Chapter 14

Standard and Reference Atmospheres

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14.1 STANDARD ATMOSPHERE

The World Meterological Organization (WMO) has defined the Standard Atmosphere as follows:

"A hypothetical vertical distribution of atmospheric temperature, pressure and density which by international agreement and for historical reasons, is roughly representative of year-round, midlatitude conditions. Typical usages are as a basis for pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables and meteorological diagrams. The air is assumed to obey the perfect gas law and the hydrostatic equation which, taken together, relate temperature, pressure, and density with geopotential. Only one standard atmosphere should be specified at a particular time and this standard atmosphere must not be subjected to amendment except at intervals of many years."

Because of the interest of aerospace engineers and atmospheric scientists in conditions at much higher altitudes than those currently being considered by the WMO, members of the U.S. Committee on Extension to the Standard Atmosphere (COESA) agreed to add the following paragraph to the above definition in describing the U.S. Standard Atmosphere, 1976, which extends to 1000 km:

"The atmosphere shall also be considered to rotate with the earth, and be an average over the diurnal cycle, semiannual variation, and the range of conditions from active to quiet geomagnetic, and active to quiet sunspot conditions. Above the turbopause (about 110 km) generalized forms of the hydrostatic equations apply."

14.1.1 U.S. Standard Atmosphere, 1976

The U.S. Standard Atmosphere, 1976 is an idealized, steady-state representation of mean annual conditions of the earth's atmosphere from the surface to 1000 km at latitude 45°N, as it is assumed to exist during a period with moderate solar activity. The defining meteorological elements are sea-level temperature and pressure, and a temperature-height profile to 1000 km. The latter includes a linearly segmented temperature-height profile in geopotential heights between the surface and 86 km. The first 32 km portion of this profile is identical to the International Civil Aviation Organization (ICAO) Standard Atmosphere. The mean annual midlatitude vertical temperature profile for the portion between 32 and 55 km was developed from both routine radiosonde observations and meterological rocketsonde observations. The portion between 55 and 86 km is based primarily on measurements derived from grenade, pitot static tube and falling sphere experiments.

The temperature-height profile between 86 and 1000 km is expressed in geometric altitude. It is not a series of linear functions as it is at altitudes below 86 km. Rather, it is defined in terms of four successive functions chosen not only to provide a reasonable approximation to observations, but also to yield a continuous first derivative with respect to altitude over the entire regime. Observational data of various kinds provided the basis for determining the four segments of the temperature-height profile between 86 and 1000 km. The observed temperatures at altitudes between 110 and 120 km were particularly important in imposing limits on the temperature-height structure for that region, while the observed density at 150 km and above strongly influenced the selection of both the temperature and the extent of the low-temperature isothermal layer immediately above 86 km. Values of the thermodynamic properties for the region between 140 and 1000 km were determined almost exclusively from satellite related observations and radar incoherent scatter techniques. For altitudes between 90 and 140 km, however, there is only a very limited amount of data from rocket soundings and incoherent scatter observations, and almost none from satellite observations.

The 1976 Standard, like its predecessors, uses the following sea-level values of temperature, pressure, and density which have been standard for decades:

Temperature	288.15 K, 15°C or 59°F
Pressure	1013.25 mb, 760 mm of Hg, or 29.92 in. of Hg
Density	1225.00 g/cm^3 or 0.076474 lbs/ft^3.

In spite of the various independent data sets upon which the several temperature-height segments are based, it is desirable, for purposes of mathematical reproducibility of the tables of the 1976 Standard, to express the temperature in a series of consecutive height functions from the surface to 1000 km, with the expression for each successive function depending upon the end-point value of the preceding function as well as upon certain terms and coefficients peculiar to the related altitude interval. This total temperature-height profile applied to the fundamental continuity models (hydrostatic equation and the equation of motion) together with all the ancillary required constants, coefficients, and functions, defines the U.S. Standard Atmosphere, 1976.

14.1.1.1 Equilibrium Assumptions. The air is assumed to be dry, and at altitudes below 86 km the atmosphere is assumed to be homogeneously mixed with a relative volume composition leading to a constant mean molecular weight M_o. The air is treated as if it were a perfect gas, and total pressure P, temperature T, and total density ρ at any point in the atmosphere are related by the equation of state, that is, the perfect gas law, one form of which is

$$P = \frac{\rho \cdot R^* \cdot T}{M_o}, \tag{14.1}$$

where R^* is the universal gas constant. An alternate form of the equation of state in terms of the total number density N and the Avogadro constant N_A is

$$P = \frac{N \cdot R^* \cdot T}{N_A}. \tag{14.2}$$

This form represents the summation of P_i, the partial pressures of the individual gas species, where P_i is related to n_i the number density of the ith gas species in the following expression:

$$P_i = n_i \cdot k \cdot T, \tag{14.3}$$

where k is the Boltzmann constant.

Within the altitude region of complete mixing, the atmosphere is assumed to be in hydrostatic equilibrium and to be horizontally stratified so that dP, the differential of pressure, is related to dZ, the differential of geometric altitude, by the relationship

$$dP = -g \cdot \rho \cdot dZ, \tag{14.4}$$

where g is the altitude-dependent acceleration of gravity. The elimination of ρ between Equations (14.1) and (14.4) yields another form of the hydrostatic equation, which serves as the basis for the low-altitude pressure calculation:

$$d \ln P = \frac{dP}{P} = \frac{-g \cdot M_o}{R^* \cdot T} \cdot dZ. \tag{14.5}$$

Above 86 km the hydrostatic equilibrium of the atmosphere gradually breaks down as diffusion and vertical transport of individual gas species lead to the need for a dynamically oriented model including diffusive separation. Under these conditions, Colegrove et al. [1965] found it convenient to express the variations with altitude of the atmospheric number density in terms of the vertical component of the flux of the molecules of individual gas species. In terms of the ith gas species, this expression is

$$n_i \cdot v_i + D_i \cdot \left(\frac{dn_i}{dZ} + \frac{n_i \cdot (1 + \alpha_i)}{T} \cdot \frac{dT}{dZ} + \frac{g \cdot n_i \cdot M_i}{R^* \cdot T}\right) + K \cdot \left(\frac{dn_i}{dZ} + \frac{n_i}{T} \cdot \frac{dT}{dZ} + \frac{g \cdot n_i \cdot M}{R^* \cdot T}\right) = 0 \tag{14.6}$$

where

n_i = number density of the ith gas species,

v_i = the vertical transport velocity of the ith species,

D_i = the altitude-dependent, molecular-diffusion coefficient of the ith species diffusing through N_2,

α_i = the thermal-diffusion coefficient of the ith species.

M_i = the molecular weight of the ith species,

M = the molecular weight of the gas through which the the ith species is diffusing,

and

K = the altitude-dependent, eddy-diffusion coefficient.

14.1.1.2 Atmospheric Properties. Because of limited space, the 1976 Standard Atmosphere Tables are not included in this handbook. For detailed tables consult *U.S. Standard Atmosphere, 1976* [COESA]. The temperature-height profile of the 1976 Standard for altitudes up to 86 km is shown in Figure 14-1. The profile is the same as the 1962 Standard for altitudes up to 51 km. From 51 to 70 km it is colder, and from 70 to 86 km it is warmer than the 1962 Standard. Temperature profiles to 500 km for the 1962 and 1976 standard and pressure and density profiles from the surface to 1000 km for the 1976 Standard are presented in Figures 14-2 and 14-3. The equations used for computing other atmospheric properties tabulated in the 1976 Standard are discussed below.

Mean Particle Speed

The mean particle speed V is the arithmetic average of the speeds of all air particles in the volume element being considered. All particles are considered to be neutral. For

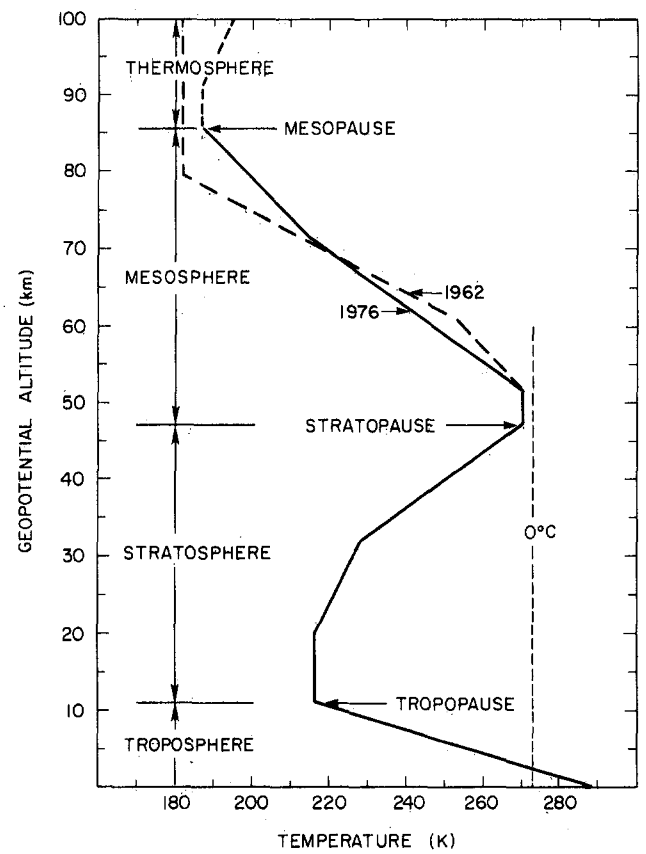

Figure 14-1. Temperature-height profile for U.S. Standard Atmosphere 0-86 km.

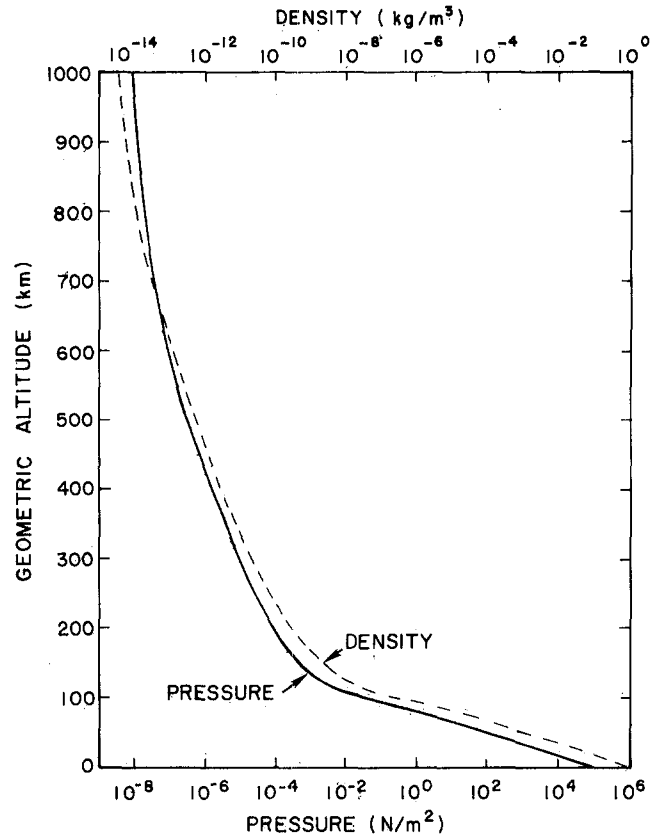

Figure 14-3. Total pressure and mass density as a function of geometric altitude.

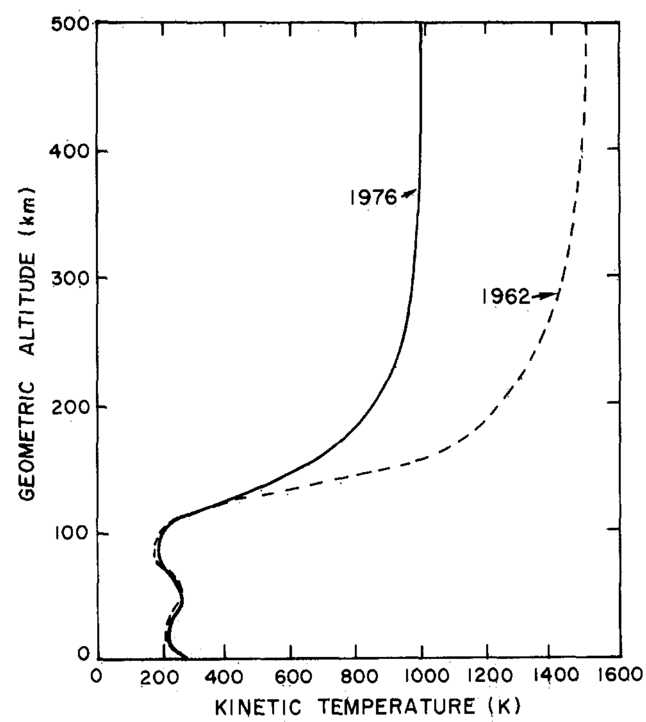

Figure 14-2. Kinetic temperature as a function of geometric altitude.

a valid average to occur, there must be a sufficient number of particles involved to represent mean conditions. Pressure and temperature gradients within the volume must be negligible. The analytical expression for V is closely related to that for the speed of sound and is proportional to the ratio of T/M.

$$V = \left[\frac{8 \cdot R^* \cdot T}{\pi \cdot M}\right]^{1/2} \qquad (14.7)$$

where M is the mean molecular weight at a specific altitude. A graph of V as a function of geometric altitude is given in Figure 14-4.

Mean Collision Frequency

The mean collision frequency, $\nu(s^{-1})$, between the hypothetical mean neutral particles is a function of pressure P, temperature T, and molecular weight M, as well as of an effective mean collision diameter σ. The expression used for computing this property is

$$\nu = 4\,\sigma^2\,N_A\,P\left(\frac{\pi}{M \cdot R^* \cdot T}\right)^{1/2}, \qquad (14.8)$$

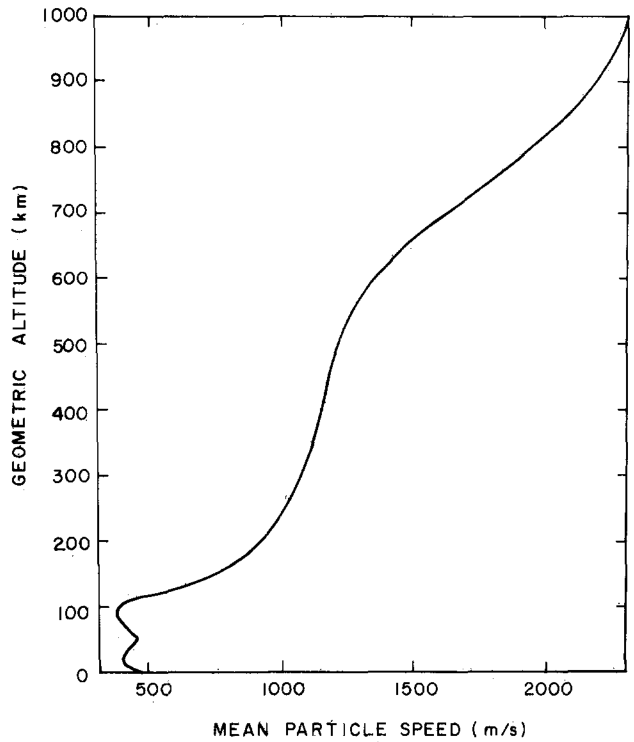

Figure 14-4. Mean particle speed as a function of geometric altitude.

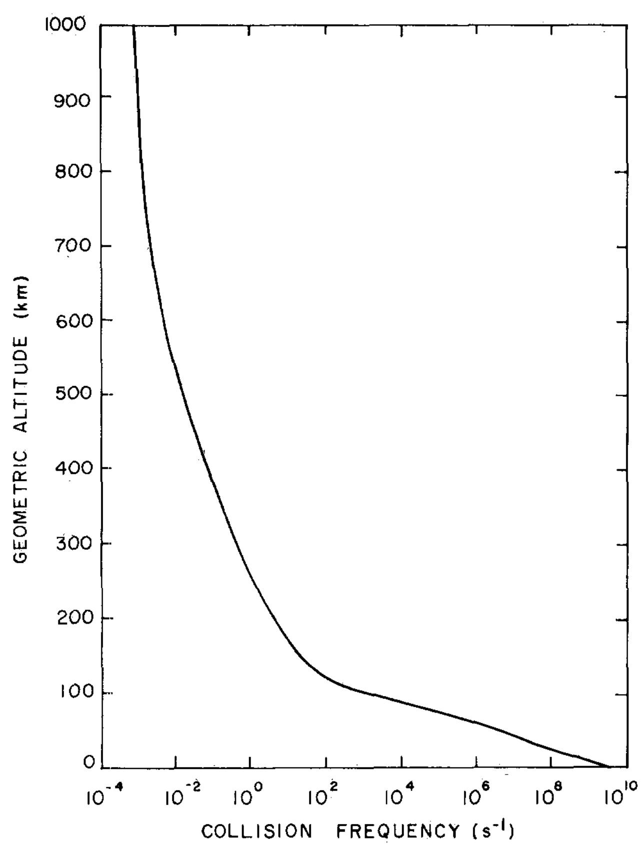

Figure 14-5. Collision frequency as a function of geometric altitude.

where $\pi =$ the ratio of the circumference to the diameter of a circle, that is 3.14159 (dimensionless) and $\sigma =$ the effective collision diameter, 3.65×10^{-10}m. Figure 14-5 shows the variation in mean collision frequency with altitude.

Mean Free Path

The mean free path L is equal to the ratio of mean particle speed to mean collision frequency,

$$L = \frac{V}{\nu} \cdot \tag{14.9}$$

This quantity represents the average travel distance between collisions of the hypothetical mean neutral particles in any direction along which the total change of number density is small over the mean free path length. Thus at the altitude of 130 km where L is less than 10 m, the concept is applicable in all directions. At altitudes above 175 km, where L is the order of 100 m or greater, the concept of mean free path, at best, becomes blurred and must be used with caution. The values of L versus altitude are plotted in Figure 14-6.

Mean Molecular Weight

The mean molecular weight M of a mixture of gases is by definition

$$M = \frac{\sum(n_i M_i)}{\sum n_i} \tag{14.10}$$

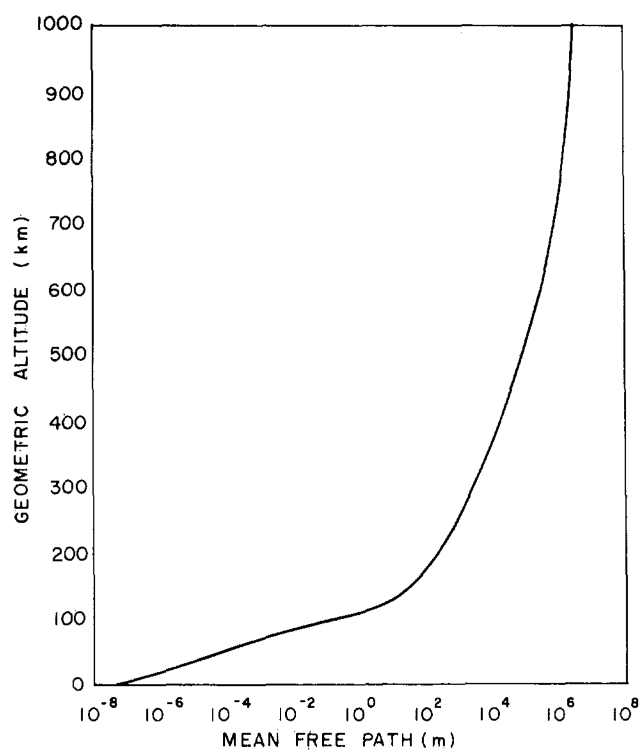

Figure 14-6. Mean free path as a function of geometric altitude.

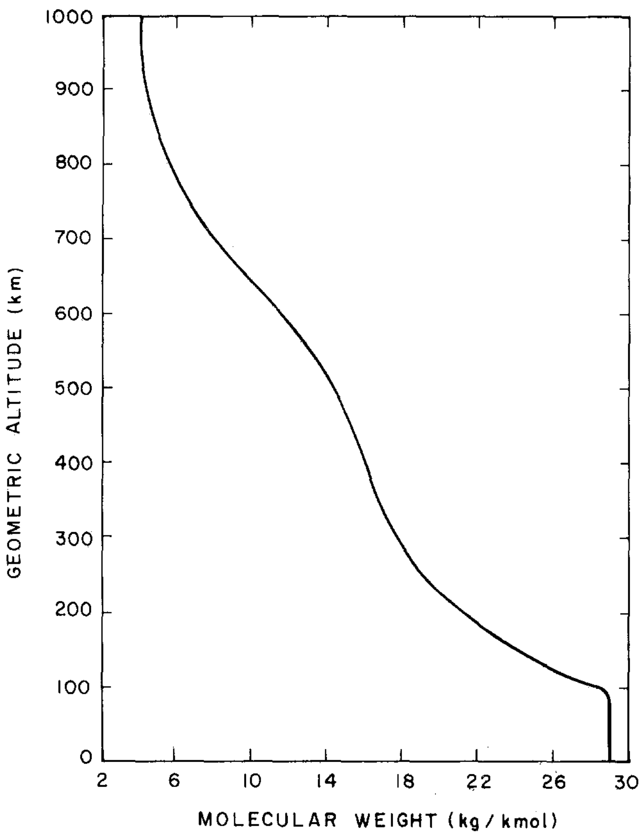

Figure 14-7. Mean molecular weight as a function of geometric altitude.

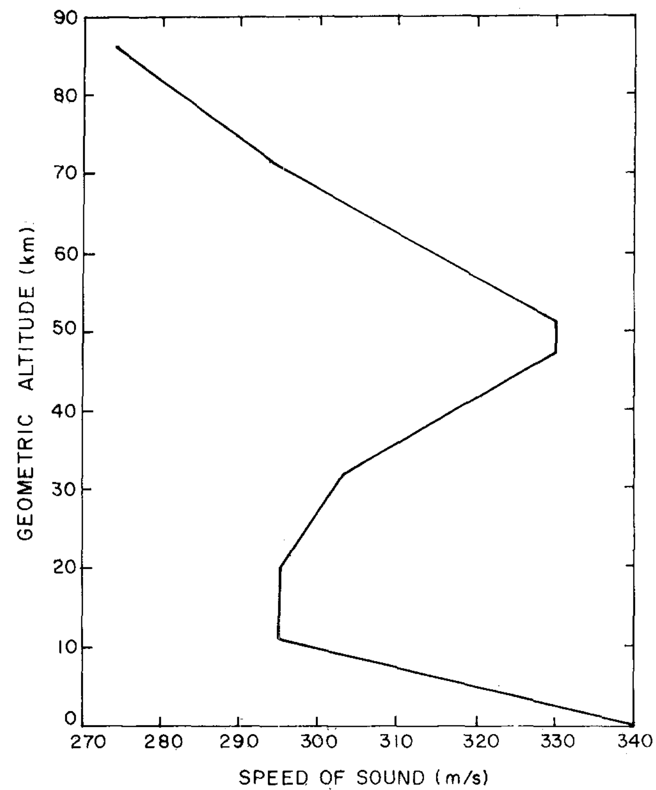

Figure 14-8. Speed of sound as a function of geometric altitude.

where n_i and M_i are the number density and molecular weight, respectively, of the ith gas species. In that part of the atmosphere between the surface and 86 km altitude, mixing is dominant, and the effect of diffusion and photochemical processes upon M is negligible. Consequently, M remains constant at its sea level value, $M_o = 28.9644$ kg/kmol. The variation of the mean molecular weight with altitude is shown in Figure 14-7.

Speed of Sound

The expression adopted for the speed of sound C_s is

$$C_s = \left(\frac{\gamma \cdot R^* \cdot T}{M}\right)^{1/2}, \qquad (14.11)$$

where γ is the ratio of specific heat of air at constant pressure to that at constant volume and is taken to be 1.40 exact (dimensionless). The above equation for speed of sound applies only when the sound wave is a small perturbation on the ambient condition. Calculated values for C_s have been found to vary slightly from experimentally determined values. The limitation of the concept of speed of sound due to extreme attenuation is also of concern. The attenuation that exists at sea level for high frequencies applies to successively lower frequencies as atmospheric pressure decreases or as the mean free path increases. For this reason, the concept of speed of sound (except for frequencies approaching zero) progressively loses its range of applicability at high altitudes. Hence the main tables listing the values of speed of sound are terminated at 86 km. The variation of the speed of sound with altitude is shown in Figure 14-8.

