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Radio Link Clear-air Fading Prediction from Surface Weather Station Data

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Abstract **- We examine the empirical prediction of terrestrial radio link clear-air fading, and the use of parameters from surface weather stations as an alternative to, or in combination with, numerical weather prediction (NWP) reanalysis parameters. We achieve desired prediction accuracy from models employing only climatic data from surface measurements, which can be further improved with additional NWP parameters.**

Index Terms **— Prediction methods, microwave radio propagation, fading channels, multipath channels.**

1. Introduction

The limiting factor in the design of terrestrial radio links is the degree of signal fading that may be experienced under difficult conditions. Prediction of this fading severity establishes the system fade-margin required for the link to meet error performance and availability objectives. Below 10 GHz, clear-air fading, caused by the vertical radio refractivity gradient structure of the atmosphere, usually dominates this link fading.

In principle, numerical atmosphere models may be used to generate this radio refractive index structure, and the parabolic equation method used to predict the resulting link fading [1], although this requires years of high resolution predictions, making it impractical for link design.

Instead, an empirical model is used that is based on the correlation of the fade depth for 0.01% of the worst month of an average year with known parameters [2], fitting the model to a dataset of observed fading statistics [3].

2. Accuracy of the current ITU-R Multipath Model

In this study we test line-of-sight records provided in [3], which have coordinates suitable to estimate climatic parameters, with the mean 'flat-Earth' ray-line height above the terrain, H_{inf} .

There are 246 such records in the table collected prior to 2007, and for these the RMS error in the ITU-R model predicted 0.01% worst-month fade-depth, $A_{0.01\%}$, is 6.6 dB.

We add 81 more recent records; 3 from Turkmenistan, 8 from Kyrgyzstan added in 2007, 10 from Australia [5] and 60 more from Australia that have been prepared for submission to ITU-R. For these 81 records the RMS error in the current ITU-R model is 11 dB, as shown graphically in Fig. 1. The RMS error for all 327 records is 8.0 dB.

Two locations of observed severe fading, Julia Creek [4] and Rosewood [5], are marked on the Fig. 2 map.

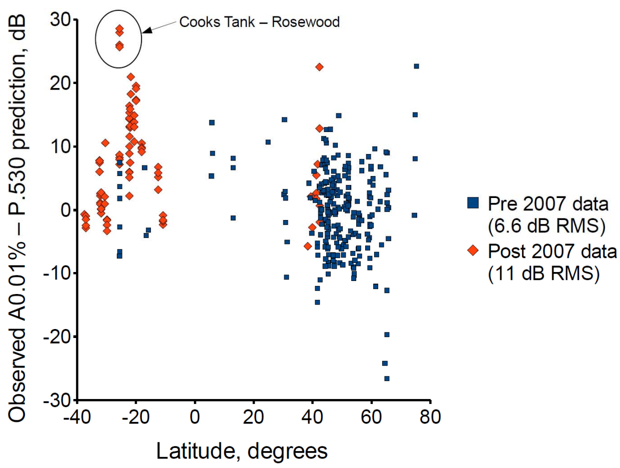

Fig. 1. Difference between observed and ITU-R predicted $A_{0.01\%}$ fade depth for the 327 paths in this study.

The current ITU-R multipath model [6] is

$$A_{0.01\%} = -24 + 34\log(D) - 10.3\log(1+|E_p|) - 0.027dN_1 - 0.0076H_L + 8\log(f) - 4.6\log(S_a+10), \quad (1)$$

where D : path length, km
E_p : path inclination, mr
dN_1 : 1% point of gradient to 65 m, N-units/km
H_L : elevation of lowest antenna, m
f : frequency, GHz
S_a : area standard deviation of terrain height, m.

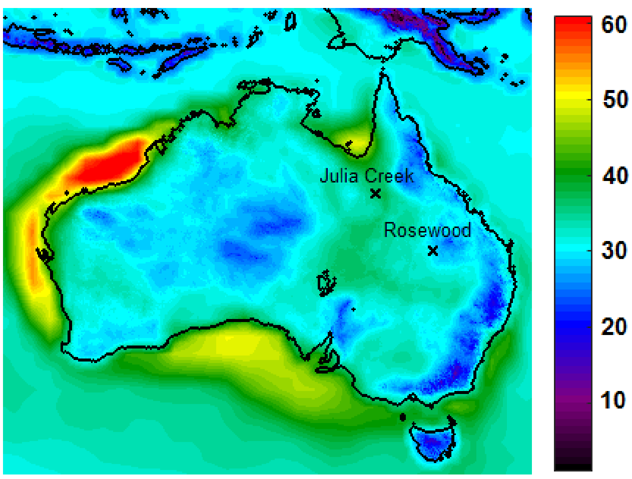

Fig. 2. ITU-R predicted $A_{0.01\%}$ fade depth, dB, for a notional 40 km 8 GHz link with 1.8 mr inclination, for Australia.

