

RECOMMENDATION ITU-R P.835-3

REFERENCE STANDARD ATMOSPHERES

(Question ITU-R 201/3)

(1992-1994-1997-1999)

The ITU Radiocommunication Assembly,

considering

a) the necessity for a reference standard atmosphere for use in calculating gaseous attenuation along an Earth-space path,

recommends

1 that the standard atmospheres in Annex 1 be used to determine temperature, pressure and water-vapour pressure as a function of altitude, for calculating gaseous attenuation when more reliable local data are not available;

2 that the experimental data in Annex 2 be used for the locations of interest when seasonal and monthly variations are concerned.

ANNEX 1

1 Mean annual global reference atmosphere

The following reference standard atmosphere reflects the annual mean profiles when averaged across the globe.

1.1 Temperature and pressure

The reference standard atmosphere is based on the United States Standard Atmosphere, 1976, in which the atmosphere is divided into seven successive layers showing linear variation with temperature, as given in Fig. 1.

The temperature T at height h is given by:

$$T(h) = T_i + L_i (h - H_i) \quad \text{K} \quad (1)$$

where:

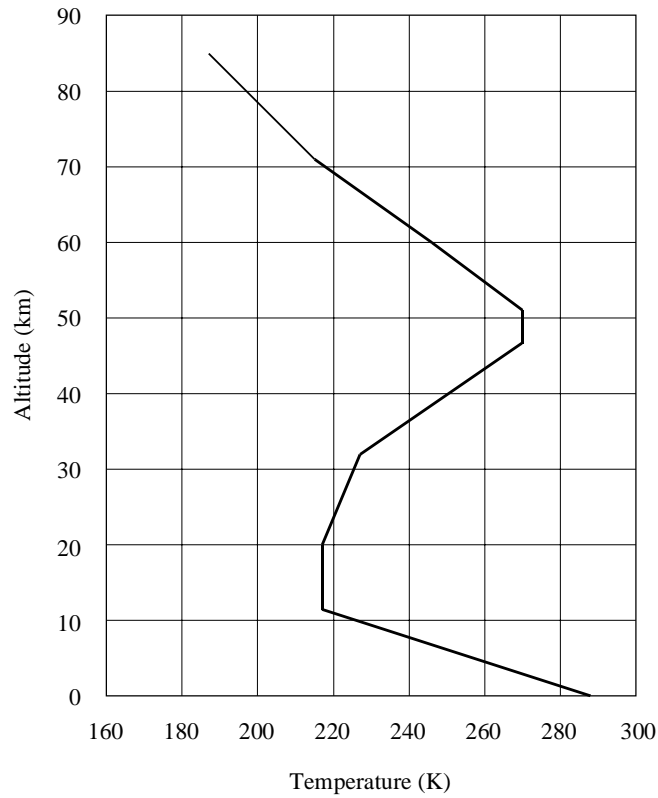
$$T_i = T(H_i) \quad (2)$$

and L_i is the temperature gradient starting at altitude H_i and is given in Table 1.

TABLE 1

Subscript, i	Altitude, H_i (km)	Temperature gradient, L_i (K/km)
0	0	-6.5
1	11	0.0
2	20	+1.0
3	32	+2.8
4	47	0.0
5	51	-2.8
6	71	-2.0
7	85	

FIGURE 1
Reference profile of atmospheric temperature



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When the temperature gradient $L_i \neq 0$, pressure is given by the equation:

$$P(h) = P_i \left[\frac{T_i}{T_i + L_i (h - H_i)} \right]^{34.163 / L_i} \quad \text{hPa} \quad (3)$$

and when the temperature gradient $L_i = 0$, pressure is obtained from the equation:

$$P(h) = P_i \exp \left[\frac{-34.163 (h - H_i)}{T_i} \right] \quad \text{hPa} \quad (4)$$

The ground-level standard temperature and pressure are:

$$\begin{aligned} T_0 &= 288.15 && \text{K} \\ P_0 &= 1013.25 && \text{hPa} \end{aligned} \quad (5)$$

Note that above about 85 km altitude, local thermodynamic equilibrium of the atmosphere starts to break down, and the hydrostatic equation, on which the above equations are based, is no longer valid.

