

T S 2 D I P
Documentation

Zonge Data Processing

Smooth-Model Resistivity and IP Inversion
with topography
version 4.10

Scott MacInnes
Mykle Raymond
November 2001

Zonge Engineering & Research Organization, Inc.
3322 East Fort Lowell Road, Tucson, AZ 85716 USA
Tel:(520) 327-5501 Fax:(520) 325-1588 Email:zonge@zonge.com

blank page

Table of Contents

Introduction.....	4
Installation.....	7
Minimum Hardware Configuration	7
Installation Procedure	7
Moving key-disk software registration to your hard drive.	9
Installing a hardware lock	9
SETUP32.....	9
Graphics	11
Program Use.....	11
Typical TS2DIP Data Processing Sequence	13
Inversion Criteria	14
Outline of TS2DIP's Menu Structure.....	15
New Model Option.....	16
Invert Menu Option.....	21
Editing gradient constraints.....	27
Inverting long lines	28
RS2DIPW command-line parameters	28
Plotting results with S2DPLOT	30
References	33
Appendix A File-Format Documentation.....	34
*.MDE File Format (Zonge data-processing-control file)	34
*.STN File Format (Zonge-format station location data)	36
*.AVG File Format (GDP data averaged by CRAVG or TDAVG)	37
*.Z File Format (Zonge plot-file format with data from CRAVG or TDAVG)	38
*.DAT File Format (GeoSoft-format IP data).....	40
*.RES and *.IP File Format (GeoSoft-format IP data).....	41
*.S2D File Format (TS2DIP inversion control file).....	42
*.IPM File Format (TS2DIP inversion-model file).....	44
*.IPD File Format (TS2DIP data file).....	45
*S.DAT File Format (S2DSURF -> SURFER data file).....	46
*S.TXT File Format (S2DSURF -> SURFER text file)	47

TS2DIP Program Documentation

Introduction

Smooth-model inversion is a robust method for converting resistivity and IP measurements to smoothly varying model cross-sections. Dipole-dipole or pole-dipole field data may be input from Zonge, Geosoft or spreadsheet format files. Either time-domain or frequency-domain data may be used with lines up to 200 dipoles long and n-spacings between 0.25 and 100. Observed apparent resistivities are averaged to initialize a background resistivity model while background-model IP values are set to one. Interactive tools allow background model editing to include known geology. Resistivity and IP values in the two-dimensional model section are then iteratively modified until calculated data values match observed data as closely as possible, subject to constraints on model smoothness and the difference between background and inverted model values.

Constraints control the character of TS2DIP's inversion models. Separate constraint parameters are included for vertical smoothness, horizontal smoothness and for difference from an arbitrary background model. Constraint weighting can be varied to suit geologic conditions. Increasing the weighting of vertical smoothness constraints is appropriate in areas with steeply dipping geology, while increasing horizontal smoothness-constraint weighting is more suitable for flat lying geology. Constraining model parameter values to stay close to a background model is useful for incorporating independent geologic information in the inversion.

The finite-element forward-modeling algorithm used in TS2DIP v4.10 calculates apparent resistivity and phase values generated by two-dimensional models to an accuracy of about 5 percent. When topographic profile information is included during model setup, TS2DIP's finite-element mesh is draped over the terrain.

Inversion results are output into tabular ASCII files, which can be contoured and displayed with general purpose plotting packages. Two plotting program drivers are included. One for creating GeoSoft plots of inversion results and one for creating plots using Golden Software's Surfer for Windows.

The most visible new feature in TS2DIP v4.10 is a Windows interface for interactive creation and editing of model sections. Model sections may be quickly reviewed on screen for quality control before making hard-copy plots. TS2DIP includes a geology drawing option for easy modification of background resistivity and IP properties when geologic control is available. Model constraints now allow resistivity and IP offsets along faults and contacts, improving inversion results when there are sudden changes in electrical properties, like conductive overburden over resistive basement. A model section plot is displayed during inversion, making it easier to keep track of how the inversion is going. Splitting a long line into overlapping segments is no longer required for inversion. Interprex Limited has added dynamic array sizing to RS2DIPW, so that long lines may be inverted in one pass.

Figure 1 shows a smooth-model inversion example. Test data were calculated using an image solution for a thick vertical dike (Keller and Frischknecht, 1966). Inversion of the test data set resulted in the smooth-model section and calculated data shown in figure 1b. TS2DIP recovers a dike with the correct position and amplitude, but with rounded edges.

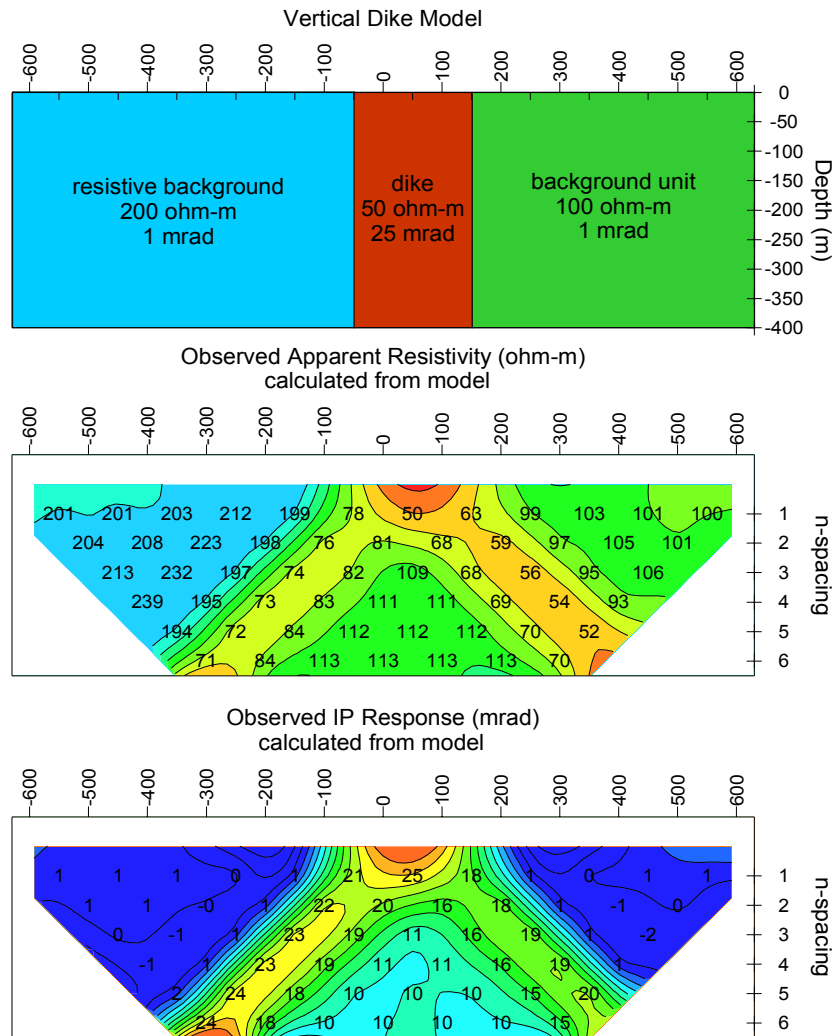


Figure 1a: A vertical dike model was used to generate a set of dipole-dipole test data. An image solution for calculating potentials across a thick vertical dike (Keller and Frischknecht, 1966) was used to generate a set of "observed" apparent resistivity and IP phase test data.

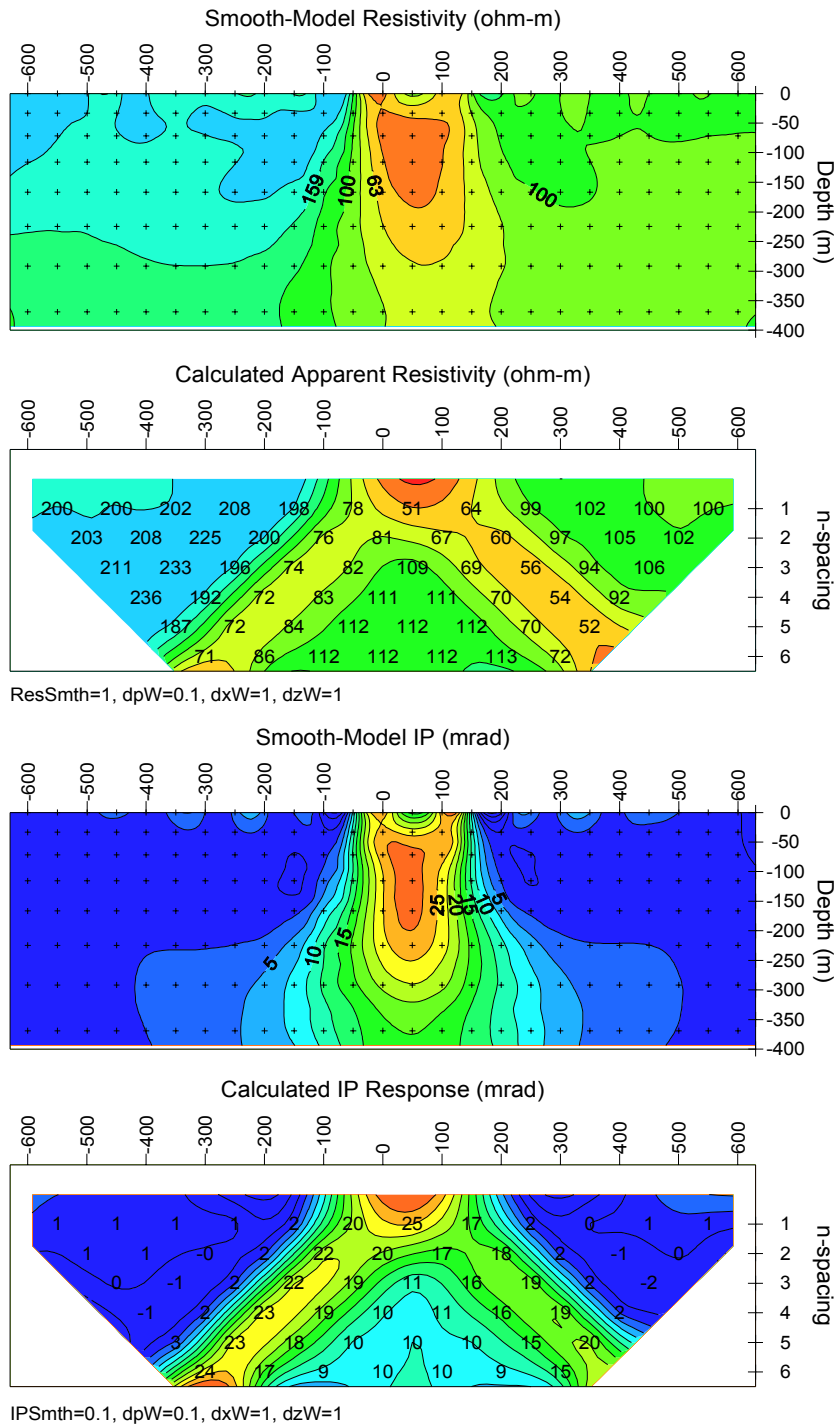


Figure 1b: Smooth-model resistivity and IP phase from inversion of vertical-dike-model test data. Inversion recovers a dike with the correct location and amplitude, but with rounded corners. Model constraints pull the dike image toward background values as data resolution drops with increasing depth.

Installation

Minimum Hardware Configuration

TS2DIP runs on computers using MS-Windows with graphics set to the high color (16-bit) graphics mode.

Installation Procedure

TS2DIP refers to a group of related programs, which are used for building and editing model sections, inverting models and plotting of results. Each distribution copy of TS2DIP programs 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 Windows 95/98/NT. 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 TS2DIP 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.

A SETUP program is provided to install TS2DIP 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 TS2DIP 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 TS2DIP from, usually floppy drive A: or B:, and the target hard drive letter and path in which TS2DIP should be installed. It is usually easiest to put TS2DIP programs in a directory that 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 #TS2DIP.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, TS2DIP may be run from the command line, from the start menu or from a Windows desktop shortcut.

After installation, the TS2DIP subdirectory should have the following files:

TS2DIP program files:

- TS2DIP.EXE - reads field-data files to build new model sections or opens existing TS2DIP files edit and review models.
- RS2DIPW.EXE - performs smooth-model inversion using files created by TS2DIP.
- RS2DREGW.EXE - registration program.
- SETUP32.EXE - installs drivers for hardware lock
- TS2DIP_UPDATE.TXT - update notes.

Demonstration files:

- S2DEMO.MDE - Zonge data processing control and annotation.
- S2DEMO.STN - station grid-coordinates file in tabular format.
- S2DEMO.AVG - Zonge averaged resistivity and IP data in tabular format.
- S2DEMO.Z - Zonge averaged resistivity and IP data in ZPLOT format.
- S2DEMO.DAT - GeoSoft-format resistivity and IP data file in tabular format.
- S2DEMO.RES - GeoSoft-format resistivity data file in pseudosection format.
- S2DEMO.IP - GeoSoft-format IP data file in pseudosection format.
- S2DEMO.S2D - TS2DIP control file with Fortran NAMELIST block.
- S2DEMO.IPM - TS2DIP model file in tabular format.
- S2DEMO.IPD - TS2DIP data file in tabular format.

S2DPLOT will plot inversion-model sections and data pseudosections on-screen. It has options for exporting plots to the Windows printer manager, a WMF file, a PNG file, to GeoSoft Oasis Montaj data and control files or to Golden Software Surfer script and data files. S2DPLOT is available on the Zonge software CD.

TS2DIP model section and data pseudosection plotting:

- S2DPLOT.EXE - reads TS2DIP files and creates multi-panel plots
- S2DPLOT.CFG - configuration file
- S2DGX.GX - Geosoft Oasis Montaj gx to build plots from files exported by S2DPLOT
- CFTABLE.CLR - color-fill spectrum in a Surfer color-table file format

Note that sample data files must be read/writeable. Test data files distributed from a CD may need their attributes modified from read only to read and write after they have been copied to your hard drive.

Moving key-disk software registration to your hard drive.

Key-disk software registration may be left on the distribution disk. RS2DIPW 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 TS2DIP 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

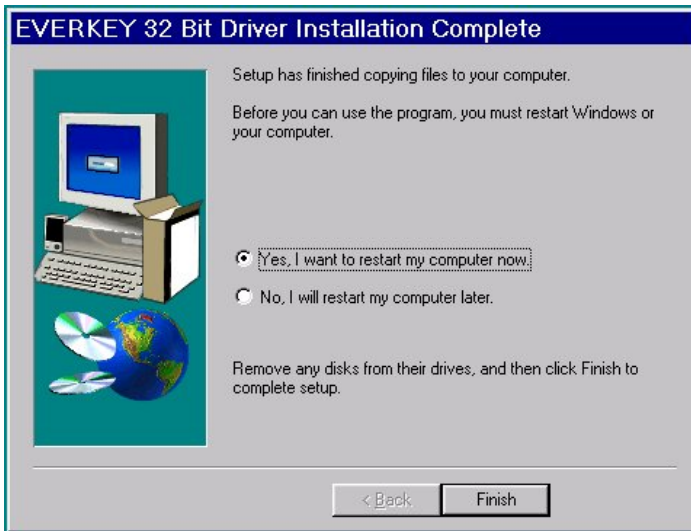
A parallel-port hardware lock or dongle is required for computers running Windows NT. Using TS2DIP's hardware-lock registration system requires additional configuration steps. If your program comes with a parallel-port hardware lock, install it by turning off power to your computer and printer. Unplug 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 TS2DIP. If you have more than one parallel port, it makes no difference which one you use.