3. Development of a New Model

The original aim of our research was to find a practical sub-refractive model that could complement the existing Rec. P.530 multipath model [6]. An effective linear sub-refractive gradient over the whole path is generally assumed to exist for a small percentage of the time [4], [6], but non-linear sub-refractive gradients may produce greater diffraction loss for the same mean gradient [7].

In this paper, we explore the alternative of adding a sub-refractive parameter to the multipath fading model.

Our data source is the NOAA FTP site [8], for the years 2012, 2013 and 2014, interpolating for the path centre. From this time-series data we generate the parameter dN_{75mH}, the median year value of the Harvey model [4] worst-case 75 m vertical increase in refractivity.

The distribution of surface refractivity anomaly N_{sA} [9], [10], is also derived from this weather station data by subtracting the median surface refractivity for the same month and hour of the day from the current refractivity.

We use multiple linear regression, progressively adding the most significant predictor variables one by one [2]. The first variable chosen is a composite one, having a correlation coefficient of 0.781 with the observed $A_{0.01\%}$:

$$v_1 = (N_{sA90\text{-}10}{}^{0.3})(D^{0.5})/(H_{8500}{}^{0.25}), \qquad (2)$$

with $N_{sA90\text{-}10}$: interdecile range of N_{sA}

H_{8500} : mean ray-line height above terrain at 8500 km effective Earth radius,

leading to a model with 6.7 dB RMS error,

$$A_{0.01\%} = 2.42 + 5.405 v_1 . \qquad (3)$$

Path inclination next becomes most significant, then the 0.1% point of the N_{sA} distribution, $N_{sA0.1}$. We now have a model with 6.45 dB RMS error that only uses surface weather station time-series climatic data:

$$A_{0.01\%} = 6.64 + 4.24 v_1 - 6.71 \log(1+|E_p|) - 0.15 N_{sA0.1}. \qquad (4)$$

However the two-year NWP reanalysis parameter [2] dN_1, as currently used in the ITU-R multipath model (1), provides a useful accuracy improvement. Including $\log(D)$, we have a model with 6.1 dB RMS error,

$$A_{0.01\%} = -2.89 + 3.35 v_1 - 8.89 \log(1+|E_p|) - 0.139 N_{sA0.1} - 0.0146 dN_1 + 6.74 \log(D) . \qquad (5)$$

4. Harvey Model, ERA-Interim data, and Frequency

A composite of the Harvey sub-refractive parameter, and mean ray-line clearance, $v_2 = (dN_{75mH}{}^3)/(H_{8500}{}^2)$ next becomes significant. Despite its negligible impact for most links in the dataset, it contributes 12 to 14 dB to the prediction for the Cooks Tank to Rosewood cases. This is followed by H_L. The next parameter to become significant, $dN_{1\text{-}ERAI}$, a recent equivalent [11] to dN_1, is a surprise because it has an opposite sign to dN_1 in the regression fit!

Although $\log(f)$ has only weak positive correlation, $\log(f+6)$ is now significant enough to be included, giving

$$A_{0.01\%} = -20.26 + 2.04 v_1 - 9.19 \log(1+|E_p|) - 0.161 N_{sA0.1} - 0.0274 dN_1 + 18 \log(D). + 0.0615 v_2 - 0.003 H_L + 0.0356 dN_{1\text{-}ERAI} + 7.65 \log(f+6) . \qquad (6)$$

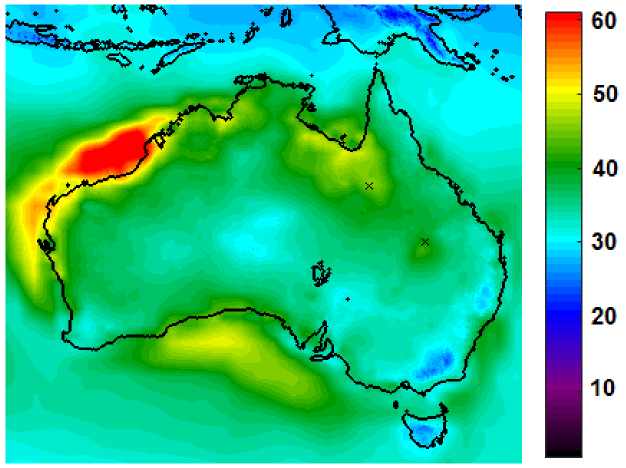

Fig. 3. New model A0.01% fade depth, dB, for a notional 40 km 8 GHz link with 1.8 mr inclination, for Australia.

The RMS error for the 81 post-2007 cases is now 4.1 dB, and 6.0 dB for the 246 pre-2007 cases, or 5.6 dB overall. Fig. 3 shows $A_{0.01\%}$ from (6), with notional H_{8500} = 80 m.

5. Conclusion

A new line-of-sight clear-air fading model combining data from surface weather stations with data from NWP models is demonstrated, with improved accuracy for inland Australia compared to the existing ITU-R model. Testing with additional data is required to verify this improvement.

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