Advances in Surface-Groundwater Modelling in Lagoon Environment with Airborne Electromagnetics and High Resolution Seismic: Example from the Venice Lagoon

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Summary
Lagoon environments are very important for groundwater modeling in costal areas, they are delicate and in rapid evolution due to global climatic changes. Airborne electromagnetics (AEM)is a very valuable methodology that can provide high density, high quality data to produce 3D hydrogeological models to depths in excess of hundred meters below surface water column. We present the results from the SkyTEM Venice lagoon survey of 2009, integrated with data from very high resolution seismic survey. The AEM data results enhance greatly the understanding of the hydrogeology and surface-groundwater interactions in the lagoon area, where indirect measurements abound but wells are missing. For example, there is clear evidence of fresh water aquifers underneath the central part of the lagoon, at depth of about 40 m. The near surface part of the AEM data compare well with seismic data, showing that main reflectors come from the interface between the superficial Late Pleistocene looser, saline water saturated sediments and the deeper, more compact and fresher Holocene sediments. There is also clear evidence of submarine groundwater discharge in the lagoon, of paleorivers, and a possible indication of gas seepage trough shallow sediments. Seismic and AEM provide complimentary datasets to discriminate between pore water salinity, lithology and gas. Seismic horizons can actually be included during inversion of AEM data, producing more robust output. AEM data from the southern part of the survey that crosses the shore line and continued also onshore allow a clear mapping of the saline water intrusion inland, and highlight the relationship between pore water salinity of the lagoon sediments and spatial distribution of salt marshes. The latter seem to act like salt sinks, increasing sediments electrical conductivity.

Introduction

Understanding the hydrogeological processes is critical for a sound management of groundwater resources in costal areas. The hydrologic setting of the transitional environments is complicated by their late Quaternary subsoil architecture. The deposits represents the transition through the fluvial in tide-dominated depositional systems triggered by the sea level changes. In particular, in the Venice area numerous geomorphological features representing i.e. fluvial paleoriver beds, ancient tidal channels, and paleobeach ridges occur (Tosi et al., 2009). These features are generally filled by sandy deposits and can be considered preferential path for the groundwater flow, both in the horizontal and vertical directions.

In order to have a better understanding of the hydrogeological setting of these areas, and also to produce more useful models, it is crucial to acquire information both inland and within the lagoon or wetland, covering both its permanent wet and tidal areas. Airborne electromagnetics (AEM) can greatly improve the data quality and coverage in such areas, while cutting significantly the acquisition costs. So far there have been extremely limited attempts of applying AEM to areas such as lagoons, wetlands, rivers or bays. This manuscript shows that AEM can produce quantitative results useful for groundwater modeling also in these areas, presenting the results of a survey carried out in the central and southern sectors of the Venice Lagoon, Italy, by the SkyTEM system, combined with very high resolution seismic (VHRS) results.

We present some of the inversion outcome as horizontal average resistivity maps at different depth intervals and cross sections obtained by SkyTEM application in the two areas where different hydrogeological processes are under investigation.

Theory and/or Method

Various AEM systems are applied in hydrogeophysical investigations. In the Venice Lagoon we have used SkyTEM (Soerensen and Auken, 2004). In this system, a large current is switched on and off very quickly and repeatedly in a multi turn coil wound around a non metallic frame hanging underneath the helicopter 30-40 m high above the ground, or water. When the current is abruptly turned off, the primary magnetic field associated to it collapses, and as a result, eddy currents are induced in the ground. They in turn decay over time due to ohmic loss and propagate in depth. The variation over time of secondary magnetic moment associated with these eddy current is recorded by the receiver and then inverted into geoelectric models using the Spatially Constrained Inversion (SCI) technique (Viezzoli et al., 2008).

The VHRS method allows the acquisition of images of the subsurface down to 15–20 m below m.s.l. with a resolution of about 10 cm operating in water depths less than 1 m. The system used in the southern Venice Lagoon consists of an impulsive energy source (boomer) and an electro-dynamic transducer UWAK05 mounted on a catamaran frame, together with a 8-hydrophone pre-amplified oilfilled streamer. The streamer is deployed parallel to the boomer and towed with a 2 m lateral offset at about 0.3 m beneath the water surface (Tosi et al., 2009).

