INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

CORRESPONDENCE GROUP 3K-1 WORKSHOP

11-13 MARCH 2008 LONDON

CG 3K-1

Document 3K-1/xxxxE

March 2008

Rutherford Appleton Laboratory [UK]

MEASUREMENT DATA FOR IMPROVING ITU-R RECOMMENDATION P.1812

CONTENTS

1 Introduction

ITU-R Recommendation P.1812 (P.1812) has been published and focus has now moved on to improving this recommendation.

Since the publication of the recommendation, comparisons against measurements have identified several areas where improvements should be made in a future revision to P.1812. This revision work is currently the responsibility of an ITU-R Working Party, 3K-1 (3K1). The working party has prioritised on improving the diffraction model, in the modelling of terminal clutter and in adapting the ducting model to warm climates. The 3K1 work programme also recognises the desire within study group 3 to increase the applicability of the recommendation, especially the time percentage range and the upper frequency limit.

In order to test candidate models against each other, an extensive database of measurement data has been assembled by 3K1 into a common database. This database covers many years of measurements made throughout the world. It has become clear in testing candidate models that while the majority of the measurements within the database are good, inevitably some errors have occurred.

As comparisons against invalid measurement data may lead to incorrect conclusions being drawn when testing models, the erroneous records needed to be identified. The aim of the activity reported in the remainder of this document was to analyse the database and to mark and where possible correct any errors. A further requirement was to consider the significance of each data set to avoid any statistical bias which may arise. For example to avoid the possibility of one large measurement campaign in one climatic region dominating the overall results.

In section 2 the data is analysed for the quality of the input parameters. Some datasets had problems with the terrain profile. In some sets some climatic parameters were not present. In some records clutter data was absent or invalid. Many records did not specify the duration of the measurement. Several measurements of height gain appear without any information about the terminal clutter environment. Several records were found to be duplicates.

In section 3 the steps taken to clean the database are reported. This exercise included adding missing climatic data based on ITU-R maps into the records where this data was missing. Height gain measurements were flagged for reference. The erroneous measurements as identified in section 1 were flagged according to the perceived seriousness of the error. Further errors were detected and marked, based on a defined set of rules, for example an incompatibility between the reported terminal locations and the path length, or inadequate path profile resolution. Further confidence checks included detecting clutter contamination through marking paths where the profile indicated a clear line of sight but the measurement showed considerable additional path loss.

The cleaned flagged data has been incorporated as XML into an SQL database. This allows data to be extracted based on SQL commands. The contents of the database and the parameter coverage of the measurements is summarised in section 4. The method of extracting the records via a web based interface is presented in section 5, together with some examples.

Section 6 demonstrates the utility of the cleaned and flagged data through some examples of model comparison. Clear differences between two rival diffraction models only become apparent using the cleaned data.

Section 7 takes the results from P.1812 and compares this with the measurement database. A set of outliers have been identified where the discrepancy between the model and the measurement is severe and these are examined in detail to determine if the discrepancies are caused by model inadequacies or by measurement error. A list of outliers is presented in Annex 1.

This document concludes in section 8 with examples of the performance of each proposed modification to P.1812 against the cleaned and filtered database.

2 Data Issues

As we have developed improved models for a future revision of P.1812 it has become clear that there are several issues with the ITU-R database. The database is an excellent facility, but as it is large and has been collected over a long period of time by many different groups, there are bound to be a small proportion of measurement records that contain errors. It is believed that these issues have, to some extent, been masking the differences between prediction models. Known problems include:

- Missing, low resolution or invalid path profile data,
- Missing radio-climatic data,
- Missing or misleading clutter data,
- Duplicated measurement sets,
- Repeated measurement sets with differing path loss measurements for the same tx, rx configuration,
- Unspecified measurement duration,
- Height gain functions without accompanying clutter information.

2.1 Profile issues

Path profiles are a vital input to P.1812 and have a significant effect on the predicted path loss. Some measurement sets contain profiles that have been extracted manually from maps. This is not a problem except where the profile spacing is too coarse or irregular. Examples include paths where the data on land is at a high resolution, but there are no heights given for the parts of the path passing over the sea. The P.1812 path analysis algorithm can not adequately handle these situations. Another profile problem noted in some data sets is non-monotonic range progression, which is also incompatible with P.1812. A final profile issue is where the specified path length from the profile is not a close match to that from calculations based on the terminal locations.

2.2 Missing radio-climatic data

Where data for radio climatic zone, dN and No are not provided, these must be supplied by the model software, for example through interpreting maps. It is possible to get differing values depending on the method used to estimate the missing climatic data which leads to different groups obtaining different results from the same model which is undesirable.

2.3 Missing or misleading clutter data

Most of the data sets do not include any information on the terminal clutter or the clutter along the path. Some data sets include a clutter code but no definition of the meaning of the code. Other data sets include clutter heights which on closer inspection

appear to be the ground heights of the previous profile point – clearly a corruption of the data has occurred at some point.

2.4 *Duplicated or repeated measurement sets*

Some measurement results are duplicated in the database. Using a measurement more than once may bias the resulting analysis. Repeated measurement sets with different measurements were only found in the USPhase2 dataset. These measurements show the time variability of spot measurements. Again, using more than one set of these will bias resulting analysis.

2.5 *Unspecified measurement duration*

Several data sets, most notably the USPhase1 and USPhase2 data contain no information on the measurement duration. It has to be assumed that these are spot measurements, which should not be confused with median 50% value measurements. Point measurements have to be assumed to be at the median level if they are to be used but should not be treated with the same confidence as long term measurements.

2.6 *Height gain tests*

Several of the data sets contain height gain tests that result in many samples along the same path with differing receiver heights. These results are very useful for clutter modelling but unfortunately the database frequently does not include any information on the local clutter. To use all these measurements would clearly bias the resulting models. There was much discussion over this as height gain may occur through reflection lobing or simply through emerging above terminal clutter. Without other information available about the measurement technique used it was decided that only the highest height measurement should be used for model comparisons as it is the most likely to be uncluttered. Measurements at other heights can be used to generate clutter models.

3 Cleaning and extending the measurement database

To address the measurement data issues the data was tested automatically against a set of criteria. Missing climatic data was added into the database where possible and all profile data was organised so that the profile originates at the transmitter. At the same time the opportunity was taken to add the COST210 and the Ron Sandell compiled datasets into the database. All measurements were included, even if out of scope for the current models under test (a flag '`InputsValid=1`' shows if measurements are in scope).

It was decided not to throw away any data but to mark each measurement based on a confidence level. These were:

- Data has no concerns – i.e. we believe this to be good data;
- Data has minor concerns – i.e. a few minor issues but data can be used for testing;
- Data has major concerns – data has problems and should not be used for testing.

Two data fields were used to flag concerns, '`IsValid`' and '`IsLongTerm`'. The following major concerns were flagged using '`IsValid`':

- Path profile resolution insufficient – '`IsValid=-2`' on fail;
- Path length incompatible with stated terminal locations – a maximum discrepancy of up to 2km was permitted – '`IsValid=-1`' on fail;
- The path profile is not monotonic – in some datasets the reason for this was clear and these sets were corrected – '`IsValid=-2`' on fail;
- Path profile missing or otherwise known to be suspect – '`IsValid=-2`' on fail;
- Path is line of sight according to profile but shows a much higher loss than expected based on a 2-ray line of sight model. This indicated probable clutter contamination, meaning the data may be useful for clutter modelling but not for overall performance assessment. 10dBs above free space was chosen as the cut-off – '`IsValid=-3`' on fail;
- Paths with losses significantly lower than free space at 50% time. This indicates an incorrect path length input, or possibly a spot measurement taken during a moment of enhancement. 6dBs below free space was chosen as the cut-off – '`IsValid=-5`' on fail.

Note that the final two points above are based on post-prediction analysis. This form of filtering is undesirable so we use it sparingly. It should also be noted that although these criteria address individual measurements, all measurements for the link are rejected.

We would have also like to filter those were we believe the measurement dynamic range was exceeded, e.g. the measured signal is too close to the noise floor. However noise floor information was not available for the datasets.

Minor concerns included:

- Data is a spot measurement – measurement duration not given – '`IsLongTerm=0`' on fail, and '`TimePercentage`' left blank if not specified;
- Risk of statistical bias – i.e. many measurements along very similar path;
- Data known to have another issue, for example some broadcast transmission based measurements were daytime only.

Not all concerns arose in practice. Finally any duplicate links were flagged with '`IsValid=-4`'.

Missing climatic data was not marked as a concern. Transmitter and receiver locations were generally of an accuracy that these parameters could be read from ITU maps and added to the database for convenience. This allows detailed comparison of model implementations without any concern over having slightly different input parameters.

Finally, two fields were added to the measurement details. The first, '`RxHeightGainGroup`' indicates a group of measurements with common parameters `Frequency_GHz, TimePercentage, TX_AHaG` (Tx antenna height above ground) and Polarization, but varying `RX_AHaG`. The second, '`IsTopRXHeightInGroup`' indicates whether a particular measurement has the highest `RX_AHaG` with it's measurement group.

4 Summary of Filtered Link Database

To summarise, for model testing purposes only link measurements satisfying the following condition should be used:

```
IsValid=1 && IsLongTerm=1 && IsWorstMonth=0 && IsTopRXHeightInGroup=1 &&
InputsValid=1
```

The condition `IsLongTerm=1` may be dropped to include all the spot measurements, if this is required, but it must be realised that this will have a bearing on the expected accuracy of model predictions. Table 1 shows the number of links and measurements in each category. The yellow area marks the highest quality data.

Field and Value		# Links (Measurements)
Total		5832 (35840)
`IsValid=0` (test links) `IsValid=-1` (TX, RX location concerns) `IsValid=-2` (profile concerns) `IsValid=-3` (clutter concerns) `IsValid=-4` (duplicate link) `IsValid=-5` (LOS path loss concerns)		8 (24) 38 (130) 32 (104) 341 (3226) 19 (27) 21 (823)

`IsValid=1 && IsLongTerm=0 (&& IsWorstMonth=0)`	Total
	`InputsValid=1`
	`InputsValid=1 && IsTopRXHeightInGroup=1`
		4922 (29061)
		4914 (25309)
		4914 (9639)

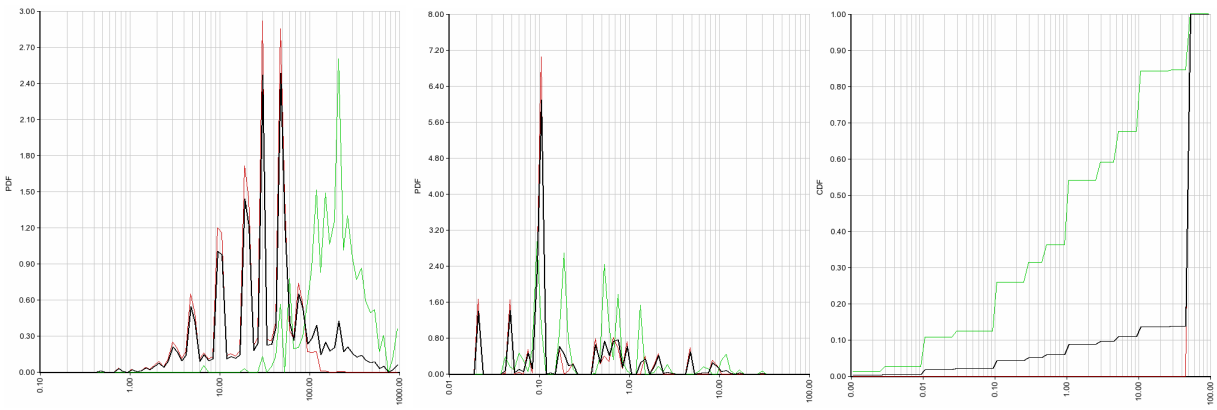
`IsValid=1 && IsLongTerm=1 && IsWorstMonth=0`	Total
	`InputsValid=1`
	`InputsValid=1 && IsTopRXHeightInGroup=1`
		428 (2307)
		402 (1410)
		402 (1410)

`IsValid=1 && IsWorstMonth=0`	`InputsValid=1 && IsTopRXHeightInGroup=1`	5316 (11049)

Table 1: Link and measurement counts

Figure 1 to Figure 6 show the distributions of several key link/measurement parameters for the entire database satisfying the condition `IsWorstMonth=0 && IsTopRXHeightInGroup=1`. Data in each plot is grouped by the parameter `IsLongTerm`. It can be seen that for some parameters the full input range of P.1812 is not tested in the database. The large number of USPhase1 and USPhase2 measurements in the database causes certain spikes in the PDFs, which may cause errors that dominate subsequent prediction analysis.

