International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.835-6

(12/2017)

Reference standard atmospheres

P Series

Radiowave propagation

International Telecommunication Union

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SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R P.835-6*

Reference standard atmospheres

(Question ITU-R 201/3)

(1992-1994-1997-1999-2005-2012-2017)

Scope

Recommendation ITU-R P.835 provides expressions and data for reference standard atmospheres required for the calculation of gaseous attenuation on Earth-space paths.

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 Annexes 2 and 3 be used for the locations of interest when seasonal and monthly variations are concerned.

Annex 1

1 Mean annual global reference atmosphere

The following mean annual global reference atmosphere reflects the mean annual temperature and pressure profiles vs. height when averaged across the globe.

1.1 Temperature and pressure

The mean annual global reference atmosphere approximates the U.S. Standard Atmosphere, 1976 with insignificant relative error. The atmospheric temperature and pressure profiles are defined in two height[1] regimes: 1) geopotential heights from 0 km′ to 84.852 km′, and 2) geometric heights from 86 km to 100 km. The conversions between geopotential height, h' (km), and geometric height, h (km), are:

$$h' = \frac{6356.766h}{6356.766+h} \quad (1a)$$

and

* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in the year 2020 in accordance with Resolution ITU-R 1.

[1] km′ are units of geopotential height, and km are units of geometric height.

$$h = \frac{6356.766h'}{6356.766-h'} \qquad (1b)$$

where a geopotential height of 84.852 km′ corresponds to a geometric height of 86 km. Since various P-series Recommendations (e.g. Recommendation ITU-R P.676 Annex 1) use geometric height, the temperature and pressure at a geometric height $h \leq 86$ km can be calculated by converting geometric height h to the corresponding geopotential height h' and calculating the temperature and pressure at the corresponding geopotential height h'.

In the first height regime, the temperature T (K) at geopotential height h' (km′) is:

$$T(h') = 288.15 - 6.5\,h' \quad \text{for} \quad 0 \leq h' \leq 11 \qquad (2a)$$

$$T(h') = 216.65 \quad \text{for} \quad 11 < h' \leq 20 \qquad (2b)$$

$$T(h') = 216.65 + (h'-20) \quad \text{for} \quad 20 < h' \leq 32 \qquad (2c)$$

$$T(h') = 228.65 + 2.8\,(h'-32) \quad \text{for} \quad 32 < h' \leq 47 \qquad (2d)$$

$$T(h') = 270.65 \quad \text{for} \quad 47 < h' \leq 51 \qquad (2e)$$

$$T(h') = 270.65 - 2.8\,(h'-51) \quad \text{for} \quad 51 < h' \leq 71 \qquad (2f)$$

$$T(h') = 214.65 - 2.0\,(h'-71) \quad \text{for} \quad 71 < h' \leq 84.852 \qquad (2g)$$

and the pressure P (hPa) at geopotential height h' (km′) is:

$$P(h') = 1013.25\left[\frac{288.15}{288.15-6.5\,h'}\right]^{-34.1632/6.5} \quad \text{for} \quad 0 \leq h' \leq 11 \qquad (3a)$$

$$P(h') = 226.3226\exp[-34.1632\,(h'-11)/216.65] \quad \text{for} \quad 11 < h' \leq 20 \qquad (3b)$$

$$P(h') = 54.74980\left[\frac{216.65}{216.65+(h'-20)}\right]^{34.1632} \quad \text{for} \quad 20 < h' \leq 32 \qquad (3c)$$

$$P(h') = 8.680422\left[\frac{228.65}{228.65+2.8\,(h'-32)}\right]^{34.1632/2.8} \quad \text{for} \quad 32 < h' \leq 47 \qquad (3d)$$

$$P(h') = 1.109106\exp[-34.1632\,(h'-47)/270.65] \quad \text{for} \quad 47 < h' \leq 51 \qquad (3e)$$

$$P(h') = 0.6694167\left[\frac{270.65}{270.65-2.8\,(h'-51)}\right]^{-34.1632/2.8} \quad \text{for} \quad 51 < h' \leq 71 \qquad (3f)$$

$$P(h') = 0.03956649\left[\frac{214.65}{214.65-2.0\,(h'-71)}\right]^{-34.1632/2.0} \quad \text{for} \quad 71 < h' \leq 84.852 \qquad (3g)$$

