# ITU WORKSHOP

# Activities of ITU-R Study Group 3 on radiowave propagation

## Working Party 3J – Propagation Fundamentals

**EuCAP 2024, Glasgow**

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# WP 3J – Propagation Fundamentals

- Scope and Motivation
- Organization of Work
- Main Results
  - Questions
  - Recommendations
  - Radiometeorology Handbook
- Critical points and future needs

# WP 3J - Propagation fundamentals

Provides information and develops models describing the fundamental principles and mechanisms of radiowave propagation in non-ionized media

# Radiowave propagation

- Radiowaves have been used to carry information from a source to a destination (or multiple destinations) for over a century
- The importance of radio communications has never been as evident as today, with globalization a fact of life and real time access to information a necessity to society and industry

**Coverage and capacity**

# The importance of propagation studies

- The effects of the propagation medium on the wave are almost always impairing, nothing can be done, in terms of engineering, to improve this
- The propagation medium is immune to engineering
- The complex nature of the propagation environment makes fully deterministic models of radiowave propagation impossible or, at best, impractical
- Only basic physical (usually idealized) models combined with empirical or semi-empirical formulations are available to the system designer

# Link budget for radiocommunication systems

The link budget for radio communication links accounts for the contribution of various gain and loss sources and ultimately relates the received power to the transmitted power

The core of the link budget is the free space loss **function of frequency and path length -** Recommendation ITU-R P.341-7 "The concept of transmission loss for radio links"

# Clear air effects

- Refraction resulting in ray bending such that the radio horizon may change
- Troposcatter from localized fluctuations in the atmospheric refractive index, which can scatter electromagnetic waves
  - Troposcatter can be used advantageously in transhorizon paths
- Temperature inversion, abrupt changes in the refractive index with height causing reflection
  - Ducting, where the refractive index is such that electromagnetic waves tend to be trapped inside a natural lossless waveguide
- Gaseous attenuation, where interactions between the incident wave and the atmospheric constituents dissipate power: **vary with altitude, geographic location, and weather conditions**

- Rec. ITU-R P.341-7 "The concept of transmission loss for radio links"
  Rec. ITU-R P.2145-0 "Digital maps related to the calculation of gaseous attenuation and related effects"

Scope

# Ground and obstacles

- Diffraction

  Rec. ITU-R P.526-15 "Propagation by diffraction"