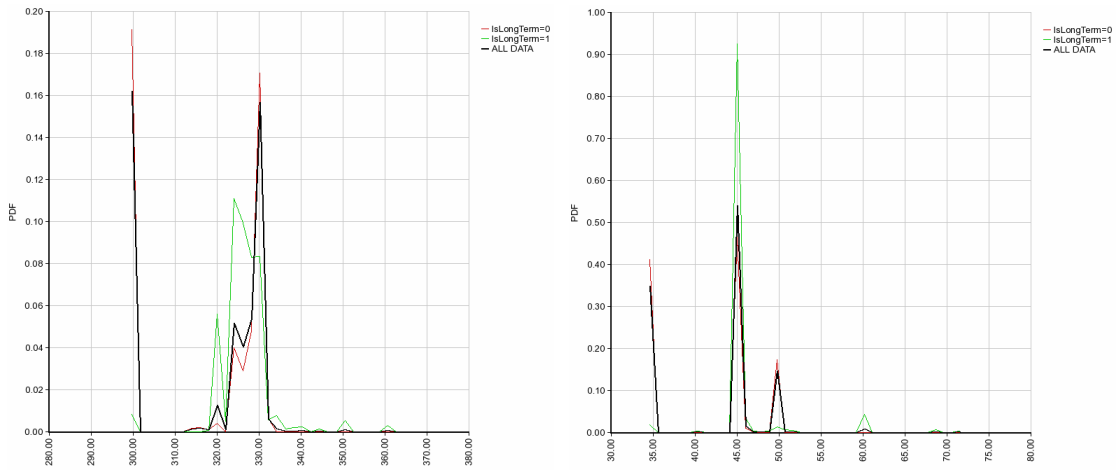
It is clear that the database is dominated by the lower frequency measurements and the median time percentages. The short term measurements tend towards being short paths whereas the longer term measurements are generally on longer paths. This means that low time percentages are not well represented for short paths.



Path length (km) **Frequency (GHz)** **Time percentage**

Figure 1:Some examples of the parameter distributions of the testing data

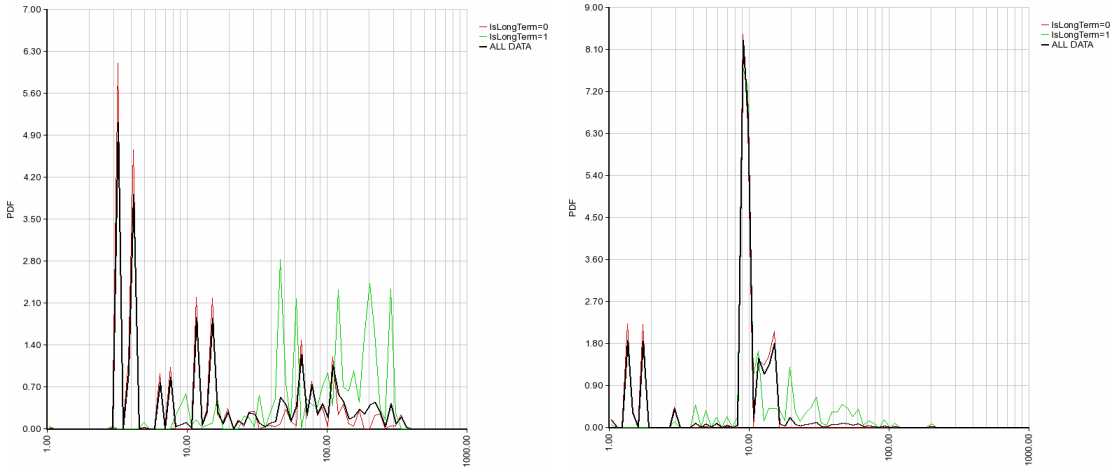
The sea level refractivity and refractivity gradients are dominated by mid latitude climates. Regions of high ducting prevalence are not well represented in the database.



Sea level refractivity Refractivity gradient

Figure 2: PDF of path centre refractivity

The distribution of antenna heights shows a good spread though many of the measurements are concentrated below ~20m with another concentration around 70m. Long term measurements tend to have higher transmitter heights than short term ones.



TX agl (m) RX agl (m)

Figure 3: PDFs of heights above ground

The vast majority of paths are overland and of the sea paths, there are very few mixed land/sea paths with sea fractions below 90%. Fortunately the majority of the sea paths are long term measurements.

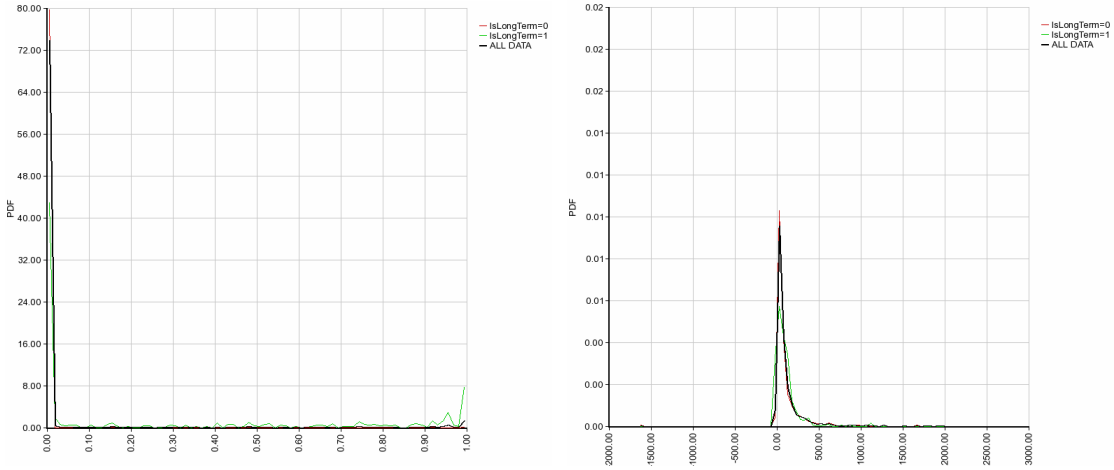


Figure 4: PDF of sea path fraction Ω **Figure 5: PDF of terrain roughness h_m (m)**

The horizon angle distributions are concentrated in the range ± 30 miliradians, equivalent to around ± 2°. This is fairly typical of terrestrial paths.

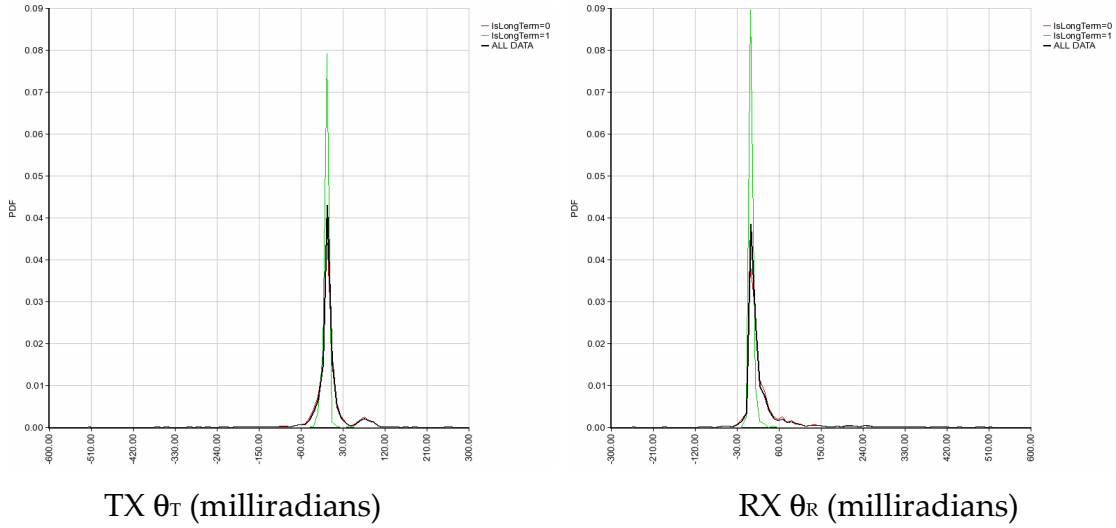


Figure 6: PDFs of horizon angles

Figure 7 shows the joint distributions of some selected parameters. It is clear that there are significant gaps in the parameter space of the measurement database. This must be borne in mind when assessing the models against each other, as for example, large errors in prediction at high frequencies on long paths may be masked by the larger number of lower frequency short path measurements.

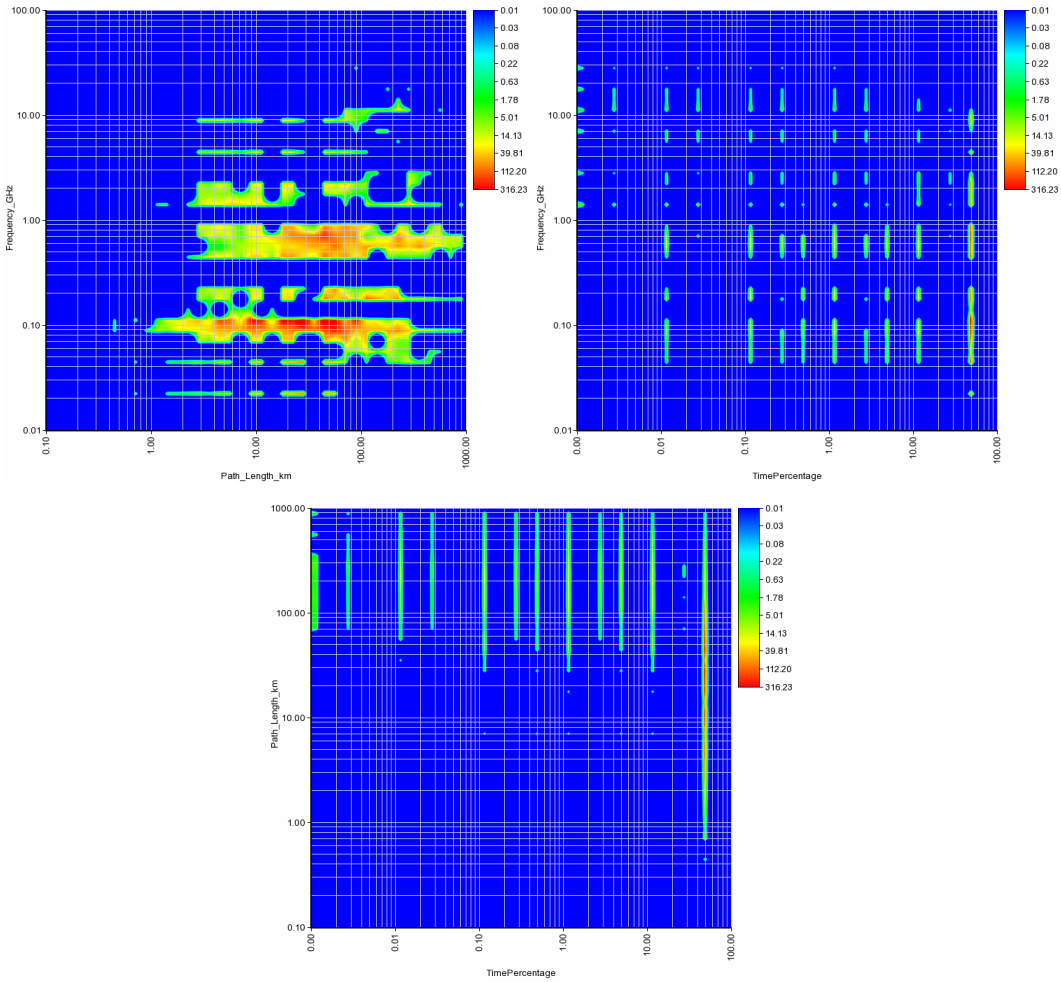


Figure 7: Joint distributions of path length, frequency and time percentage

5 Accessing the Cleaned Database

The cleaned data has been stored in an SQL database which is available via the internet from http://www.rcru.rl.ac.uk/njt/linkdatabase/linkdatabase.php. A utility is included to output data in XML and also in the original ITU-R CSV format[1] for backwards compatibility with existing software. It should be noted that added fields discussed in the previous section are not output in the CSV format. The basic structure of the SQL database is shown in Figure 8. Each box represents a separate table in the database. The sizes loosely represent the actual dimensions of each table. The colour parts to each box represent that table's unique key which should be used for cross-linking tables.

