The coordinate system

Normally, the Horizontal coordinate system is used for such systems in EMIGMA.



Horizontal Coordinate System

_direction of unit vectors change with profile direction
\$\hat{X}\$ and \$\hat{Y}\$ are horizontal and \$\hat{Z}\$ is up.
\$\hat{X}\$ is directed parallel to the tangent of the profile at each station.
\$\hat{Y}\$ is perpendicular to the tangent at each station
\$\hat{t}\$ the station locations are your normal GPS or grid values

Transmitters and Receivers



System Components • the transmitter and receiver are both wound coils • a current is injected into the transmitter coil and this produces a magnetic moment. • the magnetic field caused by the transmitter and the ground running through the receiver coil produces a voltage which is output • the voltage output can be converted to a value of magnetic field coupling with the coil if desired • the measured magnetic field is aligned with the moment of the receiver coil • mathematically the source and receiver are defined as point electric dipoles – this is satisfactory as the coils are small with respect to the tx-rx separations

Data Processing



Imag

output voltage (w) or (f)

Re complex plane

Normalization



Instrument Aspects

 \circ a square wave current of a certain frequency is injected into the transmitter

the fundamental harmonic of this boxcar is extracted in the receiver which produces a real part and an imaginary part
the real part is inphase with the current in the transmitter
the imaginary part is out of phase with the current

Inphase – a common name for the real part of the output Quadrature – a common name for the imaginary part of the output

Normalization

the strongest field is that directly from the transmitter which contains no part of the ground response
this direct (primary) field is inphase and can be computed if the coil strength and the current are known
this primary field is removed from the output voltage either by computation or by the use of a bucking coil (e.g. airborne systems)
the remaining voltage is the ground response
the remaining or secondary voltage is then divided by the primary voltage which was previously subtracted
the resulting voltage output is then dimensionless
depending upon the manufacturer the resulting voltage can be adjusted to different units



Additional Comments

○ in an airborne system, the tx and rx and housed in a bird which is flexible during flight and thus normally a bucking coil is used to reduce and normalize to the primary response

◦ in the PROMIS system, 3 components of the secondary field are measured simultaneously and so the coil orientation of tx and rx should be made accurately

 \circ in the older MaxMin system, one can measure Hx as well as Hz but the orientation of the receiver coils in both cases must be made accurately

Data Units

<u>Data Units</u>

the raw response is always calculated according to the formula below
this ratio, however, can be expressed in various units as below

Response (Re, Im) = { <u>Measured Voltage (Re,Im) – Primary Field</u> } Primary Field

InPhase Units – Percent (%), PPT, PPM Quadrature Units – Percent (%), PPT, PPM, *apparent conductivity*

Primary Field: Theoretically, this is the direct wave from the TX to the RX or what is termed the Freespace response. If calculated this is the theoretical, low frequency field in an infinitely resistive space and thus is a real number. In practice, when bucking is applied there will be a small imaginary part to this field depending upon frequency.

Data Units Apparent Conductivity

it should be noted that the word "apparent" is extremely important for understanding these units
this does mean actual conductivity, but rather the ratio expressed in terms of an approximate formula
which represents an equivalent halfspace for the ground and not the actual ground conductivity
the formula assumes a halfspace for the ground and then only one (1) term in the accurate representation
from physical principles of such a system as discussed later.

Data Units – apparent conductivity

Data Units Apparent Conductivity

it should be noted that the word "apparent" is extremely important for understanding these units
this does mean actual conductivity, but rather the ration expressed in terms of an approximate formula which represents an equivalent halfspace for the ground and not the actual ground conductivity
the formula assumes a halfspace for the ground and then only one (1) term in accurate representation of such a system from physical principles
in the formula below "s" is the distance between transmitter and receiver. This formula assumes no effect from the (1/s) term in the response (far field)
if indeed the ground is a halfspace then the expression is most accurate when the induction number, [σ ωμ₀ s²] is small
this approximation is also intended when the instrument is directly upon the ground and becomes increasing incorrect very quickly as the instrument is raised above ground
in practice with commercial systems, this approximation is reasonable for systems with 1m separation (s)

 \circ the unit is useful only for non-scientists

$$\sigma_{app} = \frac{4}{\omega \mu_0} \frac{(B)_{quadrature}}{B_{primary}}$$

Tx-Rx separations in EMIGMA



Tx-Rx separations in EMIGMA

Some Examples

standard horizontal coplanar inline system configuration (HCP): Tx – Mz ; Rx – Hz; separation (dx, 0, 0) [EM38 – (1,0,0), EM31 – (3.66,0,0), GSSI – (1.219,0,0)
standard horizontal coplanar crossline system configuration (HCP): Tx – Mz ; Rx – Hz; separation (0, dy, 0)
standard vertical coplanar in line system configuration (VCP): Tx – My ; Rx – Hy; separation (dx, 0, 0)
standard vertical coplanar crossline system configuration (broadside VCP): Tx – Mx ; Rx – Hx; separation (0, dy, 0)

