Overview TDEM Inversion in EMIGMA Jun 2022

- 1) Ground or Airborne data
- 2) Fixed Loop or Moving Loop Ground Surveys
- 3) Inversion Inside or Outside loop for Ground or Airborne
- 4) Inversion of (Hx,Hy, and/or Hz) or Inversion of (Bx, By and/or Bz)
- 5) Multi-location inversion for moving or fixed loop surveys
- 6) Multiple component inversion :
 - multiple separations
 - multiple sensor orientations (e.g x,y,z)
- 7) Multiple basefrequency
- 8) each component has individual time window selection
- 9) constrained inversions
- 10) Overparametrized (Occam) or Underparametrized Inversions
- 11) single or multiple starting models
- 12) Accurate System Response
 - precise current description
 - bandwidth controlled, instrument lowpass filters

Data format Support TDEM Inversion in EMIGMA Dec 2017

TEM Inverse 0+1

- 1) Airborne Data
 - data imported either in QCTool format or ASCII columnar
 - .gdb files may be imported to QCTool for ease of import

Instruments with automatic Support

VTEM, GeoTEM, GENESIS, HeliTEM plus AeroTEM, MegaTEM, SkyTEM, and TEMPEST (NA or African version)

However, will a little more effort by the user any instrument can be supported by the tools provided

Data format Support TDEM Inversion in EMIGMA Dec 2017

TEM Inverse 0+2

- 2) Ground Data
- most instruments are supported by their native files with some details
- a) Zonge .avg and .usf format
- b) UTEM3, UTEM4 Lamontamge native files
- c) TERRATEM .usf format
- d) TEMFAST .tem format
- e) SMARTEM AMIRA ascii
- f) PHOENIX .avg and .usf format
- g) MTEM .qct or SEGY
- h) GEONICS Protem files and .qct
- i) CRONE .pem or .raw format
- j) WalkTEM .usf format
- k) Generic .usf and AMIRA format
- 1) ASCII imported and organized in QCTOOL format

Time Domain inversion essentially began with W.L. Anderson at the USGS in the mid- to late 1970's eventually releasing an open source inversion code in the early 1980's. Anderson's code worked only for circular loops with an exact center point data location and utilizing a frequency to time domain transform that included an infinite bandwidth of DC to infinity and only an impulse response with a step-off current. Anderson's code reveals that he experimented with several important factors including: a finite ramp turn-off, frequency band limited responses, data outside the loop. His inversion code is of a style now often termed "Occam" inversion which implies, in this case, fixed layer thicknesses, allowing for more layers than data and weighting the inversion for a smooth model. All of this following, Parker's early work on MT inversion.

We have approached this problem with a more general theory of inversion. Since, the early 1990's we have been developing accurate layered earth models for virtually any type of EM source and any geometry. This was to meet the requirements of actual exploration projects and thus to provide both the background fields and Greens functions for our 3D, Integral Equation(IE) algorithms. In order to accurately meet these 3D simulation requirements, we had also incorporate as accurately as possible the actual system response (transmitted single) of a variety of instruments. This led to two key issues: accurate representation of the current injected into the source, accurate representation of the frequency limitations of the instruments. Having thus the ability to compute very accurately, 1D models of TDEM data, it was therefore a matter to integrate this capability into our inversion algorithms which we had been developing first for magnetic data, then gravity and 1D MT and later for 3D EM inversion and other controlled source 3D EM inversions such as CSAMT and Resistivity.

Finally, a comment on over-parameterized smooth models vs. under-parameterized rough models. Many, many 1D inversions for a variety of different EM data, use the so-called Occam inversion which allows more models parameters than data and to control this over-parameterization applying smoothing constraints. The problem with this method is that you have no accurate idea of the depth to different interfaces. While this is useful for deep earth studies where accuracy is never an issue as we will never know if the model is correct or not, this is not useful in exploration, environmental or engineering applications where accurate depths are important if possible. Thus, while we provide an inversion of this type, we focus more on an underparametrized approach. This is often termed a Marquardt approach. However, we do not utilize linear inversion approaches and so using this in our application is not really correct termed but we look for a word understood by most. In this case, we are attempted to resolve the major variations in the stratigraphy with as accurate as possible results for both resistivities and depths.

WORKFLOW

1. CREATE a new EMIGMA database or OPEN an old database.

(suggestion: easier to keep multiple datasets and projects in one database as easier to personal archiving)

2. Import Data

In this case, the data in file arlit1.100 contains 3 base frequencies and thus needs to imported 3 times to create 3 surveys

3. Examine the data from each base frequency

Pay careful attention to the decays to determine which channels should be used for the inversion

4. Perform some initial forward modelling using basic assumed structure,

To get a feel for the data and to use to help guide the inversions.

5. Perform controlled Marquardt or Occam Inversions

6. Create Sections

TEM Inverse 1. Open Old or Create a new EMIGMA database. GEONICS TEM Import Wizard, Step 2: Corrections × 2 Data At 2. Import Data Receiver C Transmitter C Center For Transmitter For Receiver Tx-Rx Separation (reference to profile 100.000000 3. Examine the data from each base frequency Effective Coil Area (m²) direction) Mean time of Channel 1 (ms) 0 4. Perform some initial modelling, Tx[X]-Bx[X] (m)Assum for all data points, otherwise 0 0.3525 Tx(Y)-Bx(Y) (m) select data with specified time. Check Rx offset from loop 5. Perform controlled Marquardt or Occam Inversions Loop Sizes: 6. Create Sections 100 -X Length (m) Prinary Channel Coord. System Start (ms) Absolut 100 Y Length (m) 40.087 **Check loop size** Include Horizontal primary Rigid Loop 🕻 nd (ms) O Profile channel -20.089 C Uhole Attenuation Factor 1 GEONICS TEM Import Wizard, Step 1: Input File Specification Electric Current 24 Settings related to profile (Amp) Profile name Components -0001 (arlit1.100) Apply No. of Turns $\square \times$ ΓY Assign Coordinates Receiver Direction Ramp-Time (ms) .089 .085 ΓZ $\Box \times \rightarrow \times \to \times$ System typ Default 🔻 0.089 X --> Set to $\Box \times \to \times$ C Fixed system C Moving system C Borehole system Detect Choose base frequency Default \Box Y \rightarrow Y ■ Borehole data measured only along hole axis IZ compone If defined in the file, $\Box z \rightarrow z$ Base Frequency (Hz) select 'default' Input Filename E:\Importdata\GeonicsTEM\arlit1.100 6.250000 -Browse View North American User (60 Hz) Output Locations in Decreasing 🔲 Order. Otherwise, in Increasing Not North American User (50 Hz) Order. Next> Cancel < Back Help Note: start of Ch1 will update automatically with base frequency Next> Cancel Help

