

A new coastal upwelling index generated with surface current estimations from High-frequency radars

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Abstract – Coastal upwelling has been extensively studied as it plays a critical role in the connectivity between offshore waters and coastal ecosystems, which has impacts on water quality, fisheries, and aquaculture production. Significant efforts have been devoted to the quantification of the intensity, duration, and variability of this phenomenon by means of coastal upwelling indexes (CUIs), derived from wind, sea level pressure, or sea surface temperature data. Although valuable, first-order descriptors, such as classical indexes, have been reported to present some limitations. As one of the major shortcomings is the omission of the direct influence of ocean circulation, this work introduces a novel CUI, generated from remotely sensed hourly surface current observations provided by a high-frequency radar (HFR). The consistency of the proposed index (CUI-HFR) is assessed in two different oceanographic areas during two distinct time periods: in the north-western Iberian (NWI) peninsula for 2021 and in the Bay of Biscay (BOB) for 2014. To this aim, CUI-HFR is compared against a traditional CUI based on hourly wind observations (CUI-WIND) provided by two buoys. Results revealed that HFR-derived circulation maps can be effectively used for the characterization of recurring upwelling and downwelling episodes and the noticeable agreement between CUI-HFR and CUI-WIND.

Keywords – HF radar, remote-sensing, upwelling, downwelling.

I. INTRODUCTION

High Frequency radar (HFR) has become an essential component of ocean observatories as this shore-based remote sensing technology collect, in near-real time, fine-resolution maps of the upper-layer flow over broad coastal areas, providing a dynamical framework for other traditional in situ observation platforms.

HFR-derived surface circulation is a reliable source of information for search-and-rescue operations and oil spill tracking, among other practical applications [1-2]. Equally, it can be used for a detailed investigation of upwelling and downwelling processes that modulate the connectivity between offshore waters and coastal ecosystems, which eventually has impacts on water quality, fisheries, and aquaculture production [3-4]. It occurs when alongshore winds and the Coriolis effect (due to Earth's rotation) combine to drive a near-surface layer of water offshore, a process referred to as Ekman transport [5]. Such cross-shelf transport is compensated for by the vertical uplift of cold and enriched waters that fertilize the uppermost layer. Conversely, during downwelling events winds induce net onshore displacement and subduction of surface coastal waters that foster the retention of organic matter and pollutants onto the shoreline with a subsequent impact on residence times and water renewal mechanisms.

A variety of coastal upwelling indexes (CUIs) have been derived from historical estimations of diverse met-ocean parameters (e.g. wind, sea level pressure, or sea surface temperature) in order to indirectly quantify the intensity, duration, and variability of this phenomenon [6-7]. Despite being valuable first-order descriptors, such classical indexes have been reported to provide an incomplete picture of coastal upwelling due to a number of limitations, encompassing uncertainties related to the estimation of wind stress or derived from the coarse spatio-temporal resolution of the atmospheric pressure fields used.

As one of the major shortcomings is the omission of the direct influence of ocean circulation, the present work intends to fill this gap by introducing a novel CUI, generated from HFR-derived hourly surface current observations (CUI-HFR). The consistency of CUI-HFR is assessed in two different oceanographic areas during two distinct time periods: in the north-western Iberian (NWI) peninsula for 2021 and in the Bay of Biscay (BOB) for 2014 [8].

II. DATA

A five-site CODAR SeaSonde HFR network, deployed along the Galician-Portuguese coast since 2004, is jointly operated

by Puertos del Estado, INTECMAR–Xunta de Galicia, and the Portuguese Hydrographic Institute. While the southernmost HFR site operates at 13.5 MHz, the other four sites operate at a central frequency of 4.86 MHz, providing hourly radial vectors that are representative of the currents moving toward or away from the site. All radial current vectors (from two or several sites) within a predefined search radius of 25 km are geometrically combined to estimate hourly total current vectors on a Cartesian regular mesh of 6×6 km horizontal resolution and 200 km range, which are representative of the upper 2 m of the water column. Furthermore, a 2-site CODAR SeaSonde HFR-EuskoOS network (www.euskoos.eus), deployed in the south-eastern BOB since 2009 and owned by Euskalmet, operates at a central frequency of 4.46 MHz, providing hourly current maps (representative of the first 1.5 m of the water column) with a spatial resolution of 5 km in an area up to 150 km from the coast. Complementarily, two deep-ocean buoys, deployed within each HFR footprint and operated by Puertos del Estado, provide quality-controlled estimations of sea surface temperature, salinity, and currents, among other physical parameters. Both buoys are equipped with a wind sensor, providing hourly averaged wind vectors at 3 m height. Additionally, a Seaexplorer underwater glider, equipped with a profiling conductivity-temperature-depth (CTD) sensor which provides temperature, salinity and vertically integrated currents up to 200 m depth, was used to characterize an intense downwelling event in the BOB from September 23 to October 13, 2022. Finally, surface fields of temperature and chlorophyll provided by satellite missions were downloaded from the Copernicus Marine Service catalogue and used to analyse the impact of upwelling and downwelling events on their spatial distribution.

III. RESULTS

The proposed CUI-HFR is compared against a traditional index based on hourly wind observations (CUI-WIND) provided by two buoys moored within the HFR spatial coverage and data from a glider campaign (in the BOB). Likewise, the skill of CUI-HFR to identify upwelling and downwelling processes is also qualitatively evaluated. Results obtained in these two pilot areas revealed the following: (i) noticeable agreement between CUI-HFR and CUI-WIND, with correlation coefficients above 0.67; (ii) a proven ability of CUI-HFR to categorize a variety of upwelling and downwelling episodes, which highlights their potential applicability for direct upwelling monitoring over any coastal area of the global ocean; and (iii) a credible consistency of CUI-HFR patterns when compared with independent data such as satellite-derived maps of chlorophyll and sea surface temperature along with in situ data from a profiling glider.

IV. CONCLUSIONS

Results seem to suggest that the HFR performances were sound and credible for the two distinct periods and areas analysed, providing reliable surface current estimations that could be effectively used for coastal monitoring and the characterization of recurring upwelling and downwelling episodes. Future research endeavours should include the synergetic combination of HFRs and GLOBAL model products to implement a valuable long-term ocean monitoring indicator that might be used over any coastal area of the global ocean for wise decision-making to mitigate adverse effects of climate change.

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