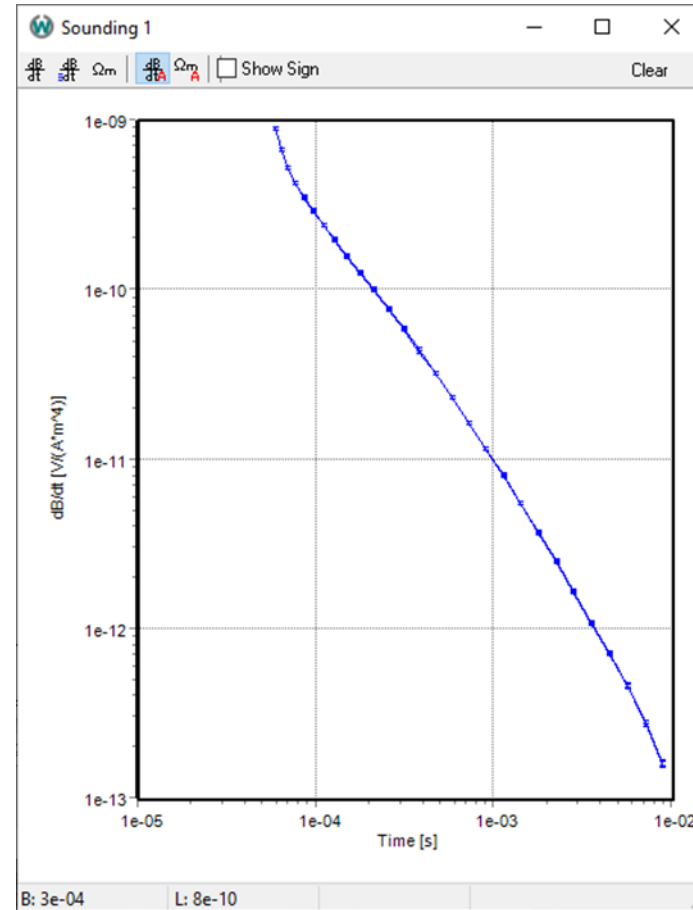


Bjarke Roth
Geophysicist

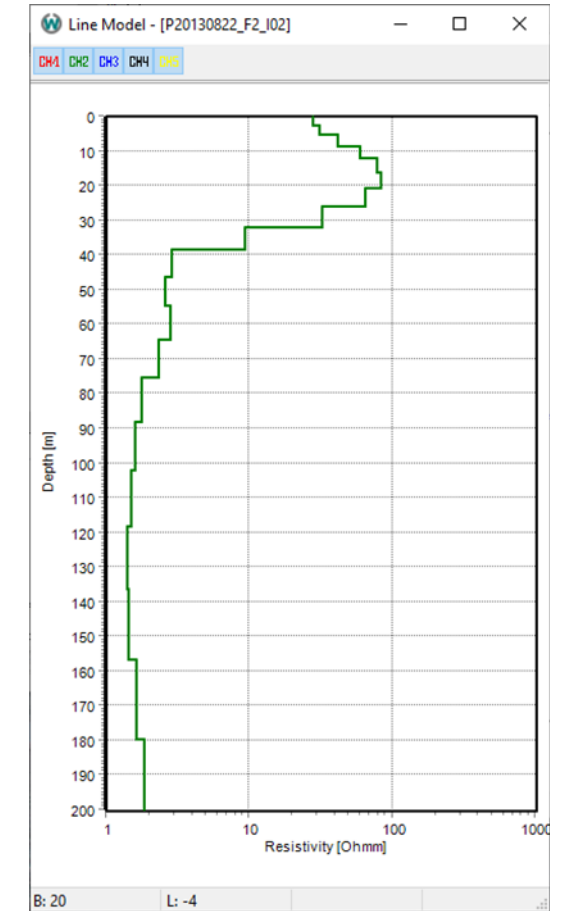
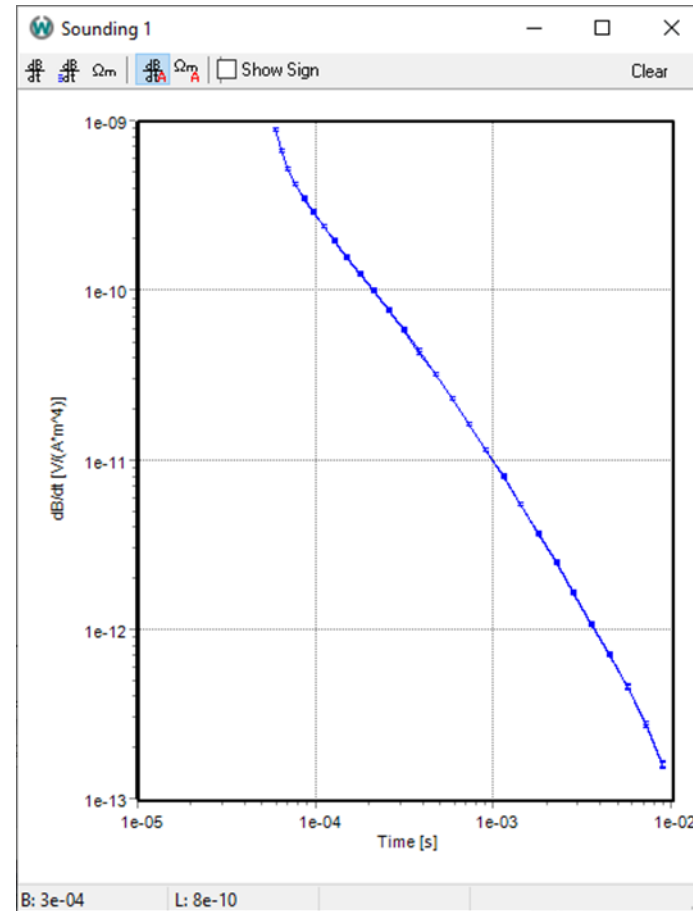
Inversion – What is inversion?

- We have measured data



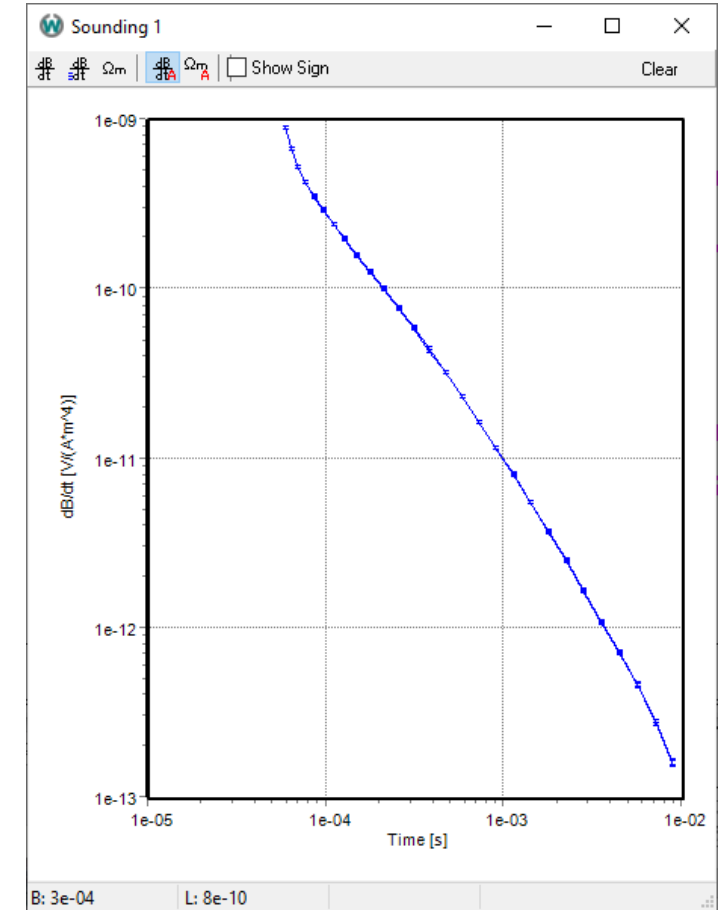
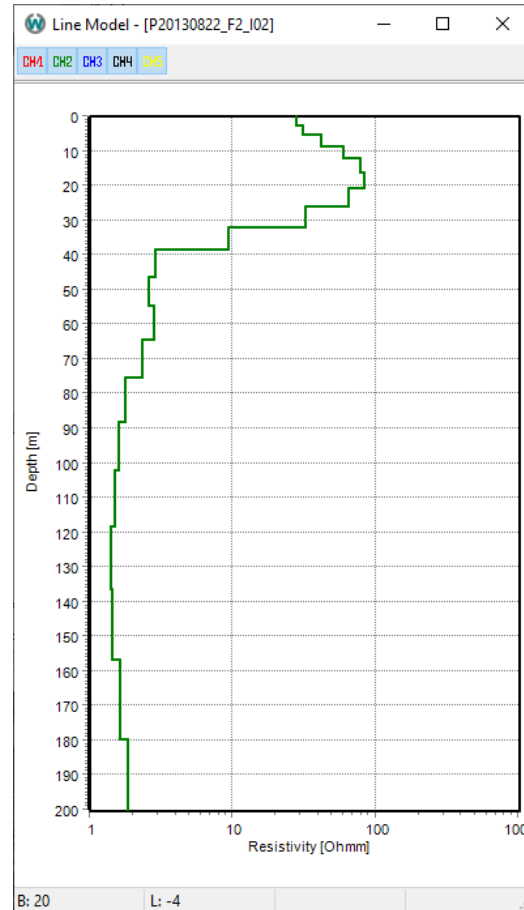
Inversion – What is inversion?

- We have measured data
- How do we go from data to a model?



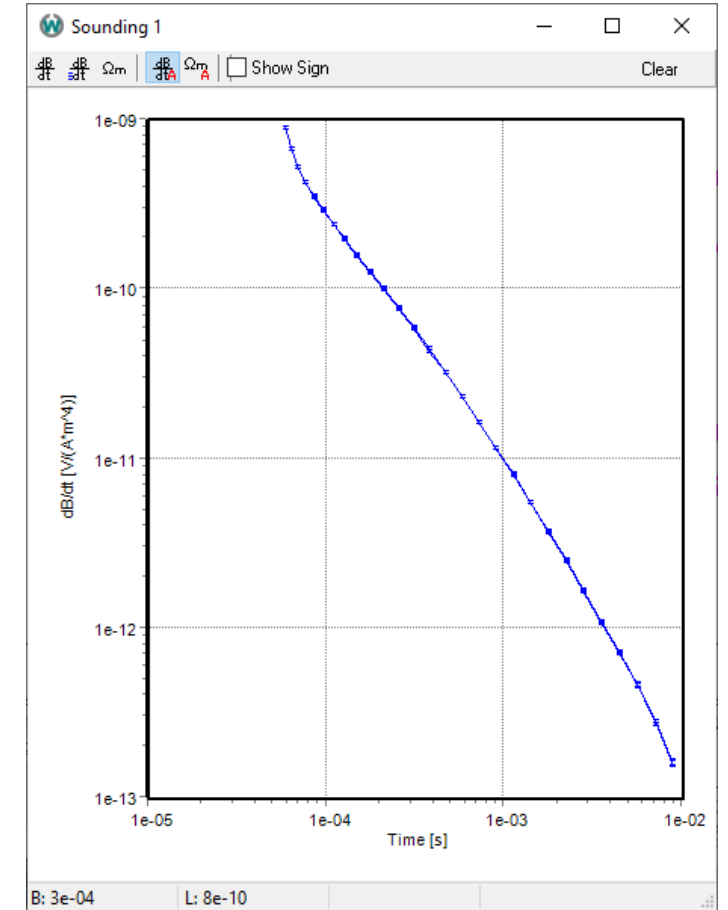
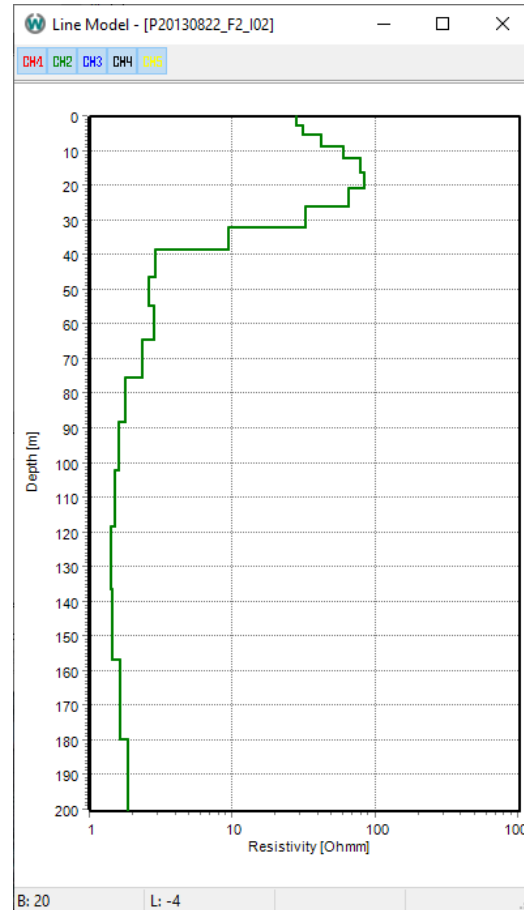
Inversion – What is inversion?

- We have measured data
- How do we go from data to a model?
- It turns out, it is easier to go the other way!



Inversion – What is inversion?

- We have measured data
- How do we go from data to a model?
- It turns out, it is easier to go the other way!
- We know the physics, and with an accurate system description, it is possible to calculate the forward response that one would measure for a given model
- So we can compare this forward response with the measured data!



Inversion – What is inversion?

- The comparison is done with an objective function
- An example of such a function could be the data residual

$$\textit{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

The $C_{obs,i}$ is the data uncertainty squared

A value below 1 means the data have fitted within the noise, anything below 1 is therefore equally correct

A value equal to 2 means that the data have fitted within an interval of 2 times the noise

Inversion – What is inversion?

- The comparison is done with an objective function
- An example of such a function could be the data residual
- By minimizing this function we will find the version of our model that comes closest to giving us the data we have observed

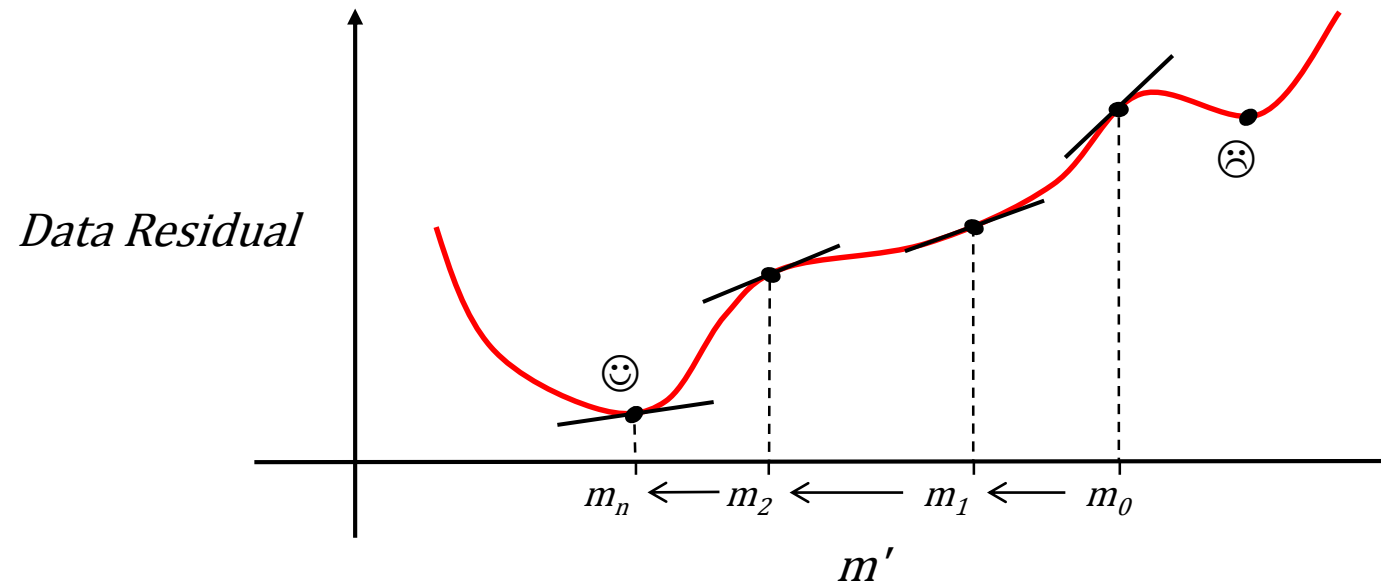
$$\textit{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

Inversion – What is inversion?

- The comparison is done with an objective function
- An example of such a function could be the data residual
- By minimizing this function we will find the version of our model that comes closest to giving us the data we have observed
- Let us see how it works for a halfspace model, that is a model with only the resistivity parameter to describe the subsurface

$$\textit{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

Inversion – What is inversion?



Inversion – What is inversion?

- This approach is called a **Levenberg-Marquardt algorithm or Damped least squares scheme**
- **It doesn't always find the global minimum, but it quite robust for well-behaved functions and reasonable starting parameters**

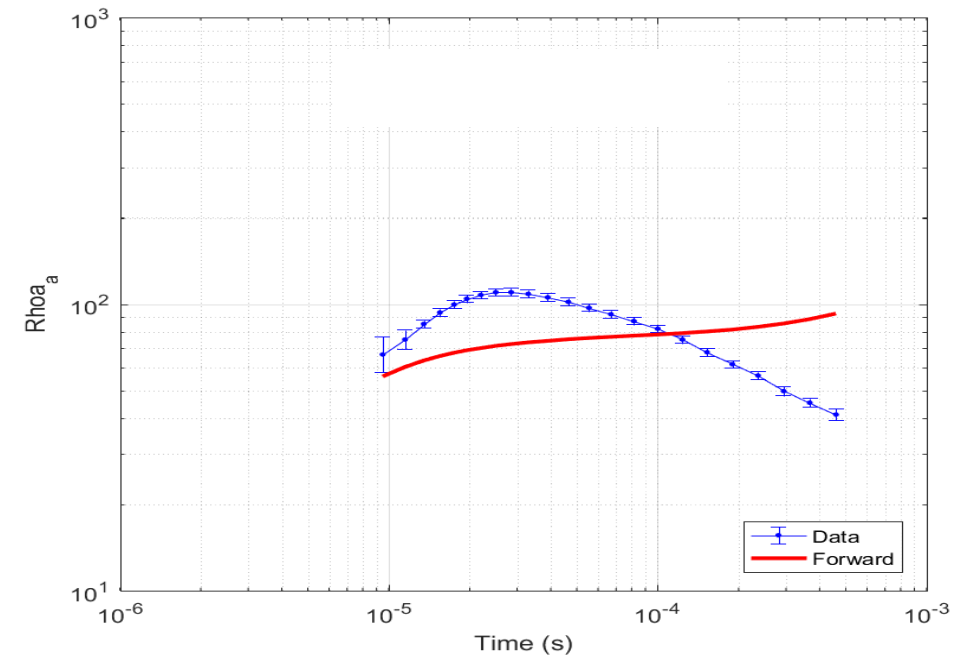
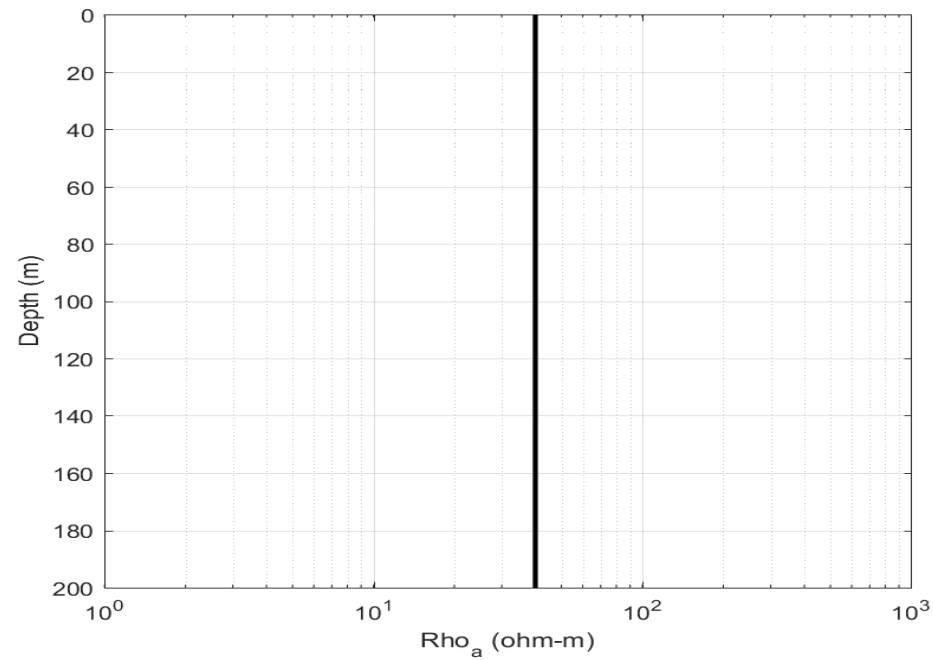
References for the mathematics:

- Menke W. (1989), Geophysical data analysis: Discrete inversion theory. Academic Press Inc: 260pp.
- Zhdanov M.S. (2002), Geophysical Inverse Theory and Regularization Problems. Elsevier, 636pp.
- Gubbins D. (2004), Time Series Analysis and Inverse Theory for Geophysicists. Cambridge University Press: 272pp.
- Auken E., Christiansen A.V. (2004), Layered and laterally constrained 2D inversion of resistivity data, Geophysics 69(3): 752-761.
- Viezzoli A., Christiansen A.V., Auken E., Sørensen K.I. (2008), Quasi-3D modeling of airborne TEM data by spatially constrained inversion. Geophysics 73(3): F105-F113.

