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THE CMEMS OCEAN MONITORING INDICATOR PORTFOLIO FOR THE IBERIAN BISCAY IRISH (IBI) WATERS: ESSENTIAL VARIABLES OPERATIONALLY MONITORED AND FUTURE PROSPECTS

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Abstract

The increase of computational resources along with the surge of observational networks and modelling products generates a vast increment of data, that are routinely produced by operational oceanographic services. However, a massive offer of data often entails a difficulty of interpretation along with a blurred perception of the panoramic picture of the marine environment.

In order to transform ocean data into tailored oceanographic information, the Copernicus Marine Environment Monitoring Service (CMEMS) produces Ocean Monitoring Indicators (OMIs). The development of OMIs aims to summarize data by delivering simplified, research-based information about relevant oceanographic processes, which is easily interpretable by end-users. Under the current climate change scenario, OMIs not only provide a conceptual framework to unveil the evolution of the ocean state and health but also facilitate policy-making, informed decisions and an effective coastal management.

The CMEMS Iberian-Biscay-Ireland Monitoring and Forecasting Center (IBI-MFC) currently provides a variety of OMIs oriented to monitor the main oceanographic processes taking place in this regional domain. Among the OMIs currently delivered by IBI-MFC, it is worth mentioning (i) the coastal upwelling index focused on the African-Iberian coast, (ii) the indicator of Mediterranean Outflow Water variability and (iii) diverse indicators of extreme events of temperature or wave height. Currently, IBI-MFC efforts are concentrated on designing bloom phenology indicators derived from chlorophyll anomalies detected within IBI regional seas.

The present work aims to provide a general overview of the IBI-MFC OMIs operationally provided nowadays and further insight into the routine OMI update strategy, as well as main conclusions from them. Finally, ongoing developments of novel upcoming OMIs for the IBI region are also introduced.

Keywords: CMEMS, IBI, Iberian-Biscay-Ireland, ocean monitoring indicators, essential variables

1. Introduction

The operational delivery of modelling products provides a complete picture of the complex processes taking place in the ocean. However, an excess of information may difficult the proper diagnosis of multidisciplinary parameters closely associated with the ocean health. Ocean Monitoring Indicators (OMIs) pursues to provide simplified metrics of the main ocean features to disentangle the ocean's response to climate-driven stressors and the related anthropogenic pressures. Since 2016 the Copernicus Marine Environment Monitoring Service (CMEMS) is developing a pool of science-based OMIs aimed to provide an accessible picture of diverse environmental aspects of the ocean state and evolution. The seamless delivered new OMIs comprise a previous stage where the indicator is implemented, and its scientific consistency is assessed. Thus, before the delivery of a novel OMI becomes operational, the methodology and its scientific validity is thoroughly peer reviewed within the frame of the CMEMS Ocean State Report (Table I).

In the CMEMS catalogue, any OMI is compound of two main elements: the high-quality figure showing the indicator, and the netCDF files with the data required to plot such a figure. Additionally, as with any regular CMEMS product, each OMI has its corresponding documentation to fully describe the product and its reliability through the Product User Manual (PUM) and Quality Information Document (QUID), respectively.

The OMIs here presented are derived products computed from a variety of CMEMS IBI outcomes from both Multi-Year (MY) and Near-Real-Time (NRT) modelling systems. Nevertheless, in order to improve the reliability and uncertainty assessment of

products, the development of multi-product OMIs is favoured by including, whenever is possible, any available CMEMS product (Tables I and II). Therefore, the resulting product is a combination of modelling, observational and reprocessed data.

Table I. List of IBI OMI products currently operational or under development.

IBI OMI	OSR REFERENCE	CMEMS OMI IDENTIFIER	USED CMEMS PRODUCTS
Coastal Upwelling Index	OSR#1: Sotillo <i>et al.</i> , 2016	IBI_OMI_CURRENTS_cui (Updated quarterly)	IBI-PHY-NRT IBI-PHY-MY
Mediterranean Outflow Water	OSR#2: Pascual <i>et al.</i> , 2018	IBI_OMI_WMHE_mow (Updated quarterly)	IBI-PHY-NRT IBI-PHY-MY GLO-PHY-MY CORA ARMOR
Variability of SST extremes	OSR#3: Álvarez Fanjul, <i>et al.</i> , 2019	OMI_TEMP_SAL_extreme_var_tem (Updated annually)	IBI-PHY-NRT IBI-PHY-MY
Variability of SWH extremes	OSR#3: Álvarez Fanjul, <i>et al.</i> , 2019	OMI_SEA_STATE_extreme_var_swh (Updated annually)	IBI-WAV-NRT IBI-WAV-MY
Stormy events	OSR#4: de Pascual Collar <i>et al.</i> , 2020	Not operational (Launch in 2021)	IBI-WAV-NRT IBI-WAV-MY
Algal bloom	OMI under development		

Table II. List of CMEMS products used on OMI computation and acronyms used in text.

IBI OMI	PRODUCT TYPE	CMEMS ID
IBI-PHY-MY	Model Multy-Year	IBI_MULTYYEAR_PHY_005_002
IBI-PHY-NRT	Model Near-Real Time	IBI_ANALYSISFORECAST_PHYS_005_001
IBI-WAV-MY	Model Multy-Year	IBI_MULTYYEAR_WAV_005_006
IBI-WAV-NRT	Model Near Real Time	IBI_ANALYSIS_FORECAST_WAV_005_005
GLO-PHY-MY	Model Multy-Year	GLOBAL_REANALYSIS_PHY_001_030
CORA	Observations	INSITU_GLO_TS_REP_OBSERVATIONS_013_002_b
ARMOR	Reprocessed observations	MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012

This work is organized as follow: Section 2 gives a description of current IBI OMI portfolio as well as a summary of the main results derived from them. Section 3 focuses on describing the future roadmap of IBI OMI evolutions; it includes a summary of the upcoming products under development and the strategy to deliver OMIs in a monthly basis.

2. The IBI operational OMI

2.1 Coastal Upwelling Index

Wind-driven coastal upwelling processes have been extensively studied along the eastern edges of the world's major ocean basins as it has relevant implications on biogeochemical activity and global fisheries production, with direct societal concerns. Along-shore equatorward winds modulate an offshore Ekman transport of surface waters that is compensated by the uplift of denser and richer deep cold waters, injecting nutrients into the near-surface euphotic zone and fostering high marine productivity (Lachkar and Gruber, 2011). The IBI domain hosts the region known as the Canary Current Upwelling System. It is composed by three adjacent regions covering from Southern Senegal (11°N) up to Cape Finisterre (~43°N), being one of the world's largest boundary upwelling ecosystems.

An operational indicator entitled Coastal Upwelling Index (CUI) was published in the first issue of OSR (Sotillo *et al.*, 2016). In this work, a SST-based upwelling index computed from the IBI-PHY products were compared against the traditional wind-derived index based on estimations of cross-shore Ekman transport. Results revealed that the IBI CUI product provides a reliable representation of the upwelling intensity and variability in the study region. The current IBI CUI product can be found on the CMEMS catalogue and it is updated on a quarterly basis. It is computed for the IBI continental façade from 27°N to 42°N, including the western African and Iberian Peninsula coasts. The CUI index is defined at each latitudinal point as the difference between the maximum and minimum surface temperatures, ranging from the coastline up to 3.5° westward.

The product delivered (Figure 1) combines the results computed from IBI-PHY-MY and IBI-PHY-NRT products. It includes the Hovmöller diagram of the index as well as the trend analysis estimated zonally.

The index shows the evolution of the upwelling activity in the IBI continental shelf. Two independent upwelling subdomains are clearly differentiated in the entire region separated by the presence of the Gulf of Cadiz, the southern one (27°N – 34°N) corresponding to the North West African (NWA) region, and to the north (37°N – 42°N) the West Iberian Peninsula (WIP) region. Both regions show remarkable seasonality with few periods of upwelling intensification. The trend analysis in the period 1993-2019 evidences a significant positive trend of the upwelling index in the WIP northern latitudes, in accordance with previous works that have reported an increased upwelling activity in the west coast of USA (García-Reyes and Largier, 2010).

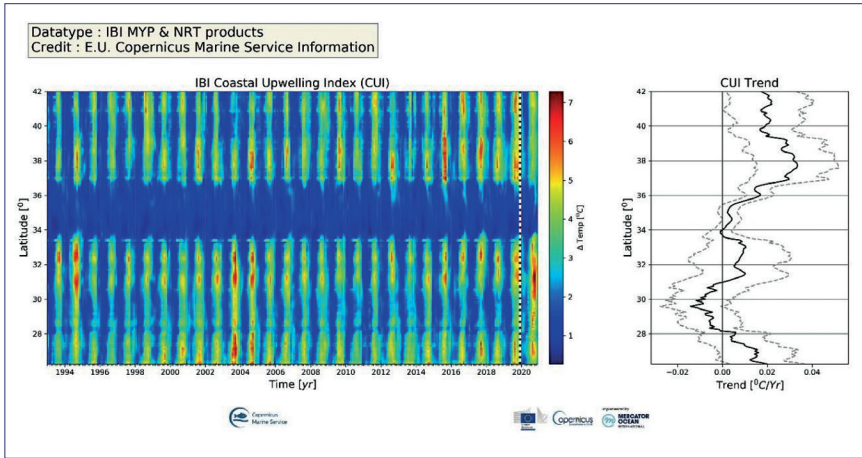


Fig. 1. Left: Zonal Hovmöller diagram of the IBI Coastal Upwelling Index. The index is computed in a daily basis from IBI-PHY-MY (for the 1993–2019 period) and from the IBI-PHY-NRT (for the period 2020 onwards). The vertical white dotted line indicates the use of both datasets. Right: Trend of the Coastal Upwelling Index (solid black line) estimated zonally from IBI-PHY-MY over the period 1993–2019. Dashed grey lines provide the 99% confidence interval of the trend estimate.

2.2 Variability of Mediterranean Outflow Water

One of the distinctive features of the IBI region is the formation and spreading of the water mass known as Mediterranean Outflow Water (MOW). MOW is a saline and warm water mass principally occupying the intermediate depths of eastern North Atlantic, which is generated by the outflow of subsurface Mediterranean water through the Strait of Gibraltar. MOW is widely recognized as a water mass involved in relevant oceanographic processes at diverse timescales such as the heat and salt transport into the inner North Atlantic and Nordic Seas (Reid, 1979, van Aken, 2000) and mixing processes with the surrounding water masses such as the Labrador Sea Water, Antarctic intermediate Water, and North Atlantic Central Water. Therefore, the establishment of a long-term monitoring program of MOW to elucidate its spatiotemporal variability remains as a priority to deep our understanding of the climate system and its evolution.

The IBI MOW index was presented in the second issue of the CMEMS OSR (Pascual *et al.*, 2018). On this study the IBI-PHY-MY product was used to investigate the spatial distribution of MOW as well as its seasonal and interannual variability in six different subregions. The salinity anomalies monitoring in few selected IBI subdomains provided a reliable representation of MOW variability. Nowadays, the IBI MOW product can be found on the CMEMS catalogue and it is updated on a quarterly basis. It is defined as the practical salinity anomaly averaged in four monitoring boxes in the IBI region (Figure 2). The product is computed as an ensemble product including the two IBI

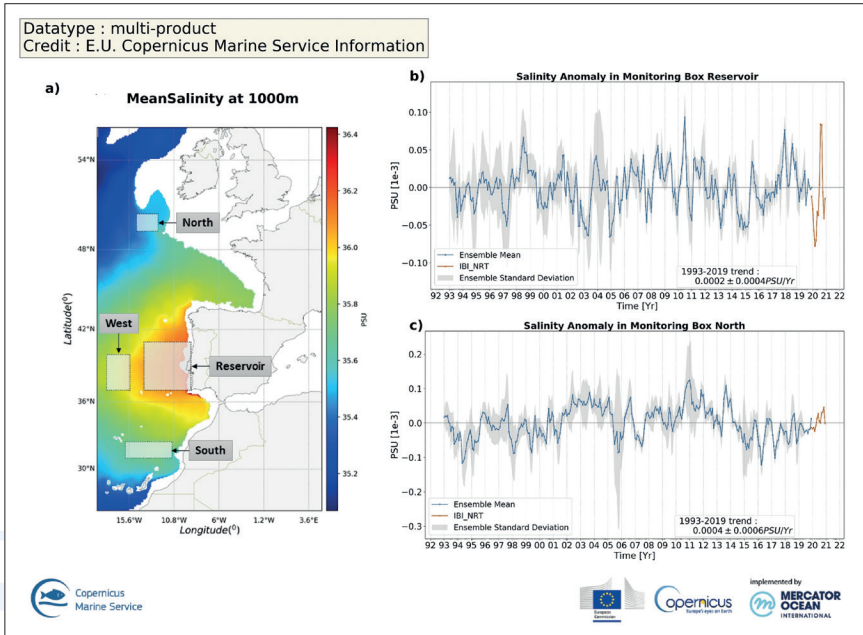


Fig. 2. (a) Mean practical salinity at 1000 m from the IBI-PHY-MY product. Light boxes denote monitoring areas where the IBI MOW index is computed. Rest of panels: Time series of practical salinity anomalies averaged in Reservoir (b), and North (c) monitoring boxes. Results are computed from merged results of diverse CMEMS systems: Ensemble mean salinity anomaly (blue line), standard deviation of ensemble members (shaded gray), and trend of ensemble mean with 99% confidence interval (bottom-right box in time series) are computed in the period 1993-2019 from multi-year products. Deterministic salinity anomaly for the year 2020 (orange line) is computed from product IBI-PHY-NRT.

products as well as other CMEMS products (Table I). Therefore, the delivered time series includes the ensemble mean and ensemble standard deviation for MY products, join with deterministic result for the period not covered by MY products. Among the results obtained, the indicator has been able to reproduce the variability of salinity in Rockall Trough (monitoring box North) in agreement with independent studies (Bozec *et al.*, 2011).

2.3 Analysis of extreme values of temperature and wave height

Extreme events have destructive effects in human infrastructures and may disrupt essential services, damage economical assets and even cause casualties, especially in densely populated urban coastal areas. Thus, the accurate monitoring and prediction of climate-driven coastal hazards within the frame of CMEMS are not only crucial to prompt a wealth of anticipatory strategies, but also of great socioeconomic value for the maritime sector.

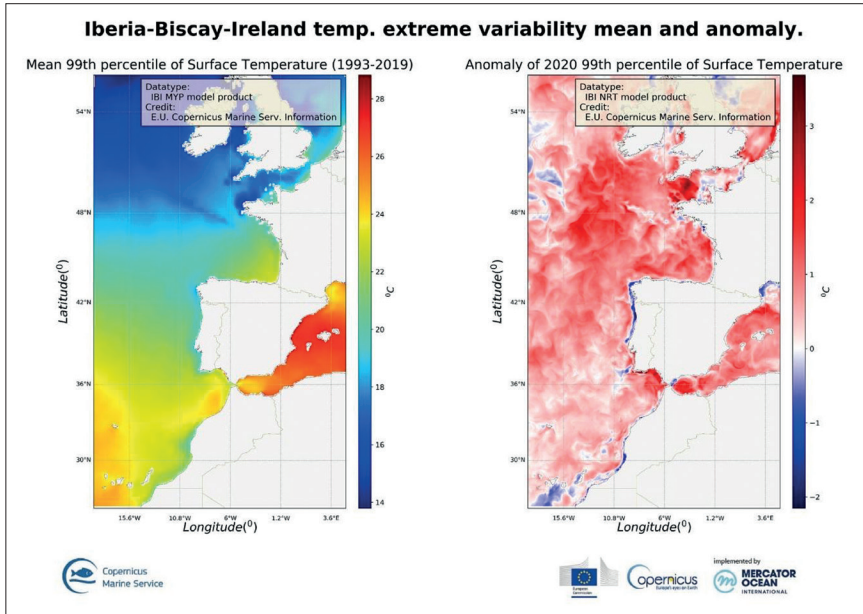


Fig. 3. IBI OMI on extreme variability of SST: Map of the 99th mean percentile computed from the IBI-PHY-MY system (left panel) and anomaly of the 99th percentile in 2020 computed from the IBI-PHY-NRT system (right panel).

Since the first steps of OSR, there is a section in OSR devoted to the analysis of extreme event variability. In the third issue of OSR (Álvarez Fanjul *et al.*, 2019), the IBI-MFC joined such initiative by participating with the annual analysis of extremes variability for sea level, Sea Surface Temperature (SST) and Significant Waves Height (SWH). Such contribution has eventually turned into two operational IBI OMI products annually updated in the CMEMS catalogue. Both share the same methodology and are focused on monitoring the variability of extreme events computed from IBI model data. However, they are applied to different variables (SST and SWH) and are computed from different IBI systems. Thus, the OMI on extreme variability of SST is computed from IBI-PHY-MY and IBI-PHY-NRT systems, and the OMI on extremes of SWH is computed from IBI-WAV-MY and IBI-WAV-NRT systems.

The current IBI OMIs on extreme variability are based on the computation of the annual 99th percentile of the corresponding variable (SST or SWH) from NRT and MY model data (Figure 3). It provides the climatic mean computed from the MY system (mean percentile) and the annual anomalies of the last year computed from the NRT system (percentile anomaly of a target year) and referenced to the MY system. Thus,

the mean percentile corresponds to the temporal average of 99th percentile computed on an annual basis from the MY product. On the contrary, the percentile anomaly is computed by subtracting the mean percentile from the 99th percentile of the target year computed from IBI NRT outcomes.

3. On-going actions and future challenges

IBI OMI products are aimed at operationally delivering a variety of monitoring diagnostics of the ocean state. Thus, OMIs are in constant evolution to expand its application to cover a broader range of ocean processes and end-user demands. One of the main work lines faced in the incoming years encompasses the launch of novel OMIs, derived from all IBI modelling systems. In this regard, it is planned the delivery of an OMI focused on monitoring the variability of stormy events. This OMI is fully described in the fourth OSR issue (de Pascual Collar *et al.*, 2020). It computes the temporal variability of stormy period in three IBI subregions and results will provide a routine monitoring of anomalous stormy periods of the last decades. Additionally, a new OMI for the BIO component is currently under development, that provides an indicator of algae blooms derived from anomalies of chlorophyll concentration. This OMI is still at an early stage, so its definition and first results are currently under analysis.

Since OMIs are derived products, they evolve following the developments of the main IBI products. Thus, they must adapt their evolution to the development of new IBI products. In this way, one of the major forthcoming changes corresponds to the launch of new INTERIM systems that will routinely update MY products on a monthly basis. Such change will be translated into OMI products by replacing the current use of NRT products to provide the analysis of the last months/year using INTERIM products instead. Thus, the use of NRT products will be removed, fostering the use of IBI MY and INTERIM systems exclusively. This change would not only homogenize the systems used to compute OMI timeseries, but also allow the monthly update of OMI products.

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