User manual for FDEMtools3

G. P. Deidda[*] P. Díaz de Alba[†] F. Pes[‡] G. Rodriguez[§]

FDEMtools3 package consists of a set of MATLAB routines for the forward and inverse computations of frequency domain electromagnetic (FDEM) data. In addition to all the solution routines, the package also includes test problems on synthetic and experimental data sets, which allow the user to experiment with different numerical strategies, compare the results, and draw conclusions. The package includes one graphical user interface (GUI) called `FDEMforward` for the forward model and one GUI called `FDEMinversion` for the inversion problem.

A first version of `FDEMinversion` can be found in

- G. P. Deidda, P. Díaz de Alba, C. Fenu, G. Lovicu, and G. Rodriguez.
  FDEMtools: a MATLAB package for FDEM data inversion
  Numer. Algorithms., 84(4): 1313-1327, 2020. DOI: 10.1007/s11075-019-00843-2.

An updated version of `FDEMinversion` together with the new GUI `FDEMforward` for the forward problem is contained in the present paper

- G. P. Deidda, P. Díaz de Alba, F. Pes, and G. Rodriguez.
  Forward electromagnetic induction modelling in a multilayered half-space: An open-source software tool
  Submitted

to which the software is attached.

The package is distributed as a compressed archive. Uncompressing the file creates the directory `FDEMtools3`. To be able to use the package from other directories, its name must be added to the MATLAB search path, either by the command `addpath` or by using the menu in the graphical user interface of MATLAB. The toolbox content are described in detail in the `Contents.m` and `README.txt` files, located in the main directory. The software uses some functions from the package *Regularization Tools*, created by P. C. Hansen (see `http://people.compute.dtu.dk/pcha/Regutools/index.html` for information). This software package can be downloaded at the website `https://it.mathworks.com/matlabcentral/fileexchange/52-regtools`, and should be installed and added to the search path, before using `FDEMtools3`. The MATLAB PDF reader should also be configured.

For any comment or suggestion about the computer code, contact by e-mail any of the authors. The package will be available also at the website `http://bugs.unica.it/cana/software`

[*]Department of Civil and Environmental Engineering and Architecture, University of Cagliari, 09123 Cagliari, Italy (gpdeidda@unica.it).

[†]Department of Mathematics, University of Salerno, 84084 Fisciano (Italy) (pdiazdealba@unisa.it).

[‡]Department of Chemistry and Industrial Chemistry, University of Pisa, 56124 Pisa (Italy) (federica.pes@dcci.unipi.it).

[§]Department of Mathematics and Computer Science, University of Cagliari, 09124 Cagliari (Italy) (rodriguez@unica.it).

1 FDEM graphical user interface

The toolbox includes a main MATLAB graphical user interface (GUI). It is started by issuing the command `FDEM` in the MATLAB command window (see Fig. 1).

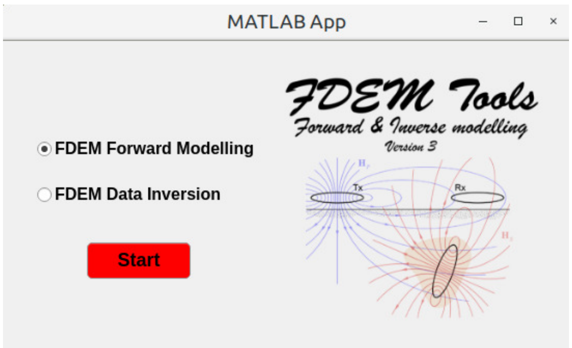


Figure 1: FDEM Graphical User Interface

Once the window is opened, the user can choose between working with FDEM Forward Modelling, and so `FDEMforward` will be opened, or working with FDEM Data Inversion, and so `FDEMinversion` will be opened.

2 FDEMforward graphical user interface

In order to simplify experimenting with the functions of the package, the toolbox includes a MATLAB graphical user interface (GUI). It is started from the FDEM window described in Section 1 or directly by issuing the command `FDEMforward` in the main MATLAB window; see Figure 2.

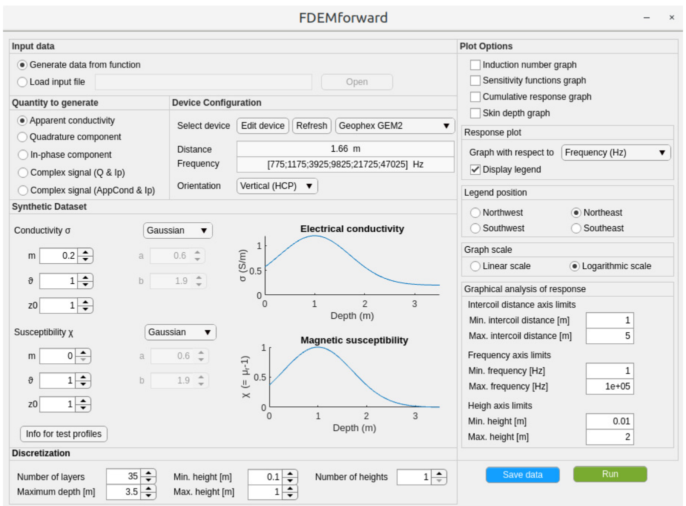


Figure 2: FDEMforward Graphical User Interface

It is composed of a set of input panels that let the user generate or load data sets, choose different approaches and parameters and, finally, visualize the computed results. Each panel is briefly described in the following paragraphs:

- **Input data**. This block allows the user to choose between generating the input data from synthetic profile functions or working with experimental data.