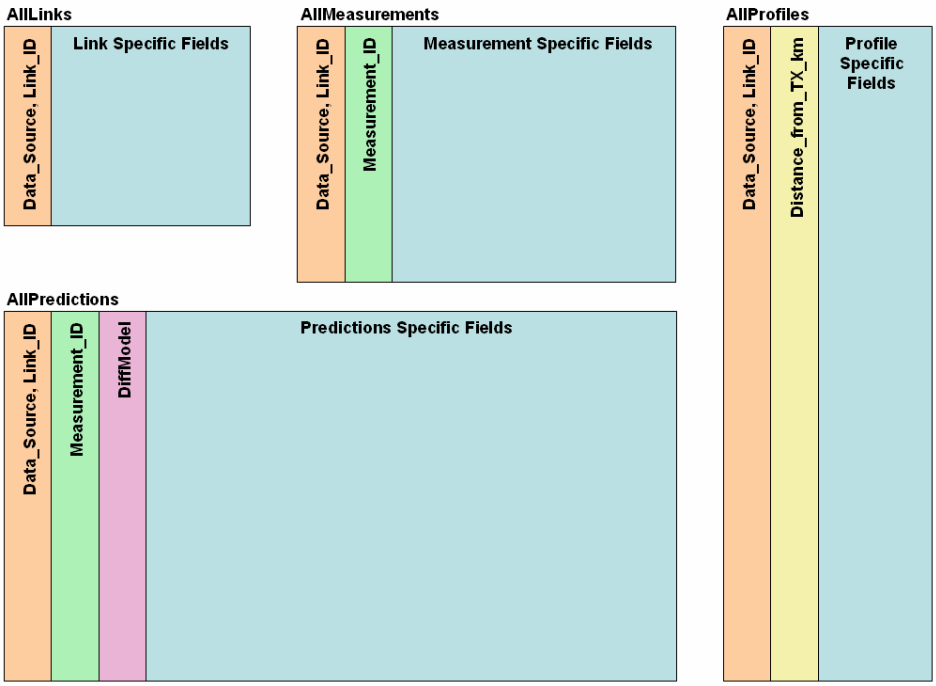


Figure 8: Link database structure

The cleaned and flagged database is offered to the community to facilitate model development. An image of the initial page is shown in Figure 9.

[1] There have been several minor modifications to the format. Firstly all fields now are of the format 'FieldName:,Value'. Secondly an additional column has been added to the profile area, namely: 'Radio Met Code' containing IDWM land sea coast codes - 4 for land, 3 for coast and 1 for sea. Thirdly the measurements area now contains additional columns at the end for 'RX height gain group' (-1 for no group, otherwise the group index) and 'Is top height in group' (1 for top height or single measurement not part of a group, otherwise 0). Finally spurious text fields found in some or all of the original formatted files have been removed.

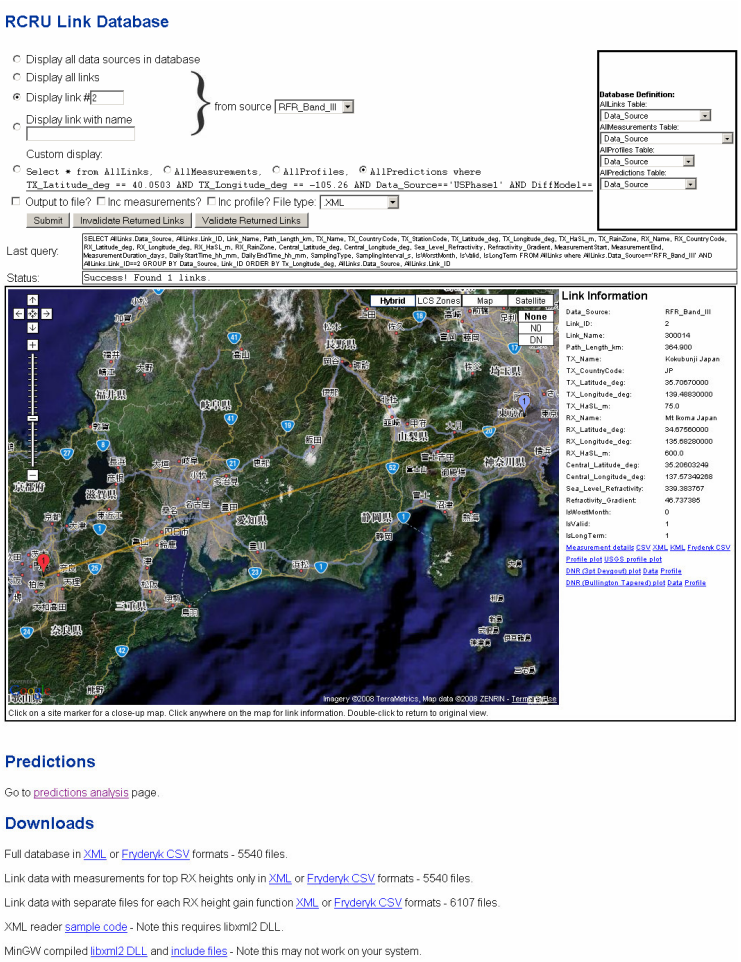


Figure 9: Link database web display

From the web page it is possible to examine the link database using the top form to display using Google Maps either whole data sets or specific paths. For further analysis the database can be exported in XML, KML (used by GoogleEarth) or CSV format, either using the top form or via the interactive frames that appear in the mapping area. It is also possible to display the supplied measurements, path profiles including clutter heights and land sea coast codes where available, SRTM path profiles and test plots of P.1812 against measurement data. Some examples for the link of Figure 9 are shown in Figure 10.

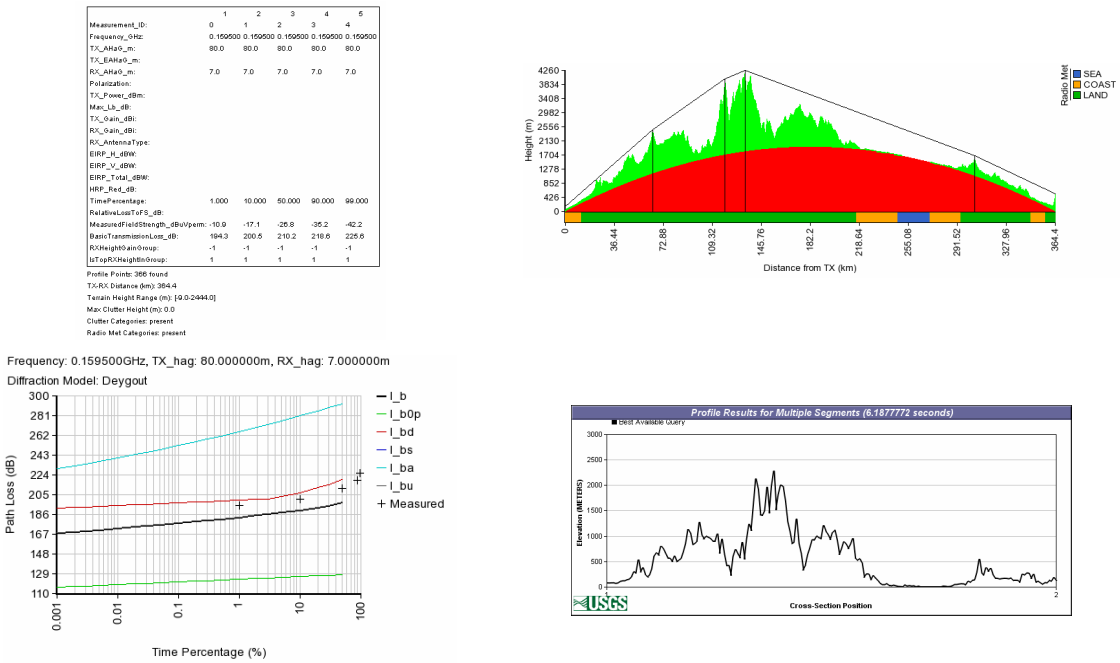


Figure 10: Sample outputs

A custom SQL search (using SQLite syntax, http://www.sqlite.org/lang.html) is also possible. The custom search allows only links exhibiting certain characteristics to be displayed, e.g. `TX_CountryCode == 'GB' AND Frequency_GHz > 2.0` will display all links regardless of data source with frequency above 2GHz and TX country code set to 'GB'. The status bar indicates if there has been a SQL syntax error or if no links satisfying the criterion are found. Note that in the previous example '`TX_CountryCode`' and '`Frequency_GHz`' exist in different tables within the database. It is possible to link the measurements, profiles or predictions table to the links table for the search (however more than one table may not be linked in) using the appropriate radio button on the form. All the column names are shown in the combo-boxes on the right hand side of the form.

The whole database is available to download as a zip file in either XML or CSV format linked at the bottom of the page. Furthermore a version only including the measurements at the top RX height for each measurement group, and a version only including measurements within a height gain group (one file per height gain group) are available. The files within the zip are arranged into a hierarchical directory structure firstly divided by the '`IsValid`' flag, secondly by the '`IsLongTerm`' flag and then finally by the '`Data_Source`' field. This is convenient since the original file format does not contain the flag information. Depending on the needs of the user only certain subdirectories from the full zip will be required.

The database not only holds link data but prediction data from candidate models in the AllPredictions table. Currently results from P.1812 and P.1812 with Bullington are included, along with some provisional models. The model identifier is stored in the '`DiffModel`' field. Table 2 identifies current '`DiffModel`' values in use.

Field and Value	Diffraction Model
`DiffModel=1`	3-edge Deygout model as in ITU-R P.1812
`DiffModel=3`	Bullington model with LOS taper
`DiffModel=5`	3-edge Deygout model as in ITU-R P.1812 with some aspects of the US PTP cylindrical edge model
`DiffModel=6`	3-edge Deygout model as in ITU-R P.1812 with Chinese spherical Earth proposal detailed in ITU document 3K/150-E
`DiffModel=7`	Bullington model with LOS taper and Markus Liniger's distance correction [9th order polynomial fit of log(path_length) to 3-edge Deygout mean]
`DiffModel=8`	Bullington model with LOS taper and Markus Liniger's distance correction as additive term
`DiffModel=9`	Bullington model with LOS taper and David Bacon's distance correction [3 point fit to 3-edge Deygout mean]

Table 2: Diffraction models currently in the prediction database

A predictions analysis web interface has been created to allow easy analysis of the predictions data, see http://www.rcru.rl.ac.uk/njt/linkdatabase/linkdatabase_predictions.php. Figure 11 shows the web interface.

