DISCLAIMER

The programs (software) included in any version of the **EM4Soil-G** packed are provided “as are” without any express or implicit warranties including their suitability for a particular purpose. The authors, EMTOMO LDA, REFLEXOS and retailers will not assume any responsibility for any indirect or consequential damages, or any loss caused using these programs. Efforts will be made to correct any program bug that appears during the usage of the package.

Contents

0. Program overview

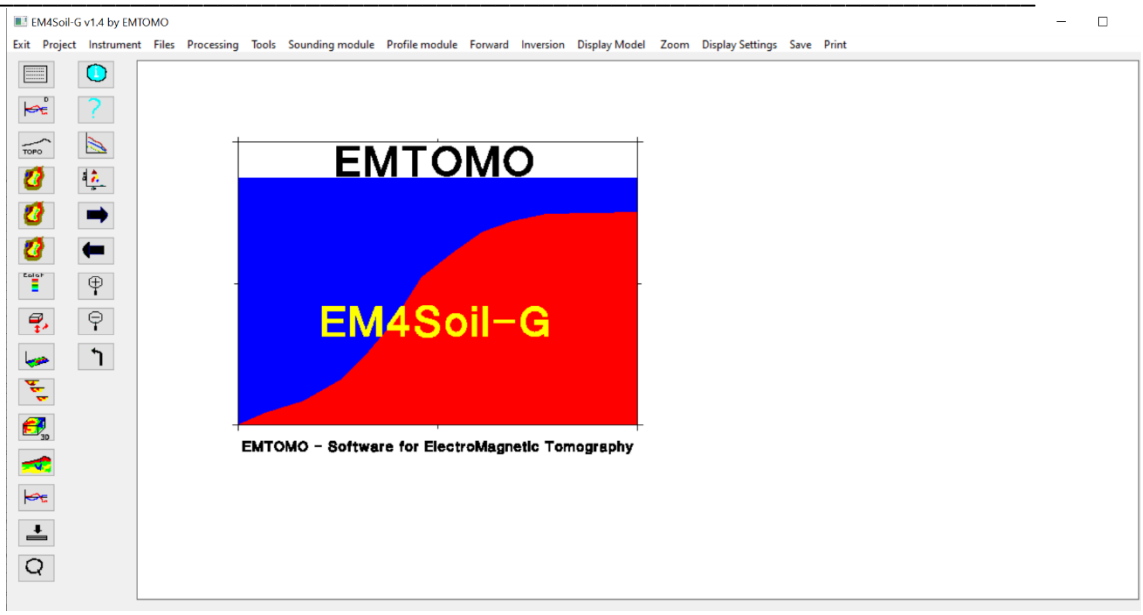
EM4Soil-G is a program for inversion of EM data collected in frequency domain (LIN domain) with GEONICS. It is mainly designed to interpret data collected with multi-coil instruments. The use of two modes of acquisition (VMD and HMD) is recommended.

The program runs in Windows (64 bits) systems.

The main parts of the program are:

- Instrument definition,
- Create a project,
- Data input (lines, survey*, or EM soundings),
- Data processing,
- Inversion,
- Save results (only 1D and Q2D models),
- Display results,
- Export and print results (1D, Q2D and Q3D),
- Save the project.

*The term survey as used here means a set of readings covering an extensa area. In general, those data are acquired continuously but can be a set of profiles acquired in the area.


EM4Soil-G v1.4 by EMTOMO
Exit Project Instrument Files Processing Tools Sounding module Profile module Forward Inversion Display Model Zoom Display Settings Save Print
EMTOMO
EM4Soil-G
EMTOMO – Software for ElectroMagnetic Tomography

Left icons


- Display survey layout,


- Display data as a line (in line display),

- Display topography as a line,


- Display Eca data (map),


- Display Inphase data (map),


- Display Quadrature data (map),


- Color scale,


- Settings of 3D view,


- Display horizontal slices (from Q3D models),


- Display a 3D view of Q2D (XYZ saved) models


- Display Q3D model (cube)


- Display 1D stitched and Q2D models,


- Display data/ model response (from 1D and Q2D models),

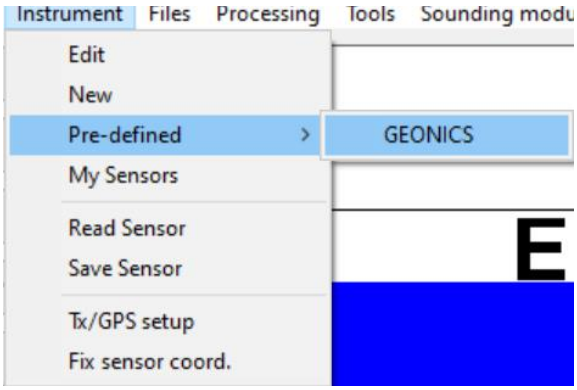

- Save 1D and Q2D models,


- Quit program.

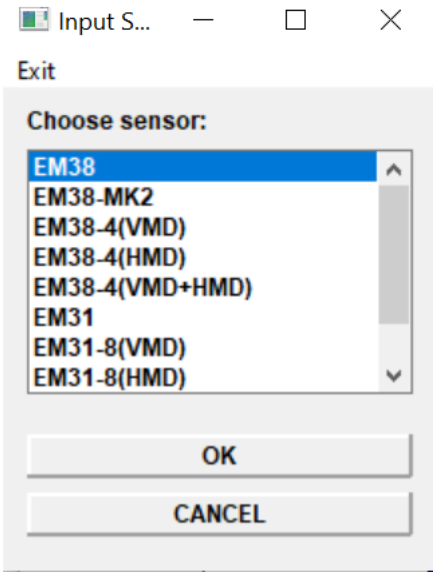
- Map settings,
- Site location (in the survey)
- Display 1D data/model
- Display ECa-Inphase correlarion
- PAN (when data are displayed “in line”),
- Zoom IN and OUT,
- UNDO (just the last modification).

1. Instrument definition/data input

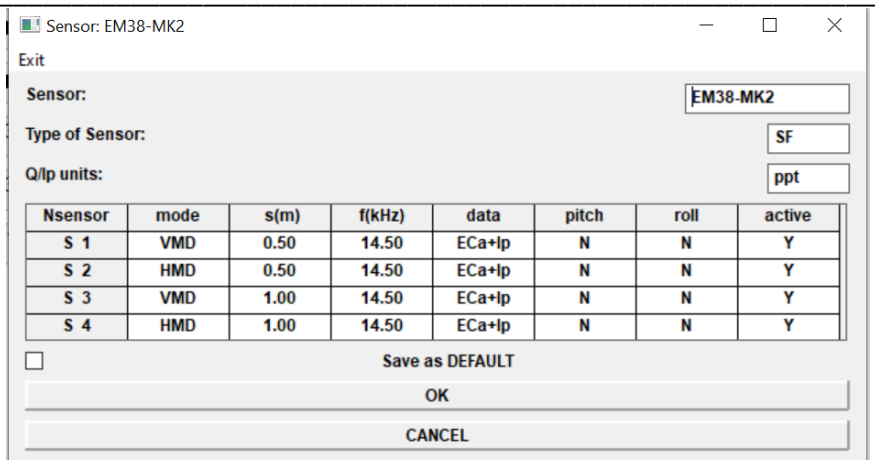
The instrument in use can be selected from pre-defined ones,



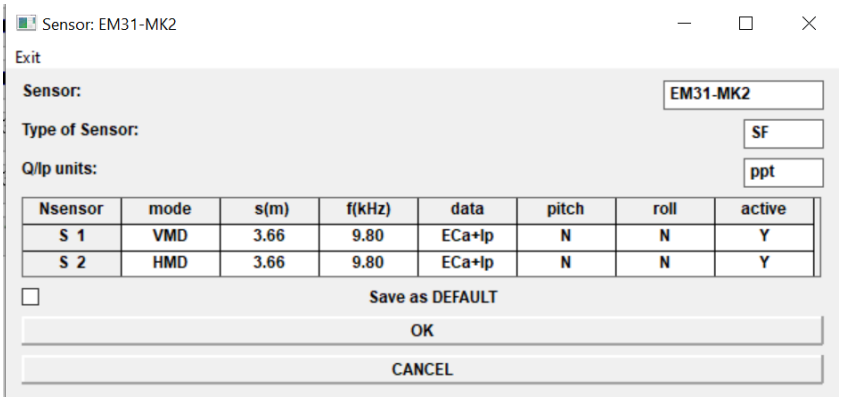
For GEONICS one has,



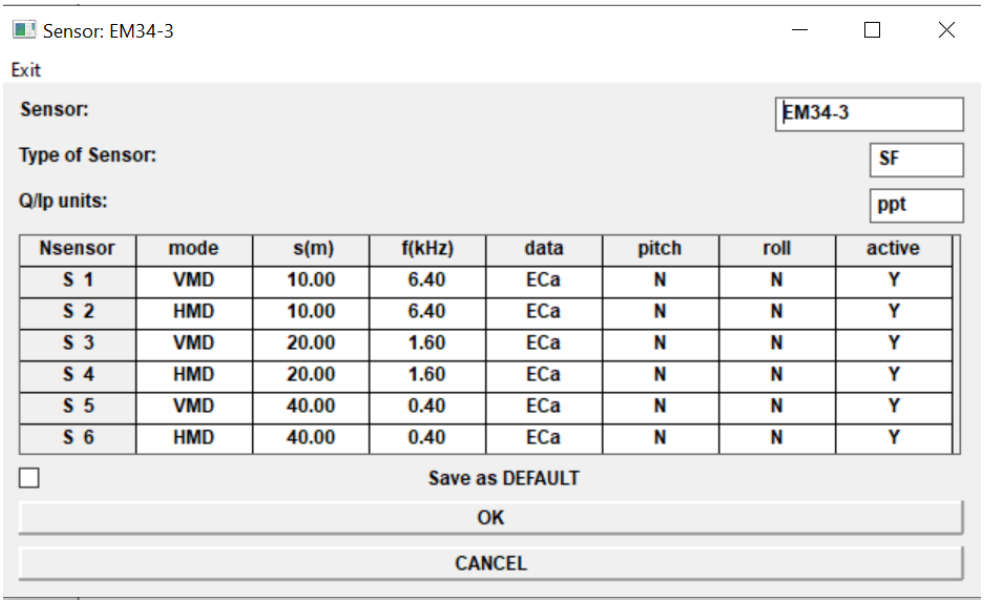
For example, for the EM38-MK2 the instrument (sensor) definition is (you can access to this definition clicking on the Instrument/Edit option),



For the EM31-MK2,



For EM34, that does not contain in-phase data,

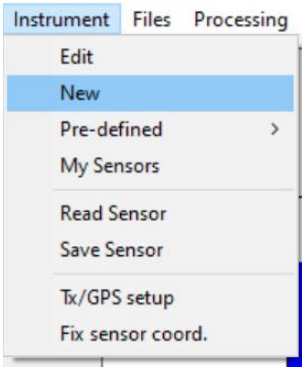


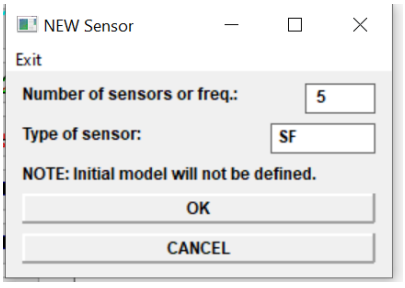
If the selected instrument will be used several times, save it as the DEFAULT instrument.

NOTE: if data file does not contain values for all sensors and channels described in the configuration, fill the missing channels columns with -9.0 or with 0.0.

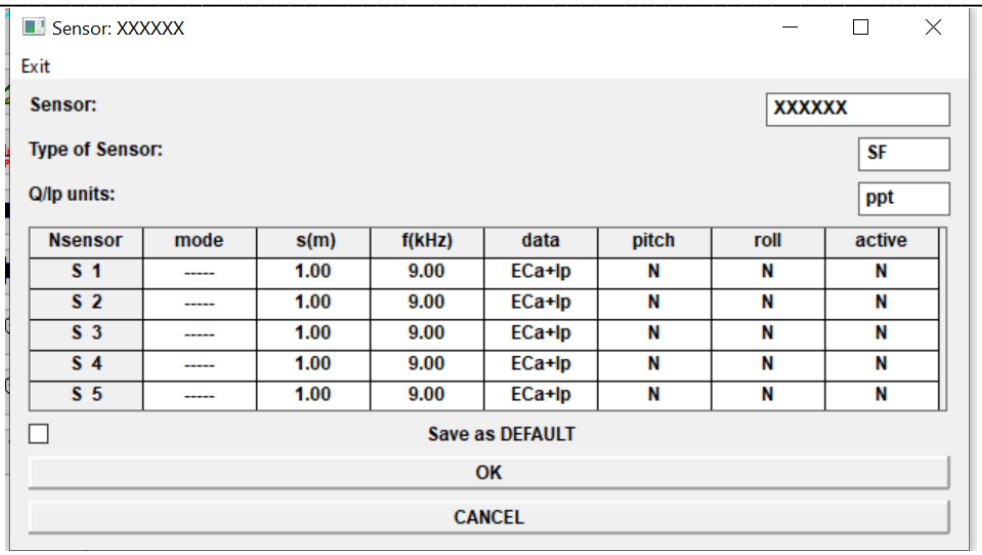
Defining a New Instrument/mixing sensors

The user can define a new instrument that contains sensors from different instruments. For example, the new instrument can mix data from EM31 and EM38-4. If the acquisition is only made using the VMD mode, the new instrument will have 5 sensors (1 from EM31 and 4 from EM38-4). Proceed as follows:



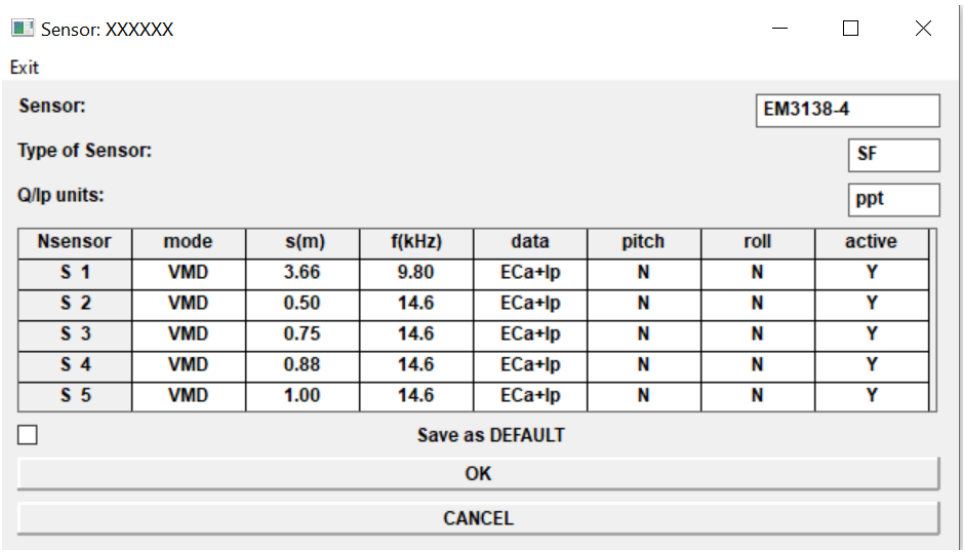


With the corresponding table that must be filled out with the appropriated information,

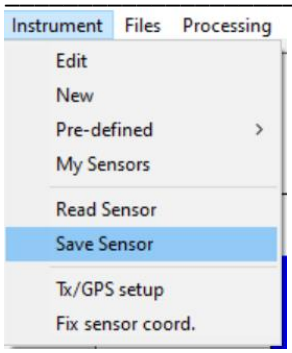


The sensor name (here filled with XXXX) must be a short name; the type of sensor is SF (Single Frequency). This designation will keep the calculations in the LIN approach even if different frequencies are used like in EM34. Q/Ip units in LIN are usually in ppt. The mode column must be filled with VMD (or HCP) or HMD according to the acquisition mode of the respective sensor. It must be noted that the program is key sensitive so take care writing the options. The distance between coils (s in meters) and the frequency must be filled with the correct values in kHz. The data type must be the same for all sensors that must be actives (Y). Usually, pitch and roll are not available (N). Data type (channels) can be like: ECa; ECa+Ip; Ip+Q; ECa+Ip+Q. Here, ECa represents the apparent conductivity (in mS/m), Ip is the inphase (usually in ppt) and Q is the quadrature (or outphase) in the same unit of the inphase. The hight of the instrument must be filled (corrected) in Processing/select sensors. The Table parameters are key sensitive.

For the example EM31 + EM38-4 (only VMD) one will have,



The new sensor should be saved to be used in other occasions,

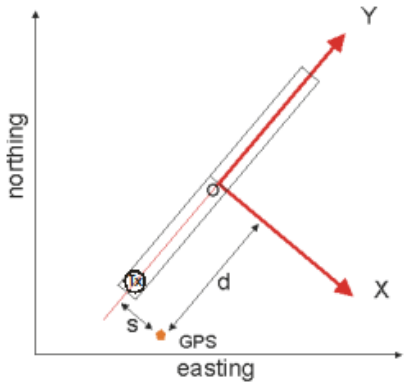


The sensor file is saved in the folder Mysensors and can be read in the option My Sensors.

Correction of reading location

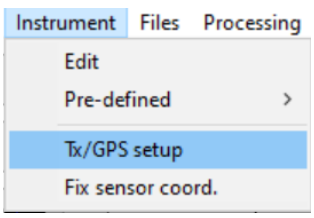
Positioning survey sites with the use of an external GPS is a common procedure. In general, the GPS does not stand in the center of the instrument at where the measured values must correspond. Moreover, in multi coils instrument the readings of the different Tx-Rx pairs did not correspond to the center of the instrument, too. For this reason, a correction of the sites coordinates and reading location are necessary. The correction can be done knowing the GPS position relatively to the center of the instrument as well as the instrument position relatively to the line survey (Figure).

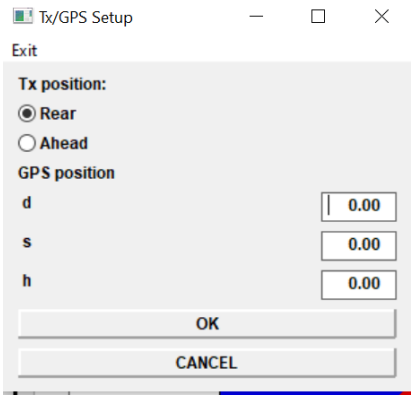
Note 1: The correction only works for multi coil instruments.



Local reference system (X,Y) to localize the external GPS assuming that the survey is carried out in the Y direction. The figures show the instrument in the in-line position. O represents the center of the instrument and Tx the transmitter position. **Note that d and s can be positive or negative values.**

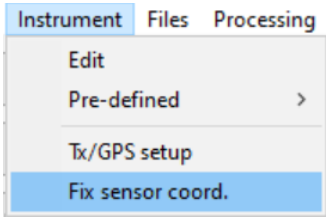
To apply the correction, it is necessary to setup the transmitter and the GPS.



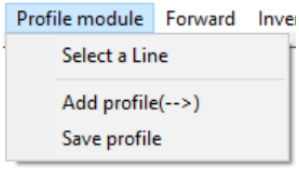


h represents the height of the GPS above the instrument.

Apply the correction,



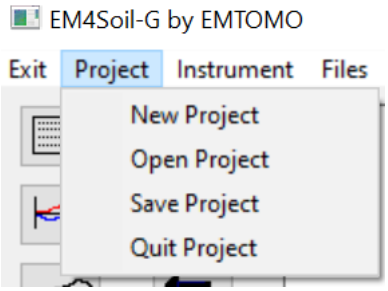
Note: The correction can be applied to profiles and to surveys.



Save the results (Save/Coord. Corr.). It must be noted that a few sites at the ends of the profiles is lost.

2. Open a project

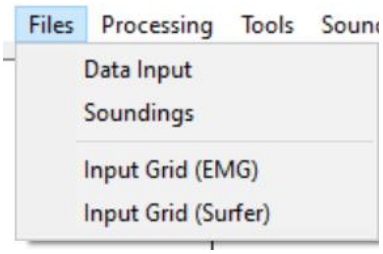
The program needs a project file were the results will be saved. Open a new project at the beginning of the session. Each project must have a different name.



3. Data input

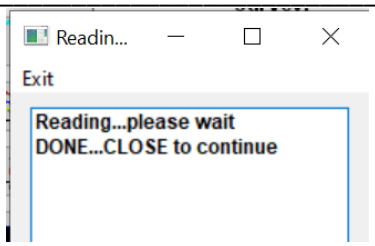
Except for EM38-4 and EM31-8, which have a special format all GEONICS data must be exported as XYZ files to be import into EM4Soil-G. The data can correspond to a set of profiles (lines), to a set of EM soundings or to a survey (set of readings covering an area). Several profiles ca be input and interpreted one by one saving results and the project at the end. However, to proceed in such a way the inversions MUST be done using the same sensors and channels. Otherwise, the interpretation MUST be done profile by profile considering each profile as a project.

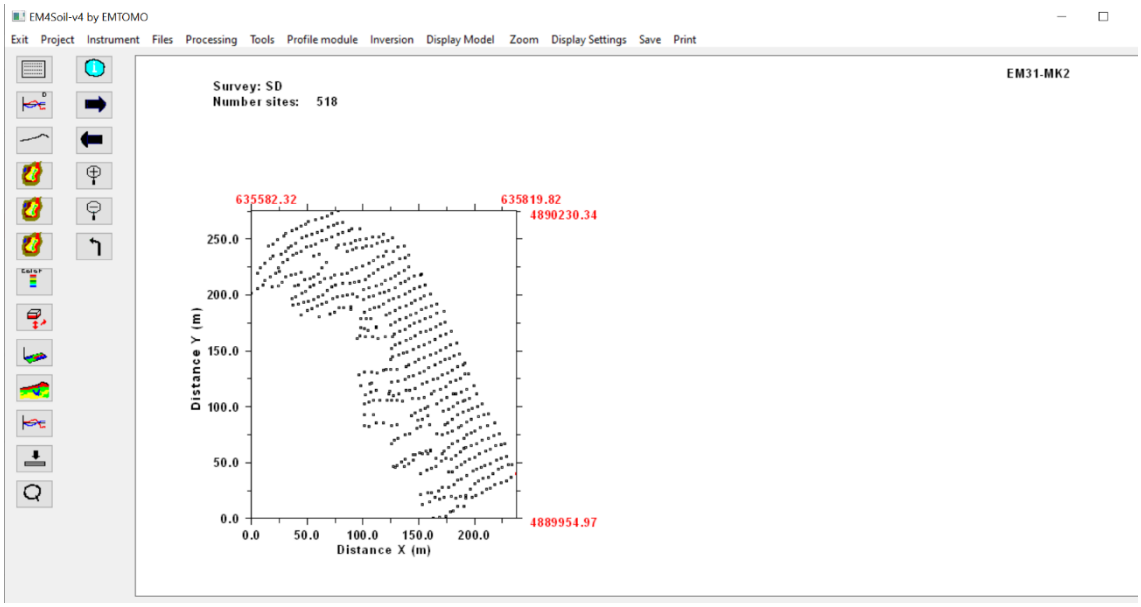
Because surveys contain a significant number of readings, a project should only contain one survey. However, it is possible to input more than one survey in the project with the same restrictions of the profiles.



There is the possibility to input gridded data from a survey. The EMG is used for data gridded by EM4Soil-G. However, data gridded by SURFER program (by GOLDEN SOFTWARE) is also possible (See here).

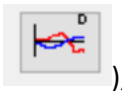
Data layout is shown after input (survey of several lines),

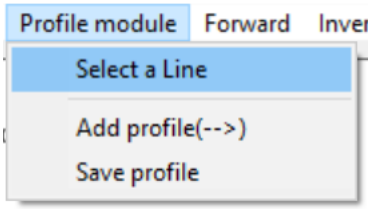




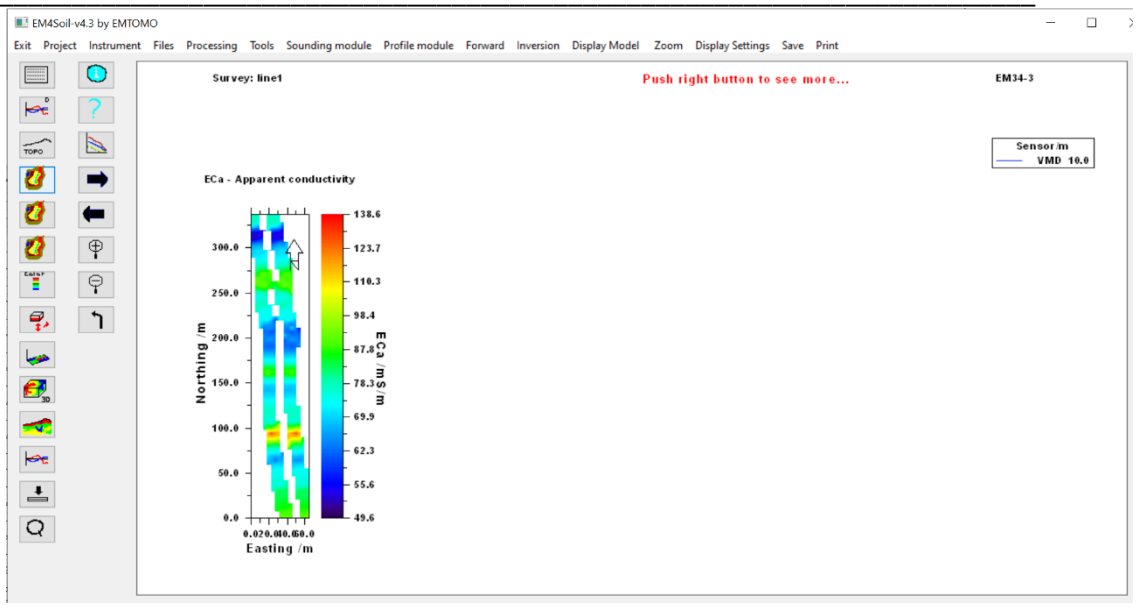
If data was collected using a geodetic coordinate it must converted in UTM (or other metric system) using the entrance Covert to UTM.

