# Some Preliminary interpretation on the Marine Controlled Source Electromagnetic (MCSEM) data acquired on Campos Basin, Brazil

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## Abstract

The Campos Basin MCSEM data was acquired on a rectangular grid with line spacing of approximately 5 km. Three component electrical field as well as two component magnetic fields were recorded, from which the in-line electrical horizontal fields at each receiver position were processed to yield ratio maps of that field to a reference remote station.

The main objectives of the survey were to calibrate the method with known oil reservoir in the area and to assess the amplitude of the anomalies associated with those reservoirs, with the expectation that some unknown prospective area would be detected.

It is shown that the expected MCSEM modeled response of known reservoir yields anomaly ratios high enough to be measured by the method and that there have been many indication correlating the real MCSEM data with known oil reservoir in several places in the area.

## Introduction

In recent years, the MCSEM method has driven the attention of major oil companies due to its sensitivity to map resistive layer beneath the ocean bottom with some success in finding oil reservoirs (Ellingsrud et al., 2002; Eidesmo et al., 2002). Some major oil companies have been applying this technology over several geological scenarios, including the north sea, west Africa and offshore Brazil, among others.

The brazilian survey was performed as a multi-client survey, so Petrobras was able to buy all the raw MCSEM data which are currently being processed and interpreted in-house.

The interpretation of MCSEM deserves a great deal of integration with seismic and geological and petrophysical data about the area under investigation. MCSEM as for all other geophysical methods, has several ambiguities that should be constrained by *a priori* information. Besides this, the method is in its early stage of application to real exploration problems and several institutions are developing multi-client consortia to tackle the method's technical issues from acquisition hardware (transmitters, receivers etc.), accurate survey engineering and data processing, to 1D, 2D and 3D modeling and inversion leading to join inversion with seismic and other available data such as gravity and magnetotellurics. Just to quote professor Steve Constable, of Scripps Institution of Oceanography, San Diego, California, USA, in a recent Spring 2005 SEG forum on Illuminating Reservoirs: Marine CSEM (unpublished): ***The rapid development of marine CSEM for petroleum exploration and reservoir characterization has been largely dependent on access to academic instrumentation and expertise*.** Thanks to two of those consortia, co-sponsored by Petrobras, we have been able not only to learn about several hidden aspects of the technique which are not normally reported in the still incipient literature but, we have been able to access the modeling and inversion softwares produced by those consortia. Those codes have helped us to develop a better understanding of the various issues related to environmental and acquisition problems that may have harmful effect on the measured MCSEM data. All those possible effects have been corrected as accurate as possible.

## Area coverage of MCSEM and 3D Modeling

Petrobras bought a total of approximately 1600 line kilometers encompassing 36 towed lines as shown on the location map of figure 1. The complete survey has been organized into three major blocks, i.e., the southern sector with 339 km covering a small portion of Santos basin, the central sector located on portions of Campos basin with 1121 km and the northern sector, on Espirito Santos basin, with 153 km of towed lines. The Campos basin block was surveyed using two distinct patterns, one in a star-like shape (green lines on the block), and another in a 5 km rectangular grid. It is for this latter survey that we focus our attention in this paper.

To demonstrate the effectiveness of the MCSEM method to detect thin resistive body at depth below seabotton, we present the result of a 3D modeling study that mimic a real reservoir commonly encountered in the Brazilian off-shore basins. The model, presented in figure 2, consists of a rectangular thin sheet (the reservoir) with dimensions of 3 km width, 10 km length and 0.05 km thickness with resistivity of 10 Ohm.m and buried 0.95 km below sea bottom. The thin sheet is illuminated by an electrical horizontal dipole source located at the position indicated on the figure (transmitter site). Resisitivities of the 1.5 km water layer and of the surrounding background are 0.3 and 0.8 Ohm.m, respectively. These values were taken from a known well, named well A, that encountered an oil reservoir at that depth. The corresponding electrical field $E_x$, as well as the vertical component of the total electrical field $E_z$ are shown in figure 3. The red lines represent the electrical field for the background structure, while the blue lines are the response due, primarily, to the presence of the resistive thin sheet. This picture clearly shows the anomalous behavior of the resistive body. The vertical component, however, seems to map the position of the sheet more accurately than the horizontal component. To better visualize this situation, a map of the ratio of $E_x$ and $E_z$ fields to the background responses are shown in figure 4.

