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English summary

Propagation measurements at VHF (30-88 MHz) and UHF (225-400 MHz) were conducted in Norwegian terrain in 2014 as a collaborative project between the Communication Research Centre (CRC) Ottawa, Canada, and FFI. The purpose was to gain knowledge about what requirements that must be set to a wideband waveform operating in Norwegian terrain. The main results concerning multipath propagation are to be published at Milcom 2015.

To support the planning of the measurements, the prediction tool WinProp [1] from AWE Communications, Germany, was procured. This report compares measurements of path loss with predicted path loss from different propagation models implemented in WinProp. The comparisons are limited to one frequency, 312 MHz, and three geographical locations in eastern Norway.

The models available in WinProp that have been compared are the empirical Okumura-Hata model and Longley-Rice area mode model (Irregular Terrain Model), and the deterministic/empirical ITU Rec P.1546 model, Longley-Rice point-to-point model (Irregular Terrain Model), Dominant Path model (AWE proprietary) and Two-Ray model (AWE proprietary). The model parameters have been selected based on best guess and without any tuning to best fit the measurements.

Generally, the prediction accuracy of the different models in the terrain that has been measured is not very high. For the best fitted model over all the measurements at the three locations, the mean difference can be up to 15 dB with a standard deviation of 5 dB. However, the accuracy is better for some models at a particular location with certain characteristics.

If there are mainly line-of-sight conditions, the deterministic models taking terrain features into account (Longley-Rice point-to-point, Okumura-Hata with diffraction and ITU Rec P.1546) perform best. When multipath is expected, the empirical model Longley-Rice area mode is the best choice, and also the Two-Ray empirical may be used. The accuracy of these models when selected based on the conditions mentioned above, can be approximately 2-3 dB and standard deviation 5-6 dB.

The use of these models in radio planning should be used with care, honoring the fact that the selection of parameter values change the predictions with many dBs, and that multipath propagation causes a very difficult propagation environment to model. This study did not find one propagation model that was clearly the best model to use in all the terrains that were considered.

Sammendrag

I 2014 ble det gjort radiobølgeutbredelsesmålinger i norsk terreng i VHF-frekvensområdet (30-88 MHz) og UHF (225-400 MHz). Hensikten var å kartlegge nødvendige krav som må stilles til en bredbåndsbølgeform som skal operere i norsk terreng. Dette var et samarbeidsprosjekt mellom Communication Research Centre (CRC) i Ottawa (Canada) og FFI. Hovedresultatene fra målingene angår flerbaneutbredelse og blir publisert på Milcom 2015.

For å støtte disse målingene ble et prediksjonsverktøy for radiobølgeutbredelse, WinProp [1], kjøpt fra AWE Communications i Tyskland. Denne rapporten sammenligner målinger av propagasjonstap (tap av signalenergi mellom sender og mottaker) med prediktert propagasjonstap fra forskjellige modeller som er implementert i WinProp. Sammenligningene begrenser seg til én frekvens, 312 MHz, og til tre geografiske områder i Øst-Norge.

Modellene som er tilgjengelige i WinProp og blitt sammenlignet, er de empiriske modellene Okumura-Hata og Longley-Rice area model (Irregular Terrain Model), og de deterministisk/empiriske ITU Rec P.1546, Longley-Rice point-to-point (Irregular Terrain Model), Dominant Path model (AWE proprietær) og Two-Ray model (AWE proprietær). De valgbare inngangsparameterne som inngår i den enkelte modell, har blitt valgt ut ifra best vurdering av det terrenget målingene ble foretatt i, og de er ikke forsøkt “tunet” til å gi best mulig overensstemmelse med målingene.

Generelt er ikke prediksjonsnøyaktigheten til de forskjellige modellene særlig høy i de terrengene som er blitt målt. For den beste modellen sett over alle dataene i de tre terrengene som er blitt målt, er gjennomsnittlig differanse mellom måling og prediksjon opp til 15 dB med et standardavvik på 5 dB. Men nøyaktigheten er bedre for enkelte modeller i spesielle typer terreng.

Dersom kanalforholdene er hovedsakelig frisikt, er de deterministiske modellene som tar terrengformasjoner i betraktning (Longley-Rice point-to-point, Okumura-Hata med diffraksjon og ITU Rec P.1546), best. Dersom flerbanerefleksjoner er svært sannsynlig, er den empiriske modellen Longley-Rice area mode det beste valget, med den empiriske Two-Ray modellen på en annenplass. Nøyaktigheten av disse modellene er da cirka 2-3 dB med et standardavvik på 5-6 dB.

Denne studien viser at bruken av disse modellene for radioplanlegging må gjøres med forsiktighet og en viss skepsis. Valg av inngangsparametere gjør store utslag i antall dB prediktert propagasjonstap, og et flerbanemiljø er svært vanskelig å modellere på en god måte. Studien fant ingen propagasjonsmodell som var klart best blant de modellene som ble testet.

Contents

1 Introduction

Propagation measurements at VHF (30-88 MHz) and UHF (225-400 MH) were conducted in Norwegian terrain in 2014 as a collaborative project between the Communication Research Centre (CRC) Ottawa, Canada, and FFI. A wideband channel sounder belonging to CRC was used, and the primary focus of the measurements was wideband characterization in terms of multipath spread. To support the planning of the measurements, a prediction tool from AWE Communications, the WinProp program [1], was procured. This prediction tool claimed to be able to predict multipath propagation in a rural terrain by using 3D ray-tracing techniques, and we intended to use it to select appropriate locations for the measurements. Another intention was to compare the accuracy of the predictions with the measurements. However, it turned out that the prediction tool required vector maps (not raster maps) to use the ray-tracing 3D method and was computationally very demanding when using this method. Consequently, in rural environments it was only applicable to areas of sizes less than about a square kilometer. The WinProp program was therefore not able to support our rural measurements the intended way.

However, the WinProp contains a number of well-known and some less known propagation models that predict path loss or received power. With our measurements not only measuring multipath delays but also path loss, we have compared the prediction of path loss with the measured path loss using the different models. The intention of the comparison is to see which propagation models match the real propagation best in the actual areas and what the size of the prediction errors is. The result can be useful as background knowledge when using such prediction tools in future military operations.

The conclusions from this study are somewhat limited by the fact that the measurements analyzed here were conducted only at one frequency, 312 MHz, and in three geographical areas.

An analysis of the multipath characteristics of the same measurement data as reported here has been published in [2].

2 The WinProp prediction program

The WinProp prediction program is a professional application that covers a variety of propagation scenarios. It contains modules for rural/residential, urban, indoor, tunnel/underground, vehicular and extra-terrestrial/satcom propagation. It contains air interface standards (for instance Digital Video Broadcasting, Long Term Evolution, WiMAX, etc) that are predefined, and it allows network planning and electromagnetic compliance analysis. Some multipath analysis and channel impulse response predictions are also possible, given the restrictions mentioned in the introduction. Even though the primary use of the program seems to be in cellular/broadcasting applications, it was easy to use it for pure scientific purposes, independent of any communication technology.

The program can be procured permanently, or a time limited license can be procured, with or without technical support. Much information about WinProp and its sub- modules can be found on the Internet [1].

Our knowledge of the program is limited to the main software module ProMan (Propagation Manager). It contains the propagation models and an interface to set up communication links as well as network planning possibilities. Many different map formats are supported, and both topographical and clutter/land usage information can be utilized. We used topographical maps in DEM format (Digital Elevation Model) with a resolution of 10 meters that the program automatically converted to an internal format. No clutter information was included in our analysis.

2.1 Propagation models

The *deterministic* models in WinProp are based on mathematical equations that model the physical radio wave propagation. They use topographical information in the vertical plane through the transmitter and the receiver to calculate the path loss depending on the distance, reflection, diffraction and scattering. The *empirical* models are based on measurements conducted at some point in time and at some location. Care should be taken to use these models to predict path loss in completely different types of terrain to where the measurements were taken. The deterministic and empirical models that are available in WinProp and have been run in our analysis are described below.

For all models and predictions the frequency was kept at 312 MHz (because of the measurements at this frequency), the antenna height was set to 2 m above local ground and the polarization was vertical to best fit a tactical mobile scenario. For the models where diffraction losses could be added, we selected the maximum number of knife edges to be 10.

2.1.1 Okumura-Hata (empirical model)

The Okumura-Hata model is an empirical prediction model based on measurements made in and around Tokyo city between 200 MHz and 2 GHz [3]. It is a widely quoted macrocell prediction model. The prediction model distinguishes between three different clutter and terrain categories, namely “open”, “suburban” and “urban”. We selected the “open” category for our comparisons, and this category is characterized by no tall trees or buildings, typical farmland and open fields. A better choice might have been the sub-urban category, since tall trees were definitely present at some of the measurement locations. There was no other parameter choice for this model.

When running this model in WinProp, the prediction surprisingly showed dependence on topography, which indicates that some deterministic calculations have been added to the empirical model. We have not received an explanation from AWE Communications on this.

In WinProp it was possible to add diffraction loss according to the Epstein-Peterson [8] or Deygout [9] models to the Okumura-Hata prediction. This would make the prediction a nonstandard Okumura-Hata prediction. This option, using the “open area” category with added diffraction, was also compared with the measurements.

2.1.2 Longley-Rice area mode (empirical model)

The Longley-Rice model, also known as the ITS (Institute of Telecommunication Sciences) Irregular Terrain Model [5], is based on electromagnetic theory and on statistical analysis of terrain features and radio measurements. It is applicable for frequencies 20 MHz to 20 GHz. It has two modes of operation; the area mode and the point-to-point mode. The two modes use almost identical algorithms, but they use different kinds of input parameters. The area mode requires no detailed information about the terrain profile and estimates path characteristics from the general kind of terrain involved. There are a number of input parameters involved to characterize the terrain. For our analysis we kept the following parameters fixed for all comparisons:

- Radio Climate: Continental Temperate
- Earth curvature: 1.333
- Electrical properties: Average ground

The other input parameters were varied in the analysis and will be given in the sections where the results are presented:

- Siting criteria – care which has been taken to site the terminals (random, careful and very careful)
- Terrain irregularity parameter Δh – inter-decile range (in meters) of terrain elevation
- Statistical parameters, time, confidence and locations (in percent). (The full understanding of these parameters were not able to obtain in the time available.)

2.1.3 Empirical Two Ray (empirical/deterministic model)

This model has no reference in the literature, so we assume that it is made by AWE Communications. We do not know the measurements upon which the empirical model is based.

The model assumes that the direct ray and the ground-reflected ray exist independent of possible terrain obstacles or shadowing. It is possible to manipulate a “break-point” which is a position between the transmitter and the receiver where the path loss exponent is changed. Both the location of the breakpoint and the value of the exponents can be selected manually. However, we did not manipulate the breakpoint, because we have no guidance/knowledge on how to do this. Our goal was not to optimize predictions against measurements, but rather find out how well existing models match the measurements when they are compared.

It is possible to add a knife edge diffraction loss calculation to the model, which makes the prediction dependent on the topology. Either the Epstein-Peterson or the Deygout diffraction model can be selected.

2.1.4 ITU Rec P1546 (empirical/deterministic model)

This model is used for point-to-area radio propagation predictions for terrestrial services in the frequency range 30-3000 MHz [6]. The method is based on interpolation/extrapolation from empirically derived field-strength curves as a function of distance, antenna height, frequency and percentage time. The curves have been derived from measurements taken in temperate regions in Europe and North America, and on sea paths in the Mediterranean and in the North Sea.

If terrain information is available, terrain clearance and effective antenna heights are taken into account to improve the predictions.

The only parameters to select when using this model are the Location probability and the Time variability. The time variability was set to 25 % in our predictions which means that the values predicted are exceeded 25 % of the time. The location probability was set to 50 % (default value) which means that 50 % of the locations within an area of 500x500 m achieved the value.

2.1.5 Longley-Rice point-to-point mode (deterministic model)

This model requires detailed information about the terrain, and topographical maps are used. Otherwise it uses the same algorithms as the Longley-Rice area mode model. For our analysis the following parameters were fixed for all comparisons (same as for Longley-Rice area mode):

- Radio Climate: Continental Temperate
- Earth curvature: 1.333
- Electrical properties: Average ground

The only other input parameters were the requirements to Reliability and Confidence.

2.1.6 Deterministic Two Ray (deterministic model)

This model exists in WinProp, but the difference to the empirical two-ray model was not made clear to us when asking AWE Communications. It was therefore not used in our evaluations.

2.1.7 Dominant Path Model (deterministic model)

The model has been developed by AWE Communications to improve predictions in rural, hilly terrain where multipath exists. The justification for this is, according to the WinProp manual, that “the empirical models only compute the direct ray between transmitter and receiver” and this leads to too pessimistic results since multipath will increase the signal power received at a particular location. We believe the first statement is true only if the empirical models are based on measurements conducted only in flat, open areas where there is no multipath. If the measurements have been conducted in hilly terrain where multipath is present, these will also be measured and form the basis for the empirical models. The diffraction models that can be used on a particular terrain profile will also contribute to a pessimistic prediction.