Data display

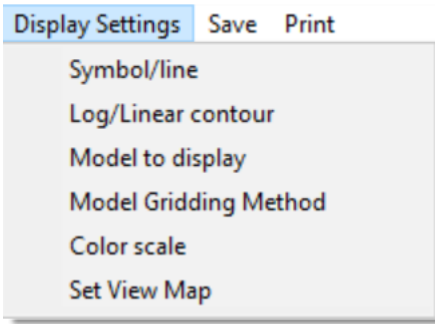
Select the line to display (or using ),



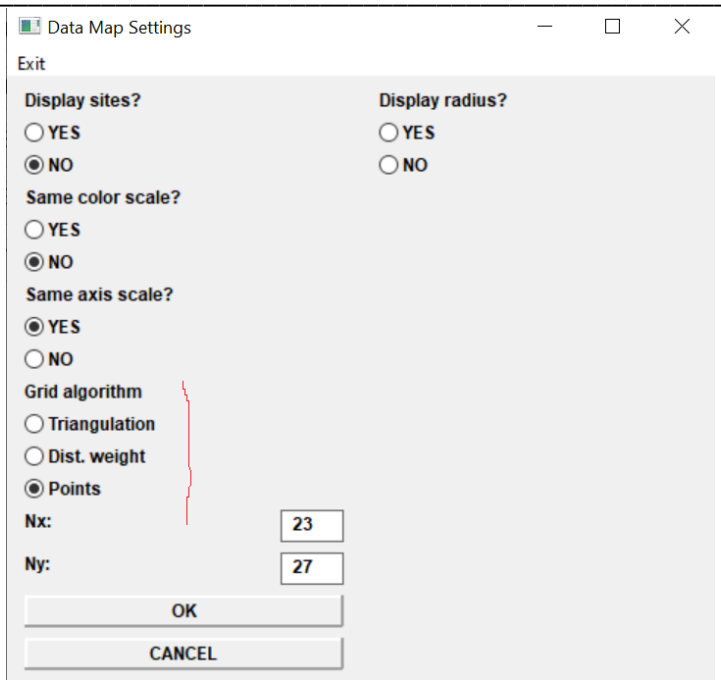
or in maps (surveys) 



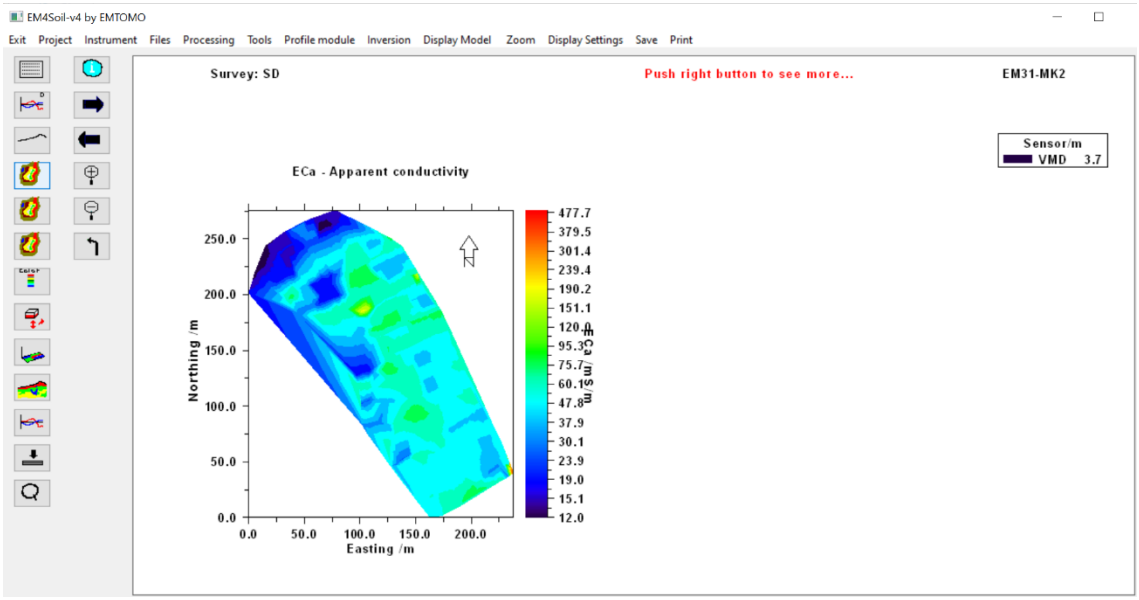
To see the rest of maps (data), push the (mouse) right button.
Options for display (including map display if input data are from a survey) can be found in Display Settings.



By default, the map is displayed as coloured dots. This can be modified in Set View Map or pushing  button,

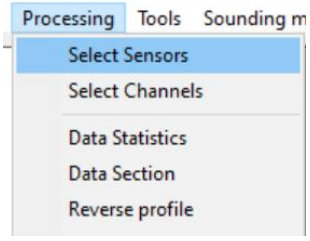


Combined with Log display (if all values are positive) and a different colour scale,

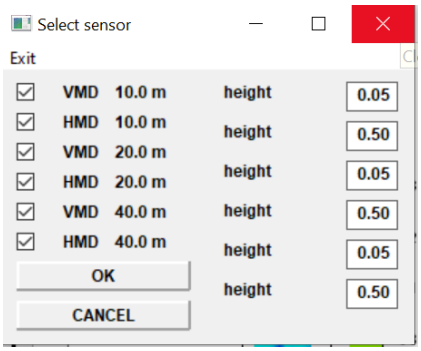


4. Data processing

The **Sensors and channels** to use in the inversion can be selected by the user,

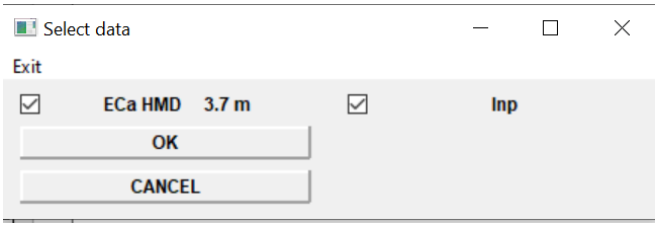


The height of the sensors, relatively to the ground, can (must be) also be adjusted,

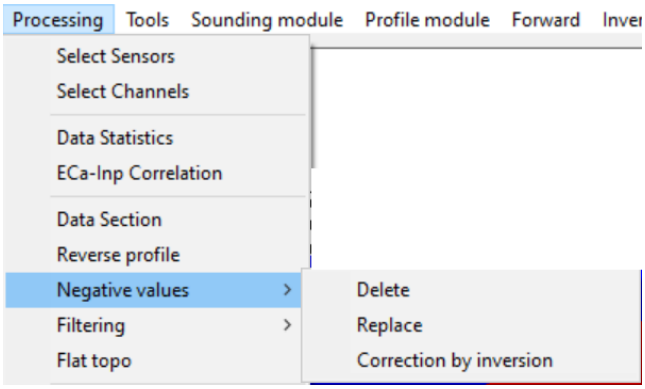


The channels to use in the inversion can also be selected.

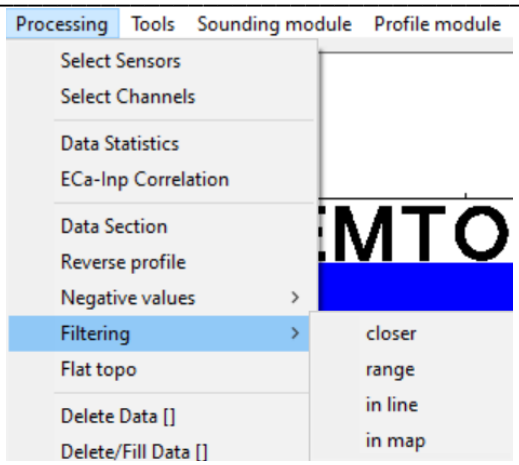
NOTE: In the current version of EM4SOIL-G ECa and Inphase data are inverted separately assuming the validity of LIN conditions. Therefore, In-phase data must be disabled (just click in the Inp rectangle when inverting ECa and vice-versa).



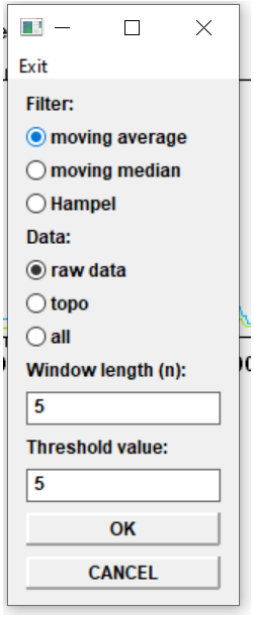
Negative values of apparent conductivity cannot be inverted (will not be considered if in the data). Such values can be removed or can be replaced by interpolating neighbour values,



There are some options for **data filtering**,

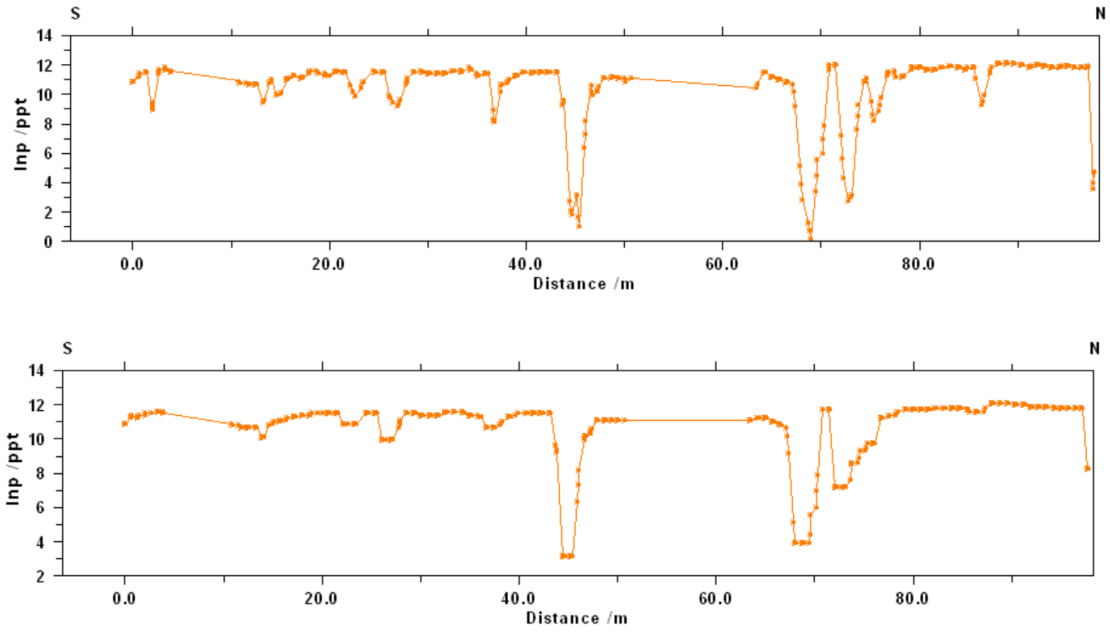


- Closer filter delete sites closer than a threshold distance,
- Range filter delete data out of a minimum and maximum values (it works only for one sensor/channel),
- In line ..filters that can only be applied when the data are displayed “in line” (they are more specific for profile data),



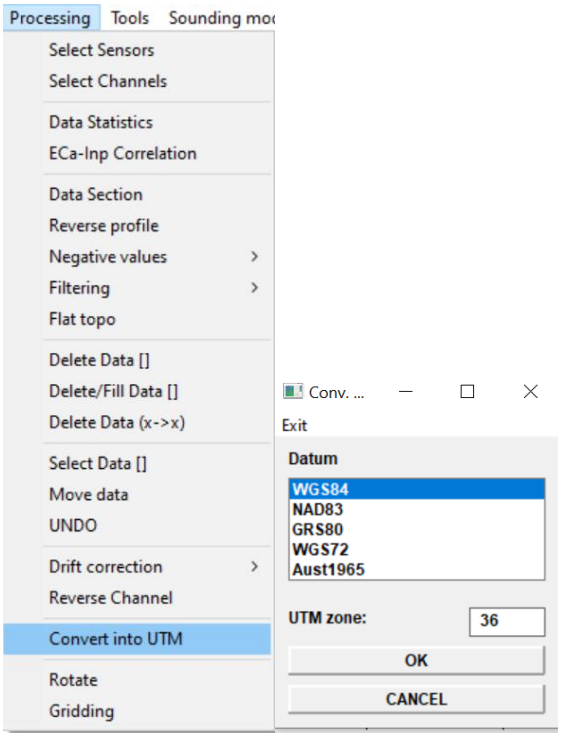
Moving average filter is a simple smoothing filter. It replaces a value by the average of the values in the windows which length is defined by the user. Moving median filter acts like the moving average filter but the values are replaced by the median calculate in the window. The moving median filter designed to remove isolated events (spikes). Moving average filter is to be applied to data contaminated with high frequency noise. Hampel filter is like moving median but is much sophisticated. This filter uses the Hampel identifier to detect outliers. The algorithm has a threshold value to identifier that a value is an outlier when compared with the

neighbor ones. As the median filter the Hampel filter acts better for isolated events. Here an example with a window length=11 and a threshold= 2.5.



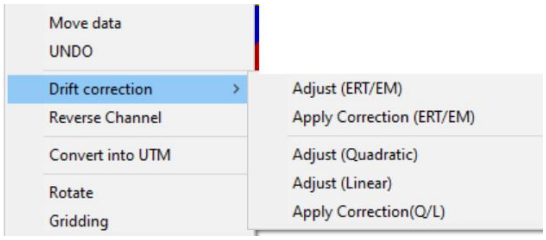
Data (upper) and filtered data (Hampel).

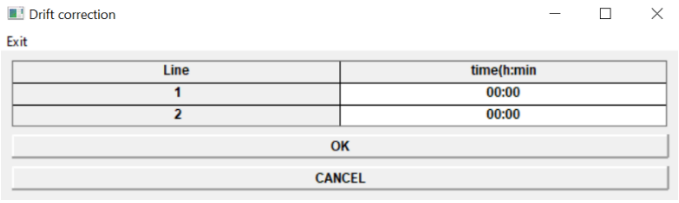
- In map…filter to apply to gridded data (survey).



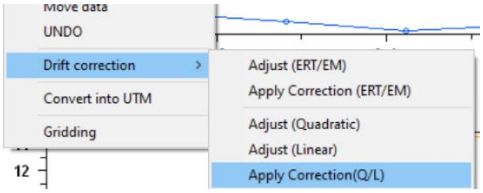
Drift/shift correction

Drift effects on the data can be corrected if data acquired on a reference line at different moments, exist. Data from these profiles must be input (Linear adjust or correction) and the first input profile is that one that correspond to the reference time. The acquisition time of each profile must be filled in a table provided by the program. The correction coefficients are calculated after and can be seen (displayed) channel by channel. The coefficients (which are values of channel variation by time) must be saved in a file to be used to correct data acquired during the survey.

