C S I N V
Documentation

Zonge Data Processing

One-dimensional CSAMT Inversion

Version 5.00

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Introduction

CSINV inverts CSAMT or AMT frequency-sounding data into a layered-earth model. For controlled-source soundings, its calculations include the effects of finite transmitter-receiver separation and three-dimensional source fields. CSINV computes accurate impedances for near-field, transition, and far-field controlled-source data. Apparent resistivity and impedance phase data from natural-source or controlled-source scalar, vector or tensor survey configurations may be inverted.

CSINV has two inversion methods, an iterative inversion algorithm that minimizes the root-mean-square difference between observed and calculated data and a controlled random search inversion that minimizes the average absolute deviation between observed and calculated data. Both the iterative inversion and the controlled random search test random variations to the starting model and end up with a group of inverted models. Model parameter errors are estimated from variation between inverted models that fit the data nearly as well as the best result. Neither algorithm changes the number of layers during inversion. Starting models can be automatically generated by CSINV or can be entered or edited manually. If geologic control limits the thickness or resistivity of a particular unit, it is possible to freeze selected model parameters so that they do not change during inversion.

CSINV includes two program modules, CSINV.EXE and RCSINV.EXE. CSINV.EXE is a shell program that provides utilities for observed data input, review of inversion results, and editing of survey and model parameters. For review of inversion results, CSINV can create log-log sounding-curve plots of observed and calculated data. Model parameters are included as plot annotation. Plots are viewed on the screen and can be saved in HPGL files for later hardcopy output. RCSINV.EXE is the core inversion program that can either be started from within CSINV.EXE when working with soundings from a single line or run independently in batch-file mode to invert data from multiple lines. RCSINV.EXE reads file names from its command line, allowing batch file operation with a sequence of input files.

Information about CSINV may be obtained by writing:

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Installation

Minimum Hardware Configuration

The minimum hardware configuration needed to operate CSINV v5.00 includes:

1. A computer running MS-DOS with 2MB of RAM and a hard disk.
2. A 80386 or higher CPU chip with a math coprocessor.
3. A VGA or SVGA graphics.

Installation procedure

CSINV can be installed on one computer at a time. Backup copies of the installed files can be made freely, but they will function only on the computer on which CSINV is installed. CSINV can be recalled from one computer for installation on another. CSINV refers to both CSINV.EXE and RCSINV.EXE.

To install CSINV, place the distribution disk in a floppy disk drive and log on to that drive. Then type "INSTALL" and press Enter. You will see a screen title showing the name of the program and version number. Below the title block a set of highlighted fields specify the source drive you are installing CSINV from, usually floppy drive A: or B: and the target hard drive letter and path in which CSINV should be installed. It is usually easiest to put CSINV programs in an existing directory that is already on the MS-DOS path. You can move from field to field on the INSTALL program screen by pressing the Tab key to move forward and Shift+Tab to move backward. You can cycle through disk-drives by pressing the space bar or left and right arrow keys. Edit the drive letters and target path to suite your computer's configuration. When you press F10, INSTALL will verify your edited changes and will extract files from #CSINV.EXE to your target directory.

After installation, the C:\CSINV subdirectory should have the following files:

<u>CSINV program modules:</u>
CSINV.EXE - shell program for data input, inversion review and model editing.
RCSINV.EXE - core 1D CSAMT/AMT inversion program.
CSIREG.EXE - registration program
LF90.EER - fortran error messages
GRAPHICS.INI - screen graphics configuration.
GRAPHICS.CHR - graphics font file.

<u>Sample observed-data files:</u>
CSDEMO.MDE - line information and data processing control file.
CSDEMO.STN - station locations.
CSDEMO.AVG - observed CSAMT data.

<u>Sample CSINV inversion files:</u>
CSDEMO.CSI - survey parameter and inversion control.
CSDEMO.CSD - observed and calculated data.
CSDEMO.M1D - layered-model parameters.

Graphics Configuration

GRAPHICS.INI and GRAPHICS.CHR must be somewhere on the MS-DOS path. GRAPHICS.INI holds graphics configuration information. If the line “DISPLAY = 13” is present in GRAPHICS.INI, CSINV will attempt to use SVGA graphics. CSINV will default to VGA graphics, if it does not detect SVGA capabilities or if “DISPLAY = 13” is not present in GRAPHICS.INI. On some portable computers with a VGA screen and external-monitor SVGA capabilities, “DISPLAY = 13” has to be deleted from GRAPHICS.INI for normal VGA operation with the built in VGA screen. If you don’t see a coherent image on your portable’s screen when you attempt to plot a sounding curve with CSINV, delete the line “DISPLAY = 13” from GRAPHICS.INI.

CSINV plots may be saved in HPGL plot files which are given the extension .X??. These HPGL files can be plotted on a HP-compatible pen plotter or a utility program, such as FPLOT, can be used to rasterize them for printer output.

Recall procedure

To recall CSINV back to the distribution disk, place the distribution disk in a floppy-disk drive and log on to that drive, then type "RECALL" and press Enter. RECALL displays a screen with fields for the drive and directory where CSINV is installed and for the letter of the floppy drive holding the distribution disk. Edit the source drive and path to match your computer’s configuration and then press F10 to start the RECALL procedure. RECALL erases CSINV.EXE, RCSINV.EXE, CSINV.LOG and CSDEMO.* from the “recall from” directory. It leaves behind GRAPHICS.INI and GRAPHICS.CHR, two graphics configuration files that may be used by other programs.

Program Use

CSINV reads observed data from Zonge-format *.AVG or *.Z files. It will also read a matching .MDE file, if it is present, to get line annotation, station number shifting and scaling, and information about transmitter length, bearing and location. Station locations are read from a *.STN file, if it is present. CSINV writes survey parameter and inversion control information into files with the extension *.CSI. It puts observed and calculated apparent resistivity and impedance phase data into *.CSD files and layered model parameters into *.M1D files. CSINV also saves a copy of screen output to a log file named CSINV.LOG. All of these file formats are in ASCII text and may be viewed and edited with a text editor. File formats are described in an appendix to this document.

CSINV is started by typing “CSINV *filename*” where *filename* could be any CSAMT *.AVG or *.Z file holding observed data, or the name of an existing set of CSINV inversion files. CSINV assumes the extension “.CSI” if *filename* is entered without an extension. Once it is running, CSINV presents a series of menus to allow selection of different utility functions. A menu choice can be selected by moving up and down the menu with the arrow keys and pressing Enter when the appropriate choice is highlighted. Editing of survey and model parameters is done in forms. You can move from field to field in a form using arrow or Tab and Shift+Tab keys, changing the values in each field as required. Pressing F10 verifies the entries that you have made and pressing ESC allows you to exit a particular menu or form.

Although there is no set procedure, the inversion of CSAMT or AMT data usually follows a fairly linear path.

Typical action sequence within CSINV

Type "CSINV CSDEMO.AVG" to start CSINV.

Choose "Create *.CSI and *.CSD files." to read data from CSDEMO.MDE, CSDEMO.AVG and CSDEMO.STN file and to write CSDEMO.CSI and CSDEMO.CSD.

Choose "Display or editing model parameters." to check data quality and to verify survey parameters. Correct transmitter location and orientation information is important in controlled-source surveys. Mode keywords TxCX and TxCY can be used in *.MDE files to specify the transmitter antenna’s center location, TxLen its length and TxBrg for its orientation. Station coordinates are specified in *.STN files.

Choose "Iterative inversion." to run RCSINV.EXE and generate layered models. RCSINV inverts each station in turn between the StnFirst and StnLast specified in *.CSI. RCSINV creates a *.M1D file if one does not already exist. If a *.M1D does exist, RCSINV scans it for starting model parameters. If there is no starting model present for a particular station, RCSINV will create one using a far-field, direct inversion algorithm. After finishing a single-station inversion, RSCSINV updates the *.M1D and *.CSD files and goes on to the next station.

Choose "Display and edit model parameters" and then “Display log-log sounding curve” to check the match between observed and calculated data values. By pressing F10 when the plot is on screen, copies of the log-log plots can be saved as HPGL files for later plotting on a printer or pen plotter. Model layer parameters can be edited to vary the starting model in “Edit layer parameters”. The number of layers can be changed or layer depths or resistivities can be fixed to match known geologic control. StnFirst and StnLast are initially set to the first and last station on the line. For inversion of just one sounding, they can be reset to bracket a particular station in “Display and edit model parameters” + “Select new station”, followed by a return to the main menu using the ESC key and selection of “Iterative inversion.” to rerun the inversion.

“Iterative inversion” minimizes the root-mean-square (RMS) difference between observed and calculated data. “Controlled-random-search inversion” minimizes the mean absolute difference between observed and calculated data and is less sensitive to noisy outlier data values. However, a controlled random search is much slower than an iterative inversion.

