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On the waters upstream of Nares Strait, Arctic Ocean, from 1991 to 2012

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ABSTRACT

The Lincoln Sea is a bifurcation point, where waters from the Canadian and Eurasian Basins flow to Nares or Fram Strait. Mechanisms that control which waters are found in the Lincoln Sea, and on its continental shelves, are unknown. Using conductivity–temperature–depth (CTD; from hydrographic and ice-tethered profiler surveys), nutrient, and mooring data with the DRAKKAR global 3-D coupled ocean/sea-ice model, the Lincoln Sea was examined from 1991 to 2012. Although both Pacific and Atlantic waters were observed on the North Ellesmere and North Greenland shelves, Atlantic water was shallower on the North Greenland shelf. Thus, deeper than 125 m, water was warmer and saltier on the North Greenland shelf than the North Ellesmere shelf. Three different water types were identified on the North Ellesmere shelf – waters from the Canadian Basin were observed 1992, 1993, 1996, 2005, and 2012, waters from both the Canadian and Eurasian Basins were observed in 2003, 2004, and 2008, and waters with no temperature minima or maxima below the surface mixed layer were observed in 1991, 2006, 2009, and 2010. Mixing with vertical advection speeds of 1×10^{-4} m s^{-1} were observed on the continental slope and this mixing could cause the disappearance of the temperature maxima. Model results suggest that currents on the North Ellesmere shelf were weak (less than 10 cm s^{-1}), baroclinic, and directed away from Nares Strait while currents on the North Greenland shelf were stronger (less than 15 cm s^{-1}), and primarily directed towards Nares Strait. CTD, mooring, and model results suggest that the water advected to Nares Strait is primarily from the North Greenland shelf while water on the North Ellesmere shelf is advected westward.
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1. Introduction

Water from the Arctic Ocean flows to the North Atlantic Ocean through Fram Strait and the Canadian Arctic Archipelago (CAA) (Aagaard and Carmack, 1989). The Arctic Ocean is fresher than the North Atlantic, so water exported from the Arctic has the potential to influence the global freshwater cycle (Dickson et al., 1988) and meridional overturning circulation (Dickson et al., 1996; Koenigk et al., 2007; Rennermalm et al., 2007). Nares Strait is one of the two main passages through the CAA and year-round mooring data have estimated that the volume flux through Nares Strait ranges from 0.47 ± 0.05 Sv (Rabe et al., in press) to 0.57 ± 0.09 Sv (Münchow and Melling, 2008), or roughly half of the total CAA transport (McGeehan and Maslowski, 2012).

Nares Strait separates northern Ellesmere Island from northern Greenland. At its northern end, Robeson Channel, Nares Strait is about 35 km wide and about 500 m deep (Fig. 1). At the southern end of Nares Strait, about 530 km south of Robeson Channel, Smith Sound separates Nares Strait from Baffin Bay. Nares Strait is covered year-round by sea-ice. Despite its relatively narrow width, the circulation through Nares Strait is complex. Based on a 3-year mooring study across southern Robeson Channel, Rabe et al. (2010) found that flow was strongest on the Ellesmere Island side of Nares Strait, with average speeds of 0.2 m s^{-1} southward. Circulation varied with sea-ice conditions – under mobile ice, a second southward current was often observed in the middle of Robeson Channel while under land-fast ice a single southward current against Ellesmere Island was observed (Rabe et al., in press). It is thought that variability in the southward flow through Nares Strait can be explained by the sea surface height in northern Baffin Bay (Münchow et al., 2006; Houssais and Herbaut, 2011; McGeehan and Maslowski, 2012; Rudels, 2012), wind speed and direction under mobile ice conditions (Samelson et al., 2006; Münchow et al., 2006; Rabe et al., in press), and tides (Münchow and Melling, 2008).

Hydrographic data collected in Nares Strait in the 1970s and 1980s showed that all of the water in Robeson Channel was from the Arctic Ocean (Sadler, 1976; Bourke et al., 1989). Both Pacific and

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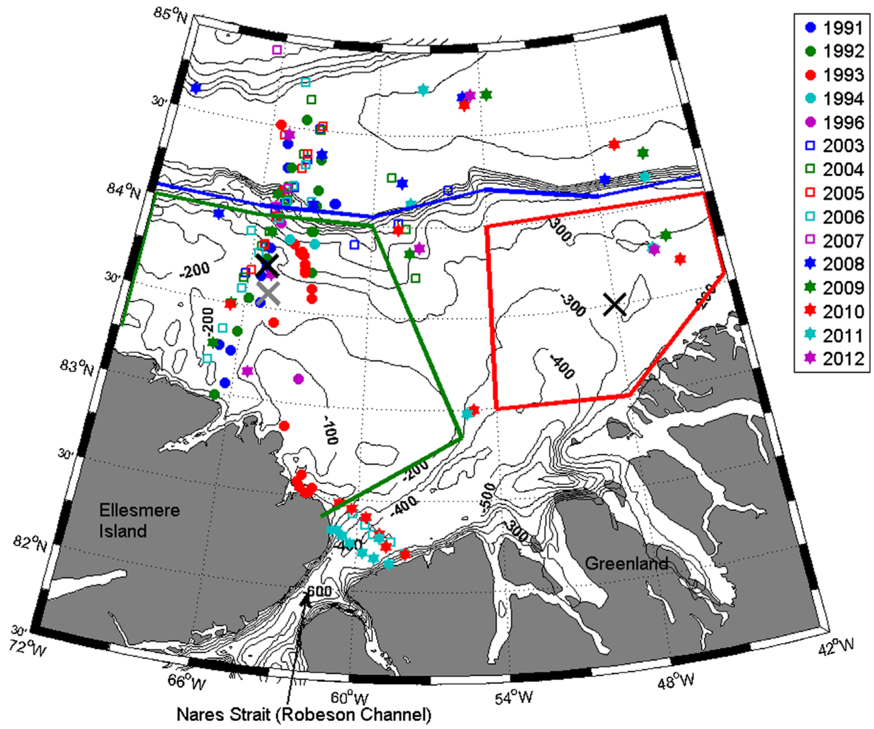

Fig. 1. Bathymetric map of the Lincoln Sea. Regions discussed in the text are labeled in the figure. Bathymetric data are from version 2.23 of the International bathymetirc chart of the Arctic Ocean (IBCAO; http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html). Colored symbols show the locations of the stations that were sampled each year. The large black ex on the North Ellesmere shelf marks the location mooring SY01, which collected data from 2008 to 2009. The large gray ex on the North Ellesmere shelf shows the location of mooring SY04, which collected data from 2010 to 2011. The large black ex on the North Greenland shelf shows the location of the virtual mooring used to calculate current speed and direction with the 3-D DRAKKAR model in Section 6. The colored lines mark the different regions defined as follows – the green lines show the North Ellesmere shelf (the region south of 84°N and to the west of Robeson Channel), the blue lines show the continental slope (the region between 84 and 85°N from 42 to 72°W), and the red lines denote the North Greenland shelf (the region north of Robeson Channel from 83 to 84°N and from 42 to 54°W).

Atlantic water masses have been identified in Nares Strait (Jones and Eert, 2006; Münchow et al., 2007; Alkire et al., 2010). Recent studies have suggested that there is variability in the water mass composition that is advected through Nares Strait. For example, mooring data collected near the bottom at southern Robeson Channel showed a freshening and warming trend from 2003 to 2006 followed by a salinification and warming trend from 2007 to 2009 (Münchow et al., 2011). Thus, it is likely that the source of water that is advected through Nares Strait is variable.

Despite the global importance of Nares Strait, very little is known about its upstream region, the Lincoln Sea. The Lincoln Sea encompasses a continental shelf that extends north from Ellesmere Island and Greenland and a continental slope that leads to the Lomonosov Ridge. A deep (about 500 m) trough, the northern extension of Robeson Channel, extends northeast from Nares Strait, along the Greenland coast. For this paper, we define the North Ellesmere shelf as the continental shelf west of Robeson Channel that extends north from Ellesmere Island to the continental slope. We define the North Greenland shelf as the continental shelf that is north and east of Robeson Channel between 83–84°N and 42–54°W. The presence of the trough makes the shelf north of Greenland narrower than the shelf north of Ellesmere Island. The Lomonosov Ridge separates the Canadian Basin (Canada and Makarov Basins) from the Eurasian Basin (Amundsen and Nansen Basins).

Hydrographic surveys of the Lincoln Sea have been sparse. A single temperature and salinity profile was collected on the North Ellesmere shelf in June 1967 (Seibert, 1968). As part of the ICESHELF project, an examination of springtime temperature and salinity profiles from 1989 to 1994 showed that waters on the North Ellesmere shelf and continental slope had similar characteristics to those in the Canada Basin (Newton and Sotirin, 1997). Based on the 1991–1996 ICESHELF data, Steele et al. (2004) suggest that Canada Basin water was advected to the Lincoln Sea via the Transpolar Drift from the Chukchi Sea. There are no known observational studies on the pathway of water from the Lincoln Sea to Nares Strait.

Using hydrographic, nutrient, and mooring data together with the DRAKKAR 3-D coupled ocean/sea-ice model and year-round conductivity–temperature–depth (CTD) data from an ice-tethered profiler, we examine the hydrography of waters on the continental shelf and slope of the Lincoln Sea to understand the source of waters that are transported to Nares Strait. In Section 2 we present a description of the data, the methods of nutrient analyses, and a description of the 3-D model used to estimate circulation. The spatial variability of the Lincoln Sea will be examined in Section 3. In Section 4, the interannual variability of the North Ellesmere shelf will be examined using data from 1991 to 2012. In Section 5 we discuss how mechanisms such as vertical diffusive heat flux and upwelling can modify water masses in the Lincoln Sea. In Section 6, water properties from Nares Strait will be compared with those from the North Greenland and North Ellesmere shelves and results from the 3-D model will be presented to examine the source of water to Nares Strait.

2. Data and methods

2.1. CTD data

Temperature and salinity CTD data were collected as a part of the ICESHELF project between 1991 and 1996 and as a part of the Switchyard project from 2003 to 2012 using instruments reported in Table 1 (Fig. 1). All samples were collected in spring (late April to mid-May) when the study area was fully ice-covered and

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