1.2 Water-vapour pressure

The distribution of water vapour in the atmosphere is generally highly variable, but may be approximated by the equation:

$$\rho(h) = \rho_0 \exp(-h / h_0) \quad \text{g/m}^3 \quad (6)$$

where the scale height $h_0 = 2$ km, and the standard ground-level water-vapour density is:

$$\rho_0 = 7.5 \quad \text{g/m}^3 \quad (7)$$

Vapour pressure is obtained from the density using the equation (see Recommendation ITU-R P.453):

$$e(h) = \frac{\rho(h) T(h)}{216.7} \quad \text{hPa} \quad (8)$$

Water-vapour density decreases exponentially with increasing altitude, up to an altitude where the mixing ratio $e(h)/P(h) = 2 \times 10^{-6}$. Above this altitude, the mixing ratio is assumed to be constant.

1.3 Dry atmosphere for attenuation calculations

The profile of the density of atmospheric gases other than water vapour (the “dry atmosphere”) may be found from the temperature and pressure profiles given in § 1.1.

For attenuation calculations, this density profile may be approximated by an exponential profile according to equation (6) with:

$$h_0 = 6 \text{ km} \quad (9)$$

2 Low-latitude annual reference atmosphere

For low latitudes (smaller than 22°) the seasonal variations are not very important and a single annual profile can be used.

The temperature T (K) at height h (km) is given by:

$T(h) = 300.4222 - 6.3533 h + 0.005886 h^2$	for	$0 \leq h \leq 17$
$T(h) = 194 + (h - 17) 2.533$	for	$17 \leq h \leq 47$
$T(h) = 270$	for	$47 \leq h \leq 52$
$T(h) = 270 - (h - 52) 3.0714$	for	$52 \leq h \leq 80$
$T(h) = 184$	for	$80 \leq h \leq 100$

while the pressure P (hPa):

$P(h) = 1012.0306 - 109.0338 h + 3.6316 h^2$	for	$0 \leq h \leq 10$
$P(h) = P_{10} \exp[-0.147 (h - 10)]$	for	$10 \leq h \leq 72$
$P(h) = P_{72} \exp[-0.165 (h - 72)]$	for	$72 \leq h \leq 100$

where P_{10} and P_{72} are the pressures at 10 and 72 km respectively.

For water vapour (g/m^3):

$\rho(h) = 19.6542 \exp[-0.2313 h - 0.1122 h^2 + 0.01351 h^3$		
$\quad - 0.0005923 h^4]$	for	$0 \leq h \leq 15$
$\rho(h) = 0$	for	$h > 15$

3 Mid-latitude reference atmosphere

For mid-latitudes (between 22° and 45°) the following profiles may be used for the summer and winter.

3.1 Summer mid-latitude

The temperature T (K) at height h (km) is given by:

$$\begin{aligned}
 T(h) &= 294.9838 - 5.2159 h - 0.07109 h^2 & \text{for} & \quad 0 \leq h \leq 13 \\
 T(h) &= 215.5 & \text{for} & \quad 13 \leq h \leq 17 \\
 T(h) &= 215.5 \exp [(h - 17) 0.008128] & \text{for} & \quad 17 \leq h \leq 47 \\
 T(h) &= 275 & \text{for} & \quad 47 \leq h \leq 53 \\
 T(h) &= 275 + \{1 - \exp [(h - 53) 0.06]\} 20 & \text{for} & \quad 53 \leq h \leq 80 \\
 T(h) &= 175 & \text{for} & \quad 80 \leq h \leq 100
 \end{aligned}$$

while the pressure P (hPa):

$$\begin{aligned}
 P(h) &= 1012.8186 - 111.5569 h + 3.8646 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\
 P(h) &= P_{10} \exp [-0.147 (h - 10)] & \text{for} & \quad 10 \leq h \leq 72 \\
 P(h) &= P_{72} \exp [-0.165 (h - 72)] & \text{for} & \quad 72 \leq h \leq 100
 \end{aligned}$$

where P_{10} and P_{72} are the pressures at 10 and 72 km respectively.

