Airborne EM Data Comparisons

in a sedimentary basin
Exploration 2007
September, 2007

Why

EXTERNAL quality control, modeling and interpretation

should be considered

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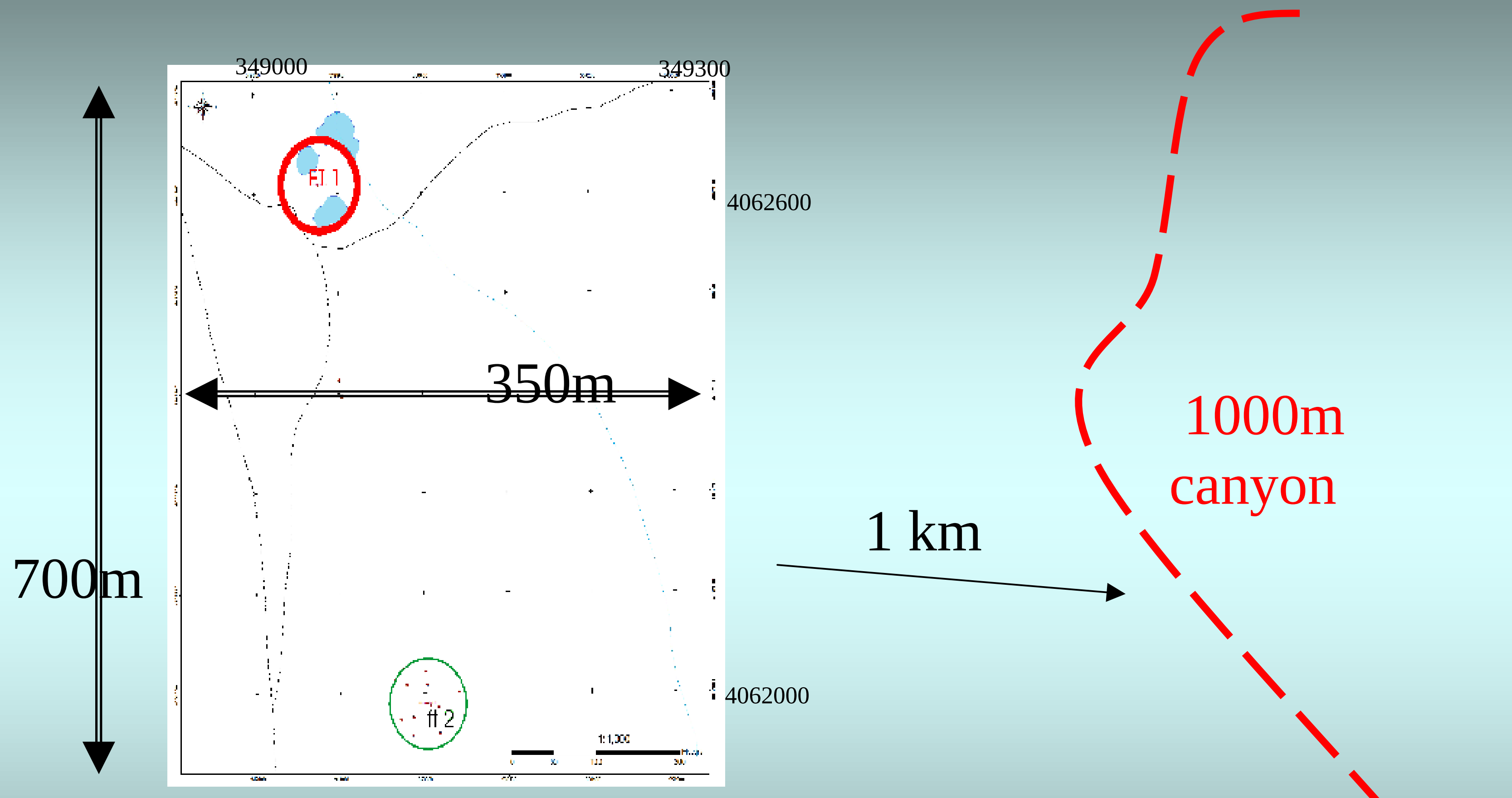
Petroseikon

Test area Northern Arizona



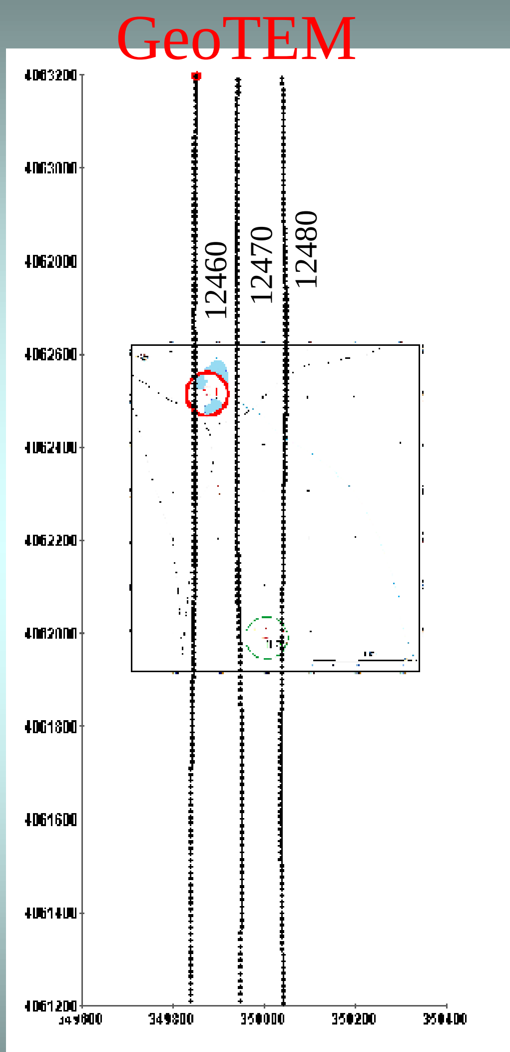
over 3000m of sedimentary sequence
sandstones, shales, limestones, conglomerates

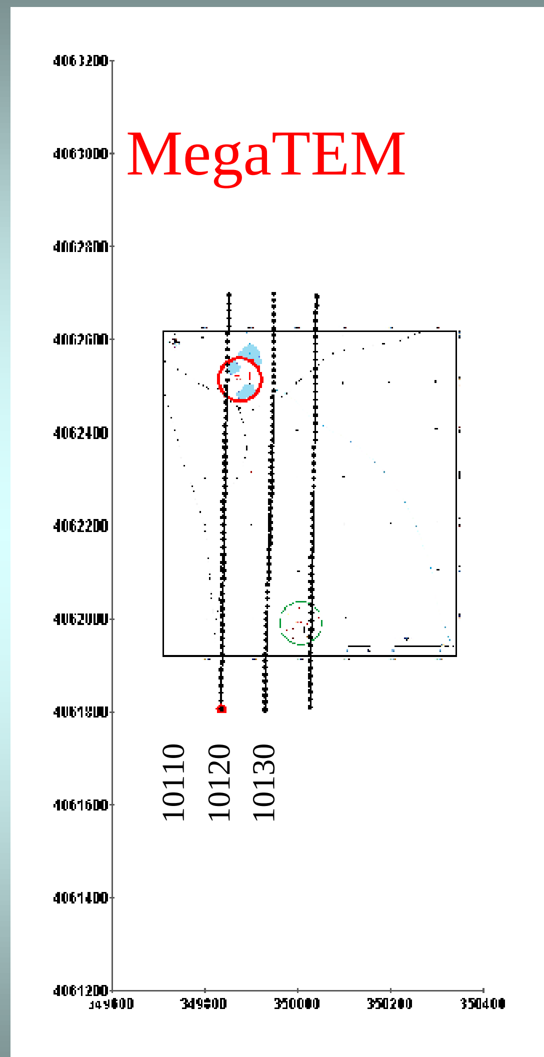
Summary of Data

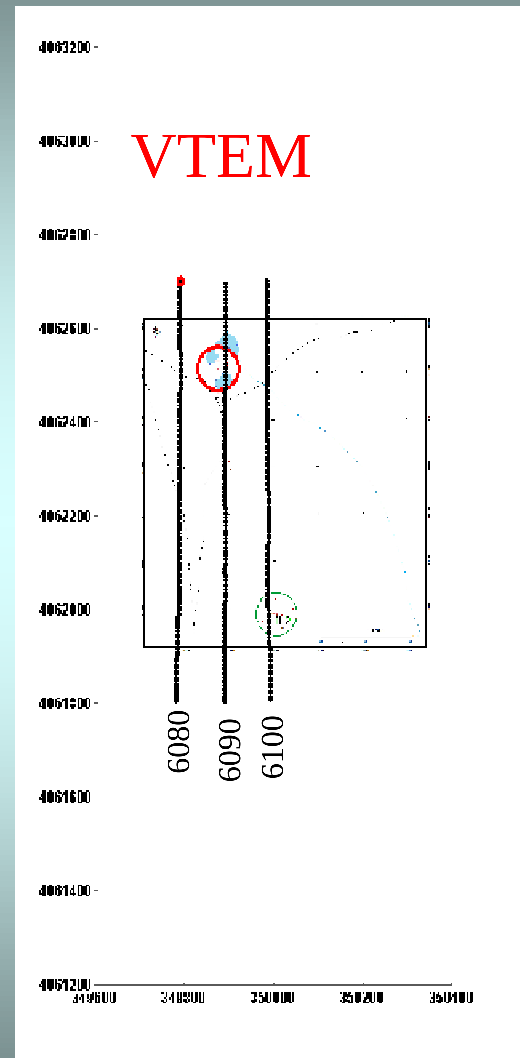
The following data is analyzed :

- **GeoTEM**– *with correct pulse,dipole moment and Tx-Rx offsets
- **MegaTEM** – *with correct, pulse, moment and Tx-Rx offset
- **MegaTEM re-windowed** – 20 off-time channels
- **VTEM**– 2 flights - suitable and unacceptable waveform

Survey Lines





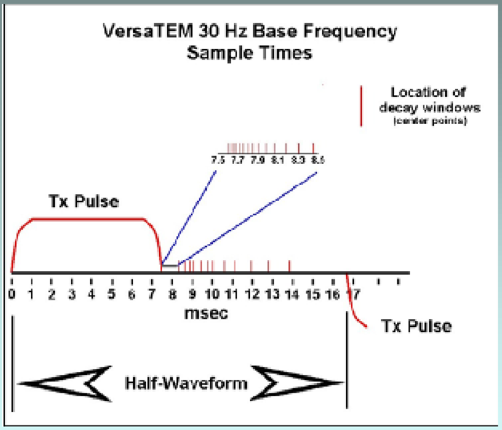


. The MegaTEM and GeoTEM surveys lines are almost identical while the VTEM lines appear to be nearly running half way between the Fugro flight lines.

VTEM Comparison – Waveforms

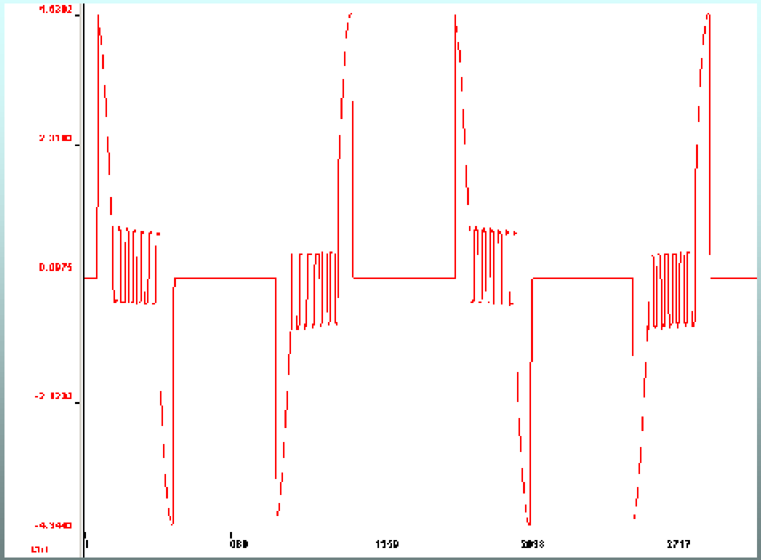
The waveforms from the two different flights are shown. The waveform plots show the coil response, which is the derivative of the current. A typical current pulse is shown to the right.

The May 8 waveform exhibits unwanted pulses in the on-time, and has a much longer pulse width. A new waveform was used on the May 14 flight. A shorter pulse width (4.56 msec) was required to remove multiple pulses.



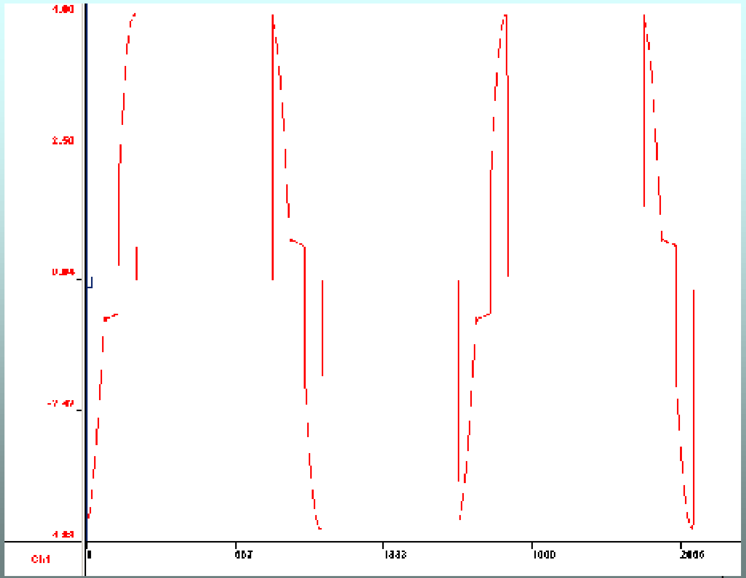
multiple source pulses leads to increased ambiguity in the models

May 8 Waveform



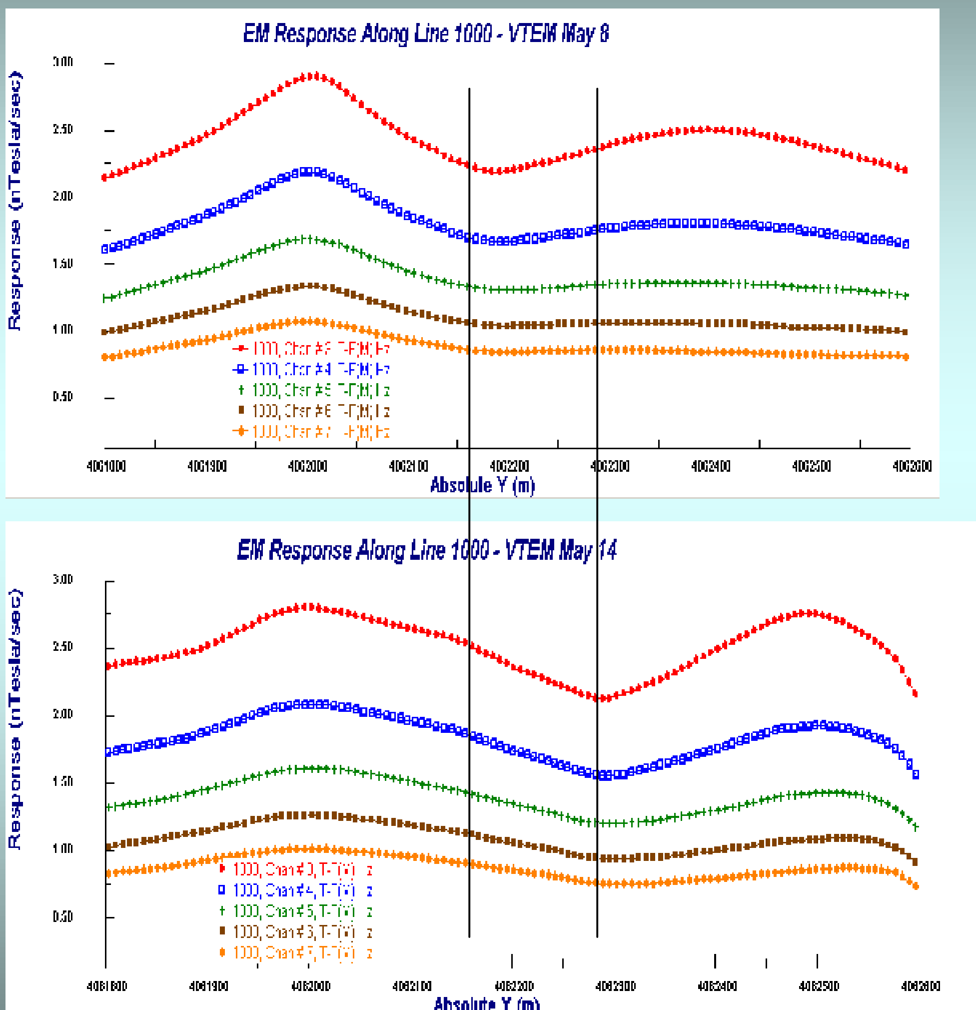
7.2 msec

May 14 Waveform



4.56 msec

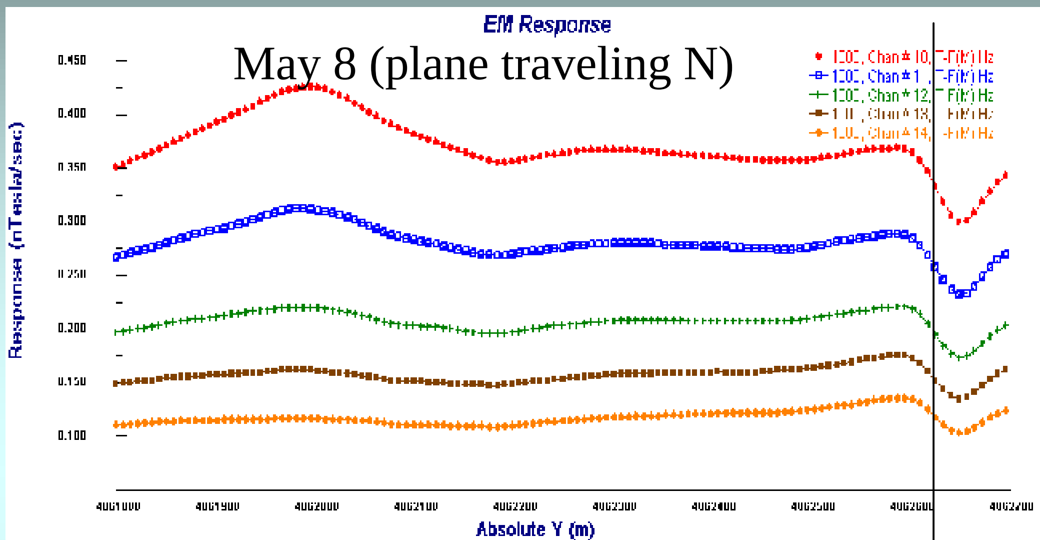
VTEM Comparison – Data

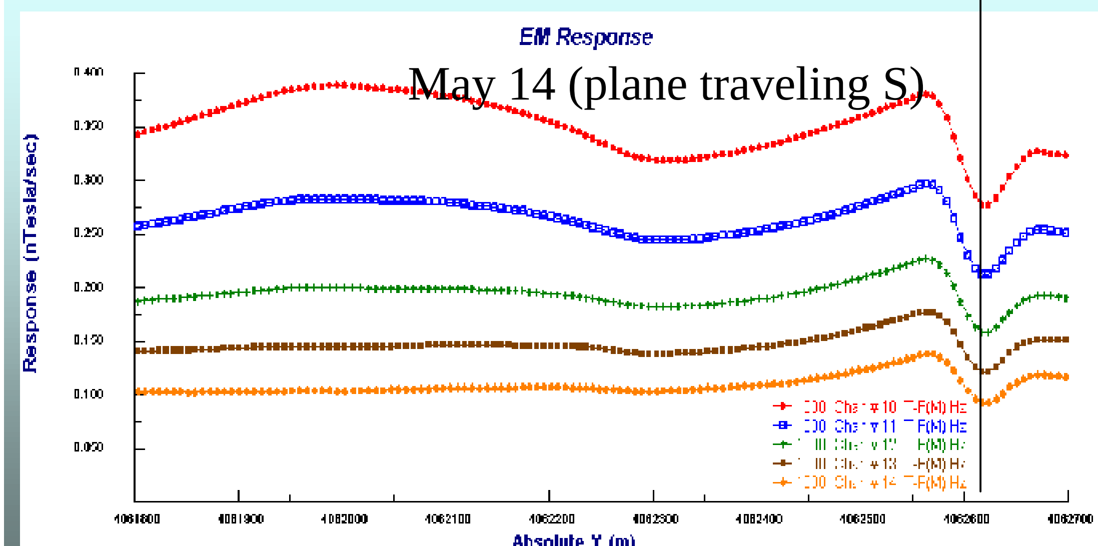


A comparison of the VTEM data on May 8 and May 14 is shown for time channels 3-7 across Line 1000. There is some difference in the response across the line on the two dates.