In the second height regime, the temperature T (K) at geometric height h (km) is:

$$T(h) = 186.8673 \quad \text{for} \quad 86 \leq h \leq 91 \qquad (4a)$$

$$T(h) = 263.1905 - 76.3232\left[1-\left(\frac{h-91}{19.9429}\right)^2\right]^{\frac{1}{2}} \quad \text{for} \quad 91 < h \leq 100 \qquad (4b)$$

and the pressure P (hPa) at geometric height h (km) is:

$$P(h) = \exp(a_0 + a_1 h + a_2 h^2 + a_3 h^3 + a_4 h^4) \quad \text{for} \quad 86 \leq h \leq 100 \qquad (5)$$

where

$a_0 = 95.571899$

$a_1 = -4.011801$

$a_2 = 6.424731 \times 10^{-2}$

$a_3 = -4.789660 \times 10^{-4}$

$a_4 = 1.340543 \times 10^{-6}$

For reference, the temperature and pressure vs. geometric height are shown in Figs 1 and 2, respectively.

FIGURE 1

Temperature vs. geometric height

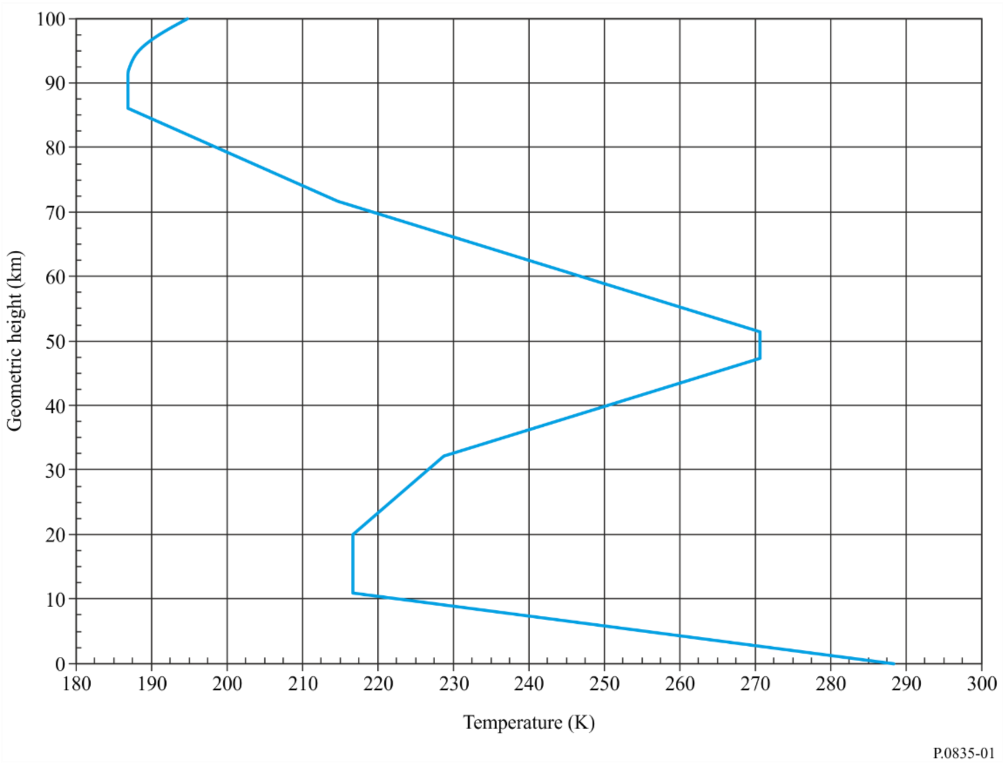
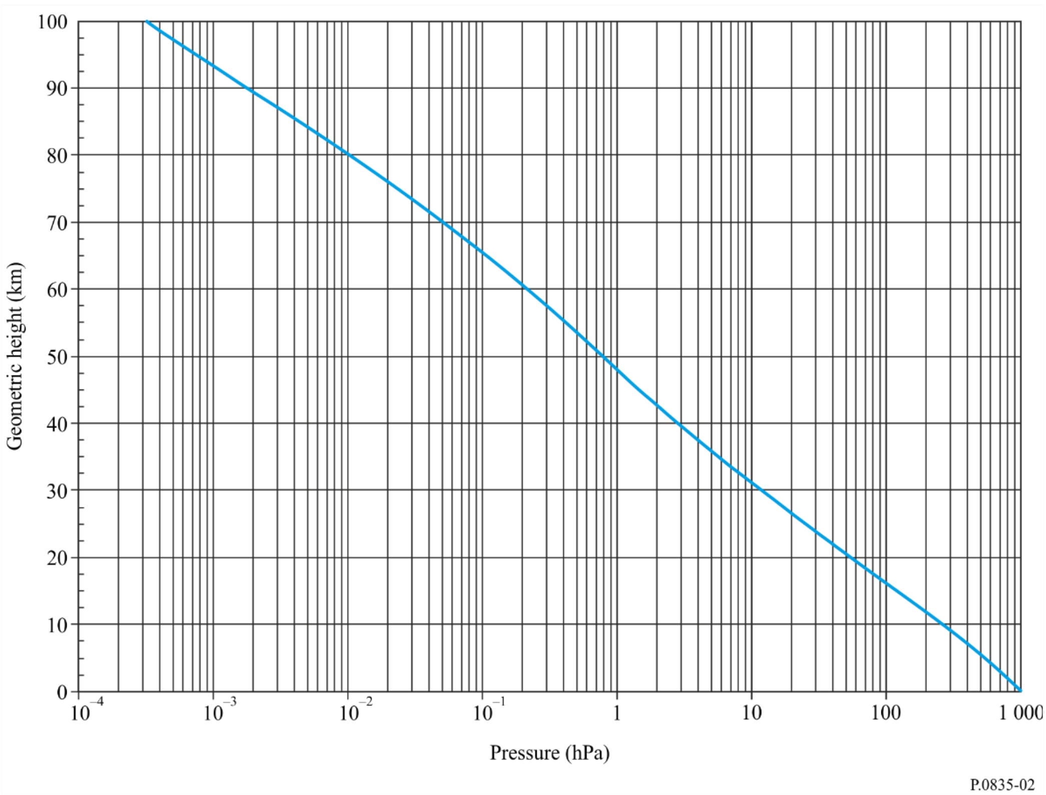


