

AUSTRALIAN SOCIETY OF
EXPLORATION GEOPHYSICISTS

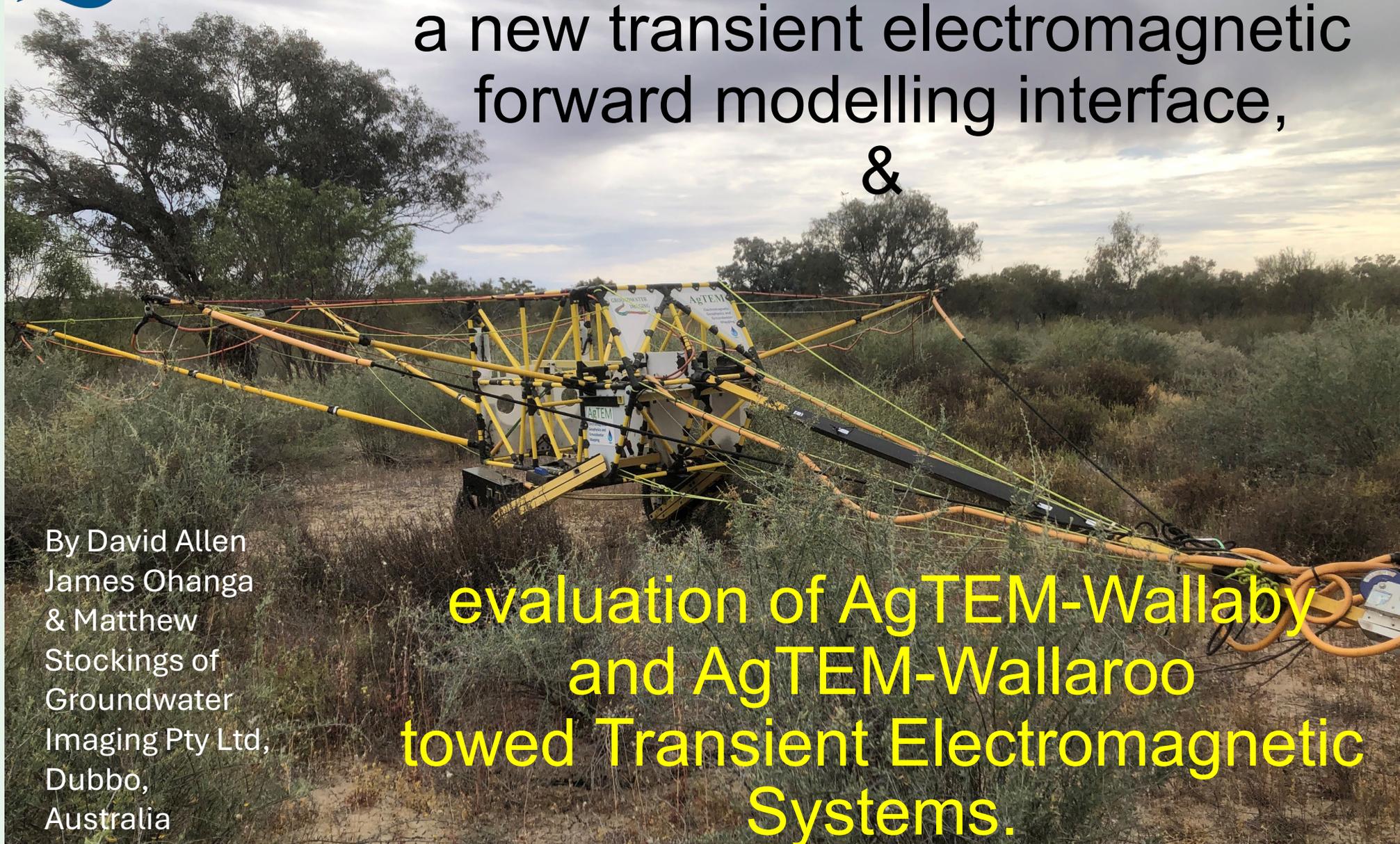
1ST ASEG DISCOVER SYMPOSIUM

www.asegdiscover.com.au

ASEG 2024



TEMConfigurator, a new transient electromagnetic forward modelling interface, &

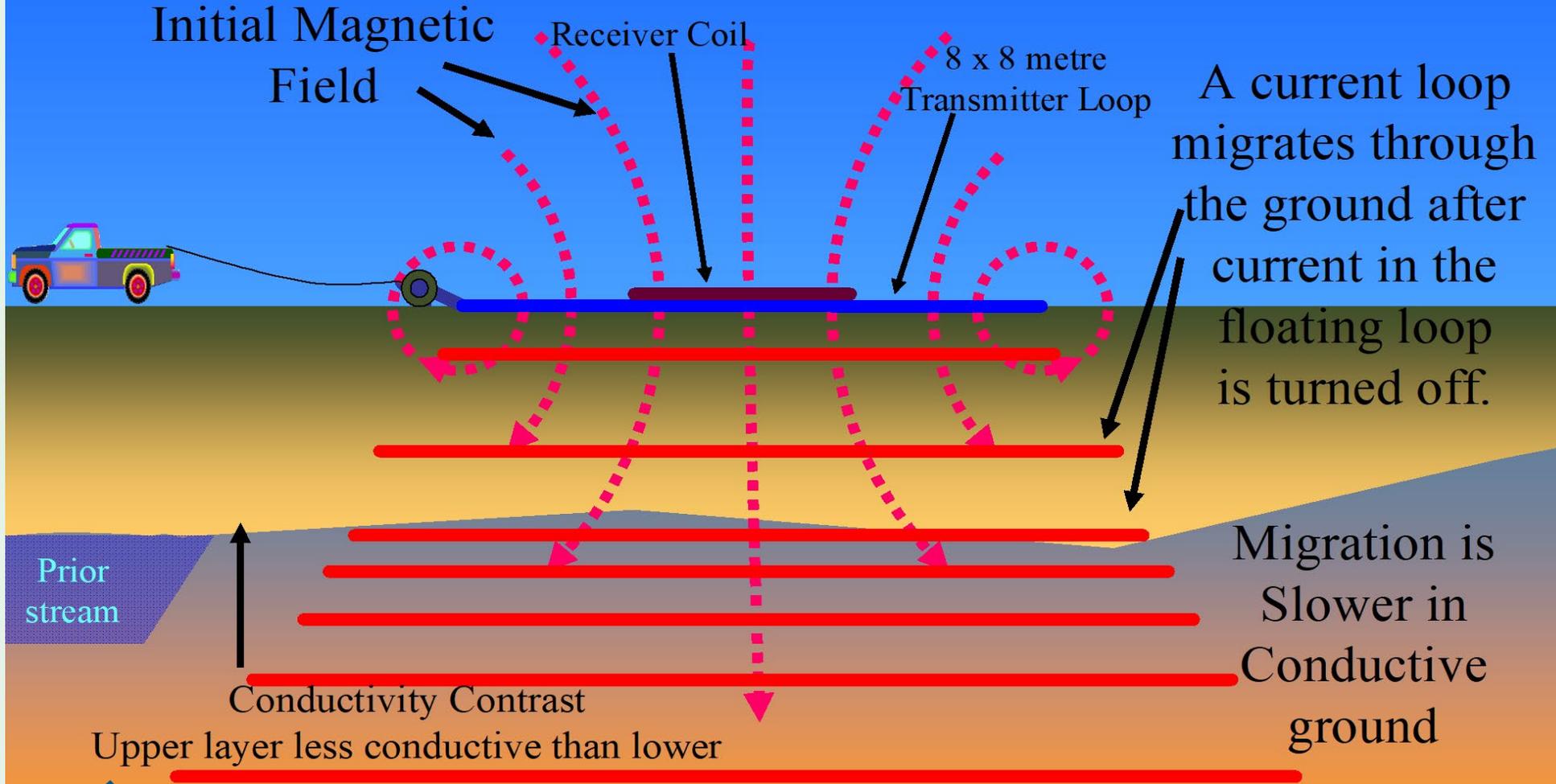


By David Allen
James Ohanga
& Matthew
Stockings of
Groundwater
Imaging Pty Ltd,
Dubbo,
Australia

evaluation of AgTEM-Wallaby and AgTEM-Wallaroo towed Transient Electromagnetic Systems.

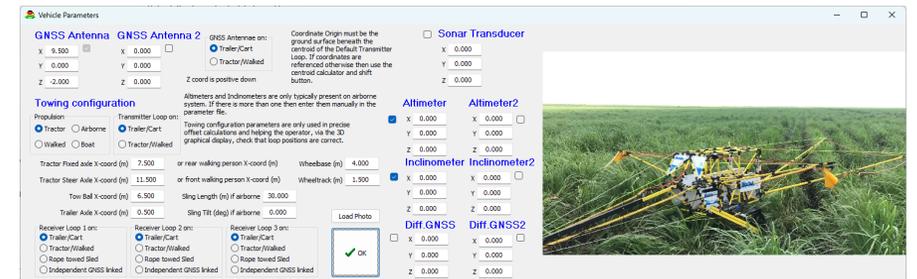
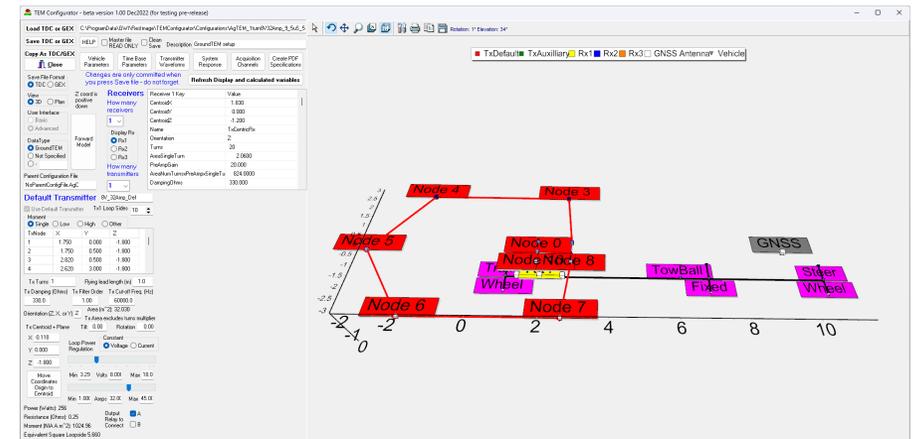
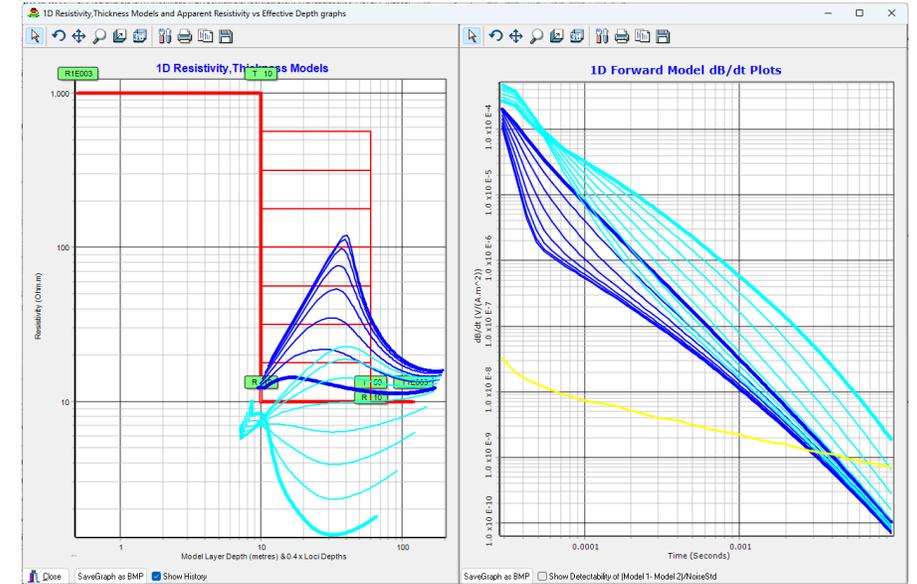


Towed Transient Electromagnetic System



TEM Configurator

- An interface for evaluating and comparing Transient Electro-Magnetic survey equipment configurations.
- 1D layered type curve generation using AarhusInv64.exe
- Open source Pascal code for reading, writing and handling configuration files.



AUSTRALIAN SOCIETY OF
EXPLORATION GEOPHYSICISTS

1ST ASEG DISCOVER SYMPOSIUM

www.asegdiscover.com.au



AgTEM - Wallaby

- An enduring off-road towed Transient Electromagnetic system suited to rapid coverage of cleared agricultural land and rangeland.
- Receiver loop null coupled with transmitter loop
- 1 to 5 turns each rated to 50 Amps
- Folds for gateways and narrow gaps.
- Optionally augmented by a front loop (Slingram)
- Towed by 400kg to 3000 kg vehicles.



AUSTRALIAN SOCIETY OF
EXPLORATION GEOPHYSICISTS

1ST ASEG DISCOVER SYMPOSIUM

www.asegdiscover.com.au



AgTEM - Wallaroo

ASEG 2024



- A lightweight collapsable system of configurable parts for transient electromagnetic survey
- 1 person can achieve 20km of survey per day walking propelled by an electric tractor controlled by walking within an a movement sensing cradle while holding a cantilevered, hand stabilized, Slingram receiver loop. Also has in-loop receiver.
- Folds for gateways and narrow gaps.
- May be towed by quad bikes
- May be carried by walking persons in most minimal form (12kg main loop)

AUSTRALIAN SOCIETY OF
EXPLORATION GEOPHYSICISTS

1ST ASEG DISCOVER SYMPOSIUM

www.asegdiscover.com.au

ASEG 2024



AgTEM-Wallaby

Main transmitter loop area
= 32m² x 1 to 5 turns
Current up to 50 Amps / turn

Strong elastic
cords hold the
Tx loop shape

Junction boxes
allow combinations
of 1 to 5 loop turns

Stop ropes oppose the elastic
cords to keep the front of the
Tx loop in an exact position

Main Receiver Loop

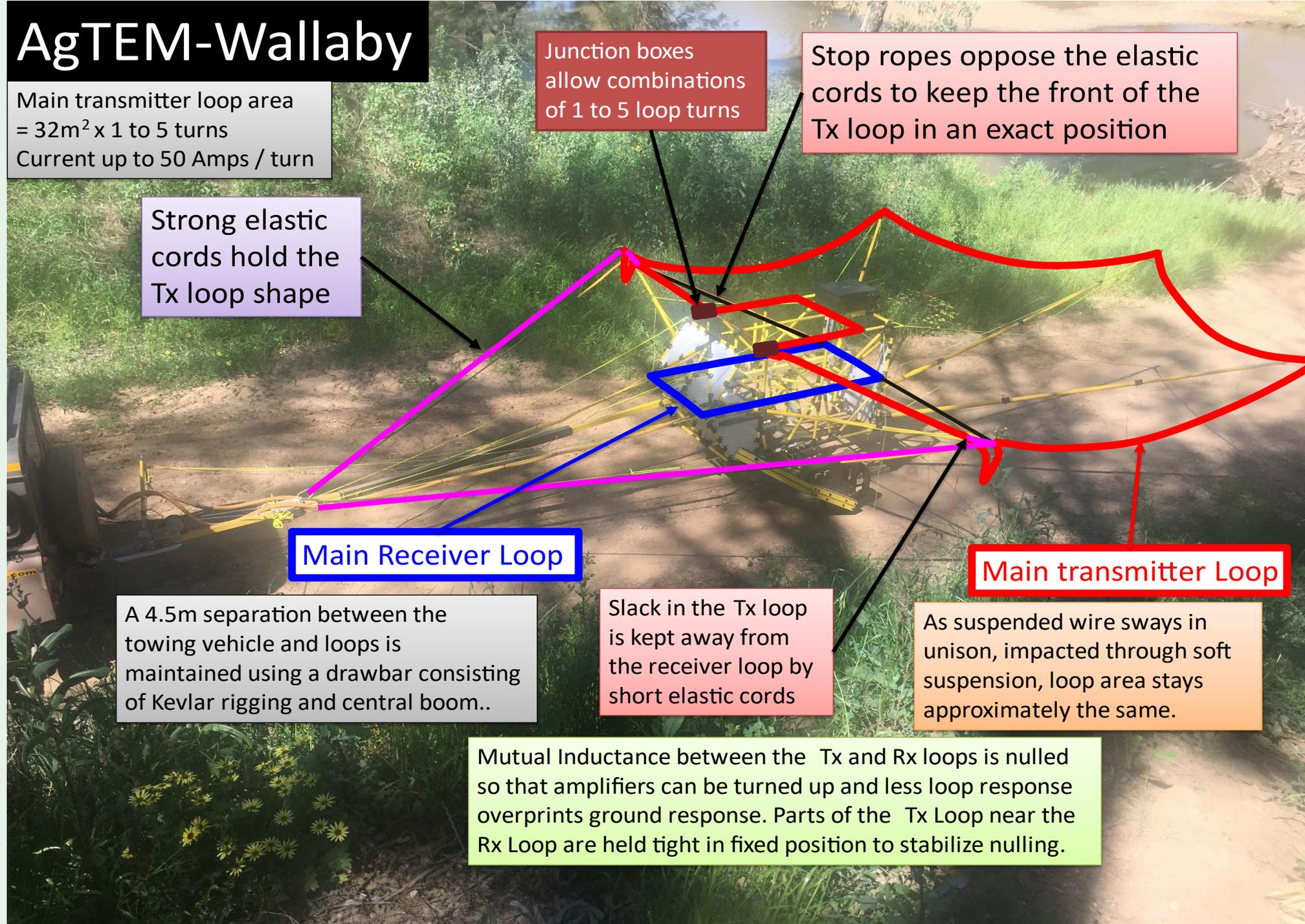
Main transmitter Loop

A 4.5m separation between the
towing vehicle and loops is
maintained using a drawbar consisting
of Kevlar rigging and central boom..

Slack in the Tx loop
is kept away from
the receiver loop by
short elastic cords

As suspended wire sways in
unison, impacted through soft
suspension, loop area stays
approximately the same.

Mutual Inductance between the Tx and Rx loops is nulled
so that amplifiers can be turned up and less loop response
overprints ground response. Parts of the Tx Loop near the
Rx Loop are held tight in fixed position to stabilize nulling.



