Permanent and mobile survey platforms, data and modelling needs in UK Polar ice sheet and glacier research

Bernd Kulessa
College of Science, Swansea University
b.kulessa@swansea.ac.uk

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Cumulative ice mass loss from glacier and ice sheets (in sea level equivalent) is 1.0 to 1.4 mm yr\(^{-1}\) for 1993-2009 and 1.2 to 2.2 mm yr\(^{-1}\) for 2005-2009.

Imperative that we get ice sheet and glacier mass balance right

<table>
<thead>
<tr>
<th>Source</th>
<th>1993–2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed contributions to global mean sea level (GMSL) rise</td>
<td></td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>1.1 [0.8 to 1.4]</td>
</tr>
<tr>
<td>Glaciers except in Greenland and Antarctica</td>
<td>0.76 [0.39 to 1.13]</td>
</tr>
<tr>
<td>Glaciers in Greenland</td>
<td>0.10 [0.07 to 0.13]</td>
</tr>
<tr>
<td>Greenland ice sheet</td>
<td>0.33 [0.25 to 0.41]</td>
</tr>
<tr>
<td>Antarctic ice sheet</td>
<td>0.27 [0.16 to 0.38]</td>
</tr>
<tr>
<td>Land water storage</td>
<td>0.38 [0.26 to 0.49]</td>
</tr>
<tr>
<td>Total of contributions</td>
<td>2.8 [2.3 to 3.4]</td>
</tr>
<tr>
<td>Observed GMSL rise</td>
<td>3.2 [2.8 to 3.6]</td>
</tr>
</tbody>
</table>

Ice grounded below sea level vulnerable to rapid retreat


Lithospheric architecture and tectonics matter

Scientific challenges

- Lithospheric architecture of Antarctic and Arctic continents
- Global GIA solutions for past and present ice sheets
- Long-term geodynamic evolution of polar gateways and mantle processes
- Basal heat flux and ice sheet – groundwater interactions
- Variability in shallow basal conditions and ice dynamics between Antarctic and Arctic ice sheets / masses
- Holocene histories as ice-sheet model constraints
Need for deployments of GPS units in Antarctica

Lack of confidence in models of Antarctic glacial isostatic adjustment (GIA) still dominates the uncertainty associated with estimates of ice sheet mass change from GRACE.

Differences in predicted GIA uplift between the two most recent models

- Easily measurable with GPS
- Note vast gaps in East Antarctica (circled)
- Same rock outcrops provide opportunity for **dating of ice sheet retreat** and co-location (or near-location) with **broadband seismometers** (see following page)

Symbols: existing (circles) and planned (squares) GPS sites
Need for deployments of seismic units in Antarctica

We currently only have a very coarse view of Earth structure
• necessary for predicting the solid Earth response to ice load changes

Dump of entire IRIS archive
- significant data gaps are circled
Need for detailed GPS/seismic deployments in Antarctica

Characterisation of much of Antarctica’s crustal/lithospheric structure is lacking

Tectonically complex regions with little data

Antarctic Peninsula 20th Century volcanism largely unexplored

Why do we need to understand the detailed Earth structure?

3d structure and upper mantle viscosity have 1st-order controls on GIA

Example: Current rapid ice loss in the Antarctic Peninsula probes the upper mantle in a very well-observed way, but we only have sparse measurements [Nield et al., EPSL, accepted]

- compare the complex pattern of predicted uplift with data density (see figure)
GIA and global water transport also impact geo-centre velocities, but large discrepancies between models and measurements.

Figure 2 | Unfiltered GIA geoid height trends. a, Estimated in this study. b, Predicted by ICE-5G/IJ05/VM2 model.

Existing BAS Airborne Geophysics Capability

Twin Otter with airborne geophysics certification:

- High-precision GPS for positioning
- Magnetometer and fluxgate magnetometer
- Radar and laser altimeters
- Ice penetrating radar (5 km penetration; 8 m resolution)
- Short-wave/thermal/near-visible IR hyperspectral imaging
- Gravimeter
- DSLR/HD video

→ Powerful but under-used facility
→ Should be used more widely incl. non-cryosphere applications (?)
Existing UK Ground-based Geophysics Capability

- NERC GEF / SeisUK (High-freq. seismics, GPR, DGPSs)
- Various university instrument pools (especially multi-channel seismics, GPR, DGPSs)
- BAS instrument pool (96-channel seismic incl. shallow drill, GPR, low-res high-power and phase-sensitive radars, DGPSs)

At BAS and selected universities:
- Static hot water drilling and ice coring facilities
- Selected borehole instrumentation
- UK at forefront of autonomous probe developments
Need for geothermal heat flux measurements

- Large uncertainties associated with geothermal heat flux (see figure)
- Very few direct observations

Why important?
- Provides a boundary condition for ice sheet dynamics
- And can be used to infer lithosphere/upper mantle rheological properties

Van Liefferinge and Pattyn, Climate of the Past (2013)

Need for detailed characterisation, Example 1: (Shallow) ice substrates exert first-order control on ice flow

Need for detailed characterisation, Example 2:

Anisotropic ice substrates exerts first-order control on ice flow


Need for detailed characterisation, Example 3:
Marine ice critically stabilises Antarctic ice shelves

Need for detailed characterisation, Example 4:
Characterisation of Holocene ice sheet histories as recorded by sedimentary legacies

IceBridge Mission Overview

IceBridge, a six-year NASA mission, is the largest airborne survey of Earth’s polar ice ever flown. It will employ an ungeodetic, three-dimensional view of Arctic and Antarctic ice sheets, ice shelves and sea ice. These efforts will provide a yearly, multi-instrument look at the dynamics of the rapidly changing features of the Greenland and Antarctic ice.

