Climate change response of Vatnajökull, Hofsjökull and Langjökull ice caps, Iceland

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1. INTRODUCTION

The surface and bed topograhy of Vatnajökull, Hofsjökull and Langjökull ice caps have been constructed from GPS and radio-echo surveys (Björnsson, 1986, 1988, Björnsson *et al.*, 2006) and mass balance measurements conducted over the last 10 to 15 years, depending on the glaciers (Björnsson *et al.* 1998, 2002, 2006; Sigurðsson 1989-2004). A degree-day mass balance model, using records of meteorological stations away from the glaciers, was calibrated against the observations of winter and summer balance (Jóhannesson *et al.*, 1995, Jóhannesson, 1997). We used the mass balance model, coupled to a 3-D ice flow model (Aðalgeirsdóttir, 2003; Aðalgeirsdóttir *et al.*, in press), to simulate the evolution of Langjökull, Hofsjökull and the southern part of Vatnajökull over the next centuries in response to a prescribed climate change scenario for Iceland (the Nordic CE project). The volume of ice caps is predicted to decrease drastically over the next 200 yrs. Runoff will increase over the next 40-60 years and remain higher than at present until the close of the 21st century.

2. LOCATION AND GEOMETRY

Locations of the three glaciers are shown in Figure 1 and parameters describing the geometry in Table 1.

Table 1. Characteristics of the Langjökull, Hofsjökull and Vatnajökull ice caps.

Ice cap	Area (km^2)	Volume (km^3)	Maximum ice thickness (m)	Range in elevation (m a.s.l.)
Langjökull	925	195	580	390-1290
Hofsjökull	880	200	760	600-1800
Vatnajökull	8100	3000	950	0-2100
Southern Vatnajökull	3710	1279	900	0-2100

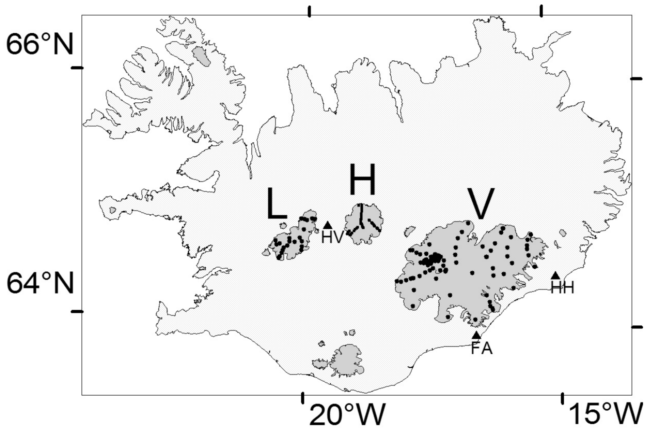

Figure 1. Langjökull (L), Hofsjökull (H) and Vatnajökull (V), sites of mass balance measurements (dots) and meteorological stations (triangles; HV: Hveravellir, FA: Fagurhólsmýri, HH: Hólar í Hornafirði).

3. OBSERVATIONS

Daily temperature and precipitation at Hveravellir were used as an input to the mass balance models of Langjökull and Hofsjökull, and temperatures at Hólar í Hornafirði and precipitation at Fagurhólsmýri for the southern Vatnajökull (Fig. 1). The mass balance models were calibrated to i) mass balance observations conducted at 22 stakes at Langjökull from 1996-2005, ii) 35 stakes on Hofsjökull from 1988 to 2005, and iii) 23 stakes on southern Vatnajökull from 1993-2005 (Fig. 1), and evaluated by using full energy balance derived at several automatic weather stations operated on Langjökull and Vatnajökull (Guðmundsson *et al.*, 2003; Björnsson *et al.*, 2006). DEMs of the glaciers surface and bed were constructed from GPS and radio echo surveys undertaken 1980-2000.

4. MASS BALANCE MODELLING

The degree-day mass balance model uses a constant vertical elevation temperature lapse rate, degree-day factors that differs for snow and ice, and both horizontal and vertical precipitation gradients. The parameters were calibrated to the observations by assuming a constant snow/rain threshold of 1 °C. The mass balance model describes 80% and 92% of the annual variation in the winter balance of Hofsjökull and southern Vatnajökull respectively, and 95% of the summer balance on both the glaciers. The model explains 86% of the variance in the summer balance of Langjökull but only 39% of the winter balance. Despite this, the model managed to describe 92% of the variation in the annual balance of Langjökull.

