USER DOCUMENTATION FOR THIN LAYER MODELING CODE SLPROG AND ACCOMPANYING SOFTWARE

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1. Brief description of the modeling algorithm

The modeling code is designed to calculate the electromagnetic field induced in a heterogeneous layer resting on the top of a stratified medium. The subsurface layer is described by its thickness

$$S(x,y)=\int_0^h \sigma(x,y,z)\cdot dz\,, \qquad (1)$$

h and conductance
where $\sigma(x,y,z)$ is the electric conductivity in the subsurface layer. The OX and OY axes are parallel to the earth surface, the vertical axis OZ is directed downwards. The displacement currents are neglected; the time factor $exp(-\imath\omega t)$ is assumed.

Calculations are carried out assuming that the requirements of the thin layer approximation are satisfied, i.e.

$$max\left\{\sqrt{\omega\mu_0 hS},\ \frac{h}{\lambda_\tau}\right\} << 1, \qquad (2)$$

where λ_τ characterizes the swiftness of the field variations along the layer. Further details on the approximation applicability can be found in Appendix A of (Singer & Fainberg, 1999, Geophysical J. Int., **138**, 125-145). Below this publication will be referred to as SF.

The distribution of the anomalous current $\mathbf{j}^{S,a}$ induced in the subsurface layer is related to the

$$\mathbf{j}^{S,a} = \frac{S(\mathbf{r})}{S(\mathbf{r})+S_0}\ \boldsymbol{\xi}(\mathbf{r})\,. \qquad (3)$$

unknown function $\boldsymbol{\xi}$ as

$$\boldsymbol{\xi}(\mathbf{r}) = \boldsymbol{\xi}_0(\mathbf{r}) + \int_{\mathbf{R}^2} \hat{\mathfrak{Z}}_0(\mathbf{r}-\mathbf{r}')\left[\frac{S(\mathbf{r}')-S_0}{S(\mathbf{r}')+S_0}\ \boldsymbol{\xi}(\mathbf{r}')\right] ds \quad , \qquad (4)$$

In its turn function $\boldsymbol{\xi}(\mathbf{r})$ satisfies the integral equation
and $\mathbf{r}=x\mathbf{e}_x+y\mathbf{e}_y$ is the horizontal radius-vector. Constant parameter S_0 is chosen to optimise convergence of the sequence of approximations to the solution of eq.(4) as it is discussed in SF. The modified Green's function used in eq. (4) is defined as

$$\hat{\mathfrak{Z}}_0(\mathbf{r}) = 2\,\hat{\mathfrak{G}}_0(\mathbf{r}) - \delta(\mathbf{r})\,\hat{\mathbb{I}} \quad , \qquad (5)$$

where $\delta(\mathbf{r})$ is the Dirac delta-function, $\hat{\mathbb{I}}$ is a unit tensor, and $\hat{\mathfrak{G}}_0$ is the current-to-current

Green's function for the so-called reference model. The reference model consists of the surface layer of the same thickness h and conductance S_0 . The underlying structure of the reference model is the same as in the model under consideration. The free term of eq. (4) is determined by the external sources. The equation is solved using a projection implementation of the modified iterative dissipative method (MIDM) also described in SF. The number of operations necessary

$$\frac{\sqrt{K}}{2} [N_x \log N_x] [N_y \log N_y] \ln\frac{\varepsilon_0}{\varepsilon} \quad , \tag{6}$$

to solve the integral equation is controlled by the factor
where N_x and N_y are numbers of the numerical grid cells in X- and Y-directions respectively; ε_0

$$K = \frac{\max\limits_{\mathbf{r}\in\mathbf{R}^2} S(\mathbf{r})}{\min\limits_{\mathbf{r}\in\mathbf{R}^2} S(\mathbf{r})} \tag{7}$$

and ε are the initial and required accuracy of the solution. The parameter
is the lateral contrast of the conductivity distribution in the model.

After finding the subsurface current, the magnetic field at the earth surface is found by the integration of the subsurface current with the current-to-magnetic field Green's function.

