14	15.06	339.8	0.4811	314.4	1.578E-05	3.281E-05	2.198E-02
8,900	8,936	245.28	−27.87	14.98	335.1	0.4759	314.0	1.575E-05	3.309E-05	2.192E-02
9,000	9,037	244.56	−28.59	14.91	330.5	0.4708	313.5	1.571E-05	3.337E-05	2.186E-02
9,100	9,137	243.83	−29.32	14.83	325.9	0.4657	313.0	1.567E-05	3.365E-05	2.180E-02
9,200	9,238	243.11	−30.04	14.76	321.4	0.4606	312.6	1.563E-05	3.394E-05	2.174E-02
9,300	9,338	242.38	−30.77	14.68	316.9	0.4555	312.1	1.560E-05	3.424E-05	2.168E-02
9,400	9,439	241.66	−31.49	14.61	312.5	0.4505	311.6	1.556E-05	3.453E-05	2.162E-02
9,500	9,539	240.94	−32.21	14.54	308.1	0.4455	311.2	1.552E-05	3.483E-05	2.156E-02
9,600	9,640	240.22	−32.93	14.47	303.8	0.4406	310.7	1.548E-05	3.514E-05	2.150E-02
9,700	9,740	239.51	−33.64	14.41	299.6	0.4357	310.2	1.544E-05	3.545E-05	2.144E-02
9,800	9,841	238.79	−34.36	14.34	295.3	0.4309	309.8	1.541E-05	3.576E-05	2.138E-02
9,900	9,942	238.08	−35.07	14.28	291.2	0.4260	309.3	1.537E-05	3.608E-05	2.132E-02
10,000	10,042	237.38	−35.77	14.23	287.0	0.4212	308.9	1.533E-05	3.640E-05	2.126E-02

Table 4.2 10° N latitude winter (metric)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	$kg\ m^{-3}$	$m\ s^{-1}$	$kg\ m^{-1}\ s^{-1}$	$m^2\ s^{-1}$	$W\ m^{-1}\ K^{-1}$
0	0	302.65	29.50	14.50	1013.3	1.1663	348.7	1.859E-05	1.593E-05	2.650E-02
100	100	301.90	28.75	14.40	1001.9	1.1561	348.3	1.855E-05	1.605E-05	2.644E-02
200	201	301.17	28.02	14.32	990.6	1.1459	347.9	1.852E-05	1.616E-05	2.638E-02
300	301	300.44	27.29	14.24	979.5	1.1357	347.5	1.848E-05	1.627E-05	2.632E-02
400	401	299.73	26.58	14.18	968.4	1.1256	347.1	1.845E-05	1.639E-05	2.627E-02
500	501	299.03	25.88	14.13	957.5	1.1154	346.7	1.841E-05	1.651E-05	2.621E-02
600	602	298.34	25.19	14.09	946.6	1.1053	346.3	1.838E-05	1.663E-05	2.616E-02
700	702	297.66	24.51	14.06	935.8	1.0953	345.9	1.835E-05	1.675E-05	2.611E-02
800	802	296.99	23.84	14.04	925.2	1.0852	345.5	1.832E-05	1.688E-05	2.606E-02
900	902	296.33	23.18	14.03	914.6	1.0752	345.1	1.829E-05	1.701E-05	2.600E-02
1,000	1,003	295.68	22.53	14.03	904.1	1.0653	344.7	1.825E-05	1.714E-05	2.595E-02
1,100	1,103	295.03	21.88	14.03	893.8	1.0554	344.3	1.822E-05	1.727E-05	2.590E-02
1,200	1,203	294.39	21.24	14.04	883.5	1.0455	344.0	1.819E-05	1.740E-05	2.585E-02
1,300	1,304	293.76	20.61	14.06	873.3	1.0357	343.6	1.816E-05	1.754E-05	2.580E-02
1,400	1,404	293.14	19.99	14.09	863.3	1.0259	343.2	1.813E-05	1.768E-05	2.575E-02
1,500	1,504	292.52	19.37	14.12	853.3	1.0162	342.9	1.810E-05	1.782E-05	2.571E-02
1,600	1,604	291.91	18.76	14.16	843.4	1.0065	342.5	1.807E-05	1.796E-05	2.566E-02
1,700	1,705	291.30	18.15	14.20	833.6	0.9969	342.1	1.805E-05	1.810E-05	2.561E-02