Inversion – What is inversion?

- TEM Inversion

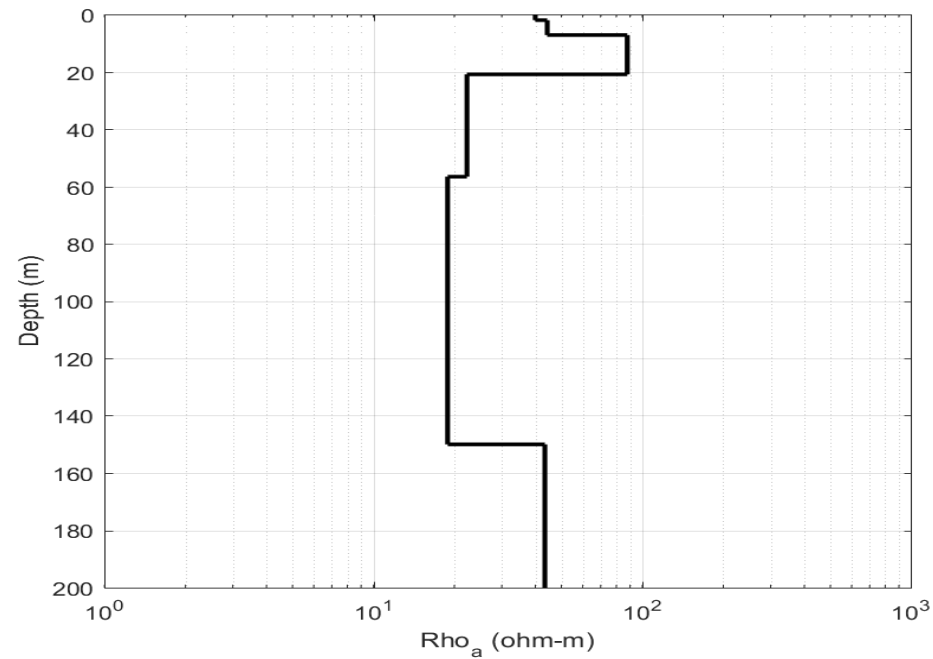
$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{c_{obs,i}} \right)^{\frac{1}{2}}$$



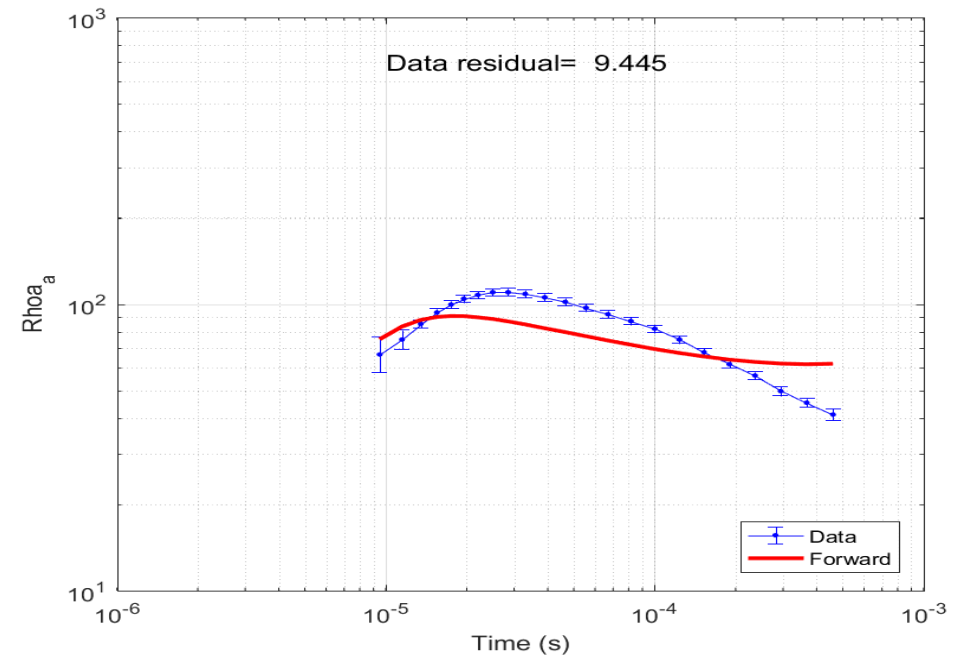
Inversion – What is inversion?

- TEM Inversion

$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{c_{obs,i}} \right)^{\frac{1}{2}}$$



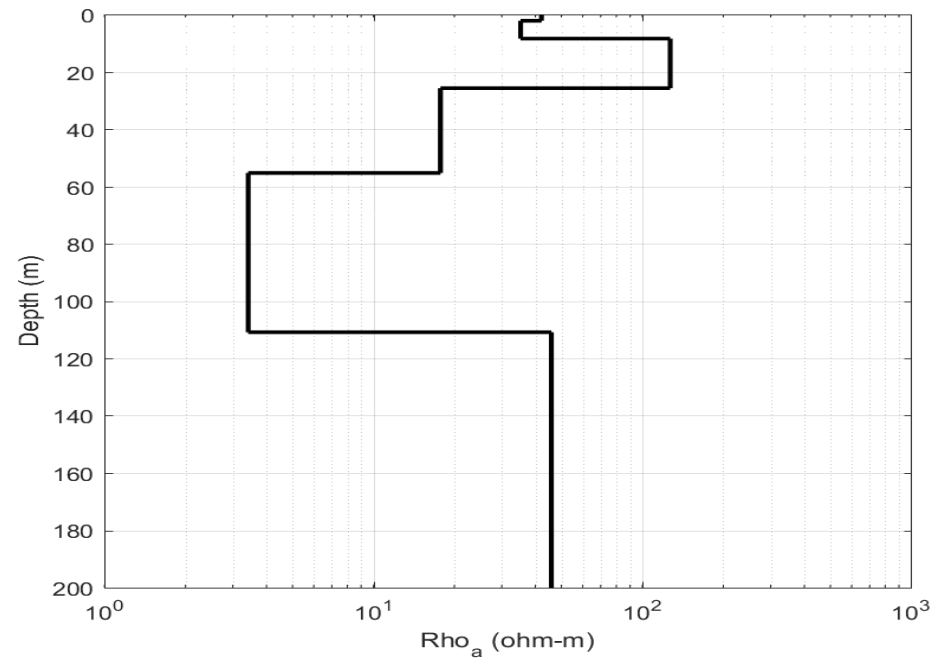
Iteration 1



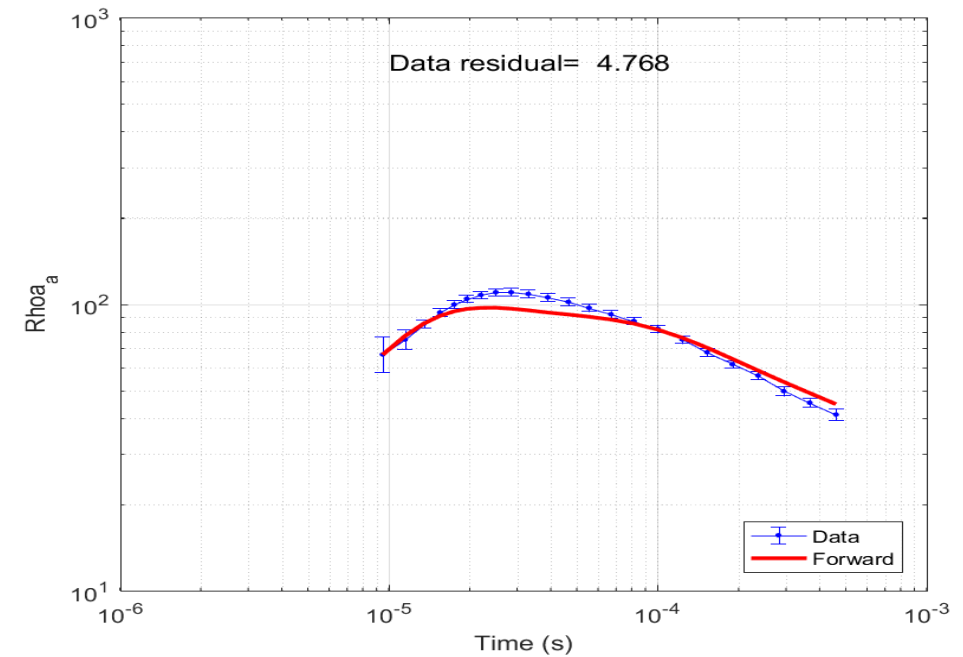
Inversion – What is inversion?

- TEM Inversion

$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{c_{obs,i}} \right)^{\frac{1}{2}}$$



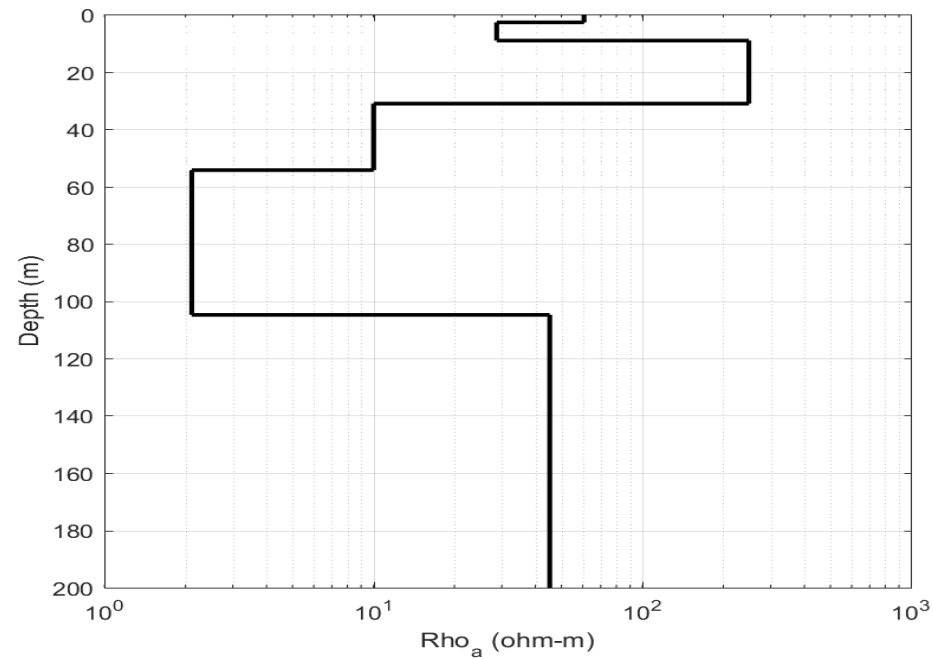
Iteration 6



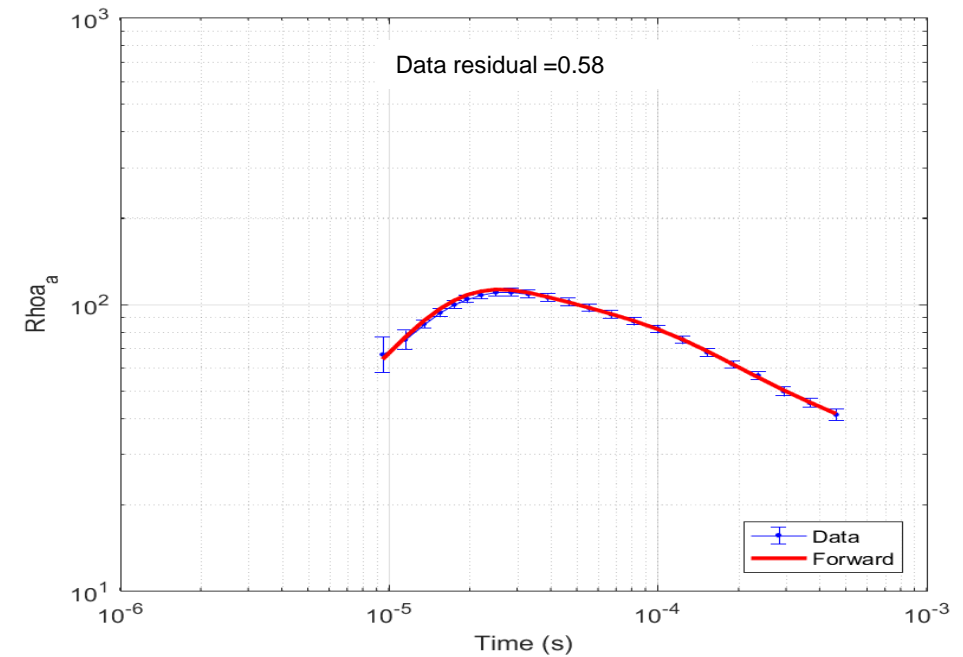
Inversion – What is inversion?

- TEM Inversion

$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{c_{obs,i}} \right)^{\frac{1}{2}}$$

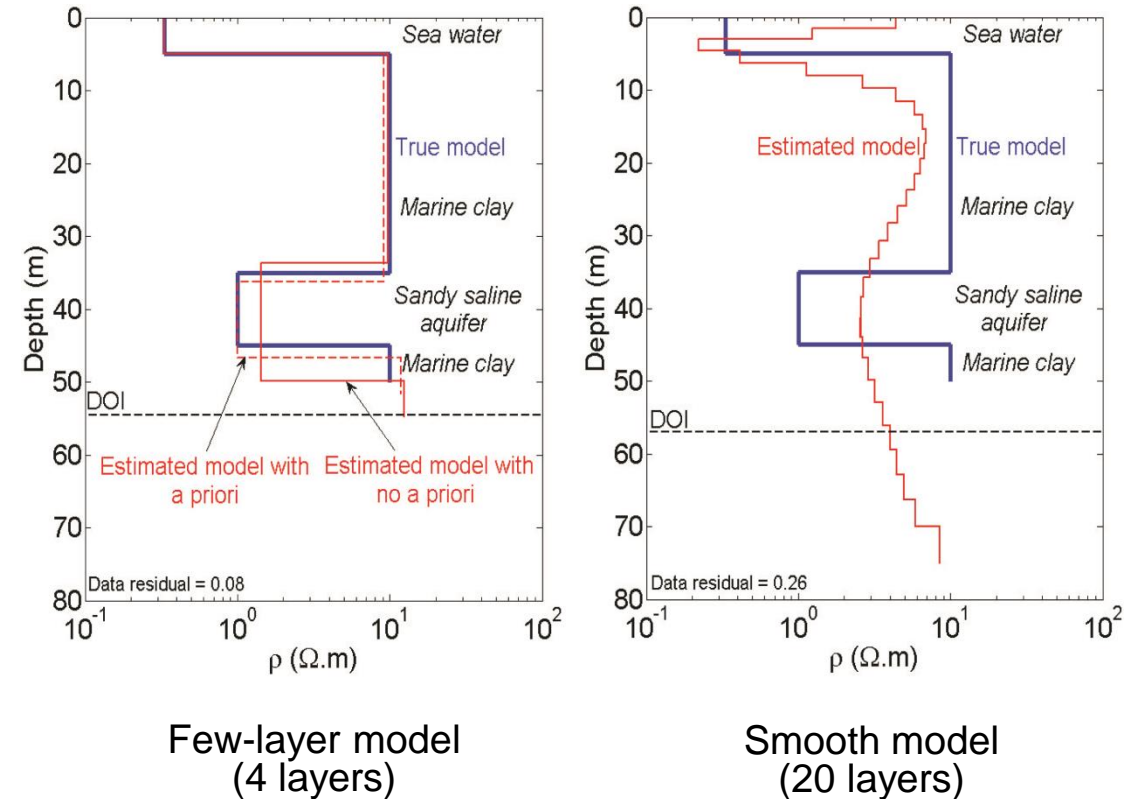


Iteration 9



Inversion – Models

- **Different types of 1-D models**
- **A few-layer or layered model**
 - Usually 4-5 layers
 - Both resistivity and thicknesses are estimated
- **A smooth model**
 - Usually 20-40 layers
 - Only resistivities are estimated. The thicknesses are kept fixed with increasing size with depth
 - The resistivities are also vertically constrained to ensure continuity between layers, hence "smooth"

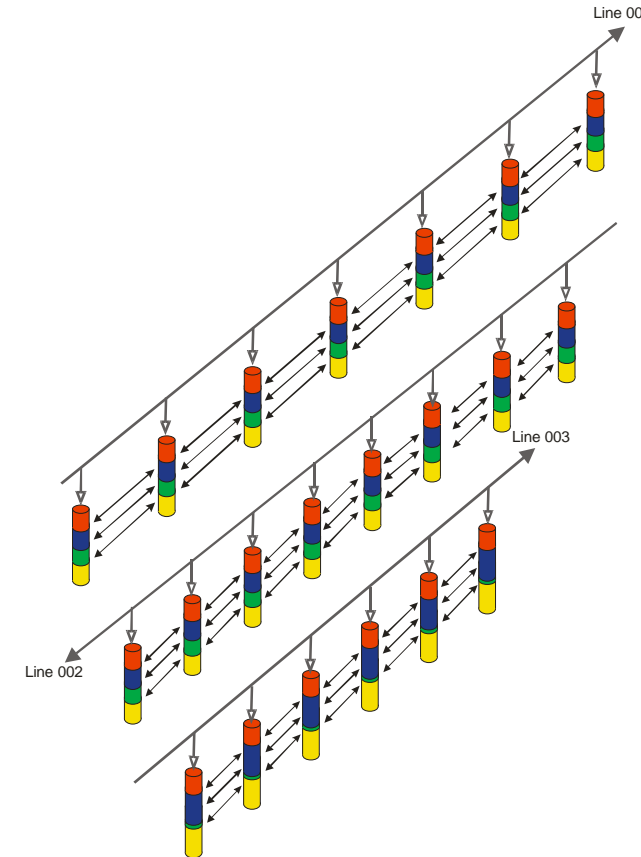


Inversion – Constrained inversion

- We can also have constraints between models
- By taking advantage of the continuity in the geology, we end up improving the resolution of the more weakly determined model parameters and it also makes the inversion more stable (nice from a production point of view)

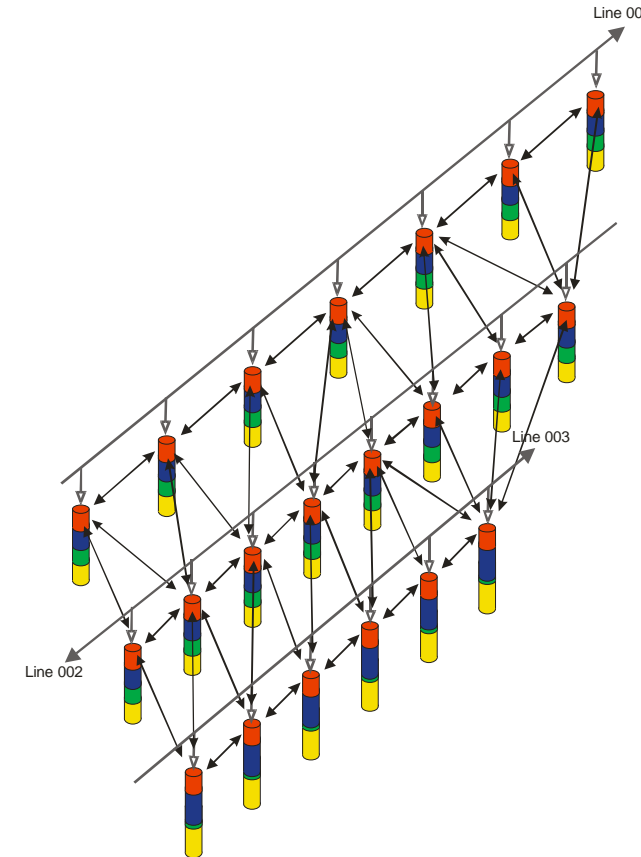
Inversion – Constrained inversion

- We can also have constraints between models
- By taking advantage of the continuity in the geology, we end up improving the resolution of the more weakly determined model parameters and it also makes the inversion more stable (nice from a production point of view)
- We can have constraints along the flight lines – This is called Laterally Constrained Inversions or LCI



