# The effect of more realistic forcings and boundary conditions on the geometry and volume of the Greenland ice sheet compared with EISMINT-3


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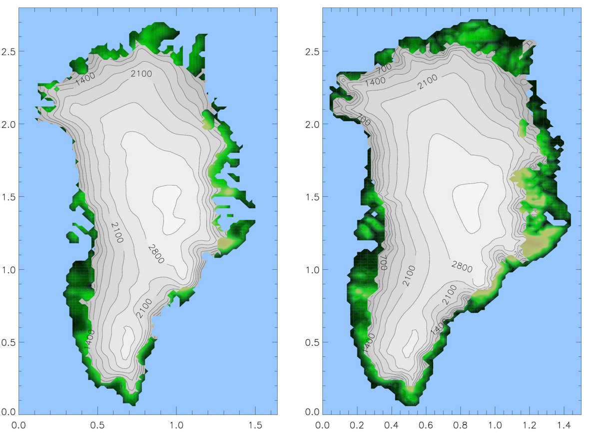
## 1. Introduction

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 (see Fig.1a) (Letreguilly *et al*., 1991). However, subsequent 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 (see Fig.1b) (Bamber *et al*., 2001). Differences between these two datasets could result in considerable impacts on the ice sheet dynamics of numerical models and ultimately the ice sheet geometry and volume. Additionally, ice sheet models are sensitive to the temperature and precipitation used to force the surface mass balance model.



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.

**Fig.1:** Observed surface topography from a) Letreguilly *et al.*(1991) and b) Bamber *et al.* (2001).

## 2. Experimental Design

GLIMMER includes a surface mass balance model, coupled ice flow, thermodynamics and ice thickness evolution and an isostatic readjustment model.

The model was 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 (see Fig.2).

