Discussion on …Time-Domain EM for Highly-Conductive Targets

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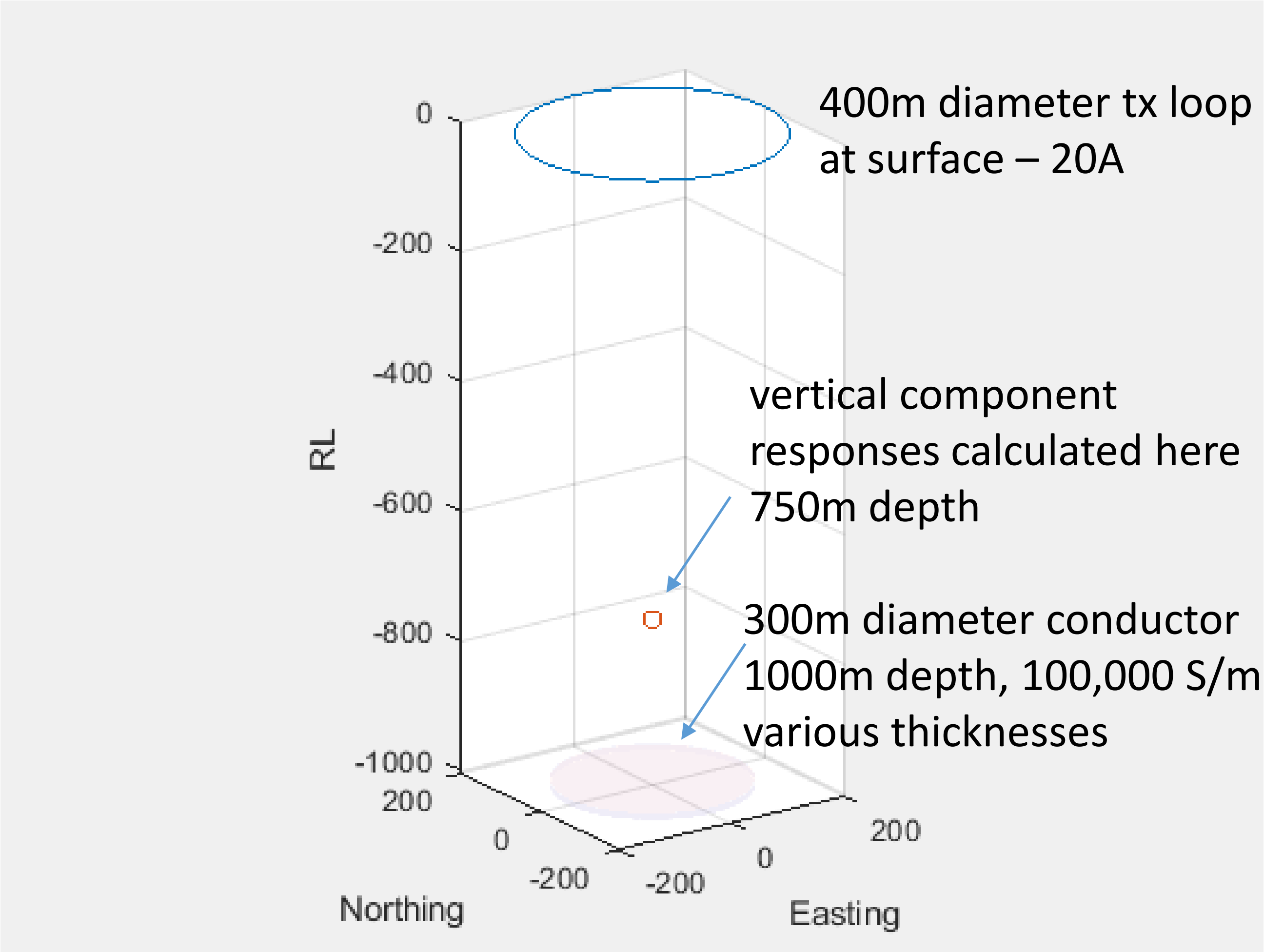
Introduction

