

# **C S I N V**

## **Documentation**

Zonge Data Processing

One-dimensional CSAMT Inversion

Version 7.00

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# Introduction

CSINV inverts CSAMT or AMT frequency-sounding data to a layered-earth model. For controlled-source soundings, its calculations include the effects of finite transmitter-receiver separation and three-dimensional source fields, i.e. CSINV computes accurate results for CSAMT near-field and transition-zone data, as well as far-field CSAMT/NSAMT values. Scalar, vector or tensor survey configurations may be inverted, and both apparent resistivity and impedance phase values are used.

CSINV has two inversion methods, an iterative inversion algorithm which minimizes the root-mean-square difference between observed and calculated data and a controlled random search inversion which minimizes the average absolute deviation between observed and calculated data. Both the iterative inversion and the controlled random search methods test multiple variations to the starting model and save a group of inversion results for each sounding station. Model parameter errors are estimated from variation between inverted models which fit the data nearly as well as the best result. Neither algorithm changes the number of layers in each stations starting model, but both adjust layer thicknesses and resistivities. CSINV automatically generates its own starting model, if one is not available from a previous run or from user entry. An interactive interface for review of inversion results and editing of layer parameters facilitates careful modeling of individual soundings. If geologic control sets the thickness or resistivity of a particular unit, it is possible to freeze 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 which provides interactive utilities for observed data input, review of inversion results, and editing of survey and model parameters. RCSINV.EXE is the core inversion program which adjusts layered model parameters to better fit the geophysical data. For review of inversion results, CSINV shows side-by-side sounding-curve data and layered-earth model plots for a single station, with a trackbar control to allow station selection. Screen plots can be exported to the printer for hardcopy, or saved as HPGL or WMF files insertion into report documents.

Information about CSINV may be obtained by writing:

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# Installation

## Minimum Hardware Configuration

The minimum hardware configuration needed to operate CSINV v7.00 is personal computer running MS Windows with screen graphics set to “true” or “high” color (16-bit) mode. 32 MB or more of RAM is required along with at least 2 MB of free disk space.

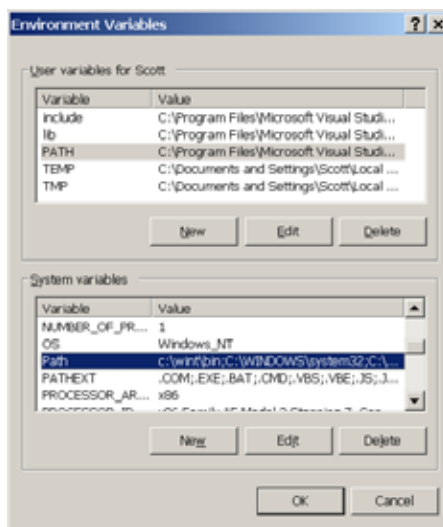
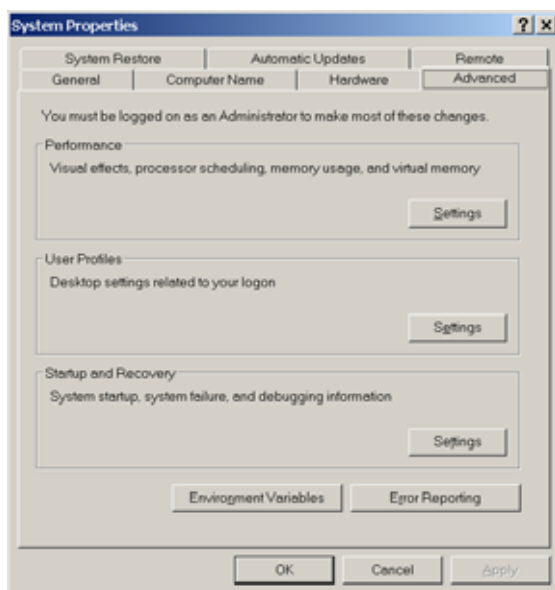
## Installation procedure

Each distribution copy of CSINV can be installed on more than one computer, but program operation requires a parallel or USB port hardware-lock or “dongle” compatible with MS Windows. Backup copies of installed files may be made freely, but they will function only with valid software registration. Once CSINV and hardware lock software is installed, dongles may be moved from one computer to another, but the parallel printer dongle should only be removed or added with computer and printer power off.

## Installing program and sample data files

A SETUP program is provided to install CSINV programs to your hard drive. SETUP copies files to your hard drive and unzips them, but does not make any changes to operating system files. SETUP allows you to move groups of program files from the distribution CD to a target hard-drive directory. It is usually easiest to put modeling programs from a CD into a single directory on your computer's operating system path (such as c:\datpro). Using a single directory from all of your Zonge data processing and modeling programs reduces the length of the PATH environment variable, which has an upper limit of 256 characters.

You can view your operating system PATH via Start | Settings | Control Panel | System, which will bring up a System Properties dialog. Select the Advanced tab, then click on the Environment Variables button.



Highlight the Path variable in the Environment Variables dialog, System Variables field and then click on the Edit button.



You can then review the directories that are already included in the operating system PATH, and add one if necessary, like the c:\datpro highlighted above. PATH directory entries are separated by semicolon characters, (i.e. ";"). Click on the OK buttons to work your way back out of the operating system configuration dialogs.

After installation, CSINV may be run from the command line, from the start menu or from a Windows desktop shortcut.

After installation, the subdirectory holding CSINV should have the following files:

**CSINV program files:**

- CSINV.EXE - shell program for data input, inversion review and model editing.
- RCSINV.EXE - core 1D CSAMT/AMT inversion program.
- CSIREG.EXE - registration program

**Sample observed-data files:**

- CSDEMO.MDE - line information and data processing control file.
- CSDEMO.STN - station locations.
- CSDEMO.AVG - observed CSAMT data.

**Sample CSINV inversion files:**

- CSDEMO.CSI - survey parameter and inversion control.
- CSDEMO.CSD - observed and calculated data.
- CSDEMO.M1D - layered-model parameters.

Note that sample data files must be read/writeable. Test data files distributed from a CD-ROM may need their attributes modified from read only to read/write.

## Installing a hardware lock

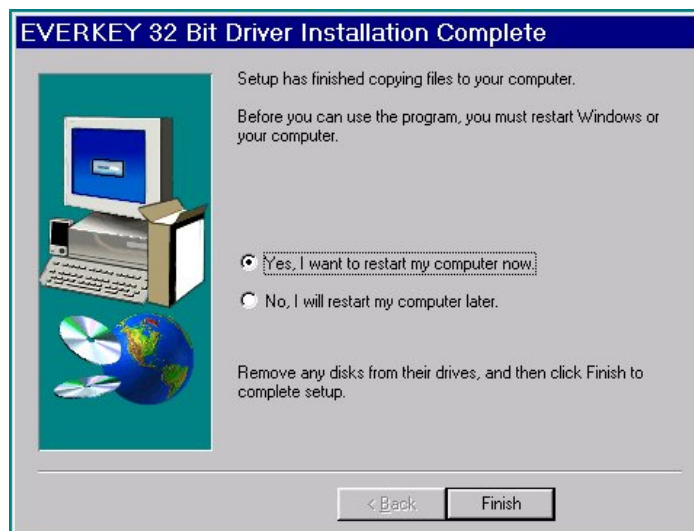
A USB or parallel-port hardware lock or "dongle" is required for computers running MS Windows. Using CSINV's hardware-lock registration system requires additional configuration steps. A USB hardware lock may be plugged directly into one of your computer's USB ports. If your program comes with a parallel-port hardware lock, install it by turning off power to your computer and printer. Unplug the parallel-port printer cable from the back of your computer and plug the hardware lock into your computer's 25-pin parallel port. Then plug the printer cable into the hardware lock, piggyback fashion.