  If *Generate data from function* is chosen, the *Synthetic Dataset* pannel is activated and the user can set the profiles functions for both the electrical conductivity and the magnetic permeability. A pdf with the different profiles information cam be opened by clicking the *Info for test profiles* button. If, on the contrary, the user wants to process experimental data profiles and *Load input file* is chosen, a `.mat` file must be loaded. The data set contained in the file has to be encoded using the data structure described in Section 2.2. An error message window will appear on the screen when an empty data file is loaded; see Figure 3.

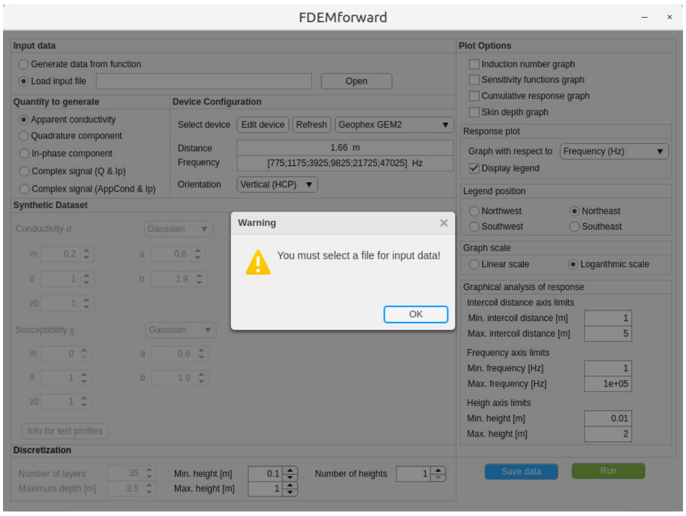


Figure 3: Warning message when an empty file data is loaded.

- **Quantity to generate**. Here, the user can decide which physical quantity wants to compute, i.e, *Apparent conductivity*, *Quadrature component*, *In-phase component*, *Complex signal Q & Ip* (quadrature and in-phase), or *Complex signal AppCond & Ip* (apparent conductivity and in-phase).

- **Device Configuration.** In this panel, the device can be selected from a list. Each stored device corresponds to a particular configuration, i.e., inter-coil distances ρ_i and frequencies f_i. The orientation of the device coils must be selected too, choosing it between: *Vertical (HCP)*, *Horizontal (VCP)*, *Perpendicular (PERP)*, *V+H (HCP+VCP)*, or *V+P (HCP+PERP)*.

  If a new configuration is needed, and is not present in the available list, it can be added by selecting the button *Edit device*. To refresh the whole panel, click the *Refresh* button.

- **Synthetic Dataset.** Using this block, the user can generate a dataset, by choosing a model function and by tuning other parameters. A few different profiles for both the electrical conductivity and the magnetic permeability are provided; more information on them can be visualized by clicking on the *Info for test profiles* button.

- **Discretization.** This block contains some useful controls to define the discretization of the subsoil, such as *Number of layers* and *Maximum depth*. In case multiple measurements are taken by placing the device at different heights above the ground surface, this section allows the user to configure the *Number of heights*, the *Min. height* and the *Max. height*, which represent, respectively, the number of heighs, the minimal height and the highest position at which the measurements are taken, all of them measured in meters.

- **Plot options.** In this section, the user can modify some parameters that influence the computation of the device readings.
  - *Induction number graph*. Allows the user to display the induction number graph.
  - *Sensitivity functions graph*. Allows the user to display the sensitivity functions graph.
  - *Cumulative response graph*. Allows the user to display the cumulative response graph.
  - *Skin depth graph*. Allows the user to display the skin depth graph.
  - *Graph with respect to*. Gives to the user the possibility of displaying the final results either with respect to the Ratio, Frequency or Height.
  - *Display Legend*. The user can activate or deactivate the legend in the final results graphs.
  - *Legend position*. If *Display Legend* is chosen, the user has the possibility to decide the position of the legend box in the final results graphs.
  - *Graph scale*. Two different scales (*Linear* or *Logarithmic*) can be chosen for the final results graphs.
  - *Graphical Analysis of response*. In this pannel, the user can choose the minimal and the maximal value for axis limits in the final graphs.

The computation is started by the *Run* button; the computed results can be saved in both the MATLAB workspace and in a MATLAB data file by clicking on *Save data*.

2.1 Tutorial for running numerical experiments

This section is a tutorial for running the test script `driverforward` included in the package, and for repeating the same computation by using the `FDEMforward` graphical interface.

Let the user run the whole algorithm to get complex (inphase and apparent conductivity) readings, starting from synthetic models for the electrical conductivity and the magentic permeability. The resulting measurements are generated by the Explorer device configuration, corresponding to the inter-coil distance 1.48 m, 2.82 m, and 4.49 m and a frequency of 10000 Hz, and both orientation of the coils, placed at a height of 0.01 m.

