Electrical Resistivity Tomographies in shallow water marine environment for detecting archaeological targets

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1 Introduction – Theory

Electrical resistivity tomography (ERT) is a well-established method used for onshore archaeological prospection (Papadopoulos et al 2011). Recently, there is a tendency in incorporating this technique within offshore geophysical surveys, especially in marine environments close to the coast line. Comparing with other geophysical methods like seismic tomography, ERT has lower resolving ability but it can be effective if it is applied in relatively shallow water environments.

The imaging of geological structures beneath water-covered areas has been in great demand because of numerous tunnel and bridge construction projects on river or lake sites. An electrical resistivity survey can be effective in such a situation because it provides a subsurface image of faults or weak zones beneath the water layer (Kwon et al., 2005). Furthermore, the electrical resistivity imaging can be useful for the characterization of waterbed sediments (Orlando, 2013). It has proved its usefulness in the geological mapping or ground water studying (Rucker et al., 2007; Rucker et al., 2011).

The application of the method doesn't require a specific instrumentation since the existing resistivity equipment can be used for this purpose. Data acquisition can be carried out by using either submerged (Kim et al., 2002) or floating electrodes in conjunction with continuous resistivity profiling (**Figure 1**).

The present study focus on examining the most appropriate electrode array that is able to handle successfully this type of measurements. The problem is further approached in terms of the effect that the thickness of the water column and the conductivity of the sea water can have on the ERT measurements. Numerous tests with synthetic data and numerical models simulating real cases scenarios of a shallow marine ERT archaeological survey were made in order to address these questions.

Some data from a real case survey were acquared where promising results prove the potential of the ERT application in marine cases.