1,800	1,805	290.70	17.55	14.25	823.9	0.9874	341.8	1.802E-05	1.825E-05	2.556E-02
1,900	1,905	290.10	16.95	14.30	814.3	0.9779	341.4	1.799E-05	1.840E-05	2.552E-02
2,000	2,006	289.50	16.35	14.35	804.8	0.9684	341.1	1.796E-05	1.854E-05	2.547E-02
2,100	2,106	288.91	15.76	14.41	795.4	0.9590	340.7	1.793E-05	1.870E-05	2.542E-02
2,200	2,206	288.32	15.17	14.47	786.0	0.9497	340.4	1.790E-05	1.885E-05	2.538E-02
2,300	2,307	287.74	14.59	14.54	776.8	0.9405	340.1	1.787E-05	1.901E-05	2.533E-02
2,400	2,407	287.16	14.01	14.61	767.6	0.9313	339.7	1.785E-05	1.916E-05	2.528E-02
2,500	2,507	286.58	13.43	14.68	758.6	0.9222	339.4	1.782E-05	1.932E-05	2.524E-02
2,600	2,608	286.00	12.85	14.75	749.6	0.9131	339.0	1.779E-05	1.948E-05	2.519E-02
2,700	2,708	285.42	12.27	14.82	740.7	0.9041	338.7	1.776E-05	1.965E-05	2.515E-02
2,800	2,808	284.84	11.69	14.89	731.9	0.8952	338.3	1.773E-05	1.981E-05	2.510E-02
2,900	2,909	284.27	11.12	14.97	723.2	0.8863	338.0	1.771E-05	1.998E-05	2.506E-02
3,000	3,009	283.69	10.54	15.04	714.6	0.8775	337.7	1.768E-05	2.015E-05	2.501E-02
3,100	3,109	283.12	9.97	15.12	706.1	0.8688	337.3	1.765E-05	2.032E-05	2.497E-02
3,200	3,210	282.55	9.40	15.20	697.6	0.8602	337.0	1.762E-05	2.049E-05	2.492E-02
3,300	3,310	281.97	8.82	15.27	689.3	0.8516	336.6	1.759E-05	2.066E-05	2.487E-02
3,400	3,410	281.39	8.24	15.34	681.0	0.8431	336.3	1.757E-05	2.084E-05	2.483E-02
3,500	3,511	280.82	7.67	15.42	672.8	0.8346	335.9	1.754E-05	2.101E-05	2.478E-02
3,600	3,611	280.24	7.09	15.49	664.7	0.8263	335.6	1.751E-05	2.119E-05	2.474E-02
3,700	3,711	279.66	6.51	15.56	656.6	0.8180	335.2	1.748E-05	2.137E-05	2.469E-02
3,800	3,812	279.08	5.93	15.63	648.7	0.8098	334.9	1.745E-05	2.155E-05	2.465E-02
3,900	3,912	278.50	5.35	15.70	640.8	0.8016	334.5	1.742E-05	2.174E-05	2.460E-02
4,000	4,013	277.92	4.77	15.77	633.0	0.7935	334.2	1.740E-05	2.192E-05	2.455E-02
4,100	4,113	277.33	4.18	15.83	625.3	0.7855	333.8	1.737E-05	2.211E-05	2.451E-02
4,200	4,213	276.74	3.59	15.89	617.7	0.7776	333.5	1.734E-05	2.230E-05	2.446E-02
4,300	4,314	276.15	3.00	15.95	610.1	0.7697	333.1	1.731E-05	2.249E-05	2.441E-02
4,400	4,414	275.56	2.41	16.01	602.6	0.7619	332.8	1.728E-05	2.268E-05	2.436E-02
4,500	4,514	274.96	1.81	16.06	595.2	0.7542	332.4	1.725E-05	2.287E-05	2.432E-02
4,600	4,615	274.36	1.21	16.11	587.9	0.7465	332.0	1.722E-05	2.307E-05	2.427E-02
4,700	4,715	273.76	0.61	16.16	580.7	0.7389	331.7	1.719E-05	2.326E-05	2.422E-02
4,800	4,816	273.15	0.00	16.20	573.5	0.7314	331.3	1.716E-05	2.346E-05	2.417E-02
4,900	4,916	272.54	−0.61	16.24	566.4	0.7240	330.9	1.713E-05	2.366E-05	2.412E-02

