New vision on the Ionian Sea abyssal variability through integrated approaches

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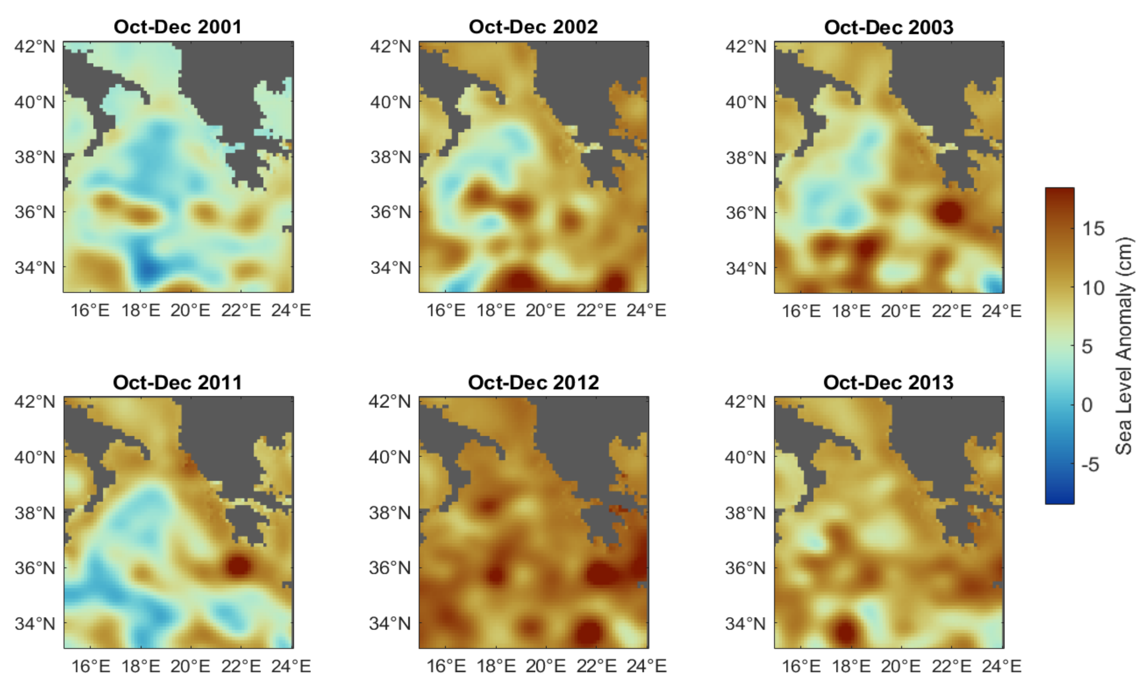
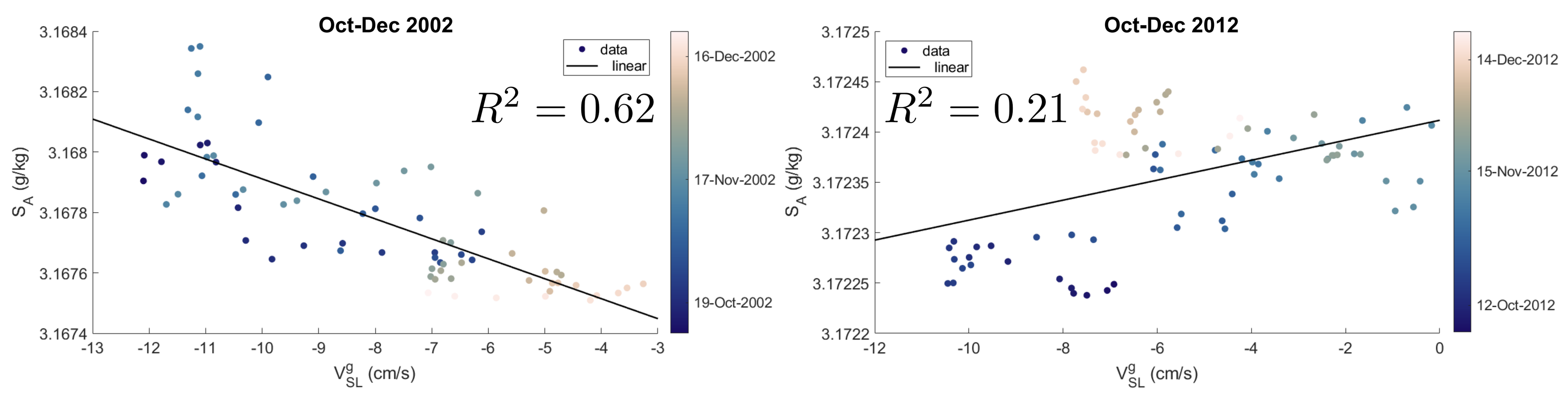
Introduction