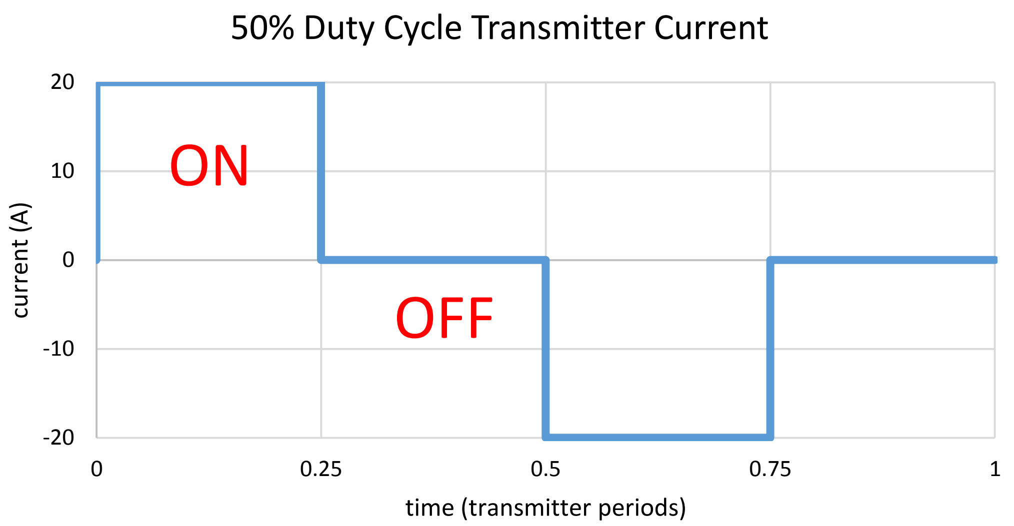
- In my Exploration ’17 paper I gave some examples of TEM responses from highly-conductive 3-D models and comparisons of responses for 50% duty cycle (on- and off-time), 100% duty cycle and late-time normalised 100% duty cycle. In an extension to that work, models will be updated here and we’ll discuss a bit more about signal/noise.
- The key issues in this topic are: detection and discrimination. <u>Detection</u> of a highly-conductive target and <u>discrimination</u> from weaker conductors.

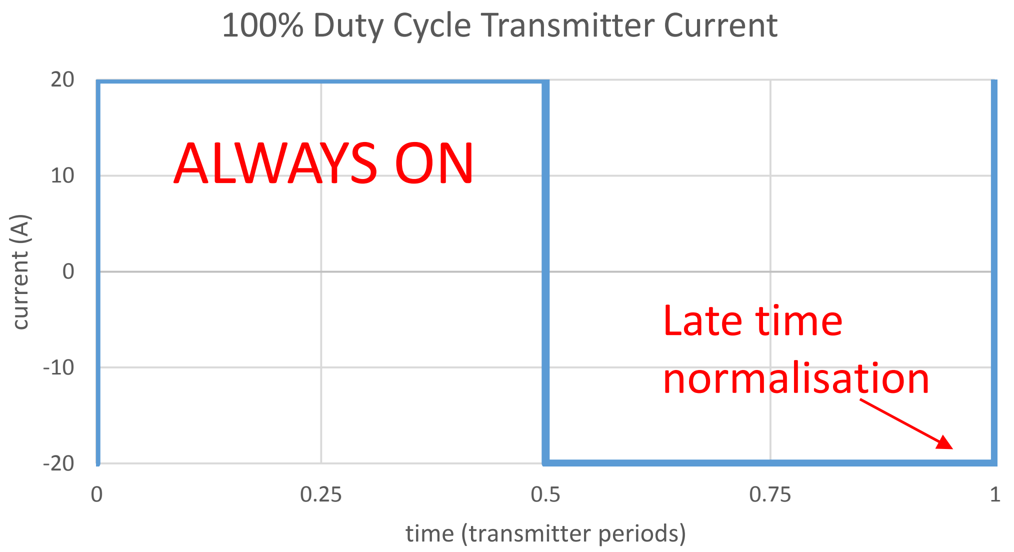
Highly Conductive

- Here we are talking about end-member targets. Massive pyrrhotite, NiS, CuS. And big, which makes them harder to see in the off-time, because bigger, more conductive targets have TEM responses in-phase with primary field
- Conductivity of the models I use is 100,000 S/m – this is end-member conductivity, with conductive halo absent
- For simplicity I am using a fairly arbitrary cylindrically-symmetric model, the aim is to demonstrate what happens when you make different types of measurements on the same target and vary its conductivity without varying any geometry
- I am going to calculate B responses for 0.1 Hz and 1 Hz transmitter waveforms (at 50% and 100% duty cycle) with 20 logarithmically-spaced time windows