(continued)

Table 4.2 (continued)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	$kg\ m^{-3}$	$m\ s^{-1}$	$kg\ m^{-1}\ s^{-1}$	$m^2\ s^{-1}$	$W\ m^{-1}\ K^{-1}$
5,000	5,016	271.93	−1.22	16.28	559.3	0.7166	330.6	1.710E-05	2.386E-05	2.408E-02
5,100	5,117	271.31	−1.84	16.31	552.4	0.7093	330.2	1.707E-05	2.407E-05	2.403E-02
5,200	5,217	270.69	−2.46	16.34	545.5	0.7020	329.8	1.704E-05	2.427E-05	2.398E-02
5,300	5,318	270.07	−3.08	16.37	538.7	0.6948	329.4	1.701E-05	2.448E-05	2.393E-02
5,400	5,418	269.44	−3.71	16.39	531.9	0.6877	329.1	1.698E-05	2.468E-05	2.388E-02
5,500	5,519	268.81	−4.34	16.41	525.2	0.6807	328.7	1.695E-05	2.489E-05	2.383E-02
5,600	5,619	268.17	−4.98	16.42	518.6	0.6737	328.3	1.691E-05	2.510E-05	2.377E-02
5,700	5,719	267.53	−5.62	16.43	512.1	0.6668	327.9	1.688E-05	2.532E-05	2.372E-02
5,800	5,820	266.89	−6.26	16.44	505.6	0.6600	327.5	1.685E-05	2.553E-05	2.367E-02
5,900	5,920	266.24	−6.91	16.44	499.2	0.6532	327.1	1.682E-05	2.575E-05	2.362E-02
6,000	6,021	265.59	−7.56	16.44	492.8	0.6465	326.7	1.678E-05	2.596E-05	2.357E-02
6,100	6,121	264.94	−8.21	16.44	486.6	0.6398	326.3	1.675E-05	2.618E-05	2.351E-02
6,200	6,222	264.28	−8.87	16.43	480.4	0.6332	325.9	1.672E-05	2.640E-05	2.346E-02
6,300	6,322	263.61	−9.54	16.41	474.2	0.6267	325.5	1.668E-05	2.662E-05	2.341E-02
6,400	6,423	262.95	−10.20	16.40	468.1	0.6202	325.1	1.665E-05	2.685E-05	2.335E-02
6,500	6,523	262.28	−10.87	16.38	462.1	0.6138	324.7	1.662E-05	2.707E-05	2.330E-02
6,600	6,623	261.60	−11.55	16.35	456.1	0.6074	324.2	1.658E-05	2.730E-05	2.324E-02
6,700	6,724	260.92	−12.23	16.32	450.2	0.6011	323.8	1.655E-05	2.753E-05	2.319E-02
6,800	6,824	260.24	−12.91	16.29	444.4	0.5949	323.4	1.651E-05	2.776E-05	2.313E-02
6,900	6,925	259.56	−13.59	16.26	438.6	0.5887	323.0	1.648E-05	2.799E-05	2.308E-02
7,000	7,025	258.87	−14.28	16.22	432.9	0.5826	322.5	1.644E-05	2.823E-05	2.302E-02
7,100	7,126	258.17	−14.98	16.17	427.2	0.5765	322.1	1.641E-05	2.846E-05	2.297E-02
7,200	7,226	257.48	−15.67	16.13	421.7	0.5705	321.7	1.637E-05	2.870E-05	2.291E-02
7,300	7,327	256.78	−16.37	16.08	416.1	0.5645	321.2	1.634E-05	2.894E-05	2.285E-02
7,400	7,427	256.07	−17.08	16.02	410.6	0.5586	320.8	1.630E-05	2.918E-05	2.280E-02
7,500	7,528	255.37	−17.78	15.97	405.2	0.5528	320.4	1.627E-05	2.943E-05	2.274E-02
7,600	7,628	254.66	−18.49	15.91	399.8	0.5470	319.9	1.623E-05	2.967E-05	2.268E-02
7,700	7,729	253.95	−19.20	15.85	394.5	0.5412	319.5	1.619E-05	2.992E-05	2.262E-02
7,800	7,829	253.24	−19.91	15.79	389.3	0.5355	319.0	1.616E-05	3.017E-05	2.257E-02
7,900	7,930	252.52	−20.63	15.72	384.1	0.5299	318.6	1.612E-05	3.042E-05	2.251E-02