Examples

The records are first processed to eliminate the data affected by infrastructures, and to increase signal to noise ratio while preserving lateral resolution and then inverted using the SCI. We used both multi- (smooth) and few layers (blocky) model. In almost-layered subsoils, the SCI can improve the inversion output with respect to other methodologies, especially at depth and near surface. Transmitter altitude is also inverted as the laser altimeters often produce erratic readings over surface water. Failure to do so would, in many cases, produce artifacts in the hydrogeological models that account for the wrong altitude. We present some of the inversion outcome as horizontal average resistivity maps at different depth intervals, and vertical cross sections. Fig. 1 shows the results of the central survey for the depth intervals between 20 and 30 m and from 40 to 60 m.

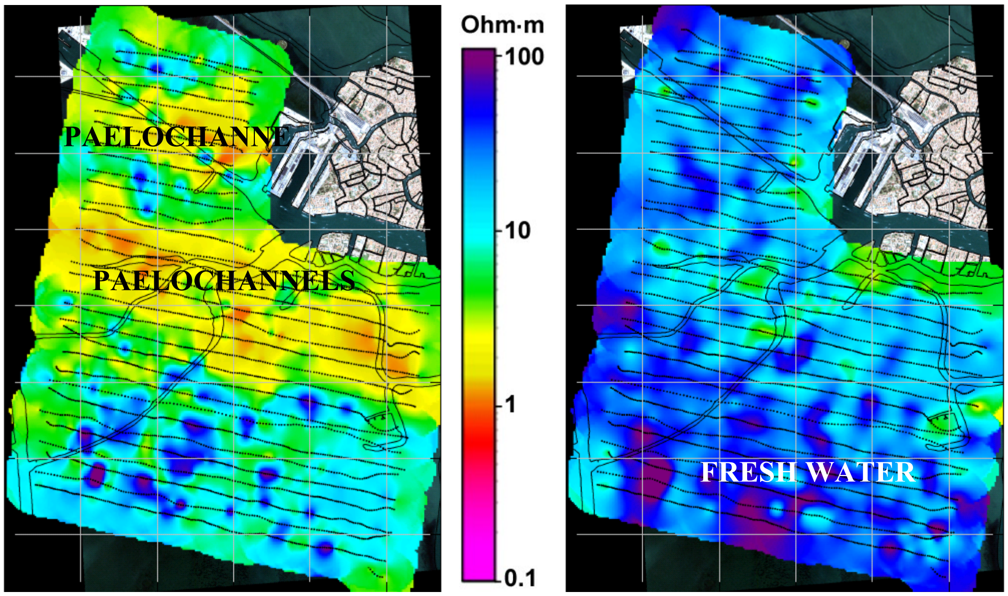

Fig. 1 - Average resistivity (central sector) at 20-30 m (left) and 40-60 m (right) depths.

We now present in figure 2 the comparison between AEM based geoelectrical models and depth to the “Caranto” (a supposedly impermeable layer present in places between Hiolocene and Plesitocene deposit) interpolated from few boreholes.

