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Measurements of the ice surface elevation of Icelandic ice caps with lidar

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Background

Climate changes predicted for Iceland in the 21st century will likely lead to the most extensive environmental changes in the country since the settlement in the 9th century. Glaciers and ice caps have been in rapid retreat over the past 15–20 years and the rate of shrinkage is predicted to increase in the coming decades, leading to nearly complete disappearance of the glaciers within 150–200 years. These changes will greatly affect glacial rivers and groundwater systems and as well as hydropower plants, roads and bridges and other infrastructure in the country. Because of their importance for various sectors of society, the glacier changes need to be closely monitored and near-future predictions of glacier variations must be updated on a regular basis. Complete melting of all ice caps and glaciers in Iceland would contribute about 1 cm to worldwide rise in sea level.

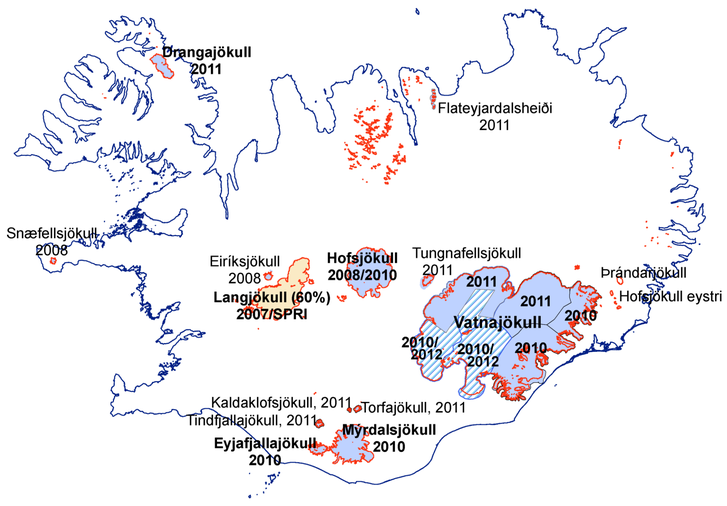


Fig. 1. The total area of glaciers in Iceland is 11.000 km², about 10% of the area of the country. The map shows the status of the lidar mapping at the end of the 2012 survey effort. The blue areas were surveyed in 2008–11. Hatched areas were surveyed in 2012. The Langjökull ice cap (yellow) was surveyed by SPRI in 2007.

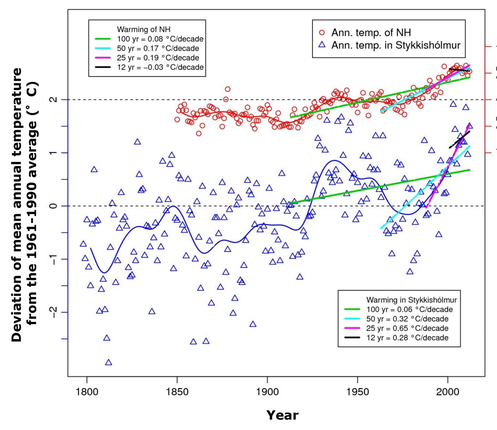


Fig. 2. Mean annual temperature in Stykkishólmur, W-Iceland 1831-2012 (blue symbols) in comparison with the Northern Hemisphere average 1850–2008 (red symbols).

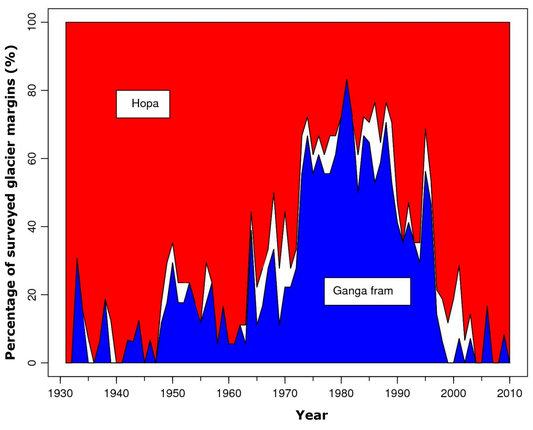


Fig. 3. The percentage of advancing (blue) and retreating (red) glaciers in Iceland 1930/31 to 2009/10. The white-coloured region represents stagnant glacier margins.

The lidar mapping project

Detailed mapping of the surface of glaciers and ice caps in Iceland was initiated during the International Polar Year 2007–2009 and completed in the summer of 2012. The new surface maps will serve as a benchmark for evaluation of current and future changes in ice volume and areal extent. Together with the SPRI lidar DEM of Langjökull from 2007, all glaciers in Iceland >10 km² and several smaller glaciers have been mapped by lidar in the period 2007–12, leaving <150 km² of small glaciers and cirque glaciers unsurveyed. The total surveyed area was >15 000 km², including proglacial areas and repeated mapping of some areas.