A way to cope with slow procedures like a controlled random search is to run them from batch files while you are working on some other task. When working with data from one line, RCSINV.EXE is usually run from within CSINV.EXE. However, CSINV.EXE can be used to prepare *.CSI and *.CSD files for multiple lines, followed by inversion using multiple calls to RCSINV.EXE from a batch file. The batch file or MS-DOS command “RCSINV *filename*” will run an iterative inversion, i.e. RCSINV will read *filename*.CSI and *filename*.CSD and will create or update *filename*.M1D. The batch file command “RCSINV *filename* -inv=CRS” will run a controlled-random search inversion on soundings in *filename*.CSI and *filename*.CSD.

An outline detailing the actions performed by the CSINV program group follows. Each segment of the outline describes a possible program action, including a summary of the action's purpose, the screen's appearance during the action, and the meaning of model parameters involved in the action.

CSINV CSDEMO.AVG

Typing “CSINV CSDEMO.AVG” initiates execution of program CSINV.EXE. After CSINV is running and has verified that the file you have named is present, it presents a menu of choices.

Main CSINV Menu

```
CSINV - CSAMT 1D Inversion
Version 5.00e
Zonge Engineering and Research

1) Enter an input-file name

2) Create *.CSI and *.CSD files.

3) Display or edit model parameters.

4) Iterative inversion of all data.

5) Controlled-random-search inversion.

6) Exit program (=ESC key).

Current model file: CSDEMO.AVG
```

Choice 1) Enter an input file name.

Menu option 1 allows a user to enter or modify the name of an model-input file, an *.AVG file or *.Z file.

Input screen for menu option 1:

```
Enter *.AVG, *.Z or *.CSI input-file name.

Input-file name:CSDEMO.CSI
```

```
Press ESC to return to main menu.
```

A file name can be entered by typing a name and then pressing Enter. Names must have the extension ".AVG", ".Z" or ".CSI". File names may include a directory path.

Choice 2) Create *.CSI and *.CSD files.

Menu option 2 allows the creation of a model-input file from scalar CSAMT data held in *.AVG or *.Z files. The program will read information from a *.MDE file, if is present. *.MDE files contain general information, such as project name, line number, transmitter antenna size, location and orientation and possibly station number scaling and shifting. If a *.STN file is present, station location information is read. *.STN files hold station number, grid E, grid N and elevation coordinates. If *.AVG file station numbers are shifted and scaled by *.MDE file parameters, then *.STN numbers should already be in the scaled system. *.MDE and *.STN files are optional, but a valid CSAMT *.Z file or *.AVG file is required. *.Z files must hold both apparent resistivity and phase data blocks. AMTAVG-format *.AVG files are the preferred source of observed data, since they include estimates of measurement error along with columns of apparent resistivity and impedance phase. File formats and content are described in Appendix A.

Option 2 scans a CSAMT *.Z or *.AVG file and collects apparent resistivity and impedance phase data. If a column of static-corrected data is present in an *.AVG file, CSINV will give you the option of using either uncorrected or static-corrected apparent resistivities. Measurement errors are read from *.AVG files and estimated for *.Z files. CSINV sorts the data by station and frequency and averages duplicate readings, then observed data and measurement error values are written to a *.CSD file.

A *.Z or *.AVG file usually contains data for a line of soundings. You are asked to pick a first and last station number for running a sequence of inversions and a single station number for plotting. Other stations may be selected later using “Display or edit model parameters”: ”Select new station”.

Choice 2) Create *.CSI and *.CSD files (continued).

Source and receiver parameters are set to default values. Information from *.MDE and *.STN files is used to set defaults, if the files are available. An interactive worksheet is displayed, so that default survey parameter values may be reviewed and edited. The same worksheet can be used later though the “Display or edit model parameters”:”Edit survey parameters” option. A good review of source and receiver parameters is necessary, since correct relative coordinates are necessary for accurate inversion of controlled-source data.

Choice 3) Display or edit model parameters.

Main menu option 3 allows you to display data and inversion results or to edit model parameters.

```
        CSINV - Scalar CSAMT 1D Inversion
          Zonge Engineering and Research
              3322 E Fort Lowell Road
              Tucson, Arizona   85716

     1) Display log-log sounding curve.

     2) Select new station.

     3) Edit layer parameters.

     4) Edit survey parameters.

     5) Save parameter changes.

     6) Return to main menu (=ESC key).

              Current model file: CSDEMO.CSI
```

Choice 3:1) Display or edit model parameters: Display log-log sounding curve.

A log-log sounding curve can be plotted on the screen. Observed apparent resistivities are indicated by vertical bars with lengths proportional to estimated resistivity error. Impedance phase values are converted to slopes, and are indicated by sloping line segments. Calculated apparent resistivities are shown by a continuous sounding curve. Calculated impedance phase values are used to fix the slope of the continuous sounding curve at each observation frequency. Current model parameters are listed in the upper right-hand corner of the plot. Both layer thicknesses and interface depths are listed. Plot annotation includes statistics showing the RMS difference between observed and calculated data and APRE. “Average predicted residual error” is useful for deciding the correct number of layers to use in the model (Hohmann and Raiche, 1988, p490). APRE should reach a minimum when you have enough layers to fit the data reasonably well, but not so many layers so as to introduce unnecessary degrees of freedom.

Pressing F10 saves the plot in a HPGL file, pressing ESC returns you to the “Display or edit model parameters” menu.

Choice 3:2) Display or edit model parameters: Select new station.

Input screen for selecting station numbers.

```
              Set Station Number Variables

  Current Station    2750. for plotting and editing.

First station    2750. to Last Station     4300. for inversion.

First Station    2750. to Last Station     4300. in line.
```

```
Tab or Shift+Tab = field to field, F10 = confirm, ESC = return to menu.
```

Both arrow and tab keys can be used to move from field to field. Current station number value selects one station for plotting and editing. First and last station number entries control the range of stations inverted using “Iterative inversion” or “Controlled-random-search inversion” choices from the main menu.

Choice 3:3) Display or edit model parameters: Edit layer parameters.

Input screen for editing layered-earth model parameters.

```
                    Edit Layer Parameters

       Layer       Resistivity     Layer     Thickness
    Resistivity       Error      Thickness     Error
      49.1o-m          50%          115m         50%
       7.9o-m          50%          230m         50%
     189.0o-m          50%             m           %
          o-m            %             m           %
          o-m            %             m           %
          o-m            %             m           %
          o-m            %

Use for starting model from      2750. to      2750.
```

```
Move from field to field with arrow ow tab keys.
Press F10 to confirm changes.
Press ESC key to return to menu.
```

Layer resistivities are entered in ohmmeters. Layer thicknesses are entered in meters or feet. (The choice of distance units is available in the "Edit source and receiver parameters" screen.)

Choice 3:3) Display or edit model parameters: Edit layer parameters (continued).

Estimated errors of layer-parameter values are entered in percent. A parameter with zero error will not be changed during inversion. Conversely, entering a large percentage error will allow larger changes during inversion. A single set of layer parameters can be used as a starting model for a range of stations by changing station number limits at the bottom of the screen.

Pressing F10 updates parameter values, while pressing ESC returns the program to the editing menu.

Choice 3:4) Display or edit model parameters: Edit survey parameters.

Input screen for editing survey parameters.

```
                        Edit Survey Parameters

Descriptive Text
CSINV  Line 4850N
for Zonge Engineering
Data from CSDEMO.AVG


Distance units m                       Survey type Scalar

Transmitter
Length      Azimuth (grid east,grid north)   Tx-Rx distance
1500         90   (    3525.0,   -1150.0)      6049.8
                  (          ,           )


  Rx Stn      Azimuth (grid east,grid north,elevation)
    2750.        90   (   2750.0,    4850.0,      0.0)


Maximum # of Inversion restarts  8    Starting Model Weight  1.00
```

```
Tab or Shift+Tab = field to field, F10 = confirm, ESC = return to menu.
```

Locations and distances are specified in meters or feet. Distance units can be selected by pressing the space bar while the cursor is on the distance-units field. Survey type can be cycled through scalar, vector, tensor or natural in the same way. Transmitter length, orientation and location can be corrected interactively, but the only way to change station locations is to edit the *.STN file. The number of inversion restarts can range from 0 to 32. If the number of restarts is 0, RCSINV calculates apparent resistivities and phase for the current model and does not attempt to adjust model parameters. Values greater than 1 generate multiple inversion restarts, improving inversion results and allowing calculation of model-parameter-error statistics.

Pressing F10 updates parameter values, while pressing ESC returns the program to the editing menu.

Choice 3:5) Display or edit model parameters: Save parameter changes.

Updates variables in current *.CSI and *.M1D files. Modified parameter values are not saved in the disk file until this option is chosen.

Choice 3:6) Display or edit model parameters: Return to main menu (=ESC key).

Pressing 6 or ESC returns to main menu in CSINV.EXE.

Choice 4) Iterative inversion.