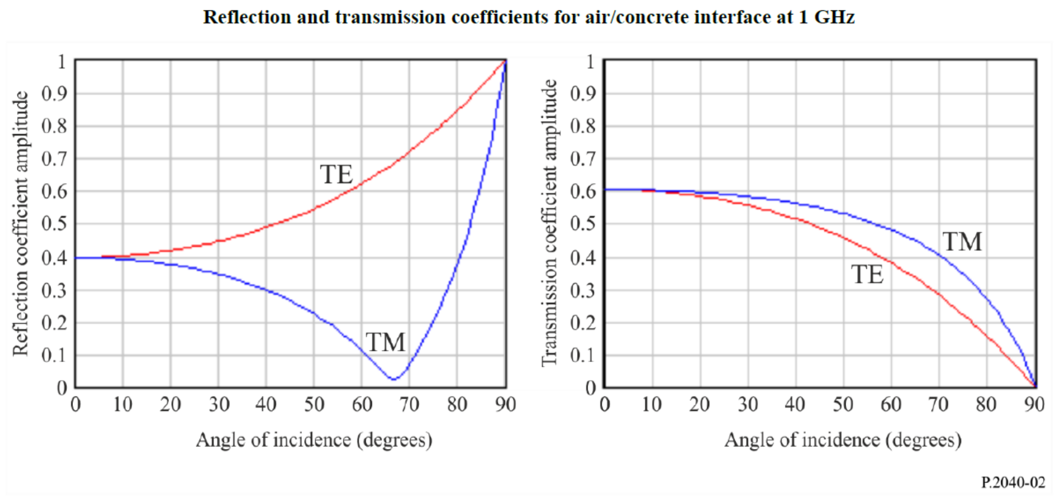
- Attenuation in vegetation

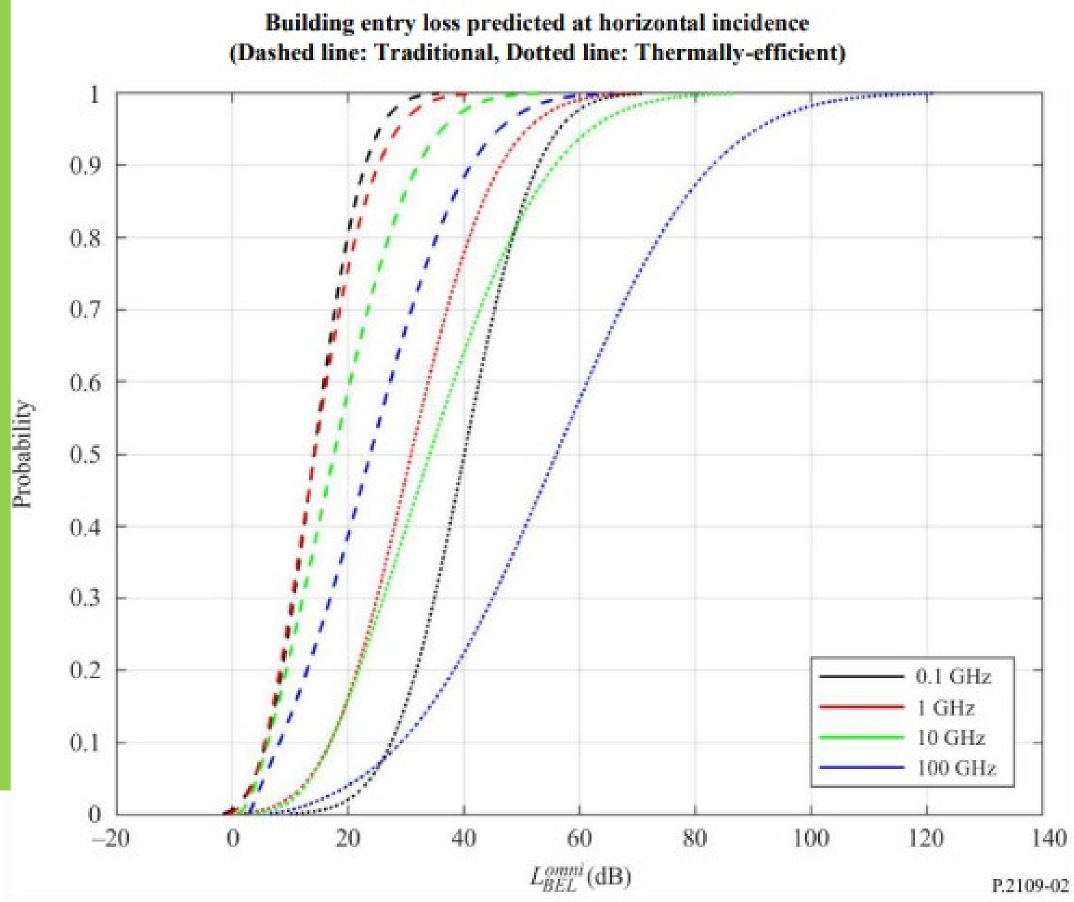
  Rec. ITU-R P.833-10 "Attenuation in vegetation"

- Effects of building materials and structures on radiowave propagation

  Rec. ITU-R P.2109-2 "Prediction of building entry loss"

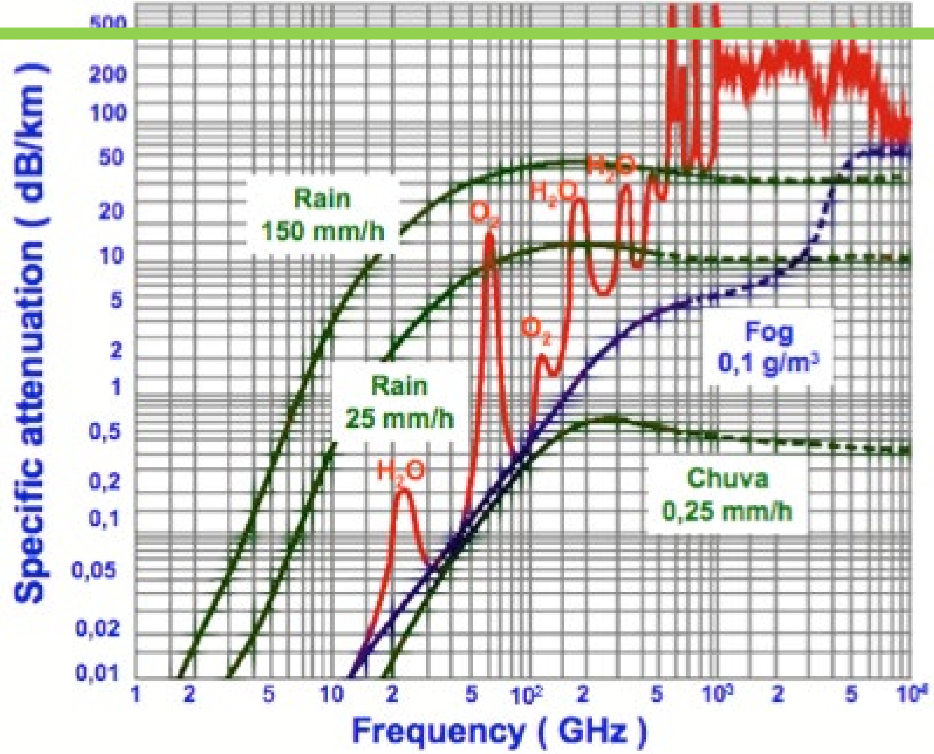
  Rec. ITU-R P.2040-3 "Effects of building materials and structures on radiowave propagation above about 100 MHz"



