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| **Recommendation ITU-R P.1144-10**  **(08/2019)** |
| **Guide to the application of the propagation methods of Radiocommunication  Study Group 3** |
| **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.

# Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU‑T/ITU‑R/ISO/IEC and the ITU-R patent information database can also be found.

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| --- | --- |
| Series of ITU-R Recommendations  (Also available online at <http://www.itu.int/publ/R-REC/en>) | |
| **Series** | Title |
| **BO** | Satellite delivery |
| **BR** | Recording for production, archival and play-out; film for television |
| **BS** | Broadcasting service (sound) |
| **BT** | Broadcasting service (television) |
| **F** | Fixed service |
| **M** | Mobile, radiodetermination, amateur and related satellite services |
| P | Radiowave propagation |
| **RA** | Radio astronomy |
| **RS** | Remote sensing systems |
| **S** | Fixed-satellite service |
| **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 |

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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.1144-10

Guide to the application of the propagation methods  
of Radiocommunication Study Group 3

(1995-1999-2001-2001-2007-2009-2012-2015-06/2017-12/2017-2019)

Scope

This Recommendation provides a guide to the Recommendations of Radiocommunication Study Group 3, which contain propagation prediction methods. It advises users on the most appropriate methods for particular applications as well as the limits, required input information, and output for each of these methods.

Keywords

Radiowave propagation, prediction methods, digital products, spatial interpolation, height reference system

The ITU Radiocommunication Assembly,

considering

that there is a need to assist users of the ITU-R Recommendations P Series (developed by Radiocommunication Study Group 3),

recommends

**1** that the information contained in Table 1 should be used for guidance on the application of the various propagation methods contained in the ITU-R Recommendations P Series (developed by Radiocommunication Study Group 3);

**2** that the information contained in Table 2 and Annex 1 should be used for guidance on the use of the various digital maps of geophysical parameters necessary for the application of the propagation methods in *recommends* 1above.

NOTE – For each of the ITU-R Recommendations in Table 1, there are associated information columns to indicate:

*Application*: the service(s) or application for which the Recommendation is intended.

*Type:* the situation to which the Recommendation applies, such as point-to-point, point‑to-area, line-of-sight, etc.

*Output*: the output parameter value produced by the method of the Recommendation, such as path loss.

*Frequency*: the applicable frequency range of the Recommendation.

*Distance*: the applicable distance range of the Recommendation.

% *time*: the applicable time percentage values or range of values of the Recommendation; % time is the percentage of time that the predicted signal is exceeded during an average year.

% *location*: the applicable per cent location range of the Recommendation; % location is the percentage of locations within, say, a square with 100 to 200 m sides that the predicted signal is exceeded.

*Terminal height*: the applicable terminal antenna height range of the Recommendation.

*Input data*: a list of parameters used by the method of the Recommendation; the list is ordered by the importance of the parameter and, in some instances, default values may be used.

The information, as shown in Table 1, is already provided in the Recommendations themselves; however, the Table allows users to quickly scan the capabilities (and limitations) of the Recommendations without the requirement to search through the text.

TABLE 1

ITU-R radiowave propagation prediction methods

| Method | Title | Application | Type | Output | Frequency | Distance | % time | % location | Terminal height | Input data |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rec. ITU-R P.368 | Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz | All services | Point-to-point | Field strength | 10 kHz to 30 MHz | 1 to 10 000 km | Not applicable | Not applicable | Ground-based | Frequency  Ground conductivity |
| Rec. ITU-R P.452 | Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz | Services employing stations on the surface of the Earth; interference | Point-to-point | Path loss | 100 MHz to 50 GHz | Not specified but up to and beyond the radio horizon | 0.001 to 50 Average year and worst month | Not applicable | No limits specified, within the surface layer of the atmosphere. (Not suitable for aeronautical applications) | Path profile data Frequency Percentage time Tx antenna height Rx antenna height Latitude and longitude of Tx Latitude and longitude of Rx Meteorological data  Polarization |
| Rec. ITU-R P.528 | Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands | Aeronautical mobile | Point-to-area | Path loss | 125 MHz to 15.5 GHz | 0 to 1 800 km (for aeronautical applications 0 km horizontal distance does not mean 0 km path length) | 1 to 99 | Not applicable | H1: Minimum of 1.5 m  H2: Minimum of 1.5 m | Distance Tx height Frequency Rx height Percentage time |
| Rec. ITU-R P.530 | Propagation data and prediction methods required for the design of terrestrial line-of-sight systems | Line-of-sight fixed links | Point-to-point line-of-sight | Path loss Diversity improvement (clear air conditions) XPD(2) Outage Error performance | Approximately 150 MHz to  100 GHz | Up to 200 km if line-of-sight | All percentages of time in clear‑air conditions; 1 to 0.001 in precipitation conditions(1)  And worst month for attenuation | Not applicable | High enough to ensure specified path clearance | Distance Tx height Frequency Rx height Percentage time Path obstruction data Climate data Terrain information |