The Dominant Path Model therefore uses a full 3D approach for searching the most important propagation path. The propagation loss for each path is determined deterministically from the distance, path loss exponent (which can be manually set) and diffraction components. We did not have the knowledge to set the breakpoint and change the path loss exponents, so these were left at the default values. Another parameter called the Maximum Interaction loss was also left at the default value of 13 dB.

3 Method of comparison of data and predictions

Our data consisted of complex channel impulse responses at 312 MHz collected between a static transmitter and a moving receiver. The chip rate of the PN (pseudo noise) sequence was 5 Mbps with a corresponding signal bandwidth of 10 MHz null-to-null. The resulting time resolution of the measured channel impulse response was 0.3 μs. Channel snapshots were collected by the receiver at a rate of 100 per second, and each snapshot was the coherent average of four consecutive PN sequences. The transmit power was 41 dBm.

To be able to accurately estimate average received power (or path loss) on mobile radio channels, spatial averaging can be applied over short segments of the channel impulse response series over which the channel can be assumed to be stationary. We have selected 10 wavelengths for the averaging interval in our analysis and we use every recorded snapshot within this distance (note $10\lambda = 9.6$ m at 312 MHz). Typically 40-100 consecutive channel impulse responses (snapshots) were used to obtain the channel's average power delay profile, depending on the driving speed of the vehicle.

Finally, a -20 dB noise threshold relative to the peak of the average power delay profile was applied, and the average received power is calculated by summing all profile samples above the threshold. The number thus contains the power contributions from all scattered and reflected signal components. The estimated received power was then recalculated into path loss taking antenna gains into account.

Summing only the earliest four profile samples above the threshold would correspond to a situation where only the direct Tx-Rx path is considered. This measure may compare better with theoretical/deterministic prediction models where only propagation in the 2D plane is considered, but for empirical prediction models where measurements have been conducted, the scattered and reflected signal components have been measured and using all profile samples above the noise threshold should be a better approach. In our comparisons we have only used the measure of path loss that encounters all profile samples above the threshold.

The location of the receiver van was recorded once per second with a GPS unit. Small scale position information was obtained through the use of a high resolution rotary encoder attached to the vehicle wheel.

To compare data and predictions, measured path loss values every 9.6 m of a path was written to a text file together with the GPS positions. These values were read by Proman and compared with the predictions at the same positions. Proman further calculates statistics such as mean, maximum and minimum difference over all data points, standard deviation, etc.

The model parameters for the different models have been selected based on our best guess and without any tuning to best fit the measurements. This is the normal procedure that will be used by military personell when planning a communication network for an operation.

4 Geographical areas for comparison of measurements and predictions

The measurements reported here were conducted on three different paths in south-eastern Norway. The following table shows some characteristics of the topography where the measurements took place. The data is calculated within a circular area of radius 20 km from the transmitter sites and with a digital map resolution of 10 m.

	Rena	**Gausdal**	**Bødalen**
Max elevation (m)	956	1242	1360
Ave elevation (m)	478	669	781
Min elevation (m)	194	122	160
Std dev elevation (m)	175	235	218
Ave slope (deg)	5,23	8,74	8,53
Std dev slope (deg)	5,00	7,95	7,93
Tx antenna elev (m)	273	432	393

Table 4.1 Topographical data for the three measurement sites

The Rena area is characterized by soft rolling hills, heavy forest basically consisting of pine trees that can be as high as 20 meters, and a rural/remote environment. There is also a town called Rena consisting of one story high buildings. The transmitter was located at a parking lot with close-by pine trees in the direction of the receiver. The trees were snow covered during the measurements. The mobile receiver van drove away from the transmitter, first experiencing non-line-of-sight (non-LoS) conditions for the first kilometer, then line-of-sight (LoS) conditions while driving through the Rena town center at around 2 km from the transmitter. After the town center the transmitter-receiver distance decreased to 1.2 km before increasing steadily while driving through varying density of forest until the signal was lost at 12 km. LoS conditions were dominating only interrupted by marginal non-LoS conditions. A Google Earth picture of Rena and the measurements is seen in Figure 4.1, and a street view picture in the direction of the transmitter in Figure 4.2.

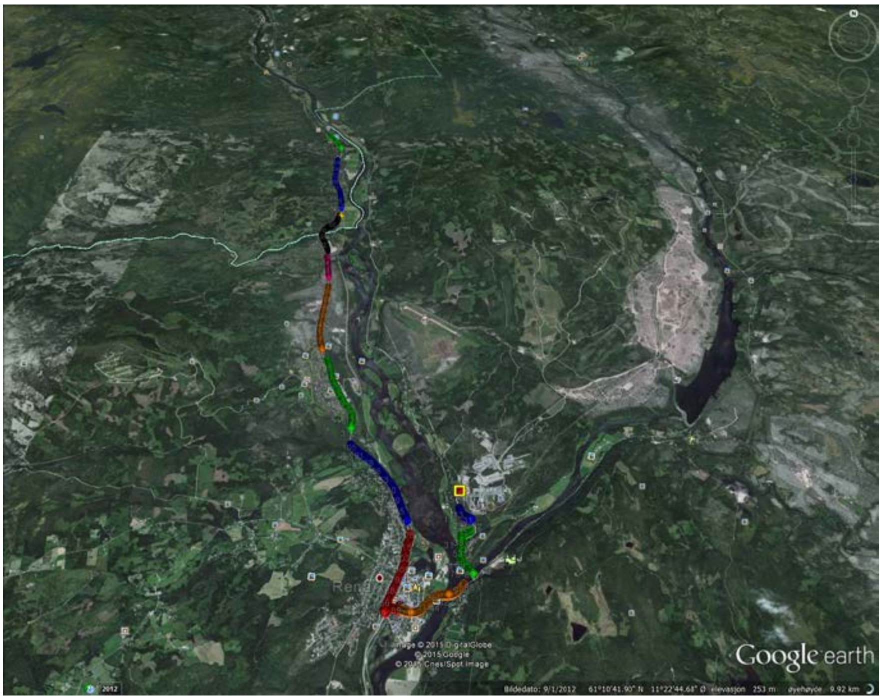


Figure 4.1 Measurements and Tx site at Rena

Figure 4.2 Google Earth street view in the direction of the Tx at Rena

60-70 km west of Rena is Gausdal, which is classified as a lower mountain valley. The relative difference between hill tops and valley bottoms is larger than at Rena. The forest is not as heavy, and the trees are lower. There is some agriculture in the area and spread housing. In this rural/remote area the transmitter was placed relatively high up on a hill side with a very clear LoS view to the mid-part of the measurement series. The receiver drove down the hill from the transmitter while experiencing non-LoS (called Gausdal 3 in the analysis), then entering the area with clear LoS which also had a shorter distance to the Tx (Gausdal 1), and then finally drove away from the Tx in non-LoS conditions until measurements were stopped at a distance of 7 km (Gausdal 2). A Google Earth picture of Gausdal and the measurements is seen in Figure 4.3, and three street view pictures in the direction of the Tx in Figures 4.4, 4.5 and 4.6, respectively.

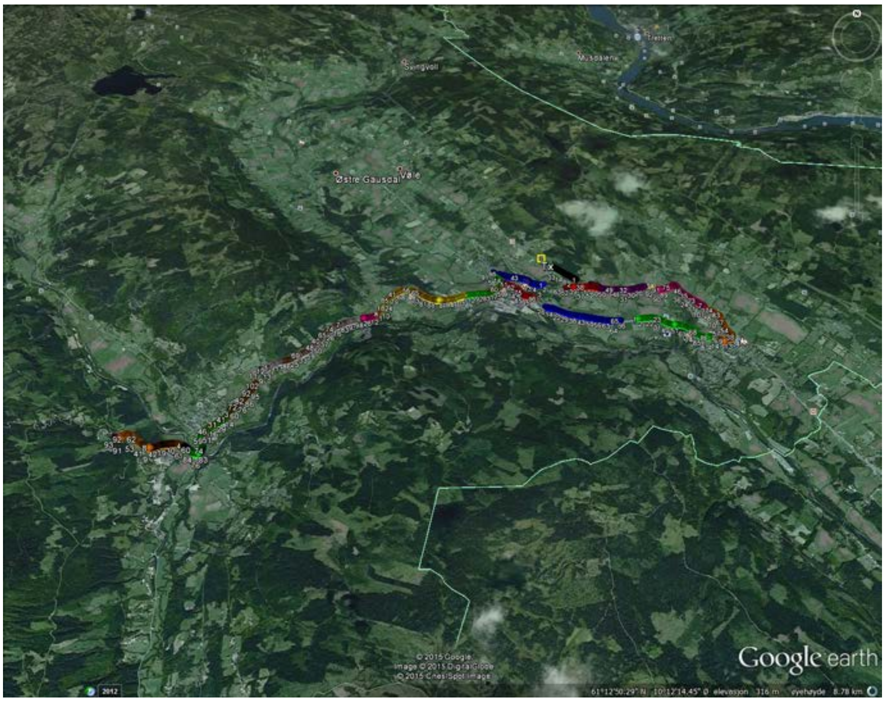


Figure 4.3 Measurements and Tx site in Gausdal

Figure 4.4 Google Earth street view in the direction of the Tx (Gausdal 1 which is LoS)

Figure 4.5 Google Earth street view in the direction of the Tx (Gausdal 2 which is at ~10 km and non-LoS)

Figure 4.6 Google Earth street view in the direction of the Tx (Gausdal 3 which is at ~2 km and non-LoS)

The transmit site of the third path in Bødalen is only about 7 km (air distance) away from the Gausdal transmit site. Bødalen is a side valley to Gausdal and it is classified as a higher mountain valley. The topographical characteristic is much the same as for Gausdal, as seen in Table 4.1.

The difference to the Gausdal measurements was that the transmitter was here located at the bottom of the valley and the transmit antenna mounted on an 8 m mast. The valley was relatively narrow with some curvature, therefore LoS conditions were quickly lost. The receiver van drove away from the transmitter approximately at the same elevation as the transmitter and out to a range of about 10.5 km. The topography imposed non-LoS conditions for the whole path except for the start of the measurement. A Google Earth picture of Bødalen and the measurements is seen in Figure 4.7, and two street view pictures are seen in Figure 4.8.

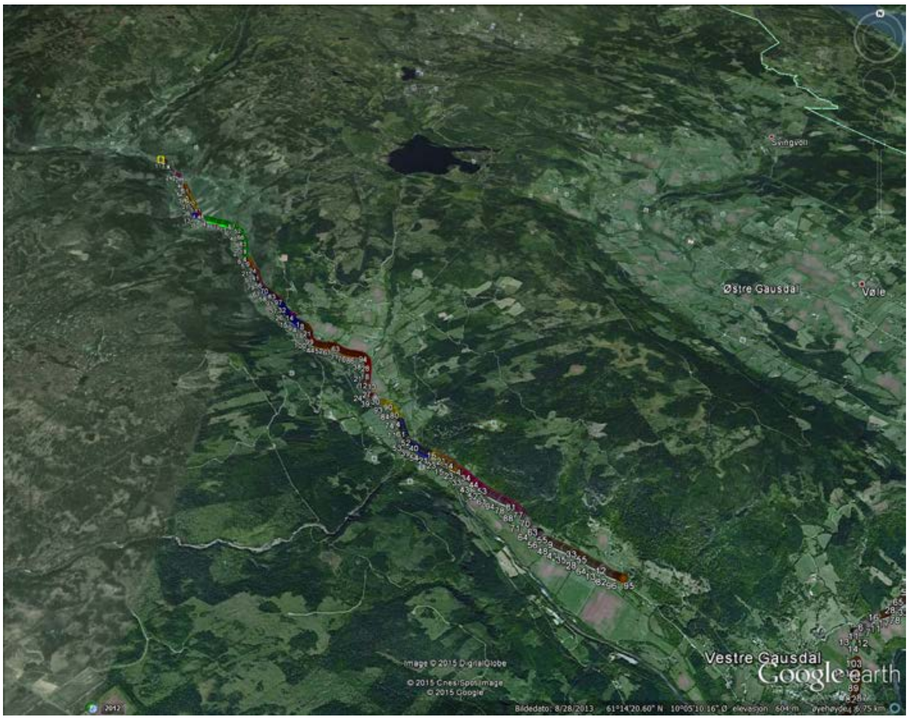


Figure 4.7 Measurements and Tx site in Bødalen

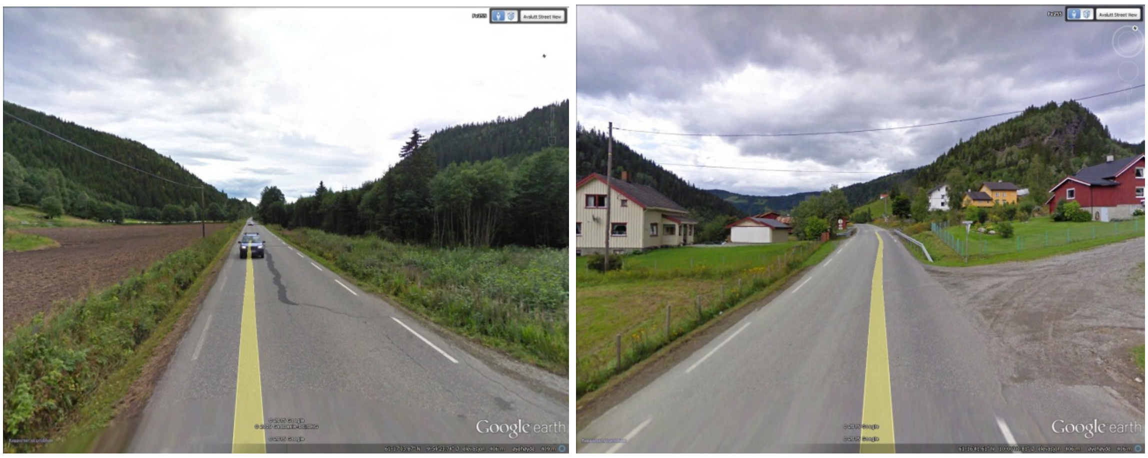


Figure 4.8 Google Earth street view at two different locations in Bødalen

5 Results

We first show the prediction results (coverage diagrams) for the various paths and models in Sections 5.1 to 5.3. The comparison between predictions and measurements are made in Section 5.4.

