White paper

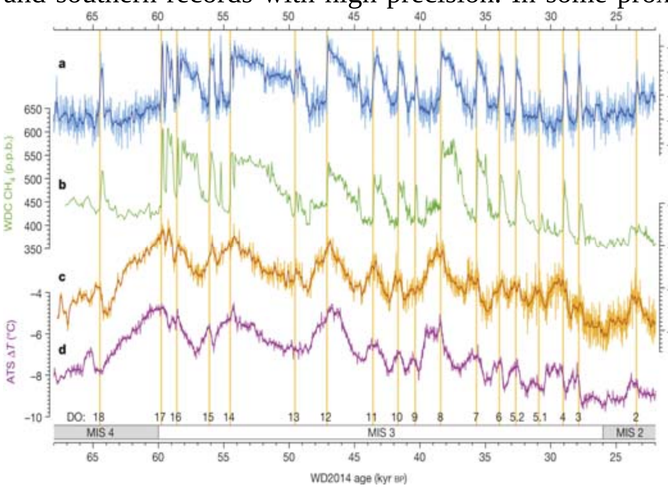
Terminations and seesaws: an ice core contribution to understanding orbital and millennial scale climate change

Introduction

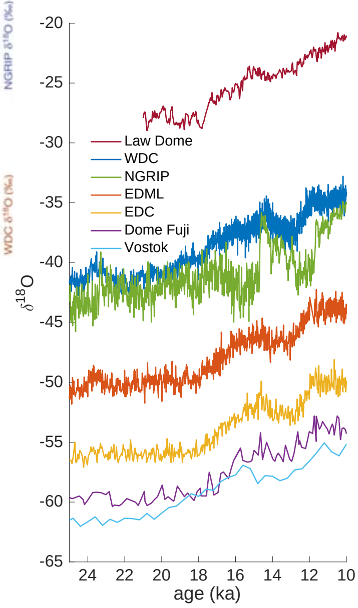
Records of our planet's climate history help to reveal the dynamics and processes by which the Earth system operates. Studies of large and rapid climate changes in the past complement recent information from instrumental and satellite records. They provide a benchmark to ensure that all relevant processes are adequately represented in Earth system models, used both to understand past variations and to assess future climate. Glacial terminations offer case studies of a large global climate response to external forcing and involve significant change and interaction among many components of the Earth system, including ice sheets, the carbon cycle, vegetation and dust. Millennial scale Dansgaard-Oeschger (D-O) cycles are case studies of very fast regional redistribution of climate, most likely resulting from rapid reorganizations internal to the climate system, involving ocean and atmospheric circulation. During these cycles, abrupt warming of parts of the northern hemisphere was accompanied by a slower, out of phase cooling in the southern hemisphere – the so-called bipolar seesaw – and vice-versa. For both types of change, ice cores have already provided evidence about spatial patterns, temporal sequences, and some of the feedbacks, for example in the carbon cycle, that have been at play. However, they still offer limited regional information, and a lack of details prior to the last glacial period. Further work is needed to complete a network of synchronized, high-resolution ice cores, from both polar regions, in order to understand the processes involved in abrupt millennial scale change and in glacial terminations. Furthermore, a small number of Antarctic ice cores now allow us to delve into previous glacial cycles in the same detail that has until now been available only for the last glacial cycle.

The scientific issues

Previous work from central Greenland and East Antarctica has documented the most recent sequence of millennial scale D-O events, and the termination of the last glacial period between about 20,000 and 10,000 years ago. The recent high resolution record from West Antarctica has provided unprecedented detail in the southern hemisphere, and links northern and southern records with high precision. In some proxies, changes within D-O events have



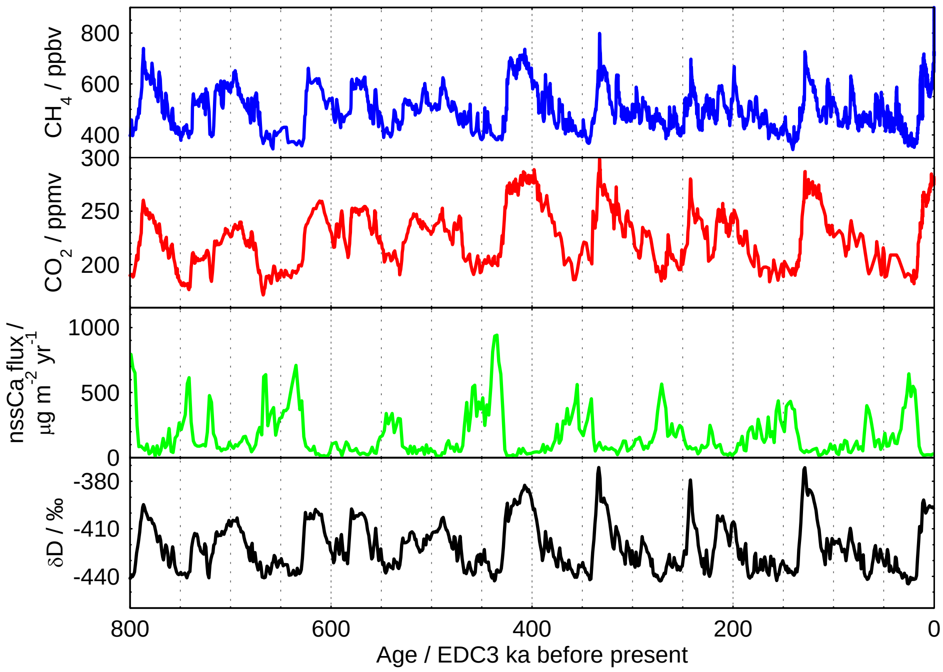
Above: Records of millennial scale variability from Greenland (NGRIP), West Antarctica (WDC) and East Antarctica (ATS). WAIS Divide Project members, Nature 520, 1-5 (2015). Right: records of the last glacial termination from around Antarctica and (green) from Greenland.



