

SCSINV

DOCUMENTATION

ZONGE Data Processing
Smooth-Model CSAMT Inversion
version 2.20

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SCSINV

Table of Contents

Introduction	5
Installation	6
Minimum Hardware Configuration	6
Installation Procedure	6
Graphics Configuration	9
Program Use	10
Overview	10
Typical SCSINV Modeling Sequence	12
Partial log from RCSINV inversion of SCSDEMO.SCS	17
RSCSINV inversion criteria	18
References	21
Data Processing File Documentation	22
MDE file (Survey annotation, configuration and processing control file)	22
AVG file (CSAVGW averaged data file)	24
Z file (ZPLOT plotting data file)	27
STN file (station location and elevation)	29
SCSINV File Documentation	30
SCS file (inversion control and observed data input file)	30
M1D file (smooth-model resistivity output file)	32
OBS file (observed and calculated data output file)	33

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Introduction

Smooth-model inversion is a robust method for converting CSAMT measurements to models of resistivity versus depth. Observed apparent resistivity and impedance phase data for each station are used to determine the parameters of a layered-earth model. Layer thicknesses are fixed before the inversion starts by calculating source-field penetration depths for each frequency. Layer resistivities are given a uniform starting value based on controlled-source apparent resistivities. During the inversion, layer resistivities are adjusted iteratively until the calculated CSAMT response is as close as possible to observed data, consistent with smoothness constraints. Including smoothness constraints in the inversion limits resistivity variation from layer to layer and produces a model with smoothly varying resistivities.

SCSINV's forward-modeling algorithm can include the effects of finite transmitter-receiver separation and a three-dimensional source field. Source types include a vertically incident plane wave for natural source modeling and grounded electric bipole or horizontal loop sources for CSAMT modeling. Accurate impedance magnitude and phase values are calculated for all frequencies and transmitter-receiver separations. Impedances can be calculated for scalar, vector or tensor survey configurations.

Lateral variation is determined by inverting successive stations along a survey line to produce a grid of smooth-model resistivity. Resistivity values are placed at the midpoint of each layer, forming a column below every station. The columns form an array representing a cross-section of model resistivity. Results for a complete line can be presented in pseudosection form by contouring model resistivities.

Inverting apparent resistivity and impedance phase to smoothly varying model resistivities is an effective way to display the information inherent in CSAMT measurements. Smooth-model inversion does not require any a priori estimates of model parameters. The data are automatically transformed to resistivity as a function of depth. Models with smoothness constraints are complementary to more detailed models incorporating specific geologic information.

Installation

Minimum Hardware Configuration

The minimum hardware configuration needed to operate SCSINV is a PC 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.

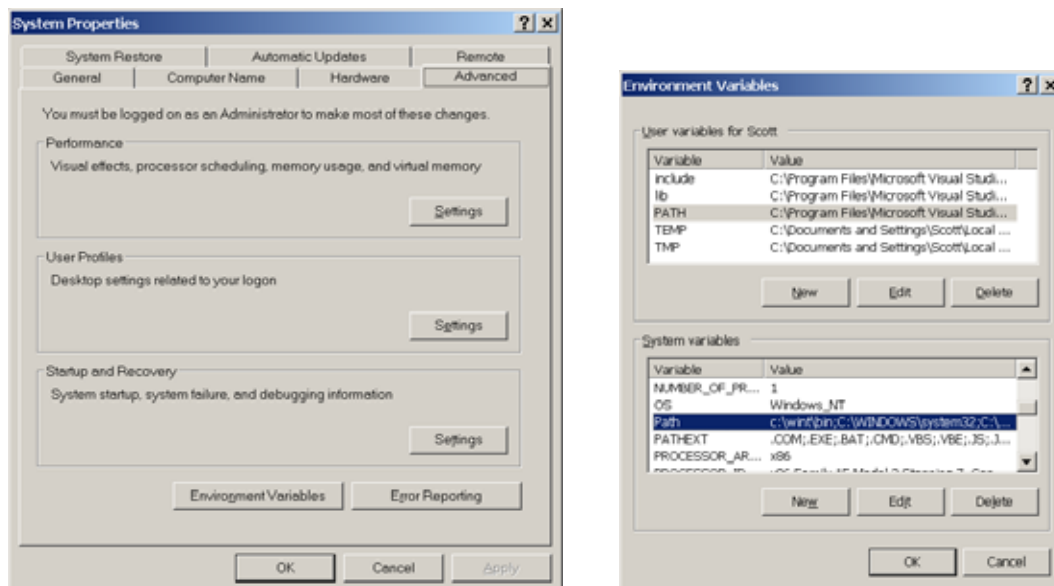
Installation Procedure

Each distribution copy of SCSINV programs may be installed on more than one computer, but it comes with 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 SCSINV and hardware lock software is installed, dongles may be moved from one computer to another, but 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 SCSINV 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, SCSINV may be run from the command line, from the start menu or from a Windows desktop shortcut.

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

SCSINV program files:

- | | |
|-------------|---|
| SCSINV.EXE | - shell to build and review models. |
| RSCSINV.EXE | - smooth-model CSAMT inversion program. |
| SCSREG.EXE | - registration program. |

Sample data files:

- | | |
|-------------|--|
| SCSDEMO.MDE | - survey annotation and configuration information. |
| SCSDEMO.AVG | - observed data and estimated measurement error. |
| SCSDEMO.STN | - station grid locations and elevations. |
| SCSDEMO.SCS | - inversion control and data RSCSINV input file. |
| SCSDEMO.M1D | - smooth-model resistivity model RSCSINV output file. |
| SCSDEMO.OBS | - smooth-model observed and calculated data RSCSINV output file. |

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

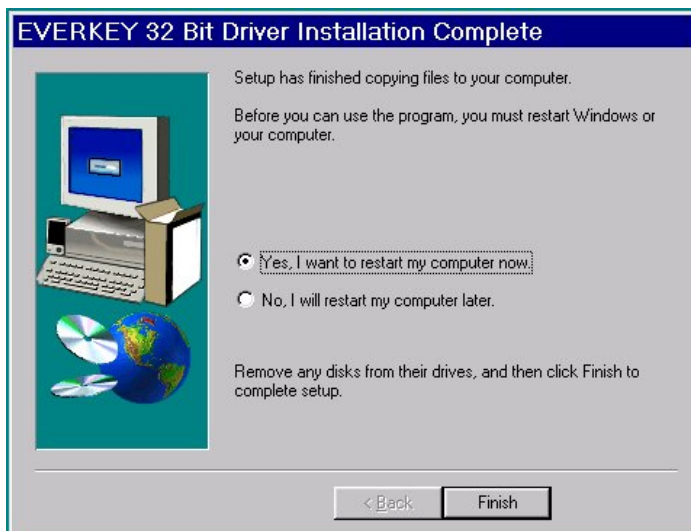
A parallel-port hardware lock or dongle is required for computers running Window. Using SCSINV's hardware-lock registration system requires additional configuration steps. If your program comes with a parallel-port hardware lock, install it by turning off power to your computer and printer. Unplug the parallel-port printer cable from the back of your computer and plug the hardware lock into your computer's 25-pin parallel or USB ports. 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 SCSINV. If you have more than one parallel port, it makes no difference which one you use.

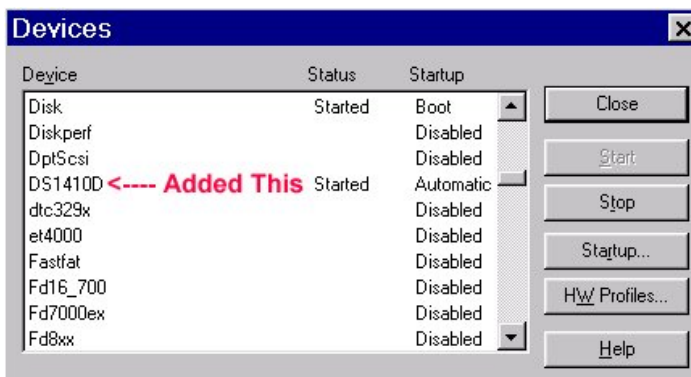
Note that you must ensure the end of the hardware lock labeled "Computer" is connected to your computer's parallel port. It is possible to plug the hardware lock in backwards, which may damage the hardware lock, the parallel port or both.