- Channel 3
- Channel 4
- Channel 5
- Channel 6
- Channel 7

VTEM Comparison - Data

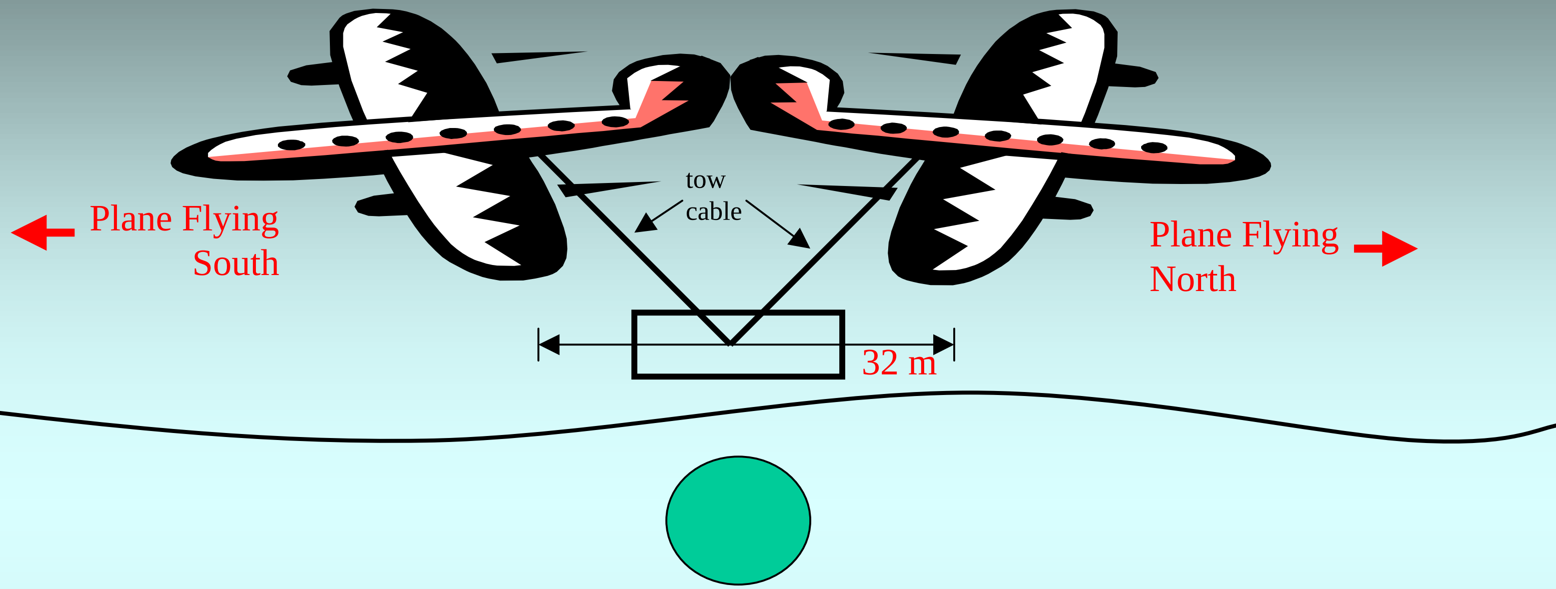




At later times, there are also some significant differences in the response across the line between May 8 and May 14. An offset for the anomaly at the north end of the lines is observed. A possible explanation is given on the following page.

- Channel 10
- Channel 11
- Channel 12
- Channel 13
- Channel 14

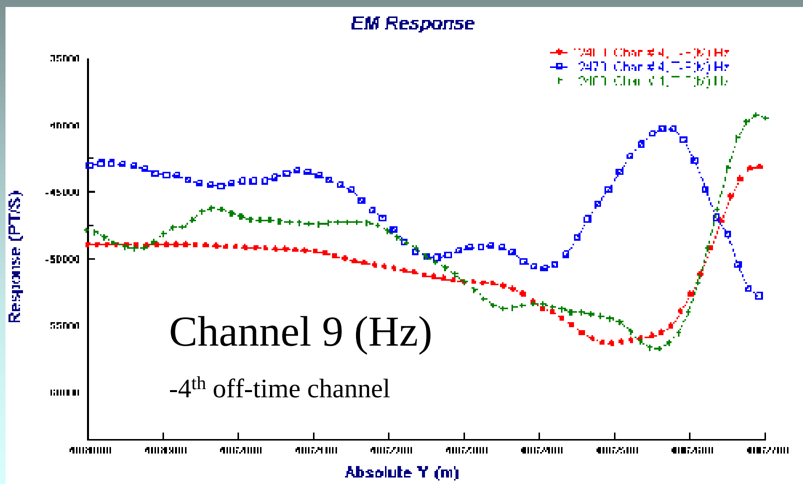
VTEM Comparison - Data

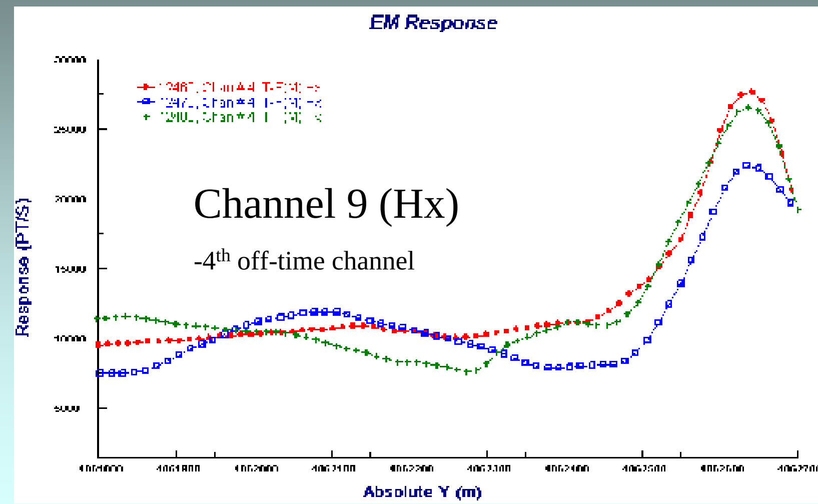


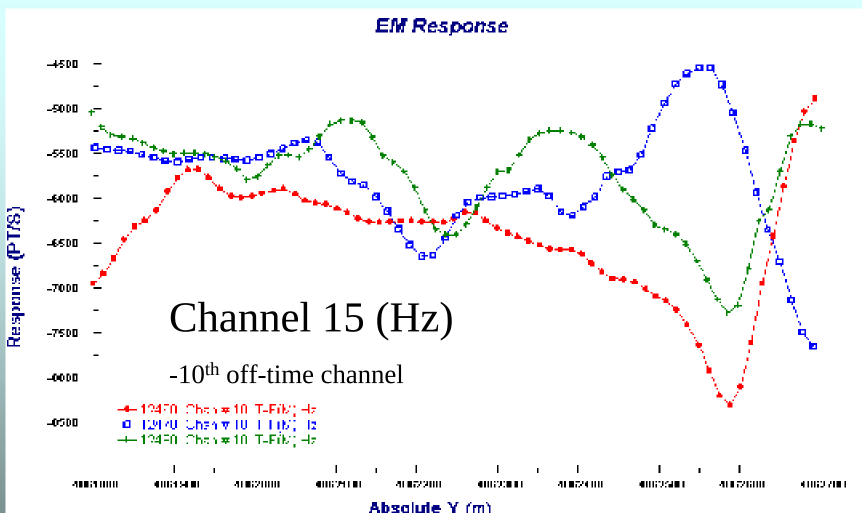
*The shift in the location of the anomaly could be due to flight direction. The lines were flown in different directions on May 8 and May 14. The co-ordinates of the data point correspond to the plane, not the transmitter and receiver, which are at an angle from the plane. If the flight direction is north, the plane will be further north when the loop is over a given feature than when it is flying south, and the anomaly would appear north of where it would appear on a line flown south. This corresponds to what is seen on the VTEM data on the two different days: the anomaly appears further to the north on May 8, when line 1000 was flown north. The difference between the location of the anomaly on the two days is 32 m, corresponding to an angle of 22^0 from vertical for a 42.4 m tow cable. This is a reasonable angle based on photos of the VTEM system; however, typical values of this angle were not provided.

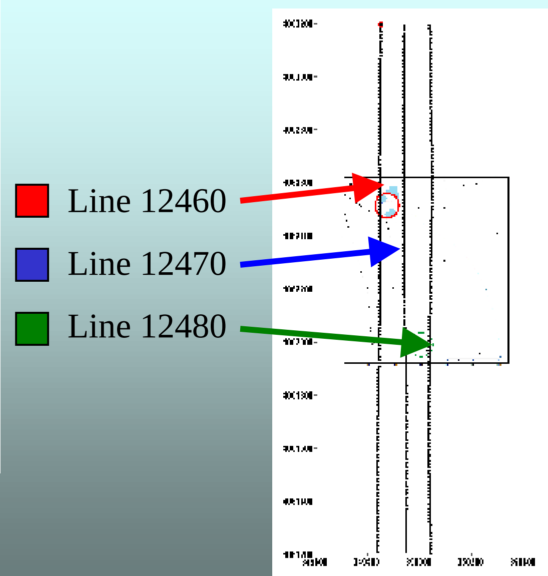
Above is a schematic of this situation, showing how the plane would be at different locations when the system is over a target, depending on flight direction.

GeoTEM Data





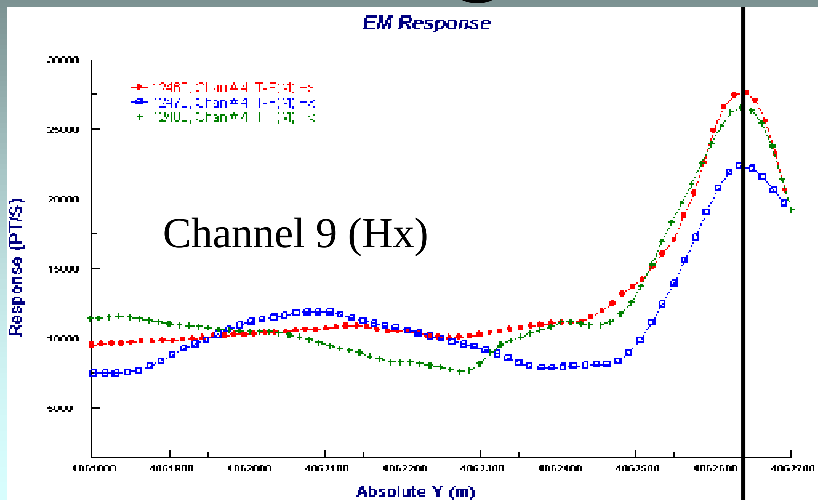




The GeoTEM data along three lines in the test area is shown. A large response is noted to the north part of the line, and as with the VTEM data, alternate lines appear to track each other in Hz.

GeoTEM/MegaTEM Comparison

GeoTEM

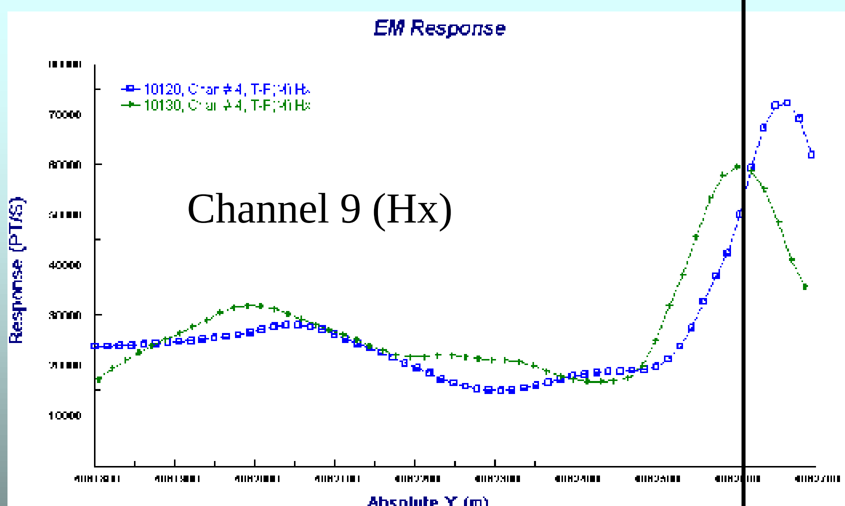


Line 12460

Line 12470/10120

Line 12480/10130

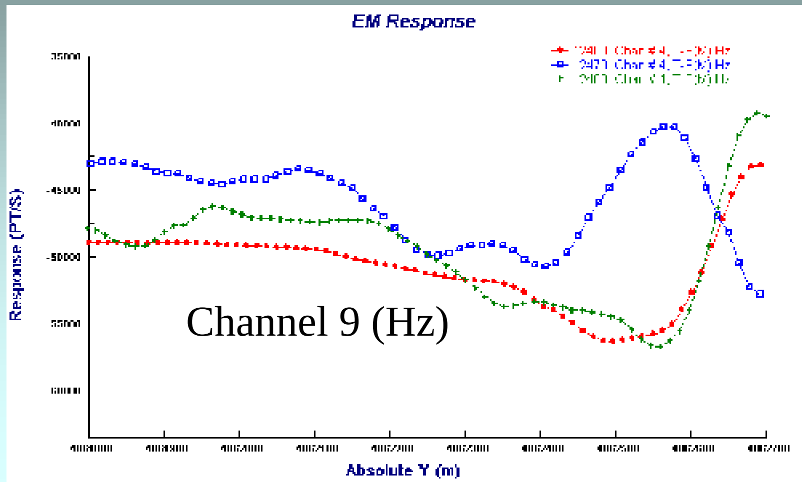
MegaTEM



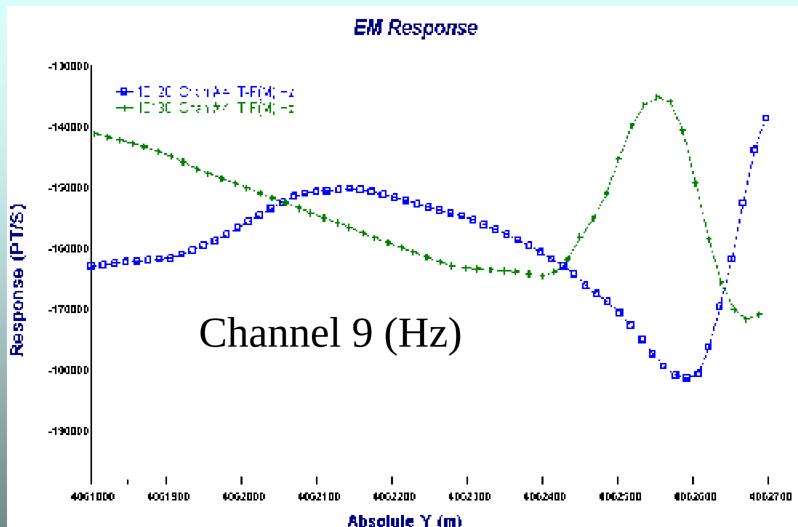
The MegaTEM and GeoTEM data are compared for Channel 9 (4th of-time channel) in the same area. Note that Lines 12470 for GeoTEM is nearly in the same position as MegaTEM line 10120, Lines 12480 (GeoTEM) and 10130 (MegaTEM) are also nearly the same. The general trends in the Hx component are similar for both, although the peaks of the anomalies do not quite line up.

GeoTEM/MegaTEM Comparison

GeoTEM



MegaTEM



- Line 12460
- Line 12470/10120
- Line 12480/10130

In Hz, Lines 12470 (GeoTEM) and 10130 (MegaTEM) show similar trends, although 12470 is closer to 10120. A similar situation is observed with 12480 and 10120.

It is noted that 12470 and 10120 were flow in opposite directions, as were 12480 and 10110. Thus, the trends in response appear to be related to flight direction.

Model and Geology

A model approximating the response of the different airborne surveys was developed. It was used to study the variation in response across the airborne lines, and the sensitivity of the response to different layers.

Model 91b

<table>
<tr><th>Resistivity (Ω m)</th><th>Thickness (m)</th><th>Depth to Bottom (m)</th><th>Lithology</th></tr>
<tr><td>100</td><td>103</td><td>103</td><td rowspan="3">Sedimentary Layers</td></tr>
<tr><td>942</td><td>100</td><td>203</td></tr>
<tr><td>73</td><td>79</td><td>282</td></tr>
<tr><td>2900</td><td>40</td><td>322</td><td>Limestone</td></tr>
<tr><td>2.95</td><td>74</td><td>396</td><td rowspan="2">Conductor</td></tr>
<tr><td>0.7753</td><td></td><td></td></tr>
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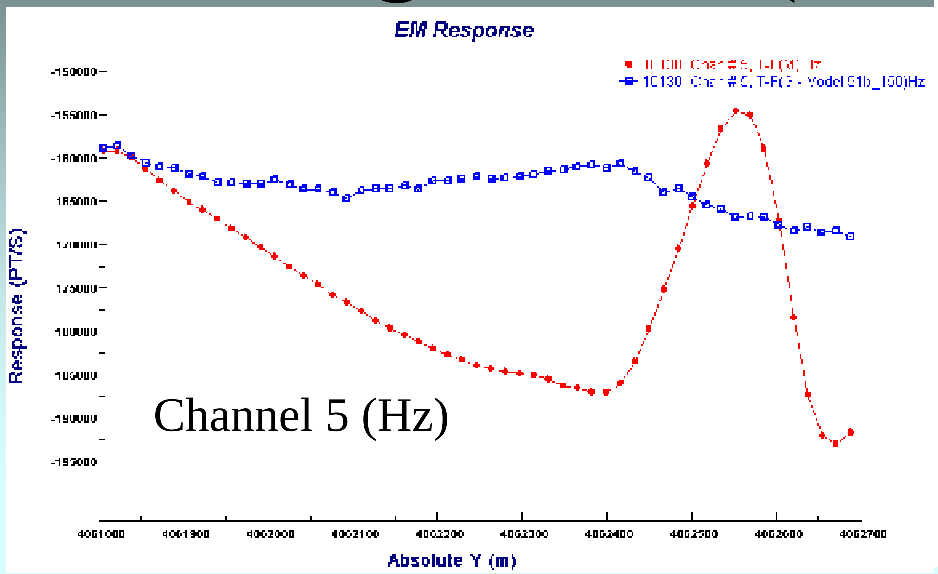
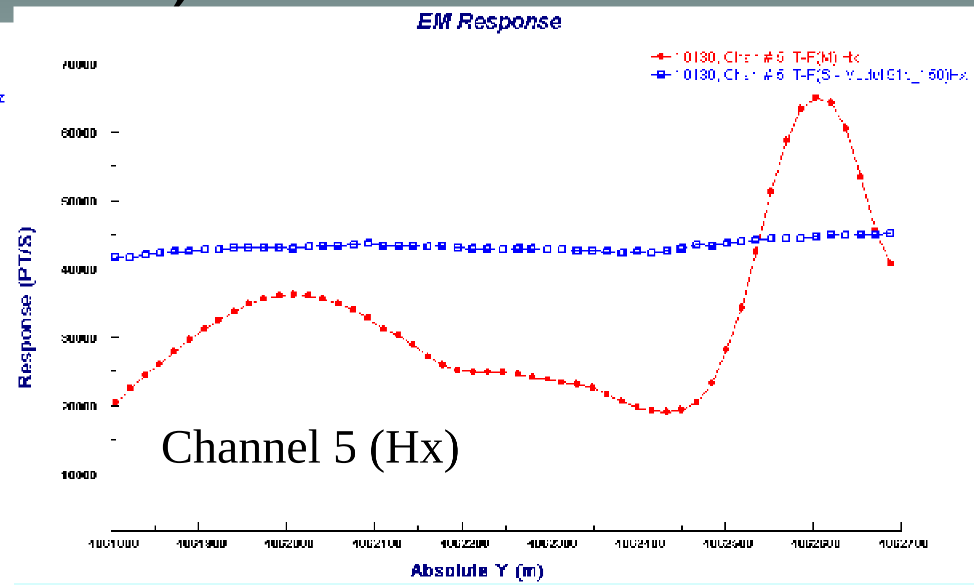
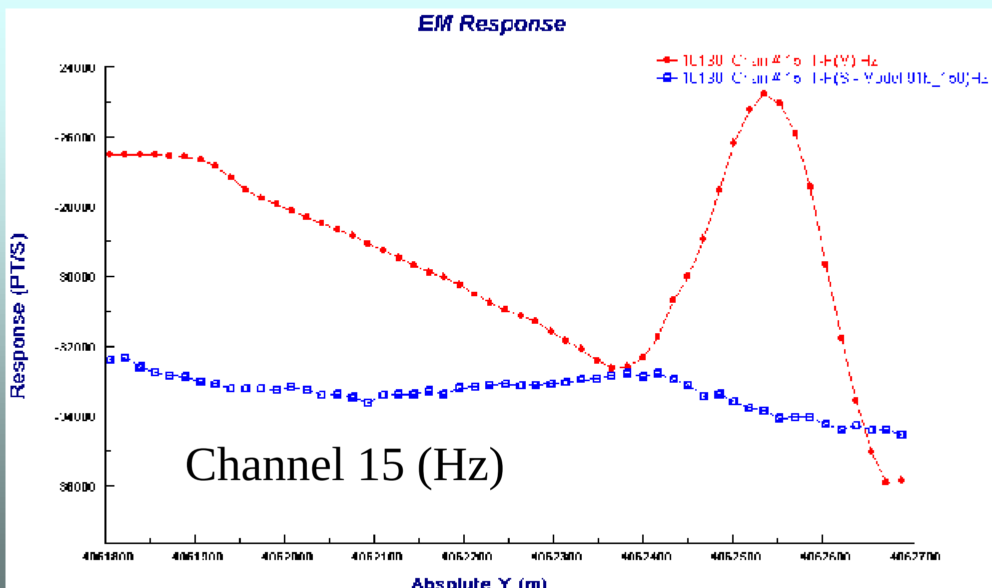
*To better fit the MegaTEM and GeoTEM data, an overburden resistivity of 150 Ω m was used (Model 91b_150).

