Universitat de Vic
Escola Politècnica
Superior

Final Career Project

Calculation of radio electrical coverage in Medium-Wave Frequencies

Marcos Crego García

Technical Industrial Engineering

Director: Prof. Dr. Thomas Lauterbach

Vic, February 2009

Index of contents:

Index of figures

Resume of the Final Career Project

Technical Industrial Engineering

Title: Calculation of radio electrical coverage in Medium-Wave Frequencies

Keyword: Groundwave, propagation, coverage, conductivity, field strength, ISI, ITU-R

Author: Marcos Crego García

Director: Prof. Dr. Thomas Lauterbach (Georg-Simon-Ohm-Hochschule. Nurnberg)

Codirector: Moisés Serra

Date: February 2009

Resume

The aim of this project is to accomplish an application software based on Matlab to calculate the radioelectrical coverage by surface wave of broadcast radiostations in the band of Medium Wave (MW) all around the world. Also, given the location of a transmitting and a receiving station, the software should be able to calculate the electric field that the receiver should receive at that specific site. In case of several transmitters, the program should search for the existence of Inter-Symbol Interference, and calculate the field strength accordingly.

The application should ask for the configuration parameters of the transmitter radiostation within a Graphical User Interface (GUI), and bring back the resulting coverage above a map of the area under study. For the development of this project, it has been used several conductivity databases of different countries, and a high-resolution elevation database (GLOBE). Also, to calculate the field strength due to groundwave propagation, it has been used ITU GRWAVE program, which must be integrated into a Matlab interface to be used by the application developed.

1 Introduction

This project deals with radioelectrical propagation in the frequency band of Medium-Wave. In this band of frequencies, between 10 KHz and 30 MHz, the main propagation method is Surface Wave or Ground-Wave Propagation. There are two different ways to calculate the electric field due to Groundwave propagation:

- The set of graphics provided by the ITU-R P.368-9 Recommendation, each one for different frequencies and terrain conductivity and permittivity.
- With ITU-R GRWAVE, a MSDOS based software used by ITU to obtain the graphics showed at Rec. ITU-R P.368-9, which allows calculating the field at one point over a path with one conductivity, given a transmitter and a receiver.

Although ITU-R Graphics and GRWAVE are recognized methods by ITU-R, they have limitations, like:

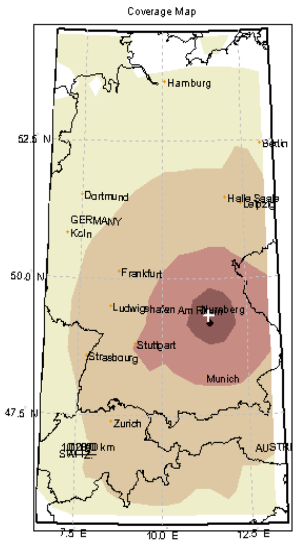
- These methods do not have in account topographical data, very important in this type of propagation due to its nature (detailed description of groundwave propagation can be found at chapter 3.1).
- Millington method for Non-Homogeneous paths calculations become tedious and complicated when calculating the field over paths with several different conductivities.

2 Objectives

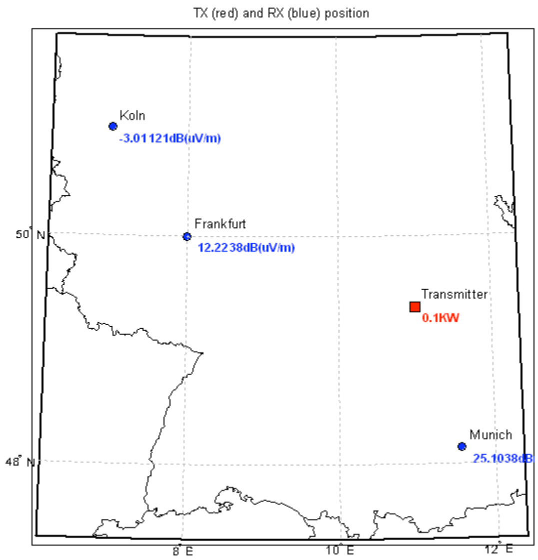
The aim of this project is the development of a software tool based on ITU-R Recommendation and ITU-R GRWAVE that will eliminate these limitations, by:

- Calculating the electric field keeping the ITU-R P.368-9 Recommendations with ITU-R GRWAVE.
- Introducing topographical data of the terrain under study.
- Introducing high-resolution conductivity maps.
- Performing automatic calculations of radio electrical coverage at one region.
- Making calculations at one single point, being able to plot the field profile between the transmitter and the receiver.
- Adapting the system to be able to calculate the effect of the Inter-Symbol Interference (ISI) and the electric field resulting at one receiver in a scenario of several transmitters.
- And packaging all this calculations into an easy-to-use Graphical User Interface.

In the figures below, some examples of the results desired are shown:

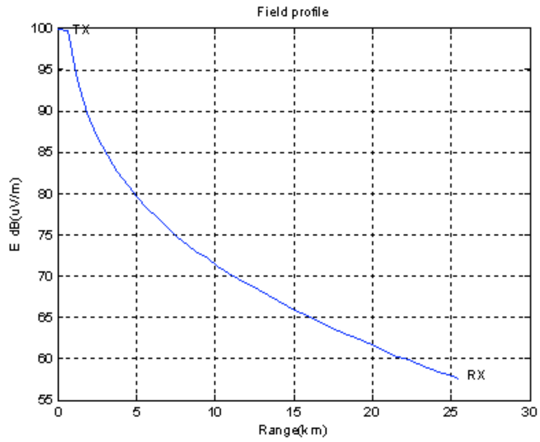


(a) Example of Coverage Map



(b) Example of field calculating results over an scenario with several receivers and transmitters

Figure 3.1.1: Examples of the maps obtained.




```
Field at Receivers:
    - Nuremberg: 71.668787 dB(uV/m)
    - Frankfurt: 12.223787 dB(uV/m)
    - Munich: 25.103787 dB(uV/m)
    - Koln: -3.011213 dB(uV/m)
```

Figure 3.1.2: Examples of profiles and results printed on screen.

3 Project exposure

This chapter is the main chapter of this document, where all the details of the project are explained. To do so, some introduction of Groundwave propagation should be given first, followed by a project description and detailed software development, as well as several practical examples are exposed.

3.1 Groundwave propagation

The Groundwave propagation method has special relevance at HF communications in the 10 KHz – 30 MHz frequency band. When the height of the transmitter antenna operating at these frequencies is small in comparison with its wavelength (λ), Groundwave propagation appears. In the lowest frequencies of the band, this propagation method can even reach hundreds of Kilometres, given worldwide coverage with a very low bandwidth, but very useful for maritime rescue applications.

The most important property of the Groundwave propagation is that it propagates parallels to the ground. In this way, the attenuation will depend strongly on the terrain constants (conductivity and permittivity), as well as other factors like polarization, antenna height, distance and frequency. Over non-homogeneous paths, the use of vertical polarization is the only practical approach, because the ground quickly absorbs horizontal polarization. Even vertical polarization suffers high attenuation over poor ground. Paths over the sea or including the sea have diminished losses because the increased sea conductivity.

Radiation over a smooth spherical surface is a radio electrical problem that has an analytical solution. The radiated field can be expressed as a sum of terms with amplitudes in function of frequency, terrain constrains, polarization, distance and antenna height. This is the analytical solution provided by ITU-R GRWAVE [GRWAVE].

The estimation of the Groundwave field strength given at one point depends on the nature of the path between transmitter and receiver. In this way, two different methods are defined by ITU-R Recommendation: Method for homogeneous paths and Millington's Method for Non-Homogeneous paths [ITU-R P.368-9].

3.2 Homogeneous paths

The ITU-R Rec. 368-9 defines a homogeneous path as the path between the transmitter and the receiver when there is only one terrain conductivity between them. In this case, both ITU-R Graphics or ITU-R GRWAVE can be used directly to calculate the field strength at the receiver.

As shown in the figure below, ITU-R graphics depend on frequency, terrain constrains and range, and so appropriate curve must be selected.

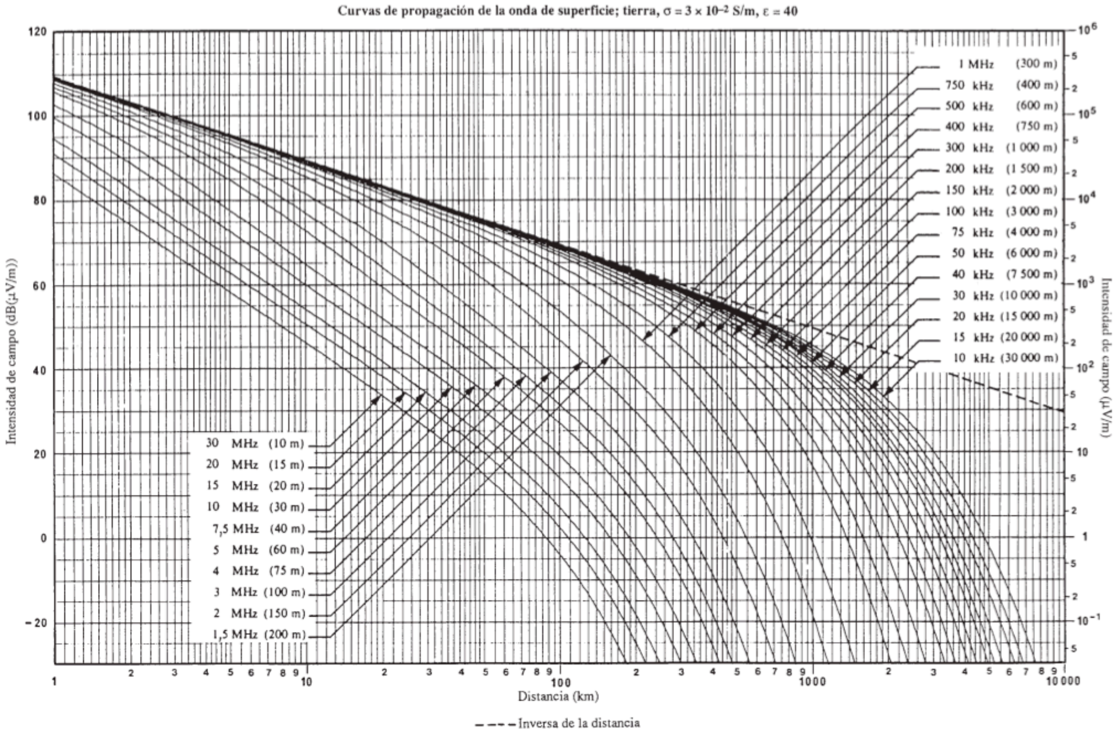


Figure 3.2.1: Example of ITU-R P. 368-9 Recommendation

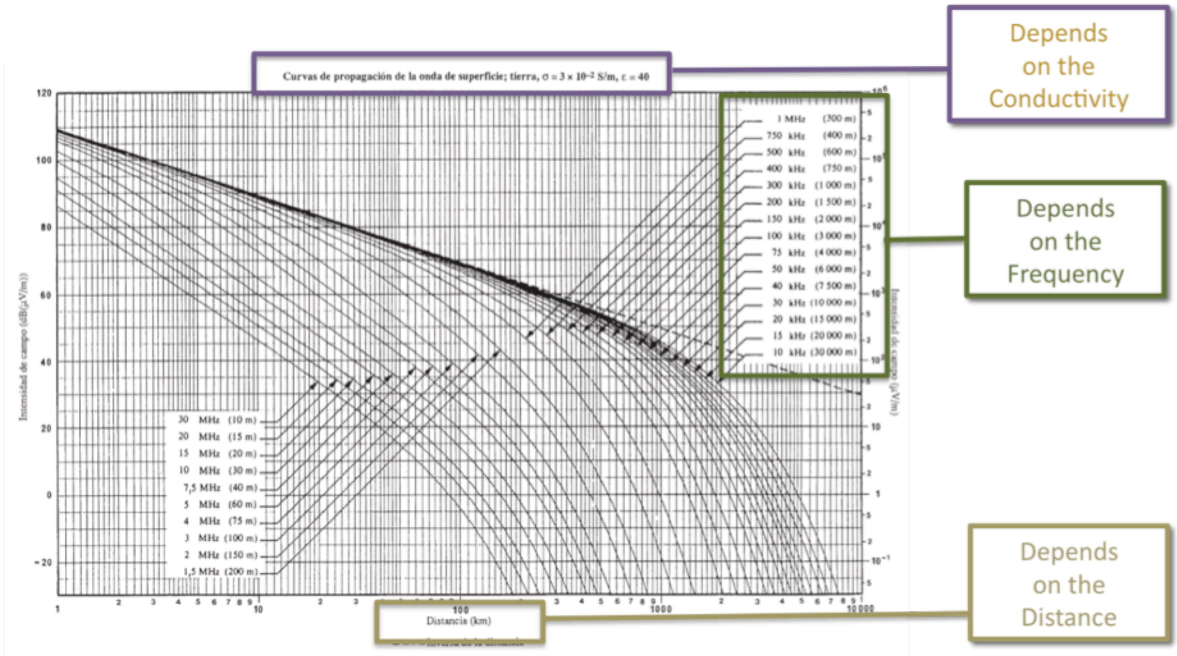


Figure 3.2.2: ITU-R P. 368-9 Rec. Remarkable parameters

As the figure shows, they are only valid over the frequency range from 10 KHz to 30 MHz for vertical polarization and antennas over the ground [ITU-R P.368-9]. Over those frequencies, GRWAVE still gives an approximation of the field strength, but it is not accurate and reliable, so it is not recommended using it out of this range.

From the graphics it can be seen that field strength diminish with frequency, so groundwave propagation is not a relevant propagation mechanism with big distances in the HF band.

ITU-R graphics and ITU-R GRWAVE return normalized field strength for a transmitter using a power of 1 KW over a short monopole antenna (3 dB gain antenna), so it will be necessary applying a Correction Factor (CF) to be able to use any other transmitter power of antenna gain [COMMERCIALFM].

The field strength, the power in KW and the antenna gain are related by the Power Density, S, as shown in the equations (3.2.1) to (3.2.4). To de-normalize the expression returned by GRWAVE, both real field and GRWAVE field can be compared. In this way, dividing S_{REAL}/S_{GRWAVE}, the correction factor is obtained. The Correction Factor (CF) expression is shown in equation (2.2.4).

$$S = E^2/Z_0 = (PxGxk) / (4 \pi r^2) = (P \text{ x } G) \text{ x } (k/ (4\pi r^2)) \quad (3.2.1)$$

$$S_{REAL}/S_{GRWAVE} = (P_{REAL} \text{ x } G_{REAL}) / (P_{GRWAVE} \text{ x } G_{GRWAVE}) \quad (3.2.2)$$

$$E_{REAL} = E_{GRWAVE} \text{ x } \sqrt{}(P_{REAL} \text{ x } G_{REAL}/3) \quad (3.2.3)$$

$$CF = \sqrt{}(P_{REAL} \text{ x } G_{REAL}/3) \quad (3.2.4)$$

3.3 Non-Homogeneous paths

The ITU-R P.368-9 Recommendation defines a non-homogeneous path as the path between the transmitter and the receiver with two or more conductivities between them. In this case, data contained in the graphics must be used following the Method of Millington described at the Recommendation.

This method implies several calculations over several graphics both in Transmitter-to-Receiver direction as in the inverse, Receiver-to-Transmitter direction.
As an example, with a path of only two conductivities, as shown in the figure, the total normalized field strength at the receiver should be the one at equation (3.3.3).

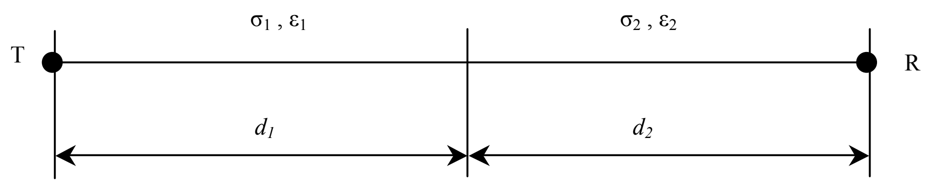


Figure 3.3.1: Example of Method of Millington with a path of two conductivities.

$$Ef = E1(d1) - E2(d1) + E2(d1+d2) \quad (3.3.1)$$

$$Eb = E2(d2) - E1(d2) + E1(d1+d2) \quad (3.3.2)$$

$$Et = (Ef + Eb) /2 \quad (3.3.3)$$

The *Ef* field is the *Forward Field*, in the direction Transmitter-to-Receiver (Eq. (3.3.1)), while the *Eb* field is the *Back Field,* in the opposite direction, Receiver-to-Transmitter (Eq. (3.3.2)). Both of them must be calculated to obtain the Reciprocal Total Field, *Et*. The intermediate fields are calculated assuming a homogeneous path, so graphics or GRWAVE can be applied.

As it can be seen in this example, for only two conductivities, six different consults to ITU-R graphics or six calls to GRWAVE are needed. This means a very tedious process and it becomes even more tedious because generally there are more than two conductivities between Transmitter and Receiver, especially when they are far enough.

3.4 Project description

As it was said in the first chapter, the aim of this project is to accomplish next objectives:

- Suit the method of calculation to the ITU-R P.368-9 for groundwave field strength coverage.
- Include topographical data.
- Include conductivity maps to be able to process the coverage under one area and fields profiles automatically.
- Extend the GRWAVE to calculate the field in one point (receiver) due to one or several transmitters, checking if there is ISI or not.
- Create an easy-to-use graphical user interface to simplify the methods described at ITU-R Rec.

To achieve these objectives, it has been chosen Matlab as the programming tool, due to its Mapping Toolbox, that allows dealing with maps and coordinates data expressed in latitude and longitude, which are the nature way to express the location of a radio station. Moreover, the version chosen has been Matlab 7 R14, because the plot of the coastal line and politics frontiers is more accuracy.

The project has been divided in two differentiated parts: the one for the scenarios with several transmitters and receivers, and the one for coverage calculation. The program allows the user to choose the option desired, or even both options, as shown in the next figure.

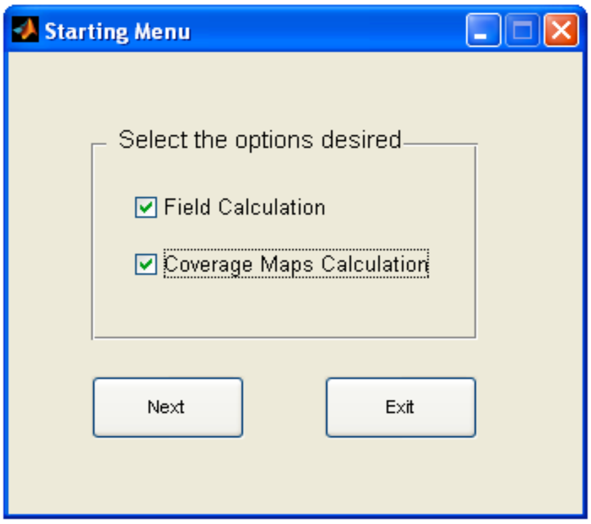


Figure 3.4.1: Start Menu Window

In case of both options chosen, the first window to be open is the corresponding to Field Calculations, because coverage calculations take a long time to finish and it is probably that it is only needed the field at one receiver, instead of one region. The window that appears in this case is shown in the figure below, and it is formed by the configuration of six transmitters and the configuration of six receivers.

Transmitters and receivers are stored in Matlab into a vector of structures. Transmitters data are the name of the site, the position given by its latitude and longitude (in format 000d00m00sN, being d: degrees, m: minutes, s: seconds, N: North), the frequency in MHz, the power in KW, the antenna gain (dB), the antenna height in metres and the polarization. Receiver's data are stored in the same way, storing name to recognize them at the map, latitude and longitude coordinates, and antenna height.

It is needed also a conductivity database from the terrain under the transmitters and the receivers. There are two options (detailed in chapter 3.5.3) for the conductivity database: a high-resolution database, only available for few countries, and a low-resolution database, containing the conductivity of the entire world, but giving a very low accuracy.

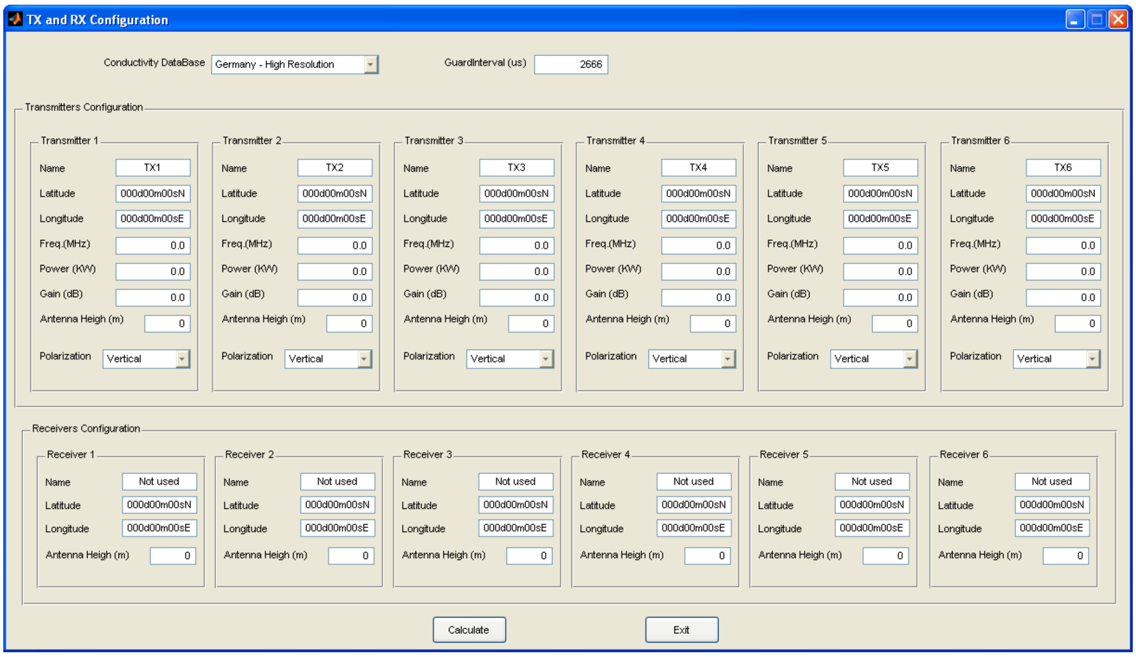


Figure 3.4.2: Field Calculation at single points Windows

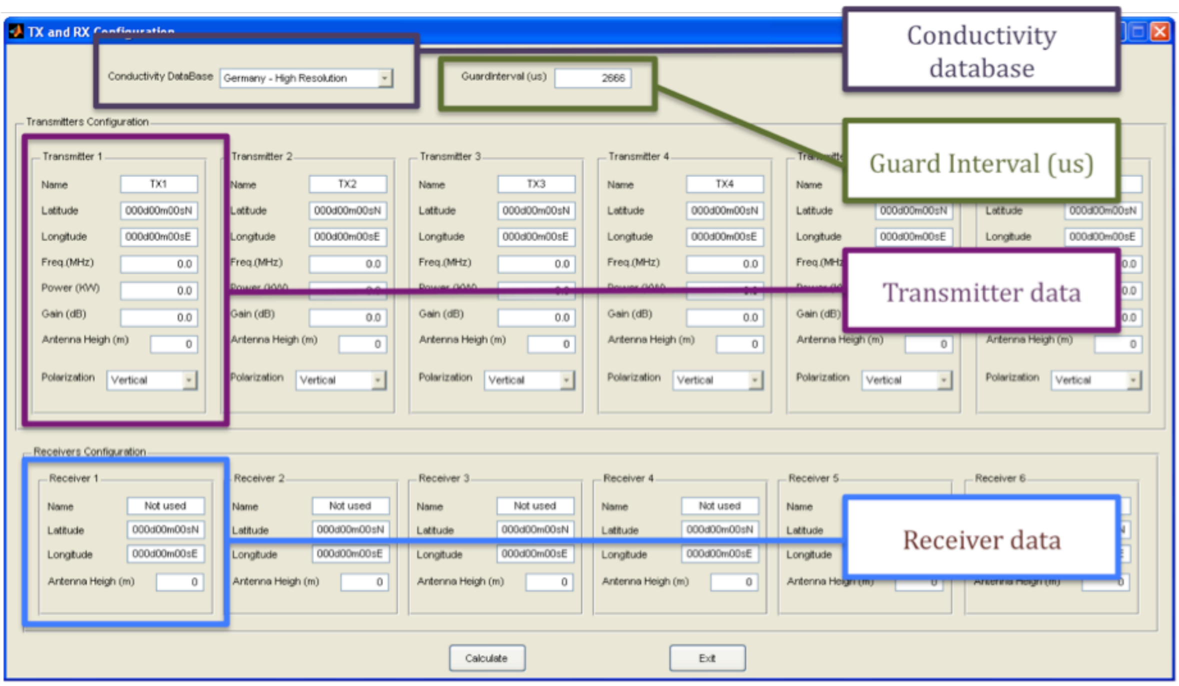


Figure 3.4.3: Parameters to configure the simulation

Data must be inserted in the format specified at user interface. This implies inserting the configuration with the correct units but also inserting latitude and longitude coordinates as specified. The format specified for both coordinates is next:

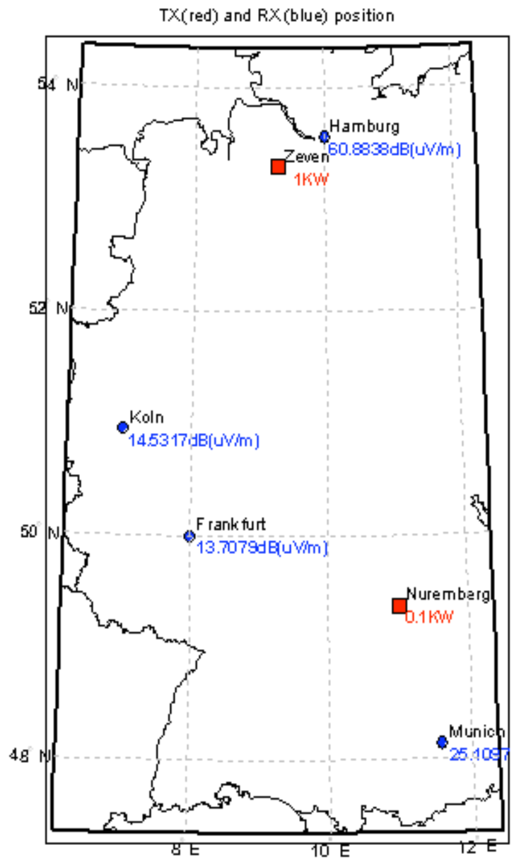
Latitude: generally it is set from -90º (what is -90º 0’ 00’) to 90º, being the Equator the 0º reference. In the notation used in this application, latitude ranges over 90d00m00sS (equivalent to -90º) and 90d00m00sN (equivalent to 90º).

Longitude: generally it takes values between -180º (what is -180º 0’ 00’) and 180º. In the format used in this project, longitude ranges over 180d00m00sW (-180º) to 180d00m00sE (equivalent to 180º).

Field strength calculation at one receiver due to one or several transmitters only has sense when all the transmitters are working at the same frequency and polarization. This fact is checked by the graphical interface previously to launching the application.

The application gives the results of the calculation in two formats: graphical and text printed by screen.

Graphical data allow the user to locate visually the transmitters and receivers, and text data allows to copy data to a file.




```
Transmitters to be used:
     - Nuremberg
     - Zeven

Field at Receivers:
     - Hamburg: 60.883788 dB(uV/m)
     - Frankfurt: 13.707902 dB(uV/m)
     - Munich: 25.109699 dB(uV/m)
     - Koln: 14.531749 dB(uV/m)
```

(a) Results over a map (b) Results printed on Matlab screen

Figure 3.4.4: Field Calculation – Results offered

When having a scenario with several transmitters, with long distances between them and DRM system, there can appear Inter-Symbol interference at one receiver. In presence of ISI, the field returned by the application and the GRWAVE is not reliable and so it is not calculated. So, in order to avoid useless calculations, the application checks previously for the presence of ISI [DRM].

There will be ISI when:

$$|d1\text{-}d2| > \textit{Guard Interval (s) x c (m/s)} \quad (3.4.1)$$

Being:

d1: distance between transmitter 1 and receiver
d2: distance between transmitter 2 and receiver
Guard interval in seconds: Guard interval defined by DRM standard
c: speed of light at the vacuum ($3x10^8$ m/s)

With a default guard interval of 2666 us, the minimum difference of distance needed to have ISI is 800 km, far enough to cover a wide region without ISI [DRM].

The second option is the **coverage calculations**. This option allows the user to define a region of the space where to calculate the map of coverage, and to configure only one transmitter inside of it. It must be pointed that **transmitter must be inside the coverage region to validate configuration and start the calculations**. The window in this case is the one showed in next figure. As it can be seen, a transmitter and the region under study must be configured. Also, the application allows configuring a receiver, but this is optional. If the receiver is configured, the application will calculate both the coverage over the region and the field profile between transmitter and receiver. To have an idea of the heights of each one, application also plots the terrain heights profile between transmitter and receiver in this case.

Examples of results given by this option are shown in Figure 3.4.8 to Figure 3.4.11. There is another parameter related with the grid of the field strength: the scale factor. The scale factor is related with the maximum number of points where the field strength will be calculated. If the scale factor is 1, the resolution is maximum and the field matrix will have the same resolution than the conductivity matrix. This implies very large simulations, so it is useful to set the scale factor with values under 1 (0.5, 0.1, etc.). Minimum scalefactor value is 0.05.

