MAPPING OF SUBMERGED CAVE SYSTEMS BY MEANS OF AIRBORNE ELECTROMAGNETICS: MULTI – LAYER 1 D INVERSION TO DERIVE SPATIALLY DISTRIBUTED PARAMETER FOR KARST MODELLING

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Abstract

Karst aquifers represent important but very vulnerable sources for water supply to a significant part of the earth's population. For sustainable use of these resources, development of integrated management tools based on numerical groundwater models is required. However a flow model for karst aquifers requires detailed, spatially distributed information on the flow-relevant characteristics of the subsurface. Methods determining the distribution of the electrical resistivities within the subsurface could provide such information. To explore the potential of airborne electromagnetic mapping for providing such innovative input information, the international scientific research initiative XPLORE was initiated. Within this paper, successful approaches to derive the subsurface cave structure and to map the depth of the halocline using multi-layer 1D inversion of frequency domain electromagnetic data are presented.

The demand for innovation in karst water modelling

In general groundwater models have been used widely as decision support tools for the last 30 years in many parts of the world. Although the numerical tools of groundwater modelling are well established, existing models still handle many questions inadequately. Models typically require input data, which, up to present, are very difficult or impossible to gather in a cost-effective way. Real progress only seems possible if new types of data can be injected into the modelling process. Innovation in groundwater modelling has to come from new methods developed during recent years in the fields of geophysics to collect data at regional scales which might be suited to close the gap between point information available and spatial information desired for hydrological / hydrogeological model building. Airborne electromagnetic mapping could be one cost-effective tool to arrive at that goal. Therefore a complex research program was initiated to investigate the potentials of airborne electromagnetic mapping. The pilot study is performed in the area of the Sian Ka'an Biosphere Reserve (SKBR), Yucatan, Mexico, a coastal wetland of international importance, famous for its fauna, flora and karst cave system. The investigation area includes the woodlands around the town of Tulum for which an extensive developing plan focused on tourism is currently discussed.

The field survey campaigns

The surveying program started in 2006, when several ground geoelectric profiles were conducted to investigate the general subsurface resistivity structure (Supper et al., 2009) of the area. Subsequent forward modelling proved the potential of the method to map karst structures (Supper et al., 2009a). Due to these promising results a pilot airborne survey was conducted in spring 2007, covering the well known parts of the Ox Bel Ha cave system followed by another survey in 2008 to investigate the unexplored area around the town of Tulum (Supper et al., 2009 a, b). For both surveys, the Austrian airborne electromagnetic system was used (Motschka, 2001).

Interpretation of results

Due to the requirements for groundwater modelling the primary efforts were concentrated on deriving the subsurface cave structure and mapping the spatial depth distribution of the halocline. After applying an empirical altitude correction on the raw data (Supper et al., 2009a) most known cave channels could be verified (light blue lines in Fig.1) and some new branches detected (dark blue lines in Fig.1). However homogenous halfspace inversion did not yield enough detailed information on the cave system. In order to investigate the inherent potential of the methodology, extensive 3D forward modelling (discussed within talk) was carried out. Subsequently a 1D multi-layer inversion algorithm (EM1DFM) was tested on synthetic data and successfully applied to the field data. As example Fig.3 displays the results of the inversion over an open sinkhole (cenote; for location see Fig.2). The results clearly show that the sinkhole could be detected and the approximate shape could be reconstructed (resistivities around 10 Ohmm near surface indicating brackish water filling, followed by a significant decrease to resistivities below 2 Ohmm showing saline water filling at depth). However one has to take into account that the inversion is 1D. Therefore results at the edges of the anomaly cannot be taken into account (shaded areas in Fig.4). Fig.5 shows the inversion results derived from measurements on several parallel profiles at different distances from the sea. Here the migration of the halocline towards greater depths at larger distances from the sea can clearly be seen. The results were verified by direct conductivity measurements and ground geoelectrics. For this purpose several ground geoelectrical profiles (for location of profiles see purple points and labels in Fig.1) were carried out in winter 2009 to verify the results (Fig.5, f - h).

Conclusions

Within a complex research program, the ability of the airborne electromagnetics to derive advanced knowledge about subsurface structures relevant for karst modelling is investigated. From the spatial distribution of raw data anomalies, the location major branches of the cave system could be derived. Furthermore the application of multi-layer 1D inversion codes allowed obtaining advanced knowledge on sinkhole structure and depths of the halocline.

