

STEMINV DOCUMENTATION

ZONGE Data Processing
Smooth-Model TEM Inversion
version 3.20

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STEMINV

Table of Contents

Introduction.....	5
Installation	5
Minimum Hardware Configuration	5
Installation Procedure	5
Installing program and sample data files	5
STEMINV program files	6
Moving key-disk software registration to your hard drive	6
Installing a hardware lock	7
SETUP32	7
Graphics Configuration	8
Uninstall Procedure.....	9
Program Use	10
Overview	10
Typical STEMINV Sequence	10
Auto Skip Menu Option	15
Invert Menu Option	15
RSTEMINV Inversion Criteria	17
Tradeoff between Fitting Data and Model Constraints	18
Review Data Menu Option	19
References	22
Data Processing File Documentation.....	23
MDE file (Survey annotation, configuration and processing control file)	23
AVG file (TEMAVG(W) averaged data file).....	25
Z file (ZPLOT plotting data file)	27
STN file (station location information)	29
AMIRA TEM and CHN (TEM survey configuration and sounding data).....	30
STEMINV File Documentation	32
STD file (inversion control and observed data input file)	32
M1D file (smooth-model resistivity output file)	34
OBS file (observed and calculated data output file)	35

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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 or 32-bit) mode.

Installation Procedure

Each distribution copy of STEMINV 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 STEMINV and hardware lock software is installed, dongles may be moved from one computer to another, but parallel port hardware locks 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. 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. It is usually easiest to put modeling programs from a CD into a single directory on your computer's path (such as c:\datpro). Using a single directory reduces the length of the operating-system PATH environment variable.

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 target installation directory 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. An easy way to change file attributes is to right-click on a file name in Windows Explorer, select Properties and uncheck the Read Only check box.

Installing a hardware lock

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. A USB dongle may be installed with the computer power on.

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.

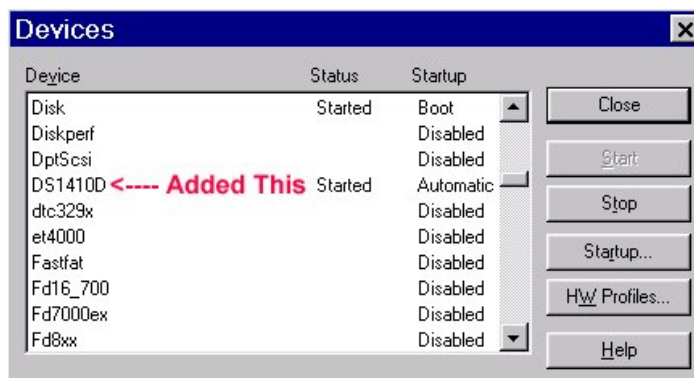
Note that you must ensure the end of the hardware lock labeled "Computer" is connected to your computer's parallel port. It is possible to plug the hardware lock in backwards, which may damage the hardware lock, the parallel port or both.

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, 2000 or XP, 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, 2000 or XP, the list of 'Devices' should include a new driver, DS1410D



Test the software registration by executing STEMREG from the STEMINV hard-disk directory. There should be no visible response unless a window pops up to display an error message. Text files on the installation CD-ROM discuss common problems with dongles.

A software registration check is done every time RSTEMINV is initiated. RSTEMINV calls STEMREG to check for valid software registration. The software registration software checks for an appropriate hardware key or “dongle” in a parallel or USB port.

Graphics Configuration

STEMINV expects Windows graphics set to high color (16-bit or 32-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 v8 or v9. MODSECT documentation details its hardcopy plot options. The program files are included on the STEMINV CD-ROM, and can be copied to the STEMINV installation directory on your computer.

Uninstall Procedure

All files in the STEMINV installation directory can be deleted without problems. No files are in any other system directory, and no changes were made to the operating system. No changes to the Windows registry were made.

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(W) 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.

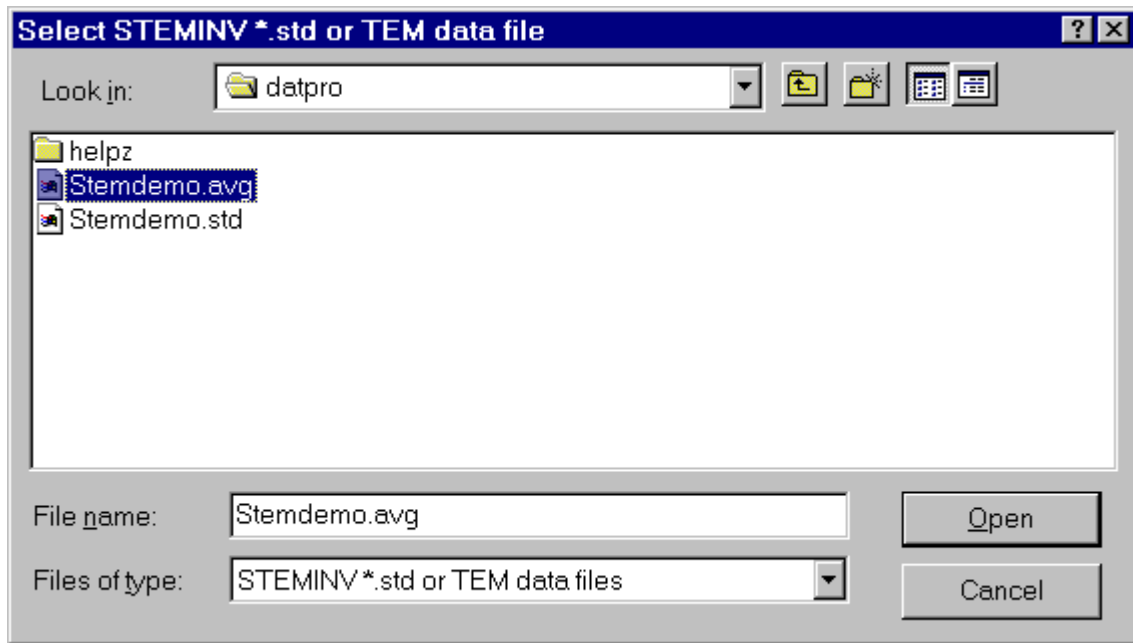
RSTEMINV, the core inversion program, reads std files, constructs a starting model, inverts observed data, and writes inverted results into a m1d file holding model resistivities versus station location and depth. RSTEMINV saves observed and calculated data in both std and obs files. The tabular format 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.

Verify TEM survey configuration

Descriptive Text

STEMINV Demo Line 0

for Zonge Engineering

Data from STEMDEMO.AVG

Job Name

STEMINV Demo

Job Area

Job For

Zonge Engineering

Job By

Line Name

0

Line Number

0.0

Line Azimuth

-18

Station # Scale

100.7

ft

▼

/Station_#

TEM Array

In-Loop

Tx-Rx Offset

0.0

ft

(across-line)

Tx Loop Size (ft)

Tx Loop

Transmitter

Repetition

along line

across line

Azimuth

Turns

Ramp Time

Rate

400.0

400.0

-18 deg

1

72.0 usec

8.000 Hz

FXL Tx Loop Center (ft)

East

0.

North

0.

Rx Coil

Effective Area

1.00E+4

m^2

TEM Data

Units uV/A

Drop Data with

Error Above

100.0 %

Background Model

Vertical Smoothness

Data Error

Floor

Maximum # of

Iterations

8

Weighting

1.000

Weighting

3.000

Floor

5.0 %

Save As

STEMDEMO

.std

Continue

Cancel

The “Verify TEM survey configuration” dialog includes three fields to hold a general description of the data set. It also has specific text fields for the project or job name, area, customer and contractor. **Line Name** is a text label, while **Line Number** is a floating point number which is sometimes used as an across-line coordinate value. **Line Azimuth** indicates the orientation of the line in the direction of increasing station numbers and is specified in degrees east of north. **Station Number Scale** specifies the relationship between station number values and distance along line feet or meters. Moving-Loop and Fixed-Loop surveys scale station numbers to distance along line when calculating the location of receiver loops relative to the transmitter loop.

The **Survey Type** may be Fixed-Loop, Moving-Loop, In-Loop or Coincident-Loop. A fixed-loop survey presumes one transmitter loop location that doesn't move. The **FXL Tx Loop Center** fields are used to specify east and north coordinates at the center of a fixed rectangular transmitter loop.

Moving-Loop surveys assume that both the transmitter and receiver loops are moving along line, with the Tx.Stn and Rx.Stn values indicating the center of the transmitter and receiver loops respectively. Moving-Loop surveys can have a fixed Tx-Rx loop separation, or may have several receiver loop positions relative to each transmitter loop location. The **Tx-Rx Offset** field allows entry of a constant transmitter-receiver loop offset if the transmitter loop is on a different line than the receiver loop. In-Loop surveys are a special case of Moving-Loop, where the receiver loop is always in the center of the transmitter loop.