Moreover, the script displays different graphs corresponding to the conductivity and permeability profiles, the skin depth, the induction number, the sensitivity functions and the cumulative response with respect to both the conductivity and the permeability, and the final results plotted with respect to the frequency.

For repeating the computation performed by the script `driverforward` using the graphical interface `FDEMforward`, the user has to select *Generate data from function* as *Input data*, *Complex Signal (AppCond & Ip)* as *Quantity to generate*, and enter the Explorer as the device configuration, with the orientation of the device set to *V+H (HCP+VCP)*. In the *Synthetic Dataset* panel, the user should choose the Gaussian test function for both the quantities with the following parameters for the electrical conductivity

- *m*: 0.2;
- θ: 1;
- z_0: 1;

and the following parameters for the magnetic susceptibility

- *m*: 0;
- θ: 1;
- z_0: 1.

Then, let the user define some other parameters for the discretization of the problem:

- *Number of layers*: 35;
- *Maximum depth*: 3.5 m;
- *Number of heights*: 1;
- *Min. height*: 0.01 m;
- *Max. height*: 1 m (in this case we consider the device placed at a fixed height, that is, the one to which "maximal height" corresponds).

In the *Plot options* panel, the user should choose *Induction number graph*, *Sensitivity functions graph*, the *Cumulative response graph*, *Skin depth graph*, and set the *Graphic with respect to Frequency*, and *Display legend* at the *Northeast* position. *Graph scale* should be set as *Logarithmic scale* and in the *Graphical analysis response* panel the following parameters:

- *Min. intercoil distance [m]*: 1;
- *Max. intercoil distance [m]*: 5;
- *Min. frequency [Hz]*: 1;
- *Max. frequency [Hz]*: 10^5;
- *Min. height [m]*: 0.01;
- *Max. height [m]*: 2;

When the *Run* button is clicked, the computation is performed and the results are displayed.

2.2 File structure for loaded experimental data

In this section, we describe the data structure used by `FDEMforward` as an input file, and we briefly explain how to create such a data structure from an Excel file which contains experimental data.

The input data is encoded in a MATLAB structure array; type `help struct` in the MATLAB command window for more information. The fields for this structure array are listed in Table 1.

Table 1: Input data structure for FDEMforward

`FDEMmodel.name`	name for the data set (string)
`FDEMmodel.z`	depth in meters (vector)
`FDEMmodel.sigma`	electrical conductivity in S/m (vector)
`FDEMmodel.mu`	magnetic permeability in H/m (vector)
`FDEMmodel.info`	information about the data set (string)

A similar structure array is used for encoding the output of the whole algorithm, when it is written in a data file; its fields are displayed in Table 2.

Table 2: Output data structure for FDEMforward

`FDEMdata.name`	name for the data set (string)
`FDEMdata.R`	intercoil distances (scalar or vector)
`FDEMdata.freq`	device frequencies (scalar or vector)
`FDEMdata.height`	device heights (scalar or vector)
`FDEMdata.vdata`	data for the vertical orientation (matrix)
`FDEMdata.hdata`	data for the horizontal orientation (matrix)
`FDEMdata.pdata`	data for the perpendicular orientation (matrix)
`FDEMdata.orient`	orientation ('vertical', 'horizontal', 'perpendicular', 'vh', or 'vp')
`FDEMdata.coors`	geographical coordinates for each sounding (matrix)
`FDEMdata.type`	either 'real', 'imag', or 'complex'
`FDEMdata.device`	device model (string)
`FDEMdata.info`	information about the data set (string)

We want to remark here that the structure of the output data of `FDEMforward` coincides with the structure of the input data of `FDEMinversion`. Moreover,

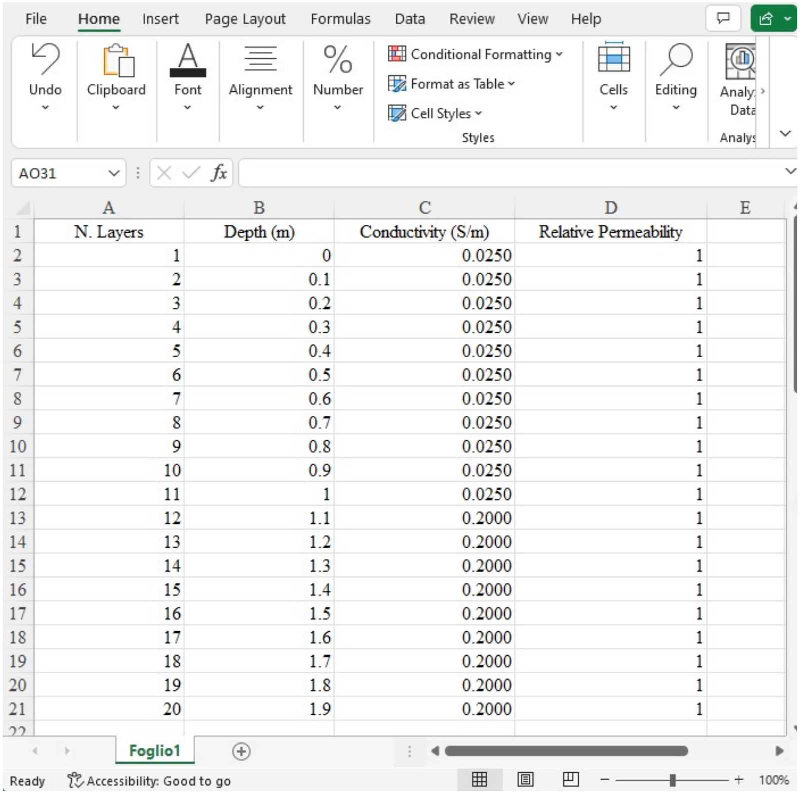
- if `type='complex'`, then both vdata and hdata are complex arrays, otherwise they are real arrays;
- if one of the orientations of the coils is not used, the corresponding data matrix (FDEMdata.vdata or FDEMdata.hdata) is empty;
- the coors field is a matrix with three columns, each row containing the three coordinates (generally read by a GPS) for the corresponding sounding.

