Structural characterization of a coastal aquifer using time-lapse electrical tomography

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I Introduction

Adequate characterization of subsurface structure is critical for a precise hydrogeological modeling and groundwater management. The electrical resistivity tomography (ERT) is a well-established method that permits to gain subsurface information with enhanced spatial and temporal resolution in comparison with traditional direct methods. Thus, in the recent years we have applied the ERT method to monitor seasonal and tide variations from a shallow coastal aquifer in the north of the Yucatan Peninsula (YP), Mexico. The peninsula is permeable due to carbonate geology with groundwater seeps and springs emanating from the coastal ocean [1]. Tides are mixed semi-diurnal with a range of 0.80 m (microtidal) [2].

II Objective

Characterize lithological changes in the subsurface towards a better definition of the geometry of the coastal aquifer. Delineate seasonal and tide regimens at two study areas (Figure 1) through the analysis of the spatial and temporal variations in the subsurface electrical properties. Investigate the correlation between subsurface variations and surface processes such as precipitation and changes in the vegetation.

III Methodology

Acquisition: AGI SuperSting R8/IP system (56 electrodes, dipole-dipole, max a=10; max n=8; 1895 quadrupoles per transect). **Data analysis.** (1) Identification of clear outliers associated with a poor galvanic contact between the electrodes and the surface, linked to poor signal-to-noise ratio (S/N). (2) Computation of the ratio in the transfer resistances for the same quadrupole along the consecutive time-lapses, with outliers defined as those measurements exceeding a ratio of 0.75. (3) Removal of quadrupoles not present in all time-lapse measurements. **Inversion.** The inverted images presented in this work were computed using the robust-constraint inversion code by Kemna (2000) [3], which permits to invert the data to a pre-defined error-level, given by the analysis of the data (Lesparre et al., 2017) [4].

