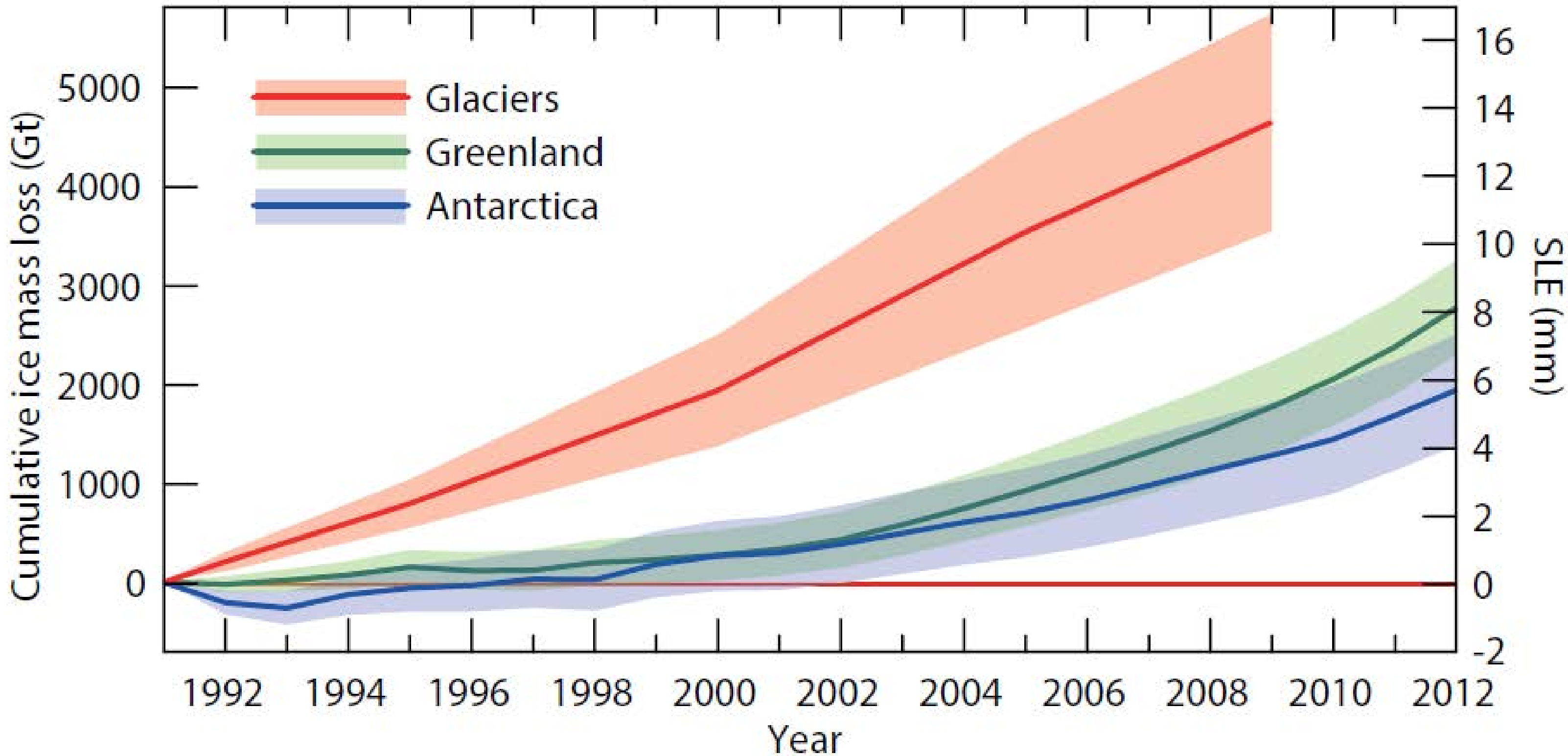
Permanent and mobile survey platforms, data and modelling needs in UK Polar ice sheet and glacier research

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

With thanks for input from: Jonathan Bamber, Alex Brisbourne and BAS colleagues, Mike Bentley, Peter Clarke, Richard Essery, David J. Evans, John Hiemstra, Matt King, Robert Larter, Matt Nolan, Martin Siegert, Pippa Whitehouse

Contribution of Glaciers and Ice Sheets to Sea Level Change



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.

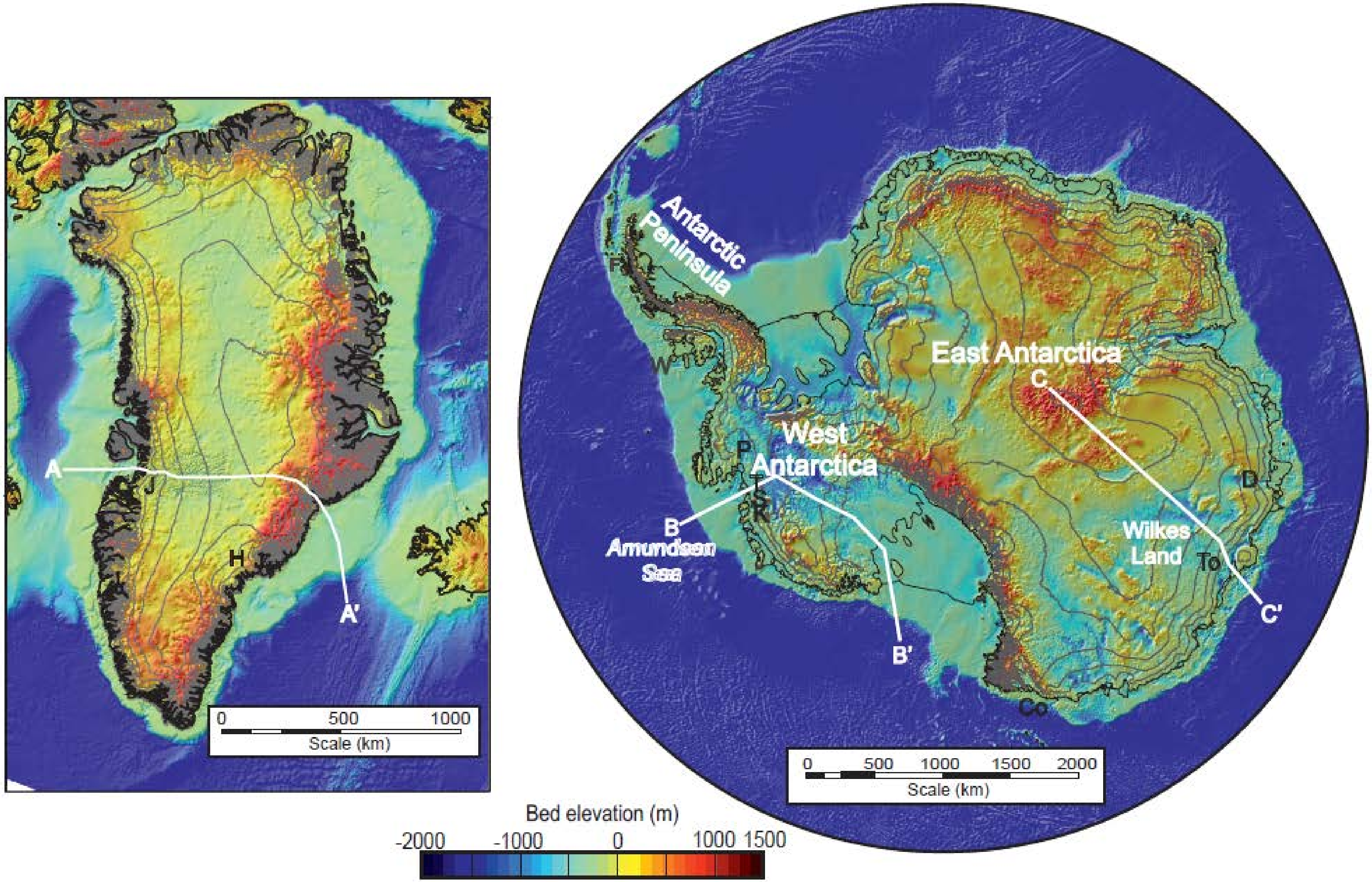
Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013: Observations: Cryosphere. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Imperative that we get ice sheet and glacier mass balance right