been identified that may allow us to key them to marine records, for example of Heinrich Events. It has also become apparent that millennial changes play a role in the events during glacial terminations. However, additional records from new drilling sites are needed to fully document the spatial pattern of change (e.g between ocean basins around Antarctica), and to better understand the range of mechanisms involved. Changes in ocean circulation are often invoked to explain past abrupt changes in climate, and observed features can be captured by climate models in response to prescribed freshwater fluxes, mimicking ice sheet meltwater. However, the exact mechanisms behind millennial events still remain to be understood: what is the role of the background climate state on potential instability of ocean circulation? What is the exact sequence of events between changes in ocean circulation and ice sheet instabilities? How can we assess the ability of climate models to correctly capture these transient reorganizations? The time period of the last 40,000 years, extensively studied to date, only covers one single termination and millennial variability in a specific ice sheet / orbital context. It is not sufficient to unveil the rules that govern the timing of terminations, or the climatic boundary conditions under which millennial scale events occur.

The challenge

The challenge is to create a library of spatial and temporal data from millennial-scale events and terminations that can be used, in combination with other paleoclimate records (e.g. deep sea sediments, speleothems, lake sediments…) as well as paleoclimate modelling, to understand the mechanisms underlying them. In practice this requires two targets: firstly, to create and synchronise high resolution records from north and south for the last glacial cycle in order to establish the spatial pattern and environmental footprint of D-O cycles and the last termination; and secondly, to analyse terminations and millennial scale events in earlier glacial cycles at high enough resolution to allow them to be compared to the collection of events from the most recent cycle.



Climate records from the last 800,000 years (800 ka) from EPICA Dome C show the sequence of terminations and hint at the pattern of millennial variability

Existing cores

Many of the cores that would be needed for this network have already been drilled:

- In central East Antarctica several cores already exist, including three (Vostok, EPICA Dome C and Dome Fuji) that encompass several glacial cycles, and a few more that pass the penultimate termination. A new core from South Pole was recently drilled.

- The WAIS Divide core provides a high resolution template for West Antarctica, with much more data to come.
- Around the Antarctic coast, several cores spanning the last glacial cycle, or at least the last glacial termination, already exist, although some, such as Roosevelt Island and Fletcher Promontory, are still in early stages of analysis
- Inland Greenland is served by a south-north span of cores from Dye 3, Summit, North GRIP and NEEM. The new Renland core adds a dimension on local climate variations around the Greenland ice sheet. The lack of ice core records spanning the penultimate deglaciation in oldest ice core records from Greenland is an enigma.
- It is challenging to find and interpret non-polar cores that span the last termination and glacial but this would be of great value, should suitable sites exist.

Meeting the challenge

The international ice core community needs to:

- Further develop ice core proxies for different aspects of the Earth system, for example to reconstruct conditions at the ocean surface (e.g., sea ice, marine biological productivity, ocean evaporation conditions), and in the boreal continental biosphere (e.g. forest fires, land ice extent).
- Improve the absolute and relative chronologies of individual ice cores, in both the ice and gas phase, and construct consistent multi-ice-core chronologies.
- Develop methods to synchronise ice core records to those from other palaeoclimate archives, in particular for previous glacial cycles where radiocarbon is unavailable.
- Identify further sites to complement the spatial picture and implement plans to fill the "gaps": examples include further cores at coastal domes around Antarctica.
- Apply newer methods to improve the resolution of data from some existing sites.
- Quantify and understand the spatial and temporal evolution of rapid climate changes, and assess how this varies with background climate (orbital forcing, greenhouse gas concentration, land ice masses).
- Construct, using ice cores carefully synchonised to other records, the sequence of events (including forcings and responses) through several glacial-interglacial transitions at the highest resolution possible.
- Use these reconstructions with Earth system modelling to provide a stringent test of mechanisms. This will require an increase in modeling capability to assess changes at sufficient resolution through multiple terminations

The international dimension

Very large ice coring projects have a long tradition of international co-operation. Many of the planned and missing sites are less ambitious in terms of depth and location, and can be drilled by relatively small teams. However, international collaboration is necessary to make sure that critical analyses, not available in all laboratories, are completed, and that new methodologies are shared and used on new and existing cores. Planning and completing the network, as well as integrating its results, will require the inclusion of all leading ice core nations.

The next steps and schedule

A group has already met to discuss possible coastal dome sites on the Amundsen Sea coast. Further sites will be discussed as part of the regular exchanges of information coordinated by IPICS. A small team should document the available and potential sites, and propose a suite of analyses that would best allow synthesis to take place. Efforts to synchronise ice core data have already started to be coordinated (e.g. AICC2012 project) and it will be important to extend this or similar efforts across other cores, and how to extend the effort to other archives. Collaboration with existing non-ice core groups – such as those of SCAR, INQUA, PMIP and PAGES – provides an efficient pathway to integrate with people realising other parts of the puzzle, including the glaciology, palaeoclimate and climate modelling communities.

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, IPICS was placed on a more formal footing. Subsequent meetings have refined and formalised the white papers and established a quadrennial open science conference. IPICS now has an international steering committee including representatives of 23 nations, and an additional international group of drillers and engineers has been organized.

The current document is one of up to 5 describing the current IPICS science priorities; a further paper looks at some of the technical challenges and drilling needs for implementing the IPICS plans. This white paper has developed from and replaced the one entitled "The IPICS 40,000 year network: a bipolar record of climate forcing and response". The currently active white papers are entitled:

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.

3. Terminations and seesaws: an ice core contribution to understanding orbital and millennial scale climate change (this document)

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

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