2. Components of the software package

The package includes fives executable (**SLPROG.EXE, SLDIAG.EXE, SLFIELD.EXE, and MTCURVES.EXE**) files.

SLPROG is the code that carries out numerical simulation based on the algorithm briefly outlined in the previous section. The code requires a number of the workfiles. Some of these workfiles are created in the process of installation. Other workfiles are created by the code. The model is described in an input file. The format of this file is shown below. The code also requires an input of control information from the console. This information can also be inputted from a separate file by redirecting the input.

The calculated components of the electromagnetic field at the earth surface can be outputted in two formats. One of the outputs represents an ASCII file that can be used to immediate view and estimate the results without deploying any graphic software. The main output represents a binary file that is used as input information for processing programs **SLFIELD or SLDIAG**.

SLFIELD is a processing code that reads the output binary file created by SLPROG. The results of calculation are outputted into an ASCII file prepared for the further use.

SLDIAG uses two output binary files created by SLPROG for two different polarizations at the same period. The program calculates the impedances as well as local and remote reference magnetic ratios.

MTCURVES.EXE gives a user possibility to calculate tables of apparent resistivities and phases when magnetotelluric modeling.

3. System requirements

The codes require any PC running under DOS, Windows 95/98/ME/2000/XP or OS2 and 3-50 Mb of disk space (depend on model and number of periods).

4. Installation

Create a special directory (for instance, SLPROG) and copy *slprog.zip* file into this directory. Unpack it there keeping the original structure of directory and MT subdirectory.

5. Using SLPROG

The code simulates electromagnetic fields and outputs results for further processing.

5.1. Model description file

The model description file contains information about the model under consideration. An example is given below.

The first record of the model description file is used to identify the problem. This record is passed to the output files. The next several lines can be used to input additional commentaries. The information from these lines is not processed by SLPROG. It is not passed to the output files.

The comment are followed by a *namelist* directed input identifying the numerical grid and allowing to refer some of the grid cells to one or several geographic points. The *namelist* block is identified by the name *Gen_Description*. The block specifies variables listed in the following table.

Variable	Meaning	Limitations	Comments
ILn	Number of numerical grid cells in *X*-direction with the conductance specified in the array that follows the *namelist* block called *Inhom_Cond_Layer*	≤ Nx	Size of the initial numerical grid in the *X*-direction
JLn	Number of numerical grid cells in *Y*-direction with the conductance specified in the array that follows the *namelist* block called *Inhom_Cond_Layer*	≤ Ny	Size of the initial numerical grid in the *Y*-direction
Dx	Size of the numerical grid cell in *X*-direction		An equidistant grid is used in *X*-direction, [*m*]
Dy	Size of the numerical grid cell in *Y*-direction		An equidistant grid is used in *Y*-direction, [*m*]
NPoint	Number of referred geographic points	≤ 64	
Point(I)	A character array containing information identifying the geographic points..	I=1,2,...,NPoint. Every element is a char*20 variable.	
XPnt(I)	Real array. Dx*XPnt(I) is the *x*-coordinate of the *I*-	I=1,2,...,NPoint	The coordinates are indicated with respect to the initial numerical grid.

	th geographic points.		The initial numerical grid is placed in the center of the numerical grid used for simulation. The program modifies the coordinates respectively.
YPnt(I)	Real array. Dy*YPnt(I) is the *y*-coordinate of the *I*-th geographic points.	I=1,2,...,NPoint	Same as above

The *namelist* block *Gen_Description* is followed by another *namelist* directed input identifying the stratified structure underlying the heterogeneous subsurface layer. This *namelist* block is called *Embed_Structure*. The block specifies the variables listed in the following table.