You do not have to have a printer physically installed for the hardware lock to function. If you do have a printer connected, it must be turned on and on-line when you run CSINV with a parallel-port hardware lock. If you have more than one parallel port, it makes no difference which one you use.

**Note that you must ensure that the end of the hardware lock labeled “Computer” is connected to your computer’s parallel port. It is possible to plug the parallel-port hardware lock in backwards, which may damage the hardware lock, the parallel port or both.**

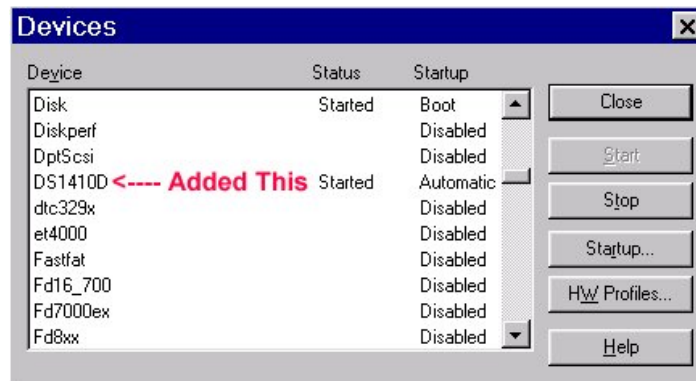
## SETUP32

This file needs to be executed once to install a driver that allows the hardware-lock software to access the parallel port. The driver file is DS1410D.SYS, which is put into your computer’s driver directory. After rebooting PCs running Windows NT or 2000, you will see this driver listed in the ‘Devices’. (START / Settings / Control Panel / Devices). This driver is automatically started when your computer boots.



Execute the program SETUP32, then reboot your PC. After re-booting a PC running Windows NT or 2000, the list of ‘Devices’ should include a new driver, DS1410D.





Test the software registration by executing CSIREG from the CSINV hard-disk directory. You should NOT see any response or error message.

A software registration check is done every time RCSINV is initiated. RCSINV calls CSIREG to check for valid software registration.

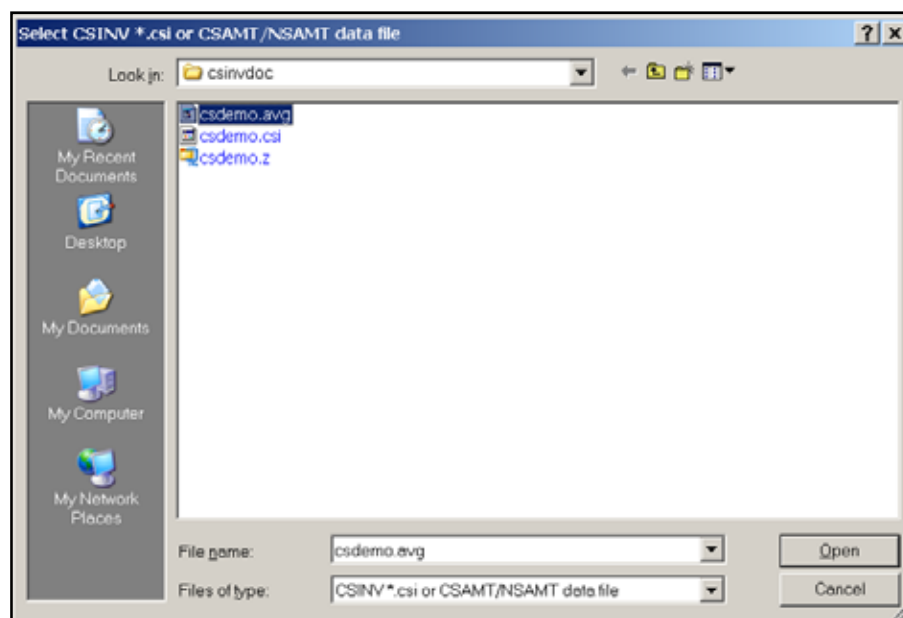
## Graphics Configuration

CSINV expects VGA, SVGA or X VGA graphics set to high color (16-bit) mode. Review Data plots may be plotted on your printer, exported to wmf files for pasting into MS-Word documents or exported to HPGL graphics files for later hardcopy plotting.

## 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 survey annotation and configuration information. Station locations are read from a matching \*.stn file, if it is present (which is a recommended option). CSINV writes survey configuration 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 files are ASCII text and may be viewed and edited with a text editor. File formats are described in an appendix to this document.

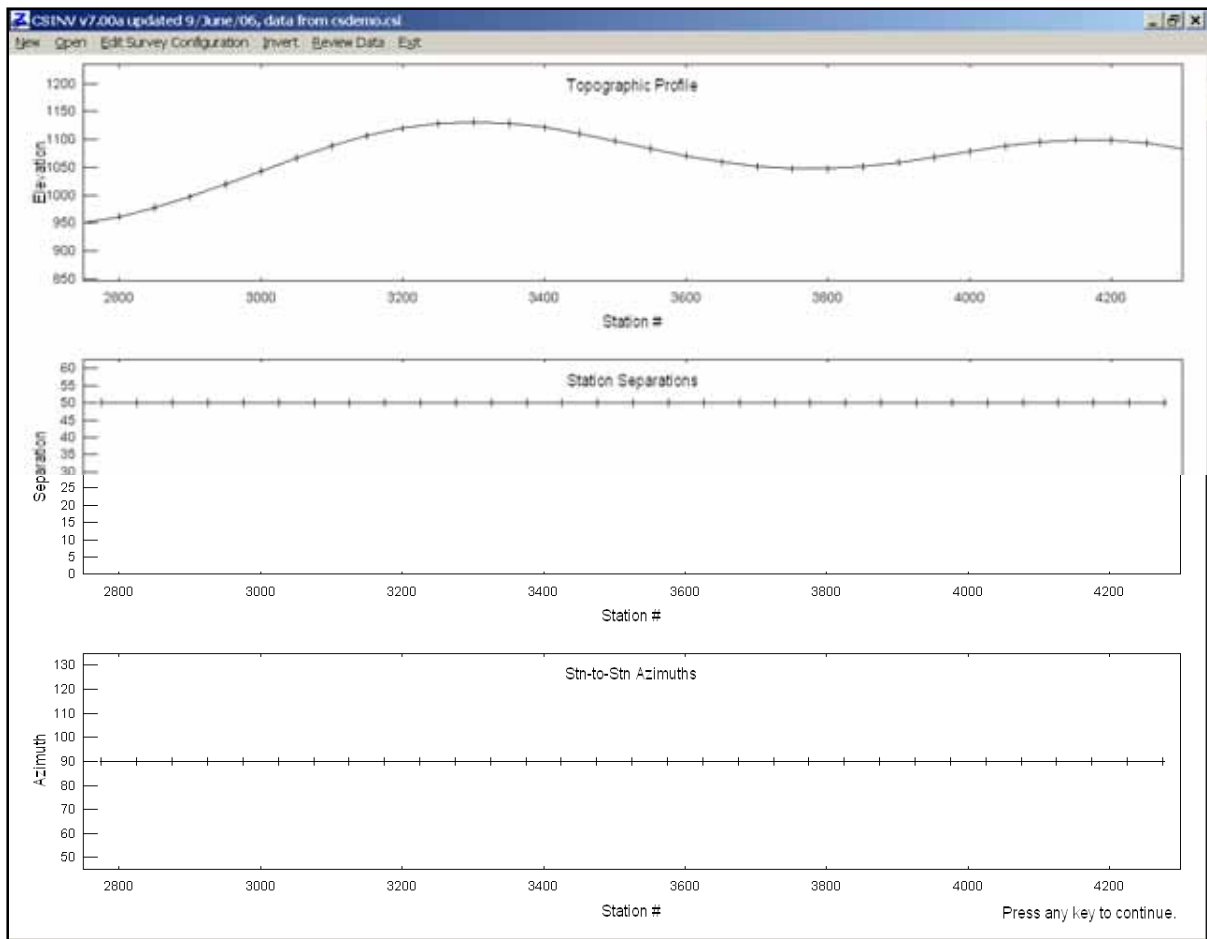
CSINV may be started from the command line, the start menu or via a shortcut icon. Typing “CSINV *filename*” on the command line can be used for quick startup, where *filename* can be a CSAMT \*.avg or \*.z file or an existing CSINV \*.csi file. If not given a valid command-line filename, CSINV will prompt you for an input file name.