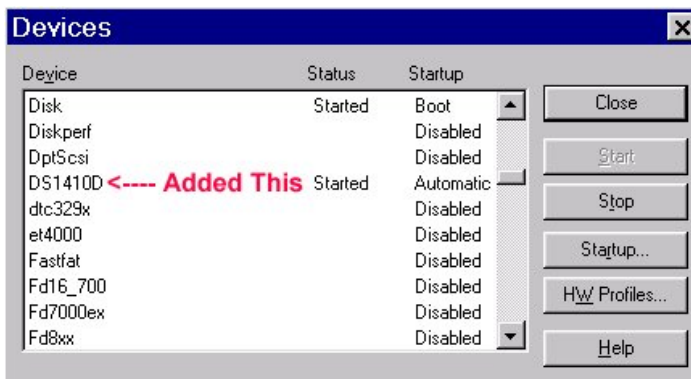
Note that you must ensure the end of the hardware lock labeled "Computer" is connected to your computer's parallel port. It is possible to plug the hardware lock in backwards, which may damage the hardware lock, the parallel port or both.

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 PC's running Windows NT or 2000, you can 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 PCs running Windows NT or 2000, the list of 'Devices' should include a new driver, DS1410D



Test the software registration by executing RS2DREGW from the TS2DIP 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 RS2DIPW is initiated. It calls RS2DREGW 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

TS2DIP builds new models and allows quick review and editing of inversion-model sections. It provides options for model-section plotting with adjustable color ranges and allows zooming in on model details. TS2DIP can save model-section plots in windows metafiles, computer graphics metafiles, postscript or Surfer grid files for pasting into report documents. Your Windows graphics display should be set to 16-bit “high color” or “true color” for TS2DIP use.

For plotting both model sections and data pseudosections, S2DGEOS.BAT and its associated files may be used to drive 1995-96 vintage GeoSoft MS-DOS programs. A copy of GeoSoft’s GRIDMASK.EXE v1.00 is included since GRIDMASK v4.02 and v4.05 do not produce acceptable results when masking topography in GeoSoft *.GRD files. CSRESIST.TBL, CSPHASE.TBL and ZLOGO.CON should be placed in your GeoSoft directory. GRIDMASK.EXE can be placed in a directory that is on the MS-DOS path before \GEOSOFT (to avoid overwriting existing GeoSoft files) or it can be placed in the GeoSoft directory with your current version of GridMask saved under a different name.

S2DSURF uses Golden Software’s Surfer contouring program to provide another option for plotting model sections and data pseudosections. S2DSURF.EXE reads TS2DIP inversion results and produces data and script files for automatic creation of plots with Golden Software’s Surfer for Windows program. It reads TS2DIP files and writes Surfer script and data files for generating color-filled model cross-section and data pseudosection plots.

Program MODSECT and its associated files may be used to plot TS2DIP model sections. MODSECT shows model section plots on screen and can export plots to windows metafiles, drive 1994-96 vintage GeoSoft MS-DOS plotting programs, or write script and data files for Surfer v6.0. MODSECT documentation details its hardcopy plot options.

Program Use

TS2DIP includes the utility program, RS2DIPW.EXE, which does the numeric work of inverting resistivity and IP data to two-dimensional smooth models. Data and model information is exchanged between TS2DIP and RS2DIPW via ASCII text files with file names passed as command-line arguments. Editing is usually done with the interactive features in TS2DIP.EXE. Sometimes it is convenient to modify TS2DIP data files directly with a text editor or spreadsheet. All files generated for a particular data set are given the same file-name stem with file-name extensions used to indicate the file type. Survey configuration and inversion control information is placed in files with the extension .S2D. Observed and calculated data values are stored in .IPD files and inversion model sections are kept in .IPM files.

TS2DIP.EXE’s **New** model option replaces the old command-line program S2DINPUT.EXE. When building a new model, TS2DIP can read field data from a variety of file formats. Field data may be

input from Zonge-format *.IPD, *.AVG or *.Z files, GeoSoft IP-format *.DAT files, or GeoSoft IPRED-format *.RES or *.IP files. If necessary, a spreadsheet may be used to create a *.DAT or *.IPD file for input into TS2DIP. Survey configuration and annotation information is read from optional Zonge-format *.MDE files. TS2DIP also looks for an optional *.STN file to collect topographic profile information. The model section is adjusted to follow topography if a *.STN file with topography is present. If no *.STN file is available, elevations are set to zero along the top of a flat model section. By default, observed apparent resistivity values are averaged to generate a starting background model and background IP values are set to one. After building a new model section, TS2DIP.EXE writes *.S2D, *.IPM and *.IPD files for input to the core inversion program RS2DIPW.EXE.

Smooth-model inversions are calculated by RS2DIPW.EXE, which modifies the starting model held in *.IPM so that calculated apparent resistivity and IP data more closely match observed data from *.IPD while simultaneously trying to honor model constraints. Apparent resistivities are inverted first, followed by inversion of the IP data. RS2DIPW.EXE updates *.IPM files with inverted model resistivity and model IP phase or chargeability and updates columns of calculated apparent resistivity and apparent IP in *.IPD files. RS2DIPW.EXE also writes inversion iteration information to a *.LOG file and any error messages to the screen and to a *.ERR file. To invert one line, RS2DIPW may be called directly from TS2DIP by choosing the **Invert** menu option. Alternatively, a group of lines may be inverted sequentially by first creating sets of TS2DIP files for each line and then driving RS2DIPW with a batch file containing the commands "start /w rs2dipw line1", "start /w rs2dipw line2", etc. for each line. After the batch file is finished, *.LOG files (and on rare occasions *.ERR files) may be reviewed to see how the inversions went.

GeoSoft data and plot control files for model cross-section and pseudosection plotting are generated by S2DGEOS.BAT, S2DGSSUB.BAT and RS2DGEOS.EXE which read *.MDE, *.S2D, *.IPM and *.IPD files and create color-filled contour plots of smooth-model sections, calculated data pseudosections and observed data pseudosections.

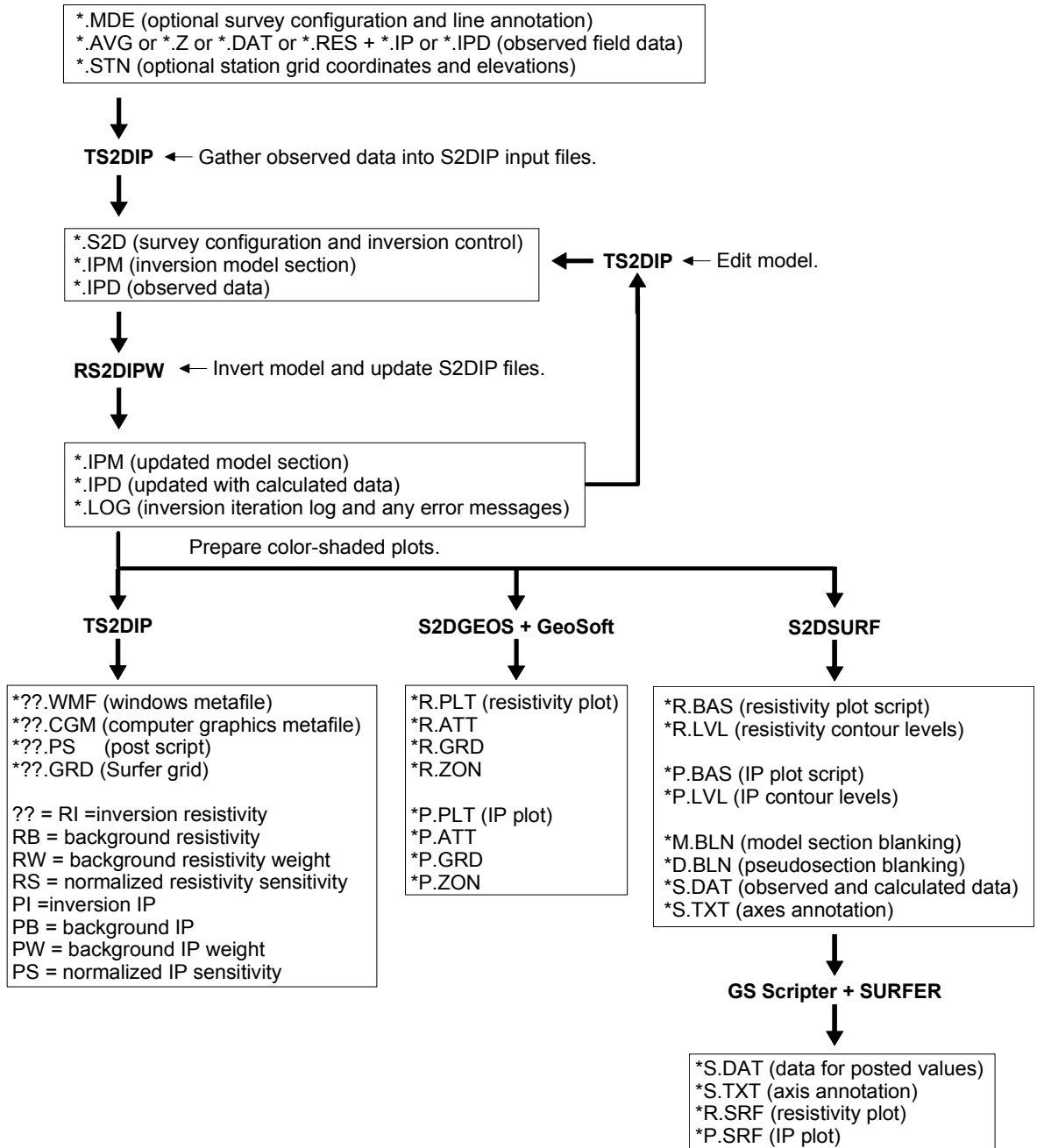
Surfer data and script files for model cross-section and pseudosection plotting are produced by S2DSURF.EXE, which reads *.MDE, *.S2D, *.IPM and *.IPD files and writes script and data files for plots of smooth-model, calculated data and observed data pseudosections. The Golden Software GSScript program reads files generated by S2DSURF and drives Surfer for Windows to produce color-filled contour plots of model sections and observed and calculated data pseudosections.

All TS2DIP programs can be run from the Windows Start | Run menu, from short cuts, from the command line or from batch files. To allow batch file operation, all programs look for a file name on the command line, if one is not present: they show an Open File dialog box listing all TS2DIP model files in the current working directory.

Typical TS2DIP Data Processing Sequence

Program names are **CAPITALIZED**.

Files are boxed.



Inversion Criteria

RS2DIPW attempts to simultaneously minimize the difference between observed and calculated data, the difference between background and inversion model parameters, and inversion model roughness. It uses a root-mean-square (RMS) error criteria to measure data misfit, distance from an a priori background model and model roughness:

$$\mathcal{E}_{\text{total}} = \sqrt{\frac{\mathcal{E}_{\text{data}}^2 + \text{smth}^2 \cdot \mathcal{E}_{\text{model}}^2}{\text{nobs} + \text{nx} \cdot \text{nz}}}$$

$$\mathcal{E}_{\text{data}}^2 = \sum_{i=1}^{\text{nobs}} \left(\frac{d_{\text{obs}_i} - d_{\text{mod}_i}}{d_{\text{err}_i}} \right)^2$$

$$\mathcal{E}_{\text{model}}^2 = dpW0^2 \cdot \sum_{i=1}^{\text{nz}} \sum_{j=1}^{\text{nx}} (p_{i,j}^k \cdot dpW_{i,j})^2 + dxW0^2 \cdot \sum_{i=1}^{\text{nz}} \sum_{j=1}^{\text{nx}-1} ((p_{i,j+1}^k - p_{i,j}^k) \cdot dxW_{i,j})^2 + dzW0^2 \cdot \sum_{i=1}^{\text{nz}-1} \sum_{j=1}^{\text{nx}} ((p_{i+1,i}^k - p_{i-1,j}^k) \cdot dzW_{i,j})^2$$

where

nobs = number of observed data values.

d_{obs_i} = observed log(apparent resistivity) or IP response.

d_{mod_i} = calculated log(apparent resistivity) or IP response.

d_{err_i} = observed data error, $d_{\text{err}_i} \geq \text{ErrFloor}$.

ErrFloor = observed data error floor in log(resistivity) or IP units.

nz = number of node rows in inversion model mesh.

nx = number of node columns in inversion model mesh.

$p_{i,j}^k$ = inversion model parameter at iteration k, log(resistivity) or IP response - a priori background value.

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

smth = ResSmth during resistivity inversion and PhzSmth during IP inversion.

dpW0 = relative weight given to starting model, ResdpW or IPdpW.

dxW0 = relative weight given to horizontal smoothness constraint, ResdxW or IPdxW.

dzW0 = relative weight given to vertical smoothness constraint, ResdzW or IPdzW.

$dxW_{i,j}$ = array of horizontal smoothness weights from *.IPM file.

$dzW_{i,j}$ = array of vertical smoothness weights from *.IPM file.

if (IP < 1) then (IP response = log(mrad or msec) + 1) else (IP response = mrad or msec).

RS2DIPW reports an average RMS data residual ($\sqrt{\mathcal{E}_{\text{data}}/\text{nobs}}$), average RMS model constrain residual ($\sqrt{\mathcal{E}_{\text{model}}/(\text{nx} \cdot \text{nz})}$), RMS minimization criteria ($\mathcal{E}_{\text{total}}$) and largest model parameter change after each inversion iteration. Model updates are not accepted if they increase $\mathcal{E}_{\text{total}}$. If an inversion step fails to improve $\mathcal{E}_{\text{total}}$, RS2DIPW tries again using a more cautious step size. Inversion is halted if the maximum step size is too small, if improvement to $\mathcal{E}_{\text{total}}$ drops below a cutoff threshold or if the maximum number of iterations is reached.

Outline of TS2DIP's Menu Structure

File

- New** = build new model section and save model in .S2D, .IPM and .IPD files
- Open** = open existing model for review or editing
- Save** = save current model in .S2D, .IPM and .IPD files
- Save As** = modify file name and then save current model
- Exit Menu** = return to main menu

Edit

- Edit Model Title** = modify title and descriptive text
- Edit Model Section** = draw geology on model sections
- Edit Model Section** = draw geology on model sections
 - Inversion model resistivity**
 - Background model resistivity**
 - Background resistivity weight**
 - Inversion model IP**
 - Background model IP**
 - Background IP weight**
- Edit Gradient Constraints** = modify smoothness constraints between model pixels
- Edit Inversion Controls** = modify model-constraint weights, data-error floor and stopping criteria
- Exit Menu** = return to main menu

View

Zoom

- Zoom In** = magnify view by a factor of two
- Zoom Back** = reduce view by a factor of two
- Zoom Rectangle** = select viewed area by setting rectangle corners with mouse
- Zoom All** = view entire model section
- Pan** = move view center point

Adjust Colors = set color-fill minimum, maximum and contour increment

Select View Parameter = select model parameter for cross-section plot

- Inversion model resistivity**
- Background model resistivity**
- Background resistivity weight**
- Inversion resistivity sensitivity**
- Inversion model IP**
- Background model IP**
- Background IP weight**
- Inversion IP sensitivity**

