Manual for the inversion program

AarhusInv

November 2017, program version 8.11

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1. INTRODUCTION

This manual for the AarhusInv inversion program contains a detailed description of the formats of all input and output files. It does not contain detailed descriptions on the forward calculations or the inversion methodology. For these specific matters, we refer to the reference list below. Comments or suggestions improving this manual are more than welcome.

To use the program a registration form needs to be filled in. It can be found at our webpage: http://hgg.au.dk/download/inversionkernel/. Once registered, updates and other important information regarding the program will be notified via e-mail.

A program description and latest manual can be found at: http://hgg.au.dk/software/aarhusinv/.

1.1 Version information

This manual is written for the program version 8.11 (November 2017).

The program was formerly known and distributed under the name em1dinv, but was changed in 2012 to AarhusInv.

The program comes only in a 64 bit version (aarhusinv64.exe).

1.2 Program description

The AarhusInv is a program for inversion and analysis of electrical and electromagnetic methods applied in geophysical investigations.

The program supports transient electromagnetic (TEM) systems, frequency domain electromagnetic (FEM) systems, helicopter-borne frequency domain (HEM), direct current and induced polarization (DC/IP) electrical systems, magnetic resonance sounding (MRS) systems, magneto telluric (MT) systems and surface wave dispersion curves (SWD). For the TEM, FEM and DC/IP responses, a detailed description of the system characteristics (transmitter waveform, receiver filters etc.) is possible, utilizing precise and detailed modeling of responses.

The program performs one-dimensional (1D) inversions except in the case of DC/IP data for which also 2D responses are implemented.

1.3 References

Below, references referring to Aarhusinv are listed. Copies are available if asked for.

The main reference for the Aarhusinv program is.

- Auken, E., Christiansen, A.V., Fiandaca, G., Schamper, C., Behroozmand, A.A., Binley, A., Nielsen, E., Effersø, F., Christensen, N.B., Sørensen, K.I., Foged, N., Vignoli, G., 2015: "An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data." Exploration Geophysics, 46, 223-235.

The LCI, MCI and SCI methods are described in detail by:

- Auken, E., Christiansen, A. V., Jacobsen, B. H., Foged, N., and Sørensen, K. I., 2005: "Piecewise 1D Laterally Constrained Inversion of resistivity data". Geophysical Prospecting, 53, 497-506.
- Auken, E., Christiansen, A. V., Jacobsen, L., and Sørensen, K. I., 2008, A resolution study of buried valleys using laterally constrained inversion of TEM data: Journal of Applied Geophysics, 2008, 10-20.
- Christiansen, A. V., Auken, E., Foged, N., and Sørensen, K. I., 2007, Mutually and laterally constrained inversion of CVES and TEM data - A case study: Near Surface Geophysics, 5, 115-124.
- Viezzoli, A., Christiansen, A. V., Auken, E., and Sørensen, K. I., 2008, Quasi-3D modeling of airborne TEM data by Spatially Constrained Inversion: Geophysics, 73, F105-F113.

A detailed description of the 2D-LCI method, also including thorough sections on the general LCI principle can be found in:

- Auken, E. and Christiansen, A. V., 2004: "Layered and laterally constrained 2D inversion of resistivity data". Geophysics, 69, 752-761.

The 2D-LCI is compared to Res2dinv using synthetic models and CVES gradient array setup in:

- Christiansen, A. V. and Auken, E., 2003: "Layered 2-D inversion of profile data, evaluated using stochastic models." 3DEM-3 proceedings volume, Adelaide, Australia.

The 2D-LCI has been optimized for a faster code. These optimizations are described in detail in:

- Christiansen, A. V. and Auken, E., 2004: "Optimizing a layered and laterally constrained 2D inversion of resistivity data using Broyden's update and 1D derivatives". Journal of Applied Geophysics, 56, 247-261.

The 1D forward modelling is described in a paper on the 1D forward modelling program EMMA:

- Auken, E., Nebel, L., Sørensen, K. I., Breiner, M., Pellerin, L. and Christensen, N. B., 2002: "EMMA - A Geophysical Training and Education Tool for Electromagnetic Modeling and Analysis." Journal of Environmental & Engineering Geophysics, 7, 57-68.

A more general and thorough explanation of the 1D time-domain and frequency-domain forward modelling can be found in:

- Ward, S.H. and Hohmann, G.W. 1988: "Electromagnetic theory for geophysical applications." In: Electromagnetic Methods In Applied Geophysics, Vol. 1 (ed. M.N. Nabighian), pp. 131-311. Society Of Exploration Geophysicists

The 2D forward modelling for DC data is described in:

- Oldenburg, D. W. and Li, Y., 1994: "Inversion of induced polarization data." Geophysics, 59, 1327-1341.

A description of the interpretation of surface wave seismic data to layered models can be found in:

- Wisén, R. and Christiansen, A. V., 2005: "Laterally and Mutually Constrained Inversion of Surface Wave Seismic Data and Resistivity Data". Journal of Environmental & Engineering Geophysics, 10, 251-262.

A description of the DC forward response for electrodes in the ground can be found in:

- Sato, H. K., 2000: "Potential field from a dc current source arbitrarily located in a non-uniform layered medium". Geophysics, 65, 1726-1732.

Calculation of the DC forward response for electrodes on the z-axis in a cylindrical symmetric model is described in:

- Drahos, D., 1984: "Electrical modeling of the inhomogeneous invaded zone". Geophysics, 49, 1580-1585.

The forward modelling of TEM data on sheet models is described in:

- Not published yet.

The IP (and DC) forward modelling in both 1D and 2D is described in:

- Fiandaca, G., Auken, E., Gazoty, A., and Christiansen, A. V., 2012, Time-domain induced polarization: Full-decay forward modeling and 1D laterally constrained inversion of Cole-Cole parameters: Geophysics, **77,** E213-E225.
- Fiandaca, G., Ramm, J., Binley, A., Gazoty, A., Christiansen, A. V., and Auken, E., 2013, Resolving spectral information from time domain induced polarization data through 2-D inversion: Geophysical Journal International, 192, 631-646.

The MRS forward modelling is described in:

- Behroozmand, A. A., Auken, E., Fiandaca, G., Christiansen, A. V., and Christensen, N. B., 2012, Efficient full decay inversion of MRS data with a stretched-exponential approximation of the T2* distribution: Geophysical Journal International, 190, 900-912.

The sharp inversion scheme is described in

- Vignoli, G., Fiandaca, G., Christiansen, A.V., Kirkegaard, C., Auken, E., 2015, "Sharp spatially constrained inversion with applications to transient electromagnetic data." Geophysical Prospecting 63: 243-255.

The scheme used to calculate Depth of Investigation (DOI) is described in:

- Christiansen, A. V., and Auken, E., 2012, “A global measure for depth of investigation”: Geophysics 77, 4, WB171-WB177.

The implementation of various hybrid inversion options, mixing approximate and accurate responses for increased computational efficiency is described in:

- Christiansen, A. V., Auken, E., Kirkegaard, C., Schamper, C., & Vignoli, G., 2015. "An efficient hybrid scheme for fast and accurate inversion of airborne transient electromagnetic data". Exploration Geophysics, 47, 323-330.

1.4 Graphical User Interfaces

A number of programs with graphical user interfaces and extensive manuals have been developed at the HydroGeophysics Group and now the continued development is with a company called Aarhusgeosoftware (aarhusgeosoftware.dk). The programs include:

- EMMA, freeware. EMMA is a geophysical electrical and electromagnetic modeling and analysis program. It provides a basis of survey design, instrument development and teaching. EMMA has a user-friendly interface allowing non-experts to calculate responses and perform model parameter analyses with a few clicks of the mouse.
- SPIA, not freeware. The SPIA program is an easy-to-use tool for processing and inversion of time domain electromagnetic data (TEM) and Geoelectrical soundings (VES).
- Aarhus Workbench, not freeware. The Aarhus Workbench is a comprehensive tool for processing, inversion and visualization of geophysical data. Geophysical processing and interpretation are carried out in a GIS environment integrating geophysical, geological and geographical data.

1.5 Contact information

Mail:
HydroGeophysics Group, Aarhus University, C. F. Møllers Alle 4, DK-8000 Aarhus C, Denmark

Authors:
esben.auken@geo.au.dk
anders.vest@geo.au.dk

Web: www.hgg.au.dk

2. TERMS OF USAGE

The AarhusInv-program is free to use for non-commercial purposes. Commercial use is not allowed. Distribution of the program is not allowed unless permitted by the authors. No warranty follows the program, and the authors take no responsibility for any side-effects caused by using the program.

If AarhusInv is included in another program or a user interface is added, this program must be freeware as well.

However, suggestions on improvements to the code and bug-reports are always welcome. See contact information on previous page.

3. THE GENERAL INPUT – OUTPUT STRUCTURE

This section describes the general input and output structure of AarhusInv and how to call the program from a command prompt.

The program is protected by an online license system. The license system is controlled by a license executable called AarhusinvLicense.exe which must be in the same directory as the executable. When using the program the first time you must be online and then every 30 days at least.

3.1 Input files

AarhusInv uses a model file, a configuration file, to set up and run the inversion, one or more data files and, if 2D-DC/IP inversion (2D-LCI) is chosen, also a mesh file.

File names including the 3-character extension can be up to 255 characters long. The file names are user-defined, but the extension must be one of the following:

- model file (mod-file):
  <file name>.mod.
- configuration file (con-file):
  <file name>.con.
- data files:
  TEM data: <file name>.tem
  FEM data: <file name>.fem
  HEM data: <file name>.hem
  DC/IP data: <file name>.dcp
  MRS data: <file name>.mrs
  SWD data: <file name>.swd
  MT data: <file name>.mtd
- mesh file (msh-file)
  <file name>.msh

AarhusInv uses a configuration file (con-file) to set up various parameters controlling the inversion processes. The con-file must be in the same directory as the AarhusInv executable, or it must be given as an input parameter together with the model file name (see 3.3 "How to call AarhusInv from a command prompt" on page 11). If no configuration file is given, the program by default looks for a file named Aarhusinv.con.

3.2 Output files

After inversion, AarhusInv writes results as data residuals, model parameters, parameter analyses, forward responses, and inversion settings in the output file (emo-file). The name of the emo-file is the same as the name of the mod-file, except the file has the extension .emo. Depending on the settings in the con-file, AarhusInv writes the emo-file iteration by iteration, the only difference being the file extension (.ems instead of .emo). When writing the .ems file, no Depth of Investigation (DOI) or model analyses are performed.

In the con-file, AarhusInv can be customized to generate an emm-file. The emm-file contains information from the emo-file in a simple matrix format, plus Jacobian, roughness and resolution matrices.

Using AarhusInv for generating forward responses results in a forward file (fwr-file) for each data-file. The forward files are formatted as data files with the new forward response in the data column. The filename of the forward file is <mod-file>nnn.fwr, where nnn is the number of the data file as given in the mod-file. The mod-file is described in detail in the section "The model file" on page 13.

If errors occur in the program, by for instance wrong settings in the input files, an error message is written to an error file. The name of the error file is the same as the name of the mod-file, except the file has the extension .err.

The screen output from the program can also be written to a log-file (see chapter 5 "The CON file (AarhusInv configuration file)". The name of the log-file is the same as the name of the mod-file, except the file has the extension .log.

3.3 How to call AarhusInv from a command prompt

AarhusInv can be called in two ways, either with command line arguments or with input-output arguments.

Command line arguments

```
Aarhusinv64 <file name>.mod
```

This will execute the program if the con-file is named aarhusinv.con. If the con-file is not located in the same directory as the mod-file type:

```
Aarhusinv64 <file name>.mod <file name>.con.
```

For 2D-LCI, an argument is needed to define a mesh-file:

```
Aarhusinv64 <file name>.mod <file name>.msh
```

When using a non-default con-file, the command line arguments become:

```
Aarhusinv64 <file name>.mod <file name>.con <file
name>.msh
```

Input-output arguments

```
Aarhusinv64
```

After this AarhusInv prompts for the mod-file. If the default con-file is not found in the same directory as the mod-file, AarhusInv will prompt for it. Input-output arguments cannot be used with 2D-DC/IP inversion.

AarhusInv will write its version number and copyright information on the screen when `aarhusinv64` is typed on the command prompt.

When AarhusInv reads the input files, various parameters are checked to ensure their validity. Errors are written to the screen as well as to a file called <mod-file name>.err. <mod-file name>.err is located in the directory from where AarhusInv is called.

Errors encountered during the inversion process are written to the screen and to the <mod-file name>.err file. No output files are created if an error occurs.

In the con-file the screen output can be customized to be written to a log-file (aarhusinv.log). This is described in section 5 ”The CON file (AarhusInv configuration file)”.

4. THE MODEL FILE

The model file (mod-file) contains names of data files, model parameters, prior information and, if any, vertical and horizontal parameter constraints. The mod-file is loaded by a command line input for AarhusInv (see chapter 3.3 “How to call AarhusInv from a command prompt”).

All the model types available can be printed to a file (“ListImplementedModelTypes.txt”) by typing “AarhusInv.exe help”.

The mod-file in Figure 4.1 contains three three-layered TEM models with both a priori information and vertical and horizontal constraints. The following description will refer to this mod-file.

```
#   Text                      Comments
1   Model label - three tem data sets
2   3 2 -1.0 -1.0 -1.0  1    !# of data files, Con. mode (vertical constraints, horiz. con.),
                              Alpha, BetaV, BetaH, ReWeightType
3   1 1 tem-file_1.tem
4   2 1 tem-file_2.tem
5   3 1 tem-file_3.tem
6   50                       !# of iterations
7   3                        !# of layers, model 1
8    50    -1   9e9  0.2     !Resistivity-1, prior STD, vert. constraints,  horiz. constraints
9    50    -1   9e9  0.1     !Resistivity-2, prior STD, vert. constraints,  horiz. constraints
10   50    -1        0.1     !Resistivity-3, prior STD,    (no value)    ,  horiz. constraints
11   20    -1   9e9  9e9     !Thicknes-1,    prior STD, vert. constraints,  horiz. constraints
12   30    -1        9e9     !Thicknes-2,    prior STD,    (no value)    ,  horiz. constraints
13   20    -1        0.2     !Depth-1,       prior STD,    (no value)    ,  horiz. constraints
14   50    -1        0.2     !Depth-2,       prior STD,    (no value)    ,  horiz. constraints
15  3                        !number of layers, model 2
16   50    -1   9e9  0.2     !Resistivity-1, priori STD of 0.1, ....
17  100   0.1   9e9  0.1
18   50    -1        0.1
19   20    -1   9e9  9e9
20   30    -1        9e9
21   20    -1        0.2
22   50    -1        0.2
23  3                        !number of layers, model 3
24   50    -1   9e9
25   50    -1   9e9
26   50    -1
27   20    -1   9e9
28   30    -1
29   20    -1
30   50    -1
```

Figure 4.1 Model file with three data files, prior STD, vertical and horizontal constraints. The data file contains tem data (file name: tem-file.tem). The comments after the ! are not required. Bold red text is not a part of the data file.

4.1 Heading part

The heading part is the first five lines of the mod-file, referring to Figure 4.1:

Line 1, text label:
A user defined label defining the model. The model label is repeated in the emo-file. Maximum length is 128 characters.

Line 2, first integer, number of data:
The total number of data files used to set up the inversion.

Line 2, second integer, constraint mode:
The constraint mode integer determines how vertical and horizontal constraints are set up. It takes the following values:

- Value 0: No vertical or horizontal constraints.
- Value 1: Vertical constraints only. Constraint mode of 1 means that there are vertical constraints between the primary parameters (resistivity and thicknesses) in the model. Vertically coupled model parameters enable the user to do inversions with many layers often referred to as minimum structure models or multi-layer models. For e.g. a 5-layer model, the resistivity of layer 1 is constrained to the resistivity of layer 2, the resistivity of layer 2 is constrained to the resistivity of layer 3, etc....
- Value >=2: Vertical and horizontal constraints with a coupling width given by the value. A coupling width of 2 indicates that only neighbouring models are constrained, a coupling width of three means that the models are constrained to the two nearest models, and so on.

Figure 4.1shows an example of a model file with horizontal constraints between neighbouring models. An example of a model constrained laterally to two models is shown in Figure 4.10.

Line 2, third real, reweighting on the prior (Alpha):
This number controls the re-weighting on the prior constraints.

- Value < 0: re-weighting turned off (classic L2-norm)
- Value > 0: re-weighting is turned on. The re-weighting type depends on ReWeightingType at the sixth integer:
    - ReWeightingType = 1: minimum support re-weighting, Alpha is the amount of variations per model columns.
    - ReWeightingType = 3: L1-norm reweigthing, Alpha is dummy, but must be positive.

Line 2, fourth real, reweighting on the vertical constraints (BetaV):
This number controls the reweighting on the vertical constraints.

- Value < 0: reweighting turned off (classic L2-norm)
- Value > 0: reweighting is turned on. The reweighting type depends on ReWeightingType at the sixth integer:
    - ReWeightingType = 1: minimum support re-weighting, BetaV is the amount of variations in the vertical constraints per model columns.
    - ReWeightingType = 3: L1-norm reweigthing, BetaV is dummy, but must be positive.

Line 2, fourth real, reweighting on the horiz. constraints (BetaH):
This number controls the reweighting on the horizontal constraints and is similar to BetaV above.

Line 2, sixth integer, ReWeightingType:
This integer is optional and select the re-weighting type.

- Value = 1: Minimum (gradient) Support.
- Value = 3: L1-norm

Line 3–5, first integer, model number:
The model number indicates which model definition to associate with the data set. In a sequence of data files the model number must either increment by 1 or stay unchanged from line to line. The last model number in a sequence of data files defines the number of different models described in the last part of the model file and is therefore smaller than or equal to the number of data files.

Line 3–5, second integer, parameter layout:
This parameter defines which parameters enter the inversion. Parameter layout takes the following values:

- Value 1: General resistivity format (Figure 4.1). The inversion contains resistivities, thicknesses and depths. The parameters must be given in the order as shown in e.g. In the case of DC data in a borehole (see chapter 7) the geometry is cylindrically symmetric which means that a thickness is the thickness of a "doughnut ring" in the horizontal direction.
- Value 2: Parameter description as for value 1, but indicates 2D inversion of DC data. See Figure 4.4.
- Value 3: Inversion of Surface Waves Dispersion curves. The inversion contains velocities, densities, Poisson's ratio, thicknesses and depths. See Figure 4.15.
- Value 4: Inversion of Surface Waves Dispersion curves. The inversion contains velocities, densities, thicknesses and depths.
- Value 5: Airborne EM data inversion. As value 1 plus transmitter altitude. See Figure 4.16.
- Value 51: As value 5 plus shift factor. See Figure 4.21.
- Value 52: As value 5 plus bias correction. See Figure 4.22.
- Value 6: As value 5 plus x-receiver angle. See Figure 4.17.
- Value 7: Airborne EM data inversion. The inversion contains altitude, resistivities, electrical permittivities, thicknesses and depths. See Figure 4.18.
- Value 71: The inversion contains altitude, resistivities, relative magnetic permeability, thicknesses and depths.
- Value 8: Airborne TEM in the off-set loop configuration. The inversion contains altitude, angle between vertical and the connection between Tx and Rx, distance between Tx and Rx, Rx pitch angle, Rx roll angle, resistivities, thicknesses and depths. See Figure 4.20.
- Value 81: As value 8 plus shift factor.

- Value 10: For Sheets inversion with EM data. The inversion contains sheet conductance, sheet x-position - center of sheet, sheet y-position - center of sheet, sheet z-position - top-center of sheet, sheet width, sheet height, strike angle and dip angle. See Figure 4.14.
- Value 11: For 1D inversion of DCIP. The inversion contains resistivities [Ohmm], and IP parameters in a Cole-Cole parameterization of the IP signal: m_0 [mV/V], tau [s] and C [dim. less] - thicknesses [m] and depths [m]. See Figure 4.5. For 2D inversion, the value is 12.

  Note: Parameters values for other parameterization of the IP effect are show in a table in Figure 4.2.
- Value 13: Magnetic resonance sounding inversion. The inversion contains resistivity [Ohmm], water content (W) [m3/m3], relaxation time (T2*) [s], stretching exponent (C) [dim less], thicknesses [m] and depths [m]. See Figure 4.8.
- Value 131: As value 13, but without the stretching exponent, C.
- Value 133: As value 13, but with a shift [rad] as an extra parameter.

Parameterization name	Inversion parameters	Parameter value 1D (2D)
Resistivity Cole-Cole (RCC)	$\rho, m_0, \tau_\rho, C, thk, depth$	11 (12)
Conductivity Cole-Cole (CCC)	$\sigma, m_0, \tau_\sigma, C, thk, depth$	112 (122)
Maximum Phase Angle Cole-Cole (MPA)	$\rho, \varphi_{max}, \tau_{peak}, C, thk, depth$	114 (124)
Maximum Imaginary Conductivity (MIC)	$\sigma, \sigma'', \tau_\sigma, C, thk, depth$	117 (127)
Minimum Imaginary Resistivity (MIR)	$\rho, \rho'', \tau_\rho, C, thk, depth$	118 (128)
Bulk Imaginary Conductivity (BIC)	$\sigma_{bulk}, \sigma''_{max}, \tau_\sigma, C, thk, depth$	119 (129)
Constant Phase Angle (CPA)	$\rho, \varphi, thk, depth$	116 (126)
Temperature Resistivity (TRES)	$\rho, thk, depth, Temp$	212 (222)

Figure 4.2: Different parameterizations of direct current induced polarization (DCIP), their inversion parameters and the value for the parameter value. Up to date list can always be retrieved typing “AarhusInv.exe help”.