(Arbitrary) Model with 100,000 S/m Targets

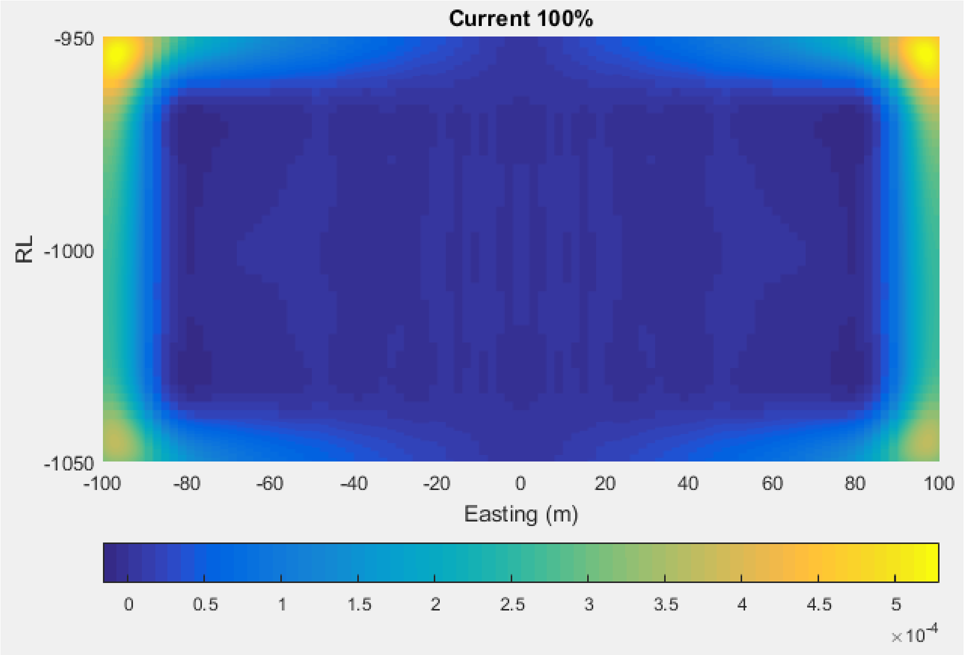






TEM Current Flow

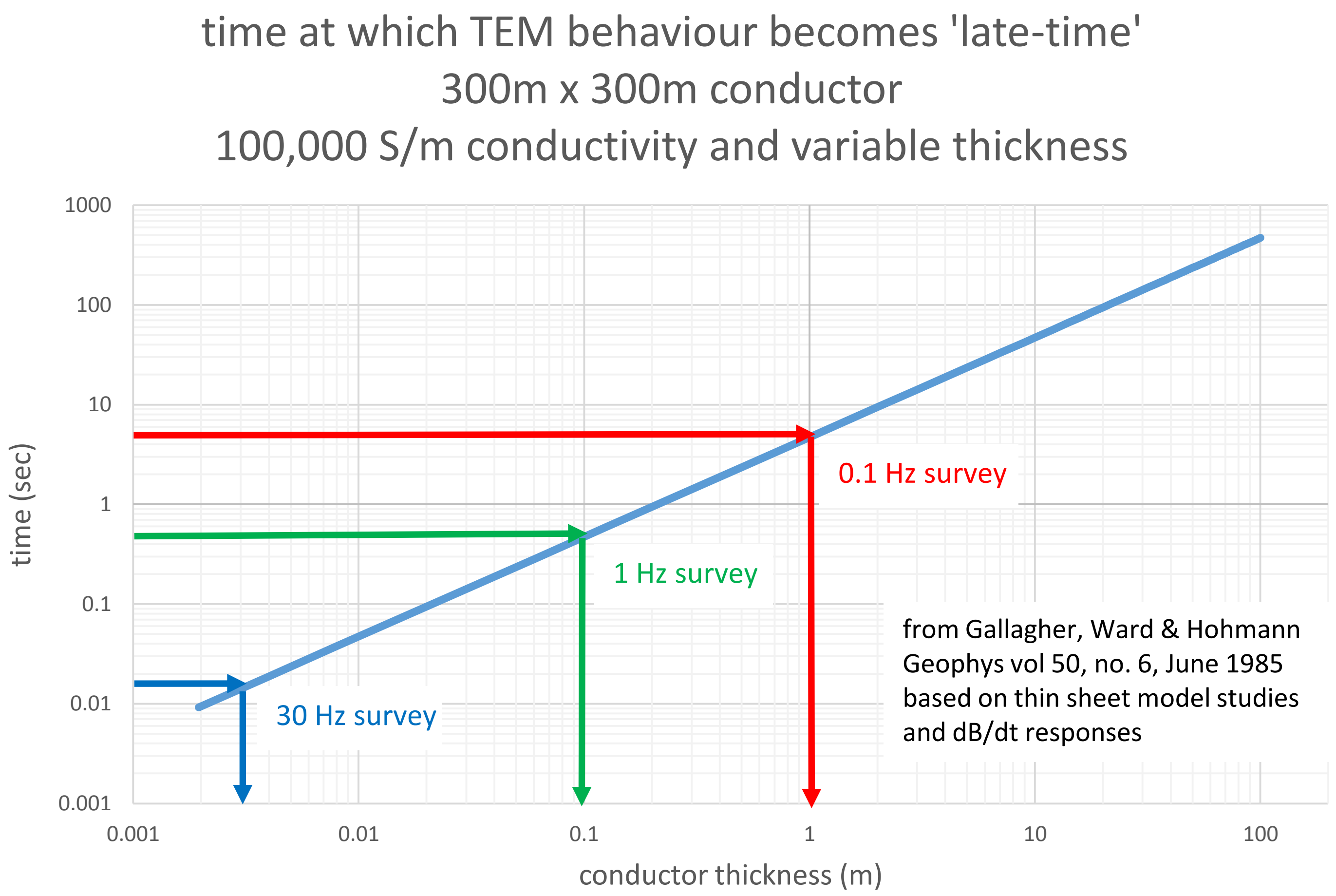
- Current Flow looks like this in a TEM survey at 0.1 Hz in The Ovoid
- Current flows in the skin of these targets and a simple view of these targets based on their overall conductance is entirely invalid