Configuration Page Example in EMIGMA – EM38

Tx-Rx			×	
System Name		System Type Moving Tx, Moving Rx		
1. System Mode EM/IP/Resistivity	Transmitter Coord.System: Horizontal: X horizontal along profile, Z ver	tica 💌		
C Fixed C Moving 2. Transmitter Type Coil C Current Dipole Dipole Moment (Amp [*] m ²) Transmitter Input> Transmitter Input> Transmitter Input>	1. TX-DIPOLE Mz 2. TX-DIPOLE My 3. TX-DIPOLE Mx	SEP-REF-POINT AT CENTER # X Y Z 1. 1.000e+000 0.000e+000 0.000e+000 2. 0.000e+000 1.000e+000 0.000e+000		
Add Replace Multiple Tx Generator	Receiver Coord System: Horizontal: X horizontal along profile, Z ver	rtice Component 4 Select All Create Comp		
3. Receiver Type Coll C Voltage Dipole Coll C Poltage	1. RX-DIPOLE Hx 2. RX-DIPOLE Hy 3. RX-DIPOLE Hz	Tx Rx Sep 1 3 1 2 2 1	-	1. Mz, Hz, (1,0,0)
Receiver Input>		1 3 2 K 3 1 F		2. My, Hy, (1,0,0)
				3. Mz, Hz, (0,1,0)
Ip/Res System Wizard				4. Mx, Hx, (0,1,0)
		<back, next=""> Cancel Help</back,>	_	

System Configurations

0 1: standard HCP

0 2: standard VCP

◦ 3: standard HCP crossline

0 4: standard VCP crossline, broadside

Opening a database







C EM34 C EM38 C EM31-3 C Max-Min C Fugro

C AeroQuest

PROMIS
 DUALEM

Importing Data - 2

Select System

For other systems select *Unknown* and provide a name

◯ GEM-2 GSSI Profiler Inputs. Import Wizard Step 1. X C Unknown GSSI Profiler System Name E:\Radenko\Example\EMP400 122 break.gct Input Filename Browse QCT file C ASCII file et header line X Y Line Station XCoord. YC 🔺 0.00 1.____ 2. 0.00 0.00 0.00 0.00 Apply first Multiplier 0.00 0.15 0.00 1.00 0.00 0.00 0.30 0.00 2.00 0.00 3. 🔻 • Apply first Separation Correction Tx - Rx Orientation Tx Rx Tx - Rx Separation dY Frequency Multiplier dΧ ďZ --15000 Z • 1.219 $\mathbf{\nabla}$ Z 0 In. Z $\mathbf{\nabla}$ Z 10000 1.219 0 O • • $\mathbf{\nabla}$ 5000 Z Z 1.219 0 Browse for .qct data file - $\overline{\mathbf{v}}$ --Г -г -**v** -- τ - $\overline{\mathbf{v}}$ Tx Leads Rx along Profile O Rx Leads Tx along Profile < Back Next > Cancel Help 帮助

First, import your data to QCTOOL making any changes required Then use the .qct file for importing

puts. Impo	ort Wizard Step 1.			×	
Input Fi C QC1 X 0.00 0.00 0.00 4	lename E:\Radenko\Example\E file C ASCII file V Line 0.00 0.00 0.15 0.00 0.30 0.00	Station XCoord YC ▲ 0.00 0.00 1. 1.00 0.00 2. 2.00 0.00 3. ▼	Browse Set header line Apply first Multiplier Apply first Separation	Chai	If the instrument was in the list on the first page default settings will be made for the system configuration. Check the system configurations and alter if required.
	Frequency Tx - Rx Orient. Tx 15000 Z Z Z 00000 Z Z Z Z 3000 Z Z Z Z 2 Z Z Z Z Z 3 Z Z Z Z Z	Lation Bx Correction Multiplier T 2 1 1.219 2 1 1.219 2 1 1.219 2 1 0 7 1 0 7 1 0	History dz 0 0 0 0 0 0 0 0 0 0 0 0 0 0	vey	If the instrument was not included in the list, then all settings must be made manually. Contact <u>support@petroseikon.com</u> to have your instrument added to the instrument list.
	Leads Tx along Profile	Y 1 0 Y 1 0 Y 1 0 Y 1 0 Y 1 0	0 0 0 0 0 0 0 0 0 0 0 0	espa	In this case, there are three instrument configurations. All three are HCP and thus the dipole settings are Z for Tx and Z for Rx. All three configurations have the same separation between Tx and Rx at 1.219m. But, each configuration is collected at a different frequency. This interface allows you to define any dipole-dipole instrument configuration.
		< Back Next	> Cancel Help 帮助		

Transmitter and Receiver location on the instrument is set by using the two choices on the lower left. If you are only considering doing 1D inversions, this issue is not relevant but for 3D modeling and 3D plate inversion this issue is critical. The Tx is usually at one end of the instrument and the Rx's are located down the instrument. Whether the instrument is carried or pulled with the Tx in the front as you move or behind is being defined by this selection.

its. Im	port Wizard	Step 1.							
Input	: Filename	E:\Rade	enko\Example\E	MP400_122_	break.gct		E	Browse	
ΘQ	ICT file	O ASCI	l file						
			Line	Station			Set	header line	
0.0	0	0.00	0.00	0.00	0.00	122	Apply	first Multiplier	
	0	0.30	0.00	2.00	0.00		Apply fi	rst Separation	1
	Frequenc	уy	Tx - Rx Orient Tx	ation Rx	Correction Multiplier	d× T×	- Rx Separati dY	on dZ	
◄	15000	X	. ×	•	1	0	1.219	0	
◄	10000	×	• ×		1	0	1.219	0	
◄	5000	X	. X	•	1	0	1.219	0	
	0	— r	-	7	<u>1</u>	0	0	0	
	0	— F		7	1	0	0	0	
	0			7	1	0	0	0	
	0			7	<u>í</u>	0	0	0	
	0		~	~	1	0	0	0	

×

In this case, the instrument is in VCP mode with a broadside separation. Thus, the instrument is turned on it side towards the direction of movement and held perpendicular to the direction of traverse.

Note 1: Dipole orientations may be X, Y, or Z. These are in reference to the 'Horizontal'' co-ordinate system (Manual). For example, Z-Z is horizontal co-planar and Y-Y or X-X or vertical coplanar. Y is perpendicular to line and X is tangential to the line.

Note 2: Separations may be dX, dY or dZ. dX is along line while dY is across line. For example, a dipole configuration with X-X and a separation of (0, dy, 0) is vertical co-planar 'broadside'.



Check that the import has recognized the columns correctly. If the instrument is not on the list, then the correct channels need be selected for each data component and IP and Quadrature.

Set the height (clearance) of the instrument if there is no altimeter channel. If the instrument has GPS then a GPSZ channel should be available. Similarly for Lat/Long and station label (FID).

Check the data units for the instrument

Note:

mS/m is not an actual data unit. The data has been converted by the instrument manufacturer through an approximation to this unit. EMIGMA converts it back to the original data units. You may later display in these approximate units.

	1			
Profile	# Locations			-
LINE1	417		Total Number of Profiles:	14
LINE2	557			
	000			5000
INES	557		I otal Number of Locations:	losen
JNE6	531		- Modify Profile	/
LINE7	130			
LINE8	420			
LINE9	616			
LINE10	628			Delete
INE12	261		Pronie:	_ ×
JNE13	233		Delete every 2	Apply
LINE14	218			
Shift Value:			×	/
			Shift Coordinate Values (e.g.)	for resolution)
	Sample Value	Shift Value	Shift X 0	Reset
× Coordi	nate 553262.625	-550000		
			Shift Y 0	Change
Y Coordi	nate 4180924	-4100000		
_	Incore in	Tucces	Average Precision (m)	
-			Average Precision (m)	

You may choose not to import all profiles or decimate the data. But, both of these operations can be performed once imported to the database.

In addition, if you require sub-metre accuracy in your data positioning you may wish to strip off the leading numbers of the UTM positions. The import handles the coordinates in double precision but the database is a single precision data structure.

Rı

Sys	tem Parameters					
	Survey Type:		Moving Tx Mov	/ing Rx 💌		
	Coordinate S	ystems:	Horizontal	▼		
	Separation R	eference Point:	Center	•		
	Normalization	Туре:	Continuous			
	Normalization	Divisor:	Inphase	•		
	Normalization	Convention:	PPM	T		
			,			
Pro	ject Name	Survey 2				
Sur	vey Name:	EMP400_122_	break			
- Imp	ort to the Database—	Messages:				
	Average Duplicates					
	Run Import 🔶					
			<u></u>			
				1		
			< Back	Finish	Cance	Help 帮助

Here, we are defining several important factors in the instrument design.

Co-ordinate System: This is not the data location coordinate system but the coordinate system associated with the moving instrument. We discussed earlier the Horizontal co-ordinate system. But, if this were a borehole instrument then the coordinate system would be Bhole.

Reference Location: Here, we are defining where on the instrument the coordinates of the station are relevant. For example, are the coordinates that of the Tx, the Rx or the midpoint between Tx and Rx. In this case, there is only one TX-RX separation and thus the reference point is probably at the center. If using an EM31-R, then your data is probably positioned at a common Tx reference point. This is because the data is collected from a common Tx antennae

Normalization Divisor: Is the amplitude or inphase or quadrature of the primary field or freespace field being used as the normalizing value.

Run Import:

Importing Data - Final



Calculating Apparent Resistivity

_ 🗆 ×



Select Algorithm

Helicopter Data:

- Homogeneous half-space apparent resistivity model
- O Pseudo-layer half-space model + Centroid depth algorithm

	Homogeneous half-space app	parent resistivity model	<u>_ </u>
0		Select Components	
			Z
	Start Resistivity:	Target Type:	
	6.82238	C Inphase	
	0.01	Quadrature	
	,		
		PROCE	SS
		Finish Cancel	Help



The approximation used on pg5 by several instrument manufacturers in their output data is a suitable approximation under certain very limited circumstances. In this application, for each frequency and each component, a half space inversion is performed. This inversion is not limited to elevation or ground resistivity but is only limited to approximating the response as a halfspace. This approach was widely used when towed airborne FEM dominated airborne EM exploration.

Calculate the best fitting half-space ρ_{app} for any dipole-dipole configuration and frequency, airborne or ground. This will give you a more reasonable estimate of the ground resistivity. The second option is for airborne data only, fixed wing or towed helicopter.

Calculate the best fitting half-space ρ_{app} choose which data elements to use. *e.g. for EM34 then Quadrature is default. In some cases, the real and imaginary parts of the signal get 'mixed' due to calibration issues. In this case, you might try amplitude.*

This will process multiple components (ie. dipole-dipole configurations, lines and frequencies. A new dataset is output containing the apparent resistivities for all stations, lines, configurations and frequencies. [*e.g. Halfspace Rho_633*] as well as the simulated data for the halfspace. The ρ_{app} data may be loaded to the pseudosection tool.



