RECOMMENDATION ITU-R P. 835-2

REFERENCE STANDARD ATMOSPHERES

(Question ITU-R 201/3)

(1992-1994-1997)

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, except when more reliable local data are available.

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:

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

where:

$$T_i = T(H_i) \tag{2}$$

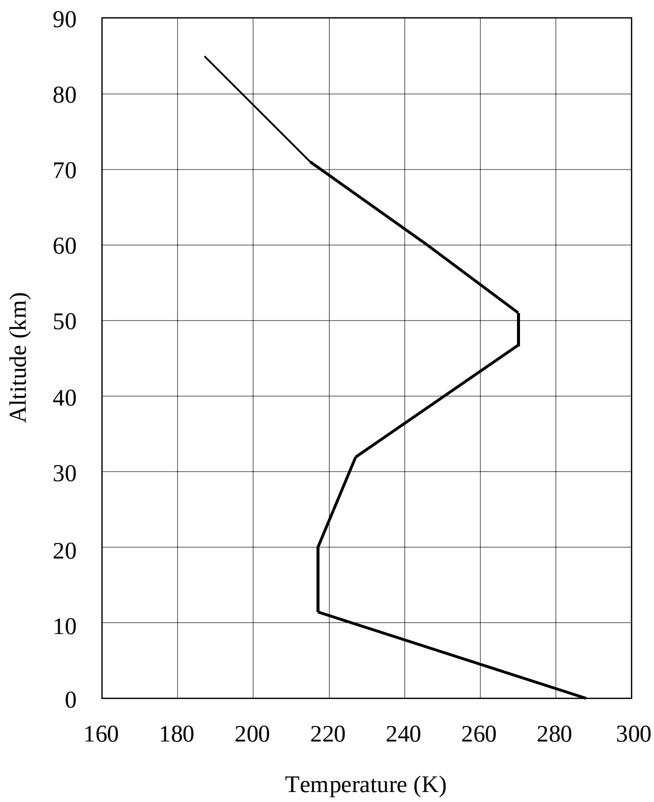
and L_i is the temperature gradient starting at altitude H_i and is given in Table 1.

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:

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

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

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

The ground-level standard temperature and pressure are:

$$T_0 = 288.15 \quad \text{K}$$

$$P_0 = 1\,013.25 \quad \text{hPa} \tag{5}$$

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of the atmosphere starts to break down, and the hydrostatic equation, on which the above equations are based, is no longer valid.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:

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

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

$$\rho_0 = 7.5 \qquad \text{g/m}^3 \tag{7}$$

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

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

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:

$$h_0 = 6 \text{ km} \tag{9}$$

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 $0 \le h \le 17$

$T(h) = 194 + (h - 17)\, 2.533$ for $17 \le h \le 47$

$T(h) = 270$ for $47 \le h \le 52$

$T(h) = 270 - (h - 52)\, 3.0714$ for $52 \le h \le 80$

$T(h) = 184$ for $80 \le h \le 100$

while the pressure P (hPa):

$P(h) = 1012.0306 - 109.0338\, h + 3.6316\, h^2$ for $0 \le h \le 10$

$P(h) = P_{10} \exp[-0.147\, (h - 10)]$ for $10 \le h \le 72$

$P(h) = P_{72} \exp[-0.165\, (h - 72)]$ for $72 \le h \le 100$

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

For water vapour (g/m^3)

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

$\rho(h) = 0$ 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:

$T(h) = 294.9838 - 5.2159\ h + 0.07109\ h^2$ for $0 \le h \le 13$

$T(h) = 215.5$ for $13 \le h \le 17$

$T(h) = 215.5 \exp [\ (h - 17)\ 0.008128]$ for $17 \le h \le 47$

$T(h) = 275$ for $47 \le h \le 53$

$T(h) = 275 + \{1 - \exp [\ (h - 53)\ 0.06]\ \}\ 20$ for $53 \le h \le 80$

$T(h) = 175$ for $80 \le h \le 100$

while the pressure P (hPa):