10,000,000S conductor
Illustrating currents flowing in a slice through Ovoid model, at the latest time, 0.1 Hz, 100% duty cycle survey

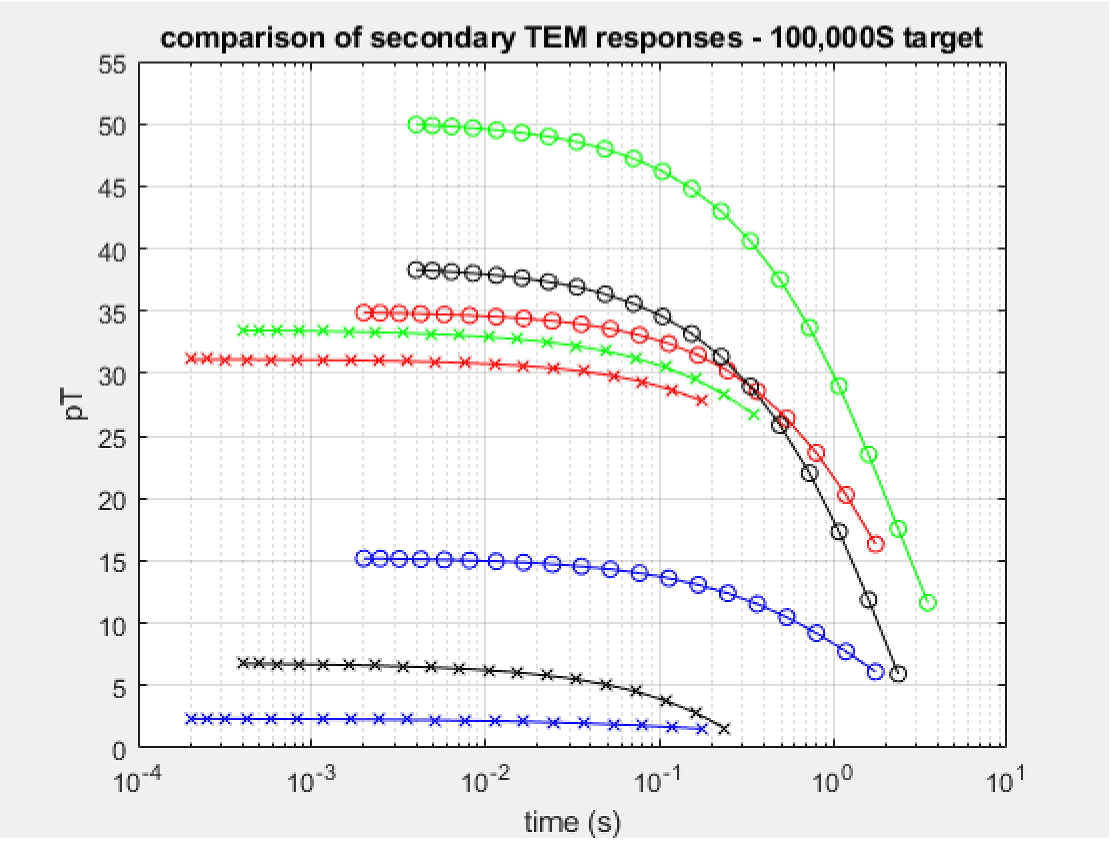
When does late-time behaviour start?

