COLEGIO
DE INGENIEROS
DE CHILE A.G.
Comisión de Telecomunicaciones

The 2-Ray model in Radio Mobile V10.1.0 and up

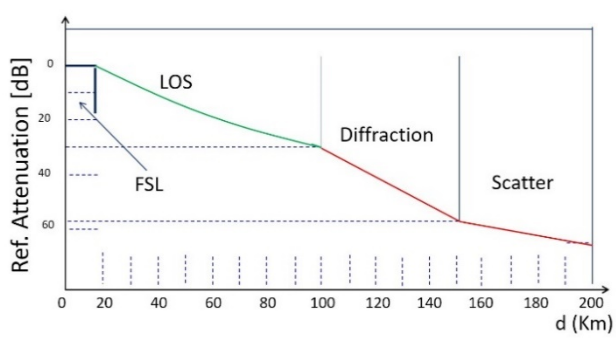
A monography by:
Eduardo Costoya A.
March / 2018.-[1]

Radio Mobile and ITM

Radio Mobile is a popular Windows program developed by Roger Coudé, based on the Irregular Terrain Model ITM, best known as Longley Rice, which is a deterministic model based on the electromagnetic theory. ITM can be operated in two modes: Point to Area (PTA) or Point to Point (PTP), but the author of RM[2] has elected to implement only the point-to-point mode. The program follows ITM V 1.2.2 [3] (1982) with some modifications described later[4].

ITM solves the reference attenuation Acr (the difference between received values and FSL) based on a continuous line that goes from: LOS (Line of Sight), diffraction and tropo-scatter zones described by the following equations:

$$A_{ref} = \begin{cases} \max\left(0,\ A_{el} + K_1 d + K_2 \ln\left(\dfrac{d}{d_{LS}}\right)\right), & d \le d_{LS} \\ A_{ed} + m_d d, & d_{LS} \le d \le d_x \\ A_{es} + m_s d, & d_x \le d \end{cases}$$



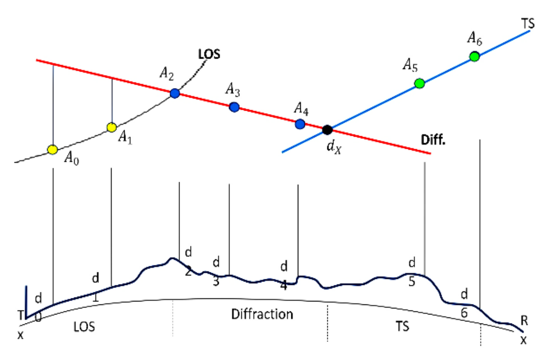


Fig.- 1

[1] *There is a 2019 update at the end of this document*
[2] *Roger Coudé. - Canadá*
[3] *ITM 1.2.2*
[4] *Guide for ITS 1.2.2*

As it can be seen, the continuous line from d_0 (A_0) to d_6 (A6) is built by solving above equations, therefore once established those distances as calculated by ITM algorithms and associated reference loss, the Acr for each point of a link or a coverage radial, is determined by those equations. This is known as the average system of ITM which saves quite a lot of memory and computer processing capabilities.

The above is the classical structure of ITM, but since version 10.1.0 (2009) the RM author modified the LOS zone by replacing A_0 to A_2 curve by a proprietary 2-Ray model, and on the LOS zone, by computing a point-to-point Acr for each path register (we assume), instead of computing discrete attenuations for the d_j distances and interpolating the values between them. That is not a big deal for present process capabilities of modern computers. Another reason for doing so, were some opinions that ITM was too optimistic in the LOS zone and/or, for an alleged error in the program, when it was converted from Fortran 77 to C^{++} 1982.[5]

1.- The problem

During the process of LOS link calculations with RM in Santiago city links on a Magister thesis, it was noticed that calculated data frequently differed significantly between links of similar characteristics (length and terrain). Sometimes the calculated value was over the expected by a few dB (4-6), but in others *below* by tens of dB! That was a textbook behavior of a 2-ray model over a perfect smooth reflecting terrain and verified in the program by modifying the path geometry by virtually raising or lowering the receiving antenna by a few meters, obtaining variations from up to +6dB and down to -30 dB from the expected value. In practice, that is seldom experienced, unless the path goes over a calm lake or a marsh. By experimenting we came to the following conclusions on how the present version of RM manages the 2-ray obstructions:

- The reflection coefficient is calculated based on electrical terrain characteristics: terrain roughness, wavelength, and incident angle. The terrain roughness is extracted from the DTED not considering the clutter (Terrain coverage).
- The land cover attenuation, as specified in "Options" in RM program and included on Radio link panel as Urban and Forest, does not affect the reflection coefficient. Its attenuation is considered only if obstructs the main beam.
- RM has no means to insert a "clutter" layer to be taken into consideration in defining the true standard deviation of the path.

[5] See [3] back.

Most of the paths mentioned before, run over built areas of Santiago Valley with urban, suburban, or even high-rise buildings; but the terrain as described by DTED (SRTM1) is essentially smooth. Therefore, the real reflection coefficients are quite different from those calculated by the program based on profile roughness only. With horizontal polarization and low grazing angles, a smooth terrain with dry soil has a reflection coefficient close to one, which means the reflected ray will have an amplitude near to the main ray. So, depending on the phase difference between direct and reflected rays, the receiving level will cover the range of +6 to -30 dB (the program negative limit) from the received level calculated without the 2-ray mode. That can be checked by raising and lowering the antennas height which modifies path geometry and phase angles.

As RM does not have the feature of adding the clutter as an additional layer overlaid to DTED, the 2R mode as included in RM could produce unacceptable errors; then a solution must be found.

2. The solution

Commercial propagation programs have the feature of accepting additional layers of geographical databases, with information such as: clutter, population distribution, crops, income distribution, etc. all of them with a granularity compatible with DTED used by the program. Radio Mobile, as well as other freeware programs do not have the feature of reading those databases, probably because that information is very expensive, has a limited market and it's upgraded on a yearly basis. The land coverage file *.lcv available in RM has a granularity of 250 x 250 m which is insufficient for accurate terrain roughness calculations, besides being completely outdated and frequently qualifying coverages as one type – probably existing 20 years ago – whilst the real coverage is now quite different. That is more common for urban and built areas.

Without an accurate land cover-clutter database, plus the capability of incorporating that database into the reflection coefficients calculations, there is no easy method for correcting the true reflection coefficients for terrain roughness and its influence on the received signal. But with the help of the excellent data produced by RM for path links and radials, plus the features of Google Earth Pro and Street View, it is possible to reduce the errors on TR's loss to acceptable values. In summary, that procedure might be:

1. On RM Radio Link panel, virtually raising and lowering Rx antenna until finding the highest negative (maximum gain) and positive (maximum attenuation) obstruction losses on Radio Link panel, which are produced when the reflected ray is in phase or out of phase with reference to the direct ray. That will give good qualitative information on the reflection factor of the terrain and in some cases, it may give a definitive assessment of the problem without further research.
2. On the Radio Link panel, Edit/Export the path data to a *.txt file and then exporting it to an Excel spreadsheet.
3. Evaluating the reflection point and incidence angle ψ of the reflected ray by means of the path and path data exported.
4. Computing the F1 intercept of the reflected ray on the on the terrain.
5. Computing the variance and standard deviation of terrain within the F1 intercept.
6. Exporting the path to GE and locating by the ruler the reflection F1 zone center on the ground, as well as the ends of F1 intercept points.
7. By naked eye, estimating on GEpro the clutter height for each register point, which would be identified by the land cover marks. (Land cover box shall be implemented)
8. On the same Excel spreadsheet of point 2, by adding the corresponding clutter heights to path elevations corrected by earth curvature and computing the new standard deviation of terrain plus clutter.
9. Finally, evaluating the reflection loss variation due to clutter inclusion and by means of that, computing the corrected Obstruction loss value and associated Rx value.

Detailed procedures for each of above points are as follows:

2.1 Rising and lowering Rx antenna.

On Radio Link panel it is easy to virtually raise or lower the Rx antenna height, even in centimeter steps. By raising and lowering the antenna height, the TR losses will reach a maximum gain (negative loss) when direct and reflected rays are in phase, and a maximum loss when both are 180° out of phase. Gain values of 6 dB, and losses of 30 dB will indicate the program is considering a perfect reflecting terrain. To the contrary, small or zero values will indicate a rough terrain with practically zero reflection factor.

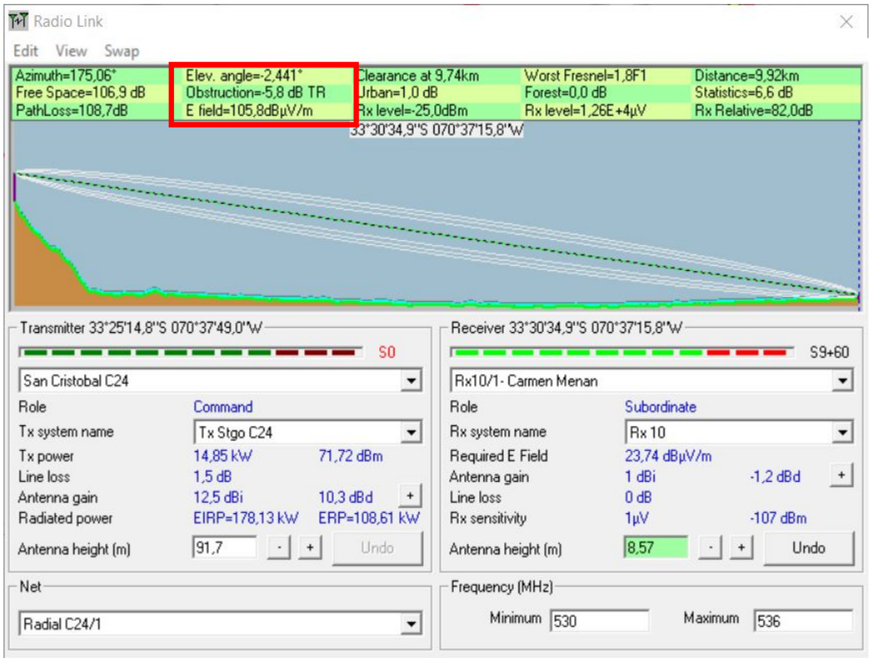


Fig.- 2.- Radio Link Panel. Obstruction loss

Note. - The parameter "obstruction" on the Radio link panel, is followed by symbols meaning:

TR=Obstruction by 2-Ray model
TRi= Obstruction by 2-Ray on interference mode
ITM= Obstruction by ITM program
MIX= Transition 2-Ray /ITM

2.2 Exporting the link data to a text file and Excel.

On Radio Link panel, export the path data by "Edit/Export to a *.text file.

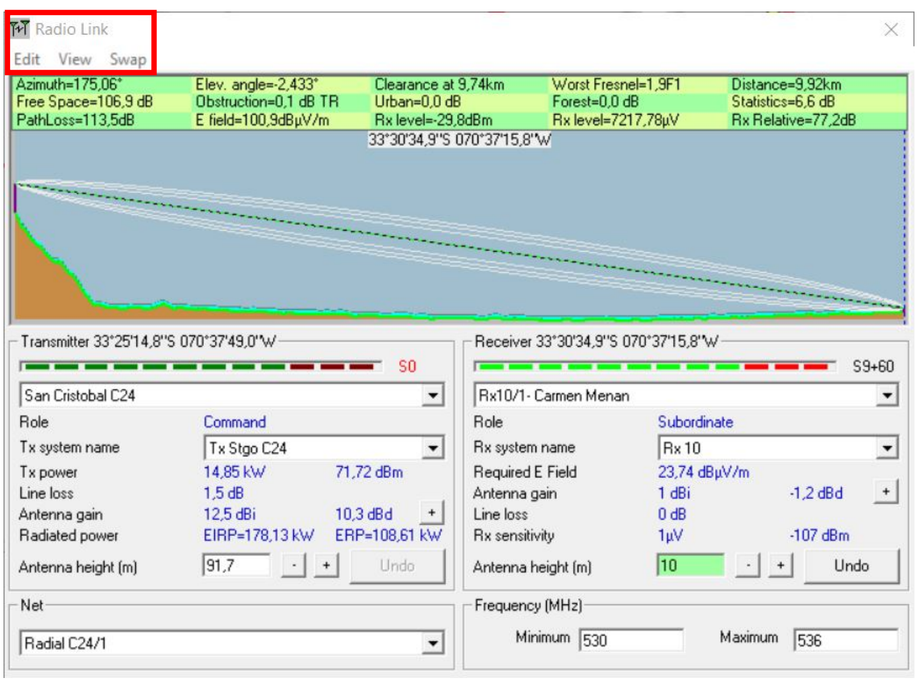


Fig.- 3. Radio Link Panel. Export to a text file

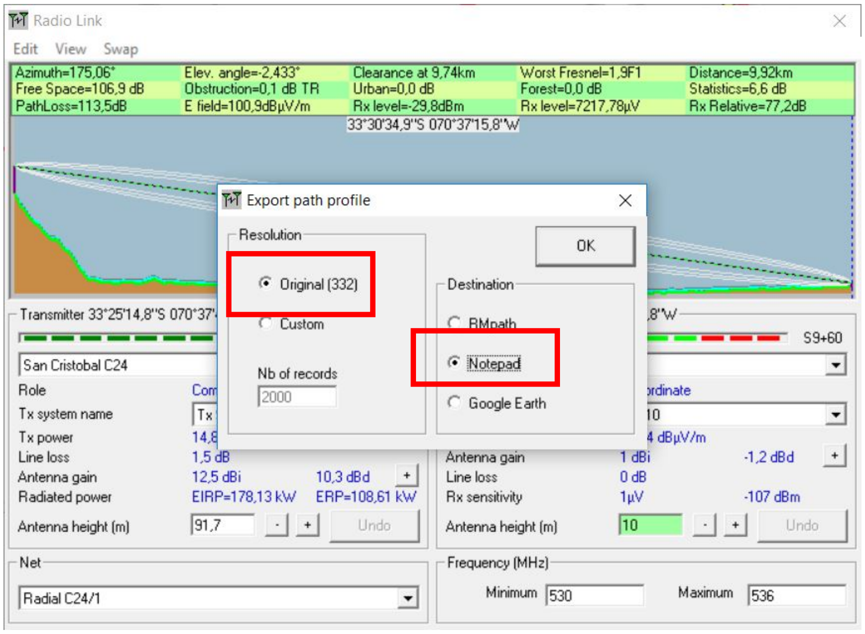


Fig.- 4. Registers to export to a text file

Make sure exporting as "original resolution", that will export one line of data for every register. That assumes that on Map Properties panel, the relationship between map height in pixels and map height in km will result on 30m/pix resolution, assuming SRTM1 is being used as DTED source. If SRTM3 is the DTED, the resolution shall be 90m.

