On the exploration of a marine aquifer offshore Israel by long offset transient electromagnetic: A 2D conductivity model

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SUMMARY

The existence of submarine fresh groundwater bodies extending offshore to distances between a few meters to several tens of kilometers was reported all over the world. In the Mediterranean coastal aquifer of Israel, recent onshore transient electromagnetic measurements close to the shoreline showed the existence of high resistivity bodies interpreted as “fresh water saturated lower sub-aquifers” located underneath the “seawater intruded upper sub-aquifers” at about 100 m depth. It was assumed that the fresh water containing aquifer extends offshore below the sea bottom.

Therefore, a long offset transient electromagnetic survey (LOTEM) was carried out offshore to detect the relative resistive marine aquifer beneath the good conductive Mediterranean sea sediments. The water depth at the survey area was about 30 m. A 400 m long dipole was set up on the sediments beneath the sea at five different distances from the coast. Mainly Ex-component was observed in broadside and inline configuration at 3 stations for each transmitter on the sea bottom with offsets of 400, 800, and 1200 m respectively.

The data were first of all interpreted by a 1D Occam and Marquardt type inversion. They show clearly the existence of a relative resistive layer up to a distance of 3.5 km from the coast. In addition, the observed data was interpreted by a 2D conductivity forward modeling and the Hedgehog technique was applied. Though the model space was sampled within certain limits, it still resulted in about 48000 forward modeling. The calculated 2D model could explain nearly all observed Ex- transients simultaneously and indicate the existence of the fresh water marine body. In addition, the edge of the aquifer could be localized more precisely. The detection of the marine freshwater body at the coast of Israel by LOTEM will play an important role for the future groundwater management.

Keywords: marine groundwater, long offset transient electromagnetic, 2D modeling

INTRODUCTION

The Mediterranean coastal aquifer of Israel is one of the main groundwater resources of the country. It has been exploited heavily and, as a result, the quality of water is gradually deteriorating. This happens due to both downward anthropogenic pollution and due to inland encroachment of seawater.

The aquifer consisting mainly of calcareous sandstones and sands is subdivided into four sub-aquifers. The upper two sub-aquifers are known to be subjected to lateral seawater intrusion and to pollution from above whereas the lower ones are assumed to be, in places, blocked to the sea as a result of facies changes.

Recent onshore resistivity (TDEM) measurements close to the shoreline proved the existence of high resistivity bodies within the depth interval of the lower sub-aquifers (Kafri and Goldman, 2006), interpreted as fresh water bodies underneath the seawater intruded upper sub-aquifers. It is reasonable to assume that these bodies extend offshore beneath the sea bottom and their thickness and lateral dimensions can be detected by the appropriate marine electromagnetic measurements. In order to explore fresh groundwater below the sea a transient electromagnetic method, which uses grounded lines (electric dipoles) as both transmitter and receiver antennae, is necessary. This modification is also known as Long Offset TEM (LOTEM) because the transmitter-receiver separation (offset) used in the method must be several times greater than the depth to the target. As a result, LOTEM is less accurate than conventional inloop transient electromagnetic, but, contrary to the latter, is sensitive to electrically resistive targets and can be much easier employed in the marine environments. No wonder, therefore, that during last few years, when electromagnetic methods began to be extensively applied in offshore hydrocarbon exploration , mostly grounded lines have been used as antennae both in frequency and time domains (Constable, 2006).

FIELD SURVEY

The LOTEM system of the University of Cologne was modified for the marine environment. Fig. 1 shows the field set-up used during the measurements offshore Israel. The proposed LOTEM-configuration has been used offshore only for the hydrocarbon exploration and not for the groundwater exploration. Since the required geo-electric parameters of the hydro-geological target significantly differ from those typical for offshore oil and gas exploration, the geophysical results of the research will be significant for future offshore groundwater investigations all over the world. We used a 400 m electrical dipole as transmitter and the minimum offset was 400 m. A current of 11 A was injected and the transmitter was built up parallel and perpendicular to the coast. Inline and broadside configurations were used to measure mainly the Ex-component (Lippert et. al., 2012). Figure 2 shows the geographical location as well as the location of the transmitters and receivers in the survey area. After having processed the time series, switch off transients were obtained which were then used for 1D and 2D modeling.