MegaTEM (20 off) and Model



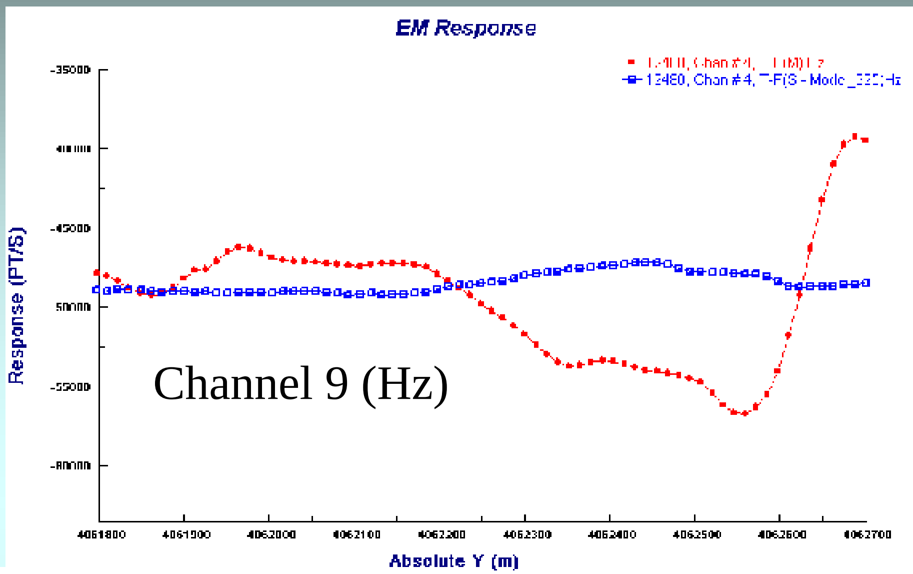


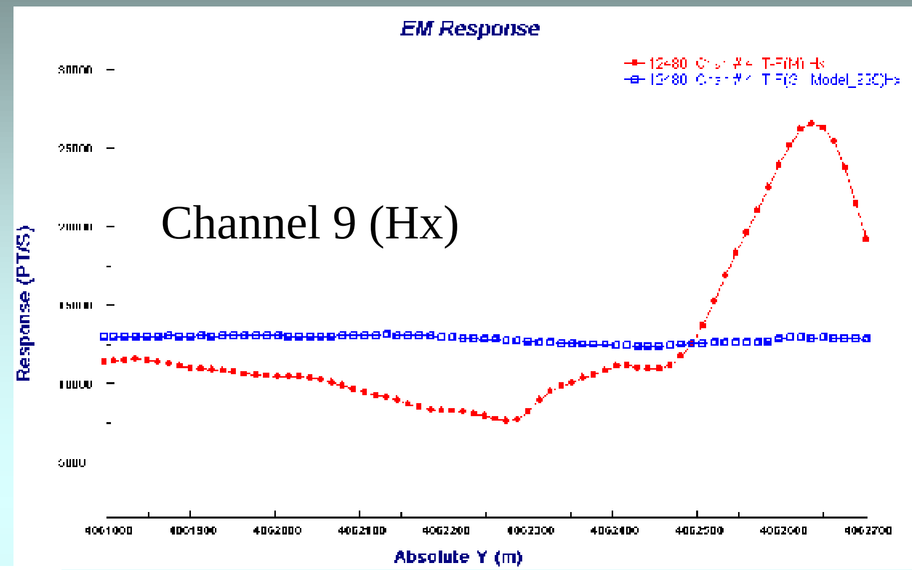


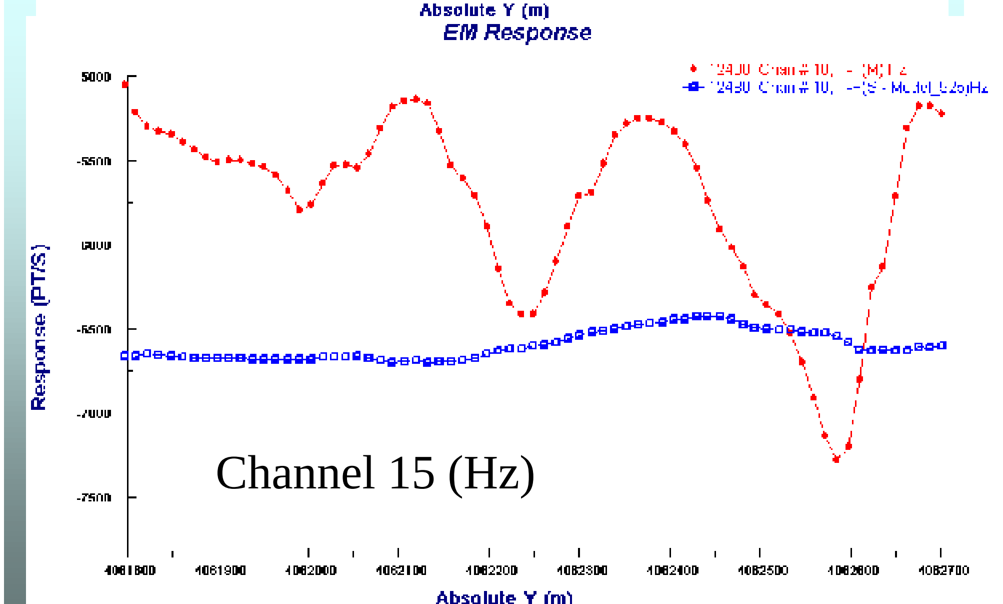
The re-windowed MegaTEM data (with 20 off-time channels) is compared with the response from Model 91b_150 along 10130. The change in altitude of the aircraft has little effect on the variation in response observed across the line.

- Data (Line 10130)
- Model 91b_150 (Line 10130)

GeoTEM and Model





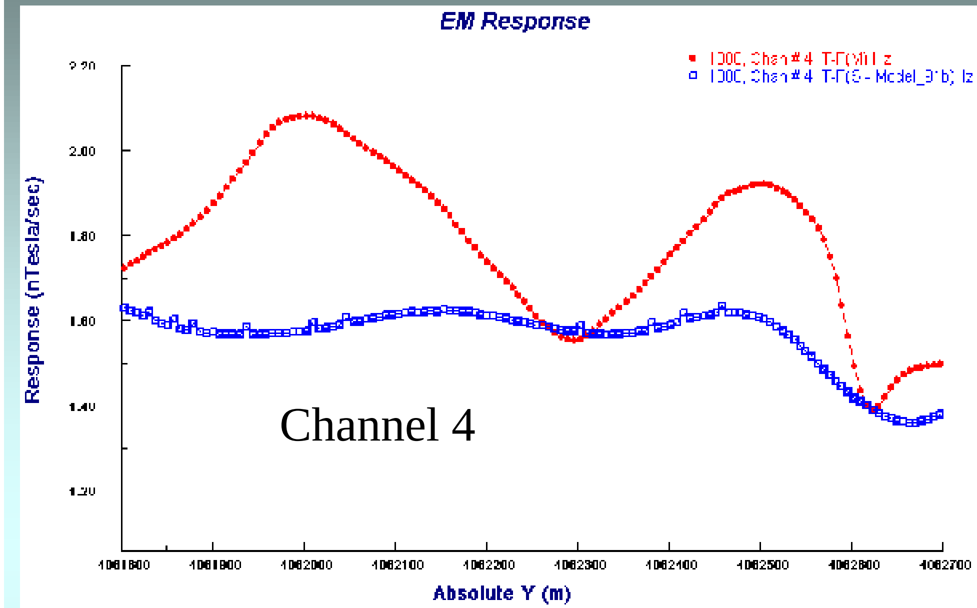


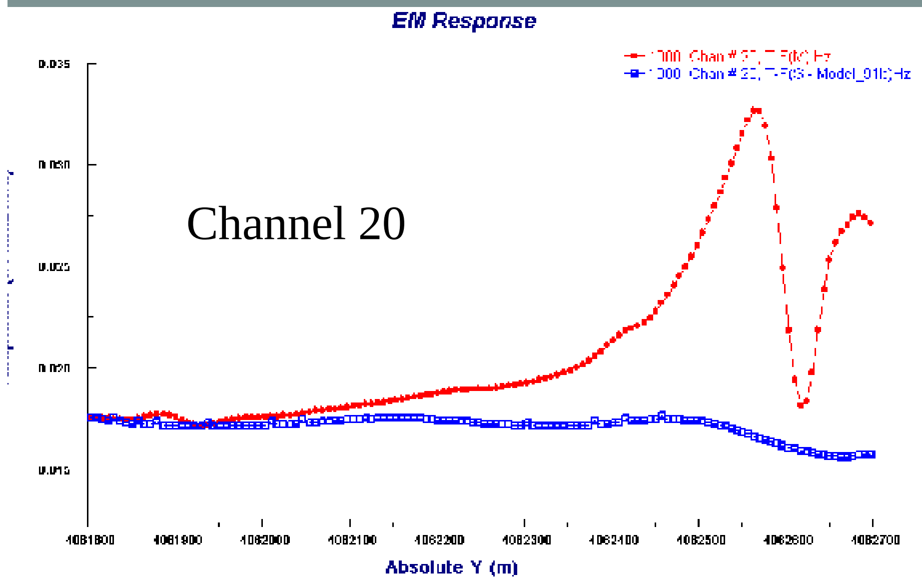
The GeoTEM is compared with the response from Model 91b_150 along 12480. The change in altitude of the aircraft has very little effect on the variation in response observed across the line, as seen in the MegaTEM data.

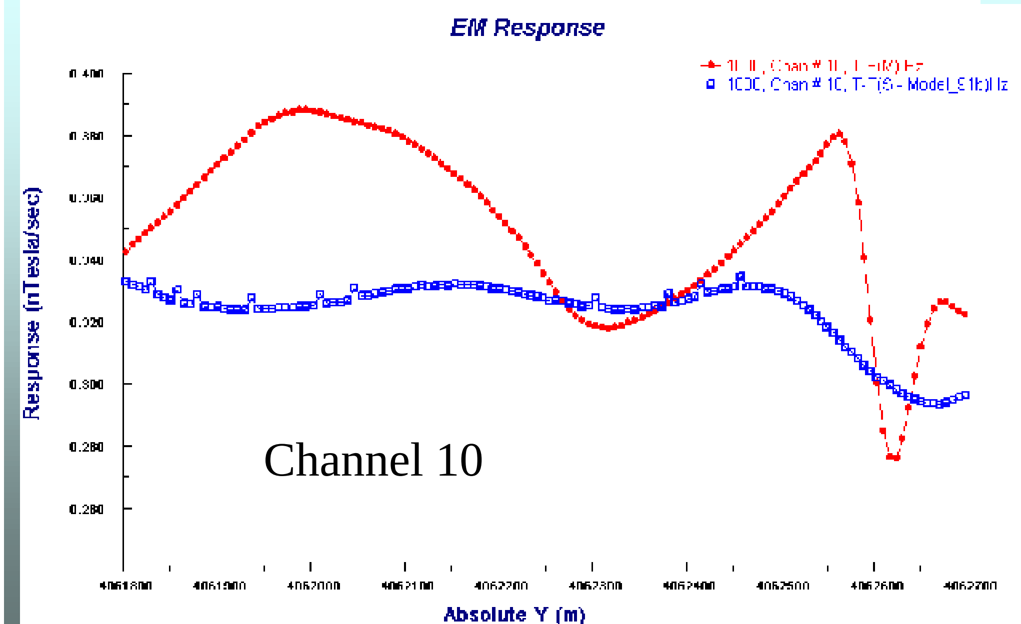
Data (Line 12480)

Model 91b_150 (Line 12480)

VTEM and Model





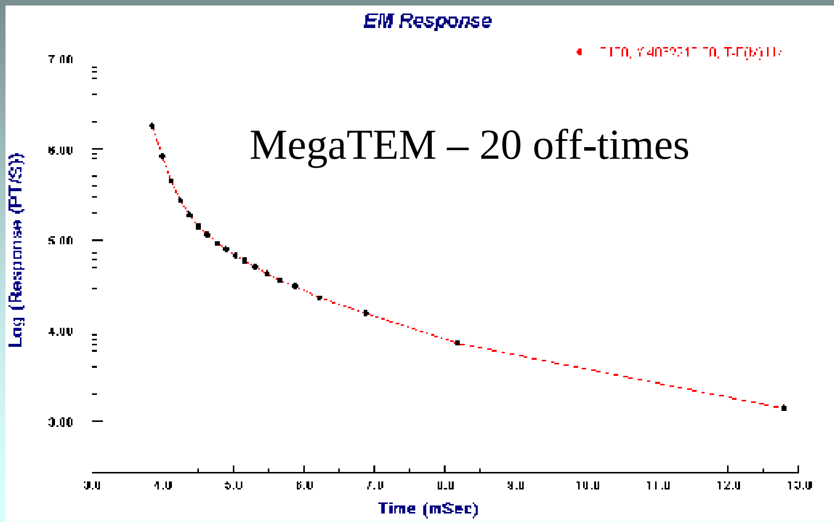


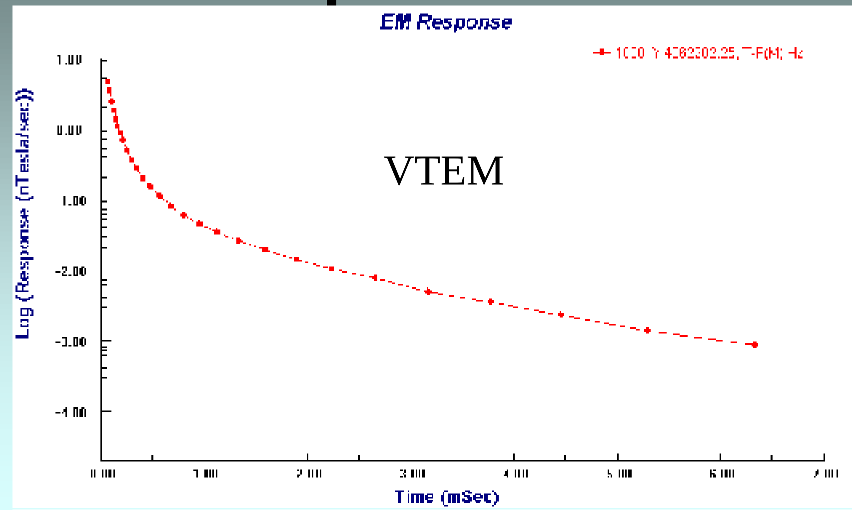
Data (Line 1000)

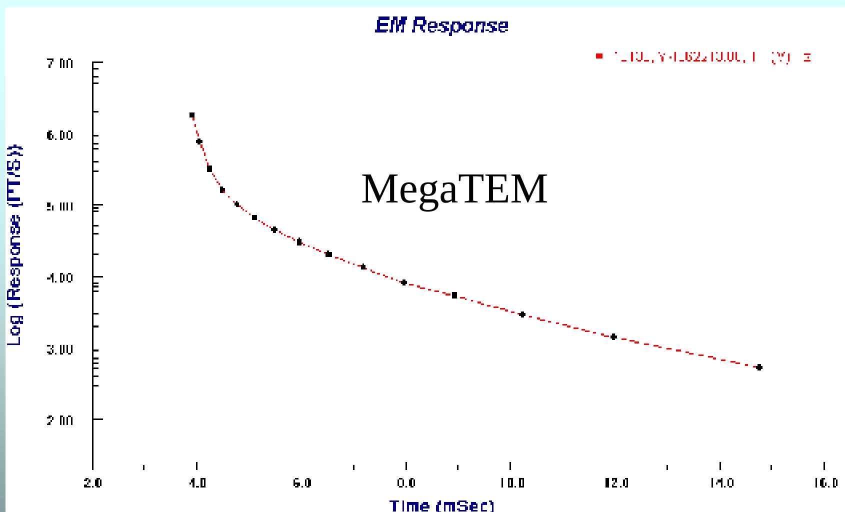
Model 91b (Line 1000)

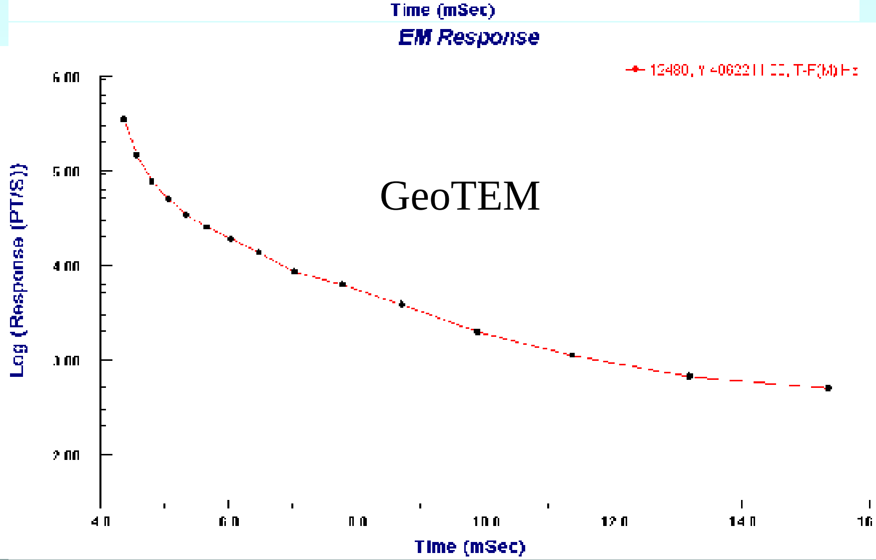
The VTEM data along Line 1000 is compared with the response from Model 91b, a layered earth model. Although some correlation is noted between changes in altitude and the measured response, much of the variation appears to be due to lateral variations in the subsurface.