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

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

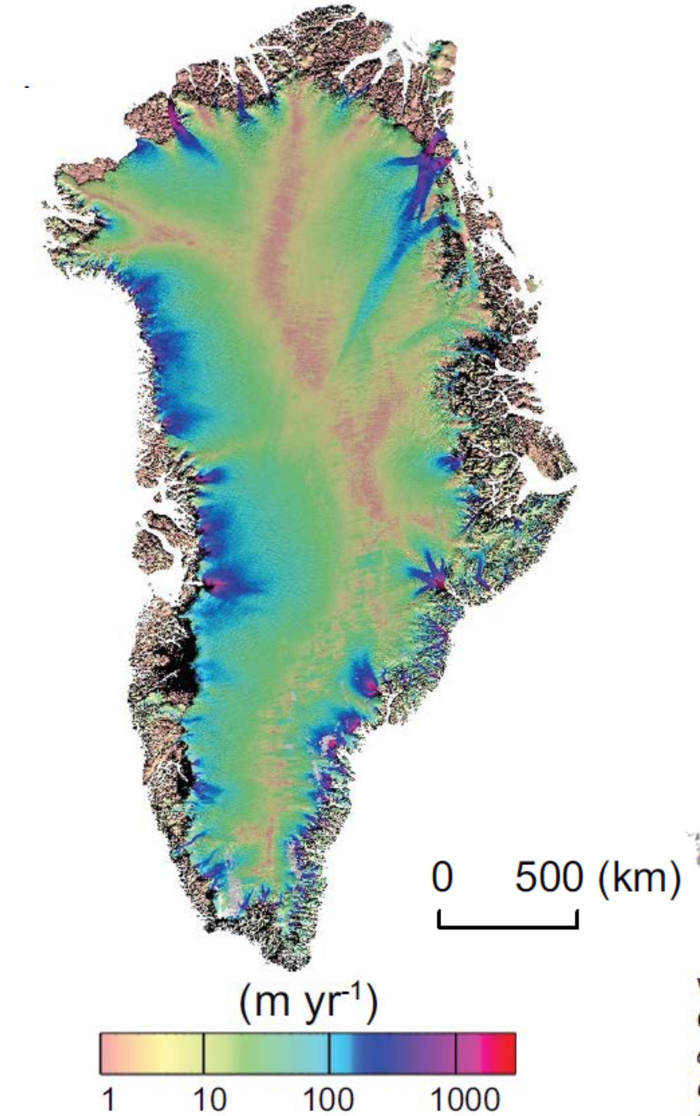
Ice grounded below sea level vulnerable to rapid retreat

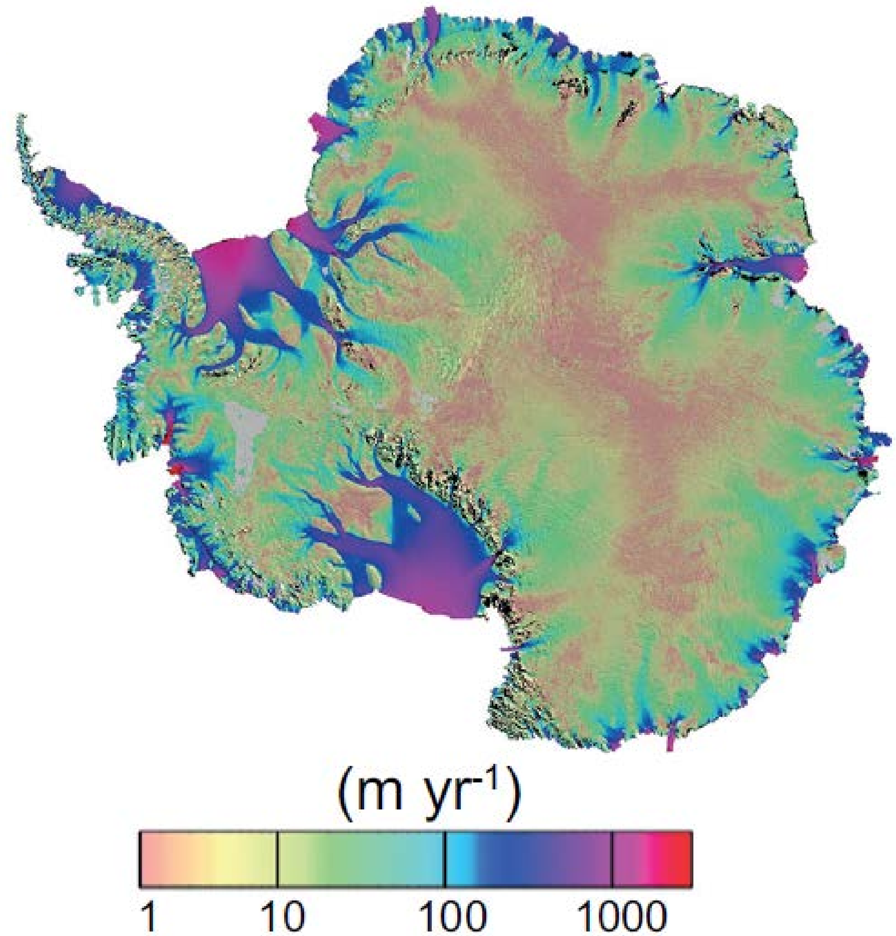


Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013: Observations: Cryosphere. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Anandakrishnan, S., Blankenship, D. D., Alley, R. B. & Stoffa, P. L. Influence of subglacial geology on the position of a West Antarctic ice stream from seismic observations. *Nature* 394, 62-65 (1998).

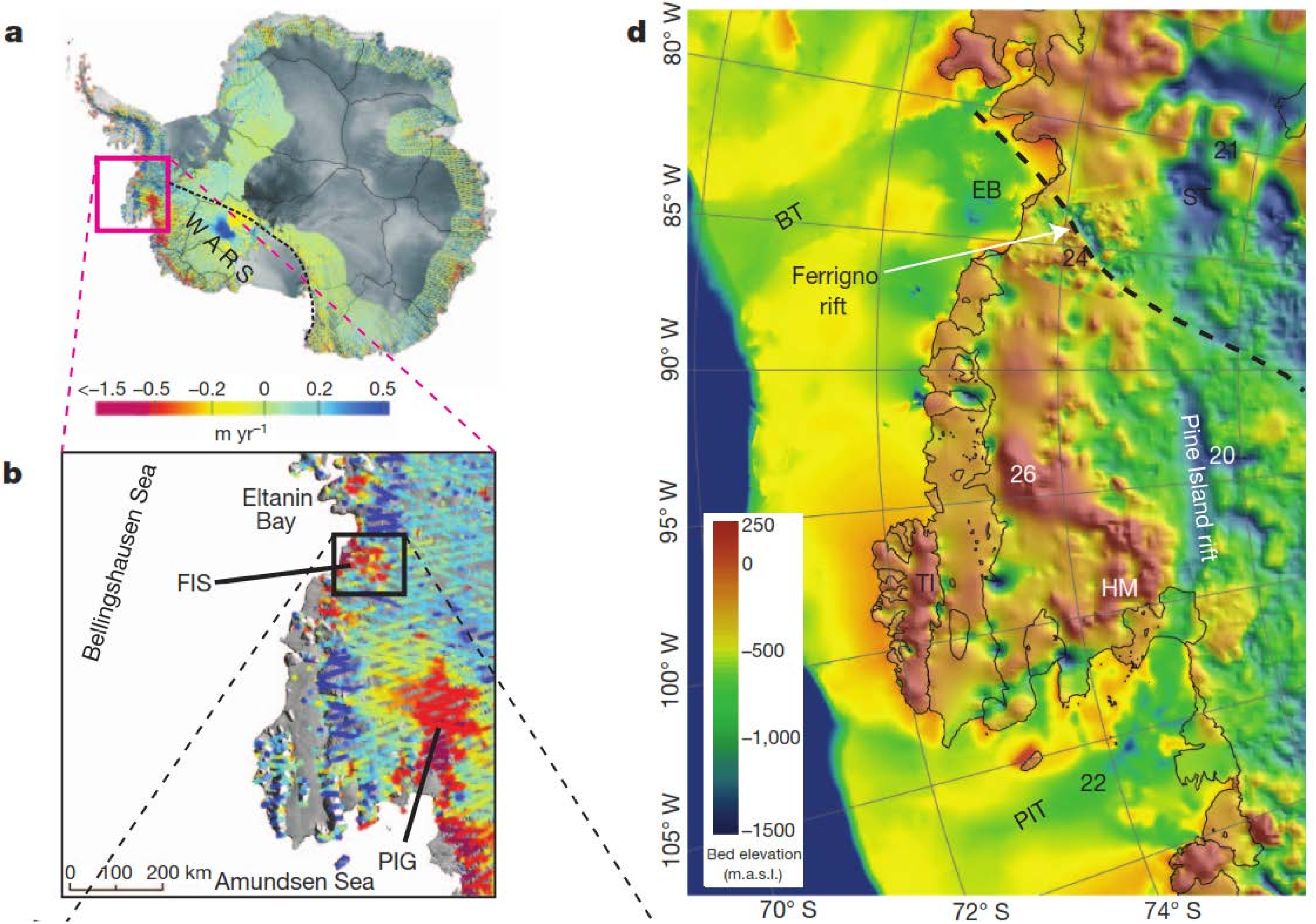
Bell, R. E. *et al.* Influence of subglacial geology on the onset of a West Antarctic ice stream from aerogeophysical observations. *Nature* 394, 58-62 (1998).





Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013: Observations: Cryosphere. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lithospheric architecture and tectonics matter



Bingham, R. G. *et al.* Inland thinning of West Antarctic Ice Sheet steered along subglacial rifts. *Nature* 487, 468-471 (2012).

Scientific challenges

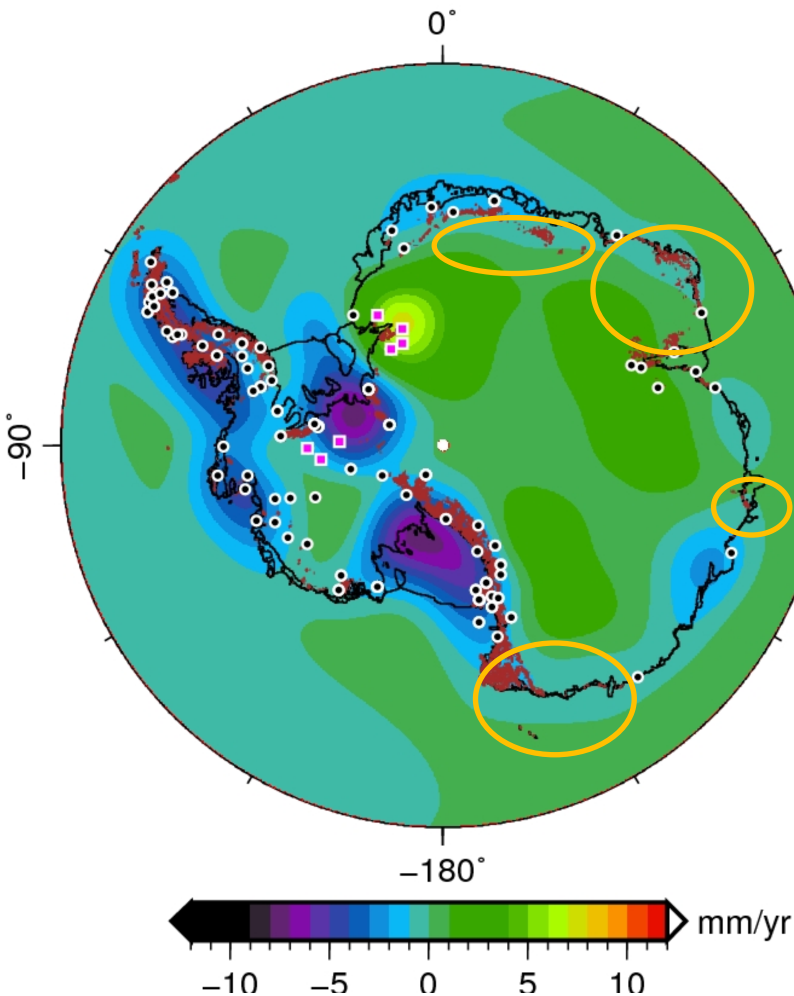
- Lithospheric architecture of Antarctic and Arctic continents
- Global GIA solutions for past and present ice sheets
- Long-term geodynamic evolution of polar gateways and mantle processes

- 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

Special thanks to Pippa Whitehouse

Need for deployments of GPS units in Antarctica



Symbols: existing (circles) and planned (squares) GPS sites

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)

Special thanks to Pippa Whitehouse

Need for deployments of seismic units in Antarctica

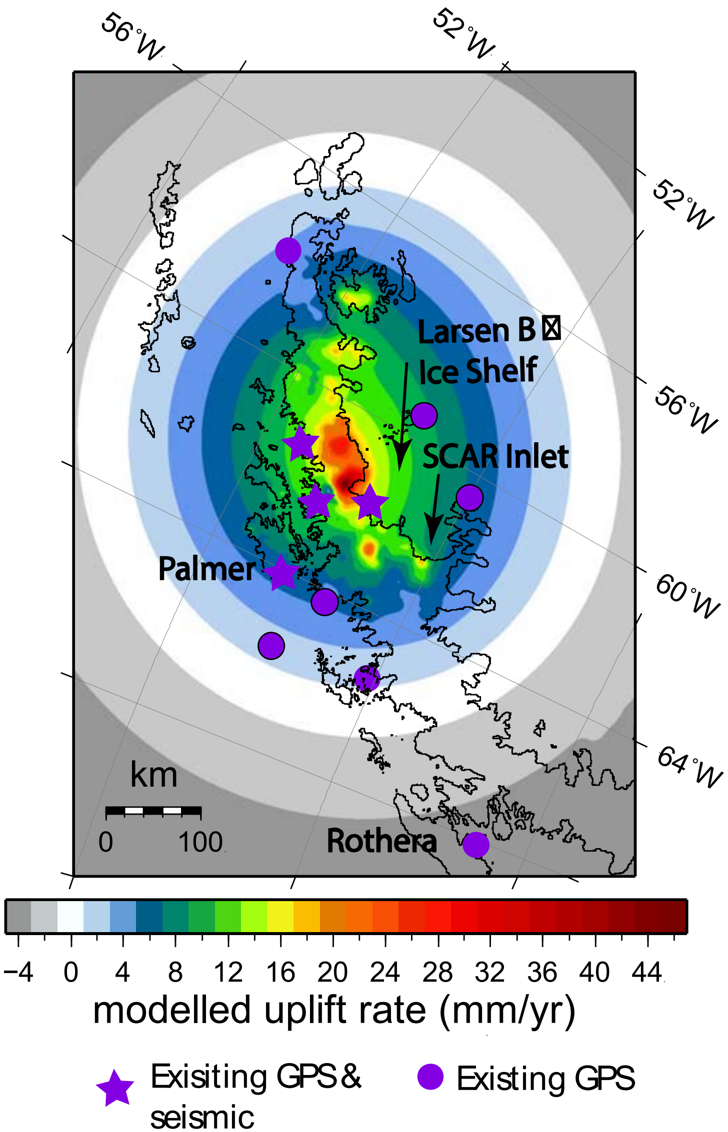
We currently only have a very coarse view of Earth structure