8,000	8,030	251.80	−21.35	15.65	378.9	0.5243	318.1	1.608E-05	3.068E-05	2.245E-02
8,100	8,131	251.08	−22.07	15.58	373.9	0.5187	317.7	1.605E-05	3.094E-05	2.239E-02
8,200	8,231	250.36	−22.79	15.51	368.8	0.5132	317.2	1.601E-05	3.120E-05	2.233E-02
8,300	8,332	249.64	−23.51	15.44	363.8	0.5077	316.7	1.597E-05	3.146E-05	2.227E-02
8,400	8,432	248.92	−24.23	15.37	358.9	0.5023	316.3	1.594E-05	3.172E-05	2.221E-02
8,500	8,533	248.19	−24.96	15.29	354.0	0.4969	315.8	1.590E-05	3.199E-05	2.215E-02
8,600	8,633	247.46	−25.69	15.21	349.2	0.4916	315.4	1.586E-05	3.226E-05	2.209E-02
8,700	8,734	246.74	−26.41	15.14	344.4	0.4863	314.9	1.582E-05	3.253E-05	2.204E-02
8,800	8,834	246.01	−27.14	15.06	339.7	0.4811	314.4	1.578E-05	3.281E-05	2.198E-02
8,900	8,935	245.28	−27.87	14.98	335.1	0.4759	314.0	1.575E-05	3.309E-05	2.192E-02
9,000	9,035	244.56	−28.59	14.91	330.4	0.4707	313.5	1.571E-05	3.337E-05	2.186E-02
9,100	9,136	243.83	−29.32	14.83	325.9	0.4656	313.0	1.567E-05	3.366E-05	2.180E-02
9,200	9,237	243.11	−30.04	14.76	321.4	0.4605	312.6	1.563E-05	3.395E-05	2.174E-02
9,300	9,337	242.38	−30.77	14.68	316.9	0.4555	312.1	1.560E-05	3.424E-05	2.168E-02
9,400	9,438	241.66	−31.49	14.61	312.5	0.4505	311.6	1.556E-05	3.454E-05	2.162E-02
9,500	9,538	240.94	−32.21	14.54	308.1	0.4455	311.2	1.552E-05	3.484E-05	2.156E-02
9,600	9,639	240.22	−32.93	14.47	303.8	0.4406	310.7	1.548E-05	3.514E-05	2.150E-02
9,700	9,739	239.51	−33.64	14.41	299.5	0.4357	310.2	1.544E-05	3.545E-05	2.144E-02
9,800	9,840	238.79	−34.36	14.34	295.3	0.4308	309.8	1.541E-05	3.576E-05	2.138E-02
9,900	9,940	238.08	−35.07	14.28	291.1	0.4260	309.3	1.537E-05	3.608E-05	2.132E-02
10,000	10,041	237.38	−35.77	14.23	287.0	0.4212	308.9	1.533E-05	3.640E-05	2.126E-02

Table 4.3 15° N latitude winter (metric)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	kg m^{-3}	m s^{-1}	kg m^{-1} s^{-1}	m^2 s^{-1}	W m^{-1} K^{-1}
0	0	302.65	29.50	14.50	1013.3	1.1663	348.7	1.859E-05	1.593E-05	2.650E-02
100	100	301.90	28.75	14.40	1001.9	1.1561	348.3	1.855E-05	1.605E-05	2.644E-02
200	200	301.17	28.02	14.32	990.6	1.1459	347.9	1.852E-05	1.616E-05	2.638E-02
300	301	300.44	27.29	14.24	979.5	1.1357	347.5	1.848E-05	1.627E-05	2.632E-02
400	401	299.73	26.58	14.18	968.4	1.1256	347.1	1.845E-05	1.639E-05	2.627E-02
500	501	299.03	25.88	14.13	957.4	1.1154	346.7	1.841E-05	1.651E-05	2.621E-02
600	601	298.34	25.19	14.09	946.6	1.1053	346.3	1.838E-05	1.663E-05	2.616E-02
700	702	297.66	24.51	14.06	935.8	1.0952	345.9	1.835E-05	1.675E-05	2.611E-02
800	802	296.99	23.84	14.04	925.2	1.0852	345.5	1.832E-05	1.688E-05	2.606E-02
