

**STEMINV**  
**DOCUMENTATION**

ZONGE Data Processing  
Smooth-Model TEM Inversion  
version 3.00

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# STEMINV

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## **Introduction**

Smooth-model inversion is a robust method for converting Transient Electro-Magnetic (TEM) measurements to profiles of resistivity versus depth. Observed TEM time and dB/dt magnitude data for each station are used to determine the parameters of a layered-earth model. Layer thicknesses are fixed by calculating source-field penetration depths for each window time. Layer resistivities are then adjusted iteratively until the model TEM response is as close as possible to observed data, consistent with smoothness constraints. The smoothness constraints limit resistivity variation from layer to layer.

The result of smooth-model inversion is a set of estimated resistivities which vary smoothly with depth. Lateral variation is determined by inverting successive stations along a survey line. Results for a complete line can be presented in pseudosection form by contouring model resistivities. For contouring, 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.

Inverting window magnitude data to smoothly varying model resistivities is an effective way to display the information inherent in TEM 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 STEMINV includes a PC using the MS-Windows operating system with graphics set to high color (16-bit) mode.

### **Installation Procedure**

Each distribution copy of STEMINV may be installed on more than one computer, but it comes with either a key-disk software registration system compatible with Windows 95/98 or a parallel 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.

Key-disk software registration can be moved from the distribution disk to a hard-drive for extensive use on one computer. Key-disk registration may later be moved back to the distribution disk for installation on another computer. Once STEMINV 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 STEMINV 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.

To install STEMINV program files from a 3.5" disk, place the distribution disk in a floppy disk drive and log-on to that drive. Then type "SETUP" and press Enter. You will see a screen title showing the program's name and version number. Below the title block a set of highlighted fields specify the source drive you are installing STEMINV from, usually floppy drive A: or B:, and the target hard drive letter and path in which STEMINV should be installed. It is usually easiest to put STEMINV

programs in a directory which is already on your computer's MS-DOS path. You can move from field to field in the SETUP program's screen by pressing the Tab key to move forward and Shift+Tab to move backward. To cycle through disk drive letters, press the space bar or left and right arrow keys. Select drive letters and edit the target path to suit your computer's configuration. When you press F10, SETUP will verify your edited changes and will extract files from #STEMINV.EXE to your target directory.

If you are installing programs from a CD, SETUP allows you to move groups of program files from the distribution CD to a target hard-drive directory. As with floppy-disk installation, it is usually easiest to put modeling programs from a CD into a single directory on your computer's MS-DOS path (such as c:\datpro). Using a single directory reduces the length of the MS-DOS path string.

SETUP does not alter any of your computer's system configuration files. After installation, STEMINV may be run from the command line, from the start menu or from a Windows desktop shortcut.

After installation, the STEMINV subdirectory should have the following files:

**STEMINV program files:**

- STEMINV.EXE - shell to drive STEMINV program set.
- RSTEMINV.EXE - smooth-model CSAMT inversion program.
- STEMREG.EXE - software registration program.
- SETUP32.EXE - installs drivers for hardware lock
- STEMINV\_update.txt – notes on changes made during incremental updates

**Sample data files:**

- STEMDEMO.MDE - survey annotation and configuration information.
- STEMDEMO.AVG - observed data and estimated measurement error.
- STEMDEMO.STN - station location coordinates.
- STEMDEMO.STD - inversion control and data RSTEMINV input file.
- STEMDEMO.M1D - smooth-model resistivity model RSTEMINV output file.
- STEMDEMO.OBS - smooth-model observed and calculated data RSTEMINV 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 and write.

**Moving key-disk software registration to your hard drive.**

Key-disk software registration may be left on the distribution disk. RSTEMINV will then run only when the distribution disk is present in your floppy-disk drive. For more convenience, you can move key-disk registration to your hard-drive. When this is done, the 3.5" key-disk will not be required to operate the program. However, if the hard disk is transferred to another person, reformatted or corrupted, that copy of the protection is lost. One spare copy of the software registration is included on each distribution disk.

IF your software was provided for demonstration purposes, then software registration may NOT be moved to a hard disk. Typically, the registration is set to expire 30 days after you first use the program. Registration may be reset by purchasing STEMINV and obtaining a reset code by fax or email.

The utility EVMOVE.COM is provided on the distribution key disk. Assuming that the 3.5" distribution disk is in drive A: and that your hard drive is labeled C:, type

"EVMOVE A: C:" to move a copy of software registration from drive A: to drive C:

"EVMOVE C: A:" to recall a copy of software registration from drive C: to drive A:

## Installing a hardware lock

A parallel-port hardware lock or dongle is required for computers running Windows NT. Using STEMINV'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 port. Then plug the parallel 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 STEMINV. 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.**

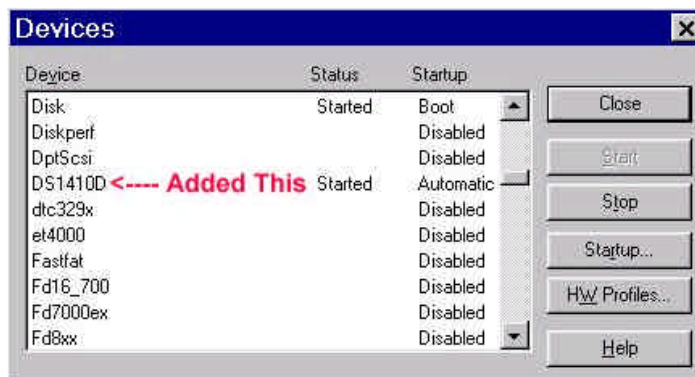
## SETUP32

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 up.





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 STEMREG from the STEMINV 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 RSTEMINV is initiated. RSTEMINV calls STEMREG 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

STEMINV 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.

### **Recall Procedure**

To recall STEMINV back to the distribution disk, place the distribution disk in a drive and log on to that drive, then type "RECALL" and press the Enter key. RECALL displays a screen with fields for the drive and directory where STEMINV is installed and for the letter of the floppy drive holding the STEMINV distribution disk. Edit the source drive and path to match your computer's configuration and then press F10 to start the RECALL procedure. RECALL erases STEMINV.EXE, RSTEMINV.EXE, STEMREG.EXE and STEMDEMO.\* from the "recall from" directory.

## Program Use

### Overview

STEMINV is a pair of programs for inverting TEM data into a smoothly varying model. STEMINV.EXE builds, edits and reviews data sets, while RSTEMINV.EXE is the core inversion program which creates a model section given a STEMINV data set. RSTEMINV can be run from within STEMINV, directly from a MS-DOS command line or from a batch file.

Information is exchanged between programs with ASCII data files which can be viewed or modified with a text editor if necessary. A file name may be passed to RSTEMINV as a command line argument. File name extensions are used to flag the file type, i.e. Zonge avg files end with the extension ".avg" and station location files end with the extension ".stn". RSTEMINV.EXE input files end with the extension ".std" and RSTEMINV.EXE produces m1d and obs files. m1d files hold inverted model parameters while obs files hold observed and calculated data in a tabular spreadsheet format.

Observed data are prepared for inversion using STEMINV.EXE. STEMINV can read TEM data from Zonge TEMAVG avg or z files or from AMIRA-format tem and chn files. TEMAVG avg files are preferable because they include information about measurement error, which is used to set data point weights for inversion. Survey configuration information, such as project name, line number, station number scaling information, transmitter loop size and placement are read from optional mde files. Station location information may be input from optional stn files. After collecting information from these diverse source files, STEMINV sorts the observed data by station number and transient delay time and saves it in a std file.

