Characterizing the ocean with acoustic waves

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1 Introduction

Seismic oceanography (SO) is a multidisciplinary research field that uses common marine multichannel seismic reflection data to imaging sub-mesoscale ocean processes hardly detected by sparse direct measurements as represented by conventional oceanographic sampling techniques.

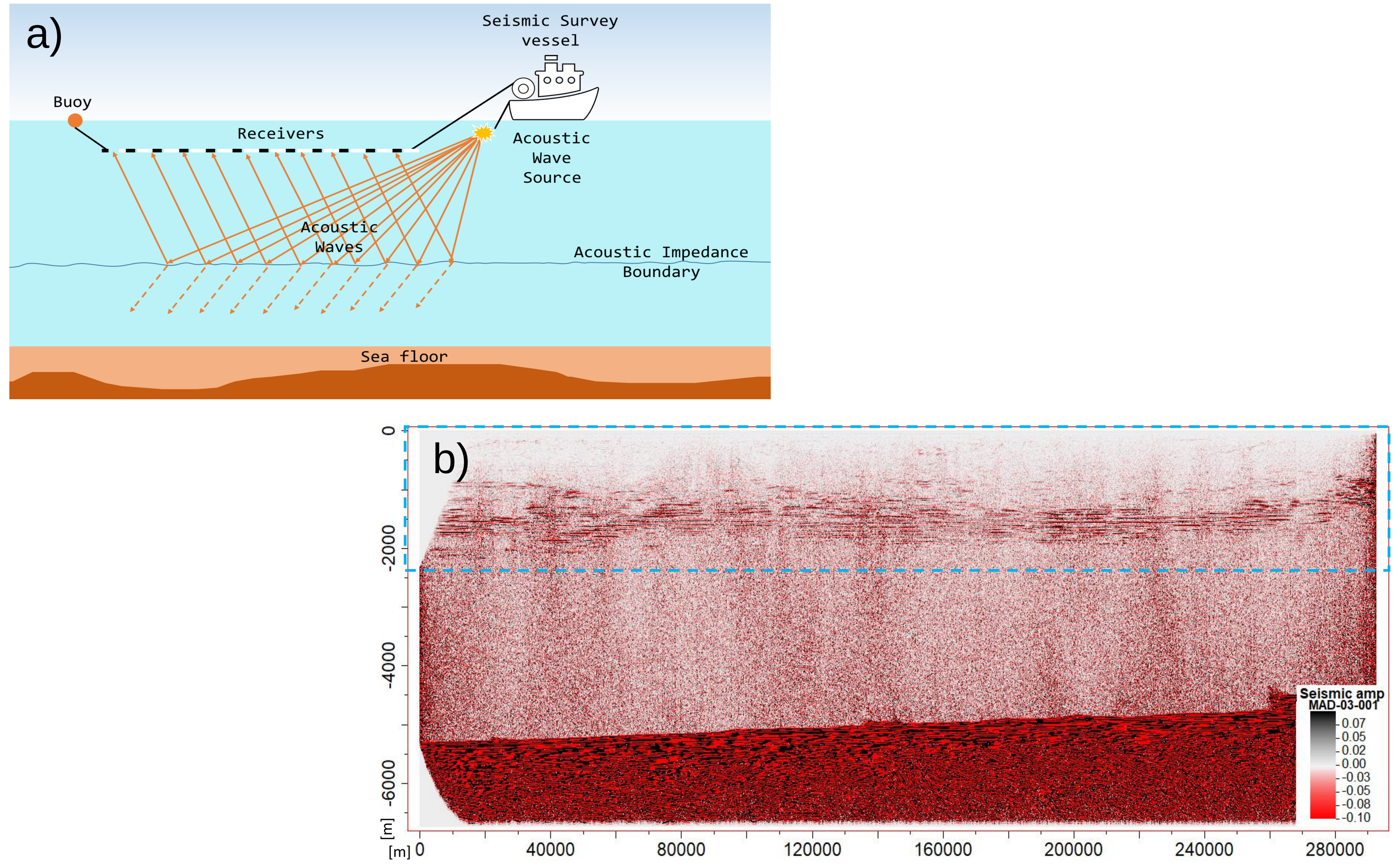

Figure 1: a) Multichannel Seismic acquisition diagram; b) Final stacked image of the ocean acquired 2D line.