The basic equipment parameters such as frequency, transmit power and antennas are the same for all the predictions. The parameters that could be selected for each model and their values are given in the text for the respective models. We have used a fixed color scaling for the path loss in all figures ranging from -20 dB to -140 dB as shown in Figure 5.1.

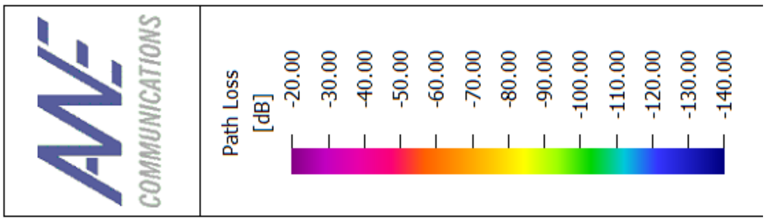


Figure 5.1 Color scaling for the path loss used in all plots

5.1 Rena predictions

5.1.1 Okumura-Hata

Figure 5.2 shows the predicted path loss with the Okumura Hata model. The “Open area” environment has been chosen which may not be quite representative of the actual terrain because of forest (as pointed out in Section 2.1.1).

Even though Okumura-Hata is a purely empirical model, the left hand side plot shows that the WinProp implementation of it uses terrain information in some way. This was surprising to find.

WinProp allows the user to add diffraction calculations to the standard Okumura-Hata model. By adding Epstein-Peterson diffraction loss with maximum 10 knife edges the predicted coverage appears as in the right panel of the figure.

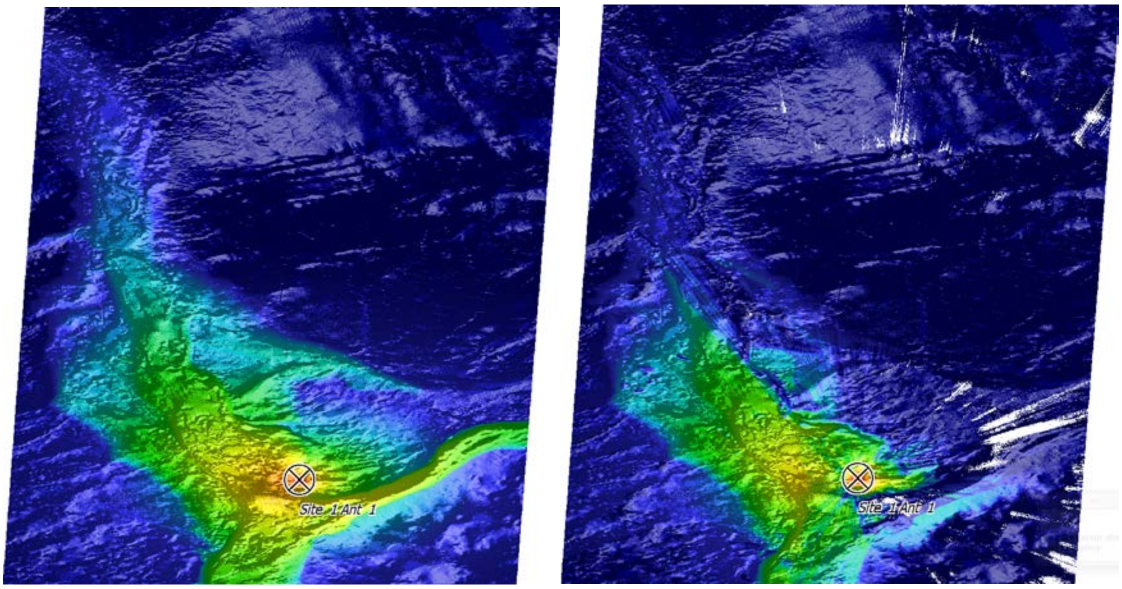


Figure 5.2 Predicted path loss using the standard Okumura-Hata model (left panel) and with added Epstein-Peterson diffraction loss (right panel)

5.1.2 Longley-Rice area mode

The predicted path loss using the Longley-Rice area mode is shown in Figure 5.3. The basic parameters were selected as described in Section 2.1.2, and the rest of the parameters were in this plot selected to be:

- Terrain irregularity: 30 m
- Siting criteria: Random
- Statistics: Time = 50%, Location=50% and Confidence=50%

This is a true empirical model not taking any terrain effects into consideration.

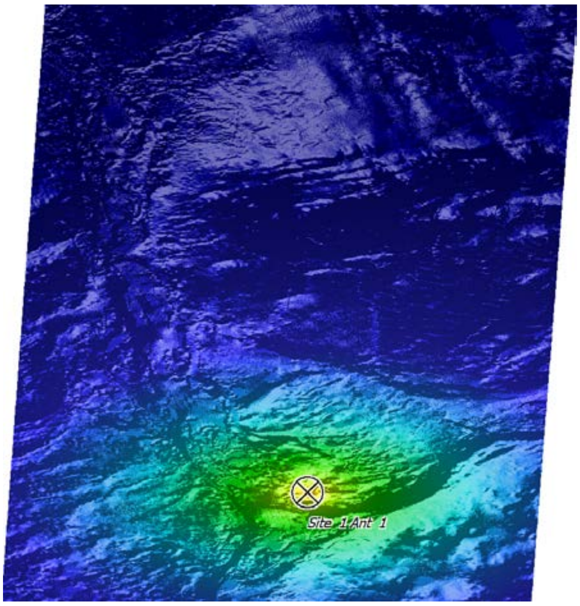


Figure 5.3 Predicted path loss using the Longley-Rice area mode model

5.1.3 Empirical two-ray

Figure 5.4 shows the predicted path loss using the Two-ray empirical model with the breakpoint determined automatically. The only other option for this model was to add a diffraction loss, and the right panel in Figure 5.4 shows the effect of added Epstein-Peterson (max 10 knife edges) diffraction loss.

We see that the predicted path loss has increased compared to the previous models, and the signal coverage is restricted to a very small area.

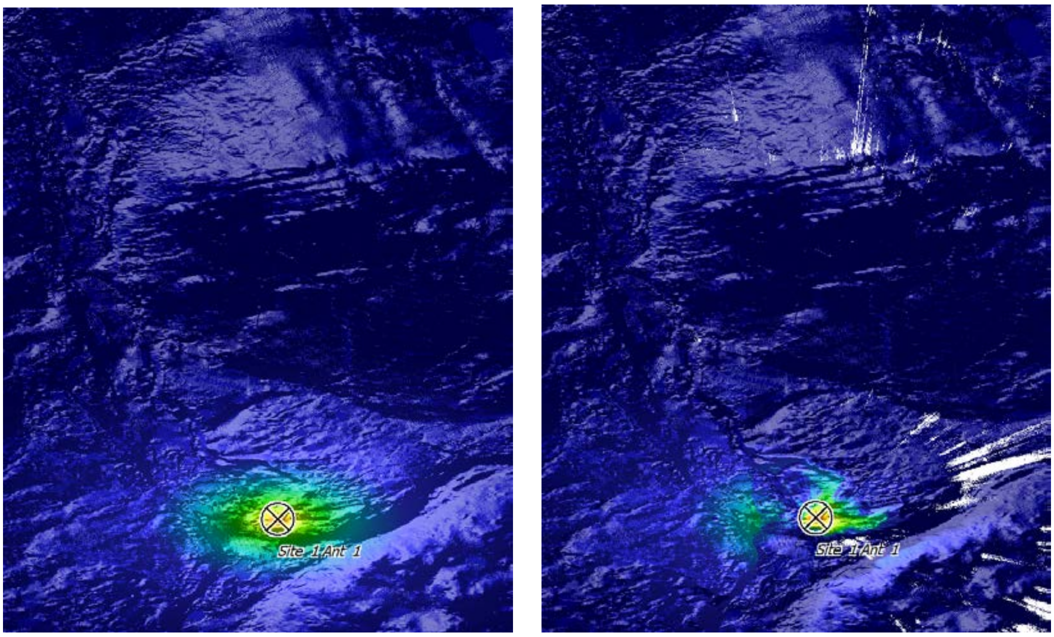


Figure 5.4 Predicted path loss using the Two-ray model. Epstein-Peterson diffraction loss added in the right panel

5.1.4 ITU Rec P.1546

In Figure 5.5 the predicted path loss with the ITU Rec P1546 is shown. Since terrain data were available, the model uses that information and the plot shows dependence on the terrain. The two parameters to set were selected as described in Section 2.1.4.

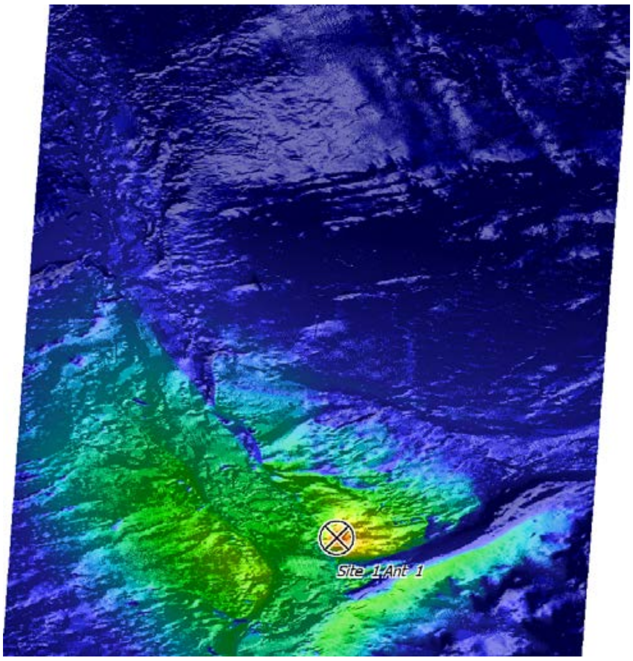


Figure 5.5 Predicted path loss using the ITU Rec P1546 model

5.1.5 Longley-Rice point-to-point mode

The Irregular Terrain Model point-to-point mode gives a more optimistic picture of path loss as shown in Figure 5.6. In addition to the basic parameters mentioned in Section 2.1.5, other parameters were set to :

- Statistics: Reliability 90%, Confidence 50%

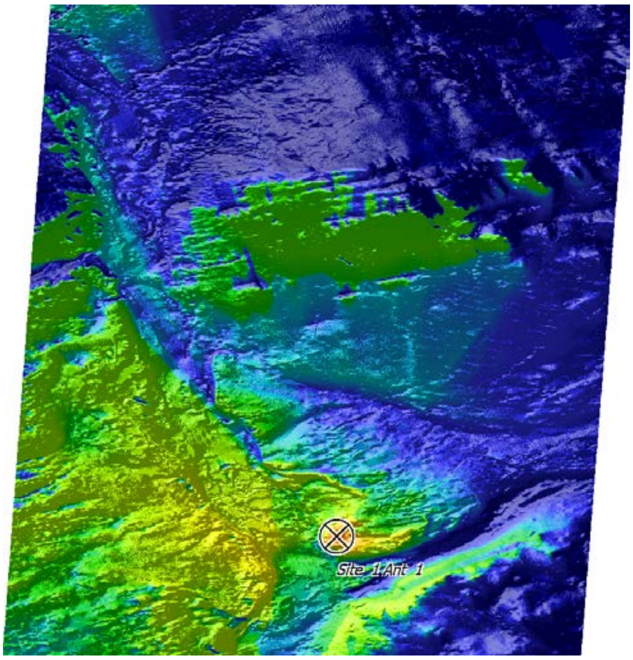


Figure 5.6 Predicted path loss using the Longley-Rice point-to-point mode

5.1.6 Dominant path

The result of the Dominant path model is shown in Figure 5.7. As mentioned in Section 2.1.7 all the parameters were left at their default value, because we did not have the knowledge to alter them. As can be seen, the resulting prediction gives a very pessimistic result, compared to the other prediction models.