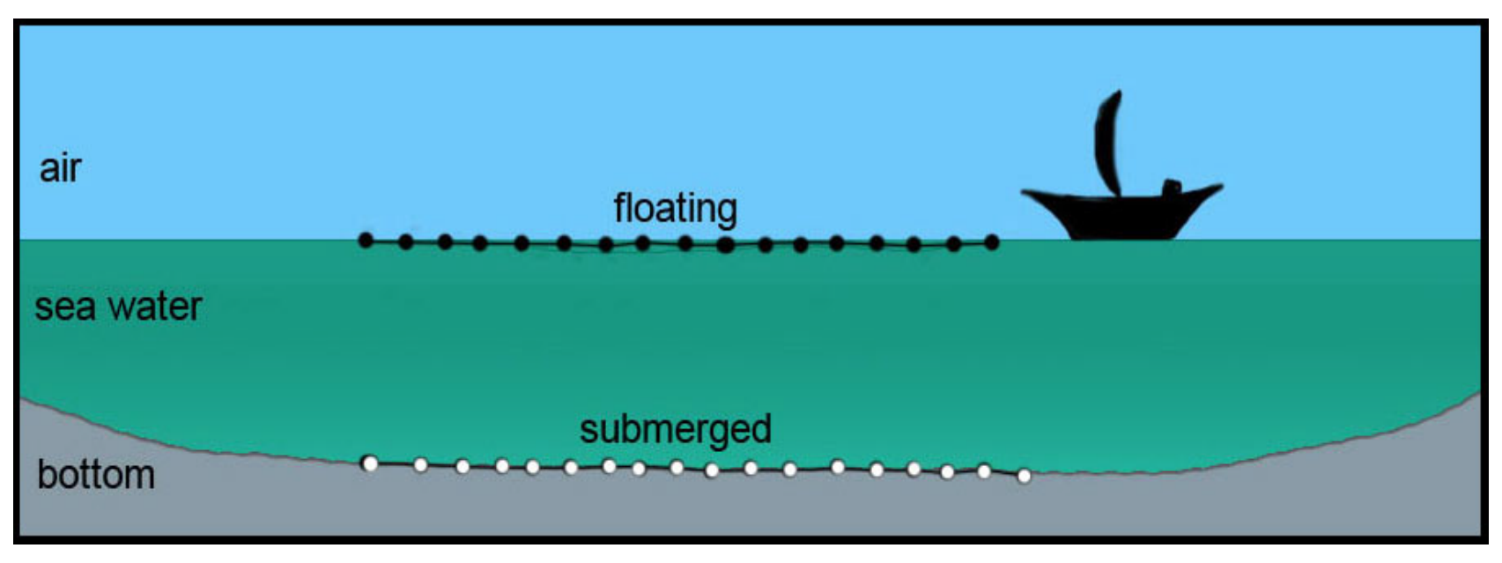

Figure 1. Floating of Submerged Electrodes for marine ERT measurements

2 Synthetic Model

The applicability of the ERT marine measurements for shallow sea water is tested using synthetic numerical data. The synthetic models were created using the 2D modeling and inversion software "DC2DPro" (Kim and Yi, 2010). One of the models that was tested is shown in **Figure 2**. Specifically, a 2D ERT line was assumed with 48 electrodes equally spaced every 1 meter (a=1m). The thickness and the resistivity of the water layer were set to D=1 meter and ρ=0.2 ohm-m, respectively. The subsurface below the water layer consists of a homogeneous layer with ρ=10 ohm-m.

A resistive target (ρ=500 ohm-m) with dimensions 5x2m was placed inside the homogeneous subsurface layer d=1m below the sea bottom. The dipole-dipole (DD), pole-dipole (PD) and gradient (GRD) electrode arrays, that are suitable for multichannel resistivity instrumentations, were used to create specific measuring ERT protocols. Noise ±5% was added during the creation of the synthetic model in order to simulate better a real case data set.