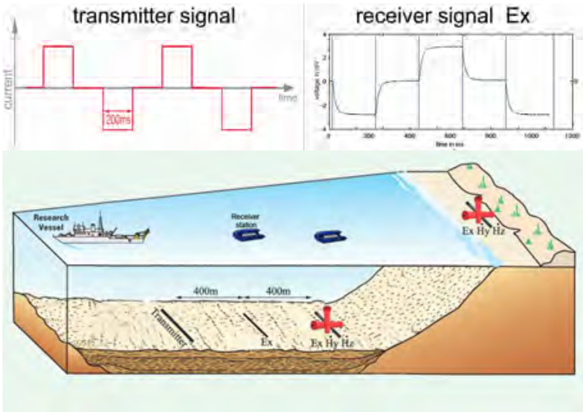

Figure 1: Schematic demonstration of the used broad side configuration and the form of the injected LOTEM signal as well as the observed signal of the electrical field.

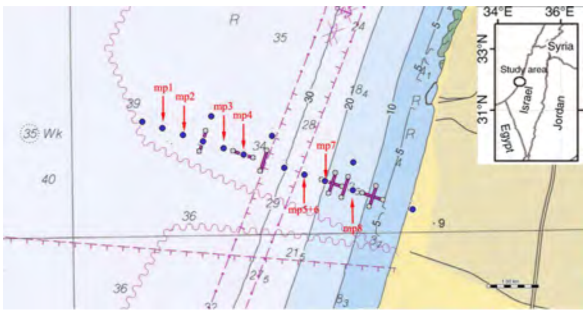

Figure 2: Location of the survey area and the location of the transmitters and receivers. The numbers on the map indicate the water depth.

INTERPRETATION OF THE Ex-DATA BY 1D INVERSION

The processed switch off transients were inverted by 1D Occam type inversions. The water depth was fixed during the inversion and the system response and the periodicity of the transmitted signal were considered. Figure 3 shows the derived Occam-conductivity models on the profile. A clear high resistive layer was found beneath the conductive sea sediments extending up to a distance of 3.5 km from the coast which can be interpreted as a freshwater body. No resistive layer was found by the inversion of Ex-data observed at stations located at distances more than 3.5 km from the coast.

INTERPRETATION OF DATA BY 2D CONDUCTIVITY MODELING

The observed transients were also interpreted by using a 2D forward modeling. The 3D spectral Lanczos decomposition forward algorithm (Druskin and Knizhnerman, 1994) was used through this study. A large number of forward calculations (ca. 48000) were carried out to find a suitable 2D model which explains most of the Ex-transients observed at different distances from the coast on the sea bottom. Figure 4 shows the calculated 2D model and Figure 5 a comparison between observed and calculated transient at different transmitter and receiver locations using the 2D model of Figure 4. The structure beneath the land side has no influence on the model fitting and, therefore, a simplified conductivity structure above the aquifer was assumed.

CONCLUSION

The field survey represents the first successful application of the LOTEM method for the exploration of marine aquifers worldwide. A resistive layer beneath the conductive Mediterranean sea sediments at about 100 m depth below the sea level could be detected by the observed electric field transients which were then interpreted as a fresh water body. 400 m long dipoles were used as transmitters which were built up offshore at different distances from the coast of Israel. Inline and broadside configurations were used. The data were interpreted by 1D inversions by setting the water depth as a constant parameter during the inversion. In addition, detailed 2D forward calculations were carried out to derive a conductivity model which explains most of the observed Ex-transients simultaneously. These 2D model calculations also show clearly the existence of a relative high resistive layer. In addition, the edge of the aquifer layer could also be located, which is an important parameter for further groundwater management studies.

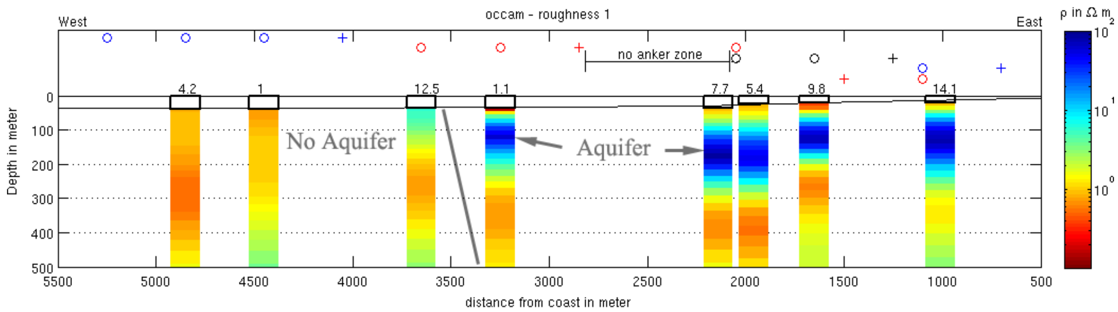

Figure 3: 1D conductivity models derived by Occam-inversion. The location of the stations can be seen in Figure 2.