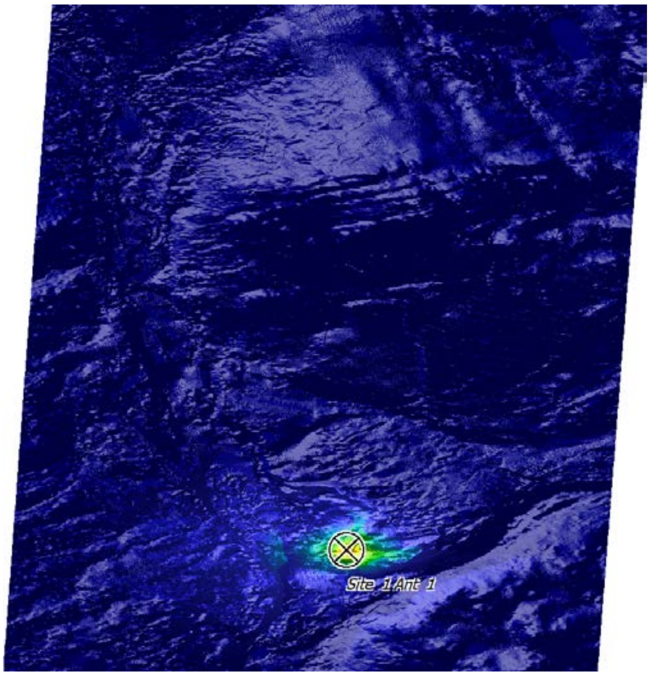


Figure 5.7 Prediction path loss using the Dominant path model

5.2 Gausdal predictions

For this path we experimented somewhat with the model parameters to see the influence on predicted path loss.

5.2.1 Okumura-Hata

The predictions using the standard Okumura-Hata, open area model is shown in Figure 5.8. Again we see that the implementation of the standard Okumura-Hata surprisingly takes account of the terrain.

For this path a comparison was made between Epstein-Peterson and Deygout diffraction loss. In Figure 5.9 Okumura-Hata predictions with added Epstein-Peterson diffraction loss, (max 10 knife edges) is shown in the upper panel and added Deygout diffraction loss (max 10 knife edges) in the lower panel. The predicted path loss is largest for the Epstein-Peterson type of diffraction.

Allowing an unlimited number of knife edges did not make any significant changes to the predictions. The only observable effect was to remove the white pixels in the plots below. For the comparison with the measurements in Section 5.4, the Epstein-Peterson diffraction was used.

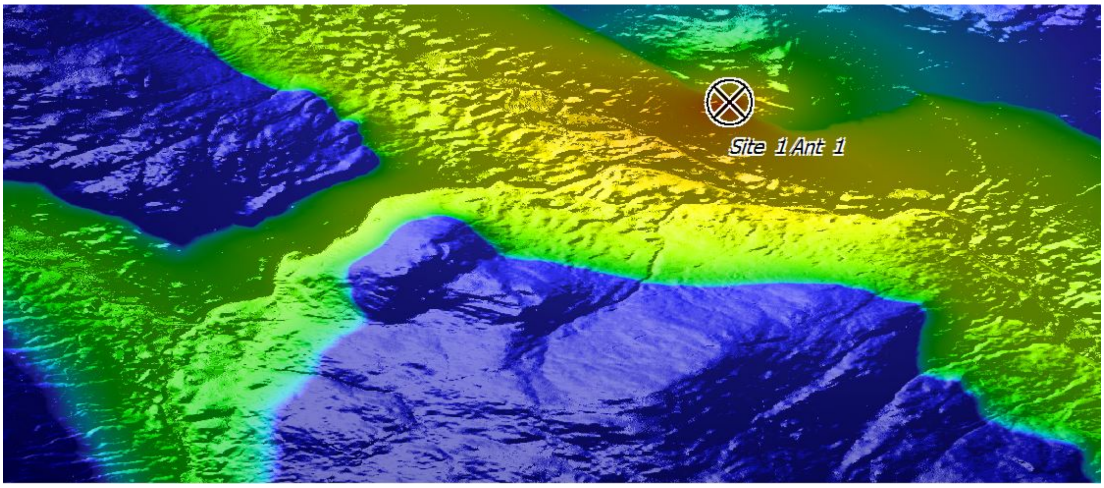


Figure 5.8 Predicted path loss using the Okumura-Hata model

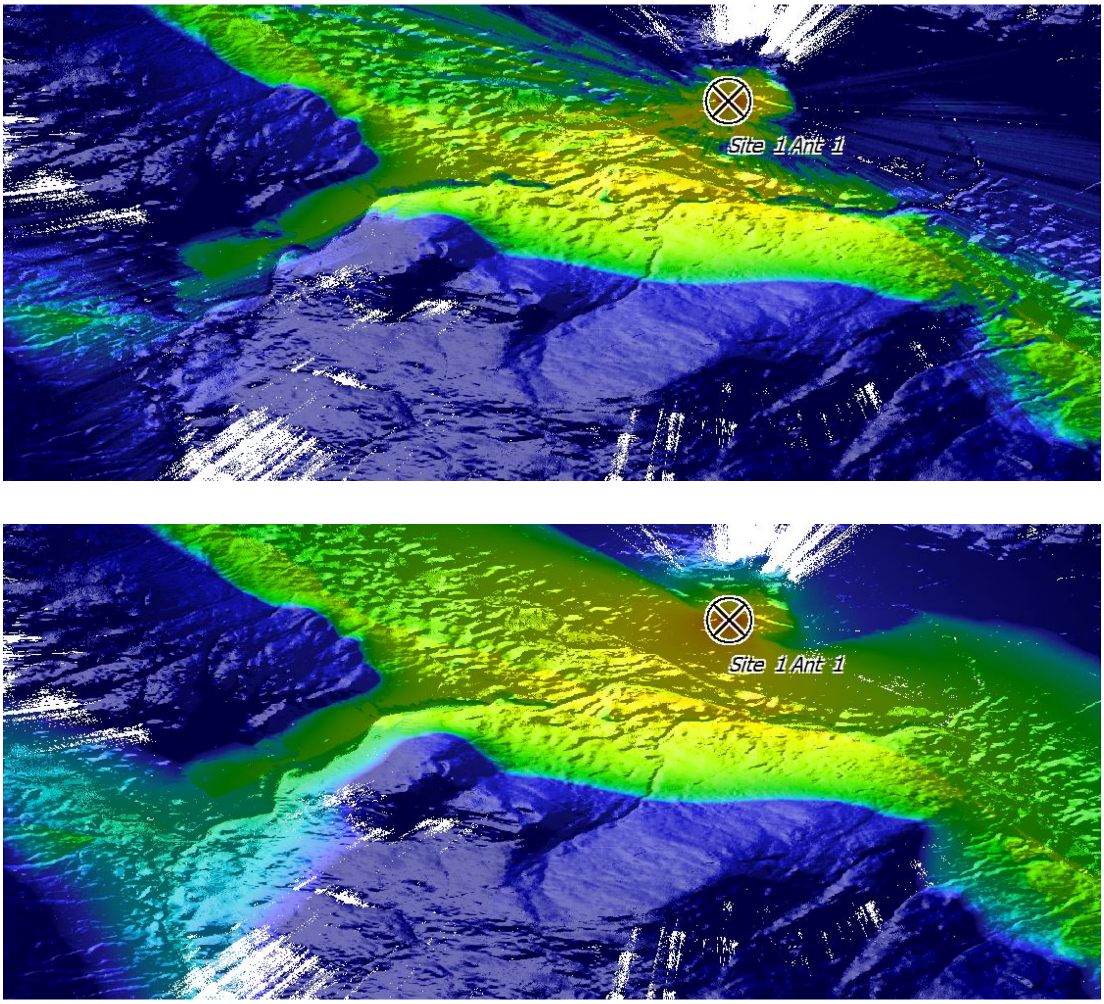


Figure 5.9 Predicted path loss using the Okumura-Hata model with added Epstein-Peterson diffraction loss in upper panel and added Deygout diffraction loss in lower panel

5.2.2 Longley-Rice area mode

Some experiments with the parameters were also conducted for this model.

For all the predictions we selected siting criteria “Careful” for the tranmitter and “Random” for the receiver reflecting the location of the transmitter high up on a hill side and a moving receiver in the bottom of the valley.

First, the statistical parameters were set to

- Time 50%, Locations 50% and Confidence 50%

Investigating the Terrain Irregularity parameter gave the result shown in Figure 5.10 by choosing Terrain Irregularity to be 200 m (upper panel) and 90 m (lower panel).

A test of the influence of the statistical parameters is made in Figure 5.11 where the

- Terrain Irregularity parameter is 90 m, and
- Confidence is set to 90%.

This should be compared with the lower panel of Figure 5.10.

For the comparison with the measurements in Section 5.4 we use a Terrain Irregularity of 90 m, and statistical parameters 50%, 50% and 50%.

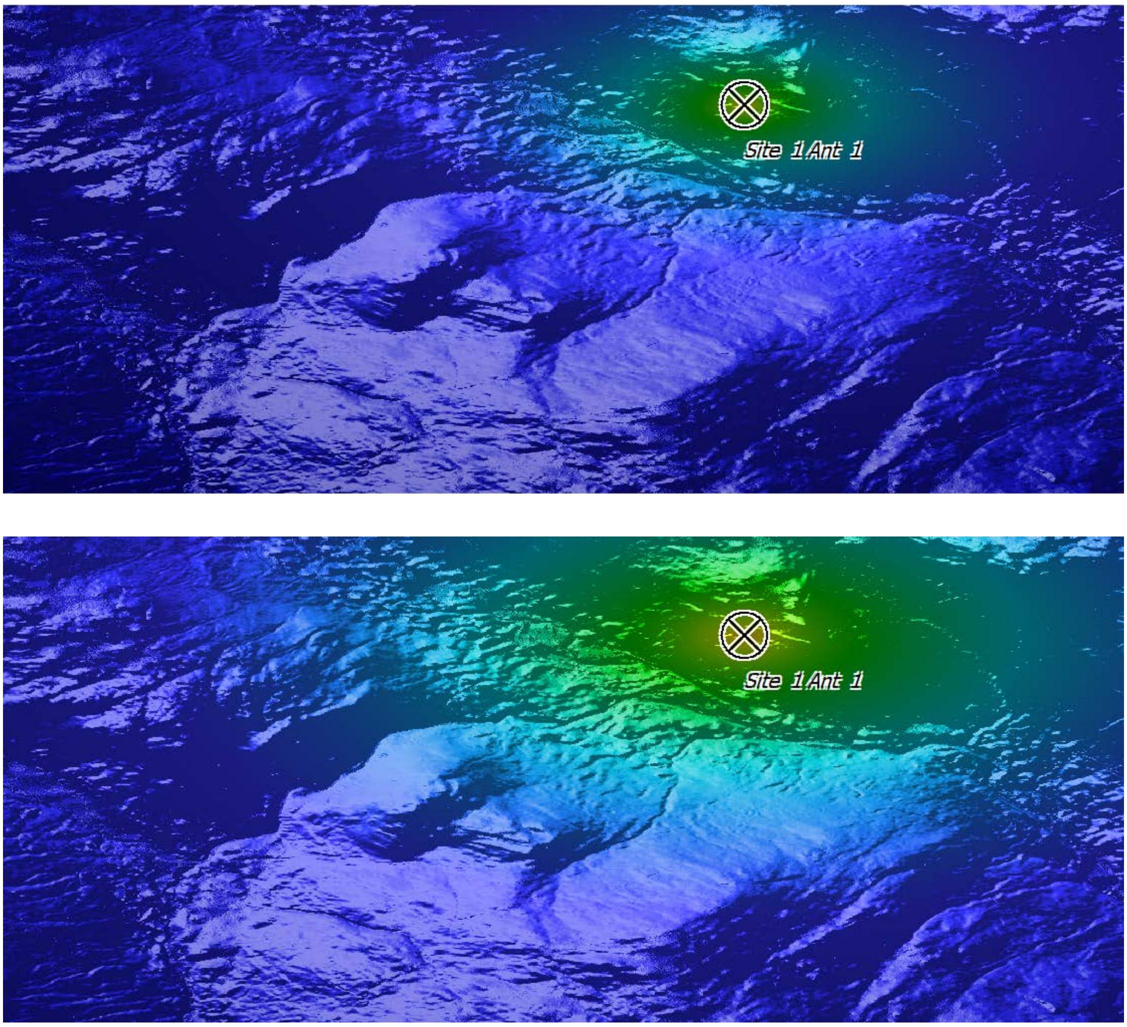


Figure 5.10 Predicted path loss using the Longley-Rice area mode model. Terrain Irregularity 200 m in upper plot and 90 m in lower plot

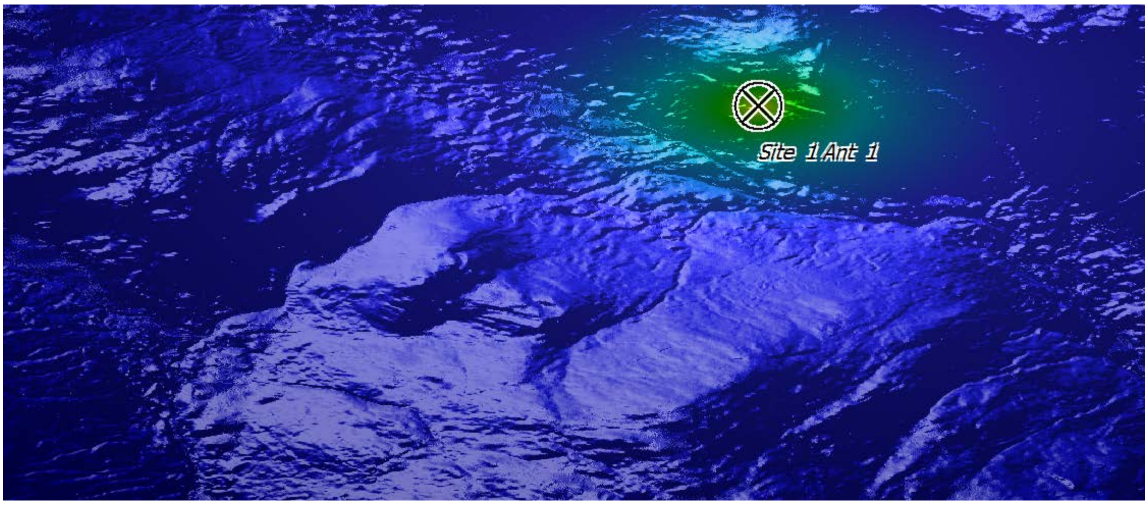


Figure 5.11 Predicted path loss using the Longley-Rice area mode model. Terrain Irregularity 90 m, Confidence 90% (50% in Figure 5.10)

5.2.3 Empirical two-ray

The results for the two-ray empirical model are shown in Figure 5.12. In the lower panel, Epstein-Peterson diffraction losses with maximum 10 knife edges have been added.

