EH3D MANUAL

Introduction

EH3D is a flexible forward modelling program fo calculating the EM fields resulting from a wide range of geophysical sources over a 3D earth that is discretized using a mesh of rectangular cells. It can be run from the command line under Solaris, LINIX, or MS-WindowsXX or, in the MS Windows environment, using a graphical user interface (GUI). The UBC-GIF utility MeshTools3D is used to examine resulting EM field scalar quantities or vectors throughout the model volume.

This document provides details regarding the use of EH3D and its associated utility programs. First an outline will be provided showing the essential procedure involved in using this program. Then there is a short section outlining some suggestions for viewing calculated fields. The bulk of this manual provides details on file structures and parameters for controlling the calculations. There are several utility programs included with the EH3D program and these are summarized in the last section. Other related documentation includes
• theoretical papers published in the scientific literature (see "references" at the end of the document);
• an introduction to the theory and practical aspects of using the program;
• the manual for the UBC-GIF 3D viewer and model builder called MeshTools3D.

General procedure for forward modelling EM fields using EH3D

The following flow charts encapsulate EH3D processing flow from a user's point of view. The first pair of charts shows the program flow when **secondary** field calculations are performed. The first chart shows functionality and the second shows the names of files in the program library that are used to carry out each step. The second pair of charts outlines program flow when **total** field calculations are performed.
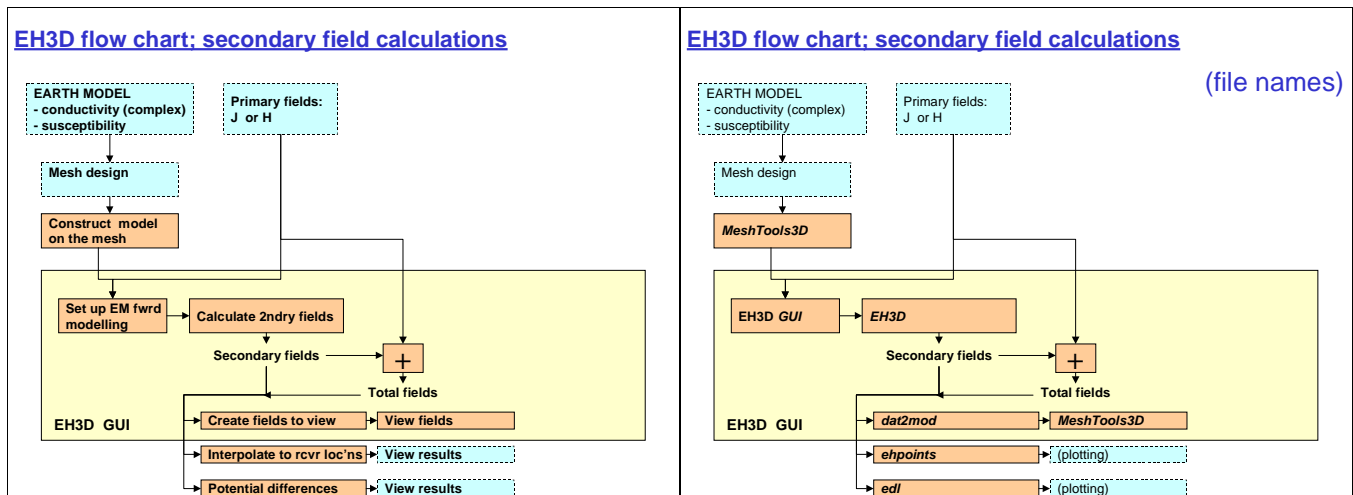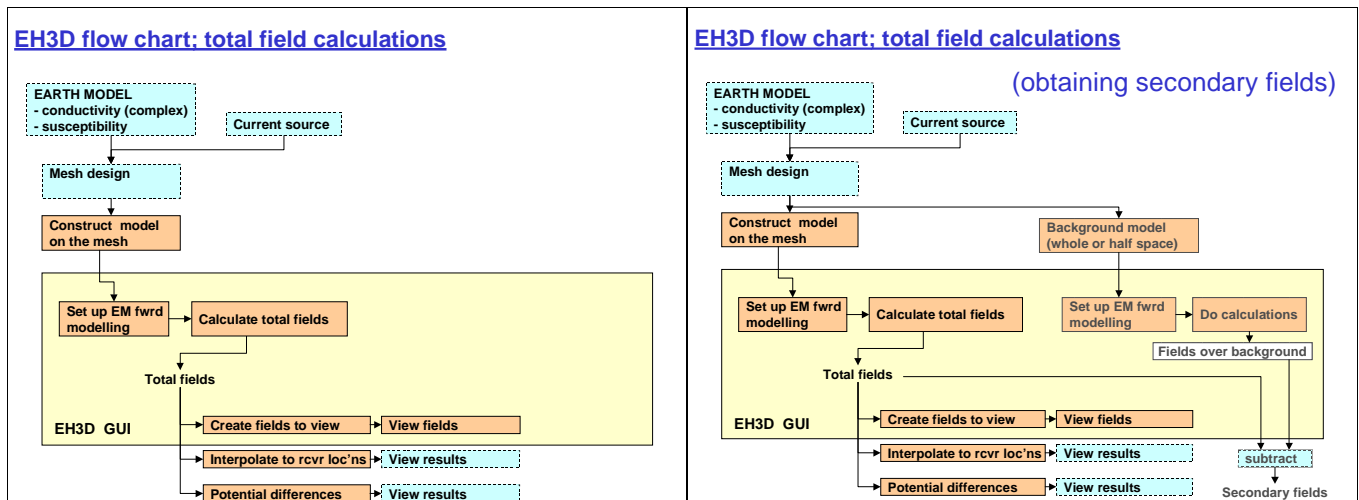

Processing flow for EH3D's secondary field calculations. Aspects included in the EH3D package have solid borders.