Plotting Data - 1



(see EMIGMA tutorial for more details)



for apparent conductivity display: Settings ► Custom ► App Conducitivity

Plotting Data - 2



Gridding data - 1

	🛞 3D interpolation		
	Data		
Griddina	Survey Bounds F Data Number 2511 Min X 3115.32 r	Min Z Min Z (Altitude) 0.44	
	Profile Number 13 Max X 3192.95 M	ax Y 80890.65 Max Z (Altitude) 0.44	
	F		Salaat Components
	Select Data Select Components	All Components Responses	select Components
	Joata 1. Tx - Mz Rx - Hz Sep(1.0 0.0 0.0) Z (Altitude) 2. Tx - Mz Rx - Hz Sep(2.0 0.0 0.0) Tx - Mz Rx - Hz Sep(3.7 0.0 0.0) 3. Tx - Mz Rx - Hz Sep(3.7 0.0 0.0)	Total - Freespace	
	Te Method		
t Internalation ann	1 Natural Neighbour		
t interpolation app	4 Max Iteration 0 Channel Interpolation 2 Resolution Progress 3 Factor 1000		
	Current Process		
	o Set to zero		
	C Estimate	Remove Extrapolated Points	
	C Use Input	- Spatial Radius 1.49643	
	Load Grid	C Slow @ Fast	elect Extrapolation remo

- Interpolate to Grid, interpolate onto a regular grid

Set Grid Settings

Gridding data - 2



Interpolate to Grid, interpolate onto a regular grid Set Grid Settings

Gridding data - 3

3D interpolation Data Data		nterpolate to grid
Data Number: 279 Min X: 8468.72 Min Y: 88741.6 Min Z: Profile Number: 11 Max X: 8954.61 Max Y: 89190.3 Max Z: Interpolation Select Data for Interpolation: Interpolation: Interpolation: Data App Resistivity 1. Tx(Dipole My) Rx(Dipole Hy) Separ(10.00 0.00 0.00) 0.00 App Resistivity 2. Tx(Dipole My) Rx(Dipole Hy) Separ(10.00 0.00 0.00) 0.00 Method: Natural Neighbour Interpole Mail Rx(Dipole Hz) Separ(20.00 0.00 0.00)	0.2 0.2	☐ Model ☐ Grid(s) View Grid
Max Iteration: 0 Channel Interpolation Progress: Fractor: 1000 Status: Grid Image: Status: Derivative Information Grid Status: Set to zero Grid Setting Z - levet: C Estimate 0.2 Slow I dX I dY I dZ Load Grid Cancel	Grid Information Grid Data Set(s) NatNeighbour_634	Min Max N ptn delta Data Type: U -61.685368 61.685368 518 0.238628 Data V -11.766812 11.766812 25 0.980568 Statistics Z 0.440000 1 0.000000 Statistics Statistics
view grid characteristics - process and export	Data Created: 6/18/2025 10:02:47 Grid Data Set NatNeighbour_634 Change Name ID: 634 Delete Grid Related to: Project EM31-3 San Franciss Survey Central Data Set Data Set Measured FEM EM31 Data Set Measured Domain Type: Frequency Remove Extrapolated Points	Centroid of Grid Grid Azimuth (degrees) Components: Y: 80843.898437! 225.545 Z: 0.4399999976* 225.545 Frequencies 225.545 1

Viewing Gridded Data - 1

EMIGMA works with multi-layered grids which means more than one data element can be stored in a grid.



Viewing Gridded Data - 2



3D Contour



1D FEM Inversion – 1 System Configuration







This example is an EM31-3 survey over a levee in the southern US.



1D FEM Inversion – 2 Data Resolution

A survey line is shown to the left. With the system set as horizontal, the tangent to the profile in the direction of motion is always defined as the x-direction, y is perpendicular and horizontal and z is up.

A section of the profile is zoomed into and shows the average distance between stations as $\delta x \approx 1$. The separations between Tx and Rx are 1m, 2m, and 3.66m and the instrument is elevated at 0.42 above the ground.

Statistical Decimation: The data sampling is too fine at 1m spacings particularly for the 3.66m separation configuration. In this case, we suggest applying a statistical decimation. This algorithm takes data in a moving window and estimates the mean within the window based upon a Gaussian distribution. The value at the center point in the window is replaced by the mean and the remaining stations are deleted. An error estimate can be saved for each remaining station. This is performed on all the data elements and frequencies.

Statistical Decimation: For each profile, the number of data stations and the average station spacing is given. Under *Statistical Decimation* define your window width. In this case, the window width is 3 stations and the new station spacing is provided (\approx 3m). If you wish to store the estimated variance then select *Calculate Statistics*.

This tool can also do standard decimation as well as decimate profiles.

Profile	#Loc	Spacing	New	Delete Selected Profiles
LINEOa	816	1.01	3.03	
LINE1a LINE0b	847 936	0.97 0.88	2.90 2.64	Direct Decimation
LINE16	903	0.90	2.71	Delete every 2 location
				Apply
				┌ Statistical Decimation
				Delete 2 of 3 locations
				Calculate Statistics Apply
✓ Sele	ct All Profi	les		

This app is found in the data and model processing toolbox under Survey Editing.

1D FEM Inversion – **3** Data Calibration - A

In theory, this survey would have 6 data measurements available for inversion at each station. The more data for an inversion, the higher the resolution and the greater the assurance of a correct model. Correct can be in regard both to data quality and the limitation on the number of possible models (i.e. degree of nonuniqueness).