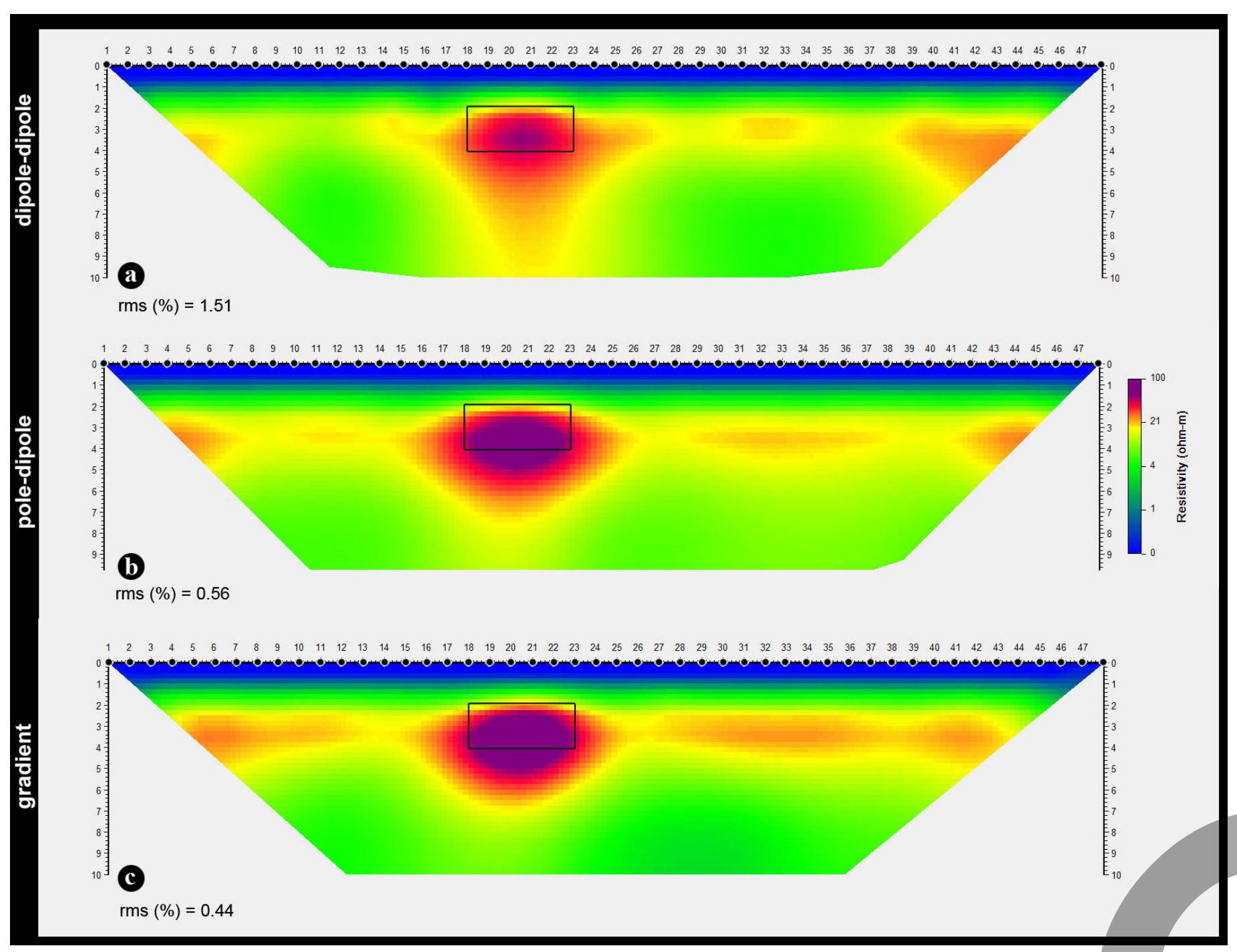

Figure 3. Inversion results between protocols (a) dipole-dipole, (b) pole-dipole and (c) gradient, using floating electrodes. Black dots indicate electrode position.

Synthetic modeling was at first implemented in order to compare the inversion results and the reconstructed models employing different electrode arrays. **Figure 3** shows the resistivity inversion model for DD, PD and GRD where the electrodes are placed on the surface of the water layer (floating electrodes) and no constraints were imposed into the inversion procedure. Generally all the arrays are able to reconstruct the target and the sea water layer. Additionally, PD and GRD seem to have superior results with respect to DD in locating the resistive target. Some artifacts are apparent on both sides of the target that can be explained due to the inversion procedure.