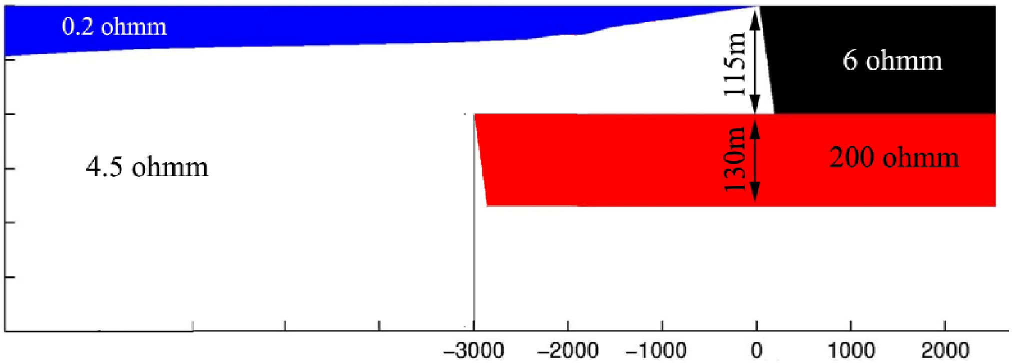

Figure 4: 2D conductivity model which explains the broadside Ex-transients at six stations.

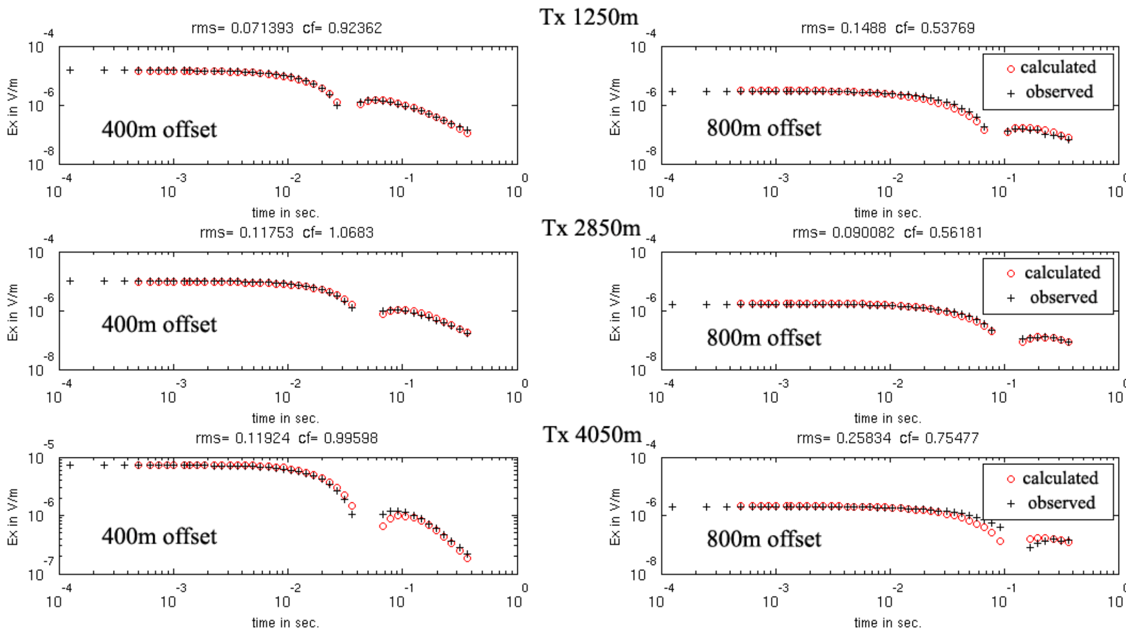

Figure 5: Data fit of the 2D conductivity model in Figure 4.

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