2 Why the Madeira abyssal plain?

The **Mediterranean outflow waters** (MOW) have high influence in the mixing layers of the Madeira abyssal plain (MAP).

The MOW is characterized by warm and high-salinity water masses, which reach the MAP in buoyancy between ~500 to 1500 meters depth creating an anomaly dividing the North Atlantic Water from the North Atlantic Deep Water (NADW).

The **three seismic sections** acquired by the Portuguese Task Force for the Extension of the Continental Shelf in the Madeira Abyssal Plain (MAP), covering 300km and ~100km apart from each other, and dating from 2006, were processed to enhance the amplitudes of the water column (Azevedo, L. et al., 2021). The **conductivity-temperature-depth (CTD)** data was acquired from Poseidon research vessel campaigns (Waniek, 2007a & 2007b; Müller, 2008; Müller & Schulz-Bull, 2003).

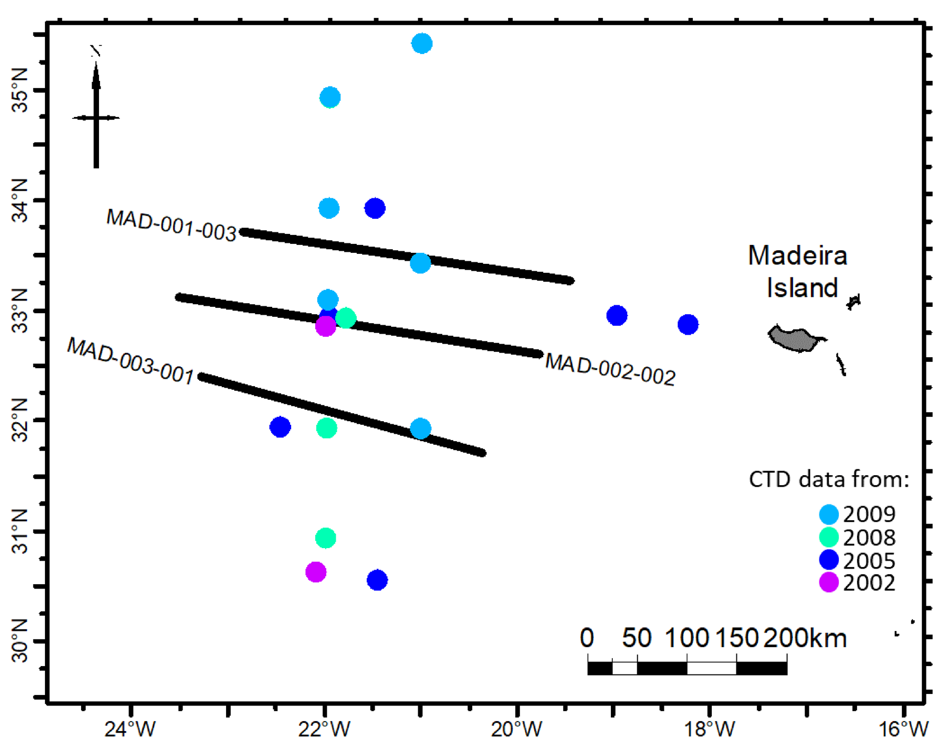

Figure 2: Data location, CTD profiles (dots), Seismic sections (black lines).

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Seismic oceanography allows studying the ocean by taking snapshots of the water layers.

We detected **thermohaline staircases** in the Madeira abyssal plain and correlated with three seismic sections.