The Excel file `example.xlsx`, contained in the *dataforward* subdirectory of the `FDEMtools3` main directory and represented in Figure 4, contains the experimental profiles for the electrical conductivity and the relative magnetic permeability together with the number of layers and the depth vector measured in meters.

The Excel file is structured as follows:

- Column A: contains the number of the layers;
- Column B: corresponds to depth vector in meters;
- Column C: represents the value of the electrical conductivity in each layer measured in S/m;
- Column D: represents the value of the relative magnetic permebaility in each layer;

The MATLAB routine `converter.m`, located in the same *dataforward* subfolder, reads the Excel file and creates the structure array `FDEMmodel` containing the dataset. Finally, it saves the data to a `.mat` file, which will be easily loaded using either the `FDEMforward`, or the `driverforward.m` example script. Here is how the newly created structure array is represented in the MATLAB command window:



N. Layers	Depth (m)	Conductivity (S/m)	Relative Permeability
1	0	0.0250	1
2	0.1	0.0250	1
3	0.2	0.0250	1
4	0.3	0.0250	1
5	0.4	0.0250	1
6	0.5	0.0250	1
7	0.6	0.0250	1
8	0.7	0.0250	1
9	0.8	0.0250	1
10	0.9	0.0250	1
11	1	0.0250	1
12	1.1	0.2000	1
13	1.2	0.2000	1
14	1.3	0.2000	1
15	1.4	0.2000	1
16	1.5	0.2000	1
17	1.6	0.2000	1
18	1.7	0.2000	1
19	1.8	0.2000	1
20	1.9	0.2000	1

Figure 4: Excel file containing the experimental profiles for the electrical conductivity and the relative magentic permeability.

```
FDEMmodel =
  struct with fields:
      name: 'example'
         z: [20x1 double]
     sigma: [20x1 double]
        mu: [20x1 double]
      info: 'example'
```

After inspecting the `converter.m` script, it should be easy for the user to modify it, in order to convert Excel files with a similar layout to a suitable format for `FDEMforward`.

3 FDEMinversion graphical user interface

In this case, the `FDEMinversion` is started from the FDEM window described in Section 1 or directly by issuing the command `FDEMinversion` in the main MATLAB window; see Figure 5.

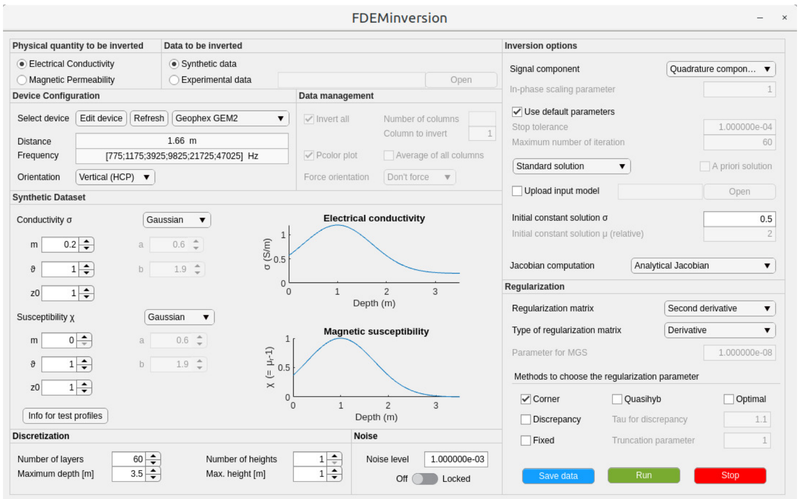


Figure 5: FDEMinversion Grphical User Interface..

It is composed of a set of input panels that let the user generate or load data sets, choose different approaches and parameters for the inversion algorithm and, finally, visualize the computed results. Each panel is briefly described in the following paragraphs:

- **Physical quantity to be inverted**. This block allows the user to choose the physical quantity to be reconstructed, i.e., either the electrical conductivity or the magnetic permeability of the soil.

- **Data to be inverted**. Here, the user chooses between inverting synthetic or experimental data.

  If synthetic data is chosen, the **Device configuration** panel is activated, where the user can select the device configuration for generating the data; see next paragraph for more information about this panel. If, on the contrary, the user wants to process experimental data, a `.mat` file must be loaded. The data set contained in the file has to be encoded using the data structure described in Section 3.2.