# Fog, Clouds and Rain

- The effects increase with frequency
  Rec. ITU-R P.840-9 “Attenuation due to clouds and fog”
  Rec. ITU-R P.838-3 “Specific attenuation model for rain for use in prediction methods”



# 5 Questions

- 201-7/3: Radiometeorological data required for the planning of terrestrial and space communication systems and space research application
- 202-5/3: Methods for predicting propagation over the surface of the Earth
- 209-2/3: Variability and risk parameters in system performance analysis
- 230-3/3: Prediction methods and models applicable to power line telecommunication systems
- 236/3: Use of machine learning methods for radiowave propagation studies

# Question 202-5/3

considering

a) that the presence of obstacles on the propagation path may modify, to a large extent, the mean value of the transmission loss, as well as the fading amplitude and characteristics;

b) that, with increase in frequency, the influence of the detailed roughness of the surface of the Earth as well as that of vegetation and natural or man-made structures on or above the surface of the Earth becomes more significant;

c) …

decides that the following Questions should be studied

1 What is the influence of terrain irregularities, vegetation and buildings, the existence of conducting structures and seasonal variability, both for locations within the service area around a transmitter and for the evaluation of interference at much greater distances, on the transmission loss, polarization, group delay and angle of arrival?

2 What is the additional transmission loss in urban areas?

3 What is the screening provided by obstacles near a terminal, taking into account the propagation mechanisms over the path?

4 What are the conditions under which obstacle gain occurs and the short-term and long term variations of transmission loss under these conditions?

5 …

# 5 Working Groups in WP 3J

- WG 3J-1 Effects of the clear atmosphere
  (P. Bouchard)
- WG 3J-2 Effects of clouds and precipitation
  (A. Martellucci)
  WG 3J-3 Global mapping and statistical aspects
  (X. Boulanger - L. Castanet)
- WG 3J-4 Vegetation and obstacle diffraction
  (S. Salamon)
- JWG3J-3K-3M Building Entry Loss
  (R. Rudd)

Result of the work

# 32 Recommendations

| | |
|---|---|
| Recommendation ITU-R P.310-10 | Definitions of terms relating to propagation in non-ionized media |
| Recommendation ITU-R P.311-18 | Acquisition, presentation and analysis of data in studies of tropospheric propagation |
| Recommendation ITU-R P.341-7 | The concept of transmission loss for radio links |
| Recommendation ITU-R P.453-14 | The radio refractive index: its formula and refractivity data |
| Recommendation ITU-R P.525-4 | Calculation of free-space attenuation |
| Recommendation ITU-R P.526-15 | Propagation by diffraction |
| Recommendation ITU-R P.527-6 | Electrical characteristics of the surface of the earth |
| Recommendation ITU-R P.581-3 | The concept of “worst month” |
| Recommendation ITU-R P.676-13 | Attenuation by atmospheric gases |
| Recommendation ITU-R P.678-3 | Characterization of the natural variability of propagation phenomena |
| Recommendation ITU-R P.833-10 | Attenuation in vegetation |
| Recommendation ITU-R P.834-9 | Effects of tropospheric refraction on radiowave propagation |
| Recommendation ITU-R P.835-6 | Reference standard atmospheres |
| Recommendation ITU-R P.836-6 | Water vapour: surface density and total columnar content |
| Recommendation ITU-R P.837-7 | Characteristics of precipitation for propagation modelling |
| Recommendation ITU-R P.838-3 | Specific attenuation model for rain for use in prediction methods |
| Recommendation ITU-R P.839-4 | Rain height model for prediction method |
| Recommendation ITU-R P.840-9 | Attenuation due to clouds and fog |
| Recommendation ITU-R P.841-7 | Conversion of annual statistics to worst-month statistics |
| Recommendation ITU-R P.1057-7 | Probability distributions relevant to radiowave propagation modelling |
| Recommendation ITU-R P.1058-2 | Digital topographic databases for propagation studies |
| Recommendation ITU-R P.1144-12 | Guide to the application of the propagation methods of Radiocommunication Study Group 3 |
| Recommendation ITU-R P.1407-8 | Multipath propagation and parameterization of its characteristics |
| Recommendation ITU-R P.1510-1 | Annual mean surface temperature |
| Recommendation ITU-R P.1511-2 | Topography for Earth-to-space propagation modelling |
| Recommendation ITU-R P.1621-2 | Propagation data required for the design of Earth-space systems operating between 20 THz and 375 THz |
| Recommendation ITU-R P.1853-2 | Tropospheric attenuation time series synthesis |
| Recommendation ITU-R P.2040-3 | Effects of building materials and structures on radiowave propagation above about 100 MHz |
| Recommendation ITU-R P.2109-2 | Prediction of Building Entry Loss |
| Recommendation ITU-R P.2145-0 | Digital maps related to the calculation of gaseous attenuation and related effects |
| Recommendation ITU-R P.2146-0 | Sea surface bistatic scattering |
| Recommendation ITU-R P.2148-0 | Digital maps related to surface wind speed statistics |