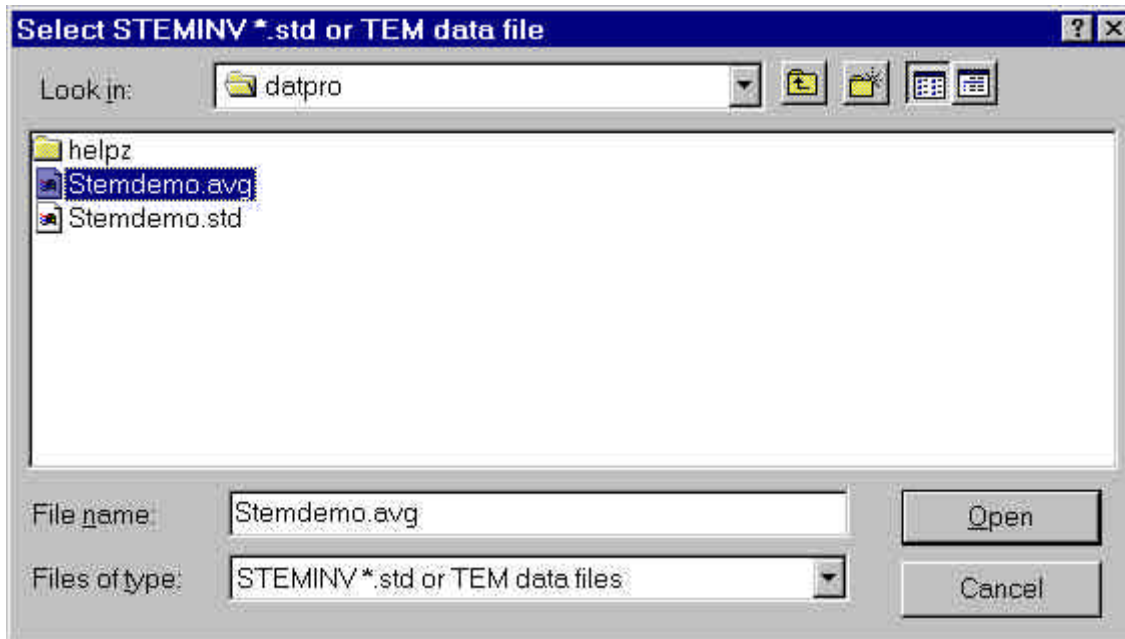
RSTEMINV, the core inversion program, reads std files, constructs a starting model, inverts observed data, and writes inverted results into a m1d file holding model resistivities versus station location and depth. RSTEMINV saves observed and calculated data in both std and obs files. The tabular format used in m1d and obs files is directly useable by spreadsheet or general-purpose contouring programs. Zonge utility program MODSECT may be used to produce color-filled, smooth-model-section plots.

STEMINV may be run from the command line, the start menu or by a short cut. Although there is no set procedure, smooth-model inversion of TEM data usually follows the STEMINV menu from left to right.

### Typical STEMINV Sequence

Noisy late-time data often seriously degrade inversion results, so starting with a good data set is important. Noisy data may also be skipped using STEMINV's **Review Data** option. STEMINV sets a skip flag by adding 1000% to observed data error. Review Data plots show skipped data points in red and RSTEMINV does not use the skipped data for inversion. Review Data also allows you to recover skipped data if you later decide to restore it for use by RSTEMINV.

To practice with STEMINV start STEMINV.EXE from the Windows Start menu. STEMINV will show an open dialog box. Navigate to the directory holding stemdemo.\* sample files and select stemdemo.avg.



If you select the **Open** button with a mouse click, STEMINV will start to create a new std file. To get the necessary information, it must read stemdemo.avg (holding station number, time, window magnitude, and relative error), the optional stemdemo.mde file to recover line annotation and station number scaling information, and the optional stemdemo.stn (holding station, easting, northing and elevation coordinates). It then shows an interactive dialog box, so that you can check survey configuration and inversion parameter values.

The “Verify TEM survey configuration” dialog includes three fields to hold a general description of the data set. It also has specific fields for the *Project* name and **Line** number which it saves for later use as plot annotation.

**Length Units** may be set to either m or ft.

If the **Survey Type** is Moving-Loop, RSTEMINV centers the Tx loop relative to each sounding location using the along-line and across-line offsets specified in **Tx-Rx Offset**. Moving-in-loop surveys with the Rx coil centered within the Tx loop have Tx-Rx offsets of (0,0). Moving-separated-loop surveys will have non-zero Tx-Rx offsets. Selecting Fixed-Loop as the survey type changes the annotation on the Tx-Rx field to **Tx-Center**. RSTEMINV uses only one Tx loop location for fixed-loop survey data and the Tx-Center field specifies Tx loop center easting and northing.

The **Tx Loop Azimuth** field is used to rotate the Tx loop and Tx-Rx offsets from along-line, across-line coordinates to grid east and north. Tx loop rotation is necessary to model data taken along lines which are not N-S or E-W, but which have station locations given by GPS eastings and northings.

**Tx Loop Size**, **# Turns**, **Ramp Time** and **Repetition Rate** have the same meaning for both moving-loop and fixed-loop surveys. STEMINV uses transient delay time = 0 at the end of the Tx turn-off

ramp. When reading data from AMIRA files, the keyword INIT\_DELAY must usually be set to shift time = 0 from the beginning of the Tx ramp (the SiroTEM convention) to time=0 at the end of the Tx ramp. After reading data from Amira files, you can verify that keyword settings and chn file entries are producing the expected transient delay times by looking at the std file with a text editor to check time values. RSTEMINV puts time = 0 at the end of the Tx turn-off ramp.

**Effective Rx Coil Area** is in  $m^2$ . **TEM Data Units** may be either in  $\mu V/A$  or  $nV/Am^2$ . When reading AMIRA files with TEM units of  $nT/sec (=nV/m^2)$ , RSTEMINV uses the Tx current from the CURRENT keyword or column to scale data to  $nV/Am^2$  and then shows  $nV/Am^2$  as the TEM data unit.

The **Drop Data Above** field sets the value of a data cutoff parameter in percent. Any data with estimate error greater than the data cutoff value is automatically skipped. The feature automatically skips late-time data with high relative noise levels. Data cutoff values can range from 0.1 to 1000.

**Background Model Weighting** sets the relative weight given to the background model constraint during inversion. An existing m1d file can be used to pass a background model to RSTEMINV. Increasing the background constraint weight holds the inversion model closer the m1d model you have passed. The feature is useful if you want to bias RSTEMINV towards a particular model section. Background model weighting can vary between 0.001 and 100.

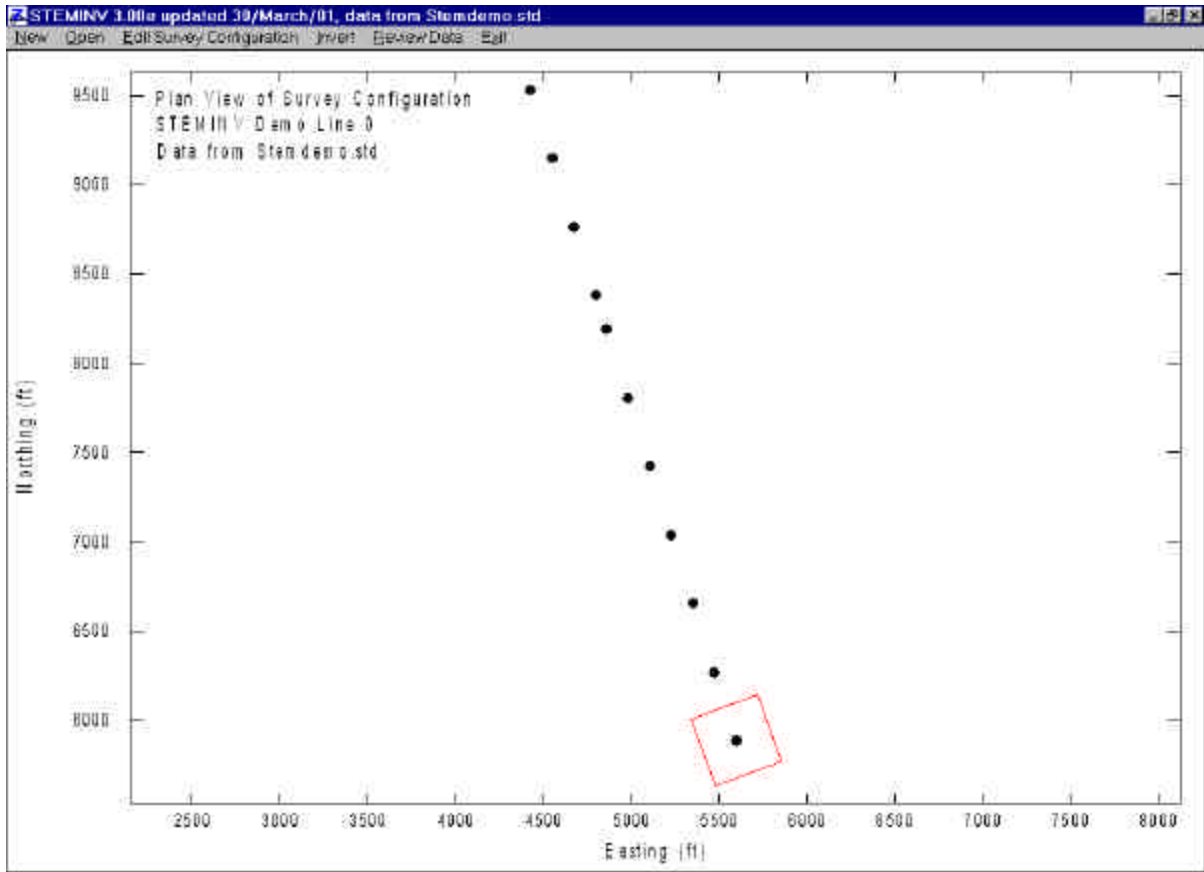
**Vertical Smoothness Weighting** controls the relative weight given smoothness constraints during inversion. Increasing smoothness-constraint weighting generates smoother models, while decreasing smoothness-constraint weighting allows rougher models and improves the fit to observed data.