## The Campos Basin Survey

The lay-out for the MCSEM survey is shown on the bathymetric map of the area (figure 5). The receiver locations are indicated at the crossing of the rectangular mesh. For the $E_x$ component at each location we have generated an electrical field map, not shown in this paper, to select a portion of the area where the electrical field presented a minimum value. This area corresponds to receiver location RC029, located at the central-southern side of the map, along tow-line RC12N (figure 5). This site has been selected as the background site that was used as a reference to normalize all other sites. In order to estimate a regional background field ,the $E_x$ field of this reference station was modeled as the 1D response of a 200 meter thick and 1.2 Ohm.m layer over a background half-space of 1.5 Ohm, for all the four frequencies used in the course of the survey; i.e; 0.125 Hz, 0,250 Hz, 0.500 Hz and 1.25 Hz. Figure 6 shows the best fits of such a model. The water depth at this site is 1660 m and the water resistivity was estimated at 0.303 Ohm.m. As expected, we can see that the model fits the observed data better at the lower frequencies, since they attenuate slower than the higher ones. The noise floor for 0.125 Hz starts outside the ± 10 km range in the data, while, for the highest frequency, 1.25 Hz, this level starts in a closer range, i.e., at ± 5 km. This has some impact in the interpretation range of the data for detecting deeper reservoirs. So, we have considered looking into the lowest frequency of the data at a range between 5-8 km offset from which we have made the ratio map of figure 7. This figure shows two distinct areas of anomalies, one, with values greater than 1.5, in the northern sector of the map, and the other with values less than 1.5. The higher anomaly area is known geologically to have larger resistivities than its surrounding, but for the purpose of this presentation, we shall focus our studies on the southern, less anomalous area around the neighborhood of receiver RC007X, along tow-line RC15N, (figure 5) or along tow-line LRC15N (figure 6). A clearly defined anomaly near receiver RC007X seems to exceeds 30% above the background, as can be seen in figure 7. This anomaly is correlated with a known Oligocene oil reservoirs (figure 8). The inbound and outbound tows of the recorded and optimally processed $E_x$ electrical field are displayed in figure 9. They show the difference in amplitudes of the inbound tow (red diamond symbols) over the outbound tow (blue square symbols). We have modeled this anomaly, using resistivities and geometry from well log and the reservoir thickness data. The two reservoirs were modeled as three distinct bodies (see figure 10) for a transmitted frequency of 0.25 Hz. Figure 10 shows a good match between the observed inbound anomaly (red diamonds) with the response of the two reservoirs (brown squares), in excess of 20% from the background response. As expected, the outbound branch does not show any anomalous behavior. The 1D background used for the normalization was computed from the blocked transverse resistivity of well 1ESS-121 as follows: water depth and resistivity (1300 meter, 0.3 Ohm.m), followed by three layers with 1.2 Ohm.m/850 meter,1.4 Ohm.m/230 meter and 1.2 Ohm.m/460 meter over a 0.7 Ohm.m half-space. A similar approach has been applied to model additional reservoirs where the anomalous observed $E_x$ field matched the modeled response of the reservoir, such as in the Cachalote oil field near receiver RC05 on tow-line RC01. These results will be presented during the oral presentation of this paper.

## Conclusion

We have shown that MCSEM data are sensitive to known oil reservoirs in selected area of Campos Basin. With state of the art processing and modeling tools & procedure we were able to model anomalies as small as 20% above the background response. We feel strongly that in order to push this technology forward, we will need to develop interpretation workflow based on a novel suite of multidimensional software tools that can be applied in a shared environemt with other geophysical data such as seismic, magnetotelurics and gravity. Optimal depth imaging should be carried out integrating all available components of measured electric and magnetic fields and by considering the simultaneous interpretation of all available frequencies

