

M2 SOAC : Fiche de stage de recherche en laboratoire

Laboratoire : Centre National de Recherches Météorologiques (Météo-France / CNRS)

Titre du stage : Characterizing Mediterranean coastal upwelling and its evolution under climate change

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Sujet du stage :

Coastal upwelling is a key oceanographic process through which subsurface waters, typically colder and richer in nutrients than surface waters, are brought toward the surface (Bakun, 1990), strongly influencing coastal hydrography, biogeochemistry and marine ecosystems. Although the Mediterranean Sea does not host large and persistent upwelling systems comparable to the major Eastern Boundary Upwelling Systems, upwelling occurs locally along several Mediterranean coastal regions. These events can substantially modify coastal environmental conditions and may therefore have important implications for marine ecosystems and socio-economic activities such as fisheries, aquaculture and tourism.

Upwelling can be characterized using different indicators based on the physical processes and oceanic responses associated with its development. These include, among others, indicators derived from sea surface temperature, wind-driven offshore transport, ocean currents or the characteristics of the ocean mixed layer (e.g. Benazzouz et al., 2014; Jacox et al., 2018). However, these indicators describe complementary aspects of the upwelling process and may respond differently depending on the regional oceanographic setting. Their ability to characterize Mediterranean coastal upwelling, as well as their consistency across observational products and climate models, remains to be systematically assessed.

The main objective of this internship will be to identify and evaluate physical indicators of coastal upwelling in the Mediterranean Sea and to investigate how this process may evolve under climate change. A literature review will first be conducted to identify a limited set of complementary upwelling indicators representing different physical mechanisms or responses. These indicators will then be implemented using reanalysis products to characterize the spatial distribution, seasonality, frequency and intensity of present-day Mediterranean coastal upwelling. Where suitable observations are available, satellite data will also be used at selected coastal locations to characterize upwelling events and evaluate the ability of the different indicators to represent their temporal variability and intensity.

In a second step, the selected indicators will be applied to regional climate system model simulations from the Med-CORDEX initiative (Ruti et al., 2016). Their ability to reproduce the main spatial and temporal characteristics identified for the present climate will be assessed. The most robust indicators will subsequently be used to investigate the future evolution of Mediterranean coastal upwelling at different global warming levels, from +1.5°C to +4°C. This analysis will allow us to determine whether changes in coastal upwelling emerge with increasing global warming and, when they do, to identify the regions most affected, the direction of these changes and their magnitude.

Skills required:

- Interest in physical oceanography and climate science
- Basic knowledge of Python and scientific data analysis
- Ability to work collaboratively
- Scientific curiosity, autonomy and initiative

References:

- Bakun, A. (1990). Global climate change and intensification of coastal ocean upwelling. *Science*, 247, 198–201. <https://doi.org/10.1126/science.247.4939.198>
- Benazzouz, A., Mordane, S., Orbi, A., Chagdali, M., Hilmi, K., Atillah, A., Pelegrí, J. L., & Hervé, D. (2014). An improved coastal upwelling index from sea surface temperature using satellite-based approach – The case of the Canary Current upwelling system. *Continental Shelf Research*, 81, 38–54. <https://doi.org/10.1016/j.csr.2014.03.012>
- Jacox, M. G., Edwards, C. A., Hazen, E. L., & Bograd, S. J. (2018). Coastal upwelling revisited: Ekman, Bakun, and improved upwelling indices for the U.S. West Coast. *Journal of Geophysical Research: Oceans*, 123, 7332–7350. <https://doi.org/10.1029/2018JC014187>
- Ruti, P. M., et al. (2016). MED-CORDEX initiative for Mediterranean climate studies. *Bulletin of the American Meteorological Society*, 97, 1187–1208. <https://doi.org/10.1175/BAMS-D-14-00176.1>