A longtime problems with FDEM systems is their tendency to become *out-of-tune*. We use this term as an analogy to a musical instrument particularly string instruments. The instruments are very sensitive to improper handling and of course, they can be returned to the manufacturer for tuning or learning to tune the equipment yourself but this is not always practical or within the user's technical capabilities. Probably, the only practical approach is to evaluate the data calibration through some simple forward models. Such models are easily done in EMIGMA and we will use this data as an example. Initially, we would suggest taking part of line where there are no sharp obvious 3D response and then statistically decimating to get the average trend over the line.

The next step is to run a few halfspace models either staring with what you may understand already about the ground resistivity or run the CDI and use these results as a start. In the case below, we used the CDI and ran a $10\Omega m$ and a $12\Omega m$ halfspace model. Below, to the left, we compare the quad data and the 2 models for all separations. The 10-12 Ωm models show we are in the ball park. The figure below, to the right, shows the response comparisons as a function of the coil separation.

This study may not be entirely sufficient to check the calibration of the quadrature data but takes us to the next step where inversion is applied. However, first, we must check the IP data.



1D FEM Inversion – 3 Data Calibration - B

Using the Inphase (IP) is often much more difficult. Many instruments only produce IP which can be used only qualitatively.



-E- L0a, Y 60221.0, 9800 Hz, T-F(I S - 1 OHMM) - MZ1 Hz L0a, Y 60221.0, 9800 Hz, T-F(I S - 10 OHIMM) - MZ1 Hz
 L0a, Y 60221.0, 9800 Hz, T-F(I S - 12 OHIMM) - MZ1 Hz - L0a, Y 60221.0, 9800 Hz, T-F(I S - 100 OHMM) - MZ1 Hz

model

VCP

8.0

6.0

4.0

2.0

1.00

1.50

2.00

2.50

Separation Length (m)

3.00

3.50

Percent

The figure at the top left is the HCP IP at 9800 Hz for the 3 separations used in this survey. The models are 1, 10, 12, 100 Ω m and a layered model which is $1\Omega m$ over $12\Omega m$. In the bottom centre is the same but for VCP.

As can be seen the IP responses are all positive and increase, monotonically, with separation and this is what is expected if the ground is primarily stratified. Of course, it the ground contains 3D structures whether conductive and/or magnetic this would change. The responses for the VCP are the same but the responses are slightly smaller as predicted by theory.

In the figure on the bottom right we plot the IP for all 3 separations for both HCP (pinks) and VCP (greens) at 7 stations ranging over 50m. The IP neither follows the model examples nor are the VCP and HCP related to each other as expected in a stratified earth. Additionally, the IP for both HCP and VCP start negative at the 1m separation. The VCP is negative for all 3 separations and the HCP's IP response drops to near zero for the 3.66m separation.



1D FEM Inversion – 3 Data Calibration - C

If we plot the data IP for all 3 separations over a slightly larger distance than in the figure on the previous page, we see that there is no obvious higher dimensional response in the IP data.



The figure on the left is the IP for the 3 separations (1m –red, 2m –blue and 3.66m green). There are not strong variations in this data over this 100m but there is a trend in both the 1m and 2m data.

The VCP data has much the same variations over this section of the line. The difference being the 3.66m separation is by far the strongest component in the VCP data while this separation is the smallest in the HCP data.

For additional confirmation, we show the quadrature data over this 100m section of the data (below). The quadrature shows a very smoothly varying 1D response.

The results are similar over other sections of the survey that we have analyzed.

<u>CONCLUSION</u>: The initial analyses indicates that the 3 quadrature data elements may be used in an stratified layered earth inversion (1D) but the IP data cannot be used in such a process.



1D FEM Inversion – 4 using the tools 1

4 inversion algorithms are provided. However, the two at the top (*L1 and Standard LS Occam*) are provided primarily for student exercises.

VERSION. Style and Data Selection Inversion Technique O L1 - Linear Begression O Standard Least Square Occam	The two choices in the bottom are -Trust Region: steepest descent fully constrained technique
 Trust Region (underparameterized method) Enhanced Conjugate Gradient Occam with Susceptibility Extension 	-Enhanced CG Occam – smooth model technique
Frequencies Components & Separations 1 9800.000 1 Rx-Hz Tx-Mz -1.000 0.000 0.000 2 2 Rx-Hz Tx-Mz -2.000 0.000 0.000 3 Rx-Hz Tx-Mz -3.660 0.000 0.000 3 3 Rx-Hz Tx-Mz -3.660 0.000 0.000 3 0.000 0.000 0.000 0.000 4 Rx-Hy Tx-My -1.000 0.000 0.000 5 Rx-Hy Tx-My -2.000 0.000 0.000 6 6 Rx-Hy Tx-My -3.660 0.000 0.000 0.000 0.000 0.000 0.000	Choose frequencies to use and data components to use. In this case, only 1 frequency but 6 components – 3 HCP and 3 VCP.