## Acknowledgements

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## References

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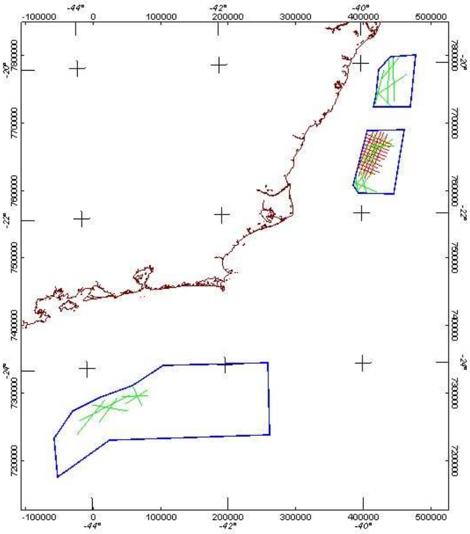

Figure 1 – MCSEM Survey Lines  Lines

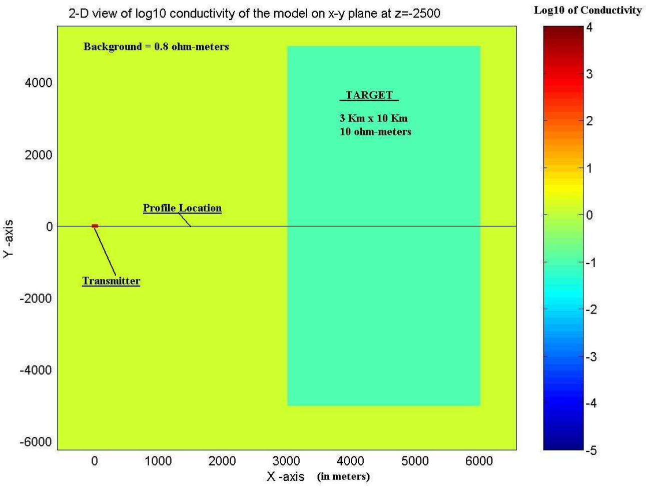

Figure 2 – Map view of the 3D slab model

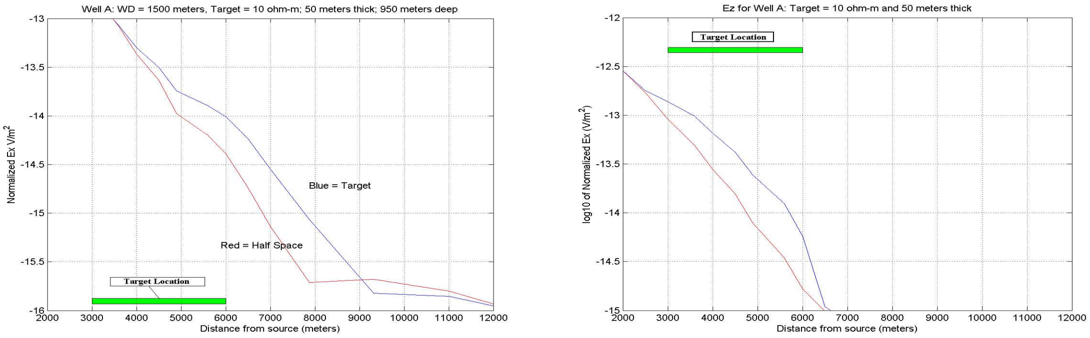

Figure 3 – $E_x$ (left) and $E_z$ (right) components of the electrical field for the target model (green)

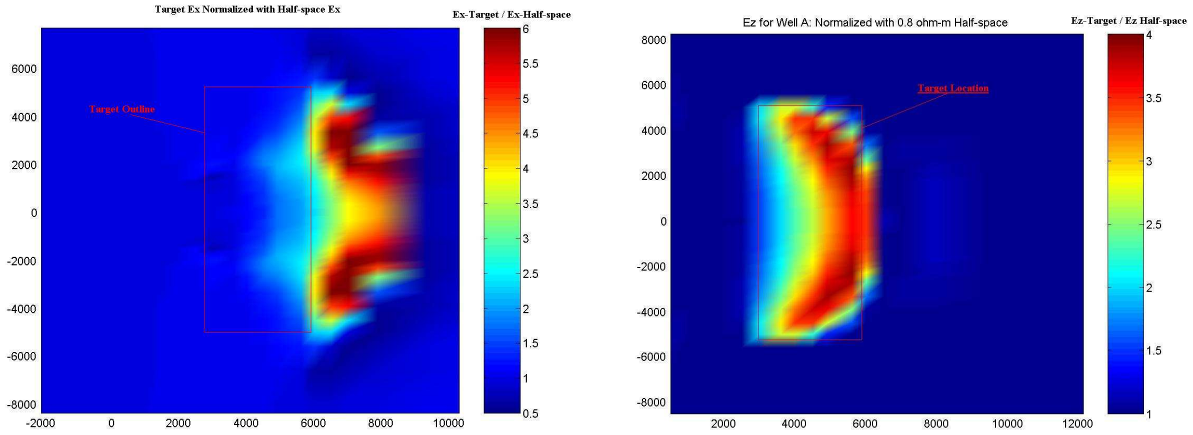

Figure 4 – Map of the normalized target electrical fields; $E_x$ (left) and $E_z$ (right), to the field of their background