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 SCSREG from the SCSINV hard-disk directory. You should see text like:

Registered to: Alaska Earth Sciences Serial # 1099
Copyright 1999 Zonge Engineering
All Rights Reserved.

A software registration check is done every time RSCSINV is initiated. RSCSINV calls SCSREG to check for valid software registration. Key-disk systems make a software check, while hardware-lock systems look for an appropriate hardware key or "dongle" in the parallel port.

Graphics Configuration

SCSINV expects VGA, SVGA or XVGA 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 MODSECT (v4.20d or higher) and its associated files may be used to plot model sections. MODSECT shows model section plots on screen and can export plots to windows metafiles, write script and data files for Oasis Montage, or write script and data files for Surfer v6.0. MODSECT documentation details its hardcopy plot options.

Program Use

Overview

SCSINV is a pair of programs for inverting CSAMT data into a smoothly varying model. SCSINV.EXE is a shell program providing utility functions for building and reviewing inversion models, while RSCSINV.EXE is the core inversion program. RSCSINV can either be run from within SCSINV, from the command line or from a batch file.

Information is exchanged between programs via ASCII text data files which may be externally edited if necessary for special projects. Both programs look for file names on the command line. File-name extensions are used to flag the file type, i.e., avg files end with the extension ".AVG" and station location files end with the extension ".STN". RSCSINV.EXE input files end with the extension ".SCS" and RSCSINV.EXE produces m1d and obs files. m1d files hold inverted model parameters and obs files hold observed and calculated CSAMT/NSAMT data.

Observed data are prepared for inversion using the shell program, SCSINV.EXE. SCSINV can read observed CSAMT data from Zonge format avg or z files. avg files are preferable because they include information about measurement error. Survey configuration information, such as transmitter bipole location, length and orientation, are read from mde files. Station location coordinates may be input from optional stn files. After collecting information from these diverse source files, SCSINV sorts the observed data and saves it in a scs file.

RSCSINV.EXE, the core inversion program, reads scs files, inverts observed data, and writes inverted results in a m1d file holding model resistivity versus station location and depth. RSCSINV saves both observed and calculated data in an obs file. The tabular format used in m1d and obs files is directly useable by most general purpose contouring programs. Zonge utility program MODSECT may be used to produce color filled model sections on-screen, exported to wmf or hppl plot files, printed via the Windows print manager, plotted with Surfer or plotted with Oasis montaj.

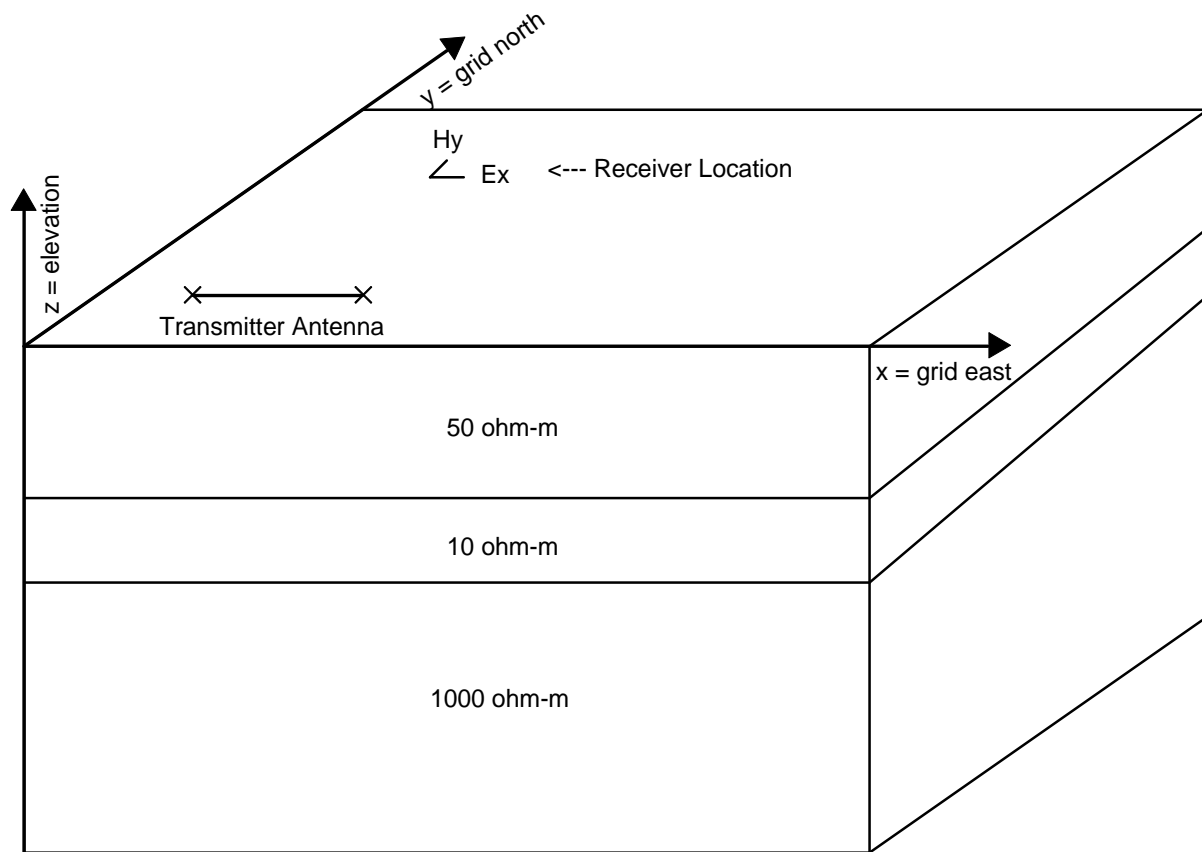
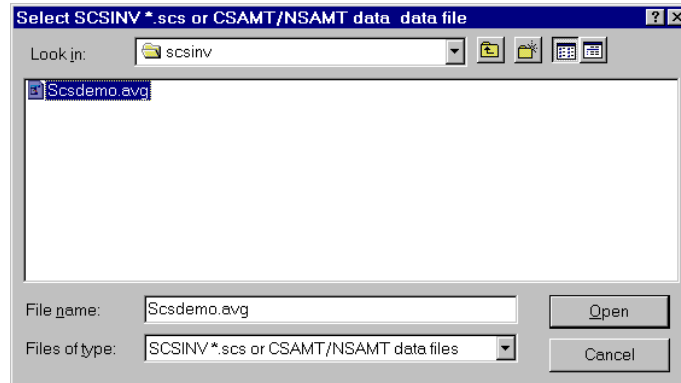


Figure 1: SCSINV uses a right-handed coordinate system. Positive x corresponds to grid east, positive y corresponds to grid north, and z corresponds to elevation. Distances are specified in meters or feet and azimuths are given in degrees clockwise from grid north. Observed data are apparent resistivity and impedance phase measured at a number of frequencies. Data are usually grouped by line, one line per file. SCSINV can model scalar data using one transmitter and two perpendicular components of E and H, vector data using one transmitter and four components of E and H or tensor data using two transmitters and four components of E and H. Source types include plane wave, grounded electric bipole or horizontal loop.

Typical SCSINV Modeling Sequence

Start SCSINV by type "SCSINV " on the command line, by running SCSINV.EXE from the Start menu or with a Windows shortcut. SCSINV will create a dialog box showing all files with .scs, .avg or .z extensions. Selecting a scs file will open an existing SCSINV model. Selecting an avg or z file holding CSAMT or NSAMT data will put SCSINV to building a new model file.