Time Channel Comparison



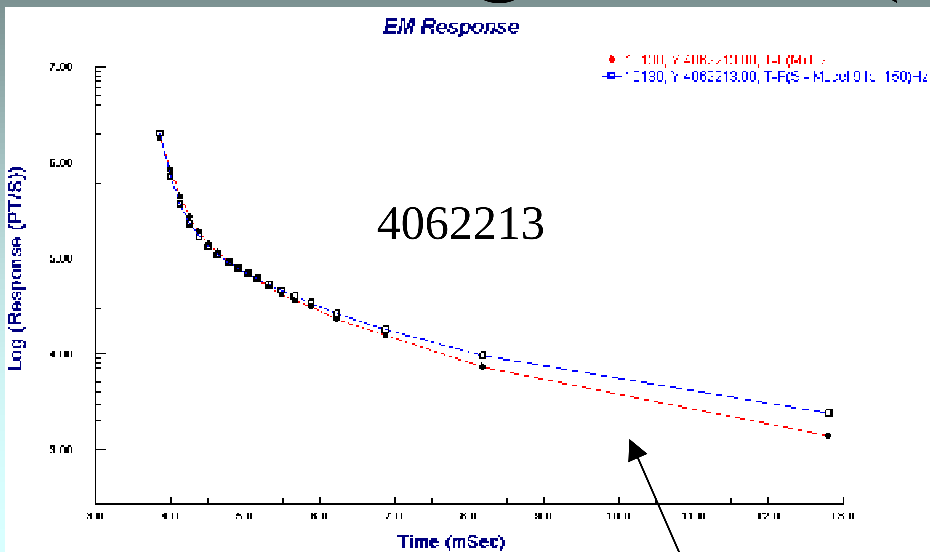


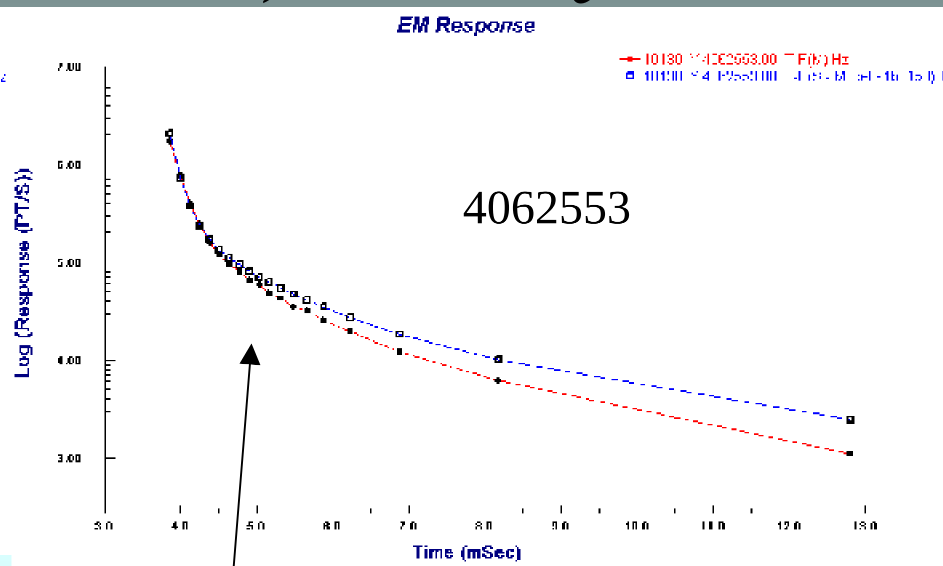




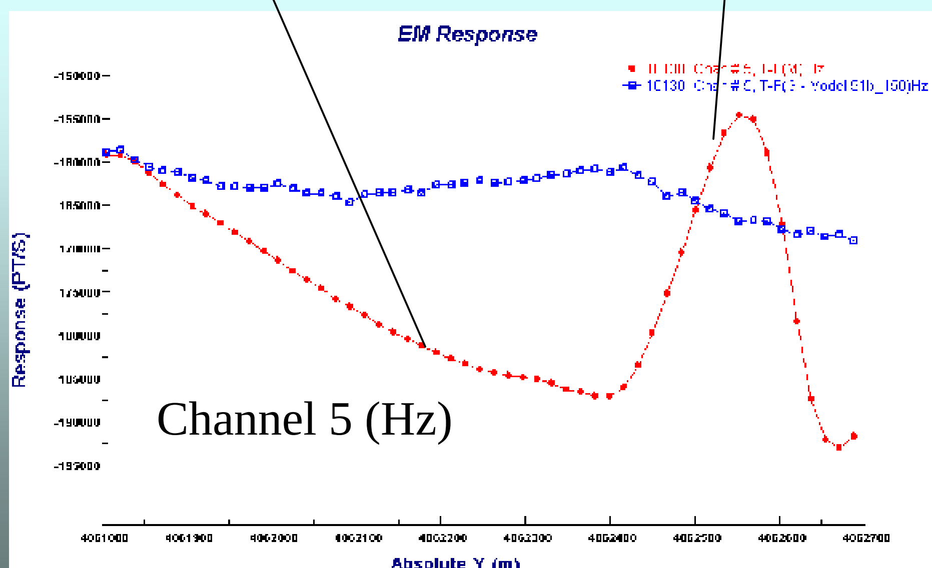
The off time channels are different for the various airborne systems. A comparison of the position of these channels can be made by observing the decays below. The re-windowed MegaTEM data has more time channels in earlier times than the initial MegaTEM data.

MegaTEM (20 off) Decay





Decay curves at two points along Line 10130. At 4062553, the decay of the data appears to be more rapid at mid-late times.



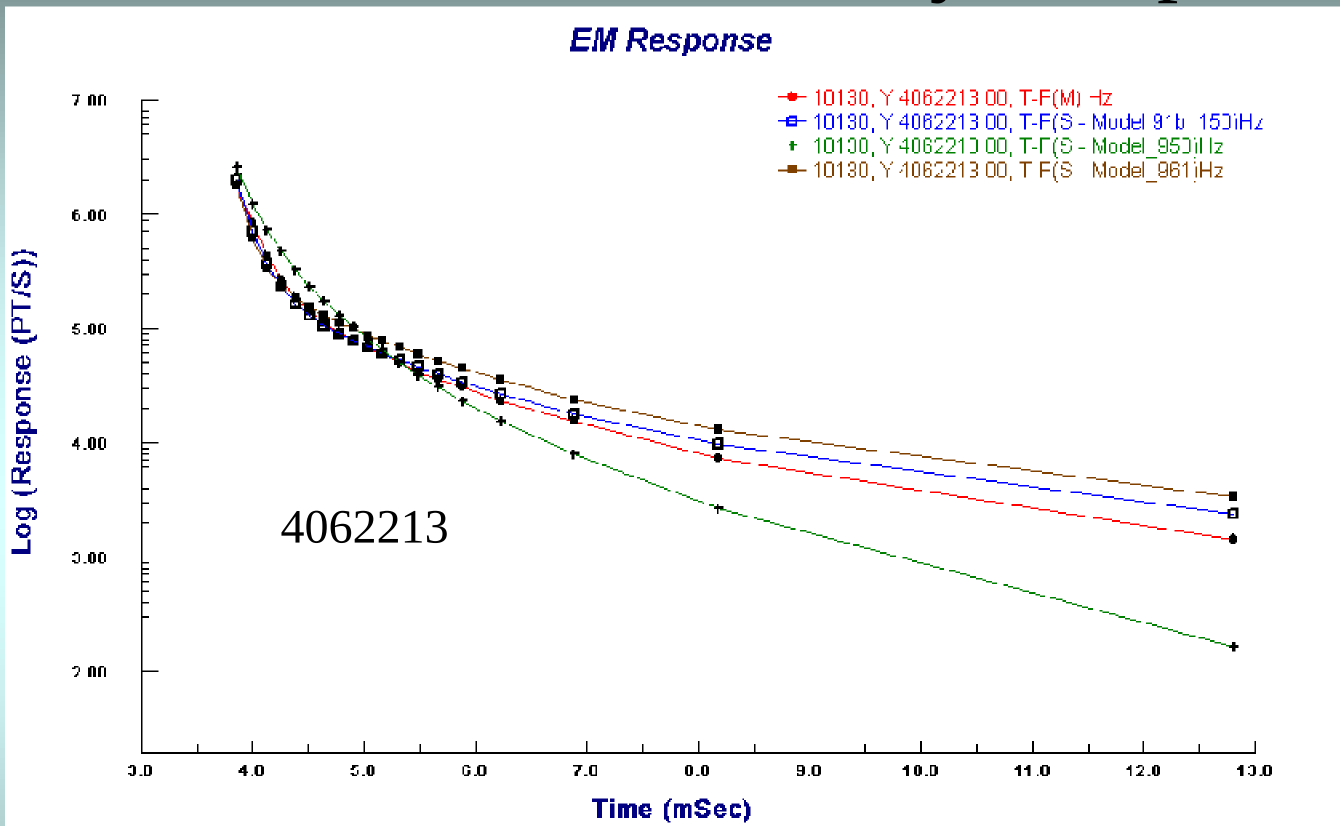
Model 91b_150

Resistivity (Ω m)	Thickness (m)	Depth to Bottom (m)	Lithology
150	103	103	Sedimentary Layers
942	100	203	
73	79	282	
2900	40	322	Limestone
2.95	74	396	Conductor
0.7753			

Data (Line 10130)

Model 91b_150 (Line 10130)

MegaTEM (20 off) Decay sensitivity at depth



Data

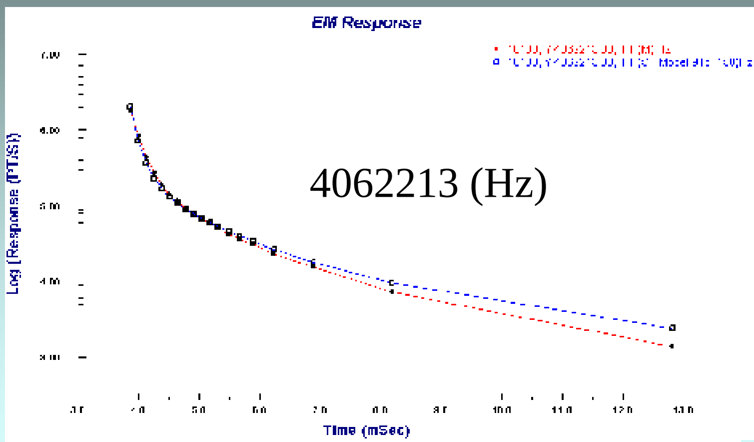
Model 91b_150

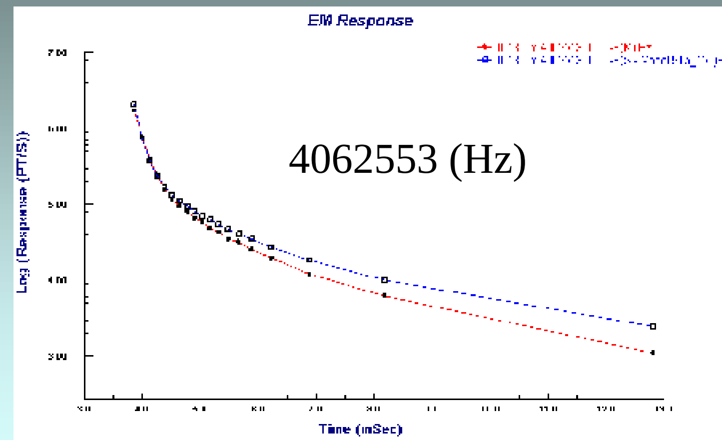
Model 91b_150 – no conductor

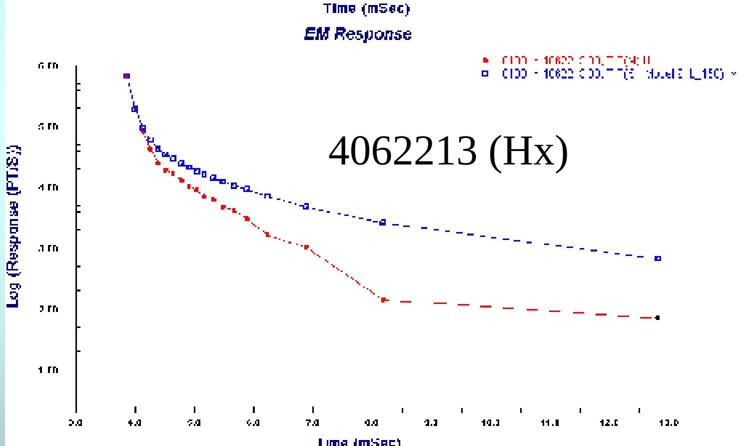
Model 91b_150 – no resistor

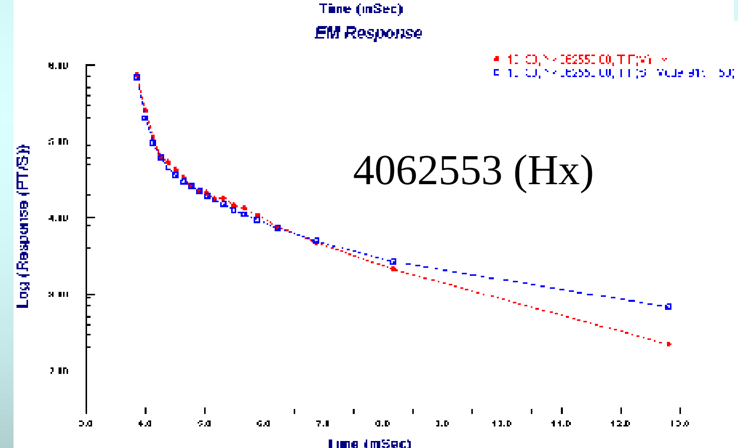
Removing the conductive layers at depth from Model 91b_150 has a significant effect on the decay curve across all time channels. Removing the resistor above the conductive layers has an effect at mid-late times.

MegaTEM Decay (20 off) – Hz and Hx







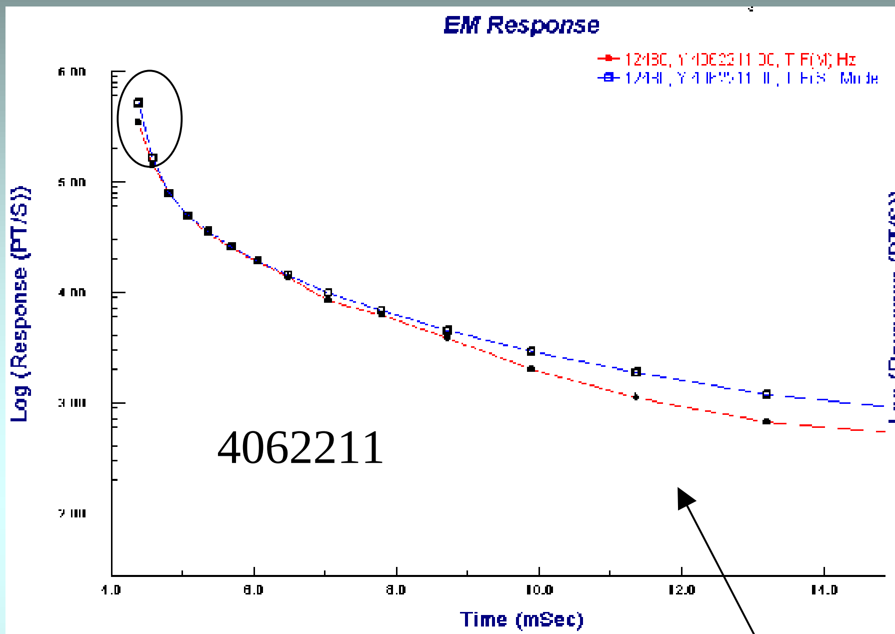


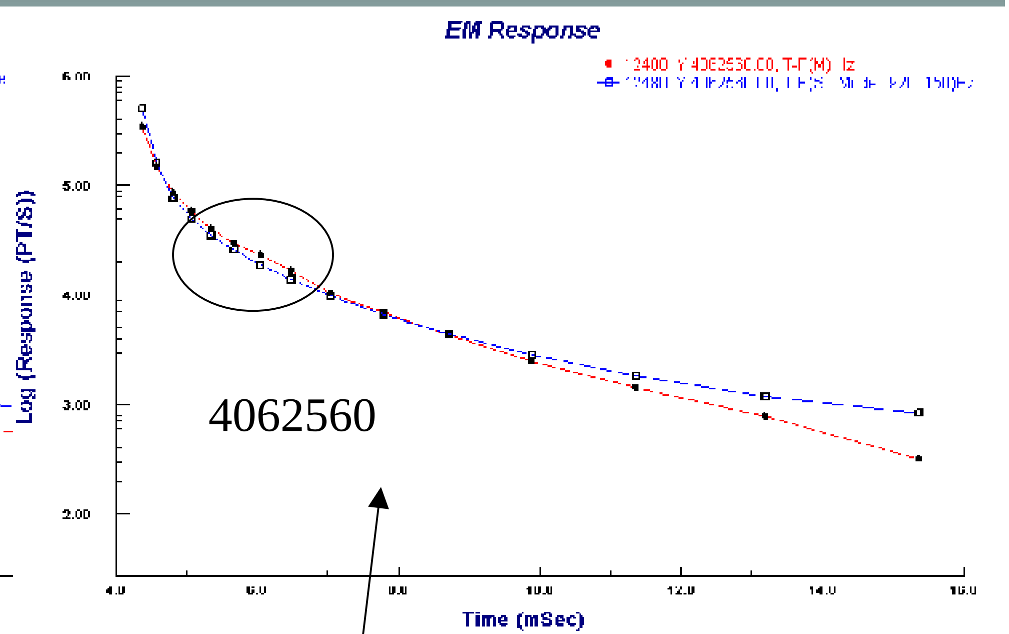
Although Model 91b_150 is a decent fit for the data along 10130 for Hz, it is a poor fit for Hx at most data points (see 4062213 above), having too slow of a decay. The Hx data also appears fairly noisy beginning at mid-times.

Data (Line 10130)

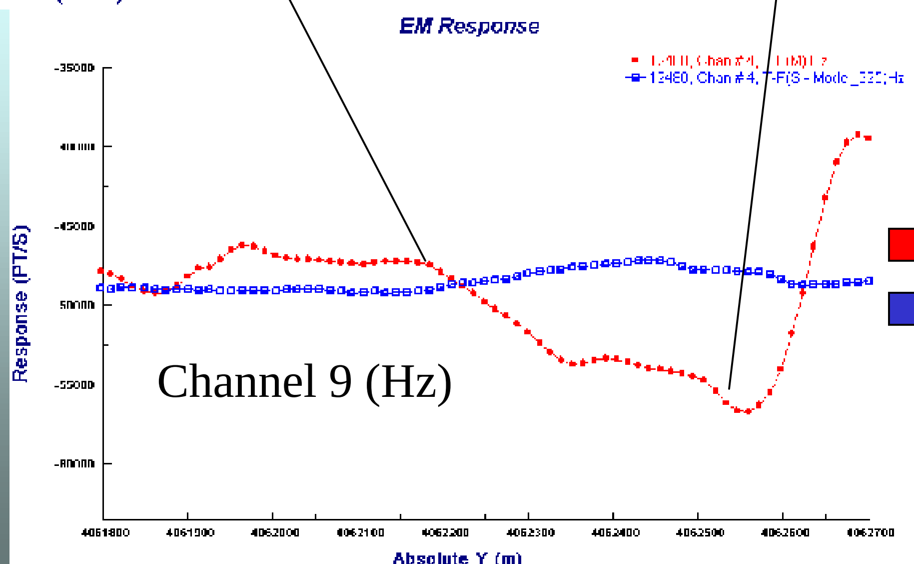
Model 91b_150 (Line 10130)

GeoTEM Decay





GeoTEM decay curves at two points along Line 12480.