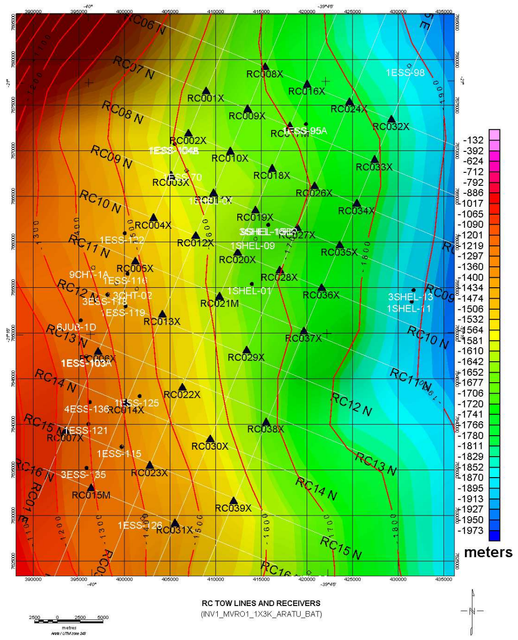

Figure 5 – Bathymetry and survey lay-out

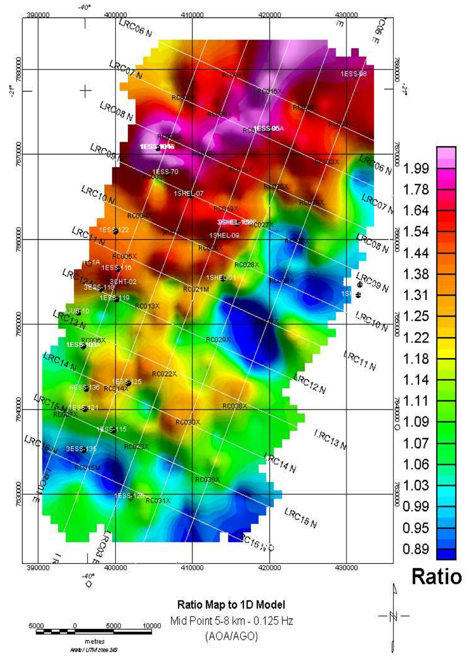

Figure 7 – Ratio map. Normalized real data to the 1D best fit model for 0.125 Hz

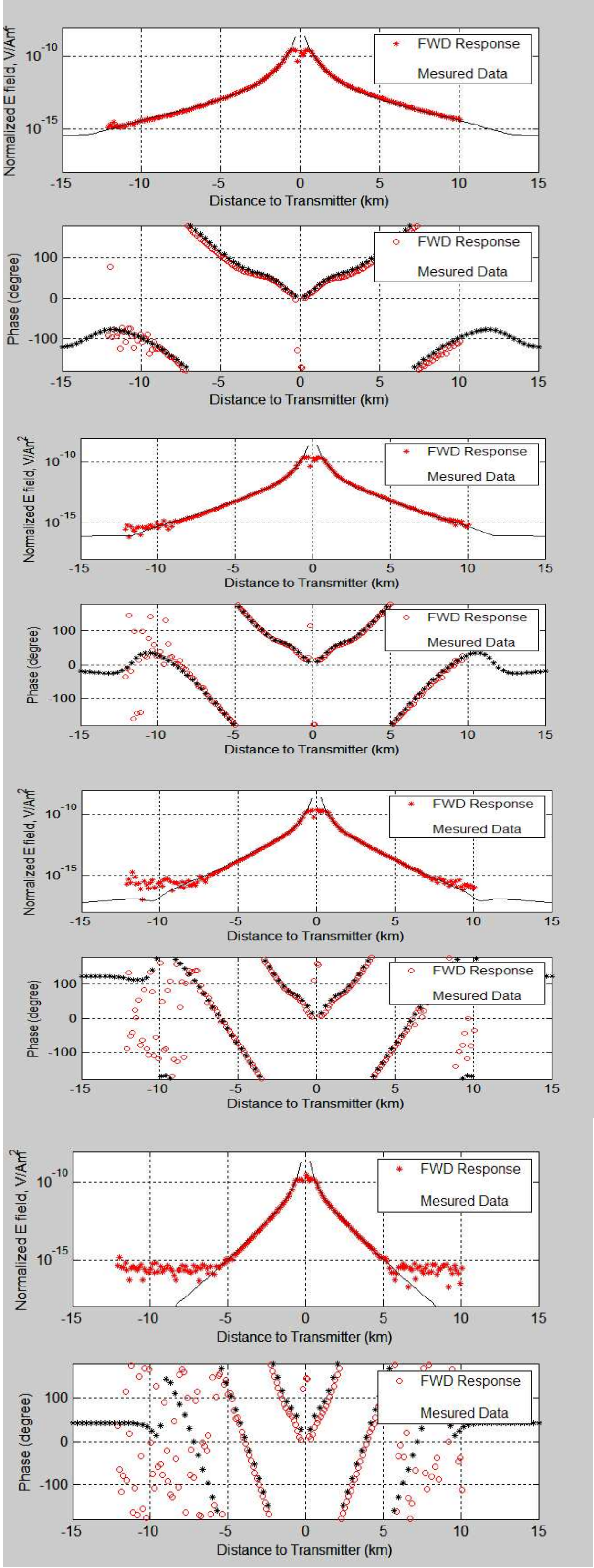

Figure 6 – 1D best fit to receiver RC029, for frequencies 0.125 Hz, 0.250 Hz, 0.50 Hz and 1.25 Hz, from top to bottom. For each frequency, it is displayed the amplitude of the $E_x$ field and its corresponding phase. The measured data are marked as red symbols

