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Why coastal upwelling is expected to increase along the western Iberian Peninsula over the next century?

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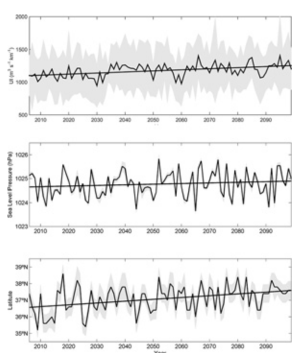
HIGHLIGHTS

- Comprehensive assessment of coastal upwelling using EURO-CORDEX simulations
- Projections suggest an intensification of coastal upwelling.
- The Azores High will drift northeastward and intensify during the 21st century.

GRAPHICAL ABSTRACT



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ABSTRACT

Former studies about coastal upwelling along the Western Iberian Peninsula (WIP) using historical data indicated contradictory results, showing either its strengthening or reduction, while previous studies using Global Climate Models (GCMs) indicated that global warming is likely to intensify this phenomenon although predicting different rates and not justifying the patterns found. Taking advantage of the recent high spatial resolution Regional Climate Models (RCMs) projections from EURO-CORDEX project (Representative Concentration Pathway, RCP 8.5), detailed higher accuracy estimations of the spatio-temporal trends of Upwelling Index (UI) along the WIP coast were performed in this study, integrating the coastal mesoscale effects within the framework of climate change. Additionally, this research brings new insights about the origin of the WIP coastal upwelling intensification over the next century. These new projections clarified the upwelling strengthening rates predicted along the coast of the WIP from 2006 to 2099 revealing more prominent changes in the northern limit of the region (25–30 $m^3\ s^{-1}\ km^{-1}$ per decade between 41.5 and 42.5°N). Trends observed at high latitudes of the region were found to be induced by the displacement of the Azores High, which will intensify (0.03 hPa per decade) and drift northeastward (10 km per decade) during the 21st century.

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1. Introduction

Coastal upwelling is of large economic importance and accounts for ~20% of wild marine capture fisheries, although the regions where this phenomenon is found represent only ~2% of the global oceans area (Pauly and Christensen, 1995). Therefore, coastal upwelling systems have been extensively studied over the last decades, especially considering the spatial and temporal upwelling changes. Early studies by Bakun (1990) hypothesized that global warming could intensify alongshore wind stress and related upwelling in coastal areas. Since the hypothesis of Bakun, several studies focused on different upwelling regions have been conducted to investigate this premise. Numerous of these researched changes on upwelling trends worldwide based on historical wind data, and some suggested a weakening in upwelling intensity contrary to the hypothesis of Bakun (1990). However, these studies revealed a high dependence on the selected region, the season analyzed, the length of the data used and also the database (Bakun et al., 2015; Barton et al., 2013; Garcia-Reyes and Largier, 2010; Gutierrez et al., 2011; Sydeman et al., 2014; Varela et al., 2015). In fact, a recent study by Sydeman et al. (2014) based on the analysis of several works published over the last two decades about upwelling trends over the most important upwelling ecosystems found contradictory results and confirmed these dependences.

The WIP is located in the northern margin of the Canary Upwelling System (Wooster et al., 1976), where alongshore winds interact with coastal topography to generate downwelling-upwelling processes. Coastal upwelling along this area shows a seasonal cycle extending from spring to early autumn, which was found related with the Azores High. This tends to migrate northward in spring and summer, resulting in northerly winds which force an offshore Ekman transport and induce the local upwelling. In winter downwelling processes are dominant most of the time. The majority of the studies dedicated to the Iberian system suggest that upwelling-favorable winds have weakened over time scales ranging up to 60 years. However, some works reported opposite trends, which were found dependent on the period of the year analyzed. A better agreement among the different works was found when data referring only to the upwelling season is considered.

The understanding of the effect of future climate modulations in upwelling variability has also become important due to the possible changes in local ecosystems and socioeconomic potential (Bakun and Weeks, 2004; Harley et al., 2006). Considering future projections along the major coastal upwelling regions worldwide (Canary, Benguela, Humboldt and Somali), Wang et al. (2015) and deCastro et al. (2016) showed a significant increase for projected upwelling, especially at high latitudes.

Coastal upwelling changes under future greenhouse warming along the Iberian system has also been analyzed through numerical modelling based on basin-scale or global circulation models (GCMs) (Miranda et al., 2013; Pires et al., 2015; Rykaczewski et al., 2015; Wang et al., 2015). Recently, using regional climate projections, Alvarez et al. (2016) analyzed the trend in upwelling index intensity along the Galician coast. These studies predicted a general increase in upwelling intensity and duration during the 21st century although with different rates and not justifying the patterns found. Moreover, once the western coast of the Iberian Peninsula is largely governed by mesoscale activity which comprises many topographical structures (such as prominent capes, promontories and submarine canyons), the typical spatial resolution of climate models used in these studies (on the order of 100–200 km), could be insufficient for resolving upwelling patterns in localized areas. In fact, recent results (Soares et al., 2012; Wang et al., 2015) suggested the need for much higher spatial resolution in atmospheric simulations to accurately estimate nearshore coastal upwelling patterns.

This work aims to present detailed higher accuracy estimations of the spatio-temporal trends of UI along the WIP coast under climate change context, as well to understand the origin of the expected upwelling intensification, using projections from several Regional Climate Models (RCMs) from CORDEX project. RCMs have a spatial resolution of ~12.5 km, giving the necessary conditions for the accurate and meticulous resolution of nearshore coastal upwelling patterns within the framework of a warming climate.

2. Material and methods

RCM simulations performed within the framework of the CORDEX project were used in this study. The EURO-CORDEX branch (http://www.euro-cordex.net/) offers model simulations over Europe at resolutions of 50 km and 12.5 km, downscaling global climate simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5) long experiments up to year 2100 (Taylor et al., 2012). This research uses results from eleven simulations with a spatial resolution of 12.5 km, with available monthly data covering the period 1951–2099. In this work, only the most upwelling-favorable months (June–September) were considered for analysis (Alvarez et al., 2008). These simulations were produced using five RCMs forced by five different GCMs (Table 1) for the control period (1951–2005) and for the future climate period (2006–2099). The control run was forced by observed atmospheric changes, both from anthropogenic and natural sources (Taylor et al., 2012). Future data were obtained for the scenario RCP 8.5, which is based on a greenhouse gas emission situation corresponding to rising radiative forcing crossing 8.5 W m^{-2} at the end of the century (Moss et al., 2010).

Extracted data from these models were organized in a multimodel mean to minimize the individual model biases. Several studies that compared individual models and multimodel ensemble means have found that the latter showed lower uncertainties and better results than each individual model (Annan and Hargreaves, 2010; Jacob et al., 2014; Pierce et al., 2009; Pires et al., 2015; Raisanen and Palmer, 2001; Rykaczewski et al., 2015).

Near surface (10 m) zonal (W_x) and meridional (W_y) wind components from the RCMs were considered at 56 points located 25 km from the WIP coast (Fig. 1, black dots) to calculate the Ekman transport (Q) and upwelling index (UI). Q and UI were calculated following Gomez-Gesteira et al. (2006) by means of

$$Q_x = \frac{\rho_a C_d}{\rho_w f}\left(W_x^2 + W_y^2\right)^{1/2} W_y \qquad (1)$$

$$Q_y = -\frac{\rho_a C_d}{\rho_w f}\left(W_x^2 + W_y^2\right)^{1/2} W_x \qquad (2)$$

Table 1
EURO-CORDEX simulations, with the GCM horizontal resolution.

GCM		RCM				
		CCLM4-8-17	RCA4	HIRHAM5	RACMO22E	WRF331F
CNRM-CM5	1.4° × 1.4°	X	X			
EC-EARTH	1.12° × 1.125°	X	X	X	X	
IPSL-CM5A-MR	1.25° × 2.5°		X			X
HadGEM2-ES	1.25° × 1.875°		X			
MPI-ESM-LR	1.8° × 1.8°	X	X			