FIGURE 2

Pressure vs. geometric height



1.2 Water-vapour pressure

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

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

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

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

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

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

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:

$$T(h) = 300.4222 - 6.3533\, h + 0.005886\, h^2 \quad \text{for} \quad 0 \le h < 17$$

$$T(h) = 194 + (h - 17)\, 2.533 \quad \text{for} \quad 17 \le h < 47$$

$$T(h) = 270 \quad \text{for} \quad 47 \le h < 52$$

$$T(h) = 270 - (h - 52)\, 3.0714 \quad \text{for} \quad 52 \le h < 80$$

$$T(h) = 184 \quad \text{for} \quad 80 \le h \le 100$$

while the pressure P (hPa):

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

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

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

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

For water vapour (g/m^3):

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

$$\rho(h) = 0 \quad \text{for} \quad h > 15$$

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:

$$T(h) = 294.9838 - 5.2159\,h - 0.07109\,h^2 \quad \text{for} \quad 0 \le h < 13$$

$$T(h) = 215.15 \quad \text{for} \quad 13 \le h < 17$$

$$T(h) = 215.15 \exp[(h - 17)\,0.008128] \quad \text{for} \quad 17 \le h < 47$$

$$T(h) = 275 \quad \text{for} \quad 47 \le h < 53$$

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

$$T(h) = 175 \quad \text{for} \quad 80 \le h \le 100$$

while the pressure P (hPa):

$$P(h) = 1012.8186 - 111.5569\,h + 3.8646\,h^2 \quad \text{for} \quad 0 \le h \le 10$$

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

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

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

For water vapour (g/m^3):

$$\rho(h) = 14.3542 \exp[-0.4174\,h - 0.02290\,h^2 + 0.001007\,h^3] \quad \text{for} \quad 0 \le h \le 15$$

$$\rho(h) = 0 \quad \text{for} \quad h > 15$$

3.2 Winter mid-latitude

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

$$T(h) = 272.7241 - 3.6217\,h - 0.1759\,h^2 \quad \text{for} \quad 0 \le h < 10$$

$$T(h) = 218 \quad \text{for} \quad 10 \le h < 33$$

$$T(h) = 218 + (h - 33)\,3.3571 \quad \text{for} \quad 33 \le h < 47$$

$$T(h) = 265 \quad \text{for} \quad 47 \le h < 53$$

$$T(h) = 265 - (h - 53)\,2.0370 \quad \text{for} \quad 53 \le h < 80$$

$$T(h) = 210 \quad \text{for} \quad 80 \le h \le 100$$

while the pressure P (hPa):

$$P(h) = 1018.8627 - 124.2954\,h + 4.8307\,h^2 \quad \text{for} \quad 0 \le h \le 10$$

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

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

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

For water vapour (g/m^3):

