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Ground-based geophysics: results from an investigation near Lucky Bay, Perth, WA.

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ACKNOWLEDGMENTS

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1. Introduction

1.1. Background

This work was undertaken as part of a collaborative study between CSIRO and the Department of Parks and Wildlife to generate a hydrogeological framework for better understanding the processes that might influence nutrient flux through the Tamala Limestone to the part of the Alfred Cove Swan Estuary Marine Park (ACSEMP), Perth. It involved the acquisition and processing of ground time-domain electromagnetic data to resolve spatial patterns of subsurface conductivity proximal to the shoreline at that locality. Previous studies of the hydrogeological characteristics of the Tamala Limestone (Davidson 1995, and Smith et al. 2011) have determined that these sediments have a large, to very large, transmissivity owing to a well-developed dual-pore system and there is potential for recharge groundwater to move rapidly away from infiltration forced hydraulic gradients towards discharge sites.

In the context of this study, although hydraulic gradients were likely to be small, the aim was see whether zones of higher resistivity could be resolved within the upper parts of the Tamala Limestone proximal to the estuary. In resistivity (geophysical) surveys undertaken elsewhere over the Tamala Limestone, Smith et al. (2011), suggested that resistive areas in the subsurface were readily identified, and that these zones could be interpreted as zones of preferred groundwater movement.

1.2. Project Aims and Scope

The specific objectives of the work reported here were, through the measurement of the ground conductivity structure along the shore at Alfred Cove/Attadale Reserve adjacent to the Swan Estuary Marine Park, to:

1) Resolve spatial variations in the groundwater discharge through the Tamala Limestone, by characterising the conductivity structure of the subsurface;
2) Identify resistive areas in the subsurface and by inference, areas with the potential for higher groundwater flux to the river;
3) Identify zones of saline water intrusion into Alfred Cove/Attadale Reserve foreshore which may indicate areas with lower flux to the river;
4) Better understand the local hydrogeology in this area of the Swan River estuary.

The scope of the work was limited to ground geophysical data acquisition, data processing and inversion and to a limited interpretation from a hydrogeological perspective; limited primarily because of the relative paucity of hydrogeological data in the area.

1.3. Study Area

The survey area (Figure 1-1) is located along the foreshore at Attadale and extended from the western edge of the Attadale Reserve to the east approximately for 1.3km and between 100 to 200m to the south of the shore. The area is characterised by slightly inclined, flat landscape with minor undulations of up to a metre.

2. Instrumentation and methods

2.1 Ground EM measurements

There are a range of geophysical techniques that measure the conductivity (or resistivity) of different parts of the subsurface profile. There is also a broad literature describing applications of land-based electromagnetic methods for identifying contrasting electrical conductivities between fresh and salinesaturated materials, including their application in seawater intrusion into coastal aquifers (e.g., McNeill 1990; Ruppel et al. 2000; Stewart 1999 Goldman, et al .1991; Mills et al 1988; Nowroozi et al., 1999). Ground based electromagnetic (EM) techniques provide information in the spatial sense to depths of between 1 and 100m depending on the system used and sampling procedure employed. For fine scale studies, supporting monitoring of surface water - groundwater interactions, these techniques can be of particular value when contrasts in groundwater conductivity are expected.

FIGURE 1 1: Map showing the area under study and location of survey soundings at Lucky Bay

Different instruments achieve different depths of penetration (the depth to which the instrument set-up allows readings to be obtained) and may also have a different depth focus (depth interval from which the bulk of the response is derived. The depth of the sediment penetrated and the signal received by the ground EM system depends on the type of electromagnetic induction equipment used and the water, clay and the total soluble salt content of the material (see for example Williams and Baker 1982; Williams and Hoey 1987). In studies conducted over many landscapes in Australia, detailed investigations have revealed that the water quality variations account for 70 to 80% of the variation observed in the apparent conductivity values.

The resolution of a ground EM system can vary depending on the configuration of the system. As a rough guide the lateral resolution of a ground-based time-domain EM system is of the order of 10's of metres (Figure 1-2).

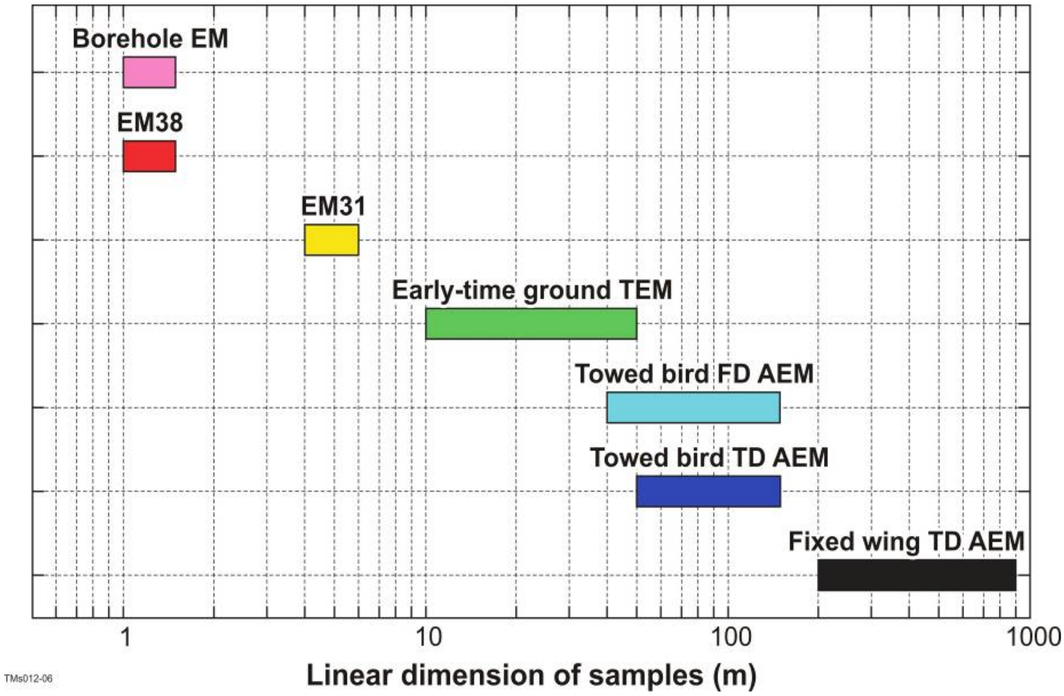

FIGURE 2-1 : Linear scale of lateral averaging as an indicator of sampling volume (Source R. Lane Geoscience Australia)

2.2 What is electrical conductivity?

Conductivity is simply the measure of a material's ability to conduct an electric current, and is measured in the S.I.[1] unit Siemens per meter (S/m). These units can be scaled depending on the material's conductivity. The term resistivity is the reciprocal or inverse of conductivity, and whose units are expressed in Ohm.m. Resistivity is simply the measure of a material to impede current flow. The following equation converts conductivity to resistivity;

$$\sigma = \frac{1}{\rho}$$

Where ρ = resistivity (Ohm.m)

σ = conductivity (S/m)

The following table lists conductivity and equivalent resistivity values in mS/m and Ohm/m respectively.

Conductivity (mS/m)	Resistivity (Ohmm)
10000	0.1
1000	1
100	10
10	100
1	1000
0.1	10000
0.01	100000

TABLE 1. Conductivity (in mS/m) and equivalent resistivity values (Ohm.m)

In terms of geophysical methods, it is common to express DC (Direct current) measurements as resistivity and for inductive techniques (electromagnetic methods) as conductivity, although the terms can be interchangeable if the data is transformed accordingly. For the non-geophysicist, DC electrical methods are typically classified as invasive, requiring electrodes to be placed into the ground, whereas electromagnetic methods are non-invasive and use coils of wire to induce current into the ground.

2.3 Principles of electromagnetic induction and measurement

EM instruments transmit a primary magnetic field, which cause, or induce, an electrical current in the earth. The current in the earth generates a secondary magnetic field, which is sensed by the receiver of the instrument. Variations in the magnitude of the secondary field can be related to the conductivity of the earth. Terrain conductivity surveys commonly involve a handheld instrument operating at a single frequency, however, some systems estimate terrain conductivity at several frequencies. Ground electromagnetic techniques are distinguished by the nature of the primary field, with transient, or time-domain EM using an intermittently pulsed primary field, and measurements are made of the change in the secondary field at various times between pulses.

In this study a time domain electromagnetic (TDEM) method was employed for the survey. This approach uses a transmitter to drive an alternating current through a square loop of insulated electrical cable laid on the ground (Figure 1-3). The current consists of equal periods of on- and off- time, produces an electromagnetic field. Termination of the current flow is not instantaneous, but occurs over a very brief period of time (a few microseconds) known as the ramp time, during which the induced magnetic field is time-variant. The time-variant nature of the primary electromagnetic field creates a secondary electromagnetic field in the ground beneath the loop, in accordance with Faraday's Law, that is a precise image of the transmitter loop itself (Halliday & Resnick, 1974). This secondary field immediately begins to decay, in the process generating additional eddy currents that propagate downward and outward into the subsurface like a series of smoke rings. Measurements of the secondary currents are made only during the time-off period by a receiver located in the centre of the transmitter loop (Figure 1-3). The depth of investigation depends on the time interval after shutoff of the current, since at later times the receiver is sensing eddy currents at progressively greater depths. The intensity of the eddy currents at specific times and depths is determined by the bulk conductivity of subsurface geological units and their contained fluids (Stewart & Gay, 1986; Mills et al., 1988; Goldman et al., 1991; McNeill, 1994).

2.4 Instrumentation

For the work over the Lucky Bay area the Zonge Nanotem NT-32 time domain electromagnetic (TDEM) system was employed. The survey configuration employed a 20 x 20 transmitter loop with a 5 x 5 metre receiver loop placed within the centre of the transmitter area (as indicated schematically in Figure 1-2), with measurements or soundings collected along five lines at 57 locations or stations, each separated by either 30 or 40m. TDEM data were collected at 35 stations on line 1, five stations on line 2, six stations on lines 3 and 4, and five stations on line 5. (Figure 1.1).

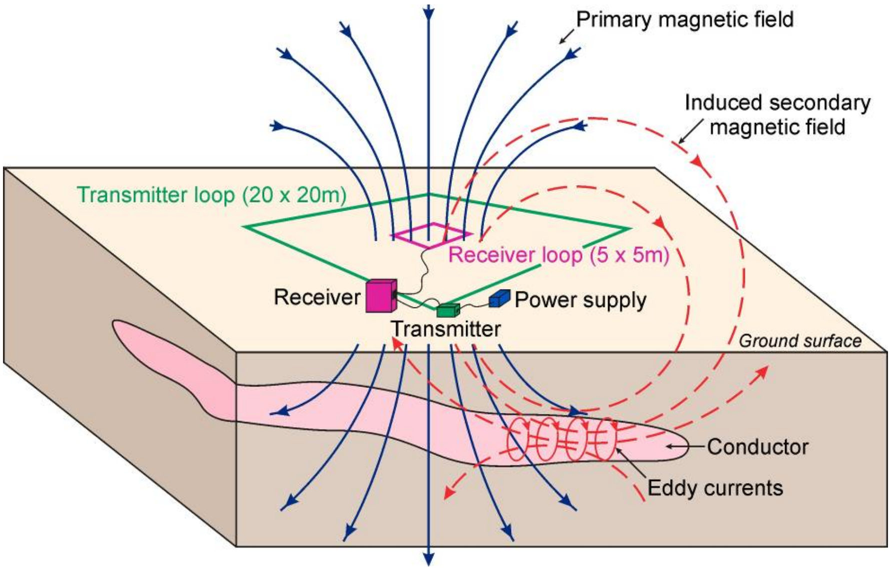

FIGURE 2-2: Schematic showing primary and induced magnetic fields during ground EM data acquisition.

3. Data Processing and Inversion

Data was inverted using Zonge STEM1DINV software (MacInnes and Raymond 2001) which employs a smooth-model inversion for transforming moving loop TEM soundings to profiles of resistivity versus depth. Observed transient data for each sounding are used to determine the parameters of a layered-earth model. Layer thicknesses are fixed and set to sum to the soundings' maximum depth of investigation. Layer resistivity's are then adjusted iteratively until model TEM responses are as close as possible to observed data. Smoothness constraints limit model resistivity variation from layer to layer. The workflow is represented schematically in Figure 3-1.

The result from the smooth-model inversion is a set of modelled ground resistivities/conductvities which vary smoothly with depth. Lateral variation is determined by inverting successive soundings along a survey line and stitching the results together (Figure 3-1 C). Results for a complete line can be presented in pseudosection form by contouring model resistivity/conductivity (Figure 3-1 D). For contouring, model resistivity values are placed at the midpoint of each layer, forming a column below every station.

4. Results

For most surveyed lines in the area, the observed responses indicated a slightly conductive upper layer, underlain by a relatively resistive layer, with variable thickness, and in turn this is underlain by a more conductive layer (see conductivity depth sections for each surveyed line in Figures 4-1 to 4-8).

The inversion results for Line 1 indicated possible buried infrastructure at stations 1150, 1180, 1210 and 1240, approximately 30 metres below surface and again at stations 1300,1330, 1370 and 1400, approximately 25 metres below surface. Results for Lines 2 (Figure 4-5), 3 (Figure 4-6) and 4 (Figure 4-7) also indicated possible buried infrastructure. On line 2 at stations 2040, 2060 and 2080, approximately 25 metres below surface where a marked increase in conductivity vs time was measured. The measured response from Line 3 shows similar changes in the electrical decay, approximately 40 metres below surface, at station 3120 and station 3150 possibly due to coupling with buried infrastructure. Similar responses were noted for Line 4 show at stations 4060, 4090, 4120 and 4150 measurements may also indicate buried infrastructure. Where measurements suggested the presence of buried infrastructure they were not included in the modelling.

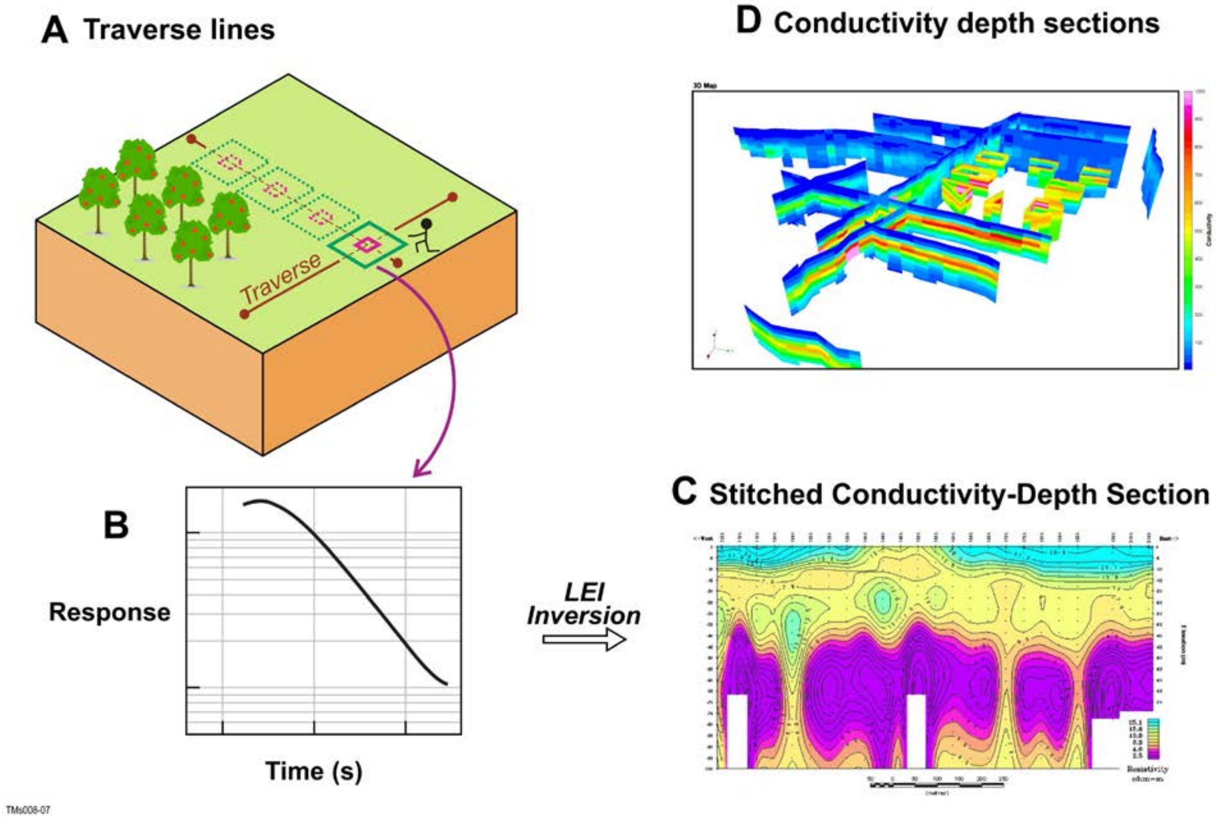

FIGURE 3.1: Ground geophysics data acquisition and processing workflow employed in the Lucky Bay study.

We interpret the moderately conductive surface layer (largely confined to the "fill" as interpreted in Bore IF14 and also in shallow bore TRMW08 described in GHD (2013) at the eastern end of Line 1) as being conductive due to the concentration of soluble salts through evaporation in the capillary fringe above the standing water level which is close to the surface (1.71 m in bore IF14 (Hamilton, 2017); see Figure 4-9). Beneath this layer the Tamala Limestone, represented by a more clay-rich facies (see Figure 4-10), is relatively resistive. This suggests that the groundwater is fresh to moderately fresh, and these resistive areas, where present along the shoreline, may represent zones of relatively high transmissivity. The exception is in the central part of Line 1 where a zone of relatively high conductivity is noted within the clay-rich unit. This could be an area of low transmissivity and where salt water from the estuary has intruded into the foreshore. In the absence of more detailed lithological data it is difficult to define the exact controls on the observed conductivity structure, but the available lithology log, and associated conductivity structure (Figure 4-10) all point to groundwater conductivity as being the primary driver of the measured variability. The results from this study also indicate the limitations of the previous investigations (see GHD 2013) further to the east of the area examined here, primarily because of the limited depth of the drilling and the shallow investigation limits of the geophysical methods employed in that study. Here, the geophysical data suggest the potential for enhanced groundwater throughflow in the Tamala Limestone between to the estuary (between 5-20m below ground level.

5. Summary and Recommendations

The survey results indicate a relatively complex substrate in the study area with a varying groundwater conductivity has been resolved by the ground EM survey. Whilst infill data would resolve greater detail in the variability of the substrate and may provide greater resolution of zones of higher transmissivity in the Tamala, their presence is identified at the scale of this study. A small zone of relatively high conductivity has been defined in the upper Tamala, and this may indicate an area where limited saltwater incursion may be occurring in the sediments beneath the foreshore.

The absence of information on the conductivity structure offshore prevents a fuller picture from being defined for the interactions between the groundwater of the Alfred Cove/Attadale Reserve areas and the sea grass beds of the Lucky Bay. To better resolve these processes, we would recommend a more detailed "in river" resistivity survey adjacent to the foreshore, extending into the estuary across the sea-grass beds of interest, to ascertain where zones of groundwater discharge may be present. The resistive zones identified in the upper parts of the Tamala Limestone, beneath fill materials identified in drilling, would suggest there may be enhanced throughflow to the estuary, and the potential for an enhanced nutrient flux. Further work would be required to verify this.

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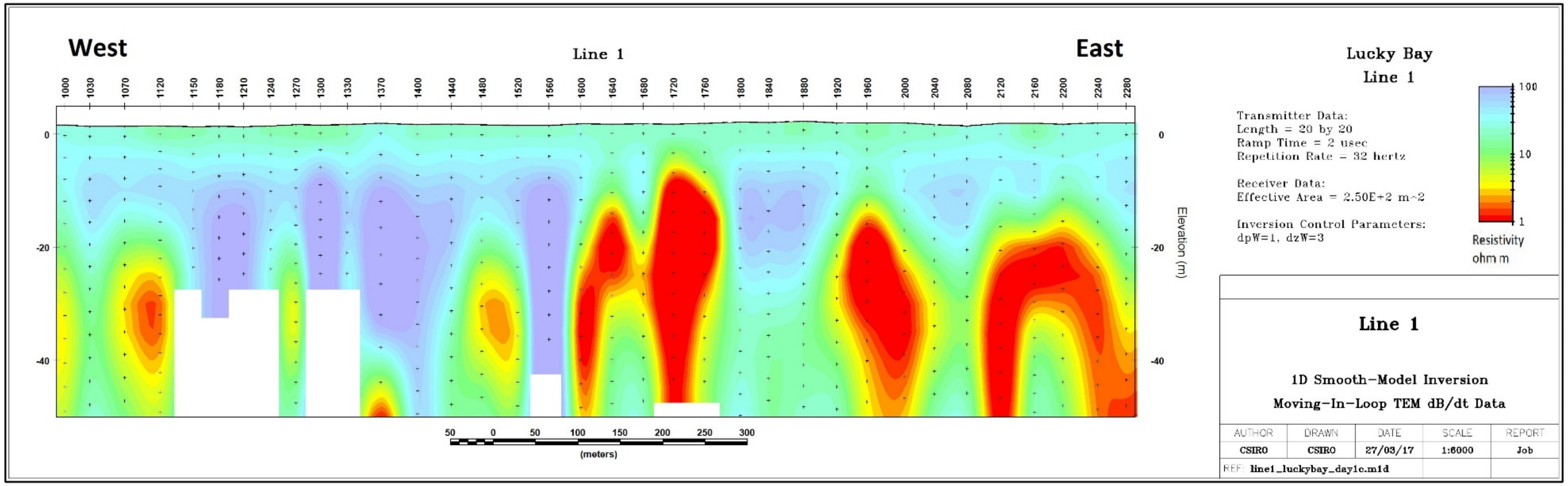


FIGURE 4-1: Modsect 1D smooth model inversion results for Line 1

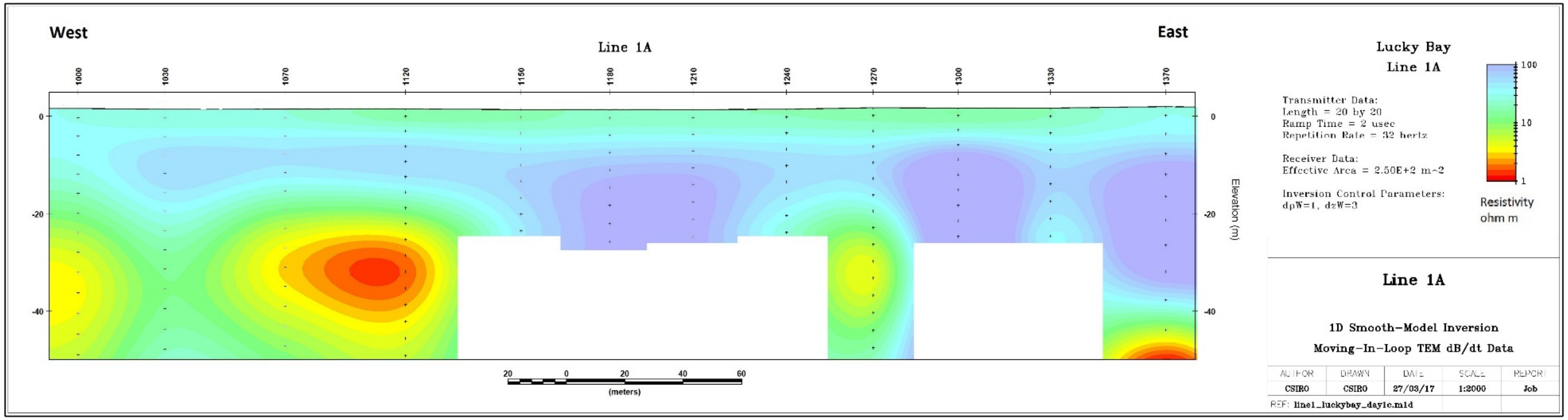


FIGURE 4-2: Modsect 1D smooth model inversion results for stations 1000 to 1370 on Line 1

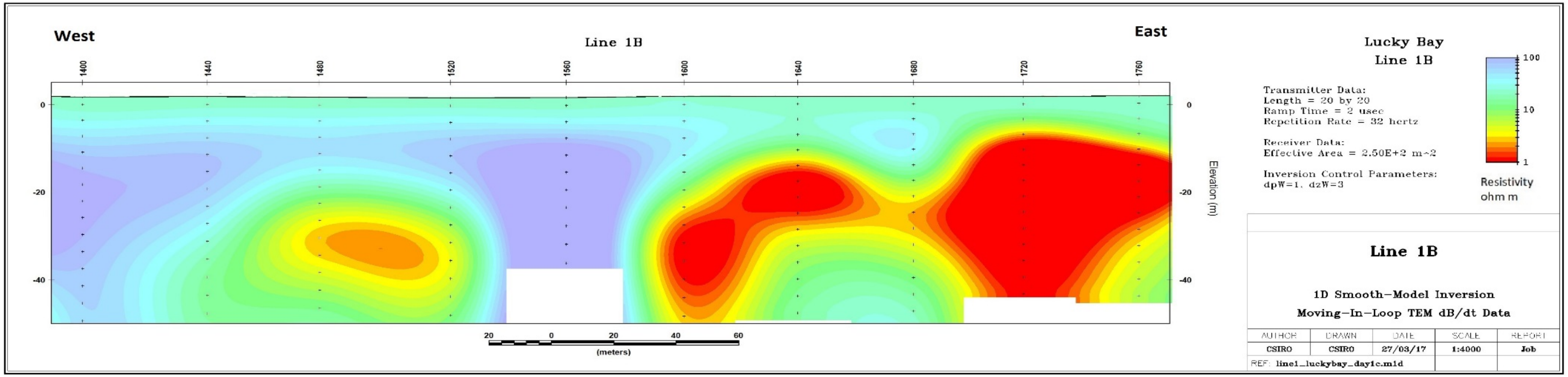


FIGURE 4-3: Modsect 1D smooth model inversion results for stations 1400 to 1760 on Line 1

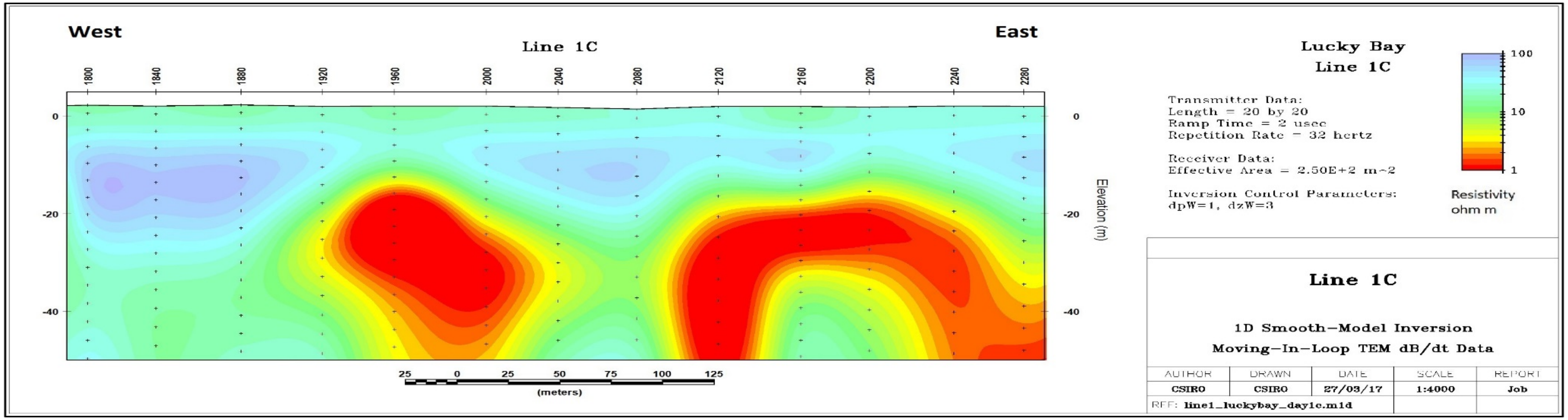


FIGURE 4-4: Modsect 1D smooth model inversion results for stations 1800 to 2280 on Line 1

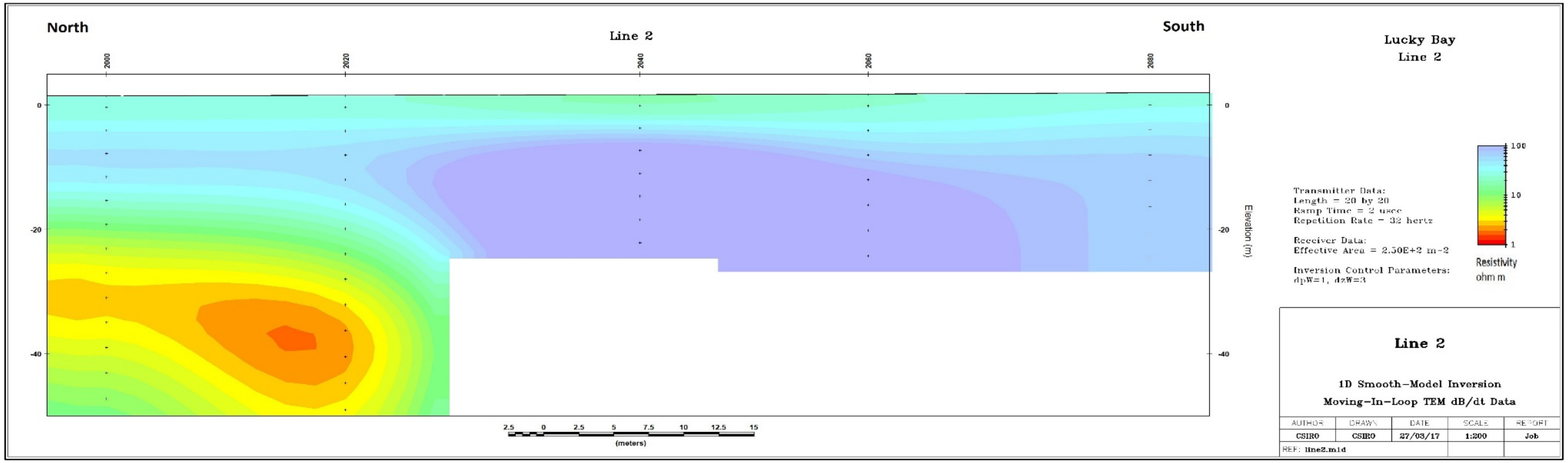


FIGURE 4-5: Modsect 1D smooth model inversion results for Line 2

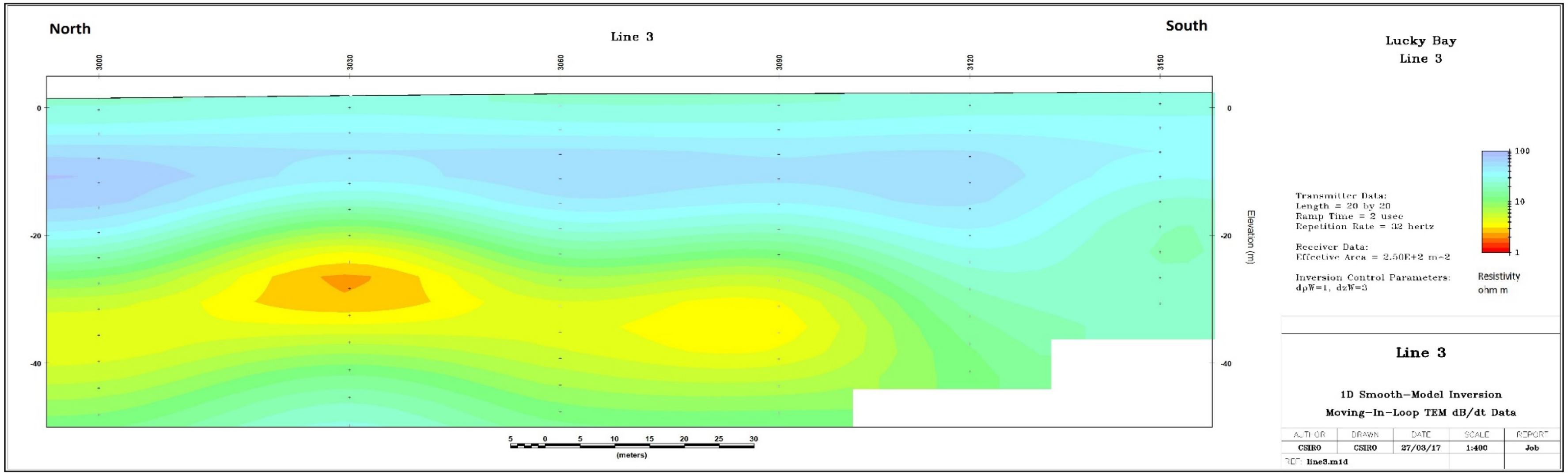


FIGURE 4-6: Modsect 1D smooth model inversion results for Line **3**

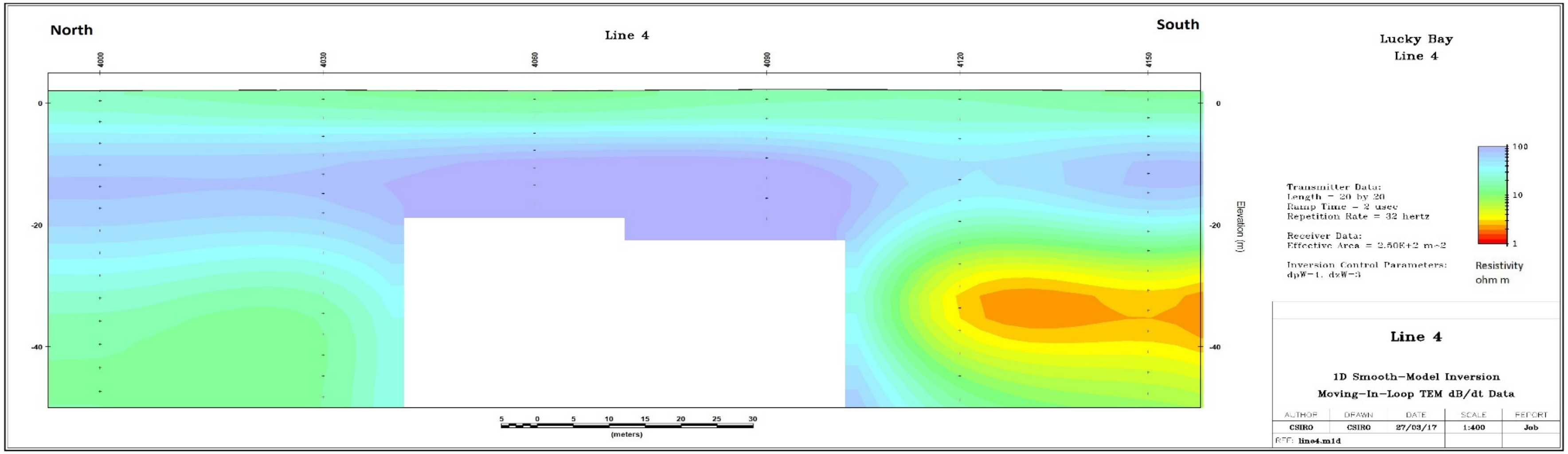


FIGURE 4-7: Modsect 1D smooth model inversion results for Line 4.