AgTEM-Wallaroo

Main Receiver Loop

Main transmitter Loop

Designed for compact shipping and conversion to a 12kg walkable loop carrying system

Optional Front Receiver Loop



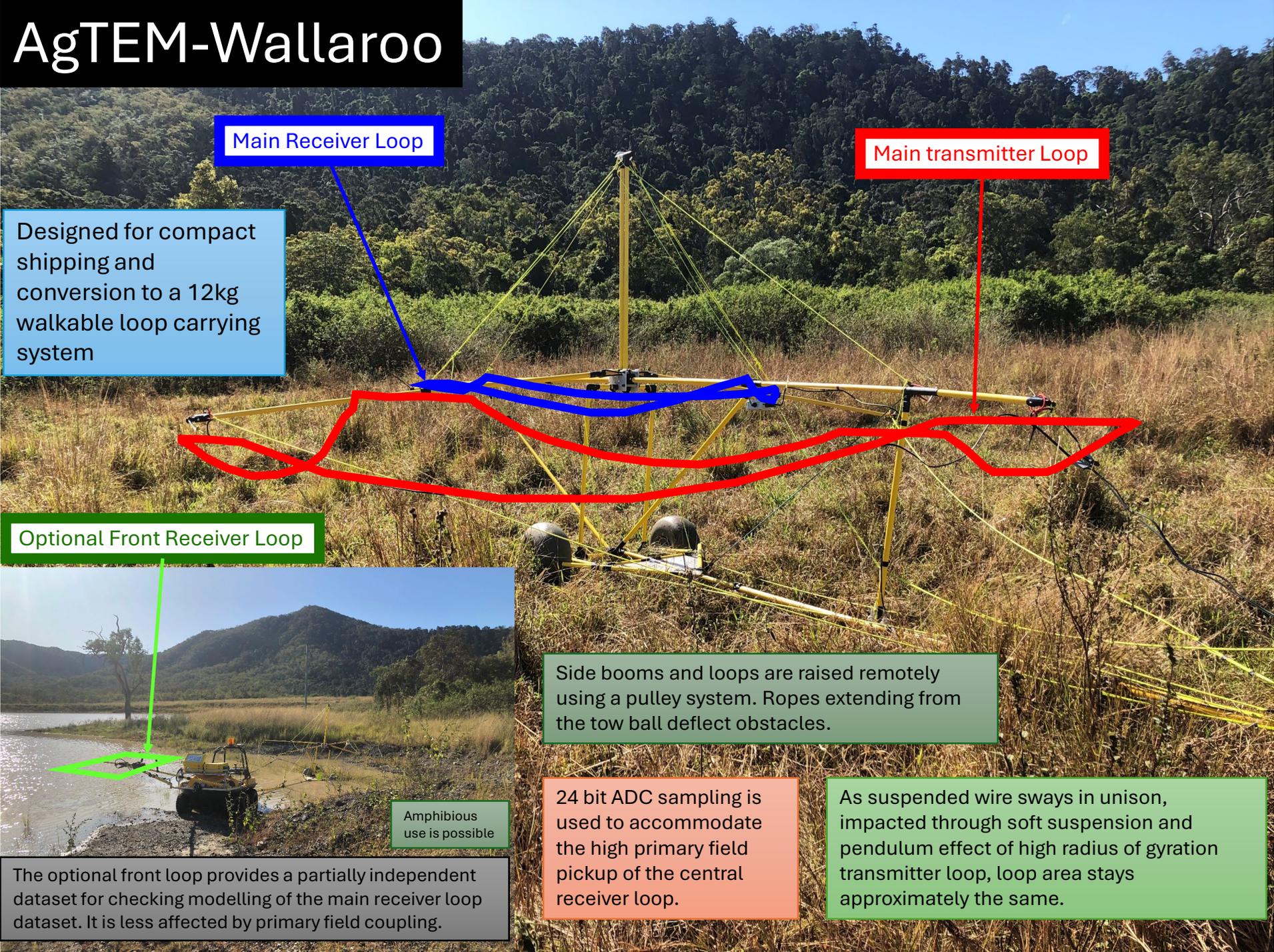
Amphibious use is possible

The optional front loop provides a partially independent dataset for checking modelling of the main receiver loop dataset. It is less affected by primary field coupling.

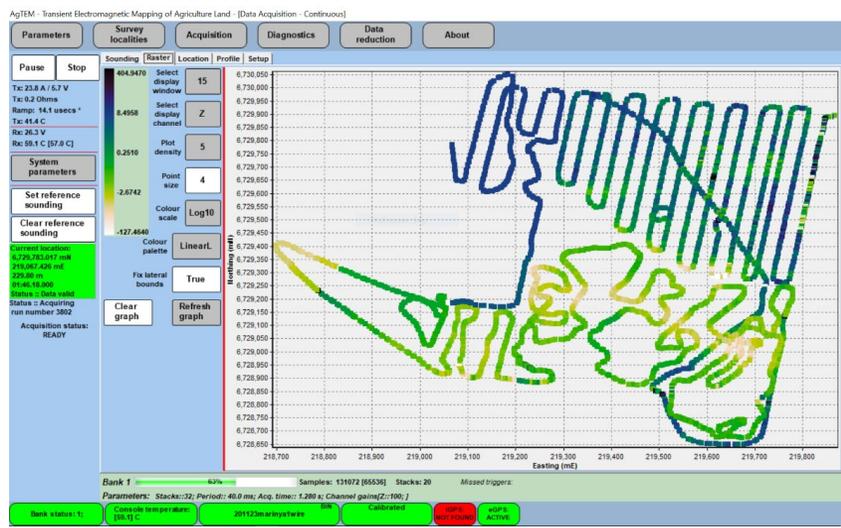
Side booms and loops are raised remotely using a pulley system. Ropes extending from the tow ball deflect obstacles.

24 bit ADC sampling is used to accommodate the high primary field pickup of the central receiver loop.

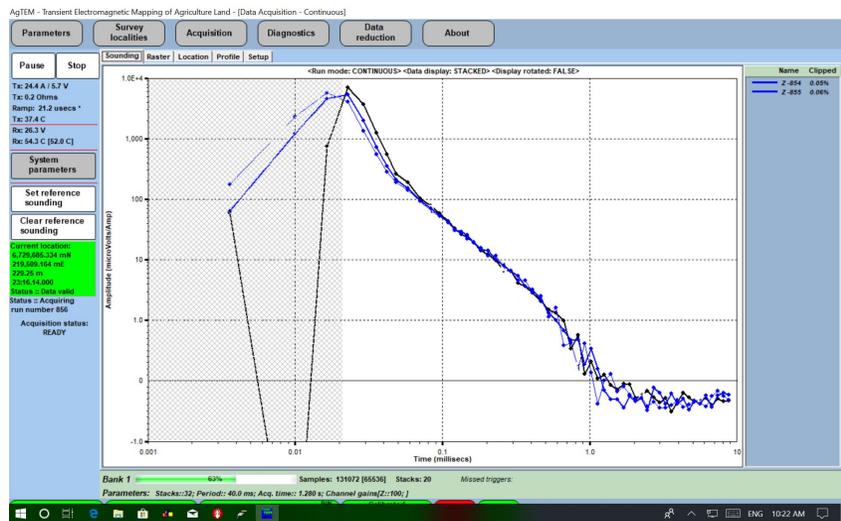
As suspended wire sways in unison, impacted through soft suspension and pendulum effect of high radius of gyration transmitter loop, loop area stays approximately the same.



AgTEM-electronics

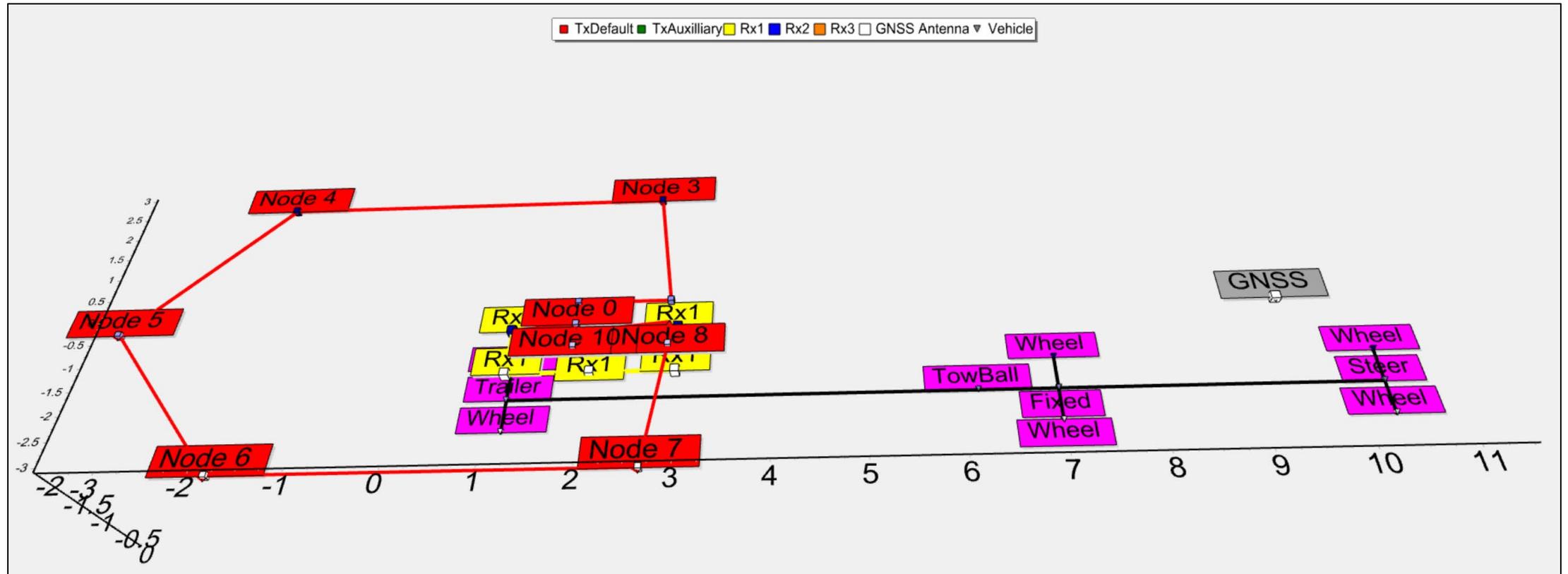


Regulated 3.5 to 18 Volt, 45 Amp TEM transmitter with 3 channel receiver & Dashboard mount operator's console. Also designed for walked operation.



TEM Configurator

TEMConfigurator displaying loop coordinates from the Wallaby overlapping receiver loop configuration file.



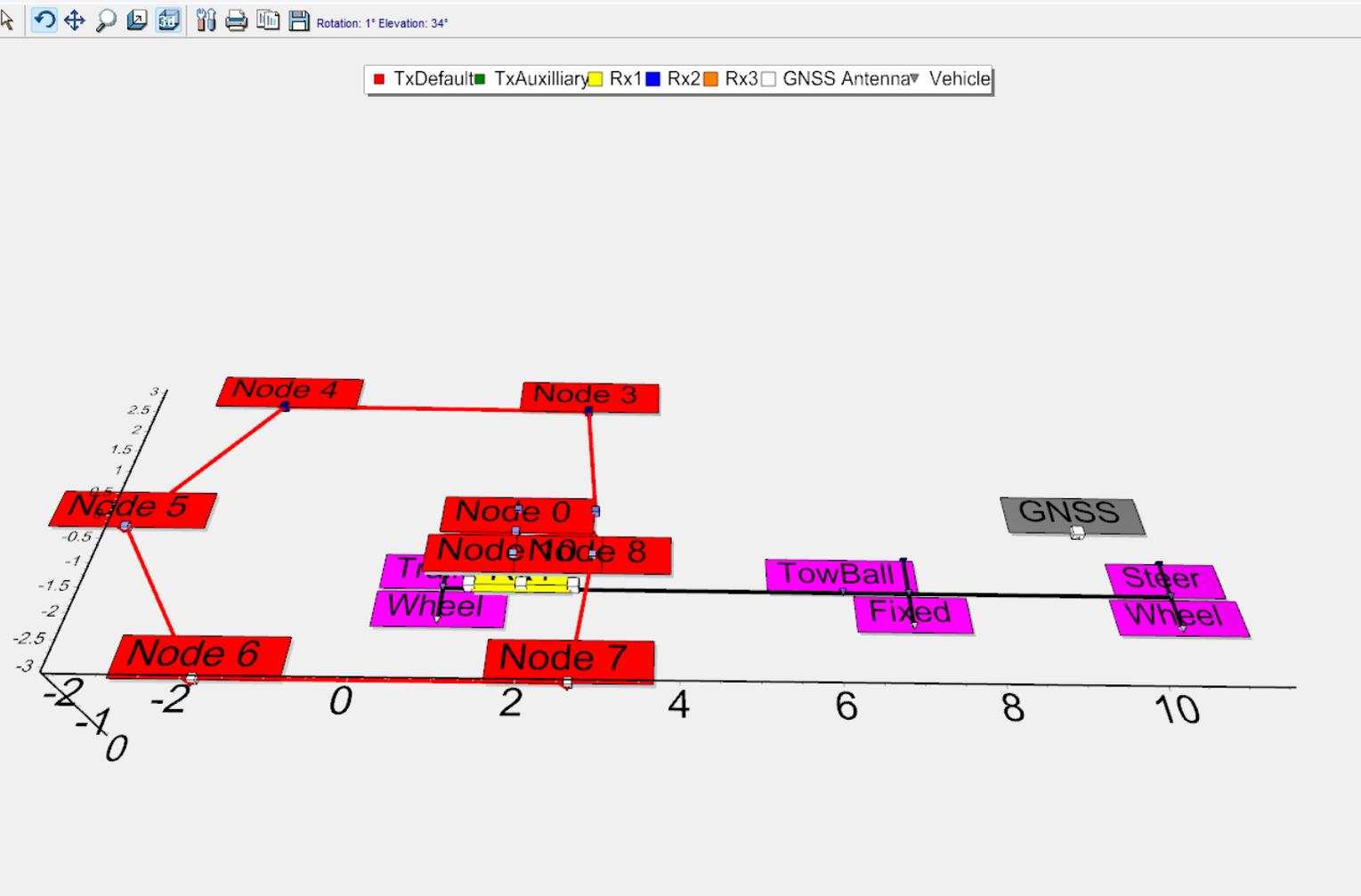
C:\ProgramData\GVW\ResImage\TEMConfigurator\Configurations\AgTEM_1turn8V32Amp_9_5uS_5
 Master file Clean Save Description GroundTEM setup

Changes are only committed when you press Save file - do not forget.

Save File Format: TDC GEX
 View: 3D Plan
 Z coord is positive down
 User Interface: Basic Advanced
 Data Type: GroundTEM Not Specified
 Parent Configuration File: NoParentConfigFile.AgC
 Default Transmitter: 8V_32Amp_Def
 Use Default Transmitter Tx1 Loop Sides: 10
 Moment: Single Low High Other

| TxNode | X | Y | Z |
|--------|-------|-------|--------|
| 1 | 1.750 | 0.000 | -1.800 |
| 2 | 1.750 | 0.500 | -1.800 |
| 3 | 2.820 | 0.500 | -1.800 |
| 4 | 2.620 | 3.000 | -1.800 |

Tx Turns: 1 Flying lead length (m): 1.0
 Tx Damping (Ohms): 330.0 Tx Filter Order: 1.00 Tx Cut-off Freq. (Hz): 60000.0
 Orientation (Z, X, or Y): Z Area (m²): 32.030
 Tx Centroid + Plane: Tilt: 0.00 Rotation: 0.00
 X: -0.118 Y: 0.000 Z: -1.800
 Loop Power Regulation: Voltage Current
 Move Coordinates Origin to Centroid: Min 3.29 Volts 8.00 Max 18.0
 Min 1.00 Amps 32.00 Max 45.00
 Power (Watts): 256 Resistance (Ohms): 0.25 Moment (NIA.A.m²): 1024.96 Equivalent Square Loopside 5.660
 Output Relay to Connect: A B



TEM Configurator Main Form, Receiver Evaluator, Transmitter Evaluator and 3D Geometry Graphics

TEM Configurator Vehicle Parameter Evaluator

Vehicle Parameters

GNSS Antenna X
Y
Z

GNSS Antenna 2 X
Y
Z Z coord is positive down

GNSS Antennae on:
 Trailer/Cart
 Tractor/Walked

Coordinate Origin must be the ground surface beneath the centroid of the Default Transmitter Loop. If coordinates are referenced otherwise then use the centroid calculator and shift button.

Sonar Transducer
X
Y
Z

Towing configuration

Propulsion: Tractor Airborne Walked Boat
Transmitter Loop on: Trailer/Cart Tractor/Walked

Altimeters and Inclinometers are only typically present on airborne system. If there is more than one then enter them manually in the parameter file.
Towing configuration parameters are only used in precise offset calculations and helping the operator, via the 3D graphical display, check that loop positions are correct.

Tractor Fixed axle X-coord (m) or rear walking person X-coord (m) Wheelbase (m)
Tractor Steer Axle X-coord (m) or front walking person X-coord (m) Wheeltrack (m)
Tow Ball X-coord (m) Sling Length (m) if airborne
Trailer Axle X-coord (m) Sling Tilt (deg) if airborne

Altimeter X
Y
Z

Altimeter2 X
Y
Z

Inclinometer X
Y
Z

Inclinometer2 X
Y
Z

Diff.GNSS X
Y
Z

Diff.GNSS2 X
Y
Z

Receiver Loop 1 on: Trailer/Cart Tractor/Walked Rope towed Sled Independent GNSS linked
Receiver Loop 2 on: Trailer/Cart Tractor/Walked Rope towed Sled Independent GNSS linked
Receiver Loop 3 on: Trailer/Cart Tractor/Walked Rope towed Sled Independent GNSS linked



External Default Transmitter Time Gate File

No_filename_selected

Update Configuration Default-Tx Timebase from this Channel File

#Timebases

1

2

more



External Auxiliary Transmitter Time Gate File

No_filename_selected

Update Configuration Auxiliary-Tx Timebase from this Channel File

Base Frequency

50 Hz 60 Hz

Default Sample Rate

156.25 kHz 6.4uS

312.50 kHz 3.2uS

625.00 kHz 1.6uS

Other 500.0000

Auxiliary Sample Rate

156.25 kHz 6.4uS

312.50 kHz 3.2uS

625.00 kHz 1.6uS

Other 500.0000

Time shifts applied for each Channel (seconds)

Front Gate Delay (uS)

0.00

Calculate Initial Gates to Remove

| ChnDelays | AcqChn01 | AcqChn02 |
|-----------------------------|-----------|-----------|
| PreBinAppliedRxDelay-Hidden | 0.0000000 | 0.0000000 |
| GateTimeShift-Modelled | 0.0000000 | 0.0000000 |
| MeaTimeDelay-AarhusInst | 0.0000000 | 0.0000000 |
| Gate1Adjusted-AsApplied | 0.0000011 | 0.0000011 |
| Gate1Adjusted-Modelling | 0.0000011 | 0.0000011 |
| Timebase# | 1 | 2 |
| Tx# | 1 | 2 |
| Rx# | 1 | 1 |
| GatesInRamp | 7 | 4 |

TEM Configurator Timebase evaluator

Default Time Gates - Timebase[1]

Gates in gate file 20

Sampling Delay (uS) 0.0000000 Name Not_Specified

| Gate | Centre (S) | Width (S) | Open (S) | Close (S) |
|------|------------|-----------|-----------|-----------|
| 1 | 0.0000011 | 0.0000022 | 0.0000000 | 0.0000022 |
| 2 | 0.0000034 | 0.0000024 | 0.0000022 | 0.0000046 |
| 3 | 0.0000060 | 0.0000028 | 0.0000046 | 0.0000074 |
| 4 | 0.0000089 | 0.0000030 | 0.0000074 | 0.0000104 |
| 5 | 0.0000123 | 0.0000038 | 0.0000104 | 0.0000142 |
| 6 | 0.0000164 | 0.0000044 | 0.0000142 | 0.0000186 |
| 7 | 0.0000213 | 0.0000054 | 0.0000186 | 0.0000240 |
| 8 | 0.0000273 | 0.0000066 | 0.0000240 | 0.0000306 |
| 9 | 0.0000348 | 0.0000084 | 0.0000306 | 0.0000390 |
| 10 | 0.0000442 | 0.0000104 | 0.0000390 | 0.0000494 |
| 11 | 0.0000559 | 0.0000130 | 0.0000494 | 0.0000624 |
| 12 | 0.0000725 | 0.0000166 | 0.0000642 | 0.0000808 |

Auxiliary Time Gates - Timebase[2]

Gates in gate file 38

Sampling Delay (uS) 0.0000000 Name Not_Specified

| Gate | Centre (S) | Width (S) | Open (S) | Close (S) |
|------|------------|-----------|-----------|-----------|
| 1 | 0.0000011 | 0.0000022 | 0.0000000 | 0.0000022 |
| 2 | 0.0000035 | 0.0000025 | 0.0000023 | 0.0000048 |
| 3 | 0.0000062 | 0.0000027 | 0.0000048 | 0.0000075 |
| 4 | 0.0000092 | 0.0000033 | 0.0000075 | 0.0000108 |
| 5 | 0.0000126 | 0.0000037 | 0.0000108 | 0.0000145 |
| 6 | 0.0000168 | 0.0000046 | 0.0000145 | 0.0000191 |
| 7 | 0.0000218 | 0.0000055 | 0.0000191 | 0.0000246 |
| 8 | 0.0000281 | 0.0000068 | 0.0000246 | 0.0000314 |
| 9 | 0.0000358 | 0.0000085 | 0.0000315 | 0.0000400 |
| 10 | 0.0000453 | 0.0000106 | 0.0000400 | 0.0000506 |
| 11 | 0.0000574 | 0.0000132 | 0.0000508 | 0.0000640 |
| 12 | 0.0000725 | 0.0000166 | 0.0000642 | 0.0000808 |

Waveform period mS: 0.95

Waveform period mS: 80.00

Off/On duration mS: 0.24

Off/On duration mS: 20.00

Default - number of gates used: 20

Auxiliary - number of gates used: 35

Stacks (full waveform) 32

Stacks (full waveform) 32

Sampling time (sec): 0.0303318

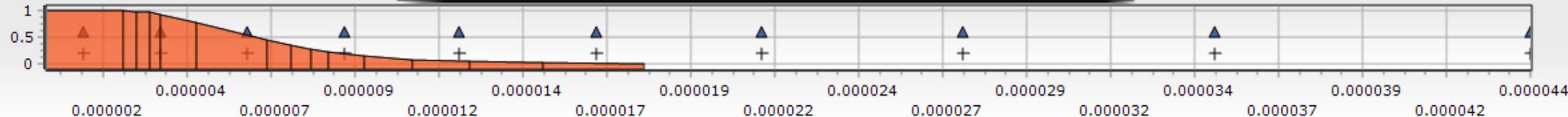
Sampling time (sec): 2.5600000

Time Scale Comparison Display

Linear 1st 10 gates Logarithmic all gates

Acquisition Channel shown on shifted gates display 1

▲ Shifted Output File Gate Centres + Gates with reference to Tx Ramp Start Trigger ■ Ramp



TEM Configurator Waveform Evaluator

TranmitterWaveforms

Sampled Waveforms normally are stored simply as part of TEM Configuration AgC files.