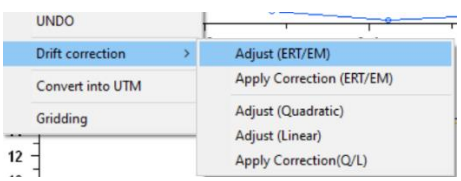




To apply the correction, use the entrance**,**

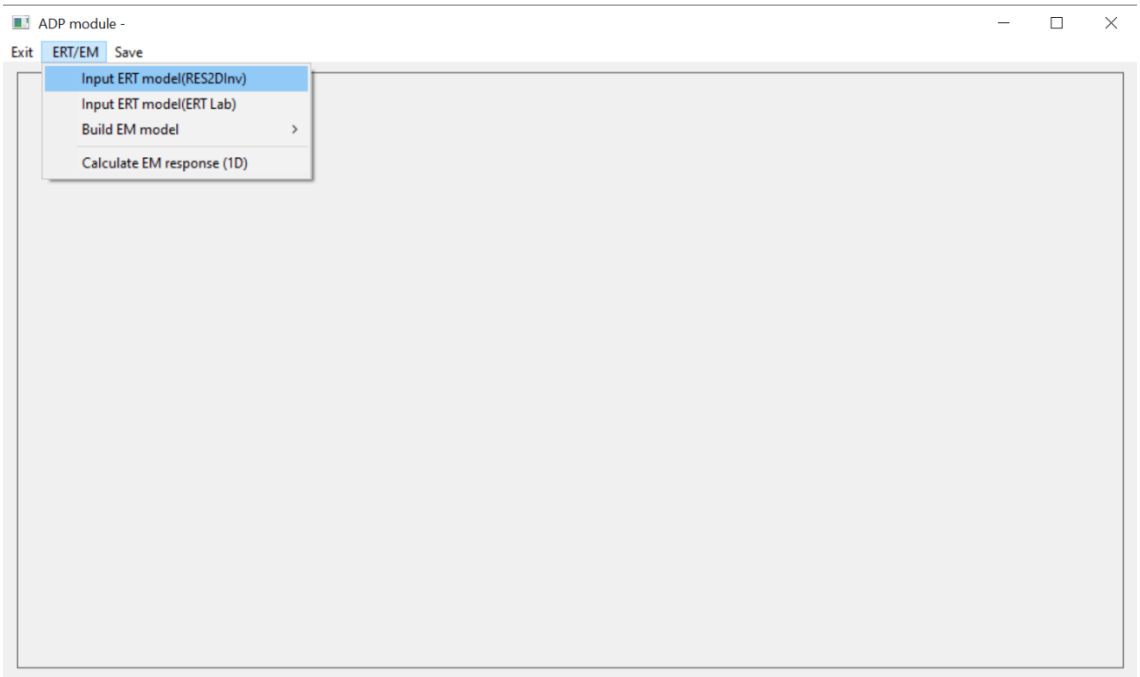


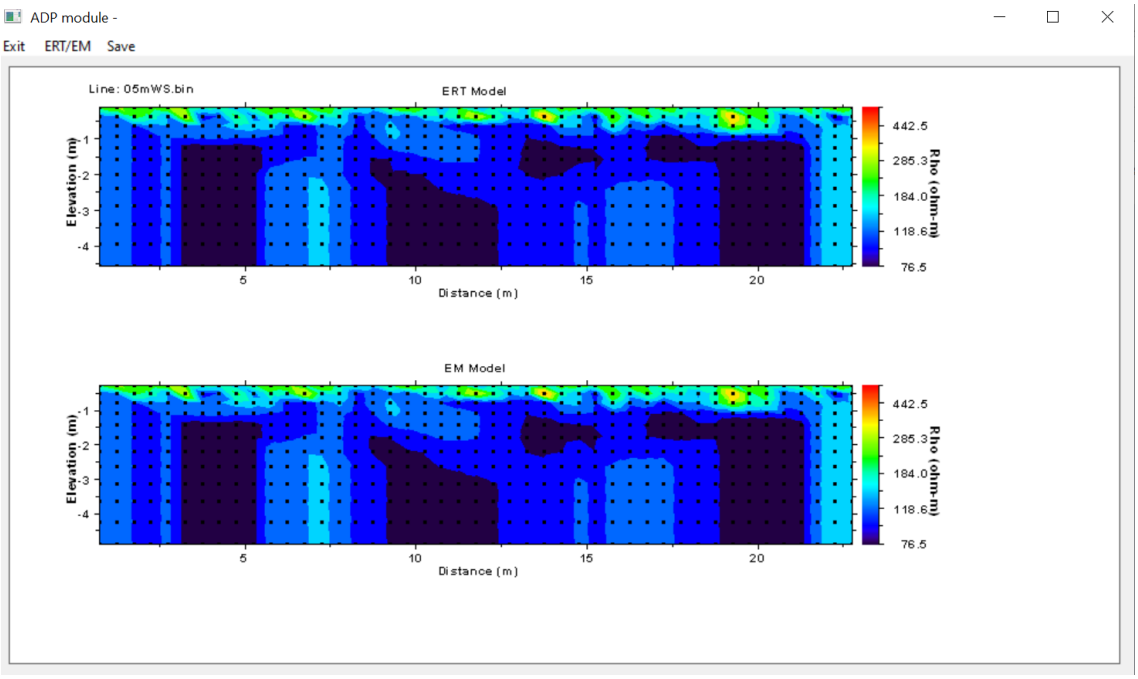
It is possible to correct the shift effect in EM data using an ERT model obtained in a reference profile where a coincident EM profile exist. First, input the EM profile acquired in the referent line. After, input the ERT model previously calculated,



This will open a new window, and the ERT model (calculated with Res2Dinv or ERTLab) can be input. From the ERT model an EM synthetic model will be built and its EM response calculated.

Based on the field and synthetic data the correction factors for each channel will be calculated. Save them in a file to be used after when applying the correction to data.

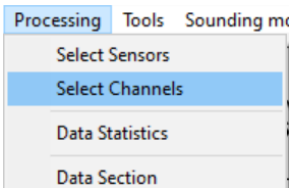




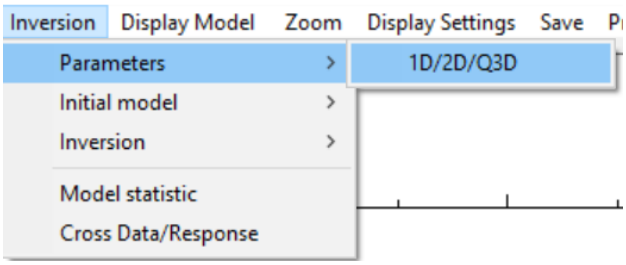
5. Inversion

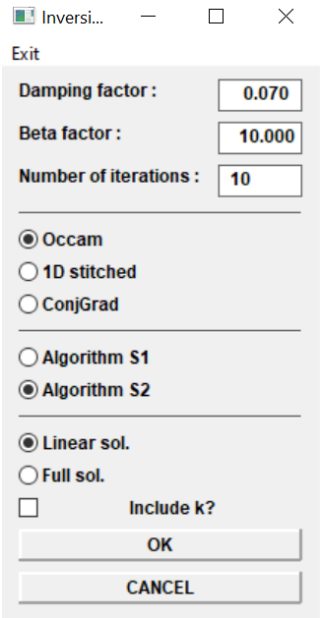
The steps for inversion are:

- ***Select the channels,***
  Inversion of ECa data and inphase data must be performed separately. Therefore, select only the right data (channels) for the inversion.



- ***Define parameters***,

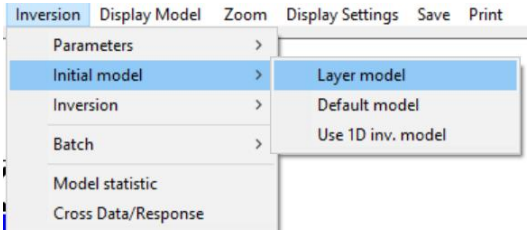




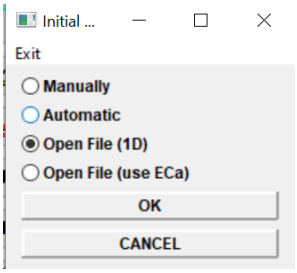
- Damping factor controls the balance between model smooth and data fitting. Higher values produce smoother models.
- The Q2D, Q3D and ConjGrad (CG) are based on Occam algorithm. Occam models have more layer than data channels (that is, the number of parameters is higher than total readings). Layer option is more convenient for 1D Stitched models, also named 1Dsti).
- ConjGrad (Conjugate Gradient is only valid for Q2D inversion).
- Algorithm S2 has 1 more constraint relatively to S1 and produce smoother models.

- Include k when inverting (only) inphase data with Linear solution.
- Linear solution uses cumulative functions (CF) in forward calculations while Full solution (FS) uses Maxwell formulation.

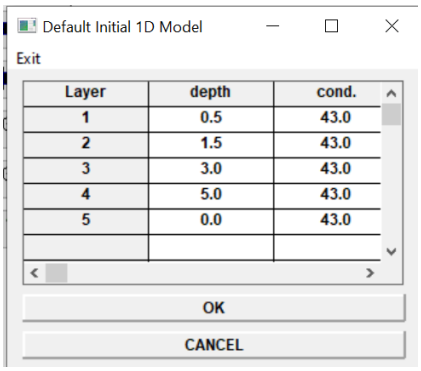
- ***Initial model***



All initial models are 1d layer models. But there is different option to build the model.

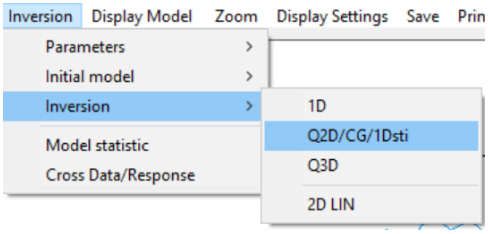


For Q3D is better to write the model in an ASCII file and read it (see data format below). Predefined instrumets have predefined models that can be accessed in the default option. These are models for Occam algorithm. For the EM31 (VMD+HMD data) the default model is a 5-layer model. The depths are predefined, and the conductivity is obtained by averaging ECa data (in mS/m).



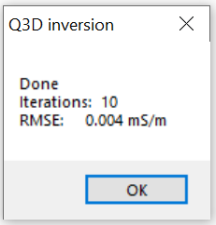
Initial model defined in a file can be read with “open file” option. With “open file (use ECa)” the conductivity in the file will be replaced by the averaged value of ECa data.

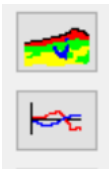
- ***Run inversion***

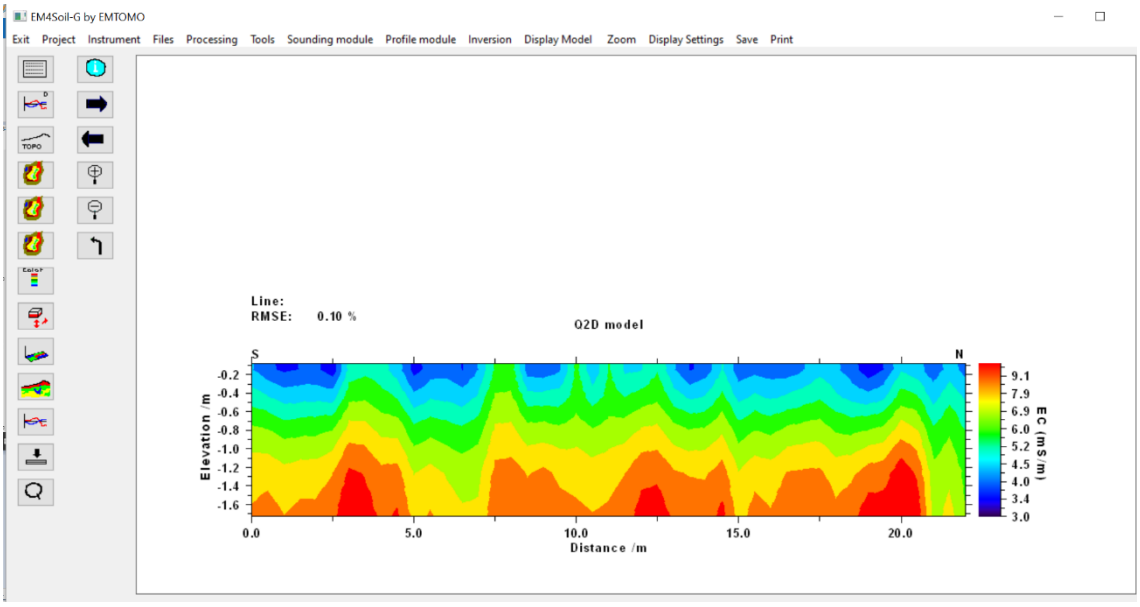


- 1D applies to EM soundings,
- Q2D/CG/1Dsti applies to individual profiles (line),
- Q3D applies to surveys with continuous measurements,
- 2D LIN applies to individual lines. This is a 2D inversion where the influence of the neighbours' cells is considered in the forward and derivatives.
-

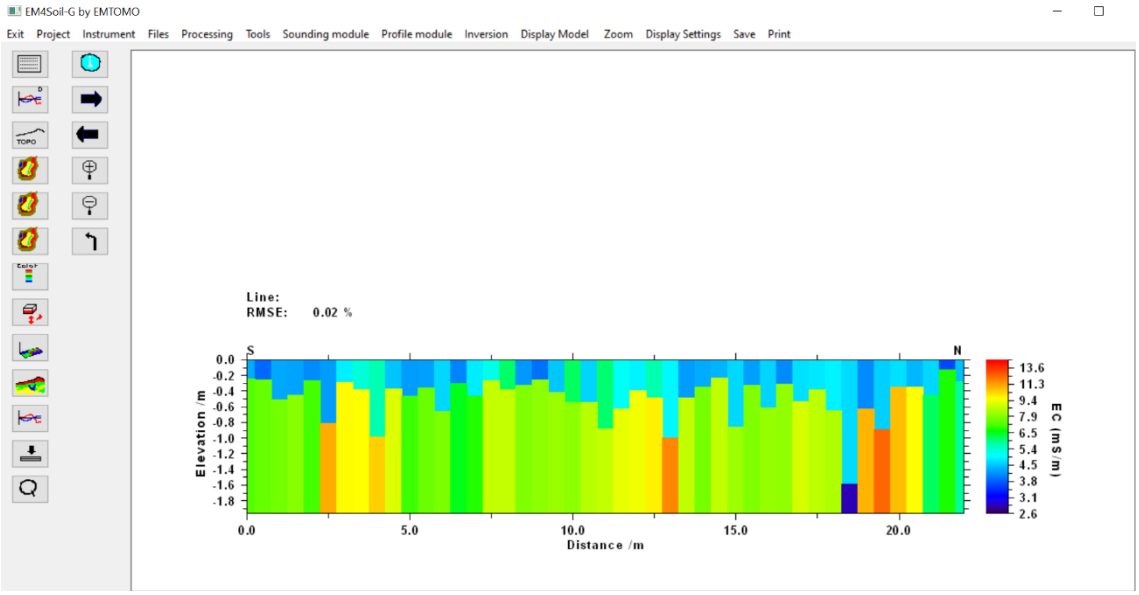
When inversion finish the program displays,



