Project information

Project title

UndersTanding and PRedicting the acidification of northern waters and its iMpacts on marine ecosystems and biogeochemistry (TRUMP)

Year

2020

Project leader

Philip Wallhead (NIVA), Solfrid Hjøllo (IMR)

Geographical localization of the research project in decimal degrees (max 5 per project, ex. 70,662°N and 23,707°E)

Task 1&2: Pan-Arctic (everywhere north of ~ 60N); Task 3: Laptev Sea (76.5–77.5N, 121–132E); Task 4: Barents Sea (68.5-82.58N, 8.0-68.4E)

Participants

Trond Kristiansen, Andre Staalstrøm, Evgeniy Yakushev, Elizaveta Protsenko, Richard Bellerby (NIVA);

Morten Skogen, Cecilie Hansen, Erik Mousing (IMR);

Gary Griffith (NPI)

Flagship

Ocean Acidification

Funding Source

FRAM

Summary of Results

Task 1: Understanding regional OA using models. Testing model output against historical and recent field data is essential for understanding the drivers of OA/climate change, for reconstructing the environmental history of organisms, and for reducing uncertainty in model projections.

During 2020, at NIVA we further developed the planktonic biogeochemical model (Nordic-ERSEM) within our A20 pan-Arctic model, adding an extra zooplankton functional group and revising the growth/grazing parameterizations. Upgrading our atmospheric forcing from ERA-Interim to ERA5 ran into technical difficulties, but we expect these to be resolved in the coming weeks.

We have also improved the methodology for producing optimal reconstructions of past variability (D1.2) and for correcting future projections. By excluding from the bias correction computation a test subset of locations where observations are available, we enabled the testing of different smoothing methods using quasi-independent observations (a form of 'cross-validation'). Of the tested methods, smoothing with an exponential kernel with bandwidth 50 km was found to give the best results, reducing e.g. the Mean Absolute Error (MAE) relative to test data for dissolved inorganic carbon (DIC) to less than half that of the uncorrected model output (see Fig. T1.1).

In related work, we have sought to develop a neural-network approaches predict OA variables (pH, total alkalinity) from more commonly-observed variables (temperature, salinity, oxygen, etc.), thus allowing to extend the coverage of the still sparsely-observed OA variables. This work came to fruition in 2020 with two published papers citing FRAM (Li et al., 2020a,b).

In 2019, IMR set up a new high-resolution OA model for Kongsfjorden, using the NORWECOM.E2E ecosystem model with the OA module. The model was using physical forcing from Sundfjord et al (2017), but the results gave some large discrepancies. Therefore, the experiment has been redone in 2020 using improved physical forcing from Torsvik et al., (2019). This forcing includes a better implementation of glacial melting and less vertical bias in both salinity and temperature. In addition to the reference and subglacial versions presented in the paper, and improved subglacial plume version has also been tested. Three different simulations using these different forcings have been done, and are in the process to be analyzed and compared to observations in the fjord.

A first exercise has been done to use the NORWECOM model to simulate different monitoring programs for OA in the Barents Sea. The results indicate that time series of OA are very dependent on where and when monitoring takes place, illustrating how models can be used to validate observations and assess their representativenes.

Fig. T1.1. Cross-validation tests of different bias-corrected methods for biogeochemical model output. (a) compares the uncorrected A20 model output (version 2b) for dissolved inorganic carbon with a test subset of observations from locations that have excluded from all bias computations; b) shows the comparison after bias correcting the model output using an exponential smoothing kernel with bandwidth 250 km, c) shows the comparison using an exponential kernel with bandwidth 50 km, and d) shows the comparison using an Cauchy kernel with bandwidth 50 km. Test observations are from latitudes >65N. Skill metrics are inserted in the top left of each subplot.

Task 2: Projecting ecosystem response and feedbacks to OA. Task 2 attempts to project the impacts of OA and climate change on Arctic ecosystems, combining data from sensitivity studies with ecosystem models. During 2020, seasonal, inter-annual and long-term changes in primary productivity have been investigated in the Barents Sea using the NORWECOM.E2E model and a regionally downscaled ocean circulation model in order to understand the primary controlling factors under climate change. The study, which will be submitted to ICES-JMS in November, showed that changes were primarily caused by changes in light availability and nutrient transport modulated by mixed layer dynamics. Skogen et al. (2014) showed that future changes in pH was primarily controlled by changes in DIC which will be directly impacted by net changes in PP. Ongoing research comparing three different ecosystem models for the Barents Sea has led to similar results, indicating an important impact of PP on seasonal and long-term carbon dynamics in the Barents Sea.

The recruitment function for Northeast Atlantic cod from Hänsel et al (2020) is implemented in NoBa. This recruitment function uses the average temperature from the Kola section as input, before being multiplied with the mortality rate calculated from process studies on Barents Sea cod (meaning a 75% reduction in the total amount of recruits). However, in the paper the whole Kola section is used, not only the southern part representing the Atlantic inflow. Due to this, we chose to calculate the timeseries offline, such that the number of polygons included in the timeseries easily can be changed. The length of the Kola section considered for calculating the average January temperature will influence the results significantly.

When comparing the temperature timeseries from ROMS to the observed temperatures at the Kola Section, it became clear that there is a relatively large temperature bias in the ROMS model, where the temperatures are lower than those observed. We therefore chose to do a bias correction, keeping the trend in the model, but adjusting the level of the forcing temperature timeseries such that it to a larger degree matches those observed. After this adjustment, the recruitment timeseries of cod produced from the recruitment time series showed a better fit to the observed ones used for fitting the recruitment function in Hänsel et al (2020).

So far, 21 different simulations are planned, and will be run before the end of the year. These can be divided into three, switching between which temperature time series is used for temperature forcing (short and long Kola section) and whether or not we're using the new recruitment forcing for Northeast Atlantic cod or the original recruitment forcing implemented in the NoBa model. In addition to the changes in recruitment, each of the set-ups will be run with different fisheries mortalities, representing fisheries mortalities for the Northeast Atlantic cod from 0.2 to 1.0. The simulations will not be run using a harvest control rule, as that was not applied in the original study. All simulations will be run using the downscaled RCP 4.5 scenario.

Fig. T2.1: Total recruitment of Northeast Atlantic cod, as a function of the spawning stock biomass (SSB; ranging from 700 000 tons to 6 000 000 tons), and the temperature at the Kola section. The figure shows that the recruitment function given in Hänsel et al (2020) peaks at around 4.5 degrees, and decreases afterwards. The temperature input is the temperature forcing file used in NoBa for calculating the recruitment.

Task 3: Local OA impacts from benthic drivers. Task 3 studies the effects (including OA) of permafrost thawing and benthic methane/alkalinity emissions on local marine biogeochemistry. In 2020 we further developed a FABM-family model BROM-BUBBLE for the bubbles dissolution-formation and rising. The model was tested against observations data on biogeochemical consequences of a controlled CO2 release experiment, carried out in Horten inner Harbor, Norway. The model results corresponded well to the observations (Fig. T3.1); a description paper with is to be submitted in 2020. The elaborated bubbles dissolution-formation and rising module is planned to be used for the CH4 seeping effects in 2021.

Fig. T3.1. Calculated changes of pH and pCO2 at 8 m depth at a transect through the leaking point positioned in the middle of 30 m transect (top) and results of measurements of temporal variability at 4 m distance from the leak.

Task 4: Tracking and forecasting OA impacts on complex multi-species interactions.

We continued to build on the Complex Adaptive Systems (CAS) framework outlined in Griffith et al. 2019, *Nature Climate Change*. First, using a novel approach we identified the species within each of the emerging core self-organizing ecological processes required to enable an Arctic food web to adapt to perturbation. Second, we extended our Bayesian approach to forecast (with uncertainty) the on-going consequences of OA and other stressors (e.g. loss of sea ice) on capacity of Arctic food webs to adapt to non-linear perturbation effects (Griffith et al., *Conservation Letters*, in review).

Results from a high resolution (4x4km) NORWECOM simulation for the period 2000-2017 have been delivered as input to the study on complex changes in resilience of food webs and multiple-species interactions.

For the Management

As climate change advances, many people have their eyes on the Arctic region. The Arctic is warming two to three times faster than the global average, and high northern latitudes are especially vulnerable to ocean acidification, requiring us to understand and mitigate the effects of climate change there earlier than elsewhere in the world. During this unprecedented change, the well-being of the ecosystems and people of the polar regions depends on Arctic resilience: the ability of the Arctic to cope with the change and adapt to it without losing the essential identity and function of the region. Also writing in ICES Journal of Marine Science Change, Gary Griffith and colleagues in a Theme Session of contributed papers show the importance of considering and developing new approaches complimentary to existing approaches to consider the non-linear and unexpected effects of OA on key Arctic public goods (e.g. fisheries).

Published Results/Planned Publications

Published 2020 (and acknowledging Fram funding where possible):

Griffith, G.P. (2020). Closing the gap between causality, prediction, emergence, and applied marine management. ICES Journal of Marine Science, 77(4), 1456–1462. doi:10.1093/icesjms/fsaa087

Li X, Bellerby R.G.J., Wallhead P., Ge J., Liu J., Liu J. and Yang A. (2020). A Neural Network-Based Analysis of the Seasonal Variability of Surface Total Alkalinity on the East China Sea Shelf. Front. Mar. Sci. 7:219. doi: 10.3389/fmars.2020.00219

Li, X., Bellerby, R.G.J., Ge, J., Wallhead, P., Liu, J., Yang, A., 2020. Retrieving monthly and interannual total-scale pH (pHT) on the East China Sea shelf using an artificial neural network: ANN-pHT-v1. Geosci. Model Dev., 13, 5103–5117. doi.org/10.5194/gmd-13-5103-2020

Planned:

Griffith, G.P et al. Emerging stable strategies of species to rapid environmental change. (*Nature Ecology and Evolution*, to be submitted next few weeks)

Yakushev et al., Modeling of biogeochemical consequences of a CO2 leak in the water column with bottom anoxia. Journal of Greenhouse Gas Control.

Wallhead et al. NERSEM: a new adaptation of the European Regional Seas Ecosystem Model for modelling high northern latitudes. Geoscientific Model Development.

Communicated Results

For Griffith, G.P (2020). In ICES News. http://ices.dk/news-and-events/news-archive/news/Pages/IJMS-themed-issue-nonlinear.aspx.

Associated cartoon:

Interdisciplinary Cooperation

TRUMP has benefited from extensive interdisciplinary cooperation, with only positive aspects. For example, in Task 1, comparisons of numerical modelling results with biogeochemical field observations disclosed weaknesses in the physical model forcing.

Disciplines included: Marine Biology, Marine Chemistry, Marine Physics, Bubble Hydrodynamics, Marine Statistical Physics, Computer Science, Oceanography, Modelling, and Complexity Science.

Budget in accordance to results

The TRUMP project is at present the only project within any of the participating institutions that is specifically aimed at modelling and projected OA changes and impacts on ecosystems. The Fram funding has also served to trigger and complement internal institutional funds that are crucial for progress in the field. The development and application of ecosystem models within TRUMP enhances the ability of the participating institutions to win funding from other sources and to contribute in future projects. Fram funding has also allowed the exploration of novel approaches, and has assisted in covering computer costs and the employment of a talented young Norwegian Researcher.

Could results from the project be subject for any commercial utilization

No

Conclusions

a) Project results have led to a new approach/paradigm for understanding how real-world food webs absorb change, recover and adapt to climate change (including cumulative effect of ocean acidification with other stressors, see Task 4). They have also given us new perspectives on weaknesses/biases in Arctic biogeochemical models (e.g. ice albedo, glacial smelting, Task 1) and sensitivities to physical forcing (e.g. of primary productivity, see Task 2) and to subsea permafrost emissions (Task 3) that in turn suggest profitable areas for future research and further improvement of model projections.

b) TRUMP has developed several new methods and analysis techniques e.g.: neural-network approaches to predict missing OA observations (Task 1), structural equation modelling of biogeochemical model output for understanding drivers of change (Task 2), a new, integrated ice-water-sediments transport and bubbles fate model for assessing impacts on Arctic marine biogeochemistry (Task 3), new analytical techniques based on complexity theory for studying multi-species interactions and OA/climate change impacts in marine ecosystems (Task 4).