Scientific Committee on Antarctic Research (SCAR) Action Group Proposal

Name of the Proposed Group:
AntArchitecture

Names of the Lead Proponents:

Robert Bingham (University of Edinburgh, UK)
Olaf Eisen (Alfred-Wegener Institute, Germany)
Nanna Karlsson (GEUS, Denmark)
Joseph MacGregor (NASA Goddard, USA)
Neil Ross (Newcastle University, UK)
Duncan Young (University of Texas at Austin, USA)

Sponsoring Science Group(s):
Geosciences and/or Physical Sciences

Summary of Group:

The goal of a proposed *AntArchitecture* Action Group is to develop a continent-wide age-depth model of Antarctica's ice using the internal layers and surfaces imaged by radar-sounding. The product underpins a wider goal to determine the stability of the Antarctic Ice Sheets over past glacial cycles.

***AntArchitecture*: Proposed SCAR Action Group**

Introduction and Background

AntArchitecture is the name ascribed to an envisioned science programme which will aim for the first time to determine the stability of the Antarctic ice sheets over past glacial cycles directly from the internal architecture of the ice. Internal architecture describes the 3-D internal structure of the ice imaged by multiple radar-sounding surveys undertaken across Antarctica over the last five decades.

Determining the stability of different parts of Antarctica is crucial because there is mounting evidence that collapses of polar ice sheets fed rapid global sea level rise up to 9 m higher than today during the last interglacial period, ~127-116 ka. In this context, the volume and current behaviour of ice in Antarctica give cause for concern: both the West Antarctic and East Antarctic ice sheets (hereafter WAIS and EAIS respectively) contain sufficient ice to raise global sea levels by 58 m. Since the onset of satellite observations in the 1990s, both have lost mass. Present losses from the WAIS contribute an estimated 10% of observed global sea-level rise, are occurring at ever-increasing rates, and appear to support the longstanding hypothesis that the WAIS is “unstable”; in other words capable of diminishing rapidly with concomitant impacts on global sea levels. There is also a growing awareness that parts of the EAIS may also be as unstable as parts of the WAIS. There is, therefore, a pressing societal imperative to assess the (in)stability of both the WAIS and EAIS, thereby to gauge how rapidly future changes to both of these ice sheets will contribute to future global sea-level rise.

The only feasible means for understanding and predicting future Antarctic ice-sheet behaviour is to use an ice-sheet model (ISM). Crucially, ISMs are typically evaluated with recourse to how well they can produce past behaviour: the user gauges how well the ISM simulates advance or retreat of the ice (typically from dated ice limits) in response to a given climate forcing (derived from deep ice-core records). When the match is “good,” the ISM is considered reasonable, and it can then, in principle, be used to predict the future ice-sheet response to projected future climate scenarios. While the last decade has witnessed significant development and expansion of ISM investigations of Antarctic ice-sheet behaviour, weaknesses in their approach include the sparsity of known glacial limits around Antarctica for the purposes of ISM validation, and a dearth of constraints for ice behaviour in the ice-sheet interior across glacial/interglacial cycles. To address these limitations, *AntArchitecture* will take the novel approach of assembling and interrogating, with ice-sheet modelling, information that the ice itself has recorded about its past behaviour: information that is provided by the radar-surveyed “internal architecture” of the Antarctic ice sheets.

What is proposed here is an ambitious programme of multidisciplinary research, wherein the first critical stage, and the focus of *AntArchitecture* as a SCAR Action Group, is the assembly of a pan-continental archive of the radar-imaged internal architecture of the Antarctic Ice Sheet. The recent publication of an equivalent dataset for the Greenland Ice Sheet (Figure 1), and the application of this dataset to reconstructing Greenland’s paleoclimate, show what is possible for Antarctica using similar datasets. To undertake the same exercise across Antarctica is, however, challenged by the fundamental issue that, unlike for Greenland where the ice sheet has been comprehensively surveyed with a single tool (the US Center for Remote Sensing of Ice Sheets, CReSIS, radar system), Antarctica has been surveyed by multiple radar systems by multiple institutions exercising multiple practices for processing and archiving data.