Dynamic Viscosity

The coefficient of dynamic viscosity μ(N s/m^2) is defined as a coefficient of internal friction developed where gas regions move adjacent to each other at different velocities:

$$\mu = \frac{\beta \cdot T^{3/2}}{T + S} \qquad (14.12)$$

where β is a constant equal to 1.458×10^{-6} kgs^{-1}m^{-1}K$^{-1/2}$ and S is Sutherland's constant, equal to 110.4 K. The equation fails for conditions of very high and very low temperatures and under conditions occurring at great altitudes. Variation of dynamic viscosity with altitude is shown graphically in Figure 14-9.

Kinematic Viscosity

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

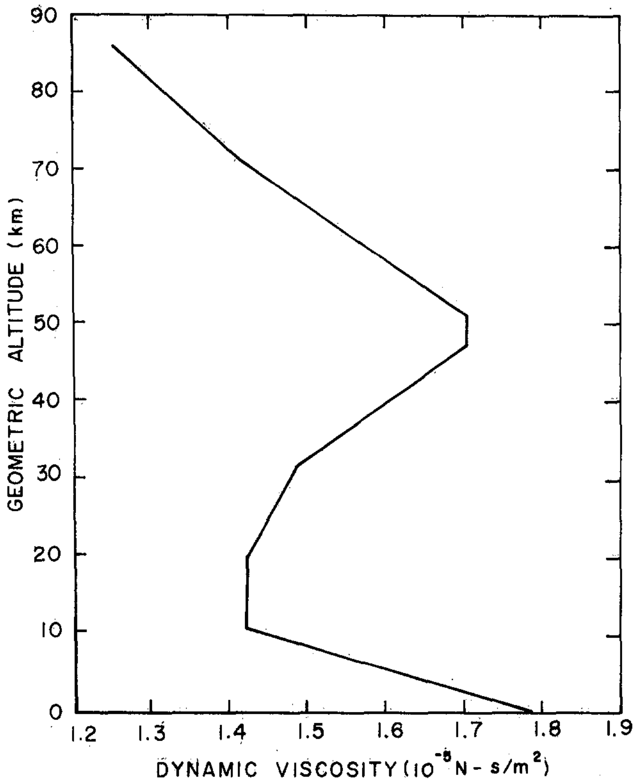

Figure 14-9. Dynamic viscosity as a function of geometric altitude.

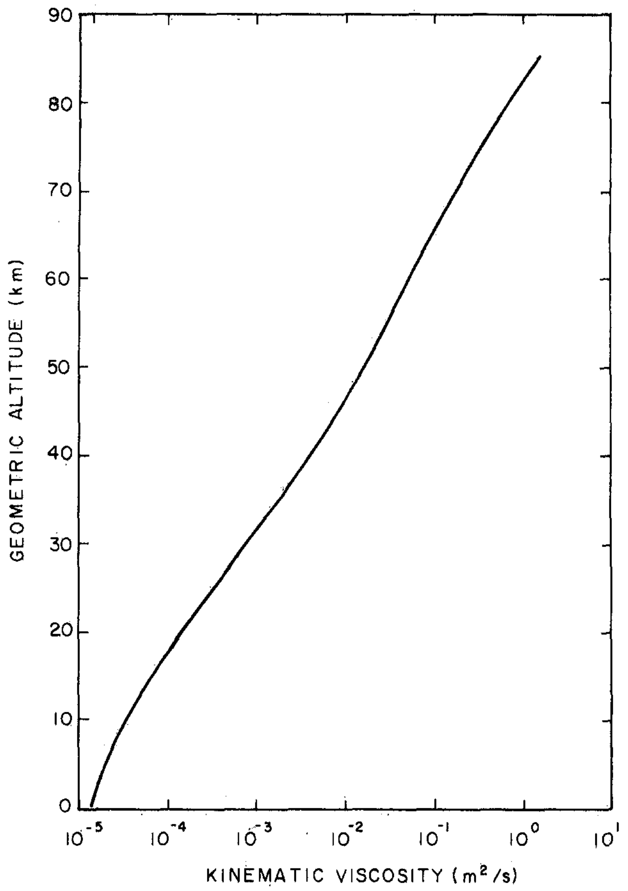

Figure 14-10. Kinematic viscosity as a function of geometric altitude.

$$\eta = \frac{\mu}{\rho} . \qquad (14.13)$$

Limitations of this equation are comparable to those associated with dynamic viscosity. A graphical representation of the variation of kinematic viscosity with altitude is shown in Figure 14-10.

Coefficient of Thermal Conductivity

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

$$k_t = \frac{2.65019 \times 10^{-3}\, T^{3/2}}{T + 245.4 \times 10^{-(12/T)}} . \qquad (14.14)$$

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 temperature-dependent kilogram calorie to the invariant joule. Thus, the values of k_t in units of J $m^{-1}s^{-1}K^{-1}$ or W $m^{-1}K^{-1}$ are greater than the values of k_t in units of kcal $m^{-1}s^{-1}K^{-1}$ by a factor of exactly 4.19002×10^3. Kinetic theory determinations of thermal conductivity of some monatomic gases agree well with observation. The variation of the coefficient of thermal conductivity with altitude is shown in Figure 14-11.

14.1.1.3 Atmospheric Structure. Temperature variation with altitude is the most pronounced feature of the earth's atmosphere and the various layers and shells can be described more easily by temperature than by any other element. This feature is illustrated in Figure 14-1 with the temperature height profile for the 1976 Standard up to 86 km. Usually, temperature decreases with increasing altitude in the lowermost several kilometers. Except for the first kilometer above the earth's surface, the normal lapse rate is about 6.5 K/km in the troposphere, which extends from the surface to the tropopause.

The tropopause is the atmospheric surface at which the temperature decrease with altitude either stops abruptly or the lapse rate becomes less than some arbitrary low value. The height of the tropopause varies with latitude, season, and weather situation; in general it is lowest (8 to 10 km) in arctic regions in winter, and highest (16 to 18 km) in the tropical and equatorial regions. Above the tropopause, temperatures increase with altitude, slowly at first, then more

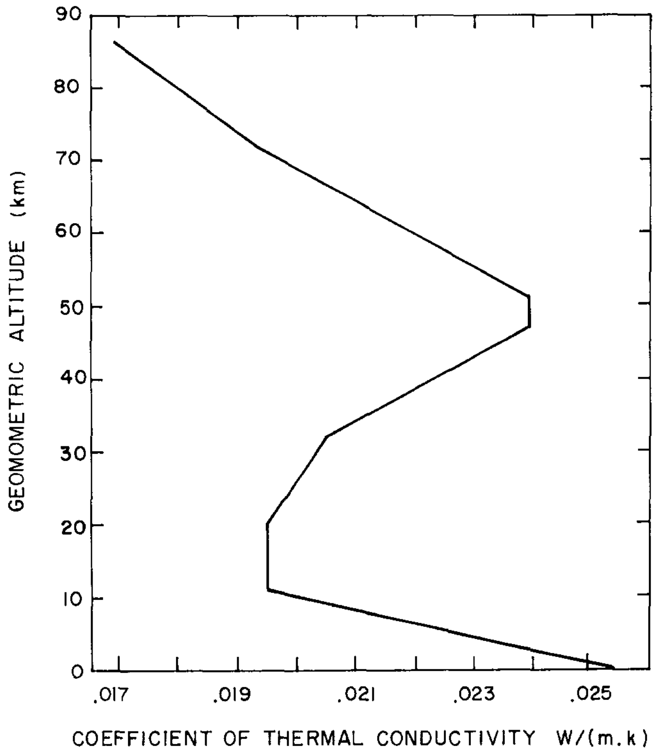

Figure 14-11. Coefficient of thermal conductivity as a function of geometric altitude.

rapidly up to about 50 km, where the average temperature is within a few degrees of the freezing point. This surface of maximum temperature is designated the stratopause, and the entire layer below it down to the tropopause is the stratosphere.

The layer above the stratopause in which the temperature normally decreases with increasing altitude is called the mesosphere. It ends at the mesopause at 80 to 90 km, where the lowest temperatures of the atmosphere are found (135 to 190 K). Above the mesopause lies the thermosphere; its upper limit varies with solar and geophysical conditions. The temperature in the thermosphere increases rapidly with altitude up to about 200 km, then, more slowly, becoming nearly isothermal above 300 to 500 km. The temperature above 200 km varies widely according to the degree of solar activity; it is about 600 K when the sun is quiet and possibly 2000 K during sunspot maxima. The exosphere, sometimes called region of escape, is the outermost, or topmost portion of the atmosphere. Its lower boundary is the critical level of escape, estimated to be 500 to 1000 km above the earth's surface. The air density is so low that the mean free path of individual particles depends upon their direction with respect to the local vertical, being greatest for upward moving particles. It is only from the exosphere that atmospheric gases can escape into outer space. In this region temperature can no longer be defined in the usual way.

14.2 REFERENCE ATMOSPHERES

14.2.1 Air Force Reference Atmospheres for Altitudes Below 90 Km

The Reference Atmospheres presented in this section [Cole and Kantor, 1978] were developed to provide Air Force engineers and designers of aerospace systems with up to date information on the seasonal, latitudinal, and longitudinal variations in the vertical distributions of the thermodynamic properties (pressure, temperature, and density) of the atmosphere in the Northern Hemisphere for altitudes up to 90 km. Special models are included to illustrate the magnitude of the changes in the vertical distributions of these atmospheric properties during extreme winter warmings and coolings of the stratosphere and mesosphere in arctic and subarctic regions.

14.2.1.1 Basic Assumptions and Formulas. The atmospheric models are defined by temperature-altitude profiles in which temperatures change linearly with respect to geopotential altitude. It is assumed that the air is dry, is in hydrostatic equilibrium, and behaves as a perfect gas. The molecular weight of air at sea level, 28.9644 kg/kmol, is assumed to be constant to 90 km. Actually, dissociation of molecular oxygen begins to take place near 80 km and molecular weight starts decreasing slowly with height. Consequently, the temperatures given in the tables for altitudes above 80 km are slightly but not significantly larger (less than one degree K) than the ambient kinetic temperature.

Numerical values for the various thermodynamic and physical constants used in computing the tables of atmospheric properties for these Reference Atmospheres are identical to those used in the preparation of the *U.S. Standard Atmosphere, 1976,* with two exceptions. Surface conditions for the atmospheres are based on mean monthly sea-level values of pressure and temperature for the appropriate latitude rather than on standard conditions. The accelerations due to gravity at sea level for the latitudes were obtained from the following expression by Lambert [List, 1968] in which gravity, g, varies with latitude ϕ:

$$g_\phi = 9.780356\,(1 + 0.0052885 \sin^2\phi - 0.0000059 \sin^2 2\phi). \quad (14.15)$$

The relationship between geopotential altitude and geometric altitude is the same as that used for the U.S. Standard Atmosphere, 1976:

$$H = \left(\frac{r_\phi Z}{r_\phi + Z}\right)\left(\frac{g_\phi}{G}\right), \quad (14.16)$$

where H is the geopotential altitude in geopotential meters (m′), Z is the geometric altitude, r_ϕ is the effective earth

Table 14-1. Sea level acceleration of gravity and the effective radius, r_ϕ, of the earth for each latitude.

Latitude ϕ	Sea Level Gravity g_ϕ (m/s^2)	Effective Earth Radius r_ϕ, (km)
0	9.78036	6334.984
15	9.78381	6337.838
30	9.79324	6345.653
45	9.80665	6356.766
60	9.81911	6367.103
75	9.82860	6374.972
90	9.83208	6377.862

radius, g_ϕ is the sea-level value for acceleration of gravity at a specific latitude ϕ as given by Lambert's equation, and G is the unit geopotential set equal to 9.80665 $m^2 s^{-2} (m')^{-1}$. Values of r_ϕ and g_ϕ are given in Table 14-1.

14.2.1.2 Data. Initial sea-level pressures for each atmosphere were taken from mean monthly sea-level charts for the northern hemisphere. Temperature-height profiles for altitudes up to 30 km were obtained for specific latitudes and months by giving equal weight to radiosonde temperatures interpolated for each 10° of longitude.

Temperature distributions between 30 and 55 km are based on Meterological Rocket Network (MRN) observations taken during the period 1964 through 1976 and temperatures from sets of 5, 2, and 0.4 mb constant pressure maps prepared by the Upper Air Branch of the National Weather Service for the years 1964 through 1968 and from January 1972 through June 1974. The temperature distributions between 55 and 90 km are based primarily on temperatures derived from grenade, falling sphere, and pressure gauge experiments. A detailed description of the analysis of these data and the development of the monthly models is contained in Air Force Surveys in Geophysics No. 382, Air Force Reference Atmospheres [Cole, 1978].

14.2.1.3 Seasonal and Latitudinal Models. Sets of mean monthly Reference Atmospheres for altitudes up to 90 km, [Cole, 1978] have been developed for 15° intervals of latitude, including the equator and north pole, to provide information on the seasonal and latitudinal variations in the thermodynamic properties of the atmosphere. Due to limitations on the length of individual presentations in the handbook, only the properties of the January, April, July, and October models are presented by geometric altitudes in Table 14-2.

The distribution of atmospheric temperature between the equator and north pole, based on the January and July Reference Atmospheres for latitudes 0°, 15°, 30°, 45°, 60°, 75° and 90°N, is shown in Figure 14-12 for geometric altitudes

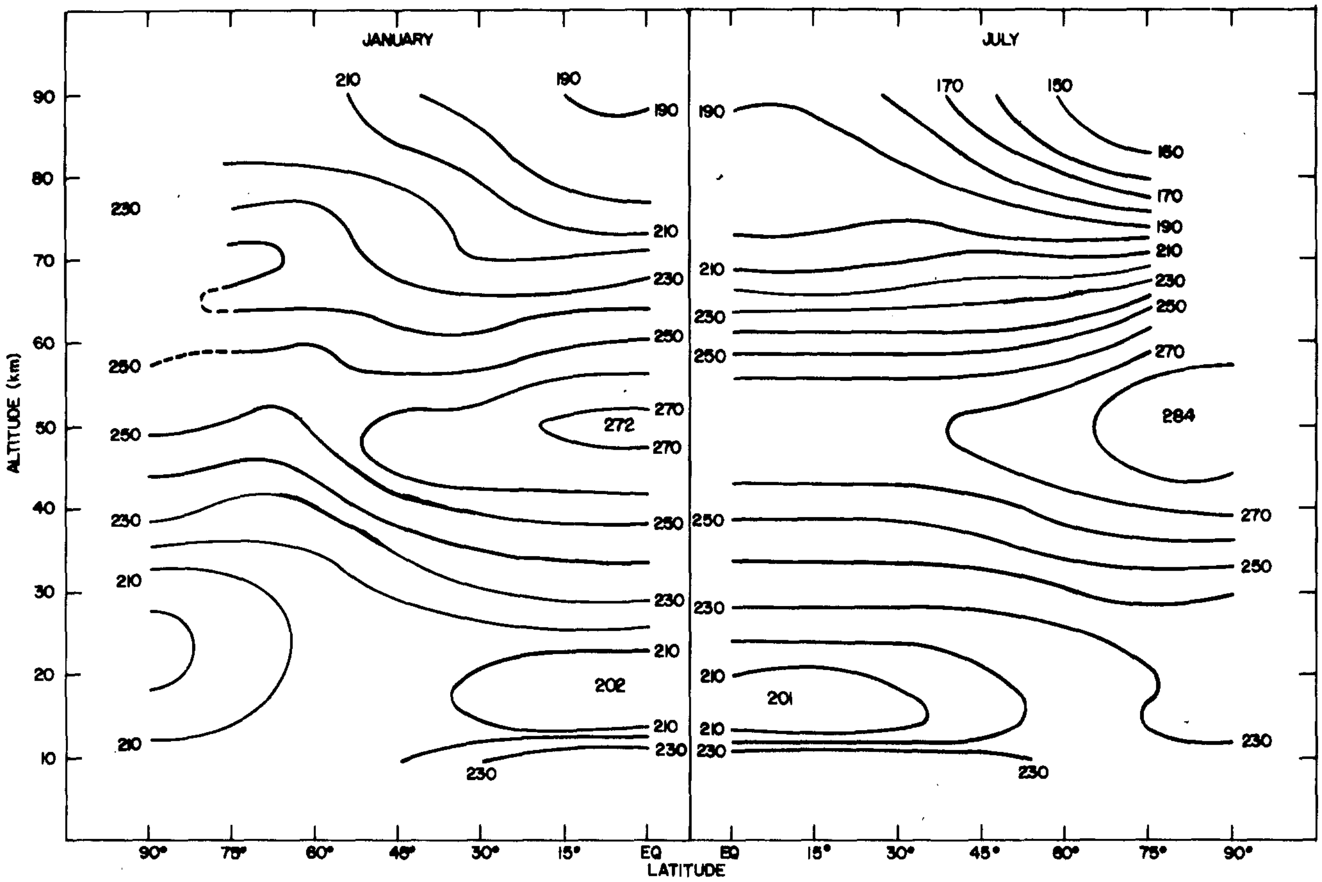

Figure 14-12. Latitudinal temperature-height cross-sections of monthly temperatures for January and July.

Table 14-2a. Reference Atmosphere Temp (K)—January

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N
0.000	299.15	296.65	287.15	272.15	257.15	248.15	237.15
2.000	288.78	287.27	281.16	265.15	255.94	251.37	245.88
4.000	278.41	277.90	268.20	255.66	247.73	240.36	236.61
6.000	268.06	266.28	255.24	243.68	234.13	229.35	226.60
8.000	256.40	252.35	242.28	231.71	220.54	218.35	216.59
10.000	240.49	238.42	229.34	219.74	217.15	214.14	212.64
12.000	224.58	224.50	216.40	218.65	217.15	212.14	210.64
14.000	208.69	210.59	211.08	217.66	217.15	210.14	208.63
16.000	197.34	199.46	205.91	216.67	216.66	208.15	204.64
18.000	195.03	195.15	203.15	215.67	215.66	206.16	200.65
20.000	201.37	203.65	207.73	215.15	214.66	204.16	196.67
22.000	207.71	212.57	212.49	215.15	213.67	202.93	196.65
24.000	214.05	217.22	217.25	215.15	212.68	204.12	196.65
26.000	220.38	221.58	221.79	215.15	212.98	205.32	196.65
28.000	226.71	225.93	225.36	217.08	214.77	206.51	196.65
30.000	232.70	230.28	228.92	221.44	216.55	209.00	203.04
32.000	236.65	234.63	233.13	225.79	218.34	212.97	209.59
34.000	240.60	238.97	237.67	230.15	220.12	216.94	216.14
36.000	244.55	244.29	242.24	235.54	222.07	220.90	222.69
38.000	249.66	250.20	246.98	241.47	224.25	224.86	229.23
40.000	254.98	256.12	251.71	247.40	226.43	228.82	232.98
42.000	260.30	262.02	256.45	253.32	232.87	232.78	236.55
44.000	265.61	265.70	261.17	259.24	239.78	236.74	240.11
46.000	270.92	268.84	265.65	262.82	245.16	240.69	243.67
48.000	272.15	271.15	265.65	264.65	247.93	244.64	247.22
50.000	272.15	271.15	265.65	264.65	250.69	248.59	250.78
52.000	269.12	268.95	261.73	261.41	251.15	252.53	252.15
54.000	265.01	264.43	256.62	255.51	251.15	255.15	252.15
56.000	260.71	259.92	251.65	250.83	250.93	254.06	
58.000	255.61	254.49	247.13	247.29	250.54	250.72	
60.000	250.52	249.01	242.62	243.76	250.11	247.37	
62.000	245.44	243.53	238.12	240.22	245.59	244.03	
64.000	240.35	238.05	233.61	236.69	241.08	240.69	
66.000	235.27	232.58	229.11	233.17	238.65	238.52	
68.000	230.19	226.62	224.62	229.64	238.65	240.09	
70.000	225.12	228.57	220.12	226.12	238.65	241.66	
72.000	217.25	214.88	218.15	225.65	238.07	239.43	
74.000	206.72	210.20	218.15	225.65	234.16	235.52	
76.000	196.20	205.53	216.35	223.44	230.25	231.60	
78.000	195.65	200.85	212.84	219.54	226.34	227.69	
80.000	195.65	198.15	209.33	215.63	222.43	223.77	
82.000	195.65	198.15	205.83	212.50	218.53	219.87	
84.000	195.65	198.15	202.32	210.16	214.65	215.96	
86.000	194.59	196.97	198.82	207.82	214.65	214.15	
88.000	191.29	193.48	195.33	205.49	214.65	214.15	
90.000	187.99	189.99	191.83	203.15	214.65	214.15	

Table 14-2b. Reference Atmosphere Temp (K)—April

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N
0.000	300.15	297.15	292.15	279.15	269.15	255.15	248.65
2.000	288.98	286.97	282.16	273.15	263.14	254.88	252.12
4.000	277.82	276.81	272.19	263.66	257.13	244.86	242.11
6.000	266.67	264.78	260.24	250.68	243.13	233.85	232.10
8.000	254.63	250.85	246.29	237.71	229.14	222.85	222.09
10.000	239.71	236.92	232.35	224.75	222.15	222.56	221.91
12.000	224.81	223.00	218.42	218.15	222.15	224.15	224.15
14.000	209.91	209.09	213.47	218.15	222.15	224.15	224.15
16.000	198.56	200.02	208.69	218.15	222.15	224.15	224.15
18.000	196.12	196.15	206.15	218.15	222.15	224.15	224.15
20.000	202.66	204.84	210.92	218.15	222.15	224.15	224.15
22.000	209.20	213.96	215.88	218.15	222.15	224.15	224.15
24.000	215.74	221.02	220.46	220.26	222.15	224.15	224.66
26.000	222.27	225.38	225.02	223.24	223.17	224.15	226.85
28.000	228.39	229.73	229.57	226.21	225.35	224.15	229.04
30.000	233.93	234.08	234.13	229.54	227.53	227.61	231.23
32.000	239.46	238.43	238.68	234.49	231.97	231.97	233.41
34.000	244.98	242.77	243.05	239.44	236.53	234.76	236.16
36.000	250.51	247.24	247.39	244.54	241.59	238.33	241.12
38.000	256.03	252.77	251.73	250.47	247.33	241.89	246.08
40.000	261.54	258.28	256.07	256.40	253.07	248.03	251.03
42.000	267.06	263.80	260.41	261.09	258.80	254.36	255.98
44.000	269.72	268.24	263.77	265.04	264.53	260.69	260.93
46.000	271.69	270.21	266.92	268.08	269.24	267.02	265.87
48.000	272.15	272.15	269.15	271.65	272.20	273.34	270.15
50.000	272.15	272.15	269.15	271.65	274.15	274.15	270.15
52.000	269.27	269.52	267.98	269.06	274.15	274.15	270.15
54.000	265.35	265.99	263.46	264.34	270.80	272.01	270.15
56.000	261.42	261.78	258.95	259.62	264.90	265.71	
58.000	256.93	254.72	253.74	254.31	259.00	259.41	
60.000	249.49	247.67	248.25	249.01	253.10	253.11	
62.000	242.05	240.62	242.76	243.71	247.21	246.82	
64.000	234.62	233.58	237.28	238.42	241.31	240.53	
66.000	227.20	226.54	231.80	233.13	236.24	234.24	
68.000	219.76	219.51	226.20	229.09	232.12	230.47	
70.000	211.95	212.48	220.53	225.53	228.01	226.75	
72.000	204.15	205.86	214.87	221.26	223.90	223.02	
74.000	196.35	199.62	209.21	217.35	219.79	219.30	
76.000	188.55	193.39	203.55	213.44	215.33	215.58	
78.000	190.73	193.15	200.17	209.54	210.25	209.96	
80.000	193.45	193.15	199.20	205.63	205.17	204.09	
82.000	196.40	195.44	198.22	201.11	200.09	198.23	
84.000	199.70	197.97	197.25	196.13	195.02	192.37	
86.000	203.00	200.49	196.28	191.27	189.95	186.51	
88.000	206.30	203.02	195.31	189.65	184.88	180.66	
90.000	209.60	205.54	194.34	189.65	179.81	176.15	

