

<p>Institution: Aberystwyth University</p>
<p>Unit of Assessment: 17: Geography, Environmental Studies and Archaeology</p>
<p>Title of case study: Informing public perception of the influence of climate change on Earth's ice masses</p>
<p>1. Summary of the impact Supported by world-leading research, Geography and Earth Sciences' Centre for Glaciology (CfG) operates as a highly-effective hub for providing information to the public concerning the relationships between climate change and Earth's ice masses. The impact of this engagement has been to <i>inform the knowledge base of an international audience of people concerning the reality of climate change and its consequences for the cryosphere</i>. This has been achieved through (i) extensive involvement in television, radio and newspaper coverage, (ii) the design and provision of a broad range of innovative internet-based and social media resources, and (iii) authorship and presentation of lectures, books and articles specifically designed to improve public understanding.</p>
<p>2. Underpinning research Since its inception in 1994, CfG staff (led by Dowdeswell 1994-1998, Glasser 1999-, Hambrey 1996-, A. Hubbard 2007-, and B. Hubbard 1994-), have combined spaceborne, airborne, shipborne and ground-based glaciology and glacial geomorphology with remote sensing, laboratory experimentation and numerical modelling to determine how glacial systems respond to, and reflect, our planet's changing environmental conditions. This world-class research has led to a substantial improvement in our ability to predict the response of the Earth's ice masses to future climatic change. Uniquely amongst UK, and probably international, glaciology groups, CfG research spans all of the Earth's glacial regions, summarized with reference to key examples of underpinning research below:</p> <p>(i) Greenland. CfG staff have led an international, interdisciplinary research effort to understand how the Greenland Ice Sheet modulates its behaviour in response to changing oceanic and atmospheric forcing. This has been achieved through several RCUK and EU-funded research projects^{3.1} integrating marine and terrestrial systems science. Ship-based investigations have, for example, allowed the reconstruction of major sedimentary structures located offshore of Polar continental margins, and for these mega-scale features to be related to former ice sheet activity and configurations^{3.2}. In parallel, remote sensing and geophysical research has focused on isolating the controls on tidewater outlet glacier dynamics and associated iceberg calving, and on the basal hydrological response of the ice sheet to increasing atmospheric temperatures, surface melt intensity and the rapid drainage of large supraglacial lakes^{3.3}.</p> <p>(ii) Antarctica. As well as ground-based geophysical investigations of ice shelf processes and radar-based reconstructions of the thermodynamics of Earth's largest subglacial lake, Lake Vostok^{3.4}, CfG staff have made major contributions based on remote sensing to reconstructing the structural evolution of Antarctic ice shelves and the way in which those structures precondition patterns of subsequent collapse^{3.5}. CfG staff have also made major contributions to reconstructions of regional Antarctic ice-mass geometrical response to environmental forcing on timescales of decades to millions of years^{3.6,3.7}.</p> <p>(iii) Arctic & Svalbard. The central theme of CfG's extensive fieldwork in the High Arctic and Svalbard has been to investigate and report the association between the dynamics of polythermal glaciers^{3.8} and the sedimentological record that they leave in the landscape^{3.9}. This research has demonstrated that many present-day glacial landforms can be used to reconstruct past climate and glaciological processes, thereby serving to calibrate and validate numerical models of environmentally-driven glacier change^{3.10}.</p> <p>(iv) Mid- and low-latitude glaciers. CfG research had documented and provided process-based explanations for the rapid and increasing rate of recession of mid-latitude glaciers in both hemispheres. These studies include reconstructing changes in the glaciers of the Southern Alps of New Zealand and the Patagonian Andes^{3.11} as well as process-informed forward numerical modelling of the response of valley glaciers to anticipated climate change^{3.12}. CfG staff have evaluated how low-latitude glaciers, especially in Peru and Nepal, represent an increasing hazard as climate warms, notably through glacial-lake outburst floods. We have improved our</p>

understanding of these events through combining remote-sensing, geophysics, sedimentology and geomorphology^{3,13}.