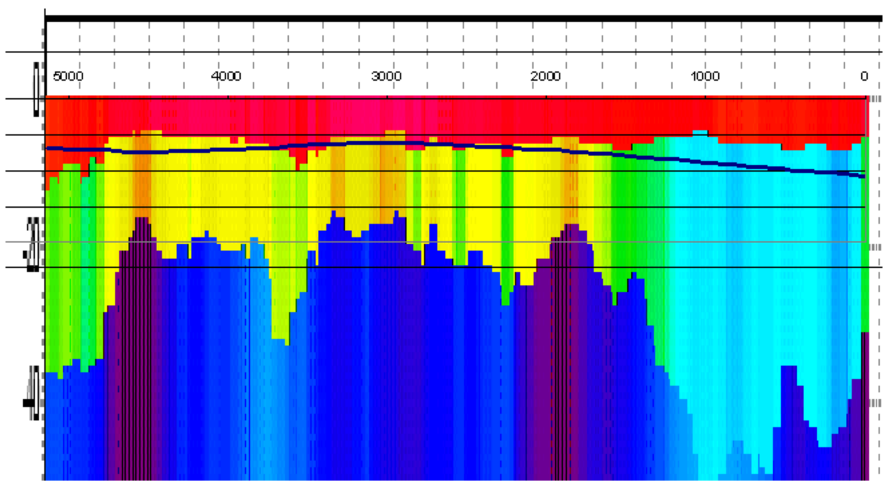

Fig. 2. Depth to the “caranto” (thick blackline) interpolated from few boreholes, and geoelectrical vertical cross section from a line of AEM data (colorscale same as in Fig. 1).

Figure 3 shows the comparion between VHRS data and main reflectors and vertical geoelectrical cross section from AEM data from one line.

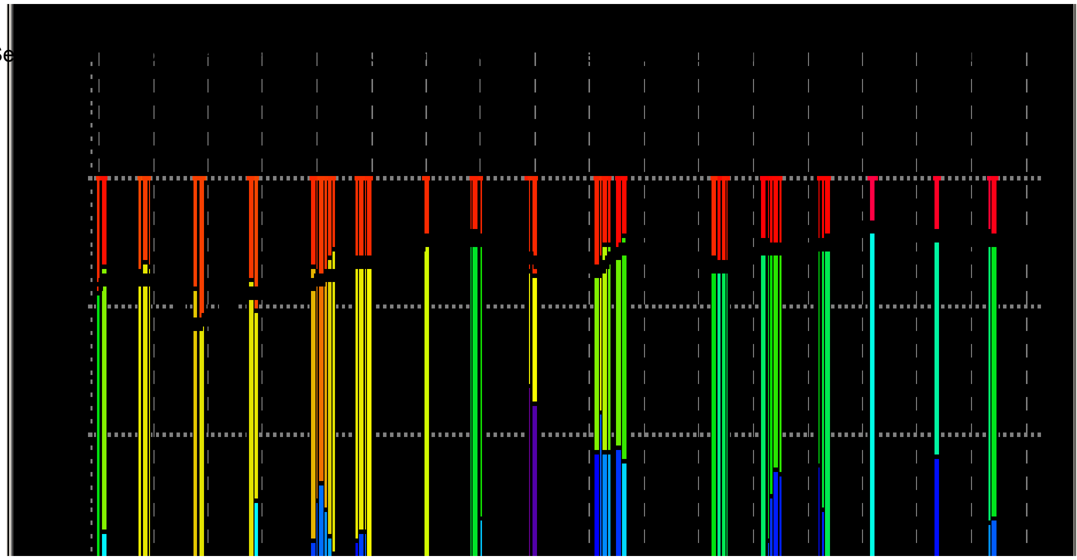

Fig. 3 – Comparison along a North-South section between the AEM results and the outcome along the same alignment produced by a VHRS survey.

Figure 2 and especially figure 3 show the good correlation between geoelectrical layers obtained from AEM data and stratigraphy. It is also clear that presence of gas, clearly visible on the right end side of the profile of fig 3, corresponds to the expected increase in sediments resistivity. The dipping structure on the left of the profile is probably a paleoriver.

Conclusions

AEM was successful in providing unparalleled data coverage, quality and depth of penetration in a difficult environment like the Venice lagoon. The AEM data compare very well with the VHRS, and can be integrated with them successfully. The hydrogeological model of the surface and groundwater within and at the edge of the lagoon has been improved significantly with this study. Some of the main outcomes are the presence of vast freshwater units underneath the lagoon from about 40 m of depth, the network of paleorivers that govern the hydrological flow in the shallow sediments, the presence of GWD and of gas underneath the lagoon. Considering that AEM also mapped clearly the extent of the saline water intrusion along the coast, and gave useful insight into integration between salt marshes and sediments, the applicability of this methodology to surface-groundwater modeling in lagoons and wetlands is very promising.

References

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