> Note: Multiple ramp times can be imported with a common ramp time Otherwise, ramp times can be imported separately

This example is for GEONICS TDEM data

1. Open old or Create new EMIGMA database.

2. Import Data

- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

If

If the data consists of multiple sections with different current, then this might be useful otherwise data may have to be normalized once imported	Data not reduce Average Duplicate Save different con	ed by current C Data already reduc o unit current Data figurations to separate data sets	ced by current
Click Process	Process	Status Geometry Waveform Profile Data	
Save to DB	Restart Save to DB	Output file will be saved automatically when you click <finish>.</finish>	Processed Lines:
		< Back	Finish Cancel Help

GEONICS TEM Import Wizard. Step 4: Run and Output.

Note: Restart will not work to import the other base frequencies You must restart the import and repeat 2 more times to import all base frequencies Eikon Technologies 1/9/2023

X



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Note: theoretically, there are no sign changes for data inside the loop for a layered earth environment. This data indicates either instrument, data collection or 3D effects as issues.

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TEM Inverse

- 1. Create a new EMIGMA database.
- 2. Import Data
- 3. Examine the data from each base frequency

4. Perform some initial modelling,

- 5. Perform controlled Marquardt or Occam Inversions
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Note: The sign of the data to be inverted should be checked with the simulation sign. If the sign is opposite, then the user can either reverse the data sign in "Data Correction" or flip the direction of current in "Configuration".



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6.25Hz Base frequency



- 2. Import Data
- 3. Examine the data from each base frequency

4. Perform some initial modelling,

- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections



2.5Hz Base frequency

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1. Create a new EMIGMA database.

2. Import Data

- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

TEM 1D Inversion Database	e: F:\Interp\Imp	ortdata\GeonicsTEM	protem_tutoria	al\protem_tut	orial.mdb	
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Inversion method

Inversion method:

There are 2 distinct methods which are now prevalent in geophysical inversion and both are offered here – Marquardt and Occam.

Marquardt Inversion:

By this name, we mean an *underparametrized* technique by which there are to be less model parameters than data. In TEM inversion, each layer consists of 2 model Parameters, namely its thickness and its resistivity. The basement has one parameter. However, we do not use a traditional line search in the inversion proces.

Each data window consists of one datum per component (e.g. Hz or Hx) or one datum per separation. The software restricts the number of layers in the model to be underparametrized.

Occam Inversion:

This is an *overparametrized* inversion but each layer has a fixed thickness and the inversion only inverts for resistivity.

1. Create a new EMIC	GMA database.
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- 2. Import Data
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- 6. Create Sections

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Forward technique selection

TEM Inverse 13

Forward Technique:

All inversion techniques consist of a series of forward models which are guided by the inversion methods to a *best* model.

Traditional TEM (TDEM) inversion has utilized an approximate technique to provide the response of the forward solution during the inversion process.

This approximation is restricted of a number of factors but most important are the location of TX and RX and the nature of the current waveform. Traditionally, the loop has been replaced by a circle of equal area and the RX was in the exact center of the loop.

The waveform was considered a perfect *impulse* response with infinite frequency bandwidth and was considered to be *causal* (i.e. turned on once and then always off). This approach is provided here by the *approximate* technique which can only be applied to central loop measurements.

This approach would prevent out-of-loop inversions to be effective.

General Technique: As EMIGMA is able to model fairly arbitrary loop and TX-RX configurations, we utilize our normal forward algorithms in this mode. This allows the user to utilize in-loop and out-of-loop configurations but also varying positions inside the loop. As in our forward simulations, the user should specify the bandwidth and accuracy of the transform to time-domain. In this case, we are using the true periodic waveform and attempt to reproduce the system bandwidth.

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2. Import Data

- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

TEM 1D Inversion Data	abase: F:\Interp\Imp	ortdata\GeonicsTEM	\orotem tutori	al\orotem tu	torial mdb		
Dataset list							
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Close application	when inversion complet		<u>B</u> un		<u>C</u> lose		Help

Choose time windows for inversion

After examining your data, choose which time windows you wish to utilize for inversion. The final inversion model will be simulated for all time windows for final comparison.

Inversion Controls

If you have measured more than one data component, for example Hx as well as Hz or more than one separation for a moving system then you must choose which one you wish to fit in the inversion process.

There may be more than one data response (especially when testing with synthetic data.)

As this inversion process is suitable when the ground is smoothly varying laterally, you may choose to use the previous data point's final model as the starting model for the next point. This also will speed up the process which is particularly important for airborne data.