Variable	**Meaning**	**Limitations**	**Comments**
NLayer	Number of layers in the stratified structure underlying the subsurface heterogeneous layer	≤ 22	
Dz(I)	Thickness of a homogeneous layer	I=1,2,...,NLayer	[*m*]
Sigma(I)	Conductivity of a homogeneous layer conductivity	I=1,2,...,NLayer	[*S/m*]

The *namelist* block *Embed_Structure* is followed by the third *namelist* directed input *Inhom_Cond_Layer* providing a summary information about the heterogeneous surface layer. In its term the block is followed by an array specifying the conductance of the layer inside each cell of the input numerical grid. The *namelist* block *Inhom_Cond_Layer* specifies the variables listed in the following table

Variable	**Meaning**	**Limitations**	**Comments**
Ind_In	Specifies the order in which cells are listed in the conductivity array that follows the *namelist*	= 0, 1	For Ind_In=0, the elements are listed *X*-wise. For Ind_In=1, the conductivity array is interpreted as being prepared *Y*-wise.
Dz0	Thickness of a heterogeneous layer		[*m*]
Smlt	The common factor used to define the parameters of conductance distribution.		The code assumes that each element of the conductance array in the model description file should be multiplied by this factor.
Snrm	Conductance outside of the part of numerical grid specified in the conductance array.		Normalized by *Smlt*
Smin	The lower cutoff threshold of conductance		Normalized by *Smlt*. To disengage set this value smaller that the smallest element of the

			conductance array.
Smax	The upper cutoff threshold of conductance		Normalized by *Smlt*. To disengage set this value larger than the largest element of the conductance array.
NS_Dpl	Number of electric dipole sources in the subsurface heterogeneous layer	≤ 64	Not used for a magnetotelluric source
aJsMlt	Common factor used in the definition of the density of the external current in the cells containing the electric dipoles.		[*A/m*]
IS_Dpl(I)	The *X*-direction number of the cell containing a horizontal electric dipole	I=1,2,...,NS_DPL	The cell number is given for the input numerical grid.
JS_Dpl(I)	The *Y*-direction number of the cell containing a horizontal electric dipole	I=1,2,...,NS_DPL	Same as above
Re_Px(I)	Normalized in-phase part of the *X*-component of the external electric current in the cell.	I=1,2,...,NS_DPL	The code assumes that the density of the external current in the cell number IS_Dpl(I), JS_Dpl(I) is $\mathrm{Re}\, j_x^e$ = aJsMlt*Re_Px(I)
Ai_Px(I)	Normalized out-of-phase part of the *X*-component of the external electric current in the cell.	I=1,2,...,NS_DPL	$\mathrm{Im}\, j_x^e$ = aJsMlt*Ai_Px(I)
Re_Py(I)	Normalized in-phase part of the *Y*-component of the external electric current in the cell.	I=1,2,...,NS_DPL	$\mathrm{Re}\, j_y^e$ = aJsMlt*Re_Py(I)
Ai_Py(I)	Normalized out-of-phase part of the *Y*-component of the external electric current in the cell.	I=1,2,...,NS_DPL	$\mathrm{Im}\, j_y^e$ = aJsMlt*Ai_Py(I)

The conductance array that follows the block *Inhom_Cond_Layer* has to have *Iln*Jln* elements. The maximum length of the record 4096 characters is allowed. Each value represents conductance of one of the cells of the input numerical grid. All conductance values are normalized by the *Smlt* factor.
The array is assumed to be inputted *X*-wise if *Id_In*=0. In this case the first element corresponds to *I*=1, *j*=2. The second element corresponds to *I*=2, *j*=1, and so on. Here *I* is the cell number in *X*-direction, and *J* is the cell number in *Y*-direction This is the recommended option. The user can see the simulated conductivity anomaly in the data description file (assuming that the *X*-axis is directed from left to right). For *Ind_In*=1, the conductivity array is interpreted as being typed in *Y*-wise.

