

Instruction Manual

for

EarthImager 3D

Version 1.3.5

Resistivity Inversion Software

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1. WELCOME

We, all of us at Advanced Geosciences Inc. (AGI), thank you for purchasing our EarthImager 3D software. After successful release of EarthImager 2D in 2002, we are proud to add this new 3D resistivity data interpretation program to our software product line. Resistivity data inversion with EarthImager is easier, more fun and productive than ever. We look forward to hearing your success stories through the use of our products.

1.1 EarthImager 3D at a Glance

AGI EarthImager 3D is a Windows 32-bit platform based computer program that interprets three-dimensional (3D) electrical resistivity data, and produces 2D (sections) and 3D (volumes) inverted resistivity images that reveal the sought-after targets and subsurface geology. EarthImager turns the complicated resistivity data inversion into a simple two-step process and it takes only a few clicks to get inversion results, i.e., reading a data file and starting the inversion. EarthImager also presents a long list of options for advanced users to play with.

There are shocking similarities between EarthImager 2D and EarthImager 3D in GUI design and functionality. This ensures a smooth transition and an easy learning curve for EarthImager 2D users to migrate to EarthImager 3D. EarthImager, hereinafter, in this manual indicates EarthImager 3D unless specified otherwise. This is a partial list of the existing features of AGI EarthImager 3D software.

- Fast hardware-accelerated 3D graphics powered by OpenGL.
- 3D volumetric rendering with transparency control.
- Inversion of 3D surface resistivity data.
- Inversion of 3D borehole resistivity data.
- Finite difference forward modeling.
- Finite element forward modeling.
- 3D Topographic correction with finite element method.
- 3D Survey Planner.
- 4D Time Lapse inversion.
- Options of boundary condition for forward modeling.
- Smooth model inversion.
- User friendly Windows GUI.
- Noisy data suppression.
- No software limit on number of data points or number of electrodes.
- No limit on array type or electrode location.
- Seamless operation with AGI resistivity instruments.
- Windows true 24-bit color.
- Trackable and retrievable user settings.
- Tool buttons for easy access to frequently used menu items.
- Inversion progress bar to show the inversion status.
- Well organized and hassle-free processing directory structure.
- Saving images in bitmap, JPEG, PostScript, PNG, and TIFF file formats.

- Saving the inverted model in XYZ format so it can be loaded into any off-shelf graphics software.
- 3D volume image of inverted resistivity.
- 3D static slice image in either X or Y or Z direction.
- 3D dynamic slice image with full user interaction and pinpoint of anomaly location.
- Data misfit cross-plot.
- Convergence curve.
- Data misfit histogram for removal of poorly-fit data.
- User-specified minimum and maximum variable values of the image.
- User-specified colors and contour levels.
- Support of both AGI's STG data files and AGI Universal Resistivity Files (URF).
- 3D command creator.
- Read inversion output (*.out files) back to EarthImager.
- 3D contour plot and iso-surface plot.
- Several utilities for transformation of electrode coordinates.

1.2 Where to Get Help

This instruction manual is the ultimate resource for everything about EarthImager 3D. This manual may be found in the installation directory and program folder of EarthImager3D as an Adobe Acrobat PDF file. EarthImager User Group on the AGI's website will have the latest updates about EarthImager 3D and free downloads with improvements and bug fixes. You are encouraged to go through the suggested readings at the end of this manual for in-depth understanding of resistivity and IP data inversion.

Your satisfaction is our top priority. If you find that any feature is missing in our EarthImager, please let us know. We will add it to EarthImager as soon as possible if we think that your proposed feature would benefit other EarthImager users. This version of EarthImager will read AGI's STG data files and AGI Universal Resistivity (data) Files (URF). If you have any other popular resistivity and/or IP data files, please send us a sample data file. We will let EarthImager support your data format.

EarthImager clients will have access to EarthImager User Group online. We frequently post new updates of EarthImager with bug-fixes, improvements and new features for free download. Download links to the latest version of EarthImager and document are available in the EarthImager User Group. To enter the User Group, go the AGI website at <http://www.agiusa.com/> and choose EarthImager User Group under the File Areas, or go to the page <http://www.agiusa.com/files/eicust/earthimageruser.shtml> directly. You will be asked to type in your user name and password that are given to you at the time you purchased EarthImager. If you do not have them, please contact us. From EarthImager, you may choose the menu item Help | EarthImager User Group to enter the User Group. Your user name and password should be shown as follows. If your EarthImager is over 6 months old, this is an indication that you have missed many new features.



For further questions, you may contact our tech support team by phone or email listed below.

Tech Support

Email: softwaresupport@agiusa.com

Phone: +1 512 335-3338 ext. 111

AGI directory is listed here <http://www.agiusa.com/directory.shtml>.

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2. INSTALLATION

2.1 System Requirements

EarthImager will run on IBM, PC, and compatible models on any 32-bit Windows operating system that include Windows NT/ME/2000/XP. The performance of EarthImager on the Windows 98 platform is not stable due to its poor OpenGL support. As for the computer physical memory (RAM) requirement, one must distinguish between total physical memory and available physical memory. A computer running Windows XP with only 128 MB RAM can barely run any application program because the XP operating system uses up almost all 128 MB RAM. A 3D data set with 500 data points and 45 electrodes may take about 25 MB memory space. The more available RAM a computer has, the more measurements and electrodes it can deal with. Here are our recommended **minimum** system requirements.

- Windows 2000/XP or up.
- Intel Pentium II or up. Pentium IV with 3GHz or higher clock speed is strongly recommended.
- 100 MB or more disk space available on the hard drive.
- 256 MB RAM or up. 1GB RAM is preferred.
- An available parallel (printer) port or USB port for the dongle connection. USB-port dongles are more reliable.
- Graphics cards that support OpenGL-powered hardware acceleration. Graphics cards by these manufacturers are recommended: 3Dfx, 3DLabs, ATI, Intel, Matrox, nVidia, PowerVR, Rendition or S3. Check <http://www.glsetup.com/> for graphics card types with OpenGL support.

2.2 Installation

2.2.1 Installation of EarthImager 3D

We created a Windows standard setup program for ease of installation. Insert CD with EarthImager setup program into the CD ROM drive and the installation wizard should popup automatically. One may also start the installation by double-clicking the AGIEarthImager3D-x.x.x.xxx.exe on the CD ROM (x indicates a variable version number). Before the installation of EarthImager, make sure that the dongle is unplugged and NOT connected to your computer. Follow the onscreen instructions until the installation finishes successfully. Read the EarthImager license agreement carefully during the installation. It is suggested that you install all AGI computer programs under C:\Program Files\AGI\.

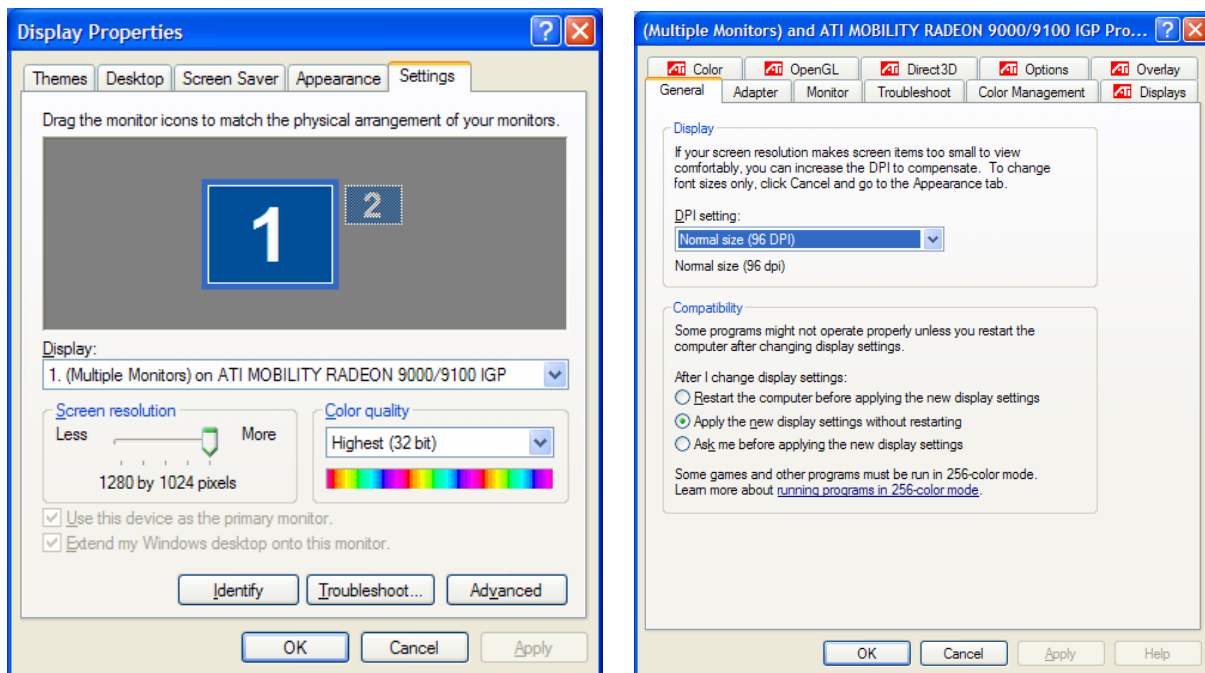
If the installation starts with errors and is unable to finish successfully, you may need to install the “dongle driver” before your installation of EarthImager. The dongle driver may be downloaded from the EarthImager User Group on the AGI website at <http://www.agiusa.com/files/eicust/earthimageruser.shtml>

2.2.2 Graphics card and driver

We noted problems of partially black screen or corrupted images due to an out-of-date graphics card driver or unsupported graphics cards or inappropriate settings. If you find any problem with graphics, you may 1) reduce the level of hardware acceleration, 2) update your graphics card driver, 3) reduce the color quality or number of colors, 4) replace your graphics card, and/or 5) buy a new computer.

To reduce the level of hardware acceleration, follow these steps.

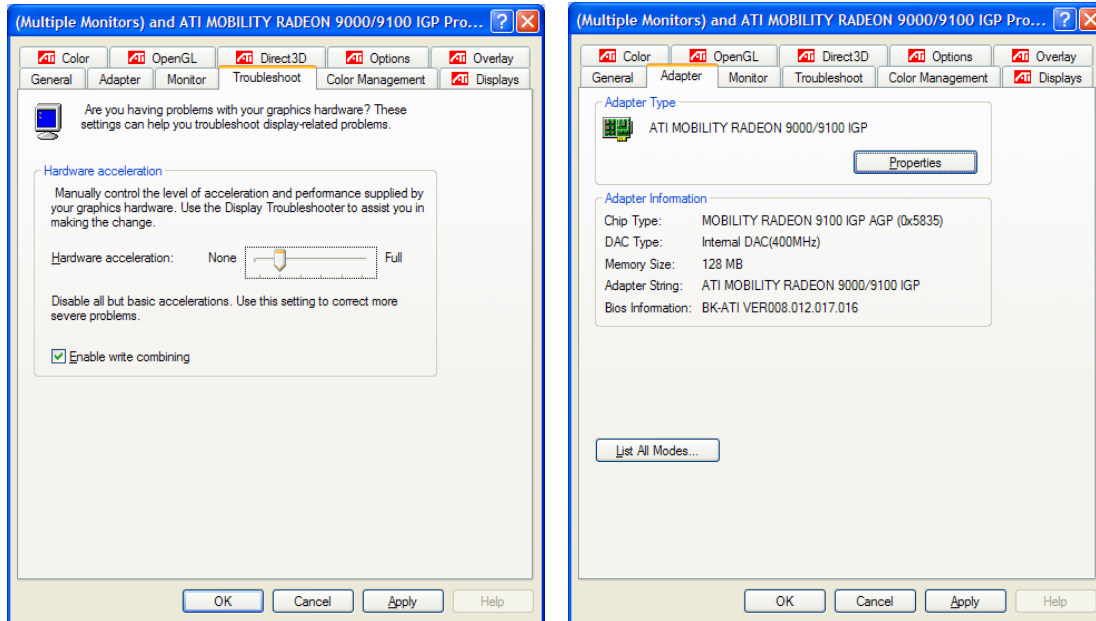
1) Right-click the desktop and choose Properties, or go to Control Panel and click Display. Then click Settings tab. The screen shots below are obtained from Windows XP.



2) Click the Advanced button.

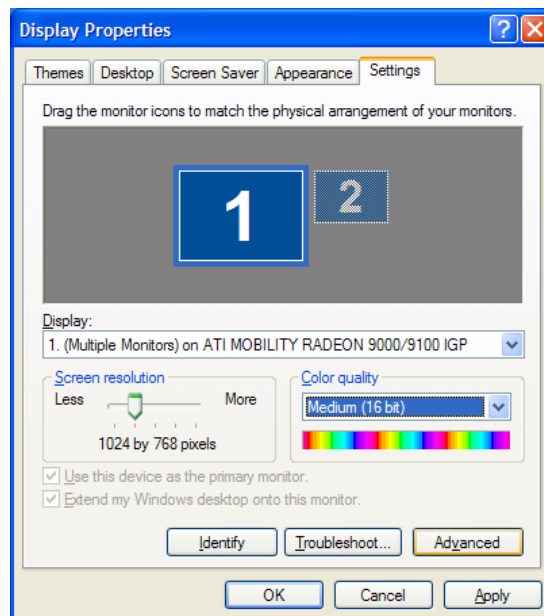
3) Click the Troubleshooting tab. Reduce the Hardware Acceleration one level at a time. If the graphics problem still exists while the hardware acceleration is set to None (all the way to the left), you have to update your graphics cards.

To find out what type of graphics card your computer has, click the Adapter tab. Then you may go to manufacturer's website and download the matching graphics card driver. You may, of course, search for the latest driver for your graphics card based on the Adapter Type using search engines such as google.com or yahoo.com.



GLSetup at <http://www.glsetup.com/> is a shareware program that helps install a matching graphics card driver on your computer. You should make sure that your graphics card and operating system are on its support list. We have not tested GLSetup, so use it at your own risk.

We noted that reducing the color quality or number of colors, for example, from 32 bit colors to 16 bits colors, may fix the problem of image corruption. One may also try to reduce the screen resolution if there is any problem.

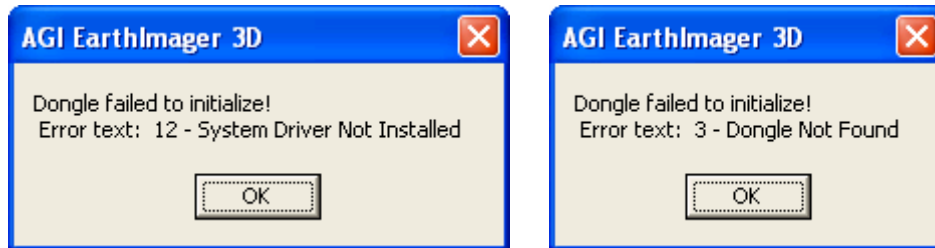


If turning off the hardware acceleration, updating the graphics card driver, reducing number of colors, and screen resolution can not solve your graphics problem; it is unfortunate that you need

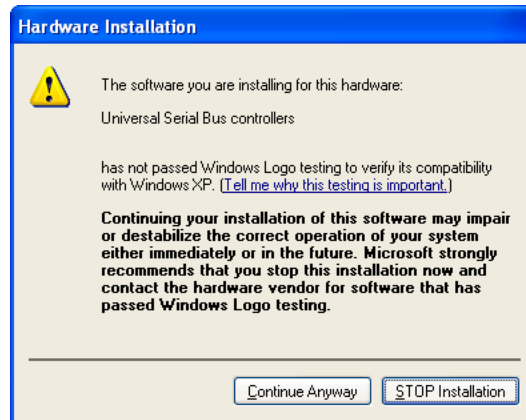
to replace your graphics card. Find a right graphics card that supports OpenGL graphics from the website <http://www.glsetup.com/>.

2.2.3 Dongle driver installation

The dongle driver, i.e., Sentinel System Driver, is automatically installed onto your computer while installing EarthImager. Before the installation of EarthImager, make sure that the dongle is unplugged and not connected to your computer. After installation of EarthImager, connect the dongle to your computer. If you observe any of the following error messages when you launch (start) EarthImager, this indicates that the dongle driver is NOT installed correctly. To fix the dongle driver problem, follow these steps:



- 1) Unplug the dongle from your computer.
- 2) Uninstall EarthImager and Sentinel System Driver by going to Control Panel | Add or Remove Programs.
- 3) Reinstall the EarthImager. If you observe the following warning message, it should be safe to click “Continue Anyway” because the dongle driver is directly from the dongle manufacturer, i.e., SafeNet Inc (formerly Rainbow Technologies).



If reinstallation does not solve the problem, you may want to get the latest version of dongle driver from SafeNet Inc website. Here is the link.

<http://www.safenet-inc.com/support/tech/sentinel.asp>.

2.3 Software Protection

We use Sentinel hardware keys, i.e., dongles, to protect EarthImager. Dongles are available for parallel printer port and USB port. Please specify the port type when ordering.

Warning: To connect both the hardware key (dongle) and the printer to the same parallel port, you must first turn off both the computer and the printer. Then connect the dongle and the printer to the parallel port. Make sure both dongle and printer are firmly connected. Finally, you may turn on the computer and the printer. Here is what the dongle looks like.



2.4 EarthImager Upgrade

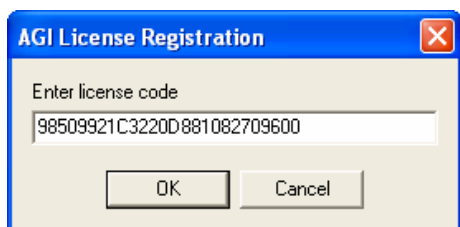
We have different definitions for EarthImager update and upgrade. An update means changes from an older EarthImager version to a newer EarthImager version. AGI gives away free updates of EarthImager year-round. Please go to AGI EarthImager User Group <http://www.agiusa.com/files/eicust/earthimageruser.shtml> to download the latest version.

An EarthImager upgrade means to add one or more special-purpose software modules to EarthImager. At present, EarthImager 3D has only one Time Lapse Inversion module. This software module is already built into the EarthImager 3D but may be disabled by the dongle. So EarthImager upgrade is accomplished by enabling the dongle with an upgrade license code.

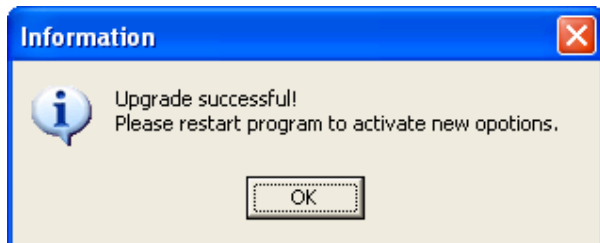
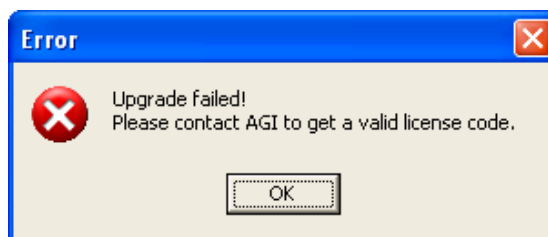
In addition, one may purchase EarthImager 2D and its modules and add the EarthImager 2D license to existing EarthImager 3D dongle. The software download is free from EarthImager User Group. After purchase of EarthImager 2D, we will email you an upgrade code to activate your dongle for both EarthImager 2D and 3D.

AGI charge an upgrade fee for adding a new module. It is easy and convenient to upgrade your EarthImager. You do not need to send the dongle (hardware key) back to AGI. Instead, AGI will send you a dongle upgrade code upon the receipt of your payment. To activate the new option(s) you purchased, please follow these steps

- 1) Connect the dongle to your computer
- 2) Start EarthImager 3D
- 3) Go to the menu item Help | Upgrade
- 4) Copy and paste (or type) the update code to the license code field.



5) Click the OK button to complete the dongle upgrade. One of the message boxes below will pop up to show the success or failure of the upgrade.



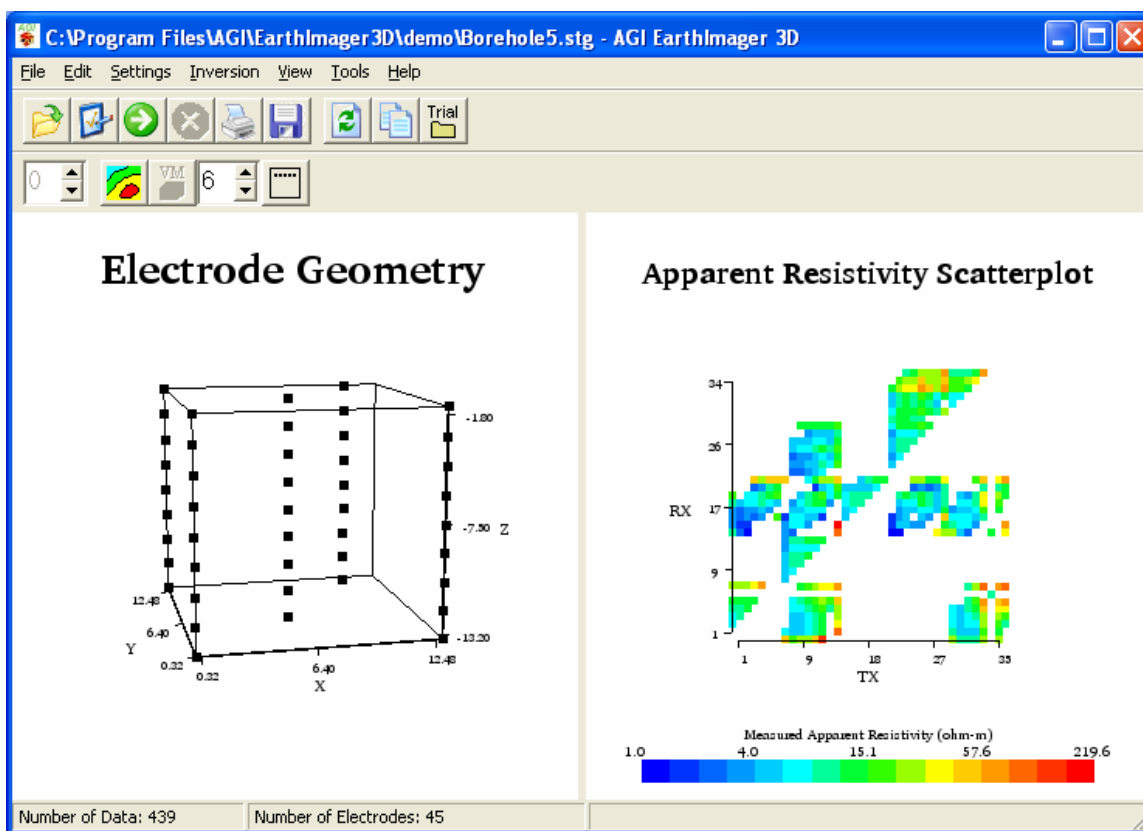
2.5 Interaction with Mouse Buttons

By default, **holding and moving** the left mouse button would rotate an image, and the right mouse button would zoom in or out. The middle mouse button or wheel, if any, would translate an image. The Shift key + Left Mouse would also translate the image if the mouse wheel does not exist. On the Interactive slice image, the key "I" would turn on the Interactive slice. On the apparent resistivity data scatter plot, the key "P" would enable a point Picking action.

3. GETTING STARTED WITH EarthImager 3D

3.1 First Look at EarthImager 3D

This is the Main Window of EarthImager 3D. EarthImager is based on Windows 32-bit platforms. Its user-friendly graphical user interface (GUI) consists of seven main menus, two image viewers (left viewer and right viewer), and two tool bars under the main menu. The top inversion tool bar consists of buttons for file handling and inversion setting, and the bottom image property tool bar consists of buttons for image properties. More tool buttons are coming. Most of the graphics are displayed in the blank area of the main window.



Here are the tool buttons on the Inversion Tool Bar.

-  Read a raw data file. The AGI's STG file is a default.
-  Bring up the Inversion Settings Window.
-  Start inversion.
-  Stop inversion.
-  Print out active on-screen image.
-  Save active on-screen image as a bitmap, JPEG, TIFF, PNG, or PostScript file.
-  Refresh current images.



Copy the active image to the clipboard.



Open the current trial directory in the Windows Explorer.

Here are the tool buttons on the Image Property Tool Bar.



Choose the iteration number for inverted resistivity image. This is the first control on the image property tool bar.



Launch the Color and Contour Properties Window.



Launch the Volume Rendering Method window to choose a volume mapper.



This tool button looks the same as the first one (iteration number) but it helps change electrode symbol size.



Launch the Image Title window to change the image title of both image windows.



Reset the image when the window is blank. This may not bring up the image to a preferred size and orientation.



Save the size and orientation of the current image(s) to a view file (*.vew).

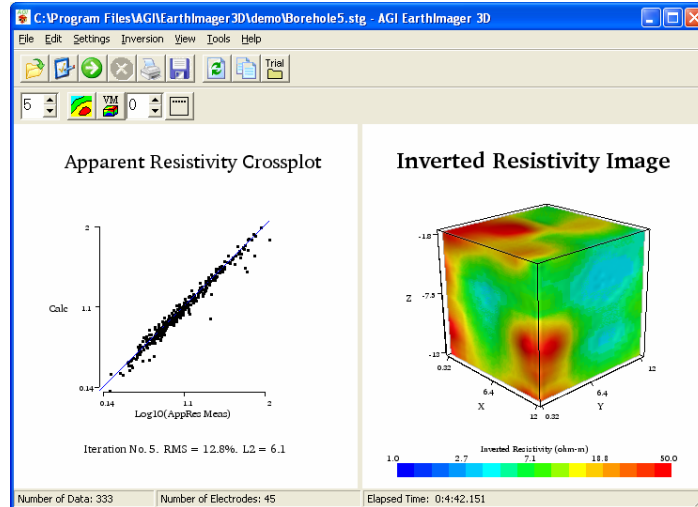


Offer three font options for labels and image titles: Arial, Courier and Times.

