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| **Recommendation ITU-R P.835-5**  **(02/2012)** |
| **Reference standard atmospheres** |
| **P Series**  **Radiowave propagation** |

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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| ***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.835-5

Reference standard atmospheres

(Question ITU-R 201/3)

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

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 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*)  *Ti*  *Li* (*h* – *Hi*)               K (1)

where:

*Ti*  *T*(*Hi*)(2)

and *Li* is the temperature gradient starting at altitude *Hi* and is given in Table 1.

TABLE 1

|  |  |  |
| --- | --- | --- |
| Subscript, *i* | Altitude, *Hi* (km) | Temperature gradient, *Li* (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



When the temperature gradient *Li*  0, pressure is given by the equation:

                 (3)

and when the temperature gradient *Li*  0, pressure is obtained from the equation:

                 (4)

The ground-level standard temperature and pressure are:

 (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:

(*h*)  0 exp (–*h* / *h*0)               g/m3 (6)

where the scale height *h*0  2 km, and the standard ground-level water-vapour density is:

0  7.5               g/m3 (7)

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

                 (8)

Water-vapour density decreases exponentially with increasing altitude, up to an altitude where the mixing ratio *e* (*h*)/*P*(*h*)  2  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 km (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  *h* < 17

*T*(*h*)  194  (*h* – 17) 2.533 for 17  *h* < 47

*T*(*h*)  270 for 47  *h* < 52

*T*(*h*)  270 – (*h* – 52) 3.0714 for 52  *h* < 80

*T*(*h*)  184 for 80  *h*  100

while the pressure *P* (hPa):

*P*(*h*)  1012.0306 – 109.0338 *h*  3.6316 *h*2 for 0  *h*  10

*P*(*h*)  *P*10 exp [–0.147 (*h* – 10)] for 10  *h*  72

*P*(*h*)  *P*72 exp [–0.165 (*h* – 72)] for 72  *h*  100

where *P*10 and *P*72 are the pressures at 10 and 72 km respectively.

For water vapour (g/m3):

(*h*)  19.6542 exp [–0.2313 *h* – 0.1122 *h*2  0.01351 *h*3

– 0.0005923 *h*4] for 0  *h*  15

(*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  *h* < 13

*T*(*h*)  215.15 for 13  *h* < 17

*T*(*h*)  215.15 exp [(*h* – 17) 0.008128] for 17  *h* < 47

*T*(*h*)  275 for 47  *h* < 53

*T*(*h*)  275  {1 – exp [(*h* – 53) 0.06] } 20 for 53  *h* < 80

*T*(*h*)  175 for 80  *h*  100

while the pressure *P* (hPa):

*P*(*h*)  1012.8186 – 111.5569 *h*  3.8646 *h*2 for 0  *h*  10

*P*(*h*)  *P*10 exp [– 0.147 (*h* – 10)] for 10  *h*  72

*P*(*h*)  *P*72 exp [– 0.165 (*h* – 72)] for 72  *h*  100

where *P*10 and *P*72 are the pressures at 10 and 72 km respectively.

For water vapour (g/m3):

(*h*)  14.3542 exp [– 0.4174 *h* – 0.02290 *h*2

 0.001007 *h*3] for 0  *h*  15

(*h*)  0 for *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 for 0  *h* < 10

*T*(*h*)  218 for 10  *h* < 33

*T*(*h*)  218  (*h* – 33) 3.3571 for 33  *h* < 47

*T*(*h*)  265 for 47  *h* < 53

*T*(*h*)  265 – (*h* – 53) 2.0370 for 53  *h* < 80

*T*(*h*)  210 for 80  *h*  100

while the pressure *P* (hPa):

*P*(*h*)  1018.8627 – 124.2954 *h*  4.8307 *h*2 for 0  *h*  10

*P*(*h*)  *P*10 exp [– 0.147 (*h* – 10)] for 10  *h*  72

*P*(*h*)  *P*72 exp [– 0.155 (*h* – 72)] for 72  *h*  100

where *P*10 and *P*72 are the pressures at 10 and 72 km respectively.

For water vapour (g/m3):

(*h*)  3.4742 exp [– 0.2697 *h –* 0.03604 *h*2

 0.0004489 *h*3] for 0  *h*  10

(*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  *h* < 10

*T*(*h*)  225 for 10  *h* < 23

*T*(*h*)  225 exp [(*h* – 23) 0.008317] for 23  *h* < 48

*T*(*h*)  277 for 48  *h* < 53

*T*(*h*)  277 – (*h* – 53) 4.0769 for 53  *h* < 79

*T*(*h*)  171 for 79  *h*  100

while the pressure *P* (hPa):

*P*(*h*)  1008.0278 – 113.2494 *h*  3.9408 *h*2 for 0  *h*  10

*P*(*h*)  *P*10 exp [–0.140 (*h* – 10)] for 10  *h*  72

*P*(*h*)  *P*72 exp [–0.165 (*h* – 72)] for 72  *h*  100

where *P*10 and *P*72 are the pressures at 10 and 72 km respectively.