Line 3-5, character string, data-file name:
The file name of the data files. The default extension of these data files must be .tem for TEM data, .fem for FEM data, .dcp for geoelectrical DC/IP data, .mrs for MRS data, .mtd for MT data or .swd for surface wave dispersion (SWD) curve data (for further details see “The general input - output structure“ on page 10).

The path of the data files is relative to the mod-file, except when the absolute path is specified (e.g. c:\temp\datafiles***.tem). The full path name cannot exceed 256 characters.

Line 6, integer, number of iterations:
The maximum number of iterations in the inversion process. The inversion process will stop either when the number of iterations is reached or when the residual stays unchanged with respect to the convergence criteria set in the con-file (section 5.2 “Expert user”). The possible values are the following:

- Value -1: A forward response is generated for the models specified below and written to the fwr-files - no emo-file is written.
- Value 0: A forward response and a parameter analysis are generated. The forward responses are written to the fwr-files and the analysis and forward response are written to the emo-file.
- Value -100: A forward response and a parameter analysis are generated. The forward response and the analyses are written to the emo-file only (no fwr-files generated).
- Value >=1: Normal iteration mode. The number indicates the maximum number of iterations allowed in the inversion process. The code does not perform more than 50 iterations, even if a higher number is written in the mod-file.

4.2 Parameter part

The parameter part (lines 7 - 30) in Figure 4.1means the following:

Line 7, first integer, number of layers:
The model definition implicitly includes an air layer above the earth. For example, a 3-layer model contains an air layer, two earth layers and a bottom layer continuing to infinite depth.

Line 7, second to fourth real, coordinates of the model:
For 2D-DC/IP calculations and when setting constraints relative to elevation, the location and elevation of each model is needed. For normal 1D calculations, it is not necessary to give the coordinates. See Figure 4.13 for an example of a 2D-LCI model file.

Line 8 – 10, first real, resistivities:
Initial resistivities of layers 1, 2 and 3. The resistivity range is defined in the con-file.

Line 8 – 10, second real, prior STD:
The prior STD takes the following values:

- Value <0: The parameter value is free, and no prior information for the parameter is included in the inversion scheme. The values of the parameters are used as the starting point in the inversion.
- Value > 1.e-3: The parameter value is allowed to vary within a factor of (1+prior STD). The constraint is "soft" in the sense that the parameter will go outside limits if data contain more information about the parameter than the prior information. The value of the parameter is taken both as the starting values of the inversion and as the prior value. The resistivity of the second layer, line 17, Figure 4.1 has a prior STD of 0.1, corresponding to a factor of 1.1.

- Value > 0.0 and <= 1.e-3: The parameter cannot be changed in the inversion, and derivatives are not calculated with respect to the parameter. This option is useful for minimum-structure models where layer boundaries are fixed. An example of a model file with this setting is shown in Figure 4.9.

Line 8-10, third and fourth real, constraints.
The presence of the vertical and horizontal constraint factors depends on the value of the constraint mode integer in line 2. For a constraint mode of:

- Value 0: Vertical and horizontal constraint factors are not present (e.g. Figure 4.11).
- Value 1: Vertical constraint factors are given in the third column. A data line looks like line 7 in Figure 4.9.
- Value >=2: Vertical constraint factors are given in column 3, and horizontal constraint factors are given in subsequent columns (columns 4 and higher). Figure 4.1shows a model file with three coupled models, and Figure 4.10 shows an example where model 1 couples to model 2 and 3, but there is no coupling between model 2 and 3.

In general: No vertical constraints are specified for the last layer. Constraints are given as relative values (>0), meaning that a constraint value of 0.1 ties models together with an uncertainty of approximately 10%. No constraints are indicated with a very high value as in line 11, Figure 4.10 , or with -1.

Note on DC borehole data: For DC data in a borehole with cylindrically symmetric coordinates the model description is identical to the one above. However, the terms "lateral" and "vertical" constraints should be interchanged because the model is described in the horizontal direction perpendicular to the borehole.

Line 11 - 12, reals, thicknesses:
All settings as for the resistivity lines, see above.

Line 13 - 14, reals, depths:
All settings as for the resistivity lines, except that there are no vertical constraints for depths.

Please note that depths are not primary parameters in the inversion, and therefore depth values are unused if the prior STD factor is <0 (see e.g. Figure 4.1). If the prior STD factor is > 0, the starting point for the inversion with respect to depths is the actual depth value. When constraining interfaces as in e.g. Figure 4.1, the depth parameter is used also if the STD factor is <0.

4.3 Examples

In the following a number of examples are shown on the construction of the mod-file. The examples are illustrations of possibilities, but are not by any means fulfilling in terms of the full potential.

MOD-file for TEM data

The simplest form of a model file for inversion of a TEM data set is seen in Figure 4.3. One data set, one model with three layers, no prior STD (-1 in model description line 6-12) and no constraints (0 in line 2, second integer). The value of the parameter layout is one, so the inversion contains resistivity, thickness and depth.

#	**Text**	**Comments**
1	3-layered model, TEM	!Text label
2	1 0	!#DataFiles, Constraints mode: 0->none, 1->vert, >=2-> vert+horiz
3	1 1 TEM_3layers.tem	!ModelNr, ParameterLayout, data-file name
4	50	!#Iterations
5	3	!#Layers, Model 1
6	30 -1	!Resistivity_1; priorSTD (-1->non)
7	100 -1	!Resistivity_2; priorSTD
8	10 -1	!Resistivity_3; priorSTD
9	2 -1	!Thickness_1; priorSTD
10	30 -1	!Thickness_2; priorSTD
11	2 -1	!Depth_1; priorSTD
12	32 -1	!Depth_2; priorSTD

Figure 4.3 Model file with one TEM data set and model. No prior STD and no constraints. The comments after the ! are not required. Bold red text is not a part of the data file.

MOD-file for resistivity data (DCP file)

An example of a model file for 2D inversion of resistivity data is seen in Figure 4.4. The model has two layers and the inversion contains resistivity, thickness and depth. No constraints or prior information is added.

#	**Text**	**Comments**
1	2-layered model, 2D DC	!Text label
2	1 0	!#DataFiles, Constraints mode: 0->non, 1->verti, >=2-> verti+horiz
3	1 2 DC2d_2layers.dcp	!ModelNr, ParaLayout, data-file name
4	50	!#Iterations
5	2	!#Layers, Model 1
6	30 -1	!Resistivity_1; priorSTD (-1->non)
7	100 -1	!Resistivity_2; priorSTD
8	20 -1	!Thickness_1; priorSTD
9	20 -1	!Depth_1; priorSTD

Figure 4.4 Model file with one DCP data set with resistivity data and one model. No prior STD, no constraints. The comments after the ! are not required. Bold red text is not a part of the model file.

MOD-file for DCIP data (DCP file)

An example of a model file for 1D inversion of DCIP data with a Cole-Cole parameterization of the IP effect is found in Figure 4.5.

A 2D inversion of DCIP data with a Maximum Phase Angle (MPA) Cole-Cole parameterization is in Figure 4.6. By changing the value of the parameter layout, the parameterization used in the inversion can be changed (see possible values and parameterizations in section 4.2 “Parameter part”).

For the inversion for the IP parameters from TEM data, the source type of the TEM data files must be 7 or 72 (section 6 “The TEM file (time domain data)”).

#	Text		Comments
1	2-layed model, 1D DCIP		!Text label
2	2 0		!#DataFiles, Constraints mode: 0->non, 1->Ver, >=2-> Ver+Hor
3	1 11 IP_DCdata.dcp		!ModelNr, ParaLayout, data-file name
4	50		!#Iterations
5	2		!#Layers, Model 1
6	30	-1	!Resistivity_1; priorSTD (-1->non)
7	100	-1	!Resistivity_2; priorSTD
8	500	-1	!m0_1; priorSTD
9	70	-1	!m0_2; priorSTD
10	1	-1	!tau_1; priorSTD
11	0.1	-1	!tau_2; priorSTD
12	0.2	-1	!C_1; priorSTD
13	0.5	-1	!C_2; priorSTD
14	7	-1	!Thickness_1; priorSTD
15	7	-1	!Depth_1; priorSTD

Figure 4.5 Model file with one DCP data set. The Cole-Cole parameterization of IP is used in the inversion. No prior STD, no constraints. The comments after the ! are not required. Bold red text is not a part of the model file.

#	Text		Comments
1	2-layed model, 2D DCIP		!Text label
2	1 0		!#DataFiles, Constraints mode: 0->non, 1->Ver, >=2-> Ver+Hor
3	1 222 DCIP2d_2layers.dcp		!ModelNr, ParaLayout, data-file name
4	50		!#Iterations
5	2		!#Layers, Model 1
6	30	-1	!Resistivity_1; priorSTD (-1->non)
7	100	-1	!Resistivity_2; priorSTD (-1->non)
8	5	-1	!phi_max_1; priorSTD (-1->non)
9	0.3	-1	!phi_max_2; priorSTD (-1->non)
10	1	-1	!tau_peak_1; priorSTD(-1->non)
11	0.1	-1	!tau_peak_2; priorSTD (-1->non)
12	0.2	-1	!C_1; priorSTD (-1->non)
13	0.5	-1	!C_2; priorSTD (-1->non)
14	7	-1	!Thickness_1; priorSTD (-1->non)
15	30	-1	!Thickness_2; priorSTD (-1->non)
16	7	-1	!Depth_1; priorSTD (-1->non)
17	37	-1	!Depth_2; priorSTD (-1->non)

Figure 4.6 Model file with one DCP data set with DCIP data. The MPA parameterization of IP is used in the inversion. No prior STD, no constraints. The comments after the ! are not required. Bold red text is not a part of the model file.

MOD-file for FEM data

An example of a mod-file with a FEM dataset is shown in Figure 4.7. The model has three layers with prior information on the resistivity values on the first two layers.

#	Text	Comments
1	3 layered model, FEM	
2	1 0	!#DataFiles, Constraints mode: 0->non, 1->Ver, >=2-> Ver+Hor
3	1 1 FEM_3layers.fem	!ModelNr, ParaLayout, data-file name
4	50	!#Iterations
5	3	!#Layers, Model 1
6	30 0.1	!Resistivity_1; priorSTD (-1->non)
7	100 0.1	!Resistivity_2; priorSTD (-1->non)
8	10 -1	!Resistivity_3; priorSTD (-1->non)
9	20 -1	!Thickness_1; priorSTD (-1->non)
10	30 -1	!Thickness_2; priorSTD (-1->non)
11	20 -1	!Depth_1, priorSTD (-1->non)
12	47 -1	!Depth_2, priorSTD (-1->non)

Figure 4.7 Model file with one FEM data set and model. The comments after the ! are not required. Bold red text is not a part of the model file.

MOD-file for MRS data

An example of a mod-file with MRS data is shown in Figure 4.8. The model has two layers. The parameters layout has the value 13, so the inversion contains resistivity, water content (W), relaxation time (T2*), stretching exponent (C), thickness and depth. No constraints are applied, but a priori std is put on the resistivities and the thickness of the first layer.

#	Text	Comments
1	2-layere model, T2 MRS with prior	!TextLabel
2	1 0	!#DataFiles, Constraints mode (0->non, 1->Ver, >=2->Ver+Hor)
3	1 13 MRS_data.mrs	!ModelNr, ParameterLayout, data file name
4	50	!#Iterations
6	2	!#Layers, Model 1
7	500 0.01	!Resistivity_1, Prior STD (-1->non)
8	50 0.01	!Resistivity_2, Prior STD (-1->non)
9	0.15 -1	!W_1, Prior STD (-1->non)
10	0.15 -1	!W_2, Prior STD (-1->non)
11	0.15 -1	!T2*_1, Prior STD (-1->non)
12	0.15 -1	!T2*_2, Prior STD (-1->non)
13	1.00 -1	!C_1, Prior STD (-1->non)
14	1.00 -1	!C_2, Prior STD (-1->non)
15	25.0 0.01	!Thickness_1, Prior STD (-1->non)
16	25.0 -1	!Depth_1, Prior STD (-1->non)

Figure 4.8 Model file with one MRS data set and model. No prior STD, no constraints. The comments after the ! are not required. Bold red text is not a part of the model file.

4.4 Examples: Constraints, joint inversion and sheets modelling

TEM with multi-layer/minimum structure model

Nine-layer model with fixed layer boundaries and decreasing vertical constraints (Figure 4.9). Layer thicknesses are fixed.

#	Text			Comments
1	Model label			
2	1 1			!#DataFiles, Constraints mode (0->non, 1->Ver, >=2->Ver+Hor)
3	1 tem-file.tem			!ModelNr, ParameterLayout (1->res,thk,depth), data file name
4	50			!#Iterations
5	9			!#Layers, Model 1
6	50	-1	0.10	!Resistivity, priori STD, vertical constraints.
7	50	-1	0.13	
8	50	-1	0.15	
9	50	-1	0.20	
10	50	-1	0.22	
11	50	-1	0.25	
12	50	-1	0.27	
13	50	-1	0.30	
14	50	-1		
15	1	1e-3	9e9	!Thickness, prior STD, vertical constraints.
16	3	1e-3	9e9	
17	6	1e-3	9e9	
18	10	1e-3	9e9	
19	15	1e-3	9e9	
20	22	1e-3	9e9	
21	30	1e-3	9e9	
22	40	1e-3	9e9	
23	1	-1		!Depth, prior STD
24	4	-1		
25	10	-1		
26	20	-1		
27	35	-1		
28	57	-1		
29	87	-1		
30	127	-1		

Figure 4.9 Model file with only one data file and vertical constraints (minimum structure model). The comments after the ! are not required. Bold red text is not a part of the model

TEM and DC with lateral constraints

Model file with three data files (one TEM-file and two DCP-files) (Figure 4.10). Lateral constrain between model 1 and model 2 as well as between model 1 and model 3. No constraints between model 2 and 3.

```
Text             Comments
Model label - tem and resistivity data sets
3 3                         !#DataFiles, Constraints mode (0->non, 1->Ver, >=2->Ver+Hor)
1 1 tem-file1.tem           !ModelNr, ParameterLayout (1->res,thk,depth), data file name
2 1 dcp-file2.dcp           !ModelNr, ParameterLayout (1->res,thk,depth), data file name
3 1 dcp-file3.dcp           !ModelNr, ParameterLayout (1->res,thk,depth), data file name
50                          !#Iterations
3                           !#Layers, Model 1
 30    -1    9e9  0.1  0.3  !Resistivity, priori STD, vert. constraints,  horiz. constraints
100    -1    9e9  0.1  0.3
 10    -1         0.1  0.3
 20    -1    9e9  9e9  9e9  !Thickness, priori STD, vert. con., horiz. con-1, horiz. con-2
 30    -1         99   99
 20    -1         0.2  0.5  !Depth, prior STD, horiz. con.
 50    -1         0.2  0.5
3                           !#Layers, Model 2
 30    -1    9e9  9e9       !Resistivity, a priori STD, vert. con.
100    -1    9e9  9e9
 10    -1         9e9
 20    -1    9e9  9e9       !Thickness, priori STD, vert. constraints, horiz. constraints
 30    -1         9e9
 20    -1         9e9       !Depth, prior STD
 50    -1         9e9
3                           !#Layers, Model 3
 30    -1    9e9            !Resistivity, prior STD, vert. con.
100    -1    9e9
 10    -1
 20    -1    9e9            !Thickness, priori STD, vert. constraints.
 30    -1
 20    -1                   !Depth, a priori STD
 50    -1
```

Figure 4.10 Model file with three data files, vertical and horizontal constraints. The parameters of the first model are coupled to the parameters of the second and third model whereas there are no constraints between the second and third model (constraint factors set to 9e9). The comments after the ! are not required. Bold red text is not a part of the model file.

FEM with joint inversion

Joint inversion of two FEM data sets (Figure 4.11). The joint inversion is executed by referring the two data sets to the same model. Prior information is given on the depth to the third layer. The FEM-files could contain data at different frequencies with two different coil separations. Each FEM-file would then contain all data for one of the coil separations

```
#   Text            Comments
1   Model label - two fem-data sets
2   2 0                         !# of data files, Con. mode
3   1 1 fem-file1.fem
4   1 1 fem-file2.fem
5   50                          !#Iterations
6   3                           !#Layers, Model 1
7    30    -1                   !Resistivity, priori STD
8   100    -1
9    10    -1
10   20    -1                   !Thickness, priori STD
11   30    -1
12   20    -1                   !Depth, prior STD
13   47     0.1
```

Figure 4.11 Model file with two fem-data files referring to the same model. The model has prior on the depths to the second layer and no vertical and horizontal constraints. The comments after the ! are not required. Bold red text is not a part of the model file.

FEM and DCP with different parameter layout/model definition

Three data files (two FEM-files and one DCP file) and two models with vertical and horizontal constraints (Figure 4.12). The two FEM-files uses model definition 1 (line 7-14) and the DCP-files uses model definition 2 (line 15-22).

```
#   Text            Comments
1   Model label - two fem-data sets and one dcp-data set
2   3 2                         !# of data files, Con. mode (verical and horizontal constraints)
3   1 1 fem-file.fem
4   1 1 fem-file.fem
5   2 1 dcp-file.dcp
6   50                          !#Iterations
7   3                           !#Layers, Model 1
8    30    -1     99    0.2     !Resistivity, priori STD, vert. constraints, horiz. constraints
9   100    -1     99    0.1
10   10    -1           0.1
11   20    -1     99    99      !Thickness, priori STD, vert. constraints, horiz. constraints
12   30    -1           99
13   20    -1           0.2     !Depth, priori STD, (no value), horiz. constraints
14   50    -1           0.2
15  3                           !#Layers, Model 2
16   30    -1     99
17  100     0.1   99
18   10    -1
19   20    -1     99
20   30    -1
21   20    -1
22   50    -1
```

Figure 4.12 Model file with three data files, two models and vertical and horizontal constraints. The two fem-files uses model definition 1 while the dcp-file use model definition 2. The comments after the ! are not required. Bold red text is not a part of the model file

DC with 2D lateral constraints

Model file for 2D-LCI inversion of 200 DC data sets (Figure 4.13).

```
Text             Comments
21.august.2003  14:13:57.57
200   2                                          !NDatafiles, NCoinstraint
  1   2  LCI_0000.dcp                            !The "2" sets the model as DC 2D-LCI
  2   2  LCI_0005.dcp
  3   2  LCI_0010.dcp
  .
  .
198   2  LCI_0985.dcp
199   2  LCI_0990.dcp
200   2  LCI_0995.dcp
 50                                              !Nite, 0=analyse
  3    0     0     0                             !#Layers, x, y, z of Model 1
   121.0     -1    1.0e+010    1.4e-001          !Resistivity, prior, vert. constraints, horiz. constr.
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010          !Thickness  , prior, vert. constraints, horiz. constr.
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001          !Depth      , prior,                  , horiz. constr.
    12.0     -1                1.0e-001
   3    5     0     0                            !#Layers, x, y, z of Model 2
   121.0     -1    1.0e+010    1.4e-001
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001
    12.0     -1                1.0e-001
  3   10     0     0                             !#Layers, x, y, z of Model 3
   121.0     -1    1.0e+010    1.4e-001
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001
    12.0     -1                1.0e-001
      .
      .
  3  985     0     0
   121.0     -1    1.0e+010    1.4e-001
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001
    12.0     -1                1.0e-001
  3  990     0     0
   121.0     -1    1.0e+010    1.4e-001
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001
    12.0     -1                1.0e-001
  3  995     0     0
   121.0     -1    1.0e+010    1.4e-001
   121.0     -1    1.0e+010    1.2e-001
   121.0     -1                1.0e-001
     4.0     -1    1.0e+010    1.0e+010
     8.0     -1                1.0e+010
     4.0     -1                1.4e-001
    12.0     -1                1.0e-001
```

Figure 4.13 Model file for 2D-LCI inversion of DC data. Constraints are applied on resistivities and depths. The comments after the ! are not required. Bold red text is not a part of the model file

Sheets modelling with EM

For TEM data there is an option to model for the geometry and parameters of a thin sheet. In this case there is just one model/sheet, but multiple data files all optimizing the same model.

The parameters that we invert for are: sheet conductance, sheet positions (x,y,z) referring to the top-center of the sheet, sheet width, sheet height, strike angle and dip angle. An example is shown in Figure 4.14.

```
 Text           Comments
Model file for sheets modelling
5 1
1 10 z1.tem
1 10 x1.tem
1 10 z2.tem
1 10 x2.tem
1 10 z3.tem
50
2 1                     !#Layer, #sheets
 10.92   0.50              !Sheet conductance = thickness*conductiivty
142.92   0.50              !Sheet x-position - center of sheet
343.92   0.50              !Sheet y-position - center of sheet
 24.92   0.50              !Sheet z-position - top - center of sheet
 45.92   0.50              !Sheet width
 46.92   0.50              !Sheet height
 47.92   0.50              !Strike angle
 48.92   0.50              !Dip
 30.00  -1.00  1.0000      !Res 1, Background Model
 10.00  -1.00              !Res 2
 20.00  -1.00              !Thk 1
 20.00  -1.00              !Dph 1
```

Figure 4.14 Model file for sheet inversion using airborne TEM data. x and a z-datafiles work on the same model. The comments after the ! are not required. Bold red text is not a part of the model file.