Menu option 4 passes the current input-file name to RCSINV.EXE. RCSINV adjusts layer resistivities and thicknesses to reduce the difference between observed and calculated apparent resistivity and impedance phase. RCSINV uses a complete forward-model solution for electromagnetic fields generated by a grounded electric bipole transmitter antenna on the surface of a layered earth to calculated controlled-source apparent resistivity and impedance phase values. RCSINV inverts each station in turn between StnFirst and StnLast. If a model already exists in *.M1D for the current station, RCSINV uses it as a starting model, otherwise it uses a far-field direct inversion algorithm to generate its own starting model. RCSINV restarts its inversion up to the restart limit set in “Display or edit model parameters”: “Edit survey parameters” screen. It saves results from each restart and uses variation between all inverted models that are close to the best result to calculate standard deviations of layer resistivity and thickness. Increasing the number of restarts improves model-parameter-error statistics and makes RCSINV’s search more exhaustive. RCSINV updates *.M1D and *.CSD files after finishing its inversions for each station.

Choice 5) Controlled-random-search inversion.

Choosing a controlled random search passes the current input-file name to RCSINV along with the command line argument “-inv=crs”. A controlled random search explores a greater range of resistivities and thickness than an iterative inversion, but is not nearly so efficient at finding good solutions. RCSINV’s search starts with random models uniformly distributed within +/- 2 standard deviations of the starting model, where one standard deviation is equal to the percent error set in the “Edit layer parameters” option. RCSINV’s controlled-random-search option minimizes the absolute value of observed minus calculated data rather than the squared difference, so it is less sensitive to outlier data values than is the iterative inversion. A controlled random search improves your chances of finding the complete range of reasonably good solutions and it is less sensitive to outlier data points than the iterative inversion, but it is relatively slow.

Choice 6) Exit program (=ESC key).

Pressing 6 or ESC stops CSINV and returns control to MS-DOS.

Inversion Example

A set of sample input and output files is included on the CSINV distribution disks. CSDEMO.* example serve both to illustrate program use and to verify that the programs are installed correctly. The following section includes listings of CSDEMO.CSI, CSDEMO.CSD and CSDEMO.M1D, as they are created and updated with each step of the inversion procedure. Listings of screen output for each major step are also included.

Both CSINV and RCSINV save a copy of screen output in CSINV.LOG. CSINV.LOG can be examined with a text editor to review what happened during an inversion sequence.

The survey configuration of a CSAMT inversion example is shown by a block diagram in figure 1. Controlled-source fields are generated by grounded electric bipoles on the surface of a layered earth. Perpendicular electric and magnetic-field components are measured at a receiver site located broadside to the source bipole at a distance of six kilometers. Observed apparent resistivity and impedance phase values are derived from E/H impedances. Scalar CSAMT data are modeled using single component of E/H and one transmitter antenna. Vector CSAMT uses vector_E/vector_H and a single transmitter antenna. For modeling tensor CSAMT, CSINV uses the determinant of a tensor E/H generated with two transmitter antennas. Natural source data are modeled with a vertical plane-wave source. Natural-source scalar, vector and tensor results are identical over layered-earth models.

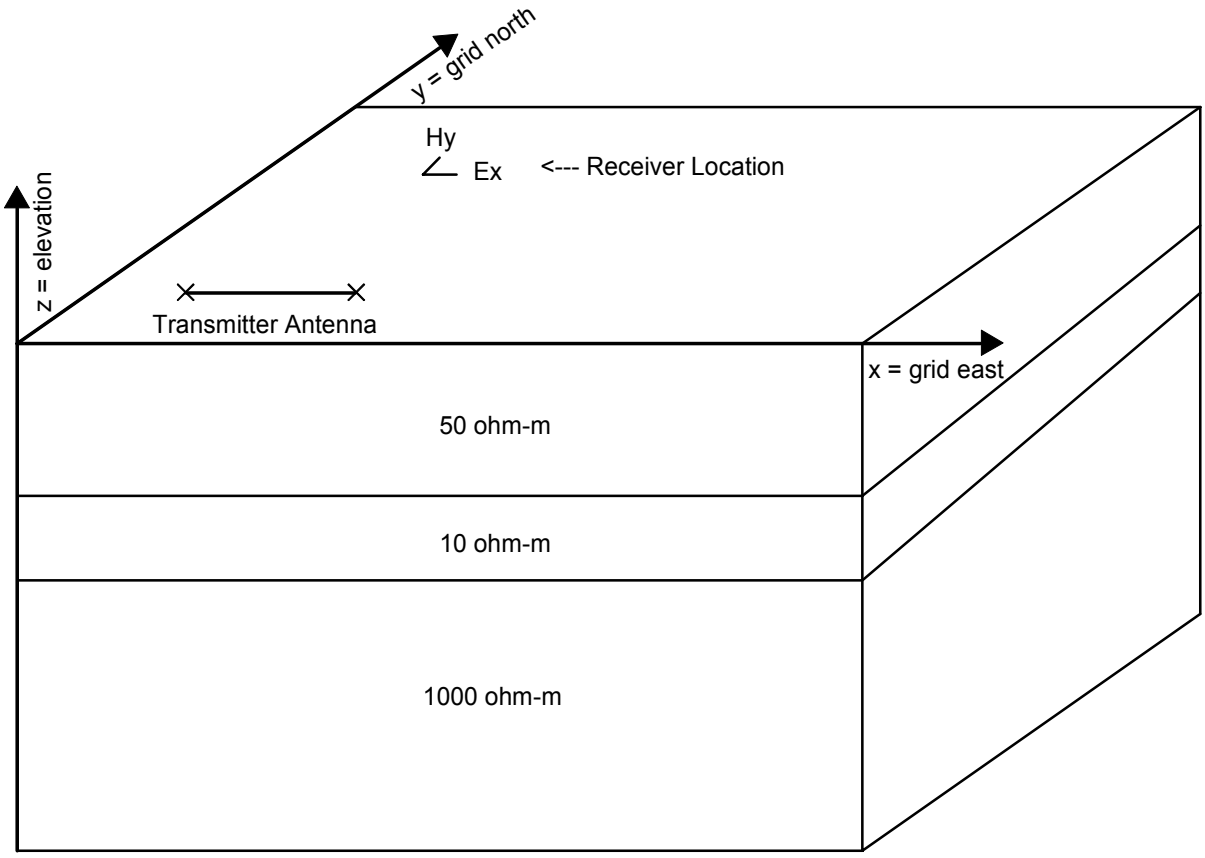

Figure 1 Block diagram of layered-earth model. The receiver is located broadside to the transmitter along the y axis. Observed data are apparent resistivity and impedance phase measured at a number of frequencies. Inversions minimize error-weighted sums of log(observed/calculated) apparent resistivity and observed - calculated impedance phase.

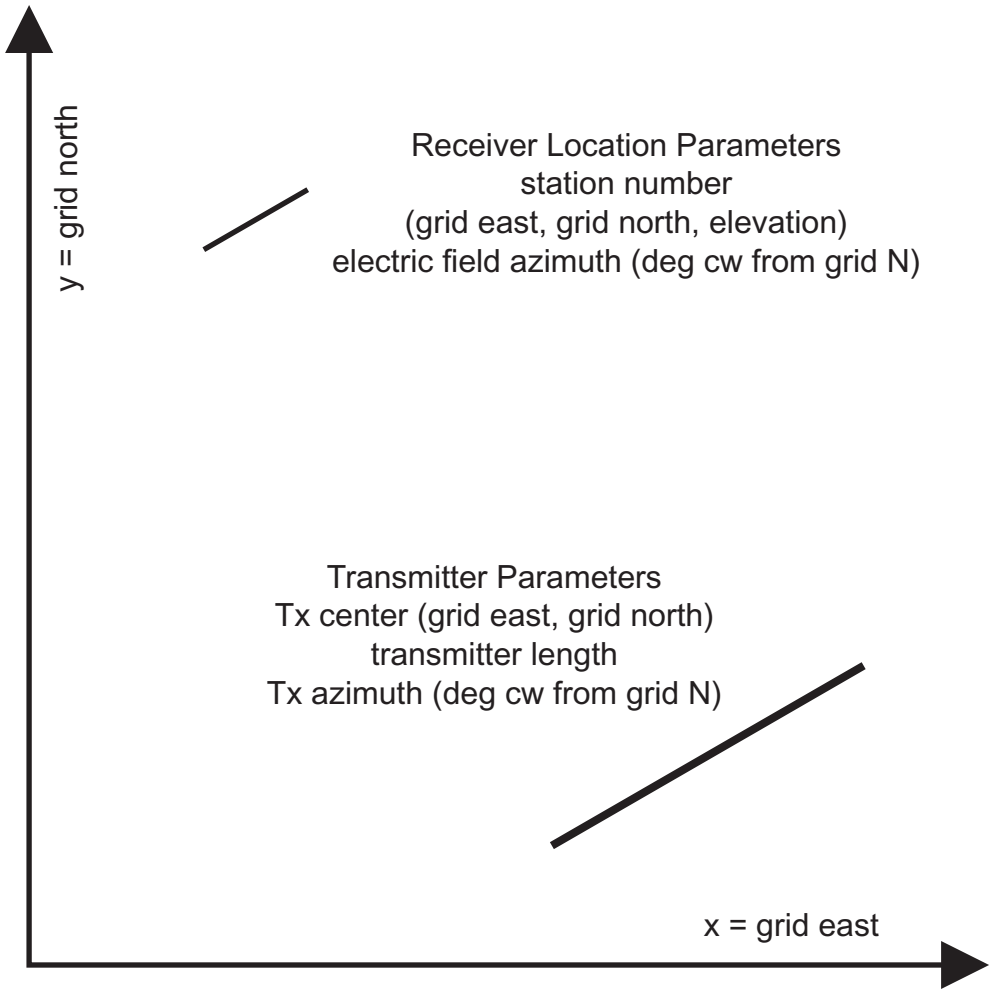

Figure 2 Map view of source-receiver geometry. Distances are specified as meters or feet in a right-handed (x,y,z) coordinate system with x positive to grid east and z positive upward. Azimuths are specified in degrees east of grid north.

