ClimDiff
Boulder, CO 3-4 June 2008

A Unified Method for the Prediction of Rain Attenuation in Slant Path and Terrestrial Links using the Full Rainfall Rate Distribution

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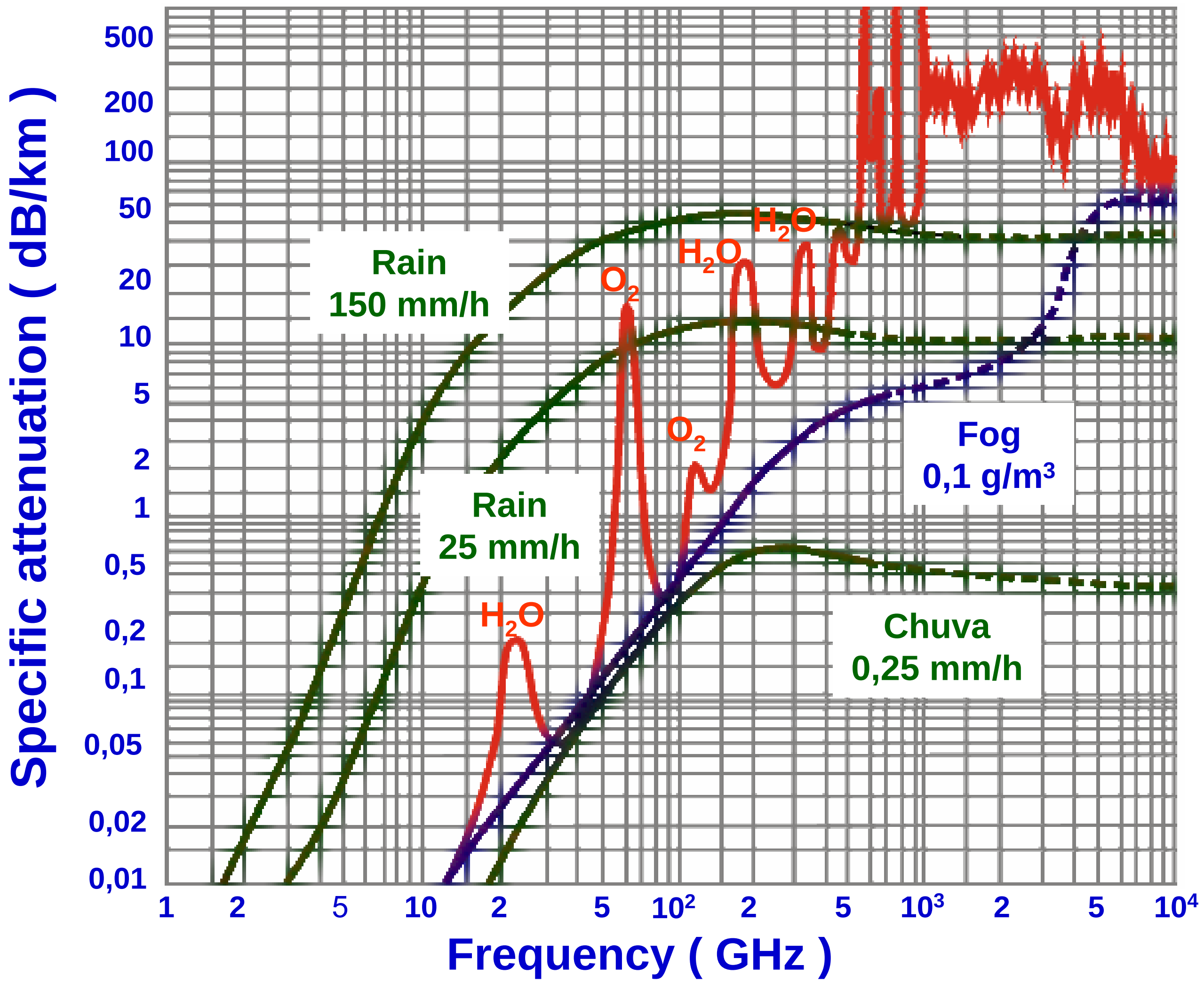
Outline

- Basis of rain attenuation prediction methods
- The ITU-R prediction method for terrestrial links
- Effective path lenght for terrestrial links
- Improved method for terrestrial links
- General method for terrestrial and slant path links
- Tests of prediction methods
- Conclusions

Gaseous absorption and rain attenuation



Specific attenuation due to rain

$$\gamma = 4,343 \int_0^{\infty} Q_t(D) N(D) dD \qquad dB/km$$

- Qt (D) [cm2] scattering and absorption cross section of a rain drop with diameter D;
- N(D) [m-3 mm-1] drop size density function.

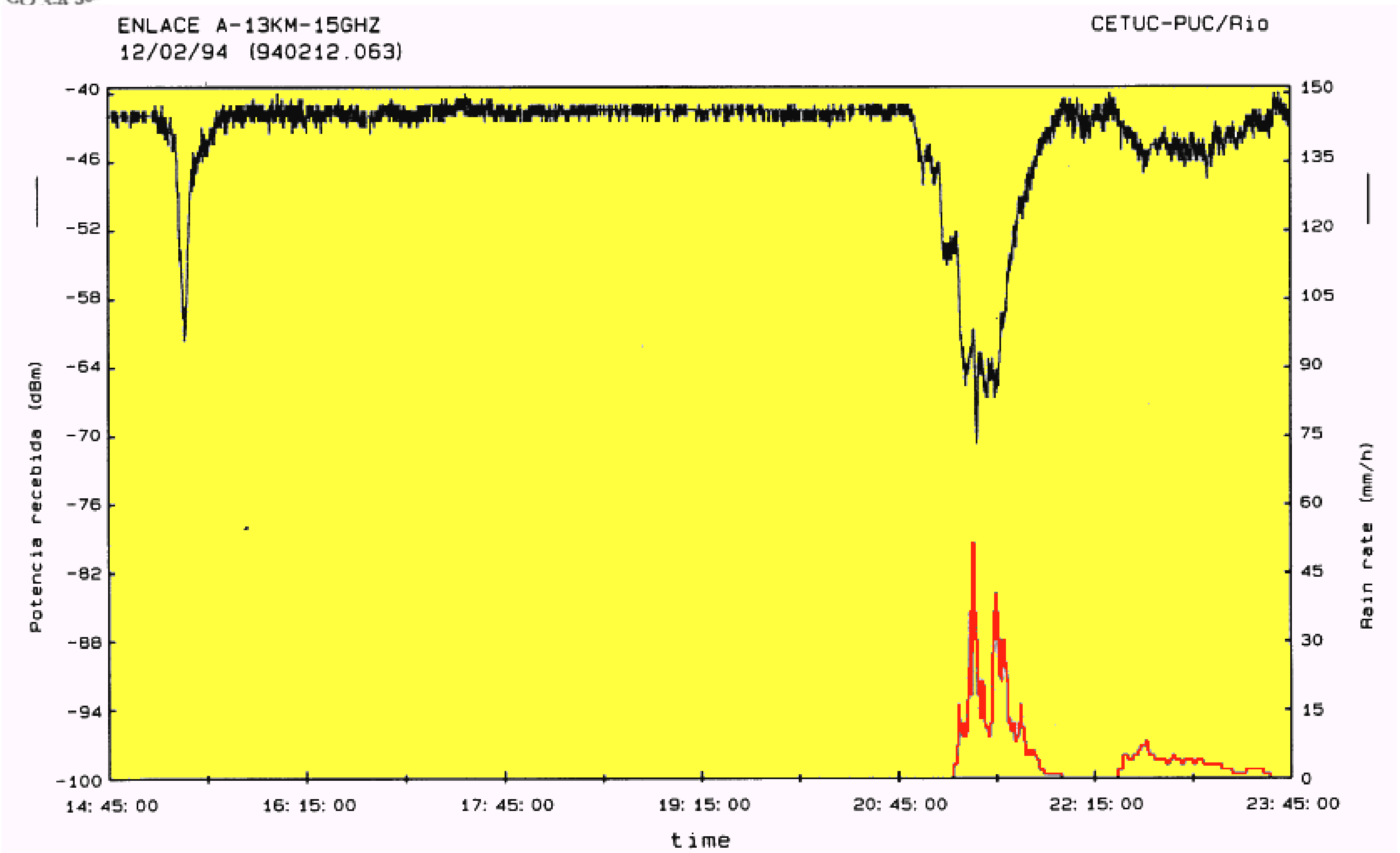
- Approximate function for practical use:

$$\gamma = kR^{\alpha} \qquad dB/km$$

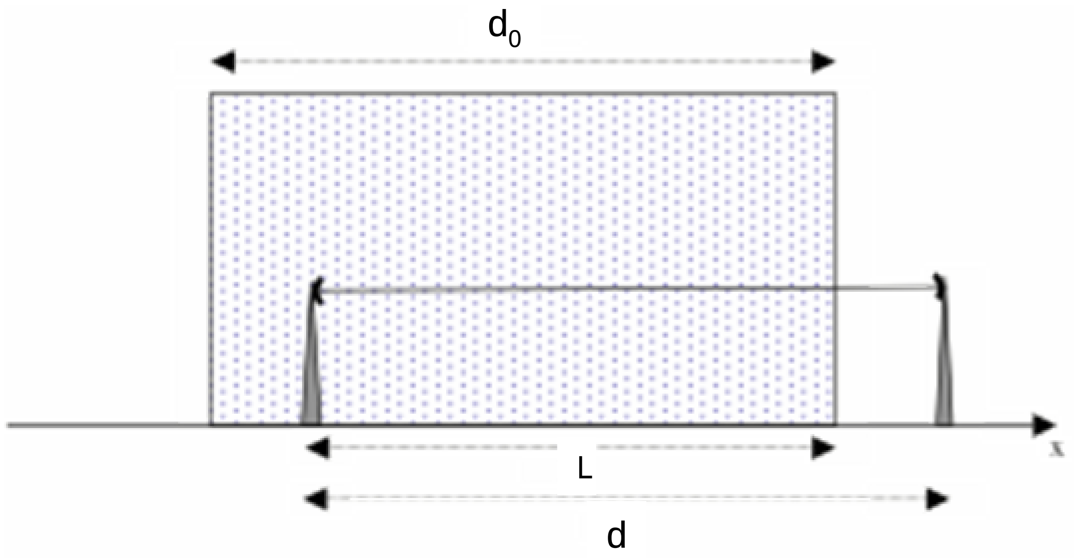
- K and α are functions of frequency and polarization.
- Rain attenuation over a path of length L:

$$A = \int_0^{L} kR^{\alpha}(l) dl \qquad dB$$

Rain attenuation events



ITU-R method - terrestrial case



$$d_{eff} = \langle L \rangle = \frac{1}{d_0 + d} \int_{-d_0}^{d} L(x)\, dx = r \cdot d = \frac{1}{1 + d / d_0} \cdot d$$

$$A_{0.01} = \gamma_R\, d_{eff} = \gamma_R\, dr \qquad r = \frac{1}{1 + d / d_0} \qquad \frac{A_p}{A_{0.01}} = 0.12\, p^{-(0.546 + 0.043 \log_{10} p)}$$

Proposed prediction method - terrestrial case

- Requirements
  - Use the full rainfall rate distributions
  - Keep the basic assumptions in the existing ITU-R method:
    - Effective path length given by the average path length in the equivalent rain cell;
    - Frequency dependency only in the specific attenuation;
  - No extrapolation - use the full rainfall rate distribution.
- Solution
  - To define an effective rainfall rate