To build a new inversion file set, select an \*.avg or \*.z file holding CSAMT or NSAMT data. To review results from a previous inversion, select a \*.csi file name. Z-files with “decorated” file name extensions, like the \*.zsr files produced by astatic, may be selected by typing in the full file name, i.e. csdemo.zsr. Once a satisfactory file is selected, click on the Open button to continue.

## New Model

If a CSAMT/NSAMT \*.z or \*.avg file is selected, (say datafile.avg) CSINV will first look for a matching datafile.mde. If it finds datafile.mde, it reads it to set default survey annotation and configuration values, otherwise it uses hard-coded default values and skips \*.mde file input. CSINV then reads the geophysical data from datafile.avg (or datafile.z). To get station location data, CSINV looks for a matching datafile.stn, again skipping input if it doesn't find an optional \*.stn file. If CSINV does find a \*.stn file, it reads the station location data and then shows a set of profile plots to catch stn file errors.



The top panel shows a topographic profile with vertical and horizontal scales adjusted to fit a fixed plot panel shape. The center station file quality control plot panel shows station-to-station separations, which should have fairly uniform values if station numbers are tabulated at regular intervals. The bottom panel displays station-to-station azimuths, which again should be nearly uniform if the line is reasonably straight. Any typographic errors in station file values should be visible in the profile plots as large outlier excursions. CSINV displays the stn file profile plots for 15 seconds or until you click on the plot with the mouse cursor or press a keyboard key.

CSINV next displays a survey configuration dialog to verify data, if any, input from datafile.mde.

**Edit survey configuration**

Descriptive Text

CSINV Line 4850N  
for Zonge Engineering  
Data from csdemo.svg

Job Name: CSINV  
Job Area:   
Job For: Zonge Engineering  
Job By:   
Job Date: Apr 96 Job Number: A755  
Line Name: 4850N Line Number: 0.0 Line Azimuth: 90.0  
Length Units: m Survey Type: Scalar

**CS Transmitter**

Length	Azimuth	Grid East	Grid North
1500.0	90.0	3525.0	-1150.0

Tx Type: Bipole  
Tx-Rx Separation: 6000.

Optional stn file with station, easting, northing, elevation  
Read stn file: csdemo.stn

**Receiver Dipoles**

Length	Azimuth
50.0	90.0

Horizontal Smoothness Weighting: 1.000 Background Model Weighting: 1.000 Observed Error Floor: 5.0 Maximum # of Iterations: 8

Inversion-data file name: C:\Modeling\1\AMT\CSINV\csinvdoc\csdemo.csi

Buttons: Continue, Cancel, Save As

General information about the model may be stored in the three text fields that are displayed at the top of the dialog box. Just below the three descriptive text fields are fields for specific survey annotation parameters; Job Name, Job Area, Job For and Job By are stored as strings in CSINV's \*.csi file namelist block. Text may be up to 128 characters long. Job Number and Job Date are stored in strings of up to 16 characters. Fields for both a string Line Name and a floating-point Line Number are provided. Line "names" may be arbitrary text like "Line A", but floating point line numbers are often required when line and station numbers are used as a two-dimensional coordinate system to recover station easting, northing and elevation values from tables in stn files. The Line Name is usually a text string equivalent of the floating-point Line Number. Line Azimuth is in degrees east of north.

Just below the line properties, three fields are provided for selecting length units, survey type and transmitter type. Length Units allows you to use either metres or feet for describing distances, coordinates and lengths. Survey Type can be scalar, vector or tensor. All three survey types are equivalent in AMT modeling, but differ when inverting CSAMT data. Scalar means one transmitter and one receiver electromagnetic field polarization, vector is used for measurements using one transmitter and two receiver polarizations, while tensor indicates data derived from two transmitter and two receiver polarizations. Transmitter Type specifies the source, either Natural for plane wave or Bipole for a grounded electric bipole.

If a bipole source is selected, then CSINV shows fields with values for transmitter location and orientation. The number of open dialog box fields is adjusted to match the survey configuration specified by survey and transmitter types. Transmitter fields specify transmitter antenna parameters. Antenna length is given in distance units. Transmitter antenna azimuth is given in degrees clockwise from grid north, i.e. an east-west antenna has an azimuth of 90 degrees. The location of the transmitter must be specified with the same grid system used to locate receiver stations.

Receiver azimuth defaults to the transmitter azimuth unless Rx.Azimuth or Rx.HPR are specified in

the \*.mde or \*.avg files. Receiver azimuths are in degrees clockwise from grid north.

The Tx-Rx Distance is displayed for controlled-source reference only. It serves as a check on the validity of Tx center and station coordinates. If the Tx-Rx separation value is implausible, there is likely to be a problem with either station or Tx coordinate values and you should correct the problem before running the inversion. Receiver station positions relative to the transmitter bipole are important in controlled-source modeling.

Station eastings, northings and elevations may be re-imported by clicking on the read station file button.

Use of Horizontal Smoothness Weighting is not implemented in RCSINV v7.00, but future versions will allow you to adjust the importance of horizontal smoothness to control layer variation along line. Horizontal smoothness weighting is stored as dxWeight in the csi file.