On every case, the "Options/Elevation data/ Max N° of registers" entry shall be larger than the longest path or radial of the project *expressed in pixels*. In that case the program will calculate one set of values per pixel, otherwise it will calculate one per register.

This will export the complete data of the path: d_x, h_x, Path loss, etc. to a *.txt file. Then select all txt columns and rows and paste them in a blank Excel sheet.

2.3 Calculating the reflection point and incident angle ψ of the reflected ray.

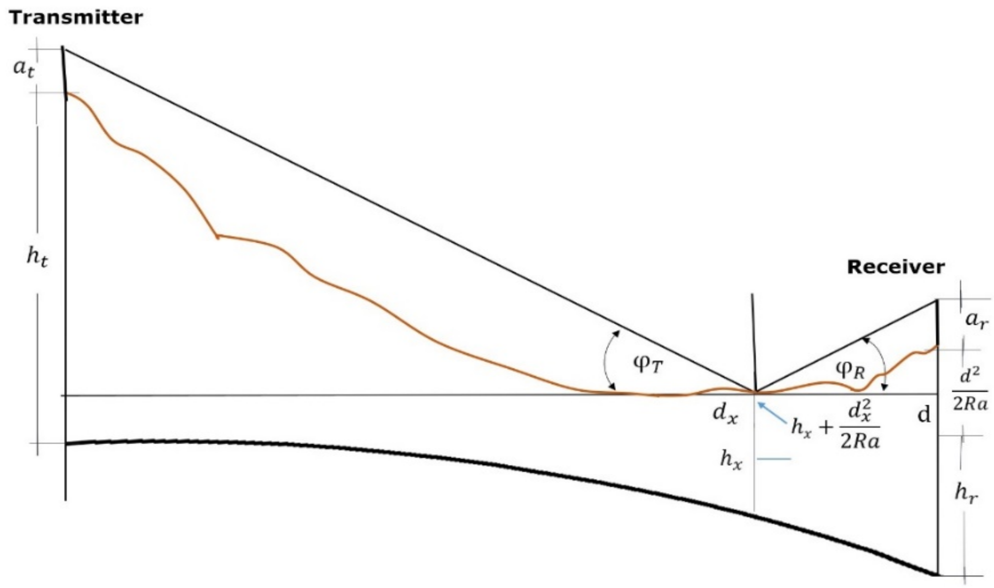
From the Radio Link panel, or better from the RMpath file[6], evaluate the possible zone of the reflection point and F1 intercept. It does not need to be large, if after calculations, the reflection area is not within the range selected, it would be easy to reload another selected zone.
Load the guessed selected zone data extracted from the Excel file into the corresponding columns of the "TR" Excel sheet for the link.

[6] *RMpath file is included with Ian D. Brown installer*

The file data exported from the link contains distances and elevations plus other data. Therefore, select and copy only the required columns and rows corresponding to the evaluated zone in the corresponding columns of the same "TR" Excel. The elevation data corrected by earth curvature will be calculated by the Excel.

From above data, Excel will calculate the tangent of both reflection angles and their differences. The distance to the reflection point will be the one with the minimum difference between tangents[7], which means reflection angles are equal with a precision dependent on the DTED used (SRTM1 or 3) or the number of registers.

Fig.5. Reference diagram of 2R model over round earth



Per reflexion definition

$$Tg\ \varphi_T = Tg\ \varphi_R$$

$$Tg\ \varphi_T = \frac{(h_T + a_T) - (h_x + \frac{d_x^2}{2R_a})}{d_x}$$

$$Tg\ \varphi_R = \frac{\left(h_R + a_R + \frac{d^2}{2R_a}\right) - (h_x + \frac{d_x^2}{2R_a})}{d - d_x}$$

[7] *The described procedure, as used on the Excel, assumes a zero-terrain slope at the F1 intercept. To be exact, the terrain slope shall be added to* φ_T *and subtracted to* φ_R *for a positive slope and the opposite for a negative one. However, the error is small and not worth the extra effort.*

$h_{T,R}$ = *Transmitter, receiver location terrain height asl (m)*
h_x = *Reflection point terrain height asl (m)*
$a_{t,R}$ = *Transmitter, receiver antenna height above terrain (m)*
d = *Total link distance (m)*
d_x = *Distance to reflection point (m)*
R_a = $R_0 * k$ = *earth equivalent radius (m)*
R_0 = *6370 (km)*
K = *1,33 equivalent flat earth radio factor.*

$$\frac{d_x^2}{2R_a} = Earth\ curvature\ correction$$

Obviously, d_x can be calculated from those equations, however, it is easier to solve it by successive approximations by an Excel sheet which at the same time can be used to obtain the value of the reflected ray incident angle (Note 6) and F1 intercept limits which will be required. See the Excel Example[8] provided with this monography.

2.4 Computing the F1 intercept of the incident ray on the path.

Once the reflection point d_x is calculated, which corresponds to the center of the radio beam, it will be necessary to calculate the intercept points of F1 Fresnel zone on the path. The area of interception of F1 on the terrain corresponds to the specular reflection of the beam, whereas the outside of that zone produces a diffuse one. The specular reflection is coherent with the direct ray; therefore, it can be added in vectorial terms of Field Strength, whilst the diffuse reflection can only be added on RMS terms.

[8] Excel Example

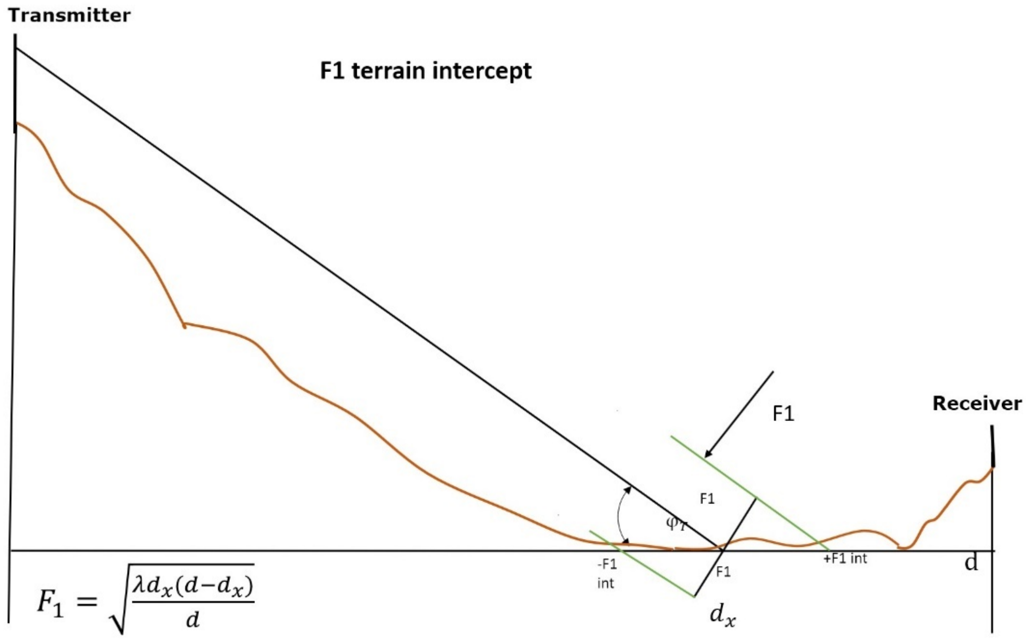


Fig.- 6. F1 Intercept over Terrain

$$+F1_{int} = -F1_{int} = \frac{F1}{sen\varphi}$$

Note. - The procedure of loading the path data from the txt file into the Excel and locating the center of the d_x reflection point plus the F1 intercept limits, is clearly shown on the *Example Excel* supplied with this work. That part is too large to be copied here.