CSDEMO.MDE, CSDEMO.AVG and CSDEMO.STN hold survey configuration information and observed data for a scalar CSAMT survey over an epithermal gold property. Given a set of observed data, CSINV must first be used to create *.CSI and *.CSD files. To run this example from the beginning, move distribution copies of CSDEMO.CSI, CSDEMO.CSD and CSDEMO.M1D out of your working directory, so that CSINV starts with only the observed-data files.

Type "CSINV CSDEMO.AVG" to generate CSDEMO.CSI and CSDEMO.CSD, then choose menu option 2 "Create *.CSI and *.CSD files". The following extract from CSINV.LOG shows what to expect.

```
 CSINV v5.00e: CSAMT 1D Inversion.
 MS-DOS version implemented 28/Mar/96
 by Zonge Engineering and Research.

 Scanning CSDEMO.MDE
 CSDEMO.MDE has been read.

 Reading input file: CSDEMO.AVG

 Reading data from file CSDEMO.AVG
   Reading header lines.

 Should static-corrected resistivities be used? (y/N)
```

Press Y for yes.

```
   Reading numerical data.
 269 points have been read from CSDEMO.AVG

 Sorting data by station and frequency.
 Averaging duplicate values.

 Reading station location data.
```

CSINV displays survey parameters for review and editing in a "Edit Survey Parameters" worksheet. No changes are necessary in this example.

CSINV then shows current, first and last station numbers in a "Set Station Number Variables" worksheet. Change the last station for inversion from 4300 to 2750, so that only station 2750 will be inverted in this demonstration run.

```
 Putting inversion control information into CSDEMO.CSI

 Putting observed data into file CSDEMO.CSD
```

CSINV has now created CSDEMO.CSI and CSDEMO.CSD and should have placed the cursor on menu choice 3, "Display or edit model parameters".

Listing of model-input file CSDEMO.CSI.

```
&CSINV
Header(1)='From CSINV 5.00e  Date:04/03/96  Time:14:45'
Header(2)='CSINV  Line 4850N'
Header(3)='for Zonge Engineering'
Header(4)='Data from CSDEMO.AVG'
LengthUnits='m',SurveyType='Scalar',
TxLength(1)=1500,TxAzimuth(1)=90,TxGridE(1)=3525.0,TxGridN(1)=-1150.0,
RxAzimuth(1)=90,
RxStn=2750.00,StnFirst=2750.00,StnLast=2750.00,
Niteration=8,dpWeight=1.00,
/
```

Parameters in *.CSI files are saved in FORTRAN namelist format. Parameter ordering is not important and if an input parameter is missing, CSINV attempts to assign a reasonable default value. The model-input files are saved as ASCII text and may be modified with a text editor. *.CSI parameter definitions are given in Appendix B.

Partial listing of data file CSDEMO.CSD.

```
\* From CSINV 5.00e  Date:04/03/96  Time:14:45
"Stn"      "GridE" "GridN" "Elev" "Freq" "ARobs" "ARerr" "ZPobs" "ZPerr"
   2750.00     2750     4850      0 8.000E+0 1.170E+3    5    22   50
   2750.00     2750     4850      0 1.600E+1 5.983E+2   10     2  200
   2750.00     2750     4850      0 3.200E+1 2.438E+2   10     1  200
   2750.00     2750     4850      0 6.400E+1 8.505E+1   10   516  200
   2750.00     2750     4850      0 1.280E+2 1.600E+2   10   666  200
   2750.00     2750     4850      0 2.560E+2 1.403E+2   10   657  200
   2750.00     2750     4850      0 5.120E+2 1.250E+2   10   659  200
   2750.00     2750     4850      0 1.024E+3 1.074E+2   10   681  200
   2750.00     2750     4850      0 2.048E+3 1.087E+2   10   786  200
   2750.00     2750     4850      0 4.096E+3 6.137E+1   10   914  200
   2800.00     2800     4850      0 8.000E+0 6.011E+2   10    17  200
   2800.00     2800     4850      0 1.600E+1 3.164E+2   10    12  200
   2800.00     2800     4850      0 3.200E+1 1.136E+2   10    27  200
   2800.00     2800     4850      0 6.400E+1 4.795E+1   10   579  200
   2800.00     2800     4850      0 1.280E+2 8.804E+1   10   681  200
      .           .        .       .    .         .        .    .    .
      .           .        .       .    .         .        .    .    .
      .           .        .       .    .         .        .    .    .
   4300.00     4300     4850      0 1.024E+3 7.726E+1   10   954  200
   4300.00     4300     4850      0 2.048E+3 9.675E+1   10   984  200
   4300.00     4300     4850      0 4.096E+3 1.020E+2   10   958  200
```

Annotation is placed at the beginning of CSDEMO.CSD in a pair of comment lines. Comment lines starting with a "\", "/", "!" or """ character in column 1 or 2 may be placed anywhere in *.CSD files. Data values are saved in a tabular format. Column 1 holds station numbers. Column 2 holds the station's grid east coordinate (m or ft). Column 3 holds the station's grid north coordinate. Column 4 holds the station's elevation. Column 5 holds frequency (hertz). Column 6 holds Cagniard apparent resistivity (ohm-m). Column 7 is the estimated apparent resistivity error (percent). Column 8 is impedance phase (mrad). Column 9 is estimated phase error (mrad). RCSINV will later add two more columns of calculated apparent resistivity and impedance phase on the right side of CSDEMO.CSD. Columns are free format and can be spaced irregularly, so long as numerical values are separated by "," or blank space.

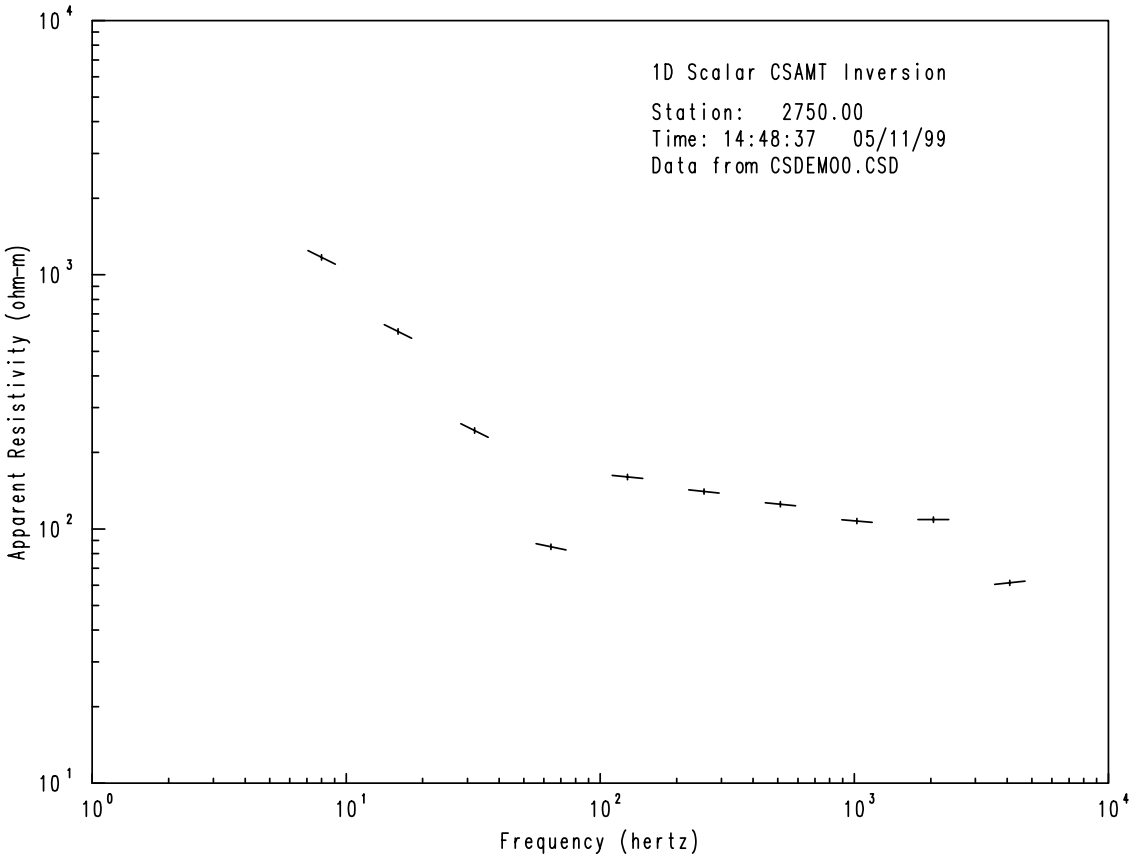

Figure 3 Log-log plot of observed apparent resistivity and impedance phase data for station 2750 in CSDEMO.CSD. Vertical bars indicate relative error in observed apparent resistivity. Short sloping lines represent observed impedance phase mapped onto slope of log(apparent resistivity) versus log(frequency).