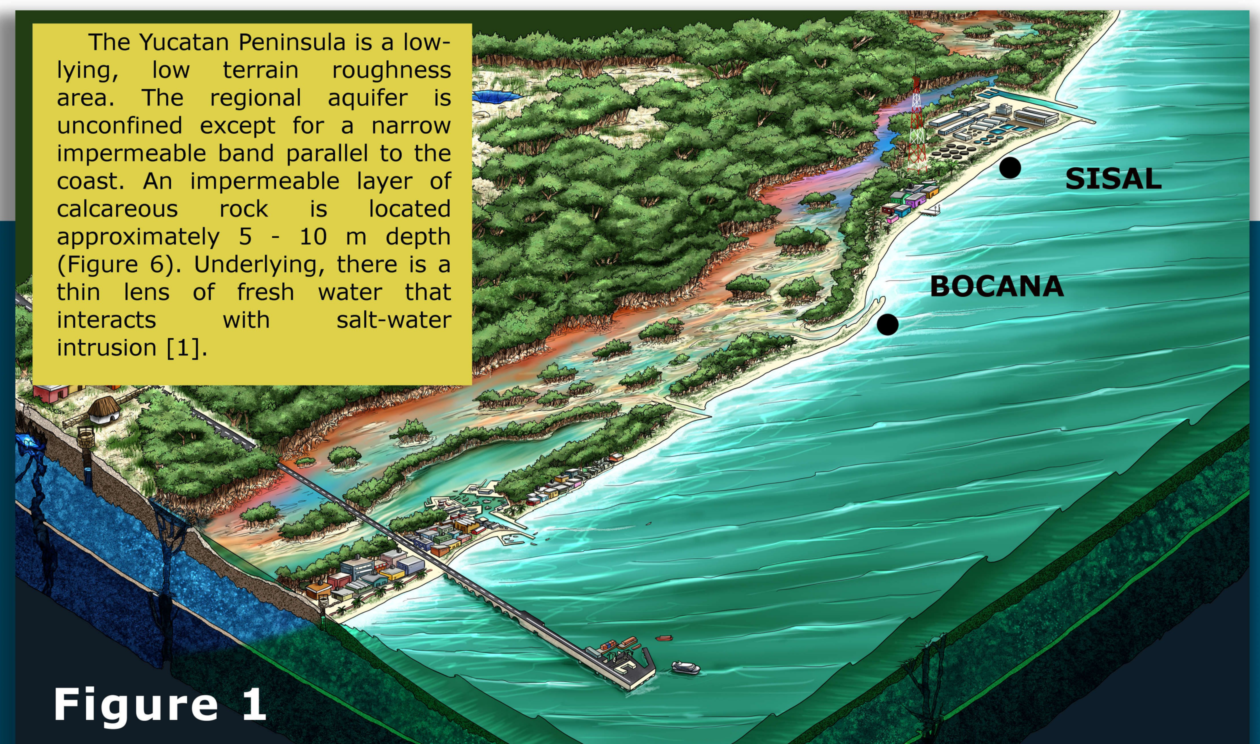

Figure 1

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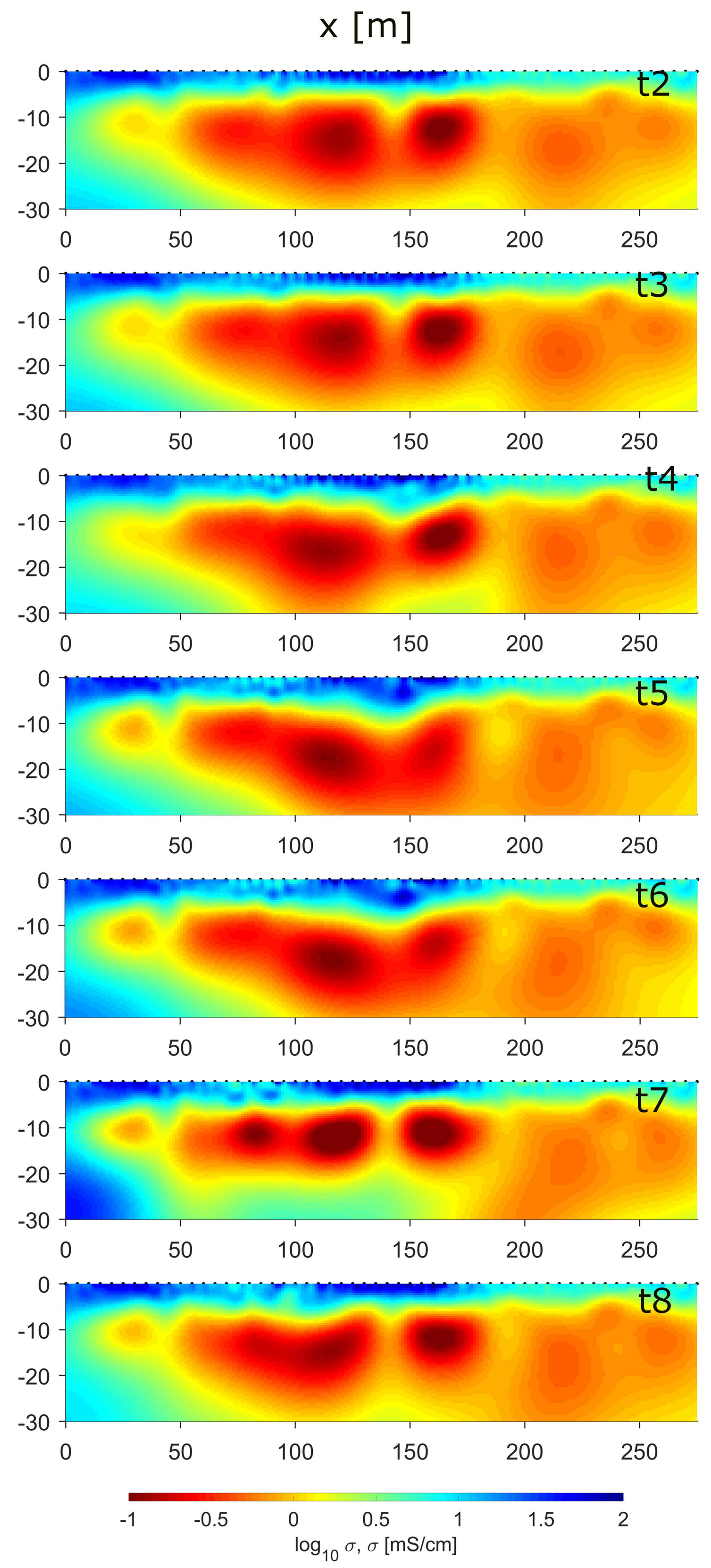
IV Results