Processing flow for EH3D's secondary field calculations with program filenames in place of functionality.

The remainder of this section outlines a six step procedure for modelling EM fields using the program EH3D. In an appendix this procedure is illustrated by working through each step for one example.

1. Define the problem.
   a. Decide whether you want to calculate total fields or secondary fields.
      i. To obtain secondary fields you must either provide primary fields as input to EH3D, or you must generate primary fields using EH3D then generate total fields using EH3D, then subtract the two to obtain secondary fields.
      ii. If total fields are required you can supply EH3D with a current source or with primary fields.
   b. Determine all dimensions of the target, source, and between target and source.

Processing flow for EH3D's total field calculations. Aspects included in the EH3D package have solid borders.

Processing flow if secondary fields are required from EH3D's total field calculations.

2. Discretize the earth.
   a. This is always a compromise between calculation speed, memory capacity and accuracy. Faster calculations require fewer total numbers of cells, yet higher accuracy requires a greater number of cells. Useful information on the tradeoffs inherent in this compromise is provided in the document on introductory background theory.
   b. A mesh file must be created by hand using a text editor. Mesh file format is defined in the section describing the EH3D input files. An example of building a mesh file is provided in the appendix.

3. Construct the model of conductivity (and susceptibility) structure.
   a. In most cases one file containing the real part of conductivity for model will suffice.
   b. It is also possible to calculate fields over a model with variable complex conductivity and susceptibility. To do this requires up to three model files; one for the real part of complex conductivity, one for the imaginary part of complex conductivity, and one for susceptibility.
   c. Use MeshTools3D to generate these models. Details of building models are provided in the MeshTools3D manual.

4. Run EH3D. It is important to understand how EH3D keeps track of input and output files because several calculations can be specified at once. Note that file names and paths should not contain spaces.
   a. Input files are specified using full path names so it does not matter where they reside on your computer.
   b. Output files have well defined file names that you can not adjust. See the section on EH3D Outputs below. To avoid over-writing previous run results the program creates a separate subdirectory for each individual run. These subdirectories have names you provide in the "Labels" box in the EH3D GUI. Therefore you should start the program in a directory which will act as the root for these subdirectories. Results from

each individual run of the program will be placed in these subdirectories.

   c. In the EH3D graphical user interface (GUI) start by specifying the following parameters:
- i. the frequency of the transmitter signal;
- ii. identify the file names (including the complete path) for the mesh and model file(s).
- iii. Note that a number can be used if the model parameter is uniform for the entire earth below $z = 0$.
- iv. Fill in the source type. (See details at **Line G** under the EH3D input file description.)
- v. Specify the solver parameters. Some information is provided in the EH3D input file description, and further details and explanations are given in the document on introductory theory.

   d. Write a short descriptive string for this run in the "Label" box.
- i. For example, if you have just filled in parameters for a calculation over some model "a" at 100 Hz, you could provide a label string such as "a_f100".
- ii. Click the "Add" button to add this specified run to the list of calculations.
- iii. There is also a "Delete" button to remove individual run-specifications from the list.

   e. Repeat steps 4.c. and 4.d. above to add more independent runs with EH3D.

   f. Once you have entered parameters for each required forward calculation, save this run-specification using the **File** menu, **Save** option. The details of this set of EH3D calculations will be saved in a file in the current directory.

   g. Now the "run" button in the GUI should be active and you can click it to begin the calculations. If more than one run was specified you are given the option of proceeding with all runs, or to calculate only the one run currently visible in the "Label" box.

   h. Note that you can return to this set of calculations and investigate results or re-run individual runs by opening EH3D's GUI and using the **File** menu **Open** option to open the run-specification file that was created when the specification set was saved.

5. When calculations are complete click the "log" button to see the log file for each run. Note that the log file shown will be the one associated with the run that is currently visible in the "Label" box. This log file should be checked to ensure that the specified tolerance was attained within a reasonable number of iterations. Log file details are provided below.

6. View EM forward calculation results by clicking the "fields" button . The next section provides details on viewing EH3D results. Again, the information shown will be associated with the run that is currently visible in the "Label" box.

Viewing EH3D results

When EH3D finishes its forward modelling calculations two files are created, one with E-field information, and one with H-field information. Current density or J-field information can also be viewed using the GUI although no file with J field data is saved. (To create a copy of J-field file you must run EH3D from the command line; see Input File Line L.) Before examining results, two questions must be answered regarding how to view EH3D results. The first question is "what region of the 3D model do we need to examine"? For example it may be necessary to view the behaviour of the chosen field component over the whole 3D volume, or it may be more appropriate to examine a field component on the surface at $z = 0$. The second question is "what component of which field should be investigated"? For example it may be appropriate to examine the real part of the vertical component of the magnetic field Re(Hz), or it may be desirable to view the imaginary part of the E-field as a vector field.