**Data Error Floor** values put a lower limit on the percent error used by RSTEMINV. Early-time data are usually measured very accurately, but a successful inversion requires a balance between fitting very accurate early-time data and noisier late-time data. Increasing the data error floor allows RSTEMINV to put more emphasis on fitting late-time data with higher relative noise levels.

The **Maximum # of Iterations** can vary between 0 and 32. You can use RSTEMINV for forward modeling by passing it a m1d-file model section and by setting the number of inversion iterations to 0, so that RSTEMINV generates an initial set of calculated data and stops without attempting to change the inversion model section. For inversion, the default setting of 8 inversion iterations is sufficient for nearly all data sets. RSTEMINV stops its iterative inversion early if it is not making significant progress in terms of model-update step size or improved fit to observed data.

The **Save As** field allows you to change the file name RSTEMINV uses for the new std file.

Once you have verified the survey configuration and inversion settings, you can select **OK** to save the data set in a std file or **Cancel** to abort data input and go directly to RSTEMINV's main menu.



If a std file has been successfully generated or read, STEMINV shows a plan-map view of station locations and a red outline of the Tx loop. Only one Tx loop is plotted for moving-loop surveys, it is shown at the first station. STEMINV's main menu shows six options. **New** will prompt you for the name of a TEM data file with the filename extension avg, z, tem or amr. The New option leads you through the sequence just described for creating stemdemo.std. Selecting the **Open** menu option prompts you for the name of an existing std file. **Edit Survey Configuration** shows the "Verify TEM survey configuration" dialog. **Invert** runs RSTEMINV to generate an inversion model section m1d file. **Review Data** shows station-by-station plots of observed data, calculated data (if it exists) and inversion model curves (if they exist). **Review Data** may also be used to skip or unskip data. **Exit** closes STEMINV.

### Invert Menu Option

Selecting **Invert** while stemdemo.std is loaded runs RSTEMINV. STEMINV starts RSTEMINV and passes it the current std file name. (Note that RSTEMINV may also be run from a batch file by using the batch file command "start /w steminv stemdemo.std". Input files for a number of lines may be prepared in advance and then evaluated by running RSTEMINV from a batch file. To avoid delays by RSTEMINV's prompt when it finds an existing m1d file, delete m1d files from your working directory before starting your batch inversion.) Once started, RSTEMINV reads the std file and checks to see if an associated m1d file already exists. If it finds an existing m1d file, it prompts you with the following dialog.



If you press Enter or click on the **No** button, RSTEMINV ignores the existing m1d file and generates its own starting model. Select **Yes** to use the existing m1d file as a background model. Select **Cancel** to abort the inversion and stop RSTEMINV.

RSTEMINV inverts each station in turn, treating it as an independent sounding. If a m1d file does not already exist from a previous inversion run or you select **No** to ignore it, RSTEMINV creates its own starting model with a uniform resistivity equal to the geometric average of all apparent resistivities for the sounding. RSTEMINV then does a preliminary inversion with  $4 \cdot dzWeight$  to obtain a heavily-smoothed model before starting its final iterative inversion constrained by  $dzWeight$ . If a m1d file does exist, RSTEMINV scans it to obtain a starting model and skips the preliminary inversion with  $4 \cdot dzWeight$ . An existing M1D file can be edited to customize starting models, changing starting-model layer thickness and/or resistivities to fit independent geologic information.

After finishing its inversion for each station, RSTEMINV.EXE updates the std file and writes new m1d and obs files. M1d files hold smooth-model parameters generated by the inversion (station, model grid-point location, model resistivity, starting-model resistivity, resistivity error and resistivity importance). obs files hold observed data, calculated data, and the difference (calculated - observed). Both m1d and obs files are in a tabular format that can be read directly by most spread sheet or general purpose contouring packages (see Appendix A for more detailed file-format descriptions).

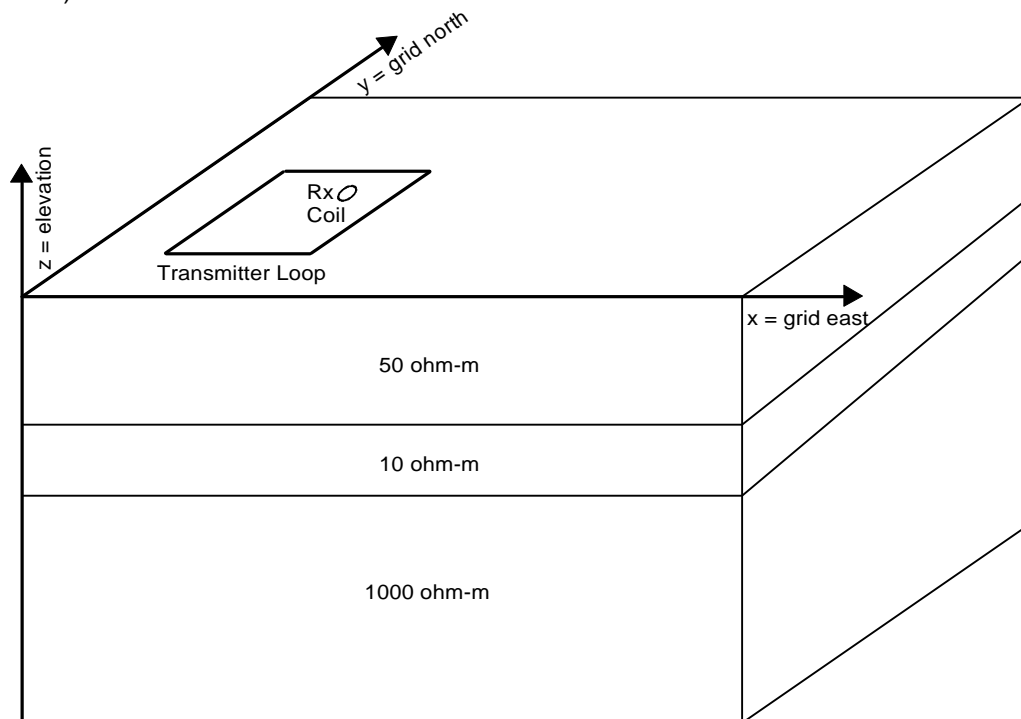


Figure 1: STEMINV and RSTEMINV use a right-handed coordinate system. The x-axis corresponds to grid east. The y-axis corresponds to grid north. The z-axis corresponds to elevations. Distances are specified in metres or feet. Azimuths are given in degrees clockwise from grid north.

## RSTEMINV Inversion Criteria

RSTEMINV 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:

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

where

nobs = number of observed data values.

$d_{\text{obs}_i}$  = observed asinh(dBz/dt in pV/Am<sup>2</sup>).

$d_{\text{mod}_i}$  = calculated asinh(dBz/dt in pV/Am<sup>2</sup>).

$d_{\text{err}_i}$  = observed data error.

nz = number of layers per station in inversion model.

$p_j^0$  = starting model parameter, log(resistivity).

$p_j^k$  = inversion model parameter at iteration k, log(resistivity).

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

dpW = dpWeight, relative weight given to starting model.

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

RSTEMINV saves  $\mathbf{e}_{\text{data}}/\text{sqrt}(\text{nobs})$  and  $\mathbf{e}_{\text{total}}$  in a log file after each inversion iteration. Model updates are not accepted if they increase  $\mathbf{e}_{\text{total}}$ . If an inversion step fails to improve  $\mathbf{e}_{\text{total}}$ , RSTEMINV tries again using a more cautious step size. RSTEMINV iterates on one station at a time, minimizing  $\mathbf{e}_{\text{total}}$  for that station. Progress is also shown by on-screen plots of dBz/dt versus time and model depth versus model resistivity.

Background model importance can be increased or decreased by adjusting **Background Model Weighting** in the "Edit Survey Configuration" dialog, or by directly editing dpWeight values in the std file. Default STEMINV starting-models are not weighted heavily. Starting-model resistivities are given an estimated error of 500 percent which is equivalent to  $p_{\text{err}_{ij}} = 1.8 \log(\text{ohm-m})$  in the definition of  $\mathbf{e}_{\text{model}}$ .

Model smoothness can be varied by changing the **Vertical Model Smoothness Weight** in the "Edit Survey Configuration" dialog, or by editing dzWeight values in the std file. dzWeight controls the relative importance of  $\mathbf{e}_{\text{model}}$  relative to the  $\mathbf{e}_{\text{data}}$  sum of (observed - calculated data)<sup>2</sup> during inversion. Increasing dzWeight by a factor of 10 and rerunning RSTEMINV, increases the relative



weight of the model's vertical smoothness constraint by a factor of 100, since  $dzW$  is squared in the definition for  $\epsilon_{\text{model}}$ .