- We never get close to late-time TEM behaviour for an economic 100,000 S/m target
- We never see the slow decays that you might estimate from conductance
- Currents are moving inwards from the skin of the target when we make our measurements
- We do still have the ability to discriminate thickness



3-D Model Response

- 100,000S target
- 1m thick x 100,000 S/m
- 300m diameter horizontal disc conductor at 1000m depth
- Vertical component response measured at 750m depth
- 300m diameter transmitter loop at surface with 20A
- Demonstrates considerable increase in signal size by dropping transmitter frequency

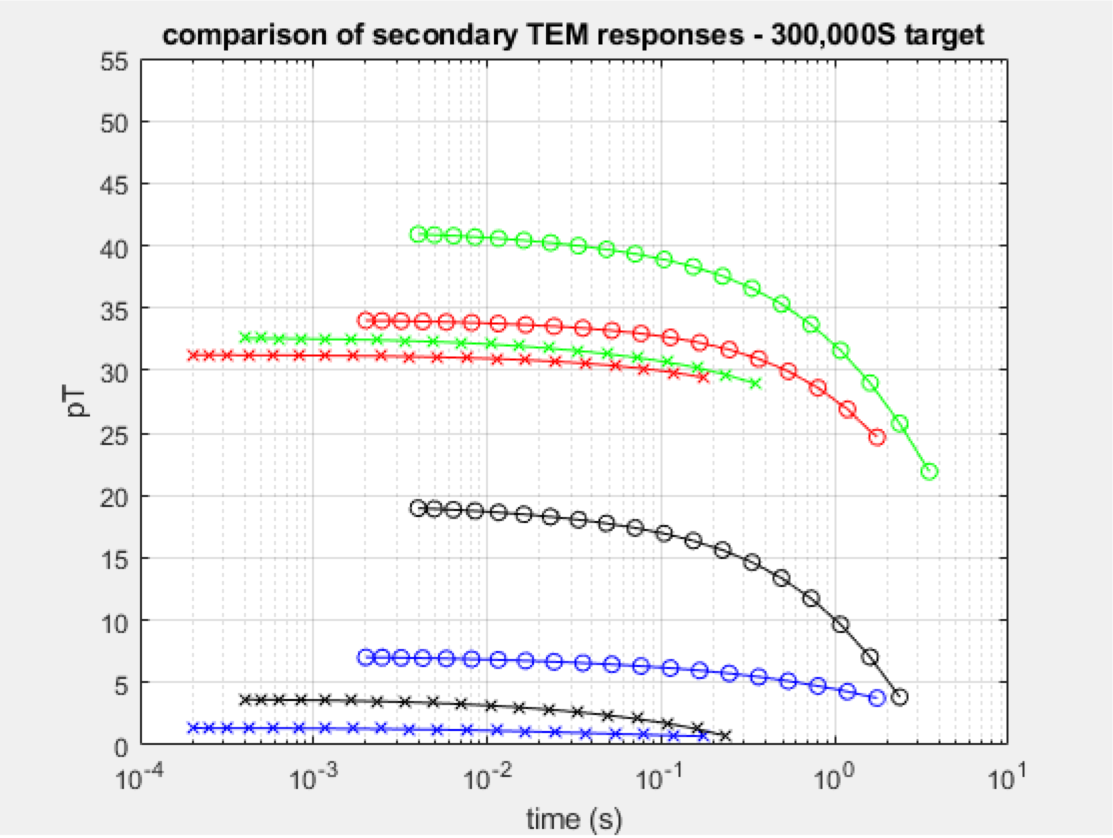


100%   Late Time Normalized 100%   50% On   50% Off

O = 0.1 Hz   X = 1 Hz

3-D Model Response

- 300,000S target
- 3m thick x 100,000 S/m
- 300m diameter horizontal disc conductor at 1000m depth
- Vertical component response measured at 750m depth
- 300m diameter transmitter loop at surface with 20A

