International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.2145-0

(08/2022)

Digital maps related to the calculation of gaseous attenuation and related effects

P Series

Radiowave propagation

International Telecommunication Union

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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.2145-0

Digital maps related to the calculation of gaseous attenuation and related effects

(Question ITU-R 201-7/3)

(2022)

Scope

This Recommendation provides methods to predict the surface total (barometric) pressure, surface temperature, surface water vapour density and integrated water vapour content[1] required for the calculation of gaseous attenuation and related effects on terrestrial and Earth-space paths.

Keywords

Surface total (barometric) pressure, surface temperature, surface water vapour density, integrated water vapour content, Weibull probability distribution, Weibull shape, Weibull scale, Earth-space paths

Acronyms/Abbreviations

ASCII	American Standard Code for Information Interchange
CCDF	Complementary cumulative distribution function
ECMWF	European Centre for Medium-Range Weather Forecasts

Related ITU-R Recommendations and Handbook

Recommendation ITU-R P.528

Recommendation ITU-R P.530

Recommendation ITU-R P.618

Recommendation ITU-R P.619

Recommendation ITU-R P.676

Recommendation ITU-R P.836

Recommendation ITU-R P.1144

Recommendation ITU-R P.1510

Recommendation ITU-R P.1511

Recommendation ITU-R P.1853

Recommendation ITU-R P.2001

Recommendation ITU-R P.2041

Handbook on Radiometeorology

NOTE – The latest revision/edition of the Recommendation/Handbook should be used.

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[1] Integrated water vapour content is the total amount of water vapour in a vertical column extending from the surface of the Earth to the top of the atmosphere. The terms integrated water vapour content, total water vapour content, total column(ar) water vapour, integrated columnar water vapour content, and total columnar content of water vapour are synonymous.

The ITU Radiocommunication Assembly,

considering

a) that for the calculation of gaseous attenuation and related effects, surface total (barometric) pressure, surface temperature, surface water vapour density, and integrated water vapour content statistics are needed;

b) that 30 years of worldwide fifth generation reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) are available for surface total (barometric) pressure, surface temperature, surface water vapour density, and integrated water vapour content; and

c) that 30 years of worldwide reanalysis data have been post-processed to provide annual and monthly statistics of surface total (barometric) pressure, surface temperature, surface water vapour density and integrated water vapour content,

recommends

that the information in the Annex should be used for the calculation of gaseous attenuation and related effects on terrestrial and Earth-space paths, when more accurate local surface total (barometric) pressure, surface temperature, surface water vapour density, or integrated water vapour content statistics are not available.

Annex

List of symbols

$\overline{P_s}$	mean total (barometric) surface pressure
σ_{P_s}	standard deviation of surface pressure
$P_s(p)$	surface total (barometric) pressure vs. exceedance probability
$\overline{T_s}$	mean surface temperature
σ_{T_s}	standard deviation of surface temperature
$T_s(p)$	surface temperature vs. exceedance probability
$\overline{\rho_{w_s}}$	mean surface water vapour density
$\sigma_{\rho_{w_s}}$	standard deviation of surface water vapour density
$\rho_{w_s}(p)$	surface water vapour density vs. exceedance probability
$\overline{V_s}$	mean integrated water vapour content
σ_{V_s}	standard deviation of integrated water vapour content
$V_s(p)$	integrated water vapour content vs. exceedance probability
$psch$	pressure scale height
$tsch$	temperature scale height

$vsch$	water vapour scale height
Z_{ground}	surface height above mean sea level
k_{V_s}	Weibull shape parameter of integrated water vapour content
λ_{V_s}	Weibull scale parameter of integrated water vapour content
p	exceedance probability (CCDF)
p_{above}	exceedance probability above the desired exceedance probability
p_{below}	exceedance probability below the desired exceedance probability
X_i	unscaled value of the parameter of interest at the i^{th} grid point
$X_i{}'$	value of the parameter of interest at the i^{th} grid point at the desired height
X	value of the parameter of interest at the desired location at the desired height

1 Annual and monthly meteorological statistical parameters

Digital maps of the worldwide annual and monthly statistics of surface total (barometric) pressure, P_s, in hPa, surface temperature, T_s, in K, and surface water vapour density, ρ_{w_s}, in g/m^3, are an integral part of this Recommendation with the characteristics shown in Tables 1, 2 and 3[2].