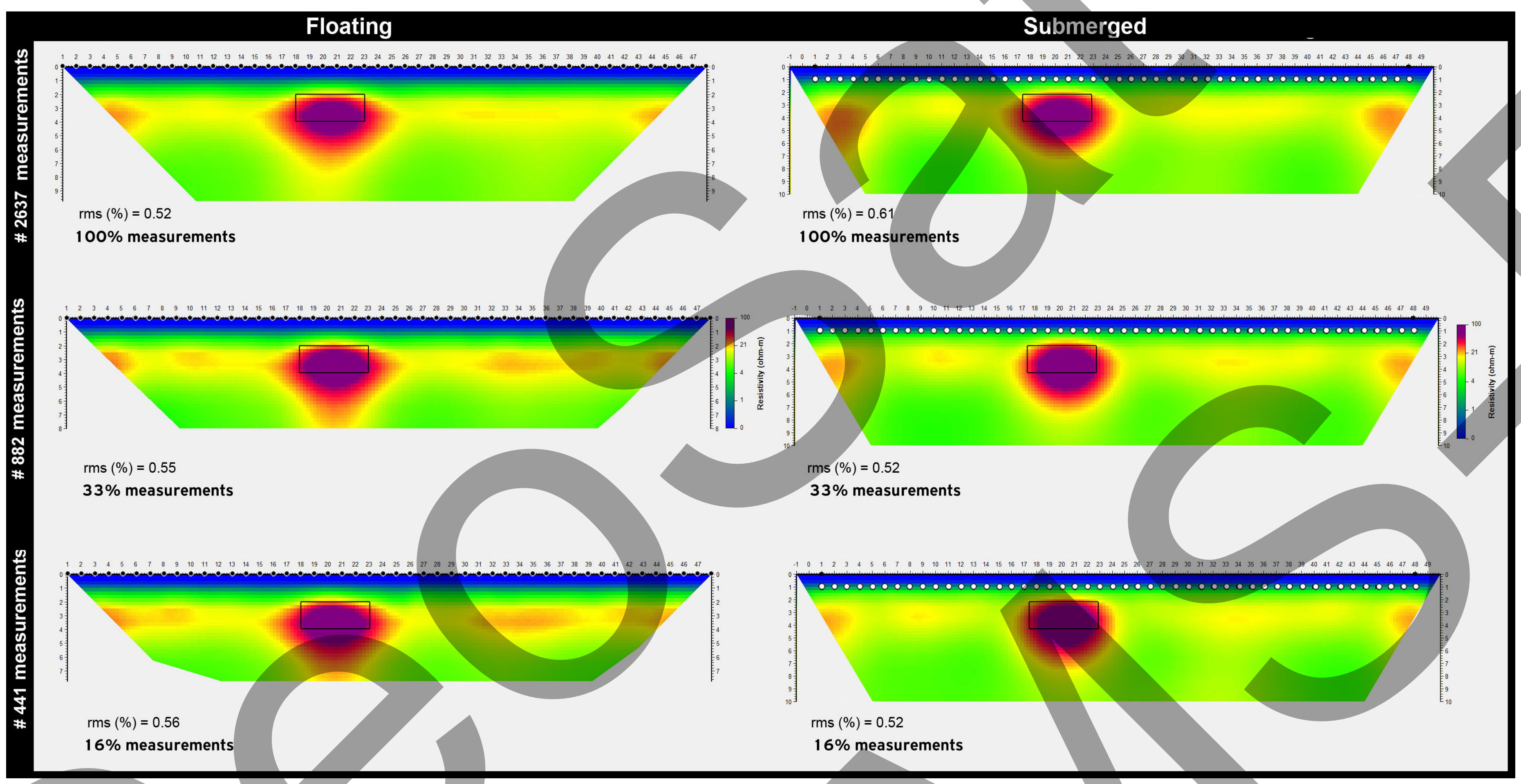

Figure 5. Inversion results comparing (a) full protocol (#2637 measurements) and (b, c) optimum protocol (#882, #441 measurements), using protocol PD.

Figure 6. Photo of the archaeological site of Ag.Theodoroi (Heraklion, Crete), where the ERT survey took place.

Figure 7. Photo of the ERT survey line with floating electrodes on sea surface and the equipment that is used for the survey.

4 Real Data

A real field survey was accomplished in Crete, at Ag.Theodoroi beach, close to Heraklion (**Figure 6**, embedded photo), where archaeological structures were identified by archaeologists (red indicated areas). For the study both floating (**Figure 7**) and submerged 33 electrodes (spacing a=1m) were used with the resistivity meter 'Syscal pro' of Iris Instruments.

As shown in **Figure 8 (**top for floating and bottom for submerged electrodes**)**, the targets (walls) were reconstructed using all protocols. As mentioned before, at the results of the synthetic data, pole-dipole has the best results regarding the target location.

5 Conclusions

The numerical modeling results of this study shows that ERT has a potential and could be used for detecting archaeological remains in shallow marine environments. Among the basic array protocols, pole-dipole and gradient seems to give the most optimum results.

The outcomes of this survey also show that it is possible to have satisfactory results by placing the electrodes inside the sea bottom as long as a priori information about the resistivity and the thickness of the sea water layer are known.

Optimization of the initial measurement protocol can yield to equally reconstructed resistivity models minimizing at the same the actual field time for data collection.

The results from real data seem to be promising, as well.