  An error message window similar to the one in the forward case will appear on the screen when an empty data file is loaded.

- **Device configuration.** When this panel is activated, the device can be selected from a list. Each stored device corresponds to a particular configuration, i.e., inter-coil distances ρ_i and frequencies f_i. The orientation of the device coils must be selected too.

  If a new configuration is needed and is not present in the available list, it can be added by selecting the button *Edit device*. To refresh the whole panel, click the *Refresh* button.

- **Data management.** When this panel is activated, the user can choose between inverting all the columns (i.e., measurements) contained in a data set loaded from a file (*Invert all*), or select just one column by clicking on *Number of columns* and choosing the column to process. Another possibility, in the case of a data set containing repeated measurements, is to consider an average of all columns, by selecting the option *Average of all columns*. If more than one column is being processed, a 2D plot will be displayed during the computation if *Pcolor plot* is selected.

- **Synthetic dataset.** This block allows the user to generate a data set, by choosing a model function and by tuning other parameters. A few different profiles for both the electrical conductivity and the magnetic permeability are provided; more information on them can be visualized by clicking on the *Info for test profiles* button.

- **Discretization.** This block contains some controls useful to define the discretization of the subsoil, such as *Number of layers*, *Maximum depth*, *Number of heights*, and *Maximal height*. In case multiple measurements are taken by placing the device at different heights above the ground surface, this section allows the user to configure the *Number of heights*, and the *Max. height*. This last option represents the highest position at which the measurements are taken.

- **Noise.** The *Noise* panel allows the user to select the noise level. This is useful to generate noisy synthetic data sets, but the selected noise level is also used for experimental data, in case the discrepancy principle is applied to estimating the regularization parameter. The *Locked* switch configures the random number generator so that exactly the same noise is generated upon subsequent computations; this is useful to experiment with a particular synthetic data set by varying some of the inversion parameters.

- **Inversion options.** In this section, the user can modify some parameters that influence the inversion process:

  – *Signal component*. Selection of the signal component to be inverted. It can be the in-phase component (i.e., the real part) of the signal, the quadrature component (the imaginary part), or the complex signal in its entirety.

  – *In-phase scaling parameter*. Positive parameter β used for scaling the in-phase component of the signal when complex data are inverted; see references in the paper.

  – The *Stop tolerance* and *Maximum number of iteration* are set to fixed values by default. If the user wants to modify them, unselect *Use default parameters*.

  – *Minimal norm solution*. This drop menu allows the user to use different methods to find the solution. The options are Standard algorithm (GN), MNGN solution, MNGN(α), MNGN(α, β) solution. and MNGN(α, β, δ). For detailed information about the algorithms see

    F. Pes and G. Rodriguez. *A doubly relaxed minimal-norm Gauss-Newton method for underdetermined nonlinear least-squares problems*. Appl. Numer. Math., 171:233-248, 2022. DOI: $10.1016/j.apnum.2021.09.002$.

    The option *A priori solution* is automatically activated for a non standar solution. The user can disactivated it.

  – *Upload input model*. Here, the user has the choice of uploading an input initial model for either the elctrical conductivity or the magnetic permeability. When this option is chosen, *Initial constant solution* σ and *Initial constant solution* μ are disactivated.

  – *Initial constant solution* σ. Sets the initial solution vector for the inversion of the electrical conductivity.

  – *Initial constant solution* μ. Sets the initial solution vector for the inversion of the magnetic permeability.

  – *Jacobian computation*. This drop menu selects the method for computing the Jacobian matrix: analytical Jacobian, Broyden update, and finite difference approximation.

- **Regularization**. Some regularization parameters can be set for the inversion algorithm.
  - *Regularization matrix*. The available choices are the identity matrix, and either the first derivative or the second derivative discrete approximations.
  - *Type of regularization matrix*. The user can choose between the direct use of the above regularization matrices (*Derivative*) or the minimum gradient support (*MGS*) sparsity promoting approach; see references in the paper. In the last case, a further parameter (*Parameter for MGS*) has to be chosen.
  - *Methods for choosing the regularization parameter*. The available methods for choosing the regularization parameter are the following: L-curve (*Corner*), a variation of quasi-optimality (*Quasihyb*), and the optimal parameter (*Optimal*, only for synthetic data sets, as it makes use of the exact solution). More simply, it is also possible to fix a value of the TSVD/TGSVD truncation parameter by the *Fixed* option.

The computation is started by the *Run* button; the computed results can be saved to both the MATLAB workspace and a data file by clicking on *Save data*. The *Stop* button allows for interrupting the computation, in case something goes wrong.

3.1 Tutorial for running numerical experiments

This section is a tutorial for running the test scripts `driver` and `driver2D` included in the package, and for repeating the same computation by using the `FDEMinversion` graphical interface.

3.1.1 1D example

The 1D example included in the package runs a single inversion for the reconstruction of the electrical conductivity, starting from a complex synthetic data set. The data set is generated for a particular configuration of the Geophex GEM-2 instrument, corresponding to the inter-coil distance $1.66\,\mathrm{m}$, six frequencies ($f_i = 775Hz, 1175Hz, 3925Hz, 9825Hz, 21725Hz, 47025Hz$), both orientations of the coils, placed at a height of 1 m. The algorithm is regularized by the second derivative operator and the L-curve method is used to choose the regularization parameter.