3. References to the research

GREENLAND

- 3.1 Research Grant: 'Subglacial Access and Fast Ice Research Experiment (SAFIRE): Resolving the basal control on ice flow and calving in Greenland' NERC (NE/K006126/1), 01.09.2013 - 31.08.2016. B. Hubbard (PI), A. Hubbard (Co-I). £426,090.
- 3.2 Journal article: Dowdeswell, J.D. + 6. 1996. Large-scale sedimentation on the glacier-influenced Polar North Atlantic margins: long-range side-scan sonar evidence. *Geophysical Research Letters* 23, 3535-3538. DOI: [10.1029/96GL03484](https://doi.org/10.1029/96GL03484)
- 3.3 Journal article: Doyle, S. + 9. 2013. Ice tectonic deformation during the rapid *in situ* drainage of a supraglacial lake on the Greenland Ice Sheet. *The Cryosphere* 7, 129-140. DOI: [10.5194/tc-7-129-2013](https://doi.org/10.5194/tc-7-129-2013)

ANTARCTICA

- 3.4 Journal article: Siegert, M.J. + 3. 2000. Water exchange between the subglacial Lake Vostok and the overlying ice sheet. *Nature* 403, 643-646. DOI: [10.1038/35001049](https://doi.org/10.1038/35001049)
- 3.5 Journal article: Glasser, N.F. + 7. 2009. Surface structure and stability of the Larsen C Ice Shelf, Antarctic Peninsula. *Journal of Glaciology* 55, 400-410. DOI: [10.3189/002214309788816597](https://doi.org/10.3189/002214309788816597)
- 3.6 Research grant: 'Glacial history of the NE Antarctic Peninsula Region over centennial to millennial timescales' NERC (NE/F012942/1), 01.04.2010 - 31.03.2013. N. Glasser (PI), M. Hambrey (Co-I). £352,611.
- 3.7 Journal article: Davies, B.J. + 4. 2012. Antarctic Peninsula Ice Sheet evolution during the Cenozoic Era. *Quaternary Science Reviews*, 31, 30-66. DOI: [10.1016/j.quascirev.2011.10.012](https://doi.org/10.1016/j.quascirev.2011.10.012)

ARCTIC/SVALBARD

- 3.8 Journal article: Hambrey, M.J. + 7. 2005. Structure and changing dynamics of a polythermal valley glacier on a centennial time-scale: Midre Lovénbreen, Svalbard. *Journal of Geophysical Research - Earth Surface* F010006, 19pp. DOI: [10.1029/2004JF000128](https://doi.org/10.1029/2004JF000128)
- 3.9 Journal article: Hambrey, M.J. and Glasser, N.F. 2012. Discriminating glacier thermal and dynamic regimes in the sedimentary record. *Sedimentary Geology* 251, 1-33. DOI: [10.1016/j.sedgeo.2012.01.008](https://doi.org/10.1016/j.sedgeo.2012.01.008)
- 3.10 Journal article: Hubbard, A. + 7. 2009. Dynamic cycles, ice streams and their impact on the extent, chronology and deglaciation of the British-Irish ice sheet. *Quaternary Science Reviews* 28, 758-776. DOI: [10.1016/j.quascirev.2008.12.026](https://doi.org/10.1016/j.quascirev.2008.12.026)

MID-LOW LATITUDES

- 3.11 Journal article: Glasser, N.F. + 4. 2011. Global sea-level contribution from the Patagonian Icefields since the Little Ice Age maximum. *Nature Geoscience* 4(5), 303-307. DOI: [10.1038/ngeo1122](https://doi.org/10.1038/ngeo1122)
- 3.12 Journal article: Hubbard, B. + 5. 2003. Spatial variability in the water content and rheology of temperate glaciers: Glacier de Tsanfleuron, Switzerland. *Annals of Glaciology* 37, 1-6. DOI: [10.3189/172756403781815474](https://doi.org/10.3189/172756403781815474)
- 3.13 Journal article: Hubbard, B. + 7. 2005. Impact of a rock avalanche on a moraine-dammed proglacial lake: Laguna Safuna Alta, Cordillera Blanca, Peru. *Earth Surface Processes and Landforms* 30, 1251-1264. DOI: [10.1002/esp.1198](https://doi.org/10.1002/esp.1198)

4. Details of the impact

With between four and six faculty staff actively engaged at any one time in outreach and dissemination activities throughout this REF period, the Centre for Glaciology's contribution to the public understanding of the response of the Earth's ice masses to climate change has been substantial. This impact has been achieved through the following outlets.