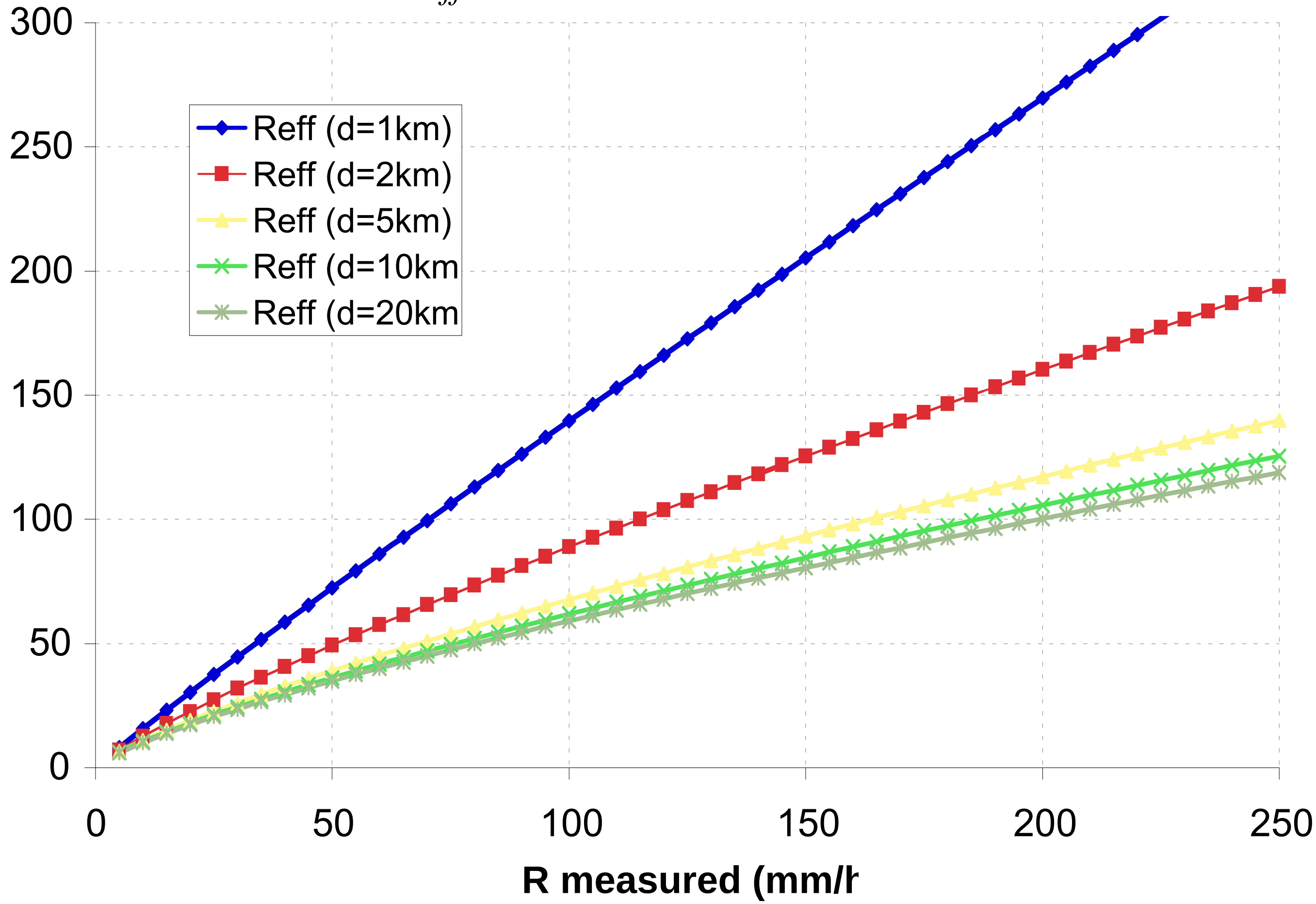
$$A_p = \gamma \cdot d_{eff} = k\left[R_{eff}(R_p, d)\right]^{\alpha} \cdot \frac{d}{1 + d / d_0(R_p)}$$

Experimental data base – terrestrial data

- Data from concurrent measurements of rainfall rate and rain attenuation currently available in the ITU-R data base DBSG3;
- Additional data from tropical regions that have already been approved for the data bank.
- The data sets available include 74 year-stations, from 64 links, at 34 sites in 15 countries.

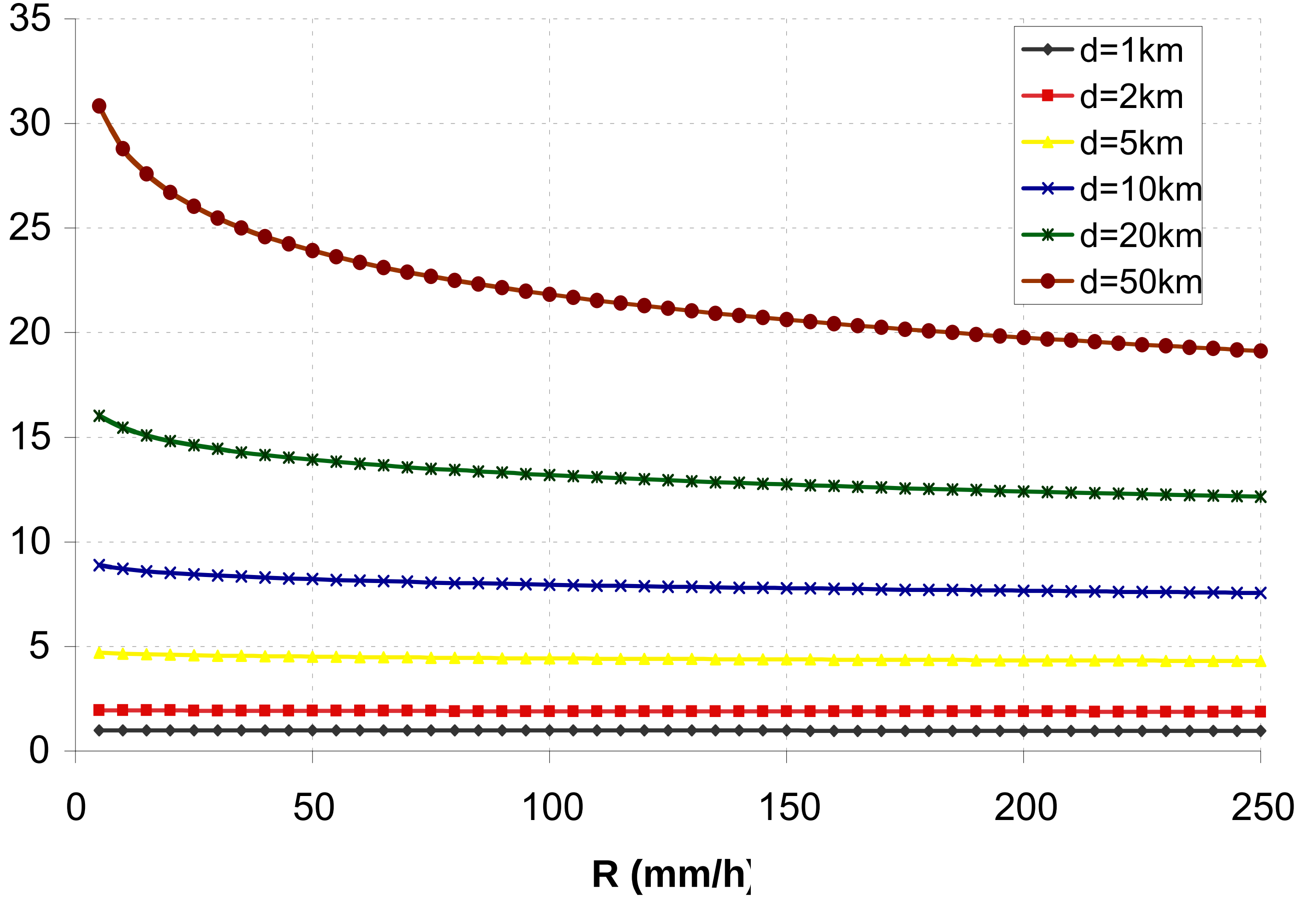
Effective rainfall rate empirical expression

$$R_{eff} = 1.763 R^{0.753+0.197/d}$$



Equivalent cell length empirical expression

$$d_0 = 119 R^{-0.244}$$



Proposed prediction method - terrestrial case

$$A_p = \gamma \cdot d_{eff} = k\left[R_{eff}(R_p, d)\right]^{\alpha} \cdot \frac{d}{1 + d/d_0(R_p)}$$

$$A(p) = k \cdot \left[1.763 \cdot R_p^{0.753+0.197/d}\right]^{\alpha} \cdot \frac{d}{1 + d/\left(119 \cdot R_p^{-0.244}\right)}$$