TABLE 1 (*continued*)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Title | Application | Type | Output | Frequency | Distance | % time | % location | Terminal height | Input data |
| Rec. ITU-R P.533 | Method for the prediction of the performance of HF circuits | Broadcasting Fixed Mobile | Point-to-point | Basic MUF Sky‑wave field strength Available receiver power Signal-to-noise ratio LUF Circuit reliability | 2 to 30 MHz | 0 to 40 000 km | All percentages | Not applicable | Not applicable | Latitude and longitude of Tx Latitude and longitude of Rx Sunspot number Month Time(s) of day Frequencies Tx power Tx antenna type Rx antenna type |
| Rec. ITU-R P.534 | Method for calculating sporadic-E field strength | Fixed Mobile Broadcasting | Point-to-point via sporadic E | Field strength | 30 to 100 MHz | 0 to 4 000 km | 0.1 to 50 | Not applicable | Not applicable | Distance Frequency |
| Rec. ITU-R P.617 | Propagation prediction techniques and data required for the design of trans-horizon radio-relay systems | Trans‑horizon fixed links | Point-to-point | Path loss | 30 MHz | 100 to 1 000 km | 0.001 to 99.999 | Not applicable | No limits specified within the surface layer of the atmosphere. (Not suitable for aeronautical applications) | Frequency Tx antenna gain Rx antenna gain Path geometry |
| Rec. ITU-R P.618 | Propagation data and prediction methods required for the design of Earth-space telecommunication systems | Satellite | Point-to-point | Path loss Diversity gain and (for precipitation condition) XPD(2) | 1 to 55 GHz | Any practical orbit height | 0.001-5 for rain attenuation;  0.001-50 for total attenuation, 0.001-1 for XPD(2)  Also worst month for attenuation | Not applicable | No limit | Meteorological data Frequency Elevation angle Height of earth station Separation and angle between earth station sites (for diversity gain) Antenna diameter and efficiency (for scintillation) Polarization angle  (for XPD(2)) |
| Rec. ITU-R P.619 | Propagation Data Required for the Evaluation of Interference Between Stations in Space and those on the Surface of the Earth | Satellite | Point-to-point | Basic transmission loss for single-entry interference  Clear-air basic transmission loss for multiple-entry interference | 0.1 to 100 GHz | Any practical orbit height | 0.001 to 50 | Not applicable | No limit | Frequency Earth-station elevation angle Angular path separation Path length Gaseous attenuation Scintillation “gain” Maximum allowed attenuation of the wanted signal |