Velocity models for surface wave dispersion curve inversion

For 1D layered inversion of surface wave dispersion (swd) curves there are just one model format, but the interpretation can be one of two. The file format always includes velocity, density, Poisson's ratio, thicknesses and depths the layers as shown in Figure 4.15.

The two ways of using the swd model format are controlled by the second integer on the line with the filenames as described in section 4.1 " Heading part".

```
#   Text                   Comments
1   Model label
2   2 2                       !# of data files, Con. mode (vertical and lateral constraints)
3   1 3 swd-file1.swd
4   1 3 swd-file2.swd
5   50                        !#Iterations
5   3                         !#Layers, Model 1
6     700   -1    1e9  0.2   !Velocity, priori STD, vertical constraints, lateral constraints.
7     700   -1    1e9  0.2
8     700   -1         0.2
9    2000  1e-3   1e9  1e9   !Density, priori STD, vertical constraints, lateral constraints.
10   2000  1e-3   1e9  1e9
11   2000  1e-3        1e9
12    0.4  1e-3   1e9  1e9   !Poissons ratio, priori STD, vertical constraints, lateral constraints.
13    0.4  1e-3   1e9  1e9
14    0.4  1e-3        1e9
15      2   -1    1e9  1e9   !Thickness, priori STD, vertical constraints, lateral constraints.
16      2   -1         1e9
17      2   -1         0.1   !Depth, priori STD, lateral constraints.
18      4   -1         0.1
19  3                         !#Layers, Model 2 (must be the same as model 1 with lateral constraints)
20    700   -1    1e9  0.2   !Velocity, priori STD, vertical constraints, lateral constraints.
21    700   -1    1e9  0.2
22    700   -1         0.2
23   2000  1e-3   1e9  1e9   !Density, priori STD, vertical constraints, lateral constraints.
24   2000  1e-3   1e9  1e9
25   2000  1e-3        1e9
26    0.4  1e-3   1e9  1e9   !Poissons ratio, priori STD, vertical constraints, lateral constraints.
27    0.4  1e-3   1e9  1e9
28    0.4  1e-3        1e9
29      2   -1    1e9  1e9   !Thickness, priori STD, vertical constraints, lateral constraints.
30      2   -1         1e9
31      2   -1         0.1   !Depth, priori STD, lateral constraints.
32      4   -1         0.1
```

Figure 4.15 Model file for surface wave dispersion curve modelling. In this case two data-files are connected with lateral constraints. The comments after the ! are not required. Bold red text is not a part of the data file.

4.5 Examples: Airborne EM

The formatting of the non-general parts of these special cases are described below.

Airborne EM with transmitter altitude

In the case of airborne EM measurements, the transmitter altitude can be included as an inversion parameter. A model file intended for that purpose is shown in Figure 4.16.

The altitude parameter is included as an extra line in the file model format, everything else is the same. The altitude is given as a positive number.

Lateral constraints and a priori constraints are applied as usual.

#	Text	Comments
1	Model label - one model	
2	1 0	!# of data files, Con. mode
3	1 5 tem-airborne-file.tem	
4	50	!# of iterations
5	3	!# of layers, model 1
6	15 0.05	!transmitter altitude, transmitter altitude prior_STD
7	30 -1	!Resistivity_1, Resistivity_1 prior_STD
8	100 -1	!Resistivity_2, Resistivity_2 prior_STD
9	10 -1	!Resistivity_3, Resistivity_3 prior_STD
10	20 -1	!Thickness_1,Thickness_1 STD
11	30 -1	!Thickness_2,Thickness_2 STD
12	20 -1	!Depth_1, Depth_1 STD
13	47 -1	!Depth_2, Depth_2 STD

Figure 4.16 Model file for EM inversion with an altitude parameter. The comments after the ! are not required. Bold red text is not a part of the model file.

Airborne EM with transmitter altitude and x-receiver tilt angle

If working with x-component airborne TEM data, the x-receiver tilt-angle can be included as an inversion parameter together with the altitude. The x-receiver is fixed to the Tx frame (SkyTEM type). A model file intended for that purpose is shown in Figure 4.17.

The angle parameter is included as an extra line in the file model format just after the altitude parameter, everything else is the same.

It is not possible to apply lateral constraints on the angle parameter, but an a priori constraint can be applied.

The angle is defined in the positive direction for a right-handed coordinate system with the z-axis pointing downwards. Thus, 270 degrees is vertical, a larger angle is when the x-receiver tilts in the positive x-direction and vice versa. The x-receiver plane is assumed to be perpendicular to the z-transmitter plane.

#	Text	Comments
1	Model label - one model	
2	1 0	!# of data files, Con. mode
3	1 6 tem-airborne-file.tem	
4	50	!# of iterations
5	3	!# of layers, model 1
6	15 0.05	!transmitter altitude, transmitter altitude prior_STD
7	272 0.01	!transmitter angle, transmitter angle prior_STD
8	30 -1	!Resistivity_1, Resistivity_1 prior_STD
9	100 -1	!Resistivity_2, Resistivity_2 prior_STD
10	10 -1	!Resistivity_3, Resistivity_3 prior_STD
11	20 -1	!Thickness_1,Thickness_1 STD
12	30 -1	!Thickness_2,Thickness_2 STD
13	20 -1	!Depth_1, Depth_1 STD
14	47 -1	!Depth_2, Depth_2 STD

Figure 4.17 Model file for EM inversion with both an altitude parameter and an transmitter angle parameter. The comments after the ! are not required. Bold red text is not a part of the model file

Airborne HEM data with electrical permittivity

For HEM you can invert for altitude and electrical permittivity of layers together with the ordinary layer parameters (resistivities, thicknesses and depths).

The altitude parameter is included as an extra line in the file model format as a positive number.

Lateral constraints and a priori constraints are applied as usual.

The electrical permittivities of layers are added similar to resistivities of layers. A model file intended for this purpose is shown in Figure 4.18.

```
#   Text               Comments
1   Model label - one model
2   1 0                        !# of data files, Con. mode
3   1 7 hem-airborne-file.hem
4   50                         !#Iterations
5   3                          !#Layers, Model 1
6    45      0.05                !transmitter altitude, transmitter altitude prior_STD
7    30     -1                   !Resistivity_1, Resistivity_1 prior_STD
8   100     -1                   !Resistivity_2, Resistivity_2 prior_STD
9    10     -1                   !Resistivity_3, Resistivity_3 prior_STD
7    7e-11  -1                   !Permitivity_1, Permitivity_1 prior_STD
8    3e-11  -1                   !Permitivity_2, Permitivity_2 prior_STD
9    4e-11  -1                   !Permitivity_3, Permitivity_3 prior_STD
10   20     -1                   !Thickness_1,Thickness_1 STD
11   30     -1                   !Thickness_2,Thickness_2 STD
12   20     -1                   !Depth_1, Depth_1 STD
13   47     -1                   !Depth_2, Depth_2 STD
```

Figure 4.18 Model file for EM inversion with an altitude parameter and electrical permitivity of layers. The comments after the ! are not required. Bold red text is not a part of the model file.

Airborne EM with towed bird geometry

In the case of an airborne towed bird TEM system that measures at least the x and z-component we can invert for bird geometry as well. The geometrical parameters that we invert for are Tx, altitude, angle between Tx and Rx, distance between Tx and Rx, Rx pitch angle and Rx roll angle. The geometry parameters inverted for are all shown in Figure 4.19. An example model file is shown in Figure 4.20.

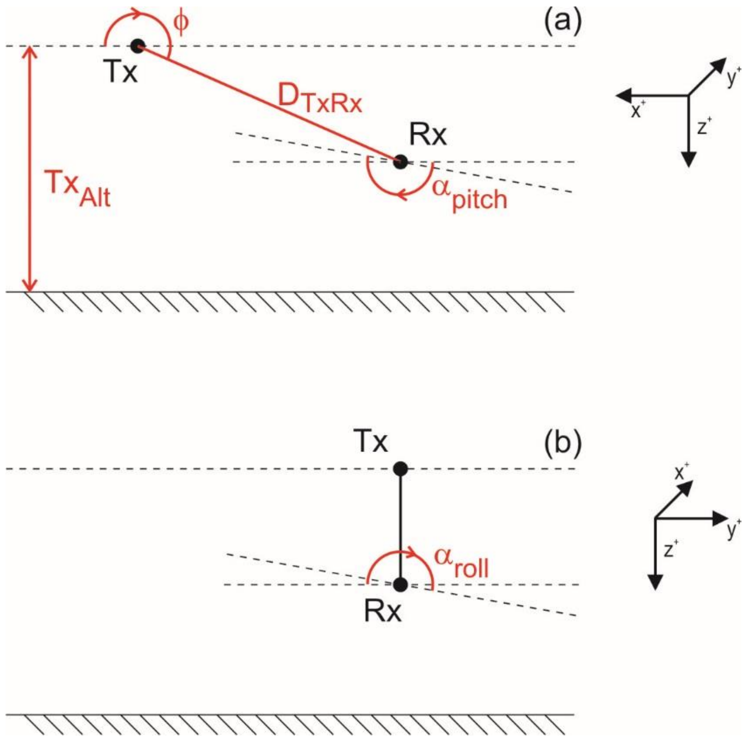

Figure 4.19. Overview of geometry parameters that can be inverted for when using the general towed bird TEM format.

```
#   Text           Comments
1   Model file for two data files working to optimize the same model
2   2 1
3   1 8 x.tem
4   1 8 z.tem
5   50
6   3
7   120.6  -1       0.3  !TxAlt
8   201.0  -1       0.05 !Theta, angle between Tx and Rx, 180 nominal
9    70.0  -1       0.05 !DTxRx, distance between Tx and Rx [m]
10  181.0  -1       0.3  !Alfa_Pitch, 180 nominal
11  175.0  -1       0.3  !Alfa_Roll, 180 nominal
12   30.0  -1  9e9  0.3  !Res_1
13   40.0  -1  9e9  0.3  !Res_2
14   10.0  -1       0.3  !Res_3
15   20.0  -1  9e9  1.4  !Thk_1
16   20.0  -1       1.6  !Thk_2
17   20.0  -1       1.7  !Dph_1
18   40.0  -1       1.9  !Dph_2
```

Figure 4.20 Model file for airborne TEM inversion with an towed bird and inversion for geometry parameters for the bird. A x and and a z-datafile work on the same model. The comments after the ! are not required. Bold red text is not a part of the model file.

Airborne TEM with transmitter altitude and shift factor

For airborne TEM data it is possible to include a shift factor as an extra inversion parameter on top of the transmitter altitude. The shift factor is simply multiplied to all of the measured data. A model file for that purpose is shown in Figure 4.21.

```
#   Text             Comments
1   Model label - one model
2   1 0                          !# of data files, Con. mode
3   1 51 tem-airborne-file.tem
4   50                           !# of iterations
5   3                            !# of layers, model 1
6    15     0.05                 !transmitter altitude, transmitter altitude prior_STD
7     1.1   0.05                 !shift factor, shift factor prior_STD
8    30    -1                    !Resistivity_1, Resistivity_1 prior_STD
9   100    -1                    !Resistivity_2, Resistivity_2 prior_STD
10   10    -1                    !Resistivity_3, Resistivity_3 prior_STD
11   20    -1                    !Thickness_1,Thickness_1 STD
12   30    -1                    !Thickness_2,Thickness_2 STD
13   20    -1                    !Depth_1, Depth_1 STD
14   47    -1                    !Depth_2, Depth_2 STD
```

Figure 4.21 Model file for TEM inversion with an altitude parameter and a shift factor. The comments after the ! are not required. Bold red text is not a part of the model file.

Airborne TEM with transmitter altitude and bias or coil response (CR) correction

For early times of airborne TEM data it is possible to consider an additional CR or system response. This CR is a small primary field due to residual current in the transmitter loop at early times and is usually measured at high altitude. It is important to note that the CR shape has to be stable (which is the case for SkyTEM system) in order to compensate it correctly! If not, removal of early times remains the best solution.

Studies with SkyTEM system have shown that if CR shape is stable, its amplitude is not and varies because of few cm bending of the frame during flight. It is thus necessary to consider a scaling factor which is evaluated as an inversion parameter.

Figure 4.22 shows an example of *.mod file using the CR correction for the inversion. Note the differences:

- Type on line 3 is now 52.
- The CR scaling factor and its prior STD on line 7: the starting value is normally equal to 1. Note that, because this factor needs to be able to change sign, the convention is to write it in the *.mod file with a shift of +100. So a starting value of 1 is actually written as 101. The prior STD can be left quite loose, the most important thing being to set the lateral constraint on the CR scaling factor relatively tight along a flight line.

Parallel to the *.mod file you need to have in the same folder a *.bia file which is a basic ascii file which has the same name as the *.mod file, but with a different file extension. Figure 4.23 shows an example of such a *.bia file. Important things you should be aware of regarding the numbers in the *.bia file:

- Check that the center gate times (1^{st} column in *.bia file) **exactly correspond** to the ones written in the tem files (with Aarhus Workbench the timing in *.geo file + calibration time shift)
- The unit of the db/dt response of the CR (2^{nd} column in *.bia file). It has to be normalized by the current and the number of wire turns, but not by the area of the transmitter loop. In fact, it is the unit convention in *.tem files, since the shape and area of the transmitter loop are considered in the modeling of the response.

You can put as many gates as you want in the *.bia file, even if the CR becomes very low in the last lines, it will simply have no impact.

Text **Comments**

```
Model file example with coil response (CR) correction
1 0
1 52 tem-airborne-file.tem
0
3                        !#Layers, Model 1
3.6841e+01  0.05         !Transmitter altitude, transmitter altitude prior_STD
101  1.0007e+00          !CR scaling factor, CR scaling factor prior_STD
 30    -1                   !Resistivity_1, Resistivity_1 prior_STD
100    -1                   !Resistivity_2, Resistivity_2 prior_STD
 10    -1                   !Resistivity_3, Resistivity_3 prior_STD
 20    -1                   !Thickness_1,Thickness_1 STD
 30    -1                   !Thickness_2,Thickness_2 STD
 20    -1                   !Depth_1, Depth_1 STD
 47    -1                   !Depth_2, Depth_2 STD
```

Figure 4.22 Model file for TEM inversion with altitude parameter and bias/coil response correction. The comments after the ! are not required. Bold red text is not a part of the data file.

Text **Comments**

```
Example of *.bia file for Coil Response (CR) correction
0.0200000E-06     2.0869769E-07 !center gate time (s), db/dt value of CR (V/(m²x A x N))
2.0200000E-06    -4.8598424E-05
4.0200000E-06    -1.8183371E-05
6.0200000E-06    -2.5425268E-06
8.0200000E-06    -2.9445568E-07
10.0200000E-06   -2.2408661E-08
```

Figure 4.23 *.bia file for TEM inversion with altitude parameter and bias/coil response correction. The comments after the ! are not required. Bold red text is not a part of the data file.

5. THE CON FILE (AARHUSINV CONFIGURATION FILE)

The con-file controls various settings in the inversion procedure.

AarhusInv is compatible with three configuration file versions: Version 15, version 20, and version 21.

Version 15 is an outdated version and is not described here. However, file examples can be downloaded from the web page. In the outdated versions all parameters must be specified in the con files. In version 20 and onwards, only the parameters that do not take the default values are specified. All specified parameters and default values can be printed out by typing "AarhusInv.exe help". The parameters are also printed in the log-file.

Here only version 20 will be described and an example is shown in Figure 5.1. The parameters specified in this example, are the parameters that can be changed by all users. Each parameter is explained in the following section.

Parameters, which should only be changed by expert users, are described in sections 5.2 - 5.14.

On the webpage you will find two con-file examples: One with the parameters which can be changed by all users (similar to Figure 5.1) and one with all the expert-user parameters.

#	Text	Comments
1	Confile settings:	%Text string
2	20	%con file version
3	%In/output settings	
4	OutputGen = 0	%0 -> general information to screen, 1 -> to file
5	OutputLog = 0	%0 -> overwrite log file, 1 -> append
6	OutputCov = 0	%1 -> write J, rough. and cov. matrices on .emm file, 0 -> don't
7	EmoWriteIte = 0	%1 -> write emo-type file after each ite. (.ems), 0 -> don't
8	%Inversion settings	
9	NCPUs = 1	%Number of CPUs used
10	CalcAnalysis = 1	%0 -> Don't Calc.; 1 -> Coup. anal.; 2 -> Coup. and uncoup. anal.
11	%Model linear/log settings	
12	LogModel = 0	%0 -> Inversion in log model space, 1 -> lin
13	LogData = 0	%0 -> Inversion in log data space, 1 -> lin
14	LogNeg = 0	%0 -> Warn for negative data, but continue inv; 1 -> Stop when negative; 2 -> Change to lin space when negative
15	LogDepth = 0	%0 -> Rel. depth const., inv. in log space, 1 -> Abs. depth const.
16	DepthRef = 1	%0 -> Depth-ref. lateral const.,1 -> Elevation-ref. lateral const.
17	AltRef = 0	%0 -> Height ref. Tx-altitudes, 1 -> Elevation ref. Tx-altitudes
18	%Parameter settings	
19	MinRes = 1.00E-01	%Min resistivity (ohmm) allowed
20	MaxRes = 2.00E+04	%Max resistivity (ohmm) allowed
21	MinThick = 1.00E-01	%Min thicknes (m) allowed
22	MaxThick = 5.00E+02	%Max thicknes (m) allowed
23	%Forward settings	
24	AddNoise2Scr = 0	%0 -> add noise to forward (.fwr) files, 1 -> no noise

Figure 5.1. Example of con-file version 20, where only a subset of parameters are specified. All parameters not listed take the default value. Lines starting with % are for comments and everything after % are comments as well.

5.1 CON file Version 20

The con-file has two mandatory lines in the beginning where the first is a comment and the second is the CON-file version. For all other lines the following apply:

- Format: [parameter_name] = value
- Lines starting with "%" are comments
- After any values, optional comments can be added by writing a "%" followed by the comment.

The following parameters can be changed by all users. The numbering refers to Figure 5.1.

Input/output settings

This section controls where and what to be written from the inversion output.

Line 4, one integer, OutputGen:

- Value 0: General information will be written to screen.
- Value 1: General information will be written to files.

Line 5, one integer, OutputLog:

- Value 0: Overwrite the log file between subsequent runs of AarhusInv.
- Value 1: The log file is appended between subsequent runs.

Line 6, one integer, OutputCov:

- Value 1: The covariance matrix, Jacobian matrix and roughness matrix will be written in the emm-file.
- Value 0: No matrices written.

Line 7, one integer, EmoWriteIte:

- Value 1: Write emo-type file after each iteration (.ems).
- Value 0: Do not write.

Inversion settings

Line 9, one integer, NCPUs:
Numbers of CPUs used.

Line 10, one integer, CalcAnalysis:

- Value 0: Do not calculate.
- Value 1: Calculate coupled analysis only.
- Value 2: Calculate coupled and un-coupled analyses

Model linear/log settings

This section control weather the computations are performed in linear or log space.

Line 12, one integer, LogModel:

- Value 0: Inversion in log model space
- Value 1: Inversion in linear model space

Line 13, one integer, LogData:

- Value 0: Inversion in log data space
- Value 1: Inversion in linear data space

Line 14, one integer, LogNeg:

All settings refer to the case when LogData=0

- Value 0: Warn for negative forward data, but continue the inversion by taking the absolute values of negative forward data.
- Value 1: Stop when negative forward data are encountered.
- Value 2: Change to linear data space when negative forward data are found.

Line 15, one integer, LogDepth:

- Value 0: Relative depth constraints (default).
- Value 1: Absolute depth constraints.

Line 16, one integer, DepthRef:

- Value 0: Depth referenced model.
- Value 1: Elevation referenced model (default).

Line 17, one integer, AltRef:

- Value 0: Height referenced altitudes.
- Value 1: Elevation referenced altitudes (default).

Parameter settings

Here the dynamic range of the model parameters is set.

Line 19-22, one real per line:

These lines set the range on the thickness and the resistivity in the inversion.

The total list of parameter maximum and minimum limits that can be specified in the con-file can always be listed typing "AarhusInv.exe help". The list includes:

- MinRes, MaxRes: resistivity [ohmm].
- MinThick, MaxThick: thickness [m].
- MinImagSigma, MaxImagSigma: imaginary conductivity (MIC/BIC/CCPA IP model) [mS/m]
- MaxM0, MinM0: M0 (RCC/CCC IP model) [mV/V].
- MaxTau, MinTau: Tau (RCC/CCC/MPA/MIC/BIC/TBIC/CCeps IP models) [s].
- MaxC, MinC: C (RCC/CCC/MPA/MIC/BIC/TBIC/CCeps IP models) [dim-less].

- MaxPhi, MinPhi: Phi (CPA/Drake/MPA IP models) [mrad].
- MaxfL, MinfL: fL (Drake IP model) [mHz].
- MinW, MaxW: W (MRS) [m^3/m^3]
- MinT2Star, MaxT2Star: Tau (MRS) [s].
- MinCmrs, MaxCmrs: C (MRS) [dimless].
- MinShift, MaxShift : shift (MRS) [rad] .
- MaxEps, MinEps: relative Permittivity (CCeps IP model) [dimless].
- MaxTemp, MinTemp: temperature (TRES/TBIC DC/IP models) [Celsius].