2.5 Computing the standard deviation of terrain within the F1 intercept

The section of the path within F1 intercept should be copied in the Excel, with elevations corrected by earth curvature. A "clutter" column may be created to use the same Excel when clutter is added. Then, as the roughness of the terrain must be referred to terrain slope, the regression line of terrain should be calculated by means of the graph feature of Excel in "trend line" mode, with the formula y=ax+b shown on the graph.

Note. - The data used heretofore corresponds to a real 10 km link part of a DTV propagation survey in Santiago.

Variance and Standard deviation (Terrain)						
X	dx	hx+(dx^ 2)/2Ra)	Clutter	Hx+clutter	Regression	Error
0	9.115	578.3	0.00	578.30	577.62	0.68
1	9.145	578.54	0.00	578.54	577.88	0.65
2	9.175	579.37	0.00	579.37	578.15	1.22
3	9.205	580.6	0.00	580.60	578.41	2.19
4	9.235	581.13	0.00	581.13	578.68	2.45
5	9.265	580.47	0.00	580.47	578.94	1.52
6	9.295	579.6	0.00	579.60	579.21	0.39
7	9.325	578.83	0.00	578.83	579.47	-0.64
8	9.355	578.56	0.00	578.56	579.74	-1.17
9	9.385	578.9	0.00	578.90	580.00	-1.10
10	9.415	579.43	0.00	579.43	580.27	-0.83
11	9.445	579.46	0.00	579.46	580.53	-1.07
12	9.475	578.7	0.00	578.70	580.80	-2.10
13	9.505	578.73	0.00	578.73	581.06	-2.33
14	9.535	579.77	0.00	579.77	581.32	-1.56
15	9.565	580.7	0.00	580.70	581.59	-0.89
16	9.595	582.03	0.00	582.03	581.85	0.18
17	9.625	583.67	0.00	583.67	582.12	1.55
18	9.655	583.4	0.00	583.40	582.38	1.02
19	9.685	583.34	0.00	583.34	582.65	0.69
20	9.715	584.17	0.00	584.17	582.91	1.26
21	9.745	585	0.00	585.00	583.18	1.83
22	9.775	584.64	0.00	584.64	583.44	1.20
23	9.805	584.47	0.00	584.47	583.71	0.77
24	9.835	584.61	0.00	584.61	583.97	0.64
					Variance	**1.72**
					$\sigma 1$	**1.31**

Fig.- 7. Standard deviation on Excel w/o clutter

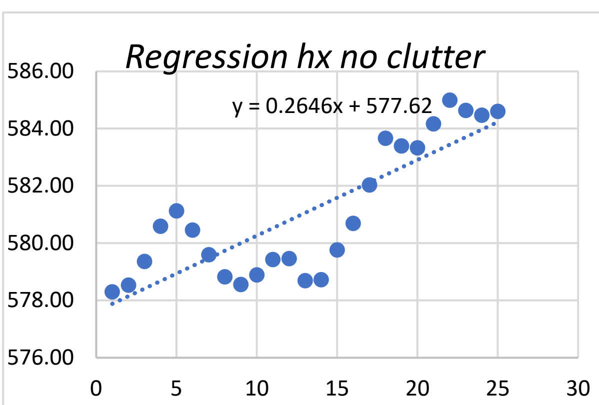


Fig.- 8 Trendline calculations

The regression (trendline) values shall be calculated with the equation on the graph and copied for each value of X in the regression column, those values shall be subtracted from hx+zero clutter to form the errors column. Excel's Variance P function calculates the variance of errors, and the standard deviation σ will be the square root of the variance.

2.6 Exporting the path to Google Earth and locating on the ground the reflection and ends of F1 intercept points.

In most cases GE, with 3D and Street View features - if available - allows an approximated evaluation of clutter composition and dimensions. Then, the estimated height of the clutter can be added manually to path profile elevations, so the ratio of reflection coefficients of the profile for both, plain terrain and terrain plus clutter can be calculated.

On the Radio Link panel, export the path to GE by "Edit/Export to/Original/Google Earth,

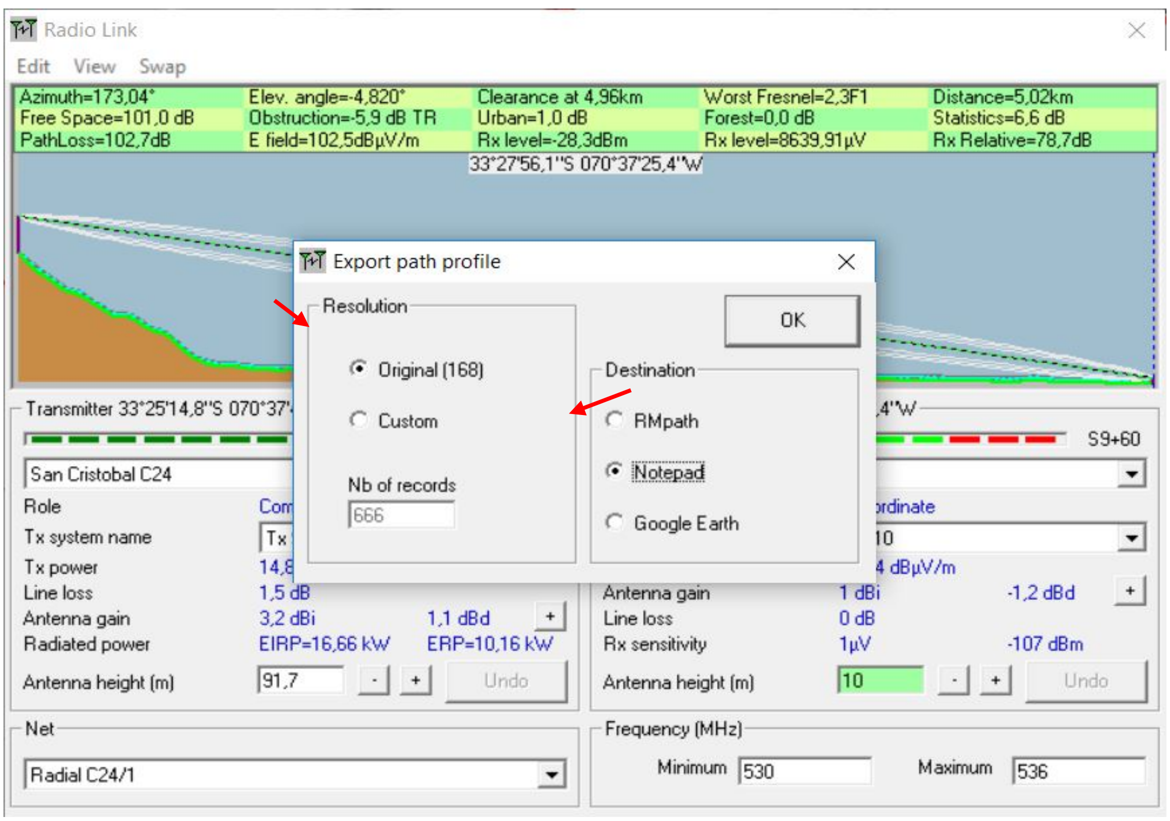


Fig.- 9. Exporting path data to a text file

Fig.- 10. View on GE Pro. The vertical bars correspond to the Land Cover pixels

Note. Make sure to export to GE with "original"resolution, otherwise the position of clutter heights will not match with land cover marks on the map.