$P(h) = 1012.8186 - 111.5569\ h + 3.8646\ h^2$ for $0 \le h \le 10$

$P(h) = P_{10} \exp [-0.147\ (h - 10)]$ for $10 \le h \le 72$

$P(h) = P_{72} \exp [-0.165\ (h - 72)]$ for $72 \le h \le 100$

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

For water vapour (g/m^3):

$\rho(h) = 14.3542 \exp [-0.4174\ h - 0.02290\ h^2 + 0.001007\ h^3]$ for $0 \le h \le 10$

$\rho(h) = 0$ for $h > 10$

3.2 Winter mid-latitude

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

$T(h) = 272.7241 - 3.6217\ h - 0.1759\ h^2$ for $0 \le h \le 10$

$T(h) = 218$ for $10 \le h \le 33$

$T(h) = 218 + (h - 33)\ 3.3571$ for $33 \le h \le 47$

$T(h) = 265$ for $47 \le h \le 53$

$T(h) = 265 - (h - 53)\ 2.0370$ for $53 \le h \le 80$

$T(h) = 210$ for $80 \le h \le 100$

while the pressure P (hPa):

$P(h) = 1018.8627 - 124.2954\ h + 4.8307\ h^2$ for $0 \le h \le 10$

$P(h) = P_{10} \exp [-0.147\ (h - 10)]$ for $10 \le h \le 72$

$P(h) = P_{72} \exp [-0.155\ (h - 72)]$ for $72 \le h \le 100$

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

For water vapour (g/m^3):

$\rho(h) = 3.4742 \exp [-0.2697\ h - 0.03604\ h^2 + 0.0004489\ h^3]$ for $0 \le h \le 10$

$\rho(h) = 0$ for $h > 10$

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:

$T(h) = 286.8374 - 4.7805\ h - 0.1402\ h^2$	for	$0 \le h \le 10$
$T(h) = 225$	for	$10 \le h \le 23$
$T(h) = 225 + \exp\ [\ (h - 23)\ 0.008317]$	for	$23 \le h \le 48$
$T(h) = 277$	for	$48 \le h \le 53$
$T(h) = 277 - (h - 53)\ 4.0769$	for	$53 \le h \le 79$
$T(h) = 171$	for	$79 \le h \le 100$

while the pressure P (hPa):

$P(h) = 1008.0278 - 113.2494\ h + 3.9408\ h^2$	for	$0 \le h \le 10$
$P(h) = P_{10} \exp\ [-0.140\ (h - 10)]$	for	$10 \le h \le 72$
$P(h) = P_{72} \exp\ [-0.165\ (h - 72)]$	for	$72 \le h \le 100$

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

For water vapour (g/m^3):

$\rho(h) = 8.988 \exp\ [-0.3614\ h - 0.005402\ h^2 - 0.001955\ h^3]$	for	$0 \le h \le 15$
$\rho(h) = 0$	for	$h > 15$

4.2 Winter high latitude

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

$T(h) = 257.4345 + 2.3474\ h - 1.5479\ h^2 + 0.08473\ h^3$	for	$0 \le h \le 8.5$
$T(h) = 217.5$	for	$8.5 \le h \le 30$
$T(h) = 217.5 + (h - 30)\ 2.125$	for	$30 \le h \le 50$
$T(h) = 260$	for	$50 \le h \le 54$
$T(h) = 260 - (h - 54)\ 1.667$	for	$54 \le h \le 100$

while the pressure P (hPa):

$P(h) = 1010.8828 - 122.2411\ h + 4.554\ h^2$	for	$0 \le h \le 10$
$P(h) = P_{10} \exp\ [-0.147\ (h - 10)]$	for	$10 \le h \le 72$
$P(h) = P_{72} \exp\ [-0.150\ (h - 72)]$	for	$72 \le h \le 100$

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

For water vapour (g/m^3):

$\rho(h) = 1.2319 \exp\ [0.07481\ h - 0.0981\ h^2 + 0.00281\ h^3]$	for	$0 \le h \le 10$
$\rho(h) = 0$	for	$h > 10$

BIBLIOGRAPHY

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