The effect of forcings and boundary conditions on the geometry and volume of the present day Greenland ice sheet

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1. Introduction

- The boundary conditions, ice thickness and bedrock topography, are essential for modelling the evolution of the Greenland Ice Sheet (GIS).
- The majority of current ice sheet modelling studies (e.g. Greve, 2000; Ridley *et al.* 2005) use datasets which are over a decade old and based on data collected from the 1970s (Letreguilly *et al*., 1991).
- Datasets consisting of an up-to-date and more accurate ice thickness and a Digital Elevation Model of the Greenland bedrock topography have been produced (Bamber *et al*., 2001).
- Differences between these datasets could result in considerable impacts on the ice sheet dynamics of numerical models and the ice sheet geometry and volume.

- **Under steady state climate conditions, we present results using the GLIMMER ice sheet model to investigate and compare the impact of the forcings and boundary conditions used in the EISMINT-3 exercise with the more recent datasets.**
- **In order to model future and past Greenland ice sheet behaviour with the more recent boundary conditions and forcings a tuning exercise has been performed.**

2. Methodology

•Run offline for 50k years starting with the initial geometry of the ice sheet for an ensemble of experiments based on EISMINT-3 input and more recent dataset inputs.

INPUTS

- **TEMPERATURE**
  - **Eismint-3** Based on Ohmura (1987)
  - **Recent** 1. 1981-2001 corrected ERA-40 temperature over GIS (Hanna *et al*., 2005)
- **BEDROCK TOPOGRAPHY & ICE THICKNESS**
  - **Eismint-3** Letreguilly *et al*. (1991)
  - **Recent** Bamber *et al*. (2001)
- **PRECIPITATION**
  - **Eismint-3** Based on Ohmura & Reeh (1991)
  - **Recent** 1979-2001 ERA-40 precipitation[1]

Model fixed Parameters
- **Lapse rate= 6.227 C km^{-1}**
- **PDD_{snow}= 3 mm d^{-1} C^{-1}**
- **PDD_{ice} = 8 mm d^{-1} C^{-1}**
- **Geothermal heat flux = 50.0 x10^{-3} W m^{-2}**
- **Enhancing flow factor = 3**

[1]European Centre for Medium-Range Weather Forecasts. ECMWF ERA-40 Re-Analysis data, [Internet]. British Atmospheric Data Centre. 2006-, [15 March 2009]. Available from http://badc.nerc.ac.uk/data/ecmwf-e40/.