Table 14-2c. Reference Atmosphere Temp (K)—July

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N
0.000	298.65	299.65	301.15	294.15	287.15	275.65	273.15
2.000	287.68	288.87	288.16	285.15	276.34	273.62	271.12
4.000	276.72	278.11	277.19	273.16	265.53	260.60	260.09
6.000	265.77	267.35	266.22	261.18	253.13	247.59	246.88
8.000	254.82	255.38	252.29	248.21	239.14	234.59	233.67
10.000	238.99	238.46	238.35	235.25	225.17	228.55	228.76
12.000	223.08	223.55	224.42	222.29	225.15	229.35	231.15
14.000	207.19	207.65	210.49	215.65	225.15	230.15	231.15
16.000	198.59	200.30	203.15	215.65	225.15	230.15	231.15
18.000	201.05	202.87	207.38	216.78	225.15	230.15	231.15
20.000	207.99	208.82	211.75	219.17	225.15	230.15	231.15
22.000	214.92	214.76	216.11	221.55	225.15	230.15	231.15
24.000	219.97	220.71	220.47	223.75	227.03	230.15	231.15
26.000	224.13	224.81	224.83	225.93	231.00	232.62	233.48
28.000	228.28	228.77	229.19	229.16	234.97	237.79	236.67
30.000	232.43	232.72	233.55	233.72	239.18	242.95	239.84
32.000	236.58	236.68	237.90	238.28	244.33	248.12	243.02
34.000	240.72	240.63	237.90	238.28	244.33	248.12	249.82
36.000	244.87	244.57	246.59	247.38	254.64	258.64	256.76
38.000	249.01	248.59	251.45	251.93	259.78	263.29	263.70
40.000	253.14	252.78	256.38	256.47	264.83	268.24	270.63
42.000	257.28	256.86	261.31	261.01	270.07	273.19	275.90
44.000	261.84	260.99	264.44	265.55	275.20	278.14	278.86
46.000	266.76	265.13	267.19	270.09	278.13	283.08	281.83
48.000	269.15	268.15	269.15	273.15	279.15	283.65	283.65
50.000	269.15	268.15	269.15	273.15	279.15	283.65	283.65
52.000	266.56	266.71	267.34	272.91	277.60	283.65	283.65
54.000	263.03	263.77	264.98	267.01	272.87	283.23	283.65
56.000	258.78	258.71	261.50	260.61	268.15	278.30	
58.000	251.33	251.07	254.04	253.73	263.43	273.38	
60.000	243.89	243.43	246.59	246.86	258.71	268.46	
62.000	236.45	235.80	239.14	239.99	252.79	263.41	
64.000	229.02	228.17	231.70	233.13	243.17	252.01	
66.000	221.57	220.54	224.27	226.27	233.56	240.62	
68.000	213.76	212.92	216.83	219.41	223.95	229.23	
70.000	205.95	205.31	209.41	212.56	214.34	217.86	
72.000	198.15	201.81	204.50	205.72	204.75	206.49	
74.000	192.59	199.47	201.58	198.88	195.16	195.12	
76.000	194.54	197.65	198.65	192.70	185.57	183.76	
78.000	196.49	197.65	195.72	188.01	175.99	172.41	
80.000	198.44	197.65	192.80	183.33	166.42	161.07	
82.000	199.65	197.65	189.88	178.65	157.09	149.73	
84.000	199.65	197.65	186.96	173.97	155.13	147.01	
86.000	197.85	193.52	184.04	169.30	153.18	146.23	
88.000	192.22	188.66	181.13	164.63	151.23	145.45	
90.000	186.59	183.81	178.22	164.15	149.29	144.67	

Table 14-2d. Reference Atmosphere Temp (K)—October

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N
0.000	299.15	298.15	293.65	284.15	275.15	262.65	252.65
2.000	288.38	288.57	283.66	274.15	267.14	259.44	254.37
4.000	277.62	277.81	273.69	263.16	259.13	248.85	243.35
6.000	265.69	266.66	261.74	251.18	246.13	235.84	232.34
8.000	252.55	254.56	247.79	239.21	233.14	222.84	221.34
10.000	239.43	239.44	233.85	227.24	220.16	219.65	220.16
12.000	223.58	224.33	219.92	215.28	220.15	219.65	222.14
14.000	207.69	209.23	211.85	215.15	220.15	219.65	220.14
16.000	196.77	197.92	203.89	215.15	220.15	219.65	218.14
18.000	199.19	200.82	203.65	215.15	219.86	217.66	216.15
20.000	206.33	207.76	205.96	215.15	218.67	215.66	214.16
22.000	213.09	214.70	210.92	217.07	217.47	213.67	212.16
24.000	218.24	219.59	215.88	219.06	218.30	211.68	210.17
26.000	223.39	224.35	219.52	221.04	219.89	211.79	210.15
28.000	228.53	229.09	223.09	223.02	221.48	214.17	210.15
30.000	233.67	223.84	226.66	225.00	223.06	216.56	210.15
32.000	238.78	238.58	230.22	227.91	224.65	218.94	210.15
34.000	243.72	243.32	233.78	232.07	227.87	221.32	213.99
36.000	248.65	248.30	237.34	236.22	231.83	225.02	217.96
38.000	253.58	253.43	241.77	240.37	235.79	230.37	221.93
40.000	258.50	258.55	246.70	244.52	339.75	235.71	225.89
42.000	263.32	263.67	251.63	249.68	244.59	241.06	231.71
44.000	266.47	266.72	256.56	256.59	249.53	246.40	237.65
46.000	269.62	269.28	261.49	261.82	254.47	251.73	243.58
48.000	271.15	271.15	266.25	266.75	259.40	257.06	249.51
50.000	271.15	271.15	267.65	267.65	260.15	262.39	253.15
52.000	267.84	267.07	267.65	266.08	260.15	263.15	253.15
54.000	263.33	261.57	263.43	260.77	257.14	263.15	253.15
56.000	258.60	255.93	257.93	255.47	251.82	259.05	
58.000	252.92	249.66	252.52	249.72	246.51	251.96	
60.000	247.24	243.39	247.42	243.83	241.20	244.88	
62.000	240.21	236.37	242.32	237.94	235.90	237.80	
64.000	232.39	228.94	232.13	233.42	232.20	230.72	
66.000	224.57	221.51	227.04	229.50	230.24	227.15	
68.000	216.76	214.08	221.96	225.59	228.28	227.15	
70.000	208.95	206.66	216.88	221.67	226.32	227.15	
72.000	201.15	201.09	211.80	217.76	224.36	227.15	
74.000	195.15	197.19	206.72	213.85	222.40	225.52	
76.000	195.15	195.15	201.65	209.94	218.75	221.60	
78.000	195.15	195.15	200.67	206.04	214.84	217.69	
80.000	195.15	195.15	199.70	202.15	210.93	213.77	
82.000	195.15	195.15	199.65	202.15	207.03	209.87	
84.000	195.15	195.15	199.65	202.15	204.15	205.96	
86.000	195.15	195.15	199.65	202.15	204.15	205.15	
88.000	195.15	195.15	199.65	202.15	204.15	205.15	
90.000	195.15	195.15	199.65	202.15	204.15	205.15	

Table 14-2e. Reference Atmosphere Density (kg/m³)—January

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.1761	1.1891	1.2363	1.3013	1.3742	1.4244	1.4910	+0*
2.000	9.6636	9.7230	9.9321	1.0357	1.0590	1.0711	1.0854	
4.000	7.8839	7.8982	8.1234	8.2700	8.3466	8.4810	8.4962	−1
6.000	6.3834	6.4218	6.5793	6.6018	6.6507	6.6428	6.6028	
8.000	5.1518	5.2127	5.2712	5.2114	5.2286	5.1417	5.0740	
10.000	4.1779	4.1820	4.1727	4.0631	3.8811	3.8185	3.7553	
12.000	3.3404	3.3114	3.2591	2.9928	2.8353	2.7984	2.7457	
14.000	2.6276	2.5835	2.4310	3.2009	2.0717	2.0452	2.0020	
16.000	1.9873	1.9567	1.7992	1.6165	1.5172	1.4905	1.4674	
18.000	1.4185	1.4158	1.3073	1.1859	1.1126	1.0832	1.0692	
20.000	0.9761	9.6547	9.1885	8.6716	8.1486	7.8497	7.7432	−2
22.000	6.7966	6.6802	6.5057	6.3254	5.9605	5.6510	5.4786	
24.000	4.7853	4.7721	4.6425	4.6148	4.3545	4.0226	3.8768	
26.000	3.4046	3.4372	3.3411	3.3675	3.1592	2.8697	2.7438	
28.000	2.4462	2.4921	2.4296	2.4375	2.2814	2.0517	1.9256	
30.000	1.7766	1.8183	1.7760	1.7546	1.6522	1.4615	1.3392	
32.000	1.3103	1.3348	1.3015	1.2715	1.2000	1.0400	9.3378	
34.000	0.9715	0.9857	0.9582	0.9272	0.8740	0.7448	0.6584	
36.000	7.2401	7.2933	7.0967	6.7763	6.3791	5.3685	4.6932	−3
38.000	5.3993	5.4221	5.2832	4.9797	4.6657	3.8925	3.3786	
40.000	4.0487	4.0598	3.9559	3.6876	3.4235	2.8388	2.4805	
42.000	3.0546	3.0605	2.9787	2.7508	2.4799	2.0819	1.8316	
44.000	2.3182	2.3396	2.2549	2.0662	1.8100	1.5352	1.3589	
46.000	1.7692	1.7981	1.7174	1.5752	1.3411	1.1379	1.0128	
48.000	1.3760	1.3906	1.3334	1.2119	1.0088	0.8477	0.7582	
50.000	1.0753	1.0856	1.0354	0.9399	0.7615	0.6347	0.5700	
52.000	8.4906	8.5422	8.1503	7.3740	5.8134	4.7744	0.4338	−4
54.000	6.7090	6.7568	6.4162	5.8169	4.4471	3.6259	3.3209	
56.000	5.2860	5.3239	5.0251	4.5435	3.4051	2.7964		
58.000	4.1600	4.1913	3.9109	3.5198	2.6086	2.1707		
60.000	3.2586	3.2837	3.0303	2.7172	1.9082	1.6796		
62.000	2.5402	2.5592	2.3371	2,0900	1.5522	1.2952		
64.000	1.9702	1.9835	1.7939	1.6016	1.2002	0.9954		
66.000	1.5200	1.5285	1.3701	1.2227	0.9162	0.7587		
68.000	1.1663	1.1730	1.0410	0.9297	0.6920	0.5695		
70.000	8.8979	8.9430	7.8672	7.0413	5.2271	0.4284		
72.000	6.8278	6.7570	5.8499	5.2477	3.9583	0.3275		
74.000	5.2406	5.0487	4.3090	3.9033	3.0319	2.5119		−5
76.000	3.9678	3.7483	3.1989	2.9301	2.3122	1.9182		
78.000	2.8323	2.7644	2.3840	2.2067	1.7555	1.4583		
80.000	2.0164	2.0059	1.7683	1.6538	1.3267	1.1037		
82.000	1.4358	1.4343	1.3053	1.2290	0.9979	0.8313		
84.000	1.0226	1.0258	0.9587	0.9069	7.4677	0.6231		−6
86.000	7.3229	7.3799	7.0051	6.6705	5.4751	4.6052		
88.000	5.2827	5.3488	5.0910	4.8902	4.0150	3.3735		
90.000	3.7900	3.8549	3.6793	3.5731	2.9448	2.4717		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2f. Reference Atmosphere Density (kg/m³)—April

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.1716	1.1857	1.2113	1.2678	1.3116	1.3884	1.4297	+0*
2.000	9.6565	9.7223	9.8903	1.0117	1.0375	1.0635	1.0745	
4.000	7.8992	7.9159	8.0172	8.1340	8.1648	8.4225	8.4831	−1
6.000	6.4096	6.4388	6.4947	6.5615	6.5709	6.6274	6.6313	
8.000	5.1728	5.2202	5.2446	5.2336	5.2213	5.1557	5.1285	
10.000	4.1737	4.1823	4.1832	4.1224	3.9711	3.7924	3.7669	
12.000	3.3219	3.3066	3.2908	3.1158	2.9216	2.7756	2.7470	
14.000	2.6032	2.5754	2.4578	2.2808	2.1499	2.0475	2.0262	
16.000	1.9726	1.9299	1.8223	1.6700	1.5823	1.5106	1.4947	
18.000	1.4115	1.3954	1.3288	1.2229	1.1648	1.1147	1.1029	
20.000	0.9725	9.5265	9.3798	8.9578	8.5768	8.2281	8.1399	−2
22.000	6.7816	6.6002	6.6703	6.5625	6.3162	6.0742	6.0084	
24.000	4.7828	4.6845	4.7883	4.7676	4.6523	4.4850	4.4260	
26.000	3.4092	3.3930	3.4617	3.4649	3.4129	3.3122	3.2438	
28.000	2.4585	2.4733	2.5195	2.5294	2.4976	2.4465	2.3849	
30.000	1.7923	1.8140	1.8456	1.8516	1.8336	1.7839	1.7589	
32.000	1.3165	1.3383	1.3603	1.3540	1.3391	1.3068	1.3011	
34.000	0.9741	0.9929	1.0092	0.9968	0.9836	0.9621	0.9631	−3
36.000	7.2575	7.4043	7.5300	7.3817	7.2550	7.1172	7.1019	
38.000	5.4428	5.5315	5.6476	5.4858	5.3740	5.2896	5.2700	
40.000	4.1077	4.1592	4.2575	4.1059	4.0089	3.9134	3.9347	
42.000	3.1189	3.1468	3.2253	3.1075	3.0108	2.9155	2.9550	
44.000	2.4044	2.4043	2.4632	2.3692	2.2758	2.1882	2.2319	
46.000	1.8624	1.8595	1.8890	1.8139	1.7371	1.6540	1.6949	
48.000	1.4527	1.4412	1.4582	1.4007	1.7371	1.6540	1.6949	
50.000	1.1352	1.1262	1.1360	1.0933	1.0396	0.9812	1.0104	
52.000	8.9597	8.8794	8.8895	8.6128	8.1322	7.6739	0.7872	−4
54.000	7.0759	7.0044	7.0239	6.8140	6.4353	6.0473	6.1347	
56.000	5.5694	5.5228	5.5281	5.3690	5.1181	4.8196		
58.000	4.3781	4.3794	4.3441	4.2210	4.0501	3.8208		
60.000	3.4619	3.4507	3.4001	3.3023	3.1882	3.0122		
62.000	2.7184	2.7007	2.6471	2.5703	2.4960	2.3609		
64.000	2.1189	2.0987	2.0495	1.9898	1.9429	1.8391		
66.000	1.6387	1.6186	1.5776	1.5319	1.4984	1.4234		
68.000	1.2568	1.2384	1.2075	1.1670	1.1456	1.0840		
70.000	9.5682	9.3944	9.1854	8.8452	8.7179	0.8218		−5
72.000	7.2109	7.0488	6.9386	6.6727	6.6024	0.6203		
74.000	5.3759	5.2331	5.2032	5.0094	4.9755	4.6613		
76.000	3.9611	3.8493	3.8718	3.7419	3.7359	3.4859		
78.000	2.7561	2.7309	2.8279	2.7806	2.7954	2.6145		
80.000	1.9224	1.9355	2.0362	2.0551	2.0773	1.9477		
82.000	1.3465	1.3584	1.4640	1.5152	1.5325	1.4389		−6
84.000	0.9471	0.9568	1.0512	1.1105	1.1220	1.0535		
86.000	6.7014	6.7706	7.5368	8.0774	8.1494	7.6418		
88.000	4.7692	4.8129	5.3958	5.7400	5.8691	5.4874		
90.000	3.4132	3.4364	3.8574	4.0433	4.1894	3.8701		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2g. Reference Atmosphere Density (kg/m^3)—July

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.1797	1.1751	1.1717	1.2003	1.2252	1.2778	1.2919	+0*
2.000	9.7077	9.6694	9.7103	0.9780	0.9987	1.0032	1.0120	
4.000	7.9287	7.8986	7.9314	7.9946	8.0757	8.1533	8.1528	−1
6.000	6.4239	6.4017	6.4266	6.4769	6.5120	6.5568	6.5576	
8.000	5.1594	5.1685	5.2140	5.2145	5.2231	5.2120	5.2124	
10.000	4.1775	4.1875	4.1827	4.1502	4.1345	3.9747	3.9519	
12.000	3.3352	3.3444	3.3109	3.2612	3.0546	2.9399	2.9076	
14.000	2.6191	2.6275	2.5823	2.4580	2.2570	2.1773	2.1645	
16.000	1.9556	1.9493	1.9214	1.7932	1.6679	1.6192	1.6116	
18.000	1.3723	1.3730	1.3521	1.3021	1.2329	1.2043	1.2001	
20.000	0.9525	9.5976	9.5807	9.4313	9.1149	8.9601	8.9390	−2
22.000	6.6925	6.7780	6.8380	6.8564	6.7399	6.6671	6.6592	
24.000	4.7926	4.8334	4.9144	5.0062	4.9463	4.9618	4.9518	
26.000	3.4691	3.5029	3.5556	3.6673	3.6143	3.6569	3.6647	
28.000	2.5265	2.5552	2.5891	2.6835	2.6556	2.6803	2.7081	
30.000	1.8509	1.8743	1.8969	1.9638	1.9598	1.9781	2.0097	
32.000	1.3637	1.3823	1.3981	1.4460	1.4495	1.4694	1.4975	
34.000	1.0103	1.0248	1.0363	1.0712	1.0791	1.0985	1.1062	
36.000	7.5248	7.6366	7.7248	7.9815	8.0839	8.2646	8.2372	−3
38.000	5.6332	5.7168	5.7779	5.9797	5.0918	6.2554	6.1828	
40.000	4.2381	4.2984	4.3456	4.5040	4.6169	4.7601	4.6763	
42.000	3.2037	3.2475	3.2867	3.4100	3.5184	3.6410	3.5820	
44.000	2.4293	2.4650	2.5144	2.5946	2.6955	2.7989	2.7782	
46.000	1.8493	1.8795	1.9321	1.9836	2.0908	2.1619	2.1604	
48.000	1.4275	1.4450	1.4931	1.5315	1.6358	1.7007	1.6911	
50.000	1.1125	1.1250	1.1632	1.1971	1.2850	1.3408	1.3332	
52.000	8.7481	8.8047	9.1197	9.3670	1.0150	1.0572	1.0511	−4
54.000	6.8831	6.9145	7.1504	7.4642	8.0867	8.3501	8.2891	
56.000	5.4137	5.4579	5.6185	5.9204	6.4179	6.6864		
58.000	4.2874	4.3247	4.4591	4.6911	5.0734	5.3337		
60.000	3.3722	3.4028	3.5152	3.6881	3.9941	4.2378		
62.000	2.6331	2.6574	2.7514	2.8804	3.1454	3.3550		
64.000	1.0402	2.0588	2.1373	2.2339	2.4948	2.7023		
66.000	1.5679	1.5815	1.6469	1.7196	1.9607	2.1552		
68.000	1.1961	1.2038	1.2581	1.3134	1.5256	1.7003		−5
70.000	9.0350	9.0750	9.5234	9.9476	1.1742	1.3256		
72.000	6.7522	6.6490	7.0578	7.4673	8.9324	1.0199		
74.000	4.9325	4.8263	5.1557	5.5522	6.7071	7.7331		
76.000	3.4623	3.4821	3.7497	4.0732	4.9649	5.7676		
78.000	2.4394	2.4867	2.7148	2.9407	3.6178	4.2228		
80.000	1.7251	1.7763	1.9564	2.1061	2.5905	3.0274		
82.000	1.2285	1.2690	1.4031	1.4957	1.8162	2.1187		
84.000	0.8809	0.9068	1.0013	1.0528	1.1999	1.3730		−6
86.000	6.3733	6.6002	7.1100	7.3426	7.8878	8.7593		
88.000	4.6691	4.7844	5.0219	5.0703	5.1588	5.5760		
90.000	3.3898	3.4399	3.5279	3.3925	3.3563	3.5420		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2h. Reference Atmosphere Density (kg/m³)—October

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.1769	1.1816	1.2063	1.2474	1.2795	1.3385	1.3981	+0*
2.000	9.6821	9.6775	9.8598	1.0122	1.0240	1.0425	1.0617	
4.000	7.9068	7.9044	8.0015	8.1810	8.1419	8.3111	8.4294	−1
6.000	6.4329	6.4133	6.4897	6.5738	6.5407	6.6134	6.6221	
8.000	5.2053	5.1764	5.2471	5.2270	5.1931	5.1955	5.1425	
10.000	4.1652	4.1790	4.1912	4.1081	4.0696	3.8648	3.7877	
12.000	3.3261	3.3274	3.3023	3.1874	2.9860	2.8327	2.7569	
14.000	2.6135	2.6080	2.5021	2.3246	2.1912	2.0766	2.0434	
16.000	1.9701	1.9722	1.8579	1.6946	1.6082	1.5226	1.5107	
18.000	1.3779	1.3810	1.3313	1.2356	1.1821	1.1252	1.1140	
20.000	0.9524	9.5802	9.3893	9.0114	8.7162	8.2945	8.1936	−2
22.000	6.6793	6.7278	6.6771	6.5238	6.4173	6.0980	6.0101	
24.000	4.7657	4.8169	4.8106	4.7364	4.6790	4.4711	4.3964	
26.000	3.4279	3.4765	3.4862	3.4493	3.4076	3.2395	3.1819	
28.000	2.4848	2.5268	2.5398	2.5196	2.4879	2.3289	2.3031	
30.000	1.8144	1.8489	1.8599	1.8460	1.8208	1.6807	1.6673	
32.000	1.3343	1.3617	1.3687	1.3512	1.3358	1.2175	1.1889	
34.000	0.9885	1.0091	1.0122	0.9890	0.9760	0.8852	0.8528	
36.000	7.3687	7.5165	7.4956	7.2803	7.1469	6.4248	6.1550	−3
38.000	5.5256	5.6298	5.5731	5.3888	5.2620	4.6616	4.4688	
40.000	4.1672	4.2419	4.1689	4.0101	3.8948	3.4080	3.2409	
42.000	3.1613	3.2145	3.1366	2.9879	2.8883	2.5095	2.3687	
44.000	2.4237	2.4664	2.3732	2.2277	2.1543	1.8607	1.7450	
46.000	1.8643	1.9011	1.8063	1.6837	1.6164	1.3888	1.2952	
48.000	1.4467	1.4728	1.3971	1.2809	1.2197	1.0431	0.9767	
50.000	1.1295	1.1498	1.0869	0.9928	0.9386	0.7882	0.7482	
52.000	8.9199	9.1029	8.5800	7.7661	7.2462	6.0836	0.5732	−4
54.000	7.0493	7.2119	6.7740	6.1400	5.6554	4.7098	4.3930	
56.000	5.5537	5.6898	5.3200	4.8317	4.4337	3.7001		
58.000	4.3709	4.4754	4.1526	3.7897	3.4585	2.9235		
60.000	3.4219	3.4993	3.2253	2.9575	2.6836	2.2949		
62.000	2.6779	2.7270	2.4920	2.2944	2.0710	1.7889		
64.000	2.0863	2.1125	1.9149	1.7597	1.5788	1.3842		
66.000	1.6118	1.6230	1.4632	1.3402	1.1915	1.9476		
68.000	1.2341	1.2360	1.1114	1.0161	8.9728	0.7798		
70.000	9.3589	9.3244	8.3906	7.6683	6.7413	0.5805		−5
72.000	7.0241	6.9050	6.2932	5.7589	5.0531	0.4323		
74.000	5.1671	5.0394	4.6880	4.3034	3.7788	3.2416		
76.000	3.6738	3.6236	3.4675	3.1991	2.8382	2.4457		
78.000	2.6127	2.5767	2.5022	2.3654	2.1236	1.8363		
80.000	1.8585	1.8326	1.8032	1.7391	1.5808	1.3719		
82.000	1.3222	1.3036	1.2925	1.2508	1.1705	1.0196		
84.000	0.9409	0.9276	0.9264	0.8998	8.5777	0.7537		−6
86.000	6.6974	6.6017	6.6420	6.4750	6.1893	5.4678		
88.000	4.7680	4.6993	4.7628	4.6600	4.4668	3.9511		
90.000	3.3951	3.3458	3.4160	3.3544	3.2244	2.8557		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2i. Reference Atmosphere Pressure (mb)—January

