White paper

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

Introduction

Understanding present and future climate change depends on knowledge of natural climate variability. For example, observed rapid warming in the Arctic is due both to greenhouse gas forcing and to atmospheric dynamical changes associated with the Arctic Oscillation (AO). Determining the magnitude and frequency of AO changes in the past is a critical part of projecting how it will behave in the future under increased greenhouse gas forcing conditions. Significant efforts have been put forth to reconstruct the AO and other natural patterns of climate variability, such as the El Niño-Southern Oscillation, using high resolved (e.g. annual) paleoclimate proxy data from geological archives – lake sediments, corals, tree rings, etc. Syntheses of these data have been used to obtain estimates of global-scale changes in climate, providing key tests for the ability of numerical general circulation models to faithfully reproduce natural climate variability.

Considerable uncertainties remain in the reconstruction of past climate. Most notably, polar regions and high altitudes remain poorly represented, yet these regions encompass areas where the climate is changing more rapidly than anywhere else on the planet. Furthermore, knowledge of past climate forcings and feedbacks (greenhouse gases, solar variability, aerosols) remains uncertain. In both contexts, ice core records have a critical role to play because they provide perhaps the best – and in many cases the only – source of information.

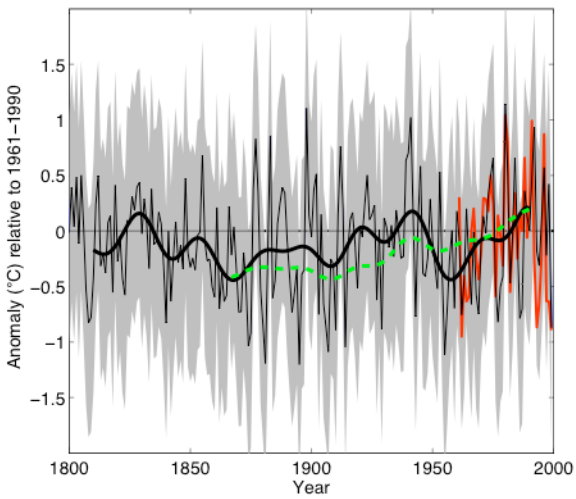

Figure 1. *Reconstructed continent-wide average Antarctic temperature anomalies from calibrated ice core stable isotope records. Black lines show annual data, 20-year smoothing (bold), and 2σ (annual) uncertainties. Also shown for comparison are annual average Antarctic temperatures from instrumental data (red), and 20-year smoothed instrumental record of Southern Hemisphere temperature (dashed green). After D.P. Schneider, Ph.D. thesis, University of Washington, 2005.*

Ice core records have been obtained from many locations in the Arctic and Antarctic, as well as on high altitude glaciers at low latitudes. However, most existing records are either at inadequate temporal resolution, or are too short to allow for quantitative reconstructions of climate and other environmental variables greater than one or two centuries in length (Fig. 1). Additional cores are needed that achieve both adequate length and high temporal resolution to be fully incorporated into climate reconstruction and modeling efforts. The IPICS 2k Array provides a framework for obtaining a network of such cores. Two thousand years (2k) is a critical time frame that includes both the industrial era and a significant length of time prior to the advent of anthropogenic influences on climate.

The scientific issues

Quantitative reconstructions of past climate provide the means to examine climate variability on centennial and longer timescales, which is impossible with the instrumental climate record. The results of existing reconstructions of the past millennium are widely debated because there is insufficient data in most regions prior to about A.D. 1600. For example, it remains

unclear to what extent the temperature change associated with the so-called "Medieval Warm Period" was a global or regional phenomenon, and how it compares in magnitude to 20th century warming. The spatial and temporal variability of past precipitation, atmospheric circulation, and sea ice extent on these timescales remains even less well known. Similarly, while greenhouse gas concentrations are globally well mixed and can be determined from a small number of records, variations in important climate feedback variables, such as continental dust and aerosol concentrations, are highly regional in nature. Finally, the magnitude of solar variability – accessible from ice core cosmogenic isotope (e.g. ^{10}Be) measurements – remains poorly known prior to the historical record of sunspot numbers.

Improved reconstructions of all of these variables are needed to answer fundamental questions about the natural variability of the climate system, and to put potential anthropogenic climate change into context. The time period of the last two millennia is an important target because it is both long enough to allow for the investigation of variability on centennial timescales, yet short enough that climate boundary conditions (such as the size of ice sheets) will not have changed substantially. The regional nature of climate and climate forcings requires that data be available from a geographically extensive area.