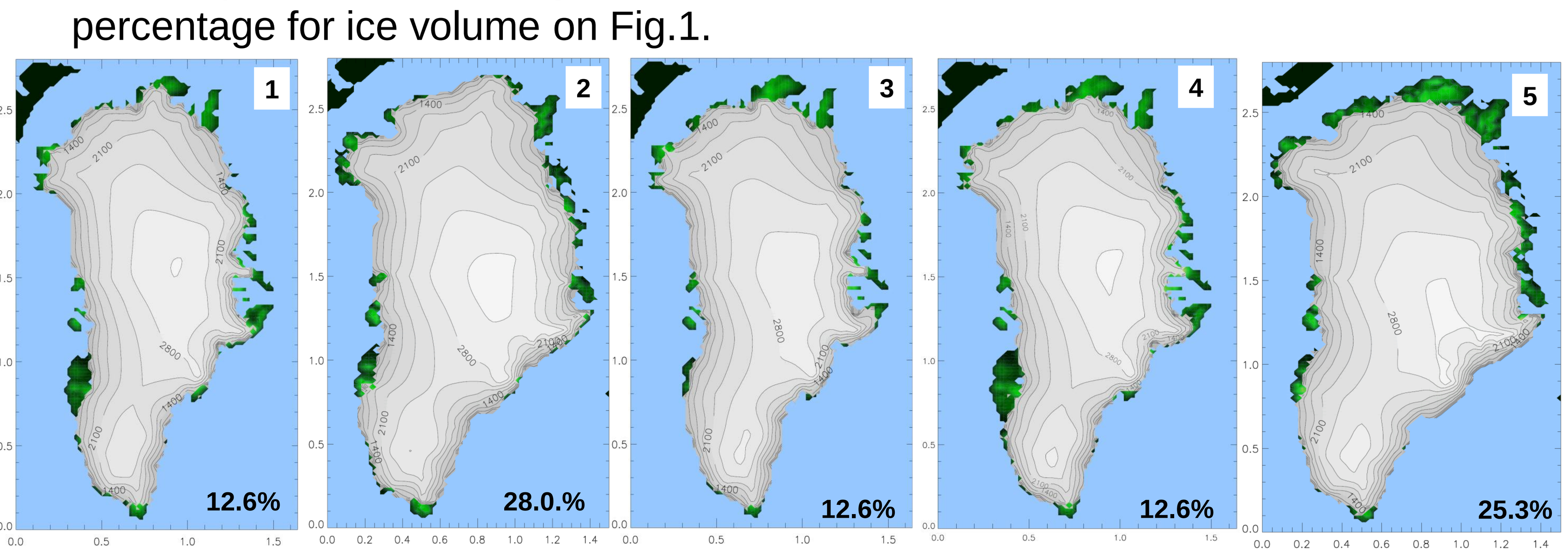
3. Results

[1]Bamber *et al.* (2001)

	Temp	Precip	Bedrock & surface elevation	Ice volume ($\times 10^6$ km^3)	Sea level equivalent height (m)	Area covered by ice ($\times 10^6$ km^2)	Max. ice thickness (km)
	Obs[1]	Obs[1]	Obs[1]	2.93	7.34	1.70	3.32
1	E	E	E	3.30 (**+0.37**)	8.32 (**+0.97**)	2.07 (**+0.37**)	3.11 (**−0.20**)
2	E	E	N	3.75 (**+0.82**)	9.46 (**+2.13**)	2.30 (**+0.60**)	3.34 (**+0.02**)
3	E	N	E	3.30 (**+0.37**)	8.32 (**+0.98**)	2.11 (**+0.41**)	2.93 (**-0.39**)
4	N	E	E	3.30 (**+0.37**)	8.31 (**+0.97**)	2.02 (**+0.32**)	3.15 (**−0.17**)
5	N	N	N	3.67 (**+0.74**)	9.26 (**+1.92**)	2.22 (**+0.52**)	3.25 (**−0.07**)

Fig.1 & Table1: Sensitivity of the Greenland ice sheet to updated modern day temperature, precipitation, bedrock and surface elevation. E refers to the EISMINT-3 bedrock, temperature and precipitation.

N refers to the more recent dataset described in section 2. The values in bold are the difference relative to the most recent observations based on Bamber *et al.* (2001) and those highlighted in red are the largest differences when one boundary condition/forcing is varied. This is also shown in terms of percentage for ice volume on Fig.1.



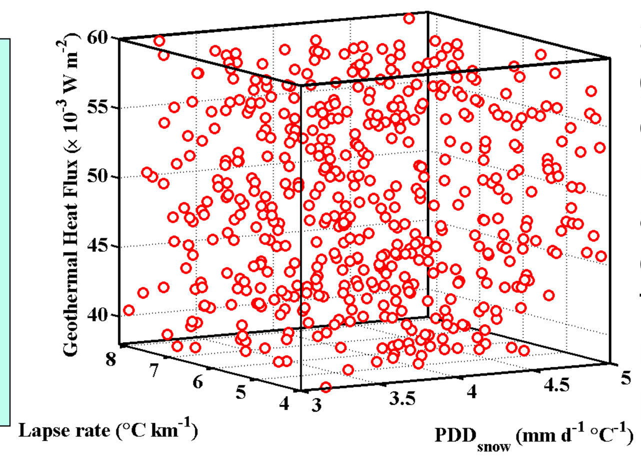
Original EISMINT-3 | Updated Bedrock | Updated precipitation | Updated Temperature | All updated

4. Tuning

SELECT PARAMETERS
- PDD_{snow}
- PDD_{ice}
- Flow factor
- Lapse rate
- Geothermal (basal) heat flux

Parameter	Minimum value	Maximum value
Positive degree day factor for snow (mm d^{-1}°C^{-1})	**3** *Braithwaite (1995)*	**5** *Braithwaite (1995)*
Positive degree day factor for ice (mm d^{-1}°C^{-1})	**8** *Braithwaite (1995)*	**20** *Braitwaite (1995)*
Enhancing flow factor	**1** *Weertman (1973)*	**5** *Dahl-Jensen & Gundestrup (1987)*
Geothermal heat flux ($\times 10^{-3}$ W m^{-2})	**38** *Dahl-Jensen & Johnsen (1986)*	**61** *Lee (1970)*
Near surface lapse rate (°C km^{-1})	**4.0** *Steffen & Box (2001)*	**8.2** *Steffen & Box (2001); Hanna et al. (2005)*

250 experiments using Latin Hypercube Sampling (LHS): generates a distribution of plausible parameter sets within the prescribed set of ranges given above.