TEM Inverse

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2. Import Data

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Initial model(s)	
Inversion Technique: Marquardt; Forward Technique: General	
Max number of layers allowed 50	
Model settings (Note: model should include lower half space.)	
Resistivity (Ohm*m) 45.5497	No. of Total Selected 1 Component(s)
Thickness (m) 61.8561	No. of Total Selected Time 20 Channels
Total number of layers 3 Insert layer 1	- Resistivity and/or thickness to invert
Generate layers Import Insert	Allowed number 20
# Resistivity Thickness (m) 1 45.549683 61.856	Selected number 5
2 22.277275 142.431 3 6.907110 10000000.000	<u>R</u> esistivity and/or thickness to invert
	Default is to invert both resistivity and thickness without bound limits. To make
<u>S</u> plit <u>Joint</u>	changes, click "Resistivity and/or thickness to invert".
To edit a value in the list, double click the value then input a new value. To delete a layer, select the layer then press DELETE key.	
	Cancel
· · · · · · · · · · · · · · · · · · ·	

Create a Starting Model as TDEM inversion, particularly inloop, is non-unique this can be important.

Import Layers: If you have created a forward model that you like, particularly when it is geologically appropriate, you may import it as a starting model or if you have a previous inversion that you like, you may import it as a starting model. Thicknesses and resistivities may be edited by selecting the appropriate box.

Insert a layer: You may insert additional layers at any stage.

Split a layer: Divides a layer in half to increase resolution.

Join Layers: Join 2 layers if they are not required for resolution.

Generate a Starting model:

First select how many layers in total that you would like in the model, set the initial resistivity and thickness. Then click "Generate Uniform Layers". Then edit if required.

Editing Starting model:

After making a starting model (whether by importing or generating), the user may edit either the resistivity or the thickness of the layer. Simply double-click on the parameter setting.

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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. 20 11 Allowed number of parameters to invert Selected number of parameters to invert Resistivity Settings-Layer # Resistivity Invert Set Bound Bound - Min Bound - Max 30.000000 Invert Resistivity Set Bound 200 30.000000 Invert Resistivity 🔲 Set Bound Invert Resistivity Set Bound 30.000000 30.000000 Invert Resistivity Set Bound 30,000000 Invert Resistivity 🔽 Set Bound 50 45 30.000000 Invert Resistivity Set Bound Apply Selected Min Apply Selected Max Remove All Invert None Set All Bounds Rounds Bound to All Bound to All



Constrain Model Parameters

Resistivity Constraints:

It is useful to constrain the layer resistivities to ranges that are realistic in the geological environment.

Thickness Constraints:

This option is only available under the Marquardt technique.

Constraining the maximum thickness can help gain resolution. Constraining the minimum is a question of geological meaningfulness.

Parameters to Invert:

If you feel a parameter is know then you choose to deselect this parameter and it will remain fixed within the inversion process.

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- 2. Import Data
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mponent	List			Time Cha	annels (ms)	
1	Transmitter	Receiver		N	Middle	
21	Loop 1	Dipole Hx		11	0.801	
12	Loop 1	Dipole Hy		12	1.016	
13	Loop 1	Dipole Hz		13	1.290	
	Loop 1	Dipole The		14	1.639	
				15	2.085	
				17	2.603	
		Select All Components	1	Selec	at All Time Chann	els
			-			
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	.180			Time Channels (ms)
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7 6	Loop 1	Dipole Hz	70.000, 0.000, 0.000	12 1.016
77	Loop 1	Dipole Hx	-150.0000.000. 0.000	13 1.290
1 8	Loop 1	Dinnle Hv	-150.000 -0.000 0.000	16 2.005
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Selecting Components

Select Component Select	R <u>e</u> sponse
No. of selected components in current set	1
No. of selected components in all sets	1
Multi Locations	
Locations No. of selected	0

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TEM Inverse

Example 1: Multiple Field Components In this case, 3 components have been collected. We have selected to invert Hx and Hz and additionally, we have specified the time channels for Hx and Hz separately.

Example 2: Multiple Field Components and Multiple Separations In this case, there are 3 receiver offsets from the centre of the loop (i.e. separations) -0.70,150m plus 3 field components. Here we select to use Hz at all 3 separations.

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Multi-location selection type: moving Radius (data points, center point included)	3
Total points that will be used	5
Weights	Moving Step
# Weight 1 0.200000	Moving 3 location(s)
2 0.200000 3 0.200000 4 0.200000	Save result at center location only
5 0.200000	C Save result at all locations
D.G. BM/Sch	
	Ç₀
OK	Cancel Help

Selecting Multiple Locations

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Select Component	Select Response
No. of selected components in curre	ent set
No. of selected components in all se	ets 1
🗖 Multi Locations 🕞	
Locations No. of	selected 0

Moving multi-location spatial window

available for moving or fixed loop but only single component If you have a need for this functionality but with multiple components, please contact us.

Example 1: Multiple Data Locations Moving Window This is an airborne example with only Hz collected at every survey point. Here we use a 5 point window for joint inversion with the data location window moving 3 survey locations along the profile for each inversion thus providing an overlapping inversion window.

- 2. Import Data
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)ata Set	No. o	f selected locations in all s	ets	10
Data Set 1	No. o	f selected locations in curr	rent set	10
Profile Informati	on			,
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ocations				1
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ocations	× 349650.000 349650.000	Y 4062900.000 4063000.000	Z 1.00 1.00	00
ocations N 1 2 3	× 349650.000 349650.000 349650.000	Y 4062900.000 4063000.000 4063100.000	Z 1.00 1.00 1.00	00 00 00
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N 1 1 2 3 3 4 5 5 6 7 7 8 9 10	× 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000	Y 4062900.000 4063000.000 4063100.000 4063200.000 4063300.000 4063500.000 4063500.000 4063500.000 4063700.000 4063700.000	Z 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.0	00 00 00 00 00 00 00 00 00 00 00
N 1 2 3 3 4 5 6 7 8 9 10 11 1	× 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000	Y 4062900.000 4063000.000 4063100.000 4063200.000 4063200.000 4063500.000 4063500.000 4063700.000 4063700.000 4063200.000	Z 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.0	00 00 00 00 00 00 00 00 00 00 00
N 1 2 3 3 4 5 6 7 8 9 10 11 1	X 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000 349650.000	Y 4062900.000 4063000.000 4063100.000 4063200.000 4063300.000 4063500.000 4063500.000 4063700.000 4063800.000 4063800.000	Z 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.0	00 00 00 00 00 00 00 00 00 00 00 00