900	902	296.33	23.18	14.03	914.6	1.0752	345.1	1.829E-05	1.701E-05	2.600E-02
1,000	1,002	295.68	22.53	14.03	904.1	1.0653	344.7	1.825E-05	1.714E-05	2.595E-02
1,100	1,103	295.03	21.88	14.03	893.8	1.0553	344.3	1.822E-05	1.727E-05	2.590E-02
1,200	1,203	294.39	21.24	14.04	883.5	1.0455	344.0	1.819E-05	1.740E-05	2.585E-02
1,300	1,303	293.76	20.61	14.06	873.3	1.0356	343.6	1.816E-05	1.754E-05	2.580E-02
1,400	1,404	293.14	19.99	14.09	863.2	1.0259	343.2	1.813E-05	1.768E-05	2.575E-02
1,500	1,504	292.52	19.37	14.12	853.2	1.0162	342.9	1.810E-05	1.782E-05	2.571E-02
1,600	1,604	291.91	18.76	14.16	843.4	1.0065	342.5	1.807E-05	1.796E-05	2.566E-02
1,700	1,704	291.30	18.15	14.20	833.6	0.9969	342.1	1.805E-05	1.810E-05	2.561E-02
1,800	1,805	290.70	17.55	14.25	823.9	0.9873	341.8	1.802E-05	1.825E-05	2.556E-02
1,900	1,905	290.10	16.95	14.30	814.3	0.9778	341.4	1.799E-05	1.840E-05	2.552E-02
2,000	2,005	289.50	16.35	14.35	804.7	0.9684	341.1	1.796E-05	1.855E-05	2.547E-02
2,100	2,106	288.91	15.76	14.41	795.3	0.9590	340.7	1.793E-05	1.870E-05	2.542E-02
2,200	2,206	288.32	15.17	14.47	786.0	0.9497	340.4	1.790E-05	1.885E-05	2.538E-02
2,300	2,306	287.74	14.59	14.54	776.7	0.9404	340.1	1.787E-05	1.901E-05	2.533E-02
2,400	2,406	287.16	14.01	14.61	767.6	0.9312	339.7	1.785E-05	1.916E-05	2.528E-02
2,500	2,507	286.58	13.43	14.68	758.5	0.9221	339.4	1.782E-05	1.932E-05	2.524E-02
2,600	2,607	286.00	12.85	14.75	749.6	0.9130	339.0	1.779E-05	1.948E-05	2.519E-02
2,700	2,707	285.42	12.27	14.82	740.7	0.9040	338.7	1.776E-05	1.965E-05	2.515E-02
2,800	2,808	284.84	11.69	14.89	731.9	0.8951	338.3	1.773E-05	1.981E-05	2.510E-02
2,900	2,908	284.27	11.12	14.97	723.2	0.8863	338.0	1.771E-05	1.998E-05	2.506E-02
3,000	3,008	283.69	10.54	15.04	714.6	0.8775	337.7	1.768E-05	2.015E-05	2.501E-02
3,100	3,109	283.12	9.97	15.12	706.0	0.8688	337.3	1.765E-05	2.032E-05	2.497E-02
3,200	3,209	282.55	9.40	15.20	697.6	0.8601	337.0	1.762E-05	2.049E-05	2.492E-02
3,300	3,309	281.97	8.82	15.27	689.2	0.8515	336.6	1.759E-05	2.066E-05	2.487E-02
3,400	3,410	281.39	8.24	15.34	680.9	0.8430	336.3	1.757E-05	2.084E-05	2.483E-02
3,500	3,510	280.82	7.67	15.42	672.7	0.8346	335.9	1.754E-05	2.101E-05	2.478E-02
3,600	3,610	280.24	7.09	15.49	664.6	0.8262	335.6	1.751E-05	2.119E-05	2.474E-02
3,700	3,711	279.66	6.51	15.56	656.6	0.8179	335.2	1.748E-05	2.137E-05	2.469E-02
3,800	3,811	279.08	5.93	15.63	648.6	0.8097	334.9	1.745E-05	2.156E-05	2.465E-02
3,900	3,911	278.50	5.35	15.70	640.8	0.8015	334.5	1.742E-05	2.174E-05	2.460E-02
4,000	4,012	277.92	4.77	15.77	633.0	0.7934	334.2	1.740E-05	2.192E-05	2.455E-02