References

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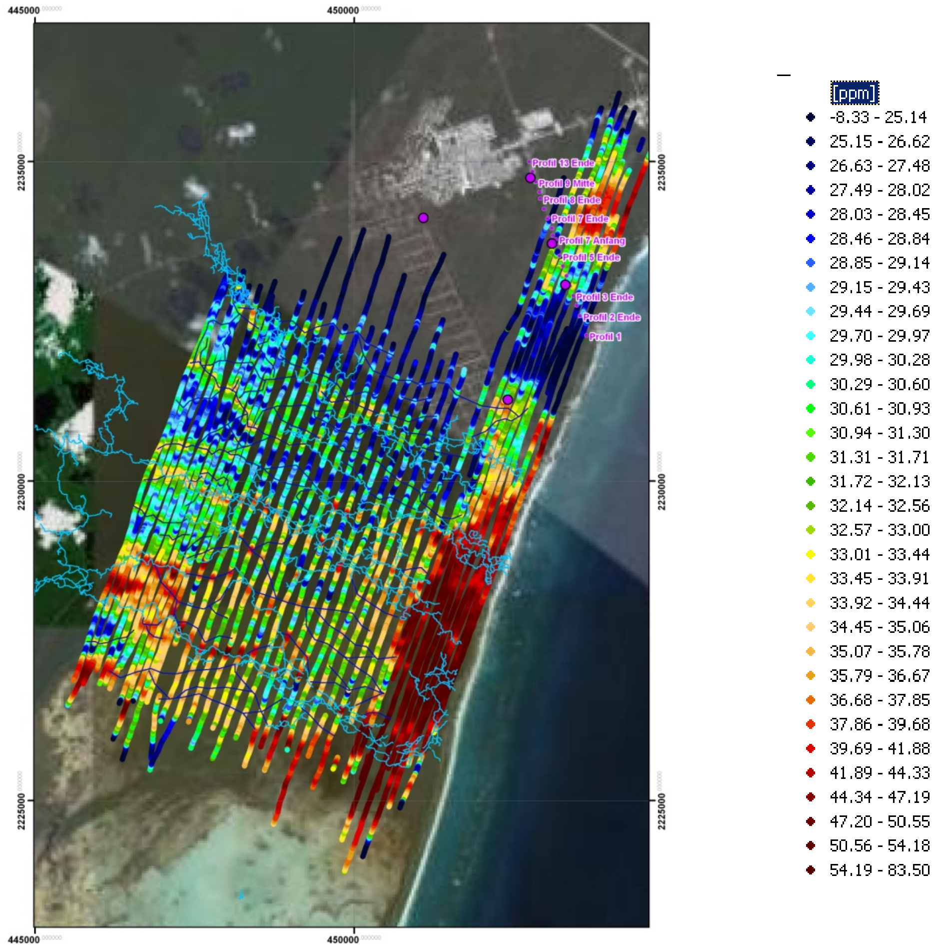

Fig.1: Results of the 7200 Hz inphase component after application of an empirical altitude correction to 70 m of altitude and micro levelling (light blue: known caves; dark blue lines: derived unknown cave branches; purple points: geoelectric profiles 2009)