Choosing the sample file `scsdemo.avg` and clicking on the OK button indicates that you are ready to build a SCSINV input file. SCSINV first reads survey annotation and configuration information from an optional `mde` file. Sample file `scsdemo.mde` includes information about length units, GDP to client station number scaling, transmitter length, Tx orientation and Tx center location. All lengths and distances should be in the length units specified by the `mde`-file keyword `Unit.Length`. Avg files created by the Zonge data processing program include survey configuration keyword records, making `*.mde` files less critical. Survey configuration values in the avg file will replace any values read from a `mde` file. SCSINV shows survey configuration values in a dialog box, giving you a chance to verify and edit the survey configuration.

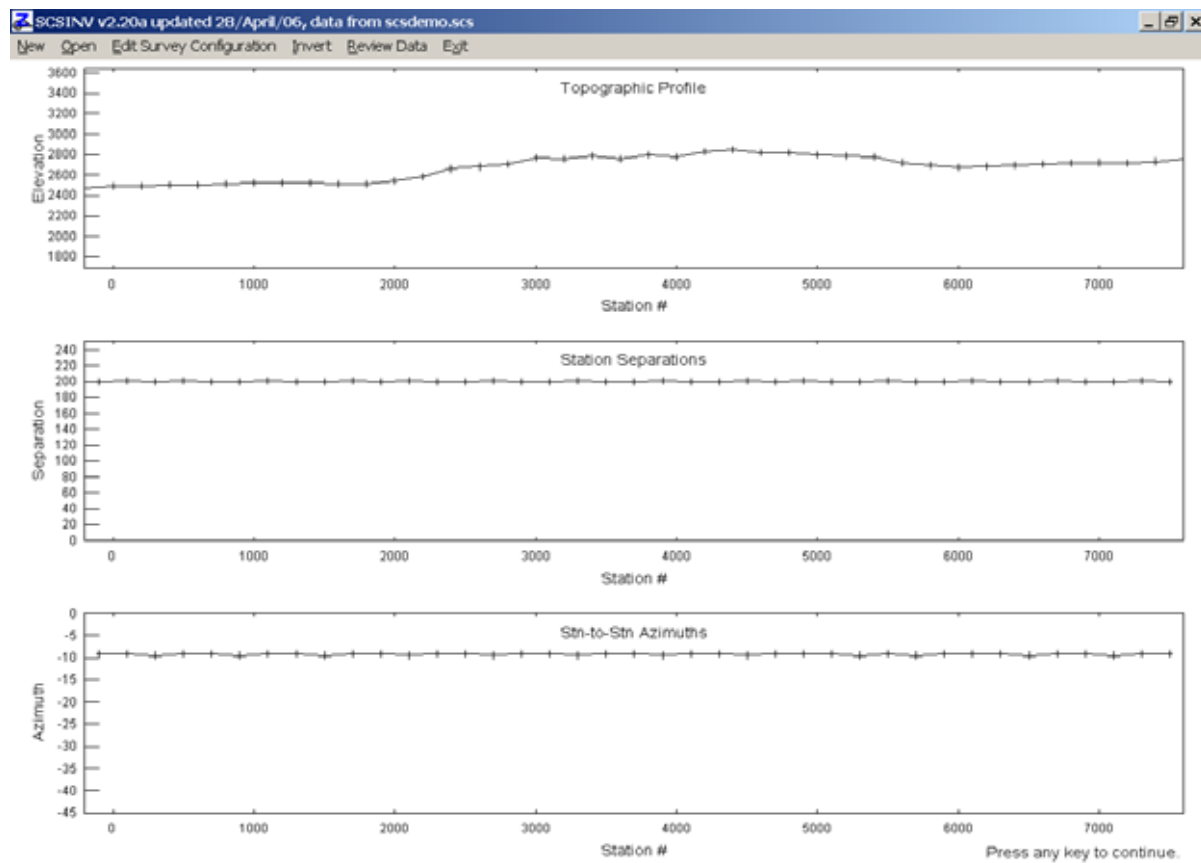
A mechanism for linear shifting and scaling of GDP to "client" station numbers is provided in `mde` and `avg` files using keywords `Stn.GdpBeg`, `Stn.GdpInc`, `Stn.Beg` and `Stn.Inc`. `Stn.GdpBeg` and `Stn.GdpInc` specify the first GDP station number on the line and the station-to-station increment. GDP station numbers are used in `avg` and `z` files. `Stn.Beg` and `Stn.Inc` define the first client station number and station-to-station increment. Client station numbers are used on plots, in `stn` files and in all modeling program files. In most cases GDP and client station numbers are the same.

SCSINV reads CSAMT or NSAMT data from Zonge format `.avg` or `.z` files. `Scsdemo.avg` includes GDP station number, frequency, apparent resistivity, impedance phase, resistivity error and phase error values. If a column of static-corrected apparent data is present in the `avg` file, SCSINV prompts you to choose either uncorrected or static-corrected values. Static-corrected apparent resistivities usually suppress the effects of near-surface features and clarify deeper structure. Inversions are often run on both uncorrected and static-corrected data sets. Controlled-source apparent resistivity data should be left in Cagniard apparent resistivity form, not "corrected" for near-field effects, since RSCSINV's forward-modeling algorithm includes the effects of three-dimensional source fields and a finite transmitter-receiver separation.

Avg files are the preferred source for observed data, since they include measurement error information. However, SCSINV can also read Zonge format `z` files which hold CSAMT or AMT apparent resistivity and impedance phase data. Z files must include matching apparent resistivity and impedance phase data blocks. Z files do not include observed-data error estimates, so apparent resistivities are given a uniform measurement error of 5 percent and impedance phase an error of 50 mrad.

SCSINV gets station location information either from values recorded in the avg file or from optional stn files, which have columns of client station number, grid east, grid north and elevation. Station numbers should be in the final or “client” station number system, which may be different from GDP station numbers if $\text{Stn.GdpBeg} \neq \text{Stn.Beg}$ or $\text{Stn.GdpInc} \neq \text{Stn.Inc}$. Station numbers represent distance along a line. Station number distances may be irregular due to topography or surveying error, so SCSINV interpolates coordinates between tabulated station locations to fill in missing information. The minimum number of entries in a stn file are two points, the locations of the line’s first and last stations. Stn file grid coordinates should be in the same length units used to specify transmitter and receiver dipole lengths. If no topographic information is available, stn file elevations may be set to zero. SCSINV then returns a model with layer mid-points specified relative to the ground’s surface. Importing station location information from a stn file is highly recommended, but if no station file is present, SCSINV use default station location values.

After reading data from a *.stn file, SCSINV shows a plot with three profile panels with plot parameters selected to highlight any glaring errors in stn file values.



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 plots as a large profile excursion.

After reading observed data and survey configuration information, SCSINV displays survey configuration parameters in an interactive dialog.

Edit survey configuration

Descriptive Text

North Silverbell Line 28
for Zonge Engineering
Data from C:\Modeling1\AMT\Scsinv\Scsinv\scsdemo.bvg

Job Name: North Silverbell
Job Area: Tucson
Job For: Zonge Engineering
Job By: Zonge
Job Date: Nov 93 Job Number: 9309
Line Name: 28 Line Number: 28.0 Line Azimuth: 100.0
Length Units: ft Survey Type: Scalar

CS Transmitter

Length	Azimuth	Grid East	Grid North
5000.0	100.0	80700.0	89200.0

Tx Type: Bipole
Tx-Rx Separation: 1.7054E+04

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

Receiver Dipoles

Length	Azimuth
50.0	100.0

Horizontal Smoothness Weighting: 1.000
Vertical Smoothness Weighting: 2.000
Observed Error Floor: 5.0
Maximum # of Iterations: 10

Inversion-data file name: C:\Modeling1\AMT\Scsinv\Scsinv\scsdemo.scs

Continue Cancel Save As

General information about the model may be stored in 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, Area, For and By are stored as strings in SCSINV's *.scs file namelist block. Text may be up to 128 characters long. Job Number and Job Date text is stored in strings of up to 16 characters. Fields for both a string Line Name and a floating-point Line Number are provided. Line "numbers" may often 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. 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, Natural for plane wave, Bipole for grounded electric bipole or Loop for a horizontal loop.

