

# Understanding the dynamics and change in the Arctic Ocean

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## Application for extending the HLRN project hbk00021

### Abstract

The Arctic ocean is a very important component in the global climate system. Many processes involved in the Arctic region, for example, the sea-ice albedo feedbacks, the freshwater export into the North Atlantic, the storage and release of greenhouse gases, are key factors controlling the climate variability. The Arctic ocean has been experiencing significant changes under global warming since the last decade. It is crucial to understand the changes in the Arctic climate dynamics and status and their impact on the climate on larger scales. In this annual project we plan to use the ocean model FESOM to study a few aspects of the Arctic Ocean, including the freshwater export variability and its influence, assessing and improving the Arctic ocean model performance, and understanding the dynamics of the Atlantic water circulation in the Arctic basins. Since the simulations will use relatively large meshes and involve integrations on multidecadal scales, our work will strongly benefit from the availability of resources provided through the HLRN.

# 1 Overview and objectives

The Earth climate is currently experiencing a profound change. The observed increase in global air and ocean temperatures, melting of snow and ice and rising sea level are manifestations of warming on the Earth in recent decades. However, the impact of climate change on ocean circulation can regionally be highly different. Global simulations with local resolution refinement can help estimate and understand the potential impacts on regional scales.

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The Canadian Arctic Archipelago (CAA) is one of the main pathways for freshwater exiting the Arctic Ocean. The amount of exported freshwater influences the deep water formation in the North Atlantic, which is crucial for the meridional overturning circulation (MOC). Modelling the ocean and sea ice conditions in the CAA is difficult because of narrow straits and complex coastlines. A model study with high resolution in the CAA region for the period 1958-2007 has been carried out in the previous project. It used the Finite Element Sea-ice Ocean Model (FESOM, Danilov et al., 2004; Wang et al., 2008; Timmermann et al., 2009) in a global configuration. The great advantage of FESOM is the use of unstructured meshes allowing for local refinement in areas of interest and accurate representation of coastlines. Volume and freshwater transports through the main straits of the CAA show a strong interannual variability. Mechanisms driving the flow through the archipelago are investigated by exploring the sea surface height difference between Baffin Bay and the Arctic Ocean, far field wind fields and large scale pressure patterns (Wekerle et al., 2012).

During the last year in this project, we also studied the impact of increased Greenland Ice Sheet (GIS) melting on dynamic sea level and ocean circulation (Wang et al., 2012). Part of the computation time is also used for coupling FESOM with the atmospheric model ECHAM. The coupling work has been finished by now. The coupled model has started to work and under detailed validation. A HLRN project for the applications of the coupled

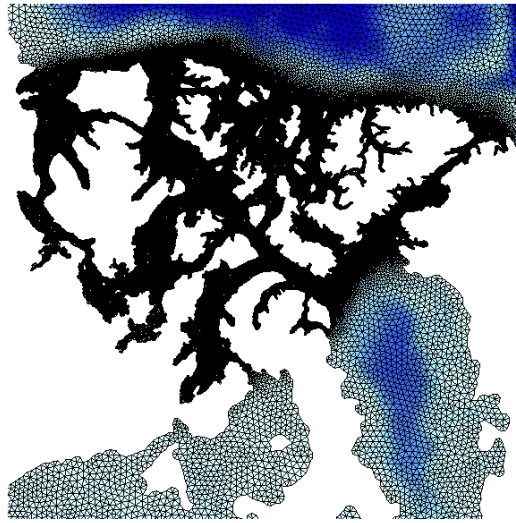


Figure 1: A global mesh with high resolution of 5 km in the CAA region.

model, including the study of the GIS melting scenarios, will be separately applied. The details about the coupled system will not be repeated here.

In this continuation project (hbk00021), we plan to only focus on the study of the Arctic Ocean using FESOM. During the last year's project, we have studied the variability of the CAA transport and the influence of mesh resolution on the CAA representation. This year we would like to continue with this topic to explore the impact of CAA freshwater export on the North Atlantic circulation.

Another sub-topic for this year is to study the dynamics of the Atlantic Water (AW) circulation in the Arctic Ocean, which has strong variability during the past decades (Karcher et al., 2007). Numerical models quite often have difficulties in proper representation of the AW in the Arctic Ocean (Holloway et al., 2007). Therefore, we will also assess and improve the model performance in this aspect in our global simulations with regional resolution refinement.

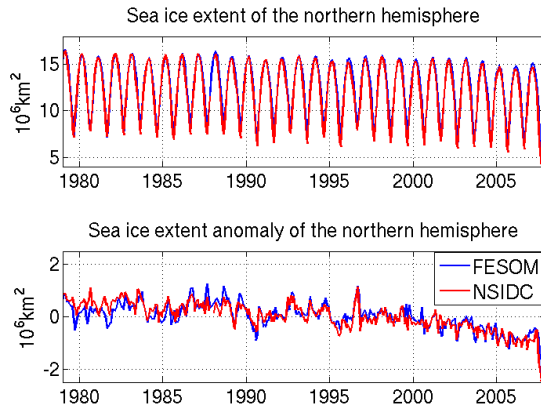


Figure 2: Arctic sea ice extent (up) and its anomaly (bottom) from the model (blue) and satellite observation (red).

## 2 Status report

In this section we summarize the main results from the CAA study from last year, and more details can be found from Wekerle et al. (2012). A global mesh is used, with a background resolution of  $1.5^\circ$ , 24 km north of  $50^\circ\text{N}$ , and 5 km in the CAA region (Fig. 1). The model is initialized from the PHC climatology and forced by the CORE interannual forcing (Large and Yeager, 2008) and run for 50 years (1958-2007). Fig. 2 shows the modeled Arctic monthly sea-ice extent and its anomaly with comparison to observations. The model well represents the sea-ice interannual variability and the observed recent decline.

Fig. 3 shows that the correlation between the freshwater transport through the main CAA straits and the along strait sea surface height (SSH) difference is very significant. This result is consistent with previous model studies (Houssais and Herbaut, 2011). Detailed analysis shows that both the dynamical and thermodynamical forcing influences the SSH gradient and thus the transport through the straits (Wekerle et al., 2012).

For a comparison, another simulation with a mesh without local refinement in the CAA region is also conducted. Except for the resolution in the CAA region, the two simulations are configured in the same way. Fig. 4 shows the time series of freshwater transport through the two main straits

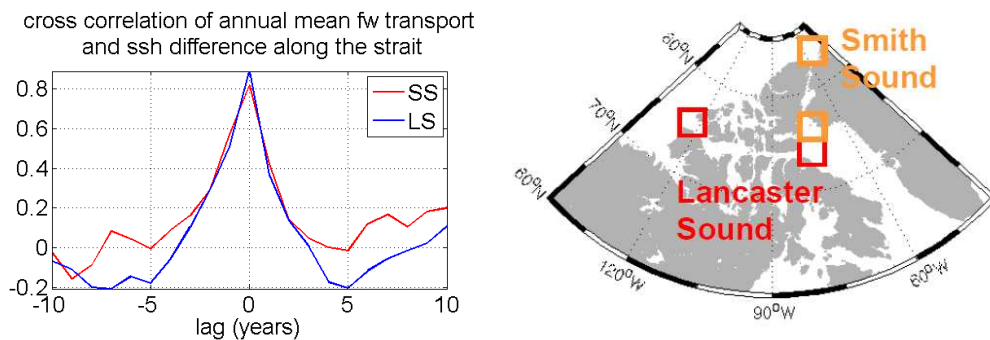


Figure 3: The correlation between the freshwater transport and the along strait sea surface height (SSH) difference for the two main straits (left). The locations where the SSH is taken are indicated on the right figure.

from the two simulations. The variability of freshwater transport is quite similar in the two simulations, indicating that the transport variability is mainly driven by external forcing and not significantly influenced by the local dynamics in the CAA. However, the magnitude of the transport is much higher in the fine resolution simulation (more closer to observation, not shown), so it is very important to properly resolve the narrow straits in model simulations in order to well represent the Arctic freshwater export. The impact of distribution of freshwater export between the CAA and the Fram Strait passages will be one of the topics in this year.

### 3 Plans and individual requirement for this year

#### 3.1 Impact of Arctic freshwater export on MOC

We plan to study the impact of the freshwater export through CAA and the Fram Strait on the variability of the Atlantic circulation. We will use similar variable resolution global meshes as in previous studies. However, we will not only increase the resolution in the CAA region, but also over the northern North Atlantic in order to properly resolve the deep water formation and advection (with resolution of 5-9 km). Vertical resolution will also be increased to have 60 z-levels. The model will be spun up for 60 years to reach

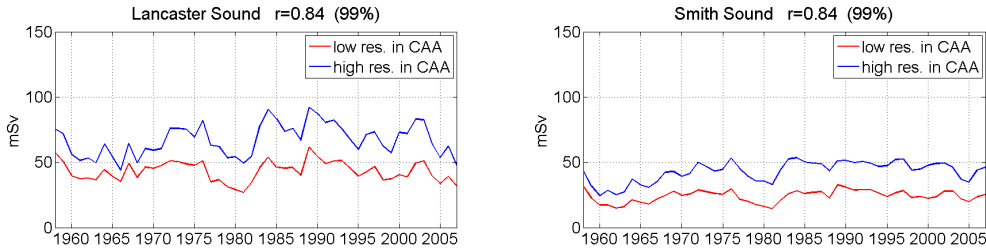


Figure 4: Freshwater transport through the Lancaster Sound (left) and Smith Sound (right) in two simulations.

a quasi-equilibrium state for the upper ocean. Then a 60 years hindcast run using the CORE interannual forcing will be conducted.

We also want to study the impact of different high resolution atmospheric forcing on the ocean in model simulations. High resolution forcing data (with resolution about 40 km) are available for the period of the recent decades, like the NCEP and ECMWF datasets. We need to understand how important is the forcing resolution in case the ocean resolution is increased to eddy resolving scales. Our focus is on the Arctic and northern North Atlantic region. The total number of years for this set of sensitivity experiments is about 60 years. We also expect that a few short runs are required for modifying the model parameters. We approximate that we need 20 years tuning experiments all together.

The approximate number of 3D grid nodes is about 15M for this mesh. One model year requires about 900 NPL. Total 200 years require 180K NPL.

### 3.2 Dynamics and variability of the Atlantic Water in the Arctic Ocean

It is important to understand the role of eddies in the AW circulation and distribution in the Arctic basins. This will add efforts to better understand the Arctic change and deep ocean variability. In this topic we also would like to improve the model representation of the AW in the Arctic Ocean, together with the overall model performance. We plan to use global meshes with different resolutions in the Arctic region.

We plan to use three different resolutions for the Arctic Ocean: 24km, 9km and 3km. The corresponding mesh size is 2.4M, 9M, and 80M 3D grid nodes, respectively. Besides comparing the model solutions on different meshes, we also plan a few sensitivity studies using the 24km and 9km resolution meshes. The sensitivity experiments planned for this year will be used together with the Green's function method for optimizing the FESOM Arctic model as done for MITgcm by Nguyen et al. (2011). They showed that the overall model-data differences are reduced by 45% after model optimization with this method.

In this year we will focus on a few major parameters for improving the model performance in the Arctic ocean, including the albedo (ocean, dry ice, wet ice, dry snow and wet snow), vertical mixing schemes (background vertical diffusivity, kpp versus pp, salt plume parameterization), the ice lead-closing parameter, the ice strength parameter, heat exchange coefficients (latent heat and sensible heat), drag coefficients (air-ocean, air-ice, ice-ocean), and forcing datasets. Our previous simulations show that different resolutions often prefer different model parameter values, so we plan to do the sensitivity studies on the two relatively coarser meshes. On each mesh a 20 years spin-up is required. The number of control parameters are 16, so 17 (with one control run) experiments will be done on each of the two meshes. Each experiment will be run for 16 model years (1992-2007), leading to 292 model years on each mesh.

At the end one 20 years run on the 3km resolution eddy-permitting mesh will be carried out, which will be used to understand the role of eddies for AW circulation, and study mechanisms in other processes like the shelf-basin interaction.

One model year requires 40 NPL, 300 NPL, 8K NPL on the three meshes, respectively. 292 model years on the 24km mesh require 12K NPL. 292 years on the 9km mesh requires 88K NPL. 20 years on the 3km mesh requires 160K NPL. The total requirement for this topic is 260K NPL.

## 4 Summary of required resources

Totally 440K (180K+260K) NPL are required for this year. It shall be equally distributed over quarters (i.e., 110 NPL per quarter).

The computation will be performed on ice2. FESOM has good scalability until about 10k grid nodes per core, as shown in our previous proposals.

Having this limit in mind, we will decide the number of cores depending on the mesh size for each experiment, and the efficiency in using the computation resources can be ensured.

The size of input file (mostly forcing data) and model output is expected to be approximately 100 TB.

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