Arctic sea ice: high resolution reconstructions

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ARCTIC SEA ICE: HIGH RESOLUTION RECONSTRUCTIONS

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Abstract

Sea ice is an essential component of the Earth climate. In the current context of global climate change, it is therefore essential to obtain a clear and detailed account of its historical variations. The recent development of IP_{25}, a novel sea ice proxy based on the preservation in marine sediments of a unique chemical fossil produced by sea ice algae has allowed for the a series high resolution accounts of Arctic sea ice over the last few millennia to be constructed.

Introduction

Given the current debate regarding climate change on Earth and, in particular, the relative contributions of natural processes and anthropogenic inputs, it is crucial to obtain a clear and detailed account of past climatic variations and the factors controlling these (Jones et al., 2001). Over the past few years, considerable attention has been given to the seasonal sea ice coverage of the Earth's Polar Regions. Advanced satellite data has revealed a considerable decline in ice cover, particularly for the seasonal sea ice which constitutes approximately 50% of total ice coverage for the Arctic and the Antarctic (Serreze *et al*., 2007, 2003; Stroeve *et al.*, 2005). The decline in seasonal ice extent is of particular concern since sea ice plays such a major role in contributing to the dominant oceanic processes and the reflection of incoming solar radiation via the so-called 'albedo' effect (Holland et al., 2001). Although satellite data exists for recent decades, there is a paucity of sea ice data prior to the 1970's and data that does exist is only available at low temporal and spatial resolution. Since predictive climate models rely so heavily on historical datasets, there is a widely accepted urgent need for high resolution accounts of past sea ice coverage (Jones *et al*., 2001). In the absence of direct observational records, acquisition of such datasets is achieved using so-called proxy methods.

Proxy methods for palaeo sea ice reconstruction exist through examination of ice cores and sediments (e.g. Gersonde *et al*., 2005), though many of such methods suffer substantial drawbacks and are usually extremely time-consuming, preventing high resolution studies to be achieved routinely. As such, there are currently relatively few detailed sea ice accounts. It is therefore imperative to develop new proxy methods which will permit rapid acquisition of high resolution sea ice data.

Artic Sea Ice extent

Recently, we have been developing the use of a new sea ice proxy which offers major advantages over traditional methods. The basis of the proxy is a lipid biomarker (IP_{25}) which is synthesised specifically by a number of sea ice associated diatoms (Belt et al., 2007). When detected in sediments below sea ice, this biomarker chemical can be readily distinguished from chemicals derived from marine or terrestrial sources. IP_{25} can be detected in extremely small sediment samples and has been detected in sediments dated >9000 years. As such, quantification of IP_{25} can be achieved at high resolution and over significant timescales (the Holocene, at least) thus allowing for high resolution reconstructions of past sea ice variations.

This lecture will focus on a detailed analysis of a series of sediment cores collected across the Arctic with a particular emphasis on those collected from the Nordic seas area. Using the variations in IP_{25} abundances in the sediments, historical sources documenting past sea ice occurrences (e.g. Koch, 1945; Bergthórsson, 1969; Ogilvie, 1992; Ogilvie and Jonsson, 2001) and several other well established proxies, we have been able to produce high resolution accounts of sea ice for the last few millennia showing evidence for abrupt changes to sea ice and/or climate conditions during that period. For example; Figures 1 & 2 show a continuous record of the relative abundance of IP_{25} for the top (ca. 300 cm) of the MD99-2275 sediment core (collected from the North Icelandic Shelf). These results, when compared with climatic data from previous studies (Ogilvie, 1992; Crowley and Lowery, 2000; Jones et al., 2001; Ogilvie and Jónsson, 2001; Knudsen et al., 2004; Eiriksson et al., 2006; Jiang et al., 2006) show a series of excellent correlations throughout the entire period (Figs. 1 & 2). On an centennial scale, abundances of IP_{25} are entirely consistent with previous estimations of the Little Ice Age (LIA), the Mediaeval Warm Period (MWP) and relative centennial temperatures (Jones et al., 2001; Ogilvie and Jónsson, 2001). At a higher temporal resolution, 1690-1700 is considered to be the coldest decade for the 17th century in the northern hemisphere (Jones et al., 1998; Crowley and Lowery, 2000) including Iceland (Ogilvie and Jónsson, 2001), and this is reflected by the highest abundance of the IP_{25} biomarker in the MD99-2275 sediment core over the past 1000 years. IP_{25} is also abundant in sediments dated 1776, 1638, 1364, 1331 and 1309 corresponding to decades where large amounts of sea ice have been reported around Iceland (Ogilvie and Jónsson, 2001). In addition, these dates correspond to cold decades as shown by both the diatom-based sea surface temperatures (Fig. 1, Jiang et al., 2005) and the mean northern hemisphere temperatures (Fig. 2; Crowley and Lowery, 2000).

