FEBRUARY 2016

#54

MAIN OUTCOMES OF THE MYOCEAN2 AND MYOCEAN FOLLOW-ON PROJECTS

MERCATOR OCEAN JOURNAL

#54

EDITORIAL

Greetings all,

This issue of the Mercator Ocean Journal is dedicated to the main outcomes of the MyOcean2 and Follow-On projects. The EC/FP7 MyOcean2 and H2020 MyOcean Follow-On projects covering the period from April 2012 to May 2015 have paved the way to the current Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/).

Papers are dedicated to the following thematic:

Dorandeu as an introduction is presenting the objectives and organization of the MyOcean2 and Follow-On projects.

Delamarche and Giordan are then describing the service to users, what kind of service MyOcean delivers and how it is being improved continuously.

Next paper by **Crosnier et al**. describes which products are delivered to users and how the content of the catalogue has been regularly updated with new and more scientifically accurate products.

The following paper by **Tonani et al**. presents the seven MFCs (Monitoring and Forecasting Centers) which provide with ocean forecast, analysis and reanalysis products at the global and regional scales. All these systems have been able to increase the number and the quality of the products during the MyOcean phases.

Simoncelli et al. follow with an overview of the principal characteristics of the physical and biogeochemical regional reanalysis. A standard validation methodology has been defined and applied to all the reanalysis products to ensure an adequate evaluation of their accuracy.

Hackett et al. are then presenting the satellite-based TACs (Thematic Assembly Centers) which produce observations of the Global Ocean and European regional seas: the Sea Level TAC (sea surface elevation products), the Ocean Colour TAC (optical products) and the Ocean and Sea Ice TAC (SST, sea ice and surface wind products).

Pouliquen et al. follow with an overview of the main achievements of the InSitu TAC. The InSitu TAC is a distributed service integrating InSitu data from different sources (e.g. floats, buoys, gliders, ferrybox, drifters, SOOP) and carries out quality control in a homogeneous manner. The goal of the TACs in MyOcean was two-fold: 1) to provide assimilation and validation data for the Monitoring and Forecasting Centres (MFCs) and 2) to provide core observational products for a broad range of downstream users.

Finally, the main achievements for NEMO ocean code evolution are presented by the **NEMO System Team**. NEMO (Nucleus for European Modelling of the Ocean) is a state-of-the-art modelling framework used in a wide variety of applications whose prime objectives are oceanographic research, operational oceanography, seasonal to decadal forecasting and climate studies. This paper will describe the NEMO development processes, the main achievements in NEMO reference code developments during MyOcean project, and the mutual contributions and benefits between MyOcean and NEMO.

Last but not least, **Maksymczuk et al**. provide with the description of the product quality achievements during MyOcean. Routine validation is performed on all products in order to objectively assess product quality. This is achieved by increasing the consistency between the validation performed on the products, and also by evaluating new metrics for understanding the scientific quality of the products.

We will meet again soon in April 2016 for a new issue jointly coordinated between Mercator Ocean and Coriolis. We wish you a pleasant reading,

Laurence CROSNIER
Editor in Chief

#54

TABLE OF CONTENTS

#54

TABLE OF CONTENTS

INTRODUCTION MYOCEAN 2 AND MYOCEAN FOLLOW ON PROJECTS

BY

J. DORANDEU(1) – MYOCEAN2 AND MYOCEAN FOLLOW-ON PROJECT MANAGER

ABSTRACT

The EC/FP7 and H2020 MyOcean 2 and MyOcean Follow-On projects have been set up in the perspective of the Copernicus Marine Service as an operational continuity of the EC/FP7 MyOcean (2009-2012) services for the period from April 2012 to May 2015. These projects have ensured the continuity of the service for the users, paving the way to the operational phase of the Marine Service in the frame of the Copernicus Programme: the Copernicus Marine Environment Monitoring Service. The main objective was to deliver and operate a rigorous, robust and sustainable Copernicus service component for Ocean Monitoring and Forecasting and thus help implement a stable and sustainable system configuration, including both service and organisation, to enable the Copernicus Marine Environment Monitoring Service operational phase to begin in early 2015.

The MyOcean Service, implemented by these projects, is committed to its users: European agencies and policy convention offices, national public institutions with operational and/or research objectives, private companies developing their own downstream services, and also European citizens on the lookout for a new vision of the oceans. MyOcean users operate in four spheres of application, marine safety, marine resources, marine and coastal environment, and weather, climate & seasonal forecasting. The MyOcean Service delivers generic information on the physical state of the ocean and ecosystem characteristics to these European and international user communities. It provides core ocean information at global and European regional scales, from satellite

[1] **Mercator Océan,** Ramonville St Agne, France,
(now at CLS, Ramonville St Agne, France).

and in-situ observations and from assimilative models in real time and over long time series. Essential ocean variables such as Currents, Temperature, Salinity, Sea Level, Sea Ice, Surface winds and Biogeochemistry are made available in a common catalogue presented in a single easy-access interface.

MyOcean 2 and MyOcean Follow On projects have been designed to provide reliable and timely information on ocean monitoring and forecasting. A central organisation operates the service, responds to user requests and feedback in accordance with Service Level Agreements. The MyOcean open and free service is in line with the Copernicus Data Policy and responsive to user wishes. The organisation implemented paves the way for the next Copernicus operational phase as it is fully integrated at the pan-European scale, integrating state-of-the-art S&T capacities, interfaced with stakeholder facilities, compliant with the INSPIRE data architecture and ready for operations.

The MyOcean "System of systems" relies on existing European operational oceanography infrastructures and is composed of 11 main Production Centres – 4 Thematic Assembly Centres (TAC) providing observation products and 7 Monitoring and Forecasting Centres (MFC) dealing with modelling and assimilation. Each Production Centre, responsible for its domain or area, reduces unnecessary duplication. It integrates into the overall MyOcean system through a Central Information System managing data flows and providing a unique and standard interface to users. The service and system have been made possible by rigorous project management and engineering methodologies for both system and organisation, including common planning, milestones and reviews according to standard guidelines and assessed by external experts. Strong standardisation efforts in product quality and performance in all Production Centres have also been centrally coordinated to provide users with reliable and unified product quality information.

At the end of the MyOcean Follow On project, more than 5000 users are registered to the service and more than 140 operational users are depending every day on the MyOcean service for providing their own downstream service to the end users. MyOcean offers a fully monitored service through a unified catalogue of products, based on an integrated System of Systems and acting as a single organisation. The MyOcean 2 and Follow On projects have totally ensured the transition from prototype operational oceanography to Copernicus full operations which took over the service from May 2015.

A USER DRIVEN SERVICE

The objective is to provide a sustainable service validated and commissioned by users. Strong links with the users are developed at different levels.

The main interfaces for the users are the MyOcean Service Desk (human organisation) and the MyOcean Web Portal. Through these interfaces, day-to-day communication and information are provided to users, for instance about production outages. Through the same interfaces, users can interact with the MyOcean Service, ask questions, raise problems, and get information about products and their quality.

The projects have also been organised so that management and governance bodies are in close and continuous relationship with the main stakeholders and reference users at European level, such as European agencies and national organisations.

Specific project tasks have been defined to deal with "User Uptake at National and regional levels". In this frame, a large number of demonstrations of the use of MyOcean products and services by the downstream sector have been performed. This also helps getting feedback from real applications and investigating new areas in which the MyOcean Service could contribute.

The MyOcean project organisation addresses Service evolution, management and support. It manages all the processes needed to translate user needs (requirements) into Service Specifications. All Service and System requirements are regularly revisited in a regular process in order to plan the next evolutions and improvements. At the same time, specific processes are dedicated to the collection of user feedback, from daily interactions with users (mainly through the Service Desk), by the organisation of user workshops or by questionnaires which proved that users are very keen to be involved in the Service definition process. Users are also engaged in the service validation process by the project with specific tasks defined for Beta-testers when a new version is being deployed in operations. This allows useful feedback from experimented users in different application areas.

Service evolutions are not only motivated by direct interactions with users but are also driven by science and technology evolutions in the operational oceanography domain. Indeed, one major objective is to maintain the European Marine Service State-of-the-Art so that it continues to be the most relevant generic source of information for downstream users and applications. To achieve this, service evolution and development strategies are defined in close link with external Research and Development frameworks, such as European FP7 or H2020 or other international initiatives. Expertise in all scientific domains is developed within the project teams so that the Service is maintained at its highest quality level through cross-fertilisation between internal scientific developments and external R&D.

A PAN-EUROPEAN ORGANIZATION

MyOcean2 and MyOcean Follow On projects have proposed and implemented a long-term service provision organisation.

The projects have proposed both structure and organisation of the Copernicus Marine Service. In particular this model proposes a unified Service from a user point of view, supported by a distributed architecture for production functions and integrated through a Central Information System. This model has been designed to serve for the future phase in the frame of the Copernicus Marine Environment Monitoring Service (CMEMS). Furthermore, in terms of organisation, the importance of cross-cutting activities, not only for high level management but also for common technical activities throughout the different sub-systems proved to be an efficient tool for managing important issues. Indeed a lot of these issues are transverse and should be managed as such: these are for instance Science and Technology for Service evolution, Product Quality, Re-processing and Re-analysis activities. One meaningful output of centrally managed cross-cutting activity is provided by the MyOcean Ocean State Report which is a unique example of a common re-processing and re-analysis effort for a description of the state of the ocean at global and regional scales.

The organisation relies on existing and experienced operational centres in Europe. The sharing of activities takes into account the specific skills of each partner and avoids duplication of efforts. Though more than 30 different production units contribute to the overall production function, they are gathered in coordinated thematic or regional production centres delivering the ocean products in a standard and unified manner so that the MyOcean Service offers a unique catalogue and interface to users. MyOcean data products are provided by 11 production centres interconnected as a system of systems, certified for operations and organized for innovation: 4 Thematic Assembly Centres (TACs) dealing with observations and 7 Monitoring and Forecasting Centres (MFCs) dealing with modelling and assimilation as shown on figure 1.

The organisation relies on existing and experienced operational centres in Europe. The sharing of activities takes into account the specific skills of each partner and avoids duplication of efforts.

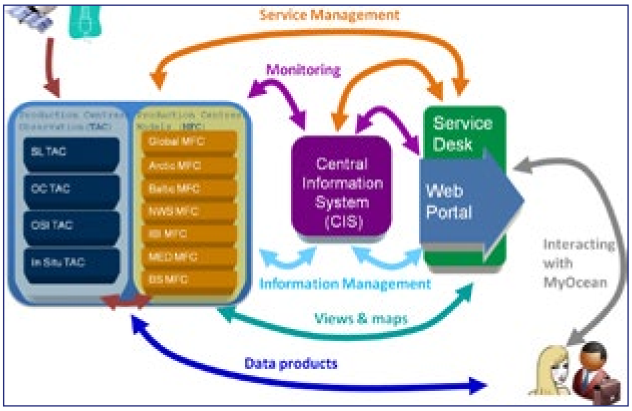


FIGURE 1

The MyOcean System of Systems: Production Centres (Thematic Assembly Centres and Monitoring and Forecasting Centres) integrated by the Central Information System and connected to users through a unique interface.

A CORE SERVICE

The MyOcean Service proposes a product and service portfolio as a precursor of the Copernicus Marine Environment Monitoring Service.

The MyOcean service offers a **core Service**, meaning generic data and information for downstream applications and services. The MyOcean Service is **Open and Free**, fully in line with the Copernicus data policy: MyOcean provides core products and services from space and in-situ ocean observations and model analyses and forecasts in a unique and standard interface freely available to downstream providers and end users.

A unique Catalogue of products and services: all products and services are freely accessible from the MyOcean user interface (Web Portal): Information, visualisation and downloading. Downloading data products requires registration, again in line with Copernicus regulations and data policy, in order to establish a strong link with the users and meant to improve the service. Service Level Agreements between MyOcean and its users establish MyOcean commitments to provide products in standard interfaces, to ensure maintenance of the system and assistance to users.

Products cover all essential **ocean variables** (see figure 2): currents, temperature and salinity, surface winds, sea level, biogeochemistry and sea ice for **different European regions and at global scale**, **in real time**, **forecast and reanalysis** modes.

FIGURE 2

The essential ocean variables provided by MyOcean data products. The geographical coverage (global, regional) and the different activation modes are also represented.

AN INTEGRATED CAPACITY

Robust and optimised production and service infrastructure are designed to achieve economies of scale.

The overall system of MyOcean 2 and MyOcean Follow On proposes an integrated production and service capacity for the Ocean Monitoring and Forecasting component of the Copernicus Marine Service. As stated previously, the production function has been gathered in coordinated Production Centres managing several Production units.

All Service functions including Evolution, Management and support are managed centrally, which brings more consistency and more collaboration between the involved teams. The projects worked efficiently to provide different functions: service definition, engineering and transition, product management, change and release management, operation of the Service Desk.

MyOcean 2 and MyOcean Follow On have implemented cross-cutting functions to manage common technical or scientific issues. This appeared to be a strong asset during the project. Indeed, cross-cutting work packages bring more coordination in their respective domains, avoiding duplication of efforts and making all actions converge towards common objectives.

The integration capacity has also been demonstrated in the scientific and technical fields for which project scientists and experts have worked together through common strategic objectives. This has fostered efficient development of new technologies to the benefit of the successive versions of the Service. European R&D efforts, through different research programs, should continue to increase the synergy with the Copernicus Marine Environment Monitoring Service.

A METHODOLOGY FOR DEVELOPMENT AND OPERATIONS

The projects have proposed a methodological approach, compliant with best European standards and practices.

The MyOcean projects have proposed a methodology of development based on standard methods used for instance in the space industry. The engineering methods have been adapted to the specificity of the operational oceanography domain and to the structure of the MyOcean system of systems. In particular, the concept of system and sub-systems has been developed as a strong driver: the MyOcean system is seen by the users as the one delivering the Service. The sub-systems are the main contributing components of the system, i.e. the Production Centres, the Central Information System and the Service Desk (human organisation), as illustrated on figure 1.

The projects have started with a system version operated from the beginning. Consequently any development, modification or evolution to the MyOcean Service had to be planned and designed taking into account the existing version in operations at the time of the new design. This has been recognised as a major driver for the development methodology with the concept of “Continuous Development in Operations”. Thus the methodology results from the continuity in the standards adopted for development and from the need to operate continuously the system at the same time. Operational service delivery and preparation of evolutions are simultaneously managed. Beside the standard full development cycle for major versions, the projects have adopted shorter and more reactive lifecycles led and controlled by the dedicated change management processes.

Besides the review process which is directly derived from the adopted methodology, the internal organisation and methodology is also based on a close collaboration between all partners, mainly coordinated by the management bodies and by the cross-cutting work packages.

CONCLUSION

MyOcean2 and MyOcean Follow On projects have delivered and operated a rigorous, robust and sustainable Copernicus service component for Ocean Monitoring and Forecasting in continuity with past and on-going initiatives in the Copernicus and EU marine research framework. The projects have helped to implement a stable and sustainable system configuration, including both service and organisation, to enable the Copernicus Marine Environment Monitoring Service operational phase in 2015.

The MyOcean service main driver is its service commitment to users operating in four spheres of application, marine safety, marine resources, marine and coastal environment, and weather, climate & seasonal forecasting.

The MyOcean service main driver is its service commitment to users operating in four spheres of application, marine safety, marine resources, marine and coastal environment, and weather, climate & seasonal forecasting. MyOcean delivers generic information on the physical state of the ocean and ecosystem characteristics to these European and international user communities.

MyOcean2 and MyOcean Follow On have ensured continuity of pre-operational capacities for Copernicus Marine users with stable core service definition, high service availability and continuous service improvement. Both projects have further developed the single "core" service to users (www.myocean.eu transitioning to marine.copernicus.eu), its performance, reliability and responsiveness to users' feedbacks.

The projects have contributed to the emergence of a technically robust and sustainable Copernicus Marine Environment Monitoring Service infrastructure in Europe, that is both modular and fully integrated at the pan-European scale, integrating state-of-the-art S&T capacities, interfaced with stakeholder facilities, compliant with the INSPIRE data architecture and ready for operations.

ACKNOWLEDGEMENTS

The authors wish to thank all the MyOcean 2 and Myocean Follow On project partners for their active collaboration as a great factor of success.

The project management team also wishes to recognise the strong support received from the Research Executive Agency project officers: Birgit Blasch, Stefano Fontana and Virginia Puzzolo. Finally, we want to specially thank the review group composed of EC and external experts, namely Peter Ryder, Guy Duchossois, Frédéric Gasiglia and Hans-Joachim Koppert, who played an important role by providing highly valuable advices and guidance at crucial project milestones.

MYOCEAN USER SERVICE

BY
A. DELAMARCHE(1), C. GIORDAN(1)

ABSTRACT

The frame of the service provided to MyOcean Users is:

- Oceanographic Products covering all European and global marine needs made from a large network of European producers with common access to all products in the catalogue
- Open and free data policy
- Unique point of access for Users (Website & Service Desk)
- Operational
    - Products available on a 24/7 basis
    - Service Desk operated during office hours, 5/7
    - Traceability of User needs and service improvements ensured
- INSPIRE directives.

And the main objective of the MyOcean User's service is to reach a service of high level in terms of reliability, sustainability and measured scientific quality.

This MyOcean service leans on:

[1] **MERCATOR OCEAN,** Toulouse, France

- 11 Production Centres (4 Thematic Assembly Centres also called TACs, 7 Monitoring and Forecasting Centres also called MFCs)
- The Central Information System:
    - The MyOcean Information System manages all information related to products and Users
    - The Web Portal provides a unique access point to Users
- The Central Service Desk: interface with Users. And depending on the requests from Users the Central service Desk can rely on a network of local service desks from Production Centres.

Then as we can see in the Figure 1 MyOcean service is based on a system of systems.

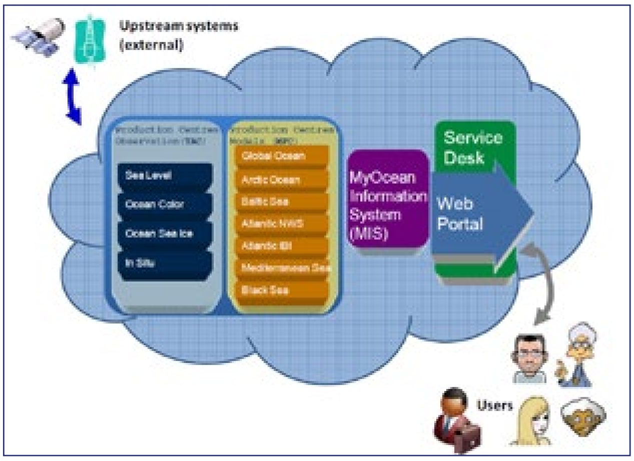


FIGURE 1

MyOcean System of Systems.

MyOcean provides a catalogue of 130 products.

Users can download any MyOcean product if they are registered. They can also benefit from following services provision without any registration:

- To discover the catalogue of products
- To get in-depth information on products
- To view products
- To access information on products quality
- To get news about products & services : «Newsflash» section also accessible through an RSS field
- To use technical FAQs
- To consult Tutorials
- To learn latest improvements on products: "Product Improvements" section
- To exchange and share on an interactive web-based forum meant for current or future Users, for scientists implied in ocean knowledge, for MyOcean partners and more generally for the whole MyOcean community.

THE SERVICE DESK

The Service Desk is an organisation of trained persons who shall follow processes and use dedicated tools to manage Users.

FIGURE 2

MyOcean Service Desk.

The Service Desk is managed by Mercator Ocean since March 2012.

Composed of 4 people and opened all working days, it is the unique human interface with Users for service delivery, requests and information.

The Service Desk is implied in several tasks:

Inform Users: in case of incident, maintenance or improvement, the Service Desk has to inform Users. This communication is done via two ways, by targeted email and through a publication in our Website. Two different pages are provided for this purpose NewsFlash page (maintenances and incidents) and Product Improvement page (improvements).

Answer questions of Users: around 40 questions per month come to the Service Desk. All questions are recorded in the CRM with a ticket reference.

Incidents / Maintenances: The Service Desk centralizes reporting of incidents and maintenance from data producers in order to inform the Users. All events are recorded in the CRM with a ticket reference.

Forum: A collaborative Forum was launched in March 2014 and allows Users to exchange their problems and experiences. The Service part of this Forum is handled by the Service Desk.

Register Users: Users ask for a registration filling in a Service Level Agreement (SLA) on-line. The Service Desk is alerted by email, information of the SLA is validated and then the account is activated.

Feedbacks: there are two different feedbacks, after the closure of a ticket (a Satisfaction Inquiry is sent in order to evaluate the service and to collect User's improvement propositions), and once a year with a more complete questionnaire.

Statistics: the Service Desk is responsible of statistics on Users and Use of data. These statistics are provided every quarter to the MyOcean partners, or upon request.

Technical FAQs: information about the download of products, Python scripts, how to use data etc... are available in the FAQs, updated regularly by the Service Desk.

Link with Local Service Desks.

The service desk relies on a:

User Management tool [GOSA] to manage all the information related to the User registration.

Customer Relationship Management tool (CRM) [SUGAR] to insure the best follow-up and thus to improve the link with Users. All information (requests, incidents ...) is registered in.

Content Management System tool [AUTOMNE] to manage the Web Portal sections (FAQ, News Flash, Product Improvement).

Forum [VANILLA] to manage structure and categories of the Forum

The following links are useful:

Copernicus Marine Service **Website**: http://marine.copernicus.eu/

To contact the **Service Desk**: servicedesk.cmems@mercator-ocean.eu

To **register:** http://marine.copernicus.eu/web/56-user-registration-form.php

To be informed of an **incident or maintenance**: http://marine.copernicus.eu/web/25-news-flash.php

To be informed of an **improvement:** http://marine.copernicus.eu/web/35-product-improvements.php

Technical FAQ: http://marine.copernicus.eu/web/34-products-and-services-faq.php

WHO ARE THE MYOCEAN USERS

There are **4583** Users registered to MyOcean at the end of 2014. The graph below (Figure 3) shows the evolution over the years:

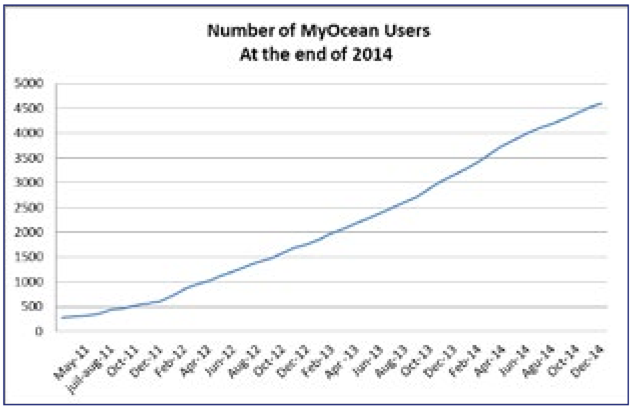


FIGURE 3

Number of users' evolution over the years – End 2014

Before January 2012, when User registered he/she should fill in a registration form and send it to the Service Desk, and the Service Desk created manually an account for the User.

From January 2012, when User registers he/she should fill in a registration form on line, and he/she is automatically registered.

In the figure 3, the slope of the curve increased after January 2012 when the online registration was proposed to Users (the increase of Users per month was lower before) and the trend is constant since this date. At the end of 2014 there are nearly 120 new registrations of Users per month.

In the registration form, the Users provide information as:

- User details (Name, Country ...)
- Organisation details (Name, Type ...)
- How the User intends to use the products (User application, area of benefit).

Then we can further analyze who are the MyOcean Users.

Their countries:

At the end of 2014 Users come from 118 countries. All EU countries and all continents are represented. The following graph (Figure 4) gives the most represented origin countries concerning all MyOcean Users:

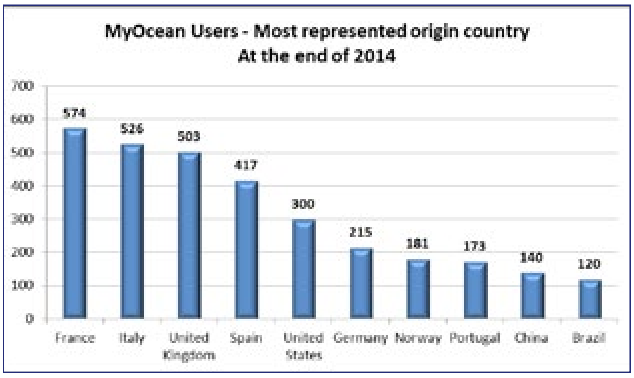


FIGURE 4

Most represented origin country of MyOcean Users – End 2014.

Their organisations:

Users are generally associated to organizations, and the total number of organizations identified since the beginning of MyOcean is **1450**.

The graph below (Figure 5) shows the distribution by type of organization of all Users registered in MyOcean (2009-2014):

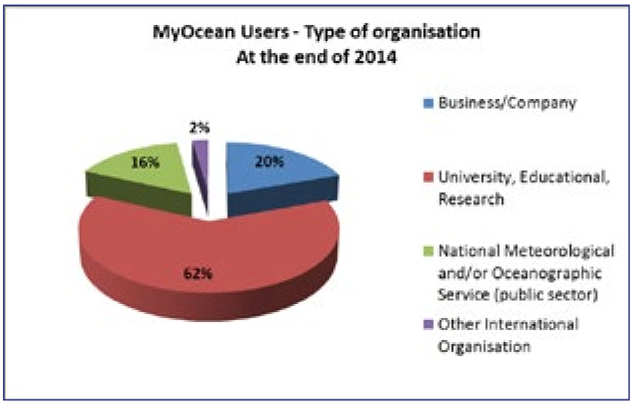


FIGURE 5

Type of organization of MyOcean Users – End 2014

More than a half of all Users (62%) come from "University, Educational & Research", 20% come from "Business/company" and 16% come from the "National and/or Oceanographic Service".

Their data usage:

The following graph (Figure 6) gives the distribution by User on how they declare to use the MyOcean data:

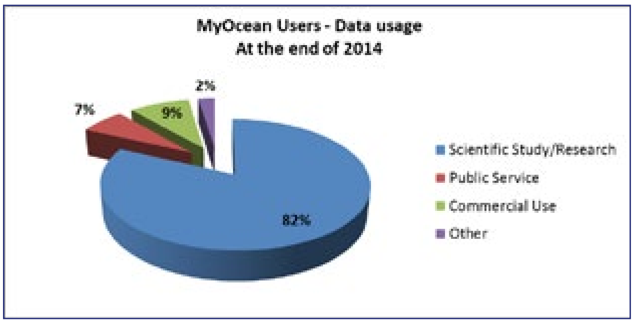


FIGURE 6

Data usage of MyOcean Users– End 2014

Users declare to use MyOcean data:

- for Scientific study/Research (82%),
- for Commercial Use (9%)
- for Public Service (7%)

Their area of benefit:

Users should declare the area of benefit where they intend to use the data:

- **Marine Safety**: any safe activities at sea including ship routing services (currents, ice), offshore operations, search & rescue operations, oil spill response & remediation.
- **Coastal Environment:** monitoring service at European and National levels with:

- Physical and marine biogeochemical components useful for water quality monitoring and pollution control, in the context of the Marine Strategy Framework Directive in particular.

- Sea level rise to predict coastal erosion.

- Sea surface temperature, one of the primary physical impacts of climate change and many marine ecosystems in European seas are affected by rising sea temperature.

- Currents useful for selecting locations for offshore windmill parks or thermal energy conversion fields.

- **Climate, Seasonal and Weather Forecasting**: reliable and robust data to the European and national meteorological services with

- Physical parameters of the ocean's surface used as boundary conditions for atmospheric models.

- Changes in sea ice extent, concentration and volume are signals used to detect global warming for instance.

- **Marine resources**: the protection and the sustainable management of living marine resources in particular for aquaculture, fishery research or regional fishery organisations and also any ecosystem-based approach to fish stock management.

The following graph (Figure 7) gives the distribution by area of benefit:

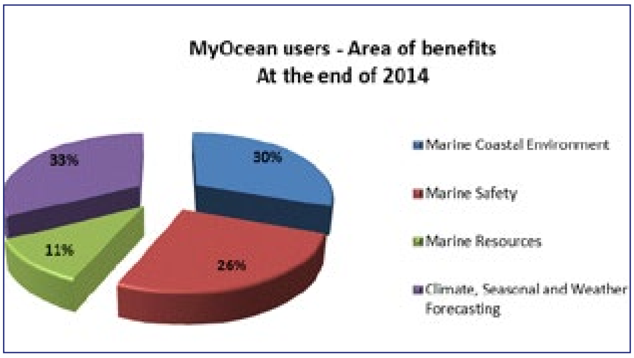


FIGURE 7

Area of benefits of MyOcean Users– End 2014.

Requests for MyOcean products are distributed almost equally between the 3 following applications, "Marine and Coastal Environment", "Marine Safety", and "Climate, Seasonal and Weather Forecasting" with around 30% each. "Marine Resources" represents 11%.

WHICH PRODUCTS DOWNLOAD THE MYOCEAN USER

The catalogue of MyOcean products is composed of 130 products with:

- model products (produced by Monitoring and Forecasting Centres - MFC)

-for Arctic (ARC)

-for Baltic (BAL)

-for Black Sea (BS)

-for Iberia Biscay Ireland Regional Seas (IBI)

-for European North West Shelf Seas (NWS)

-for Mediterranean Sea (MED)

-for Global (GLO)

- observation products (produced by Thematic Assembly Centres - TAC)

-for In Situ (INSITU)

-for Ocean Color (OC)

-for Sea Ice (SEAICE)

-for Sea Surface temperature (SST)

-for Sea Level (SEALEVEL)

-for Wind (WIND)

When a product is downloaded by a User, it is logged, so we can analyse how our products are used to be able to improve our service.

When analysing logs, we noticed that some Users come daily.

The following graph (Figure 8) provides an overview of the Users (all and daily) downloading products day after day:

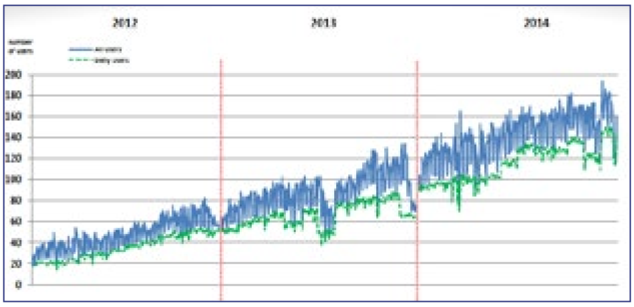


FIGURE 8

Area of benefits of MyOcean Users– End 2014.

Since the beginning of MyOcean, the number of Users downloading products has been regularly increasing.

And the following figure (Figure 9) shows the usage of products according to their family:

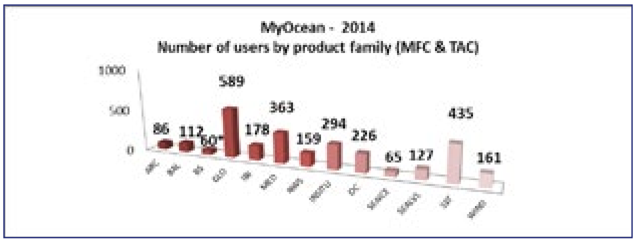


FIGURE 9

Number of users by product family during the year 2014

**note that due to the Ukrainian crisis, BS products were removed from the catalogue at the beginning of October 2014*

All product families proposed in the MyOcean catalogue are downloaded.

The products downloaded by the Users in 2014 represent:

1.5 Millions of transactions (HTTP/FTP): It is an increase of 200% compared to the previous year.

94 TeraBytes of data: it is an increase of 77% compared to the previous year.

HOW DO WE IMPROVE THE SERVICE TO MYOCEAN USERS

MyOcean is a User driven service. A process has been set up to collect the needs of the Users and to take them into account. It is composed of 3 steps:

We record User feedback

Whatever the feedback entrance (Service Desk, User Workshops, User Questionnaires, Meetings…) to MyOcean, the feedback is recorded in a table.

Records of User feedback started in July 2011 and have been done systematically since.

We analyse feedbacks

Analysis of feedbacks is done each 12-18 months to have enough feedbacks to take account on. The period of the analysis includes 1 User workshop and 1 questionnaire.

First analysis of User feedback covered a period of 11 months, from July 2011 to May 2012.

Second analysis covered a period of 19 months, from June 2012 to December 2013.

Third analysis covered a period of 16 months, from January 2014 to April 2015.

All feedback, status “open”, are considered as a whole and one compared to the others and raise to requirements or closure depending on the weight given to the requests.

Higher weight is given to:

- Same request from several Users

- Request from a regular User
- Request with common sense

than to other requests.

If one User requests several times the same need, it is counted only once.

Additional requests are closed if

- out of MyOcean service scope
- only 1 request of this type

For requests with these 2 grounds of closure, a record is kept over time to possibly be taken into account in future analysis.

We identify User requirements

According to the analysis we identify requirements to be implemented.

Once the User requirements have been accepted at Central level, these requirements are added in the requirement documentation, and planned in a version of the MyOcean service for implementation.

CONCLUSION

The MyOcean service opened at the end of 2009.

Since this date the number of Users increased regularly to reach nearly 4600 Users registered and 150 Users that downloaded data every day at the end of 2014.

The MyOcean Users downloaded more than 94 000 000 Mb in 2014.

***The MyOcean service opened at the end of 2009.
The MyOcean Users downloaded more than 94 000 000 Mb in 2014.***

The satisfaction of MyOcean Users is met, through the MyOcean questionnaires we notice that:

- MyOcean Users appreciate Service Desk support
- MyOcean Users find easy to access to the web Catalogue -products section
- MyOcean Users appreciate the scientific quality
- MyOcean Users appreciate the product availability
- MyOcean Users appreciate information about service outages
- MyOcean Users appreciate information about releases

The main User requirements identified during MyOcean are a basis for the Copernicus Marine Service:

- To have additional products specially waves
- To have product time series longer than 20 years
- To enhance and harmonise the products and the catalogue
- To ease the download of large volume of products
- To provide more information on the products: production line and scientific quality for both scientific Users and non-scientific ones
- To define and build the interface with the coastal community Users, including MSFD...

The MyOcean demonstration phase enabled to open the service on a pre-operational mode during 6 years. And its success allowed switching to Copernicus Marine Environment Monitoring Service (CMEMS) on an operational mode.

ACKNOWLEDGEMENTS

The authors wish to thank all the partners of MyOcean for their contribution in the MyOcean Service.

REFERENCES

MyOcean Follow On – *Service Monitoring Report 2014 [MYOF-SCE-SMR-2014] 18/02/2015 V1.0* - Anne Delamarche, Cédric Giordan

EVOLUTION OF THE CATALOGUE OF PRODUCTS DURING MYOCEAN2 AND MYOCEAN FOLLOW-ON

BY

L. CROSNIER(1) AND THE TAC/MFC WORK PACKAGE LEADERS : L. BERTINO(2), Y. DRILLET(1), V. HUESS(3), M. SOTILLO(4), M. TONANI(5), Y. FAUGERE(6), R. SANTOLERI(7), L.A. BREIVIK(8), S. POULIQUEN(9)

ABSTRACT

The Copernicus Marine Environment Monitoring Service (CMEMS) catalogue of products (marine.copernicus.eu/) fully inherits from the Myocean catalogue. It holds Oceanographic Products from Models (Oceanic General Circulation Numerical Models) and Observations (from Satellite and Insitu sensors). During the MyOcean2 (MYO2) and MyOcean Follow-On (MYOFO) projects time periods, every product has been fully described on the web portal and user oriented synthetic overviews have been created (one for model products, another one for observation products from satellite and in-situ). A dedicated product search engine tool has been provided to users on the web portal in order to better target their product search according to their needs. Documentation as Product User Manual have been updated and made available to users for every single product. Online tutorials and a collaborative forum were also provided helping users to register, discover, search, view and download products.

[1] **MERCATOR OCEAN,** Ramonville St Agne, France
[2] **Nansen Environmental and remote Sensing Centre**, Bergen, Norway
[3] **Danmarks Meteorologiske Institut, Center for Marine Forecasting,** Kopenhagen, Denmark
[4] **Puertos del Estado,** Madrid, Spain
[5] **Istituto Nazionale di Geofisica e Vulcanologia,** Bologna, Italy, (now at Met Office, Exeter, UK)
[6] **Collecte Localisation Satellites (CLS),** Toulouse, France
[7] **National Research Council (CNR),** Rome, Italy
[8] **Norwegian Meteorological Institute (MET Norway),** Oslo, Norway
[9] **IFREMER, Plouzané,** France

THE CATALOGUE OF PRODUCTS

The Copernicus Marine Environment Monitoring Service (CMEMS) catalogue of products (marine.copernicus.eu/) currently holds 135 ocean products from models and observations. It fully inherits from the Myocean catalogues. It contains L3 and L4 observation products as well as numerical model products which are built in the following way: After data acquisition from the ground segment of the space-based (with processing levels L1 and L2) and in situ networks as well as acquisition of atmospheric forcing data (winds, temperatures, fluxes) from National Meteorological Services, data is processed into quality-controlled datasets with processing levels L3 and L4) at Thematic Data Assembly Centers (TAC hereafter) (sea surface temperature, ocean colour, sea level, sea ice, winds and in-situ data) and runs numerical ocean models in near real time assimilating the above thematic data to generate analyses and forecasts (in Monitoring and Forecasting Centers, MFC hereafter) for the Arctic Ocean, Baltic Sea, Atlantic European North West Shelf, Atlantic Iberian Biscay Irish Ocean, Mediterranean Sea, Black Sea and Global ocean. Reprocessing (for TAC) and reanalysis (for MFC) are also performed.

Other indicator over the last 10 or 20 years for sea ice extent trend, sea level trend, chlorophyll trend and heat content have also been introduced on the website (http://www.myocean.eu/web/105-specific-scientific-developments.php).

Users can download products according to their needs in a unique format (NetCDF) and benefit from quality and validation information for each of them. Seven geographical areas are covered: Global Ocean, Arctic Ocean, Baltic Sea, European North-West Shelf Seas, Iberia-Biscay-Ireland Regional Seas, Mediterranean Sea and Black Sea. Ten parameters are displayed: Temperature, Salinity, Currents, Sea Ice, Sea Level, Wind, Ocean Optics, Ocean Chemistry, Ocean Biology and Ocean Chlorophyll, for both Near Real Time (including Forecast for models) and Multi Year categories.

PRODUCT OVERVIEWS

Two PDF printable product overviews (one for model products, another one for observation products from satellite and in-situ) (figure1) summarizing the product content in terms of parameters, horizontal and vertical resolutions, temporal coverage, temporal resolution and update frequency have been created during MYOFO. They are available online and updated regularly, along with each product update. Those 2 overviews result from the collaboration of each production center Product Managers allowing a synthetic centralization of every single product description.

MULTIYEAR MODELS

AREA — Models for areas NWS IBI and BALTIC include tidal component, meaning that all parameters include tide signal, especially UV and SSH.

PRODUCTS — CHARACTERISTICS

AREA		REFERENCES (links to online catalogue form)	PARAMETERS	HORIZONTAL AND VERTICAL RESOLUTIONS	TEMPORAL COVERAGE [START DATE; END DATE]	TEMPORAL RESOLUTION	UPDATE FREQUENCY	DATA ASSIMILATED
GLOBAL	Phy	001_009	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1993;15/12/2013]	M+D	A	●●●●
		001_011	T S UV SSH ICE	1/4°-25km; 50 levels	[01/15/1992;15/12/2013]	M+D	A	●●●●
		001_010	T S UV SSH ICE	1/4°-25km; 75 levels	[15/01/1993;15/12/2010]	M	NU	●●●●
		001_017	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1979;15/12/2013]	M+D-5D	A	●●●●
		001_004	T S UV SSH ICE	1/4°-25km; 75 levels	[16/01/1993;16/12/2011]	M	NU	
	Bio	001_018	CHL O2 NP PhytoPP Si Fe	1/4°-25km; 75 levels	[15/01/1998;15/12/2013]	M	A	
		001_019	CHL O2 NP Si	1/4°-25km; 50 levels	[15/01/1998;15/12/2013]	M	A	
ARCTIC	Phy	002_003	T S UV SSH ICE MLD	12.5km; 12 levels	[15/01/1991;15/12/2013]	M	A	●●●●
	Bio	002_005	CHL O2 NP PhytoRadflux	25 km; 12 levels	[15/01/2007;15/12/2010]	M	NU	●●●●
BALTIC	Phy	003_008	T S UV SSH ICE	3nm-5.5km; 50 levels	[01/01/1989;31/12/2013]	M+H+6H	A	●●●
		003_004	T S UV SSH ICE	6nm-11km; 25 levels	[01/01/1990;31/12/2009]	M	NU	●
		003_005	T S UV SSH ICE	3 nm-5.5km; 25levels	[01/01/1990;31/12/2009]	M	NU	●●●
	Bio	003_009	CHL O2 NP NH4	2nm-3.7km; 83 levels	[01/01/1970;31/12/1999]	M+2D	NU	●
NWS European North West Shelf Seas	Phy	004_009	T bedT S UV	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_005	T S UV SSH	12 km; 24 levels	[01/01/1960;31/12/2004]	M	NU	
		004_006	T S UV SSH	12 km; 24 levels	[15/01/1985;15/12/2008]	M	NU	
		004_010	T S UV SSH	8 km ; 26 levels	[01/01/1993;31/12/2009]	M	A	●
	Bio	004_011	CHL O2 NP PhytoPP RadFlux	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_007	CHL O2 NP PhytoPP RadFlux	12 km; 24 levels	[01/01/1967;31/12/2004]	M	NU	
		004_008	O2 N P Phyto PP Si	12 km; 24 levels	[31/01/1985;31/12/2008]	M	NU	
		004_012	O2 N P Phyto PP Si	8 km; 26 levels	[01/01/1993;31/12/2009]	M	A	●
IBI Iberia Biscay Ireland Regional Seas	Phy	005_002	T S UV SSH	1/12°-7.5km; 50 levels	[01/01/2002;23/12/2011]	M+D+H	NU	●●●
	Bio	005_003	CHL O2 NP PhytoPP Si Fe NH4 Eup	1/12°-7.5km; 50 levels	[01/01/2002;23/12/2011]	M	NU	●●●
MED Mediterranean Sea	Phy	006_004	T S UV SSH	1/16°-6km; 72 levels	[01/01/1987;31/12/2013]	M+D	A	●●●
	Bio	006_008	CHL O2 NP PhytoPP	1/16° 6km; 72 levels	[01/01/1999;31/12/2012]	M	A	●●●●

MULTIYEAR OBSERVATIONS

AREA	PRODUCTS: DATA SOURCE	REFERENCES (link to online catalogue here)	PARAMETERS	HORIZONTAL AND VERTICAL RESOLUTIONS	TEMPORAL COVERAGE [START DATE; END DATE]	TEMPORAL RESOLUTION	UPDATE FREQUENCY	PROCESSING LEVELS
GLOBAL	SATELLITE	008_018	SLA	7km,14km; 1 level (surface)	[25/09/1992; 22/04/2015]	D	TwiceA	L3 along swath mono sensors
		008_013	MDT	25km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		008_015	MSS	3km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		008_027	SLA	25km; 1 level (surface)	[01/01/1993; 22/04/2015]	PA	NU	L4 gridded merged sensors
		008_032	SLA_NOISE_NRT	200km; 1 level (surface)	N/A	PA	NU	L4 gridded mono sensors
		008_033	SLA_NOISE_REP	200km; 1 level (surface)	N/A	PA	NU	L4 gridded mono sensors
		008_034	SLA_REF	25km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		009_065	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		009_064	OPTICS	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		010_011	SST SIC	5km, 25km; 1 level (surface)	[01/01/1985; 31/12/2007]	D+M+S	NU	L4 gridded merged sensors
		011_009	SIC	12.5km; 1 level (surface)	[25/10/1978; 31/10/2009]	D	NU	L4 gridded merged sensors
		012_003	WIND	25km; 1 level (surface)	[16/05/2007; 16/04/2012]	M	A	L4 gridded merged sensors
	INSITU	013_001_b	T S	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
		013_002_b	T S	50km; 152 levels	[01/01/1990; 31/12/2013]	M	A	L4 gridded merged platforms
	SATELLITE&INSITU	001_013	T S UV gH	25km; 33 levels	[01/01/1993; 31/12/2012]	W+M	A	L4 gridded merged sensors and platforms
ARCTIC	SATELLITE	009_069	CHL	1km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		009_068	OPTICS	1km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		011_010	SID	50km; 1 level (surface)	[01/10/1999; 30/04/2012]	D	A	L3 gridded mono and merged sensors
	INSITU	013_037	T S	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
BALTIC	SATELLITE	010_016	SST SIC	3km; 1 level (surface)	[01/01/1982; 31/12/2009]	D	NU	L4 gridded merged sensors
		009_080	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L4 gridded merged sensors
	INSITU	013_038	T S	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
NORTH ATLANTIC	SATELLITE	009_067	CHL	1km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		009_066	OPTICS	1km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
EUROPE NWS IBI	INSITU	013_043	T S (NWS)	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
		013_040	T S (IBI)	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
MED Mediterranean Sea	SATELLITE	008_020	SLA	7km,14km; 1 level (surface)	[25/09/1992; 22/04/2015]	D	TwiceA	L3 along swath mono sensors
		008_014	MDT	12km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		008_029	SLA	12km; 1 level (surface)	[01/01/1993; 22/04/2015]	PA	NU	L4 gridded merged sensors
		008_035	SLA_REF	12km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		009_073	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		009_078	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L4 gridded merged sensors
		010_021	SST	4km; 1 level (surface)	[01/11/1981; 31/12/2012]	D	A	L4 gridded merged sensors
	INSITU	013_041	T S	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms
BS Black Sea	SATELLITE	008_023	SLA	7km; 1 level (surface)	[25/09/1992; 22/04/2015]	D	TwiceA	L3 along swath mono sensors
		008_031	SLA	12km; 1 level (surface)	[01/01/1993; 22/04/2015]	PA	NU	L4 gridded merged sensors
		008_036	SLA_REF	12km; 1 level (surface)	N/A	PA	NU	L4 gridded merged sensors
		009_071	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L3 gridded merged sensors
		009_079	CHL	4km; 1 level (surface)	[04/09/1997; 31/07/2012]	D	A	L4 gridded merged sensors
		010_022	SST	4km; 1 level (surface)	[01/11/1981; 31/12/2012]	D	A	L4 gridded merged sensors
	INSITU	013_042	T S	N/A	[01/01/1990; 31/12/2013]	D	A	L2 discrete mono platforms

FIGURE 1

Two PDF printable product overviews (top panel: one for model products, bottom panel: another one for observation products from satellite and in-situ) summarizing the product content in terms of parameters, horizontal and vertical resolutions, temporal coverage, temporal resolution and update frequency have been created during MYOFO. Here, a status of the catalogue is given in April 2015. Click on the following links for the present CMEMS status model products and observation products

GLOBAL EVOLUTION OF THE CATALOGUE

During the MYO2 and MYOFO time periods (18 and 8 months long respectively), the content of the catalogue of product has been evolving regularly. In this section, we provide with a quantitative summary, as a contrary to qualitative, of product updates and creations during MYO2 and MYOFO using 4 criteria: i) How many products have been created in the catalogue? ii) How many products have their numerical code or algorithm improved? iii) How many products take into account new upstream data? iv) How many products increase the length of their time series?

In terms of product creation, a total of 50 and 13 products in respectively MYO2 and MYOFO (resp. 38% and 9% of the catalogue) have been created, some superseding older products which have then been removed from catalogue. Those figures reflect the large scientific effort performed allowing producing such a product renewal rate.

In terms of product update, 36 and 48 products in respectively MYO2 and MYOFO (resp. 28% and 37% of the catalogue) had their numerical code or algorithm updated. Although the MYOFO time duration was very short, the large amount of product updated during this time period shows the great reactivity and mobilization of the Research and Development (R&D) teams.

Figure2 shows for example the evolution between the beginning of MYO2 and the end of MYOFO of the numerical codes used to run the GLO and MED MFC models. We note for example from Figure2 that, between MYO2 and MYOFO, the Global near real time physics code has increased its horizontal resolution from 1/4° to 1/12° and that the Global reanalysis has switched from Nemo3.0 (Glorys1v2) to Nemo3.1 (Glorys2v3) code. Similarly, the MED MFC codes have evolved and switched from 1/8° to 1/16° horizontal resolution for the biogeochemical near real time model, and for the physics and biogeochemical reanalysis as well. The near real time physics code is coupled to WaveWatchIII code instead of WAM previously. We also note that 4 new products have been created in the GLO MFC during this time period. The transfer of R&D into the operational systems has hence proved to be effective during the MYO2 and MYOFO periods and led to a large evolution of the product and its scientific quality.

Last column of the model products overview (see also Figure1 giving the status at the end of MYOFO) shows which data is assimilated into the MFC models. Conventional observations are assimilated and displayed with color plain circles: Sea Surface Temperature (black plain circles), Insitu Temperature and Salinity profiles (purple), along track sea level anomalies (red), gridded sea ice concentration (orange) and satellite chlorophyll (green). A large effort was provided to assimilate more conventional data between MYO2 and MYOFO (not shown), although data assimilation of all the above observations still need to be generalized for each product, as for example satellite chlorophyll data into biogeochemical models. There is also a need to work on assimilation of new generation of satellite and Insitu observations, with for example new Insitu parameters sampled by the new generation of sensors, SAR sea ice data from sentinel-1 or new generation of satellite altimetry data(SAR altimetry from Sentinel-3 and later SWOT data).

New available upstream data have been integrated into 60% and 10% of the products during respectively the MYO2 and MYOFO time periods, both in products originating from TAC (new upstream data ingested) and MFC (more data taken into account in data assimilation systems). The difference of percentage between MYO2 and MYOFO lies in the difference of availability of new satellite during the given period, and also on the occurrence of the death of the Envisat satellite during MYO2. Indeed, in April 2012, right after the beginning of MYO2, ENVISAT satellite died, hence impacting 60% of the products, especially for Ocean Colour, Sea Level, Sea Surface Temperature and Sea Ice near real time TACs products, as well as MFCs. Hence, a large effort within the MYO2 time period has been spent in order to fill in the gap with new upstream satellite data. Such an effort was reduced during MYOFO where a better satellite continuity was found.

Figure3 shows which upstream data source has been integrated during the MYO2 (in blue) and MYOFO (in red) time periods for the TACs only. As commented earlier, the death of Envisat at the beginning of MYO2 has forced the Sea Level, Ocean Colour and SST TAC to switch to other satellite sensors. For example, Cryosat2, Saral and HY2A altimeters have been implemented in the Sea Level TAC during MYO2 (Figure 3).

In terms of reanalysis or reprocessing products, 18 and 17 products during resp. MYO2 and MYOFO (about 15% of the catalogue in both cases) have been rerun in order to extend their temporal coverage towards present days. Although the MYOFO project length was short, a large effort was dedicated to updating multiyear time series, in order to provide users with no data gap between a multi year and its corresponding near real time product. Note that the need for annual update of reanalysis and reprocessing products has been kept as a strong requirement in the CMEMS service.

	Near Real Time			**Multi Year**					
	PHY		**BIO**	**PHY**				**BIO**	
GLOBAL MYO2	NEMO3.1 SEEK and 3DVAR (large scale TS) DA 1/4° 50lev		[NEMO3.1]NEMO3.2-PISCES/offline 1/2° 50 lev	NEMO3.0-Glorys1v2 with SEEK 3DVAR (large scale TS) DA 1/4° 75lev	NEMO3.2-Cglors 3Dvar DA 1/4° 50lev	NEMO3.2-UR025 OI DA 1/4° 75lev			
GLOBAL MYOFO	NEMO3.1-LIM SEEK and 3DVAR (large scale TS) DA **1/12°** 50lev	**NEMO3.2** **coupled with atm UM-N216 with CICE. NEMOVAR-3Dvar DA** **1/4°** **43lev**	[NEMO3.1]NEMO3.2 PISCES/offline 1/2° 50 lev	**NEMO3.1-Glorys2v3** with SEEK 3DVAR (large scale TS) DA 1/4° 75lev	NEMO3.2-Cglors 3DVar DA 1/4° 50lev	NEMO3.2-UR025 OI DA 1/4° 75lev	**NEMO3.4-ORAP 5** **NEMOVAR 3Dvar-FGAT DA** **1/4°** **75lev**	**[NEMO3.1]NEMO3.5-PISCES** **/offline (no DA)** **1/4°** **75lev**	**[NEMO3.4]BFM** **/offline (no DA)** **1/4°** **50lev**
MED MYO2	NEMO 3.4 OceanVar DA Coupled to WAM 1/16°72levels		[NEMO3.4]OPABFM/offline OceanVar 1/8° 72 levels	NEMO 2.3 OceanVar DA 1/8° 72 levels				[NEMO]OPATM BFM/offline OceanVar DA 1/8° 72 levels	
MED MYOFO	NEMO 3.4 OceanVar DA Coupled to **WaveWatchIII** 1/16°72levels		[NEMO3.4]OPABFM/offline OceanVar **1/16°** 72 levels	NEMO 2.3 OceanVar DA **1/16°** 72 levels				[NEMO]OPATM BFM/offline OceanVar DA **1/16°** 72 levels	

FIGURE 2

Evolution for GLO and MED MFC of the near real time and reanalysis numerical ocean codes between the beginning of MyOcean2 and the end of the MyOcean-Follow-On projects.

SEA LEVEL	OCEAN COLOUR	SST	WIND	SEA ICE	INSITU
TOPEXPOSEIDON/ALT	SEASTAR/SEAWIFS ENVISAT/MERIS AQUA/MODIS	ENVISAT/AATSR ERS-1/ATSR ERS-2/ATSR	ERS-1-2/SCATTERO	ENVISAT/SAR	SEADATANET
ENVISAT/RA-2	SUOMI-NPP/VIIRS	NOAA-19/AVHRR	QUIKSCAT/SEAWINDS	OCEANSAT-2/OSCAT	ENACTV4
ERS-1-2/ALTIMETER	SENTINEL3/OLCI	METOP-A/AVHRR	OCEANSAT-2/OSCAT	CRYOSAT2	ArcticROOS
JASON-1/POSEIDON-1		MSG2/SEVIRI GOES-East/Imager	METOP-A-B/ASCAT	METOP-AB/AVHRR-ASCAT	BOOS/NOOS
GFO/Radar Altimeter		DMSP-F15/SSM-I AQUA/AMSR-E	RAPISCAT/ASCAT	NOAA/AVHRR	IBIROOS
Geosat/Radar Alti		TRMM/TMI	HY2A/SCATTERO	DMSP/SSMI	MOON
JASON-2/POSEIDON-2		SUOMI-NPP/VIIRS	CFOSAT/RFSCAT	AQUA/AMSR	BlackSeaGOOS
CRYOSAT-2/SIRAL		METOP-B/AVHRR		LANDSAT7-8/LDCM	ARGO
SARAL/ALTIKA		SENTINEL3/SLSTR GCOMW1/AMSR2		SMOS	DBCP
HY2A/ALTIMETER				RADARSAT12/SAR	GTS/GTSPP
SENTINEL3/SARalti JASON-3/ALTI				COSMOSKYMED/SAR	FERRYBOX NDBC
SWOT/KARIN+ALTI				TERRASARX/SAR	
JASON-CS/ALTI				TANDEMX/SAR	
				SENTINEL1/SAR	
				SENTINEL3/SLST OLCI	

FIGURE 3

This table shows which upstream data source (either satellite or Insitu) has been integrated during the MYO2 (in blue) and MYOFO (in red) time periods for the TACs only. Grey colour text shows upstream sources already in use at the beginning of MYO2 and black colour text shows upstream sources likely to be integrated in the near future (CMEMS).

STATISTICS ON PRODUCTS

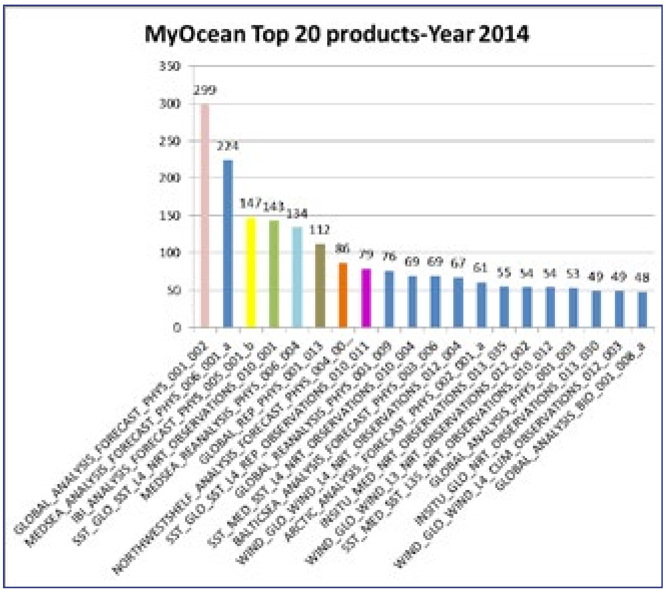


FIGURE 4

Top20 products for year 2014 in terms of number of users

Figure4 shows the TOP20 products during the year 2014 in terms of number of users. We note that:

- Most successful products are **model physics products**: physical analysis and forecast products for the Global Ocean, Mediterranean Sea, Iberia-Biscay-Ireland Regional Seas are ranked 1, 2 and 3 respectively. European North-West Shelf Seas, Baltic Sea, Arctic Ocean (ranked 7, 11 and 13 respectively) are also of large interest for users. For near real time biogeochemistry products, the user interest is lower: the Global near real time biogeochemistry product is ranked 20. Nevertheless, the user interest shall strengthen in the future as those products are "new on the market". User interest in physical reanalysis products is also high with Mediterranean Sea and Global Ocean reanalysis ranked 5 and 9 respectively. The success of models products shall be explained by the fact that they are value added product as a comparison with observations products: they cover the whole water column in 3D; they are gridded with a wide range of parameters. They also provide with forecast while this is not the case for observations products.
- Near Real Time **Sea Surface Temperature** satellite observation products for the Global Ocean and Mediterranean Sea are also successful with rank 4 and 10 respectively. Reprocessed SST for Global Ocean is ranked 8. Sea Surface Temperature is part of the basic oceanic parameters and is delivered to users since a long time (way before the MyOcean projects). It is hence very popular among users.
- **Wind** products are ranked 12, 15 and 19 for the Global L3 and L4 near real time, as well as the reprocessing respectively. Although there are few Wind products in the catalogue, they seem quite popular among users.
- **In Situ** near real time product over Mediterranean Sea and Global Ocean are ranked 14 and 18; Global Observed Ocean Physics reprocessing and processing (combining In Situ and Sea Level satellite data) are also successful with rank 6 and 17 respectively.

NEW SEARCH CRITERIA

Along with every single product description available on the web portal, a search engine is also available allowing a user to focus on its specific need. In June 2014, an advanced search engine was added on the web portal allowing searching products using new criteria such as geographical area, parameter, time coverage, observations or models, vertical coverage, processing level. This has improved greatly the navigation through the catalogue and allowed detailed and focused search of products.

PRODUCT DOCUMENTATION

A large effort was also provided during the MYO2 and MYOFO period in order to keep the Product User Manual documentation up to date and available to users.

TRAININGS

Thematic training workshops (e.g.: A workshop for the Arctic and Global MFC has taken place in Bergen in March 2015) were organized all along the MYO2 and MYOFO project duration, in order to help user understand better the content and usefulness of each product. Online tutorials and collaborative forum were also provided helping users to register, discover, search, view and download products..

CONCLUSION

During the MyOcean2 (MYO2) and MyOcean Follow-On (MYOFO) project time periods, a large effort was provided by each production center in order to describe accurately each product on the web portal: Online Product Sheet, Synthetic Overviews, Product User Manual and Tutorials were developed. The popularization of the CMEMS catalogue still needs some efforts in terms of product description and display in order to now reach a larger panel of users, especially those coming from non ocean-expert communities.

The popularization of the CMEMS catalogue still needs some efforts in terms of product description and display in order to now reach a larger panel of users, especially those coming from non ocean-expert communities

ACKNOWLEDGEMENTS

The work described here was carried out in the MyOcean2 and MyOcean Follow-On projects, which were funded in part by the European Union under the 7th Framework Programme and Horizon 2020, respectively. The support is gratefully acknowledged.

MAIN ACHIEVEMENTS ON MYOCEAN GLOBAL AND REGIONAL PREDICTION SYSTEMS

BY

M. TONANI(1,4), E. ALVAREZ FANJUL(2), L. BERTINO(3), E. BLOCKEY(4), Y. DRILLET(5), V. HUESS(6), G. KOROTAEV(7)

ABSTRACT

Seven Monitoring and Forecasting Centres (MFC) have been set up at the beginning of the MyOcean project to provide ocean forecast, analysis and reanalysis products at the global and the regional scale. This paper describes the characteristics and the evolution of each of these MFCs during the years of the MyOcean projects. All these systems have been able to increase the number and the quality of the products delivered to the MyOcean users, during the pre-operational phase of the Copernicus Marine Service.

[1] **Istituto Nazionale di Geofisica e Vulcanologia,** Bologna, Italy
[2] **Puertos del Estado,** Madrid, Spain
[3] **Nansen Environmental and remote Sensing Centre,** Bergen, Norway
[4] **Met Office,** Exeter, UK
[5] **MERCATOR-OCEAN,** Toulouse, France
[6] **Danmarks Meteorologiske Institut, Center for Marine Forecasting,** Kopenhagen, Denmark
[7] **MHI**

INTRODUCTION

One of the major goal of the MyOcean project was to monitor the Global ocean and the European seas with an eddy resolving capacity, based on assimilation of space and in situ data into 3D models, representing the physical state, the ice and the ecosystems of the ocean; in the past (25 years), in real-time and in the future (1-2 weeks). The high quality products will rely on the aggregation of European modelling tools and the scientific methodology will be produced through a strong cross-fertilisation between operational and research communities (MyOcean Description of Work). Therefore since the beginning of the project, seven Monitoring and Forecasting Centers (MFC) has been dedicated to the Global Ocean, the Arctic area, the Baltic Sea, the Atlantic North-West shelves area, the Atlantic Iberian-Biscay-Ireland area, the Mediterranean Sea and the Black sea respectively. Each MFC is lead by the Institute shown in figure 1, with the collaboration of the other institutions which play a key role in that area.

FIGURE 1

Geographical distribution of the MFCs leading centers and ocean geopraphical domain covered by each of the seven system.

From the beginning of Myocean, till the end of MyOcean Follow-On these seven MFCs have delivered model products on the state of the global ocean and the regional seas at the resolution required by intermediate users and downstream service providers. These MFCs have therefore continuosly evolved their prediction system increasing the resolution of the models, the number of observation assimilated, the processes resolved by their models and the temporal and space resolution of their products. This effort has made possible through the years to keep the systems able to deliver 'state of the art' products (Bahurel et al., 2009 and MyOcean DoW).

The MFCs together with the Thematic Assembly Centers (TACs), dedicated to ocean in situ and satellite observations (Hacket et al., this issue), constitute the Production Centres of MyOcean and since May 2015 of the Copernicus Marine Environment Monitoring Service (marine.copernicus.eu).

This paper describes the characteristics of each MFC and its evolution from the beginning of MyOcean.

MFCS EVOLUTION

The evolution and the characteristics of each MFC are described in the following sections.

Global MFC

Objectives of the Global Monitoring and Forecasting Center (GLO MFC) at the beginning of MyOcean project was to build a global real time forecasting system based on heritage of previous Mersea project where demonstration of feasibility has been performed. The GLO MFC should deliver near real time forecasts and also global ocean reanalysis. The real time forecasting system was initially designed taking into account scientific and technical requirements and state of the art knowledge of ocean model and data assimilation technic which are the main component of a forecasting system. The system should describe the global ocean from the surface to the bottom with a resolution allowing the good representation of ocean mesoscale structures and in agreement with the current available observations. This global system should answer to user requirements as for example applications using ocean surface fields (currents, sea surface temperature or sea level anomalies) and also to constrain higher resolution regional or coastal model developed everywhere in the world. This has been done internally in MyOcean as the Iberian, Biscay and Irish Sea and the Mediterranean Sea systems are already embedded in the global system. One of the major constrain in real time forecasting being the computational resources needed to provide forecast with acceptable delay for users, the global system has been developed in several phases following the development protocol put in place in the MyOcean project. Continuity of the service has been ensure during evolution and continuous improvement of the system based has been based on state of the art knowledges. The main characteristics of the versions and associated products are presented on the Figure2. The global forecasting systems are since the beginning based on the NEMO model (Madec et al, 2008) with upgrade of the model version and use of different parameterisations. The baseline of the global configurations is described in Barnier et al, 2006. One major improvement during this period concern the development of the global 1/12° configuration (Lellouche et al, 2013) based on the same model and using nearly the same characteristics (Z-level with partial step, filtered free surface), parameterisations (CORE bulk formulae, tidal mixing parameterisation), numerical schemes (TVD advection scheme, isopycnal or bilaplacian diffusion operator). Specific work has been realized on the vertical mixing scheme using tke or k-ε formulation, sea ice modeling with evolution of the LIM2 model using the EVP rheology, improvement of the atmospheric forcing frequency and representation off the diurnal cycle in the model. The other major improvement concerns the development of the ocean atmosphere coupled capability (Williams et al, 2015) using the NEMO global ocean configuration at ¼° and the Atmospheric Unified Model at 50km of resolution. The ocean sub-component of coupled system is initialised using an ocean analysis provided from the Met Office Forecast Ocean Assimilation Model (FOAM) as described in Blockley et al. (2013). The atmosphere component of the coupled forecast differs both in resolution and very slightly in scientific configuration from the operational NWP model providing the forcing for ocean-only analysis. The resolution in the coupled forecast system is ~50 km whereas the forcing for the ocean-only analysis is ~17 km. Data assimilation systems used in these different forecasting systems have also evolved during the MyOcean projects. Main physical available observations were assimilated in the global system since the beginning (insitu temperature and salinity profiles, sea surface temperature and sea level anomaly), but methods and tuning have largely evolved. A Kalman filter approach (SAM2, Lellouche et al, 2013) was used in the global high resolution forecasting system and a 3Dvar approach (Waters et al., 2014) in the ocean atmosphere couple system. To complete the global product list a biogeochemistry system has also been developed, it is operated since 2012 and an increase of resolution occurs in 2014. This system is based on the PISCES biogeochemistry and ecosystem model (Aumont and Bopp, 2006) forced in an offline mode by the global physical system. However, a system not base on ocean model but combining temperature and salinity in situ profiles, sea surface temperature maps and sea level anomalies provides weekly estimates of the global ocean (Guinehut et al,2012). Temperature and salinity fields at 1/3° were delivered at the beginning of MyOcean, geostrophic velocities (Mulet et al, 2012) has been added and finally higher resolution products at ¼° are now delivered. All these systems and the products which are delivered to users are documented (Regnier et al, 2015, Guiavarch et al, 2015, Perruche et al, 2015, Guinehut et al, 2015). Their complementarity is useful for users and for developers involved in the improvements of the GLO MFC. The Figure 3 illustrates one example over the North Atlantic area of the 3 near real time physical products currently available in the CMEMS catalogue. First fact is that at basin scale the 3 products provide coherent information. The maximum of salinity in subsurface (50m depth in this example) in June 2015 in the subtropical gyre is located at the same position and has the same level of magnitude (>37.5psu). The main fronts on this area are also consistent between the 3 products as for example the Azores front, the Gulf Stream, the North West Corner or the North Atlantic current.

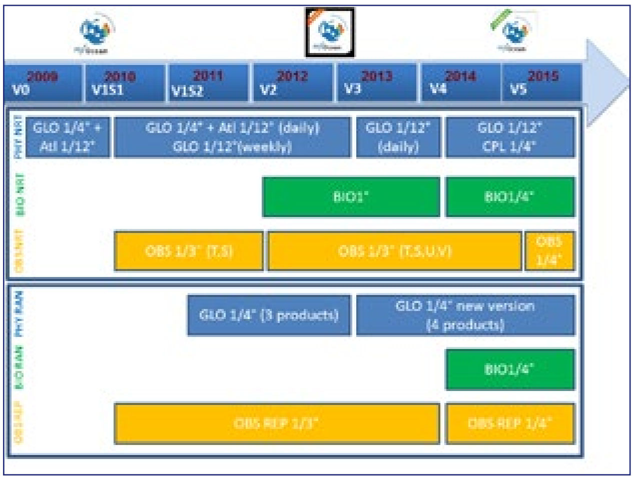


FIGURE 2

Main evolution of the global monitoring and forecasting systems during the MyOcean projects

Main differences concern, as it is expected, the resolution of the 3 products, meso scale structures, especially along the fronts but also in the center of the subtropical gyre, are more intense in the high resolution system (1/12°, left panel) than in the couple system (1/4°, middle panel) and even more than in the multi observation product. But several meso scale patterns (the bigger ones) are present in the 3 products showing that data assimilation of the observations (and especially the altimetry) allows a good constrain on the dynamical field. It is not necessary the case for smaller eddies (as for example the 2 warm eddies or meanders north of the Gulf Stream along the American coast) which are clearly identifies as coherent structures in the high resolution system but could be view as meander of the Gulf Stream in the lower resolution products. Difficulties is now to validate all the available products in comparison with the available ocean observations which currently doesn't sample the small ocean meso scale and the vertical thermohaline structure of the global ocean. A protocol based on several metrics has been defined during MyOcean in consultation between ocean modelers and observers and Estimated Accuracy Number (EAN) are documented in the QUID documentation and are regularly produced and published on the CalVal website (http://marine.copernicus.eu/web/103-validation-statistics.php).These EANs provide interesting informations for users which are "as far from available observations the products are?" and "what are the differences of the available forecast length?". To illustrate this point and to give an order of magnitude of RMS errors at global scale of the GLO MFC products few EAN are given in the Table 01, but full list including regional estimates are available in the documentation and in the web site. Global ocean reanalysis have also been produced and disseminated in the GLO MFC and some informations are given on Fig. 02, but the systems and the products are not described in this section dedicated to the near real time production. Nevertheless, the same validation protocol and documentation of the products are available for the global reanalysis.

Ocean Variable	**SST (°C)**	**SLA (cm)**	**Temperature (°C)**	**Salinity (psu)**
RMS error	0.35-0.63	6.4-9	0,33-0,6	0.12-0.17

Table 1

Estimated Accuracy Number computed with the global high resolution at the global ocean atmosphere coupled forecasting system at global scale. RMS differences between model estimate and available observation is computed for both system and several forecast lengths (from 1 to 5 days). Update of the Estimated Accuracy Number is regularly published on http://marine.copernicus.eu/web/103-validation-statistics.php To conclude, the MyOcean projects have allows large

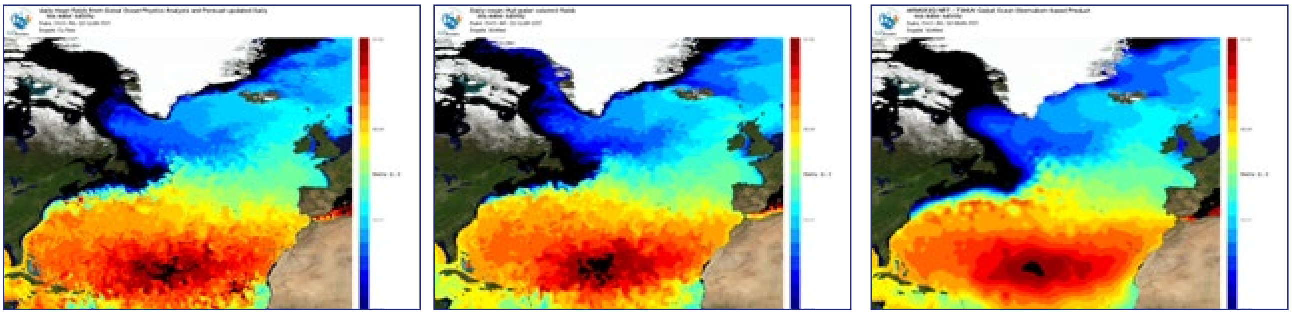


FIGURE 3

Figures from the MyOcean website illustrated the 3 near real time physical system delivering products for the GLO MFC. Salinity at 50m depth is presented here. Left panel : the global high resolution (1/12°) system providing daily global forecast of the physical ocean variables. Middle panel : the global ocean atmosphere couple system providing daily global forecast of the physical ocean variables. Right panel : the global multi observation system combining in situ and satellite observations and providing weekly estimates of the physical ocean variables. constituent.

achievements and important improvements in the global ocean forecasting systems and the continuity of the production and development tasks in CMEMS are already defined following knowledge's acquire during the last 6 years. Main objectives are now to build an assimilation capability for the ocean biogeochemistry taking advantage of the remote sensing ocean color observation (especially with the sentinel 3 mission in 2016) and in situ observations thanks to the development of the bio argo network. The development of the ocean atmosphere couple capability will continue improving the exchange between ocean and atmosphere and understanding the benefit of the couple processes in the ocean forecasts. Data assimilation technics will continuously evolve, first to take advantage of new available or higher resolution observations and secondly to increase complexity of the assimilation scheme. Ensemble and probabilistic approach will be developed to increase the efficiency of the method improving the representativity error and providing probabilistic forecasts. Finally, the resolution of the global forecasting system will increase to improve the representation of ocean small scale structures (this is still a strong limitation in the current systems) and to allow the capabilities of model to assimilate higher resolution observations that will be available in the following year with sentinel and SWOT (Surface Water & Ocean Topography) missions

Arctic MFC

The main achievements could be separated between scientific, organizational and technical, but there are dependencies between those categories because of key personnel active across them.

The ArcticMFC has started the MyOcean project with an advanced data assimilation method (the Ensemble Kalman Filter) used with the HYCOM model in forecast mode. The TOPAZ3 system was assimilating satellite altimeter maps, SST and sea ice concentrations but not yet in situ profiles. TOPAZ3 was then recently adopted at MET Norway as a heritage from the MERSEA project. After two initial years of transfer of knowledge, the number of handling errors reduced and the forecast system at NERSC could be turned off early 2011. This has freed the human resources to concentrate on improving the data assimilation method, mainly the necessary fine-tuning of the EnKF localization parameters and the problems related to the inbreeding of the ensemble, which was causing a gradual loss of performance of the assimilation. Addressing these issues allowed the use of the TOPAZ4 system in reanalysis mode, as reported in Sakov et al. (2012) and gave confidence in the performance of the real-time forecasting system. Other benefits of the updates of the EnKF were the possibility to assimilate along-track altimeter data and in situ temperature and salinity profiles from Argo floats; as a consequence the weekly operational routine were modified in order to assimilate the freshest altimeter tracks. The pilot 6-years reanalysis described in Sakov et al. (2012) has then later been followed by a 23-years reanalysis (1991-2013). The latter reanalysis incurred a heavy computational burden (about 3 million CPU hours) but benefited from an update of the HYCOM model (Morel et al. 2008), which allowed cutting down by half the computing times.

In parallel, the ecosystem model NORWECOM developed by IMR has been coupled to HYCOM and set in real-time forecasting mode in 2012. Its parameters were then re-calibrated on in-situ biological observations in the Arctic for the following year's operations (Samuelsen et al. 2015). A short pilot ecosystem reanalysis has been performed, assimilating both physical observations and ocean colour data (Simon et al. 2015).

Another major asset from the MyOcean years is the infrastructure used for routine monitoring of the system operations and forecast quality control. The quality indices of the operational system are publicly available under http://myocean.met.no/ARC-MFC/index.html and its extracts can be used to evaluate the progression over the past years. For example Figure 4 shows errors in positioning the ice edge which were much more important during the year 2010 than in the following years (from 200 km down to 40 km). This improvement is due to the transfer of know-how between partners and a better control of the operational routines.

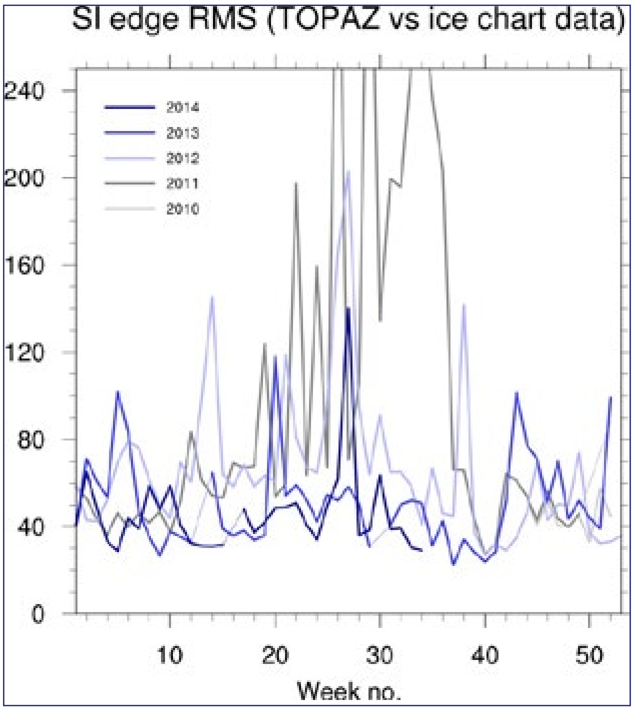


FIGURE 4

Root mean square errors of the distance between the ARC MFC ice edge analysis and that of an independent ice chart, in km (A. Melsom, MET Norway).

The oceanographic validation of the Global and the Arctic physical reanalyses also showed a good general agreement between them (Lien et al., subm. 2015).

Other achievements are the establishment of a professional local service desk and the coupling to the Central Information System in tight collaboration with the Central Desk and Information System teams.

North West Shelf MFC

The NWS MFC was formed in MyOcean from the members of the NOOS community. NOOS already had at this stage a strong collaboration on operational oceanography covering all aspects from observation's to model based forecasts, and included a range of producers, developers and users of the model based systems we now refer to as core systems. The aim of the group was to bring together specialists from the user community, the observations community and the operational modelling community to develop the North-West Shelf service.

The service was based upon the forecast modelling at the Met Office, where there was already a history of providing hydrodynamic forecasts for the region with a coupled biogeochemistry component. The system, based upon POLCOMS (Holt and James 2001) and ERSEM (Blackford et al. 2004) was established as a nested suite of models with an Atlantic Margin Model (AMM) at ~12 km resolution nesting into what was termed the Medium-Resolution Continental Shelf system at approximately 7 km which has a boundary that followed the 200 m depth contour and therefore only modelled the shelf (Siddorn et al. 2013). This model also included the coupling to the biogeochemistry and provided the first Myocean products. This setup was a good compromise between cost and resolution, given the model only simulated the shelf waters of interest. However, cross-shelf exchange is not well represented when the boundary follows the shelf, and placing the boundary away from the shelf is a better solution.

One of the first tasks of the MyOcean projects was therefore to develop an equivalent model on the full Atlantic Margin domain and to include within that model the coupling to the biogeochemistry. It was decided to develop that model in NEMO not in POLCOMS for a number of reasons. The first was to take advantage of the growing community of developers working in NEMO and to recognise the strategic benefits on working within a common European modelling framework. This also allowed the consolidation of shelf seas and open ocean model development within a common framework, allowing cross-over of research between the two communities. Finally, this allowed the shelf seas reanalysis and forecasting to take advantage of data assimilation methodologies, including science and software, that already existed within the NEMO framework for open ocean applications.

To allow this progress to be made significant updates needed to be made to the NEMO system. Much of this effort was taken on by Mercator-Ocean, already demonstrating the benefits of working within a common European framework. POLCOMS, developed at Proudman Oceanography Laboratory (now NOC), was well adapted to the North-West Shelf environment and a number of adaptations need to be developed and tested for the NEMO framework, including adaptations to the grid and the numerics. Development of POLCOMS was therefore halted and a significant hiatus in improvements of the operational systems was needed whilst NEMO was developed and tested for the AMM domain (Fig. 5). ERSEM and an associated SPM model were coupled with NEMO shelf system, including the addition of a time-splitting functionality to allow the ecosystem model to run at a reduced timestep to the physics, critical as ERSEM is significantly more expensive than NEMO and if run at the same timestep dominates the computational cost. The Optimal-Interpolation scheme was implemented for SST with adaptations made to allow it to function in a split barotropic/baroclinic model with tides.

The results of that effort are documented in Edwards et al. (2012), O'Dea et al. (2012) and O'Neill et al. (2012), which demonstrated significant improvement resulting from this effort. A reanalysis and forecasting system based on this NEMO-ERSEM system have been used within MyOcean, with incremental improvements being introduced.

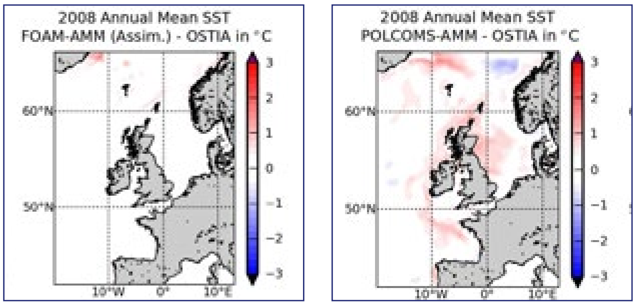


FIGURE 5

SST errors for the NEMO AMM (left) and POLCOMS AMM (right).

Since this significant upgrade was implemented a number of changes have been worked upon, not all yet pulling through to operations, but setting the basis for future significant improvements. The vertical resolution was increased from 33 levels to 50 levels and the vertical grid refined following Siddorn and Furner (2013) to reduce pressure gradient errors, improve air-sea exchange and to allow better retention of water masses over steeply changing topography. Implementation of nesting into Baltic model output from the MyOcean BAL MFC was implemented and a real time inclusion of river data from an operational hydrological model (E-Hype) were both implemented to improve the inputs of freshwater to the system, improving upon the previous hydrological inputs.

At 7 km the NWS system is not eddy resolving and taking the step to eddy resolution will be a major step forward for the NWS MFC. Intermediate resolutions of order 1/30° (4 km) were considered, but are in the grey-zone of eddy permitting models for the mid-latitude NWS region, where the radius of deformation is not resolved until resolutions of around 1.5 km are reached. Focus was therefore on developing the system at the 1.5 km resolution in parallel to understanding the skill in the system at 7 km. The major areas for research have therefore been in developing the eddy resolving model, implementing a wetting-and-drying scheme and developing numerics suitable for high resolution implementations.

Alongside the developments to the NEMO physical framework, improvements have been made to the light model, benthic model and the carbonate chemistry within ERSEM to continue the improvements in the quality of the biogeochemistry products. New phytoplankton functional types based on cellular photoresponse have been included, and stoichiometry modulation of predation in the zooplankton formulation has been implemented. There is a new formulation to describe anaerobic degradation of organic matter in the water column. Improvements to ERSEM nutrient boundary forcing have also been developed.

The data assimilation capability has also been evolving and improving, with a 3D variational scheme, the NEMOVAR 3D-Var FGAT system developed for use in NWS. This included new parameterised background error covariances and enhanced specification of the observation error variances. Improvements were also made to the way SST increments were projected into the water column to prevent assimilation interacting with the onset of stratification, a key process in much of the NWS region. Additionally a study on the use of altimeter data, using the products available from the TAPAS project, showed the potential for assimilation of SLA data in the NWS region (King and Martin, 2013). A start has also been made to the data assimilation framework to allow assimilation of profile data in a tidal, S-coordinate system.

Alongside the developments to the modelling systems that have been made through the MyOcean projects, significant advances have also been made in the operational evaluation of product quality. An operational GODAE style Cal/Val methodology has been developed and implement as part of the NWS MFC. The understanding of skill in the system is much improved as a result.

A methodology for using Multi-Model Ensemble to investigate product uncertainty estimates has been developed for sea surface temperature and salinity. This gives a user focused understanding of product quality, and allows an additional method for the routine verification of NWS operational forecasts. The multi-model ensemble has been extended to include sea bed temperature and salinity, transports and currents

Baltic MFC.

The Baltic Monitoring and Forecasting Centre (BAL MFC) has through the series of MyOcean projects (MyOcean, MyOcean2, and MyOcean2 Follow On) delivered real time and historical information for the ocean state of the Baltic Sea.

The BAL MFC group has through the six years project period been formed by the five partners BSH (Germany), DMI (Denmark), FMI (Finland), MSI (Estonia) and SMHI (Sweden). Further HZG (Germany) was included since MyOcean2 as a minor partner with the main purpose to coordinate the research activities between the Baltic Sea and the other regions within the project.

The BAL MFC group has since the start of the MyOcean project in 2009 delivered regular model forecast products with information in near real time for the physical state of the Baltic Sea. During the project period a model description of the bio-chemical state for the Baltic Sea was implemented into the model forecast system and included in the Baltic Sea product portfolio. Furthermore reanalysis products have been included with historical information of minimum 20 years of simulation. Reanalysis products for the physical state of the Baltic Sea were included in the MyOcean product catalogue in 2012 and in 2015 also a reanalysis product for bio-chemical state.

During the six years period the Baltic near real time model forecast products have been upgraded with respect to both the model code behind the products, and the products it selves with respect to spatial resolution. From the start of the MyOcean project, the BAL MFC group was only capable, due to technical storage limitations, of delivering a small subset of the native model simulations into the MyOcean data portal. This has significantly improved during the years, and we do now deliver twice per day a new two days forecast on a grid with a horizontal resolution on 1 nautical mile (1.852 km) for the whole area: the Baltic Sea including the transition area towards the North Sea. In the vertical the product includes up to 25 depth levels with high resolution in the upper 100 meters (0m, 5m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, 60m, 65m, 70m, 75m, 80m, 85m, 90m, 95m, 100m, 150m, 200m, 300m, 400m).

The model system used for the near real time - twice daily - production for the Baltic Sea forecast consists of the HBM ocean code on-line coupled with the biochemical model ERGOM. The HMB code name is an abbreviation for Hiromb-BOOS-Model. The model code was original developed at BSH, Germany back in the 1990'ties and has during the past 10-15 years been heavily rewritten and improved at mainly DMI to comply with new high level technical standards. The model code development is today done via the HBM consortium consisting of the four partners DMI, BSH, FMI and MSI. The bio-chemical model used for our Baltic ecosystem products, ERGOM is original developed at IOW, Germany. The HBM-ERGOM model systems are described in Berg and Weismann Poulsen, 2012; Berg, 2012; and Neumann, 2000.

A short overall, but non-exhaustive, list of model features that have been improved or implemented during the My Ocean projects funding includes: improvement in the heat exchange - both thermodynamics and heat flux; mixing; parameterization of unresolved bottom stress; change in the bottom friction locally; new exchange coefficients for latent and sensible heat; new snow cover and albedo model; the tidal potential has been included; the river inflow temperature has been updated; and baroclinic pressure gradient calculations improved. For the bio-geo-chemical features, silicate has been added to the model; zooplankton divided into two groups and the light attenuation improved. Further a new conceptual fast ice model has been devised and developed within the BAL MFC group. Improvements on a scientific technical level of the code have had a high priority for the BAL MFC group with focus on sanity and correctness of the implementations and for portability, scalability and sustainability reasons. This work has been internationally recognized in the scientific computational society (see Weismann Poulsen et al., 2014).

Documentation of the quality of the MyOcean products has been a focus area for the overall MyOcean projects. Within the BAL MFC group this has resulted in a new designed framework for quality calibration and verification that has been followed for every new model system upgrade. New model simulations have been tested with the new model release candidate and verified by a large amount of observations from the Baltic Sea, and compared to the existing operational system. The BAL MFC group has managed through the six years period to upgrade over system and Baltic model products once per year with documented quality improvements. One example of documented version quality improvements are shown in Figure 06, for the total Baltic ice extent. An improvement in the model's ability to handle the melting of the sea ice in the spring is seen for model version V4, released in April 2014 to the MyOcean users, compared to the previous version, V3. More examples are available on the MyOcean website (now renamed to http://marine.copernicus.eu/) under the Baltic Sea products.

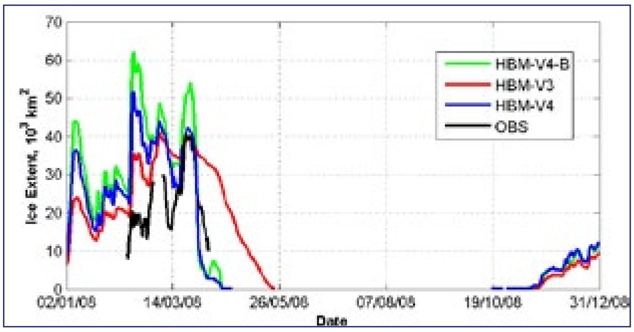


FIGURE 6

Baltic total ice extent in 2008: observed (black) and modelled (V3: red ; V4: blue). The V4 model simulation, released in April 2014, shows clear improvement in the melting season compared to the previous V3 model version..

The five main partners that have formed the BAL MFC group during the MyOcean projects will continue the work to deliver a state-of-the-art operational service for the physical and biochemical state for the Baltic Sea within the Copernicus Systems Marine Service.

Iberia Biscay Irish MFC

The main product developed in MyOcean series of projects at the IBI area is the operational IBI Ocean Analysis and Forecasting system**.** It provides daily a 5-day hydrodynamic forecast (+ 1 day of hindcast, generated as best estimate) including high frequency processes of paramount importance to characterize regional scale marine processes (i.e. tidal forcing, surges and high frequency atmospheric forcing, fresh water river discharge, etc.). The system is currently based on an eddy - resolving NEMO model application run at 1/36° horizontal resolution driven by ocean and meteorological forcing and it provides ocean predictions for the area shown in Figure 07.

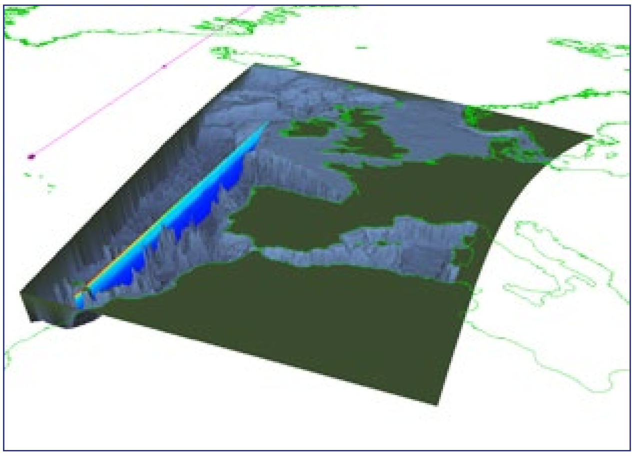


FIGURE 7

IBI-MFC model domain, showing a vertical section of temperature

The IBI forecast system is based on a NEMO-v3.4 model application driven by high-frequency meteorological, oceanographic and hydrological forcing data. The NEMO model solves the three-dimensional finite-difference primitive equations in spherical coordinates discretized on an Arakawa-C grid and, in the present implementation, at 50 geopotential vertical levels (z coordinate). It assumes hydrostatic equilibrium and Boussinesq approximation and makes use of a non-linear split explicit free surface to properly simulate fast external gravity waves such as tidal motions. Partial bottom cell representation of the bathymetry allows an accurate representation of the steep slopes characteristic of the area. Vertical mixing is parameterized according to a k-ε model, including surface wave breaking induced mixing, while tracers and momentum sub-grid lateral mixing is parameterized according to bilaplacian operators.

The IBI run is forced with 3-hourly atmospheric fields (10-m wind, surface pressure, 2-m temperature, relative humidity, precipitations, shortwave and long-wave radiative fluxes) provided by ECMWF. Lateral open boundary data (temperature, salinity, velocities and sea level) are interpolated from the daily outputs from the MyOcean Global eddy resolving system. These are complemented by 11 tidal harmonics (M2, S2, N2, K1, O1, Q1, M4, K2, P1, Mf, Mm) built from FES2004 and TPXO7.1 tidal models solutions. The atmospheric pressure component, missing in the large scale parent system sea level outputs, is included assuming pure isostatic response at open boundaries (inverse barometer approximation). Fresh water river discharge inputs are implemented as lateral open boundary condition for 33 rivers. Flow rate data imposed is based on a combination of daily observations, simulated data (from SMHI E-HYPE hydrological model (http://e-hypeweb.smhi.se and climatology, monthly climatological data from GRDC, http://www.bafg.de/GRDC and the French "Banque Hydro" dataset http://www.hydro.eaufrance.fr/).

State of the art validation is ensured in the actual IBI-MFC via NARVAL (North Atlantic Regional Validation) tool. This on-line IBI Validation process has two different modes according to their time frequency performance:

- "On-line" mode Component: Validation procedures launched after the daily IBI forecast cycle.
- Delayed mode Component: Validation procedures launched to compute specific metrics and statistics covering longer periods (different launch time frequencies are considered: .e.g. monthly, seasonal, and annual reviews)

Apart of this daily IBI forecast, multi-year products generated from physical and biogeochemical reanalysis system outputs are available. The physical reanalysis Model Application was used in MyOcean to generate the IBI reanalysis product covering the so-called "altimetric" decade (2002-2012). These products are disseminated to users by the PdE MyOcean DU since June 2014 (MyOcean-2 V4.1 release). Together with these physical ocean re-analysis products, a modelled biogeochemical state of the ocean for the IBI areas was generated through a PISCES model run coupled in the IBI-PHY-REA reanalysis.

Mediterranean Sea MFC

The development of the components of the MyOcean Med-MFC started more than ten years ago in the frame of several EU projects.The Mediterranean Forecasting System (MFS), is operational since year 2000 for the physical component and since year 2005 for the biogeochemical component (Tonani et al 2014). Since then the system has continuously improved, increasing the resolution, adding a wave component coupled with the physical system, increasing the number of observation assimilated by both the physical and the biogeochemical components and improving the model parameterizations and components. This system is composed of two key elements coupled off-line: Med-currents for the physical system, and Med-biogeochemistry, for the biogeochemical component. 10- day forecast are produced daily by Med-currents and twice weekly by Med-biogeochemistry. The Med-currents component has a back-up production and dissemination unit based on a simplified version of Med-currents system without wave-currents coupling and data assimilation developed at HCMR. The back-up system is initialized everyday from the nominal system initial conditions in order to avoid discontinuity between the products of the two production lines. The format of the products is the same in order to reduce as much as possible the impact on the users. The back-up products are released only in case of major failure of the nominal production. MyOcean Service Desk provides to the users all the needed information and support to switch to the back-up products in case of unavailability of the nominal products. Figure 8 shows the architecture of the Med-MFC.

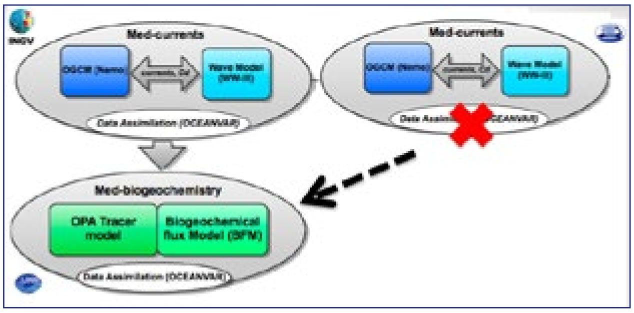


FIGURE 8

Med-MFC architecture and components: the different compoents: Med-MFC-current, the physical component of the system, Med-MFC-Biogeochemistry and the back up unit.

The oceanic equations of motion of Med-currents system are solved by two elements: an Ocean General Circulation Model (OGCM) and a Wave Model. The OGCM code is based on NEMO-OPA (Nucleus for European Modelling of the Ocean-Ocean Parallelise) version 3.4. The code is developed and maintained by the NEMO-consortium. The model solves the primitive equations in spherical coordinates. The Wave dynamic is solved by a Mediterranean implementation of the WaveWatch-III code (Tolman 2009).NEMO has been implemented in the Mediterranean at 1/16° x 1/16° horizontal resolution and 72 unevenly spaced vertical levels (Oddo et al. 2014, Oddo et al., 2009, Tonani et al. 2008) with time step of 300sec, WaveWatch follows the same horizontal discretization and has a time step of 600 sec. The NEMO model provides every hour estimates of Sea Surface Temperature and surface currents to WaveWatch which returns back to NEMO the neutral component of the surface drag coefficient taking into account wave induced effect at the air-sea interface. The two models cover the whole Mediterranean Sea and also extend into the Atlantic in order to better resolve the exchanges with the Atlantic Ocean at the Strait of Gibraltar. The NEMO code solves the primitive equations using the time-splitting technique that is the external gravity waves are explicitly resolved. Also the atmospheric pressure effect has been introduced in the model dynamic. The horizontal eddy diffusivity coefficient for tracers and the horizontal bilaplacian eddy viscosity has been set respectively equal to -6.e8 [m4/s] and -1.e9 [m4/s]. Moreover at the bottom, a quadratic bottom drag coefficient with a logarithmic formulation has been used according to Maraldi et al. (2013).The wave model takes into consideration the surface currents for wave refraction but assumes no interactions with the ocean bottom. The wave model uses 24 directional bins (15° directional resolution) and 30 frequency bins (ranging between 0.05Hz and 0.7931 Hz) to represent the wave spectra distribution. The hydrodynamic model is nested, in the Atlantic, within the daily products at 1/12 of horizontal resolution produced by the MyOcean Global Monitoring and Forecasting Centre, GLOBAL_ANALYSIS_FORECAST_PHYS_001_002. Details on the nesting technique and major impacts on the model results are in Oddo et al., 2009. The model uses vertical partial cells to fit the bottom depth shape. The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae using the 6-h, 0.25° horizontal-resolution operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) and the model predicted surface temperatures (details of the air-sea physics are in Tonani et al., 2008). The water balance is computed as Evaporation minus Precipitation and Runoff. The evaporation is derived from the latent heat flux while the precipitation and the runoff are provided by monthly mean datasets: the Climate Prediction Centre Merged Analysis of Precipitation (CMAP) Data (Xie and Arkin, 1997); the Global Runoff Data Centre dataset (Fekete et al., 1999) for the Ebro, Nile and Rhone and the dataset from Raicich (Raicich, 1996) for the Adriatic rivers (Po, Vjosë, Seman and Bojana). The Dardanelles inflow is parameterized as a river and the climatological net inflow rates are taken from Kourafalou and Barbopoulos (2003). The data assimilation system is the OCEANVAR scheme developed by Dobricic and Pinardi (2008). The background error correlation matrix is estimated from the temporal variability of parameters in a historical model simulation. Background error correlation matrices vary seasonally and in 13 regions of the Mediterranean Sea, which have different physical characteristics (Dobricic et al 2007). The assimilated data include: Sea Level Anomaly (a satellite product accounting for atmospheric pressure effect is used) from CLS SL-TAC, and vertical temperature and salinity profiles from Argo, XBT (eXpandable BathyThermograph) and Gliders. Objective Analyses-Sea Surface Temperature (OA-SST) fields from CNR-ISA OSI-TAC are used for the correction of surface heat fluxes with the relaxation constant of 40 W m-2 K-1.

Med-MFC is off line coupled with Med-biogeochemistry which is based on the OPATM-BFM model. This system has been developed at OGS after a more than a decadal experience in 3D biogeochemical and ecosystem modelling of the Mediterranean Sea within a series of Italian and European projects (see for references Lazzari et al., 2010). Within MyOcean V2 the system was upgraded by adding a 3D variational assimilation scheme that uses satellite MODIS surface chlorophyll to update the phytoplankton groups, further improved for V3. Version V3.1 basically improved the optical model (new light extinction coefficient data set) and the formulation of Vb operator used in the assimilation scheme. Version V4 is focused to increase the horizontal resolution of V3.1 system from 1/8° to 1/16°. OPATM-BFM is designed with a transport model based on the OPA system and a biogeochemical reactor featuring the Biogeochemical Flux Model (BFM). The transport model is a modified version of the OPA 8.1 transport model (Foujols et al., 2000), which resolves the advection, the vertical diffusion and the sinking terms of the tracers (biogeochemical variables). The meshgrid is based on 1/16° longitudinal scale factor and on 1/16°cos(ϕ) latitudinal scale factor. The vertical meshgrid accounts for 72 vertical z-levels: 25 in the first 200m depth, 31 between 200 and 2000 m, 16 below 2000 m.The temporal scheme of OPATM-BFM is an explicit forward time scheme for the advection and horizontal diffusion terms, whereas an implicit time step is adopted for the vertical diffusion. The sinking term is a vertical flux which acts on a sub-set of the biogeochemical variables (particulate matter and phytoplankton groups). Sinking velocity is fixed for particulate matter and dependent on nutrients for two phytoplankton groups (diatoms and dinoflagellates).The physical dynamics that are off-line coupled with the biogeochemical processes are pre-computed by the high resolution ocean general circulation model MFS run by Med-MFC-currents (INGV). MFS model supplies the temporal evolution of the fields of horizontal and vertical current velocities, vertical eddy diffusivity, potential temperature, salinity, in addition to surface data for solar shortwave irradiance and wind stress (see section on boundary and forcing for further details).The features of the biogeochemical reactor BFM (Biogeochemical Flux Model) have been chosen to target the energy and material fluxes through both “classical food chain” and “microbial food web” pathways (Thingstad and Rassoulzadegan, 1995), and to take into account co-occurring effects of multi-nutrient interactions. Both of these factors are very important in the Mediterranean Sea, wherein microbial activity fuels the trophodynamics of a large part of the system for much of the year and both phosphorus and nitrogen can play limiting roles (Krom et al., 1991; Bethoux et al., 1998). The model presently includes nine plankton functional types (PFTs). BFM model describes the biogeochemical cycles of 4 chemical compounds: carbon, nitrogen, phosphorus and silicon through the dissolved inorganic, living organic and non-living organic compartments. Nitrate and ammonia are considered for the dissolved inorganic nitrogen. The non living compartments consists of 3 groups: labile, semilabile and refractory organic matter. The last two are described in terms of carbon, nitrogen, phosphorus and silicon contents. The model is fully described in Lazzari et al. (2012), where it was corroborated for chlorophyll and primary production in the Mediterranean Sea for a 1998-2004 simulation.The BFM model is also coupled to a carbonate system model, which consists of two prognostic state variables: alkalinity (ALK) and dissolved inorganic carbon (DIC). DIC evolution is driven by biological processes (photosynthesis and respiration), exchanges at air-sea interface. Alkalinity evolution is affected by biochemical processes that alter the ions concentration in sea water (nitrification, denitrification, and uptake and release of nitrate, ammonia and phosphate by plankton cells). The data assimilation corrects the four phytoplankton functional groups included in the OPATM-BFM (see details in Teruzzi et al., 2013).

The Med-MFC produces also reanalsyis time series for both components, as described in Simoncelli et al., this issue.

All the products are evaluated using the MyOcean/CMEMS standards before being disseminated to the users and the validation statistics are available together with all the other relevant documentation on the marine copernicus web site.

Black Sea MFC

The Black Sea operational forecasting has started its development at the beginning of zero's in the framework of the Black Sea GOOS. The first basin-scale forecasting system was collected and launched manually as part of the FP5 ARENA project test study. The system transition to the real time operation was done by the FP6 ECOOP and ASCABOS projects preserving partial involvement of operators.

The Black Sea nowcasting and forecasting system was restructured according to the common European standards in the framework of FP7 MyOcean project absorbing achievements of FP6 ECOOP and SESAME. The system architecture upgrade, establishing interfaces and real-time links with MyOcean TAC's for data input, establishing of the interface with the central Service Deck were carried out. OPeNDAP server and MIS gateway started to work for serving user requests. The Black Sea system was included analysis and forecast of circulation and stratification, biooptics, sea level, the first version of reanalysis of physical state of the basin and initial version of the ecosystem model at the end of the project. The list of products included to the project catalogue consisted of temperature, salinity, current velocity, sea level, attenuation coefficient. The set of users was formed including Black Sea Commission and coastal forecasting systems of the riparian countries. A number of requests were obtained from users on call. Thus, the Black Sea monitoring and forecasting center (BS MFC) was established in Sevastopol and operated by the Marine Hydrophysical Institute with internal infrastructure and major external component prescribed by the "system of systems" concept.

Further improvement of product line, product quality corresponding to user requirements and extension of services was carried out in the MyOcean2 project. The sophisticated space altimetry and sea colour assimilation algorithms were installed to the circulation and biogeochemical models. Circulation model was coupled with bio-optical model to specify better parameterisation of absorption of the short-wave radiation. Long-term evolution of the Black Sea ecosystem was evaluated by the ecosystem model with data assimilation both space sea colour and in situ data. The production unit – PU (operational monitoring and forecasting) and the dissemination unit (DU) which distributes and displays the results of marine forecasts were developed. Specially designed hardware and software complex supports the automatic internal and external networks connections. Routine real-time assessment of the product quality was implemented as the part of the project activity. Operational analysis and forecast, and reanalysis data were freely available from the central Web-portal of the MyOcean project (http://www.myocean.eu). The product line provided by the center to users included temperature, salinity, current velocity, sea level, light diffuse attenuation coefficient, nitrates and phytoplankton concentrations. Operational forecast of oil spills drift in the Black Sea was provided on request by the Black Sea track web system which is operated by MHI using the BS MFC data. Seasonal maps of several Black Sea parameters were used by European Environmental Agency.

CONCLUSION

All the MFCs have evolved during the three segment of the MyOcean project, in order to improve their capability in monitoring and forecasting the physical and biogeochemical variables of the global ocean and of the european regional seas. All these systems, but the Black Sea MFC, are now component of the Copernicus Marine Environment Monitoring System (CMEMS).

ACKNOWLEDGEMENTS

The authors wish to thank the partners of:

- the GLOBAL ocean MFC
- the ARCTIC ocean MFC
- the BALTIC sea MFC
- the North-West shelves area MFC
- the Atlantic Iberian-Biscay-Ireland MFC
- the Mediterranean sea MFC
- the Black Sea MFC

REFERENCES

Bahurel, P. Adragna, F. Bell, M.J. Jacq, F. Johannesen, J.A. Le Traon, P-Y. Pinardi, N. and She, J. 2009. *Ocean Monitoring and Forecasting Core Services, the European MyOcean Example*, Conference proceedings, OceanObs09.

Aumont, O. and Bopp, L. 2006: *Globalizing results from ocean in situ iron fertilization studies. Global Biogeochem.* Cycles. 20 (2):10–1029

Barnier, B., Madec, G., Penduff, T., Molines, J. M., Treguier, A. M., Le Sommer, J., Beckmann, A., Biastoch, A., Böning, C., Dengg, J., Derval, C., Durand, E., Gulev, S., Remy, E., Talandier, C., Theetten, S., Maltrud, M., McClean, J., and De Cuevas, B.: I*mpact of partial steps and momentum advection schemes in a global circulation model at eddy permitting resolution*, Ocean Dynam., 56, 543-567, 2006.

Berg, P. (2012). Mixing in *HBM. DMI Scientific* Report No. 12-03. Copenhagen, 21 pp. (Available at: www.dmi.dk/fileadmin/Rapporter/ SR/sr12-03.pdf).

Berg, P., and Weismann Poulsen, J. (2012). Implementation details for *HBM. DMI Technical Report* No. 12-11. Copenhagen, 149 pp. (Available at: www.dmi.dk/fileadmin/Rapporter/TR/tr12-11.pdf).

Bethoux, J. P., Morin, P., Chaumery, C., Connan, O., Gentili, B., and Ruiz-Pino, D., 1998. *Nutrients in the Mediterranean Sea, mass balance and statistical analysis of concentrations with respect to environmental change*, Mar. Chem., 63, 155–169.

Blockley, E. W, Martin, M. J., McLaren, A. J., Ryan, A. G., Waters, J., Lea, D. J., Mirouze, I., Peterson, K. A., Sellar, A. and Storkey, D. 2013. *Recent developments of the Met Office operational ocean forecasting system: an overview and assessment of the new Global FOAM forecasts. Geosci.* Model Dev. Discuss., 6, 6219-6278,doi:10.5194/gmdd-6-6219-2013, 2013.

Dobricic, S. and Pinardi, N. 2008. *An oceanographic three-dimensional variational data ssimilation scheme.* Ocean Modelling, 22, 3-4, 89-105.

Dobricic, S., 2005. *New mean dynamic topography of the mediterranean calculated fron assimilation system diagnostic.* GRL, 32.

Dobricic, S. Pinardi, N.Adani, M. Tonani, M. Fratianni, C. Bonazzi, A. and Fernandez, V. 2007. *Daily oceanographic analyses by Mediterranean Forecasting System at the basin scale.* Ocean Sci., 3, 149-157.

Edwards, K.P., Barciela, R., and Butenschön, M. (2012) *Validation of the NEMO-ERSEM operational ecosystem model for the North West European Continental Shelf.* Ocean Sci., 8, 983–1000

Foujols, M.-A., Lévy, M., Aumont, O., Madec, G., 2000. *OPA 8.1 Tracer Model Reference Manual.* Institut Pierre Simon Laplace, pp. 39.

Guiavarc'h C., C. Harris, *QUALITY INFORMATION DOCUMENT For Global Analysis and Forecasting Product from Coupled System GLOBAL_ANALYSIS_FORECAST_PHYS_001_015.* CMEMS report, 2015

Guinehut S., A.-L. Dhomps, G. Larnicol and P.-Y. Le Traon, 2012: *High resolution 3D temperature and salinity fields derived from in situ and satellite observations.* Ocean Sci., 8, 845-857, doi:10.5194/os-8-845-2012

Guinehut S., Sandrine Mulet *QUALITY INFORMATION DOCUMENT For Global Ocean Observation-based Products GLOBAL_ANALYSIS_PHYS_001_016.* CMEMS report, 2015

King, R.R. and Martin, M. (2013). *Comparing satellite altimetry with ocean models of the North-West Shelf,* Forecasting Technical Report 581, Met Office

King, R.R. and Martin, M. (2013). *Comparing satellite altimetry with ocean models of the North-West Shelf,* Forecasting Technical Report 581, Met Office

Krom M.D., Kress N., Brenner S., Gordon L.I., 1991. *Phosphorus limitation of primary productivity in the eastern Mediterranean Sea.* Limnology and Oceanography, 36(3) 424-432.

Lazzari P., Teruzzi A., Salon S., Campagna S., Calonaci C., Colella S., Tonani M., Crise A. 2010. *Pre-operational short-term forecasts for the Mediterranean Sea biogeochemistry.* Ocean Science, 6, 25-39.

Lazzari, P., Solidoro, C., Ibello, V., Salon, S., Teruzzi, A., Béranger, K., Colella, S., and Crise, A., 2012. *Seasonal and inter-annual variability of plankton chlorophyll and primary production in the Mediterranean Sea: a modelling approach.* Biogeosciences, 9, 217-233.

Lellouche, J.-M., Le Galloudec, O., Drévillon, M., Régnier, C., Greiner, E., Garric, G., Ferry, N., Desportes, C., Testut, C.-E., Bricaud, C., Bourdallé-Badie, R., Tranchant, B., Benkiran, M., Drillet, Y., Daudin, A., and De Nicola, C.: *Evaluation of real time and future global monitoring and forecasting systems at Mercator Océan,* Ocean Sci., 9, 57-81, 2013, doi:10.5194/os-9-57-2013

Lien V., S. Hjøllo, MD. Skogen, E. Svendsen, H. Wehde, L. Bertino, F. Counillon, M. Chevallier, G. Garric. *An Assessment of the added value from data assimilation on modeled Nordic Seas hydrography and ocean transports.* Oc. Mod., Subm. 2015.

Madec, G. and the NEMO team: *NEMO ocean engine. Note du Pôle de modélisation,* Institut Pierre-Simon Laplace (IPSL), France, No. 27 ISSN, 1288-1619, 2008

Maraldi, C.Chanut, J. Levier, B. Ayoub, N. De Mey, P. Reffray, G. Lyard, F. Cailleau, F. Drévillon, M. FanjulAlvarez,E. Sotillo,M.G. Marsaleix, P. and the Mercator Research and Development Team, 2013: *NEMO on the shelf: assessment of the Iberia–Biscay–Ireland configuration.* Ocean Sci., 9, 745–771.

Morel, Y., Baraille, R., & Pichon, A. (2008). *Time splitting and linear stability of the slow part of the barotropic component.* Ocean Modelling, 23(3-4), 73–81. http://doi.org/10.1016/j.ocemod.2008.04.001

Neumann, T. (2000). *Towards a 3D-ecosystem model of the Baltic Sea.* Journal of Marine Systems, 25, 405-419.

O'Dea, E.J., Arnold, A.K., Edwards, K.P., Furner, R., Hyder, P., Martin, M.J., Siddorn, J.R., Storkey, D., While, J., Holt, J.T. and Liu, H. (2012) *An operational ocean forecast system incorporating NEMO and SST data assimilation for the tidally driven European North-West shelf.* Journal of

Operational Oceanography, 5, 3-17

O'Neill, C.K., Polton, J.A., Holt, J.T. and O'Dea, E.J. (2012) *Modelling temperature and salinity in Liverpool Bay and the Irish Sea: sensitivity to model type and surface forcing* Ocean Sci., 8, 903-913

Oddo P., Adani, M. Pinardi, N. Fratianni, C. Tonani, M. Pettenuzzo, D. 2009. *A Nested Atlantic-Mediterranean Sea General Circulation Model for Operational Forecasting. Ocean* Sci. Discuss., 6, 1093-1127.

Oddo P., Bonaduce ,A. Pinardi, N. and Guarnieri, A. 2014. *Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO.* Geosci. Model Dev., 7, 3001–3015, 2014. www.geosci-model-dev.net/7/3001/2014/ doi:10.5194/gmd-7-3001-2014.

Perruche, C. Hameau, A. Paul, J., Régnier, C. Drévillon, M. QUALITY INFORMATION DOCUMENT For Global Biogeochemical Analysis and Forecast ProductGLOBAL_ ANALYSIS_FORECAST_ BIO_001_014

Raicich, F.: *On the fresh water balance of the Adriatic Sea*, J. Marine Syst., 9, 305–319, 1996

Thingstad T.F., Rassoulzadegan F., 1995. *Nutrient limitations, microbial food webs, and 'biological C-pumps': suggested interactions in a P-limited Mediterranean.* Marine Ecology Progress Series, 117: 299-306.

Sakov, P., Counillon, F., Bertino, L., Lisæter, K. A., Oke, P. R., and Korablev, A.: TOPAZ4: *an ocean-sea ice data assimilation system for the North Atlantic and Arctic,* Ocean Sci., 8, 633-656, doi:10.5194/os-8-633-2012, 2012.

Samuelsen, A., Hansen, C., and Wehde, H.: *Tuning and assessment of the HYCOM-NORWECOM V2.1 biogeochemical modeling system for the North Atlantic and Arctic oceans,* Geosci. Model Dev., 8, 2187-2202, doi:10.5194/gmd-8-2187-2015, 2015.

Siddorn, J.R. and Furner, F. (2013) *An analytical stretching function that combines the best attributes of geopotential and terrain-following vertical coordinates,* Ocean Modelling, 66, 1–13.

Simon E., Samuelsen, A., Bertino, L., Mouysset, S., *Experiences in multiyear combined state-parameter estimation with an ecosystem model of the North Atlantic and Arctic Oceans using the Ensemble Kalman Filter.* Journal of Marine Systems, 152, 1-17, 2015. http://dx.doi.org/10.1016/j.jmarsys.2015.07.004

Teruzzi A., Dobricic S., Solidoro C., Cossarini G. 2013. *A 3D variational assimilation scheme in coupled transport biogeochemical models: Forecast of Mediterranean biogeochemical properties,* Journal of Geophysical Research, doi:10.1002/2013JC009277

Tolman H., *User Manual and system documentation of WAVEWATCH III version 3.14, 2009.* NOAA/NWS/NCEP/MMAB Technical Note 276, 194 pp + Appendices.

Tonani, M. Teruzzi, A Korres, G. Pinardi, N. Crise, A. Adani, M. Oddo, P. Dobricic, S. Fratianni, C. Drudi, M. Salon, S. Grandi, A. Girardi, G. Lyubartsev, S. and Marino, S. 2014. *The Mediterranean Monitoring and Forecasting Centre, a component of the MyOcean system.* Proceedings of the Sixth International Conference on EuroGOOS 4-6 October 2011, Sopot, Poland. Edited by H. Dahlin, N.C. Fleming and S. E. Petersson. First published 2014. Eurogoos Publication no. 30. ISBN 978-91-974828-9-9.

Tonani, M. Pinardi, N. Dobricic, S. Pujol, I and Fratianni, C. 2008. *A high-resolution free-surface model of the Mediterranean Sea.* Ocean Sci., 4, 1-14.

Xie and Arkin, 1997: *Global Precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs,* Bulletin of the American Meteorological Society, 78, 2539-2558.

Waters, J., Lea, D. J., Martin, M. J., Mirouze, I., Weaver, A. T., and While, J. 2014. *Implementing a variational data assimilation system in an operational 1/4 degree global ocean model. Q. J. Roy.* Meteor. Soc., doi:10.1002/qj.2388, 2014.

Weismann Poulsen, J., Raman K, Berg, P (2014). *Better Concurrency and SIMD On The HIROMB‐BOOS Model (HBM) 3D Ocean Code. In: J. Jeffers and Reinders (eds.)* High Performance Parallelism Pearls Volume One, 1st Edition. Multicore and Many-core Programming Approaches. Morgan Kaufmann Publishing.

Williams, K. D., Harris, C. M., Bodas-Salcedo, A., Camp, J., Comer, R. E., Copsey, D., Fereday, D., Graham, T., Hill, R., Hinton, T., Hyder, P., Ineson, S., Masato, G., Milton, S. F., Roberts, M. J., Rowell, D. P., Sanchez, C., Shelly, A., Sinha, B., Walters, D. N., West, A., Woollings, T., and Xavier, P. K., 2015. *The Met Office Global Coupled model 2.0 (GC2) configuration.* Geosci. Model Dev., 8, 1509-1524, doi:10.5194/gmd-8-1509-2015.

MYOCEAN REGIONAL REANALYSES: OVERVIEW OF REANALYSES SYSTEMS AND MAIN RESULTS

BY

S. SIMONCELLI(1), S. MASINA(2), L. AXELL(3), Y. LIU(3), S. SALON(4), G. COSSARINI(4), L. BERTINO(5), J. XIE(5), A. SAMUELSEN(5), B. LEVIER(6), G. REFFRAY(6), E. O'DEA(7), R. MCEWAN(7), R. BARCIELA(7), S. WAKELIN (8), T. KRISTIANSEN(9), M. SKOGEN(9), M. BENKIRAN(10), M. G. SOTTILLO(11)

ABSTRACT

MyOcean Project initiated the first generation of regional physical and biogeochemical reanalysis products covering all European marginal seas and the first attempt of a coordinated and shared validation methodology. An overview of the principal characteristics of all regional physical and biogeochemical reanalyses is presented with the objective to point out main results accomplished within the framework of MyOcean project and the rising challenges for future reanalysis activities in the new European Copernicus Marine Environment Monitoring Service. A standard validation methodology has been defined and applied for the first time to all the reanalysis products to ensure an adequate evaluation of their accuracy but also that information on products quality is reliable, consistent, useful, and communicated effectively. The extensive assessment of regional reanalyses promoted products uptake increasing user understanding and confidence. Reanalyses are in fact among the most demanded and downloaded products by the users owing to their wide range of applicability.

[1] **Istituto Nazionale di Geofisica e Vulcanologia (INGV)**, Bologna, Italy
[2] **Centro Euro Mediterraneo per i Cambiamenti Climatici (CMCC)**, Bologna, Italy
[3] **Swedish Meteorological and Hydrological Institute (SMHI)**, Norrköping, Sweden
[4] **Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)**, Trieste, Italy
[5] **Nansen Environmental and Remote Sensing Center (NERSC)**, Bergen, Norway
[6] **Mercator Ocean, Ramonville-Saint-Agne**, France
[7] **Met Office, Exeter**, United Kingdom
[8] **National Oceanography Centre (NOC)**, Liverpool, United Kingdom
[9] **Institute of Marine Research (IMR)**, Bergen, Norway
[10] **Collecte Localisation Satellites (CLS)**, Ramonville, France
[11] **Puertos del Estado, Madrid**, Spain

INTRODUCTION

The MyOcean projects and the consolidation of operational oceanography in Europe concurred with the advance of ocean reanalysis activities at both global and regional scales. The implementation of MyOcean as a pan-European integrated system-of-systems, dedicated to operational monitoring and forecasting, opened up the possibility of exploiting the state of the art modeling and data assimilation tools to reconstruct and study the ocean during the past decades. This was feasible also thanks to the increasing availability of long time series of qualified in situ and remote sensed observations. The present paper is dealing with ocean reanalysis activities at regional scales.

A reanalysis is a 3D retrospective reconstruction of the ocean state obtained by a data assimilative experiment that uses the same numerical model, forcing from atmospheric reanalyses, and the same data assimilation scheme throughout the considered time period. A reanalysis system differs from an operational system because it does not aim at producing the best analysis of today but the most coherent and consistent state of the past ocean. Operational analyses are usually subject to on-line model and assimilation updates, bugs fixing or atmospheric forcing variations that might determine space-time inconsistency and undesired transient phenomena that undermine the final product quality and its possible applications.

The consistency of the reanalysis products is however non-trivial to achieve owing to the evolution of the observing system in terms of sampling technology, sampling accuracy, coverage, resolution and data quality. The advancement in the field of observation and measurement collection, observation processing and data exchange within many EU funded projects and organizations like MyOcean, SeaDataNet, EMODNET, EAIMS and EuroGOOS, made available long time series of delay mode (DM) quality checked in situ data and reprocessed (REP) remote sensed data that encouraged ocean reanalyses production and their potential usage. Progresses in the field of atmospheric reanalyses over the last decade made available qualified forcing data starting from the late fifties, which are continuously updated to present time. These products have allowed researchers to run ocean reanalysis without merging different atmospheric datasets. Ocean reanalysis is at the forefront of research development, as a result of successful collaborative efforts between different scientific communities.

Emerging ocean reanalysis products are now ready to serve the downstream users like EU agencies (EEA, EMSA), coastal and marine agencies, coast guards, navies, policy makers, industry, and environmental protection agencies. MyOcean allowed also the extension of ocean prediction to biogeochemistry and the development of integrated modeling systems with data assimilation capabilities that have been utilized for prototyped biogeochemical reanalysis.

Many are the possible fields of application starting from the study of long-term variability of ocean basins and their circulation, heat content variations, air-sea fluxes interactions, water mass formation and properties, heat and freshwater transport by currents, sea ice variability and climate. The study of eutrophication and carbon cycle variability are instead important aspects of biogeochemical reanalysis activities. The evaluation of ocean synthesis or indicators from reanalysis is another important issue, which needs to evolve in parallel. The principal demand from the users community is for a concerted assessment of the quality of the accessible ocean reanalyses. Moreover a clear presentation of the various products available for certain regions, their main differences according to their characteristics (temporal coverage, horizontal and vertical resolution, performance versus reference observational datasets) would provide the user with indications about the possible usage for specific applications.

The objective of this paper is to provide an overview of the regional reanalysis systems implemented and the products available at the end of MyOcean in order to increase potential user awareness and maximize their uptake.

The paper is structured as follows: Section 1 describes the reanalysis activity evolution within MyOcean; Section 2 reviews regional physical reanalyses, while Section 3 is dedicated to biogeochemical ones. Section 4 describes the validation framework presenting examples of the proposed diagnostics. Section 5 is dedicated to the summary and discussion of main achievements. Conclusions about regional reanalysis activities within MyOcean and some recommendations for the future are given in Section 6. A list of the recurrent acronyms and abbreviations is given in the Appendix.

REGIONAL REANALYSES FROM MYOCEAN TO COPERNICUS MARINE SERVICE

During the period 2009-2012 MyOcean project exploited and strengthened past efforts in pre-operational ocean monitoring and forecasting in Europe to build an operational core infrastructure to deliver Marine Core Service (MCS) products and services. Main Research and Development (R&D) efforts were primarily dedicated to the improvement and consolidation of short-term prediction systems operating in real time to generate analyses and forecasts in a perpetually repeating cycle. Another issue was the creation of prototype reanalysis of the past few decades. Reanalyses have gradually included the biological component coupled to the physical component, exploiting operational oceanography advancements in ecosystem processes parameterization, physical/biological interactions, integrated modeling systems with data assimilation capabilities.

At the end of MyOcean in 2012 most of the Monitoring and Forecasting Centers (MFC) were able to develop and disseminate multi-year products like physical reanalysis (GLO, ARC, BAL, MED) and hindcasts (GLO, NWS), defined as reference model simulations without data assimilation. Some pioneering biogeochemical multi-year products were also produced from the ARC (reanalysis), NWS and MED (hindcasts) MFCs.. This first generation of regional reanalyses and hindcasts products covered an heterogeneous time period, mostly less than 20 years, and was produced without a coordinated approach. The different capabilities of the regional MFCs to implement reanalysis systems depended on the availability of the necessary input data like atmospheric forcing fields, remote and in situ observations for assimilation and boundary conditions. Only the GLO MFC started the reanalysis effort in a coordinated way delivering 3 global ocean reanalysis datasets at eddy permitting resolution (1/4°) and one reference hindcast, all covering the "altimetric era" (1993-2010). GLO products delivered to users were monthly averages describing the ocean from surface to bottom (sea surface height, potential temperature, salinity, currents, sea ice fraction, sea ice thickness, sea ice velocity) and their quality was assessed considering the "Mersea-GODAE metrics" (Crosnier and Le Provost, 2007).

The main issue raised by the user community on reanalysis at the end of MyOcean was the lack of common validation procedures and the diversity of products quality that led to a more unified approach during MyOcean2 (April 2012-September 2014) and MyOcean Follow On (October 2014-March 2015). The requirement for multi-year reanalyses and indices of quality lead to specific activities in a dedicated Work Package (WP) named "Multi-Year Assessment". This WP was designed to incorporate the Production Units (PU) responsible for both global and regional reanalyses computation (MFCs) and the creation of REP in situ and remote-sensed observations (TACs). The purpose was to strengthen their collaboration on the definition of concerted Calibration/Validation (Cal/Val) methodologies and reanalysis assessment procedures. The main objective of the WP was to improve, harmonize and consolidate the production and assessment of reanalyses and reprocessing of data covering the past 20 years or more. Both TACs and MFCs had to produce reports using the implemented assessment protocols. A close coordination with the specific Product Quality WP was encouraged to harmonize requirements for the assessment of REA long time series with the metrics defined for the operational systems.

There is a close relationship between the quality of reanalysis and the availability of consistent historical observations, thus one of the scientific key issue was to produce consistent time series of REP satellite observations, sea level (SL), sea surface temperature (SST), arctic sea ice (SI) and ocean color (OC), coming from different types of instruments with different error characteristics. Also in situ observations are needed to be reprocessed to limit the impact of different data set errors and biases on reanalysis estimation.

Another important task of "Multi Year Assessment" WP was the production of specific indicators, based on reprocessed observations in collaboration with relevant user communities like the European Environmental Agency (EEA). Examples of possible such products are: Sea Level Trend, Ocean Colour, Chl-a trends, Sea Ice coverage and global heat content anomalies time series (see http://marine.copernicus.eu/web/105-specific-scientific-developments.php).

PHYSICAL REANALYSIS SYSTEMS (PHY REA)

One of the main outcomes at the end of the MyOcean project in March 2015 is the release of regional PHY REA products covering all the European marginal seas. Data products are freely available through the MyOcean web catalogue. The Baltic region presents three PHY REA, the last one produced by SMHI covering the time period 1989-2013 and two previous produced during the first phase of MyOcean, one by SMHI and the other by DMI, covering the time period 1990-2009. We decided to describe here only the last available BAL REA since it is the only system that will be maintained and the products will be updated accordingly. The Atlantic NWS region presents also two PHY REA, one from UK Met Office (UKMO) and one from the Institute of Marine Research (IMR). Figure 1 and Tab. show the time coverage of the various PHY REA that span on average more than 20 years, except for the IBI region, whose REA provided by MERCATOR OCEAN, comprises 10 years from 2002 to 2011. The longest time series are NWS REA produced by UKMO (29 years) and the MED REA (27 years) from INGV. Maximum REA extension reaches 2013 (ARC, BAL and MED), which indicates approximately an offset of one year with the date of product release. This time offset is mainly related to REA system dependencies, including the time needed to retrieve all the input fields (atmospheric forcing, boundary conditions, observations for assimilation), the computational time, the product quality assessment and the dissemination time.

All MFCs release 3D monthly averaged fields of temperature (T), salinity (S), zonal (U) and meridional (V) current's components. Sea surface height (SSH) is also released, except for the UKMO NWS product, which instead released bottom temperature (bedT). The ARC MFC makes available mixed layer depth (MLD) and, together with BAL MFS, they include sea ice parameters (ICE). NWS (UKMO), IBI and MED provide also 3D daily averages (D). IBI MFC releases high frequency hourly data (H), while BAL MFC delivers both hourly and 6 hourly products. The 3D fields have been in most of the cases sub-sampled along the vertical components (Tab. 1) starting from the original model grid vertical levels (Tab.2). The ARC and both NWS products were necessarily interpolated on standard z-levels starting from hybrid or terrain following vertical coordinates. The BAL and MED REA are delivered instead keeping the original model grid resolution.

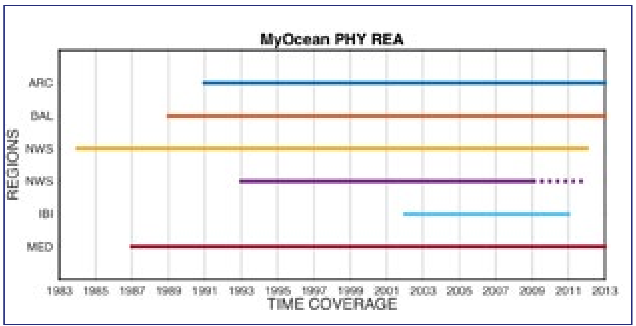


FIGURE 1

Time coverage of MyOcean PHY REA products.

Tab.1 Overview of MyOcean Physical Reanalyses products at the end of MyOcean Follow-On (April 2015). Up to date Overview table can be found here: http://marine.copernicus.eu/automne_modules_files/pmedia/public/r2201_9_overview-models-v1.1.1-web_eu.pdf

MFC	PU	TIME COVERAGE	YEARS	TEMPORAL RESOLUTION	VERTICAL RESOLUTION	RELEASED PARAMETERS
ARC	NERSC (NOR)	1991-**2013**	23	M	12	**T S UV** SSH ICE MLD
BAL	SMHI (SWE)	1989-**2013**	25	**M**+H+6H	**50**	**T S UV** SSH ICE
NWS	UKMO (UK)	1984-2012	29	**M**+D	24	**T** bedT **S UV**
	IMR (NOR)	1993-2009	17	M	26	T S UV SSH
IBI	MERCATOR (FRA)	2002-2011	10	**M**+D+H	50	T S UV SSH
MED	INGV (ITA)	1987-**2013**	27	**M**+D	**72**	T S UV SSH

Below follows a brief review of the main PHY REA systems components at the end of MyOcean (version V5 released on April the 8th, 2015), which has been extracted from QUID products documentation available at MyOcean web catalogue.

Table 2 summarizes all the regional PHY REA systems main characteristics: the Ocean General Circulation Model (OGCM), the data assimilation technique, the atmospheric forcing data and the lateral boundary data. Table 3 gives an outline of the in-situ and remote sensed observational data sets assimilated.

Table 2. Physical Reanalyses systems implemented within MyOcean and their main components: horizontal and vertical grid resolution, Ocean General Circulation Model (OGCM), the data assimilation technique, the atmospheric forcing data and the lateral boundary data.

MFC	Grid Resolution		OGCM	Data Assimilation	Atmospheric Forcing	Lateral Boundary Data
	horiz (km)	vert				
ARC	12.5	28	HYCOM2.2.18	DEnKF	ERA-Interim	monthly climatology
BAL	5.5	**50**	HIROMB	En 3D-Var	EURO4M	monthly climatology
NWS	7	51	NEMO3.4	3D-Var NEMOVAR	ERA-Interim	monthly averages ORCA025+GloSea5
	8	35	ROMS3.6	IS4DVAR	ERA-Interim	monthly averages GLORYS2V1+GLO-RYS2V3
IBI	7.5	75	NEMO2.3	SAM (SEEK filter+bias corr)	ERA-Interim	GLO REA GLORYS2V3
MED	6	**72**	NEMO3.2	OceanVar	ERA-Interim	monthly climatology GLO Mercator (1/4)

Arctic Ocean

The ARC-MFC system is TOPAZ4 (Sakov et al, 2012), a coupled ocean-sea ice data assimilation (DA) system used for both short-term forecasting and reanalysis purposes. The system is based on an advanced sequential data assimilation method, the Ensemble Kalman Filter (EnKF, Evensen 1994) in its deterministic flavor (DEnKF, Sakov and Oke, 2008). TOPAZ4 uses a simple, non-adaptive, distance-based localization method known as "local analysis" (Evensen, 2003; Sakov and Bertino, 2011), because it computes a local analysis for one horizontal grid point at a time, using observations from a local "bubble".

The OGCM is the hybrid coordinate ocean model (HYCOM version 2.2.18 e.g. Bleck, 2002; Chassignet et al., 2006) coupled with a sea-ice model (Hunke and Dukowicz, 1997). The model domain covers the North Atlantic and Arctic basins. The grid is made by 880x800 horizontal grid points, with approximately 12-16 km grid spacing in the whole domain. This is eddy-permitting resolution for low and middle latitudes, but is too coarse to properly resolve all of the mesoscale variability in the Arctic, where the Rossby radius is 1-2 km. The model uses 28 hybrid layers with carefully chosen reference potential densities. The top five target densities are purposely low to force them to remain z-coordinates. The minimum z-level thickness of the top layer is 3 m, while the maximum z-layer thickness is 450 m, to resolve the deep mixed layer in the Sub-Polar Gyre and Nordic Seas. The products are delivered on 12 z-vertical levels (Tab.1).

The model is initialized in 1973 using climatology that combines the World Ocean Atlas of 2005 (WOA05, Locarnini et al., 2006; Antonov et al., 2006) with version 3.0 of the Polar Science Center Hydrographic Climatology (PHC, Steele et al., 2001). At the lateral boundaries, model fields are relaxed towards the same monthly climatology. The model includes an additional barotropic inflow through the Bering Strait, representing the inflow of Pacific water, with volume fluxes and temperatures taken from observations (Woodgate et al. 2010). This inflow is balanced by an outflow at the southern boundary of the domain in the Atlantic Ocean.

TOPAZ4 is forced at the ocean surface with atmospheric data from the European Centre for Medium-Range Weather Forecasts (ECMWF) 6-hourly ERA-Interim reanalysis (Dee et al., 2011) that has a resolution of 0.75° (80km). The incoming short wave radiation is computed every 3h from synoptic cloud fields, and the wind stress is derived from 10 m winds, estimated as in Large and Pond (1981). Surface fluxes are computed trough bulk formula parameterization (Kara, 2000). The value of river discharge is poorly known for major basins in Siberia and Greenland, thus monthly climatological discharges are estimated by applying the ERA-Interim runoff estimates to the Total Runoff Integrating Pathways (TRIP, Oki and Sud, 1998) over the REA time period.

Observations that are assimilated by TOPAZ4 include along-track Sea Level Anomalies (SLA) from satellite altimeters, SST initially from NOAA and then the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA), in situ temperature and salinity profiles from Argo floats, Ice-Tethered Profilers and hydrographic cruises, ice concentrations (ICEC) from OSI-SAF and Lagrangian ice drift from CERSAT. The system uses a 7-day assimilation cycle, assimilates the gridded SST and ICEC on the day of the analysis; but along-track SLA, ice drift and in-situ T and S are gathered during the week prior to the day of the analysis. A brief overview of observations used in the reanalysis is given in Table 3. SST and sea surface heights are corrected for bias, with an online bias correction algorithm called EnKF state augmentation.

More information can be found in the following documents http://marine.copernicus.eu/documents/QUID/CMEMS-ARC-QUID-002-003.pdf

Baltic Sea

BAL MFC uses the HIROMB model (High-Resolution Operational Model for the Baltic), which is the operational ocean and sea ice forecasting model used at SMHI since the mid 1990s. The code was parallelized using MPI (Wilhelmsson, 2002; Funkquist and Kleine, 2007). The turbulence model is a state-of-the-art buoyancy-extended k-omega model with parameterizations for internal wave energy and Langmuir circulation (Axell, 2002, Umlauf et al., 2003). The ice model (Axell 2013) has a Hibler-type of ice rheology and has parameterizations for ice ridges included based on Lensu (2003). Last changes include improved air-ice and air-sea interaction, thermodynamics and a rotated grid. The model domain, as in the operational setup, covers the North Sea as well as the Baltic Sea. At the lateral boundary in the western English Channel and along the Scotland-Norway boundary, sea level is prescribed using a coarse resolution (44 km) storm-surge model called NOAMOD (North Atlantic Model). Climatological monthly mean values of salinity and temperature are used at the boundary and it is assumed there is no sea ice. The river runoffs are specified as daily means from the hydrological model E-HYPE (European Hydrological Predictions for the Environment, Donnelly, 2013), which operates at SMHI. The number of rivers is of the order of 500 along the coastline. Atmospheric forcing is from the recent atmospheric reanalysis Euro4M (Dahlgren et al., 2012), which used the HIRLAM (High-Resolution Limited Area Model) model with 22 km resolution and ERA-Interim at the lateral boundaries.

The data assimilation method is 3D Ensemble Variational (En 3D-Var) technique (see Liu et al., 2008, 2009 and the forthcoming paper by Axell and Liu 2015 (in manuscript). It is a multivariate method, which means that many variables are affected by each observation. The model uncertainty is specified using an ensemble of model states, which implies that the Background Error Covariances are inhomogeneous and non isotropic.

The variables assimilated are charts of SST, SIC (Sea Ice Concentration) and SIT (Sea Ice Thickness) from the Swedish Ice Service at SMHI (L4 product) as well as in-situ temperature and salinity profiles from the ICES database (http://www.ices.dk/). Independent temperature and salinity profiles from the Swedish database SHARK SMHI were used for validation only.

The forecasting system operates with a six-hour cycling, which implies a new forecast of six hours is made every six hours (at 00Z, 06Z, 12Z and 18Z) using the best weather forcing. 2D fields of observations (SST, SIC and SIT) are assimilated at 00Z whereas the T/S profiles are assimilated at 12Z.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-BAL-PUM-003-008.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-BAL-QUID-003-008.pdf.

North West Shelf

The NWS UKMO REA was produced using the Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM7), which is comprised of the Nucleus for European Modelling of the Ocean (NEMO version 3.4) model code (Madec, 2008). The model is located on the European North-West continental Shelf (NWS) on a regular grid with 1/15° latitudinal resolution and 1/9° longitudinal resolution (c.a 7km). A hybrid s-sigma terrain following coordinate system (Siddorn and Furner, 2013) with 51 levels is employed in order to retain vertical resolution on the shelf. However, the products are delivered on 24 vertical levels based upon the ICES standard depths (Tab.1).

Tidal forcing is included both on the open boundary conditions via a Flather radiation boundary condition (Flather, 1976) and through the inclusion of the equilibrium tide. With the exception of the Baltic Sea, the model was forced at its open boundaries by global ocean analyses. For the early part of the REA (January 1984-March 1989) horizontal fluxes were taken from the National Oceanography Centre's ORCA025 hindcast (Megann et al., 2014), before switching to GloSea data (MacLachlan et al., 2014) thereafter. Baltic boundary conditions were taken from IOW-GETM (General Estuarine Transport Model) model (Stips et al., 2004). Freshwater inflow was prescribed from E-HYPE hydrological reanalysis (Donnelly, 2013). Surface forcing of 3 hourly precipitation, wind stress, pressure and shortwave fluxes were taken from the ERA-Interim reanalysis (Dee et al., 2011). These fluxes were then processed through the CORE bulk forcing algorithms (Large and Yeager, 2004; Large and Yeager 2009). The inverse barometer effect of atmospheric pressure gradients on the sea surface height was also included.

Assimilation of SST was performed using a 3DVar algorithm. Calculation of the assimilation increments was done using an adapted version of the NEMOVAR (Mogensen, 2012) system in three steps. Firstly a one-day model forecast was performed and observations were compared to model output at the nearest time-step (First Guess at Appropriate Time system, FGAT). Then observation minus model differences were converted to increments by minimizing a 3DVar cost function using seasonally varying estimates of the observation representativity error variance and background error variance. The total observation error variance was obtained by adding an estimate of the measurement error variance of each observation to the representativity error variance. Information from observations was spread horizontally according to length scales that are inversely proportional to the potential vorticity gradient and have a maximum value of 130km. In the final stage the analysis was produced by re-running the model for the same day and applying the Incremental Analysis Update (IAU, Bloom et al., 1996) method. Increments were added into the model down to the base of the instantaneous mixed layer.

From January 1984 until October 1995 the REA assimilated NOAA-AVHRR data obtained from the Pathfinder Vn5.2 dataset (Casey et al., 2010). Then the REA assimilates ESA SST CCI data set (Merchant et al., 2014) until February 2010 after which a GHRSST version (see http://www.ghrsst.org) of NOAA-AVHRR data was used. ATSR data from the CCI project was assimilated from April 1991 until February 2010, with UKMO data used thereafter. Also from the CCI project, METOP-AVHRR data were assimilated from December 2006, switching to GHRSST feeds in February 2010. GHRSST data from the AMSRE and SEVIRI instruments were assimilated from August 2006, with the AMSRE instruments failing in November 2011. In-situ SST data were assimilated throughout the entire REA run using ICOADS (see http://icoads.noaa.gov/) and World Meteorological Organization's (WMO) Global Telecommunications System (GTS) data.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-009-011.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-009-011.pdf.

The NWS IMR REA system is the ROMS 3.6 (Regional Ocean Modelling System, Shchepetkin and McWilliams, 2005) based on an advanced assimilation method (Incremental Strong constraint Four-Dimensional Variational Analysis). The model domain covers the NWS with an orthogonal curvilinear coordinate system and 35 terrain-following vertical levels over a variable topography. The products are interpolated and delivered on 26 z-vertical levels (Tab.1).

The model is initialized in January 1992 using monthly averages from the Simple Ocean Data Assimilation (SODA, http://www.atmos.umd.edu/~ocean/) as lateral boundary conditions. Starting in January 1993, the lateral boundary forcing is replaced with monthly average values from the GLO REA GLORYS2V1 (ORCA025 model configuration at 1/4°, 75 vertical z-levels) produced by MERCATOR for the time period January 1993 to December 2009. IMR REA is currently being updated and will eventually include the years 2010-2012. For this update we used monthly average computed from the new MERCATOR GLO REA GLORYS2V3 as lateral boundary forcing. In addition, the lateral boundary forcing included tidal forcing. The ocean surface was forced with fluxes computed from 6-hourly ERA-Interim data (Dee et al., 2011). The atmospheric fields included: precipitation, dew point temperature, total cloud cover, air temperature at 2 m, sea level pressure, wind speed at 10 m and long wave radiation. The wind stress was estimated as in Large and Pond (1981). Heat and momentum fluxes were calculated using bulk formula parameterization from Fairall et al. (1996).

The value of river discharge was obtained from the E-HYPE model, (Donnelly, 2013) which calculates hydrological variables on a daily time-step at a high sub-basin resolution (120 km2, median) simultaneously for the entire continent. The E-HYPE hydrological model calculated water balance, dynamics of hydrological variables and daily discharge for the continental Europe (Strömqvist et al., 2009) for the period 1980-2008. Year 2008 is persisted for the period 2009-2012. The TPXO 7.1 tidal solutions (Egbert and Erofeeva, 2002) from Oregon State University with the regional solution for the Atlantic Ocean at 1/12 degree resolution (http://volkov.oce.orst.edu/tides/AO.html) were used containing the following tidal constituents: M2, S2, N2, K2, K1, O1, P1, and Q1.

Data assimilation used the Incremental Strong constraint 4D Variational (IS4DVAR) scheme embedded in the ROMS code. The goal of IS4DVAR is to identify the best-estimated circulation by minimizing in a least-squares sense the difference between the model and the observations. These estimates are also subject to prior hypotheses about errors and possibly additional constraints (Moore et al., 2011). This means that for a given simulation interval (, e.g. 7 days depending on the frequency of your observations), the model forecast is compared to available observations, and the difference between model and observations are assessed. The posterior estimates are based on prior information together with the probability of minimizing the variance of the model to observations.

Observations that are assimilated include along-track SST from the historical NOAA/AVHRR SST satellite data re-processed in the framework of the Pathfinder v5.2 project (CoRTAD V5, Selig et al., 2010). The system uses a 7-day assimilation cycle, and assimilates the gridded SST (4km resolution) for the day of the analysis.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-010-012.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-010-012.pdf

Ireland-Biscay-Iberia

IBI REA system relies on the ocean model NEMO version 2.3 (Madec, 2008) and the reduced order Kalman filter data assimilation method based on the SEEK (Singular Extended Evolutive Kalman filter) formulation introduced by Pham et al. (1998). The horizontal grid is a subset of the global 1/12° ORCA tripolar grid. The original bathymetry is derived from the 30 arc-second resolutions GEBCO08 dataset (Becker et al., 2009) merged with several local databases (F. Lyard, personal communication, 2010). At open boundaries within 10-point-wide relaxation areas, bathymetry is exactly set to the parent grid model bathymetry and progressively merged with the interpolated dataset described above. The vertical grid has 75 levels, with a resolution of 1m near the surface and 200min the deep ocean. Partial bottom cell definition of the bathymetry allows an accurate representation of the steep slopes characteristic of the area. The 3D fields were sub-sampled and they are delivered on 50 vertical levels (Tab.1).

Surface boundary conditions are prescribed using the CORE bulk formulation (Large and Yeager, 2004; Large and Yeager 2009). Forcing fields are provided from ERA-Interim every 3 hours (Dee et al., 2011) interpolated on ORCA025 native grid using an Akima interpolation algorithm. Atmospheric data include wind at 10m, air temperature and humidity at 2m, atmospheric pressure, downward long wave and short wave radiation and the daily average precipitation rate. A specific correction for radiative fluxes has been implemented following Verbrugge and Garric (2010) based on GEWEX satellites fluxes products. ERA-Interim rainfall fluxes were corrected considering GPCPV2.1 rainfalls flux allowing a more realistic surface salinity spatial distribution. Due to the high vertical resolution near the surface, a parameterization of the solar flux diurnal cycle has been implemented (Bernie, 2007) to better represent the nighttime convection. Daily mean flux is spread over the day according to the time and geographical position. River inputs are implemented as lateral points sources with flow rates based on monthly climatological data taken from Global Runoff Data Center (http://www.bafg.de/GRDC), French "Banque Hydro" dataset (http://www.hydro.eaufrance.fr/) and simulations from SMHI.

Lateral open boundary data (temperature, salinity, velocities and sea level) are interpolated from GLO REA GLORYS2V3 daily output. These are complemented by 11 tidal harmonics (M2, S2, N2, K1, O1, Q1, M4, K2, P1, Mf, Mm) built from FES2004 (Lyard et al., 2006) and TPXO7.1 (Egbert and Erofeeva, 2002) tidal models solutions. The atmospheric pressure component, missing in the large-scale parent system sea level outputs, is added hypothesizing pure isostatic response at open boundaries (inverse barometer approximation). GLO REA GLORYS2V3 provided initial conditions for temperature, salinity, velocity components and sea surface height.

The data assimilation component SAM2 (Mercator Assimilation System) is based on SEEK and an IAU method (Incremental Analysis Updates) is used to apply the increments in the system. The error statistics are represented in a sub-space spanned by a small number of dominant 3D error directions. A 3D-Var scheme corrects for the slowly evolving large-scale biases in temperature and salinity. The data assimilation system allows constraining the model in a multivariate way with SST, together with all available satellite SLA, and with in situ observations from the CORA3.2 database (Cabanes et al. 2013), including ARGO floats temperature and salinity measurements.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-IBI-PUM-005-002.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-IBI-QUID-005-002.pdf.

Mediterranean Sea

The MED REA system comprises NEMO3.2 hydrodynamic model (Madec et al 2008) and a variational data assimilation scheme (OceanVar) for temperature and salinity vertical profiles and satellite SLA along track data. The OGCM has 1/16° horizontal resolution (ca. 6-7 km) and 72 unevenly spaced vertical levels (Oddo et al., 2009). It uses vertical partial cells to fit the bottom depth shape. The model domain is located in the Mediterranean Basin and it extends into the Atlantic in order to better resolve the exchanges with the Atlantic Ocean at the Strait of Gibraltar. The model is nested in the Atlantic (Oddo et al., 2009) within monthly mean climatological fields computed from ten years of daily output of the global model (1/4°) provided by MERCATOR (Drevillon et al., 2008).

Momentum, water and heat fluxes are interactively computed by bulk formulae using ERA-Interim (every 6 hours) fields (Dee et al. 2011) and the model predicted SST (Tonani et al., 2008, Pettenuzzo et al.2010). Satellite SST is used to correct interactively the computed heat flux at air-sea interface with a relaxation constant of 60W/m2. The SST data come from a time concatenation of SST products characterized by horizontal maps optimally interpolated onto model grid (Marullo et al., 2007; Buongiorno Nardelli et al. 2013). Evaporation is derived from the latent heat flux. Runoff is provided by monthly mean datasets: the Global Runoff Data Centre dataset (Fekete et al., 1999) for the Ebro, Nile and Rhone and the dataset from Raicich (Raicich, 1996) for the Adriatic rivers (Po, Vjosë, Seman and Bojana). The Dardanelles inflow is parameterized as a river and the climatological net inflow rates are taken from Kourafalou and Barbopoulos (2003). Precipitations are prescribed every 6 hours from ERA-Interim (Dee et al. 2011).

MED REA has been initialized by a temperature and salinity monthly climatology produced within the framework of Sea-DataNet FP6 Project utilizing an extensive historical in situ data set from 1900 to 1987 to prevent the initial condition to be affected by the Eastern Mediterranean Transient (EMT), which would change consistently the water mass characteristics of the Mediterranean Basin (Pinardi et al. 2013).

The data assimilation scheme is the OceanVar developed by Dobricic and Pinardi (2008). The background error correlation matrix was estimated from an historical model simulation and it varies seasonally in 13 regions of the Mediterranean Sea having different physical characteristics (Dobricic et al 2005). The mean dynamic topography used for Sea Level Anomaly (SLA) data assimilation was computed as in Dobricic (2005).

The assimilated data include REP SLA data provided by SL TAC and in situ temperature and salinity profiles belonging from different instrumental data type: CTDs, XBTs, MBTs, bottles, ARGO floats. In situ data sets have been collected from European Marine databases: 1) SeaDataNet European infrastructure (DG-Research-FP6); 2) MEDAR-MEDATLAS data set covering the period 1985-1999 (Maillard et al., 2005); 3) MFS (Mediterranean Forecasting System) operational observation infrastructure based on ENEA and Coriolis data centers and 4) MyOcean In situ TAC. MFS operational observations are near real time (NRT) observations collected within different precursor projects spanning a time period from 1999 to April 2009: MFSPP (Mediterranean ocean Forecasting System Pilot Project, Pinardi et al., 2003), EU-MAST project, MFSTEP (Mediterranean ocean Forecasting System Towards Environmental Prediction).

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-MED-PUM-006-004.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-MED-QUID-006-004.pdf.

Tab.3 Observations assimilated in the regional PHY REA systems.

MFC	IN SITU	SST	SLA	SI
ARC	T/S profiles (GLO REP)	Reynolds (<1998)+OSTIA (>Jun1998)	GLO L3 REP	concentration (ICEC, OSI TAC), drift (CERSAT, OSI TAC)
BAL	T/S profiles (ICES database)	SMHI L4 product		SMHI L4 concentration, thickness
NWS	SST from ICOADS (before 2010) and GTS	NOAA AVHRR (<1995)+ESA CCI (1995-2010)+GRHSST UKMO (> 2010)		
		NOAA CoRTAD (AVHRR)		
IBI	T/S profiles (CORA3.2)	NOAA AVHRR-only OISST	AVISO	
MED	T/S profiles (SeaDataNet, MEDAR/MEDATLAS, MFS)	REP and DT	Med L3 REP	

BIOGEOCHEMICAL REANALYSIS SYSTEMS (BGC REA)

All regional MFCs were able to implement BGC REA systems and deliver various products, whose principal characteristics are outlined. However NWS and IBI systems do not assimilate any biogeochemical observations into the BGC models and in Table 4 are classified as hindcasts (HIN) in the model integration column instead of REA. Figure 2 shows the time coverage of BGC REA products, which is less extended and less homogeneous in time than PHY REA one. The longer time series (30 years) of data is provided from BAL MFC but it goes from 1970 to 1999 and it does not cover the recent years. The shorter REA data set is from ARC MFC, which comprises a 4 years time period from 2007 to 2010. NWS (UKMO) and MED BGC REA data sets include 2012, which is the most recent data set available. Time offset increases for BGC REAs due mainly to their input data dependency.

All MFCs delivered monthly (M) averaged data of different parameters. Only BAL and NWS (UKMO) MFCs are delivering daily data (D). Nitrate (N) and Phosphate (P) and dissolved Oxygen (O2) are delivered by all systems. Chlorophyll-a is not released by NWS IMR system. Phytoplankton data are delivered from all MFCs with the exception of BAL, which instead releases Ammonium (NH4) like the IBI MFC. Primary Production (PP) data are available for NWS, IBI and MED regions. Radiative Flux (RadFlux) is available for ARC and NWS region. IMR NWS and IBI systems provide Silicate data (Si). IBI REA is the only supplying Iron (Fe) data and the Euphotic depth (Eup). The 3D fields have been in most of the cases sub-sampled along the vertical components (Tab. 1) starting from the original model grid vertical levels (Tab.2). The BAL and MED BIO REA are delivered keeping the original model grid resolution.

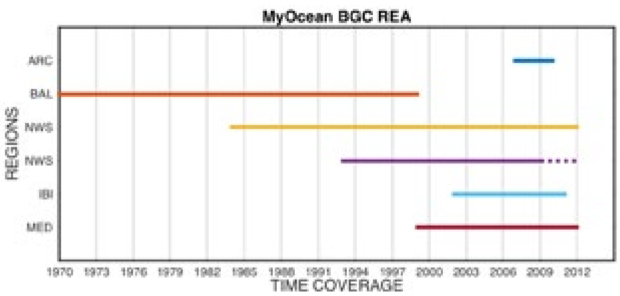


FIGURE 2

Time coverage of MyOcean BGC REA products.

Tab. 4 Overview of MyOcean BGC Reanalyses (R) and Hindcast (H) products at the end of MyOcean Follow-On (April 2015). Up to date Overview table can be found here: http://marine.copernicus.eu/automne_modules_files/pmedia/public/r2201_9_overview-models-v1.1.1-web_eu.pdf

MFC	PU	MODEL INTEGRATION	TIME COVERAGE	YEARS	TEMPORAL RESOLUTION	VERTICA RESOLUTION	RELEASED PARAMETERS
ARC	NERSC (NOR)	REA	2007-2010	4	M	12	CHL **O2 N P** Phyto RadFlux
BAL	SMHI (SWE)	REA	1970-1999	30	**M**+2D	**83**	CHL **O2 N P** NH4
NWS	UKMO (UK)	HIN	1984-**2012**	29	**M**+D	24	CHL **O2 N P** Phyto PP RadFlux
	IMR (NOR	HIN	1993-2009	17	M	26	**O2 N P** Phyto PP Si
IBI	MERCATOR (FRA)	HIN	2002-2011	10	M	50	CHL **O2 N P** Phyto PP Si Fe NH4 Eup
MED	OGS (ITA)	REA	1999-**2012**	14	M	**72**	CHL **O2 N P** Phyto PP

Below follows a brief description of BGC REA systems. The main focus is on the BGC model characteristics summarized in Table 5 : the coupling with the PHY model, the data assimilation technique adopted and the assimilated observations. Most of the BGC models have been online coupled with the physical models. Only half of the BGC systems comprehend a data assimilation scheme. In two cases (ARC, MED) satellite maps of chlorophyll are assimilated while BAL system assimilates in situ observations.

Tab. 5 BGC REA systems implemented within MyOcean and their main components.

MFC	Grid Resolution horiz (km)	Grid Resolution vert	MODEL COUPLING		Data Assimilation	ASSIMILATED OBS
ARC	40	28	HYCOM+NORWECOM	online	DEnKF	GlobColour CHL1 GSM-derived REP
BAL	3.7	**83**	RCO+SCOBI	online	EnOI	In situ O2 N P (SHARK database)
NWS	7	51	NEMO3.4+ERSEM	online		
	8	35	ROMS3.6+NORWECOM	offline		
IBI	7.5	75	NEMO3.2+PISCES	online		
MED	6	**72**	OPATM-BFM	offline	OceanVar	Med L4 CHL REP (OC TAC)

Arctic Ocean

The NORWECOM model (NORWEgian ECOlogical Model, Aksnes et al., 1995; Skogen and Søiland, 1998) is the coarse resolution prototype of TOPAZ4 system previously described, but with 40km horizontal resolution and 28 vertical levels (the products are delivered on 12 z-vertical levels). NORWECOM is coupled online to the physical HYCOM model (Samuelsen et al. 2015). It uses HYCOM facility for advection of tracers and has the same time-step as the physical model. The current model version includes two classes of phytoplankton (diatom and flagellates), two classes of zooplankton (meso and microzooplankton) derived with the same formulation from the model ECOHAM4 (Pätsch et al., 2009), several types of nutrients (inorganic nitrogen, phosphorus and silicon) and detritus (nitrogen, phosphorus), biogenic silica, and oxygen, so that the ecosystem state vector is made of 11 variables. The chlorophyll-a concentration (CHLA) is computed from the model diatom and flagellates concentrations (DIA and FLA) by the equation CHLA=(DIA+FLA)/11. The constant factor of 11gN/gChla is used to convert to chlorophyll concentration in mg/m3, the standard unit for satellite-derived phytoplankton chlorophyll products.

The analysis is performed by the DEnKF in the model grid space and divided into two steps. In the first step, the physical data (SST, SLA and ice concentration) are assimilated in the physical component (HYCOM) of the coupled model while the biological component is not included in the analysis state vector. However variations in the analyzed layer thickness might lead to changes in the amount of substance (biological tracers being defined as concentrations) that are not compensated by changes in concentrations of the species. In order to ensure the conservation of the amount of species for each tracer at each horizontal grid point (conservation in the water column), a vertical remapping of the tracer is performed. This remapping uses the WENO interpolations embedded in HYCOM. In the second step, surface CHLA data are assimilated in the biological component (NORWECOM) of the coupled model. Biological state variables and parameters are log-transformed prior to assimilation in order to prevent negative values in the analysis (Simon and Bertino, 2012).

The OC data set used for assimilation is the GlobColour reprocessed CHL1 GSM-derived product obtained merging MERIS, MODIS and SeaWiFS instruments. They correspond to the 8-day averaged CHLA concentration for case-1 water. Their spatial coverage varies strongly with seasons resulting in the absence of observations for the Arctic Ocean in winter. Data located both in water deeper than 10 m and at least 50 km away from the coast are assimilated. The assimilation cycle is weekly and the date of the analysis is used to define which 8-day averaged CHLA data set is assimilated.

More information can be found in the following documents http://marine.copernicus.eu/documents/QUID/CMEMS-ARC-QUID-002-005.pdf and http://marine.copernicus.eu/documents/PUM/CMEMS-ARC-PUM-002-ALL.pdf.

Baltic Sea

The coupled BAL model system is based on the Swedish Coastal and Ocean Biogeochemical model (SCOBI) (Eilola et al., 2009; Almroth-Rosell et al., 2011) and the Rossby Centre Ocean circulation model (RCO) (Meier et al., 2003; Meier, 2007). The model domain of RCO-SCOBI covers the Baltic Sea with open boundaries in the northern Kattegat. The horizontal grid resolution amounts to 3.7 km (eddy-permitting) with 83 vertical levels and a layer thickness of 3m. SCOBI model describes the dynamics of nutrients (phosphate, nitrate, ammonium), phytoplankton (diatoms, flagellates and others and cyanobacteria), zooplankton, detritus and oxygen. Processes like assimilation, remineralisation, nitrogen fixation, nitrification, denitrification, grazing, mortality, excretion, sedimentation, resuspension and burial are considered. With the help of a simplified wave model resuspension of organic matter is calculated from the wave and the current induced shear stresses (Almroth-Rosell et al., 2011). The carbon (C) is used as the constituent representing detritus and zooplankton. The nitrogen (N) and phosphorus (P) content of autotrophs, zooplankton and detritus are described by the Redfield molar ratio. The molar ratio of a complete oxidation of the remineralised nutrients is O2:C=138. Atmospheric forcing data are from Rossby Centre Regional Climate model (RCA3, Samuelsson et al., 2011) with a horizontal grid resolution of 25 km and driven at the boundaries by ERA40 reanalysis data from ECMWF (Uppala et al., 2005). A bias correction method is applied to wind speed following Meier et al. (2011). The hydrological forcing is based upon monthly mean river runoff observations (Bergström and Carlsson, 1994). Monthly nutrient loads from rivers and point sources and of atmospheric nitrogen deposition are calculated from historical data (Savchuk et al 2012). Initial conditions are taken from an earlier run with RCO-SCOBI.

The data assimilation method is EnOI (Evensen, 2003; Oke et al., 2005, Liu et al. 2013), which is developed from EnKF. In theory, EnOI uses a stationary ensemble to approximate the system's background error covariance. The ensemble of anomalies of states is sampled from model states in a long-term simulation. A large ensemble of model states can be used to ensure that EnOI spans a sufficiently large space for a proper analysis.

Data assimilation considers physical (temperature and salinity) and biogeochemical (oxygen, nitrate and phosphate) observations from the Swedish Oceanographic Data Centre database SHARK, which mainly contains low-resolution CTD data from the Baltic Sea as well as Kattegat and Skagerrak.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-BAL-PUM-003-009.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-BAL-QUID-003-009.pdf.

North West Shelf

The NWS BGC products from UKMO were provided using the FOAM AMM7 system described previously in which NEMO3.4 ocean model code is coupled to the European Regional Seas Ecosystem Model (ERSEM; Blackford et al. 2004). The ecosystem model used World Ocean Atlas 2009 nutrients at the boundaries and river concentration climatology for nutrients and sediment concentration. The ecosystem model is forced by the physical model via an online coupling with the same time step of the physical model. No observation has been assimilated into the BGC model. The BGC REA covers the period from January 1984 to June 2012 but it was run in three sections and re-initialized at the start of each period. This re-initialization is in turn reflected in an increase in the chlorophyll concentrations in some regions at the beginning of each section. The segmented nature of the REA is a limitation because there are temporal discontinuities at the boundaries between the three periods. These drifts and discontinuities are likely to have impacts on other parts of the biogeochemical system, which may be important in a number of user applications.

More information can be found in the following documents http://marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-009-011.pdf and http://marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-009-011.pdf.

For the BGC IMR REA system the NORWECOM (Aksnes et al., 1995; Skogen et al., 1995; Skogen & Søiland, 1998) have been run offline forced by the IMR PHY REA previously described. The initial nutrient fields are derived and extrapolated/interpolated (Ottersen, 1991) from data obtained from ICES database together with some small initial amounts of algae (0.1mgN/m3). Nutrient data (monthly means) measured in the Baltic (ICES) are used for the water flowing into Kattegat. Along the open boundaries long term nutrient means from Station M (66°N, 2°E) is used, except for the upper 100 meters where monthly values from the ERSEM model is used. The processes included are primary and secondary production, zooplankton grazing, respiration, algae death, remineralization of inorganic nutrients from dead organic matter, self shading, turbidity, sedimentation, resuspension, sedimental burial and denitrification. River nutrients (organic and inorganic nitrogen and phosphorus) are taken from E-HYPE hydrological model hindcast. Silicate is not available from E-HYPE, thus monthly mean values have been taken from available observations at nearby rivers. The E-HYPE hindcast is only available until 2008, for later years values for 2008 were used. None observation has been assimilated into the BGC model.

More information can be found in the following documents http://marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-006-008.pdf and http://marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-007-008.pdf.

Ireland-Biscay-Iberia

IBI BGC REA uses PISCES model (Aumont, 2012) in NEMO3.2. It is a model of intermediate complexity designed for global ocean applications (Aumont and Bopp, 2006) and it is part of NEMO modeling platform. PISCES is coupled online with IBI PHY REA. The time scheme is eulerian contrary to a leap- frog scheme for the physical part, thus for numerical conservation aspects, PISCES is called every two physical time-step. The advection scheme is the same used for the physical model. PISCES has 24 prognostic variables and simulates biogeochemical cycles of oxygen, carbon and the main nutrients controlling phytoplankton growth (nitrate, ammonium, phosphate, silicic acid and iron). BGC REA is initialized with World Ocean Atlas 2001 for nitrate, phosphate, oxygen and silicate (Conkright et al. 2002), with GLODAP (Global Ocean Data Analysis Project) climatology including anthropogenic CO2 for Dissolved Inorganic Carbon and Alkalinity (Key et al. 2004) and, in the absence of corresponding data products, with model fields for dissolved iron and dissolved organic carbon. Boundary fluxes account for nutrient supply from three different sources: atmospheric deposition (Aumont et al., 2008), rivers for nutrients, dissolved inorganic carbon and alkalinity (Ludwig et al., 1996) and inputs of Fe from marine sediments. None observation has been assimilated into the BGC model.

Mediterranean Sea

The MED BGC REA at 1/16 horizontal resolution consists of a transport model and a biogeochemical reactor (OGSTM-BFM system version V4.0) and a 3DVAR assimilation scheme. OGSTM-BFM is forced offline by the MED PHY REA, which provides horizontal and vertical current velocities, vertical eddy diffusivity, temperature, salinity, solar shortwave irradiance and wind stress.

The OGSTM (Lazzari et al. 2012) is a modified version of the OPA 8.1 code (Foujols et al., 2000), which resolves advection, vertical diffusion and the sinking terms of the tracers (biogeochemical variables). It uses an explicit forward time scheme for the advection and horizontal diffusion terms, whereas an implicit time step is adopted for the vertical diffusion. The sinking term is a vertical flux, which acts on a sub-set of the biogeochemical variables (particulate matter and phytoplankton groups). The features of BFM have been chosen to target the energy and material fluxes through both "classical food chain" and "microbial food web" pathways (Thingstad and Rassoulzadegan, 1995), and to take into account co-occurring effects of multi-nutrient interactions.

The BFM presently includes nine Plankton Functional Types (PFTs). Phytoplankton PFTs are diatoms, flagellates, picophytoplankton and dinoflagellates. Heterotrophic PFTs consists of carnivorous and omnivorous mesozooplankton, bacteria, heterotrophic nanoflagellates and microzooplankton. It describes the biogeochemical cycles of 4 chemical compounds: carbon, nitrogen, phosphorus and silicon through the dissolved inorganic, living organic and non-living organic compartments. Nitrate and ammonia are considered for the dissolved inorganic nitrogen. The non-living compartment consists of 3 groups: labile, semilabile and refractory organic matter. The last two are described in terms of carbon, nitrogen, phosphorus and silicon contents.

At the Strait of Gibraltar the concentrations of phosphate, nitrate, silicate, dissolved oxygen are relaxed to MEDAR-MEDATLAS climatological seasonal profiles (Rixen et al., 2005). River nutrient loads are based on the reconstruction by Ludwig et al. (2009). The nutrient discharge rates for the major rivers (Po, Rhone and Ebro) present a seasonal variability while all other inputs are treated as constants. Atmospheric deposition rates of inorganic nitrogen and phosphorus are set according to the synthesis proposed by Ribera d'Alcalà et al. (2003) and based on observations (Loye-Pilot et al., 1990; Guerzoni et al., 1999; Herut and Krom, 1996; Cornell et al., 1995; Bergametti et al., 1992), then assumed to be constant in time during the year, but with different values for the western and eastern sub-basins. The Dardanelles inputs where considered as river inputs (Somot et al., 2008).

The data assimilation scheme consists of a 3D variational method (Weaver et al., 2003) that iteratively minimizes a cost function between modelled and satellite surface chlorophyll. The solution of the minimization is found by considering a decomposition of the background error covariance matrix (Teruzzi et al., 2013; Dobricic and Pinardi, 2008). The decomposition takes into account three operators that account sequentially for the vertical, horizontal and biogeochemical components of the covariance (Teruzzi et al., 2013). MED BGC REA system assimilates daily sea surface CHL concentration maps (L4) from multi satellite observations (ESA-CCI) reprocessed by OC TAC managed by GOS-ISAC-CNR (Volpe et al., 2007).

REANALYSIS VALIDATION FRAMEWORK

One of main objectives of REA activities during the second phase of MyOcean was to harmonize the validation methods used for the REA assessment following user requirements and feedback. The adoption of shared validation strategies is very important for the user community because it enhances confidence on products and their potential adoption. The aim is to verify REA systems performance through dedicated scientific assessment and to characterize products using quality indicators and reports. Two starting points in defining a common validation protocol for GLO/REG and PHY/BGC REAs were: the experience matured on the GLO REAs inter-comparison during the first phase of MyOcean and the Cal/Val guidelines applied to the operational products developed within a dedicated Product Quality WP. This WP coordinated the validation cross-cutting activity distributed across all MFCs and TACs. Its primary objective was to ensure that the accuracy of products was adequately monitored and that information on product quality was scientifically sound, consistent, useful, and communicated effectively.

GLO REA assessment methodology applied the standard set of diagnostics called "MERSEA-GODAE metrics" (Class 1 to Class 4) that were designed to present an overview of the ocean and sea ice dynamics and to evaluate prediction systems quality, consistency and performance (Crosnier and Le Provost, 2007). REA consistency is verified with the current knowledge of the ocean circulation and climatologies. Performance and quality are measured through comparison with reference observational data sets. Validation experts identified reference data sets for verification and validation, taking into consideration the specificities of regional basins that require tailored sets of observations. This strategy has been proven to provide an efficient inter-comparison of operational forecast systems and GLO REAs and, if applied to different REG REA systems, it promotes products harmonization and advancement. It helps identifying system weaknesses and determining the necessary improvements for future update. Common metrics have been defined for the released variables: Temperature, Salinity, Sea Level, Currents, Transports, Sea Ice and Biogeochemistry.

To complement MERSEA-GODAE metrics REA producers adopted Products Quality WP guidelines on Estimated Accuracy Numbers (EAN). EAN are static numbers describing the accuracy, mainly mean and root mean square difference, computed from products and reference data sets. Guidelines cover units, precision, regions, vertical layers, averaging time and format of presentation. The purpose of these conventions was to ensure that users see validation information with a consistent style of presentation across the different products. Consistency is important, but given the wide range of products and production methods, it is not always scientifically meaningful for all systems and able to provide exactly the same types of information. This is particularly true for regional PHY and BGC REA systems and products that are still at an early stage and still need research activities to explore the best ocean synthesis and explain the ocean state evolution. Moreover, each regional basin is characterized by specific processes at different space-time scales and their common description necessitates more coordinated efforts to reach product harmonization.

Common validation guidelines have been traced also for BGC REA defining a minimum number of metrics, but the scarcity of BGC data is a limit for a comprehensive quality assessment. Reference climatologies of BGC variables at regional scales, like nutrients, chlorophyll, are missing too, preventing also the consistency analysis. SeaDataNet and EMODNET European projects worked in collaboration with MyOcean in order to retrieve the largest number of BGC historical observations, to define DM quality check procedures and to produce reference regional climatologies. The analysis of BGC variables needs additional research conducted with a new approach since observations are sparse in time and space and each BGC variable exhibits peculiar statistical characteristics linked to its underlying dynamical process.

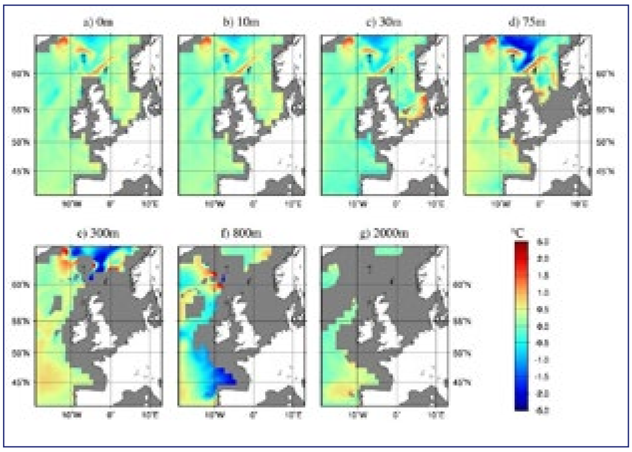


FIGURE 3

Long-term annual mean difference between NWS REA produced by UK MetOffice and WOA09at different depth levels (REA-WOA09).

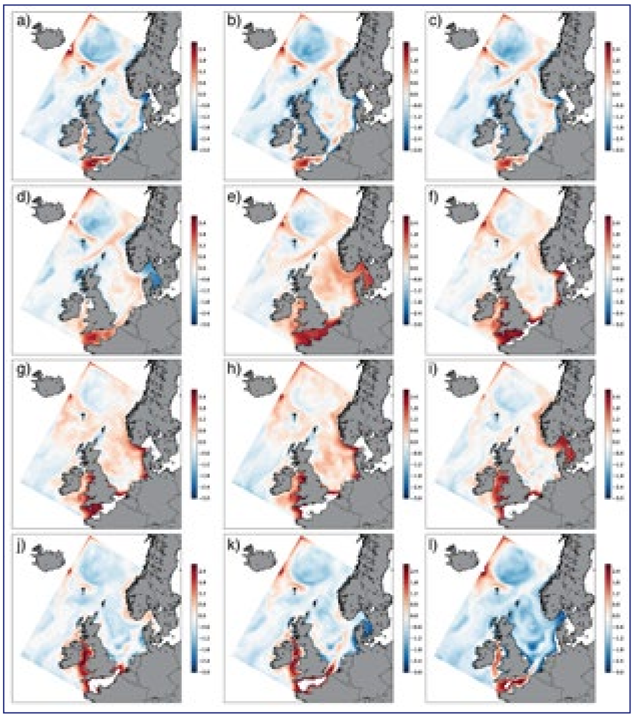


FIGURE 4

Maps of long-term annual mean difference between reference climatological data set (WOA09) and NWS REA temperature at 0 m depth: 1993-2009 averages shown for a) January, b) February, c) March, d) April, e) May, f) June, g) July, h) August, i) September, j) October, k) November, and l) December.

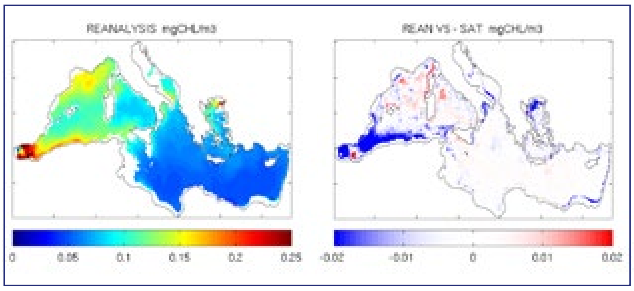


FIGURE 5

Map of mean surface chlorophyll (left) and map of errors (model – reference) computed for MED BGC REA (mean over period January 1999-December 2010). Areas shallower than 200 m are masked.

Class 1 diagnostics correspond to long-term averaged maps of a particular ocean variable (temperature, salinity, sea level, sea ice concentration) at specified levels compared to the reference data set. Maps could be differences, standard deviations, root mean square differences and trends. Figure 3 presents an example extracted from NWS REA produced by UK MetOffice (see QUID, Wakelin et al. 2015) where modeled temperature fields on various levels are compared to World Ocean Atlas 2009 (WOA09, Locarnini et al. 2010) climatology. REA data are interpolated to the climatology vertical levels and time integrated for the REA time period. Differences between REA and the climatology are generally less than 2°C. REA underestimates the climate temperature in the Norwegian Sea at 75m and 300m depth, and in the Bay of Biscay at 800m. Figure 4 displays the same diagnostic from NWS REA produced by IMR (Kristiansen et al. 2015) but presented as monthly maps of long-term mean (1993-2009) difference between WOA09 and NWS REA temperature at the surface. As the model assimilates SST it is able to resolve the surface layer dynamics, the difference between WOA09 and the model is partly caused by the coarse scale resolution of the climatology. This is especially true along the coastline where the REA resolves the temperature distribution better than the climatology. The main outcome from these examples is that, even if they consider the same metrics and the same reference data set, the results were presented with a completely different outlook, making difficult product inter-comparison. This is an aspect that has to be improved in the future to facilitate user understanding and to guide the user to select the best product available for downstream applications. Figure 5 is an example extracted from MED BGC REA (see QUID, Teruzzi et al., 2015) and it shows the climatological long-term CHL mean compared with the reference ESA-CCI data set. Mediterranean Sea can be considered as oligotrophic (mean surface CHL concentration less than 0.1 mg/m3), with the presence of some areas characterized by high CHL values (Gulf of Lions, Ligurian Sea, Sicily Channel, Alboran Sea and southern Algerian basin, south-western Adriatic Sea, and northern Aegean Sea). Main CHL spatial gradients are satisfactorily reproduced, with the largest deviations mainly located in the Alboran Sea and southwestern Mediterranean, nonetheless characterized by the highest values on basin scale.

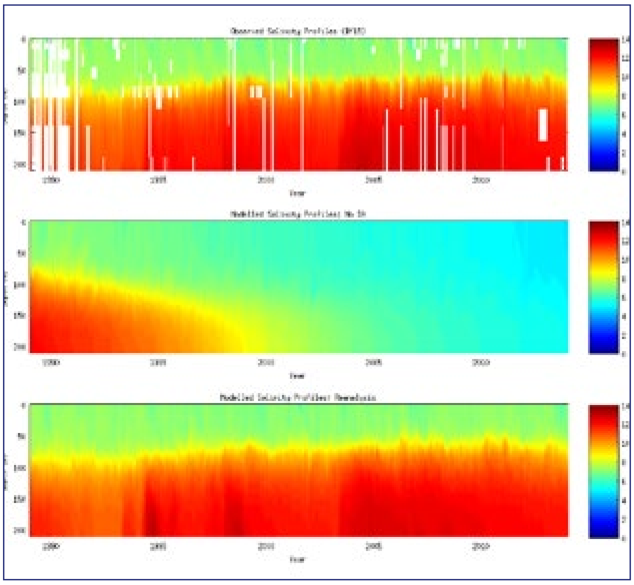


FIGURE 6

Salinity time evolution at Station BY15 (See Figure 3): (top) observations; (middle) hindcast; (bottom) BAL REA results..

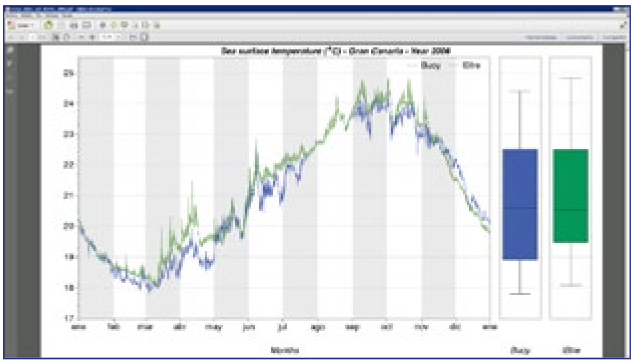


FIGURE 7

Hourly time series of temperature (°C) in Gran Canaria Buoy for year 2006. Blue line is from observations, while green line is from IBI REA.

Class 2 diagnostics are designed as virtual moorings or sections, whose selection is done on the basis of the availability of observations or to monitor mass and heat transport. Figure 6 is an example selected from BAL QUID (Axell et al., 2015) and it shows salinity hovmoller plots at BY15 station. Salinity time evolution along the water column from observations is on top, middle plot is the modeled salinity from the reference free run and bottom plot is from the BAL REA. The comparison is done on monthly basis. It infers how the BAL REA is able to reproduce the observed salinity thanks to data assimilation, while the hindcast looses salt rapidly. IBI MFC implemented instead a REA validation procedure with moorings at both monthly and hourly frequency. Monthly mean values of REA temperature, salinity and velocity components have been collocated on observed profiles to present model versus observations time series, bias, RMS error and correlation. Sea level has been verified as well at tide gauges locations on monthly basis. The high frequency validation has been produced to assess the quality of hourly REA products (see Table 1) using 14 moorings from the Puerto del Estado Deep Water Buoy Network located along the Spanish coast. Sea surface temperature, salinity and currents have been checked and yearly plots have been displayed together with the relative EANs. Figure 7 shows hourly SST at Gran Canaria Buoy during year 2006 from both observations and IBI REA data. IBI REA is slightly colder than observations and the computed RMS error is 0.46°C. Box diagrams prove that SST variability is realistically reproduced by the IBI REA.

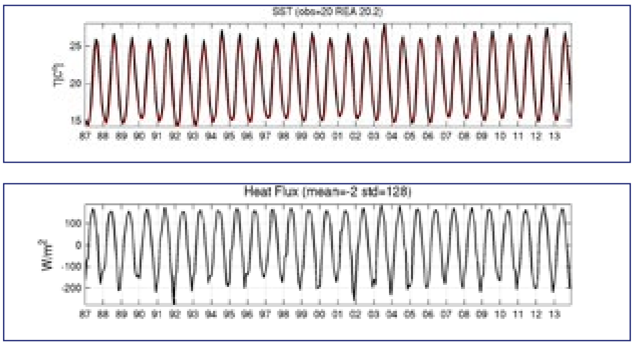


FIGURE 8

(TOP) Domain averaged monthly SST from MED REA (black line) and from reference satellite observations (Marullo, 2008; Buongiorno Nardelli et al. 2013) (red line). (Bottom) Domain averaged surface net heat flux as a function of time. Long term mean value of the surface net heat flux is displayed in the title of (b).

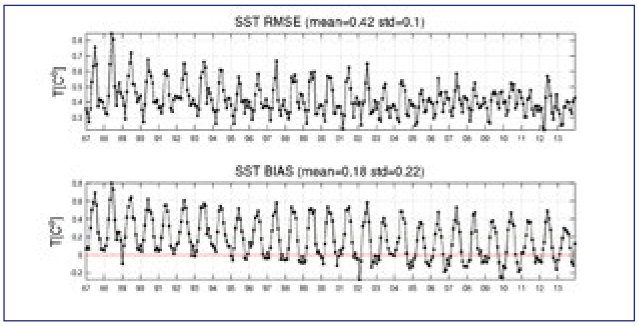


FIGURE 9

SST RMS error time series computed from MED REA and the satellite reference SST (Marullo et al., 2007; Buongiorno Nardelli et al., 2013) over the time pertiod 1987-2013: (top) on monthly basis; (bottom) on a daily basis.

Class 3 diagnostics are integrated quantities such as: volume temperature and salinity as function of time in standard layers, basin averages of SST, surface heat and water fluxes, SSS, sea level and sea ice extent as a function of time. Figure 8 is from MED QUID (Simoncelli et al., 2015) and displays time series of monthly domain averaged modeled and remote-sensed SST (Marullo et al., 2007; Buongiorno Nardelli et al., 2013) and monthly net heat flux at the surface. The long-term average for REA is 20.2°C, while for satellite observations is 20°C. The monthly net heat flux ranges from -275 to 190 Watt/m2, with a total heat budget equal to -2Watt/m2 in agreement with the well-known negative heat flux (-6±3Watt/m2) of the Mediterranean Sea (Pettenuzzo et al. 2010). Figure 9 presents the corresponding class 4 SST diagnostic measuring REA performance computed on both monthly and daily basis. Statistics presents a strong seasonal signal with largest errors during spring-early summer. Monthly and daily EANs prove the importance to measure product quality at different temporal frequencies from a user perspective, since MED MFC disseminates (see Table1) both monthly and daily fields.

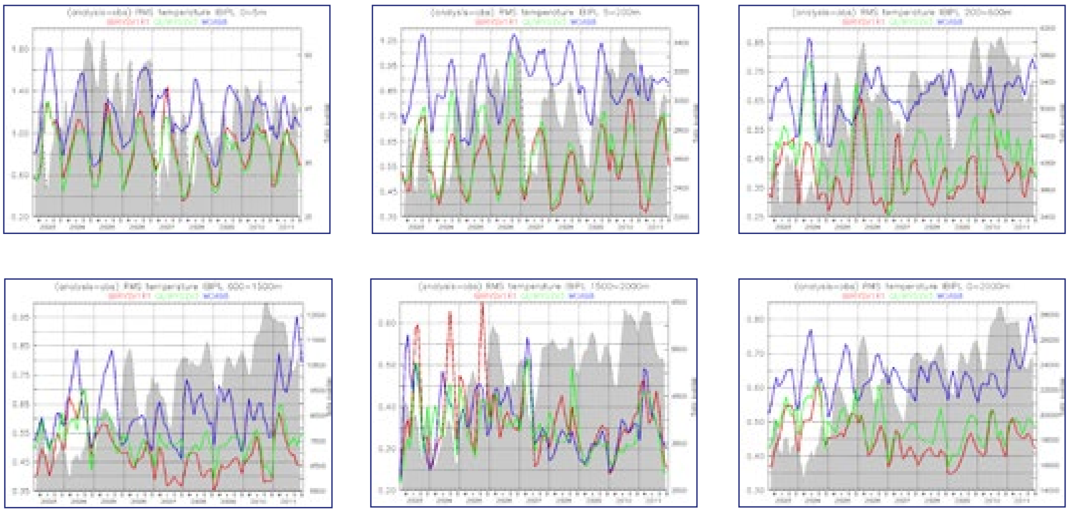


FIGURE 10

Time evolution of the rms error between the reanalysis and CORA3.4 in-situ temperature profiles (top) over the period 2003-2011 (in °C). From left to right: [0-5m], [5-200m], [200-600m], [600-1500m], [1500-2000m], [0-2000m]. WOA98 climatology (blue), IBIRYSV1R1 (red), GLORYS2V3 (green).

Class 4 metrics measure the performance of a REA system and its capability to reproduce the ocean state consistently with observations. REA fields are collocated on the observations and several quantities are computed from observation minus analysis differences (residuals). Figure 10 is extracted from IBI QUID (Levier et al., 2015) and it shows time series of temperature Root Mean Square (RMS) error from IBI REA (red line), GLO REA GLORYS2V3 (green line) and WOA98 climatology (blue line) averaged in different layers and for each month using CORA3.4 in situ data set (Cabanes et al. 2013). The time series are calculated over the whole domain in the layers using REA monthly fields. This represents the only case of REG REA that has been validated versus its parent GLO REA and it confirms the added value of REG REA proving a general error reduction for both temperature and salinity (not shown). The inter-comparison between GLO and REG products is strongly required by the user community and it should be promoted in the future. The issue is to demonstrate the consistency between GLO and REG products, the added value of REG products and their positive impact on applications.

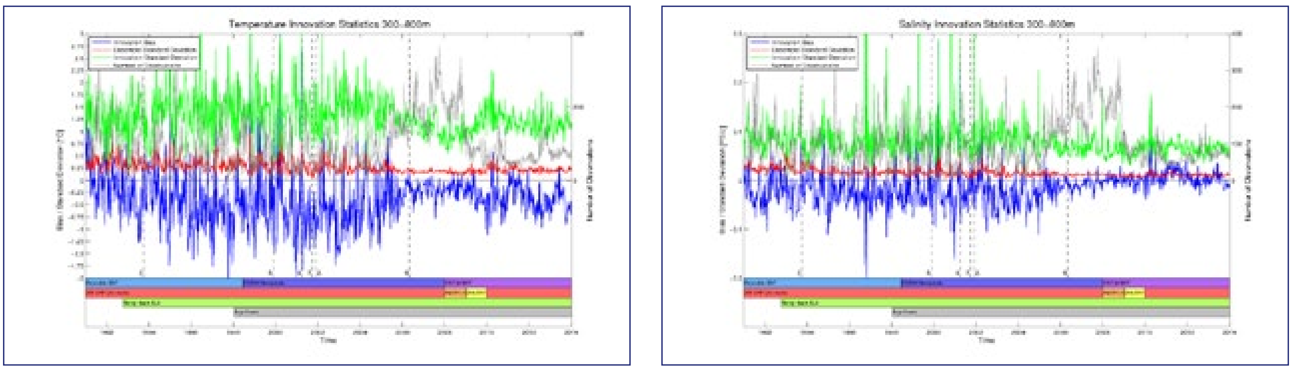


FIGURE 11

Time series of Temperature (top) and Salinity (bottom) innovation statistics from ARC REA in the layer between 300-800m depth. Blue line represents the innovation bias, red line is the ensemble standard deviation, green line is the innovation standard deviation. In grey is the number of observations used for the computed statistics..

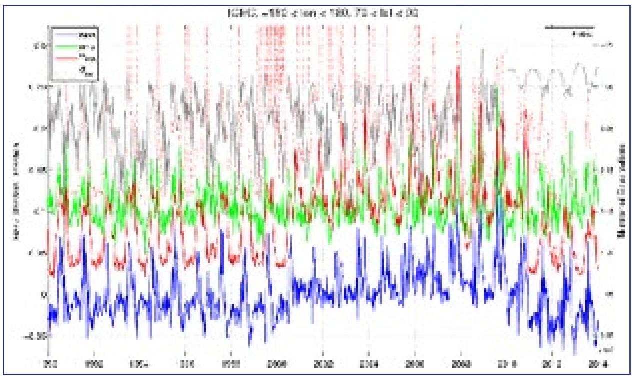


FIGURE 12

Time series of ice concentrations assimilation diagnostics from ARC REA, same colour coding as the previous figure..

Data assimilation diagnostics have been also introduced to evaluate the skill of the assimilation scheme and they are computed in the space of the observations. Figure 11 presents time series of background temperature and salinity innovation statistics computed from the ARC REA (Sakov et al., 2015) considering in situ profiles. The innovation is the difference between observations and the model estimate of the observed quantity immediately before the assimilation is performed. A large number of observations (gray line) became available in the Arctic region from 2005 thanks to the Ice-Tethered Profiler (ITP) and the International Polar Year programs (IPY 2007-2009). The blue lines indicate that the warm and fresh biases in the layer from 300m to 800m depths are significantly reduced by the assimilation of ITP profiles taken during the IPY. The ensemble spread (red line), a measure of background error standard deviation, also reduces as the number of assimilated observation increases. Figure 12 shows a similar time series for sea ice concentrations diagnostics: besides the seasonal variability of the errors (Lisæter et al. 2003) the time series shows a jump from 2000 to 2010 related to a change of the setup of the model errors with the inclusion of uncertainties in precipitations. The change is visible as a temporary increase of ensemble spread from 5% to 12%, and returning back to 5% in 2011 when the precipitation errors are corrected. The jump seems to correct a 5% ice concentration offset although probably for the wrong reason. The RMS errors remain however unaffected unchanged at a level of 10% all through the REA, reflecting that the change of setup is almost transparent for the users of ice concentration.

SUMMARY AND DISCUSSION

PHY REA cover on average a time period of approximately 20 years (see Tale 1 and Figure 1), with the exception of the IBI REA that spans only over ten years, with an horizontal resolution ranging from 5.5km (BAL) to 12.5km (ARC). Half of them extend to 2013, two include the year 2012 and one reaches 2011.They all deliver monthly fields but four of them release also daily and hourly products. Half of the regional REA systems are made by a modeling component based on **NEMO** code, ARC MFC uses HYCOM model, BAL MFC uses HIROMB, while IMR PU uses ROMS in the NWS region. Almost all REA systems are forced by **ERA-Interim** atmospheric reanalysis data with the exception of the BAL system that is forced by higher resolution (22km) data from a limited area model reanalysis driven at the boundaries by ERA-Interim as well. **Lateral boundary conditions** vary from monthly climatological data to monthly averages computed from the concatenation GLO analyses or reanalyses. IBI REA system is the only nested within the GLO REA GLORYS2V3 and prescribing daily fields at the boundaries. MED REA instead is nested in the Atlantic within monthly climatological fields computed from global analysis. All PHY REA systems have implemented **data assimilation** tools. BAL, NWS (UKMO) and MED systems use 3D-Var schemes, NWS (IMR) system applies the IS4DVAR algorithm implemented in ROMS, ARC MFC implemented a scheme based on the Ensemble Kalman Filter while IBI assimilation technique is based on SEEK filter. All REG REA assimilate satellite SST observations and in situ temperature and salinity profiles with the only exception of IMR NWS REA. ARC and BAL REA both assimilate sea ice data. ARC, IBI and MED REA systems assimilate also satellite along track SLA data. REG REP datasets provided from the TACs and assimilated within REA are still few and this is due to a time lag between the implementation of REA systems and the release of the REP datasets. Most of the REP products were released for the first time within MyOcean and some of the REG REP datasets are still missing. In fact, while the global ocean is covered by all REP products (OC, SST, SLA, SI, in situ), the in situ and OC are the only specific REP datasets available for all the European marginal seas. However REP products have been used during the validation phase and might fed the next REA generation.

All MFCs developed BGC REA systems able to provide at least products with monthly time resolution (Table 4) and half of them (ARC, BAL, MED) were able to assimilate BGC observations. Time coverage of BGC REA products is shorter than PHY REA one (Figure 2) and heterogeneous without a common overlapping period. Data products cover the year 2012 at the most. BGC REA models (NORWECOM, SCOBI, ERSEM, PISCES, BFM, see Table 5) are characterized by a diverse complexity related to both the number of Plankton Functional Types (PFT) and the degree of sophistication of process formulation. ARC, NWS (UKMO) and IBI BGC models are online coupled within the PHY REA systems, NWS (IMR) and MED (OGS) BGC models are offline driven by PHY REA fields. BAL BGC model (RCO) is online coupled with the PHY model (SCOBI) and it is independent from the described BAL PHY REA system. However time alignment between PHY and BGC REA is effective only for NWS and IBI products and this aspect should improve in the next BGC REA version for both online and offline coupled systems. The data assimilation techniques used by ARC and MED MFCs are the same applied to the PHY system component, DEnKF and OceanVar respectively. The BAL MFC introduced an EnOI scheme. ARC and MED assimilates surface CHL concentration REP datasets on weekly (GlobColour) and daily (OC TAC) basis, while BAL assimilates historical in situ observations from SHARK database.

The definition of a common validation strategy based on MERSEA-GODAE metrics and EANs permitted to objectively evaluate the quality of regional PHY and BGC REA products and it highly improves products documentation. However the quality assessment analysis of BGC REAs needs to be further investigated in order to better understand their reliability and applicability. Many examples of class1 to class4 diagnostic have been presented to point out strengths and weaknesses of the proposed methodology and its results. More efforts should be invested to harmonize the presentation of validation outcome in order to enable the **comparison between products covering the same region**, like in the case of the NWS region (Figures 3 and 4), but also between GLO and REG products (Figure 10) as demanded by the user community. The **inter-comparison between GLO and REG REA** is crucial to prove their consistency and demonstrate the advantage of higher resolution regional products for specific downstream applications. Moreover this is an obliged step towards the future nesting of REG REA into GLO REA systems assuring continuity at the boundaries between Copernicus Marine Service products.

The assessment of product's quality has been performed principally on monthly basis but higher frequency diagnostics (daily and hourly) have been introduced in BAL, IBI (Figure 7) and MED (Figure 9) QUIDs. The quality of monthly and higher frequency products could be very different for each released parameter and the users need to know both skills in order to maximize the MyOcean data exploitation. The challenge is to add this information in the documentation without adding complexity and loosing synthesis. The quality reports could improve by becoming more user-oriented providing concise but exhaustive descriptions of the REA system and assessment results. They could be further harmonized through a coordination effort that promotes the best product proposition until reaching a standard approved and perceived by the user. In the meantime MFCs carried out automated diagnostic procedures that enable to assess the quality of the REA within a short delay to the production time assuring a continuous monitoring of REA status and accuracy. This strategy might include also the comparison with reference hindcast simulations and previous REA products to drive successfully the transition to new version of products. Another frequent user requirement is the **assessment of REA versus operational analyses** especially in the recent years to orient the user in the choice of the best product for specific purposes.

The recent availability of both in-situ and remote-sensed regional REP data sets can further ameliorate and harmonize REA validation results and it promotes the verification of new ocean synthesis indicators computed from REA data. The evaluation of such ocean synthesis from REA, like the demanded SST and SL trends, is in fact controversial since REA might be subject to model drifts of the same order of magnitude. The use of REA systems to compute long time integration is a rigorous test of model and data assimilation capabilities to reconstruct the evolution of the ocean status without erroneous deviations. REA activities became thus important also to improve and calibrate the forecasting system refining or including new model parameterizations, correcting possible bugs, introducing new processes. The future adoption of REP datasets for both assimilation and verification of the upcoming REAs points out the growing importance of getting independent observational data for validation.

CONCLUSIONS

MyOcean Project initiated the first generation of regional PHY and BGC REA products covering all European marginal seas and the first attempt of a coordinated and shared validation methodology. The extensive assessment of regional REA

MyOcean Project initiated the first generation of regional PHY and BGC REA products covering all European marginal seas and the first attempt of a coordinated and shared validation methodology.

through common metrics allowed identifying their criticalities and defining the necessary R&D efforts for next REA generation, but at the same time it promoted user uptake increasing user understanding and confidence. REA are in fact among the most required and downloaded products by the users due to their wide range of applicability.

The main criticality characterizing REG REAs is time-consistency due to various reasons like: "on the fly" changes of the assimilation system (parameter tuning); changes of lateral boundary conditions (concatenation of various data sets); discontinuous numerical integrations; introduction of new observational data sets into the assimilation line; change in observations' quality and quantity over time. New REA generation will benefit of MyOcean experience to ameliorate REA products consistency in space and time, in particular through the nesting of regional PHY REA into GLO REA systems and the assimilation of REP datasets. These refinements will complement the advancements of the prediction models and the assimilation schemes brought about within the MFCs.

BGC REA systems are still at an early stage and necessitate further efforts to improve BGC models and their coupling with the PHY component and to refine data assimilation techniques able to assimilate both ocean color data and in situ observations. However the added computational expense of running a biogeochemical model may present a challenge in the future as physical model resolution will increase and coarsening techniques may be required. The scarcity of historical biogeochemical observations, the diversity of biogeochemical measurements and their re-processing still constitute a limiting factor of REA enhancement. An exhaustive review on how building the capacity for monitoring and forecasting marine biogeochemistry and ecosystem dynamics is available from Gehlen et al. 2015.

PHY REA are characterized by a time delay ranging from one to two years because of the dependency on atmospheric forcing, REP products and lateral boundary conditions. For BGC REAs, the offset increases due to additional dependencies related to the BGC component. In the meantime REA products would be extended forward in time in order to cover the recent period with a minimum delay. The challenge is to bring the REA systems aligned as much as possible with the forecasting systems, which would be feasible optimizing the REA production loop, thus mainly reinforcing the coordination between MFCs and TACs and their information exchange. TACs dealing with satellite observations estimated that the adequate frequency for a full data reprocessing and the release of a new REP version is around 3 years. The approach of the in situ TAC aims at extending the REP dataset on a yearly basis with a time delay of one year. This implies the concatenation of various observational products for data assimilation in order to arrive as close as possible at present time. In situ REP datasets could be extended switching to NRT observations, while the strategy for remote sensed observations consists on inserting the Delayed Time products (DT) between REP and NRT data to ensure the best accuracy. Qualified atmospheric forcing data, like the ERA Interim reanalysis produced at ECMWF, do not represent anymore a limit for ocean REA extension forward in time since they are available nowadays with 2 to 3 months of delay. The availability of lateral boundary data may instead represent another limit to REAs extension especially when REG systems are nested into GLO ones. A strict coordination between GLO and REG MFCs would optimize the timeliness of the data delivery.

User requirements related to multi-year products are for longer and finer resolution time series of data, but going further back in time depends again on the availability of atmospheric forcing and in situ data. New global atmospheric REA products covering the entire 21st century are now accessible, like the 20CR (1871-2012) by Compo et al. (2011) and the ERA20C (1900-2010) by ECMWF (Poli et al. 2013), but they are characterized by low horizontal resolution (2 and 1.125 degrees respectively) and the assimilation of a restricted set of observations. 20CR assimilates surface pressure and sea level pressure while ERA20C assimilates surface pressure and marine winds observations. Their usage for new ocean REA would bring about new ocean REA products with different quality but necessary to study and solve long-term (inter-decadal) processes, as demanded by the climate community. The crucial effort has to be done by the in situ TAC to recruit and process in situ historical observations to be assimilated or used for REA quality assessment prior to 1990, which is the starting date of the available regional in situ REP datasets. The synergy established between the in situ TAC and SeaDataNet needs to continue and reinforce in order to refine DM processing techniques through cross-validation and multi-data approach but also to get regional climatologies and other ocean synthesis computed from observations. High resolution climatologies are fundamental to initialize REAs, to ameliorate their consistency analysis, to study inter-annual and inter-decadal variability and to improve DM quality check automated procedures. Past collaboration activities focused on temperature and salinity historical data collections and climatologies but this experience has to be soon transferred to the DM processing of biogeochemical data that are now limiting BGC REA system evolution. The alignment of BGC REAs with PHY REAs and their time extension are also expected in order to cover at least the ocean color era starting from 1997.

The increase of resolution is the ultimate development of REA activities linked to the availability of higher resolution atmospheric forcing but also to the advancement of the computational infrastructures for running and monitoring REA systems. Nowadays all regional REA considers ERA-Interim forcing which has approximately 80 km of horizontal resolution and covers the modern observing period from 1979 until present. The ERA-Interim successor, with doubled resolution, is expected in the next years together with further development of regional atmospheric REAs (see for example the BAL PHY REA) as initiated within the framework of EURO4M Project. In the meantime regional forecasting systems will upgrade at higher resolution testing new model performance and assimilation technique to be used in future REAs.

ACKNOWLEDGEMENTS

The authors wish to thank the MyOcean2 (FP7 grant number 283367) and MyOcean-FO projects. During MyOcean2 activities our colleague Nicolas Ferry passed away. He coordinated the definition of Cal/Val procedures to be applied to reanalysis products, thus the authors would like to acknowledge him as an important contributor to the improvement of reanalysis results.

The Arctic MFC has used a grant of computer time from the Norwegian Supercomputing Project NOTUR-II (number n2993k). OGS acknowledges the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support to carry out the MED BGC REA run (project ECOMED2, n. HP10C3FZCK).

APPENDIX

List of acronyms or abbreviations used recurrently in the paper.

BAL	Baltic
BGC	Biogeochemical
CHL	Chlorophyll
DA	Data Assimilation
DM	Delay Mode
EEA	European Environmental Agency
EMSA	European Maritime Safety Agency
GLO	Global
GMES	Global Monitoring for Environment and Security
IBI	Iberian-Biscay-Irish
MCS	Marine Core Service
MED	Mediterranean
MFC	Monitoring and Forecasting Center
NRT	Near Real Time
NWS	North West Shelf
OC	Ocean Color
OGCM	Ocean General Circulation Model
PHY	Physical
PTF	Plankton Functional Types
QUID	QUality Information Document
PU	Production Unit
REA	Reanalysis
R&D	Research and Development
REG	Regional
REP	Reprocessed
RT	Real Time
SI	Sea Ice
SL	Sea Level
SLA	Sea Level Anomaly
SPC	Specific Core Products
SST	Sea Surface Temperature
TAC	Thematic Assembly Centers
WP	Work Package

REFERENCES

Aksnes DL, Ulvestad KB, Baliño BM, Berntsen J, Egge JK, Svendsen E. 1995. *Ecological modelling in coastal waters: Towards predictive physical-chemical-biological simulation models.* Ophelia 41:5-36.

Almroth-Rosell, E., Eilola, K., Hordoir, R., Meier, H. M., & Hall, P. O. (2011). *Transport of fresh and resuspended particulate organic material in the Baltic Sea—a model study.* Journal of Marine Systems, 87(1), 1-12.

Antonov, J. I., R. A. Locarnini, T. P. Boyer, A. V. Mishonov, and H. E. Garcia, 2006. *World Ocean Atlas 2005, Volume 2: Salinity. S. Levitus, Ed. NOAA Atlas NESDIS 62, U.S.* Government Printing Office, Washington, D.C., 182 pp.

Aumont, O. and Bopp, L. 2006: *Globalizing results from ocean in situ iron fertilization studies.* Global Biogeochem. Cycles. 20 (2):10–1029.

Aumont, O., Bopp, L., & Schulz, M. (2008). *What does temporal variability in aeolian dust deposition contribute to sea-surface iron and chlorophyll distributions?* Geophysical Research Letters, 35(7).

Axell, L. B. (2002). *Wind-driven internal waves and Langmuir circulations in a numerical ocean model of the southern Baltic Sea.* Journal of Geophysical Research: Oceans (1978–2012), 107(C11), 25-1.

Axell, L., 2013: BSRA-15: A Baltic Sea Reanalysis 1990-2004. *Reports Oceanography, 45, Swedish Meteorological and Hydrological Institute,* SE-601 76 Norrköping, Sweden.

Axell, L., *QUALITY INFORMATION DOCUMENT for Baltic Sea Physical Reanalysis Product BALTICSEA_REANALYSIS_PHYS_003_008, Issue 2.0, 03-15-2015,* MyOcean Follow On Project H2020-Adhoc-2014-20;

Blackford, J. C., Allen, J. I., & Gilbert, F. J. (2004). *Ecosystem dynamics at six contrasting sites: a generic modelling study.* Journal of Marine Systems, 52(1), 191-215.

Becker, J. J., Sandwell, D. T., Smith, W. H. F., Braud, J., Binder, B., Depner, J., D. Fabre, J. Factor, S. Ingalls, S-H. Kim, R. Ladner, K. Marks, S. Nelson, A. Pharaoh, R. Trimmer, J. Von Rosenberg, G. Wallace, Weatherall, P. (2009). *Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS.* Marine Geodesy, 32(4), 355-371.

Bernie, D. J., Guilyardi, E., Madec, G., Slingo, J. M., & Woolnough, S. J. (2007). *Impact of resolving the diurnal cycle in an ocean–atmosphere GCM. Part 1: a diurnally forced OGCM.* Climate Dynamics, 29(6), 575-590.

Bergametti G., Remoudaki E., Losno R., Steiner E., Chatenet B., 1992. *Source, transport* *and deposition of atmospheric Phosphorus over the northwestern Mediterranean,* J. Atmos. Chem., 14, 501–513.

Bergström, S. and Carlsson, B., (1994). *River runoff to the Baltic Sea 1950 – 1990.* AMBIO Vol. 23, No. 4-5, 280-287.

Bleck, R. (2002). *An oceanic general circulation model framed in hybrid isopycnic-Cartesian coordinates.* Ocean modelling, 4(1), 55-88.

Buongiorno Nardelli B., C.Tronconi, A. Pisano, R.Santoleri, 2013: *High and Ultra-High resolution processing of satellite Sea Surface Temperature data over Southern European Seas in the framework of MyOcean project,* Rem. Sens. Env., 129, 1-16, doi:10.1016/j.rse.2012.10.012

Cabanes, C., Grouazel, A., von Schuckmann, K., Hamon, M., Turpin, V., Coatanoan, C., Paris, F., Guinehut, S., Boone, C., Ferry, N., de Boyer Montégut, C., Carval, T., Reverdin, G., Pouliquen, S., and Le Traon, P.-Y.: *The CORA dataset: validation and diagnostics of in-situ ocean temperature and salinity measurements,* Ocean Sci., 9, 1-18, doi:10.5194/os-9-1-2013, 2013.

Casey, K. S., Brandon, T. B., Cornillon, P., & Evans, R. (2010). *The past, present, and future of the AVHRR Pathfinder SST program.* In Oceanography from space (pp. 273-287). Springer Netherlands.

Chassignet, E. P., Hurlburt, H. E., Smedstad, O. M., Halliwell, G. R., Hogan, P. J., Wallcraft, A. J., & Bleck, R. (2006). *Ocean prediction with the hybrid coordinate ocean model (HYCOM) (pp. 413-426).* Springer Netherlands.

Compo G.P., Whitaker J.S., Sardeshmukh P.D., Matsui N., Allan R.J., Yin X., Gleason B.E., Vose R.S., Rutledge G., Bessemoulin P., Bronnimann S., Brunet M., Crouthamel R.I., Grant A.N., Groisman P.Y., Jones P.D., Kruk M.C., Kruger A.C., Marshall G.J., Maugeri M., Mok H.Y., Nordli Ø., Ross T.F., Trigo R.M., Wang X.L., Woodruff S.D., Worley S.J., 2011. *The Twentieth Century Reanalysis Project. Q. J. R. Meteorol. Soc.* 137: 1–28. DOI:10.1002/qj.776

Conkright, M.E., R. A. Locarnini, H.E. Garcia, T.D. O'Brien, T.P. Boyer, C. Stephens, J.I. Antonov, 2002: *World Ocean Atlas 2001: Objective Analyses, Data Statistics, and Figures,* CD-ROM Documentation. National Oceanographic Data Center, Silver Spring, MD, 17 pp.

Cornell S., Rendell A., Jickells T., 1995. *Atmospheric inputs of dissolved organic Nitrogen to the oceans,* Nature, 376, 243–246.

Crosnier L., Le Provost C., *Inter-comparing five forecast operational systems in the North Atlantic and Mediterranean basins: The MERSEA-strand1 methodology,* Journal of Marine Systems, Volume 65, Issues 1–4, March 2007, Pages 354-375, ISSN 0924-7963, http://dx.doi.org/10.1016/j.jmarsys.2005.01.003.

Dahlgren, Per and Gustafsson, N, 2012. *Assimilating Host Model Information into a Limited* Area Model, Tellus A 2012, 64, 15836, DOI: 10.3402/tellusa.v64i0.15836

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011), *The ERA-Interim reanalysis: configuration and performance of the data assimilation system.* Q.J.R. Meteorol. Soc., 137: 553–597. doi: 10.1002/qj.828

Dobricic, S. (2005). *New mean dynamic topography of the Mediterranean calculated from assimilation system diagnostics.* Geophysical research letters, 32(11).

Dobricic, S., Pinardi, N., Adani, M., Bonazzi, A., Fratianni, C., & Tonani, M. (2005). *Mediterranean Forecasting System: An improved assimilation scheme for sea-level anomaly and its validation.* Quarterly Journal of the Royal Meteorological Society, 131(613), 3627-3642.

Dobricic S., Pinardi N., 2008. *An oceanographic three-dimensional variational data assimilation scheme.* Ocean Modelling, 22, 3-4, 89-105.

Donnelly C., Arheimer B., Bosshard T. and Pechlivanidi I. (2013). *Uncertainties beyond ensembles and parameters–experiences of impact assessments using the HYPE model at various scales.* Proceedings of Impacts World.

Drévillon, M., Bourdallé-Badie, R., Derval, C., Lellouche, J. M., Rémy, E., Tranchant, B., ... & Parent, L. (2008). The *GODAE/Mercator-Ocean global ocean forecasting system: results, applications and prospects.* Journal of Operational Oceanography, 1(1), 51-57.

Egbert G. D. and Erofeeva S.Y., 2002: *Efficient Inverse Modeling of Barotropic Ocean Tides. J. Atmos.* Oceanic Technol., 19, 183–204.

doi: http://dx.doi.org/10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2

Eilola, K., Meier, H. M., & Almroth, E. (2009). *On the dynamics of oxygen, phosphorus and cyanobacteria in the Baltic Sea; a model study.* Journal of Marine Systems, 75(1), 163-184.

Evensen, G. (2003). *The ensemble Kalman filter: Theoretical formulation and practical implementation.* Ocean dynamics, 53(4), 343-367.

Fairall, C. W., Bradley, E. F., Rogers, D. P., Edson, J. B., & Youngs, G. S. (1996). *Bulk parameterization of air-sea fluxes for tropical ocean-global atmosphere coupled-ocean atmosphere response.* Geophys. Res, 101, 3747-3764.

Fekete, B. M., Vo¨ ro¨ smarty, C. J., and Grabs, W.: *Global, Compos- ite Runoff Fields Based on Observed River Discharge and Simu- lated Water Balances,* Tech. Rep. 22, Global Runoff Data Cent., Koblenz, Germany, 1999.

Flather, R. A., (1976). *A tidal model of the northwest European continental shelf.* "Memoires de la Societe Royale de Sciences de Liege, 6, 141-164.

Foujols, M.-A., Lévy, M., Aumont, O., Madec, G., 2000. *OPA 8.1 Tracer Model Reference Manual.* Institut Pierre Simon Laplace, pp. 39.

Funkquist, L. and E. Kleine, 2007: *HIROMB: An introduction to HIROMB, an operational baroclinic model for the Baltic Sea.* Reports Oceanography, 37, Swedish Meteorological and Hydrological Institute, SE-601 76 Norrköping, Sweden.

Gehlen M., Barciela R., Bertino L., Brasseur P., Butenschön M., Chai F., Crise A., Drillet Y., Ford D., Lavoie D., Lehodey P., Perruche C., Samuelsen A. and Simon E., 2015. *Building the capacity for forecasting marine biogeochemistry and ecosystems: recent advances and future developments.*

Journal of Operational Oceanography. http://dx.doi.org/10.1080/1755876X.2015.1022350

Guerzoni, S., Chester, R., Dulac, F., Herut, B., Loÿe-Pilot, M.-D., Measures, C., Migon, C., Molinaroli, E., Moulin, C., Rossini, P., Saydam, C., Soudine, A., Ziveri, P., 1999. *The role of atmospheric deposition in the biogeochemistry of the Mediterranean Sea.Prog.* Oceanogr., 44 (1-3): 147-190.

Gustafsson, B. G., Schenk, F., Blenckner, T., Eilola, K., Meier, H. M., Müller-Karulis, B., ... & Zorita, E. (2012). *Reconstructing the development of Baltic Sea eutrophication 1850–2006.* Ambio, 41(6), 534-548.

Herut, B. and Krom, M.: *Atmospheric input of nutrients and dust to the SE Mediterranean, in: The Impact of Desert Dust Across the Mediterranean, edited by: Guerzoni, S. and Chester, R., Kluwer Acad.*, Norwell, Mass., 349–358, 1996.

Hunke, E. C., & Dukowicz, J. K. (1997). *An elastic-viscous-plastic model for sea ice dynamics.* Journal of Physical Oceanography, 27(9), 1849-1867.

Kara, A. B., Rochford, P. A., & Hurlburt, H. E. (2000). *Efficient and accurate bulk parameterizations of air-sea fluxes for use in general circulation models.* Journal of Atmospheric and Oceanic Technology, 17(10), 1421-1438.

Key, R. M., Kozyr, A., Sabine, C. L., Lee, K., Wanninkhof, R., Bullister, J. L., ... & Peng, T. H. (2004). *A global ocean carbon climatology: Results from Global Data Analysis Project (GLODAP).* Global Biogeochemical Cycles, 18(4).

Kourafalou, V. H. and Barbopoulos, K.: *High resolution simula- tions on the North Aegean Sea seasonal circulation, Ann.* Geo- phys., 21, 251–265, 2003, http://www.ann-geophys.net/21/251/2003/.

Kristiansen T., Wehde H., Albretsen J., Skogen M. D., *QUALITY INFORMATION DOCUMENT for North West Shelf Reanalysis NORTHWESTSHELF_REANALYSIS_PHYS_004_010 and NORTHWESTSHELF_REANALYSIS_BIO_004_012*, Issue 2.2, 03-13-2015, MyOcean Follow On Project H2020-Adhoc-2014-20.

Large, W. G., & Yeager, S. G. (2004). *Diurnal to decadal global forcing for ocean and sea-ice models: the data sets and flux climatologies.* Boulder: National Center for Atmospheric Research.

Large, W. G., & Yeager, S. G. (2009). *The global climatology of an interannually varying air–sea flux data set.* Climate Dynamics, 33(2-3), 341-364.

Large, W. G., and S. Pond. *"Open ocean momentum flux measurements in moderate to strong winds."* Journal of physical oceanography 11.3 (1981): 324-336.

Lazzari, P., Solidoro, C., Ibello, V., Salon, S., Teruzzi, A., Béranger, K., Colella, S., and Crise, A., 2012. *Seasonal and inter-annual variability of plankton chlorophyll and primary production in the Mediterranean Sea: a modelling approach.* Biogeosciences, 9, 217-233.

Lensu, M. (2003). T*he evolution of ridged ice fields.* Helsinki University of Technology.

Levier B., Sotillo M., Reffray G., Aznar R., *QUALITY INFORMATION DOCUMENT for IBI Physical Reanalysis Product IBI_REANALYSIS_PHYS_005_002*, Issue 1.0, 12-15-2014, MyOcean Follow On Project H2020-Adhoc-2014-20.

Lisæter, K. A., Rosanova, J., & Evensen, G. (2003). *Assimilation of ice concentration in a coupled ice-ocean model, using the Ensemble Kalman filter.* Ocean Dynamics, 53(4), 368–388. http://doi.org/10.1007/s10236-003-0049-4

Liu, C., Q. Xiao, and B. Wang, 2008: *An ensemble-based four-dimensional variational data assimilation scheme.* Part I: Technical formulation and preliminary test. Mon. Wea. Rev., 136, 3363-3373.

Liu, C., Q. Xiao, and B. Wang, 2009: *An ensemble-based four-dimensional variational data assimilation scheme.* Part II: Observing system simulation experiments with Advanced Research WRF (ARW). Mon. Wea. Rev., 137, 1687-1702.

Liu, Y., Meier, H. E. M. and Axell, L. 2013. *Reanalyzing temperature and salinity on decadal time scales using the ensemble optimal interpolation data assimilation method and a 3-D ocean circulation model of the Baltic Sea.* J. Geophys. Res. Oceans 118, 5536–5554.

Liu, Y., *QUALITY INFORMATION DOCUMENT for Baltic Sea Biogeochemical Reanalysis Product BALTICSEA_REANALYSIS_BIO_003_009, Issue 1.1, 03-13-2015,* MyOcean Follow On Project H2020-Adhoc-2014-20;

Lyard, F., Lefevre, F., Letellier, T., & Francis, O. (2006). *Modelling the global ocean tides: modern insights from FES2004.* Ocean Dynamics, 56(5-6), 394-415.

Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, H. E. Garcia, O. K. Baranova, M. M. Zweng, and D. R. Johnson, 2010. *World Ocean Atlas 2009, Volume 1: Temperature. S. Levitus*, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp.

Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, and H. E. Garcia, 2006. *World Ocean Atlas 2005,* Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C., 182 pp.

Loÿe-Pilot, M. D., J. M. Martin, and J. Morelli, 1990. *Atmospheric input of inorganic nitrogen to the western Mediterranean.*Biogeochem., 9: 117-134.

Ludwig W., Dumont E., Meybeck M., Heussner S., 2009. *River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades?*.Prog. Oceanogr., 80 (3-4): 199-217.

MacLachlan, C., Arribas, A., Peterson, D., Maidens, A., Fereday,D., Scaife, A.A., Gordon, M., Vellinga, M., Williams, A., Comer, R.E., Camp, J., and Xavier, P., (2014): *Global Seasonal Forecast System 5 (GloSea5): a high resolution seasonal forecast system,* Q. J. Roy. Meteor. Soc.

Madec, G. (2008). *NEMO ocean engine. Note du Pole de modelisation,* Institut Pierre-Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619.

Maillard, C., M. Fichaut, G. Maudire, C. Coatanoan, E. Balopoulos, A. Iona, A. Lykiardopoulos, P. Karagevrekis, J.-M. Beckers, M. Rixen, M.-J. Garcia, B. Manca, A. Giorgetti, A. Mosetti, N. Mikhailov, E. Vyazilov, A. Kuznetsov, N. Puzova, R. Boukortt, B. Boudjellal, N. Eddalia, H. Dooley, A. Drago, S. El-Agami, G. Kortchev, I. Gertman, Y. Tsehtik, S. Lakkis, G. Manzella, I. Oliounine, A. Orbi, J. Largissi, S. Zizah, M. Ozyal, F. Berkay, N. Pinardi, M. Zavatarelli, A. Suvorov, A. Khaliulin, G. Zodiatis, K. Bilashvili, Z. Savaneli, V. Dadic, V. Diaconu,

R. Gelfeld, and C. Sammari (2005). *MEDAR/MEDATLAS 1998-2001: A Mediterranean and Black Sea oceanographic data base and network. Bol*l. Geofis. Teor. Appl., 46, 329–344.

Marullo, S., Buongiorno Nardelli, B., Guarracino, M., & Santoleri, R. (2007). *Observing the Mediterranean Sea from space: 21 years of Pathfinder-AVHRR sea surface temperatures (1985 to 2005): re-analysis and validation.* Ocean Science, 3, 299-310.

Megann et al. (2014) *GO5.0: The joint NERC-Met Office NEMO global ocean model for use in coupled and forced applications,* Geosci. Model Dev., 7, 1069-1092, doi:10.5194/gmd-7-1069-2014.

Meier, H. E., & Kauker, F. (2003). *On the sensitivity of the Baltic Sea salinity to the freshwater supply.* Climate research, 24, 231-242.

Meier, H. M. (2007). *Modeling the pathways and ages of inflowing salt-and freshwater in the Baltic Sea.* Estuarine, Coastal and Shelf Science, 74(4), 610-627.

Meier, H. M., Andersson, H. C., Eilola, K., Gustafsson, B. G., Kuznetsov, I., Müller¨ Karulis, B., ... & Savchuk, O. P. (2011). *Hypoxia in future climates: A model ensemble study for the Baltic Sea.* Geophysical Research Letters, 38(24).

Merchant, C.J.; Embury, O.; Roberts-Jones, J.; Fiedler, E.K.; Bulgin, C.E.; Corlett, G.K.; Good, S.; McLaren, A.; Rayner, N.A.; Donlon, C. (2014): *ESA Sea Surface Temperature Climate Change Initiative (ESA SST CCI): Advanced Very High Resolution Radiometer (AVHRR) level 2 pre-processed (L2P) long term product version 1.0.* NERC Earth Observation Data Centre, 24th February 2014. doi:10.5285/782305d4-1ded-43f9-a0ed-40cb41ff0a43. http://dx.doi.org/10.5285/782305d4-1ded-43f9-a0ed-40cb41ff0a43

Mogensen, K., Balmaseda, M. A., & Weaver, A. (2012). *The NEMOVAR ocean data assimilation system as implemented in the ECMWF ocean analysis for System 4.* European Centre for Medium-Range Weather Forecasts.

Moore, A. M., Arango, H. G., Broquet, G., Powell, B. S., Weaver, A. T., & Zavala-Garay, J. (2011). *The Regional Ocean Modeling System (ROMS) 4-dimensional variational data assimilation systems:* Part *I–System overview and formulation.* Progress in Oceanography, 91(1), 34-49.

Oddo P., M. Adani N. Pinardi, C. Fratianni, M. Tonani, D. Pettenuzzo, 2009. *A Nested Atlantic-Mediterranean Sea General Circulation Model for Operational Forecasting.* Ocean Sci. Discuss., 6, 1093-1127.

Oke, P. R., Schiller, A., Griffin, D. A., & Brassington, G. B. (2005). *Ensemble data assimilation for an eddy-resolving ocean model of the Australian region.* Quarterly Journal of the Royal Meteorological Society, 131(613), 3301-3311.

Oki, T., & Sud, Y. C. (1998). *Design of Total Runoff Integrating Pathways (TRIP)-A global river channel network.* Earth interactions, 2(1), 1-37.

Ottersen, G. 1991. *MODgrid, a Model Oriented Data grider. Report nr. 6/1991, Dcp. of Marine Environment,* Institute of Marine Research, Norway.

Pätsch, J., Kühn, W., Moll, A., & Lenhart, H. (2010). *User Guide "Ecosystem Model, Hamburg,* Version 4". In Technical Report No. 1-2009.

Pham, D. T., Verron, J., & Roubaud, M. C. (1998). *A singular evolutive extended Kalman filter for data assimilation in oceanography.* Journal of Marine systems, 16(3), 323-340.

Pettenuzzo, D., Large W. G., and Pinardi N. *"On the corrections of ERA-40 surface flux products consistent with the Mediterranean heat and water budgets and the connection between basin surface total heat flux and NAO.* "Journal of Geophysical Research Oceans (1978–2012) 115.C6 (2010).

Pinardi N., I. Allen , E. Demirov, P. De Mey, G. Korres, A. Lascaratos, P-Y. Le Traon, C. Maillard, G. Manzella, C. Tziavos, 2003. *The Mediterranean ocean Forecasting System: first phase of implementation (1998-2001).* Annales Geophysicae, 21: 3-20.

Pinardi N., M. Zavatarelli, M. Adani, G. Coppini, C. Fratianni, P. Oddo, S. Simoncelli, M. Tonani, V. Lyubartsev, S. Dobricic, A. Bonaduce. (2013). *Mediterranean Sea large-scale low-frequency ocean variability and water mass formation rates from 1987 to 2007:* A retrospective analysis. Progress in Oceanography.

Poli P., Hersbach H., Tan D., Dee D., Thépaut J.N., Simmons A., Peubey C., Laloyaux P., Komori T., Berrisford P., Dragani R., Trémolet Y., H˙ lm E., Bonavita M., Isaksen L. and Fisher M., 2013: *The data assimilation system and initial performance evaluation of the ECMWF pilot reanalysis of the 20th-century assimilating surface observations only (ERA-20C).* ECMWF ERA Rep, 2013, 14: 59.

Raicich, F.: *On fresh water balance of the Adriatic Sea*, J. Mar. Syst., 9, 305–319, 1996.

Reffray G., Perruche C., *QUALITY INFORMATION DOCUMENT for IBI Biogeochemical Reanalysis Product IBI_REANALYSIS_PHYS_005_003, Issue 1.0, 12-15-2014,* MyOcean Follow On Project H2020-Adhoc-2014-20.

Ribera d'Alcalà M., Civitarese G., Conversano F., Lavezza R., 2003. *Nutrient ratios and fluxes hint at overlooked processes in the Mediterranean Sea.* Journal of Geophysical Research, 108(C9), 8106, doi:10.1029/2002JC001650.

Rixen, M., Beckers, J. M., Maillard, C. (2004). *A hydrographic and biochemical climatology of the Mediterranean and the Black Sea: some statistical pitfalls.* In The colour of the ocean data (pp. 227-243). IOC.

Sakov, P., & Bertino, L. (2011). *Relation between two common localisation methods for the EnKF.* Computational Geosciences, 15(2), 225-237.

Sakov, P. and Oke, P. R.: *A deterministic formulation of the ensem-ble Kalman filter: an alternative to ensemble square root filters.* Tellus, 60A, 361–371, 2008

Sakov, P., Counillon, F., Bertino, L., Lisæter, K. A., Oke, P. R., & Korablev, A. (2012). T*OPAZ4: an ocean-sea ice data assimilation system for the North Atlantic and Arctic.* Ocean Science, 8(4), 633.

Sakov P., Counillon F., Bertino L., Finck N., Renkl C., *QUALITY INFORMATION DOCUMENT for Arctic Physical Reanalysis Product ARCTIC_REANALYSIS_PHYS_002_003, Issue 2.1, 03-02-2015,* MyOcean Follow On Project H2020-Adhoc-2014-20.

Samuelson, P., Jones, C. G., Willen, U., Ullerstig, A., Gollvik, S., Hansson, U., Jansson, C., Kjellstrom, E., Nikulin, G. and Wyser, K. (2011), *The Rossby Centre Regional Climate model RCA3: model description and performance.* Tellus A, 63: 4–23. doi: 10.1111/j.1600-0870.2010.00478.x

Selig, E. R., Casey, K. S., & Bruno, J. F. (2010). *New insights into global patterns of ocean temperature anomalies: implications for coral reef health and management.* Global Ecology and Biogeography, 19(3), 397-411.

Shchepetkin, A. F., & McWilliams, J. C. (2005). *The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic mode*l. Ocean Modelling, 9(4), 347-404.

Siddorn, J. R., & Furner, R. (2013). *An analytical stretching function that combines the best attributes of geopotential and terrain-following vertical coordinates.* Ocean Modelling, 66, 1-13.

Simon, E., & Bertino, L. (2012). *Gaussian anamorphosis extension of the DEnKF for combined state parameter estimation: application to a 1D ocean ecosystem model.* Journal of Marine Systems, 89(1), 1-18.

Simon E., Samuelsen A., *QUALITY INFORMATION DOCUMENT for Arctic Biological Reanalysis Product ARCTIC_ REANALYSIS_PHYS_002_005, Issue 1.1, 02-23-2013,* MyOcean Project FP7-SPACE-20011-1.

Simoncelli S., Bonaduce A. and Tonani M., *QUALITY INFORMATION DOCUMENT for Mediterranean Sea Physical Reanalysis Product MEDSEA_ REANALYSIS_ PHYS_006_004, Issue 5.0, 02-26-2015,* MyOcean Follow On Project H2020-Adhoc-2014-20.

Skogen, M. D., Svendsen, E., Berntsen, J., Aksnes, D., & Ulvestad, K. B. (1995). *Modelling the primary production in the North Sea using a coupled three-dimensional physical-chemical-biological ocean model.* Estuarine, Coastal and Shelf Science, 41(5), 545-565.

Skogen, M. D., & Søiland, H. (1998). *A user's guide to NORVECOM V2. 0.* the norwegian ecological model system.

Somot S., Sevault F., Déqué M., Crépon M., 2008. *21st century climate change scenario for the Mediterranean using a coupled atmosphere–ocean regional climate model,* Global and Planetary Change, 63, 2–3: 112–126.

Steele, M., Morley, R., & Ermold, W. (2001). *PHC: A global ocean hydrography with a high-quality Arctic Ocean.* Journal of Climate, 14(9), 2079-2087.

Stips, A., Bolding, K., Pohlmann, T., & Burchard, H. (2004). *Simulating the temporal and spatial dynamics of the North Sea using the new model GETM (General Estuarine Transport Model).* Ocean Dynamics, 54(2), 266-283.

Teruzzi A., Dobricic S., Solidoro C., Cossarini G. 2013. *A 3D variational assimilation scheme in coupled transport biogeochemical models:* Forecast of Mediterranean biogeochemical properties, Journal of Geophysical Research, doi:10.1002/ 2013JC009277.

Teruzzi A., Cossarini G., Salon S., Bolzon G., *QUALITY INFORMATION DOCUMENT for Mediterranean Sea Biogeochemistry Reanalysis Product MEDSEA_REANALYSIS_ BIO_006_008*, Issue 5.0, 03-15-2015, MyOcean Follow On Project H2020-Adhoc-2014-20.

Thingstad T.F., Rassoulzadegan F., 1995. *Nutrient limitations, microbial food webs, and 'biological C-pumps': suggested interactions in a P-limited Mediterranean.* Marine Ecology Progress Series, 117: 299-306.

Tonani, M., Pinardi, N., Dobricic, S., Pujol, I., & Fratianni, C. (2008). *A high-resolution free-surface model of the Mediterranean Sea.* Ocean Science, 4(1), 1-14.

Umlauf, L., Burchard, H., & Hutter, K. (2003). *Extending the k–ω turbulence model towards oceanic applications.* Ocean Modelling, 5(3), 195-218.

Uppala, S. M., Kållberg, P. W., Simmons, A. J., Andrae, U., Da Costa Bechtold, V. and co-authors. 2005. *The ERA-40 Re-analysis. Q. J. R.* Meteorol. Soc. 131, 2961–3012.

Verbrugge, N., & Garric, G. (2010, May). *Large scale ECMWF radiative surface fluxes assessment, correction and application to 3D-global Ocean simulations.* In EGU General Assembly Conference Abstracts (Vol. 12, p. 12044).

Volpe, G., Santoleri, R., Vellucci, V., Ribera d Acalà, M., Marullo, S., and D Ortenzio, F. (2007). *The colour of the Mediterranean Sea: Global versus regional bio-optical algorithms evaluation and implication for satellite chlorophyll estimates.* Remote Sens. Environ., 107, 625-638

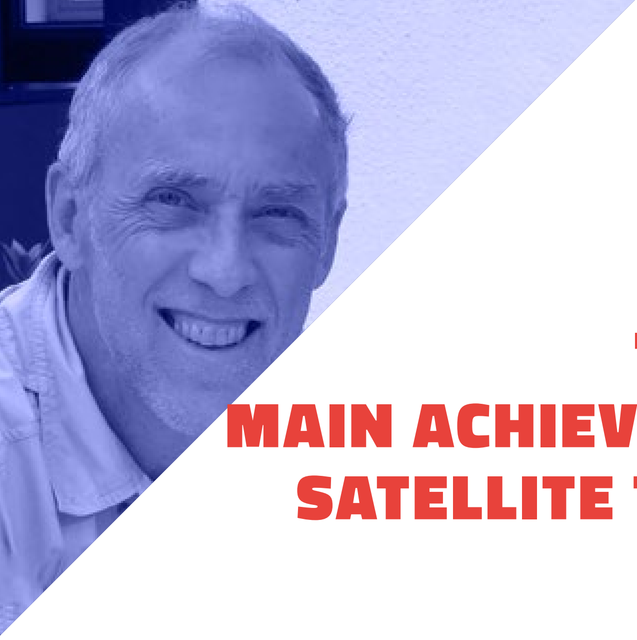
Wakelin S., While J., King R., O'Dea E., Holt J., Furner R., Siddorn J., Martin M., McEwan R. and Blockley E., *QUALITY INFORMATION DOCUMENT for North West Shelf Reanalysis NORTHWESTSHELF_ REANALYSIS_PHYS_004_009 and NORTHWESTSHELF_ REANALYSIS_BIO_004_011*, Issue 2.2, 03-15-2015, MyOcean Follow On Project H2020-Adhoc-2014-20.

Weaver, A. T., Vialard J., and Anderson D. L. T., 2003. *Three and four-dimensional variational assimilation with a general circulation model of the tropical Pacific Ocean.* Part I: Formulation, internal diagnostics, and consistency checks, Monthly Weather Review, 131(7), pp. 1360–1378.

Wilhelmsson, T., 2002: *Parallellization of the HIROMB ocean model.* Licentiate Thesis, Royal Institute of Technology, Department of Numerical and Computer Science, Stockholm, Sweden.

Woodgate, R., T. Weingartner, and R. Lindsay, The *2007 Bering Strait oceanic heat flux and anomalous Arctic sea-ice retreat*, Geophysical Research Letters, 37, L01,602, 2010.

Samuelsen, A., Hansen, C., and Wehde, H.: *Tuning and assessment of the HYCOM-NORWECOM V2.1 biogeochemical modeling system for the North Atlantic and Arctic oceans,* Geosci. Model Dev., 8, 2187-2202, doi:10.5194/ gmd-8-2187-2015, 2015.



MAIN ACHIEVEMENTS FOR MYOCEAN SATELLITE THEMATIC ASSEMBLY CENTERS

BY
B. HACKETT(1), L-A. BREIVIK(1), Y. FAUGERE(2), MI. PUJOL(2), G. LARNICOL(2), R. SANTOLERI(3)

ABSTRACT

In the MyOcean2 and MyOcean Follow-On projects there were three Thematic Assembly Centres (TAC) providing quality-controlled satellite-based observations of the global ocean and European regional seas: the Sea Level TAC (sea surface elevation products), the Ocean Colour TAC (optical products) and the Ocean and Sea Ice TAC (SST, sea ice and surface wind products). The evolution of the product suite and the main achievements during the project period (2012-2015) are described. Products encompass near-real-time and multi-year reprocessed datasets. The product suite has been expanded during the projects with particular focus on providing the MyOcean Monitoring and Forecasting Centres (MFC) with data suitable for both assimilation and validation, both near-real-time forecast mode and in reanalysis mode. The introduction of high-resolution regional products and provision of accuracy information were major developments.

(1) **Norwegian Meteorological Institute** (MET Norway), Oslo, Norway
(2) **Collecte Localisation Satellites** (CLS), Toulouse, France
(3) **National Research Council** (CNR), Rome, Italy

INTRODUCTION

In the MyOcean2 and MyOcean Follow-On projects, which are described more fully in companion articles, there were three Thematic Assembly Centers (TACs) for satellite-based observations of the ocean:

- Sea Level TAC (SL TAC), providing altimeter-based observations of the sea surface elevation;
- Ocean Color TAC (OC TAC), providing observations of the optical properties of the ocean surface layer from color radiometry;
- Ocean and Sea Ice TAC (OSI TAC), providing observations of sea surface temperature (SST), sea ice and surface winds from various satellite-borne instruments.

A fourth TAC – the In Situ TAC (IS TAC) – provided *in situ* ocean observations; it is described in a separate article in this issue.

The goal of the TACs in MyOcean was two-fold: 1) to provide assimilation and validation data for the Monitoring and Forecasting Centers (MFCs), i.e., within the MyOcean projects, and 2) to provide core observational products for a broad range of downstream users outside of the projects. Moreover, the TACs share the overall aim of the MyOcean projects: to prepare a prototype of a fully operational marine information system in the European Union's Copernicus program.

The purpose of this article is to describe the main achievements of the three satellite TACs during the MyOcean2 and MyOcean Follow-On projects, which were performed in the three-year period April 2012 to March 2015. In terms of the MyOcean release schedule, the period covers the evolution from version V2 of the system to version V5. Note that version V5 is the starting point of the Copernicus Marine Environment Monitoring System, which started operations in May 2015. The three satellite-based TACs contribute in all 80 standard products (17 SL, 30 OC, 33 OSI) to the MyOcean Catalogue at version V5.

The development and production work done in the satellite TACs during the projects was carried out by three consortia with quite different organisations, as summarised in TABLE 1. The SL TAC consisted of 4 partners of which CLS was the lead partner; all production was carried out by one partner. The OC TAC consisted of 5 partners of which CNR was the lead partner; production was carried out by 3 partners. The OSI TAC consisted of 11 partners of which MET Norway was the lead partner; production was carried out by all 11 partners.

Sea Level TAC		***Ocean and Sea Ice TAC***	
Collecte Localisation Satellites (CLS)	FR	Norwegian Meteorological Institute (MET Norway)	NO
National Centre for Scientific Research (CNRS)	FR	Royal Netherlands Meteorological Institute (KNMI)	NL
Technical University of Denmark (DTU-Space)	DK	Météo-France (MF)	FR
Spanish National Research Council (CSIC)	ES	National Research Council (CNR)	IT
Ocean Colour TAC		Danish Meteorological Institute (DMI)	DK
National Research Council (CNR)	IT	Technical University of Denmark (DTU-Space))	DK
French Research Inst for Exploitation of the Sea (IFREMER)	FR	Finnish Meteorological Institute (FMI)	FI
ACRI ST	FR	French Research Inst. for Exploitation of the Sea (IFREMER)	FR
Plymouth Marine Laboratory (PML)	UK	Nansen Environ. and Remote Sensing Center (NERSC)	NO
Helmholtz Zentrum Gestaacht (HZG)	DE	Met Office (METO)	UK

TABLE 1

Satellite TAC consortia during MyOcean2 and MyOcean Follow-On projects.

In the following, some selected achievements of each of the satellite-based TACs are presented in a separate section. First, however, there is a discussion of achievements that are common to all three TACs and deserve recognition..

COMMON TAC ACHIEVEMENTS

- Maintaining robust production under a changing satellite constellation.

A major task for all the satellite-based TACs is adapting to changes in the upstream satellite data upon which all production depends. Not only do anomalies originating in the satellite and ground segments need to be tackled on a day-to-day basis, but also planned changes in configuration as well as the ultimate failure of the data stream require remedial action. A case in point is the demise of Envisat right at the beginning of MyOcean2 (April 2012). It meant the loss of SAR (Synthetic Aperture Radar) data, which was a particularly serious blow to several NRT sea ice products that are wholly dependent on SAR data. The affected Production Units were quick to transfer their upstream data interface to the other SAR data, in particular the Canadian RADARSAT-1/2, thanks to the efforts of ESA to secure access to those data for MyOcean producers. Indeed, several of the sea ice producers had already tooled up to use RADARSAT-2 and other SAR data as a supplement to Envisat.

The failure of Envisat also meant the loss of AATSR (*Advanced Along-Track Scanning Radiometer)* data, which were the reference data set for NRT SST products, notably the much-used global OSTIA L4 product. As a result, the accuracy of the NRT SST products was impacted and required a strong effort on the part of all producers to revise and test their operational algorithms.

With the Envisat failure the MERIS (MEdium Resolution Imaging Spectrometer) data were no longer available. This had a big impact on the OC TAC, since the entire operational production then became dependent on a single source of input data: the OC MODIS-Acqua mission. In addition, at the same time a severe drift of the MODIS sensors was detected by NASA. Both problems affect the quality of OC TAC data. This problem was solved by a quick update the OC processing chains to recover the quality MODIS data and to ingest new NPP/VIIRS data.

For the SL TAC, the MyOcean2 period saw not only the loss of the Envisat altimeter, but also the orbit-reconfiguration and later failure of Jason-1. These losses were counteracted by the addition of Cryosat2 and other platforms, as described more fully below.

- Adoption by MFCs.

At the inception of MyOcean, the model systems that went into the MFCs relied on their own connections to observational data for assimilation and validation. During MyOcean1, the MFCs started the transition to obtaining data from the TACs using the standard MyOcean interfaces. In the MyOcean2 and MyOcean Follow-On projects, the transition has been largely completed. By the close of MyOcean Follow-On, all MFCs were using data delivered by the TACs to cover their operational needs for assimilation data. For the satellite-based TACs, the main deliveries are sea level anomaly data from the SL TAC, SST and sea ice concentration from the OSI TAC and chlorophyll from the OC TAC, as shown in TABLE 2. Moreover, the online validation service (http://marine.copernicus.eu/web/103-validation-statistics.php), developed and implemented in MyOcean2, relies solely on TAC data.

NEAR REAL TIME MODELS AND FORECASTS

Models for areas NWS IBI and BALTIC include tidal component, meaning that all parameters include tide signal, especially UV and SSH.

AREA		PRODUCTS: REFERENCES	PRODUCTS: PARAMETERS	CHARACTERISTICS: HORIZONTAL AND VERTICAL RESOLUTIONS	TEMPORAL COVERAGE [START DATE; END DATE]	TEMPORAL RESOLUTION	UPDATE FREQUENCY	DATA ASSIMILATED
GLOBAL	Phy	001_002	T S UV SSH ICE	1/12°-8km; 50 levels	[2-Y ago; 7-D FCST]	D+2H	D	●●●
		001_015	T S UV SSH ICE MLD	1/4°-25km; 43 levels	[15/03/2014;7-D FCST]	D	D	●●●●
	Bio	001_014	CHL O2 N P Phyto PP Si Fe	1/2°-50km; 50 levels	[2-Y ago; 7-D FCST]	W	W	●●●
ARCTIC	Phy	002_001	T S UV SSH ICE MLD	12.5 km; 12 levels	[19/10/2011; 10-D FCST]	D	D	●●●●
	Bio	002_004	CHL O2 N P Phyto PP RadFlux	12.5 km; 12 levels	[28/12/2011; 10-D FCST]	D	D	●●●●
BALTIC	Phy	003_006	T S UV SSH ICE	1nm-2 km; 25 levels	[2-Y ago; 60-H FCST]	H	TwiceD	
	Bio	003_007	CHL O2 N P	1nm-2 km; 25 levels	[2-Y ago; 60-H FCST]	H	TwiceD	
NWS European North West Shelf Seas	Phy	004_001	T S UV SSH bedTSUV	7 km; 24 levels	[01/04/2011;5-D FCST]	D+H	D	●
	Bio	004_002	CHL O2 N P Phyto PP RadFlux	7 km; 24 levels	[01/04/2011;5-D FCST]	D	D	●
IBI Iberia Biscay Ireland Regional Seas	Phy	005_001	T S UV SSH	1/36°-2.5km; 50 levels	[01/04/2011;5-D FCST]	D+H	D	*
	Bio							
MED Mediterranean Sea	Phy	006_001	T S UV WaveUV SSH	1/16°-6km; 72 levels	[01/01/2013;10-D FCST]	D+H	D	●●●*
	Bio	006_006	CHL O2 N P Phyto PP	1/16°-6km; 72 levels	[01/01/2013;10-D FCST]	D	TwiceW	●●●●

MULTIYEAR MODELS

Models for areas NWS IBI and BALTIC include tidal component, meaning that all parameters include tide signal, especially UV and SSH.

AREA		PRODUCTS: REFERENCES	PRODUCTS: PARAMETERS	CHARACTERISTICS: HORIZONTAL AND VERTICAL RESOLUTIONS	TEMPORAL COVERAGE [START DATE; END DATE]	TEMPORAL RESOLUTION	UPDATE FREQUENCY	DATA ASSIMILATED
GLOBAL	Phy	001_009	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1993;15/12/2013]	M+D	A	●●●●
		001_011	T S UV SSH ICE	1/4°-25km; 50 levels	[01/15/1982;15/12/2013]	M+D	A	●●●●
		001_010	T S UV SSH ICE	1/4°-25km; 75 levels	[15/01/1993;15/12/2010]	M	NU	●●●●
		001_017	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1979;15/12/2013]	M+D+5D	A	●●●●
		001_004	T S UV SSH ICE	1/4°-25km; 75 levels	[15/01/1993;15/12/2011]	M	NU	
	Bio	001_018	CHL O2 N P Phyto PP Si Fe	1/4°-25km; 75 levels	[15/01/1998;15/12/2013]	M	A	
		001_019	CHL O2 N P Si	1/4°-25km; 50 levels	[15/01/1998;15/12/2013]	M	A	
ARCTIC	Phy	002_003	T S UV SSH ICE MLD	12.5 km; 12 levels	[15/01/1991;15/12/2013]	M	A	●●●●
	Bio	002_005	CHL O2 N P Phyto Radflux	25 km; 12 levels	[15/01/2007;15/12/2010]	M	NU	●●●●
BALTIC	Phy	003_008	T S UV SSH ICE	3nm-5.5km; 50 levels	[01/01/1989;31/12/2013]	M+H+6H	A	●●●
		003_004	T S UV SSH ICE	6nm-11km; 25 levels	[01/01/1990;31/12/2009]	M	NU	●
		003_005	T S UV SSH ICE	3 nm-5.5 km; 25 levels	[01/01/1990;31/12/2009]	M	NU	●●●
	Bio	003_009	CHL O2 N P NH4	2nm-3.7km; 83 levels	[01/01/1970;31/12/1999]	M+2D	NU	●
NWS European North West Shelf Seas	Phy	004_009	T bedT S UV	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_005	T S UV SSH	12 km; 24 levels	[01/01/1960;31/12/2004]	M	NU	
		004_006	T S UV SSH	12 km; 24 levels	[15/01/1985;15/12/2008]	M	NU	
		004_010	T S UV SSH	8 km ; 26 levels	[01/01/1993;31/12/2012]	M	A	●
	Bio	004_011	CHL O2 N P Phyto PP RadFlux	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_007	CHL O2 N P Phyto PP RadFlux	12 km; 24 levels	[01/01/1967;31/12/2004]	M	NU	
		004_008	O2 N P Phyto PP Si	12 km; 24 levels	[31/01/1985;31/12/2008]	M	NU	
		004_012	O2 N P Phyto PP Si	8 km; 26 levels	[01/01/1993;31/12/2012]	M	A	●
IBI Iberia Biscay Ireland Regional Seas	Phy	005_002	T S UV SSH	1/12°-7.5km; 50 levels	[01/02/2002;23/12/2011]	M+D+H	NU	●●●
	Bio	005_003	CHL O2 N P Phyto PP Si Fe NH4 Eup	1/12°-7.5km; 50 levels	[01/01/2002;23/12/2011]	M	NU	●●●
MED Mediterranean Sea	Phy	006_004	T S UV SSH	1/16°-6km; 72 levels	[01/01/1987;31/12/2013]	M+D	A	●●●
	Bio	006_008	CHL O2 N P Phyto PP	1/16°-6km; 72 levels	[01/01/1999;31/12/2012]	M	A	●●●●

TABLE 2

Table 2. MFC use of TAC data for assimilation at MyOcean V5 (end of MyOcean Follow-On). Table provided by Laurence Crosnier.

SEA LEVEL TAC ACHIEVEMENTS

The main objective of the SL TAC is to provide, in an operational context, sea level based products from satellite altimetry missions for the MFCs and external users. The production and delivery of the SLTAC products (external and internal) has been performed during the 3 years of the project on a nominal basis. All the altimetry products are homogenized and cross-calibrated in order to obtain a consistent set of datasets easy to use for assimilation in ocean models. This production is composed of along track data and gridded products, generated in Near Real Time (NRT) and Delayed time (DT) modes. The SL TAC catalogue of products is composed of Global Sea level products complemented by regional products for the Mediterranean Sea, Black Sea, Arctic and European (NWS + IBI) regions.

EVOLUTION OF THE PRODUCT PORTFOLIO

TABLE 3 provides an overview of the Sea Level TAC products available to users since the start of MyOcean2. V2 denotes the status at the start of the project in April 2012. The product portfolio has primarily evolved in terms of the number of products. New regional products over Europe and the Arctic have been created at the beginning of the project. Then a new product over Mediterranean Sea was developed and produced operationally between V3 and V4 to fulfill MED MFC requirements in terms of content and resolution. Then, the product dissemination timeliness has been improved in V3. Instead of daily updated, the products were from V3 updated on an hourly basis. Finally, a complete evolution of the Sea Level Catalogue has been implemented as part of the MyOcean version V4 in order to increase the product quality, and a full reprocessing of the products has been performed. V5 denotes the final status at the end of the MyOcean Follow-On project in April 2015.

Sea Level TAC									
Release		GLO	MED	BS	ARC	BAL	NWS	IBI	Total
V2	NRT	1	2	2	1	1	1	1	4
2012	REP	3	2	1					6
V3	NRT	1	2	2	1	1	1	1	4
2013	REP	3	2	1					6
V4	NRT	3	3	2	1	1	1	1	7
2014	REP	5	3	2					10
V5	NRT	3	3	2	1	1	1	1	7
2015	REP	5	3	2					10

TABLE 3

A user's overview of the SL TAC product suite evolution, according to the MyOcean major releases (V2 to V5). Regions: GLObal, ARCtic, BALtic, NorthWest Shelf, MEDiterranean, Iberia-Biscay-Ireland, Black Sea. NRT means near-real time products. REP means reprocessed and similar time series products. The numbers indicate the number of user products that cover a given region; a low-resolution European seas product covers BAL, NWS, MED and BS, and is counted in each. Total is number of distinct products.

Highlighted achievements

During the project, the SL-TAC system has used all the altimetry missions available to provide an optimum product quality. The management of the constellation has been a priority during these three years, with integration of new missions, but also management of anomalies on flying satellites. In June 2013, an anomaly impacted Jason -1, the oldest satellite of the constellation. The system ingested then only Jason-2 and Cryosat-2 measurements. At the same time, the French/Indian satellite Altika, was integrated in the system, just 4 month after launch. Thanks to the optimal coordination between all the actors, it was possible to maintain a good level of quality of the products despite the loss of Jason-1. Since June 2014, with the integration of the Chinese satellite HY2A, the altimetry constellation is composed of 4 satellites in real time. An illustration of the NRT sampling is given in Figure 1.

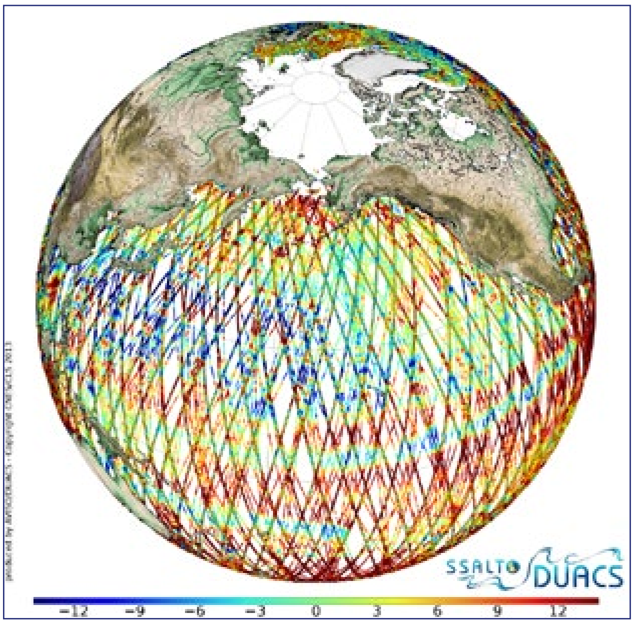


FIGURE 1

2 days of Sea Level anomaly products on February 2014 using Jason-2, Altika, Cryosat-2 and HY2A. Unit: cm

This configuration ensures a very good sampling of the ocean and thus allows us to maintain a high level of product quality. A good illustration of the constellation variation is given by the relative contribution of each altimeter in the gridded multi-mission product shown in Figure 2.

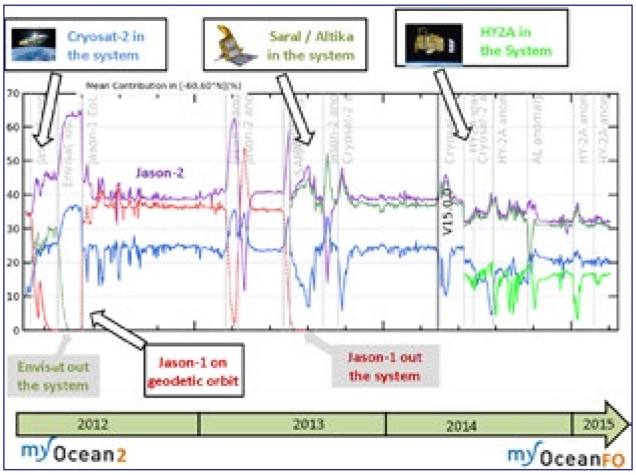


FIGURE 2

Relative contribution of each altimeter in the gridded multi-mission product for 2012-1015 and link with altimeter events. Unit: %.

The contribution is derived from the degrees of freedom of signal analysis (Dibarboure et al, 2012).

Another important achievement of Myocean2 is the success of the TAPAS initiative (Tailored Altimetry Products for ASsimilation). Started in Myocean-1, the circle from R&D to operation has been closed at the end of Myocean-2 with the creation of new Mediterranean Sea level products dedicated for assimilation. Several TAPAS meetings were organised, focusing on the consistency of the physical content between altimeter products and consistency with the physics of the models considered. In this way, Dynamic Atmospheric Corrections and Long Wavelength Errors, along-track filtering and editing, as well as impact and use of a new Mean Dynamic Topography, were analysed. TAPAS meetings also focused on the altimeter along-track product error description and the continuity in space and time between global and regions products. This collaborative work was very rewarding and led to the creation of a new product at V4 in the Mediterranean Sea, allowing improved performances of the SLA assimilation into the models (Dobricic et al, 2012).

Finally the last important achievement of Myocean2 project was the entry into service of the V4 versions. On April 15th, 2014, a new version of the products was released with several significant upgrades. The whole range of products, in near real time and delayed time, along-track and gridded, were upgraded in terms of scientific content and format. In parallel, a complete reprocessing of the whole altimeter time period (20 year time series) series was distributed at the same time. More than 60 years of data (Topex/Poseidon, Jason 1 and 2, ERS-1/2, ENVISAT, GFO, Cryosat-2) were processed using the most recently reprocessed GDR (Geophysical Data Record) to ensure a maximum of consistency between the missions used for the whole period. As 20 years of altimeter measurements were now available, it was also timely to change the reference period. Since the beginning of the Myocean project, the Sea Level Anomalies have been based on a 7-year reference period [1993-1999]. In the V4 version we replaced it with a 20-year reference period [1993-2012]. This change had a major impact for users, because of the evolution of the sea level in terms of trends, but also in terms of interannual signals at small and large scales (e.g. El Niño / La Niña) in the 13 last years. During the extensive assessment exercise, significant improvements were observed, for this reprocessed dataset, at both climate scales and short scales of the ocean. An illustration of the increase of the sea level energy at small scales is given in Figure 3.

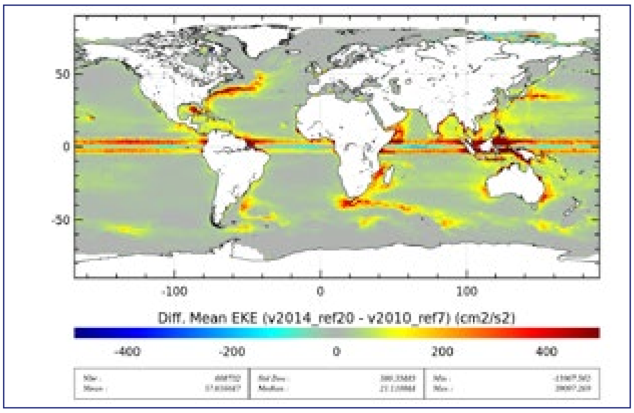


FIGURE 3

Difference of Eddy Kinetic Energy between V2 and V4 products. Unit cm2/s2.

Comparison with independent measurements underlined the improved quality of these reprocessed products (Capet et al, 2014). Reprocessed products covering the global ocean, Mediterranean and Black Sea regions have been delivered in April 2014.

OCEAN COLOR TAC ACHIEVEMENTS

The OC TAC operates European Ocean Colour Service providing global, European and regional (Atlantic, Arctic, Baltic, Mediterranean, and Black Seas) high quality products. Multi-mission OC satellite data are used to generate high-quality core biogeochemical parameters essential to the monitoring of the state of the marine ecosystem in short and long time scales. The OC TAC delivers Near Real Time (NRT) and reprocessed OC datasets. For each region, the OC TAC delivers two types of products: Chlorophyll (CHL) and OPTICS. CHL is the phytoplankton chlorophyll concentration whereas OPTICS refers to other variables retrieved from ocean colour sensors including: Inherent Optical Properties (IOPs) such as absorption and scattering, the diffuse attenuation coefficient of light at 490 nm (Kd490), Secchi depth (transparency of water), spectral Remote Sensing Reflectance (Rrs), photosynthetically available radiation (PAR), Coloured Dissolved Organic Matter (CDOM), and Suspended Particulate Matter (SPM). Ocean colour regional products differ from the global not only in their resolution and area coverage but also in the parameter retrievals. In fact, the regional datasets are produced using tailored OC processing chains and region-specific algorithms that take into account the optical characteristics of water in each region.

The user categories range from operational oceanography to downstream service providers, operating dedicated service lines supplied to the public sector, in charge of implementing the policies at the European, National and regional levels. OCTAC generates products directly useful to intermediate users and downstream service providers, as well as specific products to MyOcean MFCs (both global and regional).

Evolution of the product portfolio

TABLE 4 provides an overview of the Ocean Colour products available to users since the start of MyOcean2. The major changes were the improvement of the quality OC chlorophyll estimates over the shelf area of the European regional seas (V4), inclusion of daily L4 chlorophyll products (V3) and regional OC reprocessed datasets taking full advantage of the outcomes of the ESA OC CCI project (http://www.esa-oceancolour-cci.org/). In addition, a strong effort was devoted to defining metrics to assess the quality of OC products

Sea Level TAC									
Release		GLO	ARC	BAL	NWS	MED	IBI	BS	Total
V2	NRT	1	1	1	1	2	1	2	9
2012	REP	1				2		1	4
V3	NRT	4	1	1	1	2	1	2	12
2013	REP	2		2	2	1	2	1	10
V4	NRT	3	2	2	3	4	3	4	21
2014	REP	2	2		2	1		1	8
V5	NRT	3	2	2	4	4	4	4	19
2015	REP	2	2	1	2	2	2	2	11

TABLE 4

A user's overview of the OC TAC product suite evolution, according to the MyOcean major releases (V2 to V5). Regions: GLObal, ARCtic, BALtic, NorthWest Shelf, MEDiterranean, Iberia-Biscay-Ireland, Black Sea. NRT means near-real time products. REP means reprocessed and similar time series products. The numbers indicate the number of user products that cover a given region; lower-resolution regional products that cover several regions are counted in each. Total is number of distinct products.

Highlighted achievements

- Addressing the product quality assessment:

The assessment of ocean colour product quality faces several challenges. One is the broad range of quantities of various types that are included, some of them spectral in character (water leaving radiance or reflectance, inherent optical properties of backscattering and absorption, etc.). Another specificity is that the database of in situ field observations is fairly restricted in size (with the notable exception of chlorophyll-a), and the uncertainties associated with the field data depend on the quantity itself as well as from the sources. Furthermore, in situ observations available in near-real time are very scarce or even not available at all. Therefore, undertaking a systematic and comprehensive assessment of the OC TAC products is a difficult task. Consequently, the assessment of the OC products has been carried out by two methods: 1) an offline evaluation of the product accuracies against in situ data in the assessment of full time series performed before introduction of the product in MyOcean catalogue, 2) an online validation against satellite-derived climatology to assess the operational data consistency over time. The results of these two types of assessment are described in the Quality Information Documents provided to users. It is noteworthy to underline that the offline validation method developed by OC partners was able to reveal the drift of the MODIS sensor and send an alarm to users and to space agencies (Volpe et al, 2012).

- Improving the quality of the NRT and REP regional OC products:

One of the most important challenges for the OC TAC is to respond to the strong user demand for accurate products at regional scale and in particular to improve their quality over the shelf areas of the European Seas. This is linked to the use-tuned regional processing chains, which take into account the ad hoc atmospheric correction and bio-optical water characteristics of each region, and to the ability to merge two algorithms - one for the coastal domain, the other for the open ocean - without introducing spurious signals (e.g., fronts). The implementation of these methods has allowed the OC TAC to improve the chlorophyll estimates over the shelf areas by developing new Case1/Case2 chlorophyll merged products. These new regional products are available for the Atlantic, Mediterranean Sea and Black Sea from V4, while the Baltic regional chlorophyll products are available from V5. For the first time, daily L4 chlorophyll fields are also operationally produced by the OC TAC.

.

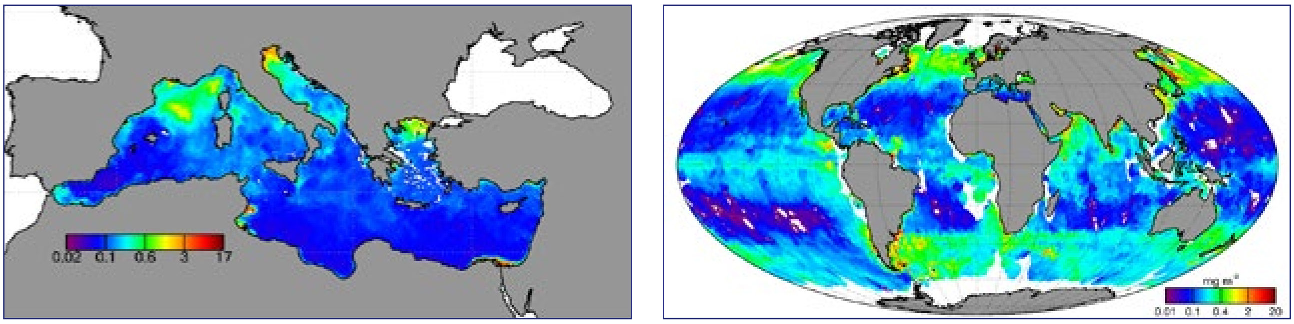


FIGURE 4

Example of the Global and Mediterranean Chlorophyll product.

The regional bio-optical algorithms were also used to produce new reprocessed time series, using the ESA OC-CCI multi-sensor reflectance data as input. The new reprocessed products are multi-sensor merged (MODIS-A, MERIS, SeaWIFS) products that supersede the previous single-sensor (SeaWIFS) products available in the MyOcean catalogue until V4. Finally, in response to European Environmental Agency user requirements, a new pan-European chlorophyll product, obtained by merging all the regional products in a single file was produced and used to compute chlorophyll climatology and trends over all the European Sseas; these are useful indicators to monitor eutrophication problem and can contribute to the various indicators needed bythe Marine Strategy Framework Directive.

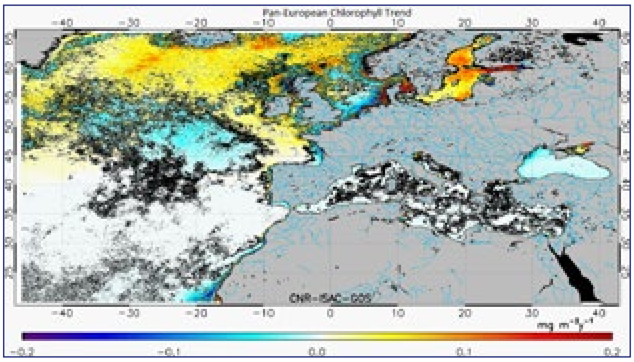


FIGURE 5

Pan-European map of the chlorophyll trend relatives to 1998-2011 time period computed from the MyOcean reprocessed regional products. Black pixels indicate non-significant values.

OCEAN AND SEA ICE TAC ACHIEVEMENTS

The OSI TAC encompasses three rather different classes of satellite ocean observations: SST, surface winds and sea ice parameters. Grouping them together in one virtual center is an acknowledgement of their origins in the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF). The OSI SAF predates the MyOcean projects. It was established to provide satellite observations in support of the member European weather services. All of the partners of the OSI SAF joined in the MyOcean projects, where the oceanographic applications of the observations were the focus. A number of other, more marine-based, remote-sensing groups were added to strengthen the MyOcean OSI TAC in this respect. [It should be noted that, in the initial MyOcean project (2009-2012), there were two TACs: an SST TAC and a Sea Ice and Wind TAC. These were merged into the OSI TAC in MyOcean2.]

As mentioned in the Introduction, a cardinal aim of the OSI TAC was to support numerical ocean prediction activities within MyOcean, primarily by providing SST and sea ice observations for assimilation at the MFCs. In addition, the OSI TAC products were intended to provide validation data and otherwise help to assess the quality of the numerical predictions. During the MyOcean projects, much effort went into accommodating the various production lines to MyOcean standards, thereby making the data products more easily available for the MFCs.

Evolution of the product portfolio

TABLE 5 gives an overview of the products available to users, following the sequence of MyOcean releases. The main advances during the period are the addition of NRT SST and Wind products at global scale and the addition of high-resolution regional SST products (both REP and NRT). Product developments were to a large degree guided by user requests, mainly from the user community outside MyOcean. There was little change to the sea ice product portfolio from V2; development effort focused on improving product quality information.

Ocean & Sea Ice TAC																						
Release	Region:	GLO			ARC/ANT			BAL			NWS		MED		IBI		BS		Total		
	Params:	ST	SI	W	ST	SI	W	ST	SI	W	ST	W	ST	W	ST	W	ST	W	ST	SI	W
V2	NRT	3	2	2	1	5		3	2		3		4		2		4		12	9	2
2012	REP	1	1	1		1													1	2	1
V3	NRT	3	2	3	1	5		3	2		3		4		2		4		12	9	3
2013	REP	1	1	1		1		1											2	2	1
V4	NRT	3	2	3	1	5		4	2		4		5		3		5		13	9	3
2014	REP	1	1	1		1		1					1				1		4	2	1
V5	NRT	4	2	3	1	5		4	2		4		5		3		5		14	9	3
2015	REP	1	1	1		1		1					1				1		4	2	1

TABLE 5

A user's overview of the OSI TAC product suite evolution, according to the MyOcean major releases (V2 to V5). Regions: GLObal, ARCtic / ANT-arctic, BALtic, NorthWest Shelf, MEDiterranean, Iberia-Biscay-Ireland, Black Sea. Params: Sea surface Temperature, Sea Ice, Wind. NRT means near-real time products. REP means reprocessed and similar time series products. The numbers indicate the number of user products that cover a given region; lower-resolution regional products that cover several regions are counted in each. Total is number of distinct products.

Highlighted achievements

SST products

- Regional high-resolution REP products.

An important addition to the SST product suite was the regional reprocessing products for the Mediterranean and Black Seas (Buongiorno Nardelli et al., 2013), and for the Baltic Sea. In particular, the MyOcean MFCs expressed interest in higher resolution data for their regional reanalyses, and the new REP SST products aimed to meet that need. The products are L4 gridded fields of daily mean SST with spatial resolution of 4 km (3 km in the Baltic). They are based primarily on Pathfinder L2 data. As an example, FIGURE 6 shows a field from the REP product for the Black Sea.

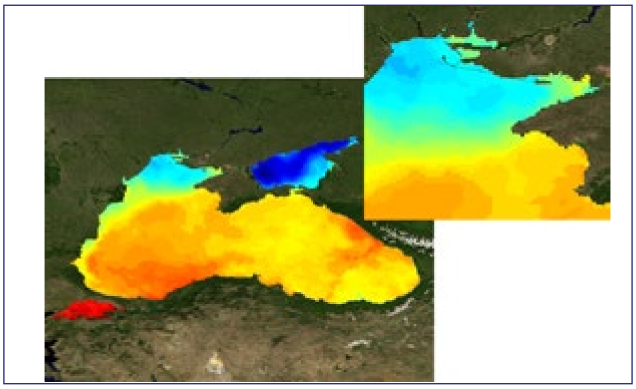


FIGURE 6

Example of the Black Sea SST reprocessed product on 2012-04-04. Whole area with detail of northwestern subarea.

- High-frequency products capturing diurnal effects.

In the course of the MyOcean projects, users expressed a need for SST data that can capture the diurnal cycle of surface temperature. These effects are particularly of interest for coupled biogeochemical modelling applications. In an effort to meet this need, two new NRT L4 multi-sensor gridded products were introduced toward the end of the project period: 1) a regional product covering the European seas (BAL, NWS, IBI, MED, BS, cf. TABLE OS1) with 3 hour frequency and 2 km spatial resolution; and 2) a global product with hourly frequency and 25 km resolution. FIGURE 7 exemplifies the diurnal warming that the high-resolution European seas product can reveal.

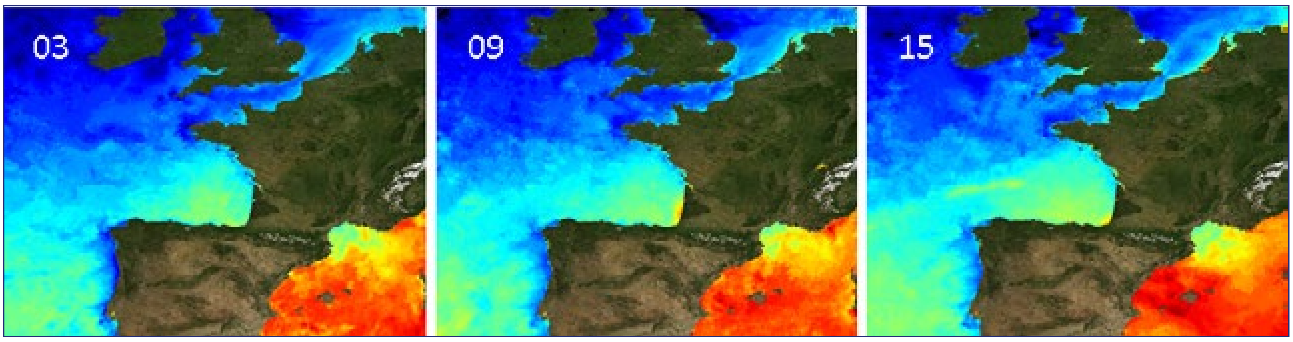


FIGURE 7

Zoomed example of the 3-hourly NRT SST product for the European seas, showing sub-diurnal variability. Times are UTC on 2015-08-09.

Sea Ice products

- Addressing quality information issues.

A fundamental problem for satellite-based sea ice observations is the dearth of ground-truth data for validation. Observations of ice conditions from ships and other in situ platforms are few and far between. Fewer still can be considered operational in any sense of the word, as witnessed by the fact that the MyOcean In Situ TAC holds no sea ice measurements at all. The validation of sea ice retrieval algorithms is relegated to sporadic campaigns and must be characterized as scientific experiments rather than routine quality control. Thus, it was not found scientifically defensible for the sea ice products to participate in the MyOcean online validation service. Considering that the provision of product quality information is a hallmark of an operational marine service, an important task for the sea ice data producers has been to find ways to maximize the information available when routine validation metrics are lacking. For example, the producers of the three Arctic sub-regional ice chart products – DMI, FMI and MET Norway – performed an intercomparison exercise that resulted in a quality assessment annex to the product Quality Information Documents provided to users. In addition, other sea ice products have added quality parameters, such estimated analysis error, to the netCDF files delivered.

- Implementing Sentinel-1a data for sea ice mapping.

As mentioned above, access to SAR data is crucial for the high-resolution regional sea ice products. These include sub-regional products for the Svalbard, Greenland and Baltic areas, as well as ice edge products for the Arctic and Antarctic. During MyOcean1, the Envisat ASAR (Advanced Synthetic Aperture Radar) was the backbone of the production, often supplemented with RADARSAT1/2 data from Canada. Envisat's demise in April 2012 forced a quick transition to RADARSAT1/2, which was made possible by ESA's efforts to obtain the data for European use. At the same time, the Sentinel program promised to cover European needs for operational SAR data with the launch of Sentinel-1a (S1a) on 3 April 2014. As S1a data became available in late 2014, the MyOcean production units were quick to start employing them operationally. This was to some extent a deed of necessity, since ESA at the same time reduced the amount of RADARSAT2 data obtained from Canada.

The transition to S1a data has been successful and, to a large extent, already beneficial. Increased daily coverage in the European Arctic during the initial operations has improved the data basis for ice charting and holds the promise of building new user products. As an example, DTUSPACE and DMI have shown the feasibility of creating ice drift maps (FIGURE 8) with much larger coverage than was previously possible. On the other hand, S1a's narrower swath width and mode configuration indicate that the benefits are less clear at lower latitudes, such as in the Baltic.

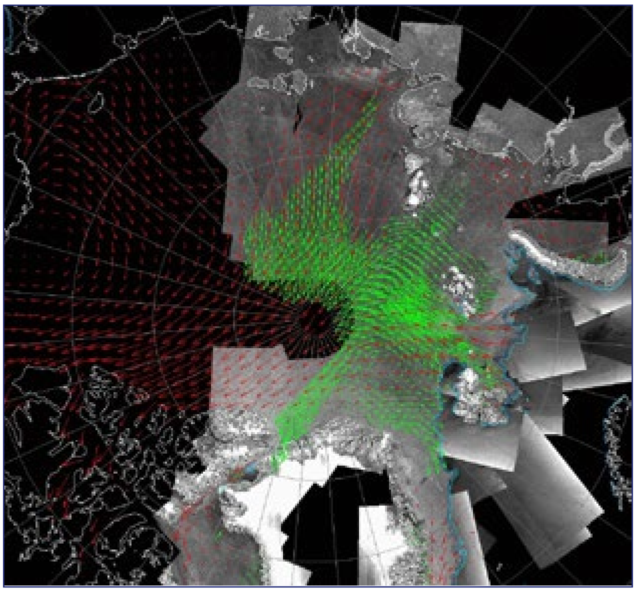


FIGURE 8

European Arctic with Sentinel-1a SAR scenes from the 3-day period 6-8 January 2015. Green arrows are ice drift vectors calculated from overlapping SAR scenes. Red arrows are forecast ice drift vectors from the Arctic MFC, provided for comparison. Image provided by R. Saldo and J. Høyer.

Wind products

- Improving usefulness.

A major aim in the development of scatterometer-based wind observations was to generate spatially and temporally consistent high-resolution gridded stress and wind fields to satisfy user needs, for both L3 and L4 products. Key achievements in addressing this aim include a) the determination of the effective spatial resolution at regional scales, b) the improvement of turbulent fluxes based on the use of the resulting wind fields, c) error attribution near moist convection (done for Metop ASCAT) and d) development and deployment of an internationally accepted «stress-equivalent wind» variable (implemented for the L3 product). The stress-equivalent wind (U10S) has been requested by oceanographers for many years and has been added to the L3 wind product as an additional variable in the final V5 release. Prior to V5, only the equivalent-neutral wind (U_{10N}) was offered. U_{10N} is a 10 meter wind estimate for neutral buoyancy conditions. U_{10S} takes air density variations into account and is a better measure of the wind stress on the sea surface. The two estimates are related by

$$U_{10S} = (\rho / \langle\rho\rangle)^{1/2}\, U_{10N},$$

where ρ is the air density and $\langle\rho\rangle$ is the average air density in a standard atmosphere. For the same U_{10N}, cold heavy air will produce more stress (and roughness) than lighter warmer air. FIGURE 9 shows an example of the difference $U_{10N} - U_{10S}$, in which there is a reduction in wind speed in the Nordic Seas of up to 0.6 m/s when choosing U_{10S}.

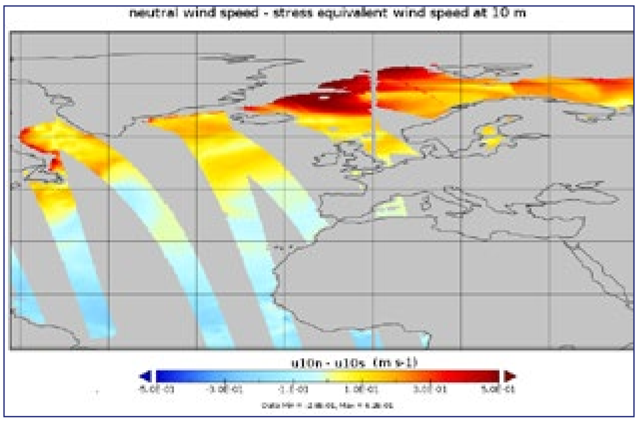


FIGURE 9

Difference between the equivalent-neutral wind speed (U10N) and the new stress-equivalent wind speed (U10S) variables in the global wind L3 NRT product.

CONCLUSIONS

In the MyOcean2 and MyOcean Follow-On projects, the satellite TACs have continued the operational production that started in MyOcean 1 and have added new products to fill gaps identified by users. In particular, new regional, high resolution products have been introduced. Two major tasks for all the satellite TACs has been adapting to the evolving constellation of satellites and meeting the observational needs of the MyOcean Monitoring and Forecasting Centres.

The SST data assimilation has improved the forecast skill of the model without marked disruption of the 3D structure of the water column.

ACKNOWLEDGEMENTS

The work described here was carried out in the MyOcean2 and MyOcean Follow-On projects, which were funded in part by the European Union under the 7th Framework Programme and Horizon 2020, respectively. The support is gratefully acknowledged.

REFERENCES

Buongiorno Nardelli B., C.Tronconi, A. Pisano, R.Santoleri, 2013: *High and Ultra-High resolution processing of satellite Sea Surface Temperature data over Southern* European Seas in the framework of MyOcean project, Rem. Sens. Env., 129, 1-16, http://dx.doi.org/doi:10.1016/j.rse.2012.10.012.

Capet, A., E. Mason, V. Rossi, Ch. Troupin, Y. Faugère, I. Pujol and A. Pascual, 2014, *Implications of Refined Altimetry on the Estimates of Mesoscale Activity and Eddy-Driven Offshore Transport in the Eastern Boundary Upwelling Systems,* Geophysical Research Letters,

Dibarboure, G., M. I. Pujol, F. Briol, P.-Y. Le Traon, G. Larnicol, N. Picot, F. Mertz and M. Ablain, 2011, *Jason-2 in DUACS: first tandem results and impact on processing and products,* Marine Geodesy, 34:3-4, 214-241. doi: 10.1080/01490419.2011.584826.

S. Dobrici, C. Dufau, P. Oddo, N. Pinardi, I. Pujol and M.-H. Rio, 2012, *Assimilation of SLA along track observations in the Mediterranean with an oceanographic model forced by atmospheric pressure,* Ocean Science, doi:10.5194/os-8-787-2012.

MAIN ACHIEVEMENTS FOR MYOCEAN IN SITU THEMATIC ASSEMBLY CENTER

BY

S. POULIQUEN(1), T. CARVAL(1), D GUILLOTIN(1) , C. COATANOAN(1), T. LOUBRIEU(1), C. GUYOT(1), K. BALEM(1) T. SZEKELY(2), J. GOURRION(2), A. GROUAZEL(2), K. VON SCHUCKMANN(2), H. WEDHE(3), L.S. RINGHEIM(3), T. HAMMARKLINT(4), A. HARTMAN(4), K. SOETJE(5), T. GIES(5), S. JANDT(5), L. MULLER(5), M. DE ALFONSO(6), F. MANZANO MUÑOZ(6), L. PERIVOLIOTIS(7), D. KASSIS(7), A. CHALKIOPOULOS(7), V. MARINOVA(8), P. JACCARD(9), A. LEDANG(9), K. SORENSEN(9), G. NOTARSTEFANO(10), J. TINTORE (11), S. KAITALA(12), P. ROIHA(13), L. RICKARDS(14), G. MANZELLA(15), F. RESEGHETTI(15)

ABSTRACT

In 2008 EUROGOOS partners endorsed the recommendations proposed by the DATA Management/Exchange/Quality working group (http://eurogoos.eu/increasing-eurogoos-awareness/working-groups/data-management-exchange-quality-working-group-data-meq/) to set up a Pan-European system for EuroGOOS articulated with the Regional Operational Oceanographic Systems (ROOS) consolidating achievements realized through projects in particular MyOcean1&2 (implementation of the Copernicus Marine Environment Monitoring System), SeaDataNet1&2 (consolidation the National Data Centres network in Europe) and EMODnet-Physics1&2 (contribution towards the definition of an operational European Marine Observation and Data Network). The in situ Thematic Assembly Centre of MyOcean is a distributed service integrating data from different sources for operational oceanography needs. It collects and carries out quality control in a homogeneous manner on data from outside MyOcean data providers, especially EuroGOOS partners in Europe, to fit the needs of internal and external users. It provides access to integrated datasets of core parameters (temperature, salinity, current, sea level, chlorophyll, oxygen and nutrient) to characterise ocean state and ocean variability, by this contributing to initialization, forcing, assimilation and validation of ocean numerical models and ocean reanalysis. It provides both near real time products aggregated from automatic observatories at sea (e.g. floats, buoys,

[1] **IFREMER**, Plouzané, France
[2]**CNRS,** Brest, France
[3]**IMR**, Bergen, Norway
[4]**SMHI**, Stockholm, Sweden
[5]**BSH**, Hamburg, Germany
[6]**Puertos Del Estado**, Madrid, Spain
[7]**HCMR**, Athens, Greece
[8]**IOBAS**, Varna, Bulgaria
[9]**Niva**, Bergen, Norway
[10]**OGS**, Trieste, Italy
[11]**IMEDEA/SOCIB**, Mallorca ,Spain
[12]**SYKE**, Helsinki, Finland
[13]**FMI**,Helsinki, Finland
[14]**BODC**, Liverpool, UK
[15]**ENEA**, La Spezia, Italy

gliders, ferrybox, drifters, SOOP) which are transmitted to the shore in real-time, and historical products over 1990-now developed jointly with SeaDataNet that provides high quality scientific data and EMODnet that foster collaboration with observing system operators in Europe. The in situ thematic assembly centre provides products useful for operational oceanography needs both for forecasting and reanalysis activities, downstream services and for the research communities.

INTRODUCTION

In the MyOcean projects (MyOcean, MyOcean2 MyOcean-Follow-On), which are described more fully in companion articles, there was the *in situ* Thematic Assembly Centre (TAC) that provided in situ ocean observations and three other TACs for satellite-based observations of the ocean that are described in a separate article in this issue.

The goal of the TACs in MyOcean was two-fold: 1) to provide assimilation and validation data for the Monitoring and Forecasting Centres (MFCs), i.e., within the MyOcean projects, and 2) to provide core observational products for a broad range of downstream users outside of the projects. Moreover, the TACs share the overall aim of the MyOcean projects: to prepare a prototype of a fully operational marine information system in the European Union's Copernicus program.

The purpose of this article is to describe the main achievements of the *in situ* TAC during the MyOcean projects. In terms of the MyOcean release schedule, the period covers the evolution from version V0 (Mersea heritage) of the system to version V5. Note that version V5 is the starting point of the Copernicus Marine Environment Monitoring System (CMEMS), which started operations in May 2015. The *in situ* TAC contributes with 16 standard products to the MyOcean Catalogue at version V5.

FIGURE 1

In Situ Tac Catalogue of products

THE MYOCEAN IN-SITU TAC EUROPEAN CONTEXT

Ocean can be observed by satellite and in situ . While satellite provide a global surface coverage, in situ is necessary to observe at depth and more parameters. Available in situ ocean observing platforms (e.g. ships, moorings, drifters, tide gauges, floats, remote sensing satellites, marine mammals, autonomous vehicles) have individual sampling limitations, weaknesses and strengths. In order to obtain a comprehensive observing system that allows multidisciplinary monitoring of the ocean at multiple scales, a combination of observing platforms is required.

Today, it is up to 800 distributed facilities in Europe, in various domains as ocean and coastal sea observation, marine biology research, blue biotechnology innovation, research in aquaculture and ocean engineering. Marine Research Infrastructures may take the form of:

- Research vessels and their underwater vehicles (sea access and deep sea exploration/sampling);
- In situ observing systems (seawater column & seabed observation and monitoring);
- Satellites (remote sensing for sea-surface monitoring);
- Marine data centres (for data validation, storage and dissemination, including access to high computing facilities & generic modelling);
- Marine land-based facilities for ocean engineering (deep wave basins, water circulation canals, hyperbaric tanks, material testing laboratories, marine sensors calibration laboratories);

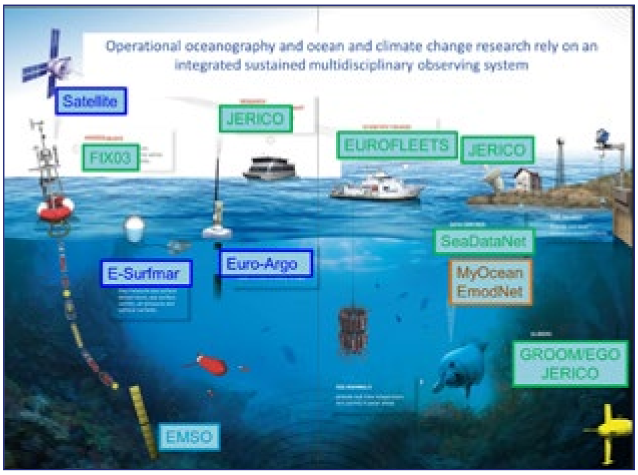


FIGURE 2

Observing the Ocean relies a wide variety of platforms coordinated either through sustained bodies (satellite and ERIC in dark blue) or in phase to be sustained (in light blue) or through I3-DG-Research projects (in green) or through other EC DG-Grow and DG-Mare programs (in brown)

The main characteristics of the Marine Research Infrastructures are that they are distributed and mainly funded through nations. They have developed as networks through ESFRI or I3 projects that have:

- increased cross institutes coordination
- enhanced interoperability of the infrastructures by defining common standards, best practices and infrastructure sharing
- allowed to conduct joint development to develop further the infrastructure

In 2008 the DATAMEQ (DATA Management Exchange and Quality) working group, composed of data managers representative from the EuroGOOS Regional Operational Oceanographic Systems (ROOS) and EU projects addressing data management issues (EuroArgo, EuroSites, SeaDataNet, ICES, Ferrybox, INSPIRE, ECOOP, MyOcean, Satellite), issued a set of recommendations [Pouliquen et al., 2008] that was endorsed by the Members at the annual EuroGOOS meeting in 2008. It was agreed that the ROOSes should set up regional portals extending what had been benchmarked in ECOOP and consolidated/certified in MyOcean as basic infrastructure for EuroGOOS Data Exchange. It was also recommended that theses portals should use standard vocabularies developed within SeaDataNet and use the OceanSites NetCDF format for data distribution. It was agreed that the ROOSes should maintain regional catalogues of the operational observing systems that should be used to update a European catalogue more easily in a semi-automatic way. Finally it was agreed that a set of quality control procedures applicable in near real time automatically should be assembled by the DATAMEQ working group and used by the EuroGOOS members as a minimum level of quality control processing. A first version was issued in [Pouliquen et al., 2010]

Setting up such a system reduced the duplication of efforts among the agencies, improved the quality and reduced cost of the observation distribution, improved access to the observations and therefore increased the benefit of the observation "observed once used multiple". It has strengthened key partnership to increase data availability inside each region making it more sustainable over time and allowing the development of downstream services. It necessitated agreement on common data policy enabling open and free access to data and agreement on common standards and protocols to share data between institutes. Such developments were managed jointly by EuroGOOS ROOSes, MyOcean in situ TAC partners, SeaDataNet NODCs and EMODnet-physics partners.

MYOCEAN IN SITU TAC

Within the MyOcean projects, the in situ Thematic Assembly Centre was set up as a distributed service integrating data from different sources for operational oceanography needs. The MyOcean in situ TAC is collecting and carrying out quality control in a homogeneous manner on data from outside MyOcean data providers (national and international networks), to fit the needs of internal and external users. It provides access to integrated datasets of core parameters to characterise ocean state and ocean variability, by this, contributing to initialization, forcing, assimilation and validation of ocean numerical models which are used for forecasting, analyses and re-analysis of ocean conditions.

Since the primary objective of MyOcean projects was to forecast ocean state, the initial focus was on observations from automatic observatories at sea (e.g. floats, buoys, gliders, ferrybox, drifters, SOOP) which are transmitted in real-time to the shore at global and regional scales both for physical and biogeochemical parameters. The second objective was to set up a system for re-analysis purposes that requires products integrated over the past 30 years for temperature and salinity parameters.

Since the elaboration of the first proposal, the MyOcean in situ TAC has been designed to rely on the EuroGOOS ROOSes with regional coordination endorsed by partners from the ROOSes and on a global component based on Coriolis data centre (http://www.coriolis.eu.org) that acts as a GDAC (Global Data Centre) for some of the JCOMM networks.

The MyOcean in situ TAC is focused on a limited number of parameters:

- Temperature and salinity: global and regional, produced in real time and delayed mode
- Currents: global and regional, produced in real time
- Sea level: regional, produced in real time
- Biogeochemical (chlorophyll, oxygen and nutrients): global and regional, produced in real time

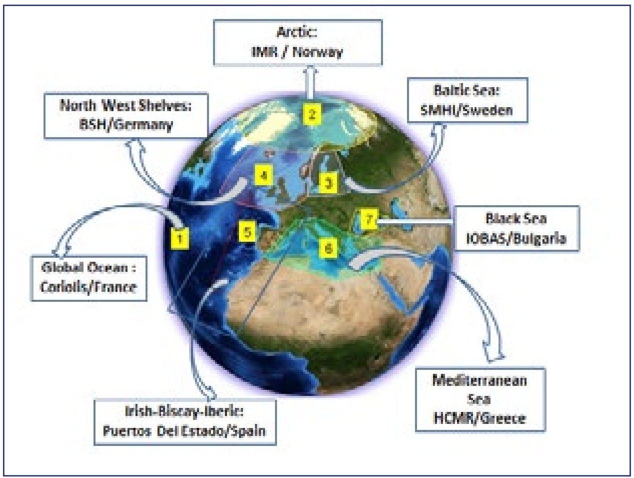


FIGURE 3

The in-situ TAC global and regional components

The in situ TAC architecture is decentralized. However, quality of the products delivered to users must be equivalent wherever the data are processed [Pouliquen et al., 2010]. The different functions implemented by the global and regional components of the in situ TAC are :

- Acquisition: Gather data available on international networks or though collaboration with regional partners.
- Quality control: apply automatic quality controls that have been agreed at the in- situ TAC level. These procedures are defined by parameter, elaborated in coherence with international agreement, in particular SeaDataNet, and documented in MyOcean catalogue.
- Product Assessment: Assess the consistency of the data over a period of time and an area to detect data not coherent with their neighbours but could not be detected by automatic quality control (QC). This function has a level of complexity on its implementation which is clearly different from the other three as it highly relies on scientist expertise.
- Product distribution: make the data available within MyOcean and to the external users.

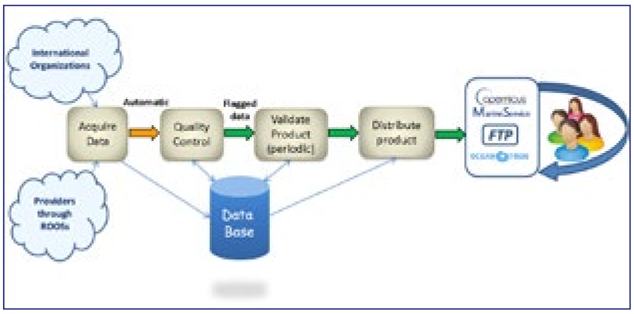


FIGURE 4

Common functions implemented by the 7 In Situ TAC components in an homogenized manner

As a consequence, for all European seas, a unique way of distributing the data has been set up:

- Same format: The OceanSites NetCDF format has been chosen because it is CF compliant, it relies on SeaDataNet vocabularies and it is able to handle profiles and time series data coming from floats, drifters, moorings, gliders and vessels.
- Same ftp portal organization: the data are organized in three main directories:

 - Latest: Providing access to a sliding window on the latest 30 days of observations for real-time applications.

 - Monthly: Accumulating the best copy of a dataset, organized by platform and by month.

 - History: Providing historical aggregated datasets (30 years) for reanalysis activities.

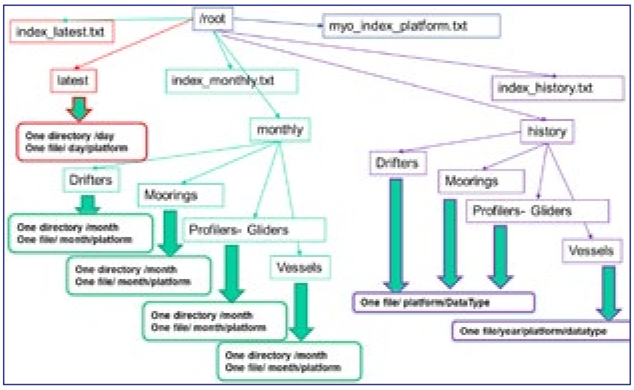


FIGURE 5

Same distribution means : Latest directory for assimilation in daily forecast, Monthly directory for operation and research community (Near Real Time product) , History for reanalysis and research activities (REP products)

THE NEAR-REAL TIME SERVICE

Presently in near real time more than 2700 platforms for the global, between less than 10 for the Black Sea and 450 for the Iberian-Biscay-Irish seas are distributed every day on the In situ TAC portals. Depending on the seas the platforms used are diverse from mainly fixed stations and ferrybox from the Baltic, to research vessels and Argo for the Arctic to a wider kinds of platforms for North and South West Shelves and Mediterranean Sea. The number of platforms is sparse in the Black Sea but improving since the start of the Argo program in the area.

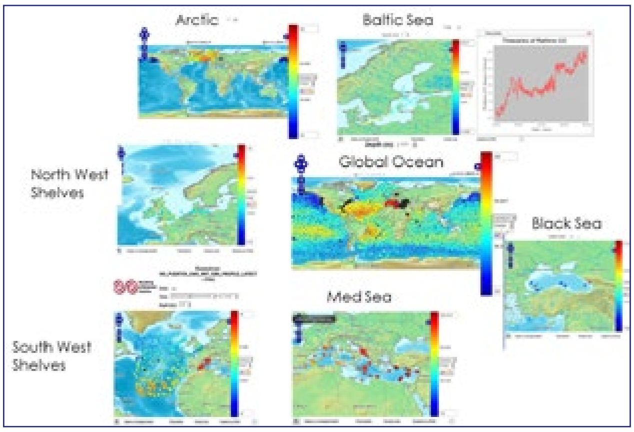


FIGURE 6

Latest 3 months of observations in each region displayed using the WMS service provided by WMS service for in situ called Oceanotron (https://forge.ifremer.fr/plugins/mediawiki/wiki/oceanotron/index.php/Accueil)

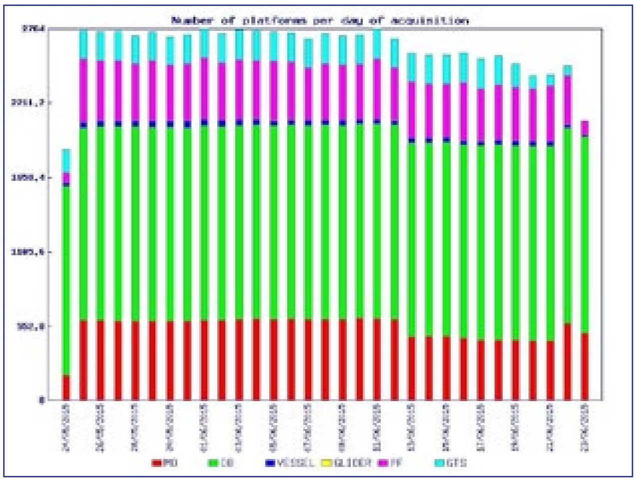


FIGURE 7

More than 2700 platforms per day acquired by different types of instruments distributed from the In Situ TAC (mooring, Drifters, Vessels, Gliders, Argo profilers, other type of platforms collected on the GTS)

A fundamental problem for *in situ* measurements is that they are considered as ground truth for satellite-based observations or model outputs and are often validated using climatology. The problem is that the ocean is changing over time, for some parameters or areas the climatologies have been elaborated within very few measurements not representative of their variability, variability that is much more important on the shelves than in deep ocean. In MyOcean an important effort has been done to improve first on the near- real-time automatic procedures to flag obviously erroneous data that would impact model output if assimilated. Important effort also has been carried in delayed mode assessment looking at the consistency of all available *in situ* data in area and also checking consistency with other type of observations such as altimetry from satellite for temperature and salinity data. This approach will be extended to chlorophyll, with comparison with satellite ocean colour in CMEMS.

Finally an important effort has been done in unlocking access to *in situ* data in partnership with EuroGOOS and EmodNet-Physics, setting up a win-win relation with the *in situ* data providers that are often users of the MyOcean products. They have now an easier access to the other *in situ* data acquired in their region of interest and also they benefit from the assessment activities carried on with MyOcean in situ TAC. The *in situ* TAC is a robust distributed system operated by professional centres that have been involved in In-Situ data management activities for decades. The system has proven its reliability with mean availability of the data better than 99% over the past 2 years both at global and regional scales. The establishment of connection to national In-Situ data providers has increased the number of platforms at global scale, from 1500 per day in 2008 to more than 2700 at the end of 2014, and from about 500 per day in 2010 at European scale to nearly 1500 in 2014 aggregating about 80% of the existing European monitoring stations, measuring the core Copernicus Marine Service parameters.

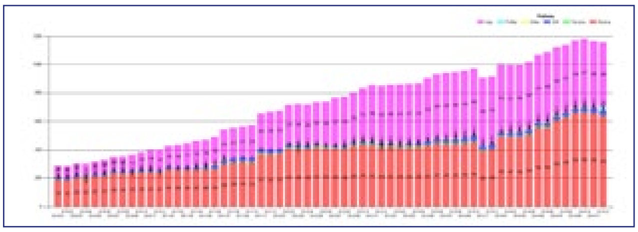


FIGURE 8

Number of European platforms made available to the users by the INSTAC from 2010 to 2014 (from EMODnet-physics dashboard tool).

THE SERVICE FOR REANALYSIS

Based on the Coriolis Global product experience (http://www.coriolis.eu.org/Science2/Global-Ocean/CORA) and in partnership with the SeaDataNet European project (http://www.seadatanet.org/), reprocessed products for the European seas have been developed. These products integrate observations aggregated from Regional EuroGOOS consortium (Arctic-ROOS, BOOS, NOOS, IBI-ROOS, MONGOOS) and Black Sea GOOS, from SeaDataNet2 National Data Centres (NODCs), from World Ocean Data Base (US-NODC), JCOMM global networks (Argo, GOSUD, OceanSITES, GTSPP, DBCP) and from the Global telecommunication system (GTS) used by the Met Offices.

Based on the Coriolis Global product experience and in partnership with the SeaDataNet European project , reprocessed products for the European seas have been developed

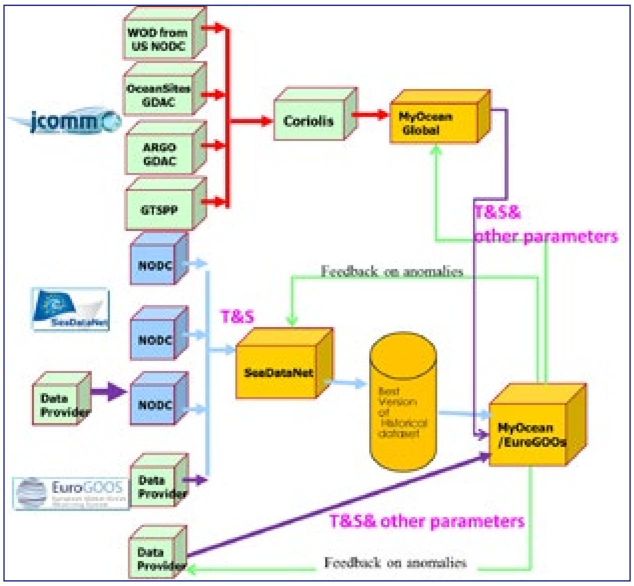


FIGURE 9

External and internal interfaces for Reprocessed in situ product elaboration

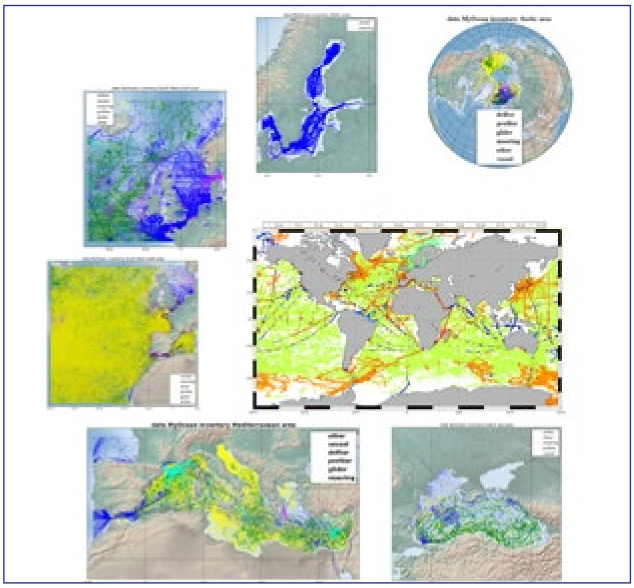


FIGURE 10

In Situ Product for Reanalysis (1990-2013) for Regional (1950-2013) for the global. (CTD from 1950-1989 comes from EN4/ Metoffice)

To elaborate these products it's important to retrieve whenever it's possible the observation qualified in delayed mode, eventually corrected from offset or drift either from ROOS national centres or SeaDataNet NODCs or JCOMM networks. In case a duplicate is detected between the new data provided and a copy that was already provided in real time, each regional *in situ* TAC has defined rules to handle them and a visual inspection is performed when it's not clear from the provided metadata which copy have been through scientific validation.

The scientific validation is performed on a frozen copy of the history directory. It consists of statistical tests to check the consistency of the observation with its neighbours, climatology test and the detected outliers are examined by a scientist to avoid flagging as bad data sampling a real phenomenon. Feedbacks to providers (ROOS partners or SeaDataNet NODCs) on the anomalies detected are performed so that this validation helps to enhance not only the MyOcean products but also the provider datasets. These fully validated T&S regional products are available since MyOcean V4 in April 2014. Each year the time coverage in extended with the latest complete year.

CONCLUSIONS

The IN SITU TAC a key element of in Situ Data Management in Europe

At the inception of MyOcean, the model systems that went into the MFCs relied on their own connections to observational data for assimilation and validation. During MyOcean1, the MFCs started the transition to obtaining data from the TACs using the standard MyOcean interfaces. In the MyOcean2 and MyOcean Follow-On projects, the transition has been largely completed. By the close of MyOcean Follow-On, all MFCs were using data delivered by the TACs to cover their operational needs for assimilation and validation data.

MULTIYEAR MODELS

Models for areas NWS IBI and BALTIC include tidal component, meaning that all parameters include tide signal, especially UV and SSH.

AREA	PRODUCTS	REFERENCES	PARAMETERS	HORIZONTAL AND VERTICAL RESOLUTIONS	TEMPORAL COVERAGE [START DATE; END DATE]	TEMPORAL RESOLUTION	UPDATE FREQUENCY	DATA ASSIMILATED
GLOBAL	Phy	001_009	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1993;15/12/2013]	M+D	A	●●●●
		001_011	T S UV SSH ICE	1/4°-25km; 50 levels	[01/15/1982;15/12/2013]	M+D	A	●●●●
		001_010	T S UV SSH ICE	1/4°-25km; 75 levels	[15/01/1993;15/12/2010]	M	NU	●●●●
		001_017	T S UV SSH ICE MLD	1/4°-25km; 75 levels	[15/01/1979;15/12/2013]	M+D+5D	A	●●●●
		001_004	T S UV SSH ICE	1/4°-25km; 75 levels	[15/01/1993;15/12/2011]	M	NU	
	Bio	001_018	CHL O2 N P Phyto PP Si Fe	1/4°-25km; 75 levels	[15/01/1998;15/12/2013]	M	A	
		001_019	CHL O2 N P Si	1/4°-25km; 50 levels	[15/01/1998;15/12/2013]	M	A	
ARCTIC	Phy	002_003	T S UV SSH ICE MLD	12.5 km; 12 levels	[15/01/1991;15/12/2013]	M	A	●●●●
	Bio	002_005	CHL O2 N P Phyto Radflux	25 km; 12 levels	[15/01/2007;15/12/2010]	M	NU	●●●●
BALTIC	Phy	003_008	T S UV SSH ICE	3nm-5.5km; 50 levels	[01/01/1989;31/12/2013]	M+H+6H	A	●●●
		003_004	T S UV SSH ICE	6nm-11km; 25 levels	[01/01/1990;31/12/2009]	M	NU	●
		003_005	T S UV SSH ICE	3 nm-5.5 km; 25 levels	[01/01/1990;31/12/2009]	M	NU	●●●
	Bio	003_009	CHL O2 N P NH4	2nm-3.7km; 83 levels	[01/01/1970;31/12/1999]	M+2D	NU	●
NWS European North West Shelf Seas	Phy	004_009	T bedT S UV	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_005	T S UV SSH	12 km; 24 levels	[01/01/1960;31/12/2004]	M	NU	
		004_006	T S UV SSH	12 km; 24 levels	[15/01/1985;15/12/2008]	M	NU	
		004_010	T S UV SSH	8 km ; 26 levels	[01/01/1993;31/12/2012]	M	A	●
	Bio	004_011	CHL O2 N P Phyto PP RadFlux	7 km; 24 levels	[01/01/1985;01/07/2012]	M+D	A	●
		004_007	CHL O2 N P Phyto PP RadFlux	12 km; 24 levels	[01/01/1967;31/12/2004]	M	NU	
		004_008	O2 N P Phyto PP Si	12 km; 24 levels	[31/01/1985;31/12/2008]	M	NU	
		004_012	O2 N P Phyto PP Si	8 km; 26 levels	[01/01/1993;31/12/2012]	M	A	●
IBI Iberia Biscay Ireland Regional Seas	Phy	005_002	T S UV SSH	1/12°-7.5km; 50 levels	[01/02/2002;23/12/2011]	M+D+H	NU	●●●
	Bio	005_003	CHL O2 N P Phyto PP Si Fe NH4 Eup	1/12°-7.5km; 50 levels	[01/01/2002;23/12/2011]	M	NU	●●●
MED Mediterranean Sea	Phy	006_004	T S UV SSH	1/16°-6km; 72 levels	[01/01/1987;31/12/2013]	M+D	A	●●●
	Bio	006_008	CHL O2 N P Phyto PP	1/16°-6km; 72 levels	[01/01/1999;31/12/2012]	M	A	●●●●

TABLE 1

DATA ASSIMILATED into MFC Near real time and Multiyear models products at V5. Color balls indicate data assimilation of ***SST/SeaLevel/InsituTSprofiles/SeaIceConcentration/SatelliteChlorophyll. See also*** http://marine.copernicus.eu/automne_modules_files/pmedia/public/r2201_9_overview-models-v1.1.1-web_eu.pdf ***for current update.***

The present *in situ TAC* has been developed in coherence with other components of the pan-European data management landscape following the EuroGOOS recommendation adopted in 2008 by the EuroGOOS assembly. The *in situ TAC* relies on standards and vocabularies developed within SeaDataNet and is interoperable both upstream with the observation provider networks and downstream with initiatives such as EMODnet. The institutes that are involved in the *in situ TAC* are key partners in past (JERICO, PERSEUS, GROOM, ODIP...) and coming (AtlantOS, Jerico-next, ENVRI-plus, ODIP2) European funded research projects supporting In-Situ observing system enhancement and data integration. Through this extensive experience and the EuroGOOS association and its related ROOSs, the *in situ TAC* partners are able to foster interoperability within the integrated European observing system.

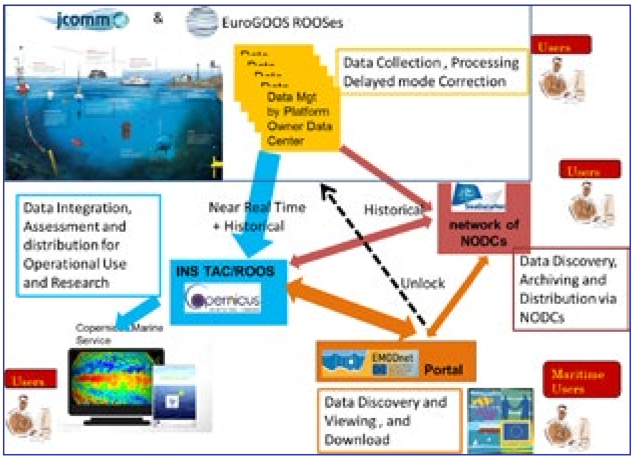


FIGURE 11

Connection of the In-Situ Thematic Assembly Centre with other actors of In-Situ data management in Europe.

The infrastructure described in this article has been set up to fulfil the MyOcean projects and users and EuroGOOS partner needs. The foundations of a reliable data exchange system have been built, for operational oceanography applications both for core and downstream applications as well as research activities. It has improved the *in situ* data services at European scale and will show its benefit to the community if it is sustained on the long term jointly by the regions and the European Commission. The main priorities for MyOcean and EuroGOOS partners are:

- Sustain the existing service in near Real Time and for reanalysis within the Copernicus Marine Environment Monitoring System.
- Consolidate interoperability with EUROGOOS , SeaDataNet , EMODNet and JCOMM systems.
- Collaborate with other EU projects to enhance the service without duplication of efforts (JERICO-Next, PERSEUS, AtlantOS,..)
- Extend some of the services developed for Temperature and Salinity to other EOVs (Earth Ocean Variable) such as current or chlorophyll, waves, current,...

ACKNOWLEDGEMENTS

This work is part of the MyOcean projects. Additional observations are acquired outside MyOcean and especially by EuroGOOS ROOS institutes at European Scale . Historical products were built in partnership with SeaDataNet2 EU and EMODnet-Physics projects.

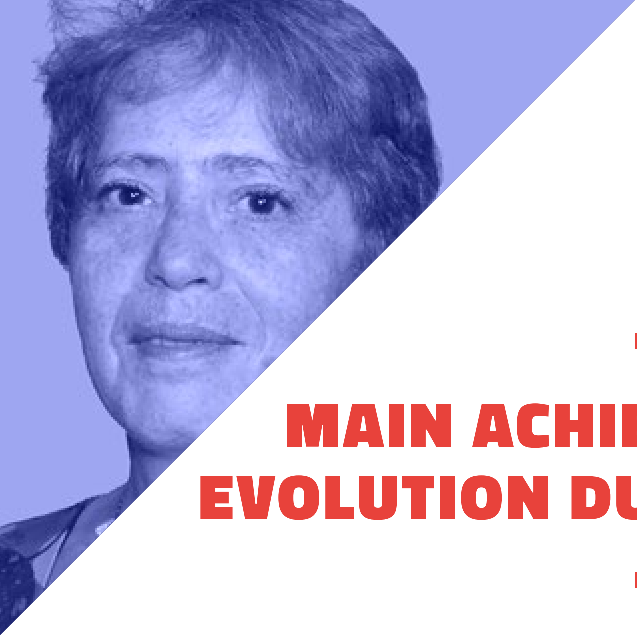
REFERENCES

Cabanes C & co-authors (2013). *The CORA dataset: validation and diagnostics of in situ ocean temperature and salinity measurements.* Ocean Science, 9(spec.issue), 1-18. Publisher's official version : http://dx.doi.org/10.5194/os-9-1-2013

Levitus, S.: *Climatological Atlas of the World Ocean, NOAA Professional Paper 13, US* Government Printing Office, Rockville, MD, 190 pp., 1982.

Pouliquen & co-authors (2008) "*Recommendations for a PAN-European data management system for operational oceanography within EuroGOOS*" (http://www.eurogoos.org/documents/eurogoos/downloads/recommendations_for_a_pan_eu_data_sysem_from_datameq-wg_v2.1.pdf)

Pouliquen & co-authors (2010) "*Recommendations for in situ data Near-real time Quality Control Procedures* http://eurogoos.eu/download/other_documents/recommendations_for_rtqc_procedures_v1_2.pdf



MAIN ACHIEVEMENTS FOR NEMO EVOLUTION DURING MYOCEAN PERIOD

BY

NEMO SYSTEM TEAM(1): R. BOURDALLE-BADIE(2), P-A. BOUTTIER(3), C. BRICAUD(2), D. BRUCIAFERRI(5), J. CHANUT(2), S A. CILIBERTI(8), E. CLEMENTI(5), A. COWARD(6), D. DELROSSO(5), C. ETHÉ(7), S. FLAVONI(7), T. GRAHAM(9), J. HARLE(10), D. IOVINO(4), D. LEA(9), C. LÉVY(7), T. LOVATO(4), G. MADEC(7), N. MARTIN(7), S. MASSON(7), P. MATHIOT(11), S. MOCAVERO(8), G. NURSER(6), E. O'DEA(9), J. PAUL(2), C. ROUSSET(7), D. STORKEY(9), A. STORTO(4)

ABSTRACT

NEMO (Nucleus for European Modelling of the Ocean) is a state-of-the-art modelling framework used in a wide variety of applications whose prime objectives are oceanographic research, operational oceanography, seasonal to decadal forecasting and climate studies. The development of the ocean component ("OPA", **Océan PArallélisé**) started in the 80's in a French research laboratory. From the very beginning, its development has been driven by ocean and computer sciences. The code quickly became open access in order to promote the sharing of expertise, and became a shared platform in 2008, after the NEMO Consortium agreement was signed by CNRS, Mercator-Ocean, the Met-Office and NOC. **The Euro-Mediterranean Center on Climate Change** (CMCC) and the National Institute of Geophysics and Volcanology (INGV) joined the Consortium in 2011. The Consortium agreement states that: "The purpose of this Agreement is to set up appropriate arrangements for the successful and sustainable development of the NEMO System as a well-organised, state-of-the-art ocean model code system suitable for both research and operational work.» The development of NEMO is driven and performed by the "NEMO System Team", a group of experts from the different institutions of the Consortium.

[1] **NEMO** System Team is the group of experts from institutions of NEMO Consortium, in charge of NEMO development
[2] **MERCATOR-OCEAN**, Toulouse, France
[3] **CNRS**, Grenoble, France
[4] **CMCC**, Bologna, Italy
[5] **INGV**, Bologna, Italy
[6] **NOC**, Southampton, UK
[7] **CNRS**, Paris, France
[8] **CMCC**, Lecce, Italy
[9] **Met-Office**, Exeter, UK
[10] **NOC**, Liverpool, UK
[11] **British Antarctic Survey**, Cambridge, UK.

NEMO is available under the free CeCILL[1] licence. At present, it is used by about a thousand users in hundreds of projects in Europe and worldwide for a large variety of application in oceanographic research, climate studies and operational forecasts.

This paper will describe the NEMO development processes, the main achievements in NEMO reference code developments during MyOcean project, and the mutual contributions and benefits between MyOcean and NEMO.

1 Details on CeCILL license can be found here: http://www.cecill.info/index.en.html

NEMO DEVELOPMENT PROCESSES

NEMO is defined through five major components: the blue ocean (NEMO-OPA), for modelling the ocean dynamics; the white ocean (NEMO-LIM, Louvain-la-Neuve Sea Ice Model), for modelling sea-ice thermodynamics and dynamics; the green ocean (NEMO-TOP, Tracer in the Ocean Paradigm) for modelling marine biogeochemistry; the adaptive mesh refinement software (AGRIF) and the tangent linear and adjoint components NEMO-TAM (tangent linear and adjoint models) and -OBS for assimilation purposes. The first three components can be used together or in standalone mode.

NEMO can also be interfaced to a number of other components such as atmospheric models (e.g. using OASIS as ocean-atmosphere coupler (Valcke et 2013ab), https://verc.enes.org/oasis/metrics/oasis4-dissemination) or alternative models of sea-ice and biogeochemistry (e.g. CICE and BFM).

NEMO also includes some "reference configurations" allowing users to set-up and validate the applications. Among those, the "ORCA family" describes the global ocean using a tri-polar grid, quasi-isotropic grid in a wide set of spatial resolutions various spatial resolutions. For these reference configurations, all input files are available to users.

The platform also includes a set of scripts and tools (including pre- and post-processing) to use the system and a documentation updated after each release (Madec et al). NEMO (the code, its history, the reference configurations and their inputs, the shared tools and the documentation) are available under the free CeCILL license from the NEMO web site: http://www.nemo-ocean.eu/.

To build an application using NEMO, i.e. a numerical model, one needs the NEMO reference code and the configuration defining the application itself. To summarize, the NEMO platform deals with the physical equations, their translation using numerical schemes and the code implementation, optimized for a set of heterogeneous architectures. A project using NEMO builds the configuration, i.e. the space and time grid definition and the associated choices of the physical parameters for numerical schemes.

The NEMO System Team is in charge of the NEMO shared platform and its development, whereas the projects build the application, taking care of the configuration.

NEMO evolution is planned through an annual work plan of the NEMO System Team. This work plan is written by the team, discussed with NEMO Developer's Committee and validated by NEMO Steering Committee. It is a joint work plan at the NEMO Consortium level, answering the needs of the community. Experts of the System Team carry out the work. At the end of each year, the developments are merged, to build a new version of the NEMO reference code. After technical and scientific validations, a new release of NEMO is announced and the code is made available.

Eventhough NEMO's performance and reliability are good enough to use the platform in a wide diversity of applications, it still needs improvements and developments. This has been particularly obvious during MyOcean projects, which brought in the NEMO community a large number of new projects and applications inducing some different views on NEMO's capabilities and results

MAIN DEVELOPMENTS OF NEMO DURING MYOCEAN2

Following the development process described above, some major breakthroughs have been carried out during the MyOcean2 period.

In 2009, at the beginning of MyOcean1, the up to date NEMO release was v3-2 whose developments mainly focused on climate studies and global configurations.

In February 2012 at the end of MyOcean1, the v3-4 major version was released with the introduction of many new features. The major ones were:

- Physics: concerning the vertical physics, the surface boundary condition of Turbulent Kinetic Energy (TKE) closure scheme was changed, especially in coupled mode (mean stress module sent by the atmosphere) and the Generic Length Scale vertical mixing scheme (Umlauf and Burchard, 2003) was introduced (Reffray et al 2014). Diurnal cycle on solar radiation (Bernie et al, 2007) and new bulk formulae for the Mediterranean Forecast System (MFS) were added into the surface. Others new features included a new pressure gradient suitable for s-coordinate, the completion of iso-neutral diffusion scheme by Griffies, the Pacanowski-Philander scheme for computation of Ekman depth, and the Neptune effect parameterization (Alvarez et al, 1994).
- Interfaces: a drag coefficient computed by wave model was introduced; the TOP/PISCES component was improved by adding light limitation, a quota model for iron, the use of atmospheric pressure - 2D spatial distribution - in gas exchange and calcite dissolution & calcon salinity dependence (Aumont et al 2015). An interface for coupling

with the CICE sea ice model was added.

- Numeric: performances were improved thanks to a point to point MPI communication scheme for the north fold and a sub time stepping scheme for biogeochemistry models when using the non-linear free surface. An interface for CICE sea ice model was made available.

Several regional ocean forecasting systems in MyOcean (Irish-Biscay-Iberian (Maraldi et al 2013), North West European Continental Shelf (Edwards, K. P et 2012), Mediterranean Sea (Oddo et al., 2009, 2014)) are based on NEMO (figure 1) ; their developments were started during Mersea (Desaubies, Y. , 2009.). Specific developments have been introduced to NEMO to provide regional capability: tidal forcing, semi-implicit bottom friction, unstructured open boundaries (the so called "bdy" module) and of non-linear free surface (called "vvl" in NEMO). The European shelf AMM12 configuration has been added to the reference configuration of NEMO (figure2). GODAE metrics (Hernandez et al, 2009) such as Meridional heat transport; transports through sections, Meridional Overturning Currents have been included in NEMO diagnostics.

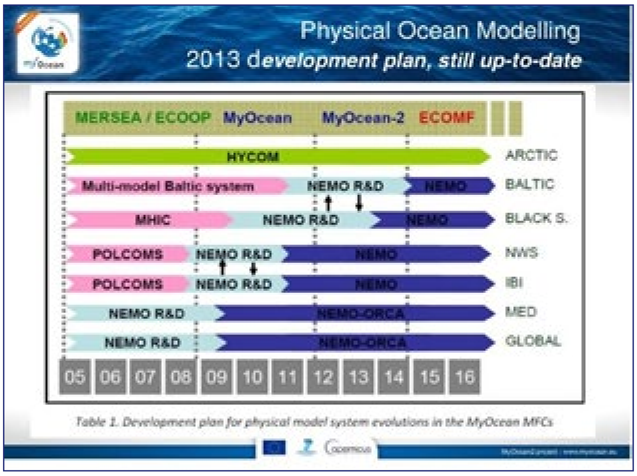


FIGURE 1

MFC model evolution, from MERSEA to CMEMS (Copernicus Marine Environment Monitoring Service). ECOMF is the former name for CMEMS.

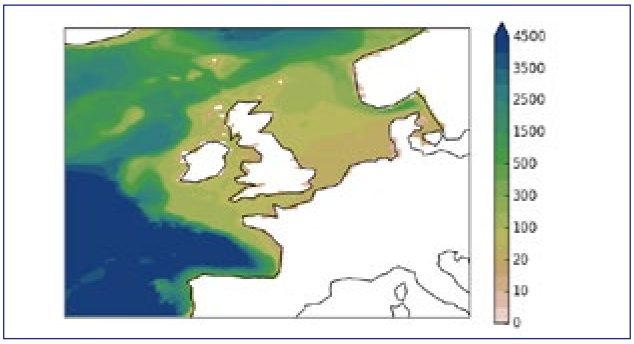


FIGURE 2

Bathymetry of the European shelf AMM12 configuration

The V3-4.1, announced in February 2013, included all these features and an up to date version of the NEMO Tangent and adjoint component NEMO-TAM. Since then, 3-4.1 version became the NEMO_v3.4_STABLE release of NEMO. This addition of a coherent version of TAM has been used by some projects for data assimilation studies, as well as for characteristic vectors computation.

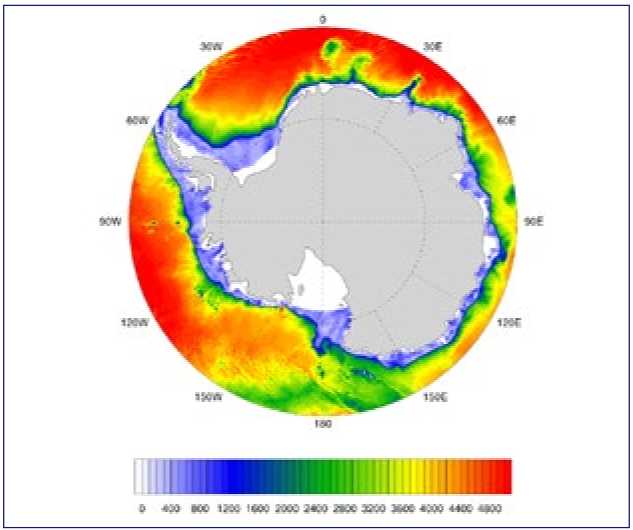
In 2012, v3-5 was built, with improved interfaces, especially at high latitudes and new features or improved representations of physical processes:

- Improved interfaces: concerning the sea-ice component, embedded sea-ice (for LIM & CICE) was available; AGRIF was made compatible with the LIM interface; the ICB module (Bigg et al 1997, Marsh et al 2015 ; Martin and Adcroft 2010) was introduced to model icebergs as lagrangian floats (~200000!) allowing improved fresh water input especially in the Southern ocean; the wave-NEMO interface module was further developed with the introduction of the reading of the 2D Stokes drift and wave number and the on-line computation of the 3D Stokes drift current; the PISCES code was made simpler and more general resulting in a reduction in code size and LOBSTER functionality was included in PISCES; The two open boundary conditions modules (OBC for the regular boundaries and BDY for the unstructured boundaries) were merged and boundary conditions for sea ice (LIM3) have been implemented to run regional simulations in ice-covered areas.

- Concerning the numeric and physics, a new vertical sigma coordinate stretching function (Siddorn and Furner, 2012) was added, an option for local up-stream advection schemes which are useful in case of rivers, straits and in proximity of open lateral boundary conditions and the possibility to switch from MUSCL to a standard up-stream scheme was included in the MUSCL advection routine; Smagorinsky type diffusivity/viscosity for lateral mixing was introduced and analytical tropical cyclones were now taken into account using track and magnitude observations (Vincent et al., 2012a,b).

During 2015, at the end of MyOcean2 project, the v3_6_STABLE has been built in order to provide a new stable version, in particular for CMIP6 experiments. Developments in this version include:

- Evolution of parameterizations from regional configurations will benefit global configurations: in particular, surface pressure gradient is now solved with split explicit time-splitting instead of an implicit filtered free surface and a non-linear free surface is used.
- The global ORCA grid is extended toward the south and under ice shelf seas can now be modelled



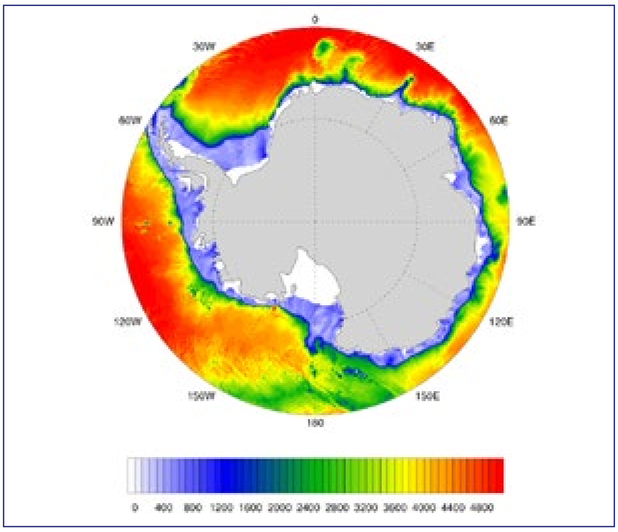


FIGURE 3

The former global ORCA025 bathymetry and the extended one: south pole

- Concerning the interfaces, the multi category LIM3 has been largely rewritten to improve its robustness, versatility and complexity and to make it the standard sea-ice model (Rousset et al., 2015). In addition, online coarsening is introduced in the biogeochemical component TOP/PISCES in order to limit the CPU cost (Figure 4);
- Performances of the model have been improved thanks to the new IO system XIOS developed at IPSL and ocean and surface module (ice and surface boundary conditions) components can be coupled through OASIS. Moreover, the scalability of the model has been improved increasing the computation/communication ratio by introducing the message packing and limiting the abuse of collective communications in LIM3.

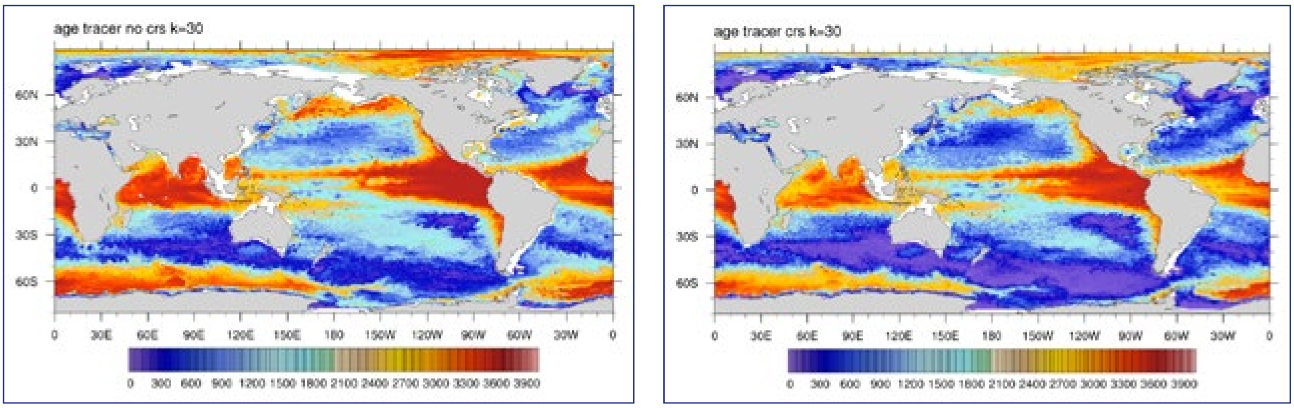


FIGURE 4

The former global ORCA025 bathymetry and the extended one: south pole

NEMO AND MYOCEAN MUTUAL BENEFITS

As a general overview, it is obvious that NEMO development in terms of organisation, so as number and diversity of applications is synchronous with MyOcean: the NEMO Consortium Agreement has been signed in 2008, MyOcean1 started in 2009, INGV and CMCC entered the NEMO Consortium in 2011 and MyOcean2 started in 2012. These simultaneous steps can be seen as mutual benefits between NEMO and MyOcean, giving more visibility to the NEMO platform and allowing easier sharing of models, tools and applications for numerical modelling of the ocean.

Others projects linked to operational oceanography are contributing to NEMO developments and to the improvement of configurations: Drakkar (http://www.drakkar-ocean.eu/) is using and improving configurations based on NEMO OGCM, such as the global configurations ORCA025 and ORCA12, with some local AGRIF zooms; SIMED projects is based on the Mediterranean extraction of ORCA12 configuration.

Projects dedicated to climate and predictability are using model and simulations based on NEMO and its global configurations at 1/4°,1° and 2° (ORCA025,ORCA1 and ORCA2) : CMIP (http://cmip-pcmdi.llnl.gov/cmip5/), Eraclim2 (http://www.era-clim.eu/), Ice-Arc (http://www.ice-arc.eu/).

Some projects dedicated to data assimilation and Ocean Observing System improvement are using NEMO components: Atlantos (https://www.atlantos-h2020.eu/) will use experiments based on NEMO ocean model and SANGOMA (http://www.data-assimilation.net/) will benefit to data assimilation methods improvement for operational oceanography.

Finally, IS-ENES and IS-ENES2 (https://verc.enes.org/ISENES2) have contributed to progress on ease-to-use of NEMO and associated services to users and projects.

CONCLUSIONS

As seen from NEMO development side, MyOcean has strongly contributed to the model improvements and developments: all the new applications build with NEMO during the project have "stressed" NEMO far beyond its known capabilities, inducing major developments efforts as shown above. The associated efforts from MyOcean projects, to contribute to the scientific validation of these developments have also speed up the process.

As seen from MyOcean, using NEMO as a common instrument to develop the wide diversity of applications has accelerated the work (shared developments, shared validations) and facilitated the exchange of expertise.

As seen from MyOcean, using NEMO as a common instrument to develop the wide diversity of applications has accelerated the work (shared developments, shared validations) and facilitated the exchange of expertise.

The intensive work done during MyOcean is now fruitful: as a result of all these efforts, Europe is now establishing the organisation of a sustainable European operational oceanography throughCMEMS.

In practice, NEMO is now indeed a European shared e-infrastructure, good enough to be used, but again, still needing developments: taking in account new physical components, new coupling processes, improving physics and parametrisations, so as taking care of the model performances on new computers architectures are still and will remain the main activity of NEMO System Team. However, for now, NEMO's sustainable development is ensured only by the NEMO consortium's institutions. At European level, it is now becoming a strong need to find a way to contribute to the development of this shared e-infrastructure which has now became the bedrock of number of ocean and climate actions.

ACKNOWLEDGEMENTS

The authors acknowledge all the PIs of MyOcean actions for their contributions to NEMO developments and validation.

REFERENCES

Alvarez, A., J. Tintoré, G. Holloway, M. Eby, and J. M. Beckers (1994), *Effect of topographic stress on circulation in the western Mediterranean, J.* Geophys. Res., 99(C8), 16053–16064, doi:10.1029/94JC00811.

Aumont, O., Ethé, C., Tagliabue, A., Bopp, L., and Gehlen, M.: *PISCES-v2: an ocean biogeochemical model for carbon and ecosystem studies,* Geosci. Model Dev. Discuss., 8, 1375-1509, doi:10.5194/gmdd-8-1375-2015, 2015.

Bernie, D., E. Guilyardi, G. Madec, J. Slingo, and S. Woolnough (2007), *Impact of resolving the diurnal cycle in an ocean–atmosphere GCM.* Part 1: A diurnally forced OGCM, Clim. Dyn. , 29, 575–590.

Bigg, G. R., Wadley, M. R., Stevens, D. P., and Johnson, J. A.: *Modelling dynamics and thermodynamics of icebergs, Cold Reg.* Sci.Technol., 26, 113–135, 1997

Desaubies, Y.: *The Mersea Project* – Introduction to the Ocean Science Special Issue June 18, 2009.

Edwards, K. P., Barciela, R., and Butenschön, M.: *Validation of the NEMO-ERSEM operational ecosystem model for the North West European Continental Shelf*, Ocean Sci., 8, 983-1000, doi:10.5194/os-8-983-2012, 2012.

Hernandez, F., L. Bertino, G. Brassington, E. Chassignet, J. Cummings, F. Davidson, M. Drévillon, G. Garric, M. Kamachi, J.-M. Lellouche, R.Mahdon, M.J. Martin, A. Ratsimandresy, and C. Regnier. 2009. *Validation and intercomparison studies within GODAE.* Oceanography 22(3):128–143, http://dx.doi.org/10.5670/oceanog.2009.71.

Madec, G., and the NEMO team: *NEMO ocean engine. Note du Pôle de mod´elisation,* Institut Pierre-Simon Laplace (IPSL), France, No 27, ISSN No 1288-1619.

Maraldi, C., Chanut, J., Levier, B., Ayoub, N., De Mey, P., Reffray, G., Lyard, F., Cailleau, S., Drévillon, M., Fanjul, E. A., Sotillo, M. G., Marsaleix, P., and the Mercator Research and Development Team: *NEMO on the shelf: assessment of the Iberia–Biscay–Ireland configuration*, Ocean Sci., 9, 745-771, doi:10.5194/os-9-745-2013, 2013.

Marsh, R., Ivchenko, V. O., Skliris, N., Alderson, S., Bigg, G. R., Madec, G., Blaker, A. T., Aksenov, Y., Sinha, B., Coward, A. C., Le Sommer, J., Merino, N., and Zalesny, V. B.: *NEMO–ICB (v1.0): interactive icebergs in the NEMO ocean model globally configured at eddy-permitting resolution,* Geosci. Model Dev., 8, 1547-1562, doi:10.5194/gmd-8-1547-2015, 2015.

Martin, T, and Alistair Adcroft, July 2010: *Parameterizing the fresh-water flux from land ice to ocean with interactive icebergs in a coupled climate model.* Ocean Modelling, 34(3-4)

Oddo, P., M. Adani, N. Pinardi, C. Fratianni, M. Tonani, and Pettenuzzo, D.: *A nested Atlantic-Mediterranean Sea general circulation model for operational forecasting*, Ocean Sci., 5, 461-47, 2009.

Oddo P., Bonaduce A., Pinardi N. and A. Guarnieri: *Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO.* Geosci. Model Dev., 7, 3001–3015, 2014.

Reffray, G., Bourdalle-Badie, R., and Calone, C.: *Modelling turbulent vertical mixing sensitivity using a 1-D version of NEMO*, Geosci. Model Dev. Discuss., 7, 5249-5293, doi:10.5194/gmdd-7-5249-2014, 2014.

Rousset, C., Vancoppenolle, M., Madec, G., Fichefet, T., Flavoni, S., Barthélemy, A., Benshila, R., Chanut, J., Levy, C., Masson, S., and Vivier, F.: *The Louvain-la-Neuve sea ice model LIM3.5: global and regional capabilities*, Geosci. Model Dev. Discuss., 8, 3403-3441, doi:10.5194/gmdd-8-3403-2015, 2015.

Siddorn, J. R., Furner, R.: *An analytical stretching function that combines the best attributes of geopotential and terrain-following vertical coordinates*, Ocean Modelling, Volume 66, June 2013, Pages 1-13, http://dx.doi.org/10.1016/j.ocemod.2013.02.001.

Umlauf, L. and H. Burchard (2003): *A generic length-scale equation for geophysical turbulence models*, J. Mar. Res., 61, 235-265.

Valcke Sophie (a) , Tony Craig, Laure Coquart, 2013: *OASIS3-MCT User Guide, OASIS3-MCT 2.0, Technical Report, TR/CMGC/13/17,* CERFACS/CNRS SUC URA No 1875, Toulouse, France

Valcke Sophie (b), 2013: *The OASIS3 coupler: a European climate modelling community software*, Geosci. Model Dev., 6, 373-388, doi:10.5194/gmd-6-373-2013

Vincent, E. M. (a), M. Lengaigne, G. Madec, J. Vialard, G. Samson, N. C. Jourdain, C. E. Menkes, and S. Jullien (2012), Processes setting the characteristics of sea surface cooling induced by tropical cyclones, J. Geophys. Res., 117, C02020, doi:10.1029/2011JC007396.

Vincent EM (b), Lengaigne M, Vialard J, Madec G, Jourdain NC, Masson S (2012)

Assessing the Oceanic Control on the Amplitude of Sea Surface Cooling induced by Tropical Cyclones, J. Geophys. Res.

PRODUCT QUALITY ACHIEVEMENTS WITHIN MYOCEAN

BY

J. MAKSYMCZUK(1), F. HERNANDEZ(2), A. SELLAR(1), K. BAETENS(3), M. DREVILLON(4), R. MAHDON(1), B. LEVIER(4), C. REGNIER(4), A. RYAN(1)

ABSTRACT

Routine validation is performed on all products within the MyOcean catalogue in order to objectively assess product quality. A fundamental goal of the MyOcean project was to make the results of this validation available to users in a clear and consistent way. This was achieved by working together with MyOcean partner organisations to increase the consistency between the validation performed on the wide range of MyOcean products, and by evaluating new metrics for understanding the scientific quality of the products. A framework to routinely assess and publish product quality information was established and made accessible to the user community. This strengthened user confidence in the products, and provided an ongoing mechanism to monitor product improvements..

[1] **Met Office**, Exeter, UK
2 **IRD/LEGOS/Mercator Océan**, Ramonville St Agne, France

[3] **RBINS, OD Nature**, Brussels, Belgium
[4] **Mercator Océan**, Ramonville St Agne, France

INTRODUCTION

Validation tasks are a routine part of research activities in ocean modelling, and aim to verify that new approaches are scientifically robust and provide numerical results that match, or are better, than the former solution, when compared against the 'ocean truth'. The first demonstrations of operational oceanography forecasting systems (OOFS) were embedding calibration, validation and verification tasks, but the difficulty with such procedures for real time assessment has always been the limited availability of data, reference information, time for expert review and other resource constraints. In the framework of EU projects like MERSEA Strand1 (2002-2003), MERSEA IP (2004-2008), or ECOOP (2007-2010), a series of diagnostics, or metrics, were tested and implemented in European OOFS global or regional demonstrators (Crosnier and Le Provost, 2007). In parallel, at an international level, similar advances were carried on in the framework of GODAE, then GODAE OceanView. Reviews and progresses on validation and performance assessment of OOFS can be found for example in Hernandez et al, 2009 and Hernandez et al, 2015.

In this context, the first phase of MyOcean (2009-2012) was defined with dedicated validation tasks performed in every production centre in order to 1) provide Product Quality information to users, and 2) allow users to see that each operational system upgrade guarantees some improvement in product quality. As requested at the start of the project, and following the heritage of MERSEA/GODAE validation tools, routine monitoring of product quality has been implemented by experts in every production unit of MyOcean. Some production centres also started to directly provide to users a subset of this operational routine monitoring on their own dedicated web pages.

In continuity, the MyOcean2 project offered the opportunity to strengthen this validation strategy, by defining a dedicated cross-cutting work package, and involving calibration/validation experts from the different production centres. This product quality transverse activity among the MyOcean2 production centres was also initiated in order to provide users with easy to access information on the accuracy of MyOcean products, which was highlighted as a high-priority requirement following the completion of the first phase of the MyOcean project. It was also seen as an opportunity to enforce consistency in the generation and reporting of product quality information within MyOcean, so that users could have confidence in the data provided and use MyOcean products to add value to their own operational systems or to contribute to their research and development programs.

The primary objectives of the product quality work package in the second phase (MyOcean2 2012-2015) were to ensure that:

- the accuracy of MyOcean products was adequately monitored
- changes to the MyOcean system were justified from a quality point of view
- information on product quality was scientifically robust, useful, and communicated effectively
- product quality assessment took into account user requirements and feedback

One of the main concerns at the start of the project was the number of different ways in which each of the centres performed routine validation activities, especially with regards to metrics, quality control procedures, and the reference datasets against which products were assessed. In order to address this, it was agreed during the initial planning phase of MyOcean2 that one of the main objectives of the project would be to develop a set of common guidelines that would enable each of the participating centres to perform validation activities in a consistent way, thereby standardising the mechanisms and subsequent results that would be distributed to users in the later stages of the project. It was also agreed to form a small team of experts to oversee the evolution and content of the product quality guidelines, and to make sure that these guidelines were adhered to by all participating centres.

Whilst it was important and useful to disseminate some of the standard validation statistics to users, following the user-driven development policy of MyOcean, it was also apparent that there could be a need to display more sophisticated results to more informed users. To address this, specific production centres were tasked with looking into the application of new user-oriented metrics, which have been commonly used within the atmospheric science community for a number of years, and applying them to selected products within the MyOcean catalogue. The areas of interest were identified as:

- biogeochemistry - numerous intermediate and end-users of MyOcean products are interested in specific, extreme events such as algal blooms, eutrophication and hypoxia, and it was felt that it would be useful to be able to quantify the levels to which products in the catalogue predicted these events.
- ocean currents - the routine validation performed by relatively simple metrics such as bias or rms errors does not describe many important aspects of ocean current

validation, such as the spatial accuracy of tidal flow, or the timing and intensity of strong current events. Evaluating site-specific metrics would enable investigations into categorical metrics and quantification of extreme events.

- quantifying consistency in MyOcean products - in some regions MyOcean users have access to more than one product for a given parameter. If a user moves from one product region to another, or is providing a service which spans the boundary between products, it is important that they are aware of the degree of consistency between these products.

The Product Quality work package was arranged to deal with each of the above aspects, with interaction between the individual working groups encouraged, and oversight of the work package carried out by the work package leader. The division of responsibilities is illustrated in the schematic below.

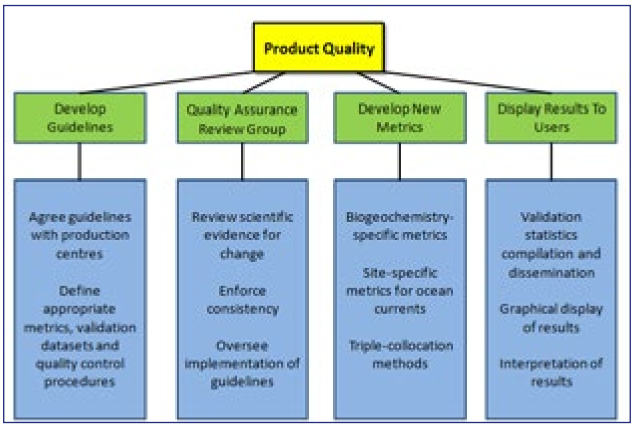


FIGURE 1

The structure and aims of the Product Quality work package.

PRODUCT QUALITY GUIDELINES

Throughout MyOcean2, the overriding principle was to ensure that users would see product quality information with a consistent look and feel across all of the different products. This included the choice of metrics displayed, the reference datasets for validation, the quality control (QC) procedures applied by both Monitoring and Forecasting Centres (MFCs) and Thematic Assembly Centres (TACs), as well as the structure and content of any quality-related documentation that was produced. In order to consolidate these requirements, guidelines were developed in the early stages of the project to ensure that:

- presentation of quality information for all MyOcean products was consistent
- a consistent and high standard of validation and accuracy monitoring was implemented
- information given to users was a good indication of the quality of the products

Enforcing consistency in the style of the documentation and metrics presented allows users to browse the range of MyOcean products and understand the product quality information provided. By complying with the guidelines, production centres improve the standard of the documentation provided to users, and the familiarity of the presentation means that users can access multiple product documents and understand where to find relevant information.

Whilst contributing to the project assurance quality, and project management procedures for system evolution, the guidelines also specify the evidence which should be provided regarding the anticipated quality of the products when a production centre is proposing an upgrade to a product. Given the wide range of products and production methods, it is not always scientifically meaningful for all centres to provide exactly the same types of information, so the guidelines attempt to strike a balance between overall project consistency and scientific integrity.

The product quality guidelines also set out the appropriate metrics, content and format that are provided by each of the centres for the quarterly validation reports that are displayed to users through the MyOcean Services Portfolio - Validation Statistics.

The guidelines have been successfully implemented by each of the production centres, which has meant that the quarterly reporting process and the standard of user documentation has continued to improve as the course of MyOcean2 has evolved.

QUALITY INFORMATION DOCUMENTS

The evidence submitted to support a change to an existing product, or implementation of a new product, is done by means of a Quality Information Document (QuID). For every product in the MyOcean catalogue there is an associated QuID, which is available for download by all MyOcean users.

The QuIDs present the results of any validation performed on a MyOcean product, and the structure and content of the QuIDs are defined within the product quality guidelines. For simplicity, a summary table of statistics is provided at the beginning of each QuID, which highlights the estimated accuracy of the product. This allows users to quickly browse the document and obtain the relevant headline product quality information. Further in-depth evidence and analysis is provided later in the document, together with a detailed and scientific description of the production methods and system, as well as an overview of the validation methodology, for those users who require more detail. The summary estimates of the accuracy are known as Estimated Accuracy

FIGURE 2

Quality Information Documents (QuIDs) exist for every product in the catalogue..

Numbers (EANs), and the product quality guidelines specify the metrics, units, precision, regions and vertical layers that should be applied when generating these.

QUALITY ASSURANCE REVIEW GROUP

In order to enforce consistency and standards, as well as scientific credibility, the Quality Assurance Review Group (QuARG) was also initiated in the early stages of the MyOcean2 project. The role of QuARG is to verify that proposed changes to any product or information that is disseminated to users are at least equivalent, or preferably an improvement, to previously disseminated/released material.

The QuARG is made up of a number of subject experts from various European institutions, whose role is to review the scientific evidence in a proposed change to a product, and advise on whether the change is justified, credible and acceptable for implementation. This review process also includes an assessment of whether the product quality guidelines have been followed. If the evidence presented is unclear or incomplete, then the QuARG will highlight any issues, make suggestions for improvements, liaise with the authors in order to understand how results should be interpreted, and make recommendations for implementation. In order to maintain standards and consistency all change proposals, as documented by the QuIDs, are reviewed by at least two members of the QuARG.

For the second phase of the MyOcean project QuARG reviewed all of the product quality documentation submitted as part of the system evolution for each of the major upgrades: V3, V3.1, V4, V4.1 and V5, providing significant feedback and focusing on the consistency and clarity of the documents, as well as the validation methods implemented within production centres.

REPORTING ON THE ACCURACY OF MYOCEAN PRODUCTS

Following on from the successful implementation of the QuIDs, it was agreed by the work package partners that a simpler mechanism was required for highlighting the accuracy of MyOcean products to users than the downloading and browsing of large quantities of documentation. Moreover, QuIDs provide product quality at each upgrade and change of the production system: accuracy of products could slightly evolve on a daily basis, due to events and causes that do not imply revision of the production systems. In parallel, some production centres were already providing to users with real-time information of product quality on specific web pages. After debating the merits of various approaches, it was agreed to implement for the whole MyOcean2 system, a series of web pages to display product quality information, which would then be updated on a regular basis. The detailed information contained within the QuIDs, complemented and updated with regular information on the web pages, would offer a complete view of the product accuracy to users in near real time.

The work package partners agreed on a process for the production of the reports, whereby the appropriate metrics, descriptive text and format would be produced by each of the centres, following conventions laid out in the guidelines. These contributions would then be collated, converted to a graphical format, and displayed to users through the MyOcean central web portal. The statistics would then be updated on a quarterly basis, along with notes to explain how the statistics were calculated, as well as an explanation of any unusual behavior in the values.

FIGURE 3

The MyOcean Product Quality home page, available through the MyOcean Services Portfolio - ***Validation Statistics***. The top panel allows users to navigate among the listed MFC and TACs, the type of product (and ocean parameter) and the type of metrics (against insitu data, against satellite data etc.).

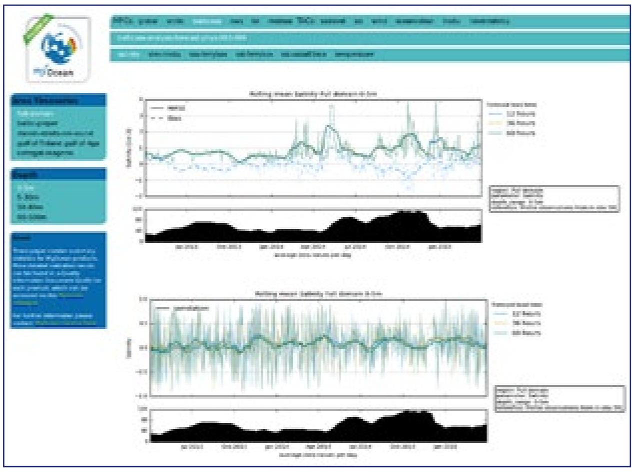


FIGURE 4

Time series plot (May 2013 to March 2015) showing summary statistics for salinity scores at 0-5m in the Baltic Sea, extracted from the MyOcean Product Quality home page. The name of the product is given in the top panel. Here are illustrated root-mean-square and mean differences against insitu observations (top figure) as well as correlation (bottom figure): forecasting skill is visualised with the superimposed scores for 12, 36 and 60-hours forecasts. The number of in-situ observations is given below each figure.

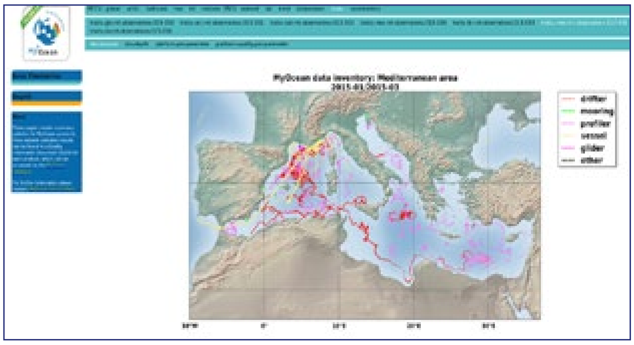


FIGURE 5

Additional information provided in the MyOcean Product Quality web server: a sample image provided by the insitu TAC for the Mediterranean area, showing the distribution and types of observations that are used in the product quality validation process.

The product quality web pages were formally released to the user community in April 2014, and users were encouraged to provide feedback via the MyOcean Collaborative Forum, which has a specific section to deal with product quality, as well as through the Local Service Desk. Ongoing interaction with the users will allow the validation process to continue to evolve over the lifecycle of the project in order to meet the needs of the MyOcean community.

RESEARCH ACTIVITIES INTO NEW METRICS APPLICATIONS

The second phase of the MyOcean project provided an opportunity to undertake research activities into the development and application of new user-oriented metrics, which could give more useful information on the quality of MyOcean products than the relatively simple metrics (such as rms errors and bias) that are commonly applied. Whilst useful in their own right, these simpler metrics can sometimes be of limited value in addressing timing or spatial errors, especially at higher model resolutions, or in capturing high impact or intense events. More sophisticated techniques, which have been successfully trialled and demonstrated in atmospheric science, have been applied to some of the products in the MyOcean archive to try and improve the validation information provided to both general MyOcean users and ocean modellers.

The research was carried out by three centres, and restricted to the following topics:

- Biogeochemistry-specific metrics (work done by OD Nature)
- Metrics for evaluating ocean currents using insitu observations (work done by Met Office)
- Quantifying consistency between MyOcean products using triple-collocation techniques (work done by Mercator Océan)

For both the biogeochemistry and ocean currents investigations the use and application of categorical metrics were trialled. As a first step, contingency tables are constructed based on the occurrence or non-occurrence of an event, and the event totals are entered into a 2x2 matrix (see Figure 6). From these contingency tables a number of categorical metrics can be derived. In a perfect system a and d would be maximised, whilst b and c would be zero – there may be cost implications for users if a false alarm (b) is raised, for example, unnecessarily implementing contingency plans or rescheduling operations, whilst a miss (c) can lead to damage to reputation and lack of user confidence in products if there is an inability to correctly forecast events, especially if it occurs a number of times.

Event Forecast	Event Observed		
	YES	NO	Marginal Total
YES	a	b	a + b
NO	c	d	c + d
Marginal Total	a + c	b + d	a + b + c + d

FIGURE 6

Standard contingency table showing Hits (a), False Alarms (b), Misses (c) and Correct Rejections (d).

For biogeochemical products the Hanssen Kuippers Discriminant (Hanssen and Kuipers, 1965) was assessed:

Hanssen Kuippers Discriminant (HKD) = (a/a+c) – (b/b+d)

The score measures the ability of the forecast to distinguish between occurrences and non-occurrences of an event, and can be used to determine whether too many false alarms are incurred by over forecasting an event. It has a range between -1 and 1, where 1 denotes a perfect score and -1 indicates that there is no skill.

For the ocean currents a number of categorical metrics were assessed, including the Critical Success Index (CSI) and the Equitable Threat Score (ETS):

Critical Success Index (CSI) = a / (a+b+c)

*Equitable Threat Score (ETS) = ((a*d)-(b*c)) / ((b+c)(a+b+c+d)+((a*d)-(b*c)))*

The CSI measures how well the forecast 'yes' events correspond to the observed 'yes' events, whilst the ETS is a skill corrected version of the CSI and removes the number of hits expected by chance from the recorded hits. The CSI has a range between 0 and 1, where 1 denotes a perfect score and 0 no skill, whilst the ETS ranges from -1/3 to 1.

Additionally, in an attempt to quantify the skill in predicting rare or extreme current events, multi-category contingency tables were constructed and the Gerrity Skill Score (Gerrity, 1992) was assessed. The Gerrity Skill Score (GSS) measures the accuracy of the forecast in predicting the correct observation category, relative to that of random chance. It does not reward conservative forecasting, but rewards forecasts for correctly predicting rare events. Through the use of a weighted scoring matrix it allows small errors to be penalised less than larger forecast errors. It has a range between -1 and 1, where 1 denotes a perfect score and -1 indicates there is no skill.

In practice, these four metrics are derived for different given values, or thresholds, in the possible range of an ocean parameter, from which the contingency tables are constructed after a series of forecasts.

Neighbourhood validation techniques (which are a subset of the wider spatial validation methods that have gained in popularity in the atmospheric science community over recent years) were also assessed for both chlorophyll and ocean currents, in an attempt to analyse spatial and temporal scale performance. These neighbourhood techniques are a departure from traditional validation approaches, which commonly rely on extracting the nearest grid point or using bilinear interpolation in order to produce a matched forecast/observation pair. Instead, the neighbourhood validation methods compare single observations to a forecast region around the observation location, as illustrated in Figure 7.

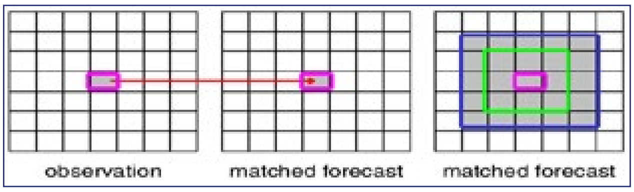


FIGURE 7

Schematic diagram showing how an observation can be matched with a single forecast cell, or with a neighbourhood region consisting of multiple cells. In this example the forecast neighbourhood expands from a standard 1x1 grid cell to 3x3 and then 5x5.

The neighbourhood techniques are particularly suited to dealing with the 'double penalty problem' which can occur when validating higher resolution models, and manifests itself by penalising forecasts that are slightly offset with regards to the observation (in either timing or location) as severely as forecasts that are significantly offset. This is typically the case when the shape or intensity of an eddy is correctly simulated, but forecast with some time lag, or not at the exact correct location: closeness is not rewarded using traditional validation techniques.

BIOGEOCHEMISTRY-SPECIFIC METRICS

Numerous intermediate and end-users of MyOcean products are interested in specific, extreme events such as algal blooms, eutrophication and hypoxia. Events are usually characterised by unknown onset, sharp gradients and consequently abnormal values, hampering the use of traditional metrics which have a tendency to strongly penalise small errors in the timing and location of the events.

In this study the forecasting of chla was assessed, since it is typically well measured with satellite data, so both the model data and the observations are well sampled. Three different biogeochemistry models were tested. The first model was the NWS MFC FOAM ERSEM model applied to the southern bight of the North Sea. The second model was the MED MFC OPATM-BFM developed for the Mediterranean Sea, and the third model, ERGOM, is the biogeochemical component of the BAL MFC operated in the region of the Baltic Sea. The skill of each model was assessed through comparisons of surface chlorophyll data with satellite observations.

North Sea:

- May 1st 2011 to April 30th 2012,
- Geographical coverage: 5°W to 5°E and 50°N to 55°N,
- Temporal resolution: 1 day.
- Model data: Forecasting Ocean Assimilation Model 7km Atlantic Margin model (FOAM AMM7). A detailed description is given in CMEMS-NWS-QUID-004-001-002 which is available from the MyOcean web portal.

Mediterranean Sea:

- April 1st 2007 to December 30th 2009,
- Geographical coverage is 6°W to 37°E and 30°N to 46°N
- Temporal resolution: weekly
- Model data: The OPATM-BFM model system, the configuration is described in CMEMS-MED-QUID-006-006, available from the MyOcean web portal

Baltic Sea:

- May 2014. Due to cloudiness and short daylight hours during winter, there are less satellite observations available for this region.
- Geographical coverage: 9°E to 13°E and 53°N to 63°N
- Temporal resolution: daily.
- Model data: The Baltic Sea biogeochemical model (DMI-ERGOM) product is based on simulations with the biogeochemical model ERGOM one way coupled to the Baltic 3D ocean model HBM (HIROMB-BOOS Model), that provides the MyOcean Baltic physical ocean product. The configuration is described in CMEMS-BAL-QUID-003-007, available from the MyOcean web portal, and the model is detailed in Neumann (2000, 2002).

Forecasts of chlorophyll from MyOcean biogeochemistry models were compared against satellite products, and were assessed using decision based skill metrics. A number of exceedance thresholds of interest were tested using categorical metrics. The Hanssen-Kuippers Discriminant was used to evaluate the decision based skill metrics, and a neighborhood method was applied in order to take into account forecasting delays (see Figure 8). To ensure that the evaluation of the neighbouring method was not biased by model or area specific anomalies, each of the three different domains were tested.

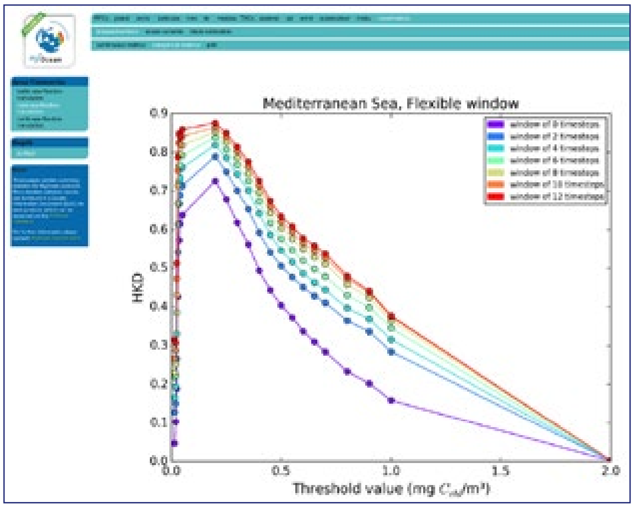


FIGURE 8

An illustration of how the Hanssen-Kuippers Discriminant varies with increasing threshold and neighbourhood values. This example is also extracted from the MyOcean Product Quality web pages, considering the Mediterranean Sea chla forecasts: HKD are given for different thresholds. Here scores are "good" for threshold values above 0.5 mg/m3.

The application of the Hanssen Kuippers Discriminant technique in this study has shown that it is able to detect systemic time lags of the model forecasts. It has also shown that expanding the time frame of the model does not necessarily lead to a huge improvement of the model skill, so the technique is not a means to improve the model performance in an unjustified way.

In the assessments discussed above a single constant threshold value was used for the whole domain, statistics were calculated, and then the threshold was increased, and so on. An alternative approach was to use the p90(x,y) value, which is a variable threshold value and is determined as the 90th percentile value of all the data measured at a fixed point. A chlorophyll measurement at (x,y) above the threshold p90(x,y) can be interpreted as a bloom event if certain other conditions are met (for example, if the p90 at (x,y) or in the neighbourhood of (x,y) should be exceeded for several consecutive days). This value can be of interest to end users interested in bloom events.

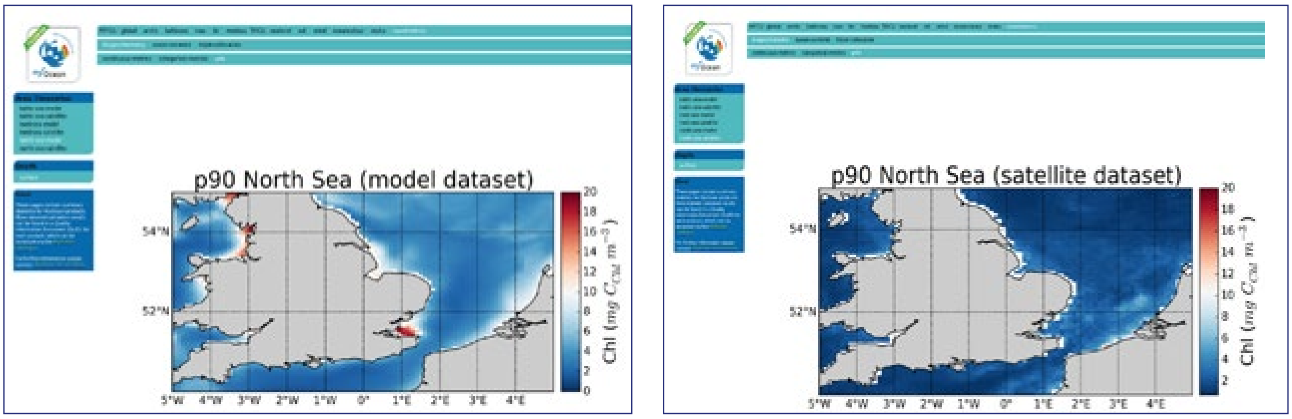


FIGURE 9

Also extracted from the MyOcean Product Quality web server: a p90 representation for the NWS MFC North Sea model and OC TAC satellite data. Simulated chla fields exhibit large values close to the English coasts that do not appear in the satellite product: either the model is erroneous or the satellite imagery cannot correctly capture chla variability near the coast.

By comparing the p90 model and corresponding p90 satellite data (Figure 9) it is possible to determine the over- or under-forecasting of chlorophyll by the model.

METRICS FOR EVALUATING OCEAN CURRENTS USING INSITU OBSERVATIONS

Surface currents are important physical fields which are closely monitored by commercial and naval stakeholders. They are key parameters for oil spills and other pollution forecasts, search and rescue support activities, and many other applications that may deal with urgent and catastrophic events. An important aspect of ocean currents is whether their speed will exceed a certain value, or if the current speed will remain below a given threshold for a specified period of time. These aspects can be assessed from a site-specific, threshold exceedance viewpoint, utilising categorical metrics. In the study reported here attention is focused on a site specific model-observation comparison of surface ocean currents, a parameter for which validation is relatively sparse in MyOcean. The results presented here focus on the IBI (Iberian-Biscay-Irish) region, as this region's MFC has the greatest number of moored buoys equipped with current meters available for assessment.

Iberia-Biscay-Ireland:

- January 1st 2012 to December 31st 2014,
- Geographical coverage: 19°W to 5°E and 26°N to 56°N,
- Temporal resolution: Hourly.
- Model data: Statistics are computed from the IBI physical forecast product data (
- Atlantic-Iberian Biscay Irish- Ocean Physics Analysis and Forecast) and available site specific observations in the same region (Atlantic Iberian Biscay Irish Ocean- In-Situ Near Real Time Observations), both of which are available from the MyOcean web portal.

Continuous statistics were used as the initial starting point of the investigations. These were chosen as they are intuitive and simple to understand, and provide a basic description of how the modelled and observed currents behave. The spatial accuracy of small-scale features and the timing of events are not explicitly assessed within the context of continuous statistics.

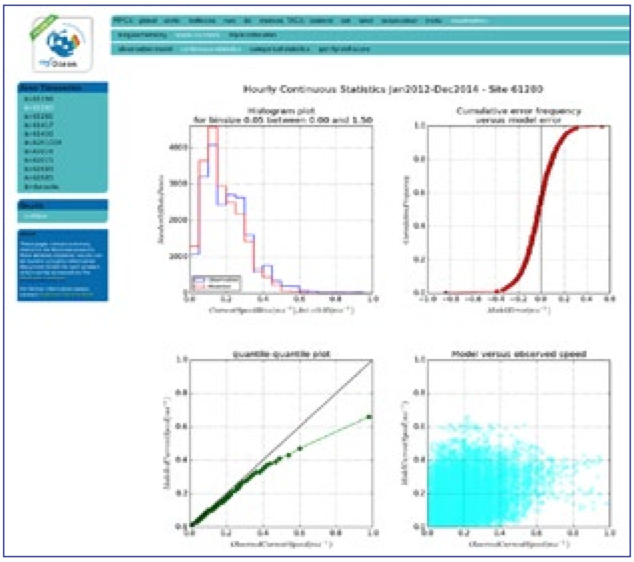


FIGURE 10

Also extracted from the MyOcean Product Quality web server: a selection of continuous statistics used to describe the modelled currents. Here using hourly currents measured by a Puertos Del Estado buoy located near Tarragona 40°41,04'N/1°28,10'E from January 2012 to December 2014. Beginning top-left and reading left to right: Histogram distribution of modelled (red) and observed (blue) currents; Cumulative error frequency; Quantile-Quantile plot (1% bins); and model versus observed current speed scatter plot.

The selection of continuous statistics include measures to interpret the underlying distribution of the modelled dataset, that is, to show whether the model under- or over-represents the current speed, in particular through the use of the quantile-quantile and scatter plots. The histogram and cumulative frequency plots show if there is a consistent bias in the whole current distribution or at certain values. It can be seen from Figure 10 that the modelled currents at this location do not exhibit a Gaussian distribution, are generally under represented by the IBI forecasting system, and that this under representation deteriorates with increased current speed.

In addition to traditional continuous statistics, categorical metrics were used to assess the skill of the model in forecasting the exceedance of certain thresholds, focusing particularly on metrics which are familiar to users of wind and wave forecasts: hits, false alarms, critical success index (CSI) and the equitable threat score (ETS).

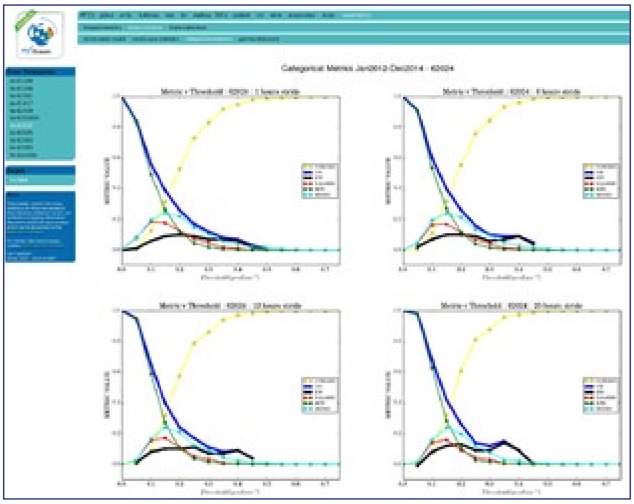


FIGURE 11

Also extracted from the MyOcean Product Quality web server: categorical metric scores as current threshold speed increases, using hourly currents measured by a Puertos Del Estado buoy located near Bilbao 43°37,8'N/ 3°2,4'W from January 2012 to December 2014.

A plot of spatially coordinated modelled and observed currents in terms of common categorical metrics is displayed in Figure 11. It can be seen that the CSI (dark blue curves) and ETS (black curves) metrics are quite poor in terms of their magnitude (~0.1) as well as quickly saturating out to their numerical limits at relatively low current threshold speeds. However, if the metrics are calculated with a coarser dataset these scores can be marginally improved, for example, by temporally averaging the modelled and observed currents over a number of hours or days.

Many of the simpler categorical statistics require the input data to have the bias removed before the categorical statistics are calculated. This raises uncertainties on how best to achieve this, as well as over what 'typical period' a bias for ocean currents should be calculated. To overcome this issue a less exacting score has been investigated, the Gerrity Skill Score (GSS, Gerrity 1992). The score has various desirable attributes (such as being equitable or non-hedgeable, large rewards for rare events, and larger penalties for larger errors), and is also a refinement of the binary category approach used for the simpler categorical statistics, by allowing multiple categories to be assessed. The GSS assesses the skill of the chosen field over climatology. A number of perturbations around the GSS were also investigated through the use of neighbourhood techniques, such as varying the number of modelled grid cells taken into account when comparing against the observed value, as well as shifting model values forward or back in time in order to see if the model captures an event too early or too late (Figure 12).

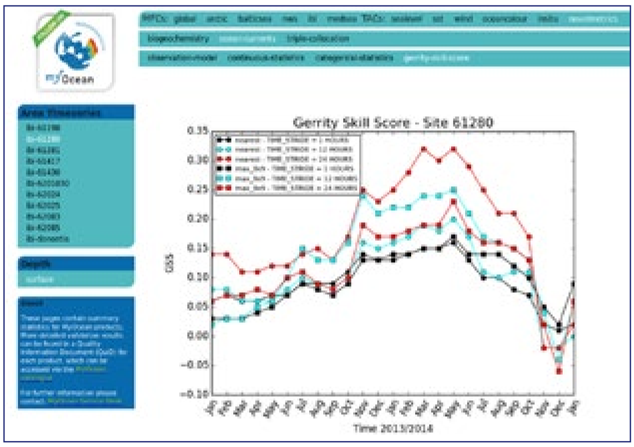


FIGURE 12

Also extracted from the MyOcean Product Quality web server: evolution of the Gerrity Skill Score using a 12-month running meaning period. Same moored data used as in figure 10. Different curves derived from using the neighbourhood technique.

The assessments presented above demonstrate that the modelled currents do not compare favorably when temporally coordinated at an hourly frequency, though this may be due to the model, even at 1/36° resolution, being unable to fully resolve the dynamical processes close to the coast. The modelled currents show some skill when both the modelled and observed currents are coarsened temporally. The level to which the data is coarsened is not known beforehand, therefore an overall measure is needed and hence why the GSS was explored. The GSSs conveniently reflect what can be deduced from the continuous statistics and the simpler categorical metrics. Where the model has a good representation of the current distribution (deduced from quantile-quantile plots or histogram distributions), as well as an accurate representation of the phase of the current cycle, e.g. demonstrates a good tidal signal, the GSS is higher relative to those that are out of phase or do not have a good current distribution or climatology. The GSS is a supplemental score to the other statistical metrics mentioned, and could prove to be a useful summary metric of the forecast system.

With regards to skill, the initial conclusions are that for forecasts with hourly resolution the skill is significantly lower than typical wind and wave forecasts. This result is not specific to the IBI model, and is consistent with comparisons which have been made against other models in different regions. Assessing forecasts with lower temporal resolution (e.g. daily) indicates that skill increases with decreasing temporal resolution, at least up to frequencies of 1 week. The next steps are to better understand which processes are affecting the skill on differing timescales, and to explore more flexible use of time and space windows in constructing the site-specific forecast.

QUANTIFYING CONSISTENCY BETWEEN MYOCEAN PRODUCTS USING TRIPLE-COLLOCATION TECHNIQUES

Many intermediate users will use MyOcean products to provide site-specific forecast products at bespoke locations. To engage these intermediate users, it is critical to be able to provide an advance indication of how the skill of MyOcean products varies for different parameters, regions, and forecast lead-times. In some regions MyOcean users have access to more than one product for a given parameter, for example, MFC products have overlapping domains, as do some TAC products, and for some parameters like SST or Sea Level, both MFCs and TACs can provide useful products. If a user moves from one product region to another, or is providing a service which spans the boundary between products, it is important that they are aware of the degree of consistency between these products.

Triple-collocation is a method used to characterise systematic biases and random errors in different data sets of the same geophysical field (at least three data sets; typically insitu measurements, satellite observations and model fields). It has already been applied to wind measurements (e.g., Stoffelen, 1998), wave heights (e.g., Janssen et al., 2007), and sea surface temperature (e.g., O'Carroll et al., 2008). The method also provides the relative linear calibration (scaling) of the three systems, and can be applied to various geophysical fields. In this assessment the satellite observations (sub-skin SST) are collocalised in space and time at the locations of the insitu measurements (temperature 20-30cm beneath the surface). The models forecasts (daily average of the first layer of the forecast of the day) are collocalised in space at the locations of the insitu measurements. If an in situ device gives several measurements per day only one is kept.

The data used within this study was obtained from the MyOcean product catalogue. The modelled sea surface temperature was extracted from a number of models, here the first day forecast (in order to offer independency with available observations), and compared against insitu drifting buoys and AVHRR METOP-A satellite data.

Various models (IBI_ANALYSIS_FORECAST_PHYS_005_001_b, GLOBAL_ANALYSIS_FORECAST_PHYS_001_002, NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_001_b) and one Insitu data product (INSITU_IBI_NRT_OBSERVATIONS_013_033) are used in order to extract the modelled Sea Surface Temperature over a common area:

January 1st 2014 to December 31st 2014,

Geographical coverage: 20°W to 13°E and 40°N to 65°N,

Temporal resolution: Daily.

Model data: IBI_ANALYSIS_FORECAST_PHYS_005_001_b, GLOBAL_ANALYSIS_FORECAST_PHYS_001_002, NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_001_b, INSITU_IBI_NRT_OBSERVATIONS_013_033.

With 5 datasets, 10 combinations of 3 datasets ("triplets") are possible:

- In-situ, satellite, GLO
- In-situ, satellite, IBI
- In-situ, satellite, NWS
- In-situ, GLO, IBI
- In-situ, GLO, NWS

- In-situ, IBI, NWS
- Satellite, GLO, IBI
- Satellite, GLO, NWS
- Satellite, IBI, NWS
- GLO, IBI, NWS

Each combination gives an estimate of the error of the three datasets, as illustrated in Figure 13.

Several applications of the method have been tested with MyOcean products of Sea Surface Temperature. The method requires having a long time period in order to gather enough data; therefore it is more suited to delayed time studies. Because of data assimilation in operational systems, and even though first day forecast are used here, the data sets compared are not independent. Moreover the data sets do not represent the same space and time scales, and there is a representativeness error which is difficult to handle. For example the satellite measures the sub-skin temperature, while the models give the average temperature of the surface layer, and the drifters measure the temperature in the first dozen of centimeter beneath the surface. The last triplet in figure 13 illustrates that the three compared operational systems (NWS, IBI and GLO) are rather consistent, while the first three triplets compared show that whichever model is used, in situ and satellite SST estimates exhibit similar level of discrepancies. Therefore the error variances obtained are not obvious to interpret, and the method must be seen as a complement to other statistical methods.

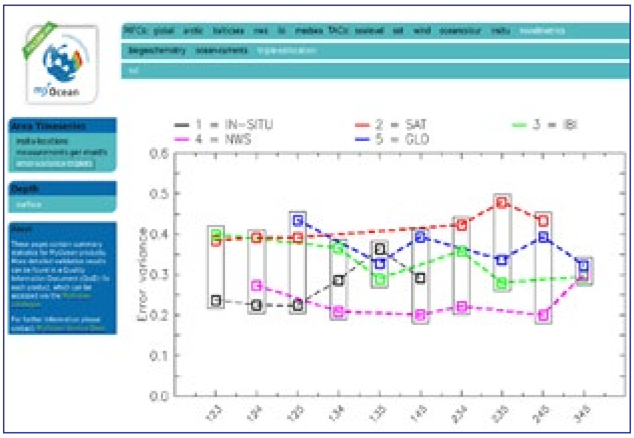


FIGURE 13

Also extracted from the MyOcean Product Quality web server: variance of the error for the 10 possible dataset combinations. Statistics are computed over 2014 in the North-West-Shelf area.

CONCLUDING REMARKS

The product quality activity started from square one, and was organised as an efficient activity at production centre level, as a transverse activity among calibration/validation experts involved in MyOcean, and as a top-to-bottom project management guidance activity. It allowed a European community of experts to offer valuable scientific outcomes and contributions at an international level, in particular in GODAE OceanView.

It allowed a European community of experts to offer valuable scientific outcomes and contributions at an international level, in particular in GODAE OceanView.

The product quality activity is considered as a key success from the European commission, dealing with both state-of-the art expertise and user oriented requirements, and offering, quite uniquely in the world of geoscience forecasting centres, full visibility and transparency in near real time product quality assessments.

In summary, the product quality calibration/validation activity described above is an essential part of the Copernicus Marine Service, taking the MyOcean structure as an inescapable heritage, and trying to unify the existing European community of experts, in order to keep carrying forward innovative developments in the field.The SST data assimilation has improved the forecast skill of the model without marked disruption of the 3D structure of the water column. The new system is undergoing extensive validation tests and is running pre-operationally at the Met Office to ensure the system's robustness before full operational implementation. In addition to the physical system described here, the ecosystem component ERSEM

ACKNOWLEDGEMENTS

The authors would like to thank the many TAC and MFC partners within the Product Quality work package that contributed and participated in the project and made it such a successful activity.

REFERENCES

Crosnier, L., and C. Le Provost, 2007. *Inter-comparing five forecast operational systems in the North Atlantic and Mediterranean basins:* The MERSEA-strand1 Methodology, J. Mar. Sys., 65 (1-4), 354-375, 10.1016/j.jmarsys.2005.01.003.

Hanssen, A. W., and W. J. A. Kuipers, 1965. *On the relationship between the frequency of rain and various meteorological parameters.* Meded. Verh.,81, 2–15.

Hernandez, F., L. Bertino, G.B. Brassington, E.P. Chassignet, J.A. Cummings, F. Davidson, M. Drévillon, G. Garric, M. Kamachi, J.-M. Lellouche, R. Mahdon, M.J. Martin, A. Ratsimandresy, and C. Regnier, 2009. *Validation and intercomparison studies within GODAE*, Oceanography Magazine, 22 (3), 128-143, http://dx.doi.org/10.5670/oceanog.2009.71.

Hernandez, F., E.W. Blockley, G.B. Brassington, F. Davidson, P. Divakaran, M. Drévillon, Y. Fujii, M. Garcia Sotillo, P.J. Hogan, S. Ishizaki, P. Lagemaa, B. Levier, M. Martin, M. Avichal, C. Mooers, N. Ferry, A.G. Ryan, C. Regnier, A. Sellar, G.C. Smith, T. Spindler, G. Volpe, J.L. Wilkin, E.D. Zaron, and A. Zhang, 2015. *Performance evaluations, near real-time assessment of operational oceanography products*, Journal of Operational Oceanography.

Gerrity, J.P., 1992. *A Note on Gandin and Murphy's Equitable Skill Score*. Monthly Weather Review, 120, 2709-2712.

Janssen, P. A. E. M., Abdalla, S., Hersbach, H., and Bidlot, J. R. (2007). *Error Estimation of Buoy, Satellite, and Model Wave Height Data*. Journal of Atmospheric and Oceanic Technology, 24(9):1665-1677.

Neumann, 2000. *Towards a 3d-ecosystem model of the Baltic Sea.* J. Mar. Syst. 25, 405–419.

Neumann et al. 2002. *Experimental simulations with an ecosystem model of the Baltic Sea: a nutrient load reduction experiment. Glob.* Biogeochem. Cycles 16, 7(1)-7(19).

O'Carroll, A. G., Eyre, J. R., and Saunders, R. W. (2008). *Three-Way Error Analysis between AATSR, AMSR-E, and In Situ Sea Surface Temperature Observations.* J. Atmos. Oceanic Technol., 25(7):1197-1207.

Stoffelen, A. (1998). *Toward the true near-surface wind speed: Error modeling and calibration using triple collocation.* Journal of Geophysical Research: Oceans, 103(C4):7755-7766.

NOTEBOOK

ARTICLES

CONTACT

Please send us your comments to the following e-mail address:
webmaster@mercator-ocean.fr

EDITORIAL BOARD

Laurence Crosnier

DESIGN

Atelier JamJam
www.atelierjamjam.com

DTP OPERATOR

Sandrine Villamot
0(33) 619.843.833
sandrine.villamot@gmail.com