The relationship between temperature and stable isotope ratios in polar ice cores is well known. Ice cores also provide direct measures of snow accumulation, which is important for ice sheet mass balance studies, and may be the most important variable obtainable from low and mid-latitude sites. Concentrations of chemical species can be quite sensitive to sea level pressure anomalies, due to their control on the entrainment and advection of marine aerosols. Melt layers in ice cores provide an unambiguous measure of maximum summer temperature. The potential exists to use combinations of chemical species, melt layers, and isotope measurements in multi-proxy statistical reconstructions.

The challenge

The IPICS 2k Array provides a framework for obtaining a network of ice core data appropriate for input to detailed climate and climate forcing reconstructions, at the highest possible resolution and extending where possible to 2000 years. The challenge for the ice core community is to design and implement an effective means for accomplishing this task. Important considerations will include:

- Identification of sites where high precision dating can be achieved. Many sites in both polar regions and low or mid-latitude glaciers have sufficient snowfall that resolution of annual or better can be obtained.
- Validation of relationships between proxy data (e.g. isotope ratios or chemical concentrations) and the variables of interest (e.g. temperature).
- Obtaining sufficient numbers of records to produce statistically meaningful reconstructions.

Existing work and plans

A significant network, comprising more than 200 shallow cores, is being produced in the Antarctic through the SCAR ITASE project. A similar network (PARCA) exists in Greenland. These networks, along with the dozens of deep ice cores collected by individual researchers on the Arctic islands and from high mountains at low latitudes, will provide an invaluable basis for the design of a smaller network of longer records. However, many existing records do not have the broad range of high resolution geochemical measurements made possible by recent analytical advances, and many provide only limited information after the 1970s when satellite measurements began, hampering calibration with the modern climate record. Some locations will therefore need to be updated with new cores, at least covering the last few decades. Current international programs are focused on obtaining long records from the major ice sheets. The upper 2000 years of these records will be at the highest resolution possible for each site, but will need to be supplemented by additional, shorter cores for

validation purposes. There are ongoing efforts by individual researchers to obtain cores from the Arctic islands, and the high mountains at low latitudes. There is possibly an un-tapped archive of records available from glaciers and ice caps at mid latitudes.

Meeting the challenge

To provide a significant contribution towards the documentation and understanding of climate variability in the last 2 millennia, we will need:

- To use existing data, models, and statistical analyses to identify a sufficiently dense network of target sites for the purposes of climate reconstruction.
- To arrange traverses and campaigns to collect the necessary cores, making the most efficient use of logistical resources.
- To put significant effort into coordinated high resolution analytical measurements as well as calibration and validation of a broad range of ice core climate proxies.
- To archive the data in a form that can be used in reconstructions and by the modeling community.

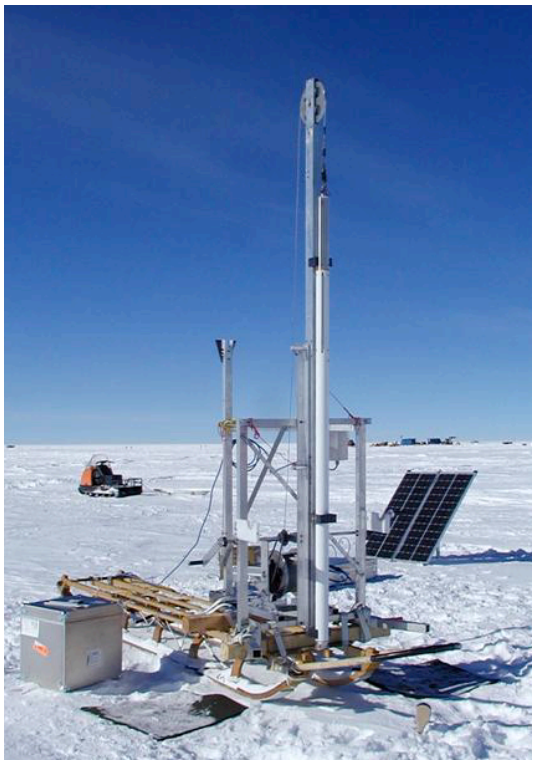

***Figure 2**: Portable ice core drill*

The international dimension

Reaching an age of 2000 years implies, in most cases, cores of a few hundred metres depth. In locations where accumulation rates are very high, reaching an age of 2000 years may require fluid drilling. It will be desirable to share planning and logistic capacity for core collection, and in some cases analytical capacity, in order to complete the network efficiently. It is also highly desirable that the data be archived at a single World Data site, to facilitate the sharing of data within the ice core research community and to ensure the timely availability of data to other researchers.

The next steps and schedule

At the second meeting of International Partnerships in Ice Core Sciences in Brussels in October 2005 the implementation of this project was discussed. The next step is to involve the wider community, and to develop plans for obtaining the cores and for common use of the data from them.

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 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. The last interglacial and beyond: A northwest Greenland deep ice core drilling project.

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

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