Tests of candidate prediction methods

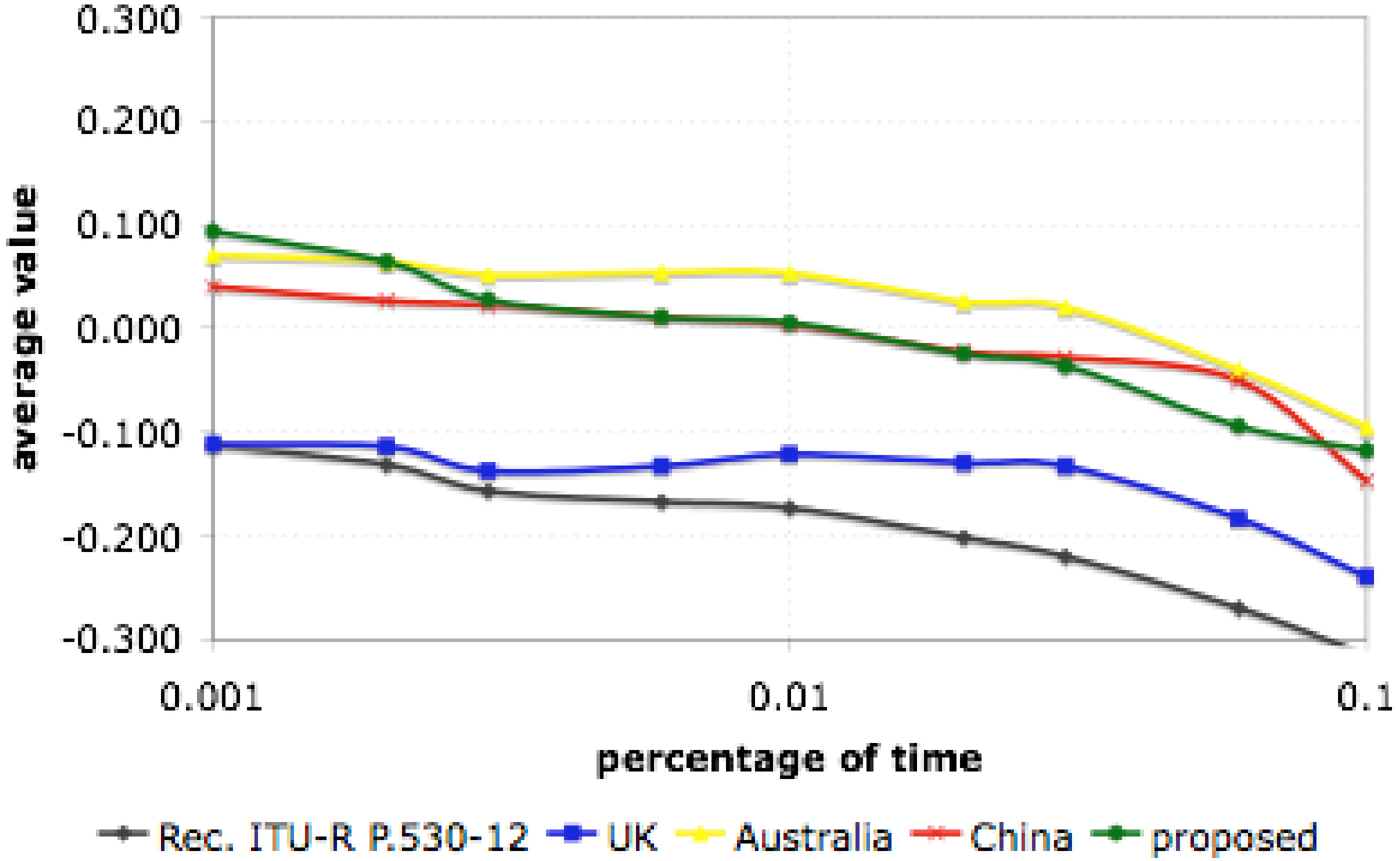
- Rec. ITU-R P.530-12;
- UK method: uses the complete rainfall rate distribution and a new fit for the path correction factor;
- Australia method: uses the rainfall rate exceeded at 0.01% of the time and a new expression for the path reduction factor;
- China method: uses the rainfall rate exceeded at 0.01% of the time and new fitted expressions for the path correction factor and the extrapolation function;
- Proposed method: uses the complete point rainfall rate distribution and fitted expressions for an effective rainfall rate and the effective path length.