- necessary for predicting the solid Earth response to ice load changes

Dump of entire IRIS archive
- significant data gaps are circled

Special thanks to Pippa Whitehouse

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

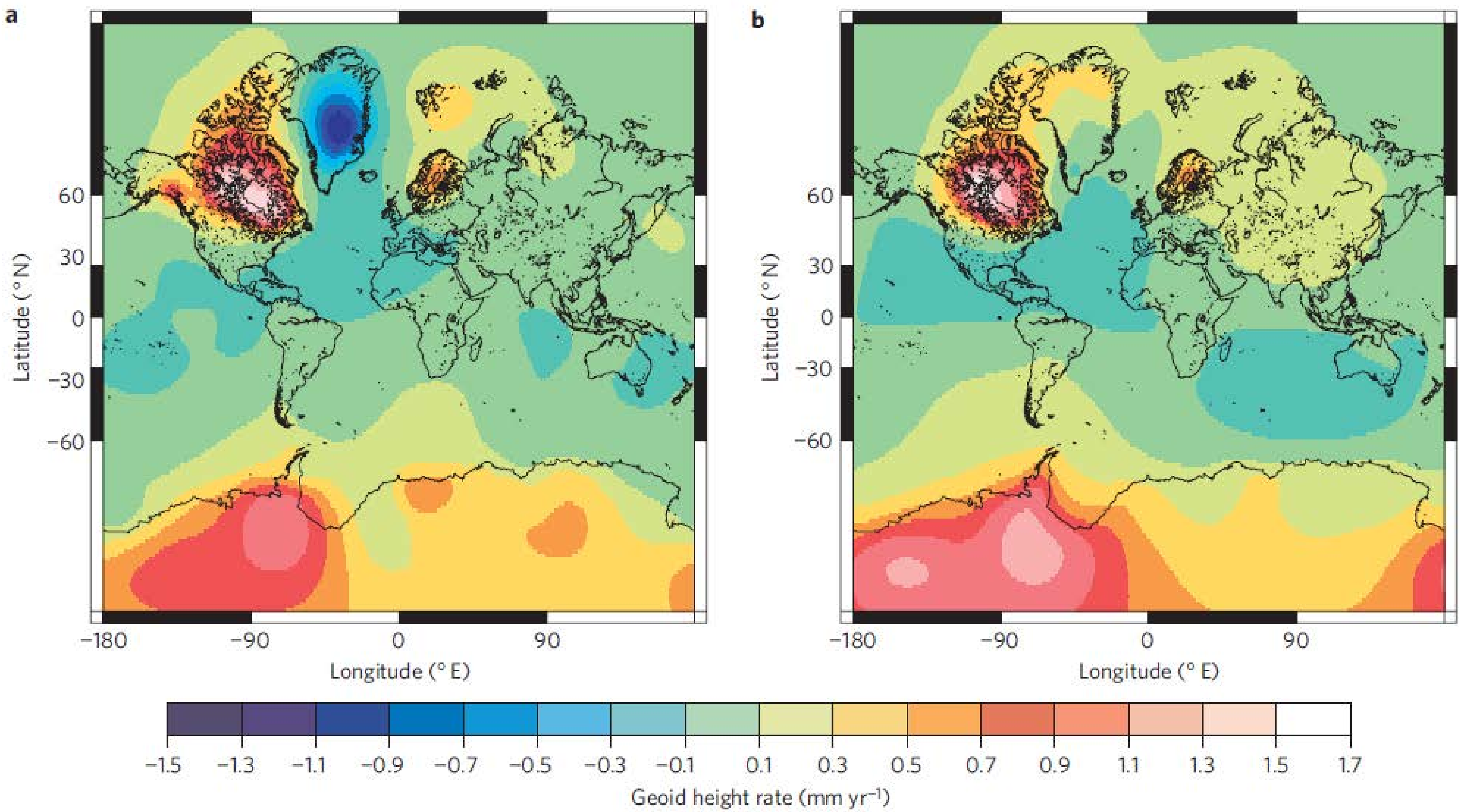


Figure 2 | Unfiltered GIA geoid height trends. a, Estimated in this study. **b**, Predicted by ICE-5G/IJ05/VM2 model.

Wu, X. and 8 others, 2010. Simultaneous estimation of global present-day water transport and glacial isostatic adjustment, Nature Geoscience, doi: 10.1038/NGEO938.

Special thanks to Alex Brisbourne

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)

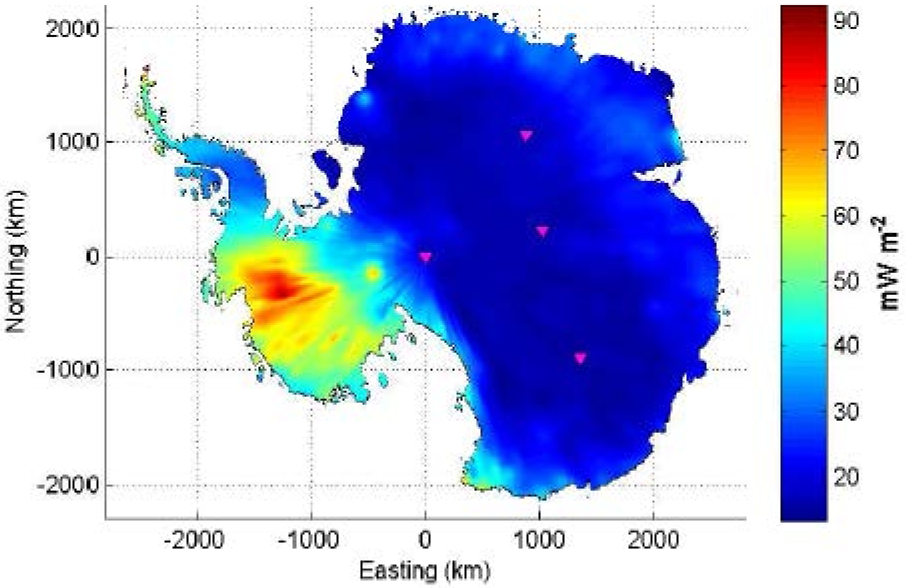
At BAS and selected universities:

- Static hot water drilling and ice coring facilities
- Selected borehole instrumentation
- UK at forefront of autonomous probe developments

Special thanks to Pippa Whitehouse

Need for geothermal heat flux measurements

<u>Standard deviation</u> of three Antarctic geothermal heat flux distributions



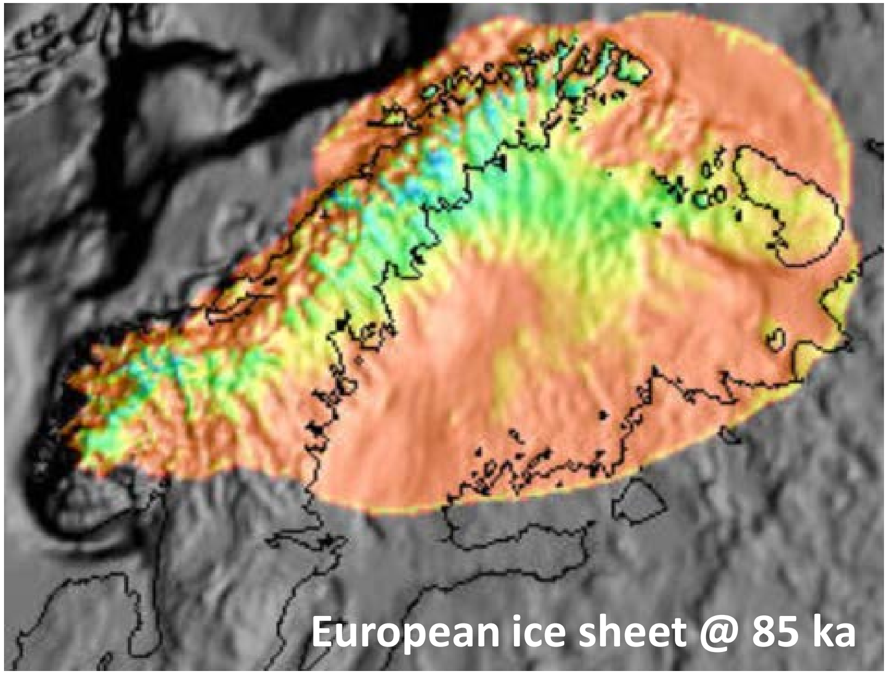
Van Liefferinge and Pattyn, Climate of the Past (2013)

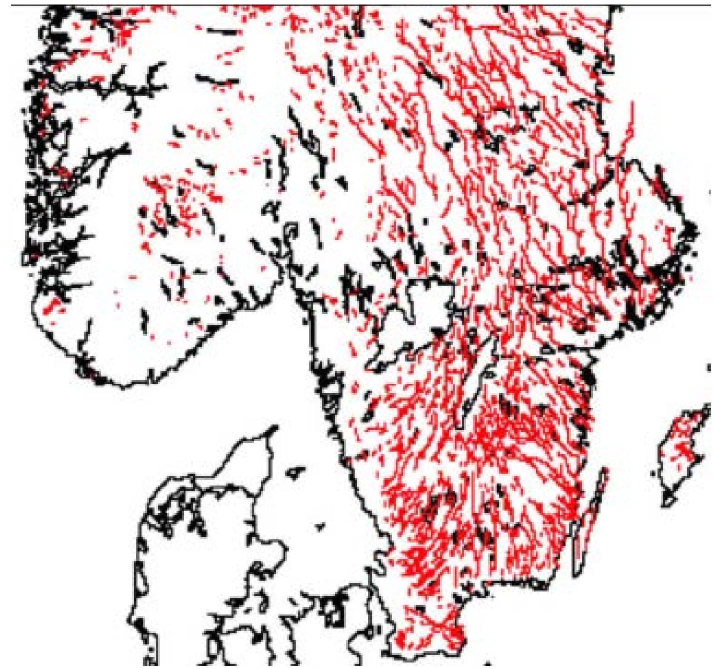
- Large uncertainties associated with geothermal heat flux (see figure)
- Very few direct observations

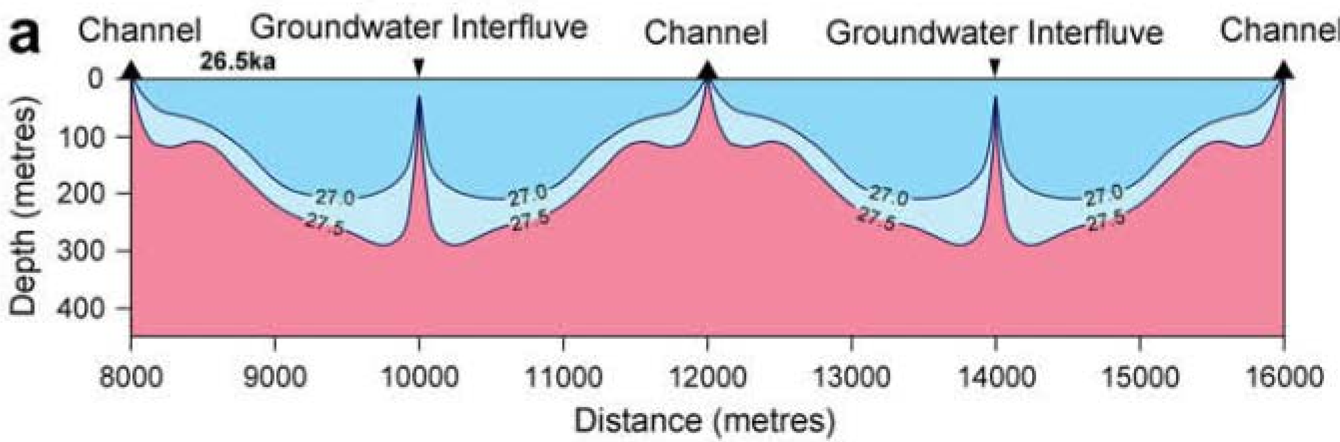
<u>Why important?</u>

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

Boulton, G. S., Hagdorn, M., Maillot, P. B. & Zatsepin, S. Drainage beneath ice sheets: groundwater–channel coupling, and the origin of esker systems from former ice sheets. Quaternary Science Reviews 28, 621-638 (2009).



