Geometry, mass balance and climate change response of Langjökull ice cap, Iceland

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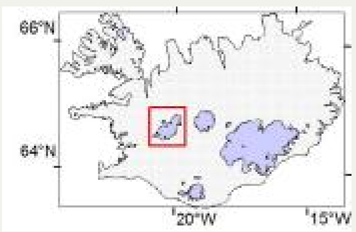
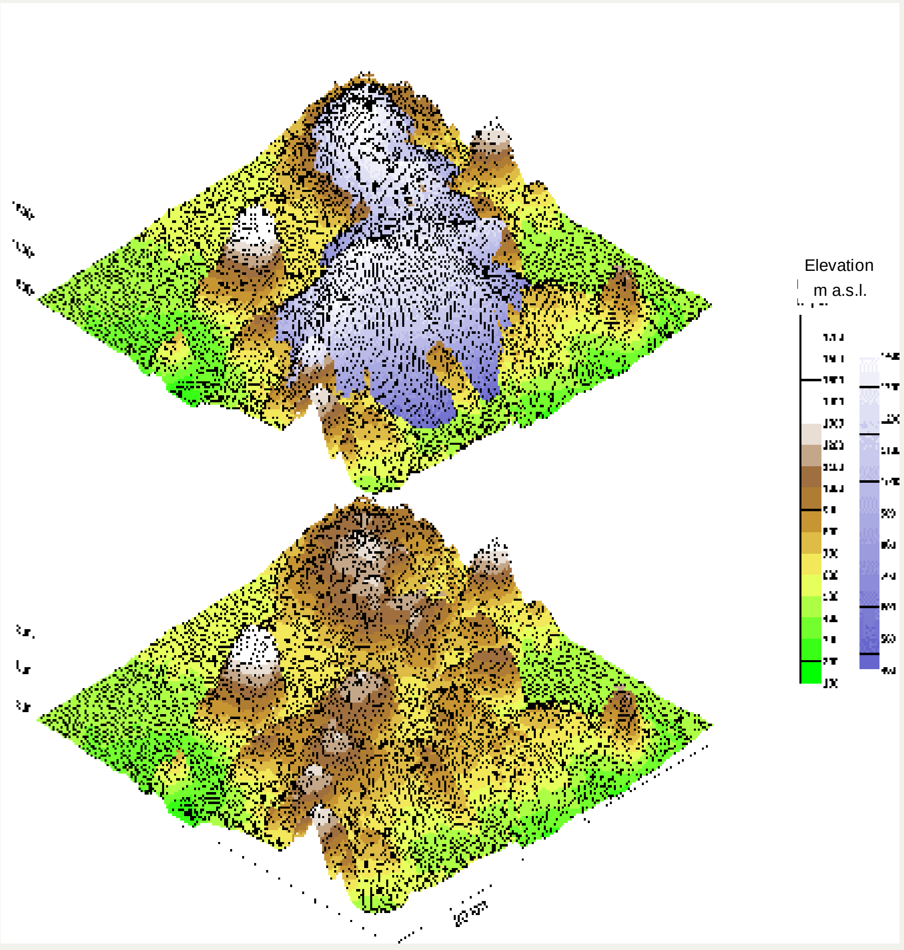
ABSTRACT The geometry of the surface and bed of Langjökull, Iceland, was constructed from GPS and radio-echo surveys in 1997. The mass balance of the ice cap was measured from 1996-1997 to 2004-2005 and linked to climatic variables recorded in automatic weather stations on the glacier every summer since yr 2001, and to the records of the Hveravellir meteorological station east of the ice cap. A degree-day mass balance model was calibrated against stake observations of winter and summer balance on the glacier for 1997 to 2004. We used the mass balance model, coupled to a 3-D ice flow model, to simulate the evolution of Langjökull, over the next two centuries in response to a prescribed climate change scenario for Iceland (the Nordic CWE project). The volume of ice is predicted to decrease by half in 150 yrs and the glacier will have disappeared within 200 yrs. Runoff will increase until the close of the 21st century but decrease thereafter.