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

$$\rho(h) = 0 \quad \text{for} \quad h > 10$$

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:

$$T(h) = 286.8374 - 4.7805\, h - 0.1402\, h^2 \quad \text{for} \quad 0 \le h < 10$$

$$T(h) = 225 \quad \text{for} \quad 10 \le h < 23$$

$$T(h) = 225 \exp\,[(h - 23)\, 0.008317] \quad \text{for} \quad 23 \le h < 48$$

$$T(h) = 277 \quad \text{for} \quad 48 \le h < 53$$

$$T(h) = 277 - (h - 53)\, 4.0769 \quad \text{for} \quad 53 \le h < 79$$

$$T(h) = 171 \quad \text{for} \quad 79 \le h \le 100$$

while the pressure P (hPa):

$$P(h) = 1008.0278 - 113.2494\, h + 3.9408\, h^2 \quad \text{for} \quad 0 \le h \le 10$$

$$P(h) = P_{10} \exp\,[-0.140\,(h - 10)] \quad \text{for} \quad 10 < h \le 72$$

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

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

For water vapour (g/m^3):

$$\rho(h) = 8.988 \exp\,[-0.3614\, h - 0.005402\, h^2 - 0.001955\, h^3] \quad \text{for} \quad 0 \le h \le 15$$

$$\rho(h) = 0 \quad \text{for} \quad h > 15$$

4.2 Winter high latitude

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

$$T(h) = 257.4345 + 2.3474\, h - 1.5479\, h^2 + 0.08473\, h^3 \quad \text{for} \quad 0 \le h < 8.5$$

$$T(h) = 217.5 \quad \text{for} \quad 8.5 \le h < 30$$

$$T(h) = 217.5 + (h - 30)\, 2.125 \quad \text{for} \quad 30 \le h < 50$$

$$T(h) = 260 \quad \text{for} \quad 50 \le h < 54$$

$$T(h) = 260 - (h - 54)\, 1.667 \quad \text{for} \quad 54 \le h \le 100$$

while the pressure P (hPa):

$$P(h) = 1010.8828 - 122.2411\, h + 4.554\, h^2 \quad \text{for} \quad 0 \le h \le 10$$

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

$$P(h) = P_{72} \exp\,[-0.150\,(h - 72)] \quad \text{for} \quad 72 < h \le 100$$

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

For water vapour (g/m^3):

$$\rho(h) = 1.2319 \exp\,[0.07481\, h - 0.0981\, h^2 + 0.00281\, h^3] \quad \text{for} \quad 0 \le h \le 10$$

$$\rho(h) = 0 \quad \text{for} \quad h > 10$$

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. The mean monthly profiles are contained in ASCII files named <*WMO_code*>.dat, where *WMO_code* is the code name of the site according to the World Meteorological Organization (e.g.: 03496.dat, 03496 is the WMO station code for Hemsby-in-Norfolk). An example of one profile is given in Table 2. The list of locations is contained in an ASCII file (using the comma separated value file, CSV, file format) called dst_std_lst.csv. Each record of this file contains the following field: WMO_CODE, Station Name, Country, Latitude, Longitude, Altitude above sea level. An example of such a record is given in Table 3.

Above the maximum 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 (station 10410)

YYMMDDHH NL			
99 199 0 33			
Press (hPa)	Z (km)	Temp (K)	RH (%/100)
1 016.905	0.00	273.62	0.864E+00
956.686	0.50	273.33	0.830E+00
898.555	1.00	271.74	0.754E+00
844.014	1.50	269.59	0.665E+00
791.860	2.00	267.15	0.591E+00
742.661	2.50	264.56	0.518E+00
696.285	3.00	261.89	0.470E+00
651.977	3.50	258.94	0.458E+00
610.086	4.00	255.88	0.448E+00
570.467	4.50	252.69	0.445E+00
533.076	5.00	249.33	0.451E+00
497.767	5.50	245.90	0.453E+00
464.123	6.00	242.32	0.450E+00
432.441	6.50	238.75	0.450E+00
402.414	7.00	235.16	0.443E+00
374.177	7.50	231.59	0.437E+00
347.236	8.00	228.12	0.433E+00
322.281	8.50	224.88	0.427E+00

TABLE 2 (*end*)

YYMMDDHH NL			
99 199 0 33			
298.474	9.00	221.89	0.421E+00
276.492	9.50	219.27	0.416E+00
255.527	10.00	217.08	0.411E+00
236.297	10.50	215.62	0.402E+00
218.415	11.00	214.79	0.393E+00
201.366	11.50	214.14	0.348E+00
186.214	12.00	214.02	0.205E+00
172.093	12.50	214.24	0.104E+00
158.709	13.00	214.66	0.368E-01
146.492	13.50	214.94	0.351E-02
135.813	14.00	214.88	0.120E-02
125.690	14.50	214.50	0.117E-02
116.027	15.00	214.01	0.113E-02
106.798	15.50	213.56	0.110E-02
98.291	16.00	213.26	0.107E-02

Legend to Table 2:

YY = Year (99 for mean monthly profiles)

MM = Month (1 = January, 2 = February, ...)