Besides these limits a few additional parameter settings can be defined:

- RefTemp: reference temperature (TRES/TBIC DC/IP models) [Celsius] for conductivity-temperature dependence.
- dSigma/dTemp: slope for DC conductivity-temperature (TRES/TBIC DC/IP models) [S/m/Celsius] dependence.
- dSigma2nd/dTemp: slope for imaginary conductivity-temperature dependence (TBIC IP model) [S/m/Celsius].
- Sigma2ndSurf/Sigma1stSurf: proportionality between real and imaginary surface conductivity at peak frequency (BIC/TBIC IP models) [dimless]

Forward settings

Line 24, one integer, AddNoise2Scr:

- Value 1: White noise is added to the forward response in the fwr-files with the STD as specified in the data files.
- Value 0: No noise is added to the forward response.

5.2 Expert user – Inversion settings

The following settings should be changed by expert users only.

MinApriori, one real:
Parameters with no prior information are assigned MinApriori as STD. Should not be changed.

MaxStep, one real:
The initial maximum parameter change. If MaxStep is exceeded, the damping continues.

MinStep, one real:
The overall minimum allowed parameter change.

StepUp, one real
The factor to increase the MaxStep after a successful iteration.

StepDown, one real:
The factor to decrease MaxStep if the norm increases.

NStepUp, one integer:
Number of iterations between increments of MaxStep.

ReUseG, one integer:

- Value 1: Reuse G from the last iteration for the analysis.
- Value 0: Recalculate G from final result.

CoupledAnalysisType, one integer:
Integer indicating the number of close neighbours used in the analysis.

- Value 0: Parallel sparse analysis for the full problem.
- Value 1: Coupled to nearest neighbours.
- Value 2: Further coupled to two nearest neighbours.
- Value -1: Parallel sparse analysis for the full problem (NPar<1000) or coupled to nearest neighbours (NPar>1000).

SolverType, one integer:
Solver type in the solution of the linear problem.

- Value 0: Sparse solver (except for 2D DCIP and MRS)
- Value 1: Dense solver and Dense algebra.
- Value 11: SSOR
- Value 12: LU0
- Value 13: LUT
- Value 14: BLUT
- Value 15: A-Phi solver for 3D TEM
- Value -1: Auto-selected sparse solver or dense solver for 2D DCIP and MRS

RelNormChange, one real:
Relative change in total norm (residual) to stop iterations for single-side derivatives.

RelNormChangeD, one real:
Relative change in total norm (residual) to stop iterations for double-side derivatives.

RelSubsetNormChange , one real:
Relative change in norm to stop iterations on any subset of size SubsetNormChangeSize.

SubsetNormChangeSize, one real:
Relative size of model space where the stop criterion must obey RelSubsetNormChange regardless of RelNormChangeD or RelNormChange

NIteAlt, one integer:
Numbers of iterations before setting the altitude free in the inversion. (Only model types 5 and 6).

NIteAng, one integer:
Numbers of iterations before setting the angle free in the inversion. (Only model type 6).

Broyden, one integer:

- Value 1: Broyden's update is used in the calculation of derivatives.
- Value 0: Broyden's update is not used.

NtwoD, one integer:
The number of full 2D iterations to be performed to initialize the Jacobian matrix before switching to Broyden's update (only if Broyden=1). This value must be ≥ 1 if Broyden's update is used with 2D-DC computations.

RelNormChangeB, one real:
Relative change in norm before recalculating the Jacobian matrix (only if Broyden=1). To use Broyden's update, RelNormChangeB must be larger than RelNormChange. Otherwise the iterations stop before starting to use Broyden's update.

NApproxDeriv, one integer:
Number of iterations in which derivatives are using approximate responses for the derivatives in the Jacobian.

For TEM it is the Fast Approximate Inversion (FAI) being used:

- Only segmented (type 72) and square (type 7) loops are supported.
- You can have only one Tx loop geometry for each single dataset.
- It works for all magnetic components, X, Y and Z.
- The initialization can last more than 20 s on a dataset with several altitudes, however it is fast when computing forward response with one altitude only or when inverting TEM data without altitude as an inversion parameter.

NApproxFor, one integer:
Number iterations with approximate forward computation. (Model type specific). IMPORTANT: for TEM a value larger than 0 will introduce a strong approximation in the calculations.

EndFull, one integer:

- Value 1: Always end with accurate (non-approximate) iterations (switch back if last iteration was using approximation)
- Value 0: Do not.

EndMinStep, one integer:

- Value 1: Always end with minimum step size.
- Value 0: Do not.

5.3 Expert user – Depth of Investigation settings

This section controls the setting used for computation the depth of investigation (DOI). The following parameters should be changed by expert users only.

For more information on the DOI see section 15.4: “Depth of Investigation”.

DOI, one integer:

- Value 1: Calculate DOI. For Nite=0 in the mod-file, the calculations are done for the input model.
- Value 0: Do not calculate DOI.

DOINLayers, one integer:
Number of layers for the DOI calculations.

DOIDepth1, one real:
Thickness of the first layer used in the DOI calculations.

DOIDepthN, one real:
Depth the last layer boundary used in the DOI calculations.

DOIAbsHigh, one real:
High absolute threshold value for the DOI (shallow).

DOIAbsLow, one real:
Low absolute threshold value for the DOI (deep).

DOIRelHigh, one real:
High relative threshold value for the DOI (shallow).

DOIRelLow, one real:
Low relative threshold value for the DOI (deep).

DOICAAHigh, one real:
High CAA (Cumulated Approximate Analysis) value for the DOI (shallow).

DOICAALow, one real:
Low CAA (Cumulated Approximate Analysis) value for the DOI (deep).

5.4 Expert user – Inversion damping settings

The following parameters should be changed by expert users only.

DampInit, one real:
Initial damping, 1st iteration: Max(diagonal)/DampInit.

MaxDampIni, one real:
Maximum value of DampInit. If a value larger than MaxDampInit is found, it is set to MaxDampInit.

DampInitUp, one real:
Factor to increase DampInit after a successful iteration.

DampFactor, one real:
Factor to increase the damping of the diagonal elements if previous damping was not sufficient.

NMaxDamp, one integer:
Maximum number of damping steps before giving up.

FirstTwoWayDamp, one integer:
First damping value.

NoDampConstrOnly, one integer:
- Value 1: No damping on the parameters driven only by constrains (with no Jacobian entries).
- Value 0: Damping on all parameters.

PartypeDamping, one integer:
- Value 1: True. Different damping for each parameter type.
- Value 0: False. Same damping value for all parameter types.

5.5 Expert user – Forward settings

The following settings should be changed by expert users only.

FDenseCSLow, one integer:
Low filter density for the cos-sine filter. (Forward responses use a filter density of FDenseCSHigh whereas derivatives are calculated with a density of FDenseCSLow.)

FDenseCShigh, one integer:
High filter density for the cos-sine filter.

FDenseJLow, one integer:
Low filter density for the J_1-J1 filter.

FDenseJHigh, one integer:
High filter density for the J_1-J1 filter.

SRConvCoarsestSampling, one integer:
The coarsest temporal sampling used for the system response convolution.

SRConvNSamplingSteps, one integer:
Refinement samplings steps used for the system response convolution. Finest sampling is 2^SRConvNSamplingSteps *SRConvCoarsestSampling.

SRConvRefinementLimit, one real:
Refinelimit which determines when to calculate more points. If a straight line approximation is more than SRConvRefinementLimit off, refinement is performed.

TDFiltConvCoarsestSamp, one integer:
The coarsest temporal sampling used for the time domain filter convolution.

TDFiltConvNSamplingSteps, one integer:
Refinement samplings steps used for the the time domain filter convolution. Finest sampling is 2^TDFiltConvNSamplingSteps *TDFiltConvCoarsestSamp.

TDFiltConvRefineLimit, one real:
Refinement limit for time domain filter convolution.

5.6 Expert user – Fast approximate TEM response settings

The following settings should be changed by expert users only.

cFAI one real:

alphaFAI, one real:

nbTxZFAIcon, one integer:
Number of different transmitter altitudes.

nbSigRefFAI, one integer:
Number of reference conductivities.

SigRefFAI, 8 reals:
Reference resistivities.

5.7 Expert user – 2D DC/IP settings

This section describes the settings used for 2D DC/IP inversions. The following parameters should be changed by expert users only.

LowerDecade, one integer:
Lower decade for the allocation of the Frequency Domain 2D DCIP Kernels. (Default value is -8)

UpperDecade, one integer:
Upper decade for the allocation of the Frequency Domain 2D DCIP Kernels. (Default value is 4).

AutoExtend, one integer:
Indicates what to do when the frequency range is exceeded:

- Value 0: Stop the inversion.
- Value 1: Warn and extend range at next iteration.
- Value 2: Warn but keep the .con range

LowResPPD, one integer:
Number of points per decade for kernel splining in low resolution mode (only when the iteration number NIte<=NApproxFor).

HighResPPD, one integer:
Number of points per decade for kernel splining in high resolution mode (only when the iteration number NIte>NApproxFor.).

LowResNCM, one integer:
Number of neighbouring models to the data point for the computation of the 2D Jacobian in low resolution mode.

HighResNCM, one integer:
Number of neighbouring models to the data point for the computation of the 2D Jacobian in high resolution mode.

LowResMinRelChange, one integer:
- Value 1: The minimum between DC total norm (residual) and IP total norm (residual) is considered as stopping criteria (in low resolution mode).
- Value 0: The global (DC+IP) norm is used.

HighResMinRelChange, one integer:
- Value 1: The minimum between DC total norm (residual) and IP total norm (residual) is considered as stopping criteria (in high resolution mode).
- Value 0: The global (DC+IP) norm is used

LowResIPFactor, one real:
Multiplicative scaling factor for IP data/model STDs, in low resolution mode (it balances the DC versus IP Jacobian/Constraints). When IPFactor>100, the IP Jacobian computation is turned off.

HighResIPFactor, one real:
Multiplicative scaling factor for IP data/model STDs, in high resolution mode (it balances the DC versus IP Jacobian/Constraints). When IPFactor>100, the IP Jacobian computation is turned off.

5.8 Expert user – SWD settings

This section the settings used for SWD computations. The following parameters should be changed by expert users only.

SWDMethod, one integer:
- Value 0: All layers are solid.
- Value 1: With liquid top layer.

SWDSearchStep, one real:
Max step in wavenumber search for SWD forward calculations (default 2e-5).

5.9 Expert user – Surface NMR/MRS settings

In this section, the settings for surface NMR/MRS are described. The following parameters should be changed by expert users only.

MinDepth, one real:
Min Z discretization limit, expressed as depth value [m].

MaxRelDepth, one real:
Max Z discretization limit, expressed as number of loop side lengths.

MinXDisc, one real:
Min horizontal discretization limit, expressed as fraction of loop side length.

MaxXDisc, one real:
Max horizontal discretization limit, expressed as fraction of loop side length.

ZDiscSwitch, one real:
Depth [m] at which z discretization (number of samples) is changed. Expressed as fraction of loop side length.

NDecShallow, one integer:
Number of points per decade for the Z discretization (Shallow setting).

NDecDeep, one integer:
Number of points per decade for the Z discretization (Deep setting).

NSampInShallow, one integer:
Horizontal discretization, number of discretization points between wire and the center (to the next wire), shallow discretization.

NSampInDeep, one integer:
Horizontal discretization, number of discretization points between wire and the center (to the next wire), deep discretization.

NMinLay, one integer:
Minimum number of discretization points in each layer.

PrintKernels, one integer:

- Value 1: Print out XYZ discretization, magnetic fields, tip angles, 3D/1D/integrated kernels.
- Value 0: Do not print.

ThetaqNo, one integer:
q number for which tip angle is printed.

5.10 Expert user – 2D HEM settings

In this section, the settings for 2D HEM are described. The following parameters should be changed by expert users only.

MaxSizeFwr, one integer:
Max number of models for forward sectioning.

MaxSizeDer, one integer:
Max number of models for derivative sectioning.

NJacobianOffDiag, one integer:
Number of neighbouring soundings included in the Jacobian matrix

Overlap, one integer:
Number of soundings to overlap

5.11 Expert user – Voxel settings

In this section, the settings for voxel computations are described. The following parameters should be changed by expert users only. This part is under development!

NExcludedNorms, one integer:
Number of norms to be excluded for un-connected nodes (i.e. model nodes not connected to any forward node).

NChangedNorms, one integer:
Number of norms to be changed for un-connected nodes (i.e. model nodes not connected to any forward node).

ExcludedNorm, one integer:
Norm indexes to be excluded, one number for each NExcludedNorms.

ChangedNorm: two integers:
Norm indexes to be changed (:,1)=old, (:,2)=new, for each NChangedNorms.

WriteCompleteMeshes, one integer:

- Value 1: Write model/constraint meshes including nodes far from flight lines to a file.
- Value 0: Do not write.

WriteExportFiles, one integer:

- Value 1: Export model, forward model and data in a Aarhus Workbench compatible format.
- Value 0: Do not.

WriteConstraintMesh, one integer:

- Value 1: Write constraint mesh to file.
- Value 0: Do not.

WriteForwardMesh, one integer:

- Value 1: Write forward mesh to file.
- Value 0: Do not.

VoxelDummyValue, one real
Dummy value for un-connected nodes in the workbench-style mesh export.

5.12 Expert user – Markov chain Monte Carlo settings

In this section, the setting for Markov chain Monte Carlo (MCMC) computations are described. The following parameters should be changed by expert users only.

MCMCType, one integer:

- Value 0: No MCMC. (default)
- Value 1: MCMC with uniform proposer.
- Value 2: MCMC with sensitivity matrix-based proposer.

MCMCStepFactor, one real:
Factor for scaling the step length of the model perturbation. Should be tuned to give an acceptance rate around 20-30%.

MCMCMaxRelWeight, one real:
Maximum relative weight to proposing steps for uncertain parameters. (i.e. N times larger than the best determined).

MCMCNoUpdateProps, one integer:
Number of steps between updating the sensitivity matrix in the proposer. Used only for MCMCType=2.

MCMCNoProps, one integer:
Number of proposes/iterations to run.

5.13 Expert user – BFGS solver settings

In this section, the settings for BFGS solver computations are described. The following parameters should be changed by expert users only.

BFGSCorrTerms, one integer:
Number of derivatives stored in the BFGS routine.

BFGSInitStepLength, one real:
Initial step length used in the BFGS.

BFGSTolModel, one real:
Tolerance of model vector in BFGS.

BFGSTolObjective, one real:
Tolerance of objective function in BFGS.

BFGSLinesearchDelta, one real:
Line search parameter delta for Wolfe conditions.

BFGSLinesearchSigma, one real:
Line search parameter sigma for Wolfe conditions.

BFGSLinesearchTau, three reals:
Line search parameters (tau) for Wolfe conditions - step lengths.

BFGSUseAdjointState, one integer:

- Value 1: Uses the adjoint state method for calculating the derivative of the objective function.
- Value 0: Uses the Jacobian.

5.14 Expert user – Advanced parallelization settings

In this section, the setting for parallelization are described. The following parameters should be changed by expert users only. This part is under development.

AffinityMode, one integer:
Mode of threads binding to cores:

- Value 0: Shared mode.
- Value 1: Dedicated mode.
- Value 2: Manual mode.

UseNested, one integer:

- Value 1: nested parallelization, typically only used for NUMA architecture

NCPUOuter, one integer:
Number of CPUs to use in outer parallelization, if set to 0 or negative numbers, it will be set automatically in InitOpenMP.

NCPUInner, one integer:
Number of CPUs to use in inner parallelization, if UseNested=.false. then NCPUInner=1.

NXeonPhis, one integer:
The number of XeonPhis available.

NCPUXeon, one integer:
Number of threads used on each XeonPhi.

NCPUsLow, one integer:
Lower limit of CPUs to use in regions of the code which are memory bandwidth limited in order to not oversaturate these regions.

NCPUInnerLow , one integer:
Number of CPUs in regions with memory saturation in order to not oversaturate the system.

NUMAdistribute, one integer:

- Value 1: Distribute across different NUMA nodes.
- Value 0: Keep on NUMA node until full

StartThread, one integer:
Thread to start the parallelization from:

- Value -1: It selects a random one
- Value > 0: Thread number

6. THE TEM FILE (TIME DOMAIN DATA)

The TEM data input file contains transmitter geometry and waveform settings along with the low pass filters of the TEM receiver and the data.

The TEM-file is a flexible way of storing the measured data. The settings in the TEM-file are used in the calculation of the forward response in the AarhusInv code. An example of a TEM data file for a central loop configuration sounding is shown in Figure 6.1.

Advanced settings regarding modelling with an arbitrary segmented loop and the use of a transmitter front gate is described in section 6.2- “Header lines with segmented loop and front gate”.

#	Text	Comments
1	Created by Emma	
2	7 3	!SourceType, Field Polar (Hx=1....Ez=6)
3	0.0 0.0 0.0 0.0 0.0 0.0	!Tx X, Y, Z, Rx X, Y, Z
4	40.0 40.0	!Tx LoopSide X and Y
5	4 4 4	!Inp/out: Inp, Out, Inv (0->H,1->dH/dt,2->B,3->dB/dt,4->rhoa
6	3 3	!WaveFormType: 0->step,1->imp.,3->user def. d/dt,NWaveForms
7	3 -1.05E-03 -9.30E-04 0.00 1.00 -9.30E-04 0.00E+00 1.00 1.00 0.00E+00 2.50E-06 1.00 0.00	!Num. of Sub WF, T0,T1,A0,A1..
8	3 -4.00E-03 -3.88E-03 0.00 1.00 -3.88E-03 0.00E+00 1.00 1.00 0.00E+00 2.50E-06 1.00 0.00	!Num. of Sub WF, T0,T1,A0,A1..
9	3 -1.00E-02 -9.88E-03 0.00 1.00 -9.88E-03 0.00E+00 1.00 1.00 0.00E+00 2.50E-06 1.00 0.00	!Num. of Sub WF, T0,T1,A0,A1..
10	3 0 0	!NFilters, 1 modelling of FrontGate, Damping fact of primary field
11	1 1 2.40E+05	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
12	0	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
13	1 1 2.40E+05	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
14	0	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
15	1 1 3.70E+04	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
16	0	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
17	9.150E-06 2.769E+01 5.00E-02 1 1	
18	1.152E-05 2.807E+01 5.00E-02 1 1	
19	1.450E-05 2.823E+01 5.00E-02 1 1	
10	1.826E-05 2.832E+01 5.00E-02 1 1	
11	2.298E-05 2.849E+01 5.00E-02 1 1	
12	2.893E-05 2.889E+01 5.00E-02 1 1	
13	3.643E-05 2.964E+01 5.00E-02 1 1	
14	4.586E-05 3.079E+01 5.00E-02 1 1	
15	5.773E-05 3.243E+01 5.00E-02 1 1	
16	7.268E-05 3.462E+01 5.00E-02 1 1	
17	9.150E-05 3.722E+01 5.00E-02 1 1	
18	1.152E-04 4.023E+01 5.00E-02 1 1	
19	1.450E-04 4.311E+01 5.00E-02 1 1	
20	1.826E-04 4.528E+01 5.00E-02 1 1	
21	2.298E-04 4.621E+01 5.00E-02 1 1	
22	2.894E-04 4.567E+01 5.00E-02 1 1	
23	3.643E-04 4.375E+01 5.00E-02 1 1	
24	4.586E-04 4.140E+01 5.00E-02 1 1	
25	5.773E-04 3.884E+01 5.00E-02 1 1	
26	7.268E-04 3.654E+01 5.00E-02 1 1	
27	4.830E-05 3.109E+01 5.00E-02 2 2	
28	6.081E-05 3.289E+01 5.00E-02 2 2	
29	7.655E-05 3.508E+01 5.00E-02 2 2	
30	9.637E-05 3.782E+01 5.00E-02 2 2	
31	1.213E-04 4.070E+01 5.00E-02 2 2	
32	. . . . .	
33	. . . . .	
34	1.923E-03 2.342E+01 5.00E-02 2 2	
35	2.421E-03 2.228E+01 5.00E-02 2 2	

```
36    1.000E-04  3.523E+01 5.00E-02  3  3
37    1.259E-04  3.862E+01 5.00E-02  3  3
38    1.585E-04  4.159E+01 5.00E-02  3  3
39    1.995E-04  4.357E+01 5.00E-02  3  3
40    2.512E-04  4.381E+01 5.00E-02  3  3
41    3.162E-04  4.235E+01 5.00E-02  3  3
42        .          .         .     .  .
43        .          .         .     .  .
44    7.943E-03  1.696E+01 5.00E-02  3  3
```

Figure 6.1 The TEM data file. The file shown uses a rectangular transmitter loop with a 40 x 40 m loop. It has three waveform definitions and three filter definitions for a TEM sounding with three segments. Data are converted to Rhoa, and the reference time is start of turn-off ramp. The empty lines in this figure are not allowed in real tem-file for input.

6.1 Header lines in the TEM file

The header lines of the TEM data file mean the following (see Figure 6.1):

Line 1, text label:
User-defined label describing the TEM data set. The label is repeated in the emo-file. Maximum 128 characters

Line 2: first integer, source type:
The source type can be one of the following:

- Value 1: Horizontal magnetic x-directed dipole. The dipole can be in the air or on the surface of the Earth. Receiver polarization has to be 1-3.
- Value 2: Horizontal magnetic y-directed dipole The dipole can be in the air or on the surface of the Earth. Receiver polarization has to be 1-3.
- Value 3: Vertical magnetic dipole. The dipole can be located anywhere in the layered model.
- Value 31: Rotated magnetic dipole with primary field. For TEMPEST. The dipole can be in the air or on the surface of the Earth. The rotated source can contain both a horizontal and a vertical component. Output has to be 1-3 (magnetic fields). If there is no waveform, the code assumes that the waveform terminates at I = -1 A. For TEMPEST, waveform type 4 should be used and the waveform should terminate at -0.5 A.
- Value 4: Horizontal electric x-directed dipole. The dipole can be in the air or at the surface of the Earth.
- Value 5: Horizontal electric y-directed dipole. The dipole can be in the air or at the surface of the Earth.
- Value 6: Vertical electrical dipole. The dipole can be located anywhere in the layered model
- Value 7: Rectangular loop source. The response is calculated by a numerical integration of electric dipoles along the wire path.