STEMINV assumes rectangular transmitter loops that are lying flat on the ground. **Tx Loop Size** specifies the loop edge length in feet or meters. Transmitter loop size has the same meaning for all four survey configurations (FXL, MVL, INL and COL). Loop sides are usually aligned with the survey lines, so the **Tx Loop Azimuth** value is usually the same as Line Azimuth, but it can be different if the transmitter loop is rotated relative to the survey lines. 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 all four survey configurations. STEMINV places transient delay time = 0 at the end of the Tx turn-off ramp. When reading data from AMIRA files, the keyword INIT_DELAY must 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.

Effective Rx Coil Area is in m^2 . **TEM Data Units** may be either in uV/A or nV/Am^2 . When reading AMIRA files with TEM units of nT/sec ($=\text{nV/m}^2$), STEMINV 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.

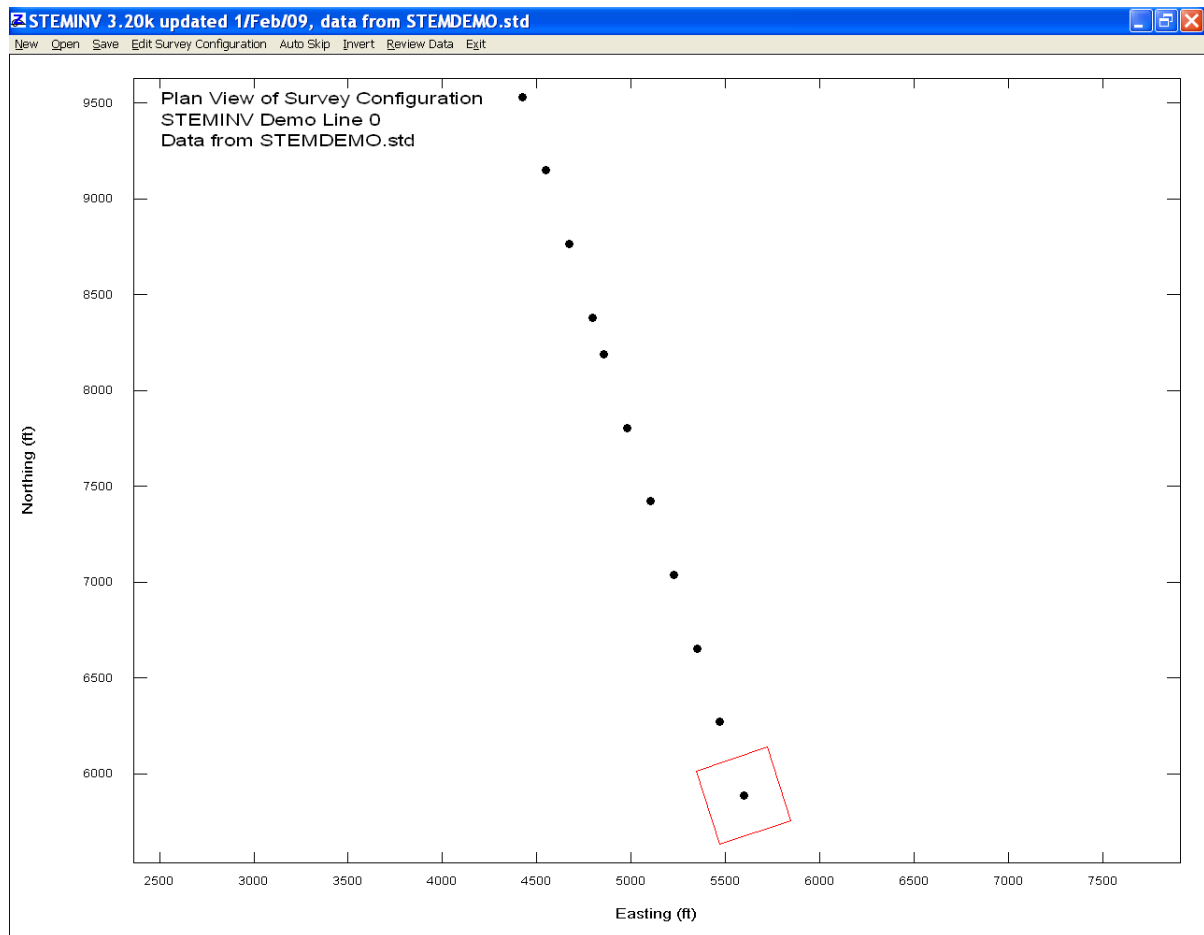
Vertical Smoothness Weighting controls the relative weight given smoothness constraints during inversion. Increasing smoothness-constraint weighting generates smoother models, while decreasing smoothness-constraint weighting allows rougher models and improves the fit to observed data.

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 STEMINV uses for the new std file.

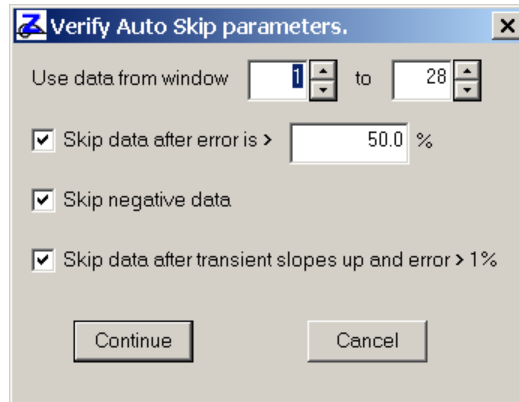
Once you have verified the survey configuration and inversion settings, you can select **Continue** to save the data set in a std file or **Cancel** to abort data input.



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, in-loop or coincident loop surveys, the transmitter loop outline for the first station is shown. STEMINV's main menu shows eight 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 a new stemdemo.std. Selecting the **Open** menu option prompts you for the name of an existing std file. **Save** shows a Save As file dialog, to allow saving an std file with a different name. **Edit Survey Configuration** shows the "Verify TEM survey configuration" dialog. **Auto Skip** shows a pop-up dialog with fields for skipping data based on time window number, error level, negative values or oscillating late-time transient values. **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.

Auto Skip Menu Option

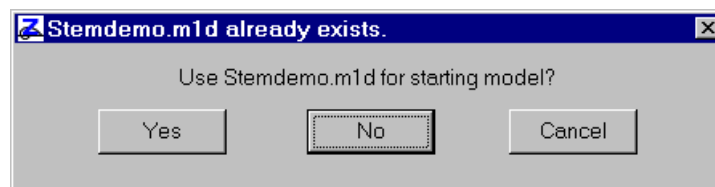
Auto Skip is useful if data have not already been carefully reviewed and bad data values skipped. Choosing **Auto Skip** from STEMINV's main menu brings up a dialog of quality control thresholds.



The **Use data from window ?? to ??** fields are useful if a fixed range of time windows should be skipped. For example, if transmitter turn-off has saturated the first 2 windows, set the lower index to 3 and time windows 1 and 2 will be skipped on all transients. If the **Skip data after error is > ??** check box is checked, then all transient values after the first point with an error level greater than the error-level floor will be skipped. Checking **Skip negative data** will skip all data with transient values less than or equal to 0. It is useful for dropping negative early-time out-of-loop data before inversion with STEMINV. **Skip data after transient slopes up and error > 1%** is a combination filter that skips all data after the first upsloping transient segment. It also checks for data error > 1%, so that upsloping early-time data (as when the Rx is outside the Tx loop) will not set skip flags over the entire transient. Click on the **Continue** button to apply the Auto Skip filters or click on **Cancel** to return to the main menu without modifying the data. Note that using Auto Skip clears all previous skip flag settings, including any that may have been set manually.

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*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*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).