For water vapour (g/m^3):

$$\begin{aligned}
 \rho(h) &= 14.3542 \exp [-0.4174 h - 0.02290 h^2 + 0.001007 h^3] & \text{for} & \quad 0 \leq h \leq 10 \\
 \rho(h) &= 0 & \text{for} & \quad h > 10
 \end{aligned}$$

3.2 Winter mid-latitude

The temperature T (K) at height h (km) is given by:

$$\begin{aligned}
 T(h) &= 272.7241 - 3.6217 h - 0.1759 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\
 T(h) &= 218 & \text{for} & \quad 10 \leq h \leq 33 \\
 T(h) &= 218 + (h - 33) 3.3571 & \text{for} & \quad 33 \leq h \leq 47 \\
 T(h) &= 265 & \text{for} & \quad 47 \leq h \leq 53 \\
 T(h) &= 265 - (h - 53) 2.0370 & \text{for} & \quad 53 \leq h \leq 80 \\
 T(h) &= 210 & \text{for} & \quad 80 \leq h \leq 100
 \end{aligned}$$

while the pressure P (hPa):

$$\begin{aligned}
 P(h) &= 1018.8627 - 124.2954 h + 4.8307 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\
 P(h) &= P_{10} \exp [-0.147 (h - 10)] & \text{for} & \quad 10 \leq h \leq 72 \\
 P(h) &= P_{72} \exp [-0.155 (h - 72)] & \text{for} & \quad 72 \leq h \leq 100
 \end{aligned}$$

where P_{10} and P_{72} are the pressures at 10 and 72 km respectively.

For water vapour (g/m^3):

$$\begin{aligned}
 \rho(h) &= 3.4742 \exp [-0.2697 h - 0.03604 h^2 + 0.0004489 h^3] & \text{for} & \quad 0 \leq h \leq 10 \\
 \rho(h) &= 0 & \text{for} & \quad h > 10
 \end{aligned}$$

4 High latitude reference atmosphere

For high latitudes (higher than 45°) the following profiles may be used for the summer and winter.

4.1 Summer high latitude

The temperature T (K) at height h (km) is given by:

$$\begin{aligned} T(h) &= 286.8374 - 4.7805 h - 0.1402 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\ T(h) &= 225 & \text{for} & \quad 10 \leq h \leq 23 \\ T(h) &= 225 \exp [(h - 23) 0.008317] & \text{for} & \quad 23 \leq h \leq 48 \\ T(h) &= 277 & \text{for} & \quad 48 \leq h \leq 53 \\ T(h) &= 277 - (h - 53) 4.0769 & \text{for} & \quad 53 \leq h \leq 79 \\ T(h) &= 171 & \text{for} & \quad 79 \leq h \leq 100 \end{aligned}$$

while the pressure P (hPa):

$$\begin{aligned} P(h) &= 1008.0278 - 113.2494 h + 3.9408 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\ P(h) &= P_{10} \exp [-0.140 (h - 10)] & \text{for} & \quad 10 \leq h \leq 72 \\ P(h) &= P_{72} \exp [-0.165 (h - 72)] & \text{for} & \quad 72 \leq h \leq 100 \end{aligned}$$

where P_{10} and P_{72} are the pressures at 10 and 72 km respectively.

For water vapour (g/m^3):

$$\begin{aligned} \rho(h) &= 8.988 \exp [-0.3614 h - 0.005402 h^2 - 0.001955 h^3] & \text{for} & \quad 0 \leq h \leq 15 \\ \rho(h) &= 0 & \text{for} & \quad h > 15 \end{aligned}$$