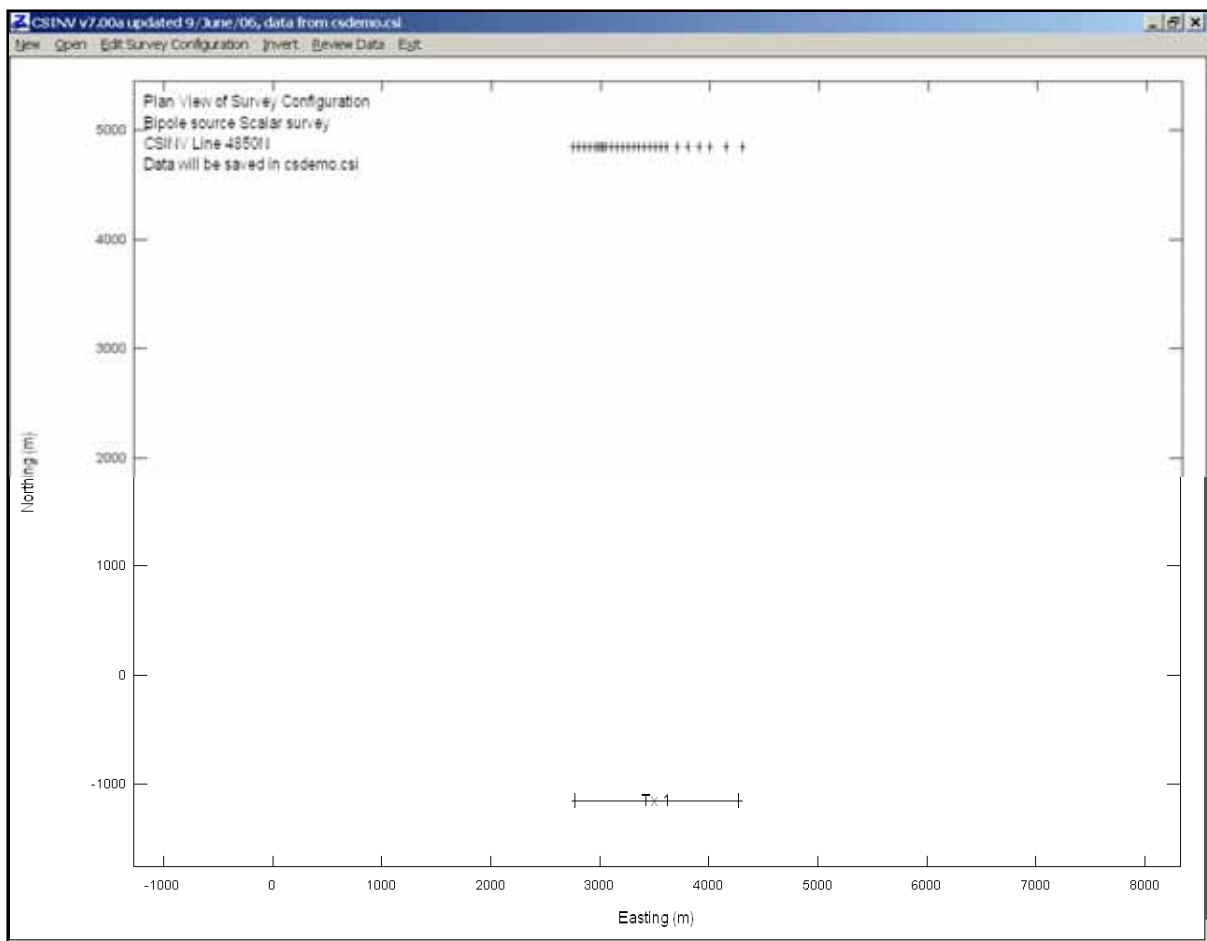
Background Model Weighting allows you to adjust the importance of the background models specified in the Review Data | Edit Layer dialog. Making the value smaller allows the model to move away from background values, while making the value larger forces a more constrained model. The default value of 1.0 is good for most situations, since the Edit Layer dialog allows constraint weighting of individual layer resistivities and thicknesses via percent error values for each layer parameter. Setting a model parameter error to 0 freezes the value of the associated layer parameter during inversion. Background model constraint weighting is stored as dpWeight in the csi file.

Observed Error Floor puts a lower limit on observed errors associated with each data point. Inversion results are often improved by limiting the smallest observed data error to five percent (and 50 mrad). Each calculated - observed data residual is weighted by the inverse of its associated error. Very small measurement errors for some data points can create excessively large weights.

Maximum # of Iterations sets a ceiling on the number of iterations that RCSINV.EXE will perform during inversion. RCSINV.EXE tests for convergence with each iteration and usually stops before the maximum number of iterations is reached.

Inversion-Data File Name allows you to change the \*.csi directory path and file name. The maximum path + file name length is 128 characters. If the \*.csi filename shown is unsatisfactory, clicking on the Save As button brings up an interactive dialog so that you can select a new directory or file name.

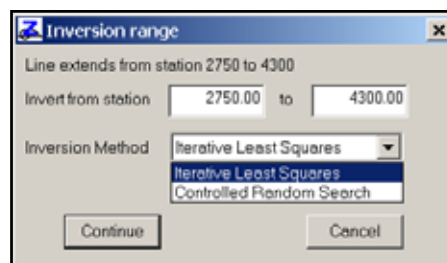
Clicking on the Continue button indicates that you are satisfied with the information showing in the survey configuration dialog and CSINV saves the configuration information to a \*.csi file and writes observed geophysical data to a matching \*.csd file. After csdemo.csi and csdemo.csd are created, CSINV returns to the main menu and shows a schematic plan map of the survey area.



Station locations are indicated with + symbols and controlled-source bipole antennas are shown as straight line segments derived from information in the survey configuration dialog. Transmitter or receiver station-location information may be corrected by selecting the Edit Survey Configuration menu item, which brings up the survey configuration dialog box you encountered while building a new model. Tx coordinates may be corrected by editing values in the Survey Configuration dialog, while problems with station locations can be corrected by editing the station file and re-importing receiver station coordinates with the Read Stn File button.

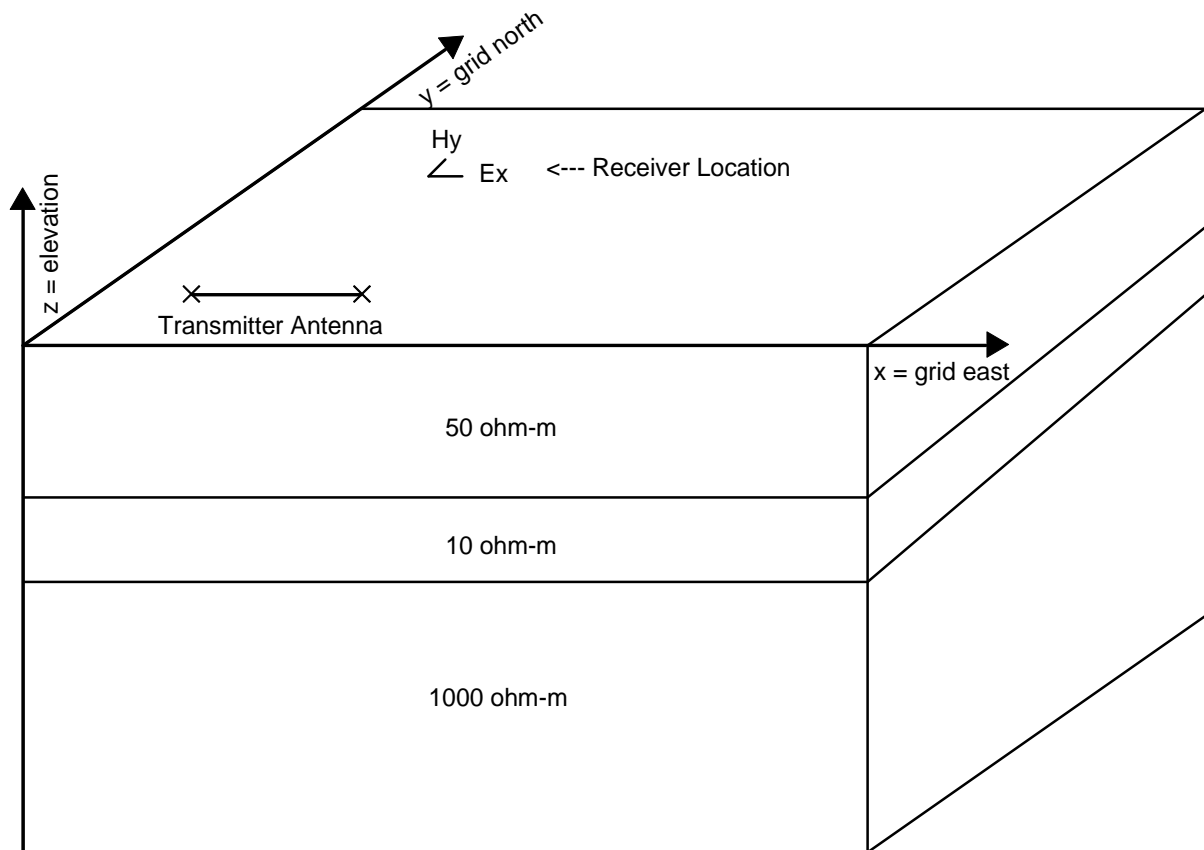
## Running and Inversion

If the plan map shows sounding stations and transmitter in the correct locations, then an inversion may be started by clicking on the Invert menu item. CSINV will show an Inversion Range dialog box with the first and last station set to cover the entire line by default.