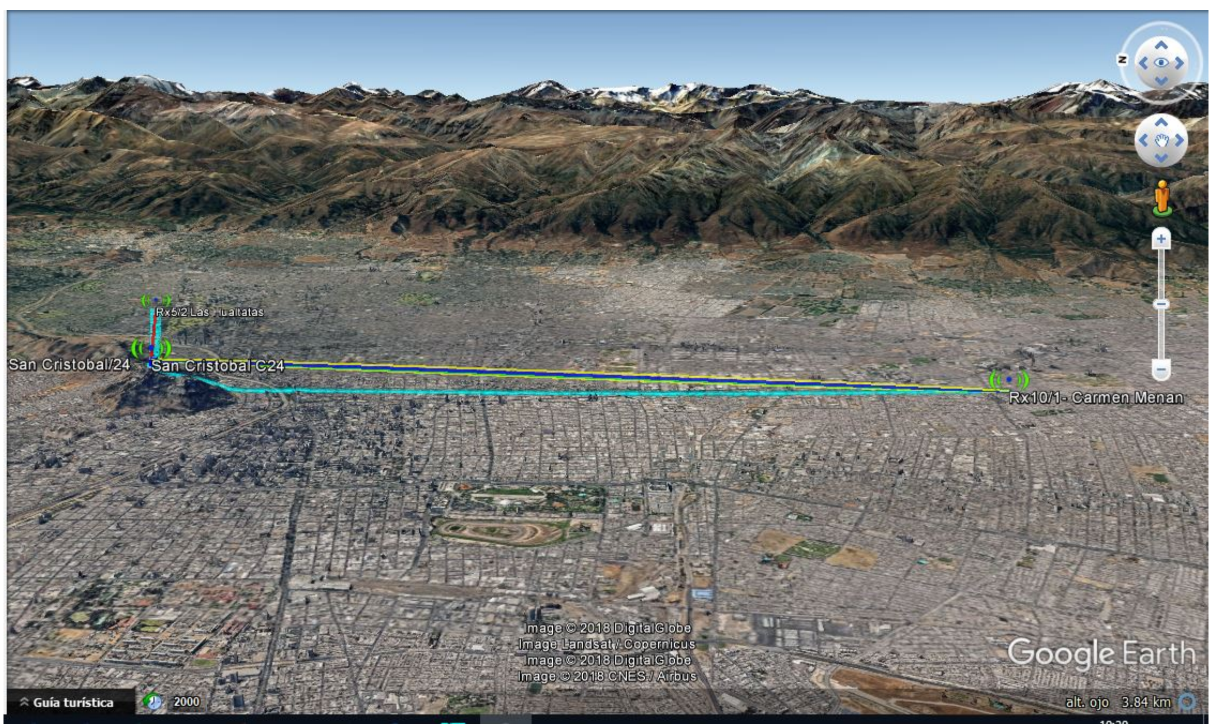


Fig.- 11. Aerial view of the complete path on Google Earth

With the ruler of GE and the distances on the path exported to Excel, the reflection point and ends of F1 intercept can be marked as waypoints.

2.7 *On the Excel. The* estimated clutter height for each register can be placed in the clutter column of the standard deviation spread sheet, so the new regression line and standard deviation can be computed for the cluttered terrain.

Variance and Standard deviation (Terrain+clutter)						
X	dx	hx+(dx^ 2)/2Ra)	Clutter	Hx+clutte	regression	Error
0	9.115	578.3	0.00	578.30	574.92	3.38
1	9.145	578.54	4.00	582.54	577.62	4.92
2	9.175	579.37	4.00	583.37	577.62	5.75
3	9.205	580.6	0.00	580.60	577.62	2.98
4	9.235	581.13	3.00	584.13	577.62	6.51
5	9.265	580.47	2.00	582.47	577.62	4.85
6	9.295	579.6	0.00	579.60	577.62	1.98
7	9.325	578.83	3.00	581.83	577.62	4.21
8	9.355	578.56	4.00	582.56	577.62	4.94
9	9.385	578.9	0.00	578.90	577.62	1.28
10	9.415	579.43	0.00	579.43	577.62	1.81
11	9.445	579.46	4.00	583.46	577.62	5.84
12	9.475	578.7	5.00	583.70	577.62	6.08
13	9.505	578.73	0.00	578.73	577.62	1.11
14	9.535	579.77	0.00	579.77	577.62	2.15
15	9.565	580.7	4.00	584.70	577.62	7.08
16	9.595	582.03	0.00	582.03	577.62	4.41
17	9.625	583.67	0.00	583.67	577.62	6.05
18	9.655	583.4	0.00	583.40	577.62	5.78
19	9.685	583.34	0.00	583.34	577.62	5.72
20	9.715	584.17	1.00	585.17	577.62	7.55
21	9.745	585	0.00	585.00	577.62	7.38
22	9.775	584.64	3.00	587.64	577.62	10.02
23	9.805	584.47	2.00	586.47	577.62	8.85
24	9.835	584.61	3.00	587.61	577.62	9.99
					Variance	**6.05**
					σ2	**2.46**

Fig.- 12. Standard deviation on Excel with clutter

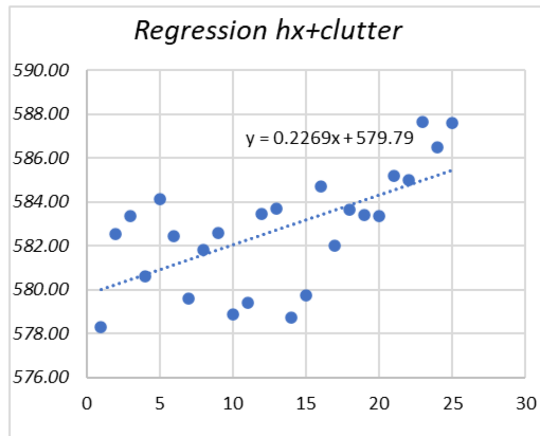
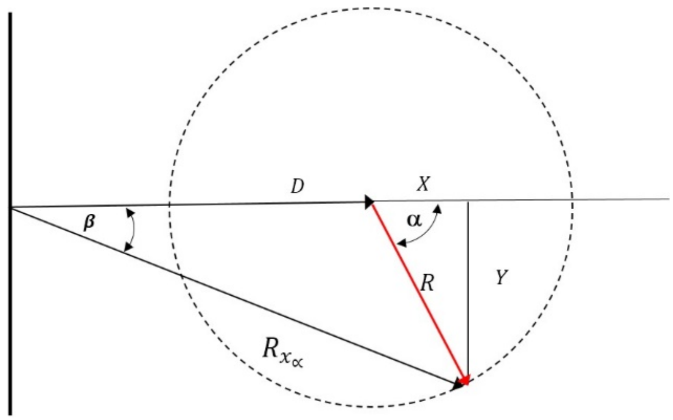


Fig.- 13

The calculated variances or standard deviations with and without clutter will be used to calculate the attenuation of the reflected ray and the obstruction loss, now with clutter.

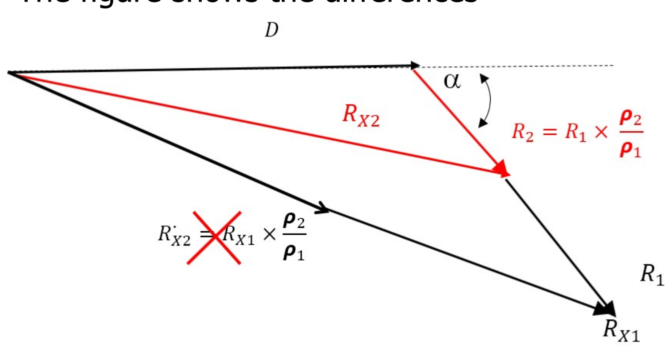
2.8 Computing corrected obstruction loss with the new terrain path roughness, and associated reflection factors.