The data file name and path are shown at the top of the window. The order of main menus is basically that of inversion steps. That is, the inversion with EarthImager, in general, consists of these six steps:

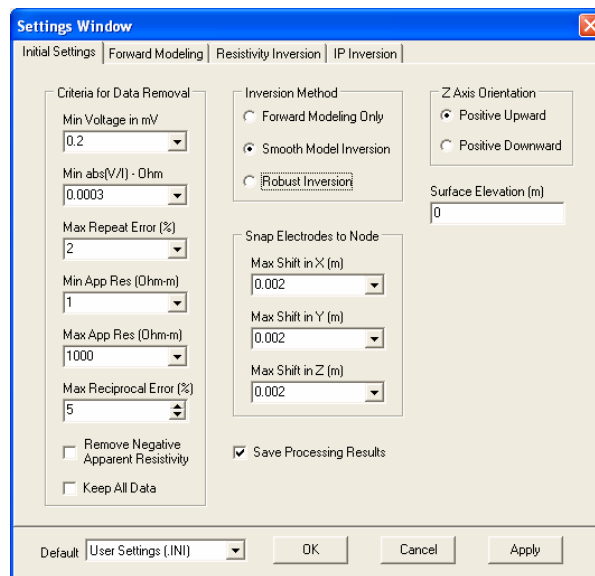
- 1) Read a data file (required),
- 2) Remove noisy data by changing the Initial Settings or editing the electrodes (optional),
- 3) Change inversion settings or read a settings file (optional),
- 4) Run inversion (required),
- 5) Stop inversion (optional).
- 5) View inversion results (optional), and
- 6) Save and print the inversion results (optional).

However, you do not have to go through all these steps. You can get some quick inversion results in only two required steps. First, read a data file by clicking the first tool button . Try Borehole5.stg in C:\Program Files\AGI\EarthImager3D\demo\ directory (your directory structure may be different if you did not use the default installation settings or you are not in the United States). Second, click the second green tool button to start inversion with default settings. You should see the inverted images like this.



3.2 Initial Settings

Click Settings | Initial Settings, then Initial Settings Window pops up. These initial settings specify what data to reject at the initial data loading, what inversion algorithm to use, the orientation of the vertical axis, electrode alignment thresholds, and whether to save the processing results automatically or not, etc. Most of these settings should be set before reading the data file for them to take effect.



There are two major STG file types. The new 3D STG file format uses three coordinates (x, y, z) to describe an electrode location. A mandatory flag "Type: 3D" is added to the end of the first header line of an STG file. The old AGI STG file uses two coordinates to identify the electrode locations. The first coordinate (X) is the horizontal distance along the profile, and the second one (Y) must be the horizontal line offset for multiple-line pseudo-3D surface survey. If Y coordinates are used to describe electrode depth, the behaviors of EarthImager is unpredictable.

EarthImager 3D is not ready for reading a 2D data file collected along a single transect on the surface or in the boreholes.

There are seven criteria for removal of noisy data on the Initial Settings window. Any data beyond these thresholds will be flagged as noisy data. These flagged noisy data are not removed before starting the inversion.

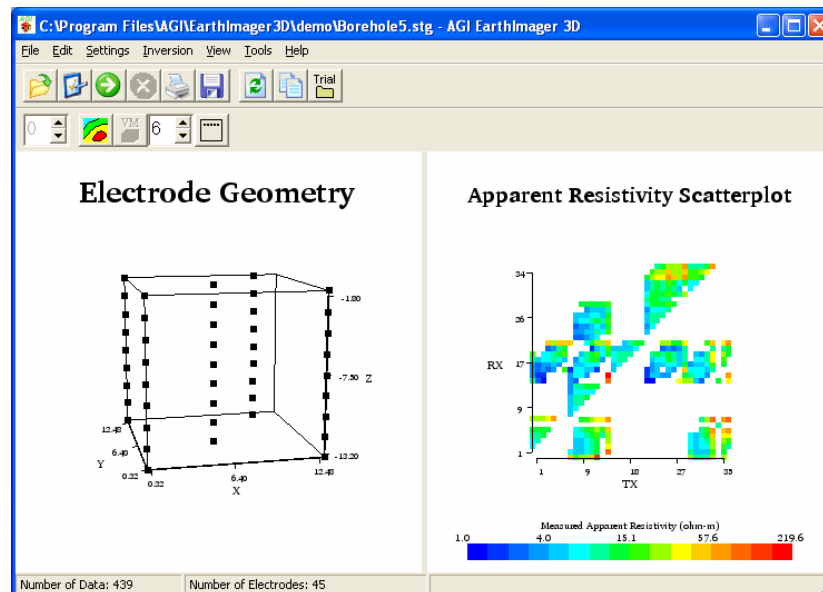
When the user clicks the Start Inversion button, a clean data set is saved in the current trial directory, and is reloaded back for inversion. You may notice some changes in the data scatter plot after choosing the Start Inversion menu item or the Start Inversion tool-button.

Inversion with the EarthImager produces many new files. It is important to keep track of inversion results in an organized way. EarthImager creates processing and trial directories, and saves inversion outputs automatically. We found that this automatic file-saving feature may fill up your hard drive quickly if you keep running the inversion for days or weeks. If you do not want to save anything, you should uncheck the box “Save Processing Results”.

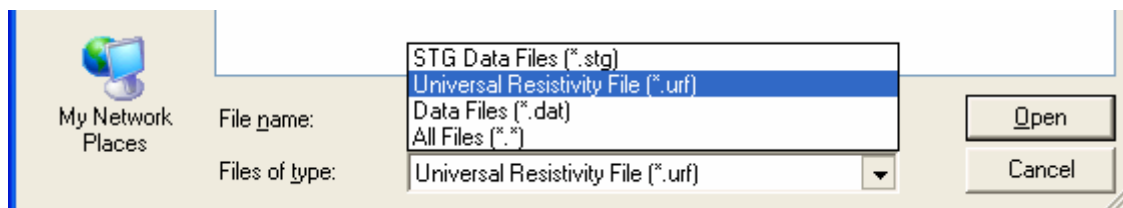
In our numerical modeling algorithm, an electrode must be on a node in the mesh. “Snap Electrode to Node” sets some thresholds to associate an electrode to its nearest node. Conversion of distance units such as meters and feet introduces rounding errors that cause misalignment of electrodes. Setting these thresholds to a few millimeters or centimeters will help avoid these problems.

3.3 Read a Data File

There are two ways to load a data file. You may either choose the Read Data menu item from the File menu or click the first tool button . Tool buttons are used for quick and easy access to some frequently-used menu items. You will be prompted to choose a data file to process.



EarthImager 3D reads STG files in both 2D (x, y) and 3D (x, y, z) formats. In the 2D (x, y) format, electrode locations are described by two coordinates (x, y). So 2D (x, y) format may be used to represent a data set collected from a 3D survey with surface electrodes only. The 3D (x, y, z) format is more flexible for both 3D surface and borehole data sets.



We also defined a Universal Resistivity (data) File (*.URF) format for you to assemble a 3D data file manually. To read a URF file, select Universal Resistivity File from the Files of Type box on the File Open Dialog. Listed below is a sample URF data file to demonstrate the URF file format. Any line starting with a semicolon (;) is a comment line. A line starting with a colon (:) defines a section header. A section header is required and must be spelled correctly. A blank line will be ignored. Data entries are comma-separated. Z = 0 on the surface and negative downwards.

This is a 3D sample Universal Resistivity Data File for testing purpose only.

Top two lines are comments and the third line defines the length unit.

Unit: meters

:Geometry

;ID, X, Y, Z

1, 0.00, 0.00, 0.00

2, 0.00, 1.00, 0.00

3, 0.00, 2.00, 0.00

4, 0.00, 3.00, 0.00

5, 0.00, 4.00, 0.00

6, 0.00, 5.00, 0.00

7, 1.00, 5.00, 0.00

8, 1.00, 4.00, 0.00

9, 1.00, 3.00, 0.00

10, 1.00, 2.00, 0.00

11, 1.00, 1.00, 0.00

12, 1.00, 0.00, 0.00

:Measurements

;A, B, M, N, V/I(ohm), I(mA), Error(%), Chargeability(mV/V)

1, 2, 3, 4, -1.0e-01

1, 2, 4, 5, -9.0e-02

1, 2, 5, 6, -7.5e-02

1, 2, 7, 8, 8.0e-02

1, 2, 8, 9, 7.0e-02

1, 2, 9, 10, 6.0e-02
1, 2, 11, 12, -4.0e-02
3, 4, 5, 6, -7.5e-02
3, 4, 6, 7, -9.0e-02
3, 4, 7, 8, 8.0e-02
3, 4, 9, 10, -6.0e-02
3, 4, 11, 12, 4.0e-02

To read the DAT resistivity data files, choose “Data Files (*.dat)” in the Files of Type field.

In addition to AGI Sting and SuperSting data files (*.stg), URF files, and DAT resistivity data files, EarthImager 3D may be customized to read other popular resistivity data file formats per user’s request. If you are interested in our program to process your non-STG data, please send us a sample data file. To find out if EarthImager supports your data format, select Read Data, and check the Files of Type box at the bottom of Open File dialog. After reading data successfully, EarthImager will display two images in the main window. The left image shows electrode locations in a 3D view, and the right image shows the apparent resistivity scatter plot.

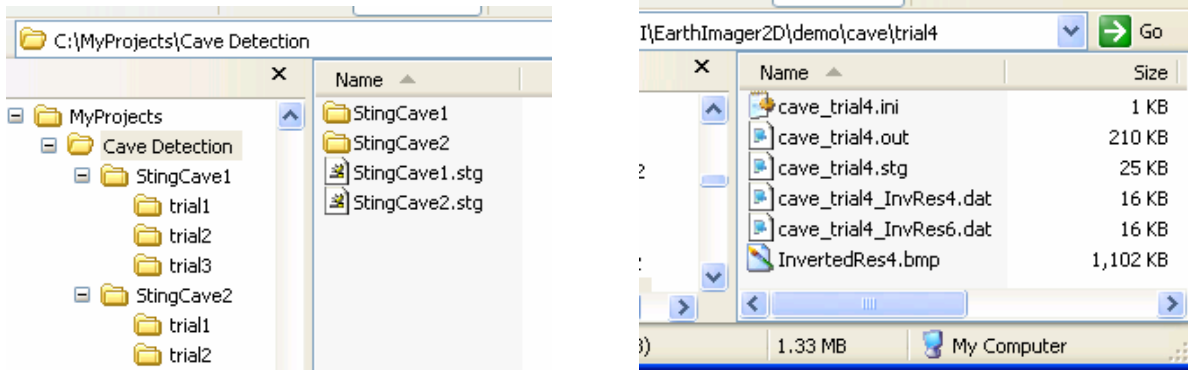
To create a data scatter plot, all transmitting electrode pairs are sorted and numbered in an ascending order. For example, an electrode pair (1, 2) may have electrode ID = 1, and an electrode pair (2, 3) will have electrode ID = 2. The same sorting and numbering is done on the receiving electrode pairs. All measurements on a horizontal line should have the identical transmitter. All measurements on a vertical line should have the same receiver.

To find out the electrodes used to collect a specific data point, move the mouse pointer over the data point and press the “p” key to pick the data point. Transmitting electrodes would be shown in red, and receiving electrodes are in blue.

If your computer does not have enough memory to process the data set just loaded, a warning message would pop up.

3.4 Directory Structure and File Extension

A resistivity survey project has a project name such as Cave Detection. The project name may be used as the top-level directory name for data processing. All data files for this project should be stored in this project directory. Each 3D data set would be collected over several profiles and/or several boreholes. Under the project directory, a subdirectory will be created for each data set automatically when you open a data file. This subdirectory will be named after the data file name without extension. StingCave1, for example, will be the subdirectory name for data file StingCave1.stg. For every inversion trial, a trial subdirectory is created automatically under the profile directory with a directory name of “trial” plus a trial sequential number. The directory hierarchy will look like the figure below.



In a trial directory, these files are saved with the default names. The INI file is the inversion settings file and may be read back into the EarthImager for inversion of other data sets. The OUT file is an inversion log file containing inversion settings, raw data, mesh definition, and inverted results of all iterations. The STG file contains the actual data used in the inversion after removal of noisy data. The DAT file consists of inverted resistivity section in an (X, Y, Z, Resistivity) format. InvRes4 indicates the inverted resistivity section at the fourth iteration. The BMP file is the bitmap image file.

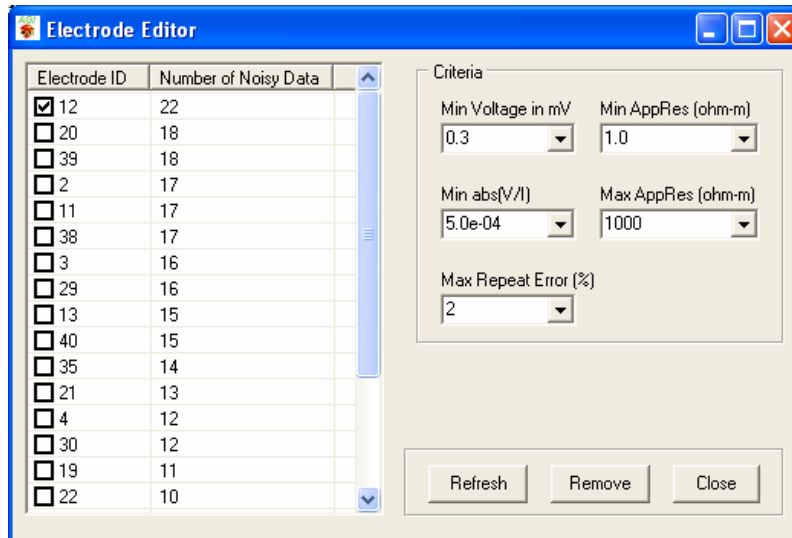
3.5 Edit Data

There are two ways to identify and remove noisy data. The first approach is based on the initial data trimming threshold on the Initial Settings window. The noisy data will be automatically removed based on the thresholds. In the second approach, some possibly bad electrodes would be singled out for removal.

3.5.1 Electrode editor

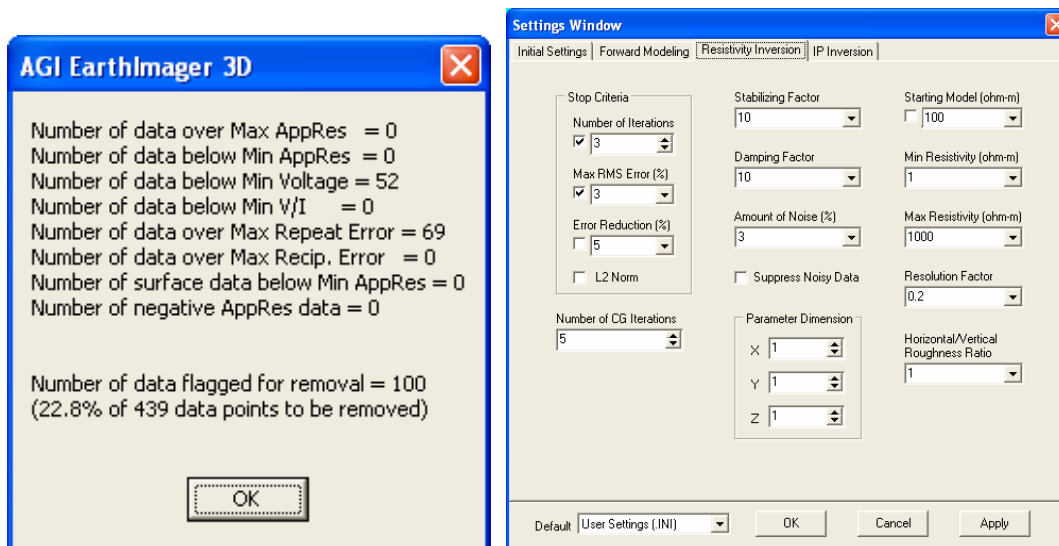
This electrode editor helps identify and remove bad electrodes. All data associated with the bad electrode will be removed. Each electrode is assigned a vote calculated from user-specified criteria on the Initial Settings window. The higher vote an electrode has, the noisier the electrode is. An electrode with a vote larger than half of the number of electrodes is a suspected bad electrode. A horizontal or vertical linear feature on the scatter plot is usually a sign of bad electrode. Here are the steps to identify possibly bad electrodes in the electrode editor.

- 1) Click the second column header Number of Noisy Data to sort this column at a descending order so that the “noisiest” electrodes are emerged at the top of the list.
- 2) Check the box in front of the electrode to be removed. Uncheck the box if you change your mind before clicking the Remove button. Note that the electrode removal is final and can not be undone. If a good electrode is removed, you may reload the data file and start from the beginning.
- 3) Click the Remove button to remove the selected electrodes.
- 4) If you change any “voting” criterion, you should click the Refresh button to update the “votes”.
- 5) Click the Close button to close the Electrode Editor.



3.5.2 Data editing statistics

Selecting this menu item under the Edit menu brings up a message box showing number of data points flagged for removal based on the data removal threshold defined on the Initial Settings Window.

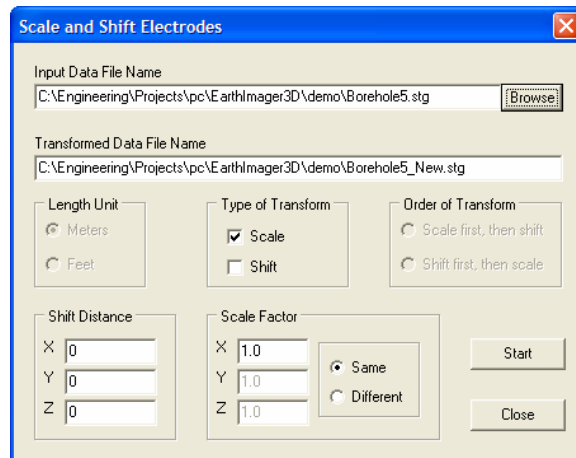


3.5.3 Scale and shift electrodes

This utility helps fix the problems of wrong electrode coordinates in the command file or due to mishandling of roll-along surveys. Scaling or shifting may be carried individually or together. To do both scaling and shift together, the order of transform matters. Here are steps to follow:

- 1) Read the resistivity raw data file by clicking the Browse button. An output file name after transform is suggested in the box below.

- 2) Choose the type of operation: scaling or shifting or both.
- 3) For both operations at the same time, choose the order of transform.
- 4) For shifting operation, choose the shifting distance in X, Y, and Z directions.
- 5) For scaling operation, first decide uniform (same) or different scaling along three axes and then input appropriate scaling factors.
- 6) Click the Start button to begin the transform. A transformed data file is saved in the specified directory.



3.6 Inversion Settings

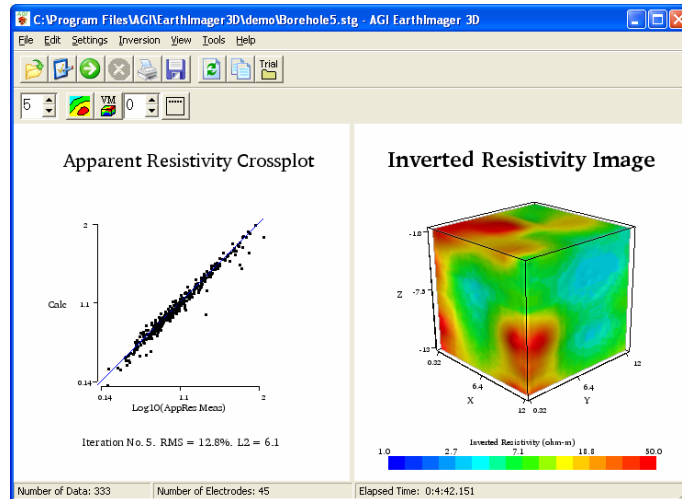
When you launch EarthImager 3D, the settings you used in the last inversion will be loaded automatically. There are several ways to set desired settings. First, you may read a settings file (*.ini) either through the menu File | Read User Settings. Second, you may change individual setting on the Settings Window. Third, you choose hard-coded settings from the Default combo-box at the bottom of the Settings Window.

There are four pages of settings for advanced users. The first page is Initial Settings that determines what inversion method to use and thresholds for noisy data removal. The second page contains all settings to condition Forward Modeling. The third page is Resistivity Inversion settings. The last page is IP Inversion settings. IP inversion will be added soon. The in-depth explanation of these settings is given in Section 4.

3.7 Run Inversion

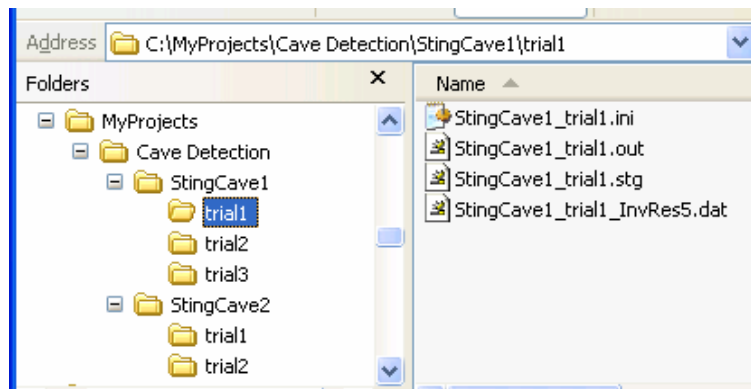
One may start inversion by either clicking the green tool button  or choosing the menu Inversion | Start Inversion. At the bottom of the window, there are text messages and one progress bar showing the progress of the inversion. The progress bar shows the inversion progress within one iteration (inner loop).

There are two images on the main window during the inversion process. The left image shows the data misfit in a cross-plot. If all points fall on the 45° line, a perfect data fit with zero RMS error is achieved, though this is impossible.



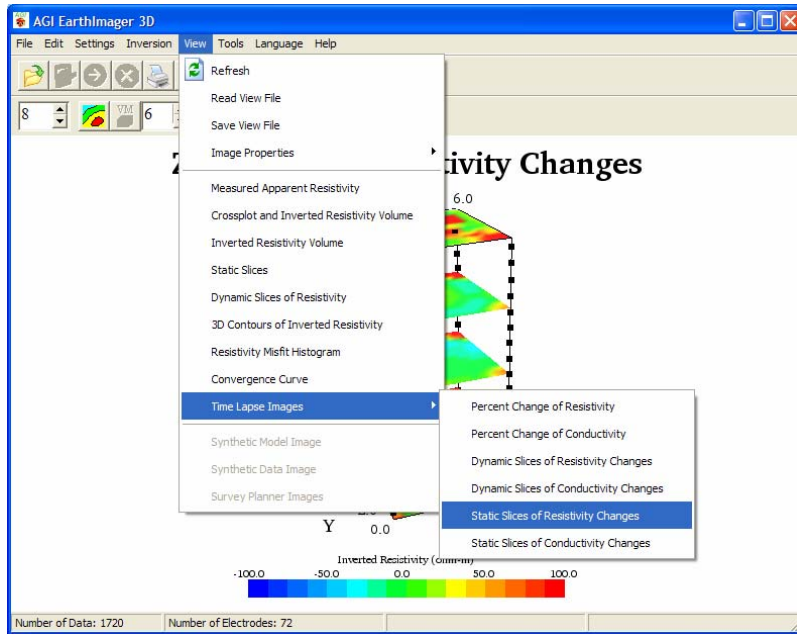
The right image is a 3D volumetric image of inverted resistivity. You do have options for manipulation of data range, color table, and color transparency. We use meters as the distance unit and ohm-m as the resistivity unit.

Three files will be created, and saved automatically in the current trial directory. The INI file contains the settings for current inversion. An STG file contains “clean” raw data used in the inversion. OUT files are inversion log files with inversion settings and results for all iterations. The inversion result is saved iteration by iteration. If an inversion is terminated prematurely, the partial results are saved. An inversion output file may be inputted into EarthImager as a starting model.



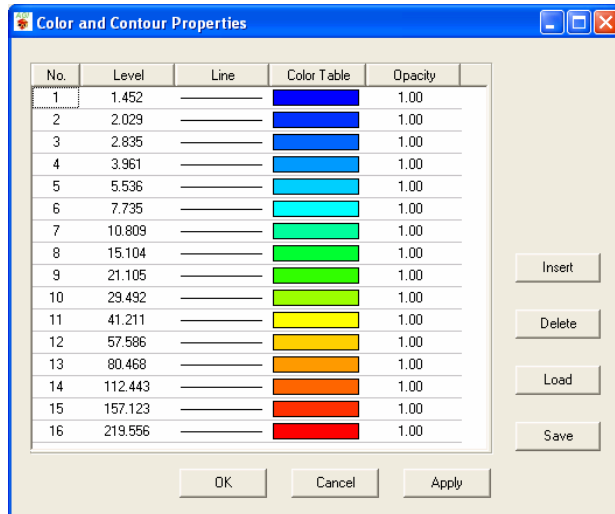
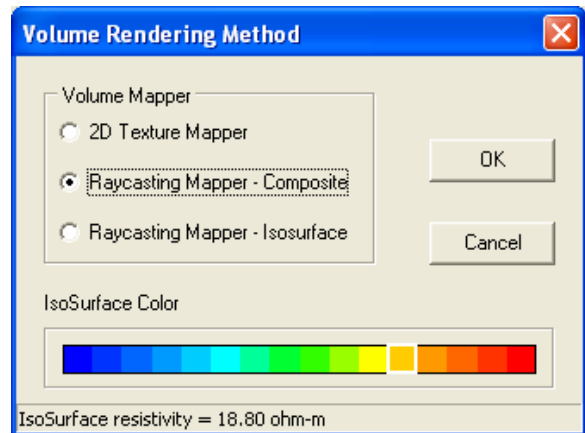
3.8 View Images

During the inversion, the images showing data misfit and inverted resistivity will be updated from iteration to iteration. At the end of inversion, you may browse inversion results from iteration to iteration by choosing the iteration number in a combo-box  on the toolbar. Volume rendering is a slow process, so be patient for the image to refresh while scrolling from one iteration to another. From the View menu, you can switch from one image to another easily.