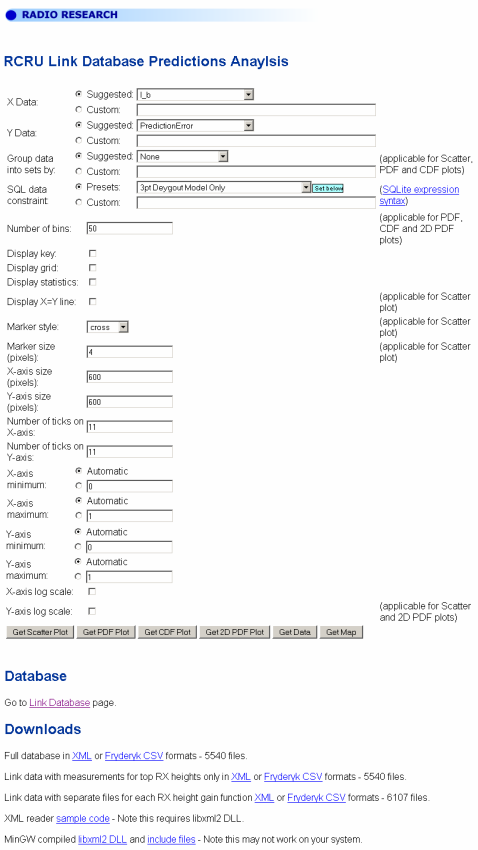


Figure 11: Prediction analysis web interface

Four types of plots are available by clicking the appropriate form buttons – scatter, pdf, cdf and 2D pdf plots. It is also possible to extract the requested prediction data to a CSV file for further analysis or display the links for the selected data on a map using the other two form buttons.

The key input fields are x and y data (where appropriate) the group by field which allows the results to be split and colour coded according to the specified columns, and finally the search constraint. A typical preset constraint would be to look at valid results from one diffraction model, e.g. use the following constraint to look at the standard implementation of P.1812.

```
DiffModel==1 AND IsTopRXHeightInGroup==1 AND IsValid==1 AND IsWorstMonth==0
                              AND InputsValid==1
```

Each of the above fields can be customised using standard SQLite syntax, e.g. the x-axis could be '`max(abs(TX_latitude_deg), abs(RX_latitude_deg))`'.

Other inputs in the form control the display format of the plot.

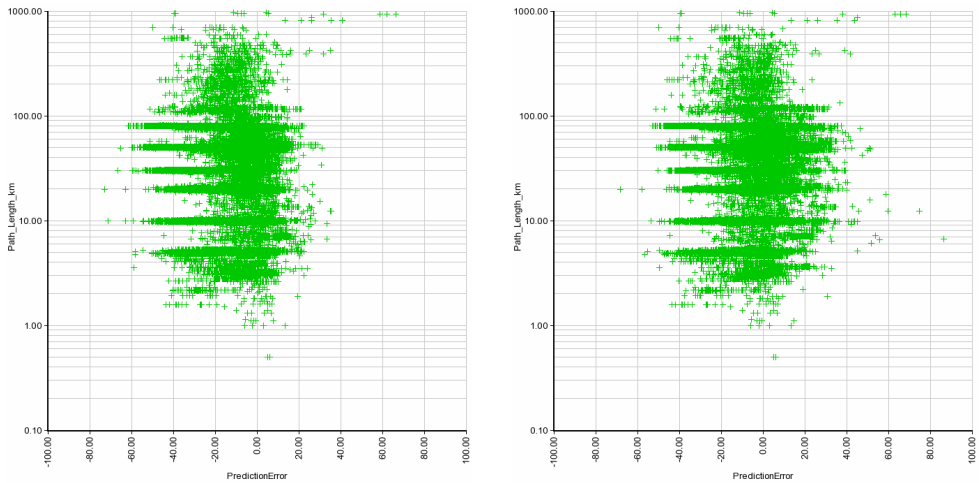
Through the use of SQL the analysis becomes highly flexible, for example if required one could plot the prediction error against any other parameter including ones not immediately obvious; for example plotting prediction error against longitude has revealed interesting effects.

6 Advantages of using flagged and cleaned data

In this section, the aim is to demonstrate how the cleaned data may be more useful for evaluating the differences between models. Two examples of P.1812 and P.1812 with the diffraction model replaced by a Bullington + taper model are used as illustrations. It is not the intention in this report to say which of these models should be used in a future update of P.1812, the answer to that is still under study but it is already evident that the answer is that neither model is the best in all situations.

Studies are based on extracting test parameters based on SQL database queries so that sets of measurement parameters and model results may be compared. The SQL command generation and visualisation of the results is facilitated by a PHP application accessed through the prediction analysis page as shown in Figure 11.

The prediction analysis can be used for comparing model results in the database. An example is shown in Figure 12 where prediction error is compared between our two test models for all valid data plotted against path length. The plots look odd with horizontal concentrations of data at certain path lengths. It is hard to tell how well each model is performing. Neither model appears to be much good.

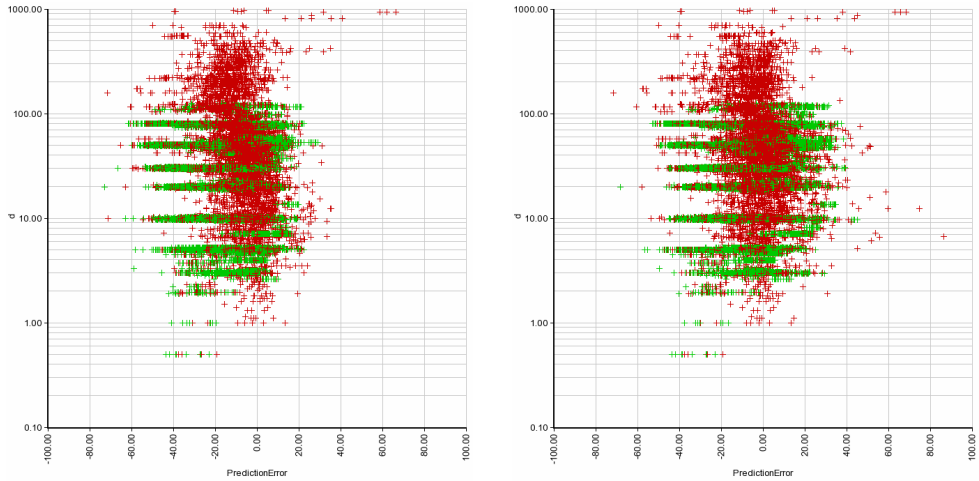


Bullington Taper 3 Edge Deygout

Figure 12: Sample analysis results – unfiltered data

Figure 13 is the same result but with the data separate into groups by the '`IsTopRXHeightInGroup`' field. Top RX height measurements are now in red. Neither model can be expected to allow for height gain where there is no terminal clutter data. It can be seen that a large number of the extreme points occur for the lower measurements in a height function. Differences between the models are starting to become clearer in Figure 13 over Figure 12, however extreme values and banding at

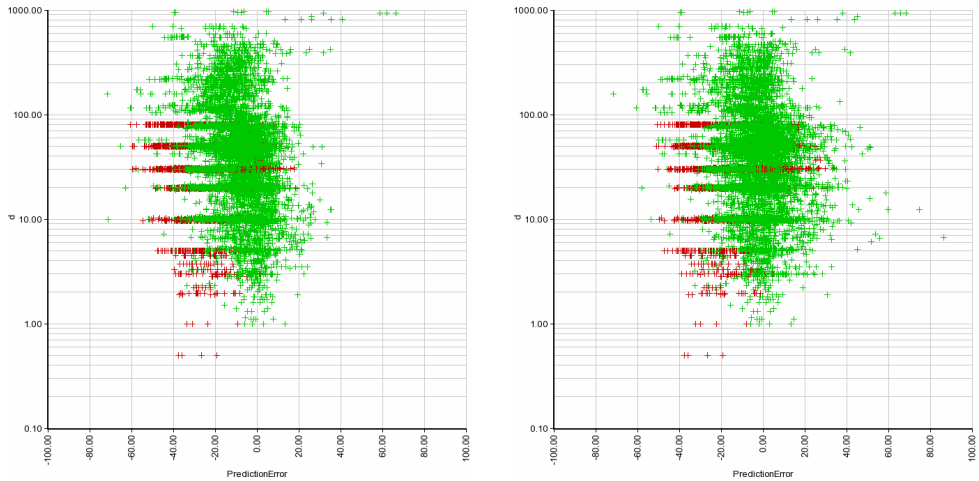
certain distances are still present in the dataset even once height gain groups are removed.



Bullington Taper 3 Edge Deygout

Figure 13: Sample analysis results – height gains grouped in Green

It was found that certain US data may be contaminated by clutter (see Section 7.2). Figure 14 shows the same result as Figure 13 but with the US data from plains (conveniently such the `Link_Name` of such data is prefixed by 'PL') separated out, and shown in red. This was achieved by grouping the data according to the SQL '`abs(Link_Name LIKE "PL_%")`'[2].



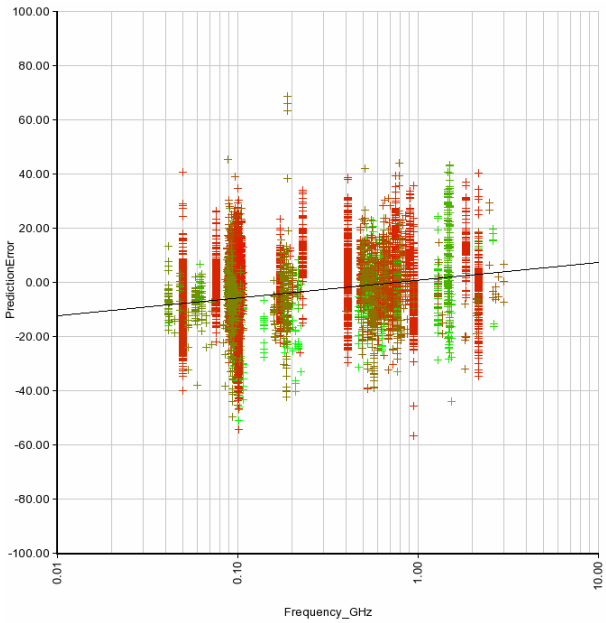
Bullington Taper 3 Edge Deygout

Figure 14: Sample analysis results – filtered data red group is US plains data

[2] Abs() is required merely to convert a boolean operation to an integer value.

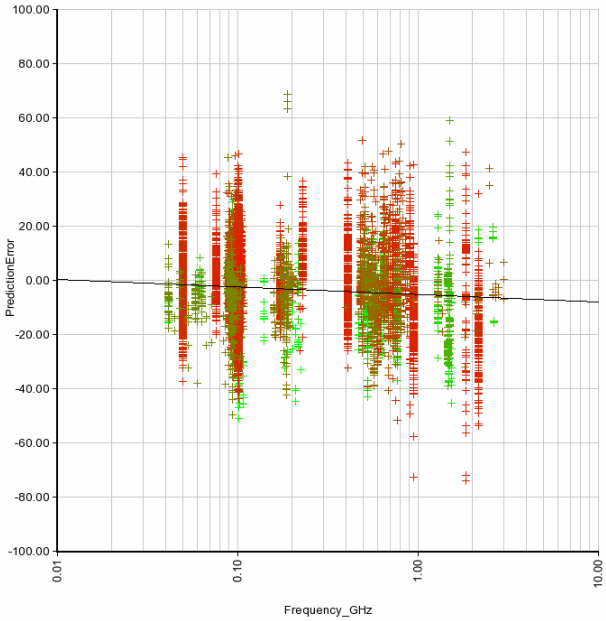
The remaining data in green is much easier to analyse. It is clear to see that Bullington has a lower spread, but a distance dependent offset as compared to the 3-edge Deygout model used in the current P.1812. The spread of both models is fairly constant with path lengths greater than 10km.

It is also possible to plot regression fits to compare the models. For example the results of applying the Swiss 9 point additive correction to the Bullington model to is plotted with a logarithmic regression fit to frequency in Figure 15 and is compared with an alternative proposal from the UK in Figure 16.