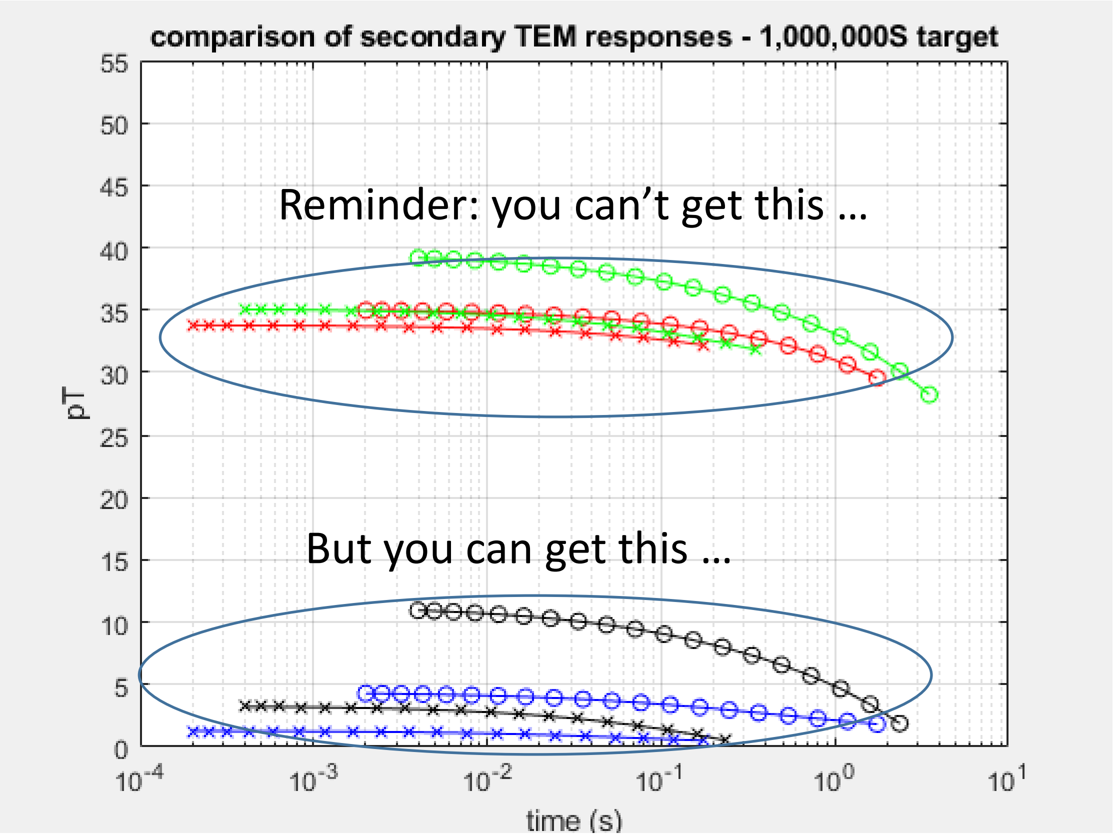


100% Late Time Normalized 100% 50% On 50% Off

O = 0.1 Hz X = 1 Hz

3-D Model Response

- 1,000,000S target
- 10m thick x 100,000 S/m
- 300m diameter horizontal disc conductor at 1000m depth
- Vertical component response measured at 750m depth
- 300m diameter transmitter loop at surface with 20A
- Bigger distinction between on-time and off-time / normalised responses