Now that files CSDEMO.CSI and CSDEMO.CSD exist, RCSINV can be used to invert station 2750 data. Since CSDEMO.M1D does not exist, RCSINV will create it. With no previous model for station 2750 present, RCSINV will generate a starting model using a far-field direct inversion algorithm and then will improve it with a series of controlled-source iterative inversions.

Choosing CSINV menu option 4, “Iterative inversion”, starts RCSINV.EXE.

```
RCSINV v5.00e: CSAMT 1D inversion program.
MS-DOS version implemented 28/Mar/96
by Zonge Engineering and Research.

Reading file: CSDEMO.CSI

Reading values from CSDEMO.CSI

Inverting model for station    2750.00
  Generating starting model.
Iteration  1,00   Data Residual:    2.666  Minimization Residual:  2.666
Iteration  1,01   Data Residual:    2.291  Minimization Residual:  2.301
Iteration  1,02   Data Residual:    2.062  Minimization Residual:  2.099
Iteration  1,03   Data Residual:    1.949  Minimization Residual:  2.006
Iteration  1,04   Data Residual:    1.927  Minimization Residual:  1.988
Iteration  1,00   Data Residual:    1.909  Minimization Residual:  1.909
Iteration  1,01,1 Data Residual:    1.908  Minimization Residual:  1.910
Iteration  1,01   Data Residual:    1.900  Minimization Residual:  0.904
    .       .       .      .          .          .         .         .
    .       .       .      .          .          .         .         .
    .       .       .      .          .          .         .         .
Iteration  7,09   Data Residual:    0.398  Minimization Residual:  0.399

Iteration  8,00   Data Residual:    3.734  Minimization Residual:  3.734
Iteration  8,01   Data Residual:    1.485  Minimization Residual:  1.644
Iteration  8,02   Data Residual:    1.110  Minimization Residual:  1.250
Iteration  8,03,1 Data Residual:    1.597  Minimization Residual:  1.667
Iteration  8,03   Data Residual:    0.891  Minimization Residual:  1.086
Iteration  8,04   Data Residual:    0.831  Minimization Residual:  0.982
Iteration  8,05   Data Residual:    0.639  Minimization Residual:  0.791
Iteration  8,06   Data Residual:    0.580  Minimization Residual:  0.721
Iteration  8,07   Data Residual:    0.568  Minimization Residual:  0.704
Iteration  8,08   Data Residual:    0.563  Minimization Residual:  0.699
Iteration  8,09,1 Data Residual:    1.104  Minimization Residual:  1.108
Iteration  8,09,2 Data Residual:    1.758  Minimization Residual:  1.763
Iteration  8,09,3 Data Residual:    2.050  Minimization Residual:  2.065

 Updating CSDEMO.M1D
 Updating CSDEMO.CSD
```

CSDEMO.M1D holds the best inversion model out of eight restarts. A listing of CSDEMO.M1D after inverting station 2750 follows:

```
\* From CSINV 5.00f  Date:04/05/96  Time:10:06
"Stn"   "GridE"   "GridN"   "Zinv" "ResInv"   "Zerr0" "Rerr0" "Zerr" "Rerr" "APRE"
2750.  2750.0  4850.0      0.00  66.49     0    500      0      4   1.3
2750.  2750.0  4850.0    -41.67  66.49   500    500      9      4   1.3
2750.  2750.0  4850.0    -41.68  222.4   500    500      9      4   1.3
2750.  2750.0  4850.0   -959.71  222.4   478    500     14      4   1.3
2750.  2750.0  4850.0   -959.72  1622.   478    500     14     58   1.3
2750.  2750.0  4850.0  -3024.92  1622.   152    500      4     58   1.3
```

Annotation is placed at the beginning of CSDEMO.M1D in a pair of comment lines. Comment lines starting with a "\", "/", "!" or """ character in column 1 or 2 may be placed anywhere in *.M1D files. Model parameter values are saved in a tabular format. Numerical value columns are free format and can be spaced irregularly, so long as values are separated by "," or blank space. Column 1 holds station numbers. Column 2 holds the station's grid east coordinate (m or ft). Column 3 holds the station's grid north coordinate. Column 4 holds an interface elevation or depth. Column 5 holds layer resistivity (ohm-m). Column 6 holds starting model interface depth error (percent). Column 7 is starting model layer resistivity error (percent). Column 8 is estimated inversion model interface depth error (percent). Column 9 is estimated inversion model layer resistivity error (percent). Column 10 is average predicted residual error, APRE, for the inverted model. Plotting model resistivity (log(ResInv) on horizontal axis) versus interface depth (Zinv on vertical axis) will create a staircase profile of inverted model resistivity.

RCSINV updates *.CSD files with calculated apparent resistivity and impedance phase values. A partial listing of CSDEMO.CSD after inverting station 2750 follows:

```
\* From CSINV 5.00f  Date:04/05/96  Time:10:06
"Stn"       "GridE" "GridN" "Elev" "Freq"    "ARobs" "ARerr" "ZPobs" "ZPerr" "ARcalc" "ZPcalc"
     2750.     2750     4850      0 8.000E+0 1.170E+3    5    22   50 1.169E+3    47
     2750.     2750     4850      0 1.600E+1 5.983E+2   10     2  200 5.918E+2    21
     2750.     2750     4850      0 3.200E+1 2.438E+2   10     1  200 2.447E+2    10
     2750.     2750     4850      0 6.400E+1 8.505E+1   10   516  200 7.818E+1   458
     2750.     2750     4850      0 1.280E+2 1.600E+2   10   666  200 1.611E+2   718
     2750.     2750     4850      0 2.560E+2 1.403E+2   10   657  200 1.478E+2   644
     2750.     2750     4850      0 5.120E+2 1.250E+2   10   659  200 1.298E+2   618
     2750.     2750     4850      0 1.024E+3 1.074E+2   10   681  200 1.080E+2   598
     2750.     2750     4850      0 2.048E+3 1.087E+2   10   786  200 8.812E+1   599
     2750.     2750     4850      0 4.096E+3 6.137E+1   10   914  200 7.240E+1   632
     2800.     2800     4850      0 8.000E+0 6.011E+2   10    17  200
     2800.     2800     4850      0 1.600E+1 3.164E+2   10    12  200
     2800.     2800     4850      0 3.200E+1 1.136E+2   10    27  200
      .         .        .         .         .         .      .    .    .        .
      .         .        .         .         .         .      .    .    .        .
      .         .        .         .         .         .      .    .    .        .
     4150.     4150     4850      0 1.024E+3 7.959E+1   10  1048  200
     4150.     4150     4850      0 2.048E+3 7.614E+1   10  1012  200
     4150.     4150     4850      0 4.096E+3 1.036E+2   10   902  200
     4300.     4300     4850      0 8.000E+0 3.323E+1   10    10  200
     4300.     4300     4850      0 1.600E+1 9.148E+0   10   517  200
     4300.     4300     4850      0 3.200E+1 2.610E+1   10  1111  200
     4300.     4300     4850      0 6.400E+1 3.809E+1   10   994  200
     4300.     4300     4850      0 1.280E+2 4.595E+1   10   982  200
     4300.     4300     4850      0 2.560E+2 5.448E+1   10   970  200
     4300.     4300     4850      0 5.120E+2 6.506E+1   10   967  200
     4300.     4300     4850      0 1.024E+3 7.726E+1   10   954  200
     4300.     4300     4850      0 2.048E+3 9.675E+1   10   984  200
     4300.     4300     4850      0 4.096E+3 1.020E+2   10   958  200
```

Note that calculated apparent resistivity (ARcalc) and impedance phase (ZPcalc) are present only for station 2750. RCSINV inverted only station 2750 since StnFirst = 2750 = StnLast.

