NE ATLANTIC SURFACE WATERS DURING THE LAST 2,400 YEARS: natural variability prior to man-made impacts on global climate

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Surface currents in the North Atlantic Ocean play a key role in modulating the regional and even global climate. Knowledge of the past behaviour of these currents is crucial to constrain their natural variability before man started to interfere with climate through emission of greenhouse gases. Here we present such reconstructions spanning the last 2,400 years, derived from a sediment core at one key N Atlantic site west of Ireland. Our results indicate that surface water temperatures and salinities were highly variable throughout this period, and suggest a general long-term cooling trend.

In the North Atlantic Ocean, the Gulf Stream and its northward extension carry huge amounts of warm and saline surface waters to high northern latitudes, maintaining the comparatively mild climate of NW Europe. Cooling of these saline waters far north increases their density, causing them to sink down and flow back southward in the deep ocean. Human greenhouse gas emissions might affect and weaken this current system and the global (combined surface and deep) thermohaline circulation, pushing climate beyond its range of natural variability. Consequences can be far-reaching, though certainly not as abrupt and dramatic as in Hollywood's "Day after tomorrow" scenario. To place possible present and future changes of the climate system in a longer-term context, it is essential to characterize its natural variability. As part of the EU-funded PACLIVA (PAtterns of CLImate Variability in the North Atlantic) project, a joint effort by 12 institutes from 10 European countries, we obtained records of surface water variability during the last 2,400 years at one key site west of Ireland (Fig. 1).

Direct instrumental temperature and salinity measurements are available at the most for the last ~150 years. Information on longer-term climate changes has to be obtained from indirect ("proxy") evidence archived in marine sediments. We sampled one sediment

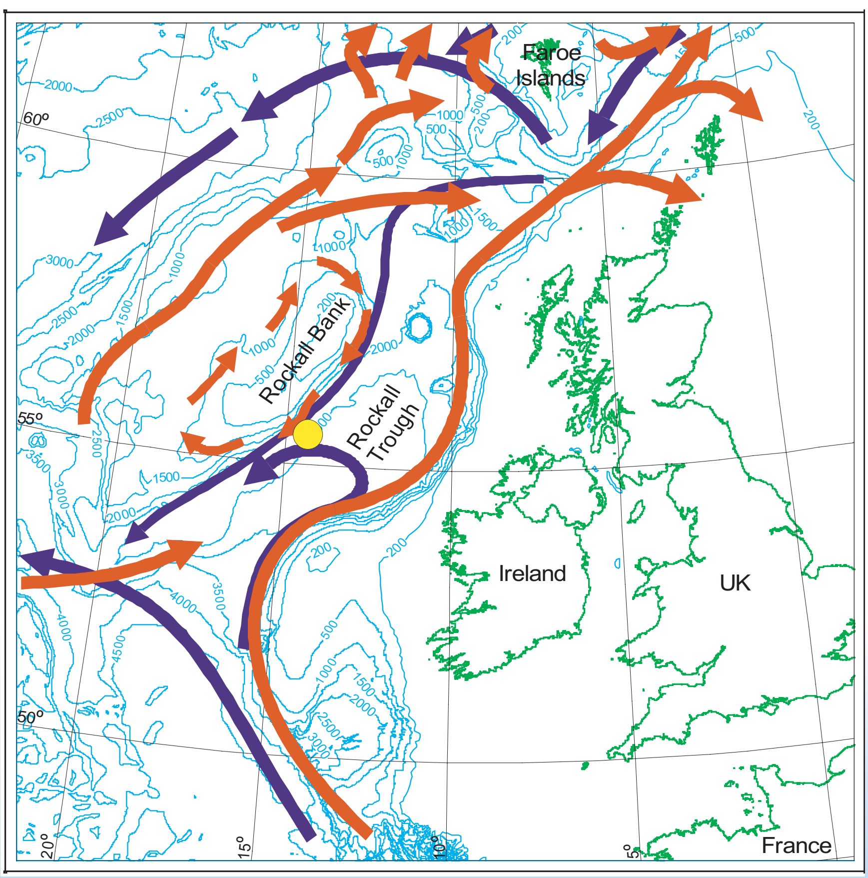

Fig. 1. Core location (yellow dot) and hydrographic setting (red arrows: surface currents, dark blue arrows: bottom currents).

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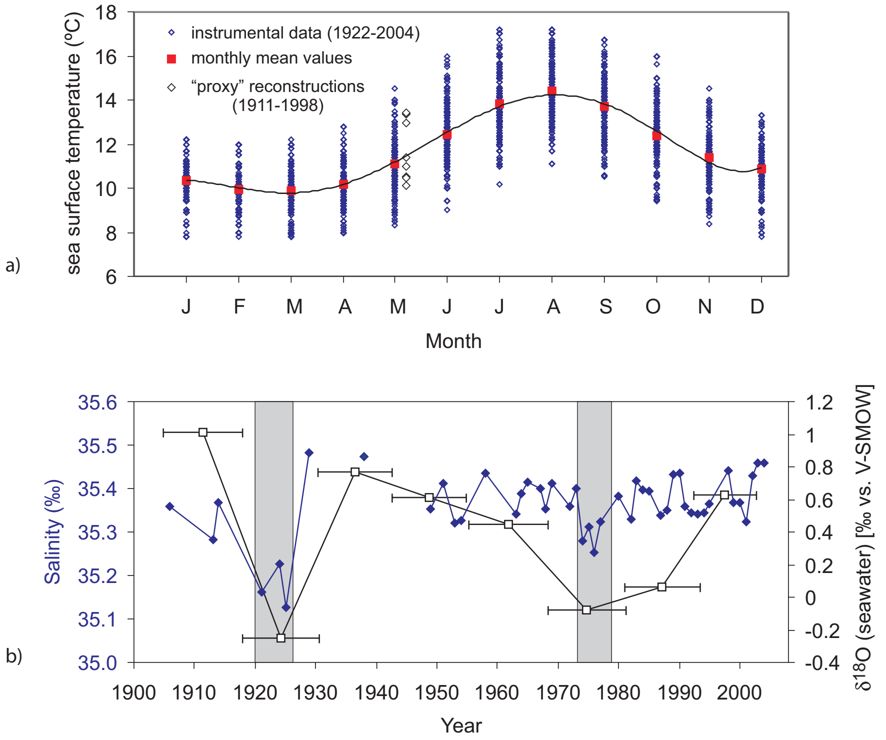

Fig. 2. Comparison of reconstructed surface water properties with 20th century direct instrumental measurements. a) Sea surface temperature. b) Salinity.

core with adjacent 'continuous' 1 cm-thick sediment slices. The age of the sediments was determined by analysing the natural radioactive isotopes ^{14}C and ^{210}Pb and the man-made isotope ^{137}Cs (derived from nuclear bomb tests and the Chernobyl nuclear accident). Proxy evidence for past surface water conditions is derived from planktonic foraminifera. These microscopic calcareous organisms live in surface waters, after dying they sink to the sea floor to form part of marine sediments. The oxygen isotopic composition ($\delta^{18}O$) of their shells reflects both water temperature and $\delta^{18}O$ of seawater, which is related to salinity. The Mg/Ca ratio of foraminiferal shells is dependent on the temperature of surrounding waters. Hence, we can simultaneously reconstruct surface water temperature and salinity with paired measurements of Mg/Ca and $\delta^{18}O$ in planktonic foraminifera.

The instrumental record helps to assess the validity of these indirect ("proxy") reconstructions (Fig. 2). Temperatures derived from our 20th century sediment record (top 8 cm of the sediment core) most closely coincide with late spring to early summer sea surface temperatures, indeed corresponding to the main growth season of the analysed foraminiferal species. The instrumental salinity record is discontinuous prior to 1950, especially during World War II. However, the available data reveal that our salinity reconstruction traces the main features of the instrumental record, particularly episodes of low salinity during the 1920's and 1970's as highlighted by shaded rectangles in Fig. 2b). Obviously, the sediment record does not resolve year-to year variability because each sediment slice was deposited during ~10-15 years (horizontal error bars in the figure) and thus represents average conditions over this time interval.

Reconstructions for the last 2,400 years (Fig. 3) reveal pronounced surface water variability over the entire record and a general long-term cooling trend. Some of the warmest temperatures and highest salinities occur from 150-400AD and 750-1150AD, coinciding with climate anomalies ("Roman and Medieval Warm Periods") described from several other records of past climate. However, temperature and salinity maxima are not sustained over several centuries, but alternate with cooler and fresher conditions in between. Surprisingly, the 20th century displays some of the lowest temperatures and salinities of the entire record. Pervasive temperature and salinity fluctuations may partly reflect internal 'unforced' variability of surface ocean currents. External forcing through variations in solar activity (inferred from fluctuations in production rate of the cosmogenic nuclide ^{14}C, Fig. 3a) may also play a role; based on the correlation between both records, it could explain up to 50% of the total variability in our sea surface temperature record.

In summary, we obtained evidence for pronounced variability in

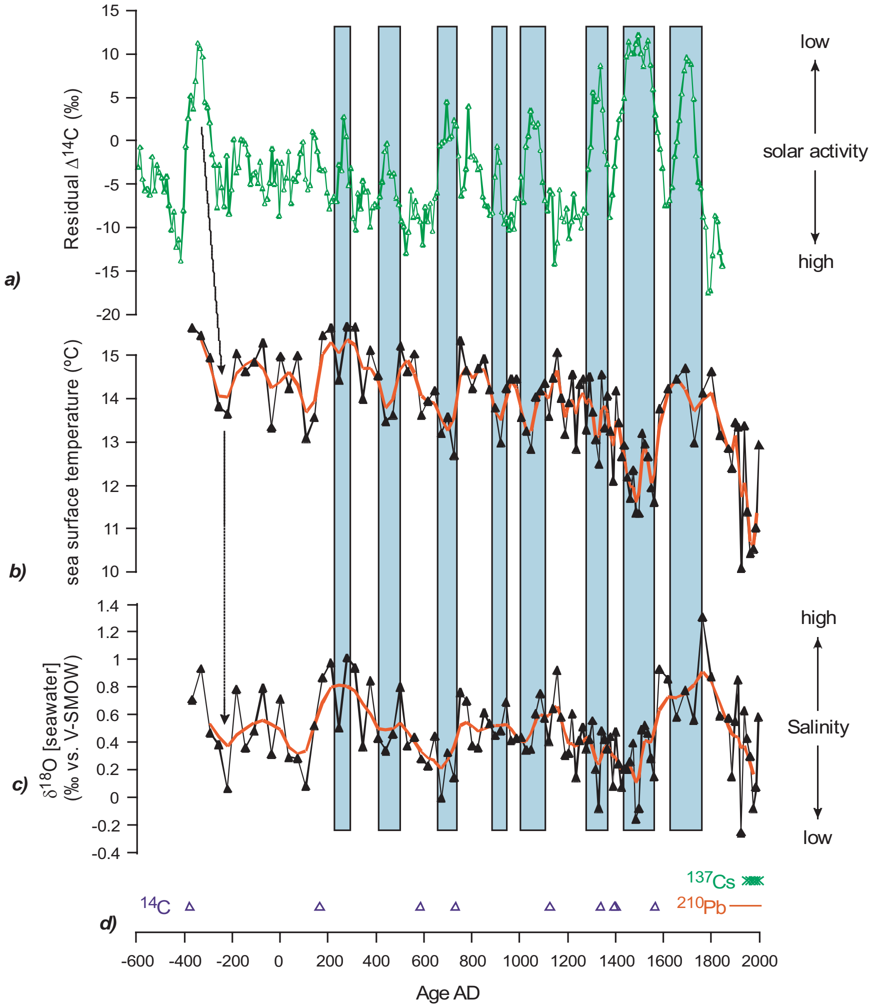

Fig. 3. Surface water reconstructions for the last 2,400 years.
a) Atmospheric ^{14}C concentrations [literature data] tracing variable solar activity. b) Reconstructed sea surface temperature. c) Oxygen isotopic composition ($\delta^{18}O$) of seawater, an indicator for salinity. d) Age control derived from analyses of natural and man-made isotopes.

surface water conditions and, by inference, in the intensity of northward surface currents, prior to the onset of human greenhouse gas emissions constituting a unique and dangerous global climate experiment. Cooling during the 20th century could be interpreted as already reflecting weakened surface currents due to anthropogenic greenhouse gas emissions. However, we caution that it may instead represent the (temporary) culmination of a long-term natural cooling trend. Moreover, our record is obviously site-specific; thus additional records from other locations will be required to assess if unprecedented circulation changes already occur on a basin-wide scale.