ANALYSIS OF TROIS RIVIÈRES PROPAGATION MEASUREMENTS

by

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Contractor

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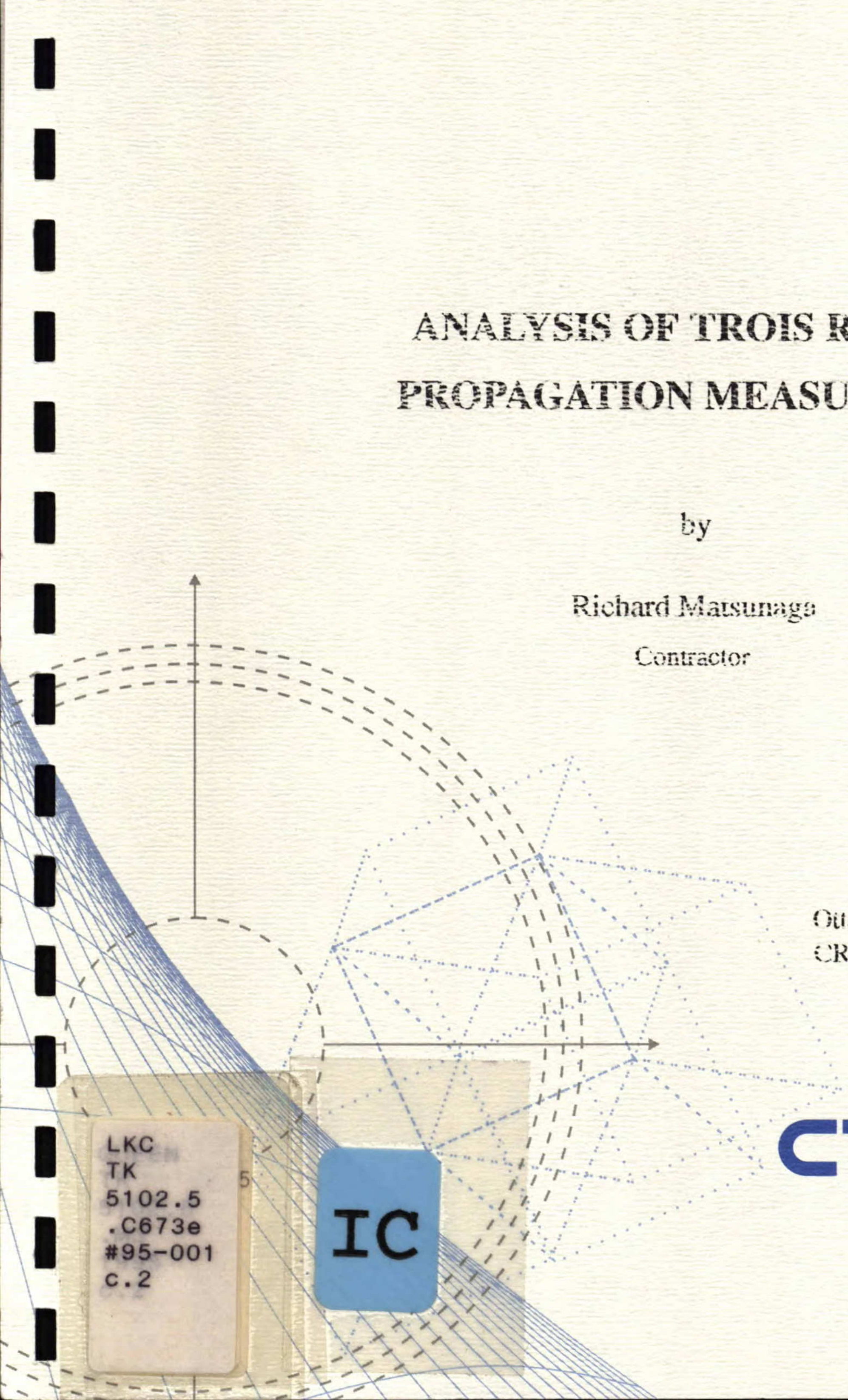

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Richard Matsunaga

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1. INTRODUCTION

1.1 BACKGROUND

In Canada, Digital Radio Broadcasting (DRB) is being implemented in the 1452 to 1492 MHz frequency band. DRB is expected to replace the current AM and FM radio services. A study of measurements in this frequency band was needed to improve prediction of area coverage. To this end, extensive measurements were made in the Trois Rivières area in the 1.5 GHz band by Industry Canada personnel (1).

The statistics of the signal variability due to terrain effects and distance from the transmitter need to be improved to reliably match the large coverage areas of the present broadcast stations. The sharp fade margin of DRB necessitates 90 or 95% service availability for both location and time, compared to the (50, 50) coverage of existing services.

1.2 OBJECT

This project has three main goals: to analyze the field strength measurements at 1.5 GHz and compare them to predictions computed with CRC PREDICT; to characterize the location variability of the measurements such that they can be predicted; and to create a subroutine which will perform the probability predictions. This report summarizes the analysis of these measurements and recommends a model for predicting the location variability of the radio signal.

2. THEORY

2.1 FADING

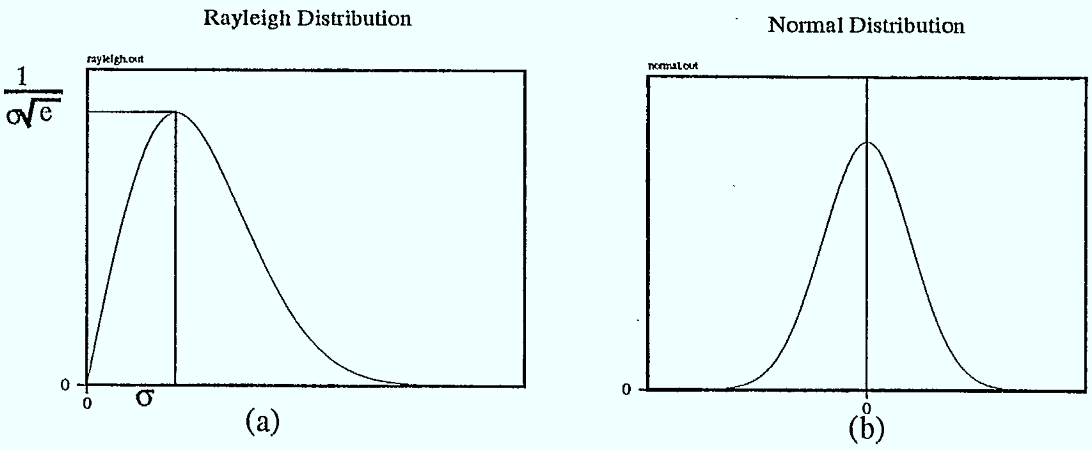
A typical mobile radio propagation situation shows two levels of fading: a fast fading signal superimposed on a slow fading signal. The fast variations are characterized by rapid and severe fading produced by multipath propagation in the vicinity of the receiver. This is caused by scattering of the signal from local obstacles, such as buildings, trees, cars, etc. The signal also exhibits a slow variation of the median signal strength due to the direct line propagation of the signal while the mobile unit is travelling (2).

The fast fading signal envelope is often characterized by the Rayleigh distribution (3, 4, 5). The probability distribution function (pdf) of the Rayleigh distribution is

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \qquad (1)$$

where r and σ are linear representations of signal strength (e.g. μV) (see Figure 1a). Okumura, et.

al. (4) suggests that signal strength data can be treated as a stationary Rayleigh process for distances up to 20 metres. This distance is known as a 'small sector'. Lee (2) has found that the proper length for a small sector is 20 to 40 wavelengths. Therefore, for 1.5 GHz, the appropriate small sector length is 4 to 8 metres. Fast fading is not of much concern to DRB because the system is designed to correct for multipath propagation.



(a) (b)

Figure 1: (a) Rayleigh Distribution (b) Normal Distribution

The slow fading is the variation of the small sector median signal with a change in position. This slow fading is generally represented by the log-normal distribution:

$$p(r) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(r-\mu)^2}{2\sigma^2}} \qquad (2)$$

where μ is the mean and σ is the standard deviation of the distribution (Figure 1b). In (2), r, μ and σ are signal strength representations expressed in decibels (dB) e.g. dBμV.

The location variability is the variation of the median signal strength over a small locality, where a small locality is any small distance such that the process can be considered statistically stationary. Okumura calculates the mean of the small sector medians over lengths of 1 km in his analysis. The standard deviation of this sample is the location variability.

2.2 VARIABILITY RESEARCH

While many authors consider the signal variability in their research, their primary goal was to characterize the shape of the distribution, not to investigate the behaviour of the variability. Okumura found that the variability is not closely connected with the base station antenna height or distance, but increases with an increase in frequency. In a suburban area at 1.5 GHz, he estimates a variability (standard deviation) of 9 dB (4). He also found that the standard deviation is higher in suburban and rolling, hilly terrain than in an urban area.

