Multitemporal Geophysical Mapping of Saltwater Intrusion in the Southern Region of the Everglades National Park

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Introduction

The Everglades National Park (ENP) is a wetland ecosystem critical for biodiversity and ecological balance. However, it faces increasing threats from climate change, particularly sea level rise, which impacts groundwater salinity and hydrogeological structures. Vertical Electrical Soundings (VES) provide an effective, non-invasive technique for assessing groundwater quality. These soundings may be used for identifying the saltwater (SW) front in the southern region of ENP and can be used to assess the effectiveness of Everglades restoration and the impact of seal level rise.

This study investigates spatial and temporal changes in groundwater salinity along the Main Park Road of the ENP extending from Flamingo on Florida Bay 20 km inland to Sweet Bay Pond (Fig 1). These stations are situated between Shark River Slough and Taylor Slough, the Everglades' natural drainage systems. VES data were collected at 4 intervals between 2021 and 2023 and inverted to smooth 6-m-deep resistivity models. Formation resistivity was converted to salinity using Archie's Law and standard formula. The soundings were interpolated on to resistivity profiles to map the saltwater intrusion front, explore transitions between freshwater and brackish water zones, and assess temporal changes in the groundwater.

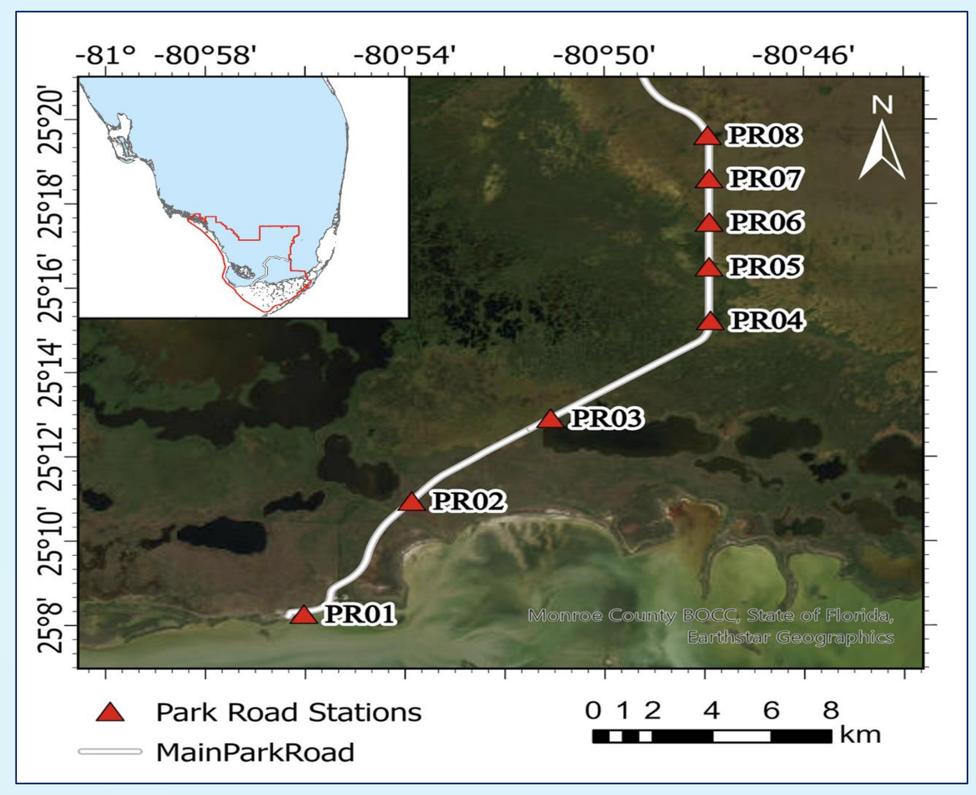

Fig. 1. Index map showing the VES stations on the Main Park Road.