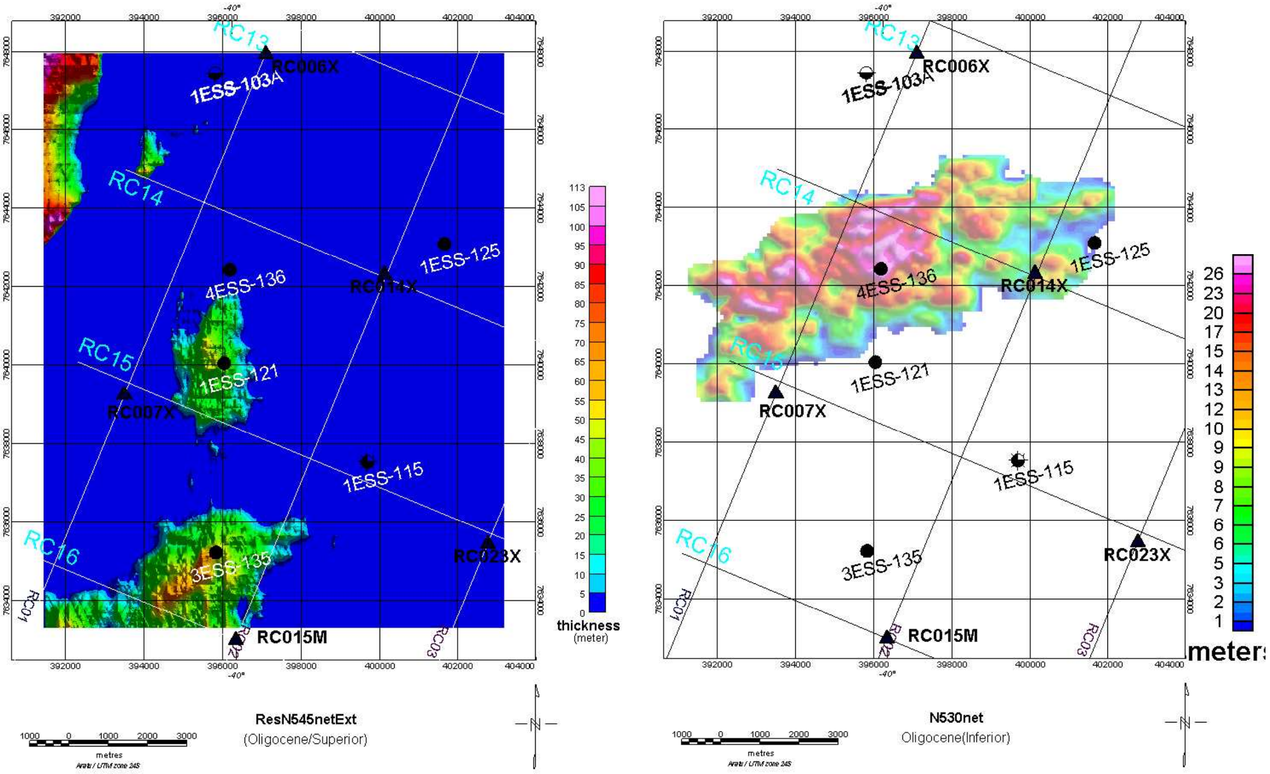

Figure 8 – Total thickness of two known oil reservoirs. Their resistivities were taken from one of each well that sample them. On the left, well 1ESS-121 and on the right, the, well 4ESS-136. The left panel is the shallower reservoir and the depth to their top are 2100 meter and 2170 meter for the shallower and deeper ones, respectively. The water depths are

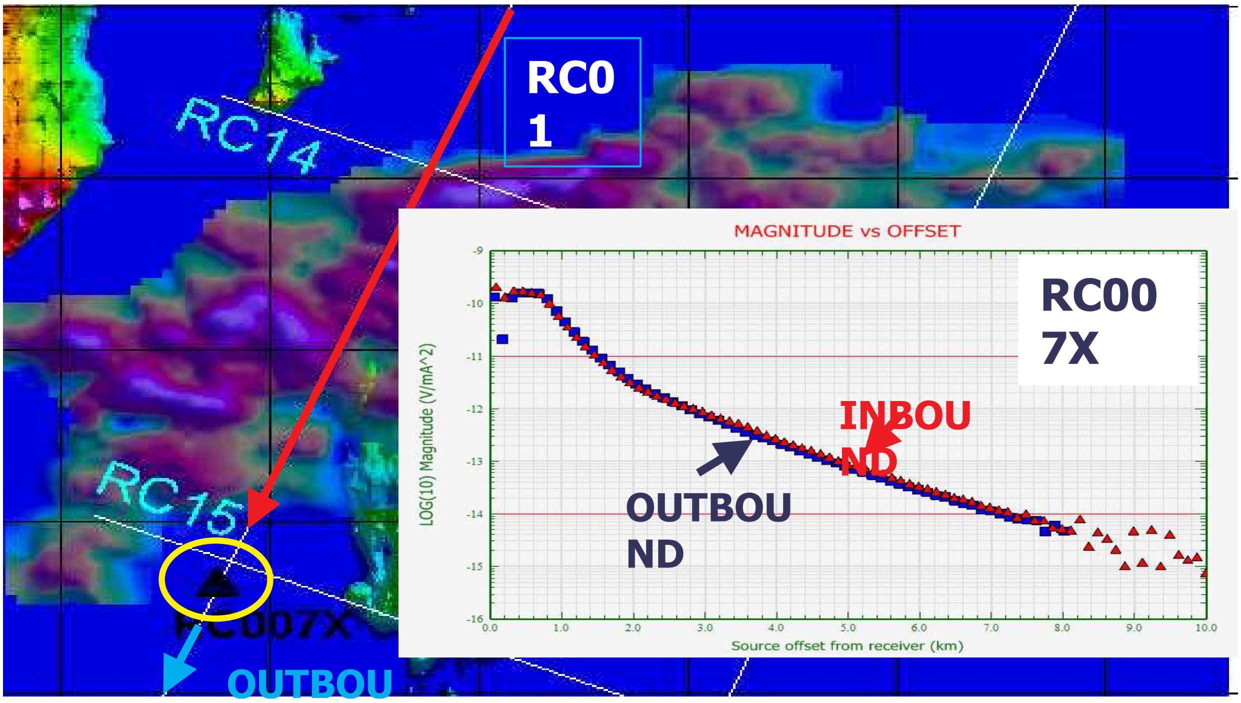

Figure 9 – Ex electrical fiel measured at station RC007x for the in-towing (red) and out-towing(blue) transmitter position