# Recommendations revised/developed in 2022-2023

## Major revisions and new recommendations approved in 2022 and 2023 for WP3J

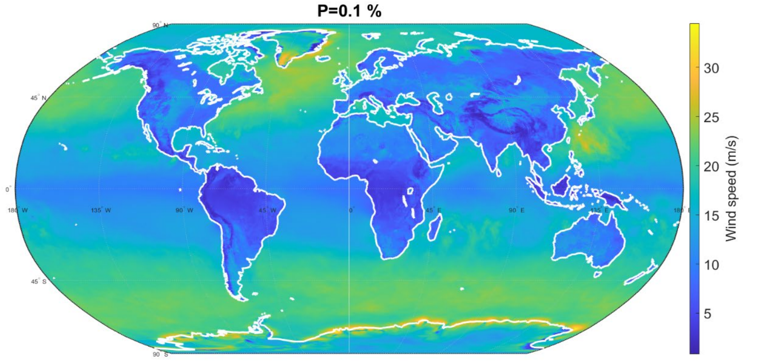
- Sea surface bistatic scattering
  - New Rec. ITU-R P.2146-0 "Sea surface bistatic scattering"
  - Maps of wind speed needed as inputs to Rec. ITU-R P.2146: new Rec. ITU-R P.2148-0 "Digital maps related to surface wind speed statistics"

- Tropospheric attenuation for Earth-space paths in non-precipitating conditions
  - Attenuation by atmospheric gases: revised Recs ITU-R P.676-13 and new ITU-R P.2145-0
  - Attenuation due to clouds and fog: revised Rec. ITU-R P.840-9

# Sea surface bistatic scattering: new Recs ITU-R P.2146 and P.2148

- Rec. ITU-R P.2146-0: "Sea surface bistatic scattering"
  - Application domain
    - Frequencies up to 100 GHz
    - Any elevation angles except grazing incidences
    - Wind speeds between 0.5 m/s and 25 m/s
  - Input parameters
    - Propagation parameters:
      Frequency, elevation angle & polarization vector of the incident wave & of the scattering direction
    - Sea surface parameters:
      Sea surface salinity, temperature, 10m wind speed, inverse wave age, cut-off roughness height wave number
  - Rec. ITU-R P.2146-0: Step-by-step procedure
    - Step 1: Sea water complex relative permittivity
    - Step 2: Sea surface roughness parameters
    - Step 3: Coherent bi-static scattering coefficient
    - Step 4: Diffuse bi-static scattering due to large scale roughness
    - Step 5: Diffuse bi-static scattering due to small-scale roughness
    - Step 6: Sum of the components

- Rec. ITU-R P.2148-0:
  "Digital maps related to surface wind speed statistics"
    - Wind speed statistics at 10 m above the surface of the Earth
    - Digital maps derived from 10 years of ERA5 database
    - Probability range between 0.01 % and 99 %




Rec. ITU-R P.2148-0

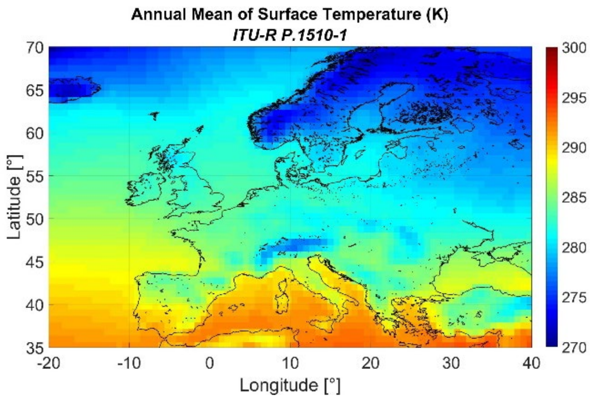
# Attenuation by atmospheric gases : Rec. ITU-R P.676-13