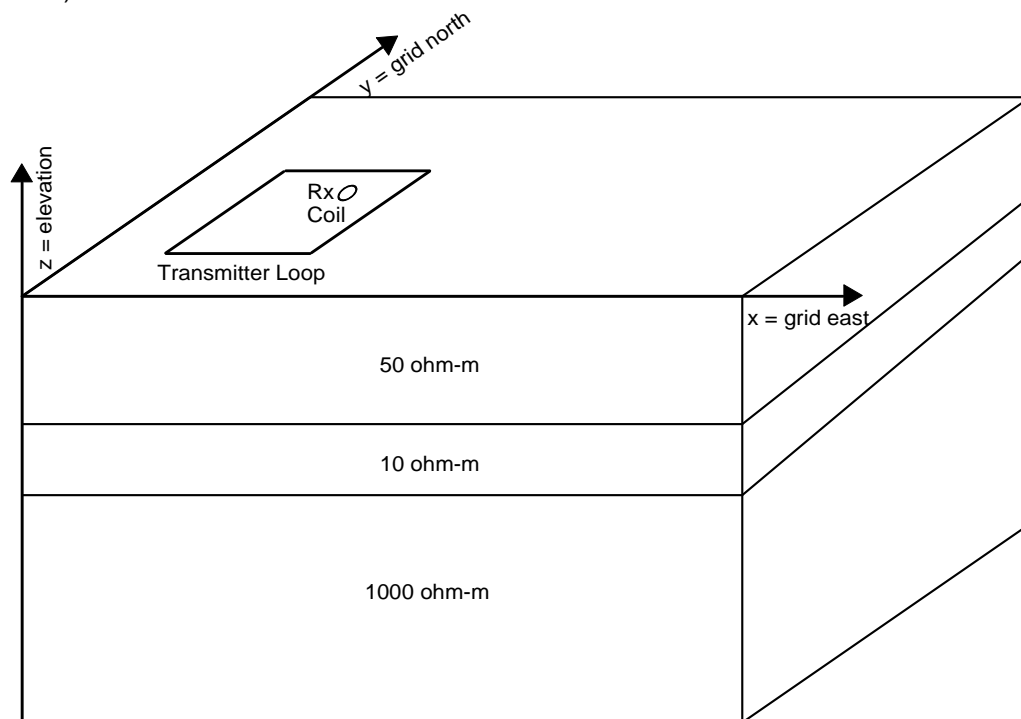


Figure 1: STEMINV and RSTEMINV use a right-handed coordinate system. The x-axis corresponds to grid east. The y-axis corresponds to grid north. The z-axis corresponds to elevations and is positive upward. Distances are specified in meters or feet. Azimuths are given in degrees clockwise from grid north.

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:

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

where

nobs = number of observed data values.

d_{obs_i} = observed asinh(dBz/dt in pV/Am2).

d_{mod_i} = calculated asinh(dBz/dt in pV/Am2).

d_{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_{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 $\epsilon_{\text{data}}/\sqrt{\text{nobs}}$ and ϵ_{total} in a log file after each inversion iteration. Model updates are not accepted if they increase ϵ_{total} . If an inversion step fails to improve ϵ_{total} , RSTEMINV tries again using a more cautious step size. RSTEMINV iterates on one station at a time, minimizing ϵ_{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 $p_{\text{err}_{i,j}} = 1.8 \log(\text{ohm-m})$ in the definition of ϵ_{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 ϵ_{model} relative to the ϵ_{data} sum of (observed - calculated data)² 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 ϵ_{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.

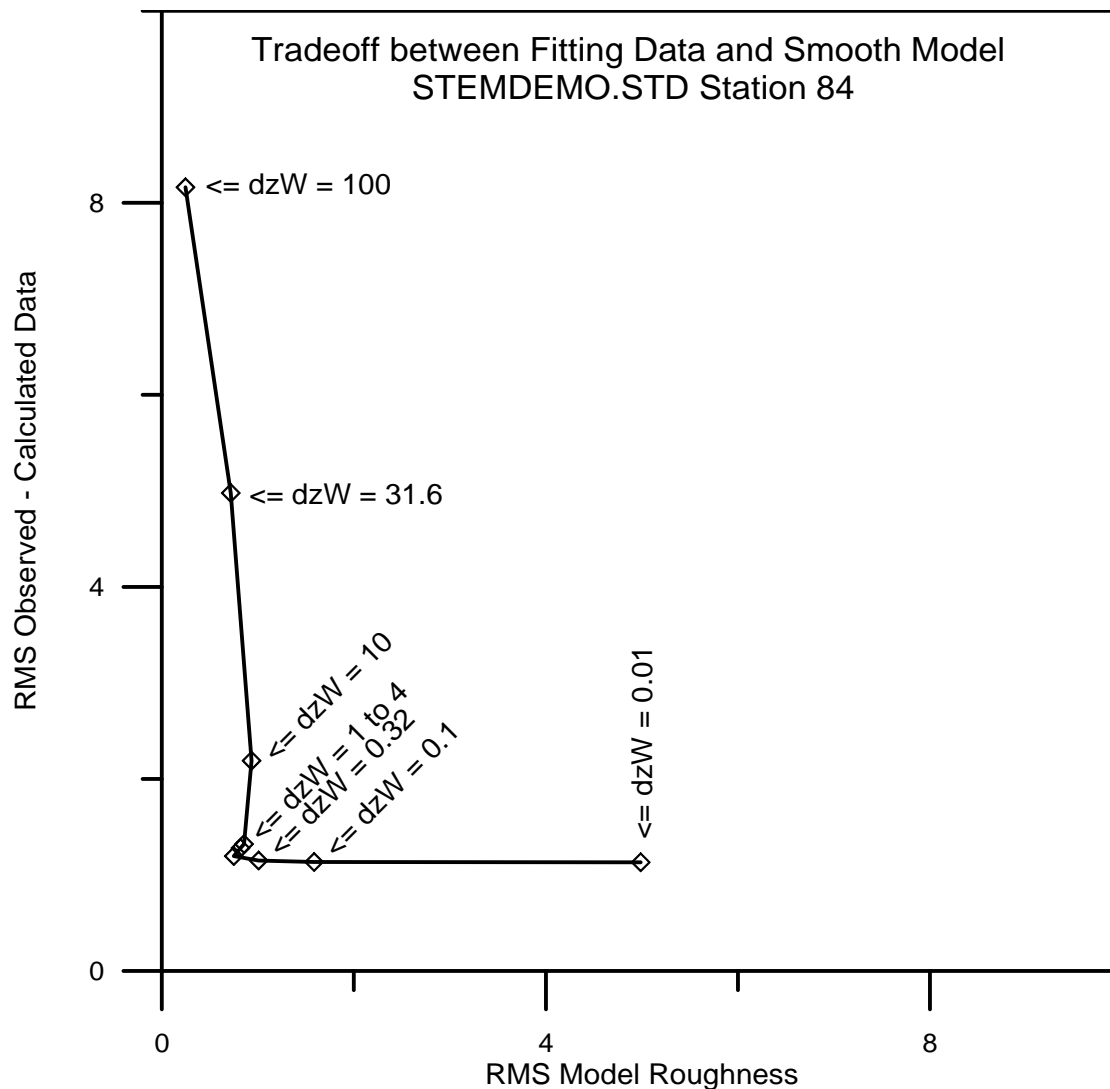
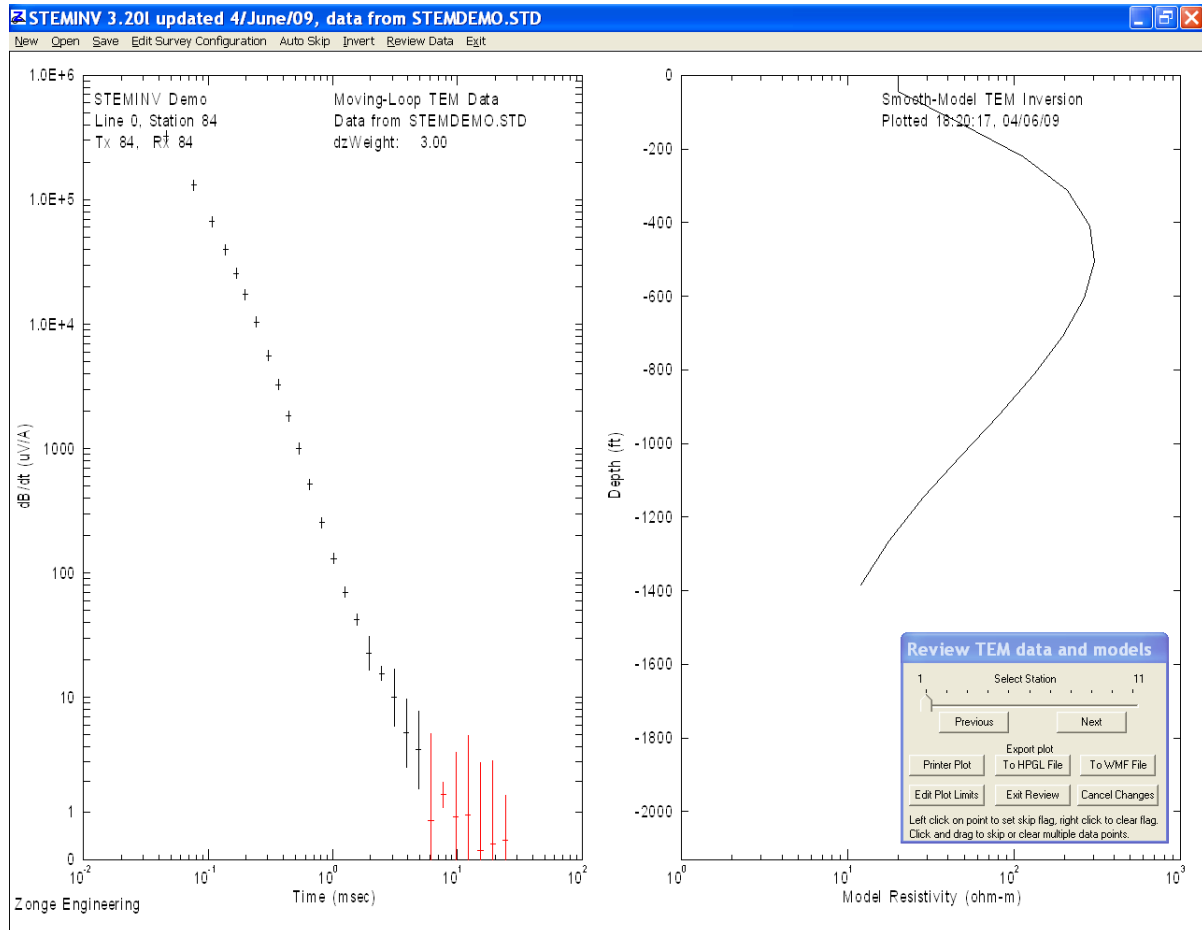