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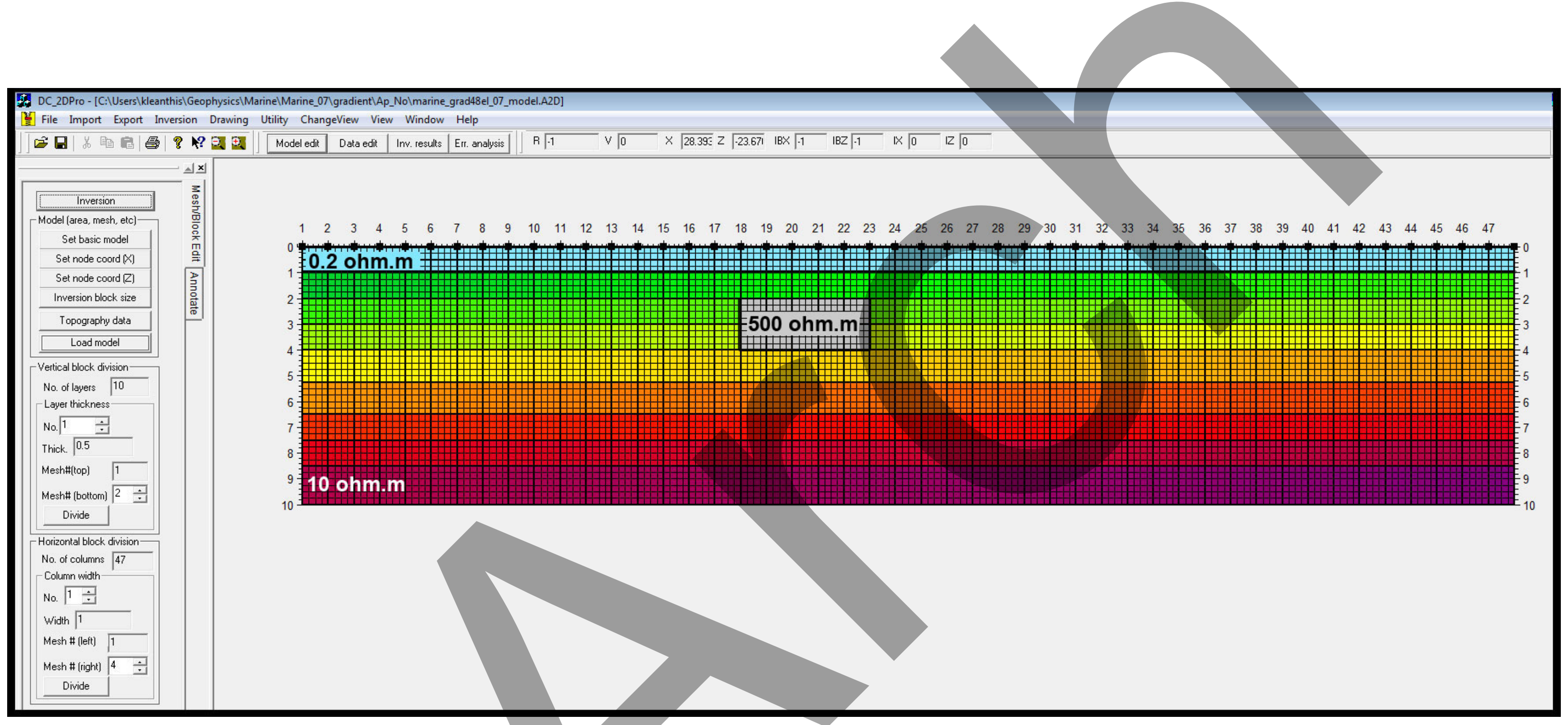

Figure 2. Synthetic model for ERT marine for shallow sea water measurements. A target (ρtarget=500 ohm.m) is embedded in a homogeneous medium (ρ=10 ohm.m). Sea water column is set to 1 m (ρ= 0.2 ohm.m).

An extra scenario involves the case of placing the electrodes on the bottom of the sea (submerged). As shown in **Figure 4 (left column)**, for a sea water column of D=1m thickness it is possible to detect the target if the electrodes (shown with white dots) are placed on the sea bottom. This case is suggested in case of sea water with depth more than D=1m, where the current attenuates due to the large conductivity value of the salted water.

If 'a priori' information (Kim et al., 2014) is taken into consideration during the inversion procedure as shown in **Figure 4 (right column)**, the thickness of the sea level and the position of the target are more clearly defined (appropriate depth location) and the inversion artifacts are minimized. Furthermore, the target is depicted more clear for the protocol DD.

It should be noted that although the 'a priori' information is useful, it should not be used in case of lack of knowledge, cause it will lead to erroneous results if not used properly.