3.8.1 Color and contour properties

Color and contour properties can be accessed through the Color and Contour Properties menu item under the View menu or the corresponding tool button . There are several windows that help customize minimum and maximum data range, choose a predefined color table or build your own color table from scratches, and specify color transparency. Section 5.1 has more detailed explanations about how to set these parameters.

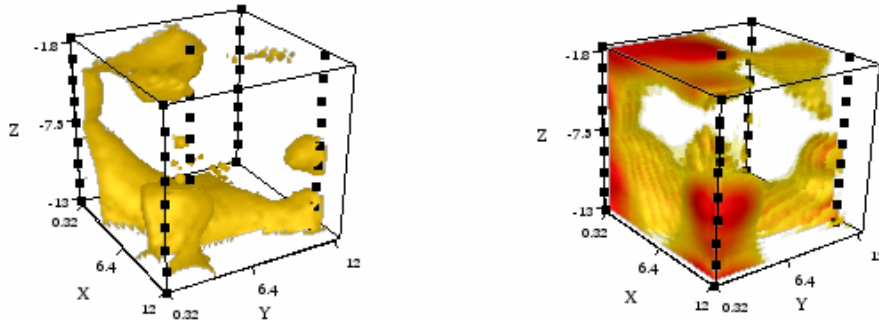


3.8.2 Volume rendering method

You may choose a volume rendering method by clicking the tool button  or choosing the menu item View | Image Properties | Volume Rendering Method. See the interface above. Two volume mapping methods are supported. 2D texture mapper is a hardware accelerated fast

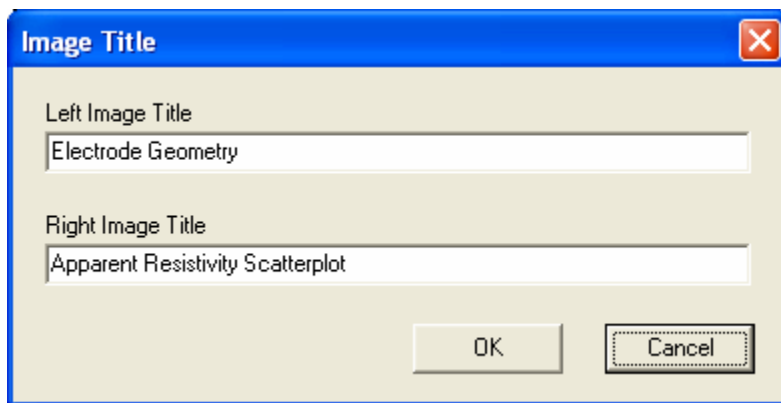
volume rendering method so the hardware acceleration should be set to the FULL level to take advantage of its high speed. The raycasting mapper has two variants: one renders a solid volume with opacity control and another renders an isosurface with a user-specified isosurface value.

Raycasting Mapper - Isosurface Raycasting Mapper - Composite



3.8.3 Image title

Choose the menu item View | Image Properties | Image Title or the tool button . It helps input the image title for a single or both images on the main window. Note that the font size will depend on the number of characters in the title. There are three font options on the tool bar.

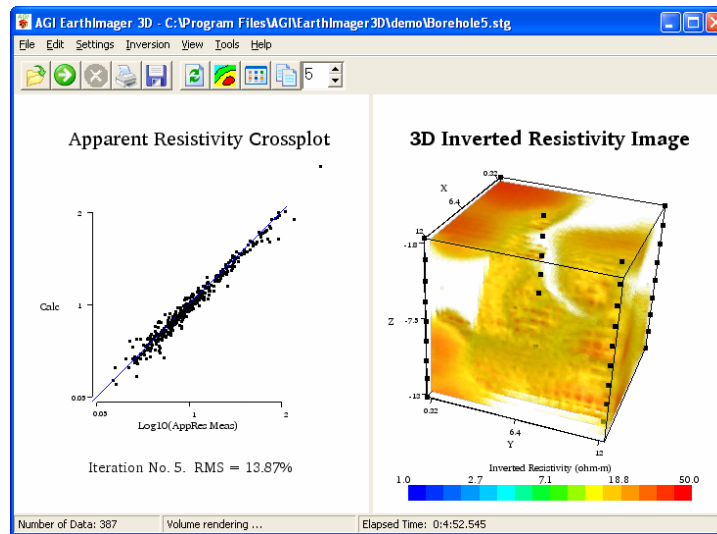


3.8.4 Measured apparent resistivity

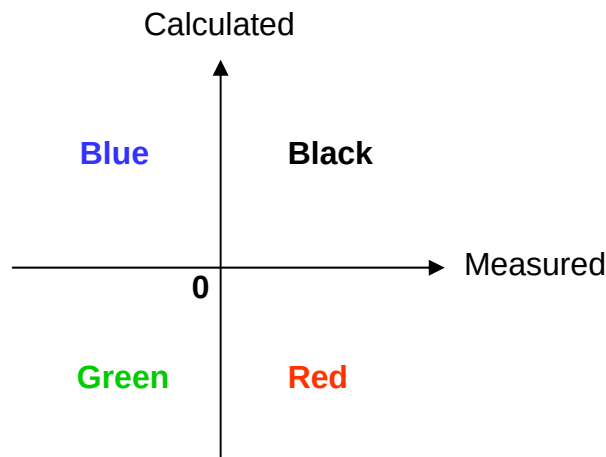
This will show measured the apparent resistivity scatter plot. There are no well-accepted ways to plot 3D resistivity measurements. We have found that the scatter plot is a satisfactory approach to present raw resistivity data. For more information, refer to the Section 3.3.

3.8.5 Crossplot and inverted resistivity volume

This will show a data misfit crossplot (left) and inverted resistivity volume image (right) at a user-specified iteration. To customize the color scale and transparency, refer to the Section 5.1.



The crossplot is color-coded because the logarithm of a negative apparent resistivity is not valid. When both calculated and measured apparent resistivities are greater than 0, a black dot is shown. This is also the most common case and black dots should dominate the crossplot. When both calculated and measured apparent resistivities are less than 0, a green dot is shown. Green dots are acceptable if on the 45 degree line and they are often seen in the borehole data set but are rare in any surface data set. When calculated and measured apparent resistivities have a sign flip, it is an indication of noisy data. A blue dot indicates a negative measured apparent resistivity but a positive calculated one. A red dot indicates a positive measured apparent resistivity but a negative calculated one. The following figure summarizes the color scheme of the crossplot.

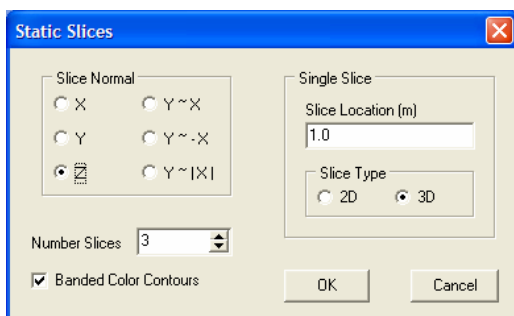
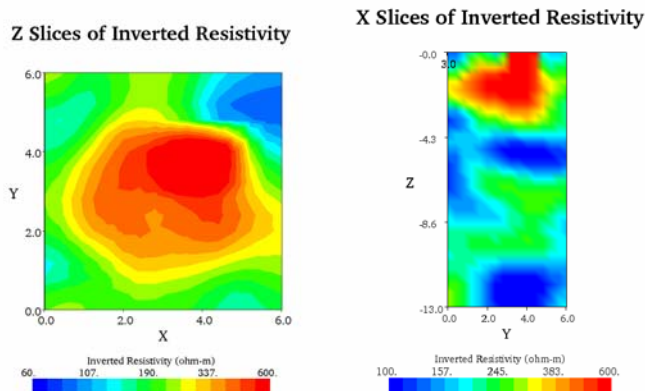
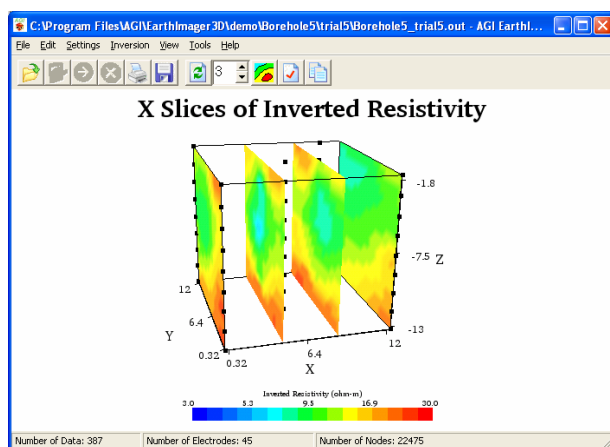
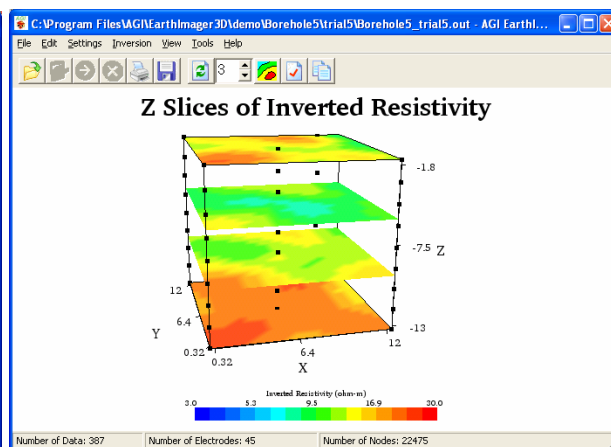


3.8.6 Static slices

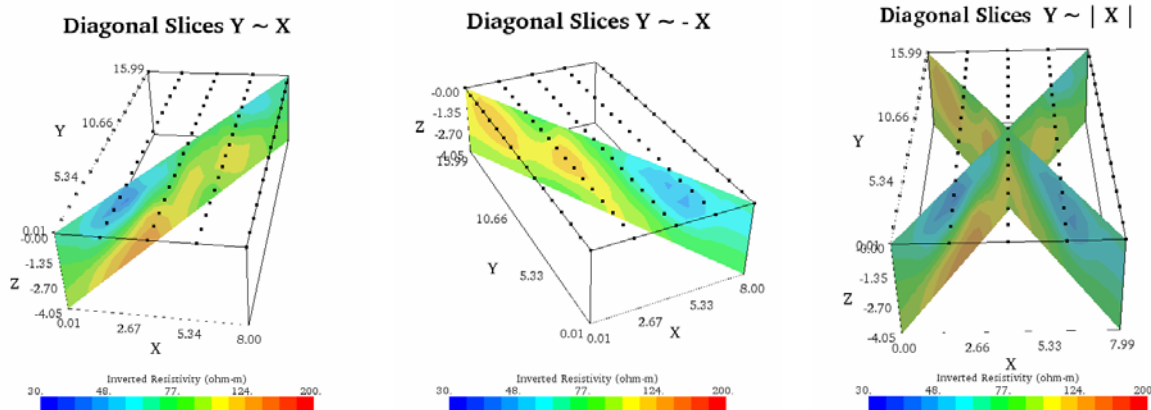
Choose View | Static Slices to show static slices normal to either X, or Y or Z axis, or a diagonal slice. A small window will pop up for the user to choose the number of slices and the normal direction of slices. The non-diagonal static slices are evenly spaced for cases with two or more

slices. The number of slices is limited to 1 to 20. If you notice any missing slice in the rendered image, simply click the Refresh button  on the tool bar.

A single slice may be rendered in a 2D map view (see a single Z slice below in banded color contours) or in a rotatable 3D view. It is also required to specify the location of a single slice. Settings inside the Single Slice box are disabled when two or more slices are selected. There is a known bug in the 2D single slice image in which the slice location (3.0 in the X slice image below) is sometimes inappropriately labeled. The “view” of a 2D single slice image can not be saved to avoid any conflict with 3D slice images.



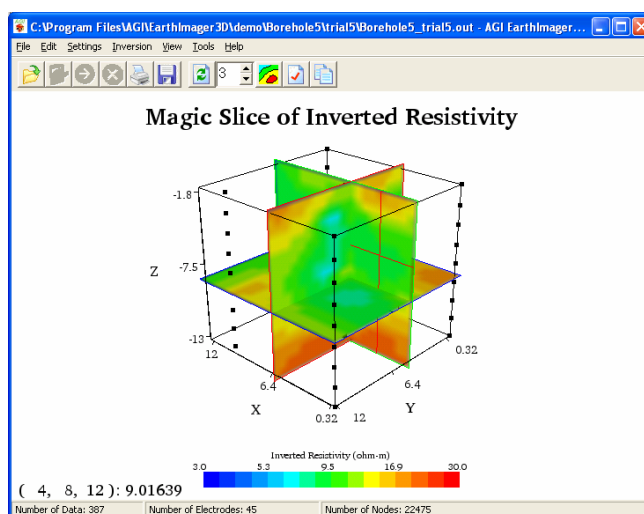
There are three options for diagonal slices which are all vertical. A $Y \sim X$ slice starts at (x-min, y-min) and ends at (x-max, y-max). A $Y \sim -X$ slice starts at (x-min, y-max) and ends at (x-max, y-min). The last diagonal slice image $Y \sim |X|$ combines both $Y \sim X$ slice and $Y \sim -X$ slice. Both inverted resistivity data and time lapse data can be viewed with diagonal slices.



3.8.7 Dynamic slices

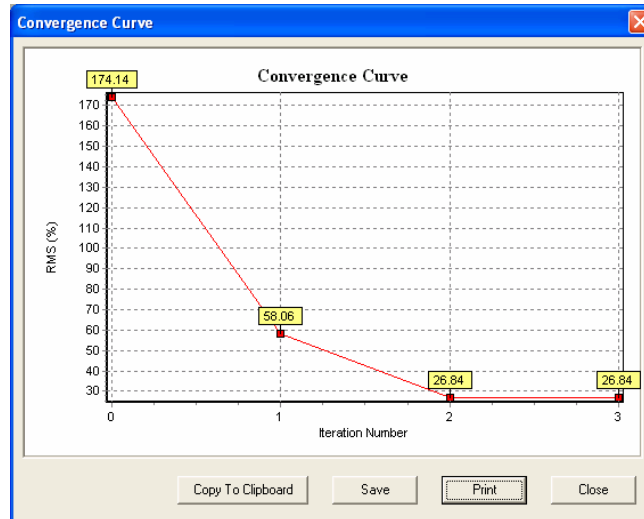
Choose View | Dynamic Slices to show up to three interactive slices in X, Y, and/or Z directions. Press the key “x” to turn on/off the X slice, and the key “y” to turn on/off the Y slice and the key “z” to turn on/off the Z slice. Here are more definitions of mouse button interaction.

- 1) Left-clicking on a slice shows the block (x, y, z) coordinate and corresponding resistivity in ohm-m at the lower left corner of the window. A crosshair on the slice marks the location of mouse clicking. Holding down and moving the left button outside the image would rotate the whole image.
- 2) Holding down and moving the middle mouse button or wheel would translate the selected slice along the axis. Holding down and moving the mid mouse button outside the image would translate (move) the whole image.
- 3) Holding down and moving the right mouse button on a slice has the same effect as the middle mouse button. But holding down and moving the right button outside the slice image zooms in/out the whole image.



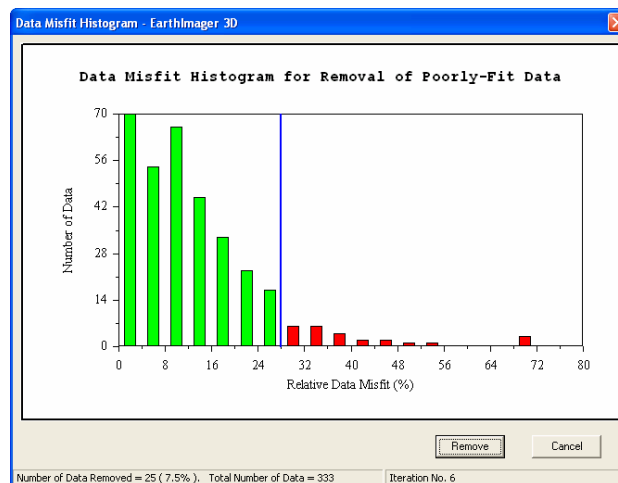
3.8.8 Convergence curve

This shows an XY chart of root mean squared (RMS) error in percentage versus the iteration number.



3.8.9 Resistivity misfit histogram

At the end of inversion, the resistivity misfit histogram can be used for removal of poorly-fit data. Use arrow keys to move the blue line for selection of a data error threshold. Click the Remove button to remove the poorly-fit data with a large relative data misfit.

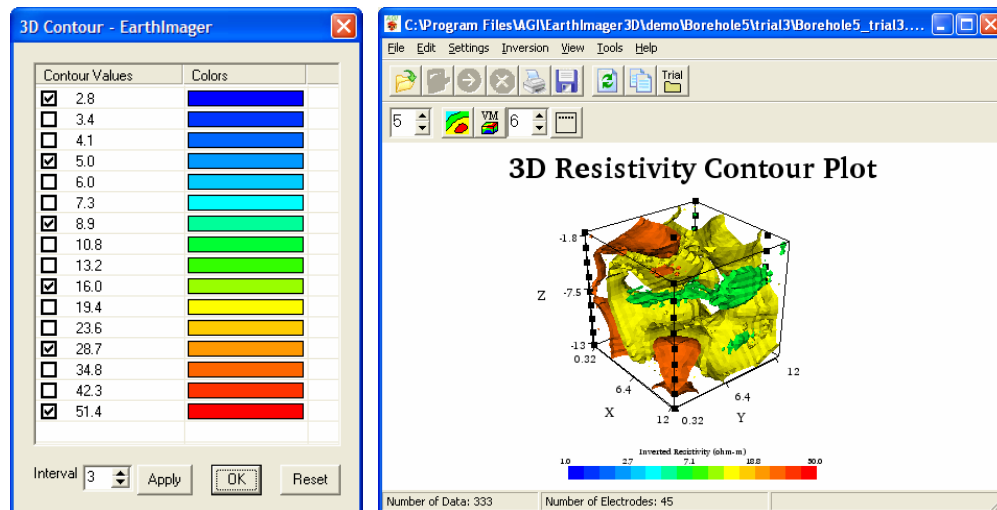


3.8.10 Inverted resistivity volume

Instead of showing both the crossplot and inverted resistivity volume images on main window, this menu item shows the 3D inverted resistivity volume image only. So the user gets a larger view of the inversion results.

3.8.11 3D contours of inverted resistivity

Choose the menu item View | 3D Contours of Inverted Resistivity to bring up 3D contours (isosurfaces) according to user specified number of contours and corresponding contour values. Unlike the isosurface by raycasting volume rendering, the 3D contours can have any number of isosurfaces up to the number of colors. Resolution of the image depends on the mesh size of the inversion. It is recommended that the user change the Color and Contour Properties first and then render 3D contours.



By default, one of every three (3) contour levels is selected. To select different contour values, a user may (1) change the “Interval” and then “Apply” the interval change; or (2) “Reset” the selections and then pick the desired “Contour Values” manually. When done, click the OK button to close the window and the 3D contour plot will be shown in the main window.

3.8.12 Read view file

A view file (*.view) consists of information of the main window size, and the size and orientation of images. “Read View File” copies a view file to the current trial folder and applies the settings to the images. To read a view file, go to the menu item View | Read View File. When EarthImager 3D finds a view file in the current trial folder, it applies view settings to corresponding images automatically. Reading a view file explicitly is not needed. Here are view parameters for a dynamic slice:

```
[DynamicSlice]
FormHeight=1032
FormWidth=1288
FocalX=3.686714828817
FocalY=3.71756107909465
FocalZ=-7.0395075213278
PosX=30.7577549333034
PosY=18.3008212336384
PosZ=6.48258068688506
```

ViewUpX=-0.360236261690418
ViewUpY=-0.180012874717668
ViewUpZ=0.915327919763837

3.8.13 Save view file

This feature saves the information of the main window size, and the size and orientation of the current image(s) to a view file (*.view) to the current trial folder. If the current image view is already in the view file, clicking “Save View File” will overwrite previous parameters. There is only one view file for each data set. One view file consists of image view data for many images.

To save a view file, manipulate the image to the desired size and orientation and resize the main window to the preferred size. Then choose the menu item View | Save View File or click the tool button . A view file will be saved or updated in the current trial folder. The default view file name would have the same file prefix as the inversion output file (*.out) but with a VEW extension. The image view is NOT saved automatically. To restore a preferred view settings later, one must save the preferred view settings to the view file explicitly.

3.8.14 Time lapse images

There are six images to help visualize the time lapse inversion results. These images are

- Volume image showing percent change of resistivity
- Volume image showing percent change of conductivity
- Dynamic slices showing percent change of resistivity
- Dynamic slices showing percent change of conductivity
- Static slices in either X, Y or Z orientation showing percent change of resistivity
- static slices in either X, Y or Z orientation showing percent change of conductivity

3.9 Copy Image to Clipboard

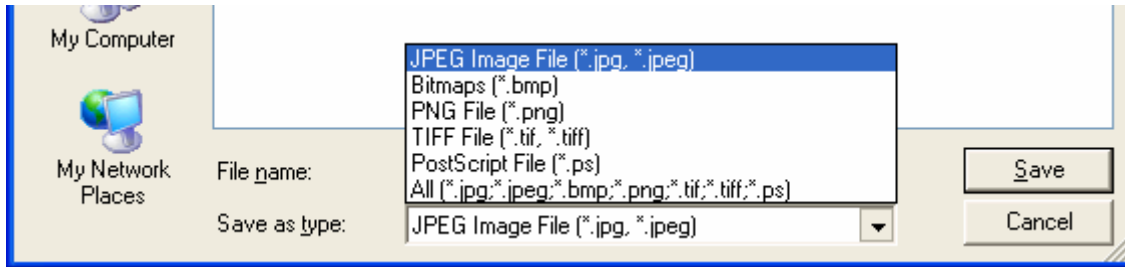
You may copy any on-screen image to the Windows clipboard by choosing Copy Image to Clipboard menu item from the Edit menu or from the tool button . Then the image on the clipboard may be pasted to any Windows program such as MS Word, Powerpoint, Paint, and Photo Editor.

Keep in mind that there are always two images on the main window. To copy, save or print an image, you have to choose the image first by clicking the desired pane.

3.10 Save Image

First of all, you must choose the image to save by clicking the desired pane. The onscreen image may be saved as a bitmap, JPEG, TIFF, PNG or PostScript file. To save an onscreen image, you may either click Save Image tool button  or choose Save Image menu item from File menu. In the “Save as type” box at the bottom, choose your desired image file type. The saved graphics

will preserve the aspect ratio of the onscreen image. So resize the window to the desired shape before you save the graphics.

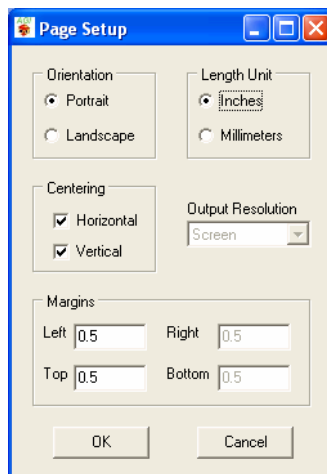


3.11 Save Model in XYZ Format

You can save inverted resistivity data in a four-column (X, Y, Z, Resistivity) format. Pick an iteration using the mouse wheel, then go to Save Model in XYZ Format under the File menu. The DAT file extension is mandatory. The current trial directory is recommended. The recommended file name will look like this: cave_trial3_InvRes5.dat. Cave is the prefix of the STG file name (cave.stg). The current trial is trial 3. You are saving the inverted resistivity data at the fifth iteration.

3.12 Print Image

To print an onscreen image, you may either click Print Image tool button  or choose Print Image menu item from File menu. For custom printing, choose Page Setup from File menu. You are given options for page orientation and margins. The printed image will be stretched to fit the settings in Page Setup, but the orientation, aspect ratio, and size may differ from the onscreen image.



3.13 Read inversion output file

From the menu item File | Read Inversion Output File, the user can read the inversion results back into EarthImager 3D. This feature is extremely useful in EarthImager 3D because 3D

inversion usually takes hours to complete. By reading the inversion output file (*.out) back into EarthImager 3D, EarthImager is positioned at the end of inversion and ready for further image manipulation. To restore the “end of inversion” status, EarthImager would require a trial directory with three files: an OUT file, an STG file and an INI file, which are saved during the inversion.

If there is any level file (*.lvl) and/or view file (*.view) in the current trial directory, the image will be rendered to the last saved colors and contour levels, and/or the size and orientation.

3.14 Read model file

This feature is part of an optional Line Source module. It is designed for (1) Read a model file as an a-priori model after reading a raw data file (*.stg), and (2) Read a model file as a synthetic model after reading a command file for survey planning. Here is a sample model file:

```
; Resistivity model file exported from AGI EarthImager 3D
; Resistivity unit is ohm-m.
unit=meters
;Background resistivity should be left blank if unknown
Background Resistivity = 100.00

; Z = 0 at the surface and negative downward
; The model blocks are listed block by block as follows:
; Block Resistivity
; The smallest X-Y coordinates and the largest Z of the block
; The block dimension in X, Y, Z directions

10.00
3.0000, 12.5000, -2.0835
2.0000, 1.0000, 1.4942

1000.00
3.0000, 4.0000, -1.2900
2.0000, 2.0000, 1.7060

1000.00
3.7500, 9.2500, -1.2900
0.5000, 0.5000, 0.7935
```

All model blocks are rectangular blocks. Each block is defined by a corner coordinate and its length (x), width (y) and height (z). There is no limit on the number of model blocks. A semicolon (;) starts a comment line. Blank lines are ignored. The valid data fields are comma separated.

For survey planning, you read a command file first, and then read a predefined model as a synthetic model. The synthetic model may be modified for simulation and saved for later use. However, an a-priori model is not supposed to be altered in EarthImager.

3.15 Input Start Model

Go to the menu File | Input Start Model to read an inversion output file from a previous inversion trial as the starting model. Be sure to read the raw data file first, and then input the start model. EarthImager 3D checks the mesh agreement and looks for an iteration with the best data fit.