Digital maps of the worldwide annual and monthly statistics of integrated water vapour content, V_s, in kg/m^2, or, equivalently, mm, are an integral part of this Recommendation with the characteristics shown in Tables 1 and 4.

Digital maps of the worldwide annual statistics of integrated water vapour content, V_s, approximated by a Weibull distribution are an integral part of this Recommendation with the characteristics shown in Tables 1 and 5.

Specifically:

– map files with "P" in the title contain values of mean surface total (barometric) pressure, $\overline{P_s}$, standard deviation of surface total (barometric) pressure, σ_{P_s}, and surface total (barometric) pressure vs. exceedance probability, $P_s(p)$;

– map files with "T" in the title contain the values of mean surface temperature, $\overline{T}_s$, standard deviation of surface temperature, σ_{T_s}, and surface temperature vs. exceedance probability, $T_s(p)$;

– map files with "RHO" in the title contain the values of mean surface water vapour density, $\overline{\rho_{w_s}}$, standard deviation of surface water vapour density, $\sigma_{\rho_{w_s}}$, and surface water vapour density vs. exceedance probability, $\rho_{w_s}(p)$;

– map files with "V" in the title contain the values of mean integrated water vapour content, $\overline{V}_s$, standard deviation of integrated water vapour content, σ_{V_s}, and integrated water vapour content vs. exceedance probability, V_s(p);

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[2] Surface temperature is defined as the temperature of the air at 2 m above the surface of the Earth. Surface water vapour density is calculated from: a) dewpoint temperature, which is defined as the temperature that the air, at 2 m above the surface of the Earth, would have to be cooled for saturation to occur, b) total surface pressure, and c) surface temperature.

– map files with “PSCH” in the title contain the values of surface total (barometric) pressure scale height, $psch$;

– map files with “TSCH” in the title contain the values of surface temperature scale height, $tsch$;

– map files with “VSCH” in the title contain the values of surface water vapour density and integrated water vapour content scale height, $vsch$;

– the map file Z_ground.TXT contains the values of the surface height above mean sea level, Z_{ground};

– the map file with “kV” in the title contains the values of the shape parameter, k_{V_s}, of the Weibull probability distribution of integrated water vapour content; and

– the map file with “lambdaV” in the title contains the values of the scale parameter, λ_{V_s}, of the Weibull probability distribution of integrated water vapour content.

TABLE 1

Map file characteristics

Parameter	**Value**
Format	ASCII
Upper left corner latitude	−90° N
Latitude increment	+0.25°
Upper left corner longitude	−180° E
Longitude increment	+0.25°
Number of rows	721
Number of columns	1 441
Column separator	Space
Row separator	Windows (CR LF)

TABLE 2

Annual surface total (barometric) pressure, surface temperature and surface water vapour density maps

Parameters		Annual pressure (hPa)	Annual temperature (K)	Annual water vapour density (g/m³)
Mean		P_mean.TXT	T_mean.TXT	RHO_mean.TXT
Standard deviation		P_std.TXT	T_std.TXT	RHO_std.TXT
Exceedance probability (CCDF)[3]	0.01%	P_001.TXT	T_001.TXT	RHO_001.TXT
	0.02%	P_002.TXT	T_002.TXT	RHO_002.TXT
	0.03%	P_003.TXT	T_003.TXT	RHO_003.TXT
	0.05%	P_005.TXT	T_005.TXT	RHO_005.TXT
	0.1%	P_01.TXT	T_01.TXT	RHO_01.TXT
	0.2%	P_02.TXT	T_02.TXT	RHO_02.TXT
	0.3%	P_03.TXT	T_03.TXT	RHO_03.TXT
	0.5%	P_05.TXT	T_05.TXT	RHO_05.TXT
	1%	P_1.TXT	T_1.TXT	RHO_1.TXT
	2%	P_2.TXT	T_2.TXT	RHO_2.TXT
	3%	P_3.TXT	T_3.TXT	RHO_3.TXT
	5%	P_5.TXT	T_5.TXT	RHO_5.TXT
	10%	P_10.TXT	T_10.TXT	RHO_10.TXT
	20%	P_20.TXT	T_20.TXT	RHO_20.TXT
	30%	P_30.TXT	T_30.TXT	RHO_30.TXT
	50%	P_50.TXT	T_50.TXT	RHO_50.TXT
	60%	P_60.TXT	T_60.TXT	RHO_60.TXT
	70%	P_70.TXT	T_70.TXT	RHO_70.TXT
	80%	P_80.TXT	T_80.TXT	RHO_80.TXT
	90%	P_90.TXT	T_90.TXT	RHO_90.TXT
	95%	P_95.TXT	T_95.TXT	RHO_95.TXT
	99%	P_99.TXT	T_99.TXT	RHO_99.TXT
Scale height		PSCH.TXT	TSCH.TXT	VSCH.TXT
Surface height		Z_ground.TXT		
File name		P_Annual.zip	T_Annual.zip	RHO_Annual.zip
Integral product file name		Annual: Part 1		

[3] The terms exceedance probability and complementary cumulative distribution function (CCDF) are synonymous.

TABLE 3

Monthly surface total (barometric) pressure, surface temperature, and surface water vapour density maps (XX: Jan = 01; Feb = 02; …; Nov = 11; Dec = 12)

Parameter		Monthly pressure (hPa)	Monthly temperature (K)	Monthly water vapour density (g/m^3)
Mean		P_mean.TXT	T_mean.TXT	RHO_mean.TXT
Standard deviation		P_std.TXT	T_std..TXT	RHO_std.TXT
Exceedance probability (CCDF)	0.1%	P_01.TXT	T_01.TXT	RHO_01.TXT
	0.2%	P_02.TXT	T_02.TXT	RHO_02.TXT
	0.3%	P_03.TXT	T_03.TXT	RHO_03.TXT
	0.5%	P_05.TXT	T_05.TXT	RHO_05.TXT
	1%	P_1.TXT	T_1.TXT	RHO_1.TXT
	2%	P_2.TXT	T_2.TXT	RHO_2.TXT
	3%	P_3.TXT	T_3.TXT	RHO_3.TXT
	5%	P_5.TXT	T_5.TXT	RHO_5.TXT
	10%	P_10.TXT	T_10.TXT	RHO_10.TXT
	20%	P_20.TXT	T_20.TXT	RHO_20.TXT
	30%	P_30.TXT	T_30.TXT	RHO_30.TXT
	50%	P_50.TXT	T_50.TXT	RHO_50.TXT
	60%	P_60.TXT	T_60.TXT	RHO_60.TXT
	70%	P_70.TXT	T_70.TXT	RHO_70.TXT
	80%	P_80.TXT	T_80.TXT	RHO_80.TXT
	90%	P_90.TXT	T_90.TXT	RHO_90.TXT
	95%	P_95.TXT	T_95.TXT	RHO_95.TXT
	99%	P_99.TXT	T_99.TXT	RHO_99.TXT
Scale height		PSCH.TXT	TSCH.TXT	VSCH.TXT
Surface height		Z_ground.TXT		
File name		P_MonthXX.zip	T_MonthXX.zip	RHO_MonthXX.zip
Integral product file name		Month01: Part 2 Month02: Part 3 Month03: Part 4 Month04: Part 5 Month05: Part 6 Month06: Part 7 Month07: Part 8 Month08: Part 9 Month09: Part 10 Month10: Part 11 Month11: Part 12 Month12: Part 13		

TABLE 4

Annual and monthly integrated water vapour content maps
(XX: Jan = 01; Feb = 02; …; Nov = 11; Dec = 12)