	Points	MeanX	StDvX	MeanY	StDvY	m	b
Data_Source=ABU	108	0.21	0.17	-21.04	14.60	26.04	-0.73
Data_Source=BBC	56	0.18	0.15	-12.36	7.63	-5.29	-16.93
Data_Source=BBCL	25	1.51	0.03	-15.69	10.57	112.28	-35.93
Data_Source=BBCn	252	0.63	0.12	-3.31	8.23	-15.95	-6.63
Data_Source=Cost210	65	1.44	0.56	-1.32	11.91	28.34	-5.00
Data_Source=ERT	9	0.22	0.00	-2.96	5.24	89.40	56.62
Data_Source=HOL	69	0.32	0.29	1.62	7.22	2.40	3.34
Data_Source=IRT	584	0.42	0.27	2.97	7.40	-5.64	-0.04
Data_Source=IRTL	154	1.48	0.02	9.56	15.33	189.19	-22.44
Data_Source=IRTs	63	0.10	0.00	-3.98	7.82	115.61	113.98
Data_Source=ORF	54	0.10	0.00	11.01	9.19	177.86	192.46
Data_Source=RAI	83	0.38	0.21	3.41	7.54	-5.93	0.26
Data_Source=RFR_Band_I	120	0.05	0.01	-8.21	7.07	-22.39	-36.83
Data_Source=RFR_Band_II	242	0.09	0.00	-8.90	11.46	-63.41	-74.17
Data_Source=RFR_Band_III	295	0.18	0.01	-5.18	12.35	99.48	67.95
Data_Source=RFR_Band_IV	250	0.54	0.03	-6.39	12.30	-147.82	-45.83
Data_Source=RFR_Band_V	174	0.76	0.08	-5.79	11.55	-1.28	-5.95
Data_Source=RFR_Band_VI	42	2.01	0.61	-4.72	11.16	12.78	-8.33
Data_Source=S	107	0.63	0.04	-5.32	10.55	58.97	6.40
Data_Source=SUI	1114	0.10	0.00	-1.14	9.63	6.49	5.46
Data_Source=Swiss	405	0.66	0.13	2.25	9.26	6.04	3.41
Data_Source=TDF	64	0.61	0.10	1.93	11.22	-48.74	-8.80
Data_Source=USPhase1	4921	0.09	0.02	-8.76	10.95	-1.94	-10.81
Data_Source=USPhase2	1642	0.72	0.68	1.47	12.86	1.01	1.83
Data_Source=YLE	100	0.11	0.00	5.72	6.70	-1.60	4.15
Data_Source=YLEs	51	0.21	0.17	-3.51	11.04	-9.69	-11.07
ALL DATA	11049	0.31	0.43	-4.43	12.18	6.56	0.64

Figure 15: Swiss 9 point distance correction to Bullington



	Points	MeanX	StDvX	MeanY	StDvY	m	b
Data_Source=ABU	108	0.21	0.17	-21.43	14.79	22.07	-4.22
Data_Source=BBC	56	0.18	0.15	-8.97	7.67	-11.21	-18.65
Data_Source=BBCL	25	1.51	0.03	-25.05	13.38	559.60	-125.91
Data_Source=BBCn	252	0.63	0.12	-11.17	9.33	-2.09	-11.60
Data_Source=Cost210	65	1.44	0.56	-1.80	12.15	29.29	-5.61
Data_Source=ERT	9	0.22	0.00	-1.40	8.87	149.75	98.38
Data_Source=HOL	69	0.32	0.29	-2.87	8.96	-9.51	-9.67
Data_Source=IRT	584	0.42	0.27	1.82	8.56	-9.63	-3.31
Data_Source=IRTL	154	1.48	0.02	-10.75	18.53	1417.26	-250.44
Data_Source=IRTs	63	0.10	0.00	-3.07	8.45	117.73	117.05
Data_Source=ORF	54	0.10	0.00	14.12	8.83	104.25	120.48
Data_Source=RAI	83	0.38	0.21	0.41	6.53	-7.07	-3.35
Data_Source=RFR_Band_I	120	0.05	0.01	-7.51	7.00	-16.74	-28.91
Data_Source=RFR_Band_II	242	0.09	0.00	-8.11	11.78	-67.64	-77.72
Data_Source=RFR_Band_III	295	0.18	0.01	-5.08	12.21	70.38	46.66
Data_Source=RFR_Band_IV	250	0.54	0.03	-6.27	12.30	-147.68	-45.66
Data_Source=RFR_Band_V	174	0.76	0.08	-5.53	11.43	12.77	-3.98
Data_Source=RFR_Band_VI	42	2.01	0.61	-4.09	12.58	13.68	-7.96
Data_Source=S	107	0.63	0.04	-14.80	11.90	164.17	17.83
Data_Source=SUI	1114	0.10	0.00	-1.22	10.13	-5.20	-6.51
Data_Source=Swiss	405	0.66	0.13	5.38	13.59	3.88	6.12
Data_Source=TDF	64	0.61	0.10	2.14	19.71	-155.57	-32.13
Data_Source=USPhase1	4921	0.09	0.02	-3.40	13.08	-3.02	-6.59
Data_Source=USPhase2	1642	0.72	0.68	-2.73	16.17	-10.72	-6.58
Data_Source=YLE	100	0.11	0.00	5.80	7.01	-2.13	3.71
Data_Source=YLEs	51	0.21	0.17	-7.59	11.38	-26.59	-28.32
ALL DATA	11049	0.31	0.43	-3.19	13.50	-2.87	-5.42

Figure 16: UK distance correction to Bullington

7 Manual analysis of data outliers

With the cleaned database, the prediction models generally perform better but there are still significant outliers. Shows the probability density function of prediction errors (prediction-measurement) using P.1812 for long term and short term measurements.

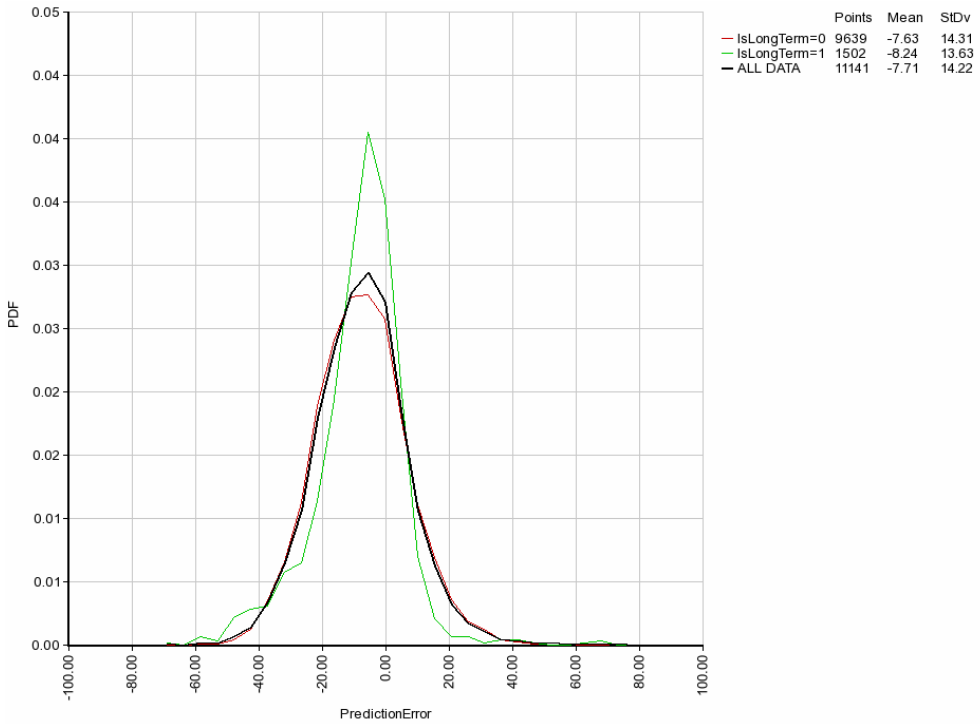


Figure 17: Prediction error distribution for P.1812

Prediction error standard deviations are about 14dB with a negative bias (under-prediction). The distributions seem Gaussian with a slight skewness (a heavier –ve tail) in the case of the long term measurements.

An exercise was carried out to investigate what was causing the large spread of outliers - whether they are due to problems in the measurement or faults in the model. After filtering the data as described above to remove points of known uncertainty[3], all outlier points with an absolute difference between the P.1812 prediction and measurement of greater than 40 dB[4] were listed. There were 130 measurements where the prediction error was greater than the threshold. These points are listed in Appendix 1. The outlier results were individually analysed using the RCRU web based database analysis tool.

[3] Data with invalid profiles, duplicate data sets, data outside the applicability space of the model and all height gain data except the for highest points of the transmitter and receiver were excluded from this analysis.

[4] The choice of 40 dB is approximately 3 standard deviations of error in the current models and this level was chosen to provide a manageable yet representative set of points for closer examination

7.1 Location Accuracy

An accurate path profile is an essential input to the P.1812 model. Profile errors can easily lead to large errors in the path loss prediction and a natural first step in analysing an outlier is to perform a confidence check on the supplied profile. The wide availability of accurate aerial photography from Google maps now facilitates this.

In very many cases, an examination of the aerial photographs showed that the accuracy of the transmitter and receiver location was imprecise, either through a limited grid resolution or an erroneous conversion between co-ordinate systems. It is not clear whether or not the exact location was used in producing the path profile. An example is given in Figure 18 where the path and tower are displaced by several hundred metres.

Figure 18: Example of suspicious transmitter location

For this measurement, the transmitter height is reported as 70m agl so the transmitter is likely to be on the tower and not on a portable mast in the field.

The displacement shown in Figure 18 is of no consequence if the correct profile has been extracted; however, as demonstrated by Figure 19 and Figure 20, in this mountainous region even a small displacement in the location of the receiver may lead to a path becoming much more or much less obstructed. Figure 19 is the profile supplied with the measurement data, Figure 20 is the profile extracted from SRTM data using the given transmitter and receiver locations.

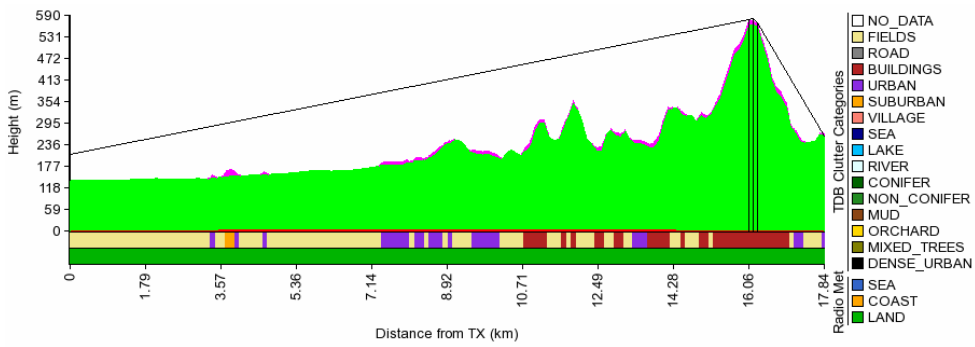


Figure 19: Supplied terrain profile for path of Figure 18

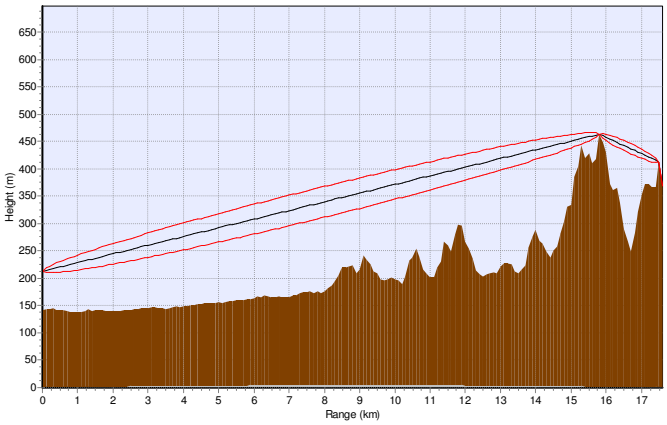


Figure 20: SRTM derived terrain profile for path of Figure 18

For this path, because of the nature of the terrain and the heights of the antennas, errors in the receiver location are more likely to lead to prediction errors than errors in the transmitter location. The latitude and longitude of the transmitter location are given in the file to many decimal places; the receiver location is only given to one decimal place. The location of the receiver is shown in Figure 21. Bearing in mind that this measurement was taken at a receiver height of 1.5m, and that the measured excess loss over free space is only 45 dB, the given location in the middle of a forest a long distance from any road does not appear at all likely to have been that chosen by the measurement team.