For repeating the computation performed by the script `driver` using the graphical interface `FDEMinversion`, the user has to select *Electrical conductivity* as the physical quantity to be reconstructed, choose *synthetic data* as the data to invert, and enter the Geophex GEM2 as the device configuration, with the orientation of the device set to *V+H (HCP+VCP)*. In the Synthetic Dataset panel the user should choose the Gaussian test function for both the profiles, and set the following parameters for the electrical conductivity

- *m*: 0.2;
- θ: 1;
- z_0: 1;

and the following parameters for the susceptibility

- *m*: 0;
- θ: 1;
- z_0: 1.

Then, define some parameters for the discretization of the problem:

- *Number of layers*: 35;
- *Maximum depth*: 3.5 m;
- *Number of heights*: 1;
- *Maximal height*: 1 m (in this case we consider the device placed at a fixed height, that is, the one to which "maximal height" corresponds);
- *Noise level*: 10^{-3}.

About the inversion options, the user should choose the *complex signal* as the signal component with the scaling factor for the in-phase component set as 1, click *use default parameters*, *standard solution*, fix the *initial solution* as 0.5, and finally choose the analytical expression of the Jacobian matrix (*Analytical Jacobian* option).

Finally, the regularization matrix should be the *Second Derivative* operator, the type of regularization matrix fixed as *Derivative*, and the method to choose the regularization parameter set to *Corner*.

When the *Run* button is clicked, the computation is performed and the results are displayed.

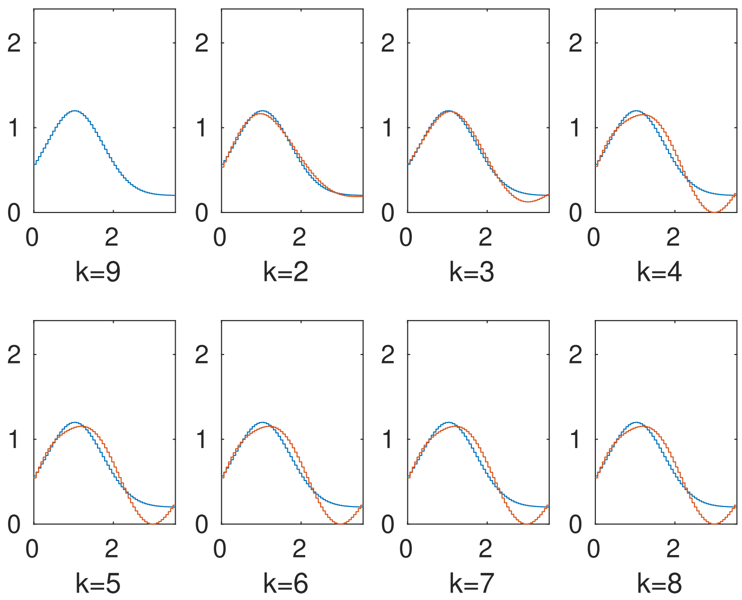


Figure 6: Reconstruction of the electrical conductivity from synthetic data. The figure displays the regularized solutions $\boldsymbol{\sigma}^{(k)}$ for $k = 1, \ldots, 8$.

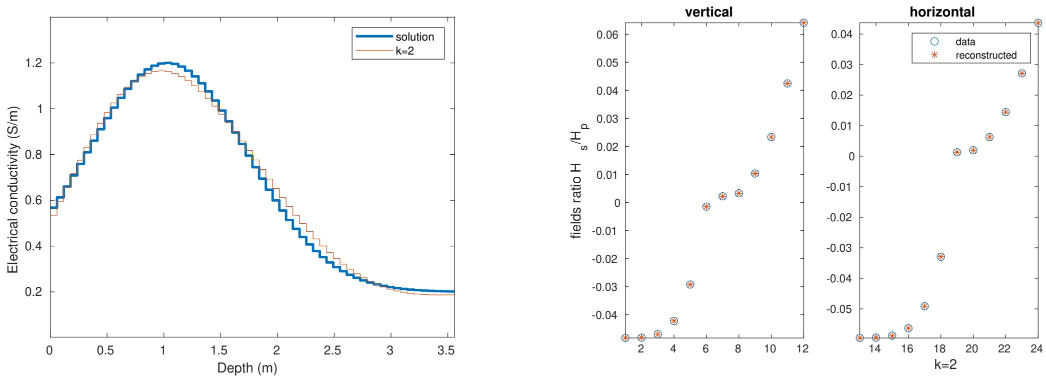


Figure 7: Reconstruction of the electrical conductivity from synthetic data. On the left, the solution selected by the L-curve method; on the right, the data fitting between the exact and reconstructed data.

Figure 6 displays the solutions computed by the regularized Gauss–Newton method. The graph on the left of Figure 7 reports the regularized solution selected by the L-curve method.