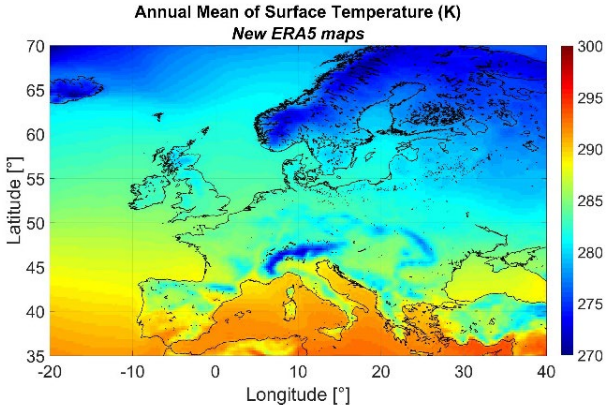
| | Instantaneous prediction method | Statistical prediction method |
|---|---|---|
| **Oxygen attenuation** | **Section 1.1**<br>$$A_o(f,P_s,T_s,\rho_{w_s}) = \frac{\gamma_o(f,p_s,T_s,e_s)\cdot h_o(f,P_s,T_s,\rho_{w_s})}{\sin\theta}$$<br>where:<br>$$h_o(f,P_s,T_s,\rho_{w_s}) = a_o(f) + b_o(f)\cdot T_s + c_o(f)\cdot P_s + d_o(f)\cdot \rho_{w_s}$$<br>and:<br>$$e_s = \frac{\rho_{w_s}T_s}{216.7}\ ;\ \ p_s = P_s - e_s$$ | **Section 1.2**<br>$$A_o(f,p) = \frac{\gamma_o(f,\overline{p_s},\overline{T_s},\overline{e_s})\cdot h_o(f,P_s(p),T_s(p),\rho_{w_s}(p))}{\sin\theta}$$<br>where:<br>$$h_o(f,P_s(p),T_s(p),\rho_{w_s}(p)) = a_o(f) + b_o(f)\cdot T_s(p) + c_o(f)\cdot P_s(p) + d_o(f)\cdot \rho_{w_s}(p)$$<br>and:<br>$$\overline{e_s} = \frac{\overline{\rho_{w_s}}\ \overline{T_s}}{216.7};\ \ \overline{p_s} = \overline{P_s} - \overline{e_s}$$ |
| **Water vapour attenuation** | **Section 2.1**<br>$$A_w(f,p_s,T_s,\rho_{w_s}) = \frac{\gamma_w(f,p_s,T_s,e_s)\cdot h_w(f)}{\sin\theta}$$<br>where:<br>$$h_w(f) = A\cdot f + B + \sum_{i=1}^{3}\frac{a_i}{(f-f_i)^2 + b_i}$$<br>and:<br>$$e_s = \frac{\rho_{w_s}T_s}{216.7}\ ;\ \ p_s = P_s - e_s$$ | |
| | **Section 2.2**<br>$$A_w(f,P_s,T_s,\rho_{w_s}) = \frac{K_V(f,P_s,T_s,\rho_{w_s})\cdot V_s}{\sin\theta}$$<br>where:<br>$$K_V(f,P_s,T_s,\rho_{w_s}) = a_V(f) + b_V(f)\cdot \rho_{w_s} + c_V(f)\cdot T_s + d_V(f)\cdot P_s$$ | **Section 2.3**<br>$$A_w(f,p) = \frac{K_V(f,\overline{P_s},\overline{T_s},\overline{\rho_{w_s}})\cdot V_s(p)}{\sin\theta}$$<br>where:<br>$$K_V(f,\overline{P_s},\overline{T_s},\overline{\rho_{w_s}}) = a_V(f) + b_V(f)\cdot \overline{\rho_{w_s}} + c_V(f)\cdot \overline{T_s} + d_V(f)\cdot \overline{P_s}$$ |

# Input meteorological maps of Integrated Water Vapour Content for Rec. ITU-R P.676-13: new Rec. ITU-R P.2145-0

## ★ Digital maps of surface temperature

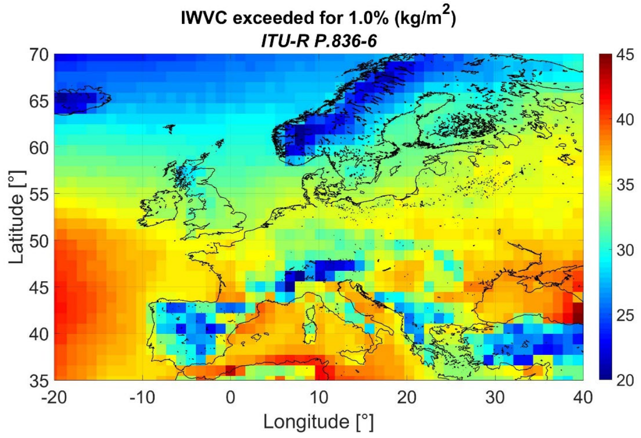
| Parameters related to surface temperature | | Rec. ITU-R P.1510-1 | Rec. ITU-R P.2145-0 |
|---|---|---|---|
| Spatial resolution | | 0.75° | 0.25° |
| Mean | Annual | Available | Available |
| | Monthly | Available | Available |
| Standard deviation | Annual | Unavailable | Available |
| | Monthly | Unavailable | Available |
| CCDF | Annual | Unavailable | Maps from 0.01% to 99% |
| | Monthly | Unavailable | Maps from 0.1% to 99% |