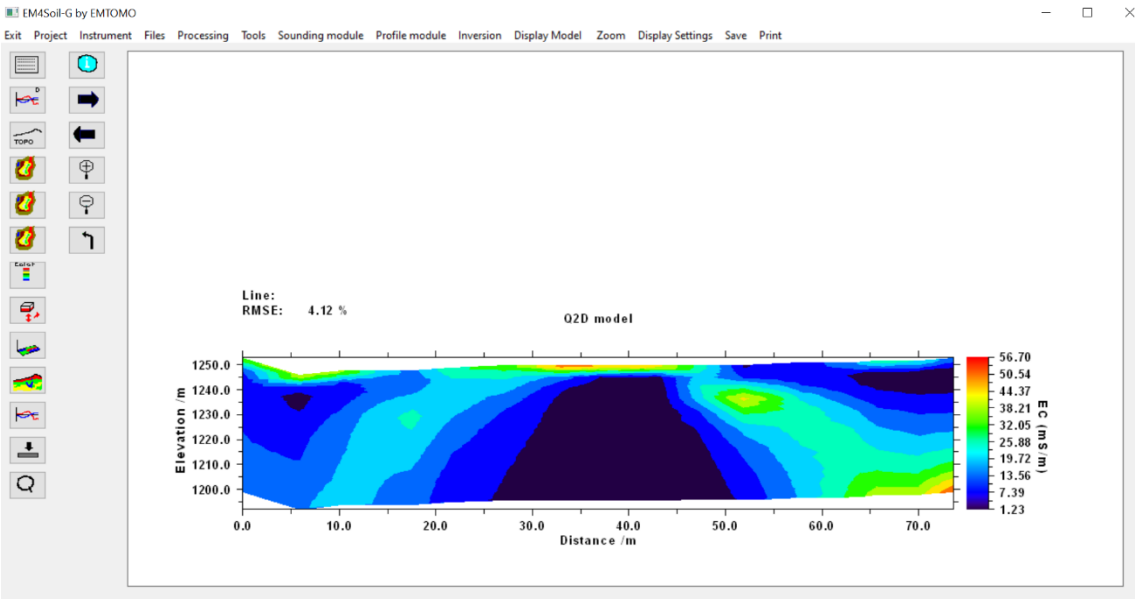
Data/model response and the model can be displayed using  buttons.



Example of a Q2D model (EM38-4).



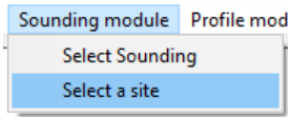
Example of a 1DSti model (EM38-4).



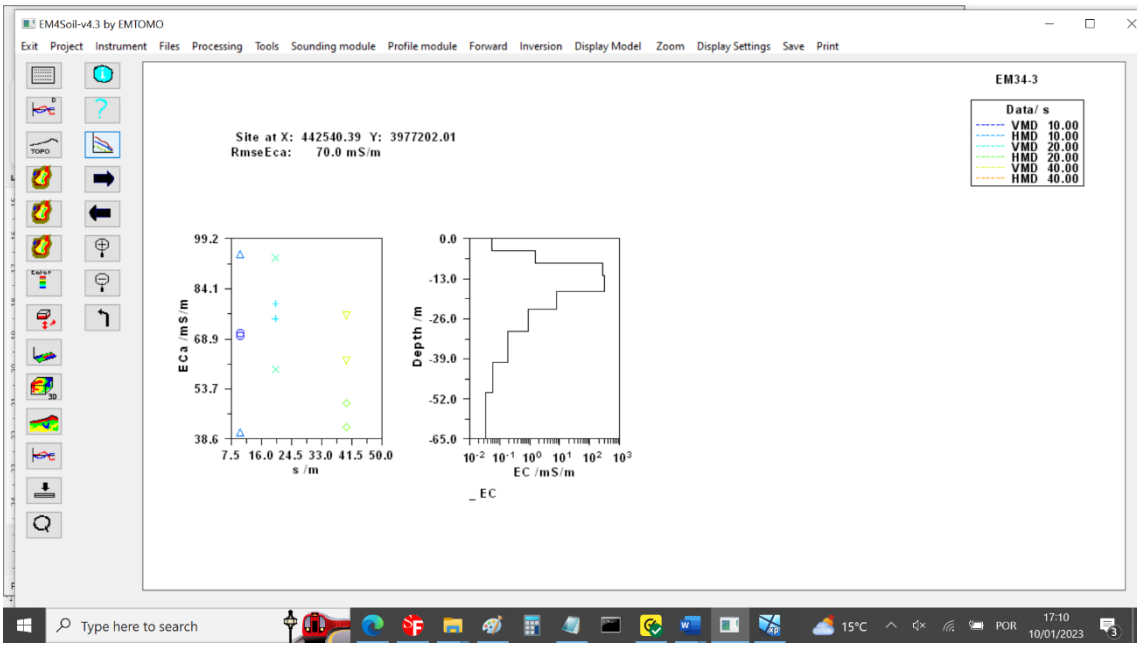
Example of a Q2D model (EM34-3).

1D inversion of EM soundings

EM soundings (EM readings acquired with the instrument at different heights from the ground surface) at a determined location can be interpreted using 1D models, with a few layers or using Occam method. EM soundings can be input through data files (see data format). 1D inversion can also be applied in the interpretation of the observations (made with different sensors) at one site of the line. This data can be selected using,



With the line data displayed on the screen, select the site pushing the left button. The data will be displayed. The inversion follows the usual procedure (select sounding/select channels/define parameters/initial model/inversion 1D).

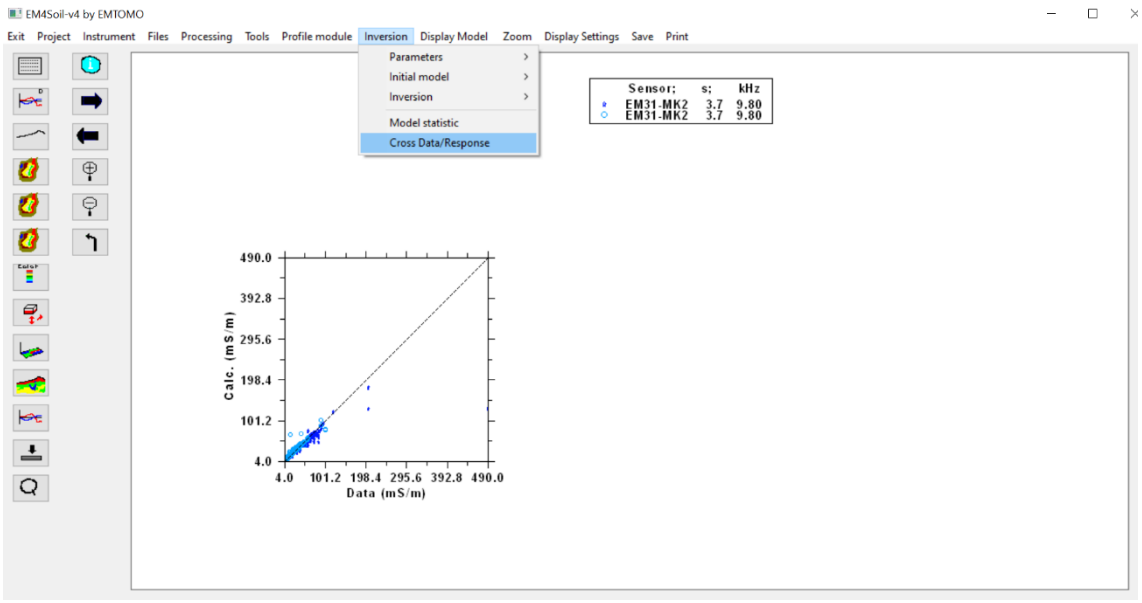


Example of 1D inversion with Occam option (data at one site of a line).

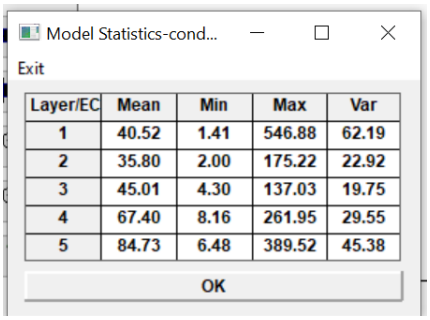
NOTE: After a good model (1D or Q2D) was obtained it should be saved (using the Save Results icon on left of the screen ), otherwise the results will not be saved during the Project saving. The model to save must be displayed before the use of the Save Results option.

6. Display results

A general evaluation of the results can be obtained displaying the data/model response cross graph,

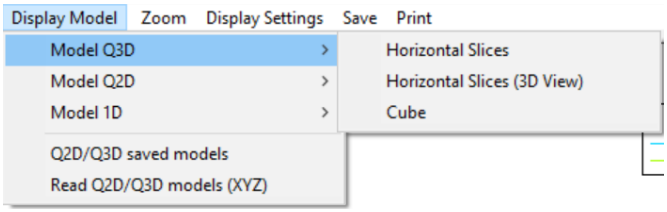


Model statistic, gives some information about the model variability,

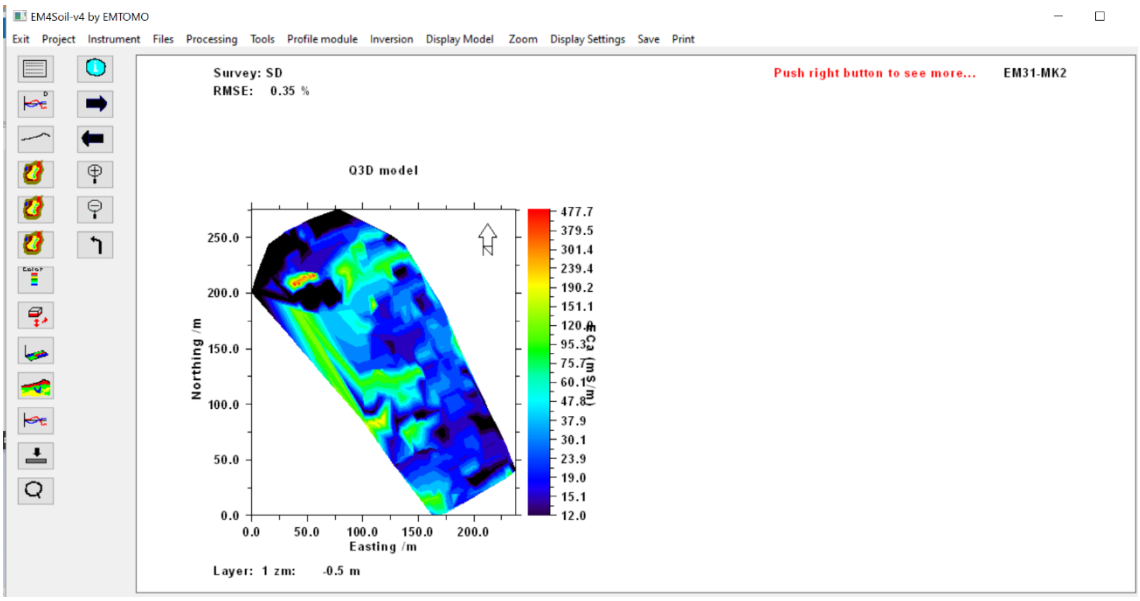


Layer/EC	Mean	Min	Max	Var
1	40.52	1.41	546.88	62.19
2	35.80	2.00	175.22	22.92
3	45.01	4.30	137.03	19.75
4	67.40	8.16	261.95	29.55
5	84.73	6.48	389.52	45.38

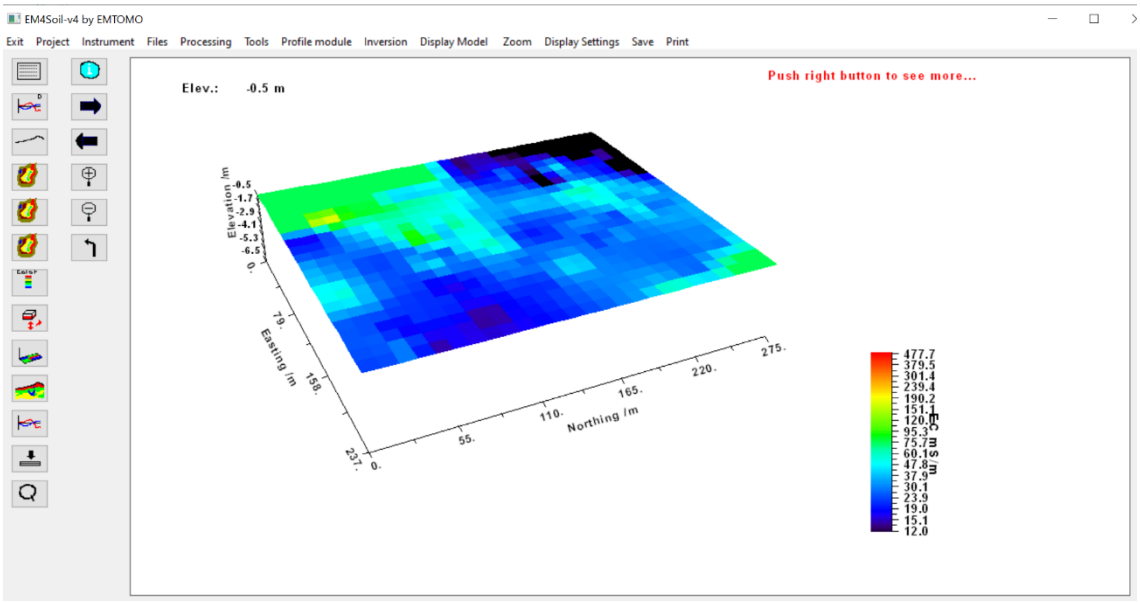
The Q3D model can be displayed by horizontal slices (vertical slices will be available in the future).