The glaciers and ice caps surveyed are of different sizes and types: Vatnajökull is the largest ice cap in Europe, hosting subglacial volcanoes and geothermal systems, which cause regular jökulhlaups (glacial outburst floods). Although Langjökull is up to 750 m thick, it lies entirely below 1450 m elevation and if 21st century climate develops as projected in recent studies it is likely that only ~10% of its volume will be left in 2100. Hofsjökull is a 860 km²/200 km³ ice cap in central Iceland, where mass-balance measurements have been carried out since 1988. The results show negative mass balance every year over the past 18 years and the ice cap has lost approximately 10% of its volume since 1995. Drangajökull is a 140 km² ice cap in NW-Iceland that survives below 900 m elevation under cool conditions close to the Arctic Circle, which lies just north of Iceland. Snæfellsjökull is a small ice cap on the summit of a 1450 m high volcano that is clearly visible from the capital region of Reykjavík in good weather. The area of the glacier has shrunk from 22 km² to 10 km² over the past century. The lidar scanning of the surface of the glacier-capped volcano Eyjafjallajökull revealed the morphology of channels formed in the ice surface, when meltwater floods and lahars (volcanic debris flows) descended down the mountainside during the 2010 eruption. And measurements of the surface of the Mýrdalsjökull ice cap, carried out in the summer of 2010 and repeated to some extent in 2011, allowed estimation of the volume of floodwater released from a subglacial lake in July 2011. The flood swept away a bridge on the main road around Iceland. This cauldron is one of several located within the caldera of the subglacial volcano Katla, where a large eruption could occur in the near future.

The lidar mapping project is an Icelandic contribution to ongoing research on the effects of global warming on Arctic/Sub-Arctic ice caps and mountain glaciers worldwide. The maps will be useful for research on glacier surges and on isostatic uplift due to decreasing lithospheric load. They can also be useful for comparison with satellite-based measurements of glacial surfaces. Mapping of glaciers in the vicinity of subglacial lakes (like Grímsvötn and Skaftárkatlar in Vatnajökull) and marginal lakes (f.ex. Grænalón) is of importance for the study of jökulhlaups and for investigations of changes in the courses of glacial rivers. The project has already produced results on the volume decrease of some ice caps in Iceland over the past few decades, by comparison with older maps and satellite measurements. The lidar maps will be available in the public domain, open for use in map production and scientific research.

Fig. 4 (right). An airborne laser scanning method (lidar) is employed and the measurements are carried out by the company TopScan GmbH (Rheine, Germany). Airborne lidar mapping can cover the entire surface of each glacier/ice cap and thus yields the first accurate maps of crevassed areas and other regions that could not be traversed in earlier, ground-based surveys. The vertical accuracy of the surveys is better than 0.5 m and Digital Elevation Models (DEMs) with a resolution of 5x5m re produced.

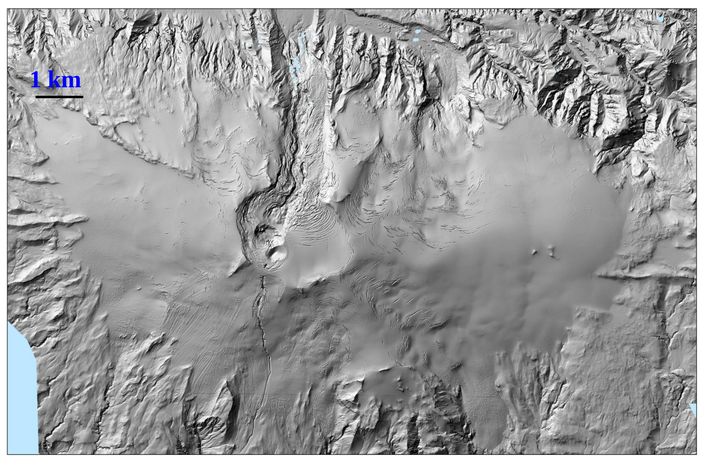
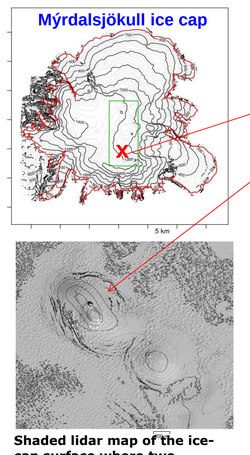
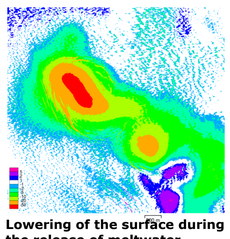


Fig. 5. A shading made from the lidar DEM of Eyjafjallajökull ice cap & volcano. Depressions within the summit crater resulting from the melting of ice during the 2010 eruption are clearly visible, as is the channel of floodwater descending down the northern slope. A smaller channel was formed on the southern slope due to a small jökulhlaup. Flow marks from lahar flows can also be seen.