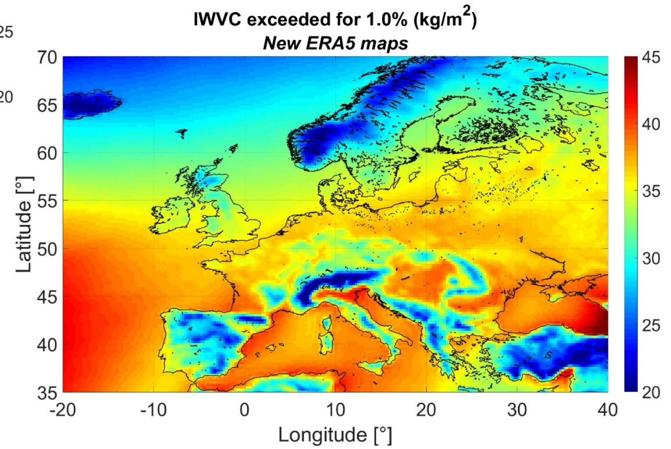



## ★ Digital maps of Integrated Water Vapour Content

| Parameters related to integrated water vapour content | | Rec. ITU-R P.836-6 | Rec. ITU-R P.2145-0 |
|---|---|---|---|
| Spatial resolution | | 1.125° | 0.25° |
| Mean | Annual | Unavailable | Available |
| | Monthly | Unavailable | Available |
| Standard deviation | Annual | Unavailable | Available |
| | Monthly | Unavailable | Available |
| CCDF | Annual | Maps from 0.1% to 99% | Maps from 0.01% to 99% |
| | Monthly | Maps from 1% to 99% | Maps from 0.1% to 99% |



# Attenuation due to clouds and fog: Rec. ITU-R P.840-9

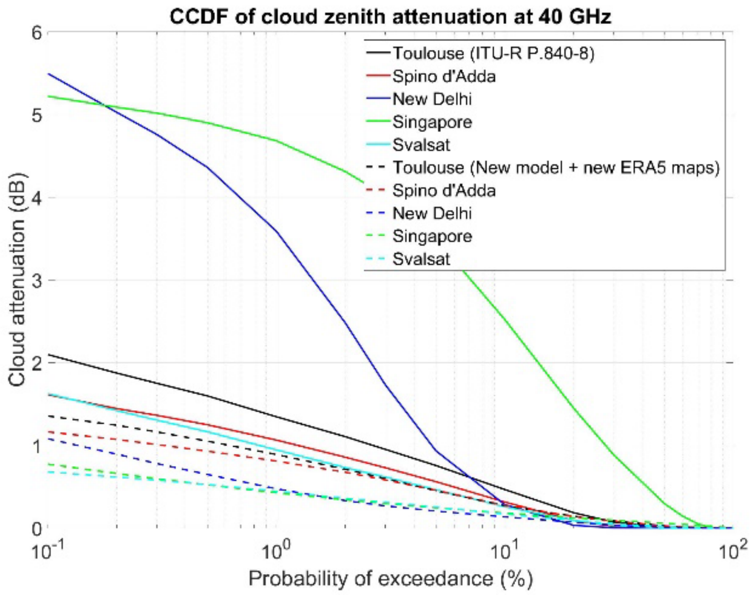
- Description of the new statistical model
  - Prediction of the CCDF of cloud attenuation, i.e. the cloud attenuation value $A_C(f,p)$ exceeded for $p$ % of the time, such that: $A_C(f,p) = \frac{K_L(f)\cdot L(p)}{\sin\theta}$

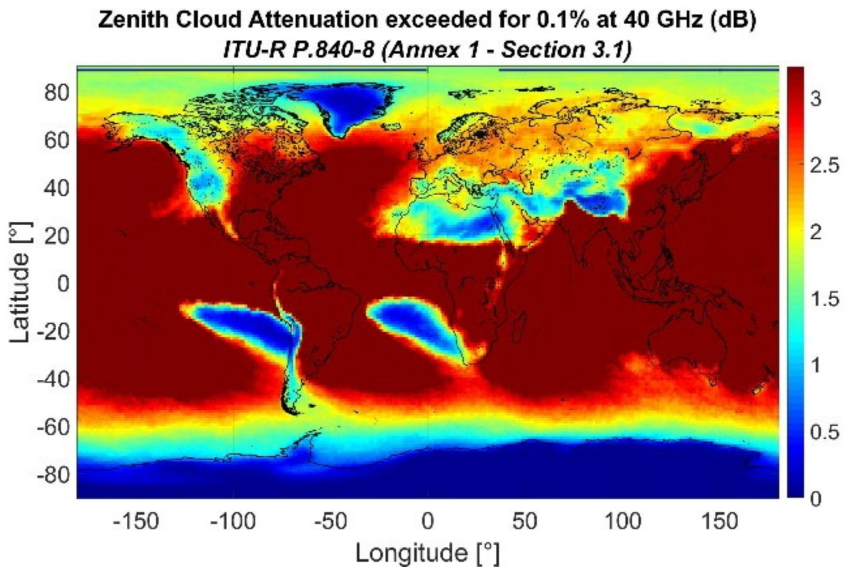
$$K_L(f) = K_l(f, T = 273.75K) \cdot \left(A_1 e^{-\frac{(f-\mu_1)^2}{\sigma_1}} + A_2 e^{-\frac{(f-\mu_2)^2}{\sigma_2}} + A_3\right)$$