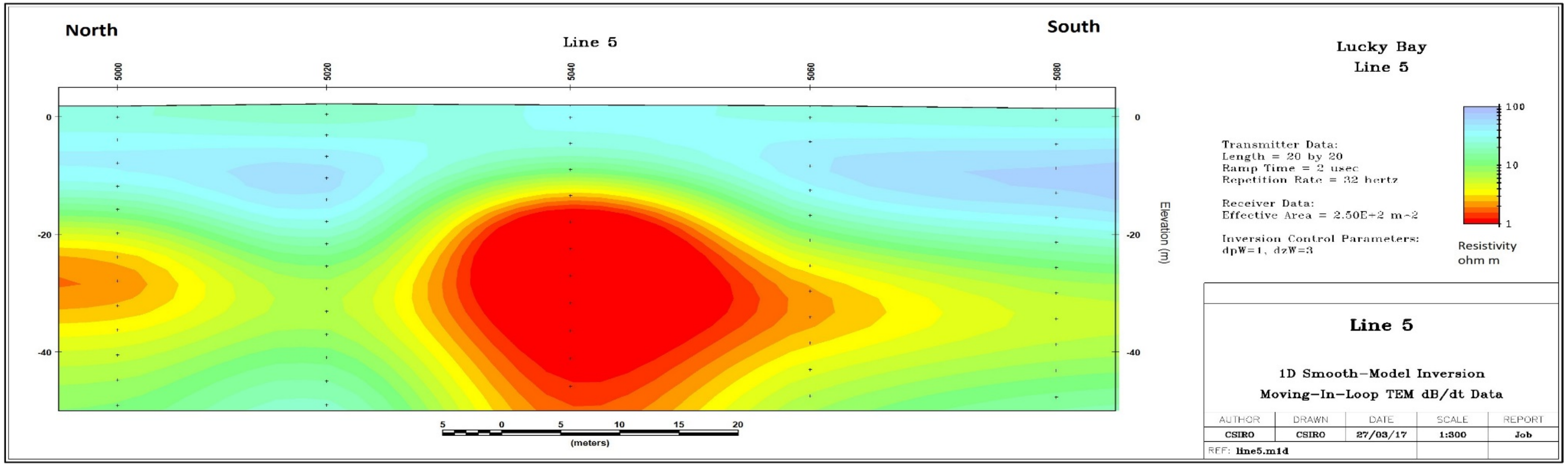


FIGURE 4-8: Modsect 1D smooth model inversion results for Line 5.

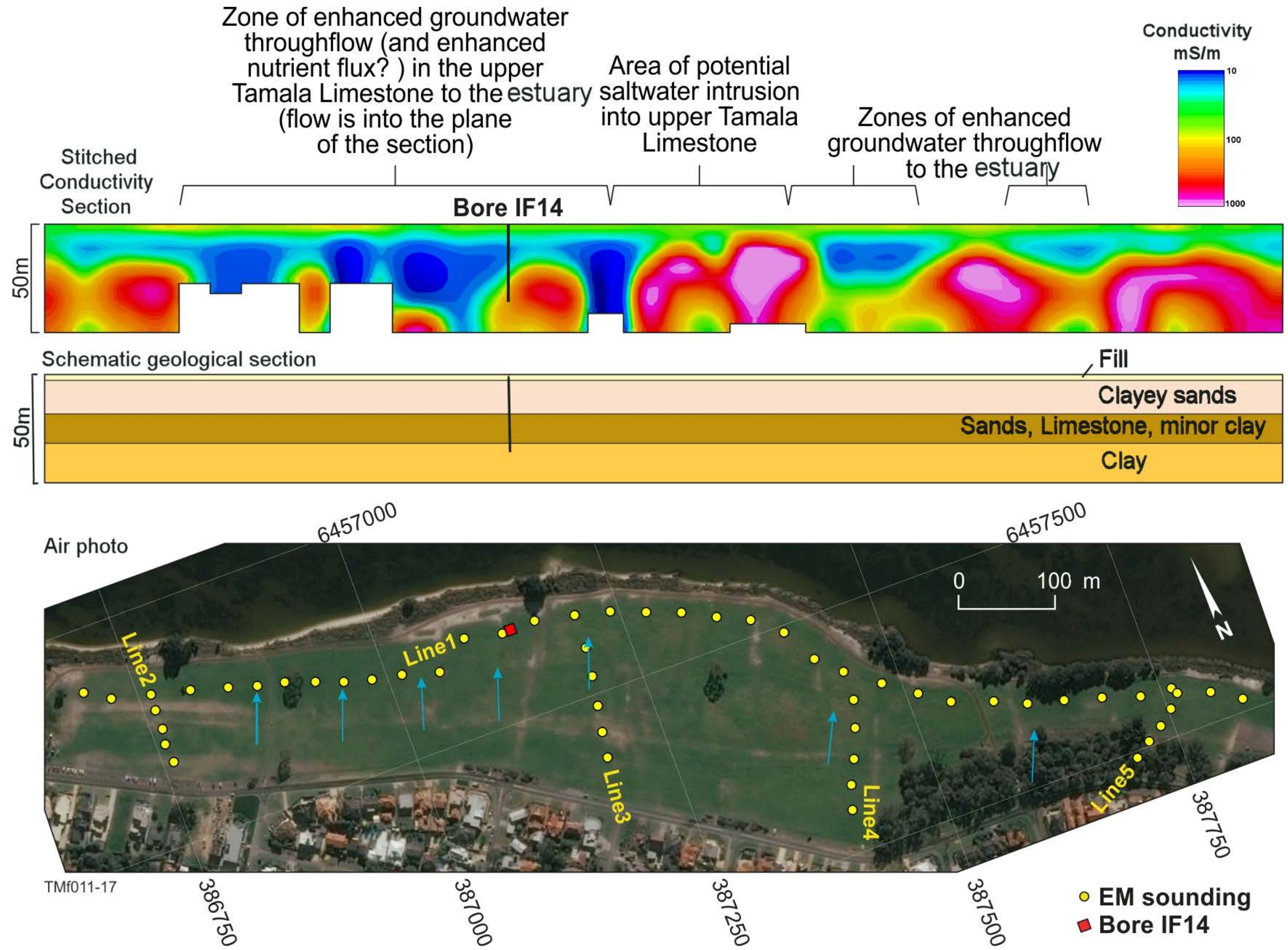


FIGURE 4-9: Stitched conductivity-depth section for Line 1 which runs along the foreshore. The simplified schematic geological section for the line is presented in the middle panel, and the locations of soundings which were inverted to generate the conductivity sections are marked on the air photo in the lower panel of the figure. The direction of groundwater flow is also indicated on the air photo with blue arrows.

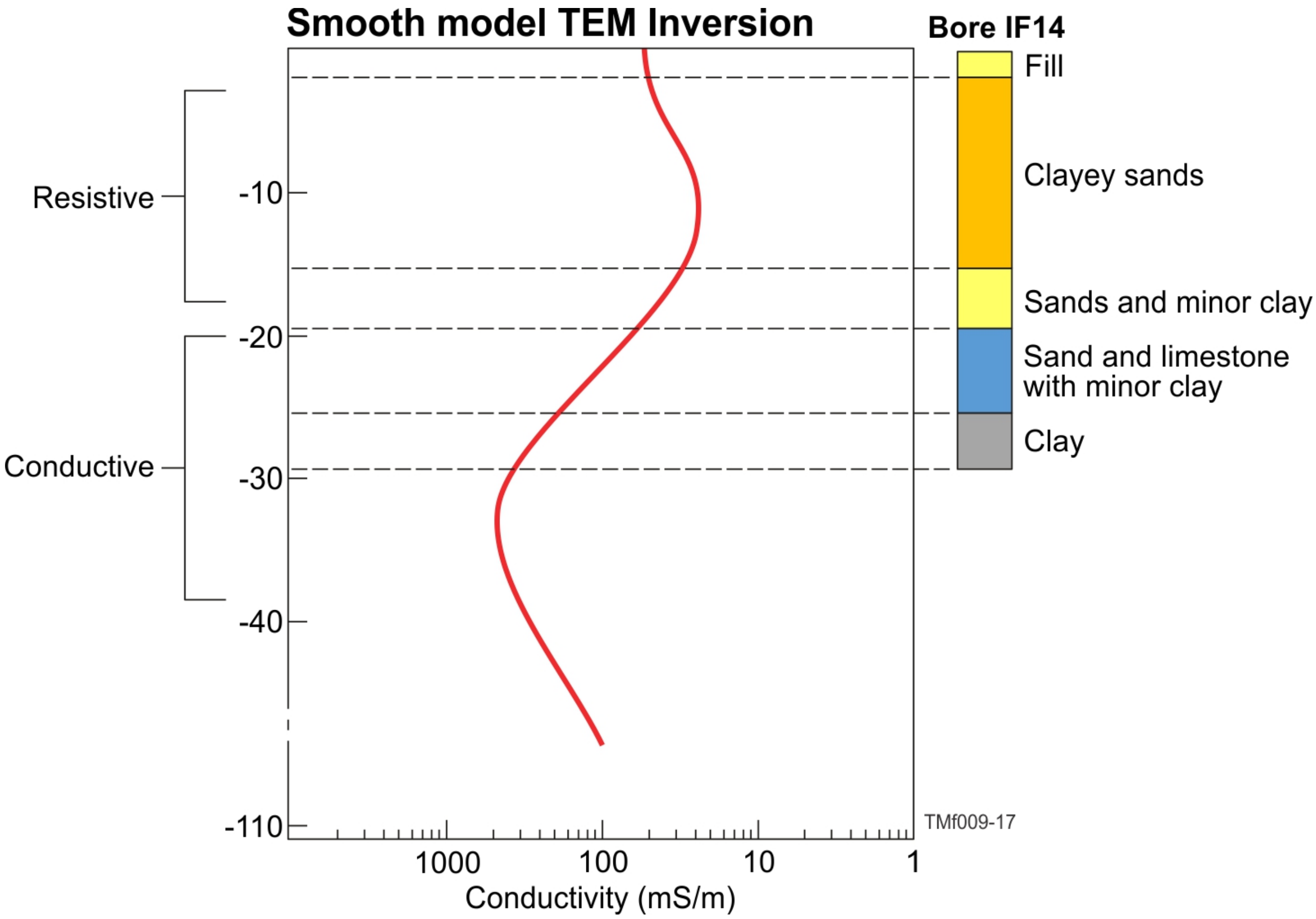


Figure 4-10: Inverted sounding for EM station adjacent to Bore IF14. The inverted sounding is result of a smooth model 1D inversion and it shows a moderately conductive near surface layer associated with a unit of fill, and then a more resistive clayey-sand unit, overlying a conductive sandier part of the Tamala.

APPENDIX A– Conductivity - Depth Slices @ 5m intervals


386700
387000
387300
387600
387900
6456900
6456600
Conductivity (mS/m)
1 - 25
25 - 50
50 - 150
150 - 300
300 - 500
500 - 750
>750
© 2017 DigitalGlobe © 2017 GeoEye Earthstar Geographics SIO © 2017 Microsoft Corporation
0 62.5 125 250 Metres
Depth Slice -10 metres


386700
387000
387300
387600
387900
6456900
6456600
Conductivity (mS/m)
1 - 25
25 - 50
50 - 150
150 - 300
300 - 500
500 - 750
>750
© 2017 DigitalGlobe © 2017 GeoEye Earthstar Geographics SIO © 2017 Microsoft Corporation
0 62.5 125 250 Metres
Depth Slice -15 metres


386700
387000
387300
387600
387900
6456900
6456600
Conductivity (mS/m)
1 - 25
25 - 50
50 - 150
150 - 300
300 - 500
500 - 750
>750
© 2017 DigitalGlobe © 2017 GeoEye Earthstar Geographics SIO © 2017 Microsoft Corporation
0
62.5
125
250 Metres
Depth Slice -20 metres


386700
387000
387300
387600
387900
6456900
6456600
Conductivity (mS/m)
1 - 25
25 - 50
50 - 150
150 - 300
300 - 500
500 - 750
>750
© 2017 DigitalGlobe © 2017 GeoEye Earthstar Geographics SIO © 2017 Microsoft Corporation
0
62.5
125
250 Metres
Depth Slice -25 metres

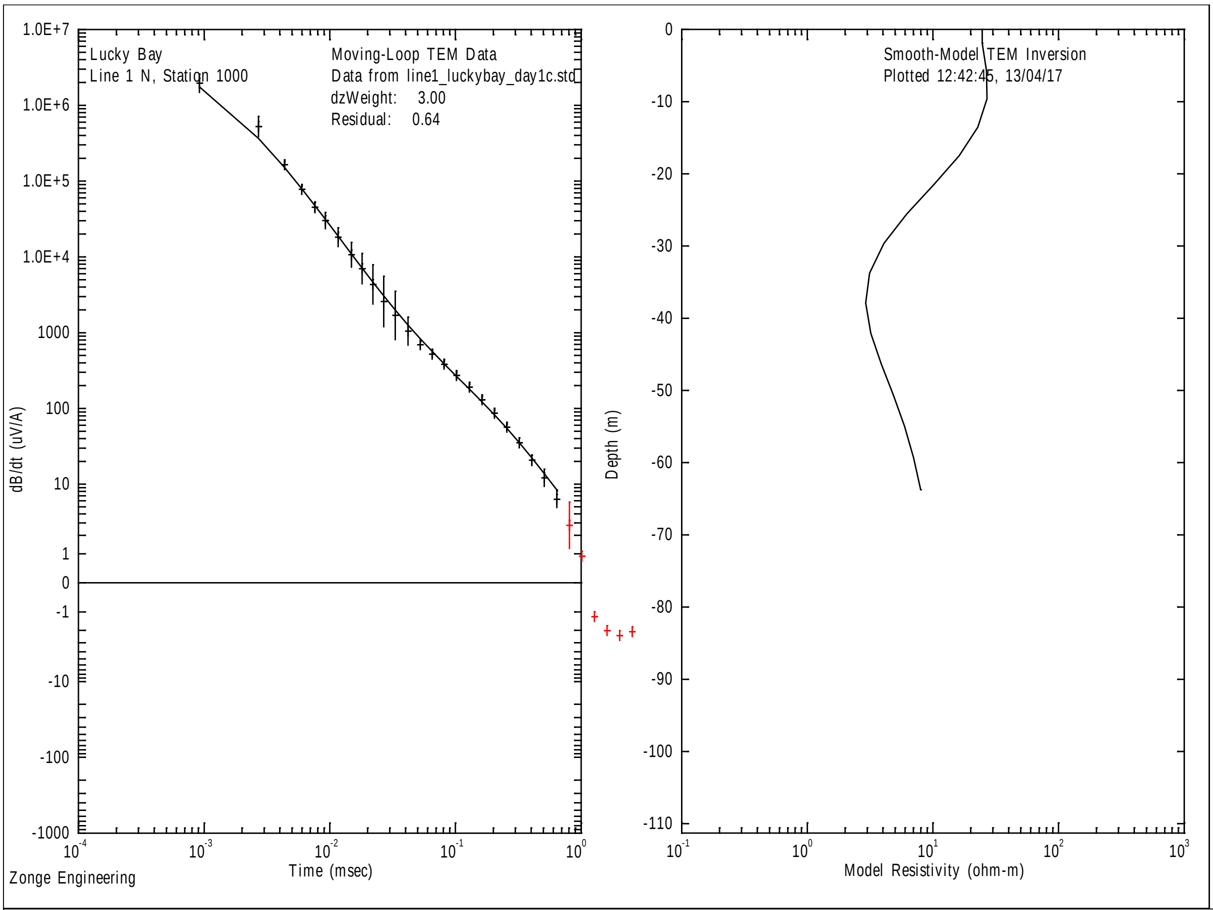
Depth Slice -30 metres

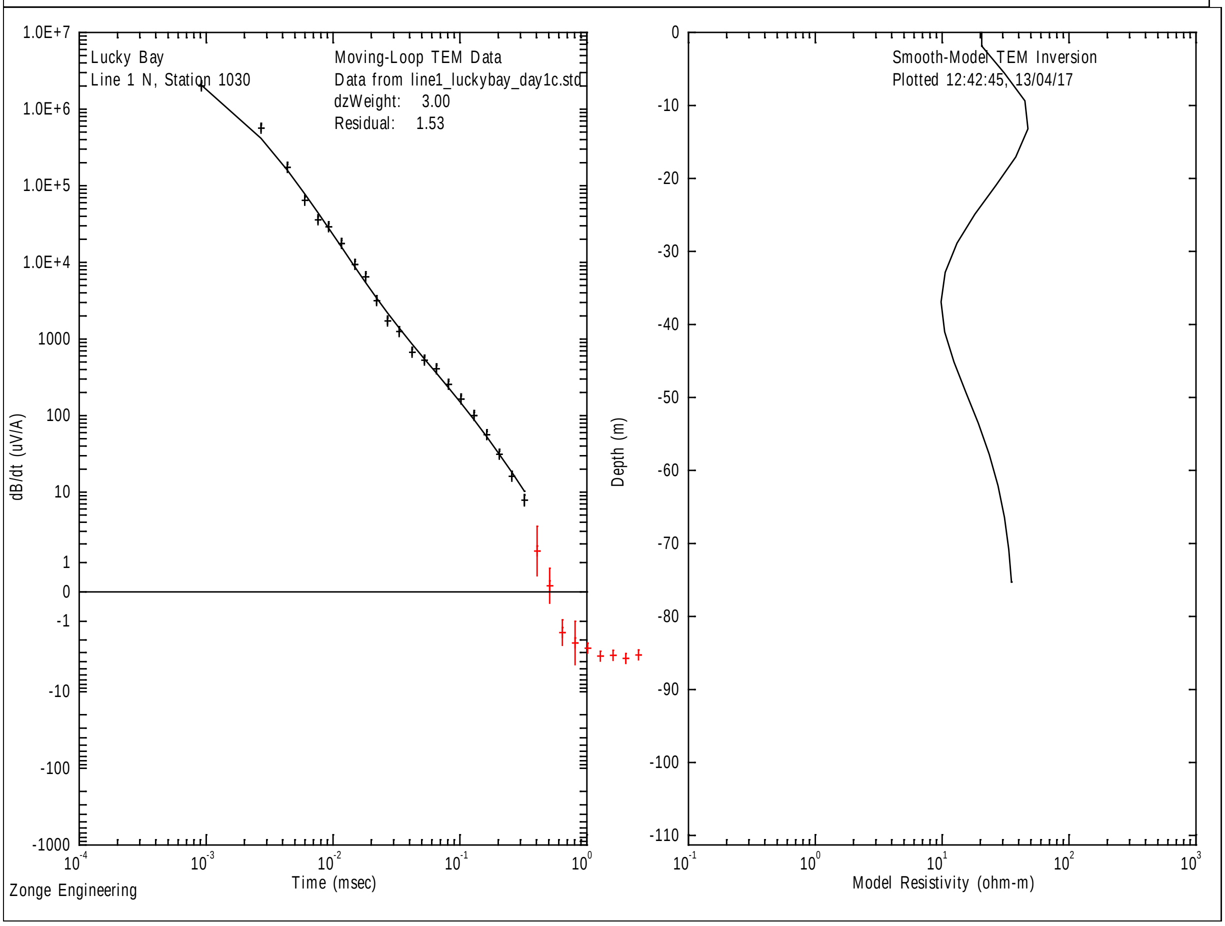
Depth Slice -35 metres

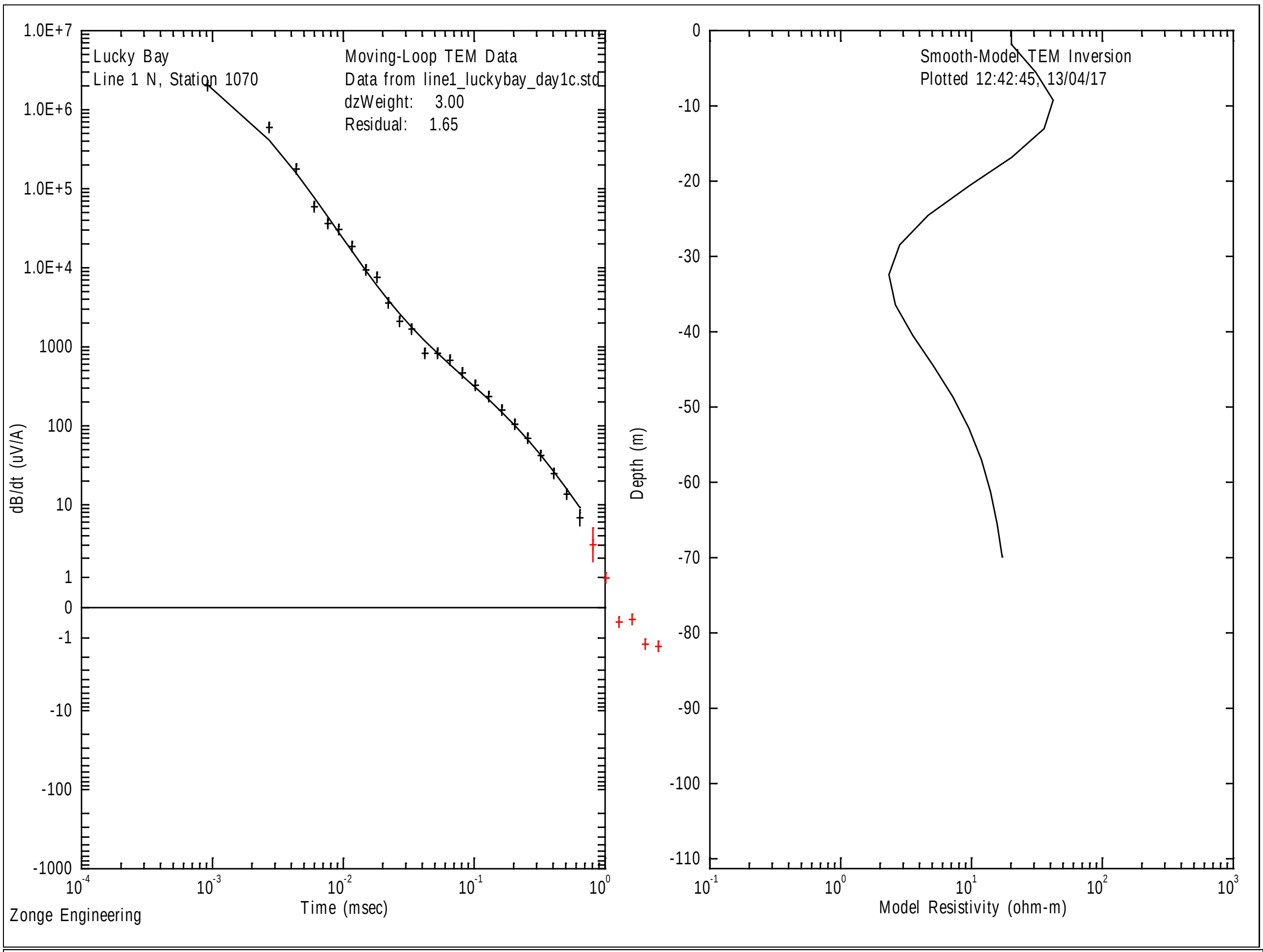

386700
387000
387300
387600
387900
6456900
6456600
Conductivity (mS/m)
1 - 25
25 - 50
50 - 150
150 - 300
300 - 500
500 - 750
>750
0
62.5
125
250 Metres
Depth Slice -40 metres

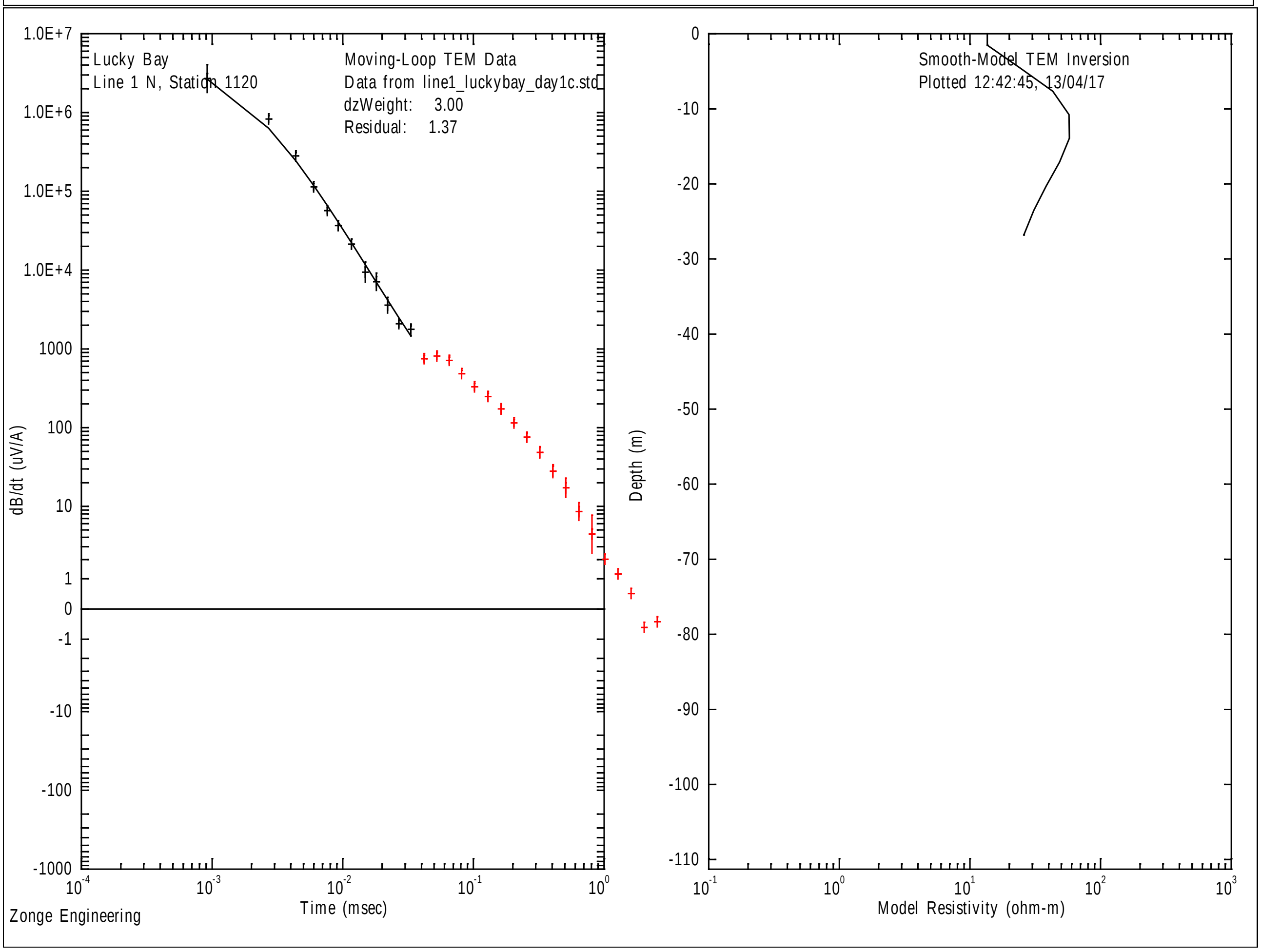
APPENDIX B – Inversion results for each station