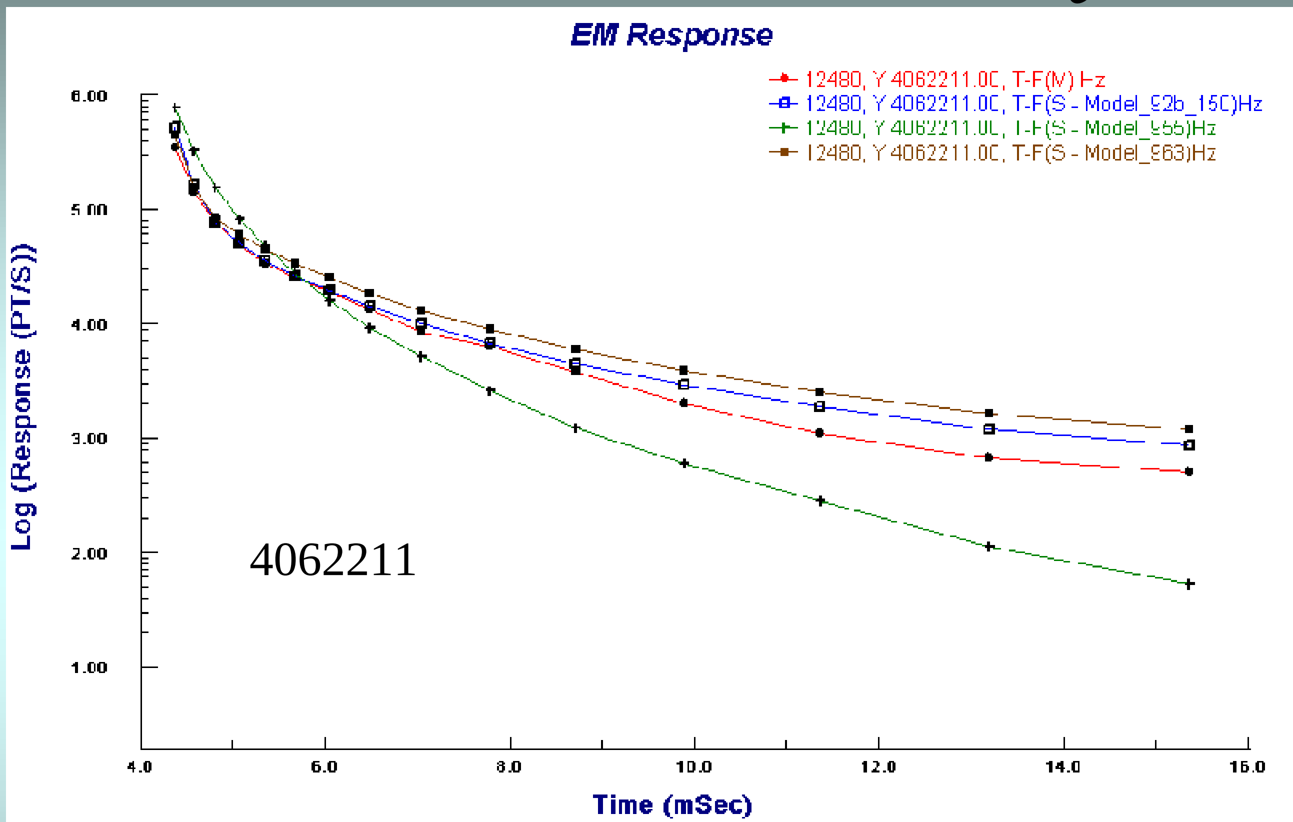
Data (Line 12480)

Model 91b_150 (Line 12480)

Model 91b_150

Resistivity (Ω m)	Thickness (m)	Depth to Bottom (m)	Lithology
150	103	103	Sedimentary Layers
942	100	203	
73	79	282	
2900	40	322	Limestone
2.95	74	396	Conductor
0.7753			

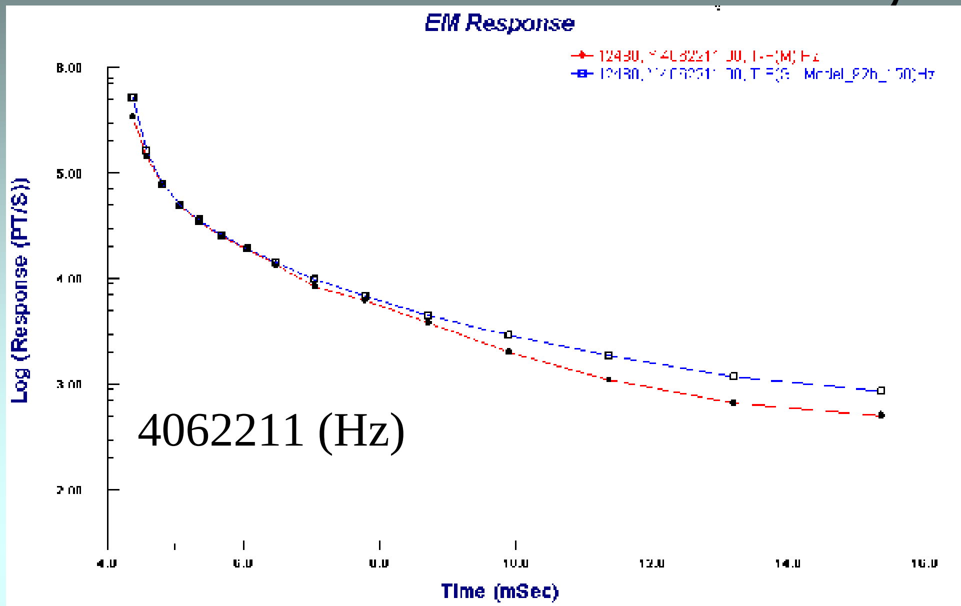
GeoTEM Decay - skip

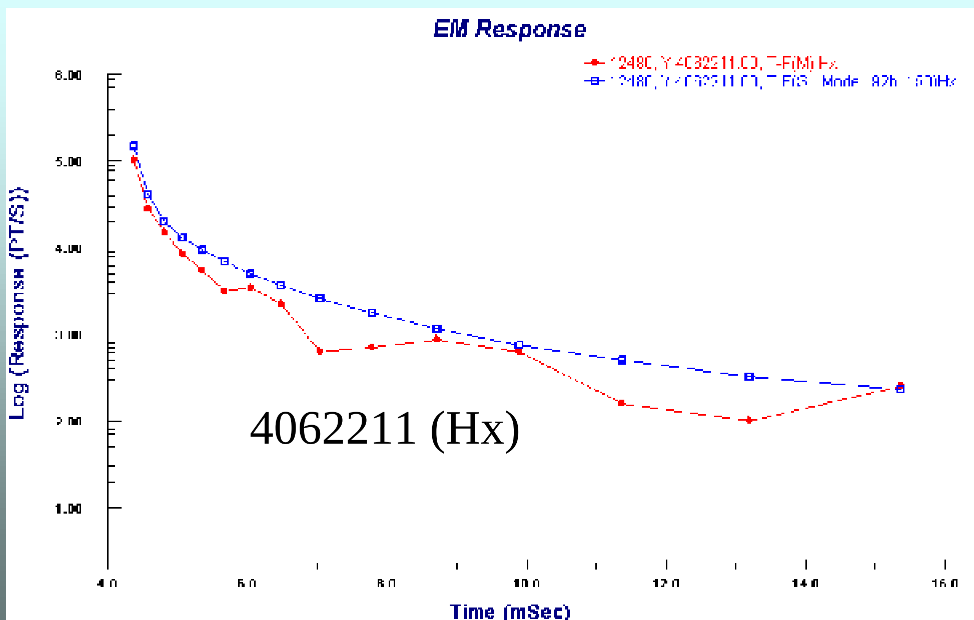


- Data
- Model 91b_150
- Model 91b_150 – no conductor
- Model 91b_150 – no resistor

If the conductive layers at depth are removed from Model 91b_150, it affects the decay curve across all time channels. Removing the resistor above the conductive layers affects the response except at very early times.

GeoTEM Decay – Hz and Hx

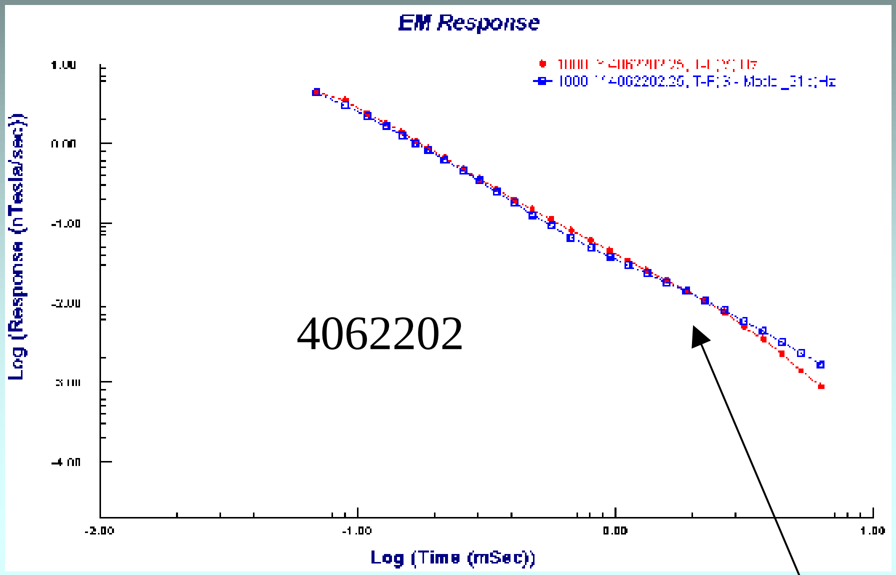


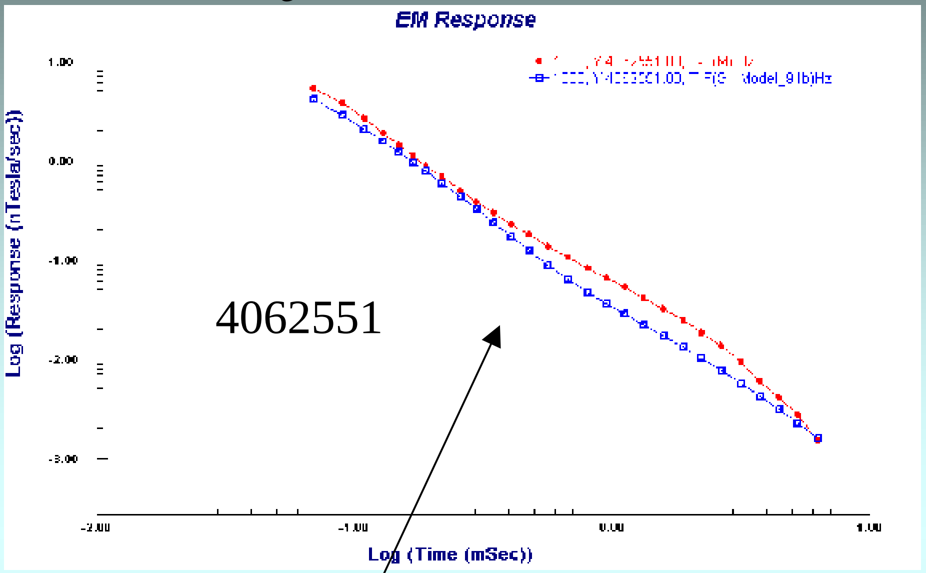


For the GeoTEM data, Hz and Hx show similar trends, although the Hx data appears noisy at mid and late times.

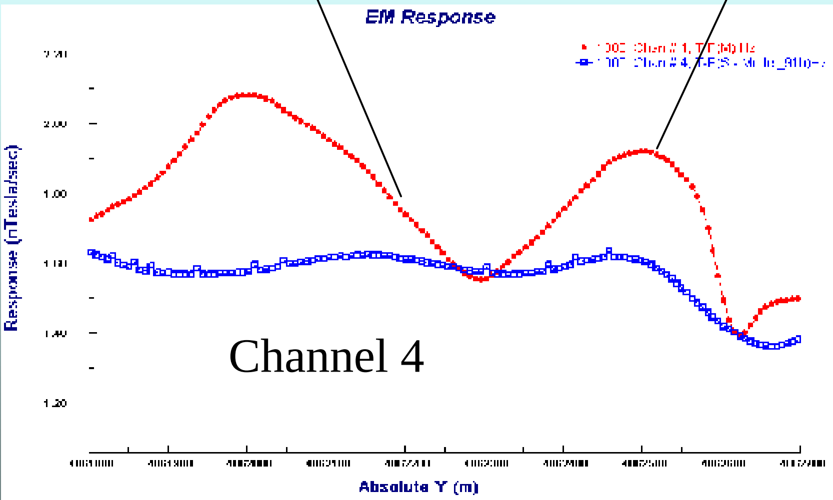
- Data (Line 12480)
- Model 91b_150 (Line 12480)

VTEM Decay





Decay curves at two points along Line 1000. Some variation in the decays is noted across the area. At 4062551, the decay at late times suggests a more conductive area at depth.



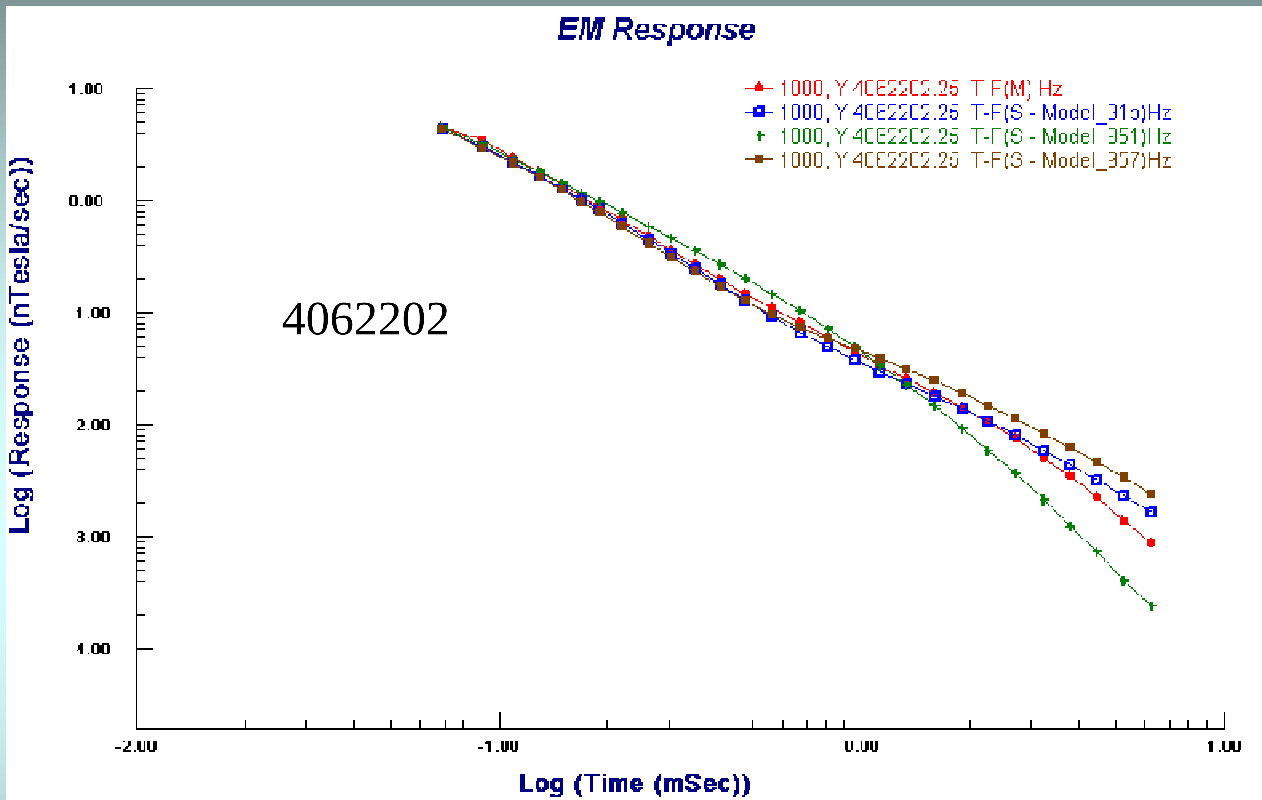
Model 91b

Resistivity (Ω m)	Thickness (m)	Depth to Bottom (m)	Lithology
100	103	103	Sedimentary Layers
942	100	203	
73	79	282	
2900	40	322	Limestone
2.95	74	396	Conductor
0.7753			

Data (Line 1000)

Model 91b (Line 1000)

VTEM Decay

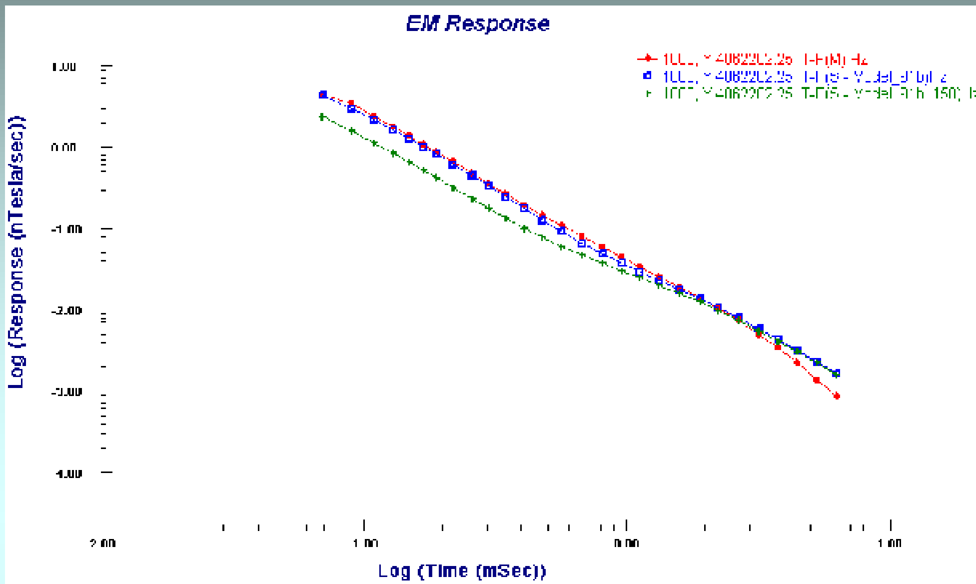


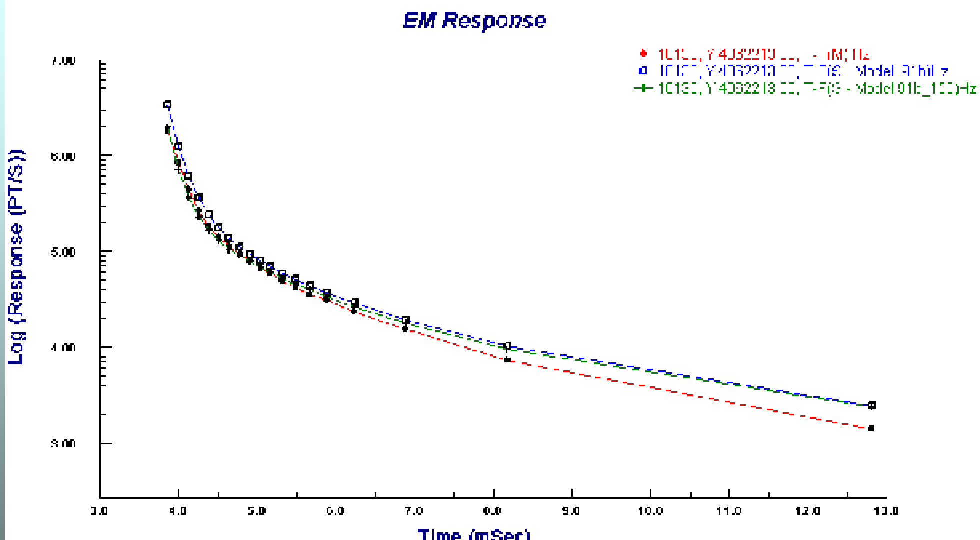
- Data
- Model 91b
- Model 91 b – no conductor
- Model 91b – no resistor

The conductive layers at depth have a significant effect on the response from the model. When the bottom two conductive layers are removed from Model 91b, it has a significant effect on the response, even at fairly early times (channels 7 and 8).

When the resistor (2900 Ω m) is removed from the model, it affects the response at mid-late times.