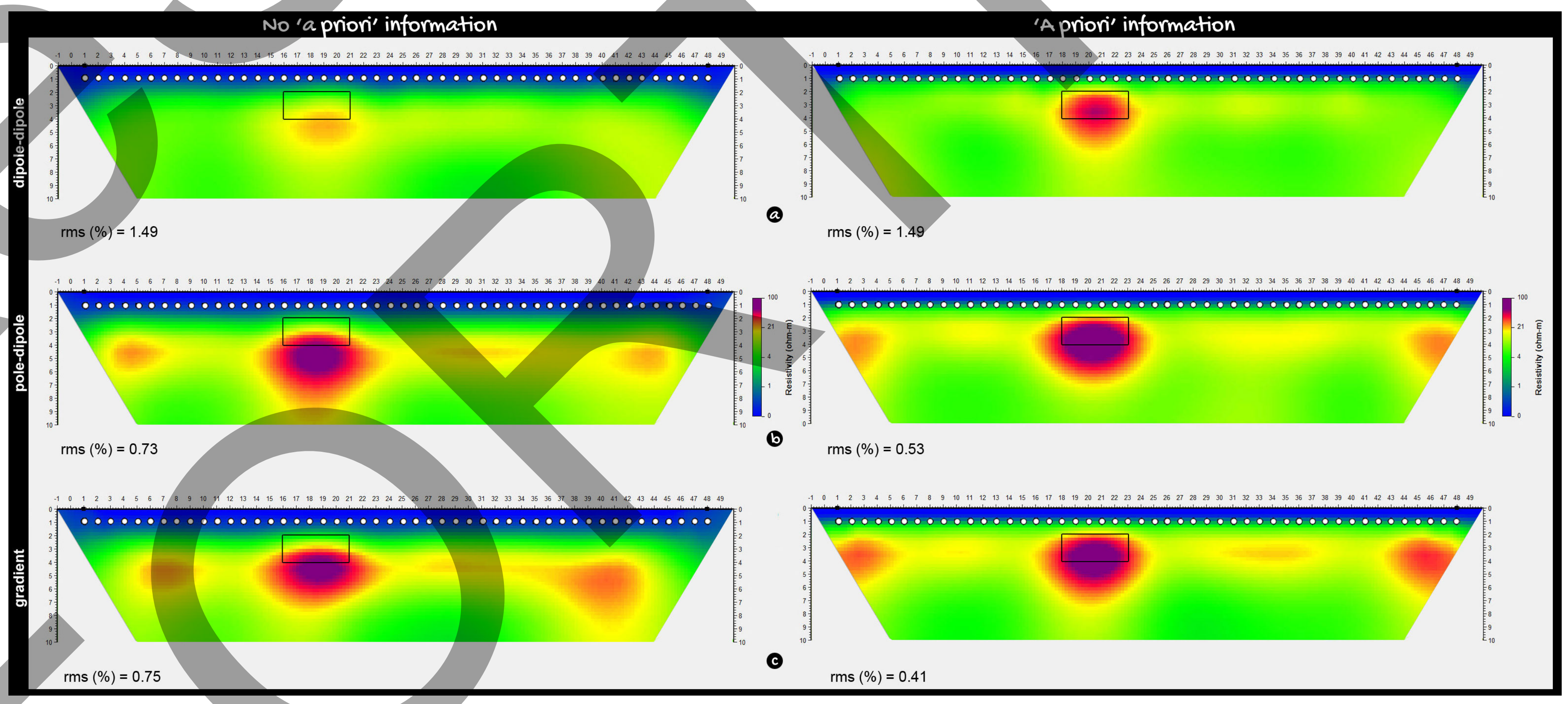

Figure 4. Inversion results between protocols (a) dipole-dipole, (b) pole-dipole and (c) gradient, using submerged electrodes, (left column) with or (right column) without a priori information. White dots indicate electrode position.

3 Optimization

Further testing involved the compilation of optimized protocols where a small subset of measurements in relation to an original comprehensive data set is extracted without compromising the quality and resolution of the inversion results. The optimization procedure was based on the Jacobian matrix method (Athanasiou, 2009), where only the measurements that exhibit the highest resolving capability are chosen during an optimization algorithm. **Figure 5** compares the results of the original and the optimized protocols (left column for floating and right for submerged electrodes). The inversion models show comparable accuracy despite the fact that the optimized protocol uses only 33% or even 16% of the measurement of the original entire protocol.