The rectangular loop source can be in the air or at the surface of the Earth. The loop is parallel to the x and y axis.

- Value 72. Segmented loop source. This type is used for arbitrarily shaped loops. The segmented loop source is described in section 6.2- “Header lines with segmented loop and front gate”.
- Value 73. Segmented loop source. The same as 72 except that it uses the inverse Laplace transform for the time transform instead of the Fourier transform used in source type 72.
- Value 8: Finite grounded x-directed dipole.
- Value 9: Finite grounded y-directed dipole. The response is calculated as the sum of the grounding terms and the numerical integration of electric dipoles along the wire path. The source can be in the air or at the surface of the Earth.
- Value 10: Infinite x-directed dipole. The source can be in the air or at the surface of the Earth. This source type is not available in the current version of AarhusInv.
- Value 11: Infinite y-directed dipole. The source can be in the air or at the surface of the Earth. This source type is not available in the current version of AarhusInv.
- Value 12. Circular central loop configuration (dipole receiver in the center of the loop). The source can be in the air or at the surface of the Earth.
- Value 123: Same as 12 except for that the inverse Laplace transform is used for the time transform instead of the Fourier transform.
- Value 13. Circular offset loop configuration (dipole receiver outside the loop). The source can be in the air or at the surface of the Earth.
- Value 14. In-loop (transmitter loop used as receiver loop). The source can be in the air or at the surface of the Earth. An example of the In-loop fil format is shown in Figure 6.2.

#	Text	Comments
1	Created by Emma	
2	14 3	!SourceType, Field Polar (Hx=1....Ez=6)
3	0.0 0.0 0.0 0.0 0.0 0.0	!Tx X, Y, Z, Rx X, Y, Z
4	22.6	!Tx/Rx Loop radius
5	4 4 4	!Inp/out: Inp, Out, Inv (0->H,1->dH/dt,2->B,3->dB/dt,4->rhoa
6	3 1	!WaveFormType: 0->step,1->imp.,3->user def. d/dt, NWaveForms
7	3 -1.05E-03 -9.30E-04 0.00 1.00 -9.30E-04 0.00E+00 1.00 1.00 0.00E+00 2.50E-06 1.00 0.00	!Num. of Sub WF, T0,T1,A0,A1..
8	1 0 0	!NFilters, 1 modelling of FrontGate, Damping fact of pri. field
9	1 1 2.40E+05	!LP/HP: NCutOff (0->no filter), FOrder(1,NCutOff), FCutOff(1,NCutOff) (Hz)
10	... Data section	

Figure 6.2 Example of a TEM data file header using the in-loop source type. The file shown uses a circular loop with an area of 1600 m2 loop (radius 22.6). Text marked red is not part of the file.

Line 2, second integer, receiver polarization:
The receiver dipole polarization can be one of the following:

- Value 1: Magnetic field, x-direction.
- Value 2: Magnetic field, y-direction.
- Value 3: Magnetic field, z-direction.
- Value 4: Electric field, x-direction.
- Value 5: Electric field, y-direction.
- Value 6: Electric field, z-direction.
- Value 7: Total magnetic field, i.e. sqrt(Hx^2+Hz^2)
- Value 8: Magnetic field, x-direction, with possible z-contamination due to tilt of the transmitter-receiver system. For this type, the Source type (line 4) must be type 7 or 72.

All receiver dipoles can be located anywhere in the layered model.

Line 3, six reals, transmitter and receiver positions:
The first three reals are the positions of the transmitter (Tx), and the last three reals are the location of the receiver dipole (Rx). Depending on the source type the Tx positions are:

- Source type 1-6 (dipoles): The positions are the x, y and z positions of the transmitter and receiver dipole.
- Source type 31 (tempest): 9 reals, Transmitter: x,y,z; receiver: x,y,z; transmitter pitch; transmitter roll (TEMPEST definition); relative standard deviation on the primary field.
- Source type 7 (square loop): The position is the center of the loop.
- Source type 8-9 (finite grounded electric dipoles): The position is at the center of the wire.
- Source type 10-11 (infinite wire source): The position is at the center of the wire.
- Source type 12-14, 123 (loop sources): The position is in the center of the transmitter loop.
- Source type 72-73 (segmented loop). Transmitter x and y coordinates are dummy, because they are calculated using the corner points.

Receiver polarization type 8 (line 2), special case, the angle of the x-coil is given as a seventh real, after the transmitter and receiver positions. See “Airborne EM with transmitter altitude and x-receiver tilt angle” on page 28.

The coordinate system is right handed with the z-axis pointing downwards. This means that z = 0 is on the surface of the Earth, z > 0 is below the surface (in the layering), and z < 0 is in the air.

Line 4, reals, Tx loop dimensions:
The transmitter dimension depends on the source type. The line takes the following values:

- Source type 1-6, 31 (dipoles): The line is present but not in use.
- Source type 7 (square loop): Two floats. Loop side length in the x-direction and loop side length in the y-direction.
- Source type 8-9 (finite grounded wire): One float. Wire length
- Source type 10-11 (infinite wire): The line is not present.
- Source type 12-14, 123 (loop source): One float. Radius of the loop. Use radius of equivalent circular loop if loop is not circular.
- Source type 72-73 (segmented loop): One integer, one real. Number of segments, area of the loop. Then follows one line for each segment with x- and y-coordinates of the corner points (same coordinate system used to give receiver position in line 3). See example in section 6.2 ”Header lines with segmented loop and front gate”.

Line 5, three integers, data transforms:
Transform of input data, data transform during the inversion process and transform on the output.

- Value 0: Magnetic field intensity (H) or the electric field (E) [V/m].
- Value 1: dH/dt or dE/dt [V/(m*s)].
- Value 2: Magnetic induction (B).
- Value 3: dB/dt. [V/m^2]
- Value 4: Late time apparent resistivity. [Ωm]

Notes:

- Choosing either the field or its time derivative is actually directed by the waveform type chosen (see line 6 just below). If for example one chooses waveform type 3, it will always be the time derivative of the field (magnetic or electric) if 0/2 or 1/3 is chosen for the data transform.
- If one wants to get the electric field (E), or its time derivative (dE/dt) the value 0 and 1 must be chosen for the data transform. If not the electric field is multiplied by the magnetic permeability (μ_0) of a vacuum [$\mu_0 = 4\pi * 10^{-7}$].

Line 6, first integer, transmitter waveform type:
The transmitter waveform can be either step or impulse response or user-defined. The transmitter waveform type takes the following values:

- Value 0. The waveform is a step function. The calculated field is either B or H (it will never be the time derivative d/dt even if 1 or 3 is set on line 5)
- Value 1. The waveform is an impulse at t=0 s. The field is either B or H, but since the waveform is an impulse, it is equivalent to the time derivative for a step response (e.g. dB/dt).

- Value 3. The waveform is user-defined. The calculated field is the time derivative of the B or H field (e.g. dB/dt). It will never be the field itself even if 0 or 2 is set on line 5.
- Value 4. The waveform is user-defined as for value 3. However, the calculated field is either B or H. It will never be the time derivative d/dt even if 1 or 3 is set on line 5.
- Value 5. The convolution of a step response with a user supplied system response which contains both waveform, receiver and amplifier characteristics. The calculated field is always the time derivative of the field. In this case no waveforms and filters should be present. The input for the system response is described below. Only usable for source type 73 and 123. Output is always in dB/dt
- Value 6. A synthetic system response is calculated based on a transmitter waveform and low pass filters. The synthetic system response is convoluted with a step response as for transmitter type 5. If AarhusInv is not able to generate an accurate system response, the execution is terminated. The generated synthetic system response is stored in file "SynSRID<number>.txt". The ID is written in the FWR file. Only usable for source type 73 and 123. Output is always dB/dt.

Line 6, second integer, transmitter waveforms:
The second integer defines the number of transmitter waveforms when the transmitter waveform type is 3 (user defined). If the transmitter waveform type is 0 or 1, this integer is dummy. For system response convolution this number is the system response ID referring to the system response file. The system response file is described in section 6.5.

Line 7-9, reals, transmitter waveform definitions, waveform type 3:
These lines are only present if the waveform is user-defined (waveform type is 3 in line 6). A user-defined waveform is piecewise linear. Each linear segment is called a sub-wave. A full transmitter waveform definition consists of a number of linear sub-waves. In the example shown in Figure 6.3, the number of lines is three. This defines three transmitter sub-waveforms. The format of one of these lines is:

- t1,t2,A1,A2. Thus the full format of a three-segmented waveform is t_{11},t_{12},A_{11},A_{12},t_{21},t_{22},A_{21},A_{22},t_{31}, t_{32},A_{31},A_{32}

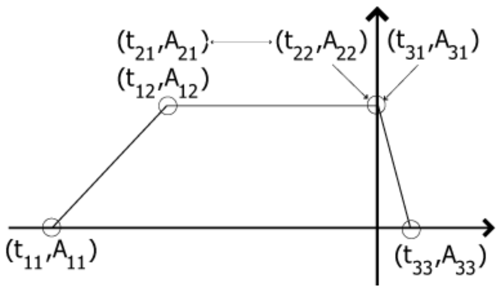

Figure 6.3. A TEM waveform with three segments. Relative sizes are out of scale.

Line 7, integers and reals, waveform period and repetitions, waveform type 6:
This line is only present for waveform 6 and it is identical to line 3 in the system response file which is described in section 6.5. Line 7-9 described above are written after this line (that is they become line 8-10).

Line 10, first integer, number of filters:
If 0 is indicated, no filters are used.

Line 10, second integer, modelling of front gate:
1 means that a front gate is modelled (described in section 6.2, "Header lines with segmented loop and front gate"). Type 0 for not modelling the front gate (default).

Line 10, third real, damping of primary field:
Damping factor of the primary field. See section 6.2 “Header lines with segmented loop and front gate” for details. Requires modelling of front gate.

Line 11–16, filters:
Two lines per number of filters as given in line 10. First line holds the low-pass filters, second line holds the high-pass filters. High-pass filters are most often not present. Each line holds the numbers (NCutOff, FOrder, FCutOff(1:NCutOff)).

- NCutOff (integers) is the number of frequencies defining the filter.
- FOrder, can be:
    - An integer, which corresponds to the order of the Butterworth filter (1 defines a first order filter, 2 a second order filter).
    - A real >0 and <1, which means that Gaussian-RLC filter is used with a real damping factor. NOTE: this filter is used only for the first filters applied before the front gate. Also, even very close to 1 you need to put a number like 0.99 to ensure that the switch to Gaussian filter is made.

- FCutOff (real) is the cut-off frequency for the filters (Hz).
- FOrder and FCutOff are repeated NCutOff times.

6.2 Header lines with segmented loop and front gate

This section describes the use of a segmented loop and front gate. The description is based on the example in Figure 6.4. Only lines that are different from the previously presented tem-file are described below.

```
#     Text                                    Comments
1     0.00 0.00 0.00 5 6553 6554 6555 6556 6557
2     72  3
3     0  0  0  -4.0 -4.0 -2.28
4     6    96.0                      !NWire, Loop area
5      5.0  5.0                      !1st knot (x,y)
6     -5.0  5.0                      !2nd knot (x,y)
7     -5.0 -3.0
8     -3.0 -3.0
9     -3.0 -5.0
10     5.0 -5.0                      !5th knot (x,y) (connected automatically to 1st knot)
11    4  4  4
12    3  1
13    3   -2.0e-3 -1.9e-3 0.0 0.63     -1.9e-3 -1.7e-3 0.63 1.0     0.0e+00 2.253e-06 1.0 0.0
14    1 1 1.00                       !NFilters, 1 modelling of FrontGate, Damping factor of primary field
15    1  1 4.500E+0005               !Filters before the front gate
16    0
17    20.e-6                         !First FrontGate in s
18    1  1 3.30E+0005                !Filters after the front Gate
19    0
...
...Data section
```

Figure 6.4 The header in a TEM data file with segmented loop and modelling of front gate with filters before and after.

Line 1, text label.

Line 2: first integer, source type:
Value 72. Segmented loop source. This type is used for arbitrarily shaped loops.

Line 2, second integer, receiver polarization.

Line 3, six reals, transmitter and receiver positions:
The first three reals are the positions of the transmitter (Tx), and the last three reals are the location of the receiver dipole (Rx). The transmitter x and y values are dummy.

Line 4, first integer, number of segments (wires):
The integer gives the number of segments (wires) used to define the segmented loop.

Line 4, second real, area of loop.
The area of the segmented loop in square meters.

Line 5-10, two reals, wire end-points:
X- and y-coordinates of the wire end-points. The loop is automatically closed by connecting the last point with the first point.

Line 11, data transform.

Line 12-13, transmitter waveform.

Line 14, first integer, number of filters before front gate:
If 0 is indicated, no filters are used.

Line 14, second integer, modelling of front gate:
1 means modelling of a front gate. If 0 no front gate is modelled (default). Note that you must have at least one filter to use a front gate.

Line 14, third real, damping of primary field:
Damping factor of the primary field. Requires modelling of front gate.

Line 15-16, filters before front gate:
Two lines per number of filters given in line 14. Format is described in the previous section.

Line 17, one real, front gate time:
One line per number of filters as given in line 14 with the front gate time (in seconds).

Line 18-19, filters after the front gate:
Two lines per number of filters as given in line 18. The format is described in the previous section.

6.3 Data lines in the TEM file

The line numbers in this section refers to the line numbers given in Figure 6.1.

Line 17-43, data section:
Each line is one data point (time-window or gate). The line consists of five or seven numbers:

- Real. Gate center time in seconds measured from the start of the turn-off ramp.
- Real. The data value with the unit indicated in line 5.
- Real. The relative standard deviation on the data value.
- Integer. The waveform used to measure the data (1:NWaveForm)
- Integer. The filter used for the measured data (1:NFilters)
- Real (optional). Gate open time in seconds measured from the start of the turn-off ramp.
- Real (optional). Gate close time in seconds measured from the start of the turn-off ramp. If gate open and gate close times are present the code will automatically model the true response over the finite length of the gate

6.4 Special formats

TEM file using system response

For inversions using a system response, one should supply the system responses using the SSR-file described in section 6.5. An example of a TEM-file is shown in Figure 6.6.

```
#    Text                           Comments
1    Header
2    73  3                          ! Use source type 73 for system response
3    0  0  0  -4.0 -4.0 -2.28
4    4    100                       !NWire, Loop area
5     5.0  5.0                      !1st knot (x,y)
6    -5.0  5.0                      !2nd knot (x,y)
7    -5.0 -5.0
8     5.0 -5.0
9    3  3  3                        ! always dB/dt when using system response
10   5  1                           ! Use system response ID 1
11   0                              ! always no filters when using system response
12   1e-6  1e-4  0.03  1 1          !Data section
...
```

Figure 6.5 An example TEM file using a system response. The comments after the ! are not required. Bold red text is not a part of the data file.

TEMPEST data

For the inversion of TEMPEST data (Fugro Airborne design), an example of model file is displayed in Figure 4.16 in section 4.4, and an example of a tem file in Figure 6.6. Use waveform type 4 with TEMPEST.

```
#  Text                                     Comments
1  test file for Tempest - 100 ohmm halfspace
2  31   1                                   !SourceType, Field Polar (Hx=1....Ez=6)
3  0.00     0.00  -120.00  -100.00     0.00   -70.00   -5    2   !Tx X, Y, Z, Rx X, Y, Z ; TEMPEST:
TxPitch,TxRoll
4  0    0                                  !Tx LoopSide X and Y
5  2    2    2                             !Inp/out: Inp, Out, Inv (0->H,1->dH/dt,2->B,3->dB/dt,4->rhoa)
6  4    1                                  !WaveFormType (0->step,1->imp.,3->user,d/dt,4->sq.),NWaveforms
7  6 -1.060E-01 -9.400E-02  0.00  1.00 -8.500E-02 -7.500E-02  1.00 -1.00 -6.400E-02 -5.600E-02 -1.00
1.00 -4.200E-02 -3.800E-02  1.00 -1.00 -2.100E-02 -1.900E-02 -1.00  1.00  0.000E+00  1.000E-06  1.00
0.00                                       !NSubWaves, T0_1,T1_1,A0_1,A1_1, .. ,T0_n,T1_n,A0_n,A1_n
8  0    0 1.000E+00                        !NFilters,UseFrontGate(0->no gate,1->gate),FrontGateScaleFac
9    0.013E-03     4.0630E-15     3.00E-02  1  1
10   0.040E-03     1.8140E-15     3.00E-02  1  1
11   0.067E-03     1.1090E-15     3.00E-02  1  1
12   0.107E-03     0.6652E-15     3.00E-02  1  1
13   0.173E-03     0.3644E-15     3.00E-02  1  1
14   0.280E-03     0.1898E-15     3.00E-02  1  1
15   0.453E-03     0.9308E-16     3.00E-02  1  1
16   0.720E-03     0.4473E-16     3.00E-02  1  1
17   1.120E-03     0.2146E-16     3.00E-02  1  1
18   1.733E-03     0.1011E-16     3.00E-02  1  1
19   2.693E-03     0.4605E-17     3.00E-02  1  1
20   4.200E-03     0.2030E-17     3.00E-02  1  1
21   6.560E-03     0.8679E-18     3.00E-02  1  1
22  10.200E-03     0.3625E-18     3.00E-02  1  1
23  16.200E-03     0.1418E-18     3.00E-02  1  1
```

Figure 6.6. TEM file for TEMPEST data (here for Hx receiver, just put “31   3” at line 2 for Hz receiver). The comments after the ! are not required. Bold red text is not a part of the data file.

6.5 System response input file

The system response used with waveform type number 5 is supplied in a separate file called the same name as the mod-file but with the extension .ssr as seen in Figure 6.7. It has the format:

Line 1: Text label, header

Line 2, integer, number of system responses in the file

Line 3, first integer, number of waveform repetitions
If 1 ignore the rest of the numbers on the line.

Line 3, second real, the period in seconds
The time between the beginning of one waveform to the beginning of the next waveform.

Line 3, integers, normalized pattern
The pattern of the waves. There should be integers equal to the first integer of the line. These numbers are multiplied with the waveform and one can therefore use waves of differing magnitudes.

Line 4, reals, times for the system response

Line 5, reals, values of the system response
The number of reals in line 5 must equal the number of reals in line 4.

Line 3-5 are repeated for the number of system responses in line 2. The system responses are numbered as they appear in the .ssr file. In other words with ID's 1,2,3,…

Remark: The code accepts more than one point at the same time value. For example times = (0,0,1,1) and responses = (0,1,1,0), which is a square. However, it might become unstable if the time intervals become very small (instability has been observed with dt = 1e-16).

#	Text	Comments
1	Header line	
2	1	! number of system responses in the file
3	2 1600e-6 +1 -1	! number of waves, period, amplitude pattern
4	0 1e-6 2e-6 3e-6 …	! Times for the system response values
5	0 1 1 0	! Values for the system response values

Figure 6.7: The SSR input file for the system response. The comments after the ! are not required. Bold red text is not a part of the file.

7. THE DCP FILE (RESISTIVITY AND IP DATA)

The DCP data input file contains settings and data for resistivity soundings (section 7.1 – "Header lines in the DCP file") and resistivity sounding with induced polarization data (section 7.3 – "Header lines in DCP file with IP ").

The DCP-file is a flexible way of storing the measured data. The settings in the DCP-file are used in the calculation of the forward response in the AarhusInv code. An example of a DCP data file for a 4-electrode resistivity sounding is shown in Figure 7.1. The content of the file is described below.

```
#   Text                                        Comments
1   PACES_01                                    !Text string
2   22                                          !SourceType
3   1  1   1  2                                 !Inp, Out, Inv, OutputMidtPoint
4   -5.0  15.0   -5.0   5.0  100.5  0.05 !XA, XM, XN, XB, data, std
5   -5.0  15.0  -34.0  34.0   99.5  0.05
6   -5.0  15.0  -45.0  45.0   88.9  0.05
7   -5.0  15.0  -45.0 -12.0  102.0  0.05
8   -5.0  15.0  -45.0 -17.0  101.2  0.05
9   -5.0  15.0  -45.0 -19.0   99.7  0.05
```

Figure 7.1 Data file for electrical data. Source type 22 (4-electrodes on a profile mode), six 4-pole configurations. The comments after the ! are not required. Bold red text is not a part of the data file.

7.1 Header lines in the DCP file

The header lines of the DCP data file mean the following (line 1-3, Figure 7.1):

Line 1, text label:
User-defined label describing the DCP-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, one integer, source type:
The source type can be one of the following:

- Value 20: Schlumberger mode - only the L/2-distance is specified for the electrode positions.
- Value 21: Wenner mode - only the a-distance is specified for the electrode positions.
- Value 22: 4-electrodes on a profile mode. x-positions for the 4 electrodes are specified.
- Value 23: 4-electrodes on the earth surface. x and y positions for the electrodes are specified.
- Value 24: 4-electrodes at arbitrary positions on the surface or in the ground, x, y and z-positions are given for all electrodes.
- Value 25: 4-electrodes in a borehole. Only the depth is given for the electrodes. This source type is used for modelling and inversion in a 1D cylindrically symmetric coordinate system.