Parsons suggests that the variability increases as the degree of urbanization increases. This is contrary to Okumura's results, which are also supported by Parker and Roper (6), as reported by Parsons. They found the standard deviation to be higher in open areas than in residential areas. Reudink (7) discovered contradicting results from tests at 800 MHz and 11.2 GHz in Philadelphia and New York, where the variability decreased with range in Philadelphia but increased with distance in New York. He suggested that the local environment exerted a much stronger influence over the variability than did the range from the transmitter. Furthermore, Grosskopf (8) has observed that the standard deviation has a tendency to decrease over distance, approaching a value of about 3.6 dB at longer distances. Some typical values of location variability are summarized in Table 1.

Table 1: Previous Variability Research

Author	Region	Frequency (MHz)	Variability (dB)
Okumura	Suburban	1500	8.95
Okumura	Urban	1500	7.1
Parker & Roper	Open area	400	7.9
P & R	Suburban	400	4.6
Parsons	Heavy Urban	455	4.85
Parsons	Urban	455	3.9

Okumura's curves for urban areas give a standard deviation of about 6 dB, which is higher than both of Parsons measurements at 455 MHz. Also, for suburban areas at 400 MHz, Okumura predicts a variability of 7.5 dB, higher than results gathered by Parker and Roper.

2.3 CRC PREDICT & CRC TOPOGRAPHICAL DATABASE

CRC PREDICT is a VHF/UHF prediction program written by J. H. Whitteker at the Communications Research Centre in Ottawa. The program uses a detailed numerical integration method along with a detailed terrain database to calculate the field strength along a path.

The CRC Terrain Database (9) is a 500 metre grid defined on the UTM (Universal Transverse Mercator) co-ordinate system. At each point on the grid an elevation is stored, and a code indicating surface type is also stored wherever available. There are seven distinct surface types based on those found on any topographical map: bare ground, tree covered, lake, sea, marsh, urban and suburban. Any reference in this report to terrain types or elevation are obtained from the CRC database.

3. DATA ANALYSIS

3.1 DATA ACQUISITION

The transmitting system consisted of an RF signal generator feeding a power output amplifier producing an unmodulated carrier frequency of 1468.75 MHz at a power level of 250 watts.The measurements were taken in the Trois Rivières area using four different configurations: two tower heights (100 and 200 metres) and two antenna beamwidths (40° and 120°) The transmission parameters are given in Table 2.

Table 2: Transmission Parameters

a)	Antenna Gain	18.0 dBi
	Beamwidth	120°
	EIRP	15.8 kW
b)	Antenna Gain	22.5 dBi
	Beamwidth	40°
	EIRP	44.5 kW
Transmitter	Latitude	46° 29'27"
	Longitude	72° 39' 0"

A Rhode and Schwarz TS9957 Test System was used to measure mobile field strength. Data was sampled every 10 milliseconds, independent of vehicle speed. At a maximum speed of 100 km/h, the system took 4 samples per metre travelled. Also included in the receiving system were an antenna, a wheel mounted pulse generator to measure distance travelled, and a GPS receiver to give location data (1).

3.2 DATA PROCESSING

3.2a Raw Data

The data files were created by continuous runs in the measurement vehicle. The data was preprocessed by the Planning and New Technology group from Industry Canada into a simple form consisting of three columns: distance from transmitter, azimuth in degrees from north, and path loss in dB. The path loss value took three forms: good measurements, measurements that were adjusted for noise and measurements that were well into the noise, and thus, unusable. It was determined during analysis that the adjusted data must also be rejected because they were unreliable. All measurements beyond 100 kilometres are of little interest for this study and have not been used.

All analysis was performed with free space path loss removed from the data because it was of greater interest to examine effects of the local environment on the signal, without contending with the well known free space loss. The analysis procedure is summarized in Figure 2.

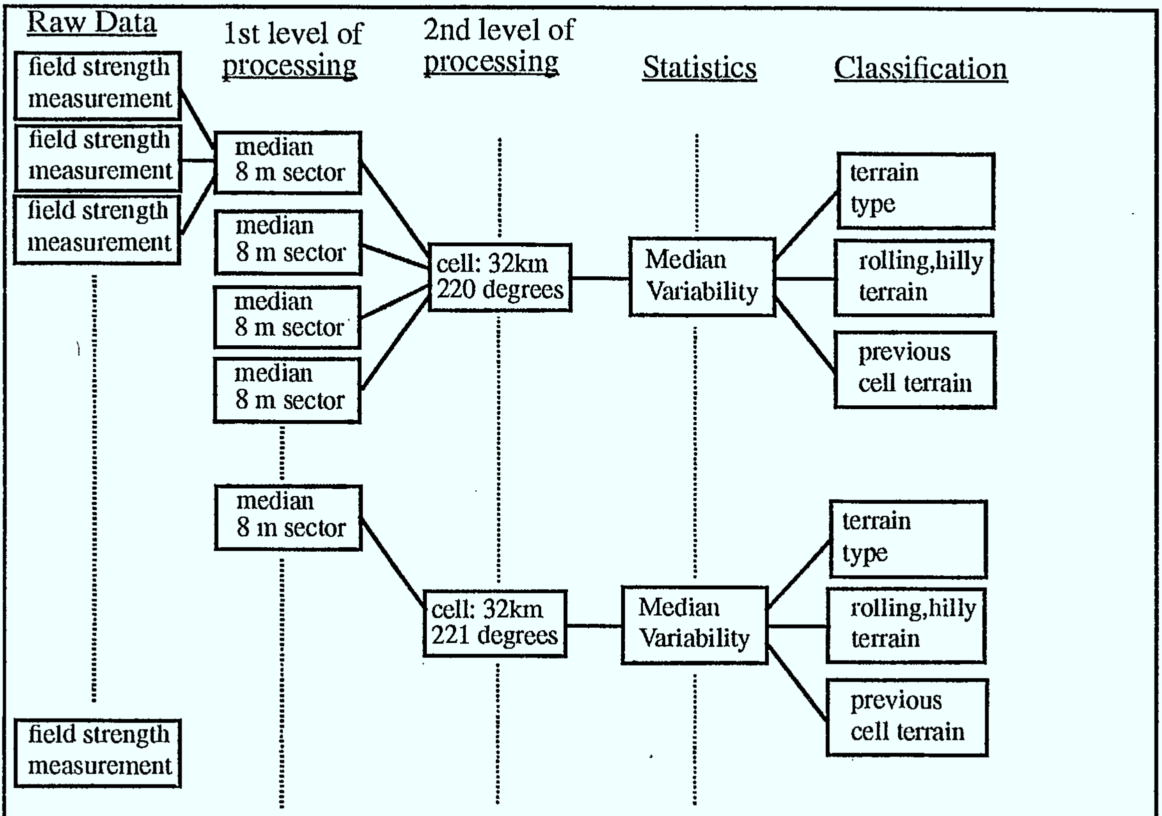


Figure 2: Data analysis procedure

3.2b Small Sector and Cell Processing

The small sector length selected for use in the analysis was 8 metres. This is the maximum distance recommended by Lee for 1.5 GHz, and was chosen to ensure a sufficient sample size for each small sector. The small sector medians were grouped into larger cells. Each cell is an area defined by polar coordinates with respect to the transmitting site. The cell size chosen was one kilometre along the radial by one degree of azimuth. This would give a cell size of roughly 1 km by 1 km at a distance of 60 km.

3.3c Statistics of Sectors and Cells

The median was used for the analysis, rather than the mean, to avoid skewing the results with the large number of unusable (noisy) data. Therefore, for each small sector, the median was calculated using all measurements. If the median of the small sector is an unreliable measurement, it was assigned a value of 999.9 dB and was still included in the sample for the appropriate cell.

Any cell with a median of 999.9 was rejected. This only occurs when greater than 50% of the cell sample were unreliable or unusable. This was justifiable because there is insufficient data in that particular cell from which any accurate conclusions could have been drawn. The same argument applied to cells which were never traversed by the measurement vehicle. It turns out that the vast majority of cells had enough good data to be included in the analysis.