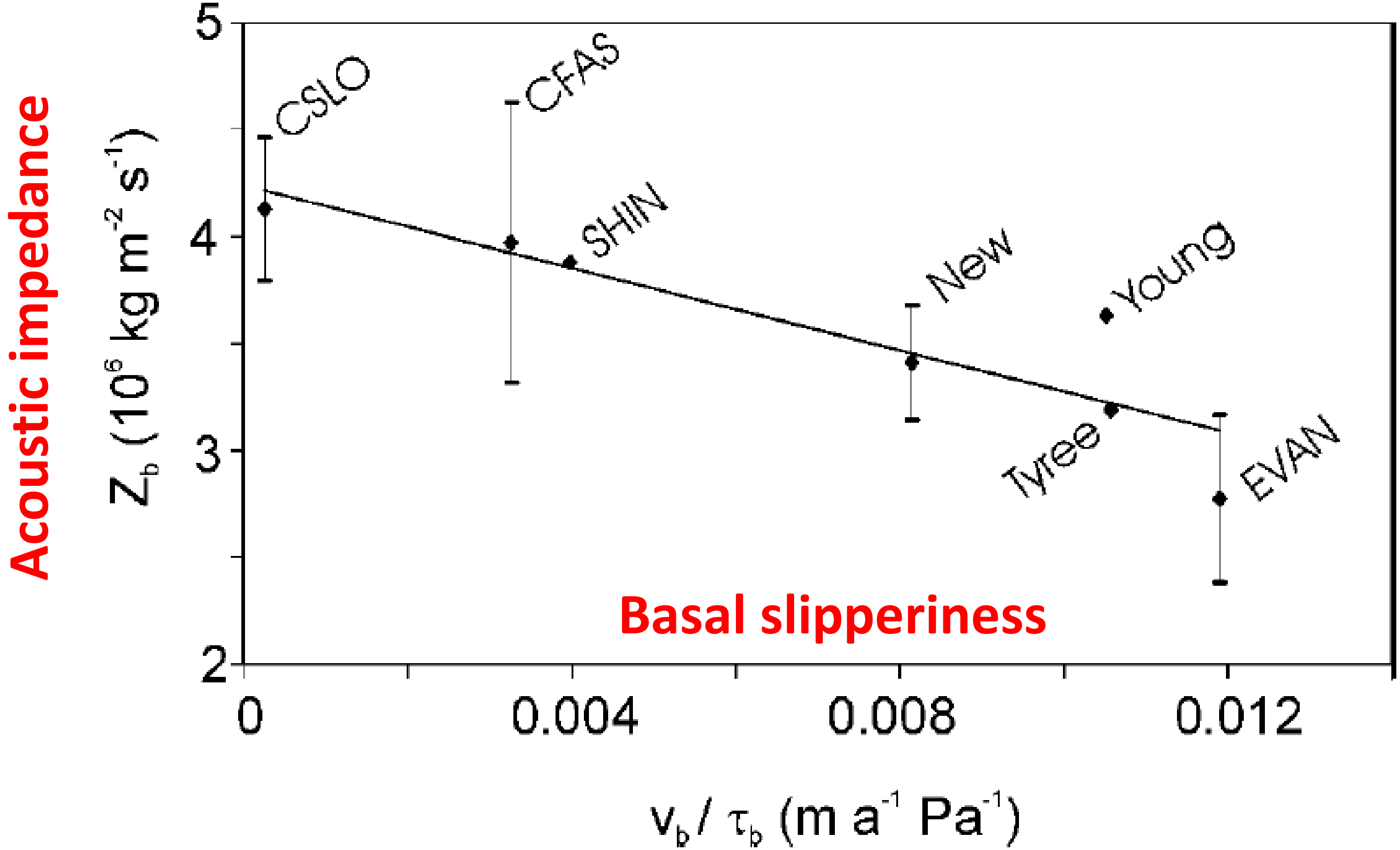




Christoffersen, P., Bougamont, M., Carter, S. P., Fricker, H. A. & Tulaczyk, S. Significant groundwater contribution to Antarctic ice streams hydrologic budget. *Geophysical Research Letters*, 2014GL059250 (2014).

Need for detailed characterisation, Example 1:

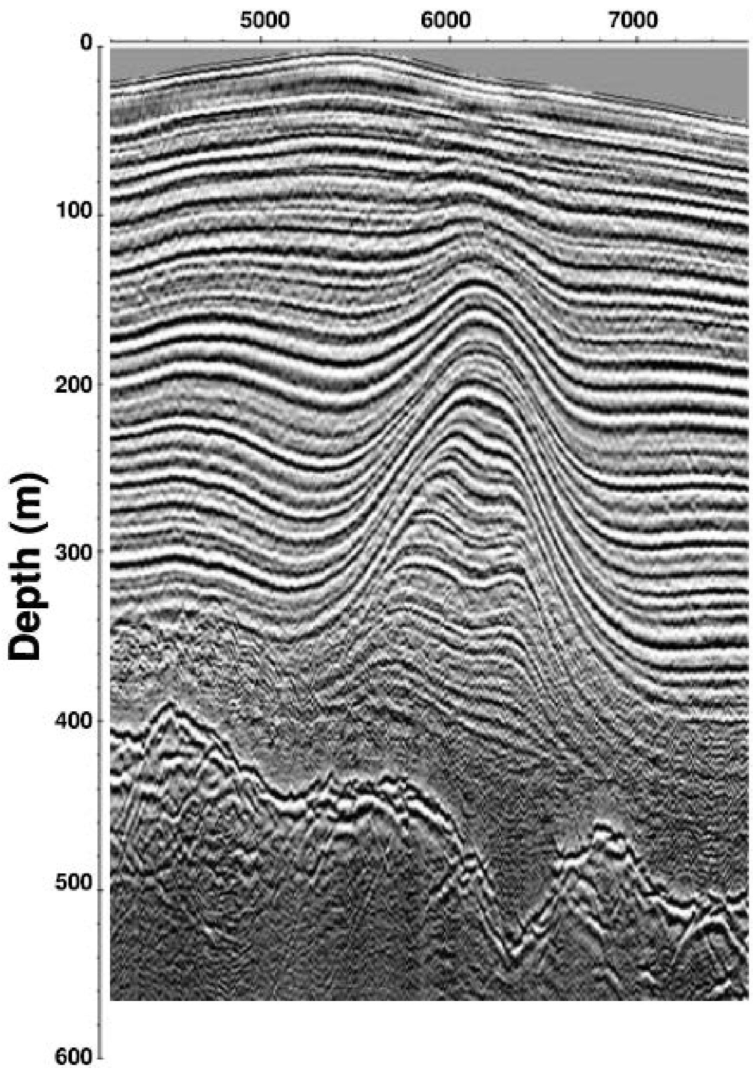
(Shallow) ice substrates exert first-order control on ice flow

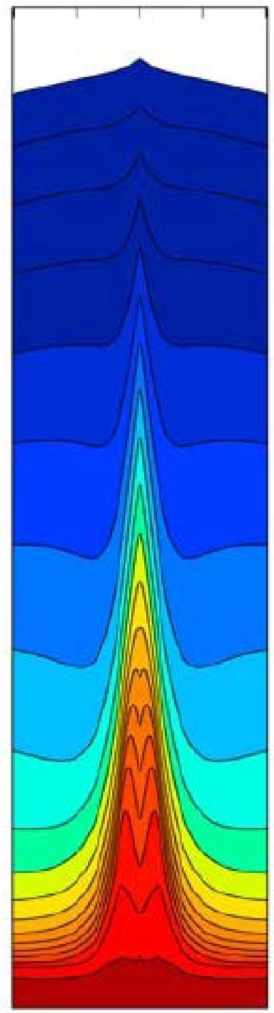


Vaughan, D. G., A. M. Smith, P. C. Nath, and E. L. Meur (2003), Acoustic impedance and basal shear stress beneath four Antarctic ice streams, *Ann Glaciol.*, *36*, 225-232.