Test variable - Rec. ITU-R P.311-12

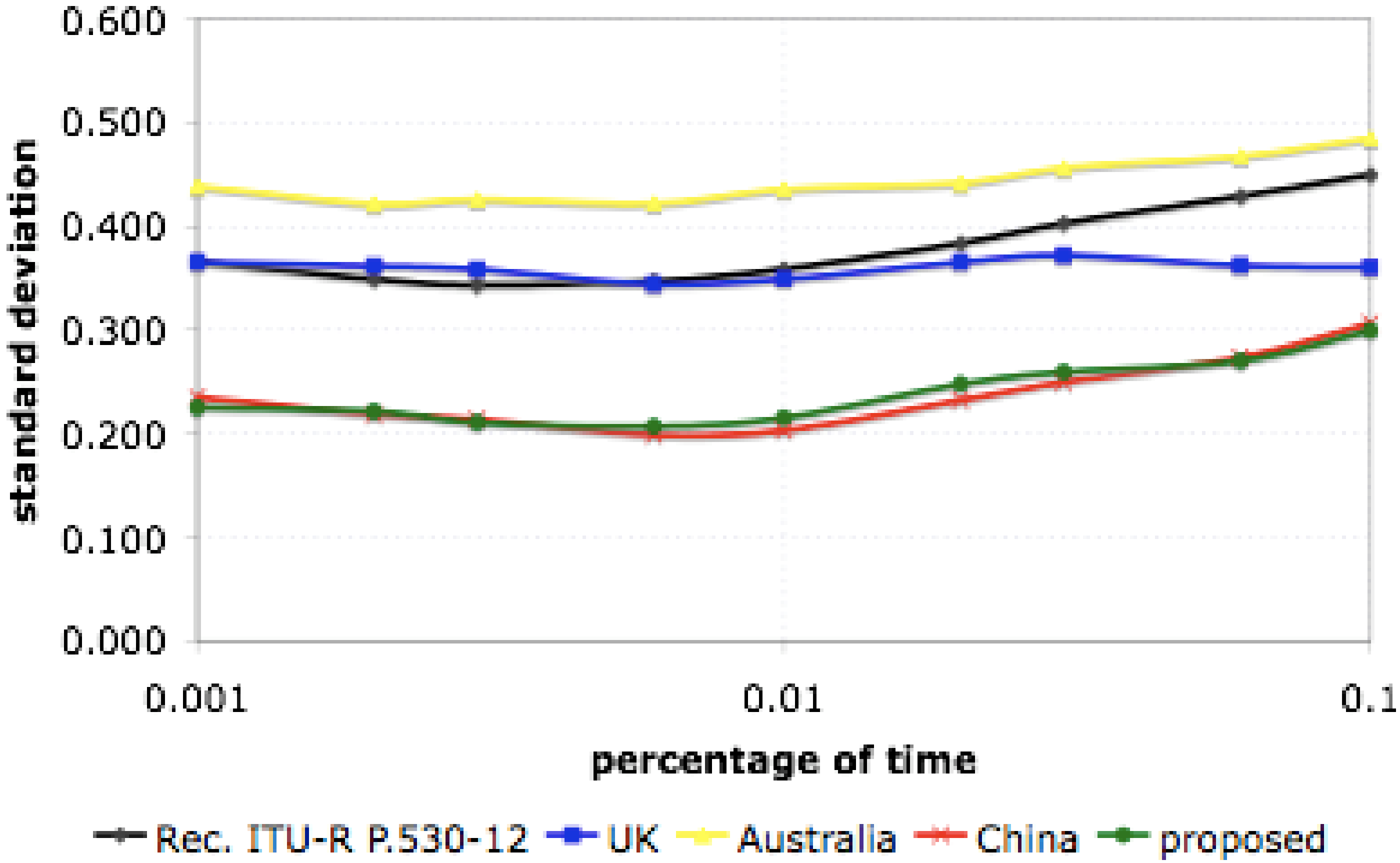
$$\varepsilon_i = \left[\ln \frac{A_{p,i}}{A_{m,i}} \right] (A_{m,i} / 10)^{0.2} \qquad \text{for } A_{m,i} < 10 \text{ dB}$$

$$\varepsilon_i = \ln \frac{A_{p,i}}{A_{m,i}} \qquad \text{for } A_{m,i} \geq 10 \text{ dB}$$