TABLE 1 (*continued*)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Title | Application | Type | Output | Frequency | Distance | % time | % location | Terminal height | Input data | |
| Rec. ITU-R P.620 | Propagation data required for the evaluation of coordination distances in the frequency range 100 MHz to 105 GHz | Earth station frequency coordination | Coordination distance | Distance of which the required propagation loss is achieved | 100 MHz to 105 GHz | Up to 1 200 km | 0.001 to 50 | Not applicable | No limits specified within the surface layer of the atmosphere. (Not suitable for aeronautical applications) | Minimum basic transmission loss Frequency Percentage of time Earth-station elevation angle | |
| Rec. ITU-R P.678 | Characterization of the variability of propagation phenomena and estimation of the risk associated with propagation margin | Rain rate models Satellite | Point-to-point | Variability of propagation phenomena | 12 to 50 GHz | Any practical orbit height | 0.01-2 for rainfall rate and rain attenuation along slant paths | Not applicable | No limit | Probability of exceedance |
| Rec. ITU-R P.679 | Propagation data required for the design of broadcasting-satellite systems | Broadcast satellite | Point-to-area | Path loss Effect of local environment | 0.5 to 5.1 GHz | Any practical orbit height | Not applicable | No limits specified | No limits specified | Frequency Elevation angle Features of local environment |
| Rec. ITU-R P.680 | Propagation data required for the design of Earth-space maritime mobile telecommunication systems | Maritime mobile satellite | Point-to-point | Sea-surface fading Fade duration Interference (adjacent satellite) | 0.8-8 GHz | Any practical orbit height | To 0.001% via Rice-Nakagami distribution Limit of 0.01% for interference(1) | Not applicable | No limit | Frequency Elevation angle Maximum antenna boresight gain |
| Rec. ITU-R P.681 | Propagation data required for the design of Earth-space land mobile telecommunication systems | Land mobile satellite | Point-to-point | Path fading Fade duration Non-fade duration | 0.8 to 20 GHz | Any practical orbit height | Not applicable Percentage of distance travelled 1 to 80%(1) | Not applicable | No limit | Frequency Elevation angle Percentage of distance travelled Approximate level of optical shadowing |
| Rec. ITU-R P.682 | Propagation data required for the design of Earth-space aeronautical mobile telecommunication systems | Aeronautical mobile satellite | Point-to-point | Sea‑surface fading Multipath from ground and aircraft during landing | 1 to 2 GHz (sea-surface fading)  1 to 3 GHz (multipath from ground) | Any practical orbit height | To 0.001% via Rice-Nakagami distribution(1) | Not applicable | No limit for sea-surface fading  Up to 1 km for ground reflection during landing | Frequency Elevation angle Polarization Maximum antenna boresight gain Antenna height |

TABLE 1 (*continued*)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Title | Application | Type | Output | Frequency | Distance | % time | % location | Terminal height | Input data |
| Rec. ITU-R P.684 | Prediction of field strength at frequencies below about 150 kHz | Fixed Mobile | Point-to-point  Point-to-area | Sky‑wave field strength | 30 to 150 kHz | 0 to 16 000 km | 50 | Not applicable | Not applicable | Latitude and longitude of Tx Latitude and longitude of Rx Distance Tx power Frequency Ground constants Season Sunspot number Hour of day |
| Rec. ITU-R P.843 | Communication by meteor-burst propagation | Fixed Mobile Broadcasting | Point-to-point via meteor‑burst | Received power Burst rate | 30 to 100 MHz | 100 to 1 000 km | 0 to 5 | Not applicable | Not applicable | Frequency Distance Tx power Antenna gains |
| Rec. ITU-R P.1147 | Prediction of sky-wave field strength at frequencies between about  150 and  1 700 kHz | Broadcasting | Point-to-area | Sky-wave field strength | 0.15 to 1.7 MHz | 50 to 12 000 km | 1, 10, 50 | Not applicable | Not applicable | Latitude and longitude of Tx Latitude and longitude of Rx Distance Sunspot number Tx power Frequency |
| Rec. ITU-R P.1238 | Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz | Mobile RLAN | In‑building propagation methods | Path loss Delay spread | 300 MHz to  450 GHz | Within buildings | Not applicable | Not applicable | Base: about 2-3 m Mobile: about 0.5‑3 m | Frequency Distance Floor and wall factors |
| Rec. ITU-R P.1410 | Propagation data and prediction methods required for the design of terrestrial broadband radio access systems operating in a frequency range from 3 to 60 GHz | Broadband radio access | Point-to-area | Coverage Temporal coverage reduction due to rain | 3 to 60 GHz | 0-5 km | 0.001 to 1 (for calculating reduction in coverage due to rain) | Up to 100 | No limit; 0-300 m (typical) | Frequency Cell size Terminal heights Building height statistical parameters |