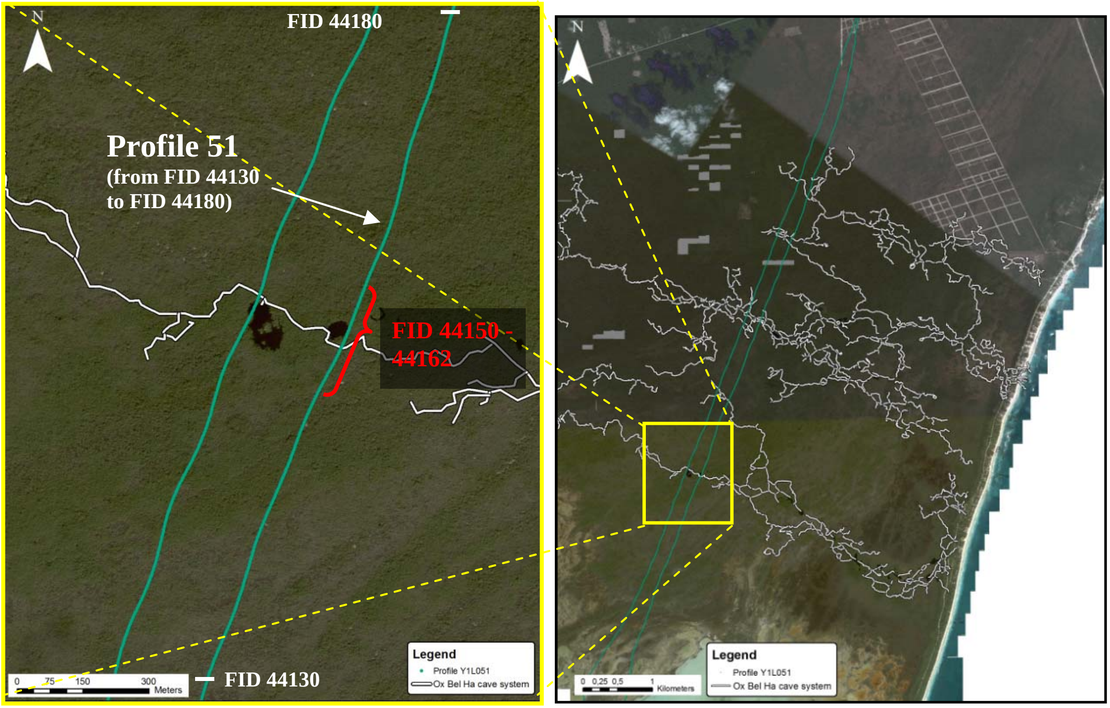

Fig.2: Section of Profile 51 (FID 44130 – 44180) with cave system (white lines) and an overview map of the investigation area

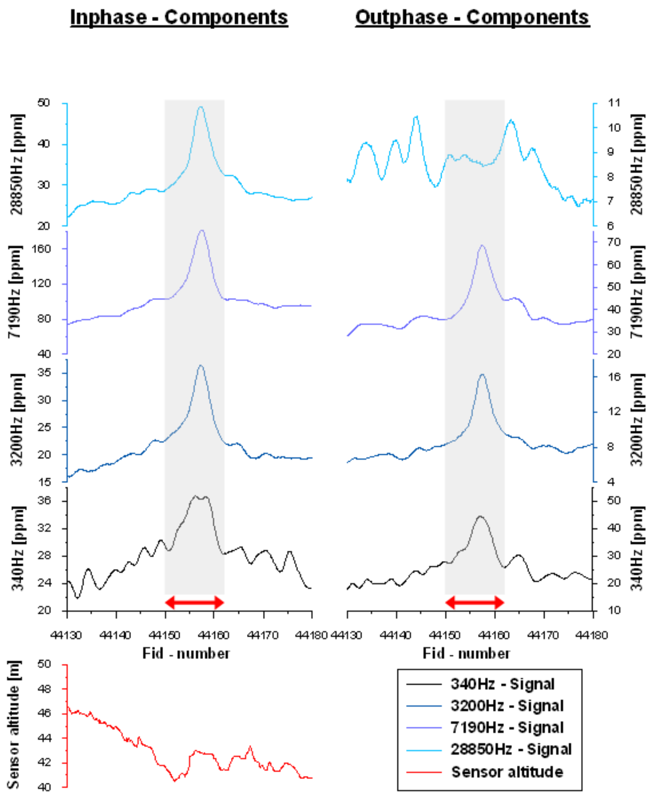

Fig. 3: Results of airborne measurements over a water filled sinkhole (cenote) structure, showing inphase and out-of-phase components and the sensor altitude (red curve) along the flight profile, shaded area indicates position of the cenote

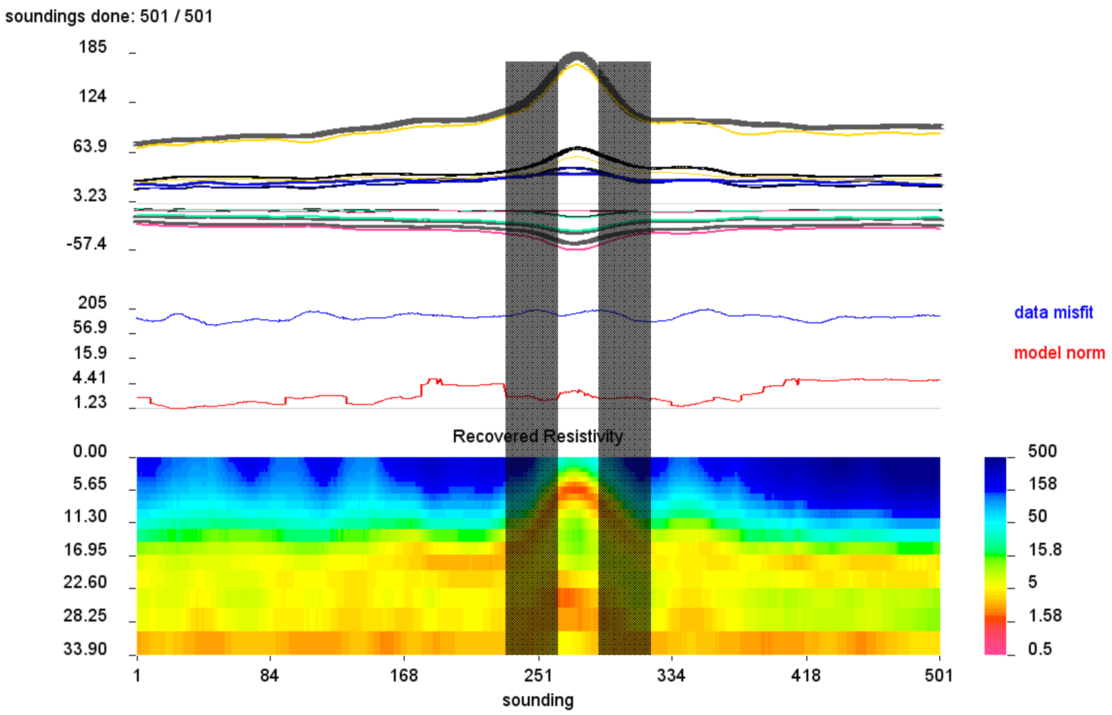

Fig.4: EM Inversion results crossing a known sinkhole structure

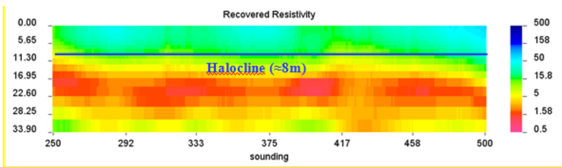

Fig. 5 a: Results along Profile 89 – nearby coastline

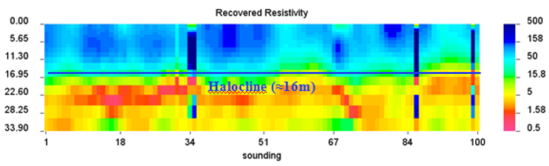

Fig. 5 b: Results along Profile 71 – distance to coastline 2 km

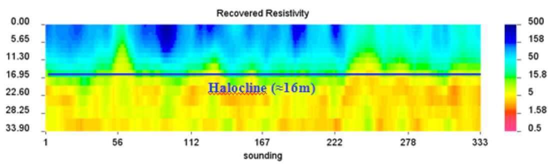

Fig. 5 c: Results along Profile 51 – distance to coastline 4 km

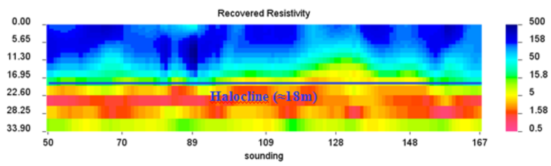

Fig. 5 d: Results along Profile 30 – distance to coastline 6 km

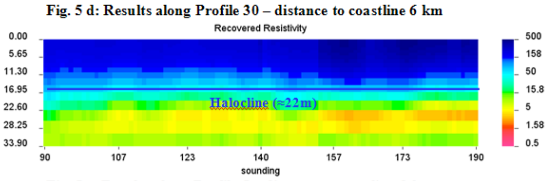

Fig. 5 e: Results along Profile 5 – distance to coastline 9 km

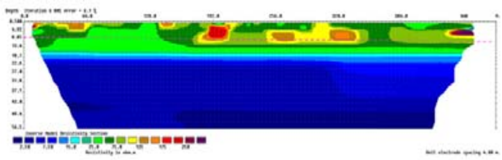

Fig. 5f: Results of geoelectrical inversion, location of profile near coastline

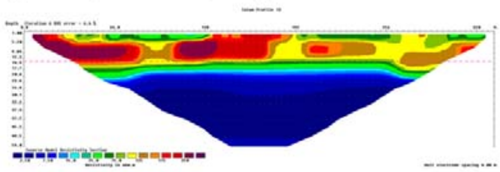

Fig. 5g: Results of geoelectrical inversion, location of profile: 2 km distance from coastline

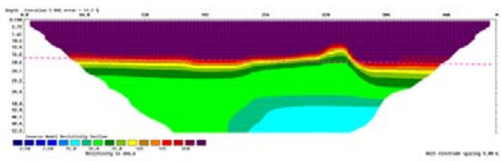

Fig. 5h: Results of geoelectrical inversion, location of profile: 6 km distance from coastline

Fig.5: EM (a - e) and geoelectric (f - h) inversion results for profiles at different distances from the coastline; colour bar of geoelectric results is inverted