If a bipole or loop controlled source is selected, then SCSINV shows fields with values for transmitter location and orientation. The number of 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 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 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 or loop are important in controlled-source modeling.

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

Horizontal Smoothness Weighting allows you to adjust the importance of horizontal smoothness. Making the value smaller allows the model to vary more from station to station. Making the value larger forces a smoother model. The default value of 1.0 is good for most situations. Horizontal smoothness weighting is stored as dxWeight in the scs file namelist block.

Vertical Smoothness Weighting allows you to adjust the importance of vertical smoothness. Making the value smaller allows the model to vary more from layer to layer, while making the value larger forces a smoother model. The default value of 1.0 is good for most situations. A more thorough approach is to invert a data set using several different values of to examine the tradeoff between fitting observed data and maintaining model smoothness (see figure 2). Vertical smoothness weighting is stored as dzWeight in the scs namelist block.

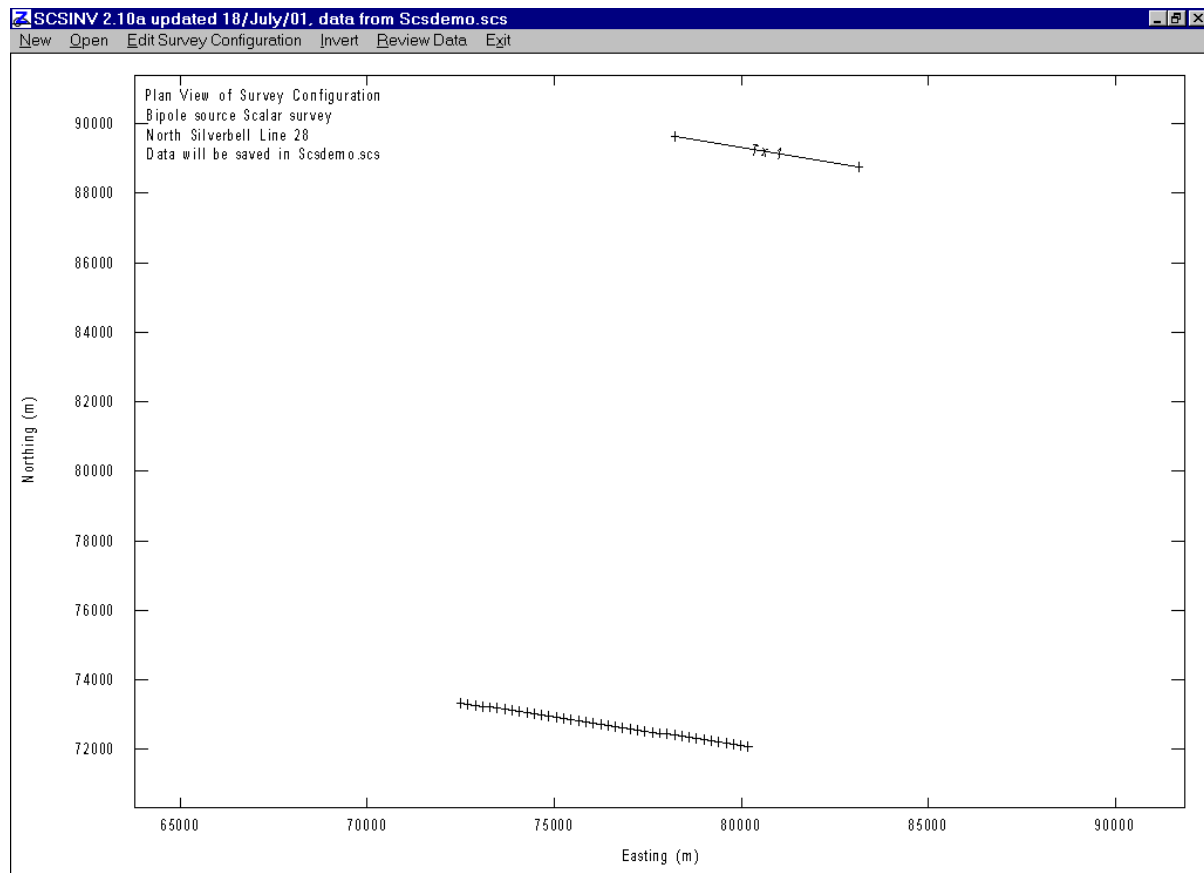
Observed Error Floor puts a lower limit on observed errors associated with each data point. Inversion results are often improved by limiting the smallest observed data error to five percent (and 50 mrad). Each calculated - observed data residual is weighted by the inverse of its associated error. Very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

Maximum Number of Iterations sets a ceiling on the number of iterations that RSCSINV.EXE will take during inversion. RSCSINV.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 scs directory path and file name. The maximum path + file name length is 128 characters. If the scs 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 OK button indicates that you are satisfied with the information showing in the survey configuration dialog and SCSINV saves the information plus observed data to a scs file.

After SCSDEMO.SCS is created, SCSINV 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 or loop 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.

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. When Invert is selected, SCSINV starts program RSCSINV to do the numerically intensive work of inverting the data set to a smooth-model section.

Partial log from RSCSINV inversion of SCSDEMO.SCS:

```
rscsinv 2.20a updated 28/April/06
Reading model parameter data from Scsdemo.scs
Reading observed data from Scsdemo.scs
Computing starting model . . .
```

```
Station      -200.    Sweep  1  Iteration  0
Data Residual:  15.360    Minimization Residual:  15.360
```

Layer	Depth	Resistivity
2	79.6	288.8
4	221.0	288.8
6	419.5	288.8
8	698.2	288.8
10	1089.5	288.8
12	1638.8	288.8
14	2410.0	288.8
.	.	.
.	.	.
.	.	.

SCSINV sweeps back and forth along line, making a few iterations at each station, until the maximum number of sweep iterations (parameter Niteration in the scs file) has been reached.

In this example, RSCSINV.EXE inverts the data held in SCSDEMO.SCS and produces two files. SCSDEMO.M1D holds the smooth model parameters generated by the inversion (station, station location, elevation, model resistivity, model error and model sensitivity). SCSDEMO.OBS holds observed and calculated data in a tabular spreadsheet format. After RSCSINV has completed its inversion, it passes control back to SCSINV.

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

```
start /w rscsinv scsdemo
start /w rscsinv yourscs1.scs
start /w rscsinv yourscs2.scs
. . . . .
. . . . .
. . . . .
```

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

RSCSINV Inversion Criteria

RSCSINV attempts to simultaneously minimize both the difference between observed and calculated data, the difference between starting and inverted model parameters and inversion model roughness. These differences are mathematically summarized by sums of squared differences:

$$\begin{aligned}\epsilon_{\text{total}} &= \sqrt{(\epsilon_{\text{data}}^2 + \epsilon_{\text{model}}^2) / \text{nobs}} \\ \epsilon_{\text{data}}^2 &= \sum_{i=1}^{\text{nobs}} \left(\frac{d_{\text{obs}_i} - d_{\text{mod}_i}}{d_{\text{err}_i}} \right)^2 \\ \epsilon_{\text{model}}^2 &= dpW^2 \cdot \sum_{i=1}^{nz} \sum_{j=1}^{nx} \left(\frac{p_{i,j}^k - p_{i,j}^0}{p_{\text{err}_{i,j}}} \right)^2 + dxW^2 \cdot \sum_{i=1}^{nz} \sum_{j=2}^{nx} (p_{i,j}^k - p_{i,j-1}^k)^2 + dzW^2 \cdot \sum_{i=2}^{nz} \sum_{j=1}^{nx} (p_{i,j}^k - p_{i-1,j}^k)^2\end{aligned}$$

where

nobs = number of observed data values.

d_{obs_i} = observed log(apparent resistivity) or impedance phase.

d_{mod_i} = calculated log(apparent resistivity) or impedance phase.

d_{err_i} = observed data error.

nx = number of stations in inversion model.

nz = number of layers per station in inversion model.

$p_{i,j}^0$ = starting model parameter, log(resistivity).

$p_{i,j}^k$ = inversion model parameter at iteration k, log(resistivity).