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.0100	1.0126	1.0191	1.0166	1.0144	1.0147	1.0150	+3*
2.000	8.0106	8.0179	8.0160	7.8835	7.7806	7.7293	7.6613	+2
4.000	6.3009	6.3007	6.2540	6.0693	5.9354	5.8516	5.7706	
6.000	4.9119	4.9087	4.8205	4.6180	4.4699	4.3734	4.2948	
8.000	3.7918	3.7760	3.6661	3.4662	3.3102	3.2228	3.1547	
10.000	2.8842	2.8621	2.7470	2.5629	2.4192	2.3472	2.2922	
12.000	2.1535	2.1340	2.0245	1.8785	1.7673	1.7041	1.6602	
14.000	1.5741	1.5618	1.4729	1.3751	1.2914	1.2337	1.1990	
16.000	1.1258	1.1203	1.0634	1.0054	1.9436	1.8906	0.8620	+1
18.000	7.9414	7.9315	7.6236	7.3420	6.8878	6.4106	6.1588	
20.000	5.6424	5.6442	5.4791	5.3555	5.0213	4.6004	4.3714	
22.000	4.0525	4.0763	3.9683	3.9065	3.6559	3.2919	3.0926	
24.000	2.9403	2.9757	2.8952	2.8501	2.6584	2.3570	2.1884	
26.000	2.1538	2.1863	2.1271	2.0797	1.9314	1.6913	1.5488	
28.000	1.5920	1.6163	1.5717	1.5189	1.4065	1.2162	1.0869	
30.000	1.1867	1.2020	1.1670	1.1153	1.0271	1.8768	1.7805	
32.000	8.9018	8.9907	8.7098	8.2413	0.7521	0.6358	0.5618	+0
34.000	6.7103	6.7618	6.5377	6.1259	5.5230	4.6386	4.0855	
36.000	5.0825	5.1143	4.9348	4.5816	4.0665	3.4042	3.0000	
38.000	3.8695	3.8943	3.7456	3.4517	3.0035	2.5126	2.2231	
40.000	2.9634	2.9848	2.8584	2.6188	2.2252	1.8647	1.6590	
42.000	2.2824	2.3019	2.1927	2.0003	1.6577	1.3912	1.2437	
44.000	1.7675	1.7844	1.6905	1.5376	1.2458	1.0432	0.9366	
46.000	1.3759	1.3876	1.3096	1.1884	0.9438	0.7862	0.7084	−1
48.000	1.0749	1.0823	1.0168	0.9207	7.1802	0.5953	0.5380	
50.000	8.4007	8.4501	7.8958	7.1403	5.4799	0.4529	0.4103	
52.000	6.5594	6.5948	6.1234	5.5334	4.1911	3.4610	3.1400	
54.000	5.1036	5.1289	4.7265	4.2665	3.2060	2.6556	2.4037	
56.000	3.9560	3.9723	3.6300	3.2713	2.4528	2.0394		
58.000	3.0525	3.0619	2.7745	2.4986	1.8761	1.5623		
60.000	2.3434	2.3472	2.1105	1.9012	1.4346	1.1926		
62.000	1.7897	1.7890	1.5975	1.4412	1.0942	1.9073		
64.000	1.3593	1.3554	1.2030	1.0882	1.8306	0.6877		
66.000	1.0265	1.0204	0.9011	0.8184	0.6276	0.5195		−2
68.000	7.7069	7.6307	6.7122	6.1291	4.7405	0.3925		
70.000	5.7500	5.6623	4.9711	4.5704	3.5808	2.9720		
72.000	4.2580	4.1680	3.6632	3.3991	2.7051	2.2512		
74.000	3.1098	3.0464	2.6983	2.5283	2.0379	1.6982		
76.000	2.2347	2.2114	1.9867	1.8794	1.5282	1.2753		
78.000	1.5906	1.5938	1.4565	1.3907	1.1406	0.9531		
80.000	1.1324	1.1409	1.0626	1.0237	0.8471	0.7089		−3
82.000	8.0642	8.1586	7.7126	7.4973	6.2598	5.2469		
84.000	5.7436	5.8351	5.5682	5.4712	4.6013	3.8628		
86.000	4.0905	4.1728	3.9981	3.9795	3.3735	2.8309		
88.000	2.9008	2.9707	2.8545	2.8846	2.4738	2.0738		
90.000	2.0453	2.1023	2.0260	2.0837	1.8144	1.5194		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2j. Reference Atmosphere Pressure (mb)—April

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.0095	1.0114	1.0159	1.0159	1.0134	1.0169	1.0205	+3*
2.000	8.0104	8.0090	8.0108	7.9327	7.8374	7.7818	7.7772	+2
4.000	6.2997	6.2899	6.2640	6.1568	6.0265	5.9201	5.8956	
6.000	4.9065	4.8940	4.8518	4.7216	4.5860	4.4489	4.4181	
8.000	3.7810	3.7589	3.7079	3.5712	3.4344	3.2982	3.2696	
10.000	2.8720	2.8444	2.7901	2.6596	2.5323	2.4228	2.3996	
12.000	2.1437	2.1167	2.0633	1.9511	1.8631	1.7859	1.7675	
14.000	1.5686	1.5457	1.5060	1.4283	1.3709	1.3174	1.3037	
16.000	1.1243	1.1081	1.0917	1.0457	1.0090	0.9720	0.9617	+1
18.000	7.9466	7.8573	7.8633	7.6583	7.4282	7.1729	7.0967	
20.000	5.6576	5.6017	5.6791	5.6094	5.4693	5.2942	5.2374	
22.000	4.0725	4.0537	4.1336	4.1095	4.0277	3.9083	3.8660	
24.000	2.9619	2.9721	3.0303	3.0144	2.9667	2.8857	2.8544	
26.000	2.1751	2.1952	2.2361	2.2204	2.1863	2.1311	2.1123	
28.000	1.6118	1.6311	1.6604	1.6425	1.6156	1.5741	1.5680	
30.000	1.2035	1.2189	1.2404	1.2200	1.1976	1.1656	1.1674	
32.000	9.0499	9.1598	9.3203	9.1144	0.8917	0.8672	0.8718	+0
34.000	6.8505	6.9201	7.0416	6.8516	6.6787	6.4835	6.5297	
36.000	5.2189	5.2550	5.3475	5.1817	5.0313	4.8691	4.9156	
38.000	4.0001	4.0135	4.0811	3.9442	3.8154	3.6729	3.7226	
40.000	3.0840	3.0837	3.1296	3.0220	2.9122	2.7863	2.8353	
42.000	2.3909	2.3829	2.4110	2.3290	2.2367	2.1288	2.1714	
44.000	1.8616	1.8513	1.8650	1.8025	1.7281	1.6375	1.6717	−1
46.000	1.4525	1.4423	1.4473	1.4006	1.3426	1.2678	1.2935	
48.000	1.1349	1.1259	1.1266	1.0922	1.0466	0.9876	1.0058	
50.000	8.8690	8.7980	8.7773	8.5260	8.1813	0.7722	0.7835	
52.000	6.9254	6.8698	6.8383	6.6521	6.3997	6.0390	6.1049	
54.000	5.3897	5.3482	5.3121	5.1704	5.0026	4.7219	4.7573	
56.000	4.1795	4.1501	4.1092	4.0012	3.8918	3.6761		
58.000	3.2290	3.2022	3.1641	3.0814	3.0111	2.8452		
60.000	2.4793	2.4533	2.4229	2.3604	2.3164	2.1886		
62.000	1.8888	1.8654	1.8447	1.7981	1.7712	1.6727		
64.000	1.4271	1.4072	1.3959	1.3618	1.3459	1.2698		
66.000	1.0687	1.0526	1.0497	1.0252	1.0161	0.9571		−2
68.000	7.9288	7.8036	7.8411	7.6744	7.6335	0.7171		
70.000	5.8214	5.7300	5.8149	5.7172	5.7060	5.3494		
72.000	4.2257	4.1655	4.2797	4.2381	4.2435	3.9715		
74.000	3.0300	2.9988	3.1248	3.1254	3.1391	2.9343		
76.000	2.1440	2.1369	2.2623	2.2926	2.3092	2.1572		
78.000	1.5090	1.5141	1.6249	1.6725	1.6871	1.5758		
80.000	1.0675	1.0731	1.1643	1.2131	1.2234	1.1411		
82.000	7.5916	7.6212	7.3308	8.7433	8.8026	8.1878		−3
84.000	5.4293	5.4373	5.9522	6.2526	6.2813	5.8179		
86.000	3.9051	3.8967	4.2465	4.4348	4.4435	4.0914		
88.000	2.8243	2.8048	3.0251	3.1248	3.1148	2.8457		
90.000	2.0536	2.0275	2.1519	2.2011	2.1624	1.9569		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-2k. Reference Atmosphere Pressure (mb)—July

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.0114	1.0108	1.0129	1.0135	1.0099	1.0111	1.0130	+3*
2.000	8.0167	8.0182	8.0323	8.0057	7.9221	7.8803	7.8763	+2
4.000	6.2981	6.3057	6.3110	6.2688	6.1556	6.0994	6.0870	
6.000	4.9007	4.9130	4.9112	4.8560	4.7319	4.6602	4.6473	
8.000	3.7740	3.7889	3.7768	3.7154	3.5855	3.5098	3.4964	
10.000	2.8659	2.8784	2.8618	2.8026	2.6724	2.6077	2.5951	
12.000	2.1358	2.1462	2.1329	2.0810	1.9742	1.9355	1.9293	
14.000	1.5577	1.5662	1.5603	1.5215	1.4587	1.4384	1.4362	
16.000	1.1148	1.1208	1.1204	1.1100	1.0780	1.0697	1.0693	+1
18.000	7.9201	7.9959	8.0491	8.1030	7.9683	7.9568	7.9632	
20.000	5.6870	5.7531	5.8235	5.9336	5.8909	5.9195	5.9312	
22.000	4.1290	4.1786	4.2420	4.3606	4.3560	4.4046	4.4185	
24.000	3.0263	3.0622	3.1103	3.2154	3.2235	3.2780	3.2922	
26.000	2.2319	2.2606	2.2948	2.3784	2.3966	2.4419	2.4562	
28.000	1.6556	1.6780	1.7034	1.7653	1.7912	1.8295	1.8398	
30.000	1.2349	1.2521	1.2717	1.2175	1.3455	1.3795	1.3836	
32.000	9.2614	9.3917	9.5480	9.8912	1.0167	1.0466	1.0447	+0
34.000	6.9815	7.0790	7.2069	7.4672	7.7286	7.9867	7.9335	
36.000	5.2893	5.3614	5.4680	5.6678	5.9090	6.1289	6.0713	
38.000	4.0266	4.0794	4.1705	4.3244	4.5428	4.7279	4.6802	
40.000	3.0797	3.1183	3.1982	3.3159	3.5111	3.6654	3.6329	
42.000	2.3661	2.3945	2.4654	2.5549	2.7277	2.8553	2.8376	
44.000	1.8260	1.8468	1.9087	1.9778	2.1294	2.2346	2.2240	−1
46.000	1.4161	1.4304	1.4819	1.5379	1.6693	1.7567	1.7478	
48.000	1.1028	1.1123	1.1536	1.2008	1.3108	1.3847	1.3770	
50.000	8.5953	8.6599	8.9876	9.3866	1.0297	1.0917	1.0855	
52.000	6.6938	6.7410	6.9986	7.3382	8.0887	8.6086	8.5588	
54.000	5.1970	5.2354	5.4389	5.7211	6.3343	6.7889	6.7492	
56.000	4.0215	4.0533	4.2174	4.4357	4.9401	5.3417		
58.000	3.0932	3.1169	3.2518	3.4168	3.8364	4.1856		
60.000	2.3609	2.3778	2.4883	2.6135	2.9661	3.2658		
62.000	1.7873	1.7987	1.8888	1.9844	2.2825	2.5368		
64.000	1.3412	1.3484	1.4216	1.4949	1.7415	1.9549		
66.000	0.9972	1.0012	1.0602	1.1169	1.3145	1.4886		−2
68.000	7.3396	7.3582	7.8313	8.2726	9.8076	1.1189		
70.000	5.3414	5.3484	5.7247	6.0699	7.2253	8.2902		
72.000	3.8406	3.8519	4.1432	4.4096	5.2499	6.0456		
74.000	2.7270	2.7636	2.9833	3.1697	2.6448	3.0425		
76.000	1.9335	1.9756	2.1382	2.2531	2.6448	3.0425		
78.000	1.3759	1.4108	1.5253	1.5871	1.8277	2.0899		
80.000	0.9826	1.0078	1.0827	1.1083	1.2375	1.3997		−3
82.000	7.0408	7.2002	7.6480	7.6707	8.1900	9.1071		
84.000	5.0489	5.1453	5.3742	5.2582	5.3435	5.7944		
86.000	3.6196	3.6665	3.7563	3.5684	2.2396	2.3281		
88.000	2.5763	2.5911	2.6111	2.3961	2.2396	2.3281		
90.000	1.8156	1.8150	1.8048	1.5985	1.4383	1.4709		

*Power of 10 by which preceding numbers should be multiplied.

Table 14-21. Reference Atmosphere Pressure (mb)—October

Alt (km)	0°	15°N	30°N	45°N	60°N	75°N	90°N	
0.000	1.0107	1.0113	1.0169	1.0175	1.0106	1.0092	1.0140	+3*
2.000	8.0149	8.0165	8.0286	7.9662	7.8528	7.7639	7.7527	
4.000	6.3010	6.6036	6.2863	6.1801	6.0564	5.9371	5.8884	+2
6.000	4.9062	4.9091	4.8760	4.7399	4.6213	4.4773	4.4166	
8.000	3.7737	3.7826	3.7323	3.5891	3.4755	3.3235	3.2674	
10.000	2.8627	2.8723	2.8135	2.6797	2.5720	2.4368	2.3937	
12.000	2.1347	2.1427	2.0847	1.9697	1.8870	1.7860	1.7580	
14.000	1.5581	1.5664	1.5216	1.4356	1.3847	1.3093	1.2913	
16.000	1.1128	1.1205	1.0974	1.0466	1.0163	0.9600	0.9460	+1
18.000	7.8791	7.9611	7.8713	7.6313	7.4607	7.0305	6.9124	
20.000	5.6412	5.7136	5.6849	5.5654	5.4712	5.1350	5.0370	
22.000	4.0858	4.1464	4.1378	4.0651	4.0062	3.7403	3.6603	
24.000	2.9857	3.0364	3.0315	2.9783	2.9321	2.7169	2.6524	
26.000	2.1982	2.2389	2.2325	2.1886	2.1509	1.9695	1.9194	
28.000	1.6300	1.6617	1.6525	1.6131	1.5817	1.4318	1.3893	
30.000	1.2170	1.2411	1.2291	1.1923	1.1659	1.0448	1.0058	
32.000	9.1464	9.3262	9.1856	8.8406	0.8614	0.7652	0.7303	+0
34.000	6.9158	7.0486	6.8961	6.5885	6.3843	5.6244	5.3358	
36.000	5.2595	5.3575	5.2020	4.9367	4.7562	4.1500	3.9211	
38.000	4.0221	4.0956	3.9467	3.7183	3.5616	3.0827	2.8978	
40.000	3.0923	3.1483	3.0113	2.8147	2.6804	2.3059	2.1556	
42.000	2.3896	2.4330	2.3100	2.1415	2.0279	1.7365	1.6158	
44.000	1.8540	1.8884	1.7813	1.6408	1.5431	1.3161	1.2201	−1
46.000	1.4429	1.4695	1.3805	1.2654	1.1807	1.0035	0.9277	
48.000	1.1260	1.1463	1.0734	0.9808	9.0823	0.7697	0.7097	
50.000	8.7921	8.9499	8.3510	7.6277	7.0097	0.5937	0.5437	
52.000	6.8580	6.9786	6.4881	5.9319	5.4112	4.5954	4.1658	
54.000	5.3285	5.4152	5.0155	4.5962	4.1744	3.5576	3.1923	
56.000	4.1227	4.1800	3.8563	3.5432	2.4473	2.7515		
58.000	3.1734	3.2073	2.9493	2.7166	2.4473	2.1145		
60.000	2.4286	2.4449	2.2435	2.0700	1.8581	1.6132		
62.000	1.8465	1.8503	1.6969	1.5671	1.4024	1.2211		
64.000	1.3917	1.3883	1.2760	1.1791	1.0524	0.9168		−2
66.000	1.0390	1.0320	0.9536	0.8829	0.7875	0.6831		
68.000	7.6789	7.5958	7.0818	6.5802	5.8798	0.5084		
70.000	5.6135	5.5316	5.2237	4.8795	4.3796	4.7856		
72.000	4.0557	3.9860	3.8261	3.5999	3.2544	2.8189		
74.000	2.8945	2.8526	2.7819	2.6417	2.4125	2.0985		
76.000	2.0580	2.0299	2.0072	1.9279	1.7822	1.5558		
78.000	1.4636	1.4434	1.4414	1.3990	1.3096	1.1475		
80.000	1.0411	1.0266	1.0336	1.0091	0.9571	0.8419		−3
82.000	7.4071	7.3031	7.4076	7.2585	6.9561	6.1426		
84.000	5.2710	5.1963	5.3096	5.2217	5.0267	4.4562		
86.000	3.7517	3.6981	3.8065	3.7572	3.6270	3.2199		
88.000	2.6709	2.6324	2.7295	2.7040	2.6176	2.3267		
90.000	1.9019	1.8742	1.9577	1.9465	1.8895	1.6817		

*Power of 10 by which preceding numbers should be multiplied.

up to 90 km. The largest seasonal changes in mean monthly temperatures occur north of 60° latitude in arctic and subarctic regions. At altitudes up to 60 km, coldest temperatures occur in January and warmest in July. Conditions are reversed at altitudes between 60 and 90 km with coldest temperatures occurring in July and warmest in January.

Cross sections of the January and July densities between the equator and north pole are shown in Figure 14-13. Densities at the various altitudes are expressed as percentages of the densities in the U.S. Standard Atmosphere. The largest departures from standard in January and July densities occur north of 65° latitude near 70 km, where mean January densities, 51% of standard, are a third of the July densities which are 168% of standard.

14.2.1.4 Longitudinal Variations. In summer, longitudinal variations in the structure of the atmosphere are relatively small at all latitudes and at all altitudes above 20 km. Isotherms and contour lines on constant pressure-height charts in the stratosphere and mesosphere parallel the latitude circles, and the associated circulation pattern is symmetrical about the pole. During the winter season, changes with longitude remain relatively small at low latitudes but become as important as changes with latitude and season in arctic and subarctic regions. The magnitude of the longitudinal variations in arctic and subarctic regions during winter is illustrated by a set of atmospheric models depicting January conditions between the surface and 54 km at 10°, 100°, and 140°W for 60°N, and 10° and 140°W for 75°N. The models are based on radiosonde observations, rocketsonde observations, constant pressure maps between 5 and 0.4 mb, hydrostatic build-up techniques from the 5- and 10-mb levels, and the thermal wind equation. The atmospheric properties for these January models at 60° and 75°N are given in Table 14-3. Temperature-height profiles for the individual models are shown in Figures 14-14 and 14-15.

The density-height profiles for the 60°N January models developed for 10°, 100° and 140°W (Figure 14-16) indicate that the longitudinal variation in mean monthly densities at 40 km in winter ranges from 5% less than standard at 140°W to 20% less at 10°W. Density profiles for longitudes 10° and 140°W at 75°N (Figure 14-17), indicate that the lon-

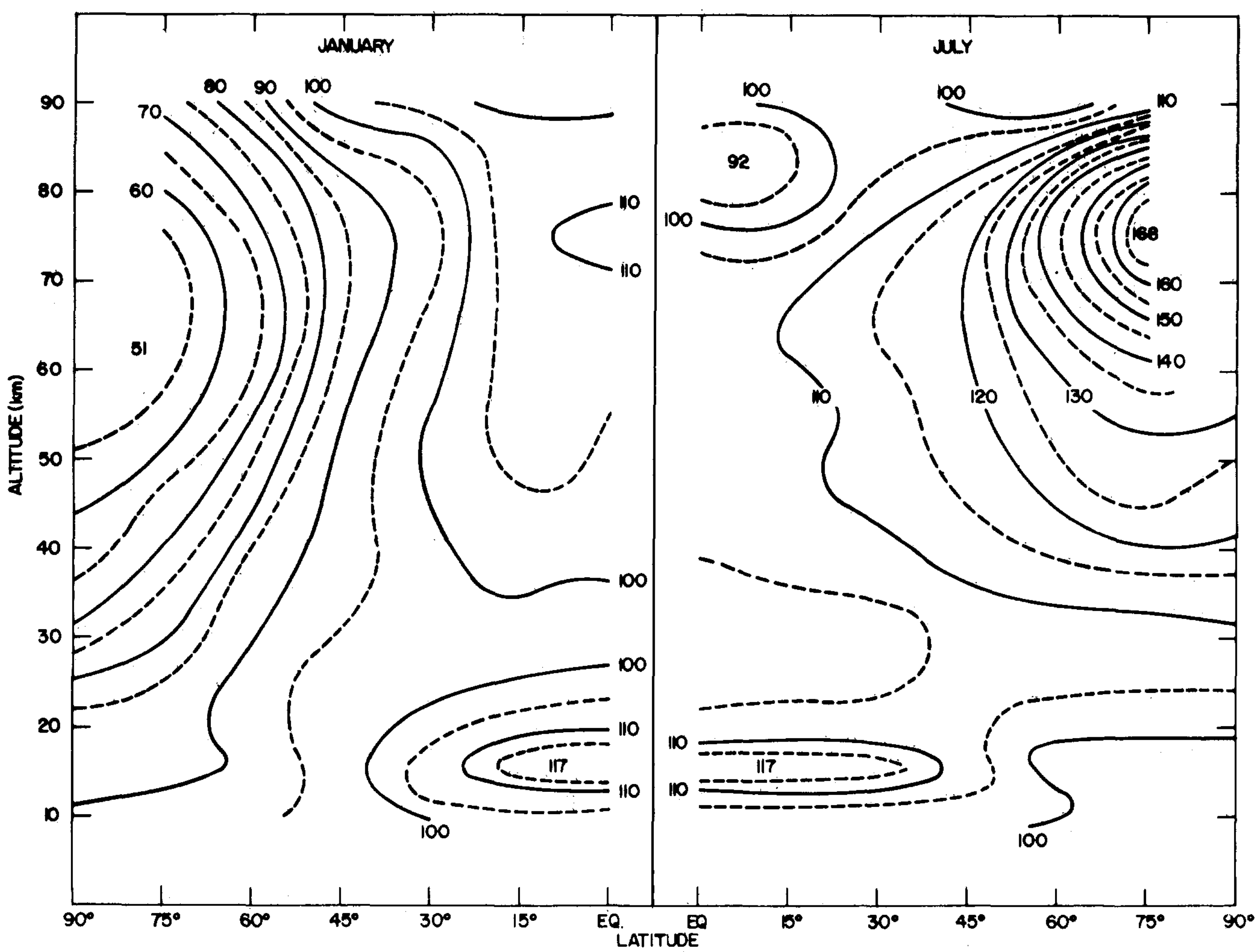

Figure 14-13. Latitudinal density-height cross-sections for January and July.

Table 14-3a. Temperature (K) in January for 60°N and 75°N at specified longitudes.