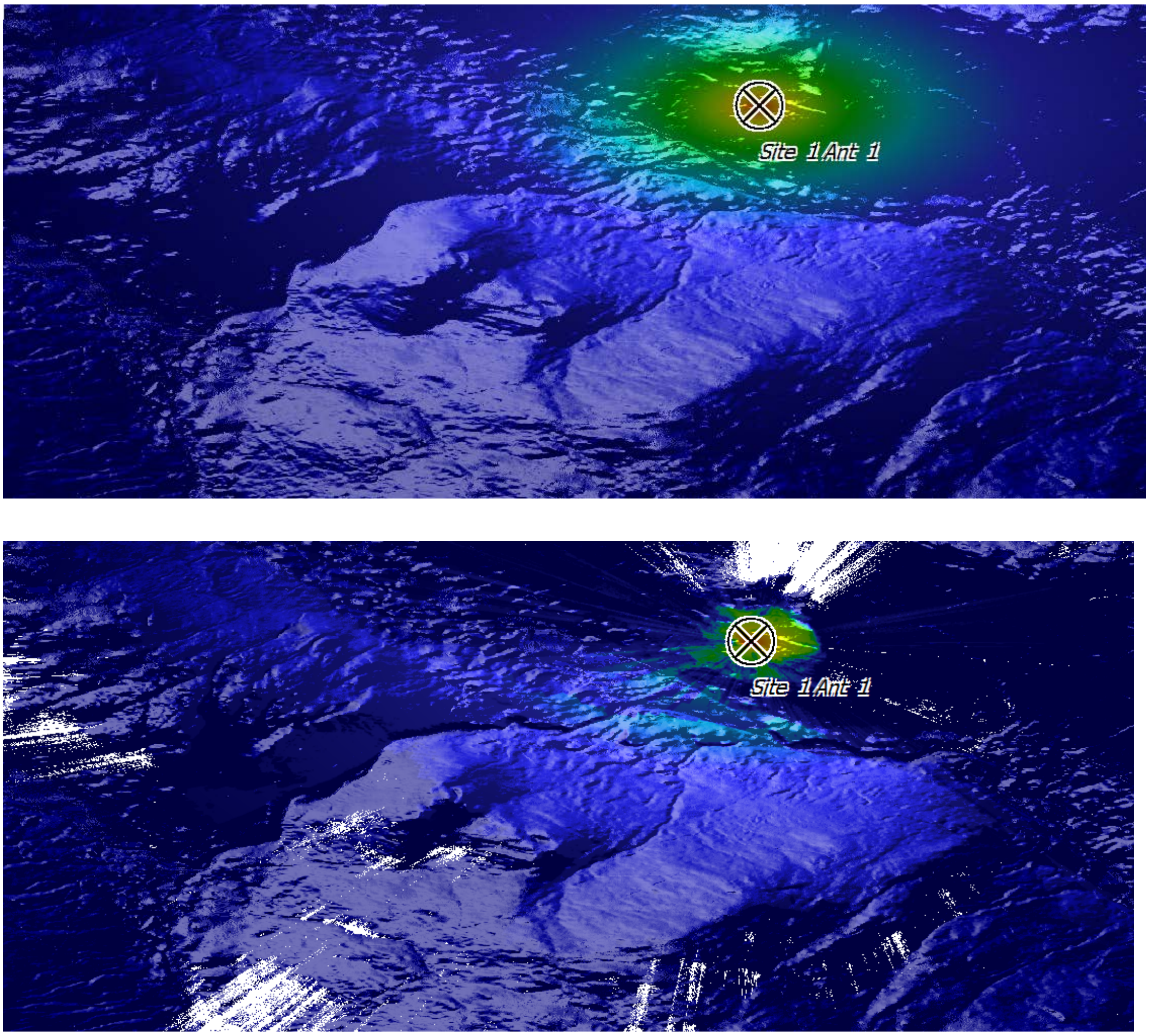


Figure 5.12 Predicted path loss using the Two-ray empirical model. Epstein-Peterson diffraction loss added in lower panel

5.2.4 ITU Rec P.1546

Predicted path loss using the ITU Rec P.1546 model is shown in Figure 5.13. The parameter choices were as described in Section 2.1.4.

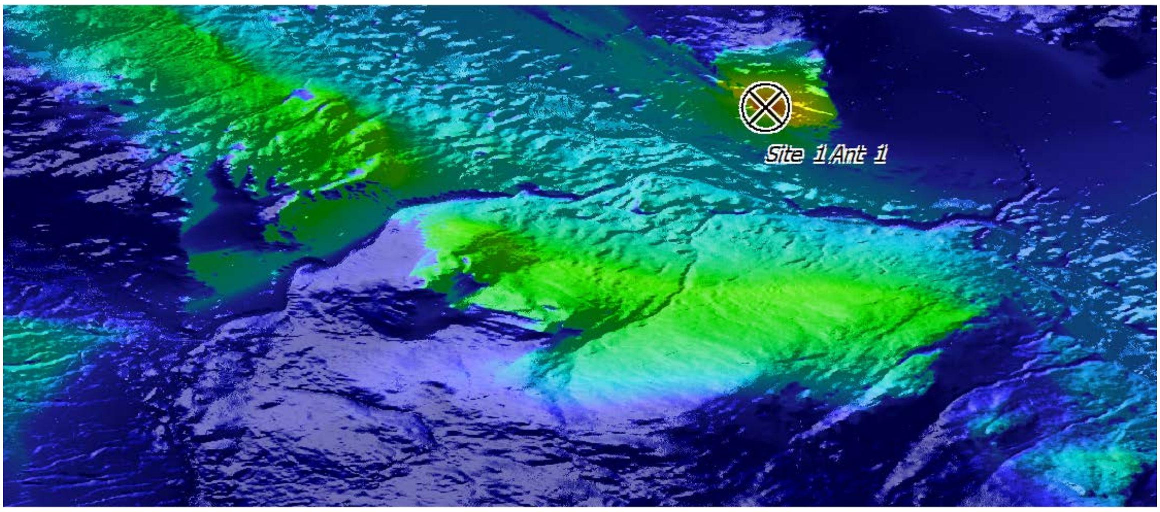


Figure 5.13 Predicted path loss using the ITU P.1546 model

5.2.5 Longley-Rice point-to-point mode

We experimented with the statistical parameters for this model. While keeping the parameters described in Section 2.1.5 fixed, the Reliability and Confidence parameters were set to 50%, 50% in the first prediction (upper panel of Figure 5.14), 90% and 50% in the second prediction (middle panel) and 50% and 90% in the third prediction (lower panel).

The Confidence parameter is more sensitive than the Reliability parameter. For the comparisons in Section 5.4, we have used the 50%, 50% and 50% values.

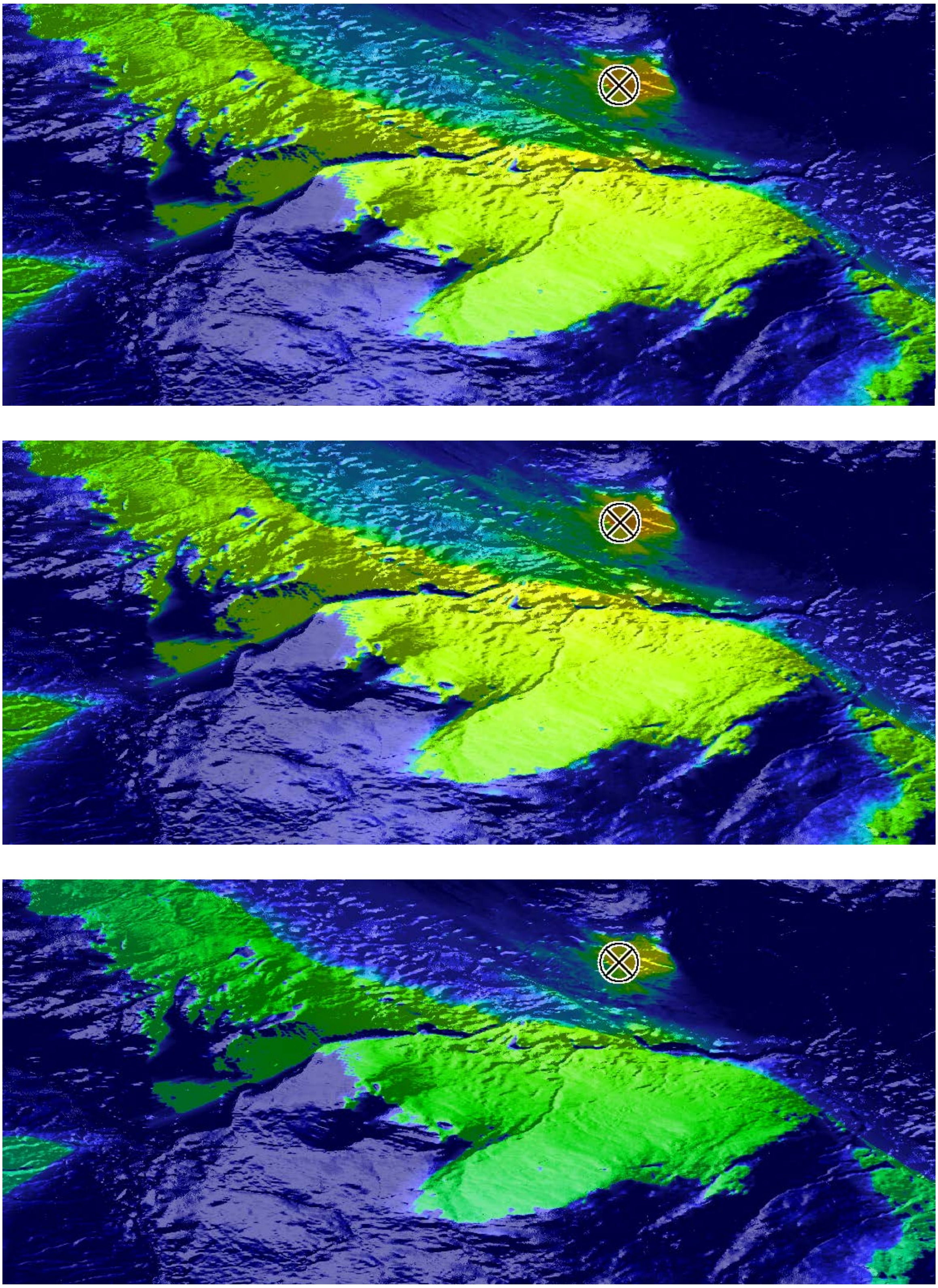


Figure 5.14 Predicted path loss using the Longley-Rice point-to-point mode. Reliability and Confidence 50%, 50% (upper panel), 90%, 50% (middle panel), 50%, 90% (lower panel)

5.2.6 Dominant path

As for the Rena data (Section 2.1 6), the Dominant path model in Figure 5.15 gives a very pessimistic picture when all the default parameters are used.