DD = Day of the month (99 for mean monthly profiles)

HH = Hour of the day (UTC)

NL = Number of vertical levels (NL = 33 for STD.DST)

Press (hPa) = Atmospheric total pressure

Z (km) = Height above the Earth's surface

Temp (K) = Air temperature

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

NOTE 1 – The level values of Temp and Press may be set to zero if unrecorded.

TABLE 3

DST_STD_LST.CSV station information file – Example of record structure

WMO code	**Station name**	**Country**	**Latitude (degrees)**	**Longitude (degrees)**	**Asl (m)**
10 410	ESSEN	DL	51.4	6.967	153

NOTE – Latitude and longitude values are in decimal degrees (i.e. 51.4 = 51º 24').

Annex 3

1 Numerical weather prediction data of atmospheric vertical profiles

Monthly averages, conditioned to the hour of the day, of vertical profiles of temperature, pressure and water-vapour density were calculated using the ECMWF 15-year data set (ERA15) from the re-analysis project. This data set contains the mean monthly vertical profiles at 00:00, 06:00, 12:00 and 18:00 UTC of total air pressure, air temperature and water-vapour density at 32 height levels from a reference height located around the local Earth's surface up to about 30 km above the Earth's surface. The data are from 0º to 360º in longitude and from +90º to −90º in latitude, with a resolution of 1.5º in both latitude and longitude. All the data are stored in files using the IEEE floating point single precision standard (4 bytes, 32 bits) in a Big-Endian format.

The data set and the associated Matlab files to access the data are an integral part of this Recommendation and are available in the Supplement file R-REC-P.835-6-201712-I!!ZIP-E.zip. The mean monthly profiles of each meteorological parameter are contained in binary files **<*param*>_<*hh*>.bin**, where *param* is the name of the meteorological parameter (**pres** = total air pressure (hPa), **temp** = air temperature (K), **vapd** = water-vapour density (g/m^3)) and *hh* is the hour of the day (i.e. 00, 06, 12 and 18 (UTC)). The associated heights of the profile levels are contained in the binary file **hght.bin**. An example profile for Latitude = 45° N, Longitude = 9° E, July, and 12:00 UTC is given in Table 4.

TABLE 4

Example Profile

Z (m)	**Press (hPa)**	**Temp (K)**	**Vapd (g/m^3)**
665.488	939.255	298.373	9.823
698.823	935.673	298.125	9.617
816.585	923.092	296.598	9.302
1 026.379	900.957	294.292	8.811
1 309.298	871.693	291.459	8.099
1 650.689	837.298	288.287	6.992
2 039.463	799.373	285.107	5.706
2 467.391	759.191	282.116	4.555
2 928.467	717.723	279.045	3.641
3 418.375	675.691	275.934	2.692
3 934.342	633.633	272.913	1.855
4 474.659	591.936	269.707	1.286
5 038.169	550.876	266.183	0.911
5 624.303	510.656	262.354	0.636
6 232.944	471.427	258.213	0.428
6 864.291	433.307	253.687	0.277
7 518.708	396.390	248.780	0.173
8 196.752	360.767	243.521	0.103
8 898.985	326.527	237.971	0.058
9 626.211	293.764	232.319	0.034
10 380.050	262.580	226.984	0.019
11 164.590	233.064	222.845	0.009

TABLE 4 (*end*)

Z (m)	**Press (hPa)**	**Temp (K)**	**Vapd (g/m^3)**
11 988.097	205.263	220.483	0.003
12 861.558	179.195	219.279	0.001
13 796.578	154.827	218.154	0.001
14 809.705	132.043	217.057	0.001
15 931.961	110.604	216.026	0.000
17 225.900	90.110	215.674	0.000
18 818.316	70.037	216.262	0.000
20 961.771	50.038	219.300	0.000
24 267.900	30.039	223.166	0.000
31 427.936	10.320	232.854	0.000

Legend to Table 4:

Z (m) = Height with respect to sea level

Press (hPa) = Atmospheric total pressure

Temp (K) = Air temperature

Vapd (g/m^3) = Water-vapour density