Trust Region: thickness and resistivity are model parameters. Allows inverting for a realistic number of layers and obtaining exact depth within the limitation of data quality. This is our suggested technique as it is the technique most likely to obtain a unique solution. **Enhanced CG Occam:** In regard to the layer thicknesses, this is a standard approach where only the resistivities are inversion parameters. This technique allows for highly over parametrized model which are thus highly non-unique solutions. Assuming the Inphase data is good, this technique can also invert for susceptibility

1D FEM Inversion – 4 using the tools 2a

Set a layered starting model for inversion. The model consists of several layers over a half space with resistivity and thickness defined for each of them. Note: the model does not include the upper half space (i.e. the air). Generate uniform layers Total layers above half space Resistivity 100 Total layers above half space Resistivity 0 Inversion Parameters Resistivity Susceptibility Layer # Resistivity Susceptibility Thickness Inversion Parameters 0 Resistivity Susceptibility Thickness 1 1 188.33 0.000 0.40 2 3.15 0.000 0.09 3 3 36.82 0.000 3.58 4 4 3.87 0.000 100000000.00 Add to List Import From previous inversion result From a dataset Import Set parameter boundary and parameters to Invert Allowed number From Parameters to invert Parameter bounds and parameters to invert	NVERSION. Starting Mo	del		_ [1×
Note: the model does not include the upper half space [i.e. the air). Generate uniform layers Total layers above half space Total layers above half space Total thickness above half space Resistivity Inversion Parameters Resistivity Resistivity Resistivity Resistivity Resistivity Susceptibility Thickness Inversion Resistivity Susceptibility Thickness Thickness Insert Replace Add to List Import a layer model From previous inversion result From previous inversion result Set parameter boundary and parameters to Invert Allowed number Set parameter boundary and parameters to Invert Allowed number Parameter bounds and parameters to invert	Set a layered starting mod resistivity and thickness d	del for inversion. The moc lefined for each of them.	lel consists of several l	ayers over a half space wit	h
Generate uniform layers 100 Total layers above half space 7.32 Susceptibility 0 Inversion Parameters Inversion Parameters Apply Inversion Parameters Susceptibility 0 1 Inversion Parameters Susceptibility Thickness 4 Inversion Parameters Susceptibility Thickness 1 Inversion Parameters Imply Susceptibility Thickness Import Import a layer model Import Import Import Import a layer model From previous inversion result From a dataset Import Allowed number 6 Parameter bounds and parameters to invert Allowed number 7 Parameter bounds and parameters to invert	Note: the model does not	include the upper half sp	ace (i.e. the air).		
Total layers above half space Resistivity 100 Total thickness above half space 7.32 Susceptibility 0 Inversion Parameters Inversion Parameters Apply Resistivity Susceptibility 0 1 Layer # Resistivity Susceptibility Thickness Inversion Parameters 0 1 1 Resistivity Susceptibility Thickness 1 Insert # Resistivity Susceptibility Thickness (m) 1 188.33 0.000 0.40 2 2 3.15 0.000 0.09 3.58 I4 3.87 0.000 100000000.00 Add to List Import Import Import Import a layer model From previous inversion result From a dataset Import Set parameter boundary and parameters to Invert Allowed number 6 Parameter bounds and parameters to invert Selected number 7 Parameter bounds and parameters to invert Import	Generate uniform layers				_
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Insert Head of the second	-Inversion Parameter	18		, , , , , , , , , , , , , , , , , , , ,	
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	Selected number	7	Parameter bounds and	I parameters to invert	
< Back Next > Cancel Help 帮助		< Back	Next >	Cancel Help 帮助	b.

Trust Region: thickness and resistivity are model parameters. Allows inverting for a realistic number of layers and obtaining exact depth within the limitation of data quality. This is our suggested technique as it is the technique most likely to obtain a unique solution.

The two choices in the bottom are

-Trust Region: steepest descent fully constrained technique example

-this is the data that we have examined, previously, and will first use the Trust Region approach.

- in this case, we have imported a starting model obtained via trial forward simulations as well as trial inversion

- it is a 3 layer over a halfspace model and this model will be the starting model for each station (unless modified in a later dialogue)

- initially, we have 7 parameters to invert with 6 data. While overparametrization is allowed this increases the possibility of non-unique models.

-we can now add extra controls using the

"Parameter bounds and parameters to invert"

1D FEM Inversion – 4 using the tools 3a

-Trust Region: steepest descent fully constrained technique example

×

Set Model Parameters to Invert

Click an "Invert" or "Set Bound" item to select/de-select the option. If "Set Bound" option is checked, to edit min/max bound value, double click the value, then input new value.

Layer #	I D L L L L				
	Hesistivity	Invert	Set Bound	Bound - Min	Bound - Max
	188.333206	🔽 Invert Resistivity	🔽 Set Bound	3.000000	376.666412
	3.147000	🔽 Invert Resistivity	🗹 Set Bound	3.000000	376.666412
	36.820499	Invert Resistivity	🗹 Set Bound	3.000000	376.666412
	3.866200	Invert Resistivity	🗹 Set Bound	3	376.666412
	Invert All	Set All Bounds	nove All	Apply Selected Min	Selected Max Bound
				Bound to All	to All
				Bound to All	to All
	<u> </u>			Bound to All	
ickness Se				Bound to All	
ickness Se	ettings		Set Bound	Bound to All	Bound - Max
ickness Se Layer #	ettings	Invert	Set Bound	Bound to All Bound - Min	Bound - Max
ickness Se Layer #	ettings Thickness (m) 0.399100 p. 0.9500	Invert Invert Thickness □ Invert Thickness	Set Bound	Bound to All Bound - Min	Bound - Max

Remove All

Bounds

Set All Bounds

OK.

Invert All

Selected Min Bound

to All

Cancel

Selected Max Bound

to All

Of course, being able to control the inversion with known information not only improves the inversion results but increases the likelihood of obtaining a unique result. This type of data is highly susceptible to multiple models fitting the data.

If we have knowledge of a layer's resistivity or thickness, we set that parameter's value and turn off the inversion for this parameter thus holding it fixed during the inversion.

The bounds for each parameter may be set individually, or as a group or not set at all. In this case, the minimum resistivity is set at $3\Omega m$ and the maximum at $377\Omega m$. The data indicates the surface is quite resistive but the ability of the instrument to resolve higher resistivities is limited.

Trust Region: thickness and resistivity are model parameters. Allows inverting for a realistic number of layers and obtaining exact depth within the limitation of data quality. This is our suggested technique as it is the technique most likely to obtain a unique solution.

1D FEM Inversion – 4 using the tools 4a

-Trust Region: steepest descent fully constrained technique example

nesisiiviiy Limits (L, M)	
Lower Bound	Absolute Values
Upper Bound 1000	Absolute values or Differences
Bounds to enforce:	Data Type (L, M)
C Upper	C Type 1 (Amplitude/Phase)
C Lower	C Type 2 (Inphase/Quadrature)
C None (not recommended)	
Soth (recommended)	 Type 3 (Unly Quadrature)
nversion technique combination	Inversion Parameters
• Individual \bigcirc L1 \rightarrow L2	
C L1→ Mg	May Iterations 20
C L2 -> Mg	
> Use previous result	Target Fit (%)
Inversion Algorithm	Model Epsilon 0.1
🔲 L1 data norm (mean abs. diff.)	Min. Tolerance
🔲 L2 (RMS) data norm (Occam)	Fit Tolerance
- Trust Region	
(underparameterized method)	Reset Default

Trust Region: thickness and resistivity are model parameters. Allows inverting for a realistic number of layers and obtaining exact depth within the limitation of data quality. This is our suggested technique as it is the technique most likely to obtain a unique solution.

On this page, only parameters may be set. This depends upon the technique utilzied.

Here, we set ONLY quadrature as we have already determined the IN Phase is not quantitatively correct.

We also set the Maximum iterations and the desired fit. If the inversion cannot reach this level of fit, it map stop before 20 iterations. 1D FEM Inversion – 4 using the tools 5a

WERSION. Run & Output	
Inversion assumes the standard geophysical frequency quadrature convention.	
\square Check to Flip Quad. Convention. Generally simulated dataset needs to use this feature.	
Note: data is processed.	
Use inversion result from previous location as initial model for current location	
✓ Store simulation for all	
No. of Total Profiles 0 Current Profile 0	
Current location in the current profile	
No. of Total Locations 0 No. of Locations Inversed 0	
Output Information	
RUN	
Clear List	
Progress	_
< Back Finish Cancel He	ap 帮助

Trust Region: thickness and resistivity are model parameters. Allows inverting for a realistic number of layers and obtaining exact depth within the limitation of data quality. This is our suggested technique as it is the technique most likely to obtain a unique solution.

-Trust Region: steepest descent fully constrained technique example

-Use inversion result from previous location as starting model - this is a 1D approach and thus we expect a smooth variation in ground resistivity. This allows to use the inversion model from the previous station for the present station as the starting model. This approach improves speed and well as the smoothness of the model along the profile

-Store simulation for all

- if this is turn on then the inversion with simulate the model for all data components and frequencies including IN Phase.

- RUN

- the inversion is applied to each station one after the other and all profiles. The results are automatically stored to the database.

> Note: EMIGMA uses the standard scientific sign convention for imaginary EM data. Many geophysical instruments have historically used the opposite sign convention from the remainder of the scientific community.

1D FEM Inversion – 4 using the tools 2b

INVERSION. Starting	Model			[<u> </u>
Set a layered starting resistivity and thickne	g model for ess defined	inversion. The mo for each of them.	del consists of several la	ayers over a half space	with
Note: the model doe	s not includ	le the upper half s	pace (i.e. the air).		
– Generate uniform I	ayers				
Total layers abov (maximum 20 laye	ve half spac ers)	e 🚺	Resistiv	rity 100	
Total thickness a	above half :	space 7.	32 Suscep	tibility 0	
- Inversion Para	meters			· · · · · · · · · · · · · · · · · · ·	
Resistivity	0 9	iusceptibility	C Joint	Apply	
	Louor #	Pooiotiuitu	Succeptibility	Thislusse	
	8	7.05266		1e+008	-
	J	1	J-	1	
C laura	#	Resistivity	Susceptibility	Thickness (m)	-
 Insert 	1	82.54	0.000	0.20	
Beplace Beplace Construction Constructin Construction Construction Construct	2	48.76	0.000	0.30	_
- Hopidoo	3	22.53	0.000	0.50	_
	4	12.57	0.000	0.50	
Add to List	C	15.04	0.000	0.50	
	7	12.23	0.000	0.50	-
Import a layer mod From previous Set parameter bou Allowed number Selected number	inversion r indary and 6 15	parameters to Inve	From a dataset ent Parameter bounds and	Import]
		< Back	Next >	Cancel Help	帮助

Enhanced CG Occam: In regard to the layer thicknesses, this is a standard approach where only the resistivities are inversion parameters. This technique allows for highly over parametrized model which are thus highly non-unique solutions. Assuming the Inphase data is good, this technique can also invert for susceptibility

The two choices in the bottom are

-Enhanced CG Occam : over parametrized "Occam" approach.