Selecting Multiple Locations

Select Component	Select Response
No. of selected components in curre	entset 1
No. of selected components in all se	its I
Multi Locations	
Locations No. of	selected

Multi-stations fixed spatial window

available for multi-component, and multi-separations

Example 2: Multiple Data Locations

In this case, we have a single profile, and 30 stations with Hx,Hy,Hz measured. We select Hx,Hz each with their own time windows and then

Multi-Locations -> Fixed-multi-location selection

then we have selected 10 of the datapoints on the profiles for a joint inversion. Note: for the simple mode, all components and all stations use the same time windows.

2. Import Data

- 3. Examine the data from each base frequency
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- 6. Create Sections

a Set					<u> </u>			
ta Set 1	-	No	o. of selected locatio	ns in all sets	1			
ile informat	ion			Tx Loop	/Bipole vertices			- Current Data Se
	Name	Location No.	Selected	N	X	Y	Z	Profiles
1	0181	16	1	1	510896.000	4706501.000	0.100	
2	0192	16	0	2	511098.000	4706498.000	0.100	p p
	0102	10	0	3	511078.000	4706314.000	0.100	
,	0183	16	0	4	510900.000	4706322.000	0.100	Locations
				5	510902.000	4706346.000	0.100	1
				6	510896.000	4706501.000	0.100	P
								Components
								1
tions								P P
				- Ime	window selection			
 Locati 	on 1: x = 510945.00	00, y = 4706525.000, a	z = 0.100	1 1110	WINDOW SCIECTOR			Data channel
🗹 Locati	on 1: x = 510945.00 mponent 1: Tx: Loc	00, y = 4706525.000, ; op; Rx: Hx	z = 0.100		WINDOW SCIECTON			Data channel
E Locati ⊡ □ Co ⊕ □ Co	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo	00, у = 4706525.000, ; ор; Рж: Нх ор: Рж: Ну	z = 0.100		Select All	1 0)e-select All	Data channel
	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo	00, y = 4706525.000, ; op; Rx: Hx op; Rx: Hy no: Rx: Hz	z = 0.100		Select All)e-select All	Data channel
V Locati ⊕ □ Co ⊕ □ Co ⊕ □ Co ⊕ V Co	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo on 2: x = 510946.00	00, y = 4706525.000, ; op; Rx: Hx op; Rx: Hy op; Rx: Hz op; Rx: Hz	z = 0.100 z = 0.100		Select All)e-select All	Data channel
Locati Locati Co Co Co Locati Locati Locati	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo on 2: x = 510946.00 on 3: x = 510948.00	00, y = 4706525.000, ; ap; Rx: Hx ap; Rx: Hy ap; Rx: Hz 00, y = 4706564.000, ; 00, y = 4706564.000, ;	z = 0.100 z = 0.100 z = 0.100		Select All	ons to all components)e-select All	Data channel 20 Current profile
Locati Locati Loc	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo on 2: x = 510946.00 on 3: x = 510948.00 on 4: x = 510948.00	00, y = 4706525.000, ; xp; Rx: Hx xp; Rx: Hy xp; Rx: Hz 100, y = 4706564.000, ; 100, y = 4706604.000, ; 100, y = 4706646.000, ;	z = 0.100 z = 0.100 z = 0.100 z = 0.100		Select All Apply current selecti	ons to all components	De-select All	Data channel 20 Current profile
Locati Co Co Locati Locati Locati Locati Locati	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo on 2: x = 510946.00 on 3: x = 510946.00 on 4: x = 510946.00 on 4: x = 510946.00	00, y = 4706525.000, ; pp; Rx: Hx pp; Rx: Hy pp; Rx: Hz 10, y = 4706564.000, ; 10, y = 4706604.000, ; 10, y = 470604.000, ;	z = 0.100 z = 0.100 z = 0.100 z = 0.100 = -0.100		Select All Apply current selecti	ons to all components	De-select All	Data channel 20 Current profile Locations
Locati Locati Locati Locati Locati Locati Locati	on 1: x = 510945.00 mponent 1: Tx: Loo mponent 2: Tx: Loo mponent 3: Tx: Loo on 2: x = 510946.00 on 3: x = 510948.00 on 4: x = 510946.00 on 5: x = 510946.00	00, y = 4706525.000, ; pp; Rx: Hx pp; Rx: Hy pp; Rx: Hy pp; Rx: Hz 00, y = 4706564.000, ; 00, y = 4706604.000, ; 00, y = 4706686.000, ; 00, y = 4706686.000, ; 00, y = 4706686.000, ; 01, y = 4706686.000, ; 02, y = 4706686.000, ; 03, y = 4706686.000, ; 04, y = 4706686.000, ; 05, y = 4706586.000, ; 05, y	z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100 = -0.100		Select All Apply current selecti	ons to all components	De-select All	Data channel 20 Current profile Locations