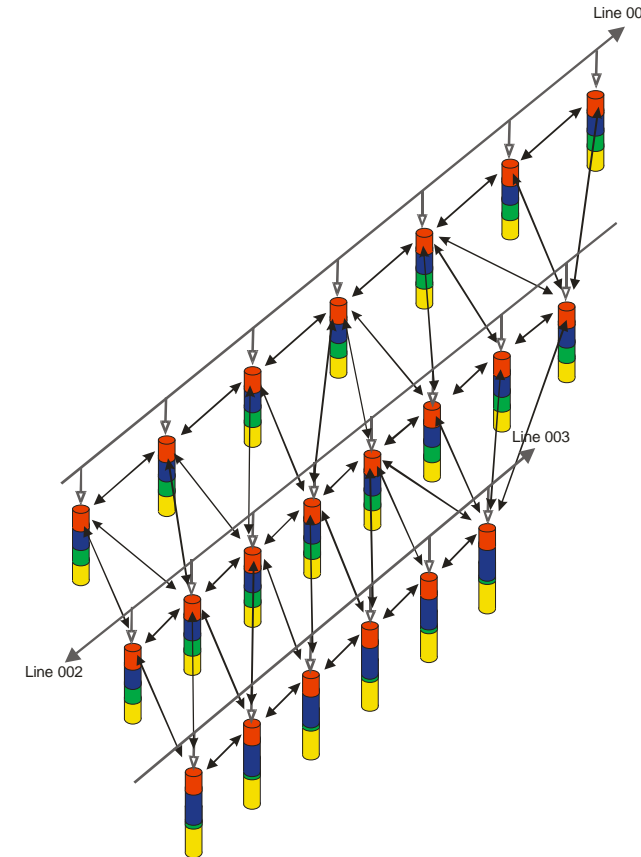
Inversion – Constrained inversion

- We can also have constraints between models
- By taking advantage of the continuity in the geology, we end up improving the resolution of the more weakly determined model parameters and it also makes the inversion more stable (nice from a production point of view)
- We can have constraints along the flight lines – This is called Laterally Constrained Inversions or LCI
- Or we can have constraints both along the flight lines and between the flight lines – This is called Spatially Constrained Inversion or SCI



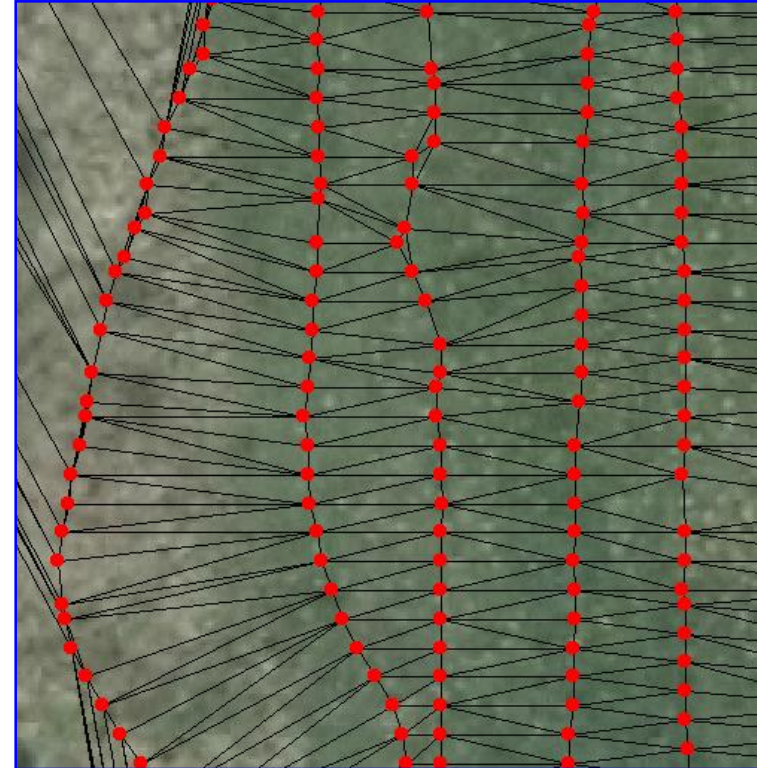
Inversion – Constrained Inversion

- We can also have constraints between models
- By taking advantage of the continuity in the geology, we end up improving the resolution of the more weakly determined model parameters and it also makes the inversion more stable (nice from a production point of view)
- We can have constraints along the flight lines – This is called Laterally Constrained Inversions or LCI
- Or we can have constraints both along the flight lines and between the flight lines – This is called Spatially Constrained Inversion or SCI
- It is still 1D inversions, but the models become quasi 2D for LCI and quasi 3D for SCI



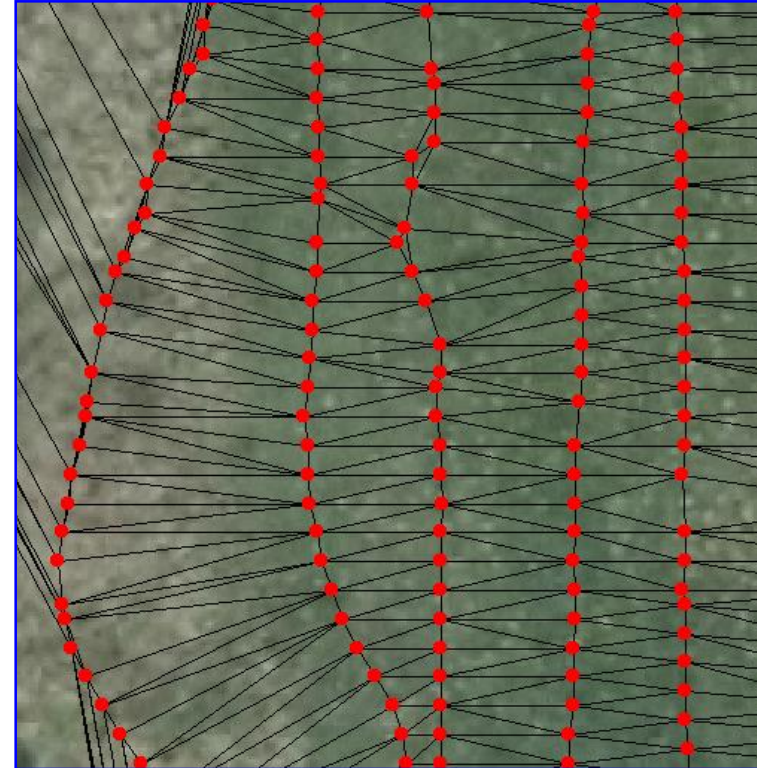
Inversion – Constrained inversion

- The distance between points determines the strength of the lateral correlation
- The lattices determines who is constrained to who
- Something like the altitude is also constrained, but those constraints are kept separate and are restricted to only be along the flight lines
- This constraint network also allows a priori information to be spread out from a source



Inversion – A priori inversion

- For SCI we have some additional options for taking advantage of a priori information
- We can add a priori based on
 - GIS selections (fx. One starting model over land, another over water)
 - Grids (fx. Fix layer boundaries based on grids created with seismics)
 - Conductivity logs (adjust starting models based on conductivity logs for models near boreholes)



Inversion – The full objective function

- We started with a simple objective function that only looked at the data residual

$$\textit{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

Inversion – The full objective function

- We started with a simple objective function that only looked at the data residual
- The final objective function include the constraints and the a priori, so that they also can help guide the inversion

$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

$$\text{Total Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}} + \left(\frac{1}{N_{con}} \sum_{i=1}^{N_{con}} \frac{(m_{par1,i} - m_{par2,i})^2}{C_{R,i}} \right)^{\frac{1}{2}} + \left(\frac{1}{M} \sum_{i=1}^M \frac{(m_i - m_{prior,i})^2}{C_{P,i}} \right)^{\frac{1}{2}}$$

Data

Constraints

A priori

Inversion – Additional model types

- We started with a simple objective function that only looked at the data residual
- The final objective function include the constraints and the a priori, so that they also can help guide the inversion
- This is not the only way you could describe these terms. The last two model types we use are variants of smooth models, just with different constraint terms here

$$\text{Data Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}}$$

$$\text{Total Residual} = \left(\frac{1}{N} \sum_{i=1}^N \frac{(d_{obs,i} - d_{forward,i})^2}{C_{obs,i}} \right)^{\frac{1}{2}} + \left(\frac{1}{N_{con}} \sum_{i=1}^{N_{con}} \frac{(m_{par1,i} - m_{par2,i})^2}{C_{R,i}} \right)^{\frac{1}{2}} + \left(\frac{1}{M} \sum_{i=1}^M \frac{(m_i - m_{prior,i})^2}{C_{P,i}} \right)^{\frac{1}{2}}$$

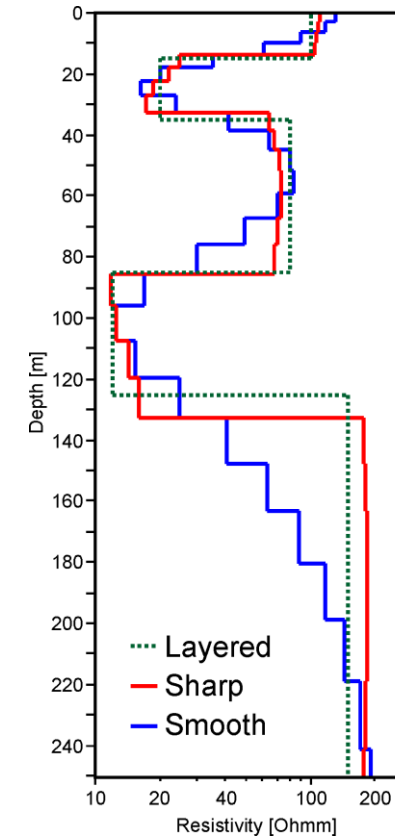
Data

Constraints

A priori

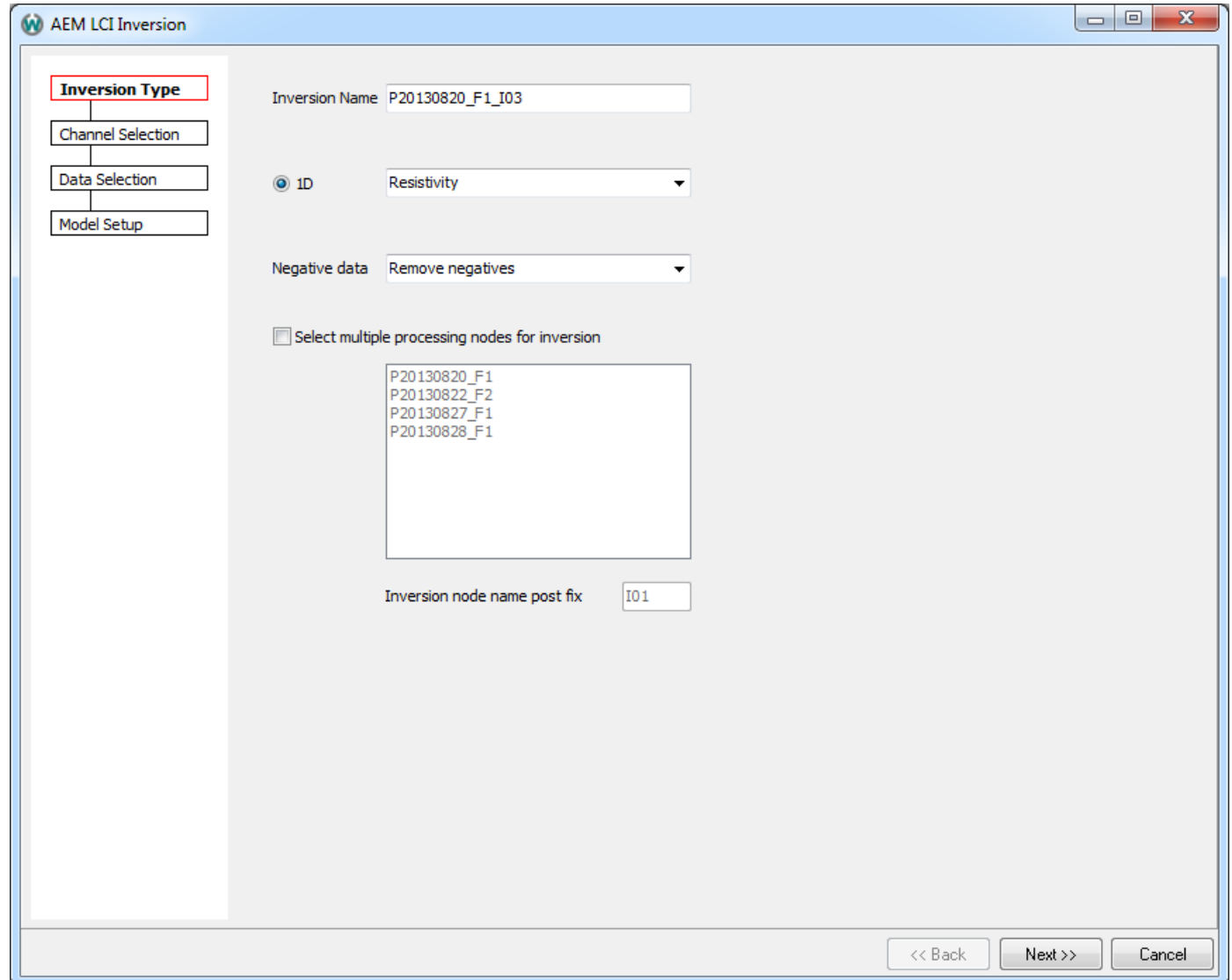
Inversion – Additional model types

- **The first one is called a blocky model**
 - Its constraint term uses absolute difference rather than a squared difference
 - This creates a blocky result, not unlike the layered model, but without needing to make as many assumptions
- **The second is called a sharp model**
 - Its constraint term makes the number of variations above a certain size costly, rather than simply the amount of variation
 - This also creates a blocky result, but with more control over both how many blocks and the amount of variation within each block



Inversion – LCI setup

- Select the processing node and then press LCI on the Inversion ribbon
- Options depend on data type and license, this is airborne TEM
- Name
- Inversion type
- Negative data
- Select multiple



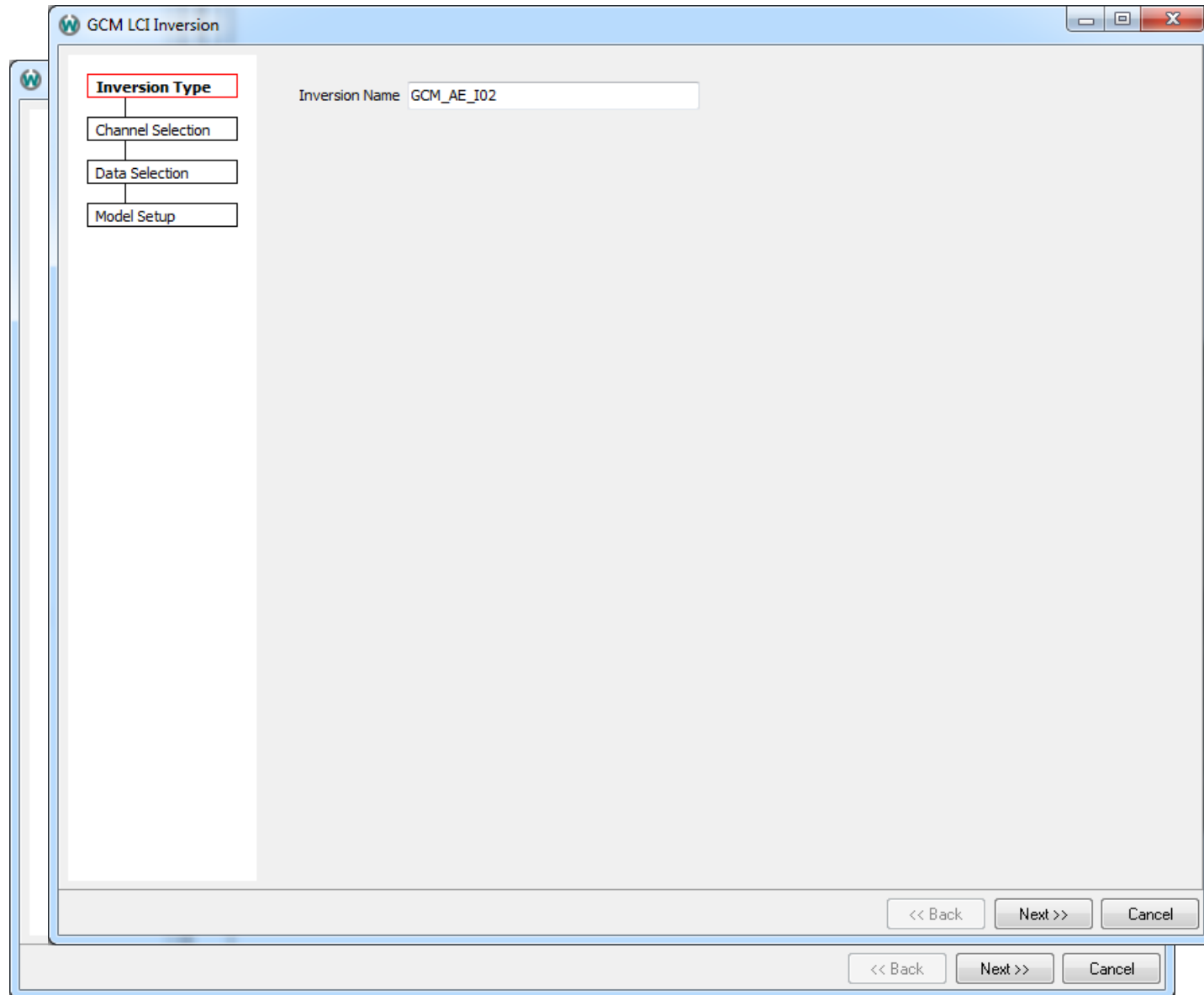
The screenshot shows the 'AEM LCI Inversion' window. On the left, a vertical stack of buttons includes 'Inversion Type' (highlighted with a red border), 'Channel Selection', 'Data Selection', and 'Model Setup'. The main area contains the following fields and options:

- Inversion Name:** P20130820_F1_I03
- 1D:** Resistivity (selected from a dropdown)
- Negative data:** Remove negatives (selected from a dropdown)
- ☐ Select multiple processing nodes for inversion
- Processing nodes list:** P20130820_F1, P20130822_F2, P20130827_F1, P20130828_F1
- Inversion node name post fix:** I01

At the bottom right, there are three buttons: '<< Back', 'Next >>', and 'Cancel'.

Inversion – LCI setup

- This is GCM



The screenshot shows a software window titled "GCM LCI Inversion". On the left side, there is a vertical stack of four buttons: "Inversion Type" (highlighted with a red border), "Channel Selection", "Data Selection", and "Model Setup". To the right of these buttons, there is a text field labeled "Inversion Name" containing the text "GCM_AE_I02". At the bottom right of the window, there are three buttons: "<< Back", "Next >>", and "Cancel".