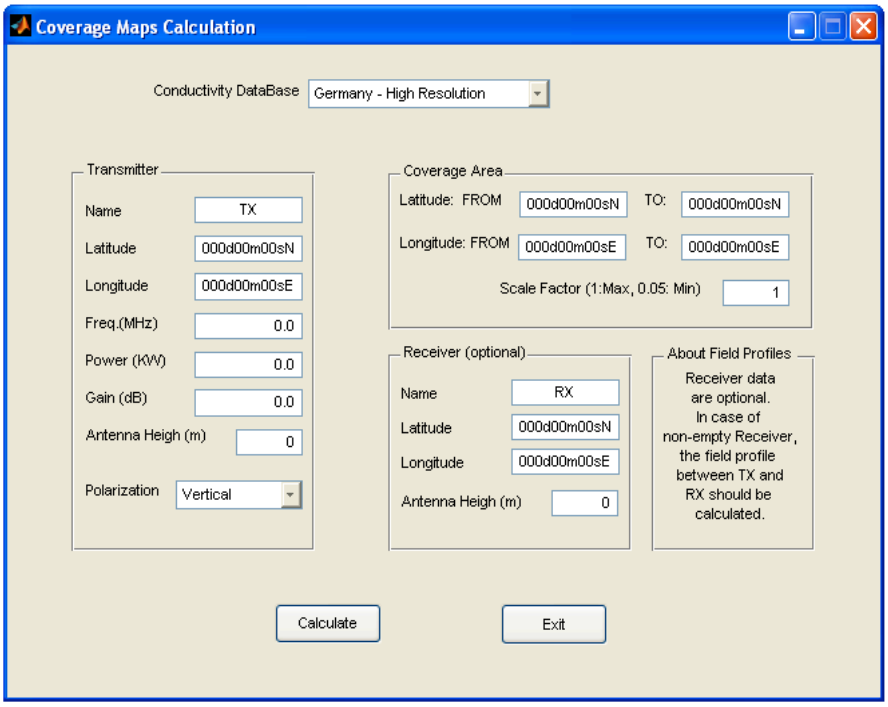


Figure 3.4.5: Coverage calculation window

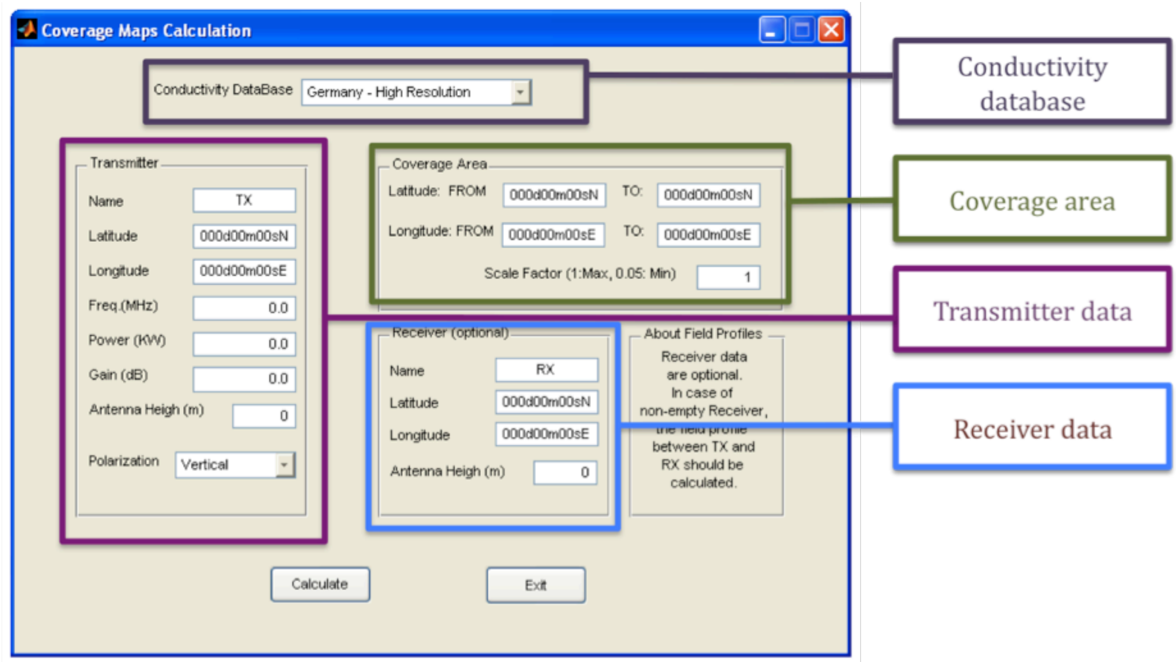


Figure 3.4.6: Configuration parameters

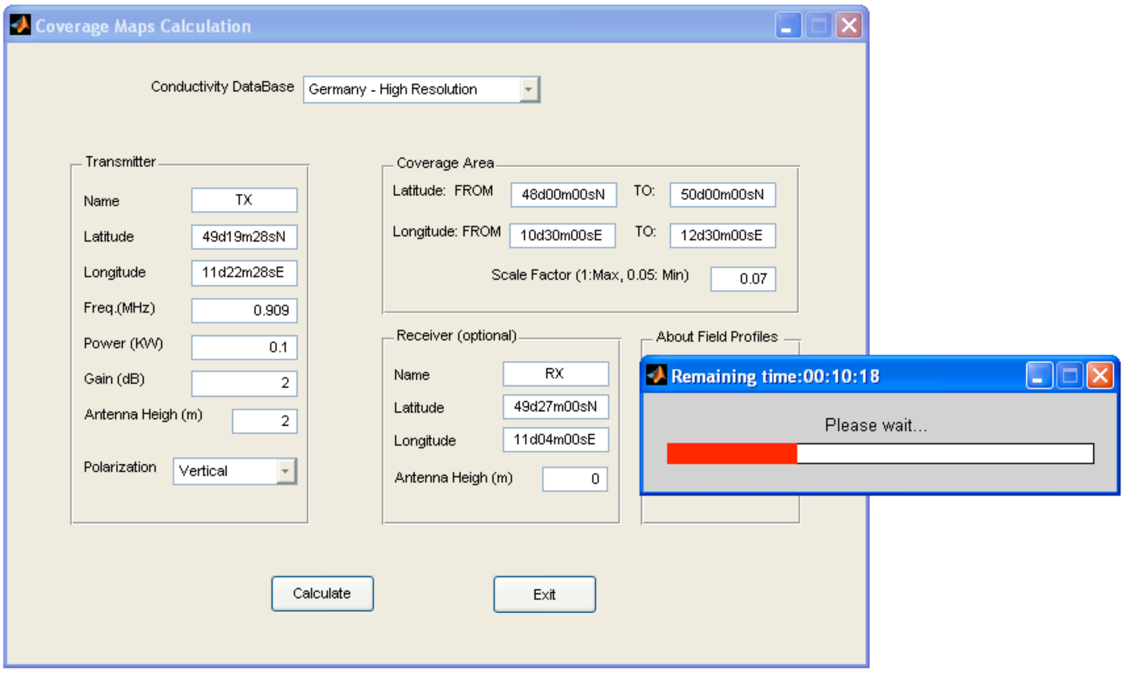


Figure 3.4.7: Example of configuration and waitbar

If the scale factor is set to a very low value and the resulting field matrix is very little, application will resize field map (and so, scale factor) to a minimum number of rows and columns, to be able to plot a map and to have accuracy results. In this way, the smaller dimension of the matrix has been established in 11 (rows or columns), by empirical data result of several simulations.

There can appear inconsistencies between the field strength observed at one point at the map and the exact field strength given by the profile, for example. This is due to the resolution grid of the coverage map where the field strength is calculated. When having Scale Factor = 1, results match exactly, but with a scale factor lower than one, the field obtained with the map at one point only gives an approximation of the real field and it will not match with the final field calculated by the profile. In this way, coverage maps can be considered as an approximation of the field strength in an area due to a transmitter, but to know the exact field strength at one point, it must be chosen the first option of the application (field strength).

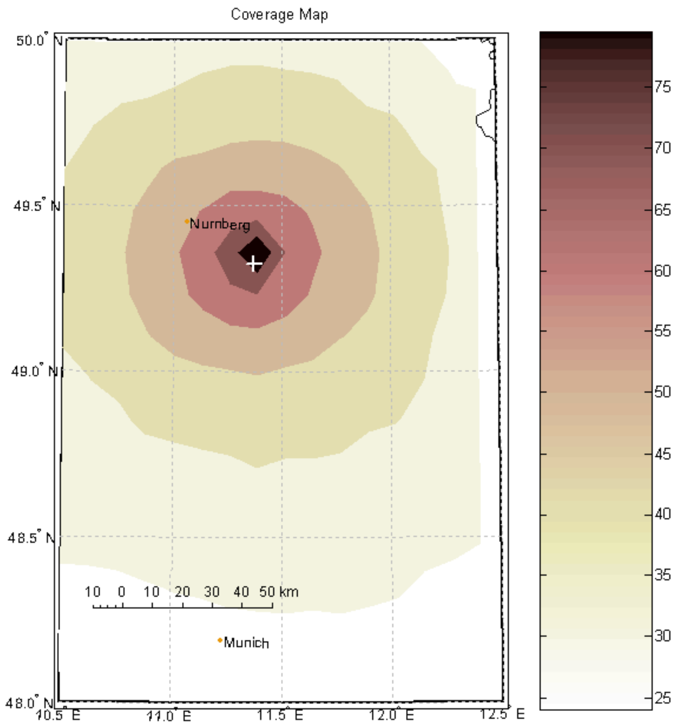


Figure 3.4.8: Coverage results in the area of Nurnberg

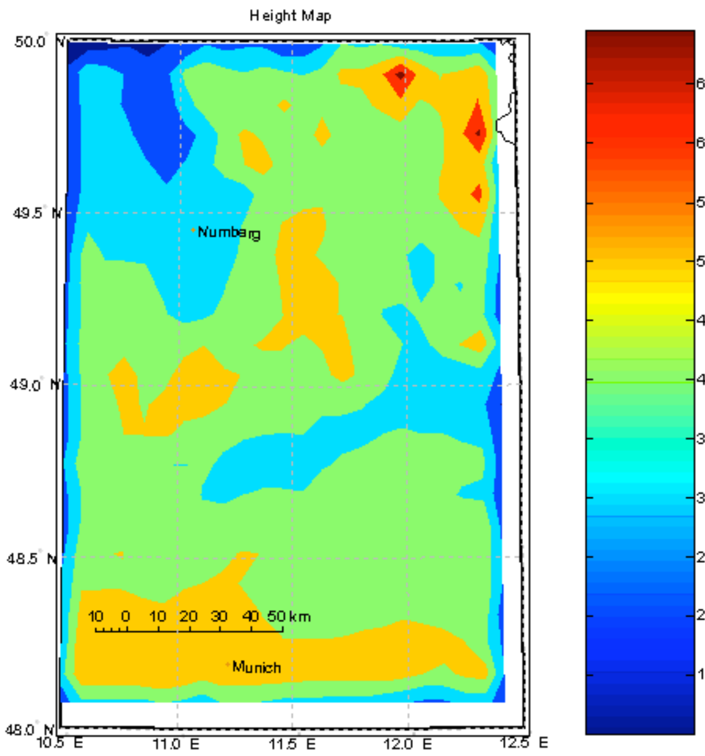


Figure 3.4.9: Elevation map in the area of Nurnberg

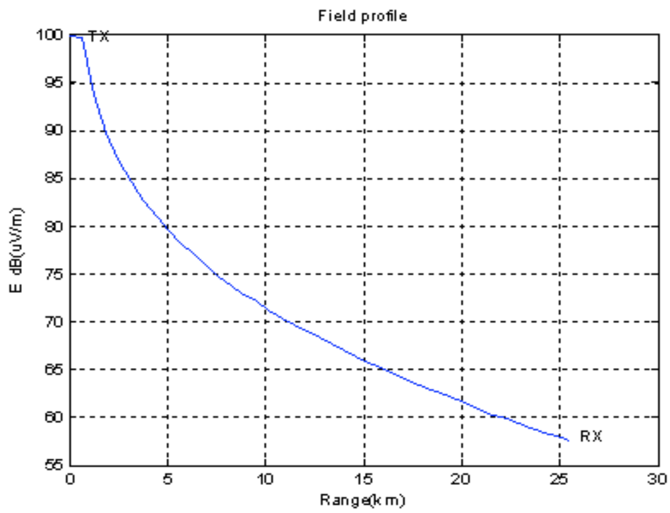


Figure 3.4.10: Field profile between a Transmitter (TX) and a Receiver (RX)

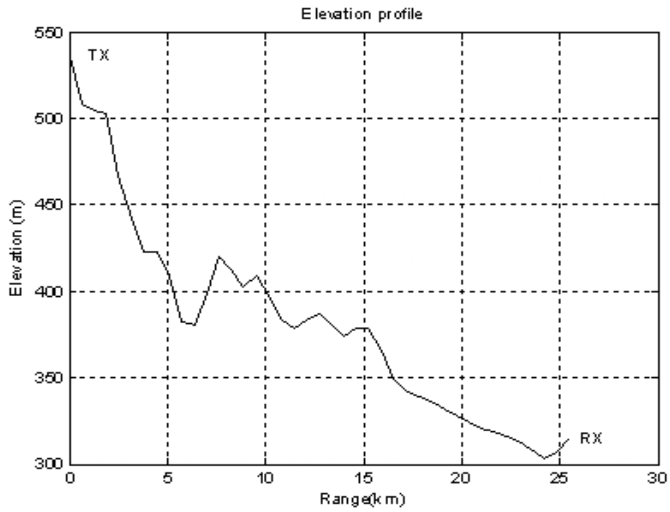


Figure 3.4.11: Elevation profile over the sea between a Transmitter and a Receiver

Also, the application shows a waitbar so the user can have an estimation of the remaining time for the calculations. GRWAVE has a slow and complex algorithm and grwave.m has to create and reading two files in each calling, so simulations will last several hours for big maps and high resolution. It is useful in this case to know the remaining time to finish simulation.

The code controlling a waitbar is shown in the next figure.

```
% Starting waitbar :
%-----------------------------------------------------
x = waitbar(0,'Please wait...');
% k will be the status bar, so it is started to zero:
k = 0;
% printing an advice:
set(x,'name','Estimating remaining time...');
% total number of iterations of the loop is calculated:
total = size(mapcob,1) * size(mapcob,2);
%-----------------------------------------------------

% loop:
for fila = 1:1:size(mapcob,1)

    % with clock the actual instant is stored into t0
    t0 = clock;

    instrucctions,...



    % Waitbar will be updated for each element of the loop calculated:
    %-------------------------------------------------------------
    % update the waitbar to advance:
    k = k + 1;
    waitbar( k/total );

    % calculate the time to simulate one cell, substracting actual
    % time (clock) with init time (t0):
    t1    = etime( clock, t0 );
    % remaining time in seconds to calculate remaining cells (number
    % of remaining cells=total-k):
    t_res = sec2hr( t1 * ( total - k ) );

    % pass the seconds to string and put as the waitbar title:
    set( x, 'name', strcat('Remaining time: ',time2str(t_res)));

    %-------------------------------------------------------------

end % of the loop

% closing waitbar
close(x);
```

Figure 3.4.12: Control code of a waitbar

In this example, extracted from 'coverage.m' function, variable 'total' represents the total number of cells of the coverage map (rows x columns). It will be decreased at every iteration of the loop. The instruction 'etime' calculates the difference in seconds between two instants of time. As 'clock' gives the actual time (of the operating system), the instruction etime(clock,t0) provides the time between t0 and now, able to give us an estimation of the time needed to process one cell, and so on, the time remaining to process the remaining cells.

