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Climate-forced change in Hudson Bay seawater composition and temperature, Arctic Canada

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ABSTRACT

Global climate change impacts marine ecosystems, directly and indirectly, especially in the Arctic and Antarctic. We show the first long-term (1920–2011) time-series of oceanographic change in Hudson Bay, an arctic marine ecosystem, based on coupled brachiopod-calcite stable and clumped isotope results. Long-term decrease in brachiopod $\delta^{13}C$ parallels that of seawater-DIC in Hudson Bay, and after considering its seasonal sea ice coverage, it is similar to that of the ^{13}C-Suess effect observed in the North Atlantic and other regions. Acidification of Hudson Bay seawater leads warming by about 10–20 years, and with intensified warming from the 1970s to 2010s closely coupled to earlier sea-ice breakup. Post-industrial warming of Hudson Bay is initially slow, but in later years, faster and of greater magnitude than of the coeval global oceans. Our observations for the past 90 years suggest that climate-forced change contributed to an average increase of about 0.1 °C and 3.6 °C in sea-surface water temperature of Hudson Bay over the first 50 and subsequent 40 years, respectively. This 3.7 °C post-industrial warming of Hudson Bay seawater is about six times the 0.67 °C increase observed during the past 100 years in global ocean sea-surface temperature, which is about double the postulated increase of about 2 °C for polar regions. Our results are consistent with the general notion that polar marine environments, such as Hudson Bay, can serve as sensitive indicators of change in climate, and of change still to come for lower latitude ecosystems.

1. Introduction

Hudson Bay, including Hudson Strait, Foxe Basin and the Canadian Archipelago, is a large arctic–subarctic marine complex, for which, it is difficult to predict oceanographic and ecosystem changes due to global warming (Melling, 2000; Fig. 1). The Hudson Bay cryosphere with its snow and ice and many feedback mechanisms parallels the amplification of global climatic change in arctic regions. Despite these complex issues, Hudson Bay plays an important role, because of its subarctic location, the polar amplification of oceanographic and climatic perturbations, in offering up early-warning signs of events still to unfold at mid and low latitudes (ACIA, 2005). According to the IPCC (2001) report, "climate change in polar regions is expected to be among the largest and most rapid of any region on the Earth", which will lead, among many impacts, to major oceanographic (sea ice retreat, sea surface warming and acidification, freshening, sea level rise), terrestrial (permafrost melting, methane discharge) and economic upheavals and other still poorly defined impacts (Westmacott and Burn, 1997; Gagnon and Gough, 2005b; Carmack and McLaughlin, 2011). Indeed, seawater warming (~2 °C) for the Arctic Ocean was postulated to be about 2 to 3 times that of the global oceans (ACIA, 2005). Some of the impacts may involve positive change(s) for this climatically sensitive region (Fig. 1; Overland et al., 2011; Roledo et al., 2008), but the overall changes tend to be negative (Gilchrist and Robertson, 2000; Grebmeier et al., 2006), and its associated uncertainties tend to overshadow the positive ones at this time. Complementary studies are starting to appear in increasing numbers documenting the ecological changes of a changing Arctic world (e.g., Li et al., 2009; Kuzyk et al., 2010; Shakhova et al., 2010); but more and long-term studies are needed to highlight the details of the anticipated changes (e.g., Spielhagen, 2012).

The Hudson Bay cryosphere is connected to the global ocean via the Arctic Ocean and Hudson Strait (ACIA, 2005; Fig. 1), and its oceanographic impacts are shared with those of the global oceans and vice versa. Waters from the Arctic Ocean wind their way through the Canadian Archipelago on to Foxe Basin and then circulate through Hudson Bay, and afterwards through Hudson Strait into the Labrador Sea and on to the North Atlantic (Prinsenberg, 1986b; AMAP, 2009;

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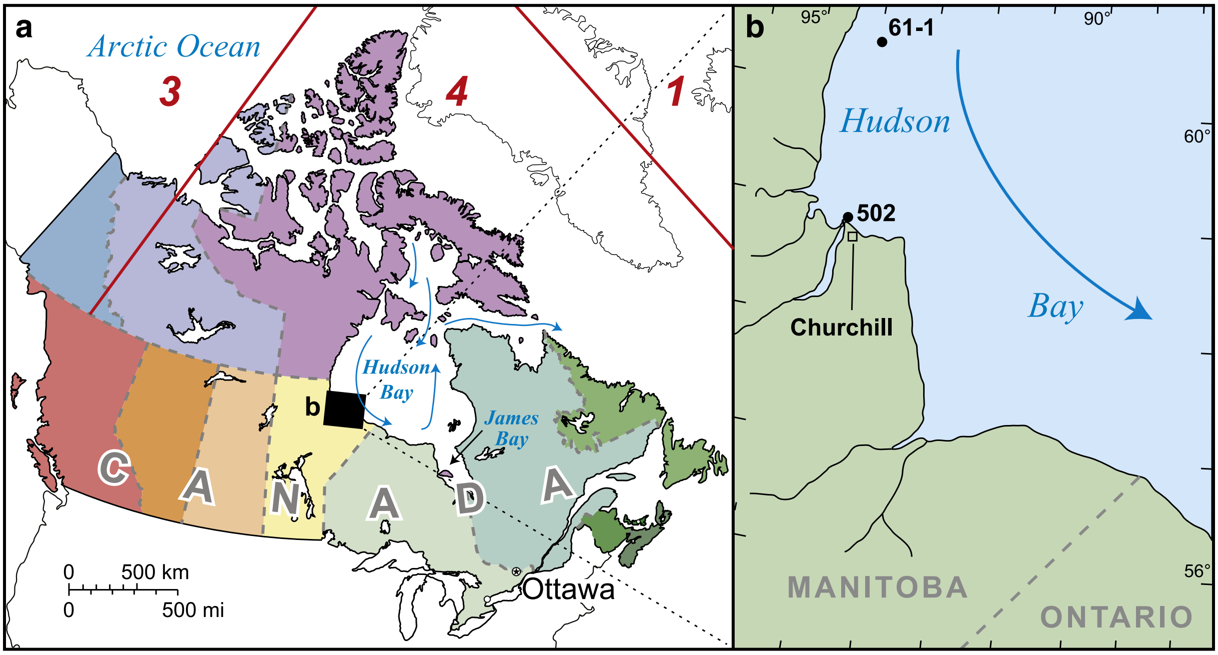

Fig. 1. Setting of Hudson Bay within Canada and the Arctic Ocean. The Arctic Climate Impact Assessment (ACIA, 2005) divided the arctic into four major regions based on large-scale differences in climate-forcing factors. a) Hudson Bay and James Bay are located and included within region 4 of the Arctic Climate Impact Assessment (ACIA, 2005) scheme. b is a close-up of Churchill, Manitoba on the west coast of Hudson Bay, and some sample locations are identified by #61-1 and #502 (Appendix 1), and the blue line(s) with arrow designate(s) the generally cyclonic circulation within the bay (Prinsenberg, 1986a).

ACIA, 2005; Yamamoto-Kawai et al., 2009; Fig. 1). Changes in this overall flow regime and its characteristics (cyclonic circulation) may have important repercussions for North Atlantic thermohaline water formation and circulation, and thus the climate/weather of large segments of the northern hemisphere, and perhaps the whole globe (Notz, 2009; Lopes dos Santos et al., 2010). Sea ice in the marine Arctic is multi-year or seasonal depending on geographic location, with maximum extent in March and minimum in September (Parkinson et al., 1999; Wadhams and Davis, 2000; Gagnon and Gough, 2005a; Hochheim et al., 2011). In Hudson Bay seasonal sea ice plays a major role, for example, in controlling surface water stratification, heat exchange, carbon dioxide dissolution, nutrient distribution and light penetration into the seawater (e.g., Prinsenberg, 1986a; Wadhams, 2000; Saucier et al., 2004; Kuzyk et al., 2010; Joly et al., 2011).

Our knowledge of Hudson Bay seawater salinity and temperature is sparse and sporadic at best despite the number of stations sampled throughout the water mass (Prinsenberg, 1986a). We have a general sense of salinity and temperature for surface and deep (50 m) seawater of Hudson Bay, but lack retrograde information that shows detailed annual oceanographic changes. The few exceptions are recent studies showing details of ice retreat, summer surface water temperatures and distribution in primary biological productivity all supplemented by modeling satellite studies (Gagnon and Gough, 2005a; Gagnon and Gough, 2005b; Kuzyk et al., 2008, 2010; Galbraith and Larouche, 2011; Granskog et al., 2011). The results of these latest studies are alarming in that they document clear changes in these parameters in Hudson Bay with progressive climate change; an epeiric sea undergoing significant change (cf. Ingram et al., 1996; Gough and Wolfe, 2001; Macdonald and Kuzyk, 2011).

Despite the major impact of climate evidenced by the polar region, observations on changes in Arctic ecosystems are rather limited, and with few exceptions, we lack reliable, long-term baseline oceanographic information for arctic seawater and its ecosystems (e.g., summary in Wassmann et al., 2011). In the absence of instrumental observations, information gathered from archives such as brachiopods may provide suitable proxy data (Brand et al., 2011) for establishing climatologic and oceanographic baselines, and for documenting changes in arctic seawater due to either post-industrial climate change and/or natural multi-decadal oscillations/variations (Kushnir, 1994; IPCC, 2007). We have several objectives with major ones tracing the $\delta^{13}C$ and $\delta^{18}O$ evolution of Hudson Bay seawater over the past 90 years. In addition, we prepare a thermal evolution of sea surface temperature (SST) and brachiopod habit water temperatures (BHTs) in comparison to that of the global oceans, Finally, data documenting climatic change in Hudson Bay will consist of carbon, oxygen and clumped isotopes archived in calcitic articulated brachiopods (*Hemithiris psittacea*) to serve as proxies of marine acidification and temperature changes for the past 90 years.

2. Brachiopod material

We obtained the brachiopod *H. psittacea* from western Hudson Bay, offshore Churchill, Manitoba, to avoid surface salinity dilution by its major rivers on the circulating seawater derived from the Arctic Ocean (Granskog et al., 2011; Fig. 1). Biological and other potential effects were minimized by using a single species from a specific area for constructing a time-series of Arctic paleoceanographic conditions. A total of 14 specimens were collected, and their ontogenetic shell sampling (100 analyses) spans the 1920–1929, 1950–1965, and 1990–2011 intervals. The brachiopod samples cover the past 90 years as well some are from marine sediments dated at 7800 years (^{14}C BP) deposited during the post-glacial marine incursion by the Tyrrell Sea, the ancient precursor of Hudson Bay (Skinner, 1973; Shilts, 1984).

Modern articulated brachiopods incorporate $\delta^{13}C$ and $\delta^{18}O$ into shell calcite in equilibrium with ambient seawater (Lowenstam, 1961; Brand et al., 2013, 2014), and thus their results should prove to be important oceanographic proxies. By sampling shell growth increments (cf. Brand et al., 2011; Parkinson et al., 2005) and complementary clumped and stable carbon and oxygen isotopes, we are able to establish reliable time-series of inter-annual and decadal climatic marine change of Hudson Bay seawater. Since there are significant differences in the original oceanographic conditions at time of the Tyrrell Sea and in Hudson Bay waters of the 1920s (Figs. 2–5) and the baseline for global oceans, we