4. INVERSION SETTINGS EXPLAINED

All inversion control parameters are arranged on Settings Window. There are four pages of inversion settings: Initial Settings, Forward Model, Resistivity Inversion, and IP Inversion. You may go to desired settings page directly from Settings menu to bring up Settings Window. The Default combo-box at the bottom of Settings Window will reset all settings to hard-coded default settings for several typical scenarios such as Surface or Borehole resistivity imaging. The User Settings option in the Default combo-box corresponds to the settings of the last inversion loading from the INI file. Other three buttons at the bottom follow the Windows convention.

4.1 Initial Settings

After reading the data file, noisy data is flagged on the basis of the Criteria for Data Removal on the Initial Settings Window. The manually deleted noisy data in the Electrode Editor by the user will also be flagged for removal. Note that these flagged noisy data are not actually removed. After you click the Start Inversion button, all flagged noisy data will be removed and a clean data set is saved in the current trial directory. You may notice some changes in the data scatter plot after clicking the Start Inversion.

The screenshot shows the 'Settings Window - AGI EarthImager 3D' with the 'Initial Settings' tab selected. The window contains several groups of settings:

- Criteria for Data Removal:**
 - Min Voltage in mV: 0.2
 - Min abs(V/I) · Ohm: 0.0002
 - Max Repeat Error (%): 3
 - Min App Res (Ohm-m): 1
 - Max App Res (Ohm-m): 10000
 - Max Reciprocal Error (%): 5
 - ☐ Remove Negative Apparent Resistivity
 - ☐ Keep All Data
- Inversion Method:**
 - ☐ Forward Modeling Only
 - ☒ Smooth Model Inversion
 - ☐ Robust Inversion
- Snap Electrodes to Node:**
 - Max Shift in X (m): 0.005
 - Max Shift in Y (m): 0.005
 - Max Shift in Z (m): 0.005
- Z Axis Orientation:**
 - ☒ Positive Upward
 - ☐ Positive Downward
- Surface Elevation (m):** 0
- ☒ Save Processing Results
- Skip Data:** 0
- Default:** User Settings (.INI)
- Buttons:** OK, Cancel, Apply

4.1.1 Minimum voltage in mV.

The measured voltage shows the actual signal strength. The minimum voltage should be set close to the hardware resolution or the environmental noise level. Any signal less than 1 mV is usually too small to measure accurately. In the case of borehole data, measured voltages less than 1 mV

are common. In particular, boreholes filled with conductive materials produce weak signals. 1 mV threshold may lead to removal of more than 50% of the data.

4.1.2 Minimum abs(V/I)

V/I is the voltage measurement normalized by the injected current, and has a unit of ohm. Any V/I measurement with an absolute value smaller than this parameter will be removed at the data input. 1.0×10^{-4} ohm is a safe setting, but a value between $2 \times 10^{-4} \sim 5 \times 10^{-4}$ ohm is recommended. Never set this parameter greater than 1×10^{-3} .

4.1.3 Maximum repeat error (%)

For AGI Sting/SuperSting resistivity systems, the error in the repeat measurements is usually smaller than 1%. Set this parameter to a value between 3% ~ 5%.

If two data sets collected at the same location and with the same command file are combined into a single data file, the duplicate errors are estimated and consolidated with the instrument repeat errors. The larger one of two errors is assigned to the corresponding data point.

4.1.4 Min apparent resistivity.

This is the smallest apparent resistivity value in ohm-m allowed in the inversion. For surface resistivity surveys, all negative apparent resistivity values will be removed at the same time. For electrical resistivity tomography (ERT) data with electrodes in boreholes, negative apparent resistivity values are common. This setting will then remove any apparent resistivity value when its absolute value is smaller than this setting. To remove all negative apparent resistivity values in ERT data, use another setting in this group. 0.1 ohm-m is a safe setting, but a value between 0.1 ~ 1.0 ohm-m is recommended.

4.1.5 Max apparent resistivity.

This is the largest absolute apparent resistivity value in ohm-m allowed in the inversion. Any measurement with its absolute value of apparent resistivity larger than this setting will be removed. 1.0×10^5 ohm-m is a safe setting, but a value between $1 \times 10^4 \sim 1 \times 10^5$ ohm-m is recommended.

4.1.6 Max reciprocal error.

This setting is effective only when reciprocal measurements exist. A reciprocal measurement is obtained by switching transmitting electrodes and receiving electrodes of the original measurement. That is, if the original measurement uses A, B, M, N four electrodes, the reciprocal measurement will have $A_r = M$, $B_r = N$, $M_r = A$, and $N_r = B$. Theoretically, the original and reciprocal measurements should have identical V/I. The reciprocal error is usually greater than the error of repeat measurements because of electrode polarization, cultural noise, natural potential, and telluric currents.

4.1.7 Remove all negative apparent resistivities in ERT data.

This setting works only with ERT data. Negative apparent resistivity values are very common in ERT data and may be good measurements. Negative apparent resistivity values are automatically removed in the surface resistivity data.

4.1.8 Keep all data

Check this box and set the criteria for data removal to the extreme values. It is hoped that all data in the (STG) data file will be kept for inversion under these extreme thresholds.

4.1.9 Inversion method

You decide what inversion method to use from the initial settings page. If you choose forward modeling only, it will produce forward solution (calculated apparent resistivity) of starting resistivity model. Smooth model inversion is stable and robust. We strongly recommend it for all types of data. It is hoped that the robust inversion is less susceptible to data noise and produces a blocky resistivity model.

4.1.10 Snap electrode to node

In our numerical modeling algorithm, an electrode must be on a node in the mesh. “Snap Electrode to Node” helps reduce unique number of x, y, and z coordinates by forcing a single coordinate to several closely spaced coordinates in either x, y, or z direction, so a smaller mesh size may be expected. Some electrodes may be shifted based on the maximum shift prescribed here.

4.1.11 Save processing output

Inversion with the EarthImager 3D produces many new files. It is important to keep track of inversion results in an organized way. EarthImager creates processing and trial directories and saves inversion outputs automatically. We found that this automatic file-saving feature may fill up your hard drive quickly if you keep running the inversion for days or weeks. If you do not want to save anything, you should uncheck “Save Processing Output”.

4.1.12 Z axis orientation

The vertical Z axis is positive upwards by default. This is also the convention inside the EarthImager 3D program. If the vertical Z axis is oriented positive downwards, you must declare it here before loading a data file.

4.1.13 Surface elevation

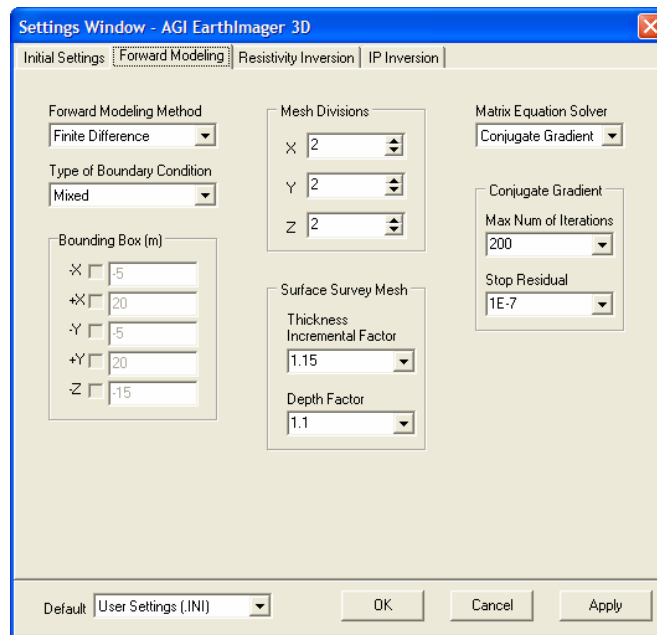
This parameter would be used to show elevation along the vertical axis instead of the depth. It is not used by EarthImager 3D in this release.

4.1.14 Skip data

This is a data decimation feature. While reading the data, EarthImager skips the specified number of data points in the raw data file and then reset this number to 0. For example, if this parameter is set to 1, EarthImager will skip “1” data point and extract every other data point in the data file for the inversion. Half of the measurements will be removed (skipped). If you want to extract every fifth data point of the raw data file for inversion, set this number to 4 to skip 4 data points. This parameter is set to 0 by default to read all data without skipping any, and resets to 0 after every data decimation operation to avoid losing data.

4.2 Forward Modeling Settings

There are 10 parameters on the Forward Modeling settings page. This page gives you options to choose a forward modeling method, forward matrix equation solver, type of boundary condition, mesh discretization, and so on.

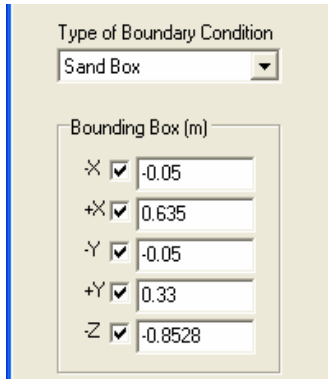


4.2.1 Forward model method

The finite difference method is the only option at this time. Other methods are coming soon.

4.2.2 Boundary condition

Neumann boundary conditions (BC) are always imposed at the ground surface. Other five boundary planes have options of Dirichlet BC or mixed BC. Mixed BC is supposed to produce more accurate forward solution with a limited extension of boundary mesh. Mixed BC is recommended for any data set with one or more remote electrodes.



For resistivity surveys in a confined space, choose the Sand Box boundary condition and input the boundary coordinates. It is also required to check the box in front of a boundary coordinate to enable a boundary coordinate. The (x, y, z) coordinates here must be defined in the same coordinate system as the one for electrodes. This utility handles rectangular domains only and does not work with spherical or cylindrical boundary surfaces. It does not work with any metal container either. This feature is a supplementary module.

4.2.3 Forward equation solver

The conjugate gradient solver is the only option at this time. We will add more solvers soon.

4.2.4 Maximum number of CG iterations

This setting is enabled only when the conjugate gradient (CG) method is chosen as the forward solver. The CG method is an iterative matrix equation solver. Sometimes the CG solver may diverge and the CG iteration becomes an infinite loop. The maximum number of iterations will prevent this. This setting should be greater than 100 but smaller than 1000. More iterations will generally lead to a more accurate forward solution, but will require a longer runtime of forward modeling.

4.2.5 CG stop residual

The conjugate gradient (CG) method is an iterative solver that requires a stop criterion. If the CG residual is smaller than the stop residual, the CG iteration exits. 1.0×10^{-6} or 1.0×10^{-7} is a recommended setting.

4.2.6 Mesh divisions

This sets the number of cells (blocks) between two electrodes in x, y, and z directions. For cross-borehole electrical resistivity tomography (ERT) without surface electrodes, the number of blocks between two boreholes depends on the vertical spacing of electrodes. A finer mesh results in higher accuracy of forward modeling with a smaller numerical error, but longer CPU run-time. Two (2) divisions is the default setting. The number of divisions should be set between 2 and 8.

We found that 3 divisions between two electrodes produce a more accurate forward solution than 2 divisions. The number of divisions in Z has no effect on the surface data.

4.2.7 Thickness incremental factor

This setting applies mainly to surface resistivity surveys where model resolution degrades with depth. It is preferred that layer thickness increases with the depth. Thickness incremental factor is defined as the ratio of the thickness of the lower layer to the thickness of the layer immediately

above it. For example, if the upper layer is 1 meter thick, the lower layer will have a thickness of 1.1 meters if the thickness incremental factor is 1.10. It is not realistic to set this factor smaller than 1.0. This factor also plays a role in determining the layer thickness below the borehole's bottom electrode for a survey combining surface and borehole electrodes.

Because the layer gets thicker and thicker, it is preferable to set this factor in the range of 1.0 to 2.0. With a large factor, you lose resolution at the depth. A large thickness incremental factor will, to some extent, reduce the runtime of inversion.

4.2.8 Depth factor

This setting applies mainly to the surface resistivity survey. The depth of the inverted section is determined by the maximum median depth times the depth factor. Median depth is a function of electrode spacing and array type. In a survey with combined surface and borehole electrodes, this depth factor also plays a role in setting the depth of inverted section. The depth factor should be set between 1.0 and 1.5. For a pole-pole array dataset, set the depth factor to 1.0 or smaller.

4.3 Resistivity Inversion Settings

4.3.1 Stop Criteria

Resistivity data inversion is a nonlinear iterative process. This group of parameters sets the rules that stop the iteration. Four factors within this group have a logical OR relation, that is, if any of the criteria is met, the inversion will stop. To activate or enable a rule, check the box in front of parameter.

The screenshot shows the 'Settings Window - AGI EarthImager 3D' with the 'Resistivity Inversion' tab selected. The window is divided into several sections:

- Stop Criteria:**
 - ☒ Number of Iterations: 8
 - ☒ Max RMS Error (%): 5
 - ☒ Error Reduction (%): 5
 - ☐ L2 Norm
 - Number of CG Iterations: 5
- Stabilizing Factor:** 10
- Damping Factor:** 10
- Amount of Noise (%):** 5
- ☐ Suppress Noisy Data
- Parameter Dimension:**
 - X: 1
 - Y: 1
 - Z: 1
- Starting Model:**
 - ☒ Homogeneous
 - ☐ Layered
 - Resistivity (ohm-m): 976.8
 - Min Resistivity (ohm-m): 1
 - Max Resistivity (ohm-m): 10000
 - Resolution Factor: 0.2
 - Horizontal/Vertical Roughness Ratio: 0.5

At the bottom, there is a 'Default' dropdown set to 'User Settings (.INI)', and buttons for 'OK', 'Cancel', and 'Apply'.

4.3.2 Number of iterations

This sets a maximum number of iterations for an iterative nonlinear inversion stop. If the inversion diverges, it will stop after the prescribed maximum number of iterations. Thus infinite loops can be avoided. For surface resistivity surveys, inversion usually converges in 5~6 iterations. Set this number to 6 ~ 10 in this case. For ERT data, it often takes more than 10 iterations to converge. Set this number to 10 ~ 15 for ERT data.

4.3.3 Maximum RMS error

The primary objective of inversion is to reduce data misfit between field measurements and calculated data of a reconstructed model. Measurement errors usually range from 1% to 5%. But do not forget about numerical errors and rounding errors. This number should be equal to or larger than percentage of noise estimate. 3% is a default setting.

One of the objectives of the resistivity inversion is to find a resistivity model whose response (predicted data) best fits the measured data. The goodness of the fit may be characterized by the **root mean squared** (RMS) error in percent (%) defined below.

$$\text{RMS} = \sqrt{\frac{\sum_{i=1}^N \left(\frac{d_i^{\text{Pred}} - d_i^{\text{Meas}}}{d_i^{\text{Meas}}} \right)^2}{N}} \times 100\%,$$

where N is the total number of measurements, d^{Pred} is the predicted data, and d^{Meas} is the measured data. It is clear that the RMS error depends on the number of bad data points, and how bad each bad data point is.

Note that the RMS error is an average data misfit over all data points. A single erroneous data point could lead to a large RMS error. For example, we have a data set of 100 measurements (N=100). As an extreme case, the measured voltage is 1mV but the predicted voltage is 1V. If we have a perfect fit (no errors) to all other 99 data points, the RMS error would be **9990%** due to this single erroneous data point. Therefore, the RMS error does NOT indicate the percentage of bad data points.

In the case above, there is no way to reduce the RMS to below 10% even if one gets perfect data fits to the remaining 99% data. The only way to reduce the RMS error in this case is to remove the bad data point. In the following section, we will show that removal of some bad or good data points would not reduce the resolving power of the original data set significantly.

To compare the RMS errors resulted from different inversion programs, one must compare the definition of the RMS error first because the RMS error may be defined differently.

A large RMS error is the result of (1) Data noise, (2) Numerical modeling error, (3) Inability to model 3D objects with a 2D modeling program, and (4) Poor inversion settings.

4.3.4 Error reduction

It is generally expected that data misfit, e.g. RMS error, be reduced from iteration to iteration. The first several iterations have a larger RMS error reduction than later iterations. When RMS error reduction is very small or RMS error increases, the inversion should be terminated. This parameter sets a threshold for this purpose. It is recommended that the inversion stop when error reduction is smaller than 5%. Sometimes it is normal that the convergence of inversion is not monotonic. This error reduction factor may cause termination of the inversion prematurely. This is why the box in front of this setting is unchecked by default.

4.3.5 L2 norm

L2-norm is another measure of data misfit. It is defined as the sum of the squared weighted data errors. N is the number of measurements. W_i is the data weight; d_i^{calc} is the calculated data, and d_i^{meas} is the measured data. The L2-norm depends on the estimate of data weights (errors). Set the percentage of data errors (noises) to 3% if you have no knowledge of data noises. Any inversion in a least squares sense, such as damped least squares and smooth model inversion in EarthImager, should stop when the L2-norm is smaller than the number of measurements.

$$L2 - Norm = \sum_{i=1}^N \left(\frac{d_i^{calc} - d_i^{meas}}{W_i} \right)^2$$

The number of measurements (data points) varies from data set to data set. To avoid confusion, we define a normalized L2-Norm measure as

$$\text{Normalized L2-Norm} = \text{L2-Norm} / (\text{Number of Data}).$$

When the normalized L2-norm reduces to the unity (1.0) or smaller, the inversion is converged. Check L2-Norm box to set this measure in effect.

4.3.6 Number of CG iterations

This number should be set between 5 and 10. There are two loops in an iterative nonlinear inversion. First, a nonlinear inverse problem is linearized and solved iteratively. This is the outer loop of the nonlinear inversion. The number of steps here is the number of iterations people are generally referred to. Second, to solve the linearized system at each step, an iterative conjugate gradient (CG) solver is used. This is the inner loop. This parameter sets the number of iterations for this inner loop.

4.3.7 Stabilizing factor

This is a Lagrange multiplier whose effect is to balance data misfit and model constraints. Our suggested setting is 10 for surface data, and 100 for ERT data. If you have noisy data, a relatively large stabilizing factor is preferred. The stabilizing factor will be reduced from iteration to iteration. A small stabilizing factor will produce a relatively rough model with a

small RMS error, and a large stabilizing factor will produce a relative smooth model with a large RMS error.

4.3.8 Damping factor

We suggest you set this parameter to the same value as the above stabilizing factor. This factor suppresses the effect of small eigenvalues of the Hessian matrix at earlier iterations and speeds up the convergence at the early stage of inversion.

4.3.9 Amount of noise

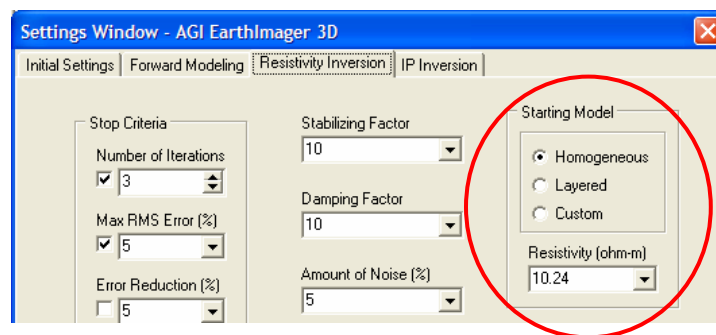
Without prior knowledge of the standard deviation of the data such as reciprocal error, you may assume a certain percentage of error in data. This number usually ranges from 1% to 5% with a default of 3%. With the L2-norm stop criterion enabled, a too large noisy estimate produces a too smooth model. A too small noisy estimate forces the inversion to fit data noise and produce artifacts.

4.3.10 Suppress noisy data

If you have noisy data or a slow convergence, you should check this box. This scheme gives less weight to noisy and hard-to-fit data. This will not improve RMS convergence because RMS is not a weighted quantity. Instead, the L2-norm convergence should improve dramatically. By checking this box, L2-norm stop criterion will be also enabled automatically.

4.3.11 Model parameter width

These settings tell EarthImager 3D how to combine model blocks in x, y, and z directions. Combining model blocks horizontally helps suppress the lateral variation in the inverted resistivity model for cases of strongly layered earth or surveys on the water.



4.3.12 Starting model

This setting is designed for advanced users to test the effect of different starting models. You should not touch this setting if you have no knowledge of average resistivity of your survey area. Inversion of borehole data will always start from homogeneous half space, but inversion of surface data may start from either homogenous half space or a layered earth (see screen shot

above). By default, any inversion will start from a homogeneous half space with a resistivity value equal to the average apparent resistivity values calculated in the logarithmic domain.

To have a homogenous starting model with a resistivity value other than the average apparent resistivity, choose the Custom setting and input a resistivity.

You may input a start model from an inversion output file (*.out) from a previous trial. After reading the raw data file, you go to the menu File | Input Start Model to read an inversion output file. EarthImager checks the mesh agreement between the start model and current inversion trial.

4.3.13 Min resistivity

Any resistivity value smaller than this minimum resistivity will be trimmed off during the inversion process. The default value is 1 ohm-m. If you do marine resistivity imaging, you should set it to 0.1 (or smaller) because sea water resistivity can be as low as 0.1 ohm-m.

4.3.14 Max resistivity

Resistivity of soils and rocks is rarely over 10,000 ohm-m, a default setting. Moreover, inversion may not be able to resolve a very large resistivity contrast. Modify this parameter if you work in a very resistive area.

4.3.15 Resolution factor

The model blocks closer to electrodes usually have a larger sensitivity. The bottom layers in surface resistivity imaging and the central area between two ERT boreholes usually have a very small sensitivity that results in poor resolution. This resolution factor will, to some extent, enhance model resolution in areas with a small sensitivity. Setting this factor to 0 will disable this factor. Typical values of this factor range from 0 to 0.3. 0.20 is a preferred default. Note that a large resolution factor will also enhance inversion artifacts.

4.3.16 Horizontal/vertical roughness ratio

Set this parameter larger than 1 for an area with a strong lateral resistivity variation (vertical features), but smaller than 1 for a layered earth. By default, the roughness ratio is set to 0.5 for a surface data set and set to 0.5 for a borehole data set.

4.4 IP Inversion Settings

Coming soon.

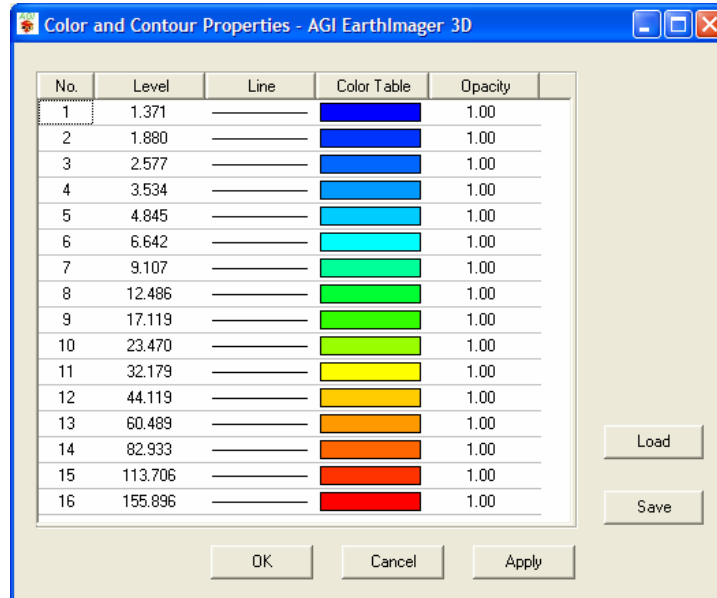
5. BEYOND THE BASICS

5.1 Color and Contour Properties

This section shows how to customize the color, contour level, and color transparency of the graphics.

5.1.1 Color and contour properties window

There are two ways to launch the Color and Contour Properties Window: 1) from the menu, View | Color and Contour Properties; and 2) by clicking the tool-button . When the tool button  is disabled, the custom color and contour are not supported for the current view. All graphics start with 16 pseudo-inverted-rainbow colors from blue to red.



There are five columns in the Color and Contour Properties Window. The first column is simply the row number and row count. No user interaction is supported for the first column. The second column shows the contour levels of the current image. These numbers are the actual contour level values no matter what scale of contour levels (linear or LOG10) are used. To set contour levels with a constant contour interval, click the header “Level” of the second column. The detail on how to set contour levels is discussed in the section of Contour Level Window.

The third column shows the contour line color and thickness (width). All contour lines will have the same color and width. The user can not specify the color and width of an individual contour line. To change the contour line color and width, click the header “Line” of the third column. The detail on how to set contour line color and width is discussed in the section of Contour Line Window.

The fourth column shows the fill colors of each contour level. To customize fill colors, click the header “Fill” of the fourth column. To change the specific fill colors, double-click the corresponding cell. The detail on how to set fill colors is discussed in the section of Contour Fill Window.

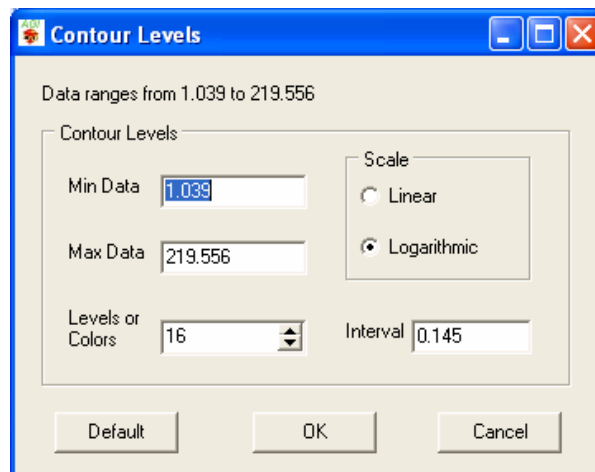
The last column shows the opacity of each color. Note that Opacity + Transparency = 1.0. When the opacity equals 1.0, a solid color would show up. While the opacity equals 0, the corresponding would be completely transparent and invisible.

The user may save current color and contour properties as a level file (*.lvl). This level file is an extended Surfer (a graphics package by Golden Software) level file with the last column being the color opacity. You may also load any level file into EarthImager. The level file is variable-dependent; that is, a resistivity level file may not apply to the data misfit image because the actual contour values are stored in the level files.

When the OK button or Apply button is clicked, a level file (*.lvl) is saved in the current processing trial directory. This saved level file will be automatically loaded back when the user comes back a previously viewed image. That is, EarthImager will memorize custom color and contour properties for all different images.