$p_{\text{err}_{i,j}}$ = inversion model error, log(resistivity).

dpW = dpWeight, relative weight given to starting model.

dxW = dxWeight, relative weight given to horizontal smoothness constraint.

dzW = dzWeight, relative weight given to vertical smoothness constraint.

RSCSINV reports $\epsilon_{\text{data}}/\sqrt{\text{nobs}}$ and ϵ_{total} for a station after each inversion iteration. Model updates are not accepted if they increase ϵ_{total} . If an inversion step fails to improve ϵ_{total} , RSCSINV tries again using a more cautious step size. RSCSINV iterates on one station at a time, minimizing ϵ_{total} for that station and its horizontal smoothness relative to neighboring stations. RSCSINV makes a few iterations at each station, then moves on to the next, sweeping back and forth along line a total of Niteration times.

Starting model importance can be increased or decreased by adjusting dpWeight in scs files. Default SCSINV starting-models are not weighted heavily. Starting-model resistivities are given an estimated error of 500 percent which is equivalent to $p_{\text{err}_{i,j}} = 1.8 \log(\text{ohm-m})$ in the definition of ϵ_{model} .

Model smoothness can be varied by changing the weight of dxWeight and dzWeight sums in ϵ_{model} relative to the sum of (observed - calculated data)² in ϵ_{data} . Increasing dzWeight by a factor of 10 in a scs file and then rerunning RSCSINV, increases the relative weight of the model's vertical smoothness constraint by a factor of 100, since dzW is squared in the definition for ϵ_{model} .

Horizontal smoothness can be increased or decreased by adjusting dxWeight in scs files. Increasing horizontal smoothness might be desirable if data are collected in an area with flat lying geology.

The tradeoff between fitting observed data values and keeping the model as smooth as possible can be mapped by inverting a station or line with a range of dxWeight or dzWeight values.

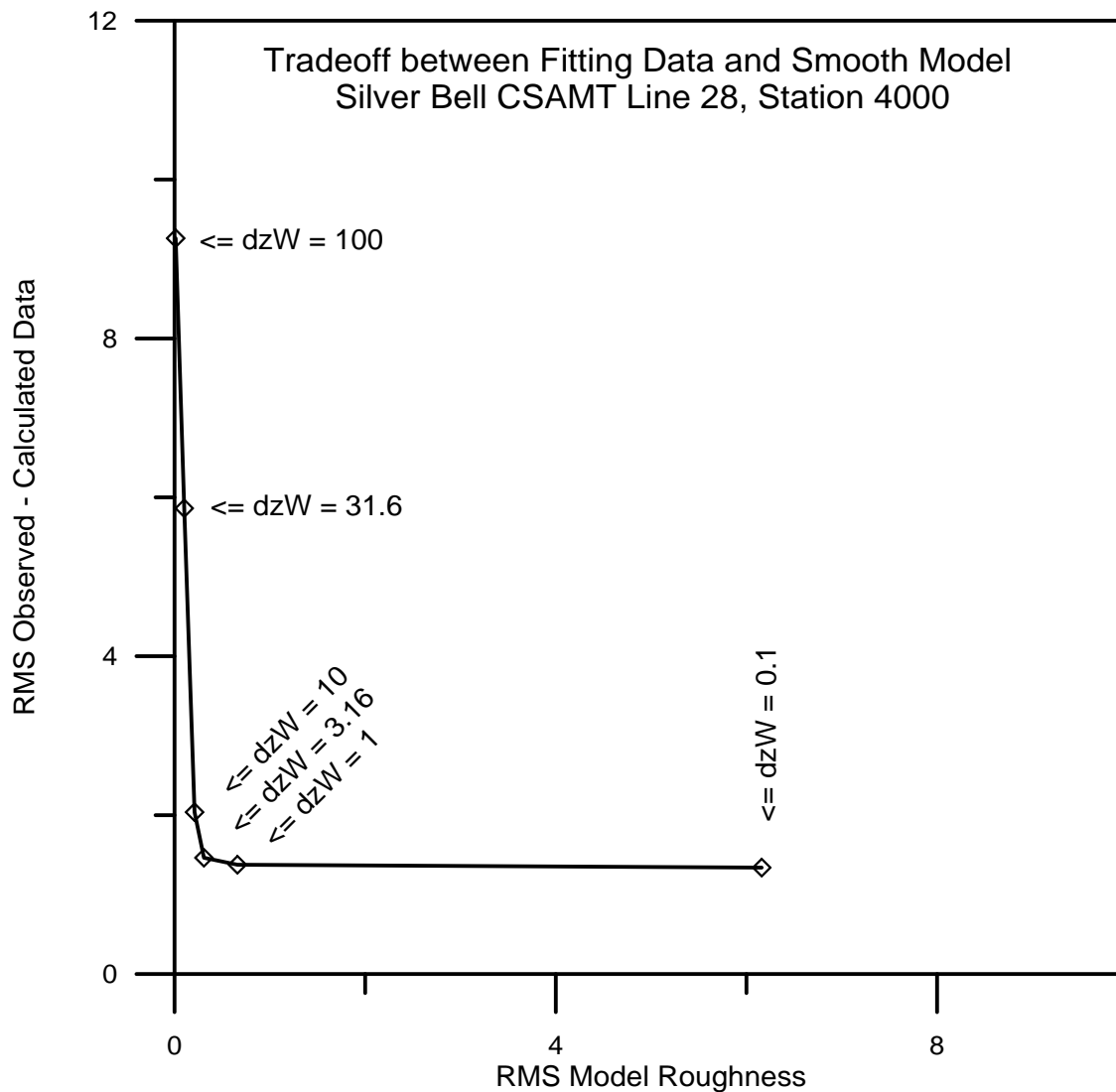
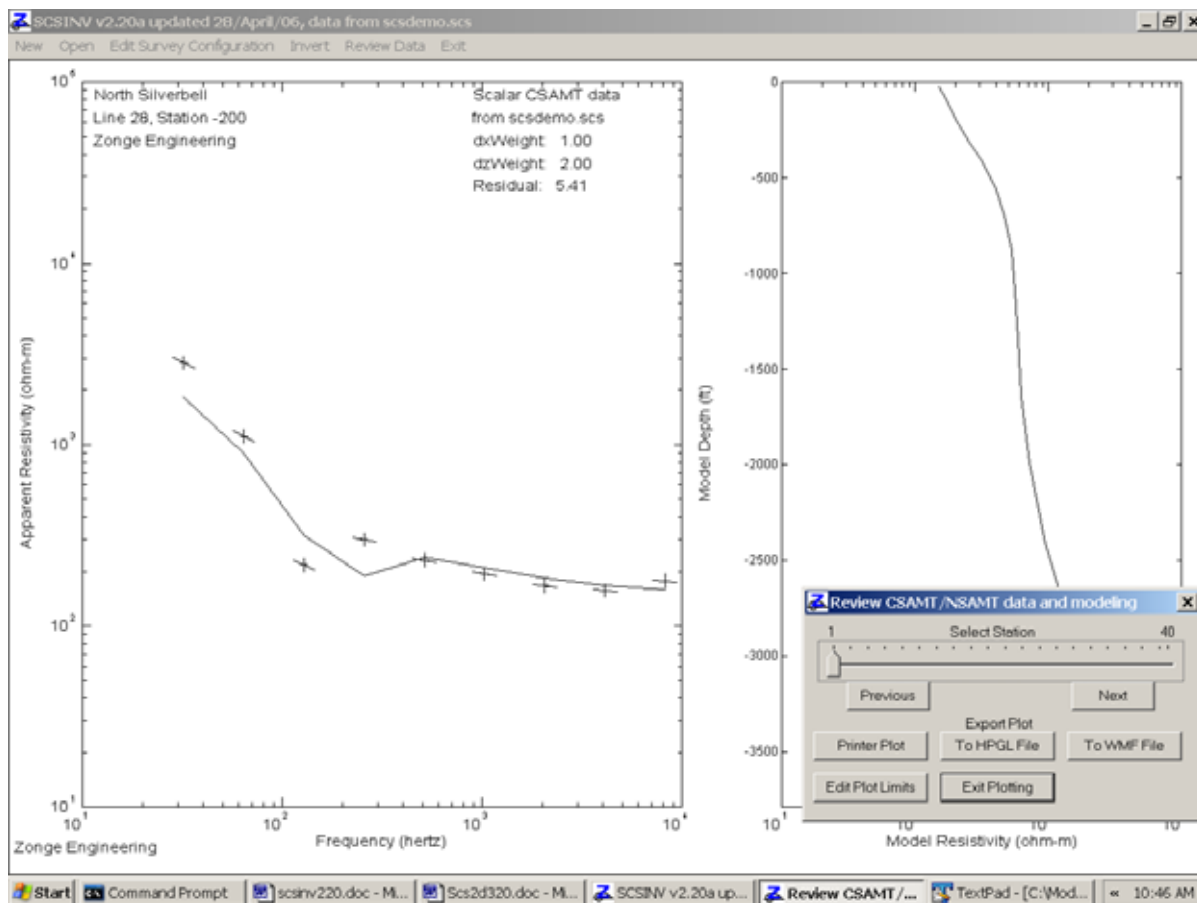