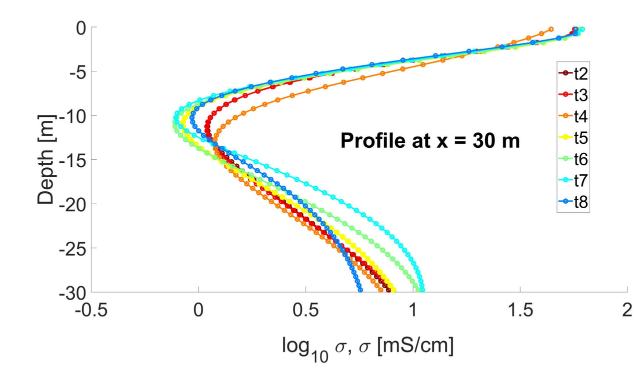


Figure 2

Bocana. 24-hour monitoring dataset collected every three hours at a coastal lagoon to investigate interactions between the sea and the coastal aquifer during spring high tide (September 23th 2016). Electrode spacing 5m.

ERT images show temporal and spatial changes related to tide variations along the monitoring period.

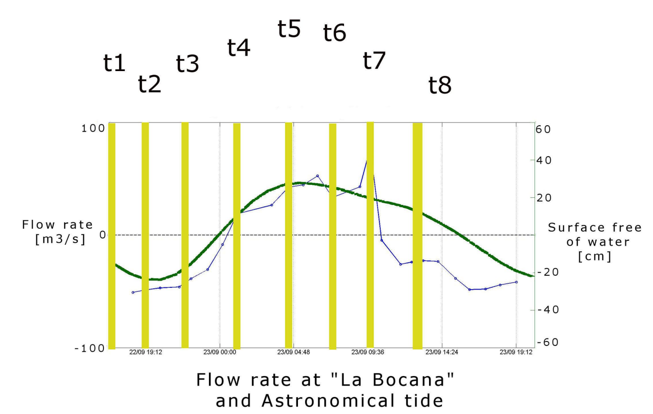


Figure 3

Bocana analysis. A vertical profile at x = 30m reveals two different trends: when 0< depth <-15m electrical conductivity decrease as tide increase; in contrast, for -15m < depth < -30m electrical conductivity increase as tide increase.

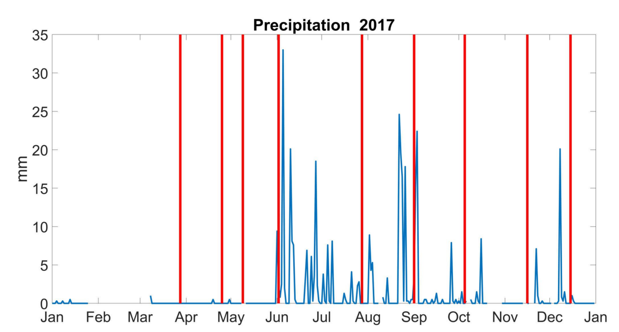


Figure 4

Sisal. Monthly monitoring measurements (March - December 2017) of the backshore of Sisal beach to improve our understanding on the geometry of the aquifer, as well as to delineate changes in the groundwater salinity in a shallow aquifer. Measurements were collected at electrode spacing of 3m. Distribution of electrical conductivity in ERT images show a clear correlation with the geological units identified in a near stratigraphic column (Figure 6).