Show/Hide Gradient Constraints = toggle gradient constraint display on or off

Exit Menu = return to main menu

Plot File = make hardcopy plot or plot file

To Printer = plot current model section on printer via Windows Print Manager

***.WMF** = windows metafile, may be pasted into other plots or documents

***.CGM** = computer graphics metafile, may be pasted into other plots or documents

***.PS** = color postscript file

Surfer Grid = surfer grid file, may be imported into Surfer or GeoSoft Montaj

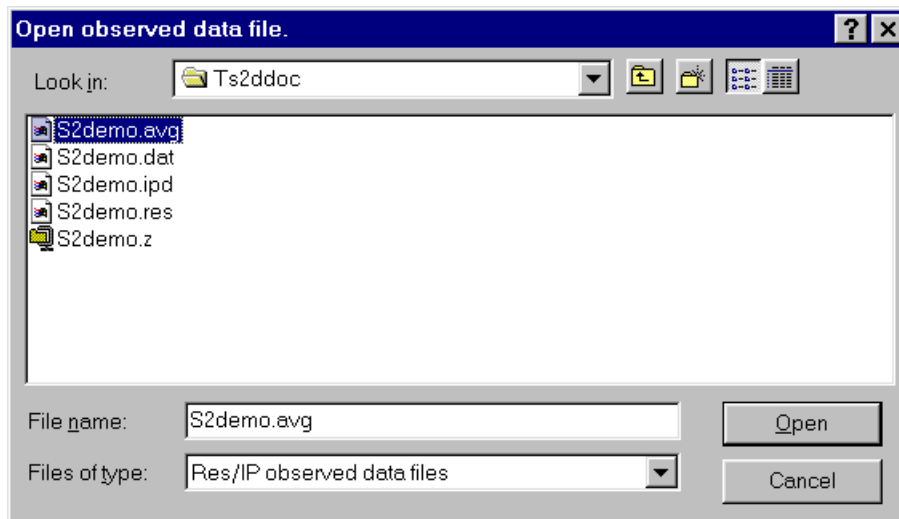
Exit Menu = return to main menu

Invert = calls RS2DIPW.EXE to invert current model

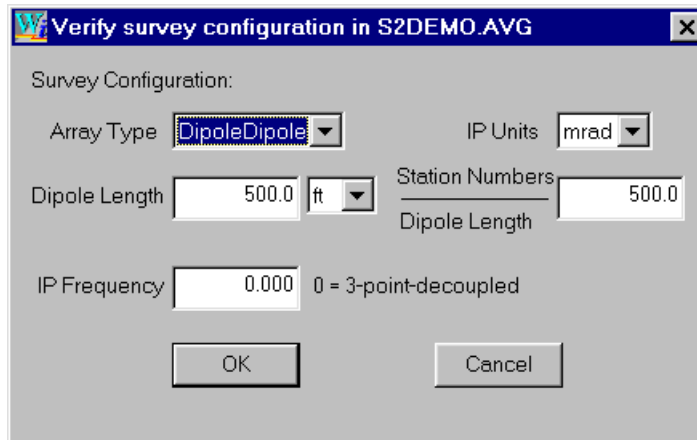
Exit = exit TS2DIP.EXE

New Model Option

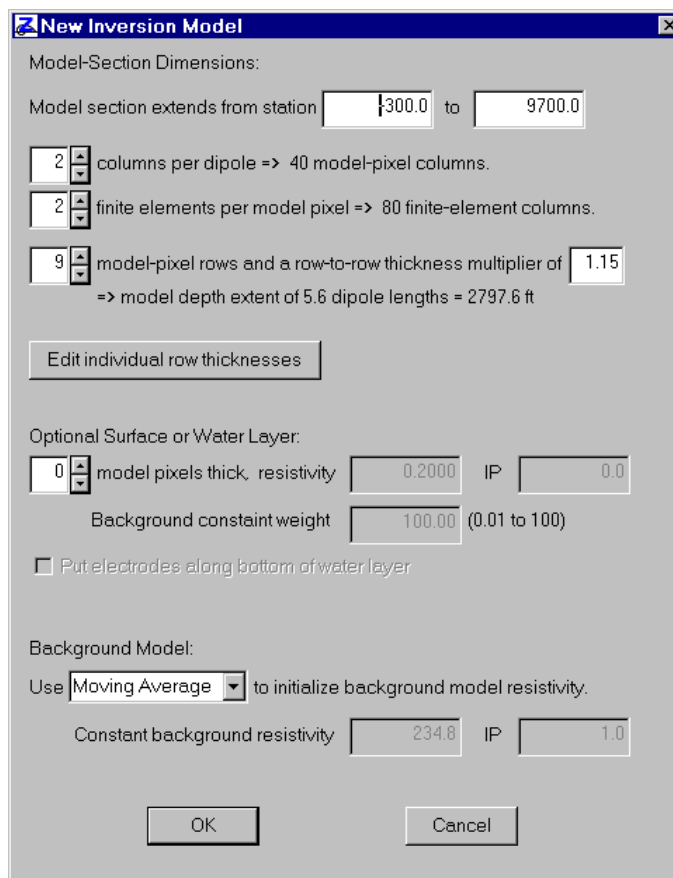
To build a new model using the sample TS2DIP field-data file S2DEMO.AVG, run TS2DIP from a directory holding S2DEMO.AVG and select the **New** option from the initial menu or from **File** on the main menu. TS2DIP will first display a file selection dialog. TS2DIP allows input from a variety of field-data formats. Least favored are Zonge *.Z and GeoSoft *.RES+*.IP files, as they do not include information about the relative position of transmitter and receiver electrodes nor do they include measurement error. Zonge-format *.AVG files are more suitable for pole-dipole field data, as they include separate columns to record transmitter and receiver dipole locations, removing ambiguity about whether the transmitter pole electrode is trailing or leading the receiver dipole. *.AVG files also include columns of apparent resistivity and IP repeatability, so that noisy points may be deweighted during inversion. More general still are GeoSoft IP-format *.DAT files, which keep track of all electrode positions along the survey line and may include measurement error columns. *.DAT files may be used to store field data from unconventional in-line surface surveys using arrays with variable dipole lengths or mixed array configurations. Zonge *.IPD files are the most general format, as they keep track of all electrode locations, include measurement error information and may hold either in-line surface, down-hole or surface-to-hole data using unconventional array configurations. TS2DIP will display all data files in the current directory that have an appropriate file-name extension.



To follow this example using sample files distributed with TS2DIP, select the field-data file S2DEMO.AVG by moving the mouse cursor over the S2DEMO.AVG name and clicking the left mouse button. Then mouse click on the **Open** button to open the data file and continue. TS2DIP first looks for an optional *.MDE file to get survey annotation and configuration information, then it opens the field-data file. When reading field data, TS2DIP shows a dialog box to verify the survey configuration.



S2DEMO.AVG holds frequency-domain dipole-dipole data collected with 500-foot dipoles. The data are very clean, so three-point decoupled values are suitable for inversion. Information about dipole length and station numbers per dipole comes from mode keywords in S2DEMO.MDE and S2DEMO.AVG. The default IP frequency of 0 hertz selects three-point decoupled data from S2DEMO.AVG. Entering 0.125 would use 1/8 hertz data. Three-point decoupling removes inductive coupling effects, but amplifies measurement noise. In noisy areas it is sometimes preferable to use 0.125 hertz data, particularly if apparent resistivities are high, so that inductive coupling is not appreciable. After verifying survey configuration parameters, click on the **OK** button to continue building a new model or **Cancel** to abort the new-model build. After reading observed data, TS2DIP looks for an optional *STN file to get topographic and station location values. After sorting and averaging observed data values, TS2DIP displays a dialog showing model-section parameters.



By default, the model section runs from the first electrode position on the line to the last, with a maximum model-section length of 200 dipoles. The section may have one to four columns of model pixels per dipole length, with two pixels/dipole being the default. Using one column of model pixels per dipole length will generate a coarse model, which inverts more quickly. Using three or four model pixels per dipole generates a more detailed model, which will take longer to evaluate. TS2DIP also allows control over the number of finite elements per model pixel, with a default of two. A coarser finite-element mesh is quicker but less accurate, while a finer finite-element mesh is slower, but more accurate for very irregular topography. If you are inverting data with multiple dipole lengths, another consideration is that every electrode location must coincide with a finite-element node. First pick a standard dipole length. Then adjusting the number of model pixels per standard dipole and the number finite-element columns per model pixel can be used to get from one to sixteen finite-element columns per standard dipole length.

Default model-section depth extent for each data set is adjusted to roughly twice the estimated half-space depth of investigation. The number of model-pixel rows and the row-to-row thickness may be modified. Selecting the **Edit individual row thickness** button to edit individual row thicknesses. Up to thirty-two pixel rows may be used to customize model sections. Row height is specified in dipole lengths and may vary between 0.1 and 100. Once you have created custom row heights, avoid changing the number of columns per dipole or the row-to-row thickness multiplier, changing either one will reset row heights and erase your custom heights.

Using model sections with extra depth extent (like the default model section) produces better inversion results than models with too little depth extent. Model sections can always be trimmed back after inversion to get final plots with more limited depth extent.

Dialog fields grouped under **Optional Surface or Water Layer** allow the addition of a surface layer to represent overburden or water. If the number of model-pixel rows in the layer is greater than 0, additional dialog fields are activated to allow specification of the surface layer resistivity, IP and background-model constraint weighting. By default the surface layer resistivity is set to 0.2 ohm-m (for salt water) and its IP is set to 0. Default surface-layer background constraint weighting is set to the maximum of 100 and smoothness constraints are sheared along the bottom of the layer. The defaults generate a surface layer that will remain unchanged during inversion.

Surface layer thickness can be controlled changing the number of model pixel rows in the layer and by editing model-pixel row thicknesses via the **Edit individual row thickness** button. A variable thickness layer can be introduced by using a STN file with column labels and a **depth** column. If a depth column is present in a STN file, TS2DIP adjusts the model section so that an interface between rows of model pixels follows the layer bottom specified in the STN file. The surface layer feature is typically used with marine data where bathymetry data are available, but could also be used to model conductive overburden.

If **Put electrodes along bottom of water layer** is selected, then TS2DIP will drop all electrodes to the bottom of the water layer. It then changes the s2d file array type to DH to indicate subsurface data and writes an IPD file with additional columns specifying elevation values for each electrode.

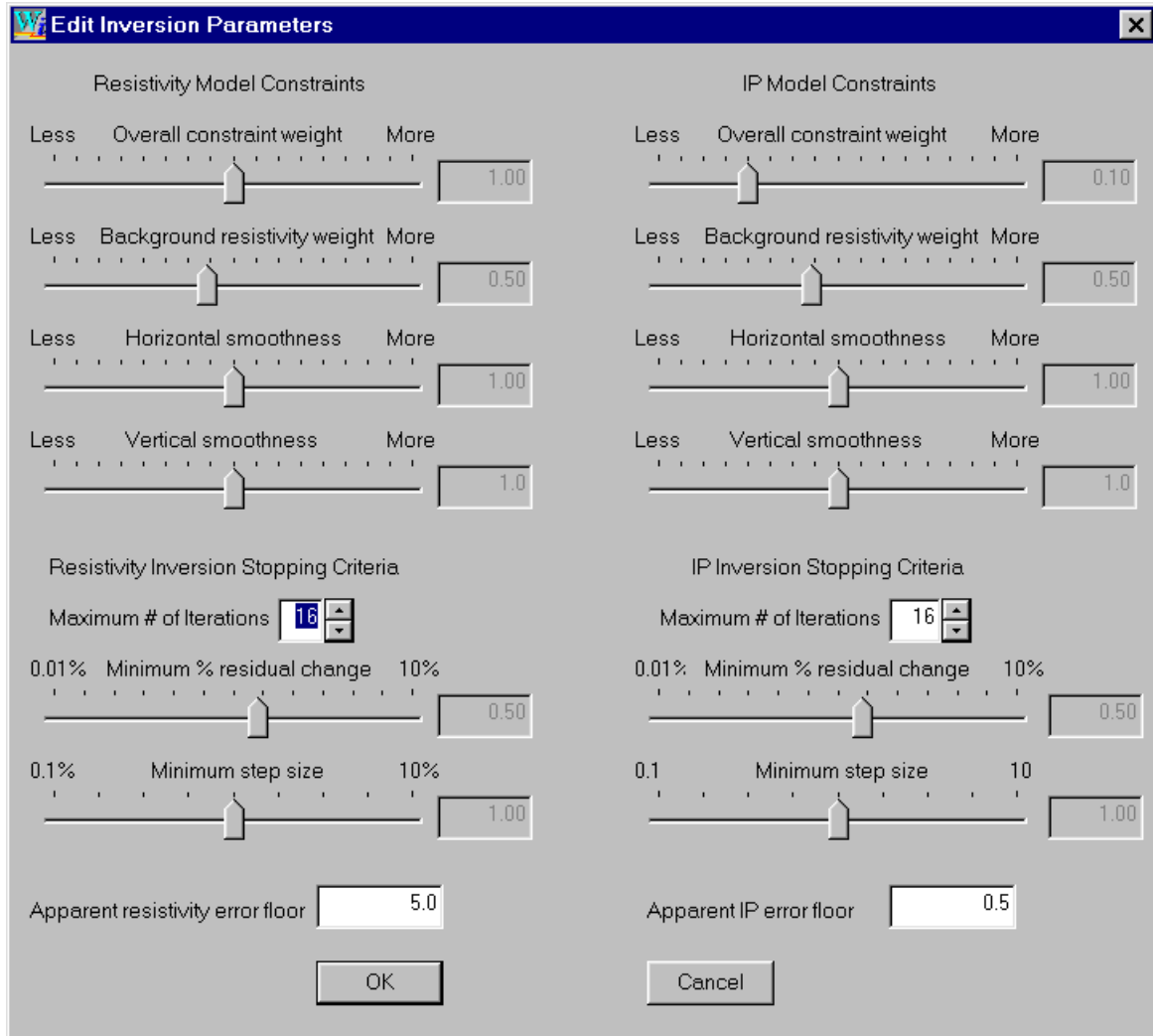
If an IPD file is being used as a data source during creation of a new model section, it should have a line with keywords specifying the array configuration, such as
"Array=DipoleDipole, DipoleLength=500, StnPerDipole=500, LengthUnits=ft, IPUnits=mrad"

If the new model is to have electrodes on the bottom of a water layer and the ipd file has electrode elevation columns, then the key-word line should have Array=DHDipoleDipole or Array=DHPoleDipole. The DH prefix means "drill hole" and is used to flag an IPD file with extra columns specifying electrode elevations so that subsurface electrodes can be positioned properly.

Background-model resistivities may be initialized to either a broad moving average of observed apparent resistivity or to a constant value (initially set to average observed apparent resistivity). On long lines with apparent resistivities changing from one end to the other, a broad moving average is better than a uniform value. Background IP values are always initialized to one.

Edit | Edit Model Section | Background Resistivity and **Background IP** menu options may be used to add arbitrary geology to the background model section after the new model build is complete.

Selecting the **OK** button after verifying model-section parameters leads to a dialog box showing inversion-control parameters.

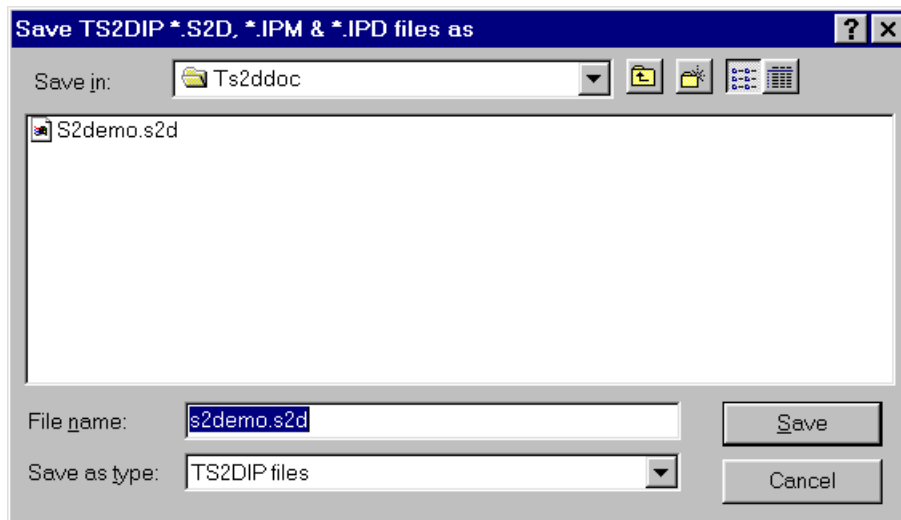


Resistivity inversion controls are displayed on the left half of the "Edit Inversion Parameters" dialog box and IP inversion controls are shown on the right. Model constraint weights may be adjusted by moving track-bar pointers with the mouse. To adjust a constraint weight, put the mouse cursor on a pointer, hold down the left mouse button and move the mouse. Reducing a model constraint weight makes the constraint less important relative to matching observed data. If horizontal resistivity smoothness is set to "more", the inverted resistivity model will be very smooth from side-to-side, looking like a layered model. Increasing vertical smoothness weighting favors dike-like model features.