Modelled average specific net mass balance of the three ice caps 1981-2000 is close to zero; positive during the first but negative during the latter part of the time interval. Thus, the average climate of 1981-2000 was chosen as an initial reference climate for all model runs and the year 1990 as the initial year.

5. COUPLED DYNAMIC ICE FLOW AND MASS BALANCE MODEL

The glaciers dynamic were described by a vertical integrated finite-difference ice flow model with shallow-ice approximation. The parameters describing the rheology of ice (Glen´s law) and Weertman type of basal sliding are the same as those determined for Hofsjökull and

Vatnajökull by Aðalgeirsdóttir *et al.*, (in press). The model neglects longitudinal stresses and surges, and excludes bed-isostatic adjustments and seasonal sliding.

Simulation of the glaciers response to the future climate scenario was initialized with stable ice geometries derived after a few hundred years spin-up with a zero mass balance input, representing the average climate condition of 1981-2000.

6. RESPONSE TO A PRESCRIPED CLIMATE CHANGE SCENARIO

A climate change scenario was defined in the Nordic CE project (Fig. 2). The simulation was started from the year 1990 by using the stable ice geometries for the three glaciers and the 1981-2000 initial reference climate. Observed temperature and precipitation changes were used until 2005 and the CE scenario thereafter. The simulation predicts that Langjökull disappears within 150 years from now and the more elevated Hofsjökull and Vatnajökull almost vanish within 200 years from now (Fig. 3a,b). The runoff is predicted to increase as the climate gets warmer, but peak after 40-60 years due to the reduced area of the glaciers (Fig. 3c). The specific runoff rate is highest for Langjökull and lowest for Hofsjökull as expected from their elevation range (Fig. 3c and Table 1).

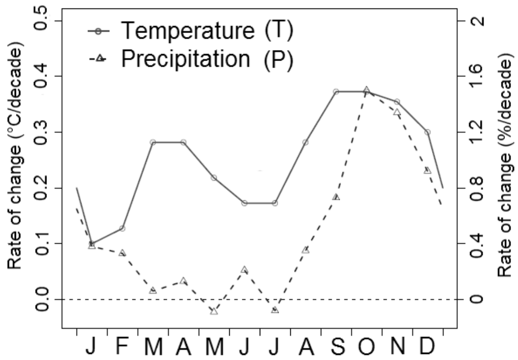

Figure 2. Average monthly temperature and precipitation change per decade between the periods 1961-1990 and 2071-2100 for the Icelandic highland according to the CE climate change scenario.

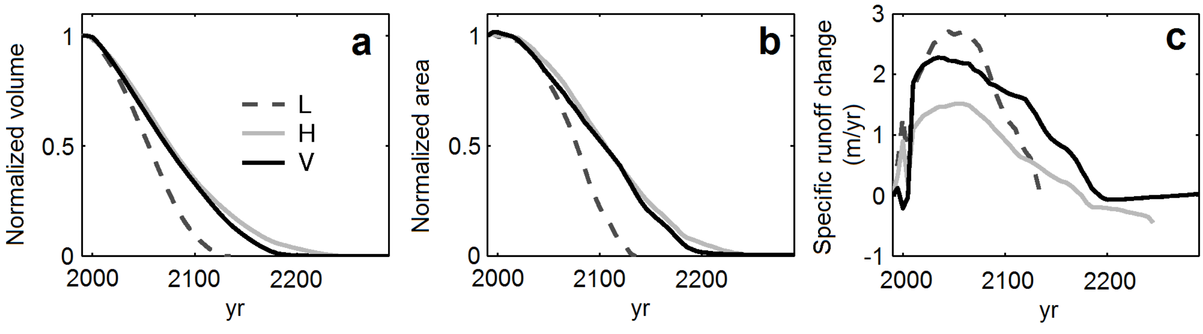

Figure 3. Change in volume (a), area (b), and specific runoff (c) of Langjökull (L), Hofsjökull (H) and Vatnajökull (V). The volumes and areas are normalized to the present-day values (Table 1). The specific runoff rate is in m yr^{-1} per the present-day glacier area.

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