The processes involved in deep sea circulation, their connections to the whole water column, and their vulnerability to climate variability are still unclear. This is mainly due to a **lack of long-term observations below 2000 m of depth** [1]. To address this gap, we used different datasets and methodologies exploiting the available resources. In particular, we used nearly full-depth CTD profiles collected near the Malta Escarpment between 1999 and 2003 (ER-0121 site), time series from the NEMO-SN1 seafloor observatory located off the Sicily coast at 2100 m of depth, and satellite altimetry data. We combined these datasets with different analysis techniques, theory, and numerical modeling.

Satellite Altimetry Data

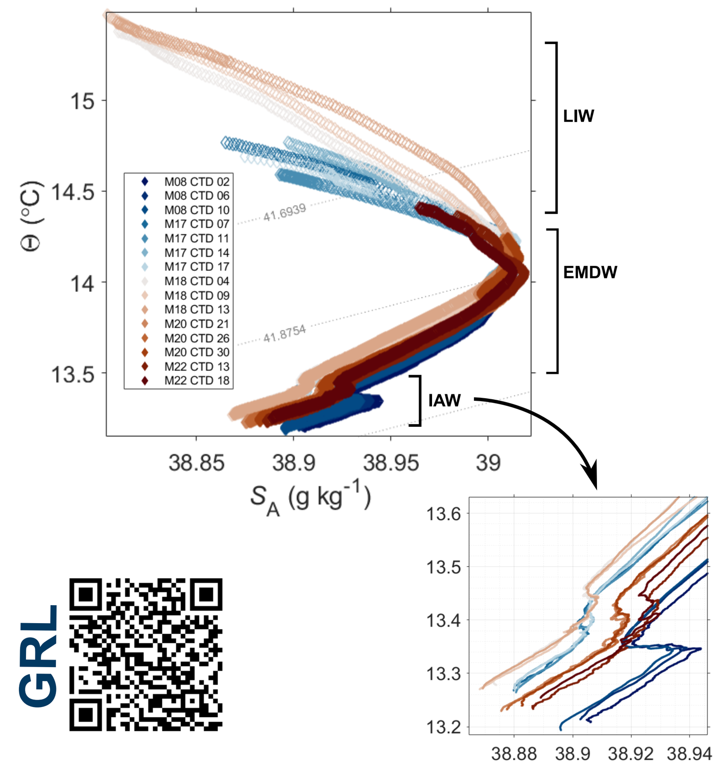
The observed changes in thermohaline properties and the current reversal at NEMO-SN1 raises interesting questions in light of the BiOS hypothesis [5]. Analysis of satellite altimetry data around the periods corresponding to the NEMO-SN1 observations reveals **surface circulation reversal**. Data comparison shows a 62% correlation between salinity measured at 2100 m depth and satellite meridional velocity at the surface, suggesting a **connection between surface and bottom** layers. However, this correlation is absent in the 2012 data, possibly indicating a temporary disruption in the usual surface-bottom connection due to the unusual winter conditions of that year [6].