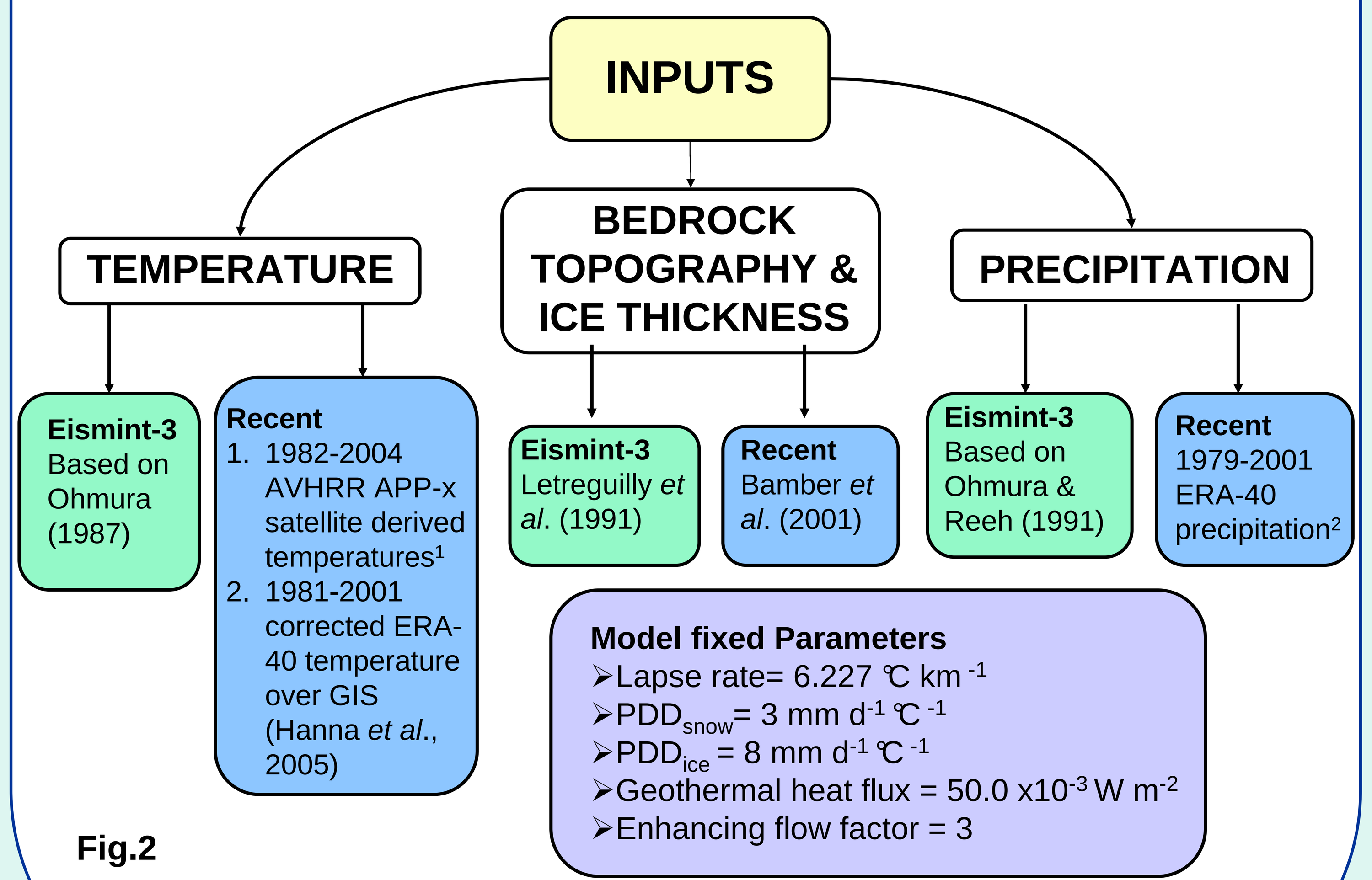
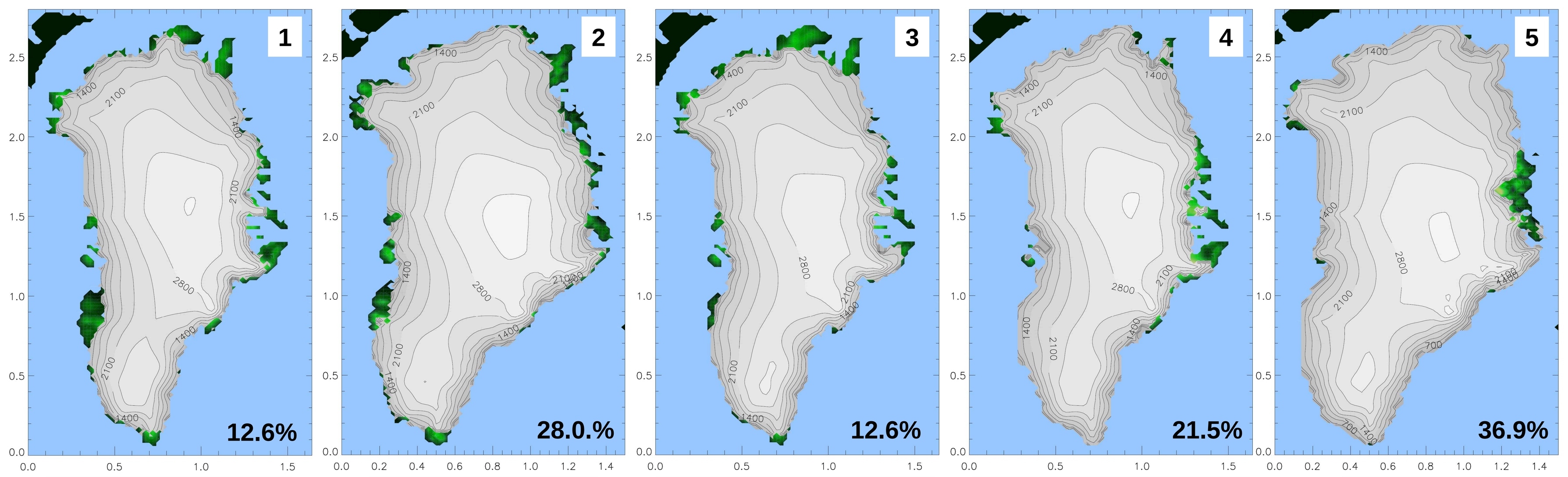



**Fig.2**

[1]The Extended AVHRR Polar Pathfinder (APP-x) Product Version 2.0,[March 2007]. Available from http://stratus.ssec.wisc.edu/products/appx/appx.html

[2]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




| | Temp | Precip | Bedrock & surface elevation | Ice volume ($\times10^6$ km$^3$) | Sea level equivalent height (m) | Area covered by ice ($\times10^6$ 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 | 3.56 (**+0.62**) | 8.97 (**+1.63**) | 2.24 (**+0.54**) | 3.14 (**−0.17**) |
| 5 | N | N | N | 4.01 (**+1.14**) | 10.25 (**+2.91**) | 2.49 (**+0.79**) | 3.25 (**−0.06**) |

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

**Fig.3 & Table 1 :** 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, whereas N refers to the more recent datasets as 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.3. The results indicate that the most recent **bedrock and surface elevation** dataset result in the largest difference when compared with observations. Precipitation has the least affect although underestimates the maximum thickness the most.

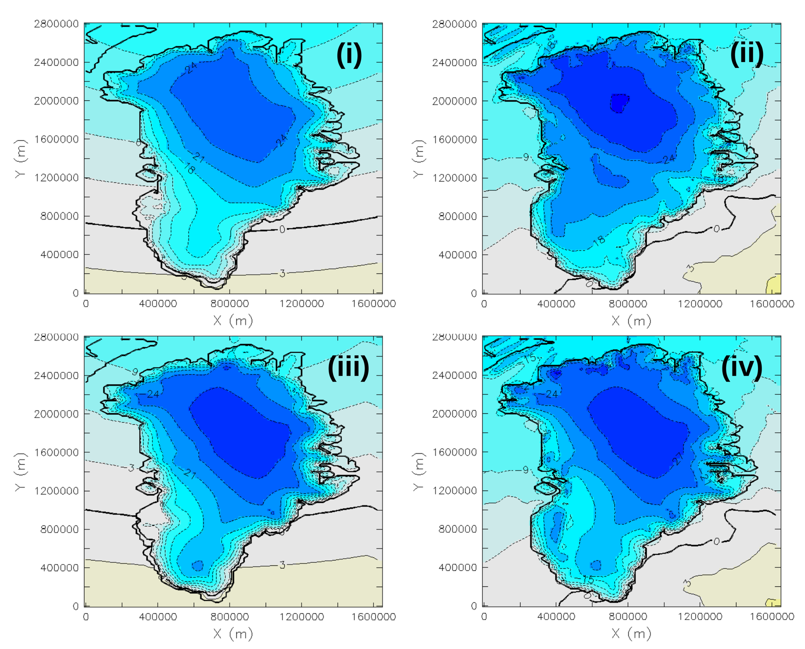



**Fig. 4b**

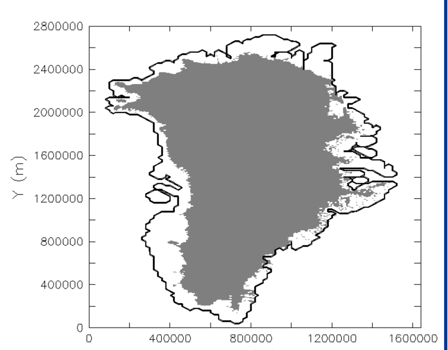


**Fig. 4a**

**Fig 4 and Table 2:** Sensitivity to different temperature forcings where (a) grey region denotes temperatures from Hanna *et al.*, (2005) and white region denotes EISMINT-3/AVHRR APP-x temperatures, (b) temperature distribution after 50kyrs and (c) Ablation rate/year over Greenland after 50kyrs for (i) EISMINT-3 forcing only, (ii) AVHRR APP-x only, (iii) EISMINT-3 & Hanna *et al.* (2005) forcing, (iv) AVHRR APP-x & Hanna *et al.* (2005) forcing. Table 2 shows that the ice sheet volume is highly dependent on surface temperatures surrounding the margins of the ice sheet rather than the temperature of the ice sheet itself, with the AVHRR APP-x temperatures resulting in almost a metre of extra sea level height. Fig.4b and 4c show that the AVHRR APP-x temperatures are colder than the threshold for ice melt over Greenland resulting in no ablation on the western margin. Although the lack of ablation can be attributed partly to a positive ice-elevation feedback the AVHRR APP-x temperatures were consistently colder than EISMINT-3 temperatures at the beginning of the experiments with no ablation occurring from the onset.