## 1D BACKGROUND

## MVO at each offset computed with Tx dip angle and Tx horizontal angle from receivers

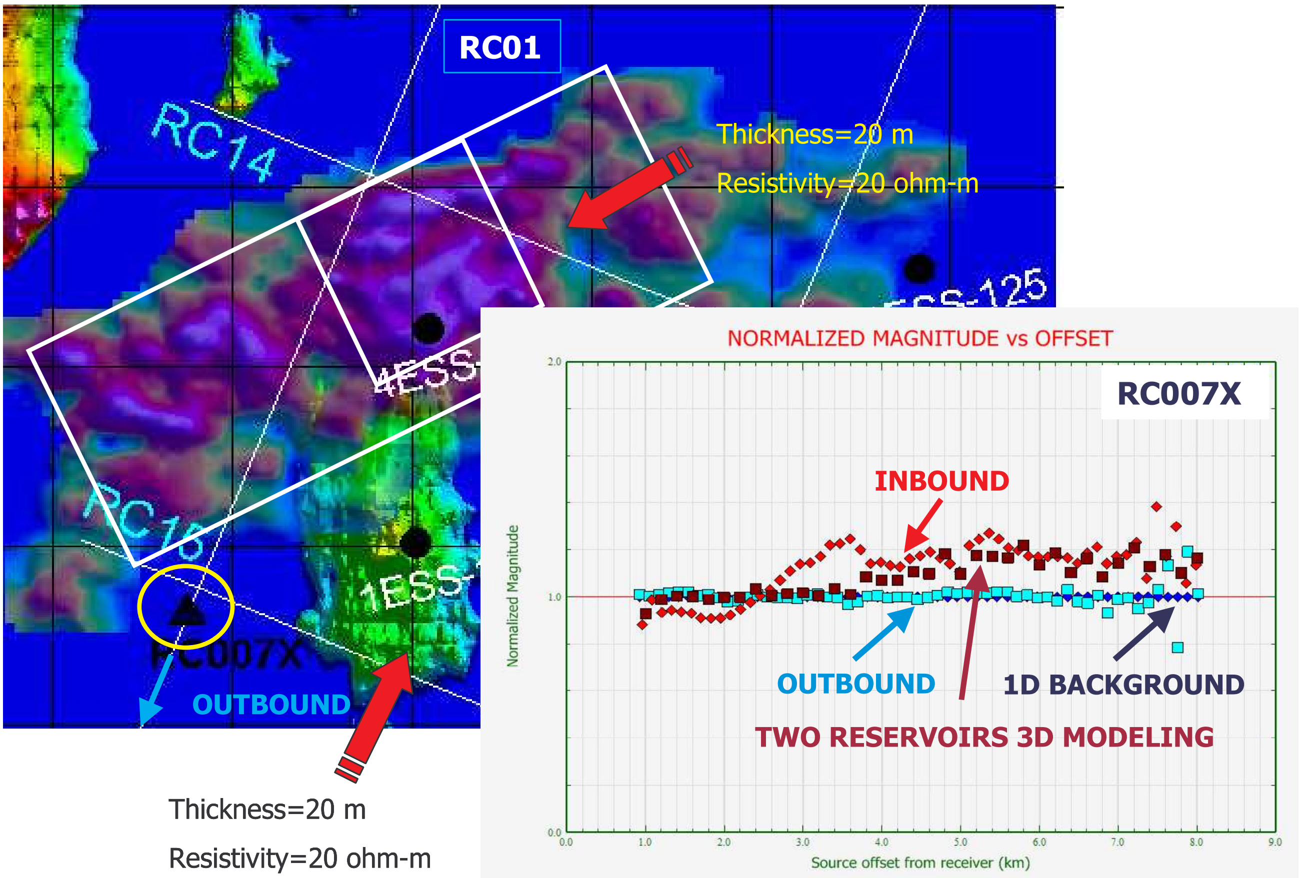

Figure 10 – 3D normalized $E_x$ field response for two knonw oil reservoirs. Both, the inbound original optimally processed