### Tradeoff between Fitting Data and Model Constraints

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  $dzWeight$  values.

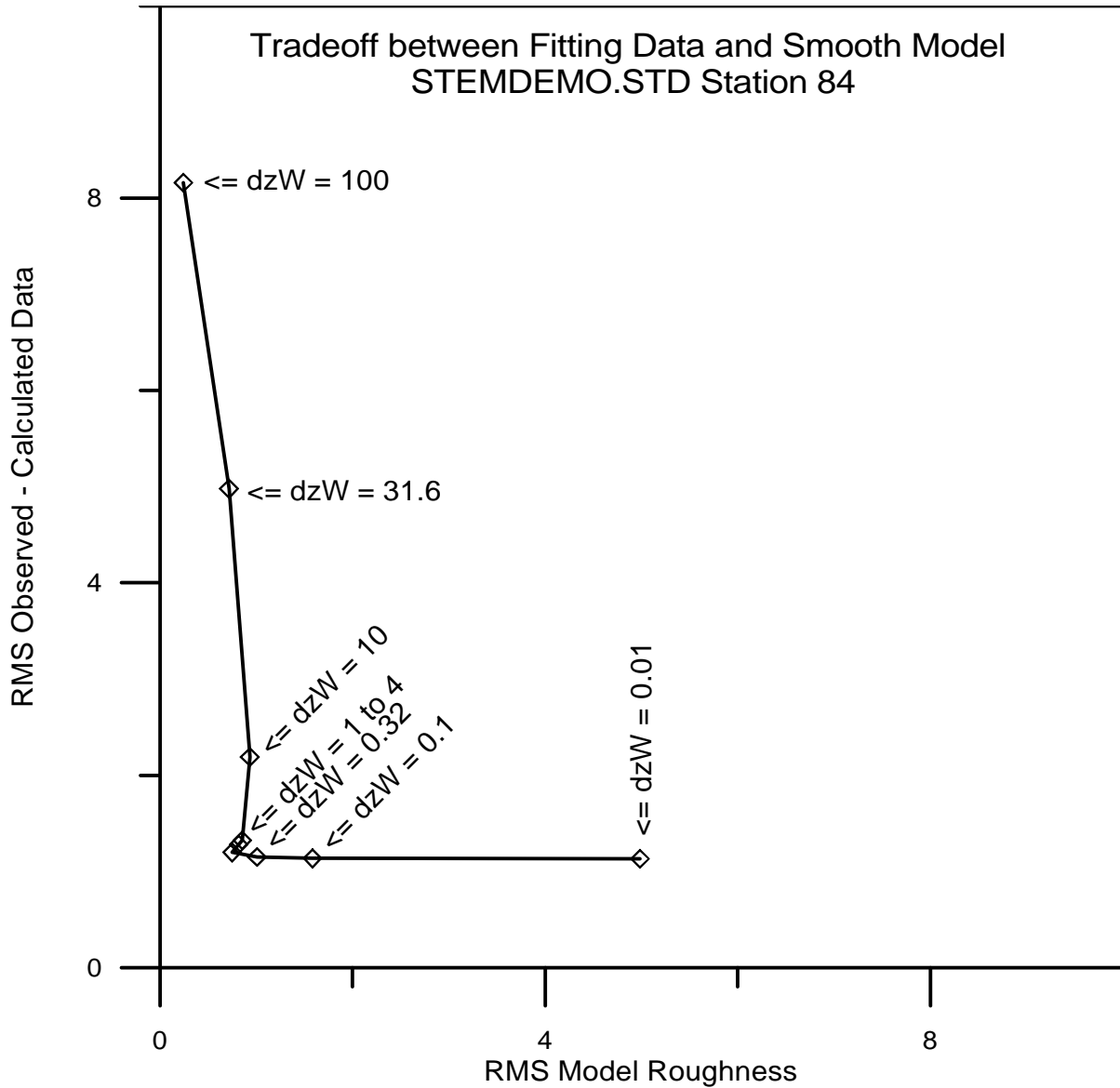
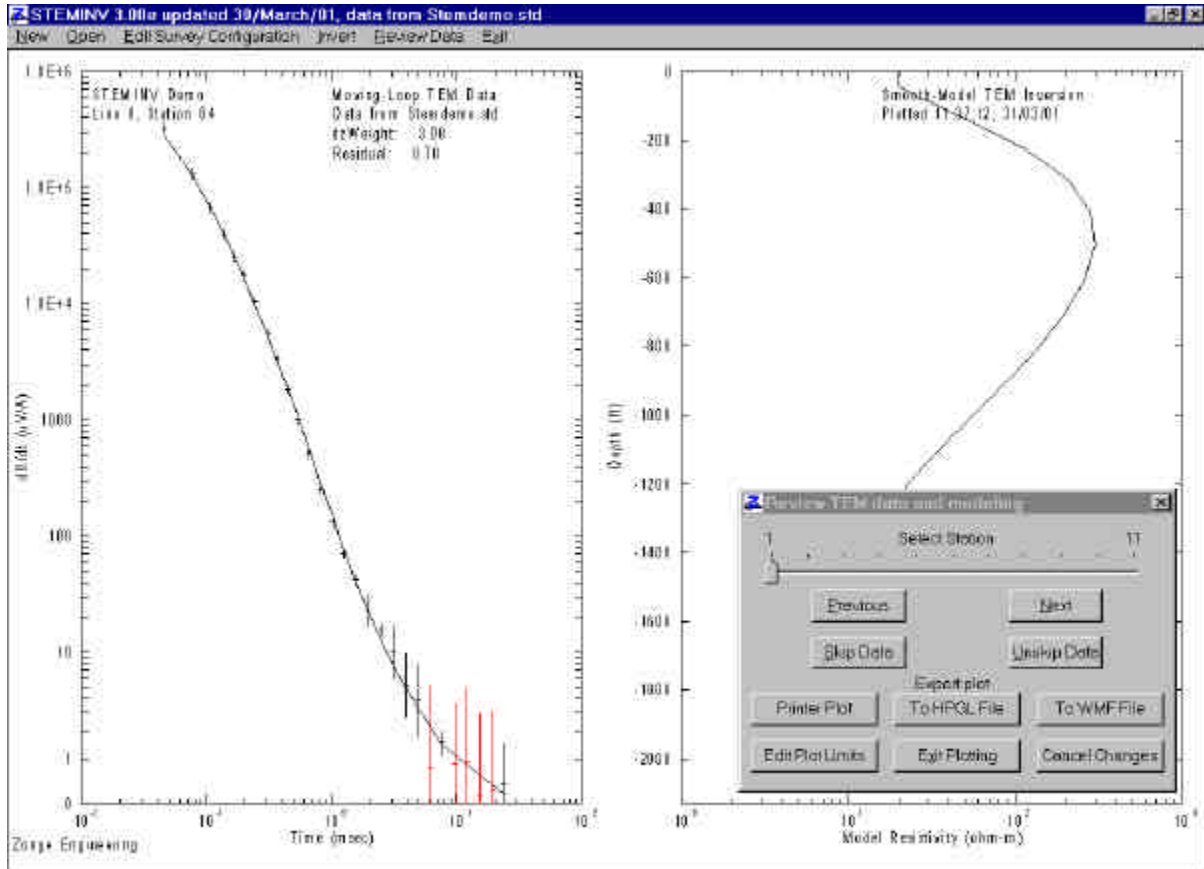


Figure 2: Inverting data for a single station with different values for  $dzWeight$  shows the tradeoff between fitting observed data and keeping model smoothness. Data from station 84 in STEMDEMO.STD were inverted with  $dzWeight$  varying between 100 and 0.01. Plotting RMS (root-mean-square) observed - calculated data residuals versus RMS model roughness shows how a  $dzWeight=100$  returns a poorly fitting, but very smooth model. Conversely, using  $dzWeight = 0.01$  gives a good fit to observed data, but with increased model roughness. Using  $dzWeight = 1$  to 4 is nearly optimal, returning both a good fit to observed data and a smooth model.

## Review Data Menu Option

STEMINV's **Review Data** menu option creates individual plots for each TEM sounding. There are two panels for each plot. Observed and calculated data are shown in plot of  $\text{asinh}(dB/dt)$  versus  $\log(\text{time})$ . Modeling results are displayed as log-linear plots of smooth-model resistivity versus depth.



STEMINV default plot-axis limits are set to show all data. An interactive dialog box allows you to move from station to station, skip or unskip data, export plots for hardcopy, edit plot limits, exit Review Data plotting, or cancel any skip flag changes and exit Review Data plotting.

Observed data values are shown in the left plot panel by a short horizontal dash and a vertical error bar. Skipped data with error levels above the Data Cutoff value are plotted in red. Calculated data (if available) are shown with a solid black line tracing out the calculated transient. Model parameters are plotted in the right panel in a log-linear plot of model resistivity versus model depth.