Need for detailed characterisation, Example 2:

Anisotropic ice substrates exerts first-order control on ice flow



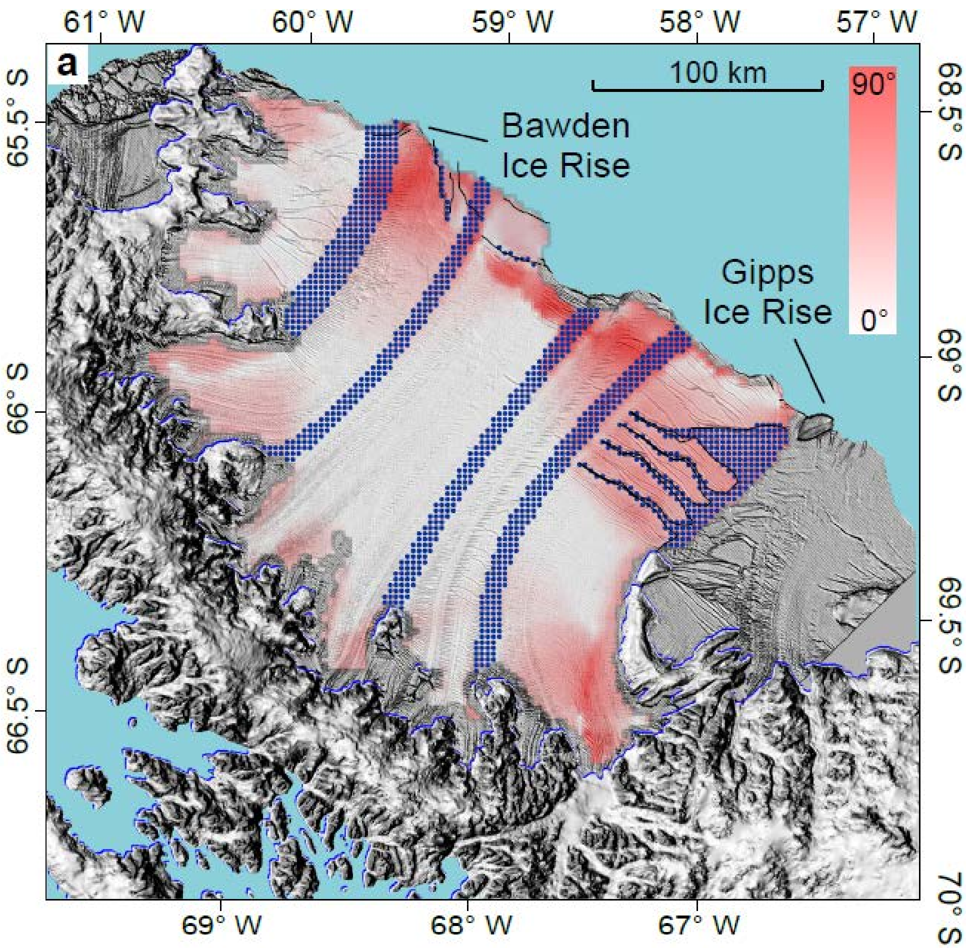


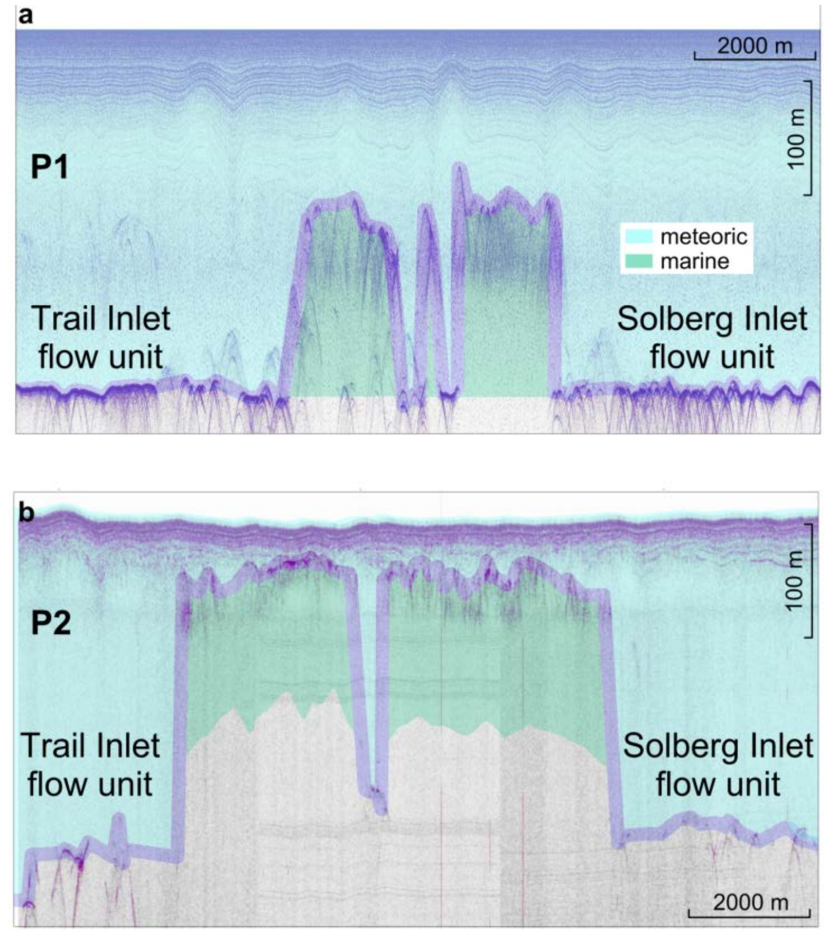
Martin, C., G. H. Gudmundsson, H. D. Pritchard, and O. Gagliardini (2009), On the effects of anisotropic rheology on ice flow, internal structure, and the age-depth relationship at ice divides, J. Geophys. Res., 114, F04001.

Wang, W., H. J. Zwally, C. L. Hulbe, M. J. Siegert, and I. Joughin (2003), Anisotropic ice flow leading to the onset of Ice Stream D, West Antarctica: numerical modelling based on the observations from Byrd Station borehole, Ann. Glaciol., 37, 397-403.

Need for detailed characterisation, Example 3:

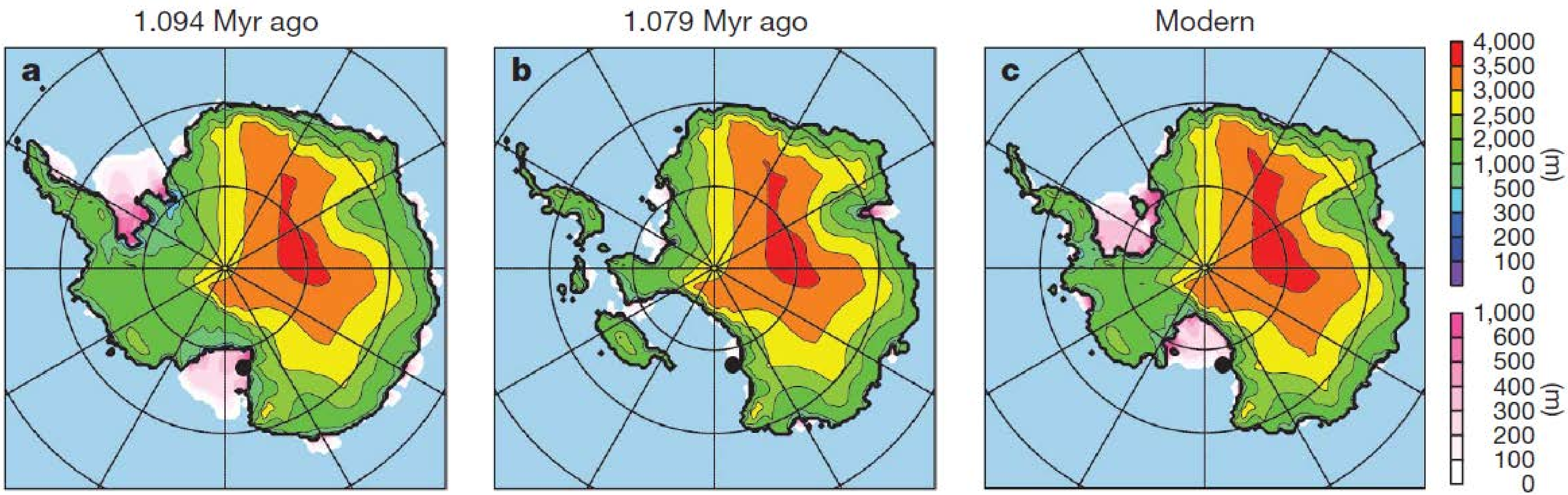
Marine ice critically stabilises Antarctic ice shelves