Viewing 3D volumes

If the chosen field component must be viewed over all or a portion of the 3D volume then the UBC-GIF **MeshTools3D** utility can be used. In this case a file with the required **E**-field, **H**-field or **J**-field component(s) must be generated. There are 40 field components that can be generated from the two **EH3D** output files. When **EH3D** is being run using the Graphical User Interface (GUI), upon completion of the calculations the "fields" button will be active. Clicking it presents the dialogue shown to the right. Select a field component to view by selecting a radio button, then clicking one of the associated buttons labelled with the desired component. The required fields file will be generated, then **MeshTools3D** will run and automatically load this information. (Note that the programs **dat2mod, MeshTools3D** and **EH3Dgui** must be in the same directory for this to happen.) The source location will be shown as solid red line segments. Details on using **MeshTools3D** are provided in a separate manual.
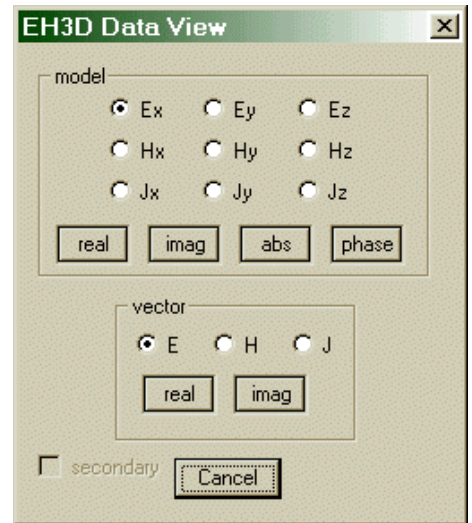

Figure 6

When MeshTools3D is closed, the field file that was generated will be destroyed. If you want to keep this file for later use, you must generate it from the command line using the **dat2mod** utility described next.

When the **dat2mod** utility is run from the command line, the options for generating field components that can be viewed are listed as follows.

```
 1) Real (Ex)    13) Real (Hx)    25) E (real) vector
 2) Imag (Ex)    14) Imag (Hx)    26) E (imag) vector
 3) Abs  (Ex)    15) Abs  (Hx)    27) H (real) vector
 4) Phase(Ex)    16) Phase(Hx)    28) H (imag) vector
 5) Real (Ey)    17) Real (Hy)
 6) Imag (Ey)    18) Imag (Hy)
 7) Abs  (Ey)    19) Abs  (Hy)
 8) Phase(Ey)    20) Phase(Hy)
 9) Real (Ez)    21) Real (Hz)
10) Imag (Ez)    22) Imag (Hz)
11) Abs  (Ez)    23) Abs  (Hz)
12) Phase(Ez)    24) Phase(Hz)

Add 30 to display J (current density)
Add 60 to display secondary fields (option valid only after running EH3D in
the "secondary fields" mode.)
```

Upon typing the desired option on the command-line, the program will generate the required field component and save it to a file with a pre-determined name representing the field and component requested. These names should be self-explanatory.

Viewing fields at specified locations

The command-line utility **ehpoints** can be used to translate **EH3D** output files into a 15-column text file that contains all E- and H-field parameters interpolated onto any set of positions you specify in a "locations" file. Details are provided below in the description of **ehpoints** in the section on utilities.

Fields can also be viewed as potential differences by using the utility **edl**. This is also described in the section on utilities. The appendix includes an example of using MeshTools3D, **ehpoints** and **edl** to view **EH3D** results.

EH3D outputs

Depending upon what is entered on **Line L** of the **EH3D** input file (described below) some or all of the following output files will be produced.

```
e.dat (binary) or  e.txt  (ascii) - E field  (and/or    e_s.dat, e_s.txt)
h.dat (binary) or  h.txt  (ascii) - H field  (and/or    h_s.dat, h_s.txt)
j.dat (binary) or  j.txt  (ascii) - J field
eh3d.log - log file
```

The log file is always generated. Information in the log file should be self explanatory. The frequency is noted, followed by the source location (including the centre of cells through which current flows) or primary field sources. Then there are some details regarding the CPU times involved at each calculation step, as well as the final tolerance (norm) and total number of iterations. The tolerance should be within the value specified on input file line H, and the number of iterations should be less than the maximum specified (also on input file line H) if forward calculations converged successfully.

Binary output can be converted to ascii using the **bin2a.exe** utility described below. Text file format is not similar to UBC-GIF model file format (described above under input file line C). The real and imaginary parts of all three coordinates must be included. In these two-column files, column one contains the real part and column two contains the imaginary part. For each field file (E, H, or J) X-component values for all cells are provided in the first third of the file, then all the Y-component values, then all the Z-component values. These field files will be six times the size of simple parameter files (such as conductivity files described above) because there are three sets of values in two columns rather than one set of values in one column.

When ascii output is requested (input file **Line K**) two extra files specifying locations of E and H vectors are generated. These are for the user's benefit and are not used by any other utilities. They are in a similar format to field files, but they have three columns identifying coordinates of E and H vectors. The file names are:
•   e_pos.txt - coordinates of E vector
•   h_pos.txt - coordinates of H vector

When binary output files are requested (input file **Line K**) location information is not output. Other UBC-GIF utilities use the binary files for data, and they find locations using the **EH3D** input file which points to a mesh file. This input file (described next) is called eh3d.inp.

EH3D Input file format

The operation of EH3D is controlled by a series of parameters that are provided to the program via an input file that must be called `eh3d.inp`. In order to understand what EH3D is doing and how results are generated it is necessary to understand the meaning of each parameter. When running EH3D using the Windows - hosted GUI this input file is generated automatically for each run specified in the GUI's "Label" section. Note that file names and paths should not contain spaces.

The input file is a text file with 13 lines containing parameters as follows (the "|" symbol means "or"). Each line is described in detail below.

```
A) frequency
B) mesh file
C) real conductivity file | ground conductivity
D) imaginary conductivity file | ground conductivity | null
E) susceptibility file | ground susceptibility | null
F) TOTAL | SECONDARY
G) source file(s)
H) solver parameters: droptol, tol, iter
I) preconditioner type
J) output precision
K) output format
L) output_total_E  output_total_H  output_total_J
M) output_secondary_E output_secondary_H
```
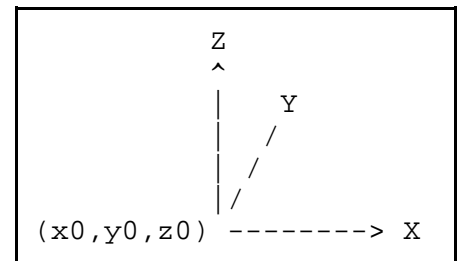
Input File Line A:
Source frequency in units of Hz.