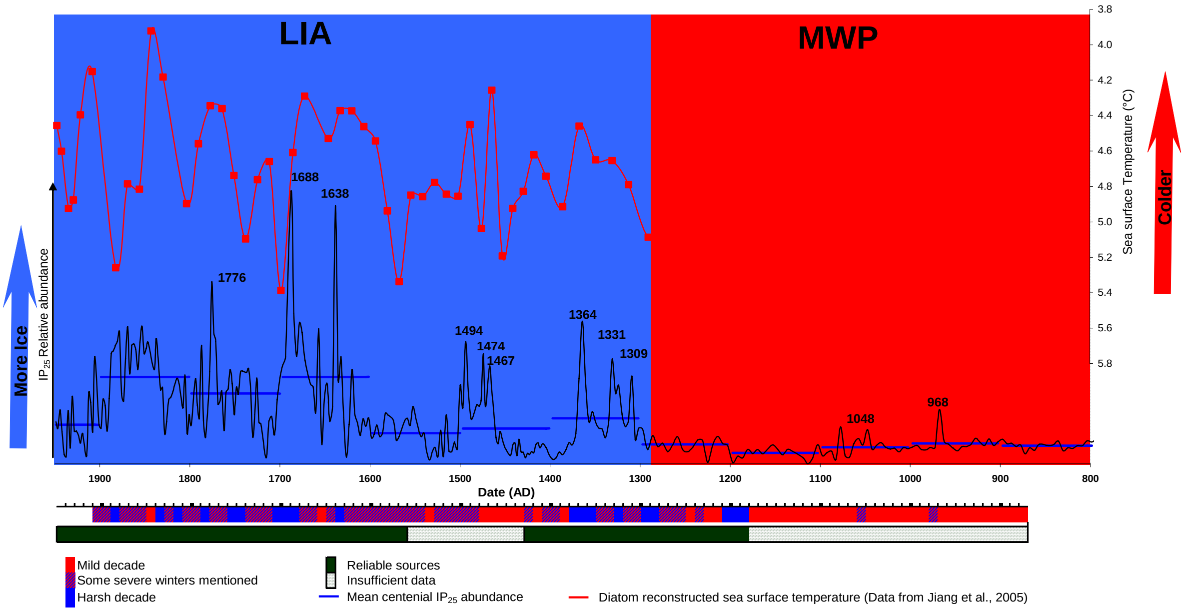

Figure 1 Relative concentrations of IP_{25} found in the core MD99-2275 for the period 800-1950 AD plotted against historical records of Icelandic sea ice interpreted from Ogilvie (1992) and Ogilvie and Jónsson (2001) (bottom scales) and diatom-based reconstructed sea surface temperature (Jiang, 2005).

The current IP_{25} data also provide additional sea ice information for periods where the historical sources are limited or unreliable. For example, very little data about Icelandic climate is available for periods corresponding to the earliest days of Iceland colonisation (ca. 870) to the end of the 13th century and from 1430 to 1560 (Ogilvie and Jónsson, 2001). The epoch immediately following the first colonisation period corresponds to the end of the MWP and therefore little or no sea ice might be predicted for this time. Consistent with this hypothesis and also in agreement with diatom-based sea surface temperature reconstructions and northern hemisphere temperature profiles, IP_{25} abundances are low with mean values for 800-1300 lower than the subsequent 700 years (Fig. 1). However, our data shows dramatic differences for the mid-late 15th century, where there are abrupt increases in the abundance of IP_{25} (particularly 1494, 1474 and 1467), reflecting enhanced sea ice occurrences due to more severe conditions during this period, with the centennial mean close to that of the preceding 14th century, for which reliable historical records suggest several severe decades (Ogilvie and Jónsson, 2001). Thus, despite a paucity of historical climate records for the 1430-1560 era, we provide compelling evidence for substantial changes in climate during this time including a 40-50 year period of extensive sea ice cover. Interestingly, these rapid and dramatic changes in the abundance of IP_{25} during the mid-late 15th century are also consistent with substantial oscillations observed in the diatom-based temperature record (Fig.1). Additional abrupt and coincident changes in both the IP_{25} abundances and sea surface temperatures are observed during the 14th, 17th and 18th

centuries (e.g. 1364, 1638, 1688 and 1776) confirming that a number of substantial climate changes occurred in Iceland during the LIA.

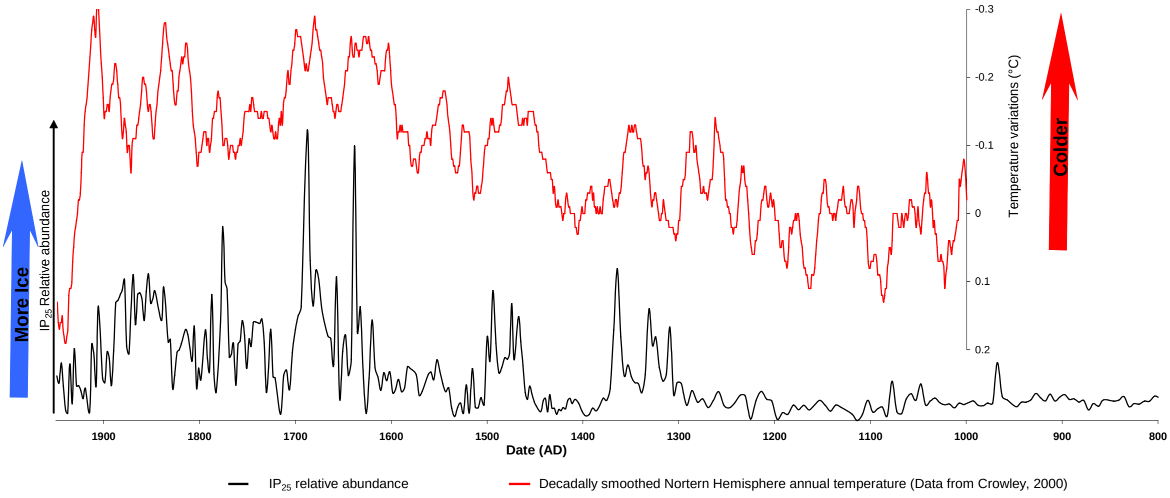

Figure 2 Relative concentrations of IP25 found in the core MD99-2275 for the period 800-1950 AD plotted against reconstructed Northern Hemisphere annual temperatures (Crowley, 2000).

As such, the high resolution and continuous dataset achieved in this study has enabled several abrupt changes to sea ice conditions to be determined for which there have been little or no precedent from previous decadal (or longer timescale) determinations (Fig. 1). Similar datasets were produced for various locations across the Arctic showing that such abrupt changes to sea ice conditions have occurred during the past few millennia and provided essential insights into the role of sea ice onto the earth climate system. Finally, not only will such data enhance the quality of climate prediction models but, for locations where there is the additional impact on past human populations, a more accurate account of climate-induced control over human activity should become achievable.

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