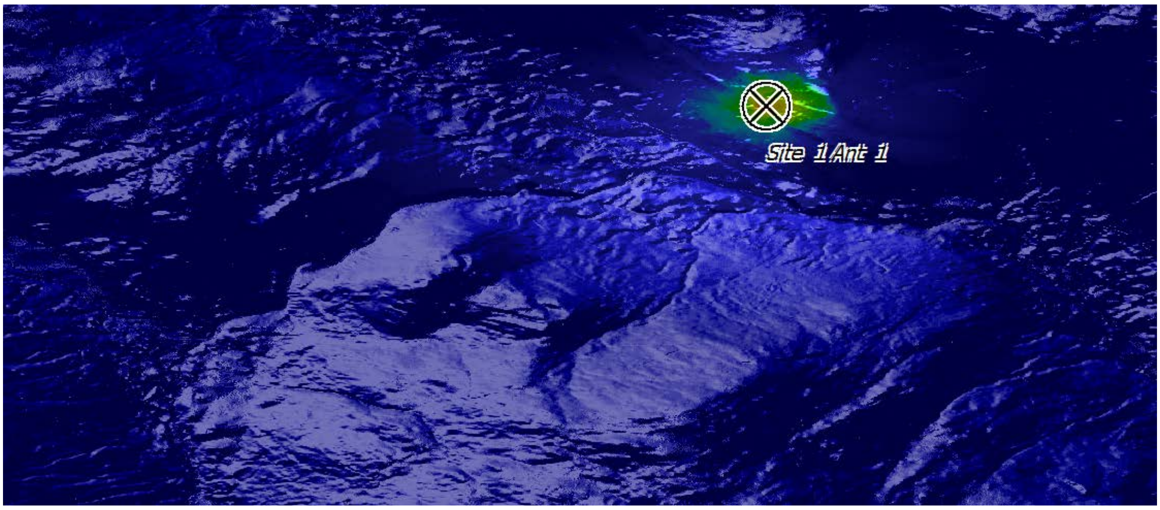


Figure 5.15 Predicted path loss using the Dominant Path Model

5.3 Bødalen predictions

5.3.1 Okumura-Hata

The predicted path loss using Okumura-Hata, open area for this upper mountain valley is shown in Figure 5.16. In the lower panel, Epstein-Peterson diffraction losses with maximum 10 knife edges are added.

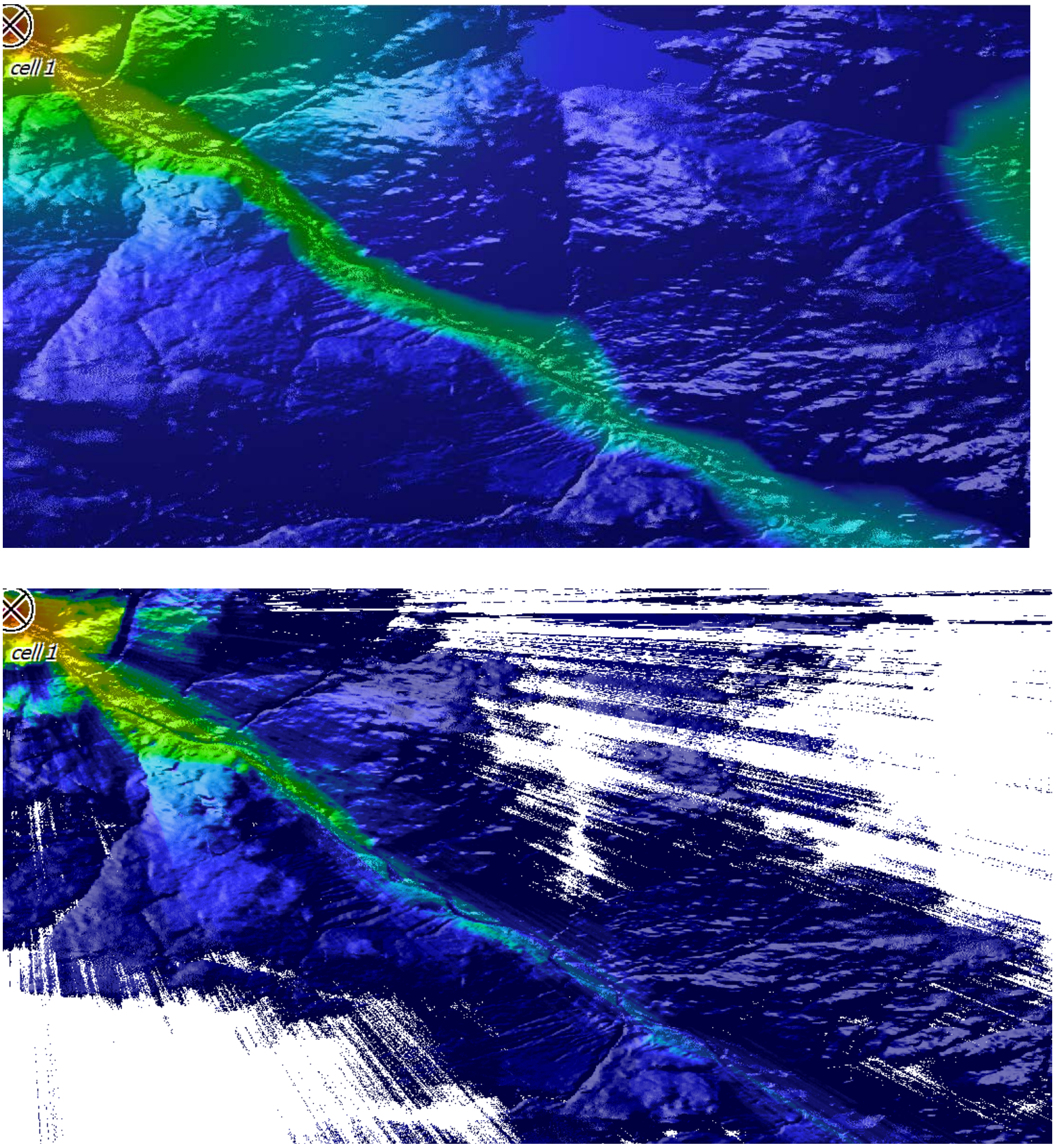


Figure 5.16 Predicted path loss using the Okumura-Hata open area model. Epstein-Peterson diffraction added in lower panel

5.3.2 Longley-Rice area mode

Two plots of the predicted path loss are shown in Figure 5.17 with the statistical parameters set to:

- Time 50%, Location 50% and Confidence 50%

The Terrain Irregularity parameter is set to 0 m and 90 m respectively in the two plots. 90 m would be our best guess of the actual terrain irregularity, and this value is used in the comparisons in Section 5.4. We see that the prediction is quite dependent on this parameter.

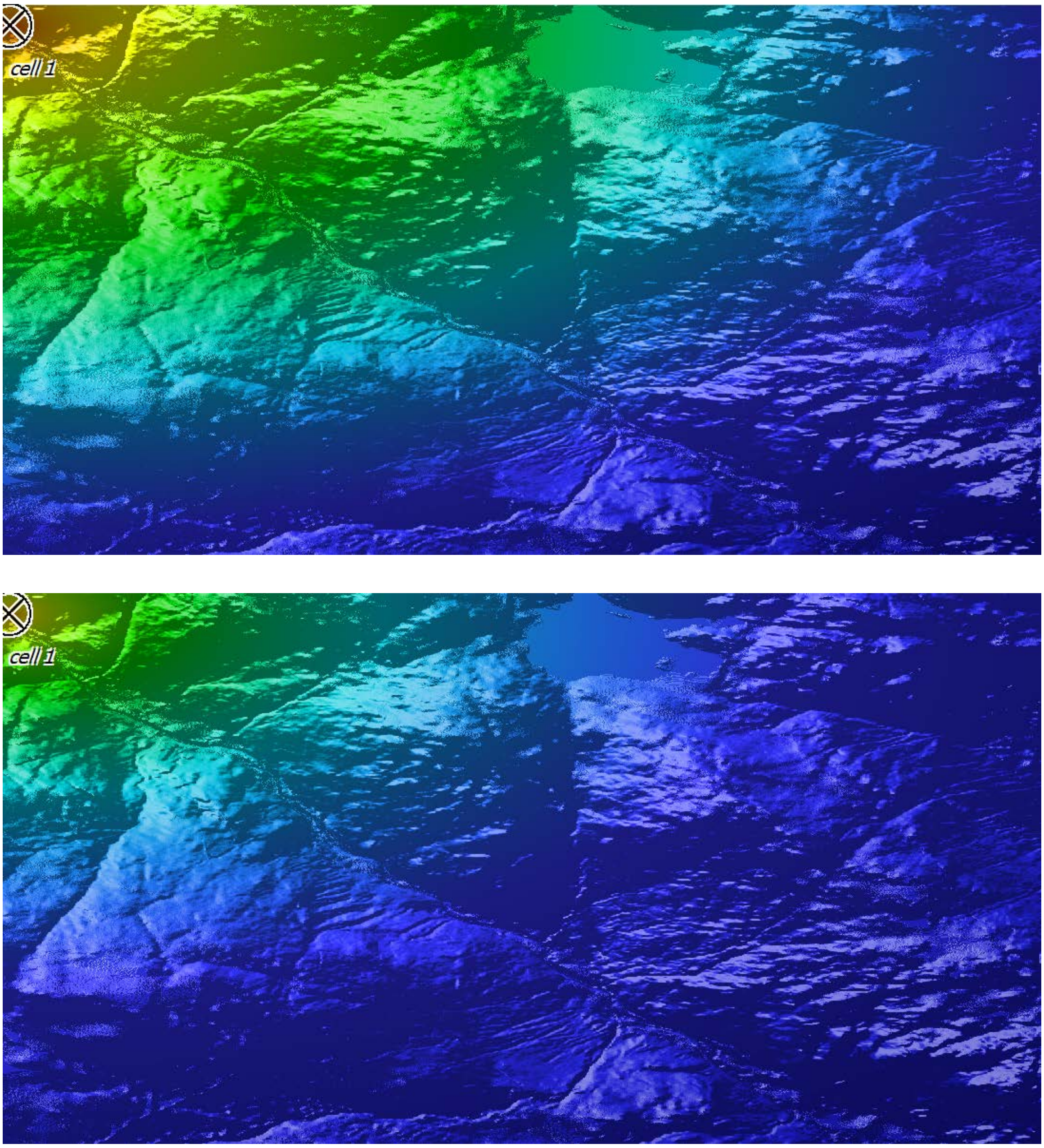


Figure 5.17 Predicted path loss using the Longley-Rice area mode model. Terrain irregularity 0 m in upper plot and 90 m in lower plot

5.3.3 Empirical two-ray

Predictions using the two-ray empirical model are shown in Figure 5.18, with added Epstein-Peterson diffraction (maximum 10 knife edges) in the lower panel.

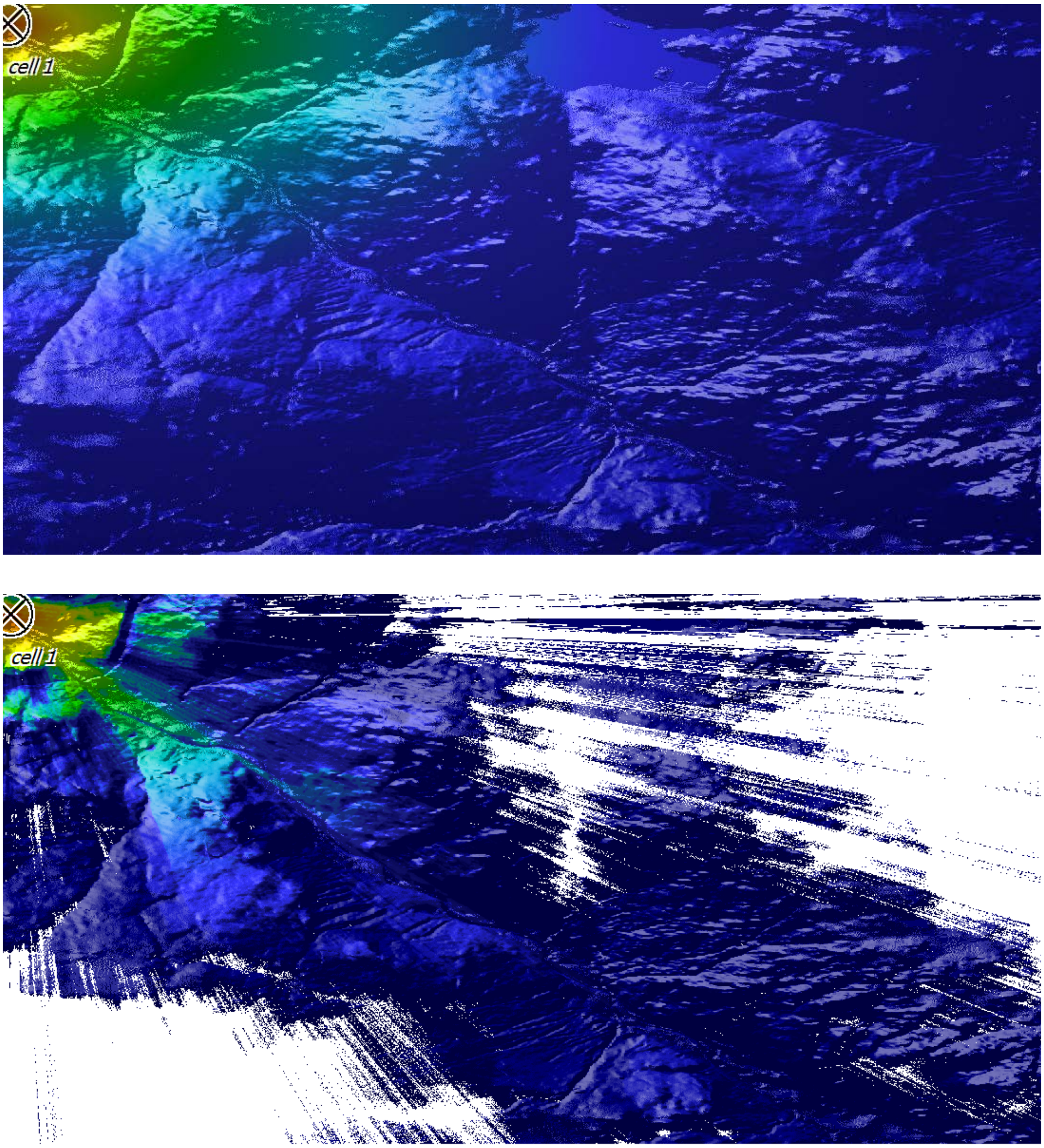


Figure 5.18 Predicted path loss using the empirical Two-ray model. Added Epstein-Peterson diffraction in lower panel

5.3.4 ITU Rec P.1546

In Figure 5.19 the predicted path loss with the ITU Rec P.1546 is shown. Since terrain data were available, the plot shows dependence on the terrain. The only two parameters to select were set as described in Section 2.1.4.