Parameter		Annual integrated water vapour content (kg/m^2 or mm)	Monthly integrated water vapour content (kg/m^2 or mm)
Mean		V_mean.TXT	V_mean.TXT
Standard deviation		V_std.TXT	V_std.TXT
Exceedance probability (CCDF)	0.01%	V_001.TXT	-
	0.02%	V_002.TXT	-
	0.03%	V_003.TXT	-
	0.05%	V_005.TXT	-
	0.1%	V_01.TXT	V_01.TXT
	0.2%	V_02.TXT	V_02.TXT
	0.3%	V_03.TXT	V_03.TXT
	0.5%	V_05.TXT	V_05.TXT
	1%	V_1.TXT	V_1.TXT
	2%	V_2.TXT	V_2.TXT
	3%	V_3.TXT	V_3.TXT
	5%	V_5.TXT	V_5.TXT
	10%	V_10.TXT	V_10.TXT
	20%	V_20.TXT	V_20.TXT
	30%	V_30.TXT	V_30.TXT
	50%	V_50.TXT	V_50.TXT
	60%	V_60.TXT	V_60.TXT
	70%	V_70.TXT	V_70.TXT
	80%	V_80.TXT	V_80.TXT
	90%	V_90.TXT	V_90.TXT
	95%	V_95.TXT	V_95.TXT
	99%	V_99.TXT	V_99.TXT
Scale height		VSCH.TXT	VSCH.TXT
Surface height		Z_ground.TXT	
File name		V_Annual.zip	V_MonthXX.zip
Integral product file name		Annual: Part 1	Month01: Part 2 Month02: Part 3 Month03: Part 4 Month04: Part 5 Month05: Part 6 Month06: Part 7 Month07: Part 8 Month08: Part 9 Month09: Part 10 Month10: Part 11 Month11: Part 12 Month12: Part 13

TABLE 5

Annual statistics of integrated water vapour content approximated by a Weibull distribution

Parameter	Annual Weibull approximation
Weibull scale	lambdaV.TXT
Weibull shape	kV.TXT
Scale height	VSCH.TXT
Surface height	Z_ground.TXT
File name	Weibull_Annual.zip
Integral product file name	Part 14

2 Interpolation

Section 2.1 provides the statistical and spatial interpolation method to calculate the annual and monthly pressure, temperature, water vapour density, and integrated water vapour content vs. exceedance probability (CCDF) at any desired location on the surface of the Earth.

Section 2.2 provides a statistical and spatial interpolation method to calculate the annual and monthly mean and standard deviation of pressure, temperature, water vapour density, integrated water vapour content, and Weibull integrated water vapour content shape and scale parameters at any desired location on the surface of the Earth.

2.1 Spatial and statistical (CCDF) interpolation

The annual or monthly surface total (barometric) pressure statistics, $P_s(p)$, surface temperature statistics, $T_s(p)$, surface water vapour density statistics, $\rho_s(p)$, or integrated water vapour content statistics, $V_s(p)$, at any desired location on the surface of the Earth and exceedance probability (CCDF), p, within the exceedance probability range of the integral digital maps can be calculated using the following interpolation method:

a) determine the height above mean sea level of the desired location, alt, from local data, or, if local data is not available, from Recommendation ITU-R P.1511;

b) determine the two exceedance probabilities, p_{above} and p_{below}, above and below the desired exceedance probability, p, from the set: 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% for annual statistics and from the set: 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% for monthly statistics;

c) for each of the four surrounding grid points, i = 1, 2, 3 and 4, and for the two exceedance probabilities, p_{above} and p_{below}, determine the desired parameter of interest, X_i', from the appropriate annual or monthly map of $P_s(p), T_s(p)$, $\rho_{w_s}(p)$, or V_s(p);

d) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine the applicable scale height, $psch_i$, $tsch_i$, or $vsch_i$, from the appropriate annual or monthly pressure, temperature, or water vapour scale height map;

e) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine the topographic height, alt_i, as the value of Z_{ground} at each grid point from the Z_ground map;

f) for each of the four surrounding grid points, i = 1, 2, 3 and 4, and for the two exceedance probabilities, p_{above} and p_{below}, determine X_i, at the desired height, alt, by scaling X_i', using the applicable relation:

$$X_i = X_i' \cdot e^{-\frac{(alt - alt_i)}{psch_i}}$$ for surface total (barometric) pressure, $P_s(p)$;