4.2 Winter high latitude

The temperature T (K) at height h (km) is given by:

$$\begin{aligned} T(h) &= 257.4345 + 2.3474 h - 1.5479 h^2 + 0.08473 h^3 & \text{for} & \quad 0 \leq h \leq 8.5 \\ T(h) &= 217.5 & \text{for} & \quad 8.5 \leq h \leq 30 \\ T(h) &= 217.5 + (h - 30) 2.125 & \text{for} & \quad 30 \leq h \leq 50 \\ T(h) &= 260 & \text{for} & \quad 50 \leq h \leq 54 \\ T(h) &= 260 - (h - 54) 1.667 & \text{for} & \quad 54 \leq h \leq 100 \end{aligned}$$

while the pressure P (hPa):

$$\begin{aligned} P(h) &= 1010.8828 - 122.2411 h + 4.554 h^2 & \text{for} & \quad 0 \leq h \leq 10 \\ P(h) &= P_{10} \exp [-0.147 (h - 10)] & \text{for} & \quad 10 \leq h \leq 72 \\ P(h) &= P_{72} \exp [-0.150 (h - 72)] & \text{for} & \quad 72 \leq h \leq 100 \end{aligned}$$

where P_{10} and P_{72} are the pressures at 10 and 72 km respectively.

For water vapour (g/m^3):

$$\begin{aligned} \rho(h) &= 1.2319 \exp [0.07481 h - 0.0981 h^2 + 0.00281 h^3] & \text{for} & \quad 0 \leq h \leq 10 \\ \rho(h) &= 0 & \text{for} & \quad h > 10 \end{aligned}$$

BIBLIOGRAPHY

BRUSSAARD, G., DAMOSSO, E. and STOLA, L. [October, 1983] Characterisation of the 50-70 GHz band for space communications. *CSELT Rapporti Tecnici*, Vol. XI, No. 5.

ANNEX 2

1 Experimental data of atmospheric vertical profiles

Monthly averages of vertical profiles of temperature, pressure and relative humidity were calculated for 353 locations over the world, using 10 years (1980-1989) of radiosonde observations. This dataset (DST.STD) is available from ITU/BR and contains the mean monthly vertical profiles, for both 00.00 UTC and 12.00 UTC, of pressure, temperature and relative humidity. These profiles, calculated in the absence of rain, range from 0 to 16 km with a step of 500 m. An example of one profile is given in Table 2.

Above that altitude, extrapolation can be performed by using the reference profiles given in Annex 1. To translate the relative humidity into absolute values of water vapour density, the formulae contained in Recommendation ITU-R P.453 should be used.

TABLE 2

DST.STD data format – Example of month average profile

NNNNNMMT NL 01384111 33			
Press(hPa)	Z(km)	Temp(K)	RH(%/100)
.000	.00	273.16	.000E+00
950.734	.50	273.14	.730E+00
892.926	1.00	271.16	.672E+00
837.925	1.50	269.03	.581E+00
786.709	2.00	266.60	.516E+00
737.580	2.50	264.01	.467E+00
691.017	3.00	261.18	.445E+00
647.037	3.50	258.14	.427E+00
605.609	4.00	255.07	.413E+00
566.371	4.50	251.86	.402E+00
528.962	5.00	248.62	.400E+00
493.406	5.50	245.34	.362E+00
460.513	6.00	241.99	.329E+00
429.041	6.50	238.62	.297E+00
398.949	7.00	235.19	.275E+00
371.513	7.50	231.82	.237E+00
345.238	8.00	228.65	.179E+00
319.967	8.50	225.70	.139E+00
296.107	9.00	223.06	.107E+00
271.381	9.50	221.51	.943E-01
250.931	10.00	219.68	.815E-01
232.328	10.50	218.39	.723E-01
214.863	11.00	217.63	.642E-01
196.348	11.50	217.70	.539E-01
181.888	12.00	217.56	.477E-01
167.454	12.50	217.86	.421E-01
153.456	13.00	218.37	.366E-01
140.897	13.50	218.51	.317E-01
129.541	14.00	218.67	.272E-01
120.027	14.50	218.27	.253E-01
110.853	15.00	217.74	.235E-01
101.978	15.50	217.22	.220E-01
91.925	16.00	217.89	.196E-01

Legend

NNNNN = WMO Station Number: 01384

MM = Month: 11

T = Launch time: 1 (1 = 00.00 UTC, 2 = 12.00 UTC)

NL = Fixed number of profile levels: 33

Press(hPa) = Atmospheric Pressure

Z(km) = Height above sea level

Temp(K) = Air Temperature

RH(%/100) = Relative Humidity (as a fraction)

NOTE 1 – The first level (at surface) may be set to zero if unrecorded.