Default sampled waveform file

Currently locked to main menu TDC file

Auxiliary sampled waveform file

Currently locked to main menu TDC file



Close

Digitized Tx Waveforms for Modelling

Default Tx Waveform Points 58

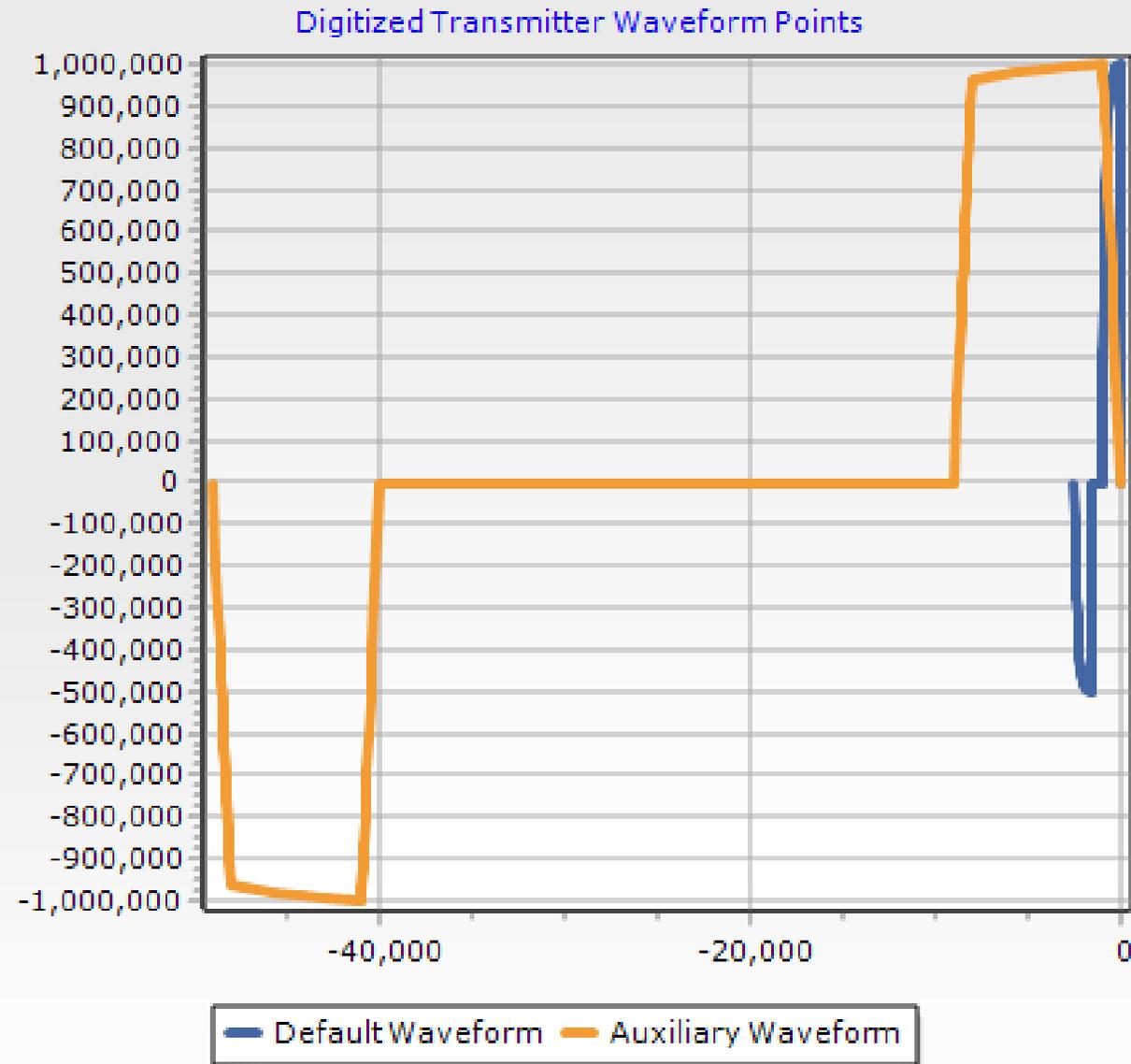
Auxiliary Tx Waveform Points 64

Default Tx Ramp (uS) 17.8

Auxiliary Tx Ramp (uS) 8.0

| Time (seconds) | Volts |
|----------------|-------------|
| -0.00249600 | 0.00000000 |
| -0.00246410 | -0.08995380 |
| -0.00243630 | -0.15703800 |
| -0.00240520 | -0.21894800 |
| -0.00237170 | -0.27307200 |
| -0.00233640 | -0.31881500 |
| -0.00229650 | -0.35950000 |
| -0.00225400 | -0.39287600 |
| -0.00220490 | -0.42171900 |
| -0.00215440 | -0.44330700 |
| -0.00209840 | -0.46049200 |

| Time (seconds) | Volts |
|----------------|------------|
| -0.0489810 | 0.0000000 |
| -0.0487830 | -0.2123560 |
| -0.0486808 | -0.3187510 |
| -0.0486120 | -0.3892250 |
| -0.0485282 | -0.4735580 |
| -0.0484794 | -0.5218030 |
| -0.0484256 | -0.5741720 |
| -0.0483660 | -0.6311000 |
| -0.0483000 | -0.6926940 |
| -0.0482270 | -0.7589060 |
| -0.0481464 | -0.8294780 |



TEM Configurator Acquisition Channel Evaluator

TEM Acquisition Channels

Number of Acquisition Channels

Acquisition Channel numbers in GEX file Enter 0 if the combination has no acquisition channel

| AcqChns | TxDef | TxAux |
|---------|-------|-------|
| Rx1 | 1 | 2 |
| Rx2 | | |
| Rx3 | | |

For Original Aarhus Workbench GEX restrictions Transmitter Alias Mapping - GEX convention is either LM = TxDef, HM = TxAux or Single = Any

Single Tx: None, Default, Auxiliary

Low Moment Tx: None, Default, Auxiliary

High Moment Tx: None, Default, Auxiliary

If other transmitter Aliases or more than two transmitters or transmitter moments are to be used then original GEX format is inadequate - adopt AgC format or (less preferably) extended GEX format.

Validate and Propagate data entry

Sever link to Tx[#].Amps.

Aarhus Workbench require a TxApproximateCurrent for each [Channel#]. Linking to Tx[#].Amps will override Tx[#].Amps. If output data is current normalized or you do not need this problematic variable then sever the link.

Acquisition Channel Displayed below

| Key | Value |
|---------------------------|--------------------|
| RowID | X |
| Description | SkyTEM_High_Moment |
| RxCoilNumber | 1 |
| ReceiverPolarizationXYZ | Z |
| TransmitterMoment | HM |
| TxNumber | 2 |
| TimebaseNumber | 2 |
| AtoDConvGain | 100 |
| GateTimeShift | 0 |
| GateFactor | 1 |
| SystemResponseConvolution | 0 |

Final Front Gate Time =
 AcqChn.FrontGateTime +
 AcqChn.GateTimeShift +
 FrontGateDelay =
 0.0000400

To improve modelling, a system response can be subtracted from data. Ideally one should be able to load a resistive field sounding and a known 1D layered model for that site and compare the difference, subtract it and use it to fit a system response. The system response could also be fitted as a combination of loop self response modelling, an exponential decay, and a damped single frequency oscillation. Once parameters are determined that fit well then a set of values for all gates can be saved. You can load field data from an averaged segment of data saved as a CSV file in ResImage or from a standard AgTEM System Test Station 8 CSV file or make your own CSV file.

Either: Simulate using an equation

| Key | Value |
|----------------|--------|
| LateTimeConst | 3E-005 |
| LateInitMagn | 3E-008 |
| RxTimeConst | 8E-007 |
| RxInitMagn | 2E-005 |
| OscillInitMagn | 4E-008 |
| OscillFreq | 22000 |
| OscillDamp | 20000 |
| LowPassFreq | 60000 |
| LowPassOrder | 1 |
| RxDelay_uS | 0 |

Noise StdDev @1ms (uV/(A.m²)) 2.00E-009
 Update Noise LogLog Noise Slope (V/s) -0.5

System Response Seed Type SysResp Exists
 Field - Fwd model Equation

After seeding, optionally, manually edit System Resp.

| # | Text | X | Y |
|----|-------------|-------|--------|
| 0 | -4.98363148 | 3.6 | -4.602 |
| 1 | 2.601311860 | 10 | 3.952 |
| 2 | 5.352017776 | 16.4 | 6.976 |
| 3 | -9.33986433 | 22.8 | -9.835 |
| 4 | -1.68250460 | 29.2 | -8.121 |
| 5 | -2.23984936 | 35.6 | -6.105 |
| 6 | -4.43876100 | 42 | -4.485 |
| 7 | -1.95 | | |
| 8 | -5.58 | | |
| 9 | -2.63043821 | 61.2 | -1.695 |
| 10 | -3.08331472 | 67.6 | -0.003 |
| 11 | 2.046412090 | 74 | 0.203 |
| 12 | 3.707931742 | 80.4 | 0.363 |
| 13 | 5.321390018 | 86.8 | 0.51 |
| 14 | 5.462312351 | 93.2 | 0.522 |
| 15 | 5.521720234 | 99.6 | 0.527 |
| 16 | 5.712690006 | 109.2 | 0.544 |
| 17 | 5.608703590 | 122 | 0.535 |
| 18 | 5.314745354 | 134.8 | 0.509 |
| 19 | 4.945168322 | 147.6 | 0.476 |
| 20 | 4.708495280 | 160.4 | 0.455 |
| 21 | 4.469965092 | 173.2 | 0.433 |

Or: Subtract Fwd Model from Field

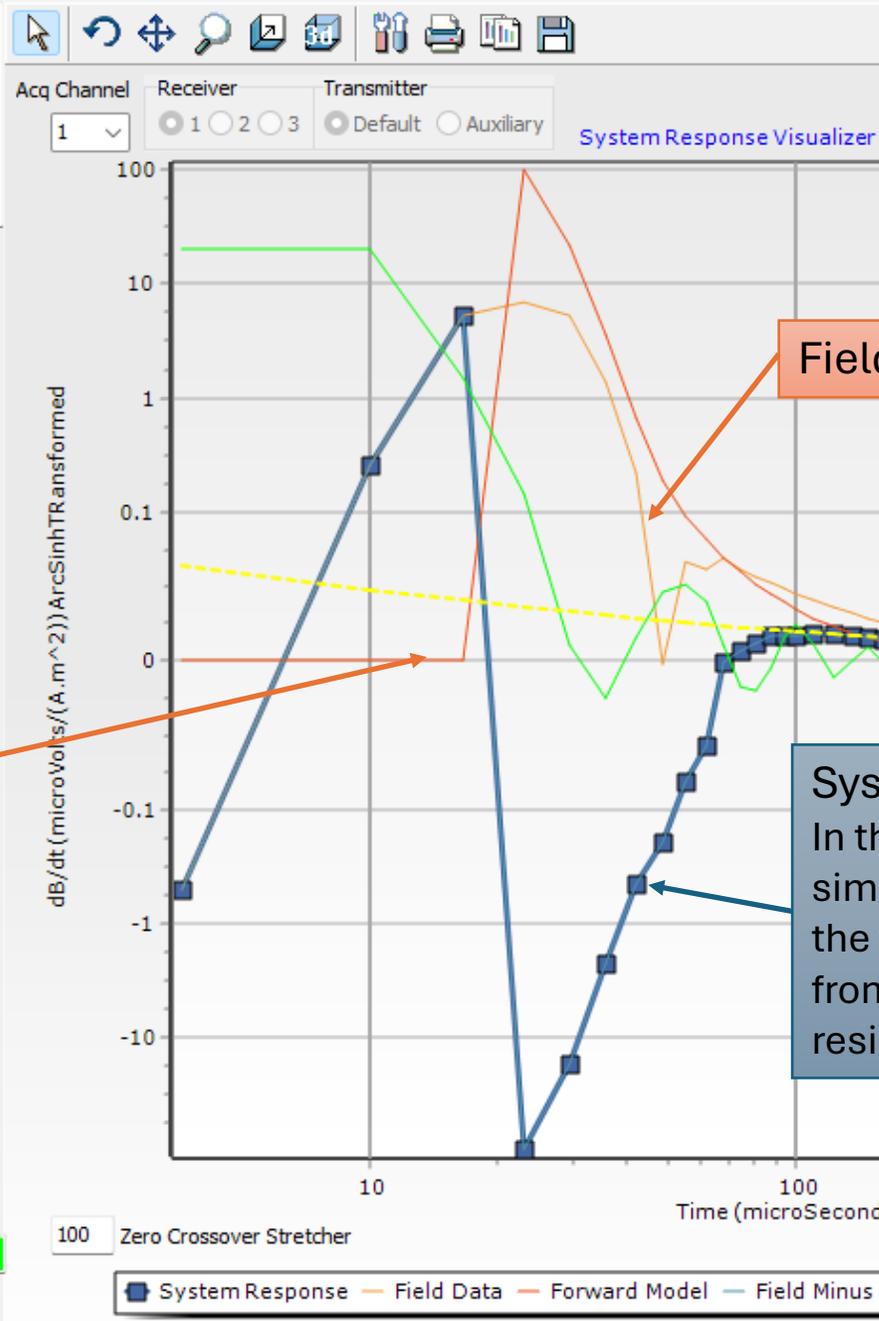
Model Layers 4

| Thickness(m) | Resistivity |
|--------------|-------------|
| 16 | 180 |
| 14 | 40 |
| 32 | 120 |
| inf | 20 |

Forward Model or Model Params
 Option: Run System Test
 Load Field Data Data Loaded
 Subtract Model from Field

Commit Changes for Displayed Acquisition Channel
 Option: Load System Response Save System Response

TEM Configurator System Response Evaluator



Forward Model

Field data

Noise
2e-9V/A.m²

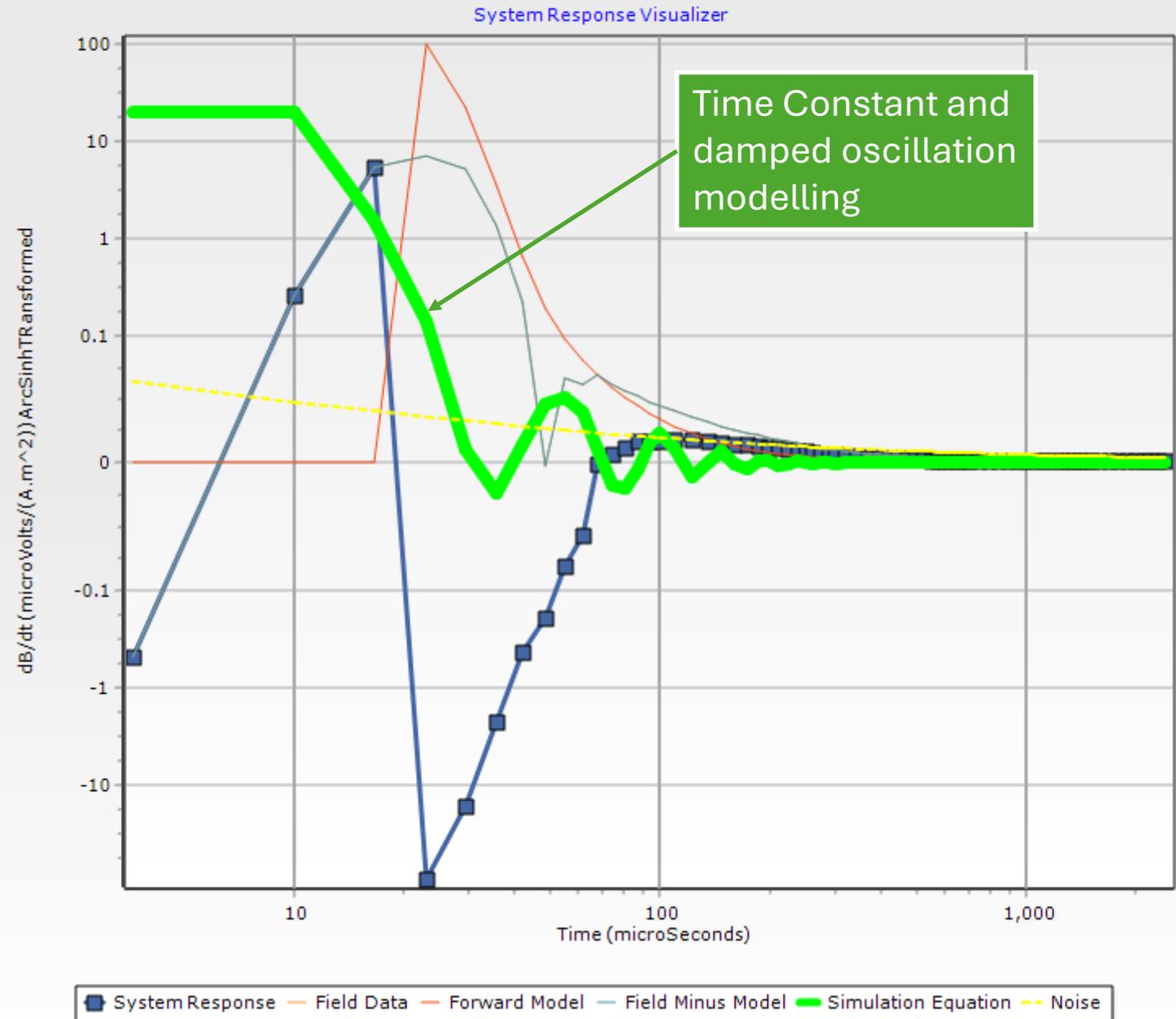
System response
In this case, from simple subtraction of the forward model from field data at a resistive site.

TEM Configurator System Response Evaluator

Modelling multiple time constants with damped oscillating resonance

This can be used to model and understand both designed and unwanted parasitic components of system response such as:

- loop self response,
- inductive coupling with the towing vehicle, and
- passing receiver loop wire too close to an inductor on a pre-amp.



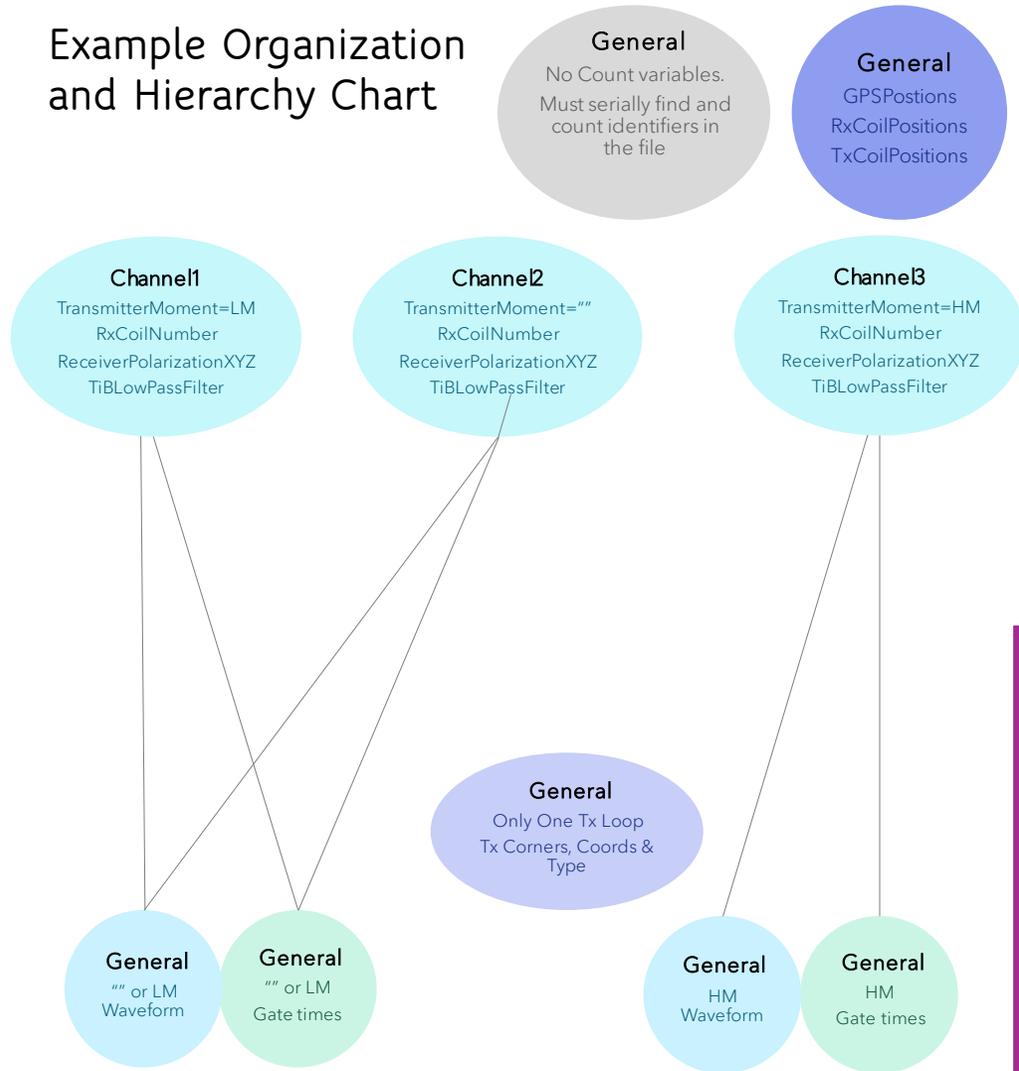
TEM Configurator Shorted Loop System Testing

AgTEM Wallaby In-loop system testing - shorted loop turn test. In this test a stored reference shorted loop decay constant response is compared with contrast of shorted loop measured data minus single loop data with the 2nd loop open circuit. This establishes a largely ground response free dataset for comparison. Noise data is plotted also for comparison. Observe that the shorted loop response excellently matches the decay constant equation response beyond where digital delays, ramp, and coil self-responses are significant.



TEM Configurator - GEX format

Example Organization and Hierarchy Chart



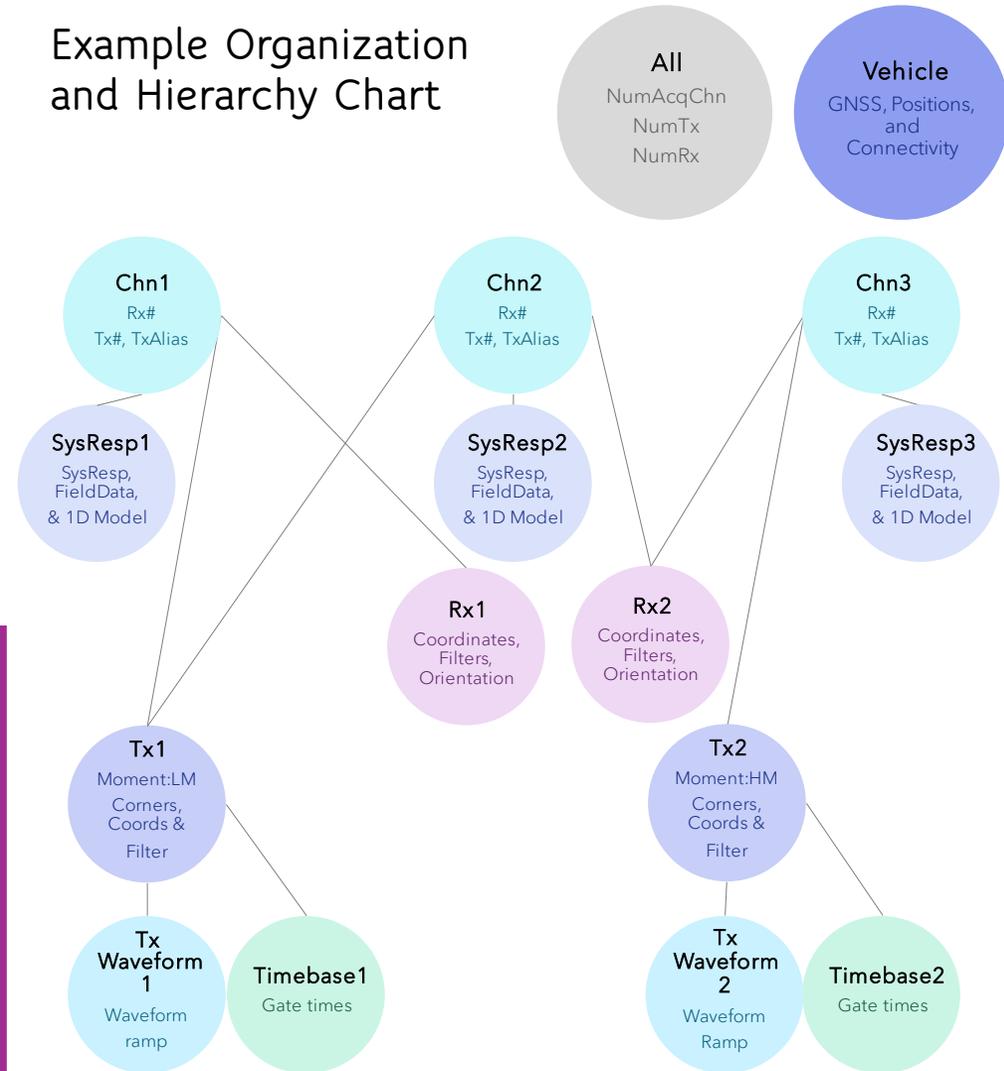
**TDC -
A new
data
format
for TEM
metadata**

TEM Configurator uses the new TDC data structure that logically and fully describes any TEM system.

It can also convert to and from legacy GEX format

TEM Configurator - TDC format

Example Organization and Hierarchy Chart



TEM Configurator – Type Curve Generation

- Type curves present potential field data responding to sets of earth models. TEM Configurator conducts 1D modelling using **AarhusInv64.exe** from Aarhus Hydrogeophysics Group.
- Presentation of type curves transformed to **Apparent Resistivity** versus $0.4 \times$ current ring **Loci Depth** helps us conceptualize how the earth is responding and to see sensitivity issues and equivalence complications
- Actual layered models are superimposed on the type curves.
- **Apparent Resistivity** is the resistivity that is expected from a homogeneous earth for the voltage detected.
- **Current ring loci depth** is the depth of greatest concentration of current in a ‘smoke ring’ of current diffusing into the ground after excitation from an artificial source such as a quickly shut down current in a loop of wire. We multiply by 0.4 as the receiver loop has greater sensitivity to the near surface.

EQUIPMENT DETAILS

Current Propagation Method
 TDEM Direct FDEM

C:\ProgramData\GW\ResImage\TEMConfigurator'

1D MODEL DETAILS

Number of Layers

For Multiple Models enter parameter ranges and log10 steps per decade

Only 8 models will be plotted

RESPONSE

AarhusInv64 location

AarhusInv64 Control File location

Temp Dir. for Fwd.TEM, Fwd.Mod and Fwd.Fwd

Acq Chn

Recalculate Responses

Save Input - Chn/DepthDBF

Noise StdDev @1ms ($\mu V / (A \cdot m^2)$) to add

Add Noise Noise Log Log Slope (V/s)

Save Output VoltDBF Save Output TXT

| Layer | Thickness(m) | Resistivity | to Thickness | to Resist. | Thick. Step | Resist. Step |
|-------|--------------|-------------|--------------|------------|-------------|--------------|
| 1 | 1 | 10000 | | | | 1 |
| 2 | 10 | 50 | 1000 | | 4 | 1 |
| 3 | ***** | 5 | ***** | | ***** | 1 |

TEM Configurator Forward modelling Type Curve Generation

| Window | Voltage | App.Res.l | Loci Depth | Time |
|--------|------------|-----------|------------|-----------|
| 63 | 2.596E-010 | 6.53401 | 132.569 | 0.00169 |
| 64 | 2.231E-010 | 6.55317 | 136.727 | 0.0017924 |
| 65 | 1.932E-010 | 6.57513 | 140.813 | 0.0018948 |
| 66 | 1.685E-010 | 6.59908 | 144.831 | 0.0019972 |
| 67 | 1.478E-010 | 6.62543 | 148.794 | 0.0020996 |
| 68 | 1.304E-010 | 6.65383 | 152.705 | 0.002202 |
| 69 | 1.156E-010 | 6.68356 | 156.564 | 0.0023044 |
| 70 | 1.03E-010 | 6.71467 | 160.377 | 0.0024068 |

Forward Modelling generates sets of type curves essential for providing geophysicists with knowledge of response of their systems. This helps with system design, appropriation, and calibration.

For system response determination, a test site with known resistivity/depth model is surveyed. Forward modelling is conducted with the exact system description and discrepancy between the forward model and real field data is analysed. Numerous parameters may be adjusted until a suitable fit is obtained. Finally a smoothed fit

Yet to add: Column for model 1 minus model 2, columns for gate specific system noise, column for (1-2)/gatenoise and a label for $\text{sum}(\text{abs}(1-2)/\text{gatenoise})/(\text{avg}(\text{noise})/\text{numchn})$. This will answer the question 'Can a system detect a defined percentage change in resistivity or thickness of a particular layer.'

TDEM Voltages are given in $V/(A \cdot m^2)$ where m^2 refers to effective receiver area. Consider that noise will be in these units too, not $\mu V/A$ like in datafiles.

Sum of gate detectability (1-2)/Noise

 **Close**

Homogeneous half space mathematics

Terminology:

- **Homogeneous Half Space** – Just imagine the earth beneath the surface as if it was all the same. It is a common concept used in geophysics where all the sensors are on the surface.
- **Apparent Resistivity** – The resistivity that could be calculated from a voltage received by an instrument if the earth was homogeneous.
- **Effective Depth** – The depth by which 50% of signal to an instrument is contributed, assuming the earth is homogeneous.

Depth for TEM

Diffusion Depth – The depth at which maximum current flows in the earth in a transient electromagnetic system at a time after current in a horizontal loop is switched off. In TEM systems this is dependent on earth resistivity and simple calculations assume a homogeneous earth. It is not the same as effective depth as receiver loops disproportionately sense in their proximity.

Loci Depth – Old terminology for diffusion depth (definition may be slightly different)

$$d = \sqrt{\frac{2t\rho_a(t)}{\mu}}$$

1D Imaging of Central Loop Transient
Electromagnetic Sounding.
Niels B. Christensen
Aarhus University, Department of Earth
Sciences, Laboratory of Geophysics

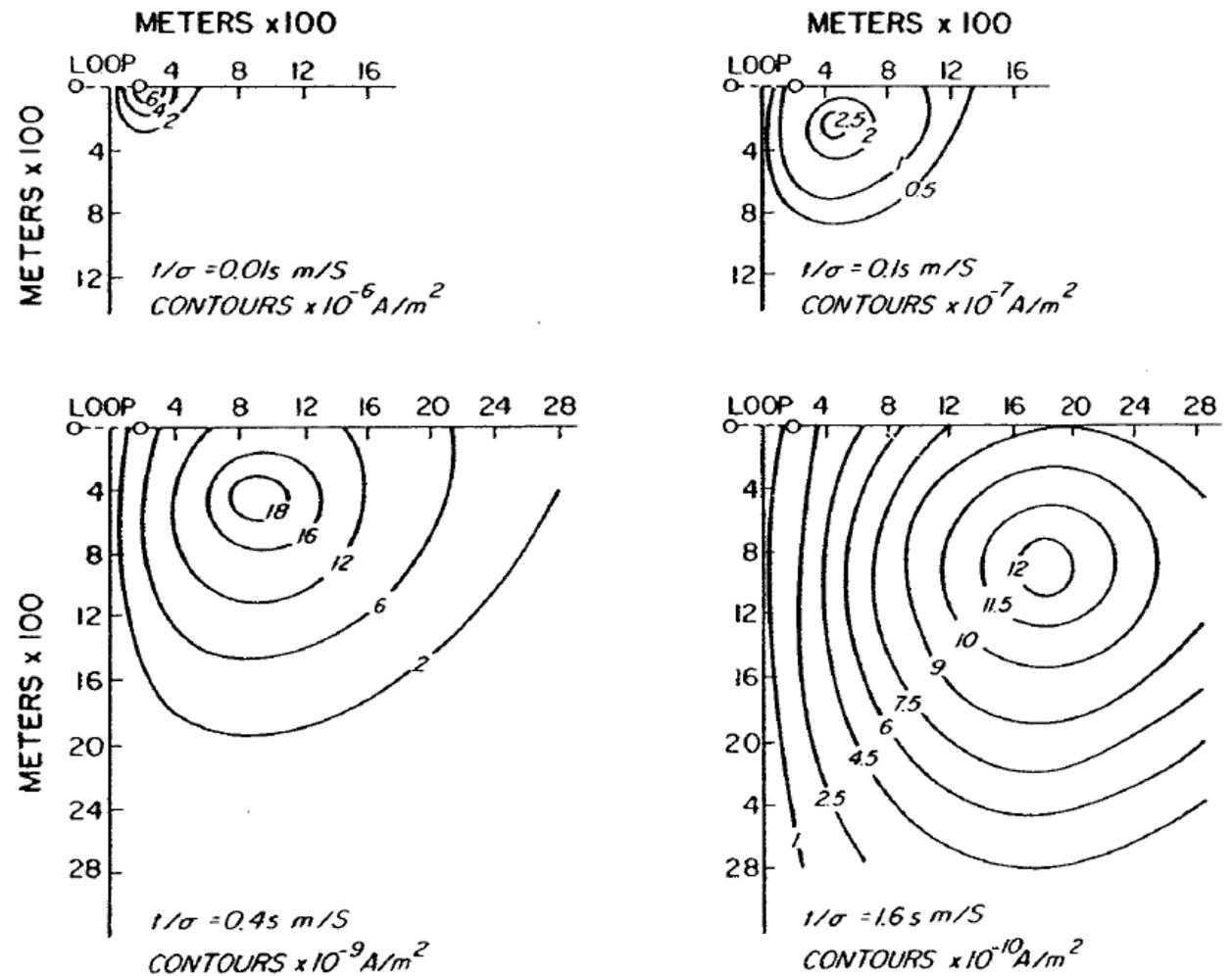


Fig. 19. Contours of the current density in the "smoke ring" of current induced in a uniform conductive half space by a step transient current in a horizontal transmitter loop. Four snapshots in time are provided. The induced current is flowing azimuthally around the vertical axis of the loop, i.e., normal to the plotted section (after Nabighian, 1979).

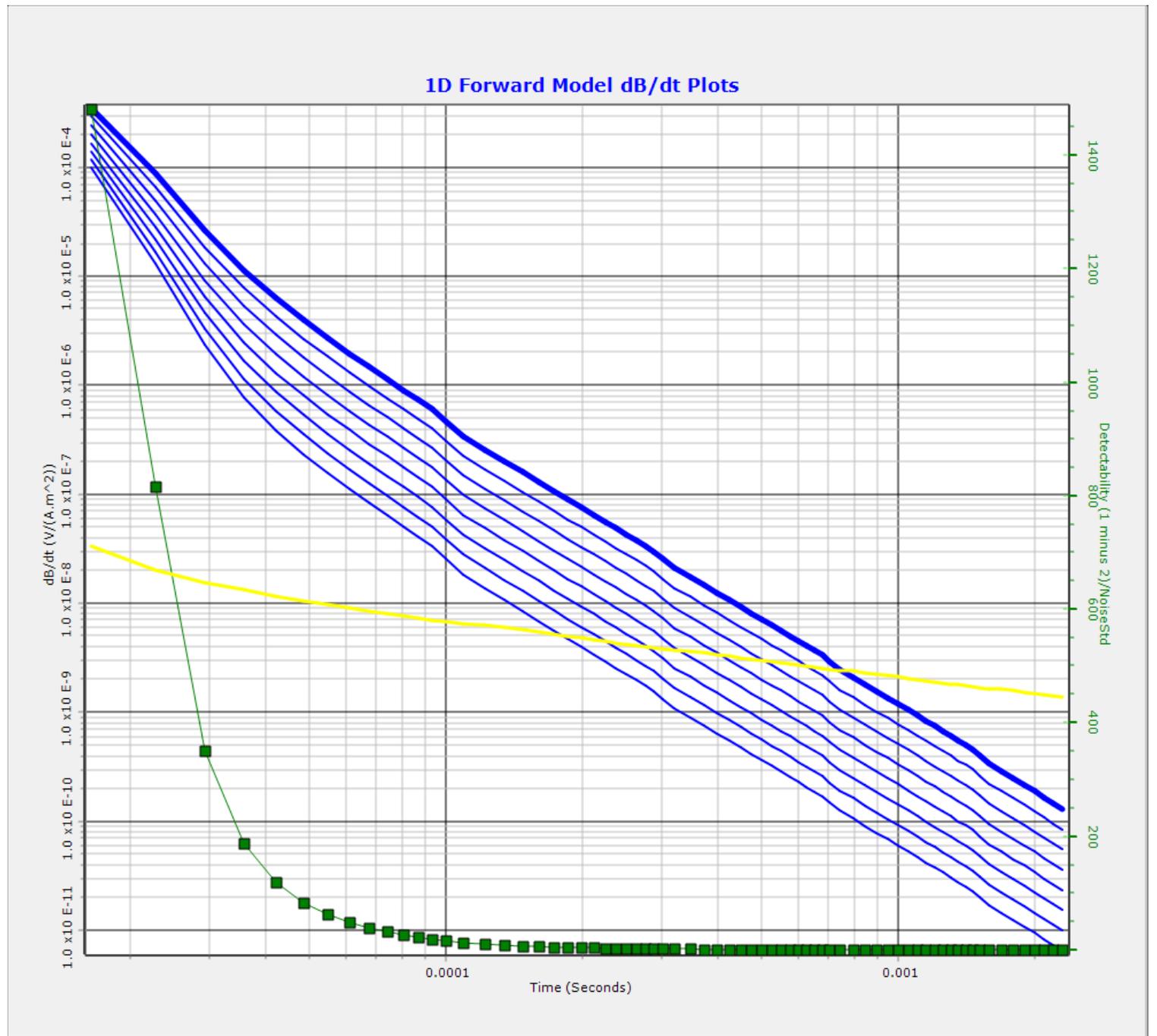
From: **PHYSICS OF THE ELECTROMAGNETIC INDUCTION
EXPLORATION METHOD**

G. F. West* and J. C. Macnae[†]

TEM Configurator Forward Models of Halfspaces

Halfspace Model
Resistivities:
Starting with the
bold line are:

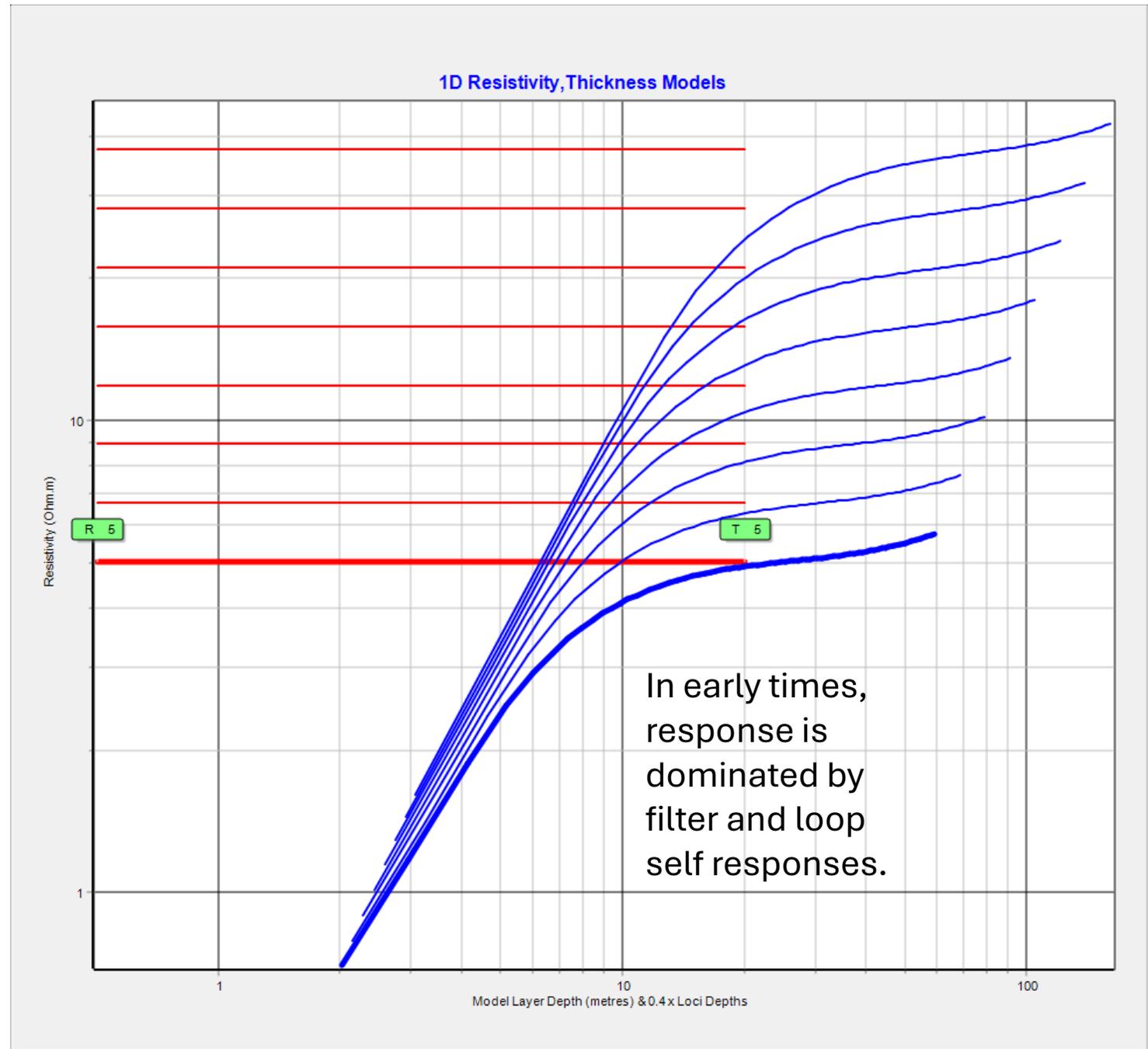
- 1 – 5.0 ohm.m
- 2 – 6.7 ohm.m
- 3 – 8.9 ohm.m
- 4 – 11.9 ohm.m
- 5 – 15.8 ohm.m
- 6 – 21.1 ohm.m
- 7 – 28.1 ohm.m
- 8 – 37.5 ohm.m



TEM Configurator Forward Models of Halfspaces

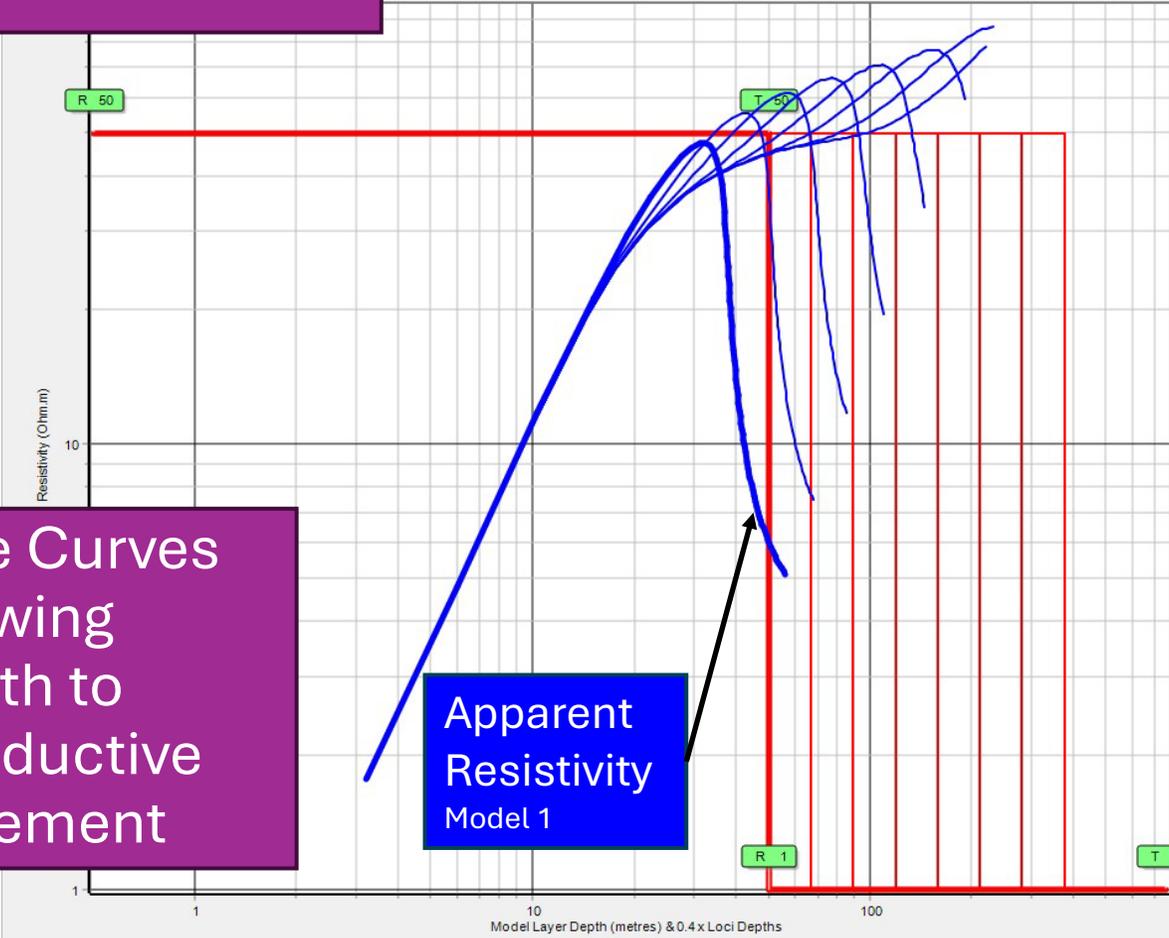
Halfspace Model
Resistivities:
Starting with the
bold line are:

- 1 – 5.0 ohm.m
- 2 – 6.7 ohm.m
- 3 – 8.9 ohm.m
- 4 – 11.9 ohm.m
- 5 – 15.8 ohm.m
- 6 – 21.1 ohm.m
- 7 – 28.1 ohm.m
- 8 – 37.5 ohm.m



TEM Configurator

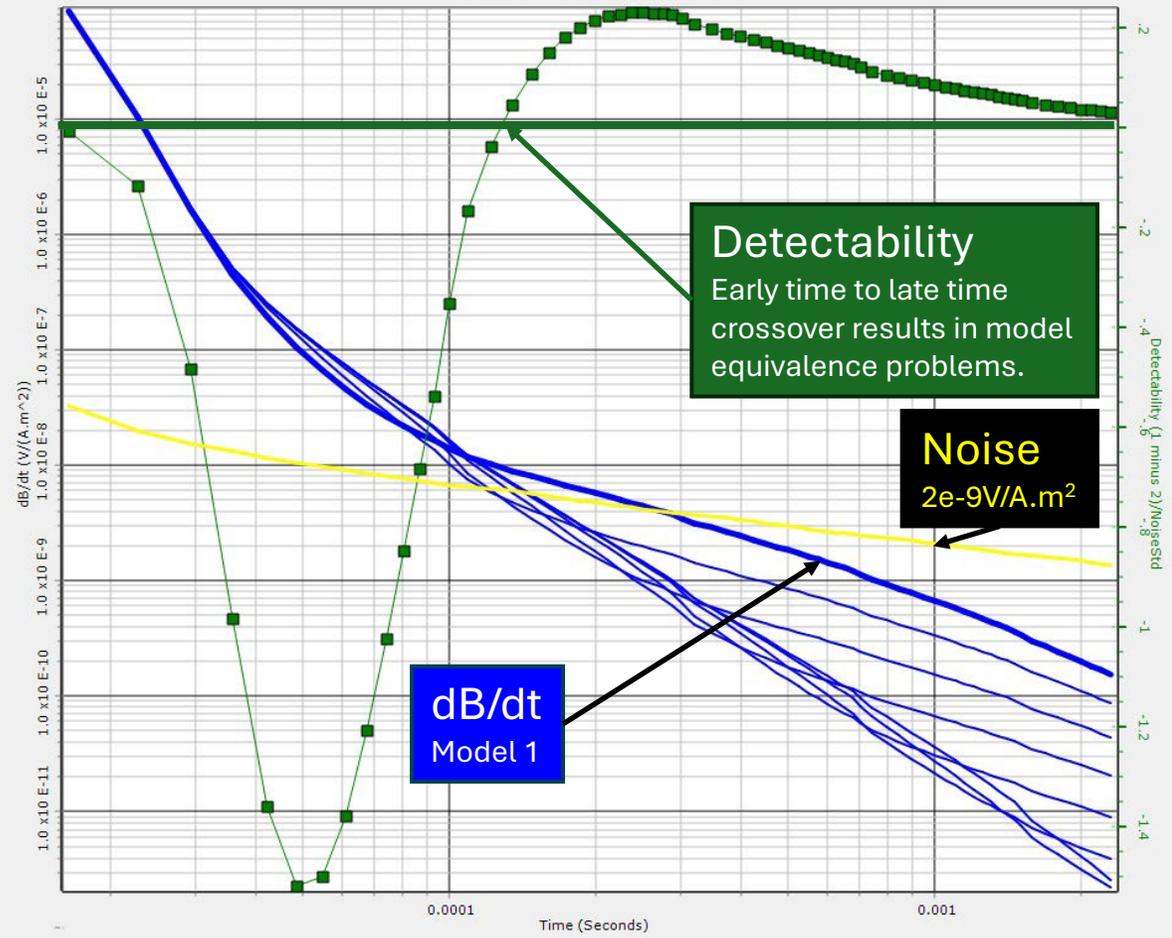
1D Resistivity, Thickness Models



Type Curves showing Depth to Conductive Basement

Apparent Resistivity Model 1

1D Forward Model dB/dt Plots



Detectability Early time to late time crossover results in model equivalence problems.

Noise $2e-9V/A.m^2$

dB/dt Model 1

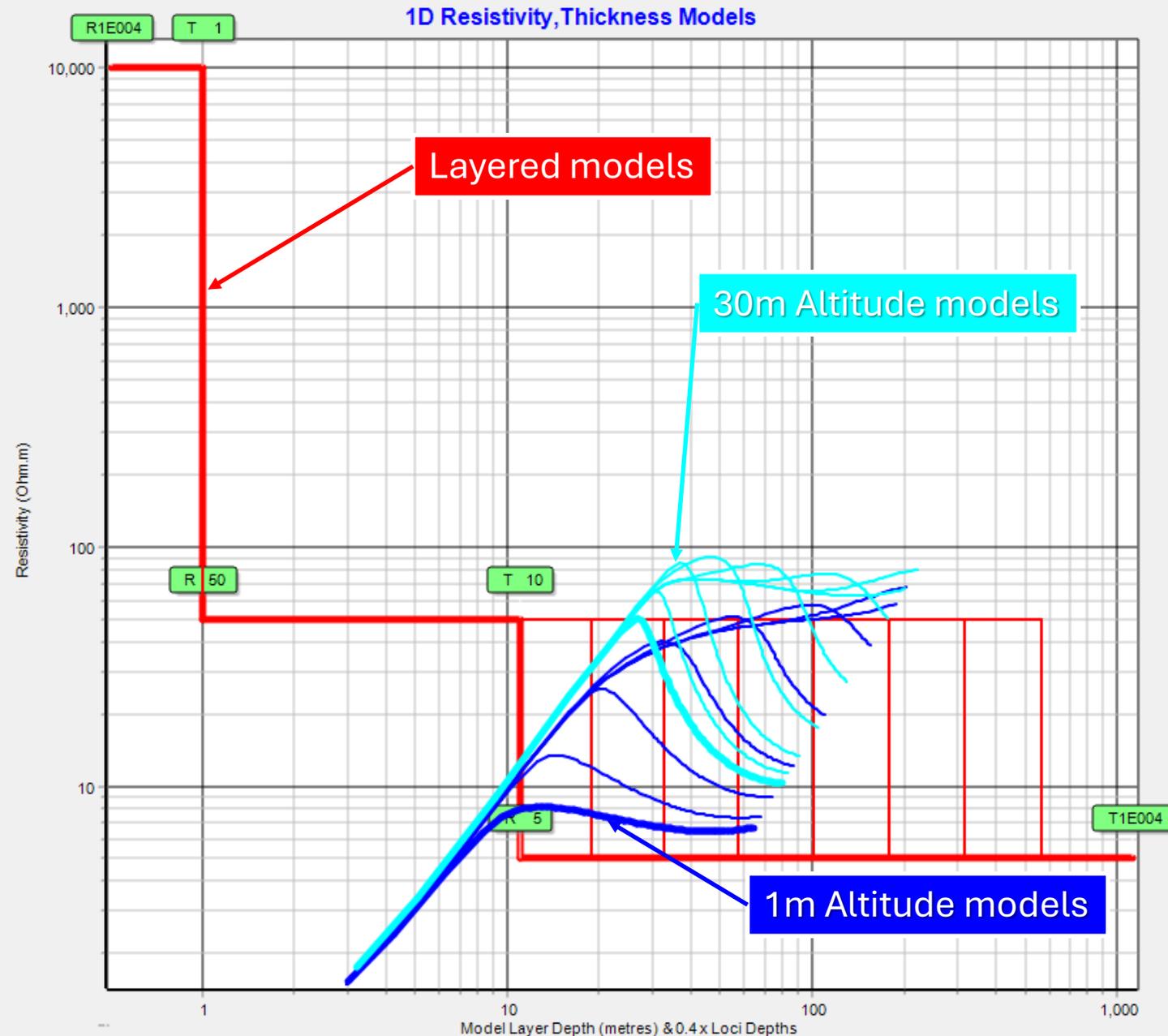
| Layer | Resistivity | Thickness |
|------------|-------------|---|
| 1-Alluvium | 50 Ohm.m | 50m 67m 89m 115m 158m 211m 281m 375m |
| 2-Basement | 1 Ohm.m | infinite |

Noise: $2e-9$ @ 1mS with slope of 0.5

Evaluation of a detectability curve (Green) for a given noise threshold (Yellow) for forward models (Blue) of layered models (Red) as given in the table included for Wallaby In-loop configuration with 36 Amps and one Tx loop turn. The left graph presents forward models as late time apparent resistivity versus $0.4 \times$ Loci Depth while the right graph presents the same forward models as dB/dt versus time. Detectability is calculated contrasting the heavy blue curve with the adjacent curve. The noise threshold in this example is high such as is typical for short stack times and rapid travel over rough ground.