Line segments or individual stations can be inverted by setting the station range to bracket the line segment of interest. A menu field allows selection of either Iterative Least Squares or Controlled Random Search inversion methods. Iterative Least Squares minimizes the squared difference between observed and calculated geophysical data and is appropriate for most situations. Controlled Random Search minimizes the absolute value difference between observed and calculated geophysical data, so it is a less sensitive to outlier data point values. Running the inversion twice, once with each method, sometimes helps to improve results. For stations with difficult sounding curves, it also helps to manually edit the layered model with Review Data | Edit Layers and rerun the inversion for that single station. Getting a starting model in the right ball park helps produce a satisfactory inversion result. Click on the Continue button to run the inversion, or Cancel to go back to the main menu.

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  $\log(\text{observed/calculated})$  apparent resistivity and observed - calculated impedance phase.*

RCSINV inverts each station in turn between the StnFirst and StnLast values specified in the \*.csi file. If a matching \*.m1d exists, RCSINV scans it for starting model parameters. If a matching \*.m1d file doesn't exist or there is no starting model present for a particular station, RCSINV will create a starting model using a far-field, direct inversion algorithm.

### Partial log from RCSINV inversion of SCSDEMO.CSI + CSDEMO.CSD:

rcsinv 7.00a updated 9/June/06

Reading file csdemo.csi  
269 data points for 26 stations read from csdemo.csd  
Using iterative least squares inversion.

Inverting model for station 2750.00

Iteration	1,00	Data Residual:	11.006	Minimization Residual:	11.006
Iteration	1,01	Data Residual:	5.251	Minimization Residual:	5.252
Iteration	1,02	Data Residual:	5.945	Minimization Residual:	5.947
Iteration	2,00	Data Residual:	29.448	Minimization Residual:	29.448
Iteration	2,01	Data Residual:	11.459	Minimization Residual:	11.475
Iteration	2,02	Data Residual:	18.917	Minimization Residual:	18.963
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

CSINV's Iterative Least Squares method restarts the inversion from a number of different starting model perturbations to help ensure a thorough search for a good inversion result. In this example, RCSINV.EXE inverts the data held in CSDEMO.SCD and produces two files. CSDEMO.M1D holds its best estimate of model parameters generated by the inversion, while CSDEMO.RSD holds the groups of solutions to allow detailed analysis of correlations between model parameter values and the distribution of inversion model parameter estimates. CSDEMO.CSD is updated with columns of calculated apparent resistivity and impedance phase. After RCSINV has completed its inversion, it passes control back to CSINV.

RCSINV.EXE may also be run directly by typing "RCSINV CSDEMO.SCS" from the command line or from within a batch file. On a large project, is sometimes more efficient to use CSINV to prepare a group of csi files and to then invert them using a batch file with repeated calls to RCSINV, i.e:

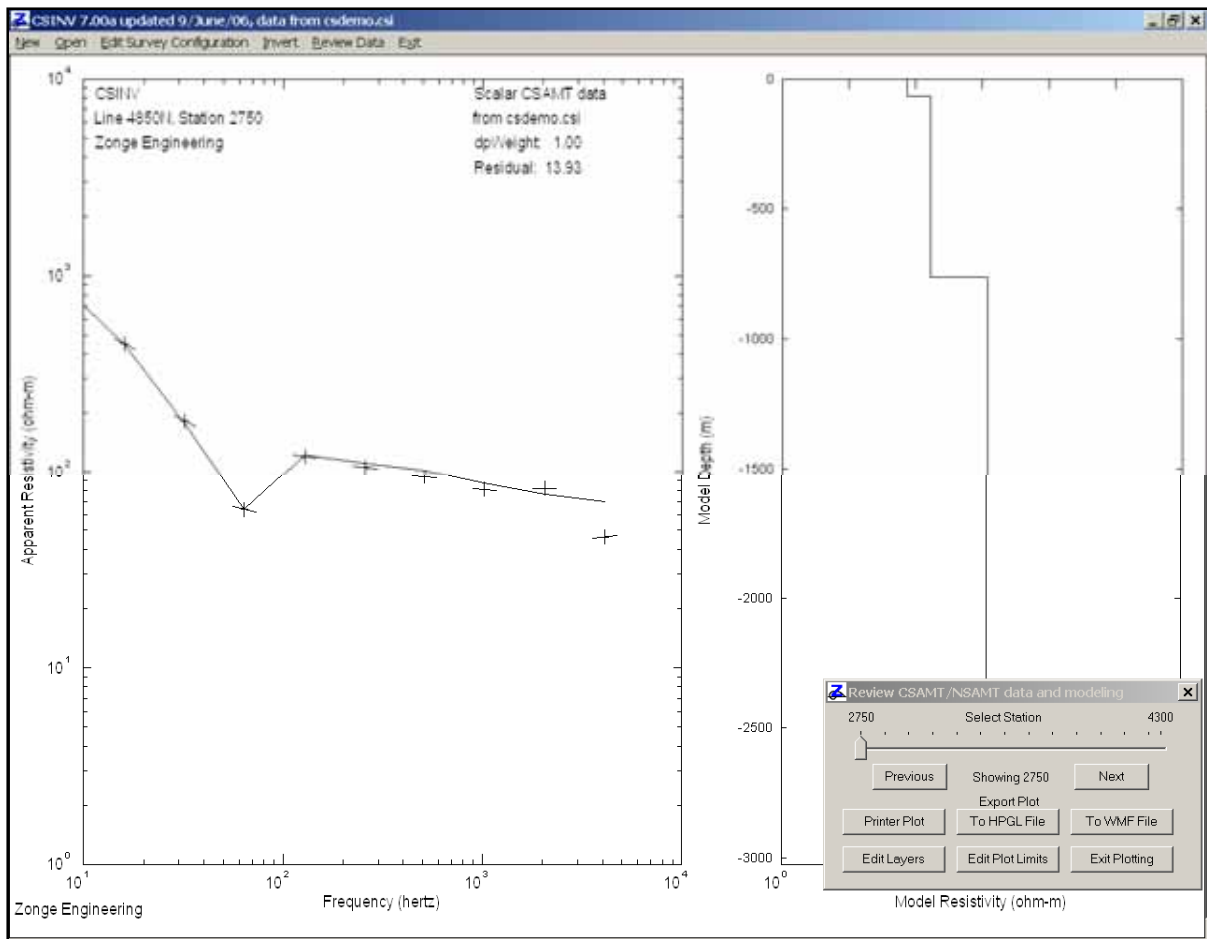
```
start /w rcsinv csdemo.csi
start /w rcsinv yourcsi1.csi
start /w rcsinv yourcsi2.csi
. . . . .
. . . . .
. . . . .
```

The "start /w rcsinv" command starts RCSINV running and instructs the operating system to wait until RCSINV is finished before going to the next line in the batch file. RCSINV looks for file names on its command line, allowing convenient batch file operation.