Figure 21: Indicated receiver location for path of Figure 18

This particular measurement is suspect as while the measurement shows 45 dB excess loss in addition to the 121 dB free space loss, a total of 166 dB, Figure 22 shows that both the P.1812 and the Bullington models indicate very much higher losses.

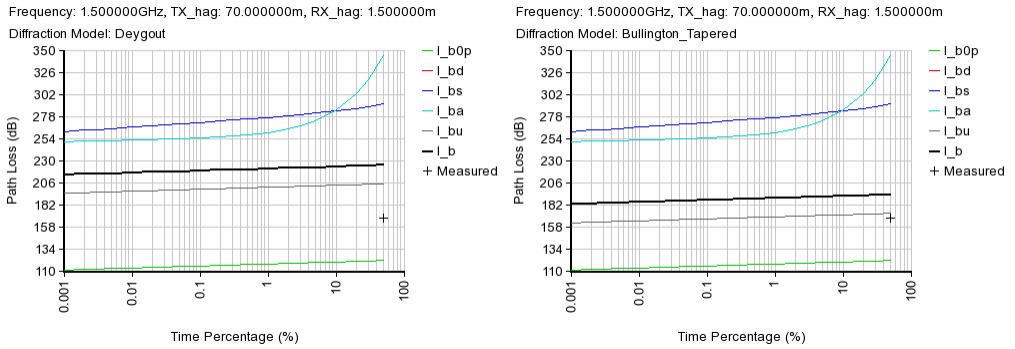


Figure 22: Model results for path of Figure 19

Because of the lack of information about the measurement it is not possible to tell if the error in this path is due to profile inaccuracy or issues with the diffraction model. It should be concluded that without further confirmation on the accuracy of the supplied profile, this data is not usable in model testing.

As an exercise, the receiver location was adjusted to be on the top of the local hill and the profile re-generated using SRTM data.

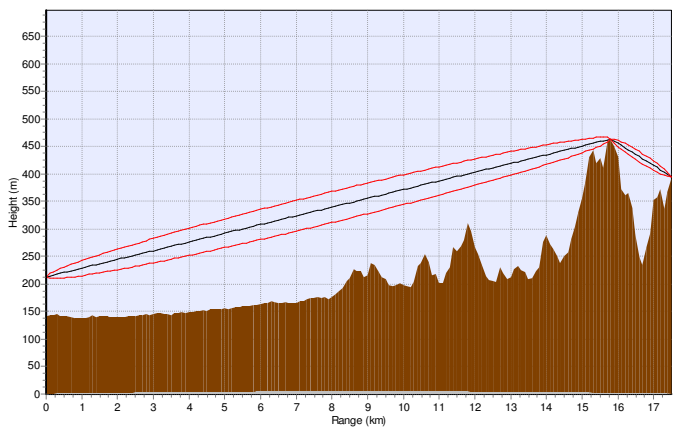


Figure 23: Possible alternative profile based on SRTM data and moving receiver to local hill top

The P.1812 model loss was found to be 161dB which compared favourably with the 166 dB measurement result. This result can not be used, but it does illustrate that highly accurate locations are necessary for modelling the path losses in mountainous regions.

It is interesting that almost all the large positive prediction errors come from data sets in this type of terrain. Because of the high sensitivity to location, using this data in diffraction modelling carries a high risk except where the data regarding site location and path profiles are known to be good – e.g. the recent Swiss data where the locations have been corrected and verified. It may be appropriate to exclude the IRTL data set.

The inaccuracy in transmitter and receiver locations unfortunately applies to a large subset of the database and because of this it is not possible to re-generate more accurate profiles based on terrain data.

7.2 *Clutter*

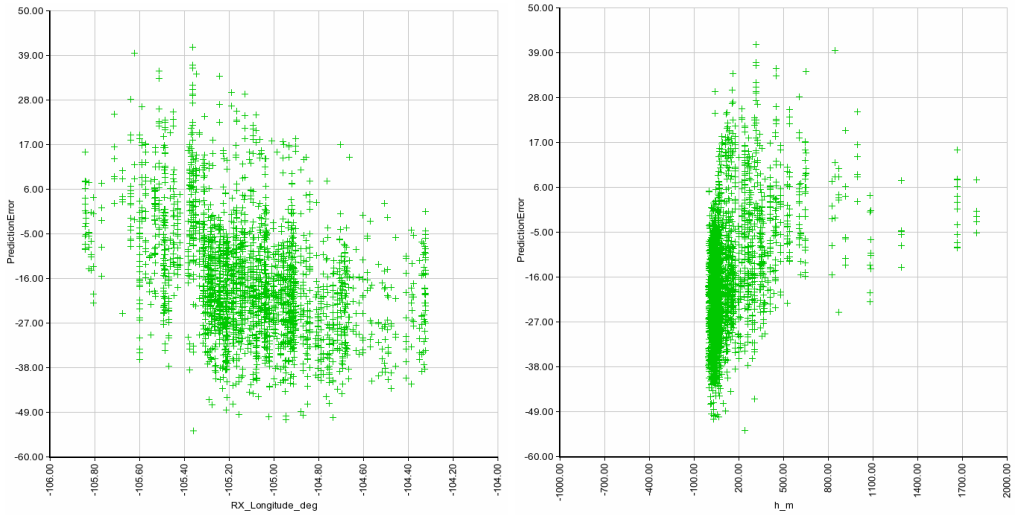
We are already aware several data sets contain height gain measurements around local clutter. These height gain measurements are useful for testing clutter models.

For overall model testing, where no clutter data is available, a filtering process has been applied to the data to only select the highest transmitter and receiver points for each measurement path, in the belief that these points are the least likely to be affected by local clutter.

After this filtering several paths still show large differences between the modelled and the measured signal levels. In all cases the measured signal is much lower than that predicted. [Note that some of the shorter LOS links exhibiting this property have been classified as '`IsValid=-3`'.] Many of these outliers occur in the USPhase1 dataset and further investigation showed that most of the poorly modelled paths were made in the vicinity of Boulder, Colorado using a 68m (300ft) mast at frequencies around 50 MHz and 100 MHz. The location of the mast is shown in Figure 24. There is no longer any visible evidence of the mast, but this is not unexpected as the measurements were taken many years ago. Measurement path lengths ranged from several km to many km and in all cases the receiver mast height was limited to 9m (30ft). The height of the transmitter mast ensures the transmitter was not cluttered while the height of the receiver mast makes local clutter likely. Along-path clutter is not given in the dataset and is unknown.

Figure 24: Indicated location of USPhase1 transmitter mast

It is not possible to tell if clutter would have been present at the time because of the age of the dataset. However indirect evidence exists to show clutter must have been present. Figure 25 shows scatter plots of measurement error against receiver longitude and h_m for all paths using the Boulder transmitter. The reason for the rather unusual choice of longitude as a parameter here is because of the unique location of Boulder which has mountainous terrain to the immediate West and rolling plans to the East. The h_m parameter while not used in the diffraction calculation does relate to terrain roughness.



Longitude h_m

Figure 25: USPhase1 data set scatter plot

It might be expected that paths on plains would be cluttered along the path as the radio path will tend to be close to the ground, but this is less likely for paths within the mountains where much of the radio path is elevated. Figure 25 nicely demonstrates a shift in the data at around 105.3 W of around 20 dB. This longitude is exactly where the mountains start. This could be a co-incidence; there are other possibilities for this shift, the major one being the effect of the transmitter antenna pattern. However, we believe it can be safely assumed that the effects of the antenna pattern were taken into account in the campaign.

The results for h_m demonstrate that as h_m increases, the mean error shifts towards zero. This is consistent with the theory that the probability of along-path clutter is reduced for the paths through the mountains.

It is most likely that much of the excess losses are due to clutter. This is a highly significant dataset and we must bear this in mind when testing the candidate models. It is not entirely clear what to do about this, but if we do include all the USPhase1 results then, because of the large number of paths contained in this dataset it will dominate the statistics. It may be best to exclude the plains set, which are readily identified by the PL prefix to the link name.

The data is not redundant however as a useful output of this analysis is that a generic clutter model should allow around 20 dB additional loss at 100 MHz in similar situations for propagation over arable plains where no clutter information is available.

7.3 Ducting Climates

A notable error is found in the paths in the Gulf region. Several of the RFR_Band_III measurements show losses underpredicted by over 60 dB. An example of one path is shown in Figure 26. In this region, ducting is likely to occur for much of the time and it is clear that the ducting model within P.1812 needs modification to take account of this climatic region.

Figure 26: Example of measurement in the Gulf region

Producing a model that correctly predicts paths over warm sea is a priority, these paths should be excluded for the evaluation of the current diffraction model as the principle mechanism is ducting.

7.4 Summary on data outliers

Although there is every indication that some of the outliers are due to data quality issues, for the time being these links have been left in the database. The reason for this is that the prediction error distribution does not have a 'heavy-tail' to suggest that the outliers are anything more than a normal statistic extreme of a large dataset where numerous uncertainties and inaccuracies contribute to overall error. It should be noted that such outliers will in all probability not affect relative comparisons between different models. It should also be of some comfort to note that any model prediction accuracies generated from this database will tend to be pessimistic for predicting path loss for new links with good quality input characterisation.

It is recommended that the US Plains data is used with care owing to the evidence of contamination from clutter. The reason for identifying this particular set is because there are so many measurements that these may dominate statistics. The IRTL data set also carries concerns owing to the uncertainty over the supplied profiles and the very high sensitivity to positional accuracy of these high frequency measurements at low receiver height in mountainous terrain.

8 Conclusion

An activity has been undertaken to include all the available measurement sets appropriate to testing P.1812 into a uniform database. It is understood that in a large set of measurements, several records will inevitably contain errors. An exercise to identify and flag measurements where some aspect of the measurement record is suspect has been completed. This flagged database has been made available to the correspondence group.

Several candidate modifications to P.1812 have been implemented and their key parameters also stored in a database. A web based analysis tool has been developed to assist in quantitatively analysing the relative performance of each model and to enable the detailed analysis of individual records. All measurements showing a >40 dB offset from P.1812 have been studied in order to understand the cause of the discrepancy and whether the measurement or the model is at fault.

A summary set of plots of the results for the seven models implemented so far in the database against the measurements, taking only the top heights and excluding the US plains data[5] are given in Figure 27 through to Figure 33.