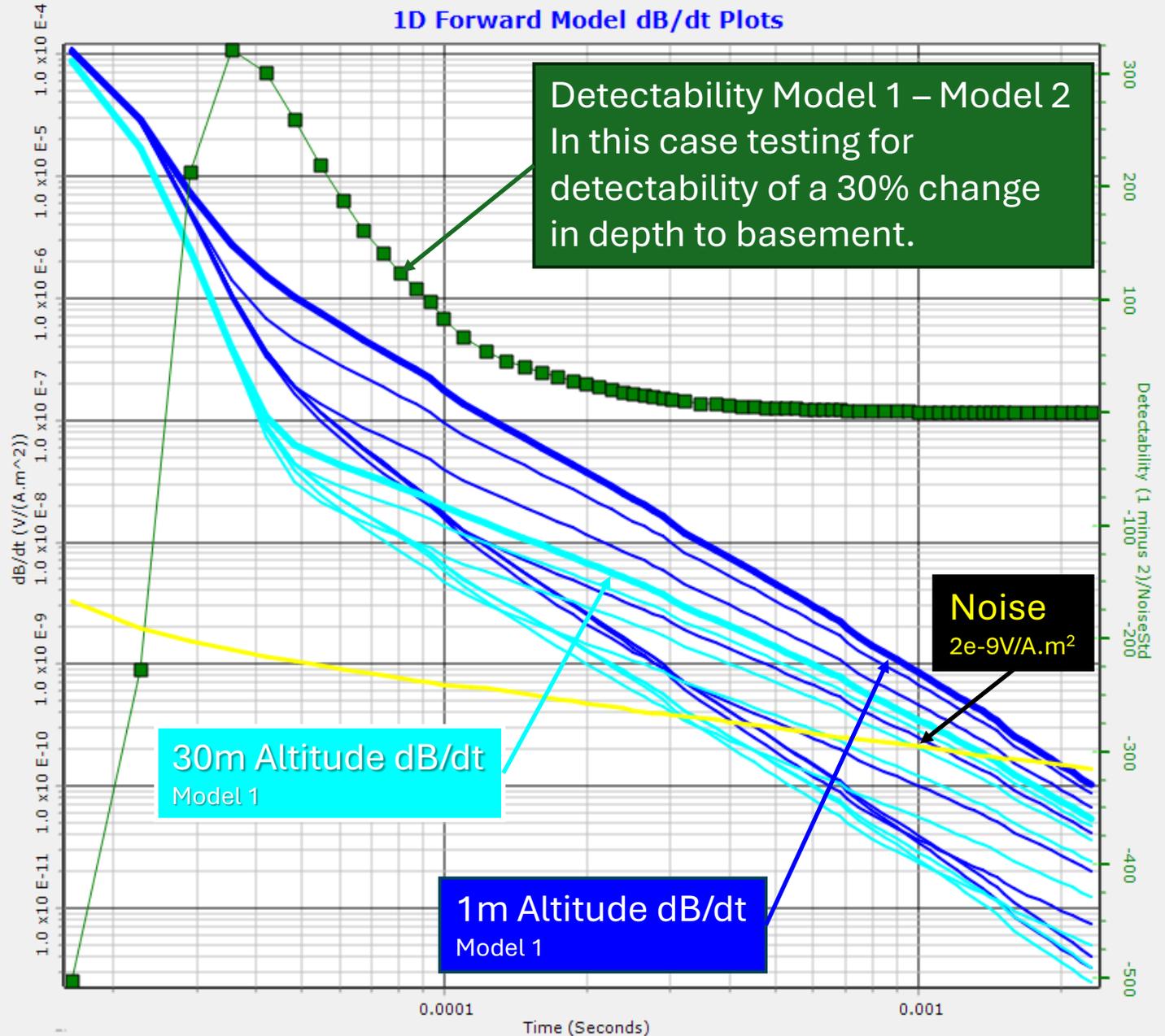
TEM Configurator 30m altitude versus 1m altitude

A resistivity versus $0.4 \times \text{loci depth}$ example from the forward modeller. Red lines present modelled resistivities and depths, green boxes display resistivity of the layer below, and thickness of the layer above each box. Type curves for eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne.



TEM Configurator 30m altitude versus 1m altitude

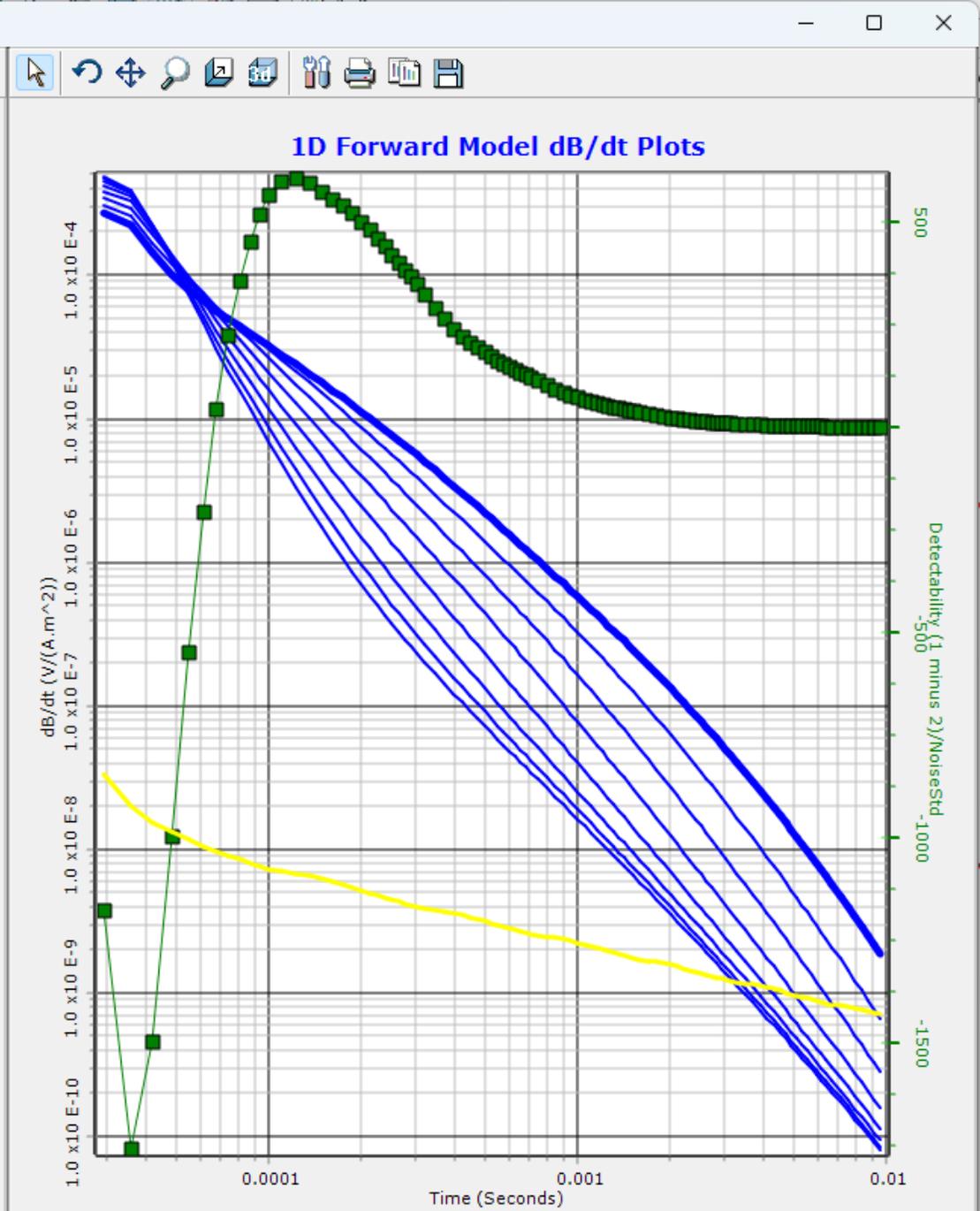
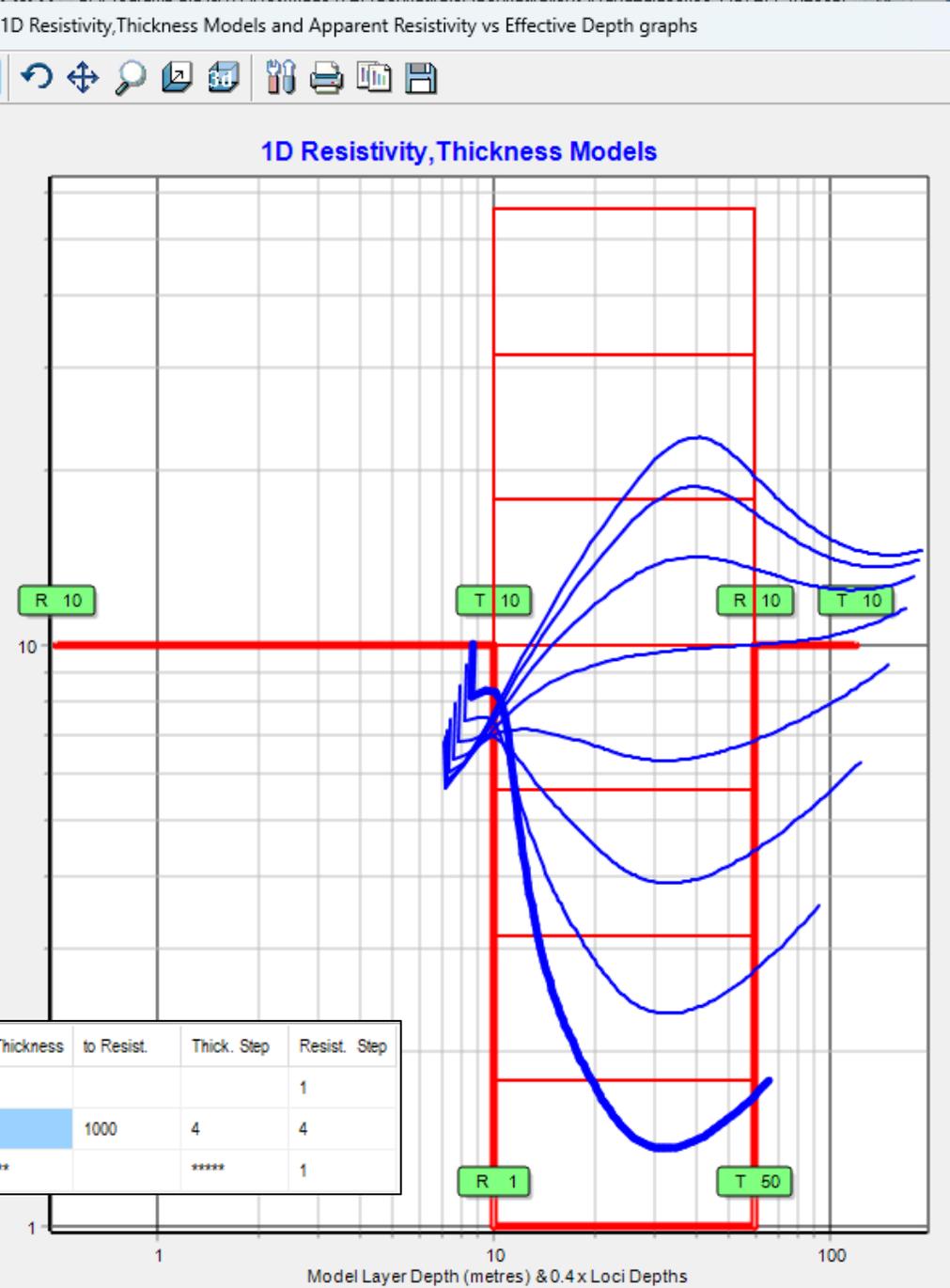
For the models in the previous graph, this is example from the forward modeller of dB/dt versus time type curve generation. Eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne. A green detectability curve displays relative contrast between model 1 and 2 normalized to noise standard deviation, which is provided in the yellow curve.



TEM Configurator

Type curves

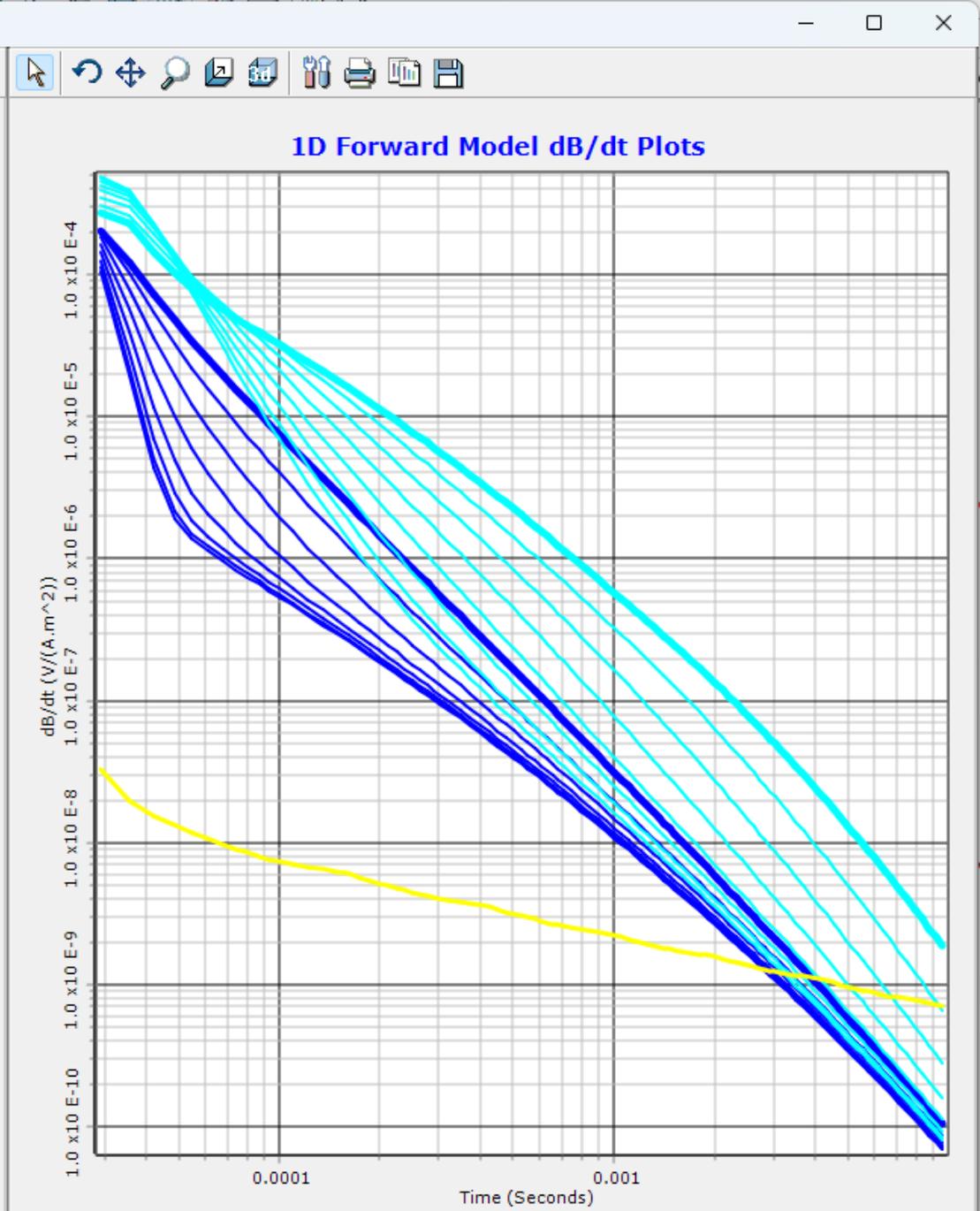
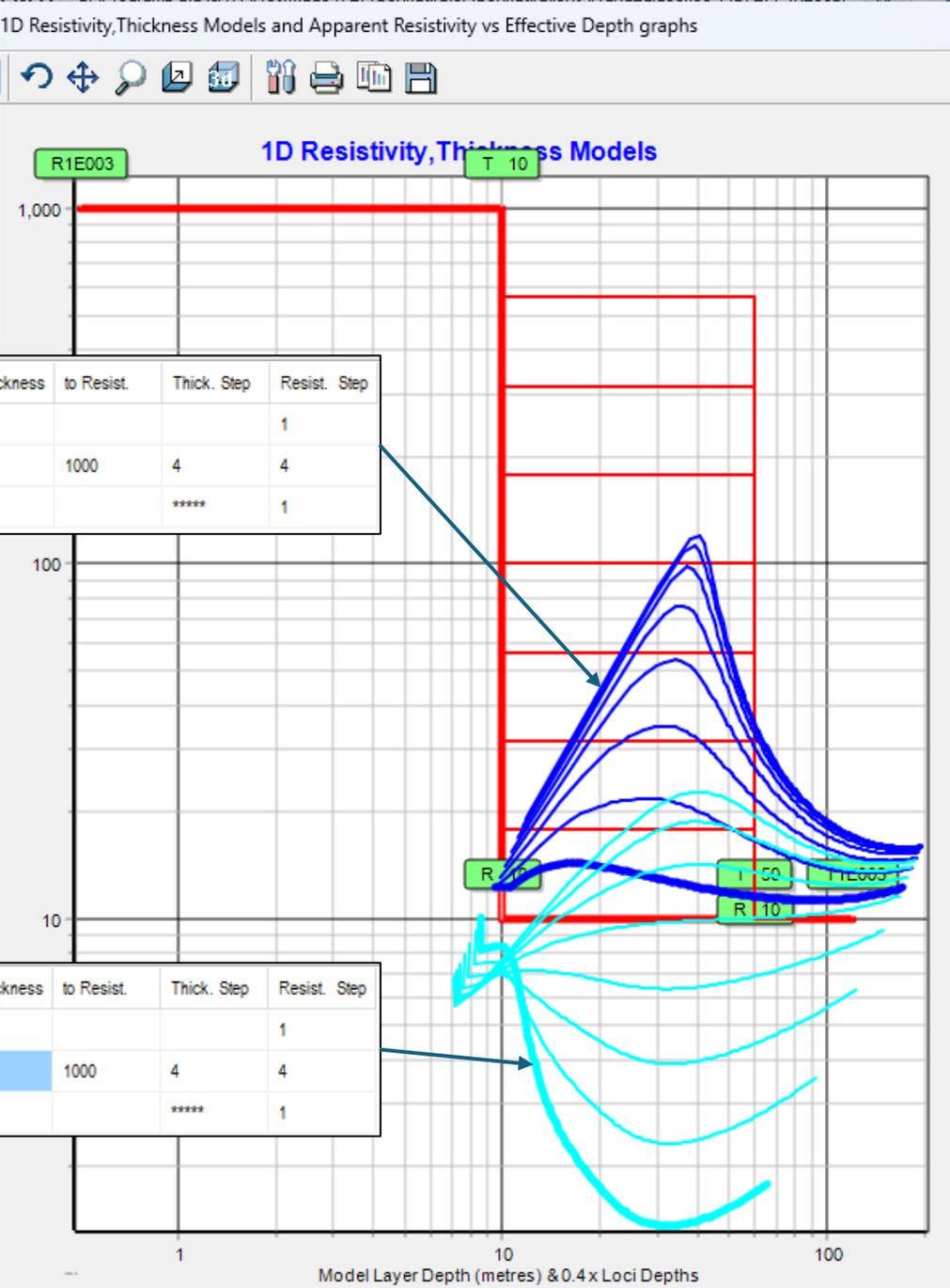
with layers:
 1: Neutral
 2: Conductive to Resistive
 3: Neutral