The graph on the right of Figure 7 shows the fitting between the input data set and the model prediction for the solution selected, for the two orientation of the coils. The order in which the data point are displayed is the internal ordering adopted in the package; see, e.g., the help for the `hratio` function.

3.1.2 2D example

The `driver2D` test script performs a pseudo-2D inversion in order to reconstruct the electrical conductivity starting from an experimental data set. The data corresponds to the Geonics EM38 configuration (the user should add it to the list of devices), with a pair of coils at distance $\rho = 1\,\mathrm{m}$, and operating at the frequency $f = 14600\,\mathrm{Hz}$. Also in this case, the algorithm is regularized by the second derivative operator and applies the L-curve method for the choice of the regularization parameter.

For performing the same computation using the graphical user interface `FDEMinversion`, we fix the susceptibility to 0 ($m = 0$ and $\theta = 0$). We set the following parameters for the discretization:

- *Number of layers*: 60;
- *Maximum depth*: 3.5m;
- *Number of heights*: 16;
- *Maximal height*: 1.5m.

This data set contains just the quadrature component of the signal, and this configuration option is automatically selected by the GUI. We set *standard solution*, the *initial solution* to 0.5, and choose the analytical expression of the Jacobian matrix (*Analytical Jacobian*).

Finally, the regularization matrix is the *Second derivative*, the type of regularization matrix is *Derivative*, and the method for the choice of the regularization parameter is *Corner*. In this case, rather than generating a synthetic data set, the user must load the file `test2Ddata.mat`, located in the subfolder *data* of the main FDEMtools directory. So, *Experimental data* must be checked, and the user should select, in the Data management panel, *Invert all* columns, *Don't force* the orientation, and make a *Pcolor plot*.

When the *Run* button is activated, the plot in Figure 8) is visualized. The results are saved in the file `FDEMoutput.mat` by clicking on *Save data*.

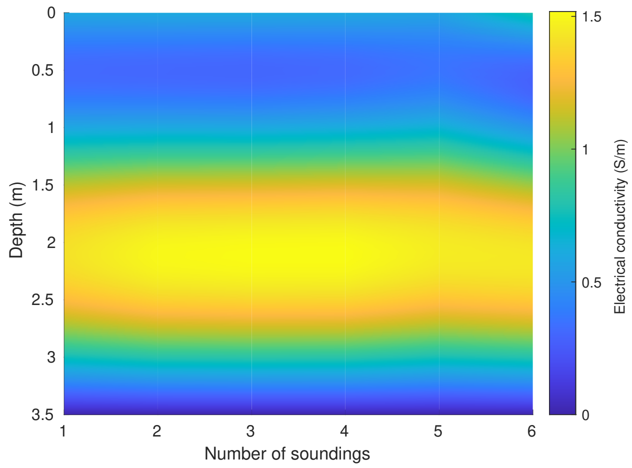


Figure 8: Test script `driver2D`: reconstruction of the electrical conductivity from experimental data.

3.2 File structure for loaded experimental data

In this section, we describe the data structure used by `FDEMinversion` as an input format, and we briefly explain how to create such a data structure from an Excel file which contains experimental data.

The input data is encoded in a MATLAB structure array; type `help struct` in the MATLAB command window for more information. The fields for this structure array are listed in Table 3. Here are some remarks:

- if `type='complex'`, then both `vdata` and `hdata` are complex arrays, otherwise they are real arrays;
- if one of the orientations of the coils is not used, the corresponding data matrix is empty;
- the `coors` field is a matrix with three columns, each row containing the three coordinates (generally read by a GPS) for the corresponding sounding.

Table 3: Input data structure for FDEMinversion.

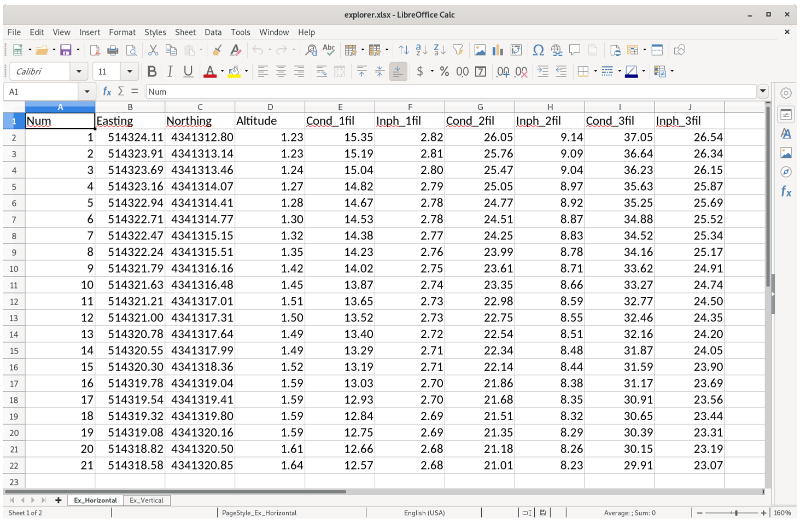
`FDEMdata.name`	name for the data set (string)
`FDEMdata.R`	coil distances (scalar or vector)
`FDEMdata.freq`	device frequencies (scalar or vector)
`FDEMdata.height`	device heights (scalar or vector)
`FDEMdata.vdata`	data for the vertical orientation (matrix)
`FDEMdata.hdata`	data for the horizontal orientation (matrix)
`FDEMdata.orient`	orientation ('vertical', 'horizontal', 'perpendicular', 'vh' or 'vp')
`FDEMdata.coors`	geographical coordinates for each sounding (matrix)
`FDEMdata.type`	either 'real', 'imag', or 'complex'
`FDEMdata.device`	device model (string)
`FDEMdata.info`	information about the data set (string)

A similar structure array is used for encoding the output of the inversion algorithm, when it is written in a data file; its fields are displayed in Table 4.