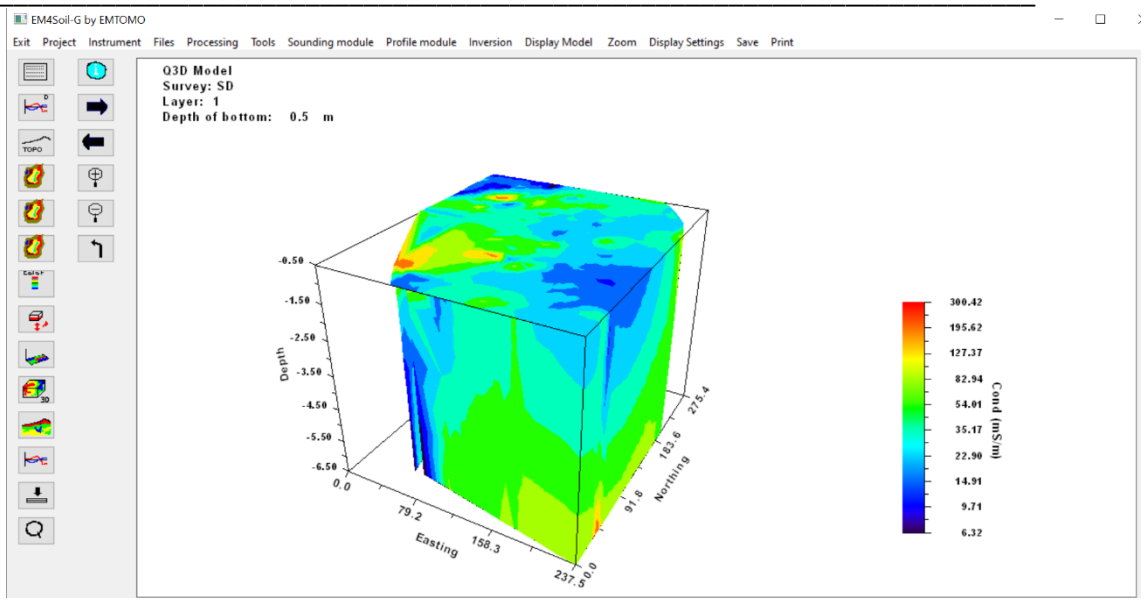


Horizontal slices at depths can be displayed pushing the right button. Map settings, colour scale and log/linear display can be used to improve the display. It's a good practice to display all slices before going to other screen (option).

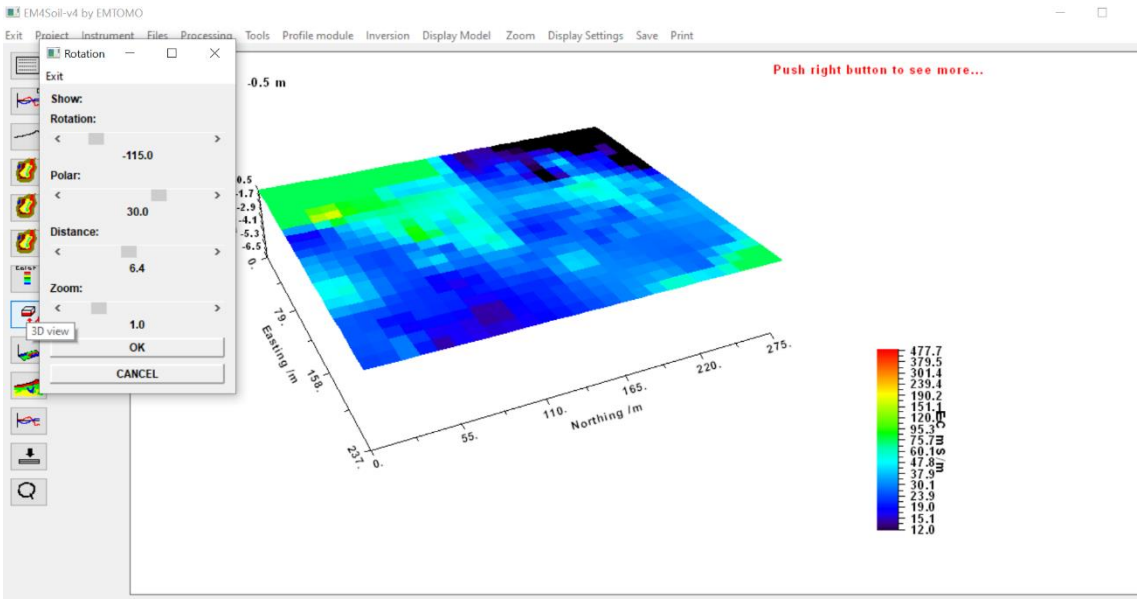


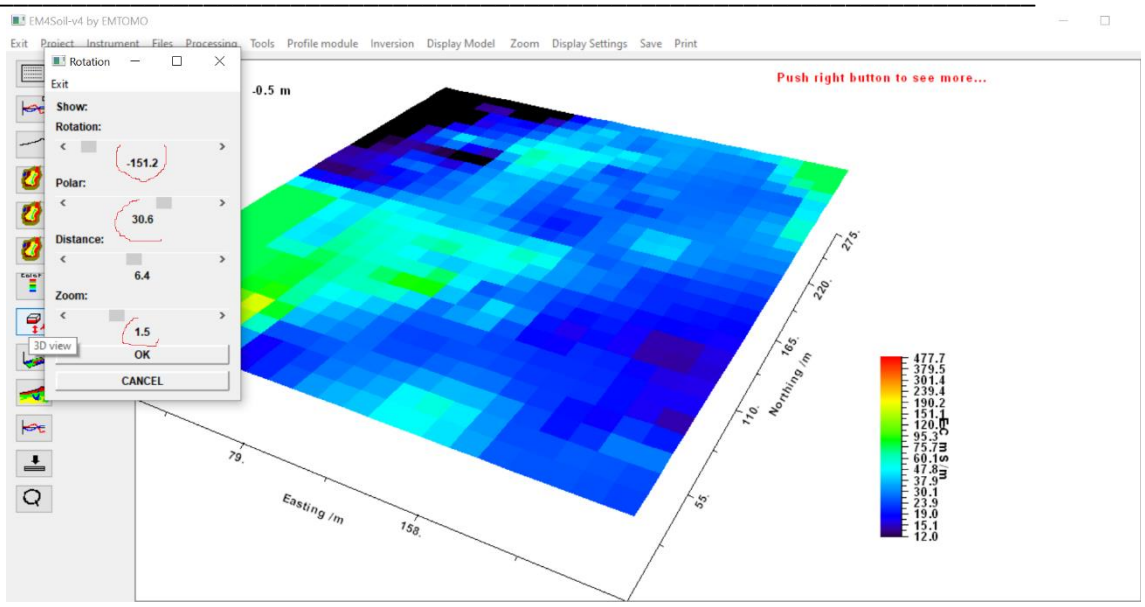
Horizontal slices (3D view)



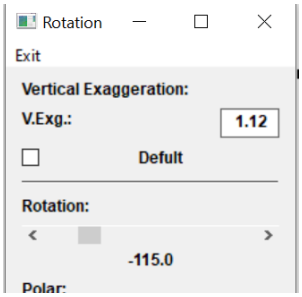


The 3D view can be controlled using the 3D view button  ,

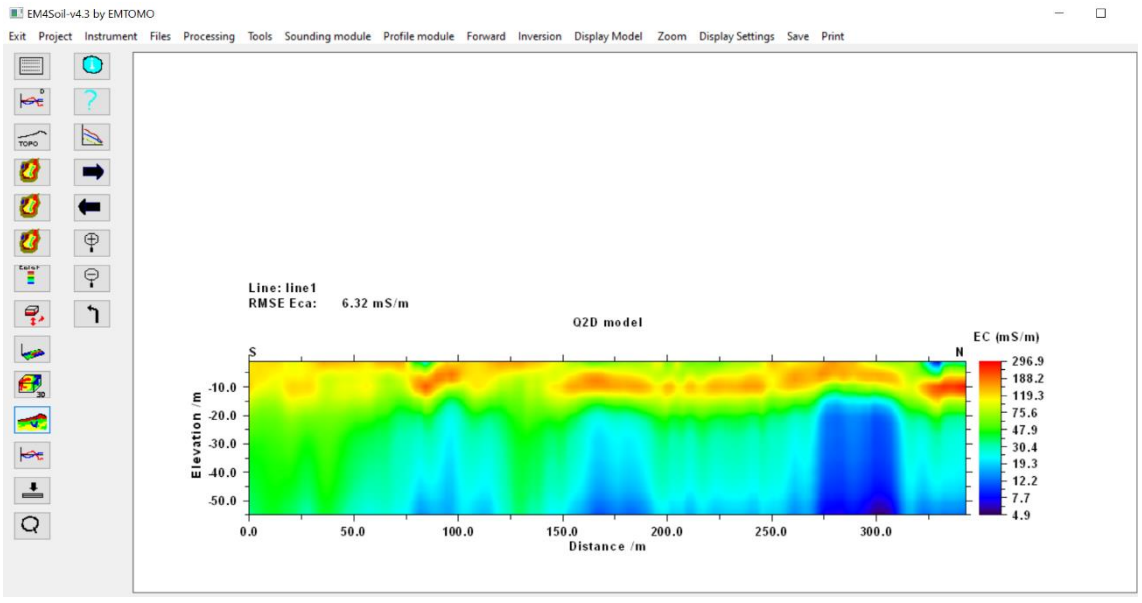




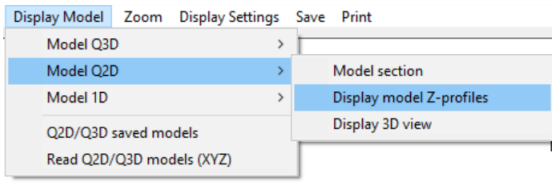
For the 3D display and the [3D view of Q2D models] it is possible to change the scale of the vertical axes,



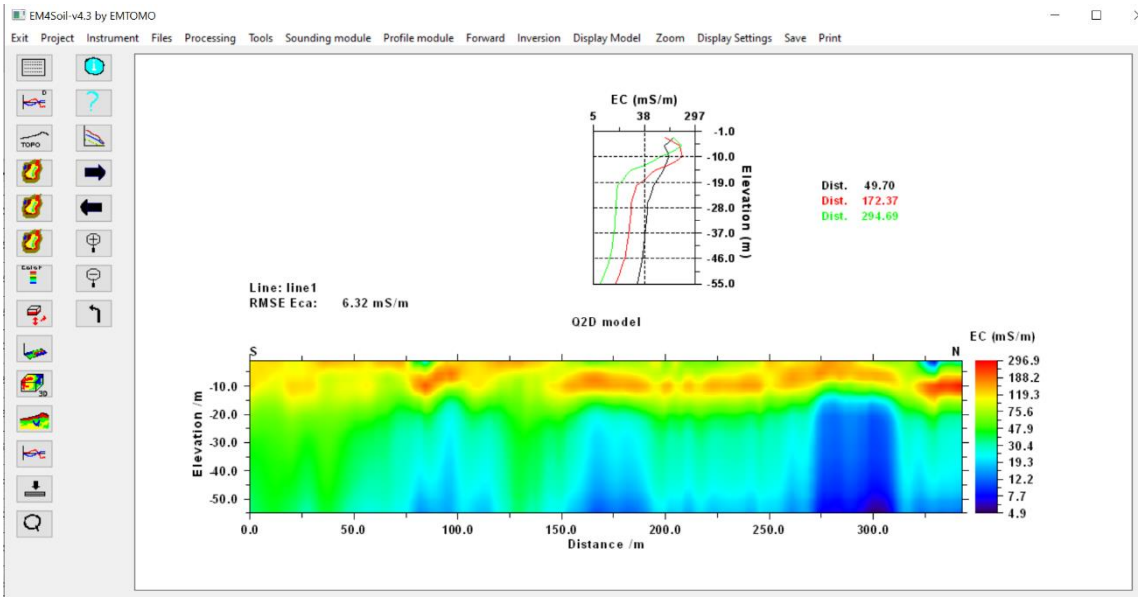
Q2D models are presented by model sections along the profile (see here for 3D view),



It is also possible to display vertical profiles of the model at selected sites,

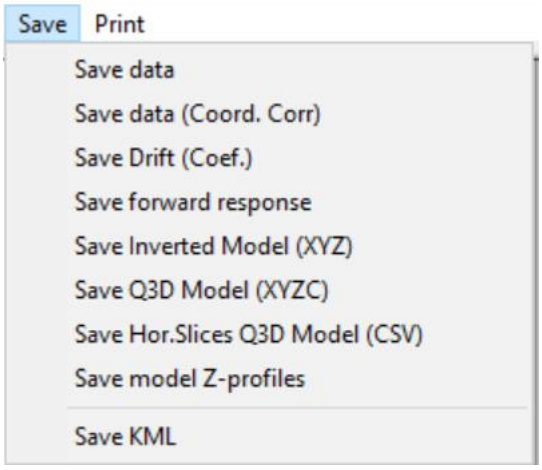


The sites are selected by moving the mouse till the sites and clicking on the left button. You can select a few numbers of sites. Finish clicking the right button.