The standard deviation of each cell's sample is the location variability of the signal in that region. For any cell that contains 100% reliable data, the standard deviation σ may be found as

$$\sigma^2 = \frac{1}{n+1}\sum_{1}^{n}(r-\mu)^2 \tag{3}$$

where μ is the mean of the sample and n is the sample size. If less than 100% reliable data is available, a graphical approximation is necessary. A distribution that is approximately normal (or lognormal) will appear as a straight line when plotted on normal probability paper. For a normal distribution, the standard deviation is the difference between the 15.87% level and the median (50%) level, and also the difference between the median level and the 84.13% level (the 84.13% may be found in any table of the normal distribution function Φ(z) under the entry z=1) (11). The standard deviation approximation was calculated using either a one-tail approximation or a two-tailed approximation (see Figure 3). The single tail approximation was calculated by subtracting the 15.87% path loss value from the median value, while the double tail averages the single tail approximation with the value obtained by subtracting the median from the 84.13% value. The rel-

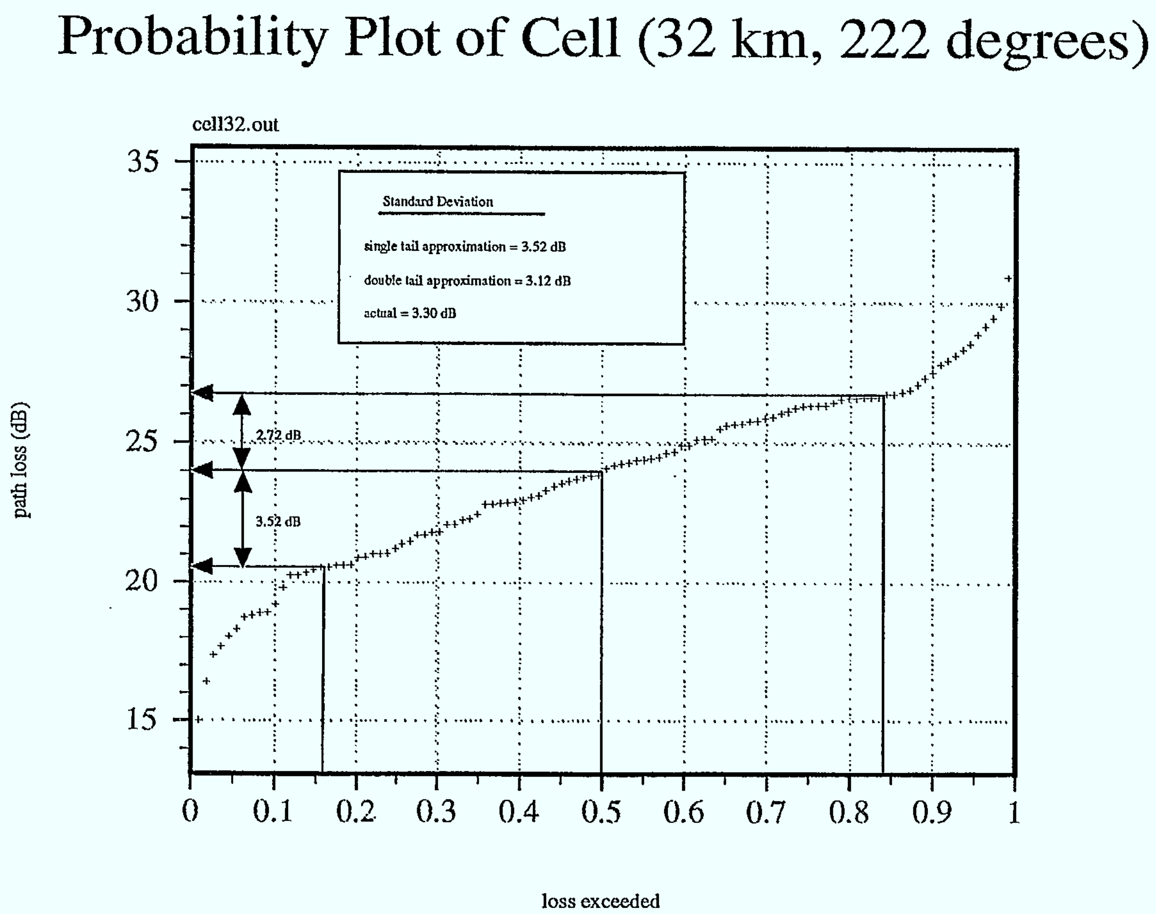


Figure 3: Standard Deviation approximations

ative error is given by (σ_{approx} - σ_{calc}) / σ_{calc} where σ_{calc} is obtained from equation (3). In the example shown in Figure 3, the relative error is 6.67% for the single tail approximation, and 5.45% for the double tail approximation. Figure 4 shows an example of cell with noisy measurements from which an accurate median and standard deviation can still be calculated.

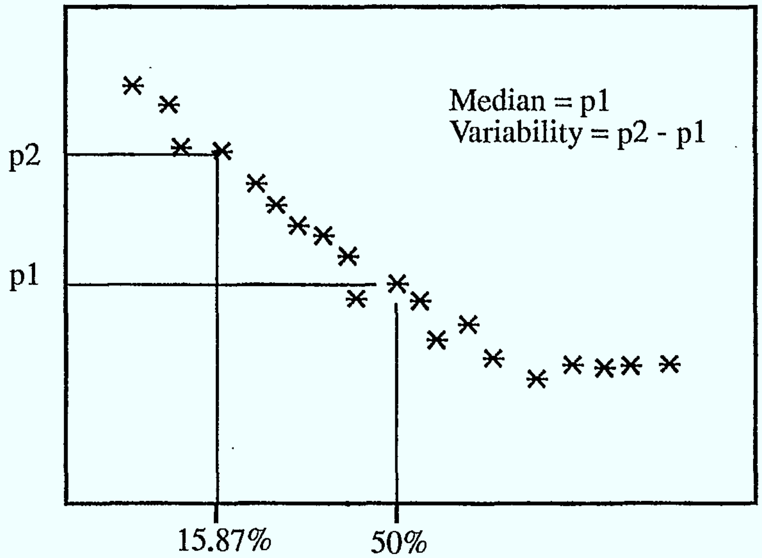


Figure 4: Example of a cell with measurements extending into the noise level. Median value is still accurate and a single tailed approximation is used for the variability.

3.2d Classification of the Location Variability

To characterize the variability of signal strength the cell data was grouped in many ways in an effort to find patterns. Groupings were made according to the cell terrain type, the terrain type of the adjacent cell back along the path towards the transmitter, the terrain roughness along the transmission path, and distance from the transmitter.

The terrain type of the cell was determined by obtaining the terrain types of all the database grid locations within a cell, and using the most common. This method was used since there may be multiple terrain types within a single cell at greater distances (>50 km). Terrain undulations are defined by Okumura (2) as the difference between the 10% and 90% terrain elevation levels within a distance of 10 km from the receiving point to the transmitting point. For the purposes of this analysis, rolling, hilly terrain was defined as any region with an undulation height (Δh) of greater than 60 metres. In addition, for terrain to be considered rough, there must have been more than one peak in the 10 km section. In other words, there must have been multiple diffraction taking place.

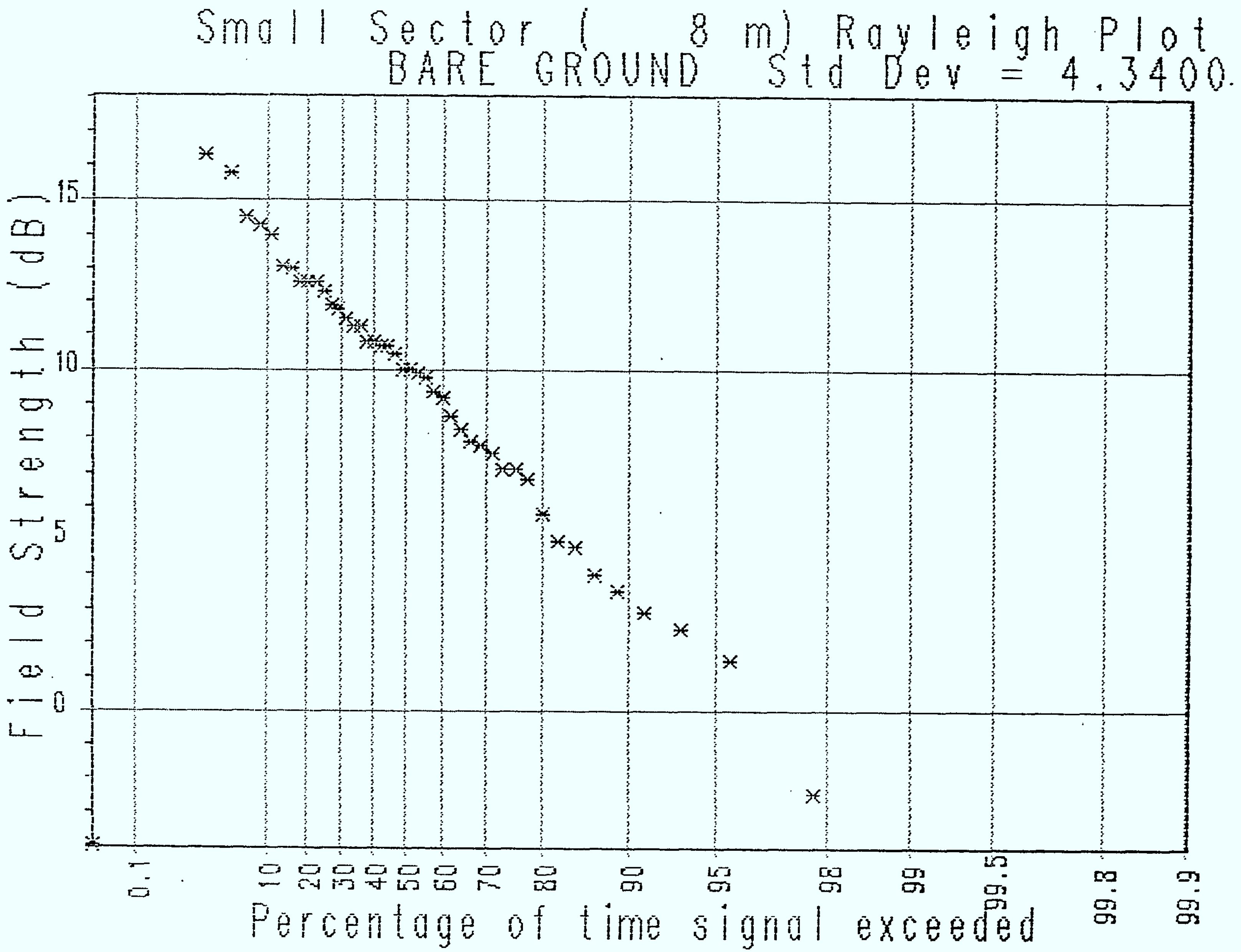


Figure 5: Rayleigh Probability Plot of Small Sector

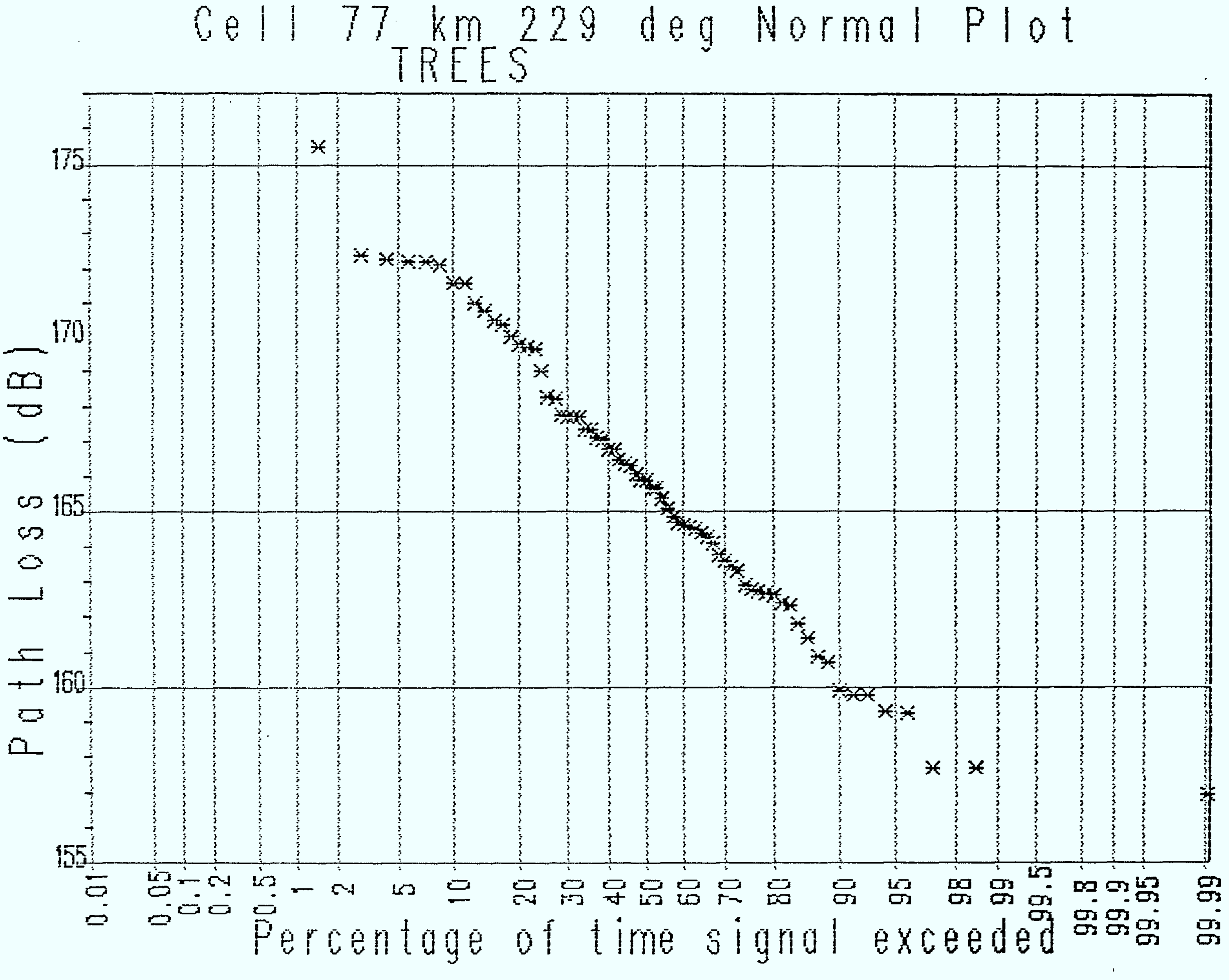


Figure 6: Normal Probability Plot of Cell

4. RESULTS

4.1 FADING CHARACTERISTICS

It has been widely reported that rapid variations of signal strength can be modelled as a Rayleigh distribution while slow variations are well approximated by the log-normal distribution (3, 4, 5). The two methods used to test these assertions were plotting the data on probability paper, and performing Kolmogorov-Smirnov goodness of fit test on all distributions.

A plot of a small sector on Rayleigh paper should be a straight line, while a cell plot should produce a straight line on normal probability paper. A small sample (0.01%) of small sectors were plotted and analyzed visually and a majority were predominantly straight on Rayleigh paper. There were slight curves to many of the plots. The tails of the plot usually strayed from the body, but overall, the Rayleigh distribution was the most convenient model for fast fading. A larger percentage (1%) of cell data was plotted on normal probability paper. As with the small sector data, the cell plots were generally straight. The exceptions were most likely due to terrain irregularities within the cell. On the whole, slow fading seemed to most resemble the log normal distribution. Figures 5 and 6 show, respectively, a Rayleigh plot of a small sector sample and a normal plot of a cell sample.

Kolmogorov-Smirnov (K-S) tests were performed for all sectors and cells used in the analysis. The K-S test measures the goodness of fit between a continuous theoretical distribution and an empirical distribution function. The K-S test outputs a value representing the absolute value of the largest deviation from the theoretical distribution and a significance level (10, 12). This test is more strict than the graphical analysis mentioned previously. For this reason, both the small sector distributions and the cell distributions did not compare well with the theoretical. However, it can be said that cell distributions resemble the log normal more than any other distribution. In addition, the K-S statistics suggest that small sector distributions are more similar to the log normal distribution than the Rayleigh.

4.2 PREDICTION ERROR ANALYSIS

4.2a Overall Error

The final cell statistics (median, standard deviation) were compared against predictions made using the computer program CRC PREDICT. Table 3 contains the average differences for each antenna/tower height combination as well as the overall difference.A positive field strength figure represents an optimistic predictions. It is evident that PREDICT gives optimistic predictions in most situations at 1.5 GHz. A positive variability difference means that PREDICT gives greater variability than measured.

Table 3: PREDICT ERROR

Antenna Beamwidth (degrees)	Tower Height (metres)	field strength difference (dB)	variability difference (dB)
40	200	8.82	1.16
120	200	7.36	1.16
40	100	6.66	0.71
120	100	5.15	1.06
Overall	---------------	6.74	1.04

4.2b Error by Surface Type

To characterize the differences further, each cell has been grouped according to its surface type. The overall mean differences by surface type are shown in Table 4.