5.1.1. Sample model description file of SLPROG

There are two examples of the model data: 3d-sexpl.dat and 3d-dexpl.dat. First model is excited by a plane wave; second one is excited by electric dipoles. Below 3d-dexpl.dat is shown with some commentaries.

```
A line identifying the model or task       This line is be passed to the output files
Comment # 1                                This line is not passed to the output files
Comment # 2                                This line is not passed to the output files
                                           This line is not passed to the output files
Comment # N                                This line is not passed to the output files
&Gen_Description
 ILn=16       JLn=32        Dx=20e3              Dy=20e3
 NPoint=1
 Point(01)='  Moscow        ',  XPnt(01)=007.,   Ypnt(01)=010.
&END

&Embed_Structure    NLAYER=03
                Dz(00)=00.d+3,      Sigma(00)=0.00d00
                Dz(01)=50.d+3,      Sigma(01)=0.33d-3
                Dz(02)=50.d+3,      Sigma(02)=0.33d-2
                Dz(03)=00.d+3,      Sigma(03)=0.33d00
&END

&Inhom_Cond_Layer
 Ind_In=0,    Dz0=1d3
 Smlt=80.     Snrm=10.              Smin=1.              Smax=100.
 NS_Dpl=2,   aJSMlt=1.
 IS_Dpl(01)=4,JS_Dpl(01)=6,Re_Px(01)=1.,Ai_Px(01)=0.,Re_Py(01)=0.,Ai_Py(01)=0.
 IS_Dpl(02)=4,JS_Dpl(02)=7,Re_Px(02)=1.,Ai_Px(02)=0.,Re_Py(02)=0.,Ai_Py(02)=0.
&END

 10. 10. 10. 10. 10. 32. 39. 41. 39. 32. 10. 10. 10. 10. 10. 10.
 10. 10. 10. 10. 38. 47. 52. 54. 52. 47. 38. 10. 10. 10. 10. 10.
 10. 10. 10. 37. 50. 57. 61. 62. 61. 57. 50. 37. 10. 10. 10. 10.
 10. 10. 29. 49. 59. 65. 68. 70. 68. 65. 59. 49. 29. 10. 10. 10.
 10. 10. 43. 57. 66. 71. 74. 75. 74. 71. 66. 57. 43. 10. 10. 10.
 10. 29. 52. 64. 72. 77. 79. 80. 79. 77. 72. 64. 52. 29. 10. 10.
 10. 41. 59. 69. 76. 81. 84. 84. 84. 81. 76. 69. 59. 41. 10. 10.
 10. 49. 64. 74. 80. 85. 87. 88. 87. 85. 80. 74. 64. 49. 10. 10.
 29. 55. 68. 77. 84. 88. 90. 91. 90. 88. 84. 77. 68. 55. 29. 10.
 38. 59. 72. 80. 86. 90. 93. 93. 93. 90. 86. 80. 72. 59. 38. 10.
 43. 62. 74. 83. 89. 92. 95. 95. 95. 92. 89. 83. 74. 62. 43. 10.
 47. 65. 77. 85. 90. 94. 96. 97. 96. 94. 90. 85. 77. 65. 47. 10.
 50. 67. 78. 86. 92. 95. 98. 98. 98. 95. 92. 86. 78. 67. 50. 10.
 52. 68. 79. 87. 93. 96. 99. 99. 99. 96. 93. 87. 79. 68. 52. 10.
 53. 69. 80. 88. 93. 97. 99.100. 99. 97. 93. 88. 80. 69. 53. 10.
 54. 70. 80. 88. 93. 97. 99.100. 99. 97. 93. 88. 80. 70. 54. 10.
 53. 69. 80. 88. 93. 97. 99.100. 99. 97. 93. 88. 80. 69. 53. 10.
 52. 68. 79. 87. 93. 96. 99. 99. 99. 96. 93. 87. 79. 68. 52. 10.
 50. 67. 78. 86. 92. 95. 98. 98. 98. 95. 92. 86. 78. 67. 50. 10.
 47. 65. 77. 85. 90. 94. 96. 97. 96. 94. 90. 85. 77. 65. 47. 10.
 43. 62. 74. 83. 89. 92. 95. 95. 95. 92. 89. 83. 74. 62. 43. 10.
 38. 59. 72. 80. 86. 90. 93. 93. 93. 90. 86. 80. 72. 59. 38. 10.
 29. 55. 68. 77. 84. 88. 90. 91. 90. 88. 84. 77. 68. 55. 29. 10.
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10. 49. 64. 74. 80. 85. 87. 88. 87. 85. 80. 74. 64. 49. 10. 10.
10. 41. 59. 69. 76. 81. 84. 84. 84. 81. 76. 69. 59. 41. 10. 10.
10. 29. 52. 64. 72. 77. 79. 80. 79. 77. 72. 64. 52. 29. 10. 10.
10. 10. 43. 57. 66. 71. 74. 75. 74. 71. 66. 57. 43. 10. 10. 10.
10. 10. 29. 49. 59. 65. 68. 70. 68. 65. 59. 49. 29. 10. 10. 10.
10. 10. 10. 37. 50. 57. 61. 62. 61. 57. 50. 37. 10. 10. 10. 10.
10. 10. 10. 10. 38. 47. 52. 54. 52. 47. 38. 10. 10. 10. 10. 10.
10. 10. 10. 10. 10. 32. 39. 41. 39. 32. 10. 10. 10. 10. 10. 10.
10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10.

5.2. Executing SLPROG

In the interactive mode, typing SLPROG.EXE starts the code execution. The code will request to specify the size of the numerical grid, names of the necessary files, the period, polarization, etc. The description of the dialogue is given below. (The prompts outputted by the program are shown in red). Alternatively, the user can prepare a command response file (three sample files, i.e *sl_taskx, sl_tasky,* and *sl_45deg* for plane wave model and *sld_task* for dipoles) and start the program by typing SLPROG.EXE < sl_taskx, etc.

At the beginning the code will output the line

<< NX, NY :