Methodology

➢ <u>Field Data Collection</u>

VES were conducted by using the AGI Super Sting RI IP resistivity imaging system. These soundings employed an expanding Schlumberger array with 6 AB/2 lengths ranging from 0.5 to 16 m. This provides an effective depth resolution of ~ 6 m. Array lengths of up to 60 m were used but did not produce consistent results for all the sites and dates. Soundings were collected at eight park road stations (Fig. 1) in May 2021, May 2022, November of 2022 and May 2023.

➢ <u>Data Analysis and Modeling</u>

The sounding data were inverted to resistivity-depth models with the Python PyGIMLi package[1]. The models consisted of 30 layers with thicknesses increasing with depth using the smooth Occam's Inversion algorithm[2]. An example of the sounding data and model at station "PR01-M21" , "PR04-M21" and "PR08-M21" are shown in Fig 2. Individual vertical sounding models for each date were interpolated by using the log of the resistivity onto a south-north profile extending from Flamingo to west of Sweet Bay Pond (Fig. 3). Water table data were obtained through the Everglades Depth Estimation Network (EDEN). To visualize changes in aquifer salinity, the modeled resistivity was converted into pore fluid conductivity using a regional formation factor of 5.5[3]. Pore fluid conductivity was converted to salinity in PSU with standard formula[4] (Fig 4).

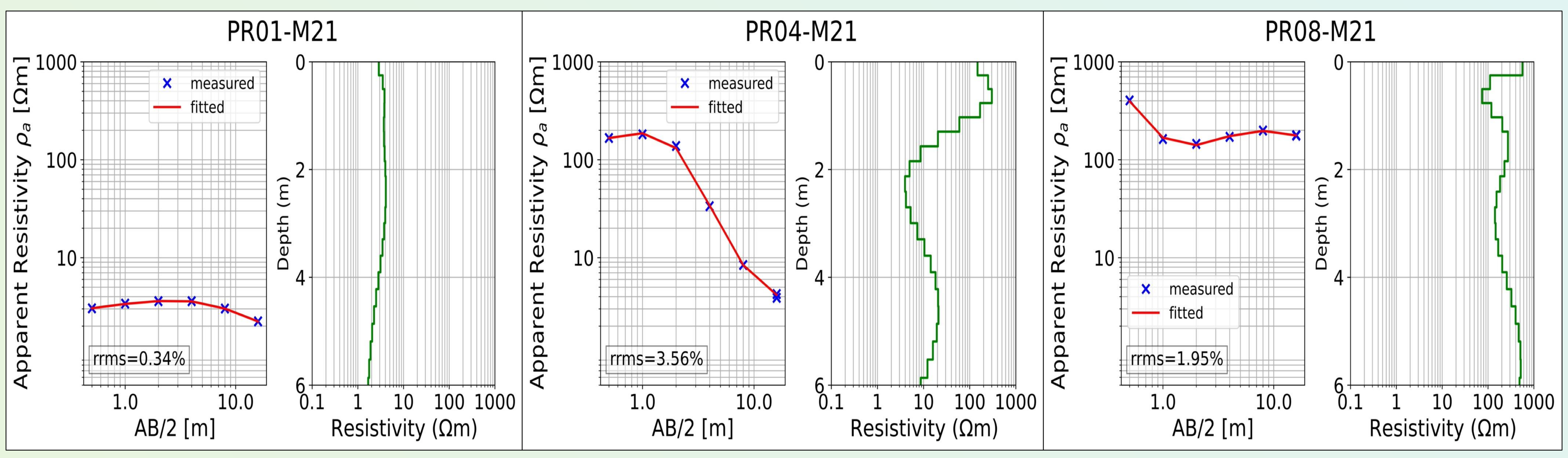

Fig. 2. Examples of observed and fitted data and inverted models (green) collected in May 2021.