TABLE 1 (*continued*)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Title | Application | Type | Output | Frequency | Distance | | % time | % location | Terminal height | | Input data |
| Rec. ITU-R P.1411 | Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz | Mobile | Short-path propagation methods | Path loss Delay spread | 300 MHz to 100 GHz | < 1 km | | Not applicable | Not applicable | Base: about 4-50 m Mobile: about 0.5‑3 m | | Frequency Distance Street dimensions Structure heights |
| Rec. ITU-R P.1546 | Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz | Terrestrial services | Point-to-area | Field strength | 30 to 4 000 MHz | 1 to 1 000 km | | 1 to 50 | 1 to 99 | *Tx/base:* effective height from less than 0 m to 3 000 m *Rx/mobile:*   m | | Terrain height and ground cover (optional) Path classification Distance Tx antenna height Frequency Percentage time Rx antenna height Terrain clearance angle Percentage locations Refractivity gradient |
| Rec. ITU-R P.1622 | Prediction methods required for the design of Earth-space systems operating between 20 THz and 375 THz | Satellite optical links | Point-to-point | Absorption loss Scattering loss Background noise Amplitude scintillation Angle of arrival Beam wander Beam spreading | 20 to 375 THz | | Far-field Earth-to-space optical links | Not applicable | Not applicable | No limit | Wavelength Terminal height Elevation angle Turbulence structure parameter | |
| Rec. ITU-R P.1623 | Prediction method of fade dynamics on Earth-space paths | Satellite | Point-to-point | Fade duration, fade slope | 10 to 50 GHz | | Any practical orbit height | Not applicable | Not applicable | No limit | Frequency Elevation angle Attenuation threshold Filter bandwidth | |
| Rec. ITU-R P.1812 | A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands | Terrestrial services | Point-to-area | Field strength | 30 MHz to 3 000 MHz | | Not specified but up to and beyond the radio horizon | 1 to 50 | 1 to 99 | No limits specified, within the surface layer of the atmosphere. (Not suitable for aeronautical applications) | Path profile data Frequency Percentage time Tx antenna height Rx antenna height Latitude and longitude of Tx Latitude and longitude of Rx Meteorological data  Polarization | |

TABLE 1 (*end*)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Title | Application | Type | Output | Frequency | Distance | % time | % location | Terminal height | Input data |
| Rec. ITU-R P.1814 | Prediction methods required for the design of terrestrial free-space optical links | Terrestrial optical links | Point-to-point | Absorption loss Scattering loss Background noise Amplitude scintillation Beam spreading | 20 to 375 THz | No limit | Not applicable | Not applicable | No limit | Wavelength Visibility (in fog) Path length  Turbulence structure parameter |
| Rec. ITU-R P.1853 | Tropospheric attenuation time series synthesis | Terrestrial  satellite | Point-to-point | Rain attenuation for terrestrial paths  Total attenuation and tropospheric scintillation for Earth-space paths | 4 to 40 GHz for terrestrial paths  4 to 55 GHz for Earth-space paths | Between 2 and 60 km for terrestrial paths  GEO satellite | Not applicable | Not applicable | No limit | Meteorological data Frequency Elevation angle Height of earth station Separation and angle between earth station sites (for diversity gain) Antenna diameter and efficiency (for scintillation) |
| Rec. ITU-R P.2001 | A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to  50 GHz | Terrestrial services | Point-to-point | Path loss | 30 MHz to 50 GHz | 3 to 1 000 km | 0.001 to 99.999 | Not applicable | <8000 m above m.s.l. but near the ground, within the troposphere | Path profile data Frequency Percentage time Tx antenna height, gain and azimuthal direction Rx antenna height, gain and azimuthal direction Latitude and longitude of Tx Latitude and longitude of Rx Polarization |
| Rec. ITU-R P.2041 | Prediction of path attenuation on links between an airborne platform and Space and between an airborne platform and the surface of the Earth | Airborne | Point-to-point | Path loss | 1 to 55 GHz | Any height | 0.001 to 50 | Not applicable | Between the surface of the Earth and space | Meteorological data Frequency Elevation angle  Availability Height of airborne platform Antenna diameter and efficiency (for scintillation) |
| (1) Time percentage of outage; for service availability, subtract value from 100.  (2) XPD: Cross-polarization discrimination. | | | | | | | | | | |