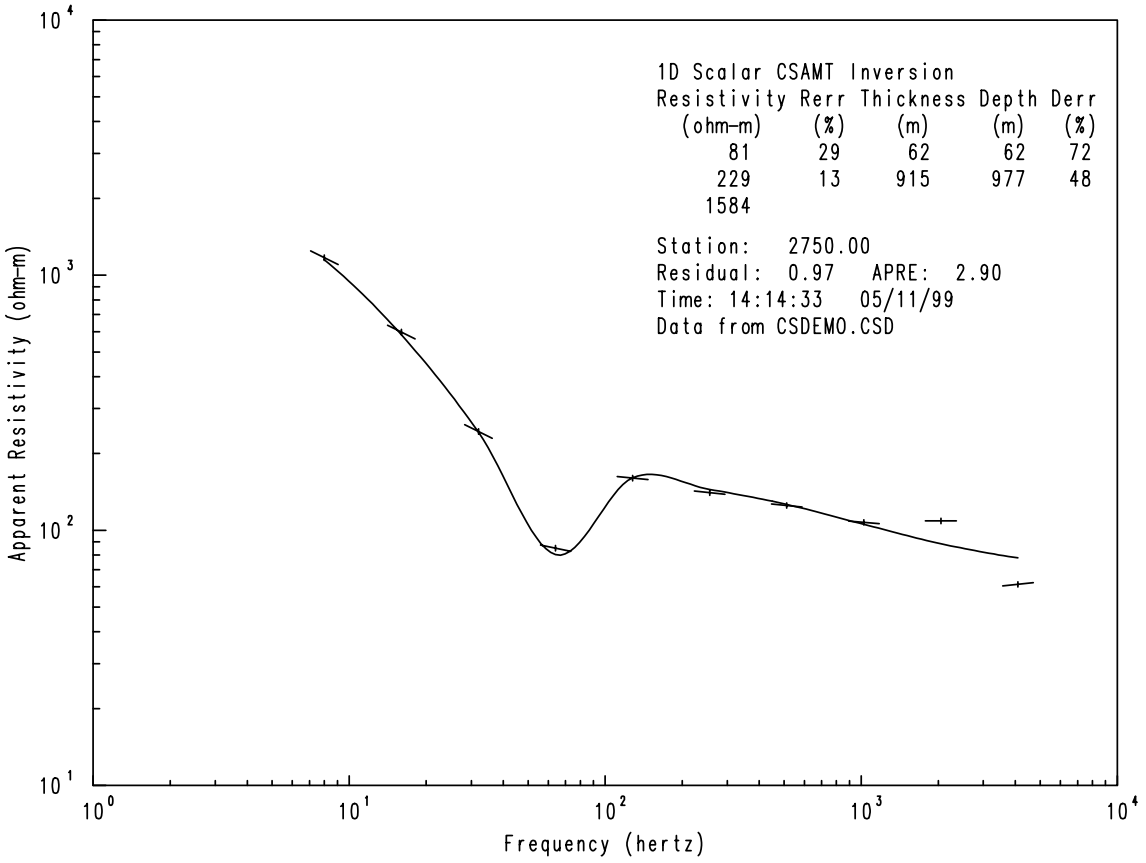

Figure 4 Log-log plot of apparent resistivity and impedance phase data from CSDEMO.CSD after running RCSINV. RCSINV generated a three-layer starting model using a direct inversion algorithm on higher frequency, far-field data, then iteratively improved the model using complete controlled-source forward modeling. The solid line shows calculated apparent resistivities for the best-fit model, which has a RMS residual of 0.39.

References

Anderson, W., 1974, Electromagnetic fields about a finite electrical wire source, USGS, NTIS report # PB 238 199.

Hohmann, G.W., and Raiche, A.P, 1988, Inversion of controlled soure electromagnetic data, in Electromagnetic methods in applied geophysics, vol. 1, theory, editor M. N. Nabighian, SEG, Tulsa, OK.

MacInnes, S., 1988, Lateral effects in controlled source audiomagnetotellurics, unpublished PhD dissertation, University of Arizona, Tucson, Arizona.

Pedersen, L.B., and Rasmussen, T.M., 1989, Inversion of magnetotelluric data: a non-linear least-squares approach, Geophysical Prospecting, v37, p669-695.

Price, W.L., 1977, A controlled random search procedure for global optimization: The Computer Journal, v. 20, p 367-370.

Tarantola, A., and Valette, B., 1982, Generalized nonlinear inverse problems solved using the least squares criterion, Reviews of Geophysics and Space Physics, v20, p219-232.

Wait, J.R., 1961, The electromagnetic fields of a horizontal dipole in the presence of a conducting half-space, Can. J. Phys., v39, p1017-1028.

Appendix A: Data Processing File Documentation

***.MDE file** - line annotation, survey configuration and data processing control

Listing of CSDEMO.MDE:

```
$ CLIENT  =Zonge Engineering
$ PROJECT =CSINV
$ JOBNUMB =A755
$ JOBDATE =Apr 96
$ JOBLINE =4850N
$ BRGLINE =N90E
$ BRGBACK =S90W
$ STNLO   =  2750.0
$ LBLFRST =  2750.0
$ STNDELT =    50.0
$ LBLDELT =    50.0
$ TXLEN   =1500m
$ TXBRG   =N90E
$ TXCX    =3525
$ TXCY    =-1150
$ TXDIS   =6 km
$ RX2TX   =S00E
$ RXBRG   =N90E
$ZPLOT: SIZEX=1
$ZPLOT: SIZEY=1
$ZPLOT: AXSTN=VERT
$AUTO=YES
```

*.MDE files hold annotation information about each line, survey configuration parameters and Zonge Engineering data processing control parameters. A *.MDE file consists of one or more “mode” lines, each of which begins with a "$" in the first column, optionally followed by a program name and colon ":". The name of the mode keyword is followed by an equal sign "=", then the value to assign to the variable. Spaces may be included between the elements of the mode line. Spaces in values defined as text will be included as part of the value.

STNLO, LBLFRST, STNDELT and LBLDELT can be used to shift and scale station numbers from values used in *.RAW, *.AVG and *.Z files to some other station number system. STNLO and LBLFRST may be used to define a station number shift. STNDELT and LBLDELT may be used to scale station numbers. Default values produce no station number shifting or scaling.

STNLO - first station number in *.RAW, *.AVG and *.Z file station number units.
LBLFRST - first station number in scaled and shifted station number units.
STNDELT - station number increment in *.RAW, *.AVG and *.Z file station number units.
LBLDELT - station number increment in scaled and shifted station number units.

The following mode keywords are used by CSINV for default positioning and orientation of the transmitter antenna.
UNITS - length units used for distances (m or ft).
TXLEN - transmitter bipole antenna length (units).
TXBRG - transmitter bipole antenna bearing in N??E format.
TXCX - transmitter antenna center grid E coordinate (units).
TXCY - transmitter antenna center grid N coordinate (units).
TXDIS - distance from line center to transmitter center (units).
RX2TX - bearing from line center to transmitter center in N??E format.
RXBRG - receiver E-field bearing in scalar surveys in N??E format.

***.AVG file** - averaged CSAMT data and measurement error estimates

Partial listing of *.AVG file:

```
\ AMTAVG 7.20: "L28.FLD", Dated 93-11-17, Processed 19 Nov 93
\$ ASPACE=  200.ft
\$ XMTR  =    1.
\ ASTATIC v2.00 added TMARES/SRES column on 01/15/96
\ 5.0 dipole FLMA Filter at 4096 hertz.
skp Station Freq  Comp Amps     Emag     Ephz      Hmag    Hphz  Resistivity   Phase  %Emag  sEphz  %Hmag  sHphz   %Rho  sPhz TMARES/SRES
 2     0.    8192 ExHy  7.    7.1637e+3 -2555.4  2.6594e+0  3089.1  1.7716e+2   638.6    0.4    4.4    0.1   10.1    0.9   7.2  1.6404E+2
 2     0.    4096 ExHy 11.    6.6556e+3 -1749.9  3.5677e+0 -2371.4  1.6993e+2   621.6    0.1    1.8    0.8    8.3    0.8   9.9  1.5735E+2
 2     0.    2048 ExHy 16.    6.8889e+3 -1180.6  4.9804e+0 -1780.0  1.8684e+2   599.4    0.3    2.5    0.2    3.1    0.3   3.3  1.7300E+2
 2     0.    1024 ExHy 20.    7.2575e+3  -795.0  6.9107e+0 -1365.8  2.1540e+2   570.8    0.2    2.0    0.2    2.4    0.7   6.0  1.9945E+2
 2     0.     512 ExHy 22.    7.6680e+3  -608.6  9.5484e+0 -1141.3  2.5192e+2   532.7    0.7    7.2    0.1    1.6    1.2   8.6  2.3327E+2
 2     0.     256 ExHy 22.    8.5168e+3  -450.5  1.3391e+1 -1021.6  3.1604e+2   571.1    0.2    1.5    0.4    4.9    0.6   6.4  2.9264E+2
 2     0.     128 ExHy 22.    8.5507e+3 -1113.6  2.2357e+1 -1091.8  2.2856e+2   -21.8    0.3    2.4    0.5    3.3    0.5   1.1  2.1164E+2
 2     0.      64 ExHy 22.    2.4669e+4  -950.4  4.0949e+1  -769.0  1.1341e+3  -181.4    0.1    1.1    0.4    3.9    0.8   1.5  1.0501E+3
 2     0.      32 ExHy 22.    3.6149e+4  -357.9  5.3420e+1  -291.1  2.8619e+3   -66.8    0.1    0.9    0.4    4.3    0.6   2.9  2.6500E+3
 2     2.    8192 ExHy  7.    6.4907e+3 -2597.9  2.6594e+0  3089.1  1.4544e+2   596.1    0.3    4.0    0.1   10.1    0.9   7.4  1.5561E+2
 2     2.    4096 ExHy 11.    6.1855e+3 -1740.7  3.5677e+0 -2371.4  1.4677e+2   630.8    0.0    0.9    0.8    8.3    0.6   8.4  1.5703E+2
```