Figure 2: Inverting data for a single station with different values for dzWeight shows the tradeoff between fitting observed data and keeping model smoothness. Data from station 4000 in SCSDEMO.SCS were inverted with dzWeight varying between 100 and 0.1. Plotting RMS (root-mean-square) observed - calculated data residuals versus RMS model roughness shows how a dzWeight=100 returns a poorly fitting, but very smooth model. Conversely, using dzWeight = 0.1 gives a good fit to observed data, but the inverted model is not smooth. Using dzWeight = 3 is nearly optimal, returning both a good fit to observed data and a smooth model.

After the inversion is complete, you may review inversion results on a station-by-station basis with the Review Data menu option, which generates log-log plots of observed and calculated apparent resistivity versus frequency and log-linear plots of model resistivity versus elevation.



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

A small dialog box pops up to allow control of Review Data plots. Stations may be selected for display by clicking on the Previous or Next buttons or by moving the trackbar slider. (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. SCSINV 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.

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 SCSINV by choosing Exit.

Both m1d and obs files are in a tabular format that can be read directly by most general purpose contouring packages. Zonge utility program MODSECT may be used to generate color-filled inversion model sections. It includes options for printing model-section plots, exporting to hpgl or wmf plot files, generating Surfer script and data files, or creating Oasis montaj script and data files.

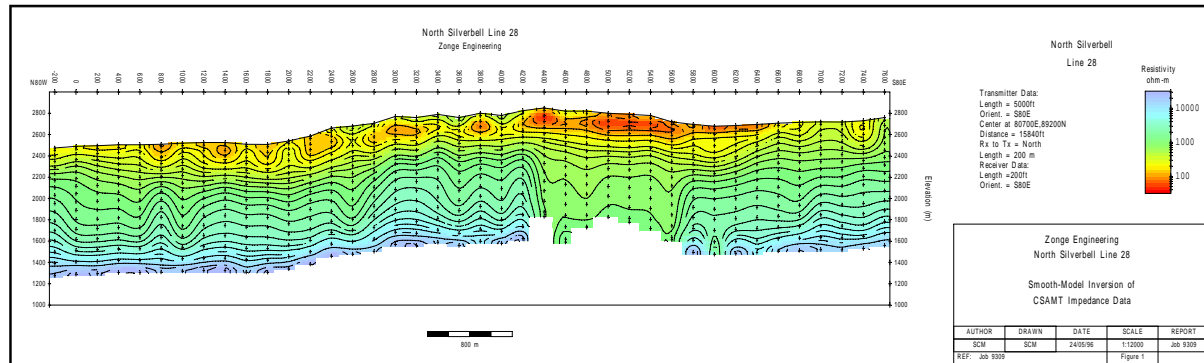


Figure 3: Smooth-model cross section from inversion of SCSDEMO.SCS using dzWeight = 3.0. MODSECT was used to plot the smooth-model section and save it in a wmf file.

References

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- Twomey, 1979, *Introduction to the mathematics of inversion in remote sensing and indirect measurements*, 2nd ed.: Elsevier Scientific Publishing Co., New York.
- 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.

Data Processing File Documentation

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

Partial listing of SCSDEMO.MDE:

```
$Job.Name="North Silverbell"  
$Job.Area="Tucson"  
$Job.For="Zonge International"  
$Job.By="Zonge"  
$Job.Number="9309"  
$Job.Date="Nov 93"  
$Survey.Type=CSAMT  
$Survey.Array=Scalar  
$Unit.Length=ft  
$Line.Name="28"  
$Line.Number=28  
$Line.Azimuth=100  
$Stn.GdpBeg=-2  
$Stn.GdpInc=2  
$Stn.Beg=-200  
$Stn.Inc=200  
$Tx.Type=Bipole  
$Tx.Center=80700,89200,0  
$Tx.Azimuth=100  
$Tx.Length=5000 ft  
$Rx.HPR=100,0,0  
$Rx.Length=200 ft
```

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 (GDP station numbers, 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 SCSINV 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).

These modes are used to control plot annotation, scaling and color fill when making smooth-model-section plots with Zonge utility program MODSECT.

```

$ MODSECT: PlotExport = Surfer
$ MODSECT: LNUNITS = m
$ MODSECT: LNTITLE1 = North Silverbell Line 28
$ MODSECT: LNTITLE2 = Zonge International
$ MODSECT: BRGLEFT= N80W
$ MODSECT: BRGRIGHT= S80E
$ MODSECT: TBTITLE1 = Zonge International
$ MODSECT: TBTITLE2 = North Silverbell Line 28
$ MODSECT: TBTITLE3 =
$ MODSECT: TBTITLE4 = Smooth-Model Inversion of
$ MODSECT: TBTITLE5 = CSAMT Impedance Data
$ MODSECT: TBLABEL1 = AUTHOR
$ MODSECT: TBLABEL2 = DRAWN
$ MODSECT: TBLABEL3 = DATE
$ MODSECT: TBLABEL4 = SCALE
$ MODSECT: TBLABEL5 = REPORT
$ MODSECT: TBLABEL6 = REF:
$ MODSECT: TBTEXT1 = SCM
$ MODSECT: TBTEXT2 = SCM
$ MODSECT: TBTEXT3 = 24/05/96
$ MODSECT: TBTEXT4 = 1:24000
$ MODSECT: TBTEXT5 = Job 9309
$ MODSECT: TBTEXT6 = Job 9309
$ MODSECT: TBTEXT7 = Figure 1
$ MODSECT: TBGLOSS01 = Transmitter Data:
$ MODSECT: TBGLOSS02 = Length = 5000ft
$ MODSECT: TBGLOSS03 = Orient. = S80E
$ MODSECT: TBGLOSS04 = Center at 80700E,89200N
$ MODSECT: TBGLOSS05 = Distance = 15840ft
$ MODSECT: TBGLOSS06 = Rx to Tx = North
$ MODSECT: TBGLOSS07 = Length = 200 m
$ MODSECT: TBGLOSS08 = Receiver Data:
$ MODSECT: TBGLOSS09 = Length =200ft
$ MODSECT: TBGLOSS10 = Orient. = S80E
$ MODSECT: XSCALE = 2.4000E+4 Horizontal scale (plot X-axis)
$ MODSECT: YSCALE = 2.4000E+4 Vertical scale (plot Y-axis)
$ MODSECT: YSIZE = 14.00 Min plot height including margins (cm)
$ MODSECT: StnLeft = -200. First station on left edge of plot
$ MODSECT: StnRight = 7600. Last station on right edge of plot
$ MODSECT: StnDec = 0 # station-number decimals (0 to 3)
$ MODSECT: StnInc = 200.00 Station interval (stn #)
$ MODSECT: ElvMin = 1000.00 Minimum elevation (plot Y-axis)
$ MODSECT: ElvMax = 3000.00 Maximum elevation (plot Y-axis)
$ MODSECT: ElvInc = 200.00 Elevation tick interval
$ MODSECT: TOPO = YES Draw line along topographic surface?
$ MODSECT: CNTVAR = Resistivity Contour variable (resistivity or IP)
$ MODSECT: CRMIN = 1.50 Res contour color minimum (log10(ohm-m))
$ MODSECT: CRMAX = 4.50 Res contour color maximum (log10(ohm-m))
$ MODSECT: CRINC = 0.10 Res contour interval (log10(ohm-m))
$ MODSECT: CRDEC = 0 # res-contour-label decimals (0 to 3)
$ MODSECT: RScutoff = 0.01 Resistivity-sensitivity cutoff (percent)

