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THE OPERATIONAL CMEMS IBI-MFC SERVICE TODAY: REVIEW OF MAJOR ACHIEVEMENTS ALONG THE COPERNICUS-1 SERVICE PHASE (2015-2021)

Marcos Garcia Sotillo ^(1, 7), Cailleau S. ⁽¹⁾, Aznar R. ^(2, 7), Aouf L. ⁽³⁾, Barrera E. ⁽⁴⁾, Dabrowski T. ⁽⁵⁾, Rey P. ⁽⁶⁾, Lorente P. ^(2, 7), Levier B. ⁽¹⁾, Amo-Baladrón A. ^(2, 7), Reffray G. ⁽¹⁾, Toledano C. ^(2, 7), Gutknecht E. ⁽¹⁾, Pascual A. ^(2, 7), A. Dalphinnet ⁽³⁾, Guihou K. ⁽²⁾, McGovern J. ⁽⁵⁾, Rodríguez A. ⁽⁶⁾, Renaud R. ⁽³⁾, Bowyer P. ⁽⁵⁾, Ghantous M. ⁽³⁾, García L. ⁽⁴⁾, Benkiran M. ⁽¹⁾, Álvarez-Fanjul E. ⁽⁷⁾

⁽¹⁾ Mercator Ocean International

⁽²⁾ Nologin

⁽³⁾ Météo-France

⁽⁴⁾ AEMET

⁽⁵⁾ Marine Institute

⁽⁶⁾ CESGA

⁽⁷⁾ Puertos del Estado

Abstract

The CMEMS IBI-MFC (Iberia-Biscay-Ireland Monitoring & Forecasting Centre) delivers daily ocean model forecasts, analysis and reanalysis of different physical and biogeochemical parameters for the Atlantic façade, supporting all kind of marine applications. Along Copernicus-1, this IBI operational service has continuously evolved, upgrading both its forecast capabilities (in 2015, only a circulation forecast in place; today, 3 operational services, including waves and biogeochemical forecasts) and its multi-Year production (covering altimetric era with ocean and wave reanalysis products, together with a non-assimilative biogeochemical hindcast). The main IBI-MFC operational achievements and product upgrades are here reviewed. An overview of main IBI service milestones, in terms of both operational production (with inclusion of new variables, increase of product resolution and temporal frequency, extension of forecast horizons and reanalysis coverages) and product quality enhancement is provided. The IBI model applications are routinely validated through meaningful skill scores and a wide range of statistical metrics computed to quantitatively assess the quality and reliability of these model solutions. The CMEMS IBI-MFC delivers today a reliable operational service, meeting user needs for a widespread end-user community (with strong IBI-ROOS connections and marked by a high number of 'regular' operational users linked to downstream services). The IBI-MFC service is expected to

be upgraded, already in a Copernicus-2 context, and major guidelines of the roadmap are here outlined.

Keywords: CMEMS, IBI, operational oceanography, ocean forecasting, ocean models, reanalysis, biogeochemistry, waves

1. The CMEMS IBI-MFC Mission

The CMEMS IBI-MFC (Iberia-Biscay-Ireland Monitoring & Forecasting Centre) offers a comprehensive portfolio of regular and systematic regional information on the state of the ocean for the European Atlantic façade, supporting all kind of marine applications. The mission of this IBI-MFC is to provide operational Near-Real-Time (NRT) short-term forecasts (plus analysis) and multi-year (MY) reanalysis/hindcast products for the so called IBI area, covering the Blue (physics and waves) and Green (biogeochemical) ocean components. To this aim, different IBI high-resolution model applications (to run forecasts), together with data assimilation schemes (to integrate observations in IBI regional NRT analyses and MY reanalyses) have been developed and evolved along Copernicus-1 (2015-2021) and are today the base of the IBI-MFC operational service, here described. The IBI-MFC is managed by a consortium of centres, coordinated by Mercator Ocean International, and that includes Nologin, Météo-France, the Galician Supercomputing Centre (CESGA), the Spanish Met Office (AEMET), and the Irish Marine Institute (IMI).

2. The IBI-MFC Service today (at the end of Copernicus-1)

The IBI-MFC routinely delivers data products for a diversity of ocean variables of the three ocean components: physics (PHY), biogeochemistry (BIO) and waves (WAV). The NRT forecast/analysis products (with horizontal resolution ranging from 2.5 to 5 km resolution) are updated on daily to weekly basis, providing up to + 10 days of forecast ahead, together with a historical catalogue composed of analysis/hindcast for a 2-year period. On the other hand, the IBI MY reanalyses (for circulation and waves) and non-assimilative hindcast (for biogeochemistry) products cover from 1993 till present time and are updated twice a year. In 2021, the IBI-MFC delivers 6 products (those corresponding to the short-term forecast/analysis: PHY-NRT, BIO-NRT, and WAV-NRT; and those for the long-term MY production: PHY-MY, BIO-MY, and WAV-MY), accounting for 20 datasets (with a wide range of temporal frequencies: i.e., 15-minute data, together with hourly, daily, and monthly means) that currently include 37 variables for ocean physics (temperature, salinity, currents, sea level, etc.), waves (significant wave height, peak period, etc.) and biogeochemistry (chlorophyll, oxygen, nutrients, etc.). Further details and references on the IBI-MFC portfolio are provided in Table I.

Table I. Summary of the IBI-MFC Products Portfolio (status at the end of Copernicus-1; year 2021).

		IBI NRT PRODUCTS	IBI MY PRODUCTS
P H Y S I C S	CMEMS ID	IBI_ANALYSISFORECAST_PHY_005_001	IBI_MULTIYEAR_PHY_005_002
	Model	NEMO v3.6	NEMO v3.6
	Data Assim.	Yes (SSH, SST, <i>in situ</i> TS)	Yes (SSH, SST, <i>in situ</i> TS)
	Resolution	1/36° (~2-3 Km); 50 levels	1/12° (~8-9 Km); 50 levels
	Temporal Coverage	-2 Years + 5-days forecast (daily/weekly FC/AN update)	1993 – Present Regularly updated (2x Year)
	Temporal Frequencies	Monthly & Daily (3D) Hourly (Surface) Hourly (3D for subregions) 15 mins. (Surface)	Monthly & Daily (3D) Hourly (Surface)
	Variables	Temperature, Salinity, Currents, Sea Surface Height, Ocean Mixed Layer Thickness	
	Product Access & Documents	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_ANALYSISFORECAST_PHY_005_001	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_MULTIYEAR_PHY_005_002
B I O G E O C H E M I S T R Y	CMEMS ID	IBI_ANALYSISFORECAST_BGC_005_004	IBI_MULTIYEAR_BGC_005_003
	Model	PISCESv2 (coupled to NEMO v3.6)	PISCESv2 (coupled to NEMO v3.6)
	Data Assim.	PHY data assimilated (SSH, SST, <i>in situ</i> TS), no BIO data assimilated.	PHY data assimilated (SSH, SST, <i>in situ</i> TS), no BIO data assimilated.
	Resolution	1/36° (~2-3 Km); 50 levels	1/12° (~8-9 Km); 50 levels
	Temporal Coverage	-2 Years + 10-days forecast (weekly FC/AN update)	1993 – Present Regularly updated (2x Year)
	Temporal Frequencies	Daily (3D) Monthly (3D)	Daily (3D) Monthly (3D)
	Variables	Chl-a concentration, Dissolved concentration of O ₂ , Fe, NO ₃ , NH ₄ , PO ₄ , Si, Net primary productivity, Phytoplankton concentration, Euphotic depth, Surface CO ₂ partial pressure, Dissolved inorganic carbon, pH.	
	Product Access & Documents	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_ANALYSISFORECAST_BGC_005_004	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_MULTIYEAR_BGC_005_003
W A V E S	CMEMS ID	IBI_ANALYSIS_FORECAST_WAV_005_005	IBI_MULTIYEAR_WAV_005_006
	Model	MFWAM	MFWAM
	Data Assim.	Yes	Yes
	Resolution	1/20° (~5 Km)	1/20° (~5 Km)
	Temporal Coverage	-2 Years + 10-days forecast (FC/AN update: x2 a day)	1993 – Present Regularly updated (2x Year)
	Temporal Frequencies	Hourly	Hourly
	Variables	Significant Wave Height, wave direction, wave period variables and wind and swell (primary and secondary) parameters.	
	Product Access & Documents	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_ANALYSIS_FORECAST_WAV_005_005	https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=IBI_MULTIYEAR_WAV_005_006

Each IBI product is built upon an operational suite that carries out four main tasks: 1) the acquisition of the best upstream data available to force the models and assimilate observations, 2) the running of models and post-processing procedures for generating the products, 3) the validation of the modelling solutions based on comparisons against all available observational data and 4) the timely delivery to users of the final IBI products. Using internal monitoring tools, the IBI team routinely oversees the correct functioning of all operational chains, checking the status of the operations, managing the HPC & storage resources, and controlling the product dissemination. The rigorous design, control, and management of the suites and all the related incidents ensure a highly reliable, robust, and fully monitored IBI-MFC service, with timeliness always higher than 94% along the Copernicus-1 (2015-2021) service period. On top of it, the IBI-MFC counts with a Service Desk, responsible of maintaining a communication channel with users to inform about any operational incident occurred, programed service outages, products updates, and to respond to any user question on the IBI products and services.

The MY and NRT products provide a complete picture of the complex processes taking place in the IBI region, and they can help to characterize extreme events (Sotillo *et al.*, 2021). The IBI-MFC uses the combination of both approaches to provide a quick look of the current and past state of the ocean. In the context of CMEMS, the development of Ocean Monitoring Indicators (OMIs) aims to summarize data by delivering simplified, research-based information about relevant oceanographic processes. The IBI-MFC currently produces (with a periodic update) 4 OMIs, including a Coastal Upwelling Index, an index to monitor variability of the Mediterranean Outflow Water (MOW) in intermediate levels of the Northeast Atlantic and two indicators on extreme events of temperature and wave height. Additionally, there are two IBI OMIs, currently under development: one to characterize variability of stormy periods in the IBI domain, and a second one focused on the algae bloom phenology, derived from chlorophyll anomaly. Further details about all these IBI OMIs are provided in Pascual *et al.*, 2021.

The IBI-MFC aims at providing high quality verified state-of-the-art ocean model products. The continuous improvement of the service, and the implementation of a service evolution strategy ensure that the best operational oceanography products are disseminated. To carry this out, the IBI-MFC performs: 1) routine (online near-real-time and delayed-mode) product validation through the IBI-MFC NARVAL validation tool (Lorente *et al.*, 2019a); 2) dedicated assessment of the IBI MY products; 3) pre-operational qualification of any new or upgraded future IBI released systems (see in Figure 2, an example of the product quality enhancement achieved through different IBI-PHY-NRT product releases); 4) the required Product Quality documentation requested by CMEMS to be issued for each product delivered, and 5) specific research to design new product quality metrics and to evaluate the quality of the IBI-MFC products (see Lorente *et al.*, 2019b and Gutcknecht *et al.*, 2019 for examples on the physical and biogeochemical IBI products, respectively).

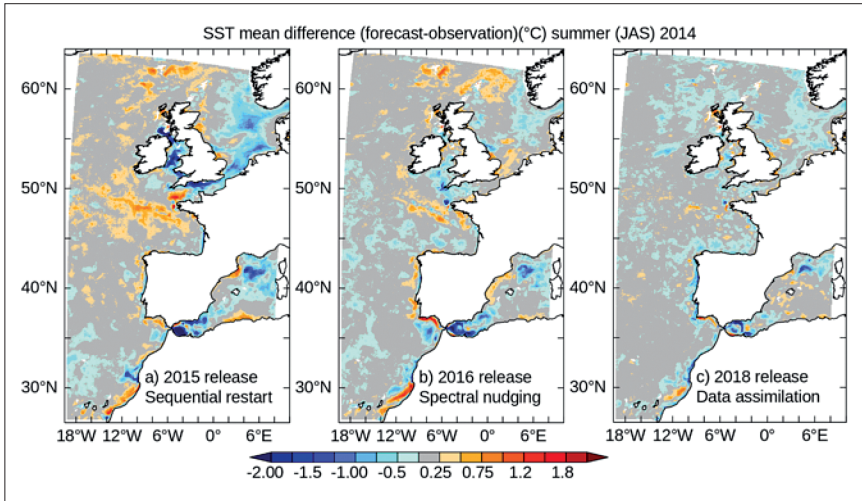


Fig. 1. Example of IBI Product Quality enhancement: SST differences between IBI-PHY-NRT solutions and satellite observations (CMEMS L3 satellite product 010_009a) for Summer (JAS) 2014. IBI data from (left panel) the 2015 system version (with periodic sequential forecast re-initialization from the CMEMS Global solution) and (right panel) the 2018 system version (already with data assimilation scheme included).

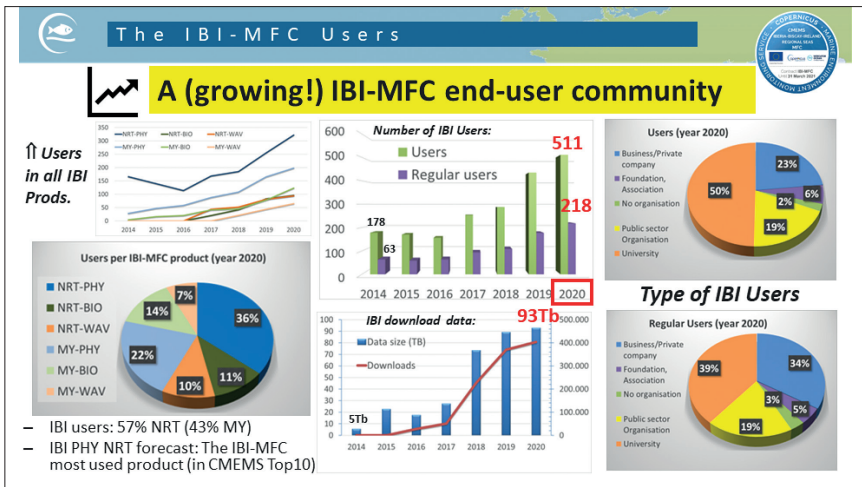


Fig. 2. IBI product users: Temporal evolution in the number of IBI users (occasional and regular/operational ones) and in the data amount downloaded (central panels); information on the number of users per product line (left panels); Information on the type of end-users (right panels).

Finally, emphasize that the IBI-MFC delivers a service always devoted to meet the requirements of an ever-growing community of end-users (from 178 users in 2014 to more than 500 ones in 2020; half of them operational regular users that get IBI products at least twice a week). The increasing interest in using IBI-MFC products is reflected by the fact that almost 100 TB of IBI physics, biogeochemistry and waves data were downloaded in 2020 by users coming mainly from academia, private companies, and public sector organizations (further details on IBI users in Figure 2).

3. The IBI-MFC Service evolution (along Copernicus-1) and future roadmap

The IBI-MFC provides a service in constant evolution since 2015. Its service evolution roadmap is fully aligned with the general CMEMS scientific objectives and it also responds, as main driver, to meet identified end-users needs. Along Copernicus-1 (2015 – 2021), the following IBI-MFC service improvements (see Table II for further details) have been achieved:

- Delivery of a complete product portfolio (today, the IBI-MFC delivers NRT forecasts and MY products for the 3 ocean components, i.e. PHY, WAV, BIO; to this aim, new WAV and BIO NRT operational forecast suites were developed);
- Enhancement of IBI products, increasing their spatial and temporal resolutions (thus, the currently delivered IBI NRT and MY WAV products has duplicated their spatial resolution and the PHY NRT product counts with new higher frequency datasets such as the 3D hourly and surface 15-min data);
- Extension of forecast horizon and temporal coverages (today, the IBI NRT WAV and BIO forecasts deliver up to +10 days leading times and all the IBI MY products covered back to 1993);
- Inclusion of Data Assimilation schemes (IBI analyses and reanalyses products are today delivered for the PHY and WAV components);
- Continuous improvement of model set-ups (including periodic upgrade of IBI model codes and the use of best available forcings, with special attention to the atmospheric one);
- Enhancement of system interactions through model coupling (the IBI PHY and BIO NRT and MY model applications are on-line coupled; additionally, the IBI NRT PHY and WAV forecast systems have been recently off-line coupled).

Table II. Evolution of the IBI-MFC product lines. Main milestones achieved from 2015 (start of Copernicus-1) up to 2021 (situation at the start of next Copernicus-2).

	C-1 START (2015)	C-1 PHASE 2 (2018)	COPERNICUS-2 (2021)
IBI-PHY-NRT	- 1/36° NEMO3.4 App. - Sequential Periodic restart - ATM: ECMWF-1/8° (3-h)	- NEMO3.6 - Data Assimilation - ATM: 1-h ECMWF.	- IBI Wave coupling - New tidal forcing
IBI-BIO-NRT		- 1/36° PISCES3.6 - No permanent burial - Improved carbon cycle - Carbon vars distributed	- Revised inputs from rivers - Permanent burial - Improved OBC/IC (CMEMS GLO)
IBI-WAV-NRT		- 1/10° MFWAM App	- 1/20° MFWAM + DA - IBI Currents inputs
IBI-PHY-MY	- 1/12° NEMO3.2 (ERA-Int) - DA (SST, SSH, InSitu TS) - Coverage: 2002-2011	- 1/12° NEMO 3.6 - Coverage: back to 1993	- ATM: ECMWF ERA5 - improved DA - New OBS (OSTIA SST)
IBI-BIO-MY	- 1/12° PISCES 3.2 - Non-assimilative hindcast - Coverage: 2002-2011	- 1/12° PISCES 3.6 - No permanent burial - Improved carbon cycle - Carbon vars distributed - Coverage: back to 1993	- Revised inputs from rivers - Permanent burial - Improved OBC/IC (CMEMS GLO)
IBI-WAV-MY		- 1/10° MF-WAM - Winds: ERA-int - OBC: ECMWF	- 1/20° MFWAM + DA - Winds: ERA5 - OBC: CMEMS GLO - IBI Currents inputs

Maturity of the IBI-MFC operational service is a reality today. Nevertheless, the IBI-MFC service will continuously evolve in the Copernicus-2 framework. The research and development actions planned to evolve the post-2021 IBI service are aimed at:

- Ensuring service continuity: keeping as up to now NRT forecast updates – mostly in daily basis – and bringing MY product updates closer to present time (monthly update planned through the implementation of new ‘Interim’ reanalysis streams);
- Enhancing homogeneity in services: specially, increasing analogy between NRT and MY IBI products (using same grids to deliver same variables at same temporal frequencies);
- Making IBI products more coastal-oriented. Most IBI-MFC end-users are interested in coastal areas. Thus, the IBI-MFC put a good deal of effort into IBI products to get a better representation of ocean scales driving the coastal ocean, including eddie mesoscale, sub-mesoscale features (such as fronts) and a general better reproduction of high frequency processes. Enhancement of the IBI model capacities on shelf and coastal environments will foster further IBI downstreaming by coastal stakeholders.

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