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Analysis of a dense water pulse following mid-winter opening of polynyas in western Foxe Basin, Canada

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ABSTRACT

A recent study has shown that Foxe Basin's dense waters originate from coastal latent heat polynyas and each year replace 2/3rd of the basin's deep waters by propagating southeastwards in Foxe Channel as a gravity current. The formation mechanisms in 2004 of these dense waters are examined here. Strong meteorological events occurring in mid-winter over the domain are responsible for the simultaneous opening of two large polynyas at Lyon Inlet and along Melville Peninsula's eastern coast while a third important and recurrent polynya opens earlier at Hall Beach (northwestern Foxe Basin). Large sea-atmosphere heat exchanges take place in these polynyas, leading to the production of 21.2×10^{12} kg of sea-ice and 1.53×10^{12} m^3 of dense water. The ice production rate is on average five to six times higher in the polynyas than in the rest of the basin. Following the topography, the dense waters formed at Hall Beach and along Melville Peninsula cascade into Foxe Channel, while those produced at Lyon Inlet sink directly in the channel through deep convection. The two mechanisms synchronize and combine together when Lyon Inlet and Melville Peninsula polynyas open up. The heat exchanges, sea-ice and brine production rates estimated with a 21-year near-climatology are similar to those found in 2004. The results also show that the produced dense waters can overflow into Hudson Bay.

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1. Introduction

Continental shelves in polar regions produce large amounts of brine rich dense waters. Using two different methods (the first based on the residence time and thickness of the upper part of the pycnocline and the second on the transformation of Atlantic water in the Arctic), Aagaard et al. (1981) estimated that around 2.5 Sv ($1\,Sv \equiv 10^6\,m^3\,s^{-1}$) of dense water is produced on the shelves and contributes to the maintenance of the cold upper halocline in the Arctic Ocean. This halocline also helps to shield the ice cover from the heat flux of the warmer and saltier underlying water coming from the Atlantic, and the dense water therefore interacts indirectly with the thermohaline circulation in the northern Atlantic. Cavalieri and Martin (1994) studied the heat losses, ice and salt production specifically in the Arctic coastal polynyas and found that their contribution to the halocline is significant and lies between 0.7 and 1.2 Sv. In order to understand the impact of global warming in polar regions, it is therefore necessary to carry out detailed surveys of Arctic polynyas, including those located in adjacent seas, since they are by nature very sensitive to climate change.

It is in this context that the program MERs Intérieures du CAnada (MERICA, Saucier et al., 2004b) was initiated in 2003. It is funded by the Department of Fisheries and Oceans, Canada, and involves the long-term monitoring of the climate variability and biological productivity of the Hudson Bay system (Fig. 1a), consisting of three large Arctic marginal seas: Hudson Bay (HB), Foxe Basin (FB, detailed map in Fig. 1b) and Hudson Strait. The most comprehensive review to date of the oceanography of this system is found in Prinsenberg (1986); more recently, Saucier et al. (2004a) modeled its general sea-ice and ocean circulation.

FB is located north of HB and is crossed by the Arctic Polar Circle (66.56°N). The basin is connected to the Arctic via the Gulf of Boothia and Fury and Hecla Strait, to HB via Roes Welcome Sound and the fairway between Southampton Island and Nottingham Island, and to the Labrador Sea via Hudson Strait. Foxe Channel (FC) is the deepest depression of FB; it is a straight channel approximately 400 km long and 100 km wide, with a maximal depth of 450 m, that follows Southampton Island's northern coast for most of its length. Table 1 summarizes some of FB's main characteristics.

For three consecutive winters, 2004–2006, an abrupt arrival of cold and saline waters at the bottom of FC was observed by Defossez et al. (2008). These authors have shown that this gravity current is responsible for the renewal of more than 2/3rd of the channel's deep waters each year. Using Lagrangian tracers, they have also shown that the dense water forming this current comes from the sea surface in the vicinity of Hall Beach (HaB, Fig. 1b), skirts along Melville Peninsula (MP) and then cascades into FC. The trajectory of the gravity current corresponds well to the location of three polynyas commonly found at western FB in winter: at HaB, along MP and at Lyon Inlet (LI). This indicates that the dense water observed at depth in FC is likely produced in these three polynyas and all what follows will therefore rely on this assumption.

The aim of this study is to provide a quantitative analysis based on oceanographic, meteorological and satellite data in order to explain the mechanisms leading to the pulse-like propagation of the dense water mass at the bottom of FC. The observations and data processing are described in Section 2. These data allow the calculation in Section 3 of heat exchanges arising at the sea-atmosphere interface of western FB's polynyas and thence, of the amount of ice and dense water produced yearly. The results are discussed in Section 4, with a special emphasis on the relationship between atmospheric events occurring in mid-winter, polynyas opening and the dense water pulse detection at the bottom of FC. The conclusion of this paper is given in Section 5.

Table 1
Main topographic elements of Foxe Basin (based on ETOPO2, NOAA).

Surface area (m^2)	0.2×10^{12}
Mean depth (m)	90
Maximal depth (m)	450
Volume (m^3)	18×10^{12}
Volume (depth > 220 m) (m^3)	1.4×10^{12}

The volume deeper than 220 m depth represents an overestimation of Foxe Channel's deep waters (see Section 3.2.2).