Table 4: Output data structure for FDEMinversion.

`FDEMresults.solution`	computed solutions (matrix)
`FDEMresults.model`	forward model adopted (function handle)
`FDEMresults.z`	subsoil discretization (vector)
`FDEMresults.parameter_choice`	method for choosing the regularization parameter (string)
`FDEMresults.opts`	inversion parameters setting (`struct`)
`FDEMresults.kappa`	regularization parameter (scalar)

The Excel file `explorer.xlsx`, contained in the `data` subdirectory of the FDEMtools main directory and represented in Figure 9, contains a set of soundings performed by a GF Intrument Explorer (three intercoil distances and one operating frequency). The two sheets contain the data recorded by the vertical and the horizontal orientations of the coil, respectively.



	A	B	C	D	E	F	G	H	I	J
1	Num	Easting	Northing	Altitude	Cond_1fil	Inph_1fil	Cond_2fil	Inph_2fil	Cond_3fil	Inph_3fil
2	1	514324.11	4341312.80	1.23	15.35	2.82	26.05	9.14	37.05	26.54
3	2	514323.91	4341313.14	1.23	15.19	2.81	25.76	9.09	36.64	26.34
4	3	514323.69	4341313.46	1.24	15.04	2.80	25.47	9.04	36.23	26.15
5	4	514323.16	4341314.07	1.27	14.82	2.79	25.05	8.97	35.63	25.87
6	5	514322.94	4341314.41	1.28	14.67	2.78	24.77	8.92	35.25	25.69
7	6	514322.71	4341314.77	1.30	14.53	2.78	24.51	8.87	34.88	25.52
8	7	514322.47	4341315.15	1.32	14.38	2.77	24.25	8.83	34.52	25.34
9	8	514322.24	4341315.51	1.35	14.23	2.76	23.99	8.78	34.16	25.17
10	9	514321.79	4341316.16	1.42	14.02	2.75	23.61	8.71	33.62	24.91
11	10	514321.63	4341316.48	1.45	13.87	2.74	23.35	8.66	33.27	24.74
12	11	514321.21	4341317.01	1.51	13.65	2.73	22.98	8.59	32.77	24.50
13	12	514321.00	4341317.31	1.50	13.52	2.73	22.75	8.55	32.46	24.35
14	13	514320.78	4341317.64	1.49	13.40	2.72	22.54	8.51	32.16	24.20
15	14	514320.55	4341317.99	1.49	13.29	2.71	22.34	8.48	31.87	24.05
16	15	514320.30	4341318.36	1.52	13.19	2.71	22.14	8.44	31.59	23.90
17	16	514319.78	4341319.04	1.59	13.03	2.70	21.86	8.38	31.17	23.69
18	17	514319.54	4341319.41	1.59	12.93	2.70	21.68	8.35	30.91	23.56
19	18	514319.32	4341319.80	1.59	12.84	2.69	21.51	8.32	30.65	23.44
20	19	514319.08	4341320.16	1.59	12.75	2.69	21.35	8.29	30.39	23.31
21	20	514318.82	4341320.50	1.61	12.66	2.68	21.18	8.26	30.15	23.19
22	21	514318.58	4341320.85	1.64	12.57	2.68	21.01	8.23	29.91	23.07
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Figure 9: Excel file containing the experimental data to be inverted.

The Excel file is structured as follows:

- Column A: contains an order index for the measurements;

- Column B and C: correspond to the coordinates of the points at which the measurements have been taken;
- Column D: represents the elevation in meters;
- Columns E, G and I: contain the apparent conductivity in mS/m (that is, a rescaling of the quadrature component of the signal) for each of the three different intercoil distances;
- Columns F, H, and J: contain the in-phase component in ppt (parts per thousands) for each different intercoil distance.

The MATLAB routine `converter.m`, located in the same *data* subfolder, reads the Excel file and creates the structure array `FDEMdata` containing the data set. Finally, it saves the data to a `.mat` file, which will be easily loaded using either the GUI, or the `driver.m` example script. Here is how the newly created structure array is represented in the MATLAB command window:

```
FDEMdata =
  struct with fields:
      name: 'explorer_data'
         R: [3x1 double]
      freq: 10000
    height: 0.900000000000000
     vdata: [3x20 double]
     hdata: [3x20 double]
    orient: 'both'
     coors: [3x20 double]
      type: 'complex'
    device: 'CMD-Explorer'
      info: 'conversion example for CMD-Explorer'
```

After inspecting the `converter.m` script, it should be easy for the user to modify it, in order to convert Excel files with a similar layout to a format suitable for FDEMtools.