Table 4: Mean field strength prediction error by surface type.

surface type	#cells	difference (dB)
tree cover	969	1.90
bare ground	3169	8.15
water (fresh)	142	8.76
marsh	75	7.61
suburban	39	3.77

4.2c Error by Distance from Transmitter

Next, the prediction errors have been grouped into sections determined by their distance from the transmitter. Each section is 10 kilometres long, i.e. in this case, the sections would be 0-10 km, 10-20 km, 20-30 km, etc. Figure 7 shows the results of this grouping, with the plots smoothed to aid in viewing. The largest difference (~13 dB) occurred in open areas and lake areas at approximately 30 kilometres from the transmitter. Thus, it appears that the greatest error in prediction occurred in cells defined as bare ground, fresh water, or marsh areas. The two surface types with the greatest number of interference obstacles, trees and suburban, have much lower mean prediction errors. There are two (optimistic) peaks in the error for all terrain types at approximately 25 km and 85 km. A puzzling characteristic is that the prediction becomes pessi-

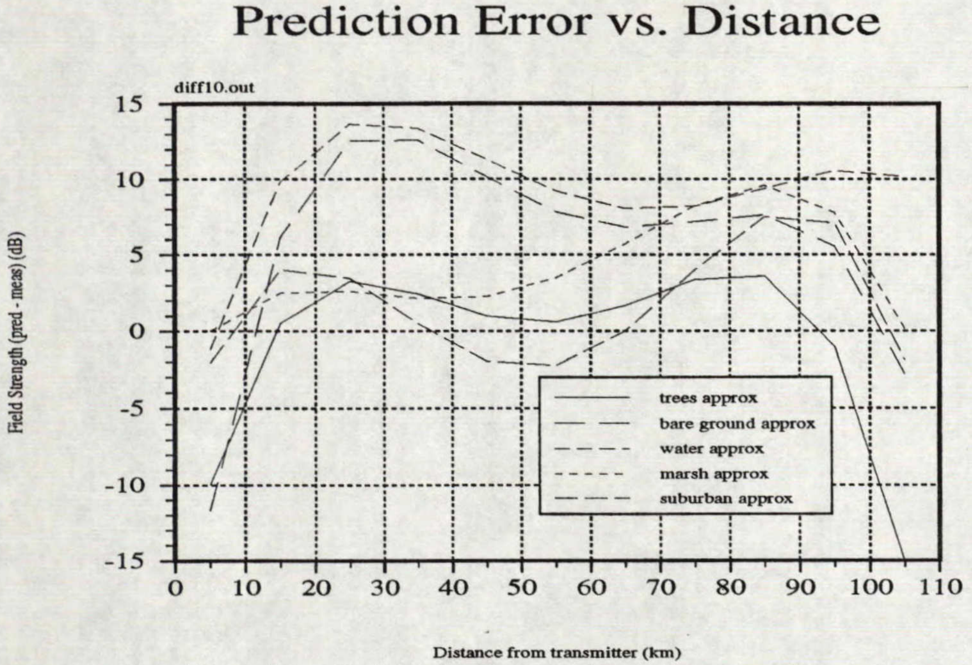


Figure 7: Prediction error grouped in to distance sections and different terrain types.

mistic for forested and bare areas at less than 15 km and for forested areas at distances greater than 95 km.

A couple of typical azimuths for this data set are shown in figures 8 and 9. A 4/3 earth approximation was used to draw the terrain. Blocks representing trees and buildings are drawn above the terrain. The transmitter is located on the left hand y-axis. The dotted line represents the predicted path loss values, while the stars (*) are actual measurements made at that location. The variability is also shown by error bars for each measurement.