Functions *'etime'* and *'clock'* are Matlab reference functions, available in the basic Matlab toolbox. However, the instruction *'time2str'* is only available in the Mapping Toolbox, as one of the huge amount of conversion between units function.

Furthermore, to work with the data resulting once the simulation is made, the program stores the data acquired into three different files in .mat binary format: *FieldData.mat*, saves the variables resulting from the simulation of several transmitters and receivers. *CoverageData.mat*, saves the coverage maps and data resulting from coverage simulation. *SimulationData.mat*, that saves all variables available in the workspace.

To load the data once the simulation is finished, type *"load filename.mat"* in the Matlab command windows (or workspace) to access the data.

3.5 Software development

The application consists on several functions developed in Matlab. All of them converge in two primary functions: *loadmap*, in charge of loading conductivity and elevation maps and *MillingtonH*, the function in charge of the field calculation at one point, given one transmitter and one receiver. This function implements Millington's Method of calculation, which implies the calculation of the paths of different conductivity between transmitter and receiver and several callings to the Matlab GRWAVE Interface.

The main steps followed in the software development of the application were these:

- Programming ITU-R P. 368-9 Recommendation for homogeneous paths: Calling GRWAVE from Matlab.
- Programming ITU-R P. 368-9 Recommendation for non-homogeneous paths: Programming method of Millington. This means the previous obtaining of the path between two points in a map: conductivity interpolation and effective heights.
- The nature of the project means working with maps, so it is needed to use Matlab Mapping Toolbox, which will be discussed, in the last place.
- This project works with two databases: terrain conductivity and permittivity and elevation database. Both are necessary data to call GRWAVE following the instructions from the ITU-R.
- Loading conductivity and elevation maps.

The flow diagram is shown below.

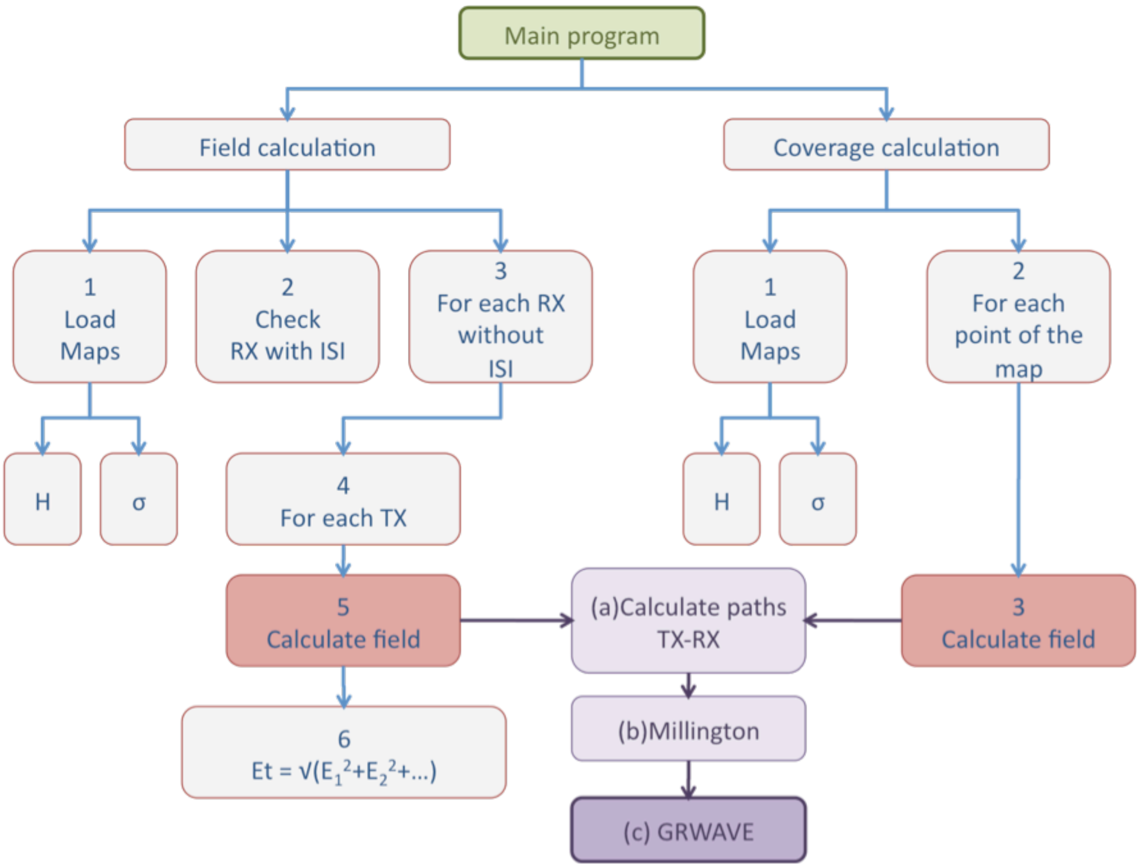


Figure 3.5.1: Flow chart of the application

3.5.1 GRWAVE Matlab interface

ITU-R GRWAVE is software developed in FORTRAN to estimate the field produced for Groundwave propagation. The results obtained are only reliable under certain conditions of frequency and height [ITU-R P.368-9], which are fully contemplated in the program. The field strength given is normalized to a transmitter power of 1 KW and an antenna gain of 3 dB, so, as it was said before, a Correction Factor must be applied after calling GRWAVE when using other power or antenna gain. Binary and source code files are available at the ITU-R Website.

GRWAVE has a MSDOS command window interface to insert data needed, but also allows the user to insert data into a file following a fixed format. In the same way, results obtained can be printed by GRWAVE either in the screen or into a text file.

The option chosen to communicate Matlab with GRWAVE was using the binary and the 'system' command from Matlab, and input and output text files to insert configuration and reading data. The full instruction used to call GRWAVE is:

```
[ ergrw, res ] = system('grwave <data.inp  >data.out');
```

The instruction system('command') execute operating system command and return the result on success or an explanatory message of error in other case. In this case, command to execute is GRWAVE, which must be located in the same directory of the application, and data.inp and data.out are the names of the input and output directory, respectively. Both input and output files are text files with a format specified by GRWAVE Instruction Manual [GRWAVE]. An example of the input file, data.inp, is shown below:

```
HTT 9.146930e+001
HRR 9.875478e+001
IPOLRN 1
FREQ 0.909000
SIGMA 0.008000
EPSLON 14.000000
dmin 1.231949e+001
dmax 1.331949e+001
dstep 1
go
stop
```

Figure 3.5.2: Example of GRWAVE input data file, data.inp

Where:

HTT: Effective height of the Transmitter (m)

HRR: Effective height of the Receiver (m)

IPOLRN: Polarization (1 for vertical and 2 for horizontal)
FREQ: Frequency in MHz
SIGMA, EPSLON: Condutivity (S/m) and permitivity of the terrain.
dmin: Distance (km) where the field needs to be calculated.
dmax and *dstep* are required but not used, and take values next to dmin.

With the command *'go'*, GRWAVE starts calculating the field strength, and after that, it returns to the input file, and when reading the command *'stop'*, it exits GRWAVE and returns the control to the Matlab command Windows. Units of Frequency, heights, conductivity and distance must be respected, because this is the way of calling GRWAVE. Before exit, GRWAVE store the results into a file, *data.out*, with the format shown in next figure.

```
******GRWAVE  (RELEASE 2 AT 23/10/1985 )*********
*****COPYRIGHT  (C)   GEC   PLC   1985   **********
CCIR Personal Computer Version 1989 Study Group 5 IWP5/1

GRWAVE COMPUTES FIELD STRENGTH-DISTANCE VARIATIONS
FOR A HOMOGENEOUS CURVED EARTH WITH EXPONENTIALLY
DECREASING REFRACTIVE INDEX


                    ATMOSPHERIC CONSTANTS
                        REFRACTIVITY =315.00  (N-UNITS)
                        SCALE HEIGHT = 7.350  KM

                    GROUND CONSTANTS
                        RELATIVE PERMITTIVITY =    14.000
                        CONDUCTIVITY =8.0000D-03  SIEMENS/METRE

                    VERTICAL POLARISATION

                    MINIMUM DISTANCE =    12.319  KILOMETRES
                    MAXIMUM DISTANCE =    13.319  KILOMETRES
                    DSTEP            =     1.000  KILOMETRES


                    FREQUENCY =     .909 MHZ

                    TRANSMITTER HEIGHT =    91.5  METRES
                    RECIEVER HEIGHT    =    98.8  METRES

                    DISTANCE      FIELD STRENGTH     BASIC TRANSMISSION LOSS
                       KM           DB(UV/M)              DB            (F)
                      12.32         82.89                53.64
                      13.32         81.97                54.56
                                                                        (R)
                      13.32           .00                  .00
Stop - Program terminated.
```

Figure 3.5.3: Example of GRWAVE output data file, data.out

This file has all the information of the configuration in the header, and the value desired is near the bottom of the file, so it means that, to be able to read the data desired, the file pointer must be located first at the beginning of the corresponding line. GRWAVE always print two values of field strength, but the only one needed is the first one. In the example below, data required should be 82.89 dB(uV/m).

Next figure shows an extract of the reading data instructions programmed at the grwave.m Matlab function.

```
% grwave system callback:
[ ergrw, res ] = system('grwave <data.inp >data.out');

% open data.out for reading:
fid = fopen('data.out','r');

% ndata = number of chars of the header:
ndata = 1169;

% put the pointer ndatos chars after the begining of the file:
fseek(fid, ndata ,'bof');

% reading row:
a = fscanf(fid, '%f %f %f', [3 1]);

% data required is the second element of vector a:
EdB = a(2,1);
```

Figure 3.5.4: Extract of instructions from grwave.m

After creating the input file with the configuration desired (not at the figure), the system calling to GRWAVE is done. Figure 3.5.4 is an extract of the real code, where all the operations with files are checked for errors.

After calling GRWAVE, the function opens the output file to read the data. Before reading the data, the file pointer is set at the beginning of the line desired. There are approximately 1169 chars at the header (having in account carrier returns), so the pointer is moved 1169 chars from the beginning of the file (*bof*) with the command *fseek*. This is indeed an approximation, and in the real function several validations of the position are done, because sometimes GRWAVE inserts some more characters, so an approximation is done.

When the pointer is correctly located, the function reads the file with the command *fscanf*, and returns in *'a'* a vector of tree elements in column format. The field strength should be the second one, that is the data returned by grwave.m function.

So, Matlab GRWAVE interface is a file (grwave.m) that creates the input file, calls GRWAVE, and reads the data of the output file. Dealing with text files decreases the simulation speed.

After programming grwave.m routine, it must be tested with ITU-R graphics to contrast both results and be able to check whether the function is correct. Several probes have been made, and results are given in the table below and an example in the next figure.

Frequency, σ, ε, distance	ITU-R Graphics	GRWAVE
20 MHz, σ = 1, ε = 80, distance = 100km	30 dB(uV/m)	30.54 dB(uV/m)
20 MHz, σ = 0.003, ε = 80, d = 100km	6 - 7 dB(uV/m)	7.06 dB(uV/m)
20 MHz, σ = 0.01, ε = 80, d = 100km	-1 or -2 dB(uV/m)	-1.23 dB(uV/m)
20 MHz, σ = 0.001, ε = 15, d = 100km	≅-8 dB(uV/m)	-7.44 dB(uV/m)
20 MHz, σ = 0.0001, ε = 15, d = 100km	≅-19 dB(uV/m)	-18.70 dB(uV/m)

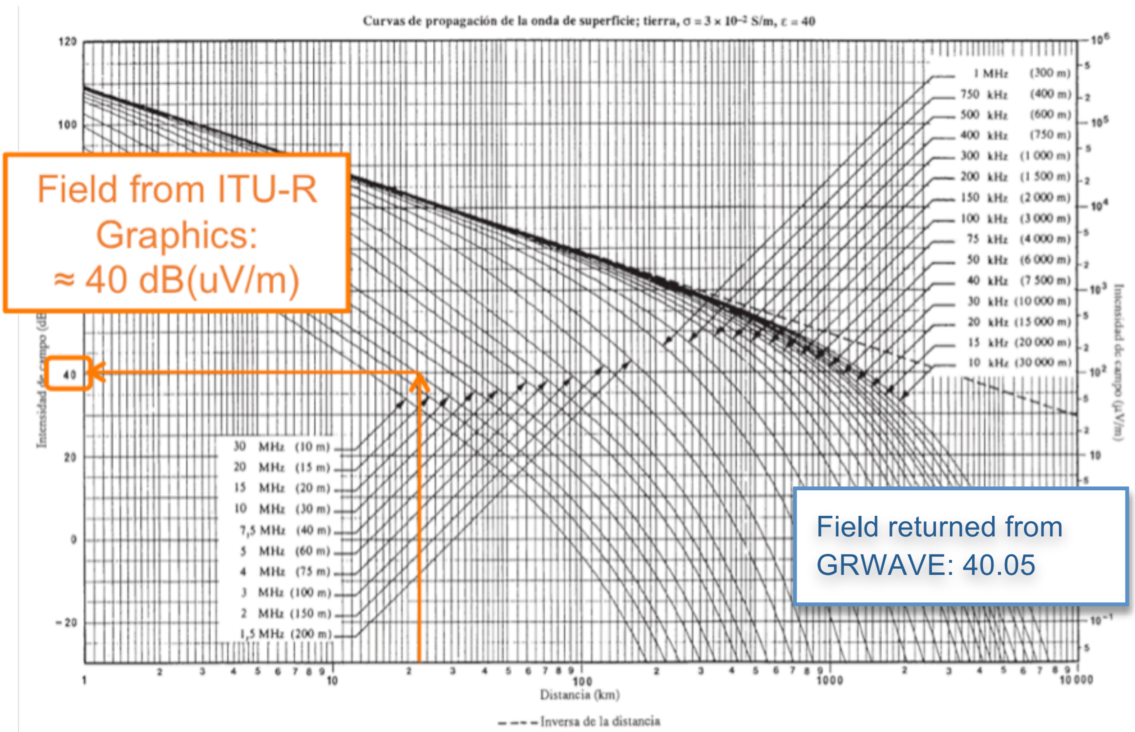


Figure 3.5.5: GRWAVE result vs. ITU-R graphics result

3.5.2 Millington Method

GRWAVE can only be called when having one conductivity between transmitter and receiver. This means that, when several conductivities appear, Millington method must be applied. This method requires the knowledge of the parts of the path with different conductivity. But not only conductivity data and paths are needed. Also, the data of antenna height to enter the ITU-R GRWAVE is referred to effective antenna height. Effective height is defined at the ITU-R P.368-9 as the height of the antenna over the mean height of the path between transmitter and receiver, so the entire path must be had in account.