Electrical conductivity in the upper layer (z < 5m depth) shows variations that correlate with the time series of local precipitation. The impermeable layer "caliche" is shown as a transition zone highlighted between dash black lines. The regional aquifer is defined by low electrical values.

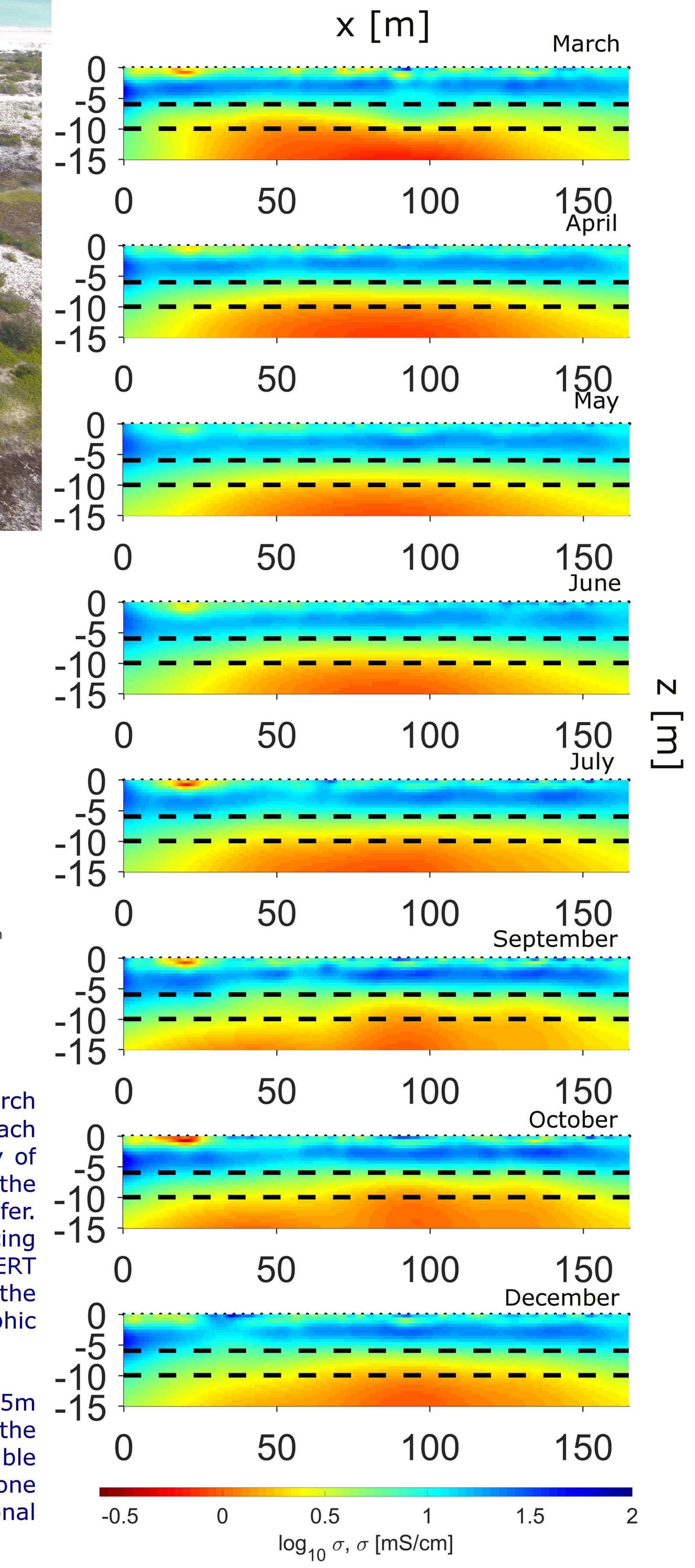
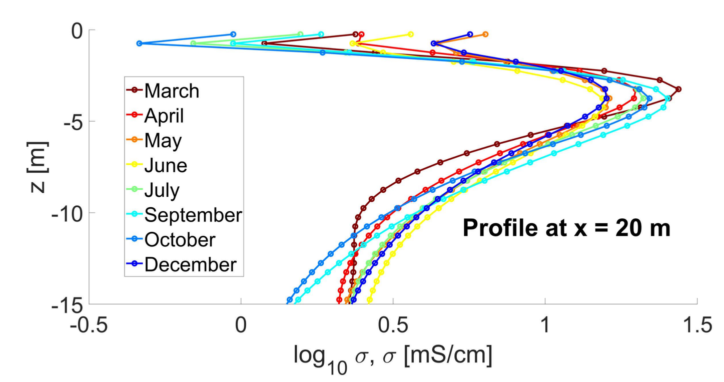