Locati Co Co Co Locati Locati Locati Locati Locati	on 1: x = 510945.00 mponent 1: Tx Loo mponent 2: Tx Loo mponent 3: Tx Loo no 2: x = 510946.00 on 4: x = 510946.00 on 5: x = 510946.00 on 6: x = 510946.00	$\begin{array}{l} 00, y = 4706525.000, :\\ \text{ap; Rx: Hx}\\ \text{ap; Rx: Hy}\\ \text{ap; Rx: Hz}\\ 00, y = 4706564.000, :\\ 00, y = 4706564.000, :\\ 00, y = 4706646.000, :\\ 00, y = 4706646.000, :\\ 00, y = 4706686.000, :\\ 00, y = 4706728.000, :\\ 00$	z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100		Select All Apply current selection	ons to all components	De-select All	Data channel 20 Current profile Locations 1
Locati Co Co Locati	on 1: x = 510945.00 mponent 1: Tx: Loc mponent 2: Tx: Loc mponent 3: Tx: Loc on 2: x = 510946.00 on 3: x = 510946.00 on 4: x = 510946.00 on 6: x = 510946.00 on 6: x = 510946.00 on 7: x = 510945.00	00, y = 4706525.000, ; p; Fix Hx p; Fix Hx p; Fix Hz 00, y = 4706564.000, ; 00, y = 4706646.000, ; 00, y = 4706646.000, ; 00, y = 4706686.000, ; 00, y = 4706728.000, ; 01, y = 4706766.000, ; 02, y = 4706766.000, ; 03, y = 4706766.000, ; 04, y = 4706766.000, ; 05, y = 47067660.000, ; 05, y =	z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100 z = 0.100		Select All Apply current selecti Apply current selecti	ons to all components	De-select All	Data channel 20 Current profile Locations 1 Components
Locati	on 1: x = 510945.00 mponent 1: Tx Loo mponent 2: Tx Loo mponent 3: Tx Loo on 3: x = 510946.00 on 3: x = 510946.00 on 5: x = 510946.00 on 5: x = 510946.00 on 6: x = 510946.00 on 8: x = 510946.00 on 8: x = 510946.00	00, y = 4706525.000, ; sp; Rx; Hx sp; Rx; Hy sp; Rx; Hz 10, y = 4706564.000, ; 10, y = 4706646.000, ; 10, y = 4706646.000, ; 10, y = 4706646.000, ; 10, y = 4706766.000, ; 10, y = 47067660, ; 10, y = 4706760, ; 10, y = 4706760, ; 10, y = 4706760, ; 10, y = 4706760	z = 0.100 z = 0.100		Select All Apply current selecti Apply current selecti	ons to all components	De-select All	Data channel 20 Current profile Locations 1 Components
Locati	an 1: x = 510945.00 mponent 1: Tx Loo mponent 2: Tx Loo mponent 3: Tx Loo an 2: x = 510946.00 an 4: x = 510946.00 an 5: x = 510946.00 an 6: x = 510946.00 an 7: x = 510945.00 an 8: x = 510945.00 an 8: x = 510946.00 an 9: x = 510946.00	00, y = 4706525.000, ; pp; Rx; Hx pp; Rx; Hz 10, y = 4706564.000, ; 10, y = 4706564.000, ; 10, y = 4706646.000, ; 10, y = 4706646.000, ; 10, y = 4706768.000, ; 10, y = 4706768.000, ; 10, y = 4706605.000, ; 10, y = 4706805.000, ; 10, y	z = 0.100 z = 0.100		Select All Apply current selecti Apply current selecti	ons to all components	De-select All	Data channel 20 - Current profile Locations 1 Components 1
Locati	on 1: x = 510945.00 mponent 1: Tx: Loc mponent 3: Tx: Loc on 2: x = 510946.00 on 3: x = 510946.00 on 5: x = 510946.00 on 6: x = 510946.00 on 6: x = 510946.00 on 8: x = 510946.00 on 8: x = 510946.00 on 9: x = 510946.00 on 9: x = 510946.00	$\begin{array}{l} 0, y = 4706525,000, ;\\ \mathrm{sp; Rx; Hx}\\ \mathrm{sp; Rx; Hy}\\ \mathrm{sp; Rx; Hy}\\ \mathrm{sp; Rx; Hy}\\ \mathrm{sp; Rx; Hz}\\ 0, y = 4706664,000, ;\\ 0, y = 4706680,000, ;\\ 0, y = 4706728,000, ;\\ 0, y = 4706728,000, ;\\ 0, y = 4706695,000, ;\\ 0, y = 470683,000, ;\\ 000, y = 4706883,000, ;\\ 000, y = 470688,000, ;\\ 000, y = 4706883,000, ;\\ 000, y = 4706883,000, ;\\ 000, y = 470688,000, ;\\ 000, y = 470683,000, ;\\ 000, y = 470683,000, ;\\ 000, y = 470683,000, ;\\ 000, y = 470680,000, ;\\ 000, y = 470680,000, ;\\ 000, y = 470680,000, ;\\ 000, y = 47068,000, ;\\ 000, y = 47068,000$	z = 0.100 z = 0.100		Select All Apply current selecti Apply current selecti	ons to all components	De-select All of this location of all locations	Data channel 20 Current profile Locations 1 Components 1