Figure 2: Inverting data for a single station with different values for $dzWeight$ shows the tradeoff between fitting observed data and keeping model smoothness. Data from station 84 in STEMDEMO.STD were inverted with $dzWeight$ varying between 100 and 0.01. Plotting RMS (root-mean-square) observed - 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, by pressing the left or right arrow keys, pressing the P or N keys, or easiest of all with the mouse scroll wheel.

To skip a noisy data point, press the left mouse button while the mouse cursor is over the point (a "left-click"). To skip a group of points, press the left mouse button to anchor one corner of a rubber band selection box, and hold the left mouse button down while moving the mouse cursor to the other corner of the selection box (a "left click and drag"). The selection box corners will be set when you release the mouse button and all transient data points within the selection box will be skipped. The

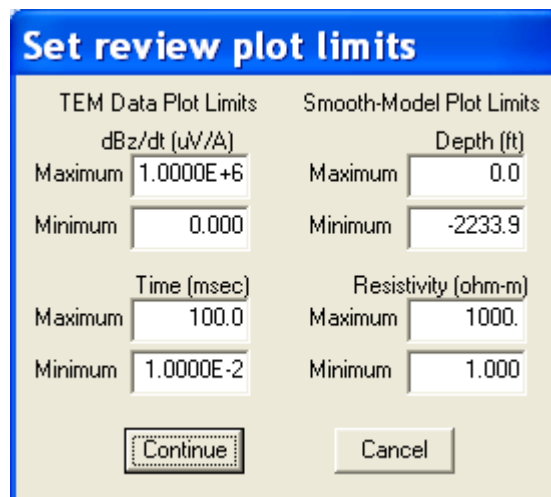
plot colors skipped points red. Similarly use a right click to clear the skip flag on a point or right click and drag to clear a group of points. Unskipped “good data” points that will be used for the inversion are plotted in black.

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.



The dialog box titled "Set review plot limits" has a blue header bar. It contains two columns of settings. The left column is titled "TEM Data Plot Limits" and includes a label "dBz/dt (uV/A)". It has "Maximum" and "Minimum" labels with input fields containing "1.0000E+6" and "0.000" respectively. The right column is titled "Smooth-Model Plot Limits" and includes a label "Depth (ft)". It has "Maximum" and "Minimum" labels with input fields containing "0.0" and "-2233.9" respectively. Below these, there are two more rows of settings. The first row is titled "Time (msec)" and "Resistivity (ohm-m)". The "Time (msec)" row has "Maximum" and "Minimum" labels with input fields containing "100.0" and "1.0000E-2" respectively. The "Resistivity (ohm-m)" row has "Maximum" and "Minimum" labels with input fields containing "1000." and "1.000" respectively. At the bottom of the dialog are two buttons: "Continue" and "Cancel".

TEM Data Plot Limits		Smooth-Model Plot Limits	
dBz/dt (uV/A)		Depth (ft)	
Maximum	1.0000E+6	Maximum	0.0
Minimum	0.000	Minimum	-2233.9
Time (msec)		Resistivity (ohm-m)	
Maximum	100.0	Maximum	1000.
Minimum	1.0000E-2	Minimum	1.000
Continue		Cancel	

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.

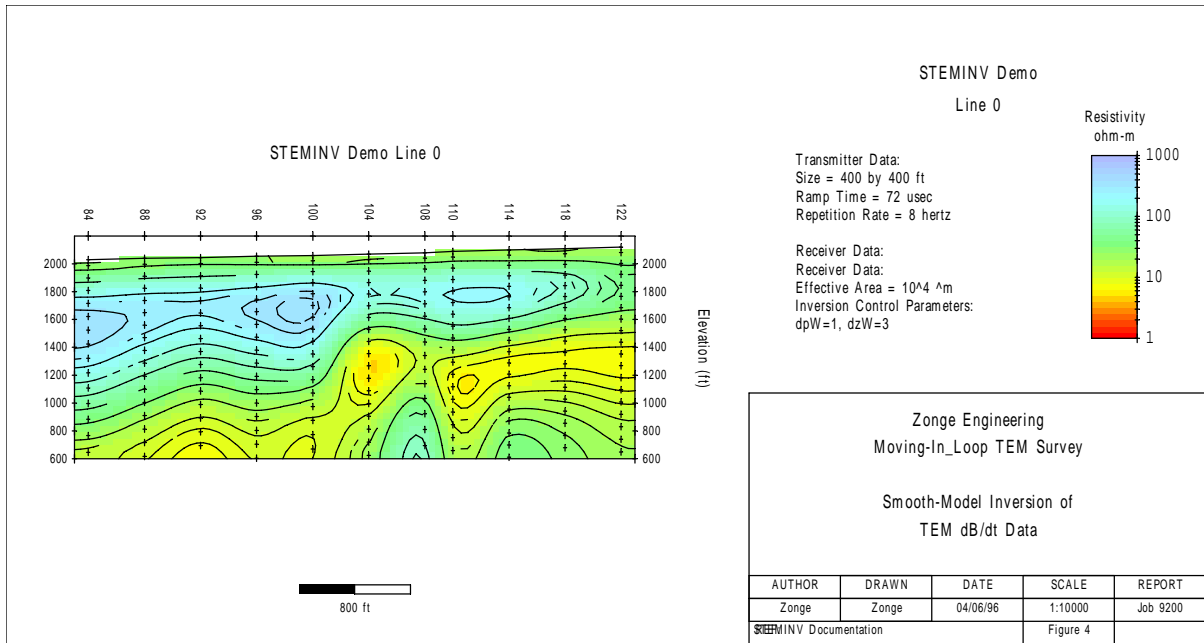


Figure 3: Smooth-model cross section from inversion of STEMDEMO.STD using dzWeight = 4.0. This plot was created using MODSECT v4.20d to read the std and m1d files, create a model section plot, and export a wmf file.

References

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- Tarantola, A., 1987, *Inverse problem theory, methods for data fitting and model parameter estimation*, Elsevier, Amsterdam, The Netherlands.
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Data Processing File Documentation

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

Partial listing of STEMDEMO.MDE:

```
$ Job.Name = "STEMINV Demo"
$ Job.Area = " "
$ Job.For = "Zonge Engineering"
$ Job.By = " "
$ Job.Number = "9200"
$ Job.Date = Sep 93
$ Survey.Array = INL
$ Line.Name = "0E"
$ Line.Number = 0
$ Line.Azimuth = -18
$ Rx.HPR = -18,0,0
$ Unit.Length = ft
$ Unit.Time = msec
$ Unit.dBdt = uV/A
$ Stn.GdpBeg = 84
$ Stn.GdpInc = 2
$ Stn.Beg = 84
$ Stn.Inc = 2
$ Tx.Center = 0,0,0 ft
$ Tx.Length = 400,400 ft
$ Tx.Area = 1.4884E+04 m^2
$ Stn.Left=84.0
$ Stn.Right=122.0
```

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. Some keywords, like Rx.HPR, take multiple comma-separated values. Annotation text strings should be enclosed in quotes, so that any enclosed commas are not parsed as value field separators. Lines that begin with a leading !, \, / or “ character are interpreted as comment lines and skipped over during mde file input.