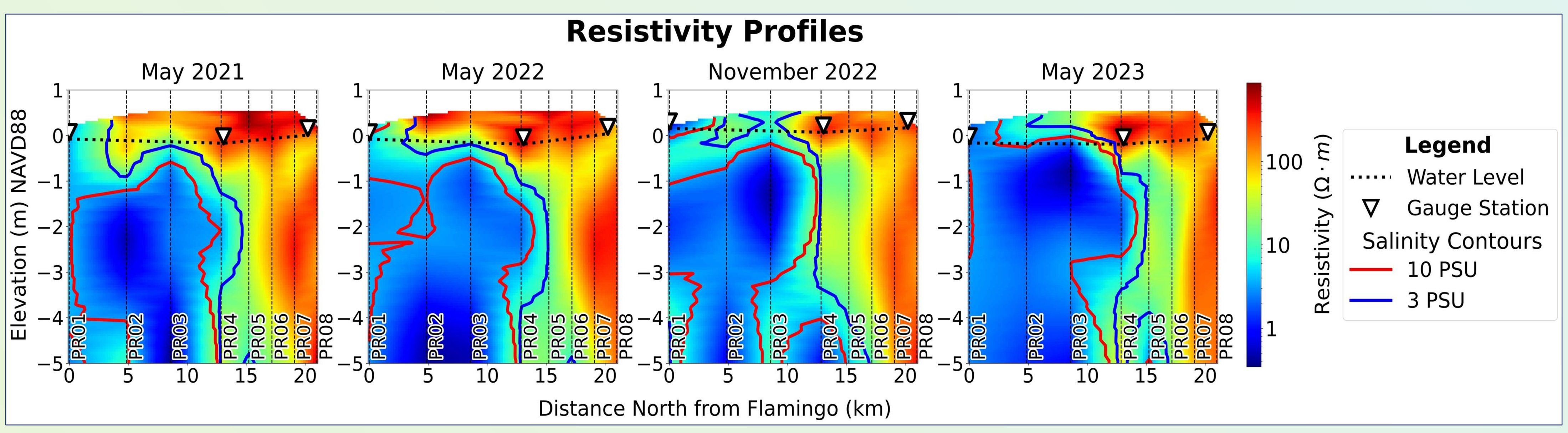

Fig. 3. Linear interpolated resistivity profiles along the Main Park Road for each deployment. Station locations are indicated with dashed vertical lines. Dashed horizontal lines are the water level. Salinity contours at 3 and 10 PSU are overlain. Depths are relative to NAVD88 datum. Upside down triangles indicate the water level from gauge stations mentioned figure 6.