Line 1 all stations






Lucky Bay
Line 1 N, Station 1070
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.65
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)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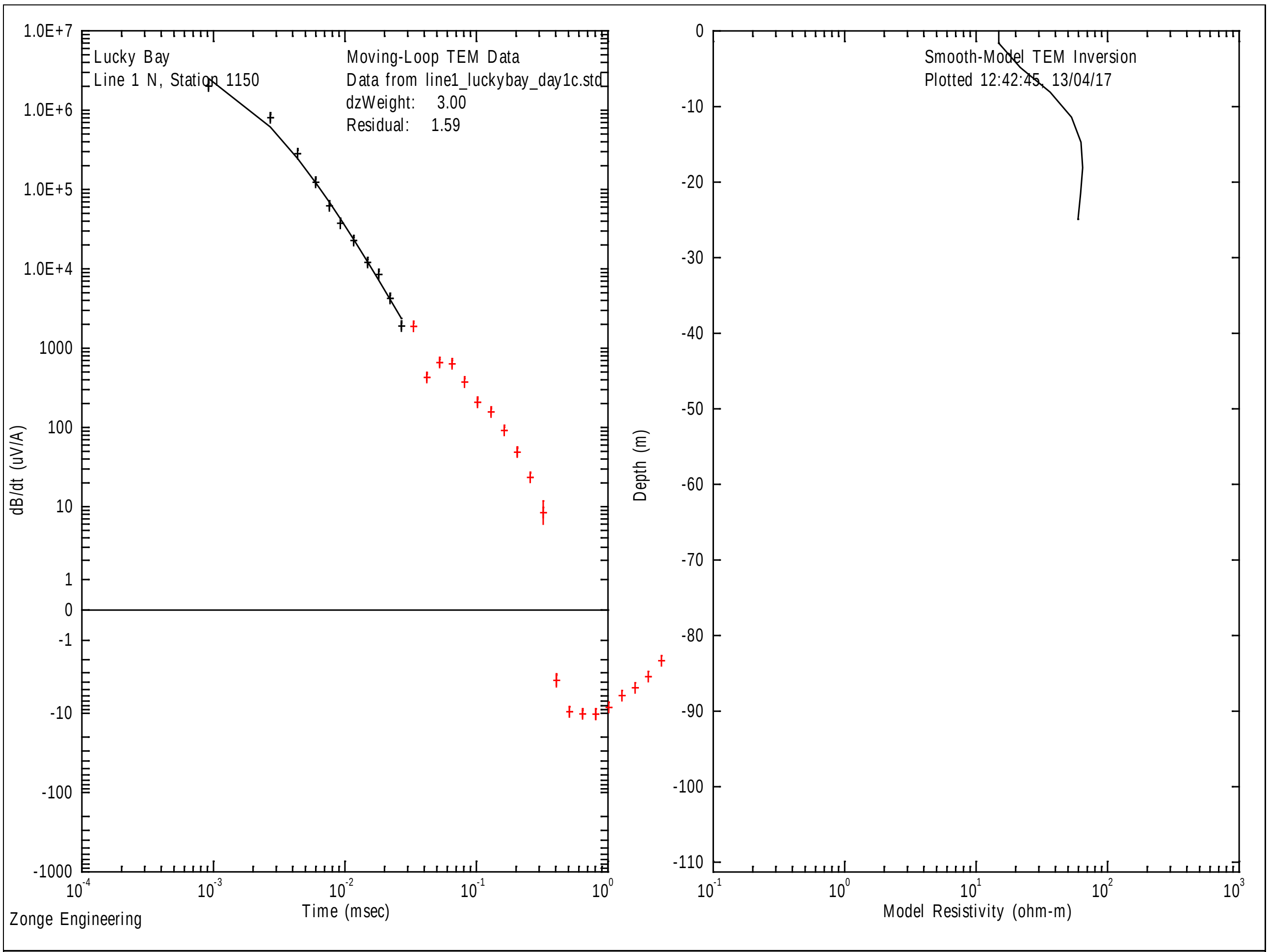
Line 1 N, Station 1120
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.37
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
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Moving-Loop TEM Data
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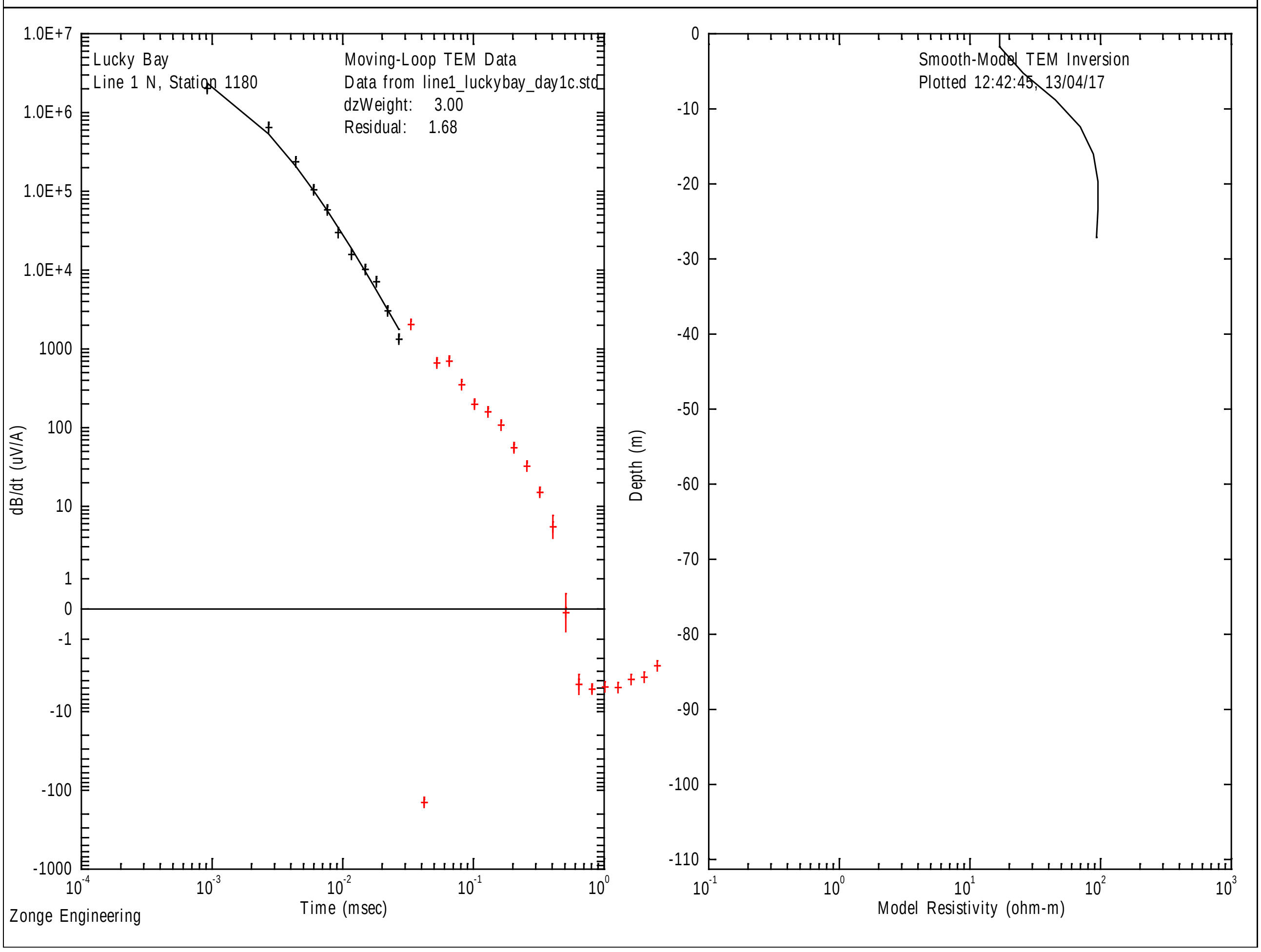
dzWeight: 3.00
Residual: 1.59
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)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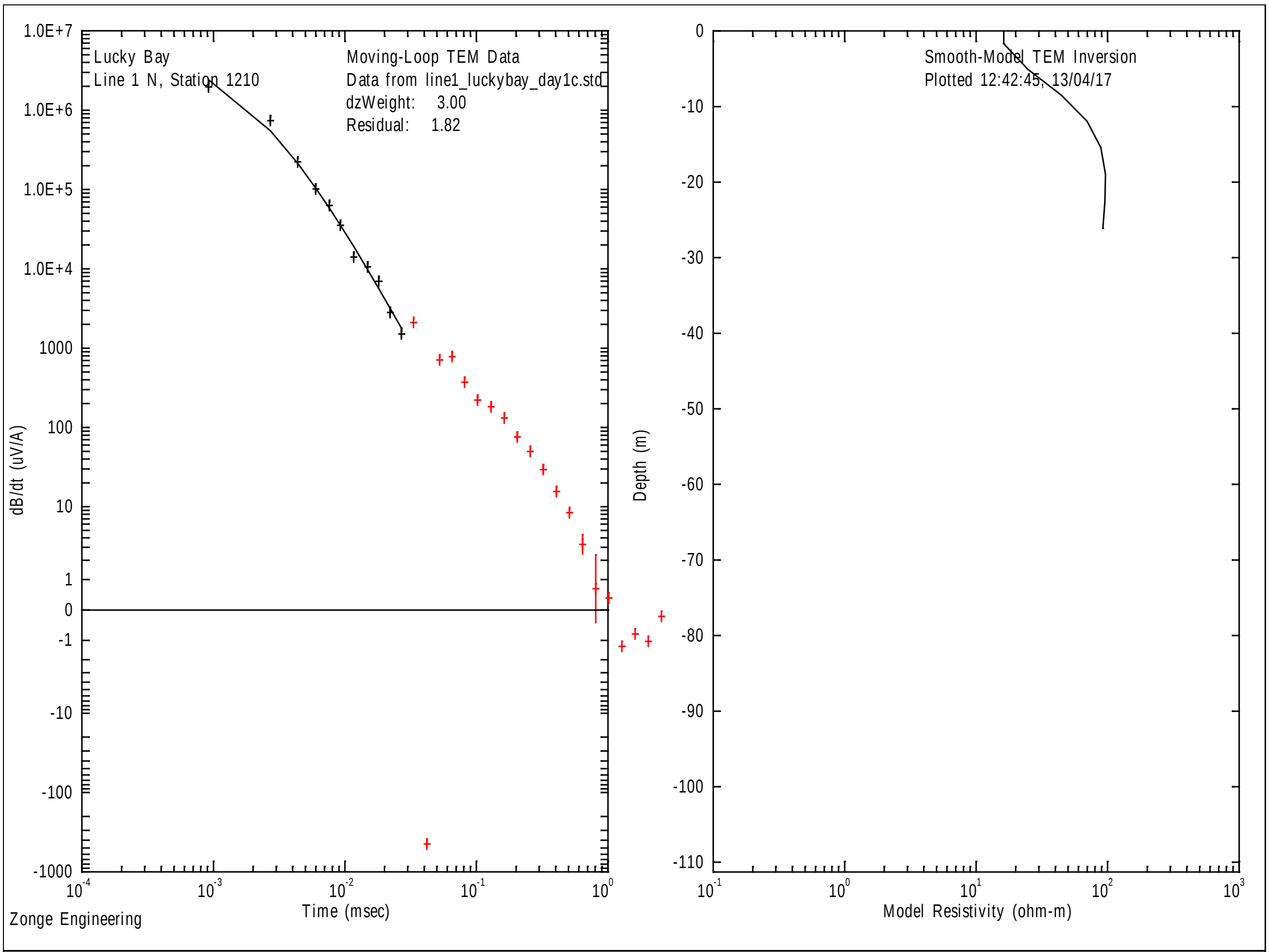
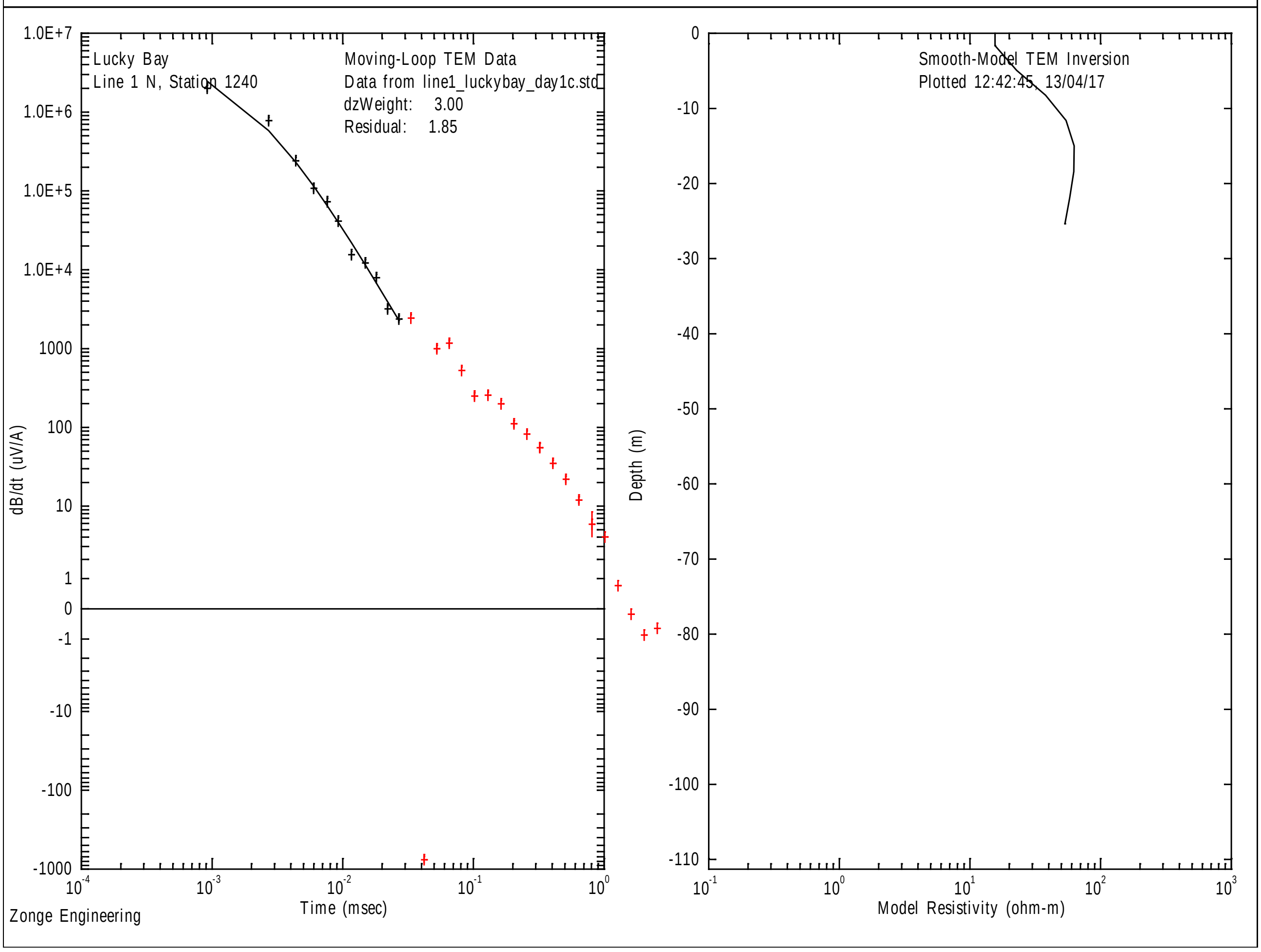
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.68
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
Line 1 N, Station 1210
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.82
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)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Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
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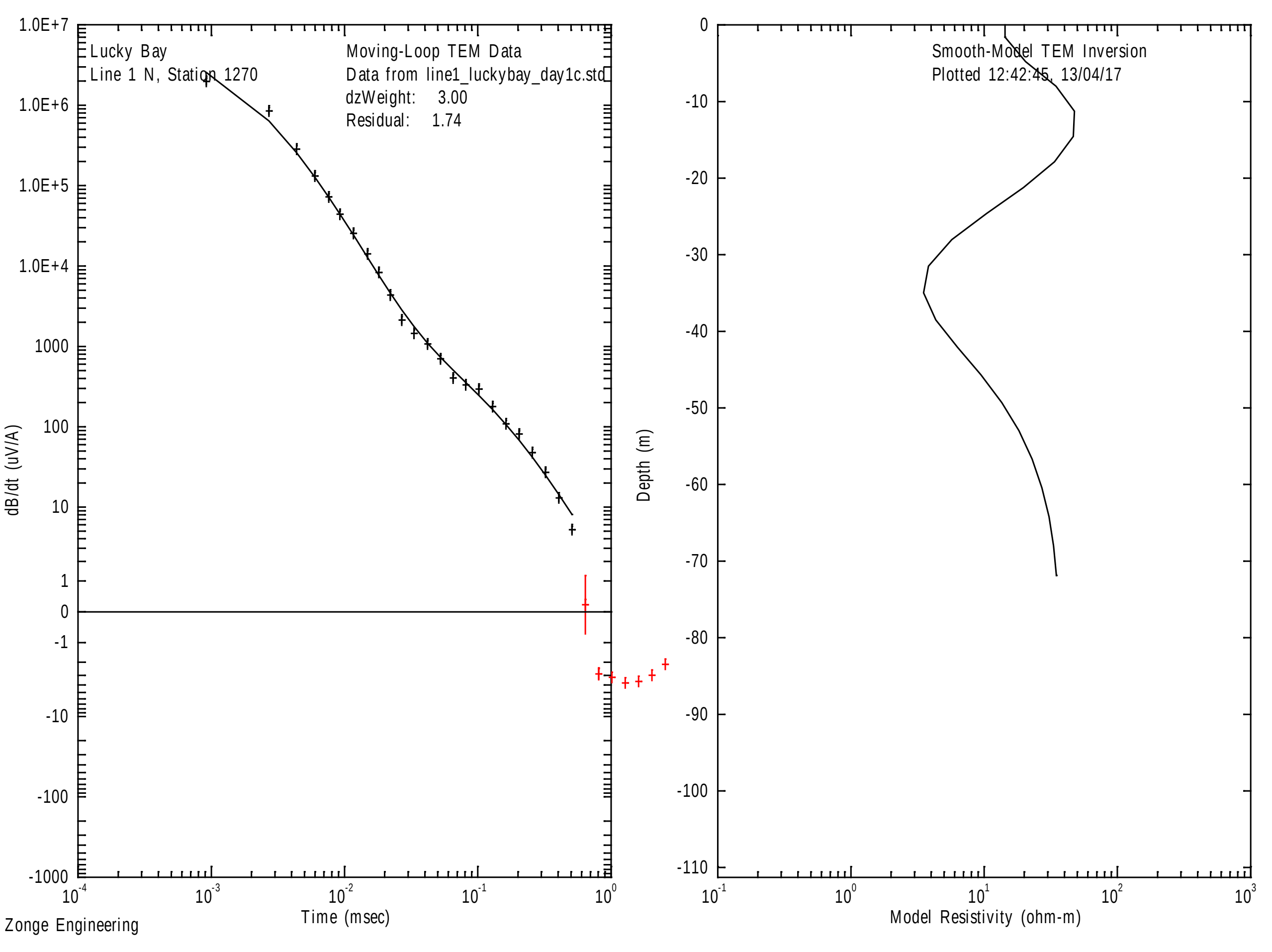
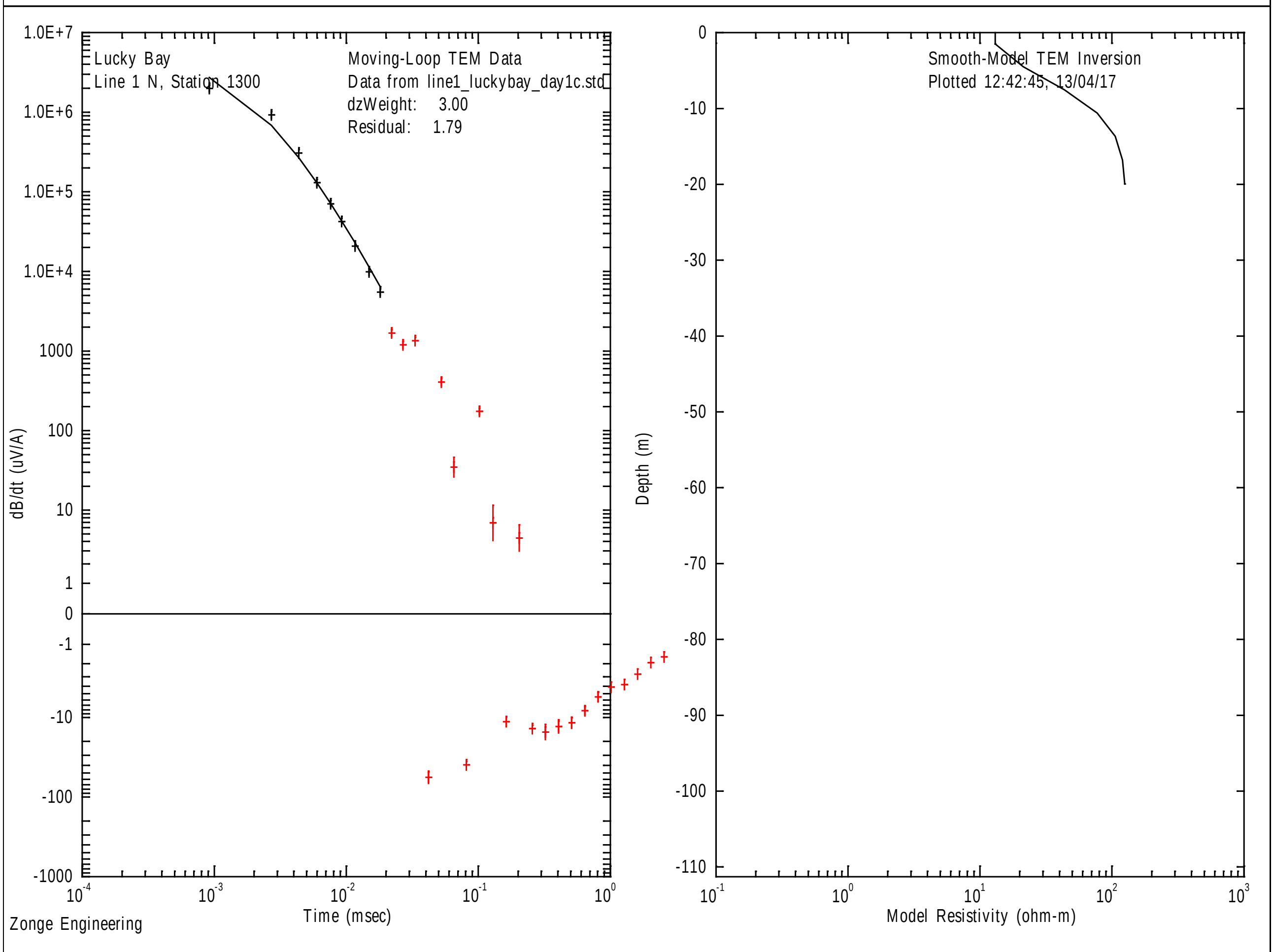
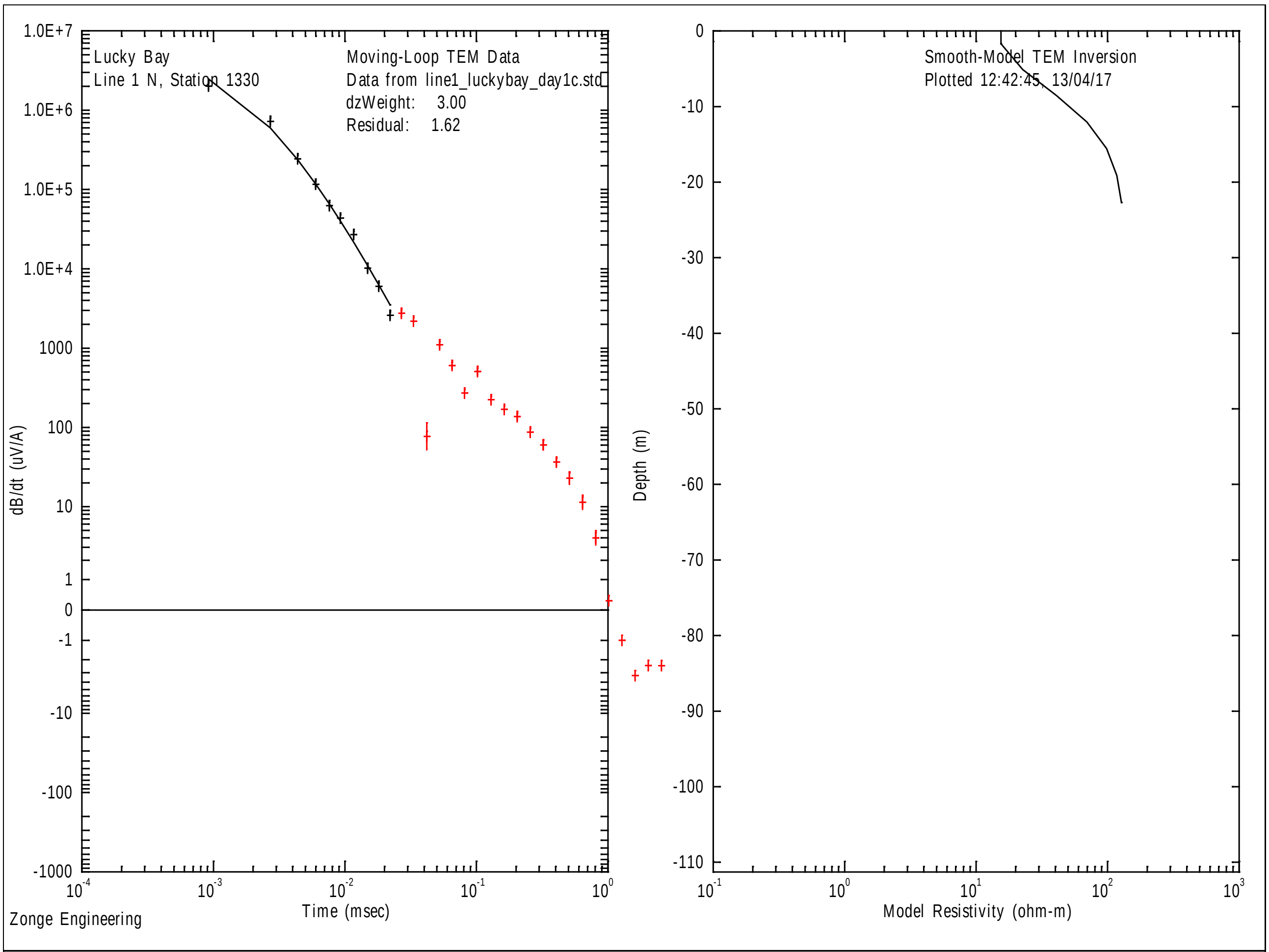
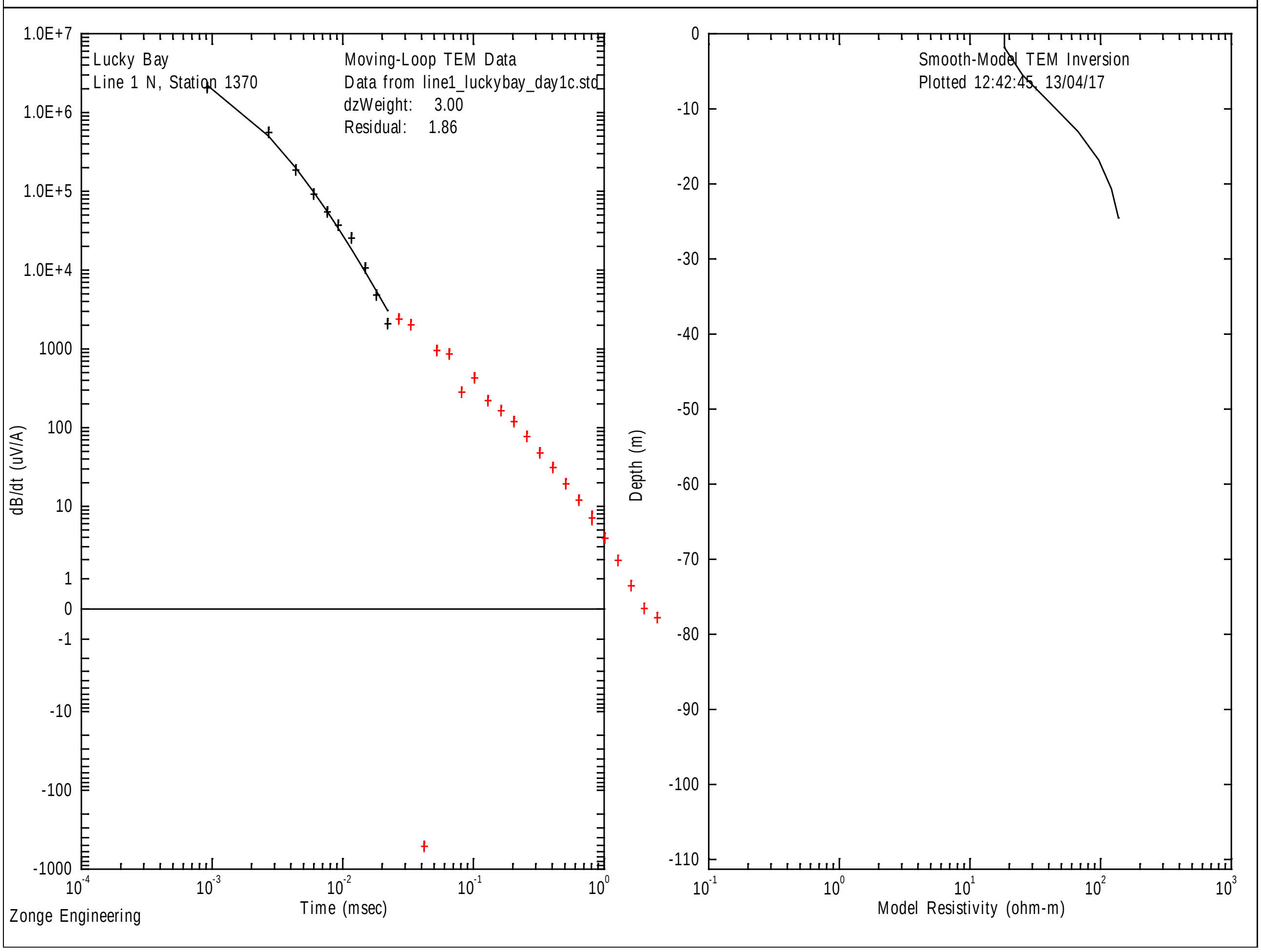
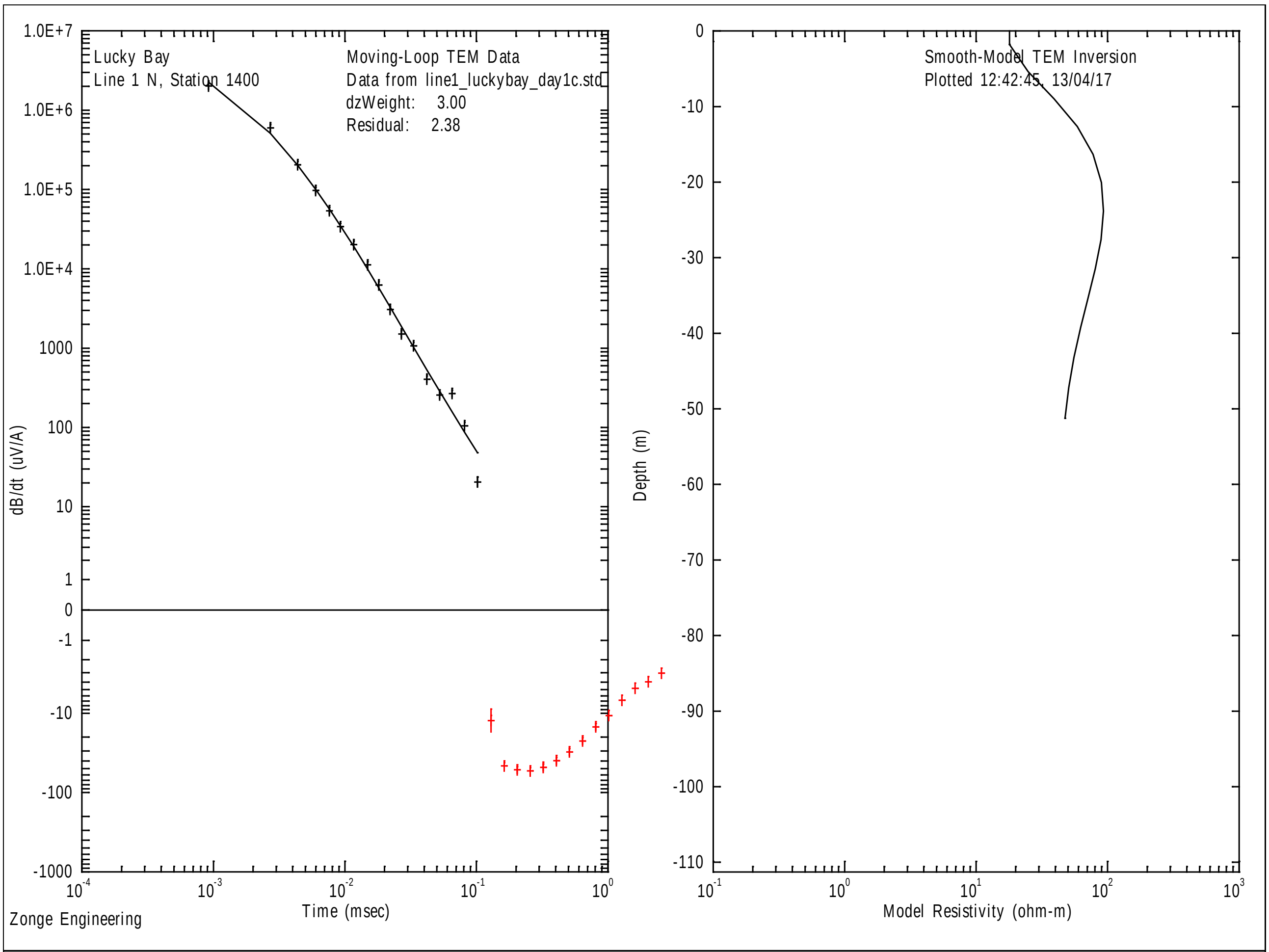
Residual: 1.85
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