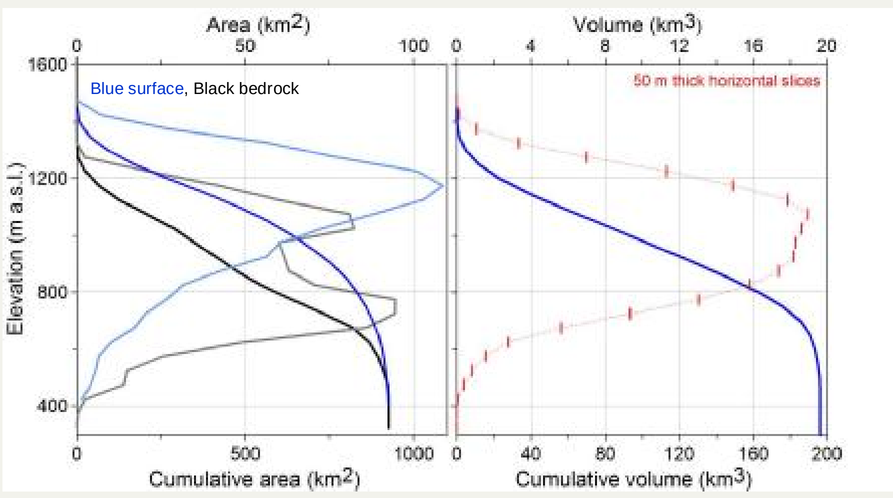
I. LOCATION AND GEOMETRY

Langjökull is the second largest ice cap in Iceland, 925 km² in area and 195 km³ in volume, with a maximum ice thickness of 580 m. Surface elevation ranges from 400 up to 1450 m and bed elevation from 390 to 1290 m a.s.l.



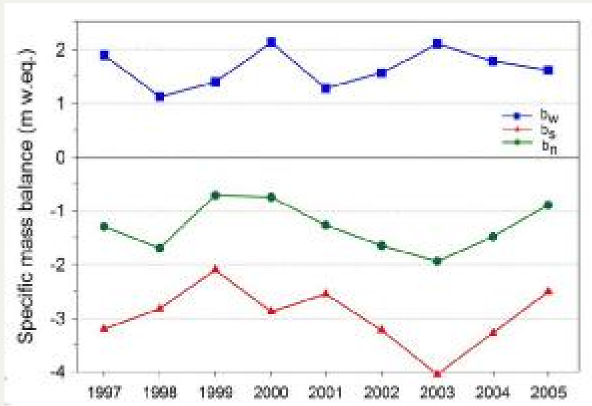


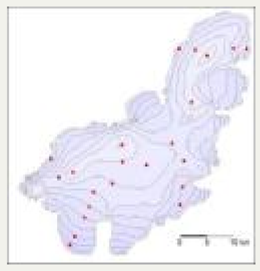
Geometry: DEMs of the glacier surface and bed were constructed from GPS and radio-echo surveys in 1997. Area and volume distribution is shown below.



II. MASS BALANCE

Mass balance observations were carried out at 22 balance stakes (red dots, right) from 1996-1997 to 2005 (Björnsson et al. 2002).

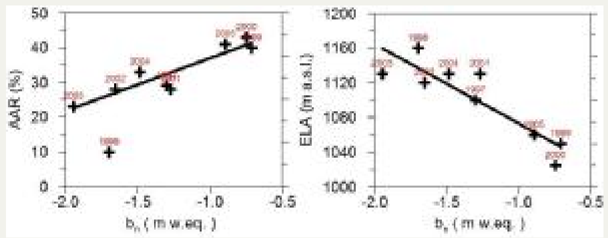




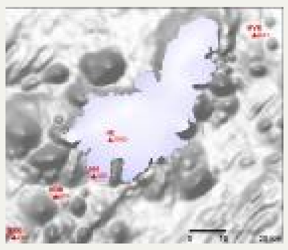
The mass balance was negative during the 9 yr period and the ice cap lost 6% of its total mass, equivalent to 11.7 $m_{w.e.}$ distributed equally over its surface.

A typical specific runoff was about 3 $m_{w.e.}$ a^{-1} (left).

Equilibrium line altitude (ELA) and accumulation area ratio (AAR) in relation to annual mass balance (b_n) during 1997-2005.

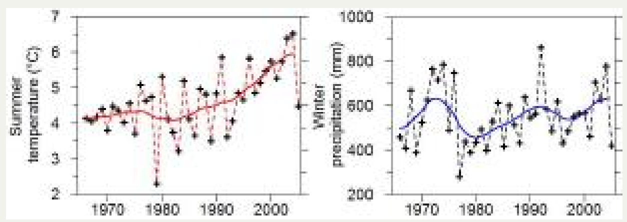


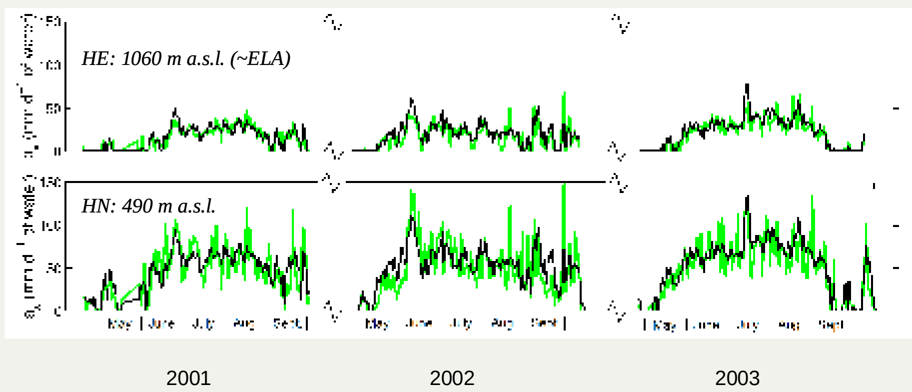
III. METEOROLOGICAL OBSERVATIONS, ENERGY BALANCE AND DEGREE-DAY MELTING MODELS



Automatic weather stations (AWS, red triangles) have been run during summer at two locations, HN and HE (providing energy balance) on the glacier and on two locations, SÖD and NSK south of the glacier since 2001. HVE is a meteorological station (run by the Icelandic Meteorological Office) east of the ice cap where temperature and precipitation have been recorded since 1962.

HVE summer temperatures increased after 1980 but there is no apparent trend in winter precipitation. Measured HVE precipitation shows low correlation with the mean glacier winter balance.





Comparison of daily values of melting at the two AWS sites, computed by energy balance models (green) and degree-day temperature index models (black), calibrated to the 2001 temperature data at SÖD. The correlation is 0.87 (HE) and 0.86 (HN),

IV. MASS BALANCE MODELING

A degree-day mass balance model (Jóhannesson et al.,1995; Jóhannesson, 1997) uses daily temperature and precipitation data from Hveravellir (HVE, 641 m a.s.l.). Glacier surface temperature and precipitation fields were spatially-distributed and the mass balance model calibrated against 22 stake observations of winter and summer balance 1997 to 2004.

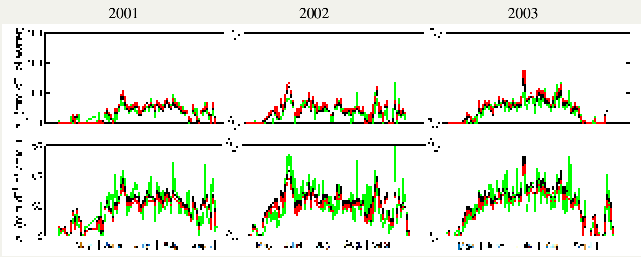
Model parameters:

Constant vertical elevation lapse rate of 0.6 °C per 100 m

Constant snow/rain temperature threshold of 1 °C .

Degree-day factors: for ice 0.0071 $m_{w.e.}$ $°C^{-1} d^{-1}$; for snow 0.0049 $m_{w.e.}$ $°C^{-1} d^{-1}$

The parameters were in good agreement with those obtained for the degree-day model described in section III.

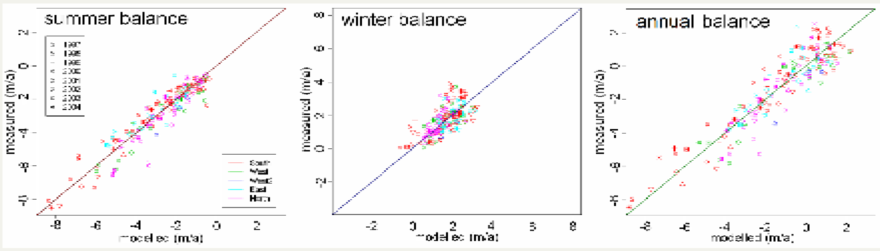


green = energy balance model,

black = dd model of SÖD station, section III

red = HVE mass balance model

Measured and modeled mass balance on Langjökull 1996-2005

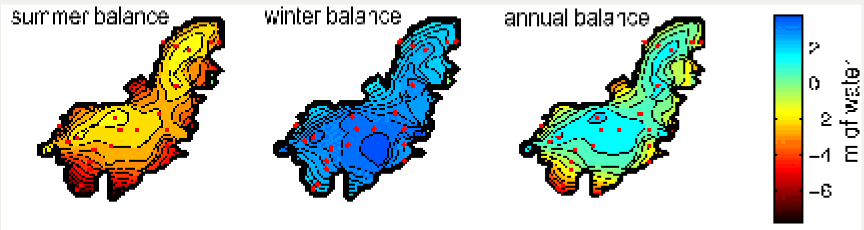


The mass balance model explains:

86% of the variance in the summer balance

39% of the variance in the winter balance

92% of the variance in the annual balance



Modelled average annual mass balance of Langjökull 1981-2000 in $m_{w.e}$ a^{-1} predicts specific net mass balance close to zero averaged over the ice cap. The modelled mass balance was positive during the first part and negative the later part of the time interval.