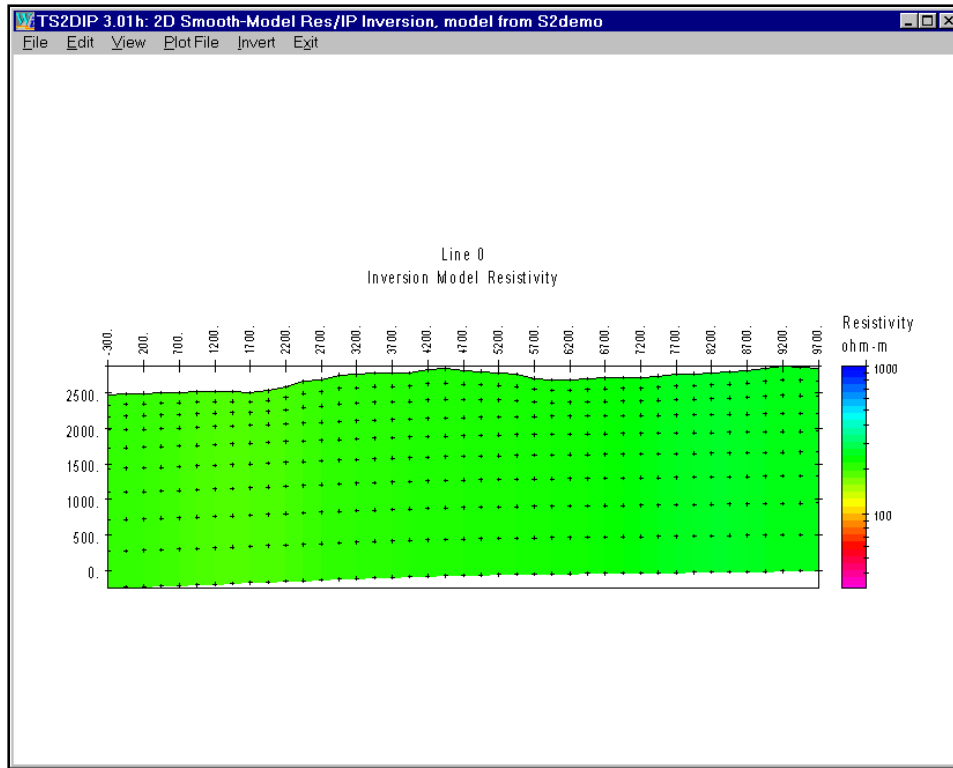
Stopping criteria are shown on the bottom of the “Edit Inversion Parameters” dialog box. Increasing stopping criteria thresholds will reduce the number of iterations before RSDIPW decides that the inversion is complete. Lowering stopping criteria thresholds will improve inversion results slightly, at the expense of more iterations.

Apparent resistivity and IP error floor values set minimum observed data error and affect the balance between fitting observed data and honoring model constraints. Measurement repeatability usually generates an overly optimistic error estimate for inversion, because it does not take into account modeling error generated by using a simple two-dimensional section to represent a complex three-dimensional world. Default TS2DIP values work well most of the time, but some data-set inversions may be improved by a different trade-off between fitting field data and maintaining a smooth model section. Experimenting with different model constraint weights and observed-data error floors may improve your inversion results.

Select the **OK** button once you are happy with values in the “Edit Inversion Parameters” dialog box and want to continue or select the **Cancel** button to abort the new-model build. Selecting **OK** brings up a “Save As” file-name dialog box to give you a chance to change TS2DIP file names.



You may enter a different name in the “file name” field or go right to the **Save** button if you are happy with the default file name. If you are about to overwrite existing files, TS2DIP give you a warning and a chance to go back and change file names, otherwise TS2DIP writes a *.S2D + *.IPM + *.IPD file set, returns to the main menu and plots the new model section

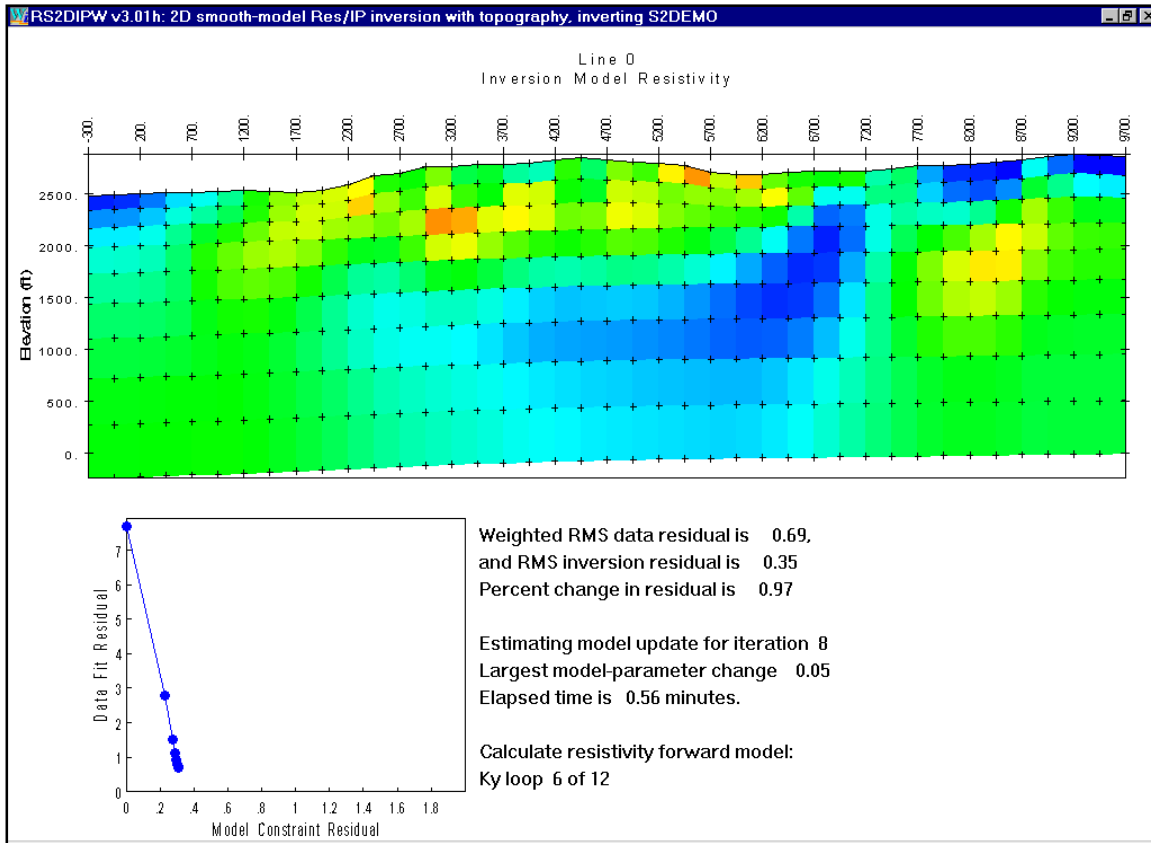


Invert Menu Option

An existing model may be inverted by selecting the **Invert** menu option from TS2DIP's main menu, by running RS2DIPW.EXE from a MS-DOS box command line or run from a batch file. After creating a new model section from S2DEMO.AVG, select **Invert** from the main menu to start RS2DIPW. RS2DIPW inverts the starting model in S2DEMO.IPM so as to fit the observed data in S2DEMO.IPD, subject to model constraints. RS2DIPW shows the current model section as it is updated during the iterative inversion.

Apparent resistivities are inverted first, followed by inversion of IP phase or chargeability. RS2DIPW plots the inversion model section across the top half of its window. Scrolling text describing the inversion's progress is shown on the lower right quarter of the window and a plot of model-constraint residuals versus observed-calculated data residuals is displayed on the lower left. RS2DIPW usually makes rapid progress during the first few inversion iterations and then tapers off to incremental improvement.

Plotting data-fit residuals versus model-constraint residuals emphasizes the trade-off between fitting observed data versus maintaining a smoothly varying model. A new model is very smooth, but its calculated data do not match field data very well. That puts a trade-off plot point high on the vertical axis, indicating a very small model-constraint residual and a large data-fit residual. As the inversion progresses, RS2DIPW improves the fit to observed data at the expense of larger model-constraint residuals and plot points move down and to the left.

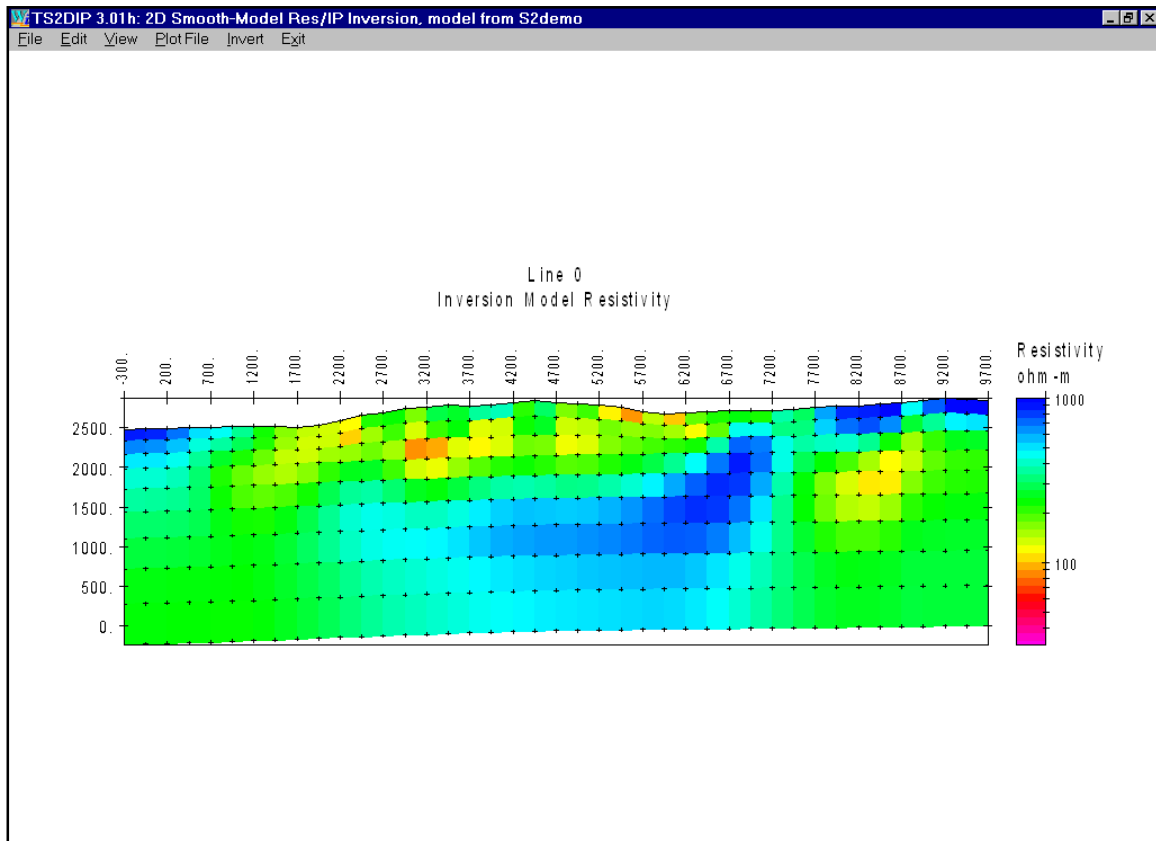


The trade off between fitting data and maintaining a smooth model can be varied by adjusting model-constraint weighting parameters with TS2DIP's **Edit | Edit Inversion Controls** menu option. If you are inclined to experiment, you can try inversions with a range of model-constraint weights. Lowering model-constraint weighting improves the fit to observed data, up to a point. Using very low model-constraint weights will not produce a perfect fit to observed data, but it will generate a rough model, so the final trade-off plot point will be near the horizontal axis and off to the right. Final results from repeated inversion runs with model constraint weights varying from large to small should trace out a hyperbola-like curve with asymptotic arms near the positive x- and y-axis. Optimal model-constraint weights give a final plot point as close as possible to the trade-off plot origin.

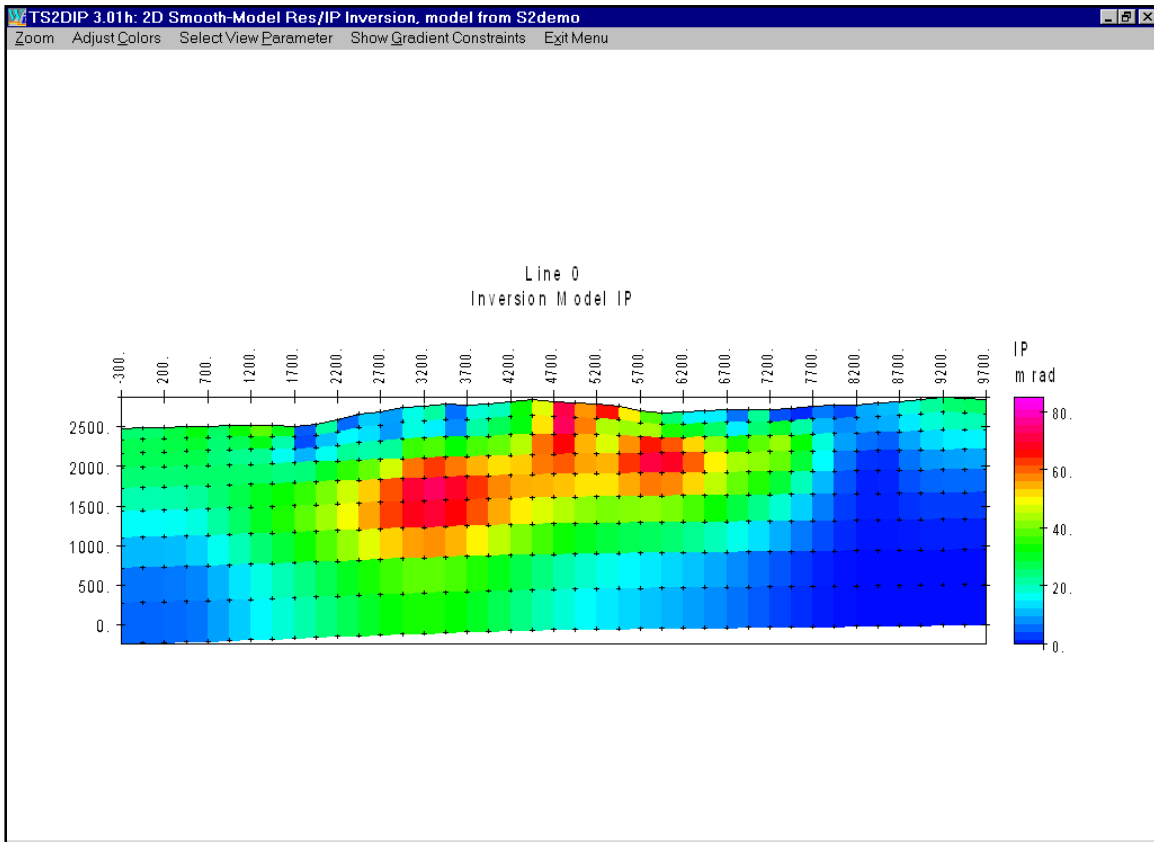
Work from smooth towards rough models when running repeating inversions with the same data set. RS2DIPW does a better job at adding structure to a smooth model than it does at smoothing a rough model section. Adding the parameters `res0=100` and `IP0=1` to the *.S2D NAMELIST block resets the starting model to 100 ohm-m and 1 mrad (or msec). You can also include inversion control parameters when you run RS2DIPW from the command line or from a batch file. Typing "RS2DIPW s2demo -res0=250 -ip0=1" on the command line will restart RS2DIPW with the S2DEMO.IPM resistivity inversion model set to 250 ohm-m and the IP inversion model set to 1 mrad.

When an inversion is running, you can minimize RS2DIPW to a text label on the Windows task bar by clicking on the small box with a minus sign at the upper right corner of RS2DIPW's window. Clicking on the small box with an X aborts the inversion run. RS2DIPW does not update *.S2D, *.IPM or *.IPD files until after it has successfully finished an inversion, so stopping part way through an inversion will leave your TS2DIP files unmodified.