Inversion – LCI setup

- Next page of the wizard for airborne TEM
- Choose software channels
- Omit gates

AEM LCI Inversion

Inversion Type

Channel Selection

Data Selection

Model Setup

Channels

☒ 1, Ch. #1 - Low Moment - z component

☒ 2, Ch. #2 - High Moment - z component

☐ 6, Ch. #3 - Noise - z component

Frontgate Time: N/A

Gate Times

Gate number	Gate center time [s]
1	1.000E-07
2	8.150E-07
3	2.815E-06
4	4.815E-06
5	6.815E-06
6	8.815E-06
7	1.082E-05
8	1.332E-05
9	1.631E-05
10	1.982E-05
11	2.432E-05
12	2.982E-05
13	3.681E-05
14	4.581E-05
15	5.681E-05
16	7.031E-05
17	8.731E-05
18	1.093E-04
19	1.373E-04
20	1.723E-04
21	2.163E-04
22	2.718E-04
23	3.423E-04
24	4.318E-04
25	5.448E-04
26	6.873E-04
27	8.673E-04
28	1.095E-03

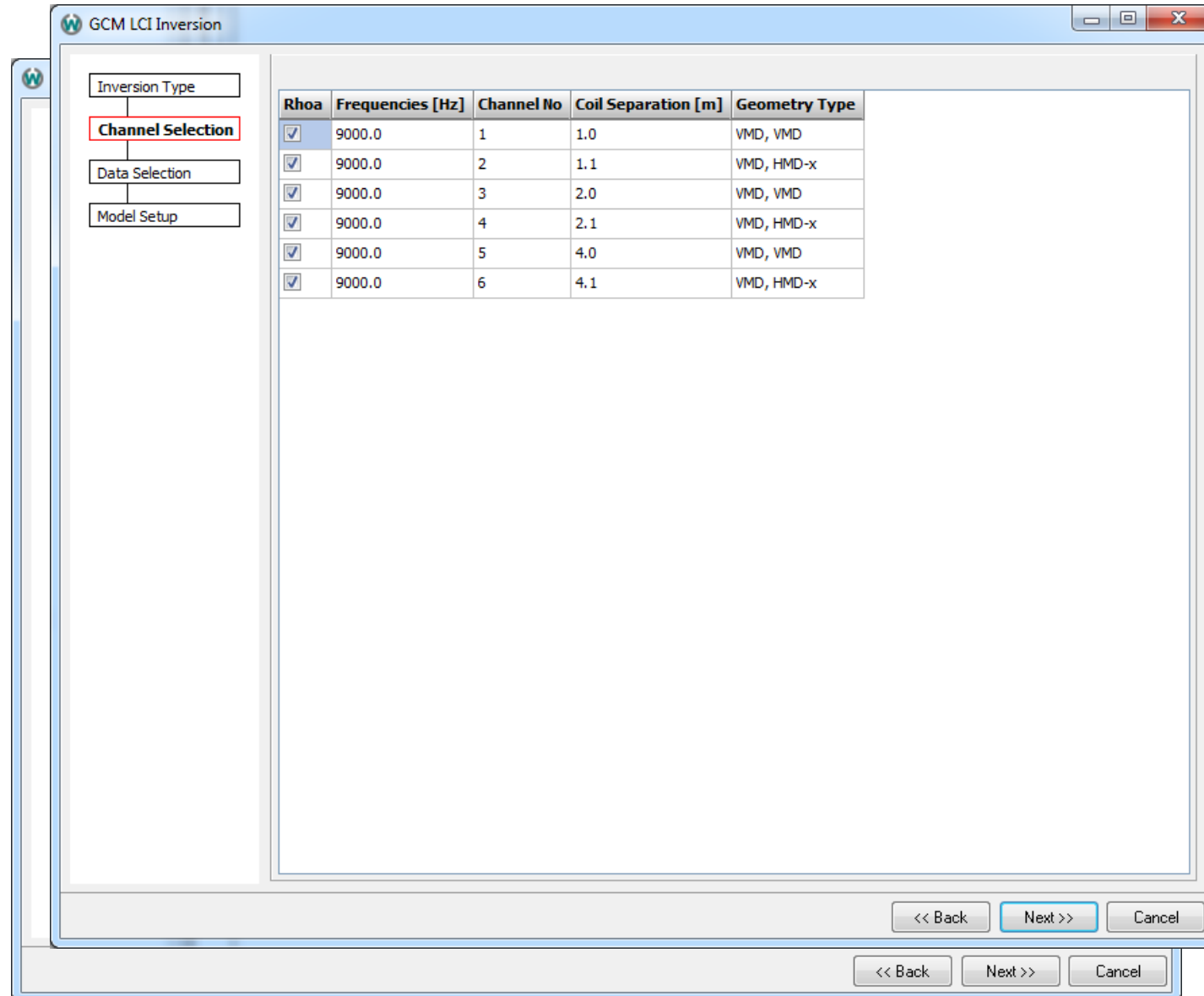
Omit Gates

Channel	Gates
Channel 1	1-5
Channel 2	10
Channel 6	

<< Back Next >> Cancel

Inversion – LCI setup

- This is GCM
- Choose software channels



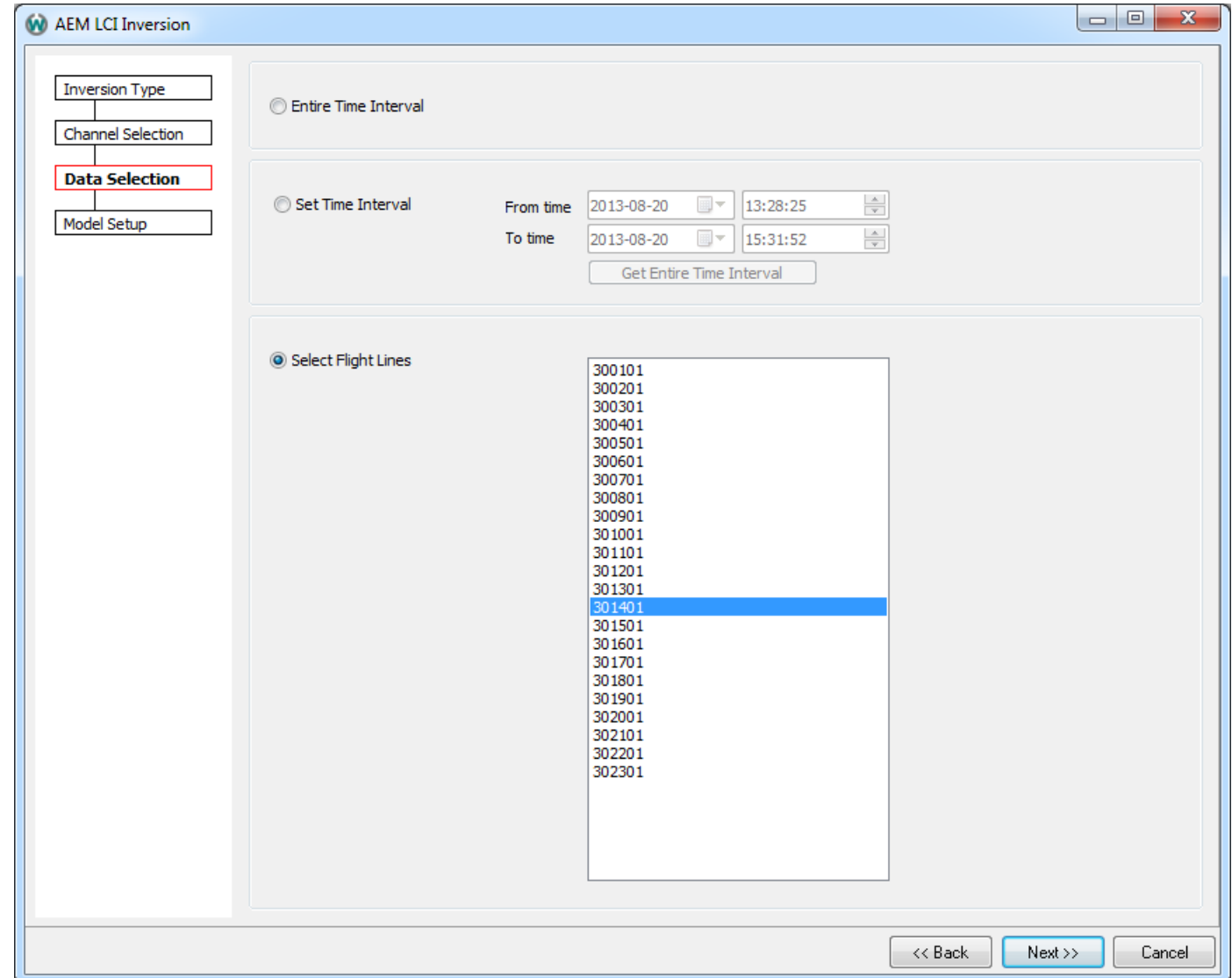
The screenshot shows the 'GCM LCI Inversion' window. On the left, a vertical navigation pane contains four buttons: 'Inversion Type', 'Channel Selection' (highlighted with a red border), 'Data Selection', and 'Model Setup'. The main area of the window displays a table with the following data:

Rhoa	Frequencies [Hz]	Channel No	Coil Separation [m]	Geometry Type
<input checked="" type="checkbox"/>	9000.0	1	1.0	VMD, VMD
<input checked="" type="checkbox"/>	9000.0	2	1.1	VMD, HMD-x
<input checked="" type="checkbox"/>	9000.0	3	2.0	VMD, VMD
<input checked="" type="checkbox"/>	9000.0	4	2.1	VMD, HMD-x
<input checked="" type="checkbox"/>	9000.0	5	4.0	VMD, VMD
<input checked="" type="checkbox"/>	9000.0	6	4.1	VMD, HMD-x

At the bottom of the window, there are three buttons: '<< Back', 'Next >>' (highlighted with a blue border), and 'Cancel'.

Inversion – LCI setup

- Next page of the wizard for airborne TEM
- Entire time interval, specific time interval, or specific flight lines



The screenshot shows the 'AEM LCI Inversion' window. On the left, a vertical navigation pane contains four steps: 'Inversion Type', 'Channel Selection', 'Data Selection' (highlighted with a red border), and 'Model Setup'. The main area of the window is divided into three sections. The first section, 'Entire Time Interval', is inactive. The second section, 'Set Time Interval', is also inactive and shows 'From time' and 'To time' fields set to '2013-08-20' with times '13:28:25' and '15:31:52' respectively, along with a 'Get Entire Time Interval' button. The third section, 'Select Flight Lines', is active and contains a list of flight line IDs. The ID '301401' is selected and highlighted with a blue background. At the bottom of the window, there are three buttons: '<< Back', 'Next >>', and 'Cancel'.

AEM LCI Inversion

Data Selection

☐ Entire Time Interval

☐ Set Time Interval

From time: 2013-08-20 13:28:25

To time: 2013-08-20 15:31:52

Get Entire Time Interval

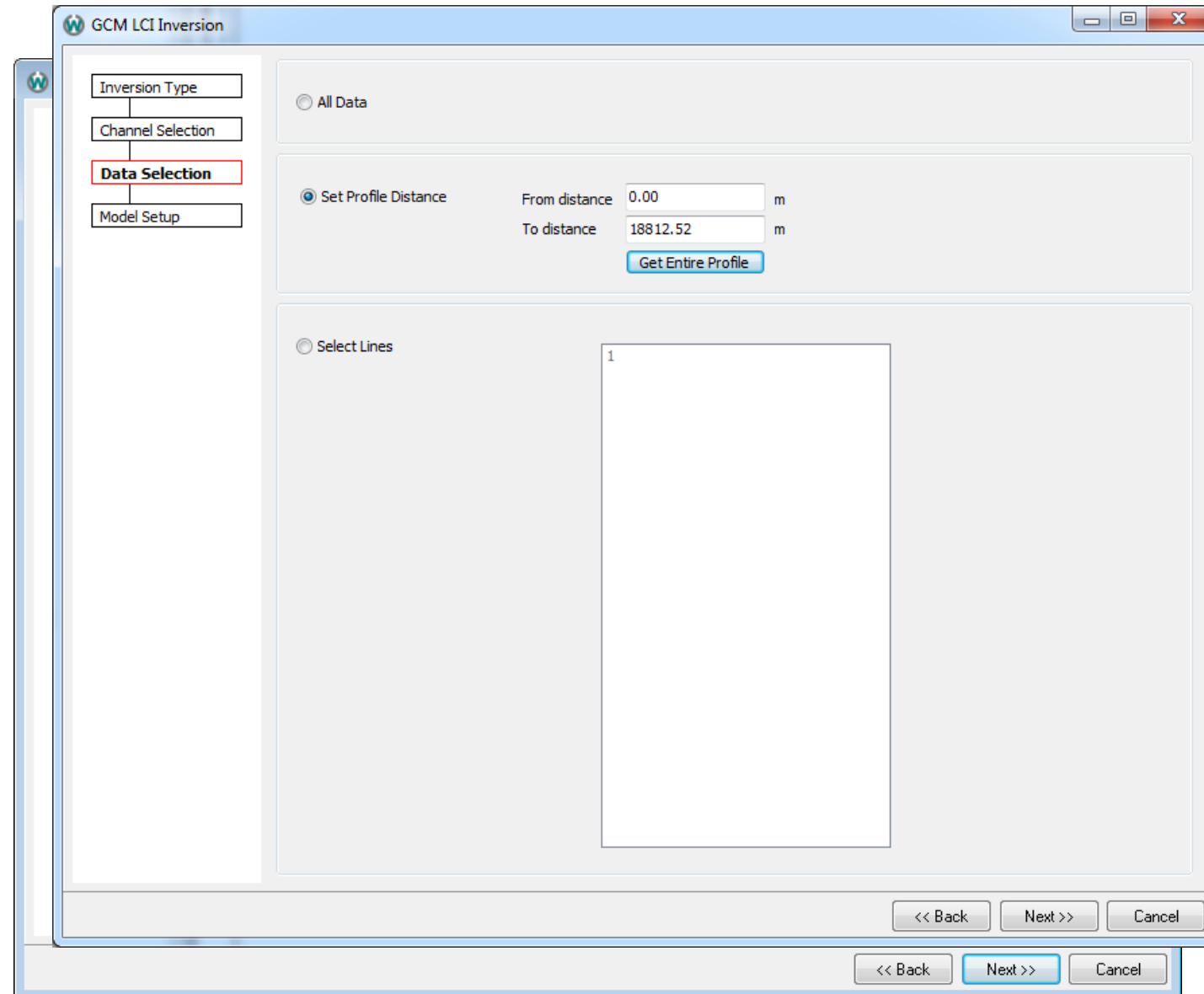
☒ Select Flight Lines

300101
300201
300301
300401
300501
300601
300701
300801
300901
301001
301101
301201
301301
301401
301501
301601
301701
301801
301901
302001
302101
302201
302301

<< Back Next >> Cancel

Inversion – LCI setup

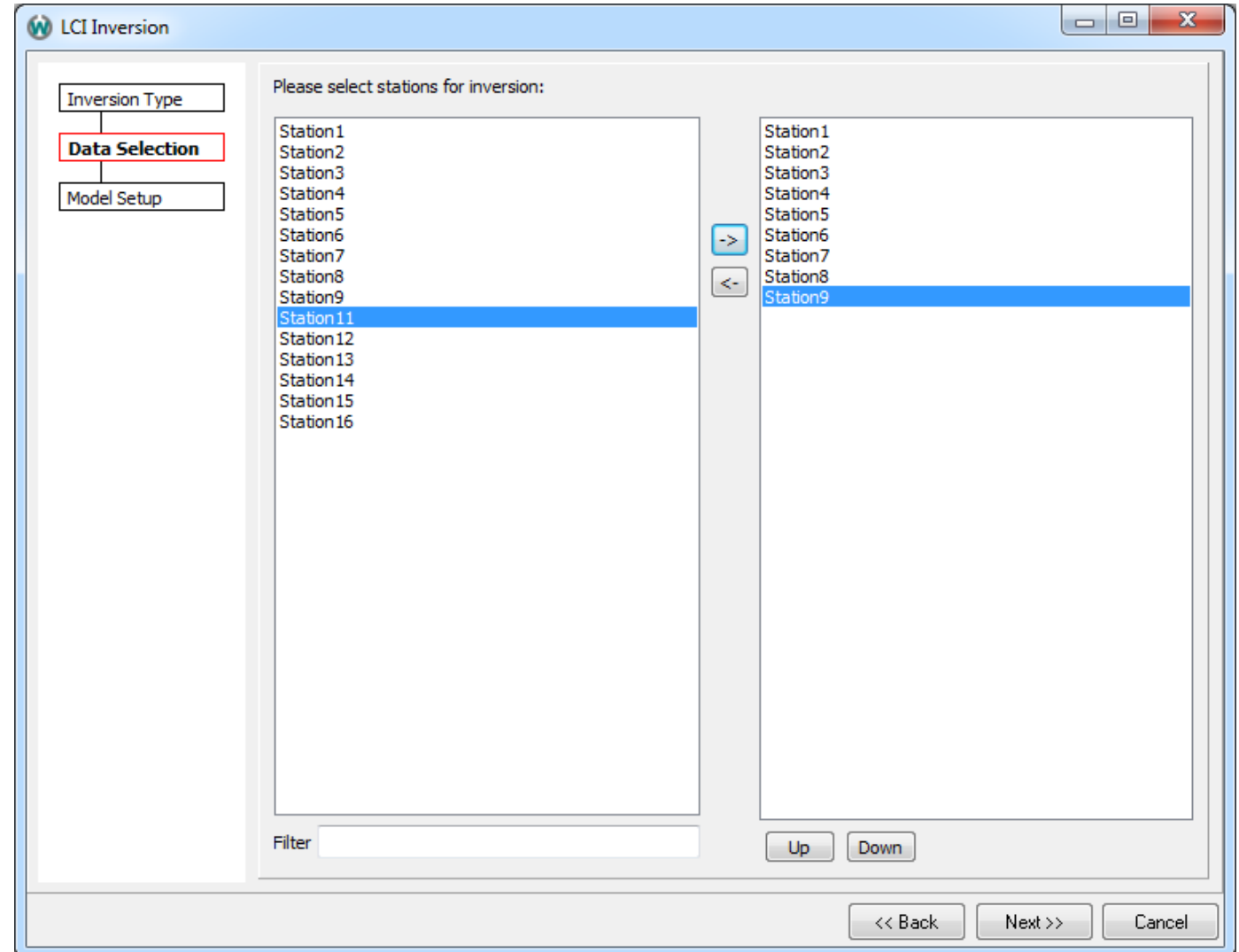
- This is GCM
- All data, specific distance along profile or specific flight lines
- GCM rarely use line number, but HEM usually does



The screenshot shows the 'GCM LCI Inversion' window. On the left is a vertical navigation pane with four buttons: 'Inversion Type', 'Channel Selection', 'Data Selection' (highlighted with a red border), and 'Model Setup'. The main area contains two radio button options: 'All Data' and 'Set Profile Distance'. The 'Set Profile Distance' option is selected. Below it are two input fields: 'From distance' with the value '0.00' and 'To distance' with the value '18812.52', both followed by a unit 'm'. A 'Get Entire Profile' button is located below these fields. At the bottom of the main area is a 'Select Lines' radio button and a large empty rectangular box. The number '1' is visible in the top-left corner of this box. At the bottom of the window are three buttons: '<< Back', 'Next >>', and 'Cancel'.

Inversion – LCI setup

- There is a third variant used for SPIATEM data nodes
- Need labels on the GIS to identify the different stations (press F1)
- Add the stations using the arrows, sort them as needed using the up and down buttons



Inversion – LCI setup

- Last page for airborne TEM but this is largely shared by all data types

- Model types

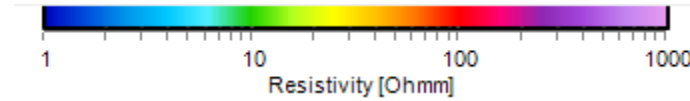
- Start with Smooth

- Each data type has some suggested values

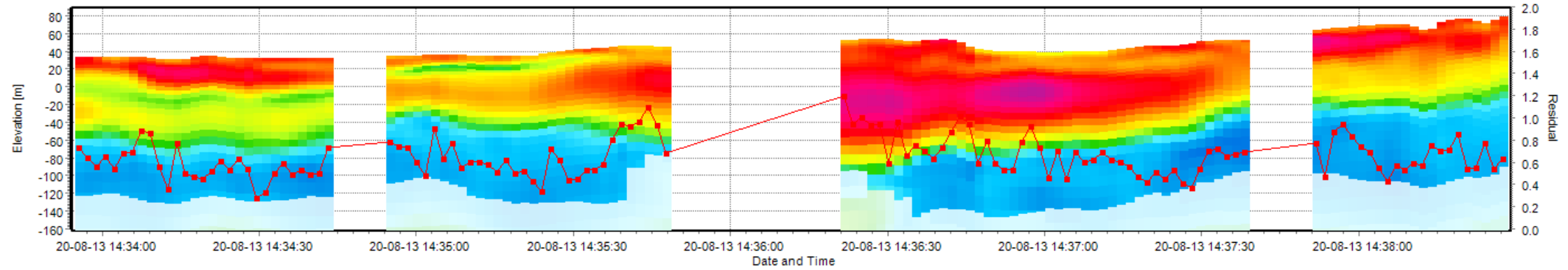
- Number of layers

The screenshot displays the 'AEM LCI Inversion' software window. On the left, a vertical navigation pane shows four tabs: 'Inversion Type', 'Channel Selection', 'Data Selection', and 'Model Setup' (which is highlighted with a red border). The main window is divided into several sections. At the top, there are two tabs: 'Inversion Settings' (active) and 'Table View'. Below these, the 'Inversion Types' section contains four radio buttons: 'Smooth' (selected), 'Blocky', 'Sharp', and 'Layered'. A 'Number of layers' field is set to 25. The 'Calculate Vertical Model Discretization' section has two input fields: 'First layer boundary' (2.5 [m]) and 'Last layer boundary' (300 [m]), with an 'Update' button. The 'Additional Settings' section includes a 'Number of processors' dropdown (7), a 'Minimum number of data points' spinner (5), a 'Use Sections' checkbox (unchecked), a 'Max number of iterations' spinner (50), a 'Reference distance' field (20 [m]), and a 'Power law' dropdown (0.75). On the right, the 'Constraints' section lists 'Resistivity' (with sub-options: Start Value, Lateral Constraint, Vertical Constraint, Prior Constraint, Altitude, Additional) and 'Auto' (selected) / 'Manual' radio buttons. At the bottom right, there are buttons for 'Save Settings...', 'Load Settings...', and 'Change Adv. Configuration...'. The bottom of the window features a navigation bar with '<< Back', 'Run', and 'Cancel' buttons.