I. **Informing television, radio and newspaper coverage.** Geography and Earth Sciences staff have been closely involved in the planning, production and filming of a wide range of traditional media reports. CfG researchers, led by A. Hubbard, have guided and featured in several flagship TV documentaries addressing the causes and consequences of climate change on the

Greenland Ice Sheet (GrIS). Foremost amongst these, *Frozen Planet* was partly filmed at CfG field locations and influenced by the advice and logistical management of the CfG's research team^{5.1}. Indeed, the initial decision to film this series in Greenland was made on the basis of meetings between Hubbard and the programme's Executive and Series Producers at BBC's Natural History Unit in 2008. *Frozen Planet* was shown on BBC1 and Discovery Channel at the end of 2011, when it broke all previous viewing records for natural history documentary in both the UK and the US^{5.1}. The series was viewed by over 9 million people in the UK alone, and the final episode, 'On Thin Ice' (in which Sir David Attenborough challenges society to come to terms with the profound influence of anthropogenic climate change on the GrIS [and the episode with the greatest CfG involvement]), was watched by 10.85 million viewers in the UK alone, who awarded it an unprecedented 'audience appreciation index' score of 94%^{5.1}. Similarly, the first episode of *Operation Iceberg*, 'Birth of an Iceberg', was filmed exclusively at CfG's field location of Store Glacier, while its evidence-based portrayal of the response of the GrIS to climate change was guided by CfG staff at all stages from inception and commissioning in early 2011, through to scripting to final production^{5.2}. *Operation Iceberg* was shown on BBC2 in late 2012, and on Discovery Channel (USA) in late 2013. Like *Frozen Planet*, the breadth and impact of this series have been significant, reaching an average audience of 3.15 million UK viewers and with 60% of poll respondents replying that they had learnt 'a lot' (over double the genre average)^{5.2}. The successful influence of these landmark documentaries on public perception is further supported by individual comments on feedback forums. These include, for example: "What a powerful documentary. Loved every second ... but concerned for our planet's future"^{5.1}, "Thank you for a programme both educating and inspiring for myself and my 10 year old son"^{5.2}, and "This was a marvellous science programme (from) which I learned genuinely new things"^{5.3}. CfG staff have also featured in many national and international news features, including the BBC, Sky News, CNN, NBC, C4, and ITN. For example, an extended article featured in the Daily Mail and Mail Online followed from a 3-day visit by their Science Editor to CfG's Greenland ice camp in 2010. The Mail Online reaches an average of 5.5 million visitors per day, and this particular article stimulated >300 online comments^{5.4}. The article is notable in that it unequivocally supports CfG's research-driven evidence for climate-change-induced impacts on the Greenland Ice Sheet - a rare position for this particular newspaper and therefore bringing evidence-based information to those who may not already have been sympathetic. Away from Greenland, Glasser for example recently appeared on BBC news to report research on the accelerating recession of Patagonian glaciers^{5.5}, a story that also featured both in print and on-line in the Daily Mirror and the New York Times^{5.6}, the latter being accessed by an average of just under 5 million visitors per day.

Together, these newspaper and TV outlets have reached several tens of millions of people. The impact of these media representations has been widespread and demonstrably profound^{5.1-5.6}, moulding attitudes to the impact of climate change on the cryosphere.

II. Informing the public through web resources and social media

The CfG and its outreach programmes have always maintained a strong web-based presence. CfG's AU-based web page (www.aber.ac.uk/en/iges/research-groups/centre-glaciology/), Twitter site (twitter.com/AU_CfG) and Facebook site (www.facebook.com/AUCfG) report up-to-the-minute developments in cryospheric research and act as discussion forums connecting the public with these research activities and publications. Outreach thereby forms a central plank of these internet-based resources, summarizing glaciological findings in language that is easy to understand and hosting bespoke engagement-based sections, often inviting queries from visitors to the sites. These internet and social media sites are extremely popular, with the CfG's Facebook page having >350 followers and typically being accessed by >400 'unique users' each month^{5.7}.

Hambrey was co-founder of, and remains the principal contributor to, the world's most comprehensive repository of photographic images of ice-mass, hosted by 'Glaciers Online' (www.glaciers-online.net). This internet site includes scientific descriptions of several thousand images illustrating the variety of Earth's ice masses and their dramatic geometrical response to climate change. The site is very widely accessed by the general public, schools, and the media; a snapshot for the calendar month of September 2013 indicates that the site successfully received 115,279 views from 7,770 unique international visitors^{5.8}.