TEM Configurator

Type curves

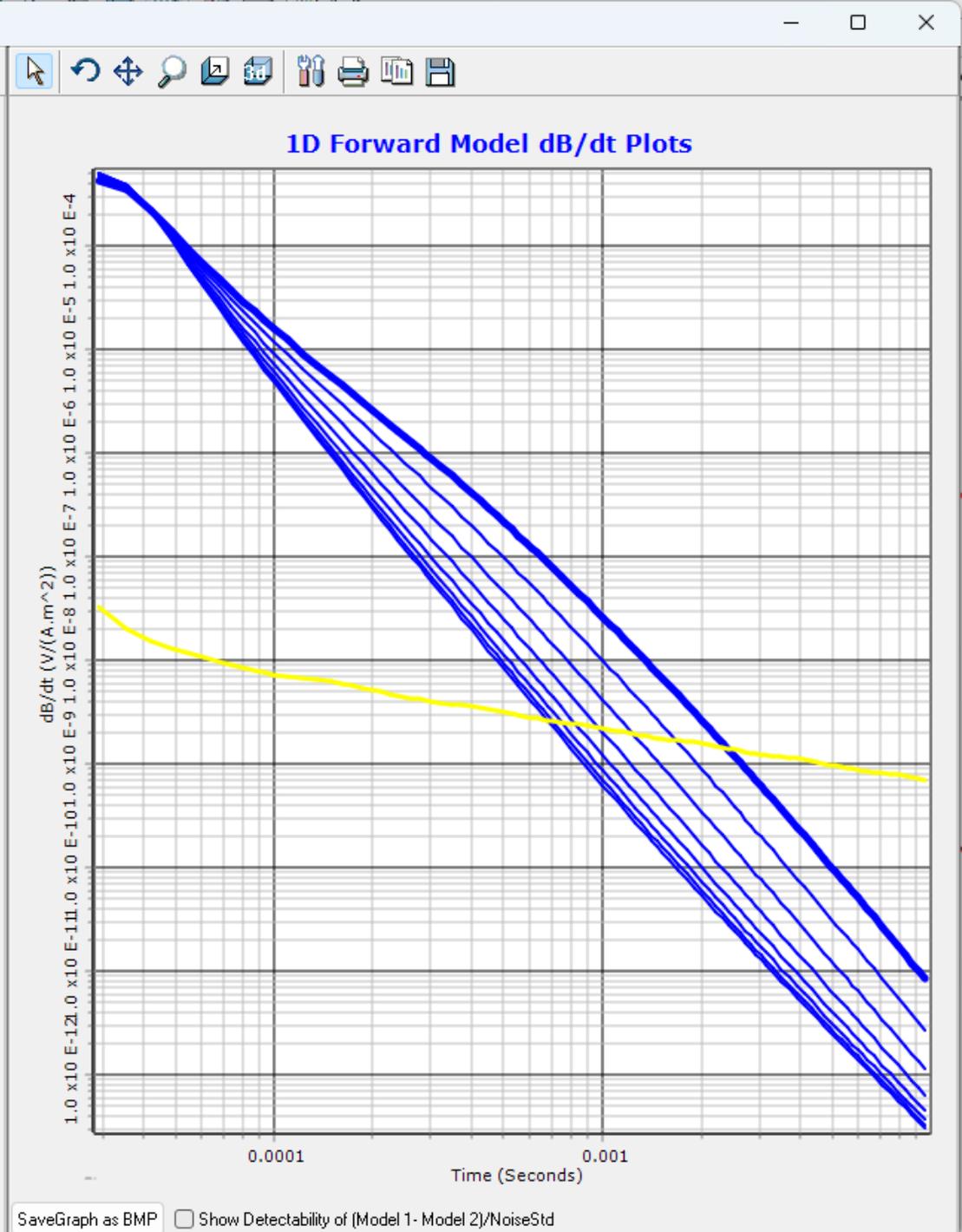
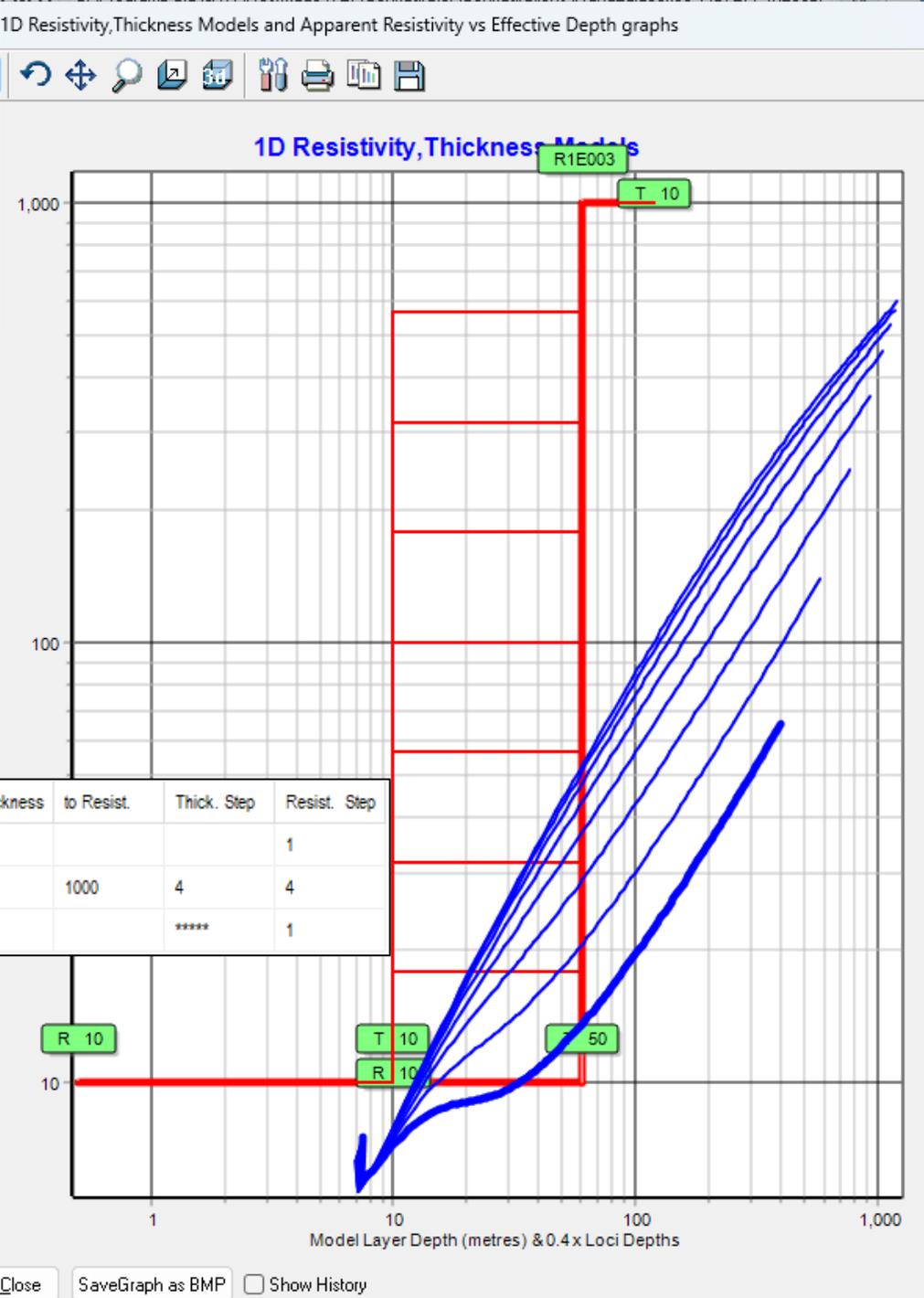
with layers:
 1: Resistive
 2: Conductive to Neutral
 3: Neutral (10 ohm.m)



TEM Configurator

Type curves

with layers:
 1: Neutral (10 ohm.m)
 2: Neutral to Resistive
 3: Resistive



Blue - Receiver Axes with X-Orientation.

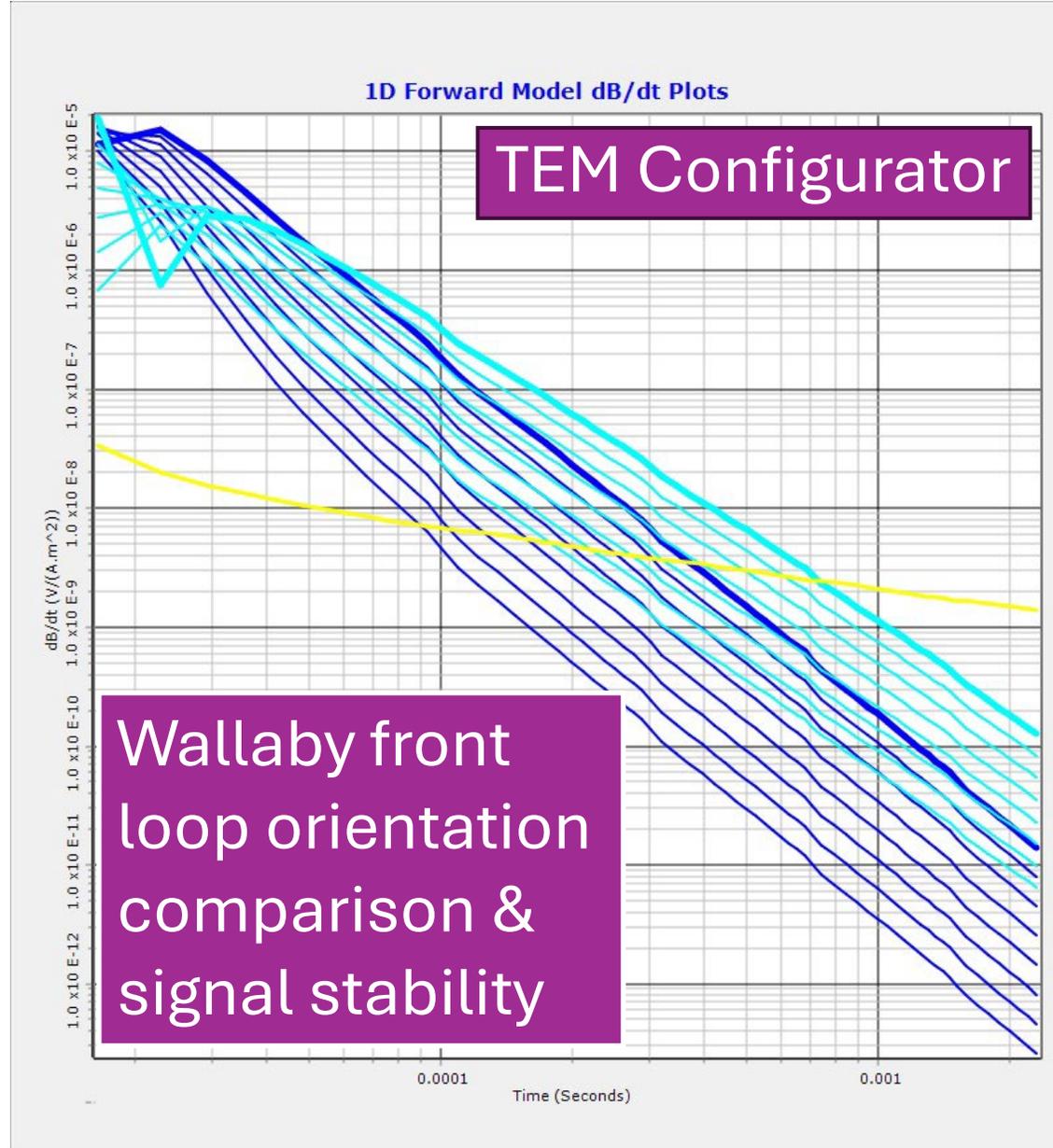
Aqua - Receiver Axes with Z-Orientation.

Yellow - Noise @ $1\text{mV}=2\text{e-}9\text{ V}/(\text{A.m}^2)$ with 0.5slope.

In early channels, X-Orientation signal dominates making Z-Orientation data sensitive to tilting.

Note that X-Orientation could also have a dominance of metal vehicle response as it couples axially with the vehicle.

Observing this data we can see that a 20 degree pitch change will change the $2.8\text{e-}5$ z-component data at $30\mu\text{s}$ over a 5 ohm.m half space to $(2.8\text{e-}5) \cdot (\cos(20)) + (8.0\text{e-}5) \cdot \sin(20) = 5.36\text{e-}5$ or 1.91 time of the correct value. On tussocky or ploughed ground a 20 degree tilt on a short base sled is common.



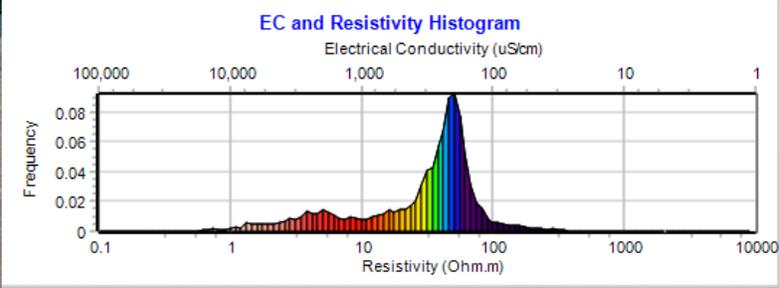
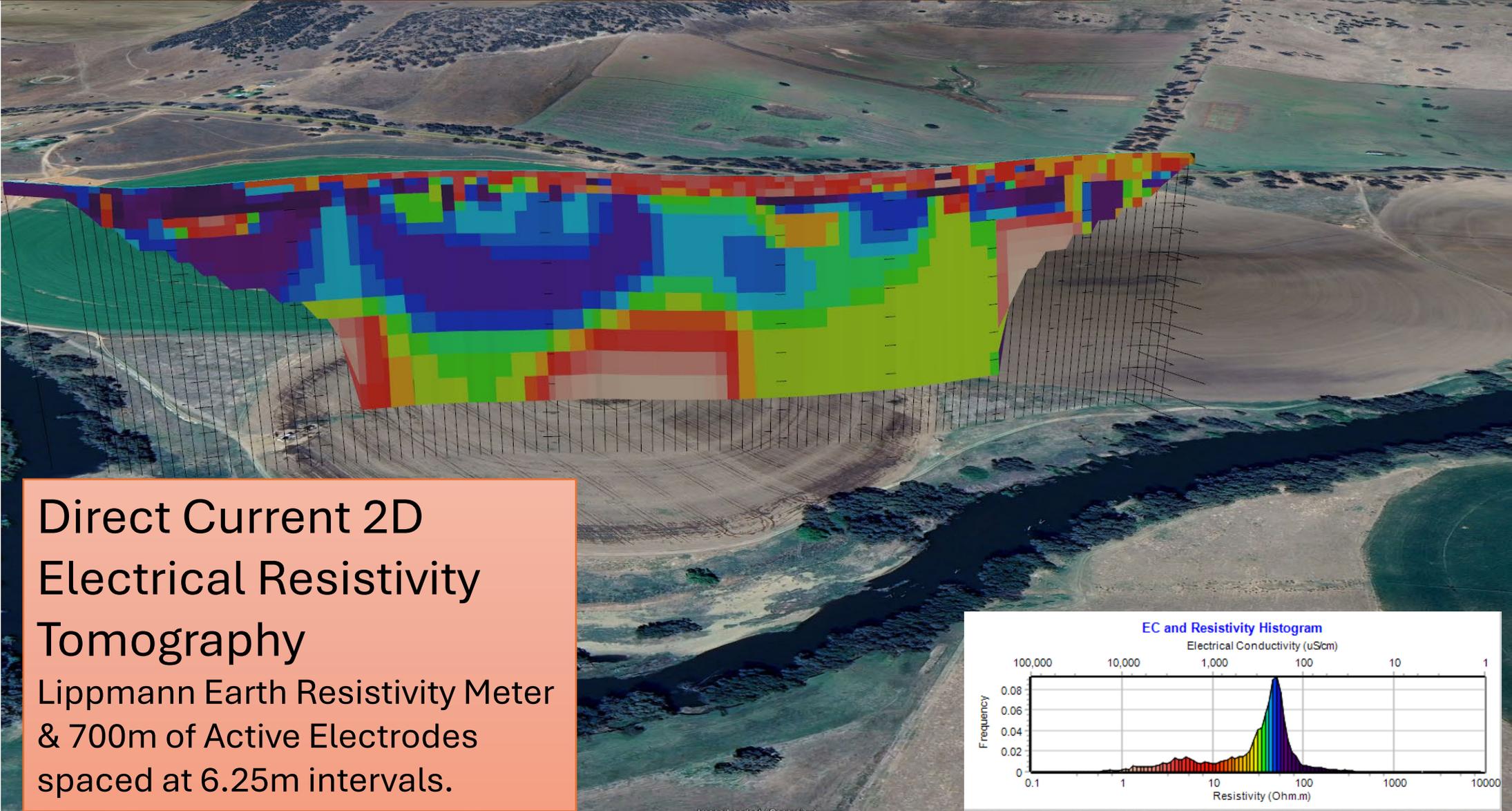
Halfspace Model Resistivities:
Starting with the bold line are:

- 1 – 5.0 ohm.m
- 2 – 6.7 ohm.m
- 3 – 8.9 ohm.m
- 4 – 11.9 ohm.m
- 5 – 15.8 ohm.m
- 6 – 21.1 ohm.m
- 7 – 28.1 ohm.m
- 8 – 37.5 ohm.m

This analysis is also relevant to other instruments. tTEM, which has ONLY a Slingram Z-component loop, is vulnerable to Z and X orientation mixing as the short-base sled pitches across rough ground. Loupe collects only Slingram data but in three components and they model data as change in total field, thus eliminating the orientation sensitivity problem. An additional problem, however, is generated when a relatively low sensitivity coil is used to detect X-orientation data and the high noise on this component is mixed into total field data, unduly affecting the noise floor.

Calibrating towed TEM data: Test site data

**Direct Current
Electrical
Resistivity
Tomography –
Zhou array
configuration.
Modelled
resistivity is
projected up
160m**



Test site data

Hand Laid 50 x 50 m Loop TEM

Transient Electromagnetics with 50m x 50m hand laid loops. Modelled resistivity projected up 160m. This image is modelled with system response corrected to reveal the near surface conductive layer for which loops of this dimension are otherwise unable to discriminate very effectively. The aqua colour line represents depth of investigation characteristic.

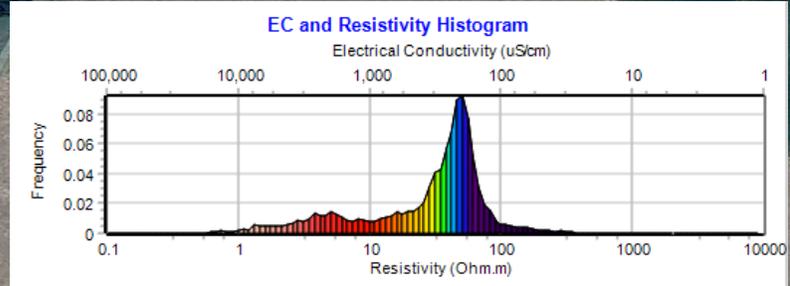
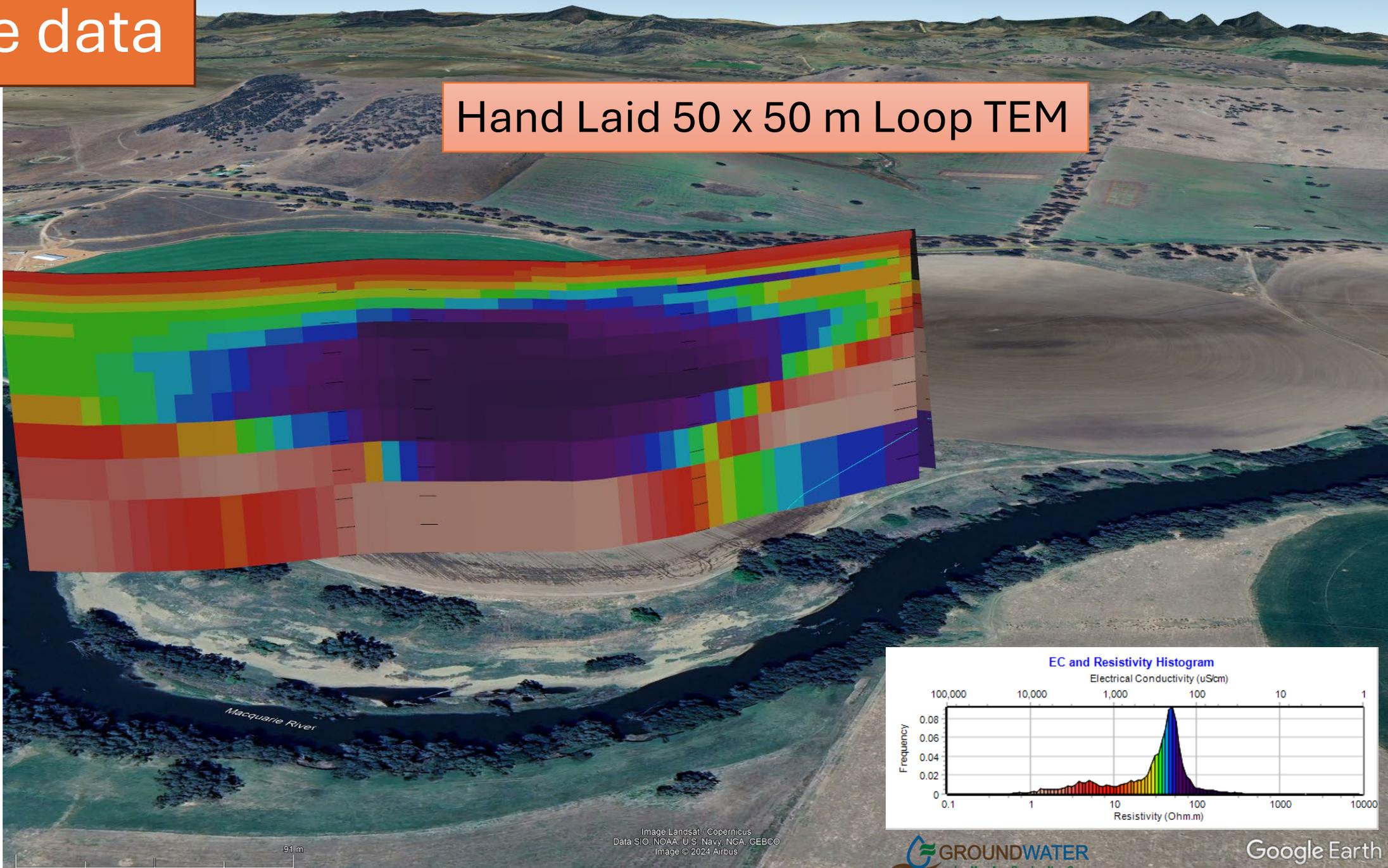


Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2024 Airbus

Test site data

Determining a layered model at the test site to forward model.