TABLE 2

ITU-R digital products for radiowave propagation predictions methods

| Recommendation ITU-R | Description | Grid resolution | Spatial interpolation required (see Annex 1) | Interpolation in probability | Interpolation of the variable | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| P.452 | Median annual Δ*N*  Median annual *N*0 | 1.5° × 1.5° | Bi-linear | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.453 | Annual and monthly probability distributions of the wet term of the refractivity at the surface (Nwet) | 0.75° × 0.75° | Bi-linear | Logarithmic | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| • Refractivity gradient in the lowest  65 m of the atmosphere (N-units/km)  • Refractivity gradient in the lowest 1 km of the atmosphere (N-units/km)  • Percentage of time for which refractivity gradient in the lowest 100 m < −100 N-unit/km | 0.75° × 0.75° | Bi-linear | Not defined | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| Surface duct data | 1.5° × 1.5° | Bi-linear | Not defined | Not applicable | Refer to the Software for ionospheric and tropospheric propagation and radio noise web page |
| Elevated duct data | 1.5° × 1.5° | Bi-linear | Not defined | Not applicable | Refer to the Software for ionospheric and tropospheric propagation and radio noise web page |
|  |  |  |  |  |  |
| P.617 | Median annual Δ*N*  Median annual *N*0 | 1.5° × 1.5° | Bi-linear | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.678 | Map of the climatic ratio | 0.5° × 0.5° | Bi-linear | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.834 | • Harmonic coefficients of excess path length along Earth-space paths  • Harmonic coefficients of the hydrostatic and wet mapping functions | 1.5° × 1.5°  5° × 5° | Bi-linear  Not Required | Not defined | Not applicable | Refer to the associated Readme file for the applicable file names(2) |

TABLE 2 (*continued*)

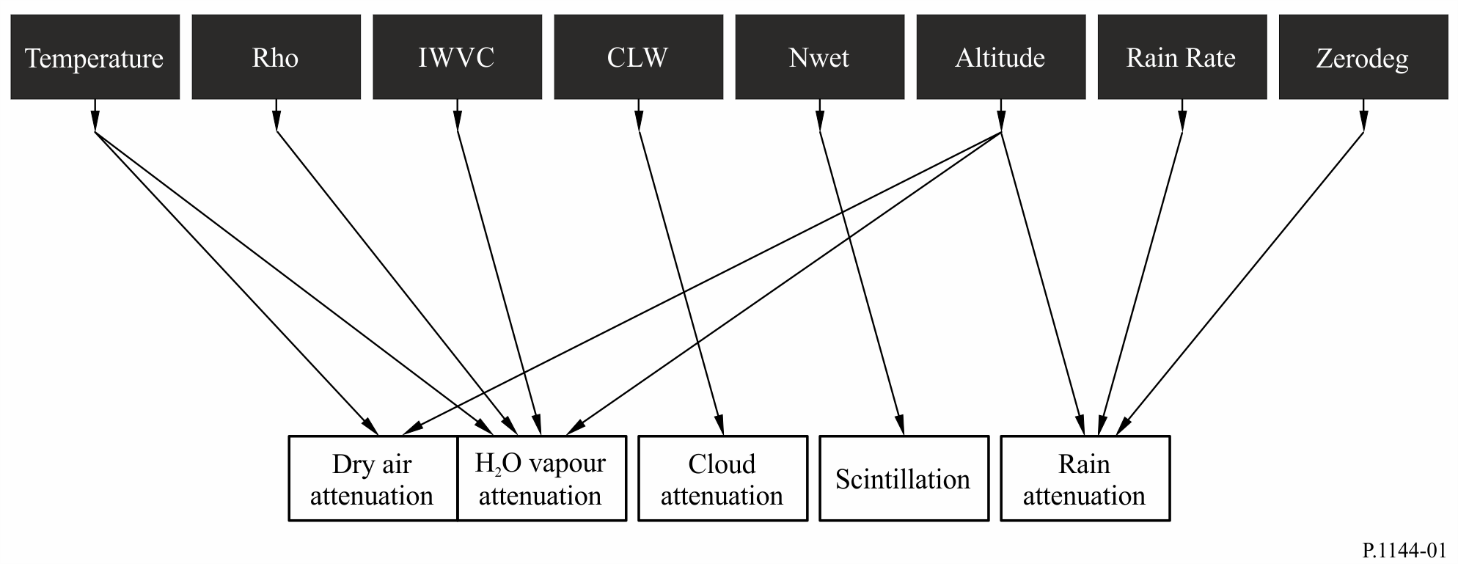
| Recommendation ITU-R | Description | Grid resolution | Spatial interpolation required (see Annex 1) | Interpolation in probability | Interpolation of the variable | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| P.835 | Experimental Data of Atmospheric Vertical Profiles (Annex 2) | 353 Locations | Not required | Not applicable | Not applicable | Refer to the Software for ionospheric and tropospheric propagation and radio noise web page |
| Weather Prediction Data of Atmospheric Vertical Profiles (Annex 3) | 1.5° × 1.5° | Not specified | Not applicable | Not applicable | Refer to the Software for ionospheric and tropospheric propagation and radio noise web page |
| P.836 | Total columnar water vapour exceedance probability (%) (IWVC) | 1.125° × 1.125° | Bi-linear(1) | Logarithmic | Linear | Refer to the associated Readme file for the applicable file names(2) |
| Surface water vapour density exceedance probability (%) (Rho) | 1.125° × 1.125° | Bi-linear(1) | Logarithmic | Linear | Refer to the associated Readme file for the applicable file names(2) |
| Water vapour scale height | 1.125° × 1.125° | Bi-linear(1) | Logarithmic | Linear | Refer to the associated Readme file for the applicable file names(2) |
| Topographic altitude (a.m.s.l.) (km) | 0.5° × 0.5° | Bi-cubic | Not applicable | Not applicable | Refer to the recommendation |
| P.837 | Monthly mean total rainfall (mm) R0.01 (mm/h) | 0.25° × 0.25°  0.125° × 0.125° | Bi-linear  Bi-linear | Not applicable  Not applicable | Not applicable  Not applicable | Refer to the associated readme file for the applicable filenames(2) |
| Conversion of rain rate statistics at different integration times (Annex 2) | Not applicable | Not required | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.839 | Mean annual 0°C isotherm height (km) | 1.5° × 1.5° | Bi-linear | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.840 | Annual statistics of columnar reduced cloud liquid water content  Monthly statistics of columnar reduced cloud liquid water content  Approximation of reduced cloud liquid water content by a log-normal distribution | 1.125° × 1.125° | Bi-linear | Logarithmic | Linear | Refer to the associated Readme file for the applicable file names(2) |
| P.1510 | Mean monthly and annual surface temperature | 0.75° × 0.75° | Bi-linear | Not applicable | Not applicable | Refer to the associated readme file for the applicable filenames(2) |