Effect of Overburden Resistivity



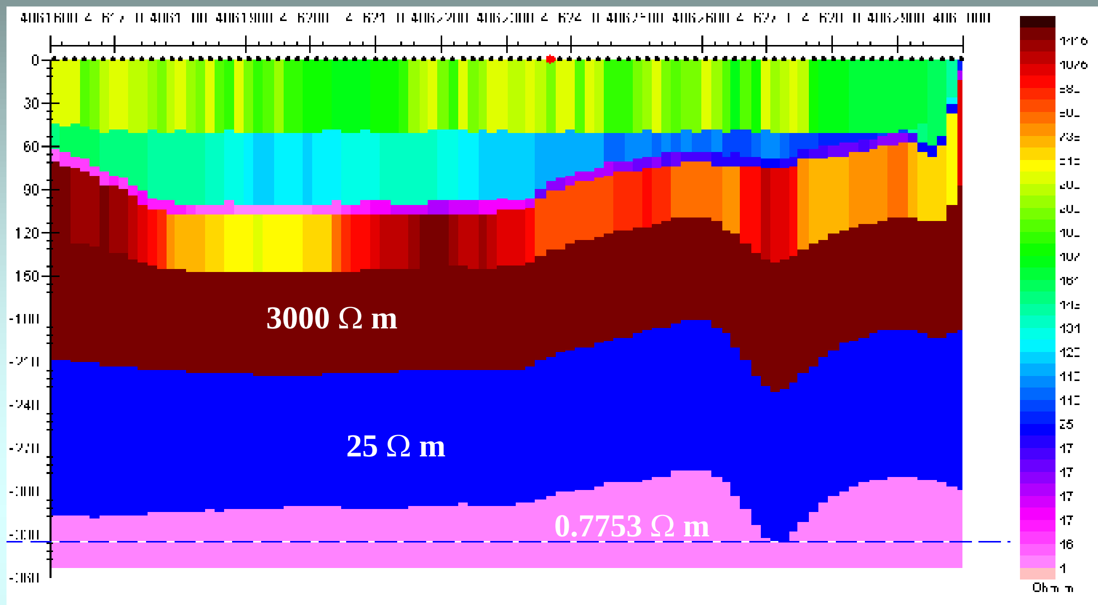


As noted, the resistivity of the overburden was adjusted slightly in the VTEM vs the GeoTEM/MegaTEM models: the resistivity of the top layer used in the model was 100 Ω m for VTEM, and 150 Ω m for MegaTEM/GeoTEM. The reason for this discrepancy is not known, and limited data analysis and modeling has been done thus far. The response of the model is very sensitive to the resistivity of this layer, as shown for the VTEM and MegaTEM data (particularly noticeable for VTEM). Changing this resistivity affects all but the very late time channels.

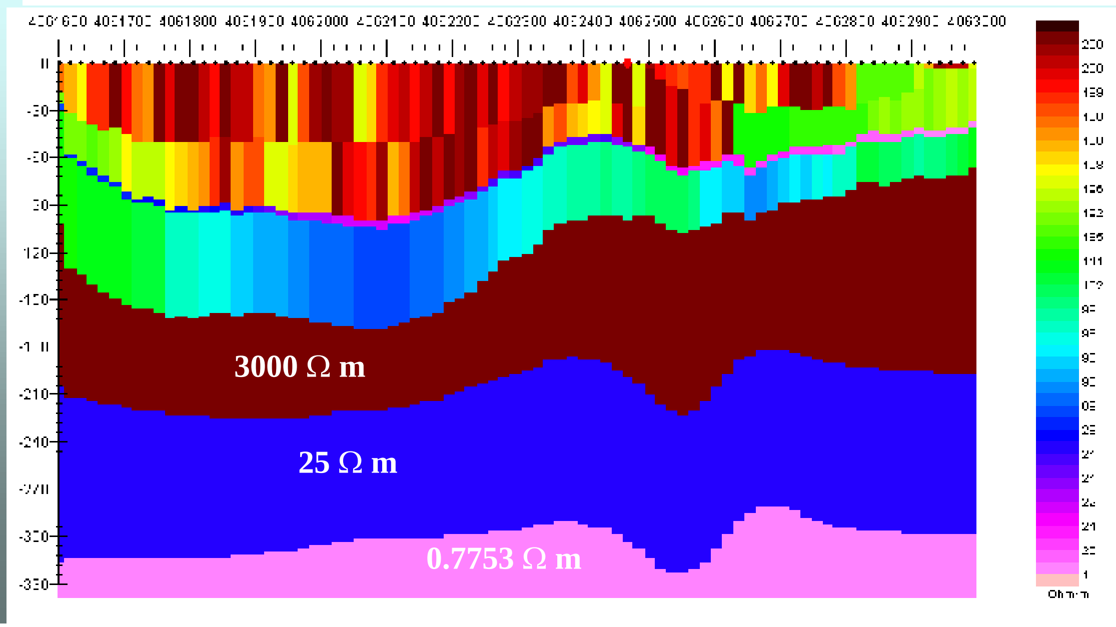
- Data
- Model 91b
- Model 91b_150

MegaTEM Inversion

10120



10130

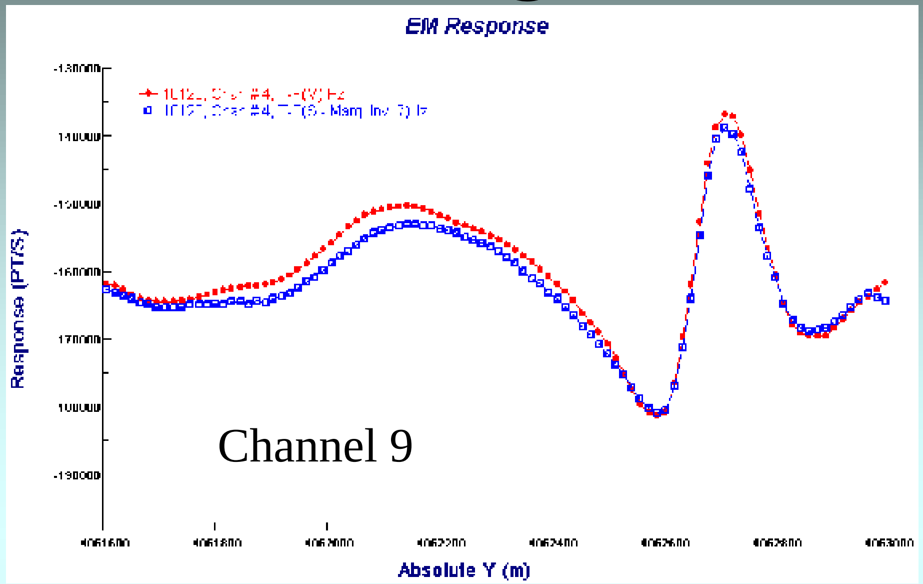


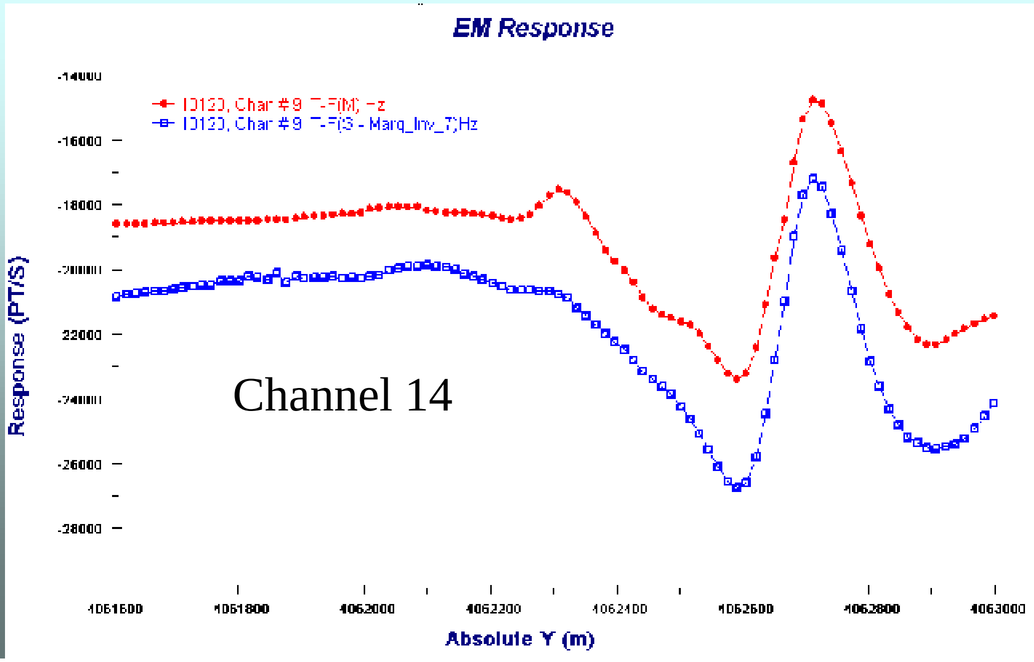
This 7-layer Marquardt inversion is for the original MegaTEM data (with correct windows and pulse, but not rewindowed). The resistivity of the bottom three layers were fixed at 3000 Ω m, 25 Ω m and 0.7753 Ω m.

Marq_Inv_7

original windows

MegaTEM Inversion





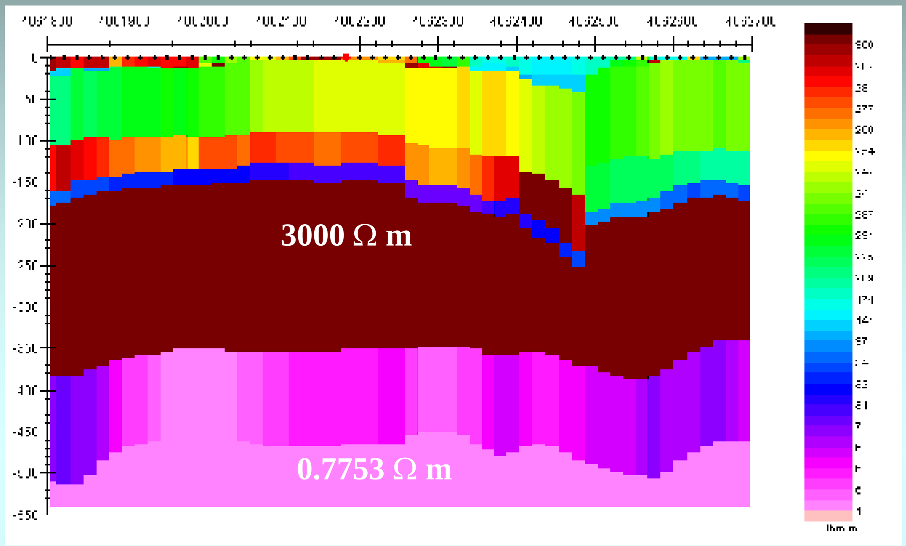
Marq_Inv_7

Data (Line 10120)

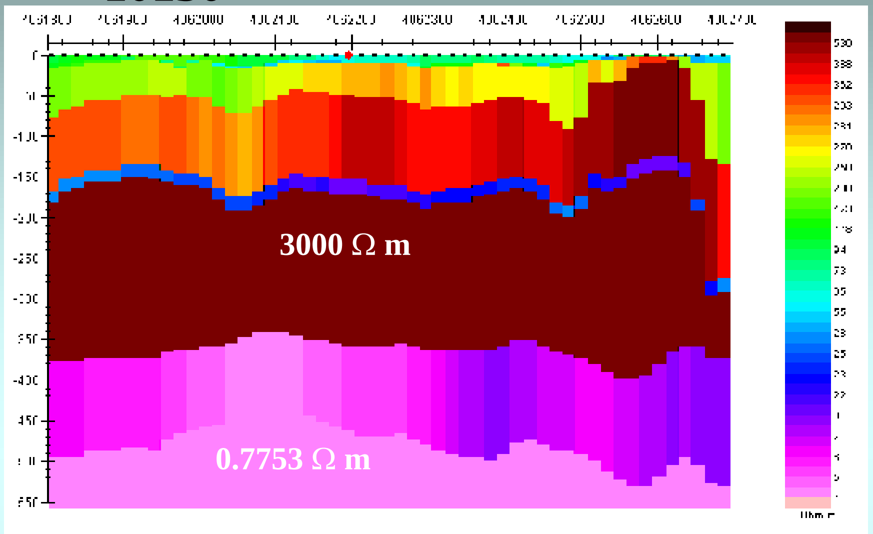
Marq_Inv_7 (Line 10120)

MegaTEM Inversion (rewindowed)

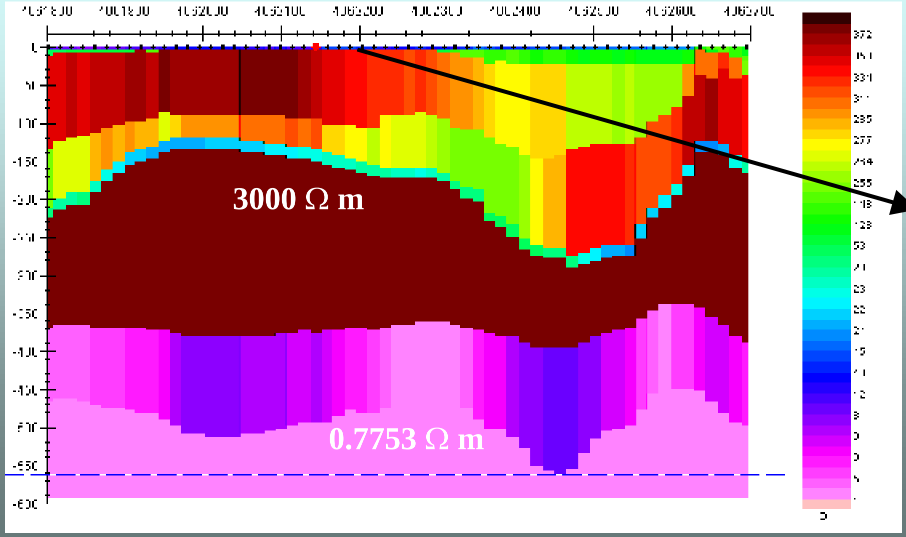
10110

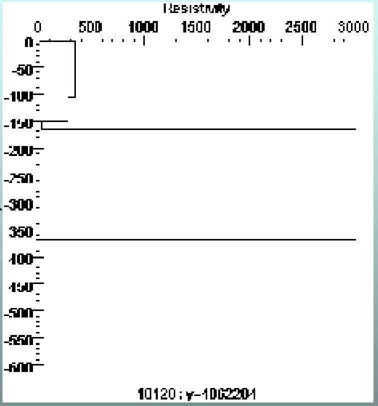


10130



10120

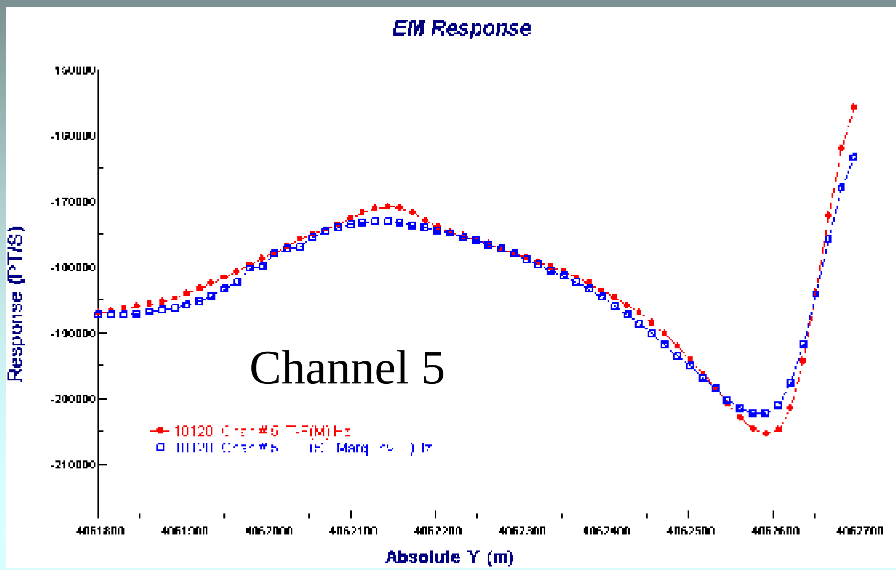


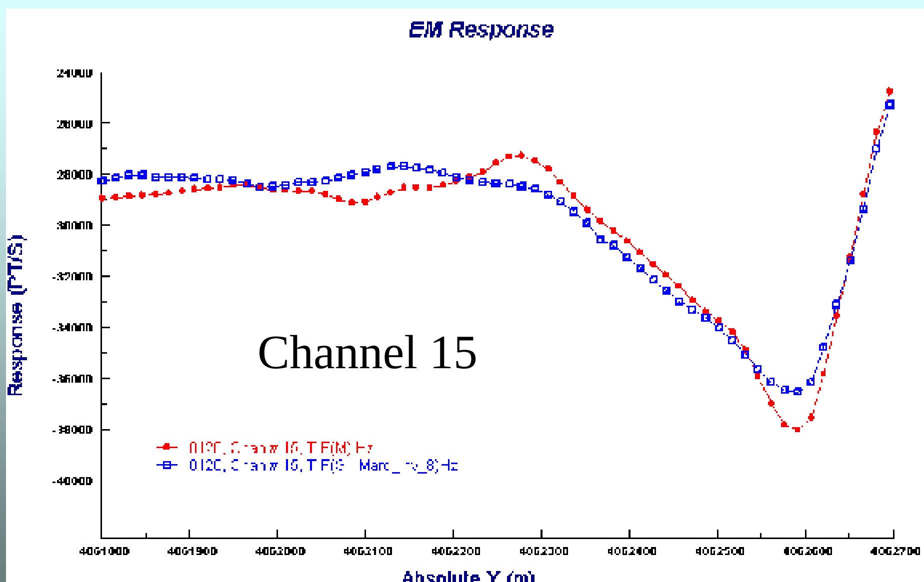


The rewindowed MegaTEM data was inverted using an 8-layer Marquardt inversion. The resistivity of two of the layers were fixed at 3000 Ω m and 0.7753 Ω m.