An *.AVG file contains averaged CSAMT data for discrete frequencies. CSAMT *.AVG files are produced by the Zonge data processing program AMTAVG, which reads files with repeat readings, averages them and calculates measurement error from variation between repeats. *.AVG files are archived together with GDP-format files (*.RAW) and station location files (*.STN). *.AVG files are used by programs that provide plot files, options for further data processing, or modeling.

Comment lines preceded by a “\”, “/”, “!” or “”” in column 1 may be placed anywhere within *.AVG files. Data processing mode lines preceded by a “$” in column 1 may also be present. A line holding column labels must precede the numerical data. Column order is not fixed and all columns may not be present in a particular file. Missing values are flagged by a “*”. Numerical values are free format with columns separated by spaces or commas.

CSAMT *.AVG file column definitions:

Skp - skip flag, 2 = good data, 1= bad data, 0 = very bad data.
Station - receiver station number in unscaled and unshifted units.
Comp - measured E and H field component pair (ExHy or EyHx).
Amps - peak-to-peak square-wave current = pi/4*Fourier component current (amps).
Freq. - measurement frequency (hertz).
Emerge - electric-field magnitude (uV/(km*amp)=nV/(m*amp)).
Ephz - electric-field phase (mrad).
Hag - magnetic-field magnitude (pT/amp).
Hphz - magnetic-field phase (mrad).
Resistivity - Cagniard resistivity (ohm-m) .
Phase - impedance phase = phase(E/H) (mrad).
%Emag - E-field magnitude error = 100*standard_deviation(Emag)/Emag (percent).
sEphz - E-field phase error = 100*standard_deviation of Ephz (mrad).
sHphz - H-field phase error = 100*standard_deviation of Hphz (mrad).
%Hmag - H-field magnitude error = 100*standard_deviation(Hmag)/Hmag (percent).
%Rho - apparent resistivity error = 100*standard_deviation(Rho)/Rho (percent).
sPhz - impedance phase error = standard deviation (mrad).
TMARES/SRES - static-corrected apparent resistivity (ohm-m) (added by program ASTATIC).

***.Z file** - averaged CSAMT data

Partial listing of *.Z file:

```
$ ZPLOT: DATA = FLOG
$ ASPACE =    60.960m
 Contour Plot Z-File
 Cl Cn Ce Ns Nd Yl  Plot file  1
  1  5  0  3  1  1
 CSAMT SURVEY DATA
 CAGNIARD APP. RES.
 values in ohm-m
 Data from ASTDEMO.AVG
IIxxxxxxxxYYYYYYYYzzzzzzzzzzzz
 2     -2.  14.000    2.831E+3
 2     -2.  15.000    1.113E+3
 2     -2.  16.000    2.168E+2
 2     -2.  17.000    2.998E+2
 2     -2.  18.000    2.306E+2
 2     -2.  19.000    1.940E+2
 2     -2.  20.000    1.665E+2
 2     -2.  21.000    1.566E+2
 2     -2.  22.000    1.771E+2
 2      0.  14.000    2.862E+3
 2      0.  15.000    1.134E+3
 .      .     .         .
 .      .     .         .
 .      .     .         .
 2     76.  20.000    4.299E+2
 2     76.  21.000    4.192E+2
 2     76.  22.000    4.444E+2
 9999.00
 Cl Cn Ce Ns Nd Yl  Plot file  2
  0 10  3  3  0  1
 CSAMT SURVEY DATA
 IMPEDANCE PHASE
 values in milliradians
IIxxxxxxxxYYYYYYYYzzzzzzzzzzzz
 2     -2.  14.000   -7.650E+1
 2     -2.  15.000   -1.974E+2
 2     -2.  16.000   -3.920E+1
 .      .     .         .
 .      .     .         .
 .      .     .         .
 2     76.  20.000    6.787E+2
 2     76.  21.000    6.589E+2
 2     76.  22.000    6.129E+2
 9999.00
```

*.Z files are used for storing plot file data in multiple (skp,x,y,z) data blocks. Numerical values are stored in a fixed format, so column position is important. Numerical field widths are indicated by the "`IxYz`" record preceding numerical data. A `"IxYz"` record flags the beginning of a block of numerical (skp,x,y,z) data and a `"9999.0"` value flags the end of the block. For CSINV input, the *.Z file must have both apparent resistivity and impedance phase data blocks. Apparent resistivities may be uncorrected, static-corrected or filtered.

Description of lines in sample *.Z file:

```
$ ZPLOT: DATA= FLOG   - mode line, y-value data type (log(freq))
$ ASPACE = 60.960m    - mode line, receiver dipole length
AMTAVG 7.20           - program name and version that generated this file.
Cl Cn Ce Ns Nd Yl     - labels for integer contour control flags.
```

`Cl` - label for contour type:

- `0` = linear
- `1` = logarithmic
- `2` = pseudo-log: Pseudo-log contours = positive and negative values are contoured separately, using log10(abs(value)), plus a zero contour.

`Cn` - label for number of contours per interval.

`Ce` - label for exponent of the contour interval, interval=10^{Ce}.

`Ns` - label for number of significant digits when posting values.

Values: `-1, 3, 4, 5.` (`-1` = free format for small values)

`Nd` - label for the number of digits after the decimal.

`Yl` - label for vertical axis:

- `0` = none
- `1` = log frequency axis
- `2` = linear frequency axis
- `3` = linear depth

```
 1   5   0   3   1   1  - integer values for contour control flags.
```

`1` - value of `Cl` => logarithmic contours

`5` - value of `Cn` => 5 contours per "interval"

`0` - value of `Ce` => interval= 10^{Ce} => 10^{0} => `1`

`3` - value of `Ns` => use 3 significant digits for contouring

`1` - value of `Nd` => plot 1 digit after the decimal

`1` - value of `Yl` => log frequency axis

```
 CSAMT SURVEY DATA       Data description for this plot file.  Two to six lines are available.
 CAGNIARD APP. RES.      Column one is not read by ZPLOT.
 values in ohm-m         ZPLOT plots these lines as title annotation.
 Data from ASTDEMO.AVG
IIxxxxxxxxYYYYYYYYzzzzzzzzzzzz - Header line for the data that follows.
```

`II` - skip flag field:

- `0` = Skip this line of data.
- `1` = Omit for contouring, but post the bracketed value.
- `2` = Use for contouring and post the value (most common).
- `3` = Label a point or station by plotting a symbol under the X-axis at the X-coordinate.
- `4` = Use for contouring, post the symbol and not the value. Used for depth plots where interpolated values are used at the bottom of the plot to improve gridding.
- `5` = Use to set plot limits, do not contour or post. Used for depth plots to set zero depth. Also used to provide a margin around the data, as for plan maps.

`xxxxxxxx` - x value field, usually unscaled and unshifted station numbers.

`YYYYYYYY` - y value field, for CSAMT y=log2(freq)-9, not used when skip flag = 3

`zzzzzzzzzzzz` - z value field, to be plotted at (x,y) when skip flag=1, 2, or 4.

`AAA` - annotation field, when skip flag=1 or 2, ZPLOT posts any characters in the AAA column instead of plotting the z value. When skip flag=3, ZPLOT plots a symbol below the x-axis at the x-value according to an integer in column AAA. A zero or positive integer refers to symbols in TABLE 1 of the PLOT Manual. A negative integer refers to topographic symbols in the CTOPO Manual.

`9999.0` - marks end of (stn,x,y,z) data block.

