

A Study of Glacial Isostatic Adjustment in Greenland.

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Introduction

Glacial isostatic adjustment (GIA) is the viscoelastic response of the Earth caused by changes in ice loads during glaciations and deglaciations. Knowledge of the GIA signal is particularly important in cryospheric applications of satellite gravimetry and altimetry, where the origin of the observed changes must be separated into past and present response.

Modeling the present-day GIA signal must include knowledge of both the ice loading history and the Earth's rheology. Neither of these models are well constrained in Greenland, and hence the GIA estimates here are uncertain.

We have implemented a loading history of the Greenland Ice Sheet derived from the ice sheet model SICOPOLIS and we have studied the present-day vertical crustal motion derived from using this ice history. The results are compared with those derived from the widely used ICE-5G ice history.

For calculation of the present day GIA signal, we assume the Earth's rheology to be a simplified version of the VM2 Earth model. The calculated GIA signal in Greenland, derived from the two ice loading histories are compared with geodetic measurements of vertical crustal motion from GPS time series corrected for present-day ice mass changes.

The freely available code SELEN is used to calculate the effects of the Earth model and the different ice loading histories. This study is performed within the Working Group 4 of the ESF COST Action ES0701 "Improved constraints on models of Glacial Isostatic Adjustment".

Ice models

The ice loading histories used for this study are derived from the ICE-5G model (Peltier, 2004) and the thermomechanical ice flow model SICOPOLIS (Greve, 1997). The ICE-5G is a global ice sheet reconstruction consistent with isostatic rebound of the earth and sea level records. The SICOPOLIS model simulates ice volume of the Greenland Ice Sheet over two glacial-interglacial cycles by forcing the model with climate that is based on surface temperature records from the GRIP and Vostok ice cores and interpolation between the present climatic conditions and the Last Glacial Maximum climate anomalies (Greve, 2005). The two ice loading histories from 20 ky BP until present are used to compute present day uplift rates for Greenland with the code SELEN (Spada and Stocchi, 2007). The figures below show the difference in ice thickness between the two ice loading histories, ICE-5G and SICOPOLIS, at a few time steps. Starting from 9 ky BP the two models show different trends in ice thickness variation, mostly at the ice margin.

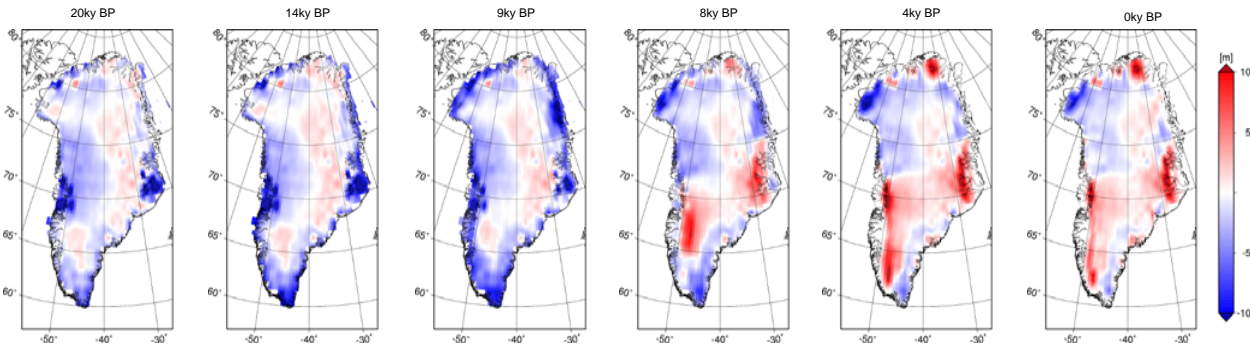


Figure 1. Snap shots of the thickness difference between the SICOPOLIS and ICE-5G ($\Delta H = H_{SICOPOLIS} - H_{ICE-5G}$) resulting from the two ice loading histories. It is clearly seen that starting from 9ky BP the two ice histories show very different ice thickness variation.

Data

To validate the ice model we use available GPS data (Khan et al. 2008). The uplift rate for Nuuk is derived from tide gauge data.

The uplift rate from present day ice mass changes has been removed. The data spans 96-08 (Kellyville, Thule, Kulusuk), 98-08 (Scoresbysund), 02-08 (Qaqortoq) and 94-04 (Nuuk).