```

AVG file - averaged CSAMT data and measurement error estimates

A Csavegw *.avg file contains averaged CSAMT 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 CAC2CSAMT *.avg file:

```
\AMTAVG 7.20: "L28.FLD", Dated 93-11-17, Processed 19 Nov 93
\5-point TMA Filter at 4096 hertz
\ASTATIC v3.30d updated skip flags and SRES on 26/04/06
```

```
$Job.Name="North Silverbell"
$Job.Area="Tucson"
$Job.For="Zonge International"
$Job.By="Zonge"
$Job.Number="9309"
$Job.Date="Nov 93"
$Survey.Type=CSAMT
$Survey.Array=Scalar
$Line.Name="28"
$Line.Number=28
$Line.Azimuth=100
$Stn.GdpBeg=-2
$Stn.GdpInc=2
$Stn.Beg=-200
$Stn.Inc=200
$Stn.Left=-200
$Stn.Right=7600
$Unit.Length=ft
$Unit.E=nV/Am
$Unit.B=pT/A
$Unit.Phase=mrad
```

```
$Tx.Type=Bipole
$Tx.GdpStn=1
$Tx.Stn=1
$Tx.Center=80700,89200,0
$Tx.HPR=100,0,0
$Tx.Length=5000 ft
```

```
$Rx.GdpStn=-2
$Rx.Stn=-200
$Rx.Center=72490,73343,2475
$Rx.HPR=100,0,0
$Rx.Length=200 ft
$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,
E.%err,E.perr,B.%err,B.perr,Z.%err,Z.perr,ARes.%err
2, 32, 22, 35954, -367.6, 53.42, -291.1, 673.035, -76.5, 2831.1, 2832.1, 1, 1, 0.1, 0.9, 0.4, 4.3, 0.3, 3, 0.6
2, 64, 22, 24432, -966.4, 40.949, -769, 596.657, -197.4, 1112.5, 1112.9, 1, 1, 0.1, 1.1, 0.4, 3.9, 0.4, 1.7, 0.8
2, 128, 22, 8327.1, -1131, 22.357, -1091.8, 372.46, -39.2, 216.76, 216.84, 1, 1, 0.3, 2.7, 0.5, 3.3, 0.2, 1, 0.5
```


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:

skip	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
$ ASPACE =      60.960m
Contour Plot Z-File
C1 Cn Ce Ns Nd Yl  Plot file  1
  1  5  0  3  1  1
CSAMT SURVEY DATA
STATIC-CORRECTED APP. RES.
5-point TMA Filter at 4096 hertz
ASTATIC v2.01a 05/24/96
IIxxxxxxxxxYYYYYYYzzzzzzzzzzzz
2      -2.  14.000    2.832E+3
2      -2.  15.000    1.113E+3
2      -2.  16.000    2.168E+2
2      -2.  17.000    2.999E+2
2      -2.  18.000    2.307E+2
2      -2.  19.000    1.941E+2
2      -2.  20.000    1.666E+2
2      -2.  21.000    1.567E+2
2      -2.  22.000    1.772E+2
2       0.  14.000    2.679E+3
2       0.  15.000    1.062E+3
.       .       .       .
.       .       .       .
.       .       .       .
2      76.  20.000    2.448E+2
2      76.  21.000    2.387E+2
2      76.  22.000    2.530E+2
9999.00
C1 Cn Ce Ns Nd Yl  Plot file  2
  0 10  3  3  0  1
CSAMT SURVEY DATA
IMPEDANCE PHASE
values in milliradians
IIxxxxxxxxxYYYYYYYzzzzzzzzzzzz
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 = 60.960 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

lxxxxxxxxYYYYYYYYzzzzzzzzzzzz - 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.

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

Listing of SCSDEMO.STN:

```
Station,Easting,Northing,Elevation
-200, 72490, 73343, 2475
  0, 72687, 73311, 2490
 200, 72885, 73279, 2495
 400, 73082, 73246, 2505
 600, 73280, 73214, 2505
 800, 73477, 73182, 2510
1000, 73674, 73149, 2520
1200, 73872, 73117, 2525
1400, 74069, 73085, 2525
1600, 74266, 73052, 2510
1800, 74464, 73020, 2508
2000, 74661, 72988, 2540
.      .      .      .
.      .      .      .
7200, 79792, 72147, 2718
7400, 79990, 72115, 2730
7600, 80187, 72083, 2760
```

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. SCSINV 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, SCSINV assumes columns of station, easting, northing and elevation.

Some grid coordinate systems, such as UTM coordinates, can generate very large coordinate values. As SCSINV 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 in proportional to distance along line.
East	- grid east (length units).
North	- grid north (length units).
Elevation	- elevation (length units).

SCSINV File Documentation

SCS file - survey configuration, inversion control and observed data

Partial Listing of SCSDEMO.SCS:

```
&SCSINV
Header(1)="From SCSINV v2.20a  Date:28/04/06  Time:09:55:50"
Header(2)="North Silverbell  Line 28"
Header(3)="for Zonge International"
Header(4)="Data from C:\Modeling1\AMT\Scsinv\Scsinv\scsdemo.zsr"
JobName="North Silverbell"
JobArea="Tucson"
JobBy="Zonge"
JobFor="Zonge International"
JobNumber="9309",JobDate="Nov 93"
LineName="28",LineNumber=28,LineAzimuth=100
SurveyType="Scalar",TxType="Bipole",LengthUnits="ft"
TxLength(1)=5000,TxAzimuth(1)=100,TxGridE(1)=80700,TxGridN(1)=89200
RxLength(1)=200,RxAzimuth(1)=100
ErrFloor=5.00
dpWeight=1.00,dxWeight=1.00,dzWeight=2.00,Niteration=10
/
"Stn","GridE","GridN","Elev","Freq","ARobs","ARerr","PZobs","PZerr"
-200,72490,73343,2475,32,2.83200E+3,5,-76.5,50
-200,72490,73343,2475,64,1.11300E+3,5,-197.4,50
-200,72490,73343,2475,128,2.16800E+2,5,-39.2,50
-200,72490,73343,2475,256,2.99900E+2,5,556.2,50
-200,72490,73343,2475,512,2.30700E+2,5,519.1,50
-200,72490,73343,2475,1024,1.94100E+2,5,568.3,50
-200,72490,73343,2475,2048,1.66600E+2,5,620.3,50
-200,72490,73343,2475,4096,1.56700E+2,5,676.2,50
-200,72490,73343,2475,8192,1.77100E+2,5,662.6,50
0,72687,73311,2490,32,2.67900E+3,5,-66.8,50
0,72687,73311,2490,64,1.06200E+3,5,-181.4,50
. . . . .
. . . . .
. . . . .
7600,80187,72083,2760,2048,2.44800E+2,5,678.7,50
7600,80187,72083,2760,4096,2.38600E+2,5,658.9,50
7600,80187,72083,2760,8192,2.53000E+2,5,612.9,50
```

SCSINV Fortran Namelist block:

Header(1) - program name, version, date, and time.
..... - free format text describing model.
Header(4) - up to four header lines can be included.
JobName - project name (128 chr string)
JobArea - project area (128 chr string)
JobBy - client name (128 chr string)
JobFor - contractor name (128 chr string)
JobNumber - job number (16 chr string)
JobDate - data acquisition date (16 chr string)
LineName - line name (16 chr string)
LineNumber - numeric line number (float)
LineAzimuth - line azimuth (float, deg E of north)
LengthUnits - distance units (m or ft).
SurveyType - CSAMT/NSAMT array type (Scalar, Vector or Tensor).
TxType - CSAMT/NSAMT transmitter type (Natural, Bipole or Loop).
TxLength - length of transmitter bipole length or loop width (positive float, LengthUnits).
TxAzimuth - azimuth of transmitter antenna (float, degrees east of north).
TxGridE - Tx center grid east (float, LengthUnits).
TxGridN - Tx center grid north (float, LengthUnits).
RxAzimuth - Rx E-field azimuth in scalar survey (float, deg east of north).
ErrFloor - minimum apparent resistivity error (float, %)
Niteration - number of restarts to use in iterative inversion (integer).
dpWeight - relative weight of starting model (float, default=1.0).
dxWeight - relative weight of horizontal smoothness constraints (float, default=1.0).
dzWeight - relative weight of vertical smoothness constraints (float, default=2.0).
/ - marks end of namelist input block.