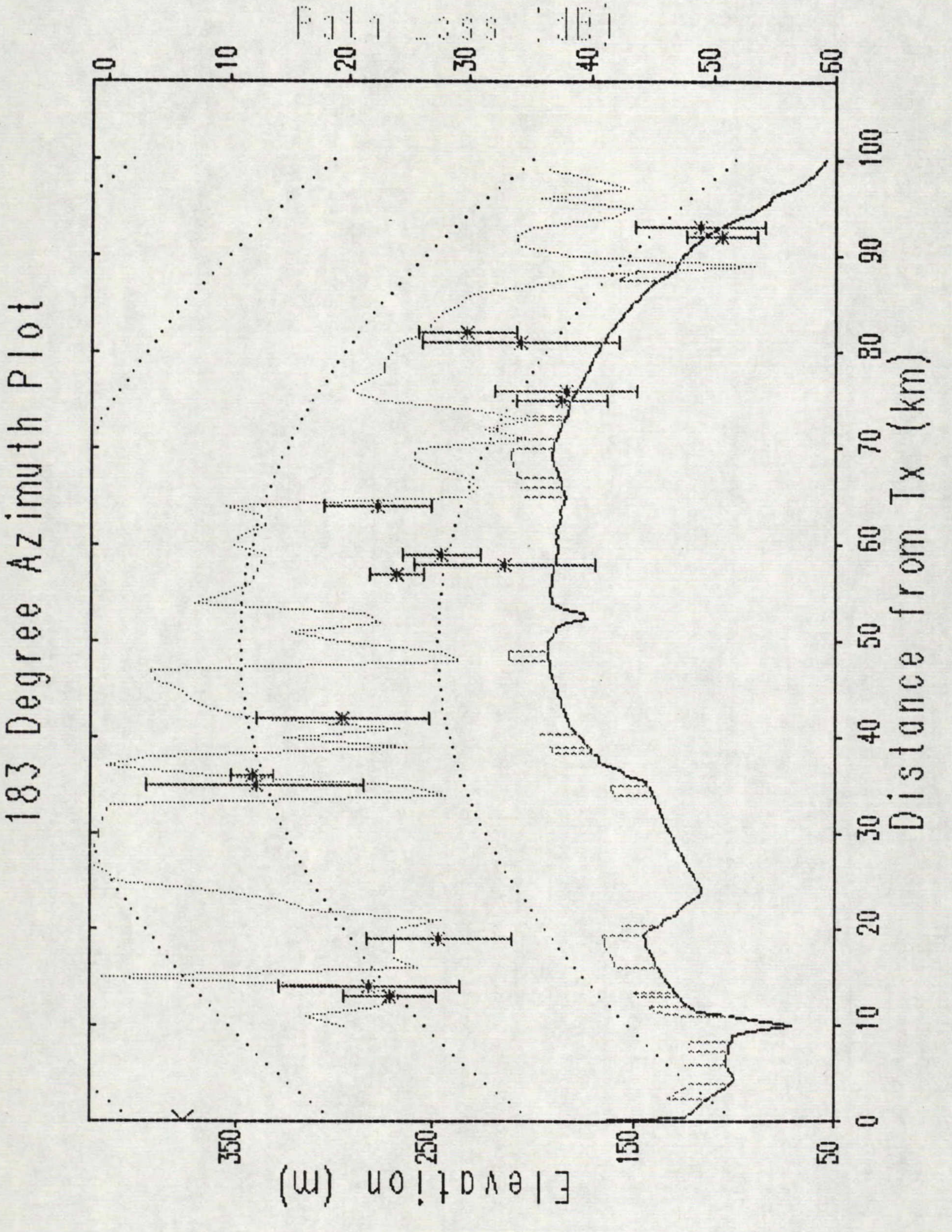


Figure 8: Plot of Predicted and Measured Path Loss for single azimuth

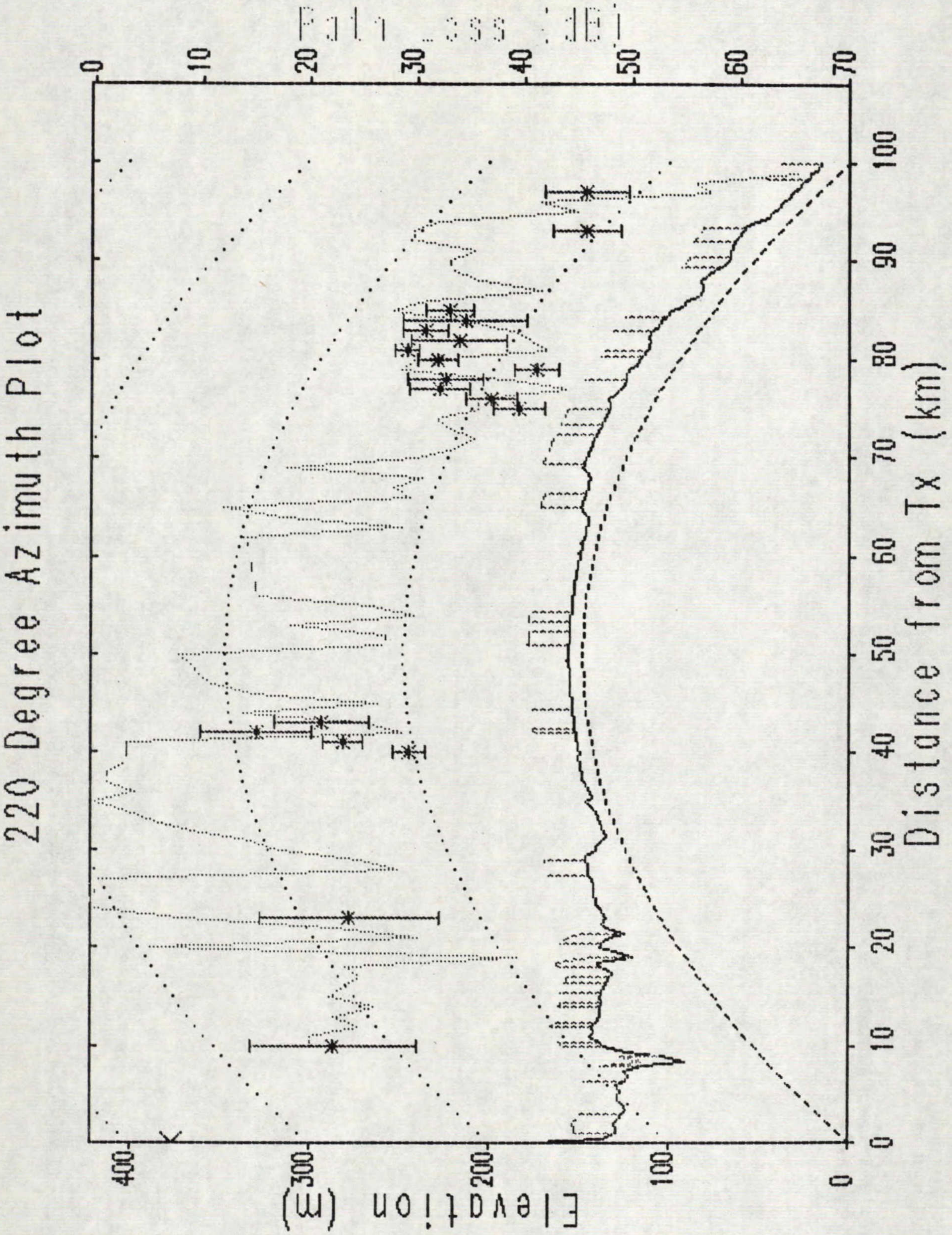


Figure 9: Plot of Predicted and Measured Path Loss for single azimuth

4.3 VARIABILITY ANALYSIS

To characterize the variability of the signal level at 1.5 GHz, there were many ways to group the data to find patterns. The groupings that have been implemented here are: surface type of the cell; surface type of the preceding cell; rolling, hilly terrain; and distance from transmitter.

4.3a Surface Type of Cell

The variability by surface type comparison is given in Table 5. It is not immediately obvious whether the surface type had any effect on the variability. Both forested and bare areas have quite large samples and there was only a 0.7% difference between them. Water and marsh cells are both about 15% lower than both forested and bare cells.

Table 5: Effect of Surface Type on Variability

Surface Type	# of cells	Mean Variability (dB)
Tree cover	969	4.24
Bare ground	3169	4.27
Water (fresh)	142	3.72
Marsh	75	3.65
Suburban	39	4.35

4.3b Preceding Cell Surface Type

If there are sufficient scattering objects in the propagation path, it is conceivable that this would increase the variability, just as local scatter increases multipath. The effect of the preceding cell's surface type is investigated here. The preceding cell is that which the signal would pass through before entering the cell being analyzed. Figure 10 shows the effect of the preceding cell. A more detailed table of data is included in Figure 1 in Appendix A.

There is some evidence that the opposite of the above speculation is true. In some cases, cells which are preceded by relatively open areas (bare ground, water, marsh) had a larger variability than with cells that are preceded by many scattering objects (treed areas, suburban). However, this was not a consistent pattern.

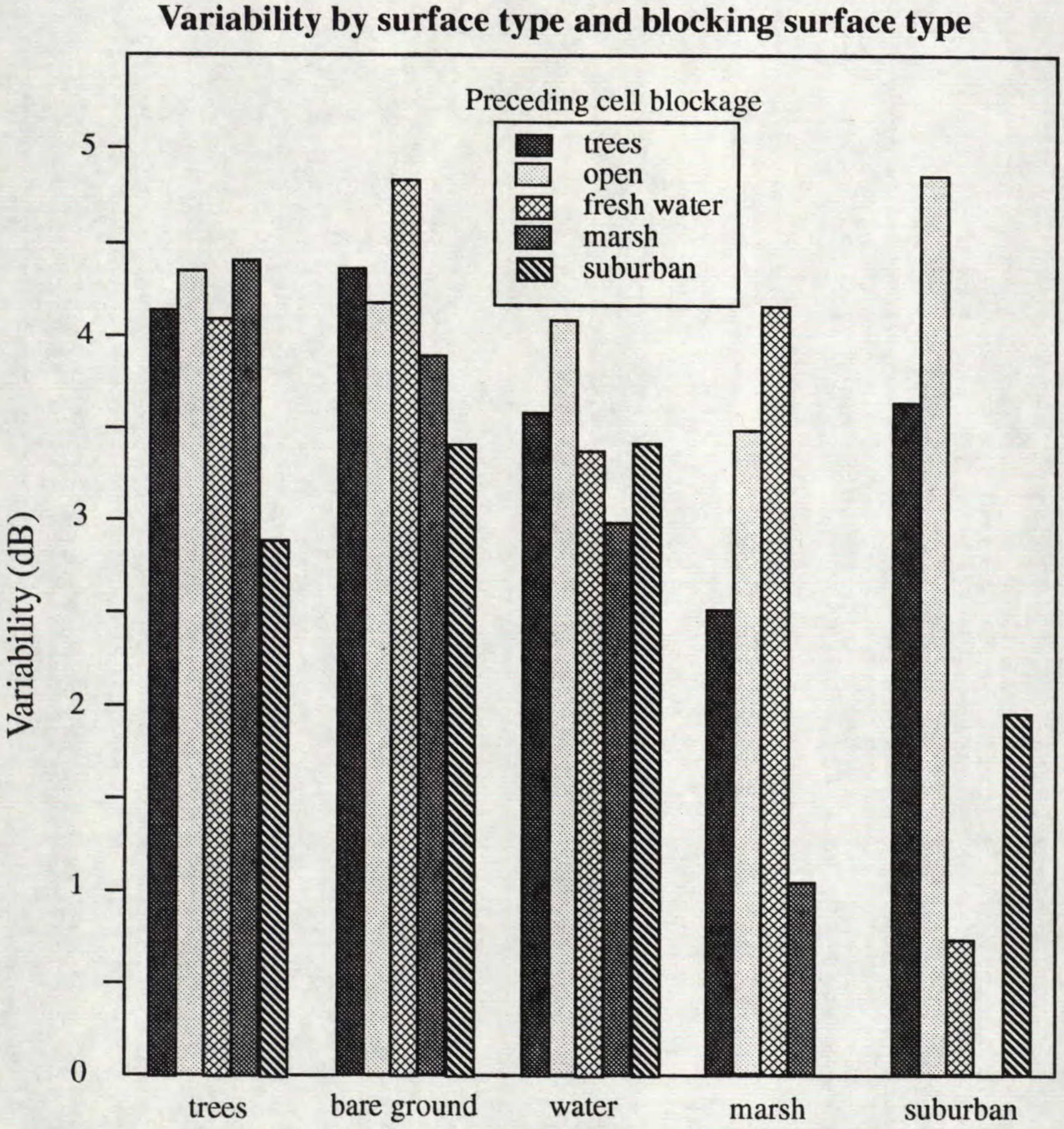


Figure 10: Effect of preceding cell surface type on the signal variability

<u>4.3c Rolling, Hilly Terrain</u>

Rolling, hilly terrain was defined in section 3.2 above. For this analysis, data was grouped by surface type and then divided into two groups: hilly and not hilly. Again, hilly terrain is terrain with a Δh of 60 metres or greater. The results of this analysis are shown in figure 11.There are very few areas in this data set that had rolling, hilly terrain. The majority of these cells were to the west of the transmitter site in the hills, where few measurements were taken. The majority of the coverage area was flat terrain, with a gentle slope towards sea level. From this limited data set, it appears that hilly terrain along the propagation path will actually reduce the variability.