TABLE 2 (*end*)

| Recommendation ITU-R | Description | Grid resolution | Spatial interpolation required (see Annex 1) | Interpolation in probability | Interpolation of the variable | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| P.1511 | Topographic altitude (a.m.s.l.) (m) | 0.08333° × 0.08333° | Bi-cubic | Not applicable | Not applicable | This Recommendation contains definitions of latitude, longitude, and height in P-Series Recommendations. Refer to the associated Readme file for the applicable file names(2) |
| Earth gravitational model 2008 (EGM2008) (m) | 0.08333° × 0.08333° | Bi-cubic | Not applicable | Not applicable | Refer to the associated readme file for the applicable filenames(2) |
| P.1812 | Median annual Δ*N*  Median annual *N*0 | 1.5° × 1.5° | Bi-linear | Not applicable | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| P.2001 | Surface level refractivity and gradient in the lowest 1 km of the atmosphere | Multiple | Bi-linear | Not applicable | Linear | Refer to the associated Readme file for the applicable file names(2) |
| P.2001 and P.534 | Critical frequency for sporadic-*E* (*F*0*Es*) | 1.5° × 1.5° | Bi-linear | Linear | Linear | FoEs50.txt FoEs10.txt FoEs01.txt FoEs0.1.txt |
| (1) The variables at the surrounding grid points are scaled to the desired altitude prior to spatial interpolation per the scaling procedure in the Recommendation.  (2) The readme file is contained within the Zip (Components) file on the web page associated with the Recommendation. | | | | | | |

For easy reference, Fig. 1 shows the relationship between the geophysical maps (black boxes) and propagation effects (white boxes).