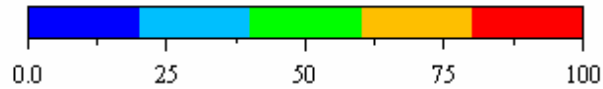
5.1.2. Contour level window

To launch the Contour Level Window, click the header “Level” of the second column in the Color and Contour Properties Window. This helps set uniform contour levels in either a linear or logarithmic scale.



The actual data range is shown at the top of the window. These two numbers are actual data minimum and maximum values without taking logarithm if applicable.

The definition of contour levels in EarthImager 3D may be different from commercial graphics package. To plot the data between 0 and 100 at an interval of 20, one should set the number of Levels (or Colors) to 5. The Min Data should be set to 0, the the minimum contour level would be 20. A linear color scale will be shown like this.



According to this color scale, any value below 20 will be shown in blue and any value above 80 will be shown in red, if a linear scale is used. For a logarithmic scale, the labels of color scale will vary. The Interval property in the window is a read-only setting and can not be changed.

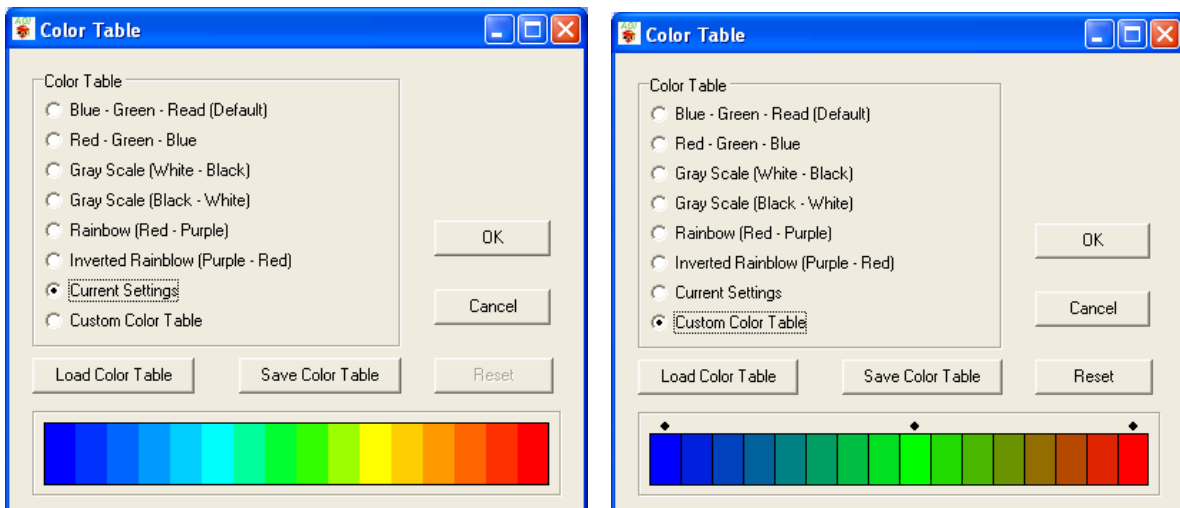
Note that logarithm of 0 or negative values is undefined. So be careful when switching from the linear to logarithmic scale. Negative values in data misfit and IP data are very common, so the logarithmic scale is disabled when viewing these images.

5.1.3. Contour line window

Coming soon.

5.1.4. Color table window

To choose a predefined color spectrum as the contour fill colors, click the header “Color Table” of the fourth column in the Color and Contour Properties Window. This brings up the Color Table Window.



EarthImager 3D has six predefined color spectra. The Current Settings is the color scale of the current image and the colors in the Color and Contour Properties Window before the Color Table Window is launched. Current colors settings may not be any of these predefined color spectra.

EarthImager uses Blue-Green-Red color spectrum as the default if no custom color scale is specified. The number of colors is specified in the Contour Level Window.

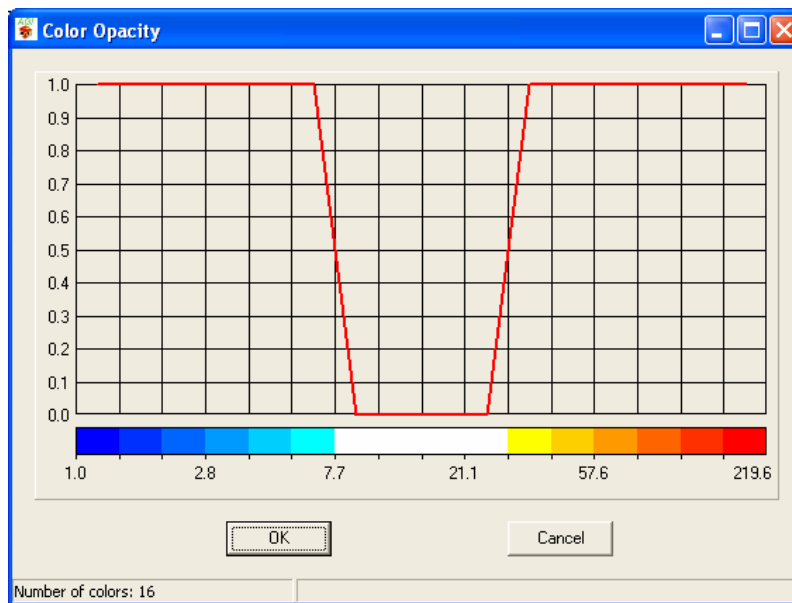
To create your own custom color, select “Custom Color Table” option. The sample color scale at the bottom of the window would be divided into small blocks with the number of blocks equal to the number of colors. All blocks are filled with white color initially. You may click any block to

bring up a color dialog box from which you pick a color for the selected block. EarthImager would blend the new color with predefined colors with an anchor point.

5.1.5. Color opacity window

To see things inside a volume image, one has to make part of image semi-transparent or completely transparent. Opacity is also called alpha value or alpha channel in the field of computer graphics. By defining opacity of each color, you can render part of volume invisible and single out the object you look for. Note that $\text{Opacity} + \text{Transparency} = 1.0$. When the opacity equals 1.0, a solid color would show up. While the opacity equals 0, the corresponding would be completely transparent and invisible. To define the opacity curve, use the left mouse button to click or drag inside the grid. The figure below shows that the green color is removed from the volume.

The total volume, opaque volume and clear (transparent) volume of the image are shown on the status bar at the bottom of the main window. If part of the image is semi-transparent, the clear volume and opaque volume may not add up to the total volume.



5.2 Inversion with Terrains

5.2.1 Electrode layout

Resistivity inversion with 3D topography requires that both electrode geometry and terrain survey data are defined by the projected horizontal distances. Tape measures or slope distances are not acceptable. In addition, electrodes must be laid out in a rectangular or ideally square grid for surface surveys in horizontal distances. Maintain a constant line spacing between any two lines and align corresponding electrodes across all lines. Electrodes at different boreholes should be aligned at the same depth levels regardless of its surface elevation.

Adequate topographic elevation measurements are required to reconstruct the geometry of ground surface. Number of elevation measurement points will depend on the terrain complexity. Note that elevation measurement points do not have to coincide with electrode locations. It is vital to survey the site in advance for electrode locations and elevations. Here are some basic steps to follow:

- Design your line spacing and electrode separation based on the dimension of the objects you are looking for and the electrode separation on your cable. With a cable of 5-feet electrode separation you should not design a grid over 4 ft horizontal distance.
- Layout a rectangular grid in horizontal distances. Survey the elevation of the site. A non-rectangular grid would not fail EarthImager, but it would produce a much larger modeling mesh, greatly slow down the inversion and affect the resolution. This step must be completed before the resistivity survey.
- Create a geometry file for the command creator. The (X, Y) coordinates in a geometry file are the horizontal distances. The Z coordinate does not carry the elevation information and it is defined in a way as if there is no topography. That is, the surface Z coordinate is 0. A downhole electrode would have a negative Z coordinate whose value is the depth from the surface. The electrode geometry in the command file will be transferred to the STG data file without changes. An erroneous geometry file would mess up the resistivity data file.
- Build a terrain file in a format described below.
- Conduct the resistivity survey.
- Download the data from the resistivity meter to a PC.
- Invert the STG data file together with the terrain file.

5.2.2 Terrain file format

A terrain file defines the surface topography of the survey site. It is a comma separated ASCII text file and may be created in any text editor such as Microsoft NotePad or our built-in text editor under the Edit menu in EarthImager. If you edit your terrain file in Microsoft Word or WordPad, be sure to save the file as a plain text file. It is NOT required to take terrain elevation measurements at electrode locations or in any form of a regular grid. However, the (X, Y) coordinates in a terrain file must be horizontal distances.

```
; TRN File           // Semicolon “;” starts a comment line
unit=meters          // Distance (length) unit
;X, Y, Elevation_Z
-1, -1, 102.2         // Horizontal distance X, Y and elevation Z
0.5, 4.5, 103.5
-0.2, 10, 97.7
0, 15.8, 99.4
7, 13, 101.1
5.5, 6, 100
12, -1.5, 102.4
15, 4, 101
```

14, 11.7, 98.6
13, 16.2, 99.8

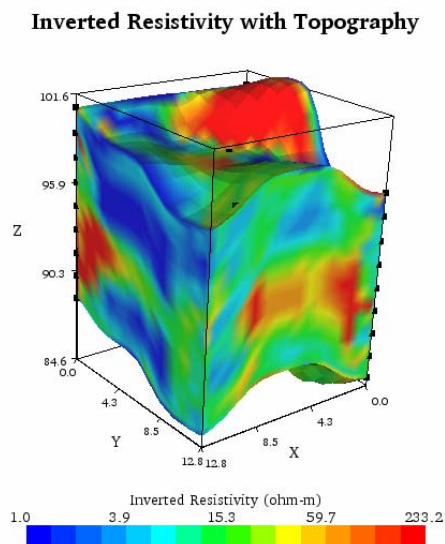
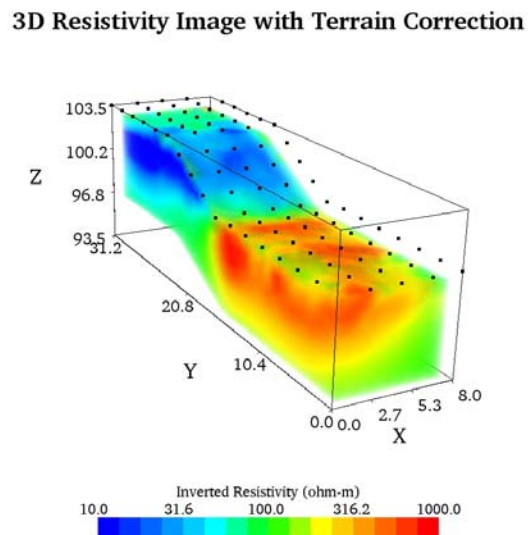
5.2.3 Run inversion with terrain

There are two terrain files in the EarthImager3D\demo directory: Borehole5.trn and Hill3d.trn. Hill3d is a surface data set collected on a hill. Borehole5 is a borehole data set collected from five boreholes without topography at all. So Borehole5.trn is a fictitious terrain file that was created for testing and demonstration purpose. Follow these steps to invert a data set with topography.

- 1) Start EarthImager 3D and choose your preferred settings such default ERT settings.
- 2) Click the Read Data button or the menu item File | Read Data, e.g., Borehole5.stg.
- 3) Choose the menu item File | Read Terrain File and select the file Borehole5.trn.
- 4) Click the green Start Inversion button. The image showing electrode geometry is updated with topographic fluctuation.
- 5) Images available in the terrain mode include 3D opaque surface image, 3D volume raycasting image, 3D contours, static slices, convergence curve and histogram.

Inversion of resistivity data with topography uses the finite element modeling method that is handled automatically. When a valid terrain file is detected, EarthImager 3D sets the forward modeling method to the finite element method. Note that the finite element method is much slower than the finite difference method.

The 3D volume image shows inverted resistivity with topography. The dynamic slice image and 3D isosurface image are not available at this time. The 3D raycasting volume image with opacity control is very slow. The 3D opaque surface image is a quick way to browse the volume surface. Static slices and 3D contour plot give more perspective about your data.



5.3 4D Time Lapse Inversion

The optional 4D Time Lapse Inversion module is used for in-situ monitoring applications. It could, for example, be used to detect leakage at a landfill site, a dam, or underground storage tank. In such a case, electrodes are installed at fixed locations during the period of monitoring to facilitate image comparison and high sensitivity of small changes in the ground. First, a base (or baseline, background) resistivity data set is collected, so a base resistivity model of the site can be established as a reference model. Then, the monitor survey is repeated during the period of monitoring with the same command file as the one used in the base survey. Our Time Lapse Inversion algorithm takes advantage of the base survey data and base resistivity model. Instead of inverting the monitor data set alone, our algorithm inverts the difference between the monitor and base data sets. Moreover, the base resistivity model is used as the a-priori model in the time lapse inversion. Therefore, our time lapse inversion converges faster than standard inversion and is more sensitive to small subsurface changes. The coherent inversion artifacts may be canceled in the difference images.

A time lapse monitoring application may have one base dataset and one or more monitor datasets. The time lapse inversion produces difference images between any monitor dataset and the base data set.

The result of time lapse inversion is presented as the difference between the two sections. The time lapse method may be used for monitoring of any subsurface processes. Some common situations include potential leakage from landfills, dams and underground storage tanks. Other monitoring situations include fracture tracing by injection of a conductive solution such as a salt solution, saltwater intrusion in coastal areas, environmental remediation progress, groundwater recharge, infiltration studies, and so on.

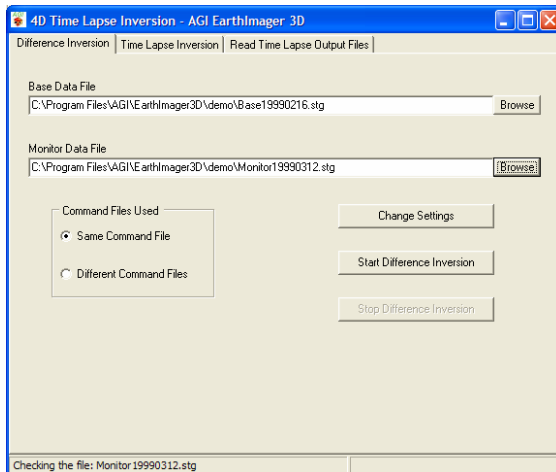
The time lapse inversion may be carried out in two different ways depending on the type of input. Difference inversion accepts two raw data files (STG) as inputs. This is a comparison of before and after images. Time lapse inversion requires the output of base data inversion and inverts a list of monitor data sets in a batch mode.

5.3.1 Difference inversion

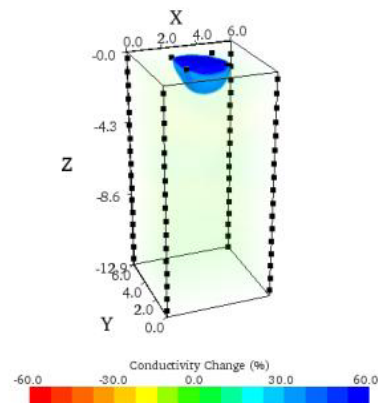
Difference inversion combines the inversion of the base dataset and time lapse inversion of a single monitor dataset in one step. It is applicable to the cases with one base dataset and a single monitor dataset. Here are the steps to follow for a difference inversion.

- 1) Start EarthImager 3D. A dongle option code for time lapse inversion must be activated in order to proceed with the difference inversion.
- 2) Choose the menu Inversion | Time Lapse Inversion and then the “Difference Inversion” tab.
- 3) Input the base data file by clicking the corresponding Browse button.
- 4) Input the monitor data file by clicking the corresponding Browse button.

- 5) Choose “Same Command File” or “Different Command Files”. It is strongly recommended that you use the same command file for the base data and monitor data collections.
- 6) Change the inversion settings by clicking the “Change Settings” button.
- 7) Start Difference Inversion. EarthImager will invert the base dataset first and then do a difference inversion of the monitor dataset. The inverted results at the optimal iteration based on the RMS error and/or L2-norm will be saved in the output (OUT) file together with 3D resistivity volume image (JPG file) and inverted resistivity data (DAT file) in the XYZ format. The output (OUT) file may be loaded back into EarthImager 3D for custom settings and visualization.
- 8) At the end of difference inversion, percent difference of resistivity image is shown. It is preferred to set the absolute value of minimum and maximum plot bounds to be equal, so zero (no change) will be in the center of the color scale and in a green color by default.
- 9) Percent difference of conductivity image below shows the wetting fronts in a water infiltration experiment. The wetted zone has a higher electrical conductivity and showed a conductivity increase.
- 10) In addition to all images for standard data inversion, we provided six more images for time lapse inversion: percent change of resistivity, percent change of conductivity, and dynamic slices of resistivity changes, dynamic slices of conductivity changes, static slices of resistivity changes, and static slices of conductivity changes under the menu item View | Time Lapse Images (see a screen shot in the next section 5.3.2) .



Percent Difference of Conductivity (03-16-1999)



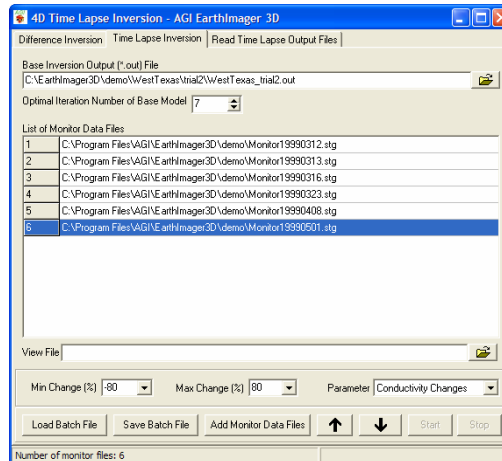
5.3.2 Time lapse inversion

The difference inversion scheme in the last section requires inversion of the base dataset for every monitor dataset. This turns out to be unrealistic for a long term monitoring application that usually has many monitor datasets. So we developed a time lapse inversion scheme that can handle a large number of monitor datasets in a batch mode.

In our time lapse inversion scheme, the base dataset must be inverted first like a standard 3D data inversion. We suggest that the user runs the inversion of base dataset two or more times to clean up the base dataset with the histogram. However, excessive data removal is discouraged because any data point removed from the base dataset will also be removed from all monitor datasets.

The inversion output file of the base dataset is served as the input of the time lapse inversion. All monitor datasets are inverted with the base inversion results as the a-priori information. To start the time lapse inversion, follow these steps.

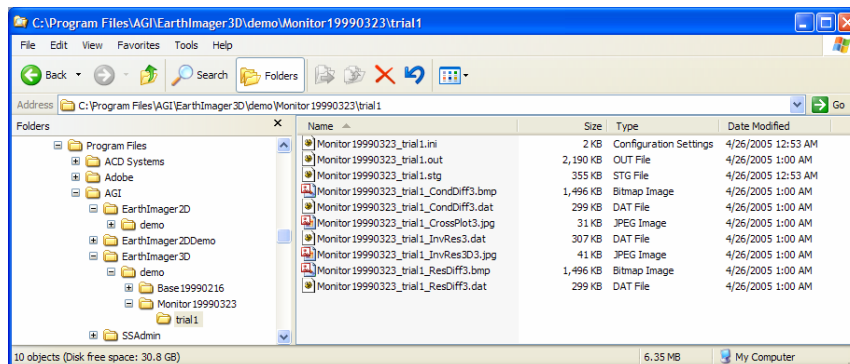
- 1) Choose the Time Lapse Inversion menu item from the Inversion menu and select the Time Lapse Inversion page.



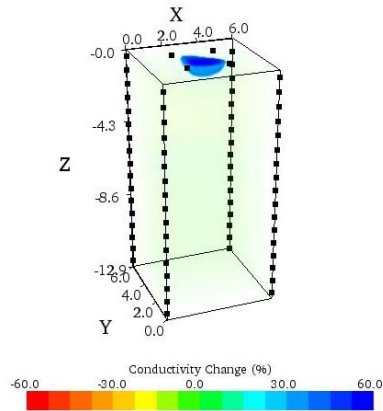
- 2) Input the Base Inversion Output (*.out) File by clicking the Browse button. This file consists of previously inverted results of the base dataset. The base inversion output is served as the a-priori information of the time lapse inversion. While adding the OUT file to the input box, EarthImager checks the availability of the inversion settings file in the same directory of the OUT file. The settings file will be used for the time lapse inversion. It is preferred that the same settings are used for both base data inversion and monitor data inversion.
- 3) EarthImager 3D searches for an optimal iteration number from the inversion output file based on the RMS error and/or L2 norm automatically. The optimal iteration number will be shown after opening the base inversion output file. However, a user may change the recommended iteration number and choose his/her preferred iteration number.
- 4) Add monitor data files to the list. There are two ways to add monitor data file names. First, the user may click the “Add Monitor Data Files” button and select multiple data files from the Windows File Open Dialog. Second, an ASCII batch file with a list of (STG) data file names and, if any, the base output file name may be loaded into EarthImager 3D. A batch file is a simple list of file names with a complete file path. If an OUT file is found in the batch file, it will overwrite the OUT file already in the input box. But the monitor data files will be simply appended to the current monitor file list without any check on duplicates. Here is a sample batch file (timelapse.bch) in the demo directory:

```
C:\Program Files\AGI\EarthImager3D\demo\Base19990216\trial2\Base19990216_trial2.out
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990312.stg
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990313.stg
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990316.stg
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990323.stg
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990408.stg
C:\Program Files\AGI\EarthImager3D\demo\Monitor19990501.stg
```

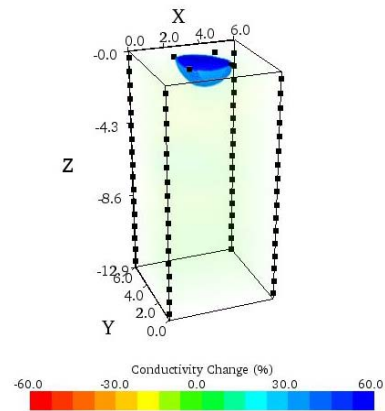
- 5) To delete a monitor file from the file list, select the file and then press the Delete key. To change the order of a monitor file, use the Up and Down arrow to move it up or down. All monitor files must be listed in a sequential order based on the data collection time because an AVI movie will be created at the end of inversion to show time lapse changes.
- 6) Choose a view file to customize the image size and orientation.
- 7) Save the batch file for future use.
- 8) The user may change the inversion settings by going to the Main Window and choosing any settings page, but this is strongly discouraged.
- 9) An AVI movie file may be produced with the difference images from all monitor datasets when three or more monitor datasets are listed. To create an AVI file, all difference images must be presented with the same color scale and data range (Min and Max). As a convention, we use cool colors such as blue and cyan to represent increasing conductivity (water infiltration or saltwater intrusion), and warm colors such as red and orange to represent increasing resistivity (air-sparging or leaking gas tank). So the green color is neutral and indicates no-change zones.
- 10) Set Min Change and Max Change based on the above discussion and convention. It is going to be difficult to set these two numbers without any prior knowledge. We recommend that you set $\text{Min_Change} = -1 * \text{Max_Change}$. This will help suppress some artifacts and make the green color no-change zones.
- 11) The selection of the plotting Parameter will depend on the application type. For a case with increasing conductivity, it is almost mandatory to choose "Conductivity Change" as the parameter to plot. For a case with increasing resistivity, select "Resistivity Change" as the plotting parameter. Choice of Min Change, Max Change and Parameter is not fatal but an inappropriate selection will fail the attempt of AVI movie creation. The time lapse inversion results can be read back into EarthImager for visualization and data analysis.
- 12) Click the Start button to start the time lapse inversion in a batch mode. The monitor data files are inverted one by one.
- 13) At the end of inversion of each monitor data set, the inverted resistivity data is saved as an image in the JPG format and ASCII XYZ format. Moreover, both resistivity difference and conductivity difference between the monitor model and base model are saved in the bitmap format and ASCII XYZ format. Here are some typical output files from a time lapse inversion of one monitor dataset. Bitmap files are used to create an AVI movie to demonstrate the time lapse change of the subsurface. Go the AVI Maker under the Tools menu for detail.