Locati	on 1: x = 510945.00 mponent 1: Tx: Loc mponent 3: Tx: Loc mponent 3: Tx: Loc mponent 3: Tx: Loc m 3: x = 510948.00 on 4: x = 510946.00 on 6: x = 510946.00 on 6: x = 510946.00 on 9: x = 510946.00 on 9: x = 510946.00 on 9: x = 510946.00 on 10: x = 510946.00 on 11: x = 510947.00	$\begin{array}{l} 0, y = 4706525,000, ;\\ p_0, R_X, H_X\\ p_0, R_X, H_Y\\ p_0, R_X, H_Z\\ p_0, R_X, H_Z\\ p_0, R_X, H_Z\\ 0, y = 4706564,000, ;\\ 0, y = 4706564,000, ;\\ 0, y = 4706568,000, ;\\ 0, y = 4706728,000, ;\\ 0, y = 4706728,000, ;\\ 0, y = 4706768,000, ;\\ 0, y = 4706805,000, ;\\ 0, y = 4706825,000, ;\\ 0, y = 47$	z = 0.100 z = 0.100 ; z = 0.100 ; z = 0.100		Select All Apply current selection apply current selection	ons to all components	Deselect All of this location of all locations nt of all locations	Data channel 20 - Current profile Locations 1 Components 1 Data channel
Locati	on 1: $x = 510945$ 000 mponent 1: Tx. Loc mponent 2: Tx. Loc mponent 3: Tx. Loc on 2: $x = 510946$ 00 on 5: $x = 510946$ 00 on 5: $x = 510946$ 00 on 6: $x = 510946$ 00 on 6: $x = 510946$ 00 on 9: $x = 510946$ 00 on 10: $x = 510946$ 00 on 11: $x = 510946$ 00 on 11: $x = 510945$ 00	0), y = 4705525.000, ; pp; Fk; Hx pp; Fk; Hy pp; Fk	z = 0.100 z = 0.100 , z = 0.100 , z = 0.100		Select All Apply current selection	ons to all components	Deselect All of this location of all locations nt of all locations	Data channel 20 Current profile Locations 1 Components 1 Data channel
Locati	on 1: x = 510945.00 mponent 1: Tx: Loc mponent 2: Tx: Loc mponent 3: Tx: Loc mponent 3: Tx: Loc mponent 3: Tx: Loc m 0: x = 510946.00 on 5: x = 510946.00 on 7: x = 510945.00 on 7: x = 510945.00 on 10: x = 510945.00 on 11: x = 510947.0 on 12: x = 510947.0	01, y = 4705625, 000, z yp; Ric Hy yp; Ric Hy yp; Ric Hy yp; Ric Hy 10, y = 4705654, 000, z 10, y = 4705654, 000, z 10, y = 4706664, 000, z 10, y = 4706664, 000, z 10, y = 47066765, 000, z 10, y = 47056756, 000, z 10, y = 47056765, 000, z 10, y = 47056756, 000, z 10, y = 47056756, 000, z 100, y = 4705675, 000, z 100,	z = 0.100 z = 0.100 , z = 0.100 , z = 0.100 , z = 0.100		Select All Apply current selection Apply current selection	ons to all components	Deselect All of this location of all locations nt of all locations	Data channel 20 Current profile Locations 1 Components 1 Data channel 20
Locati Co Co Co Co Co Locati Loca	on 1: x = 510945.00 mponent 2: 1x Loc mponent 2: 1x Loc mponent 3: 1x Loc on 2: x = 510946.00 on 4: x = 510946.00 on 6: x = 510946.00 on 7: x = 510946.00 on 7: x = 510946.00 on 10: x = 510946.00 on 10: x = 510946.00 on 11: x = 510947.00 on 11: x = 510947.00	0.0 = 4705625.000.; $p_{\rm e}$ Ric Ha $p_{\rm e}$ Ric Ha $p_{\rm e}$ Ric Ha $p_{\rm e}$ Ric Ha 0.0 = 470664.000.; 0.0 = 470664.000.; 0.0 = 470664.000.; 0.0 = 470664.000.; 0.0 = 4706680.000.; 0.0 = 4706680.000.; 0.0 = 4706880.000.; 0.0 = 4706880.000.; 0.0 = 4706880.000.; 0.0 = 4706880.000.; 0.0 = 4706880.000.; 0.0 = 4706880.000.; 0.0 = 4706887.000.; 0.000. = 47070687.000.; 0.000. = 47070687.0000.; 0.0000. = 47070687.0000.; 0.00	z = 0.100 z = 0.100 , z = 0.100 , z = 0.100 , z = 0.100		Select All Apply current selecti Apply current selection	ons to all components	Pe-select All of this location of all locations nt of all locations	Data channel 20 Current profile Locations 1 Components 1 Data channels 20
Locati	on 1: x = 510945.00 mponent 1: Tx Loc mponent 2: Tx Loc mponent 3: Tx Loc mponent 3: Tx Loc mponent 3: Tx Loc status 4: x = 510946.00 on 3: x = 510946.00 on 6: x = 510945.00 on 6: x = 510945.00 on 9: x = 510945.00 on 9: x = 510945.00 on 10: x = 510945.00 on 11: x = 510947.00 on 12: x = 510947.00 on 12: x = 510947.00 on 12: x = 510947.00 on 13: x = 510947.00 on 13: x = 510947.00 on 13: x = 510947.00 on 13: x = 510947.00 on 14: x = 510947.00 on 15: x = 510947.	0.0 = 4705625.000.; p_{e} Fix Hx p_{e} Fix Hy p_{e} Fix Hy p_{e} Fix Hy p_{e} Fix Hy 0.0 = 4705654.000.; 0.0 = 4705646.000.; 0.0 = 4705646.000.; 0.0 = 4705672.000.; 0.0 = 4705720.000.; 0.0 = 4705725.000.; 0.0 = 4705725.000.; 0.0 = 4705825.000.; 0.0 = 4705825.000.; 0.0 = 4705825.000.; 0.0 = 4705825.000.; 0.0 = 4705825.000.; 0.0 = 4707685.000.; 0.0 = 4707048.000.; 0.0 = 470	z = 0.100 z = 0.100		Select All Apply current selection Apply current selection pply current selections	ons to all components	Perselect All of this location of all locations nt of all locations	Data channel 20 Current profile Locations 1 Components 1 Data channels 20