To go from one station to the next, you can move the trackbar cursor by selecting it with the mouse cursor and dragging it back and forth, by clicking on the **Previous** or **Next** buttons, or by pressing the P or N keys.

Clicking on the **Skip Data** button or pressing the S key allows you to skip data. The mouse cursor will change to a circle with a slash when you move it over the transient data plot. Click a mouse button to set one corner of a rubber band box and move the mouse cursor to expand or contract the selection field. Clicking a mouse button a second time sets the size of the selection box and all data within the box are skipped and shown in red.

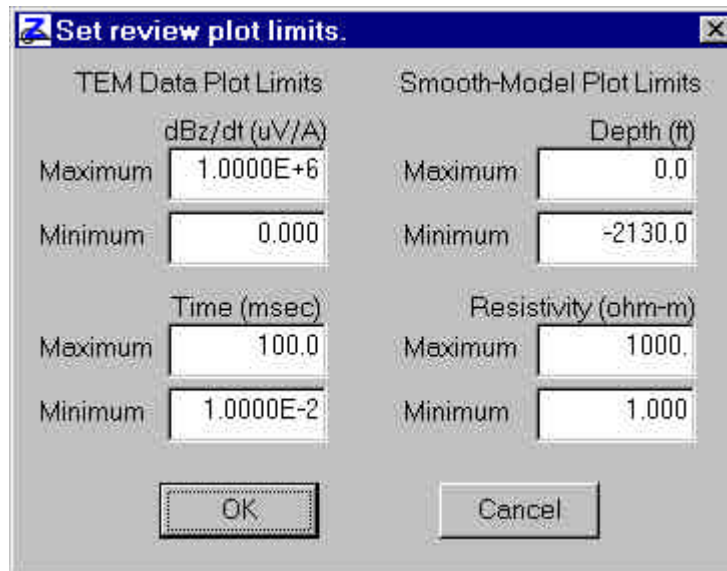
Clicking on the **Unskip Data** button or pressing the U key allows you to recover skipped data. The mouse cursor will change to an open circle when you move it over the transient plot. Click a mouse button to set one corner of a rubber band box and move the mouse cursor to expand or contract the selection field. Clicking a mouse button a second time sets the size of the selection box and all data within the box with error levels less than Data Cutoff are unskipped and plotted in black.

You can make plot hardcopies by selecting the **Printer Plot**, **To HPGL File** or **To WMF File** buttons with the mouse.

Selecting the **Exit Plotting** button closes the Data Review plots and returns you to a plan map of station locations and the main STEMINV menu. Any skip data changes you have made are saved by rewriting the current std file.

Selecting the **Cancel Changes** button closes the Data Review plots and returns you to a plan map of station locations and the main STEMINV menu. However any skip data changes you might have made are dropped by rereading the std file.

Selecting the **Edit Plot Limits** button brings up a secondary dialog box with fields for plot limits.



Plot axis ranges may be modified by editing minimum and maximum field values. Selecting the **OK** button closes the "Set Review Plot limits" dialog box and saves any changes you have made to plot-axis limits. Selecting **Cancel** closes the dialog box without saving any changes.

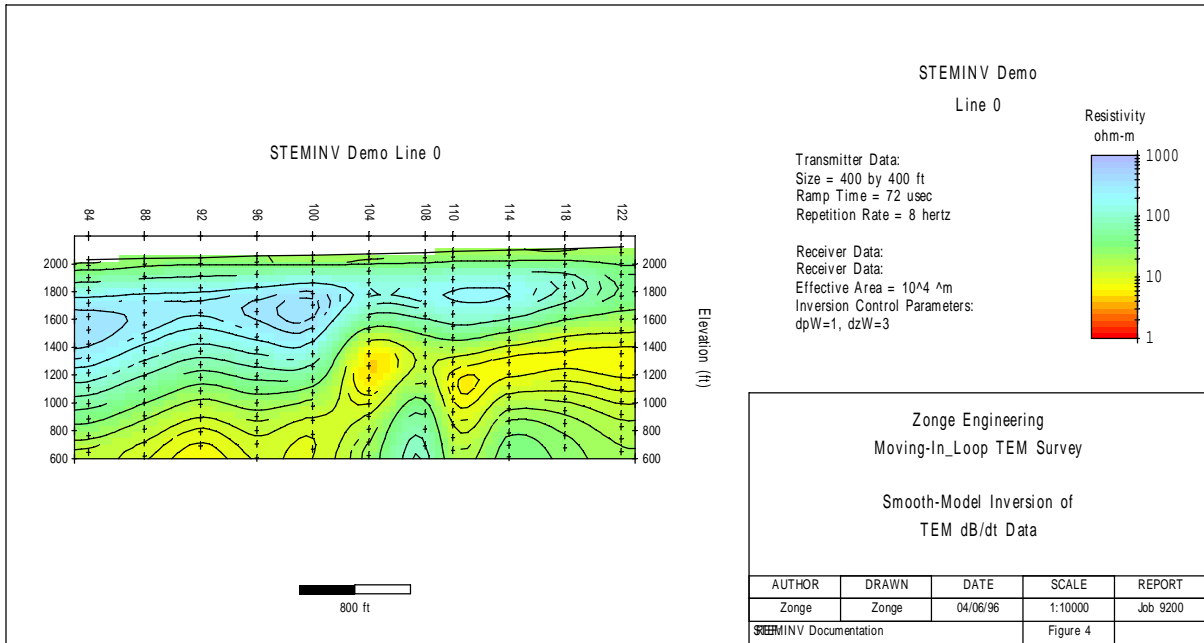


Figure 3: Smooth-model cross section from inversion of STEMDEMO.STD using dzWeight = 4.0. This plot was created using MODSECT v4.20d to read the std and m1d files, create a model section plot, and export a wmf file.

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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.

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 STEMDEMO.MDE:

```
$ CLIENT=Zonge Engineering
$ PROJECT=STEMINV Demo
$ JOBNUMB=9200
$ JOBDATE=Sep 93
$ JOBLINE=0
$ BRGLINE=N20W
$ BRGBACK=S20E
$ STNLO= 84.0
$ STNHI= 122.0
$ LBLDELTA= 2.0
$ STNDELTA= 2.0
$ UNITS= FEET
$ TXdx= 400. ft
$ TXdy= 400. ft
$ TXramp= 72.0 us
$ RXarea= 10000 m^2
```

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

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

STNLO - first station number in RAW, AVG and Z file GDP station number units.  
LBLFRST - first station number in scaled and shifted client station number units.  
STNDELTA - station number increment in RAW, AVG and Z file GDP station # units.  
LBLDELTA - station number increment in scaled and shifted client station number units.

The following mode keywords are used by STEMINV for default survey configuration.

PROJECT - project name.  
JOBLINE - line number.  
BRGLINE - line bearing in direction of increasing station numbers (degrees)  
UNITS - length units used for distances (m or ft).  
TxdX - transmitter loop length in grid-E direction (length units).  
TxdY - transmitter loop length in grid-N direction (length units).  
TxCX - transmitter loop center grid E coordinate (length units).  
TxCY - transmitter loop center grid N coordinate (length units).  
TxRamp - transmitter turn-off time (usec).  
RxArea - receiver coil effective surface area (m<sup>2</sup>).

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

```

$ MODSECT: PLOT = Surfer
$ MODSECT: LNUNITS = ft
$ MODSECT: LNTITLE1 = STEMINV Demo Line 0
$ MODSECT: BRGLEFT= N20W
$ MODSECT: BRGRIGHT= S20E
$ MODSECT: TBTITLE1 = Zonge Engineering
$ MODSECT: TBTITLE2 = Moving-In_Loop TEM Survey
$ MODSECT: TBTITLE3 =
$ MODSECT: TBTITLE4 = Smooth-Model Inversion of
$ MODSECT: TBTITLE5 = TEM dB/dt Data
$ MODSECT: TBLABEL1 = AUTHOR
$ MODSECT: TBLABEL2 = DRAWN
$ MODSECT: TBLABEL3 = DATE
$ MODSECT: TBLABEL4 = SCALE
$ MODSECT: TBLABEL5 = REPORT
$ MODSECT: TBLABEL6 = REF:
$ MODSECT: TBTEXT1 = Zonge
$ MODSECT: TBTEXT2 = Zonge
$ MODSECT: TBTEXT3 = 04/06/96
$ MODSECT: TBTEXT4 = 1:10000
$ MODSECT: TBTEXT5 = Job 9200
$ MODSECT: TBTEXT6 = STEMINV Documentation
$ MODSECT: TBTEXT7 = Figure 4
$ MODSECT: TBGLOSS01 = Transmitter Data:
$ MODSECT: TBGLOSS02 = Size = 400 by 400 ft
$ MODSECT: TBGLOSS03 = Ramp Time = 72 usec
$ MODSECT: TBGLOSS04 = Repetition Rate = 8 hertz
$ MODSECT: TBGLOSS05 =
$ MODSECT: TBGLOSS06 = Receiver Data:
$ MODSECT: TBGLOSS07 = Receiver Data:
$ MODSECT: TBGLOSS08 = Effective Area = 10^4 ^m
$ MODSECT: TBGLOSS09 = Inversion Control Parameters:
$ MODSECT: TBGLOSS10 = dpW=1, dzW=3
$ MODSECT: XSCALE = 1.0000E+4 Horizontal scale (plot X-axis)
$ MODSECT: YSCALE = 1.0000E+4 Vertical scale (plot Y-axis)
$ MODSECT: YSIZE = 14.00 Minimum plot height including margins (cm)
$ MODSECT: StnLeft = 84. First station on left edge of plot
$ MODSECT: StnRight = 122. Last station on right edge of plot
$ MODSECT: StnDec = 0 # station-number decimals (0 to 3)
$ MODSECT: StnInc = 2.00 Station interval (stn #)
$ MODSECT: ElvMin = 600.00 Minimum elevation (plot Y-axis)
$ MODSECT: ElvMax = 2200.00 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 = 0.00 Res contour color minimum (log10(ohm-m))
$ MODSECT: CRMAX = 3.00 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 TEM data and measurement error estimates

### Partial listing of STEMDEMO.AVG file:

```

\ TEMAVG 7.20: "STEMDEMO.FLD", Dated 92-01-03, Processed 08 Sep 93
$ TEM: Array=In Loop (Central Loop)
$ TEM: TxRamp= 72.0 us
$ TEM: TxDX= 400. ft
$ TEM: TxDY= 400. ft
$ TEM: TxArea= 14884 m^2
$ TEM: RxArea= 10000 m^2

```

skp	Station	Freq	Cmp	Amps	Win	Time	Magnitude	RampAppRes	Depth	%Mag
2	84.00	8 Hz	3.30	1	0.046	3.2343e+5	1.6668e+1	8.0440e+1	0.5	
2	84.00	8 Hz	3.30	2	0.0764	1.3097e+5	2.1763e+1	1.1845e+2	0.4	
2	84.00	8 Hz	3.30	3	0.1068	6.6870e+4	2.4185e+1	1.4764e+2	0.4	
2	84.00	8 Hz	3.30	4	0.1372	3.9800e+4	2.5457e+1	1.7168e+2	0.3	
2	84.00	8 Hz	3.30	5	0.1676	2.5615e+4	2.6564e+1	1.9383e+2	0.3	
2	84.00	8 Hz	3.30	6	0.198	1.7297e+4	2.7756e+1	2.1535e+2	0.3	
2	84.00	8 Hz	3.30	7	0.243	1.0403e+4	2.9498e+1	2.4596e+2	0.3	
2	84.00	8 Hz	3.30	8	0.304	5.6044e+3	3.2553e+1	2.8896e+2	0.4	
2	84.00	8 Hz	3.30	9	0.3648	3.2564e+3	3.5902e+1	3.3247e+2	0.2	
2	84.00	8 Hz	3.30	10	0.44	1.8347e+3	3.9854e+1	3.8470e+2	0.1	
2	84.00	8 Hz	3.30	11	0.5314	1.0040e+3	4.4749e+1	4.4799e+2	0.7	
2	84.00	8 Hz	3.30	12	0.651	5.1652e+2	5.0964e+1	5.2912e+2	0.7	
2	84.00	8 Hz	3.30	13	0.8175	2.5543e+2	5.6969e+1	6.2690e+2	2.7	
2	84.00	8 Hz	3.30	14	1.0145	1.3129e+2	6.2953e+1	7.3414e+2	0.6	
2	84.00	8 Hz	3.30	15	1.2559	7.0447e+1	6.7643e+1	8.4670e+2	3.6	
2	84.00	8 Hz	3.30	16	1.5584	4.2245e+1	6.7033e+1	9.3891e+2	5.3	
2	84.00	8 Hz	3.30	17	1.9493	2.2802e+1	7.0219e+1	1.0748e+3	18.5	
2	84.00	8 Hz	3.30	18	2.4626	1.5583e+1	6.1692e+1	1.1323e+3	6.8	
2	84.00	8 Hz	3.30	19	3.0981	1.0010e+1	5.6809e+1	1.2187e+3	34.6	
2	84.00	8 Hz	3.30	20	3.8833	5.1514e+0	6.0988e+1	1.4137e+3	44.1	
2	84.00	8 Hz	3.30	21	4.8655	3.7640e+0	5.1783e+1	1.4582e+3	52.6	
2	84.00	8 Hz	3.30	22	6.1163	7.9410e-1	1.0019e+2	2.2741e+3	199.1	
2	84.00	8 Hz	3.30	23	7.7035	1.5104e+0	4.4472e+1	1.7003e+3	13.5	
2	84.00	8 Hz	3.30	24	9.6681	8.8540e-1	4.3562e+1	1.8852e+3	113.2	
2	84.00	8 Hz	3.30	25	12.142	9.1543e-1	2.9166e+1	1.7288e+3	167.0	
2	84.00	8 Hz	3.30	26	15.283	1.6923e-1	6.1388e+1	2.8138e+3	205.0	
2	84.00	8 Hz	3.30	27	19.226	2.9407e-1	2.8980e+1	2.1683e+3	183.6	
2	84.00	8 Hz	3.30	28	24.191	3.7493e-1	1.6808e+1	1.8524e+3	63.8	
2	88.00	8 Hz	3.50	1	0.043	3.5985e+5	1.5033e+1	7.3859e+1	0.5	
2	88.00	8 Hz	3.50	2	0.0734	1.3595e+5	2.1816e+1	1.1625e+2	0.5	
2	88.00	8 Hz	3.50	3	0.1038	6.2277e+4	2.6365e+1	1.5197e+2	0.4	
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.

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

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



**TEM AVG file column definitions:**

Skp	- skip flag, 2 = good data, 1= bad data, 0 = very bad data.
Station	- receiver station number in unscaled and unshifted units.
Freq.	- repetition rate frequency (hertz).
Cmp	- measured field component (Hx, Hy or Hz).
Amps	- peak-to-peak square-wave current (amps).
Window	- time window index.
Time	- time window center (msec).
Magnitude	- dB/dt magnitude (uV/amp).
RampAppRes	- ramp-corrected apparent resistivity (ohm-m) (only calculated for in-loop data).
Depth	- diffusion depth = $28 \cdot \sqrt{\text{resistivity} \cdot \text{time}}$ (m) (only calculated for in-loop data).
%Mag	- relative dB/dt magnitude error (percent).

### Z file - averaged TEM data

The .Z file is expected to contain window magnitude data for use with STEMINV.