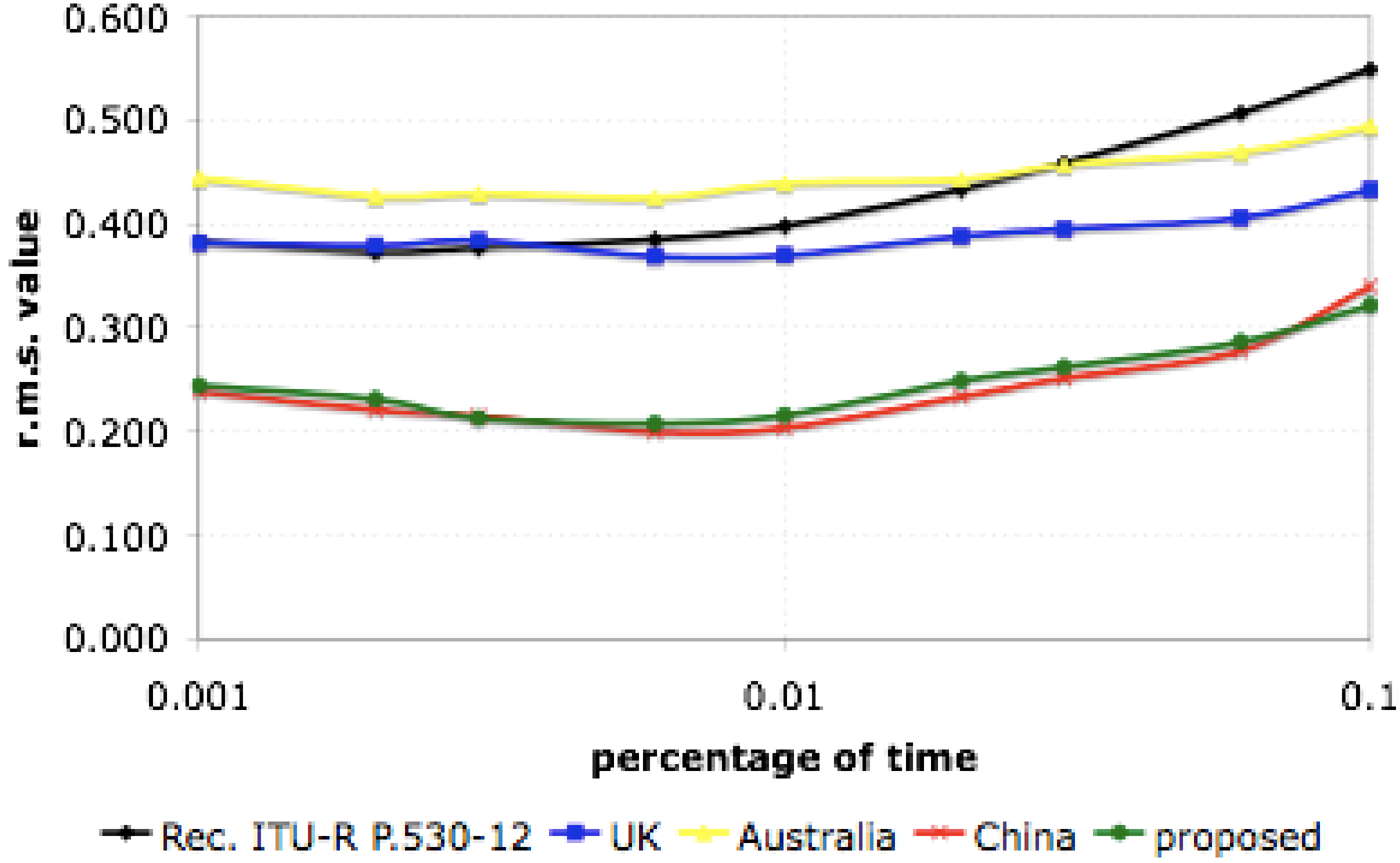
Test results - average error



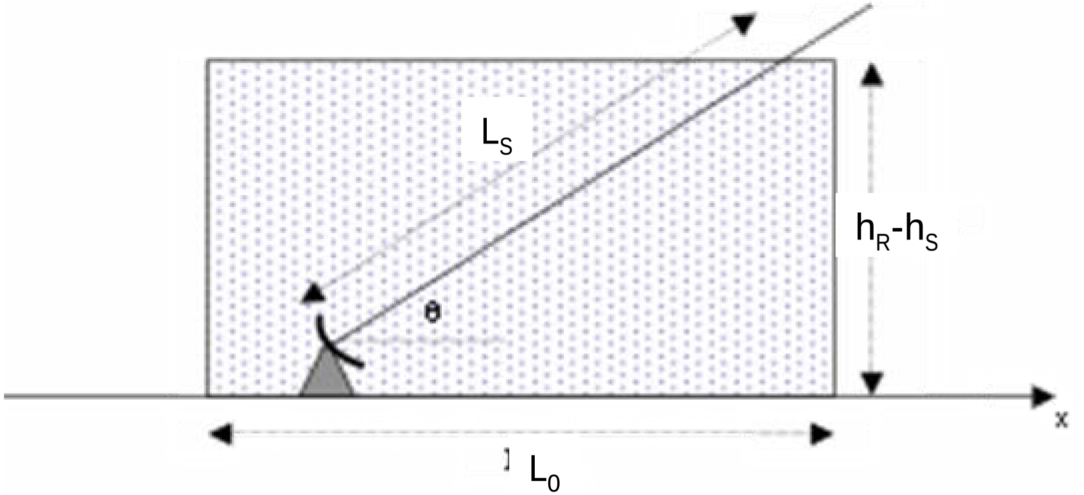
Test results - standard deviation



Test results - r.m.s error



Effective path length - slant path case



$$L_{eff} = \langle L \rangle = \frac{1}{L_0 + L_S \cos\theta} \int_{-L_0}^{L_S \cos\theta} L_S(x)\,dx = \frac{1}{1 + \dfrac{L_s \cos\theta}{L_0}} \cdot L_S$$

Proposed prediction method - slant path case

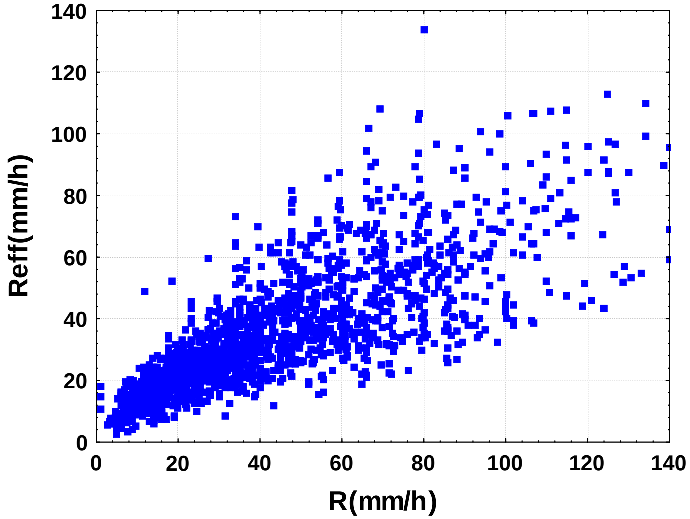
- Requirements
  - Keep the basic assumptions in the original ITU-R method:
    - Effective path length given by the average path length in the equivalent rain cell;
    - Frequency dependency only in the specific attenuation;
  - No extrapolation - use the full rainfall rate distribution;
  - Consistency with the terrestrial prediction method.
- Solution
  - To redefine the effective rainfall rate

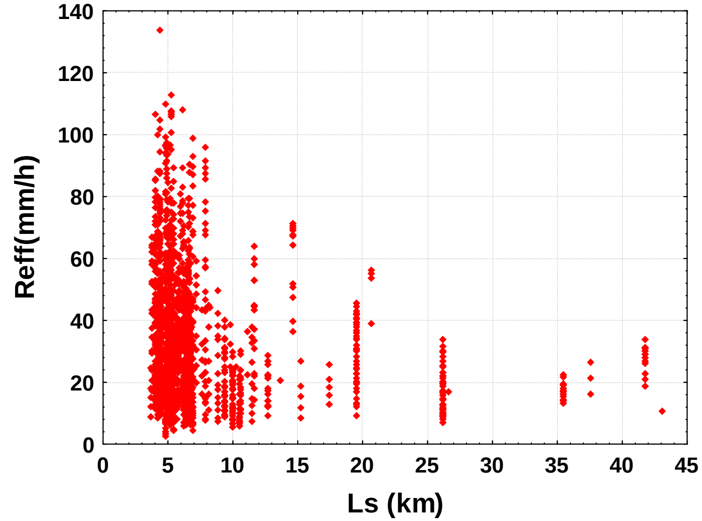
$$A_p = \gamma_p \cdot L_{eff} = k\left[\left(R_{eff}(R_p, L_S, \theta)\right)\right]^{\alpha} \cdot \frac{L_S}{1 + L_S \cos\theta / L_0}$$

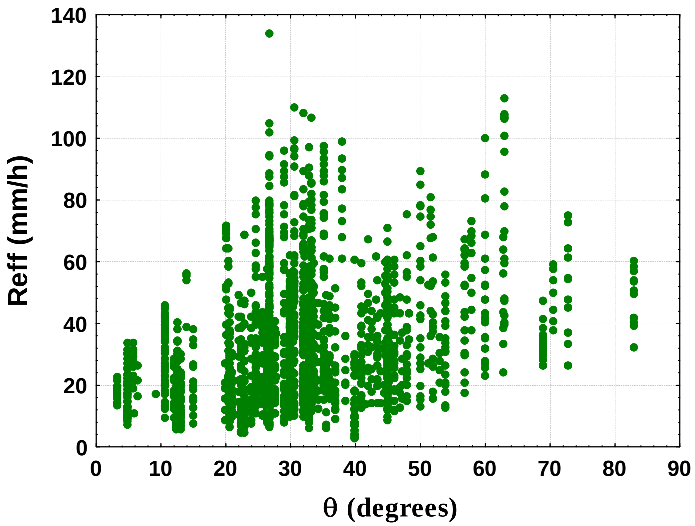
Experimental data base – slant path data

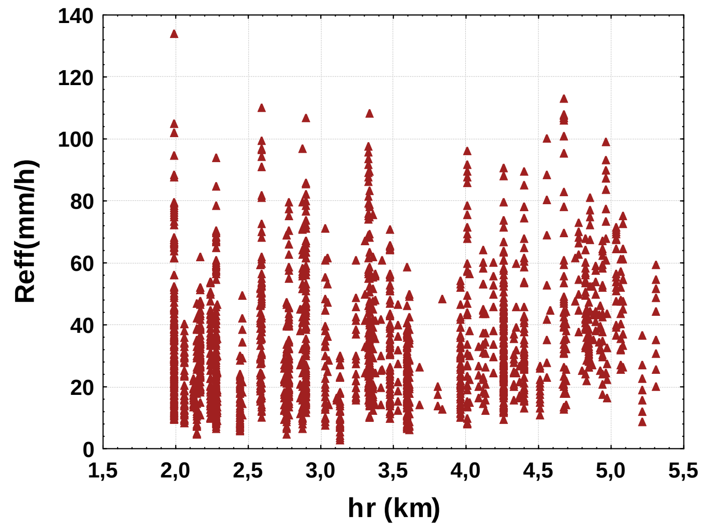
- Data from concurrent measurements of rainfall rate and slant path rain attenuation currently available in the ITU-R data base DBSG3;
- Only beacon measurements were considered (not radiometric measurements);
- The data sets used include 280 year-stations from 68 sites in 24 countries.