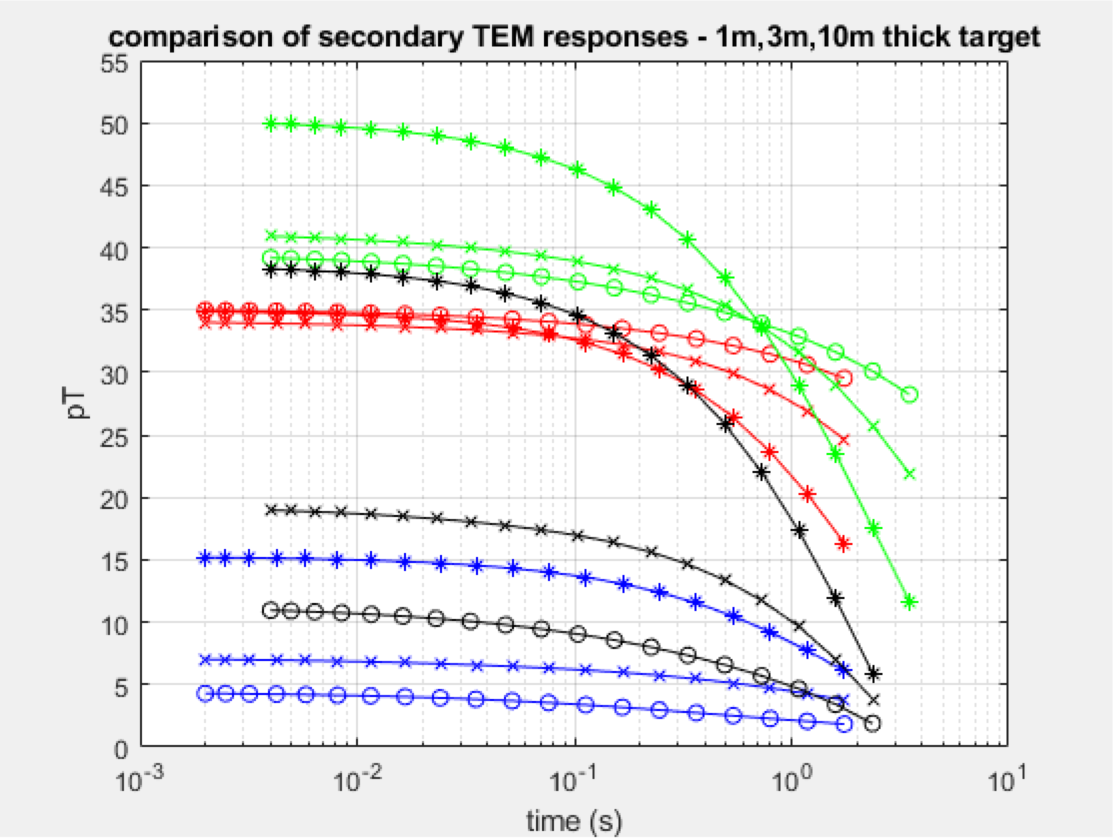


100% Late Time Normalized 100% 50% On 50% Off

O = 0.1 Hz X = 1 Hz

3-D Model Response

- 0.1 Hz only – 1, 3m and 10m thickness x 100,000 S/m
- Comparison of responses of different conductances
- 0.1 Hz TEM theoretically has the ability to discriminate target conductance at 1,000,000S
- The best technique for discrimination depends on the S/N of the measurement techniques