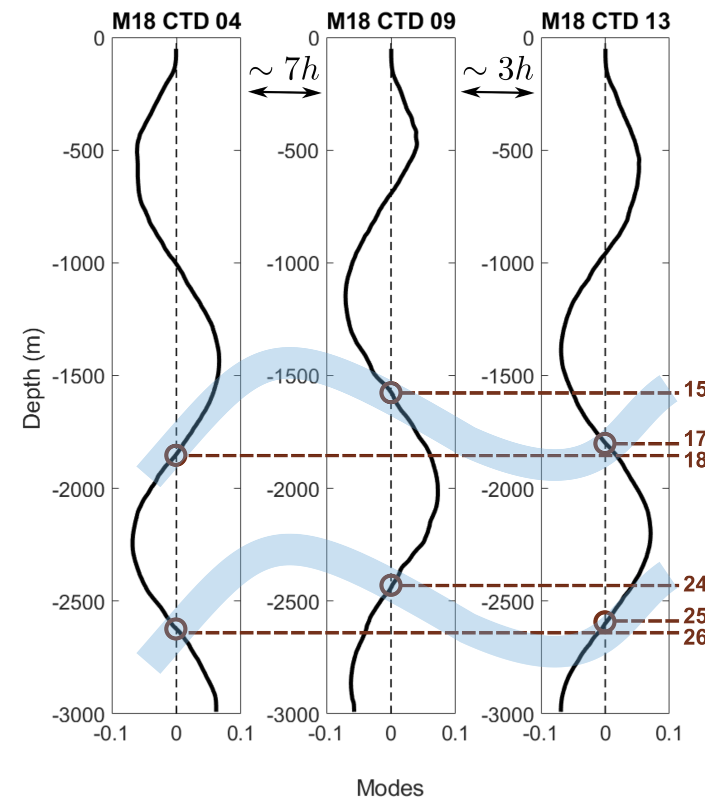




Nearly full-depth CTD profiles

There is a stratification change in the deepest layer over the years [2], with a **well-defined denser water mass**, Ionian Abyssal Water (IAW), that is changing and homogenizing over the sampled years. The normal modes associated with the IAW reveal the presence of **variability at tidal period**, which is not so straightforward to observe, both because of depth and because of the tides' small amplitudes in the Mediterranean Sea [3].





Semi-analytical approach

To investigate the possible impact of the stratification on the dynamics at the bottom, we started from the observed mean structure of the Ionian Sea stratification, which suggests a **4-layer** scheme. For simplicity, we decided to study how much and under which conditions a potential vorticity input can propagate in the abyss in a Quasi-Geostrophic framework [7].

QG potential vorticity equation:

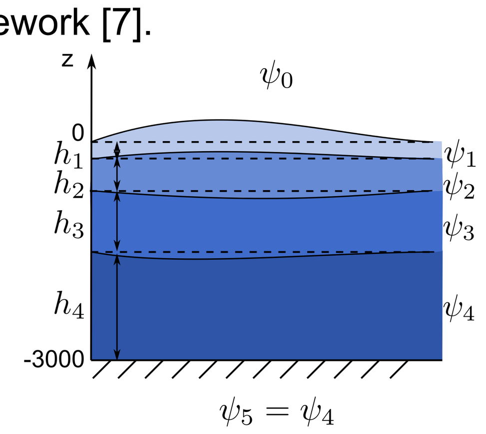
$$q = \nabla^2\Psi + \frac{\partial}{\partial z}\left(\frac{f^2}{N^2}\frac{\partial \Psi}{\partial z}\right) \longrightarrow \mathbf{q} = \nabla^2\vec{\Psi} + A\vec{\Psi}$$

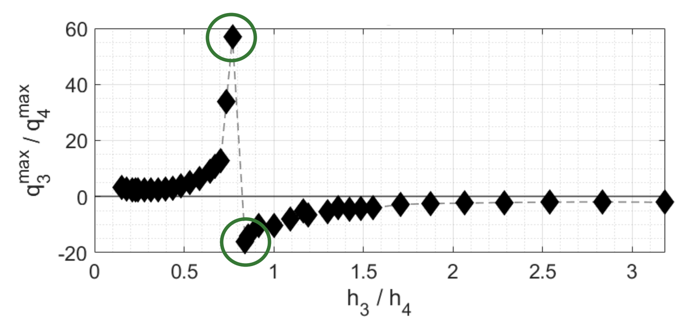
$$\frac{\partial q}{\partial t} + J(\Psi, q) = 0$$

$$A = f^2\begin{pmatrix} -\frac{\rho_1/\rho_0}{h_1 g'_1} & \frac{1}{h_1 g'_1} & 0 & 0 \\ \frac{1}{h_2 g'_2} & -\frac{2}{h_2 g'_2} & \frac{1}{h_2 g'_2} & 0 \\ 0 & \frac{1}{h_3 g'_3} & -\frac{2}{h_3 g'_3} & \frac{1}{h_3 g'_3} \\ 0 & 0 & \frac{1}{h_4 g'_4} & -\frac{1}{h_4 g'_4} \end{pmatrix}$$

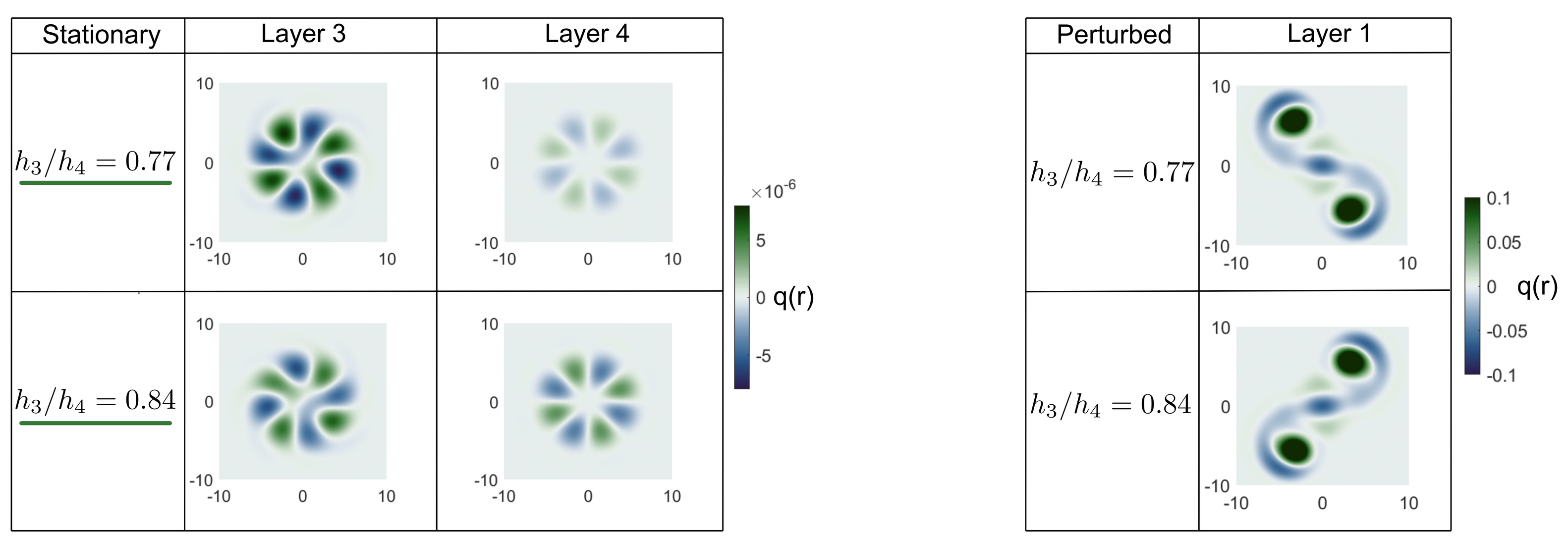
Assumptions:

- discretization in z
- free surface
- rigid bottom
- long-time parametrization



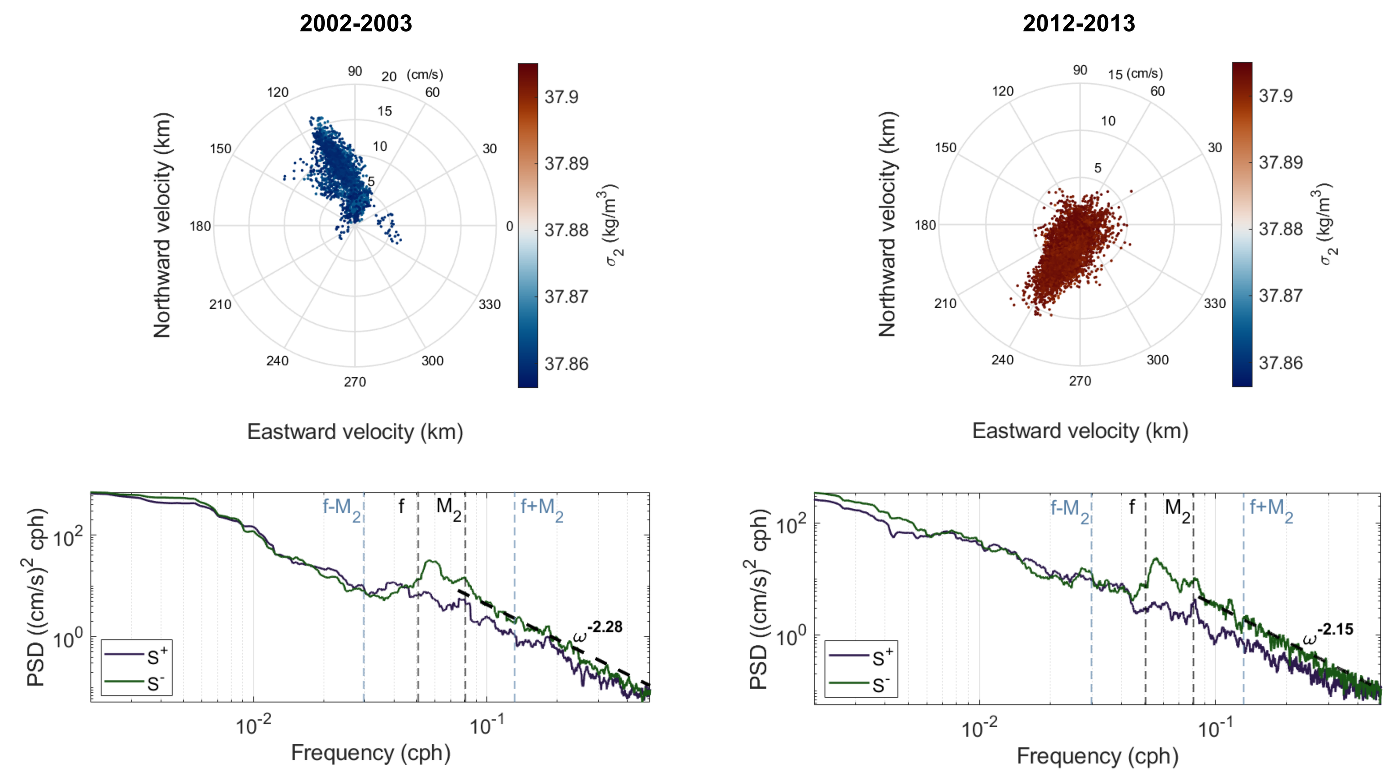


As the relative thickness of the 3rd and 4th layers changes there is a sort of phase transition for a critical ratio, where **the rotation direction inverts**. Moreover, when adding a perturbation, the direction inversion involves also the 1st layer.



Seafloor Observatory Time Series

Data collected 10 years apart by NEMO-SN1 show a **current's direction inversion and a drastic change in the thermohaline properties** of the bottom waters. The currents' rotary spectra analysis revealed both **tidal and near-inertial peaks**, which hint at the presence of a local vorticity that can be connected to many processes [4]. The decadal change in the thermohaline properties of the bottom layers can impact the properties, propagation, and interactions of near-inertial waves with internal tides.



Conclusions

Through the **integration of diverse approaches**, we were able to identify some of the factors influencing the deep dynamics in the Ionian Sea. Our observations revealed that **abyssal stratification significantly influences deep dynamic processes**. Long time series from the seafloor observatory underscored the complex dynamics of the bottom layer, allowing us to identify **significant changes in the thermohaline structure and current properties** of the Ionian Sea abyss over a decade. The surface circulation also displays a current reversal in those years, as shown by satellite altimetry data, and we found **hints of a surface-bottom connection** in the Ionian Sea that goes beyond the typical 2-layer view. With our simplified quasi-geostrophic model, based on observations, we found that the **net effect of the long-term deep stratification variability is to reshape the structure of the mean circulation** and mass distributions for the whole water column. These findings suggest a **deeper connection between surface and abyssal processes**, enriching our comprehension of long-term Ionian Sea processes and offering potential insights into the broader context of global ocean dynamics.

References:

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