NEMO IN MYOCEAN MONITORING AND FORECASTING CENTERS (MFCS)

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Introduction

During the MyOcean project, all the Monitoring and Forecasting Centers (MFCs, delivering services each in one region as shown in Figure 1) have implemented operational model configurations in order to cover the global ocean with a focus on the European waters. These numerical model configurations are used to provide real-time forecasts of the physical state of the ocean.

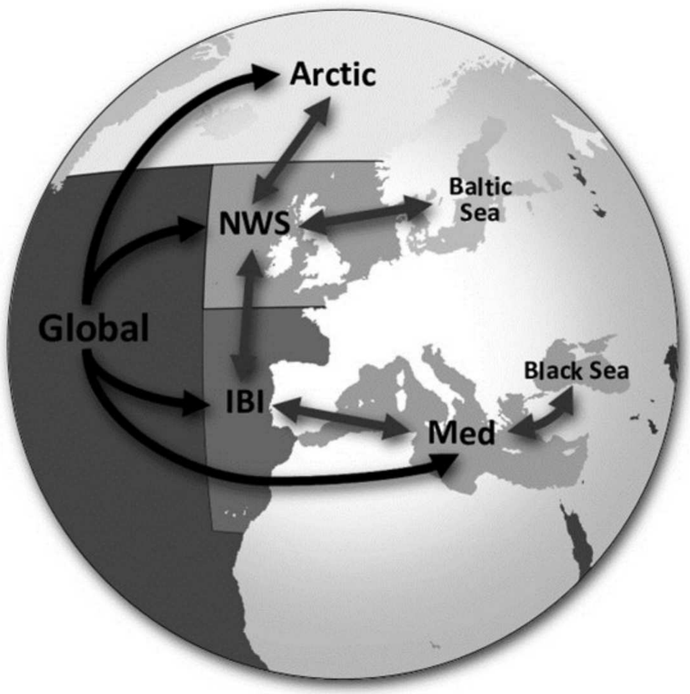

Figure 1: The MyOcean MFCs geographic service coverage. The arrows show the boundaries between these domains. Note that these domains do not correspond to the model domains as described in Table 1.

Most MFCs have also used these OGCM (Ocean General Circulation Model) configurations to couple with Biogeochemical (BGC) model that provide real-time forecast for the major BGC variables. Within NEMO, several options are possible with respect to the use of BGC models: The use of BGC codes that are embedded into NEMO (including PISCES) that can be coupled with the OGCM (OPA), the coupling could be online (both component being integrated simultaneously) or offline (the BGC uses the physics produced by a previous run). If offline coupling is selected, the horizontal and temporal resolution can be degraded. This is the approach used by Mercator (see table 4, and Gehlen et al., 2012, this issue) for the global model configurations. For the IBI region Mercator is presently developing R&D that will enable to do online coupling at 1/12°. Other groups using NEMO within MyOcean have taken a different approach, e.g. the Met Office is using a version of ERSEM (European Regional Seas Ecosystem Model) (developed by PML (Plymouth Marine Laboratory)) which is coupled online with the NWS (North Western Shelves) model, the Med group (led by Italy) is using the Biogeochemical Flux Model (BFM) coupled with a specific transport model (OPATM) that uses off-line ocean physics from the Med MFC degraded in horizontal resolution.

Also, most MFCs have used model configurations derived from the real-time ones to produce reanalysis of the past observations over the recent decades. This is true for the Global Ocean where Mercator has used a 1/4° global configuration developed together with CNRS in the DRAKKAR context, used also by the University of Reading in the UK and CMCC in Italy to provide an ensemble of global reanalysis over the modern altimeter period (from 1992, see Ferry et al., 2012, this issue). This is also true for the Med, the Arctic, the Baltic and the Black seas for which reanalysis have been produced with configurations derived from the real-time systems. The reanalysis produced for the NWS differs from this as it has been produced by 2 groups using their own OGCMs configurations (namely based on POLCOMS and HYCOM).

Finally, all the MFCs are working on R&D mode on upgrading these OGCM configurations for further releases. This is illustrated in the tables 1 to 4.

Most MFCs are using NEMO or have plans to use NEMO as the baseline for their OGCM component configuration in the near future.

This has been the case since the beginning of MyOcean with the global ocean (Lellouche et al., 2012), the Mediterranean sea (Tonani et al. 2008 and Oddo et al. 2009), the IBI (Cailleau et al 2012, Maraldi et al. 2012) and NWS regions (O'Dea et al. 2012) as illustrated in the tables 1, 2 and 3. The corresponding working groups, namely Mercator Ocean, the Met Office, INGV and CMCC, together with CNRS and NERC form the working force of the NEMO consortium as discussed in Lévy and Benshila, 2012 (this issue).

In addition, for global model configurations, the Met Office people are concentrating their efforts towards the development of coupling with the atmosphere at eddy permitting resolution for the ocean (namely at 1/4°), while Mercator Océan people are concentrating their efforts on forced configurations at higher resolution (1/12°), in order to better resolve the meso-scale. In the MyOcean 2 project, the development of a coupled prediction system based on NEMO at 1/4° has started at the Met Office in R&D mode, and ocean products obtained from a coupled prediction system are planned to be disseminated through MyOcean catalogue at 6 month prior to the end of the MyOcean 2 project (end of 2013).

There are several developments on NEMO tests implementations conducted in R&D mode by most MFCs that currently use other OGCM. This is the case for the Baltic and the Black sea (see below). The work on the black sea is well advanced, most R&D tasks have been done within the MyOcean project (the configuration has been developed, has been tested), while the work for the Baltic has not started yet, which explains that plenty of the options are still to be defined (TBD) in the tables 1 to 4. Only the Arctic MFC has no plans yet to transition to NEMO. This is discussed in more details in the conclusions of this paper.

Finally NEMO has been considered as a potential OGCM to be used to implement a regional configuration for the Marmara Sea to connect physically the Black and Med seas through the Dardanelles and Bosphorus straits. For the moment the two MFCs dealing with these two seas are disconnected. This work is planned to be done within the MyOcean 2 project. The final choice of the OGCM will take into account the fact that the straits are very narrow (below 1km in some places), and the choice of a finite volume/elements OGCM will probably be preferred to NEMO which is implementing finite differences on the horizontal. The final choice of the OGCM that will be used has not been made yet.

MFC	Domain	OGCM version	Usage	Horizontal grid	Vertical grid
GLO	Global ocean	NEMO 3.1	R/T	1/12° - 1/4° ORCA	50 z-levels
		NEMO 3.2	Reanalysis	1/4° ORCA	75 z-levels
		NEMO 3.4	R&D	1/12° - 1/4° ORCA	50 – 75 z-levels
ARC	North Atlantic	HYCOM 2.2.37	R/T	~ 1/8° (10-15 km)	28 hybrid layers
		HYCOM 2.2.12	Reanalysis	~ 1/8° (10-15km)	28 hybrid layers
		HYCOM 2.2.37	R&D	~ 1/8° (10-15 km)	28 hybrid layers
BAL	North and Baltic Sea	HBM (MyO V2)	R/T	~1 to 6 km	109 z-levels
		HBM (MyO V1)	Reanalysis	~6 to 12 km	50 z-levels
		HBM (MyOV3) - NEMO	R&D	~ 2 km	122 layers (HBM) – *TBD (NEMO)*
NWS	North western Atlantic shelves	NEMO 3.2	R/T	1/15°x1/9°	34 s-levels
		NEMO 3.4	R&D	1/15°x1/9°	34 s-levels
IBI	IBIROOS domain	NEMO 2.3*	R/T	1/36°	50 z*-levels
		NEMO 2.3*	Reanalysis	1/12°	75 z*-levels
		NEMO 2.3* – NEMO 3.4	R&D	1/12° – 1/36°	50 z*-levels
MED	Mediterranean	NEMO 2.3 **	R/T	1/16°	72 z levels
		NEMO 2.3 **	Reanalysis	1/16°	72 z levels
		NEMO 2.3 ** - NEMO 3.4	R&D	1/16°	72 z levels
BS	The black sea	MHIC***	R/T	0.061°x0.044° (~5x5km)	38 z-levels
		POM	Reanalysis	1/10°x1/16 (~7x8km)	26 σ-surfaces
		NEMO 3.3	R&D	0.061°x0.044° (~5x5km)	38 full step z-levels

Table 1: the MFCs major OGCM geographical characteristics. z-levels indicate coordinates for which the total column depth is varying with time (following the total sea level, developed for and used on IBI configuration), while z-levels denotes fixed depth levels and s-levels terrain following levels. All the z-level and z*-levels configurations use partial cells (Barnier et al. 2006) at the bottom.*

** NEMO 2.3 has been used as the base line for the IBI configuration development several years ago, a large part of the NEMO code has been rewritten to improve the numerical core on this shelf tidal open ocean region. These developments were done on NEMO2.3 at the origin, and most of them are currently being transferred to more recent NEMO version (namely version 3) by the IBI group (in France) in collaboration with the NWS people (in the UK).*

*** NEMO 2.3 has been also been used as the baseline for the Med configuration development several years ago. Several adaptations have been done to the code to allow scientific performances in the Mediterranean Sea, the R/T system is made from this updated NEMO 2.3 version.*

**** MHIC is an OGCM developed by the Marine Hydrophysical Institute (Demyshev and Korotaev, 1992)*

MFC	Usage	Forcing fields	Freq of forcing	Analytical Daily cycle	Atm pressure forcing	Tides	Using Bulk	Vertical mixing scheme
GLO	R/T	ECMWF	Daily - 3 hourly	No - No	No - No	No - No	CLIO - CORE	TKE
	Reanalysis	ERA-interim	3 hourly	Yes	No	No	CORE	TKE
	R&D	ECMWF	3 hourly	Yes	No	No	CORE	TKE
ARC	R/T	ECMWF	6 hourly	Yes	No	No	Kara *et al.* 2000	GISS (Canuto)
	Reanalysis	ERA-Interim	6 hourly	Yes	No	No	Kara *et al.* 2000	GISS (Canuto)
	R&D	ERA interim	6 hourly	Yes	No	No	Kara *et al.* 2000	GISS (Canuto)
BAL	R/T	DMI– Hirlam & DWD	Hourly	No	Yes	Yes	Neutral Kara *et al.* 2000	K-omega (Canuto) part 2
	Reanalysis	DMI and SMHI – Hirlam, ERS-40	Hourly	No	Yes	Yes	Neutral Kara *et al* 2000	K-omega
	R&D	AS in R/T and reanalysis	Hourly	No	Yes	Yes	Neutral Kara *et al* 2000 (HBM) - *TBD (NEMO)*	K-omega (HBM) - *TBD (NEMO)*
NWS	R/T	Met Office	Hourly	No	Yes	Yes	Flux driven*	K-Epsilon
	R&D	Met Office	Hourly	No	Yes	Yes	CORE	K-Epsilon
IBI	R/T	ECMWF	3 hourly	Yes	Yes	Yes	CORE	K-Epsilon
	Reanalysis	ERA-interim	3 hourly	Yes	Yes	Yes	CORE	K-Epsilon
	R&D	ECMWF	3 hourly	Yes	Yes	Yes	CORE	K-Epsilon
MED	R/T	ECMWF	6 hourly	No	No	No	MFS	Packanowski and Philander (1981)
	Reanalysis	ECMWF	6 hourly	No	No	No	MFS	Packanowski and Philander (1981)
	R&D	ECMWF	6 hourly	No	No - Yes	No	MFS	Packanowski and Philander (1981)
BS	R/T	Skiron**	6 houly	No	No	No	Flux driven	Mellor and Yamada
	Reanalysis	ECMWF	6 hourly	No	No	No	Flux driven	Mellor and Yamada
	R&D	RNMA ***	6 hourly	No	No	No	Flux driven	Mellor and Yamada

Table 2: OGCM atmospheric forcing and vertical physics characteristics. Note that for the global R&D configuration, the table describes only the forced configurations maintained at Mercator Océan, not the coupled configuration developed at the Met Office. We note also that K-epsilon vertical mixing has been adopted on the two tidal domains on the European shelf: NWS and IBI.

** the NWS NEMO configuration operated in real-time do not use any classical bulk formulation to recompute interactive fluxes, but forces the ocean with fluxes computed by the UKMO UM atmospheric model, using COARE3.0 bulk formulae, assuming a zero motion ocean with a SST equal to OSTIA products (derived from observations)*

*** These are fields of the Atmospheric Modeling and Weather Forecasting Group, University of Athens, Greece, developed during the MFSTEP project*

**** RNMA is the Romanian National Meteorological Agency. The AGCM is Alladin (Stefanescu et al., 2004).*

MFC	Usage	Free surface type	Tracer advection scheme	Momentum advection scheme
GLO	R/T	Implicit filtered *	TVD	Vector form – een**
	Reanalysis	Implicit filtered	TVD	Vector form – een
	R&D	Implicit filtered	TVD	Vector form – een
ARC	R/T	Explicit time split	FCT2	4^{th} order
	Reanalysis	Explicit time split	FCT2	2^{nd} order
	R&D	Explicit time split	FCT2	4^{th} order
BAL	R/T	Explicit	TVD	Vector upwind
	Reanalysis	Explicit	TVD	Vector upwind
	R&D	Explicit (HBM) - *TBD (NEMO)*	TVD (HBM) – *TBD (NEMO)*	Vector upwind (HBM) - *TBD (NEMO)*
NWS	R/T	Explicit time split	TVD	Vector form – een
	R&D	Explicit time split	TVD/PPM	Vector form – een
IBI	R/T	Explicit time split	Quickest	Vector form – een
	Reanalysis	Explicit time split	Quickest	Vector form – een
	R&D	Explicit time split	Quickest	Vector form – een
MED	R/T	Implicit filtered	MUSCL + upwind	Vector form – een
	Reanalysis	Implicit filtered	MUSCL + upwind	Vector form – een
	R&D	Implicit filtered - Explicit time split	MUSCL + upwind	Vector form – een
BS	R/T	Implicit***	TVD	Vector form - een
	Reanalysis	Explicit time split	2^{nd} order centered	2^{nd} order centered
	R&D	Implicit filtered *	MUSCL	Vector form - een

Table 3: some numerical aspects of the OGCM

**NEMO Implicit filtered free surface is schematically a free surface without variation of the top level thickness (see Roullet and Madec, 2000) while explicit time split means that the free surface is explicitly resolved (see Madec et al. 2008), using time splitting method (different time steps for the external and internal modes). NEMO implicit filtered free surfaces are used in domains where the tidal elevations + high frequency signals are not considered (GLO, MED and BS).*

*** een stands for Energy and Enstrophy conserving schemes*

**** For the current R/T implementation of the BS, they use an implicit scheme for the free surface which differs from the one used in NEMO. See Demyshev and Korotaev, 1992.*

MFC	Usage	Ice model (code/ rheology)	BGC model	Wave model coupled	Atmospheric model
GLO	R/T	LIM2/VP – LIM2 /EVP	No – Yes PISCES offline at 1° weekly physics	No	No
	Reanalysis	LIM2/EVP	PISCES offline at 1° weekly physics	No	No
	R&D	LIM2/EVP (forced configs) – CICE/EVP (coupled configs)	PISCES offline at 1/4° weekly physics (forced configs) – no BGC (Coupled configs)	No***	No (forced configs) – Met Office UM, fully coupled, COARE3.0 based
ARC	R/T	NERCS 1 cat/EVP	Norwecom online	No	No
	Reanalysis	NERSC 1 cat/EVP	Norwecom online (at ½° horiz resol)	No	No
	R&D	NERSC 5 cat/EVP	Norwecom online	Wave in ice *	No
BAL	R/T	Thermodynamic only	DMI ERGOM	No	No
	Reanalysis	Thermodynamic only	No	No	No
	R&D	New developments (HBM) - *TBD (NEMO)*	DMI-ERGOM and SMHI -SCOBI	In test mode	No
NWS	R/T	Non applicable	PML ERSEM online		No
	R&D	Non applicable	PML ERSEM online		No
IBI	R/T	Non applicable	No	No	No
	Reanalysis	Non applicable	No	No	No
	R&D	Non applicable	PISCES online (at 1/12° horiz resol)	No **	No
MED	R/T	Non applicable	OPATM BFM offline at 1/8° biweekly	WAM	No
	Reanalysis	Non applicable	OPATM BFM offline at 1/8° biweekly	No	No
	R&D	Non applicable	OPATM BFM offline at 1/8° biweekly	WAM- Wavewatch	No
BS	R/T	No	MHI Biogeochemical model v1	No	No
	Reanalysis	No	MHI Biogeochemical model v1	No	No
	R&D	No	No	No	No

Table 4: the model coupled to the OGCMs. Note that all the regions concerned by Ice NEMO-based configurations are coupled to a prognostic ice model, either from Louvain la Neuve (LIM) or Los Alamos (CICE). Note that the Arctic region is covered by a "home-made" ice model, the Arctic R&D group is working on a more sophisticated version of the ice model implementing more ice categories. Finally, note that there is a great variety of BGC model used.

** Waves taken into account in the ice model of the ARC MFC, see Dumont et al. 2011*

*** Some tests are planned to implement mixing parameterizations using outputs of wave models. This is not fully coupling, but will test the impact of waves on the ocean vertical mixing. This work will follow some successful test (that have already been done within in a R&D MyOcean sub project led by Met No) to test the impact on the ocean of wind stresses coming from an atmospheric model coupled with waves in forced mode.*

**** There will ultimately be coupled with wave model in the coupled global modeling system, but for the moment, there is no coupling to any wave models applied, and the future is not yet defined.*

NEMO for the global and basin-scale ocean

The global ocean forecasting system operated by Mercator Océan and available through MyOcean data server is based on the NEMO ocean model since the first version which was operated in real time in 2001. The current global system is based on two global configurations at 1/4° and 1/12° of horizontal resolution and a regional one at 1/12° which cover the North Atlantic and the Mediterranean Sea. The main characteristics of these configurations are described in the Tables 1 to 4. They have been developed at Mercator Océan and through several collaborations with research partners especially with the DRAKKAR project as said above, and so have used state of the art parameterization for global ocean configurations. The first global 1/4° simulation performed with NEMO is described in Barnier et al. (2006), authors show that this model simulation has already a high level of quality especially concerning the level of eddy kinetic energy and the position of the main currents. Several other recent studies, based on NEMO global ocean configurations, have proved the importance of the model resolution to improve the realism of the ocean circulation, for example with the Gulf Stream pathway in Hulburt et al., (2011), the ability of a model to forecast oceanic structures (Hulburt et al., 2009) and also for several applications as for the oil spill drift (Law Chune et al., 2012) or the transfer time of eel larvae across Atlantic Ocean (Blanke et al., 2012). In the operational system the impact of a higher resolution is less clear than in a forced simulation because the data assimilation constrains the meso scales field which is mainly observed with the current observation network thanks to the altimetry satellites. As an example, a zoom on the south Atlantic along the African coast is presented in Figure 2, the top panel shows the observed sea level anomaly (black contour) for August 15th 2011 delivered by MyOcean. This field is assimilated (not directly the map but the along track observations which are also used to produce this map) in the global 1/12° system (bottom panel, Figure 2). The main meso scales structures are well represented in the model solution, with several eddies at the same place in the model and in the observations. The color field on the top panel (Figure 2) is the satellite observed chlorophyll distributed by MyOcean, this field exhibits more small scale structures as smaller eddies or filaments which are not assimilated in the global system . The sea surface salinity and the velocity fields (Figure 2, bottom panel) show also smaller structures which can be simulated thanks to the high resolution of the global system. More details and analysis performed with the global operational system are presented in the quarterly validation Quo Va Dis bulletin (http://www.mercator-ocean.fr/eng/science/qualification) and the performance of the future release of the system are described in Lellouche, et al (2012).