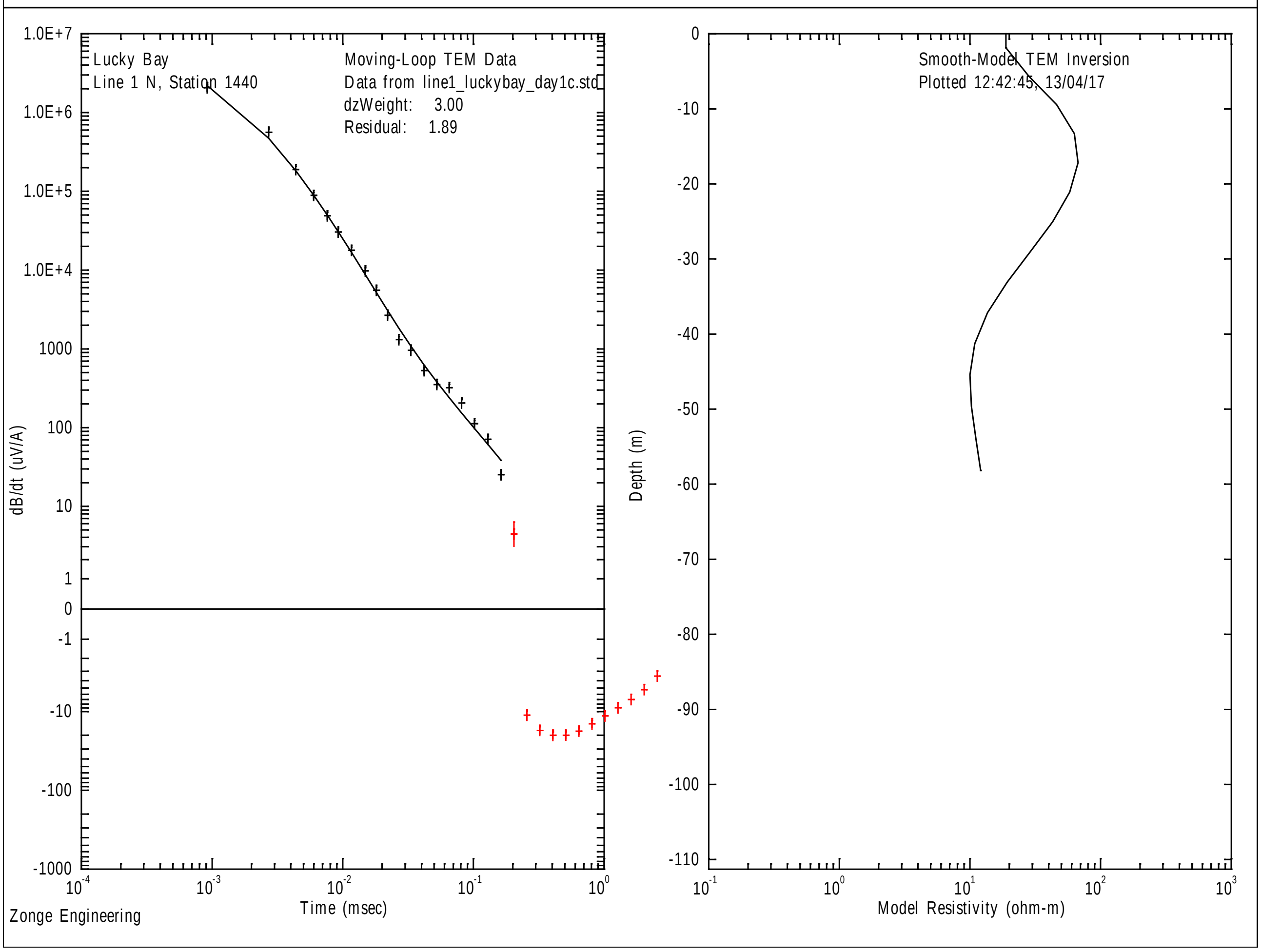

Lucky Bay
Line 1 N, Station 1270
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.74
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

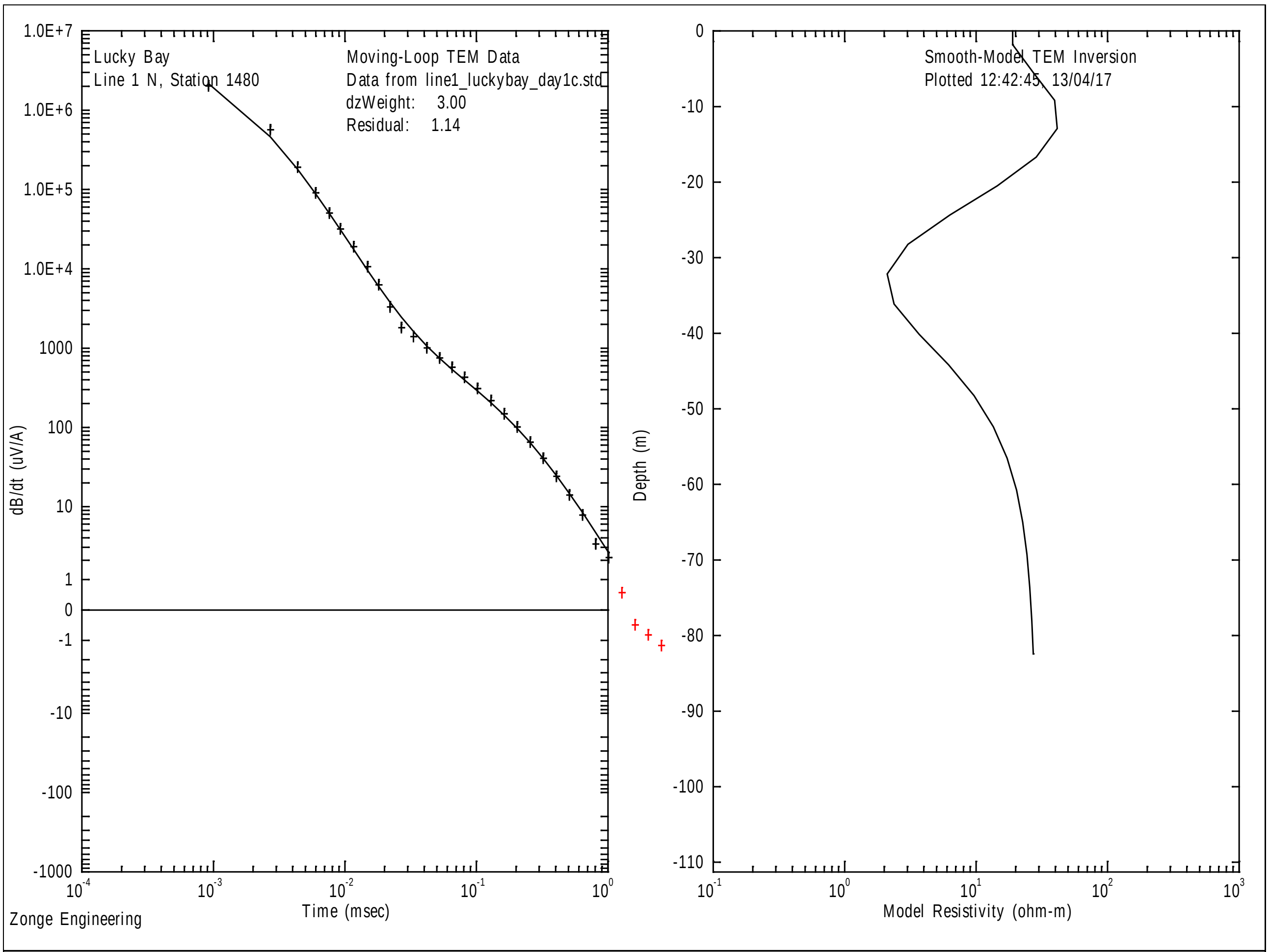

Lucky Bay
Line 1 N, Station 1300
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.79
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

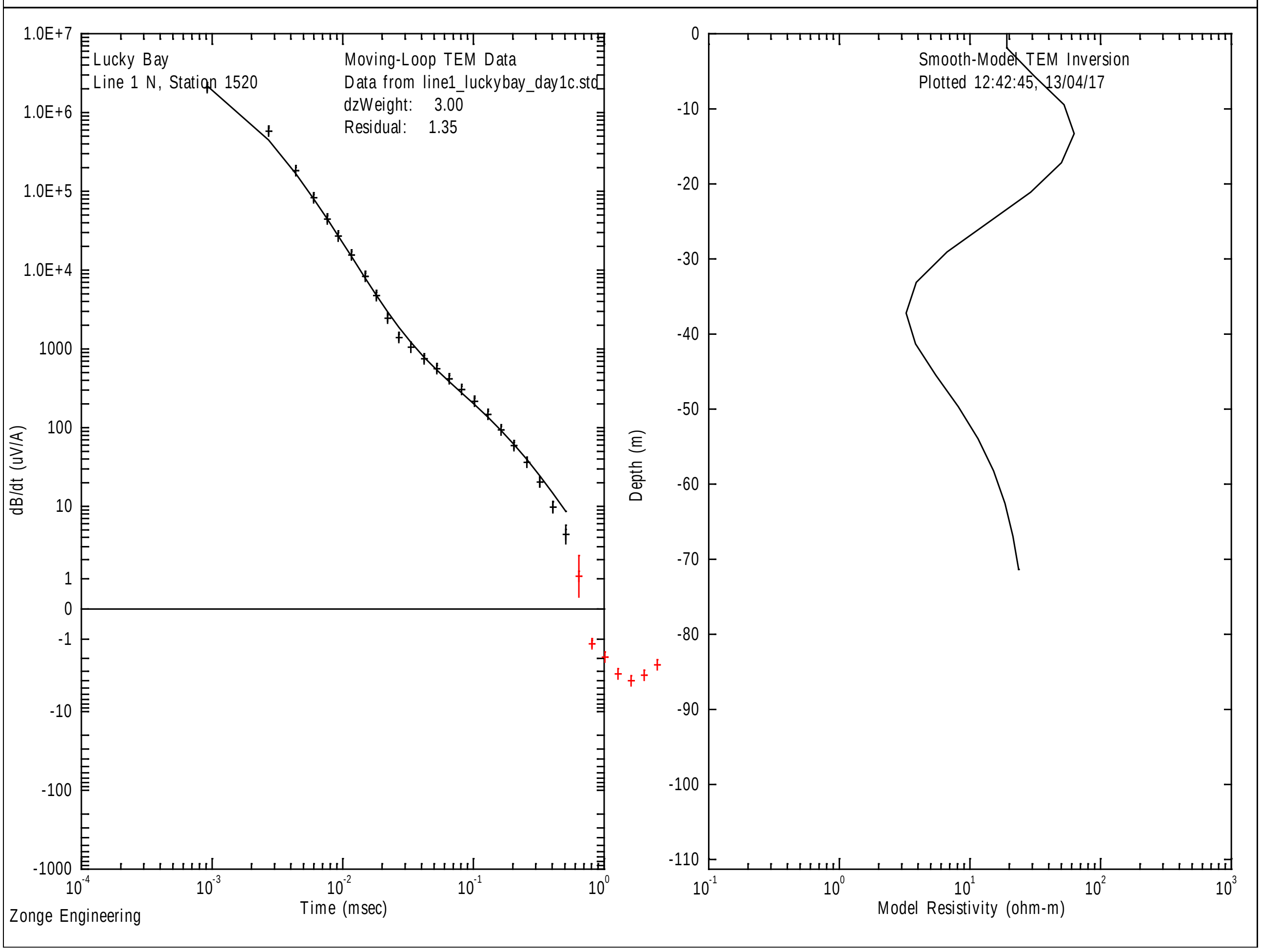

Lucky Bay
Line 1 N, Station 1330
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.62
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

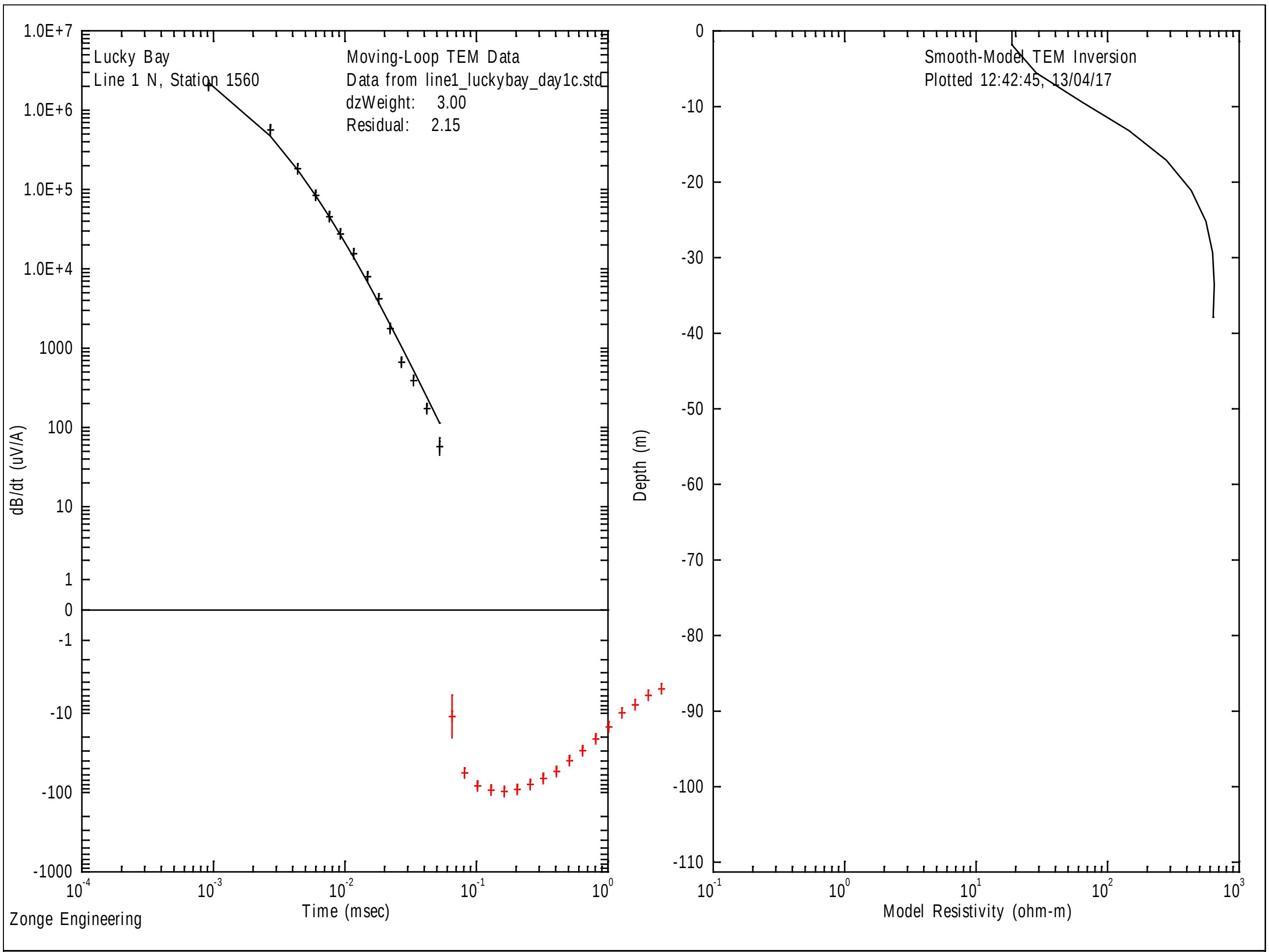

Lucky Bay
Line 1 N, Station 1370
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.86
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

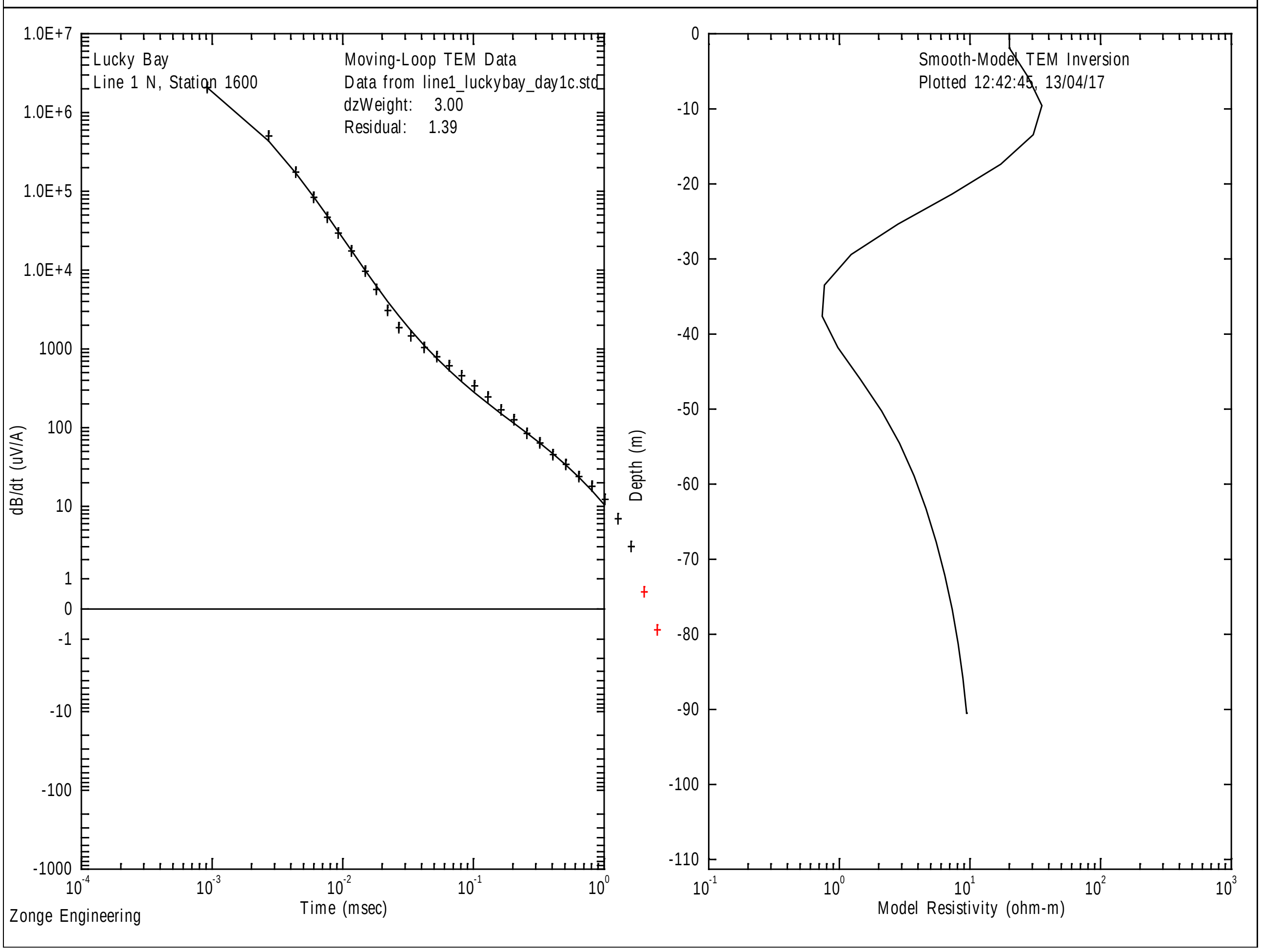

Lucky Bay
Line 1 N, Station 1400
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 2.38
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

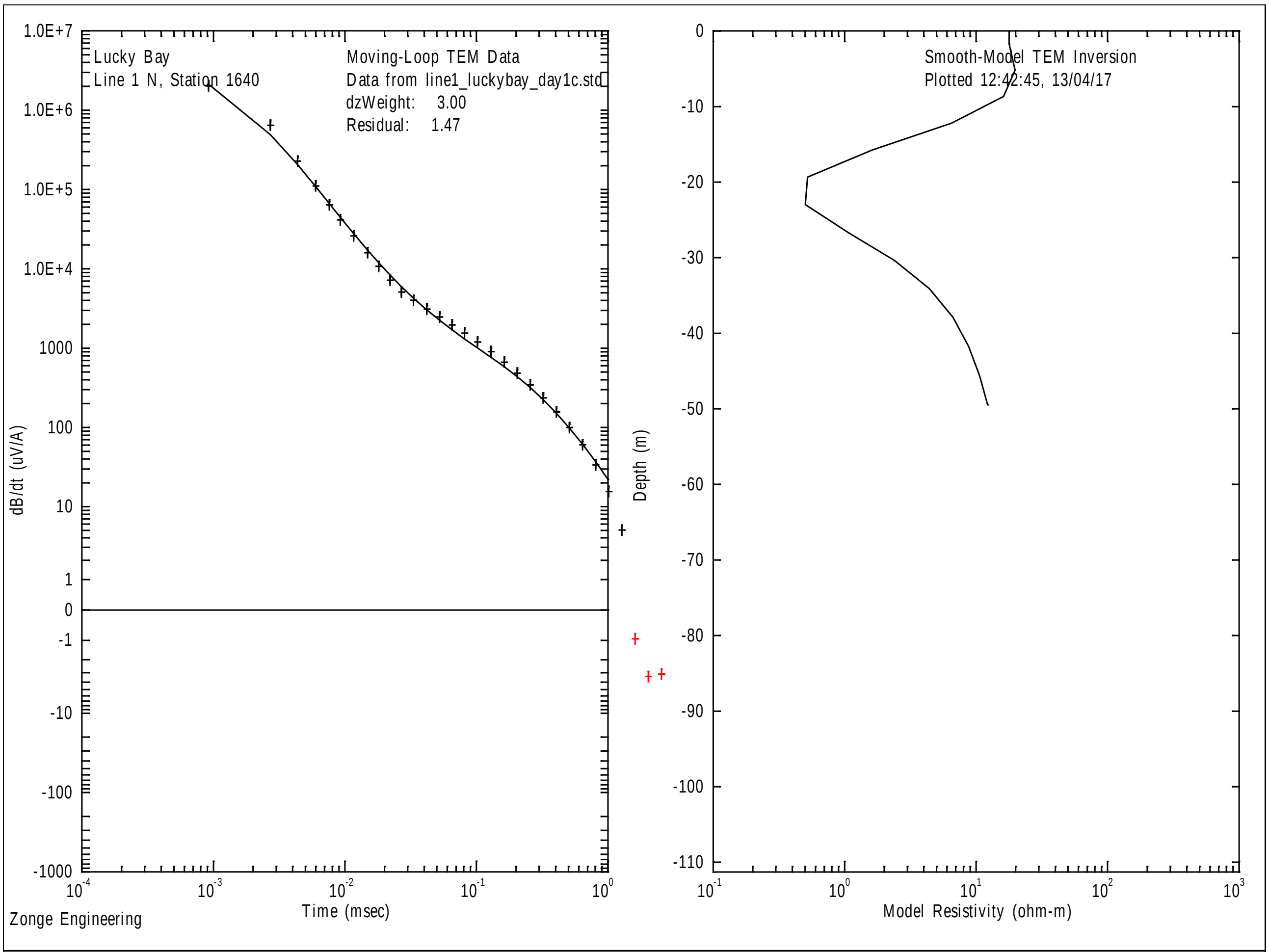

Lucky Bay
Line 1 N, Station 1440
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.89
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

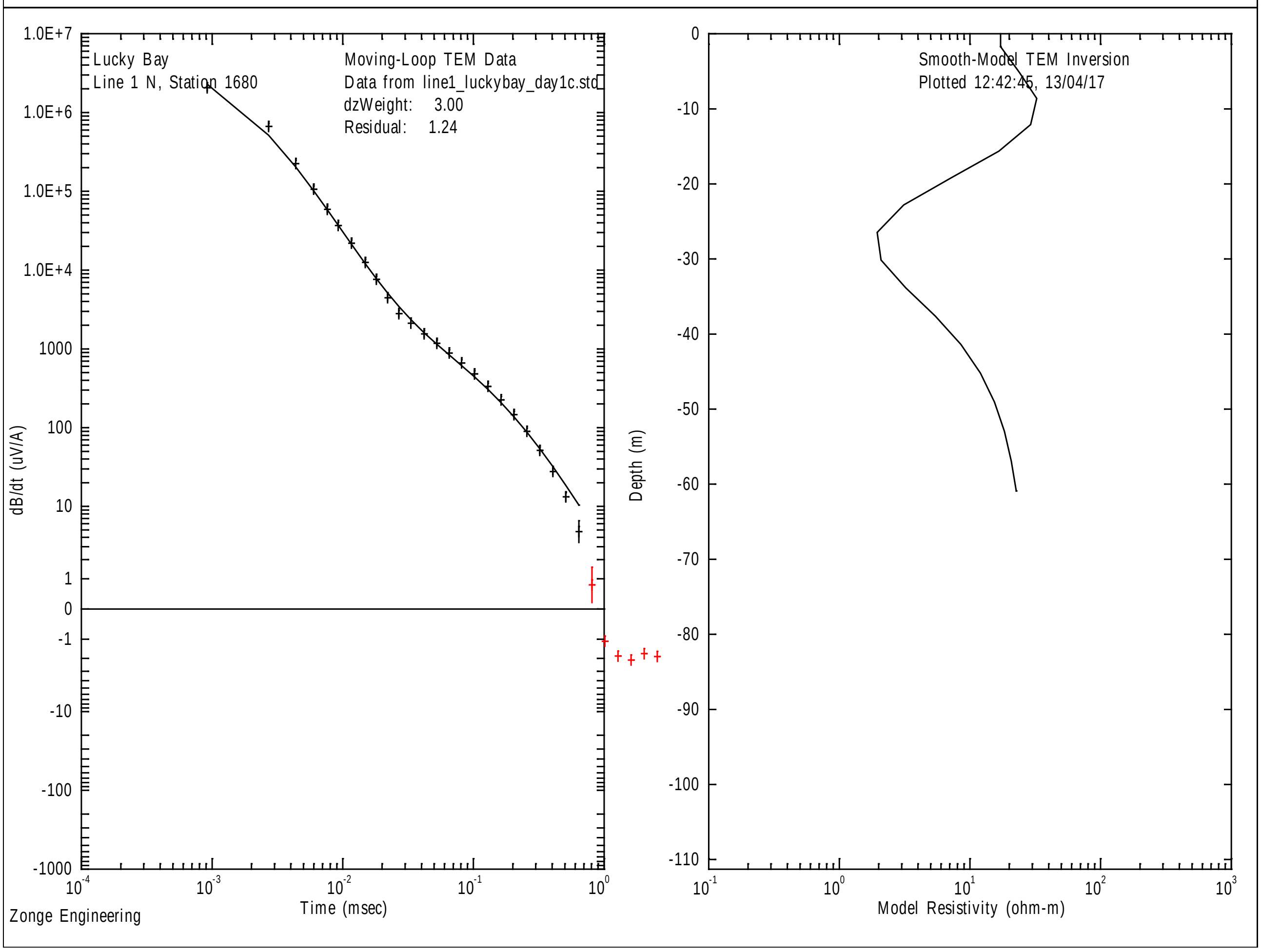

Lucky Bay
Line 1 N, Station 1480
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.14
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

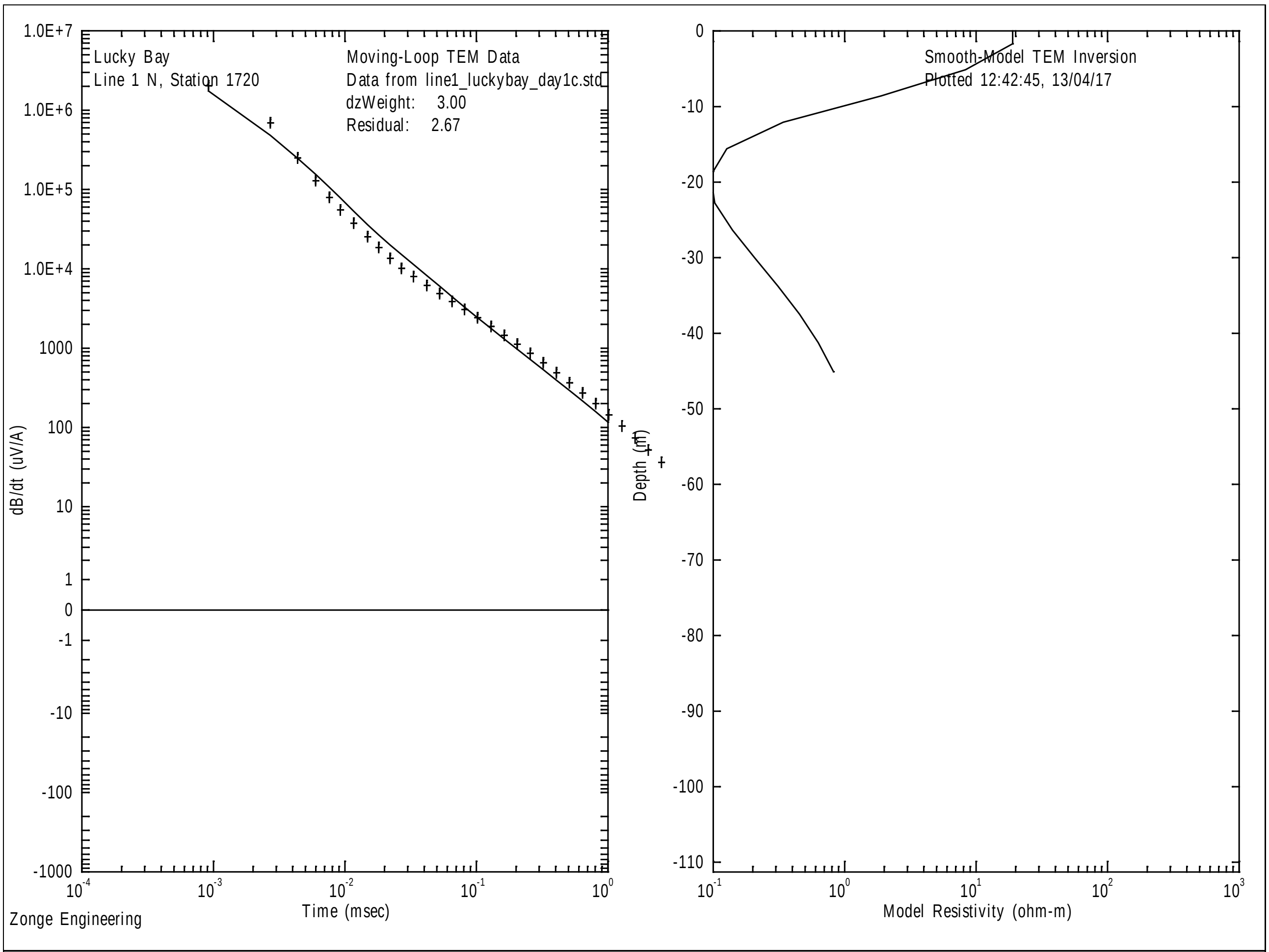

Lucky Bay
Line 1 N, Station 1520
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.35
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

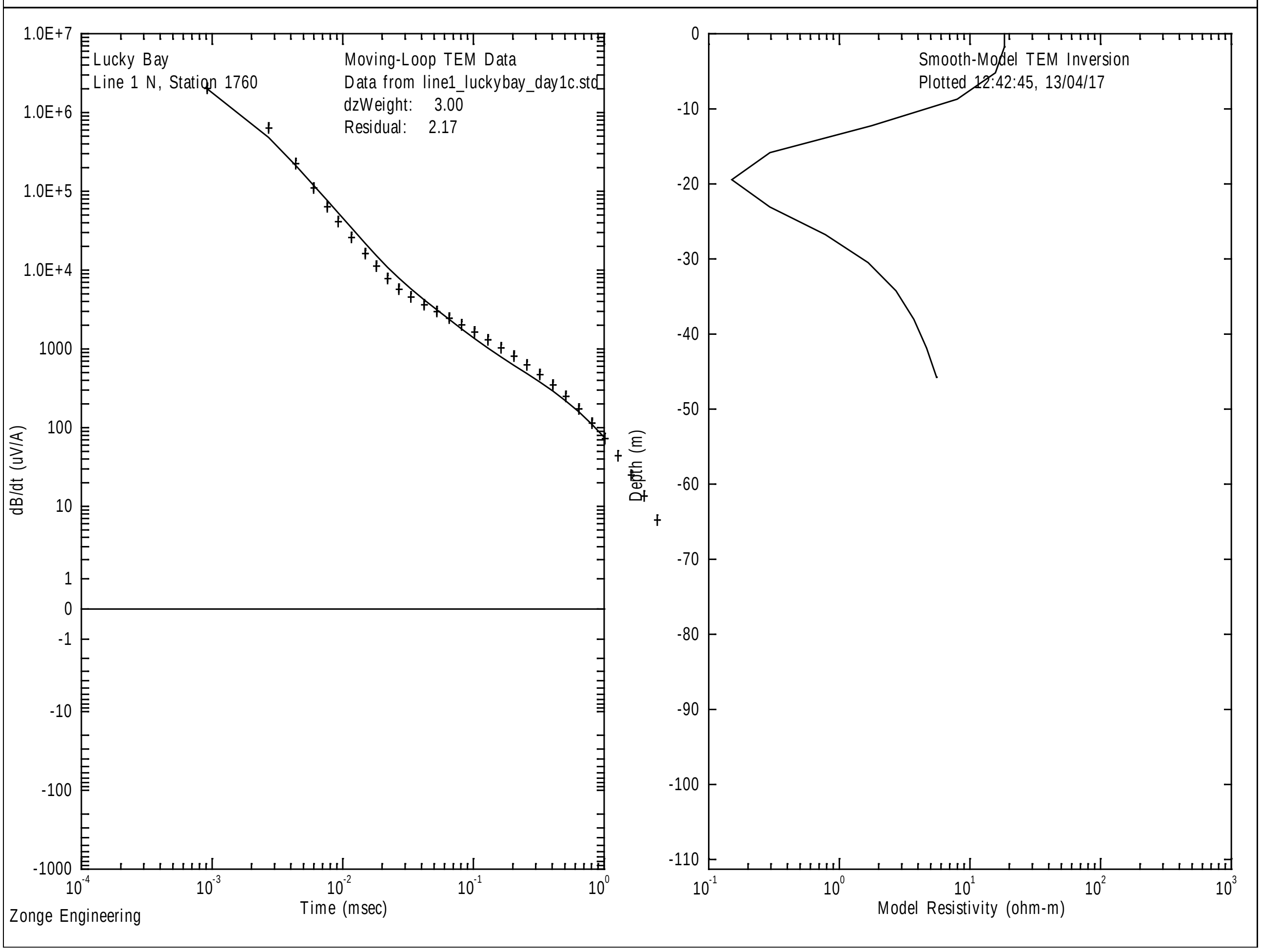

Lucky Bay
Line 1 N, Station 1560
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 2.15
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

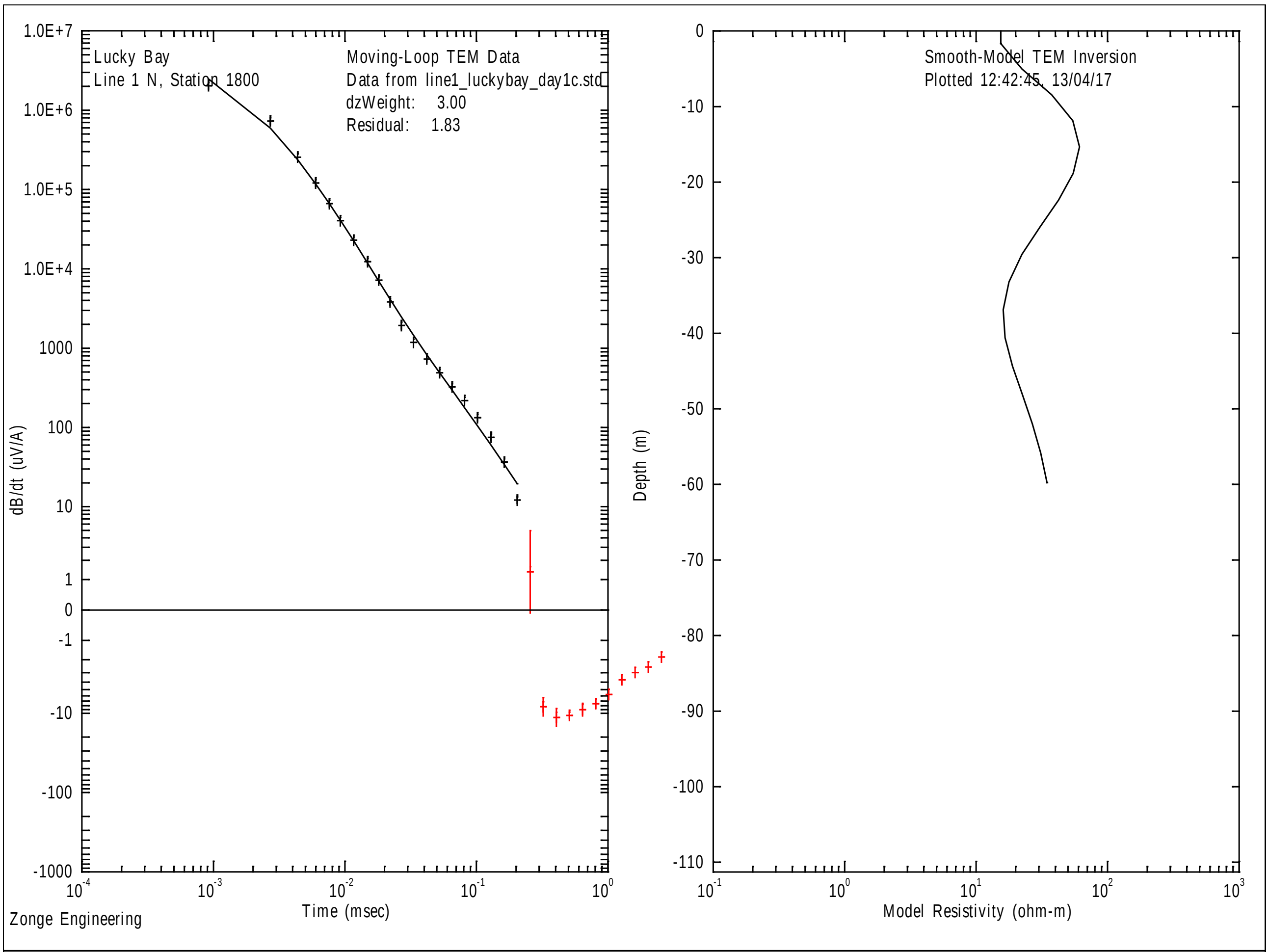

Lucky Bay
Line 1 N, Station 1600
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.39
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

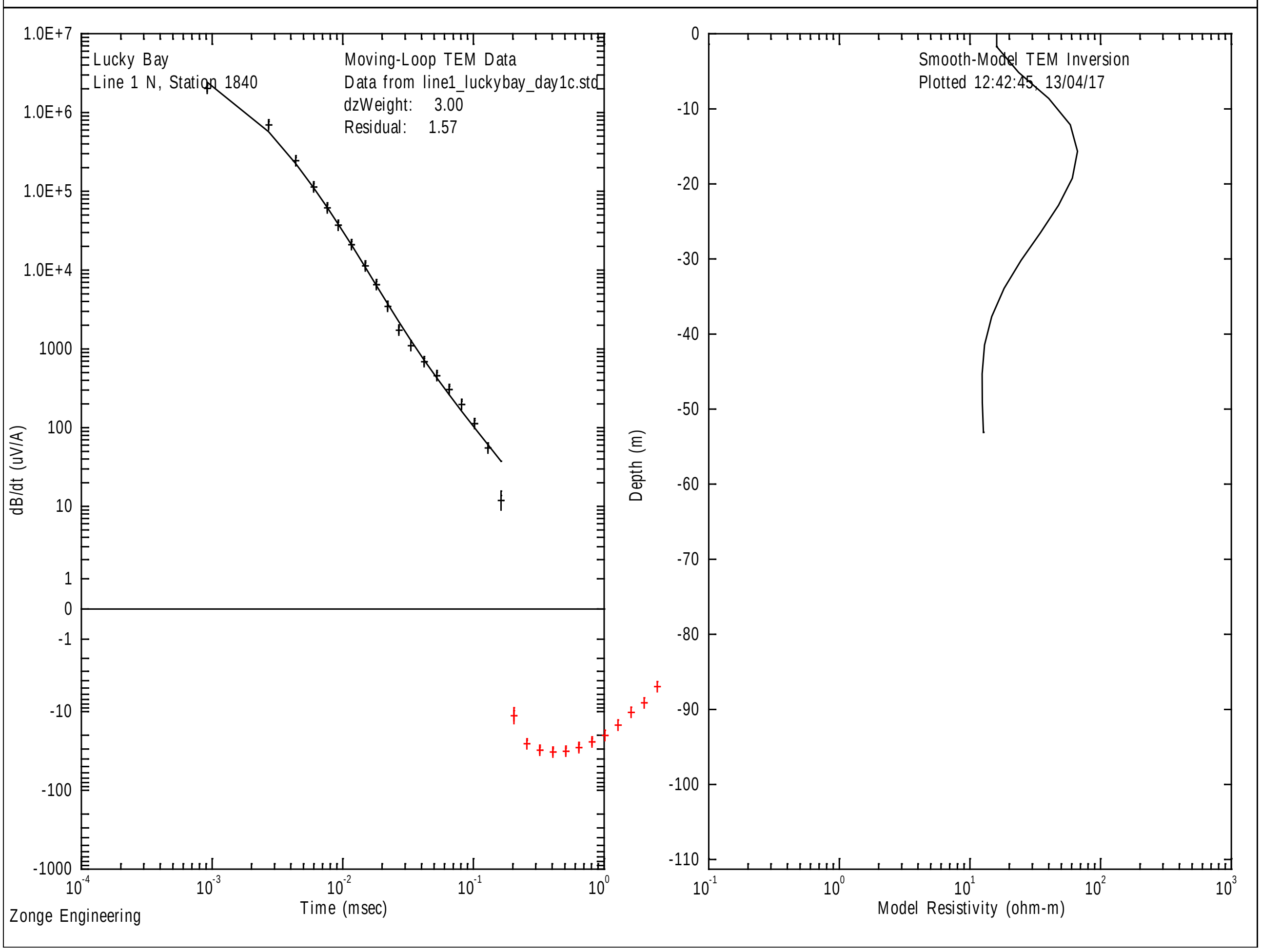

Lucky Bay
Line 1 N, Station 1640
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.47
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

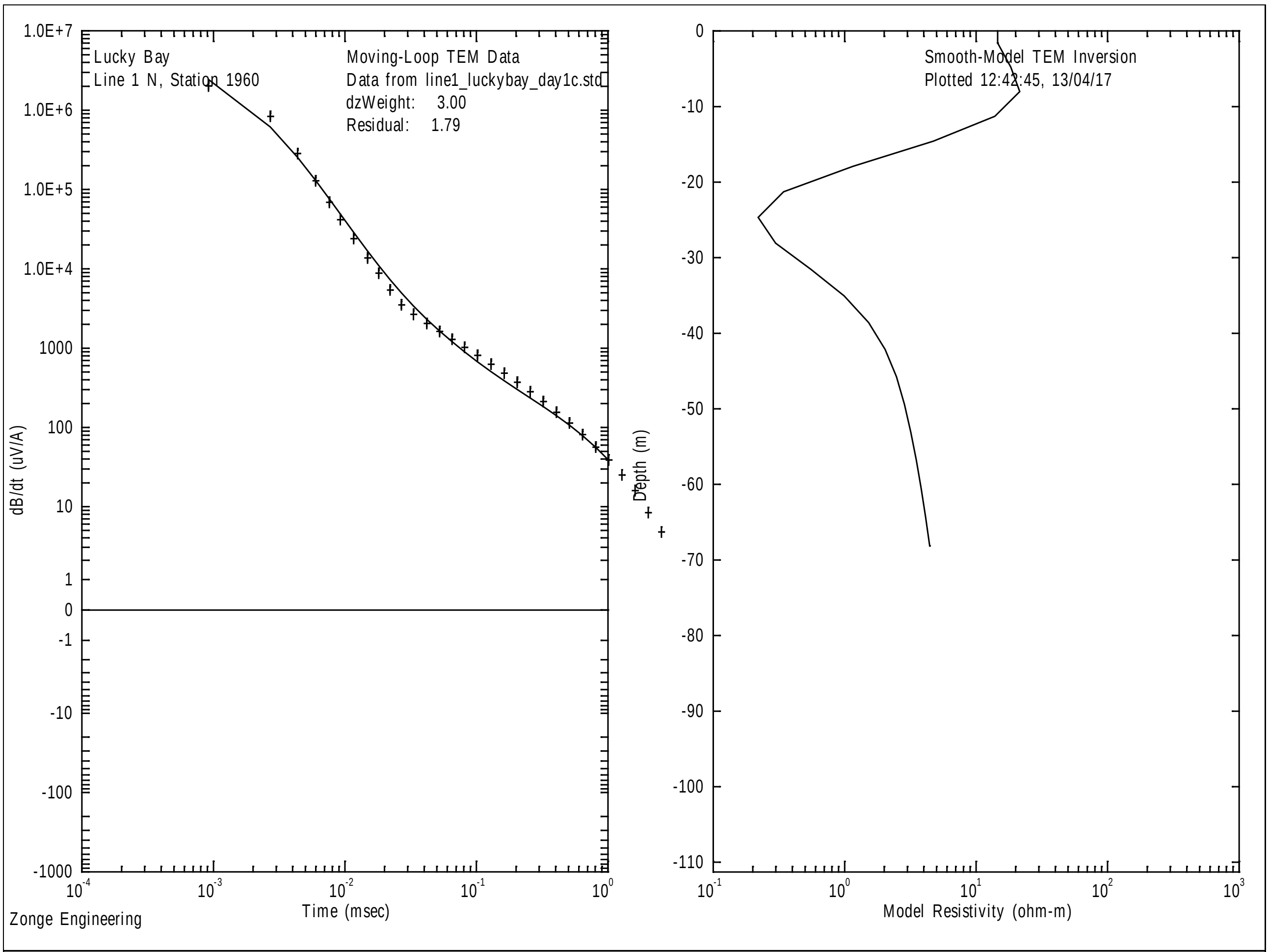

Lucky Bay
Line 1 N, Station 1680
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.24
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

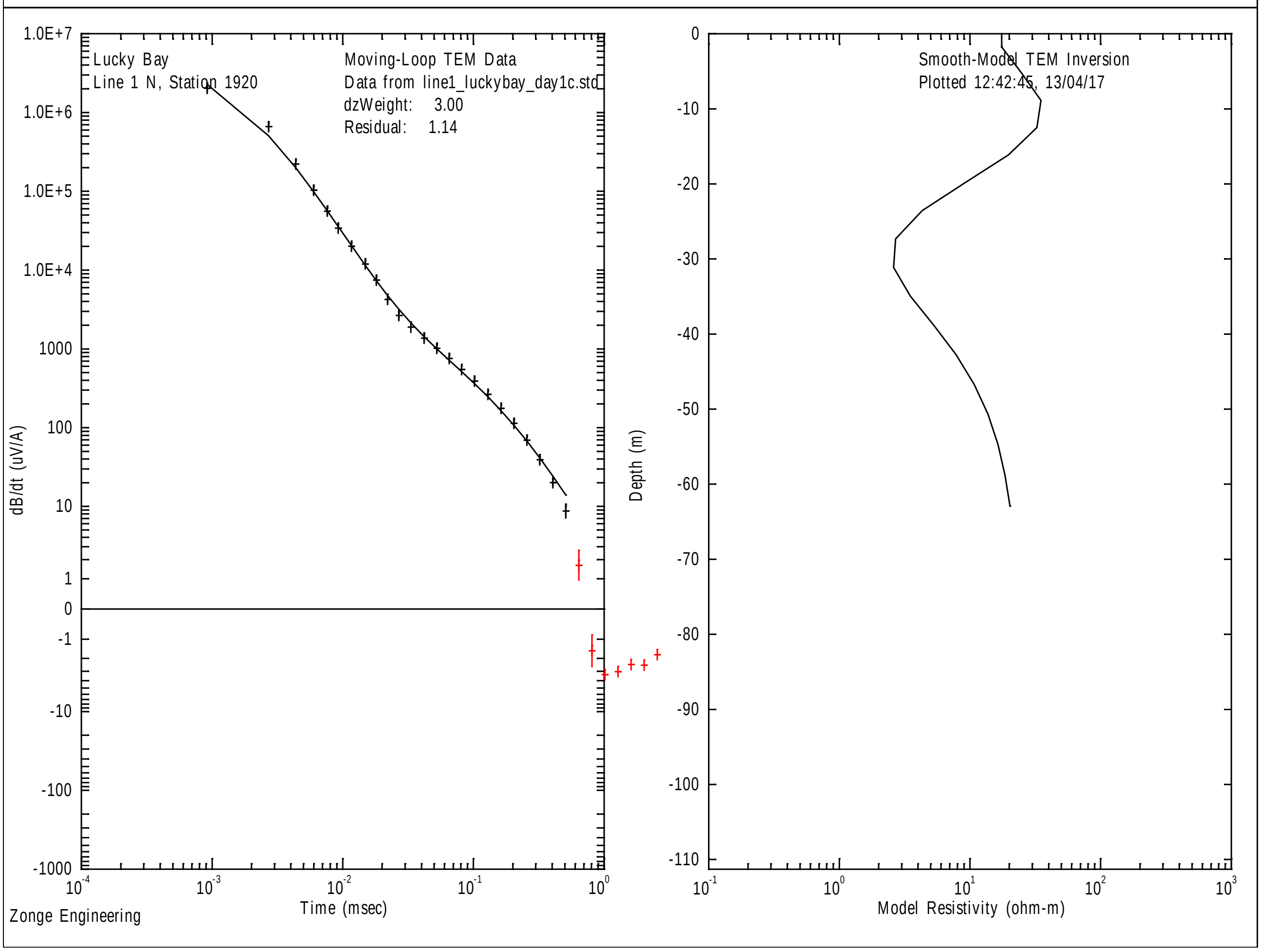

Lucky Bay
Line 1 N, Station 1720
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 2.67
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

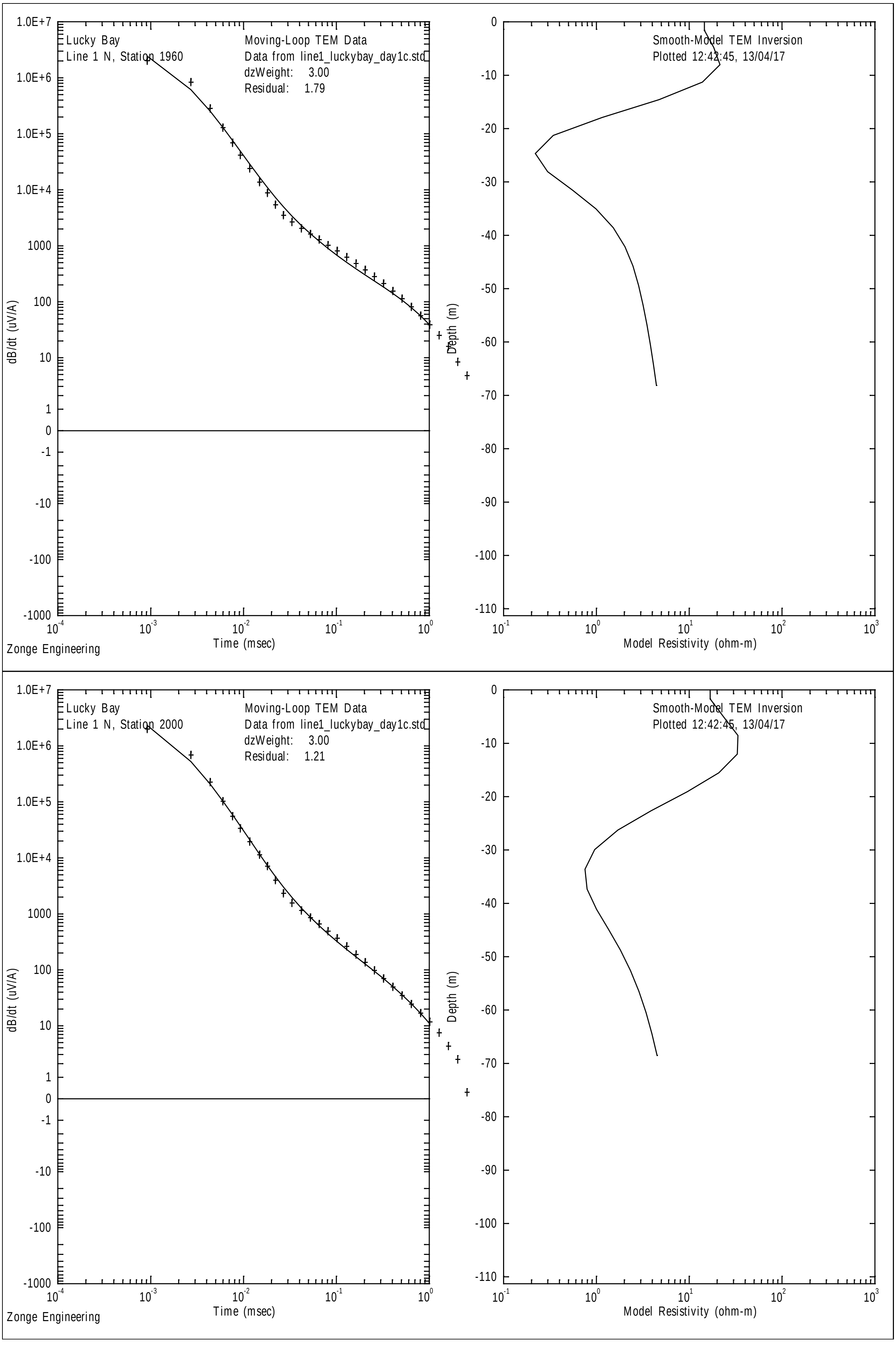

Lucky Bay
Line 1 N, Station 1760
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 2.17
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

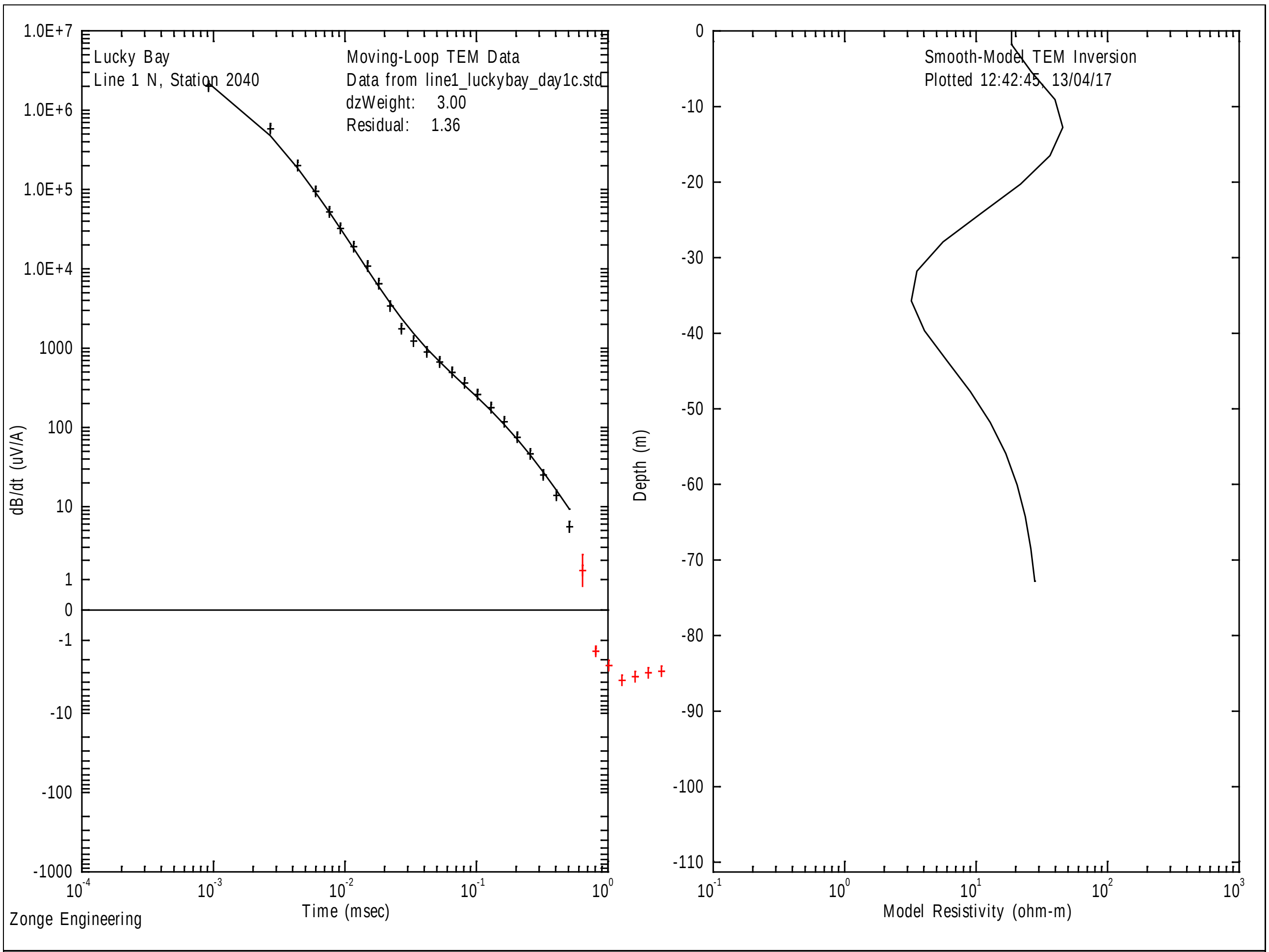

Lucky Bay
Line 1 N, Station 1800
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.83
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

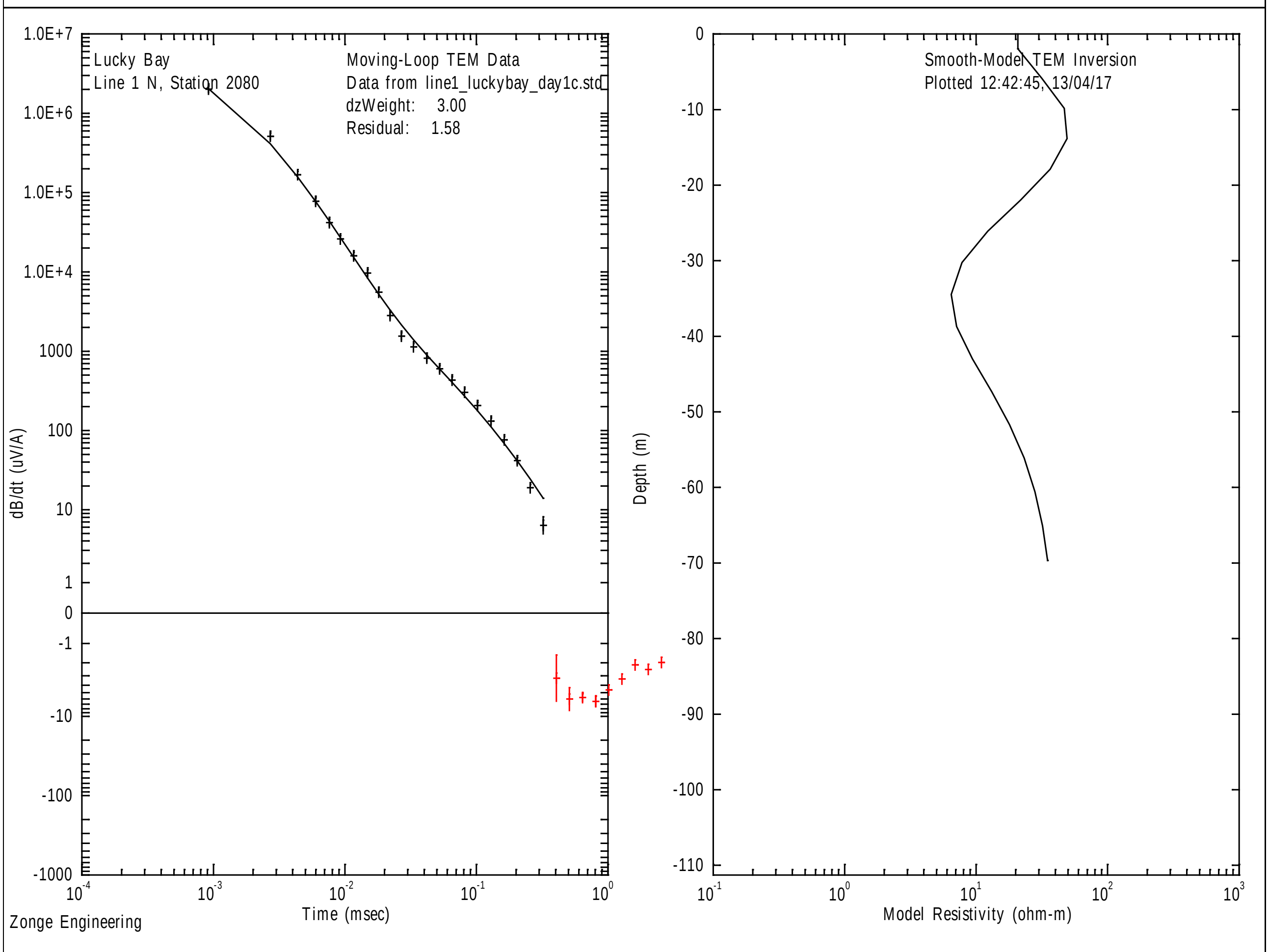

Lucky Bay
Line 1 N, Station 1840
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.57
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

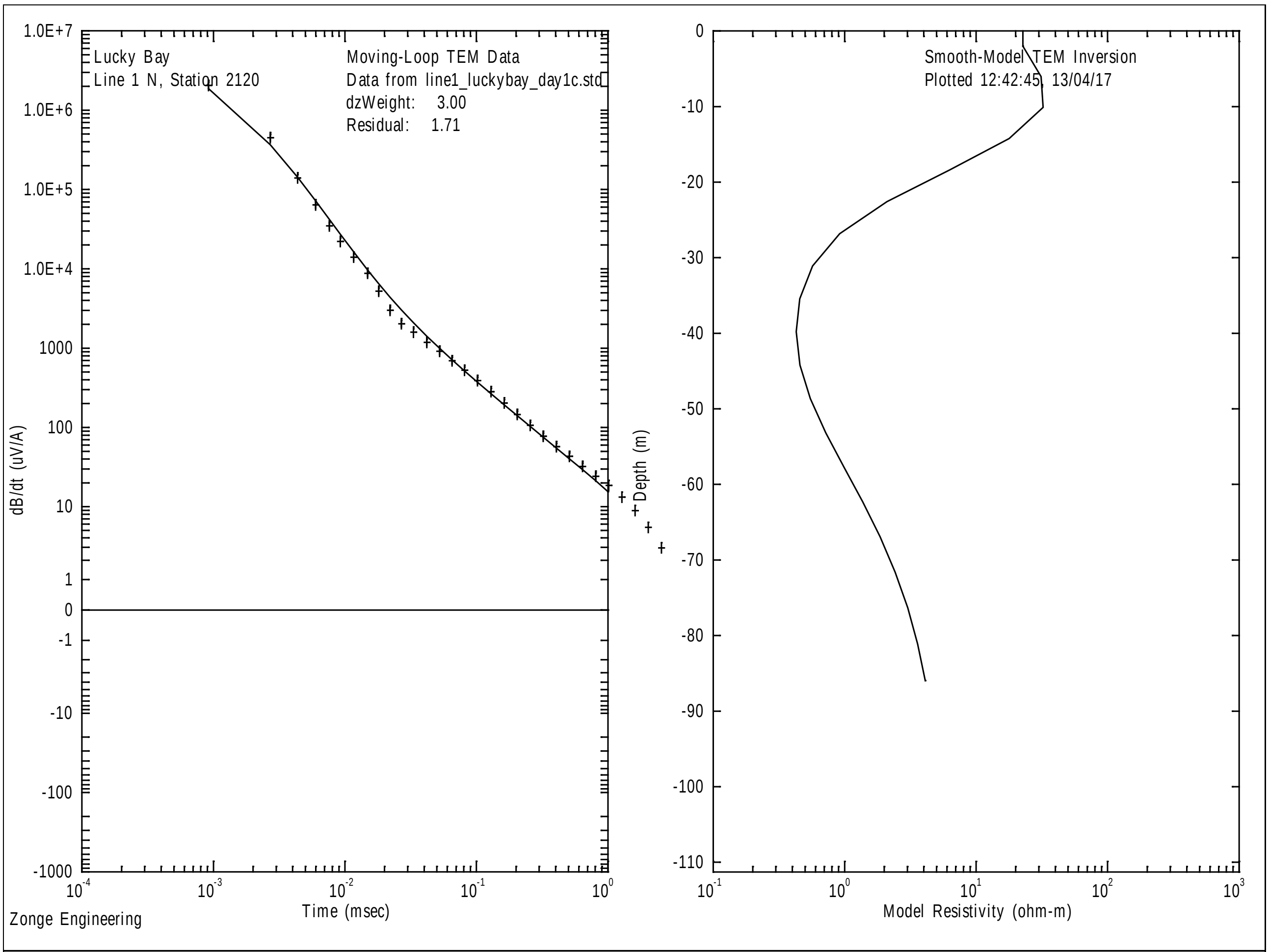

Lucky Bay
Line 1 N, Station 1960
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.79
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

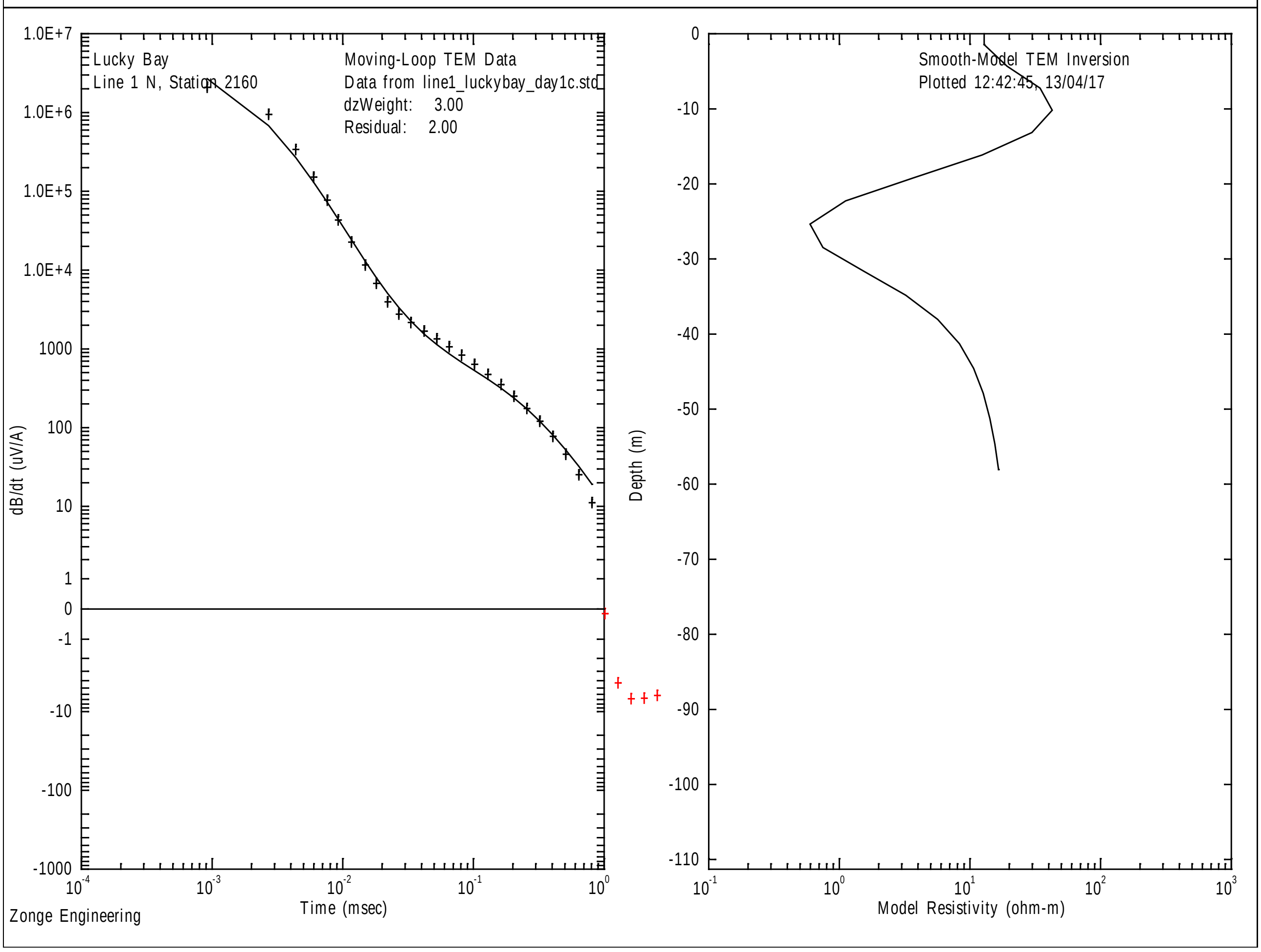

Lucky Bay
Line 1 N, Station 1920
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.14
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

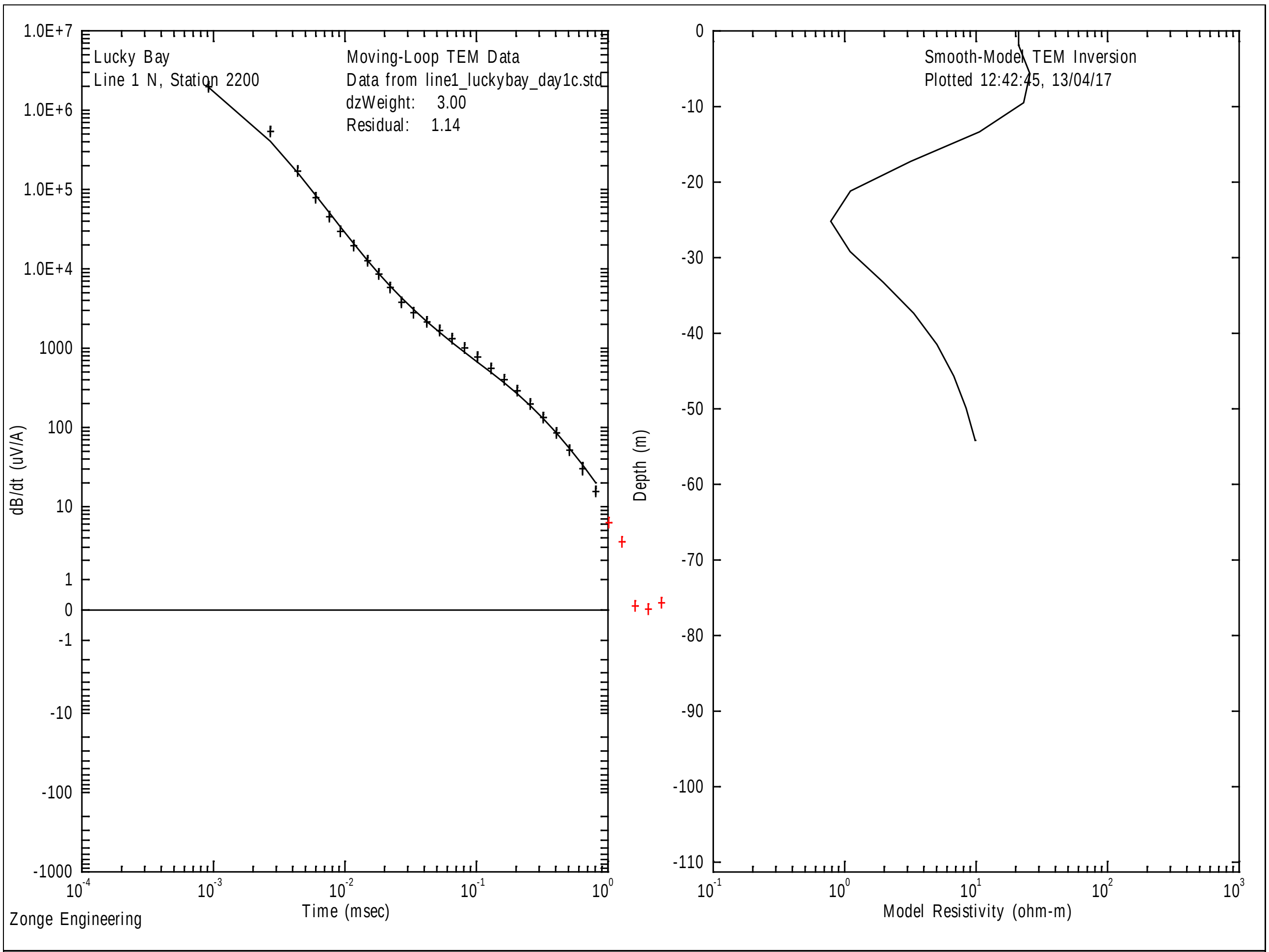

Lucky Bay
Line 1 N, Station 1960
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.79
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)
Lucky Bay
Line 1 N, Station 2000
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.21
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

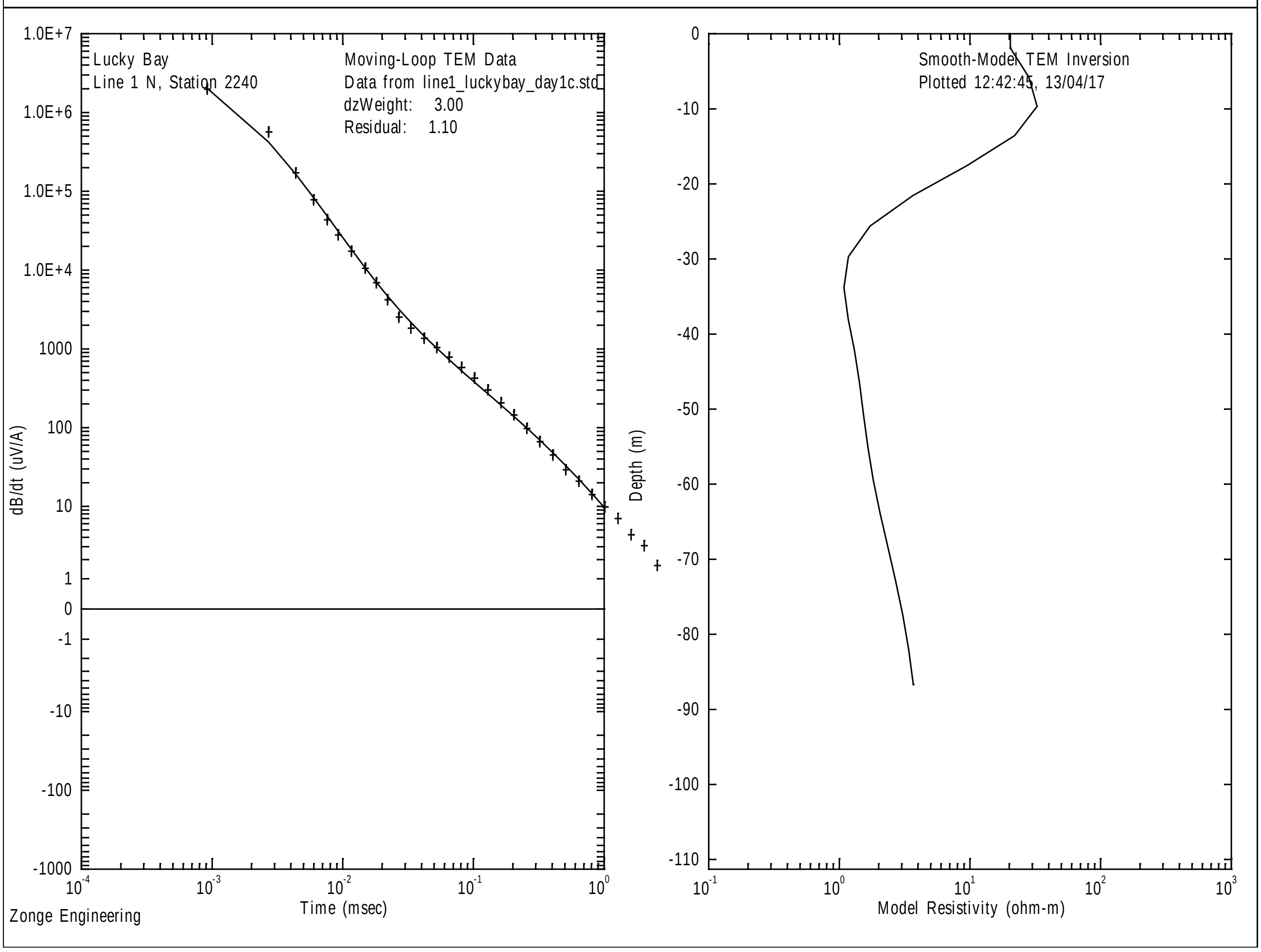

Lucky Bay
Line 1 N, Station 2040
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.36
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

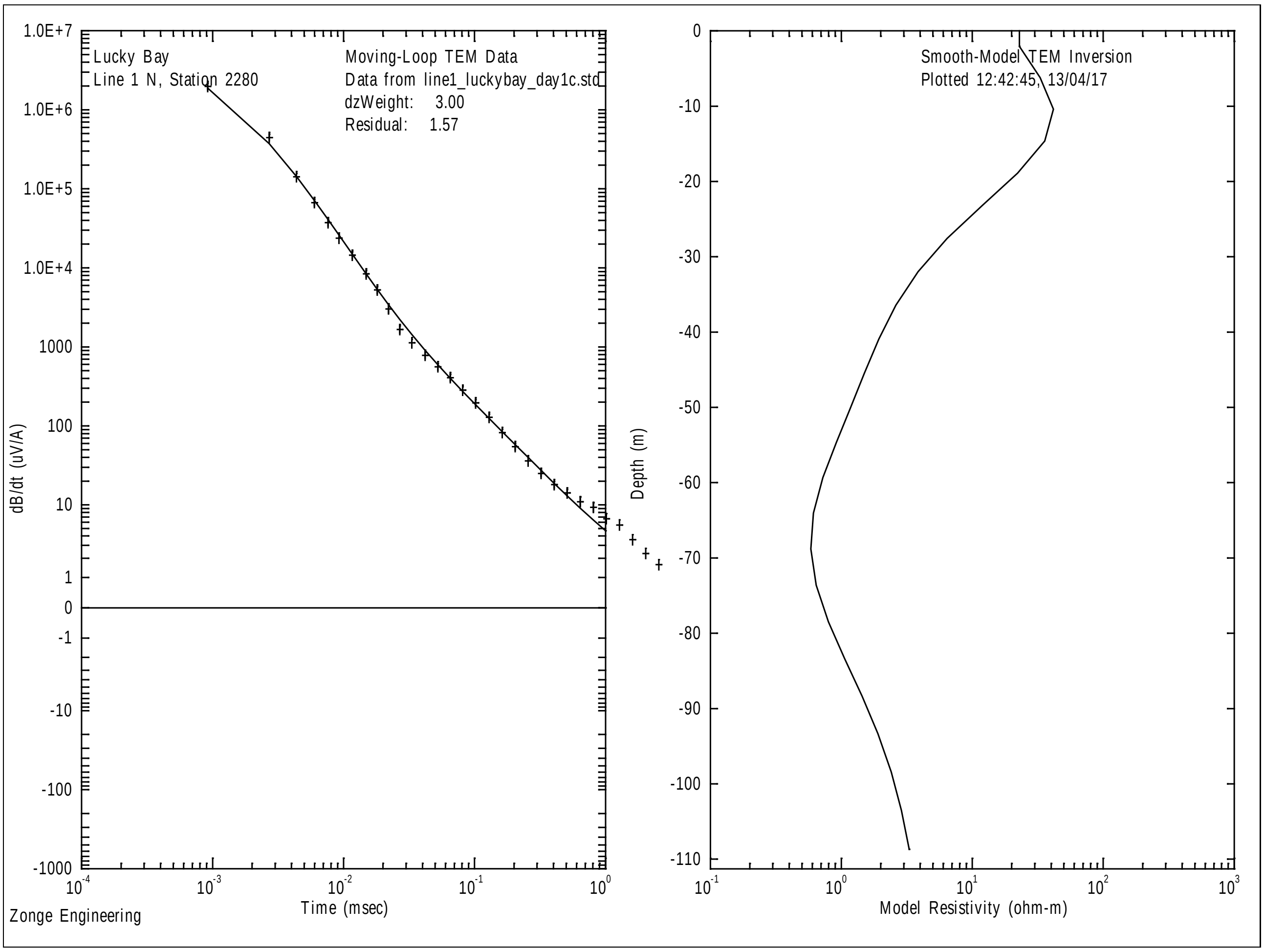

Lucky Bay
Line 1 N, Station 2080
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.58
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
Line 1 N, Station 2120
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.71
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
Line 1 N, Station 2160
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 2.00
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

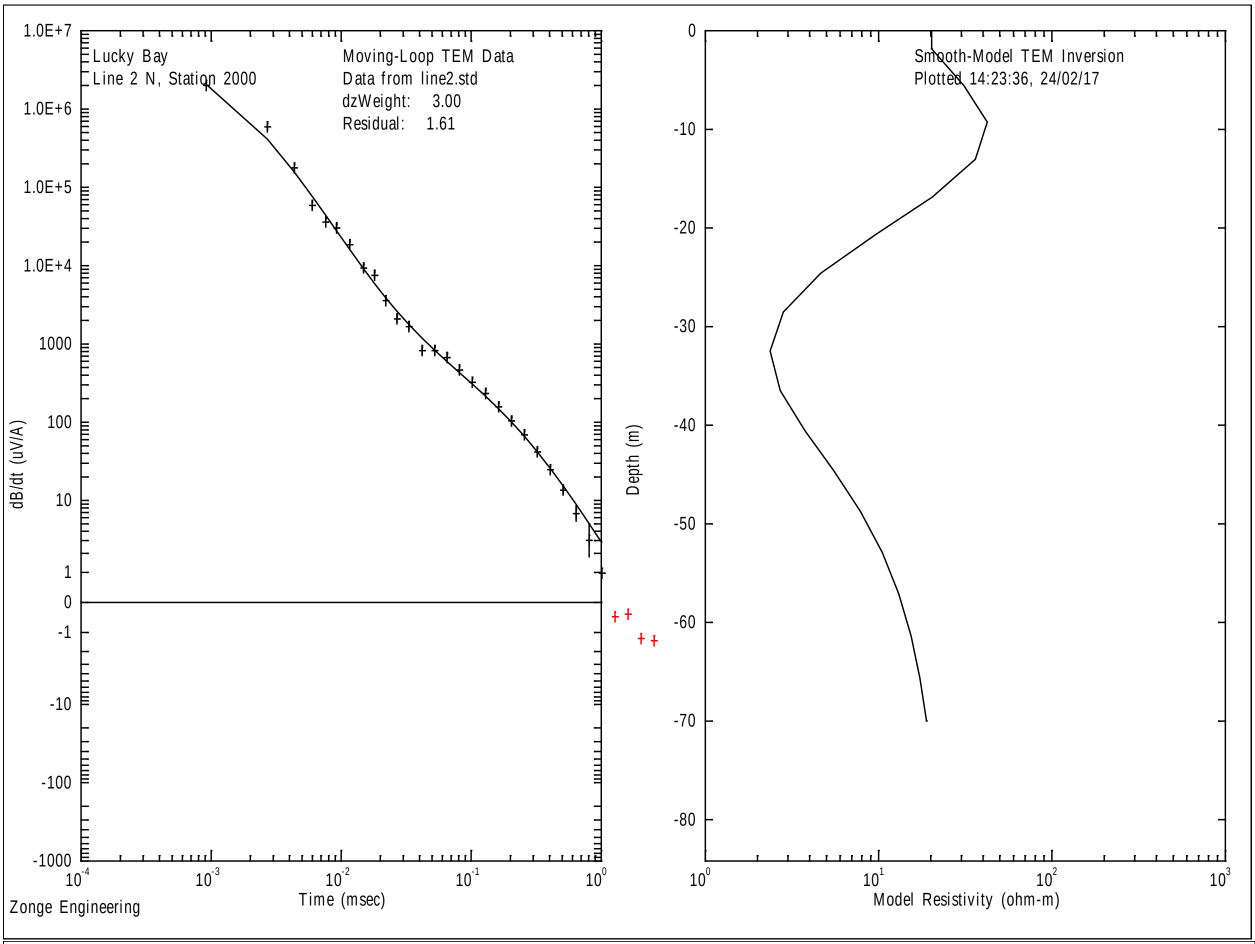

Lucky Bay
Line 1 N, Station 2200
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.14
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

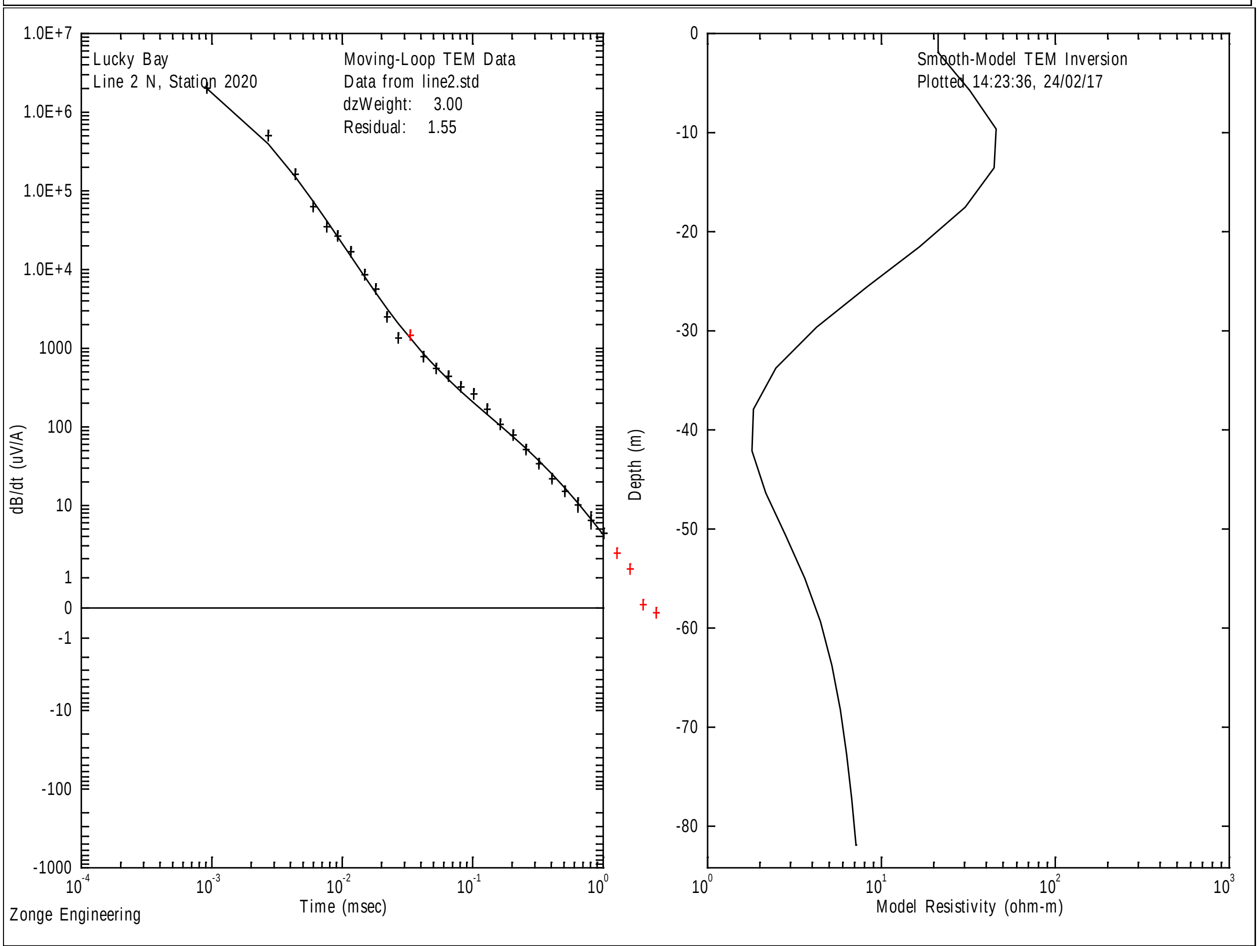

Lucky Bay
Line 1 N, Station 2240
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.10
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

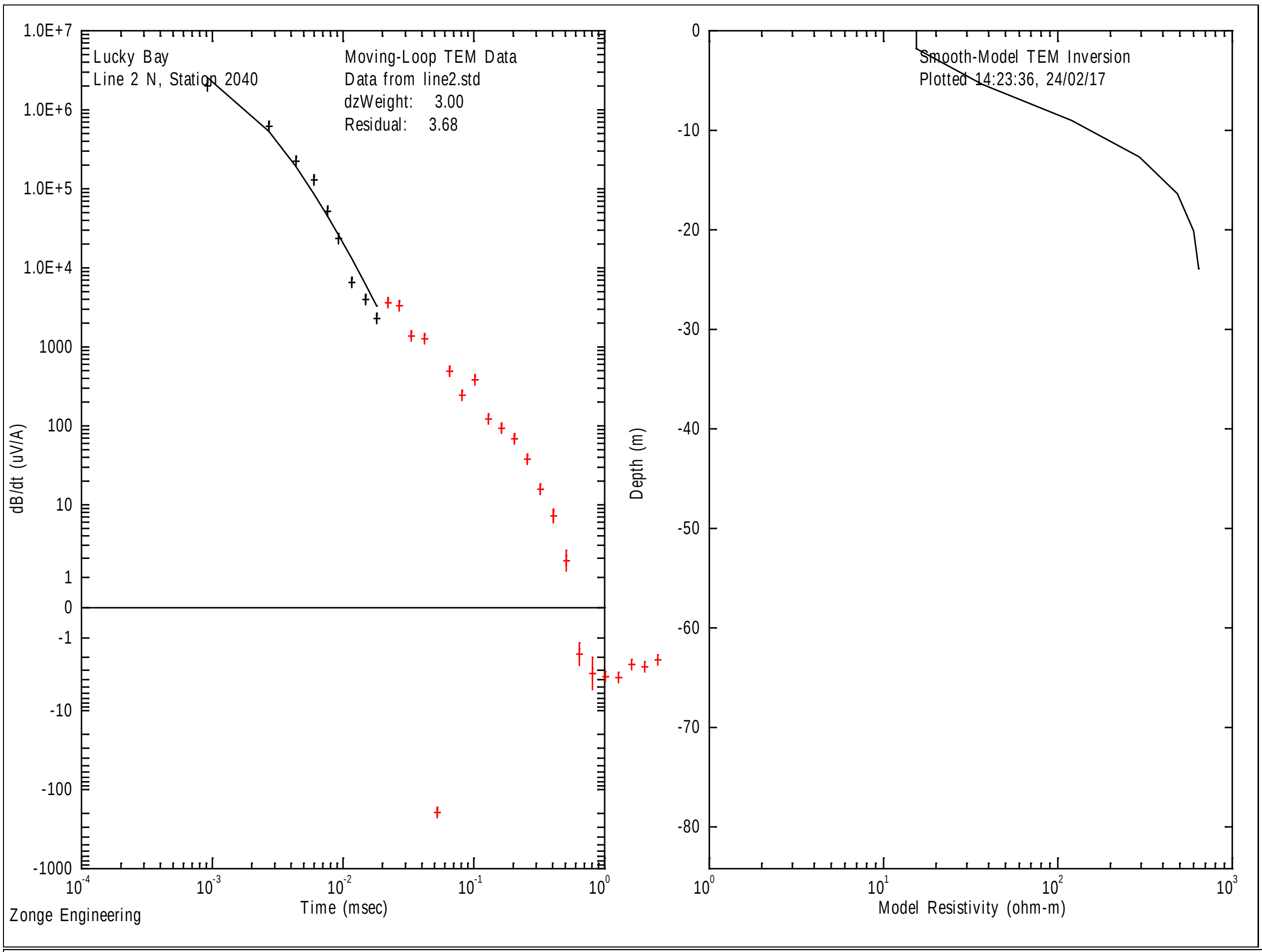


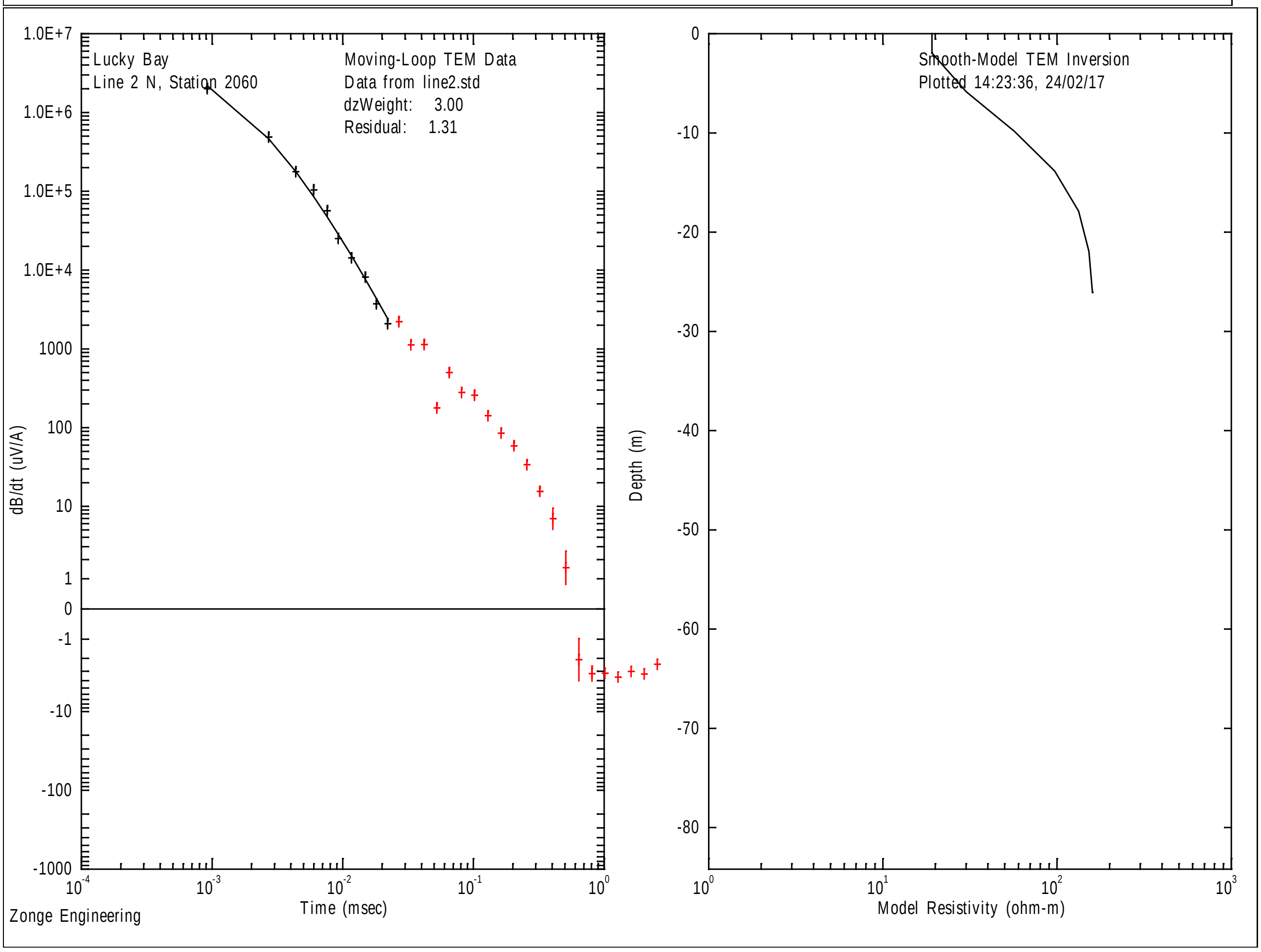
Lucky Bay
Line 1 N, Station 2280
Moving-Loop TEM Data
Data from line1_luckybay_day1c.std
dzWeight: 3.00
Residual: 1.57
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 12:42:45, 13/04/17
Depth (m)
Model Resistivity (ohm-m)