## Review Data

Inversion results may be evaluated by selecting the Review Data option on the main menu after an inversion is complete. Review Data shows log-log plots of observed and calculated apparent resistivity versus frequency and log-linear plots of model resistivity versus elevation for each station.





In the left plot panel, observed apparent resistivities are marked by the intersection of a sloping horizontal line derived from impedance phase and a vertical line scaled by measurement error. Calculated apparent resistivities are indicated by a solid curve. Layered-earth model resistivities are shown in the right panel as a log-linear plot of resistivity versus depth. 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.

A small dialog box in the lower-right corner of the screen allows control of Review Data plots. Stations may be selected for display by clicking on the Previous or Next buttons or by dragging the trackbar slider with the mouse. (To adjust the trackbar slider, move the mouse cursor over the slider, then hold down the left mouse button while you move the slider sideways.) The dialog box may be moved around on the screen to expose hidden plot sections. Plots may be exported to the printer for hardcopy with the Printer Plot button or saved in plot files for later use with the To HPGL File or To WMF File buttons. CSINV generates plot file names which include sequential numbers indicating each sounding's location along line, starting with 001 for the first station. HPGL (HP graphics language) files can be imported or plotted by many graphics programs. WMF (windows metafile) files may be pasted into MS Word documents and are useful for report writing.

Clicking on the Edit Layers button brings up a dialog for editing layer resistivity, layer thickness, resistivity error and thickness error for the current station.

Layer Properties		Layer Parameter Error		
	Resistivity	Thickness	Res. Error (%)	Thk. Error (%)
1	72.7	64.3	500.0	500.0
2	168.5	696.1	500.0	499.2
3	1207.2		500.0	
4				
5				
6				
7				
8				

Line extends from station 2750 to 4300

Apply this model to stations  to

Layer resistivities are entered in ohm-meters. Layer thicknesses are entered in the survey's length units, either meters or feet. Layer thickness and resistivity errors of layer-parameter values are percentages. A parameter with zero error will not be changed during inversion. Conversely, entering a large percentage error will allow large changes during inversion. At the bottom of the Edit Layer dialog, station range fields are displayed. By default, any changes to layered model parameters are applied only to the current station. However, 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. Selecting Continue accepts any layer parameter changes, while Cancel drops any editing. In either case, program control returns to the Review Data plots.

Clicking on the Review Data's Exit Plotting button returns program control to the main menu. Working from left to right along the main menu options takes you through the model building, inversion and review sequence in an ordered manner. Additional models may be generated by selecting New or you can close CSINV by choosing Exit.

## 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 source 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 – survey annotation, survey configuration, data processing control

Listing of CSDEMO.MDE:

```
$Job.Name="CSINV"  
$Job.For="Zonge International"  
$Job.By="Zonge"  
$Job.Number="A775"  
$Job.Date="Apr 96"  
$Survey.Type=CSAMT  
$Survey.Array=Scalar  
$Unit.Length=m  
$Line.Name="4850N"  
$Line.Number=4850  
$Line.Azimuth=90  
$Stn.GdpBeg=2750  
$Stn.GdpInc=50  
$Stn.Beg=2750  
$Stn.Inc=50  
$Tx.Type=Bipole  
$Tx.Center=3525,-1150,0  
$Tx.Azimuth=90  
$Tx.Length=1500 m  
$Rx.HPR=90,0,0  
$Rx.Length=50 M
```

Mde files hold survey annotation, configuration and 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 ("=") and then one or more comma-separated values. Spaces may be included between elements of a \$program:keyword=value(s) record. Text string values, like the values for Job.Name and Job.Area should be enclosed in quotes, especially if the text string includes any commas.

Stn.GdpBeg, Stn.GdpInc, Stn.Beg and Stn.Inc can be used to shift and scale GDP station numbers (used in raw, legacy-format avg and z files) to a “client” station number system. Stn.GdpBeg and Stn.Beg may be used to define a station number offset, while Stn.GdpInc and Stn.Inc may be used to re-scale the station-to-station increment. A negative Stn.GdpInc or Stn.Inc value will reverse the direction of increasing station numbers. Default station beg and inc values produce no station number shifting or scaling.

Stn.GdpBeg	- first GDP station number (used in raw, legacy avg and z files).
Stn.Beg	- first client station number (client stn #s are used in modeling files and on plots).
Stn.GdpInc	- GDP station number increment.
Stn.Inc	- client station number increment.

The following mode keywords are used by CSINV for default positioning and orientation of the transmitter antenna.

Unit.Length	- length units (m, ft).
Tx.Type	- transmitter type (bipole,loop,natural).
Tx.Length	- transmitter bipole length or loop length and width (length units).
Tx.Azimuth	- transmitter bipole azimuth (deg E of N)
Tx.Center	- transmitter antenna center east, north, & elevation coordinate (length units).
Rx.HPR	- receiver heading,pitch,roll heading = x component in degrees E of N pitch = x component in degrees up from horizontal (usually 0) roll = z component rotation about x, 0 = z+ up, 180 = z+ down
Rx.Length	- receiver dipole length (length units).

## \*.AVG file – averaged CSAMT data and measurement error estimates

A CSAVGW, AMTAVG, NSAVG or MTEDIT \*.avg file contains averaged CSAMT/NSAMT data for discrete frequencies. Avg files are used by programs that provide plot files, options for further data processing, and modeling.

Comment lines preceded by a “\”, “/”, “!” or “”” in column 1 may be placed anywhere within an avg file. \$Keyword=value records flagged by a leading “\$” character are used to store survey configuration and data processing parameters. All lines starting with an alphabet character are assumed to be column-label lines. Column order or the columns present in a particular avg file may vary. Consequently, a column label line must precede any blocks of numeric data. Numeric data are stored in spreadsheet-like blocks of comma- or space-separated values. Missing numeric values are flagged by a “\*”.