250 sensitivity experiments generated using LHS. Each experiment (represented by a red circle) has an additional associated PDD for ice and enhancement flow factor value. This builds on the method used in Ritz *et al.* (1997) where each parameter is varied individually.

RUN GLIMMER
1. Bamber orography
2. ERA-40 precipitation
3. Hanna temperatures

SKILL SCORE METRICS
1. Ice Volume
2. Ice surface area extent
3. Maximum altitude
4. Normalised RMS error of ice thickness & upper surface elevation

5. Tuning Results

Fig.2

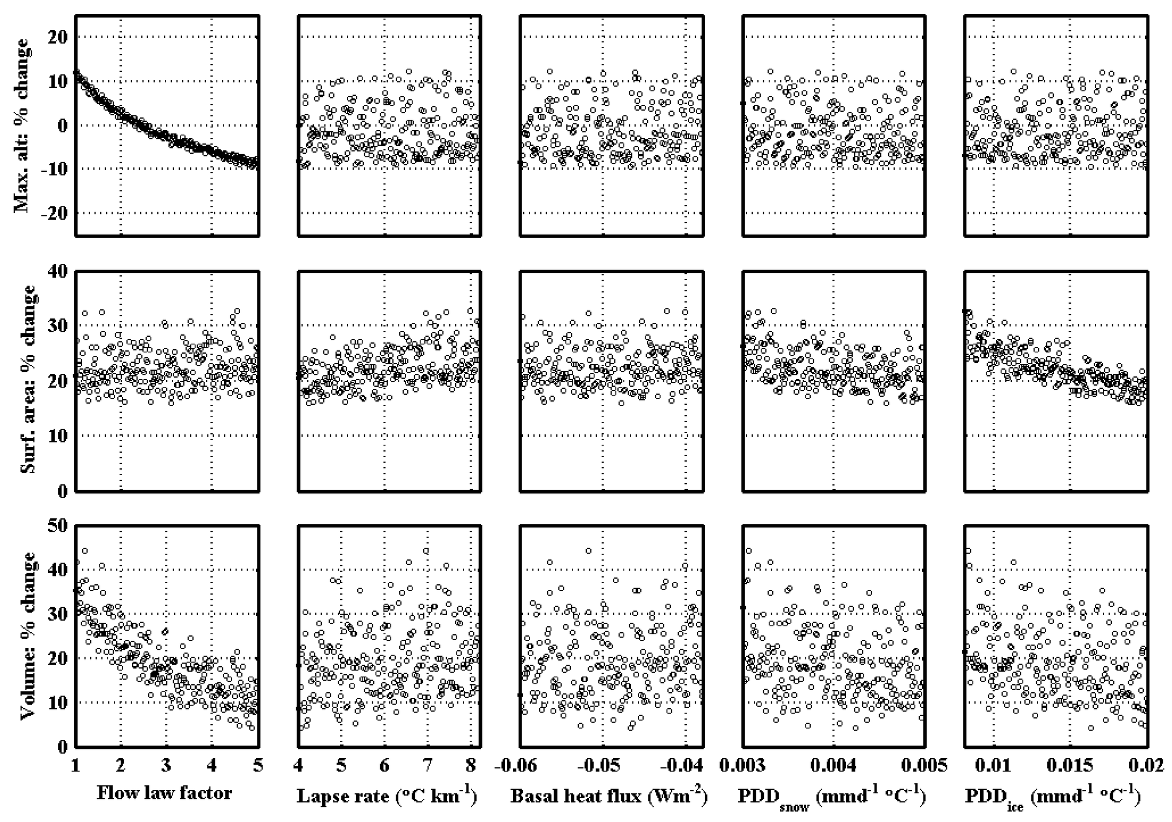
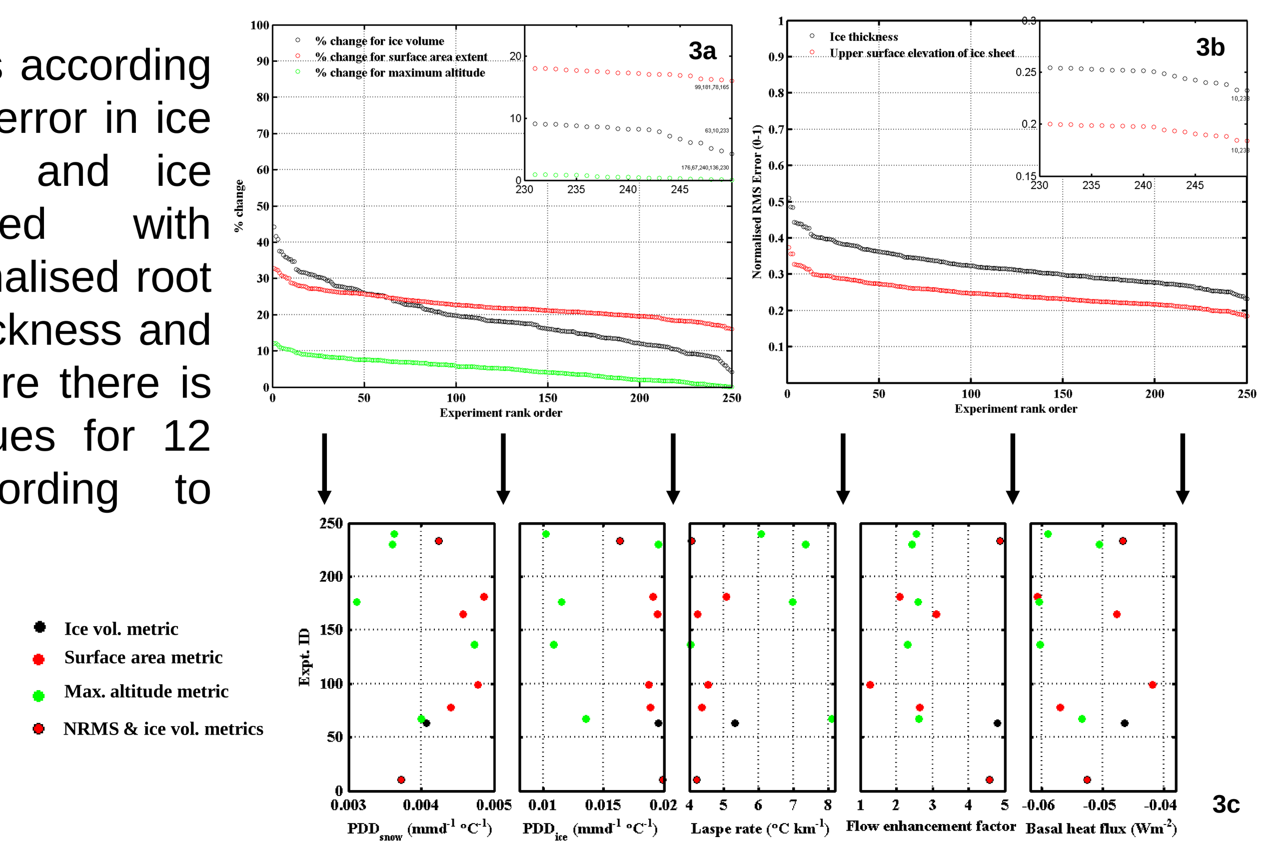