Altitude	60°N			75°N	
(km)	10°W	100°W	140°W	10°W	140°W
0.000	278.15	246.15	269.15	257.65	242.15
2.000	265.73	248.64	261.14	252.64	246.95
4.000	253.33	242.13	251.73	244.11	242.12
6.000	240.93	232.14	238.13	232.10	232.34
8.000	228.54	222.14	224.54	220.10	217.34
10.000	216.16	217.15	221.15	213.64	213.65
12.000	216.15	217.15	221.15	212.64	213.65
14.000	216.15	217.15	221.15	211.65	213.65
16.000	216.15	215.96	221.15	210.65	213.65
18.000	214.17	214.76	221.15	209.65	213.65
20.000	212.18	213.57	221.15	206.40	212.16
22.000	207.27	212.37	218.22	200.82	210.17
24.000	202.29	211.18	215.24	195.25	208.18
26.000	204.84	213.07	217.46	195.15	211.27
28.000	207.62	215.06	219.84	199.22	214.45
30.000	210.40	217.04	222.22	203.39	217.63
32.000	213.18	219.03	224.60	207.56	220.80
34.000	215.95	221.94	226.98	211.73	223.98
36.000	220.38	224.91	229.36	215.89	227.15
38.000	224.94	227.88	231.73	221.17	230.32
40.000	229.49	232.65	234.03	226.51	233.49
42.000	234.03	237.59	236.20	231.86	236.66
44.000	238.58	242.53	238.37	237.20	239.82
46.000	243.12	247.47	240.55	242.53	242.80
48.000	247.66	249.85	242.72	244.89	245.77
50.000	252.19	251.82	245.83	246.87	248.73
52.000	256.73	252.15	250.76	248.84	251.69
54.000	257.55	252.15	254.15	250.15	252.15

Table 14.3b Density (kg/m^3) in January for 60°N and 75°N at Specified Longitudes

Altitude	60°N			75°N		
(km)	10°W	100°W	140°W	10°W	140°W	
0.000	1.2555	1.4400	1.3075	1.3608	1.4681	+0*
2.000	1.0219	1.0829	1.0412	1.0612	1.0880	
4.000	8.2374	8.4250	8.2788	8.3467	8.4007	−1
6.000	6.5693	6.5882	6.6212	6.5870	6.5674	
8.000	5.1775	5.0972	5.2271	5.1341	5.1802	
10.000	4.0275	3.8155	3.9010	3.8527	3.8306	
12.000	2.9382	2.7874	2.8660	2.8103	2.7832	
14.000	2.1438	2.0367	2.1061	2.0473	2.0226	
16.000	1.5645	1.4954	1.5479	1.4895	1.4701	
18.000	1.1508	1.0963	1.1379	1.0822	1.0688	
20.000	8.4435	8.0254	8.3672	7.9325	7.8198	−2
22.000	6.2514	5.8655	6.2233	5.8370	5.7198	
24.000	4.5969	4.2802	4.6120	4.2589	4.1721	
26.000	3.2519	3.0803	3.3352	3.0083	2.9732	
28.000	2.3090	2.2230	2.4190	2.0881	2.1291	
30.000	1.6474	1.6094	1.7610	1.4600	1.5325	
32.000	1.1808	1.1689	1.2865	1.0284	1.1085	
34.000	8.5018	8.4851	9.4326	7.2973	8.0574	−3
36.000	6.1087	6.1851	6.9392	5.2134	5.8840	
38.000	4.4174	4.5282	5.1221	3.7332	4.3165	
40.000	3.2158	3.3069	3.7944	2.6943	3.1806	
42.000	2.3561	2.4296	2.8208	1.9597	2.3537	
44.000	1.7370	1.7967	2.1031	1.4361	1.7491	
46.000	1.2881	1.3370	1.5724	1.0599	1.3059	
48.000	0.9607	1.0100	1.1790	0.7959	0.9788	
50.000	7.2057	7.6608	8.8318	6.0021	7.3628	−4
52.000	5.4328	5.8578	6.6017	4.5369	5.5581	
54.000	4.1700	4.4858	4.9924	3.4462	4.2473	

*Power of 10 by which preceding numbers should be multiplied.

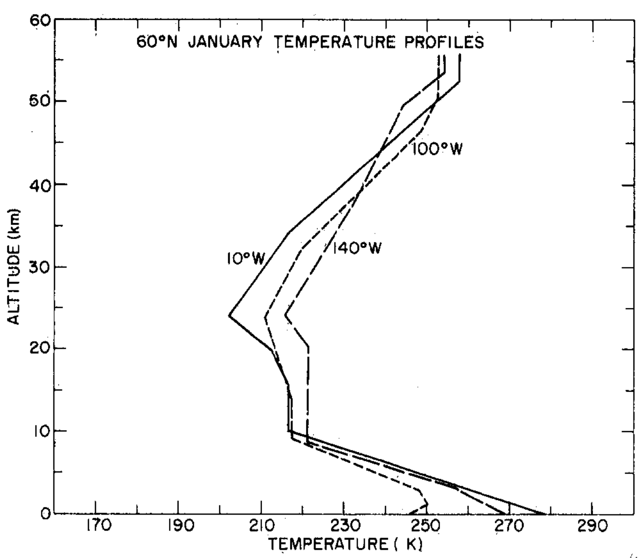

Figure 14-14. Mean monthly temperature-height profiles for the 60°N models at longitudes 10°, 100°, and 140°W.

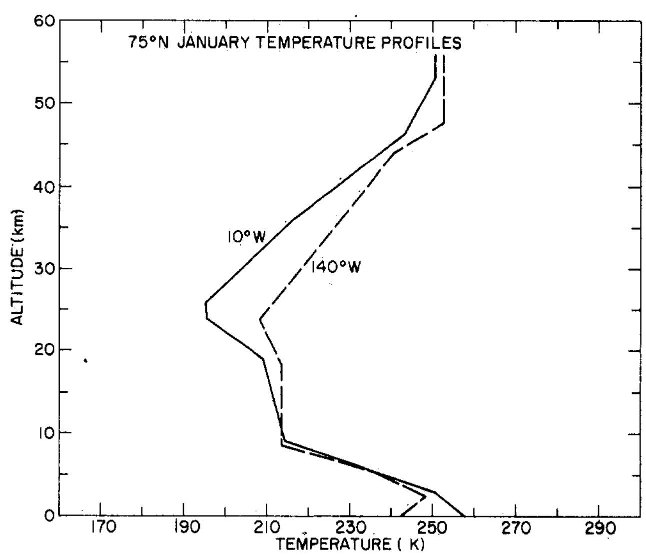

Figure 14-15. Mean monthly temperature-height profiles for the 75°N models at 10° and 140°W.

Table 14-3c. Pressure (mb) in January for 60°N and 75°N at Specified Longitudes

Altitude (km)	60°N 10°W	60°N 100°W	60°N 140°W	75°N 10°W	75°N 140°W	
0.000	1.0025	1.0175	1.0102	1.0065	1.0205	+3*
2.000	7.7954	7.7292	7.8054	7.6963	7.7132	+2
4.000	5.9903	5.8559	5.9823	5.8488	5.8387	
6.000	4.5435	4.3901	4.5261	4.3886	4.3801	
8.000	3.3967	3.2504	3.3693	3.2438	3.2318	
10.000	2.4991	2.3783	2.4764	2.3628	2.3493	
12.000	1.8230	1.7375	1.8194	1.7154	1.7069	
14.000	1.3301	1.2695	1.3370	1.2438	1.2404	
16.000	9.7072	9.2705	9.8268	9.0069	9.0164	+1
18.000	7.0753	6.7589	7.2240	6.5134	6.5550	
20.000	5.1428	4.9201	5.3116	4.6998	4.7625	
22.000	3.7194	3.5758	3.8983	3.3648	3.4508	
24.000	2.6695	2.5947	2.8495	2.3870	2.4933	
26.000	1.9122	1.8840	2.0819	1.6852	1.8032	
28.000	1.3762	1.3723	1.5266	1.1941	1.3106	
30.000	0.9949	1.0027	1.1233	0.8524	0.9573	
32.000	7.2258	7.3493	8.2951	6.1279	7.0263	+0
34.000	5.2703	5.4058	6.1459	4.4351	5.1805	
36.000	3.8645	3.9933	4.5687	3.2309	3.8367	
38.000	2.8523	2.9621	3.4072	2.3701	2.8539	
40.000	2.1184	2.2084	2.5490	1.7519	2.1318	
42.000	1.5829	1.6570	1.9126	1.3043	1.5990	
44.000	1.1896	1.2508	1.4391	0.9778	1.2041	
46.000	0.8990	0.9498	1.0858	0.7379	0.9102	
48.000	6.8305	7.2441	8.2146	5.5957	6.9055	−1
50.000	5.2165	5.5378	6.2323	4.2534	5.2570	
52.000	4.0037	4.2399	4.7520	3.2407	4.0156	
54.000	3.0829	3.2468	3.6422	2.4746	3.0742	

*Power of 10 by which preceding numbers should be multiplied.

gitudinal variability is slightly smaller at 75°N than at 60°N. The lowest mean monthly densities between 35 and 55 km occur at 10°W at both 60° and 75°N.

14.2.1.5 Cold and Warm Winter Stratosphere/Mesosphere. In arctic and subarctic regions, sudden warmings and coolings of the winter stratosphere and mesosphere produce large changes in the vertical and horizontal structure of the atmosphere. Both the magnitude and altitude of maximum temperature and density fluctuations during major warmings and coolings vary considerably. Some of the largest changes in the vertical temperature profiles have been observed in the upper stratosphere between 35 and 45 km. The observed 35- to 45-km temperatures have a range of roughly 85 K in winter compared with 20 K in summer. As a result, mean monthly atmospheric models for the winter months are of limited value for specifying temperatures at these altitudes since the day-to-day variations in temperature are in some cases as great or greater than the seasonal or latitudinal changes. Although these warmings and coolings occur throughout the arctic and subarctic region, the largest changes generally occur between latitude 60° and 75°N; they have been observed much more frequently at some longitudes than at others.

A family of warm and cold atmospheric models typical of the region between 60° and 75°N has been prepared to provide an indication of the magnitude of the variations that can occur in the vertical distributions of temperature, density, and pressure in winter for altitudes up to 90 km. The

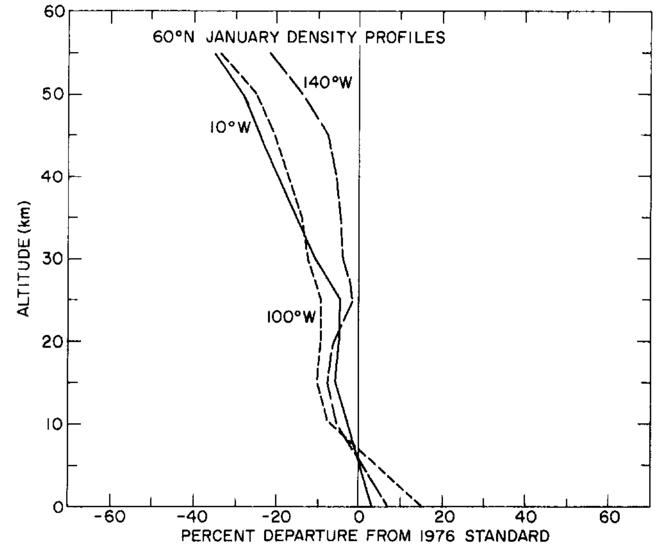

Figure 14-16. Density-height profiles for the 60°N models at 10°, 100°, and 140°W.

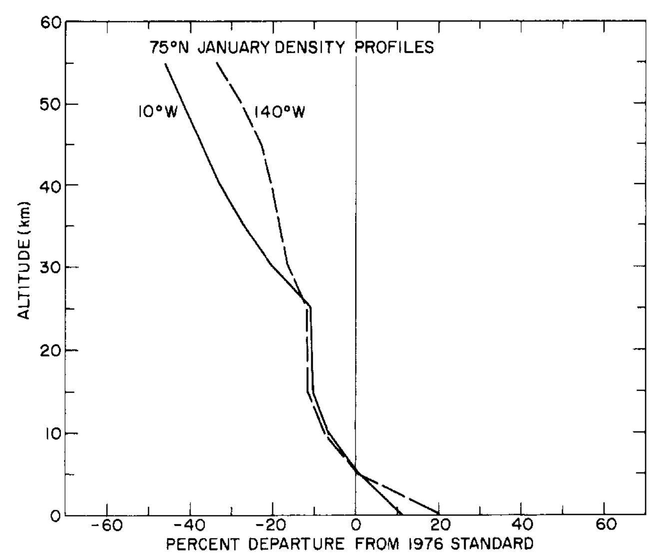

Figure 14-17. Density-height profiles for the 75°N models at 10° and 140°W.

atmospheric properties representative of one cold and three warm stratospheric regimes that occur at these latitudes are given in Table 14-4. The temperature-height profiles are shown in Figure 14-18. They are based on radiosonde, meteorological rocket, and experimental observations (grenades, falling spheres, and pressure gauges) taken at Poker Flat, 64°N, Ft. Churchill, 59°N, Pt. Barrow, 71°N and West Geirinish 57°N during the period 1965 to 1976. Mean January conditions at 60°N are assumed below 9 km since the temperature-height profiles for this region during the various

Table 14-4. High-latitude thermodynamic properties of warm and cold winter stratosphere/mesosphere.

Altitude (km)	Model A (Warm)	Model B (Warm)	Model C (Warm)	Model D (Cold)	Model A (Warm)	Model B (Warm)	Model C (Warm)	Model D (Cold)		Model A (Warm)	Model B (Warm)	Model C (Warm)	Model D (Cold)	
	Temperature (K)				Density (kg/m³)					Pressure (mb)				
0.000	257.15	257.15	257.15	257.15	1.3742	1.3742	1.3742	1.3742	+0	1.0144	1.0144	1.0144	1.0144	+3*
2.000	255.94	255.94	255.94	255.94	1.0590	1.0590	1.0590	1.0590		7.7806	7.7806	7.7806	7.7806	+2
4.000	247.73	247.73	247.73	247.73	8.3466	8.3466	8.3466	8.3466	−1	5.9354	5.9354	5.9354	5.9354	
6.000	234.13	234.13	234.13	234.13	6.6507	6.6507	6.6507	6.6507		4.4699	4.4699	4.4699	4.4699	
8.000	220.54	220.54	220.54	220.54	5.2286	5.2286	5.2286	5.2286		3.3102	3.3102	3.3102	3.3102	
10.000	217.15	217.15	217.15	219.39	3.8811	3.8811	3.8811	3.8460		2.4192	2.4192	2.4192	2.4221	
12.000	215.16	215.66	214.17	222.38	2.8495	2.8534	2.8716	2.7866		1.7661	1.7664	1.7654	1.7789	
14.000	211.17	212.66	208.18	223.15	2.1163	2.1050	2.1394	2.0461		1.2829	1.2850	1.2785	1.3106	
16.000	207.19	209.68	202.21	223.15	1.5577	1.5465	1.5806	1.5080		9.2646	9.3087	9.1750	9.6600	+1
18.000	203.20	206.69	196.23	223.15	1.1399	1.1314	1.1574	1.1116		6.6496	6.7132	6.5200	7.1210	
20.000	199.22	203.70	196.15	223.15	8.2929	8.2419	8.1870	8.1965	−2	4.7425	4.8194	4.6097	5.2503	
22.000	195.24	200.72	204.93	222.17	5.9953	5.9767	5.5825	6.0670		3.3601	3.4436	3.2840	3.8693	
24.000	194.56	201.50	213.88	221.18	4.2395	4.2401	3.8671	4.4895		2.3677	2.4525	2.3742	2.8481	
26.000	197.54	206.46	222.82	220.18	2.9535	2.9667	2.7200	3.3130		1.6747	1.7583	1.7397	2.0940	
28.000	200.51	211.43	231.75	219.19	2.0692	2.0939	1.9402	2.4439		1.1910	1.2708	1.2908	1.5377	
30.000	203.49	216.39	240.68	218.20	1.4576	1.4901	1.4021	1.8006		0.8514	0.9256	0.9687	1.1278	
32.000	215.87	227.36	253.37	217.21	0.9942	1.0447	1.0122	1.3251		6.1609	6.8189	7.3624	8.2621	+0
34.000	228.75	238.66	266.25	214.35	6.9184	7.4429	7.4226	9.8119	−3	4.5429	5.0991	5.6730	6.0374	
36.000	241.63	248.52	279.13	211.38	4.9118	5.4164	5.5241	7.2403		3.4068	3.8640	4.4261	4.3933	
38.000	254.49	256.44	275.59	208.41	3.5505	4.0156	4.3868	5.3208		2.5938	2.9560	3.4704	3.1832	
40.000	267.35	264.35	270.64	211.39	2.6084	3.0049	3.4878	3.8002		2.0018	2.2802	2.7096	2.3060	
42.000	282.87	272.26	265.70	214.95	1.9283	2.2683	2.7617	2.7224		1.5657	1.7727	2.1063	1.6798	
44.000	298.67	278.41	260.76	219.78	1.4478	1.7360	2.1775	1.9506		1.2413	1.3874	1.6299	1.2306	
46.000	296.64	280.65	255.83	226.69	1.1640	1.3537	1.7093	1.3979		0.9912	1.0906	1.2553	0.9097	
48.000	285.79	278.24	250.89	233.60	0.9585	1.0732	1.3357	1.0121		7.8635	8.5719	9.6204	6.7872	−1
50.000	274.94	274.30	246.43	240.50	0.7834	0.8530	1.0370	0.7398		6.1836	6.7169	7.3358	5.1080	
52.000	264.10	270.36	242.89	245.76	6.3533	6.7591	7.9903	5.4900	−4	4.8166	5.2456	5.5710	3.8730	
54.000	253.27	266.42	239.34	250.68	5.1074	5.3380	6.1340	4.1041		3.7132	4.0823	4.2143	2.9533	
56.000	244.48	260.58	235.80	255.60	4.0350	4.2290	4.6913	3.0861		2.8317	3.1633	3.1754	2.2643	
58.000	240.55	254.29	232.26	255.87	3.1084	3.3379	3.5739	2.3716		2.1464	2.4365	2.3828	1.7419	
60.000	236.61	248.00	228.72	254.89	2.3847	2.6194	2.7118	1.8302		1.6197	1.8647	1.7804	1.3391	
62.000	232.69	241.71	225.18	253.91	1.8217	2.0431	2.0492	1.4112		1.2168	1.4176	1.3246	1.0285	
64.000	228.76	235.43	221.65	252.92	1.3855	1.5835	1.5419	1.0872		0.9098	1.0701	0.9810	0.7893	
66.000	224.83	229.15	218.11	251.94	1.0489	1.2190	1.1551	0.8369		6.7699	8.0188	7.2325	6.0527	−2
68.000	220.91	222.87	214.59	250.28	7.9039	9.3184	8.6146	6.4526	−5	5.0122	5.9616	5.3064	4.6359	
70.000	216.99	216.60	211.32	248.32	5.9267	7.0697	6.3867	4.9718		3.6917	4.3957	3.8742	3.5440	
72.000	213.07	210.33	209.36	246.36	4.4216	5.3212	4.6899	3.8235		2.7045	3.2128	2.8186	2.7040	
74.000	209.16	204.07	207.40	244.40	3.2815	3.9716	3.4346	2.9348		1.9702	2.3266	2.0448	2.0590	
76.000	205.35	199.73	205.45	242.45	2.4210	2.9126	2.5084	2.2482		1.4271	1.6699	1.4793	1.5646	
78.000	202.41	196.60	203.49	239.80	1.7700	2.1123	1.8268	1.7234		1.0284	1.1921	1.0671	1.1863	
80.000	199.48	193.47	201.54	236.67	1.2884	1.5244	1.3266	1.3195		7.3779	8.4664	7.6749	8.9645	−3
82.000	198.15	190.35	199.59	233.55	0.9268	1.0945	0.9605	1.0068		5.2718	5.9806	5.5034	6.7501	
84.000	198.15	187.23	197.63	230.43	6.6205	7.8172	6.9347	7.6561	−6	3.7657	4.2013	3.9342	5.0642	
86.000	198.15	184.68	196.65	227.31	4.7301	5.5370	4.9689	5.8011		2.6904	2.9354	2.8049	3.7852	
88.000	198.15	182.73	196.65	223.82	3.3802	3.8948	3.5417	4.3861		1.9226	2.0430	1.9992	2.8181	
90.000	198.15	180.79	196.65	219.93	2.4160	2.7299	2.5250	3.3072		1.3742	1.4167	1.4253	2.0879	

*Power of 10 by which preceding numbers should be multiplied.

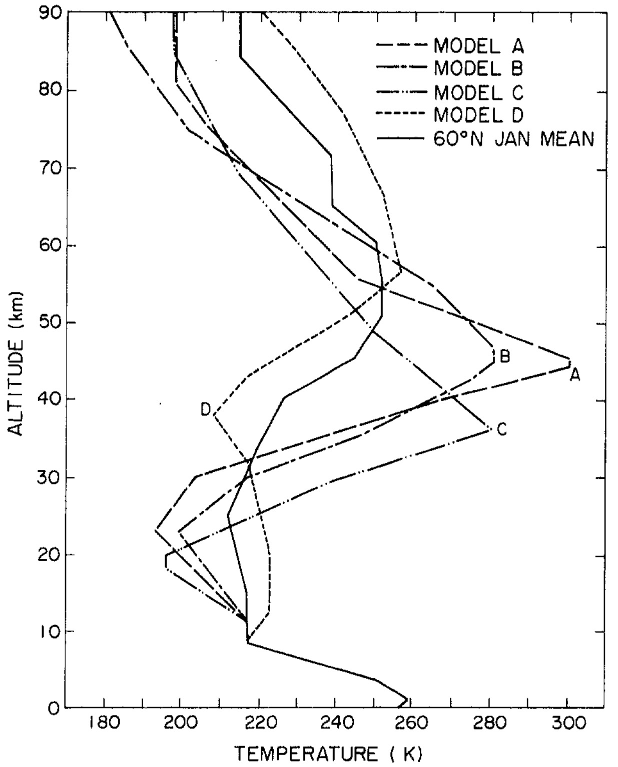

Figure 14-18. Temperature-height profiles associated with extreme warm and cold regimes in the winter stratosphere and mesosphere near 60°N.

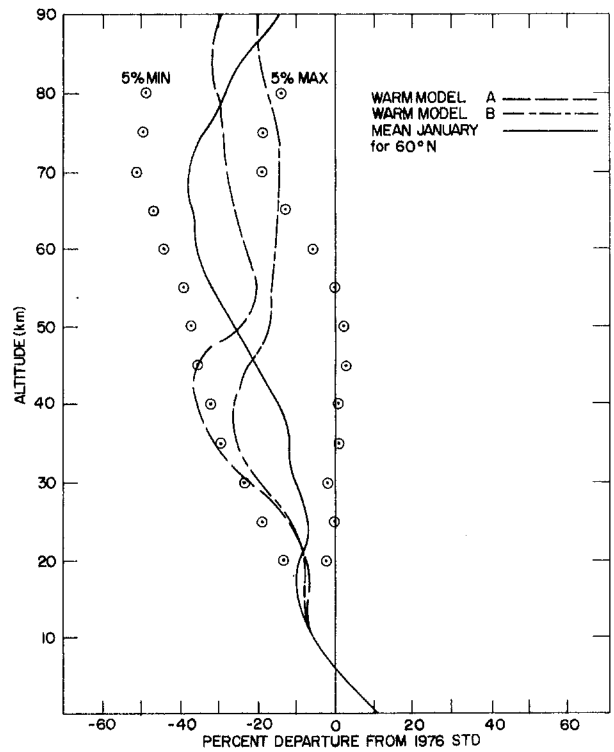

Figure 14-19. Density profiles (warm) associated with extreme temperatures in the upper stratosphere and mean January conditions at 60°N. Circled points form an envelope of high and low densities equaled or surpassed 5% of time.

warmings and coolings are not significantly different from the mean January 60°N atmosphere.

The three warm models could all occur during various stages of one large-scale warming. However, available observations indicate that a temperature of 300 K at 45 km is equaled or exceeded 2% of the time at West Geirinish and 0.4% of the time at Ft. Churchill during January, whereas a temperature of 280 K at 45 km is equaled or exceeded 10% of the time at West Geirinish and 4% of the time at Ft. Churchill. A temperature of 280 K near 36 km is equaled or exceeded 0.6% of the time at West Geirinish and 0.1% of the time at Ft. Churchill. Frequencies of occurrence were obtained by plotting the observed temperature distributions on probability paper.