```
TEMAVG 7.36 Contour file.
/* 01 Jun 96
$ DATE= 96-06-01
$ ZPLOT: DATA= TIME
Cl Cn Ce Ns Nd Yl Plot file 1
 0 1 0 3 1 0
TRANSIENT EM SURVEY DATA
Window MAGNITUDE
  values in microV/ampere
  Component: Hz, Rxna: 10000.0
$ CONTOUR= NONE
$ PROFILE= AUTO
$ POST = NONE
IIxxxxxxxxYYYYYYYzzzzzzzzzzzz AAA ffffffffwww
2 0.00 0.0366 -9.55983e+03 32Hz W 1
2 0.00 0.06712-7.14530e+03 32Hz W 2
2 0.00 0.09764-4.06307e+03 32Hz W 3
2 0.00 0.12815-1.77413e+03 32Hz W 4
2 0.00 0.15867-3.56687e+02 32Hz W 5
2 0.00 0.18919 4.20503e+02 32Hz W 6
2 0.00 0.23438 8.54600e+02 32Hz W 7
2 0.00 0.29555 8.91040e+02 32Hz W 8
2 0.00 0.35667 7.21070e+02 32Hz W 9
2 0.00 0.43215 4.96700e+02 32Hz W10
2 0.00 0.52393 2.99623e+02 32Hz W11
2 0.00 0.64389 1.54230e+02 32Hz W12
2 0.00 0.81105 6.28587e+01 32Hz W13
2 0.00 1.00886 2.35730e+01 32Hz W14
2 0.00 1.25118 7.84533e+00 32Hz W15
2 0.00 1.55483 2.14923e+00 32Hz W16
2 0.00 1.9473 7.98333e-02 32Hz W17
2 0.00 2.46251-1.83467e-01 32Hz W18
2 0.00 3.10054-2.50000e-01 32Hz W19
2 0.00 3.88871-4.03267e-01 32Hz W20
2 0.00 4.87477-3.67400e-01 32Hz W21
2 0.00 6.13034-2.57000e-01 32Hz W22
2 25.00 0.0366 -1.15100e+04 32Hz W 1
2 25.00 0.06712-7.85410e+03 32Hz W 2
2 25.00 0.09764-3.92493e+03 32Hz W 3
2 25.00 0.12815-1.34250e+03 32Hz W 4
2 25.00 0.15867 1.16260e+02 32Hz W 5
2 25.00 0.18919 8.42287e+02 32Hz W 6
: : : : : :
: : : : : :
9999.0
```

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 STEMINV input, the Z file must have TEM magnitude data.

## Description of lines in sample Z file:

\$ ZPLOT: DATA= FLOG - mode line, y-value data type (log(freq))

\$ ASPACE = 60.960m - receiver dipole length

AMTAVG 7.20 - program name and version that generated this file.

CI Cn Ce Ns Nd Yl - 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.

Yl - label for vertical axis: 0 = none

1 = log frequency axis

2 = linear frequency axis

3 = linear depth

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

1 - value of CI => logarithmic contours

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

0 - value of Ce =>  $\text{interval}=10^{\text{Ce}}$

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

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

1 - value of Yl => log frequency axis

TEM SURVEY DATA - Data description for this plot file. Two to six lines are available.

values in microV/ampere ZPLOT plots these lines as title annotation.

Component: Hz, Rxna: 10000.0

\$ CONTOUR= NONE - ZPLOT plot control keywords, no contours.

\$ PROFILE= AUTO - plot magnitude profiles.

\$ POST = NONE - do not post data values.

llxxxxxxxYYYYYYYYzzzzzzzzzzzz - 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 TEM, time window center (msec).

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.

ffffff - repetition rate frequency (hertz).

www - time window number.

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

## STN file - station location and elevation

### Listing of STEMDEMO.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 with space or comma separated values. A STN file should have at least two entries, corresponding to the first and last stations. Additional entries may be necessary to trace out topographic changes or curved lines. STEMINV assumes that station numbers are related to distance along line. Station number values are used to linearly interpolate (easting,northing,elevation) coordinates of stations without a matching entry in the STN file. If station numbers are scaled by entries in the MDE file, STN-file station numbers should be in the scaled and shifted client station numbers defined by MDE LBLFRST and LBLDELTA, not the unscaled and unshifted GDP station numbers defined by STNBEG, STNDELTA.

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

### STN file column definitions:

Station - client station numbers.

Easting - grid east (m or ft, length units specified when STEMINV creates a new std file)

Northing - grid north (m or ft)

Elevation - elevation (m or ft)

# STEMINV File Documentation

## STD file - survey configuration, inversion control and observed data

### Partial Listing of STEMDEMO.STD:

```
&STEMINV
Header(1)='From STEMINV v3.00e Date:31/03/01 Time:09:49:53'
Header(2)='STEMINV Demo Line 0'
Header(3)='for Zonge Engineering'
Header(4)='Data from Stemdemo.avg'
Project='STEMINV Demo',Line='0',
SurveyType='Moving-Loop',TEMUnits='uV/A',LengthUnits='ft',
XTxLength=400.00,YTxLength=400.00,TxAzimuth=-20,NTxTurn=1,
RepRate=8.000,TxRamp=72.00,
XTxCenter=0.0,YTxCenter=0.0,
XRxOffset=0.0,YRxOffset=0.0,RxArea=1.0000E+4,
dpWeight=1.00,dzWeight=3.00,Niteration=8,
ErrorFloor=5.0,DataCutoff=100.0,
/
"Stn", "GridE", "GridN", "Elev", "TWcenter", "TWwidth", "uVobs", "uVerr", "uVcalc"
84.00, 5595, 5887, 2030, 4.600E-2, 0.000E+0, 3.234E+5, 0.5, 2.793E+05
84.00, 5595, 5887, 2030, 7.640E-2, 0.000E+0, 1.310E+5, 0.4, 1.274E+05
84.00, 5595, 5887, 2030, 1.068E-1, 0.000E+0, 6.687E+4, 0.4, 6.717E+04
84.00, 5595, 5887, 2030, 1.372E-1, 0.000E+0, 3.980E+4, 0.3, 3.923E+04
84.00, 5595, 5887, 2030, 1.676E-1, 0.000E+0, 2.562E+4, 0.3, 2.468E+04
84.00, 5595, 5887, 2030, 1.980E-1, 3.770E-2, 1.730E+4, 0.3, 1.662E+04
84.00, 5595, 5887, 2030, 2.430E-1, 5.300E-2, 1.040E+4, 0.3, 9.870E+03
84.00, 5595, 5887, 2030, 3.040E-1, 6.090E-2, 5.604E+3, 0.4, 5.381E+03
84.00, 5595, 5887, 2030, 3.648E-1, 6.800E-2, 3.256E+3, 0.2, 3.216E+03
84.00, 5595, 5887, 2030, 4.400E-1, 8.330E-2, 1.835E+3, 0.1, 1.867E+03
84.00, 5595, 5887, 2030, 5.314E-1, 1.055E-1, 1.004E+3, 0.7, 1.064E+03
84.00, 5595, 5887, 2030, 6.510E-1, 1.430E-1, 5.165E+2, 0.7, 5.750E+02
84.00, 5595, 5887, 2030, 8.175E-1, 1.817E-1, 2.554E+2, 2.7, 2.841E+02
84.00, 5595, 5887, 2030, 1.015E+0, 2.192E-1, 1.313E+2, 0.6, 1.450E+02
84.00, 5595, 5887, 2030, 1.256E+0, 2.720E-1, 7.045E+1, 3.6, 7.581E+01
84.00, 5595, 5887, 2030, 1.558E+0, 3.467E-1, 4.224E+1, 5.3, 4.056E+01
84.00, 5595, 5887, 2030, 1.949E+0, 4.521E-1, 2.280E+1, 18.5, 2.224E+01
84.00, 5595, 5887, 2030, 2.463E+0, 5.744E-1, 1.558E+1, 6.8, 1.263E+01
84.00, 5595, 5887, 2030, 3.098E+0, 7.104E-1, 1.001E+1, 34.6, 7.709E+00
84.00, 5595, 5887, 2030, 3.883E+0, 8.837E-1, 5.151E+0, 44.1, 4.962E+00
84.00, 5595, 5887, 2030, 4.865E+0, 1.117E+0, 3.764E+0, 52.6, 3.287E+00
84.00, 5595, 5887, 2030, 6.116E+0, 1.419E+0, 7.941E-1, 199.1,
84.00, 5595, 5887, 2030, 7.703E+0, 1.776E+0, 1.510E+0, 13.5, 1.461E+00
84.00, 5595, 5887, 2030, 9.668E+0, 2.219E+0, 8.854E-1, 113.2,
84.00, 5595, 5887, 2030, 1.214E+1, 2.807E+0, 9.154E-1, 167.0,
84.00, 5595, 5887, 2030, 1.528E+1, 3.542E+0, 1.692E-1, 205.0,
84.00, 5595, 5887, 2030, 1.923E+1, 4.454E+0, 2.941E-1, 183.6,
84.00, 5595, 5887, 2030, 2.419E+1, 4.965E+0, 3.749E-1, 63.8, 1.769E-01
88.00, 5471, 6271, 2040, 4.300E-2, 0.000E+0, 3.599E+5, 0.5, 2.802E+05
88.00, 5471, 6271, 2040, 7.340E-2, 0.000E+0, 1.360E+5, 0.5, 1.202E+05
88.00, 5471, 6271, 2040, 1.038E-1, 0.000E+0, 6.228E+4, 0.4, 6.094E+04
. . . . .
. . . . .
. . . . .
```

### STEMINV 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.  
Project - project name character string.  
Line - line number character string.  
SurveyType - character, 'Moving-Loop' or 'Fixed-Loop'.  
TEMUnits - character, TEM data units (uV/A or nV/Am<sup>2</sup>)  
LengthUnits - character, distance units (m or ft).  
XTxLength - real, across-line transmitter-loop width (LengthUnits).  
YTxLength - real, along-line transmitter-loop width (LengthUnits).  
NtxTurn - integer, number Tx loop turns (1 to 32)  
TxAzimuth - real, Tx loop rotation (deg cw).  
TxRamp - real, Tx turn-off ramp time (usec).  
RepRate - real, repetition rate (hertz).  
XTxCenter - real array, grid east coordinates of Tx center (LengthUnits).  
YTxCenter - real array, grid north coordinates of Tx center (LengthUnits).  
RxArea - real, receiver coil's effective surface area (m<sup>2</sup>).  
XRxOffset - real, along-line offset between moving-loop Tx center and Rx coil (LengthUnits).  
YRxOffset - real, across-line offset between moving-loop Tx center and Rx coil (LengthUnits).  
Niteration - integer, number of restarts to use in iterative inversion.  
dpWeight - relative weight of starting model (default=1.0).  
dzWeight - relative weight of vertical smoothness constraints (default=1.0).  
DataCutoff - real, upper limit on acceptable data error (%)  
ErrorFloor - real, all inversion data error values are kept above ErrorFloor (%)  
/ - 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 - time window center, ordered low to high for each station (msec).  
Column 6 - time window width (msec).  
Column 7 - observed dBz/dt magnitude (uV/amp or nV/Am<sup>2</sup>).  
Column 8 - observed dBz/dt relative error, if above DataCutoff data point is skipped (percent).  
Column 9 - calculated dBz/dt magnitude, may be missing (uV/amp or nV/Am<sup>2</sup>).

## M1D file - inversion model

### Partial Listing of STEMDEMO.M1D:

```
"Stn", "GridE", "GridN", "Zinv", "ResInv", "Res0", "Rerr0", "dzW", "Rerr", "Rsns"
"From STEMINV v3.00e Date:31/03/01 Time:11:01:15"
84.00, 5595, 5887, 2030.0, 1.991E+1, 2.660E+1, 500.00, 2.00, 3.99, 99.58
84.00, 5595, 5887, 1986.7, 1.991E+1, 2.660E+1, 500.00, 2.00, 3.99, 99.58
84.00, 5595, 5887, 1898.8, 4.608E+1, 3.810E+1, 500.00, 1.00, 9.54, 79.33
84.00, 5595, 5887, 1808.7, 1.116E+2, 5.777E+1, 500.00, 1.00, 15.30, 24.15
84.00, 5595, 5887, 1716.2, 2.072E+2, 7.947E+1, 500.00, 1.00, 20.39, 9.06
84.00, 5595, 5887, 1621.3, 2.835E+2, 9.514E+1, 500.00, 1.00, 24.57, 5.13
84.00, 5595, 5887, 1523.9, 3.003E+2, 1.009E+2, 500.00, 1.00, 26.71, 4.43
84.00, 5595, 5887, 1423.9, 2.611E+2, 9.787E+1, 500.00, 1.00, 26.81, 5.02
84.00, 5595, 5887, 1321.2, 1.955E+2, 8.949E+1, 500.00, 1.00, 25.50, 6.59
84.00, 5595, 5887, 1215.9, 1.308E+2, 7.910E+1, 500.00, 1.00, 23.75, 9.34
84.00, 5595, 5887, 1107.8, 8.076E+1, 6.895E+1, 500.00, 1.00, 22.48, 13.48
84.00, 5595, 5887, 996.9, 4.774E+1, 6.019E+1, 500.00, 1.00, 21.78, 18.29
84.00, 5595, 5887, 883.0, 2.829E+1, 5.322E+1, 500.00, 1.00, 20.12, 21.01
84.00, 5595, 5887, 766.2, 1.765E+1, 4.797E+1, 500.00, 1.00, 14.78, 20.85
84.00, 5595, 5887, 646.3, 1.188E+1, 4.423E+1, 500.00, 1.00, 12.93, 83.72
88.00, 5471, 6271, 2040.0, 2.157E+1, 2.954E+1, 500.00, 2.00, 4.22, 98.96
88.00, 5471, 6271, 1997.3, 2.157E+1, 2.954E+1, 500.00, 2.00, 4.22, 98.96
88.00, 5471, 6271, 1911.6, 5.326E+1, 4.144E+1, 500.00, 1.00, 10.54, 68.20
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. . . . .
. . . . .
```

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

### M1D-file column definitions :

- Stn - station numbers. Station numbers can be arbitrarily scaled units, but they should be proportional to distance along line.
- GridE - grid east (LengthUnits).
- GridN - grid north (LengthUnits).
- Zinv - layer midpoint elevations (LengthUnits) (if station elevations=0, RSTEMINV 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 STEMDEMO.OBS:

```
"Stn", "GridE", "GridN", "Elev", "TWcenter", "TWwidth", "uVobs", "uVerr", "uVcalc", "%diff"
"From RSTEMINV v3.00e Date:31/03/01 Time:11:01:15"
84.00, 5595, 5887, 2030, 4.600E-2, 0.000E+0, 3.234E+5, 0.5, 2.793E+05, 14.
84.00, 5595, 5887, 2030, 7.640E-2, 0.000E+0, 1.310E+5, 0.4, 1.274E+05, 2.8
84.00, 5595, 5887, 2030, 1.068E-1, 0.000E+0, 6.687E+4, 0.4, 6.717E+04, -0.44
84.00, 5595, 5887, 2030, 1.372E-1, 0.000E+0, 3.980E+4, 0.3, 3.923E+04, 1.4
84.00, 5595, 5887, 2030, 1.676E-1, 0.000E+0, 2.562E+4, 0.3, 2.468E+04, 3.7
84.00, 5595, 5887, 2030, 1.980E-1, 3.770E-2, 1.730E+4, 0.3, 1.662E+04, 4.0
84.00, 5595, 5887, 2030, 2.430E-1, 5.300E-2, 1.040E+4, 0.3, 9.870E+03, 5.1
84.00, 5595, 5887, 2030, 3.040E-1, 6.090E-2, 5.604E+3, 0.4, 5.381E+03, 4.0
84.00, 5595, 5887, 2030, 3.648E-1, 6.800E-2, 3.256E+3, 0.2, 3.216E+03, 1.2
84.00, 5595, 5887, 2030, 4.400E-1, 8.330E-2, 1.835E+3, 0.1, 1.867E+03, -1.7
84.00, 5595, 5887, 2030, 5.314E-1, 1.055E-1, 1.004E+3, 0.7, 1.064E+03, -5.7
84.00, 5595, 5887, 2030, 6.510E-1, 1.430E-1, 5.165E+2, 0.7, 5.750E+02, -10.
84.00, 5595, 5887, 2030, 8.175E-1, 1.817E-1, 2.554E+2, 2.7, 2.841E+02, -10.
84.00, 5595, 5887, 2030, 1.015E+0, 2.192E-1, 1.313E+2, 0.6, 1.450E+02, -9.4
84.00, 5595, 5887, 2030, 1.256E+0, 2.720E-1, 7.045E+1, 3.6, 7.581E+01, -7.1
84.00, 5595, 5887, 2030, 1.558E+0, 3.467E-1, 4.224E+1, 5.3, 4.056E+01, 4.0
84.00, 5595, 5887, 2030, 1.949E+0, 4.521E-1, 2.280E+1, 18.5, 2.224E+01, 2.5
84.00, 5595, 5887, 2030, 2.463E+0, 5.744E-1, 1.558E+1, 6.8, 1.263E+01, 19.
84.00, 5595, 5887, 2030, 3.098E+0, 7.104E-1, 1.001E+1, 34.6, 7.709E+00, 23.
84.00, 5595, 5887, 2030, 3.883E+0, 8.837E-1, 5.151E+0, 44.1, 4.962E+00, 3.7
84.00, 5595, 5887, 2030, 4.865E+0, 1.117E+0, 3.764E+0, 52.6, 3.287E+00, 13.
84.00, 5595, 5887, 2030, 6.116E+0, 1.419E+0, 7.941E-1, 199.1,,
84.00, 5595, 5887, 2030, 7.703E+0, 1.776E+0, 1.510E+0, 13.5, 1.461E+00, 3.3
84.00, 5595, 5887, 2030, 9.668E+0, 2.219E+0, 8.854E-1, 113.2,,
84.00, 5595, 5887, 2030, 1.214E+1, 2.807E+0, 9.154E-1, 167.0,,
84.00, 5595, 5887, 2030, 1.528E+1, 3.542E+0, 1.692E-1, 205.0,,
84.00, 5595, 5887, 2030, 1.923E+1, 4.454E+0, 2.941E-1, 183.6,,
84.00, 5595, 5887, 2030, 2.419E+1, 4.965E+0, 3.749E-1, 63.8, 1.769E-01, 53.
88.00, 5471, 6271, 2040, 4.300E-2, 0.000E+0, 3.599E+5, 0.5, 2.802E+05, 22.
88.00, 5471, 6271, 2040, 7.340E-2, 0.000E+0, 1.360E+5, 0.5, 1.202E+05, 12.
88.00, 5471, 6271, 2040, 1.038E-1, 0.000E+0, 6.228E+4, 0.4, 6.094E+04, 2.1
. . . . .
. . . . .
. . . . .
```

### Observed Data Columns (columns 1 through 8 are the same as STD 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 - time window center, ordered low to high for each station (msec).
- Column 6 - time window width (msec).
- Column 7 - observed dBz/dt (uV/A or nV/Am2) (TEMUnits).
- Column 8 - observed dBz/dt relative error (percent).
- Column 9 - calculated dBz/dt, will be missing if data skipped (uV/A or nV/Am2) (TEMUnits).
- Column 10 - relative calculated - observed difference (percent).