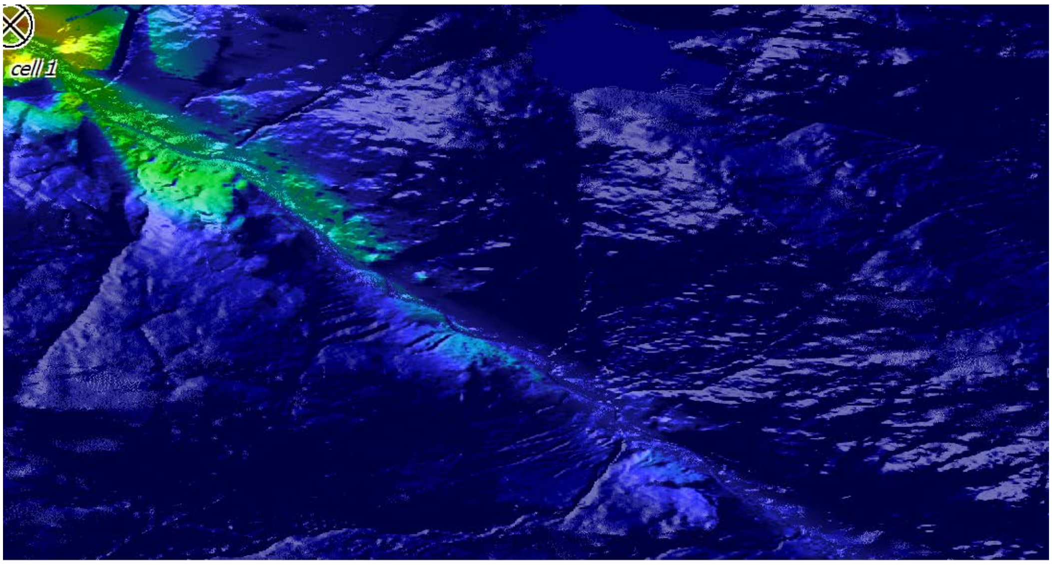


Figure 5.19 Predicted path loss using the ITU Rec P.1546 model

5.3.5 Longley-Rice point-to-point mode

The Longley-Rice point-to-point prediction is shown in Figure 5.20. Parameters that were set:

- Reliability 90% and Confidence 50%

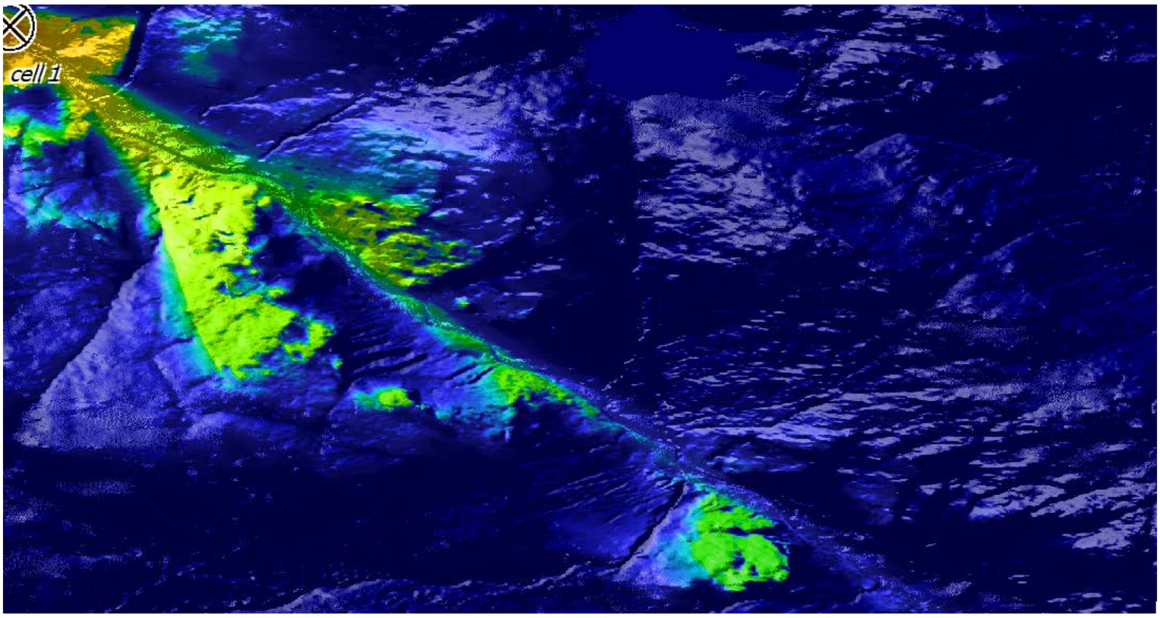


Figure 5.20 Predicted path loss using the Longley-Rice point-to-point model

5.3.6 Dominant path

The Dominant path model in Figure 5.21 gives again a very pessimistic picture when all the default parameters are used.

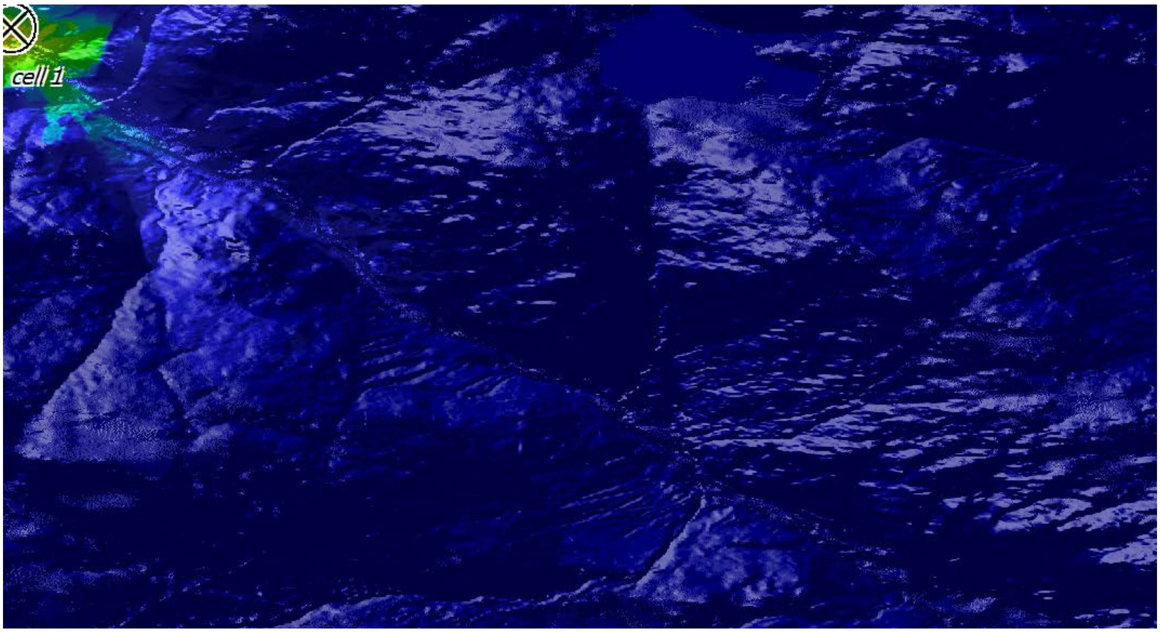


Figure 5.21 Predicted path loss using the Dominant Path Model

5.4 Summary of the predictions using different models

It was surprising to find that the Okumura-Hata model takes account of terrain features and is not a pure empirical model. This can be an AWE implementation feature. The unconventional possibility of adding diffraction losses to this model reduces coverage slightly.

The empirical Longley-Rice area mode model predicts higher path loss compared to the Okumura-Hata model, with our selection (and best guess) of the parameter Terrain Irregularity.

The empirical Two-ray model with default parameter values gives increased path loss compared to Longley-Rice area mode, unless the Terrain Irregularity parameter in Longley-Rice is set very low.

For the deterministic models the ITU Rec P.1546 seems to take well care of the terrain features and produce realistic coverage diagrams. It predicts slightly lower path loss than the Longley-Rice area mode model.

The Longley-Rice point-to-point model predicts lower path loss than the Rec P.1546, and it seems to give a better spatial resolution than Rec P.1546.

Finally, the Dominant Path model with default parameters gives the largest path loss of all the models.

5.5 Comparison of predictions with measurements

Importing the measured values of path loss into WinProp and subtracting them from the predicted values gives a plot shown in Figure 5.22. It shows a color-coded difference between measured path loss and predicted path loss at geographical points along the road where the measurements were taken. If the difference is positive (red/warm colors), the measured path loss is larger than the predicted. The data shown in Figure 5.22 are from the Gausdal (2) area and it is the empirical Okumura-Hata open area prediction that has been compared in the upper panel and the deterministic Longley-Rise point-to-point prediction in the lower panel.

In the “road curve” in the middle of the figure where the Longley-Rice shows blue points (predicted path loss is largest) the LoS path towards the transmitter is obstructed by a small hill top close to the road (see picture in Figure 5.23 taken from the receiver towards the transmitter), whereas a large mountain behind the receiver gives multipath reflections that increase the signal power received. The path loss estimate is therefore too high when the prediction program does not take account of the 3D reflections. As expected, the empirical Okumura-Hata does not consider the topography at all.

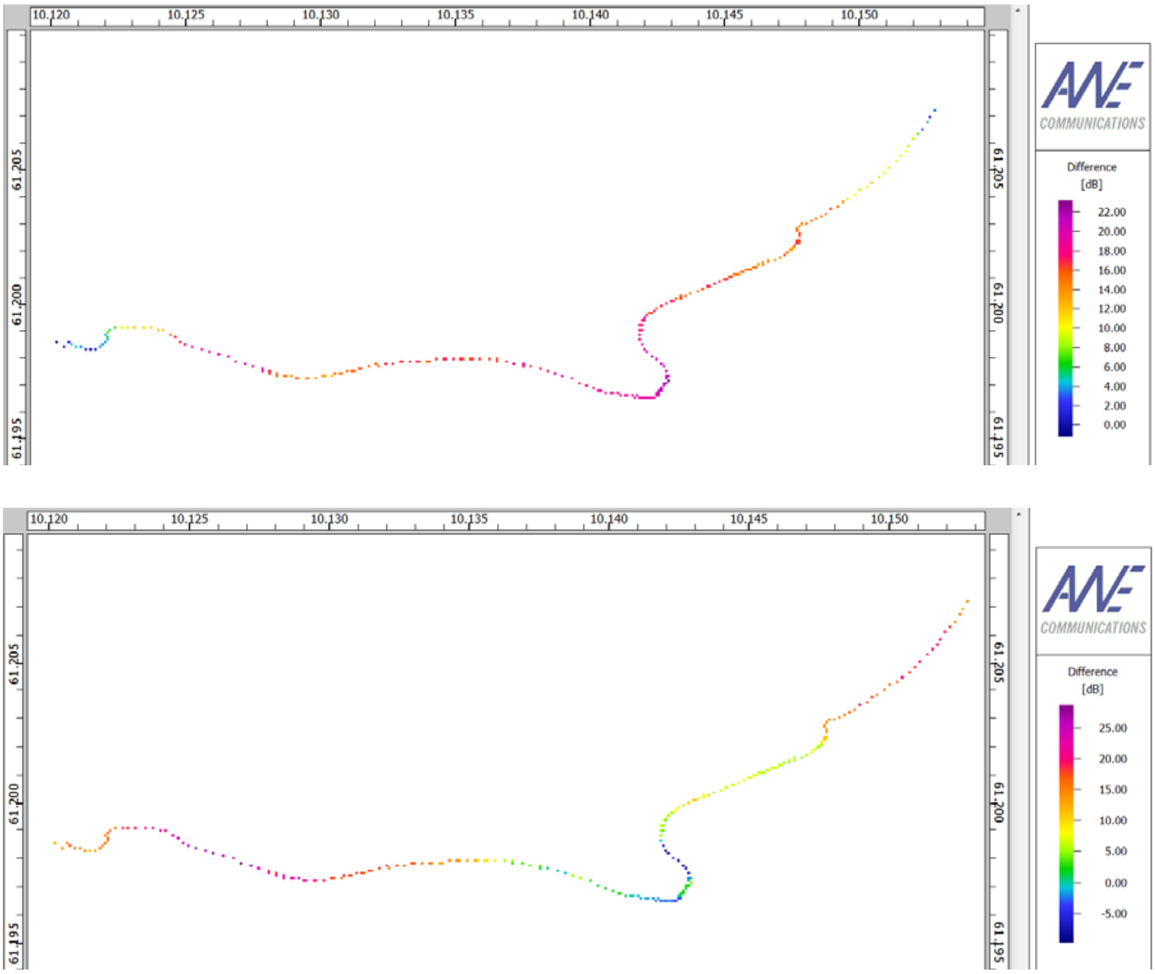


Figure 5.22 Difference between measured and predicted path loss using the empirical Okumura-Hata (upper panel) and the deterministic Longley-Rice (lower panel)

Figure 5.23 Google Earth street view towards the Tx in the road curve where a delayed strong echo is present

A series of power delay profiles measured while the receiver moves from north to south through the road curves is shown in Figure 5.24.The power delay profiles show the relative strengths of the signal components at different delays. In the first panel the LoS signal component (shortest delay) is the strongest and the delayed components are around 5 dB weaker. As the receiver moves into the road curve, the LoS component is strongly attenuated whereas the delayed components are received at the same power level. The last power delay profile in Figure 5.24 shows that the LoS component is again the strongest as the receiver moves out of the road curve.