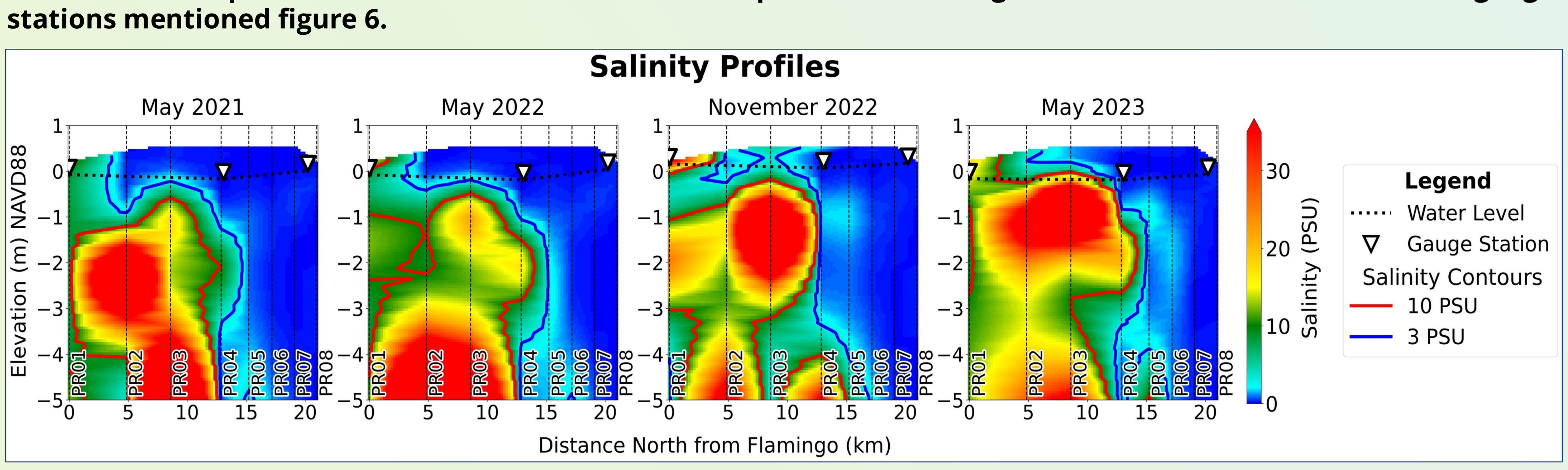

Fig. 4. Linear interpolated salinity profiles with water level and salinity contours. The color scale has blue as freshwater, cyan to green as brackish water and yellow to red are saline.

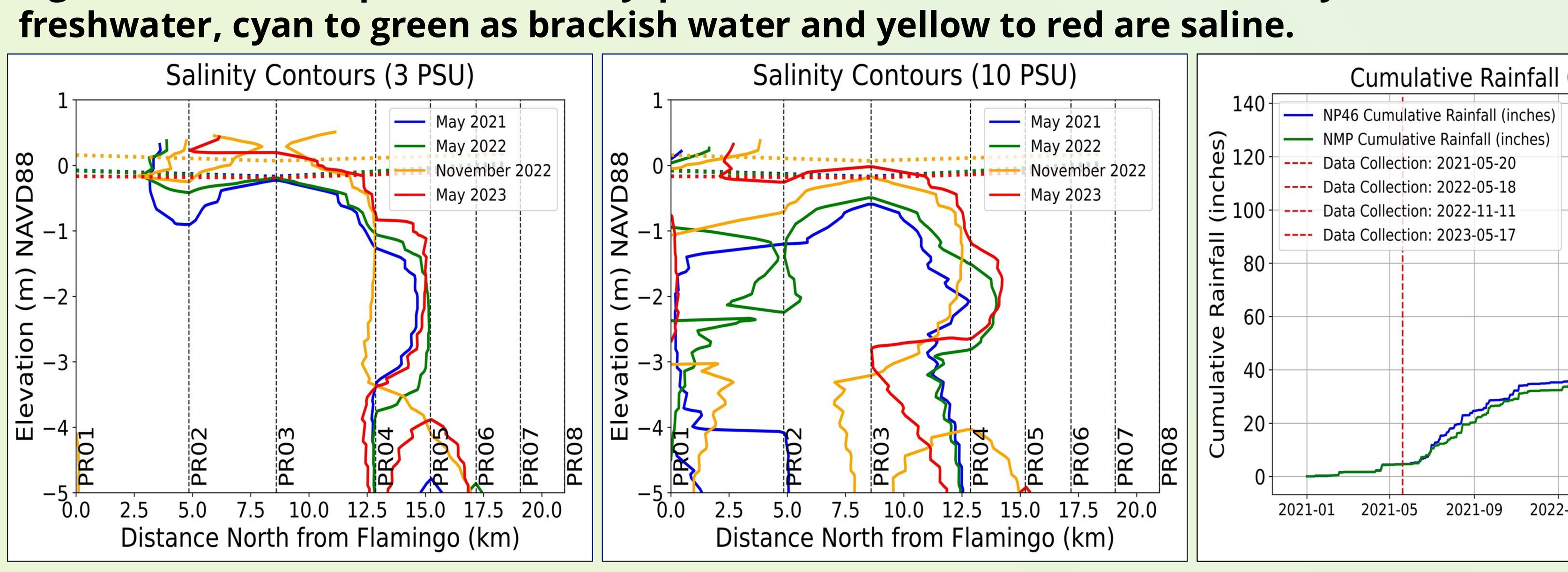

Fig. 5. Salinity contours for 3 PSU and 10 PSU for the data collection dates. Horizontal dashed lines represent water level.

