Recommendation ITU-R P.1144-12

(08/2023)

P Series: Radiowave propagation

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

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.

|  |
| --- |
| Series of ITU-R Recommendations (Also available online at <https://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.1144-12

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

(1995-1999-2001-2001-2007-2009-2012-2015-06/2017-12/2017-2019-2021-2023)

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

**Glossary**

|  |  |
| --- | --- |
| **Symbol** | **Description** |
| n | number of Gaussian quadrature points (nodes) |
|  | Gaussian quadrature weights |
|   | Gaussian quadrature points |

Other symbols not listed in the table above are intermediate in nature and have no definition.

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 considered 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 considered 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 basic transmission 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 | Basic transmission loss | 100 MHz to 50 GHz | Not specified but up to and beyond the radio horizon | 0.001 to 50Average year and worst month | Not applicable | No limits specified, within the surface layer of the atmosphere.(Not suitable for aeronautical applications) | Path profile dataFrequencyPercentage timeTx antenna heightRx antenna heightLatitude and longitude of TxLatitude and longitude of Rx Meteorological dataPolarization |
| Rec. ITU-R P.528 | Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands  | Aeronauticalmobile | Point-to-area | Basic transmission loss | 100 MHz to 30 GHz | Not specified but up to and beyond the radio horizonFor aeronautical applications 0 km great circle distance does not mean 0 km path length. | 1 to 99 | Not applicable | Terminal heights: 1.5 - 20 000 m | DistanceTx heightFrequencyRx heightPercentage timePolarization |
| 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 | Propagation lossDiversity improvement (clear air conditions)XPD(2)OutageError performance | Approximately150 MHz to 100 GHz | Up to 200 km if line-of-sight | All percentages of time in clear‑air conditions;1 to 0.001 inprecipitation conditionsAnd worst month for attenuation | Not applicable | High enough to ensure specified path clearance | DistanceTx heightFrequencyRx heightPercentage timePath obstruction dataClimate dataTerrain 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 FixedMobile | Point-to-point | Basic MUF Sky‑wave field strengthAvailable receiver powerSignal-to-noise ratioLUFCircuit reliability | 2 to 30 MHz | 0 to 40 000 km | All percentages | Not applicable | Not applicable | Latitude and longitude of TxLatitude and longitude of RxSunspot numberMonthTime(s) of dayFrequenciesTx powerTx antenna typeRx antenna type |
| Rec. ITU-R P.534 | Method for calculating sporadic-E field strength | FixedMobile Broadcasting | Point-to-pointvia sporadic E | Field strength | 30 to 100 MHz | 0 to 4 000 km | 0.1 to 50 | Not applicable | Not applicable | DistanceFrequency |
| 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 | Basic transmission 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) | FrequencyTx antenna gainRx antenna gainPath geometry |
| Rec. ITU-R P.618 | Propagation data and prediction methods required for the design of Earth-space telecommunication systems  | Satellite | Point-to-point | Propagation lossDiversity 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 dataFrequencyElevation angleHeight of earth stationSeparation 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 interferenceClear-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 | FrequencyEarth-station elevation angleAngular path separationPath lengthGaseous attenuationScintillation “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 lossFrequencyPercentage of timeEarth-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 modelsSatellite | 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 | Excess basic transmission lossEffect of local environment | 0.5 to 5.1 GHz | Any practical orbit height | Not applicable | No limits specified | No limits specified | FrequencyElevation angleFeatures 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 fadingFade duration Interference (adjacent satellite) | 0.8-8 GHz | Any practical orbit height | To 0.001% via Rice-Nakagami distributionLimit of 0.01% for interference(1) | Not applicable | No limit | FrequencyElevation angleMaximum 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 fadingFade durationNon-fade duration | 0.8 to 20 GHz | Any practical orbit height | Not applicablePercentage of distance travelled 1 to 80%(1) | Not applicable | No limit | FrequencyElevation anglePercentage of distance travelledApproximate 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 fadingMultipath 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 fadingUp to 1 km for ground reflection during landing | FrequencyElevation anglePolarizationMaximum antenna boresight gainAntenna 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 | FixedMobile | 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 TxLatitude and longitude of RxDistanceTx powerFrequencyGround constantsSeasonSunspot numberHour of day |
| Rec. ITU-R P.843 | Communication by meteor-burst propagation | FixedMobile Broadcasting | Point-to-point via meteor‑burst | Received powerBurst rate | 30 to 100 MHz | 100 to 1 000 km | 0 to 5 | Not applicable | Not applicable | FrequencyDistanceTx powerAntenna 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 TxLatitude and longitude of RxDistanceSunspot numberTx powerFrequency |
| 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  | MobileRLAN | In‑building propagation methods | Basic transmission lossDelay spread | 300 MHz to 450 GHz | Within buildings | Not applicable | Not applicable | Base: about 2-3 mMobile: about 0.5‑3 m | FrequencyDistanceFloor 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 | CoverageTemporal 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) | FrequencyCell sizeTerminal heightsBuilding 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 | Basic transmission lossDelay spread | 300 MHz to 100 GHz | < 1 km | Not applicable | Not applicable | Base: about 4-50 mMobile: about 0.5‑3 m | FrequencyDistanceStreet dimensionsStructure heights |
| Rec. ITU-R P.1546 | Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 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 classificationDistanceTx antenna heightFrequencyPercentage timeRx antenna heightTerrain clearance anglePercentage locationsRefractivity 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 lossScattering lossBackground noiseAmplitude scintillationAngle of arrivalBeam wanderBeam spreading | 20 to 375 THz | Far-field Earth-to-space optical links | Not applicable | Not applicable | No limit | WavelengthTerminal heightElevation angleTurbulence 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 | FrequencyElevation angleAttenuation thresholdFilter bandwidth |
| Rec. ITU-R P.1812 | A path-specific propagation prediction method for point-to-area terrestrial services in the frequency range 30 MHz to 6 000 MHz | Terrestrial services | Point-to-area | Field strength | 30 MHz to 6 000 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 dataFrequencyPercentage timeTx antenna heightRx antenna heightLatitude and longitude of TxLatitude and longitude of Rx Meteorological dataPolarization |