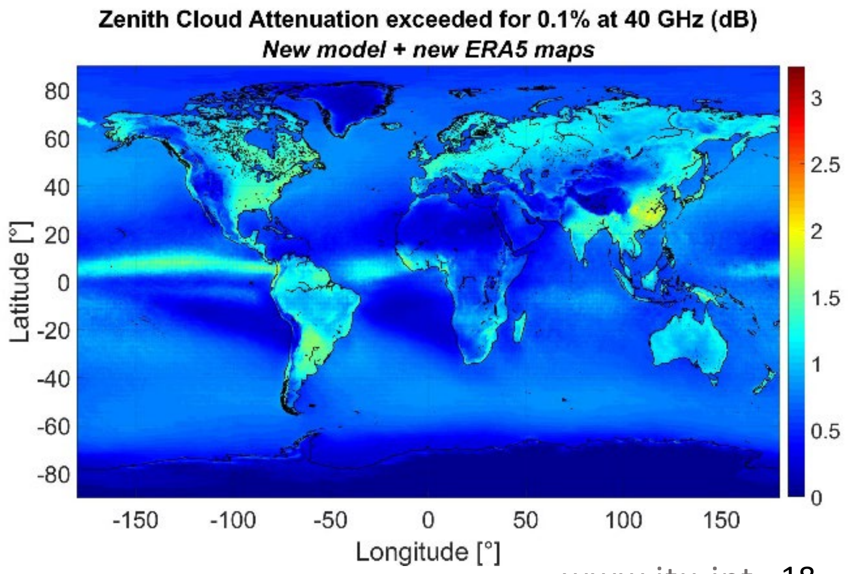
*Cloud liquid water specific attenuation coefficient given in Annex 1 - Section 2 of ITU-R P.840*

- Digital maps of $L(p)$, derived from 30 years (1991-2020) of the ECMWF ERA5 reanalysis database, are an integral part of Rec. ITU-R P.840-9 (Section 4.1)

| Parameters related to integrated cloud liquid water content | | Rec. ITU-R P.840-8 | Rec. ITU-R P.840-9 |
|---|---|---|---|
| Spatial resolution | | 1.125° | 0.25° |
| Mean | Annual | Unavailable | Available |
| | Monthly | Unavailable | Available |
| Standard deviation | Annual | Unavailable | Available |
| | Monthly | Unavailable | Available |
| CCDF | Annual | Maps reduced to 0° C<br>Maps from 0.1% to 99% | Maps not reduced to 0° C<br>Maps from 0.01% to 99% |
| | Monthly | Maps reduced to 0° C<br>Maps from 1% to 99% | Maps not reduced to 0° C<br>Maps from 0.1% to 99% |