While running, RS2DIPW creates a *.LOG file with text recording how the inversion proceeded. If any error conditions come up during an inversion, RS2DIP will also create a *.ERR file to hold error messages. When run from the **Invert** menu option, RS2DIPW returns control to TS2DIP after it is finished. TS2DIP then displays the inverted model section. Inversion resistivity is shown by default.

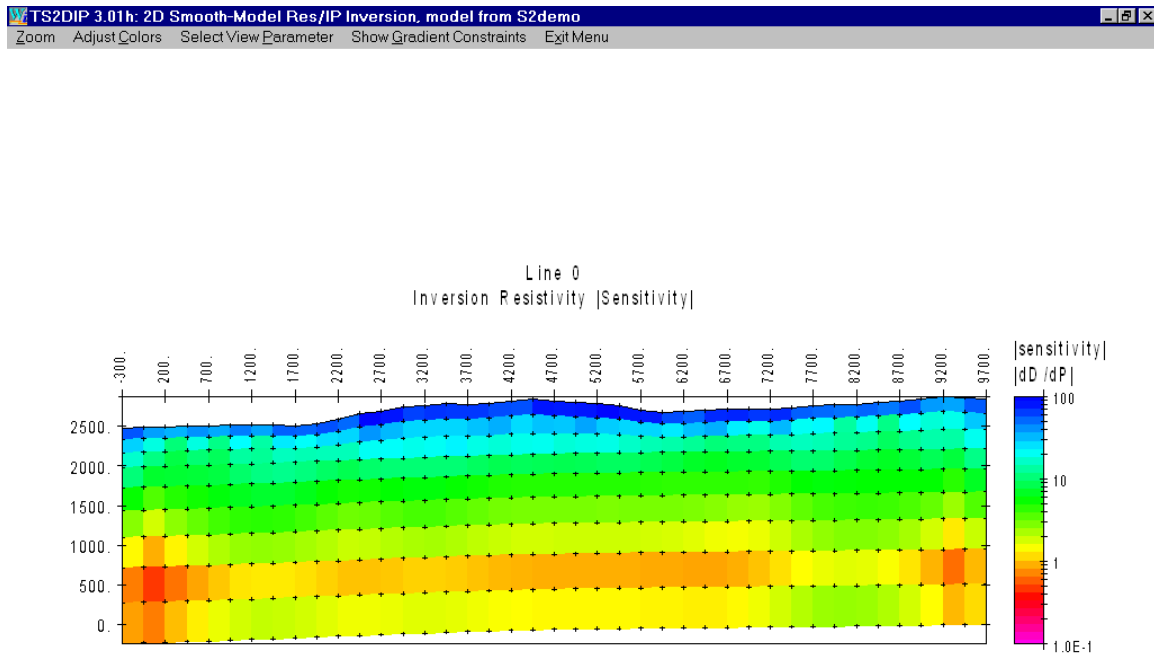


To look at the inverted IP model section, select **View | Select View Parameter | then Inversion Model IP.**



S2DEMO.AVG data is from a dipole-dipole line over a porphyry copper system. Low resistivity follows supergene enrichment while high IP phase values track phyllic alteration.

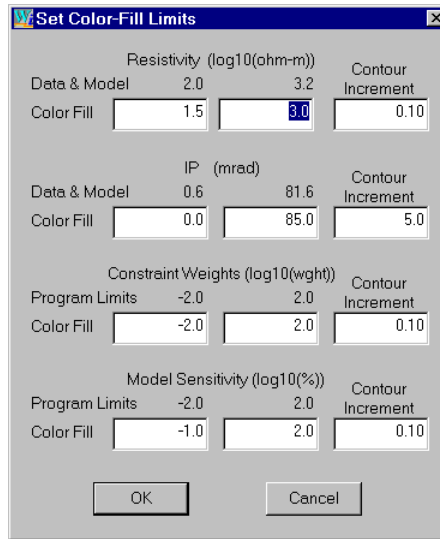
Another interesting model property is model sensitivity. Selecting **View | Select View Parameter | Inversion Resistivity Sensitivity** or **Inversion IP Sensitivity** brings up a plot of normalized sensitivity.



Model parameter sensitivities are saved as percentage values. Areas with 100 percent values are fully resolved by observed data. As data resolution of model-section features drops off, so does percent sensitivity. One to two percent sensitivity roughly contours the maximum depth of investigation. Model structure below the one percent sensitivity contour is primarily controlled by model constraints, not field data. Although TS2DIP saves both resistivity and IP sensitivity values, the two parameters are very similar. Either one can be used as a criteria for mapping a survey's maximum depth of investigation. Low-over-high resistivity layering channels currents close to the surface and reduces the maximum depth of investigation. Conversely, high-over-low resistivity features increase the depth of investigation relative to a uniform half space.

Model-section details may be examined by looking at part of the section with **View | Zoom | Zoom In** or **Zoom Rectangle**. You can move around in a magnified view of the model section with the **Zoom | Pan** menu option. To get back to a plot of the entire section, select **Zoom Back** or **Zoom All**.

Color-fill limits may be adjusted with the **View | Adjust Colors** menu option.

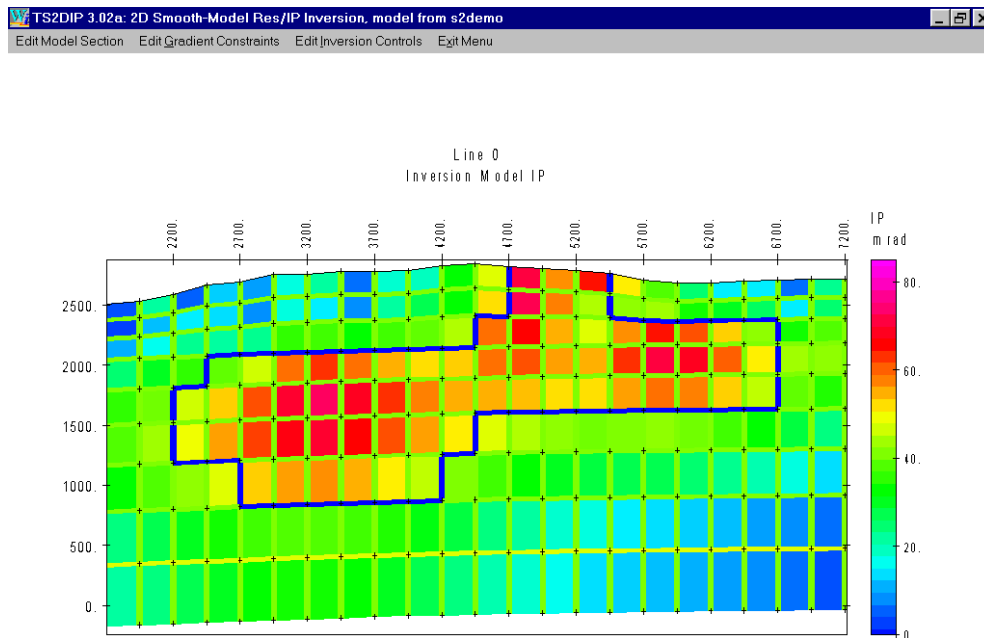


TS2DIP's set color-fill limits dialog box includes fields for editing resistivity color-fill limits in units of $\log_{10}(\text{ohm-m})$. Constraint weight and model sensitivity color limits are also in \log_{10} units, while IP colors are specified in mrad, msec or PFE. TS2DIP saves color-fill limits in *.S2D files, so that they don't have to be reset when you reopen an existing file set.

Editing gradient constraints

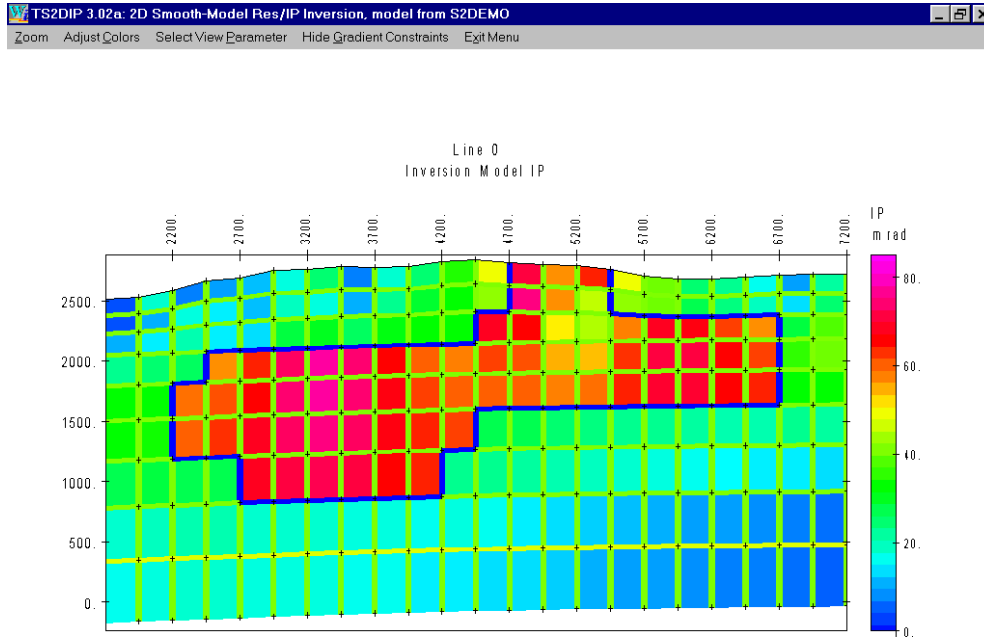
After running a preliminary inversion it is sometimes helpful to cut smoothness constraints in areas with steep model-section gradients indicating high-contrast contacts. A common case is inversion of data collected in areas with conductive overburden. A preliminary inversion will give a good indication of overburden thickness, but the interaction between smoothness constraints and the high contrast between overburden and basement can obscure deeper features. Cutting smoothness constraints along the bottom of the overburden layer and then re-running the inversion often improves resolution of basement features.

Basic steps can be illustrated with S2DEMO.IPM after a first inversion run. Open the S2DEMO file set by running TS2DIP, selecting **Open** from the initial menu and then selecting S2DEMO.S2D from the open-file dialog box list. TS2DIP will then be showing the S2DEMO inversion resistivity model section and main-menu options. Select **Edit | Edit Gradient Constraints** and a “Select new gradient constraint values” dialog box will appear in the upper left corner of your monitor screen. To cut gradient constraints move the track-bar cursor left to the “Low = Cut” setting by dragging it with your mouse (put the mouse pointer on the track-bar cursor and hold the left mouse key down). Then click on the **OK** button. TS2DIP will now be showing the model section with an overlay of color-coded lines between model pixels. The lines represent gradient-constraint weights. Cool colors indicate low weight, green is neutral and warm colors indicate high gradient-constraint weights. You can draw in the new gradient constraint value along boundaries between pixels by moving the mouse cursor to model pixel corners and clicking the left mouse button at every point you wish to place a line-segment endpoint. When you have finished drawing a polygonal line tracing out your gradient-constraint change, click the right mouse button. TS2DIP will update the model section with new line colors indicating current gradient-constraint weights.



Blue lines between model pixels show where I have sheared gradient constraints along the edge of a high IP anomaly in S2DEMO.IPM. I first used **View | Select View Parameter | Inversion Model IP** to show a plot of the IP model section. I then used **View | Zoom | Zoom Rectangle** to get a magnified

plot of the most interesting area. Finally I used **Edit | Edit Gradient Constraints** to turn on the gradient constraint display and cut gradient constraints around the edge of the high IP area. **View | Hide Gradient Constraints** will turn off the gradient constraint display if you want to get back to a normal view of the model section. Next is re-running the inversion with the **Invert** menu choice to update inversion-model resistivity and IP.



Re-running the inversion with gradient constraints cut around the high IP area lets RS2DIPW introduce a sharp offset between high IP values and surrounding lower IP host material.

Inverting long lines

TS2DIP can build lines up to 200 dipole lengths long and RS2DIPW will invert them in one piece, although inversion of a long line will take awhile. Interprex Limited implemented the dynamic memory features in RS2DIPW that allow one-piece inversion of very long lines.

RS2DIPW command-line parameters

To facilitate sequential inversion of multiple lines from a batch file or repeated inversion of one line with varying constraint weights, RS2DIPW takes command-line arguments the model-file name and inversion-control parameters. Inversion-control parameters set from the command line override values set in *.S2D files. As an example, a batch files with the following two lines:

```
start /w rs2dipw Line1 -Res0=100 -IP0=1
start /w rs2dipw Line2 -Res0=100 -IP0=1
```

will invert LINE1.S2D + LINE1.IPM + LINE1.IPD and LINE2.S2D + LINE2.IPM + LINE2.IPD with the resistivity starting model set to 100 ohm-m and the IP starting model set to 1 mrad or msec. Using the

Windows command-line function “start /w” instructs Windows to wait until RS2DIPW.EXE is done with Line1 before starting “rs2dipw Line2”. Command line arguments –Res0=100 and –IP0=1 set the inversion starting model to 100 ohm-m and 1 mrad (or msec). Resetting the starting model to near background is a good idea when re-inverting models after editing model constraint weighting or background geology. Command line arguments are preceded by a - character and the parameter name is separated from its value by a = character. Multiple command-line arguments must be separated by one or more spaces.

Command line arguments are also handy for running repeated inversion on one line with varying model-constraint weights. Using

```
start /w rs2dipw s2demo -ResSmth=4 -IPSmth=4 -Res0=100 -IP0=1
copy s2demo.s2d s2demo1.s2d
copy s2demo.ipm s2demo1.ipm
copy s2demo.ipd s2demo1.ipd
copy s2demo.log s2demo1.log

start /w rs2dipw s2demo -ResSmth=1 -IPSmth=1 -Res0=100 -IP0=1
copy s2demo.s2d s2demo2.s2d
copy s2demo.ipm s2demo2.ipm
copy s2demo.ipd s2demo2.ipd
copy s2demo.log s2demo2.log

start /w rs2dipw s2demo -ResSmth=0.25 -IPSmth=0.25 -Res0=100 -IP0=1
copy s2demo.s2d s2demo3.s2d
copy s2demo.ipm s2demo3.ipm
copy s2demo.ipd s2demo3.ipd
copy s2demo.log s2demo3.log
```

will generate three sets of inversion results with model constraint weighting set to 4, 1 and 0.25 with the –ResSmth= and –IPSmth= command line arguments. Using –Res0=100 and –IP0=1 each time resets the starting model to 100 ohm-m and 1 mrad (or msec) each time, making the inversion results more consistent.

Inversion control parameters which can be used as command line arguments:

- Res0 - constant value starting model resistivity.
- IP0 - constant value starting model IP.
- NXSplit - number of finite-element columns per model-pixel column (1 to 4).
- NZSplit - number of finite-element rows per model-pixel row (1 to 4).
- StnBeg - first station to use in inversion = left edge of active model section.
- StnEnd - last station to use in inversion = right edge of active model section.
- NReslter - maximum number of iterations during resistivity inversion (0 to 32).
- NIPIter - maximum number of iterations during IP inversion (0 to 32).
- ResSmth - tradeoff between resistivity data and constraints (0.01 to 100).
- IPSmth - tradeoff between IP data and constraints (0.01 to 100).
- ResdpW - relative weight of resistivity background model (0.01 to 100).
- ResdxW - relative weight of horizontal resistivity smoothness (0.01 to 100).
- ResdzW - relative weight of vertical resistivity smoothness (0.01 to 100).
- IPdpW - relative weight of IP background model (0.01 to 100).
- IPdxW - relative weight of horizontal IP smoothness (0.01 to 100).
- IPdzW - relative weight of vertical IP smoothness (0.01 to 100).

Plotting results with S2DPLOT

Typing "s2dplot s2demo" on the command line runs S2DPLOT to produce a screen plot from the sample data files s2ddemo.s2d, s2demo.ipm and s2demp.ipd. If you type "s2dplot" without a command-line argument, s2dplot will ask you to choose from a list of model files present in the current working directory. Once s2dplot has the name of a valid model file, it shows a series of interactive dialog boxes to allow plot-parameter editing. (If \$auto=yes in the *.MDE file, s2dplot skips interactive verification of plot attributes, exports a plot to the hardcopy format specified in the MDE file, and then stops.)