Winter balance is probably slightly overestimated on the highest crests as well as in the SW part where no observations were available. Some of the discrepancies between measurements and simulations may be due to snow drift.

V. COUPLED DYNAMIC ICE FLOW AND MASS BALANCE MODEL

The glacier dynamics were described by a vertically integrated finite-difference ice flow model with a shallow-ice approximation (Aðalgeirsdóttir, 2003; Aðalgeirsdóttir et al. in press).

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 ice caps by comparing the computed and measured velocities.

Limitations:

Neglecting longitudinal stresses and surges

No bed-isostatic adjustment

No seasonal sliding

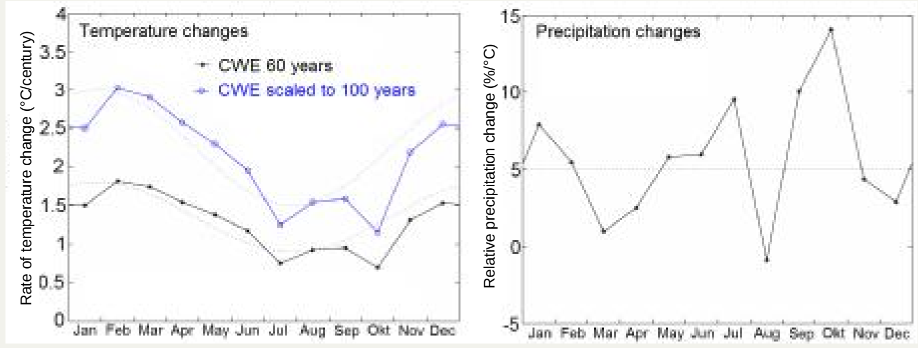
Model initialization:

Simulation of glacier response to future climate scenarios was initialized with a stable ice geometry derived after a 350 year spin-up with a zero mass balance input, representing the average climate condition of 1981-2000.

Geometry of Langjökull with the zero mass balance climate held fixed for 350 and 2240 years. The southern ice cap grows slightly toward SE because modelled winter balance is slightly too high and a NE outlet, which may be fed by snowdrift, disappears.

VI. RESPONSE TO A PRESCRIBED CLIMATE CHANGE SCENARIO FOR ICELAND

The mass balance and ice flow models were coupled to simulate the response of the glacier to climate change. A climate change scenario, near Iceland 1990-2050, was defined in the Nordic CWE research program (Rummukainen et al. 2003).



The dashed curves were used in the glacier model simulations

Temperature changes with time:

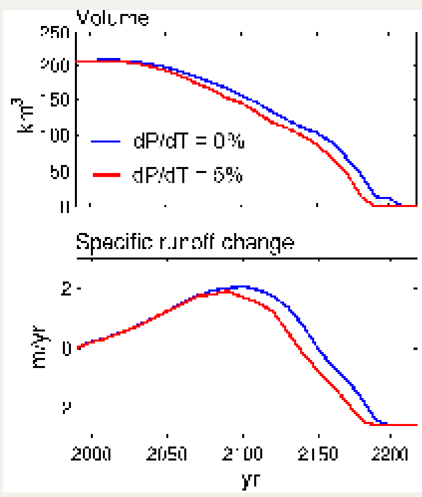
Sinusoidal variation through the year.

Continuous linear warming rate of +0,3 °C per decade in mid-winter and 0,15 °C per decade in mid-summer, starting from 1990.

Precipitation changes with temperature (dP/dT):

5% per 1°C of warming, independent of season.

The period 1981-2000 was chosen as initial reference climate and the simulation started in 1990.



Model prediction:

The volume of the ice cap is reduced by half within 150 years from now and the glacier disappears within 200 years. The retreat is relatively slow during the next 50 years but after just over 100 years the ice cap will be split into two separate parts.

Specific runoff rate from the area covered by the present-day glacier (925 km^2) is predicted to have increased by 1 m a^{-1} (30%) 50 years from now and by 2 m a^{-1} (or by 60 $m^3 s^{-1}$; 70%) toward the end of the 21st century and decrease thereafter. Present day specific runoff rate is 3 m a^{-1}

Mass balance measurements on Langjökull

ACKNOWLEDGEMENTS

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