N_x and N_y specify the number of grid intervals in *X* and *Y*-directions, respectively. On input these two integer numbers should be separated by one or several spaces or a coma and followed by the *CR*. N_x should not be exceeded by parameter *ILn* specified in the *Gen_Description* namelist block of the model description file. Similarly, N_y should be larger than or equal to *JLn*.

Each of the parameters N_x and N_y should be equal 2^n3^m, where *n* and *m* are the integer numbers. This restriction is due to the use of a FFT (Fast Fourier Transform) algorithm for the convolution carried out in eq. (4).

The overall size of the horizontal numerical ($N_x N_y$) grid in this version of the code is restricted by the 256×256 cells.

Another limitation is caused by the use of the FHT (Fast Hankel transform). A filter with a

$$\frac{\sqrt{N_x^2 D_x^2 + N_y^2 D_y^2}}{\min [D_x, D_y]} < 100\sqrt{10} \cong 316 \qquad (8)$$

dynamic range of 2.5 decades is used to calculate the kernel of integral equation (4). A condition should be satisfied.

<< PRNTFN :

The user should proved the name of the file for the non-graphical output of the results. The name can include the path if the user wishes to store this file in a different directory. The code understands symbolic like ...\ for the parent directory. The output can be suppressed by inputting

DUMMY for the name of the file. Any abbreviation of word TERMINAL (i.e. T, TERM, etc,) instructs the code to redirect the output to the screen.

<< DATAFN :

The user should specify the name of the model description file. The same conventions as for the output file are applied.

<< WORKFN :

This file represents the output binary file. The file stores full information on the model, numerical grid, and other parameters of the computation, as well as the calculated field. This file is used by the processing programs *SLDIAG* and/or *SLFIELD*.

<< GKRNFN :

The file is used to store the kernel of the integral equation (4), the magnetic part of the Green function, and intermediate results of computations. The file may be overwritten on each run of the code.

<< NBSTEP [-1,0] :

On the first run for a particular period, the user has to enter 0. On a second run for the same period (the polarization may be different) the user may enter -1, provided the same *gkrnfn* file is used to store the kernel.

<< EPS0, IT_MAX :

The user has to specify the required accuracy of computations and a maximum number of iterations he or she is willing to commit to achieving this accuracy (free format). The iterations are stropped after achieving the required accuracy or specified number of iterations, whatever comes first.

The parameter *EPS0* represents an estimate of the error introduced by the truncation of the convergent sequence of approximations. The error is estimates as

$$\frac{Anorm}{Snorm}\quad\frac{1}{1-1/R}\quad , \tag{9}$$

where *Anorm* and *Snorm* represent the norm of the increment and the norm of solution achieved at the current iteration. For the *k*-th iteration *Anorm* is $\|\mathbf{j}_k^{S,a}-\mathbf{j}_{k-1}^{S,a}\|$, *Snorm* equals $\|\mathbf{j}_k^{S,a}\|$. The norms of the vector field **U** is calculated as

$$\sqrt{\frac{D_x D_y}{S_0}\sum_{i\,1}^{N_x}\sum_{j\,1}^{N_y}\left|\mathbf{j}_{i,j}^{S,a}\right|^2}\quad , \tag{10}$$

where indexes i and j are used to number the cells of the numerical grid. Parameter R equals

$$\frac{\left\| \mathbf{j}^{S,a}_{k\,1} - \mathbf{j}^{S,a}_{k\,2} \right\|}{\left\| \mathbf{j}^{S,a}_{k} - \mathbf{j}^{S,a}_{k} \right\|} \qquad (11)$$

the ratio of two consecutive increments of the solution. To achieve a truncation error smaller that 0.1% the user has to use *EPS0*= 0.001.

<< SBL (intl/extl) and
SYB (locl/rgnl/edip) :

The user has to enter a character constant consisting of 8 characters. The first four characters specify the initial approximation in the iterative process. If the user enters *intl* in the first half of the character constant (the code is not sensitive to the case of the character constants), the iterations start with the null initial value for the solution. Alternatively, if *extl* is used, the electromagnetic field calculated at some period, can be used as an initial approximation for computations at a close period. The corresponding information is read from the file specified at the GKRNFN: line.