The general scheme of a 2 Ray path



At a first glance, it seems a straightforward procedure to determine the corrected obstruction loss, by computing the ratio between the reflection factors, with and without clutter; and then calculate the new obstruction loss by means of the ratio of factors. Unfortunately, the procedure is more complicated as illustrated in the following drawing, assuming, for example purposes a ratio of 0.5 between reflection factors ρ_1 and ρ_2:

The figure shows the differences



D = Direct ray
R = Reflected ray
R_x = Received signal
ρ = Reflection factor
<u>Sub index</u>
1= Terrain only
2= Terrain + Clutter

The received value is not linear referred to the ratio of reflection's coefficients, as it modifies only the magnitude of the reflected ray but not the phase angle. However, there is one case where the received signal is linear with the reflection coefficient: that is when α =0 (in phase) and that can be used to solve the problem, as we will see later.

RM calculates the TR attenuation based on terrain irregularity provided by the DTED (SRTM) but does not have a feature allowing to incorporate a digital clutter data base to terrain. RM has access to a Land cover data which is only used for the other losses associated with the path loss: Urban and Forest, but even in the case that the author incorporated that data, it will be useless as it has a granularity of 250X250 m pixels and is completely outdated setting land cover classifications valid 20 years ago or even more.

The procedure suggested may sound as a disproportionate labor, but a bad data on terrain coefficients, as consequence of bad assessment of terrain roughness produces errors, not of a few dB but in the order of tens of them.

This mathematical analysis set by this work, on the terrain clutter and its effects on reflection's coefficients, is based on assumptions which are not 100% true from the point of view of a rigorous analysis, but they represent a "best effort" or the "least of evils" to overcome a limitation of RM, producing values that are acceptable from an engineering point of view. Those assumptions are:

- The clutter has the same reflection coefficient than terrain. (permittivity and conductance)
- The geometry of the path, which determines the reflection center point and the phase difference between direct and reflected ray, will not significantly change by raising and lowering antennas is search of zero phase angle. This assumes sub-metric λ.
- Phase angle α (D-R) will not be modified by roughness changes.
- Reflection coefficients will be proportional to Rayleigh´s roughness criterion

RM Radio link panel provides the following data related to a link in LOS:

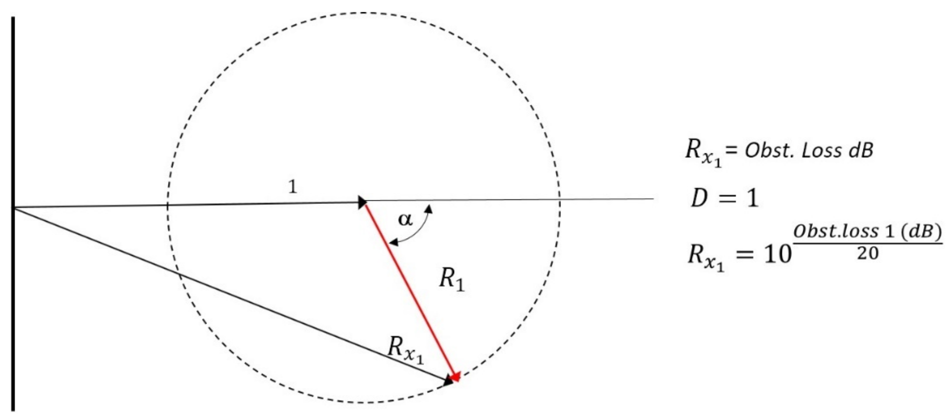
1.- Obstruction loss followed by "TR" label. TR= Two Ray Model

It should be remembered that RM after V10.1.0 does not follow ITM in LOS, but a proprietary model based on a combination of the 2-Ray model plus a transition to ITM (MIX). The other labels are: TRi (TR in interference mode) MIX (transition between proprietary TR and ITM) and ITM (original ITM 1.2.2 o V7). Obstruction loss is the ratio in dB of Rx/D. In following diagrams, the value of D (direct ray) will be set to 1 (number) and all other values will be expressed relative to D and in numbers, not in dB..

Note. - In all figures and values heretofore, the suffix 1 means reflected ray over terrain only. Suffix 2, terrain plus clutter. Suffix 0, α =0.

Note. – Detailed development of equations in Annex 1 at the end

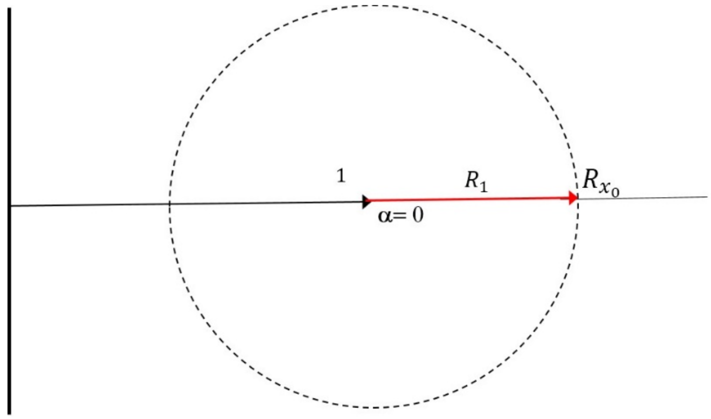
Vectors. TR over terrain only



From above figure, only the value of R_{x1} is known expressed as a multiplier of D (as obstruction loss in dB). With that info, is not possible to know the values of R1 or α. It would be possible by knowing the reflection coefficient, but in the case of ITM will mean reverse engineering of ALOS sub routine which is overly complicated involving the calculation of Δh. In the case of RM after V10.1.0, TR algorithms are proprietary.

But with the assumptions expressed before, it’s possible in RM virtually to raise or lower the Rx antenna (also Tx) even in cm steps, and at the same time note the values of Obst. Loss (OL heretofore). The minimum OL (negative values) will mean max. Rx1 and α=0

Vectors raising or lowering Rx antenna until α =0 reflected by a maximum received signal.



R_{x_0}= Obst. Loss 0 (dB)

$$R_{x_0} = 10^{\frac{Obst.\ loss\ 0\ (dB)}{20}}$$

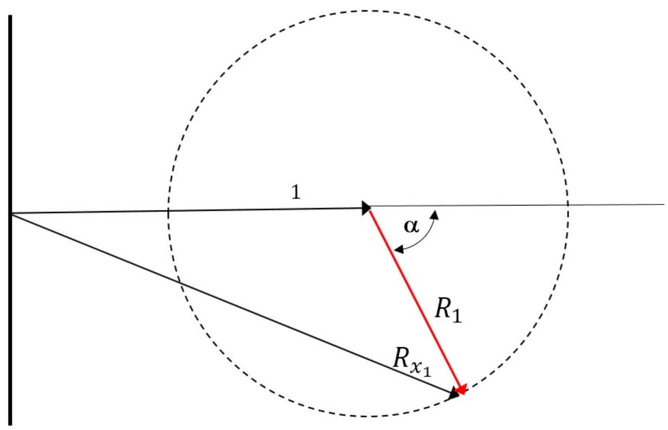
$$R_{x_0} = 1 + R_1$$

$$R_1 = 1 * \rho_{rm_1} = D * \rho_{rm_1}$$

$$\rho_{rm_1} = R_1 = 10^{\frac{Obst.loss\ 0\ (dB)}{20}}$$

Under above condition, $Rx_0 = 1+R_1$ as the magnitude doesn't depends of α, only from ρ_{rm1} the unknown reflection coefficient of RM

Now, with the value of R_1 known, it's possible to calculate α.



$$\cos\alpha = \frac{R_{x_1}^2 - R_1^2 - 1}{2R_1}$$

With the values of R_1 and cos α, it is possible to calculate the value of R_2 from the ratio of reflection coefficients ρ of terrain with and without clutter.

We now know the RM reflection coefficient of terrain, as it is the ratio between R_1 and D. As D=1, $\rho_{rm1}= R_1$. But the function $\rho(\sigma)$,at least in present RM V11.6.6 is not known. On ITM 1.2.2 it could be known by:

$$A_t = -20\log\left|1 + R_e e^{i\delta}\right|$$

In ITM 1.2.2, R_e and δ are defined by 6 equations: *3.10 and 4.46 to 4.50* so reverse engineering can be a nightmare. In case of RM the function $\rho(\sigma)$ is proprietary, so an equation such as:

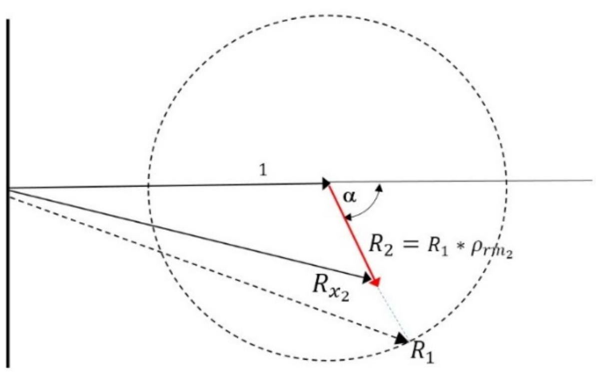
$R_2 = R_1 * \frac{\rho_2}{\rho_{rm1}}$ will not be valid as the reflection coefficients will not follow the same functions, however, an equation such as:

$R_2 = R_1 * \frac{\rho_2}{\rho_1}$ where both coefficients are calculated with the same function may be the "best effort" to solve the problem

For that purpose, the Rayleigh roughness criteria will be used together with a well-known function relating the criteria to a reflection coefficient by means of an exponential equation valid for low grazing angles, which is the normal case of a radio link.

Rayleigh roughness criterion $g = 4\,\pi\ (\sigma_h/\lambda)\ sen\ \varphi$

The development of the equations is in Annex 1.



$$k = \left(\pi \sin\varphi/\lambda\right)^2$$

$$\frac{\rho_2}{\rho_1} = e^{-k(\sigma_{h_2}^2 - \sigma_{h_1}^2)}$$

$$\rho_{rm_2} = \rho_{rm_1} \cdot \frac{\rho_2}{\rho_1}$$

$$R_2 = R_1 * \rho_{rm_2} = R_1 * \frac{\rho_2}{\rho_1}$$

$$\boxed{R_{x_2} = \sqrt{R_2^2 + 2\,R_2 \cos\alpha + 1}}$$

$$Obstr.\,Loss\ 2\ (dB) = 20\ \mathrm{log}(R_2)$$

Conclusions. –

1.- The procedure explained above to calculate a near-precise TR obstruction loss, is cumbersome but not always necessary. The first and easy action should be to raise and lower Rx antenna until finding the maximum negative obstruction value (max. Rx level) and the highest positive one, (min. Rx level). On the link used as an example, negative OL α=0 was - 5.8 dB and positive OL α=180 of 27.5 dB and that was obtained just moving the antenna aprox.0,8 m up and 1.1 m down from Rx antenna height; λ=0,56 m. Such a link project must be further analyzed with the procedure described above. If GE shows plain ground or low-density vegetation, it means the values obtained by RM are OK. However, such a link will be very unstable as slight changes in refraction will swing the received value in the order of tens of dB. Then classical techniques should be used – Vertical polarization, high directivity antennas, etc.

Even more, it may be enough to calculate σ on the Excel with clutter without further analysis, by using the following table based on Rayleigh roughness criteria f (σ/λ). In the case of the sample link, $\lambda = 0.56$ m so with a $\sigma >$ 2.2m the obst. loss variation is acceptable.

σ/λ	*g*	ρ	*obst loss max*	*Obst. Loss min.*
0,5	0,24	0,97	-5,90	31,16
1	0,47	0,89	-5,55	19,48
1,5	0,71	0,78	-4,99	13,03
2	0,95	0,64	-4,29	8,83
3	1,42	0,36	-2,70	3,93
4	1,90	0,17	-1,33	1,58
6	2,84	0,02	-0,15	0,15
8	3,79	0,00	-0,01	0,01
10	4,74	0,00	0,00	0,00

With an acceptable obst. loss variation, it's possible to forget the TR and just tick off the feature box in RM "Network properties/Propagation mode". That will also be an acceptable solution for a Radio /TV coverage. Just going to the "good old days" by tracing a few radials, computing σ for each of them (forget about F1 intercept) and if σ/λ > 3 or 4, kick off the TR. Off course it´s not precise, but much better than a coverture with hundreds of "shadow zones",

2.- In a future work it may be possible to provide a better (and more precise) way of overcoming the problem of computing TR with clutter, without the obvious need to modify RM program to accept clutter data.

ESA – the European Space Agency with their free Copernicus program and Sentinel satellites provides free of charge land coverage data with a granularity better than SRTM1. That detailed terrain data may be used to modify the SRTM files, adding the clutter data to the terrain and then using those modify files in RM. In other words: SRTM with clutter.

It will require the ability to read SRTM and convert Sentinel files to SRTM. This has been done in Chile to evaluate the modifications of a volcano terrain during an eruption measuring displacements in the submeter range. [9]. A future project would be to create a program converting specific SRTM files incorporating Sentinel data.

Addendum1 (0ctober 2019)

The NASA ASTER2 DTED was investigated as an alternative to SRTM1 as Sentinel is cumbersome to convert to SRTM1. ASTER is a very complete 30m Global Elevation Dataset. It is a photographic satellite of land information designed to acquire land surface temperature, emissivity, reflectance, and elevation . of Economy. For those purposes uses various wavelengths from visible light up to near infrared. Being photographic recognizes clutter, which is not the case of SRTM based on radar and that can easily show, both for SRTM an ASTER with RM by tracing a flat profile on the RMpath program included on Ian D. Brown RM installer. It is also capable of improvements as its data is continuously received from the satellite whilst SRTM was performed in one Space Shuttle Mission on year 2000. In early 2019 our team downloaded the whole Chile on ASTER2 and developed a program to easily convert ASTER to SRTM.
A series of comparisons was then performed between 48 LOS links calculated both with ASTER and SRTM. The use of ASTER had a slight improvement on the accuracy of the results. That was covered on a paper submitted and accepted in IEEE- Chilecon Congress. Valparaíso-Chile which is included in the Library of the Telecom Commission of Colegio de Ingenieros de Chile together with this Monography. Download HERE

At the present, the improved ASTER3 is available from NASA site, but its structure is different from ASTER2, which has been discontinued, so a new converting tool is now under development.