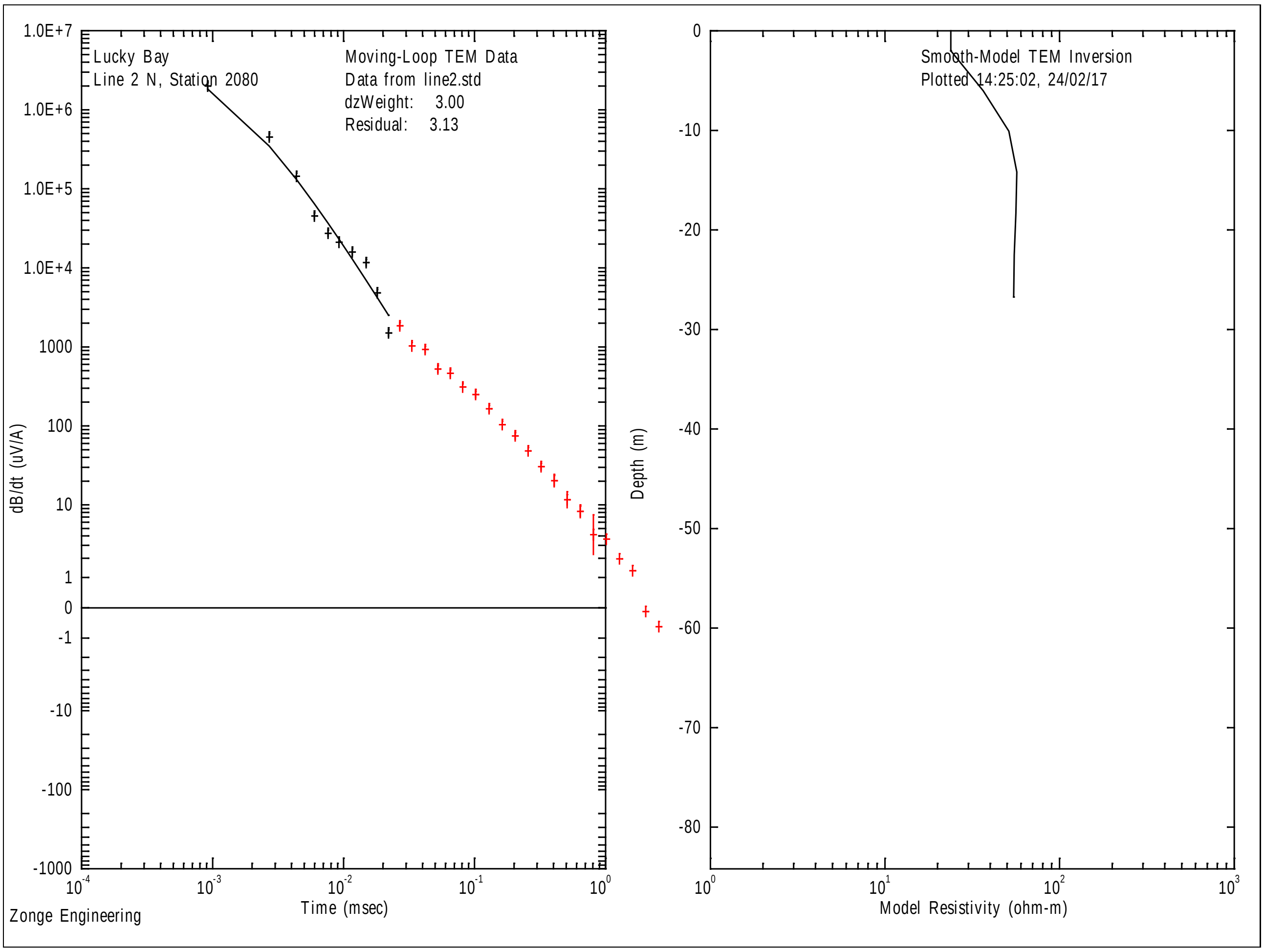
Line 2 all stations



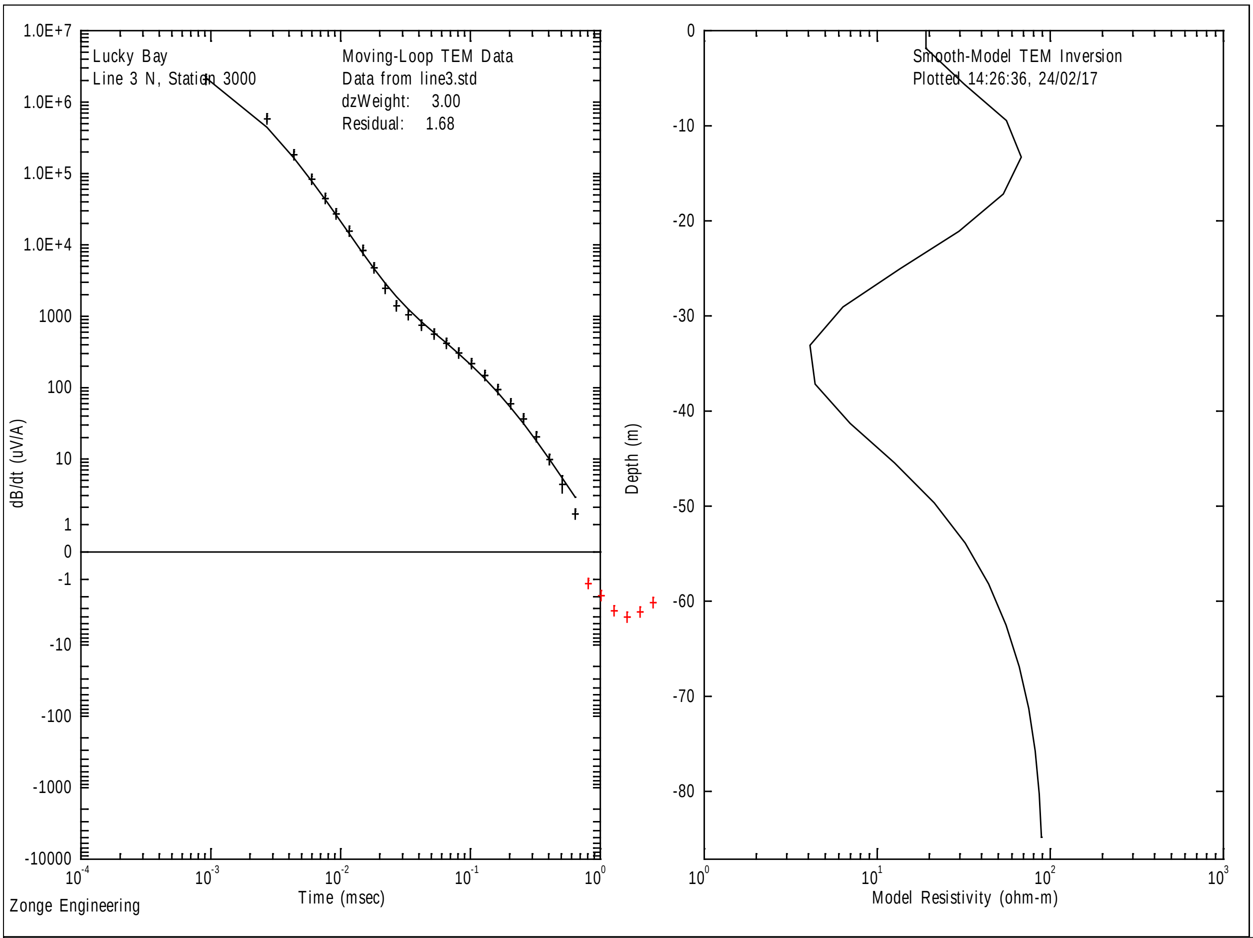


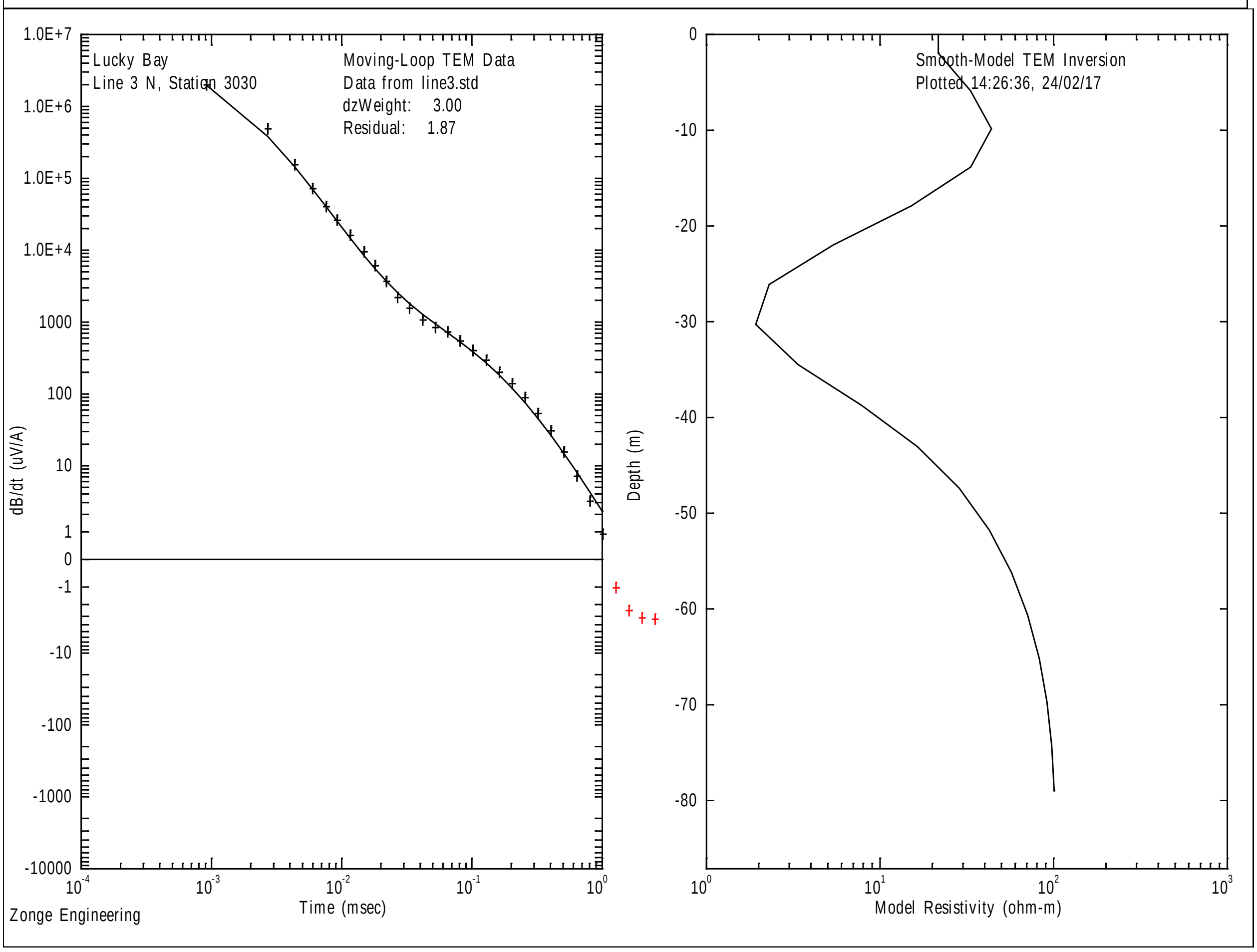

Lucky Bay
Line 2 N, Station 2040
Moving-Loop TEM Data
Data from line2.std
dzWeight: 3.00
Residual: 3.68
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:23:36, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

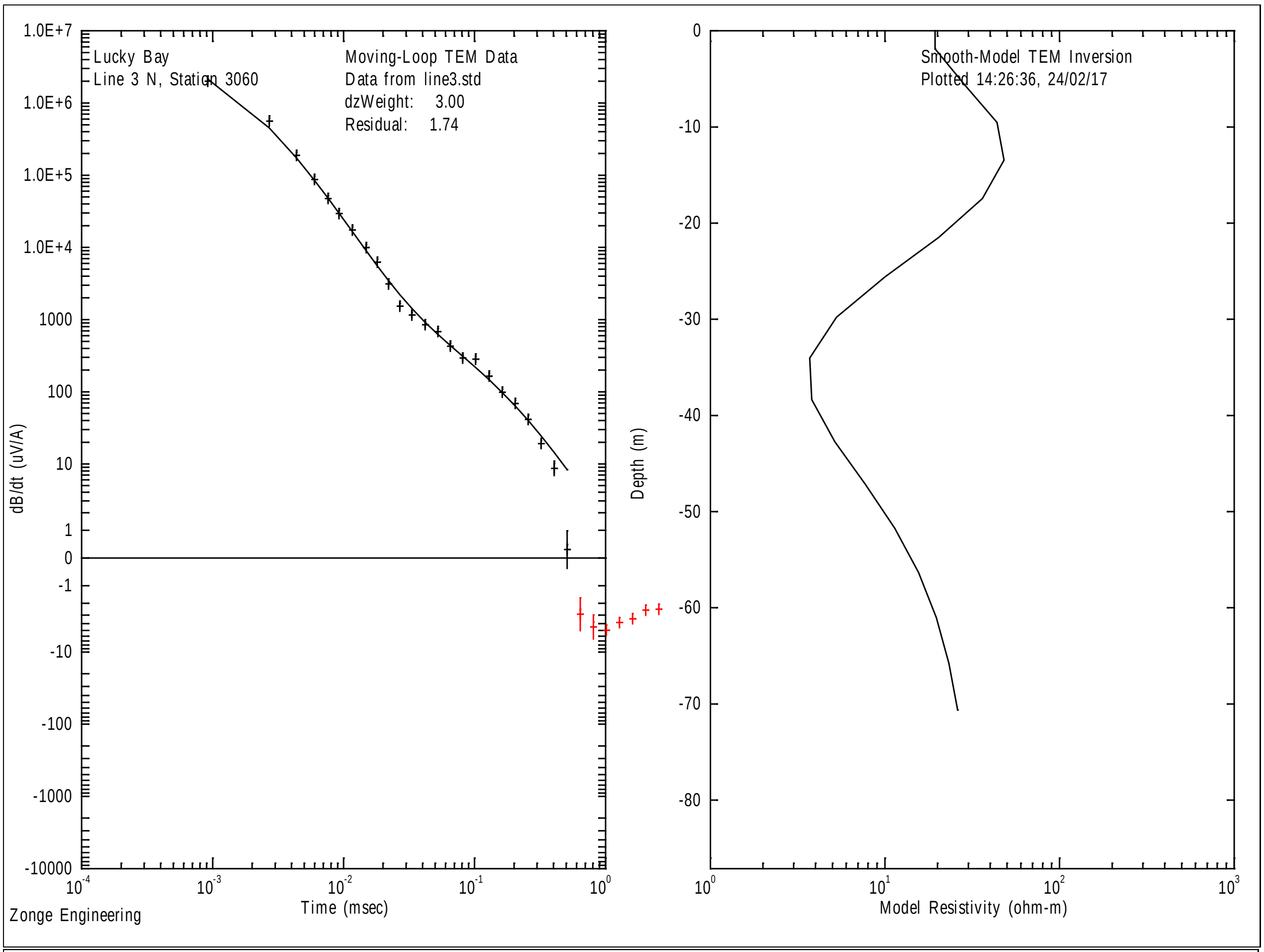

Lucky Bay
Line 2 N, Station 2060
Moving-Loop TEM Data
Data from line2.std
dzWeight: 3.00
Residual: 1.31
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:23:36, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

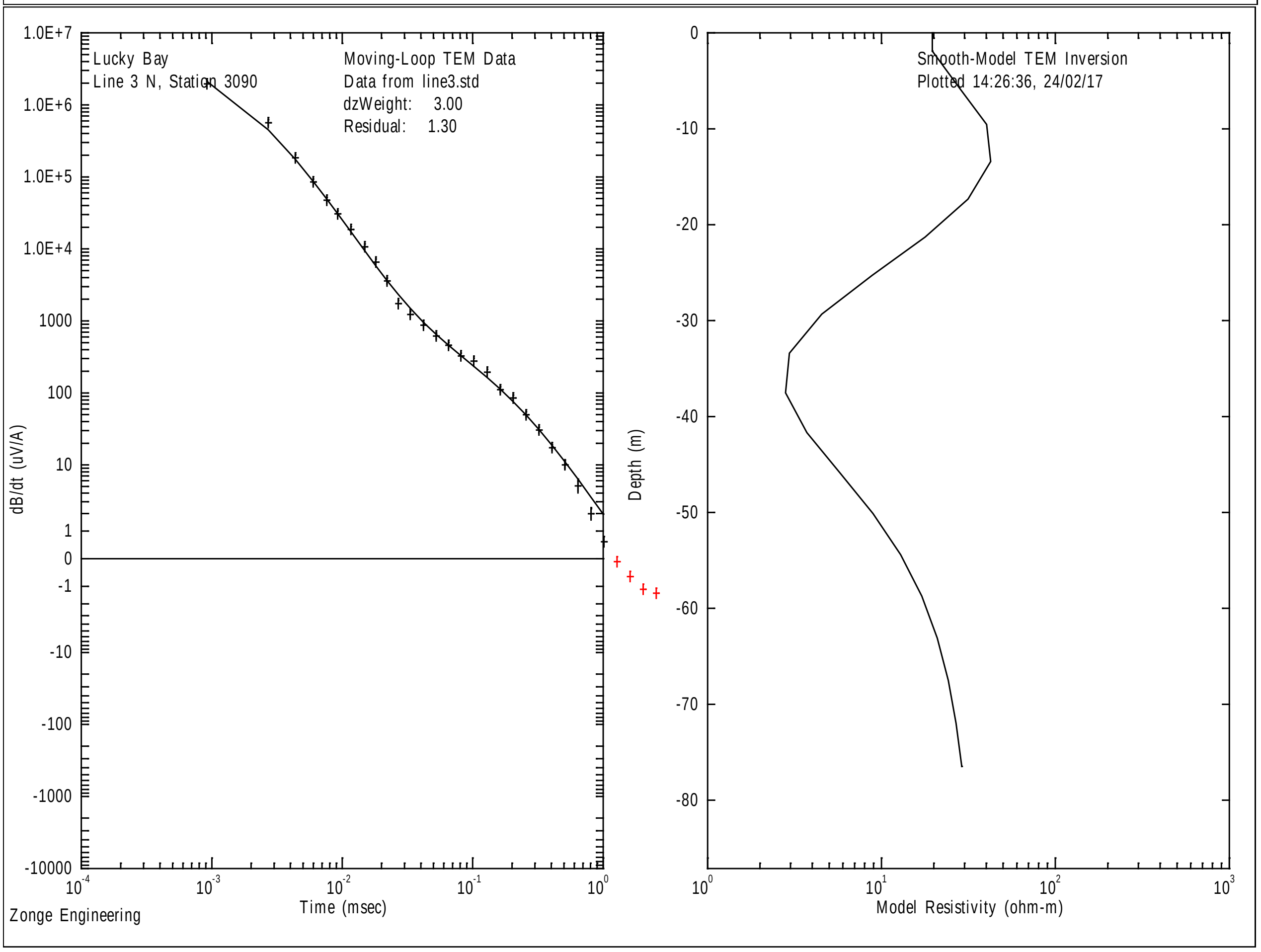

Lucky Bay
Line 2 N, Station 2080
Moving-Loop TEM Data
Data from line2.std
dzWeight: 3.00
Residual: 3.13
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:25:02, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

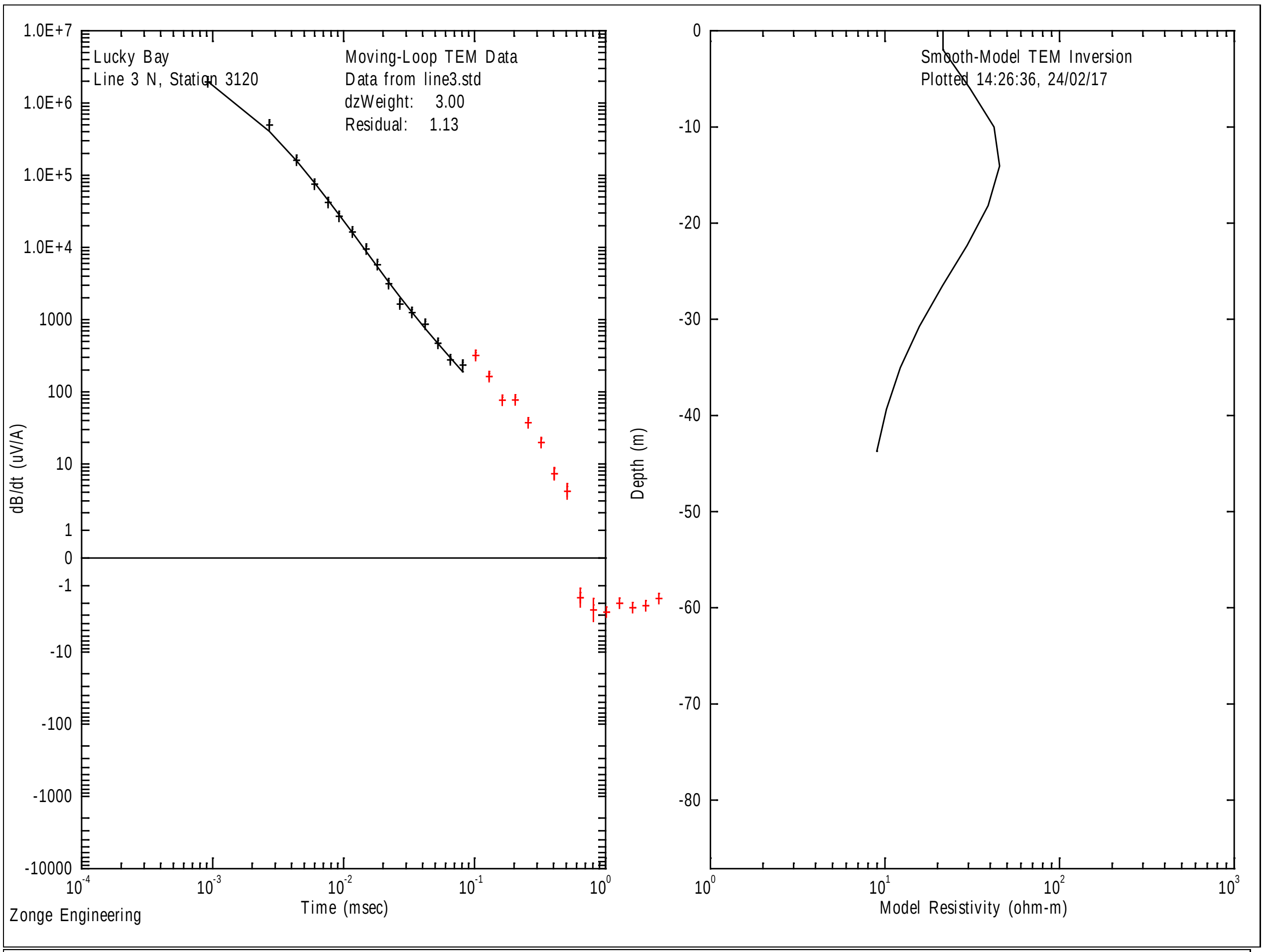
Line 3 all stations

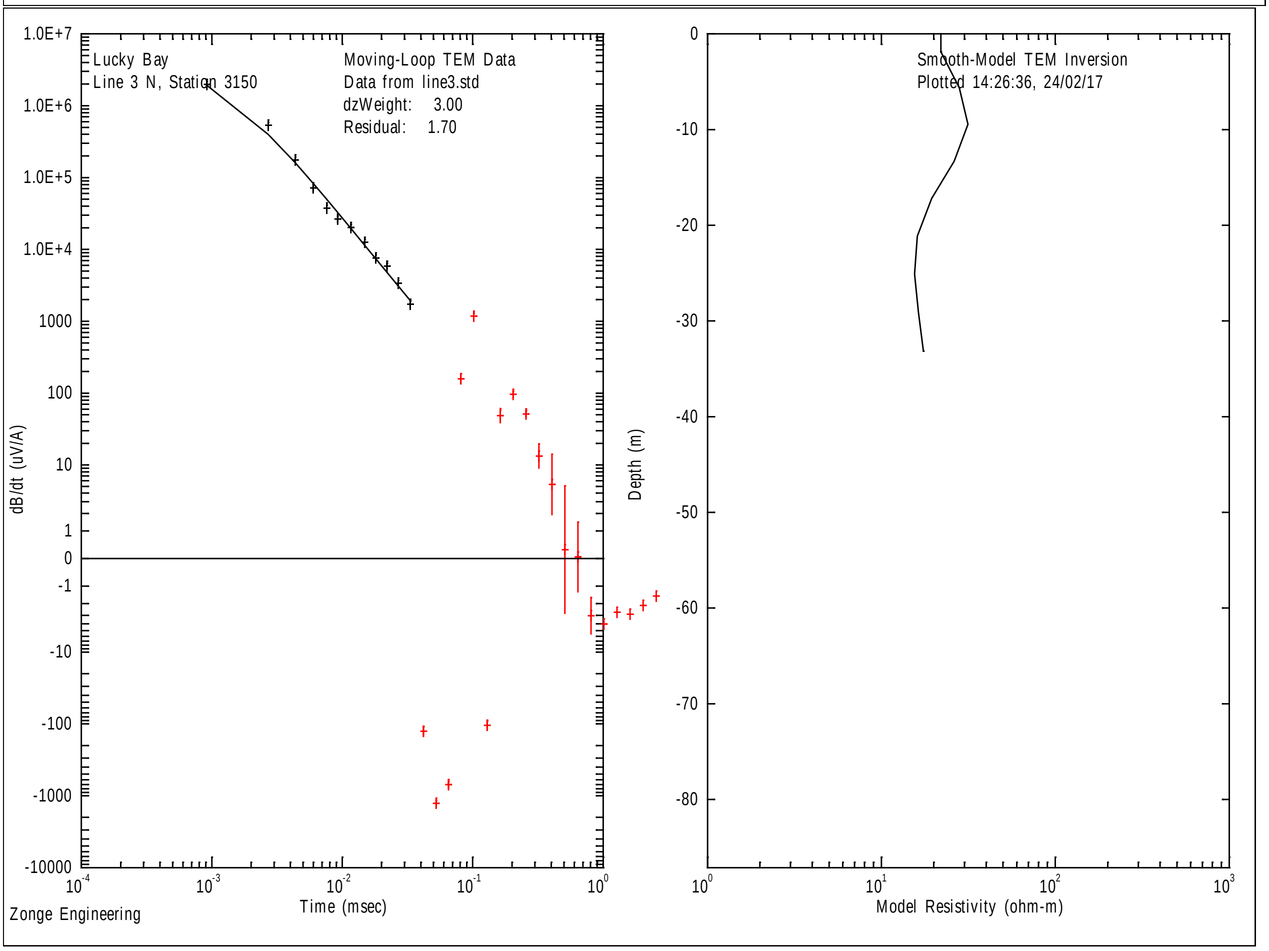




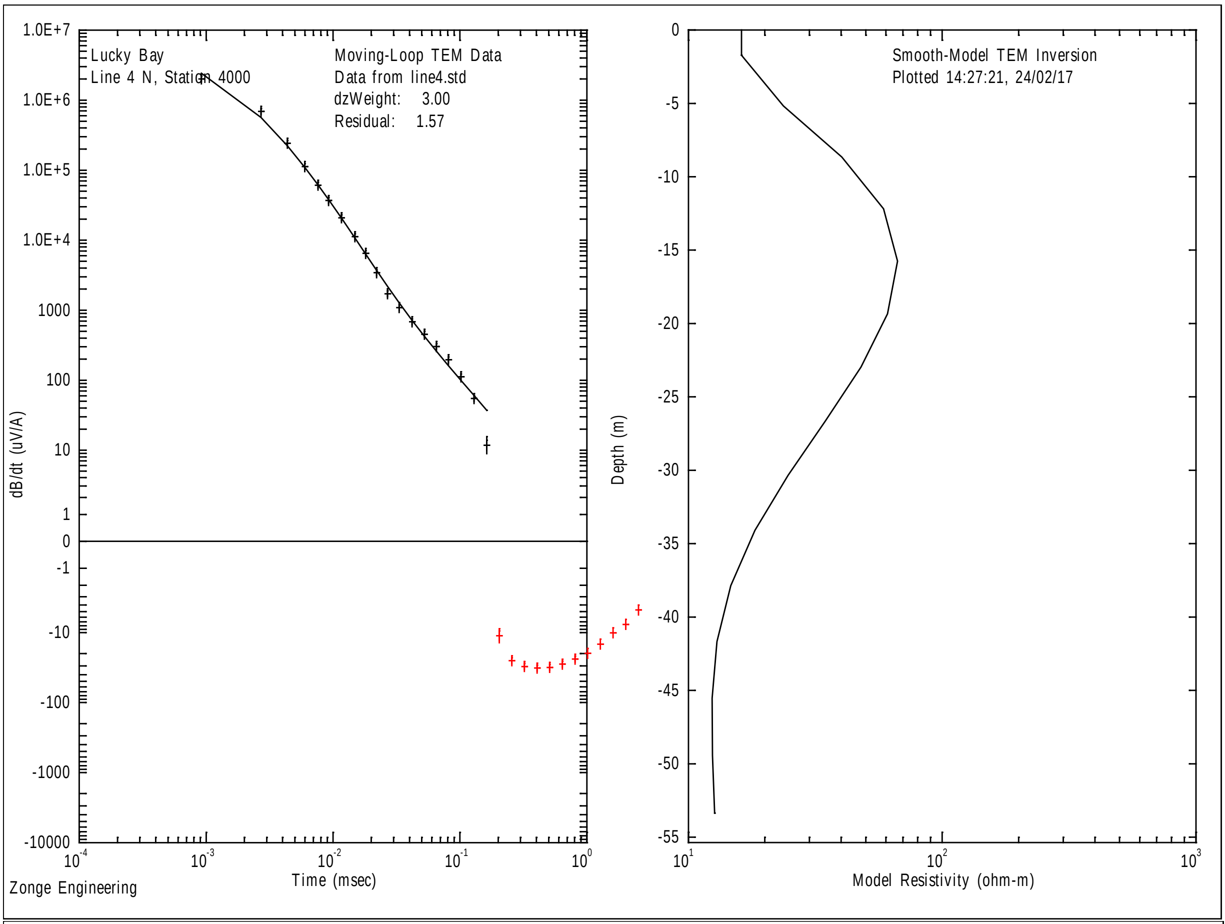

Lucky Bay
Line 3 N, Station 3060
Moving-Loop TEM Data
Data from line3.std
dzWeight: 3.00
Residual: 1.74
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:26:36, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

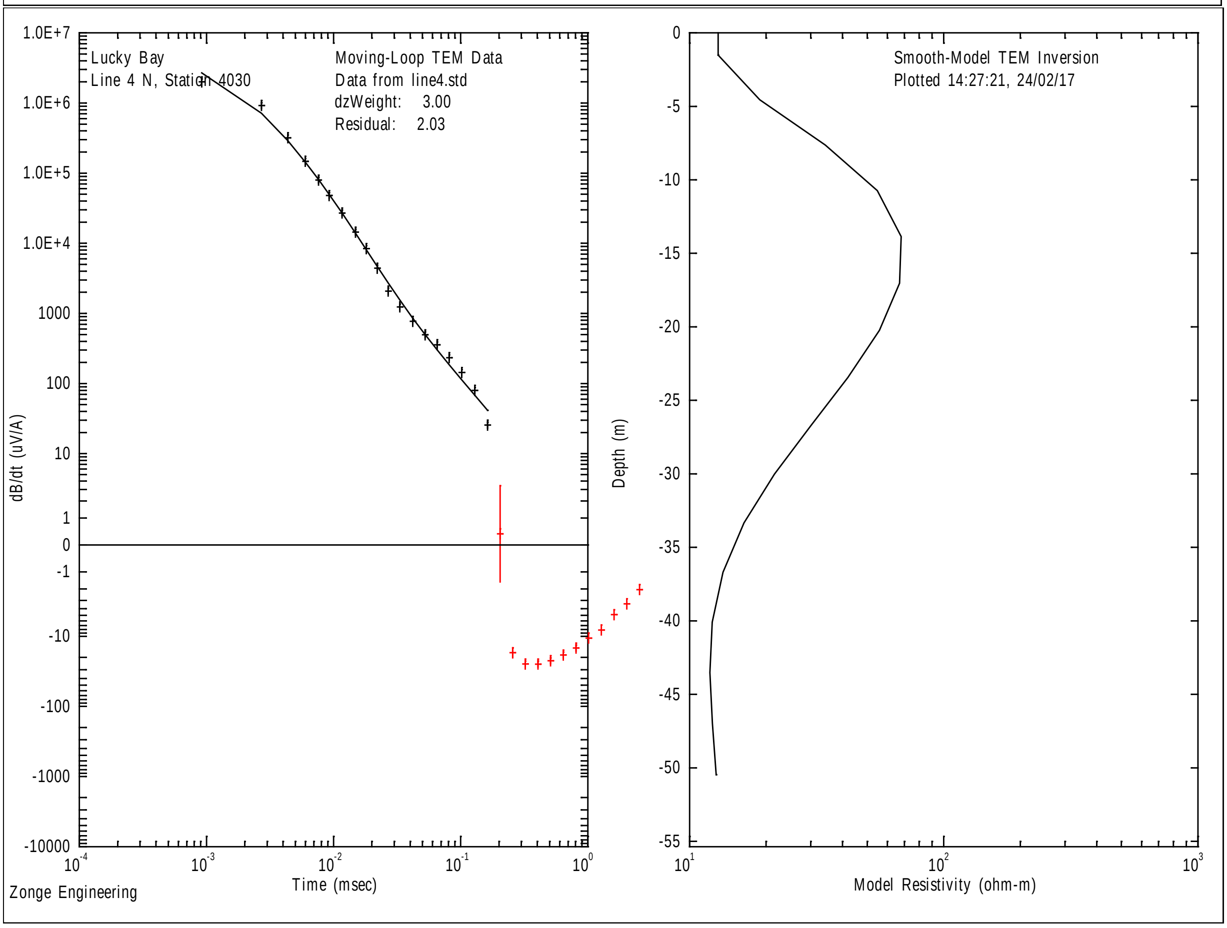

Lucky Bay
Line 3 N, Station 3090
Moving-Loop TEM Data
Data from line3.std
dzWeight: 3.00
Residual: 1.30
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:26:36, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

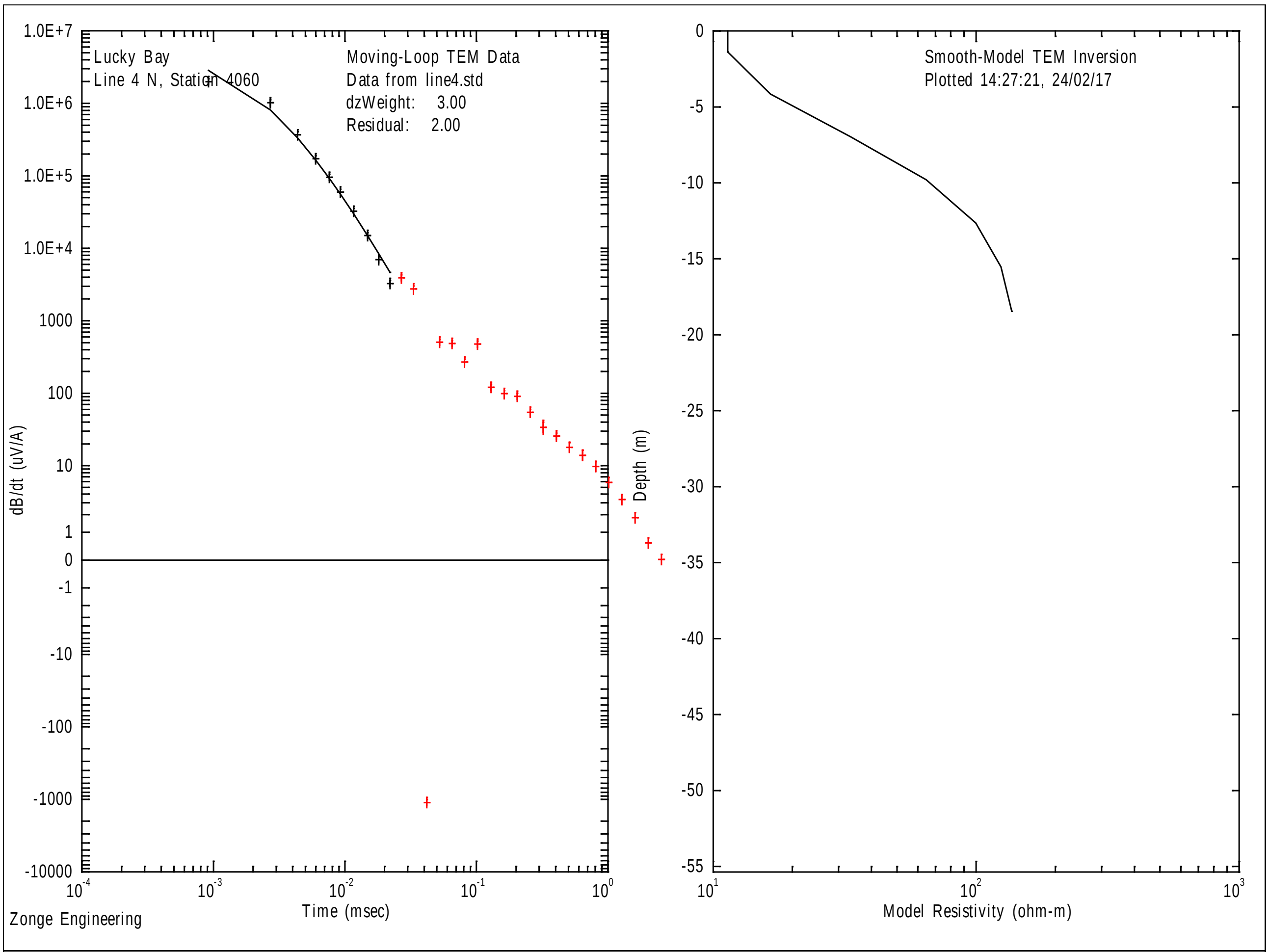

Lucky Bay
Line 3 N, Station 3120
Moving-Loop TEM Data
Data from line3.std
dzWeight: 3.00
Residual: 1.13
Smooth-Model TEM Inversion
Plotted 14:26:36, 24/02/17
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

