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OPerational ECology

Ecosystem forecast products to enhance marine GMES applications

DG SPACE

Collaborative Project - small or medium-scale focused research project

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OPEC Overview

"OPEC provides an enhanced capability to predict indicators of good environmental status in European regional Seas"

The OPEC project (Operational Ecology) will help develop and evaluate ecosystem forecast tools to help assess and manage the risks posed by human activities on the marine environment, thus improving the ability to predict the "health" of European marine ecosystems. The programme will focus on four European regional seas (North-East Atlantic, Baltic, Mediterranean and Black Seas) and plans to implement a prototype ecological Marine Forecast System, which will include hydrodynamics, lower and higher trophic levels (plankton to fish) and biological data assimilation.

Products and services generated by OPEC will provide tools and information for environmental managers, policymakers and other related industries, laying the foundations for the next generation of operational ecological products and identification of knowledge / data gaps.

OPEC will use the EU's Global Monitoring for Environment and Security Marine Service as a framework and feed directly into the research and development of innovative global monitoring products or applications. This in turn will advise policies such as the European Marine Strategy Framework Directive and Common Fisheries Policy, as well as the continued monitoring of climate change and assessments of mitigation and adaptation strategies.

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Executive Summary

As a contribution for the next generation model setup and benchmarking planned to be done in the WP2 of the OPEC project, Task 2.1 provided the assembly of boundary conditions and forcing functions for four European regional seas, namely the N.E. Atlantic (PML), the Baltic Sea (DMI), the Mediterranean Sea (OGS and HCMR) and the Black Sea (METU). Briefly, the assembly includes:

- A common regional climate hindcast from 1990-2009 performed by DMI were used to provide atmospheric forcing for the hindcast simulation of the four regional seas. There is an exception at OGS who have no regional ocean model and will run the ecological model in off-line mode.
- For each region the responsible partner assembled the best available river input (e.g. runoff and nutrient loads) and open ocean boundary condition data. Those data are available from previous European and national projects.
- The assembly of forcing fields and boundary conditions will be used to force a different ocean model in each region to perform 20 yr hindcast and to benchmark model performance by each responsible partner as it was planned to be done in other sub-tasks of the WP2.

Relevance to Policy

The aim of D2.2 was to assemble boundary conditions for each region, including atmospheric forcing, river input and open ocean boundary condition data. DMI provided the atmospheric forcing for each region based on a common regional climate hindcast. For each region the responsible partner assembled the best available river input (e.g. runoff and nutrient loads) and open ocean boundary condition data. The assembly of boundary conditions will be used to force a different ocean model in each region to perform 20 yr hindcast and to benchmark model performance by each responsible partner as it was planned to be done in other sub-tasks of the WP2.

The present report summarizes the information of assembled boundary conditions and forcing functions in Task 2.1.

A common regional climate hindcast

The regional climate hindcast was performed by Danish Climate Centre at DMI using a regional climate model HIRHAM5. The latter is a combination of the dynamic core of the HIRLAM (High Resolution Limited Area Model) weather forecasting model and the climate physical core of the ECHAM5 GCM. Details on HIRHAM5 can be found in Christensen et al. (2006).

The hindcast simulation was driven with the ERA-interim reanalysis data during the period 1989-2009, performed as a “poor man’s reanalysis” (Laprise, 2008, Lucas-Picher et al. 2011). It has a spatial resolution of 12-km (0.11 degree) with grids 452 (zonal) by 432 (meridional) in the European CORDEX-like domain (Fig. 1).