Line 3, first three integers, data format
The formatting is either:

- Value 0 0 0. Input data, output data, and the inversion runs with electrical potentials.
- Value 1 1 1. Input data, output data, and the inversion runs with apparent resistivity values.

Combinations of the input/output values are not recommended at the current stage of the program.

Line 3, fourth integer, center point:
The center point of the output is written to the emo-file. Center points are only written for source type 22 and 23:

- Value 1: Center point: (A+B)/2
- Value 2: Center point: (M+N)/2
- Value 3: Center point: (N+A)/2
- Value 4: Center point: (M+B)/2

7.2 Data lines in the DCP file

Line 4-9, reals, data:
Each line represents a measured configuration. Electrode positions, data, and std are specified. A and B are current electrodes. M and N are potential electrodes. X, Y and Z [m] are electrode positions. For formats without the z-position, the electrodes are assumed to be on the surface.

- Source type 20: three floats: AM-distance [m], data, std.
- Source type 21: three floats: a-distance [m], data, std.
- Source type 22 (Figure 7.1): six floats: XA, XM, XN, XB [m], data, std.
- Source type 23: ten floats: XA, YA, XM, YM, XN,YN, XB, YB [m], data, std.
- Source type 24: fourteen floats: XA, YA, ZA, XM, YM, ZM, XN, YN, ZN, XB, YB, ZB [m], data, std.
- Source type 25: six floats: ZA, ZM, ZN, ZB [m], data, std.

Comments:

The apparent resistivity for source type 20 to 23 is calculated with respect to a half-space, while 24 and 25 is calculated with respect to a full-space.

7.3 Header lines in DCP file with IP data

For the inversion of resistivity and IP data, an example of the model file (mod-file) holding the inversion parameters, prior information, constraints etc. is shown in Figure 4.6.

An example of a dcp-file holding DCIP data is shown below in Figure 7.2 and described in the following. The file is similar to the dcp-file for resistivity data, but must also be given a waveform and chargeability data.

```
#  Text               Comments
1  DCIP data file     !Text
2  272                !SourceType
3  1  1  1            !Inp, Out, Inv
4  1                  !#Filters
5  1  1  2.40E+05     !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
6  0                  !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
7  1                  !#WaveFormType
8  2  3  3.35 3.50  4 0 1  4 0 -1  4 0 1  !WaveType (2->100%),Npulses, startDCint,endDCind, Ton,Toff,Amp
9  0                  !ModelGateTimes
10  -3.75 -1.25 1.25 3.76    1.9805E+01  0.02  1  1 1 !Res: xA,xM,xN,xB,Data,std,ID,FilterID,WaveID
11  -6.26 -1.25 1.25 6.25   2.0381E+01  0.02  2  1 1
12  -8.75 -1.25 1.25 8.75   2.1477E+01  0.02  3  1 1
13  -11.25 -1.25 1.25 11.25 2.2985E+01  0.02  4  1 1
14  -3.75 -1.25 1.25 3.76   4.2789E+02  0.05  1  1 1  2.95E-03 !Char: Pos,Data,std,ID,FilterID,WaveID,Time
15  -3.75 -1.25 1.25 3.76   4.0697E+02  0.05  1  1 1  5.06E-03
16  -3.75 -1.25 1.25 3.76   3.8237E+02  0.05  1  1 1  8.36E-03
17  -3.75 -1.25 1.25 3.76   3.5314E+02  0.05  1  1 1  1.36E-02
18  -3.75 -1.25 1.25 3.76   3.2074E+02  0.05  1  1 1  2.17E-02
19  -3.75 -1.25 1.25 3.76   2.8391E+02  0.05  1  1 1  3.47E-02
20  -3.75 -1.25 1.25 3.76   2.2322E+02  0.05  1  1 1  5.56E-02
21  -6.26 -1.25 1.25 6.25   2.0381E+01  0.05  2  1 1  2.95E-03
22  -6.26 -1.25 1.25 6.25   2.0381E+01  0.05  2  1 1  5.06E-03
…
28  -6.26 -1.25 1.25 6.25   2.0381E+01  0.05  2  1 1  5.56E-02
29  -8.75 -1.25 1.25 8.75   2.1477E+01  0.05  3  1 1  2.95E-03
…
34  -8.75 -1.25 1.25 8.75   2.1477E+01  0.05  3  1 1  3.47E-02
35  -11.25 -1.25 1.25 11.25 2.2985E+01  0.05  4  1 1  2.95E-03
…
45  -11.25 -1.25 1.25 11.25 2.2985E+01  0.05  4  1 1  2.26E-01
```

Figure 7.2. Data file for DCIP data - source type 272 (four electrodes on a profile). Four different electrodes configurations have been measured and a low-pass filter is applied. The waveform has a 50% duty cycle with 4 sec on- and off-time. The comments after the ! are not required. Bold red text and … is not a part of the data file.

The following description of the DCP-file refers to Figure 7.2.

Line 1, text label
User-defined label describing the DCP-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, one integer, source type:
The source type can be one of the following:

- Value 272: Four electrode on a profile model. The x-positions are specified for the four electrode positions in the data lines.
- Value 274: Four electrodes at arbitrary positions on the surface or in the ground. The x-, y- and z-positions are specified for the four electrode in the data line.

Line 3, three integers, data format:

- Value: 0 0 0: Input data, output data, and the inversion runs with electrical potentials.
- Value: 1 1 1: Input data, output data, and the inversion runs with apparent resistivity and chargeability values.

Line 4, one integer, number of filters:

- Value = 0: no filters are used and line 5-6 can be left out of the DCP-file.
- Value > 0: number of filters

Line 5–6, filters:
Two lines per number of filters given in line 4. Fist line holds the low-pass filters and the second line hold the high-pass filters. Each line hold the numbers NCutOff, FOrder, FCutOff. FOrder and FCutOff are repeated NCutOff times.

- NCutOff, integer: The number of frequencies defining the filter.
- Forder, integer: The order of the Butterworth filter (1 defines a first order filter, 2 a second order filter).
- FCutOff, real: The cut-off frequency for the filters (Hz).

Line 7, one integer, number of waveforms:

- Value >= 1: specifies the number of waveforms.
- Value < 1: not allowed

Line 8, waveform:
One line per number of waveforms given in line 7. Each line consists of two integers plus the definition of each pulse (three reals per pulse):

- First integer: The transmitter waveform:
    - Value 0: Step response.
    - Value 1: 50% duty cycle.
    - Value 2: 100% duty cycle.
    - Value 4: 100% duty cycle, skipping the first pulse.
- Second integer: Number of pulses.
- Third real: StartDC, the start time of the DC integration.
- Fourth real: EndDC, the end time of the DC integration.

For each number of pulses, the four integers/reals described above are follow by reals for Ton, Toff and Amp:

- Ton: The duration of the current on-time.
- Toff: The duration of the current off-time. For a 100% duty cycle, this is 0.
- Amp: The amplitude of the pulse. Can be positive and negative.

Line 9, one integer, modelling of gate width:
The modelling of the gate width is not yet implemented

- Value 0: no modelling of gate width.

7.4 Data lines in the DCP file with IP data

Each data line (line 10-45 in Figure 7.2) is a data point with a resistivity or a chargeability value. Each data line have nine or ten reals or integers:

First –fourth real, positions of electrodes:
The electrode positions for the measured configuration are listed here. A and B are current electrodes. M and N are potential electrodes. The positions needed depends on the source type:

- Source type 272: Four reals, xA, xM, xN, xB [m]. For example see Figure 7.8.
- Source type 274: nine reals, xA, yA, zA, xM, yM, zM, xN, yN, zN, xB, yB, zB [m]. For example see Figure 7.9.

Fifth real, resistivity/chargeability value:
The measured resistivity (res) or chargeability (char) value. If the data format is 0 (electric potential), the respective units are [V] and [mV/V]. If the data format is 1 (apparent resistivity), the respective units are [Ohmm] and [mV/V].

Sixth real, std:
The standard deviation on the data.

Seventh integer, ID number:
Each measurement at each electrode configuration is given an ID number. All the resistivity data are listed fist in the data section with their individual ID number. Hereafter follow the chargeability data, which are connected to the resistivity data of the configuration through their corresponding ID numbers. For example with four different electrode configurations see Figure 7.9.

Eighth integer, filter ID:
The filter used for the measured data. If no filters are used (Nfilters =0), the filterID must still be set to 1.

Ninth integer, waveform ID:
The waveform used for the measured data.

Tenth real, gate center time:
Gate center time is only listed for chargeability data lines.

Comments:
In the data line section, all the resistivity data are listed first, followed by the IP data. Each data line represents either a measured resistivity or a chargeability value from one gate on the IP decay.

7.5 Examples: Resistivity data

Figure 7.3: Resistivity. Schlumberger configurations with a-spacings from 1 to 100 m. Source type 21 (Schlumberger mode).

Figure 7.4: Resistivity. Three Wenner configurations with a-spacings of 10 m, 20 m, and 30 m. Source type 20 (Wenner mode).

Figure 7.5: Resistivity. Two 4-pole configurations. XY-layout on the surface of the earth (source type 23).

Figure 7.6: Resistivity. Four 4-pole configurations in the ground defined with x, y and z-coordinates for all electrodes (source type 24).

Figure 7.7: Resistivity. Four 4-pole configurations in a borehole. Electrode positions are defined by their z-coordinate only (source type 25).

#	**Text**	**Comments**
1	Schlumberger config.	!text string
2	20	!SourceType
3	1 1 1 1	!Inp, Out, Inv, OutputMidtPoint
4	1.00 99.99 0.05	!AM-spacing, data, std
5	1.33 99.99 0.05	
6	1.78 99.97 0.05	
7	2.37 99.93 0.05	
8	3.16 99.82 0.05	
9	4.22 99.59 0.05	
10	5.62 99.07 0.05	
11	7.50 97.88 0.05	
12	10.00 95.30 0.05	
13	13.30 90.18 0.05	
14	17.80 80.74 0.05	
15	23.70 66.31 0.05	
16	31.60 48.19 0.05	
17	42.20 30.81 0.05	
18	56.20 18.88 0.05	
19	75.00 13.05 0.05	
20	100.00 11.03 0.05	

Figure 7.3. Data file for resistivity data - source type 20 (Schlumberger mode). Three Schlumberger configurations with AM-spacings from 1 to 100 m. The comments after the ! are not required. Bold red text is not a part of the data file.

#	**Text**	**Comments**
1	3 Wenner config.	!text string
2	21	!Source type
3	1 1 1 1	!Inp, Out, Inv, OutputMidtPoint
4	10 47.5 0.05	!AM-spacing, data, std
5	20 99.5 0.05	
6	30 88.9 0.05	

Figure 7.4. Data file for resistivity data - source type 21 (Wenner mode). 3 Wenner configurations with a-spacing 10 m, 20 m, and 30 m. The comments after the ! are not required. Bold red text is not a part of the data file.

```
Text                Comments
yx-layout           !text string
23                  !Source type
1   1   1   1       !Inp, Out, Inv, OutputMidtPoint
0 0 1 5 3 3 9 8 42.2e-3 0.03 !XA,YA,XM,YM,XN,YN,XB,YB,data,std
5 5 6 9 8 8 4 3 10.2e-3 0.03
```

Figure 7.5. Data file for resistivity data - source type 23 (xy-mode). Two 4-pole configurations. The comments after the ! are not required. Bold red text is not a part of the data file.

```
Text                Comments
yxz-layout          !text string
24                  !Source type
1   1   1   1       !Inp, Out, Inv, OutputMidtPoint
0.0 0.0 5.0   0.2 0.0 5.0   0.4 0.0 5.0   0.6 0.0 5.0   9.45 0.01
!XA,YA,ZA,XM,YM,ZM,XN,YN,ZN,XB,YB,ZB,data,std
0.0 0.0 5.0   0.2 0.0 5.1   0.4 0.0 5.1   0.6 0.0 5.1   9.63 0.01
0.0 0.0 5.0   0.2 0.0 5.2   0.4 0.0 5.2   0.6 0.0 5.2   8.89 0.01
0.0 0.0 5.0   0.2 0.0 5.3   0.4 0.0 5.3   0.6 0.0 5.3   7.50 0.01
```

Figure 7.6. Data file for resistivity data - source type 24 (xyz-mode). Four 4-pole configurations. The comments after the ! are not required. Bold red text is not a part of the data file.

```
Text                Comments
z-layout            !text string
25                  !Source type
1   1   1   1       !Inp, Out, Inv, OutputMidtPoint
10.0    10.2  10.4   10.6    10.0   0.01 !ZA,ZM,ZN,ZB,data,std
10.0    10.4  10.8   11.2     9.0   0.01
10.0    10.6  11.2   11.8    15.0   0.01
10.0    11.2  12.4   13.6    16.0   0.01
```

Figure 7.7. Data file for resistivity data - source type 25 (z-mode, borehole). Four 4-pole configurations. The comments after the ! are not required. Bold red text is not a part of the data file.

7.6 Examples: DCIP data

Figure 7.8 DCIP data from one electrode configuration. Source type 272 - four electrodes on a profile with defined x-coordinate. No filters and a 100% duty cycle.

Figure 7.9: DCIP data from four different electrode configurations (ID 1-4). Source type 272 – electrode in a layered earth with x-, y- and z-coordinates. Two different low-pass filters and a 50% duty cycle waveform.

```
#  Text                   Comments
1  DCIP data              !TextLabel
2  272                    !SourceType (272->4-electrodes on a profile)
3  1  1  1                !Inp, Out, Inv (0->pot,1->rhoa)
4  0                      !#Filters
5  1                      !#Waves
6  2  3  3.35  4   4 0 1   4 0 -1   4 0 1  !UserDefWF:
7  0                      !ModelG (0 -> No Gates Modeling)
8  0  25  30  55   9.23170E+01  2.00E-02  1  1  1         !Res: xA,xM,xN,B,Res,STD,ID,FilterID,WaveID
9  0  25  30  55   8.38426E+01  5.00E-02  1  1  1  1.1870E-02  !Char: xA,xM,xN,B,Res,STD,ID,FilterID,…
10 0  25  30  55   7.98574E+01  5.00E-02  1  1  1  1.6490E-02  ! …WaveID,time
11 0  25  30  55   7.57249E+01  5.00E-02  1  1  1  2.2800E-02
12 0  25  30  55   7.13599E+01  5.00E-02  1  1  1  3.1610E-02
13 0  25  30  55   6.67997E+01  5.00E-02  1  1  1  4.3840E-02
14 0  25  30  55   6.20620E+01  5.00E-02  1  1  1  6.0810E-02
15 0  25  30  55   5.77763E+01  5.00E-02  1  1  1  8.1020E-02
16 0  25  30  55   5.31190E+01  5.00E-02  1  1  1  1.0980E-01
17 0  25  30  55   4.73344E+01  5.00E-02  1  1  1  1.5880E-01
18 0  25  30  55   4.15553E+01  5.00E-02  1  1  1  2.2810E-01
19 0  25  30  55   3.62228E+01  5.00E-02  1  1  1  3.1770E-01
```

Figure 7.8. Data file with DCIP data for one electrode configurations, source type 272 (Four electrodes on a profile). A user defined waveform and no filters. The comments after the ! are not required. Bold red text is not a part of the data file.

```
#   Text                   Comments
1   DCIP data              !TextLabel
2   274                    !SourceType (274->4-electrodes in layered halfspace)
3   1  1  1                !Inp, Out, Inv (0->pot,1->rhoa)
4   2                      !NFilters
5   1  1  2.4E+5           !Filter 1, low-pass: NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
6   0                      !Filter 1, high-pass: NCutOff
7   1  1  3.7E+4           !Filter 2, low-pass: NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
8   0                      !Filter 2, high-pass: NCutOff
9   1                      !NWaves
10  1  3  3 3.35  4 4 1  4 4 -1  4 4 1 !WaveType, NPulses, startDCint,endDCint, Ton,Toff,Amp
11  0                      !ModelG (0 -> No Gates Modeling)
12    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  1.9558E+02  2E-02   1 1 1
13    -6.25  0    0  -1.25  0  0  1.25  0  0   6.25  0  0  1.9048E+02  2E-02   2 1 1
14    -8.75  0.2  0  -1.25  0  0  1.25  0  0   8.75  0  0  1.8098E+02  2E-02   3 1 1
15   -11.25  0.5  0  -1.25  0  0  1.25  0  0  11.25  0  0  1.6828E+02  2E-02   4 2 1
16    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  8.0432E+01  5E-02   1 1 1  1.0750E-02
17    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  7.9386E+01  5E-02   1 1 1  1.3670E-02
18    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  7.8243E+01  5E-02   1 1 1  1.7240E-02
19    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  7.6955E+01  5E-02   1 1 1  2.1740E-02
…
24    -3.75  0    0  -1.25  0  0  1.25  0  0   3.75  0  0  1.1947E+01  5E-02   1 1 1  2.7890E+00
25    -6.25  0    0  -1.25  0  0  1.25  0  0   6.25  0  0  8.7133E+01  5E-02   2 1 1  2.9530E-03
26    -6.25  0    0  -1.25  0  0  1.25  0  0   6.25  0  0  8.6526E+01  5E-02   2 1 1  3.8740E-03
…
33    -6.25  0    0  -1.25  0  0  1.25  0  0   6.25  0  0  1.2321E+01  5E-02   2 1 1  2.7890E+00
34    -8.75  0.2  0  -1.25  0  0  1.25  0  0   8.75  0  0  9.3111E+01  5E-02   3 1 1  2.9530E-03
35    -8.75  0.2  0  -1.25  0  0  1.25  0  0   8.75  0  0  9.2459E+01  5E-02   3 1 1  3.8740E-03
…
42    -8.75  0.2  0  -1.25  0  0  1.25  0  0   8.75  0  0  9.8374E+00 5E-02   3 1 1  3.5340E+00
43   -11.25  0.5  0  -1.25  0  0  1.25  0  0  11.25  0  0  1.0284E+02 5E-02   4 2 1  2.9530E-03
44   -11.25  0.5  0  -1.25  0  0  1.25  0  0  11.25  0  0  1.0211E+02 5E-02   4 2 1  3.8740E-03
…
51   -11.25  0.5  0  -1.25  0  0  1.25  0  0  11.25  0  0  1.0757E+01 5E-02   4 2 1  3.5340E+00
```

Figure 7.9. Data file with DCIP data for four electrode configurations, source type 274 (Four electrodes in a layered half-space). A 50% duty cycle waveform and two different filters. The comments after the ! are not required. Bold red text and … is not a part of the data file.

8. THE SIP FILE (FREQUENCY DOMAIN IP DATA)

The SIP data input file contains filter settings and frequency-domain IP data. An example of the data files is seen in Figure 8.1 and the content is described below.

```
#  Text                 Comments
1  SIP data file        !Text
2  272                  !SourceType
3  1                    !#Filters
4  1   1   2.40E+05     !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
5  0                    !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
6   -3.75  -1.25  1.25  3.76     0.04  99.69  0.02  0  1!xA,xM,xN,xB,freq,Data,std,TransID,FilterID
7   -3.75  -1.25  1.25  3.76     0.08  99.60  0.02  0  1
8   -3.75  -1.25  1.25  3.76     0.16  99.50  0.02  0  1
9   -3.75  -1.25  1.25  3.76     0.32  99.40  0.02  0  1
10  -3.75  -1.25  1.25  3.76     0.64  99.31  0.02  0  1
11  -3.75  -1.25  1.25  3.76     1.28  99.23  0.02  0  1
…
19  -3.75  -1.25  1.25  3.76   655     99.01  0.02  0  1
20  -6.26  -1.25  1.25  6.25     0.04  99.53  0.02  0  1
21  -6.26  -1.25  1.25  6.25     0.08  99.47  0.02  0  1
…
35  -6.26  -1.25  1.25  6.25   655     98.68  0.02  0  1
```

Figure 8.1. Example of SIP file with frequency-domain IP data from measurement at two different electrode configurations. The source type is 272 – four electrodes on a profile. One low-pass filter is defined. The comments after the ! are not required. Bold red text and … is not a part of the data file.

8.1 Header lines in the SIP file

Line 1, text label
User-defined label describing the sip-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, one integer, source type:
The source type can be one of the following:

- Value 272: Four electrode on a profile model. The x-positions are specified for the four electrode positions in the data lines.

For 2D inversion, the position of the electrodes must also be listed in a mesh file, which goes into the inversion. See section 14 – "The mesh file (2D DCIP)".

Line 3, one integer, number of filters:
If 0 is indicated, no filters are used and line 4-5 can be left out of the sip-file.

Line 4–5, filters:
Two lines per number of filters given in line 4. Fist line holds the low-pass filters and the second line hold the high-pass filters. Each line holds the numbers NCutOff, FOrder, FCutOff. FOrder and FCutOff are repeated NCutOff times.

- NCutOff, integer: The number of frequencies defining the filter.
- Forder, integer: The order of the Butterworth filter (1 defines a first order filter, 2 a second order filter).
- FCutOff, real: The cut-off frequency for the filters (Hz).

If no filters are used, these lines are removed from the sip-file.