Data collected during IceBridge will help scientists bridge the gap in polar observations between NASA’s Icesheet, Clouds and the Earth’s Radiant Energy System (ICESAT) – in orbit from 2003 – and ICESat-2, planned for early 2016. IceBridge is expected to collect science data in 2016, making IceBridge critical for ensuring a continuous series of observations.

IceBridge will use airborne instruments to map Arctic and Antarctic areas once a year. IceBridge flights are conducted in March-May over Greenland and in October-November over Antarctica. Other smaller airborne surveys around the world are also part of the IceBridge campaign.

Related Multimedia

A Tour of the Cygnus: 2009 Application showing the impact of recent cryospheric changes on our planet.

Stirring Sea Ice Hypotheses: Changing Climate Ice Sheets show deep, persistent, global changes more readily than other regions of the planet. This video shows an example of the large-scale changes that have occurred in the past 30 years.

Guided Tour of LIMA: Flyover: Take a virtual tour of Antarctica using the Landsat Image Mosaic of Antarctica (LIMA) database.

UNMANNED AIRCRAFT

SUCCESSFULLY TESTED AS A TOOL FOR MEASURING CHANGES IN POLAR ICE SHEETS

NSF launches press release of CReSIS test flights in Antarctica

Click here to read the full press release Learn more.

Data Products

CReSIS DATA PRODUCTS

Photo: From the 2013 IGBP Meeting

Check out Photos & Presentations from the 2013 IGBP Meeting

INSTITUTE FOR GEOPHYSICS

Aerogeophysical Systems

UTIG has developed, maintained, and operated a suite of aerogeophysical instrumentation since the early 1960s with continual improvements since inception. The suite is installed aboard a Dornier Do-228 ("Dornier" up to 2000) and aboard a Cessna 402 (a version of DC-3) refitted with towing engines since 2004. For more information, please check out the Center website.

The current instruments are:
- **High Capability Radar Sounder (HCIRS)**: A W-band (15 cm) radar that operates in frequency-modulated phase-modulated (FMPM) mode from 5.5 to 7.5 GHz. HCIRS allows for phase coherent recording of radar returns for advanced processing. For antennas the system uses two flat plates, one mounted under each aircraft wing providing approximately 15 dB of antenna gain. The peak instantaneous output power is 850 W. HCIRS has been operated extensively in Antarctica and has regularly sounded deep and highly crystalline ice.

  **Multibeam, Seismic Photon Counting Lidar (MPL)**: Delineates the surface below the aircraft with a highly-focused laser beam which is mechanically scanned in a south-north, east-west fashion. MPL also records the time of flight and time delay at the frequency of each retransmitted reflection from the surface to the system.

  **A census of the survey area (CENSUS)**: Measures the surface area of the survey area to the nearest square kilometer.

  **A move-along, near-surface Laser Altimeter** (NOMAD): Measures the surface topography to the nearest millimeter.

  **A sounder, near-surface Laser Altimeter** (SOMA): Measures the surface topography to the nearest millimeter.
Requirements to compete with international state of science and technology

- Enhanced range and coverage
  → Longer-range aircraft, large-scale UAV developments

- Detailed surveying of key inaccessible areas (e.g. outlet glaciers)
  → Helicopter deployments, small-scale UAV developments

- Better data through improved instrumentation, e.g.
  - Higher resolution airborne gravity systems
  - Airborne low-frequency radar, for both fixed-wing and helicopter
  - Airborne accumulation radar for sea-ice and ice sheets.
  - Airborne swath imaging radar focusing both along-track and cross-track
Cryosphere scientists are traditionally ‘slow’ at adapting geophysical techniques from other areas of earth sciences/practice. Considerable scope for future developments and applications, especially as regards active-source and passive seismic techniques.
UK Ground-based Geophysics Capability: Requirements

• Characterisation of electrical conductivity structure
  → Magnetotellurics (GEF?)

• Rapid flexible data collection over large areas
  → Vibrator truck with p- and s-wave capability + streamers

• Detailed characterisation of ice (anisotropy) and substrate
  → High-frequency passive seismic stations
  → 2.5-3km depth capability, transportable hot-water drill
  → Portable downhole instrument strings

• Sediment characterisation (exposed, subglacial, grounding lines)
  → Dedicated airborne / UAV radar sounder for exposed sediments
  → Autonomous probes for subglacial sub-ice shelf deployment
Establishment of a SCAR-type organisation for Arctic research incl. solid earth community

Enhanced European linkages and industry partnerships could be transformative for Arctic research
Technological / organisational needs: Summary

- Permanent GPS and seismic arrays in Antarctica and Arctic
- UK airborne geophysics capability for sub-ice characterisation
- UAV technology
- New on-ground geophysical technology
- Transportable hot-water drill and borehole instrumentation
- Transfer of state-of-the-science geophysical techniques
- Integration across scientific communities and industry