*The first time channel was not inverted

MegaTEM Inversion (rewindowed)





Marq_Inv_8

Data (Line 10120)

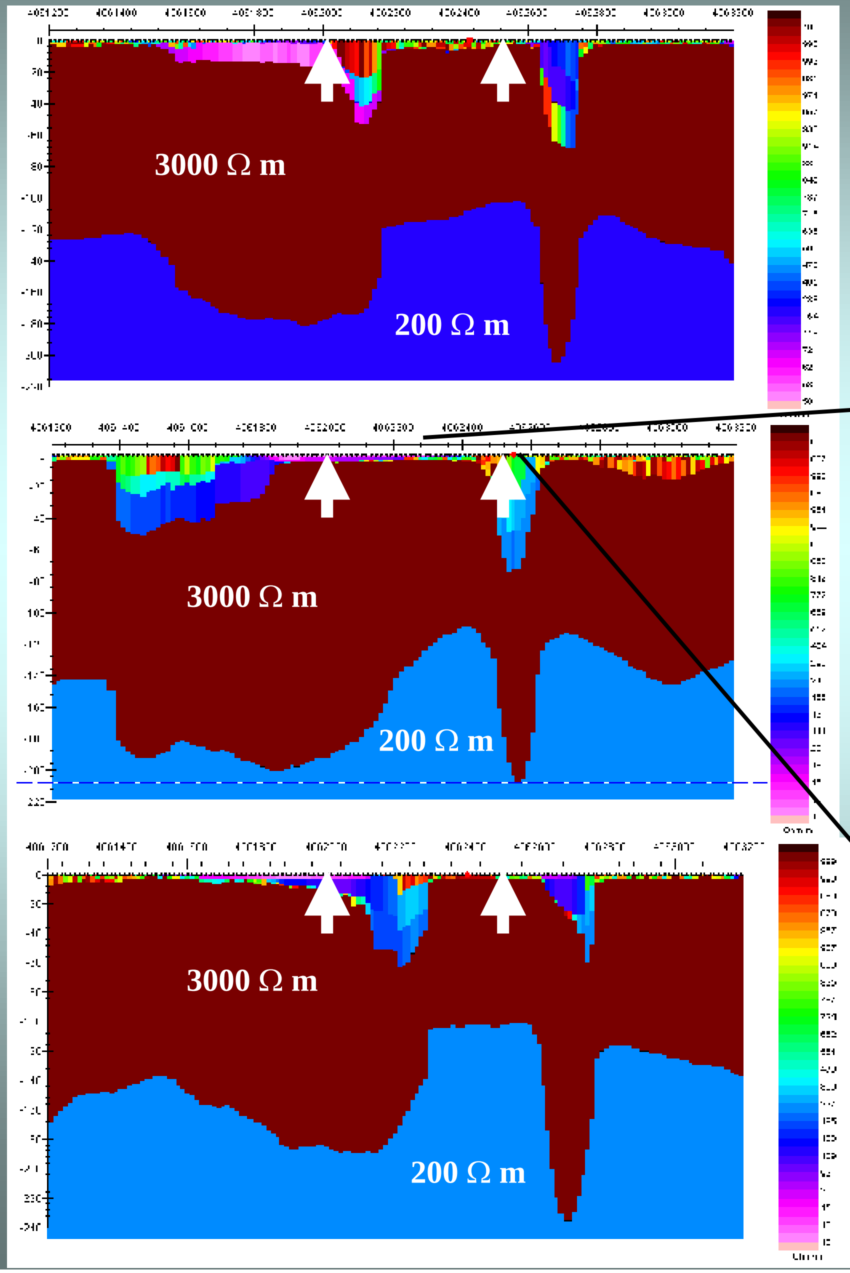
Marq_Inv_8 (Line 10120)

GeoTEM Inversion

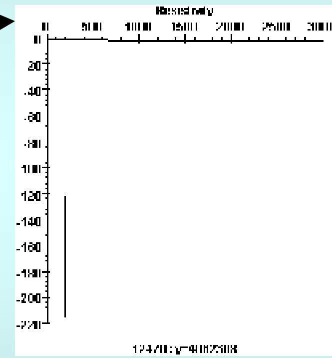
12460

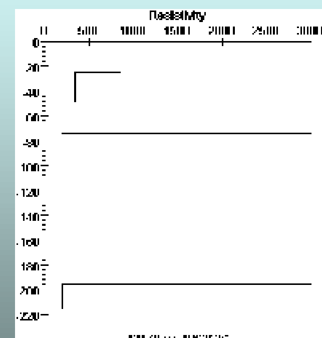
12470

12480

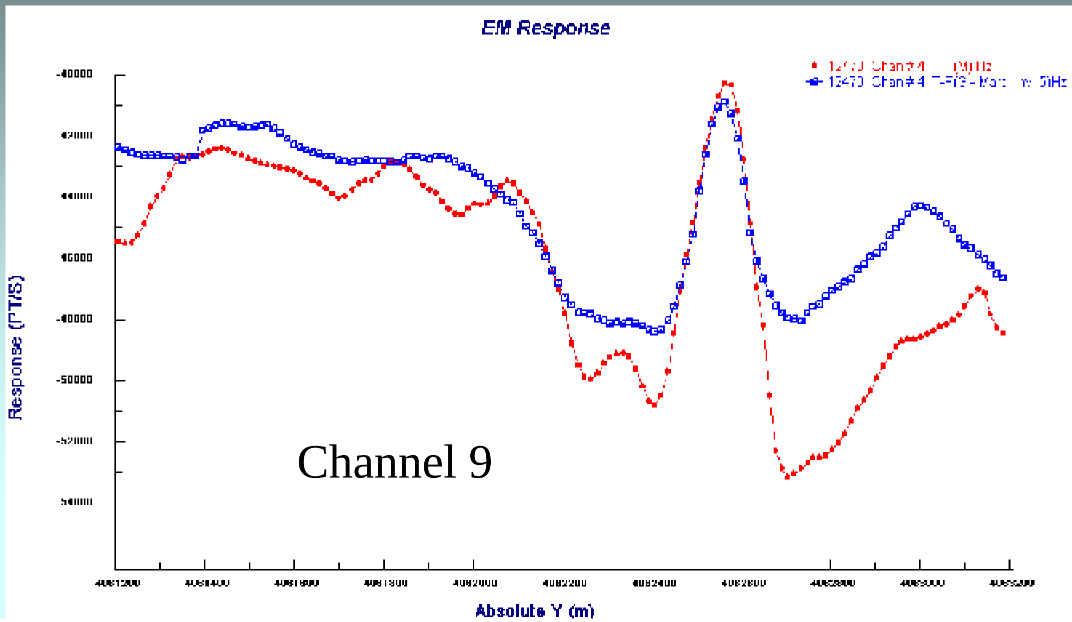


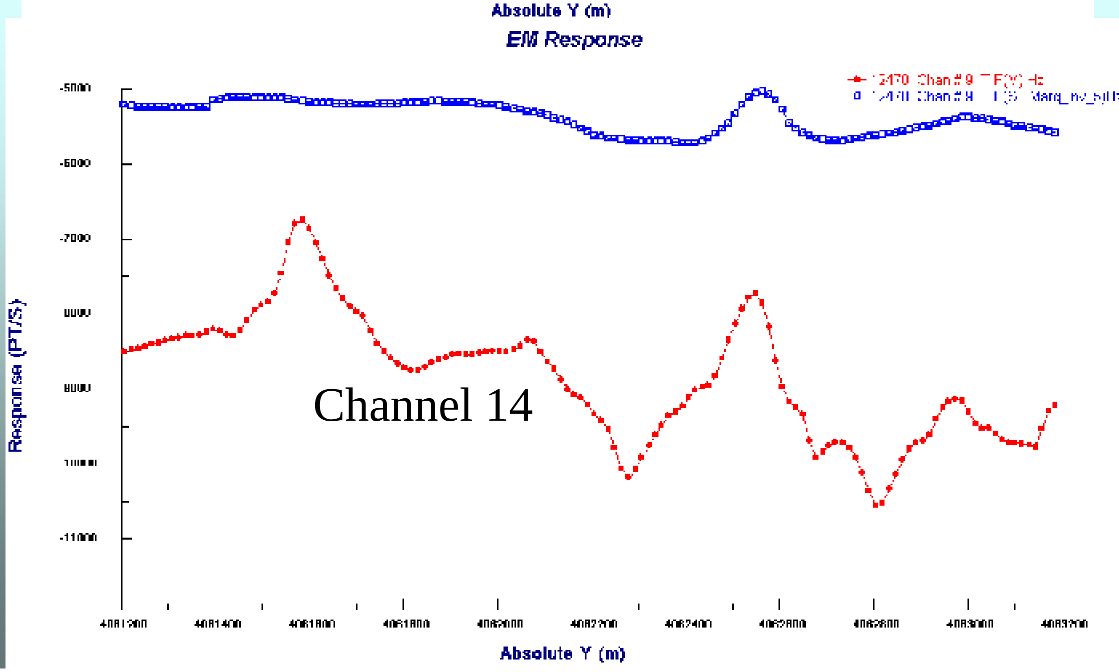
The GeoTEM data was inverted using an 5-layer Marquardt inversion. The resistivities of the two bottom layers were fixed at 3000 Ω m and 200 Ω m. The north/south locations of the two tanks are noted with arrows.





GeoTEM Inversion





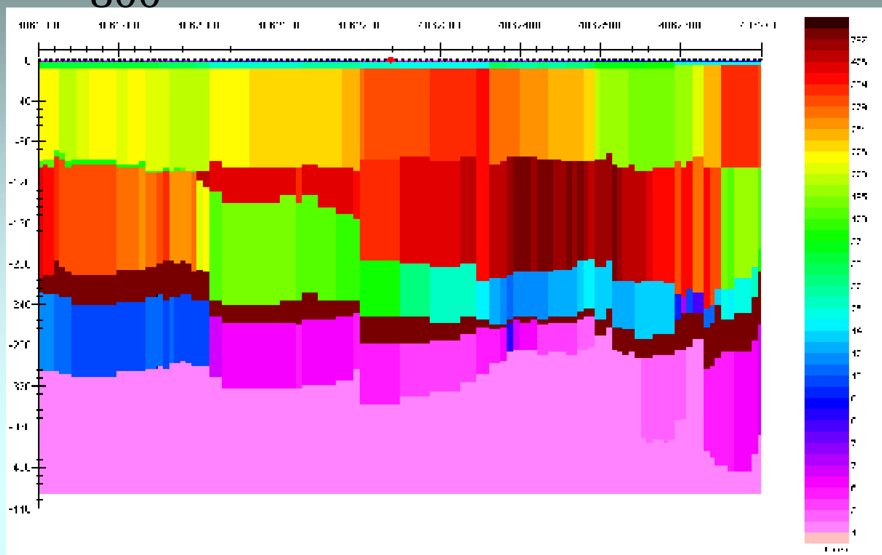
Marq_Inv_5

Data (Line 12470)

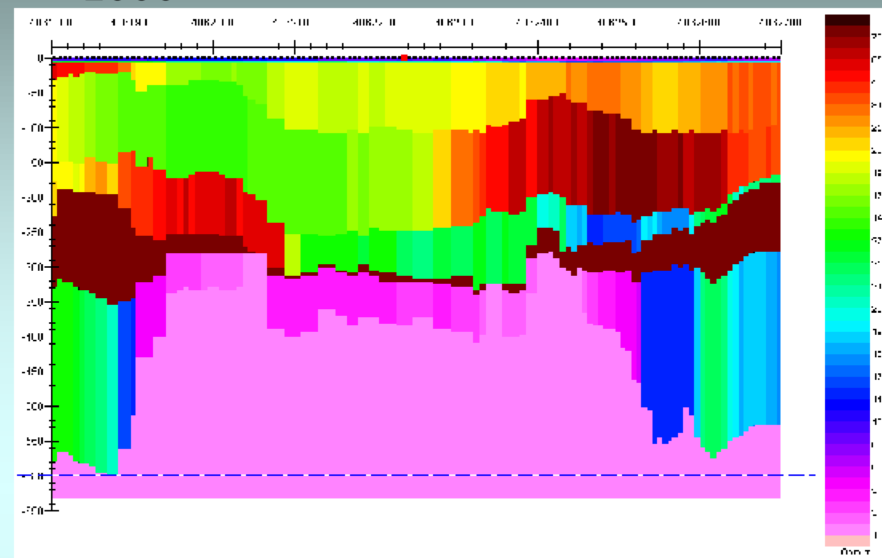
Marq_Inv_5 (Line 12470)

VTEM Inversion

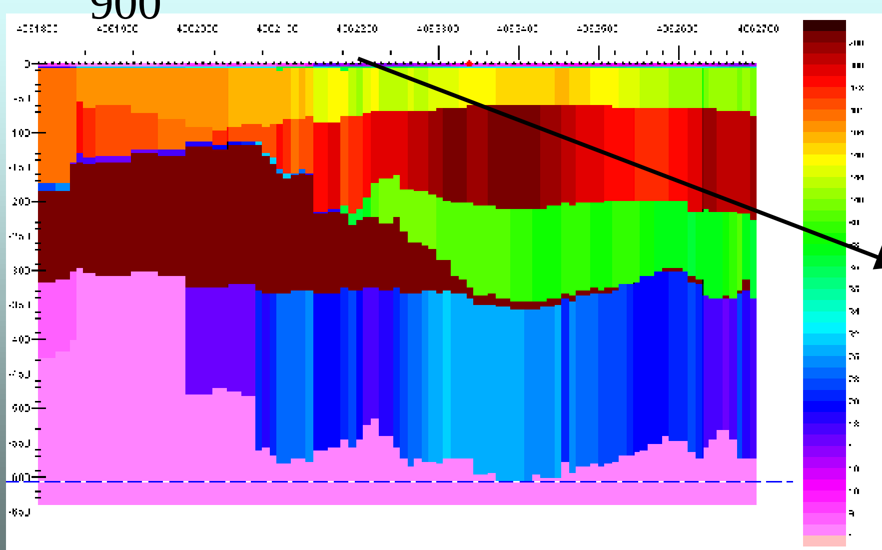
800

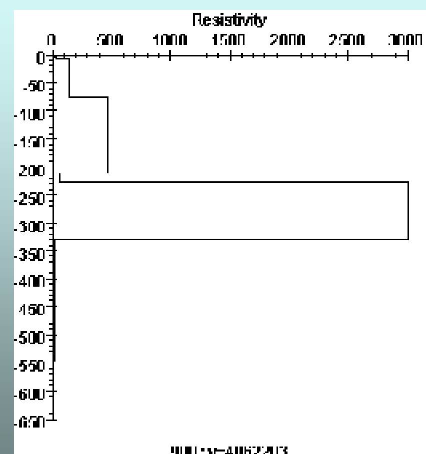


1000



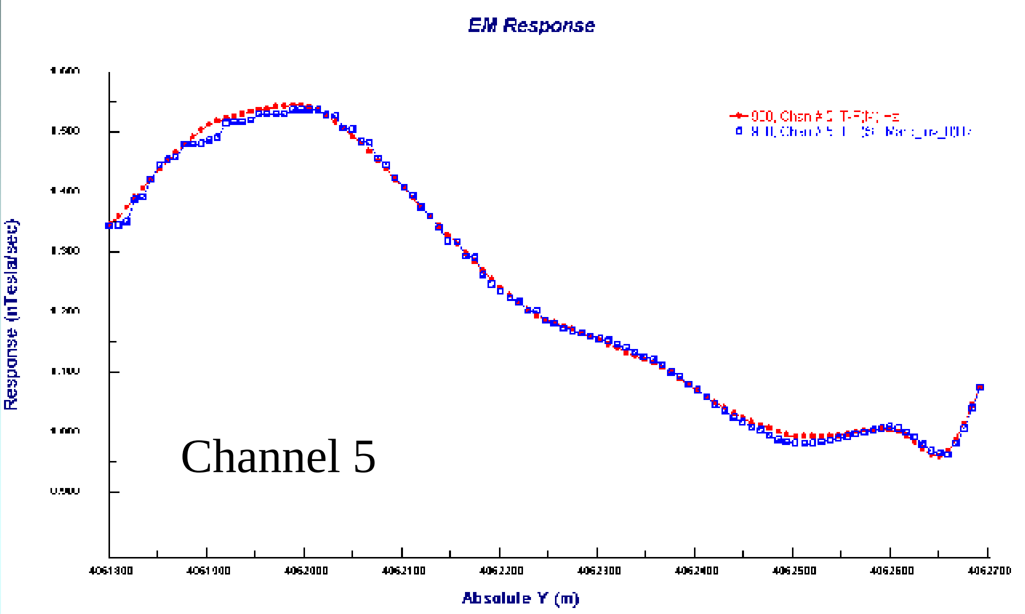
900

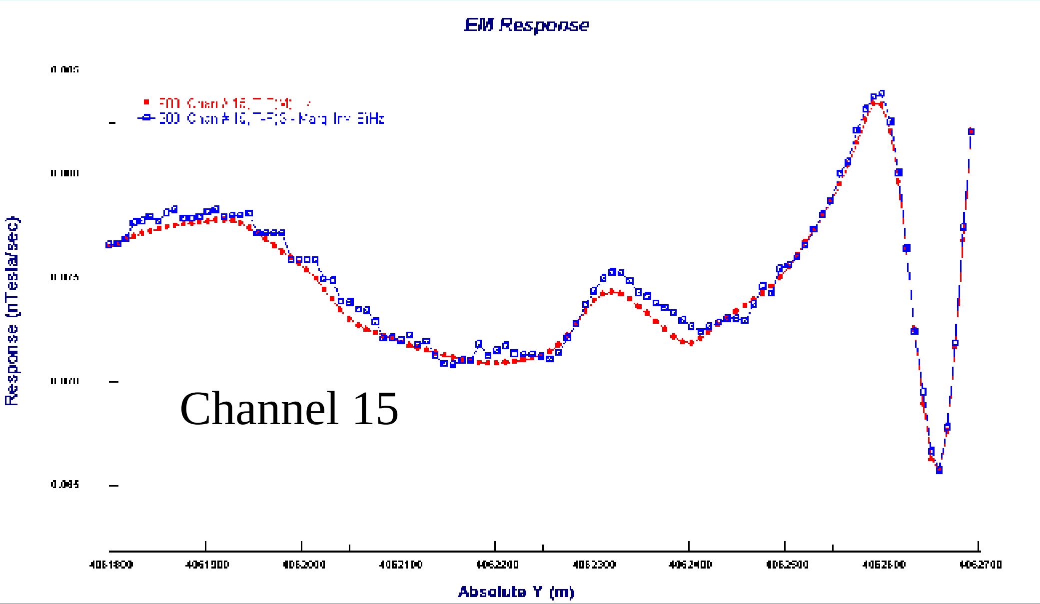




An 8-layer Marquardt inversion on the VTEM data is shown. Note that the high resistivity layer is much thinner than in the inversions for the other systems. *As seen in the decays, the VTEM survey was not as sensitive to this layer as the other surveys.

VTEM Inversion





Marq_Inv_8

Data (Line 900)

Marq_Inv_8 (Line 900)

Summary

many critical issues when interpreting and inverting airborne EM data in sedimentary environments

careful control and analyses of the data should be carried out

pre-modeling to determine appropriate system settings
careful data control

and then excellent results can be obtained by virtually any of the present systems

GeoTEM 2006

-*comparison of 2006/2007 original data*

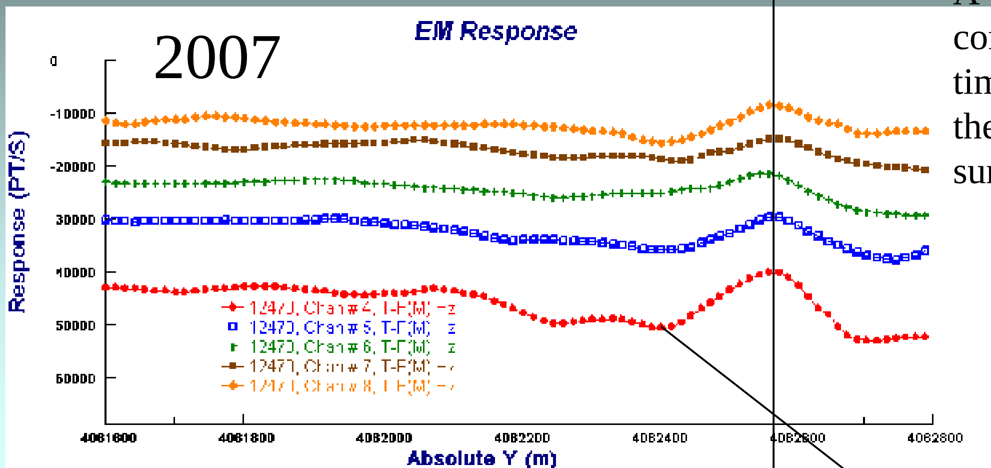
-*comparison of 2006 original/rewindowed data; discuss noise*

-comparison of time channels wth 2006 rewindowed data + fit with model

-inversions for 2006 data – original

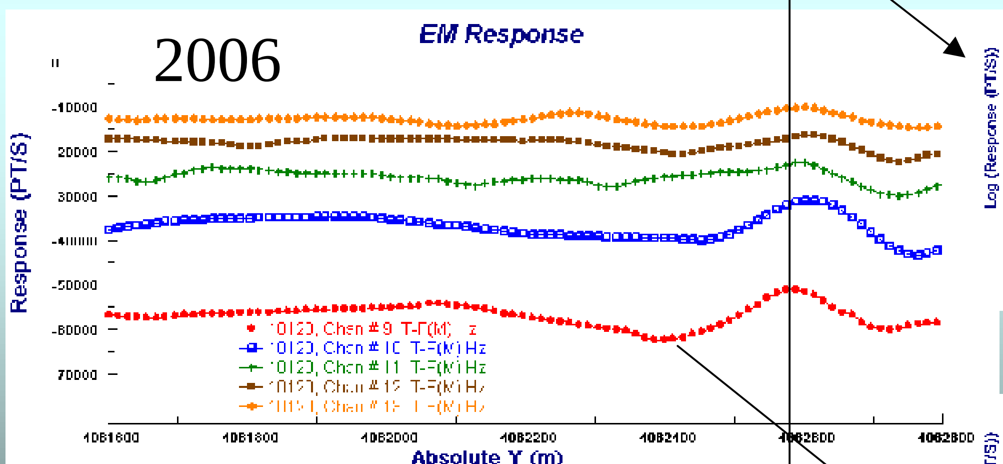
inversions for 2006 data – rewindowed

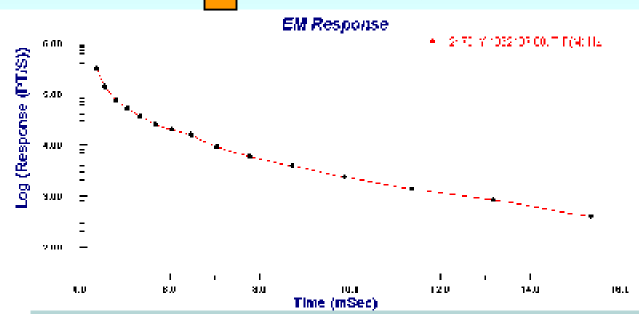
GeoTEM 2006/2007

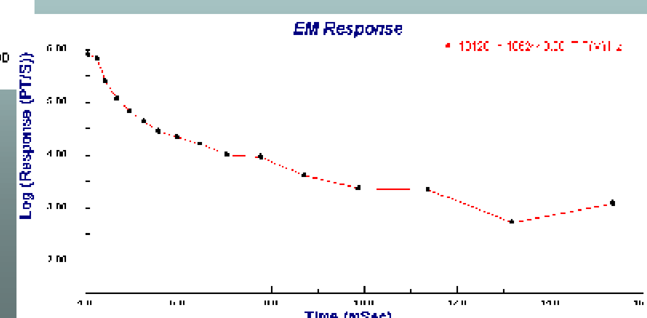


A test GeoTEM survey was also conducted in 2006. A comparison of the data for these two surveys for a few time channels is shown (Line 12470/10120). Note that there are some differences in response between these two surveys.