Effective rain height (measured values)









Proposed prediction method - general

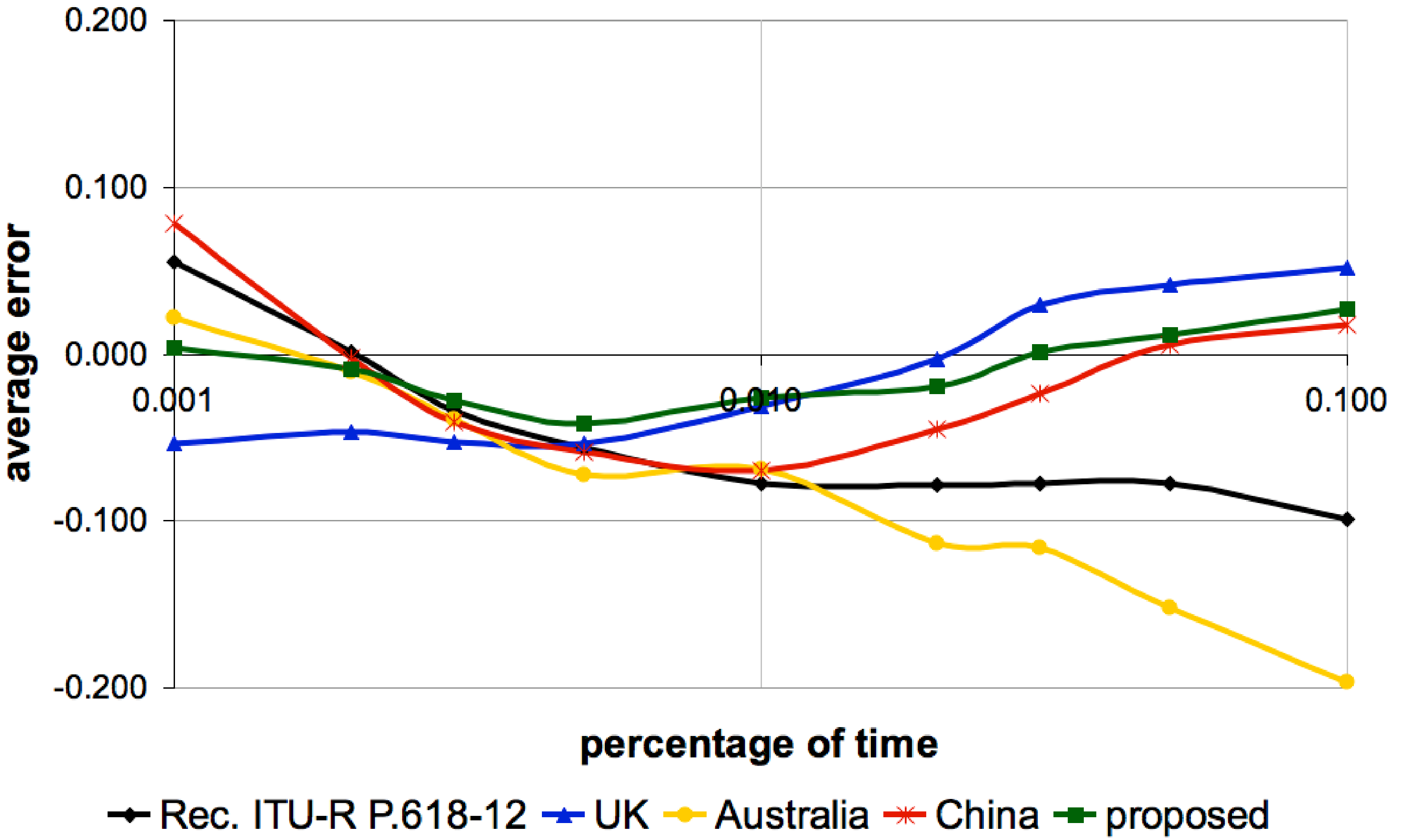
$$R_{eff}(R_p, L_S, \theta) = R_{effT}\left(\cos\theta + a_1 \cdot R^{a_2 + a_3/L_S\cos\theta} \cdot L_S^{a_4} \cdot \sin\theta\right)$$

$$A_p = k\left[1.763R^{0.753+0.197/L_S\cos\theta}\cos\theta + \frac{203.6}{L_S^{2.455}}R^{0.354+0.088/L_S\cos\theta}\sin\theta\right]^{\alpha}\frac{L_S}{1+\dfrac{L_s\cos\theta}{119R^{-0.244}}}$$