Input File Line B:
The name of the file that defines the 3D mesh. This mesh file has the following format:

```
nx ny nz
x0 y0 z0
dx_1 dx_2 ... dx_nx
dy_1 dy_2 ... dy_ny
dz_1 dz_2 ... dz_nz
```

```
                Z
                ^
                |    Y
                |   /
                |  /
                | /
  (x0,y0,z0) --------> X
```

Coordinate axis for UBC-GIF meshes.

Parameters are defined as follows:
`nx,ny,nz` - number of cells in the X, Y, and Z directions.
`x0,y0,z0` - coordinates of the top south west corner of the mesh:
`dx,dy,dz` - cell widths.

Mesh design is a critical step, and there are guidelines in the introductory document titled "Practical Aspects of running EH3D". Also, Appendix I includes an example showing how the mesh was designed for a specific scenario.

Input File Line C:
The name of a file containing the real part of conductivity for all cells in the model. This model file is in the same format as input files to **MeshTools3D** and it must be compatible with the mesh file on **Line B**. The file is stored

as one column of numbers, one for each cell. The first number is the value of the top south-western cell. The values are ordered such that Z (depth) changes the fastest, followed by X(easting), followed by Y(northing).

For constant real conductivity, a value in units of S/m can be entered. All cells below z = 0 will then be set to this value. The cells above z = 0 will be set to 1.0×10^{-8} S/m.

Input File Line D:
The name of a file containing the imaginary part of conductivity for all cells in the model. It has the same format as that of the file identified on **Line C**.

For constant imaginary conductivity, a value in units of S/m can be entered. All cells below z = 0 will then be set to this value. The cells above z = 0 will be set to 0 S/m. If 'null' is entered, all cells will be set to 0 S/m.

Input File Line E:
The name of a file containing magnetic susceptibility in S.I. units for all cells in the model. It has the same format as that of the file identified on **Line C**:

For constant susceptibility, a value in S.I. can be entered. All cells below z = 0 will then be set to this value. The cells above z = 0 will be set to 0 (S.I.). If 'null' is entered, all cells will be set to 0.

Input File Line F:
This line specifies the type of calculation to be performed by EH3D.
- Enter **TOTAL** if EH3D is to calculate total fields based upon a current-source specified on **Line G**. For this option the outputs will be the total fields calculated by EH3D according to requirements specified on **Line L**. **Line M** will be ignored.
- Enter **SECONDARY** if EH3D is to perform a secondary-field calculation based upon primary **J** or **H** fields supplied using files specified on **Line G**. For this option, output can be total fields and/or secondary fields, according to requirements specified on **Lines L** and **M**.

Input File Line G:
Source information is specified here. Two formats are possible depending upon the choice on **Line F:**
(1) If TOTAL field calculations were specified on **Line F** there must be one line here with a filename.
(2) If SECONDARY field calculations were specified on **Line F** there must be three lines here, including two lines which describe the background complex conductivity used to generate the primary fields and one line containing the name of a file that contains the primary fields. This last line must begin with a one-character field-type specifier (J or H). More details for both options follow.

(1) <u>For TOTAL field calculations</u>, **Line G** contains the name of a three column file which contains point locations specifying the current source (i.e. specifying the location of the transmitter). This source specification file is a simple text file with the following format:

```
xs1 ys1 zs1                  ! 1st point
xs2 ys2 zs2
:
xs_nsp ys_nsp zs_nsp         ! last point
```

NOTES on specifying current sources:

- When EH3D runs, the source locations are specified by identifying the centres of cells through which the current source is flowing. This does not change the result because conceptually the source involves a uniform current density within the cell where source current flows. For more details see the introductory theory document.
- For a loop source, the first and last points should be identical (i.e. a square loop must be specified with 5 points).
- For a grounded line source, the user is responsible for terminating the wire inside the ground. That means there must be small segments that go from just above the ground to just below the ground.
- For the purposes of forward modelling calculations, current in the transmitter loop (a single wire) is assumed to be 1 Amp.

(2) <u>For SECONDARY field calculations</u>, three lines are required. First the real part of the background conductivity is specified (a number in units of S/m or a filename). Second the imaginary part of the background conductivity is specified (a number in units of S/m or a filename). Third, one character specifies whether primary fields are **J** or **H** fields, then there is the name of the file containing those input fields. All this input information should be entered at EH3D input file **Line G** in the following order:

```
background real conductivity (number or file)
background imaginary conductivity (number or file)
J | H   filename
```

NOTES on specifying input in terms of primary fields:
- In this case "primary field" means the fields due to the required source in the presence of host geology without a "target".
- **J** or **H** field files must be in the same format as EH3D text-style output files. See the output file specification section for details. Units must be A/m^2 or A/m respectively.
- Conductivity files (one file for real and one file for imaginary parts) are stored in the same format as described in Lines (C) and (D) above.
- The **J** file can have **H** appended to it.
- A primary **H** field can only be used when the source is outside of the mesh.
- Exactly how primary fields are calculated depends upon what tools are available for calculating **J** or **H** fields with the required source over a halfspace or 1D earth.