- Channel 9 (4TH OF-TIME)
- Channel 10
- Channel 11
- Channel 12
- Channel 13

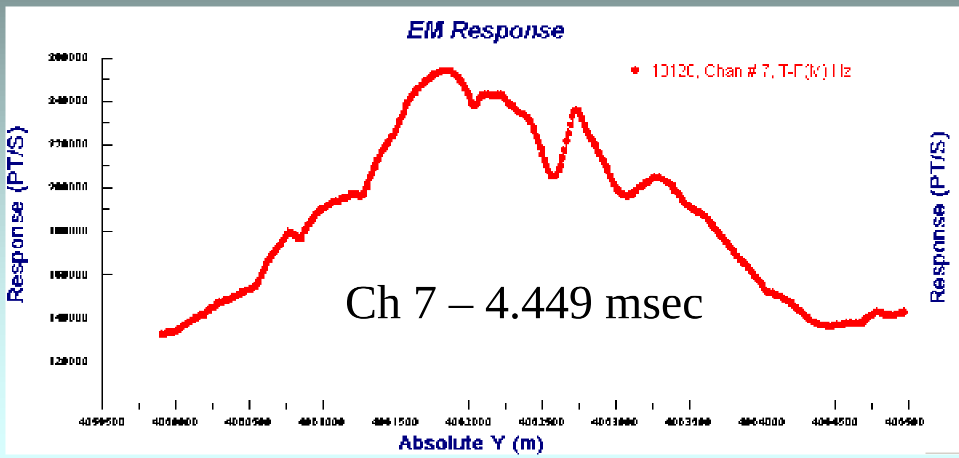


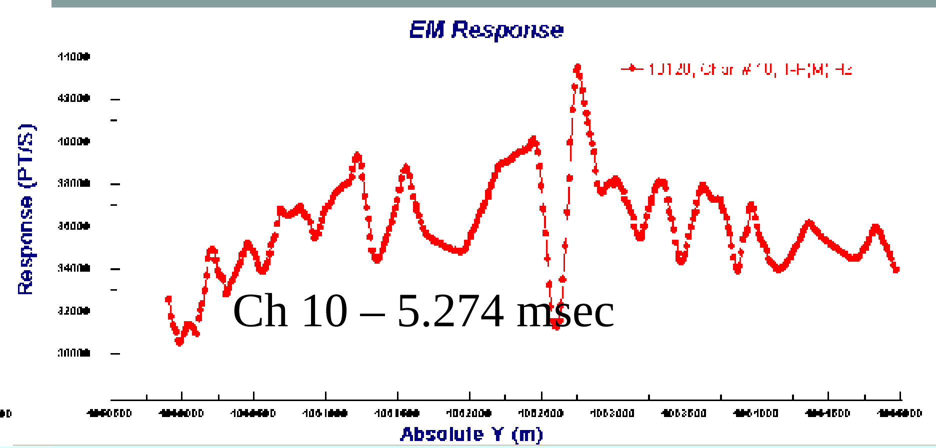


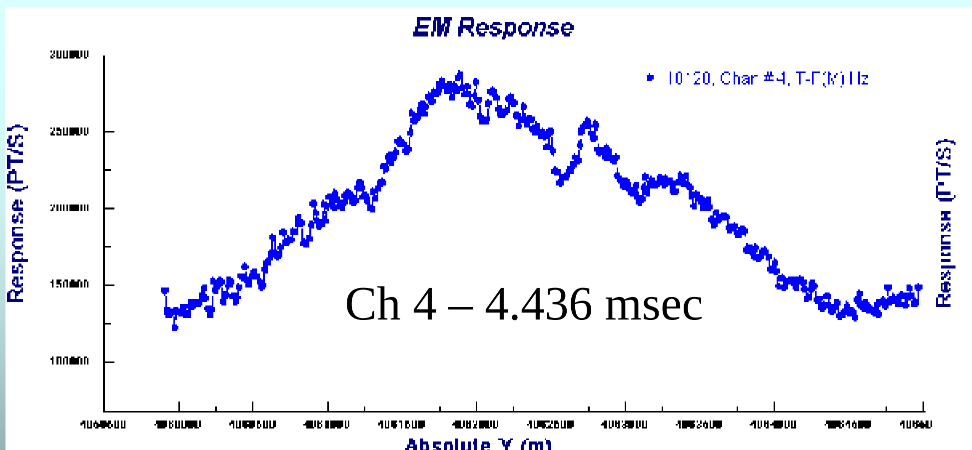


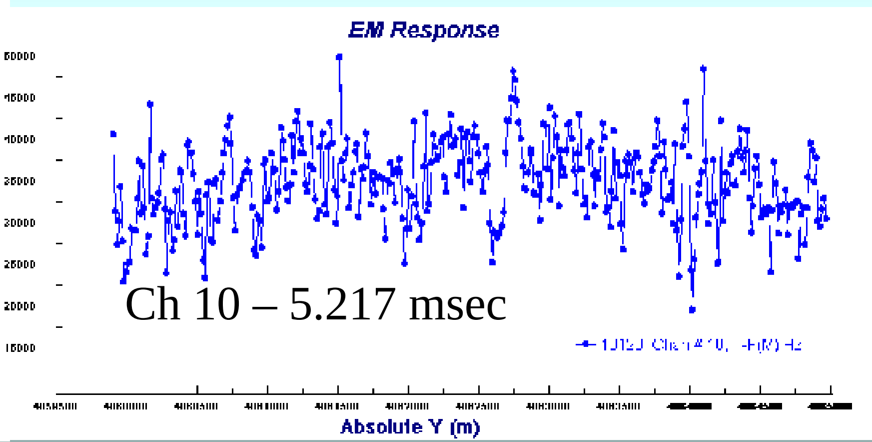
*Decays are typically cleaner in the 2007 data.

GeoTEM 2006 Rewindowing





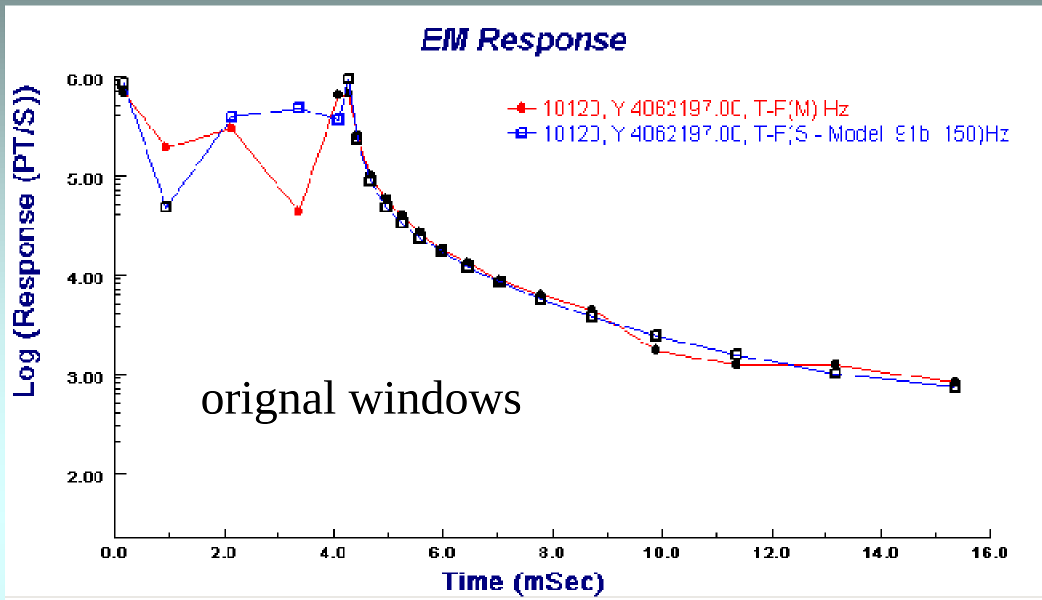


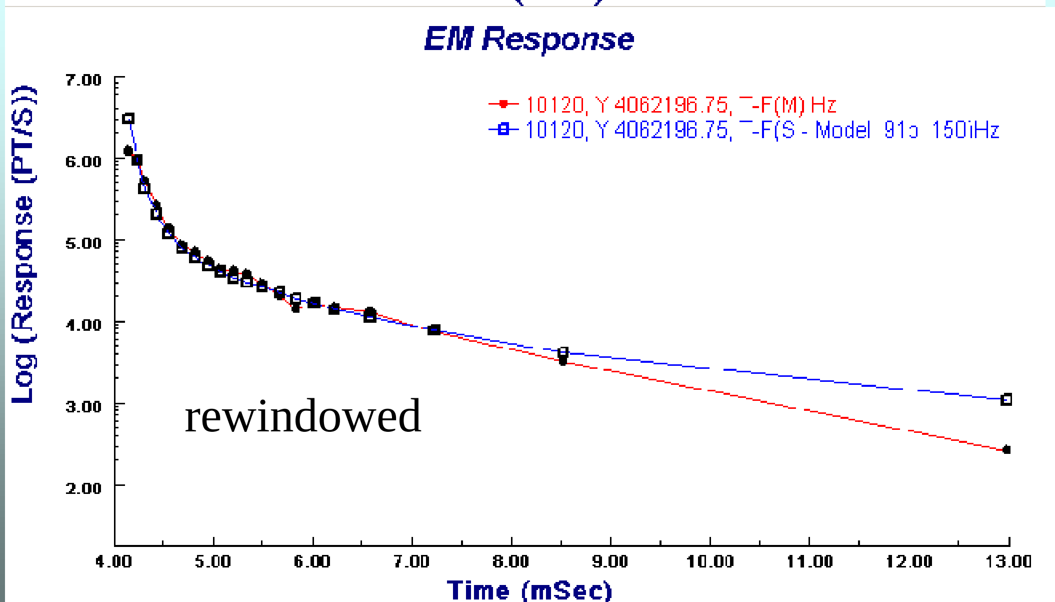


Plots of the data along 10120 are shown for the original data and the rewindowed data at two similar times. The rewindowed data appears much noiser across the profile. This may be due to different processing – eg, filtering that was not applied when the data was rewindowed.

- 2006 original
- 2006 rewindowed

GeoTEM 2006 Decay





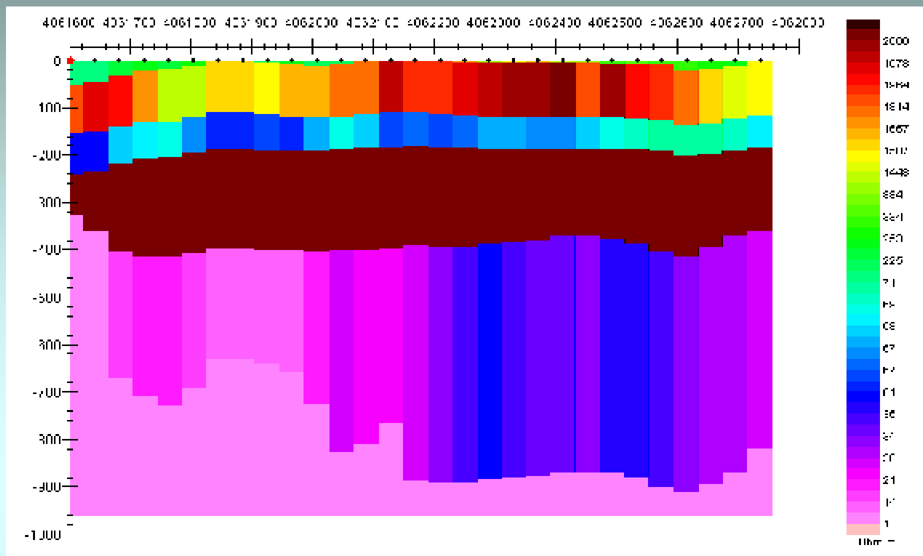
The rewindowed data contains more time channels in early off times, as seen in the decays. Comparisons of the original and rewindowed data with Model 91b_150 are shown for 4062197 (north) along 10120.

Data

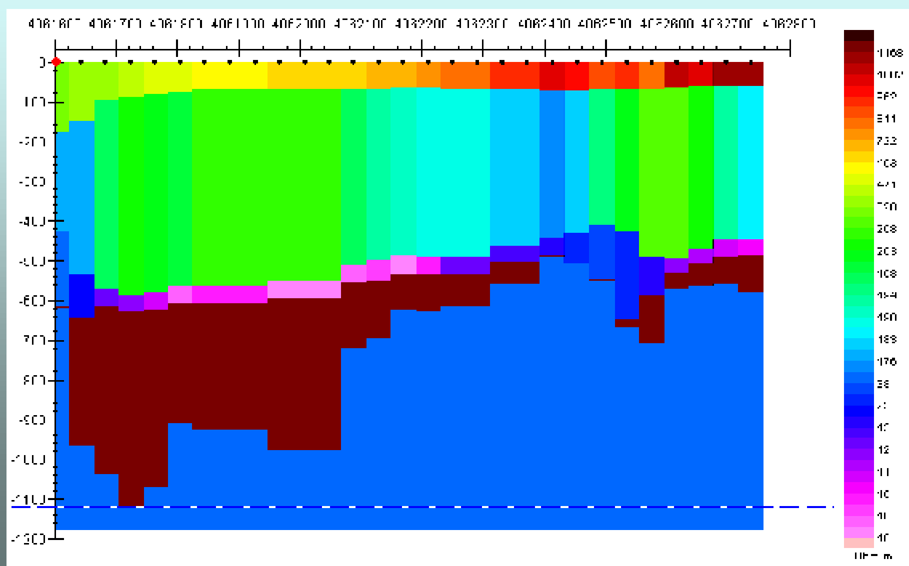
Model 91b_150

GeoTEM 2006 Inversions

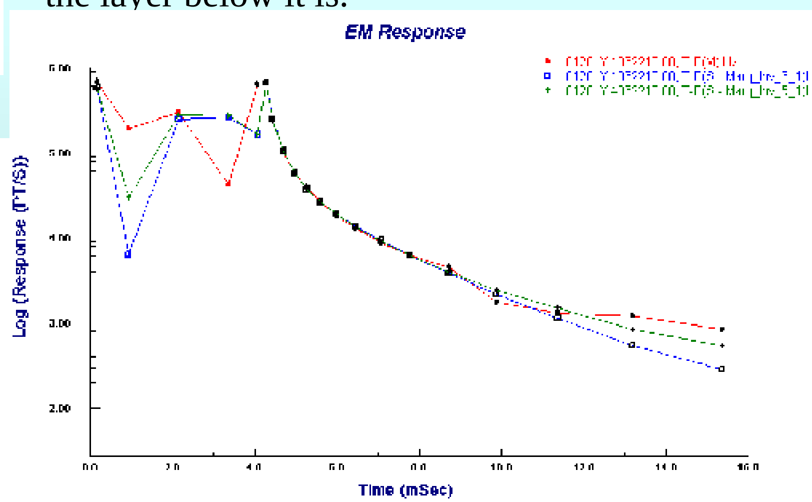
Marq_Inv_6_1



Marq_Inv_5_1



Two inversions performed on the original GeoTEM data (Line 10120) are shown. In the Marquardt 6 inversion, Model 91b_150 was used as a starting model, and the resistivities of the fourth and sixth layers were kept constant at 2900 Ω m and 0.7753 Ω m . In the Marquardt 5 inversion, the bottom two layers were kept constant at 2900 Ω m and 50 Ω m . These show quite a different depth to the resistive layer, depending on how conductive the layer below it is.



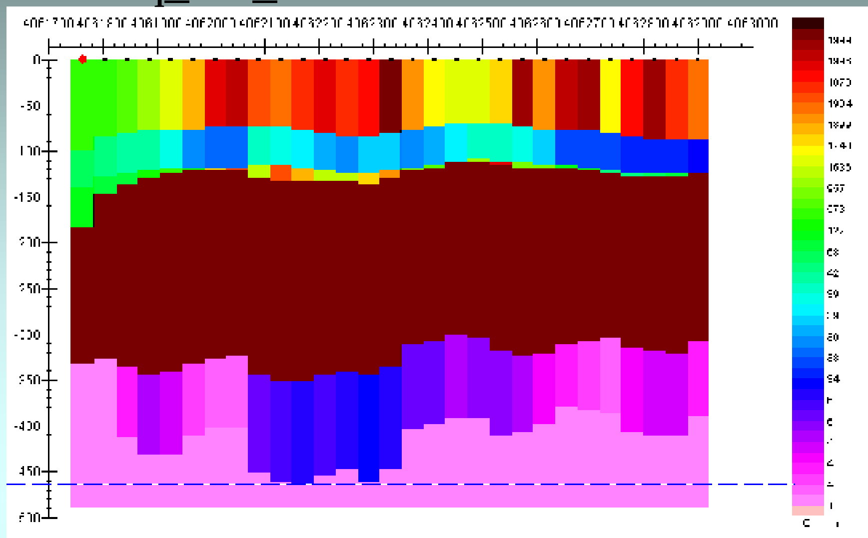
Data

Marq_Inv_6_1

Marq_Inv_5_1

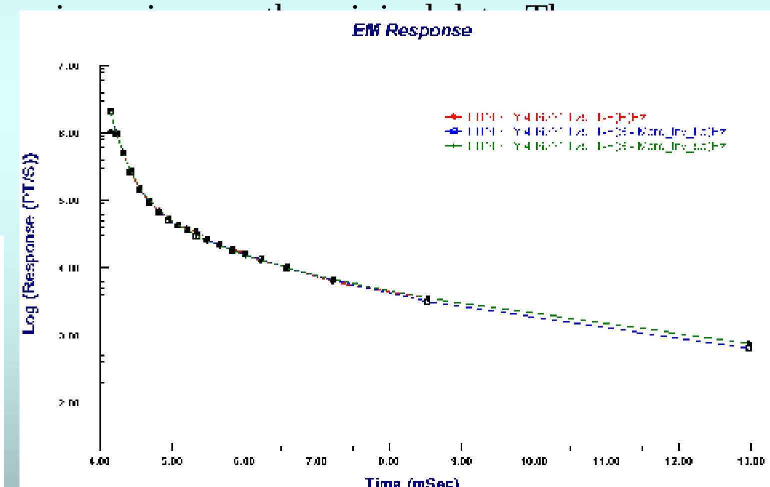
GeoTEM 2006 – rewindowed Inversions

Marq_Inv_6a



Marq_Inv_5a

Before inverting, a Gaussian filter was applied to the data to remove some of the noise (see slide 44). The filtered data was then decimated. Inversions were performed on the rewindowed data with the same parameters as the original data. These inversions show more consistent results for the depth to the resistive layer and in the resistivities above this layer, than do the



- Data
- Marq_Inv_6a
- Marq_Inv_5a

Summary and Conclusions

- The anomalies appear to be shifted on every other line. This seems to be due to differences in response depending on which direction the aircraft was flying.
- There is a strong anomaly to the north part of the Findlay tank area seen on all airborne surveys (around 4062600 north), which may be near to where there is a dead powerline. There is a broader anomaly to the south part of the area (around 4062000 north), which appears to be approxiamtely were one of the tanks is. This anomaly is most clear in the VTEM data.
- Little variation in response is due to changes in altitude of the aircraft.
- Modeling suggests a conductor at depth (~300 m), and the response is fairly sensitive to this. There also appears to be a fairly resistive layer above it (limestone?).
- All three airborne surveys suggest similar subsurface structure.
- Hx and Hz do not always agree for the MegaTEM data.