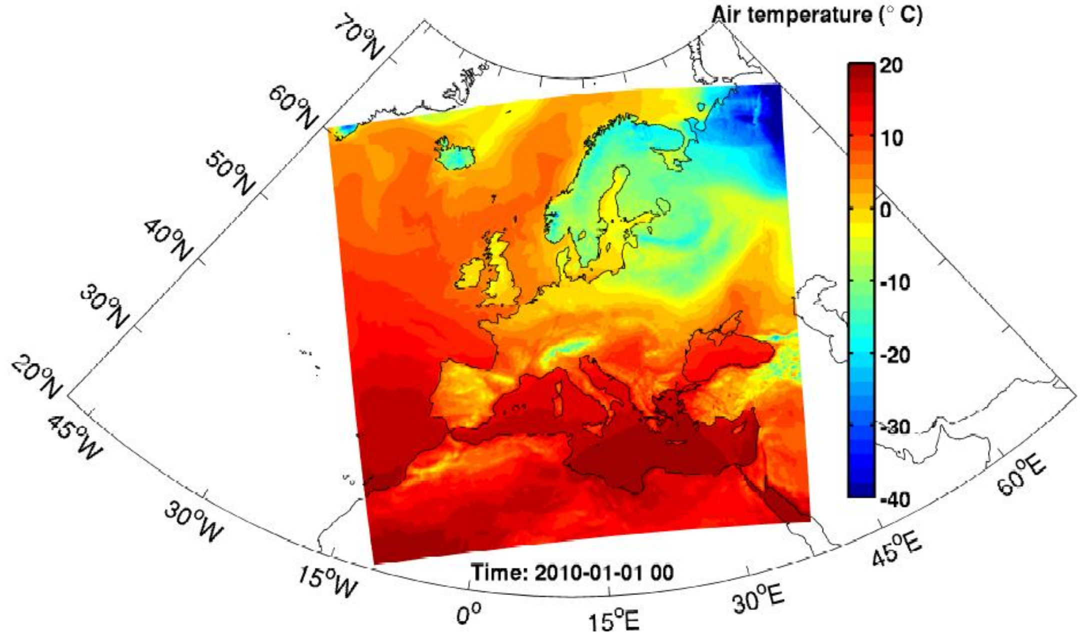

Fig. 1 Air temperature at mid-night Jan 1st 2010.

For each region, the responsible partner has their own regional ocean model, which requires a different set of atmospheric surface variables (see Table 1-4). Those were extracted to force the hindcast simulations of the four regional seas, respectively. The description of boundary conditions, including atmospheric forcing, river input and open ocean boundary condition data, are given for each region as follows.

N.E. Atlantic (PML)

The atmospheric forcing used for the regional ocean model of the NE Atlantic is given by data from the DMI regional climate model provided for OPEC and described above. Surface fluxes are computed using COAREv3 formula. The data used for this particular model configuration is summarised below in Table1.

The oceanic conditions at the open boundaries (temperature, salinity, currents and sea surface elevation) are extracted from the GLORYS reanalysis product (MERCATOR) provided within the MyOcean project. The corresponding conditions for dissolved nutrients and oxygen were extracted from WOA climatology (2005) dissolved inorganic carbon from GLODAP. The rest of the ecosystem variables are solved using no-flux conditions at the open boundaries. The 250 rivers considered in the present configuration are forcing the model through an inflow climatology of fresh-water and dissolved nutrients. For freshwater fluxes, daily discharge data for 250 rivers are used from the Global River Discharge Data Base and from data prepared by the Centre for Ecology and Hydrology. River nutrient loading matches that used by Lenhart et al. (2010), with raw data for the UK, Northern Ireland, Ireland, France, Norway, Denmark and the Baltic processed by van Leeuwen (CEFAS, UK) and raw data for Germany and the Netherlands was processed by Pätsch and Lenhart (2004).

In addition, Baltic inflow at the belt is idealised as river-inflow. Atmospheric input of nutrients is derived from EMEP. An additional particularity of this configuration is the use of satellite derived adsorption of detritus and gelbstoff, which the model assimilates by a simple relaxation term (see e.g. Holt et al. 2012).

Table 1. List of atmospheric surface variables used for the ocean model at PML

Name	code	Level	Description	Unit	Resolution
MSLP	1	0m	Mean sea level pressure	Pa	Every 3 h
TEMP2	11	2m	2-m temperature	K	Hourly
U10	33	10m	10-m zonal wind	m/s	Hourly
V10	34	10m	10-m meridional wind	m/s	Hourly
Q2M	51	2m	2-m specific humidity	Kg/kg	Every 3h
ACLCOV	71	0m	Total cloud cover	-	Daily
APRS	65	0m	Snow fall	Mm/d	Daily
APRL	62	0m	Large scale precipitation	Mm/h	Hourly
APRC	63	0m	Convective precipitation	Mm/h	Hourly
SRADS	111	0m	Net SW radiation at surface	W/m2	Every 3h
TRADSU	115	0m	Downw./Upw. LW radiation at surface	W/m2	Every 3h

Baltic Sea (DMI)

The model has been used as a common Baltic Sea model (HIROMB-BOOS Model - HBM) for providing GMES Marine Core Service since 2009. The model domain covers the North Sea and the Baltic Sea (~5 km resolution, 48.55^o N -65.85^o N and 4.08^o W - 30.25^o E) with a two-way nested fine grid ocean domain for the transition area (~1 km resolution, 53.59^o N -57.59^o N and 9.35^o E - 14.82^o E).