-For this technique, the number of allowed layers is very high. But, the thickness of the layers is defined initially and does not change. Only the resistivities change in the inversion.

In this case, we have defined a starting model as 7 layers over a halfspace. The top layer is 0.2m because of the short 1m separation's sensitivity to only shallow ground and the remain layers are 0.50m in thickness. The top layers are slightly more resistive decreasing in resistivity to the basement layer. The initial layer resistivities are defined because of the apparent resistivities from the CDI and from some forward models.

The RUN dialogue page does not differ from the Trust Region technique.

1D FEM Inversion – 4 using the tools 3b

Enhanced CG Occam: In regard to the layer thicknesses, this is a standard approach where only the resistivities are inversion parameters. This technique allows for highly over parametrized model which are thus highly nonunique solutions. Assuming the Inphase data is good, this technique can also invert for susceptibility

The two choices in the bottom are

-Enhanced CG Occam : over parametrized "Occam" approach.

-For this technique, the bounds on the layer resistivities cannot be selected individually but are only for all layers. Here, we define the minimum to be $4\Omega m$ and the maximum to $300 \Omega m$.

Inphase/Quadrature are only Quadrature is defined as input. Maximum Iterations and Target Fit are set by the user.

There are two other settings.

Join Adjacent Layers: as there can be many layers, it is useful to join adjacent layers into one layer during the inversion when the resistivities become close.

log(Conductivity)

If there is a wide range of conductivities/resistivities in the ground, you may want the inversion to perform inversions based on the logarithm of the conductivity.

1D FEM Inversion – 5 Examining Results

Inv_Trust_4	Data Set Name
Inv_Trust_4 6 L0a Y0159	Inv_Trust_5
Inv_Trust_5 Inv_Trust_5_GPSZ	Model Name:
Data File Name:	Inv_Trust_5
FDEM_demo_755.dat	Model
<u>C</u> onfiguration	Grid(s)

When the inversion completes, the results will be saved to the database in a new dataset. Here, for example, the inversion was the Trust technique and the model consists of a section of 4 layer over halfspace models. This data set contains the results of simulating the inversion models for comparison to the data and a structure which contains the inversion models.

If we click 'Model', the following interface opens:

т					
Model Configuration					×
Prisms/Plates/Polyhedra La	yers				
N Susceptibility 1 0 2 0 3 0 4 0 5 0 6 0	Resistivity 1e+009 348.716 17.5056 1 16.9397 33.9514	Density 0 0 0 0 0 0	Thickness 1e+008 0.269612 6.02086 1.60412 1.82491 1e+008	Configuration Survey Name [Inv_Truit_5 Model Name [Inv_Truit_5 Total Number of Layers 6 Depth 6	
Save Model	Join La	vers	Split Layer	Bottom Depth -0.269612	
Edit Mode Insert Layer Replace Layer Delete Layer Undo Delete Restore	Layer I Layer I Resi Resi Rela Susc	arameters	2 348.716 1 1 0	Cole-Cole Polarization Mode Parameters C (exponent) parameter dimensionless M parameter (chargeability) T (time constant) parameter seconds Resistivity & Susceptibility Grid Data Files Models/EDEM_demoi/765_118 pex	
< Import Layers	s Thick	uness (m)	0.269612	View File Convet to GPSZ Delete File Layer(s)	
				OK Cancel Apply Help	帮助

The inversion models (all stations/all lines) are stored n a .pex file which is saved to the db and is linked here for viewing. If your data file has GPS elevation or some other true elevation (not altitude), you may convert to GPSZ here. A new data file will be produced as seen in the image at the top.

1D FEM Inversion – 5 Examining Results

Project ID: 100	Inv_Trust_4_GPSZ	Domain Type
6/20/2014 1:16:05 PM	Inv_Occam_8_GPSZ Inv_Trust_4	Data Set M
Project Name: EM31-3 levee	Inv_Trust_4 6 LOa Y0159 Inv_Trust_5 Inv_Trust_5_GPSZ	Vinv_Trust_5
Change Name	Data File Name:	Jinv_Trust_t
Delete Project	FDEM_demo_756.dat	Model
Create Project	Configuration	Grid(s)

If we select a data file which contains a .pex File, then we may use the PEX Viewer (called the CDI viewer) .



FDEM_demo_756_119.pex - EM31-3 levee - D	ecim_Merge_FILTER LOA/ LOB_SOUTH - Inv_Trust_5_G	PSZ - Inv_Trust_5_GPSZ		
	C Conductivity C Linear C Equal Range C Conductivity C Log C Equal Weight C Susceptibility	Abscissa Min 0 0.014310462 Y Max 2.542476857 2.5	Full Hold Loa Range Min& Exp	ad PEX Help 帮助



The initial display does not contour results but displays the "raw" inversion models. The small subplot is a resistivity/conductivity or susceptibility vs. depth display. If you select a point in the graph it will show depth and model data at that point. You may export the inversion results using the Export PEX button.

1D FEM Inversion – 5 Examining Results

For each data point, the response of the inversion model is computed and saved to the database in the output data file. To compare the inversion model's data to the field data, load the field data and the dataset output from the inversion to the plotter.

You may navigate through the data by separation, frequency, IP /Quadrature, etc once loaded to the plotter.



0.00

1.00

1.50

2.00

2.58

Separation Length (m)

3.00

3.50

there are multiple frequency.

4.00