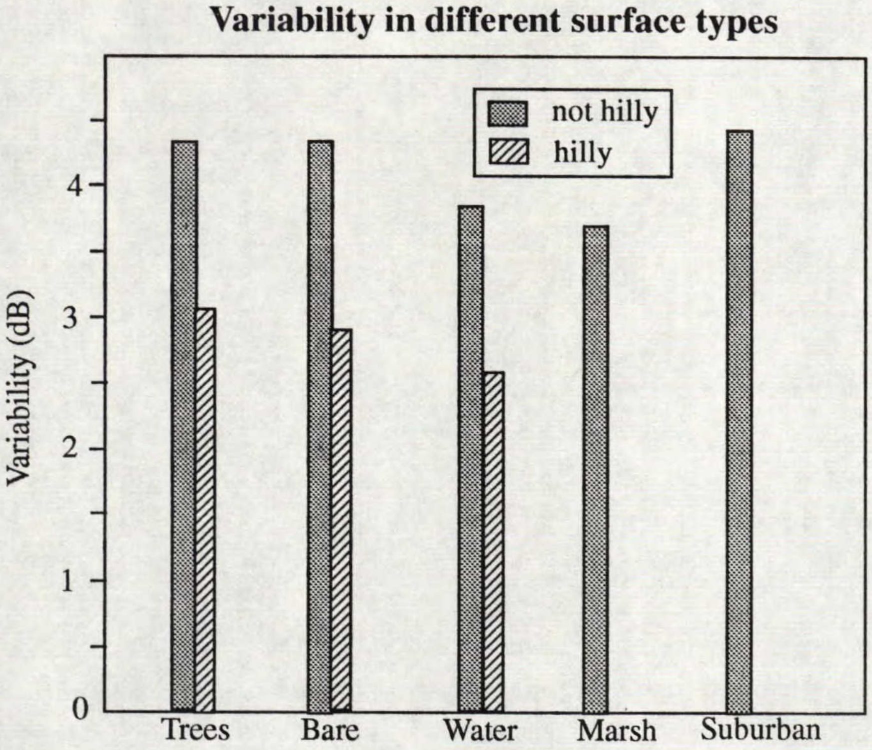


Figure 11: Effect of rolling, hilly terrain on variability

4.3d Distance from the Transmitter

As with the prediction error analysis, the measured variability data was grouped into sections defined by distance from the transmitter. After some trial and error, the clearest results were achieved using sections with a length of 12 kilometres. Figures 11-14 show the results of this analysis. Each plot is accompanied by a second order polynomial fit to the data. The plots have been separated to avoid confusion, but all axes are scaled identically to allow comparison.

The variability is decreasing with distance in all plots except for the suburban case, which had much less data than the other cases. In the analyses above, there did not appear to be any differences in the variability between cells with different surface types. The largest variability occurs in bare ground areas. The forested areas has a variability which is lower than that of bare areas by about 0.5 dB up to 50 km and then the difference decreases gradually to zero at 95 km. In fresh water areas, the variability approximation closely follows that of the forested areas' curve. The variability in marsh areas is lower than that of bare areas by as much as 1.5 dB at 50 km, with smaller differences before and beyond 50 km. A lack of data has produced a less satisfying approximation for suburban areas. The variability seems to rise with increased distance from the transmitter, but its average variability is close to that of both forested and bare ground areas.