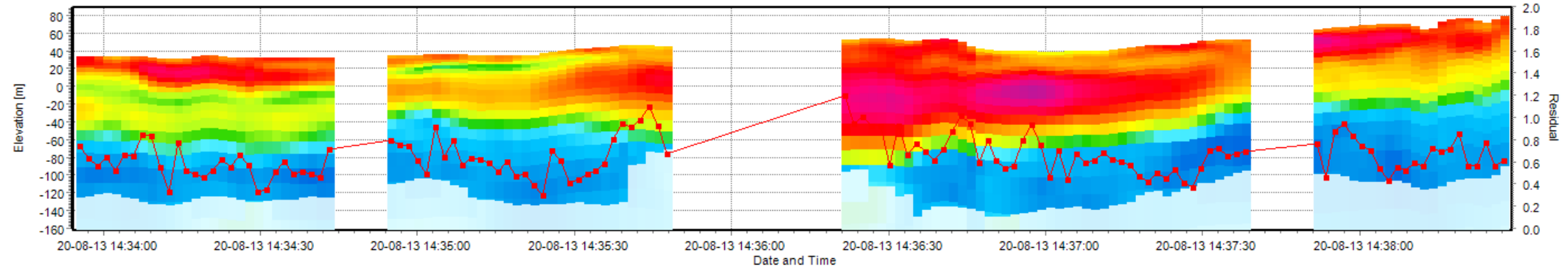
Inversion – LCI setup



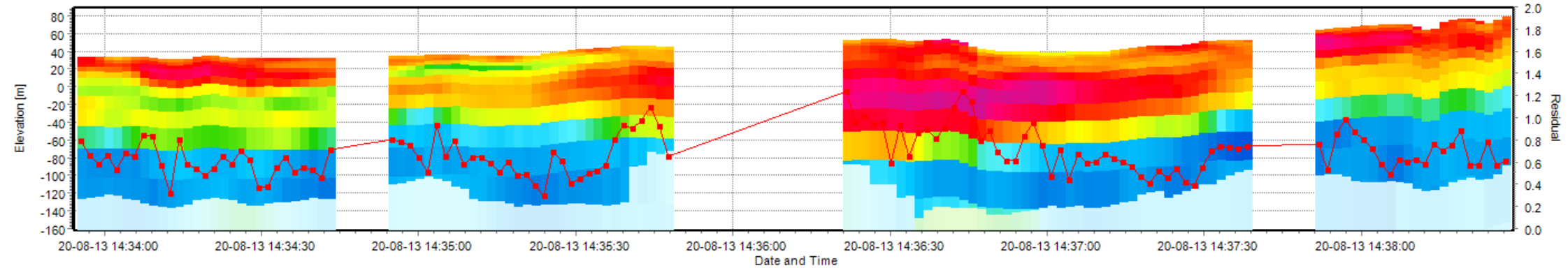
- 35 layers



- 25 layers



- 15 layers



Inversion – LCI setup

- Vertical model discretization calculator
- Enter first and last layer boundary and let it distribute the layers with logarithmically increasing thickness with depth
- First layer boundary?
- Last layer boundary?

The screenshot displays the 'AEM LCI Inversion' software window. On the left, a vertical navigation pane shows four options: 'Inversion Type', 'Channel Selection', 'Data Selection', and 'Model Setup' (which is highlighted with a red border). The main window is divided into two tabs: 'Inversion Settings' (active) and 'Table View'. The 'Inversion Settings' tab contains several sections:

- Inversion Types:** Includes radio buttons for 'Smooth' (selected), 'Blocky', 'Sharp', and 'Layered'. Below these is a 'Number of layers' field set to 25.
- Calculate Vertical Model Discretization:** Features input fields for 'First layer boundary' (2.5 [m]) and 'Last layer boundary' (300 [m]), with an 'Update' button.
- Additional Settings:** Includes a 'Number of processors' dropdown (7), a 'Minimum number of data points' spinner (5), a 'Use Sections' checkbox, a 'Max number of iterations' spinner (50), a 'Reference distance' field (20 [m]), and a 'Power law' dropdown (0.75).
- Constraints:** A tree view on the right shows 'Resistivity' expanded, with sub-items 'Start Value', 'Lateral Constraint', 'Vertical Constraint', 'Prior Constraint', 'Altitude', and 'Additional'. To the right of this tree are 'Auto' (selected) and 'Manual' radio buttons.

On the far right, there are 'Save Settings...' and 'Load Settings...' buttons. At the bottom right, a 'Change Adv. Configuration...' button is visible. The bottom of the window features a navigation bar with '<< Back', 'Run', and 'Cancel' buttons.

Inversion – LCI setup

- Vertical model discretization calculator
- Enter first and last layer boundary and let it distribute the layers with logarithmically increasing thickness with depth
- First layer boundary?
- Last layer boundary?

AEM LCI Inversion

Inversion Settings | Table View

☒ Model ☐ Constraints

Export to cvs file

Save Settings... Load Settings...

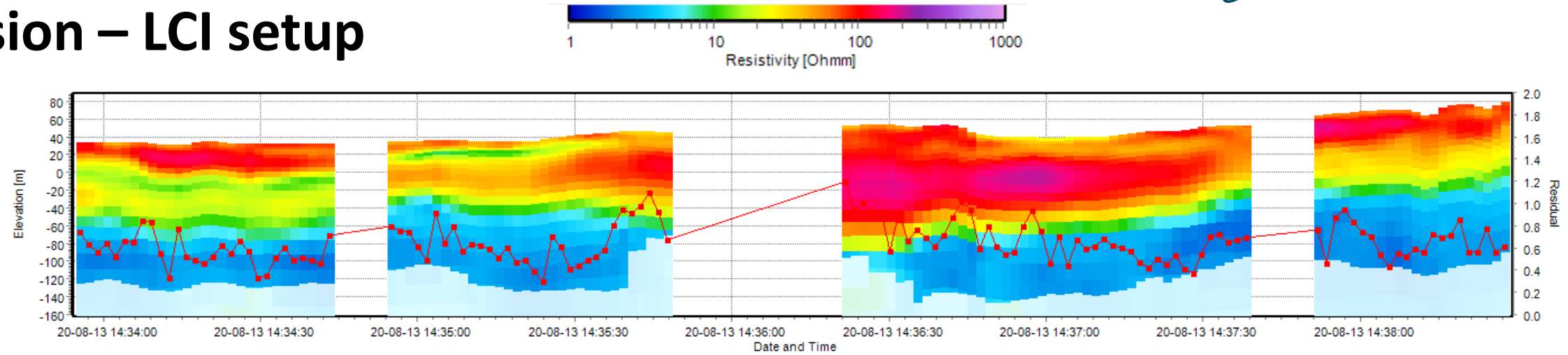
Change Adv. Configuration...

<< Back Run Cancel

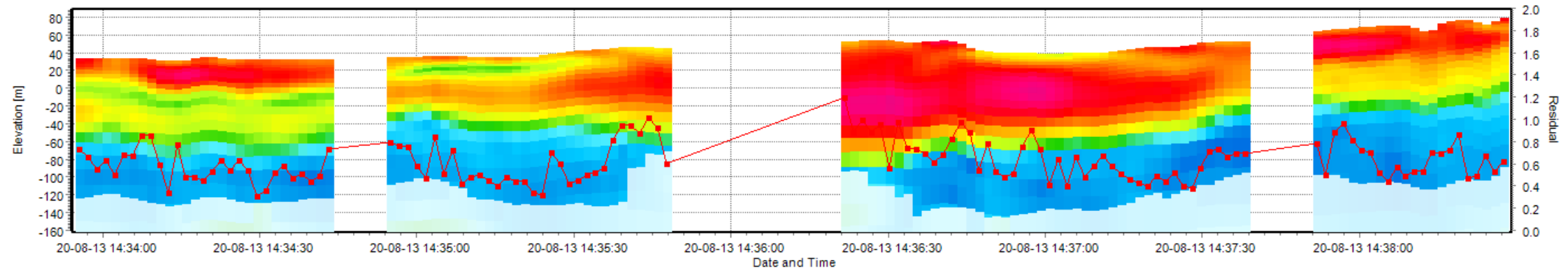
	Res	ResAprSTD	Thk	ThkAprSTD	Dep	DepAprSTD
Layer1	Auto	99.000	2.5	1.001	2.5	99.000
Layer2	Auto	99.000	2.8	1.001	5.3	99.000
Layer3	Auto	99.000	3.1	1.001	8.4	99.000
Layer4	Auto	99.000	3.5	1.001	12.0	99.000
Layer5	Auto	99.000	3.9	1.001	15.9	99.000
Layer6	Auto	99.000	4.4	1.001	20.3	99.000
Layer7	Auto	99.000	5.0	1.001	25.3	99.000
Layer8	Auto	99.000	5.6	1.001	30.9	99.000
Layer9	Auto	99.000	6.2	1.001	37.1	99.000
Layer10	Auto	99.000	7.0	1.001	44.1	99.000
Layer11	Auto	99.000	7.8	1.001	51.9	99.000
Layer12	Auto	99.000	8.8	1.001	60.7	99.000
Layer13	Auto	99.000	9.9	1.001	70.6	99.000
Layer14	Auto	99.000	11.0	1.001	81.6	99.000
Layer15	Auto	99.000	12.4	1.001	94.0	99.000
Layer16	Auto	99.000	13.9	1.001	107.9	99.000
Layer17	Auto	99.000	15.6	1.001	123.4	99.000
Layer18	Auto	99.000	17.4	1.001	140.9	99.000
Layer19	Auto	99.000	19.6	1.001	160.4	99.000
Layer20	Auto	99.000	21.9	1.001	182.4	99.000
Layer21	Auto	99.000	24.6	1.001	206.9	99.000
Layer22	Auto	99.000	27.6	1.001	234.5	99.000
Layer23	Auto	99.000	30.9	1.001	265.4	99.000
Layer24	Auto	99.000	34.6	1.001	300.0	99.000

Inversion – LCI setup

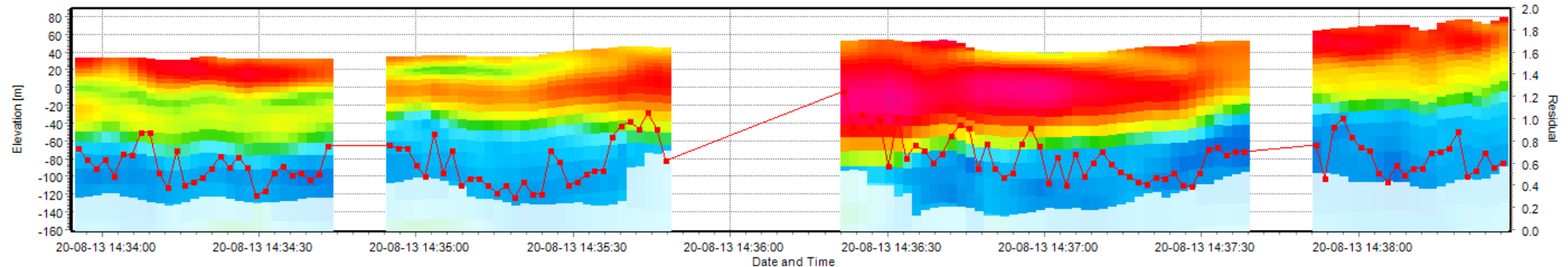
- 6,8 μ s first gate



- 10,8 μ s first gate



- 16,3 μ s first gate



Inversion – LCI setup

- Resistivity
- Starting value
- Auto
- Auto (with halfspace switched on in preferences)
- Manual

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

☒ Resistivity

☐ Start Value

☐ Lateral Constraint

☐ Vertical Constraint

☐ Prior Constraint

☐ Altitude

☐ Additional

☐ Auto

☒ Manual

Depth [m]

Resistivity [Ohmm]

Layer Editor

☒ All Layers

Current Layer: 1

Resistivity: 40

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- **Lateral constraints**
- **All constraints are given as factors.**
- **The interval [Res/STD, Res*STD] being one standard deviation for this constraint**
- **Lateral constraints are scaled beyond the reference distance**

The screenshot displays the 'AEM LCI Inversion' software window. The 'Model Setup' tab is active, showing various configuration options for the inversion process. The interface includes a sidebar with navigation buttons (Inversion Type, Channel Selection, Data Selection, Model Setup), a main settings area with tabs for Inversion Settings and Table View, and a right-hand panel with a depth plot and buttons for saving and loading settings.

Model Setup Tab:

- Inversion Types:**
 - ☒ Smooth
 - ☐ Blocky
 - ☐ Sharp
 - ☐ Layered
 - 25 Number of layers
- Calculate Vertical Model Discretization:**
 - 2.5 [m] First layer boundary
 - 300 [m] Last layer boundary
 -
- Additional Settings:**
 - 7 Number of processors
 - 5 Minimum number of data points
 - ☐ Use Sections
 - 50 Max number of iterations
 - Reference distance: 20 [m]
 - Power law: 0.75

Constraints Panel:

- Resistivity:**
 - ☐ Start Value
 - ☒ Lateral Constraint
 - ☐ Vertical Constraint
 - ☐ Prior Constraint
 - ☐ Altitude
 - ☐ Additional
- Constraint Type:**
 - ☐ Loose
 - ☒ Medium
 - ☐ Tight
 - ☐ Manual

Depth Plot: A graph showing Depth [m] on the y-axis (0 to 340) and STD on the x-axis (1 to 100). A vertical blue line is plotted at a depth of approximately 100m.

Layer Editor:

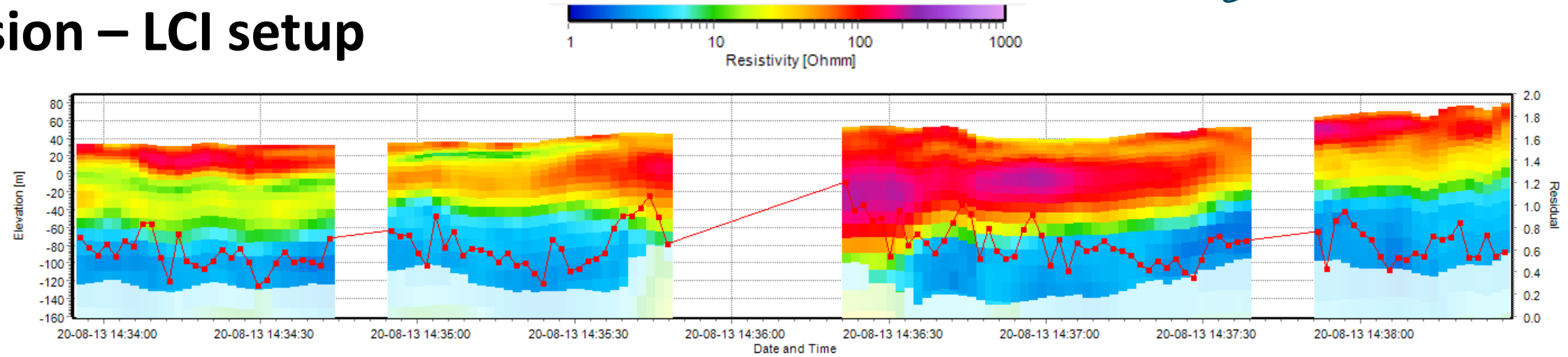
- ☒ All Layers
- Current Layer: 1
- STD: 1.300
-

Buttons:

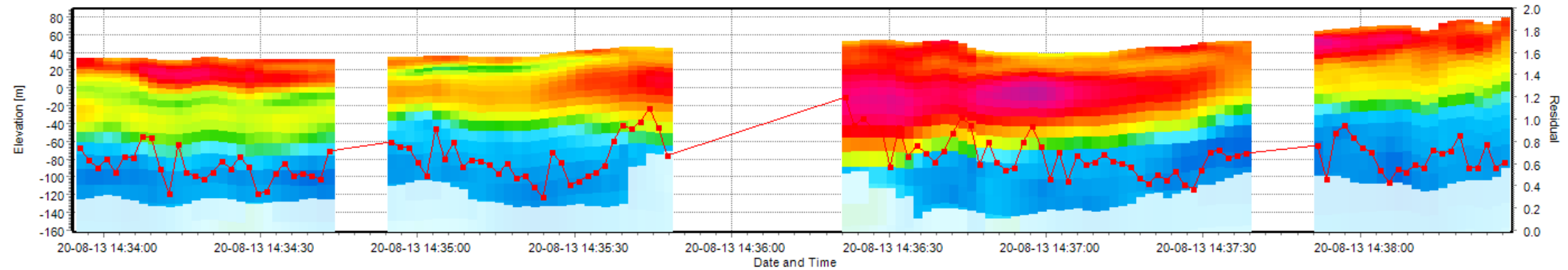
-
-
-
-
-

Inversion – LCI setup

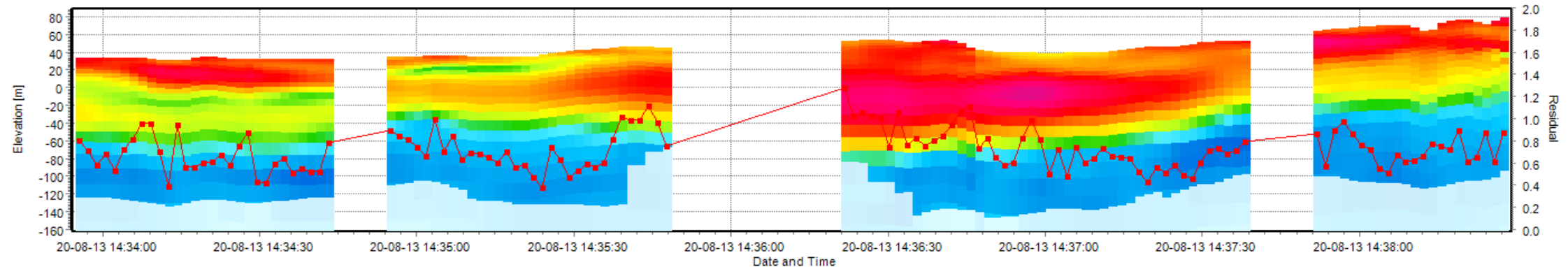
- Loose (1,6)



- Medium (1,3)



- Tight (1,1)



Inversion – LCI setup

- Vertical constraints
- Based on geology

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

☒ Resistivity

☐ Start Value

☐ Lateral Constraint

☒ Vertical Constraint

☐ Prior Constraint

☐ Altitude

☐ Additional

☐ Loose

☒ Medium

☐ Tight

☐ Manual

Depth [m]

0

20

40

60

80

100

120

140

160

180

200

220

240

260

280

300

320

340

STD

1

10

100

Layer Editor

☒ All Layers

Current Layer: 1

STD: 2.000

Save Settings...

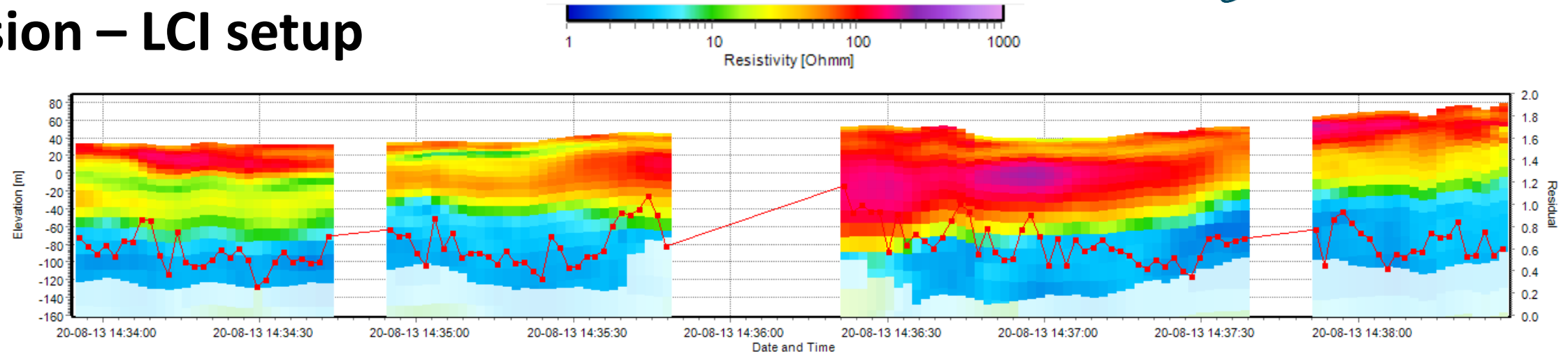
Load Settings...

Change Adv. Configuration...

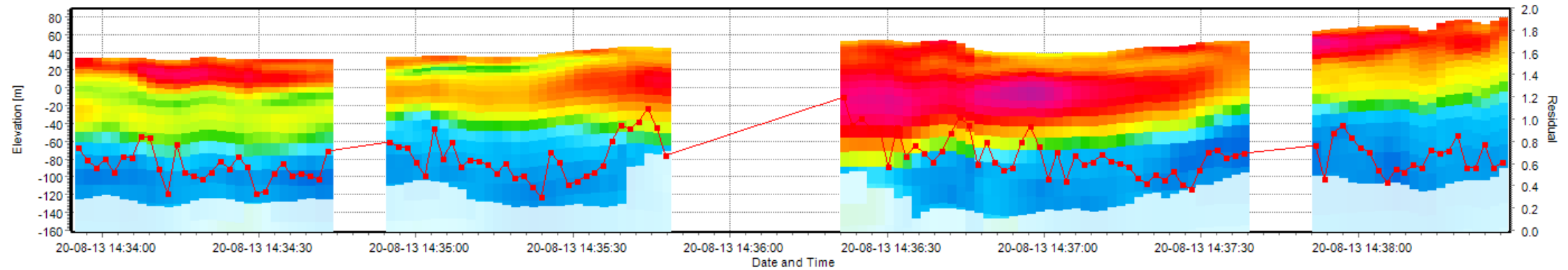
<< Back Run Cancel

Inversion – LCI setup

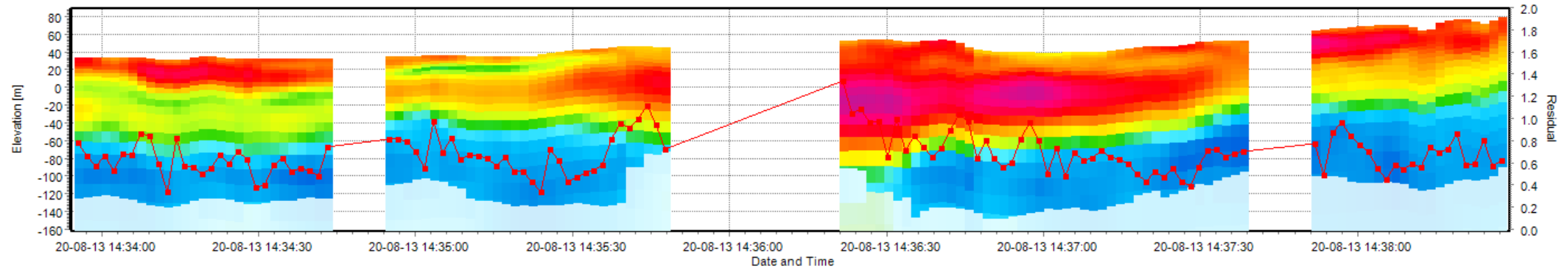
• Loose
(4)



• Medium
(2)



• Tight
(1,5)



Inversion – LCI setup

- Prior constraints

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

☒ Unconstrained

☐ Manual

Resistivity

Start Value

Lateral Constraint

Vertical Constraint

Prior Constraint

Altitude

Additional

Depth [m]

0

20

40

60

80

100

120

140

160

180

200

220

240

260

280

300

320

340

STD

1

10

100

Layer Editor

☒ All Layers

Current Layer: 1

STD: 99

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- Prior constraints

AEM LCI Inversion

Inversion Settings | Table View

☐ Model ☒ Constraints

Export to cvs file

Save Settings... Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

	ResVerSTD	ResLatSTD	ThkLatSTD	DepLatSTD
Layer1	2.000	1.300	99.000	99.000
Layer2	2.000	1.300	99.000	99.000
Layer3	2.000	1.300	99.000	99.000
Layer4	2.000	1.300	99.000	99.000
Layer5	2.000	1.300	99.000	99.000
Layer6	2.000	1.300	99.000	99.000
Layer7	2.000	1.300	99.000	99.000
Layer8	2.000	1.300	99.000	99.000
Layer9	2.000	1.300	99.000	99.000
Layer10	2.000	1.300	99.000	99.000
Layer11	2.000	1.300	99.000	99.000
Layer12	2.000	1.300	99.000	99.000
Layer13	2.000	1.300	99.000	99.000
Layer14	2.000	1.300	99.000	99.000
Layer15	2.000	1.300	99.000	99.000
Layer16	2.000	1.300	99.000	99.000
Layer17	2.000	1.300	99.000	99.000
Layer18	2.000	1.300	99.000	99.000
Layer19	2.000	1.300	99.000	99.000
Layer20	2.000	1.300	99.000	99.000
Layer21	2.000	1.300	99.000	99.000
Layer22	2.000	1.300	99.000	99.000
Layer23	2.000	1.300	99.000	99.000
Layer24	2.000	1.300	99.000	99.000

Inversion – LCI setup

- IP parameters works in the same way

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

4.0 [m] First layer boundary

300.0 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

- Resistivity
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint
- Phi
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint
- TauPhi
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint
- C
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- Number of processors
- Minimum number of data points
- Max number of iterations
- Sections

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Update

Additional Settings

7 Number of processors

5 Minimum number of data points

☒ Use Sections

Section length 5000 [number of soundings]

Max sounding gap 500 [m]

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

Resistivity

Start Value

Lateral Constraint

Vertical Constraint

Prior Constraint

Altitude

Additional

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- Altitude

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 [Number of layers]

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Update

Additional Settings

7 [Number of processors]

5 [Minimum number of data points]

☐ Use Sections

50 [Max number of iterations]

Reference distance 20 [m]

Power law 0.75

Constraints

Resistivity

Start Value

Lateral Constraint

Vertical Constraint

Prior Constraint

Altitude

Additional

Flight Altitude

A-priori STD 1.00 [m]

Lateral constraint STD 1.30 [factor]

A-priori if not recorded 30.00 [m]

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- 1st layer a-priori

The screenshot displays the 'GCM LCI Inversion' software window. The 'Model Setup' tab is selected in the left sidebar. The main panel is divided into several sections:

- Inversion Settings**: Includes 'Inversion Types' with radio buttons for Smooth (selected), Blocky, Sharp, and Layered. Below this is a 'Number of layers' spinner set to 12. The 'Calculate Vertical Model Discretization' section has input fields for 'First layer boundary' (0.2 [m]) and 'Last layer boundary' (10.0 [m]), with an 'Update' button. The 'Additional Settings' section includes a 'Number of processors' dropdown (4), a 'Minimum number of data points' spinner (2), a 'Use Sections' checkbox, and a 'Max number of iterations' spinner (50).
- Constraints**: A tree view showing 'Resistivity' expanded, with sub-items: Start Value, Lateral Constraint, Vertical Constraint, Prior Constraint, and '1st layer A-priori' (highlighted).
- A-priori Resistivity**: A section with a checkbox (unchecked) and three dropdown menus: 'A-priori STD' (empty), 'Lateral constraint STD' (empty), and 'A-priori if not recorded' (empty). Units are [factor] for STD and [ohmm] for the last.
- A-priori Depth**: A section with a checked checkbox and three dropdown menus: 'A-priori STD' (1.00 [m]), 'Lateral constraint STD' (1.30 [factor]), and 'A-priori if not recorded' (3 [m]).

Buttons on the right include 'Save Settings...', 'Load Settings...', and 'Change Adv. Configuration...'. At the bottom right are '<< Back', 'Run', and 'Cancel' buttons.

Inversion – LCI setup

- Additional

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☒ Smooth

☐ Blocky

☐ Sharp

☐ Layered

25 [Number of layers]

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Update

Additional Settings

7 [Number of processors]

5 [Minimum number of data points]

☐ Use Sections

50 [Max number of iterations]

Reference distance 20 [m]

Power law 0.75

Constraints

Resistivity

Start Value

Lateral Constraint

Vertical Constraint

Prior Constraint

Altitude

Additional

☐ Pitch (X-component data required)

A-priori STD 0.5 [degree]

Lateral constraint STD 1.01 [factor]

A-priori if not recorded 0 [degree]

Save Settings...

Load Settings...

Change Adv. Configuration...

<< Back Run Cancel

Inversion – LCI setup

- Now layered
- Thickness

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☐ Smooth

☐ Blocky

☐ Sharp

☒ Layered

5 Number of layers

Calculate Vertical Model Discretization

10 [m] First layer boundary

85 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

Reference distance 20 [m]

Power law 0.75

50 Max number of iterations

Constraints

☒ Resistivity

Start Value

Lateral Constraint

Prior Constraint

Altitude

Additional

☒ Thickness

Start Value

Lateral Constraint

Prior Constraint

☐ Loose

☒ Medium

☐ Tight

☐ Manual

Depth [m]

STD

Layer Editor

☐ All Layers

Current Layer: 1

STD: 1.300

Save Settings...

Load Settings...

Change Adv. Configuration...

Use Constraints on

☒ Thickness ☐ Depth

<< Back **Run** **Cancel**

Inversion – LCI setup

- Now layered
- Thickness
- Depth

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☐ Smooth

☐ Blocky

☐ Sharp

☒ Layered

5 Number of layers

Calculate Vertical Model Discretization

10 [m] First layer boundary

85 [m] Last layer boundary

Additional Settings

7 Number of processors

5 Minimum number of data points

☐ Use Sections

Reference distance 20 [m]

Power law 0.75

50 Max number of iterations

Constraints

☒ Resistivity

Start Value

Lateral Constraint

Prior Constraint

Altitude

Additional

☒ Depth

Start Value

Lateral Constraint

Prior Constraint

☐ Loose

☐ Medium

☐ Tight

☒ Manual

Depth [m]

STD

Layer Editor

☐ All Layers

Current Layer: 1

STD: 1.850

Save Settings...

Load Settings...

Change Adv. Configuration...

Use Constraints on

☐ Thickness

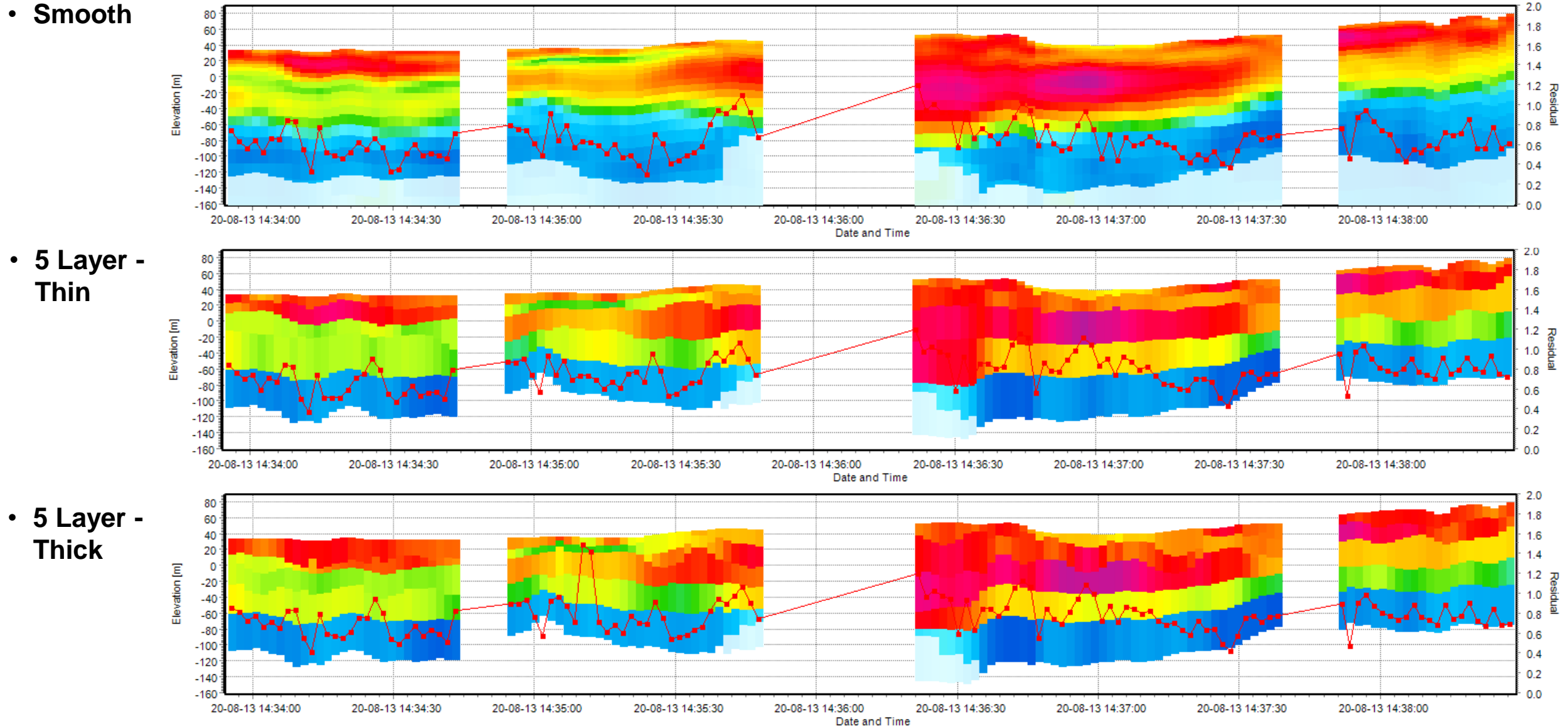
☒ Depth

<< Back

Run

Cancel

Inversion – LCI setup



Inversion – LCI setup

- Now blocky

AEM LCI Inversion

Inversion Settings | Table View

Inversion Type

Channel Selection

Data Selection

Model Setup

Inversion Types

☐ Smooth

☒ Blocky

☐ Sharp

☐ Layered

25 [Number of layers]

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Additional Settings

7 [Number of processors]

5 [Minimum number of data points]

☐ Use Sections

Reference distance 20 [m]

Power law 0.75

50 [Max number of iterations]

Constraints

- Resistivity
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint
 - Altitude
 - Additional

Save Settings...

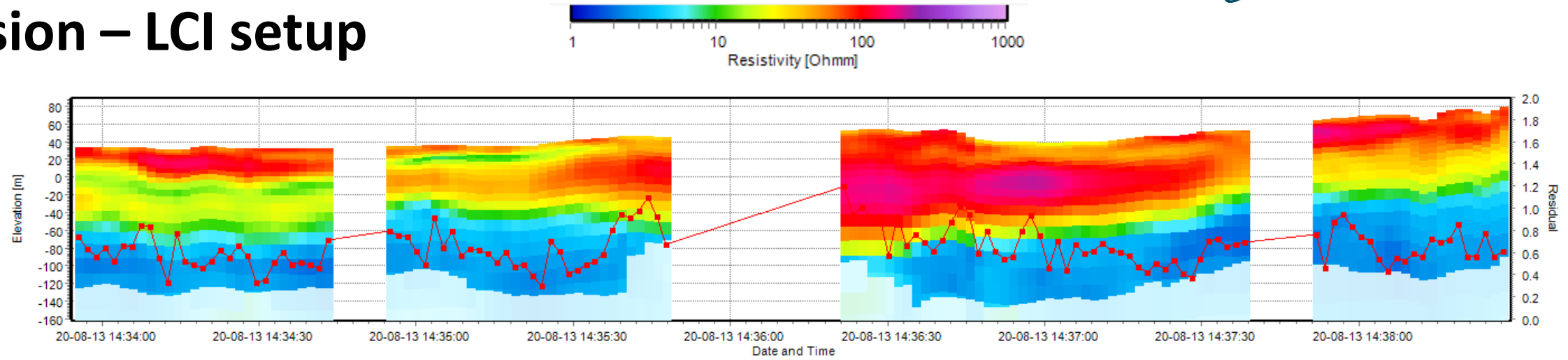
Load Settings...

Change Adv. Configuration...

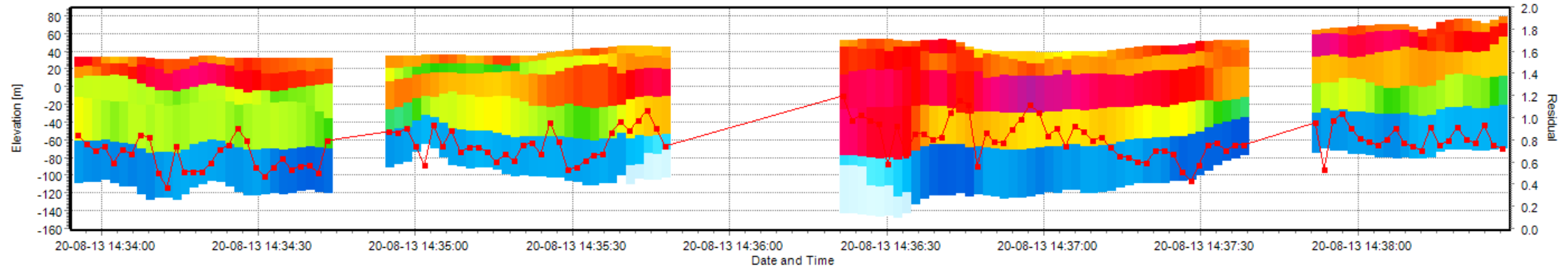
<< Back Run Cancel

Inversion – LCI setup

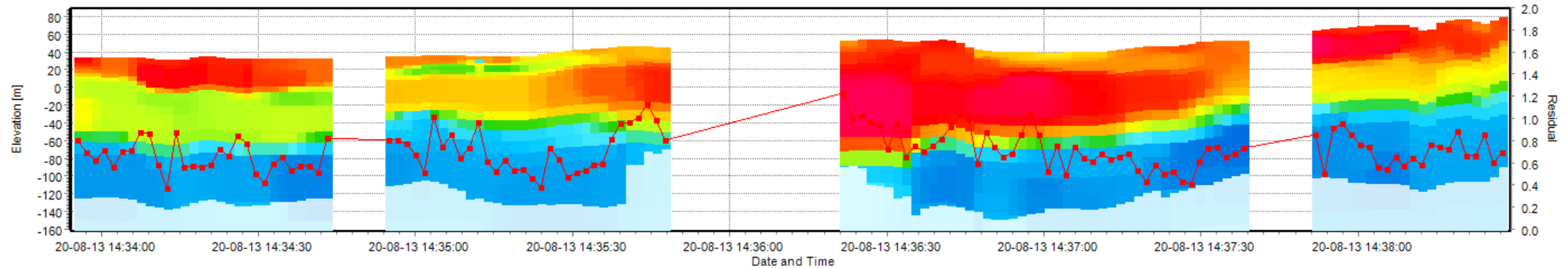
- Smooth



- 5 Layer - Thin



- Blocky



Inversion – LCI setup

- And sharp

AEM LCI Inversion

Inversion Types
☐ Smooth
☐ Blocky
☒ Sharp
☐ Layered
 25 Number of layers

Calculate Vertical Model Discretization
 2.5 [m] First layer boundary
 300 [m] Last layer boundary

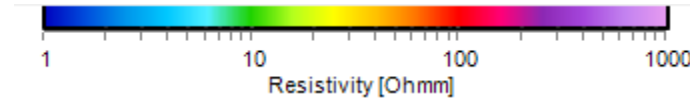
Additional Settings
 7 Number of processors
 5 Minimum number of data points
☐ Use Sections
 Reference distance 20 [m]
 Power law 0.75
 50 Max number of iterations

Constraints
☐ Resistivity
 ☐ Start Value
 ☐ Lateral Constraint
 ☐ Vertical Constraint
 ☐ Prior Constraint
☐ Altitude
☐ Additional
☒ Sharp parameters