The last four characters of the constant specify the type of the external source that generates the field. If *locl* is entered, the plain wave with polarization specified is assumed; the normal field (i.e. the electromagnetic field that would be induced in the model that does not include the anomaly) is calculated by the code. If *rgnl* is specified, it is assumed that the normal structure and field has already been specified and written into corresponding sectors of the main output file. This mode of execution allows the user to detail the results of a previous computation. In particular, the 3-D anomaly of interest can be placed on the background of a 2-D model (see Singer & Fainberg, Geophys. J. Int., 1999). In case of *edip*, it is assumed that a set of electrical dipoles placed into the heterogeneous layer is used to generate the field.

<< Period :

The user should specify the period of the excitation in seconds.

<< Polariz/Angle :

The prompt is outputted only for the plane wave source. The user can enter characters *X* or *Y* if the normal electric field is polarized either along the *OX* or *OY* axis, respectively. The user can also enter a number in the range from 0 to 360 to specify the angle (in degrees) between the normal electric field and the *OX*-axis.

6. Using SLFIELD program

This program prints out results of calculations into an ASCII file that may be used for analysis or graphical presentation. The execution can be initiated in the interactive mode by typing SLFIELD.EXE. The code will request to specify the names of the necessary files and parameters, which are clear from the text. Alternatively, the user can prepare a command response file (i.e. *sl_fld1, sl_fld2,* or *sl_fld45*) and start the program by typing
SLFIELD.EXE < "response_file_name".

6.1. Data description file for SLFIELD program

This code allows the user to read the binary work files, which serve as the main output of the modeling code. In the interactive mode, typing SLFIELD.EXE starts the code execution

At the beginning the code will output the line

<< Enter WorkFileName [.wkf]:

The user should specify the name of the output binary file created by SLPROG.EXE. If no extension is provided, the code will be looking for a file with "*wkf*" in the extension field.

The next prompt outputted by the code, i.e.

<< Specify Output Option :

ask the user to specify if he wants the output to be suppressed (enter 0), printed out in the form of a set of digital maps (enter 1), or put into an ASCII output file (enter 2).

On the next step, the code asks to define the output file by outputting the prompt

<< Enter FnPrnt [.prn] :

is the input at previous prompt was 1, or

<< Enter FnGraf [.dat]:

is the input to previous prompt was 2. In both cases, the default extension of the file is indicated at the end of the prompt. If the output is in a digital map format, the code will ask the user to define the pre-processing that has to be carried out before printing out the different components of the data. This done by outputting the prompt

<< Scale S,Et,Jz,Ht,Hz ? :

at which the user is expected to enter 5 integer numbers (in a free format). The meaning of these numbers is briefly described before the prompt. If we denote the numbers as *Is*, *Ie*, *Ij*, *Ih*, and *Iz*, then these numbers will indicate the scaling procedure that must be applied to the S, $\mathbf{E}_\tau$, J_z, $\mathbf{H}_\tau$, and H_z, respectively. The scaling procedures are defined in the following table

Scaling Parameter Value	**Transformation**
0, 1, 2, ...	$A_{out} = \sqrt[2k+1]{A}$.
-1	$A_{out} = \lg \lvert A \rvert$;
-2	$A_{out} = \text{sign}(A) \cdot \lg(A_{max}/\lvert A \rvert)$

where A represents the value of the parameter and A_{out} is the value that is printed out.

The last two of the following prompts :

<< Specify Ouput Area. Enter Imin=Imax or Jmin=Jmax for a profile.

<< Enter Imin, Imax :

<< Enter Jmin, Jmax :

ask the user to specify the rectangular area, for which the data are requested to be outputted.

The next prompt is present only if the user made a request for the ASCII output.

<< Specify Coordinates of the Left Upper Corner of the Numerical Grid.

<< Numerical Grid Cell Centers : x(i)=x0+(i-0.5)*Dx, y(j)=y0+(j-0.5)*Dy