Selecting Multiple Locations

TEM Inverse 20

Select Component	Select Response
No. of selected components in curre	ntset 1
No. or selected components in all se	
Multi Locations	elected

Multi-stations fixed window Advanced Mode

available for multi-component, and multi-separations, *multiple data stations*

Example 3: In Advanced Mode, each component at each station can be adjusted for specific time window.

Uses: *suggestions* a)determination of best layered model prior to 3D modeling b)finding layered stratigraphy for different regions in a large survey c)comparing to moving window inversions

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<mark>"</mark> 1D Inversion Select time channel ar	nd initial model		
Database C:\Program Files\EmigmaV8.5\D	emo Databases\Example Database\ExampleDatabase.mdb		
Project TEM moving loop ID: 11	Survey Moving Loop Sask Synthetic ID: 28 Dataset	EM37 ID: 38	
Inversion Technique Marquardt © Docam Forward Technique General C Approximate Eorward Accuracy	Initial layer model (SI units) Set Initial Model Use advanced initial model settings Use inversion result of the previous location as initial model	Start End Skip 2 4 8 Current Profile Index Total No. of Locations No. of Locations Done	
Apparent Resistivity Model Type Cate-time Resistivity Model C All time Resistivity Model	Select Component Select Response Process No. of Selected Component(s) 1	ing Message	
Time channels (time unit: ms)	Multi Locations	Parameters for Occam in	ersion
8 0.441000 9 0.561000 10 0.705000 11 0.855000 12 1.070000 13 1.3755000	Select Locations Advanced No. of Selected 0	Max number of iteration:	10
14 1.745000 15 2.190000 16 2.815000 17 3.555000	Set Output Log File Name	Target fit:	1e-005
18 4.365000 19 5.540000 20 7.035000	Select <u>O</u> utput Type to Store Inversion Result	Model epsilon:	0.1
Select All <u>T</u> ime Channels No. of Selected Time channels 20	Save every 200 data points Processing progress	Min tolerance:	0.1
,	Bun	º₀ Fit tolerance:	0.01
		ОК]

Executing the Inversion

TEM Inverse

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Upon clicking Run, a window will pop-up. Unless the user is familiar with these items then it is suggested that the defaults be maintained. The OCCAM selections are shown here.

> Number of Iterations: A higher value will help ensure accuracy but execution times increases

Target Fit: The residual between the estimated data under the best model and the measured data.

Model epsilon: Occam is a smooth inversion and the model epsilon controls the smoothness.

Min tolerance: Specifies how accurately the search algorithms determine minima in the fit.

Fit tolerance: Specifies how close to determine the final fit.

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TEM 1D Inversion Dat	abase: F:\Interp\Co	pper Reef\Copper_Re	ef\Copper_Re	ef.mdb		_ 🗆 ×
Dataset list						
# Project (ID)	Survey (ID)	Dataset (ID)	Base Freq	Start Index	End Index N Skips	Add
1 BigIsland_Albert (17)	Decim_L1150_BigIsl	Measured Time (1769)	30	2	5 8	
						Remove
1						
Inversion Technique	Initial	ayer model (SI units)				
C Marquardt C D			- od ropod initial			
- Forward Technique	3.		aavancea milai	model settings	Current Profile Index	μ
C General	·				Total No. of Locations	37
C Approximate	Accuracy	se inversion result of the p	revious location a	is initial model	No. of Locations Done	3
						P
Apparent Resistivity Model Typ	Se S	elect C <u>o</u> mponent	Select F	lesponse	Processing Message	
C Late-time Resistivity Mod	el				SW MISFIT 0.67919	_
	No. c	t selected components in (current set	Ľ	SW MISFIT OF BEST MODEL	0.67919
Time channels (time unit: ms)	No. o	f selected components in a	all sets	1	LS misrit or best model 120.84	+23%
21 1.531	<u> </u>				Line 1: 1150 Location 6: x=336288.1875 v	=6078026.0000
23 2.021		Vulti Locations Tu	e: Movina	3	SW MISFIT of previous model	1.02467
24 2.323 25 2.667					Using previous inversion model	to start.
26 3.063		Locations No	of selected	5	SW MISFIT 1.02467	1
28 4.042					LS misfit 121.9012%	2
29 4.641 30 5.333	🔄 🗖 Sta	art inversion from the last lo	cation of profile		SW MISFIT 1.02467	2
31 6.125	<u> </u>				Performing adaptive iteration	3
Select All <u>T</u> ime Channels	in List	<u>G</u> et Inversion Settin	gs From a Log Fil	в	SW MISFIT 1.02467	
No. of colocted data observals in		Select Output Type to :	itore Inversion B	esult	Performing adaptive iteration	4
current set	160				LS misfit 121.9012%	•
No. of selected data channels in	all 160	Save every 200	data point:	s		
sets	Proc	essing				
			P			1
Liose application	n when inversion compl	etes	Hun	<u> </u>	stop, save and Llose	

Executing the Inversion

Finally, click the Run button. The total number of data points in all the profiles will be shown as well as the number of data points completed to the right. The right corner (white) window shows each data point's progress.

NOTE: When the inversions are running, you may minimize the window and the processing will run in the background allowing you to continue to work on the computer. Any extra CPU cycles will be used by the inversion process. For some datasets containing 10's of thousands 100's of thousands of data points, the process may take many hours.

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1/9/2023

TEM Inverse 22

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Inversion Evaluation

After import, there will be several surveys. In this case, 3 surveys, one for each base frequency

In each survey, there will be several data sets after modelling, inversion and processing. In this case, we have performed several ½ space models and 2 inversions. Each of the forward models, has a new data set containing the simulated data under the model. Similarly, each inversion contains a new dataset containing the simulated data set under the inversion model (for each point) and attached to that data set is the inversion model.

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2. Import Data

6. Create Sections

1. Create a new EMIGMA database.

4. Perform some initial modelling,

arlit_100_25Hz arlit_100_6.25Hz arlit_100_2.5Hz

-Data Sets in Survey-

arlit_100_25Hz Model_200H

Marg Inv 9 50 Ohm_m 30 Ohm_m Sim Time

Marg_Inv_9

Data File Name: arlit_db_7.dat

3. Examine the data from each base frequency

5. Perform controlled Marquardt or Occam Inversions

Survey Name: arlit_100_25H;

Survey Comments

Add Survey

R

This license mainten

Simulated

Marq_Inv_9

Marq_Inv_9

Time

2

Survey ID:

Data Set

Data Set

Model Name:

Model

Grid(s)

Domain Type:

Inversion Evaluation

An inversion is selected. You will note the "Model" button is checked.