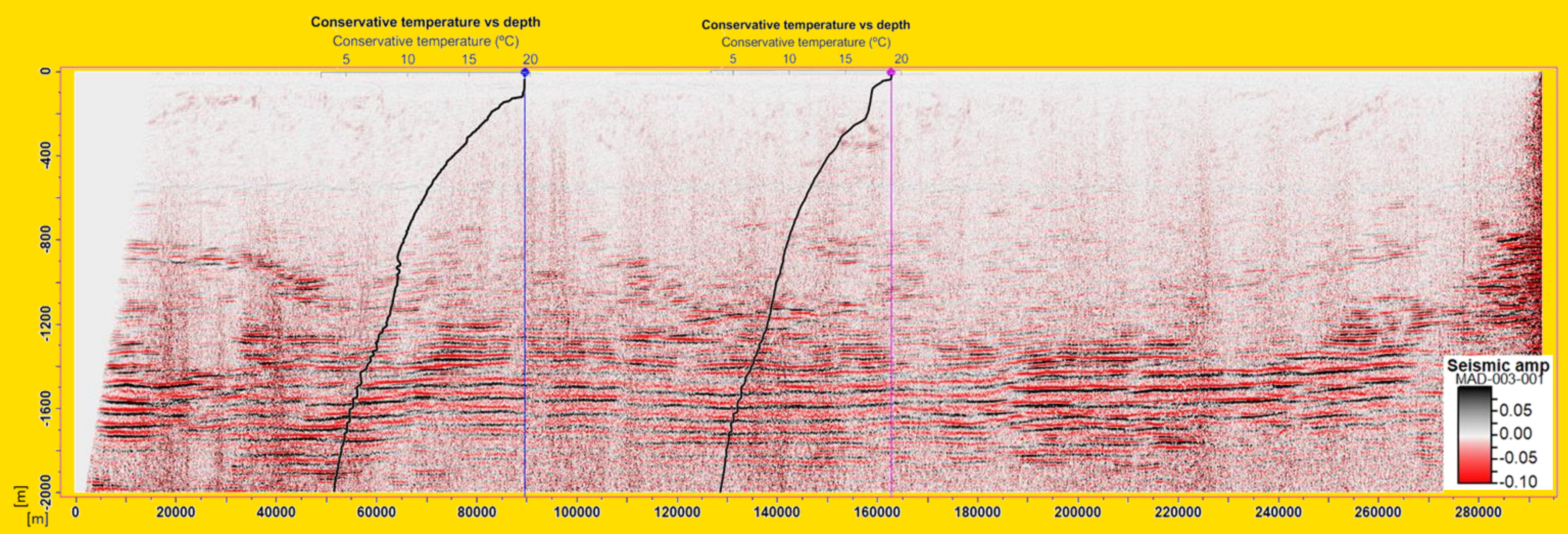


Figure 6: Shows that the staircases seen on the vertical profiles are corresponding to the reflections on the seismic which is a good validation to use the seismic images to infer the lateral continuity of those structures.

3 Temperature and Salinity measurements

This salinity gradient anomaly is auspicious for developing double-diffusive mixing (Radko, 2013; van der Boog, C. et al., 2021), in particular **thermohaline staircases** formed by mixing of the MOW with NADW, between ~1600 to 2000m deep.