So, before calling Millington method, two previous calculations must be done: effective heights of transmitter and receiver antenna, and the characteristics of each path of one single conductivity. To find out the conductivity paths, a line between transmitter and receiver must be done over the conductivity map. Using the mapping toolbox, it can be created this line with an interpolation to the 'nearest' conductivity, as shown in the figure.

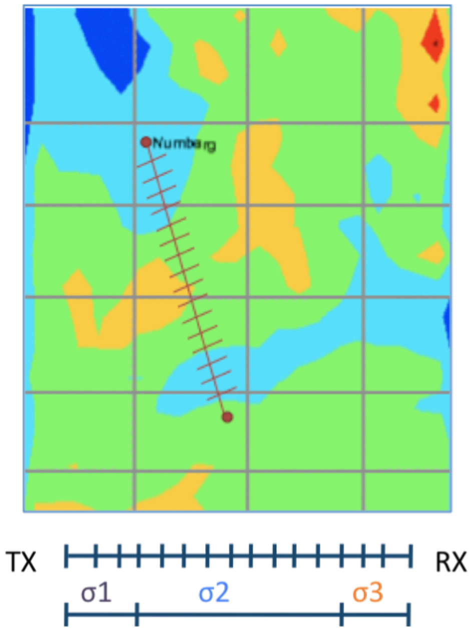


Figure 3.5.6: Acquiring the stretches of the path of the same conductivity

Once the path and all their conductivities are obtained, they must be grouped into stretches of the same conductivity. The receiver should be placed in each one of these points to calculate the Millington method described above. As effective height depends on the path, effective antenna height for receiver and transmitter should be different in every point when field is calculated.

So, for each point of the final path, effective height must be calculated for transmitter and receiver.

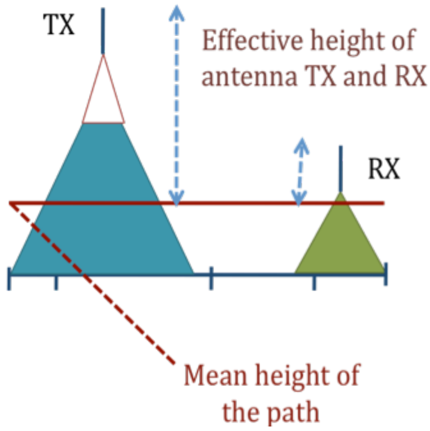


Figure 3.5.7: Calculation of the effective height

After calculated the paths, Millington method can be called. This function (*MillingtonH.m*) is responsible for requesting GRWAVE several times depending on the number of paths of different conductivity. It returns the value of field strength at the receiver, also normalized.

The detailed code is shown below. This function has as input parameters the system configuration (frequency, polarization, etc.), and several vectors with the terrain constants (MSIGMA, MEPSLON) and a vector of distances of each value to transmitter (MDIST).

When MillingtonH.m is called, it is supposed to be under ITU-R conditions, so the field strength can be calculated. To do so, the program first calculate the field in direction transmitter-to-receiver (forward), and, once it is calculated, it flips all the vectors to reverse them and do the calculations again to obtain the receiver-to-transmitter field strength (back). After obtaining both values, the arithmetic mean is made and the total field is returned.

```
function Et = MillingtonH( MIPOL,MFREQ,MEPSLON,MSIGMA,MDIST,MHTXef, h )

% EdB: 2-element vector:[ Ef Eb ]
EdB     = zeros(1,2);

% distances for non-homogeneous paths
d       = MDIST;

% terrain vector constraints at the path
sig     = MSIGMA;
epslon = MEPSLON;

% Effective height of the terrain in sense tx -> rx
hh      = h(1,:);

% this loop will calculate field Ef and Eb
for j = 1:1:2

    % setup value
    EdB(j)  = 0;

    % to calculate the lengths of the homogeneous paths, i do the
    % cumulative sum:
    d       = cumsum( d );

    % millington:
    for i = 1:1:( length(d)-1 )
        EdB(j)  = EdB(j)  + grwave( MIPOL,MFREQ,epslon(i),sig(i),d(i),MHTXef(j),hh(i)  );
        EdB(j)  = EdB(j)  - grwave( MIPOL,MFREQ,epslon(i+1),sig(i+1),d(i),MHTXef(j),hh(i));
    end


    % adding the last element of millington outside the loop
    EdB(j) = EdB(j) + grwave( MIPOL,MFREQ,epslon(length(d)),sig(length(d)),d(length(d)),MHTXef(j),hh(length(d)) );

    % to be able to calculate field strength in sense rx -> tx, i flip the
    % vectors of distance and terrain constraints
    d      = flipdim( MDIST,   1 );
    sig    = flipdim( MSIGMA,  1 );
    epslon = flipdim( MEPSLON,1 );

    % Effective height of the terrain in sense rx -> tx
    hh = h(2,:);

end

% calculating total field strength:
Et = ( EdB(1) + EdB(2) )/2;


end % del function
```

Figure 3.5.8: MillingtonH.m source code

As the field returned is a result of several callings to GRWAVE, it should be also normalized, so the correction factor must be later applied.

To check if Millington was working well, several test have been made. In the test, normalized field strength was calculated, with no height data in account, so the Matlab function should return the same field than the graphics and Millington manual method should do.

Here are two of the tests done, one for the highest side of the frequency band (30 MHz) and the other one for an approximation of the lower extreme of the frequency band (1Mhz):

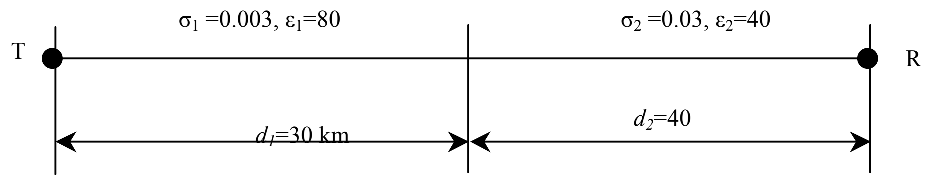


Figure 3.5.9: Millington example for testing Matlab function

Using ITU-R Graphics, for vertical polarization at 30 MHz, the highest frequency available:

Ef = E1(d1) – E2(d1) + E2(d1+d2) = 20

E1(d1) = 30

E2(d1) = 25

E2(d1+d2) = 15

Eb = E2(d2) – E1(d2) + E1(d1+d2) = 16

E2(d2) = 34

E1(d2) = 38

E1(d1+d2) = 20

Et = (Ef + Eb) /2 = 18 dB(uV/m)

By Millington programmed Matlab function, the field strength returned is, directly: *Et = 17.70 dB(uV/m)* approximately equal to the field strength calculated manually with two graphics.

The second test, using ITU-R Graphics, for vertical polarization at 1 MHz, low frequencies:

$Ef = E1(d1) - E2(d1) + E2(d1+d2) = 58$

$E1(d1) = 64$

$E2(d1) = 77$

$E2(d1+d2) = 71$

$Eb = E2(d2) - E1(d2) + E1(d1+d2) = 66$

$E2(d2) = 81$

$E1(d2) = 70$

$E1(d1+d2) = 55$

$Et = (Ef + Eb) /2 = 62\ dB(uV/m)$

By Millington, the field strength returned is, directly: *Et = 62.14 dB(uV/m)* approximately equal to the field strength calculated manually with two graphics.

3.5.3 Elevation and conductivity database

Due to the nature of the Groundwave propagation, it is needed to know the terrain conductivity and the antenna height, and so, digital conductivity and elevation or topography databases are required. Nowadays there is no digital High Resolution Conductivity Database available. However, there is available a digital Global Elevation Terrain database with a resolution of one km available at NOAA's Project Website [GLOBE].

GLOBE is an atlas elevation database. World data are separated into several 'tiles' to be able to manage them, each tile representing an area of the world. The limits of latitude and longitude are specified into headers text files that must be downloaded with the elevation tiles.

To deal with GLOBE database and being capable of extract a region of the world even if it is separated in tiles, MATLAB Mapping Toolbox [MATLAB] can be used with the function 'globedem'.

```
[ mapg, mapglegend ] = globedem('c:\globe', ScaleFactor, Latlim, Lonlim );
```

This command specifies Matlab:

'c:\globe': The directory where the files of GLOBE are stored (both elevation tiles and headers).

ScaleFactor: The Scale Factor, that is, the resolution desired (1 means maximum resolution, 1 km between points of the matrix returned).

Latlim and Lonlim: These two variables specify the limits of latitude and longitude of the region desired.

Data returned are:
mapg: The map containing the elevation data of the area selected by Latlim and Lonlim.
mapglegend: The reference vector or maplegend of all map, which will be specified in the Mapping Toolbox section.

GLOBE returns the elevation of the points over the sea, and the sea marked with a NaN. This must be changed inside the application to assign sea a zero elevation. An example of the maps returned by GLOBE for the area of Nuremberg is shown in next figure.

Example of the command:

```
ScaleFactor = 1;
Latlim  = [ 48       50 ];
Lonlim = [ 10.5 12.5 ] ;
[ mapg, mapglegend ] = globedem('c:\globe', ScaleFactor, Latlim, Lonlim );
worldmap(Latlim, Lonlim);
contourfm(mapg, mapglegend);
colormap(pink);
```

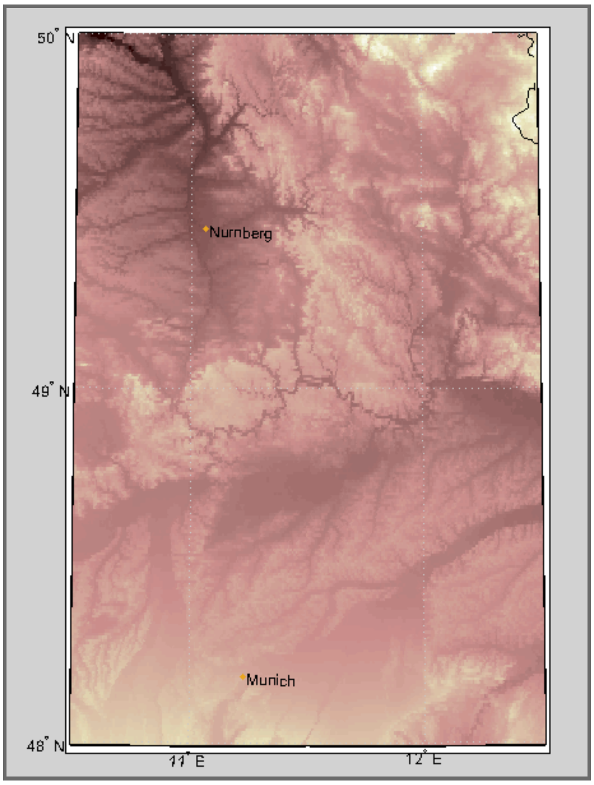


Figure 3.5.10: GLOBE elevation data for Nurnberg area

There is no digital <u>conductivity</u> database in high resolution. There is a digital conductivity database coming from a vegetation database, with poor resolution and not having in account rivers and lakes (with good conductivity and so, very important). However, ITU-R provides a detailed atlas of conductivities in its ITU-R P.832-2 Recommendation [ITU-R P.832-2]. This atlas cover almost all the world except Germany, so, for this project, high-resolution conductivity database must be created also.

The conductivity data of Germany terrain is fully documented at Internet [CONDUCT]. Here the image containing the map of the conductivities can be downloaded, but this map yields several problems: It has no latitude and longitude references, and the image has poor resolution, so it has to be pre-processed.

The first step is editing the map with one image editor, and cleans the pixels to obtain pure colours for each zone of conductivity. RGB code of each zone is assigned to one conductivity, establishing the relationship between colours and conductivities.

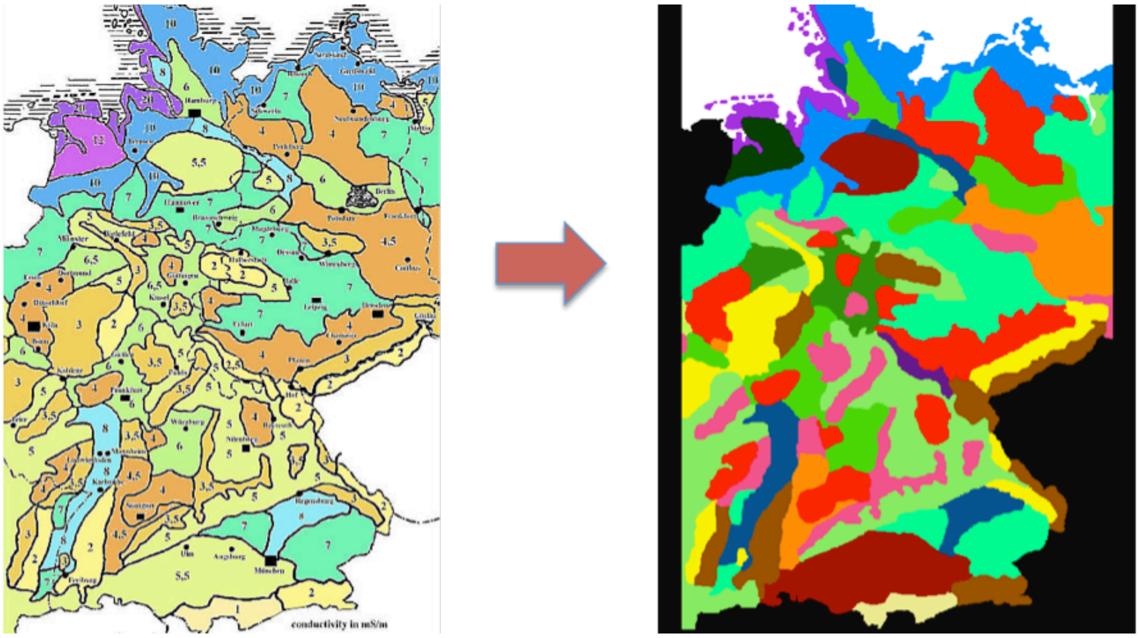


Figure 3.5.11: Cleaning the image with an image editor.

Sea has been assigned to white colour, while non-defined areas remain in black. The second step is obtaining the latitude and longitude limits using Germany image from ITU-R P.832-2 Recommendation. So to achieve that, with the image editor, a new image is made with two layers: the first one (bottom) the ITU-R image from Germany, containing the latitude and longitude references, and the second layer containing the coloured conductivity map. In this way, conductivity map is adjusted to ITU-R map and it is trimmed following the guides of the ITU-R Layer, and it is achieved a new image with conductivity data and latitude and the longitude limits already set.