Keywords Stn.GdpBeg, Stn.GdpInc, Stn.Beg and Stn.Inc can be used to shift and scale the GDP station numbers used in RAW, AVG and Z files to a different set of “client” station numbers suitable for report plots. Note that stn files use client station numbers, since station location information is often provided by the client. Client station numbers are calculated from GDP station numbers using $Stn = (Stn.Gdp - Stn.GdbBeg) * Stn.Inc / Stn.Gdplnc + Stn.Beg$. Default values produce no station number shifting or scaling.

Stn.GdpBeg	- first GDP station number origin
Stn.Gdplnc	- GDP station number increment
Stn.Beg	- client station number origin
Stn.Inc	- client station number increment
Stn.Left	- client station number on left side of pseudosection & section plots
Stn.Right	- client station number on right side of section plots

Stn.Left may be greater than Stn.Right to reverse plot axis station number order

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

Job.Name	- project name (up to 128 characters).
Job.Area	- project area (up to 128 characters).
Job.For	- client name (up to 128 characters).
Job.By	- contractor name (up to 128 characters).
Job.Number	- project ID number (up to 16 characters).
Job.Date	- data acquisition date (up to 16 characters).
Line.Name	- line name (text string up to 16 characters).
Line.Number	- line number (numeric value).
Line.Azimuth	- azimuth in direction of increasing stn # (deg E of N)
Rx.HPR	- EM X component heading(deg E of N), X component pitch (deg up from horizontal), Z component roll (deg clockwise around X axis)
Unit.Length	- length unit used for geographic coordinates (m or ft).
Unit.Time	- transient time unit (usec,msec,sec)
Unit.dBdt	- transient dB/dt unit (uV/A,nV/Am ²)
Tx.Center	- transmitter loop center (east,north,elevation) (length units)
Tx.Length	- transmitter loop side length (along-line,across-line) (length units)
Tx.Area	- transmitter loop area (meters ²)

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

```
$ MODSECT: PlotExport = Surfer
$ MODSECT: LengthUnit = 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 Min 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: XPostType= 1 1=post stn_#, 2=eastings, 3=northings
$ 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: DrawTopo = 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: CRERV = yes reverse resistivity color-fill order
$ 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 data reviewed with TEMTRIM v3.30b on 26/05/09

\$ Job.Name = "STEMINV Demo"

\$ Job.Area = ""

\$ Job.For = "Zonge Engineering"

\$ Job.By = "Zonge"

\$ Job.Number = "9200"

\$ Job.Date = Sep 93

\$ Survey.Type = LOTEM

\$ Survey.Array = INL

\$ Line.Name = "0E"

\$ Line.Number = 0

\$ Line.Azimuth = -18

\$ Stn.GdpBeg = 84

\$ Stn.GdpInc = 2

\$ Stn.Beg = 84

\$ Stn.Inc = 2

\$ Unit.Length = ft

\$ Unit.Time = msec

\$ Unit.dBdt = uV/A

\$ Unit.B = pT/A

\$ Tx.Length = 400,400 ft

\$ Tx.Area = 1.4864E+04 m^2

\$ Gdp.TxStn = 84

\$ Gdp.RxStn = 84

\$ Tx.Stn = 84

\$ Tx.Center = 0,0,0 ft

\$ Tx.Freq = 8

\$ Tx.Amp = 3.7

\$ Tx.Ramp = 72 usec

\$ Rx.Stn = 84

\$ Rx.HPR = -18,0,0

\$ Rx.Area = 1.0000E+04 m^2

\$ Rx.Cmp = Hz

TWin.Index,TWin.Center,TWin.Beg,TWin.End,dBdt.Mag,dBdt.Err,dBdt.%Err,dBdt.Wgt,ARes.Mag,Depth.Image,B.Mag

1,	4.6000E-2,	3.5694E-2,	5.9282E-2,	3.23430E+05,	1.62E+03,	0.5,	1.0,	1.667E+01,	2.452E+1,	1.79871E+03
2,	7.6400E-2,	5.9282E-2,	9.0330E-2,	1.30970E+05,	5.24E+02,	0.4,	1.0,	2.176E+01,	3.610E+1,	1.03578E+03
3,	1.0680E-1,	9.0330E-2,	1.2105E-1,	6.68700E+04,	2.67E+02,	0.4,	1.0,	2.418E+01,	4.500E+1,	6.29149E+02
4,	1.3720E-1,	1.2105E-1,	1.5164E-1,	3.98000E+04,	1.19E+02,	0.3,	1.0,	2.546E+01,	5.233E+1,	4.23729E+02
5,	1.6760E-1,	1.5164E-1,	1.8217E-1,	2.56150E+04,	7.68E+01,	0.3,	1.0,	2.656E+01,	5.908E+1,	3.01978E+02
6,	1.9800E-1,	1.8217E-1,	2.1935E-1,	1.72970E+04,	5.19E+01,	0.3,	1.0,	2.776E+01,	6.564E+1,	2.23783E+02
7,	2.4300E-1,	2.1935E-1,	2.7179E-1,	1.04030E+04,	3.12E+01,	0.3,	1.0,	2.950E+01,	7.496E+1,	1.59470E+02
8,	3.0400E-1,	2.7179E-1,	3.3302E-1,	5.60440E+03,	2.24E+01,	0.4,	1.0,	3.255E+01,	8.808E+1,	1.04911E+02
9,	3.6480E-1,	3.3302E-1,	4.0064E-1,	3.25640E+03,	6.51E+00,	0.2,	1.0,	3.590E+01,	1.013E+2,	7.06002E+01
10,	4.4000E-1,	4.0064E-1,	4.8355E-1,	1.83470E+03,	1.83E+00,	0.1,	1.0,	3.985E+01,	1.173E+2,	4.85790E+01
11,	5.3140E-1,	4.8355E-1,	5.8817E-1,	1.00400E+03,	7.03E+00,	0.7,	1.0,	4.475E+01,	1.365E+2,	3.33683E+01
12,	6.5100E-1,	5.8817E-1,	7.2952E-1,	5.16520E+02,	3.62E+00,	0.7,	1.0,	5.096E+01,	1.613E+2,	2.28642E+01
13,	8.1750E-1,	7.2952E-1,	9.1069E-1,	2.55430E+02,	6.90E+00,	2.7,	1.0,	5.697E+01,	1.911E+2,	1.55633E+01
14,	1.0145E+0,	9.1069E-1,	1.1288E+0,	1.31290E+02,	7.88E-01,	0.6,	1.0,	6.295E+01,	2.238E+2,	1.09356E+01
15,	1.2559E+0,	1.1288E+0,	1.3990E+0,	7.04470E+01,	2.54E+00,	3.6,	1.0,	6.764E+01,	2.581E+2,	8.07250E+00
16,	1.5584E+0,	1.3990E+0,	1.7429E+0,	4.22450E+01,	2.24E+00,	5.3,	1.0,	6.703E+01,	2.862E+2,	6.16880E+00
17,	1.9493E+0,	1.7429E+0,	2.1910E+0,	2.28020E+01,	4.22E+00,	18.5,	1.0,	7.022E+01,	3.276E+2,	4.71587E+00
18,	2.4626E+0,	2.1910E+0,	2.7621E+0,	1.55830E+01,	1.06E+00,	6.8,	1.0,	6.169E+01,	3.451E+2,	3.69424E+00
19,	3.0981E+0,	2.7621E+0,	3.4686E+0,	1.00100E+01,	3.46E+00,	34.6,	1.0,	5.681E+01,	3.715E+2,	2.80420E+00
20,	3.8833E+0,	3.4686E+0,	4.3467E+0,	5.15140E+00,	2.27E+00,	44.1,	1.0,	6.099E+01,	4.309E+2,	2.09707E+00
21,	4.8655E+0,	4.3467E+0,	5.4552E+0,	3.76400E+00,	1.98E+00,	52.6,	1.0,	5.178E+01,	4.444E+2,	1.64468E+00
22,	6.1163E+0,	5.4552E+0,	6.8642E+0,	7.94100E-01,	1.58E+00,	199.1,	1.0,	1.002E+02,	6.931E+2,	1.22747E+00
23,	7.7035E+0,	6.8642E+0,	8.6301E+0,	1.51040E+00,	2.04E-01,	13.5,	1.0,	4.447E+01,	5.183E+2,	1.11558E+00
24,	9.6681E+0,	8.6301E+0,	1.0835E+1,	8.85400E-01,	1.00E+00,	113.2,	1.0,	4.356E+01,	5.746E+2,	4.48860E-01

.
.
.

An AVG file contains averaged TEM data for discrete times. TEM AVG files are produced by the Zonge data processing programs TEMAVG or TEMAVGW, which read raw, fld or cac files with repeat readings, average like values, and write the averaged results to avg files. AVG files are usually archived together with GDP-format files (RAW) and station location files (STN). AVG files are used by Zonge programs that provide plots, options for further data processing, or modeling.

Comment lines with a leading “\”, “/”, “!” or “”” character may be placed anywhere within AVG files and are ignored by program input software. Keyword lines with a leading “\$” character are used to store survey annotation and configuration data that does not fit into a tabular numeric spreadsheet format. Data input software ignores lines with unknown keywords, so new parameters can be added to avg files without breaking old software. Numeric data are held in blocks with a tabular spreadsheet format of space- or comma-separated values. A column-label line must precede numerical data blocks to specify the parameters associated with each column. Column order is not fixed and all columns may not be present in a particular file. Data input software ignores columns with unknown labels, so new numeric data may be added to avg files without breaking old programs. Missing values are flagged by a “*”. Numerical values are free format with columns separated by spaces or commas.

TEM AVG header block keywords:

Job.Name	- project name (up to 128 characters).
Job.Area	- project area (up to 128 characters).
Job.For	- client name (up to 128 characters).
Job.By	- contractor name (up to 128 characters).
Job.Number	- project ID number (up to 16 characters).
Job.Date	- data acquisition date (up to 16 characters).
Survey.Type	- survey type, should always be TEM
Survey.Array	- TEM array (FXL,MVL,INL,COL,CNT,LOT)
Line.Name	- line name (text string up to 16 characters).
Line.Number	- line number (numeric value).
Line.Azimuth	- azimuth in direction of increasing stn # (deg E of N)
Stn.GdpBeg	- first GDP station number origin
Stn.GdpInc	- GDP station number increment
Stn.Beg	- client station number origin
Stn.Inc	- client station number increment
Unit.Length	- length unit used for geographic coordinates (m or ft).
Unit.Time	- transient time unit (usec,msec,sec)
Unit.dBdt	- transient dB/dt unit (uV/A,nV/Am ²)
Unit.B	- magnetic field unit (pT/A,nT/A,T,pT,nT,T)
Tx.Center	- fixed transmitter loop center (east,north,elevation) (length units)
Tx.Length	- transmitter loop side length (along-line,across-line) (length units)
Tx.Area	- transmitter loop area (meters ²)

TEM AVG data block keywords:

Gdp.TxStn	- GDP Tx station number (for MVL) or Tx ID (for FXL)
Gdp.RxStn	- GDP Rx station number, related to distance along line
Tx.Stn	- client Tx station number (for MVL) or Tx ID (for FXL)
Tx.Center	- Tx loop center (east,north,elevation) for FXL
Tx.Freq	- Tx waveform repetition rate (hertz)
Tx.Amp	- Tx waveform peak current (amp)
Tx.Ramp	- Tx turn-off ramp duration (usec)
Rx.Stn	- receiver loop client station number
Rx.HPR	- EM X component heading & pitch, Z component roll (deg)
Rx.Area	- receiver loop effective area (m ²)
Rx.Cmp	- receiver component (Hx,Hy, Hz)

TEM AVG file column definitions:

TWin.Index	- time window index.
TWin.Center	- time window geometric center = $\sqrt{\text{TWin.Beg} * \text{Twin.End}}$ (msec).
TWin.Beg	- time window beginning w.r.t. the end of Tx turn-off (msec).
TWin.End	- time window end w.r.t. the end of Tx turn-off (msec).
dBdt.Mag	- dB/dt magnitude (uV/A).
dBdt.Err	- dB/dt absolute error (uV/A).
dBdt.%Err	- dB/dt relative error (%).
dBdt.Wgt	- dB/dt weight, 0=skip data, 1=use data, intermediate values for robust averaging
Ares.Mag	- apparent resistivity (ohm-m)
Depth.Image	- diffusion depth = $28 * \sqrt{\text{ares.mag} * \text{twin.center}}$ (meters)
B.mag	- B(t) from integration of dB/dt transient (pT/A)

Z file - averaged TEM data

The .Z file format is primarily for input into the legacy Zonge plotting program ZPLOT. Z files are not recommended for input into STEMINV as they do not include survey configuration parameters and are missing data error. Avg files are the preferred STEMINV input format.

