Changes in Eyjafjallajökull ice cap 1945-2015 based on multiple archives of elevation data

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In a nutshell

-Vast archives of stereo imagery available in Iceland, with potential for extraction of Digital Elevation Models (DEMs)

-Reconstruction of Geodetic Mass Balance (GMB) in decadal time span from 1945-present in Icelandic glaciers helps understanding regional climate

Aims of the study:

-Develop a highly automated processing chain for DEM & ortho processing from stereo imagery based on open source software

-Use Eyjafjallajökull as test area to study different scenarios of data availability and reference data, and study results of accuracy and changes in Eyjafjallajökull

Eyjafjallajökull [ˈeɪjaˌfjatlaˌjœːkʏtʲ]

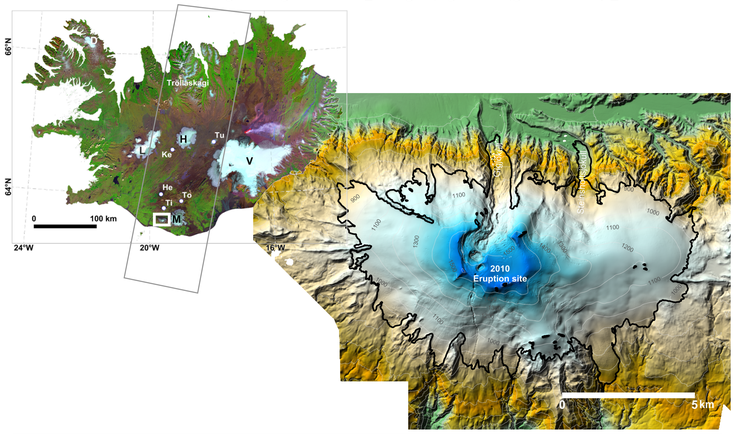

Figure 1: (Left) Map of Iceland with main glaciated areas. A gray polygon shows the footprints of the Hexagon KH-9 images, and a white rectangle marks Eyjafjallajökull. **(Right)** Lidar DEM from Eyjafjallajökull 2010 [1].

Time series of elevation changes in Eyjafjallajökull

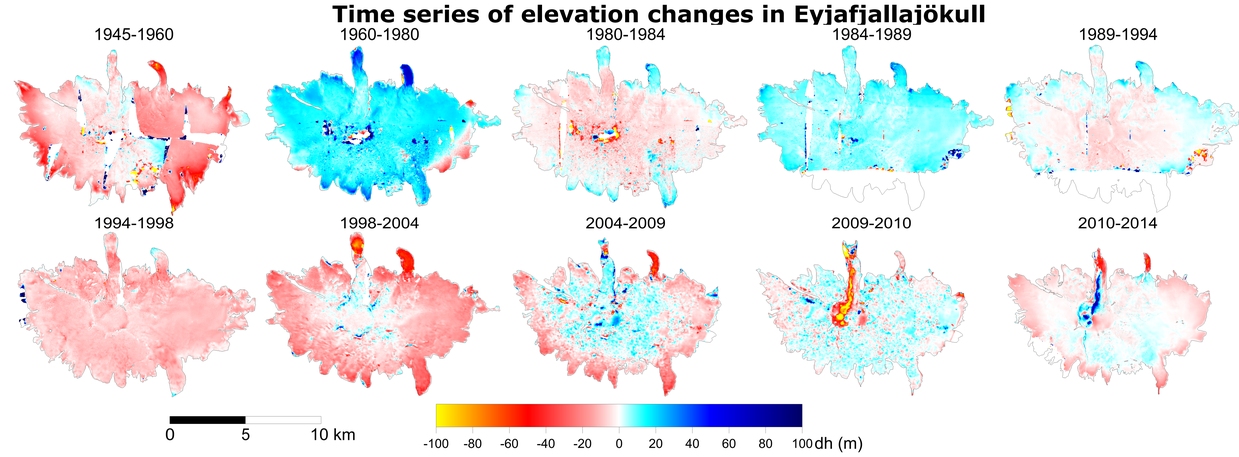

Figure 3: Net elevation change from different time periods in Eyjafjallajökull ice cap. Red indicates thinning and blue thickening. The glacier front at Gigjökull and Steinsholtsjökull advanced during the period 1960-1994. The period 2009-2010 reveals the melted surface of the ice cap due to the April 2010 Eyjafjallajökull eruption, and in 2010-2014 the melted channel was refilled due to the ice dynamics

Data & Methods

	Date	Series	GSD* DEM (m)
Frame images	29 Sep 1945	AMS	5
	5 Aug 1960	DMA	5
	13 Aug 1960	LMÍ	5
	28 Jul 1980	LMÍ	5
	22 Aug 1980	KH-9	20
	4 Sep 1984	LMÍ	5
	31 Jul 1989	LMÍ	5
	6 Aug 1994	LMÍ	5
	12 Aug 1998	EMISAR [2]	5
Pushbroom images	5 Oct 2004	Spot5	20
	7 Oct 2009	ASTER	30
	10 Aug 2010	Lidar	1
	11 Aug 2014	Pléiades	4
	26 Oct 2015	WV	2

HR DEM

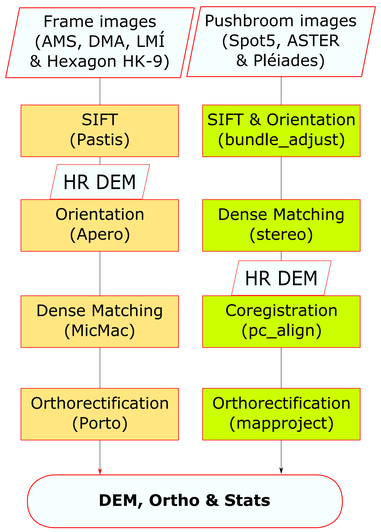

Table 1 (left): Elevation data available in the study. Blue names indicate High Resolution (HR) DEMs used as reference. *GSD: Ground Sampling Distance. **Figure 2 (right):** Workflow for processing DEMs and orthoimages. Orange and green boxes are processes carried out with MicMac (IGN, France) and ASP (NASA), respectively.