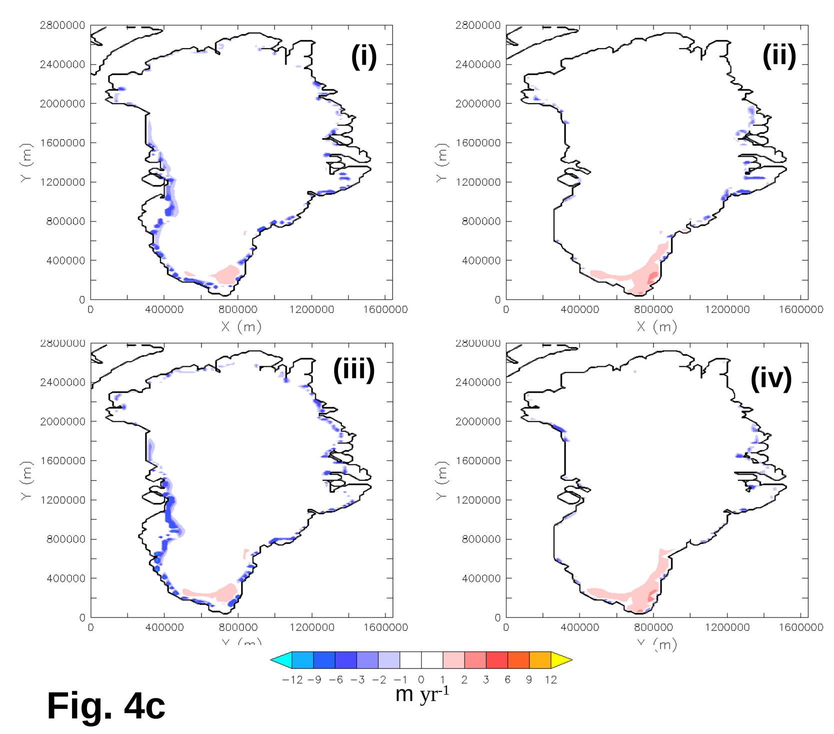



**Fig. 4c**

| | Temp | Ice volume ($\times10^6$ km$^3$) | Sea level equivalent height (m) | Area covered by ice ($\times10^6$ km$^2$) | Max. ice thickness (km) |
|---|---|---|---|---|---|
| (iii) | EISMINT-3 & ERA-40 | 3.30 (**+0.38**) | 8.31 (**+0.97**) | 2.02 (**+0.32**) | 3.15 (**−0.17**) |
| (iv) | AVHRR APP-x & ERA-40 | 3.59 (**+0.66**) | 9.05 (**+1.71**) | 2.28 (**+0.58**) | 3.15 (**−0.17**) |

**Table 2**

**Values in brackets are differences relative to observations in Table 1. Corresponding values for (i) and (ii) are [1] & [4] respectively in Table 1.**

## 4. Discussion & Conclusions

- The present modelled Greenland ice sheet is highly sensitive to the bedrock input resulting in an ice sheet volume 13.6% greater than with the EISMINT-3 bedrock.
- **The 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 37% greater than observations. This new dataset will be tuned in order to produce a reasonable best fit between modelled and observed geometry (see section 5).**
- Temperature sensitivity studies have shown that the surface mass balance is particularly sensitive to the temperature surrounding the margins of the ice sheet.
- This work highlights the need to assess carefully future and past Greenland ice sheet modelling results in terms of the forcings and boundary conditions applied.

## 5. Future Work

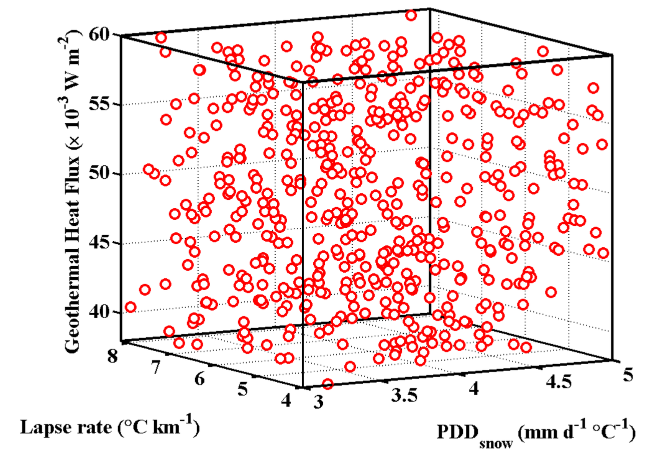
Several parameters are not well constrained in large-scale ice sheet modelling and can influence ice sheet volume and extent. EISMINT-3 and the more recent input datasets will be tuned using the statistical method of Latin-Hypercube sampling which generates a distribution of plausible parameter sets within a prescribed set of ranges.

**Aim-** to determine a set of parameters which give the best-fit between modelled and observed geometry for present day conditions by looking at:
1. Ice volume
2. Surface area covered by ice
3. Maximum ice thickness
4. Sea level equivalent height.

| 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 | **1.5** *Weertman (1973)* | **5** *Dahl-Jensen & Gundestrup (1987)* |
| Geothermal heat flux ($\times10^{-3}$ W m$^{-2}$) | **38** *Dahl-Jensen & Johnsen (1986)* | **60** *Lee (1970)* |
| Near surface lapse rate (°C km$^{-1}$) | **4.0** *Steffen & Box (2001)* | **8.2** *Steffen & Box (2001); Hanna et al. (2005)* |

**Table 3:** Outline of the five parameters to be varied according to the ranges shown based on literature. The $PDD_{snow}$, $PDD_{ice}$, geothermal heat flux and enhancement flow factor ranges are similar to those used in the study of Ritz *et al.* (1997).

**Fig.5:** Example of 250 sensitivity experiments generated using Latin-hypercube sampling showing geothermal heat flux, lapse rate and $PDD_{snow}$. Each experiment (represented by a red circle) has an additional associated $PDD_{ice}$ and enhancement flow factor value. This method ensures that parameter space is covered sufficiently and builds on the method used in Ritz *et al.* (1997) where each parameter is varied individually.

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