White paper - updated version 2020

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

Introduction

Climate scientists have an obligation to provide realistic assessments of how climate will change in the future. Doing so requires accurate models of how the Earth's climate system works and responds to changes. This in turn requires that we understand all the processes that can occur, and how they interact. This knowledge may come from studying Earth's climate in the past, where we have observational evidence stored in natural climate archives, and in particular for times when critical climate boundary conditions were different (e.g., different atmospheric greenhouse gas concentrations). As the only direct archives of the past atmosphere, studies of polar ice cores have already revolutionized our view of the Earth system, documenting the recent rise of greenhouse gas concentrations beyond historical levels, the existence of abrupt climate changes, and the tight coupling in the past of climate and greenhouse-gas concentrations.

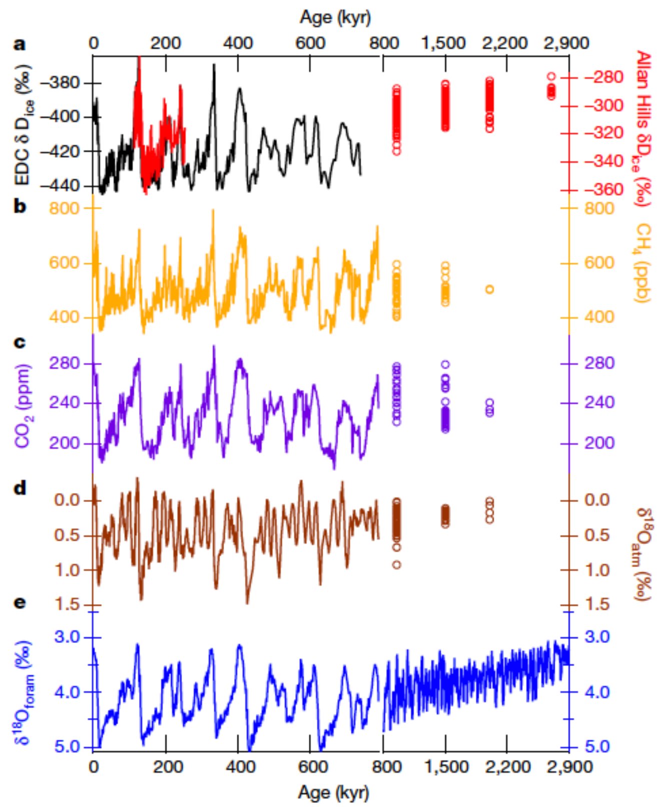

Figure 1: The ice core record over the last 800,000 years and its extension from blue ice and marine sediments ($\delta^{18}O_{foram}$) (from Yan et al., Nature 2019)

In deep Antarctic ice cores, we can observe that we are currently living in a relatively mild "interglacial" phase within a series of warm/cold oscillations occurring every 100,000 years. These cycles must initially arise from a strong amplification of weak changes in the amount and distribution of incoming solar radiation. We can see that the small changes in energy input also cause major changes in the partitioning of carbon dioxide and other greenhouse gases between the atmosphere and other reservoirs. However, we still lack a fundamental mechanistic understanding of why these processes occur. As a result, we still lack crucial knowledge about the natural regulation of carbon dioxide or the feedbacks which amplify the subtle changes in boundary conditions that altered the Earth's climate system. Both these factors are important as we try to predict how Earth's climate will respond to anthropogenic perturbation in the future.

The scientific issues

Our longest continuous ice core record today extends over 800,000 years into the past, where extended warm climate periods punctuated ice ages about every 100,000 years. However, from marine sediments we know that before about 1 million years ago this time ice age cycles lasted only 40,000 years. This change of the rhythm in the glacial/interglacial cycles is also called the Mid Pleistocene Transition (MPT) and although there are a number of hypotheses for why this fundamental transition occurred, its origins remain enigmatic. If we are to understand the state our climate is in now, we also need to understand what caused the length of the cycles to change. In line, studying the interactions of climate and biogeochemistry in this earlier period will allow us to:

- understand the natural variability that has led us to our current climate
- better assess the likely course our climate would take in the next few centuries to millennia in the absence of human interference
- see numerous examples of the natural relationship between greenhouse gases and climate, allowing us to deduce the underlying rules
- test the hypothesis that the change from 40,000- to 100,000-year cycles was caused by a long-term lowering of atmospheric carbon dioxide concentrations
- better understand the timescales and processes that control exchange of carbon dioxide (including excess CO_2 from human activities) between reservoirs

Many of these questions can only be addressed by a deep ice core, because only ice cores can provide an accurate, continuous measure of past greenhouse gases, mean ocean temperature, and polar climate in the same archive. The ice cores with the longest, continuous climate record are from the interior of the East Antarctic ice sheet, which is now the focus of exploration to extend the ice core record back in time. Recently, discontinuous old ice has also been discovered in blue ice areas around the margin of the ice sheet. This archive provides additional snapshots of past climate and atmospheric composition at least as far back as 2.7 million years, and possibly earlier (Figure 1). New dating methods allow us to tie both continuous and discontinuous records to other climate records and external forcings, thus adding new value to existing studies of this time period.

The challenge

In order to confront the issues outlined above, the goal is:

- to obtain a reliable, continuous Antarctic ice core record of climate and biogeochemistry extending through several of the 40,000-year cycles and up to the present
- In practice this means that we need to obtain a replicated Antarctic ice core record extending at least 1.2 million and preferably 1.5 million years, into the past.

To complement the deep, continuous ice core record and to extend it back as far as possible we need

- to explore archives of discontinuous ice from blue ice areas and to develop techniques for developing paleoclimate records in discontinuous ice.

Meeting the challenge

We will need

- to carry out detailed survey and modeling work to identify sites where we can expect to find the oldest ice
- to assemble an international team capable of supplying the logistic effort, drilling expertise and intellectual knowledge to obtain the core and the scientific returns from it
- to drill and analyze at least two cores at different sites in order to fully validate the records obtained

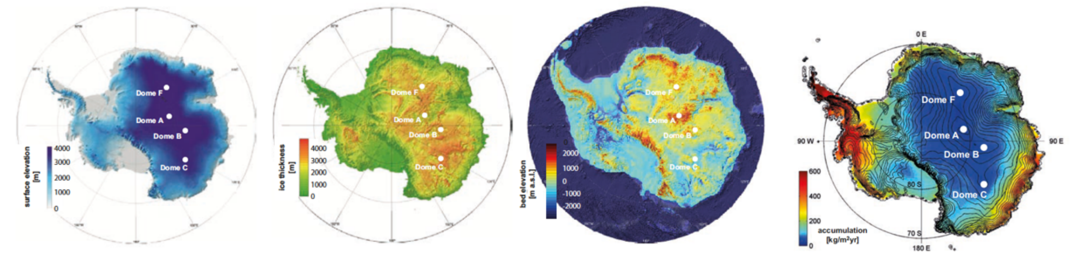

Figure 2: Important site characteristics for the selection of an Oldest Ice deep ice coring site: From left to right: surface topography, ice thickness, bedrock topography, surface accumulation (from Fischer et al., Climate of the Past, 2013)

Identifying the site(s)

Undoubtedly, ice older than 800,000 years does exist close to the bottom of the Antarctic ice sheet and in outcropping areas. Candidate sites for a continuous ice core covering the MPT are likely to have relatively thick ice, but not so thick that there is excessive melting at the base, a low snow accumulation rate, and low ice velocity. Suitable sites will also have a rather flat bedrock and recent experience suggests that a slight melting at the base may be favorable for getting undisturbed sequences near the bed.

Although large areas of the East Antarctic Plateau remain still unexplored in view of their chance to provide Oldest Ice, several potential drill areas have been identified in recent years, (for example in the Dome C and Dome F area) using an iterative process of modeling and field surveys that includes measurements of:

- Ice thickness, elevation, velocity, surface and basal topography
- Snow accumulation rate
- Temperature, including estimates of basal temperature
- Internal radar layers, allowing us to follow deep layers of known age from existing drill sites
- Present-day measurements of meteorology and atmospheric chemistry

Moreover, latest developments in (non-coring) rapid access drilling in several nations attempts to provide datable ice core material from ice close to bedrock to directly explore the existence of ice from or before the MPT.

Such a combination of airborne and ground-based survey, combined with shallow coring traverses, satellite remote sensing data and modeling as well as rapid access drilling promises to identify further potential drill sites in other areas of the sparsely-sampled interior of East Antarctica.

Moreover, blue ice areas that may harbor stranded glacial ice >800,000 years exist over a large area of Antarctica (~1%) and apart from a few sites, much of this potential archive is still unexplored. Again, the IPICS Oldest Ice initiative hope to act as a catalyst for blue ice exploration and a hub for the synthesis of international blue ice activities within the Oldest Ice plans.

The international dimension

Ice coring has been an intensely international business: two of the most successful projects of recent times have involved nine nations (NorthGRIP, Greenland) and ten nations (European Project for Ice Coring in Antarctica) respectively, while almost all the large projects have included an international dimension. The Oldest Ice project, certain to be set in logistically remote sites, is a challenge that can only be fully met through an international initiative. All the major ice coring nations have expressed interest in the project and mutual support.

Drilling and analyzing the core

Beyond the logistics of working at such remote sites, the retrieval of a continuous ice core at potential Oldest Ice sites does not throw up any technical challenges we have not already met in earlier drillings. A different drill fluid needs to be used to meet the scientific, technical and legislative requirements, and improved drilling techniques will allow better core recovery. The ice core community currently has the analytical and intellectual capacity to carry out such a project and is constantly expanding and improving their analytical portfolio.

Although retrieval of a single core would be a fine achievement, there are important reasons for drilling at least two cores:

- Replication is the only way to ensure that the results have not been affected by flow disturbance or other artifacts
- Despite our survey work, there is a risk that local variability near the bed could deny us very old ice in a single core; drilling two cores doubles the probability of finding the very oldest ice

The next steps and schedule

The second meeting of International Partnerships in Ice Core Sciences met in Brussels in October 2005 and confirmed its wish to develop this project, which led to a first version of this white paper. In the meantime, several national and multi-national activities were launched in the 2010s to carry out the required reconnaissance to identify potential Oldest Ice drill sites and to develop rapid access drilling techniques. Moreover, a few outstanding blue ice studies confirmed the potential of the Oldest Ice branch to extend the ice core record beyond the MPT. A European Oldest Ice project has been launched in the meantime, building a drill camp at Little Dome C in 2019 and several other nations are in the starting blocks to follow. Drilling of such an Oldest Ice core, however, will take a few years and first results on the ice older than 800,000 cannot be expected before 2025.

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.

The current document is one of four describing the science proposals; a fifth looks at some of the technical challenges and drilling needs for implementing the IPICS plans. The five documents 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: A comprehensive record of environmental change during the last interglacial period
3. Terminations and Seesaws: an ice core contribution to understanding orbital and millennial scale climate change.
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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