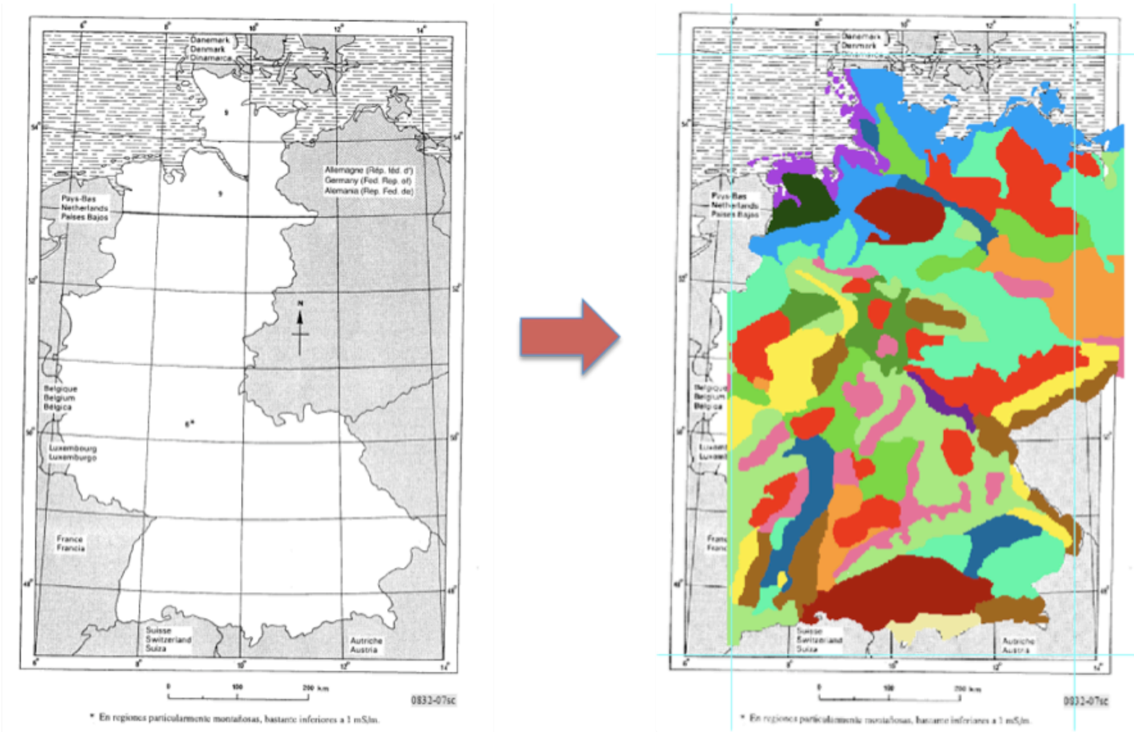


Figure 3.5.12: Setting latitude and longitude limits.

Now we have the image cut with references known, the third step is loading the image into Matlab and converting the image into a map format. Matlab can load images in different formats. PNG format has been chosen because of the high definition of its pixels and colours. It can not be JPG format because of the fading of the colours. To be able to convert colours to conductivities, pure colours are needed.

With the instruction *imread('germany.png')*, the image created (germany.png) is loaded as a matrix of three dimensions or layers: Red, Green and Blue, corresponding to RGB Code. With the matrix loaded, a simple Matlab script would find the index of the matrix corresponding to the known Photoshop colours and assign them to their conductivity.

Next figures show extracts of the source code used to create de database from the png format.

```
% defining latlim and lonlim
latlim = [ 47  55 ];
lonlim = [ 6   14 ];

% loading the image of germany:
x = imread('germany.png');

% setting up map as a zeros matrix
map = zeros(size(x,1),size(x,2));
```

Figure 3.5.13: Converting image to conductivity database (I).

The instruction *'imread'* loads the image in brackets to Matlab, in the format described above. This means that x will be a matrix NxMx3, being each of the three dimensions a RGB code, correspondingly. The variable 'map' is then create to a zero matrix with the same size than one layer of x, so it will be a NxM matrix.

Once the image is loaded, the script looks for the elements having a specific code. This search is made with instruction 'find' of Matab, and the index returned are stored into several vectors.

For example, if having:

a = find((R==3) & (G == 255) & (B==123) s);

Will store in vector a all the indexes of a matrix (expressed as elements of a very big vector) so, that indexes can be selected at variable map in this way:

map(a) = 5; to assign all the elements of 'map' at the positions indicated by a the value 5.

```
% finding positions inside x for RGB codes:

uno     = find( ( x(:,:,1) == 164 ) & ( x(:,:,2) == 15  ) & ( x(:,:,3) == 225 ) );
dos     = find( ( x(:,:,1) == 0   ) & ( x(:,:,2) == 143 ) & ( x(:,:,3) == 250 ) );
tres    = find( ( x(:,:,1) == 21  ) & ( x(:,:,2) == 66  ) & ( x(:,:,3) == 3   ) );
cuatro  = find( ( x(:,:,1) == 77  ) & ( x(:,:,2) == 215 ) & ( x(:,:,3) == 22  ) );
cinco   = find( ( x(:,:,1) == 252 ) & ( x(:,:,2) == 5   ) & ( x(:,:,3) == 5   ) );
seis    = find( ( x(:,:,1) == 0   ) & ( x(:,:,2) == 255 ) & ( x(:,:,3) == 146 ) );
siete   = find( ( x(:,:,1) == 137 ) & ( x(:,:,2) == 234 ) & ( x(:,:,3) == 98  ) );
ocho    = find( ( x(:,:,1) == 164 ) & ( x(:,:,2) == 1   ) & ( x(:,:,3) == 1   ) );
nueve   = find( ( x(:,:,1) == 10  ) & ( x(:,:,2) == 87  ) & ( x(:,:,3) == 144 ) );
diez    = find( ( x(:,:,1) == 255 ) & ( x(:,:,2) == 140 ) & ( x(:,:,3) == 19  ) );
once    = find( ( x(:,:,1) == 242 ) & ( x(:,:,2) == 85  ) & ( x(:,:,3) == 138 ) );
doce    = find( ( x(:,:,1) == 250 ) & ( x(:,:,2) == 241 ) & ( x(:,:,3) == 3   ) );
trece   = find( ( x(:,:,1) == 153 ) & ( x(:,:,2) == 84  ) & ( x(:,:,3) == 9   ) );
catorce= find( ( x(:,:,1) == 237 ) & ( x(:,:,2) == 235 ) & ( x(:,:,3) == 143 ) );
quince  = find( ( x(:,:,1) == 102 ) & ( x(:,:,2) == 8   ) & ( x(:,:,3) == 141 ) );
diezsei= find( ( x(:,:,1) == 54  ) & ( x(:,:,2) == 147 ) & ( x(:,:,3) == 17  ) );

negro   = find( (x(:,:,1)==0  ) & (x(:,:,2)==0  ) & (x(:,:,3)==0  ) );
blanco = find( (x(:,:,1)==255) & (x(:,:,2)==255) & (x(:,:,3)==255) );
```

Figure 3.5.14: Converting image to conductivity database (II)

Now we have the position inside the matrix founded for each colour, the colours must be assigned to one conductivity. This is made by the next set of instructions:

```
% assign conductivities to the colours
map(negro)    = NaN;      % black: non-defined conductivity data
map(blanco)   = 5000e-3;  % white: sea

map(uno)      = 20e-3;
map(dos)      = 10e-3;
map(tres)     = 13e-3;
map(cuatro)   = 6e-3;
map(cinco)    = 4e-3;
map(seis)     = 7e-3;
map(siete)    = 5e-3;
map(ocho)     = 5.5e-3;
map(nueve)    = 8e-3;
map(diez)     = 4.5e-3;
map(once)     = 3.5e-3;
map(doce)     = 3e-3;
map(trece)    = 2e-3;
map(catorce)  = 1e-3;
map(quince)   = 2.5e-3;
map(diezsei)  = 6.5e-3;
```

Figure 3.5.15: Converting image to conductivity database (II)

Permittivity is also needed for this project because it has strong influence on the terrain properties. It is no needed having another matrix of the same dimensions of 'map' with the parameters of the permittivity. There is only one permittivity for each conductivity, and conductivity values are known for a specific map, so permittivity can be stored in a matrix of two rows, one being the conductivities (sigma) of the map and the other the corresponding permittivity (epsilon). This matrix is called *'sig_ep'* and it exists in every conductivity database file.

```
% updating conductivity-permitivity relationship matrix:
sig_ep = [  5000e-3 81;
            20e-3   17;
            10e-3   14;
            13e-3   15;
            6e-3    13;
            4e-3    12;
            7e-3    13;
            5e-3    13;
            5.5e-3  13;
            8e-3    14;
            4.5e-3  12;
            3.5e-3  11;
            3e-3    11;
            2e-3    10;
            1e-3    5;
            2.5e-3  10;
            6.5e-3  13;
            NaN     NaN ];
```

Figure 3.5.16: Converting image to conductivity database. Sig_ep matrix (III)

Not all the conductivities have an exact permittivity assigned. In this case, there is needed and approximation, so an interpolation between the nearest must be done.

There is a four and very important step: calculating the **maplegend** of our map.

Dealing with maps in Matlab requires a reference vector for every map: the *maplegend* or *refvec*. This vector gives information about the resolution in degrees of the map, and the latitude and longitude of the upper left element of the matrix, as detailed in next chapters. The procedure to achieve a maplegend from a map coming from an image is quite difficult and inaccurate. To avoid inaccuracies, the maplegend will be taken the equivalent map of GLOBE, and, to do so, a GLOBE map should be created for the same limits of latitude and longitude. The maplegend of GLOBE will be created in calling to GLOBEDEM instruction. After that, conductivity map is resized to the GLOBE map. In this way, both maplegends should be the same, and the obtaining of the maplegend of the conductivity map is done.

As conductivity database has been created from GLOBE, and both have same resolution, this means that the resolution should be also 1Km with Scale Factor of 1, accurate enough to groundwave propagation.

The same procedure can be followed to complete the database with other countries conductivities defined in the ITU-R Recommendation. In this project, due to time restrictions, only two countries have been digitalized: Germany and South Korea. Resulting conductivity maps are shown in next figures:

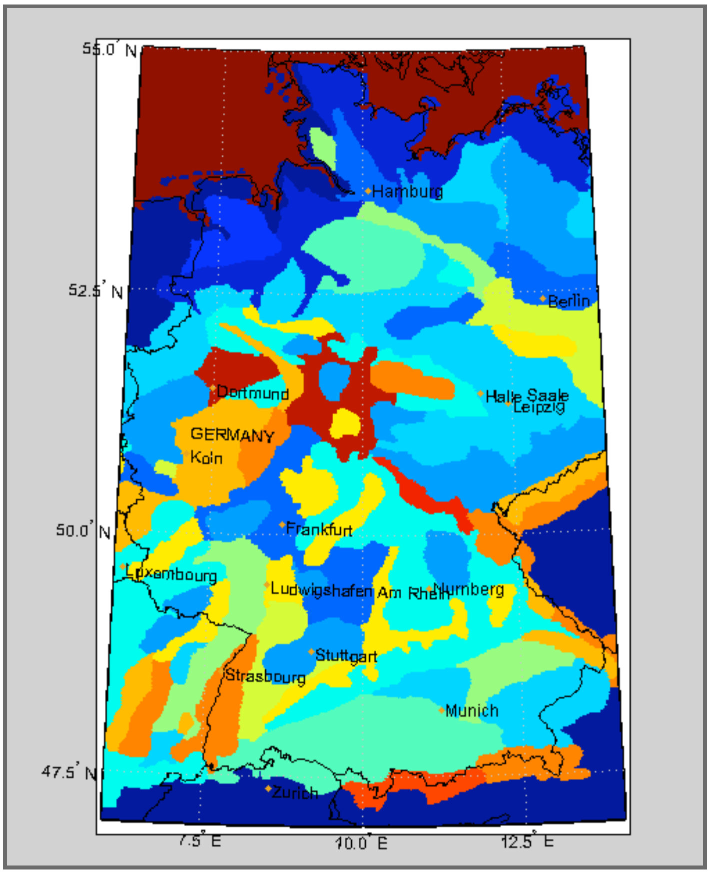


Figure 3.5.17: High resolution Germany conductivity database.

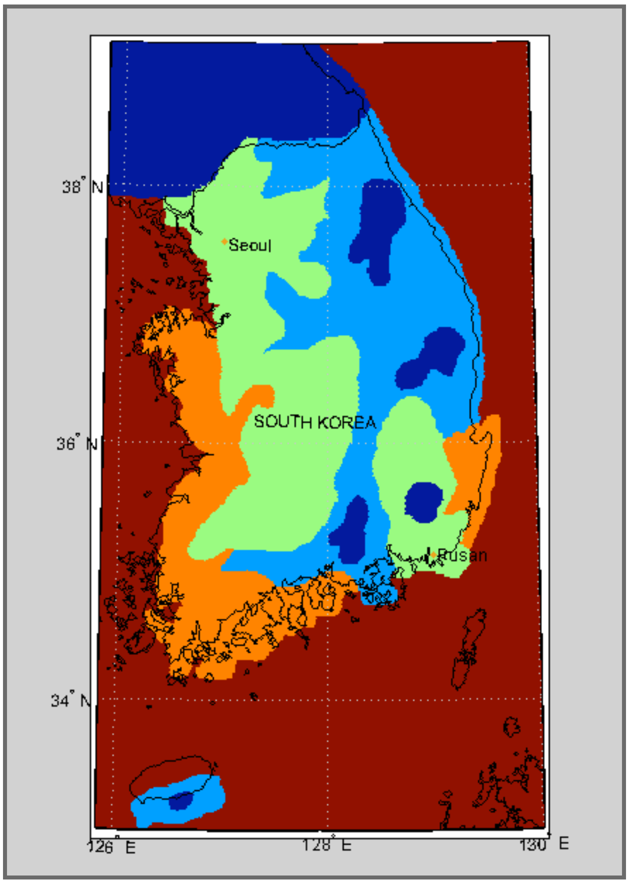


Figure 3.5.18: High resolution South Korea conductivity database.

They do not fit exactly to the maps plotted by Matlab because the source of the images is different than the one in Matlab. To obtain an exact database by this method, Matlab maps, Germany images and ITU-R images should fit exactly, and that is very difficult to achieve.

These maps have exact limits of latitude and longitude. Out of this range, they can not be used, and it must be use the low resolution database instead. Limits for these databases are:

Germany: Latitude from 47º to 55º, and Longitude from 6º to 14º.

South Korea: Latitude from 33º to 39º, and Longitude form 126º to 130º.

3.5.4 Code errors returned

The application exits when certain errors appear. These errors are not produced by an application malfunction, and they are the result of checking the input configuration of the system. The input data are verified at the User Interface, but also at the beginning of some functions. This has been made in this way to make the functions independent of the guided user interface, and, in this way, be able to improve and add functionalities to it in the future.

So, errors returned are next:

- **Code Error '0':** Non-error code. The returning of a zero means that the simulation has finished correctly.

- **Code Error '1':** Error in Frequencies. This error will appear when calling Millington function with a frequency out of the range of the ITU-R, that is, with a frequency lower than 0.1 MHz or higher than 30 MHz.

- **Code Error '2':** Error in Elevation. This error will appear when, checking paths to call Millington function, it is detected some possible elevation that does not match with ITU-R maximum available.

- **Code Error '3':** Error in the conductivities of the path between transmitter and receiver. Due to the nature of the conductivity high-resolution database, it is possible to have in the path a non-defined value of conductivity. In this case, two options were possible: the first one should be ignore that intermediate points and keep on calculating the field strength with the other points with conductivity defined, and the second option should be do not calculate the field strength at all. In the first case, Millington's Method and GRWAVE should give a value, but, since there are intermediate points where there is no information of conductivity, the result is not reliable and it yields to a very inaccurate result. To avoid inaccuracies and reliabilities, the second option has been chosen, so in these cases, field strength will not be calculated.