Figure 5

Sisal analysis. Variation in electrical conductivity, at depth, reveals a decrease in the electrical conductivity in shallow regions over the year, likely associated to increase in the saturation following precipitation events



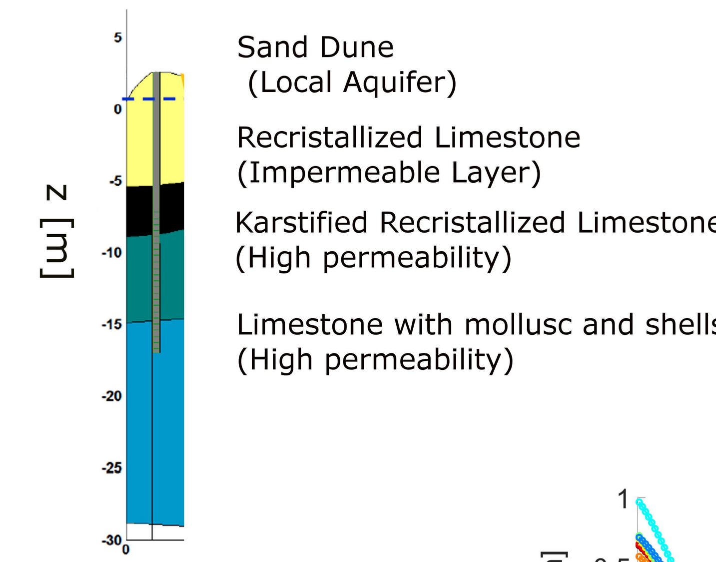
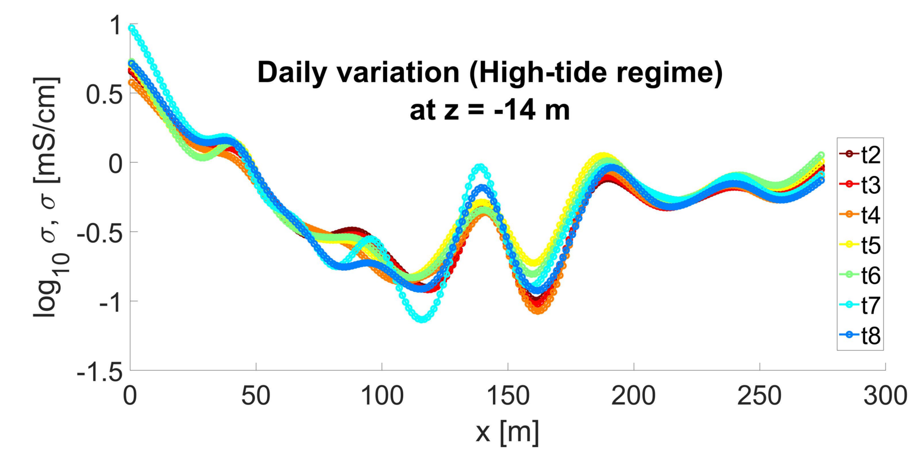


Figure 6

Stratigraphic column obtained from a well located 200m apart from the ERT profile at Sisal. It presents four geological units. The first unit is composed by the *dune ridge* that corresponds with a local phreatic aquifer. The second unit is an impermeable layer of caliche which conforms the aquitard that confines the regional aquifer along the Yucatan coast. The three and four units contain the regional aquifer.

