

Investigating ocean acidification off the Iberian Margin: Oceanographic results from the CARBO-ACID cruise

Investigação da acidificação dos oceanos ao longo da Margem Ibérica: Resultados oceanográficos da campanha CARBO-ACID

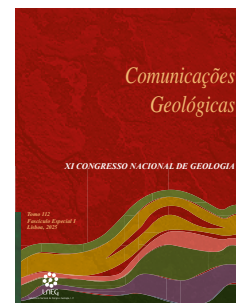
E. Salgueiro^{1,2*}, V. Magalhães^{1,3}, L. Matos^{1,2}, A. Rebotim^{1,2}, F. Sousa⁴, M. Schweizer⁵,
M. González Martín⁶, A. Mega^{1,2,7}, L. Batista¹, and on-shore team

DOI: <https://doi.org/10.34637/Sat1-cr63>

Recebido em 02/10/2023 / Aceite em 01/03/2024

Publicado online em abril de 2025

© 2025 LNEG – Laboratório Nacional de Energia e Geologia IP



Artigo original
Original article

Abstract: The EUROFLEETS+ CARBO-ACID cruise was carried out to investigate the ocean acidification effects on the carbonate organisms (coccolithophores, pteropods, foraminifera, and corals) along the W Iberian Margin. Samples of the water column, plankton, corals and sediments were collected to investigate the acidification effects since the pre-industrial Era until the present. These samples will allow not only to reconstruct the pH variability under different environmental conditions, but also to estimate the biogeochemical changes along the oceanic coastal waters as the anthropogenic influence increases. The obtained results will contribute to better understand and model the biological response to the expected ocean temperature and pH changes in the future. This work aims to document the type of samples collected, the planned analyses strategy and to show the first oceanographic obtained results in the study area.

Keywords: Coastal upwelling, acidification, carbonated organisms, temperature, (paleo) oceanography

Resumo: Para investigar os potenciais efeitos da acidificação nos organismos carbonatados (coccolitóforos, pterópodes, foraminíferos planctónicos e béticos, e corais) ao longo da margem Ibérica, realizou-se a Campanha Oceanográfica CARBO-ACID, financiada pelo programa EUROFLEETS+. Nessa campanha foram recolhidas amostras da coluna de água, plâncton, corais e sedimentos para avaliar os efeitos da acidificação em toda a coluna de água desde a Era pré-industrial até ao Presente. As amostras recolhidas permitirão comparar as variações de pH da água sob diferentes condições ambientais e estimar a amplitude das mudanças biogeoquímicas no oceano costeiro, à medida que a influência antropogénica aumenta. Os resultados obtidos irão contribuir para melhorar a modelação da resposta da biota às alterações da temperatura e do pH esperadas no oceano num futuro próximo. Pretende-se neste trabalho divulgar o tipo de amostras colhidas, as análises planeadas e os primeiros resultados oceanográficos obtidos na área em estudo.

Palavras-chave: Afloramento costeiro, acidificação, organismos carbonatados, temperatura, (paleo) oceanografia

⁵ LPG-BIAF UMR CNRS 6112, University of Angers, 2 Boulevard Lavoisier, 49045 Angers Cedex 01, France

⁶ Department of Geology, University of Salamanca, 37008 Salamanca, Spain.

⁷ Institut de Ciències del Mar, Pg. Marítim de la Barceloneta 37, 08003 Barcelona, Spain.

#On-Shore Team:

F. Abrantes (IPMA, CCMAR, Portugal); V. Brotas (MARE, ARNET, DEGGE, Ciências_ULisboa-, Portugal); C.G. Castro (IIM-CSIC, Vigo, Spain); E. Douville (L.SCE, France); J-A. Flores (Salamanca Univ., Spain); M. Frojan (IIM-CSIC, Vigo, Spain); M. Fontela (CCMAR, Portugal –Vigo Univ., Spain); N. Frank (Heidelberg Univ., Germany); F. Mienis (NIOZ, Netherlands); E. Moe (ITQB, Portugal); P. Oliveira (IPMA, Portugal); C. Roque (IDL/EMEPC); H. de Stigter (NIOZ, Netherlands); A. Tracana (MARE, ARNET, DEGGE, Ciências_ULisboa-, Portugal)

*Corresponding author / Autor correspondente: emilia.salgueiro@ipma.pt

1. Introduction

Since the pre-industrial Era, atmospheric carbon dioxide (CO₂) concentrations increased from 280 parts per million vol. (ppmv) to more than 418 ppmv (Dlugokencky and Tans, 2023), reaching the highest concentration experienced on Earth for the last 800 thousand years (Lüthi *et al.*, 2008). If global CO₂ emissions continue to increase at the same rate as in the 2006-2015 period, atmospheric and oceanic temperatures will increase along with CO₂, and the pH of the ocean will decrease by ~0.3 pH units by the end of this century (Bindoff *et al.*, 2019). At the coastal upwelling regions, the ocean acidification can regionally be amplified by the combination of higher CO₂ concentrations in the upwelled waters with high rates of primary production and respiration which strongly control seawater carbonate chemistry (*e.g.* Feely *et al.*, 2008). This scenario can regionally potentiate dramatic impacts, some of which already observed in the marine biota, especially in calcifying organisms, *e.g.* diversity loss and reduction of the calcification rate (*e.g.* Bijma *et al.*, 2013).

To investigate the evolution of ocean acidification along the Iberian coastal upwelling system and evaluate its impact on carbonated organisms (coccolithophores, pteropods, planktonic and benthic foraminifera, and corals), the research cruise CARBO-ACID (EUROFLEETS+) was carried out, between the 2nd and 11th August 2022, onboard of the RV Ramón Margalef (Salgueiro *et al.*, 2022). In this work we present the data and samples collected during this cruise, the planned analyses, and the discussion of the first oceanographic results.

¹ Instituto Português do Mar e da Atmosfera, I.P. (IPMA, IP), Av. Alfredo Magalhães Ramalho 6, 1495-165 Alge, Portugal.

² Centro de Ciências do Mar do Algarve (CCMAR), Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal.

³ Instituto Dom Luís, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal.

⁴ MARE/ARNET (Centro de Ciências do Mar e do Ambiente/Aquatic Research Network), Ciências_ULisboa & Departamento de Engenharia Geográfica, Geofísica e Energia (DEGGE), Ciências_ULisboa, 1749-016 Lisboa, Portugal.

2. Methodology

Sampling was conducted in seven stations along two transects off the Iberian margin (Figura 1): four stations in the northern transect between 42°30' and 42°50' N (W - E: CA3, CA2, CA7, CA8), under the influence of the Cape Finisterra upwelling filament; and three stations (W - E: CA6, CA5, CA4) in a southern transect between 38°30' and 39°10' N, under the influence of the Cape Roca upwelling filament. Nearby each station and during the transects, whenever possible, a multibeam survey (bathymetry and backscatter) was run, providing important information about the seafloor characterization prior to the seabed sampling operations. During this cruise, 237.6 nautical miles of multibeam survey were acquired, corresponding to a total area of 673.1 km² of seafloor coverage. Each station started with a CTD-Rosette cast that allowed recording several parameters (pressure, temperature, conductivity, oxygen, fluorescence, and turbidity) to characterize the water column and to collect seawater samples at specific depth levels. The CTD data were used to calculate the water depth, potential temperature (θ), salinity and sigma-theta (density), allowing to characterize the upper layer, the seasonal thermocline, fluorescence maximum, and identify the different water masses. The Rosette water samples were subsampled onboard, preserved in cold conditions or with chemicals and/or filtered for several further analysis in the shore-based laboratories: DNA, chlorophyll, phytoplankton, coccolithophores, pH, alkalinity, stable isotopic composition, trace elements' concentration and suspended particulate matter. Subsequently to these operations, at each station,

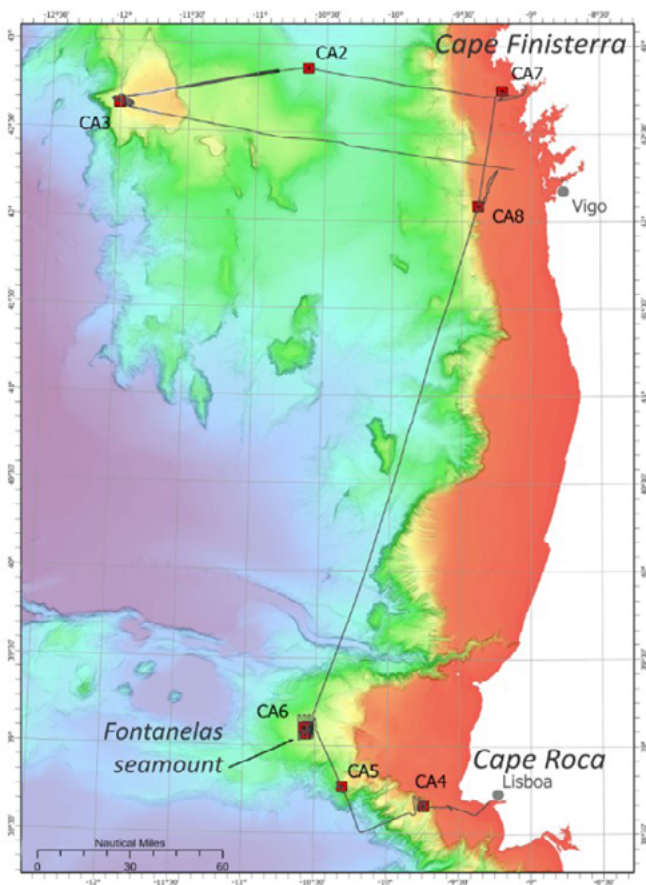


Figure 1. CARBO-ACID cruise track and stations.

Figura 1. Trajetória e estações efetuadas durante o cruzeiro CARBO-ACID.

two vertical tows were done on the top 700 m of the water column using a plankton multinet (with 5 nets) to sample zooplankton of five different pre-selected water layers, and confirmed based on the temperature, salinity, and fluorescence profiles obtained during the downcast. A total of fourteen vertical plankton tows allowed the collection of the live planktonic communities living at the different water depths and water masses. After this, seafloor sediments and cold-water coral samples were recovered with a box-corer and a shipek grab to study past oceanographic conditions applying a multiproxy paleoceanographic and sedimentological approach (Figura 2). A total of ten box-corer stations allowed the recovery of the top 11 to 60 cm of seafloor sediments to establish the paleoceanographic conditions between the pre-industrial Era and the Present, according to the regional sedimentation rate (*e.g.* Jouanneau *et al.*, 2002). Fifteen shipek grab samples were additionally collected at the Fontanelas seamount (station CA6) to characterize the sedimentary cover and to collect cold-water corals.

3. Results

Stations CA7, CA8, and CA4, located closer to the coast (Figura 1), show colder surface waters and higher values of fluorescence. At station CA4, near Cape Roca, the temperature was higher, and the fluorescence showed lower values than the stations up in the North. The CTD profiles and the potential temperature-salinity (θ/S) diagrams (Figura 3) allowed to identify the upper layer and the main water masses present in the Iberian coastal ocean. In the upper layer, the seasonal thermocline and the fluorescence maximum were identified between 25 m (station closest to the coast, CA7) and 175 m (deep stations *e.g.* CA3). The presence of the Eastern North Atlantic Central Water with subtropical (ENACWst: 18.50°C; 36.75) and subpolar origin (ENACWsp: 10.00°C; 35.40) (Figura 3) was detected between 175 m and 400 m water depth. Below 400 m, and until ~1200-1400 m, the influence of the warm, salty, and low oxygen Mediterranean Outflow Water (MOW) was observed. In the deeper layers of station CA2 (the deepest one sampled at Cape Finisterra transect), the Labrador Sea Water (LSW) and the North Atlantic Deep Water (NADW) were detected in the CTD data through the temperature and salinity decrease (Figura 3) and an oxygen increase.

Seafloor sediment samples showed significant differences between the stations. Along the northern transect (Cape Finisterra), the seafloor sediments showed an increase in grain size from offshore towards the coast. The offshore stations CA3 and CA2 revealed finer grained sediments; CA8 was composed of coarser sand; while the sediment at station CA7, the shallowest station (77 m depth), was mainly composed of shell fragments and coarse grain sand. Along the southern transect (Cape Roca), the offshore station CA6 (Fontanelas seamount) had coarser sandy sediments with rock clasts and cold-water coral fragments, while the stations CA5 and CA4 revealed fine sand to muddy sediments.

4. Discussion

The coastal stations, CA7, CA8, and CA4 were the most influenced by coastal upwelling, showing, colder surface water and higher values of fluorescence, reflecting higher phytoplankton concentrations, as typical under upwelling conditions. At station CA4, close to Cape Roca, the less cold and productive waters, suggest less persistent upwelling filament or/ and different upwelling source waters from those upwelled further north.

The Cape Roca stations (green in Figura 3) show stronger influence of the ENACWst, while the ones at Cape Finisterra (blue in Figura 3) are more influenced by the ENACWsp. The ENACW presented in this study show thermohaline properties shifted to the left of the

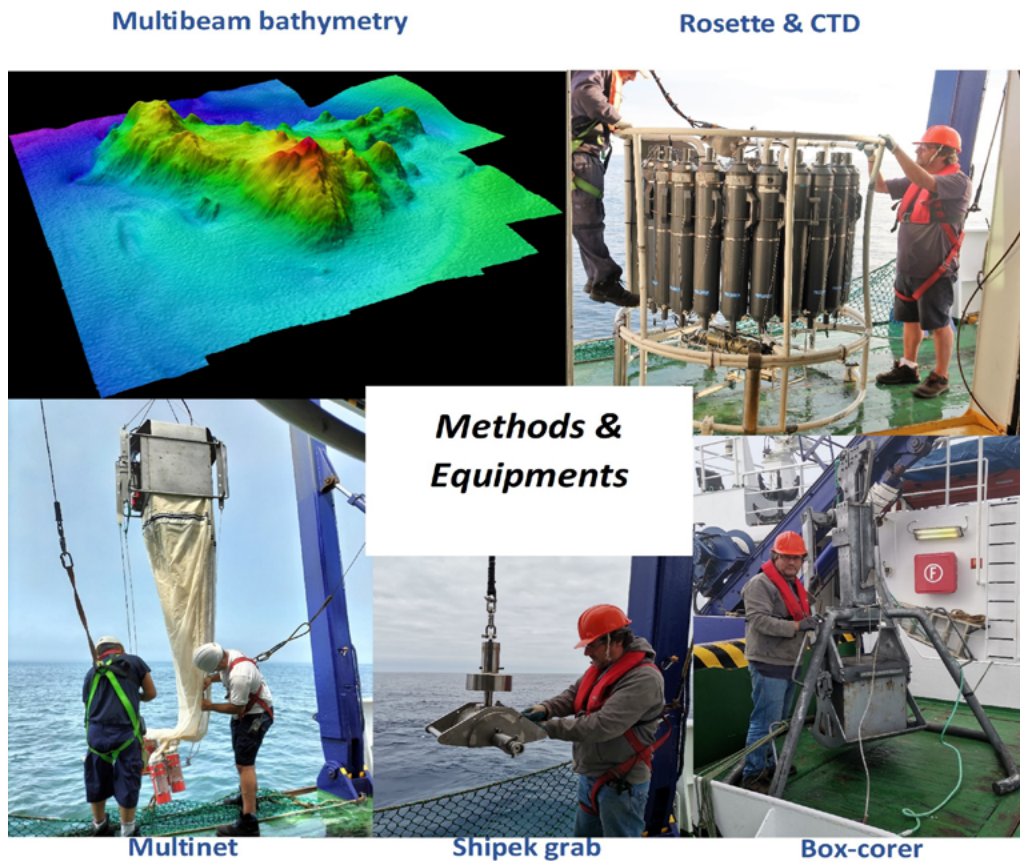


Figure 2. Methods and sampling gears.

Figura 2. Métodos e equipamentos de amostragem.

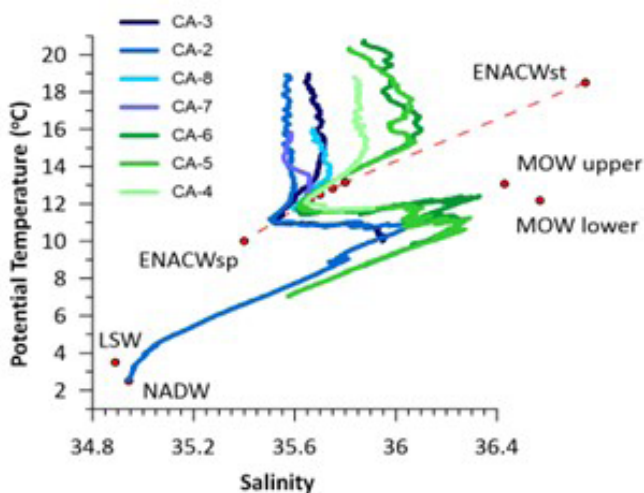


Figure 3. Potential temperature-salinity (θ/S) diagrams of the 7 CTD stations conducted during the cruise. Presence of the Eastern North Atlantic Central Water subtropical (ENACWst) and subpolar (ENACWsp) branches; Mediterranean Outflow Water (MOW); Labrador Sea Water (LSW), and the North Atlantic Deep Water (NADW). The ENACW reference curve is shown in red (Fiúza, 1984).

Figura 3. Diagramas Temperatura potencial – Salinidade (θ/S) das 7 estações de CTD realizadas durante a campanha. Identifica-se a presença da Eastern North Atlantic Central Water ramos subtropical (ENACWst) e subpolar (ENACWsp); Mediterranean Outflow Water (MOW); Labrador Sea Water (LSW), e a North Atlantic Deep Water (NADW). A curva de referência da ENACW está representada a vermelho (Fiúza, 1984).

Fiúza’s (1984) reference curve. This happens for the first time after the analysis of 60 years (1955-2016) of hydrological profiles, collected in the Iberian coastal ocean (Valente *et al.*, 2019), where a tendency for θ/S points be shifted to the right of the reference curve was observed for a couple of times. The MOW at station CA2 has its maximum in salinity at ~1000 m, showing a good agreement with the data collected by Prieto *et al.* (2013), offshore Cape Finisterra. In the southern station CA5, the presence of the two cores of MOW is very clear: the upper core centred at ~800 m and the lower core centred at ~1200 m (Figura 3). Both deep waters, LSW and NADW, were only observed at station CA2 (the deepest one) with the LSW present until 1900 m, and then the influence of the NADW. Below the layers of MOW, station CA5 (along Cape Roca transect), also shows a tendency to follow the slope of the LSW (Figura 3).

All the other bio-geochemical, sedimentological and micropaleontological analysis are still ongoing.

5. Conclusion

The Cape Roca transect is more influenced by the ENACWst, while the Cape Finisterra transect is more influenced by the ENACWsp. At both transects, this central water mass is shifted to the left of the reference curve, indicating differences in temperatures and/or salinities relative to the Fiúza’s (1984) ENACW reference curve. Furthermore (paleo)oceanographic, geochemical, sedimentological and micropaleontological analysis are in progress to understand if the observed changes in temperature and/or salinity are an effect of climate change and/ or changes in the Iberian upwelling conditions.

Acknowledgments

The CARBO-ACID cruise was funded by the Eurofleets+ project. This project has received funding from the EU H2020 research and innovation programme under Grant Agreement No 824077. We thank the captain and crew of RV Ramón Margalef for their cooperation and help during the cruise. We also thank the UTM-CSIC technicians by their professional work on-board. The analysis are supported by several projects: FCT-CCMAR funding UIDB/04326/2020, MIT-EXPL/SOE/0024/2019, 2022.05765.PTDC, and EXPL/CTA-GEO/1518/2021. Fátima Sousa had the support of national funds through Fundação para a Ciência e Tecnologia, I. P (FCT), under the projects UIDB/04292/2020, UIDP/04292/2020, granted to MARE, and LA/P/0069/2020, granted to the Associate Laboratory ARNET.

References

- Bijma, J., Pörtner, H.-O., Yesson, C., Rogers, A.D., 2013. Climate change and the oceans - what does the future hold? *Marine Pollution Bulletin*, **74**: 495-505.
- Bindoff, N. L. and co-authors, 2019. Changing Ocean, Marine Ecosystems, and Dependent Communities. In: Pörtner, H.-O. *et al.* (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Cambridge University Press, New York.
- Dlugokencky, E., Tans, P., 2023. Trends in Atmospheric Carbon Dioxide. National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL), available at: <http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>
- Feely, R.A., Sabine, C.L., Hernandez-Ayon, J.M., 2008. Evidence for Upwelling of Corrosive “Acidified” Water onto the Continental Shelf. *Science*, **320**: 1490-1492.
- Fiúza, A.F.G., 1984. Hidrologia e dinâmica das águas costeiras de Portugal. Ph.D. thesis. Universidade de Lisboa, Portugal.
- Jouanneau, J.M., Weber, O., Drago, T., Rodrigues, A., Oliveira, A., Dias, J.M.A., Garcia, C., Schmidt S., Reyss, J.L., 2002. Recent sedimentation and sedimentary budgets on the western Iberian shelf. *Progress in Oceanography*, **52** (2-4): 261-275.
- Lüthi, D. and co-authors, 2008. High-resolution carbon dioxide concentration record 650,000-800,000 years before present. *Nature*, **453**: 379-382. doi:10.1038/nature06949.
- Prieto, E., González-Pola, C., Lavín, A., Sánchez, R.F., Ruiz-Villarreal, M., 2013. Seasonality of intermediate waters hydrography west of the Iberian Peninsula from an 8 year semiannual time series of an oceanographic section. *Ocean Sci.*, **9**: 411–429. <https://doi.org/10.5194/os-9-411-2013>.
- Salgueiro, E., Magalhães, V., Matos, L., Rebotim, A., Schweizer, M., Sousa, F., González, M.M., Batista, L., 2022. Eurofleets+ Cruise Report CARBO-ACID RV Ramón Margalef, SEA02_10, 02.08.2022 - 11.08.2022, Vigo (Spain) - Lisbon (Portugal)
- Valente, A., Sousa, F., Dias, J., 2019. Decadal changes in temperature and salinity of Central Waters off Western Iberia. *Deep Sea Research Part I: Oceanographic Research Papers*, **151**: 103068. <https://doi.org/10.1016/j.dsr.2019.103068>.