***.STN file** - station location and elevation

Listing of CSDEMO.STN:

```
\Stn GridE  GridN Elevation
2750 2750   4850    0
4300 4300   4850    0
```

*.STN files hold information about station locations in a tabular format. A *.STN file should have at least two entries, corresponding to the first and last stations. Additional entries may be necessary to trace out topographic changes or curved lines. CSINV assumes that station numbers represent distance along line and uses station numbers to interpolate coordinates of stations without a matching entry in the *.STN file. If station numbers are scaled by entries in the *.MDE file, *.STN-file station numbers should be in the scaled and shifted units defined by *.MDE STNBEG, STNDELT, LBLFRST and LBLDELT, not the unscaled and unshifted units in *.AVG or *.Z.

Some grid coordinate systems, such as UTM coordinates, can generate very large coordinate values. STEMINV stores station locations as floating-point numbers with about six significant figures. It may be necessary to subtract a constant from large coordinate values in order to allow accurate representation with six significant figures.

*.STN-file column definitions:

Stn - station numbers. Station numbers can be in any unit, but they should be proportional to distance along line.

GridE - grid east (LengthUnits).

GridN - grid north (LengthUnits).

Elev - elevation (LengthUnits).

Appendix B: CSINV File Documentation

***.CSI file** - survey configuration and inversion control

Listing of CSDEMO.CSI:

```
&CSINV
Header(1)='From CSINV 5.00e  Date:04/03/96  Time:14:45'
Header(2)='CSINV  Line 4850N'
Header(3)='for Zonge Engineering'
Header(4)='Data from CSDEMO.AVG'
LengthUnits='m',SurveyType='Scalar',
TxLength(1)=1500,TxAzimuth(1)=90,TxGridE(1)=3525.0,TxGridN(1)=-1150.0,

RxAzimuth(1)=90,
RxStn=2750.00,StnFirst=2750.00,StnLast=2750.00,
Niteration=8,dpWeight=1.00,
/
```

Parameters in *.CSI files are saved in FORTRAN namelist format. Parameter ordering is not important and if an input parameter is missing, CSINV attempts to assign a reasonable default value. The model-input files are saved as ASCII text and may be modified with a text editor.

&CSINV	-	marks beginning of namelist input.
Header	-	character array, text describing data and model.
LengthUnits	-	character, distance units (m or ft).
SurveyType	-	character, ‘Scalar’, ‘Vector’, ‘Tensor’ or ‘Natural’.
NTx	-	integer, number of transmitter bipoles, NTx=1 for scalar and vector surveys, NTx=2 for tensor surveys.
TxLength	-	real array, length of transmitter bipole (LengthUnits).
TxAzimuth	-	real array, azimuth of transmitter antenna (degrees east of north).
TxGridE	-	real array, grid east coordinates of Tx center (LengthUnits).
TxGridN	-	real array, grid north coordinates of Tx center (LengthUnits).
RxAximuth	-	real array, azimuth of Rx E-field in scalar survey (degrees east of north).
RxStn	-	real, current receiver station (station numbers).
StnFirst	-	real, first station to invert (station numbers).
StnLast	-	real, last station to invert (station numbers).
Niteration	-	integer, number of restarts to use in iterative inversion.
dpWeight	-	real, relative weight of starting model (default=1).
/	-	marks end of namelist input block.

***.CSD file** - observed and calculated data

Partial listing of CSDEMO.CSD:

```
\* From CSINV 5.00f  Date:04/04/96  Time:13:15
"Stn"       "GridE" "GridN" "Elev" "Freq"   "ARobs" "ARerr" "ZPobs" "ZPerr" "ARcalc" "ZPcalc"
     2750.     2750     4850      0 8.000E+0 1.170E+3    5    22   50 1.168E+3    52
     2750.     2750     4850      0 1.600E+1 5.983E+2   10     2  200 5.953E+2    27
     2750.     2750     4850      0 3.200E+1 2.438E+2   10     1  200 2.490E+2    17
     2750.     2750     4850      0 6.400E+1 8.505E+1   10   516  200 8.216E+1   450
     2750.     2750     4850      0 1.280E+2 1.600E+2   10   666  200 1.614E+2   714
     2750.     2750     4850      0 2.560E+2 1.403E+2   10   657  200 1.475E+2   640
     2750.     2750     4850      0 5.120E+2 1.250E+2   10   659  200 1.291E+2   616
     2750.     2750     4850      0 1.024E+3 1.074E+2   10   681  200 1.071E+2   599
     2750.     2750     4850      0 2.048E+3 1.087E+2   10   786  200 8.746E+1   606
     2750.     2750     4850      0 4.096E+3 6.137E+1   10   914  200 7.261E+1   645
     2800.     2800     4850      0 8.000E+0 6.011E+2   10    17  200 6.281E+2    45
     2800.     2800     4850      0 1.600E+1 3.164E+2   10    12  200 3.108E+2    -1
      .         .        .         .         .         .     .    .        .
      .         .        .         .         .         .     .    .        .
      .         .        .         .         .         .     .    .        .
     4300.     4300     4850      0 6.400E+1 3.809E+1   10   994  200 3.549E+1   967
     4300.     4300     4850      0 1.280E+2 4.595E+1   10   982  200 4.241E+1   991
     4300.     4300     4850      0 2.560E+2 5.448E+1   10   970  200 5.248E+1  1010
     4300.     4300     4850      0 5.120E+2 6.506E+1   10   967  200 6.698E+1  1004
     4300.     4300     4850      0 1.024E+3 7.726E+1   10   954  200 8.410E+1   960
     4300.     4300     4850      0 2.048E+3 9.675E+1   10   984  200 9.725E+1   881
     4300.     4300     4850      0 4.096E+3 1.020E+2   10   958  200 9.866E+1   805
```

*.CSD files hold observed and calculated data values. RCSINV updates the *.CSD file whenever new values are calculated. Data are arranged in free-format columns separated by commas or spaces. Column spacing is not important, but column order is critical. Comment lines starting with a “\”, “/”, “!” or “”” character in column 1 or 2 may be placed anywhere within *.CSD files.

*.CSD-file column definitions :

Stn - station numbers. Station numbers can be scaled arbitrarily units, but they should be proportional to distance along line.

GridE - grid east (LengthUnits).

GridN - grid north (LengthUnits).

Elev - elevation (stn elev=0 returns model interface elevations as depths) (LengthUnits).

Freq - frequency (hertz).

ARobs - static-corrected or uncorrected Cagniard apparent resistivity (ohm-m).

ARerr - apparent resistivity measurement error (percent).

APobs - Impedance phase (mrad).

APerr - Impedance phase measurement error (mrad).

ARcalc - Calculated apparent resistivity (ohm-m).

APcalc - Calculated impedance phase (mrad).

***.M1D file** - layered model parameters

Partial listing of CSDEMO.M1D:

```
\* From CSINV 5.00f  Date:04/05/96  Time:10:35
"Stn"       "GridE"   "GridN"   "Zinv" "ResInv"   "Zerr0" "Rerr0" "Zerr" "Rerr" "APRE"
    2750.    2750.0    4850.0      0.00  67.60         0    500      0     10     1.3
    2750.    2750.0    4850.0    -42.27  67.60       500    500     18     10     1.3
    2750.    2750.0    4850.0    -42.28  220.1       500    500     18      5     1.3
    2750.    2750.0    4850.0   -943.56  220.1       477    500     15      5     1.3
    2750.    2750.0    4850.0   -943.57  1601.       477    500     15     39     1.3
    2750.    2750.0    4850.0  -3024.92  1601.       149    500      5     39     1.3
    2800.    2800.0    4850.0      0.00  54.49         0    500      0      7     0.9
    2800.    2800.0    4850.0    -24.89  54.49       500    500     38      7     0.9
    2800.    2800.0    4850.0    -24.90  80.13       500    500     38     13     0.9
      .        .         .          .     .           .      .       .      .      .
      .        .         .          .     .           .      .       .      .      .
      .        .         .          .     .           .      .       .      .      .
    4300.    4300.0    4850.0   -584.34  13.86       267    500     20     37     0.4
    4300.    4300.0    4850.0   -584.35  1365.       267    500     20     29     0.4
    4300.    4300.0    4850.0  -2418.09  1365.        65    500      5     29     0.4
```

*.M1D files hold layer model parameters. RCSINV will update a *.M1D file if it already exists, otherwise it creates one. Numerical values are arranged in free-format columns separated by commas or spaces. Column spacing is not important, but column order is critical. Comment lines starting with a “\”, “/”, “!” or “”” character in column 1 or 2 may be placed anywhere within *.M1D files.

*.M1D-file column definitions :

Stn - station numbers. Station numbers can be scaled arbitrarily units, but they should be proportional to distance along line.

GridE - grid east (LengthUnits).

GridN - grid north (LengthUnits).

Zinv - layer interface elevations (LengthUnits) (if station elevations=0, CSINV returns model interface elevations as depths, depths = elevations with respect to the surface).

ResInv - layer resistivity (ohm-m).

Zerr0 - starting model interface depth error (percent).

Rerr0 - starting model layer resistivity error (percent).

Zerr - inverted model estimated interface depth error (percent).

Rerr - inverted model layer resistivity error (percent).

APRE - average predicted residual error (reduced chi-square).