Modelling in the North East Atlantic

by the group at PML (Plymouth Marine Laboratory) and Cefas, UK

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Data Providers

A suite of physical and lower trophic level models have been developed at **Plymouth Marine Laboratory** (PML), an International Centre of Excellence in Marine Science & Technology and a Collaborative Centre of the UK Natural Environment Research Council. The modelling group is led by Professor Icarus Allen.

Higher trophic level modelling in the NE Atlantic was carried out by **Centre for Environment, Fisheries and Aquaculture Science** (Cefas), an Executive Agency of the UK Department for Environment, Food and Rural Affairs (Defra), led by Dr Jonathan Beecham.

Regional summary

The applied North East Atlantic region spans the area from 40˚ to 65˚ North in latitudinal direction (approximately Lisbon to Iceland) and from 20˚ West to 13˚ East in longitudinal direction (Iceland to the Belt). This vast area spans across the entire North West European shelf and ranges from estuarine and coastal waters over typical shelf seas (like the North Sea or the Celtic Sea) to parts of the deep North Atlantic Ocean basin. The region can largely be described as a seasonally stratified, downwelling shelf sea system with a net inflow of surface waters and a net outflow on the sea floor across the shelf break into the deep Atlantic with a generally anti-clockwise circulation of the North-Sea. It is further characterized by two strong northward currents (the slope current along the shelf break and the current along the Norwegian trench), that enclose the Northern part of the shelf. Local conditions in the area can be highly diverse due to strong tidal dynamics, riverine inflow and the interface with the brackish waters of the Baltic Sea.

The biogeochemical dynamics on the shelf are the result of an interaction of nutrient supply largely controlled through the inflow of oceanic surface waters (Holt et al. 2012) and riverine inputs (Lenhart et al. 2010), depletion as a result of production and the seasonal stratification and light limitation. The Southern North Sea has been shown to be phosphorus limited while in the large part of the rest of the domain Nitrogen appears to be the limiting nutrient (e.g. Skogen et al., 2004). The growing season on the shelf is generally characterised by a long sustained growth over the light period of the year controlled by grazing of zooplankton, particularly in the second half of the season. However, the complex dynamics and heterogeneous conditions particularly in the near coastal areas with significant anthropogenic impact can lead to strong local variations like eutrophication events fuelled by high riverine discharges of nutrient rich water up to anoxic state. Off the shelf the system shows more oligotrophic conditions with marked spring blooms launched along the shelf break.

The result of these environmental factors is a diverse fauna of commercial fish species: cod, haddock, saithe, herring, sandeel, flatfish such as plaice and invertebrates including crabs, lobsters and nethrops and marine mammals and sea birds. Most of these species have abundance gradients across the North Sea, necessitating spatial modeling to characterize food web composition. There are many human inputs in the North Sea system including pollution and nutrients from rivers, fishing and a variety of industrial activities such as mineral extraction in the North Sea and along its coasts.

Justification of model selection

The model deployed for the hydrodynamic and lower trophic level component of this area (including data assimilation) is the coupled POLCOMS-ERSEM system, a well-established system subject to numerous peer-reviewed scientific publications (Allen et al. 2001; Siddorn et al. 2007; Holt et al. 2012) and applied in a variety of international research projects covering subjects from operational forecast over climate change projections to impact studies, such as ocean acidification or fisheries management. This system was preferred over the next generation operational model due to its robustness and efficiency, two elements that are crucial for the data assimilation component within this project involving the computational heavy Ensemble Kalman Filter.

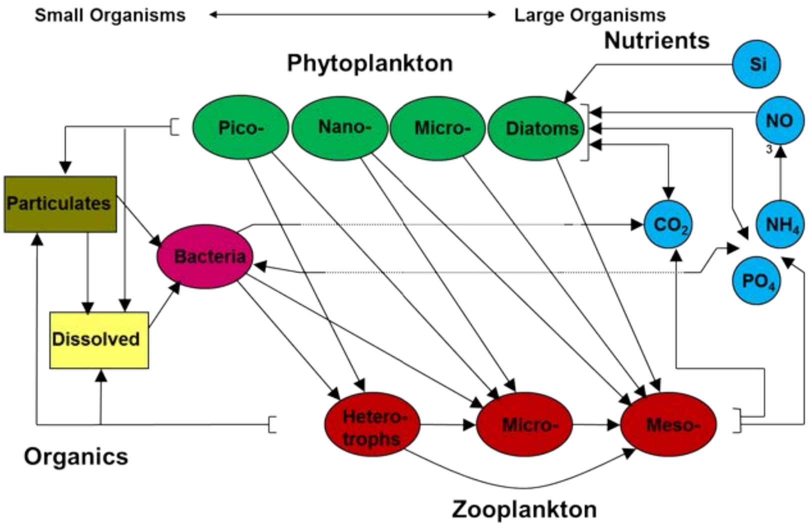
The size based model encompasses two linked size-spectra: a pelagic spectrum and a benthic detritivore spectrum (Blanchard *et al*., 2009). The pelagic spectrum comprises primary producers (plankton) and pelagic predators (i.e. fish). The size based model is therefore able to link the dynamics of the lower trophic levels (plankton and benthic detritivores) and higher trophic levels (pelagic predators). Previous studies with the model have shown that the model captures the trophic interactions that occur in many aquatic ecosystems. The biological processes underlying growth and mortality in the model have led to patterns consistent with data from the North Sea.

The EwE (Ecopath with Ecosim) model (Christensen et al. 2005) has been chosen because of its ability to handle large food webs (66 species / functional groups for the Cefas North Sea Model) and its ability to find a balance point between the flows of energy into and out of a group without giving rise to an unstable attractor round the equilibrium point. The spatial model: Ecospace will be used to encapsulate the various gradients contained within the North Sea. Linking to the LTL model will be accomplished using Couplerlib which uses a managed interface using xml metadata to transfer data between models.

Hydrodynamic model

The hydrodynamic component (POLCOMS) is a 3D baroclinic finite difference model which uses an Arakawa-B grid in the horizontal and sigma coordinates in the vertical. This choice of grid, the decision not to model explicitly the horizontal diffusion and the use of a sophisticated horizontal advection scheme – the Piecewise Parabolic Method– combine to give the model good fronts conserving properties (Holt and James, 2001).

Lower Trophic level model



Simplified Model Diagram - ERSEM (pelagic part)

The model for the lower trophic level (ERSEM, Blackford et al. 2004) is a functional type based model with 4 classes of phytoplankton, 3 classes of zooplankton, bacteria, dissolved and labile organic matter (DOM) and 3 classes of particulate organic matter (POM). The dynamics of the main chemical constituents of the coastal marine system carbon, nitrate, phosphate ammonium and silicate are uncoupled allowing for fully dynamic stoichiometric ratios. In addition, the dynamics of the compound chlorophyll-a are resolved explicitly based on a photo-acclimation model driving dynamic chlorophyll-a to carbon ratios of the phytoplankton. The benthic system resolves the dynamics of filter and suspension feeders, meiobenthos, aerobic and anaerobic bacteria and the benthic cycles of Nitrogen, Phosphorus, Silicate, Oxygen and Carbon. The parameterisation in this study is identical to the one presented in Blackford et al. (2004), apart from a lowered chlorophyll-a to carbon ratio.

Higher trophic level models

The size based model runs on a daily time step, though results are provided on a monthly average scale. Growth rates of the benthic detritivores and pelagic predators are dependent on feeding rates and temperature values provided by the hydrodynamic model (POLCOMS). The benthic detritivores eat from a ‘pool’ of detritus which is treated as non-size structured shared resource. The pelagic predators eat from the plankton and predator parts of the pelagic spectrum and from the benthic detritivore spectrum. Food preference of the pelagic predators is determined by the prey size preference of the predator. Plankton and detritus abundance at each time step is taken from the output of ERSEM (Baretta et al. 1997) and used to feed the size based communities. Used phytoplankton groups from ERSEM include diatoms, flagellates and picoplankton. Two zooplankton groups (microzooplankton and heterotrophic nanoflagellates) are also included but are considered as part of the predator part of the pelagic spectrum due to their size. The size based model is run in each ICES rectangle (1 degree longitude by 0.5 degree latitude) to co-incide with the spatial resolution on which fisheries observations are usually gathered. The scale of the output from ERSEM is finer than the scale of the size based model so it is necessary to integrate the ERSEM outputs over the appropriate area. The size based model outputs the abundances at size of the pelagic and benthic detritivore spectra. This allows size structured community indicators such as the proportion of large organisms (e.g. the large fish indicator), the slope of the community and the mean weight of organisms in the community to be calculated. For the pelagic spectra these metrics can be compared to empirical survey data collected. The model also provides information on the local relative importance of the pelagic food chain versus the benthic food chain, and therefore whether the main carbon pathway is via the faster pelagic route or the slower (due to lower food quality) benthic route.

North Sea Ecopath Model: This Ecopath / Ecosim / Ecospace model (Mackinson & Daskalov 2007) had 65 functional groups as follows: 4 mammal bird groups, 8 sharks and Rays, 15 demersal commercial fish, 6 small pelagic fish, 11 demersal flatfish, 5 miscellaneous fish groups, herbivorous, carnivorous, phytoplankton, icthyoplankton and microbial groups, 9 commercial and non-commercial invertebrate non-plankton groups. In addition there were groups for detritus and discards. The Ecosim model describes the interactions between the ecosystem components in terms of:

- The diet composition of predators
- Rates of production and consumption of energy by each group
- The vulnerability of the prey to each predator e.g. what proportion of the prey pool is available to the predators at different times.
- The starting biomass of each species
- Natural mortality
- There is a fishing model which describes the fishing mortality of each group / species by any of a number of fleets.
- The spatial model defines cells of the habitat in terms of suitability in terms of predation rates, related to depth and habitat type, diffusion and areas of fishing activity.

The connection between the HTL and LTL components is via couplerlib. This links the EwE groups to the LTL functional groups in the netCDF input file in which the LTL model is stored. It also synchronizes the timestep between models, reprojects the grid and converts units between multiple models where necessary.

Variables read in through Couplerlib (mg / m^3 unless stated):

Z3 – Carnivorous Zooplankton

Z4 – Omnivorous Zooplankton

Z5,Z6 – Microzooplankton : Combine to make

B – Bacteria : Planktonic Microfolora EwE group

P1,P2,P3,P4 – Phytoplankton Combine to a single Phytoplankton EwE group

R1, R6 – Detritus groups

SDp – depth (m)

ETW – temperature (deg C)

ESW – salinity (psu)

Data Assimilation

The data assimilation system for the North East Atlantic system is based on the Ensemble Kalman filter (EnKf; Evensen, 1990; Evensen, 2003), applied following Ciavatta et al. [2011], and using an ensemble of 100 members.

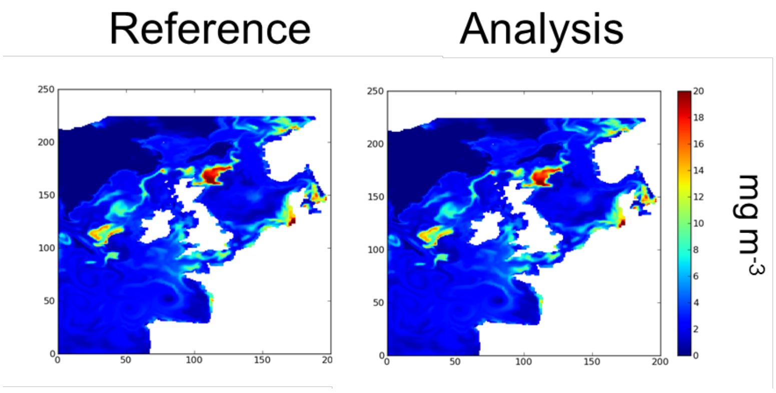
The system assimilates surface chlorophyll observations from satellite and “analyses” (i.e. updates directly) 39 ERSEM variables out of the 49 of the full state vector. The remaining 10 variables are updated through the model equation during the simulation runtime (“forecast” step).

We apply a localized EnKF (Evensen, 2003), i.e. the analysis is carried out grid point by grid point by processing data within a spatial “radius” around the grid point.

State variables and observations are log-transformed prior to the analysis, and then exponentially back-transformed, to guarantee the positiveness of the state corrections.

Model error is accounted for by the random perturbation of the model forcing, namely the incident irradiance field. A Gaussian perturbation with standard deviation equal 20% of the irradiance value is added during the model simulation step. Furthermore, model error is added to all the analyzed variables prior to the assimilation step, as white noise drawn from a distribution of pseudo-random fields with error equal to 10% of the value of the variables.

The data assimilation system was tested in a “twin-experiment” within OPEC. In this experiment, the model was run in a one year long reference simulation, without stochastic perturbations of the light field. This run produced twelve monthly, surface fields of chlorophyll data. The DA system was then applied in a one year long simulation to assimilate these chlorophyll fields, as they were satellite products. The “twin-experiment” demonstrated the correct implementation of the DA system and its numerical stability, as exemplified by the output shown in Figure below . As you can see, the analysis output reproduced the assimilated reference chlorophyll distribution in the North-East Atlantic in April 2000.



Example of the output from the twin experiment: surface distribution of the chlorophyll concentration in the North-East Atlantic in April 2000. The left panel shows the assimilated reference values, the panel on the right shows the analysis output of the data assimilation system.

Forcing and Boundary Conditions

The model is forced by meteorological data from a regional atmospheric model provided by DMI within this project and the GLORYS reanalysis at a ¼ provided through the MyOcean project as boundary conditions for temperature, salinity, currents and sea surface elevation. Light attenuation by non-biotic component and particulate organic matter is simulated as in Wakelin by forcing the related attenuation coefficient with a climatology of its adsorption coefficients (neglecting the impact of backscatter) derived from satellite data (1998–2007 from the Sea-viewing Wide Field-of-view Sensor Project — SeaWiFS) using the algorithm developed by Smyth et al. (2006).
Input from rivers and from the Baltic Sea is explicitly accounted, updating at every timestep the height, the salinity and the concentration of 3 nutrients, DIC and TA of all s-layers of the receiving cell following a simple mass balance.

Riverine nutrient loads are from Lenhart et al. (2010), while the Baltic inflow is treated crudely as an inflow source using a mean annual cycle of depth averaged transport, salinity and nutrients. Flow and salinity are derived from the Danish Hydrographic Institute DYNOCS experiment (more detail in Holt and James, 2001). Nutrient concentration has been calculated imposing a sinusoidal cycle between the winter and summer value of depth averaged nutrients measurements. Open ocean boundary conditions for nutrients, oxygen, DIC and alkalinity are taken from World Ocean Atlas climatology.

Both HTL models are forced using the outputs of the Lower trophic level ERSEM model. This provides the initial abundances of the lower trophic levels at each time-step. The time-step is daily data over 40 layers, of variable width in an area from 51 – 60 deg N and -5 to +8 deg East. Data is daily timestep from January 2000. Critical forcing species are Mesozooplankton and Phytoplankton. Since the emphasis of the OPEC project is on short term effects of weather on fish populations, the EwE component will only model the effect of pelagic connections.

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