Fig.2 250 sensitivity experiments with different values of flow factor, lapse rate the basal heat flux and the snow and ice coefficients of the positive degree-day method for ablation against skill score metrics.

- **Max. altitude & ice volume dependent on flow factor**
- **Ice surface extent dependent on PDD_{ice} & lapse rate**

Fig.3 Ranking of experiments according to skill score . Fig. 3a) the error in ice volume, maximum altitude and ice surface extent compared with observation and 3b) the normalised root mean square error for ice thickness and upper surface elevation (where there is ice). Fig 3c) parameter values for 12 experiments selected according to different skill scores.



6. Conclusions

- The present modelled Greenland ice sheet is highly sensitive to the bedrock input resulting in an ice sheet volume 15.6% greater than with the EISMINT-3 bedrock.
- Results indicate that when the most up-to-date boundary conditions and forcings are used GLIMMER gives a poor representation of the modern ice sheet with an ice volume 25% greater than observations.
- Tuning using LHS shows basal heat flux is not important compared with other parameters
  - **Maximum altitude**: controlled by parameter affecting ice flow
  - **Ice surface extent**: sensitive to parameters affecting strength of ablation (PDD factors and lapse rate)
- 12 experiment setups which perform well for different skill score metrics will be used for past and future climate simulations over Greenland.

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