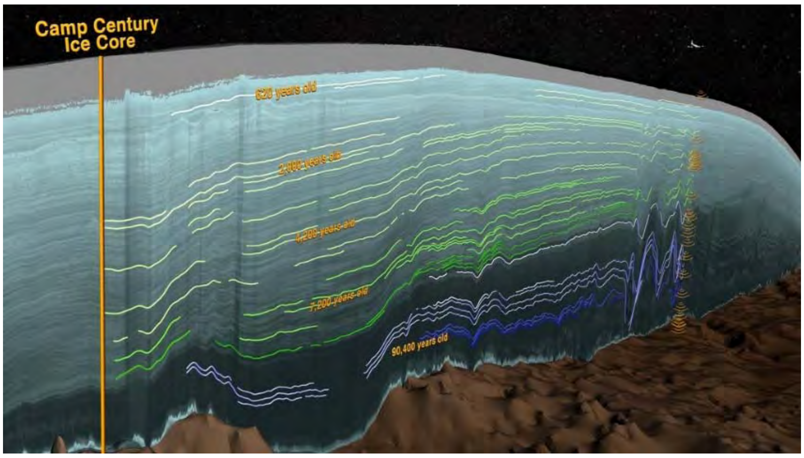

Figure 1: Example of traced internal architecture from the Greenland Ice Sheet, used to produce an age-depth structure for the whole ice sheet. Image from https://svs.gsfc.nasa.gov/4249; research published in MacGregor et al., 2015, Journal of Geophysical Research.

The *AntArchitecture* SCAR Action Group will bring together key datasets on Antarctic Ice Sheet internal layering from the principal institutions and scientists who have been responsible for acquiring, processing and storing them over the last four decades. Key activities will be coordinating data transfer and data lodging exercises between institutions/countries that will allow datasets acquired by different radar systems to be combined for pan-continental analysis, and the development of an optimised processing flow for analysis of past data and advice on where future data acquisition needs to be targeted. A fuller list of aims, goals and objectives is provided in the next section.

We stress the timeliness of *AntArchitecture* and its fit with existing SCAR activities as follows. The proposed activities directly address two priorities for Antarctic science as outlined by the 2014 SCAR Horizon Scan, namely *Understanding how, where and why ice sheets lose mass* and *Revealing Antarctica's history*. More specifically, the development of a pan-continental age-depth database of Antarctic ice will inform the International Partnerships for Ice Core Sciences (IPICS) activities, including the current major initiative to locate the site to obtain Antarctica's oldest ice core. Similarly, interaction with IPICS scientists will be crucial for providing dating control on an age-depth model for Antarctica using internal layering. *AntArchitecture*'s age-depth volume across Antarctica will provide a resource for testing ideas developed under the remit of SCAR's Past Antarctic Ice-Sheet Dynamics (PAIS) Science Research Programme, and will provide datasets of high relevance to the AntClim[21] Group. Finally, we note that *AntArchitecture's* vision to provide maps of internal surfaces of given ice age across Antarctica builds upon the SCAR-coordinated Bedmap2 and ADMAP efforts, wherein distinct datasets were successfully brought together to produce reconciled maps of Antarctica's subglacial topography and magnetic signals. Therefore, a model for successful collaboration between the relevant data providers spread throughout the SCAR community already exists.

Aims, Goals, Objectives/Timeline

The long-term (10 years) goal of *AntArchitecture* is to determine the stability of the Antarctic ice sheets over past glacial cycles by interrogating the internal architecture of the ice.

The aim of the proposed *AntArchitecture* Action Group (initial scope 4 years) is to undertake an important first step towards the above goal, namely to assemble the first pan-Antarctic database of radar-imaged palaeo-surfaces. The group will provide a forum for coordinating proposals to national funding agencies and foundations to support this work.

In July 2017, a two-day workshop at the University of Edinburgh was convened to identify the main challenges in assembling an Antarctic-wide database from radar data. The full report of the Edinburgh workshop may be downloaded here:
http://www.sages.ac.uk/wp-content/uploads/2018/03/BINGHAM-R-EDi-2017-AntArchitecture-Workshop-Final-Report.pdf

From this workshop, the following objectives were identified, here given aspirational timescales:

- Starting activities: Bring together Antarctic radar data providers; compile a list of the main users and applications of Antarctic radar data; identify the wider possibilities by integrating with ice-sheet modellers, members of IPICS, and other relevant science groups as may be identified.
- Years 1-2: Identify with numerical modellers the data formats required to drive models. Identify best format and practices for lodging and sharing data on radar-imaged internal architecture. Converge on standards for metadata and data formats, and nomenclature. Undertake radar-system intercomparison exercises where overlapping areas have been surveyed with different instruments. Develop a document outlining the optimised processing flow for internal layering analysis of different datasets, which will also guide future data collection.
- Milestone at end of Year 2: Produce a white paper, intended for submission to a relevant interdisciplinary peer-reviewed journal, e.g. Global and Planetary Change, Climate of the Past, Frontiers of Earth Sciences, outlining the need for an Antarctic radar-layers database, the potential applications, and methods for achieving it. Activities in the bullet points above will underpin this activity.
- Years 3-4: Compile the first pan-Antarctic database of ice-sheet stratigraphy from radar internal architecture, in a form suitable for informing numerical models, and informed by ice-core age-depth profiles.
- Milestone at end of Year 4: Publication of an online dataset and paper reporting the 3D internal architecture of the Antarctic Ice Sheet.

Capacity Building, Education and Outreach Plans

AntArchitecture offers a mechanism for building capacity, and offering significant training opportunities and knowledge transfer in geophysics across the SCAR community. The various proposed activities provide manifold research topics for postdoctoral researchers and a range of graduate and undergraduate students who would all make significant contributions to addressing a pressing Antarctic science challenge. They also facilitate multiple opportunities for international collaboration – for example, when comparing datasets acquired by different institutions; and in the process of synthesising age-depth models compiled by different groups for different regions of Antarctica.

We anticipate the main methods of collaboration being through researcher exchanges between countries/institutions, including through the SCAR Visiting Professorship and Fellowship schemes, and in annual meetings of the *AntArchitecture* consortium hosted at SCAR meetings or other appropriate international symposia.

We will undertake to publish all materials from *AntArchitecture* in open-source repositories and open-access journal papers. Where appropriate, we will also liaise with our institutional media offices to report high-impact results arising from the activities to the press. All the lead proponents have considerable experience in these regards.

Finally, we anticipate that the age-depth model of Antarctic ice that *AntArchitecture* aims to develop has potential to be represented in a strikingly visual manner with appropriate use of 3-D visualisation technology. We will work with experts in data visualisation, both in our institutions and exploring commercial contacts, in ways of best representing the results to the wider community and the public.

Data Management Plans

The starting point for *AntArchitecture* is to work with radar datasets that have already been acquired and are variously available on the institutional repositories of the data collectors. For our purposes there is no need to relocate these raw data, which can easily exceed several terrabytes.

There will be a requirement, as work progresses on the project, to store processed data files, and ultimately the end product of the action group, a 3-D age-depth volume of the Antarctic Ice Sheet. Here we anticipate following a similar strategy to the SCAR Bedmap2 process, wherein data processing and lodging is handled by the data owners, while the final product is reposed in an open access location, e.g. Pangaea. Many of the data owners are already making raw and processed data openly available too, which is a practice *AntArchitecture* will encourage through its commitment to open publishing and open data access.

A key requirement for the final product of the *AntArchitecture* Action Group will be to develop data products, in file formats that will allow the internal structure of Antarctica's ice to be used as input and calibration/validation for numerical modelling experiments. We will therefore liaise with experienced numerical modellers, e.g. from the International Ice Sheet Model Intercomparison Project (ISMIP, led by Professor Frank Pattyn) and CMIP (Climate Model Intercomparison Project (CMIP) communities, on the formats required as we proceed.

Terms of Reference

AntArchitecture's primary goal is to determine the stability of the Antarctic ice sheets over past glacial cycles by interrogating the internal architecture of the ice.

As a SCAR Action Group, *AntArchitecture* aims to:

- Unite the international Antarctic communities concerned with the acquisition and application of geophysical data;
- Synthesise geophysical datasets with the common objective of recovering pan-Antarctic age-depth structure;
- Bring together expertise from geophysical imaging, ice-core sciences and numerical modelling with the common aim of using the internal architecture of the Antarctic Ice Sheet as a major resource for Antarctica and Southern Ocean palaeoclimate reconstruction and projection of future ice behaviour.

Membership of *AntArchitecture* is open to all scientists, and will be of particular interest to those operating or interested in operating in the fields of polar geophysics, climate reconstruction, ice-sheet history and dynamics, ice-core science and numerical modelling.