Plot scales and annotation can be controlled with keywords flagged by "\$S2DPLOT" in *.MDE files (see appendix A, *.MDE files for a list of keywords). If s2dplot keywords are not present in the *.MDE file, S2dplot sets scales to create plots with one dipole length per plot cm and initializes plot annotation text strings with information from the *.MDE file. S2dplot updates the MDE file after plot attributes have been verified via a series of dialogs. Saving plot-control keywords in *.MDE files makes it easier to recreate duplicate plots and provides a record of plot control values.

S2dplot can export plots to the Windows print manager, WMF or PNG files for pasting into reports. It can also write Geosoft Oasis Montaj control and data files for plotting by S2DGX.GX from within Oasis Montaj. S2DPLOT can also export script and data files for plotting with Golden Software's Surfer. Windows Surfer versions 6 and 7 provides for automatic plot production using script files.

Separate documentation is available for s2dplot in S2DPLOT.PDF.

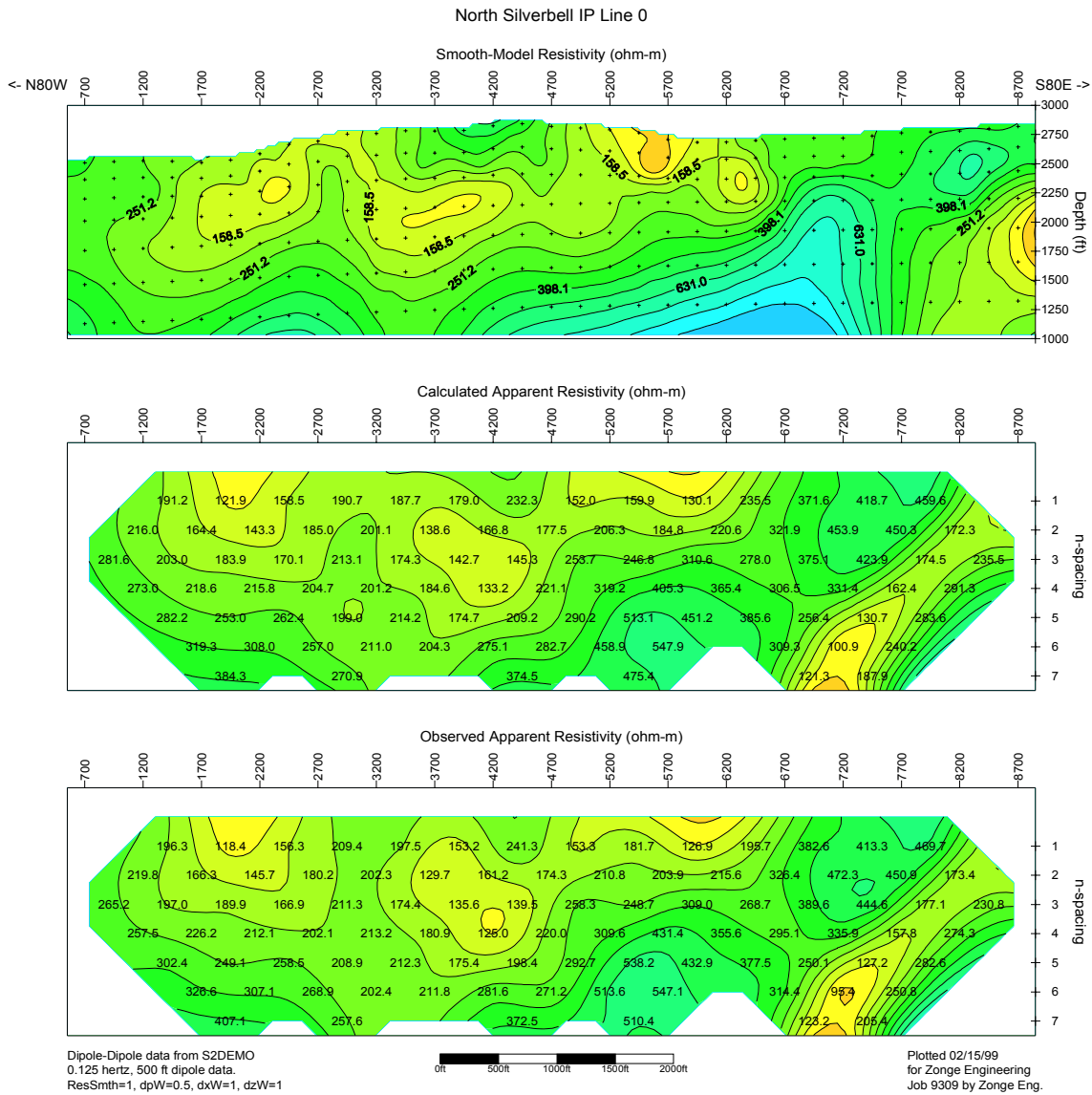


Figure 2a: Resistivity inversion results from S2DEMO plotted with S2DPLOT, GS Scriptor and Surfer for Windows. The low resistivity layer tracks a supergene enrichment zone.

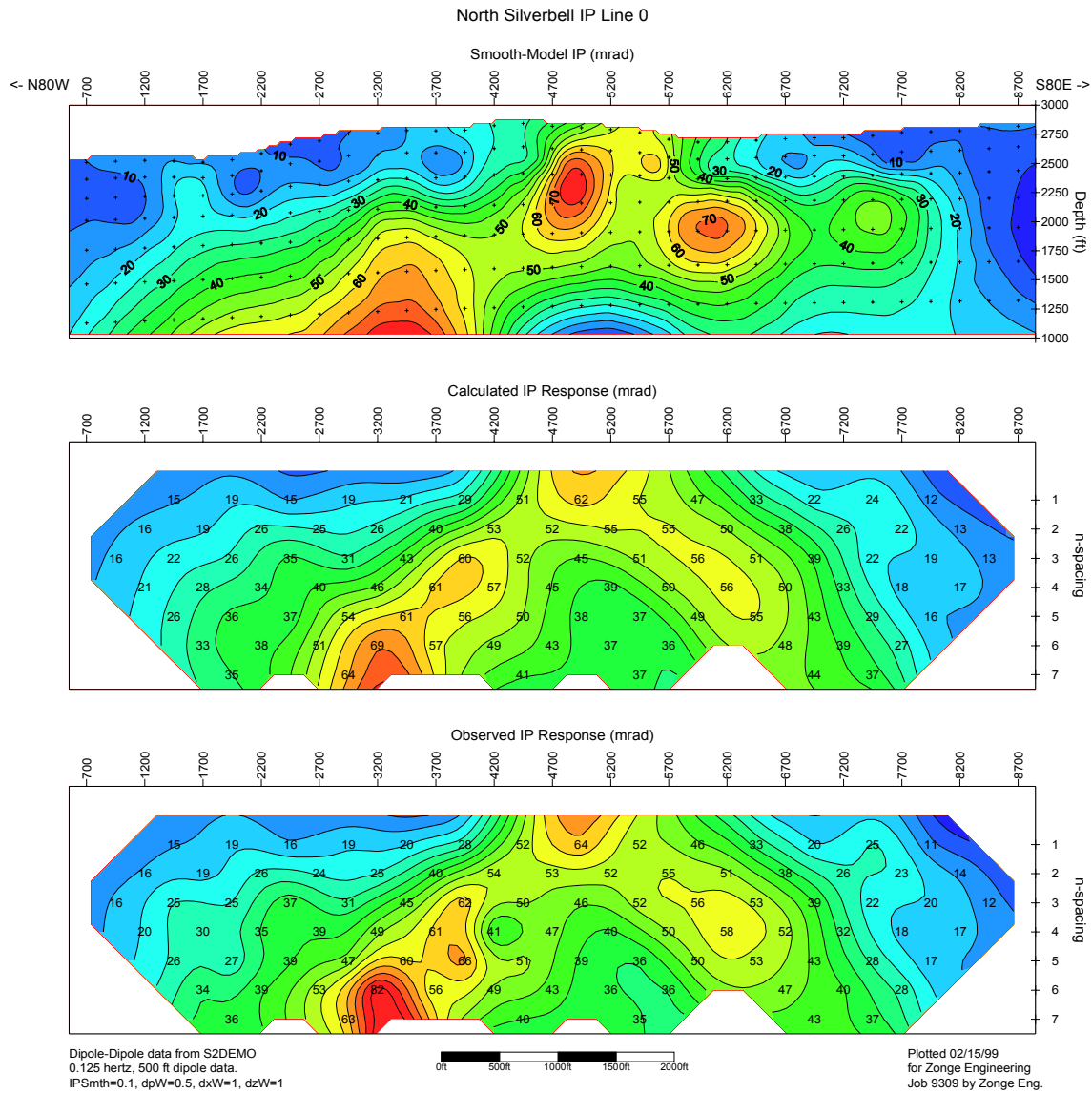


Figure 2b: IP inversion results from S2DEMO plotted with S2DPLOT, GS Scripser and Surfer for Windows. High IP phase values map phyllic alteration.

References

- Constable, Parker and Constable, 1987, Occam's inversion: a practical algorithm for generating smooth models from EM sounding data: *Geophysics*, v52, p289-300.
- Dennis and Schnabel, 1983, *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, Prentice-Hall Inc., Englewood Cliffs, New Jersey.
- Keller and Frischknecht, 1966, *Electrical methods in geophysical prospecting*, Pergamon, Oxford.
- Menke, 1984, *Geophysical Data Analysis: Discrete Inverse Theory*, Academic Press, Inc., Orlando, Florida.
- Oldenburg and Li, 1994, Inversion of induced polarization data, *Geophysics*, v59, p1327-1341.
- Sasaki, 1989, Two-dimensional joint inversion of MT and dipole-dipole resistivity data, *Geophysics*, v54, p254-262.
- Tarantola and Valette, 1982, Generalized nonlinear inverse problems solved using the least squares criterion: *Reviews of Geophysics and Space Physics*, v20, p219-232.
- Tarantola, 1987, *Inverse Problem Theory, Methods for Data Fitting and Model Parameter Estimation*, Elsevier Science B.V., Amsterdam, The Netherlands.
- Tripp, Hohmann and Swift, 1984, Two-dimensional resistivity inversion, *Geophysics*, v49, p1708-1717.
- Twomey, 1979, *Introduction to the mathematics of inversion in remote sensing and indirect measurements*, 2nd ed.: Elsevier Scientific Publishing Co, New York.
- Wannamaker, 1992, IP2DI-v1.00: Finite element program for dipole-dipole resistivity forward and parameterized inversion of two-dimensional earth resistivity/IP structure: Univ. of Utah Research Inst. Rept. ESL-92002-TR.
- Whittall and Oldenburg, 1992, *Geophysical Monograph Series, Number 5, Inversion of Magnetotelluric Data for a One-Dimensional Conductivity*, Soc. of Expl. Geoph., Tulsa, Oklahoma.

Appendix A File-Format Documentation

*.MDE File Format (Zonge data-processing-control file)

*.MDE files hold plot annotation and Zonge data-processing-control information. A *.MDE-file consists of one or more 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 a value to assign to that variable. Spaces may be included between elements of a mode line. Spaces in values defined as text will be included in the text string.

*.MDE file listing:

```
$ COMPANY=Zonge Engineering
$ CLIENT=Zonge Engineering
$ PROJECT=North Silverbell
$ JOBNUMB=9309
$ JOBDATE=March 1993
$ JOBLINE=0
$ BRGLINE=S80E
$ BRGBACK=N80W
$ STNLO= -3.0
$ STNHI= 17.0
$ STNDELTA= 1.0
$ LBLFRST=-300
$ LBLDELTA= 500
$ UNITS= feet
$ AUTO= YES
$ S2DPLOT: LNTITLE = North Silverbell IP Line 0
$ S2DPLOT: TBTITLE= Zonge Engineering
$ S2DPLOT: TBTITLE= North Silverbell
$ S2DPLOT: TBTITLE= Line 0
$ S2DPLOT: TBTITLE= Smooth-model Inversion of
$ S2DPLOT: TBTITLE= Dipole-Dipole Resistivity Data
$ S2DPLOT: TBLABEL= AUTHOR
$ S2DPLOT: TBLABEL= DRAWN
$ S2DPLOT: TBLABEL= DATE
$ S2DPLOT: TBLABEL= SCALE
$ S2DPLOT: TBLABEL= REPORT
$ S2DPLOT: TBTEXT= SCM
$ S2DPLOT: TBTEXT= Zonge
$ S2DPLOT: TBTEXT= 18/Dec/96
$ S2DPLOT: TBTEXT= 1:10000
$ S2DPLOT: TBTEXT= Job 9309
$ S2DPLOT: TBTEXT= S2DGEOS.*
$ S2DPLOT: TBTEXT= Figure 2a
$ S2DPLOT: TBGLOSS= Survey Parameters:
$ S2DPLOT: TBGLOSS= 500 ft dipole-dipole data
$ S2DPLOT: TBGLOSS= 0.125 hertz repetition rate
$ S2DPLOT: TBGLOSS= Observed data from S2DEMO.AVG
$ S2DPLOT: TBGLOSS=
$ S2DPLOT: TBGLOSS= Inversion control parameters:
$ S2DPLOT: TBGLOSS= ResSmth=1.0, dpW=1, dxW=1, dzW=1
$ S2DPLOT: TBGLOSS=
$ S2DPLOT: TBGLOSS=
$ S2DPLOT: TBGLOSS=
```

```

$ S2DPLOT: XSCALE = 1.0000E+4 Horizontal scale (X-axis)
$ S2DPLOT: YSCALE = 1.0000E+4 Vertical scale (Y-axis)
$ S2DPLOT: STNDEC = 0 Number of station number decimals
$ S2DPLOT: ELVMIN = 1000.0 Minimum elevation (Y-axis)
$ S2DPLOT: ELVMAX = 3000.0 Maximum elevation (Y-axis)
$ S2DPLOT: ELVINC = 250.0 Elevation tick interval
$ S2DPLOT: CRMIN = 1.5 Res contour color min (log10(ohm-m))
$ S2DPLOT: CRMAX = 3.5 Res contour color max (log10(ohm-m))
$ S2DPLOT: CRINC = 0.1 Res contour interval (log10(ohm-m))
$ S2DPLOT: CRDEC = 1 Number of res contour label decimals
$ S2DPLOT: CPMIN = 0.1 IP contour color minimum (mrad)
$ S2DPLOT: CPMAX = 75.0 IP contour color maximum (mrad)
$ S2DPLOT: CPINC = 5.0 IP contour interval (mrad)
$ S2DPLOT: CPDEC = 0 Number of IP contour label decimals

```

*.MDE file variables:

```

COMPANY - company running survey (text).
CLIENT - company for which survey was run (text).
PROJECT - project name (text).
JOBNUMB - Zonge job number.
JOBDATE - date when survey was conducted.
JOBLINE - line number.
BRGLINE - forward line bearing (in direction of increasing station numbers).
BRGBACK - line back bearing (in direction of decreasing station numbers).
STNLO - low unscaled station number.
STNHI - high unscaled station number.
STNDELTA - unscaled station-number increment, default: STNDELTA=1.0
LBLFRST - 1st scaled stn # corresponding to unscaled STNLO, default: LBLFRST=STNLOW
LBLDELTA - scaled station-number increment along axis, default: LBLDELTA=STNDELTA
UNITS - length units (m or ft).
AUTO - yes = batch file mode, no = interactive mode in Zonge data processing programs.

$ S2DPLOT: - identifies keywords for TS2DIP plotting programs, S2DGEOS and S2DSURF.
LNTITLE - project and line number text in TS2DIP plots (up to 2 lines).
TBTITLE - title block titles in TS2DIP plots (up to 5 lines).
TBLABEL - title block subtext labels (5 labels).
TBTEXT - title block subtext (up to 7 lines).
TBGLOSS - survey configuration annotation text (up to 10 lines).
XSCALE - horizontal scale of TS2DIP plots (ground m per plot m).
YSCALE - vertical scale of TS2DIP model section (ground m per plot m).
YMAX - maximum elevation on TS2DIP model section (length units).
YMIN - minimum elevation on TS2DIP model section (length units).
YTICK - tick mark increment on model section elevation axis (length units).
CRMIN - minimum resistivity contour-color-fill level (log10(ohm-m)).
CRMAX - maximum resistivity contour-color-fill level (log10(ohm-m)).
CRINC - resistivity contour interval (log10(ohm-m)).
CRDEC - number of decimal places on resistivity contour label (0 to 3).
CPMIN - minimum IP contour-color-fill level (mrad or msec).
CPMAX - maximum IP contour-color-fill level (mrad or msec).
CPINC - IP contour interval (mrad or msec).
CPDEC - number of decimal places on IP contour label (0 to 3).
NSDEC - number of decimal places on posted station numbers (0 to 3).