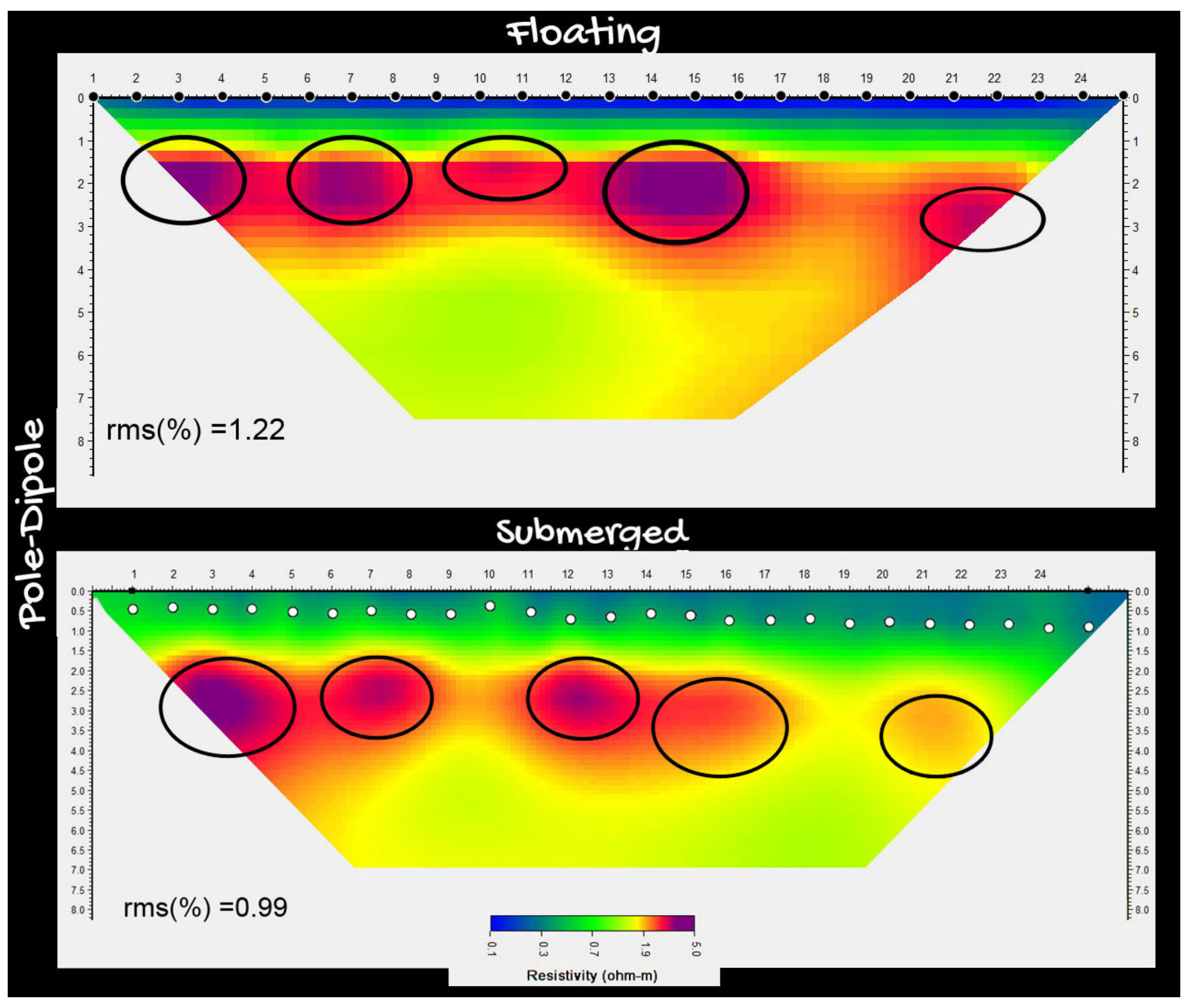

Figure 8. Inversion results using protocol pole-dipole, with floating (top) and submerged (bottom).

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