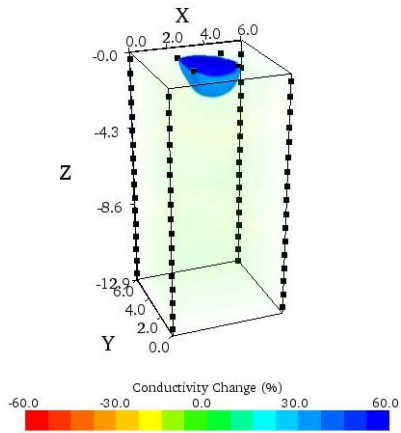
Percent Difference of Conductivity (03-12-1999)



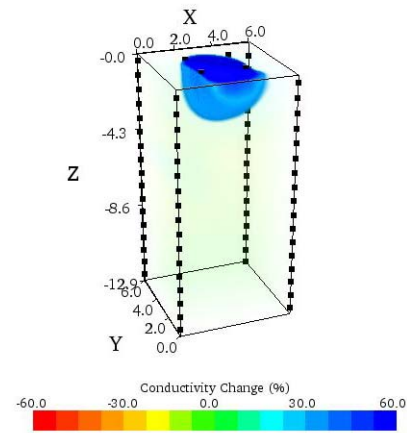
Percent Difference of Conductivity (03-13-1999)



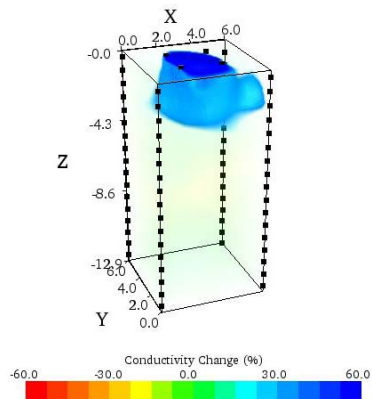
Percent Difference of Conductivity (03-16-1999)



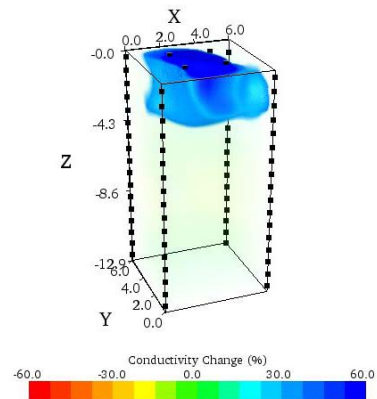
Percent Difference of Conductivity (03-23-1999)



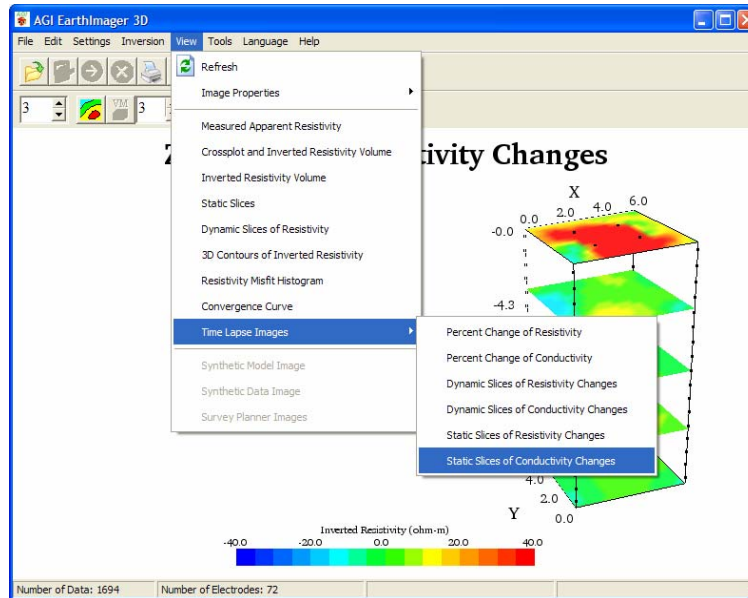
Percent Difference of Conductivity (04-08-1999)



Percent Difference of Conductivity (05-01-1999)



- 14) It is critical to keep the EarthImager 3D main window on top of all other windows and not to minimize the EarthImager main window because all images saved are the screen captures. If the EarthImager 3D main window is minimized, a blank image is saved. If the main window is partially or completely blocked, the image saved would also be partially or completely blocked. In addition, the size of a saved image would have the same size of the image rendering window on the main window.
- 15) There are six resistivity/conductivity difference images from time lapse inversion for users to visualize.



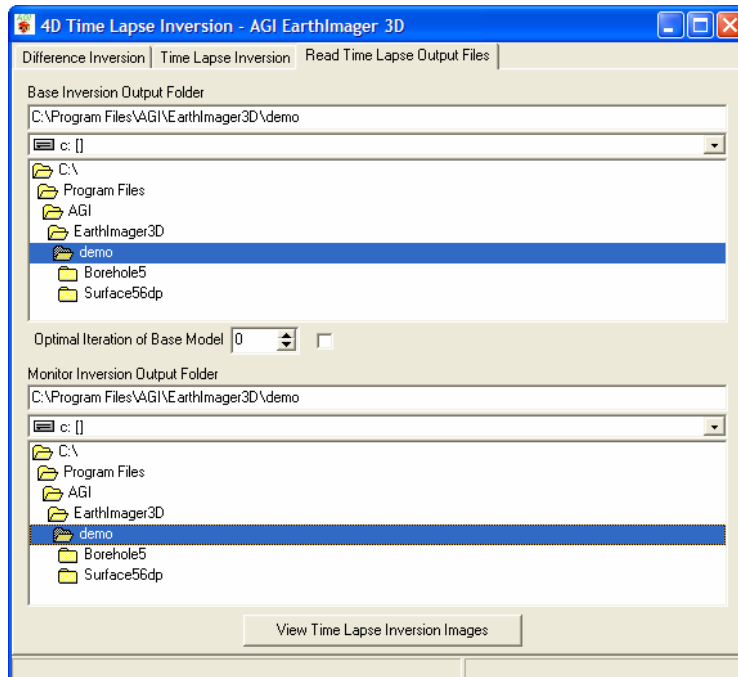
- 16) The user may browse all images generated from the time lapse inversion. The six time lapse images with increasing conductivity on the last page from the Socorro Infiltration Experiment show downward movement of wetting fronts. These six datasets were collected 1 day, 2 days, 5 days, 12 days, 28 days and 51 days after the infiltration began on March 12, 1999. The date in the image title was extracted from the STG data file. So it is important to maintain a correct date in the date stamp column of STG data files.
- 17) A time lapse inversion output file may be read back into EarthImager one at a time for visualization and further data analysis. This will be discussed in the next section.
- 18) At the end of inversion, an AVI movie file is created and displayed automatically.

5.3.3 Read time lapse output file

To load the time-lapse inversion results back into EarthImager 3D, go to the menu item File | Read Time Lapse Output File or the menu Inversion | Time Lapse Inversion and then choose the page "Read Time Lapse Output File".

Trial directories for both base data inversion and monitor data inversion are required to produce the percent difference images. The user is simply prompted to choose or enter these two directories. Note that the inversion settings (INI) files in these two directories must be intact for

successful display of difference images. If a user-specified iteration number is chosen during the time lapse inversion, it is required to set the same iteration number here when viewing the time lapse inversion results and check the box after the Iteration Number setting.



5.3.4 Acknowledgments

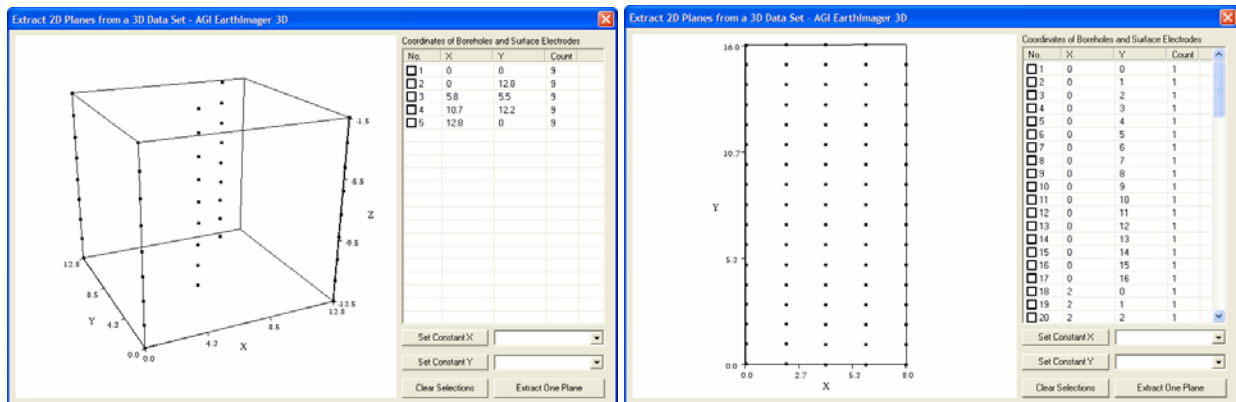
We demonstrated our time lapse inversion module with seven time lapse datasets from the Socorro Infiltration Experiment that was performed at then SteamTech Environmental Services, Sandia National Laboratories, and New Mexico Tech with funding provided by the U.S. Department of Energy's Office of Energy Research, Environmental Science Management Program. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000. More information about this water infiltration experiment and inversion results of these seven datasets with different inversion algorithms may be found in a dissertation by Yang (1999).

6. TOOLS

6.1 Extract 2D Plane

This utility extracts one or more 2D data sets from a 3D data set for 2D inversion with EarthImager 2D. 3D inversion often takes hours even days. For a quick look of the results, one may want to extract a small set of data from a large 3D data set for 2D inversion.

To launch “Extract 2D Plane” window, choose the “Extract 2D Plane” menu item from the Tool menu. You will be prompted to give a 3D data file name. After reading the data file successfully, a 3D electrode scatter plot would show up to the left. (X, Y) coordinates of boreholes and surface electrodes would be displayed to the right. The fourth column of this table shows the number electrodes in the “borehole” which can be a single surface electrode.

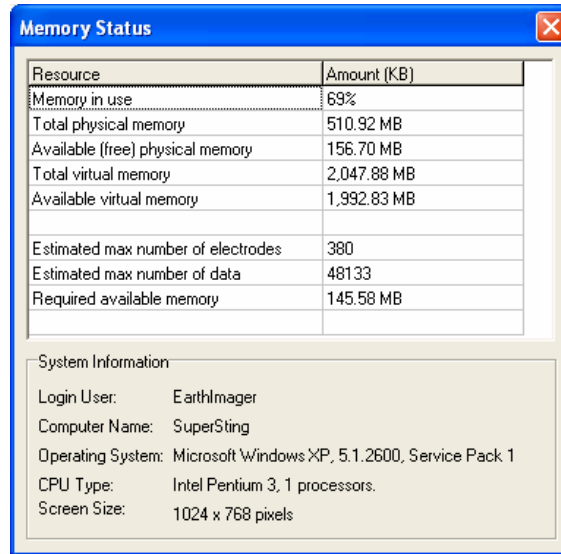


EarthImager 3D does not check if the selected boreholes or electrodes are on a 2D profile or survey line. In the figure above, boreholes #1, #3, and #5 are selected though they are not on a straight line. EarthImager 3D ensures the distance between boreholes 1 and 3 are correct, and the distance between boreholes 3 and 5 are correct. However, the distance between boreholes 1 and 5 will not be right if boreholes 1, 3, and 5 are not on a straight line. Here are the steps to extract a 2D data set from a 3D data set.

- 1) Choose Tools | Extract 2D Plane menu item, and read a 3D data set.
- 2) Select boreholes or electrodes to form a 2D data set by checking the box in front of the borehole/electrode ID No. in the first column of the upper right table. You may choose multiple boreholes as far as they are on a straight line.
- 3) For a surface data collected on multiple parallel lines, it is convenient to choose a line at a time by setting either a constant X or constant Y.
- 4) To clear your selections, click the “Clear Selection” button.
- 5) Click “Extract One Plane” to extract the selected 2D data set and save it.

6.2 Check Memory

This tool checks total and available memory sizes and estimates the maximum number of electrodes and data allowed in the inversion. The estimates are a rough guideline. If the actual number of electrodes is smaller than the estimated number of electrodes, your computer may be able to accommodate more data than the estimated number of data.



Resource	Amount (KB)
Memory in use	69%
Total physical memory	510.92 MB
Available (free) physical memory	156.70 MB
Total virtual memory	2,047.88 MB
Available virtual memory	1,992.83 MB
Estimated max number of electrodes	380
Estimated max number of data	48133
Required available memory	145.58 MB

System Information	
Login User:	EarthImager
Computer Name:	SuperSting
Operating System:	Microsoft Windows XP, 5.1.2600, Service Pack 1
CPU Type:	Intel Pentium 3, 1 processors.
Screen Size:	1024 x 768 pixels

To check the memory status, choose the menu item Tools | Check Memory. You may observe that the available physical memory is always smaller than the total memory (RAM). The Windows XP operating system alone may take about 120MB. If your computer has only 128MB RAM and runs the Windows XP operating system, you can hardly run any application. We suggest that you run “Check Memory” immediately after the installation of EarthImager, so you will have a rough idea how many electrodes and data points your computer can handle.

Note that the estimated numbers may vary depending on how many application programs are running while you Check Memory.

After loading a data set, “Check Memory” reports the amount of memory needed for processing of the loaded data set. After loading a data set, EarthImager 3D also compares the memory needed for inversion with free memory space and gives a warning message if your computer does not have enough memory to process the loaded data set.

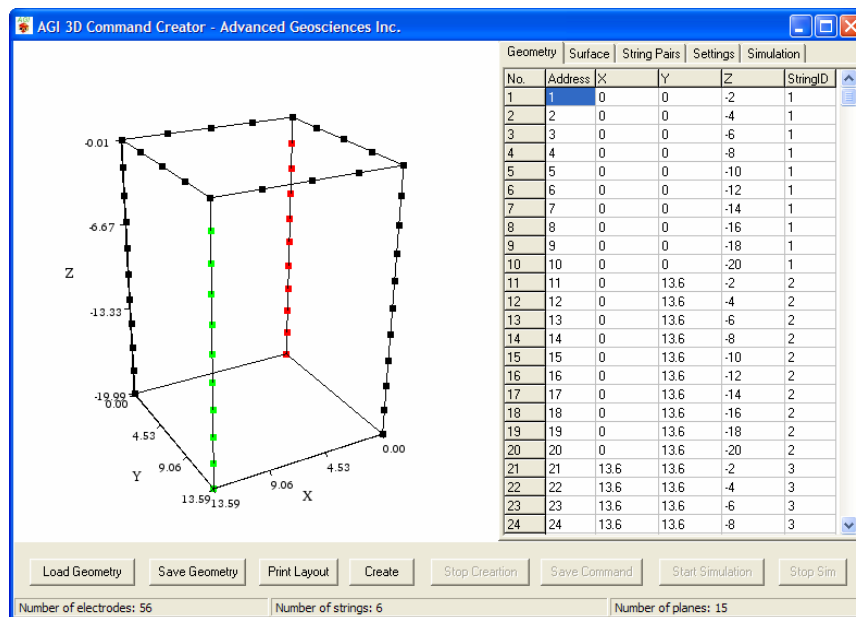
6.3 Command Creator

Command creation is a critical step leading to a successful 3D survey. A good command file would help ensure a quality data set with a high signal-to-noise ratio and a good data coverage that produces a good model resolution. An effective way to enhance the signal-to-noise ratio is to increase the signal strength, that is, not to collect the data with low signal strength. The data coverage depends on how to collect the data and how much useful data to collect. In our 3D Command Creator, the user is given options to set signal thresholds which are based on the type

of earth materials, and a list of six different electrode configurations (arrays) to choose from. The EarthImager 3D Command Creator was developed to maximize the signal-to-noisy ratio and data coverage so that you will get a high-resolution resistivity image.

There are five tabbed pages on the Command Creator window. The first tab Geometry show the electrode coordinates. The second tab Surface displays settings to generate electrode geometry for a surface electrode layout. The String Pairs tab is on only if the bipole-bipole array is chosen and it is used to select borehole pairs for cross borehole measurements. The Settings tab helps select an instrument type, an array type and other constraints. The last tab Simulation is to demonstrate how measurements proceed. All settings on this page will NOT be saved in a command file.

Hold and move the left mouse button to rotate the graphics, the right mouse button to zoom in and out, and the mouse wheel to translate the image. The Shift key + Left Mouse would also translate the image if the mouse wheel does not exist.



6.3.1 Electrode geometry

The electrode geometry is required to visualize the electrode configuration, to show the simulation of commands, and to estimate the signal strength for an effective command file. A geometry file consists of several comment lines at the beginning of the file, a line showing the length unit, and electrode coordinates. Here are first few lines of a sample geometry file.

```
;Electrode geometry for combined borehole and surface resistivity survey
;This is a demo geometry file
unit=meters
;Electrode address, X, Y, Z, StringID
253, -500, 0, 0, 0
254, 500, 0, 0, 0
```

```

1, 0, 0, -3, 1
2, 0, 0, -6, 1
3, 0, 0, -9, 1
4, 0, 0, -12, 1
5, 0, 0, -15, 1
6, 0, 0, -18, 1
7, 0, 0, -21, 1
8, 18, 0, -3, 2
9, 18, 0, -6, 2
    
```

Note that any line starting with a semicolon “;” is a comment line. A comment line may be placed anywhere in the file. A line starting with “unit=” gives the length unit, which is assumed to be meters if this line is missing or given inappropriately. A geometry file may be created in any ASCII text editor such as NotePad or any spreadsheet program.

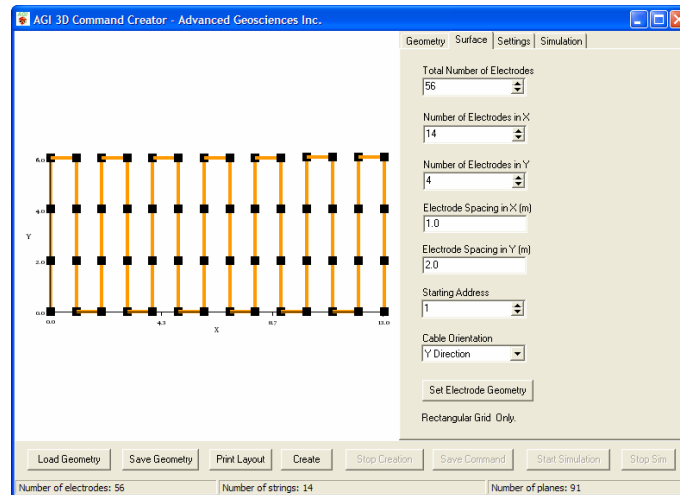
The electrode geometry consists of five columns that are comma-separated. The first column is the electrode address that must start from 1 and end with the number of electrodes. The address “253” on the first geometry line is reserved for the remote B (current) electrode of the Sting instrument. The address “254” following “253” line or on the first geometry line is reserved for the remote N (potential) electrode of the Sting instrument. The addresses “253” and “254” on any other lines have no such effects and they are not required in any SuperSting geometry file. The remote electrode coordinates for the SuperSting instruments are not defined in the geometry file. If your instrument has a different set of electrode addresses, you should modify the electrode mapping table on the instrument. The columns 2, 3, and 4 show the (X, Y, Z) coordinates of the electrodes. Note that the Z coordinate is zero (0) on the ground surface and negative downward.

The last column of a geometry file is the electrode String ID. An electrode string is defined as a line of electrodes with consecutive addresses. It does not have to be on a straight line. For a borehole resistivity survey, a string is a borehole. For several survey lines on the surface, electrodes on a survey line can be grouped together as one string. For electrodes laid out in an irregular shape such as some surface electrodes in a borehole resistivity imaging project, combine all surface electrodes into one string. It is preferred that each string has at least five or more electrodes.

The String ID column is not required and it is used only for the bipole-bipole array for cross borehole resistivity tomography.

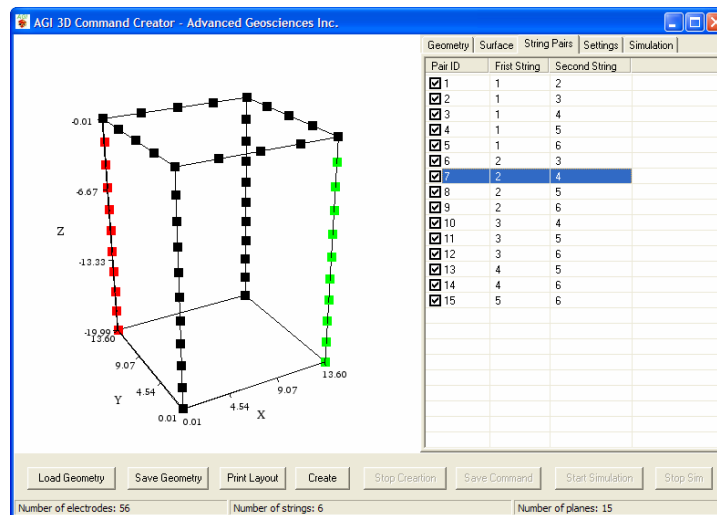
There are two ways to input electrode geometry to this command creator. First, one may create a geometry file in a text editor such as Microsoft NotePad and load the geometry file directly into the command creator. Second, a quick and easy way is implemented for a 3D surface survey with electrodes laid out in a rectangular grid. Simply go to the “Surface” page of the command creator, define an electrode grid and spacing, and then click the button “Set Electrode Geometry”. The command creator would generate electrode geometry based on your assumption. A cable may be oriented either in X or in Y direction. This geometry input method does not work with irregular (non-rectangular) electrode grid.

The spreadsheet on the Geometry page is not designed to input electrode geometry manually. So it is strongly recommended to create an electrode geometry file in a text editor such as NotePad or a spreadsheet program. Minor editing in the Geometry spreadsheet is allowed. Make sure to save your input as a geometry file before closing the command creator after making any modifications. You may also print out a graphical electrode layout as your record.



6.3.2 String pairs

The commands using electrodes on the same string would be usually created. These are called the same string measurements. The String ID is used to identify which pair of strings should be used for cross-string, i.e., cross-borehole or cross-line, measurements.



To image a volume, one should collect both same-string measurements and cross-string measurements. The same string measurements are collected with both transmitting and receiving electrodes on the same string, but the cross string data are taken with transmitting electrodes on one string and receiving electrodes on another string. For efficient field surveys and data processing, some pairs of strings may not be used to collect data. After loading electrode

geometry into the command creator, all possible combinations of string pairs are listed and selected in a spreadsheet on the “String Pairs” page. It is your responsibility to deselect some of unnecessary pairs of strings by un-checking the box at the beginning of each string pair. The command creator, of course, offers visual help in your decision process. The selected first string would be highlighted in red and the second one in green.

“String Pairs” will affect bipole-bipole array only. This page will be invisible or be disabled if any of other arrays is selected.

6.3.3 Array type

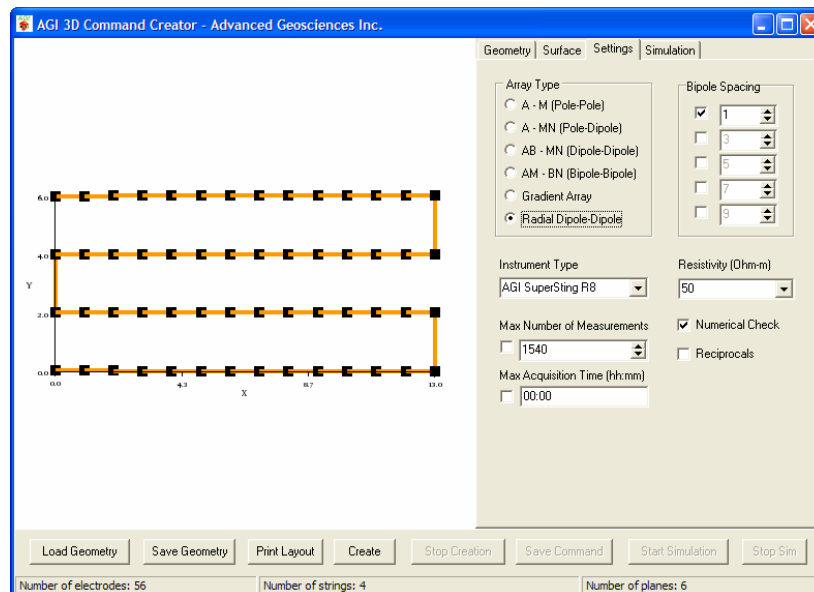
Some known electrode configurations such as Wenner and Schlumberger arrays are not applicable to 3D cross string measurements. Some of our array definitions are adapted from Zhou and Greenhalph (2000, *Geophysical Prospecting*, pp. 887-912). A and B are used to denote current electrodes, and M and N are potential electrodes. We implemented six array configurations.

- 1) **Pole-pole array (A – M).** This array is the same as the conventional pole-pole array. The bipole length has no effect on the A – M array because there is no bipole length involved in this array. The pole-pole array produces strong signals but a low model resolution. The maximum number of measurements equals $N * (N-1) / 2$ where N is the number of electrodes.
- 2) **Pole-dipole array (A – MN).** This array is a compromise between the pole-pole array and dipole-dipole array, so it has good signal strength of the pole-pole array and a high model resolution of the dipole-dipole array. The number of measurements depends on the signal strength, i.e., average resistivity value of imaging volume. We implemented a radial pole-dipole array adapted from *Nyquist, J. and Roth, M., 2005, Improved 3D pole-dipole resistivity surveys using radial measurement pairs, Geophysical Research Letters, Vol 32, L21416.*
- 3) **Dipole-dipole array (AB – MN).** This array has a high model resolution but low signal strength when the n-spacing is large. The 3D data set collected with the dipole-dipole array often produces a large RMS error during the inversion. One can not collect adequate data with this array in a conductive environment, so the data coverage suffers. To increase the number of measurements, one may either collect data at multiple Dipole-Lengths or lower the acceptable signal strength, i.e., increase the resistivity value.
- 4) **Bipole-bipole array (AM – BN).** This array produces very strong signals due to a large AB separation, large MN separation, and small transmitter-receiver spacing. The bipole-bipole array is ideal for cross borehole tomography. Separated transmitting electrodes in two different boreholes would force the electric currents to penetrating the formation and reduce the current channeling effect. This array should not be used for surface data collection.
- 5) **Gradient array.** This is a nonstandard gradient array, that is, the potential electrodes may be between two current electrodes AB or outside AB. This array generates great number of measurements. Our gradient array has a roaming “A” electrode and a fixed “B” electrode at two ends of a diagonal line of the rectangular electrode grid. This array is not appropriate for cross borehole measurements.

- 6) **Radial dipole-dipole array (AB – MN).** This is a special case of the dipole-dipole array with all four A, B, M and N electrodes on a straight line in a 3D rectangular electrode grid, either on the same line or across four lines. This array is not appropriate for cross borehole data acquisition. It is hoped that this array would have fewer measurements but stronger signal and higher model resolution compared with the standard dipole-dipole array.

Note electrical noises such as telluric currents and cultural noises around the remote electrode often contaminate the data and results in noisy data. The remote electrodes are often not placed far enough to honor the “infinite” distance, which makes the contribution of the remote electrode not negligible.

Checking the Reciprocal box would produce the reciprocal commands only. No forward commands are created. To create a command file with both forward and reciprocal commands, one must create two separate command files first and then copy-paste them together.



6.3.4 Signal strength and numerical check

Data with low signal strength is relatively noisier due to its low signal-to-noisy ratio and is usually difficult to fit in the inversion process. Therefore it is better not to collect data with small signal strength. In 3D command creator, we estimate the signal strength for each measurement command based on your estimate of background resistivity value on the Settings tab (see above). A minimum voltage threshold is hard-coded internally in the command creator. Any command that produces a signal lower than the threshold would be rejected and not included in the command file.

