Short-term high-resolution physical-chemical-biological coupled observations on the inner shelf of the Northern Margin of the Gulf of Cadiz

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Context

What is the impact of current shifts on phytoplankton development ?

- **Where ?** Artificial reef in shallow inner-shelf waters (~20 m) - Northern Margin of the Gulf of Cadiz (NMGoC)
- **Scope ?** High-intensity observational experiment for 12 days during April 2022
- **Equipment - Datasets ?**
  Water column properties: Moored wave-powered vertical profiler - high-resolution **~120 profiles/h (2 Hz)**
  Current velocities : Acoustic Doppler Current Profiler (ADCP) - hourly means of 0.5 m cells
  Local wind : ERA5 Reanalysis Wind - hourly means
- **Observable conditions ?** Unprecedented description of the changing water column properties (temperature, salinity, dissolved oxygen, turbidity, and chlorophyll-a, Chl-a) with changing physical forcing

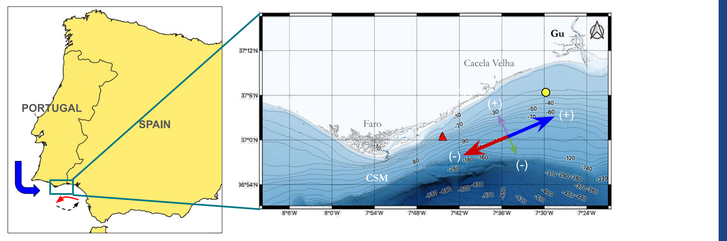

Fig. 1: Maps of the study area, southeast NMGoC, and location of the *in-situ* monitoring equipment: the ADCP (red triangle) and the vertical-profiler (yellow dot) at the artificial reef. The arrows represent the along-shore and cross-shore current color code displayed in Fig. 4. The black arrow (left map) shows cyclonic recirculation events east of CSM under low wind conditions. Key locations: Cape of St. Mary (CSM), Guadiana River (Gu), and the town of Cacela Velha.

In-situ observations: 3 distinct phases

(1) UPWELLING RELAXATION

- Intermittent stratification (Fig. 4,5):
  - reduction of dominant upwelled north-eastward current (0.2 m s^{-1} at surface, half the velocity at the surface compared to the upwelling flow)
  - vertical thermal gradient of up to 2.5 °C along the water column
- Along-shore wind relaxation (Fig. 3):
  - low intensity along-shore wind (< 5 m s^{-1})
- High phytoplankton concentration (Fig. 5,6):
  - increased residence time post-upwelling (before the observed period)
  → increased biological activity (3-4 mg m^{-3})

(2) UPWELLING:

- Physical and chemical signature (Fig.5):
  - for 5 days, seawater temperature drop (avg. 4°C)
  - salinity drop (avg. 0.8 g kg^{-1})
- Upwelling favourable winds (Fig. 3):
  - intensification of wind stress (4 to 12 m s^{-1})
- Low phytoplankton concentration (Fig. 5):
  - at its lowest (< 1.5 mg m^{-3}) - typical of upwelled waters in the area
- Increased flow velocity (Fig. 4):
  - highest intensity of the surface current (0.4 m s^{-1})
  - increased turbidity
  - well mixed water column

(3) DAY-LONG CURRENT INVERSION

- South-westward flow (Fig. 4):
  - inversion of the along-shore current
- High phytoplankton concentration (Fig. 2,6):
  - high spring seasonal levels of Chl-a (3-4 mg m^{-3})
  - independent of vertical stratification

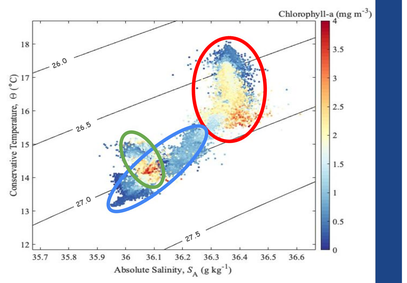

Fig. 2: T-S-Chl-a diagram of the vertical profiler deployment (14-26 April 2022). Three dotted ellipses show the water masses and chlorophyll-a concentration during different oceanographic events: upwelling relaxation (red), upwelling (blue), and current inversion (green).
The black lines represent the isopycnic lines expressed in g cm^3 -1000.

High-resolution time series

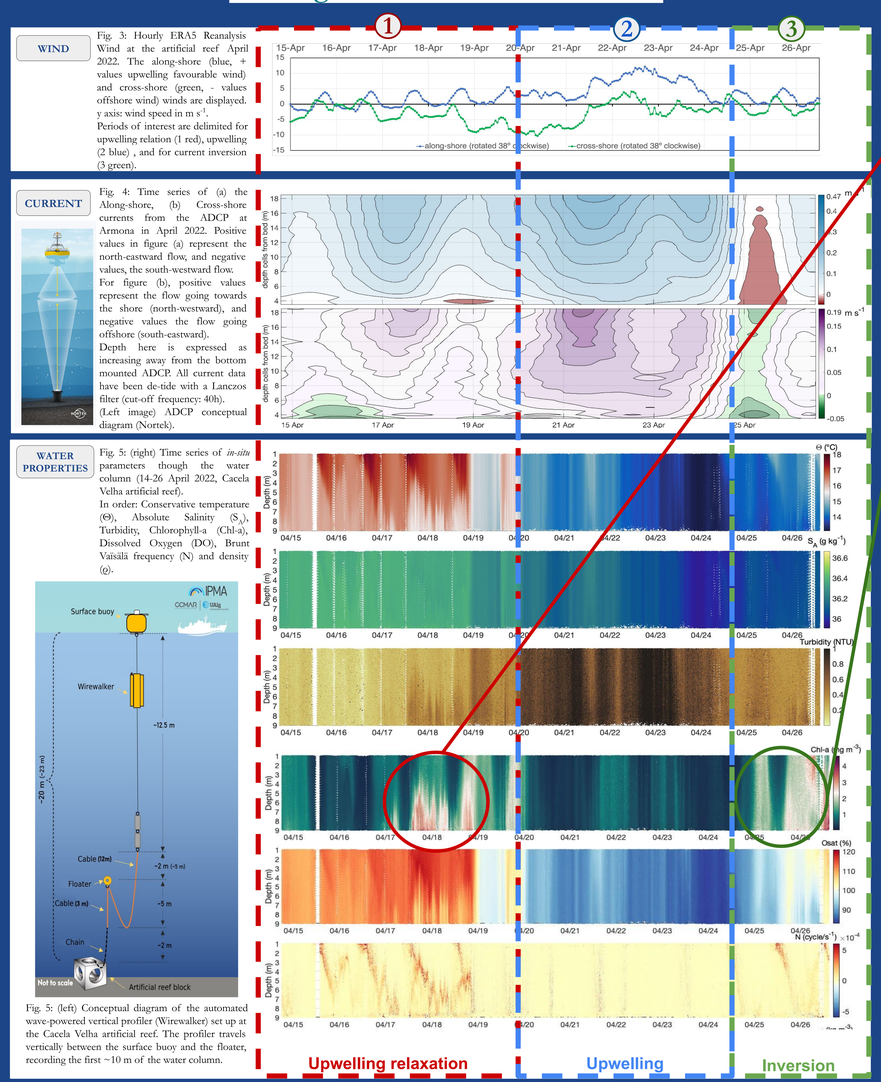

Fig. 3: Hourly ERA5 Reanalysis Wind at the artificial reef April 2022. The along-shore (blue, + values upwelling favourable wind) and cross-shore (green, - values offshore wind) winds are displayed. y axis: wind speed in m s^{-1}.
Periods of interest are delimited for upwelling relation (1 red), upwelling (2 blue) , and for current inversion (3 green).

Fig. 4: Time series of (a) the Along-shore, (b) Cross-shore currents from the ADCP at Armona in April 2022. Positive values in figure (a) represent the north-eastward flow, and negative values, the south-westward flow.
For figure (b), positive values represent the flow going towards the shore (north-westward), and negative values the flow going offshore (south-eastward).
Depth here is expressed as increasing away from the bottom mounted ADCP. All current data have been de-tide with a Lanczos filter (cut-off frequency: 40h).
(Left image) ADCP conceptual diagram (Nortek).

Fig. 5: (right) Time series of *in-situ* parameters though the water column (14-26 April 2022, Cacela Velha artificial reef).
In order: Conservative temperature (Θ), Absolute Salinity (S_A), Turbidity, Chlorophyll-a (Chl-a), Dissolved Oxygen (DO), Brunt Vaisälä frequency (N) and density (ϱ).

Fig. 5: (left) Conceptual diagram of the automated wave-powered vertical profiler (Wirewalker) set up at the Cacela Velha artificial reef. The profiler travels vertically between the surface buoy and the floater, recording the first ~10 m of the water column.

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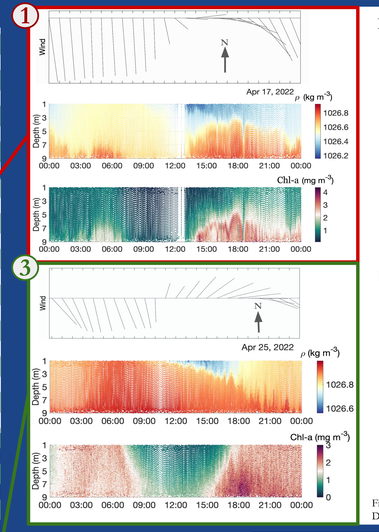
Zoom in



Biological activity during **upwelling relaxation** (Fig. 6 top)

- Localised phytoplankton growth:
  - increased phytoplankton biomass (4 mg m^{-3}) underneath the warmer strata in the morning and late-afternoon/evening times
  - surging from deeper as midday irradiance weakened : following the depth of the pycnocline
- Cross-shelf mixing:
  - upwelling favourable winds (broadly south-westeries) reduced
  - afternoon land-breeze : enhancing cross-shelf mixing
- Dissolved oxygen supersaturation:
  - photosynthesis by phytoplankton resulting in supersaturation of oxygen (110-120%)

Biological activity during **current inversion** (Fig. 6 bottom)

- Phytoplankton advection from retention area:
  - only during the current inversion (south-westward)
  → concentrations homogeneously mixed in the water column
  - suggesting the advection of phytoplankton-rich waters from the retention "shadow" area in the vicinity of the Guadiana River (see Fig.1)
- Midday low phytoplankton levels:
  - strong midday irradiance inhibiting phytoplankton development : systematic concentration drop from morning to midday, increase only after 3 pm.

Fig. 6: Daily time series at the Cacela Velha reef of hourly local wind (ERA5 Reanalysis); water column Density (ϱ) and Chlorophyll-a (Chl-a): (1) during upwelling relaxation, and (3) during current inversion.

Conclusion

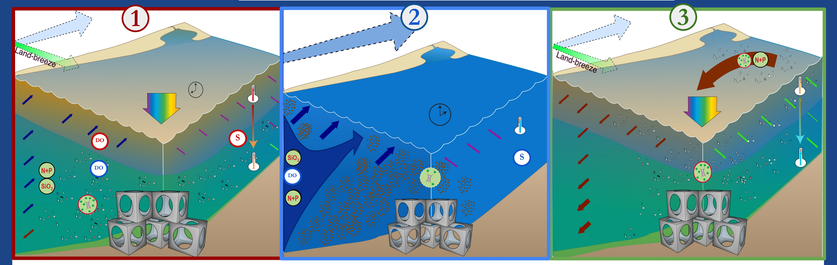


Fig. 7: Conceptual diagrams of the 3 observed phases during the vertical profiler deployment (14-26 April 2022) at the Cacela Velha artificial reef: (1) upwelling relaxation, (2) upwelling, and (3) current inversion.

Legend

- Upwelling favourable winds
- Currents: along-shore (blue/ red) cross-shore (green/ purple)
- Temperature gradient
- Higher/ lower salinity
- Higher/ lower residence time
- Higher turbidity
- Higher/ lower phytoplankton
- High nutrients concentration
- Supersaturation/ subsaturation of dissolved oxygen

- Upwelling may be an important source of nutrients enabling phytoplankton development, but rapid dynamic changes in biomass leave open speculation on the importance of current relaxation and longer residence time.
- Both enhanced thermal stratification and water column stability favoured phytoplankton growth.
- Diurnal local wind shifts played a role in cross-shelf mixing and the advection of near-shore and mid-shelf communities.

These data demonstrate the importance of high-resolution observational systems in productive coastal areas, contributing to better understanding the processes involved (Fig.7).