4,100	4,112	277.33	4.18	15.83	625.3	0.7854	333.8	1.737E-05	2.211E-05	2.451E-02
4,200	4,212	276.74	3.59	15.89	617.6	0.7775	333.5	1.734E-05	2.230E-05	2.446E-02
4,300	4,313	276.15	3.00	15.95	610.1	0.7696	333.1	1.731E-05	2.249E-05	2.441E-02
4,400	4,413	275.56	2.41	16.01	602.6	0.7618	332.8	1.728E-05	2.268E-05	2.436E-02
4,500	4,514	274.96	1.81	16.06	595.2	0.7541	332.4	1.725E-05	2.288E-05	2.432E-02
4,600	4,614	274.36	1.21	16.11	587.9	0.7464	332.0	1.722E-05	2.307E-05	2.427E-02
4,700	4,714	273.76	0.61	16.16	580.6	0.7388	331.7	1.719E-05	2.327E-05	2.422E-02
4,800	4,815	273.15	0.00	16.20	573.4	0.7313	331.3	1.716E-05	2.347E-05	2.417E-02
4,900	4,915	272.54	−0.61	16.24	566.3	0.7239	330.9	1.713E-05	2.367E-05	2.412E-02

(continued)

Table 4.3 (continued)

Altitude		Temperature			Pressure	Density	Sound speed	Coeff. of dynamic viscosity	Coeff. of kinematic viscosity	Thermal conductivity
H	**Z**	**T**	**t**	**t – Tstd**	**P**	**ρ**	**Cs**	**μ**	**η**	***k***
m	m	K	°C	°C	hPa	kg m^{-3}	m s^{-1}	kg m^{-1} s^{-1}	m^2 s^{-1}	W m^{-1} K^{-1}
5,000	5,015	271.93	−1.22	16.28	559.3	0.7165	330.6	1.710E-05	2.387E-05	2.408E-02
5,100	5,116	271.31	−1.84	16.31	552.3	0.7092	330.2	1.707E-05	2.407E-05	2.403E-02
5,200	5,216	270.69	−2.46	16.34	545.4	0.7019	329.8	1.704E-05	2.427E-05	2.398E-02
5,300	5,317	270.07	−3.08	16.37	538.6	0.6948	329.4	1.701E-05	2.448E-05	2.393E-02
5,400	5,417	269.44	−3.71	16.39	531.8	0.6876	329.1	1.698E-05	2.469E-05	2.388E-02
5,500	5,517	268.81	−4.34	16.41	525.2	0.6806	328.7	1.695E-05	2.490E-05	2.383E-02
5,600	5,618	268.17	−4.98	16.42	518.6	0.6736	328.3	1.691E-05	2.511E-05	2.377E-02
5,700	5,718	267.53	−5.62	16.43	512.0	0.6667	327.9	1.688E-05	2.532E-05	2.372E-02
5,800	5,819	266.89	−6.26	16.44	505.5	0.6599	327.5	1.685E-05	2.553E-05	2.367E-02
5,900	5,919	266.24	−6.91	16.44	499.1	0.6531	327.1	1.682E-05	2.575E-05	2.362E-02
6,000	6,020	265.59	−7.56	16.44	492.8	0.6464	326.7	1.678E-05	2.597E-05	2.357E-02
6,100	6,120	264.94	−8.21	16.44	486.5	0.6397	326.3	1.675E-05	2.619E-05	2.351E-02
6,200	6,220	264.28	−8.87	16.43	480.3	0.6331	325.9	1.672E-05	2.641E-05	2.346E-02
6,300	6,321	263.61	−9.54	16.41	474.1	0.6266	325.5	1.668E-05	2.663E-05	2.341E-02
6,400	6,421	262.95	−10.20	16.40	468.0	0.6201	325.1	1.665E-05	2.685E-05	2.335E-02
6,500	6,522	262.28	−10.87	16.38	462.0	0.6137	324.7	1.662E-05	2.708E-05	2.330E-02
6,600	6,622	261.60	−11.55	16.35	456.1	0.6073	324.2	1.658E-05	2.731E-05	2.324E-02
6,700	6,723	260.92	−12.23	16.32	450.2	0.6010	323.8	1.655E-05	2.753E-05	2.319E-02
6,800	6,823	260.24	−12.91	16.29	444.3	0.5948	323.4	1.651E-05	2.777E-05	2.313E-02
