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Dense overflow from an Arctic fjord: Mean seasonal cycle, variability and wind influence

F. Geyer [a,b,*], I. Fer [c,b], T. Eldevik [a,b]

[a] Nansen Environmental and Remote Sensing Center, Thormølensgate 47, 5006 Bergen, Norway
[b] Bjerknes Center for Climate Research, Allégaten 55, 5007 Bergen, Norway
[c] Geophysical Institute, University of Bergen, Allégaten 70, 5007 Bergen, Norway

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ABSTRACT

Storfjorden, an Arctic fjord in the Svalbard archipelago, is separated by a submarine sill from the adjacent shelf areas and produces one of the densest water masses in the Barents Sea. The cold and dense brine-enriched shelf water is produced through ice formation in an annually recurrent polynya in Storfjorden and overflows across the sill. We present current profiles and bottom temperature measurements from the Storfjorden sill from 2003 to 2007, which is the longest time series collected at this site, and study the interannual variability of the overflow and the influence of atmospheric forcing. The mean structure of the overflow averaged over four seasons shows that the overflow is initially strong with high volume transport, about 50 m thick and bottom-enhanced, and then gradually diminishes, becoming increasingly intermittent during the last third of the overflow season. The annual average overflow transport is about 0.03 Sv ($1\,\text{Sv} \equiv 10^6\,\text{m}^3\,\text{s}^{-1}$). Overflow is observed 55% of the total record length of 958 days and cross-sill flow averaged in the bottom 20 m is greater than $10\,\text{cm}\,\text{s}^{-1}$ for 49% of the overflow duration. The overflow strength increases with decreasing near-bottom temperatures. The annual variability is within 0.01 Sv whereas the seasonal variability can be as large as 0.05 Sv. In spite of the relatively constant annual overflow flux, the onset of the overflow can vary by up to 50 days. Variability on the scale of 1–2 weeks is connected to wind forcing through surface Ekman transport with significant coherence between the current at the Storfjorden sill and wind measured on Hopen Island and Edgeøya. Surface Ekman transport and the ice conditions in the Barents Sea also influence the intra-seasonal development and interannual variability of the overflow.

1. Introduction

The continental shelves of the Arctic Ocean are broad and play a key role in the distribution of water properties in the Arctic basins through water mass transformations and shelf-basin interactions. Wind forcing is crucial in this complex chain of events where, for instance, summertime upwelling events can bring relatively warm and saline waters onto the shelf or wintertime prevailing offshore winds can maintain open ice-free areas (coastal polynyas). Strong heat exchange in coastal polynyas leads to ice freezing, brine-drainage and formation of dense brine-enriched shelf water (BSW), which contributes to the cold halocline in the Arctic Ocean (Aagaard et al., 1981) and significantly influences the overall heat and salt budget of the deep basins (Aagaard et al., 1985). The summertime forcing preconditions the following freezing period: upwelled saline water can lead to denser BSW or accumulated ice melt can hinder enhanced salinity regardless of significant ice production. Carmack and Chapman (2003) reported an extraordinary sensitivity of the exchange between the shelf and the deep basin to the position of summertime ice edge location. Abrupt and very effective exchange occurs when the ice edge retreats seaward off the shelf break and upwelling brings warm, salty and nutrient rich waters onto the shelf. The recent unprecedented retreat in summertime Arctic ice cover (Perovich et al., 2008) suggests that ice-free Arctic shelves can be exposed to wind forcing for longer durations. In addition to physical effects, distinct biological consequences are anticipated with enhanced Arctic spring productivity, altered marine ecosystem structure and pelagic-benthic coupling (Arrigo et al., 2008).

Storfjorden in Svalbard Archipelago (Fig. 1) is a semi-enclosed bay and provides for a relatively easily accessible and full-scale "laboratory" to study the Arctic shelf processes. The annually recurrent polynya activity in Storfjorden produces highly BSW

* Corresponding author at: Nansen Environmental and Remote Sensing Center, Thormølensgate 47, 5006 Bergen, Norway. Tel.: +47 5520 5890.
E-mail addresses: florian.geyer@nersc.no (F. Geyer), ilker.fer@gfi.uib.no (I. Fer), tor.eldevik@nersc.no (T. Eldevik).

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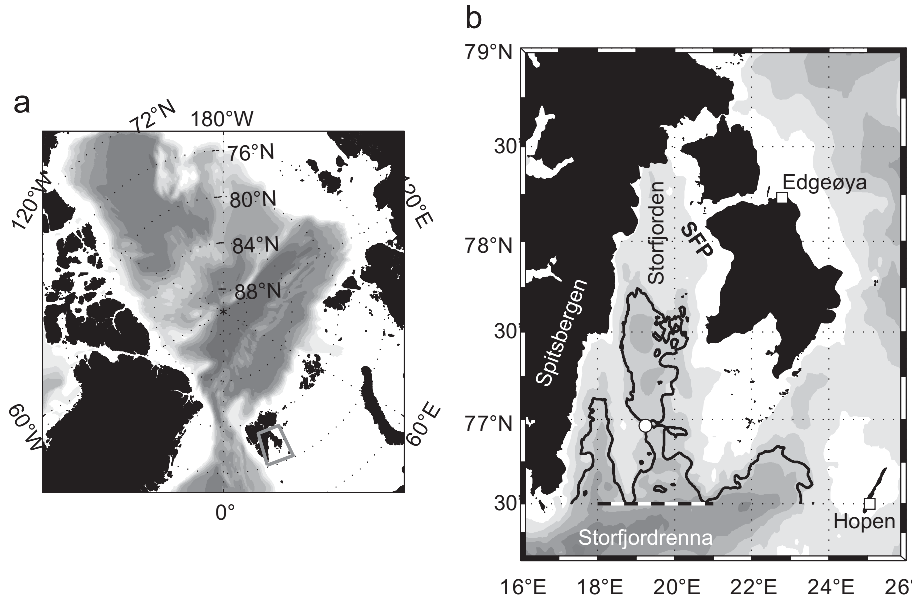

Fig. 1. (a) Overview map of the Arctic showing the enclosed region (gray) enlarged in (b). (b) Map of Storfjorden and surrounding areas showing the location of the ADCP (white circle) and the weather stations at Edgeøya and Hopen (squares). Also indicated are the most common position of the Storfjorden polynya (SFP) and the section used to calculate surface Ekman transports from ERA40 data (dashed black-and-white line). Isobaths are shaded at 500 m intervals in (a) and 50 m intervals in (b). The additional 120 m isobath in (b) is from the high-resolution bathymetry reported in Skogseth et al. (2005b), shown to identify the sill.

that fills the fjord to the sill level (115 m) and initiates a gravity driven overflow of the dense polynya-origin water (Schauer, 1995; Fer et al., 2003, 2004; Skogseth et al., 2005a). The overflow is dense enough to penetrate below the Atlantic Water in the region. Water originating from the Storfjorden polynya has been observed in the deep Fram Strait (Quadfasel et al., 1988) and may contribute to the ventilation of the Arctic Ocean (Schauer and Fahrbach, 1999). According to the estimate by Quadfasel et al. (1988), Storfjorden supplies 5–10% of the dense waters formed in the Arctic Ocean. The reader is referred to Skogseth et al. (2005b) for hydrographic characteristics and water mass transformations in Storfjorden, to Skogseth et al. (2007) for meso-scale surface circulation in Storfjorden, to Skogseth et al. (2008) for recent observations of the polynya processes and the polynya-overflow link, and to Fer and Ådlandsvik (2008) for a model description of the descent and mixing of the overflow plume.

The objective of this paper is to quantify the volume transport of the dense overflow from the sill and explain the interannual and mesoscale variability. While we focus on Storfjorden, the processes will be relevant to other polynyas on Arctic shelves. Under the DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) project, an acoustic Doppler current profiler (ADCP) is maintained at the sill separating Storfjorden from Storfjordrenna north of Storfjordbanken on the Barents Sea shelf (Fig. 1). Current profiles and bottom temperatures recorded by the ADCP cover four consecutive years from early winter 2003 to late spring 2007. This is the longest time series acquired at the Storfjorden sill so far. Furthermore, the ADCP offers the advantage of continuous profiling of a large fraction of the water column with high vertical resolution. The longest earlier time series (Schauer and Fahrbach, 1999) covers two non-consecutive years during the early 1990s using moored current meters measuring at two levels, supplemented by thermistor chains. Here, based on the four-year long time series, we describe the mean seasonal cycle and vertical structure of the overflow and investigate the influence of wind forcing on the preconditioning and export of water from the fjord. The data used in this study are summarized in Section 2. Following a description of the methods given in Section 3, the salient features, mean seasonal cycle, interannual, and mesoscale variability of the overflow are presented in Section 4. Subsequently the results are discussed in Section 5 followed by conclusions in Section 6.

Table 1
ADCP data recovery and periods of available meteorological data.

Location	Start	End	Instruments
Storfjorden sill	4.9.2003	19.8.2004	ADCP
	18.12.2004	11.8.2005	ADCP
	12.12.2005	9.8.2006	ADCP, Microcat
	13.8.2006	22.4.2007	ADCP
Hopen	1.1.2003	31.1.2005	met data
	25.5.2005	31.12.2007	met data
Edgeøya	19.7.2005	6.11.2007	met data[a]

[a] Wind direction data erroneous between 20.4.2006–10.10.2006 and 18.9.2007–6.11.2007.

2. Data

2.1. Current measurements

The current measurements reported here are collected by a 307 kHz Workhorse RD Instruments ADCP. The ADCP was mounted, looking upward, in a trawl-proof bottom frame. The frame was deployed at the Storfjorden sill (76°58′N, 19°15′E, Fig. 1) before the freezing period, and recorded through the freezing and overflow season before it was recovered in summer. Four deployments were made from 2003 to 2007 (Table 1). Recovered data cover the complete overflow seasons of 2004–2006, but coverage in 2007 lasts only until 22 April 2007 1630 UTC when the frame was hit by a trawler. During all deployments current profiles were sampled at 4-m vertical bin size, with the first bin centered at about 6 mab (meter above bottom). Profiles were averaged at 10 min intervals (33 pings per ensemble) in 2004–2006 and at 2 min intervals (13 pings per ensemble) in