```

TEMAVG 7.36 Contour file.
/* 01 Jun 96
$ DATE= 96-06-01
$ ZPLOT: DATA= TIME
C1 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
IIXxxxxxxxxxYYYYYYYzzzzzzzzzzzz 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 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 => $\text{interval}=10^{\text{Ce}}$

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

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

1 - value of YI => 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.

llxxxxxxxxYYYYYYYYzzzzzzzzzzzz - Header line for the data that follows.

ll - skip flag field:

0 = Skip this line of data.

1 = Omit for contouring, but post the bracketed value.

2 = Use for contouring and post the value (most common).

3 = Label a point or station by plotting a symbol under the X-axis at the X-coordinate.

4 = Use for contouring, post the symbol and not the value. Used for depth plots where interpolated values are used at the bottom of the plot to improve gridding.

5 = Use to set plot limits, do not contour or post. Used for depth plots to set zero depth.

Also used to provide a margin around the data, as for plan maps.

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

YYYYYYYY - y value field, for 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
84.0,	5595,	5887,	2030
86.0,	5533,	6079,	2035
88.0,	5471,	6271,	2040
90.0,	5410,	6463,	2040
92.0,	5348,	6654,	2045
94.0,	5287,	6846,	2050
96.0,	5225,	7038,	2055
98.0,	5164,	7230,	2060
100.0,	5102,	7422,	2060
102.0,	5041,	7613,	2070
104.0,	4979,	7805,	2070
106.0,	4918,	7997,	2080
108.0,	4856,	8189,	2080
110.0,	4795,	8381,	2090
112.0,	4733,	8572,	2090
114.0,	4671,	8764,	2100
116.0,	4610,	8956,	2100
118.0,	4548,	9148,	2110
120.0,	4487,	9340,	2120
122.0,	4425,	9531,	2120

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 Stn.Beg and Stn.Inc, not the unscaled and unshifted GDP station numbers defined by Stn.GdpBeg, Stn.GdpInc.

Some grid coordinate systems, such as UTM coordinates, can generate very large coordinate values. STEMINV stores station locations as floating-point numbers with 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)

AMIRA TEM and CHN files –TEM data

Partial listing of STEMDEMO.TEM:

```
GDP AVERAGED TEM DATA    AMIRA FORMAT    For: Zonge Engineering and Research
UNITS=(uV/A) RMP=0.0020 LSIDE=20 CHANNELFILE=STEMDEMO.CHN INITDELAY=0.0020 RXAREA=1000~
STN  NCH    CH1      CH2      CH3      CH4      CH5      CH6      CH7      ~
\ Project: STEMINV documentation
\ Date   : 6/May/03
\ Window Times: 0.00163    0.00354    0.00544    0.00735    0.00926    0.01117    0.01399~
0.00  31  2.2172e+6  1.1601e+6  7.3170e+5  4.9388e+5  3.5008e+5  2.5773e+5  1.7373e+5~
1.00  31  2.4427e+6  1.2668e+6  7.4013e+5  4.6903e+5  3.1583e+5  2.2287e+5  1.4267e+5~
2.00  31  1.9517e+6  8.9937e+5  5.1887e+5  3.2897e+5  2.2287e+5  1.5883e+5  1.0343e+5~
3.00  31  1.7650e+6  8.4856e+5  4.8012e+5  2.9722e+5  1.9676e+5  1.3708e+5  8.7027e+4~
4.00  31  2.5292e+6  1.0718e+6  5.8050e+5  3.4173e+5  2.1465e+5  1.4225e+5  8.4471e+4~
5.00  31  2.5617e+6  1.1213e+6  6.1373e+5  3.6393e+5  2.2943e+5  1.5180e+5  8.9411e+4~
6.00  31  2.5703e+6  1.2325e+6  6.9310e+5  4.1553e+5  2.6260e+5  1.7370e+5  1.0290e+5~
7.00  31  2.4854e+6  1.0533e+6  5.8950e+5  3.6733e+5  2.4823e+5  1.7883e+5  1.2070e+5~
```

AMIRA-format TEM and CHN files are in a standard format widely used in Australia. AMIRA .tem files hold survey configuration metadata, optional station locations and TEM transient data in a column-oriented profile format. AMIRA.tem generally have an associated.chn file with TEM transient delay times. Comment lines starting with a \ may appear anywhere in AMIRA-format files. Other than comment lines, AMIRA TEM file records fall into three categories. First, TEM files must start with a single unflagged comment line which may contain any text and is ignored by programs reading the file. Second is a line of keywords and keyword values, each with a keyword=value or keyword:value format separated by spaces. Keywords can contain letters and numbers, but no other special characters or spaces. Third is a list of column labels which are space separated keywords indicating the content of columns in subsequent numerical records. The remainder of a .tem file is a block of numeric records in space separated columns. Missing values are indicated by a * symbol.