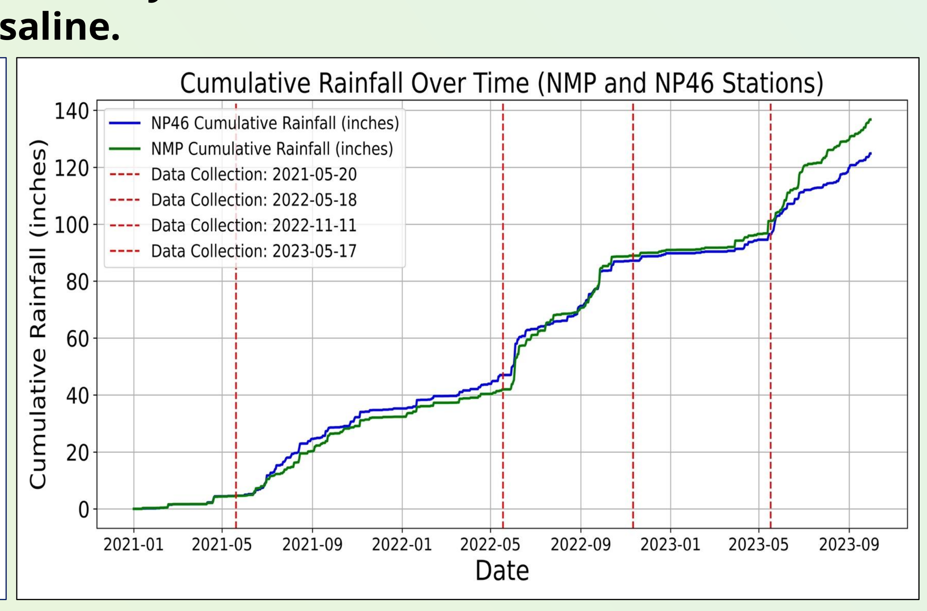

Fig. 6. Cumulative rainfall from 2021 to 2023 observed at 2 stations in ENP.

Results

There are clear spatial and temporal trends observed in both the resistivity and salinity profiles. The resistivity profiles reveal higher resistivity values in the upper surface (0.5 to -1 m) of PR02 during the dry seasons of May 2021 and May 2022, followed by a decrease in resistivity in November 2022 and May 2023. This pattern aligns with the precipitation data (Fig. 6), where higher precipitation in November 2022 and May 2023 illustrates the influence of freshwater recharge and seasonal changes. The resistivity profiles also indicate the unsaturated zone, characterized by resistivity values of 100 Ohm-m or higher, while resistivity values of 1 to 2 Ohm-m correspond to seawater, and 2 to 100 Ohm-m represent variations in salinity.

During the dry seasons (May 2021-2023), the 3 PSU salinity contours were located 1 to 2 km further inland at elevations of -1 to -3 m compared to the wet season (November 2022) (Fig. 5). Salinity contours of 3 and 10 PSU were closely spaced during the dry seasons, indicating steeper salinity gradients. In contrast, these contours were more widely spaced during the wet season, reflecting the dilution and redistribution of salts due to increased precipitation.

Below -3 m, groundwater dynamics become more complex due to increased noise in the data and the natural heterogeneity of the aquifer. While Archie's Law assumes a homogeneous aquifer, which introduces some uncertainty in regions with greater variability in porosity, the profiles above -3 m exhibit clear trends and consistent results. These trends strongly support the reliability of the observed salinity patterns within this depth range.

Conclusion

- The SW intrusion front is around 12 to 14 km north of Florida Bay. This lies between PR04 and PR05 and is associated with the vegetation (Fig. 1) where there's a clear distinction between mangroves (south) and the freshwater marl prairie (north).
- During the end of the wet season, the SW front at elevations of -1 to -3 m moves 1 to 2 km inland relative to the wet season.
- Deeper groundwater dynamics below -3 m are more complex due to natural aquifer heterogeneity and data noise, however, clear and reliable salinity patterns are observed above this depth.

Acknowledgements

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