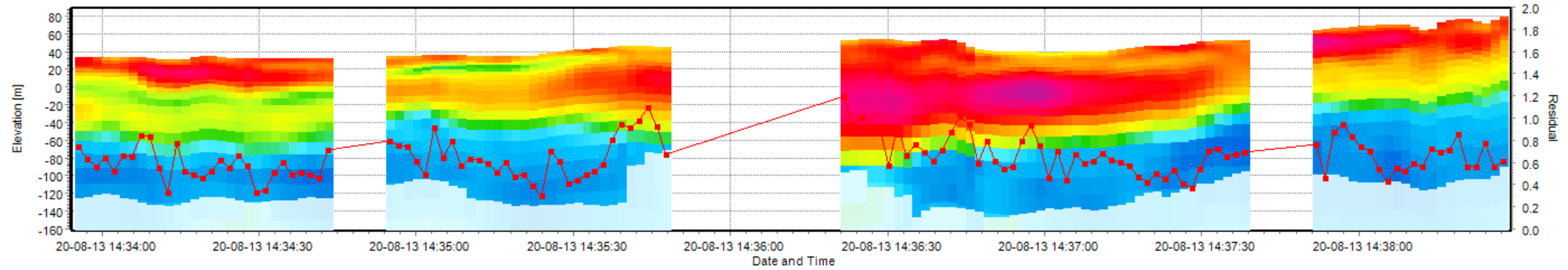
Vertical Sharpness
☒ Auto
☐ Manual 300

Lateral Sharpness
☒ Auto
☐ Manual 300

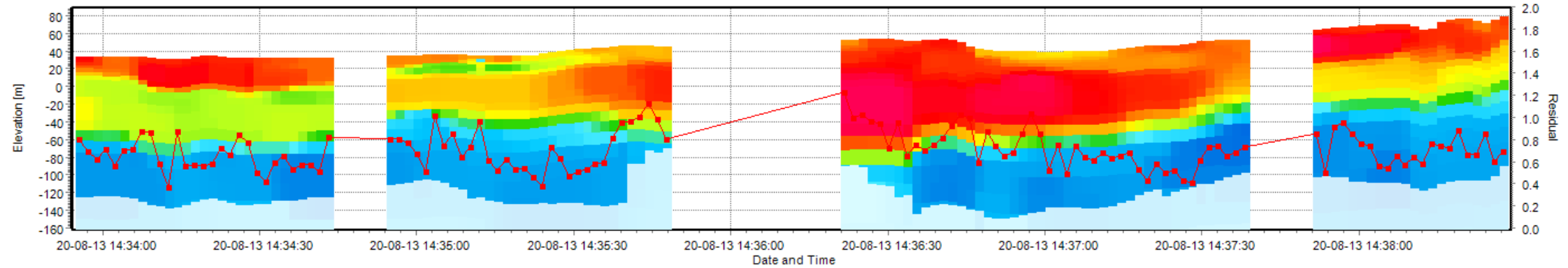
Inversion – LCI setup



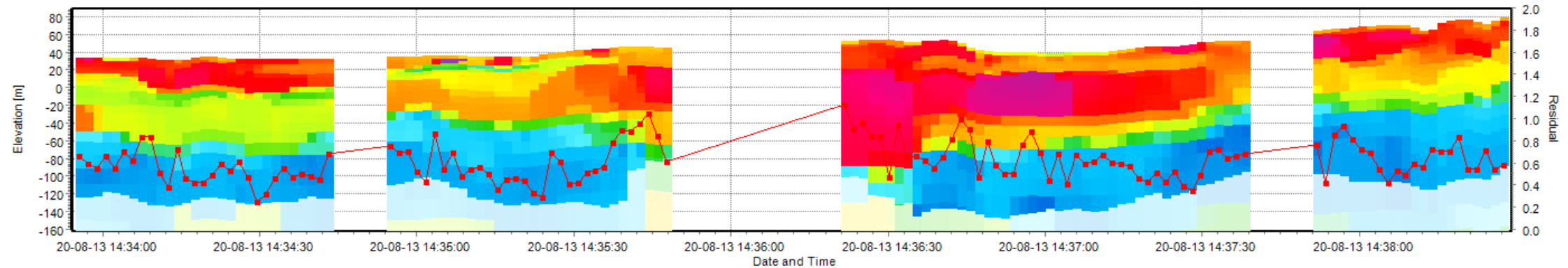
• Smooth



• Blocky

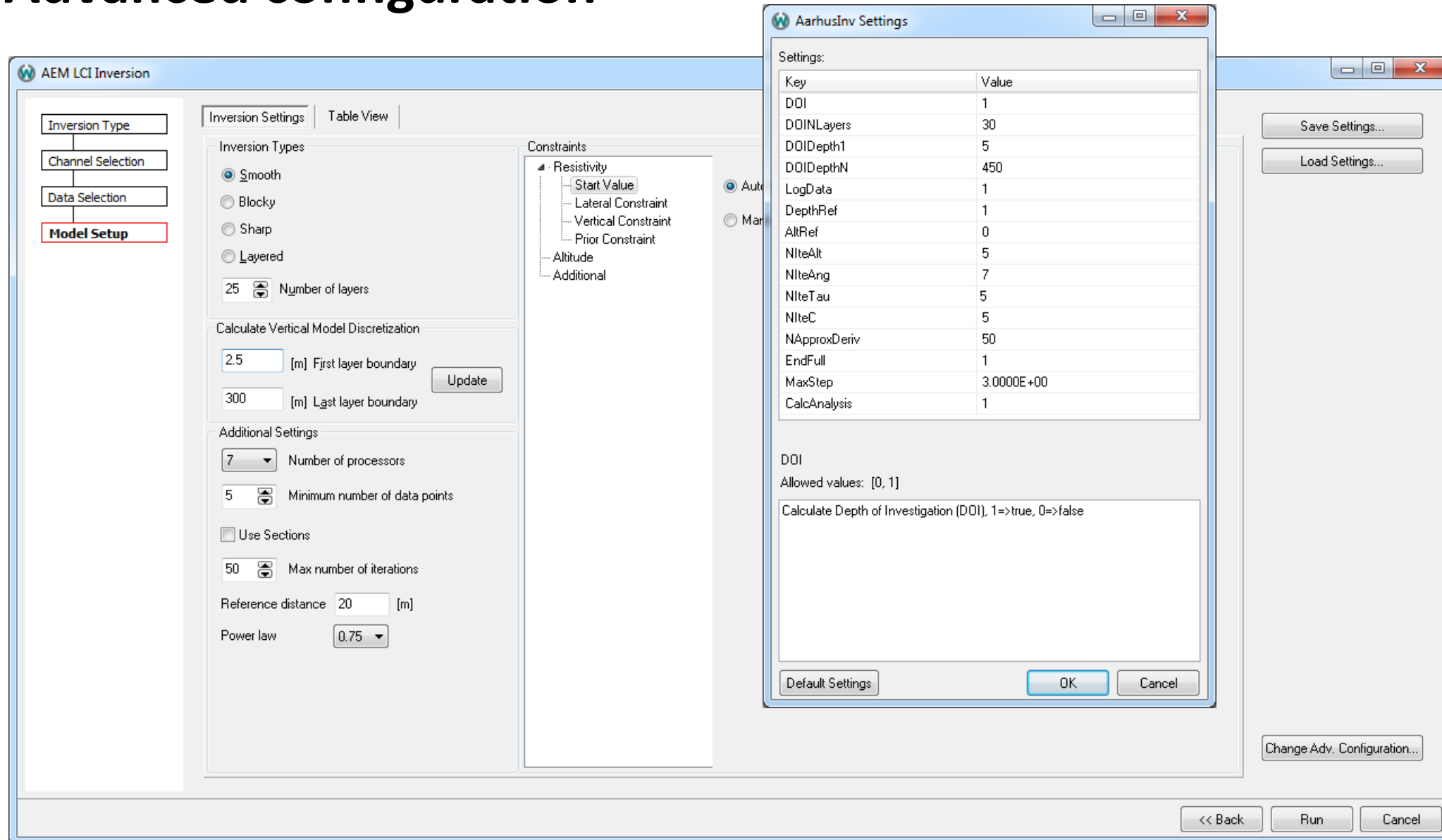


• Sharp



Inversion – Advanced configuration

- Depth of investigation



The screenshot displays the AarhusInv Settings dialog box, which is used for configuring the Aarhus LCI Inversion software. The dialog is divided into several sections:

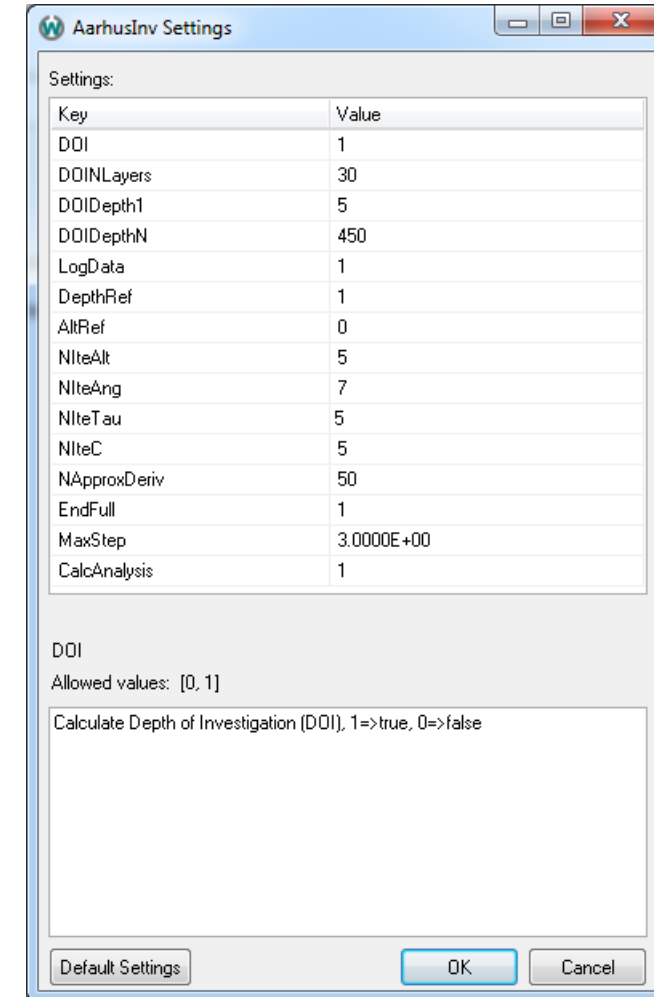
- Settings:** A table listing various parameters and their values.

Key	Value
DOI	1
DOIINLayers	30
DOIDepth1	5
DOIDepthN	450
LogData	1
DepthRef	1
AltRef	0
NlItAlt	5
NlItAng	7
NlItTau	5
NlItC	5
NApproxDeriv	50
EndFull	1
MaxStep	3.0000E+00
CalcAnalysis	1
- DOI:** A section for configuring the Depth of Investigation (DOI). It includes a text box for "Calculate Depth of Investigation (DOI), 1=>true, 0=>false".
- Buttons:** The dialog includes buttons for "Default Settings", "OK", and "Cancel".

The background window, titled "AEM LCI Inversion", shows the "Model Setup" tab selected in the left sidebar. The main area contains various configuration options for the inversion process, including "Inversion Types" (Smooth, Blocky, Sharp, Layered), "Calculate Vertical Model Discretization" (First layer boundary, Last layer boundary), "Additional Settings" (Number of processors, Minimum number of data points, Use Sections, Max number of iterations, Reference distance, Power law), and "Constraints" (Resistivity, Lateral Constraint, Vertical Constraint, Prior Constraint, Altitude, Additional).

Inversion – Advanced configuration

- Depth of Investigation
- The first is simply yes or no to calculate the DOI
- The number of layers and layer distribution is used to discretize the calculation
- Based on the found model, the data and the system parameters (including noise) a sensitivity is calculated



AarhusInv Settings

Settings:

Key	Value
DOI	1
DOILayers	30
DOIDepth1	5
DOIDepthN	450
LogData	1
DepthRef	1
AltRef	0
NlItAlt	5
NlItAng	7
NlItTau	5
NlItC	5
NApproxDeriv	50
EndFull	1
MaxStep	3.0000E+00
CalcAnalysis	1

DOI

Allowed values: [0, 1]

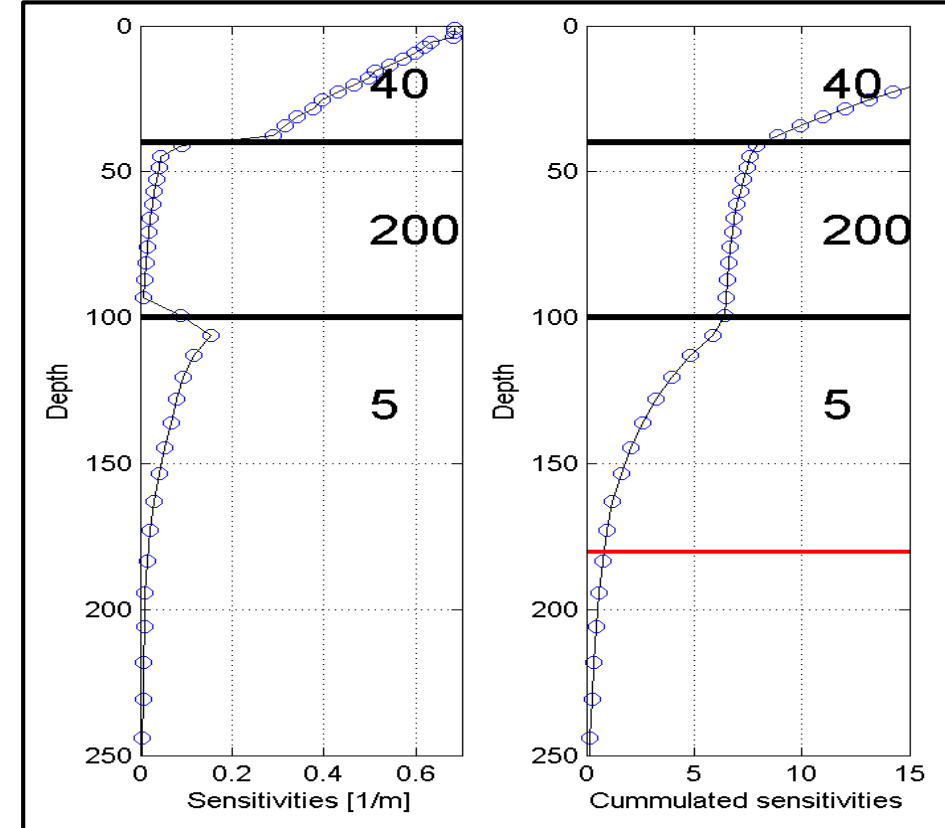
Calculate Depth of Investigation (DOI), 1=>true, 0=>false

Default Settings OK Cancel

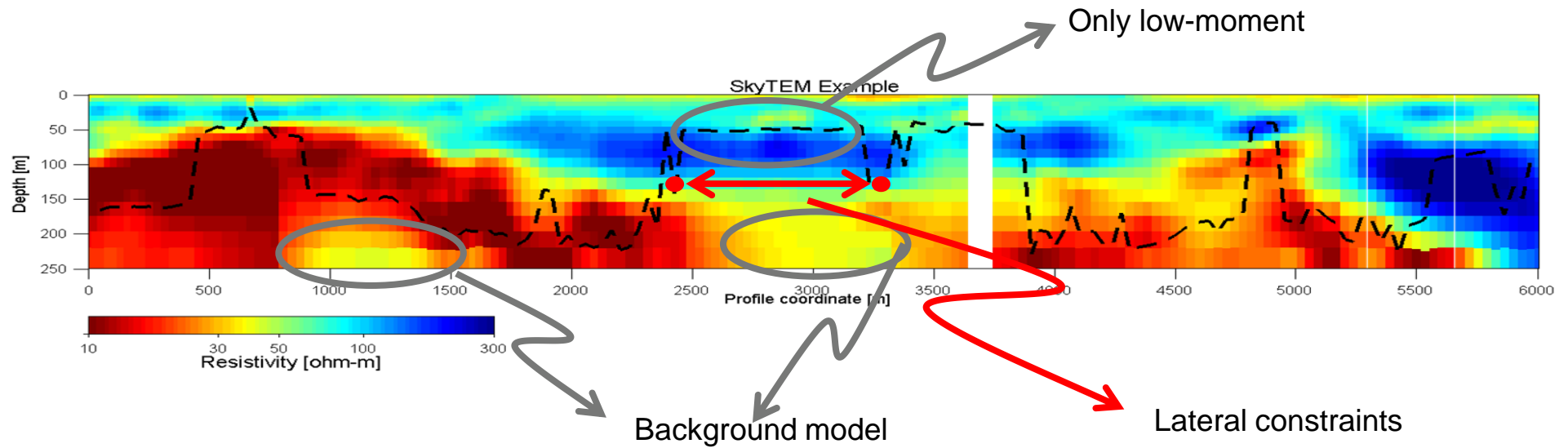
Inversion – Advanced configuration

- In the cumulative sensitivity we then look for an empirically set threshold value – this is the DOI!
- The part above the threshold value is considered data driven, the part below will largely be based on starting value and constraints
- Use two threshold values to get a conservative and a standard DOI to also get an idea about how quickly it changes from those values

Christiansen, A. V. and Auken, E., 2012,
A global measure for depth of investigation
Geophysics, 77, WB171-WB177



Inversion – Advanced configuration



Inversion – Advanced configuration

- LogData
- DepthRef
- AltRef

The screenshot shows the 'AarhusInv Settings' dialog box in the foreground, which is a configuration window for the Aarhus GeoSoftware inversion tool. The background window is 'AEM LCI Inversion', showing various settings tabs like 'Inversion Settings' and 'Table View'. The 'Model Setup' tab is highlighted in the background window.

AarhusInv Settings Dialog:

- Settings:** A table listing various parameters and their values.

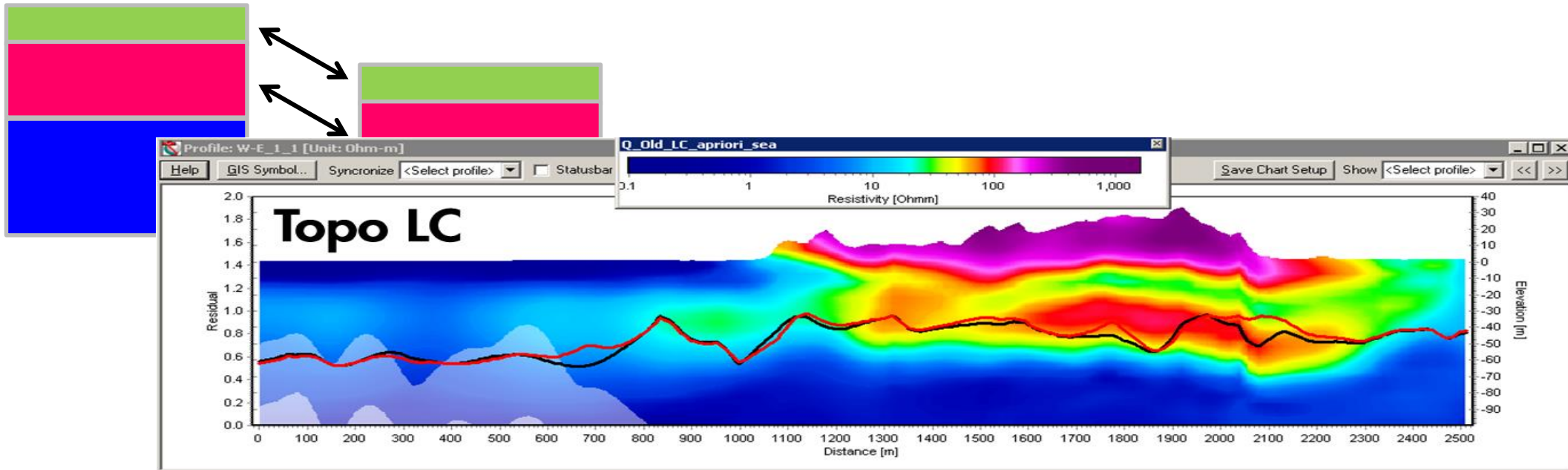
Key	Value
DOI	1
DOIINLayers	30
DOIDepth1	5
DOIDepthN	450
LogData	1
DepthRef	1
AltRef	0
NlItAlt	5
NlItAng	7
NlItTau	5
NlItC	5
NApproxDeriv	50
EndFull	1
MaxStep	3.0000E+00
CalcAnalysis	1
- DOI:** A section for the Depth of Investigation (DOI) parameter.
 - Allowed values: [0, 1]
 - Calculate Depth of Investigation (DOI), 1=>true, 0=>false
- Buttons:** 'Default Settings', 'OK', and 'Cancel'.

AEM LCI Inversion Main Window (Background):

- Left Panel:** A vertical stack of buttons: 'Inversion Type', 'Channel Selection', 'Data Selection', and 'Model Setup' (highlighted with a red border).
- Center Panel:**
 - Inversion Settings:** Includes 'Inversion Types' (Smooth, Blocky, Sharp, Layered), 'Number of layers' (25), 'Calculate Vertical Model Discretization' (First layer boundary: 2.5 [m], Last layer boundary: 300 [m]), 'Additional Settings' (Number of processors: 7, Minimum number of data points: 5, Use Sections: unchecked, Max number of iterations: 50, Reference distance: 20 [m], Power law: 0.75), and 'Constraints' (Resistivity: Start Value, Lateral Constraint, Vertical Constraint, Prior Constraint, Altitude, Additional).
 - Table View:** A tab for viewing data in a table format.
- Right Panel:** Contains 'Save Settings...' and 'Load Settings...' buttons.
- Bottom Panel:** Contains '<< Back', 'Run', and 'Cancel' buttons.