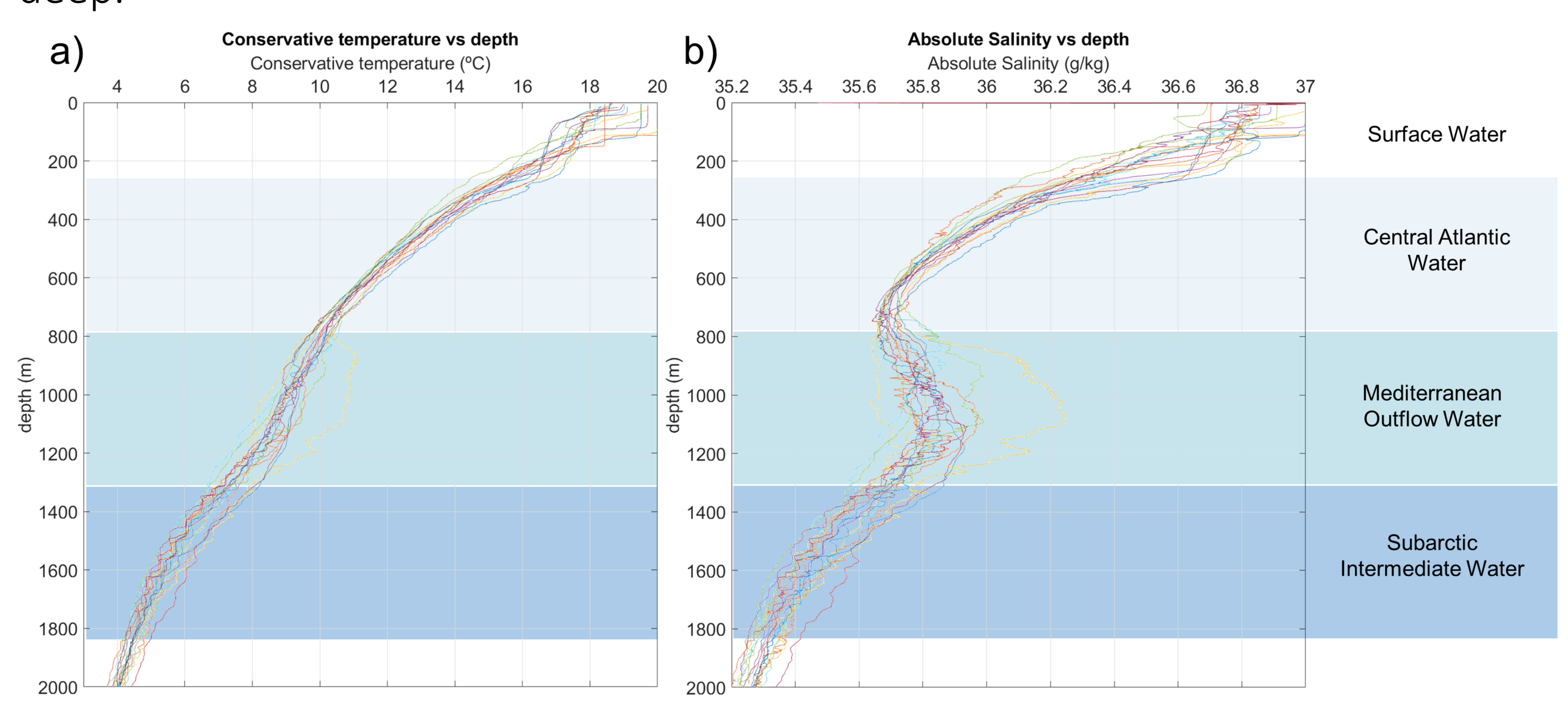


Figure 3: Temperature (a) and Salinity (b) vertical plots and its correspondence in depth to the different water masses.

4 Thermohaline staircases

Thermohaline staircases are regular, relatively homogeneous, horizontal structures, that spread laterally in well-defined layers. Those layers are formed by different mixing gradients of heat and salt, they are also observed in vertical temperature and salinity profiles as step-like variations.