Most keywords can be either in the keyword line or used as column labels. If a parameter has a constant value for all stations, then it is best specified as a constant in the keyword record. If it varies, then it must be included as a column of values. The minimum required columns include STATION and CH1, CH2, ..., all other columns are optional.

AMIRA Keywords recognized by STEMINV

UNITS = uV/A, nV/Am² or nT/sec (default = uV/A)
CONFIGURATION or CONFIG = Moving_Loop, Slingram, InLoop, In_Loop, InOut,
Fixed, FixedLoop, Fixed_Loop (default = moving-loop)
If CONFIG type doesn't start with Fixed, STEMINV assumes a moving loop survey
CHANNELFILE = channel file name (default = same file name stem as *.tem file)
PROFILE = line number
NCH or NUMTIMES = # transient delay time windows, also read from *.chn file
FREQUENCY, FREQ or F = transmitter repetition rate (hertz)
CURRENT, CURR or CUR = transmitter current (amps)
TURNOFF, RAMP or RMP = transmitter turn-off ramp time (msec)
INIT_DELAY, INITDELAY or INIT = offset between beginning of Tx ramp and transient time = 0
(msec) (default = 0)
TXAREA or LOOPAREA = Tx loop area (m²)
RXAREA = Rx effective loop area (m²)

Custom comment lines with Tx loop center coordinates

/TXX = Tx loop easting
/TXY = Tx loop northing

AMIRA Column Labels recognized by STEMINV

STATION or STN = station numbers (required column)
LINE or PROFILE = line number (optional column)
LSIDE = Tx loop width (m) (optional column)
CURRENT or CUR = Tx current (optional column)
COMPONENT or C = Rx component (X,Y,Z,A,U,V,C,I)
NUMTIMES or NCH = number of dB/dt values, also in channel file
CH1, CH2, CH3, ... or CH01, CH02, CH03, ... = dB/dt values (required columns)

Listing of STEMDEMO.CHN:

GDP Zonge delay times

NUMTIMES=31

DELAY

0.00163
0.00354
0.00544
0.00735
0.00926
0.01117
0.01399
0.01781
0.02163
0.02635
0.03209
0.03958
0.05003
0.0624
0.07754
0.09652
0.12105
0.15325
0.19313
0.24239
0.30401
0.38249
0.48208
0.60533
0.76058
0.95762
1.20498
1.51653
1.90976
2.40258
3.02546

STEMINV File Documentation

STD file - survey configuration, inversion control and observed data

Partial Listing of STEMDEMO.STD:

```
//From STEMINV v3.20k Date:26/05/09 Time:15:52:18"
&STEMINV
ProgramVersion="STEMINV v3.20k"
Header(1)='From STEMINV v3.20k Date:26/05/09 Time:14:51:53',
Header(2)='STEMINV Demo Line 0',
Header(3)='for Zonge Engineering',
Header(4)='Data from STEMDEMO.AVG',
JobName="STEMINV Demo"
JobArea=""
JobBy=""
JobFor="Zonge Engineering"
JobNumber="9200"
JobDate="Sep 93"
LineName="0"
LineNumber=0
LineAzimuth=-18
SurveyType='In-Loop',TEMUnits='uV/A',LengthUnits='ft',StnScale=100.7286
XTxLength=400,YTxLength=400,TxAzimuth=-18,NTxTurn=1
RepRate=8,TxRamp=72
XTxCenter=0,YTxCenter=0
XRxOffset=0,YRxOffset=0,RxArea=1.0000E+4
dpWeight=1,dzWeight=3,Niteration=8
ErrorFloor=5,DataCutoff=100
/
Station,East,North,Elevation,RxStn,TxStn,TWcenter,TWwidth,uVobs,uVerr,uVwgtX,uVwgtY,uVwgtZ,uV
calc
84,5595,5887,2030,84,0,4.6000E-2,2.3589E-2,3.23430E+05,0.5,0,0,1,2.71297E+05
84,5595,5887,2030,84,0,7.6400E-2,3.1048E-2,1.30970E+05,0.4,0,0,1,1.24139E+05
84,5595,5887,2030,84,0,0.1068,3.0719E-2,6.68700E+04,0.4,0,0,1,6.55181E+04
84,5595,5887,2030,84,0,0.1372,3.0591E-2,3.98000E+04,0.3,0,0,1,3.81949E+04
84,5595,5887,2030,84,0,0.1676,3.0527E-2,2.56150E+04,0.3,0,0,1,2.39693E+04
84,5595,5887,2030,84,0,0.198,3.7182E-2,1.72970E+04,0.3,0,0,1,1.59134E+04
84,5595,5887,2030,84,0,0.243,5.2445E-2,1.04030E+04,0.3,0,0,1,9.38816E+03
84,5595,5887,2030,84,0,0.304,6.1221E-2,5.60440E+03,0.4,0,0,1,5.11854E+03
84,5595,5887,2030,84,0,0.3648,6.7624E-2,3.25640E+03,0.2,0,0,1,3.06211E+03
84,5595,5887,2030,84,0,0.44,8.2906E-2,1.83470E+03,0.1,0,0,1,1.77875E+03
84,5595,5887,2030,84,0,0.5314,0.1046,1.00400E+03,0.7,0,0,1,1.01679E+03
84,5595,5887,2030,84,0,0.651,0.1413,5.16520E+02,0.7,0,0,1,5.52345E+02
84,5595,5887,2030,84,0,0.8175,0.1812,2.55430E+02,2.7,0,0,1,2.77877E+02
84,5595,5887,2030,84,0,1.015,0.2181,1.31290E+02,0.6,0,0,1,1.45908E+02
84,5595,5887,2030,84,0,1.256,0.2702,7.04470E+01,3.6,0,0,1,7.89986E+01
84,5595,5887,2030,84,0,1.558,0.3439,4.22450E+01,5.3,0,0,1,4.37890E+01
84,5595,5887,2030,84,0,1.949,0.448,2.28020E+01,18.5,0,0,1,2.46212E+01
84,5595,5887,2030,84,0,2.463,0.5712,1.55830E+01,6.8,0,0,1,1.40111E+01
84,5595,5887,2030,84,0,3.098,0.7064,1.00100E+01,34.6,0,0,1,8.30643E+00
84,5595,5887,2030,84,0,3.883,0.8782,5.15140E+00,44.1,0,0,1,5.05608E+00
84,5595,5887,2030,84,0,4.865,1.108,3.76400E+00,52.6,0,0,1,3.10781E+00
84,5595,5887,2030,84,0,6.116,1.409,7.94100E-01,1199.1,0,0,1,
84,5595,5887,2030,84,0,7.703,1.766,1.51040E+00,13.5,0,0,1,1.15293E+00
84,5595,5887,2030,84,0,9.668,2.205,8.85400E-01,1113.2,0,0,1,
84,5595,5887,2030,84,0,12.14,2.788,9.15430E-01,1167,0,0,1,
84,5595,5887,2030,84,0,15.28,3.519,1.69230E-01,1205,0,0,1,
84,5595,5887,2030,84,0,19.23,4.425,2.94070E-01,1183.6,0,0,1,
84,5595,5887,2030,84,0,24.19,5.569,3.74930E-01,63.8,0,0,1,8.36706E-02
88,5471,6271,2040,88,0,4.3000E-2,2.3268E-2,3.59850E+05,0.5,0,0,1,2.73472E+05
88,5471,6271,2040,88,0,7.3400E-2,3.1106E-2,1.35950E+05,0.5,0,0,1,1.18753E+05
88,5471,6271,2040,88,0,0.1038,3.0739E-2,6.22770E+04,0.4,0,0,1,6.06554E+04
. . . . .
. . . . .
. . . . .
```

STEMINV Fortran Namelist block:

ProgramVersion - program name and version
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, up to 128 characters.
JobArea - project area, up to 128 characters.
JobBy - contractor name, up to 128 characters.
JobFor - client name, up to 128 characters.
JobNumber - job number, up to 16 characters.
JobDate - data acquisition date, up to 16 characters.
LineName - line label character string, up to 16 characters.
LineNumber - real, line number, floating point numeric value
LineAzimuth - real, line azimuth in direction of increasing client station numbers (deg E of N)
SurveyType - character, 'Fixed-Loop', 'Moving-Loop', 'In-Loop', 'Coincident-Loop'
TEMUnits - character, TEM data units (uV/A or nV/Am²)
LengthUnits - character, distance units (m or ft).
StnScale - real, length unit per client station number
XTxLength - real, along-line transmitter-loop length (LengthUnits).
YTxLength - real, across-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, Tx waveform 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 (m²).
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=3.0).
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:

Station - client station number.
East - station grid-east coordinate (m or ft) (LengthUnits).
North - station grid-north coordinate (m or ft) (LengthUnits).
Elevation - station elevation (m or ft) (+ upwards, LengthUnits).
RxStn - receiver loop center client station number
TxStn - transmitter loop center client station number (MVL), or Tx ID (FXL)
TWcenter - time window center, ordered low to high for each station (msec).
TWwidth - time window width (msec).
uVobs - observed dBz/dt magnitude (TEMUnits).
uVerr - observed dBz/dt relative error, if above DataCutoff data point is skipped (percent).
uVwgtX - x-component weight in uVobs (0 to 1)
uVwgtY - y-component weight in uVobs (0 to 1)
uVwgtZ - z-component weight in uVobs (0 to 1)
uVcalc - calculated dBz/dt magnitude, may be missing (TEMUnits).

M1D file - inversion model

Partial Listing of STEMDEMO.M1D:

```
Station,East,North,Zinv,ResInv,Res0,Rerr0,dzW,Rerr,Rsns
"From RSTEMINV v3.20k Date:26/05/09 Time:15:46:58"
84,5595,5887,2030,2.0088E+1,2.6861E+1,500,2,5.06,99.25
84,5595,5887,1986.66,2.0088E+1,2.6861E+1,500,2,5.06,99.25
84,5595,5887,1898.84,4.7928E+1,3.7635E+1,500,1,11.13,90.36
84,5595,5887,1808.71,1.1701E+2,5.4981E+1,500,1,18.47,13.13
84,5595,5887,1716.21,2.1001E+2,7.1199E+1,500,1,20.24,13.75
84,5595,5887,1621.276,2.6866E+2,7.8866E+1,500,1,20,14.8
84,5595,5887,1523.846,2.5949E+2,7.7100E+1,500,1,19.16,20.39
84,5595,5887,1423.854,2.0261E+2,6.9813E+1,500,1,18.07,22.48
84,5595,5887,1321.231,1.3782E+2,6.1197E+1,500,1,15.54,24.66
84,5595,5887,1215.91,8.8642E+1,5.3653E+1,500,1,12.26,28.87
84,5595,5887,1107.818,5.7250E+1,4.7972E+1,500,1,11.52,38.43
84,5595,5887,996.884,3.8761E+1,4.4095E+1,500,1,10.68,43.7
84,5595,5887,883.031,2.8302E+1,4.1661E+1,500,1,7.05,90.18
88,5471,6271,2040,2.1628E+1,2.9741E+1,500,2,5.53,99.06
88,5471,6271,1997.323,2.1628E+1,2.9741E+1,500,2,5.53,99.06
88,5471,6271,1911.542,5.3233E+1,4.1192E+1,500,1,10.26,75.34
. . . . .
. . . . .
. . . . .
```

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

M1D-file column definitions :

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

East - grid east (LengthUnits).

North - 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:

```
Station,East,North,Elevation,RxStn,TxStn,TWcenter,TWwidth,uVobs,uVerr,uVwgtX,uVwgtY,uVwgtZ,uV
calc,%diff
"From RSTEMINV v3.20k Date:26/05/09 Time:15:46:58"
84,5595,5887,2030,84,0,4.6000E-2,2.3589E-2,3.23430E+05,0.5,0,0,1,2.71297E+05,1.61187E+01
84,5595,5887,2030,84,0,7.6400E-2,3.1048E-2,1.30970E+05,0.4,0,0,1,1.24139E+05,5.21598E+00
84,5595,5887,2030,84,0,0.1068,3.0719E-2,6.68700E+04,0.4,0,0,1,6.55181E+04,2.02169E+00
84,5595,5887,2030,84,0,0.1372,3.0591E-2,3.98000E+04,0.3,0,0,1,3.81949E+04,4.03299E+00
84,5595,5887,2030,84,0,0.1676,3.0527E-2,2.56150E+04,0.3,0,0,1,2.39693E+04,6.42490E+00
84,5595,5887,2030,84,0,0.198,3.7182E-2,1.72970E+04,0.3,0,0,1,1.59134E+04,7.99934E+00
84,5595,5887,2030,84,0,0.243,5.2445E-2,1.04030E+04,0.3,0,0,1,9.38816E+03,9.75523E+00
84,5595,5887,2030,84,0,0.304,6.1221E-2,5.60440E+03,0.4,0,0,1,5.11854E+03,8.66928E+00
84,5595,5887,2030,84,0,0.3648,6.7624E-2,3.25640E+03,0.2,0,0,1,3.06211E+03,5.96638E+00
84,5595,5887,2030,84,0,0.44,8.2906E-2,1.83470E+03,0.1,0,0,1,1.77875E+03,3.04965E+00
84,5595,5887,2030,84,0,0.5314,0.1046,1.00400E+03,0.7,0,0,1,1.01679E+03,-1.25775E+00
84,5595,5887,2030,84,0,0.651,0.1413,5.16520E+02,0.7,0,0,1,5.52345E+02,-6.48593E+00
84,5595,5887,2030,84,0,0.8175,0.1812,2.55430E+02,2.7,0,0,1,2.77877E+02,-8.07805E+00
84,5595,5887,2030,84,0,1.015,0.2181,1.31290E+02,0.6,0,0,1,1.45908E+02,-1.00187E+01
84,5595,5887,2030,84,0,1.256,0.2702,7.04470E+01,3.6,0,0,1,7.89986E+01,-1.08250E+01
84,5595,5887,2030,84,0,1.558,0.3439,4.22450E+01,5.3,0,0,1,4.37890E+01,-3.52597E+00
84,5595,5887,2030,84,0,1.949,0.448,2.28020E+01,18.5,0,0,1,2.46212E+01,-7.38861E+00
84,5595,5887,2030,84,0,2.463,0.5712,1.55830E+01,6.8,0,0,1,1.40111E+01,1.00872E+01
84,5595,5887,2030,84,0,3.098,0.7064,1.00100E+01,34.6,0,0,1,8.30643E+00,1.70186E+01
84,5595,5887,2030,84,0,3.883,0.8782,5.15140E+00,44.1,0,0,1,5.05608E+00,1.85045E+00
84,5595,5887,2030,84,0,4.865,1.108,3.76400E+00,52.6,0,0,1,3.10781E+00,1.74333E+01
84,5595,5887,2030,84,0,6.116,1.409,7.94100E-01,1199.1,0,0,1,,
84,5595,5887,2030,84,0,7.703,1.766,1.51040E+00,13.5,0,0,1,1.15293E+00,2.36673E+01
84,5595,5887,2030,84,0,9.668,2.205,8.85400E-01,1113.2,0,0,1,,
84,5595,5887,2030,84,0,12.14,2.788,9.15430E-01,1167,0,0,1,,
84,5595,5887,2030,84,0,15.28,3.519,1.69230E-01,1205,0,0,1,,
84,5595,5887,2030,84,0,19.23,4.425,2.94070E-01,1183.6,0,0,1,,
84,5595,5887,2030,84,0,24.19,5.569,3.74930E-01,63.8,0,0,1,8.36706E-02,7.76837E+01
88,5471,6271,2040,88,0,4.3000E-2,2.3268E-2,3.59850E+05,0.5,0,0,1,2.73472E+05,2.40039E+01
88,5471,6271,2040,88,0,7.3400E-2,3.1106E-2,1.35950E+05,0.5,0,0,1,1.18753E+05,1.26499E+01
88,5471,6271,2040,88,0,0.1038,3.0739E-2,6.22770E+04,0.4,0,0,1,6.06554E+04,2.60386E+00
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Observed Data Columns (columns 1 through 8 are the same as STD files):

Station	– client station number.
East	- station grid-east coordinate (m or ft) (LengthUnits).
North	- station grid-north coordinate (m or ft) (LengthUnits).
Elevation	- station elevation (m or ft) (+ upwards, LengthUnits).
RxStn	- receiver loop center client station number
TxStn	- transmitter loop center client station number (MVL), or Tx ID (FXL)
TWcenter	- time window center, ordered low to high for each station (msec).
TWwidth	-time window width (msec).
uVobs	- observed dBz/dt magnitude (TEMUnits).
uVerr	- observed dBz/dt relative error, if above DataCutoff data point is skipped (percent).
uVwgtX	- x-component weight in uVobs (0 to 1)
uVwgtY	- y-component weight in uVobs (0 to 1)
uVwgtZ	- z-component weight in uVobs (0 to 1)
uVcalc	- calculated dBz/dt magnitude, may be missing (TEMUnits).
%diff	- relative calculated - observed difference (percent).