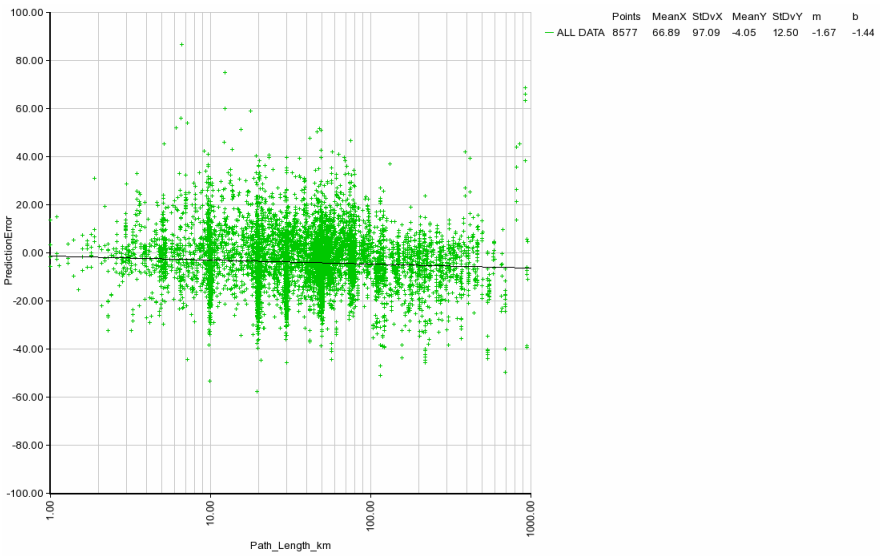


Figure 27: 3-edge Deygout model as in P.1812

[5] The typical command is `abs(Link_Name LIKE "PL_%")==0 AND DiffModel==1 AND IsTopRXHeightInGroup==1 AND IsValid==1 AND IsWorstMonth==0 AND InputsValid==1 AND ProgramName=="calculateITUPS_0.exe"`

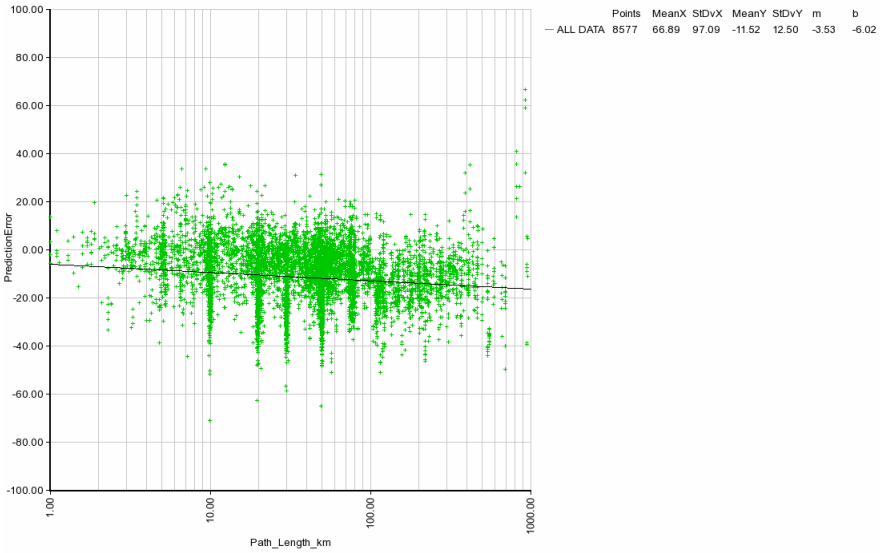


Figure 28: Bullington model with LOS taper

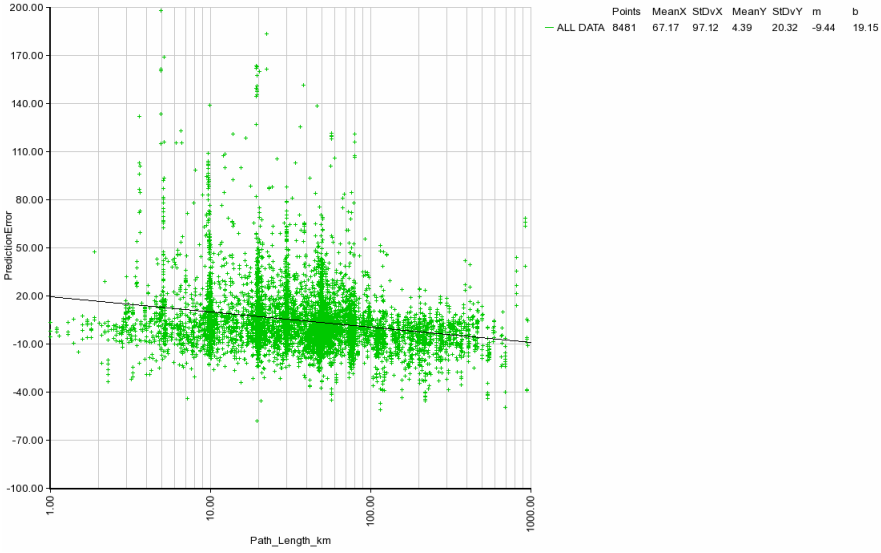


Figure 29: 3-edge Deygout model as in P.1812 with some aspects of the US PTP cylindrical edge model

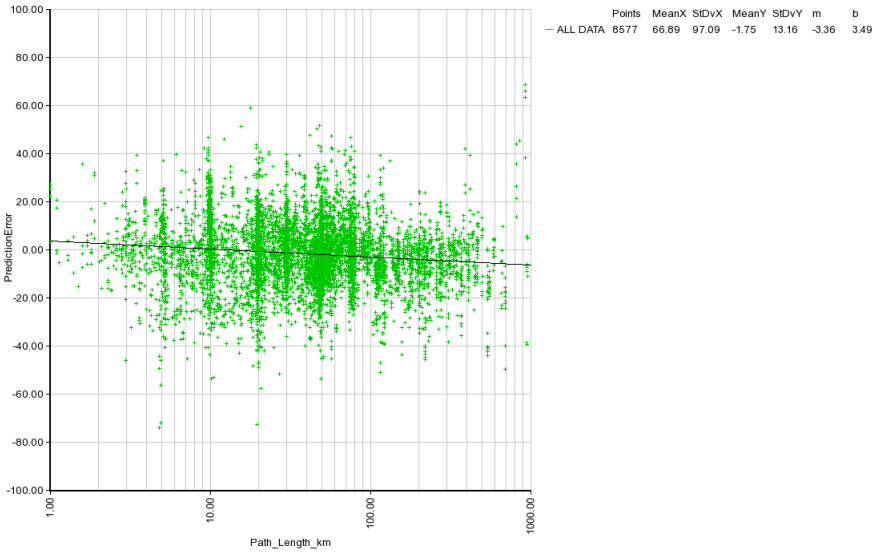


Figure 30: 3-edge Deygout model as in P.1812 with Chinese spherical Earth proposal detailed in ITU document 3K/150-E

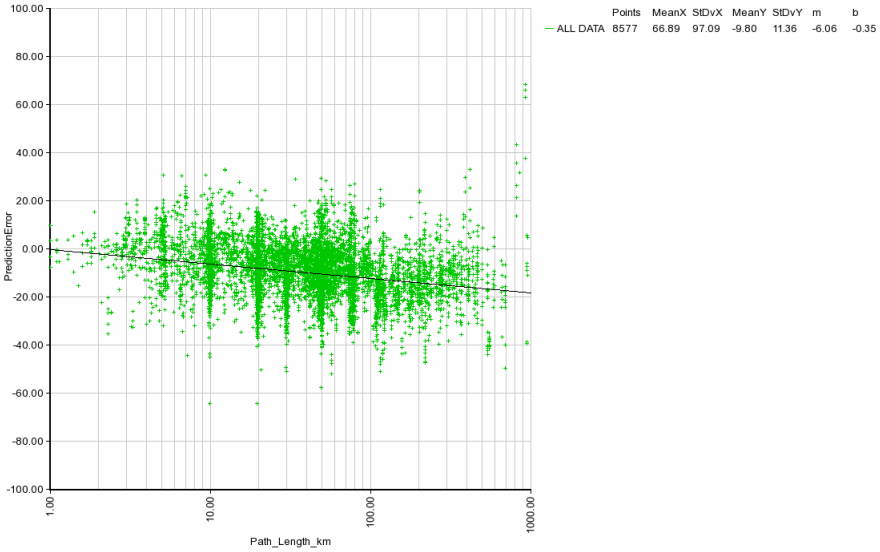


Figure 31: Bullington model with LOS taper and Swiss distance correction [9th order polynomial fit of log(path_length) to 3-edge Deygout mean]

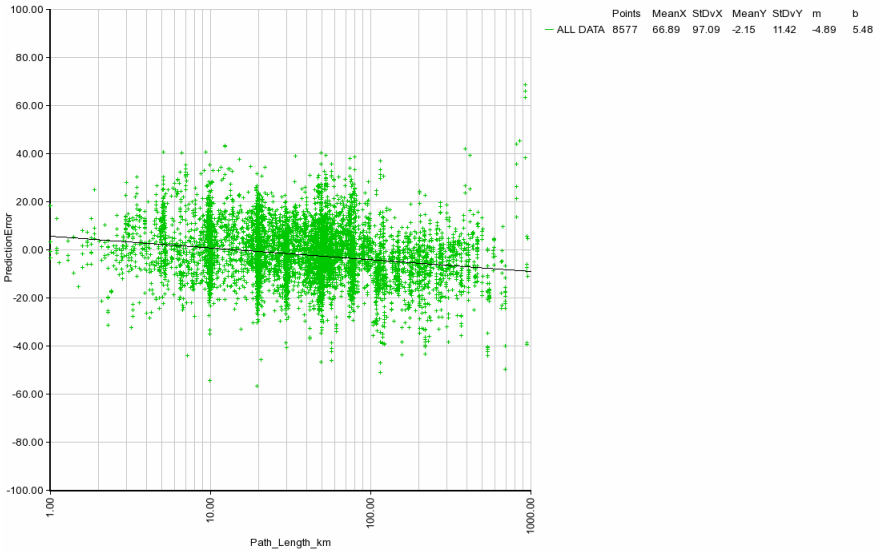


Figure 32: Bullington model with LOS taper and Markus Liniger's distance correction as additive term

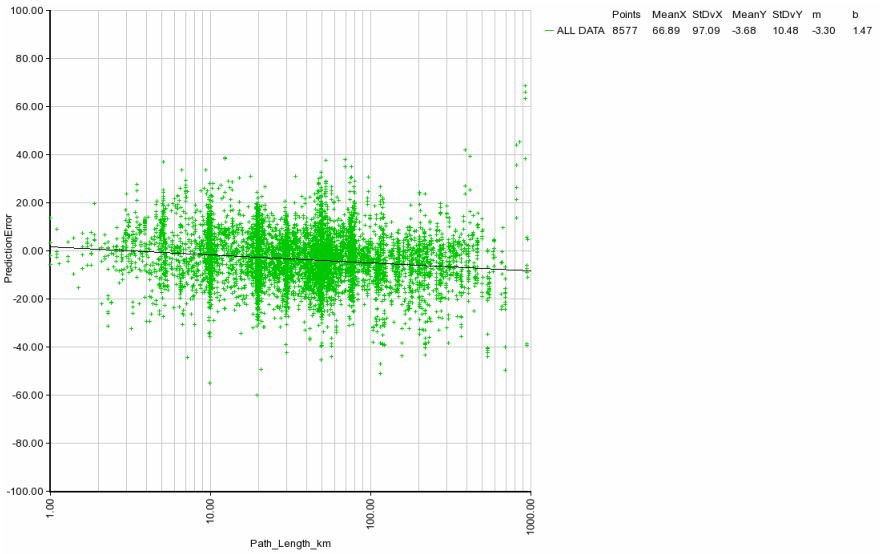


Figure 33: Bullington model with LOS taper and David Bacon's distance correction [3 point fit to 3-edge Deygout mean]