Observed Data Columns:

Column 1 - station number.
Column 2 - station grid-east coordinate (m or ft) (LengthUnits).
Column 3 - station grid-north coordinate (m or ft) (LengthUnits).
Column 4 - station elevation (m or ft) (+ upwards, LengthUnits).
Column 5 - frequency (hertz), ordered low to high for each station.
Column 6 - observed apparent resistivity (ohm-m).
Column 7 - relative resistivity error (percent).
Column 8 - observed impedance phase (mrad).
Column 9 - impedance phase error (mrad).

M1D file - inversion model

Partial Listing of SCSDEMO.M1D:

```
"Stn", "GridE", "GridN", "Zinv", "ResInv", "Res0", "Rerr0", "Rerr", "Rsns"
-200,72490.00,73343.00,2475.00,1.70283E+2,2.88842E+2,500.00,4.59,99.915
-200,72490.00,73343.00,2395.92,1.70283E+2,2.88842E+2,500.00,4.59,99.915
-200,72490.00,73343.00,2233.64,2.01059E+2,2.88842E+2,500.00,11.63,97.138
-200,72490.00,73343.00,2062.88,2.70566E+2,2.88842E+2,500.00,14.16,71.368
-200,72490.00,73343.00,1883.19,3.87769E+2,2.88842E+2,500.00,19.08,37.481
-200,72490.00,73343.00,1694.12,5.38599E+2,2.88842E+2,500.00,23.13,29.219
-200,72490.00,73343.00,1495.16,6.97741E+2,2.88842E+2,500.00,26.72,25.589
-200,72490.00,73343.00,1285.81,8.45813E+2,2.88842E+2,500.00,29.70,19.375
-200,72490.00,73343.00,1065.52,9.72023E+2,2.88842E+2,500.00,31.75,14.043
-200,72490.00,73343.00,833.71,1.06747E+3,2.88842E+2,500.00,32.81,11.367
-200,72490.00,73343.00,589.80,1.12329E+3,2.88842E+2,500.00,33.09,11.401
-200,72490.00,73343.00,333.14,1.13553E+3,2.88842E+2,500.00,32.98,13.663
-200,72490.00,73343.00,63.06,1.11426E+3,2.88842E+2,500.00,33.05,17.475
-200,72490.00,73343.00,-221.13,1.09686E+3,2.88842E+2,500.00,33.63,21.059
-200,72490.00,73343.00,-520.16,1.17223E+3,2.88842E+2,500.00,33.55,19.958
-200,72490.00,73343.00,-834.83,1.55810E+3,2.88842E+2,500.00,28.68,11.140
-200,72490.00,73343.00,-1165.93,2.79191E+3,2.88842E+2,500.00,20.65,99.808
0,72687.00,73311.00,2490.00,1.63005E+2,2.78895E+2,500.00,4.38,99.912
0,72687.00,73311.00,2410.92,1.63005E+2,2.78895E+2,500.00,4.38,99.912
0,72687.00,73311.00,2248.64,2.16102E+2,2.78895E+2,500.00,11.89,96.363
. . . . .
. . . . .
7600,80187.00,72083.00,-235.16,1.34530E+3,3.16212E+2,500.00,35.98,14.574
7600,80187.00,72083.00,-549.83,1.87915E+3,3.16212E+2,500.00,30.72,8.022
7600,80187.00,72083.00,-880.93,2.79771E+3,3.16212E+2,500.00,23.25,99.856
```

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 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 may be in arbitrarily scaled units, but they should be roughly proportional to distance along line.
GridE	- grid east (LengthUnits).
GridN	- grid north (LengthUnits).
Zinv	- layer midpoint elevations (LengthUnits) (if station elevations=0, RCSINV returns layer elevations as depths, depth = elevation relative to surface).
ResInv	- layer resistivity (ohm-m).
Rerr0	- starting model layer resistivity error (percent).
Rerr	- linear estimate of inverted model layer resistivity error (percent).
Rsns	- normalized layer-resistivity sensitivity or importance (percent).

OBS file - observed and calculated data

Partial Listing of SCSDEMO.OBS:

```
"Stn", "GridE", "GridN", "Elev", "Freq", "ARobs", "ARerr", "PZobs", "PZerr", "ARcalc", "PZcalc"
-200,72490.00,73343.00,2475.00,32.00,2.83200E+3,5.00,-76.5,50.0,1.91760E+3,80.2
-200,72490.00,73343.00,2475.00,64.00,1.11300E+3,5.00,-197.4,50.0,9.85753E+2,31.4
-200,72490.00,73343.00,2475.00,128.0,2.16800E+2,5.00,-39.2,50.0,3.81003E+2,18.3
-200,72490.00,73343.00,2475.00,256.0,2.99900E+2,5.00,556.2,50.0,1.83071E+2,577.2
-200,72490.00,73343.00,2475.00,512.0,2.30700E+2,5.00,519.1,50.0,2.34569E+2,560.8
-200,72490.00,73343.00,2475.00,1024.,1.94100E+2,5.00,568.3,50.0,1.95786E+2,619.5
-200,72490.00,73343.00,2475.00,2048.,1.66600E+2,5.00,620.3,50.0,1.74913E+2,684.6
-200,72490.00,73343.00,2475.00,4096.,1.56700E+2,5.00,676.2,50.0,1.68688E+2,735.3
-200,72490.00,73343.00,2475.00,8192.,1.77100E+2,5.00,662.6,50.0,1.67909E+2,762.4
0,72687.00,73311.00,2490.00,32.00,2.67900E+3,5.00,-66.8,50.0,1.86496E+3,82.9
0,72687.00,73311.00,2490.00,64.00,1.06200E+3,5.00,-181.4,50.0,9.56752E+2,37.3
0,72687.00,73311.00,2490.00,128.0,2.14000E+2,5.00,-21.8,50.0,3.68395E+2,37.3
. . . . .
. . . . .
7600,80187.00,72083.00,2760.00,2048.,2.44800E+2,5.00,678.7,50.0,2.52018E+2,731.0
7600,80187.00,72083.00,2760.00,4096.,2.38600E+2,5.00,658.9,50.0,2.42325E+2,738.3
7600,80187.00,72083.00,2760.00,8192.,2.53000E+2,5.00,612.9,50.0,2.32235E+2,745.4
```

Observed Data Columns (columns 1 through 9 are the same as scs files):

- Column 1 - station number.
- Column 2 - station grid-east coordinate (m or ft) (LengthUnits).
- Column 3 - station grid-north coordinate (m or ft) (LengthUnits).
- Column 4 - station elevation (m or ft) (+ upwards, LengthUnits).
- Column 5 - frequency (hertz), ordered low to high for each station.
- Column 6 - observed apparent resistivity (ohm-m).
- Column 7 - relative resistivity error (percent).
- Column 8 - observed impedance phase (mrad).
- Column 9 - impedance phase error (mrad).
- Column 10 - calculated apparent resistivity (ohm-m).
- Column 11 - calculated impedance phase (mrad).