MicMac [3]: DEM & Ortho processing of frame photographs:
-American Mapping Service (AMS)
-Defense Mapping Agency (DMA)
-Landmælingar Íslands (LMÍ)
-Hexagon KH-9 Photoreconnaissance

ASP [4]: DEM & Ortho processing of pushbroom imagery
-Spot5
-ASTER
-Pléiades

Statistics using different HR DEMs available to extract GCPs & co-register DEMs:
-Lidar
-Pléiades
-WorldView (WV) via ArcticDEM [5]

Seasonal correction of GMB to summer layer:
-Energy balance model 1980-2015 [6]
-Degree-day model 1960-1980

	Stats Icefree				Stats on-glacier
Time period	Mean (m)	Median (m)	SD (m)	NMAD (m)	bias-corrected Mean dH (m)
1945-1960	-3.33	-3.13	7.29	6.34	-13.61
1984-1989	1.02	0.73	2.49	1.54	7.81
1998-2004	0.66	0.23	7.38	4.38	-11.48
2010-2014	-0.20	-0.18	1.45	0.43	-2.26

Table 2 (left): Examples of statistics calculated over differential DEMs (dDEMs). Case of lidar as HR reference DEM. The statistics over icefree areas are used to estimate remaining bias of the dDEM and error dispersion. They are calculated over 1km buffer of areas surrounding the glacier margin. The errors increase with older datasets and coarser GSD of the dataset

Glacier-wide GMB

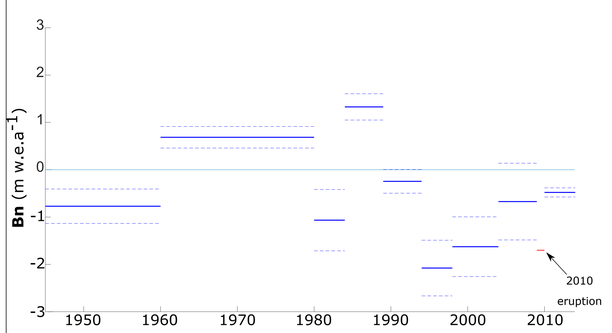

Figure 4: Average specific net mass balance. The geodetic records are calculated relative to the dates of acquisition of the elevation data, and can be affected by seasonal melting. Geodetic records from the period 2009-2010 (red line) mainly indicate the melting produced from the 2010 eruption

Hexagon KH-9 Photoreconnaissance mission

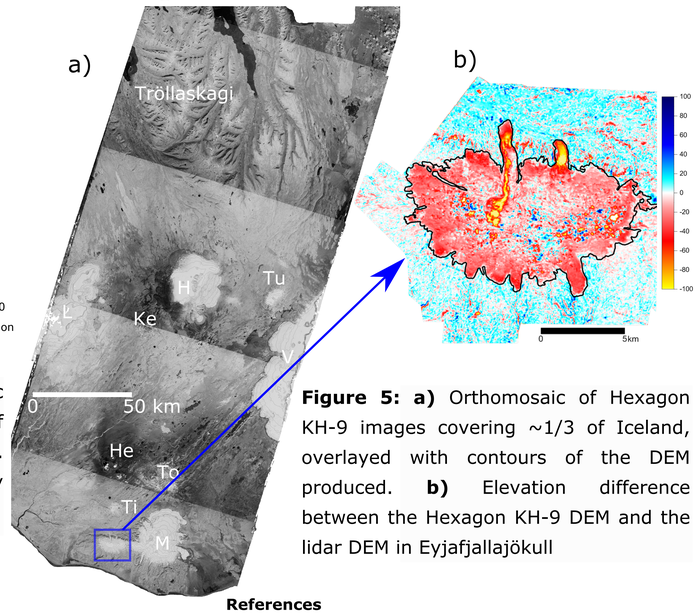

Figure 5: a) Orthomosaic of Hexagon KH-9 images covering ~1/3 of Iceland, overlayed with contours of the DEM produced. **b)** Elevation difference between the Hexagon KH-9 DEM and the lidar DEM in Eyjafjallajökull

Perspectives & Conclusions

The pipeline for processing elevation data in Iceland with open source software and multiple options of HR DEMs will be used for future work in areas with limited data

Benchmark for Hexagon KH-9 processing in Iceland. ~1/3 of Iceland and several glaciated areas covered with six images from 1980

Eyjafjallajökull, GMB records & stories of changes from 1945-2015
-Rapid changes on mass balance as response to changes in climate
-GMB = XXX for period 1945-2014; XXX for cold period 1969-1994
-2010 eruption: XXX Gt ice melted and post eruption ice readjustment

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