Appendix 1

Data_Source	Link_ID	Link_Name	Measurement ID	Frequency_ GHz	PredictionError	Dominant Mechanism	Comments
ABU	35	27-2fm10260E - total time	0	0.1026	-44.580754	1	Link Looks OK - Clutter?
ABU	35	27-2fm10260E - total time	1	0.1026	-41.151922	1	Link Looks OK - Clutter?
ABU	35	27-2fm10260E - total time	2	0.1026	-40.243941	1	Link Looks OK - Clutter?
ABU	39	29-2tv21025E - total time	1	0.21025	-40.221124	1	Link Looks OK - Clutter?
ABU	39	29-2tv21025E - total time	2	0.21025	-44.683399	0	Link Looks OK - Clutter?
ABU	39	29-2tv21025E - total time	3	0.21025	-40.800721	0	Link Looks OK - Clutter?
ABU	43	30-2fm10720E - total time	1	0.1072	-42.619094	1	Link Looks OK - Clutter?
ABU	43	30-2fm10720E - total time	2	0.1072	-45.833879	1	Link Looks OK - Clutter?
ABU	43	30-2fm10720E - total time	3	0.1072	-43.387379	2	Link Looks OK - Clutter?
ABU	49	33-2fm10020E - total time	3	0.1002	-43.948428	2	Link Looks OK - Both TX and RX sites Urban
ABU	51	34-2fm10140E - total time	2	0.1014	-47.218519	2	Unsure about both TX and RX positions
ABU	51	34-2fm10140E - total time	3	0.1014	-51.11065	2	Unsure about both TX and RX positions
BBCL	51	lband54	0	1.546	-44.444267	1	Unsure about both TX and RX positions
IRTL	2	ache002	0	1.5	86.529682	1	Both End locations appear incorrect - the path is very hilly and a small error in location would lead to large profile errors
IRTL	3	ache003	0	1.5	53.912709	1	Both End locations appear incorrect
IRTL	4	ache004	0	1.5	45.008312	1	Both End locations appear incorrect
IRTL	6	ache006	0	1.5	51.799945	1	Both End locations appear incorrect
IRTL	8	ache008	0	1.5	42.210333	1	Both End locations appear

							incorrect
IRTL	14	ache014	0	1.5	55.9515	1	Both End locations appear incorrect
IRTL	133	will002	0	1.5	58.755618	1	TX Location is clearly incorrect. RX location also looks wrong.
IRTL	136	will005	0	1.5	42.778635	1	TX Location is clearly incorrect. RX location also looks wrong.
IRTL	137	will006	0	1.5	59.938936	1	TX Location is clearly incorrect. RX location also looks wrong.
IRTL	138	will007	0	1.5	74.907313	1	The receiver position appears unlikely. The transmitter position is clearly wrong from the aerial photography
IRTL	143	will012	0	1.5	51.166186	1	TX Location is clearly incorrect. RX location also looks wrong.
S	12	O12	0	0.69	47.503593	1	Looks OK - Unsure about exact TX/RX location
SUI	646	compgru077	0	0.0975	45.804455	1	Unsure about both TX and RX positions
Swiss	46	Cortébert2a_100604_ORDS_K34_kauft_ITUold	0	0.5753	40.430797	1	
Swiss	59	Dombresson1a_100604_PELR_K44_kauft_ITUold	0	0.6553	40.848497	1	
Swiss	241	Ranfluh1a_030604_RIGI_K32_kauft_ITUold	0	0.5593	41.820853	1	
Swiss	357	StImier1a_100604_OTEN_K42_kauft_ITUold	0	0.6393	46.575598	3	
Swiss	385	Trubschachen1a_030604_OTEN_K63_kauft_ITUold	0	0.8073	50.19338	1	
TDF	44	gex6	0	0.494	51.44165	1	Inaccurate locations given. Looking at the map, there is an error in the TX location that may make the link pass between hills rather then

							over them.
USPhase1	33	MT-10-P16	11	0.1003	40.926345	1	
USPhase1	40	MT-10-V13X	5	0.1015	-53.63316	1	
USPhase1	132	MT-30-P37X	5	0.1015	-45.945825	1	
USPhase1	309	PL-05-H2X	2	0.1015	-40.510217	1	Boulder city set, possibility of RX clutter
USPhase1	314	PL-05-H5	11	0.1003	-45.391078	1	Boulder city set, possibility of RX clutter
USPhase1	324	PL-05-P10X	2	0.1015	-40.869488	1	Boulder city set, possibility of RX clutter
USPhase1	325	PL-05-P11	11	0.1003	-47.293578	1	Boulder city set, possibility of RX clutter
USPhase1	362	PL-05-P5	11	0.1003	-41.491078	1	Boulder city set, possibility of RX clutter
USPhase1	415	PL-05-V8X	2	0.1015	-43.218168	1	Boulder city set, possibility of RX clutter
USPhase1	418	PL-10-H10X	2	0.1015	-48.60576	1	Boulder area set
USPhase1	420	PL-10-H11X	2	0.1015	-40.946878	1	Boulder area set
USPhase1	429	PL-10-H3X	2	0.1015	-47.131751	1	Boulder area set
USPhase1	437	PL-10-H7X	2	0.1015	-40.388208	1	Boulder area set
USPhase1	444	PL-10-P10X	2	0.1015	-48.60576	1	Boulder area set
USPhase1	463	PL-10-P7X	1	0.1015	-49.659617	1	Boulder area set
USPhase1	481	PL-10-V3X	2	0.1015	-42.431751	1	Boulder area set
USPhase1	488	PL-10-V7	11	0.1003	-41.581328	1	Boulder area set
USPhase1	491	PL-10-V8X	2	0.1015	-42.169724	1	Boulder area set
USPhase1	520	PL-20-H5	2	0.04972	-40.695465	1	Boulder Regional set
USPhase1	520	PL-20-H5	9	0.1003	-41.267731	1	Boulder Regional set
USPhase1	555	PL-20-P4X	5	0.1015	-42.267112	1	Boulder Regional set
USPhase1	588	PL-20-V3	2	0.04972	-40.541766	1	Boulder Regional set
USPhase1	591	PL-20-V5	9	0.1003	-40.767731	1	Boulder Regional set
USPhase1	604	PL-30-H11	9	0.1003	-41.089456	1	Boulder Regional set
USPhase1	661	PL-30-H4	2	0.04972	-44.474695	1	Boulder Regional set
USPhase1	663	PL-30-H5	2	0.04972	-45.248657	1	Boulder Regional set

USPhase1	674	PL-30-P11	9	0.1003	-41.189456	1	Boulder Regional set
USPhase1	688	PL-30-P18	2	0.04972	-40.21911	1	Boulder Regional set
USPhase1	715	PL-30-P3	2	0.04972	-40.146906	1	Boulder Regional set
USPhase1	721	PL-30-P32X	2	0.1015	-44.097418	1	Boulder Regional set
USPhase1	742	PL-30-V10	2	0.04972	-41.831846	1	Boulder Regional set
USPhase1	744	PL-30-V11	9	0.1003	-43.989456	1	Boulder Regional set
USPhase1	758	PL-30-V18	2	0.04972	-42.11911	1	Boulder Regional set
USPhase1	772	PL-30-V24	2	0.04972	-41.234608	1	Boulder Regional set
USPhase1	801	PL-30-V4	2	0.04972	-40.974695	1	Boulder Regional set
USPhase1	805	PL-30-V7	2	0.04972	-50.193117	1	Boulder Regional set
USPhase1	812	PL-50-H10	11	0.1003	-41.984977	1	Boulder Regional set
USPhase1	817	PL-50-H12X	2	0.1015	-49.82017	1	Boulder Regional set
USPhase1	818	PL-50-H13	11	0.1003	-42.726003	1	Boulder Regional set
USPhase1	823	PL-50-H16X	2	0.1015	-41.209157	1	Boulder Regional set
USPhase1	827	PL-50-H18X	2	0.1015	-40.583042	1	Boulder Regional set
USPhase1	829	PL-50-H19X	2	0.1015	-41.612829	1	Boulder Regional set
USPhase1	833	PL-50-H20X	2	0.1015	-43.482213	1	Boulder Regional set
USPhase1	849	PL-50-H28X	5	0.1015	-42.102349	1	Boulder Regional set
USPhase1	887	PL-50-H5	2	0.04972	-40.678715	1	Boulder Regional set
USPhase1	896	PL-50-H9X	2	0.1015	-50.84013	1	Boulder Regional set
USPhase1	898	PL-50-P10	11	0.1003	-41.984977	1	Boulder Regional set
USPhase1	903	PL-50-P12X	2	0.1015	-49.82017	1	Boulder Regional set
USPhase1	905	PL-50-P13X	5	0.1015	-40.355512	1	Boulder Regional set
USPhase1	913	PL-50-P18X	2	0.1015	-46.983042	1	Boulder Regional set
USPhase1	915	PL-50-P19X	2	0.1015	-41.612829	1	Boulder Regional set
USPhase1	935	PL-50-P28X	5	0.1015	-42.102349	1	Boulder Regional set
USPhase1	973	PL-50-P5	2	0.04972	-40.678715	1	Boulder Regional set
USPhase1	977	PL-50-P7	2	0.04972	-42.745263	1	Boulder Regional set
USPhase1	978	PL-50-P7X	2	0.1015	-42.846687	1	Boulder Regional set
USPhase1	982	PL-50-P9X	0	0.1015	-49.94013	1	Boulder Regional set
USPhase1	985	PL-50-V10X	2	0.1015	-40.585563	1	Boulder Regional set
USPhase1	990	PL-50-V13	11	0.1003	-42.726003	1	Boulder Regional set
USPhase1	993	PL-50-V15X	2	0.1015	-40.403335	1	Boulder Regional set

USPhase1	999	PL-50-V18X	2	0.1015	-41.783042	1	Boulder Regional set
USPhase1	1066	PL-50-V8X	2	0.1015	-42.22577	1	Boulder Regional set
USPhase1	1068	PL-50-V9X	2	0.1015	-50.84013	1	Boulder Regional set
USPhase1	1070	PL-80-P10X	2	0.1015	-48.881058	1	Boulder Regional set
USPhase1	1070	PL-80-P10X	5	0.1015	-48.981058	1	Boulder Regional set
USPhase1	1072	PL-80-P11X	2	0.1015	-47.028776	1	Boulder Regional set
USPhase1	1074	PL-80-P12X	2	0.1015	-40.002254	1	Boulder Regional set
USPhase1	1076	PL-80-P13X	2	0.1015	-45.203508	1	Boulder Regional set
USPhase1	1076	PL-80-P13X	5	0.1015	-45.303508	1	Boulder Regional set
USPhase1	1078	PL-80-P14X	2	0.1015	-50.446804	1	Boulder Regional set
USPhase1	1078	PL-80-P14X	5	0.1015	-41.146804	1	Boulder Regional set
USPhase1	1080	PL-80-P15X	5	0.1015	-44.594992	1	Boulder Regional set
USPhase1	1082	PL-80-P16X	5	0.1015	-40.860234	1	Boulder Regional set
USPhase1	1093	PL-80-P21X	5	0.1015	-41.384734	1	Boulder Regional set
USPhase1	1095	PL-80-P22X	5	0.1015	-40.147288	1	Boulder Regional set
USPhase1	1101	PL-80-P25X	5	0.1015	-41.04435	1	Boulder Regional set
USPhase1	1103	PL-80-P26X	5	0.1015	-43.239202	1	Boulder Regional set
USPhase1	1134	PL-80-P44X	2	0.1015	-42.185343	1	Boulder Regional set
USPhase1	1136	PL-80-P45X	5	0.1015	-40.66094	1	Boulder Regional set
USPhase1	1166	PL-80-P7X	5	0.1015	-40.799285	1	Boulder Regional set
USPhase1	1168	PL-80-P8X	5	0.1015	-41.178291	1	Boulder Regional set
USPhase2	158	020r2t1	64	1.846	40.296357	1	
USPhase2	181	020t1r2	6	0.95	-57.958055	1	
USPhase2	185	020t1r6	6	0.95	-44.914376	1	
USPhase2	289	050t4r6	6	0.95	42.612188	1	
USPhase2	289	050t4r6	8	2.18	50.71522	1	
RFR_Band_II	6	200126	0	0.0883	45.221069	3	Very long Path UK - France
RFR_Band_II	52	200519	4	0.09435	-44.017166	2	Long North Sea Path - The Hague to Low Newton
RFR_Band_II	52	200519	5	0.09435	-41.609749	2	Long North Sea Path - The Hague to Low Newton
RFR_Band_II	52	200519	6	0.09435	-40.718515	2	Long North Sea Path - The Hague to Low Newton

RFR_Band_II	53	200520	3	0.09435	-49.849079	2	Long North Sea Path - The Hague to Aberdeen
RFR_Band_III	49	300338	1	0.187	-40.230673	2	
RFR_Band_III	53	300382	1	0.187	-40.591839	2	Long North Sea Path - The Hague to Aberdeen
RFR_Band_III	53	300382	2	0.187	-42.447197	2	Long North Sea Path - The Hague to Aberdeen
RFR_Band_III	55	300384	2	0.18925	68.350944	3	Gulf
RFR_Band_III	55	300384	3	0.18925	65.899217	3	Gulf
RFR_Band_III	55	300384	4	0.18925	63.144403	3	Gulf
RFR_Band_IV	21	400334	2	0.51125	41.903804	3	
RFR_Band_V	38	500434	6	0.79125	43.998275	3	