The cold profile, Model D, is based on an average of five observations in which the temperature at 45 km was within 2° of 223 K. Observed data indicate that a temperature of 223 K or colder occurs at Ft. Churchill 6% of the time, at West Geirinish 4% of the time, and at Poker Flat 9% of the time in January.

The portions of the temperature-height profiles between 55 and 85 km are based on estimates obtained by using interlevel temperature correlations with the temperatures adopted at 40, 45, and 50 km.

The density profiles associated with both the warm and cold models are provided along with the mean January 60°N profile in Figures 14-19 and 14-20. The densities are portrayed as percent departures from the 1976 Standard Atmosphere. Envelopes of the high and low values of density which are equaled or surpassed 5% of the time at 60°N in January are also shown. They are envelopes rather than realistic profiles since 5% values do not occur simultaneously at all altitudes. The density profiles for the warm and cold models illustrate the negative correlations that exist between the densities at various levels in the atmosphere [Quiroz, 1971; Labitzke, 1971; Cole, 1972]. For example, when the density is much less than the mean monthly value at altitudes between 25 and 40 km (Figure 14-20), it is greater than the mean value between 45 and 75 km. In most cases the departures of density from the monthly mean fall within the 5% envelope. However, as shown in Figure 14-20, density profiles associated with an extreme winter warming or cooling will approach both the 5% maximum and 5% minimum values at different altitudes.

The altitudes of the maximum density departures from the monthly mean are related to the altitudes of maximum temperature deviations in that the maximum density departures are roughly 10 to 20 km above the maximum temperature deviations. For example, the largest positive density departure for profile C (Figure 14-20) occurs near 49 km, whereas the maximum stratospheric temperature, 280 K for profile C (Figure 14-18), is at 36 km. The largest

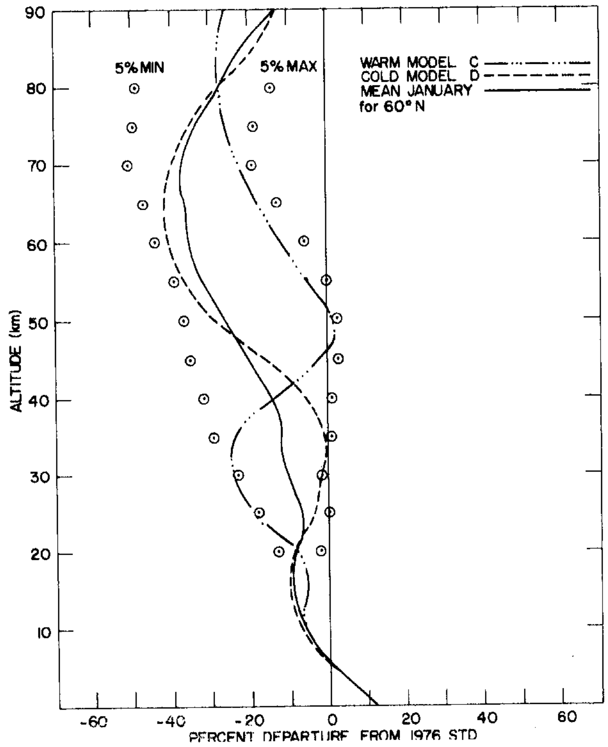

Figure 14-20. Density profiles associated with extreme temperatures in the upper stratosphere and mean January conditions at 60°N. Circled points form an envelope of high and low densities equaled or surpassed 5% of time.

negative density departure for the same profile occurs near 33 km and its minimum stratospheric temperature, 196 K is at 18-20 km.

14.2.2 High Altitude Reference Atmospheres

Although there were early high altitude model atmospheres based on upward extrapolation of rocket data, they were not accurate and the first official U.S. models of the satellite era, including density values derived from satellite drag, were the *ARDC Model Atmosphere, 1959* [Minzner, 1959] and the *U.S. Standard Atmosphere, 1962* [COESA]. These models accurately represented thermospheric density at the time the observations were made, but since the observations were made at the peak of solar cycle 19 which had unusually high activity, they represented conditions that are not frequently observed.

The next generation of reference atmospheres started with the COSPAR International Reference Atmosphere (CIRA) 1965 (COSPAR). These atmospheres included a Mean CIRA between 30 and 300 km prepared by Champion and a set of models for 120 to 800 km prepared by Harris and Priester. The latter are semi-theoretical models but with some free parameters whose values were chosen so that the models reproduced observed densities. The following year the *U.S. Standard Atmosphere Supplements, 1966* [COESA] were published. This publication included models up to 1000 km. The lower thermospheric models were based on work by Champion and the upper thermospheric models on work by Jacchia. An updated set of COSPAR models was published in 1972 as *CIRA 1972* (COSPAR). In these models Champion and Schweinfurth [1972] prepared the Mean CIRA for altitudes between 25 and 500 km and Jacchia [1971] prepared a set of models for the altitude range 110 to 2000 km. More recent models include the U.S. Standard Atmosphere, 1976 (COESA), and the Jacchia [1977] model.

The preceding models have all been based principally on density data from orbital drag and *in situ* measurements of density and composition. Recently, models have been developed which are also based on airglow temperatures (DTM) [Barlier et al., 1978] or incoherent radar scatter temperatures (MSIS) [Hedin et al., 1977]. A number of theoretical models are being developed, including the NCAR thermospheric general circulation model by Roble and colleagues [Dickinson et al., 1981]. This is a three-dimensional model of the global neutral gas temperatures and circulation of the thermosphere. Rees and colleagues [Fuller-Rowell and Rees, 1980] are also developing a three-dimensional global model of the thermosphere. They start with a realistic steady-state model and then progressively modify it in response to the sources and sinks of energy and momentum and to the winds that result from the various driving forces redistributing mass, momentum, and energy. Important components of theoretical models are the amplitudes and phases of the tidal effects. The principal tides are the solar diurnal, semidiurnal and terdiurnal. The magnitudes of these tides and their effects on density and composition are reviewed by Champion [1981].

14.2.2.1 Development of Reference Atmospheres. Since the earliest upper atmosphere models, it has been customary to define them in part by means of temperature profiles which, by means of the appropriate physical relations, yield density profiles, and in the more modern models, composition and other properties.

At this point we will review the temperature profiles of some models of particular interest. Figure 14-21 shows the temperature profiles of the U.S. Standard 1962, Mean CIRA 1965, Mean CIRA 1972 and U.S. Standard 1976. It can be seen that as time progressed the mean model temperatures in the thermosphere have become lower. There is a good reason for this which can be understood by referring to Figure 14-22. This figure shows a plot of the mean annual number of sunspots from 1820 to 1976. The 11-yr cycle of activity can be seen and also the wide variation in the number of sunspots at the cycle peaks. Table 14-5 shows that the succeeding models, which are based on satellite orbital drag and *in situ* measurements, have sampled the atmosphere starting from very non-typical conditions in 1957 to increasingly representative conditions with time. In addition, Slowey [1979] has done a study using both sunspot numbers

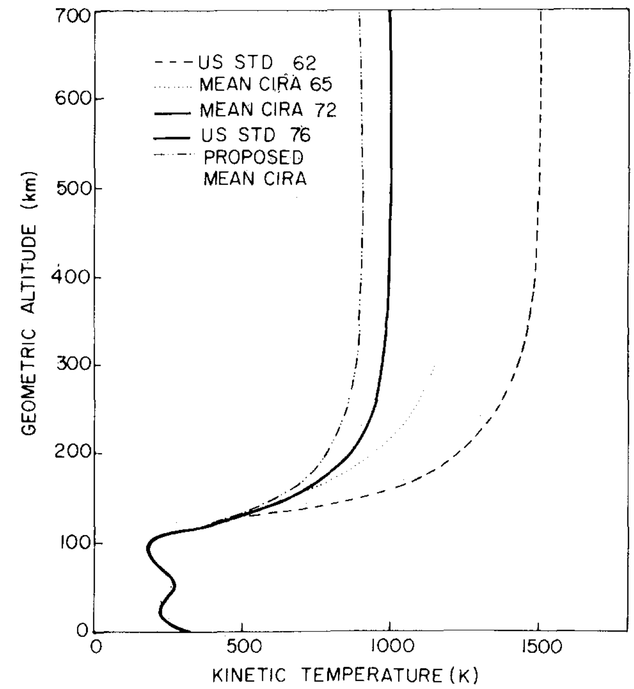

Figure 14-21. Kinetic temperature profiles for several standard and reference atmospheres, including a proposed new mean CIRA.

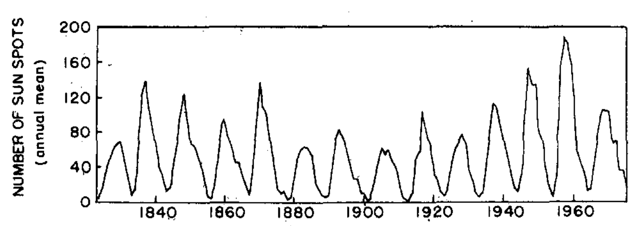

Figure 14-22. The mean annual number of sunspots from 1820 to 1976.

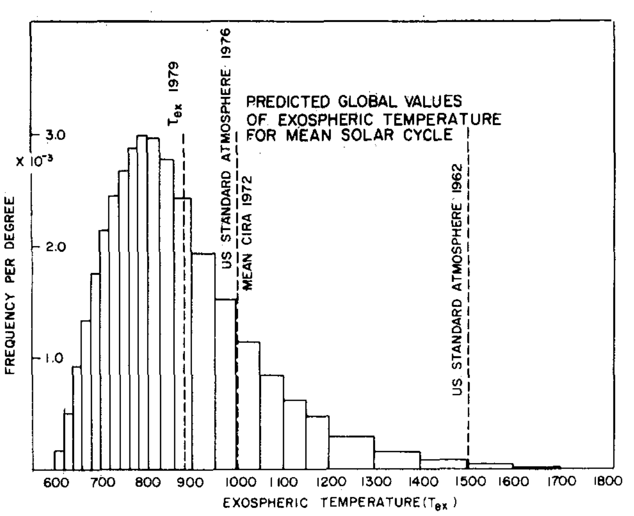

Figure 14-23. Histogram of frequency per degree of predicted exospheric temperatures for a mean solar cycle.

Table 14-5. Average exospheric temperature.

	AVERAGE
US STANDARD ATMOSPHERE 1962 (3 YRS)	1500 K
MEAN CIRA 65	1200 K
MEAN CIRA 72	1000 K
US STANDARD ATMOSPHERE 1976 (1½ SOLAR CYCLES)	1000 K
SPECIAL STUDY (12 SOLAR CYCLES)	882 K

back to 1847 (12 cycles) and the Jacchia 1971 model to determine relative values and has found that the expected mean exospheric temperature averaged over all conditions for this period would be 882 K. A histogram showing the predicted exospheric temperature distribution is given in Figure 14-23. The exact mean temperature will depend on the time period chosen (for example, including the Maunder minimum would have a profound effect) and the model used to determine relative values. However, it is recommended that 900 K be used for the exospheric temperature for the next Mean CIRA as being appropriate to this phase of solar activity. The corresponding density profiles of the four previous standard or mean models and that of the proposed new model are shown in Figure 14-24.

The most up-to-date set of approved reference atmospheres for altitudes above 90 km is that contained in *CIRA 72*. There are plans to prepare revised versions of both CIRA and the U.S. Standard Atmosphere Supplements. The latest published version of the latter is the *U.S. Standard Atmosphere Supplements, 1966*.

The CIRA 1972 models up to 120 km were prepared by Groves of University College, London, England and the Air Force Cambridge Research Laboratory (AFCRL). An independent set of models for the region 110 to 2000 km were prepared by Jacchia of the Smithsonian Astrophysical

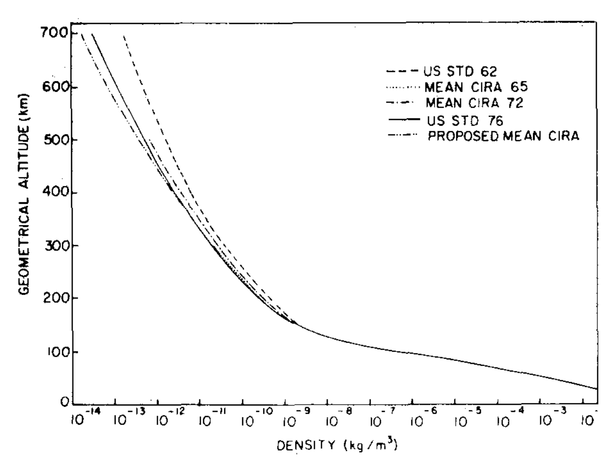

Figure 14-24. Density profiles of several standard and reference atmospheres, including a proposed new mean CIRA.

Observatory. Since these two sets of models do not, in general, match at 110 km, Champion and Schweinfurth of AFCRL developed the Mean CIRA which is continuous from 25 to 500 km and applies under specified conditions.

14.2.2.2 Mean CIRA Reference Atmosphere. The basis of the mean reference atmosphere is as follows: Between 25 and 75 km the model represents annual mean conditions for latitudes near 30°. Between 120 and 500 km the model corresponds to diurnal, seasonal, and semi-annual variation average conditions for a latitude near 30° and a solar flux $\bar{F}$ of 145 × 10^{-22} W m^{-2} Hz^{-1}. Between 75 and 120 km a model has been developed which provides a smooth connection between the lower and upper sections of the mean atmosphere. This atmosphere contains kinetic temperature, molecular-scale temperature, density, pressure, density and pressure scale heights, mean molecular weight, densities of major constituents, and total number densities.

The data used to develop the model between 25 and 75 km were the values at 30° latitude of the annual mean pressure at 25 km and the annual mean temperature between 25 and 75 km. The pressure equation was integrated numerically.

$$p = p_l \exp\left[-\frac{M_0}{R} \int_{z_l}^{z} g dz/T_M \right] \qquad (14.17)$$

where

p = pressure at altitude z

p_l = pressure at reference altitude z_l

M_0 = sea level value of mean molecular weight = 28.96

R = 8.31432 × 10^7 ergs K^{-1} g mol^{-1}

g = acceleration due to gravity at 30° latitude

T_M = molecular-scale temperature

$= \frac{M_0 T}{M}$

where

M = mean molecular weight

T = kinetic temperature.

The model between 75 and 120 km was constrained to provide a transition between the low altitude model and the high altitude model. These two models are not only different but are functions of different parameters. Thus a compromise was devised. A temperature profile was developed with a constraint that it yield a specified density value at 120 km. The equations and method used to determine the composition are given in Champion and Schweinfurth [1972].

Table 14-6. Mean Reference Atmosphere Structure Parameters 25 to 120 km.

Height km	Mol Temp K	Density kg/m³	Pressure N/m²	Number Density m⁻³	Pressure Scale Ht(km)	g m/s²
25	221.7	3.899E−02	2.483E+03	8.111E+23	6.55	9.716
30	230.7	1.774E−02	1.175E+03	3.690E+23	6.83	9.701
35	241.5	8.279E−03	5.741E+02	1.722E+23	7.16	9.686
40	255.3	3.972E−03	2.911E+02	8.265E+22	7.58	9.671
45	267.7	1.995E−03	1.535E+02	4.148E+22	7.96	9.656
50	271.6	1.057E−03	8.241E+01	2.198E+22	8.09	9.641
55	263.9	5.821E−04	4.406E+01	1.210E+22	7.87	9.626
60	249.3	3.206E−04	2.296E+01	6.669E+21	7.45	9.611
65	232.7	1.718E−04	1.146E+01	3.568E+21	6.96	9.596
70	216.2	8.770E−05	5.445E+00	1.822E+21	6.48	9.581
75	205.0	4.178E−05	2.460E+00	8.696E+20	6.15	9.566
80	195.0	1.905E−05	1.067E+00	3.964E+20	5.86	9.551
85	185.1	8.337E−06	4.426E−01	1.736E+20	5.57	9.536
90	183.8	3.396E−06	1.795E−01	7.087E+19	5.54	9.521
95	190.3	1.343E−96	7.345E−02	2.808E+19	5.75	9.506
100	203.5	5.297E−07	3.090E−02	1.125E+19	6.16	9.492
105	228.0	2.173E−07	1.422E−02	4.768E+18	6.91	9.477
110	265.5	9.661E−08	7.362E−03	2.182E+18	8.06	9.462
115	317.1	4.645E−08	4.236E−03	1.076E+18	9.64	9.448
120	380.6	2.438E−08	2.667E−03	5.772E+17	11.58	9.433

Table 14-7. Kinetic Temperature and Composition of the Mean Reference Atmosphere, 75 to 120 km

Height km	Temp K	Mean Mol Wt	Log N(N_2) m^{-3}	Log N(O_2) m^{-3}	Log N(O) m^{-3}	Log N(Ar) m^{-3}	Log N(HE) m^{-3}	Log N(O_3) m^{-3}
75	205.0	28.96	20.832	20.261		18.910	15.659	
80	194.9	28.95	20.492	19.914	16.794	18.563	15.315	14.495
85	184.9	28.93	20.135	19.550	17.144	18.199	14.954	14.098
90	183.4	28.89	19.747	19.153	17.220	17.802	14.565	13.425
95	189.3	28.81	19.346	18.739	17.280	17.389	14.178	12.665
100	199.4	28.37	18.940	18.299	17.618	16.945	13.928	12.099
105	216.6	27.51	18.556	17.823	17.647	16.435	13.811	11.178
110	245.1	26.73	18.200	17.398	17.509	15.961	13.711	10.132
115	285.2	26.05	17.872	17.036	17.332	15.539	13.620	9.098
120	334.5	25.45	17.579	16.734	17.153	15.173	13.538	8.167

The exospheric temperature for the conditions specified above is 1000 K. The Jacchia models were recomputed using the acceleration due to gravity for 30° latitude. The original models use a value valid only near latitude 45°. The model values were then changed at all altitudes so that they matched the values at 120 km for the intermediate altitude model.

The properties of the Mean Reference Atmosphere are presented in abbreviated form in Tables 14-6 to 14-9. (The complete tables are provided in CIRA, 1972 [COSPAR, 1972]. Table 14-6 contains values of molecular-scale temperature, density, pressure, number density, pressure scale height, and acceleration due to gravity over the altitude range 25–120 km. Table 14-7 contains values of kinetic temperature, mean molecular weight and log number densities of N_2,O_2,O, Ar, He, and O_3 over the altitude range 75–120 km. In Table 14-8 molecular-scale temperature, density, density scale height, pressure, pressure scale height, and acceleration due to gravity for the altitude range 120–500 km are given. Table 14-9 contains the corresponding values of kinetic temperature, mean molecular weight, number density, and log number density of N_2,O_2, O, Ar, and He for the altitudes 120–500 km.

Some of the properties are illustrated in Figures 14-25 to 14-30. Figure 14-25 shows the kinetic temperature of the mean atmosphere plus curves indicating low extreme and high extreme temperatures whose frequency of occurrence is 1% or less. Figure 14-26 shows the pressure scale heights

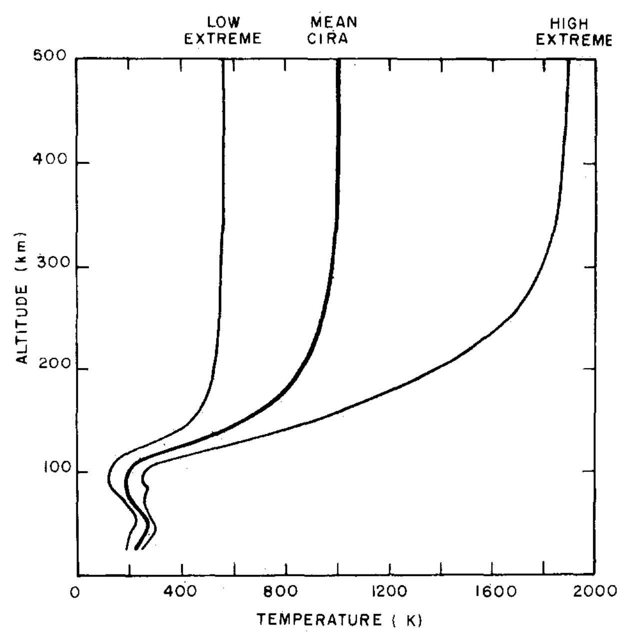

Figure 14-25. Mean CIRA temperatures and low extreme and high extreme temperatures.

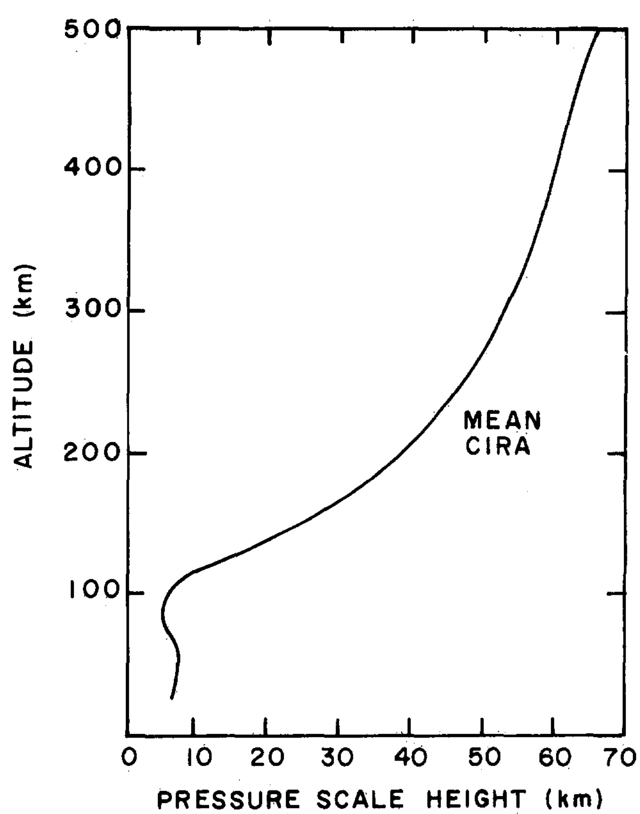

Figure 14-26. Pressure scale heights of the mean CIRA.

Table 14-8. Mean Reference Atmosphere Structure Parameters 120 to 500 km.

Height km	Molec Temp K	Density kg/m³	Density Scale Ht (km)	Pressure N/m²	Pressure Scale Ht(km)	g m/s²
120	380.6	2.440E−08	8.17	2.666E−03	11.58	9.433
125	452.3	1.382E−08	9.51	1.795E−03	13.79	9.418
130	526.9	8.484E−09	11.05	1.283E−03	16.08	9.404
135	600.9	5.563E−09	12.70	9.597E−04	18.37	9.389
140	672.4	3.845E−09	14.44	7.423E−04	20.59	9.375
145	739.8	2774E−09	16.21	5.891E−04	22.69	9.360
150	802.7	2.070E−09	17.98	4.770E−04	24.66	9.346
155	861.0	1.587E−09	19.70	3.923E−04	26.49	9.332
160	914.8	1.244E−09	21.37	3.267E−04	28.19	9.317
165	964.7	9.927E−10	22.96	2.749E−04	29.77	9.303
170	1011.1	8.040E−10	24.48	2.334E−04	31.25	9.289
175	1054.4	6.593E−10	25.92	1.996E−04	32.64	9.274
180	1095.0	5.464E−10	27.29	1.718E−04	33.95	9.260
185	1133.2	4.568E−10	28.60	1.468E−04	35.19	9.246
190	1169.3	3.850E−10	29.85	1.292E−04	36.36	9.232
195	1203.4	3.267E−10	31.05	1.129E−04	37.48	9.218
200	1235.8	2.789E−10	32.21	9.896E−05	38.55	9.204
210	1295.9	2.066E−10	34.40	7.686E−05	40.55	9.176
220	1350.3	1.558E−10	36.45	6.039E−05	42.38	9.148
230	1399.6	1.192E−10	38.39	4.792E−05	44.06	9.120
240	1444.4	9.246E−11	40.21	3.834E−05	45.61	9.092
250	1484.9	7.248E−11	41.92	3.090E−05	47.03	9.065
260	1521.5	5.735E−11	43.52	2.505E−05	48.33	9.037
270	1554.6	4.576E−11	45.03	2.042E−05	49.54	9.010
280	1584.5	3.677E−11	46.43	1.673E−05	50.64	8.983
290	1611.5	2.974E−11	47.73	1.376E−05	51.66	8.955
300	1636.0	2.418E−11	48.95	1.136E−05	52.60	8.928
310	1658.1	1.976E−11	50.07	9.405E−06	53.48	8.902
320	1678.2	1.621E−11	51.12	7.812E−06	54.29	8.875
330	1696.5	1.336E−11	52.09	6.507E−06	55.05	8.848
340	1713.4	1.104E−11	52.98	5.432E−06	55.76	8.822
350	1728.8	9.158E−12	53.81	4.545E−06	56.43	8.795
360	1743.2	7.615E−12	54.59	3.811E−06	57.07	8.769
370	1756.7	6.348E−12	55.31	3.202E−06	57.69	8.743
380	1769.5	5.304E−12	55.98	2.694E−06	58.28	8.717
390	1781.8	4.441E−12	56.60	2.272E−06	58.86	8.691
400	1793.7	3.725E−12	57.20	1.918E−06	59.43	8.665
410	1805.4	3.130E−12	57.75	1.622E−06	60.00	8.639
420	1817.2	2.635E−12	58.28	1.374E−06	60.57	8.614
430	1829.1	2.221E−12	58.79	1.166E−06	61.14	8.588
440	1841.3	1.875E−12	59.26	9.910E−07	61.74	8.563
450	1854.0	1.585E−12	59.73	8.435E−07	62.35	8.537
460	1867.4	1.341E−12	60.18	7.191E−07	62.98	8.512
470	1881.6	1.137E−12	60.63	6.140E−07	63.65	8.487
480	1896.9	9.644E−13	61.08	5.252E−07	64.36	8.462
490	1913.4	8.192E−13	61.52	4.500E−07	65.11	8.437
500	1931.4	6.967E−13	61.95	3.863E−07	65.91	8.412

Table 14-9. Kinetic Temperature and Composition of the Mean Reference Atmosphere, 120 to 500 km.