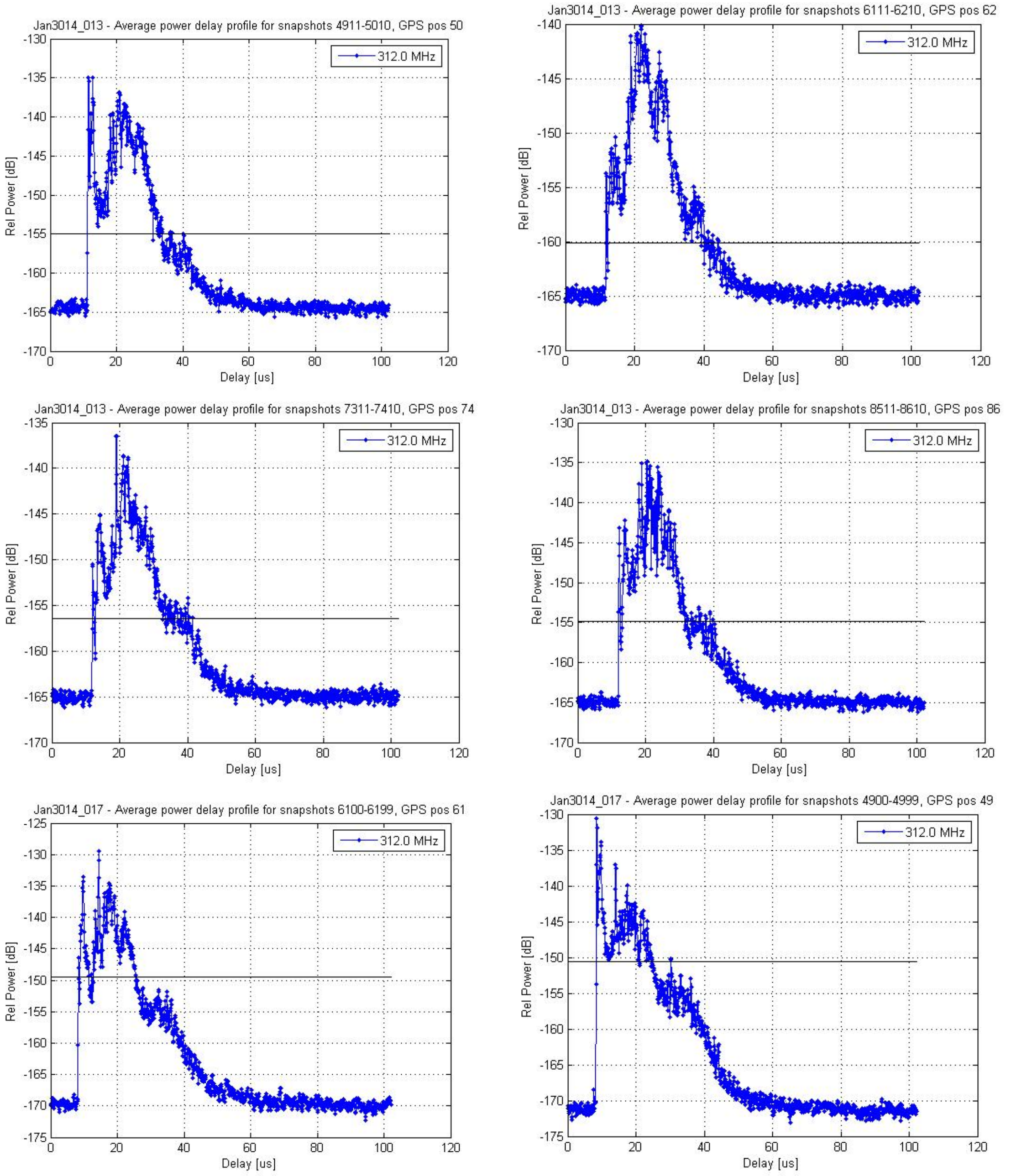
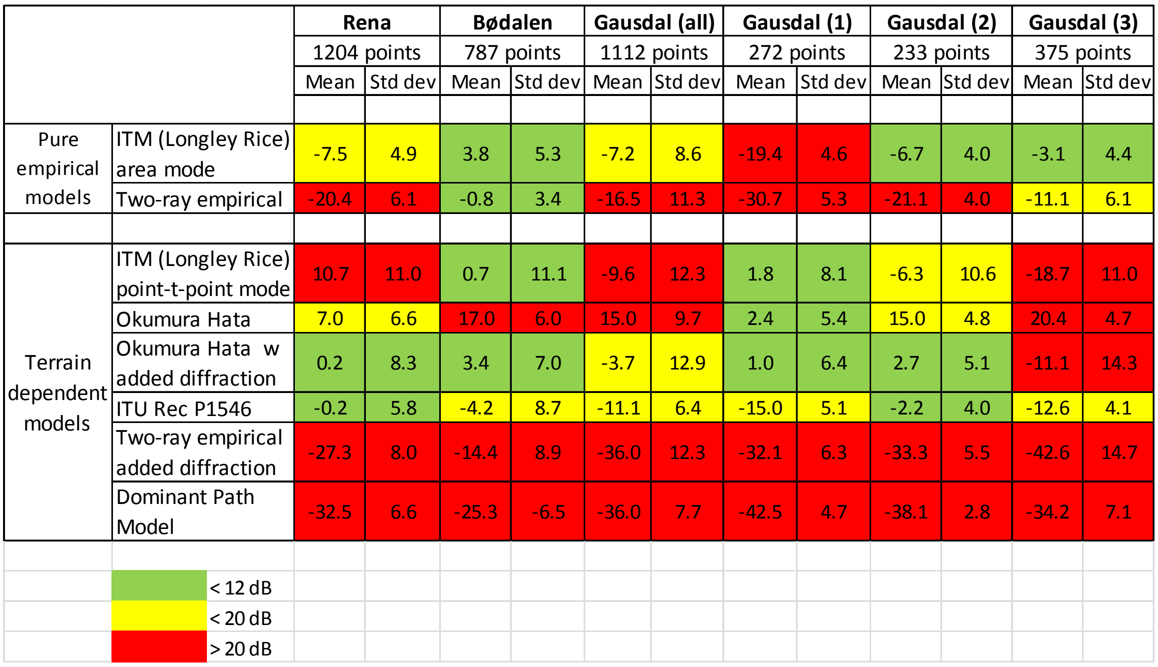


Figure 5.24 Average power delay profiles taken at approximately 100 m distance through a road curve

The result of the comparison between predictions and measurements for all paths and prediction models is shown in Table 5.1. The number of data points considered for each path is written below the path name. If the Mean value is positive, it means that the measured path loss is larger than the predicted path loss. The standard deviation has been calculated assuming a Gaussian distribution of the data. We have applied a color coding to the table. If the value of the absolute value of the mean plus the standard deviation exceeds 20 dB, the entry has been colored red. If it exceeds 12 dB but is below 20 dB, the color is yellow, and if it is less than 12 dB the color is green.



		Rena		Bødalen		Gausdal (all)		Gausdal (1)		Gausdal (2)		Gausdal (3)	
		1204 points		787 points		1112 points		272 points		233 points		375 points	
		Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
Pure empirical models	ITM (Longley Rice) area mode	-7.5	4.9	3.8	5.3	-7.2	8.6	-19.4	4.6	-6.7	4.0	-3.1	4.4
	Two-ray empirical	-20.4	6.1	-0.8	3.4	-16.5	11.3	-30.7	5.3	-21.1	4.0	-11.1	6.1
Terrain dependent models	ITM (Longley Rice) point-t-point mode	10.7	11.0	0.7	11.1	-9.6	12.3	1.8	8.1	-6.3	10.6	-18.7	11.0
	Okumura Hata	7.0	6.6	17.0	6.0	15.0	9.7	2.4	5.4	15.0	4.8	20.4	4.7
	Okumura Hata w added diffraction	0.2	8.3	3.4	7.0	-3.7	12.9	1.0	6.4	2.7	5.1	-11.1	14.3
	ITU Rec P1546	-0.2	5.8	-4.2	8.7	-11.1	6.4	-15.0	5.1	-2.2	4.0	-12.6	4.1
	Two-ray empirical added diffraction	-27.3	8.0	-14.4	8.9	-36.0	12.3	-32.1	6.3	-33.3	5.5	-42.6	14.7
	Dominant Path Model	-32.5	6.6	-25.3	-6.5	-36.0	7.7	-42.5	4.7	-38.1	2.8	-34.2	7.1

🟩 < 12 dB
🟨 < 20 dB
🟥 > 20 dB

Table 5.1 Summary of all results

The difference between measurements and predictions is generally quite large.

From the table, the ITU Rec P.1546 model performs best over all environments that have been compared. The Okumura-Hata model with added diffraction loss is second best and the ITM Longley-Rice area mode model comes third. The deterministic models using detailed terrain information do not outperform the empirical models.

The two WinProp “proprietary” models Two-ray empirical and Dominant Path Model are generally over-estimating the path loss by tens of dB. This is the result when using the default parameter values. However, we believe that the physical basis for the Dominant Path model is good, and if a qualified selection of the model parameters had been made, the result for this model would probably have been better.

The deterministic models perform best on the Gausdal (1) path where there were clear LoS. Here the empirical models overestimate the path loss. This is according to theory: The deterministic models calculate the path loss on the most probable path between Tx and Rx, not taking 3D reflections into account. This will give an accurate estimate on a true LoS path. The measurements that form the basis for the empirical models have received not only LoS signal components, but also the multipath, and therefore the models estimate the path loss to be less than what would be measured on a LoS path. And the other way around: On the Gausdal (3) path, where there were much multipath, the empirical models perform better than the deterministic models. We should also have compared the predictions with the measurements taking only the first samples of a power delay profile into account (corresponding to the LoS path), but time did not permit.

The predictions are most accurate in a “well-defined, simple” environment such as the narrow valley Bødalen. Both at Rena and in Gausdal there were more complicated terrains with rolling hills and side valleys in many directions.

6 Conclusions

WinProp from AWE Communications has been used to assess the accuracy of certain propagation models when compared with measurements. The prediction tool is easy to use, has many good features for scientific use, is robust and professional. Some well-known propagation models are implemented, and some less known propagation models are available. The less known models require deep scientific knowledge of radio propagation in order to set the parameters correctly. These models may also be “tuned” to measurements by scientific personell, but they are not useful for operational people that need to run predictions for their radio planning.

A very limited number of comparisons between measurements and predictions have been made. We have only compared data from three different locations in eastern Norway collected at one frequency 312 MHz. The conclusions may therefore not be generally applicable to other areas or other frequencies.

Generally, the prediction accuracy of the different models in the terrain that has been measured is not very high. For the best fitted model over all the measurements at the three locations, the mean difference can be up to 15 dB with a standard deviation of 5 dB. However, the accuracy is better for some models at a particular location with certain characteristics.

If there are mainly LoS conditions, the deterministic models taking terrain features into account (Longley-Rice point-to-point, Okumura-Hata with diffraction and Rec P.1546) perform best. When multipath is expected as for the Bødalen, Gausdal (2) and Gausdal (3) locations, the empirical model Longley-Rice, area mode is the best choice and even the Two-ray empirical may be used. The accuracy of these models when selected based on the conditions mentioned above can be approximately mean 2-3 dB and standard deviation 5-6 dB.

The use of these models in radio planning should be used with care, honoring the fact that the selection of parameter values change the predictions with many dBs, and that multipath propagation causes a very difficult propagation environment to model. This study did not find one propagation model that was clearly the best model to use in all the terrains that were considered. There exist other models not implemented in WinProp, for instance DETVAG 90/FOA [7], that would be interesting to evaluate in the future.

Acknowledgement

We would like to thank the Communication Research Centre in Ottawa represented by Phil Vigneron, for providing the channel sounder and enabling us to do these measurements in Norwegian terrain. And in particular we thank Jeffrey Pugh for support during the measurements and in the preparation of the data.

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