- **Code Error '4':** Error in Map. Application deals with two different types of databases: high-resolution and low-resolution database. When choosing low-resolution one, the user can choose any area of the world desired to calculate, for example, the coverage, with no problem, because any part of the world can be trimmed from a worldwide map. However, high resolution databases have exact limits of latitude and longitude and, if the user choose a region, a receiver or a transmitter falling out of this range, the application will not be able to calculate the field strength with the database desired by user, and so on, it will exit.

3.5.5 Mapping Toolbox

Matlab Mapping Toolbox [MATLAB] is a huge set of functions to allow the management and representation of maps. A map in Matlab is a NxM matrix with a reference vector, called *maplegend* or *refvec*.

3.5.5.1 Common variables

This maplegend is very important and provides next information, explained using as an example the maplegend of the Germany's conductivity database:

maplegend = [120 55 6];

The first element of maplegend gives the number of elements (cells) per grade. In this case, horizontal (longitude) resolution should be 120 columns per degree, while latitude resolution should be 120 rows per degree.

The second element gives the Latitude in degrees of the upper left corner of the map, and the third element gives the Longitude of the upper left corner of the map. This is graphically shown in the next figure.

Matlab mapping toolbox versions (until "Release 2007b" version) take maps with the same resolution in latitude and in longitude, so the first element of the maplegend resolves the resolution in both dimensions (this not means square matrix).

A map without maplegend will be interpreted as a simple matrix containing simple data, never as a map. But when working with maps, there are three more variables very frequently used: LatLim, that is a 2-elements vector with latitude limits of the map, Lonlim, that is the 2-elements vector with longitude limits of the map, and ScaleFactor, value related with the resolution between 2 maps.

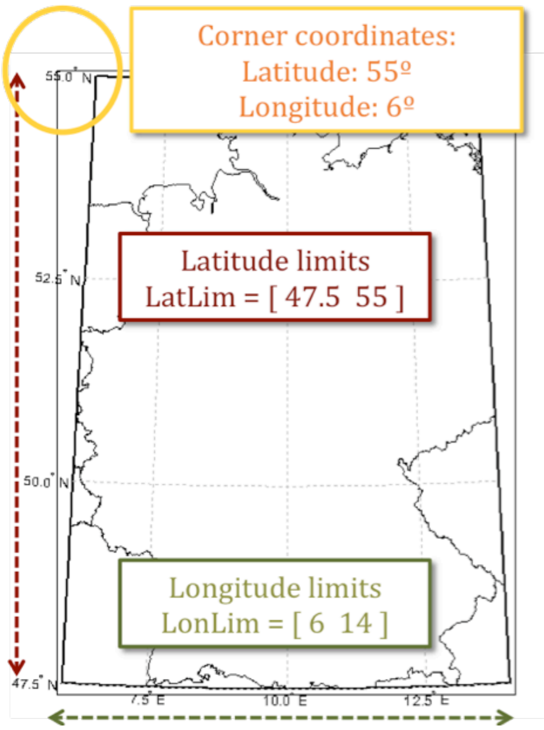


Figure 3.5.19: Graphical example of the map variables

3.5.5.2 Resolution of a Map

Another important question is how to calculate the resolution in degrees or kilometres of one map. If the map has been obtained from GLOBE to maximum resolution, then, by the characteristics of GLOBE, it is known that the resolution is 1 km and 120 cells per degree.

To calculate the resolution of any map, the maplegend is the only element needed to calculate the resolution in degrees or in Km of a map. So on, the resolution in degrees can be calculated as:

$$\text{Resolution } (^{o}) = 1/\text{maplegend}(1) \qquad (3.5.5.2.1)$$

And the resolution in Km can be calculated using Mapping Toolbox as:

$$\text{Resolution (Km)} = \text{deg2km(Resolution}(^{o})\text{)} \qquad (3.5.5.2.2)$$

Functions referring to maps used to have a common header structure with the variables seen before. In this project, most used dealing with maps were:

- Globedem: Load GLOBE maps from a directory.
- Resizem: Resize a map with a scale factor or to a size desired.
- Mapprofile: Given two points inside a map, create the interpolation line joining them, with distances, latitudes and longitudes of each them.
- Maptrims: Trims an area from a bigger map.
- Setltln: Given a position in a matrix by its row and column, this function returns its latitude and longitude.
- Setpostn: Given a latitude and longitude, returns the position in the matrix as row and column.

3.5.5.3 Most used functions

Some examples of the most important functions for this application are:

a. Mapprofile: [z, d, lat, lon] = mapprofile(map,maplegend, Lat, Lon, method)

This useful function creates the interpolated line between a receiver and a transmitter to calculate the paths for Millington. Both Lat and Lon are 2-elements vector containing the information of both latitude and longitude of the two point to join with a interpolated line. In this project, these two points used to be the transmitter and the receiver, so these two vectors used to have the sintaxis:

Lat = [latTX latRX];

Lon = [lonTX lonRX];

Method is the interpolation method to be used, that can be nearest, bilinear or bicubic. In case of conductivities, values are fixed, so 'nearest' is the interpolation needed. In case of elevation profiles, it should be more accurate interpolate the value of height at one point with another method. Bilinear method has been chosen in this case.

The values returned are:

z: A vector of interpolated values between transmitter and receiver. The origin of the data contained in this vector (conductivities, elevations, etc.) depends on the map over this function is applied. If the map is elevation map, z will be an elevation vector.

d: Vector of distances of every point of z to the first point located in vectors Lat and Lon, in this case, the transmitter.

lat and lon: Similar to d, but containing the latitude and longitude over the map of each element of z.

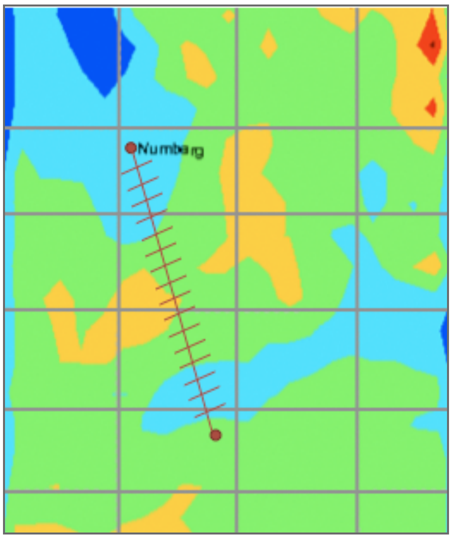


Figure 3.5.20: Example of mapprofile

b. **Resizem: This function has two different sintaxis, depending on the data available for the resize:**

submap = RESIZEM(map,[r c],'method')

[submap,sublegend] = RESIZEM(map,SF,maplegend,'method')

This function is used to increase or decrease the number of points, and so on, the resolution of the map. The new size can be provided for the elements of row and columns desired ([r c]) or by giving a Scale Factor. For example, a Scalefactor = 0.5 means that should be taken 1 of each two points of the original map, for example.

Interpolation method can be the same than mapprofile.

This is the function used to reduce the grid of field strength from the high-resolution conductivity map.

The variable returned is the submap created, what is a map with the same latlim and lonlim than the original, but with different number of points, and so different resolution.

As the resolution in points (and degrees) is different, the first maplegend element of variable submap will be different than the maplegend of map. This is why it is very recommendable calling resizem in the second format to return the new sublegend (or submap-legend).

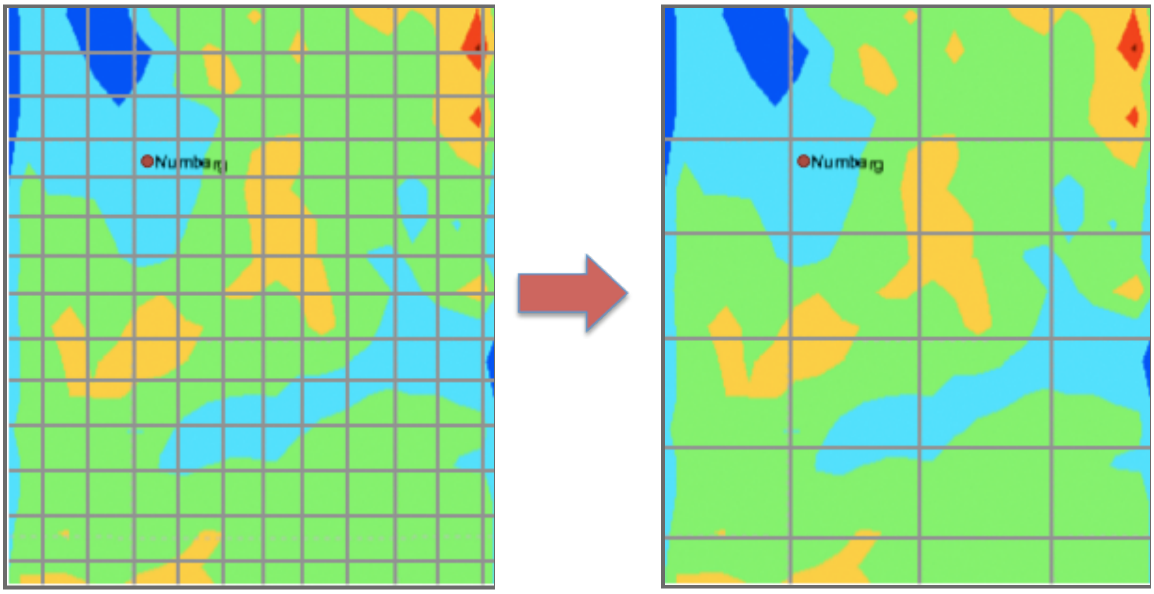


Figure 3.5.21: Example of resizem

c. Maptrims: [submap, sublegend] = maptrims(map, maplegend, Latlim, Lonlim)

This function, given a map, a maplegend and a region limited by its latitude and longitude limits, trims a map to extract a submap of the area defined.

When working with conductivity database, all Germany map is loaded, but, generally, only a small area is needed. This instruction extracts the area desired from the original map, returning the submap with its reference vector, sublegend.

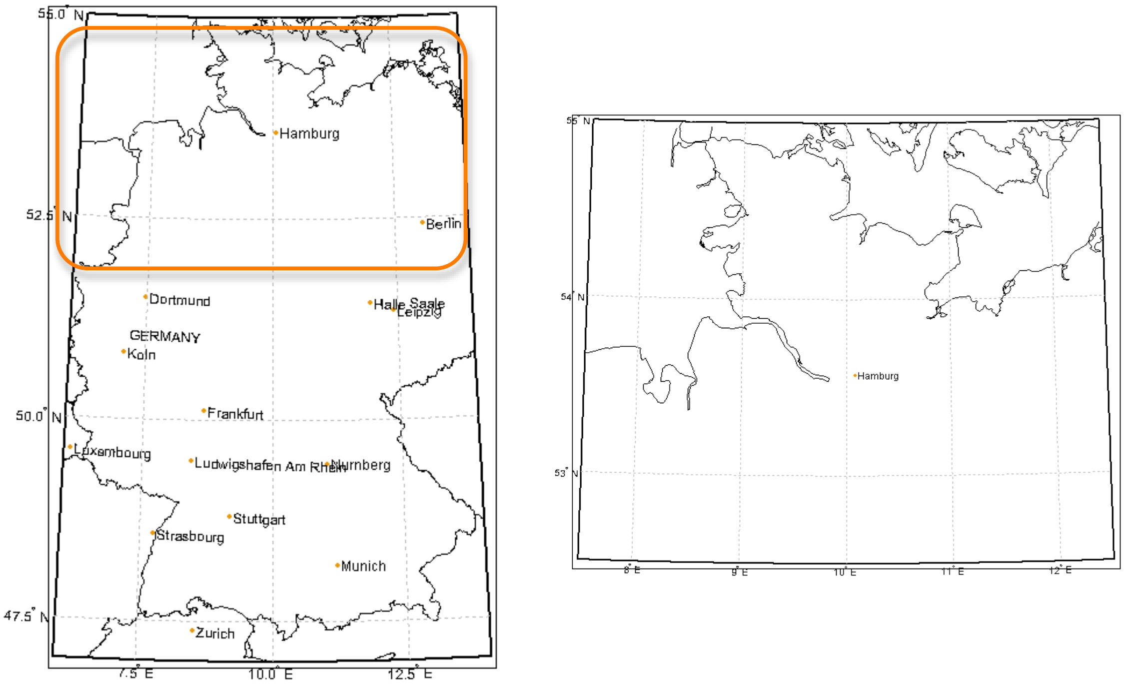


Figure 3.5.22: Example of maptrims

d. Plotting maps functions

To plot the maps needed in this project, next functions were used:

- Worldmap: Creates de new figure with the axes. Also paints the main cities with their name.
- Contourfm: Plots de data into the figure making grouping the data into contours.
- Scaleruler: Plots the scale used to measure distances in a map.
- Textm: Write strings into a map, given a latitude and longitude.
- Plotm: Plots an element into a map, with its latitude and longitude.

e. Unit conversion functions and others:

Mapping Toolbox also has several functions to convert from one format to another, as:

- Deg2km: Converts degrees to km.
- Str2deg: Converts a string 00d00m00sN (for example) into latitude in degrees.
- Distance: Measures distance in degrees from two elements given by their latitude and longitude.
- Time2str: Converts timing format to a string.
- Etime: Calculates the difference between two time vectors in seconds.

3.5.5.4 Application function LOADMAP

The application has to load several maps. Most of the requests to maps are done in the function loadmap, so here will be explained an extraction of its code to show how to deal with maps.

In the first instance, database must be loaded. The database selected by user is stored in the variable Country, which can take the values of Germany, Korea or other. In the two first cases, high-resolution databases will be loaded. In any other case, low-resolution will be the one selected.
So, loadmap, first check, with a case sentence, the value of the variable 'Country' to load one database or the other, as shown in the figure below.

```
% loading the conductivity map selected:
switch lower( Country )
    case 'germany'
        load germany.mat;
    case 'korea'
        load korea.mat;
    otherwise
        load conduct.mat;
end

% having in 'map' the global database, this instruction trims the range of
% latitude and longitude required and return results overwritting map and
% maplegend.
[ map, maplegend ] = maptrims( map, maplegend, Latlim,Lonlim );

% if ScaleFactor is lower than one, matrix must be reduced:
[ map, maplegend ] = resizem( map, ScaleFactor, maplegend );

% load the elevation map at maximum resolution (scalefactor=1):
[ mapg, mapglegend ] = globedem('c:\globe', 1, Latlim, Lonlim );

% elevation of the sea is changed form NaN to 0:
mapg( find( isnan( mapg ) ) ) = 0;

% fit the size of the elevation map to be the same than the conductivity
% map:
mapg = resizem( mapg, size(map), 'bilinear' );
```

Figure 3.5.23: loadmap.m partial code

After selecting database, it has to be trimmed to select only the region specified by range limited in latlim and lonlim. If the high-resolution database is selected and latitude and longitude ranges over several degrees, it is possible to have a huge matrix, so it can be resized by a scale factor if its value is lower than one.