8.2 Data lines in the SIP file

Each data line (line 10-45 in Figure 7.2) is a data point with a resistivity or a chargeability value. Each data line have nine or ten reals or integers:

First – fourth real, position of electrodes:
The electrode position for the measured configuration is listed here. A and B are current electrodes. M and N are potential electrodes. The positions needed depends on the source type:

- Source type 272: Four real, xA, xM, xN, xB [m].

Fifth real, frequency:
The frequency [Hz] at which the data point is measured.

Sixth real, data:
The data value in the data transform determined by the 8^{th} integer (see below).

Seventh real, STD:
The standard deviation on the data point.

Eighth integer, data transform ID:

- Value 0: Apparent resistivity [Ohmm]
- Value 1: Amplitude [Ohm]
- Value 2: Phase [-mrad]
- Value 3: Real [Ohm]
- Value 4: Imaginary [Ohm]

Figure 8.1 shows an example where the data transform is 0-> apparent resistivity Figure 8.2 shows an example where amplitude and phase data have been measured for each frequency, so both the data transform ID 1 and 2 have been used.

Ninth integer, filter ID:
The filter used for the measured data. If no filters are used (Nfilters =0), the filterID must still be set to 1.

8.3 Examples

```
#   Text                  Comments
1   DCIP data file        !Text
2   272                   !SourceType
3   1                     !#Filters
4   1  1  2.40E+05        !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
5   0                     !NCutOff, FOrder(1:NCutOff), FCutOff(1:NCutOff)
6    -3.75  -1.25  1.25  3.76     0.04  1.058  0.10  1  1   !xA,xM,xN,xB,freq,…
7    -3.75  -1.25  1.25  3.76     0.04  1.81   0.10  2  1   ! …Data,std,TransID,FilterID
8    -3.75  -1.25  1.25  3.76     0.08  1.057  0.10  1  1
9    -3.75  -1.25  1.25  3.76     0.08  2.01   0.10  2  1
10   -3.75  -1.25  1.25  3.76     0.16  1.056  0.10  1  1
11   -3.75  -1.25  1.25  3.76     1.16  1.08   0.10  2  1
…
19   -3.75  -1.25  1.25  3.76   655     0.11   0.10  2  1
20   -6.26  -1.25  1.25  6.25     0.04  1.045  0.10  1  1
21   -6.26  -1.25  1.25  6.25     0.04  1.75   0.10  2  1
…
35   -6.26  -1.25  1.25  6.25   655     1.06   0.10  2  1
```

Figure 8.2. Example of a SIP data file with data measured as amplitude and phase (data transform 1 and 2). The comments after the ! are not required. Bold red text and … is not part of the data file.

9. THE HEM FILE (FREQUENCY-DOMAIN HELICOPTER OR GCM DATA)

The HEM data input file is specialized to input helicopter EM data or ground conductivity meter data like DualEM or EM31/EM38 data. The settings in the HEM-file are used in the calculation of the forward response in the AarhusInv code. Sources are limited to dipoles. An example of a HEM data file is shown in Figure 9.1.

```
 #   Text                                                        Comments
 1   HEM data - BGR bird                                         !Textstring
 2   0.00   0.00   -40.00   8.00   0.00   -40.00                 !Tx X, Y, Z, Rx X, Y, Z
 3   3.750E+02  8.270E+01  5.0E-02  7.920E+00  5  1  3     !Freq,DataVal,DataValStd,CoilSep, ....
 4   3.750E+02  1.293E+02  5.0E-02  7.920E+00  6  1  3     !..DataType,SourceType(1),Receiverype(1-3)
 5   1.778E+03  2.724E+02  2.5E-02  7.910E+00  5  1  3
 6   1.778E+03  2.393E+02  2.5E-02  7.910E+00  6  1  3
 7   8.510E+03  5.803E+02  5.0E-02  7.960E+00  5  1  3
 8   8.510E+03  2.869E+02  5.0E-02  7.960E+00  6  1  3
 9   3.783E+04  8.673E+02  2.5E-02  8.030E+00  5  1  3
10   3.783E+04  2.839E+02  2.5E-02  8.030E+00  6  1  3
11   1.285E+05  1.064E+03  5.0E-02  7.920E+00  5  1  3
12   1.285E+05  3.125E+02  5.0E-02  7.920E+00  6  1  3
```

Figure 9.1. Data file for frequency domain HEM data. The transmitter is a vertical magnetic dipole. One imaginary and one real part are stored for the frequencies. The data shown is for a two layer model with resisitivites 100ohm-m/10 ohm-m and thickness of the first layer of 10 m. The comments after the ! are not required. Bold red text is not a part of the data file.

9.1 Header lines in the HEM-file

Line 1, text label:
User-defined label describing the HEM data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, six reals, transmitter and receiver positions:
The x, y and z-coordinates of the transmitter (first three numbers) and the receiver (last three numbers). The z-coordinates must be negative or zero (the receiver or the transmitter must be in the air or on the ground).

9.2 Data lines of the HEM-file

Line 3-12, integers and reals, data section:
Each line is one data point (one frequency, real ppm, imaginary ppm, amplitude or phase). The line consists of seven numbers:

1. Real. Transmitter frequency in Hz (1/s).
2. Real. The data value with the unit indicated in column 5.
3. Real. The relative standard deviation on the data value.
4. Real. The coil-separation in meters. In the code it is always assumed that the transmitter has coordinates (0,0,Transmitter

z) and the receiver has coordinates (Coil-Separation, 0, Receiver z), thus overriding information given on line 2.

5. Integer. The type of data:
    - Value 0: Apparent resistivity
    - Value 2: Phase
    - Value 5: Real in ppm**
    - Value 6: Imaginary in ppm**
6. Integer. The source type - source direction. 1 - Hx, 2 - Hy and 3 - Hz.
7. Integer. The receiver type. 1 - Hx, 2 - Hy and 3 - Hz.

**For data in ppm which are normalized by the primary field the Hx (or Hr) is normalized by the primary Hz since the primary Hr (in a homogeneous space) is zero for transmitter and receiver loops at the same altitude

10. THE FEM FILE (FREQUENCY DOMAIN DATA)

The FEM data input file is somewhat similar to the tem input file (“The TEM file (time domain data)” on page 48). The fem input file contains transmitter geometry and low- and high-pass of the receiver and the data.

The fem-file is a flexible way of storing the measured data. The settings in the fem-file are used in the calculation of the forward response in the AarhusInv code. An example of a FEM data file for an offset loop configuration sounding is shown in Figure 10.1.

```
Text                                                      Comments
Created by Emma
0.0      0.0      0.0    100.0     0.0      0.0 !Tx X, Y, Z, Rx X, Y, Z
40.0 40.0                                       !Loop dimensions
2   2                                           !Inp/out: Inp, Out (0->H,2->B,4->rhoa)
3                          !NFilters (0->no filters at all, else 1,2 ...)
1    1 2.40E+05            !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
0                          !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
1    1 2.40E+05            !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
0                          !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
1    1 3.70E+04            !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
0                          !LP/HP: NCutOff (0->no filter),FOrder(1,NCutOff),FCutOff(1,NCutOff)(Hz)
2.371E-01   5.506E-18  5.00E-02  3  0  7  1
2.371E-01   1.563E-15  5.00E-02  4  0  7  1
3.162E-01   9.233E-18  5.00E-02  3  0  7  1
3.162E-01   2.084E-15  5.00E-02  4  0  7  1
4.217E-01   1.549E-17  5.00E-02  3  0  7  1
4.217E-01   2.778E-15  5.00E-02  4  0  7  1
5.623E-01   2.586E-17  5.00E-02  3  0  7  1
5.623E-01   3.703E-15  5.00E-02  4  0  7  1
7.499E-01   4.312E-17  5.00E-02  3  0  7  1
7.499E-01   4.934E-15  5.00E-02  4  0  7  1
1.000E+00   7.159E-17  5.00E-02  3  0  7  1
1.000E+00   6.573E-15  5.00E-02  4  0  7  1
    .           .          .      .  .  .  .
    .           .          .      .  .  .  .
1.000E+05   2.827E-12  5.00E-02  3  0  7  1
1.000E+05  -2.648E-12  5.00E-02  4  0  7  1
1.334E+05   2.437E-12  5.00E-02  3  0  7  1
1.334E+05  -2.334E-12  5.00E-02  4  0  7  1
1.778E+05   2.112E-12  5.00E-02  3  0  7  1
1.778E+05  -2.055E-12  5.00E-02  4  0  7  1
2.371E+05   1.848E-12  5.00E-02  3  0  7  1
2.371E+05  -1.815E-12  5.00E-02  4  0  7  1
3.162E+05   1.645E-12  5.00E-02  3  0  7  1
3.162E+05  -1.626E-12  5.00E-02  4  0  7  1
4.217E+05   1.505E-12  5.00E-02  3  0  7  1
4.217E+05  -1.506E-12  5.00E-02  4  0  7  1
5.623E+05   1.427E-12  5.00E-02  3  0  7  1
5.623E+05  -1.491E-12  5.00E-02  4  0  7  1
7.499E+05   1.419E-12  5.00E-02  3  0  7  1
7.499E+05  -1.672E-12  5.00E-02  4  0  7  1
1.000E+06   1.177E-12  5.00E-02  3  0  7  1
1.000E+06  -2.310E-12  5.00E-02  4  0  7  1
```

Figure 10.1. Data file for frequency domain data. The transmitter is a 40 x 40 m square loop and the receiver is offset 100 m. One imaginary and one real part are stored for the frequencies. The comments after the ! are not required. Bold red text is not a part of the data file.

10.1 Header lines in the FEM-file

Line 1, text label:
User-defined label describing the FEM data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, six reals, transmitter and receiver positions:
The x, y and z-coordinates of the transmitter (first three numbers) and the receiver (last three numbers).

Line 3, two reals, transmitter loop size:
Side-lengths of the transmitter loop.

Line 4, two integers, data format:
The input and the output format of the FEM data. First integer is input, second integer is output:

- Value 0: Magnetic field intensity (H)
- Value 2: Magnetic induction (B)
- Value 4: Apparent resistivity

Line 5, one integer, filters:
Number of filters. If 0 is indicated, no filters are used.

Line 6-11, integers and reals, filters:
Two lines per number of filters as given in line 5. First line holds the low-pass filters, second line holds the high-pass filters. High-pass filters are most often not present. The format of one line is [NCutOff, FOrder, FCutOff(1:NCutOff)]

- NCutOff (integer) is an integer with the number of frequencies defining the filter.
- FOrder (integer) is the order of the filter (1 defines a first order filter, 2 a second order filter).
- FCutOff (real) is the cut-off frequency for the filters.
- FOrder and FCutOff are repeated NCutOff times.

10.2 Data lines of the FEM-file

Line 12-43, integers and reals, data section:
Each line is one data point (one frequency, real or imaginary part or amplitude and phase). The line consists of seven numbers:

1. Real. Transmitter frequency.
2. Real. The data value with the unit indicated in line 4.
3. Real. The relative standard deviation on the data value.
4. Integer. The type of data: 0 - apparent resistivity, 1 - amplitude, 2 - phase, 3 - real or 4 - imaginary part.
5. Integer. The filter number given in line 5 (0 for dummy).

6. Integer. The source type. 1- horizontal magnetic x-directed dipole, 2- horizontal magnetic y-directed dipole, 3 vertical magnetic dipole, 7 - rectangular loop, 72 – segmented loop, 12 - circular central loop and 13 - circular offset loop. For further specification see section: 6.1- Header lines in the TEM file.
7. Integer. The receiver type. 1 - Hx, 2 – Hy, 3 – Hz, 4 – Ex, 5 - Ey and 6 – Ez.

11. THE MRS FILE (MAGNETIC RESONANCE SOUNDING DATA)

The MRS data input file contains transmitter/receiver loop geometry, Earth's magnetic field information and data obtained from magnetic resonance soundings. An example of a MRS data file for a separated-loop configuration sounding is shown in Figure 13.1).

```
#   Text                                         Comments
1   MRS data file
2   72   1                      !Source type (Tx/Rx), Loop configuration (0-> coindident, 1-> separate)
3   0.0 0.0 0.0 0.0 0.0 0.0     !X,Y,Z coordinates of Tx [and Rx] loop centers
4   4                           !Number of Tx loop apexes (loop is centralized at origin)
5   -50     -50                 !x1,y1 -> coordinates of the 1st apex
6    50     -50                 !x2,y2 -> coordinates of the 2nd apex
7    50      50                 !x3,y3 -> coordinates of the 3rd apex
8   -50      50                 !x4,y4 -> coordinates of the 4th apex
9   4                           !Number of Rx loop apexes (loop is centralized at origin)
10  -25     -25                 !x1,y1 -> coordinates of the 1st apex
11   25     -25                 !x2,y2 -> coordinates of the 2nd apex
12   25      25                 !x3,y3 -> coordinates of the 3rd apex
13  -25      25                 !x4,y4 -> coordinates of the 4th apex
14  70   2                      !Earth's magnetic field inclination and declination (degree)
15  0.04                        !Tx pulse length (s)
16  1  1                        !Number of wire turns on Tx and Rx loops
17  2132.8                      !Larmor frequency (Hz)
18  282                         !Ground temperature (K)
19  0.0668  1.16E-007  9.00E-002  1.11E-001 0 0   !time(s), data(V), STD, q(As), freq. offset, ID
20  0.1164  9.90E-008  9.32E-002  1.39E+001 0 0
21  0.1660  6.76E-008  1.24E-001  1.11E-001 0 0
22  0.2160  5.20E-008  1.42E-001  1.11E-001 0 0
23  0.2650  3.87E-008  1.47E-001  1.11E-001 0 0
24  0.3150  3.47E-008  1.74E-001  1.11E-001 0 0
25  0.3640  2.52E-008  3.09E-001  1.11E-001 0 0
25  0.4140  2.10E-008  4.22E-001  1.11E-001 0 0
27  0.4640  1.73E-008  5.59E-001  1.11E-001 0 0
28  0.5130  1.42E-008  5.32E-001  1.11E-001 0 0
29  0.0668  1.60E-007  9.79E-002  1.59E-001 0 0
30  0.1164  1.16E-007  9.81E-002  1.59E-001 0 0
31     .         .          .        .  .  .  .
32     .         .          .        .  .  .  .
33  0.5130  2.23E-008  3.29E-001  1.59E-001 0 0
34     .         .          .        .  .  .  .
35     .         .          .        .  .  .  .
36  0.0668  1.32E-007  1.15E-001  1.39E+001 0 0
37  0.1164  9.90E-008  9.32E-002  1.39E+001 0 0
38  0.1660  7.56E-008  1.05E-001  1.39E+001 0 0
39  0.2160  6.34E-008  8.19E-002  1.39E+001 0 0
40  0.2650  5.46E-008  1.80E-001  1.39E+001 0 0
41  0.3150  4.58E-008  1.71E-001  1.39E+001 0 0
42  0.3640  3.97E-008  1.90E-001  1.39E+001 0 0
43  0.4140  3.38E-008  1.95E-001  1.39E+001 0 0
44  0.4640  2.41E-008  2.53E-001  1.39E+001 0 0
45  0.5130  2.07E-008  3.47E-001  1.39E+001 0 0
```

Figure 10.11.1. The MRS data file. A separated-loop configuration (Tx: 100-m side, Rx: 50-m side) is used. The comments after the ! are not required. Bold red text is not a part of the data file.

11.1 Header lines in the MRS file

Line 1, text label:
User-defined label describing the MRS-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, first integer, source type:
The MRS forward modeling code supports the following source type:

- Value 72. Segmented loop source. This type is used for arbitrarily shaped loops. The segmented loop source is also described in section 6.2- “Header lines with segmented loop and front gate”.

Line 2, second integer, loop configuration:

- Value 0: coincident loop configuration
- Value 1: separated loop configuration

Line 3, six [three] reals, Loop center coordinates
Transmitter and receiver loop center coordinates. In the case of coincident loop configuration, only three reals appear in this line.

Line 4, one integer, number of Tx loop segments (wires):
This integer gives the number of transmitter wire segments used to define the segmented loop.

Line 5-8, two reals, Tx wire end-points:
X- and y-coordinates of Tx wire end-point (loop is centralized at origin). The loop is automatically closed by connecting the last point to the first point.

Line 9, one integer, number of Rx loop segments (wires):
This integer gives the number of receiver wire segments used to define the segmented loop.

Line 10-13, two reals, Rx wire end-points:
X- and y-coordinates of Tx wire end-point (loop is centralized at origin). The loop is automatically closed by connecting the last point to the first point.

Line 14, first real, Earht’s field inclination:
Inclination of the Earth’s magnetic field, in degrees.

Line 14, second real, Earht’s field declination:
Declination of the Earth’s magnetic field in the loop coordinate system, in degrees.

Line 15, Tx pulse length
Transmitter pulse length, in sec. This information is used is frequency-offset is taken into account (see data section below).

Line 16, two reals, number of wire turns on Tx [and Rx] loop:
If coincident-loop configuration is used (0 value in line 2, integer 2), one real value appears here.

Line 17, one real, Larmor frequency:
Resonance (Larmor) frequency calculated from the Earth’s field intensity.

Line 18, Ground temperature:
Average temperature of the top 100m subsurface, in Kelvin.

11.2 Data section

Line 19–45, data section:

Each line represents a measured data point at a certain time and a certain pulse moment. Each line consists of six numbers:

- Real: Gate center time in seconds measured from the middle of the transmitter pulse (in this example 10 gates).
- Real: Data value in Volt.
- Real: Data value uncertainty given as a relative number.
- Real: Pulse moment value in Ampere-second (As).
- Real: Frequency offset between the system transmitted pulse and the measured frequency, in Hertz (Hz)
- Integer: Data transform ID. Five different values can be used to specify the type of output data (rotated amplitude, amplitude, phase, real, imaginary). Any combination of these data can be used during the inversion. For instance, for inversion of real and imaginary (complex) signal, lines 19-28 are repeated, one with value 3 in the last column, another time with value 4, meaning that total number of data is doubled compared to this example. The values are:
    - Value 0: Rotated Amplitude
    - Value 1: Amplitude
    - Value 2: Phase
    - Value 3: Real
    - Value 4: Imaginary

12. THE MTD FILE (MT DATA)

The MT data input file contains settings and data for MT soundings. The following refers to the data file in Figure 12.1.

12.1 Header lines in the MTD file

Line 1, text label:
User-defined label describing the MTD-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, one integer, polarization:
The polarization can be one of the following:

- Value 1: Ex/Hy.
- Value 2: Ey/Hx.

12.2 Data lines in the MTD file

Line 3-15, data:

Each line represents a measured data point at a certain frequency.

- First real: Frequency in Hz.
- Second real: Data value
- Third real: Data value uncertainty given as a relative number, i.e. 0.05 for 5%.
- Fourth integer: Data type. 0 is apparent resistivity; 2 is phase.

12.3 Example

Figure 12.1: A simple MT data file with synthetic RMT data calculated at a variety of frequencies. Each frequency has two data values - an apparent resistivity value and a phase value.

```
 # comment
 1 Test-file, MTD
 2 1
 3 1.000E+04     4.284E+01     5.00E-02     0
 4 1.000E+04     2.904E+01     2.50E-02     2
 5 1.500E+04     3.653E+01     5.00E-02     0
 6 1.500E+04     3.276E+01     2.50E-02     2
 7 2.000E+04     3.353E+01     5.00E-02     0
 8 2.000E+04     3.630E+01     2.50E-02     2
 9 3.000E+04     3.150E+01     5.00E-02     0
10 3.000E+04     4.134E+01     2.50E-02     2
11    :             :             :         :
12 9.000E+05     6.742E+01     5.00E-02     0
13 9.000E+05     5.577E+01     2.50E-02     2
14 1.000E+06     6.956E+01     5.00E-02     0
15 1.000E+06     5.576E+01     2.50E-02     2
```

Figure 12.1. Data file for MT data. The comments after the ! are not required. Bold red text is not a part of the data file.

13. THE SWD FILE (SWD DATA)

The SWD data input file contains settings and data for seismic surface wave dispersion curves obtained from surface wave soundings. The following refers to the data file in Figure 13.1.

13.1 Header lines in the SWD file

Line 1, text label:
User-defined label describing the SWD-data set. The label is repeated in the emo-file. Max. 128 characters.

Line 2, three integers, data transformation:
The data can be either wavenumber (0) or phase velocity (1). The integers specifies for the format of:

- First integer: Input.
- Second integer: Inversion.
- Third integer: Output.

Thus, data can be given as wavenumber on input, an inversion parameter, but with the output in phase velocity.

13.2 Data lines in the SWD file

Line 3-15, three reals, one integer, data:
Each line represents a point on the dispersion curve obtained from an SWD analysis.

- First real: Frequency in Hz.
- Second real: Data value (phase velocity or wavenumber)
- Third real: Data value uncertainty given as a relative number, i.e. 0.05 for 5%.
- Fourth integer: mode of the dispersion curve. 1 - fundamental mode, 2 - first ?.

