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Modelling the sea ice in the Nares Strait

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ABSTRACT

A three dimensional coupled ocean (HYCOM) and sea ice model (CICE) is applied to a regional setup of the Lincoln Sea, the Nares Strait, and the Baffin Bay. As the sea ice model is originally developed for global simulations, boundary conditions have been implemented for the regional setup. The model results are compared with satellite images and with the large scale simulation that is specified for the boundary conditions. The main focus in this paper is on the simulated variations in the modeled sea ice flux and oceanic volume flux through the Nares Strait in the period September 2005–August 2008. The total sea ice area flux in 2006 is 14×10^3 km^2/year and in 2007 it is 69×10^3 km^2/year. The reason for this difference is mainly the blocking of the ice flow in the Nares Strait in spring 2006. The corresponding volume fluxes are 20 km^3/year and 120 km^3/year. The average annual oceanic volume flux varies from 0.6 Sv to 1.3 Sv from 2006 to 2008. The freshwater flux with a reference salinity of 34.8 varies in the same period from 12 mSv to 29 mSv.

The opening and closing of the North Water, which is one of the largest polynyas in the world, are investigated. A February storm event with opening and refreezing of the North Water is well reproduced. The model results show that the net heat flux in the polynya area at the surface is positive into the ocean from May until the end of July, and hence while the wind is responsible for opening the polynya, the main mechanism for maintaining the polynya in late spring and early summer is the surface heat flux.

1. Introduction

The Nares Strait is one of five main gateways from the Arctic Ocean with respect to freshwater and sea ice transport (the Fram Strait, the Bering Strait, the Barents Sea and the Canadian Archipelago being the other four (Jones and Eert, 2004; Kwok et al., 2005)). The main source of export of sea ice and freshwater from the Arctic Ocean is Fram Strait. In a review of previous estimates Dickson et al. (2007) estimates that the export through Fram Strait is 80 mSv as sea ice and 65–95 mSv as freshwater based on a reference salinity of 34.8. There is an import of sea ice to the Arctic Ocean from the Canadian Archipelago excluding the Nares Strait. According to Kwok (2006) the magnitude of the sea ice area flux is approximately 100×10^3 km^2/year or a volume flux of 3.16 mSv into the Arctic Ocean. Sea ice is also exported from the Canadian Archipelago and into the Baffin Bay through Lancaster Sound with a magnitude of 3.23 mSv (Agnew et al., 2008). The Bering Strait imports freshwater to the Arctic Ocean. According to Melling et al. (2008) the magnitude of the imported freshwater has a large seasonal variation, with a mean observed volume flux of 0.8 Sv and a freshwater flux of 53 mSv. The average sea ice volume through the Barents Sea is 1.27 mSv, however large variations are observed (Kwok et al., 2005).

The ice flux in the Nares Strait is generally southwards, however there are large seasonal and annual variations. The formation of an ice arch between the Kane Basin and the Baffin Bay blocks the ice flow into the Nares Strait from the Lincoln Sea. This ice arch is mainly observed during spring time, but the lifetime of the ice arch varies from year to year. The duration of the blocking is correlated to the magnitude of the annual sea ice flux into the Nares Strait (Kwok et al., 2010). The formation of this ice arch depends on the internal strength of the sea ice and external forcing from the atmosphere and the ocean. Another ice arch forms north of the Robeson Channel. The entire domain is ice covered during winter. The Lincoln Sea is in general ice covered all year, whereas the Nares Strait becomes partly ice free in summer and the Baffin Bay gradually becomes ice free during summer.

The winds in the Nares Strait are associated with ageostrophic orographically channeled flow (Gudmandsen, 2004). Therefore a high resolution atmospheric forcing is very important in order to model the sea ice in the Nares Strait correctly. Samelson et al. (2006) showed that there is a strong correlation between the wind and the ice motion when the ice actually moves in the Nares Strait. This shows that the wind is important, but it is not the only parameter that governs the sea ice flow.

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Most of the available data in this region is derived from satellite images and these will be used to validate the model. Kwok (2005) has calculated the ice flux based on satellite images in section A, see Fig. 1. His results indicated an annual area ice drift into the Nares Strait ranging from 15×10^3 km^2/year to 45×10^3 km^2/year in the period from 1996 to 2002. On average based on an assumption of 4 m thick ice this corresponds to a volume flux of $\sim$130 km^3/year ($\sim$4 mSv) or 5% of the Arctic sea ice outflow through Fram Strait. Kwok et al. (2010) showed that the Nares Strait did not block in spring 2007. This resulted in the highest ice flux into the Nares strait during the period between 1997 and 2009 with a magnitude of 87×10^3 km^2/year and an estimated volume flux of 254 km^3/year (8 mSv) or 10% of the Fram Strait outflow. This indicates that the impact of the sea ice outflow through the Nares Strait could increase with a changing climate.

In general, the oceanic flow is southwards in the Nares Strait from the Arctic with two main components. The surface part mainly takes its origin in the Pacific Waters, while the bottom part takes its origin in the North Atlantic Ocean (Jones and Eert, 2004). The exception is warmer water from the Atlantic Ocean through the Baffin Bay that runs northwards along the west coast of Greenland (Tang et al., 2004).

The first estimate of the oceanic volume flux through the Nares Strait was made by Sadler (1976). He estimated the flux to 0.67 Sv based on hydrographic measurements from April and until May 1972.

The only continuous array of hydrographic measurements in the Nares Strait is located at section B in Fig. 1 (Münchow and Melling, 2008). A volume flux of 0.57 Sv is found from 30 m and down. It is expected that the estimate is in the lower end, as the top 30 m is not included. This part of the water column is influenced by the sea ice drift towards south. Rabe et al. (2010) have in connection with the mooring calculated a geostrophic volume flux of 0.43 Sv.

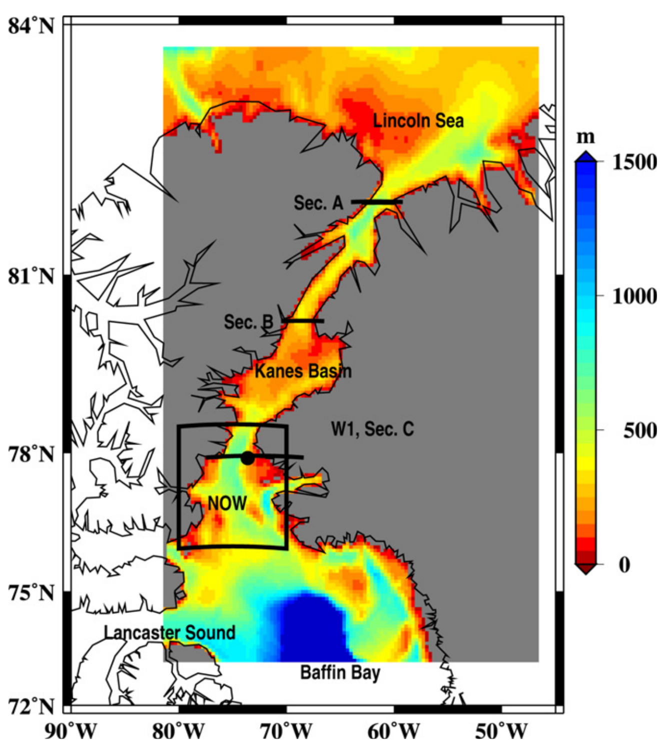

Fig. 1. Bathymetry and the location of the Lincoln Sea, the Baffin Bay and the Nares Strait. The Nares Strait connects the Baffin Bay and the Lincoln Sea. NOW is the approximate location of the North Water. Section A is the cross section where Kwok (2005), Kwok et al. (2010) calculated the sea ice drift. Section B is the location of the three year mooring (Münchow and Melling, 2008). W1 shows where the atmospheric forcing has been extracted.

The same study provides a freshwater flux of 20 mSv with a reference salinity of 34.8. All estimates by Rabe et al. (2010) represents the cross-section that was measured; it does not cover section B, Fig. 1, from coast to coast or the surface layer above 35 m depth.

Based on a short term campaign in August 2003, Münchow et al. (2007) found a volume flux of around 0.91 Sv and a freshwater flux of 31 mSv relative to a salinity of 34.8. These estimates do not include the uppermost 26 m of the ocean, where the currents could not be measured by ship-based ADCP.

Kliem and Greenberg (2003) showed that the volume flux is very sensitive to the sea surface height difference between Baffin Bay and the Arctic Ocean. A difference of 10 cm can give a change in the volume flux of more than 0.5 Sv. The study also provided a database with measured temperature and salinity fields for the Canadian Archipelago including the Nares Strait.

The flow of sea ice and water from the Nares Strait continues into the Baffin Bay along with the flow from Lancaster Sound and Jones Sound. Lancaster Sound provides water and sea ice into Baffin Bay. Prinsenberg and Hamilton (2005) found a oceanic volume flux of 0.75 Sv in the period from 1998 to 2000. The freshwater flux is estimated to be approximately 50 mSv, however large variations are observed. The third and smallest contribution to the Baffin Bay is Jones Sound, which has a volume flux of 0.3 Sv (Melling et al., 2008).

Goosse et al. (1997) describe the influence of including the freshwater flux through the Canadian Archipelago and the Nares Strait in global climate models. They find that the contribution of freshwater in the Baffin Bay somewhat reduces the deep water convection in the Labrador Sea.

Sou and Flato (2009) describe a model setup of the Canadian Archipelago including the Nares Strait using a model setup with a resolution of 22 km and a very coarse atmospheric model (resolution 200 km). They find that the general ice extent is modeled reasonably well in the model, but the atmospheric forcing is to coarse to model the ice flux into the Nares Strait and that the ice arches in the narrow straits are impossible to capture due to the low resolution of the model. Both issues have been addressed in this model setup.

The North Water, which forms in the southern part of the Nares Strait/northern part of Baffin Bay and is bounded to the north by the ice arch, is active most of the year, but is only kept open during late spring/early summer. A polynya is an area of recurrent open water within a region dominated by thick ice pack. This leads to an increased latent, sensible, and longwave heat flux from the ocean into the atmosphere. Maqueda et al. (2004) have classified polynyas into two categories. The first is a wind-driven polynya. This type is opened by the wind stress and leads to an enhanced ice formation due to the loss of heat at the sea surface. The second type is a sensible heat polynya. In this type of polynya the ocean provides enough heat from upwelling and other processes to replace the heat lost to the atmosphere. In the case of the North Water, wind stress is considered the main factor (Ingram et al., 2002) for opening the polynya.

The extent of the North Water is outlined by Dunbar (1969). The polynya has always attracted great interest as the open water increases the biological production compared to the surrounding ice covered area (Deming et al., 2002; Klein et al., 2002; Barber et al., 2001a). According to the international North Water Study (Barber et al., 2001b), Inuit's have known the North Water as a dangerous place to travel on a sledge during winter due to the thin ice, however a great hunting place as many animals stayed here in the winter. The name the North Water was given by whalers in the last century, who saw the area as an opportunity to go whaling in late May or early June, much earlier than elsewhere in the area.

The first model study of the North Water with a realistic bathymetry is described in Yao and Tang (2003). They showed that