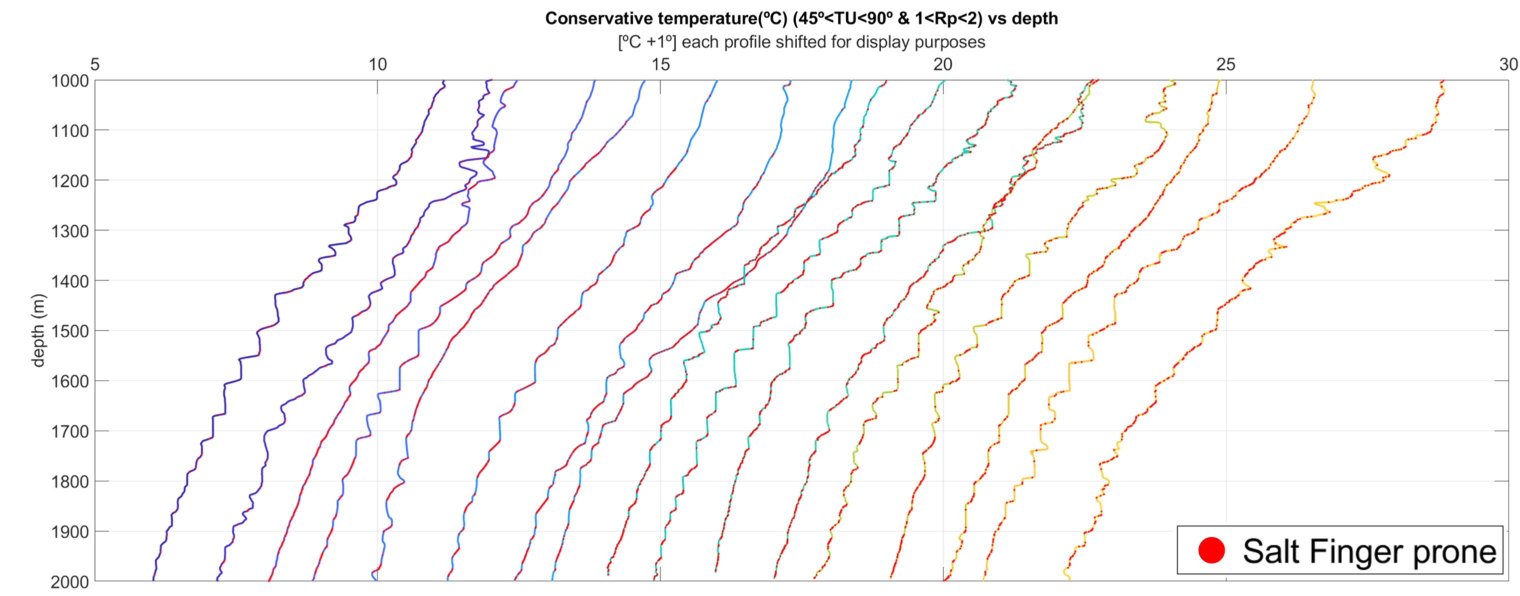
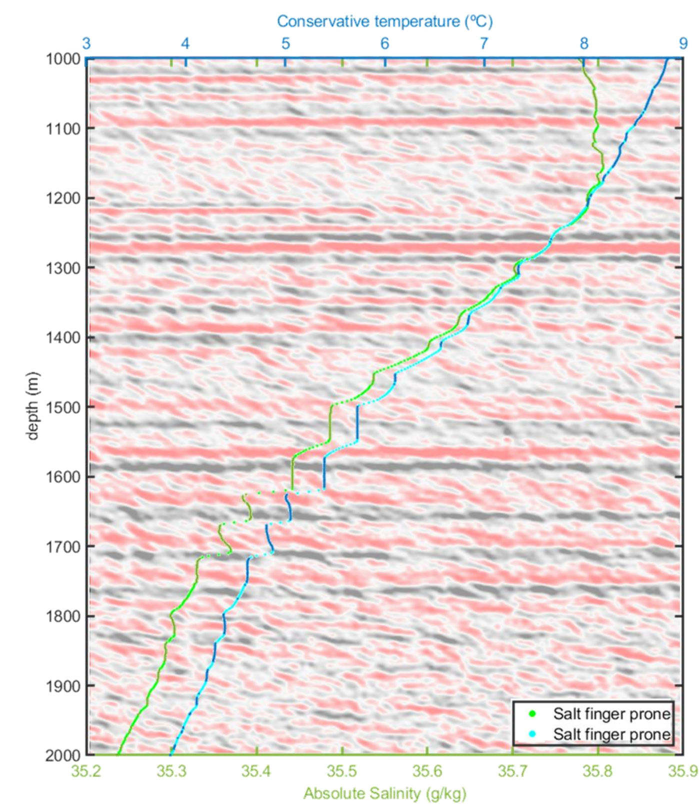


Figure 4: Conservative temperature of the CTD profiles which show step-like features. Red dots correspond to salt finger prone depths computed with Turner Angle between 45º - 90º and density ratio between 1-2.

5 Correspondence between seismic reflections and thermohaline staircases



We found horizontal reflections on the three seismic sections (between ~1200m to ~1900m) which correspond to thermohaline staircases depths. By integrating the seismic images with the direct measurements, it is noted that those reflections correspond to the staircases. When there is a jump of the properties, there is a reflection associated to it.

Figure 5: Vertical plots of T and S between 1000 and 2000m with thermohaline staircases plotted against seismic reflections, highlighted colours capturing the salt finger prone depths of the profiles.

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