Height km	Temp K	Mean Mol Wt	Number Density m^{-3}	Log $N(N_2)$ m^{-3}	Log $N(O_2)$ m^{-3}	Log N(O) m^{-3}	Log N(Ar) m^{-3}	Log N(HE) m^{-3}
120	334.5	25.45	5.772E+17	17.579	16.734	17.153	15.173	13.538
125	389.7	24.95	3.336E+17	17.322	16.449	16.978	14.835	13.469
130	445.4	24.48	2.087E+17	17.098	16.203	16.826	14.541	13.410
135	499.0	24.05	1.393E+17	16.903	15.987	16.693	14.284	13.358
140	549.0	23.65	9.793E+16	16.731	15.796	16.577	14.056	13.314
145	594.5	23.27	7.178E+16	16.577	15.624	16.474	13.850	13.275
150	635.2	22.92	5.439E+16	16.437	15.469	16.381	13.663	13.241
155	671.3	22.58	4.233E+16	16.308	15.325	16.298	13.490	13.212
160	703.1	22.26	3.366E+16	16.189	15.192	16.221	13.328	13.185
165	731.3	21.95	2.723E+16	16.077	15.066	16.150	13.176	13.161
170	756.2	21.66	2.236E+16	15.971	14.947	16.083	13.031	13.139
175	778.4	21.38	1.857E+16	15.870	14.834	16.020	12.892	13.118
180	798.1	21.11	1.559E+16	15.773	14.724	15.960	12.758	13.099
185	815.9	20.85	1.319E+16	15.679	14.619	15.902	12.629	13.081
190	831.9	20.60	1.125E+16	15.589	14.517	15.847	12.504	13.064
195	846.3	20.37	9.661E+15	15.501	14.418	15.794	12.382	13.048
200	859.3	20.14	8.342E+15	15.415	14.321	15.742	12.262	13.033
210	882.0	19.71	6.312E+15	15.250	14.133	15.642	12.031	13.004
220	900.7	19.32	4.856E+15	15.090	13.952	15.547	11.807	12.977
230	916.4	18.96	3.788E+15	14.936	13.777	15.456	11.590	12.951
240	929.4	18.63	2.988E+15	14.785	13.606	15.367	11.378	12.927
250	940.2	18.34	2.380E+15	14.638	13.438	15.281	11.171	12.903
260	949.3	18.07	1.912E+15	14.494	13.274	15.197	10.967	12.881
270	956.8	17.82	1.546E+15	14.352	13.112	15.114	10.766	12.859
280	963.1	17.60	1.258E+15	14.212	12.953	15.033	10.567	12.837
290	968.4	17.40	1.029E+15	14.073	12.795	14.953	10.371	12.816
300	972.8	17.22	8.456E+14	13.937	12.639	14.874	10.177	12.796
310	976.5	17.06	6.977E+14	13.801	12.485	14.796	9.984	12.776
320	979.7	16.91	5.776E+14	13.667	12.332	14.719	9.793	12.756
330	982.3	16.77	4.798E+14	13.533	12.179	14.642	9.604	12.736
340	984.6	16.64	3.997E+14	13.401	12.028	14.566	9.415	12.717
350	986.5	16.52	3.338E+14	13.269	11.878	14.490	9.228	12.698
360	988.1	16.42	2.794E+14	13.139	11.729	14.415	9.041	12.679
370	989.5	16.31	2.344E+14	13.008	11.580	14.341	8.856	12.660
380	990.7	16.21	1.970E+14	12.879	11.432	14.267	8.672	12.641
390	991.7	16.12	1.659E+14	12.750	11.285	14.193	8.488	12.622
400	992.6	16.03	1.400E+14	12.621	11.138	14.119	8.305	12.604
410	993.4	15.93	1.183E+14	12.494	10.992	14.046	8.123	12.585
420	994.1	15.84	1.001E+14	12.366	10.847	13.973	7.941	12.567
430	994.7	15.75	8.493E+13	12.239	10.702	13.901	7.761	12.549
440	995.2	15.65	7.213E+13	12.113	10.558	13.829	7.581	12.531
450	995.7	15.55	6.136E+13	11.987	10.414	13.757	7.401	12.513
460	996.1	15.45	5.229E+13	11.862	10.271	13.685	7.222	12.495
470	996.4	15.34	4.464E+13	11.737	10.128	13.613	7.044	12.477
480	996.8	15.22	3.817E+13	11.612	9.986	13.542	6.867	12.459
490	997.0	15.09	3.269E+13	11.488	9.844	13.471	6.690	12.441
500	997.3	14.95	2.806E+12	11.364	9.703	13.400	6.513	12.423

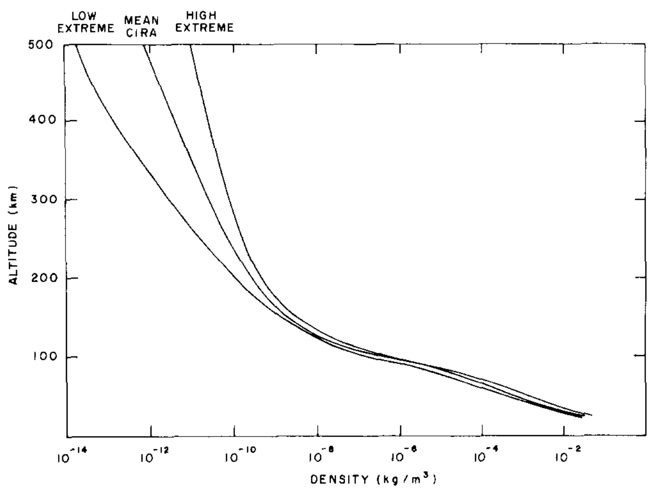

Figure 14-27. Mean CIRA densities and curves of extreme densities.

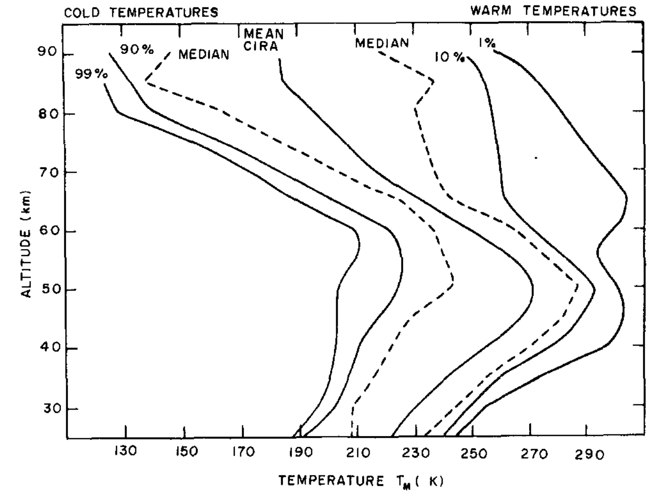

Figure 14-29. Mean CIRA temperatures and temperatures which are exceeded 50%, 10%, 1% of the time during warmest months, and temperatures exceeded 50%, 90%, and 99% of the time during coldest months, at latitudes between 0° and 80°N.

of the mean atmosphere as a function of altitude. Figure 14-27 contains low extreme, high extreme, and mean density values. Total number densities and densities of N_2, O_2, O, O_3, Ar, He, and H are given in Figure 14-28. Figure 14-29 contains the Mean CIRA temperature profile, median warm temperatures and those exceeded 10% and 1% of the time and, similarly, median cold temperatures and those above which 90% or 99%, respectively, of the temperatures lie. The corresponding density curves are shown in Figure 14-30.

14.2.2.3 Reference Atmospheres 90 to 120 km. These empirical atmospheres are based on a report entitled, "Atmospheric Structure and its Variations in the region from 25 to 120 km" by Groves [1971]. In this section only the properties above 90 km are presented. The upper altitude of the models varies with latitude and time of year, depending on the availability of data. Above 90 km the data are primarily from rocketborne falling sphere, grenade and chemical release techniques. Table 14-10 contains average values of zonal (W - E) winds at latitudes from the equator to 50° for the first day of each month. Data used are from all longitudes, with southern hemisphere data shifted by six months. Mean temperature values at latitudes from the equator to 70° are given in Table 14-11. Less accurate values (based on few data points) are indicated by an asterisk. Table 14-12 gives the corresponding pressure values and Table 14-13 the density values.

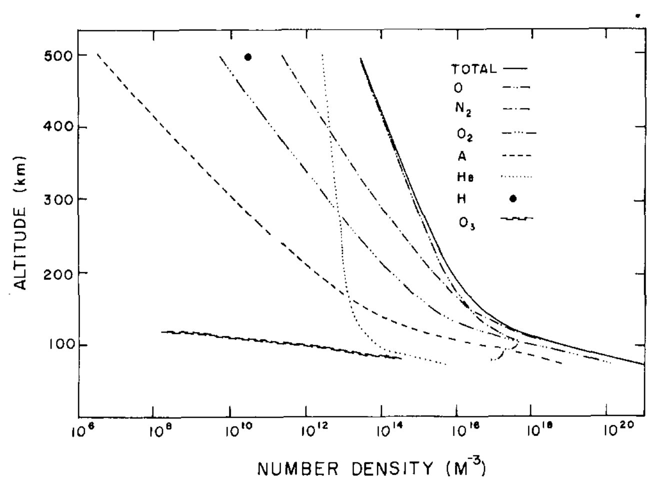

Figure 14-28. Total number densities and densities of N_2, O_2, O, O_3, A, He, and H.

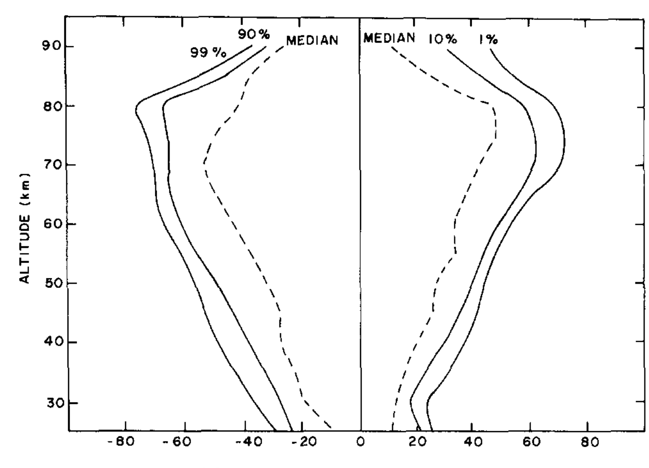

Figure 14-30. Densities relative to Mean CIRA exceeded 50%, 10%, and 1% of the time during months with highest densities, and densities exceeded 50%, 90%, and 99% of the time during months with lowest densities, at latitudes between 0° and 80°N.

Table 14-10. W-E Winds 90 to 130 km based on data from all longitudes with S. Hemisphere data shifted six months in time. Winds to the east are positive in m/s. Values apply to the first day of each month.

km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 Degrees N												
90	−9	−31	−22	−34	−15	−23	−9	−31	−22	−34	−15	−23
95	−28	−23	−13	−21	−22	−32	−28	−23	−13	−21	−22	−32
100	−28	−3	7	−3	−22	−29	−28	−3	7	−3	−22	−29
105	−7	22	26	3	−11	−11	−7	22	26	3	−11	−11
110	17	37	30	−13	10	14	17	37	30	−13	10	14
115	31	37	20	−29	32	33	31	37	20	−29	32	33
10 Degrees N												
90	−14	−30	−36	−54	−5	−7	0	−21	4	3	−2	−22
95	−39	−41	−43	−52	−15	−8	−14	−5	15	14	−5	−36
100	−40	−29	−27	−25	−19	1	−21	19	28	15	−10	−43
105	−20	8	7	−3	−10	5	1	36	31	2	−10	−21
110	1	41	27	−20	9	3	22	40	19	−17	2	20
115	18	49	27	−44	30	13	30	32	1	−27	19	41
20 Degrees N												
90	−8	−29	−23	−32	16	17	12	5	19	22	19	−6
95	−23	−36	−34	−40	6	21	−6	23	25	28	18	−18
100	−28	−16	−48	−36	−2	22	−12	45	29	15	9	−32
105	−18	17	−41	−28	−3	11	−3	55	20	−11	−3	−24
110	0	34	−21	−31	5	2	7	46	−1	−27	−8	5
115	20	27	−7	−36	19	8	12	26	−19	−25	−1	31
30 Degrees N												
90	5	−18	15	0	29	34	22	14	24	27	45	11
95	0	−19	17	−16	25	42	1	31	12	21	38	−3
100	−8	5	0	−30	18	40	−1	50	6	−5	21	−19
105	−9	39	−8	−31	4	15	0	63	−6	−39	−2	−25
110	2	36	1	−26	−4	−12	0	52	−28	−43	−19	−11
115	11	0	12	−22	−1	−18	−5	26	−44	−21	−30	16
120	7	−27	10	−21	−1	−7	−7	−1	−42	−5	−28	34
125	−12	−39	−1	−15	−12	−4	−13	−17	−25	−16	−17	37
130	−33	−50	−13	−8	−24	−4	−19	−32	−9	−32	−2	38
40 Degrees N												
90	31	32	20	−6	−10	28	34	15	29	24	29	37
95	17	15	17	−3	20	54	43	27	22	23	20	37
100	7	14	32	6	57	60	58	33	19	28	−4	31
105	1	17	20	12	73	36	65	28	9	29	−19	17
110	1	6	−33	3	56	−7	49	16	−21	5	−15	9
115	1	−18	7	−16	19	−43	13	−4	−55	−39	−9	4
50 Degrees N												
90	28	21	21	−18	−18	−13	8	22	27	8	22	20
95	14	21	19	−20	−6	12	18	18	20	−2	7	10
100	8	8	13	−3	27	18	43	11	12	−5	−13	11

The preceding tables contain mean climatological values. One variation of these values that is important and can be readily modeled is that due to solar tides. Figure 14-31 contains the amplitude and phase of the solar diurnal tide in density as a function of latitude and Figure 14-32 contains the corresponding amplitude and phase of the solar semidiurnal tide. Note that the tide amplitudes are quite small at low altitudes, but rapidly increase at higher altitudes. These values were calculated theoretically by Forbes [Private Communication, 1982].

Table 14-11. Temperatures (K) 90 to 110 km.

km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 Degrees N												
90	185	193	198	200	193	189	185	193	198	200	193	189
95	187	200*	204*	199*	187*	184*	187	200*	204*	199*	187*	184*
100	204	219*	220*	209*	193*	191*	204	219*	220*	209*	193*	191*
105	231	251*	255*	239*	219*	215*	231	251*	255*	239*	219*	215*
110	273	296*	306*	293*	269*	261*	273	296*	306*	293*	269*	261*
10 Degrees N												
90	185	191*	193	197	194	189	186	194	199	200	192	188
95	187*	197*	199	193	187*	186	189	199	207*	203*	191	184
100	203*	215*	214*	201*	191*	193*	204	216*	225*	217*	200	193
105	232*	246*	245*	229*	215*	214*	229	247*	257*	247*	227*	220*
110	276*	290*	291*	278*	259*	253*	265	291*	307*	301*	282*	270*
20 Degrees N												
90	186*	189	190	194	192	188	186	191	197	198	191	189
95	190*	197	195	190*	187*	189	193	197	206*	206*	196	187
100	204*	213	210	195*	194*	198*	206	211*	222*	222*	210	197*
105	228*	237*	236*	220*	216*	221*	229	236*	248*	250*	239*	225*
110	271*	278*	275*	264*	255*	253*	260	276*	294*	299*	286*	271*
30 Degrees N												
90	189*	190	189	190	185	179	179	187	193	195	194	194
95	195*	197	195	189*	187	189*	195	197	205	205	202	196
100	204*	210	208	196*	197*	206*	214	208	216	221	219	204*
105	222*	230*	227	216*	220*	232*	237	226	236*	249*	245*	225*
110	259*	266*	265	256*	259*	264*	265	263	278*	290*	284*	263*
40 Degrees N												
90	199*	195	191	185	172	162	167	180	191	197	200	203
95	203*	197	196	191	184	182	192	199	203	202	208	207*
100	206*	207	207	201	204	213	222	212	211	217	222	212*
105	217*	225*	226	218	230	247	246	225*	226*	241	241*	222*
110	248*	258*	263	262	274	285	276	256*	261*	276*	272*	250*
50 Degrees N												
90	208*	202	192*	179*	161*	147	153	170	185	198	207	213
95	210*	200*	197*	191*	180*	173	184	194	196*	201	214	219*
100	210*	206*	209*	210*	212*	219	221	211*	204*	209	220*	220*
105	215*	224*	231*	237*	253*	265	255	224*	216*	228*	231*	219*
110	240*	259*	274*	284*	304*	313	293	254*	244*	256*	253*	238*
60 Degrees N												
90	214	207	196*	181*	159*	144*	145	159	177	197	211*	217
95	214*	206*	199*	193*	180*	171*	174*	181	188*	199	215*	222
100	214*	210*	215*	221*	223*	222*	216*	203*	195*	201	215*	221
105	217*	228*	245*	263*	279*	282*	258*	220*	202*	209*	217*	215*
110	235*	261*	291*	317*	343*	343*	306*	250*	223*	227*	231*	227*
70 Degrees N												
90	214	208	199*	183*	162*	145*	141*	150	173*	196*	212*	217
95	216*	209*	205*	197*	184*	173*	168*	170*	179*	195*	212*	219*
100	215*	214*	223*	232*	234*	226*	212*	193*	184*	193*	209*	217*
105	215*	230*	256*	285*	302*	295*	260*	213*	187*	192*	206*	211*
110	229*	261*	303*	344*	373*	366*	314*	241*	198*	199*	212*	216*

*Temperature data lacking (i.e., less than two data points within about one month and 10 deg latitude)
Values apply to the first day of each month.

Table 14-12. Pressure (N/m^2) 90 to 110 km. Insert decimal point on the right of the three digits and multiply by 10^N.

km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N
0 Degrees N													
90	197	200	206	212	213	208	197	200	206	212	213	208	−3
95	803	855*	903*	920*	887*	853*	803	855*	903*	920*	887*	853*	−4
100	350	395*	419*	416*	379*	360*	350	395*	419*	416*	379*	360*	−4
105	168	199*	213*	202*	172*	162*	168	199*	213*	202*	172*	162*	−4
110	090	113*	122*	112*	091*	084*	090	113*	122*	112*	091*	084*	−4
10 Degrees N													
90	194	188*	191	206	214	206	198	214	230	228	216	204	−3
95	079*	080*	081	088	090*	085	081	093	101*	099*	090	083	−3
100	345*	364*	374*	386*	379*	362*	357	421*	480*	462*	395	353	−4
105	164*	182*	183*	182*	172*	164*	170	213*	246*	230*	184*	161*	−4
110	089*	101*	104*	098*	088*	084*	090	117*	141*	130*	100*	085*	−4
20 Degrees N													
90	187*	188	191	213	215	201	191	214	236	233	212	199	−3
95	077*	080	080	090*	090*	083	079	090	104*	102*	089	081	−3
100	338*	362	362	386*	382*	361*	354	412*	487*	480*	405	353*	−4
105	160*	178*	175*	178*	175*	167*	168	199*	247*	242*	195*	161*	−4
110	086*	096*	096*	093*	089*	087*	089	109*	138*	137*	109*	087*	−4
30 Degrees N													
90	184*	187	188	212	199	183	170	189	200	202	192	194	−3
95	778*	784	789	873*	819	737*	688	796	872	876	826	822	−4
100	345*	357	354	380*	351*	327*	317	359	404	413	384	368*	−4
105	163*	171*	169	172*	163*	156*	153	171	199*	207*	192*	173*	−4
110	084*	091*	089	089*	084*	084*	083	090	107*	116*	106*	091*	−4
40 Degrees N													
90	190*	191	187	198	181	156	145	158	166	172	175	191	−3
95	833*	814	785	813	700	577	569	660	721	751	774	849*	−4
100	379*	366	354	359	308	260	262	301	328	343	365	393*	−4
105	177*	174*	167	165	145	127	132	145*	158*	172	183*	188*	−4
110	899*	908*	885	858	784	719	725	748*	823*	928*	988*	962*	−5
50 Degrees N													
90	191*	192	191*	192*	169*	141	131	140	150	158	169	185	−3
95	873*	843*	804*	769*	619*	480	479	567	633*	694	772	867*	−4
100	401*	377*	365*	348*	276*	214	218	255*	280*	310	364*	412*	−4
105	190*	179*	174*	167*	135*	108	110	122*	131*	151*	180*	210*	−4
110	939*	929*	937*	923*	785*	640	626	629*	656*	778*	933*	992*	−5
60 Degrees N													
90	174	175	182*	184*	170*	145*	131	134	153	169	178*	179	−3
95	813*	792*	783*	754*	622*	489*	458*	504	619*	737	819*	841	−4
100	376*	359*	355*	341*	280*	216*	198*	216*	265*	325	386*	405	−4
105	181*	174*	177*	176*	145*	112*	101*	102*	119*	150*	184*	195*	−4
110	089*	090*	098*	102*	089*	069*	058*	052*	056*	072*	091*	095*	−4

Table 14-12. *(Continued)*

km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N
70 Degrees N													
90	138	133	146*	158*	170*	152*	135*	138	164*	170*	176*	162	−3
95	646*	600*	645*	658*	649*	526*	456*	489*	638*	735*	811*	764*	−4
100	301*	278*	298*	305*	292*	230*	191*	199*	261*	316*	372*	361*	−4
105	145*	135*	153*	164*	162*	124*	098*	091*	110*	139*	174*	172*	−4
110	070*	071*	086*	099*	100*	077*	056*	045*	048*	061*	081*	082*	−4

*Data lacking (i.e., less than two data points within about one month and 10 deg. latitude)
Values apply to the first day of each month.

14.2.2.4 Reference Atmospheres Above 120 km. These atmospheres are based on a report by Jacchia [1971]. Previous thermospheric models that assumed a single, constant set of boundary conditions at 120 km did not accurately represent variations in properties in the altitude region 120 to 180 km. To attempt to remedy this problem, Jacchia lowered the boundary to 90 km where it is known that there is an approximate isopycnic (constant density) layer, although the temperature shows important variations. In his models, all temperature profiles start from a constant value 183 K at 90 km. He did not print out the model values below 110 km in order to disregard the less accurate region.