$$X_i = X_i' + tsch_i\ (alt - alt_i)$$ for surface temperature, $T_s(p)$;

$$X_i = X_i' \cdot e^{-\frac{(alt - alt_i)}{vsch_i}}$$ for surface water vapour density, $\rho_{w_s}(p)$; or

$$X_i = X_i' \cdot e^{-\frac{(alt - alt_i)}{vsch_i}}$$ for integrated water vapour content, $V_s(p)$;

g) determine X_{above} and X_{below} at the desired location and the two probabilities p_{above} and p_{below} by performing a bilinear interpolation of X_i, i = 1, 2, 3 and 4 at the four surrounding grid points using the bilinear interpolation method specified in Annex 1 of Recommendation ITU-R P.1144;

h) determine the parameter of interest, X, at the desired location and exceedance probability, p, by interpolating X_{above} and X_{below} vs. p_{above} and p_{below} to p on a linear X vs. $\log_{10} p$ scale, where $X = P_s(p)$, $T_s(p)$, $\rho_{w_s}(p)$, or $V_s(p)$.

2.2 Spatial and statistical (mean and standard deviation) interpolation

The monthly or annual mean or standard deviation of surface total (barometric) pressure, $\overline{P_s}$ or σ_{P_s}, mean or standard deviation of surface temperature, $\overline{T_s}$ or σ_{T_s}, mean or standard deviation of surface water vapour density, $\overline{\rho_{w_s}}$ or $\sigma_{\rho_{w_s}}$, mean or standard deviation of integrated water vapour content, $\overline{V_s}$ or σ_{V_s}, or Weibull integrated water vapour content shape or scale parameter, k_{V_s} or λ_{V_s}, at any desired location on the surface of the Earth can be calculated using the following interpolation method:

a) determine the height above mean sea level of the desired location, alt, from local data, or, if local data is not available, from Recommendation ITU-R P.1511;

b) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine the desired parameter of interest, X_i', from the appropriate annual or monthly map;

c) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine the applicable scale height, $psch_i$, $tsch_i$, or $vsch_i$, from the appropriate annual or monthly pressure, temperature, or water vapour scale height map;

d) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine the topographic height, alt_i, as the value of Z_{ground} at each grid point from the Z ground map;

e) for each of the four surrounding grid points, i = 1, 2, 3 and 4, determine X_i, at the desired height, alt, by scaling X_i', using the applicable relation:

$X_i = X_i' \cdot e^{-\frac{(alt-alt_i)}{psch_i}}$	for surface total (barometric) pressure, $\overline{P_s}$ or σ_{P_s};
$X_i = X_i' + tsch_i\,(alt - alt_i)$	for surface temperature, $\overline{T_s}$;
$X_i = X_i'$	for surface temperature, σ_{T_s};
$X_i = X_i' \cdot e^{-\frac{(alt-alt_i)}{vsch_i}}$	for surface water vapour density, $\overline{\rho_{w_s}}$ or $\sigma_{\rho_{w_s}}$;
$X_i = X_i' \cdot e^{-\frac{(alt-alt_i)}{vsch_i}}$	for integrated water vapour content, $\overline{V_s}$ or σ_{V_s};
$X_i = X_i' \cdot e^{-\frac{(alt-alt_i)}{vsch_i}}$	for the scale parameter, λ_{V_s}, of the Weibull probability distribution of integrated water vapour content; or
$X_i = X_i'$	for the shape parameter, k_{V_s}, of the Weibull probability distribution of integrated water vapour content;

f) determine the parameter of interest, X, at the desired location by performing a bilinear interpolation of X_i, i = 1, 2, 3, and 4 at the four surrounding grid points using the bilinear interpolation method specified in Annex 1 of Recommendation ITU-R P.1144, where $X = \overline{P_s}$ or σ_{P_s}, $\overline{T_s}$ or σ_{T_s}, $\overline{\rho_{w_s}}$ or $\sigma_{\rho_{w_s}}$, $\overline{V_s}$ or σ_{V_s}, λ_{V_s}, or k_{V_s} at the desired location.

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