6,900	6,923	259.56	−13.59	16.26	438.5	0.5886	323.0	1.648E-05	2.800E-05	2.308E-02
7,000	7,024	258.87	−14.28	16.22	432.8	0.5825	322.5	1.644E-05	2.823E-05	2.302E-02
7,100	7,124	258.17	−14.98	16.17	427.2	0.5764	322.1	1.641E-05	2.847E-05	2.297E-02
7,200	7,225	257.48	−15.67	16.13	421.6	0.5704	321.7	1.637E-05	2.871E-05	2.291E-02
7,300	7,325	256.78	−16.37	16.08	416.0	0.5644	321.2	1.634E-05	2.895E-05	2.285E-02
7,400	7,426	256.07	−17.08	16.02	410.6	0.5585	320.8	1.630E-05	2.919E-05	2.280E-02
7,500	7,526	255.37	−17.78	15.97	405.1	0.5527	320.4	1.627E-05	2.943E-05	2.274E-02
7,600	7,627	254.66	−18.49	15.91	399.8	0.5469	319.9	1.623E-05	2.968E-05	2.268E-02
7,700	7,727	253.95	−19.20	15.85	394.5	0.5411	319.5	1.619E-05	2.993E-05	2.262E-02
7,800	7,828	253.24	−19.91	15.79	389.2	0.5354	319.0	1.616E-05	3.018E-05	2.257E-02
7,900	7,928	252.52	−20.63	15.72	384.0	0.5298	318.6	1.612E-05	3.043E-05	2.251E-02
8,000	8,029	251.80	−21.35	15.65	378.9	0.5242	318.1	1.608E-05	3.069E-05	2.245E-02
8,100	8,129	251.08	−22.07	15.58	373.8	0.5186	317.7	1.605E-05	3.094E-05	2.239E-02
8,200	8,230	250.36	−22.79	15.51	368.7	0.5131	317.2	1.601E-05	3.120E-05	2.233E-02
8,300	8,330	249.64	−23.51	15.44	363.8	0.5076	316.7	1.597E-05	3.146E-05	2.227E-02
8,400	8,431	248.92	−24.23	15.37	358.8	0.5022	316.3	1.594E-05	3.173E-05	2.221E-02
8,500	8,531	248.19	−24.96	15.29	354.0	0.4968	315.8	1.590E-05	3.200E-05	2.215E-02
8,600	8,632	247.46	−25.69	15.21	349.1	0.4915	315.4	1.586E-05	3.227E-05	2.209E-02
8,700	8,732	246.74	−26.41	15.14	344.4	0.4862	314.9	1.582E-05	3.254E-05	2.204E-02
8,800	8,833	246.01	−27.14	15.06	339.7	0.4810	314.4	1.578E-05	3.282E-05	2.198E-02
8,900	8,933	245.28	−27.87	14.98	335.0	0.4758	314.0	1.575E-05	3.310E-05	2.192E-02
9,000	9,034	244.56	−28.59	14.91	330.4	0.4706	313.5	1.571E-05	3.338E-05	2.186E-02
9,100	9,134	243.83	−29.32	14.83	325.8	0.4655	313.0	1.567E-05	3.367E-05	2.180E-02
9,200	9,235	243.11	−30.04	14.76	321.3	0.4604	312.6	1.563E-05	3.396E-05	2.174E-02
9,300	9,335	242.38	−30.77	14.68	316.8	0.4554	312.1	1.560E-05	3.425E-05	2.168E-02
9,400	9,436	241.66	−31.49	14.61	312.4	0.4504	311.6	1.556E-05	3.455E-05	2.162E-02
9,500	9,536	240.94	−32.21	14.54	308.0	0.4454	311.2	1.552E-05	3.485E-05	2.156E-02
9,600	9,637	240.22	−32.93	14.47	303.7	0.4404	310.7	1.548E-05	3.515E-05	2.150E-02
9,700	9,737	239.51	−33.64	14.41	299.4	0.4356	310.2	1.544E-05	3.546E-05	2.144E-02
9,800	9,838	238.79	−34.36	14.34	295.2	0.4307	309.8	1.541E-05	3.577E-05	2.138E-02
9,900	9,938	238.08	−35.07	14.28	291.0	0.4259	309.3	1.537E-05	3.609E-05	2.132E-02
10,000	10,039	237.38	−35.77	14.23	286.9	0.4211	308.9	1.533E-05	3.641E-05	2.126E-02