The following are the major types of variation of properties of the thermosphere:

1. Variations with the solar cycle
2. Variations with daily changes in solar activity
3. Diurnal and semidiurnal variations
4. Atmospheric response to storms of various kinds
5. Semi-annual variation
6. Seasonal-latitudinal variations of the lower thermosphere
7. Effects of large scale circulation
8. Fluctuations associated with gravity waves.

The models described in this section include both long and short-term solar activity effects and diurnal, but not semidiurnal, variations. Atmospheric response to storms is represented in terms of Kp, the 3-h geomagnetic planetary index. This provides reasonable representation of the response to most storms, but not all. For example, the Auroral Electrojet (AE) index is better for high latitude response, both because it provides a better measure of the change in energy input in that region, and because of its much smaller time resolution. Unfortunately, values of the AE index are not always available.

The average semi-annual variation is reasonably modeled, but it must be pointed out that the amplitude of this effect, whose cause is not completely understood, varies from year to year. The seasonal-latitudinal variations of the lower thermosphere are not modeled, except for an empirical expression for density but not temperature changes. Champion [COESA, 1966] developed a limited set of models for this portion of the atmosphere, but further modeling efforts have been delayed because of a lack of information on the systematic variations of this part of the atmosphere. Attempts have been made to model empirically some of the effects of large scale circulation which primarily affect the

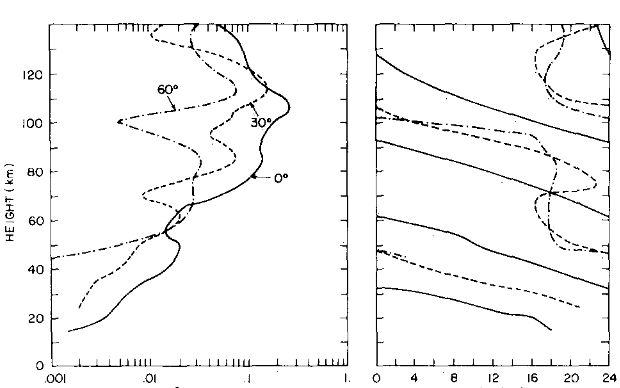

Figure 14-31. Relative amplitude and phase of density variation for the diurnal tide at 0°, 30°, and 60° latitude under equinox conditions.

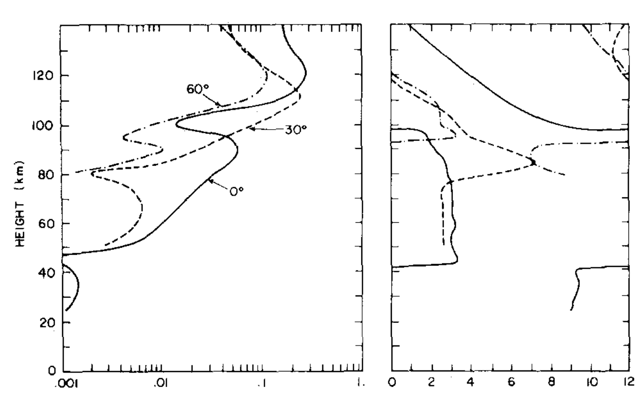

Figure 14-32. Relative amplitude and phase of density variation for the semidiurnal tide at 0°, 30°, and 60° latitude under equinox conditions.

Table 14-13. Densities (kg/m³) 90 to 110 km. Insert decimal point on the right of the three digits and multiply by 10^N.

km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N
0 Degrees N													
90	370	360	361	368	384	384	370	360	361	368	384	384	−8
95	148	147*	153*	159*	163*	160*	148	147*	153*	159*	163*	160*	−8
100	580	610*	644*	673*	663*	636*	580	610*	644*	673*	663*	636*	−9
105	242	264*	279*	282*	262*	252*	242	264*	279*	282*	262*	252*	−9
110	108	125*	131*	126*	111*	106*	108	125*	131*	126*	111*	106*	−9
10 Degrees N													
90	365	343*	345	364	383	380	370	384	403	396	390	378	−8
95	146*	140*	140	157	166*	158	148	161	169*	169*	162	156	−8
100	574*	571*	591*	648*	670*	633*	591	658*	721*	719*	668	617	−9
105	236*	246*	249*	265*	266*	256*	247	287*	318*	310*	270*	244*	−9
110	106*	114*	117*	116*	112*	109*	112	133*	151*	142*	116*	103*	−9
20 Degrees N													
90	349*	347	350	382	390	372	358	390	417	409	386	366	−8
95	139*	139	142	163*	166*	152	142	158	174*	170*	156	149	−8
100	560*	574	583	669*	665*	616*	581	659*	741*	731*	651*	605*	−9
105	234*	249*	247*	269*	270*	252*	245	281*	332*	322*	272*	239*	−9
110	104*	114*	114*	115*	115*	113*	113	129*	154*	150*	125*	106*	−9
30 Degrees N													
90	339*	342	345	388	375	355	329	351	361	361	345	347	−8
95	138*	137	139	159*	151	134*	122	139	147	147	141	145	−8
100	571*	574	574	654*	602*	535*	500	583	633	631	593	609*	−9
105	244*	247*	248	265*	246*	224*	215	252	280*	276*	260*	256*	−9
110	107*	113*	110	114*	107*	104*	103	112	127*	132*	123*	114*	−9
40 Degrees N													
90	333*	341	340	373	366	335	302	305	302	303	304	327	−8
95	141*	142	138	147	131	109	102	114	122	128	128	141	−8
100	622*	598	578	603	510	412	399	479	526	534	555	627*	−9
105	271*	257*	247	253	210	171	178	214*	233*	237	252*	281*	−9
110	119*	116*	110	108	094	083	086	096*	104*	110*	119*	126*	−9
50 Degrees N													
90	320*	331	346*	374*	365*	333	297	287	282	277	283	302	−8
95	143*	145*	141*	139*	119*	096	090	101	111*	119	124	136*	−8
100	645*	619*	589*	560*	439*	330	333	408*	464*	502	559*	633*	−9
105	294*	266*	251*	234*	178*	136	143	182*	202*	220*	259*	305*	−9
110	128*	118*	112*	107*	085*	067	070	081*	088*	100*	121*	137*	−9
60 Degrees N													
90	283	295	323*	353*	372*	350*	314	293	300	298	294*	286	−8
95	131*	133*	136*	135*	119*	099*	091*	096	113*	128	131*	131	−8
100	593*	578*	559*	522*	424*	328*	310*	360*	459*	546	606*	619	−9
105	278*	254*	241*	223*	173*	132*	130*	154*	196*	239*	282*	302*	−9
110	124*	114*	111*	106*	085*	066*	062*	068*	083*	104*	129*	137*	−9
70 Degrees N													
90	225	222	255*	301*	365*	365*	332*	321	329*	302*	288*	260	−8
95	103*	099*	108*	115*	122*	105*	094*	099*	123*	130*	132*	120*	−8
100	474*	439*	451*	445*	422*	345*	305*	349*	479*	553*	602*	563*	−9
105	224*	195*	200*	192*	178*	140*	125*	142*	197*	241*	281*	272*	−9
110	101*	089*	094*	095*	088*	069*	058*	062*	080*	101*	125*	124*	−9

*Data lacking (i.e. less than two data points within about one month and 10 deg. latitude)
Values apply to the first day of each month.

composition of the thermosphere. For example, the strong increase in helium concentration above the winter pole (the helium winter bulge) is a result of large scale circulation, which causes preferential transport of lighter constituents away from the summer hemisphere. Density and composition fluctuations caused by gravity waves are not modeled.

The tables in this section are given with the exospheric temperature as the defining parameter. To determine the exospheric temperature for a particular time and location the following equations are used. The temperature T_c is the global night-time minimum of the exospheric temperature when Kp is zero.

$$T_c = 379 + 3.24\,\bar{F}_{10.7} + 1.3\,(F_{10.7} - \bar{F}_{10.7}) \quad (14.18)$$

where $F_{10.7}$ is in units of 10^{-22} W m^{-2} Hz^{-1}. The diurnal variation of the exospheric temperature can be represented by

$$T_D = T_c\,(1 + R\cos^m\eta)$$
$$T_N = T_c\,(1 + R\sin^m\theta), \quad (14.19)$$

where T_D is the maximum daily temperature and T_N is the minimum daily temperature. R is a coefficient with a value of approximately 0.3,

$$\eta = 1/2\,|\,\phi - \delta_o\,|$$
$$\theta = 1/2\,|\,\phi + \delta_o\,|$$

where ϕ is the latitude and δ_o is the sun's declination. A value of 2.2 can be used for m.

For Kp above zero the exospheric temperature is increased by

$$\Delta T_\infty = 28\,\mathrm{Kp} + 0.08\exp\mathrm{Kp}\,. \quad (14.20)$$

Formulas to give the exospheric temperature at any time of day, to include the effect of the semi-annual variation, and to include the winter helium bulge are given in the reference [Jacchia, 1971].

Table 14-14 contains model values of kinetic temperature, logarithms of the concentrations of N_2, O_2, O, Ar, He, and H, mean molecular weight, and density as functions of altitude for exospheric temperatures ranging from 500 to 1600 K.

Table 14-14. Atmospheric temperature, density and composition as functions of height and exospheric temperature.

Height km	Temp K	LogN(N_2) m^{-3}	LogN(O_2) m^{-3}	LogN(O) m^{-3}	LogN(Ar) m^{-3}	LogN(HE) m^{-3}	LogN(H) m^{-3}	Mean Mol Wt	Density kg/m^3
Exospheric Temperature = 500 K									
120	267.1	17.536	16.672	17.169	15.073	13.579		25.10	2.25E−08
130	328.3	16.981	16.051	16.814	14.320	13.457		23.74	6.80E−09
140	378.8	16.531	15.545	16.530	13.704	13.363		22.51	2.67E−09
150	411.9	16.149	15.114	16.296	13.174	13.291		21.39	1.25E−09
160	433.1	15.804	14.723	16.089	12.691	13.231		20.40	6.51E−10
180	457.7	15.170	14.002	15.717	11.798	13.129		18.78	2.13E−10
200	471.4	14.576	13.325	15.372	10.956	13.038		17.62	8.13E−11
250	488.1	13.169	11.721	14.562	8.956	12.830		15.79	1.05E−11
300	494.6	11.823	10.184	13.791	7.039	12.635		13.30	1.72E−12
350	497.3	10.512	8.686	13.041		12.446		8.33	3.29E−13
400	498.5	9.226	7.218	12.306		12.262		3.82	8.10E−14
500	499.5	6.718		10.873		11.903	12.860	1.44	1.94E−14
600	499.8			9.484		11.555	12.772	1.19	1.24E−14
800	499.9			6.822		10.889	12.604	1.06	7.24E−15
1000	500.0					10.260	12.445	1.03	4.79E−15
1500	500.0					8.827	12.084	1.01	2.04E−15
2000	500.0					7.565	11.767	1.01	9.78E−16
Exospheric Temperature = 600 K									
120	285.2	17.549	16.690	17.165	15.103	13.567		25.21	2.30E−08
130	359.6	17.018	16.098	16.818	14.389	13.443		23.98	7.29E−09
140	423.6	16.597	15.627	16.547	13.817	13.349		22.87	3.00E−09
150	468.4	16.246	15.232	16.328	13.336	13.278		21.89	1.48E−09
160	498.6	15.937	14.883	16.140	12.906	13.221		20.99	8.10E−10

Table 14-14. (*Continued*)

Height km	Temp K	LogN(N_2) m^{-3}	LogN(O_2) m^{-3}	LogN(O) m^{-3}	LogN(Ar) m^{-3}	LogN(HE) m^{-3}	LogN(H) m^{-3}	Mean Mol Wt	Density kg/m^3
180	534.9	15.381	14.252	15.809	12.127	13.127		19.49	2.93E−10
200	555.8	14.869	13.670	15.510	11.404	13.046		18.35	1.23E−10
250	581.6	13.676	12.310	14.820	9.711	12.866		16.67	1.99E−11
300	591.6	12.546	11.021	14.171	8.103	12.701		15.72	4.15E−12
350	595.8	11.450	9.769	13.544	6.541	12.543		14.41	9.69E−13
400	597.7	10.377	8.543	12.931		12.389		11.79	2.46E−13
500	599.2	8.285	6.154	11.735		12.090	12.126	4.81	2.49E−14
600	599.6	6.257		10.577		11.800	12.053	2.37	7.08E−15
800	599.9			8.359		11.245	11.913	1.54	2.54E−15
1000	600.0			6.262		10.720	11.780	1.25	1.36E−15
1500	600.0					9.525	11.484	1.04	5.27E−16
2000	600.0					8.474	11.215	1.01	2.76E−16
	Exospheric Temperature = 700 K								
120	300.5	17.559	16.705	17.161	15.126	13.558		25.29	2.35E−08
130	386.2	17.046	16.134	16.821	14.440	13.433		24.15	7.67E−09
140	462.0	16.644	15.686	16.558	13.900	13.338		23.14	3.27E−09
150	518.2	16.315	15.317	16.349	13.452	13.267		22.24	1.67E−09
160	557.8	16.029	14.995	16.172	13.058	13.211		21.43	9.46E−10
180	607.5	15.526	14.426	15.869	12.357	13.122		20.03	3.67E−10
200	636.8	15.072	13.910	15.601	11.718	13.047		18.92	1.65E−10
250	673.5	14.030	12.723	14.995	10.242	12.886		17.15	3.16E−11
300	688.0	13.054	11.610	14.434	8.854	12.742		16.24	7.80E−12
350	694.0	12.111	10.533	13.894	7.511	12.606		15.53	2.17E−12
400	696.8	11.189	9.481	13.367	6.198	12.473		14.50	6.46E−13
500	698.8	9.395	7.431	12.341		12.216	11.559	10.02	6.99E−14
600	699.5	7.656		11.348		11.968	11.496	5.19	1.26E−14
800	699.8			9.446		11.492	11.376	2.77	2.54E−15
1000	699.9			7.649		11.042	11.263	2.13	1.04E−15
1500	700.0					10.018	11.005	1.29	2.39E−16
2000	700.0					9.117	10.778	1.07	1.09E−16
	Exospheric Temperature = 800 K								
120	313.5	17.567	16.716	17.158	15.145	13.550		25.35	2.39E−08
130	408.8	17.067	16.162	16.823	14.481	13.424		24.28	7.99E−09
140	495.1	16.680	15.731	16.566	13.964	13.329		23.35	3.50E−09
150	562.1	16.366	15.380	16.363	13.539	13.258		22.52	1.82E−09
160	611.3	16.096	15.078	16.194	13.171	13.202		21.77	1.06E−09
180	675.4	15.632	14.553	15.910	12.526	13.115		20.46	4.34E−10
200	714.4	15.218	14.084	15.664	11.948	13.044		19.39	2.06E−10
250	764.0	14.288	13.026	15.120	10.633	12.897		17.57	4.46E−11
300	783.7	13.427	12.043	14.623	9.410	12.769		16.59	1.25E−11
350	791.9	12.598	11.098	14.148	8.230	12.648		15.96	3.96E−12
400	795.6	11.791	10.175	13.686	7.079	12.532		15.33	1.34E−12
500	798.4	10.219	8.381	12.788		12.307	11.108	12.86	1.77E−13

Table 14-14. (*Continued*)

Height km	Temp K	LogN(N_2) m^{-3}	LogN(O_2) m^{-3}	LogN(O) m^{-3}	LogN(Ar) m^{-3}	LogN(HE) m^{-3}	LogN(H) m^{-3}	Mean Mol Wt	Density kg/m^3
	Exospheric Temperature = 800 K								
600	799.3	8.697	6.642	11.918		12.089	11.053	8.43	3.04E-14
800	799.8			10.254		11.673	10.948	3.92	3.75E-15
1000	799.9			8.681		11.279	10.849	3.22	1.39E-15
1500	800					10.383	10.623	2.10	2.31E-16
2000	800.0					9.594	10.425	1.39	7.06E-17
	Exospheric Temperature = 900 K								
120	324.7	17.574	16.726	17.156	15.160	13.544		25.41	2.41E-08
130	428.4	17.084	16.184	16.825	14.513	13.417		24.39	8.25E-09
140	523.9	16.708	15.766	16.572	14.013	13.321		23.51	3.68E-09
150	600.9	16.404	15.428	16.373	13.606	13.249		22.73	1.95E-09
160	659.6	16.147	15.140	16.209	13.257	13.193		22.03	1.16E-09
180	738.9	15.710	14.648	15.938	12.654	13.107		20.81	4.93E-10
200	788.5	15.328	14.216	15.708	12.122	13.039		19.79	2.44E-10
250	852.9	14.483	13.255	15.211	10.931	12.902		17.97	5.83E-11
300	878.6	13.710	12.374	14.764	9.835	12.786		16.91	1.80E-11
350	889.3	12.971	11.530	14.339	8.783	12.678		16.26	6.29E-12
400	894.2	12.251	10.709	13.927	7.758	12.574		15.74	2.36E-12
500	897.9	10.853	9.112	13.128		12.373	10.741	14.22	3.76E-13
600	899.0	9.500	7.566	12.355		12.179	10.692	11.08	7.04E-14
800	899.7	6.910		10.876		11.809	10.599	5.03	6.35E-15
1000	899.9			9.478		11.459	10.511	3.81	2.05E-15
1500	900.0			6.294		10.663	10.310	3.08	3.40E-16
2000	900.0					9.962	10.133	2.21	8.36E-17
	Exospheric Temperature = 1000 K								
120	334.5	17.579	16.733	17.154	15.172	13.539		25.45	2.44E-08
130	445.4	17.098	16.202	16.826	14.539	13.411		24.48	8.47E-09
140	549.0	16.730	15.794	16.577	14.053	13.315		23.64	3.84E-09
150	635.2	16.435	15.467	16.381	13.660	13.242		22.91	2.06E-09
160	703.1	16.187	15.189	16.220	13.325	13.186		22.25	1.24E-09
180	798.1	15.770	14.721	15.959	12.755	13.100		21.10	5.44E-10
200	859.3	15.413	14.317	15.741	12.258	13.034		20.13	2.78E-10
250	940.2	14.634	13.434	15.279	11.164	12.904		18.33	7.21E-11
300	972.8	13.932	12.633	14.872	10.169	12.796		17.21	2.40E-11
350	986.5	13.263	11.871	14.488	9.219	12.698		16.52	9.09E-12
400	992.6	12.614	11.130	14.116	8.294	12.604		16.02	3.69E-12
500	997.3	11.355	9.692	13.396	6.499	12.423	10.438	14.94	6.89E-13
600	998.8	10.137	8.300	12.699		12.249	10.393	12.85	1.45E-13
800	999.6	7.805		11.368		11.915	10.309	6.55	1.17E-14
1000	999.9			10.109		11.601	10.229	4.24	3.02E-15
1500	1000.0			7.244		10.884	10.049	3.62	5.28E-16
2000	1000.0					10.253	9.890	3.10	1.32E-16

Table 14-14. *(Continued)*

Height km	Temp K	LogN(N_2) m^{-3}	LogN(O_2) m^{-3}	LogN(O) m^{-3}	LogN(Ar) m^{-3}	LogN(HE) m^{-3}	LogN(H) m^{-3}	Mean Mol Wt	Density kg/m^3
	Exospheric Temperature = 1200 K								
120	350.9	17.587	16.745	17.150	15.192	13.530		25.52	2.48E−08
130	473.8	17.119	16.229	16.827	14.580	13.401		24.61	8.82E−09
140	591.1	16.764	15.837	16.583	14.115	13.304		23.84	4.09E−09
150	693.3	16.481	15.524	16.391	13.741	13.231		23.17	2.24E−09
160	778.3	16.245	15.262	16.235	13.426	13.173		22.57	1.37E−09
180	905.0	15.857	14.828	15.985	12.901	13.087		21.54	6.28E−10
200	991.4	15.533	14.463	15.783	12.455	13.021		20.65	3.36E−10
250	1110.3	14.851	13.691	15.373	11.504	12.901		18.95	9.84E−11
300	1159.1	14.253	13.011	15.023	10.659	12.806		17.79	3.70E−11
350	1179.6	13.691	12.370	14.699	9.860	12.722		17.01	1.57E−11
400	1188.9	13.147	11.750	14.387	9.087	12.643		16.47	7.19E−12
500	1195.9	12.096	10.549	13.785	7.589	12.491	9.966	15.67	1.70E−12
600	1198.2	11.080	9.388	13.205	6.140	12.346	9.929	14.62	4.46E−13
800	1199.4	9.136	7.169	12.095		12.068	9.858	10.17	4.09E−14
1000	1199.8	7.300		11.046		11.806	9.792	5.74	7.21E−15
1500	1200.0			8.658		11.208	9.642	3.96	1.09E−15
2000	1200.0			6.557		10.682	9.509	3.82	3.25E−16
	Exospheric Temperature = 1400 K								
120	364.1	17.593	16.754	17.147	15.207	13.523		25.57	2.51E−08
130	496.8	17.134	16.250	16.827	14.611	13.393		24.71	9.10E−09
140	625.2	16.789	15.869	16.587	14.160	13.296		23.99	4.29E−09
150	740.8	16.514	15.566	16.398	13.800	13.222		23.36	2.38E−09
160	841.0	16.286	15.313	16.245	13.498	13.163		22.81	1.48E−09
180	998.5	15.916	14.901	16.001	13.003	13.075		21.86	6.93E−10
200	1111.9	15.613	14.562	15.809	12.591	13.009		21.05	3.82E−10
250	1274.4	14.998	13.867	15.431	11.738	12.893		19.45	1.22E−10
300	1342.6	14.473	13.271	15.122	10.999	12.807		18.30	5.00E−11
350	1371.4	13.986	12.716	14.840	10.309	12.733		17.48	2.32E−11
400	1384.4	13.518	12.182	14.571	9.643	12.664		16.89	1.15E−11
500	1394.3	12.614	11.151	14.054	8.356	12.534	9.621	16.09	3.23E−12
600	1397.4	11.743	10.155	13.555	7.113	12.409	9.588	15.39	9.98E−13
800	1399.2	10.077	8.252	12.603		12.171	9.528	12.79	1.17E−13
1000	1399.7	8.503	6.454	11.704		11.946	9.471	8.37	1.93E−14
1500	1399.9			9.658		11.434	9.342	4.18	1.93E−15
2000	1400.0			7.856		10.983	9.229	3.96	6.44E−16
	Exospheric Temperature = 1600 K								
120	375.4	17.598	16.762	17.144	15.219	13.518		25.62	2.53E−08
130	516.4	17.147	16.266	16.827	14.635	13.387		24.79	9.32E−09
140	654.1	16.808	15.894	16.590	14.196	13.290		24.10	4.45E−09
150	781.1	16.540	15.598	16.404	13.846	13.215		23.51	2.50E−09
160	894.6	16.318	15.353	16.252	13.554	13.155		23.00	1.56E−09

Table 14-14. *(Continued)*

Height km	Temp K	Log(N(N_2) /m^3)	Log(N(O_2) /m^3)	Log(N(O) /m^3)	Log(N(A) /m^3)	Log(N(HE) /m^3)	Log(N(H) /m^3)	Mean Mol Wt	Density kg/m^3
180	1081.3	15.960	14.956	16.012	13.080	13.065		22.11	7.46E−10
200	1222.4	15.672	14.635	15.825	12.692	12.998		21.36	4.20E−10
250	1433.1	15.103	13.995	15.470	11.910	12.884		19.87	1.43E−10
300	1523.5	14.633	13.461	15.190	11.250	12.804		18.75	6.27E−11
350	1561.9	14.201	12.970	14.939	10.640	12.737		17.91	3.10E−11
400	1579.2	13.790	12.500	14.702	10.055	12.676		17.28	1.64E−11
500	1592.4	12.997	11.596	14.248	8.926	12.561	9.361	16.43	5.21E−12
600	1596.5	12.234	10.724	13.811	7.838	12.452	9.333	15.82	1.82E−12
800	1599.0	10.776	9.059	12.978		12.243	9.280	14.21	2.67E−13
1000	1599.6	9.398	7.485	12.192		12.046	9.230	11.01	4.88E−14
1500	1599.9	6.263		10.401		11.598	9.117	4.71	3.30E−15
2000	1600.0			8.824		11.204	9.018	4.03	1.08E−15

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