figure 1



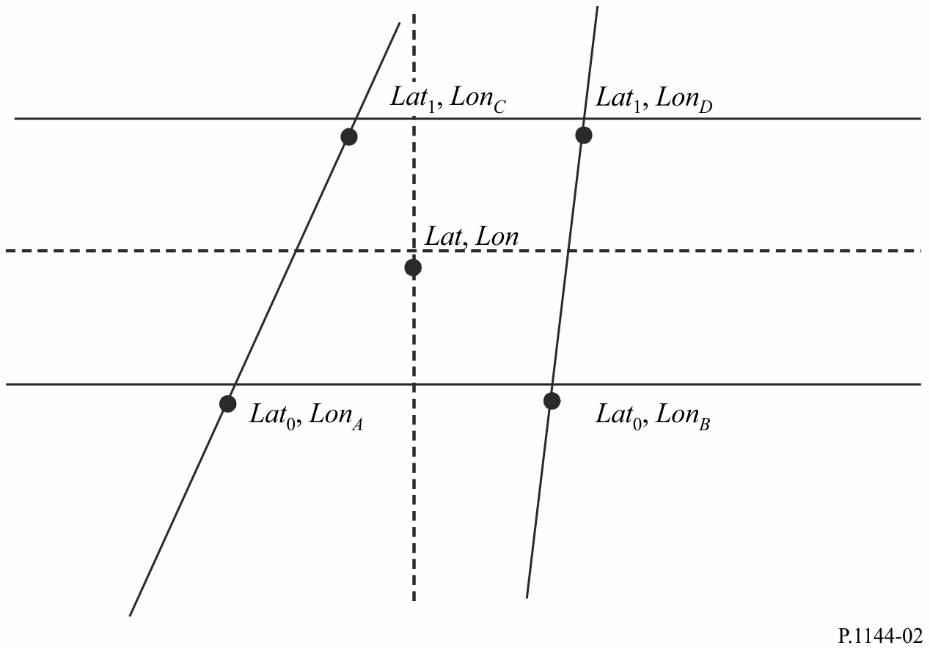
Annex 1

# 1a Bi-linear interpolation on a trapezoidal grid

Given: Values of *X* at four surrounding points:, , , and ; i.e. , , , and .

*Problem*:Determine the value at an intervening point using bi-linear interpolation.

Figure 2

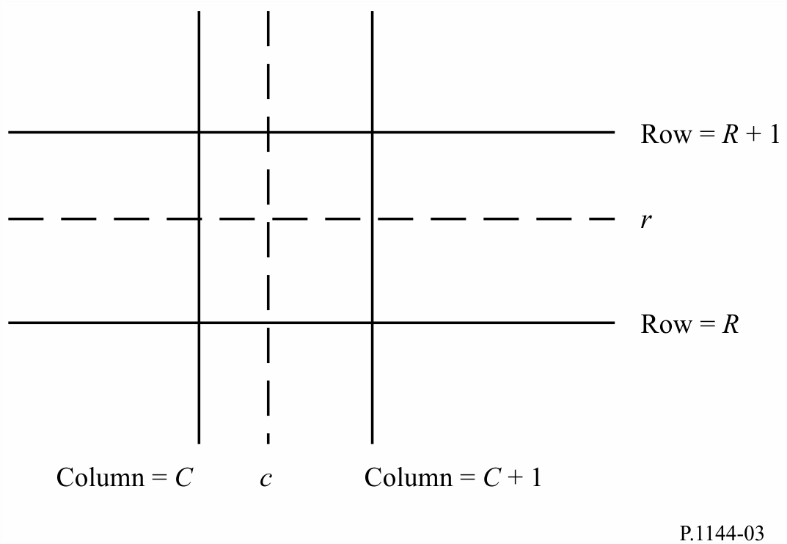


*Solution*: Define two auxiliary variables, and :

and calculate:

# 1b Bi-linear interpolation on a square grid

figure 3



*Given*: Values of *I* at four surrounding grid points: *I*(*R*,*C*), *I*(*R*,*C*1), *I*(*R*1,*C*),and *I*(*R*1,*C*1), where *R*, *R*+ 1, *C*, and *C*+ 1 are integer row and column numbers.

*Problem*:Determine *I*(*r,c*), where *r* is a fractional row number between *R* and *R*+ 1 and *c* is a fractional column number between *C* and *C*+ 1, using bi-linear interpolation.

*Solution*: Calculate:

*I*(*r,c*) *I*(*R*,*C*)[(*R*1–*r*)(*C*1–*c*)]