### Partial listing of a CSAMT \*.avg file:

\\ AD-AD 7.12: from "755S48.AD", Converted 02 Jan 96  
\\ ASTATIC v3.30e updated skip flags and SRES on 12/06/06

```
$Job.Name="CSINV"
$Job.For="Zonge Engineering"
$Job.By="Zonge"
$Job.Number="A775"
$Job.Date="Apr 96"
$Survey.Type=CSAMT
$Survey.Array=Scalar
$Line.Name="4850N"
$Line.Number=4850
$Line.Azimuth=90
$Stn.GdpBeg=2750
$Stn.GdpInc=50
$Stn.Beg=2750
$Stn.Inc=50
$Stn.Left=2750
$Stn.Right=4300
$Unit.Length=m
$Unit.E=nV/Am
$Unit.B=pT/A
$Unit.Phase=mrad

$Tx.Type=Bipole
$Tx.GdpStn=0
$Tx.Stn=0
$Tx.Center=3525,-1150,0
$Tx.HPR=90,0,0
$Tx.Length=1500 m

$Rx.GdpStn=2750
$Rx.Stn=2750
$Rx.HPR=90,0,0
$Rx.Length=50 m
$Rx.Cmp=ExHy
Skp,Freq,Tx.Amp,E.mag, E.phz, B.mag, B.phz, Z.mag, Z.phz, ARes.mag,SRes, E.wgt,B.wgt, Z.perr,ARes.%err
2, 8, 1, 13705, -3481.6, 73.082, -3503.6, 187.529, 22, 879.18, 879.18, 1, 1, 100, 10
2, 16, 1, 10548, -3837.7, 55.615, -3839.5, 189.661, 1.8, 449.64, 449.64, 1, 1, 100, 10
2, 32, 1, 5582.9, -4121.9, 32.608, -4122.7, 171.212, 0.8, 183.21, 183.21, 1, 1, 100, 10
2, 64, 1, 2195.1, -3476.4, 15.349, -3992, 143.012, 515.6, 63.914, 63.914, 1, 1, 100, 10
2, 128, 1, 2877.7, -2817.7, 10.373, -3483.4, 277.417, 665.7, 120.25, 120.25, 1, 1, 100, 10
```

## CSAMT \*.AVG file keywords:

### Survey annotation

\$Job.Name project name (128 character string)  
\$Job.Area project area (128 character string)  
\$Job.For customer company name (128 character string)  
\$Job.By contractor company name (128 character string)  
\$Job.Number job label or number (16 character string)  
\$Job.Date data acquisition date (16 character string)

### Survey configuration

\$Survey.Type survey type (CSAMT, TEM, CR, TDIP)  
\$Survey.Array array type (for CSAMT: Scalar, Vector, Tensor)  
\$Line.Name line label (16 character string) (alias = JobLine)  
\$Line.Number line number (float)  
\$Line.Azimuth line azimuth (float, deg E of N) (alias = BrgLine)  
\$Stn.GdpBeg first GDP station number (float) (alias = StnBeg)  
\$Stn.GdpInc GDP station number increment (non-zero float) (alias = StnDelt)  
\$Stn.Beg possibly rescaled first station number (float) (alias = LblFrst)  
\$Stn.Inc possibly rescaled station number increment (float) (alias = LblDelt)  
\$Stn.Left rescaled station number on left edge of pseudosection plot (float) (alias=LblFrst)  
\$Stn.Right rescaled station number on right edge of pseudosection plot (float)  
\$Unit.Length length units (m,ft) (alias = Units)  
\$Unit.E electric field units (nV/m,nV/Am)  
\$Unit.B magnetic field units (pT,pT/A)  
\$Unit.Phase phase units (mrad,deg)

### Transmitter properties

\$Tx.Type source type (for NSAMT /CSAMT: Natural, Bipole,Loop)  
\$Tx.GdpStn transmitter ID from GDP Tx field (GDP stn #) (alias = XMTR)  
\$Tx.Stn rescaled Tx ID (rescaled client stn #)  
\$Tx.Center` transmitter center-point easting, northing, elevation (float, length units)  
(aliases = TxCX, TxCY)  
\$Tx.HPR transmitter orientation heading, pitch, roll (Tx heading alias = TxBrg)  
(heading = bipole azimuth, pitch=0, roll=0 for z+up or 180 for z positive down)  
\$Tx.Length transmitter bipole length or square loop width (positive float, length units)

### Receiver properties

\$Rx.GdpStn receiver GDP station number (alias = Station)  
\$Rx.Stn receiver client station number  
\$Rx.HPR EM component heading, pitch, roll (floats, Rx heading alias = RxBrg, ExAzM)  
(heading = x component azimuth in degrees east of north,  
pitch = x component orientation in degrees. up from horizontal,  
pitch = z cmp rotation about x cmp, 0=z+up, 180 = z+ down)  
\$Rx.Length E-field dipole length or loop widths (positive float(s), length units) (alias = aspace)  
\$Rx.Cmp EM component/impedance label  
(ExHx, ExHy, EyHx, EyHy, Zxx, Zxy, Zyx, Zyy, Zvec, Zdet)

**CSAMT avg file column definitions:**

skp	skip flag (0=drop data, 1=skip data, 2=good data)
Freq	frequency (hertz)
Tx.Amp	Tx current (square-wave peak amps), legacy alias Amps
E.mag	electric field magnitude (Unit.E), legacy alias = Emag
E.phz	electric field phase (mrad), legacy alias = Ephz
B.mag	magnetic field magnitude (Unit.B), legacy alias = Hmag
B.phz	magnetic field phase (mrad), legacy alias = Hphz
Z.mag	impedance magnitude (km/sec)
Z.phz	impedance phase (mrad),, legacy alias = Phase
Ares.mag	Cagniard apparent resistivity magnitude (ohm-m), legacy alias = Resistivity
SRes	static-corrected apparent resistivity added by Astatic (ohm-m) , alias = TMARES
E.wgt	electric field weight, -1 indicates polarity flip
H.wgt	magnetic field weight, -1 indicates polarity flip
E.%err	relative  E  error (%), legacy alias = %Emag
E.perr	phase(E) error (mrad) , legacy alias = sEphz
B.%err	relative  H  error (%), legacy alias = %Hmag
B.perr	phase(H) error (mrad) , legacy alias = sHmag
Z.%err	relative  Z  error (%)
Z.perr	phase(Z) error (mrad) , legacy alias = sPhz
ARes.%err	relative apparent resistivity error (%), legacy alias = %Rho
Gdp.Blk	first GDP block number in average
Gdp.Chn	GDP chn1.chn2 analog channel #s
Gdp.Time	data acquisition time (hh:mm:ss)

## \*.Z file – averaged CSAMT data

### Partial listing of z file:

```
$ ZPLOT: DATA = FLOG
$ ZPLOT: AXSTN = Vertical
$ ZPLOT: SIZEX = 1.0
$ ZPLOT: SIZEY = 1.0
$ ZPLOT: PLTREV = No
Contour Plot Z-File
Cl Cn Ce Ns Nd Yl Plot file 1
 1 5 0 3 1 1
CSAMT ExHy DATA
CAGNIARD APP. RES.
values in ohm-m
Data from csdemo.avg
$ TXID = 0
$ TXLEN = 1500 m
$ TXBRG = 90
$ TXCX = 3525 m
$ TXY = -1150 m
$ ASPACE = 50 m
$ RXBRG = 90
IIxxxxxxxxYYYYYYYzzzzzzzzzzzz
 2 2750 12 8.7918E+02
 2 2750 13 4.4964E+02
. . . .
. . . .
. . . .
 2 4300 20 1.5325E+02
 2 4300 21 1.6158E+02
9999.00
Cl Cn Ce Ns Nd Yl Plot file 2
 0 10 3 3 0 1
CSAMT ExHy DATA
IMPEDANCE PHASE
values in milliradians
IIxxxxxxxxYYYYYYYzzzzzzzzzzzz
 2 2750 12 22
. . . .
. . . .
. . . .
 2 4300 20 983.7
 2 4300 21 957.7
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 = 60.960 m - receiver dipole length  
AMTAVG 7.20 - program name and version that generated this file.  
CI Cn Ce Ns Nd YI - labels for integer contour control flags.  
CI - label for contour type: 0 = linear  
1 = logarithmic  
2 = pseudo-log: Pseudo-log contours = positive and negative values are contoured separately, using  $\log_{10}(\text{abs}(\text{value}))$ , plus a zero contour.  
Cn - label for number of contours per interval.  
Ce - label for exponent of the contour interval,  $\text{interval}=10^{\text{Ce}}$ .  
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.  
YI - 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 CI => logarithmic contours  
5 - value of Cn => 5 contours per "interval"  
0 - value of Ce =>  $\text{interval}=10 \leq \text{Ce}=1$   
3 - value of Ns => use 3 significant digits for contouring  
1 - value of Nd => plot 1 digit after the decimal  
1 - value of YI => 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  
llxxxxxxxxYYYYYYYYzzzzzzzzzzzz - Header line for the data that follows.  
ll - 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.  
xxxxxxx - x value field, usually unscaled and unshifted station numbers.  
YYYYYYYY - y value field, for CSAMT  $y=\log_2(\text{freq})-9$ , not used when skip flag = 3  
zzzzzzzzzz - 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**

### **Partial Listing of CSDEMO.STN:**