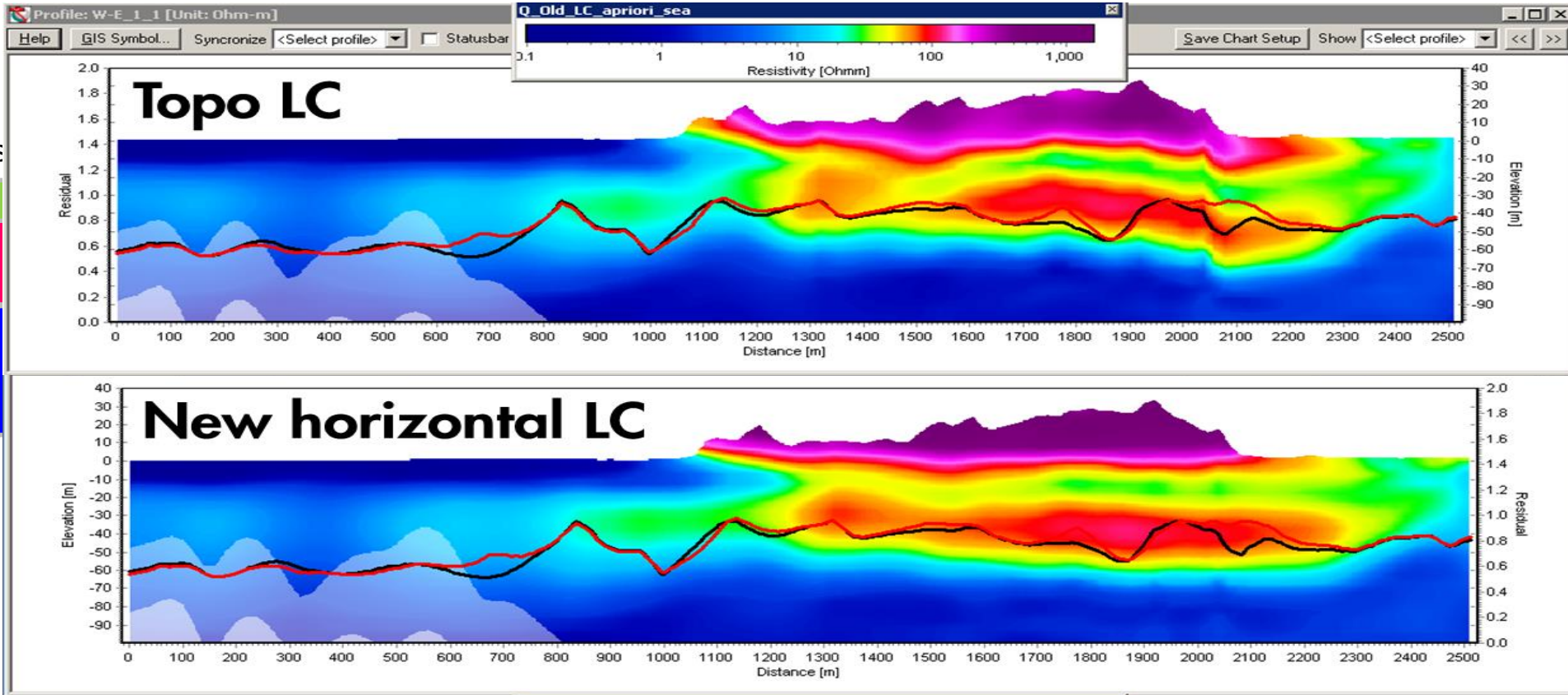
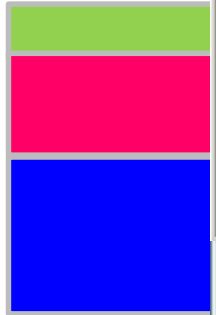
Inversion – Constraints follow topography (“depth”)

Constraints follow topography



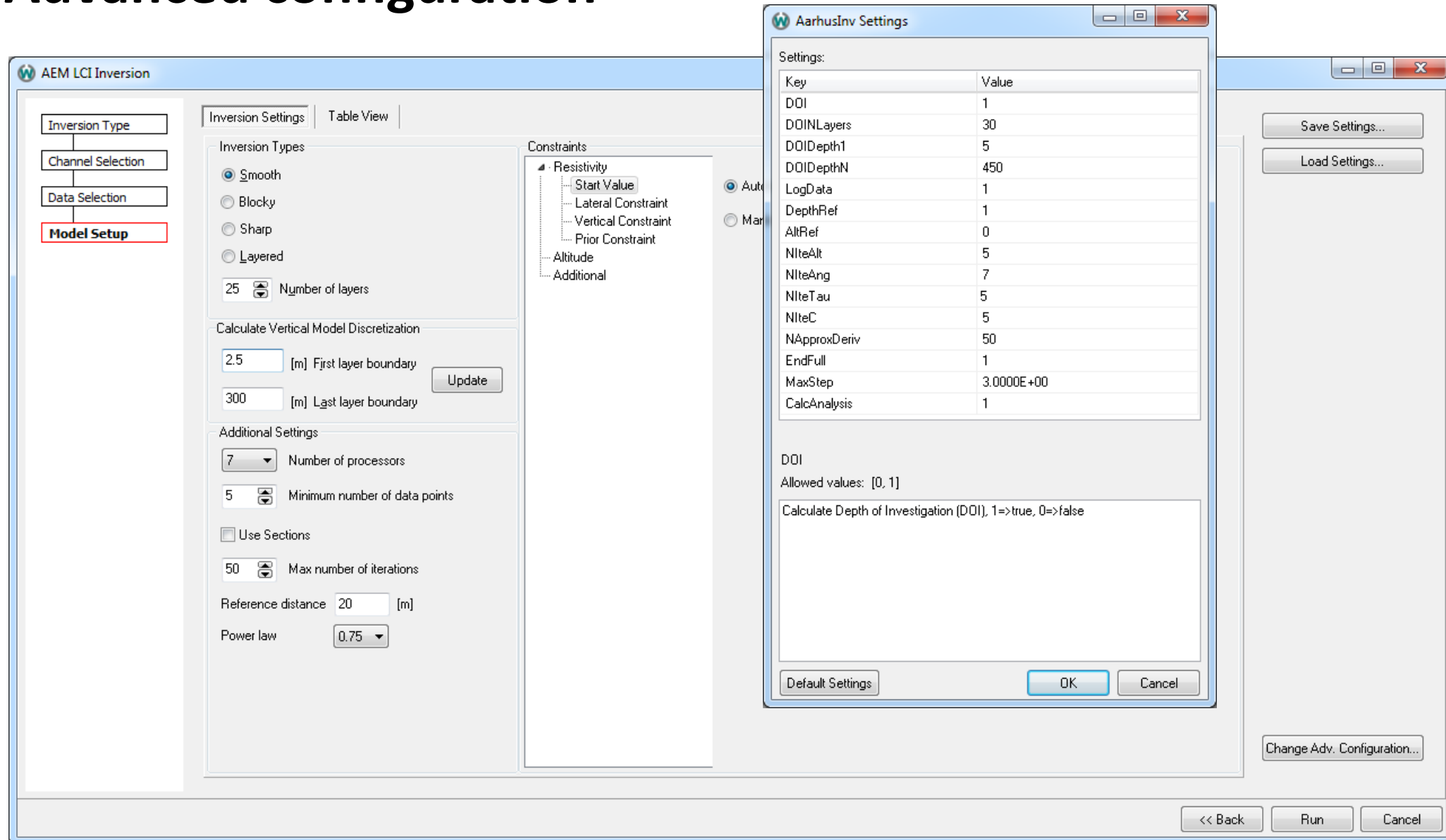
Inversion – Constraints are horizontal (“elevation”)

Constraints



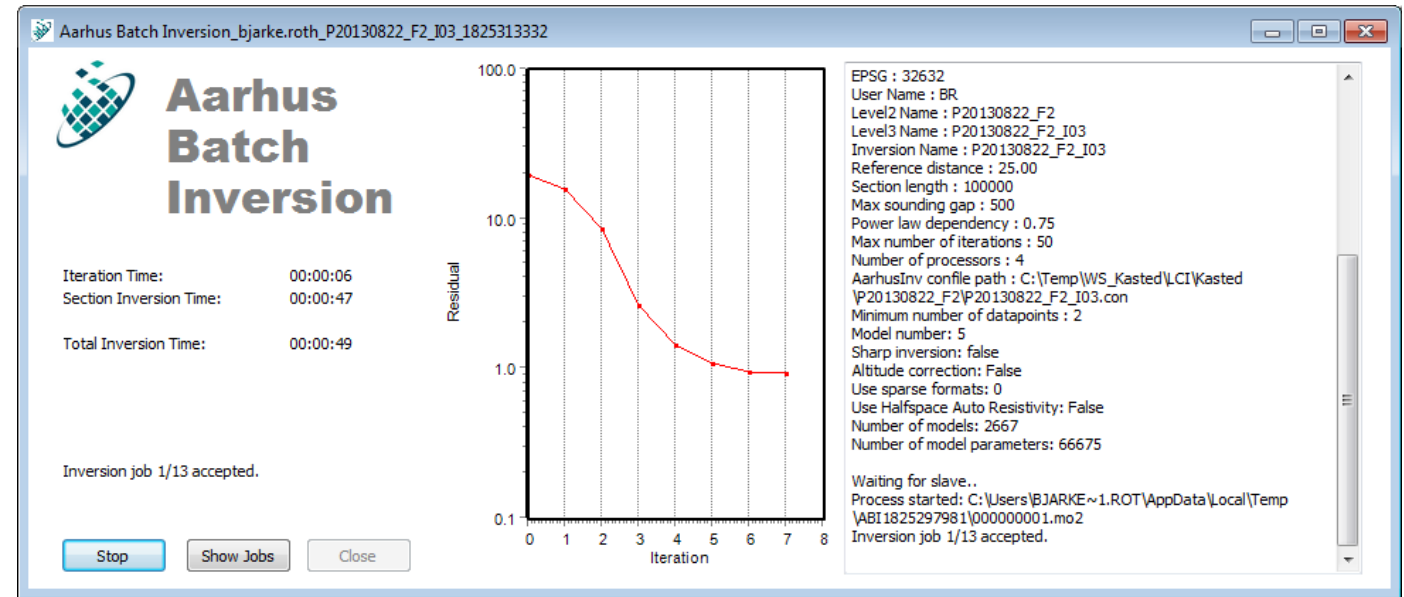
Inversion – Advanced configuration

- NlTeX
- NApproxDeriv
- Endfull



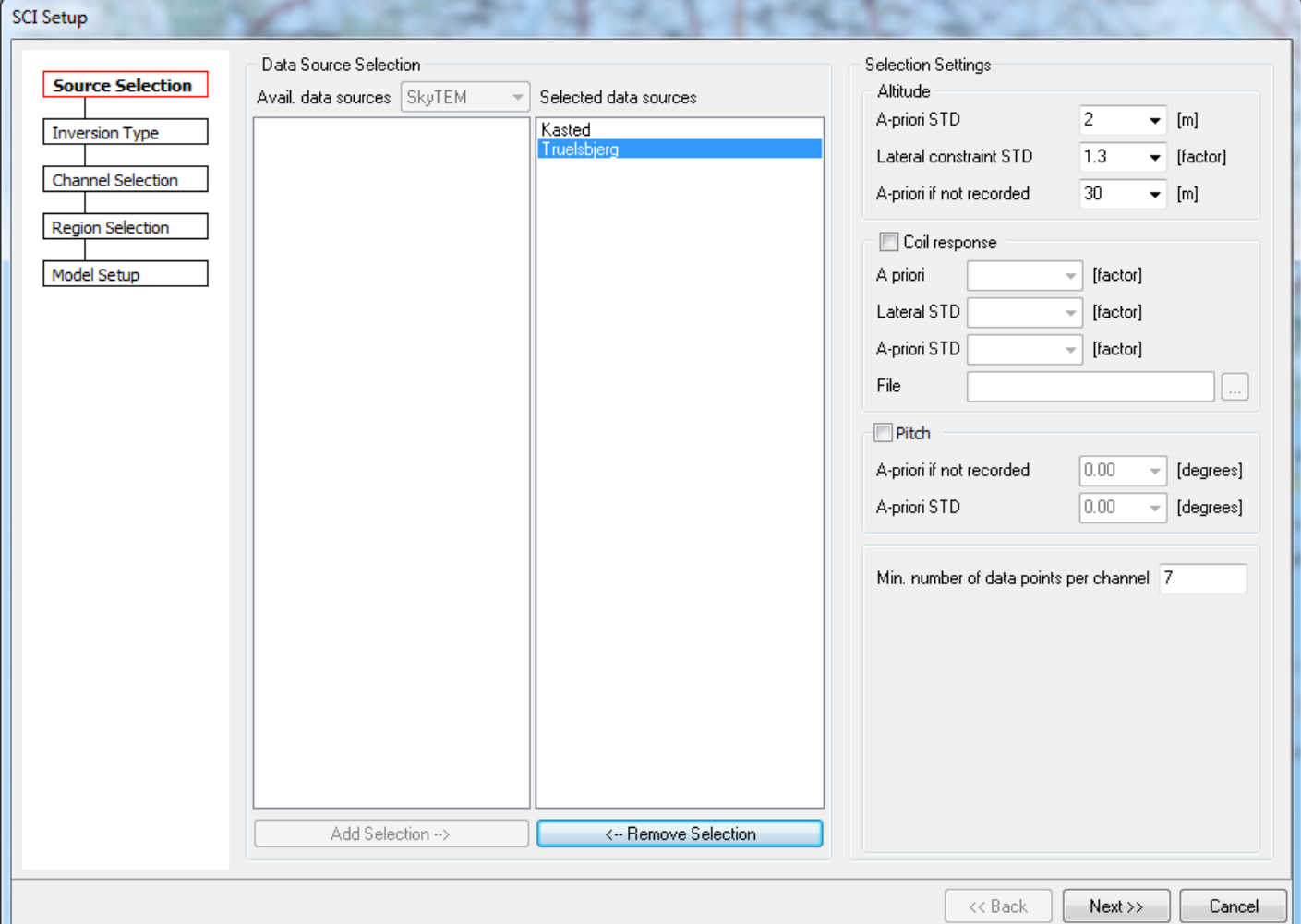
Inversion – Aarhus Batch Inversion

- When the inversion is started it opens Aarhus Batch Inversion that controls the inversion independently of Workbench
- It must have access back to the database, but you can close the workspace
- The inversion can be set to run locally or on cloud servers!
- If you have your own servers, we have some additional options



Inversion – SCI setup

- Press SCI on the Inversion ribbon
- Add the relevant data sources
- The data dependent options of the model setup must be set per dataset



The screenshot shows the 'SCI Setup' dialog box. On the left is a vertical navigation pane with buttons: 'Source Selection' (highlighted with a red border), 'Inversion Type', 'Channel Selection', 'Region Selection', and 'Model Setup'. The main area is titled 'Data Source Selection' and contains two lists. The 'Avail. data sources' list has a dropdown menu set to 'SkyTEM'. The 'Selected data sources' list contains 'Kasted' and 'Truelsenbjerg', with 'Truelsenbjerg' selected. Below these lists are buttons 'Add Selection -->' and '<-- Remove Selection'. To the right of the lists is the 'Selection Settings' section, which includes: 'Altitude' (2 [m]), 'A-priori STD' (1.3 [factor]), 'Lateral constraint STD' (30 [m]), 'A-priori if not recorded' (30 [m]), 'Coil response' (checkbox), 'A priori' (factor), 'Lateral STD' (factor), 'A-priori STD' (factor), 'File' (text field), 'Pitch' (checkbox), 'A-priori if not recorded' (0.00 [degrees]), 'A-priori STD' (0.00 [degrees]), and 'Min. number of data points per channel' (7). At the bottom right are '<< Back', 'Next >>', and 'Cancel' buttons.

SCI Setup

Data Source Selection

Avail. data sources: SkyTEM

Selected data sources:

- Kasted
- Truelsenbjerg

Add Selection --> <-- Remove Selection

Selection Settings

Altitude: 2 [m]

A-priori STD: 1.3 [factor]

Lateral constraint STD: 30 [m]

A-priori if not recorded: 30 [m]

☐ Coil response

A priori: [factor]

Lateral STD: [factor]

A-priori STD: [factor]

File: [text field]

☐ Pitch

A-priori if not recorded: 0.00 [degrees]

A-priori STD: 0.00 [degrees]

Min. number of data points per channel: 7

<< Back Next >> Cancel

Inversion – SCI setup

- Inversion type

SCI Setup

Source Selection

Inversion Type

Channel Selection

Region Selection

Model Setup

Node Name: SCI

Inversion Name: SCI_I01

☒ 1D Resistivity

Negative data: Remove negatives

<< Back Next >> Cancel

Inversion – SCI setup

- Channel selection

SCI Setup

Source Selection
Inversion Type
Channel Selection
Region Selection
Model Setup

Selected datasets

Kasted
Truelsbjerg

Channels

<input checked="" type="checkbox"/>	1, Ch. #1 - Low Moment - z component
<input checked="" type="checkbox"/>	2, Ch. #2 - High Moment - z component
<input type="checkbox"/>	3, Ch. #3 - Low Moment - x component
<input type="checkbox"/>	4, Ch. #4 - High Moment - x component

Omit Gates

Channel 1	1-5
Channel 2	10
Channel 3	
Channel 4	

<< Back Next >> Cancel

Inversion – SCI setup

- Region selection

SCI Setup

Source Selection
Inversion Type
Channel Selection
Region Selection
Model Setup

☐ Use entire area

☐ Selection on map

UTMX UTM Y
Minimum 3568152 5720218 Select on Map
Maximum 3568426 5720441

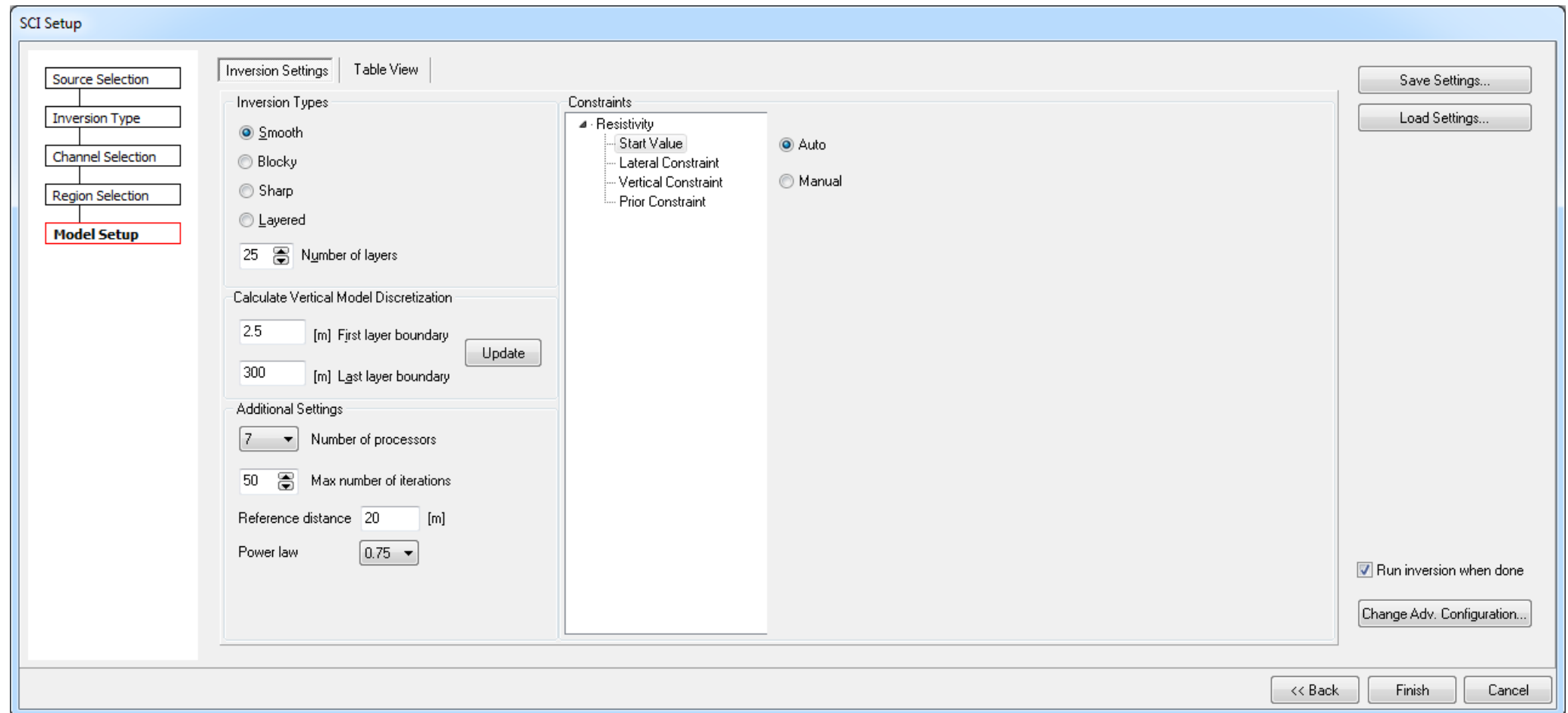
☒ Polygon selection

Layer name Polygon Layer

<< Back Next >> Cancel

Inversion – SCI setup

- Model setup
- Power law
- Run when done



The screenshot shows the 'SCI Setup' dialog box with the 'Inversion Settings' tab selected. On the left, a vertical navigation pane contains buttons for 'Source Selection', 'Inversion Type', 'Channel Selection', 'Region Selection', and 'Model Setup' (which is highlighted with a red border). The main area is divided into three sections: 'Inversion Types' with radio buttons for 'Smooth' (selected), 'Blocky', 'Sharp', and 'Layered', and a 'Number of layers' spinner set to 25; 'Calculate Vertical Model Discretization' with input fields for 'First layer boundary' (2.5 [m]) and 'Last layer boundary' (300 [m]), and an 'Update' button; and 'Additional Settings' with a 'Number of processors' dropdown set to 7, a 'Max number of iterations' spinner set to 50, a 'Reference distance' input field set to 20 [m], and a 'Power law' dropdown set to 0.75. To the right of these sections is a 'Constraints' panel with a tree view showing 'Resistivity' expanded, containing 'Start Value', 'Lateral Constraint', 'Vertical Constraint', and 'Prior Constraint'. Next to this panel are 'Auto' (selected) and 'Manual' radio buttons. On the far right, there are 'Save Settings...' and 'Load Settings...' buttons, a checkbox for 'Run inversion when done' (checked), and a 'Change Adv. Configuration...' button. At the bottom right are '<< Back', 'Finish', and 'Cancel' buttons.

SCI Setup

Source Selection
Inversion Type
Channel Selection
Region Selection
Model Setup

Inversion Settings | Table View

Inversion Types

- ☒ Smooth
- ☐ Blocky
- ☐ Sharp
- ☐ Layered

25 Number of layers

Calculate Vertical Model Discretization

2.5 [m] First layer boundary

300 [m] Last layer boundary

Update

Additional Settings

7 Number of processors

50 Max number of iterations

Reference distance 20 [m]

Power law 0.75

Constraints

- Resistivity
 - Start Value
 - Lateral Constraint
 - Vertical Constraint
 - Prior Constraint

Auto Manual

Save Settings...
Load Settings...

☒ Run inversion when done

Change Adv. Configuration...

<< Back Finish Cancel

Questions