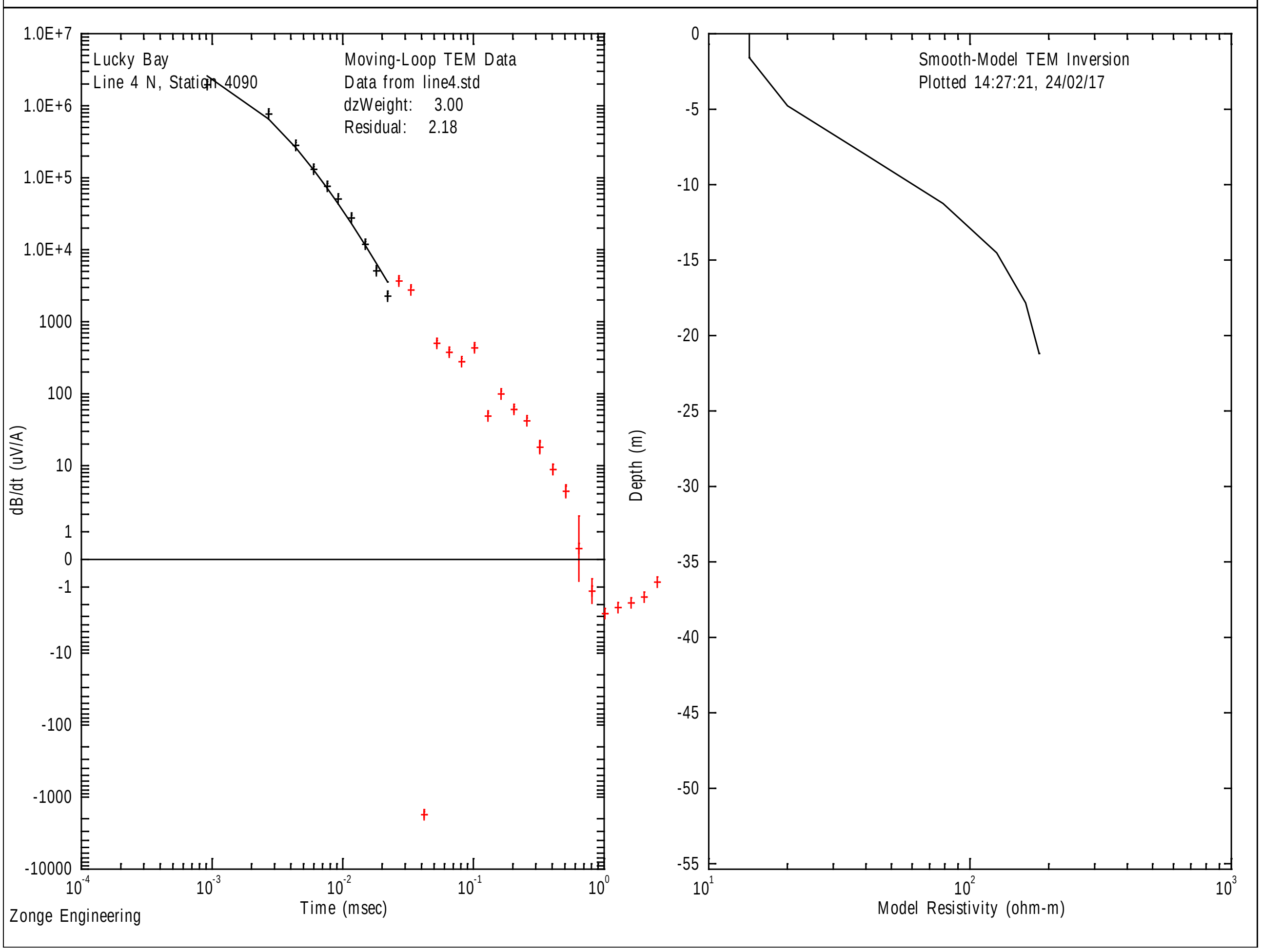

Lucky Bay
Line 3 N, Station 3150
Moving-Loop TEM Data
Data from line3.std
dzWeight: 3.00
Residual: 1.70
Smooth-Model TEM Inversion
Plotted 14:26:36, 24/02/17
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

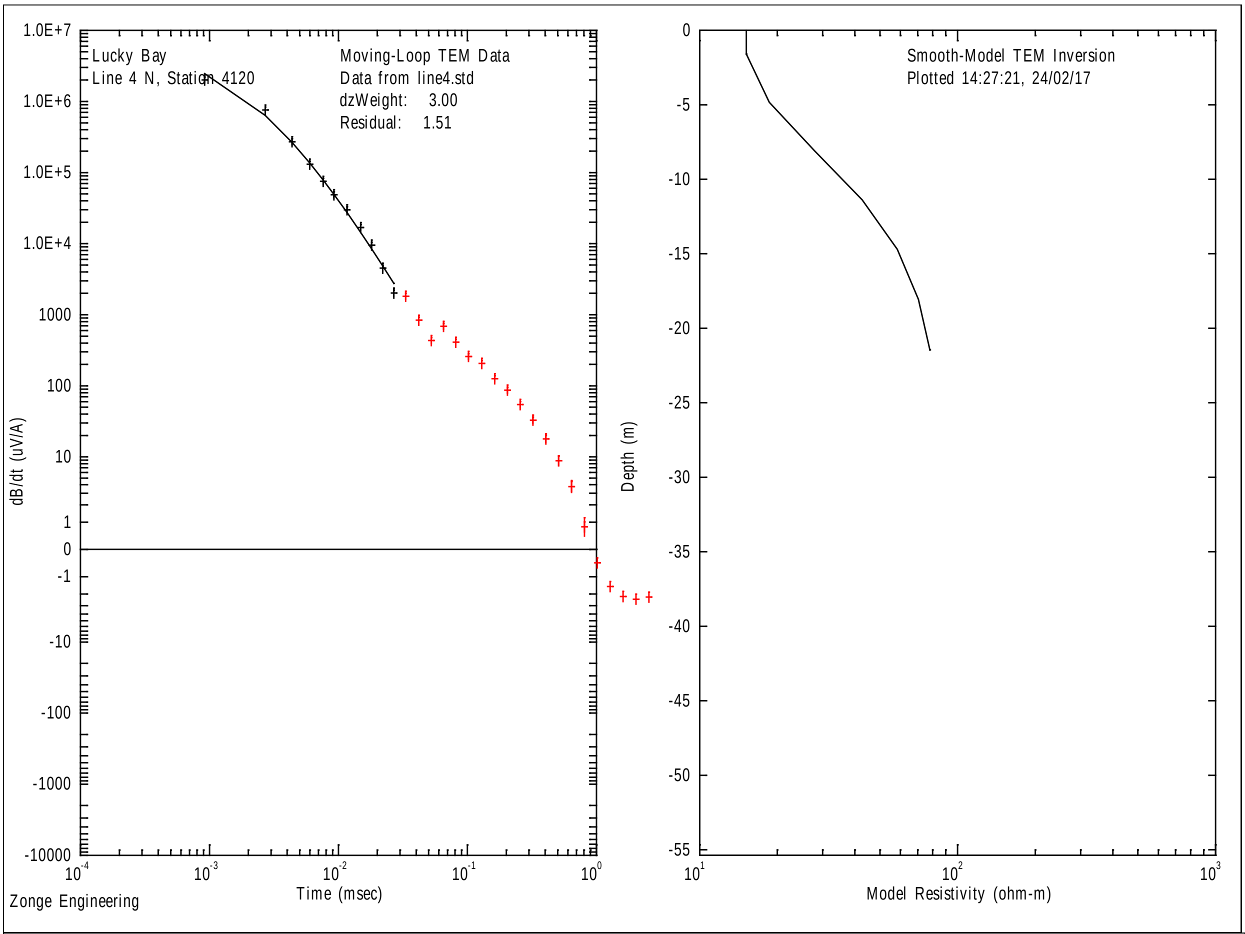
Line 4 all stations

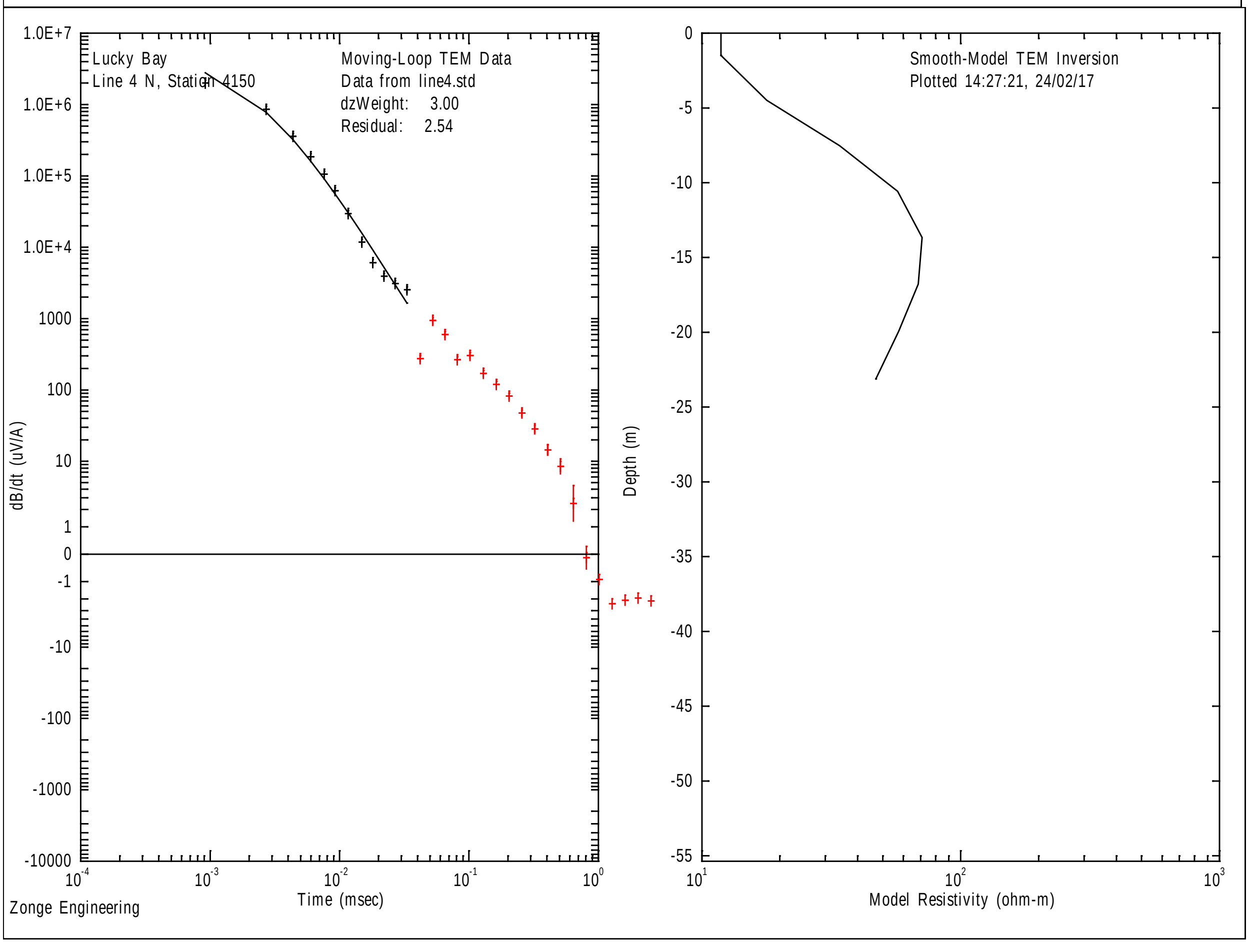




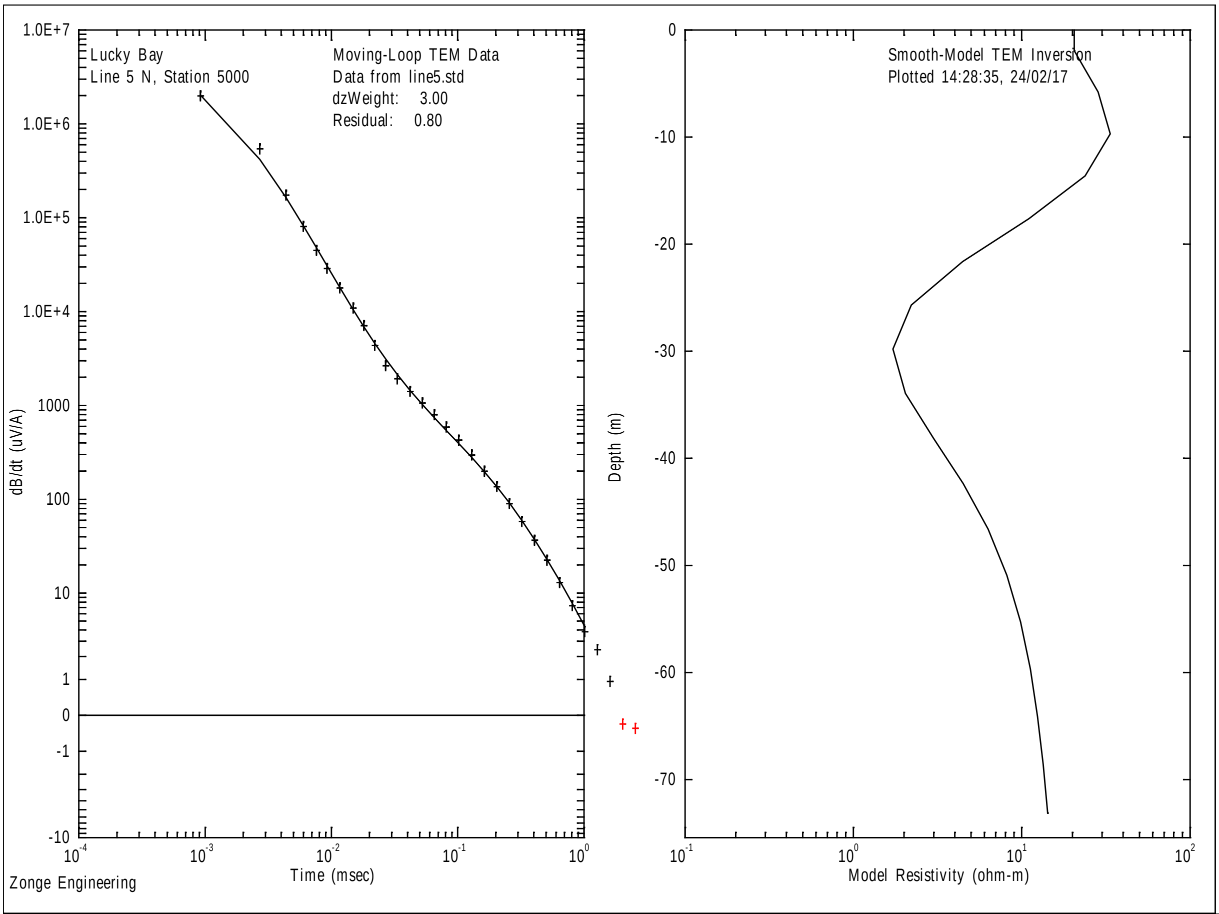

Lucky Bay
Line 4 N, Station 4060
Moving-Loop TEM Data
Data from line4.std
dzWeight: 3.00
Residual: 2.00
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:27:21, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

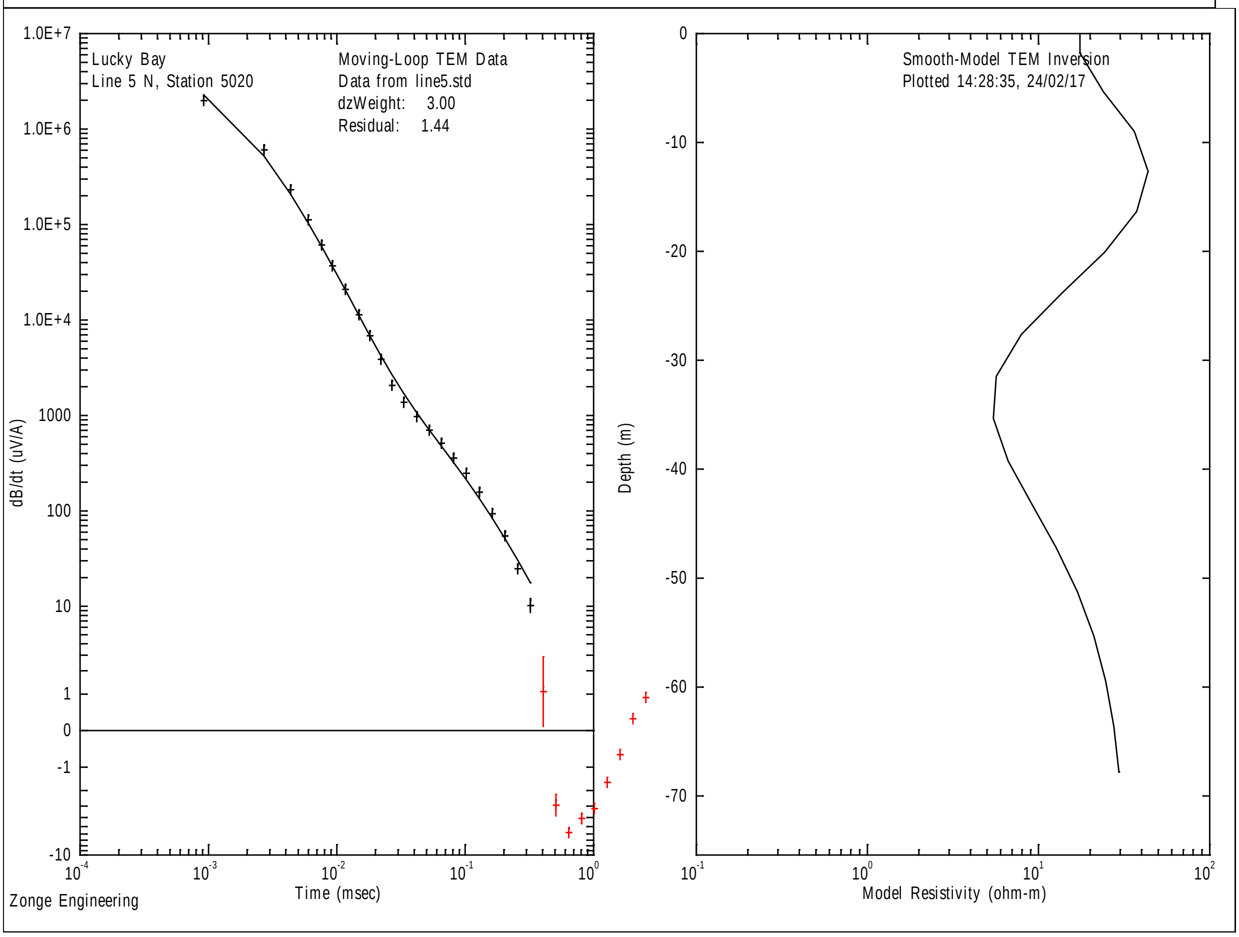

Lucky Bay
Line 4 N, Station 4090
Moving-Loop TEM Data
Data from line4.std
dzWeight: 3.00
Residual: 2.18
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:27:21, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

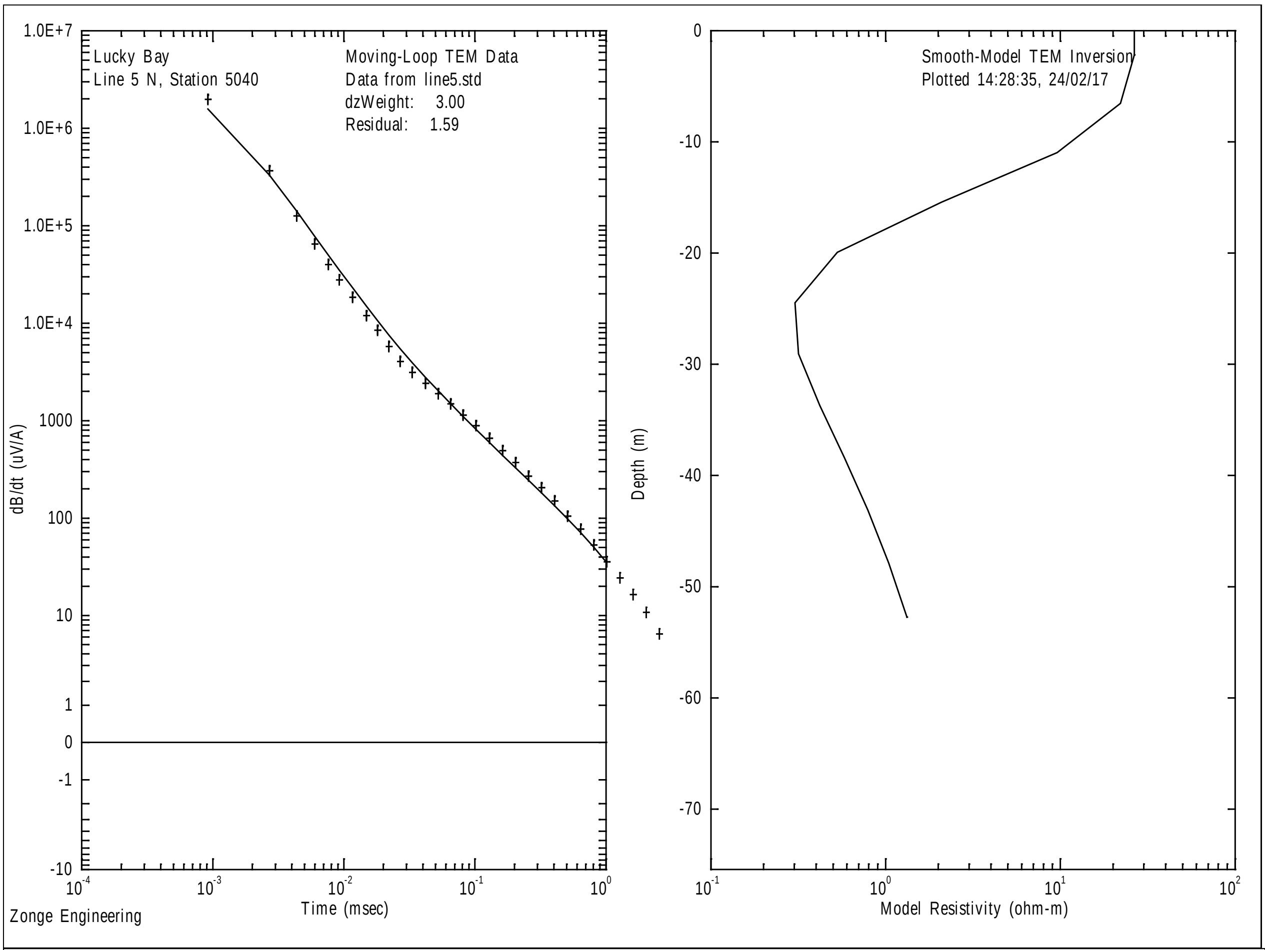

Lucky Bay
Line 4 N, Station 4120
Moving-Loop TEM Data
Data from line4.std
dzWeight: 3.00
Residual: 1.51
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:27:21, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

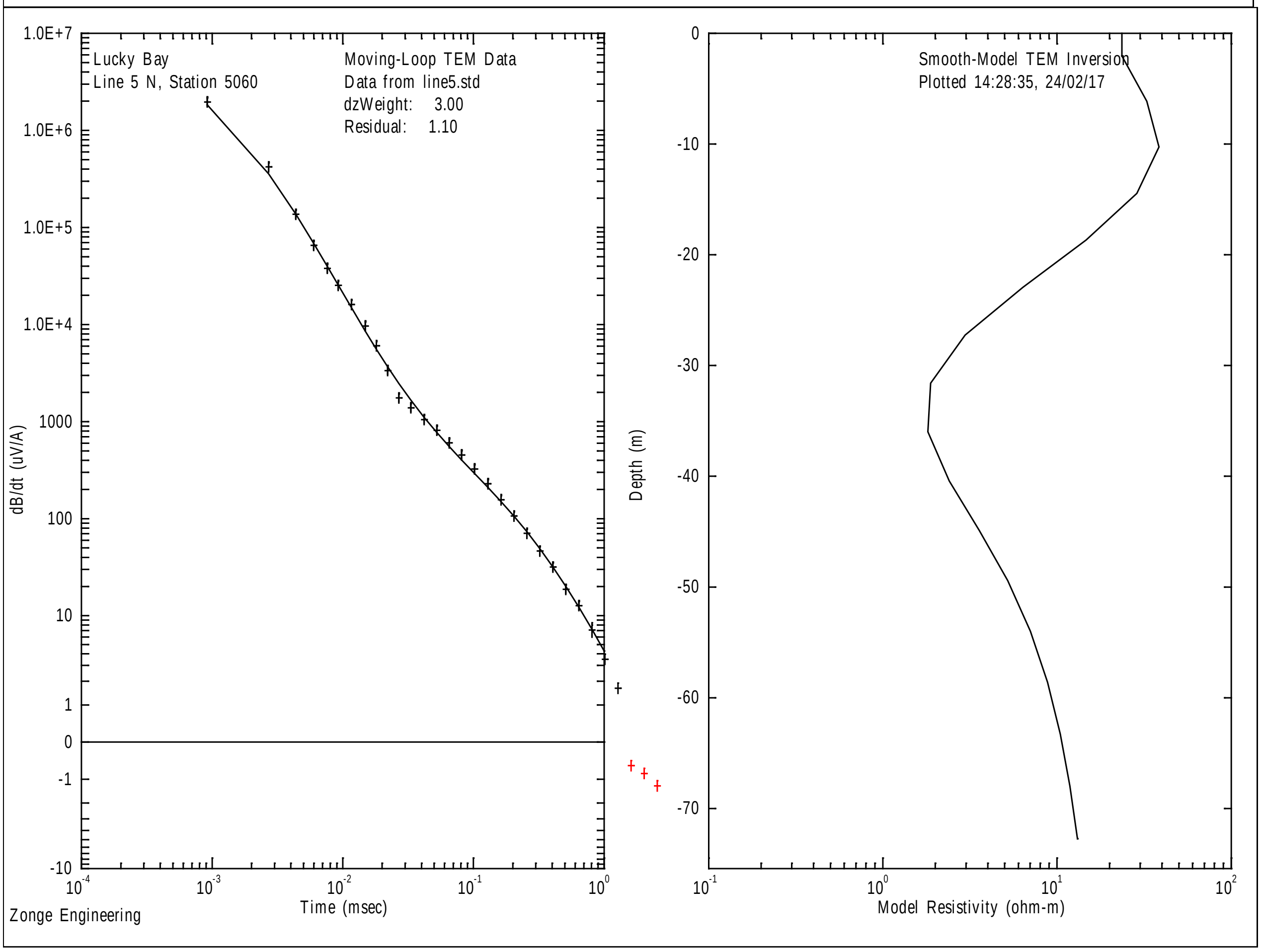

Lucky Bay
Line 4 N, Station 4150
Moving-Loop TEM Data
Data from line4.std
dzWeight: 3.00
Residual: 2.54
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:27:21, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

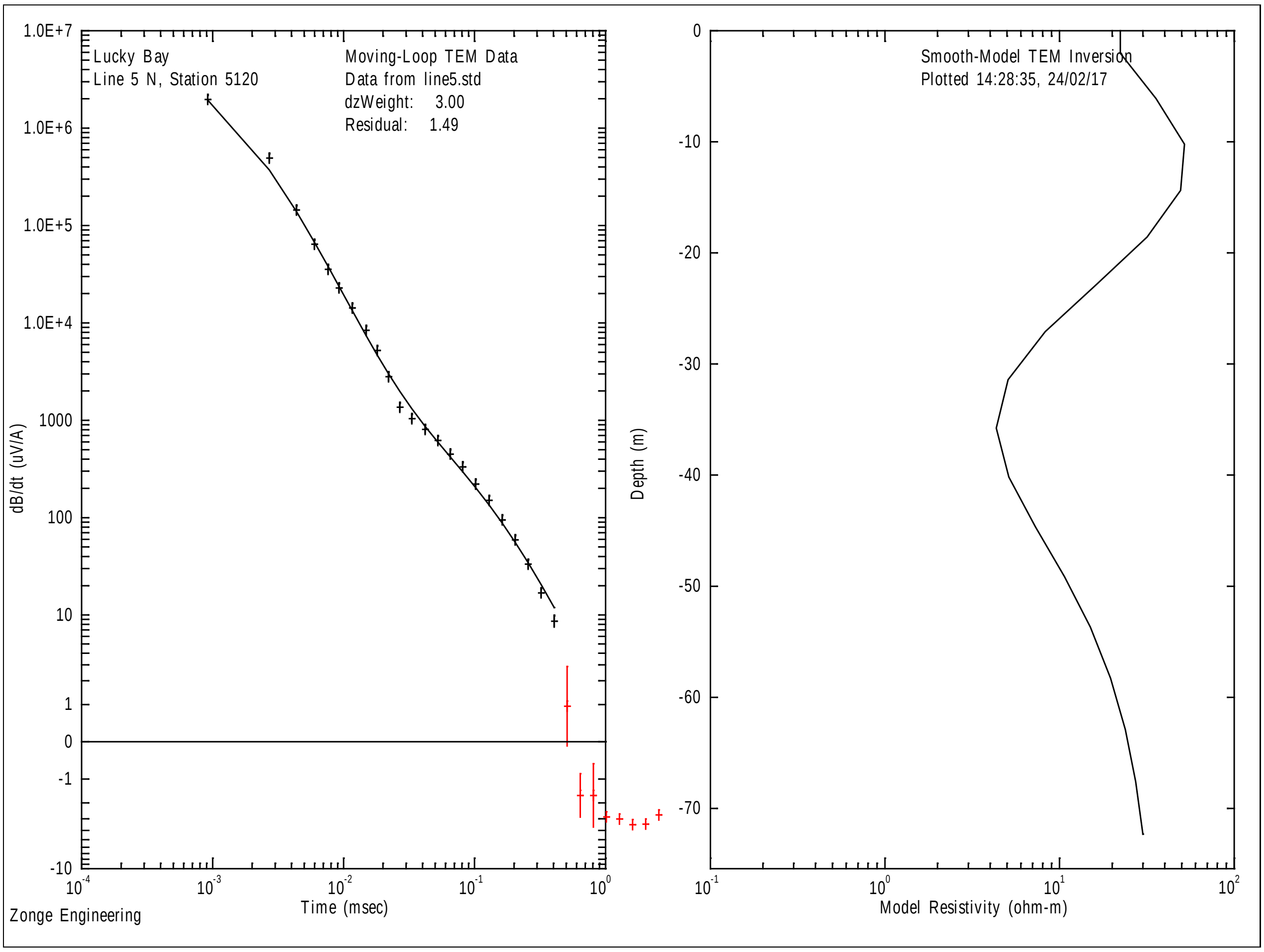
Line 5 all stations






Lucky Bay
Line 5 N, Station 5040
Moving-Loop TEM Data
Data from line5.std
dzWeight: 3.00
Residual: 1.59
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:28:35, 24/02/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
Line 5 N, Station 5060
Moving-Loop TEM Data
Data from line5.std
dzWeight: 3.00
Residual: 1.10
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:28:35, 24/02/17
Depth (m)
Model Resistivity (ohm-m)


Lucky Bay
Line 5 N, Station 5120
Moving-Loop TEM Data
Data from line5.std
dzWeight: 3.00
Residual: 1.49
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 14:28:35, 24/02/17
Depth (m)
Model Resistivity (ohm-m)

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EXTRAORDINARY EVERY DAY

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