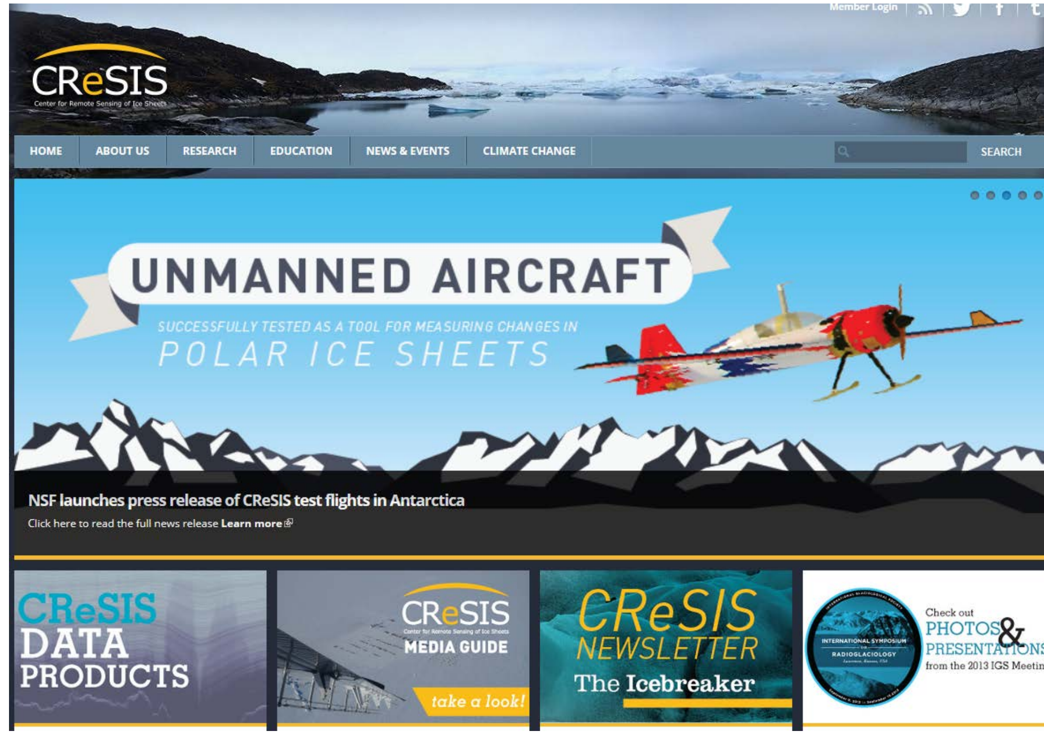
Kulessa, B., D. Jansen, A. J. Luckman, E. C. King, and P. R. Sammonds. Marine ice stabilises a large Antarctic ice shelf. *Nature Communications*, in press.

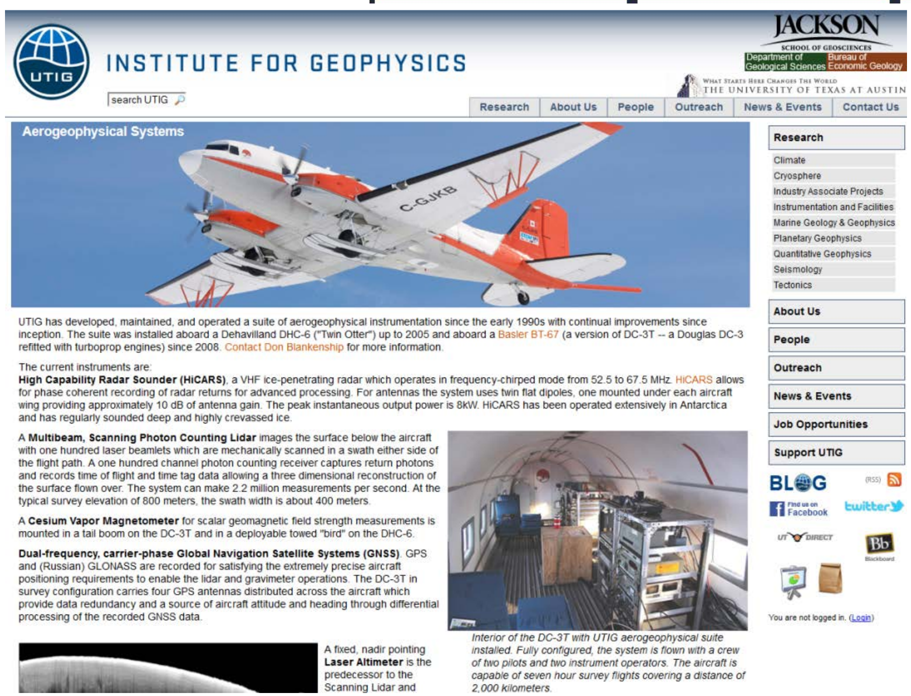
Need for detailed characterisation, Example 4:
Characterisation of Holocene ice sheet histories as recorded by sedimentary legacies



Pollard, D. & DeConto, R. M. Modelling West Antarctic ice sheet growth and collapse through the past five million years. *Nature* 458, 329-332 (2009).


NASA
NEWS
News, features & press releases
MISSIONS
Current, future, past missions & launch dates
MULTIMEDIA
Images, videos, NASA TV & more
CONNECT
Social media channels & NASA apps
ABOUT NASA
Leadership, organization, budget, careers & more
Search
For Public | For Educators | For Students | For Media
Send Share
IceBridge
Current Campaign
Past Campaigns
Mission Overview
Science
Team
News & Media Resources
Multimedia
Education
Aircraft & Instruments
All NASA Missions
IceBridge - Arctic 2014
An Airborne Mission for Earth's Polar Ice
IceBridge Mission Overview
IceBridge, a six-year NASA mission, is the largest airborne survey of Earth's polar ice ever flown. It will yield an unprecedented three-dimensional view of Arctic and Antarctic ice sheets, ice shelves and sea ice. These flights will provide a yearly, multi-instrument look at the behavior of the rapidly changing features of the Greenland and Antarctic ice.
Operation IceBridge NASA
IceBridge - Flying over the poles to monitor critical areas of Earth's ice sheets, glaciers and sea ice
Data collected during IceBridge will help scientists bridge the gap in polar observations between NASA's Ice, Cloud and Land Elevation Satellite (ICESat) -- in orbit since 2003 -- and ICESat-2, planned for early 2016. ICESat stopped collecting science data in 2009, 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 Cryosphere 2009
Animation showing the impact of recent cryospheric changes on our planet.
Shrinking Sea Ice Highlights Changing Climate
Ice shows deep, persistent, global changes more readily than other kinds of geographic features. This video shows actual measurements of total sea ice area in the north, showing a dramatic decrease in the past 30 years.
Guided Tour of LIMA Flyover
Take a guided tour of Antarctica using the Landsat Image Mosaic of Antarctica
IceBridge Science
Find IceBridge data and publications at our science website
› Visit site
IceBridge Blog
Check our blog for the latest from IceBridge researchers
› Visit IceBridge blog
Connect with IceBridge


Member Login
CReSIS
Center for Remote Sensing of Ice Sheets
HOME
ABOUT US
RESEARCH
EDUCATION
NEWS & EVENTS
CLIMATE CHANGE
SEARCH
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 news release Learn more
CReSIS DATA PRODUCTS
CReSIS MEDIA GUIDE
take a look!
CReSIS NEWSLETTER
The Icebreaker
Check out PHOTOS & PRESENTATIONS from the 2013 IGS Meeting


