White paper

History and Dynamics of the Last Interglacial Period from Ice Cores

Introduction

As concern about future climate change due to anthropogenic activities grows, it is increasingly important to have a long-term perspective on Earth system feedbacks operating during past warm (interglacial) climate periods. In the ice core record, the last interglacial period, identified in marine sediment records as marine isotope stage 5E, and in northwest Europe pollen records as the Eemian, is the most accessible interglacial period prior to the well-documented current interglacial, the Holocene. It is also marked by global mean sea level six m (or possibly more) above today’s level, reflecting warmer conditions and partial deglaciation of Greenland and Antarctica, providing a benchmark period to assess the response of polar ice sheets to warm climates.

The scientific issues

The last interglacial (LIG) period is critical for understanding climate change because it offers a period of bipolar warmth reaching magnitudes comparable to those simulated in response to increased greenhouse gas emissions during this century. Although not a perfect analogue for the future, the LIG is the only pre-Holocene interglacial where detailed ice core data from both poles can be obtained. Accurate data provide critical benchmarks against which to test feedbacks from climate models, such as those associated with ice sheet size, sea ice, water vapour and clouds. While Arctic warmth is explained due to several feedbacks converting orbital forcing into annual mean temperature response, mechanisms leading to Antarctic warming remain enigmatic and may involve ocean, atmosphere, sea ice and ice sheet modifications. Ice core data are also crucial to constrain past changes in ice sheet mass balance and outflow. So far, ice core data from Greenland are consistent with ice sheet simulations showing a contribution of 1.5 to 4.3 m to the global mean sea level, implying up to several meters of contribution from Antarctica.

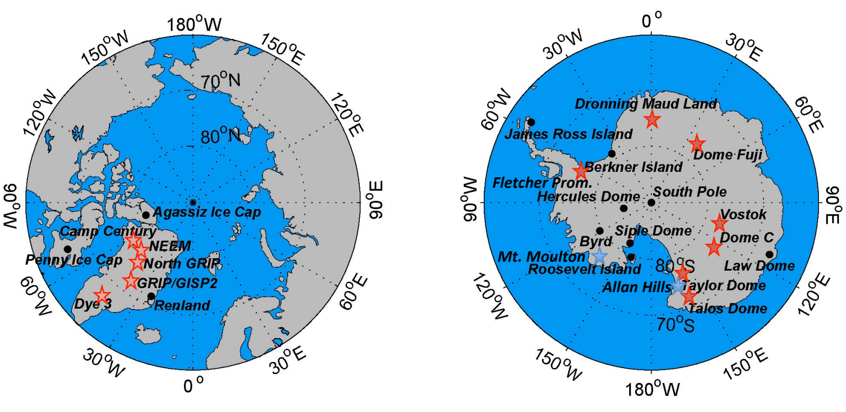

Figure 1. Locations of deep ice cores containing sections from the last interglacial are shown with red stars. Filled star indicates complete intact Eemian record; open star indicates records that contain Eemian ice but are either not complete or not stratigraphically intact (that is, sections are missing and/or not in order).

Existing work

Existing ice core records of the LIG have been very informative, but have important limitations. In Greenland, six deep ice-coring projects (Fig. 1) have reached last interglacial (LIG) ice. NEEM provides the most complete picture, but none have succeeded in finding an intact continuous section of ice from this time period. LIG ice is often folded and not in stratigraphic order, making it more difficult to date and interpret than traditional records, and affected by percolation effects associated with surface melt. In Antarctica, eight sites (seven deep ice cores and two horizontal cores) include the LIG (Figures 1 and 2), but additional records with higher resolution, and new records from additional sites, are necessary to characterize regional climate, ice sheet, and environmental change during this important time period.

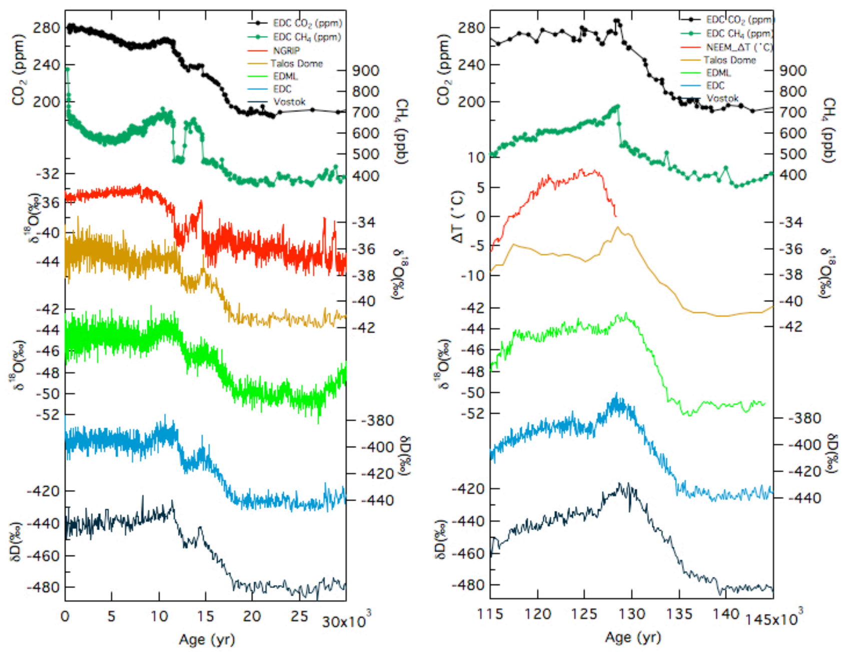

Figure 2. Selected Holocene and Eemian data plotted on AICC2012 or GICC05 timescales. Eemian climate reconstructions from NEEM (NEEM Community Members, 2013), Holocene NGRIP isotopic data (NGRIP Community, 2004,) Holocene and Eemian Antarctic isotopic data (Bazin et al, 2013; Veres et al., 2013), and EDC CO_2 and CH_4 records (Spahni et al., 2008; Siegenthaler et al., 2005).

To fully understand these issues, and their implications for the future, we need to:

- Characterize the spatio-temporal structures of Greenland and Antarctic climate and mass balance, including regional variations, by combining ice core records with marine and other data.
- Document changes in atmospheric composition and natural climate forcings linked with solar and volcanic activity during this period.
- Constrain the evolution of the Greenland and Antarctic ice sheets, their contributions to global mean sea level under a warmer climate, and the rates at which these ice sheets can contribute to sea level change.
- Relate the processes controlling polar climate and ice sheet variations from the present and the LIG to the predicted scenarios under future global warming.

The challenge

In order to answer these questions we need to chart the full course of an interglacial from the penultimate glacial termination to the next glacial inception at very high resolution in numerous parameters, including greenhouse gases, and in numerous places in Greenland, Antarctica, and possibly mountain ice caps. The aim is to obtain information on forcings and responses at a level comparable to that available for the Holocene.

Meeting the challenge

Answering these questions requires new ice core records from Greenland and Antarctica. We will need:

- To identify any suitable sites in Greenland where undisturbed ice layers spanning the Eemian and penultimate termination might be present. Coastal domes such as Renland (to be drilled by Denmark in 2015) are candidates, and other Greenland sites should be considered. Additional analysis of the disturbed records is also needed.
- Determine which Antarctic locations would be most suitable for further constraints on the EAIS and WAIS history, through a combination of modelling studies and remote sensing. In Antarctica, coring in regions sensitive to potential collapse of the West Antarctic Ice Sheet is especially critical.
- Improve the quantitative interpretation of ice core records in order to improve dating of LIG layers, deconvolve elevation and temperature signals, and understand post-deposition effects in areas affected by surface melt.
- Drill, analyse and date multiple cores from both polar regions, likely over a decade or more.
- Continue to identify and drill possible sites in lower latitude mountain regions where Eemian ice may be preserved.
- Integrate ice core information into the climate and ice sheet-modelling framework, which requires developments in data assimilation and proxy modelling.
- Improve temporal and spatial temperature reconstructions for the last interglacial from better understanding of relationships between water stable isotopes and climate, using climate models equipped with water stable isotopes and abundant modern data.

Choosing the sites

Radar surveys in Greenland that can image internal layering to the bedrock will be needed to choose appropriate sites, and may help synchronize records, as will ice sheet modeling to understand Greenland ice sheet history. In Antarctica a program of combining ice sheet and climate modeling and remote sensing data should determine what locations would be most sensitive to changes in the size of the WAIS during the LIG. In both Greenland and Antarctica further investigation of coastal ice domes as archives of Eemian ice should be a priority.

International collaboration

We anticipate that coring and modelling addressing the last interglacial would be conducted by individual countries or consortia of countries, within a comprehensive framework created by IPICS.

Drilling and analysing the cores

Technically, drilling at any potential sites to study the last interglacial is fully possible using existing drilling technologies in several research programs within the IPICS community.

The next steps and schedule

An international workshop should be held to clarify the current state of knowledge, key questions, and next steps. Such a workshop could build on the legacy of large collaborative efforts like PAST4FUTURE.

International Partnerships in Ice Core Sciences (IPICS) is a group of scientists, engineers and logistics experts from the leading laboratories and national operators carrying out ice core science. At the first IPICS meeting, in Washington, DC in 2004, participants identified several high priority international scientific projects to be undertaken over the next decade or more. At the second IPICS meeting, in Brussels, Belgium, in October 2005, these projects were further defined, and routes to implementation were discussed. The 2005 meeting also placed IPICS on a more formal footing. It now has an international steering committee including representatives of 18 nations, planning groups are being formed around each of the scientific projects, and an additional international group of drillers and engineers has been organized. IPICS has been officially approved as an IPY project by the International IPY Committee.

The current document is a new version of one of the four original IPICS white papers on scientific topics. The IPICS focus on the last interglacial was originally only directed to the NEEM ice core project, which has now been completed, and this new white paper is an outgrowth of that project. The fifth white paper looks at some of the technical challenges and drilling needs for implementing the IPICS plans. The five IPICS core topics are currently:

1. The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica.

2. History and Dynamics of the Last Interglacial Period from Ice Cores (this white paper).

3. The IPICS 40,000 year network: a bipolar record of climate forcing and response.

4. The IPICS 2k Array: a network of ice core climate and climate forcing records for the last two millennia

5. Ice core drilling technical challenges

For more information about IPICS or any of these projects please see the IPICS web site (http://www.pages-igbp.org/ipics/) or contact the IPICS co-chairs:

Edward Brook
Department of Geosciences
Oregon State University
Corvallis, OR 97330
USA
brooke@geo.oregonstate.edu

Eric Wolff
Department of Earth Sciences, University of Cambridge,
Downing Street, Cambridge, CB2 3EQ, UK.
Phone: (+44) (0)1223 333486; Email: ew428@cam.ac.uk

Drafting committee for this document:
Valérie Masson-Delmotte, LSCE, France
Edward Brook, Oregon State University, USA