For water vapour (g/m3):

(*h*)  8.988 exp [– 0.3614 *h –* 0.005402 *h*2

– 0.001955 *h*3] for 0  *h*  15

(*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  *h* < 8.5

*T*(*h*)  217.5 for 8.5  *h* < 30

*T*(*h*)  217.5  (*h* – 30) 2.125 for 30  *h* < 50

*T*(*h*)  260 for 50  *h* < 54

*T*(*h*)  260 – (*h* – 54) 1.667 for 54  *h*  100

while the pressure *P* (hPa):

*P*(*h*)  1010.8828 – 122.2411 *h*  4.554 *h*2 for 0  *h*  10

*P*(*h*)  *P*10 exp [–0.147 (*h* – 10)] for 10  *h*  72

*P*(*h*)  *P*72 exp [–0.150 (*h* – 72)] for 72  *h*  100

where *P*10 and *P*72 are the pressures at 10 and 72 km respectively.

For water vapour (g/m3):

(*h*)  1.2319 exp [0.07481 *h –* 0.0981 *h*2  0.00281 *h*3] for 0  *h*  10

(*h*)  0 for *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 |
| 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 |

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| *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 1 – 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 dataset (ESA\_STD\_PROF) is available from ITU/BR and contains the mean monthly vertical profiles, for 00.00, 06.00, 12.00 and 18.00 UTC, of total air pressure, air temperature and water-vapour density. These profiles extend from a reference height located around the local Earth’s surface up to about 30 km above the Earth’s surface and contains 32 levels derived from ERA15 model levels. The data are from 0 to 360 in longitude and from +90 to −90 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 mean monthly profiles of each meteorological parameter are contained in binary files named **<*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/m3]) and *hh* is the hour of the day (i.e. 00, 06, 12 and 18 [UTC]). The heights of the profile levels are contained in a separate binary file, named **hght.bin**, in which vertical profiles of mean monthly level heights are contained. An example of the data contained in the database for a specific is given in Table 4.

TABLE 4

ESA\_STD\_PROF content – Example of profile at grid point  
(latitude = 45 (degrees) and longitude = 9 (degrees))  
at 12 UTC of July

|  |  |  |  |
| --- | --- | --- | --- |
| Height (m) | Press (hPa) | Temp (K) | Vapd (g/m3) |
| 668.309 | 939.255 | 298.373 | 9.823 |
| 701.645 | 935.673 | 298.125 | 9.617 |
| 819.406 | 923.092 | 296.598 | 9.302 |
| 1 029.200 | 900.957 | 294.292 | 8.811 |
| 1 312.119 | 871.693 | 291.459 | 8.099 |
| 1 653.510 | 837.298 | 288.287 | 6.992 |
| 2 042.286 | 799.373 | 285.107 | 5.706 |
| 2 470.212 | 759.191 | 282.116 | 4.555 |
| 2 931.283 | 717.723 | 279.045 | 3.641 |
| 3 421.197 | 675.691 | 275.934 | 2.692 |
| 3 937.159 | 633.633 | 272.913 | 1.855 |
| 4 477.475 | 591.936 | 269.707 | 1.286 |
| 5 040.996 | 550.876 | 266.183 | 0.911 |
| 5 627.126 | 510.656 | 262.354 | 0.636 |
| 6 235.769 | 471.427 | 258.213 | 0.428 |
| 6 867.105 | 433.307 | 253.687 | 0.277 |
| 7 521.528 | 396.390 | 248.780 | 0.173 |
| 8 199.571 | 360.767 | 243.521 | 0.103 |
| 8 901.801 | 326.527 | 237.971 | 0.058 |
| 9 629.047 | 293.764 | 232.319 | 0.034 |
| 10 382.883 | 262.580 | 226.984 | 0.019 |
| 11 167.396 | 233.064 | 222.845 | 0.009 |
| 11 990.928 | 205.263 | 220.483 | 0.003 |
| 12 864.380 | 179.195 | 219.279 | 0.001 |
| 13 799.389 | 154.827 | 218.154 | 0.001 |
| 14 812.536 | 132.043 | 217.057 | 0.001 |
| 15 934.765 | 110.604 | 216.026 | 0.000 |
| 17 228.709 | 90.110 | 215.674 | 0.000 |
| 18 821.158 | 70.037 | 216.262 | 0.000 |
| 20 964.607 | 50.038 | 219.300 | 0.000 |
| 24 270.756 | 30.039 | 223.166 | 0.000 |
| 31 430.756 | 10.320 | 232.854 | 0.000 |

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| *Legend to Table 4:*  Z (m) = Height with respect to sea level  Press (hPa) = Atmospheric total pressure  Temp (K) = Air temperature  Vapd (g/m3) = Water-vapour density  NOTE 1 – The Matlab and Fortran procedures to access the ESA\_STD\_ PROF dataset are available from the ITU-R website dealing with Radiocommunication Study Group 3. |

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