Input File Line H:
Parameters specifying convergence criteria:

droptol – only used if ILU preconditioner is chosen. Sets the threshold for dropping small terms in the factorization.
tol   – tolerance for convergence.
iter   – maximum number of iterations to perform.

Input File Line I:
A parameter specifying which preconditioner is to be used in the calculations. Enter 0 or 1 to specify which preconditioner to use as follows. More details are provided in the introductory theory document.

0 - SSOR
1 - ILU

Input File Line J:
Enter a 1 or 0 to specify output precision. Regardless of the value of this parameter the arithmetic inside EH3D is always performed in double precision.

0 - output is in single precision (recommended for smaller output files)
1 - output is in double precision

Input File Line K:
Enter a 1 or 0 to specify output format. Binary output format is faster, more accurate and produces smaller files, however, it is not portable.

0 - output is in binary format.
1 - output is in ascii format.

Input File Line L:
Enter a set of three 1's or 0's to indicate which fields EH3D should output. For example, to have the program output only **E** and **H** fields, enter: 1 1 0

0 - do not output.
1 - output the fields.

Input File Line M:
Enter two 1's or 0's to indicate whether to output secondary fields. This line is relevant if and only if a SECONDARY fields calculation was specified on **Line F**. If TOTAL field calculations were specified on **Line F** then secondary fields can not be provided and **Line M** will be ignored. Note that secondary **J** fields can not be provided. For example, to have the program output secondary **E** but NOT the secondary **H** fields, enter 1 0.

This is the end of EH3D input file description.

Four EH3D Utilities:

Note that all these utilities operate upon EH3D files called `eh3d.inp, e.dat, h.dat` or `e.txt,`
`h.txt`. These inputs are implied, NOT specified, therefore the utilities must be run at the command line from the subdirectories that contain these EH3D output files. Batch files can be written to perform operations on several outputs at once by including "cd" (change directory) commands between separate invocations of the utility.

BIN2A
Convert the output of EH3D from binary to ascii.

Usage: bin2a [coord]
coord: to output coordinates, enter 1

input: e.dat, h.dat
output: e.txt, h.txt
     bin2a.log
     e_pos.txt (optional) - coordinates of E vector
     h_pos.txt (optional) - coordinates of H vector

DAT2MOD
Convert the output of EH3D into model or vector files that can be displayed with MeshTools3D. See also "Viewing 3D Volumes" above.

Usage: dat2mod

input: e.dat, h.dat or e.txt, h.txt
output: model or vector file suitable for use by MeshTools3D.

EHPOINTS
Interpolate the output of EH3D to get E and H values at any receiver point.

Usage: ehpoints recv-file [*]
recv-file: three column file that contains the locations of receivers
* can be 1 to specify secondary fields, or 2 to ask that J-field files be output.

input: e.dat, h.dat or e.txt, h.txt
output: recv.txt | sec_recv.txt | recv_J.txt

Output file format: For each receiver location one row of values is saved in 15 columns as follows:
X Y Z Re(Ex) Im(Ex) Re(Ey) Im(Ey) Re(Ez) Im(Ez) Re(Hx) Im(Hx) Re(Hy) Im(Hy) Re(Hz) Im(Hz)

EDL
Calculate potential difference between points.

Usage: ehpoints recv-file
recv-file: file containing the receivers

The format of recv-file:
```
npt1                ! # of points defining the 1st receiver
x_1 y_1 z_1
:
x_npt1 y_npt1 z_npt1

npt2                ! # of points defining the 2nd receiver
x_1 y_1 z_1
:
x_npt2 y_npt2 z_npt2
```

input: e.dat, h.dat or e.txt, h.txt
output: edl.txt

References

1. E. Haber, U. Ascher, D. Aruliah and D. Oldenburg. *Fast simulation of 3D electromagnetic problems using potentials*, J. Comp. Phys., 2000.

2. E. Haber, U. Ascher *Fast finite volume modeling of 3D electromagnetic problems with highly discontinuous coefficients*, To appear in SIAM J. Scient. Comp.

3. E. Haber, *A mixed finite element method for the solution of the magnetostatic problem in 3D,* Computational Geoscience, 4, 323-336, 2000.

4. D. Aruliah, U. Ascher, E. Haber and D. Oldenburg *A method for the forward modelling of 3D electromagnetic quasi-static problems,* To appear in M3AS, 2001.

Appendix: An example

This example involves a 1 kilometre square loop source, and a 1.0 Ohm-m block 500 metres away from this source buried at 50 m depth in host rocks with resistivity of 200 Ohm-m. We are interested in characterizing the EM fields arising in the vicinity of the target due to sinusoidal source currents with a range of frequencies. Figure A1 shows target and source locations, and the mesh that was designed to forward model EM fields for this scenario is shown in Figure A2.
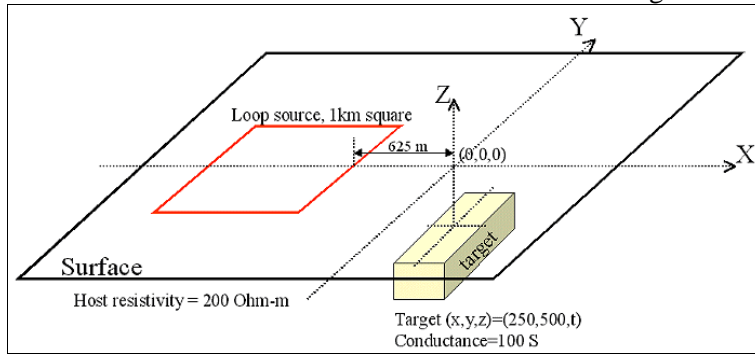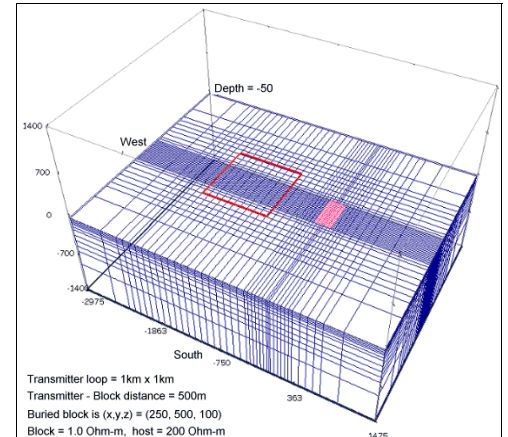

Fig. A1

Fig. A2

Mesh design:

A simple spreadsheet can help with mesh design. Figure A3 below is a representation of a spreadsheet that was used to generate the mesh above.