The atmospheric forcing used for the regional ocean model is given by data from the DMI regional climate model provided for OPEC and described above. The data used for this particular model configuration is summarised below in Table 2. The surface heat flux is parameterized using bulk quantities of both lower atmosphere and upper ocean or sea ice, respectively. The evaporation flux is taken into account only through the heat budget, and changes of water volume due to evaporation, precipitation and ice formation are ignored; this is a reasonable approximation since the annual net-change in water volume due to these sources is close to zero for the North Sea – Baltic Sea region.

At the open model boundaries in the North Sea and in the English Channel, the model is forced by tides, surges and lateral temperature and salinity fields. The tides along the North Sea boundary are determined from 8 tidal constituents obtained from satellite altimetry observations (Jason-1, Topex/Poseidon, Envisat, ERS) while the tides along the English Channel boundary are determined from 14 tidal constituents obtained from BSH (S. Dick, personal communication). The surge is obtained from a NE Atlantic barotropic surge model. For temperature and salinity at the open lateral boundaries, the ICES T/S monthly climatology is used (Janssen et al., 1999); a sponge layer acts as a buffer zone between the inner model domain and the prescribed T/S boundary values. The gradient of the vertically integrated pressure (through density variations from the prescribed T/S fields) along the open boundary gives rise to a baroclinic increment in the sea surface elevation. Based on a previous European project (i.e. MERSEA WP10) , the choice of using lateral T/S and related baroclinic water level correction from climatology has shown advantages in describing Atlantic inflow into the North Sea and the related high-saline tongue reaching into Skagerrak over using dynamical T/S boundaries from the MERSEA NE Atlantic model.

A total of 79 rivers are applied in this region. Daily river run-off is obtained from BSH for the major rivers in the southern North Sea. For the rest of the rivers in the North Sea, climatology run-off is used. For the Baltic region, the daily river run-off from 1990-2008 is obtained from a hindcast simulation of the HYPE model for the entire Baltic Sea runoff basin (http://balt-hypeweb.smhi.se/). The run-off data in 2009 is obtained from an operational hydrological model provided by the Swedish Meteorological and Hydrological Institute (SMHI). The temperature of the river run-off is not available and therefore river inflows are prescribed with a temperature equal to the ambient ocean water. The river inflow to the model is fresh water of zero salinity.

The ecological model ERGOM (Neumann, 2000) has been further developed with the 3D application in the North Sea and the Baltic Sea through previous European and national projects, such as ECOOP, MYOCEAN and ModREC (Wan et al., 2011). The open boundary conditions for nitrate, phosphate and DO are configured with the data of WOA01 and the rest state variables are set with zero. River loadings (total N and total P) are taken from the same sources as for the runoff.

Table 2. List of atmospheric surface variables used for HBM at DMI

Name	code	Level	Description	Unit	Resolution
MSLP	1	0m	Mean sea level pressure	Pa	Every 3 h
TEMP2	11	2m	2-m temperature	K	Hourly
U10	33	10m	10-m zonal wind	m/s	Hourly
V10	34	10m	10-m meridional wind	m/s	Hourly
Q2M	51	2m	2-m specific humidity	Kg/kg	Every 3h
ACLCOV	71	105 (0m)	Total cloud cover	-	Daily

Black Sea (METU)

The hydrodynamic model applied to the Black Sea is the Princeton Ocean model (POM; Blumberg and Mellor, 1987) expressed in Cartesian coordinates in the horizontal direction and terrain following sigma coordinates in the vertical. The model has 7 km horizontal resolution and 26 – sigma levels which are compressed towards the surface and bottom. The atmospheric forcing used for the regional ocean model of the Black Sea is given by data from the DMI regional climate model provided for OPEC and described above. The data used for this particular model configuration is summarised below in Table 3.

Because the Black Sea is a semi-enclosed basin, the lateral boundary conditions are no-slip and zero heat flux and salt fluxes everywhere except at the mouths of the Bosphorus and Kerch strait, and the 9 largest rivers surrounding the Black Sea (listed in Table 4). Here temperature and salinity boundary conditions are specified as inflow conditions. Diffusive heat and salt fluxes are set to zero in the straits outflow points.

The three largest rivers surrounding the Black Sea are the Danube which contributes about half of the total river input to the basin, and the Dniester and Dnieper which together contribute 1/6 of the total river input. Exchanges through the Danube and Kerch Straits and inflows from the Danube, Dniester and Dnieper are defined by monthly mean volume flux time series that currently extend to 2005. Nitrate and Phosphate concentrations from the Danube, Dniester, and Dnieper are also available as monthly mean time series extending until 2005. Volume fluxes and nutrient concentrations of all other rivers inputs are defined by monthly mean climatologies as time series are not available. This data was collated within the framework of the MEECE FP7 programme.

Table 3. List of atmospheric surface variables used for the ocean model at METU

Name	Code	Level	Description	Unit	Resolution
U10	33	10m	10-m zonal wind	m/s	Hourly
V10	34	10m	10-m meridional wind	m/s	Hourly
TS	11	0m	Sea surface temperature	K	Hourly
APRL	62	0m	Large scale precipitation	mm/h	Hourly
APRC	63	0m	Convective precipitation	mm/h	Hourly
SRADS	111	0m	Net SW radiation at surface	W/m2	Every 3h
TRADS	112	0m	Net LW radiation at surface	W/m2	Every 3h
AHFL	121	0m	Surface latent heat flux	W/m2	Every 3h
AHFS	122	0m	Surface sensible heat flux	W/m2	Every 3h
EVAP	057	0m	Evaporation	m/s	Every 3h

Table 4. Rivers included in Black Sea model domain, T=temperature, S = salinity, VF = volume flux, Po = phosphate, Ni = nitrate.

River	Data Type	Data frequency
Bosphorous	T,S,VF	monthly (1990-2005)
Kerch	T,S,VF	monthly (1990-2005)
Danube	VF,Po,Ni	monthly (1990-2005)
Dniester	VF,Po,Ni	monthly (1990-2005)
Dnieper	VF,Po,Ni	monthly (1990-2006)
Kodori	VF,Po,Ni	monthly climatology
Inguri	VF,Po,Ni	monthly climatology
Rioni	VF,Po,Ni	monthly climatology
Yesilirmak	VF,Po,Ni	monthly climatology
Kizilirmak	VF,Po,Ni	monthly climatology
Sakarya	VF,Po,Ni	monthly climatology

Mediterranean Sea (HCMR)

The atmospheric forcing for the hindcast simulation of the HCMR Mediterranean coupled hydrodynamic/biogeochemical model (~10Km resolution, 30.25^{o} N - 45.75^{o} N and 7.0^{o} W - 36.0^{o} E) is obtained from the regional climate model HIRHAM5 simulation that is provided by DMI (Table 5). The momentum, heat and freshwater fluxes at the air-sea interface are calculated using hourly fields of wind velocity (10m), relative humidity (2m) (calculated from 2m-specific humidity and mean sea level pressure), air temperature (2m), precipitation, net incoming short wave radiation and incoming long wave radiation, based on the bulk formulae set described in Kourafalou and Tsiaras (2007).

Before the hindcast simulation, the hydrodynamic model was first initialized with MODB-MED4 temperature and salinity and then integrated perpetually for 19-years, adopting a monthly mean climatological forcing, derived from ECMWF (6-hour, 1^{o} x 1^{o}) re-analysis atmospheric dataset (Korres and Lascaratos, 2003). The initial conditions for dissolved inorganic nutrients (nitrates, phosphates, silicates) were obtained from the Medatlas 2002 climatology (http://www.ifremer.fr/medar/)), while the coupled model was initially integrated for a 5-year spin-up period.

Average water discharge and dissolved nutrient loads for major Mediterranean (Po, Rhone, Ebro, Nile) along with Greek (Axios, Evros, Strymon, Nestos) and Turkish (Gokso, Seyhan) rivers, were adopted from hydrological/nutrient emission modelling of the Mediterranean drainage basin (Ludwig et al., 2009, Dumont et al., 2005), provided within EU-SESAME project. River inputs of dissolved and particulate organic carbon, silicate and ammonium were based on available data from the literature (Soulikidis et al., 1993 for N. Aegean Rivers; Moutin et al., 1998 for river Rhone; Deggobis et al., 1990 for river Po). Average river inputs of alkalinity and dissolved inorganic carbon were obtained from GEMS/GLORI database (http://www.gemswater.org/publications/index-e.html) and available data from the literature (Skoulikidis et al., 1993, N. Aegean rivers).

The Dardanelles water exchange is parameterized through a two-layer open boundary condition (Nittis et al., 2006) with prescribed water inflow/outflow and salinity, adopting climatological data of seasonally varying water inflow and dissolved inorganic nutrients (Tugrul et al., 2002) and annual mean organic matter and ammonium concentrations (Polat et al., 1996; 1997). Average alkalinity and dissolved inorganic carbon concentration of the inflowing BSW was adopted from Copin-Montegut (1993).

Along the western open boundary near Gibraltar strait, the following boundary conditions are used:

- -Flather (1976) boundary condition, for the integrated (barotropic) velocity.
- -Sommerfeld radiation condition, for Baroclinic velocities.
- -Zero-gradient condition for free-surface elevation.
- -Upstream advection scheme for tracers (Temperature, Salinity, biogeochemical variables), during outflow. During inflow, temperature and salinity are prescribed from MODB seasonal climatology, while biogeochemical variables are obtained from 1-D (water column) applications of the coupled model along the boundary.

Table 5. List of atmospheric surface variables used for the ocean model at HCMR

Name	Code	Level	Description	Unit	Resolution
MSLP	1	0m	Mean sea level pressure	Pa	Every 3 h
TEMP2	11	2m	2-m temperature	K	Hourly
U10	33	10m	10-m zonal wind	m/s	Hourly
V10	34	10m	10-m meridional wind	m/s	Hourly
Q2M	51	2m	2-m specific humidity	Kg/kg	Every 3h
ACLCOV	71	0m	Total cloud cover	-	Daily
TS	11	0m	Sea surface temperature	K	Hourly
APRL	62	0m	Large scale precipitation	mm/h	Hourly
APRC	63	0m	Convective precipitation	mm/h	Hourly
SRADS	111	0m	Net SW radiation at surface	W/m2	Every 3h
TRADSU	115	0m	Downw./Upw. LW radiation at surface	W/m2	Every 3h

Mediterranean Sea (OGS)

At OGS, the hindcast simulation of the Mediterranean Sea will be forced by the MyOcean product produced by the MFS OGCM running at INGV, which uses the OCEANVAR data assimilation scheme and was forced by Medium-Range Weather Forecasts (ECMWF).

Available riverine inputs and open ocean boundary conditions data for the OGS Mediterranean Sea biogeochemical model are described. A Newtonian dumping (D) term regulates the Atlantic buffer zone that is outside of the Strait of Gibraltar:

$$D^N = \frac{1}{\tau}(c_i^D - c_i^t)$$

where τ is the time scale of the relaxation, and the model tracer concentration c_i is relaxed to the seasonally varying value c_i^D, which is derived from climatological MEDAR-MEDATLAS data (phosphate, nitrate, silicate, dissolved oxygen) measured outside Gibraltar.

Atmospheric deposition rates of inorganic nitrogen and phosphorus were set according to the synthesis proposed by Ribera d'Alcalà et al. (2003) and based on measurements of field data (Loye-Pilot et al., 1990; Guerzoni et al., 1999; Herut and Krom, 1996; Cornell et al., 1995; Bergametti et al., 1992). No distinction is made between dry and wet depositions, and all of the deposited nutrients were considered to be bio-available. Atmospheric deposition rates of nitrate and phopshate were assumed to be constant during the year, albeit with different values for the western and eastern sub-basins. The rates were calculated from estimates reported by Ribera d'Alcalà et al. (2003). Nutrient load from rivers and other coastal nutrient sources were set based on the reconstruction of the spatial and temporal water discharge variability estimated following the method described by Ludwig et al. (2009).

These values are based on available field data for nutrient concentrations, climate parameters that have been available since the early 1960s, and on model results for areas that are not covered by the data accounts for 37 rivers. The nutrient discharge rates for the major rivers (Po, Rhone and Ebro) take into account seasonal variability on a monthly scale and are calculated on the basis of direct observations. All other inputs are treated as constants throughout the year due to a lack of associated data.

Table 6. List of boundary conditions

Model	**Open boundary**	**River input**	**Surface boundary**
OPATM-BFM (1/8 bio+carbonate system)	Location:Gibraltar Nutrients: MEDAR MEDATLAS 2002 dataset (seasonal) Phosphates, nitrates, Silicates, Oxygen DIC: Westernmost profile from METEOR 51 cruise ALK: FICARAMII cruise (eastern Atlantic profiles)	Nutrients:PO4,NO3,SiO4 Sesame dataset No. of rivers:37+Bosphorus Diffused sources: Y	Nutrients:PO4,NO3 from climatological estimates

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