The holocene climatic history of the Circum-icelandic oceanic realms

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Abstract

One of the achievements of the IPY was to foster an unprecedented amount of research initiatives aiming at studying recent (Holocene) changes in ocean circulation and climate in the subarctic and arctic domains. Paleo-investigations offer invaluable information on natural environmental changes at decadal to millennial scale, as well as on the processes driving them. We hereby present some recent results based on proxy records from circum Icelandic areas.

Introduction

The northern North Atlantic and its subarctic and arctic seas have shown in recent decades unprecedented changes in physical and chemical conditions, which directly influence the ecosystem structure and processes. This region is extremely sensitive to the changes related to the human-induced global warming (IPCC 2007) since there is an intricate connection of cryospheric (ice-sheets and sea-ice), atmospheric (winds related to strong gradients in sea-level pressures) and oceanic (through the opposition of northward flowing Atlantic water and southward flowing polar waters) processes. In particular, satellite observations have revealed a considerable decline in sea ice cover, mostly for the seasonal sea ice which constitutes approximately 50% of total ice coverage for the Arctic and the Antarctic (Serreze et al., 2007). The decline in seasonal ice extent is of particular concern since sea ice not only plays a central role in polar ecosystems but also has a great influence onto the Earth climate system itself. The sensibility of the marine biosphere to changes in local physico-chemical characteristics of the northern North Atlantic has been evidenced in the last decades by in-situ observations of biogeographical shifts of plankton biodiversity (e.g. Beaugrand et al., 2002) or satellite observations showing drastic modifications in phytoplankton community (e.g. coccolithophore blooms in the Iceland Sea and the Barents Sea). Theses changes are thought to reflect modifications in the stratification and temperature of the water column linked with freshening of the northern ocean induced by sea-ice melting (Curry and Maulitzen, 2005) and increased surficial temperature due to increased northward inflow of Atlantic water (Hatun et al., 2005).

The instrumental record is far too short to document the full range of natural variability. In order to produce more reliable predictions of future change, data on longer time scales than the instrumental records, are needed. The climatic history of the past 2000 years with a succession of warm (Roman, Mediaeval) and cold (Little Ice Age) periods shows that rapid climate changes have occurred repeatedly in the recent past with major implications for human settlement throughout the Nordic seas (i.e. Inuit and Viking cultures). In addition, new evidences for optimal thermal conditions during the early part of the present interglacial (Holocene) suggest that the Arctic might have been seasonally ice-free around 9000 yrs before present (Fisher et al., 2006) to an extent which might only be reached by the mid-21st century (Johannessen et al. 2004). However, discrepancies between observed and simulated sea ice distribution raises a need for improving our understanding of the sensitivity of the high latitude feedbacks. There is a crucial need to gain detailed information on the amplitude, the regional patterns, and the mechanisms of past environmental changes observed during the Holocene in order to predict the scale of current climate change. This information can be obtained using two complementary approaches, namely proxy records from marine sedimentary archives and paleoclimate modelling experiments. Proxy records are ideal to document regional ecosystem changes and to assess the physical-chemical processes which drove these ecological shifts.

The aim of this presentation is to question the view of a climatically stable Holocene period, and to provide, based on new proxy-based data, some tips on the regional complexity of both long and short-term (millennial to centennial) climate and ocean circulation changes in the circum-Icelandic oceanic realms.

Oceanographic setting

The Iceland shelf and nearby oceanic realms bear essential components of the present surface, intermediate and deep circulation of the northern North Atlantic (Hopkins, 2001; Fig. 1). It is located close to the Arctic front which separates Arctic/Polar water masses carried by the southeastward East Iceland Current from Atlantic waters (AW). Atlantic waters bathing the western and north-central Iceland shelf originate from the North Iceland Irminger Current, a branch of the Irminger Current; whereas the eastern and north-eastern shelf are fed with warm waters from the main corridor of Atlantic waters toward the Nordic Seas (the North Atlantic Drift and Norwegian Atlantic Current).
Iceland separates an eastern (Iceland-Scotland) strait from a western (Denmark) strait, the passageways of surface Atlantic water inflow to the Nordic Seas and Arctic Ocean, and surface and bottom outflow to the mid-latitudes of the Atlantic Ocean. In terms of volume, the AW inflow to the Nordic Seas has been assessed through year-long instrumental measurements within both straits as ca. 8 Sv, most of this inflow being compensated by outflow from the bottom as ca. 6 Sv (surface outflow carried by the East Greenland Current being assessed at about 1.3 Sv (Blindheim, 2004).

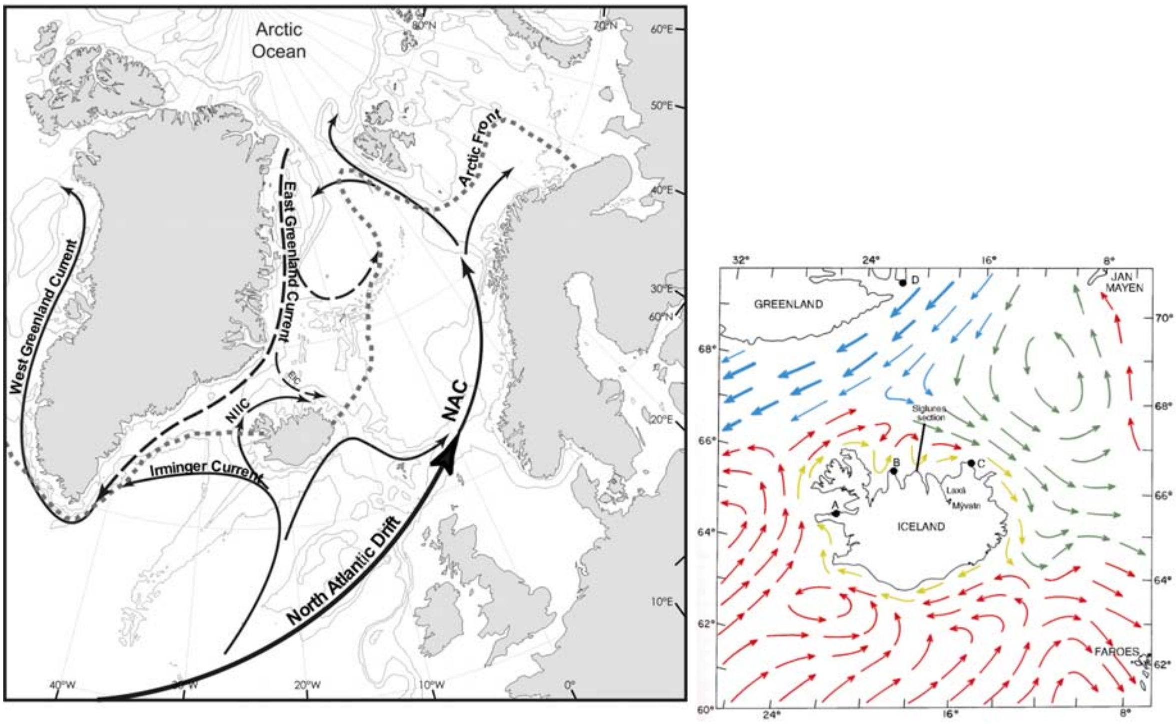

Fig. 1: Main component of the surface circulation. Left: Solid and dashed arrows represent warm and cold currents, respectively (NAC-North Atlantic Current, NIIC-North Iceland Irminger Current). The dotted line refers to the present position of the Arctic Front (after Giraudeau et al., 2010). Right: surface circulation around Iceland (red to dark blue colors refer to the SST gradient from warm Atlantic to cold Polar waters).

Together with the contour drifts moulded by the Norwegian Sea Overflow Water, and distributed along the eastern flank of the Reikjanes Ridge south of Iceland, the North Iceland Shelf stands as one the favourite play-ground for the late Quaternary/Holocene paleoceanographers. It owes it mainly because of the vertical distribution of key-elements of the surface and intermediate water masses of the Nordic Seas within a spatially restricted area.

Holocene long-term trends

A zonal diachronism in long-term Holocene sea-surface temperature (SST) trends in the mid/high latitudes of the North Atlantic, equivalent to a ca. 3.5 kyr delay between the eastern and western North

Atlantic has been documented from sediment cores in the Labrador, Irminger and Iceland Seas (as summarized by Solignac et al., 2006) and the Norwegian Sea (as summarized by Jansen et al., 2008). This zonal SST delay across the northern North Atlantic (Fig. 2; after Kaufman et al., 2004) corresponds to a similar zonal diachronism in long-term Holocene pattern of AW flow between the Denmark Strait and the Iceland-Scotland Strait (Giraudeau et al., 2010).

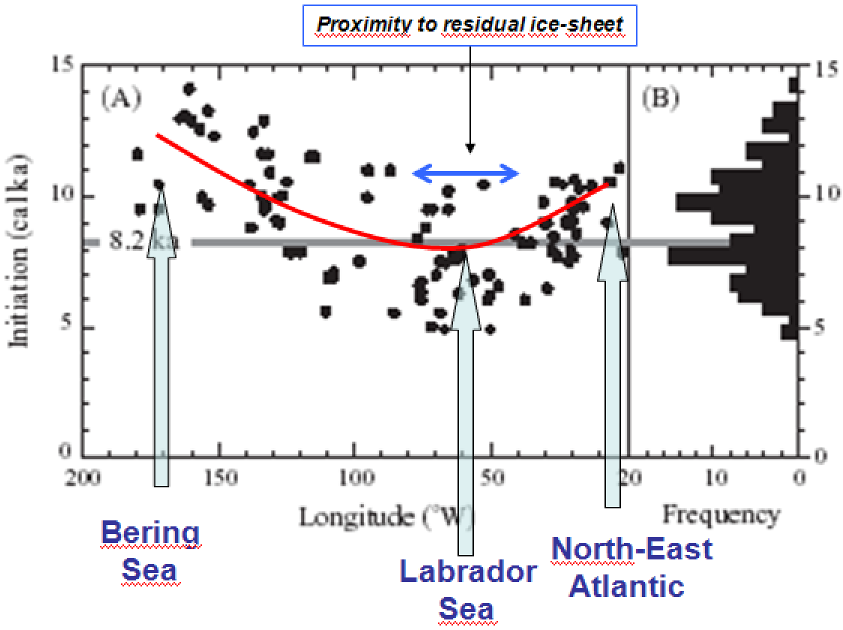

Fig. 2: Proxy-based timing of the initiation of the Holocene altithermal across a longitudinal transect from the North-East Atlantic to the Barents sea (after Kaufman et al., 2004). The horizontal blue arrow points to the area close to the remnant Laurentide ice-sheet, where the maximum delays are recorded.

As suggested by Marchal et al. (2002), this delayed recovery of the circulation pattern close to Greenland might be related to the relative inertia of the remnant Laurentide ice sheet compared to the Fennoscandian following the last deglaciation. Surface circulation off north-west Iceland seems to follow this western Atlantic pattern, some biotic proxy-records indicating peak penetration of Irminger Current Water (in the form of Intermediate waters) between 3.5 and 5.5 cal kyr BP (Fig. 3; Giraudeau et al., 2004).

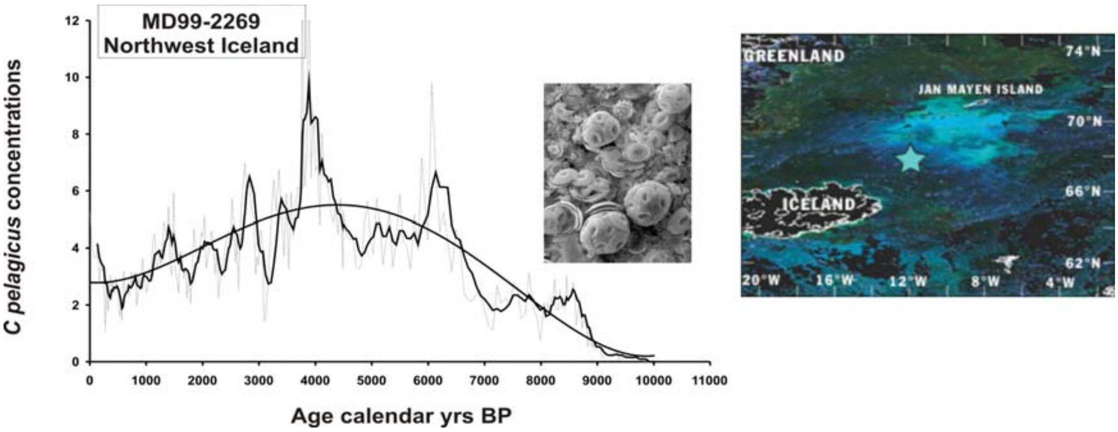

Fig. 3: The overwhelming contributor to carbonate production and sedimentation off Iceland is the coccolithophore species C. pelagicus (central picture) who might occasionally bloom in arctic waters (right picture). Carbonate production off Iceland is tightly linked with input of nutrient-rich Irminger waters. The Holocene record of C. pelagicus concentration off NW Iceland suggest maximum input of Atlantic/Irminger water between 3.5 and 4.5 cal kyr BP (Giraudeau et al., 2004).

A potential influence of the more proximal Greenland ice cap as shown by Jennings et al. (2006) for the last glaciations might also partly explain this diachronism, although the volume of fresh water released by this ice cap was much smaller than that from the Laurentide Ice Sheet. Foraminiferal-based SST estimates in the nearby Irminger Sea also provide evidence for maximum thermocline temperature centred at 4-5 cal kyr BP (Came et al., 2007), hereby confirming the circulation trend reconstructed off NW Iceland. A special point should however be raised on differences in reconstructed SSTs and circulation trends between the northwestern and the north central-eastern Icelandic shelf, this last area showing an Holocene climatic optimum 2 to 3000 years before its western counterpart. Such local disagreements might be explained by differences in environmental signature of the various proxies, and/or the influence of the local topography on circulation features.

Millenial-scale variability

Terrestrial and ice-core data from circum-North Atlantic locations point to millennial-scale anomalies of Holocene climate in relation with changes in the modes of atmospheric and oceanic circulation and transport of heat to high latitudes (e.g. Denton and Karlen, 1973; Magny, 2004; Dahl and Nesje, 1996). Although hardly temporarily consistent and reproducible, geochemical (Came et al., 2007; Oppo et al, 2003) and sedimentological (Andrews 2009; Bianchi and McCave, 1999; Bond et al., 1997; Hall et al., 2004, Rousse et al., 2006) records from the subpolar and polar North Atlantic, support the implication of the surface and deep ocean circulation patterns in the amplification of these recurrent recent climate anomalies and their transmission to distant areas. A major pitfall in this last assumption on Holocene times is the lack of firm, direct evidences for recurrent millennial-scale changes in the dynamics of the North Atlantic Drift (NAD) component of the meridional overturning circulation. While suggesting the existence of centennial to millennial-scale modulations of the surface circulation in the Nordic seas (Risebrobakken et al., 2003; Andersen et al., 2004) and the subpolar gyre (Giraudeau et al., 2000; Came et al., 2007), biotic proxy-records available so-far often suffer from either subdued amplitude of changes or limited temporal resolution, and are therefore hardly conclusive.

Still, the most undisputable evidences for pervasive millennial-scale changes in Holocene climate are provided by terrestrial and ice-core records which all highlight recurrent changes in the modes of atmospheric circulation in the boreal Atlantic.
The time series of sea-salt sodium (ssNa) flux in the Greenland Ice Sheet Project Two (GISP2) core (O'Brien et al., 1995), believed to be an indicator of winter storminess and sea spray in the atmosphere of the high-latitude North Atlantic, strikingly exhibits peaks at times similar to the Holmsa loess record of windy, winter-like conditions over southern Iceland compiled by Jackson et al. (2005). The mean grain size of the loess from Holmsa, in turn shows a succession of peaks coeval with higher than average winter precipitation in the maritime climate-influenced southern Norway (Bjune et al., 2005).

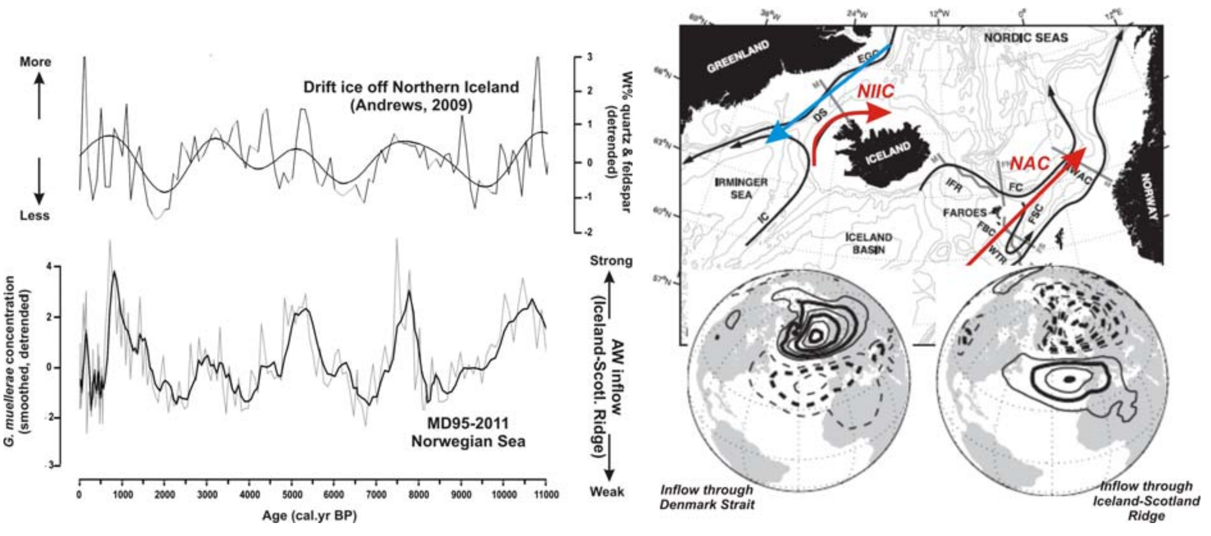

Figure 4: Left - Detrended and smotthed biotic record of AW flow into the Norwegian Sea (Giraudeau et al., 2010) compared with the detrended stacked record of IRD-based drift ice off Northern Iceland (Andrews, 2009). Right – Winter mean sea level pressure regressed on standardized simulated inflows of Atlantic waters into the Nordic Seas. Isolines are drawn at 0.5 mb intervals, negative values with dashed lines (from Nilsen et al., 2003).

Recent marine proxy-records (Fig. 4 left) such as drift ice abundances off Northern Iceland (Andrews, 2009) or the Holocene paleodynamics of AW flow through the Denmark and Iceland-Scotland Straits (Giraudeau, 2010) suggest that the intensity of the southward polar and arctic water outflow carried by the East Greenland Current varied according to a millennial pacing, and in phase with the inflow of the North Atlantic Current to the Norwegian Sea. Such a pattern is consistent with dynamical considerations which relate the present tight link between the AW inflow in the Iceland Scotland Ridge and the polar outflow to the Denmark Strait to the winter-average cyclonic conditions over the Greenland, Iceland and Irminger seas (Fig. 4 right; Blindheim et al., 2000; Nilsen et al., 2003).

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