It allows the code to define the coordinates of the sites for which the output will be produced. The second line of the prompt describes the definition used in the code.

7. Using SLDIAG

When *SLPROG* is used to calculate a response of a model for two independent polarizations of the plane wave source (the same period), the results of the computation are outputted into two binary output files. These files provide input information for *SLDIAG*, which in its term calculates impedance tensors, and diagrams of the apparent resistivity, phase, and local or remote reference magnetic parameters. The code execution is controlled by the information provide in the file named *sl_diag* and also a file, which specified the site location and is referred to in *sl_diag*.

The control file *sl_diag* consists of 5 records. The records are described in the following table.

Record	Meaning	Examples	Comments
1	Name of the output file for printing out the results	diagram.prn	
2	Name of the binary output file containing results of the numerical simulation of the electromagnetic field for the first polarization of the plane wave source	xpol-out.wrk	
3	Name of the binary output file containing results of the numerical simulation of the electromagnetic field for the second polarization of the plane wave source	ypol-out.wrk	
4	An 8-digit integer number. The first 2 digits (from the left) are not used and can be set to 0. The remaining 6 digits, which we denote as I_FLDn, I_FLD, I_ZIJ, I_V3I, I0VIJ, I0V3I, can accept values of 0 or 1 . Each of these digits instructs the code to skip or output the normal electromagnetic field, the total	00111111	If a switch is set to 1, the code calculates and outputs corresponding parameter. The I_ZIJ switch can also be set to 2. In this case, the code prints out a polar diagram of the apparent resistivity instead of the

	electromagnetic field, components of the impedance tensor, tippers, remote reference magnetic parameters, and remote reference tippers, respectively.		impedance amplitude.
5	The name of the input file that specifies the cells of the numerical grid for which the above parameters must be calculated	dg-expl.dat	

A special file (*dg-expl.dat* in the above example) defines the coordinates of the site for which the calculation and output have been requested. The coordinates represent numbers of the corresponding cells of the numerical grid used in simulation. The input is organized in the namelist directed format. The *namelist* block name is *Output_Points*. The code allows for two types of the site definitions. First the sites can be listed in a random order. Second, a request can be made to process all the cells of the numerical grid from a rectangular area. It specifies variables listed in the following table.

Variable	**Meaning**	**Limitations**	**Comments**
NDiag	Number of randomly distributes sites. At list one such site must be indicated if remote reference is requested	≤1024	
PDg(i)	A char*20 variable indicating the "name" of the *i*-th randomly distributed site	i:=1,2,..., NDiag	
IDg(i)	Integer variable defining the *x*-coordinate of the *i*-th randomly distributed site		
JDg(i)	Integer variable defining the *y*-coordinate of the *i*-th randomly distributed site		
NBase	The number of the site in the set of randomly distributed sites that must be used a remote reference base		
ID0	The smallest of the *i*-coordinates of the sites from the rectangular area		
IDl	The largest of the *i*-coordinates of the sites from the rectangular area.		.
IDs	The distance (in grid spacing) between the *i*-coordinates of the sites from the rectangular area		
JD0	The smallest of the *j*-coordinates of the sites from the rectangular area		
JDl	The largest of the *j*-coordinates of the sites from the rectangular area		
JDs	The distance (in grid spacing) between the *j*-coordinates of the sites from the rectangular area		

When polar diagrams of the impedance, apparent resistivity, phase, or magnetic parameters are calculated, the corresponding parameter is calculated for angular positions separated by 15° starting from the *X*-axis and proceeding in clockwise direction.

An example of the input file defining the sites is shown below.