By checking a checkbox “Numerical Check” on the Settings page, the forward modeling will be invoked at the end of command creation and numerical errors are assessed. This may take

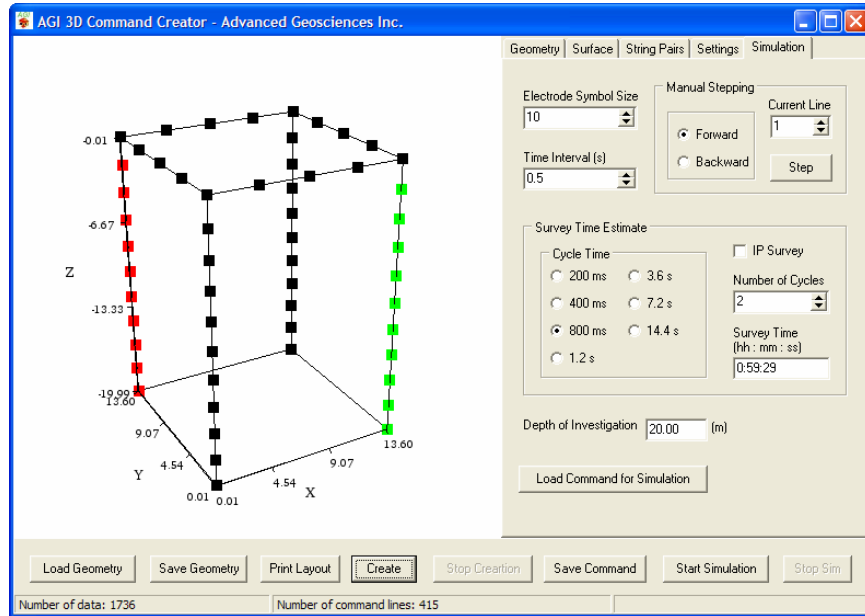
minutes or even hours if the mesh is too large or there are too many electrodes. Excessive commands with largest numerical errors will be removed.

6.3.5 Create commands

Follow these steps to create commands.

- 1) Load a geometry file. Click the Load Geometry button and choose a geometry file. A sample geometry file (ERT56.geo) is included for demonstration purpose. To browse electrodes in the geometry spreadsheet, click any line in the Geometry spreadsheet. You may also use arrow keys to scroll through the electrodes. The selected electrode would be shown in red. To change the electrode symbol size, go to the Settings page. Electrode geometry may be inputted manually into the spreadsheet or generated automatically based on the assumptions on the Surface page (refer to the Section 6.3.1 for detail).
- 2) Save electrode geometry as a geometry file for later user if the geometry is entered manually.
- 3) Choose an array type.
- 4) Choose an instrument type.
- 5) Select pairs of strings if the bipole-bipole is chosen. Go the String Pairs page by clicking the String Pairs tab at the top. All possible pairs are listed and selected by default. To deselect a pair, un-check the box at the beginning of each pair list. The electrodes of the selected pair would show up in different colors. The first string is in red and the second string in green. To avoid over sampling, it is suggested that you deselect some pairs.
- 6) Choose Bipole Spacing which corresponds to the a-spacing in the dipole-dipole array. One may choose multiple a-spacing's to get better data coverage at depth. This setting applied to the dipole-dipole array only and it is disabled for any other array.
- 7) Set the background resistivity value which is used to estimate the signal strength. ***A small resistivity value will result in poor data coverage, i.e., too few measurements.***
- 8) Check the checkbox "Numerical Check" if you want to reduce the number of measurements based on numerical errors. This modeling process may take hours for a large electrode grid with hundreds of electrodes.
- 9) Set the Max Number of Measurements and check the checkbox in front of it if you do not want over-sampling.
- 10) Set the Max Acquisition Time and check the checkbox in front of it if you do not want over-sampling. You may set both Max Number of Measurements and Max Acquisition Time. The command creator will meet both conditions.
- 11) Click the Create button to create the commands. Note that no new commands would be created without clicking this button. Changing a setting would not update the commands automatically. Click the Stop button to terminate command creation.
- 12) Go to the Simulation page to check how much time needed to collect a data set with this command. The estimated depth of investigation shows at the bottom of the page.
- 13) Start Simulation. You may change the simulation speed by altering the Simulation Time Interval. The progress of simulation can be monitored with the status bar at the bottom. To stop simulation, click the Stop Simulation button.
- 14) Click the Step button for step by step command simulation. You may step forward or backward in the command file or start stepping from any command line.

- 15) Save the command file by clicking the Save button. Give a command file name when prompted.



- 16) To view the simulation of a previously-created command file, click the Load Command button to load the command file and then Start Simulation.

6.4 Change Y Coordinate

This utility changes the Y coordinates of a 2D data set that is collected along a survey line. The Y coordinates of a 2D data set are usually set to 0. To combine several 2D data sets collected over parallel lines into a single 3D data set for 3D inversion, a correct line offset or Y coordinate must be defined to describe the geometry of electrodes. In EarthImager 3D, Z is defined as the elevation with $Z = 0$ at the ground surface. Before we move further, let's define a few terms.

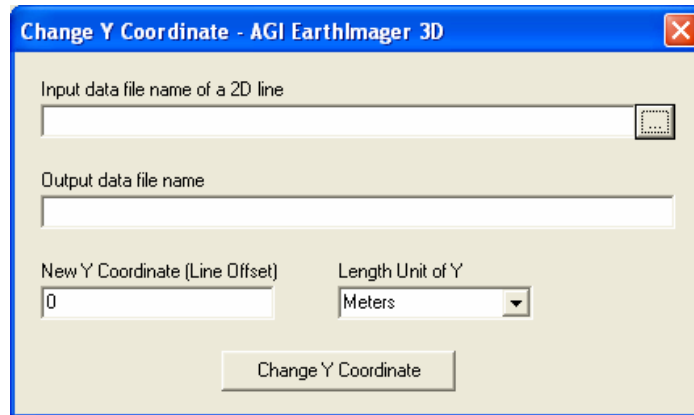
A **2D Data Set** is collected along a survey line on the ground surface or between several boreholes on a straight line. That is, all electrodes must reside in a 2D vertical plane.

In a **3D Data Set**, the electrodes are NOT limited in a 2D vertical plane. They are usually arranged in a rectangular grid on the surface or in several boreholes that are not on a straight line.

In a **2D Data Format**, the electrode geometry is defined by two coordinates (X, Y). For a surface data set, the coordinate Y is used to define the line offset. But in a borehole data set, the coordinate Y is used to describe the depth of the electrodes. The 2D data format was developed for AGI Sting resistivity meter and may be used for all 2D data sets and 3D surface data sets. The 2D data format supports several modes based on the electrode configuration used. But this utility supports the USER mode only.

The **3D Data Format** was developed for 3D data sets and 3D surveys. In a 3D data format, the electrode geometry is defined by three coordinates (X, Y, Z). Therefore, the 3D data format may

be used to define any kind of electrode geometry and can be used for all types of 2D and 3D data sets.



Input data file name: The data file must be a 2D data set either in 2D or 3D STG data format. For an STG data file in the 2D data format, this utility supports the USER mode only. It may also read some 2D data sets in 3D DAT format and 3D URF format. However, this utility can not be used to change Y coordinates of a 2D borehole data set in the 2D data format because the Y coordinate is used to define the electrode depth and it is not constant.

A recommended **Output Data File Name** is automatically generated. The converted output data file with a new Y coordinate will be saved in the 3D STG data format. So several 2D data sets along parallel survey lines may be combined into a single 3D data set by copy and paste.

Here are the steps to Change Y Coordinate:

- 1) Start EarthImager 3D, and choose the menu item Tools | Change Y Coordinate.
- 2) Find the input data file by clicking the small button to the right of the text field.
- 3) A recommended output file name is generated and may be altered.
- 4) Choose the new Y coordinate and the distance (length) unit.
- 5) Click the “Change Y Coordinate” button to save the converted file in the 3D STG data format.

6.5 Modify Electrode Coordinates

Electrode coordinates must be defined during the design phase of resistivity surveys and they are required by the command creator. The actual electrode layout in the field may differ from the electrode geometry in the command file. This results in an invalid STG data file. Editing the STG data file manually is extremely tedious and error-prone. This “Modify Electrode Coordinates” utility is intended to free the user from such worrisome situation.

With this tool a user can reassign new coordinates to all electrodes. To use this feature, follow these steps:

- 1) Start EarthImager 3D.
- 2) Choose the menu item Tools | Modify Electrode Coordinates.

- 3) Click the button “Read Data” to input the STG data file with incorrect electrode geometry.
- 4) Input new and correct electrode geometry by either reading a geometry file or inputting the coordinates manually into the spreadsheet below. A geometry file is a comma-separated four-column file. A leading semicolon signals a comment line. The length unit is meters by default. A geometry file may look like this.

```
; Electrode Geometry File
;Electrode address, X, Y, Z
1,0,4,0
2,0,8,0
3,0,12,0
```

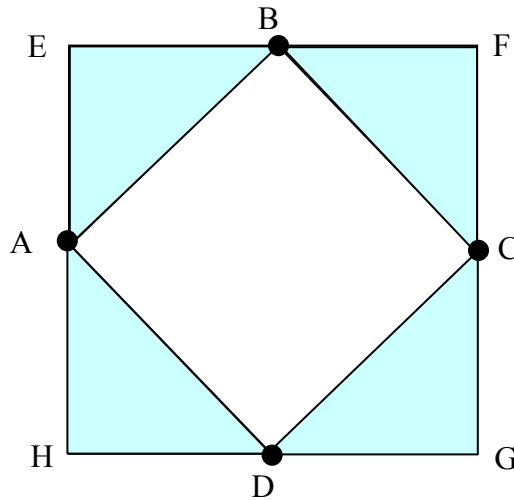
- 5) After inputting new geometry, one may save a new STG data file with new electrode geometry. The new geometry may be saved in a different geometry file.

No.	X - old	Y - old	Z - old	X - new	Y - new	Z - new
1	694.2	239	-23			
2	694.2	239	-21			
3	694.2	239	-19			
4	694.2	239	-17			
5	694.2	239	-15			
6	694.2	239	-13			
7	694.2	239	-11			
8	694.2	239	-20			
9	694.2	239	-14			
10	694.2	239	-8			
11	694.2	239	-5			
12	694.2	239	-9			
13	694.2	239	-7			
14	694.2	239	-2			
15	694.2	239	-18			
16	694.2	239	-16			
17	694.2	239	-12			
18	694.2	239	-10			
19	694.2	239	-22			
20	694.2	239	-6			
21	694.2	239	-4			
22	694.2	239	-3			
23	709.5	253	-22			
24	709.5	253	-23			
25	709.5	253	-21			
26	709.5	253	-20			
27	709.5	253	-19			
28	709.5	253	-18			

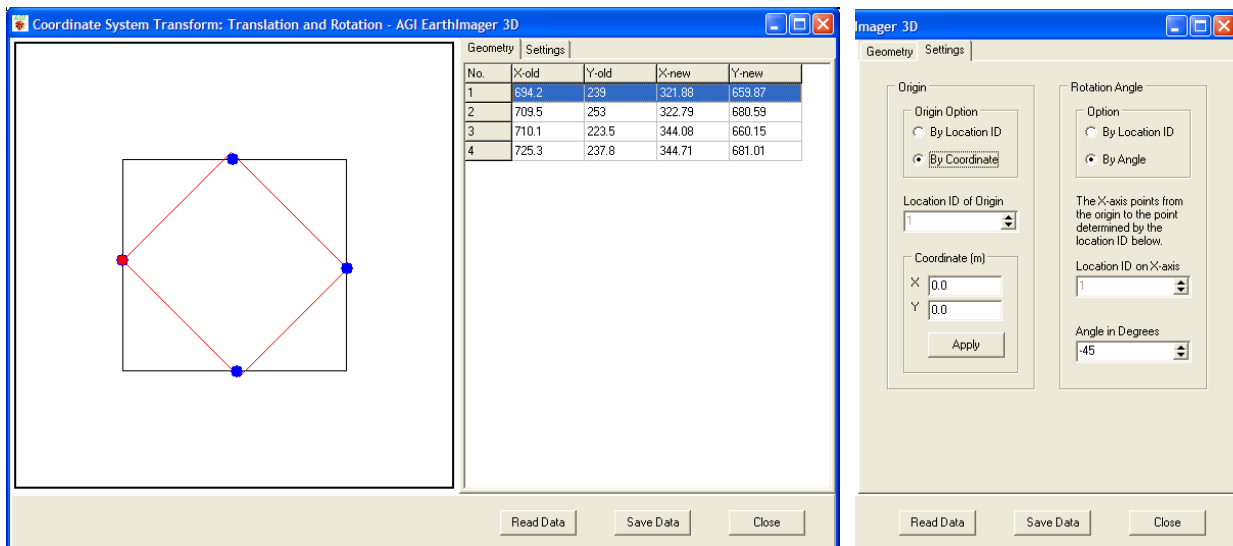
6.6 Coordinate System Transform

This tool helps improve the performance of inversion. The figure below illustrates a possible field scenario. Four boreholes A, B, C and D are arranged in a diamond shape. EarthImager 3D defines the surface imaging boundary based on the minimum X and Y coordinates, and maximum X and Y coordinates. This would set the rectangle EFGH as the imaging boundary. However, the intended imaging boundary is the rectangle ABCD. This discrepancy causes a larger modeling mesh and poor model resolution within the four corner triangles. The problem is originated from an inappropriate orientation of the coordinate system, that is, the positive X points to the HG direction and positive Y points to HE direction. To obtain the intended imaging boundary, the coordinate system must be rotated so that one of the axes (X or Y) would parallel

to one side of the boundary outlines and the area of imaging boundary arrives at the minimum or close to the minimum. In this case, the X axis may rotate -45° so it parallels to the line AD.



Translation is another type of coordinate system transform and it shifts the origin around. Translation may be used to reduce number of digits of electrode coordinates. For example, your electrode coordinates are defined with the 7-digit UTM coordinates, but your imaging dimension may be within 10 meters. So all you need is 2 to 3 digits. Translation of the origin would be ideal for this purpose.



Follow these steps to transform coordinate system.

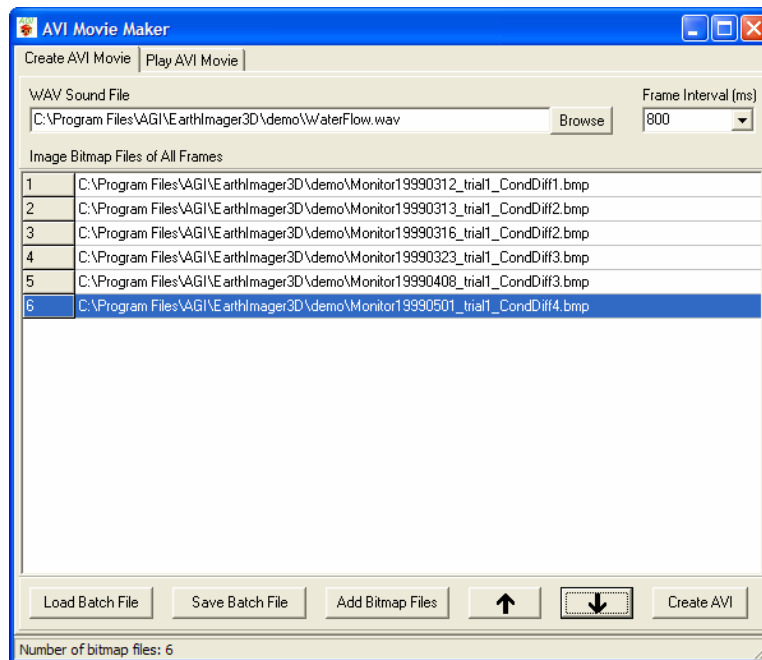
- 1) Start EarthImager 3D.
- 2) Choose the menu item Tools | Coordinate System Transform.
- 3) Read the STG data file to be transformed by clicking the button "Read Data". The data and electrode geometry would be displayed in the main window. This transform utility will find unique (X, Y) pairs from electrode coordinates and list the unique pairs on the Geometry page to the right and show the image to the left. In addition, a search for the

minimum surface imaging area is carried out by rotating the coordinate system from -45° to 45° at a 1° interval. The optimal orientation of the coordinate system found would be shown in a red rectangle. The original imaging boundary is shown in a black rectangle. The original coordinates from the data file are listed under X-old and Y-old, and the rotated coordinates are under X-new and Y-new.

- 4) To customize the origin and X-axis orientation of new coordinate system, manipulate the settings on the Setting page (window). Both the origin and a point on the X-axis can be defined by two different methods.
- 5) To set the new origin, one may give a new pair of (x, y) coordinate or choose a location ID from a list of unique (x, y) pairs. Note that the chosen point is shown in the left image in red.
- 6) To set the x-axis orientation, one must define the origin first because we need either two points or one point plus an angle to define the x-axis. To set a point from the unique pair list onto the positive x-axis, choose defining the rotation angle "By Location ID". A rotation angle is then calculated with the origin and the chosen point on the positive axis. Keep an eye on the image to the left to monitor the effect of your choice.

6.7 Create AVI Movie

This utility creates an AVI movie file with sound from multiple time lapse bitmap images and a WAV sound file. A simple AVI player is also provided.



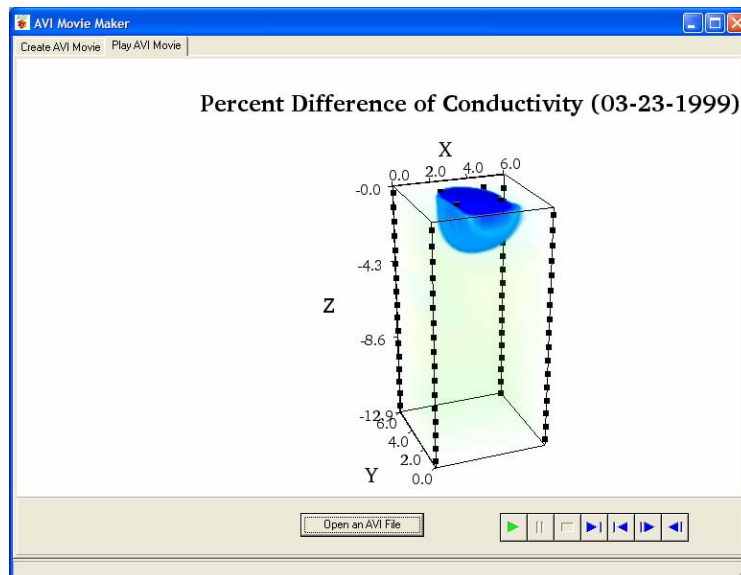
To create an AVI movie file, please follow these steps.

- 1) Add multiple bitmaps files. One or two frames would not produce any decent animation. Three or more frames are required. There are two approaches to add bitmap files to the list. First, one may load a batch file with a list of bitmap file names and file path. Second,

click the button “Add Bitmap Files” to choose multiple bitmap files from Windows File Open Dialog. Note that image files other than bitmap files are not a valid input.

- 2) Arrange the bitmap files in a temporal sequential order by using the up and/or the down arrow button. To delete any bitmap file, press the Delete key on the keyboard.
- 3) Add a WAV sound file if any. It would be difficult to synchronize the length of a sound file to the duration of bitmap sequence.
- 4) Set the time interval between two neighboring frames.
- 5) Click the Create AVI button to create an AVI animation file. If successful, the new AVI movie would be played in the built-in AVI player.
- 6) Save the bitmap file list and the WAV sound file to a batch file in the ASCII text format. This batch file may be loaded back into the AVI movie maker.

To play an AVI movie, simply open an AVI file and then click the green universal play button. During the time lapse inversion, a bitmap file showing resistivity or conductivity changes for each monitor data file is created and added to the bitmap file list. At the end of time lapse inversion, an AVI file is created and played automatically in the media player below.



6.8 Survey Planner

6.8.1 Survey planning process

Our survey planner is a two-step process. First, a synthetic dataset is created based on your assumption of subsurface resistivity distribution and electrode configuration, i.e., a command file. This step is a virtual survey and also called forward simulation.

Second, the synthetic data is inverted to reconstruct the subsurface resistivity distribution. Your assumption of resistivity distribution and the inverted resistivity section will be displayed on the screen side by side for comparison. The second step is called inverse simulation or inverse

modeling. You may find out if resistivity imaging is feasible or appropriate to attack your problem.

Any failure to reconstruct the assumed resistivity distribution may be caused by 1) a poor command file, 2) incorrect forward modeling settings, 3) incorrect inversion settings, and/or 4) inability of resistivity imaging to solve your problem such as too small resistivity contrast, too small target, and/or too large depth of the target. It is suggested that you try different command files, different forward modeling settings, and different inversion settings. You may also vary the properties of your target.

The goals of our survey planner are to help you:

- 1) find the optimal data collection strategy, i.e., the command file,
- 2) find the optimal forward modeling settings,
- 3) find the optimal inversion settings, and
- 4) find the limitation of resistivity imaging, that is, what resistivity contrast, what target size, what target depth and/or what kind of subsurface geology the resistivity imaging can resolve.

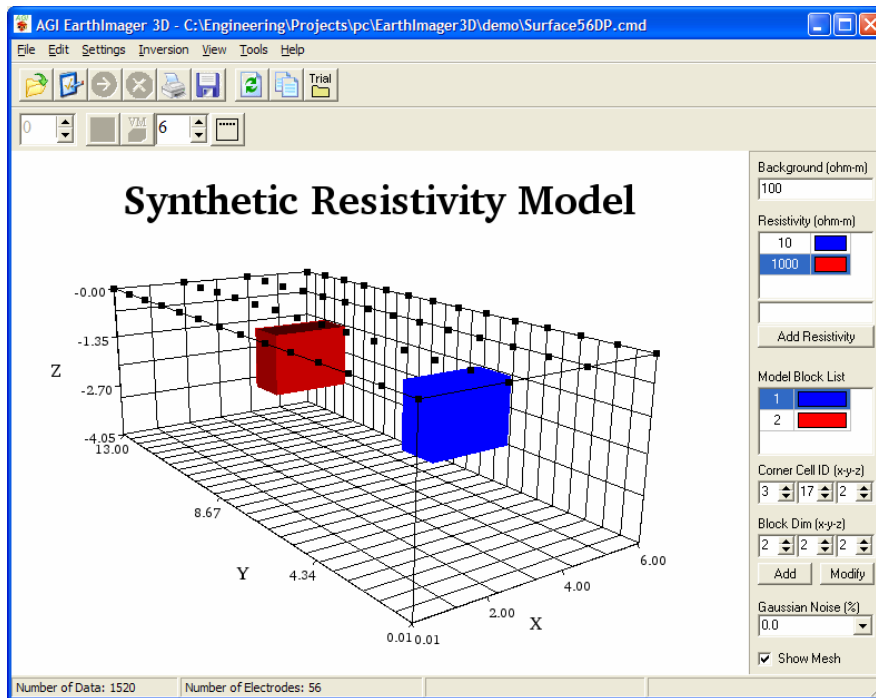
Our survey planner helps you achieve these goals without costly trial-and-error tests in the field. Therefore you will make the right decision from the beginning.

6.8.2 Forward Simulation

Forward simulation is the first step of survey planning. It runs a virtual survey and creates a synthetic data set. It is strongly recommended to select appropriate settings before loading a command file. To run forward simulation, follow these steps:

- 1) Choose Read Command File from the File menu. This will load an AGI command file (*.cmd) and create a mesh based on the settings after successful loading of the command file. The synthetic model settings panel will appear to the right of the main window and it can be turned off by choosing the menu item Settings | Synthetic Model Settings.
- 2) Choose Forward Modeling Settings from the Settings menu and change the settings as you desire. By doing so, your model may be scaled or shifted or truncated or removed. However, you may modify your model with the Modify button on the Synthetic Model Settings panel.
- 3) Set the background resistivity value. The default is 100 ohm-m.
- 4) Add all possible resistivity values that will appear in the model to the resistivity value list. Type the value in the text box first, then click the Add Resistivity button.
- 5) To delete a value from the resistivity list, select the item to be deleted and then press the Delete key.
- 6) Add resistivity model blocks to the mesh. There are some trials and errors involved here. You may add only one rectangular block at a time. The location and dimension of a rectangular block are defined in a mesh cell coordinate system by the cell ID and number of cells, not by the distance or length.