More regionally-specific web sites established by the CfG include 'The Greenland Ice Sheet' (www.aber.ac.uk/greenland/index.shtml) and 'AntarcticGlaciers.org' (www.antarcticglaciers.org) which provide comprehensive information relating to our research addressing the response of

these ice masses to climate change. These sites include public engagement sections such as 'Why study glaciers?', 'Ask a scientist', as well as hosting blogs from scientists actively engaged in field campaigns. As an illustration of their reach, AntarcticGlaciers.org receives over 4,000 unique visits every month from a global following of over 26,000 unique visitors^{5.9}.

III. Informing the public through lectures, books and articles

Since 2008, CfG staff have contributed to a wide variety of public lectures covering the full range of venues and scales. For example, B. Hubbard and Hambrey lectured to ~200 members of the public as part of the Climate Change Consortium for Wales' (C3W) lecture series entitled 'Climate Change: The Evidence' hosted by Bangor University, while A. Hubbard presented a lecture to >800 attendees at the Royal Geographical Society^{5.10}, both in 2011. The former is just one of many such engagements organised and presented under the auspices of C3W, a £4M body established in 2009 as a direct result of CfG initiatives (led by Hambrey, who was also C3W's inaugural Director). C3W organised a launch event for politicians and the user community (<http://news.bbc.co.uk/1/hi/wales/8381744.stm>) in 2009, and the body continues to host numerous outreach events for the wider public, each with a strong cryospheric component (<http://c3wales.org/resources/>), including a bespoke 'Climate Day' in 2009. C3W's formal outreach programme provides a 'platform for interaction ... between scientists, social scientists, government, business and the public', summarized on C3W's outreach internet site (<http://c3wales.org/category/news/outreach-news/>). To date, these lectures have reached several thousand attendees and continue right up to the end of the REF census period with a series of 12 public lecture evenings hosted by AU, and to include presentations on ice-mass change by CfG's Hambrey, B. Hubbard and Glasser (see: <http://c3wales.org/events/category/aber-lecture/>). These public lectures typically attract >150 attendees from a broad cross-section of the community.

As well as contributing to public lectures, CfG staff have written a number of books and articles, aimed at informing the wider public about glacier and ice mass response to climate change. At a very general level, Hambrey's recent *Gletscher der Welt* (2013) supplements previous general-interest books that together engage the public by conveying both the beauty of our planet's glacial regions and the dramatic changes they are currently undergoing. As well as books, CfG staff have also written popular science articles broadly addressing the response of Earth's glacierized regions to climate change. These include, for example, a very widely-reported correction to the Times Atlas' flawed mapping of ice loss from the Greenland Ice Sheet^{5.11} and a broad rebuttal of scientifically-flawed arguments that climate change has not been responsible for measured cryospheric change^{5.12}, both heavily informed by research but also written to be accessible to an educated, but non-expert, readership.

5. Sources to corroborate the impact

- 5.1 Letter from Series Producer and Episode Producer of 'Frozen Planet'.
- 5.2 Letter from Series Producer and Executive Producer of 'Operation Iceberg'.
- 5.3 Transcript of user comment on BBC's 'Operation Iceberg' blog (http://www.bbc.co.uk/blogs/blogbbctv/posts/operation-iceberg-risks?comments_page=2).
- 5.4 'Mail Online' newspaper article with comments (<http://www.dailymail.co.uk/sciencetech/article-1301713/The-crack-roof-world-Yes-global-warming-real--deeply-worrying.html#comments>).
- 5.5 BBC news report on Patagonian glacier recession (<http://www.bbc.co.uk/news/uk-wales-12950246>).
- 5.6 New York Times report on Patagonian glacier recession (<http://www.green.blogs.nytimes.com/2011/04/03/in-the-mountains-of-patagonia-a-harbinger-of-a-rising-ocean>).
- 5.7 Facebook Insights Data Export - AU Centre for Glaciology (08-10-2013).
- 5.8 E-mail of Glaciers Online logfile data from internet site manager.
- 5.9 Annotated report on AntarcticGlaciers.org website usage prepared from logfile data.
- 5.10 Letter from Head of Research and Higher Education at the Royal Geographical Society, regarding public lecture given by A Hubbard.
- 5.11 Hubbard, A. 2011. The Times Atlas and actual Greenland ice loss. *Geology Today* 27(6), 214-217. DOI: [10.1111/j.1365-2451.2011.00812.x](https://doi.org/10.1111/j.1365-2451.2011.00812.x).
- 5.12 Hambrey, M.J. + 6. 2010. Glaciers - no nonsense science. *Geoscientist* 20, 18-23.