Surface cauldron formed due to sudden release of sub-glacial water on July 9 2011.

Shaded lidar map of the ice-cap surface where two cauldrons formed.



Lowering of the surface during the release of meltwater, calculated from repeated lidar measurements.

Fig. 6. Lidar-measured surface changes during a jökulhlaup event in Mýrdalsjökull on July 9 2011.

Thinning of Snæfellsjökull and Hofsjökull

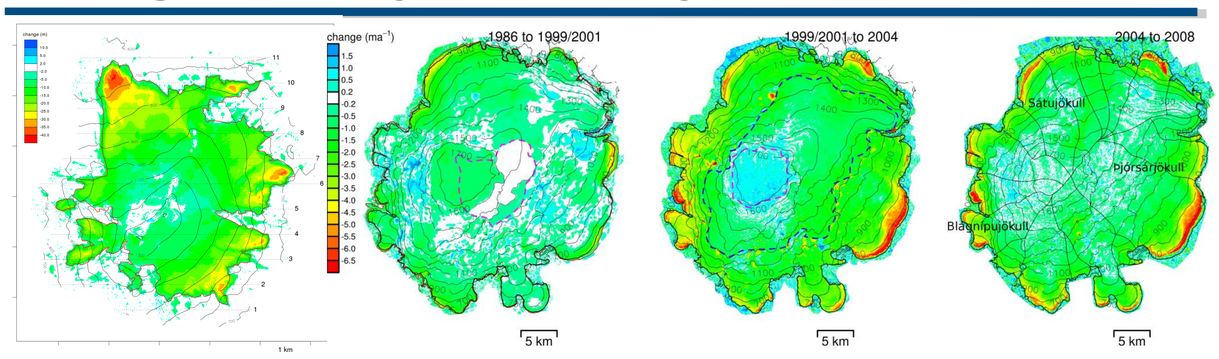


Fig. 7. Elevation changes of Snæfellsjökull (1999–2008, leftmost map) and Hofsjökull (1986–1999–2004–2008, right) calculated from lidar maps based on the 2008 survey and from older maps made from aerial photogrammetry and remote sensing (Loftmyndir ehf., SPOT5/HRS).

SE-Hofsjökull, Múlajökull, Hjartafell

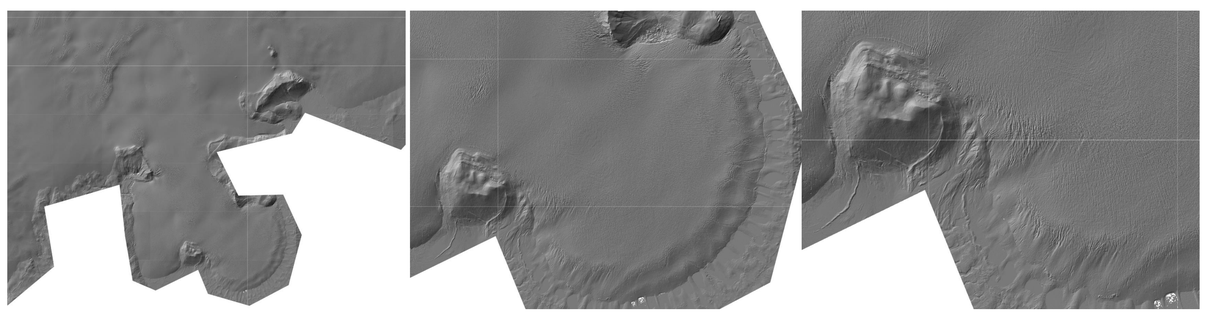


Fig. 8. Shaded lidar DEMs of the southern part of Hofsjökull, zooming in on the Múlajökull outlet glacier and the nunatak Hjartafell. Landforms in front of the receding glacier margin can be observed, as well as crevasses and water courses on the glacier surface.

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Reference: Jóhannesson, Björnsson, Magnússon, Guðmundsson, Pálsson, Sigurðsson, Thorsteinsson and Berthier. 2013. Ice-volume changes, bias estimation of mass-balance measurements and changes in subglacial lakes derived by lidar mapping of the surface of Icelandic glaciers, *Annals of Glaciology*, 54, 63–74, 10.3189/2013AoG63-A422.