We propose the *AntArchitecture* Action Group to last for 4 years with objectives and activities guided by the same Chair (Bingham) and a Steering Committee initially consisting of the five additional leads of this document (Eisen, Karlsson, MacGregor, Ross, Young) and 1-2 Early Career Researchers (subject to open call should the Action Group be confirmed). We will review this structure internally at annual *AntArchitecture* workshops and, after 3 years, assess the scope for *AntArchitecture* to become a SCAR Science Programme.

Budget and Justification

We request an annual budget of $5000, subject to annual review by SCAR. Our main requirement is to facilitate annual workshops of the group which we will target to be held in association with major conferences (e.g. biannual SCAR OSC meetings, SCAR ISAES meetings, AGU, EGU). Bringing members together at larger conferences is more cost- and carbon-footprint- effective than organising workshops at individual institutions, and has the added benefit that we will be able to interest other relevant conference attendees in participating in the workshops. We propose to offer funding only to participants who can match-fund, and to prioritise Early Career Researchers. In our experience, being in the position of being able to offer match funds to encourage conference attendance hugely increases the critical mass of researchers that can be attracted to a given meeting, and will greatly enhance the required interaction amongst different international institutions that is required to make *AntArchitecture* a success.

Confirmed and/or Potential Members

Two meetings of a proto-*AntArchitecture* group have already taken place, firstly a dedicated Town Hall Meeting at the 2016 AGU, and secondly a 2-day Workshop held at the University of Edinburgh in July 2017. The list below gives attendees/speakers of both meetings and additional members of the scientific community who have explicitly expressed support for the initiative. They can all be considered Confirmed Members. Early Career Researchers are indicated with **.

Sridhar Anandakrishnan (Pennsylvania State University, USA); David Ashmore (University of Liverpool, UK)**; Robin Bell (Columbia University, USA); Robert Bingham (University of Edinburgh, UK); Don Blankenship (University of Texas, USA); Edward Brook (Oregon State University, USA); Marie Cavitte (University of Texas, USA)**; Knut Christianson (University of Washington, USA); Winnie Chu (Stanford University, USA)**; Tim Creyts (Columbia University, USA); Dorthe Dahl-Jensen (University of Copenhagen, Denmark); Indrani Das (Columbia University, USA); Damon Davies (University of Edinburgh, UK)**; Anja Diez (Norwegian Polar Institute, Norway)**; Reinhard Drews (University of Tübingen, Germany); Julian Dowdeswell (University of Cambridge, UK); Olaf Eisen (Alfred Wegener Institute, Germany); Fausto Ferraccioli (British Antarctic Survey, UK); Rene Forsberg (Technical University Denmark); Nick Frearson (Columbia University, USA); Nicholas Holschuh (University of Washington)**; Edward King (British Antarctic Survey, UK); Jonathan Kingslake (Columbia University, USA)**; Michelle Koutnik (University of Washington; USA); Daniela Jansen (Alfred Wegener Institute, Germany)**; Tom Jordan (British Antarctic Survey, UK); Gwendolyn Leysinger Vieli (University of Zürich, Switzerland); Joseph MacGregor (NASA Goddard, USA); Carlos Martin (British Antarctic Survey, UK); Kenichi Matsuoka (Norwegian Polar Institute, Norway); Gail Muldoon (University of Texas, USA)**; John Paden (Kansas University, USA); Frédéric Parrenin (Joseph Fourier University, France); Frank Pattyn (Universite Libre Brussels, Belgium); Hamish Pritchard (British Antarctic Survey, UK); Neil Ross (Newcastle University, UK); Dustin Schroeder (Stanford University, USA); Martin Siegert (Imperial College London, UK); Eric Steig (University of Washington, USA); Johannes Sutter (Alfred Wegener Institute, Germany)**; (David Vaughan (British Antarctic Survey, UK); Anna Winter (Alfred Wegener Institute, Germany)**; Kate Winter (Northumbria University,UK)**; Eric Wolff (University of Cambridge, UK); John Woodward (Northumbria University, UK); Duncan Young (University of Texas, USA).

Webpages and Communication Plans

We are pleased SCAR will provide our group with a webpage and will send information upon approval. We would also like to set up a mailing list, and would welcome advice from SCAR on communicating our activities via social media and other channels.