GPS station	Vert. uplift rate
Kellyville	-1.2 ± 1.1 mm/a
Thule	3.6 ± 1.1 mm/a
Scoresbysund	0.0 ± 1.1 mm/a
Kulusuk	-0.4 ± 1.1 mm/a
Qaqortoq	-0.3 ± 1.1 mm/a
Nuuk	-2.2 ± 1.3 mm/a

Table 1. Rate of vertical uplift from 6 permanent GPS stations.

Rate of vertical uplift today - GREENLAND

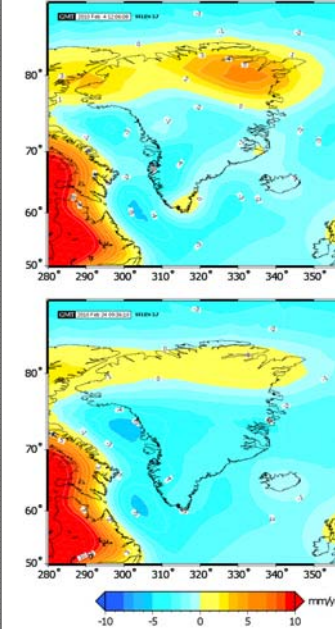


Figure 2. Vertical uplift rate from ICE-5G (top) and SICOPOLIS (bottom) ice loading histories

Results

The present the uplift rate is obtained using the SELEN code (Spada and Stocchi, 2007). The figures show the rate of the vertical movement using the ICE-5G (top) and the SICOPOLIS (bottom) ice loading histories for Greenland.

The Earth model used for the calculations is the VM2 model, a three layered averaged PREM model with a lithosphere of 90km. The viscosities of the lithosphere, upper and lower mantle are 0.4, 0.4 and 4.0 x 10²¹ Pa-s, respectively.

The largest difference is in the North and Southeast Greenland. The uplift rate derived from the SICOPOLIS ice loading history is lower, which is a result of the slower changing ice volume.

GPS station	SICOPOLIS	ICE-5G
Kellyville	-4.4 mm/a	-3.9 mm/a
Thule	-0.9 mm/a	2.3 mm/a
Scoresbysund	-2.5 mm/a	-0.2 mm/a
Kulusuk	-2.9 mm/a	-0.9 mm/a
Qaqortoq	-2.7 mm/a	0.9 mm/a
Nuuk	-4.1 mm/a	-3.7 mm/a

Table 2. Vertical uplift rate from the ICE-5G and SICOPOLIS ice histories at 6 locations

Conclusions

Due to the fact that Greenland is still covered with ice, the number of uplift measurements is very limited. This means that the ice loading history of the Greenland Ice Sheet is poorly constrained. We show that present day uplift rate based on the two different ice histories (ICE-5G and SICOPOLIS) give different patterns of present-day uplift rate. The difference in the ice thickness (Figure 1) shows significantly different ice volume evolution starting from 9 ky BP. SICOPOLIS has thicker ice in some areas compared to ICE-5G from 8 ky BP until present, this results in a larger present day rate of subsidence (see Table 2).

We find that the GIA signal from neither of the ice loading histories agrees with the GPS derived uplift rate, which highlights the need for further studies in this region in order to better constrain the ice loading histories as well as present and future sea level change in this region.

References

- Greve, R. 1997. Application of a polythermal three-dimensional ice sheet model to the Greenland ice sheet: response to steady-state and transient climate scenarios. *J. Climate*, 10(5), 901-918
- Greve, R. 2005. Relation of measured basal temperatures and the spatial distribution of the geothermal heat flux for the Greenland Ice Sheet. *Annals of Glaciology*, 42, 424-432
- Khan et al., *Geodetic measurements of postglacial adjustment in Greenland*, *J. of Geo. Rev.*, Vol.113, 2008.
- Peltier, W.R., 2004. *Global glacial isostasy and the surface of the ice-Age Earth: the ICE5G(VM2) model and GRACE*. *Ann. Rev. Earth Pl.*
- Spada, G. and Stocchi P., 2007. *SELEN: A Fortran 90 program for solving the "sea-level equation"*, *Comp. & Geo. Sci.*, Vol 33.