```
Station, East, North, Elevation
2750, 2750, 4850, 950.0
2800, 2800, 4850, 961.4
2850, 2850, 4850, 977.4
2900, 2900, 4850, 997.2
2950, 2950, 4850, 1019.7
3000, 3000, 4850, 1043.4
3050, 3050, 4850, 1066.7
3100, 3100, 4850, 1088.2
3150, 3150, 4850, 1106.2
3200, 3200, 4850, 1119.8
3250, 3250, 4850, 1128.2
3300, 3300, 4850, 1131.0
3350, 3350, 4850, 1128.5
.      .      .      .
.      .      .      .
4200, 4200, 4850, 1098.8
4250, 4250, 4850, 1093.4
4300, 4300, 4850, 1082.7
```

stn files hold information about station locations in a tabular format. A stn file should have at least two numerical records, 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 stn file entry. If station numbers are scaled by entries in the mde file, stn-file station numbers should be in the scaled and shifted client value defined by the keywords Stn.Beg and Stn.Inc, not the GDP station numbers defined by Stn.GdpBeg, Stn.GdpInc. For most surveys it is not an issue as GDP and client station numbers are the same. A column label line is recommended, but if one is not present, CSINV assumes columns of station, easting, northing and elevation.

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

### **stn file column definitions:**

Station	- station numbers. Station numbers should increase monotonically, proportional to distance along line.
East	- grid east (length units).
North	- grid north (length units).
Elevation	- elevation (length units).

## Appendix B: CSINV File Documentation

### \*.CSI file – survey configuration and inversion control

#### Listing of CSDEMO.CSI:

```
&CSINV
Header(1)="From CSINV v7.00a  Date:12/06/06  Time:16:14:18"
Header(2)="CSINV  Line 4850N"
Header(3)="for Zonge Engineering"
Header(4)="Data from csdemo.z"
JobName="CSINV"
JobArea=" "
JobBy="Zonge"
JobFor="Zonge Engineering"
JobNumber="A775",JobDate="Apr 96"
LineName="4850N",LineNumber=4850,LineAzimuth=90
SurveyType="Scalar",TxType="Bipole",LengthUnits="m"
TxLength(1)=1500,TxAzimuth(1)=90,TxGridE(1)=3525,TxGridN(1)=-1150
RxLength(1)=50,RxAzimuth(1)=90
StnFirst=2750.00,StnLast=4300.00
ErrFloor=5.00
InvMethod=2
dpWeight=1.00,dxWeight=1.00,Niteration=8
/
```

Parameters in \*.csi files are saved in a FORTRAN namelist format. Parameter ordering is not important and if an input parameter is missing, CSINV attempts to assign a reasonable default value. Csi 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 (up to 80 chr string).
JobName	- project name (up to 128 character string).
JobArea	- project geographic area (up to 128 character string).
JobFor	- client name (up to 128 character string).
JobBy	- contractor name (up to 128 character string).
JobNumber	- project ID number (up to 16 character string).
JobDate	- data acquisition date (up to 16 character string).
LineName	- line label (up to 16 character string)
LineNumber	- floating point line number (line,stn) = coordinate pairs
LineAzimuth	-- direction of increasing stn numbers (deg east of north)
LengthUnits	- character, distance units (m or ft).
SurveyType	- character, 'Scalar', 'Vector', 'Tensor' or 'Natural'.
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).
ErrFloor	- minimum observed data error for inversion data weighting (% ,mrad)
InvMethod	- enumeration index (1=iterative least squares, 2=controlled random search)
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:

```
"Stn","GridE","GridN","Elev","Freq","ARobs","ARerr","ZPobs","ZPerr","ARcalc","ZPcalc"
"From RCSINV v7.00a Date:12/06/06 Time:16:18"
2750, 2750, 4850, 950, 8, 879.2, 1, 22, 10, 886.8, 50
2750, 2750, 4850, 950, 16, 449.6, 1, 2, 10, 449.3, 16
2750, 2750, 4850, 950, 32, 183.2, 1, 1, 10, 178.5, -2
2750, 2750, 4850, 950, 64, 63.91, 1, 516, 10, 61.73, 534
2750, 2750, 4850, 950, 128, 120.2, 1, 666, 10, 120, 672
2750, 2750, 4850, 950, 256, 105.4, 1, 657, 10, 107.1, 644
2750, 2750, 4850, 950, 512, 93.93, 1, 659, 10, 94.54, 624
2750, 2750, 4850, 950, 1024, 80.68, 1, 681, 10, 78.75, 623
2750, 2750, 4850, 950, 2048, 81.72, 1, 786, 10, 66.31, 651
2750, 2750, 4850, 950, 4096, 46.12, 1, 914, 10, 58.98, 707
2800, 2800, 4850, 961.4, 8, 401.3, 1, 17, 10, 416.8, 39
. . . . .
. . . . .
. . . . .
4300, 4300, 4850, 1082.7, 256, 86.3, 1, 970, 10, 88, 994
4300, 4300, 4850, 1082.7, 512, 103.1, 1, 967, 10, 105.7, 973
4300, 4300, 4850, 1082.7, 1024, 122.4, 1, 954, 10, 122.2, 957
4300, 4300, 4850, 1082.7, 2048, 153.3, 1, 984, 10, 142.2, 956
4300, 4300, 4850, 1082.7, 4096, 161.6, 1, 958, 10, 170.5, 939
```

\*.csd files hold observed and calculated CSAMT/NSAMT 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 to 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).  
ZPerr - Impedance phase measurement error (mrad).  
ARcalc - Calculated apparent resistivity (ohm-m).  
ZPcalc - Calculated impedance phase (mrad).

## **\*.M1D file – layered model parameters**

### **Partial listing of CSDEMO.M1D:**

```
"Stn","GridE","GridN","Zinv","ResInv","Zerr0","Rerr0","Zerr","Rerr","APRE"
"From RCSINV v7.00a Date:12/06/06 Time:16:18"
2750, 2750, 4850, 950, 61.578, 0, 500, 0, 9, 1.401
2750, 2750, 4850, 893.254, 61.578, 500, 500, 22, 9, 1.401
2750, 2750, 4850, 893.244, 175.31, 500, 500, 22, 20, 1.401
2750, 2750, 4850, 172.873, 175.31, 463, 500, 15, 20, 1.401
. . . . .
. . . . .
4300, 4300, 4850, 257.081, 27.807, 369, 500, 2, 2, 0.657
4300, 4300, 4850, 257.071, 1494.3, 369, 500, 2, 5, 0.657
4300, 4300, 4850, -1235.745, 1494.3, 131, 500, 1, 5, 0.657
```

\*.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 to 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).