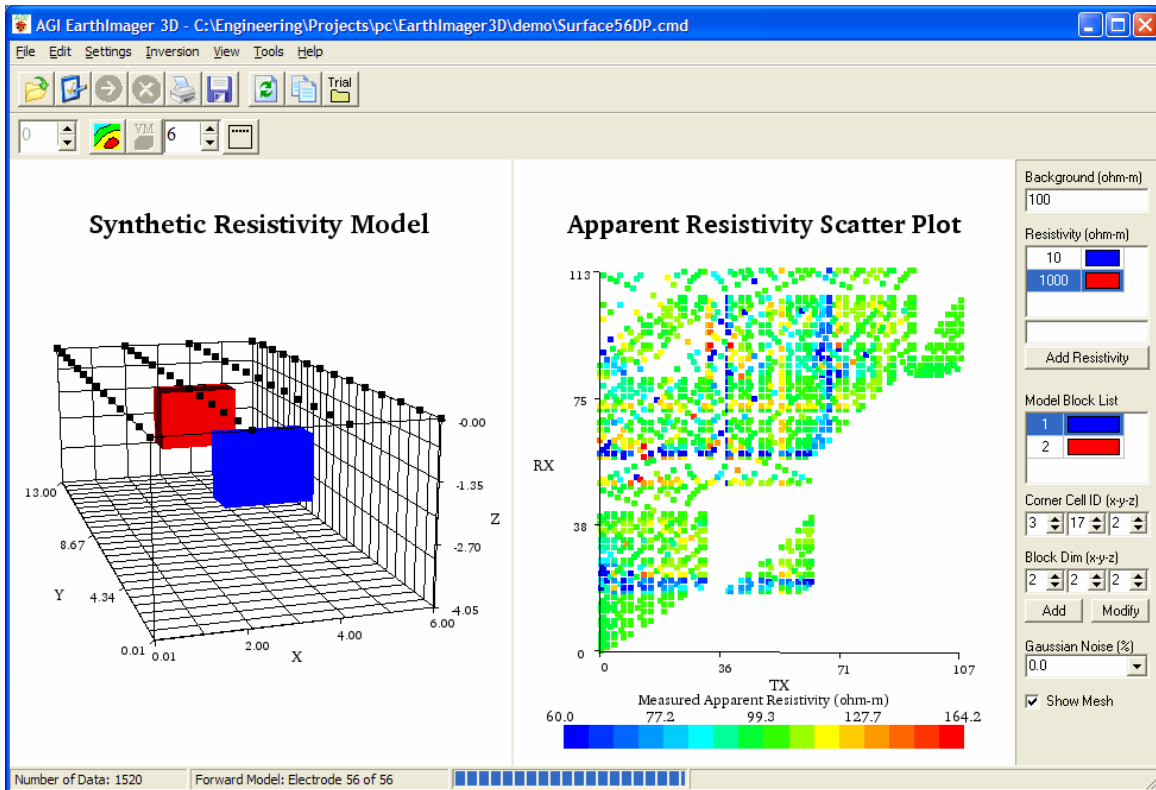
- 7) The location of a rectangular block is defined by the Corner Cell ID of the block with the lowest X and Y coordinates and the highest Z coordinate. The cell is numbered from smaller coordinate to the larger coordinate for both X and Y axes. But for the Z axis, the cell is numbered from the larger coordinate (top) to the smaller coordinate (bottom). To show the discretization, check the “Show Mesh” box. After reading a command file, the Corner Cell ID is set close to the mesh center by default.
- 8) The dimension of the model block is defined by the number of cells in X, Y and Z directions. After reading a command file, the block dimension is initialized to 2 cells in all directions by default.
- 9) Select a resistivity value from the resistivity list as the resistivity of the current model block.
- 10) Add a new model block by clicking the Add button.
- 11) The model block location can be changed by clicking three settings for Corner Cell ID, and the model block size can be changed by clicking three settings for Block Dim.
- 12) You may modify the block resistivity by first selecting the model block from the Block List, then selecting a resistivity value from Resistivity value list, and finally clicking the Modify button. The selected model block is shown brighter in the mesh.
- 13) To delete a model block, select the block in the Block List and press the Delete key.



- 14) To add random noises to the synthetic data, set Gaussian Noise to a non-zero positive value. Note that the measurement noises and numerical errors are usually below 3%.
- 15) Choose the menu item Forward Simulation from the Tools menu. This will start the forward simulation. The forward modeling solution is computed electrode by

electrode. At the end, you will see an apparent resistivity scatter plot to the right and the synthetic model to the left of the main window.

- 16) To format the graphics, choose tool buttons on the top toolbar under the main menu.
- 17) To browse different images, choose a desired menu item under the View menu.
- 18) You may save or print your on-screen image through the File menu or tool buttons.



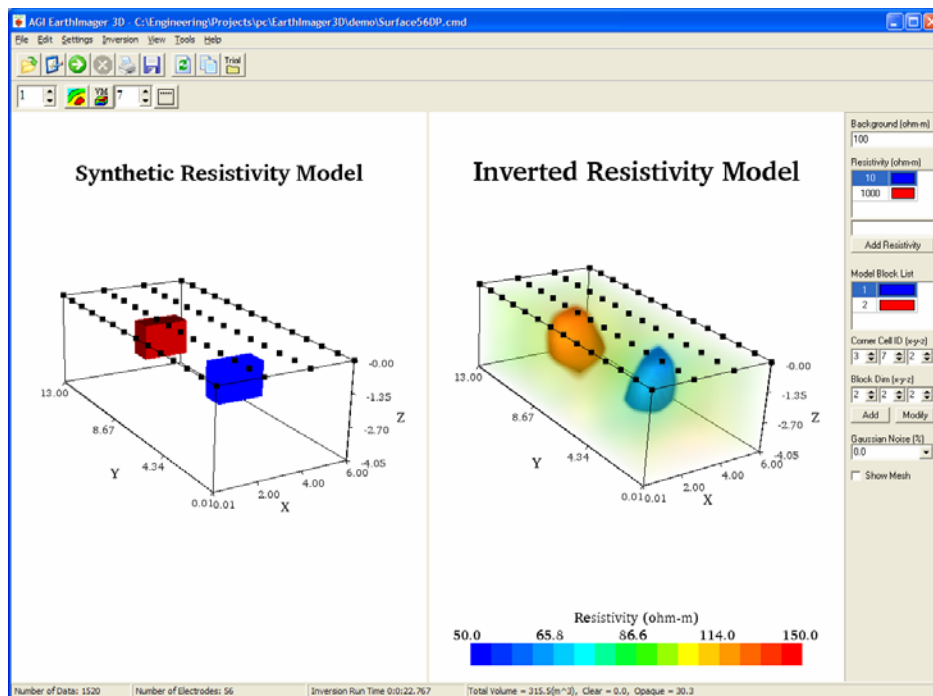
At the end of forward simulation, you will find four files saved in the current trial directory automatically. The INI file is a formatted inversion settings file and may be loaded into EarthImager later. The OUT file contains some descriptive information but it is not very useful here. The STG file contains synthetic data and may be read into EarthImager for inversion. The MOD file is a model file that contains information about the model you built. The MOD file is not usable by EarthImager at this time.

6.8.3 Survey planner

To run Survey Planner, follow steps (1) through (12) of forward simulation. In addition, you should

- 1) Choose an inversion method from the Initial Settings page of the Settings Window,
- 2) Set your desired inversion settings from the Resistivity Inversion settings page of the Settings Window. This should be done before loading the command file.
- 3) Instead of Forward Simulation, choose Survey Planner from the Tools menu.

- 4) The Survey Planner will generate the synthetic data first, and then invert the synthetic data. So the Synthetic Data Image is displayed first and then the iterative inversion images with the cross plot and inverted resistivity volume plot.
- 5) At the end of inversion, you may view all kinds of images from the View menu. The most useful image would be the Survey Planner Images with the synthetic model and inverted model shown side by side for comparison of the model resolution.
- 6) At the end of inversion, you will find seven files saved in the current trial directory automatically. Here are descriptions of these seven files:
 - INI file is a formatted inversion settings file and may be loaded into EarthImager later.
 - OUT file contains some descriptive information about inversion settings, mesh and statistics, and predicated data and inverted model from iteration to iteration. The OUT file can be read back in EarthImager for data analysis and visualization.
 - STG file contains synthetic data and may be read into EarthImager for inversion.
 - MOD file is a model file that contains information about the model you built. The MOD file is not usable by EarthImager at this time.
 - JPG files (2) are the cross plot and inverted 3D volume image at the optimal iteration with either lowest RMS error or lowest L2 norm.
 - DAT file contains the inverted resistivity model in an ASCII XYZ format.

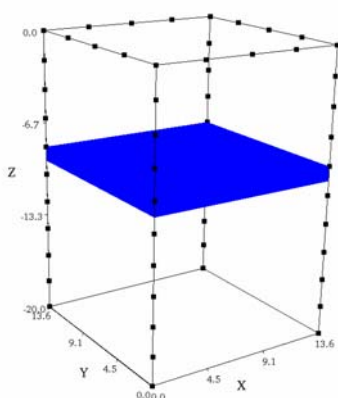


6.9 Electric Field Modeling

This tool models electric field distribution of a pair of current electrodes. Electric potential and electric current density fields are modeled and displayed. Follow these steps to run this modeling tool.

- 1) Read a command file which contains information about the number of electrodes and electrode coordinates. A pair of electrodes A(+) and B(-) will be chosen from this electrode list as current electrodes.
- 2) Build a synthetic resistivity model in the same way as in the survey planner, for example, a conductive thin layer in a homogeneous half space (see below).
- 3) Choose to the menu Tools | Electric Field Modeling to launch an interface to choose a pair of current electrodes, for example, electrodes #3 and #22.

Synthetic Resistivity Model



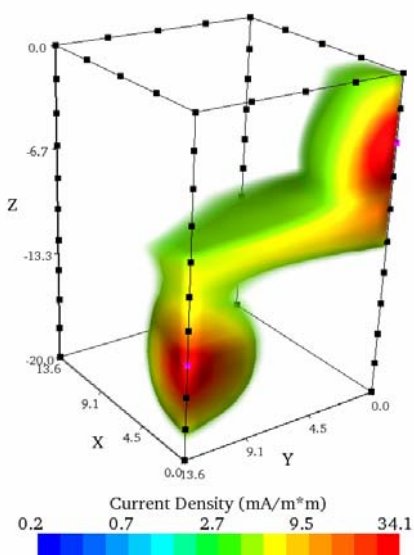
Choose A Pair of Current Electrodes

Current Electrode A(+)		Current Electrode B(-)	
ID	3	ID	22
X	0.000	X	0.000
Y	0.000	Y	13.600
Z	-4.000	Z	-14.000

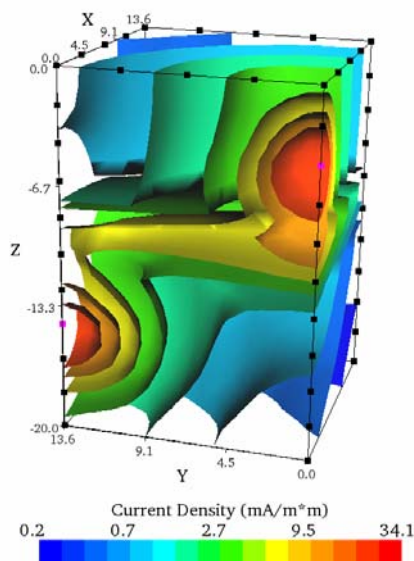
Model Electric Field

- 4) Click the button Model Electric Field to start numerical modeling. At the end of modeling, a volume image showing electric current density distribution will be shown as below. To view more images, go to the menu View | Electric Field Images.

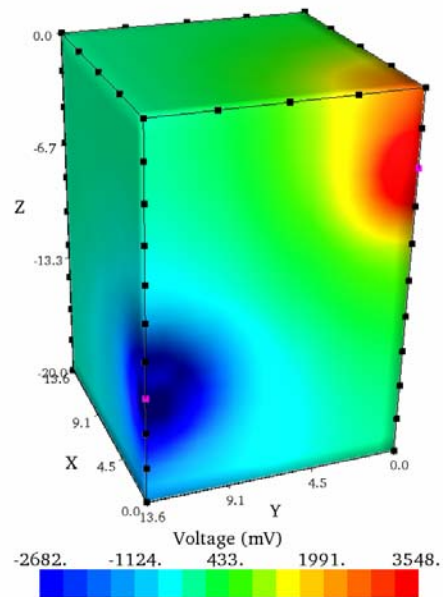
Electric Current Density Image



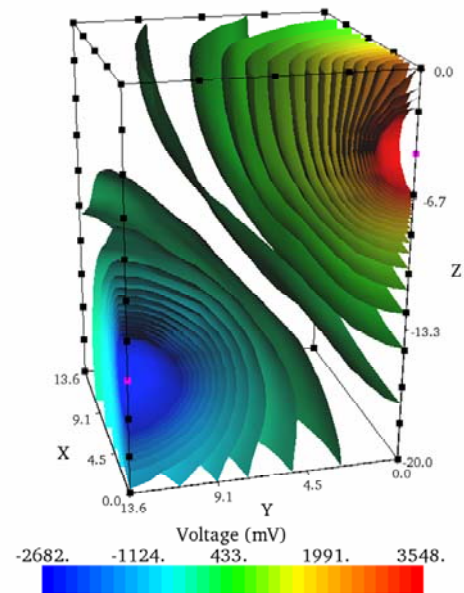
Electric Current Density Isosurfaces



Electric Potential Image



Electric Equipotential Surfaces



7. THEORY OF INVERSION

7.1 What Is Inversion?

Resistivity surveys measure injected current (I) through transmitting electrodes and potential difference (voltage V) between two receiving electrodes. Measured current and voltage together with electrode geometry (K) may be converted into apparent resistivity (ρ_a). Normalized voltage by current (V/I) and apparent resistivity ρ_a are data in the inversion. V/I and ρ_a data are equivalent quantities that can be converted back and forth with the help of a geometric factor K .

The goal of resistivity survey is to image a subsurface resistivity distribution which is closely correlated with subsurface geology. The subsurface resistivity distribution (or its reciprocal electrical conductivity) is the model parameter in the inversion.

The model is the partial differential equation that governs the relationship between data and model parameters.

Forward modeling is defined as the process of predicting the data on the basis of the known distribution of model parameter, electrode configuration, and model. It is a mapping from the model space to the data space. Forward modeling creates synthetic data sets. It is also known as forward simulation, forward problem, and forward solution.

Inversion is defined as the process of determining the estimates of the model parameter on the basis of the data and the model. Inversion is a mapping from data space to model space, and it reconstructs the subsurface resistivity distribution from measured voltage and current data. Inversion is also known as inverse modeling, inverse simulation, and inverse problem.

The resistivity data inversion proceeds as follows.

- 1) A starting resistivity model is constructed based on either the average apparent resistivity, apparent resistivity distribution, user assumption, or a-priori knowledge of subsurface resistivity distribution.
- 2) A virtual survey (forward modeling) is carried out for a predicted data set over the starting model. The initial root mean squared (RMS) error at the 0th iteration may be calculated at this step.
- 3) Solve a linearized inverse problem based on the current model and data misfit for a model update ($\Delta\mathbf{m}$).
- 4) Update the resistivity model using a formula like this: $\mathbf{m}_{i+1} = \mathbf{m}_i + \Delta\mathbf{m}$. The model parameter $\mathbf{m}$ consists of electrical conductivity of all model blocks in the finite difference or finite element mesh. The symbol i is the iteration number.
- 5) Run a forward modeling (virtual survey) based on the updated model for an updated predicted data set.
- 6) Calculate a new RMS error between the predicted data and the measured data.
- 7) If any of inversion stop criteria is satisfied, stop the inversion. Otherwise, repeat the Steps (3) to (7).

For a thorough understanding of inversion theory, the user is encouraged to go through the suggested readings at the end of this manual.

7.2 Forward Modeling

We are dealing with a 3D problem here, that is, a 3D earth model with a 3D arbitrary resistivity distribution and 3D electrical field due to a point source. It has become a standard practice to solve 3D resistivity forward modeling problem using numerical methods by discretization of the domain of investigation.

The forward solution can be obtained by solving the partial differential equation:

$$\frac{\partial}{\partial x} \left(\sigma \frac{\partial V}{\partial x} \right) + \frac{\partial}{\partial y} \left(\sigma \frac{\partial V}{\partial y} \right) + \frac{\partial}{\partial z} \left(\sigma \frac{\partial V}{\partial z} \right) = I(x, y, z),$$

where V is the scalar electrical potential, and $I(x,y,z)$ is the electric current source term. The finite difference method with an elemental volume (Dey and Morrison, 1979) was used to discretize the partial differential equation above. Dirichlet and mixed boundary conditions (Dey and Morrison, 1979) were implemented. The matrix system was iteratively solved by a conjugate gradient (CG) method.

7.3 Smooth Model Inversion

The underdetermined and ill-posed nature of 3D resistivity inverse problems makes the inverse solution inherently non-unique. Additional constraints, or regularization, must be imposed on the model to single out one optimal solution. The smooth model inversion, also known as Occam's inversion, finds the smoothest possible model whose response fits the data to *a-priori* Chi-squared statistic. The true model must be at least as, but never less complex than, the smooth model obtained through smooth model inversion. Smooth model inversion is based on the assumption of Gaussian distribution of data errors. The objective function of smooth model inversion is given by

$$\mathbf{S}(\mathbf{m}) = (\mathbf{d}_{obs} - g(\mathbf{m}))^T \mathbf{W}_d (\mathbf{d}_{obs} - g(\mathbf{m})) + \alpha \cdot \mathbf{m}^T \mathbf{R} \mathbf{m}$$

α is a Lagrange multiplier and a stabilizing factor. It determines the amount of model roughness imposed on the model during the inversion. $\mathbf{R}$ is a roughness operator. The smooth model inversion algorithm was originally described in Constable et al. (1987) and DeGroot-Hedlin and Constable (1990).

8. HELP

8.1 Instruction Manual in PDF

This menu item brings up a PDF help file in Acrobat Reader.

8.2 AGI Home Page

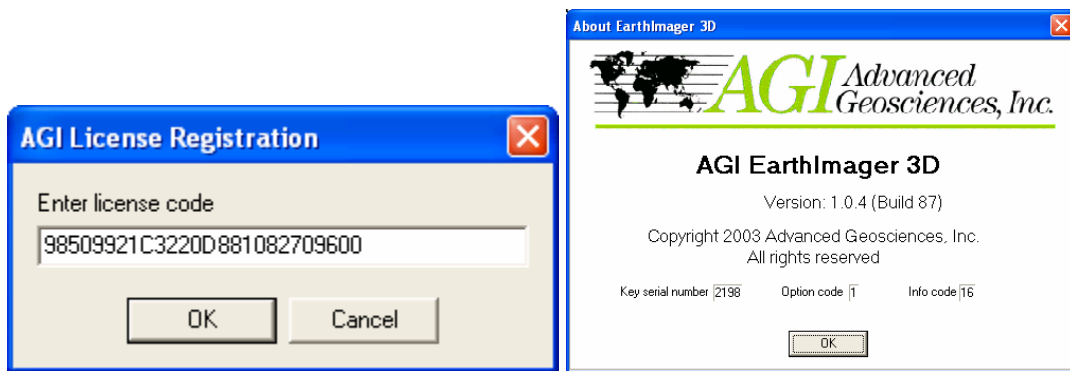
This will lead to the website of Advanced Geosciences, Inc. at <http://www.agiusa.com/>.

8.3 EarthImager User Group

This is an AGI EarthImager support page with software updates for users to download. The website address is <http://www.agiusa.com/files/eicust/earthimageruser.shtml>. Refer to the Section 1.2 for more detail.

8.4 Upgrade

The menu item Help | Upgrade brings up a dialog box for user to enter an upgrade license code. An EarthImager upgrade means to add one or more special-purpose software modules to EarthImager and AGI charges an upgrade fee to add a new module. Refer to the Section 2.4 for more detail. The license code below is invalid and it is for illustration only.



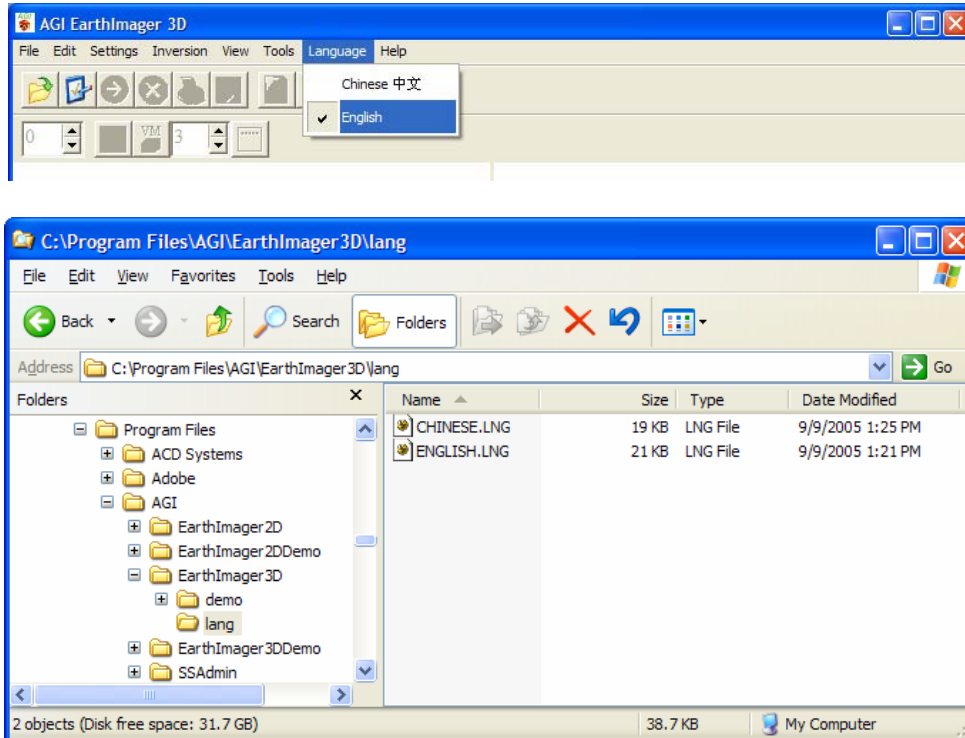
8.5 About EarthImager 3D

This will display a message box showing program name and copyright information. The AGI logo is also a link to the AGI website.

9. MULTILINGUAL SUPPORT

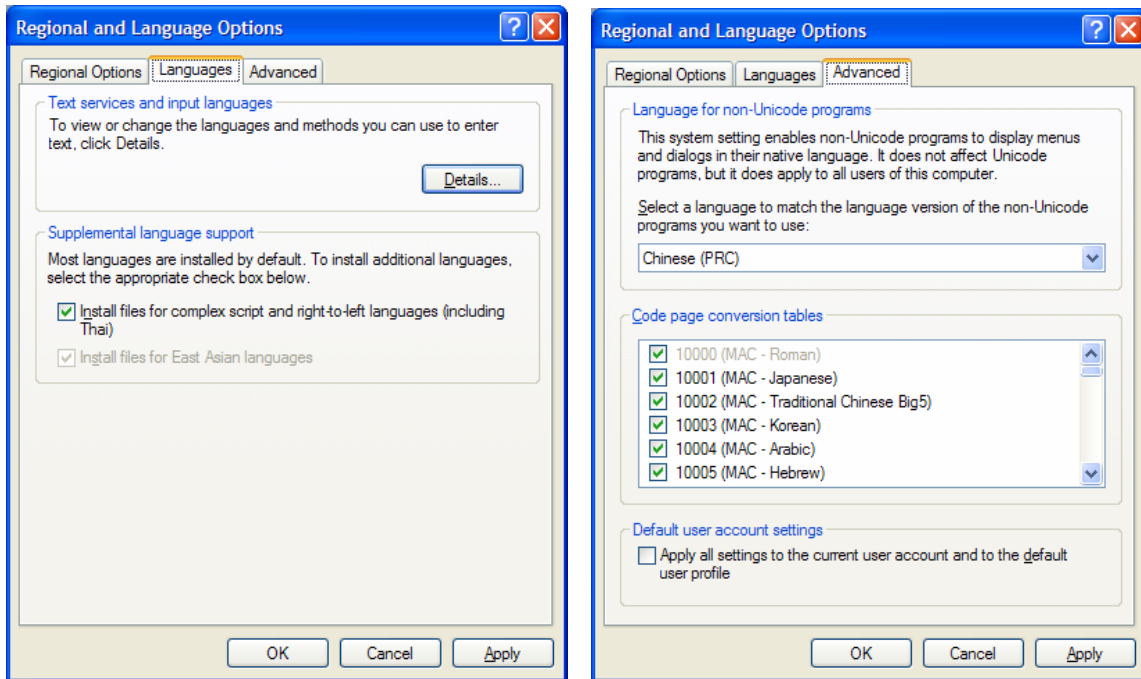
9.1 Introduction

We added multilingual support to our data processing software such as AGI SuperSting Administrator, EarthImager 2D and EarthImager 3D. Now you can translate EarthImager GUI into your own language by yourself. To add support for a new language, all you need to do is to translate the language file.



A “Language” menu was added on the main menu of EarthImager. Supported languages are listed under the language menu. In the figure above, both English and Chinese are supported. More languages will be added soon. The language files are installed, by default, in the folder: C:\Program Files\AGI\EarthImager3D\lang. All supported languages would have a language file listed in this folder.

To display EarthImager user interface in a different language, one needs either a local-language version of Windows or appropriate setups for the local language. These settings are located in Control Panels | Regional and Language Options. The two screen shots below show the English-version Windows setups for display of the EarthImager user interface in Chinese.



9.2 Add Your Language to EarthImager

To turn EarthImager GUI in your language, simply make a copy of ENGLISH.LNG as MYLANGUAGE.LNG, for example, FRENCH.LNG, and translate the key words in the new language file into your language. **Please do not delete or modify the English language file ENGLISH.LNG.** Here are first few lines of ENGLISH.LNG:

```

1      [Info]
2      Language=English
3      [Font]
4      Name=MS Sans Serif
5      Charset=1
6      [TfrmMain]
7      Caption="AGI EarthImager 3D"
8      ToolBar1.Hint="Tool Bar"
9      tbSettings.Caption="Inversion Settings Window"
10     tbSettings.Hint="Inversion Settings Window"
11     ToolButton9.Caption="ToolButton9"
12     tbClipboard.Caption="tbClipboard"
13     tbClipboard.Hint="Copy image to clipboard"
14     tbCurrentTrialDir.Caption="Current trial directory"
15     tbCurrentTrialDir.Hint="Current trial directory"

```

The line numbers from 1 to 15 are not part of the language file and they are added for illustration purpose only. On the second line *Language=English*, change the word “English” into your language name. This name will be the menu item name under the Language menu. On Line 4,

choose a font name of your native language. Finally, translate all quoted text on the right hand side of “=” sign from Line 7. That is, you should translate *"AGI EarthImager 3D"*, *"Inversion Settings Window"*, etc. into your own language. The double quotation signs should be kept and your translation should be kept inside the double quotation. Here is a sample translated Chinese language file (CHINESE.LNG):

```
[Info]
Language=Chinese 中文
[Font]
Name=MS SONG
Charset=1
[TfrmMain]
Caption="AGI 三维地质成像软件"
ToolBar1.Hint="Tool Bar"
tbSettings.Caption="反演参数窗口"
tbSettings.Hint="反演参数窗口"
ToolButton9.Caption="ToolButton9"
tbClipboard.Caption="tbClipboard"
tbClipboard.Hint="复制图像到粘贴板"
tbCurrentTrialDir.Caption="当前输出路径"
tbCurrentTrialDir.Hint="当前输出路径"
```

Once you complete the translation of English language file into your language, please email us a copy of your new language file (yang@agiusa.com). If you find any inappropriate translation in any language file, please inform us or email us the corrected language file.

SUGGESTED READINGS

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