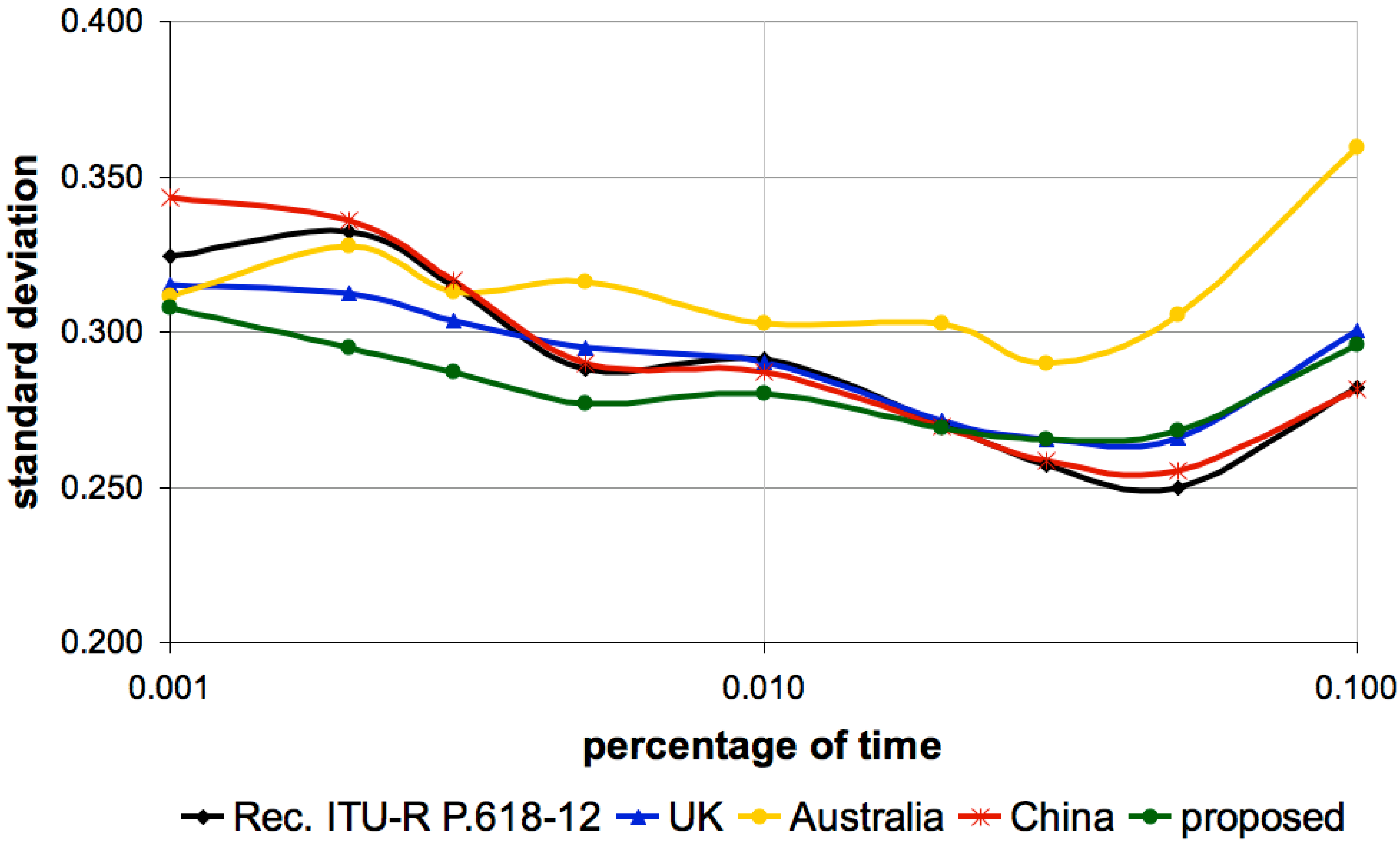
For the terrestrial case Ls = d, the second term in the brackets vanishes ($\theta = 0$) and

$$A_p = k\left[1.763R^{0.753+0.197/L_S\cos\theta}\right]^{\alpha}\frac{d}{1+\dfrac{d}{119R^{-0.244}}}$$

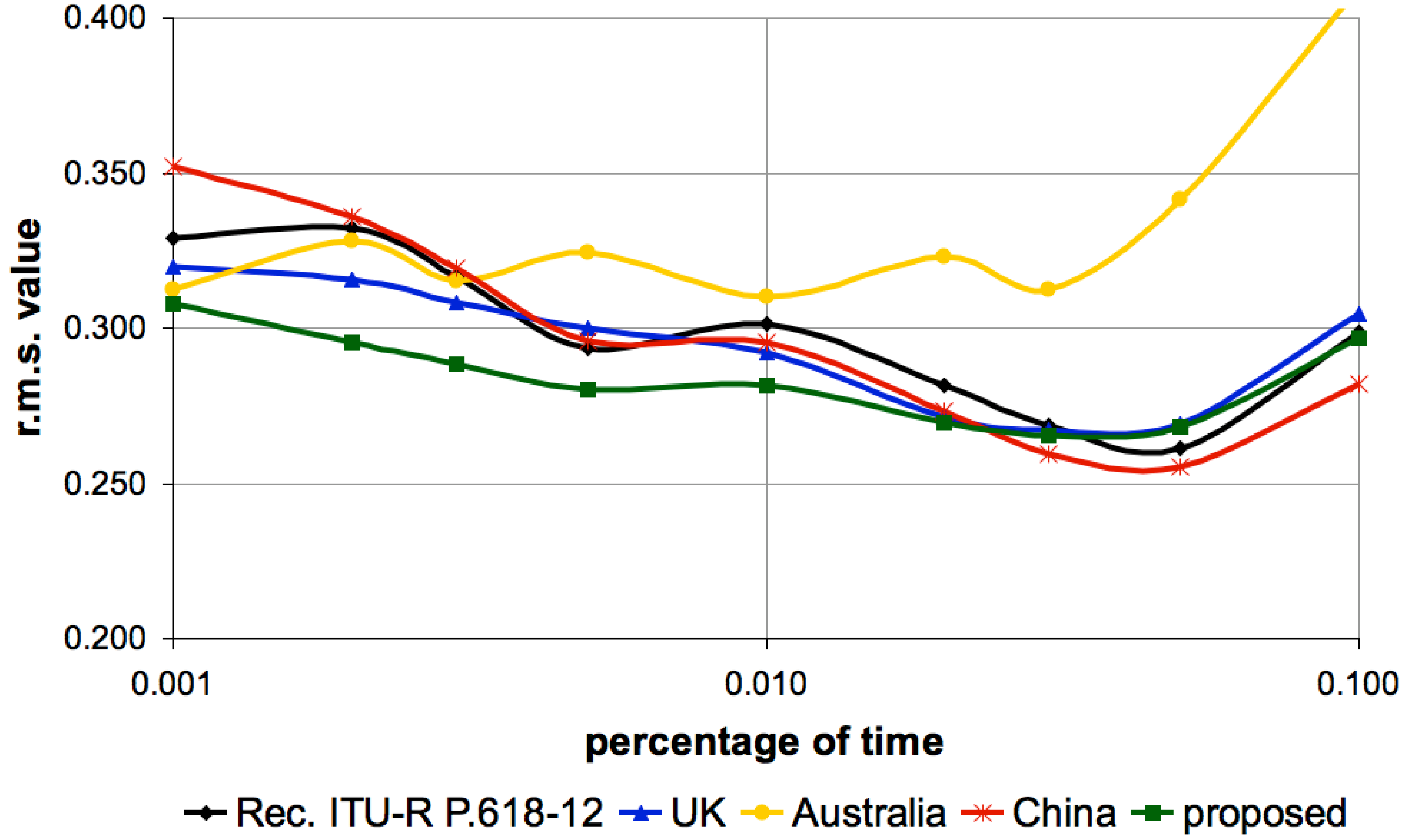
Slant path test results - average error



Slant path test results - standard deviation



Slant path test results - r.m.s error



Conclusions

- Test results indicate that the proposed method provides a large improvement over the current ITU-R method for terrestrial links.
- A significant improvement is also obtained for low percentages of time for Earth-space links.
- The proposed method is simple to apply and uses the full rain rate distribution to predict the attenuation distribution.
- The concept of an equivalent rain cell, which is the basis of the original ITU-R methods, is retained.
- The attenuation dependence on frequency is completely described by the parameters k and α.
- Consistency between the terrestrial and the slant path cases was achieved.