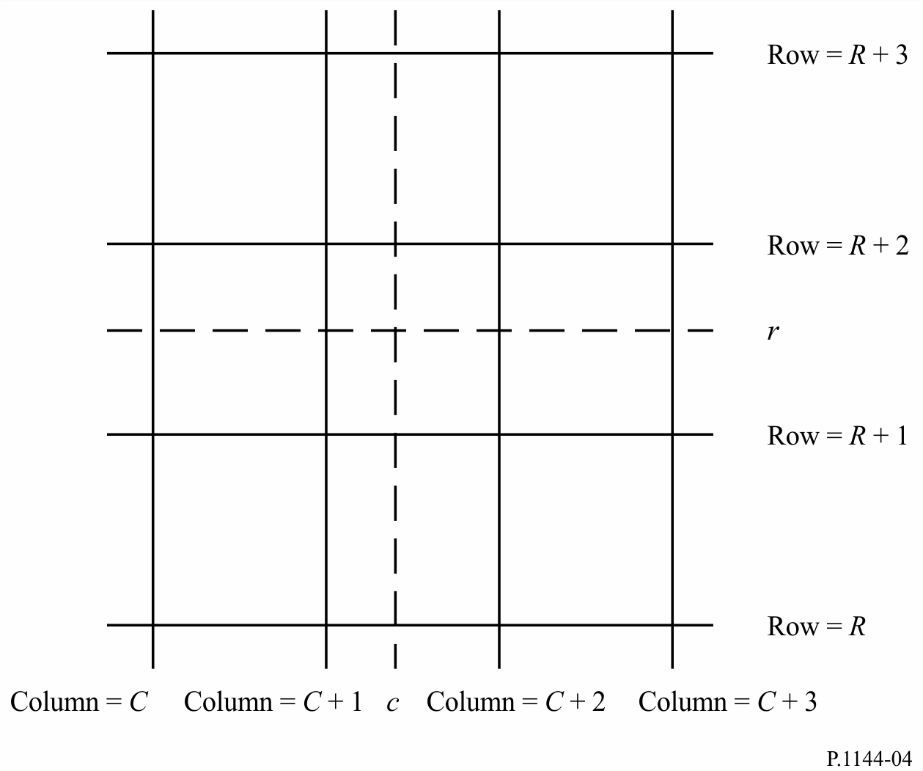
*I*(*R*1*,C)* [(*r*–*R*)(*C*1*– c*)]

 *I*(*R*,*C**1*)[(*R*1*– r*)(*c*–*C*)]

*I*(*R* 1,*C**1*) [(*r – R*)(*c*–*C*)]

# 2 Bi-cubic interpolation

figure 4



*Given*:Values of *I* at 16 surrounding grid points:

*I*(*R*,*C*), *I*(*R*,*C*1), *I*(*R*,*C*2), *I*(*R*,*C*3),

*I*(*R* 1,*C*), *I*(*R* 1,*C*1), *I*(*R* 1,*C*2), *I*(*R*1,*C*3),

*I*(*R*2,*C*), *I*(*R*2,*C*1), *I*(*R*2,*C*2), *I*(*R*2,*C*3),

*I(R*3,*C*), *I*(*R**C* 1), *I*(*R*3,*C* 2), *I*(*R*3,*C*3)

where *R*, *R*+ 1, etc.; and *C*, *C*+ 1, etc. are integers*.*

*Problem*: Calculate *I*(*r*,*c*), where *r* is a fractional row number between *R*+ 1 and *R*+ 2 and *c* is a fractional column number between *C*+ 1 and *C*+ 2, using bi-cubic interpolation.

*Solution*:

*Step 1*: For each row, *X*, where *X*  {*R*, *R*  1, *R*  2, *R*  3}, compute the interpolated value at the desired fractional column *c* as:



where:



and

*a*  –0.5

*Step 2*: Calculate *I*(*r*,*c*) by interpolating the one-dimensional interpolations, *RI*(*R*,*c*), *RI*(*R*1,*c*), *RI*(*R*2,*c*), and *RI*(*R*3,*c*) in the same manner as the row interpolations.

# 3 Gaussian quadrature integration

Gaussian quadrature integration is an accurate approximation to a definite integral if the integrand, *f*(*x*), is well-approximated by a polynomial of degree 2*n*-1 or less over the integration interval. The value of should be selected based on the desired accuracy.

The values of , the Gaussian quadrature points, and the Gaussian quadrature weights, are an integral part of this Recommendation and are provided in the GaussQuadrature\_n.txt files where n = 16, 32, 64, 128, and 256 within the supplement file [R-REC-P.1144-10-201908-I!!ZIP-E.zip](https://www.itu.int/rec/R-REC-P.1144-10-201908-I/en).

## 3.1 Single integral

A single integral can be well-approximated by Gaussian quadrature integration noting that:

where:

## 3.2 Double integral

A double integral can be well-approximated by Gaussian quadrature integration noting that:

where: