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Research paper

Reconstruction of inflow of Atlantic Water to Isfjorden, Svalbard during the Holocene: Correlation to climate and seasonality

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ABSTRACT

The distribution patterns of benthic foraminifera faunas, stable isotopes and ice rafted debris (IRD) have been studied in piston core JM98-845-PC from Isfjorden, western Svalbard to reconstruct changes in the flow of Atlantic Water during the Holocene interglacial. The paleoenvironmental conditions in Isfjorden and the inflow of the Atlantic Water followed closely the changes in insolation with strong seasonality in the early Holocene and weaker seasonality in the middle to late Holocene. A summer temperature maximum of the bottom water occurred in the early Holocene 10,500–c. 8200 years BP. Cooling began at 9000 years BP with stepwise coolings at c. 8200, 7400 and 4000 years BP. The cooling correlated with an increase in ice rafting and increased influence of polar water and seasonal sea ice cover. Between 4000 and 2000 years BP bottom water temperatures reached a minimum. After 2000 years BP episodic inflow of warmer Atlantic Water at the bottom of the fjord occurred and conditions became more unstable. The data indicate close interaction of the flow of Atlantic Water with the development of the terrestrial climate and the amount of polar meltwater and sea ice.

1. Introduction

Recent studies have indicated that Holocene climatic changes in the Arctic are of higher amplitude than in subpolar areas (e.g., Holland and Bitz, 2003; CAPE — Last Interglacial Project Members, 2006; Miller et al., 2010). The change from a warmer early Holocene with strong seasonality to a cooler mid-late Holocene with weaker seasonal contrasts is more pronounced at high latitudes compared to lower latitudes (Kaufman et al., 2004; Kaplan and Wolfe, 2006; Miller et al., 2010) and follows closely the insolation signals (see e.g., Berger and Loutre, 1991; Harrison et al., 1992).

The Svalbard archipelago 76–80°N is of particular interest, because it is located at the centre of exchange of major surface water masses between the North Atlantic Ocean and the Arctic Ocean (Fig. 1A). The climate of Svalbard is dependent on the flow of warm Atlantic Water that reaches the western Svalbard margin as the West Spitsbergen Current and the cold East Spitsbergen Current that exit the Arctic Ocean and circulate along the Svalbard inner margin. Any change in the oceanography around Svalbard will have a profound effect on the climate in the region, the distribution of sea ice and the growth/retreat of ice caps and glaciers.

The fjords on Spitsbergen act as sediment traps and records from the Holocene generally have high temporal resolution (e.g., Svendsen et al., 1992; Hald et al., 2004; Forwick and Vorren, 2007, 2009; Majewski et al., 2009; Szczuciński et al., 2009; Baeten et al., 2010; Forwick et al., 2010). The early Holocene was characterised by relatively warm oceanographic and climatic conditions with reduced ice rafting from sea ice and icebergs. A deterioration of the environmental conditions with increased glacial activity began around 9000 years BP. The cooling culminated during the Little Ice Age with maximum extent of glaciers.

We present results from sediment core JM98-845-PC from central Isfjorden, Spitsbergen (Fig. 1B). The purpose of the study is to reconstruct the inflow of Atlantic Water to Isfjorden in relation to climate change during the Holocene based on the distribution patterns of benthic foraminifera faunas, benthic stable isotopes and ice-rafted debris (IRD). The results are compared to records of Atlantic Water inflow to the northern and western shelf areas of Svalbard and to other previously published marine and terrestrial records from Svalbard and other areas.

2. Study area and setting

Isfjorden is the largest fjord of the island of Spitsbergen (Fig. 1). It is c. 70 km long and up to 425 m deep. The fjord mouth is wide and without a sill and topographically steered Atlantic Water of the West Spitsbergen Current can enter the fjord (Ślubowska-Woldengen et al., 2007; Nilsen et al., 2008) (Fig. 1B). The Atlantic Water is defined by a temperature higher than 3 °C and a salinity of >34.9 (Swift and Aagaard, 1981). It flows into the fjord in the southern part and exits through the northern part (Nilsen et al., 2008). The flow varies seasonally, with warm and saline conditions during summer and colder and

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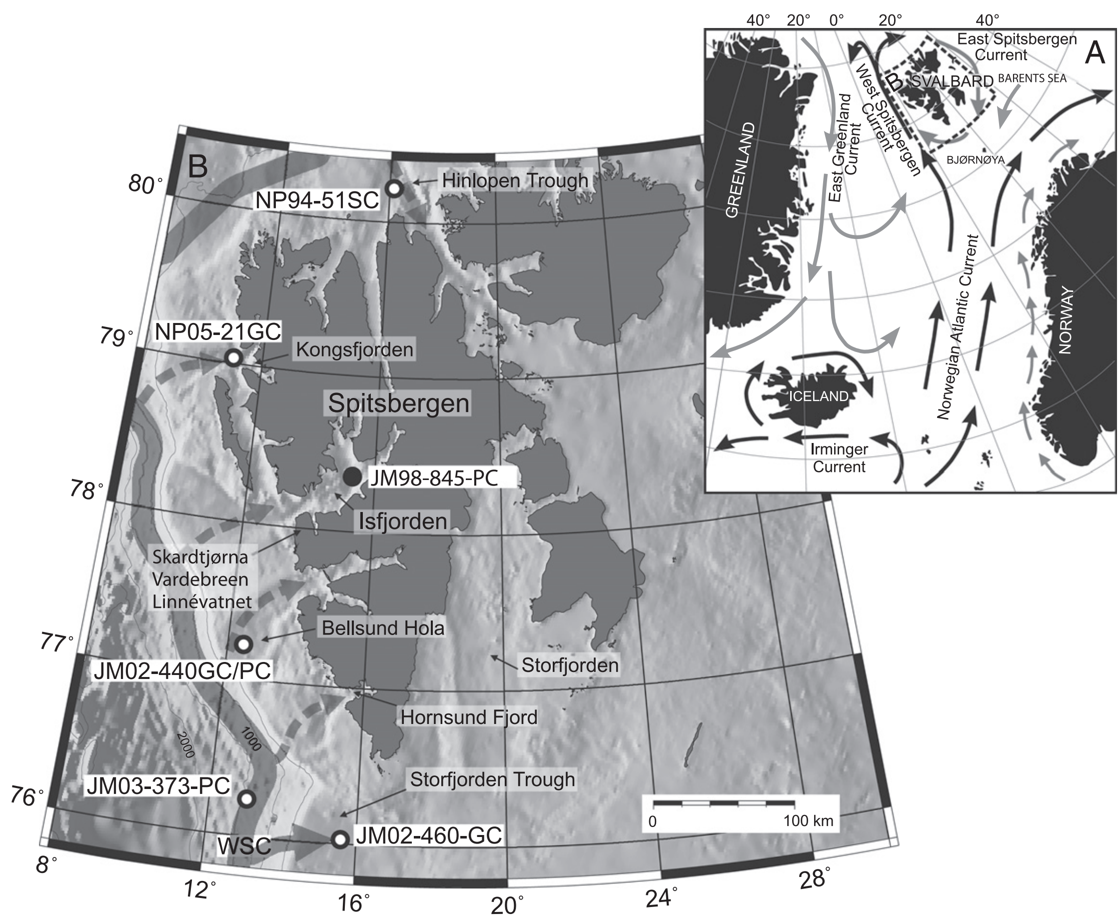

Fig. 1. (A) Map of the Nordic seas showing major surface currents. (B) Map of Svalbard with flow path of the West Spitsbergen Current (WSC) indicated (after Ślubowska-Woldengen et al., 2007) together with location of studied core JM98-845-PC (closed circle) and other cores (open circles).

slightly less saline conditions in winter, and its volume inflow varies inter-annually (Svendsen et al., 2002).

Arctic surface water is derived from the East Spitsbergen Current. It flows northwards along the west Spitsbergen coast (Fig. 1A), separated from the West Spitsbergen Current by the Arctic Front (Loeng, 1991). In Isfjorden the Atlantic Water is typically located beneath the Arctic surface water and a layer of summer meltwater (Fig. 2). The Atlantic Water can mix with the Arctic water to become the colder and slightly fresher Transformed Atlantic Water ($T>1$ °C, salinity >34.7; Svendsen et al., 2002; Cottier et al., 2005; Nilsen et al., 2008). Winter cooled water is generated by brine formation during winter. It sometimes reaches high enough density to mix with and cool the Atlantic Water. The intensity of winter water formation may influence the exchange of water masses between the fjord and the adjacent shelf. Strong formation of winter cooled water can lead to a stronger inflow of Atlantic Water the following summer (Nilsen et al., 2008).

Freshwater in the fjord mainly derives from melting of icebergs and sea ice, run-off from glacial rivers and precipitation (Nilsen et al., 2008). Nine tidewater glaciers presently drain into several tributaries of the fjord. Generally, in winter the tributary fjords and the inner parts of Isfjorden are covered by seasonal fast ice, while the outer fjord is ice free. However, sea ice extent and the duration of sea ice coverage can vary inter-annually (Węsławski et al, 1995; Svendsen et al., 2002; Nilsen et al., 2008). Since the year 2002 periodically a strong inflow of Atlantic Water to Isfjorden as well as to other western Svalbard fjords has been observed (Cottier et al., 2007; Nilsen et al., 2008; Jernas et al., 2010).

Bottom water temperature varies from winter temperatures sometimes close to −2 °C to summer temperatures of >2 °C (Nilsen et al., 2008). The salinity changes in the bottom water masses are small (<0.2) and vary much less on a seasonal basis (Fig. 2). The water mass exchange in Isfjorden is similar to Kongsfjorden (see Cottier et al., 2005; Nilsen et al., 2008) (Fig. 1B). The $\delta^{18}O$ values of the Atlantic Water and Transformed Atlantic Water in Kongsfjorden vary between 0.13 and 0.5‰ (average 0.24‰) and between 0.06 and 0.40‰ (average 0.2‰), respectively (MacLachlan et al., 2007).

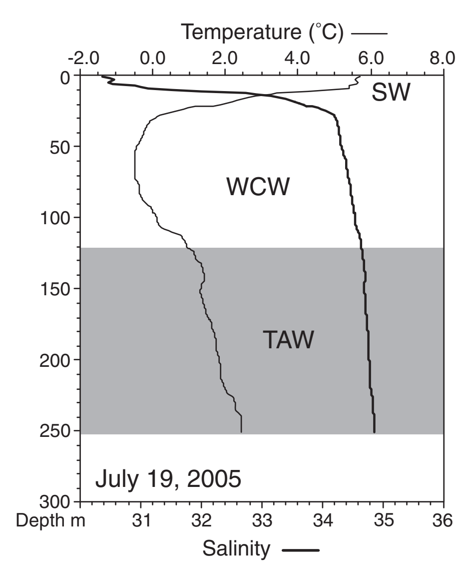

Fig. 2. Conductivity, temperature, depth (CTD) profile taken in 2005 at the location of core JM98-845-PC. Abbreviations: TAW, Transformed Atlantic Water; WCW, Winter Cooled Water; SW, Surface Water.