```
&OutPut_Points      NDiag=5        NBase=5
      PDg(00001)='Point 00001 Text Id ', IDg(00001)=16,   JDg(00001)=19
      PDg(00002)='Point 00002 Text Id ', IDg(00002)=17,   JDg(00002)=20
      PDg(00003)='Point 00003 Text Id ', IDg(00003)=18,   JDg(00003)=21
      PDg(00004)='Point 00004 Text Id ', IDg(00004)=19,   JDg(00004)=20
      PDg(00005)='Point 00005 Text Id ', IDg(00005)=05,   JDg(00005)=07
      ID0=25,   IDl=35,   IDs=1,   JD0=15,   JDl=25,   JDs=1
&END
```

8. Using MTCURVES program

The program combines calculation of the electromagnetic fields induced by a plane wave source at a give set of periods and calculation of the polar diagrams, apparent resistivity and phase curves. Typing MTCURVES.EXE starts the program in the interactive mode. When started the code outputs a prompt

```
<<  Enter 3D_mesh NX, NY :
```

which expect definition of the grid to be used for the numerical simulation in the same for and with the same restrictions as described in section 5.2. At the next prompt

```
<<  Enter DATAFN    [.dat]  :
```

the code expect the user to specify the name of the file that contains description of the model in the same format as for *SLPROG* (section 5.2). For instance, *3d-sexpl.dat* is a valid reply
The third prompt

```
<<  Enter PERIODS    [.dat] :
```

asks the user to specify the name of the file that contains the definition of the periods for which the simulation must be carried out. The first record of the file defined the total number of the periods, which cannot exceed 100. In the next record the user should list the corresponding periods in the free format.
The fourth prompt

```
<< Enter PointsFn    [.dat]  :
```

At this point the code expects the name of the file specifying locations of the sites in the same format as used by *SLDIAG* and explained in section 7. File *dg-expl.dat* can be used as an example.
Finally, the fifth prompt

```
<< Enter MT-RESFn   [.dat]  :
```

request the user to define the output file for storing results of the computations.

Alternatively, the user can prepare a response file (i.e. *MT-task*) and start the job by typing MT-curves < “response_file_name”.

10. References

Fainberg E. B. & Zinger, B. Sh., 1980. Electromagnetic induction in a non-uniform spherical model of the Earth, *Ann. Geophys*., **36**, 127-134.

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Singer, B. Sh., 1995. Method for solution of Maxwell's equations in non-uniform media, *Geohys. J. Int.,* **120**, 590-598.

Singer B.Sh., Fainberg E.B., 1995. Generalization of the iterative dissipative method for modeling electromagnetic fields in non-uniform media with displacement currents. *Applied Geophysics*, **34**, 41-46.

11. Contact Information

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