7. Save results

Some results can be saved in ASCII files to be used in other programs.

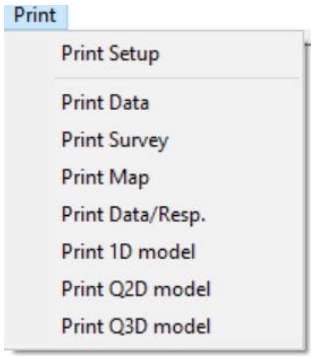


NOTE: The option Save data only save activated channels.

8. Print results

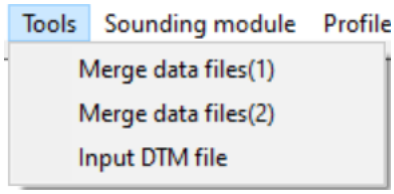
Figures can be printed. Choose in Print Setup the file format.

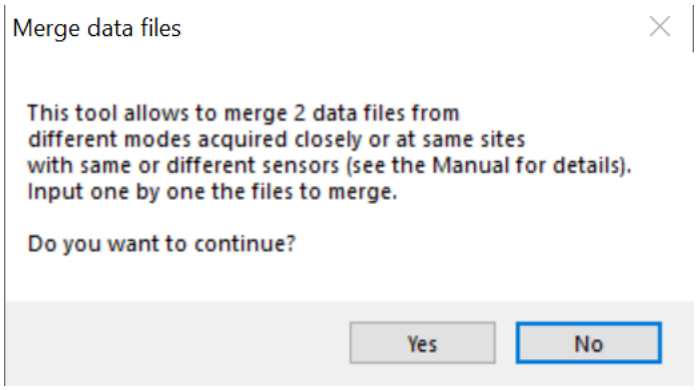
For models the program prints the figure which is displayed in the screen. To get all slices print, all of them must be displayed in the screen before go for print (print only when the last slice is in the screen).



9. Tools

Merge files

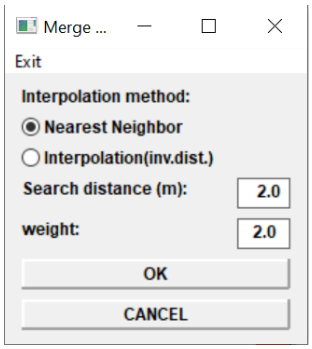




Steps to merge files:

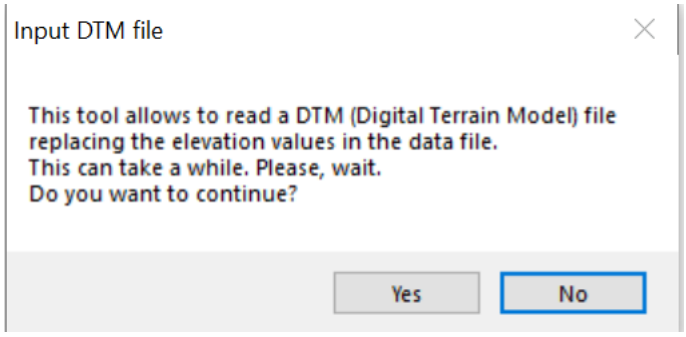
- Select the correct instrument.
- Go to Tool/merge data files.
- Input the XYZ files to merge one by one starting with the file having the data for the shortest Tx-Rx distance (or with the file with VMD data).
- Finish pushing the CANCEL button.

- Save the merged file.



Because the lines are not coincident, we must interpolate using the first line as a reference for the position. Using the weight value is not important if we use the nearest option. Finally, we can push OK and give the output file name.

Include UTM coordinates



10. Files Formats

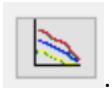
Input data (EM soundings)

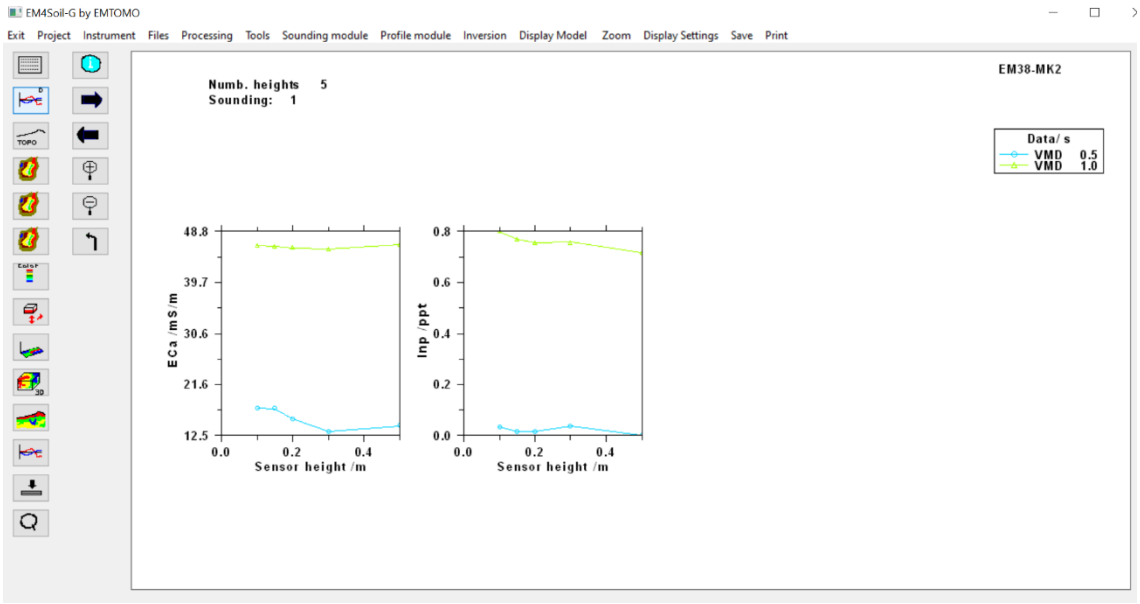
Files containing EM soundings have the same format of the data line file, except that the instrument height must be included in the first column. The format is (row by row),

site
number of heights, heights of sensors replaced by 0
header
data height by height.

Example (synthetic data) of an EM sounding data file (EM38-MK2), collected at a site of coordinates X=0, Y=0, Z=0, with the sensor at 6 heights (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 m).

```
site1
6 0 0 0 0
hs,x,y,z,v1,h1,v2,h2,lat,lon,time
0.0  0 0 0   18.828  26.680     36.484  28.047  0   0  0
0.2  0 0 0     18.555  14.180     31.641  23.789  0   0  0
0.4  0 0 0     15.781  9.609      29.102  19.805  0   0  0
0.6  0 0 0     13.398  8.008      26.563  17.383  0   0  0
0.8  0 0 0     11.680  6.133      23.867  14.648  0   0  0
1.0  0 0 0     10.703  6.133      21.523  13.125  0   0  0
```

This data does not contain in-phase data. Only VMD and HMD apparent conductivity data. Display of the EM sounding  .



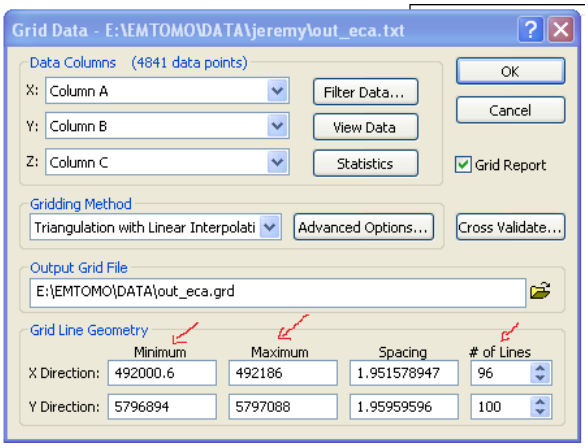
Here an example of a survey data file (EM38-MK2) with both modes and ECa and inphase data,

```
//UTM zone 11,  Datum: WGS84
//Easting[m], Northing[m], CV-1.0m, IV-1.0m,CH-1.0m, IH-1.0m, CV-0.5m, IV-0.5m,CH-0.5m, IH-0.5m, Quality, Sat, HDOP, Elevation, Time
LINE 0
 284954.245     4051297.18     46.211  0.795   55.4532 14.6583 17.344  0.059   31.2073 9.3012  1       10      0.8     110.724  13:03:59.211
284954.163      4051297.066    46.172  0.766   55.4064 14.6176 17.305  0.042   31.1566 9.2764  1       10      0.8     110.743  13:03:59.401
284954.08       4051296.952    45.859  0.752   55.0308 14.5097 15.391  0.043   29.1487 9.2148  1       10      0.8     110.762  13:03:59.591
284953.997      4051296.838    45.547  0.754   54.6564 14.4181 13.164  0.063   26.8281 9.1724  1       10      0.8     110.781  13:03:59.781
284953.916      4051296.761    46.445  0.715   55.734  14.6485 14.258  0.028   28.1915 9.317   1       10      0.8     110.801  13:03:59.970
284953.835      4051296.752    47.461  0.697   56.9532 14.9353 15.117  -0.001  29.3553 9.4912  1       10      0.8     110.82   13:04:00.160
284953.755      4051296.775    46.641  0.674   55.9692 14.6663 16.172  -0.009  30.1643 9.3192  1       10      0.8     110.839  13:04:00.350
284953.674      4051396.798    45.43   0.67    54.516  14.299  17.227  -0.015  30.856  9.071   1       10      0.8     110.858  13:04:00.540
284953.593      4051396.821    45.195  0.661   54.234  14.2195 17.031  -0.005  30.5895 9.034   1       10      0.8     110.877  13:04:00.730
284953.493      4051396.842    44.688  0.742   53.6256 14.1484 17.148  0.008   30.5544 8.9456  1       10      0.8     110.896  13:04:00.919
284953.313      4051396.855    44.336  0.756   53.2032 14.0568 14.492  0.02    27.7928 8.8872  1       10      0.8     110.929  13:04:01.109
284963.064      4051396.861    44.766  0.758   53.7192 14.1878 12.773  0.038   26.2028 8.9912  1       10      0.8     110.967  13:04:01.299
284962.815      4051396.867    45.273  0.744   54.3276 14.3259 12.578  0.017   26.1599 9.0716  1       10      0.8     111.005  13:04:01.489
```

Grid formats (EMG and Surfer files)

EMG files are generated by EM4Soil-G (gridding option in data processing). These files are the output of the interpolation process applied to data covering a zone (area) to have a regular grid of measurements.

The other grid files are the GRD Surfer 6 text grid files generated with SURFER. A GRD file must be generated for each sensor and for the topography, too. The number of rows (Ny) and columns (Nx) must be the same in each file. In general, the surveys made with different instruments do not cover the same areas. To have the same Nx and Ny in all surfer files the Minimum and Maximum values (in the Output Grid Geometry) must correspond to an area that is common to all surveys. Such values, as well as, the #of Lines must be the same for all created output files.



GRD files can be used to input data if a Mix Instrument was defined.

Using Mix Instrument data can be input in the “standard EM4Soil-G format” which is as follows (row by row):

Name of the survey
Number of sites, height of the sensors
X Y Z vmdECa1 vmdInp1 hmdECa1 hmdInp1….. lat long time
…..data values…

Example (EM31, only VMD and HMD ECa data):

```
line  29
        19   1.00000000       1.00000000
     X                    Y                    Z                    vmd                  hmd                  lat                  long                 time
   635664.04279096785   4890220.3176090308   10.0000000   17.3333340   10.2025452   4890220.3176090308   635664.04279096785   0.00000000
   635658.78313887783   4890219.3201439623   10.0000000   16.6666679   9.43460655   4890219.3201439623   635658.78313887783   0.00000000
   635655.55250974873   4890216.9199862201   10.0000000   14.6666670   9.19670105   4890216.9199862201   635655.55250974873   0.00000000
   635650.77037960978   4890216.0434983186   11.0000000   14.0000010   8.42876244   4890216.0434983186   635650.77037960978   0.00000000
   635645.80103728443   4890212.6074024122   11.0000000   20.3333340   12.5145931   4890212.6074024122   635645.80103728443   0.00000000
   635641.43249741290   4890211.0727357194   12.0000000   26.6666679   16.0858307   4890211.0727357194   635641.43249741290   0.00000000
   635636.19116342172   4890209.1867106622   12.0000000   33.0000000   21.1793041   4890209.1867106622   635636.19116342172   0.00000000
   635631.42506225395   4890207.5327310022   11.0000000   31.4000015   21.0934734   4890207.5327310022   635631.42506225395   0.00000000
```

1D initial model

Files with 1D initial model have the following format (row by row):

Nlayers
Depth of the bottom of the layers (nlayers-1 values) in meters
Conductivity of each layer (in mS/m)
Magnetic susceptibility (in ppt)

Example of a model with 5 layers with constant 20 mS/m conductivity and magnetic susceptibility 10 ppt.

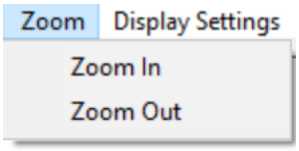
```
5
10.3      0.6  0.9  1.2
20   20  20  20  20
10   10  10  10  10
```

The initial model for the 2DLIN models has the same format. However, the number of layers and the maximum reached depth should be approximately twice of the maximum depth reached by the instrument.