UTIG
INSTITUTE FOR GEOPHYSICS
JACKSON SCHOOL OF GEOSCIENCES
Department of Geological Sciences
Bureau of Economic Geology
WHAT STARTS HERE CHANGES THE WORLD
THE UNIVERSITY OF TEXAS AT AUSTIN
search UTIG
Research
About Us
People
Outreach
News & Events
Contact Us
Aerogeophysical Systems
C-GJKB
UTIG has developed, maintained, and operated a suite of aerogeophysical instrumentation since the early 1990s with continual improvements since inception. The suite was installed aboard a Dehavilland DHC-6 ("Twin Otter") up to 2005 and aboard a Basler BT-67 (a version of DC-3T -- a Douglas DC-3 refitted with turboprop engines) since 2008. Contact Don Blankenship for more information.
The current instruments are:
High Capability Radar Sounder (HiCARS), a VHF ice-penetrating radar which operates in frequency-chirped mode from 52.5 to 67.5 MHz. HiCARS allows for phase coherent recording of radar returns for advanced processing. For antennas the system uses twin flat dipoles, one mounted under each aircraft wing providing approximately 10 dB of antenna gain. The peak instantaneous output power is 8kW. HiCARS has been operated extensively in Antarctica and has regularly sounded deep and highly crevassed ice.
A Multibeam, Scanning Photon Counting Lidar images the surface below the aircraft with one hundred laser beamlets which are mechanically scanned in a swath either side of the flight path. A one hundred channel photon counting receiver captures return photons and records time of flight and time tag data allowing a three dimensional reconstruction of the surface flown over. The system can make 2.2 million measurements per second. At the typical survey elevation of 800 meters, the swath width is about 400 meters.
A Cesium Vapor Magnetometer for scalar geomagnetic field strength measurements is mounted in a tail boom on the DC-3T and in a deployable towed "bird" on the DHC-6.
Dual-frequency, carrier-phase Global Navigation Satellite Systems (GNSS). GPS and (Russian) GLONASS are recorded for satisfying the extremely precise aircraft positioning requirements to enable the lidar and gravimeter operations. The DC-3T survey configuration carries four GPS antennas distributed across the aircraft which provide data redundancy and a source of aircraft attitude and heading through differential processing of the recorded GNSS data.
A fixed, nadir pointing Laser Altimeter is the predecessor to the Scanning Lidar and
Interior of the DC-3T with UTIG aerogeophysical suite installed. Fully configured, the system is flown with a crew of two pilots and two instrument operators. The aircraft is capable of seven hour survey flights covering a distance of 2,000 kilometers.
Research
Climate
Cryosphere
Industry Associate Projects
Instrumentation and Facilities
Marine Geology & Geophysics
Planetary Geophysics
Quantitative Geophysics
Seismology
Tectonics
About Us
People
Outreach
News & Events
Job Opportunities
Support UTIG
BLOG
Find us on Facebook
twitter
UT DIRECT
Bb
You are not logged in. (Login)

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

Special thanks to Alex Brisbourne

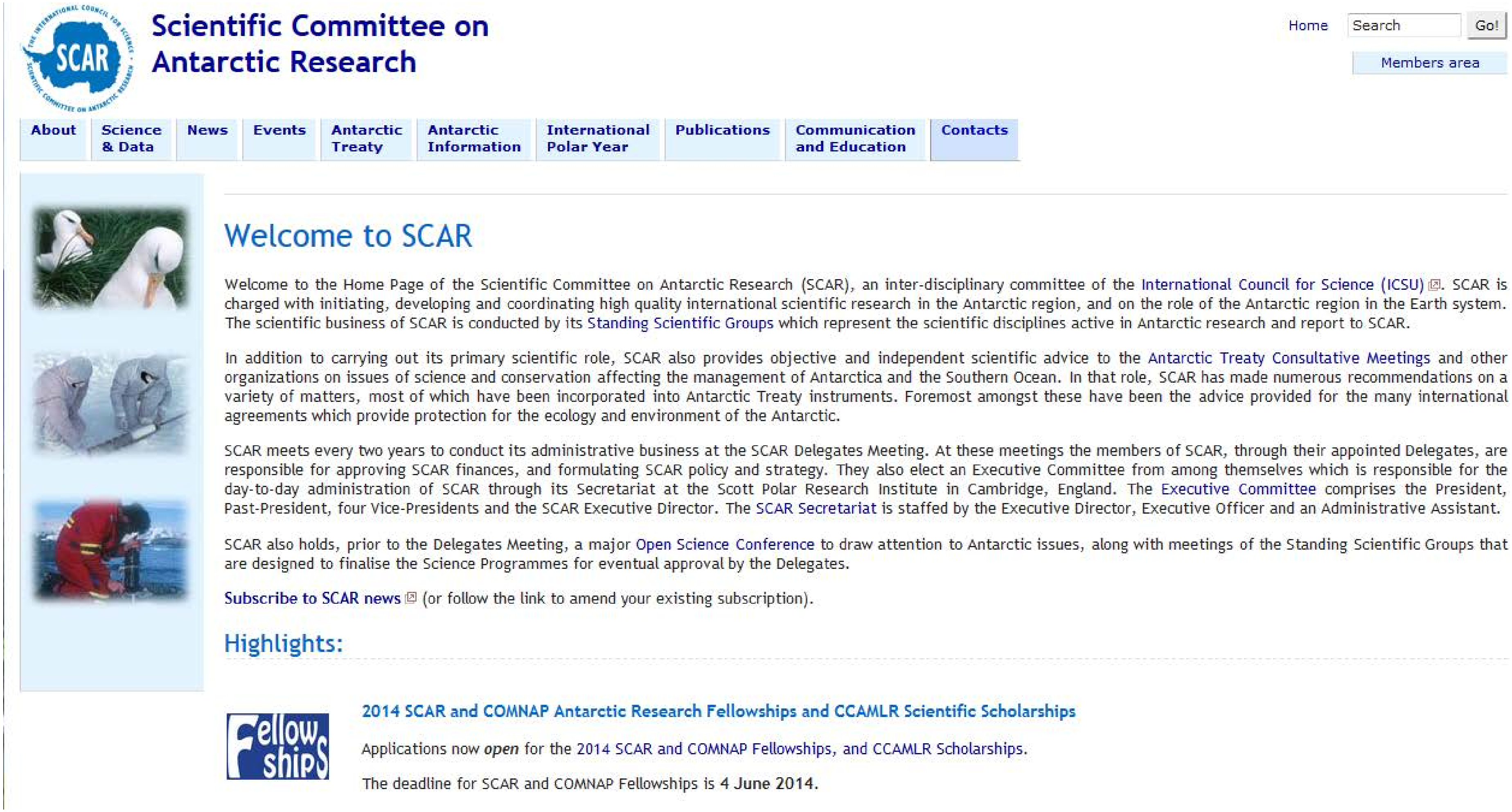
UK Ground-based Geophysics Capability: Requirements

- 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



Scientific Committee on Antarctic Research

Home | Search | Go!

Members area

About | Science & Data | News | Events | Antarctic Treaty | Antarctic Information | International Polar Year | Publications | Communication and Education | Contacts

Welcome to SCAR

Welcome to the Home Page of the Scientific Committee on Antarctic Research (SCAR), an inter-disciplinary committee of the International Council for Science (ICSU). SCAR is charged with initiating, developing and coordinating high quality international scientific research in the Antarctic region, and on the role of the Antarctic region in the Earth system. The scientific business of SCAR is conducted by its Standing Scientific Groups which represent the scientific disciplines active in Antarctic research and report to SCAR.

In addition to carrying out its primary scientific role, SCAR also provides objective and independent scientific advice to the Antarctic Treaty Consultative Meetings and other organizations on issues of science and conservation affecting the management of Antarctica and the Southern Ocean. In that role, SCAR has made numerous recommendations on a variety of matters, most of which have been incorporated into Antarctic Treaty instruments. Foremost amongst these have been the advice provided for the many international agreements which provide protection for the ecology and environment of the Antarctic.

SCAR meets every two years to conduct its administrative business at the SCAR Delegates Meeting. At these meetings the members of SCAR, through their appointed Delegates, are responsible for approving SCAR finances, and formulating SCAR policy and strategy. They also elect an Executive Committee from among themselves which is responsible for the day-to-day administration of SCAR through its Secretariat at the Scott Polar Research Institute in Cambridge, England. The Executive Committee comprises the President, Past-President, four Vice-Presidents and the SCAR Executive Director. The SCAR Secretariat is staffed by the Executive Director, Executive Officer and an Administrative Assistant.

SCAR also holds, prior to the Delegates Meeting, a major Open Science Conference to draw attention to Antarctic issues, along with meetings of the Standing Scientific Groups that are designed to finalise the Science Programmes for eventual approval by the Delegates.

Subscribe to SCAR news (or follow the link to amend your existing subscription).

Highlights:

Fellow ships

2014 SCAR and COMNAP Antarctic Research Fellowships and CCAMLR Scientific Scholarships

Applications now *open* for the 2014 SCAR and COMNAP Fellowships, and CCAMLR Scholarships.

The deadline for SCAR and COMNAP Fellowships is **4 June 2014**.

- 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**