Addendum2 (January2020)

The Radio Mobile program had the invaluable collaboration of the Eng. Iam D. Brown who wrote two complete Handbooks on the installation and operation of the program: The Radio Mobile Handbook and the Radio Mobile Companion. Ian passed away on September 2019 and his family, on his loving memory decided to make those handbooks available for free to the worldwide radio community. This author has been appointed by the family to be in charge of making those handbooks available to the worldwide Radio Community at the library of the telecommunications commission of Colegio de Ingenieros de Chile. HERE

STATEMENT

Under no circumstances this work should be interpreted as a criticism or derogative opinion on the Radio Mobile program and/or its author. Radio Mobile is an excellent freeware having made valuable contributions to radio propagation knowledge and continues to do so. The problem here addressed applies to specific cases, easy to detect and easy to manually correct until a fix is obtained. The author intent has only been to promote a solution which will improve, even more Radio Mobile. The author of this work extends its deepest appreciation to Mr. Roger Coudé for his valuable contributions to the Radio Community.

For further reading

--Ian D. Brown, Radio Mobile Handbook y Radio Mobile Companion. Traducción al español: Ing. Eduardo Costoya, Colegio de Ingenieros de Chile. Santiago de Chile, 2015.

--**Compilation S. Shumate**, Givens & Bell.
--S. Shumate, Givens & Bell. "The Irregular Terrain Model (ITM) Averaging System ". IEEE Broadcast Technology Society Newsletter. Volume 16, Number 2, pp. 19-21, Fall, 2008. Shumate, Givens & Bell. "The Irregular Terrain Model (ITM) Averaging System ". IEEE Broadcast Technology Society Newsletter. Volume 16, Number 3, pp. 22-23, Summer, 2008.
S. Shumate, Givens & Bell. "Longley-Rice's Terrain Irregularity Parameter, Delta-H ". IEEE Broadcast Technology Society Newsletter. Volume 16, Number 1, pp. 23-25, Winter, 2008.
S. Shumate, Givens & Bell. "Longley-Rice's Faulty Subroutines, Part 2: dlthx ". IEEE Broadcast Technology Society Newsletter. Volume 16, Number 2, pp. 26-27, Fall, 2009.

--**Reflection** from the surface of the Earth. ITU Report 1008-1

- **David Hermosilla D**. Interferometría radar de apertura sintética (insar) aplicada al estudio del movimiento En laderas aledañas al volcán Calbuco con ayuda de imágenes sSntinel-1a Universidad Técnica Federico Sta.María.201]

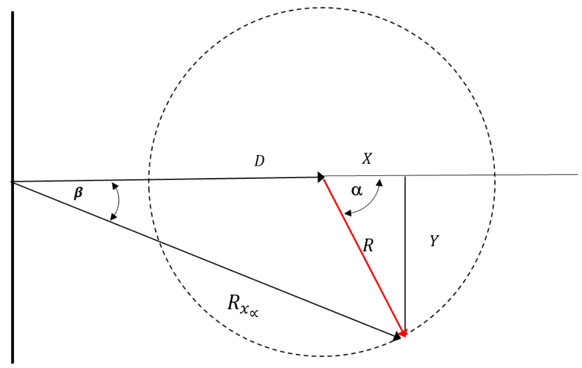
-H. Kaschel, S. Cordero, and E. Costoya, Members IEEE " Analysis and Evaluation of Radio Mobile program online of Sight paths with SRTM and ASTER DTEDs and its v11.6.6 / v9.1.6 versions". CHILECON, Valparaíso, Chile 2019.

-H. Kaschel, S. Cordero, and E. Costoya, Members IEEE Modeling and Simulation of the ITM Model for Point-to-Point Prediction on Digital Television Extensible to other Technologies

Annex 1.

1.1 -The Geometry of the Two Ray Model

General TR scheme $\boldsymbol{\alpha} \neq 0$



$x = D + R\cos\alpha$
$y = R\sin\alpha$

Referring all values to the direct ray D

$D = 1$
$0 \leq R \leq 1$
$x = 1 + R\cos\alpha$
$y = R\sin\alpha$

$$R_{x_\alpha}^2 = x^2 + y^2 = 1 + 2R\cos\alpha + R^2cos^2\alpha + R^2sen^2\alpha$$

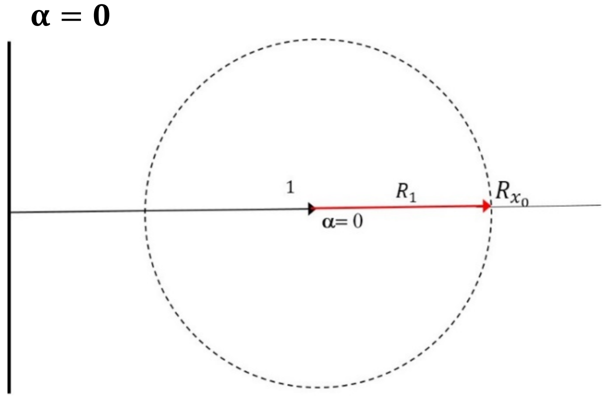
$$R_{x_\alpha}^2 = 1 + 2\,R\cos\alpha + R^2\overbrace{(cos^2\alpha + sen^2\alpha)}^{1}$$

$$R_{x_\alpha}^2 = 1 + R^2 + 2\,R\cos\alpha$$

$$\boxed{\cos\alpha = \frac{R_{x_1}^2 - R_1^2 - 1}{2R_1}}$$

1.2 If RX antenna height is modified until Obstruction loss is minimum (max. negative)

$\boldsymbol{\alpha = 0}$



$Cos\,\alpha = 1$

$R_{x_0} = 10^{\frac{Obst.\ loss\ 0\ (dB)}{20}}$

$R_1 = R_{x_0} - 1$ *but also*

$R_1 = 1 * \rho_{rm_1}$

ρ_{rm_1} = *RM Ref. Coefficient w/o clutter*

-

$$\boxed{\rho_{rm_1} = R_1 = 10^{\frac{Obst.\ loss\ 0\ (dB)}{20}}}$$

1.3 Obstruction loss with clutter[9]

The suffix 1 means reflected ray over terrain only. Suffix 2 to terrain plus clutter. Suffix 0 condition of α =0.

Rayleigh roughness criterion g.

$$g = 4\,\pi\ (\sigma_h/\lambda)\ sen\ \varphi$$
$$\rho = e^{(-\frac{1}{2}g^2)}$$

$$g_1 = 4\,\pi\ (\sigma_{h_1}/\lambda)\ sen\ \varphi \qquad \rho_1, g_1\ \in terrain$$
$$g_2 = 4\,\pi\ (\sigma_{h_2}/\lambda)\ sen\ \varphi \qquad \rho_2, g_2\ \in terrain + clutter$$

$$\rho_1 = e^{\left(-\frac{1}{2}g_1^2\right)} = e^{-\frac{1}{2}(4\,\pi\,(\sigma_{h_1}/\lambda)\ sen\ \varphi\,)^2}$$

$$\rho_2 = e^{\left(-\frac{1}{2}g_2^2\right)} = e^{-\frac{1}{2}(4\,\pi\,(\sigma_{h_2}/\lambda)\ sen\ \varphi\,)^2}$$

σ_h= *Standard deviation of terrain over F1 interception, corrected by earth curvature and slope regression.*

$$k=\frac{1}{2}\left(\frac{4\,\pi\ sen\ \varphi}{\lambda}\right)^2$$
$$\rho_1 = e^{-k\ \sigma_{h_1}^2}$$
$$\rho_2 = e^{-k\ \sigma_{h_2}^2}$$
$$\frac{\rho_2}{\rho_1} = \frac{e^{-k\ \sigma_{h_2}^2}}{e^{-k\ \sigma_{h_1}^2}}$$

$$\boxed{\frac{\rho_2}{\rho_1} = e^{-k(\ \sigma_{h_2}^2 - \sigma_{h_1}^2)}}$$

[9] ITU-R Report 1008-1