At this point, conductivity database is already done.

To load the elevation database from GLOBE (GLOBE files must be recorded into the path ‘c:\globe’), the application makes the calling to ‘globedem’, with the same latitude and longitude limits than for the conductivity map.

The result is stored into a matrix called mapg (map from Globe) and with its maplegend (mapglegend).

GLOBE database marks the sea level as a NaN to differentiate from the rest of the elevations. We need to work with entire numbers, so it is needed to change the NaN by, for example, a zero. This is made with the instruction find to locate de index having a NaN.

To be accurate, it is needed that elevation map and conductivity map have the same resolution, rows and columns. So this is why the last instruction is included: to resize GLOBE map to the same size than the conductivity map.

3.6 Practical examples

The Groundwave propagation is very important in the lowest part of the frequency band and in vertical polarization. To demonstrate those facts, lets compare the coverage results in both cases with a practical example.

At the first instance, the coverage for low and high frequencies is compared. The figures below show that at low frequencies, the effect of the conductivity and/or the elevation of the terrain and antennas are negligible. But, as the frequency is increased, both effects turn important and coverage is reduced dramatically.

As the colours of the map are relative, there is attached the colour bar to indicate the field strength assigned to each colour.

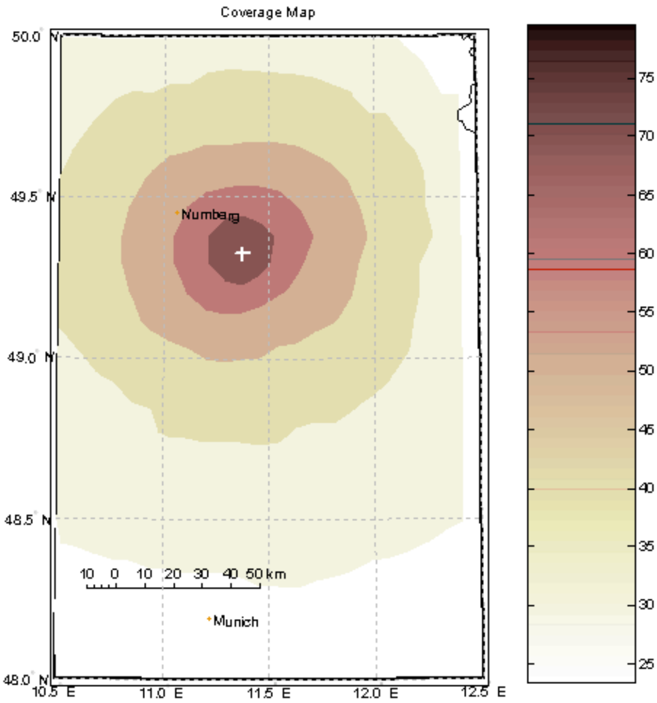


Figure 3.6.1: Example of coverage at 0.909 MHz, Vertical polarization

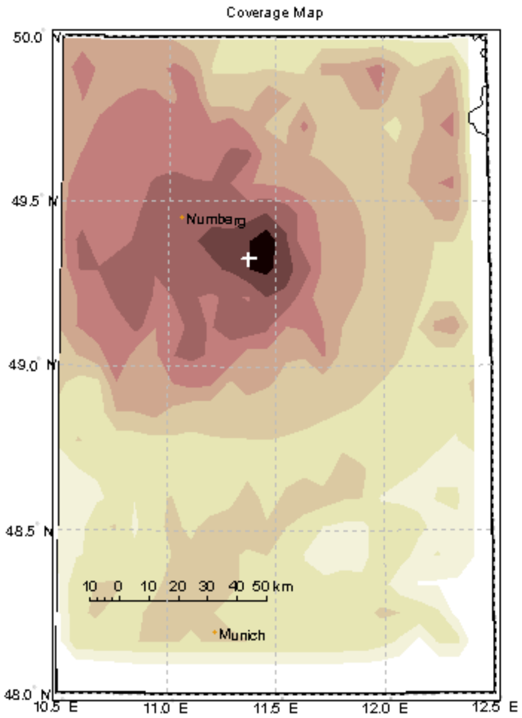


Figure 3.6.2: Example of coverage at 24 MHz, Vertical polarization

The second comparison is between both vertical and horizontal polarization. As it can be seen in the colour bar, the horizontal polarization decreases dramatically at little distance from transmitter.

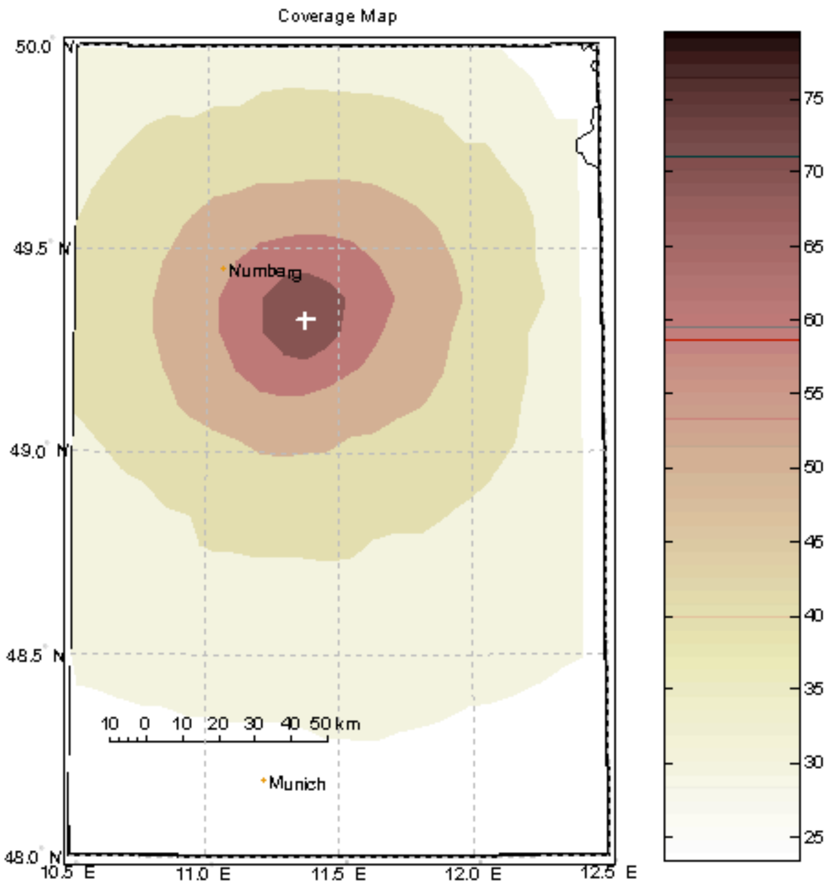


Figure 3.6.3: Example of coverage at 0.909 MHz, Vertical polarization

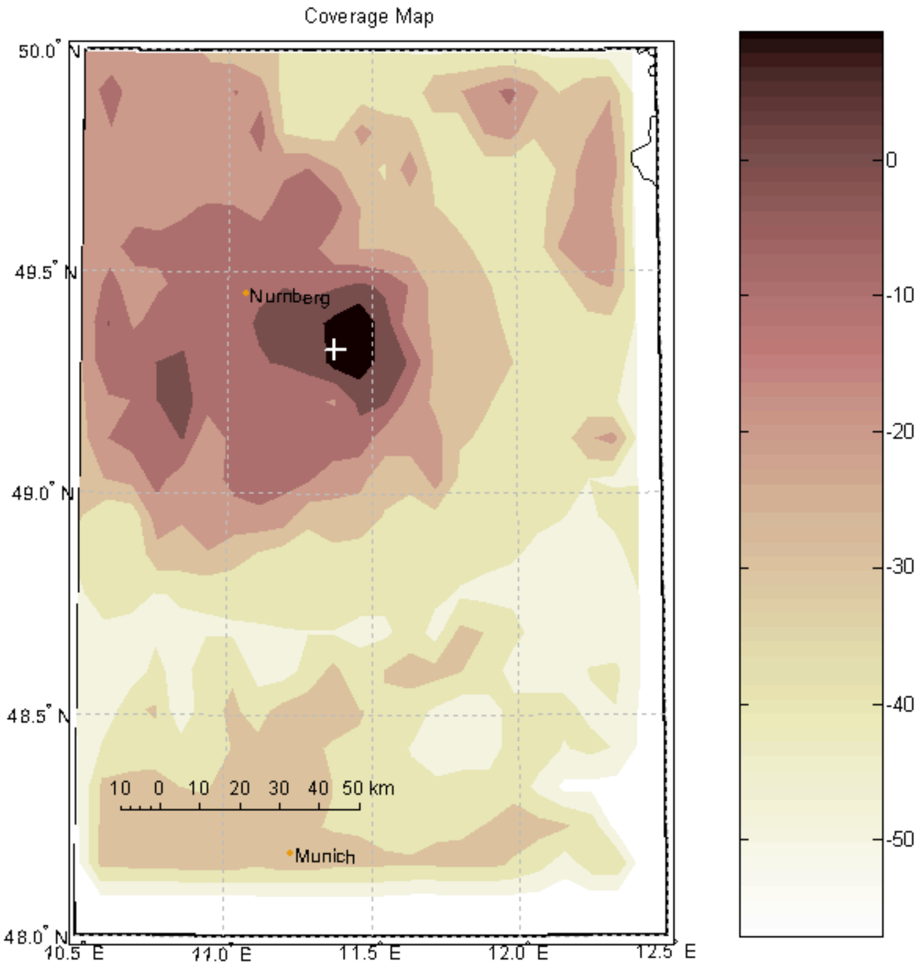


Figure 3.6.4: Example of coverage at 0.909 MHz, Horizontal polarization

4 Conclusions

The software developed fits with all the objectives:

- Matlab interface for GRWAVE has been done.
- Fitting to the ITU-R Recommendations.
    - With homogeneous paths
    - With non-homogeneous paths and Millington method
    - With frequency and elevation ITU-R limits.
- Calculate areas of coverage fields due to a single transmitter operating in a site.
- Calculate field strength at single points (receivers) due to one or several transmitters.
- Checking in case of several transmitters if there should be ISI at one point or not.
- Printing data at the screen when needed.
- A graphical interface make the application easy-to-use.
- Saving data at binary .mat files to be able to load them after the simulation is done in Matlab to have a data post-process.

Radioelectrical conclusions obtained from the data observed from several simulations are:

- Vertical polarization is stronger than horizontal polarization in every path and distance between transmitter and receiver.
- At low frequencies elevation and conductivity terrain is negligible and coverage diagrams are very rounded.
- At high frequencies conductivity and elevation affect strongly to the Groundwave propagation, and distance of coverage (and so, field strength) is reduced dramatically in comparison to low frequencies.
- Antenna elevation has its influence over the field calculated, so the transmitter site must be the highest site inside the area of coverage.

5 Future guidelines

This project could be expanded in several ways:

- Adding more countries to the high-resolution conductivity database. This point was not made at this Project due to time restrictions.
- Matlab is optimized to work with matrix. Dealing with files at the main function, GRWAVE decreases dramatically the application speed. This could be solved partially modifying GRWAVE source code in Fortran, and making a MEX file to be able to work with a binary DLL at Matlab, instead of working with files.
- The application has been developed in Matlab, and, right now, Matlab 7 R14 is needed to be executed. Another improvement should be assembling a .EXE file to make the application independent from Matlab.
- Add tools for DRM Calculations or for any other specific system working in this frequency band.

All this improvements have not been made at this project by time restrictions.

6 Bibliography and references

[CONDUCT]

BRUMMER, Walter. *Über die Ausbreitung von Lang- und Mittelwellen*. Germany conductivity image map in HF Frequencies to be load as a database.
http://members.aon.at/wabweb/radio/grundl3.htm
(Consultation: November 2008)

[COMMERCIALFM]

MOLLO, J.C. *Campos electromagnéticos. Determinación de la zona de protección a las personas por transmisiones de FM comerciales*. INTI- Electrónica e Informática.
http://www.inti.gov.ar/sabercomo/sc23/inti9.php
(Consultation: December 2008)

[DRM]

MATÍAS, José María. *La Radio Digital Terrestre en Europa Eureka 147 y DRM"*.
www.sincompromisos.com/Documentos/Radiocomunicacion/Radio-Digital-Terrestre.pdf
(Consultation: December 2008)

[GLOBE]

THE GLOBAL LAND ONE-KM BASE ELEVATION PROJECT (GLOBE). *A 30-arc-second (1-km) gridded, quality-controlled global Digital Elevation Model (DEM)*. NOAA. http://www.ngdc.noaa.gov/mgg/topo/globe.html
(Consultation: October 2008)

[GRWAVE]

GRWAVE USER MANUAL. *Software concerning Tropospheric Propagation: Ground-wave propagation (GRWAVE).* International Telecommunication Union, Radiocommunication Sector (ITU-R), Study Group 3 (SG 3) - Radiowave propagation. http://www.itu.int/ITU-R/index.asp?category=documents&link=rsg3&lang=en
(Consultation: October 2008)

[ITU-R P.368-9]

ITU-R P.368-9 RECOMMENDATION. *"Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz"*. Approved on February 2007 (in force).

[ITU-R P.832-2]

ITU-R P.832-2 RECOMMENDATION. *"Atlas mundial de la conductividad del suelo"*. Approved on July 1997 (in force).

[MATLAB]

MATHWORKS. *Mapping Toolbox User's Guide: Analyze and visualize geographic information.*
http://www.mathworks.com/access/helpdesk/help/toolbox/map/
(Consultation: October 2008)

Appendix: List of abbreviations

BOF	Beginning of file
CF	Correction Factor
dB	Decibels
DLL	Dynamic Linking Library: binaries functions inserted into a file
Dmax	Maximal distance
Dmin	Minimal distance
DRM	Digital Radio Mondiale
Dstep	Step in distance to calculate *dmax* based on *dmin*
E	East (to refer to field strength, *Et* is used)
Eb	Back Field: Field in direction receiver to transmitter used in Millington
Ef	Forward Field: Field in direction transmitter to receiver used in Millington
Et	Total reciprocal field returned by the Method of Millington
EPSLON	ε, Permittivity of the terrain
EXE	Executable file
FREQ	Frequency
G	Antenna gain
GLOBE	Global Land One-km Base Elevation (GLOBE) Project

GRWAVE	MSDOS software to calculate the field strength due to Groundwave propagation
GUI	Guided User Interface
HF	High Frequency
HRR	Effective height receiver antenna
HTT	Effective height transmitter antenna
IPOLRN	Polarization
ISI	Inter-Symbol Interference
ITU-R	International Telecommunication Union – Radiocommunication Section
JPG	Joint Photographic Experts Group , Image format
KW	Kilowatts
MEX	Matlab interface to be able to call Fortran or C codes in Matlab
MF	Medium Frequency
MW	Medium-Wave
N	North
NaN	Not a number
NOAA	Organization in charge of GLOBE project
P	Transmitter power
PNG	Portable Network Graphics, Image format

R	Range from transmitter to receiver
RX	Receiver
S	Power density or South, if talking about latitude
SIGMA	σ, Conductivity of the terrain
TX	Transmitter
W	West