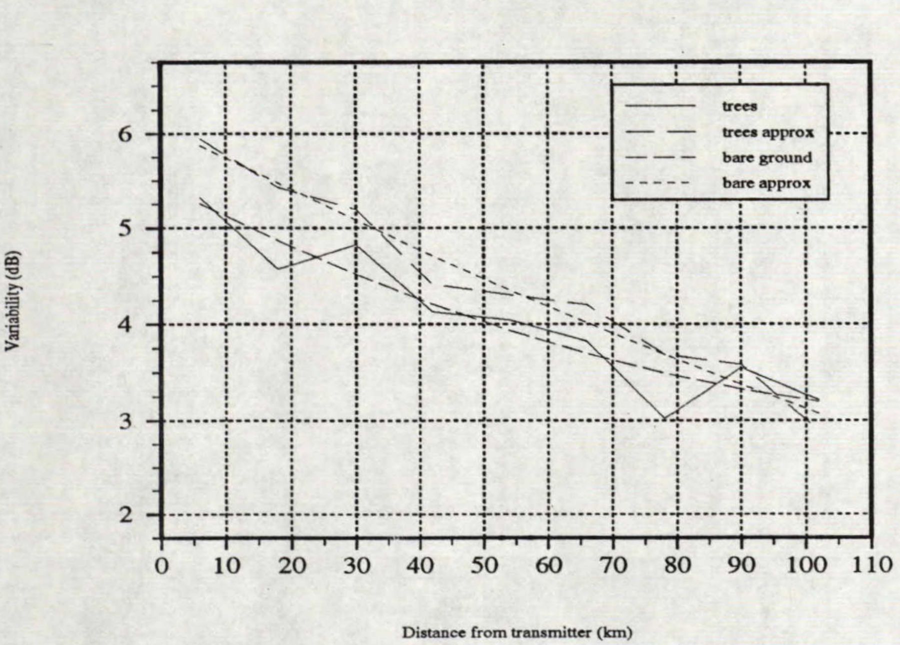


Figure 12: Variability in treed and bare areas by distance

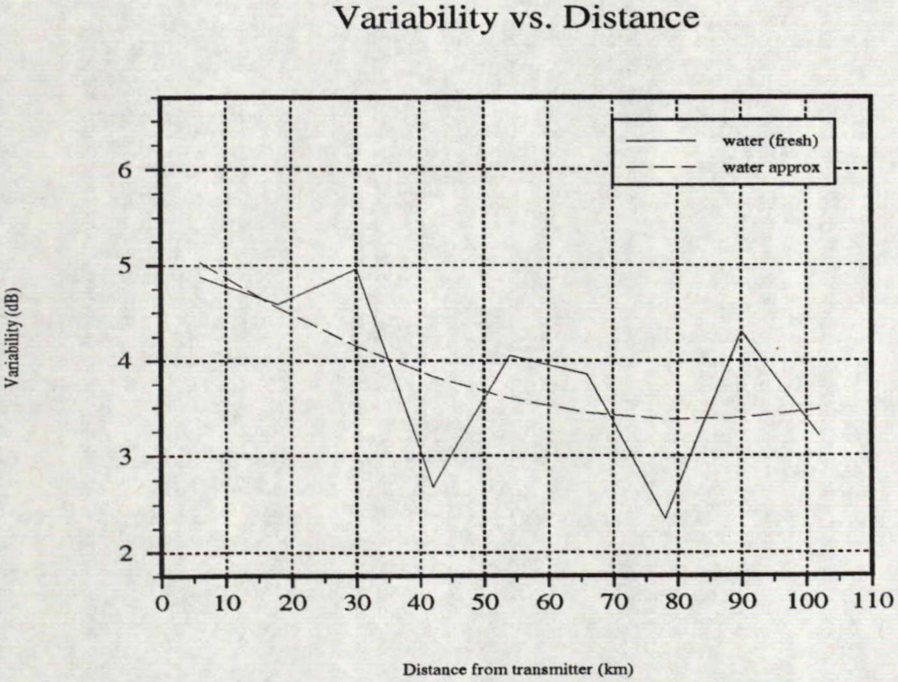


Figure 13: Variability in fresh water areas by distance

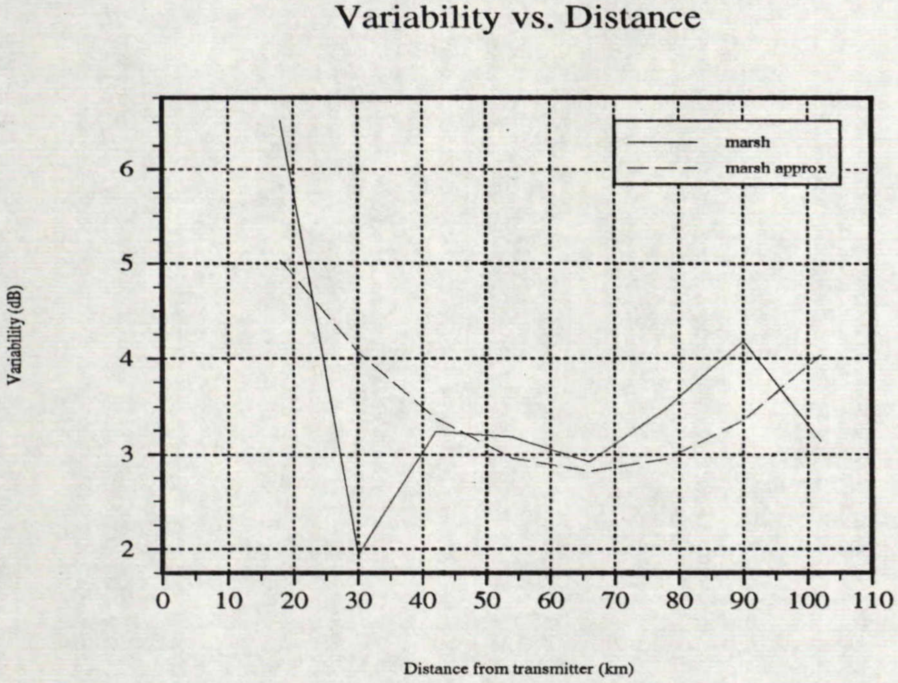


Figure 14: Variability in marsh areas by distance

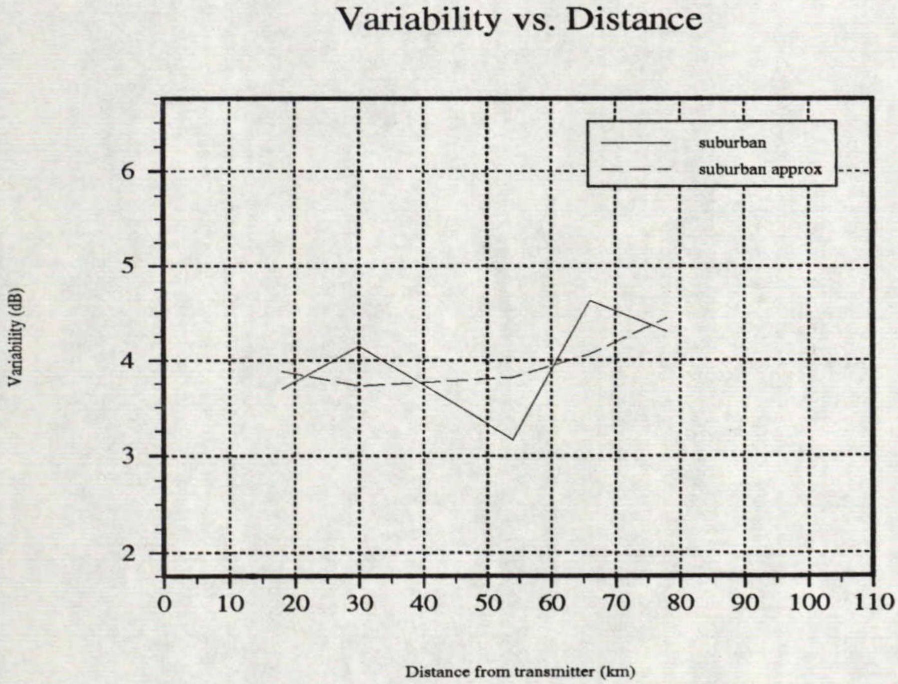


Figure 15: Variability in suburban areas by distance

5. DISCUSSION

5.1 TERRAIN DATABASE

The Trois Rivières data includes extensive coverage of forested and bare ground areas. There are also measurements taken in areas defined by the terrain database as marsh and fresh water areas. It is not obvious what sort of terrain is being traversed with the latter two. It is certain that the measurement vehicle was travelling on a road, therefore it was not actually on the water, but travelling beside a lake or river. On the other side of the vehicle is some other type of terrain, which, in the majority of cases, is not water. In the measurement area, there are one or two cells in which the vehicle passed over the river on a bridge. The same reasoning applies to marsh areas as well; precise terrain details are not known with a 500 metre database.

5.2 PREDICTION ERROR

There is an overall error of 6.7 dB. As shown in Table 3, the error is greatest in water, bare ground, and marsh areas, and is much smaller in forested and suburban areas. Intuitively, the error would be larger for forested and suburban areas, due to the larger number of obstacles affecting the signal, and the difficulty in modelling such complex situations. However, since the prediction is best in these situations, it is possible that less frequent obstacles that cannot be represented in the terrain database can have a significant influence on the received signal strength at this frequency.

The error by distance from the transmitter (Figure 7) also suggests that the local terrain has an effect on the signal strength that cannot be represented in the 500 metre database. The peaks in prediction error occur at approximately the same distance for each terrain type, suggesting that some local terrain feature, such as hilly terrain or large, unknown obstacles, is causing the signal strength to be lower than would be expected (thus making the prediction more optimistic).

5.3 VARIABILITY

While the terrain type of the local area doesn't seem to have any effect on the signal variability, there is some evidence here that suggests that rolling, hilly terrain does have some effect. An intuitive assumption is that areas with more blockage and scattering objects would increase the variability in that location. However, the data shows that the opposite may be true. Variability along a path defined as ‘hilly’ in this analysis is lower than for non-hilly paths (Figure 10). Further analysis in hilly terrain is required to verify this effect.

The effect of the preceding cell's terrain type shows no clear patterns and may have no predictable effect on the variability (see Figure 9). As mentioned above, there is much less data for marsh, fresh water and suburban areas than for forested and open areas.As a result, some of the results in figure 9 are drawn from a very small sample.

There is a definite correlation between the variability and the distance from the transmitter. In all but the suburban case, the variability decreased over distance. Very smooth curves were produced for forested and bare ground cells illustrating this effect (Figure 11). Smaller sample sizes produced more choppy curves for the remaining cells, though the same pattern is evident (Figures 12-14). The approximation curves in the above figures are second order polynomials of the form

$$v = k_0 + k_1 d + k_2 d^2 \qquad (3)$$

where v is the variability in decibels and d is the distance from the transmitter in kilometres. The values of the coefficients are given in Table 6.

Table 6: Variability Models

Terrain type	k_0	k_1	k_2
Trees	5.463186375	-0.035200042	0.000127495
Bare Ground	6.083009889	-0.034802956	5.2406494e-5
Water	5.301087008	-0.046881350	0.000285218
Marsh	6.985521613	-0.125767947	0.000949364
Suburban	4.36708579	-0.035257360	0.000464875

While it is difficult to compare these results with those of previous researchers, the variability measured in the Trois Rivières area seems to be lower than that found by Okumura. Parker and Roper's 7.9 dB variability in open areas is much higher than the bare ground results in Trois Rivières. In addition, the variability is influenced by the distance from the transmitter, which is contrary to Okumura's findings.

6. RECOMMENDATIONS

The Trois Rivières measurements provide excellent coverage of forested and open areas. The analysis above could be used to improve the prediction of field strength and signal variability at 1.5 GHz in these areas. The variability curves in Figure 11 (Table 5) could be used as a model.

The much smaller samples of marsh, fresh water and suburban areas provide some clues to the behaviour of the radio transmission at this frequency, but should only be used to prompt further measurements and analysis in these areas. It is especially important to further characterize the behaviour of signals in a suburban area, since most digital radio reception will likely occur in this medium. Since there are a large amount of cells in areas defined as marsh or fresh water in the topographical database, more information should be gathered about these areas, such as the type of scattering objects (if any) commonly found.

A subroutine in the C language has been written which will calculate the predicted variability and provide a path loss adjustment for area coverage. The variability prediction uses the models in Table 5. Inputs to the subroutine are: terrain type, distance from the transmitter, and the percentage signal exceeded. The source code is included in Appendix B.

7. REFERENCES

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APPENDIX A

Tables of Data for Figures 10 and 11

Table 1: Effect of Preceding Cell on Variability

Surface Type	Blocking Surface Type	#cells	Mean Variability (dB)
Tree cover	Tree cover	609	4.185
	Bare ground	327	4.351
	Water (fresh)	13	4.148
	Marsh	17	4.402
	Suburban	3	2.907
Bare ground	Tree cover	474	4.363
	Bare ground	2547	4.244
	Water (fresh)	80	4.808
	Marsh	34	3.863
	Suburban	34	3.428
Water (fresh)	Tree cover	18	3.577
	Bare ground	49	4.134
	Water (fresh)	59	3.409
	Marsh	8	3.021
	Suburban	8	3.457
Marsh	Tree cover	7	2.617
	Bare ground	31	3.635
	Water (fresh)	13	4.211
	Marsh	24	3.679
	Suburban	0	----
Suburban	Tree cover	2	3.695
	Bare ground	26	4.850
	Water (fresh)	8	3.711
	Marsh	0	----
	Suburban	3	2.207

Table 2: Effect of Hilly Terrain on Variability

Terrain Type	Mean Variability - Hilly (dB)	#cells	Mean Variability - Not hilly (dB)	# cells
Trees	3.0167	27	4.2724	942
Bare Ground	2.8496	25	4.2781	3144
Fresh Water	2.5475	4	3.7522	138
Marsh	--	0	3.6540	75
Suburban	--	0	4.3541	39

APPENDIX B

Source Code for Variability Subroutine

```
#include <stdio.h>
#include <math.h>
#include "rich.h"

typedef struct variab {
 float variab;
 float adjust;
} VARIAB_OUT;

VARIAB_OUT Variability_Adjust(int terrain, float percent,
    float distance)
/*%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
     This function will calculate the adjustment to be made to a
     path loss prediction given the %age signal exceeded, the
     terrain type and the distance from the transmitter.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
*/
{
    const double K0[8] = { 0, 5.463186375227, 6.083009888633,
                           5.301087008484, 4.36708579304,
                           6.985521613169, 0, 0 };
    const double K1[8] = { 0, -0.035200042041, -0.034802956534,
                           -0.046881351722, -0.035257359722,
                           -0.125767947456, 0, 0 };
    const double K2[8] = { 0, 0.00012749523, 5.2406494034e-5,
                           0.000285218269, 0.00046487528635,
                           0.000949364143872, 0, 0 };

    float      n=0, sum=0.5, pre, cutoff;
    VARIAB_OUT results;

    results.variab = K0[terrain] + K1[terrain] * distance +
                        K2[terrain] * distance * distance;

    result.adjust = -results.variab * sqrt(2.0) * Erfinv(percent);

    return results;
}
```

Analysis of Trois Rivieres
propagation measurements