Mesh calculator		Mesh file = mesh4.msh											
						(X, Y, Z) = (0, 0, 0)							
X - Direction	**West**												**East**
Absolute position (m)		-2975	-2475	-2225	-325	-25	0	25	325	725	975	1475	
incremental position (m)		-500	-250	-1900	-300	-25	0	25	300	400	250	500	
cell width (m)		500	250	100	50	25		25	50	100	250	500	**Total X cells**
incremental # of cells		1	1	19	6	1		1	6	4	1	1	**41**
Y - Direction	**South**												**North**
Absolute position (m)		-1700	-1200	-950	-350	-250	0	250	350	950	1200	1700	
incremental position (m)		-500	-250	-600	-100	-250	0	250	100	600	250	500	
cell width (m)		500	250	100	50	25		25	50	100	250	500	**Total Y cells**
incremental # of cells		1	1	6	2	10		10	2	6	1	1	**40**
Z - Direction	**Top**												**Bottom**
Absolute position (m)		1400	900	650	250	150	0	-150	-250	-650	-900	-1400	
incremental position (m)		500	250	400	100	150	0	-150	-100	-400	-250	-500	
cell width (m)		500	250	100	50	25		25	50	100	250	500	**Total Z cells**
incremental # of cells		1	1	4	2	6		6	2	4	1	1	**28**

Resulting mesh file:				Total number of cells =	45,920
automatic:	41	40	28		
by hand:	-2975	-1700	1400		
by hand:	500 250 19*100 6*50 2*25 6*50 4*100 250 500				
by hand:	500 250 6*100 2*50 20*25 2*50 6*100 250 500				
by hand:	500 250 4*100 2*50 12*25 2*50 4*100 250 500				

Fig. A3

Here are instructions for designing the mesh using this spreadsheet:
1) Use a paper sketch to help.
2) Locate your desired origin. In this case we wanted (x, y, z) = (0, 0, 0) to be on surface above the centre of the conductive target.
3) Work west along the X-axis from the origin, enter incremental positions where cell width changes (row labelled "incremental position"). Use negative values for west, south and down with respect to the origin.
4) Include the cell width for each region (row labelled "cell width"). The absolute position and number of cells

will be calculated for each region (rows labelled "absolute position" and "incremental # of cells" respectively).

5) Repeat for the remainder of the X-axis East of the origin
6) Repeat for the Y-Axis.
7) Repeat for the Z-axis.
8) Resulting mesh file must be completed based upon results. See the five lines in Figure A3. These must be copied out to a text file and saved as the mesh file for this problem.

Further notes regarding mesh design:
1) Mesh line 1 is number of cells for X, Y, Z directions respectively
2) Mesh line 2 is west, south, top corner respectively of the model volume.
3) Symmetry about the origin is not necessary, but ensure there are enough cells of suitable size to avoid compromising accuracy.
4) Padding cells outside the region of interest are recommended. Increase cell size by a factor of no more than two for adjacent cells.

Input and output files for this scenario

eh3d.inp
```
100  ! frequency
C:\gif\eh3d\cominco_fj\mesh4.msh  ! mesh file
C:\gif\eh3d\cominco_fj\j4.mod  ! real conductivity
0.0  ! imaginary conductivity
0.0  ! susceptibility
TOTAL
src-points.dat  ! transmitter location file
0.01 1e-006 500  ! droptol, tol, iter
1  ! preconditioner type: ilu
0  ! single precision output
0  ! binary output
1 1 0  ! output E and H files
```

mesh file
```
41 40 28
-2975 -1700 1400
500 250 19*100 6*50 2*25 6*50 4*100 250 500
500 250 6*100 2*50 20*25 2*50 6*100 250 500
500 250 4*100 2*50 12*25 2*50 4*100 250 500
```

conductivity model
Other possible model files are one model file with the imaginary part of conductivity if the target has a complex conductivity and a model file with susceptibility if the target is magnetic.

src-points.dat
```
-1625 -500 0
-1625 500 0
-625 500 0
-625 -500 0
-1625 -500 0
```

EH3D output files are:

eh3d.log
```
 EH3D started on:  6/04/2001  16:27:02

 frequency:  1.0000E+02

 Loop source
 -1.6250E+03 -5.0000E+02  0.0000E+00
 -1.6250E+03  5.0000E+02  0.0000E+00
 -6.2500E+02  5.0000E+02  0.0000E+00
 -6.2500E+02 -5.0000E+02  0.0000E+00
 -1.6250E+03 -5.0000E+02  0.0000E+00

 path            X                      Y                    Z
   -1675.00,            -500.00   500.00,     12.50
   -1675.00  -675.00,    500.00,             12.50
    -675.00,            500.00  -500.00,     12.50
    -675.00 -1675.00,  -500.00,             12.50

     setup cpu time:    0:00:06.33
 Using the ILU preconditioner.
       ilu cpu time:    0:00:05.08
     solve cpu time:    0:01:31.02

 norm:   6.8442E-07
 number of iterations:  74

 E field written to file: e.dat

 H field written to file: h.dat

    fields cpu time:    0:00:00.26

     TOTAL cpu time:    0:01:42.71

 EH3D ended on:  6/04/2001  16:28:45
```

e.dat   (binary output file)
h.dat   (binary output file)

**Results of generating EM fields**

Images below are examples of using MeshTools3D to visualize various components of the electromagnetic fields generated by EH3D. Padding cells have been removed, the colour bar shows amplitudes of results, and the source loop is shown as a solid red line. Note that all results are total fields. Some responses to the target may be more visible when secondary fields are plotted as in examples of results on the surface following these MeshTools3D image examples.
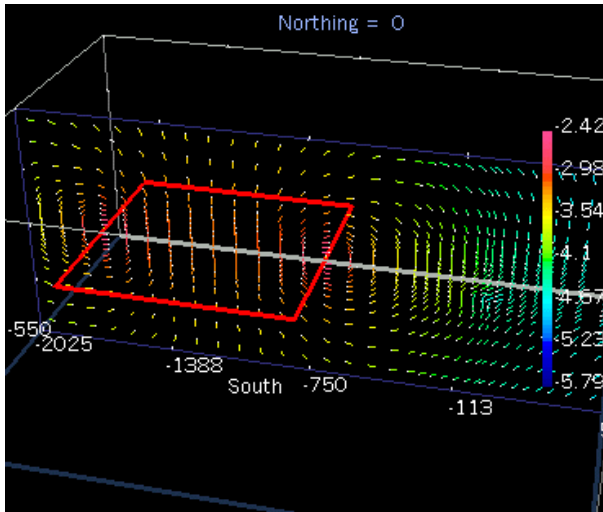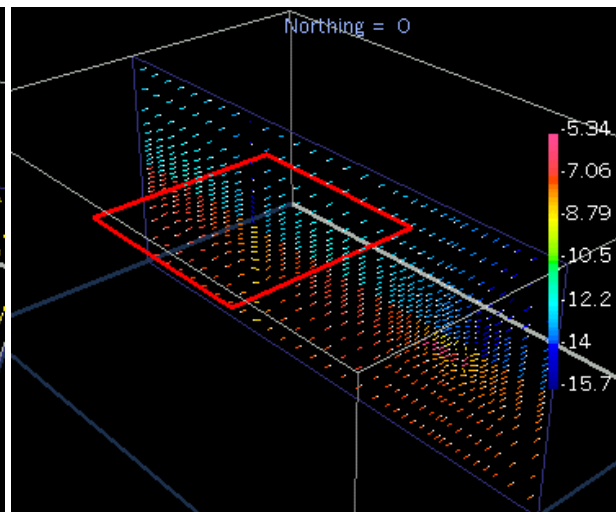

Vectors showing the real part of the magnetic field sliced along the y=0 axis.
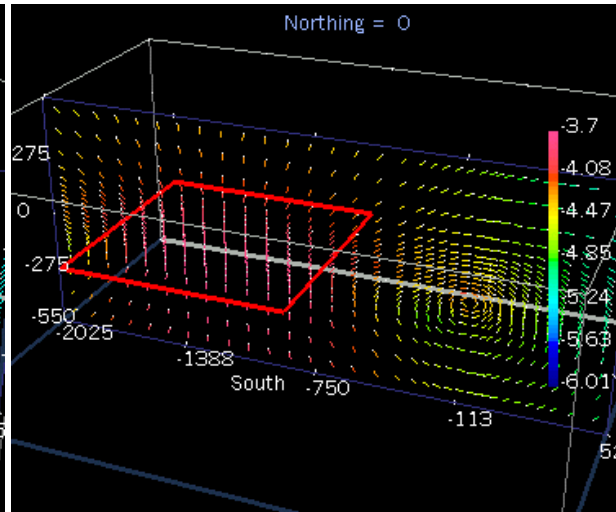
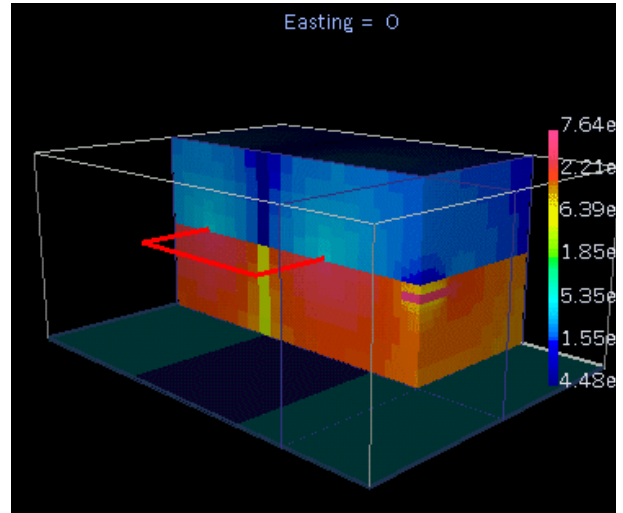Vectors showing the imaginary part of the H-field sliced on the X = 0 plane.
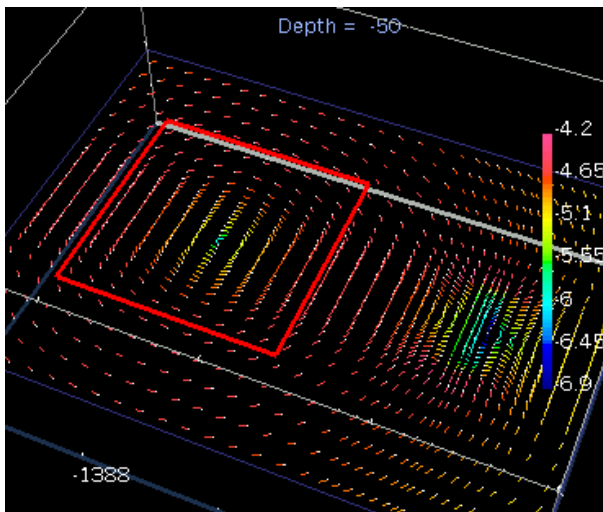
Vectors showing the real part of the E-field sliced on the Z = -50 plane (through the target's centre).

Vectors showing the real part of the current density field sliced along the y=0 axis.
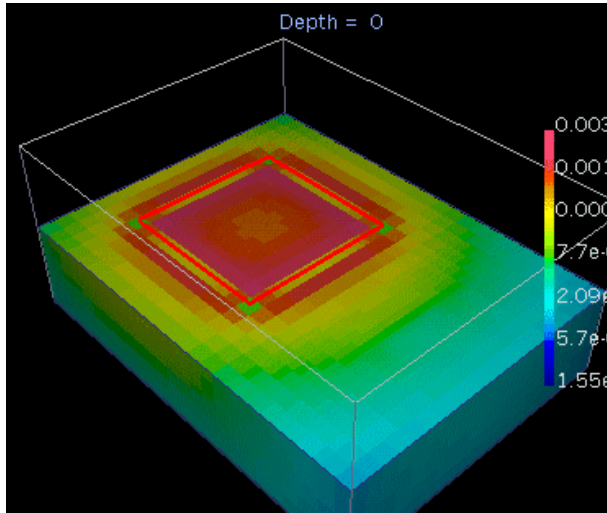
Magnitude of the Z-component of the magnetic field sliced along the Z=0 axis.

Magnitude of the Y-component of the current density sliced along the Y=0 and the X=0 axis.

Images below are examples of using `ehpoints` to interpolate EM fields at specified locations, then contour plotting the results. Locations specified were a square region of the surface (z = 0) ranging ±500 m on either side of the origin.
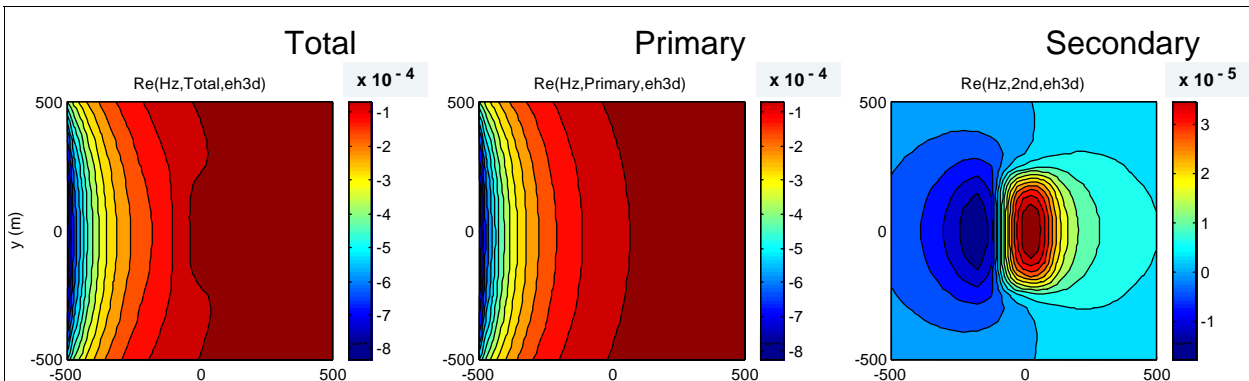
Real part of Hz plotted on the earth's surface, centred over the buried target. Total fields are the combination of primary fields (no target) and secondary fields (response of the target alone).
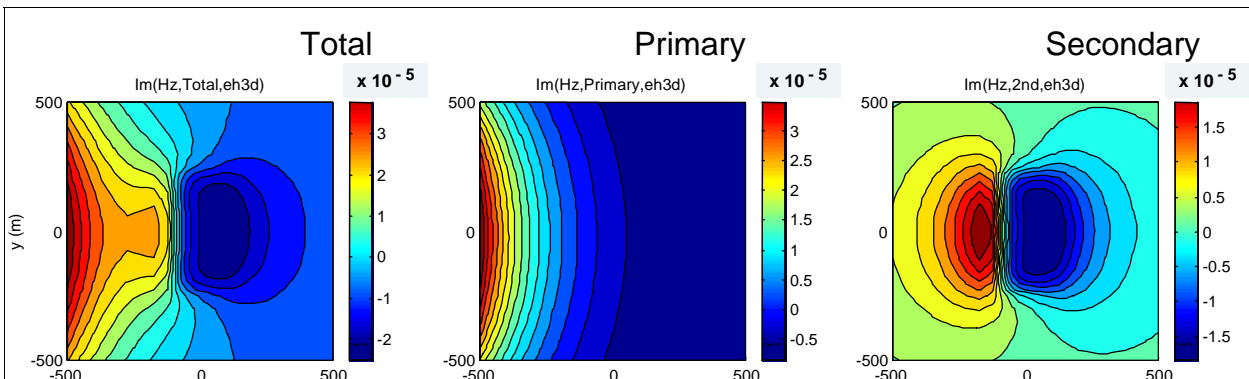
Imaginary part of Hz plotted on the earth's surface, centred over the buried target. Total fields are the combination of primary fields (no target) and secondary fields (response of the target alone).