If the model button is clicked...

Configuration

- 1. Create a new EMIGMA database.
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- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

Model Configuration Prisms/Plates/Polyhedra Layers N Susceptibility Resi 1 0 1er 2 0 73 3 0 353 4 0 120 5 0 120 Edit Mode Insert Layer Replace Layer Delete Layer Undo Delete Restore	Stivity Density Thickness 008 0 1e+008 0 0 44,1154 507 0 210,244 554 0 350 519 0 1e+008 Layer Parameters Layer # 2 Resistivity (Ohm.m) 70 Relative Permeability 1 Susceptibility 0 Density (g/cm^3) 0	Configuration Survey Name Marq_Inv_4 Model Name Marq_Inv_4 Total Number of Layers 5 Depth Top Deptn Q Bottom Depth 44.1154 Cole-Cole Polarization Mode Parameter dimensionless (C (exponent) parameter dimensionless T (chargeability) Cole-Cole Susceptibility Grid Data Files Resistivity & Susceptibility Grid Data Files ModelsVL1_calibration_small_oct03_124_9 pex View File	 Attached to the database, in a subdirectory called "Models", are the inversion results in a simple ASCII XYZ file (*.pex) which may be view here. This file may easily be imported to another application although graphical viewing tools are provided within EMIGMA. The 1D model for the final data point also included. The inversion may be adjusted w.r.t. GPS elevation in order to view in
Restore	Density (g/cm ²) Discretion 0 Thickness (m) 44.1154	View File Convert to GPSZ	GPS elevation in order to view in conjunction with topography. This is available ONLY when GPSZ is
		OK Cancel Apply Help	To view the results in EMIGMA close

a window will open

ed

is

e the window.

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Inversion Evaluation



1. Create a new EMIGMA database.

- 2. Import Data
- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- **6.** Create Sections

	arlit_100_25Hz arlit_100_6.25Hz arlit_100_2.5Hz	Survey Name: arlit_100_25H Survey ID: 2 Survey Comments Add Survey
	Data Sets in Survey	Data Cat
	Model_200H Model_200H Marg_Inv_9	Domain Type: Time
00!	30 Ohm_m Sim Time Marq_Inv_9	Data Set Marq_Inv_9
-		Model Name: Marg_Inv_9
	Data File Name: arlit_db_7.dat	🔽 Model 👌
	<u>C</u> onfiguration	Grid(s)
		This license mainten



Choose CDI Viewer to graphically view the results

- 1. Create a new EMIGMA database.
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Inversion Displays TEM Inverse 27

Choose CDI viewer to graphically view the results

The results for each **data point** are shown (without interpolation) initially in **linear(Resistivity)** with **Equal Range** display.





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Equal Range: color intervals are equal in size

Equal Weight: color intervals are equally distributed in data

Min: Any data values below Min will be displayed as the color to the right of the edit field Max: Any data values above Max will be displayed as the color to the right of the edit field

- 1. Create a new EMIGMA database.
- 2. Import Data
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- 6. Create Sections



Choose CDI viewer to graphically view the results



Axes may be edited by double-clicking Interpolated may be repeated (note: the results of previous interpolations are used in the next interpolation so use with care.) Legends turned on and controlled by double clicking the legend

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Ohm ·m

- 2. Import Data
- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections



To assess the success of the inversion, select the measured data and then select

the plotter.



Emigma			×
?	Do you want to compare with other Data Sets?		
Yes	No Load Settings Cancel	Help	

Select "Yes"

TEM Inverse 30

- 1. Create a new EMIGMA database.
- 2. Import Data
- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

All selected data sets are then loaded to the plotter application and the plot appears showing the the first channel of the measured data.

Inversion Evaluation

Survey Selection

TEM Inverse 31

Select the data sets required for comparison and then "Load"

Name	vey:	O Type	Add to the Selected Add All to the Selected Remove from the Selected	Selected Data Se arlit_100_25Hz Model_200H Marq_Inv_9 50 Ohm_m 30 Ohm_m Sim Time Marq_Inv_9	ts to plot: Model_200H Marq_Inv_9 500hm_m 30 0hm_m 30 0hm-m Marq_Inv_9	Ty N 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
Show IMPE	DANCE Data Set	s in Survey		,		



- 1. Create a new EMIGMA database.
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- 6. Create Sections

TEM Inverse 32

The user may select other data sets to plot by simply clicking on the plot.



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- 1. Create a new EMIGMA database.
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- 6. Create Sections

TEM Inverse 33

Here, multiple plots are shown for various inversions and models in "Profile" mode. The user may step through time windows by simply clicking the arrow.



To show in "Decay" mode use the "Domain" button or right-click and choose Decay

- 1. Create a new EMIGMA database.
- 2. Import Data
- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions
- 6. Create Sections

TEM Inverse 34

Here, decays are compared for a single data point in linear-linear mode. The user may move to other data points by simply clicking the arrows.



The step-time function of the arrows is now converted to step position.

It is useful to compare in a variety of log or linear modes. This functionality is accessed by double-clicking either axis.





2. Import Data

Scale Settings

Scaling For Plot 1

- 3. Examine the data from each base frequency
- 4. Perform some initial modelling,
- 5. Perform controlled Marquardt or Occam Inversions

X

6. Create Sections

Inversion Evaluation

TEM Inverse 35

Here, we select log(time) vs log(amplitude)...

Log-Log Decay Mode



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These papers are available from our download site , <u>http://www.petroseikon.com/resources/technical.php</u> A variety of other references may be found at the end of each of these papers.

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