Project information

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Ecosystem modeling of the Arctic Ocean around Svalbard
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Summary of Results

Introduction

This introduction repeats the text presented in the previous report in order to provide the proper context for the remaining of this report.

Activities planned for 2015 are:

(i) Collection of available data for model parameterization, calibration and validation;
(ii) Implementation of biogeochemical subroutines with EcoDynamo, for ice algae and ice biogeochemistry and zooplankton physiology with the Dynamic Energy Budget (DEB) approach;
(iii) Integration of the CICE model or, alternatively, the ice sub-model of the Regional Ocean Modeling System (ROMS) in the SYMBIOSES platform;
(iv) Coupling of EcoDynamo – an object oriented ecosystem modeling software - and other biogeochemical sub-models with ROMS;
(v) Start of model testing and calibration.

During the first seven months of the current year we worked mostly on activities i) and iv). Regarding the former, we took advantage of the N-ICE2015 cruise, during which a significant amount of data was collected in the Arctic Ocean regarding physical, chemical and biological variables and processes in the sea water and in the sea ice. Amongst this data, it is important to emphasize that obtained from experimental work with phytoplankton and ice algae, to measure photosynthetic rates as a function of light intensity and under different nutrient concentrations, and with zooplankton, to measure respiration and excretion rates of main Arctic meso-zooplankters. These experiments allowed to obtain an important number of physiological parameters that will be incorporated in the ecosystem model under development in the current project.

In what concerns (iv), we managed to couple the Regional Ocean Modeling System (ROMS) (https://www.myroms.org/) with EcoDynamo (Pereira et al., 2006). This was one of the most challenging and important goals of the project. After gaining some experience with the biogeochemical models available in ROMS, such as the Powell and the BESTNPZ, we found out some serious limitations such as: (i)

representation of some biogeochemical processes based on outdated paradigms; (ii) **lack of modularity to combine or to add to one of the available models the most adequate simulation algorithms from different models described in the literature**.

ROMS biogeochemical models are implemented as long subroutines that resolve sequentially the marine food web and some biogeochemical processes. Therefore, replacement of a calculation method by another one implies changing the subroutine. The methodology we followed here is to call EcoDynamo object subroutines from a ROMS biogeochemical model to resolve specific processes. This approach has several advantages such as: (i) **EcoDynamo includes a large number of biogeochemical processes and alternative ways to calculate them**; (ii) **The inheritance and polymorphic properties of objects allows reusing the same object with different parameters and with a minimum programming overhead**. For example, let's suppose that it is necessary to include more than one phytoplankton species group in the ROMS version of the Powell model. This implies changing the corresponding subroutine, adding the code for the new phytoplankton group or, as a minimum, introduce some code changes to rerun the phytoplankton part of the code as many times as phytoplankton groups are defined, even if the simulated processes for each group are exactly the same. In the case of EcoDynamo, it is necessary to "construct" and initialize a pointer to the same object as many times as different phytoplankton groups are to be simulated and each time a different set of parameters is associated with each instance of the object. Unlike subroutines, that reinitialize their parameters every time they are called, objects "memorize" their properties. Knowing the memory addresses of each pointer, object properties, parameters and variables may be accessed at any time during a simulation. Therefore, each time the object functions are called there is no need to send arguments with the values of object "local" parameters but only the memory address of the object being used and the variables that are relevant for object calculations and that are changed elsewhere in the code. So, if, at some point, it is decided to change the algorithm used for some process, another object may be called from ROMS and this implies only changes in compiling directories and, at most, one line of code creating a pointer to a different object. This easiness of incorporating new object functions and changing available ones adds to the modularity of these mixed code subroutines and to their flexibility for usage in different simulations.

EcoDynamo was originally developed to be used as a standalone modeling software, coupling physical and biogeochemical processes and running in Windows, with a user friendly interface. It was implemented using C++ and an object oriented methodology. Different functional groups or important processes are represented by different objects. Thermodynamic objects calculate energy exchanges between the water and the atmosphere. Hydrodynamic processes are simulated by objects that encapsulate equations and variables to solve the primitive and the continuity equations. Biogeochemical cycles are simulated by objects that include mineralization, nitrification, denitrification and other relevant processes. Phytoplankton objects simulate physiologic and population level processes explaining growth and biomass decay. The same applies to many other functional groups such as ice algae, zooplankton, macroalgae, shellfish, finfish, etc. Objects also encapsulate interactions with other objects to account for trophic relationships and feedbacks with the biogeochemical cycles. Furthermore, properties that are dissolved or suspended in the water are transported by physical processes, simulated by the hydrodynamic objects. Each object is represented by a number of variables, parameters and methods that define and control their behavior. During a model run, these methods are called sequentially and calculated by independent subroutines or functions. EcoDynamo was used to implement fully coupled physical-biogeochemical models for several coastal ecosystems such as Ria Formosa coastal lagoon (Duarte et al., 2007; 2008), the Douro estuary (both in Portugal) (Azevedo et al., 2010; 2014) and Ria de Ares-Betanzos in Galicia (Spain) (Duarte et al., 2014) and aquaculture systems (Serpa et al., 2012; 2013a). It was also used to implement models for several species or groups of species allowing their possible later inclusion in ecosystem models, such as mussels (Duarte et al., 2010; 2012), finfish (Serpa et al., 2013b) and ice algae (Duarte et al., 2015a).

Since the beginning of EcoDynamo implementation, one of the goals was to make it possible to link its objects with other modeling environments. Therefore, a methodology was developed and tested (Pereira et al., 2006) whereby EcoDynamo objects were coupled with COHERENS (Luyten et al., 1999) – a 3D marine coastal model implemented in Fortran. This served to show that coupling could be achieved and helped defining some "general rules" to mix Fortran code based on structured programming with C++ code based on object oriented programming.

Considering the overall goal of the present project –implement a fully coupled physical-biogeochemical model to simulate the Arctic Ocean – the magnitude of the spatial domain and the time resolution requirements demand the usage of super computer facilities. Therefore, one of the first tasks was to have a Linux version of the EcoDynamo software that could run in the supercomputers available through Notur - The Norwegian metacenter for computational science (https://www.notur.no/about). This was accomplished in a previous Fram Centre project - **Coupling different modeling platforms: an activity across Fram Centre Flagships** – that took place in 2013-2014, during which EcoDynamo was coupled with SINMOD using SYMBIOSES as the model coupler. The results achieved then and the availability of a three dimensional circulation and sea-ice model for the Arctic Ocean, implemented with ROMS in another Fram Centre project (**Mesoscale modeling of ice, ocean and ecology of the Arctic Ocean**), stimulated the elaboration of the present project. One of the challenges was to couple EcoDynamo with ROMS, as a way to deal with some of the limitations found in available biogeochemical code for ROMS (see above). Therefore, two coupling options were considered: (i) ROMS provide the velocity field used by other models that receive the corresponding data through the SYMBIOSES platform and perform the relevant transport calculations in their own spatial grids; (ii) ROMS "transport" all "pelagic" variables using its transport equation by receiving data from the other models. The experience gained during the first year of the present project lead to the conclusion that option (i) is not efficient for variables that are calculated all over the model grid, such as those related with the biogeochemical cycles and lower trophic levels, and that are computationally very demanding, using the same spatial and temporal resolution of the circulation processes. However, it may be a good option to handle higher trophic levels that, most likely, will require different spatial and temporal resolutions due to the spatial and time scales associated with their life cycles. Thus, option (ii) seems to be more adequate to couple biogeochemical cycles and lower trophic levels with circulation processes. In fact, this is the type of approach followed in ROMS.

Technical description of performed activities

Technical coupling details of EcoDynamo with ROMS were given in the previous report. Most of the work developed since the last report consisted in coupling more biogeochemical processes in order to construct, step-by-step, an ecosystem model with the specifications provided in the project proposal. Some modifications were implemented in the coupling methodology in order to take advantage of the iso_c_binding standard available since Fortran 2003 and now supported by most compilers of interest (ifort and GFortran). This standard facilitates interoperability between C and fortran types, variables, and procedures. Therefore, a new interface module was created (ecodynamo_cpp.F) that is used by all ROMS subroutines that access EcoDynamo functions. This module contains an interface to each of these functions as exemplified below.

This interface includes the function name, its arguments, the “BIND(C)” instruction and the definition of variable types used in the arguments. This allowed simplifying the name conventions of the EcoDynamo interface functions called from ROMS, removing the previous underscore at the end of each function name. Now the function name (phytoplankton_go in the example above) if exactly the same used in the EcoDynamo C code. This is a standard Fortran/C interface that makes our code more transparent for future users. All remaining coupling details are as described in the previous report.

The model is now being intensively tested to debug the code and correct any errors. Also, more processes are being added such as inorganic carbon chemistry, relevant for pH and ocean acidification simulations, and oxygen biogeochemical cycle and those listed in the previous report.

A project workshop was organized at the Norwegian Polar Institute, between the 30th of October and the 2nd of November, where all project partners participated. During the workshop, access to the coupled ROMS-CICE system, implemented within the project “**Mesoscale modeling of ice, ocean and ecology of the Arctic Ocean”,** was granted by Tore Hattermann (leader of the mentioned project) so that we may integrate in this code version all the changes done regarding the biogeochemical coupling towards a ROMS-CICE-EcoDynamo coupling system.

A collaboration agreement was established with the Los Alamos National Laboratory in the USA to start using a columnar version of the CICE model and testing biogeochemical processes with it. This vertically resolved model will be tested with data collected during the N-ICE2015 project for later inclusion (in a 3D mode) in the coupled ROMS-CICE-EcoDynamo model.

During the workshop other coupling solutions were discussed such as the usage of the Framework for Aquatic Biogeochemical Models (FABM) (http://sourceforge.net/projects/fabm/).

Project activities until the end of the year

Until the end of the year we plan to add EcoDynamo objects to simulate the biogeochemical cycles of nitrogen, phosphorus, oxygen and carbon and an ice algal object. We also plan to add another phytoplankton object to make it possible to simulate simultaneously the two main phytoplankton groups present in the Arctic Ocean: diatoms and dinoflagellates. Each new addition requires some code writing in Fortran and in C, compilation and linking procedures and test runs to check for possible errors. A “hands on modeling” meeting is scheduled with other project partners for the end of October to conclude the inclusion of some of the biogeochemical components mentioned above, with emphasis on the carbon cycle.

Another important aspect is to start defining boundary and initial conditions for the ecosystem model of the Arctic Ocean, regarding the newly included chemical and biological variables, to allow for realistic simulations and model tests. This is dependent on gathering information from several databases and scientific publications and it is also an ongoing task. All this preparatory work should be as completed as possible until December for we plan to carry on model calibration and validation during 2016, according to the project proposal.

Finally, the “mixed” modelling approach, using ROMS and EcoDynamo will be evaluated in terms of the time overhead associated with the usage of different EcoDynamo objects. This may be easily done by switching on/off the calls to EcoDynamo routines in different simulations and measuring the CPU time required to perform simulations with the same temporal domain.

Dmitri Shcherbin has been hired during part of 2014 and 2015 and he provided a valuable help in setting up the coupled ROMS-EcoDynamo system, organizing a GIT project to keep track of all software changes and producing a large number of Python functions for graphical output of model results.

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For the Management

Synthesis

The following table was taken from the project proposal and it summarizes the workpackages (WPs) planned for 2015 and 2016. WP1 and 2 are completed. In fact, a paper was published at the beginning of this year (Duarte et al. 2015a), describing an ice algal model implemented with EcoDynamo. Activity 4 shall be completed until the end of the year, following the work described in detail above. Activity 3 depends mostly on the UiT partner. Recently, there was a change of staff at the UiT that may lead to some delay of this activity. Activity 5 is a sort of ongoing one as more processes and variables are integrated in the model. We plan to start working with model calibration and validation in 2016.

We plan to submit a paper to a scientific journal until the end of the year describing and discussing the "mixed" model methodology described above. Also, posters and oral communications are planned to the Forum for Arctic Model and Observational Synthesis (FAMOS) Workshop, 4 – 5th November, and to the FRAM Science Days, 10-11th November.

A paper was published in the 2015 Fram Forum describing most of the modeling work developed in this project (Duarte et al., 2015b).

WPs	Task and partners involved	2015				2016			
1	Collection of available data for model parameterization, calibration and validation (NPI)	X	X	X	X				
2	Implementation of biogeochemical subroutines with EcoDynamo, for ice	X							

	algae and ice biogeochemistry and zooplankton physiology with the DEB approach (NPI)								
3	Integration of the CICE model or, alternatively, the ice sub-model of ROMS in the SYMBIOSES platform (UiT)	X	X						
4	Coupling of EcoDynamo and other biogeochemical submodels with ROMS (AKV, NPI and NIVA)	X	X	X					
5	Full model testing and calibration (NPI, AKV, UiT and NIVA)			X	X	X			
6	Model validation (NPI and AKV)						X	X	
7	Model usage for hypothesis testing (NPI and AKV)								X
8	Reporting (NPI, AKV, UiT and NIVA)				X				X
9	Outreach (NPI)				X				X

Published Results/Planned Publications

Published

Duarte, P., Assmy, P., Hop, H., Spreen, G., Gerland, S., Hudson, S.R., 2015a. The importance of vertical resolution in sea ice algae production models. J Marine Syst 145: 69-90. http://dx.doi.org/10.1016/j.jmarsys.2014.12.004.

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Planned until February 2016

Duarte et al. A methodology for merging structured and object oriented modeling platforms.

Communicated Results

The following talks included a synthetic description of the modeling work developed during the ArctisMod project in relation to the N-ICE2015 project.

Duarte, P., Assmy, P., Hop, H., Kauko, H., Fernández-Méndez, M., Mork Olsen, L., Sandbu, M. and Wold, A. 2015. The Norwegian Young sea ICE cruise (N-ICE2015). 7a Portuguese Conference of Polar Sciences, 28-29 October 2015, Instituto de Ciências da Terra, Universidade de Évora

Duarte, P., Assmy, P., Hop, H., Kauko, H., Fernández-Méndez, M., Mork Olsen, L., Sandbu, M. and Wold, A. 2015. The ice associated-ecosystem studied during the Norwegian Young Sea Ice cruise (N-ICE2015) in the Arctic Ocean: preliminary results. FAMOS 2015 Meeting, 2-7 November 2015, Cape Codder Hotel, Hyannis, Massachusetts, USA.

Interdisciplinary Cooperation

This project benefits from inter-disciplinary cooperation. In fact, the modeling work done so far includes ice physicists and marine biologists. Therefore, the main disciplines involved in the project were Ice Physics and Marine Biology and Ecology. Furthermore, contacts were established with colleagues at the University of Alaska Fairbanks regarding biogeochemical modeling that, hopefully, may boost some important collaboration in the near future. Also, contacts were established with the CICE modeling team at the Los Alamos National Laboratory (USA) and the Finnish Environmental Institute.

Budget in accordance to results

Funding from the Fram Centre is fundamental to pay for the project expenses, with emphasis on labor and technical assistance. The project was not completed yet. Fram Centre funding for 2016 and 2017 is a necessary condition for completing the project. The Norwegian Polar Institute and its Centre for Ice Climate and Ecosystem have substantially contributed with in-house funding for this project. Following recommendations from the Fram Centre flagship financing this project, other sources of financing were and will be attempted.

Could results from the project be subject for any commercial utilization

No

Conclusions

The work developed so far suggests that the coupling methodology described in this report is a good solution to combine the community model ROMS with EcoDynamo, facilitating to a great extent the implementation of relatively complex ecosystem models. Also, the project work has been according to what was planned and proposed to the Fram Centre, except in what concerns the hiring of a post-doc. This was attempted last year and again this year but without success, due to the absence of qualified candidates. Therefore, we anticipate that, in case the project will be approved for following-up next year, efforts should be made to hire a technician as was done last year and also this year. This will boost our capacity to speed-up the immense technical tasks associated with the implementation of the ecosystem model.