```

*.STN File Format (Zonge-format station location data)

Zonge-format *.STN files hold station grid coordinates and elevations in a simple tabular format. A *.STN file should have at least two entries, corresponding to the first and last stations. Additional entries may be necessary to trace out topographic changes or curved lines. TS2DIP assumes that station numbers represent distance along line and uses station numbers to interpolate stations coordinates if necessary. If station numbers are scaled by entries in a *.MDE file, **STN file station numbers should be in the scaled and shifted client station numbers defined by *.MDE LBLFRST and LBLDEL**T, not the unscaled and unshifted GDP station numbers defined by STNBEG, STNDELT. Left-justified comment lines beginning with a "!", "\ " or a "" may be included for annotation.

The first line that is not a comment line or numeric data is treated as a column label line. By default, TS2DIP assumes four columns with Stn, GridE, GridN and Elevation data. Station files holding an extra **depth** column to specify surface layer or water depths, must have column labels without quote marks and precise spelling, so that TS2DIP can correctly identify the additional column.

Partial *.STN listing:

Station	GridEast	GridNorth	Elevation
-300	1472391	11773359	2470
-200	1472490	11773343	2475
0	1472687	11773311	2490
200	1472885	11773279	2495
400	1473082	11773246	2505
600	1473280	11773214	2505
800	1473477	11773182	2510
1000	1473674	11773149	2520
1200	1473872	11773117	2525
1400	1474069	11773085	2525
1600	1474266	11773052	2510
1800	1474464	11773020	2508
2000	1474661	11772988	2540
.	.	.	.
.	.	.	.
.	.	.	.
7600	1480187	11772083	2760
8200	1480779	11771986	2780
8700	1481272	11771905	2820
9200	1481766	11771824	2880
11200	1483739	11771501	2760

*.STN file variables:

- Station** - station number, proportional to distance along line (client station numbers).
- GridEast** - station grid east coordinate (length units specified in *.S2D file).
- GridNorth** - station grid north coordinate (length units).
- Elevation** - station elevation, use 0 if elevations are not available (length units).
- Depth** - optional water depth (or surface layer thickness), mainly used for marine surveys (length units).

*.AVG File Format (GDP data averaged by CRAVG or TDAVG)

Zonge data-processing-format *.AVG files contain data values averaged from multiple GDP stacks. The tabular format includes columns showing data variation.

Partial CRAVG *.AVG file listing:

```
$ ASPACE= 152.4m
\ 0.Hz Mag= RhoA @ 0.125 Hz, Phz= 3-Pt Phz @ .125,.375,.625 Hz
skp Tx Rx PltPt NSp Freq Cmp Amps Resistivity Phase Real Imag %Rho sPhz
2 8.00 2.00 5.50 5.0 0.000 Ex 0. 1.7219e+2 57.9 1.0000e+0 0.0000e+0 0.9 49.5
2 8.00 2.00 5.50 5.0 .1250 Ex 7.72 2.1768e-3 58.5 1.0000e+0 5.8567e-2 0.8 1.8
2 8.00 2.00 5.50 5.0 .3750 Ex 7.72 2.0755e-3 58.5 9.5344e-1 5.5888e-2 0.3 2.8
2 8.00 2.00 5.50 5.0 .6250 Ex 7.72 2.0711e-3 57.2 9.5150e-1 5.4438e-2 0.1 1.1
2 8.00 2.00 5.50 5.0 .8750 Ex 7.72 2.0150e-3 11.6 9.2720e-1 1.0710e-2 0.3 0.5
2 8.00 2.00 5.50 5.0 1.125 Ex 7.72 2.1021e-3 -8.7 9.6729e-1 -8.4157e-3 0.8 6.3
2 8.00 1.00 5.00 6.0 0.000 Ex 0. 2.1177e+2 56.3 1.0000e+0 0.0000e+0 0.0 0.7
2 8.00 1.00 5.00 6.0 .1250 Ex 7.72 1.6734e-3 56.8 1.0000e+0 5.6811e-2 0.1 0.1
. . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . .
```

*.AVG file variables:

- skp** - skip flag, 0 = skip data, 1 = post value, but don't contour, 2 = post and contour data.
- Tx** - station number of lowest numbered Tx-dipole electrode (GDP stn #s).
- Rx** - station number of lowest numbered Rx-dipole electrode (GDP stn #s).
- PltPt** - station number at plot point, midway between Tx and Rx dipoles.
- NSp** - n-spacing between Tx and Rx dipoles (dipole lengths).
- Freq** - Frequency at which data was measured (hertz). If frequency is zero, values are corrected for inductive coupling (when possible).
- Cmp** - component measured (Ex, Ey, Ez, Hx, Hy, or Hz).
- Amps** - average square-wave transmitter current (amps), as entered into the GDP-32, or as calculated from a reference channel magnitude.
- Resistivity** - average apparent resistivity (ohm-m) when frequency = 0, otherwise magnitude in volts/amp. When frequency is zero, calculated values are based on an extrapolation. Frequencies used for extrapolation to 0 hertz are noted in *.AVG file header.
- Phase** - average phase angle (mrad). When frequency is 0, calculated values are based on an extrapolation. Frequencies used for extrapolation to 0 hertz are noted in the *.AVG file header.
- Real** - in-phase component of complex apparent resistivity (unitless, normalized to 1.0 at 0 hertz).
- Imag** - out-of-phase component of complex apparent resistivity (unitless, arbitrarily set to 0.0 at 0 hertz).
- %Mag** - Relative variation of apparent resistivity data averaged for this point (standard_deviation / apparent_resistivity * 100 (percent).)
- sPhz** - standard deviation of phase data averaged for this point (mrad).

*.Z File Format (Zonge plot-file format with data from CRAVG or TDAVG)

Zonge plot-file-format *.Z files contain data values averaged from multiple GDP stacks. Apparent resistivity data are written in a single block of tabular (x,y,z) values, followed by IP phase in a second (x,y,z) data block. Three-point IP phase values are usually written into a third (x,y,z) data block.

Partial CRAVG *.Z file listing:

```
/* 06 Feb 97
$ DATE= 93-03-17
$ ASPACE= 500.ft
$ ZPLOT: DATA= N-SP
CRAVG 7.22 Contour file.
Cl Cn Ce Ns Nd Yl Plot file 1
 1 5 0 3 0 0
CR-IP SURVEY DATA
Apparent RESISTIVITY
values in ohm-meters
0.125 Hz
IIxxxxxxxxYYYYYYYzzzzzzzzzzz AAA
2 5.5 5. 1.722E+02
2 5. 6. 2.118E+02
2 5. 4. 1.769E+02
. . . . .
. . . . .
2 14.5 3. 2.308E+02
9999.0
Cl Cn Ce Ns Nd Yl Plot file 2
 0 20 2 3 1 0
CR-IP SURVEY DATA
Raw PHASE Angle
values in milliRadians
0.125 Hz
IIxxxxxxxxYYYYYYYzzzzzzzzzzz AAA
2 5.5 5. 5.850E+01
2 5. 6. 5.675E+01
2 5. 4. 6.125E+01
. . . . .
. . . . .
2 14.5 3. 1.230E+01
9999.0
Cl Cn Ce Ns Nd Yl Plot file 3
 0 20 2 3 1 0
CR-IP SURVEY DATA
3-PT DC PHASE
values in milliRadians
.125,.375,.625 Hz
IIxxxxxxxxYYYYYYYzzzzzzzzzzz AAA
2 5.5 5. 5.793E+01
2 5. 6. 5.627E+01
2 5. 4. 5.682E+01
. . . . .
. . . . .
2 14.5 3. 1.177E+01
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 "lXyZ" record preceding numerical data. A "lXyZ" 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 TS2DIP, the *.Z file must have both apparent resistivity and IP phase or chargeability data blocks.

Description of lines in sample *.Z file:

\$ ZPLOT: DATA= N-SP - mode line, y-value data type (n-spacing)
\$ ASPACE = 500ft - dipole length
CRAVG 7.22 - program name and version that generated this file.
CI Cn Ce Ns Nd YI - labels for integer contour control flags.
CI - label for contour type: 0 = linear
1 = logarithmic
2 = pseudo-log: Pseudo-log contours = positive and negative values are contoured separately, using $\log_{10}(\text{abs}(\text{value}))$, plus a zero contour.
Cn - label for number of contours per interval.
Ce - label for exponent of the contour interval, $\text{interval}=10^{\text{Ce}}$.
Ns - label for number of significant digits when posting values.
Values: -1, 3, 4, 5. (-1 = free format for small values)
Nd - label for the number of digits after the decimal.
YI - label for vertical axis: 0 = none
1 = log frequency axis
2 = linear frequency axis
3 = linear depth
1 5 0 3 1 1 - integer values for contour control flags.
1 - value of CI => logarithmic contours
5 - value of Cn => 5 contours per "interval"
0 - value of Ce => $\text{interval}=10 \leq \text{Ce}=1$
3 - value of Ns => use 3 significant digits for contouring
1 - value of Nd => plot 1 digit after the decimal
1 - value of YI => log frequency axis
CR-IP SURVEY DATA - Data description for this plot file. Two to six lines are available.
Apparent Resistivity Column one is not read by ZPLOT.
values in ohm-m ZPLOT plots these lines as title annotation.
llxxxxxxxYYYYYYYzzzzzzzzzzz - 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 GDP station numbers.
YYYYYYY - y value field, for IP $y=n$ -spacing, not used when skip flag = 3
zzzzzzzzzzz - z value field, to be plotted at (x,y) when skip flag=1, 2, or 4.
AAA - annotation field, when skip flag=1 or 2, ZPLOT posts any characters in the AAA column instead of plotting the z value. When skip flag=3, ZPLOT plots a symbol below the x-axis at the x-value according to an integer in column AAA. A zero or positive integer refers to symbols in TABLE 1 of the PLOT Manual. A negative integer refers to topographic symbols in the CTOPO Manual.
9999.0 - marks end of (stn,x,y,z) data block.

*.DAT File Format (GeoSoft-format IP data)

GeoSoft-format *.DAT files provide a generic IP data-file format. *.DAT files have three header lines holding descriptive information, followed by numerical data in a tabular format. Input from *.RES & *.IP files is preferred for time-domain data. Geosoft's IPRED program reads *.DAT files, calculates apparent resistivities and combines selected time-slice values into a single chargeability value for each data point. For time-domain data, GeoSoft-format *.RES+*.IP are preferable to *.DAT files since TS2DIP does not duplicate GeoSoft program IPRED's ability to selectively average groups of IP transient time slices.

Partial GeoSoft *.DAT file listing:

```
AVG-GDAT 1.28: North Silverbell
LINE:0 ARRAY:DPDP DIPOLE:500. UNITS:FT T=10,30,30,30
  F1x  F2x  M1x  M2x  Mag  I  Rho  3Pt  Phz  SEM
5200. 5700. 2200. 2700. 1.320e+1 7.72 1.722e+2 57.9 58.5 1.8
5200. 5700. 1700. 2200. 1.015e+1 7.72 2.118e+2 56.3 56.8 0.1
4700. 5200. 2200. 2700. 1.783e+1 5.8 1.769e+2 56.8 61.3 *
4700. 5200. 1700. 2200. 1.222e+1 5.8 2.123e+2 60.1 59.9 *
4200. 4700. 2200. 2700. 3.594e+1 5.9 1.752e+2 44.9 44.2 *
4200. 4700. 1700. 2200. 2.187e+1 5.9 2.132e+2 48.5 48.7 *
3700. 4200. 2200. 2700. 1.008e+2 5.83 1.987e+2 20. 23.8 *
3700. 4200. 1700. 2200. 4.286e+1 5.83 2.113e+2 31.1 30.9 *
3200. 3700. 2200. 2700. 4.220e+2 5.79 2.094e+2 19.1 19.5 *
3200. 3700. 1700. 2200. 9.080e+1 5.79 1.803e+2 24.4 24.8 *
. . . . .
. . . . .
. . . . .
```

*.DAT file variables:

Line 1: - general descriptive information, this sample file was created from S2DEMO.AVG with the reformatting program AVG-GDAT.EXE.

Line 2:

LINE - line number.
ARRAY - array type (DPDP or PDP).
DIPOLE - dipole length (length units).
UNITS - length units (m or ft).
T - time-domain chargeability information, not used by TS2DIP.

Line 3:

F1 - transmitter electrode position (length units), x or y label extension optional.
F2 - transmitter electrode position (length units), x or y label extension optional.
M1 - receiver electrode position (length units), x or y label extension optional.
M2 - receiver electrode position (length units), x or y label extension optional.
Mag - magnitude (mV), **Vp** is an alternative used with time-domain data.
I - current (amps).
Rho - apparent resistivity (ohm-m), **Mag** and **I** are used if **Rho** column is not present.
3Pt - 3-point 0-hertz phase (mrad), **IP** column used with time-domain data (msec).
Phz - 0.125 hertz phase (mrad), **IP** column used with time-domain data (msec).
SEM - estimated IP measurement error (mrad), optional.

*.RES and *.IP File Format (GeoSoft-format IP data)

GeoSoft-format *.RES and *.IP files provide a second generic IP data-file format. *.RES and *.IP files are produced by GeoSoft's IP data reduction and receiver dump programs. *.RES and *.IP files have two header lines holding descriptive information, followed by numerical data in a sideways pseudosection format. Missing values are denoted with a "*".

Partial GeoSoft *.RES file listing:

```
AVG-GDAT 1.28: North Silverbell CR Line 0N
LINE:0N ARRAY:DPDP DIPOLE:500. UNITS:FT T=10,30,30,30 RES_UNIT:OHM_M FILTER:4
  stn      filt      n=1      n=2      n=3      n=4      n=5      n=6      n=7
  8450.00  192.      *        *        231.     *        *        *        *
  8200.00  *         *        173.     *        274.     *        *        *
  7950.00  301.     470.     *        177.     *        283.     *        *
  7700.00  *         *        450.     *        158.     *        250.     *
  7450.00  329.     412.     *        444.     *        127.     *        205.
  7200.00  *         *        472.     *        336.     *        95.3     *
  6950.00  336.     382.     *        389.     *        250.     *        123.
  6700.00  *         *        326.     *        295.     *        314.     *
  6450.00  299.     196.     *        267.     *        377.     *        *
  6200.00  *         *        192.     *        352.     *        *        *
  5950.00  277.     127.     *        277.     *        432.     *        *
  5700.00  *         *        204.     *        431.     *        547.     *
  .        .        .        .        .        .        .        .        .
  .        .        .        .        .        .        .        .        .
  .        .        .        .        .        .        .        .        .
```

Partial GeoSoft *.RES file listing:

```
AVG-GDAT 1.28: North Silverbell CR Line 0N
LINE:0N ARRAY:DPDP DIPOLE:500. UNITS:FT T=10,30,30,30 RES_UNIT:OHM_M FILTER:4
  stn      filt      n=1      n=2      n=3      n=4      n=5      n=6      n=7
  8450.00  21.4     *        *        11.8     *        *        *        *
  8200.00  *         *        13.6     *        16.5     *        *        *
  7950.00  21.8     10.8     *        19.5     *        16.7     *        *
  7700.00  *         *        23.4     *        18.3     *        27.8     *
  7450.00  29.6     25.1     *        22.2     *        28.4     *        36.6
  7200.00  *         *        26.0     *        32.4     *        40.0     *
  .        .        .        .        .        .        .        .        .
  .        .        .        .        .        .        .        .        .
  .        .        .        .        .        .        .        .        .
```

*.RES file variables:

Line 1: - general descriptive information, this sample file was created from S2DEMO.DAT with "IPRED S2DEMO.DAT -IP=0".

Line 2:

- LINE** - line number.
- ARRAY** - array type (DPDP or PDP).
- DIPOLE** - dipole length (length units).
- UNITS** - length units (m or ft).
- T** - place holder time-domain chargeability information, not used by TS2DIP.
- RES_UNIT** - apparent resistivity units (ohm-m).
- FILTER** - filter type, see GeoSoft documentation.

*.S2D File Format (TS2DIP inversion control file)

*.S2D files hold inversion control information in a Fortran NAMELIST format with missing variables given default values when possible. Left-justified comment lines beginning with a "!", "!" or "\!" can be included for annotation before or after the NAMELIST block, but not within the NAMELIST block.

*.S2D file listing:

```
"From RS2DIPW v4.10a  Date:10/02/99  Time:15:26"
&S2DIP
  Header(1)='North Silverbell',
  Header(2)='Line 0',
  Header(3)='Job 9309  for Zonge Engineering',
  Header(4)='Observed data from S2DEMO.AVG',
  Array='DipoleDipole', StnBeg=-300.00, StnEnd=9700.00,
  DipoleLength=500.0, StnPerDipole=500.0, LengthUnits='ft', IPUnits='mrad',
  NXSPPLIT=2, NZSPPLIT=2,
  ARerrFloor=5.0, IPerrFloor=0.5,
  NResIter=16, ResSmth=1.00, ResdpW=0.50, ResdxW=1.00, ResdzW=1.00,
  NIPIter=16, IPSmth=0.10, IPdpW=0.50, IPdxW=1.00, IPdzW=1.00,
  dRmodStop=1.00, dRRMSStop=0.50, dPmodStop=1.00, dPRMSStop=0.50,
  RMSRdat=0.67, RMSRmod=0.31, RMSRdat=2.98, RMSRmod=11.64,
  CRMIN=1.00, CRMAX=3.00, CRINC=0.10,
  CPMIN=0.0, CPMAX=30.0, CPINC=2.5,
  CWMIN=-2.00, CWMAX=2.00, CWINC=0.10,
  CSMIN=-1.00, CSMAX=2.00, CSINC=0.10,
/
```

*.S2D file variables:

Header(4)	- character array, descriptive text (up to 72 characters) (default=blank).
Array	- character, "DipoleDipole", "PoleDipole", "DHDipoleDipole", "DHPoleDipole" (default=DipoleDipole).
DipoleLength	- dipole length in LengthUnits (m, km, ft or kft) (default=1).
StnPerDipole	- dipole length in station number units (default=1).
LengthUnits	- character, length units (m, km, ft or kft) (default=m).
IPUnits	- character, IP units (mrad, msec or PFE) (default=mrad).
NXSplit	- # of finite-element columns per inversion-model column (1 to 4), (default=2).
NZSplit	- number of finite-element rows per inversion-model row (1 to 4) (default=2).
StnBeg	- first station in active inversion panel (-9.999E7 to 9.999E8) (default=left edge of model section).
StnEnd	- last station in active inversion panel (-9.999E7 to 9.999E8) (default=right edge of model section).
Res0	- background model resistivity (ohm-m) (1.0E-4 to 1.0E6).
NResIter	- maximum number of iterations on resistivity inversion (0 to 32) (default=16).
ARerrFloor	- minimum observed apparent resistivity error (percent) (0.1 to 9999.9) (default=5).
ResSmth	- tradeoff between resistivity data and constraints (0.01 to 100) (default=1).
ResdpW	- relative weight of resistivity background model (0.01 to 100) (default=0.5).
ResdxW	- relative weight of horizontal resistivity smoothness (0.01 to 100) (default=1).
ResdzW	- relative weight of vertical resistivity smoothness (0.01 to 100) (default=1).

IPO	- background model IP (IPUnits) (0.01 to 3141).
NIPIter	- maximum number of iterations on IP inversion (0 to 32) (default=16).
IPerrFloor	- minimum observed IP error (IPUnits) (0.1 to 9999.9) (default=0.1).
IPSmith	- tradeoff between IP data and constraints (0.01 to 100) (default=1).
IPdpW	- relative weight of IP background model (0.01 to 100) (default=0.5).
IPdxW	- relative weight of horizontal IP smoothness (0.01 to 100) (default=1).
IPdzW	- relative weight of vertical IP smoothness (0.01 to 100) (default=1).
RMSRdat	- output with resistivity data residual.
RMSRmod	- output with resistivity model residual.
RMSPdat	- output with IP-response data residual.
RMSPmod	- output with IP-response model residual.
dRmodStop	- stop when log(resistivity) step size < dRmodStop (0.01 to 10) (default=0.1).
dRRMSStop	- stop when RMSRdat change < dRRMSStop (0.1 to 10%) (default=0.5).
dPmodStop	- stop when IP step size < dPmodStop (0.01 to 10) (default=1).
dPRMSStop	- stop when RMSPdat change < dPRMSStop (0.1 to 10%) (default=0.5).
CRMIN	- resistivity color-fill minimum (log10(ohm-m)) (-1 to 5) (default=1).
CRMAX	- resistivity color-fill maximum (log10(ohm-m)) (-1 to 5) (default=3).
CRINC	- resistivity contour increment (log10(ohm-m)) (0.05 to 1) (default=0.1).
CPMIN	- IP color fill minimum (IPUnits) (0 to 1000) (default=0).
CPMAX	- IP color fill maximum (IPUnits) (0 to 1000) (default=30).
CPINC	- IP contour increment (IPUnits) (0.1 to 100) (default=2.5).
CWMIN	- constraint weight color-fill minimum (log10(weight)) (-2 to 2) (default=-2).
CWMAX	- constraint weight color-fill maximum (log10(weight)) (-2 to 2) (default=2).
CWINC	- constraint weight contour increment (log10(weight)) (0.05 to 1) (default=0.1).
CSMIN	- relative sensitivity color-fill minimum (log10(%)) (-2 to 2) (default=-1).
CSMAX	- relative sensitivity color-fill maximum (log10(%)) (-2 to 2) (default=2).
CSINC	- relative sensitivity contour increment (log10(%)) (0.1 to 1) (default=0.1).

*.IPD Data File Format (TS2DIP data file)

*.IPD files hold observed and calculated data in a tabular format with numbers separated by commas or spaces. Left-justified comment lines beginning with a "!", "I" or "\" can be included for annotation. Note that Rx and Tx electrodes must coincide with finite-element-mesh nodes, which are spaced at NXSplit and NZSplit intervals between inversion-model-section nodes. Note that drill hole or water bottom data have an array name starting with DH and both horizontal (stn #) and vertical (elevation) electrode coordinates in SRx1, ZRx1, SRx2, ZRx2, STx1, ZTx1, STx2, and ZTx2 columns.

Partial *.IPD file listing for surface-array data:

```
"Splt", "Zplt", "SRx1", "SRx2", "STx1", "STx2", "ARobs", "ARerr", "IPobs", "IPerr", "ARmod", "IPmod"
>Data from TS2DIP v4.10a Date:10/02/99 Time:12:23:56"
"Array=DipoleDipole, DipoleLength=500., StnPerDipole=500., LengthUnits=ft, IPUnits=mrad"
950., -1000., -300., 200., 1700., 2200., 265.2, 5., 15.5, 0.5, 273.9, 15.3
1200., -750., 200., 700., 1700., 2200., 219.8, 5., 15.6, 0.5, 216.4, 16.8
1200., -1250., -300., 200., 2200., 2700., 257.5, 5., 20.3, 0.5, 263.9, 20.6
1450., -500., 700., 1200., 1700., 2200., 196.3, 5., 14.6, 0.5, 195.8, 14.0
1450., -1000., 200., 700., 2200., 2700., 197.0, 5., 24.7, 0.5, 200.3, 23.2
1450., -1500., -300., 200., 2700., 3200., 302.4, 5., 25.7, 0.5, 279.7, 25.4
1700., -750., 700., 1200., 2200., 2700., 166.4, 5., 18.6, 0.5, 165.1, 19.6
```

*.IPD file column variables:

When *.S2D array = DipoleDipole or PoleDipole for surface in-line surveys:

Splt - horizontal plot-point location (station numbers).
Zplt - vertical plot-point location (station numbers).
SRx1 - lower Rx electrode location (station numbers).
SRx2 - upper Rx electrode location (station numbers).
STx1 - lower Tx electrode location (station numbers).
STx2 - upper Tx electrode location (station numbers) (pole-dipole => use filler values).
ARobs - observed apparent resistivity (ohm-m).
ARerr - measurement error in observed app. res. (percent).
When ARerr > 5000, the matching ARobs will not be used for inversion.
IPobs - observed apparent IP response (IPUnits = mrad, msec or PFE).
IPerr - measurement error in observed app. IP (IPUnits = mrad, msec or PFE).
When IPerr > 5000, the matching IPobs will not be used for inversion.
ARmod - calculated apparent resistivity (ohm-m).
IPmod - calculated apparent IP response (IPUnits = mrad, msec or PFE).

When *.S2D array = DHDipoleDipole or DHPoleDipole for hole-to-surface or hole-to-hole surveys:

Splt - horizontal plot-point location (station numbers).
Zplt - vertical plot-point location (station numbers).
SRx1 - lower receiver electrode location (station numbers).
ZRx1 - lower receiver electrode RL (length units).
SRx2 - upper receiver electrode location (station numbers).
ZRx2 - upper receiver electrode RL (length units).
STx1 - lower transmitter electrode location (station numbers).
ZTx1 - lower transmitter electrode RL (length units).
STx2 - upper Tx electrode location (station numbers) (pole-dipole => use filler values).
ZTx2 - upper Tx electrode RL (length units) (pole-dipole => use filler values).
ARobs - observed apparent resistivity (ohm-m).
ARerr - measurement error in observed app. res. (percent).
IPobs - observed apparent IP response (IPUnits = mrad, msec or PFE).
IPerr - measurement error in observed app. IP (IPUnits = mrad, msec or PFE).
ARmod - calculated apparent resistivity (ohm-m).
IPmod - calculated apparent IP response (IPUnits = mrad, msec or PFE).

*S.DAT File Format (S2DSURF -> SURFER data file)

*S.DAT files hold model values, observed and calculated data in a tabular format suitable for use by Golden Software's Windows SURFER v6 program.

Partial *S.DAT file listing:

```
"Xplt","Yplt","mod res","mod phz","res err","phz err","log10(mod res)","Xplt","Yplt","obs
ares","calc ares","obs aphz","calc aphz","log10(obs ares)","log10(calc ares)"
700.00,2507.50,283.9,12.7,47.7,0.8,2.453,950.00,-1000.00,265.2,285.0,15.5,14.1,2.424,2.455
700.00,2363.77,274.7,16.9,32.3,0.6,2.439,1200.00,-750.00,219.8,215.4,15.6,15.6,2.342,2.333
700.00,2198.49,255.7,21.1,33.5,0.6,2.408,1200.00,-1250.00,257.5,268.8,20.3,19.7,2.411,2.429
700.00,2008.41,247.7,24.2,35.3,0.6,2.394,1450.00,-500.00,196.3,188.8,14.6,14.4,2.293,2.276
700.00,1754.93,261.2,24.9,36.9,0.6,2.417,1450.00,-1000.00,197.0,200.9,24.7,21.9,2.294,2.303
700.00,1463.43,284.3,23.4,39.1,0.7,2.454,1450.00,-1500.00,302.4,276.8,25.7,25.8,2.481,2.442
700.00,1128.20,302.4,21.4,41.6,0.7,2.481,1700.00,-750.00,166.4,165.9,18.6,19.8,2.221,2.220
700.00,742.69,317.7,20.9,55.0,0.9,2.502,1700.00,-1250.00,226.2,216.3,29.7,28.6,2.354,2.335
950.00,2517.50,267.8,16.6,42.1,0.7,2.428,1700.00,-1750.00,326.6,317.2,34.3,30.8,2.514,2.501
950.00,2373.46,270.1,18.6,27.5,0.5,2.432,1950.00,-500.00,118.4,118.7,18.9,18.9,2.073,2.074
950.00,2207.82,240.7,20.9,31.3,0.6,2.381,1950.00,-1000.00,189.9,185.9,24.8,26.7,2.279,2.269
. . . . .
. . . . .
. . . . .
```

*S.DAT file variables:

Line one holds column labels.

Smooth-model data:

- XPlt - location along line (station numbers).
- YPlt - elevation (station numbers).
- Mod Res - model resistivity (ohm-m).
- Mod Phz - model IP (mrad, msec or PFE).
- Res Err - estimated model-resistivity error (percent).
- Phz Err - estimated model-IP error (mrad, msec or PFE).
- log10(Mod Res) - log10 of model resistivity (log10(ohm-m)).

Observed and calculated data:

- XPlt - location along line (station numbers).
- YPlt - vertical plot position (station numbers).
- obs ares - observed apparent resistivity (ohm-m).
- calc ares - calculated apparent resistivity (ohm-m).
- obs aphz - observed apparent IP (mrad, msec or PFE).
- calc aphz - calculated apparent IP (mrad, msec or PFE).
- log10(obs ares) - observed app. resistivity (log10(ohm-m)).
- log10(calc ares) - calculated app. resistivity (log10(ohm-m)).

*S.TXT File Format (S2DSURF -> SURFER text file)

*S.TXT files hold plot scale and annotation information in a spreadsheet format suitable for use by Golden Software's Windows GSScript and SURFER programs.

*S.TXT file listing:

```
"Xmin", "Xmax", "Yplt", "n-sp", "Xmin", "Xmax", "Yplt", "elev"  
550.00, 8850.00, -500.00, 1.00, 550.00, 8850.00, 500.00, 500.00, "Res contours=1.50to3.50step0.10"  
550.00, 8850.00, -750.00, 2.00, 550.00, 8850.00, 750.00, 750.00, "IP contours=0.10to75.00step5.00"  
550.00, 8850.00, -1000.00, 3.00, 550.00, 8850.00, 1000.00, 1000.00,  
550.00, 8850.00, -1250.00, 4.00, 550.00, 8850.00, 1250.00, 1250.00,  
550.00, 8850.00, -1500.00, 5.00, 550.00, 8850.00, 1500.00, 1500.00,  
550.00, 8850.00, -1750.00, 6.00, 550.00, 8850.00, 1750.00, 1750.00,  
550.00, 8850.00, -2000.00, 7.00, 550.00, 8850.00, 2000.00, 2000.00,  
,,, 550.00, 8850.00, 2250.00, 2250.00,  
,,, 550.00, 8850.00, 2500.00, 2500.00,  
,,, 550.00, 8850.00, 2750.00, 2750.00,
```

*S.TXT file variables:

Line one holds column labels.

Data pseudosection y-axis annotation:

Xmin - x-coordinate of left y-axis (station numbers).
Xmax - x-coordinate of right y-axis (station numbers).
Yplt - y-coordinate of y-axis annotation (station numbers).
n-sp - y-axis annotation values (n-spacing).

Smooth-model cross-section y-axis annotation:

Xmin - x-coordinate of left y-axis (station numbers).
Xmax - x-coordinate of right y-axis (station numbers).
Yplt - y-coordinate of y-axis annotation (station numbers).
elev - y-axis annotation values (length units).

Plot parameters on right end of line two:

Dipole - dipole length (length units).
length units - length scaling (m or ft).
IP units - IP response units (mrad, msec, PFE).
StnPerDipole - dipole length (station numbers).
ymin - minimum Yplt value in smooth-model section (stn #).
ymax - maximum Yplt value in smooth-model section (stn #).
dymin - minimum Yplt value in data pseudosections (stn #).
dymax - maximum Yplt value in data pseudosections (stn #).

Additional annotation text is placed on right ends of lines 3-14.