Statistical description of sporadic upwelling events along French Mediterranean coastlines

Context
A growing societal demand concerns the development of simple environmental indicators to inform both the public and the decision makers on the status and health of coastal zones, where anthropogenic pressures and activities are concentrated. This need concerns, among other, the biogeochemical and physical properties of seawater (exemplified here by sea water temperature, nutrient and phytoplankton concentrations) in the coastal ocean as they are known to exhibit strong variability at high frequency and small spatial scales. Indeed, sporadic physical processes forced by winds are known to strongly influence the temperature and nutrient loads of the coastal ocean by creating horizontal and vertical movements of cold nutrient-rich subsurface waters (Bakun, 1973; Rossi et al. 2014).

This process, called “coastal upwelling”, is due to the friction of winds on the ocean surface which drags the upper 10-100m of the water column (Ekman layer) with it. Due to the Coriolis effect, surface waters are pushed away at a 45° angle from the direction of the surface winds while subsurface waters deviate further (Ekman spiral). Overall, it creates a net transport integrated over the Ekman layer that is perpendicular to the wind direction. In the northern hemisphere and considering alongshore winds (e.g. parallel to the coastline) blowing toward the equator, the Ekman layer moves offshore creating coastal divergence. Cold water then rises up from beneath the surface to replace this surface layer that was pushed away. The reverse process, called “downwelling,” also occurs when wind causes surface warm water to build up along a coastline (that is, in the northern hemisphere, for alongshore winds blowing toward the pole) and eventually sinks toward the bottom. While wind is the main forcing mechanism, other physical mechanisms, such as stratification and geostrophic currents, may also reinforce or dampen the upwelling signal (Marchesiello and Estrade, 2010; Taupier-Letage et al. 2013; Rossi et al. 2016).

Eastern-boundary upwelling systems are spatially-extended (several thousands of kilometers) and under permanent upwelling-favorable wind forcing, constituting the most biologically productive regions of the world ocean (Pauly and Christensen 1995; Rossi et al. 2009). In contrast, sporadic coastal upwelling events, such as those occurring in the Mediterranean Sea, concern restricted portions of coastline and are only intermittent in time. They occur occasionally at several locations; they have been documented in the Gulf of Lion forced by Mistral and Tramontane winds (Millot, 1979, Millot and Wald, 1980; Johns et al. 1992), in the Adriatic Sea forced by the Bora winds and in the Aegean Sea forced by the Etesian winds (Bakun and Agostini, 2001).

Recent work and observations suggest that those sporadic upwelling events, despite being short-living and spatially-limited, can occur more often and affect wider coastal regions than previously thought. They could be largely responsible of the high-frequency (at daily to weekly time-scales) variability of temperature, nutrients and plankton in the coastal ocean (Bensoussan et al. 2010; Rossi et al. 2014), having potential consequences for marine professional and leisure activities. They can also significantly modulate the local manifestations of marine heatwaves and of their deleterious ecological impacts (Garrabou et al. 2009). Last but not least, the repeated occurrence of such sporadic processes could have a non-negligible impacts for large-scale oceanic hydrography.
Robust information about the preferential occurrence of such sporadic upwelling events is still missing. Unknown characteristics include the time of the year and the portions of coastline that are concerned by such process, as well as the averaged events’ duration and their long-term evolution under climate change. Spatial extension, which has been studied in the past based only on a few events, needs to be revisited considering high-resolution datasets and a longer period of analysis.

Objectives & methods

This internship aims at developing simple indices to study the statistical occurrence of sporadic wind-driven physical processes along French Mediterranean shores. It will address the following questions:
- Which portion of coastlines are subjected to sporadic upwelling events and what are the required characteristics?
- When, how frequent and how long are these events? Is there a significant long-term trend in their manifestation?
- By comparing our upwelling indices against in-situ observations, can we ascertain that they are indeed capturing properly such occasional process and can we gain understanding of their spatial extend?

Focusing first on the physical forcing, we will develop wind-based upwelling indices by combining a bathymetric dataset with high-resolution gridded data of sea surface winds (measured by satellite or from atmospheric re-analyses such as ERA-INTERIM), validated by meteorological observations (on-land wind stations) when available. Sea Surface Height data will be exploited to estimate the large-scale geostrophic pressure gradients which may modulate coastal upwelling. To characterize the oceanic response, we will analyze remote-sensed oceanic datasets (e.g. Sea Surface Temperature SST), while multi-sensor in-situ observations will be used for validation purposes. We plan to analyze the statistical occurrence and the long-term trends of intermittent up- and down-welling events over the last few decades. Spatial analyses and validation procedures will focus on a few specific years (2012-2013) during which particularly intense upwelling events were already identified.

Temporal validation of upwelling index time-series will be conducted at a few locations (especially the “Côte Bleue” and the “Calanques” regions) by considering compiled in-situ data sets from national/regional observational networks. It includes nearshore in-situ temperature series (TMED-Net) and high-frequency information about plankton and temperature in Marseille bay (SSLAMM - Seawater Sensing Laboratory At MIO Marseille). To gain understanding on the spatial extension and the fate of upwelling plumes we will use horizontal transects of temperature (TRANSMED surface data) as well as satellite thermal imagery, using the high-resolution SST data available from the OSIS database over 2001-2017 (Taupier-Letage, 2008).

By evaluating the statistical occurrence of coastal upwelling events, which are associated with the uplift of cold and usually enriched waters supporting plankton blooms, this study contributes to the assessment of the hydrographic properties of the coastal ocean and its variability.

Supervision

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Informations pratiques :
Profil de l'étudiant(e) : bases en Océanographie physique ou Dynamique des fluides, intéressé(e) par la dynamique océanique à haute-fréquence, les processus côtiers et leurs impacts potentiels sur les activités humaines ; goût et compétence pour l’analyse de gros jeux de données (météorologiques et océanographiques) et pour les statistiques.

Maitrise d'un langage de programmation souhaitée (Matlab de préférence ; alternatives : R, Python).

Compétences acquises pendant le stage : réflexion et démarche scientifique, connaissances en océanographie physique côtière, programmation scientifique, intégration modèle-données, analyses de données ‘big data’ et statistiques.

Durée du stage : 6 mois (Janvier à Juin ou Mars à Aout 2020).

Lieu du stage : Institut Méditerranéen d'Océanologie (MIO), Luminy, 13288, Marseille.

Gratification : env. 550 euros/mois.

Bibliography: