Mercator Ocean is the French center for analysis and forecasting of the global ocean, i.e. a service provider of ocean information in real and delayed time. The company is located in South-West France near Toulouse.

Mercator Ocean is a privately-owned non-profit company, funded by five major French institutions involved in operational oceanography, our privileged user: CNRS (National Center of Scientific Research), Ifremer (French Research Institute for Exploitation of the Sea), IRD (Institute of Research for Development), Météo-France and SHOM (Hydrographic and Oceanographic Service of the French Navy). Mercator Ocean Director General is Pierre Bahurel. He was MyOcean projects coordinator for 6 years.

After having successfully coordinated the European MyOcean projects since 2009, Mercator Ocean was officially appointed by the European Commission on 11 November, 2014 to implement and operate the "Copernicus Marine Environment Monitoring Service", as part of the European Earth observation programme, Copernicus (formerly named GMES, for Global Monitoring for Environment and Security).

The digital systems and the global models (of all the oceans of the Earth) developed by Mercator Ocean are able to describe the physical and biogeochemical states of the ocean at any time, above and beneath the surface, on the scale of the globe or of a region of the globe: Temperature, salinity, currents, sea surface height, thickness of ice, chlorophyll, nutrients... Mercator Ocean ensures the production and evolution of the Global Analysis and Forecast product in the CMEMS catalogue.

The European Union delegates to Mercator Ocean the role and responsibility of managing the EU budget for delivering the COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE (CMEMS) on its current multi-annual financial framework 2014-2020.

Mercator Ocean manages on behalf of the European Union and report to the European Commission. Mercator Ocean organizes the design, development and operations of the service with its own skills and the support of contractors duly selected through open competition.

The new missions assigned to Mercator Ocean by the European Union will be undertaken through comprehensive, open and transparent networking, by entrusting the development of services to expert partners from all backgrounds: the private sector, research institutions or public service operators.

The delegation agreement between the European Union, represented by the European Commission, and Mercator Ocean for setting-up the CMEMS, led and will lead Mercator Ocean to issue a range of calls for tender to create the necessary strong network of partners.

The CMEMS encompasses two major Framework Service Elements which will power the Copernicus Marine Service developments: User Uptake (addressing downstream services) and Service Evolution (addressing the scientific progress of the Service). The MyOcean demonstration phase enabled to open the service on a pre-operational mode during 6years. From May 2015, your Copernicus Marine Environment Monitoring Service (CMEMS) is working on an operational mode.

- A unique European Marine capability and core-knowledge base

Marine data is an engine for “smart and sustainable growth” in the European Union, as stated in the recent Marine Knowledge 2020 EC Communication. The Copernicus Marine Service has been
designed to respond to issues emerging in the environmental, business and scientific sectors. Using information from both satellite and in situ observations, it provides state-of-the-art analyses and forecasts daily, which offer an unprecedented capability to observe, understand and anticipate marine environment events.

- **A catalogue of services meeting users requirements**

The CMEMS provides regular and systematic core reference information on the state of the physical oceans and regional seas. The observations and forecasts produced by the service support all marine applications.

The CMEMS is driven by quality and simplicity: quality of the ocean information provided to users, and simplicity of the access to information.

The service is meant for any user requesting generic information on the ocean, and especially downstream service providers who use this information as an input to their own value-added services to end-users. The CMEMS can be defined as:

1. An integrated Service
2. An Open and Free service
3. Providing access to a single Catalogue of products
4. A reliable service
5. A sustainable service
6. Serving many areas of benefits

Both Public and Private users need response to today’s climate and marine challenges. The CMEMS supports and contributes to the data and information tools for many domains:

- Improving knowledge of the seas and oceans is one of the three cross-cutting tools of the EU’s Integrated Maritime Policy. A good knowledge of the environmental status of the marine waters is necessary, in accordance with the Marine Strategy Framework Directive (MSFD), currently prepared by Member states with the support of the European Environment agency (EEA). In a general way, CMEMS brings support to European and Regional decision makers implied in European policies linked to the Marine Environment and Security (EC Diretorate, European Agencies, Regional Conventions)

- Member states' National Agencies and public bodies also rely on CMEMS for their own regional service provision, related to Pollution combat and Monitoring, Coastal Environment, Water Quality, Maritime Safety, Renewable Energies, Offshore activities...

- The CMEMS delivers a core information service to any user related to 4 areas of benefits be they service providers or end-users from the commercial sector or from the R&D sector: Maritime Safety, Coastal and Marine Environment, Marine Resources, and Weather, Seasonal Forecasting and Climate activities

1. **Input data**

Mercator Océan relies on existing observational data assembly centers to collect, to process and to validate its input data. Real time and delayed mode observations are used for data assimilation and for analysis / forecast validation and verification (CAL/VAL) and include:

- **Altimetry** (SSALTO /DUACS product from AVISO data center, disseminated through CMEMS): Along-track and inter-calibrated sea level anomalies from all available satellite for the reprocessing observation period and Jason-2 & Jason-3, Cryosat, SARAL and HY2, weekly retrieval; Mean Dynamic Topography (also called Mean-Sea-Surface-Height) combining gravity (CHAMP, GRACE) measurements, and altimeter and in situ data (Rio et al., 2011, CNES-CLS09).
- **In-situ temperature and salinity data** (from CORIOLIS center, disseminated through CMEMS): ARGO profiling floats, XBT, CTD, TAO-TRITON/PIRATA/ARAMA, surface drifters; weekly retrieval; off line quality control at CORIOLIS and CLS. The CORA data base is also used for delayed time production.
- **Sea Surface Temperature**: Global NCEP/RTG 0.5° and OSTIA CMEMS SST product for operational assimilation; Reynolds 0.25° AVHRR-only SST product for reanalyses; OSTIA CMEMS sea surface temperature product, Eumetsat / Météo-France SAF Ocean&Ice Atlantic high resolution SST product (10 km, daily) for routine validation.
- **Forcing data**: 3-hour analyses and forecast from ECMWF for operational forcing / ERA-Interim for reanalysis forcing; GEWEX and GPCP heat and fresh water flux products are used to correct ECMWF forcing during GLORYS reanalysis computation.
- **Surface velocity**, from the Global Drifter Program, collected and processed by the CORIOLIS center.
- **Sea level** from tide gauges: GLOSS, SHOM and ESEOO database, processed and corrected at CLS.
- **Sea ice concentration and drift** from CERSAT (Ifremer) for GLORYS reanalysis and CMEMS product for the near real time global system.
- **Ocean Colour chlorophyll products** from AQUA/MODIS distributed by ACRI and the global L3 products from CMEMS 2.

2. Data serving

Dissemination of MERCATOR products (products@mercator-ocean.fr) is made through www, Opendap, FTP tools and hard disk drives both for real-time and delayed-time and reanalyses. Specific procedures are set up for operational users requesting secured links. Mercator Océan also contributes to CMEMS (http://marine.copernicus.eu) by providing ocean reanalyses, analyses and forecasts at the global scale and regional scale for both ocean physical and biogeochemical parameters.

3. Models

Mercator Océan uses the NEMO z-coordinate primitive equation ocean code (Madec, 2008). It is coupled with the LIM2 and LIM3 Sea Ice Model from Louvain La Neuve with elastic-viscous-plastic rheology. The model system is also coupled with biogeochemical models (e.g. PISCES). Modelisation studies at global and regional scale are in the continuity of the previous year with specific focus in 2016 on i) coarsening of the physics to constrain biogeochemical model with a coarsed resolution ii) transition of the configuration toward new version of NEMO model and use of the orca extended grid, iii) LIM3 sea ice model with multi category sea ice model and impact on sea ice thickness distribution iv) tide and pressure forcing in global ocean configuration using vvl option v) use of AGRIF two way nesting approach and vi) hybrid vertical coordinates

The Mercator Océan modelling team is committed in the development and maintenance of the reference NEMO ocean code, in 2016 the main work concerns the NEMO configuration manager, compatibility of AGRIF with the time splitting implementation and the hybrid vertical coordinate.

4. Assimilation method

Mercator Océan is developing a suite of assimilation tools (called "SAM" for Mercator Assimilation System) of increasing complexity. The data assimilation method currently used (SAM-2) relies on a reduced-order Kalman filter based on the Singular Evolutive Extended Kalman Filter (SEEK) formulation introduced by Pham et al. (1998). For the physical component of the ocean forecasting system, the SAM-2 version is used to assimilate altimetry, sea surface temperature, vertical
temperature and salinity in situ profiles and more recently sea ice concentration in a fully multivariate manner using multivariate 3D error modes for the background error covariance matrix (Brasseur et al., 2005). It includes an adaptative error and a localization algorithm. It has been successfully implemented in all physical operational systems and is used since April 2007 (Lellouche et al., 2013). In parallel to SAM-2, a 3D-VAR bias correction algorithm for temperature and salinity is currently used in operational forecasting systems and in GLORIES, IBIRYS and MEDRYS reanalyses (see section 6 for the description of the systems and reanalyses). The objective is to correct the slowly varying large scale temperature and salinity forecast errors due to models shortcomings (lack of resolution, missing physical parameterizations, surface forcing errors...).

This assimilation system is still under development and the main ongoing work concerns i) tuning of the observation error in the assimilation scheme, this development has been realized and implemented in the operational system in 2016 ii) the anamorphosis transformation useful to assimilate some non Gaussian variables, iii) a 4D approach in the computation of the error covariance, iv) ensemble approach in the assimilation scheme.

5. Assimilation products and dissemination

The Mercator Océan system provides a full 3D depiction of the ocean dynamics and thermohaline circulation (T, S, currents, sea surface height, mixed layer depth...), with a high priority given to eddies. In association, the biogeochemical content of the ocean (Chl concentration, primary production, carbon, dissolved oxygen, nitrate, phosphate content) is also provided in near real time.

Information is available on a near-real-time and routine basis, by providing weekly Near-Real-Time Analysis and 2-week Forecasts; and on a Reanalysis mode (2 weeks behind real time), with data assimilation. For biogeochemical products, a one week forecast is delivered in NRT.

Each weekly ocean bulletins provides:

- Near-real-time ocean nowcasts and forecasts issued from routine assimilation and modelling runs
- Input data assessments and analysis (comparison & combination of data sets before assimilation)
- A set of predefined maps and 3D files giving a complete depiction of the ocean (http://bulletin.mercator-ocean.fr/html/welcome_en.jsp)
- Technical information on the ocean forecasting systems, including monitoring of the system and measurement of the timeliness.

The PSY2V4, PSY3V3 and PSY4V2/V3 systems (see section 6 for the description of the systems) are also producing 7-day forecasts updated every day (i.e. using updated analysed and forecast surface atmospheric fields). IBI36 system performs 5-day forecasts updated on a daily basis. BIOMER4 system performs 7-day forecasts updated on a weekly basis.

A quarterly newsletter is edited since 2001 which highlight scientific advances at Mercator Océan, and results obtained by the ocean science community using operational oceanography products. A quarterly validation bulletin (Quo Va Dis?) is published since 2010 which gives up-to-date Mercator Océan system validation results. The different issues are available on http://www.mercator-ocean.fr/eng/actualites-agenda/newsletter and http://www.mercator-ocean.fr/eng/science/Qualification-validation2. They give a good overview of the system products validation activity.

Products are gridded data (native model grid or interpolated standard projection grid) covering 1980 up to now period. Forecasts are served in real-time through Opendap, FTP and through CMEMS portal (http://marine.copernicus.eu/web/69-interactive-catalogue.php). Analysis/reanalysis products are served on FTP or hard drives depending of the volume. Mercator Océan products are freely available for Research and Educational applications. A service desk provides user support via a single point of contact: products@mercator-ocean.fr.

6. Systems

Six operational analysis and forecasting systems are currently operated in real time at Mercator Océan:

- PSY4V2 and V3 is a global high resolution system (1/12° horizontal resolution, 50 vertical levels, implicit free surface); This system focuses on mesoscale processes and provides high resolution boundary conditions to regional / costal models.
PSY3V3 is a global middle resolution system (1/4° horizontal resolution, 50 vertical levels, implicit free surface).

PSY2V4 is a basin high resolution system (1/12° horizontal resolution, 50 vertical levels, implicit free surface) covering North Atlantic and Mediterranean sea; this configuration focuses on mesoscale processes and links with coastal modeling in European seas.

PSY2G3 is a global coarse resolution configuration (1° horizontal resolution, 0.3° near the Equator, 42 vertical levels, implicit free surface) covering the global ocean; this configuration aims at providing the best ocean initial conditions for coupled seasonal forecasts done at Météo-France. The coupled seasonal forecasts are also used in the context of EURO SIP project (ECMWF).

IB36V4 is a regional high resolution (1/36°) configuration along the French-Portuguese-Spanish coast of the Eastern-North Atlantic (Iberian Biscay Irish seas). It has an explicit free surface and takes into account the dynamics of the tides. The objective is to provide analyses and forecasts at very high resolution to coastal models (i.e. boundary conditions). This system is operational since June 2011.

BIOMER4V1 is the 1/4° resolution global ocean bio geochemical analysis system. It is based on PISCES bio geochemical model off line coupled to PSY3V3 operational system. It follows the real time and produces one week forecast.

The high resolution global analysis and forecasting system PSY4V3R1 uses version 3.1 of NEMO ocean model (Madec et al., 2008). The physical configuration is based on the tripolar ORCA grid type (Madec and Imbard, 1996) with a horizontal resolution of 9 km at the equator, 7 km at Cape Hatteras (mid-latitudes) and 2 km toward the Ross and Weddell seas. The 50-level vertical discretization retained for this system has 1 m resolution at the surface decreasing to 450 m at the bottom, and 22 levels within the upper 100 m. “Partial cells” parameterization (Adcroft et al., 1997) is chosen for a better representation of the topographic floor (Barnier et al., 2006) and the momentum advection term is computed with the energy and enstrophy conserving scheme proposed by Arakawa and Lamb (1981). The advection of the tracers (temperature and salinity) is computed with a total variance diminishing (TVD) advection scheme (Lévy et al., 2001; Cravatte et al., 2007). The high frequency gravity waves are filtered out by a free surface (Roullet and Madec, 2000). A laplacian lateral isopycnal diffusion on tracers and a horizontal biharmonic viscosity for momentum are used. In addition, the vertical mixing is parameterized according to a turbulent closure model (order 1.5) adapted by Blanke and Delecluse (1993), the lateral friction condition is a partial-slip condition with a regionalisation of a no-slip condition (over the Mediterranean Sea) and the Elastic-Viscous-Plastic rheology formulation for the LIM2 ice model (hereafter called LIM2_EVP, Fichefet and Maqueda, 1997) has been activated (Hunke and Dukowicz, 1997). Instead of being constant, the depth of light extinction is separated in Red-Green-Blue bands depending on the chlorophyll data distribution from mean monthly SeaWIFS climatology. The bathymetry used in the system is a combination of interpolated ETOPO1 (Amante and Eakins, 2009) and GEBCO8 (Becker et al., 2009) databases. ETOPO1 datasets are used in regions deeper than 300 m and GEBCO8 is used in regions shallower than 200 m with a linear interpolation in the 200 m – 300 m layer. Barotropic mixing due to tidal currents in the semi-enclosed Indonesian throughflow region has been parameterized following Koch-Larrouy et al. (2008). The atmospheric fields forcing the ocean model are taken from the ECMWF (European Centre for Medium-Range Weather Forecasts) Integrated Forecast System. A 3 h sampling is used to reproduce the diurnal cycle. Momentum and heat turbulent surface fluxes are computed from the Large and Yeager (2009) bulk formulae using the following set of atmospheric variables: surface air temperature and surface humidity at a height of 2 m, mean sea level pressure and wind at a height of 10 m. Downward longwave and shortwave radiative fluxes and rainfall (solid + liquid) fluxes are also used in the surface heat and freshwater budgets. The estimation of Silva et al. (2006) is implemented in the system to represent the amount and distribution of meltwater which can be attributed to giant and small icebergs calving from Antarctica, in the form of a monthly climatological runoff at the southern ocean surface. Lastly, the system does not include tides.

The data are assimilated by means of a reduced-order Kalman filter with a 3-D multivariate modal decomposition of the forecast error and a 7-day assimilation cycle (Lellouche et al., 2013). It includes an adaptive-error estimate and a localization algorithm. The forecast error covariance is based on the statistics of a collection of 3-D ocean state anomalies, typically a few hundred. This approach is based on the concept of statistical ensembles in which an ensemble of anomalies is representative of the error covariances. In this way, truncation no longer occurs and all that is needed is to generate the appropriate number of anomalies. This approach is similar to the Ensemble Optimal Interpolation developed by Oke et al. (2008). In our case, the anomalies are computed from a long numerical experiment (typically around 10 years) with respect to a running mean in order to estimate the 7-day scale error on the ocean state at a given period of the year. In addition, a 3D-Var scheme provides a
correction for the slowly-evolving large-scale biases in temperature and salinity. Altimeter data, in situ temperature and salinity vertical profiles and satellite sea surface temperature are jointly assimilated to estimate the initial conditions for numerical ocean forecasting. Moreover, satellite sea ice concentration is now assimilated in the PSY4V3R1 system in a monovariate/monodata mode. In addition to the quality control performed by data producers, the system carries out two internal quality controls on temperature and salinity vertical profiles in order to minimise the risk of erroneous observed profiles being assimilated in the model.

The analysis is not performed at the end of the assimilation window but at the middle of the 7-day assimilation cycle. The objective is to take into account both past and future information and to provide the best estimate of the ocean centred in time. With such an approach, the analysis, to some extent, acts like a Smoother algorithm. After each analysis, the data assimilation produces increments of barotropic height, sea level height, temperature, salinity and zonal and meridional velocity. These increments are applied progressively using the Incremental Analysis Update (IAU) method (Bloom et al., 1996; Benkiran and Greiner, 2008) which makes it possible to avoid model shock every week due to the imbalance between the analysis increments and the model physics. In this way, the IAU reduces spin-up effects. It is fairly similar to a nudging technique but does not exhibit weaknesses such as frequency aliasing and signal damping. Following the analysis performed at the end of the forecast (or background) model trajectory (referred to as “FORECAST” first trajectory, with analysis time at the 4th day of the cycle), a classical forward scheme would continue straight on from this analysis, integrating from day 7 until day 14. Instead, the IAU scheme renews the model and starts again from the beginning of the assimilation cycle, integrating the model for 7 days (referred to as “BEST” second trajectory) with a tendency term added in the model prognostics equations for temperature, salinity, sea surface height, horizontal velocities and sea ice concentration. The tendency term (which is equal to the increment divided by the length of the cycle) is modulated by an increment distribution function. The time integral of this function equals 1 over the cycle length. In practice, the IAU scheme is more costly than the “classical” model correction (increment applied on one time step) because of the additional model integration (“BEST” trajectory) over the assimilation window. The first guess at appropriate time (FGAT) method (Huang et al., 2002) is used, which means that the forecast model equivalent of the observation for the innovation computation is taken at the time for which the data is available, even if the analysis is delayed. The concept of “pseudo-observations” or “Observed-No Change” (innovation equal to zero) has also been used to overcome the deficiencies of the background errors, in particular for extrapolated and/or poorly observed variables. We apply this approach to the barotropic height and the 3-D coastal salinity at river mouths and all along the coasts (run off rivers). Pseudo-observations are also used for the 3-D variables T, S, U and V under the ice, between 6° S and 6° N below a depth of 200 m. These observations are geographically positioned on the analysis grid points rather than on a coarser grid in order to avoid generating aliasing on the horizontal dimension. The time of these observations is the same as for the analysis, namely the fourth day of a 7-day assimilation cycle. Lastly, a Mean Dynamic Topography (MDT) derived from observations is used as a reference for SLA assimilation.

To correct some deficiencies of the previous system PSY4V2R1, R&D activities have been conducted at Mercator Ocean these last years to improve it. The ocean/sea-ice model and the assimilation scheme benefited of the following additions and changes.

Concerning the physical model:

- The bathymetry used in the system benefited from a specific correction for Indonesian Sea inherited from INDESO system (Tranchant et al., 2016).
- A relaxation toward Levitus 2013 temperature and salinity has been added at Gibraltar and Bab-el-Mandeb straits.
- 50% of surface model currents are now used in the computation of the wind stress.
- The monthly runoff climatology is built with data on coastal runoffs and 100 major rivers from Dai et al. (2009) database (instead of Dai and Trenberth (2002) for PSY4V2R1). This database uses new data, mostly from recent years, streamflow simulated by Community Land Model version 3 (CLM3) to fill the gaps, in all lands areas except Antarctica and Greenland. In addition, we built the runoff fluxes coming from Greenland and Antarctica ice sheets and glaciers melting using Altimber icebergs database project (Tournadre et al., 2013). This complements the estimation of Silva et al. (2006) for Antarctica.
- As the Boussinesq approximation is applied to the model equations, conserving the volume and varying the mass, the simulations do not properly represent the steric effect on the sea level (Greatbatch, 1994). For this reason, the global steric effect has been computed as the gradient between two successive daily mean dynamic heights (vertical integration, from the surface to the

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bottom, of the specific volume anomaly) and added to the sea level in the simulation. This improves the comparison between the model and the sea level observation that contains the steric component.

- Large-scale correction of precipitations (no change of synoptic patterns like cyclones and of interannual signal) has been performed using satellite data (PMWC climatology 1992-2006), except at high latitudes (poleward 65°N and 60°S). The mean bias compared with PMWC is reduced from 0.47 to 0.19 mm/day. Nevertheless, we noticed in the first years of simulation the concentration/dilution water flux injected too much salt in the model, probably due to an excessive evaporation in summer at mid-latitudes. The salt penetrates deeper during winter by subduction and mixes. To avoid this slow salinity drift, a constant of 2.3e-6 kg/m2/s (0.2 mm/day) has been removed to the concentration/dilution water flux term.

- Despite the previous correction and updates, the freshwater budget was far from balanced. In order to avoid any mean sea-surface-height drift due to the poor water budget closure, the following treatments were applied:
  - A trend of 2.2mm/year has been added to the runoffs in order to represent somehow the recent estimation of the global mass (glaciers, land water storage, Greenland and Antarctica) (Chambers et al., 2016).
  - The surface freshwater budget is set to zero at each time step with a superimposed seasonal cycle (Chen et al., 2005).

Concerning the assimilation:

- CMEMS TAC’s sea ice concentration OSI-SAF is now assimilated in the system in a monovariate/monodata mode.
- CMEMS TAC’s OSTIA SST has been assimilated in the new system, instead of AVHRR SST. A particular attention has been devoted in the computation of the model equivalent (day or night SST).
- In addition to the quality control based on temperature and salinity innovation statistics (detection of spikes, large biases, …), already present in the previous system, a second quality control has been developed and is based on dynamic height innovation statistics (detection of small vertically constant biases).
- A new MDT based on the “CNES-CLS13” MDT (Rio et al., 2014) with adjustment using high resolution analysis and with improvement of the Post Glacial Rebound, has been used. This new product takes also into account the last version of GOCE geoid and is replacing the MDT named “CNES-CLS09” derived from observations (Rio et al., 2011) used in the previous system.
- New 20-year altimeter reference period have been used in place of the previous 7-year reference for assimilated SLA products. Numerous innovative changes have been introduced at each step of an extensively revised data processing protocol, modifying significantly SLA patterns.
- New CORA 4.1 database produced by CORIOLIS center has been assimilated for the real time catching up. This database includes temperature and salinity vertical profiles from the sea mammal (elephant seals) database (Roquet et al., 2011) to compensate for the lack of such data at high latitudes.
- The prescription of observation errors in the previous assimilation system was often too approximate. For this reason, adaptive tuning of observation errors for the SLA and SST (Desroziers et al., 2005) has been implemented. The method consists in the computation of a ratio which is a function of observation errors, innovations and residuals. It helps to correct for inconsistency on the specified observation errors. As a first guess of the method, the initial error matches the one used in the previous system where the observation error variance was increased for the assimilation of SLA near the coast and on the shelves, and for the assimilation of SST near the coast (within 50 km of the coast).
- A week constraint has been imposed on temperature and salinity in the deep ocean (below 2000 m) to prevent drift and as a consequence to obtain a better representation of the sea level trend at global scale in the system. The method consists to assimilate vertical climatological (Levitus 2013) profiles of temperature and salinity at large scale and below 2000 m, using a non-Gaussian error at depth. This allows the system to capture a potential climate drift at depth.
- The time scale for the 3D-Var bias correction moved from 3 to 1 month.
- In the previous system, the SSH increment was the sum of barotropic and dynamic height increments. Dynamic height increment was calculated from the temperature and salinity increments. In the current system, we use directly the SSH increment given by the analysis to take into account, among other things, the wind effect.
- The sparsity of the observation networks (both altimetry and in situ profiles) and the uncertainties in the MDT estimation on the 7-day assimilation window do not allow for correctly estimating the mean global sea level. Then, the global mean increment of the total sea surface height is set to zero.
- New 3D observation errors files for the assimilation of in situ temperature and salinity data have been re-computed from the GLORYS2V2 Mercator reanalysis.
- Anomalies necessary to assimilation are now computed from a long simulation with 3D-Var large-scale biases in temperature and salinity, instead from a free simulation (without any data assimilation). Moreover, these anomalies are spatially filtered in order to retain only the effective model resolution to avoid injecting noise when applying increments into the model.
- The velocity increments are no more cut in an equatorial band, as it was the case in the previous system between 6°S and 6°N.

A simulation for calibration of the PSY4V3R1 system was started in October 2006 from a 3D temperature and salinity initial condition based on EN4 climatology. The PSY4V3R1 system starts operation in October 2016. Note that two other simulations over the same period are available. The first one is a free simulation (without any data assimilation) and the second one benefits only of the 3D-Var large-scale biases correction in temperature and salinity.

The new version PSY4V3R1 is operational since October 2016.

Ocean Reanalysis are produced to provide the best estimation and interannual variability of the physical state of the ocean in the past:
- GLORYS2V3 and V4 are the global ¼° reanalysis covering the period 1992-2013 with several upgrades and especially the data assimilation of the sea ice coverage.
- BIOMER_FREEGLORYS2V3 is a global ¼° non assimilative hindcast forced by a global ¼° simulation and covering the period of available satellite Chl-a observation (1998 to 2013).
- IBIRYS1V1 is a regional reanalysis of the North East Atlantic at 1/12° of resolution including new physics as the tide. It covers the period 2002-2011.

7. Observations - Links to Argo, GHRSST...

Argo T&S data are retrieved through the Coriolis global data assembly center, and assimilated on an operational basis. CORA delayed time in situ data base is provided by Coriolis and is used in reanalyses. GHRSST data are retrieved through the SAF Ocean&Ice data center, and used on an operational basis for validation, and assimilated on research mode.  
Along track satellite altimetry data is provided by AVISO.  
Operational MERCATOR systems are assimilating SST jointly with altimetry and vertical T&S in situ profiles since January 2003.

8. Internal metrics and intercomparison plans

Mercator Océan has been routinely producing a “technical bulletin” associated to each weekly ocean bulletin since January 2001, providing internal diagnostics of data assimilation. These internal metrics were defined at European and international level in the framework of MERSEA Strand 1 GMES/EC and GODAE projects. The synthesis of these metrics can be found in Hernandez et al. (2009). Most of these metrics are implemented and monitored in order to calibrate and assess the quality of the systems operated at Mercator Océan. Special metrics for reanalyses have been designed and implemented in the framework of MyOcean project. They are based on both on MERSEA/GODAE metrics and on CLIVAR/GSOP metrics plus metrics inherited from MyOcean operational quality control monitoring.
More recently, in the framework of GMES/EC MyOcean project, a “Product Quality and Calibration Validation” working group has defined common methods and datasets for the calibration and validation of the systems. These calibration and validation metrics are implemented at Mercator Océan since the end of 2010 and since 2014 results of validation are available online on the CMEMS website (http://marine.copernicus.eu/web/103-validation-statistics.php) with information on the global and regional IBI systems.

Since 2010, a “Quarterly Ocean Validation Display” (QuO Va Dis?) is published which gives an estimate of the accuracy of Mercator Océan’s analyses and forecasts over the last 3 months. It also provides a summary of useful informations on the production context for this period. Diagnostics are displayed for all monitoring and forecasting systems currently operated. The “QuO Va Dis?” quarterly report is available on Mercator website (http://www.mercator-ocean.fr/eng/science/Qualification-validation2).

In the framework of the GOV IV Task Team, Mercator Océan is contributing to the CAL/VAL effort. Most advances of this work are implemented routinely into the operational monitoring, and integrated as part of the “technical bulletin”. In 2015 the following IV-TT activity has been carried on:

- Class 4 intercomparison: temperature and salinity, and sea level anomaly gathered by the UK-Met are downloaded every day. Then Class 4 files with the PSY3V3R3 (global ¼°), PSY4V2R2 and PSY4V3R1 (global 1/12°) model values are computed and up-loaded on the GODAE data server. Then the Mercator Océan CAL/VAL team collects Class 4 files from other GOV centres, and compute statistics on GODAE regions.
- MultiModel Ensemble approach: Mercator Océan provides on a daily basis the surface parameters from the PSY3V3R3 system on the native grid. GOV/CLIVAR/GSOP project on ocean reprocessed products and reanalysis: Mercator Océan is providing all the ocean parameters for this intercomparison project, based on GLORYS2V3 and GLORYS2V4 ocean reanalysis. Moreover, Mercator Océan is conducting the intercomparison for Sea Level and Depth of the 20°C isotherm (D20). Global and regional metrics, as well as ensemble estimates are tested, with the objective to define ocean index for near-real time monitoring.

9. Targeted Users and envisioned external metrics

Targeted users of Mercator Océan systems are the five Mercator Océan Patrons Agencies and their application sectors, the National and European Policy Makers, GODAE OceanView partners, Research, and Commercial applications.

Application Centers identified among the Mercator Océan partners, are e.g. SHOM for Navy applications, Météo-France for marine safety, oil spill monitoring, and seasonal forecasting (with a collaboration with ECMWF), and IFREMER for coastal and ecosystem monitoring.

If research is one of the leading applications in the scope of the Mercator Océan Science Working Team, more than 50% of the users are today outside the research field, both on the operational institutional (e.g. marine safety) and commercial (e.g. offshore) sectors.

Mercator Océan is serving an increasing number of users, in each of the different user targeted sectors, and with specific collaborations with each of them.

Statistics on users and services are produced every month for the CMEMS service and for the Mercator Ocean dedicated service. More than 7700 users are now register in the CMEMS service and since the beginning of 2016 number of download transaction is around 22 millions and the volume downloaded by users is larger than 220Tb.

10. Reanalysis activities

Providing reanalysis with multi data assimilation (i.e. on the period 1993-present time for the availability of accurate altimetry) is an important objective of Mercator Océan.

The previous version of the global ¼° ocean reanalysis (GLORYS2V3) has been produced in 2013/2014, in 2016 a updated version of this reanalysis has been produced and is currently disseminated (GLORYS2V4). Development and production of global biogeochemistry reanalysis has
also begun and R&D tasks are still needed to improve the system and to solve the main known problems. At this time an interannual global simulation at ¼° without data assimilation has been produced and disseminated to users.

In the framework of the ERACLIM2 project, Mercator Ocean is in charge of the production of the global biogeochemistry reanalysis which will cover the 20th century. During 2015, development of the global configuration has been performed. It will be based on the PISCES model at 1° of resolution. The global ocean atmosphere coupled reanalysis that is performed in the framework of this project will be used to constrain the biogeochemical model. A simulation has been produced covering the 20th century, this simulation is based on a 1° global configuration coupled with PISCES biogeochemistry model and forced by the ERA20C atmospheric forcing already produced by ECMWF.

Other reanalysis activities concerning IBI and Mediterranean Sea regions have begun in 2013. A 1/12° reanalysis covering the IBI area over the “Argo” period (from 2002 until now) has been produced and is regularly extended. This reanalysis is embedded in the global GLORYS2V3 and benefits from several improvements (tide, atmospheric pressure forcing and PISCES biogeochemistry model coupled online …). A reanalysis covering the Mediterranean Sea at 1/12° has also been produced. The main specificity of this reanalysis is the atmospheric forcing which is a downsampling of the ERAinterim ECMWF reanalysis with the Météo France Aladin atmospheric model with a 12 km horizontal resolution and some dedicated tuning of the data assimilation scheme for the Mediterranean Sea.

In 2016, an Ocean State Report has been produced and submitted to Journal of Operational Oceanography. This report is currently under review.

The Copernicus Marine Environment Monitoring 4 Service Ocean State Report (CMEMS OSR)


11. Computing resources

The Mercator Océan systems are developed on a Linux network of workstations. For supercomputing needs, the team works on Météo-France (BULL) and ECMWF (Cray) high performance computing centers facilities.

12. Consolidation phase and transition to operational system (activities)

The Mercator Océan systems are operated on a daily basis. The systems run on Météo-France super computer and the storage is also performed on Météo-France resources. Real time dissemination of the global product in the context of CMEMS is performed internally at Mercator Océan since 2016. A team is dedicated to the routine tasks. It operates and validates the system every day. Developing scientists and engineers are present every week to correct anomalies (maintenance) when they are detected in the short loop validation phase.

Routine operations have been regular since January 2001, without any failure in the delivery of the products. Some degraded cases with delayed production have been observed, but they were not frequent (a few cases per year), and the delay was never larger that one production cycle (1 week).
Mercator Océan entered in fully operational mode end 2010 within MyOcean project. This consists in having operational teams, redundancy in computing resources, and qualified operation/maintenance procedures. The operational production, the data delivery from the production centers to the data servers, the access of the users to the products are monitored using a common framework agreed at European level. The global daily 1/12° forecasting system has been delivered in time (before 12h00 every day) in 100% of the cases one year. Most of the time products are delivered at 4:00AM, last year products have been delivered 6 time after 12h00 but never with one day of delay. All this reinforces the operationally of Mercator Océan systems.

13. GODAE OceanView related achievements and measures of success

A new version of the global forecasting system has been developed and is operated in near real time since octobre 2016. The new version of the high resolution (1/36°) physical and biogeochemical coupling system covering the North East Atlantic Area (IBI area) has been developed and transferred to Puertos Del Estado partner who is in charge of the operation. OSE experiments have been produced to quantified impact of altimetry, especially the number of altimeter missions. OSSE experiments has been produce to prepare assimilation of high resolution SWOT observation in high resolution (1/36°) regional configuration on North East Atlantic area. OSSE experiments, concerning evolution of the in situ network, has been defined in a coordinated way in the context of AtlantOS project with other partners (UKmetOffice, CLS, CMCC, ECMWF).

**Contribution to Godae Ocean View Task Team Workshop**

- Joint DA-MEAP-TT workshop, Santa Cruz, USA, July 2016
- IV-TT workshop, 20-22 sep 2016, St Lawrence centre, Montreal, Canada
- The Global Ocean Week, Toulouse, France, October 2016

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**System information overview**

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<th>Mercator Océan</th>
<th>Operational ocean forecasting systems</th>
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<tr>
<td>OGCM</td>
<td>NEMO ocean model coupled to LIM2_EVP sea ice model</td>
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<tr>
<td>Domain</td>
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<tr>
<td>1. PSY4: Global (77°S-90°N)</td>
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<tr>
<td>2. PSY2: North Atlantic + Mediterranean Sea (20°S-80°N)</td>
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<td>3. PSY3: Global (77°S-90°N)</td>
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### Horizontal resolution

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<tr>
<td>1.</td>
<td>PSY4: 1/12°</td>
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<tr>
<td>2.</td>
<td>PSY2: 1/12°</td>
</tr>
<tr>
<td>3.</td>
<td>PSY3: 1/4°</td>
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<tr>
<td>4.</td>
<td>IBI36: 1/36°</td>
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<td>5.</td>
<td>BIOMER4: 1/4°</td>
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<tr>
<td>6.</td>
<td>PSY2G3: 1° (1/3° near equator)</td>
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<tr>
<td>7.</td>
<td>GLORYS2V3/V4: ¼°</td>
</tr>
<tr>
<td>8.</td>
<td>MEDRYS : 1/12°</td>
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<td>9.</td>
<td>IBIRYS : 1/12°</td>
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### Vertical sampling

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<tbody>
<tr>
<td>1.</td>
<td>PSY4: 50 Z levels with partial step, 1m near surface</td>
</tr>
<tr>
<td>2.</td>
<td>PSY2: 50 Z levels with partial step, 1m near surface</td>
</tr>
<tr>
<td>3.</td>
<td>PSY3: 50 Z levels with partial step, 1m near surface</td>
</tr>
<tr>
<td>4.</td>
<td>IBI36: 50 Z levels with partial step, 1m near surface</td>
</tr>
<tr>
<td>5.</td>
<td>BIOMER4: 50 Z levels, 1m near surface</td>
</tr>
<tr>
<td>6.</td>
<td>PSY2G3: 42 Z levels with partial step, 10m near surface</td>
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<tr>
<td>7.</td>
<td>GLORYS2: 75 Z levels with partial step, 1m near surface</td>
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<tr>
<td>8.</td>
<td>MEDRYS: 75 Z levels with partial step, 1m near surface. Grid optimized for the Mediterranean water masses</td>
</tr>
<tr>
<td>9.</td>
<td>IBIRYS : 75 Z levels with partial step, 1m near surface</td>
</tr>
</tbody>
</table>

### Atmospheric Forcing

ECMWF analyses and forecast for the real time and ERAinterim reanalysis for ocean reanalysis, 3H forcing frequency, bulk formulation (COARE)

### Assimilation characteristics

*“Mercator Assimilation System” version 2 (SAM-2), reduced-order Kalman filter based on the SEEK formulation with a 3DVAR bias correction for temperature and salinity*

### SST data

Reynolds AVHRR 0.25° SST and OSTIA/CMEMS SST

### SSH data

SSALTO/DUACS along track SLA (AVISO), Mean Dynamic Topography constructed with CNES_CLS09 MDT and GLORYS reanalysis

### In situ profiles

In situ temperature and salinity profiles provided by CORIOLIS GDAC. CORA data base for the reanalysis

### Sea-ice data

Sea ice concentration from CERSAT and from CMEMS

### System Set-ups

**Forecast range**

Once a week a 2-week forecast is produced with PSY2 and PSY3 and 1-week forecast with PSY4 and BIOMER4

Every day a 1-week forecast is produced with PSY2, PSY3 and PSY4 and a 5-day forecast
The new version of PSY4 (PSY4V4R1) produced daily 10-day forecast

Update frequency
Analysis is produced every week and the forecasts are updated every day taking into account the update of the atmospheric forcing

Hindcast length
2-week of hindcast are produced every week

System website links

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<tr>
<td>Technical description</td>
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<td>Viewing service</td>
<td><a href="http://bulletin.mercator-ocean.fr/html/welcome_en.jsp">http://bulletin.mercator-ocean.fr/html/welcome_en.jsp</a></td>
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Publications 2016


References