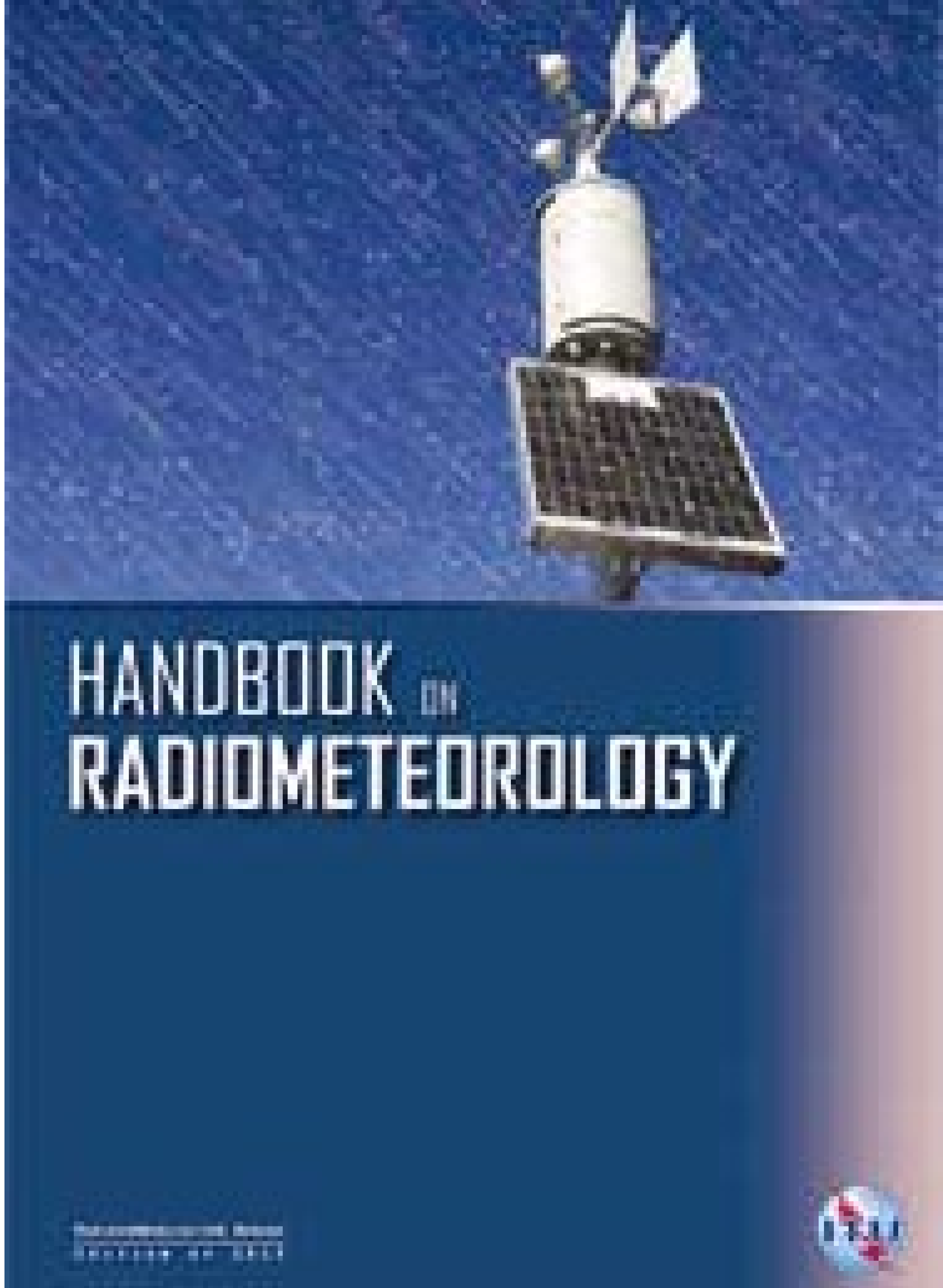



# Handbook

Provides general information on radiometeorology for those who use the ITU-R P series Recommendations

Contents

- Physical characteristics of the atmosphere
- Atmospheric refraction
- Influence of refraction on propagation
- Single-particle scattering
- Attenuation and dispersion by atmospheric gases
- Attenuation by atmospheric particles
- Radio emissivity of atmosphere and ground
- Cross-polarization and anisotropy
- Statistical aspects of modelling



# 9 Fascicles

1. Doc. 3J/FAS/2 Fascicle concerning Annex 3 on Rec. ITU-R P.837-6 - Physical modelling for the conversion of rain rate statistics at different integration times
2. Doc. 3J/FAS/3 Fascicle concerning the rainfall rate model given in Annex 1 to Rec. ITU-R P.837
3. Doc. 3J/FAS/4 Fascicle concerning the use of Rec. ITU-R P.678
4. Doc. 3J/FAS/5 Fascicle on statistical distributions of integrated water vapour (Rec. ITU-R P.836-5) and the prediction method for water vapour attenuation for a slant path in Rec. ITU-R P.676-10)
5. Doc. 3J/FAS/6 Fascicle on statistical distributions of reduced integrated cloud liquid water and prediction of the associated attenuation (Rec. ITU-R P.840-6)
6. Doc. 3J/FAS/7 Fascicle on the processing of drop size distribution and data for Study Group 3 Experimental Database
7. Doc. 3J/FAS/8 Fascicle on topography for Earth-space paths in Rec. ITU-R P.1511-2
8. Doc. 3J/FAS/9 Fascicle on rain specific attenuation
9. Doc. 3J/FAS/10 Background information on tropospheric attenuation time series synthesizer in Rec. ITU-R P.1853

# Plan of work

1. Estimating atmospheric refractive index and tropospheric excess path length (variability); new data need to be provided by administrations to assess the prediction error
2. Improving modelling of gaseous loss and related effects for the design of Earth-space systems operating between 20-375 THz
3. Assessing and characterizing the return period of extreme precipitation events
4. Improving characterization of rain specific attenuation in the 100-1000 GHz frequency interval (Rec. ITU-R P.838)
5. Developing Recommendation ITU-R P.1853-2 on time series synthesis
6. Developing general terrain diffraction model suitable for slant paths in Rec. ITU-R P.526
7. Collecting detailed information on the characteristics of diffuse scattering from building surfaces
8. Contributions on the topic are welcome

# Invitation to collaborate

1. It is important to assemble propagation data bases and made then available to researchers/partners interested in working in new, more accurate and more reliable prediction methods and channel models
   - Populate DBSG3 database
2. Researchers, specialists are invited to collaborate in the activities of WP 3J
   - Correspondence Groups

| CG | Title |
|---|---|
| 3J-1 | Gaseous attenuation |
| 3J-2 | Modelling of monthly variability of precipitation in Rec. ITU-R P.837-7 |
| 3J-3 | Time series synthesisers |
| 3J-3M-4 | Statistical issues for testing and testing metric definition |
| 3J-3M-5 | Effect of clouds and precipitation on attenuation and depolarization on slant path |
| 3J-3K-3M-8 | Building Entry Loss |
| 3J-9 | Phase scintillation statistics |
| 3J-10 | Coordination of WP 3J |
| 3J-11 | Reference standard atmospheres in Rec. ITU-R P.835 |
| 3J-3M-13 | Validation examples for Study Group 3 Earth-Space propagation prediction methods |
| 3J-3K-3M-14 | Revision to Rec. ITU-R P.1409 |
| 3J-3K-3M-16 | The atmospheric radio refractive index and its effects on radiowave propagation |
| 3J-17 | Modelling of Earth or other surfaces bistatic scattering |
| 3J-23 | General path modelling of slant path terrain diffraction |