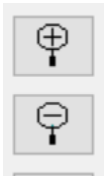
```
18
0. 3. 6. 10. 15. 20.  25.  30. 35. 40.  45. 50. 60. 70.  80. 90. 100. 120.
70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
```

11. Zoom

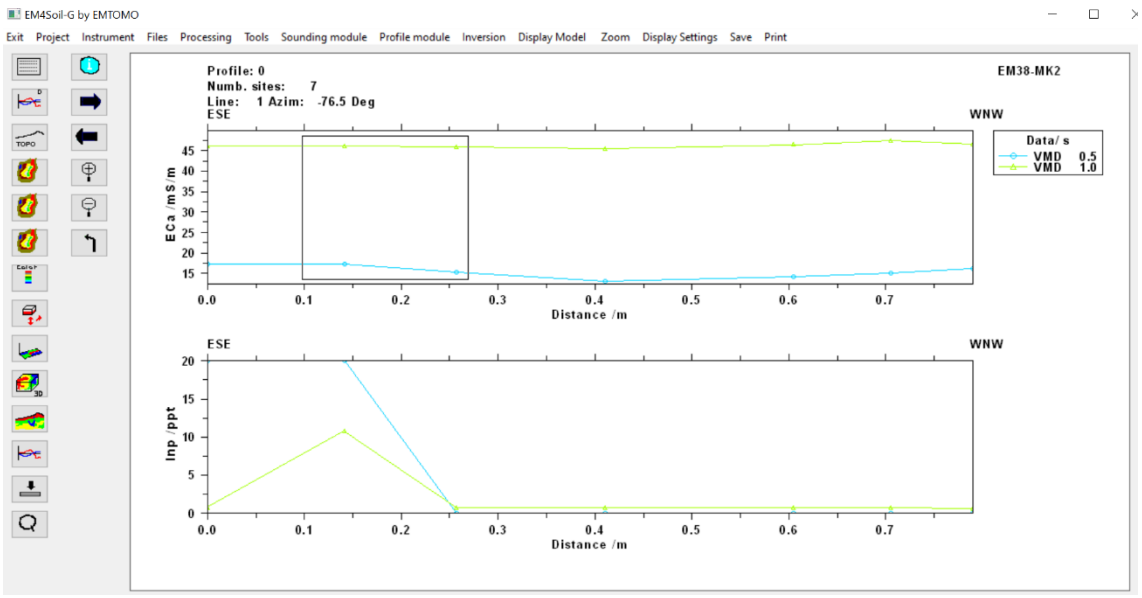
Zoom of maps or in line data display are accessible through the entrance.



Or,



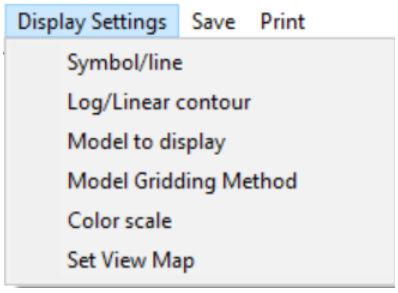
The mouse pointer will change into a cross. Define a rectangle around the area to zoom keeping the left button pushed. Leave it when has the rectangle defined.



With an “in line” data display and with zoom in applied, the two buttons,

Allow to move along the line, displaying short portions of the data.

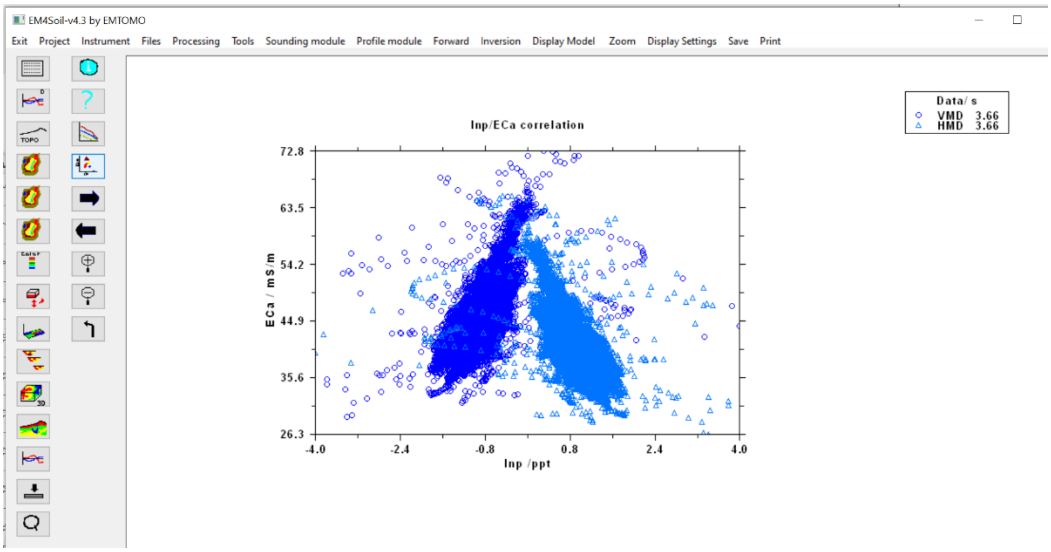
12. Display settings



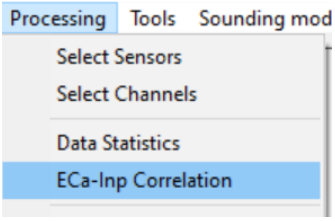
Allows to modify some characteristics of the display of some results (data, models, maps,..).

13. ECa and inphase data correlation

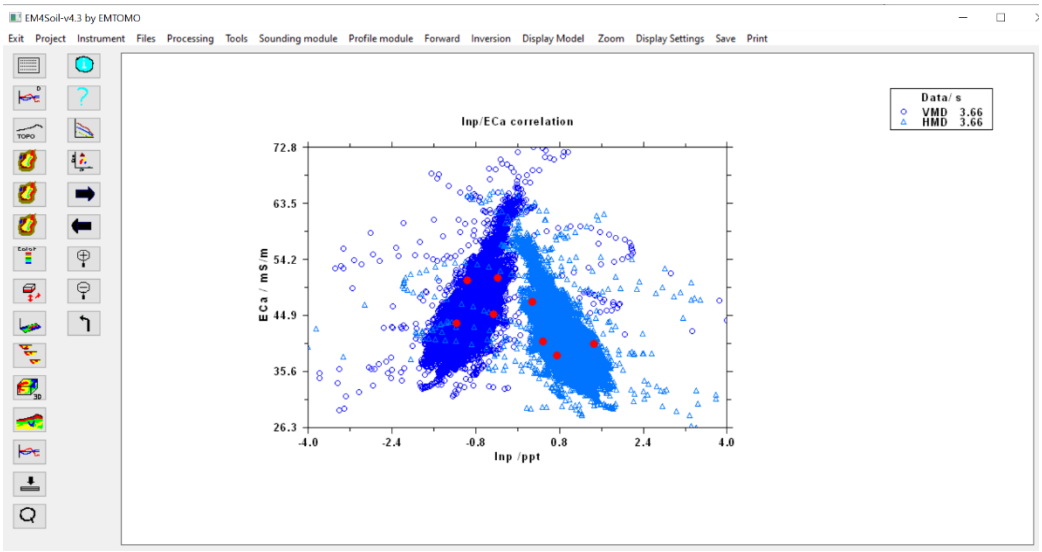
Inphase data can be important to detect high conductive materials or map magnetic susceptibility. The correlation between apparent conductivity and inphase data can give useful indications. EM4Soil-G allows to do and display such correlation. Pushing



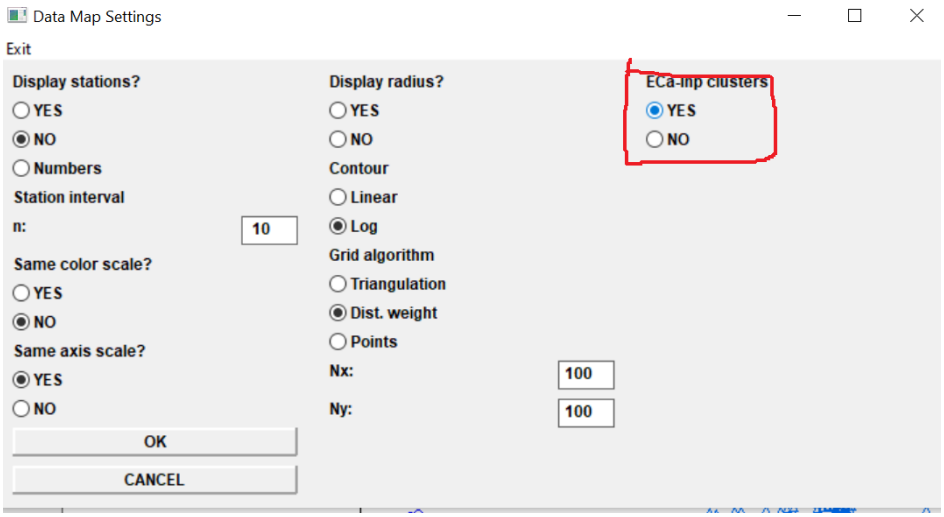
Define the clusters,



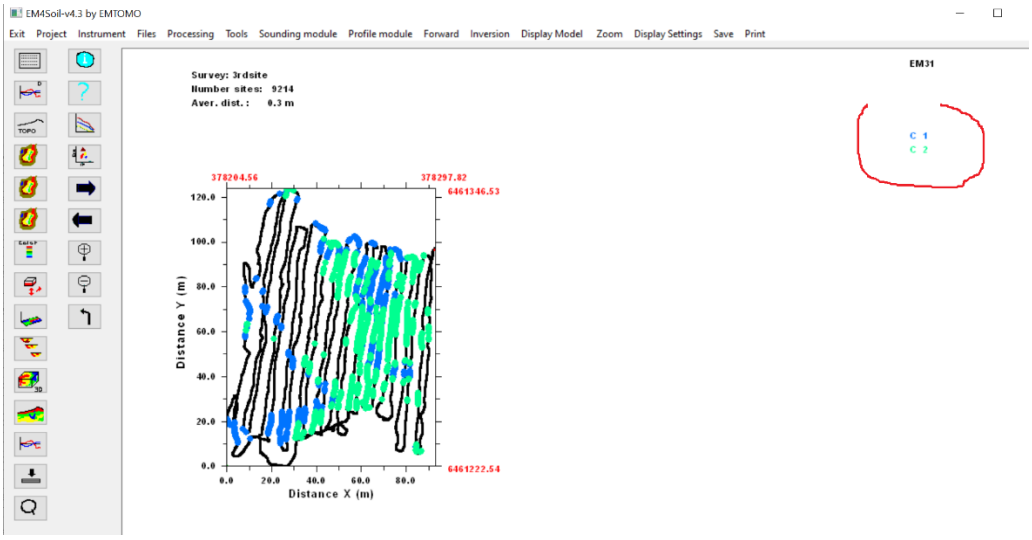
Using the left button to mark points to circulate the clusters (always clockwise) and finish pushing the right button.



Select the option to display the cluster in  ,



Display the survey to see the clusters position,



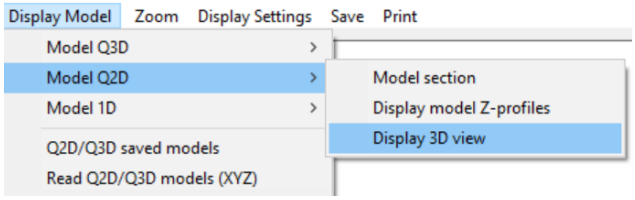
NOTE 1: the sites included in the clusters are in the file **Clusters_Report.tmp** localized in the \outs folder. This file is deleted each time the process is ran. Rename the file if you want to keep it.

NOTE 2: data used in this example are not realistic.

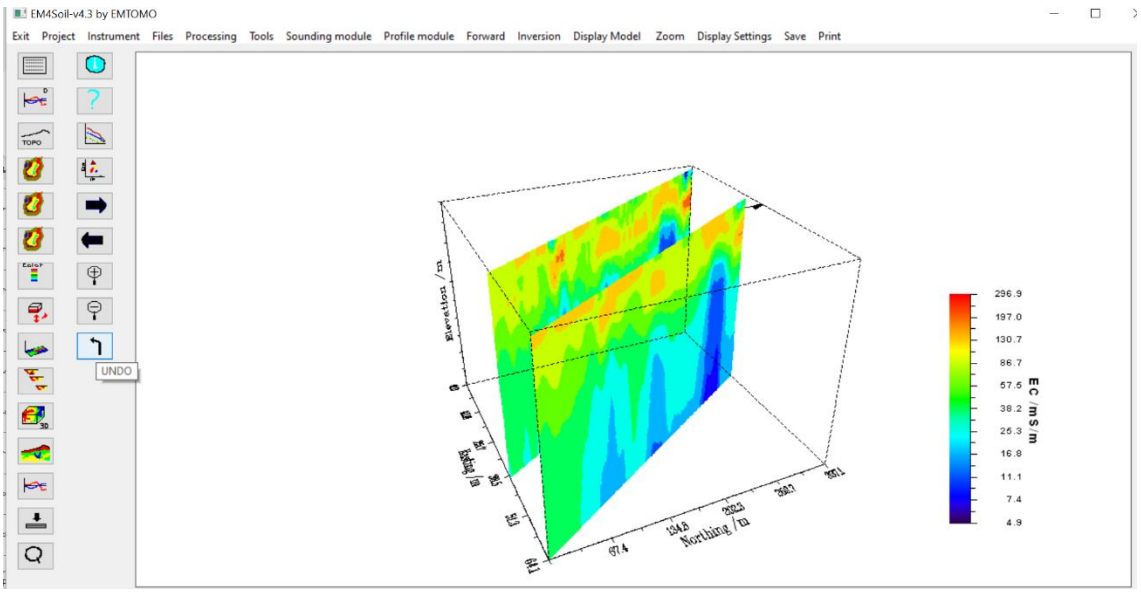
14. 3D view of Q2D models

The Q2D models can be displayed in a 3D view. The process uses the (XYZ) files saved after the inversion. He steps are:

- Input the files with models,



- The pseudo-sections will be displayed,



The colour scale and models view can be modified through the use of  and  . The display can be repeated pushing  .

15. How to use the program (workflow)

- Select the instrument,
- Merge data files if necessary,
- Create a new project (always use a different name),
- Input the data,
- Select a profile to process and invert (if you have profiles),
- Process the data (delete negatives ECa values; apply filter, etc),
- Select the channels (in this version only ECa data can be inverted so, disable Inp data),
- Invert the data (profile or survey),
- Display results,
- Save/print results,
- Save the project,
- QUIT the program.