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 lossScattering lossBackground noiseAmplitude scintillationBeam spreading | 20 to 375 THz | No limit | Not applicable | Not applicable | No limit | WavelengthVisibility (in fog)Path length Turbulence structure parameter |
| Rec. ITU-R P.1853 | Tropospheric attenuation time series synthesis | Terrestrialsatellite | Point-to-point | Rain attenuation for terrestrial pathsTotal attenuation and tropospheric scintillation for Earth-space paths | 4 to 40 GHz for terrestrial paths4 to 55 GHz for Earth-space paths | Between 2 and 60 km for terrestrial pathsGEO satellite | Not applicable | Not applicable | No limit | Meteorological dataFrequencyElevation angleHeight of earth stationSeparation 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 | Basic transmission 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 dataFrequencyPercentage timeTx antenna height, gain and azimuthal directionRx antenna height, gain and azimuthal directionLatitude and longitude of TxLatitude and longitude of RxPolarization |
| 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 | Total attenuation | 1 to 55 GHz | Any height | 0.001 to 50 | Not applicable | Between the surface of the Earth and space | Meteorological dataFrequencyElevation angleAvailabilityHeight of airborne platformAntenna 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.530 | *LogK* logarithm of *K*%, the geoclimatic factor for the average worst month | 0.25 × 0.25 | Bi-linear | Not defined | Linear | See the Recommendation for the application and use of these data sets. |
| *dN*75 empirical prediction of 0.1% of the average worst month refractivity increase with height over the lowest 75 m of the atmosphere | 0.25 × 0.25 | Bi-linear | Not defined | Linear | See the Recommendation for the application and use of these data sets. |
| P.534 | foEs exceeded for annual percentage times | 1.5° × 1.5° | Bi-linear | Linear | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| 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) |

TABLE 2 (*continued*)

| Recommendation ITU-R | Description | Grid resolution | Spatial interpolation required (see Annex 1) | Interpolation in probability | Interpolation of the variable | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| 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-linearNot Required | Not defined | Not applicable | Refer to the associated Readme file for the applicable file names(2) |
| 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-linearBi-linear | Not applicableNot applicable | Not applicableNot 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 and monthly statistics (mean, standard deviation and CCDF) statistics of integrated cloud liquid water contentApproximation of annual integrated cloud liquid water content by a log-normal distribution | 0.25° × 0.25° | Bi-linear | Logarithmic | Linear | 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.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) |
| 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.1853 | Annual mean surface pressureAnnual mean water vapour density | 0.75° × 0.75° | Bi-linear | Not applicable | Not applicable | WV\_Annual.txtP\_Annual.txt |
| 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.txtFoEs10.txtFoEs01.txtFoEs0.1.txt |
| P.2145 | Annual and monthly statistics (mean, standard deviation and CCDF) of surface pressureAnnual and monthly statistics (mean, standard deviation and CCDF) of surface temperatureAnnual and monthly statistics (mean, standard deviation and CCDF) of surface water vapour densityAnnual and monthly statistics (mean, standard deviation and CCDF) of integrated water vapour contentApproximation of annual integrated water vapour content by a Weibull distribution | 0.25° × 0.25° | Bi-linear | Logarithmic | Linear | Refer to the Recommendation |

TABLE 2 (*end*)

| Recommendation ITU-R | Description | Grid resolution | Spatial interpolation required (see Annex 1) | Interpolation in probability | Interpolation of the variable | Comments |
| --- | --- | --- | --- | --- | --- | --- |
| P.2148 | Annual statistics of wind speed at a height of 10 m above the surface of the Earth | 0.25° × 0.25° | Bi-linear | Logarithmic | Linear | Refer to the Recommendation |
| (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 accurately approximate 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 approximation accuracy.

## 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:

## 3.3 Algorithm to calculate Gaussian quadrature points (nodes) and weights

This algorithm calculates the points (nodes), , and weights, , for , where is the number of Gaussian quadrature points (nodes). The variable is the accuracy of the machine’s floating-point system[[1]](#footnote-1). On machines that support IEEE floating point arithmetic,  is approximately 2.2204e-16 for double precision. The function rounds x to the nearest integer less than or equal to

Step 1: Calculate

Repeat Steps 2 to 13 for to

Step 2: Calculate

Step 3: Calculate and

Repeat Steps 4 and 5 for

Step 4: Calculate and

Step 5: Calculate

Step 6: Calculate

Step 7: Calculate

Step 8: Calculate

Step 9: If then go to Step 3, otherwise go to Step 10

Step 10: Calculate

Step 11: Calculate

Step 12: Calculate

Step 13: Calculate

Repeat Step 14 for to

Step 14: Calculate and

1. Example values of $X\_{i}$, the Gaussian quadrature points, and $W\_{i}$, the Gaussian quadrature weights, are provided in a supplemental product on the ITU-R Study Group 3 website on digital products. [↑](#footnote-ref-1)