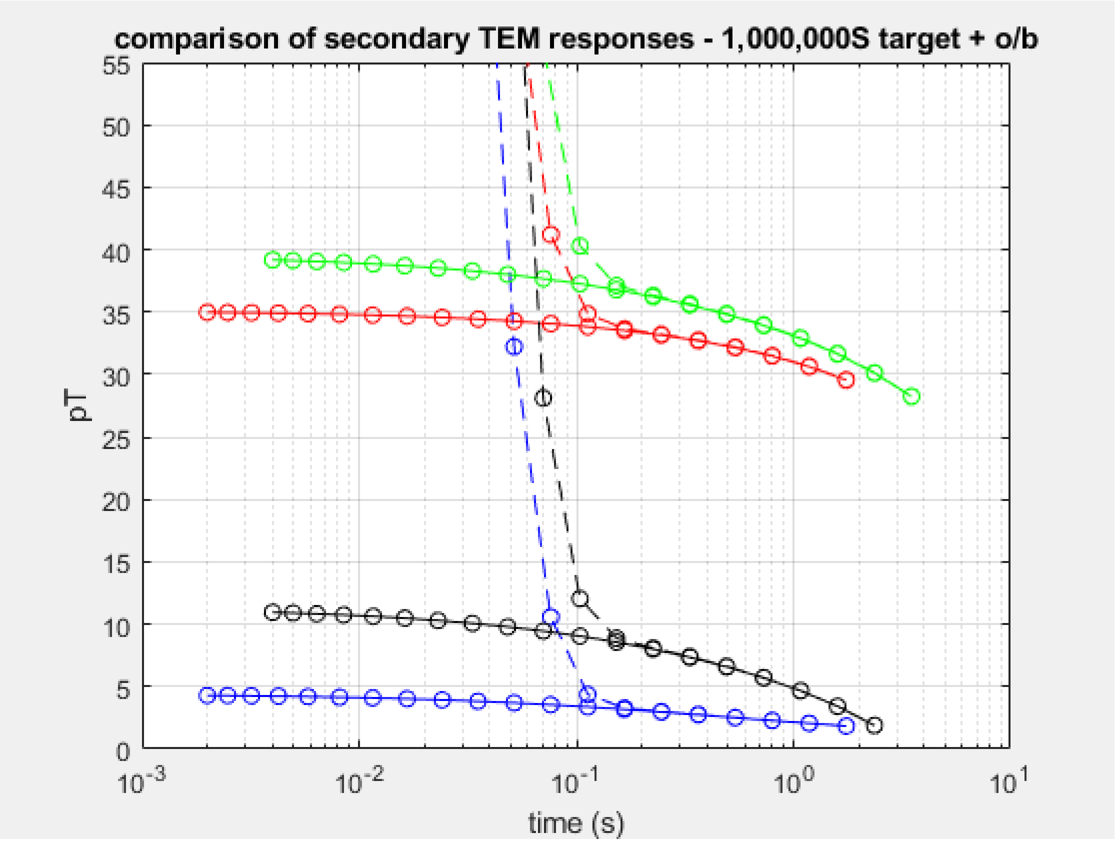


100% Late Time Normalized 100% 50% On 50% Off

* = 1m thick X = 3m thick O = 10m thick

3-D Model Response

- 0.1 Hz only
- 1,000,000S conductor
- 100S overburden, 100m thick x 1 S/m at surface (0m to 100m depth)
- Overburden model is a 2000m diameter disc, centred on transmitter loop
- Asymptote to target response occurs at similar time (about 200 msec) regardless of the type of field calculation
- A conductive host may affect late-time responses, but not in this case of a thick overburden well above the target



100% Late Time Normalized 100% 50% On 50% Off

O = 0.1 Hz

Model Responses Discussion

- TEM signals in the on-time are larger than in the off-time (assuming same transmitter current) by an amount that depends on the target and the transmitter frequency
- As you go to lower transmitter frequency, like 0.1 Hz, on-time and off-time responses become fairly close for all but the most conductive, large targets [these are the nice ones to find]
- Late-time-normalised 100% duty cycle responses are around the same as 50% off-time responses at late time – this is important.
- For an extremely good conductor like the ones presented here … there is not much difference between the on-time response from a 50% duty cycle waveform and a 100% duty cycle waveform

That was Signal, how about the other half of the S/N equation: Noise?

- The considerations of noise are very different for on and off-time surveys. This seems to be ignored in many discussions
- Generally, the noise in an off-time measurement is a result of either the sensor noise floor OR external noise factors. Interestingly, these issues can both be addressed by increasing transmitter power.
- In an on-time survey, the biggest source of noise is generally the primary field, the secondary field rides on top of it. If you are measuring a long distance from the transmitter loop, then this may not be the case. The primary field (which is large) needs to be estimated somehow (eg. by measuring the geometry of the survey) or dealt with somehow (eg. by late-time-normalization). Increasing transmitter power doesn't help. This source of noise is absent in off-time surveys and secondary fields that are a very small fraction of the primary field can be measured in an off-time survey
- In an on-time survey, if variations in current (either by design or not) are significant then they need to be measured and corrected for, otherwise they are another source of noise in general.

Summary

- I’ve been talking about end-member conductors. Less conductive or thinner or smaller targets are relatively easier to see in off-time TEM, assuming same transmitter frequency etc
- Without full 3-D modelling of highly-conductive targets, the wrong conclusions are easily drawn about signal size
- A consideration of noise must be made in any analysis of detectability. Calculate the primary field
- Low noise magnetometers and low frequency surveys have changed the way that discoveries of highly-conductive targets are made everywhere
- Model or estimate a survey S/N – this is important. Review the noise of different survey style in the same units

Acknowledgements

- BCGS
- MTNet
- James, Ben and Daryl
- DMEC (material pulled from Exploration ’17 paper)