13.3 Example

Figure 13.1: A simple dispersion curve from a SWD field data set at a variety of frequencies and two different modes.

```
 # comment
  1 Test dataset for SWD
  2 1   1   1              !Inp, Out, Inv (0->wavenumber,1->phase vel.)
  3 12.000     596.640      0.05    1
  4 13.000     493.091      0.05    1
  5 14.000     400.204      0.05    1
  6 15.000     345.577      0.05    1
  7 16.000     341.144      0.05    1
  8 17.000     310.823      0.05    1
  9 18.000     305.197      0.05    1
 10 19.000     298.301      0.05    1
 11 20.000     288.143      0.05    1
 12 21.000     287.562      0.05    1
 13 22.000     285.207      0.05    1
```

```
14 23.000     282.323       0.05   1
15 24.000     273.119       0.05   1
16 25.000     261.654       0.05   1
17 26.000     263.770       0.05   1
19 21.000     287.562       0.05   2
20 22.000     285.207       0.05   2
21 23.000     282.323       0.05   2
22 24.000     273.119       0.05   2
23 25.000     261.654       0.05   2
24 26.000     263.770       0.05   2
```

Figure 13.1. Data file for SWD data. The comments after the ! are not required. Bold red text is not a part of the data file.

14. THE MESH FILE (2D-DC/IP)

The mesh file (msh-file) is only in use for 2D inversion of DC data and only in that case has to be specified (The 2D option is set in the model file as described in “The model file” on page 13).

The msh-file is used to define a finite difference mesh for 2D modelling and inversions. In the file, the x-z plane is divided into a structured grid. Note that electrodes must be placed on nodes.

An example of a mesh files is shown in Figure 14.1.

```
                                                                        Comments
1   547   47                                                            !NxNodes, NzNodes
2
3   4.9445381589E+05   4.94687722572E+05 …  4.9568396256E+05             !UTMx (size NxNodes)
4   6.1779395006E+06   6.17764146596E+06 …  6.1765714950E+06             !UTMy (size NxNodes)
5
6   -6.287501+02    -2.501939E+0.2 …   1.215919E+03                     !x position (size NxNodes)
7    0               0             …   0                                !y position (size NxNodes)
8
9    3.9570E+01     3.9570E+01   …    4.2600E+01                        !z elevation, shallowest…
10   3.9070E+01     3.9070E+01   …    3.9770E+01                            … node (sixe NxNodes)
11   3.8054E+01     3.8560E+01   …    3.9110E+01
…
55   -1.7381E+03    -1.7381E+03   …   -1.7381E+03                       !z elevation, deepest node
56
57   119                                                                !Number of electrode
58   1    38    1                                                       !El. Nr, Xnode nr, Znode nr
59   2    42    1
60   3    46    1
…
176  119  510   1
```

Figure 14.1. meh-file. The comments after the ! are not required. Bold red text is not a part of the data file.

14.1 Description of the msh-file

The following description follows the example in Figure 14.1.

Line 1: Two integers, NxNodes, NzNodes
Number of nodes in the x- and z-direction

Line 3: NxNodes reals, UTMx
The UTMx coordinates of the nodes.

Line 4: NxNodes reals, UTMy
The UTMy coordinates of the nodes.

Line 6: NxNodes reals, x-positions
X-positions along the profile. 0 is usually the position of the first electrode.

Line 6: NxNodes reals, y-positions
Y-positions along the profile.

Line 9-55: NxNodes reals, z-elevations
One line for each node in the z-direction (NzNodes). The first line must be the shallowest node. Each line has the length NxNodes.

Line 57: One integer, Number of electrodes
The number of electrodes used in the profile

Line 58-176: Three reals, Electrode number, Xnode number, Znode number
One line for each electrode. Each electrode is assigned an Xnode and Znode number, which is linked to its position through the node numbers. Note: Electrodes must be placed on a node.

15. THE EMO FILE (INVERSION OUTPUT DATA)

The emo-file is the inversion output file. The emo-file contains model parameters, model parameter analyses, forward responses, inversion settings, etc. The name of the emo-file is the same as the name of the mod-file, except that the file has the extension .emo

An example of an emo files is shown in Figure 15.1. Each line of the example is described below.

```
AarhusInv, version
   8.00
Compile (HH:MM:SS) time and date (DD.MM.YYYY)
   00:00:00  00.00.0000
Time (HH:MM:SS) and date (DD.MM.YYYY) of run:
   14:30:59  05.05.2017
Total run time (s)
   1.1
N iterations (NI, 0 -> analysis and forward resp.)
   5
N data sets (NDS)
   1   -1.0   -1.0   -1.0   !NDS, SharpPrior, SharpVer, SharpHor (<0 -> standard inversion)
N data in each data set (1..NDS)
   20
Data file name(s) (1..NDS)
   o:\aarhusinv_manual\dc_example\3L_data.dcp
Model file name
   O:\AarhusInv_Manual\DC_example\3L.mod
Number of models (NM), Depth Of Investigation (Yes->1, No->0)
   1        1
Total number of model parameters
   5
Number of layers per model (1..NM)
   3
Inversion log/lin space (0->log), [Data,Model,Ana]
   1        0       -1
Resistivity/thicknes limits [min,max]
   0.1    20000.0        0.1      500.0
Anisotropy/chargeability limits [min,max]
   0.0        0.0        0.0        0.0
Min apriori STD on any parameter
   1.0E+60
Inp/Out/Inv trans (1..NDS)
   1        1        1
Data type ID(s) (1..NDS)
   3
Source types (1..NDS)
   22
Rx field polar. (TDEM,Frq) (1..NDS)
   0
TxX,TxY,TxZ,RxX,RxY,RxZ (1..NDS)
   0.0              0.0              0.0              0.0              0.0              0.0
Norm factor
   1.
Norm's (0..NIte)
Ite_#        Data     VCon     HCon    Depth     Apri    Total
    0      32.502    0.000    0.000    0.000    0.000   32.502
    1       7.089    0.000    0.000    0.000    0.000    7.089
    2       1.053    0.000    0.000    0.000    0.000    1.053
    3       0.404    0.000    0.000    0.000    0.000    0.404
    4       0.400    0.000    0.000    0.000    0.000    0.400
    5       0.400    0.000    0.000    0.000    0.000    0.400
Model #, Model type (loop over NModels), x, y, z
    1    1         0.00         0.00         0.00
Parameters (0..NIte)
              Res_#01    Res_#02    Res_#03   Thic_#01   Thic_#02     Dep_#01     Dep_#02    Prod_#01 …
     0      2.000E+02  1.000E+01  2.000E+02  5.000E+00  5.000E+00
     1      1.105E+02  2.190E+01  2.720E+02  5.706E+00  1.806E+00
     2      8.272E+01  2.282E+01  2.985E+02  5.640E+00  1.571E+00
     3      7.861E+01  2.347E+01  2.977E+02  5.470E+00  1.494E+00
     4      7.862E+01  2.369E+01  2.976E+02  5.386E+00  1.526E+00
```

```
62      5    7.865E+01  2.371E+01  2.976E+02  5.373E+00  1.531E+00
63  Analysis: apriori/coupled/uncoupled, (-1 -> unconstrained)
64            -1.00E+00  -1.00E+00  -1.00E+00  -1.00E+00  -1.00E+00  -1.00E+00  -1.00E+00
65             2.52E-02  -1.00E+00   2.50E-02   1.33E+00  -1.00E+00   1.33E+00   1.88E+00   1.30E+00
66             1.00E+03   1.00E+03   1.00E+03   1.00E+03   1.00E+03   1.00E+03   1.00E+03   1.00E+03
67  Apriori parameters
68                200.0       10.0      200.0         5.0        5.0        5.0       10.0
69  Constraints: CouplingWidth/Vertical/Horizontal (-1 -> no constraint, 1:CouplingWidth-1)
70       0
71 None normalized, normalized covariance matrix (0->not present, 1->present)
72       0       0
73 Output, data set #, model # for dataset
74      1      1
75 Data type ID
76      3
77          Ax          Mx          Nx          Bx    Inp_Data       STD  DSet#       Ite#005   …
78  -3.8000E+00 -1.2000E+00  1.2000E+00  3.8000E+00  7.948E+01 2.00E-02      1  7.80743E+01   …
79  -6.2000E+00 -1.2000E+00  1.2000E+00  6.2000E+00  7.573E+01 2.00E-02      1  7.74376E+01   …
80  -8.8000E+00 -1.2000E+00  1.2000E+00  8.8000E+00  7.817E+01 2.00E-02      1  7.86972E+01   …
…     …           …           …           …           …          …          …       …
96  -1.9500E+02 -3.2500E+01  3.2500E+01  1.9500E+02  2.724E+02 2.00E-02      1  2.71551E+02   …
97  -2.5000E+02 -3.2500E+01  3.2500E+01  2.5000E+02  2.815E+02 2.00E-02      1  2.80172E+02   …
98  Depth Of Investigation (DOI)
99   DOI # of Depths
100   19
101  Depth1, DepthN
102      2.500   300.000
103  Abs_High  Abs_Low
104      1.500     0.750
105  Rel_High  Rel_Low
106      0.050     0.020
107  Model #
108       1
109       Depths  Sensitivity   Cummulated   Normalized
110    2.500E+00    8.206E+00    1.943E+01    1.000E+00
111    7.803E+00    3.148E+00    1.122E+01    5.777E-01
112    1.375E+01    1.833E+00    8.077E+00    4.157E-01
113    2.042E+01    1.260E+00    6.245E+00    3.214E-01
114    2.790E+01    9.520E-01    4.984E+00    2.565E-01
115    3.628E+01    7.628E-01    4.032E+00    2.075E-01
116    4.568E+01    6.300E-01    3.270E+00    1.683E-01
117    5.622E+01    5.266E-01    2.640E+00    1.358E-01
118    6.804E+01    4.401E-01    2.113E+00    1.087E-01
119    8.130E+01    3.650E-01    1.673E+00    8.610E-02
120    9.616E+01    2.990E-01    1.308E+00    6.731E-02
121    1.128E+02    2.411E-01    1.009E+00    5.192E-02
122    1.315E+02    1.910E-01    7.678E-01    3.952E-02
123    1.525E+02    1.486E-01    5.768E-01    2.969E-02
124    1.760E+02    1.137E-01    4.282E-01    2.204E-02
125    2.023E+02    8.559E-02    3.145E-01    1.619E-02
126    2.319E+02    6.354E-02    2.289E-01    1.178E-02
127    2.650E+02    4.661E-02    1.654E-01    8.512E-03
128    3.000E+02    1.188E-01    1.188E-01    6.113E-03
129  DOI absolute [Abs_High Abs_Low]
130     88.339   133.472
131  DOI relative [Rel_High Rel_Low]
132    115.723   185.147
```

Figure 15.1. emo file for a simple inversion of one DC dataset with one model and no constrain or prior information. Bold red text is not a part of the data file

15.1 Inversion setup information

Lines 1-42 contain information about which data and model files have been used. This information comes from the data files, the emo-file, and the con-file. A few comments on specific lines:

- Lines 21-22: For a DC inversion, a model with three layers gives three resistivity values and two thickness. A total of five parameters.
- Lines 25-32: These settings are set in the con-file. Anisotropy is not implemented in the inversion-code yet. Therefore, the numbers in line 30 will always be 0 0 0 0.
- Lines 35-36: Each data type is associated with an ID-number in the inversion code.

15.2 Iteration progress – model parameters, model analysis

Line 43-70 contain information on the inversion result with respect to models and data. A few specific comments follow.

Residuals (norms), line 43–52:

- Lines 43-44: Norm factor. Norms are scaled by the factor norm-factor.
- Lines 45-52: The norm (residual) progress through the iteration steps. Column 1: Iteration number. Column 2-6: residuals for data, vertical constraints, horizontal constraints (resistivities and depths only), horizontal depth constraints, model prior. Column 7: Total residual.

Model iterations, line 53–70:

- Lines 53-54: Model number
- Lines 57-62: The model parameters through the iteration steps. No values for depths or the product of resistivities and thickness are given. Start model is iteration number 0 (line 57). Model parameters for the last iteration (line 62) are the final inversion result.
- Line 64: Parameter analysis on prior values from the parameters in line 62. -1 is an unconstrained parameter.
- Line 65: Coupled model parameters analysis (with respect to the parameters in line 62) where the information from the constraints are taken into account. -1 is for an undetermined parameter.
- Line 66: Uncoupled model parameter analysis (with respect to the parameters in line 62). No constraint information.

In the model parameter analysis, the standard deviation on the parameter *p*, STD_p, as given in the emo-file, is calculated as:

$$\mathrm{STD}_p = \exp\left(\sqrt{\mathrm{cov}(p,p)}\right) - 1$$

where cov(*p*,*p*) is the covariance of the *p*'th parameter in the covariance matrix.

- Lines 67-68: Prior model parameters (starting model).
- Line 70: Constraints mode as given in the mod-file

Covariance matrix:

- Line 71-72: In the con-file, AarhusInv can be customized to write out the covariance matrix and the normalized covariance matrix.

15.3 Iteration progress – forward data

Line 73-76 contains the settings from the mod-files.

Dataset, lines 77–97:

- Lines 78-97: Data belonging to the dataset (20 electrode configurations). Column 1-4: Position of electrodes. Column 5: Input data. Column 6: data STD. Column 7: Dataset number. Column 8-end: Forward data for each iterations step.

15.4 Depth of Investigation

The last section of the emo-files (line 98-end) describes the data used for calculating the depth of investigation (DOI) for the final model.

Information on the DOI is crucial for interpreting the geophysical models, as the validity of the models varies considerably with data noise and parameter distribution.

The calculated DOI is based on an approximated covariance analysis that uses both the actual model output from the inversion and the actual number of data and theirdata standard deviation.

DOI model information, lines 99–106:

- Line 100: Number of layers as defined in the con-file. Default value is 19 layers.
- Line 101-102: Depth1 is the thickness of the first layer (default 2.5 m) and DepthN is the depth to the last layer boundary (default 300 m). The values are defined in the con-file.
- Line 103-104: High and low (shallow and deep) absolute values for DOI calculations. These values determine for which absolute sensitivity values, the absolute DOI values are given (line 130). The values are defined in the con-file.
- Line 105-106: High and low (shallow and deep) relative values for DOI calculations. These values determine for which relative sensitivities value (e.g. 0.05 (5%) of total sensitivity), the relative DOI values are given (line 132). The values are defined in the con-file.

DOI data, lines 109–128:

- Column 1: Depth of the DOI model.
- Column 2: Sensitivity at the given depth.
- Column 3: Cumulated sensitivity (cumulated from the bottom).
- Column 4: Normalized cumulated sensitivity.

Note: If the inversion had more parameters, these columns would be repeated for each parameter (except thickness and depth).

DOI results, lines 129-132:

- Line 130: DOI absolute - the depths where cumulated sensitivity (listed in line 104) is reached.
- Line 132. DOI relative - the depths where normalized cumulated sensitivity (listed in line 106) is reached.

Different formats, Figure 15.2:

For inversion of 2D DC, 2D HEM, 1D/2D DCIP and 1D MRS, the DOI data format varies from the example above. Instead of the absolute analysis, a cumulated approximate analysis (CAA) is given.

An example from an 2D inversion of resistivity and temperature data is given in Figure 15.2. The lines different from the previous example are commented below.

Line 139-163:

- Column 2: Normalized cumulated sensitivity for the resistivity model.
- Column 3: CCA for the resistivity model.
- Column 4: Normalized cumulated sensitivity for the temperature model.
- Column 5: CCA for the temperature model.
- Column 6-8: The square root of the Jacobian (without normalization). These columns show the parameter correlations.

```
128  Depth Of Invistigation (DOI)
129  DOI # of Depths
130   24
131  Depth1, DepthN
132      1.320  186.466
133  CAA_High   CAA_Low
134      2.000     5.000
135  Rel_High   Rel_Low
136      0.050     0.020
137 Model #
138        1
139  Depths    Res#  Relative  CAA       Temp# Relative  CAA       CumGTG:[Res#Res#]  [Res#Temp#]  [Temp#Temp#]
140  6.60E-01        1.00E+00  1.09E+00        1.00E+00  1.50E+00          4.61E+04    -1.05E+04    2.40E+03
141  2.03E+00        9.08E-01  1.11E+00        9.28E-01  1.59E+00          3.73E+04    -8.71E+03    2.03E+03
142  3.52E+00        8.16E-01  1.21E+00        8.56E-01  2.22E+00          2.78E+04    -6.75E+03    1.63E+03
…
163  1.30E+02        5.08E-02  1.26E+01        5.68E-02  1.59E+04          6.89E+01    -1.80E+01    4.72E+00
164  DOI CAA        Res_#  [CAA_High  CAA_Low]  Temp_#  [CAA_High  CAA_Low]
165                         4.650     6.669              1.498     3.551
166  DOI relative   Res_#  [Rel_High  Rel_Low]  Temp_#  [Rel_High  Rel_Low]
                            37.022    66.344             42.465    77.839
```

Figure 15.2. DOI section of emo file of an inversion of resistivity (Res) and temperature (Temp) data. Bold red text is not a part of the data file

16. THE EMM FILE (AARHUSINV MATRIX OUTPUT FILE)

The emm-file contains information similar to the emo-file, but in a matrix format. In the con-file AarhusInv can be customized to write out the emm-file or not. The name of the emm-file is the same as the name of the mod-file, except that the file has the extension .emm.

The following refers to the emm-file in Figure 16.1.

16.1 Inversion setup information

Lines 1-10 contain inversion set up information in the same way as in the emo-file (see “The EMO file (inversion output data)” on page 83 for an explanation).

16.2 Various matrices

For each matrix, a text line is given, then the matrix size [row, column], and then the matrix. In the matrices the primary order for model parameters in a model with n layers is: resistivities 1…n, thicknesses 1...n-1. When constraints are present, the primary order is: resistivities 1…n, thickness 1…n-1, vertical constraints, horizontal constraints. Secondary order is model 1...m (m is the number of models).

```
1      aarhusinv, version
2      2.13
3       .
4       .
5      Rx field polar. (TDEM,Frq) (1..NDS)
6              0
7              0
8      TxX,TxY,TxZ,RxX,RxY,RxZ (1..NDS)
9            0.0       0.0       0.0       0.0       0.0       0.0
10           0.0       0.0       0.0       0.0       0.0       0.0
11     Model parameters (MPar), 0..NIte
12                10            12
13       5.00000E+01  4.30501E+01  3.54727E+01  3.48167E+01  3.42342E+01  3.09143E+01  3.07567E+01 ...
14       5.00000E+01  4.67947E+01  4.99121E+01  5.16638E+01  5.35122E+01  8.06627E+01  9.48817E+01 ...
15           .            .            .            .            .            .            .
.
16       1.00000E+01  9.99999E+00  1.00322E+01  1.01210E+01  1.02379E+01  1.13854E+01  1.02446E+01 ...
17       5.00000E+01  3.72107E+01  2.65952E+01  2.61286E+01  2.58303E+01  2.42177E+01  2.45158E+01 ...
18     Forward data (FData), 0..NIte
19                16            12
20       5.00000E+01  4.50633E+01  4.14044E+01  4.17061E+01  4.21317E+01  4.40815E+01  4.54457E+01 ...
21       5.00000E+01  4.64492E+01  4.25640E+01  4.24476E+01  4.25223E+01  4.62622E+01  4.54702E+01 ...
22           .            .            .            .            .            .            .
.
23       5.00000E+01  4.45513E+01  3.94377E+01  3.93718E+01  3.94321E+01  3.92054E+01  3.96312E+01 ...
24       5.00000E+01  4.03183E+01  3.28847E+01  3.29824E+01  3.32180E+01  3.32902E+01  3.47362E+01 ...
25     G matrix (Jacobian), last iteration
26                19            10
27       6.78514E-01  3.08536E-01  1.29670E-02 -4.60243E-01  1.63663E-01  0.00000E+00  0.00000E+00 ...
28           .            .            .            .            .            .            .
.
29       0.00000E+00  0.00000E+00  0.00000E+00  3.75605E-01  6.24395E-01  0.00000E+00  0.00000E+00 ...
30     Model resolution matrix, coupled parameters (MRes)
31                10            10
32       9.35425E-01  3.41030E-02  5.87651E-04 -2.63836E-04  1.89504E-04  6.45035E-02 -3.47399E-02 ...
33           .            .            .            .            .            .            .
.
34      -7.38884E-02 -3.20687E-01 -3.00496E-02  1.27771E-03 -2.03564E-03  7.37603E-02  3.27174E-01 ...
35     Model covariance matrix, coupled parameters (MCovC)
36                10            10
```

```
  3.52123E-03  1.04618E-02 -3.16476E-02  1.05864E-02 -7.25190E-03  1.37670E-03  1.07744E-02 ...
       .             .            .            .             .            .            .
 -5.35253E-03 -1.11160E-01  2.45865E-01 -4.87348E-02  8.41847E-02 -7.80569E-03 -1.14103E-01 ...
Model covariance matrix, normalized, coupled parameters
           10          10
  1.00000E+00  3.41810E-01 -2.67272E-01  6.83784E-01 -3.62243E-01  4.32235E-01  3.47242E-01 ...
       .             .            .            .             .            .            .
 -3.31010E-01 -7.90872E-01  4.52154E-01 -6.85466E-01  9.15711E-01 -5.33667E-01 -8.00776E-01 ...
Model covariance matrix, uncoupled parameters (MCovUC)
           10          10
  1.73729E-02  8.93619E-01  1.03026E+00  2.51284E-01 -1.12663E+00  0.00000E+00  0.00000E+00 ...
       .             .            .            .             .            .            .
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00 -3.09332E+00 -7.59170E+02 ...
Analysis, coupled parameters (AnaC)
           22             1
  6.11359E-02
  6.74960E-01
       .
 -1.00000E+00
  5.51414E-02
Analysis, uncoupled parameters (AnaUC)
           22             1
  1.40887E-01
 -1.00000E+00
       .
```

Figure 16.1. The emm-file. Bold red text is not part of the file.