Figure 7

Variation of electrical conductivity along the profile for depth = 14 m shows a region (between 50 and 100m) highly dynamic that responds to the interactions between lagoon and ocean.



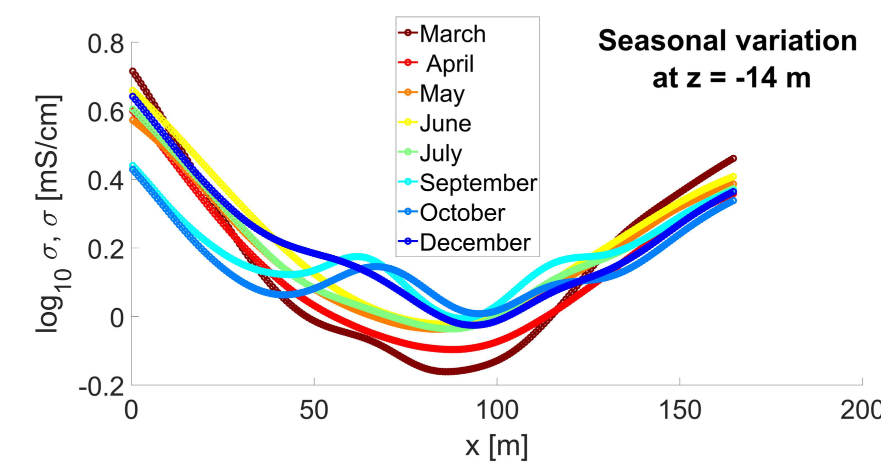


Figure 8

Sisal has three weather seasons:

(1) Dry season (March to mid-June)
(2) Rainy season (mid-June to October)
(3) "Nortes" season (November-February), characterized by synoptic-scale events associated with short-duration high-pressure systems with rain and strong winds that originate from large masses of cold polar air from high latitudes [2].

Variation of electrical conductivity along a profile for depth = 14 m shows one anomaly in rain season around 60 m.

V Conclusion

Our imaging results show correlation with available lithological and precipitation data, demonstrating that the methodology used for collection and processing of ERT monitoring measurements can be used to further understand hydrogeological processes in the Yucatan Peninsula. Electrical images permitted to improve our understanding about the architecture of hydrogeological units and to delineate temporal variations in groundwater associated to meteorological events.

In the data collected at La Bocana lagoon, the increase in the electrical resistivity is linked to variations in surface water accompanying tides, with ongoing work related to quantify the hydraulic connection between surface and groundwater.

In the case of the Sisal beach, the analysis of seasonal changes reveals the ability of ERT results to delineate aquifer recharge and two different patterns: an decrease in the electrical conductivity in the shallow unconfined aquifer due to raining events, and the decrease in electrical conductivity at depth due to the regression of the seawater intrusion following the "nortes" period.

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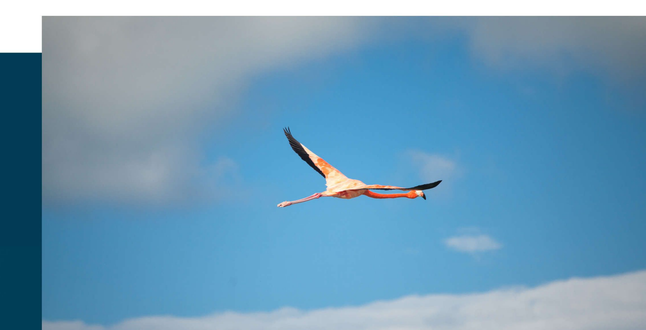

Credits
Figure 1. Yucatan Coast, Ilustration by Alberto Guerra.
Figure 2. Carbonera Picture by Sergio Medellín.
Figure 3. Carbonera Tie (Modified from Paladio et al. 2016).
Figure 6. Modified from Canul et al. 2017.
Extra Pictures by Abraham Reyes.
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