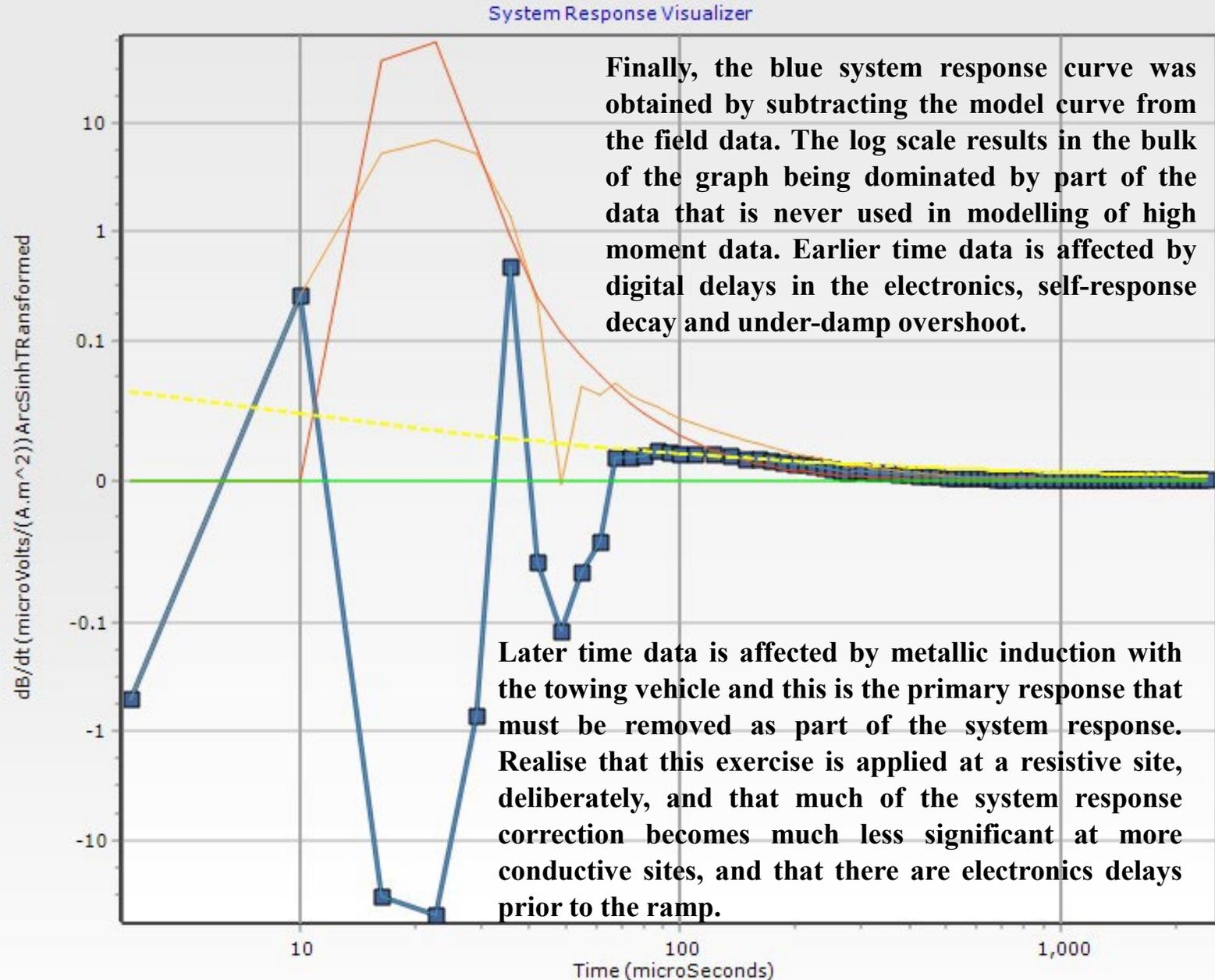
| Zhou | | | Wenner | | | TEM 50 x 50 | | | Fwd Model | | |
|------|-----|-----|--------|-----|-----|-------------|-----|------|-----------|-----|-----|
| From | To | Res | From | To | Res | From | To | Res | From | To | Res |
| 0 | 16 | 180 | 0 | 10 | 200 | 0 | 30 | 1000 | 0 | 16 | 180 |
| 16 | 30 | 40 | 10 | 20 | 50 | 30 | 60 | 15 | 16 | 30 | 40 |
| 30 | 72 | 120 | 20 | 60 | 120 | 60 | 70 | 5 | 30 | 62 | 120 |
| 72 | inf | 20 | 60 | inf | 45 | 70 | inf | 30 | 62 | inf | 20 |

In_loop Receiver
20xGain
20 turn

Test site data

High moment (38 Amps x 32m²) Wallaby system response assessment for the in-loop receiver with 20 turns and 20x pre-amplification. Field data is displayed in orange, assessed noise threshold in yellow, and the forward model in red

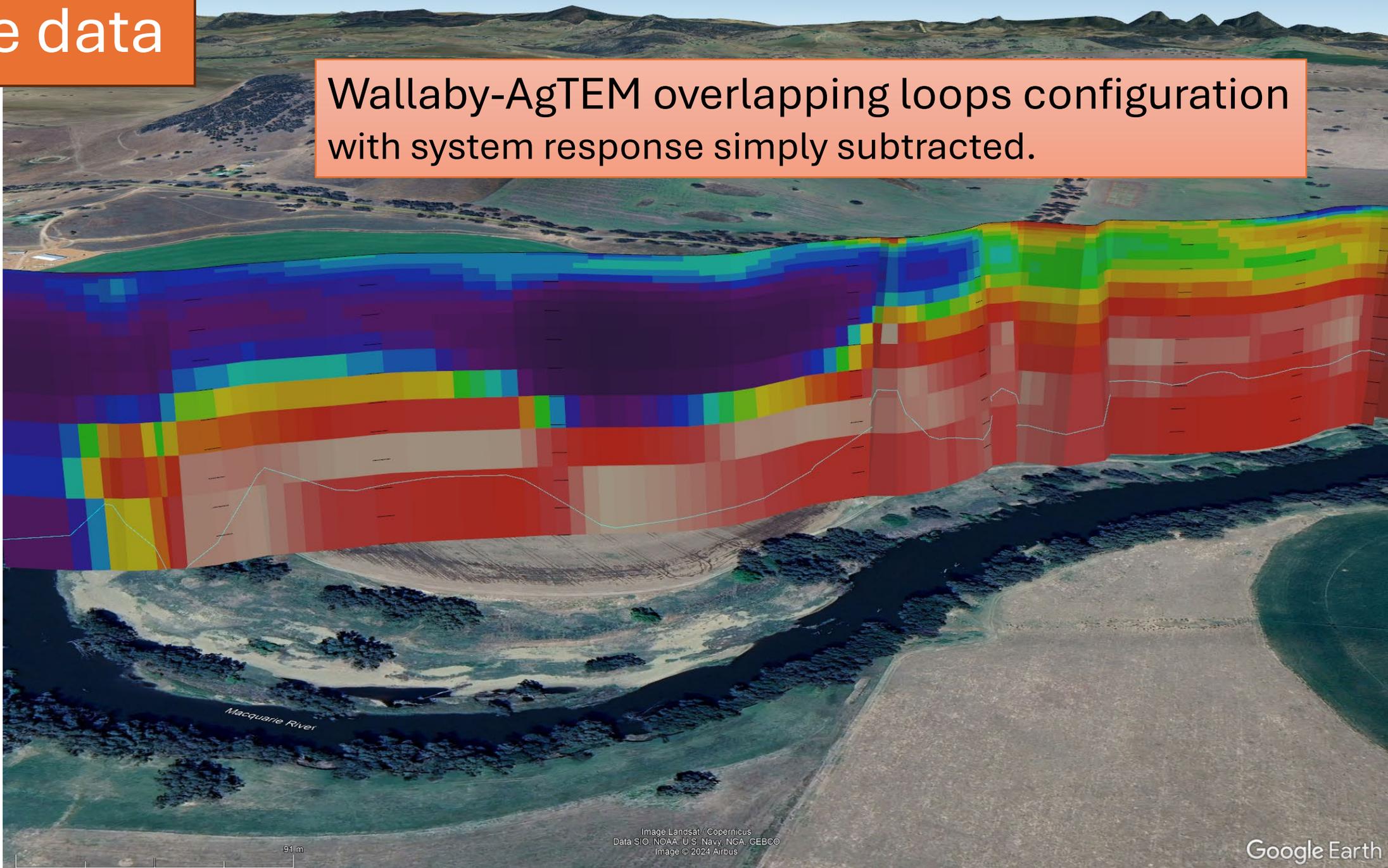
| Thickness(m) | Resistivity |
|--------------|-------------|
| 16 | 180 |
| 14 | 40 |
| 32 | 120 |
| inf | 20 |



Test site data

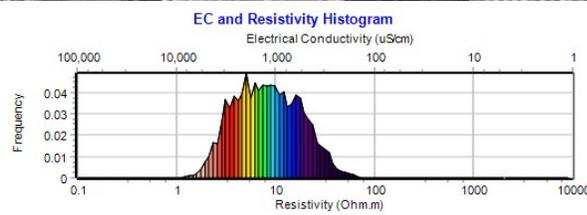
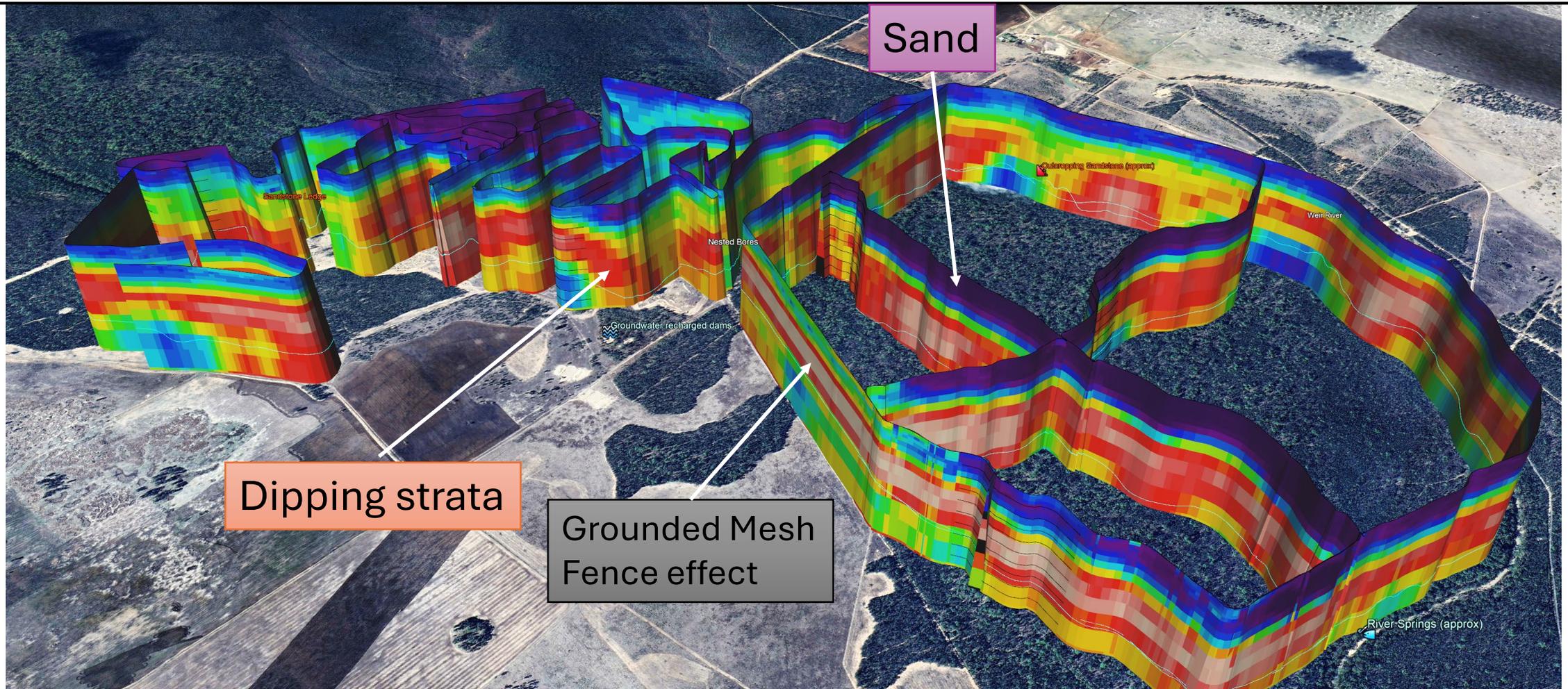
Wallaby In-Loop transient electromagnetics. Modelled Resistivity projected up 160m (525 feet), 2 Parallel 1 Series Turns, 38Amps, 150 Watts

Wallaby-AgTEM overlapping loops configuration with system response simply subtracted.



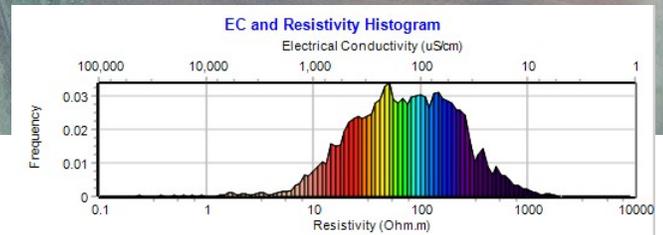
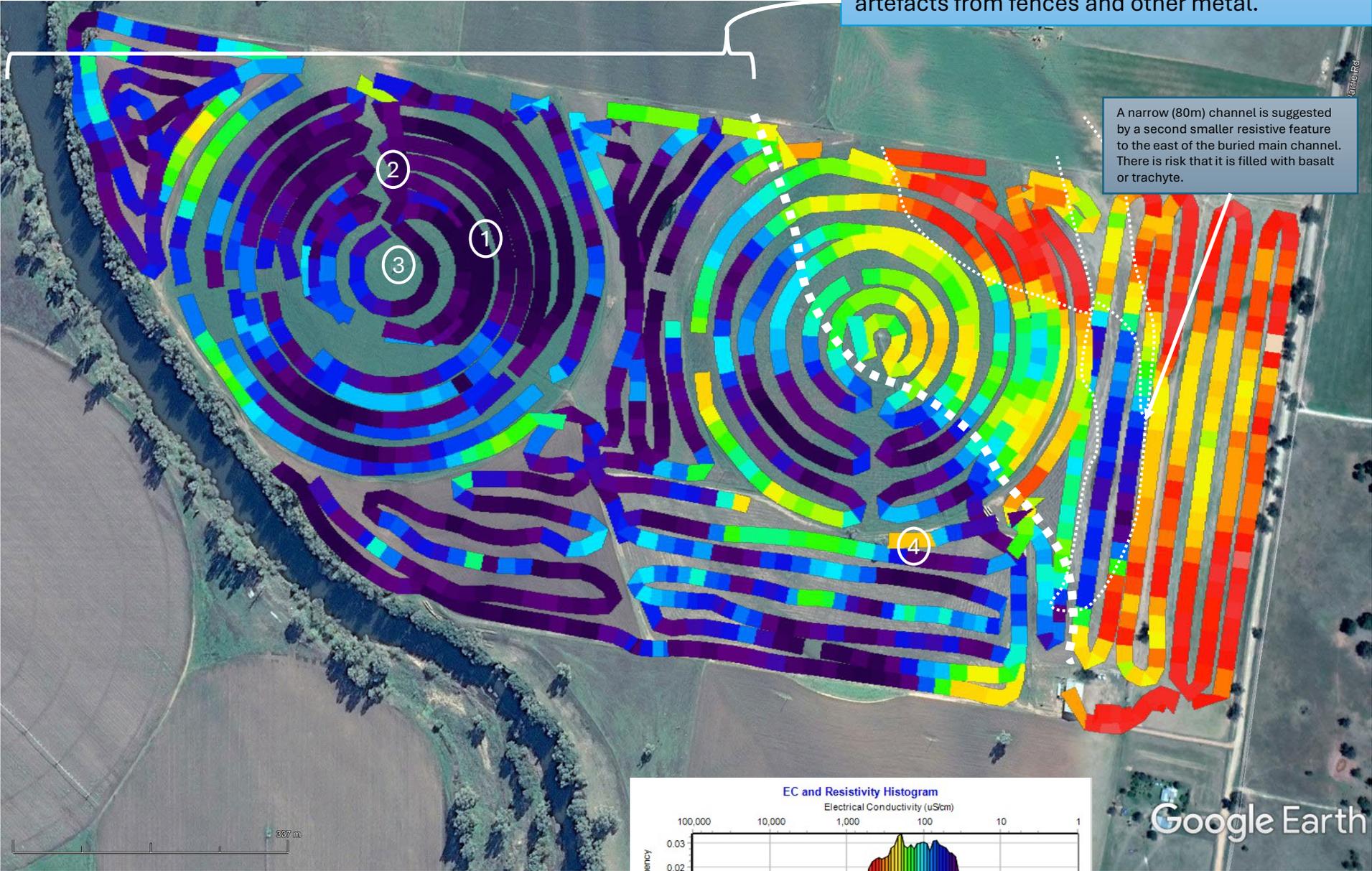
Wallaroo_AgTEM - Modelled Resistivity projected up 100m.

Aqua line reveals estimated Depth of Investigation. Vertical Exaggeration x4.



A broad layer of deep resistive sediment (Cobbles) is inferred here interrupted by artefacts from fences and other metal.

A narrow (80m) channel is suggested by a second smaller resistive feature to the east of the buried main channel. There is risk that it is filled with basalt or trachyte.



AUSTRALIAN SOCIETY OF
EXPLORATION GEOPHYSICISTS

1ST ASEG DISCOVER SYMPOSIUM

www.asegdiscover.com.au

ASEG 2024

