

Implications for the lithospheric structure of Greenland by applying different heat flow models

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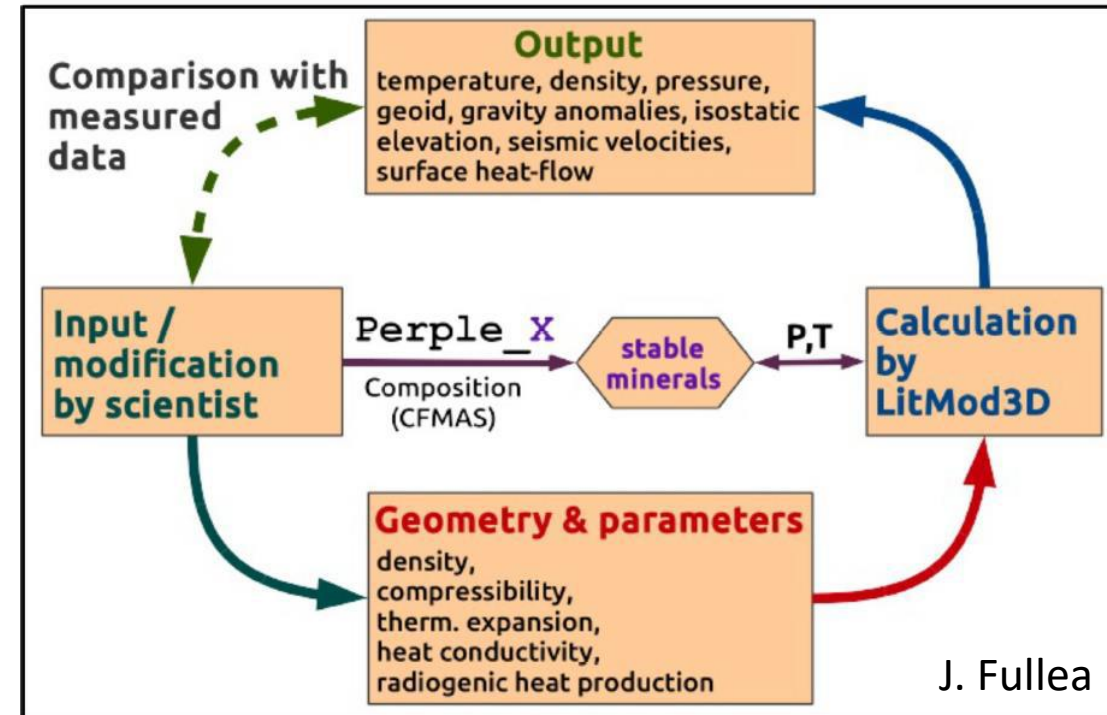
Introduction

- Greenland's geothermal heat flow (GHF) is an important parameter for the assessment of the development of the Greenland ice sheet
- GHF is dependent on the underlying lithospheric architecture, e.g. the Moho and LAB depth as well as the thermal crustal parameters, but measurements of GHF in Greenland are sparse and Greenland's lithosphere is only poorly constrained
- we examine the lithospheric implications from **three different GHF** estimates by building 3D models which reproduce the GHF from these three estimates
- these 3D models include besides the **thermal field** also a **density** and **velocity structure**, thus the gravity signal of the model and the isostatic topography can be calculated
- in the end we are able to evaluate which of the three GHF estimates has the least contradictions with the measured satellite gravity data and the observed topography

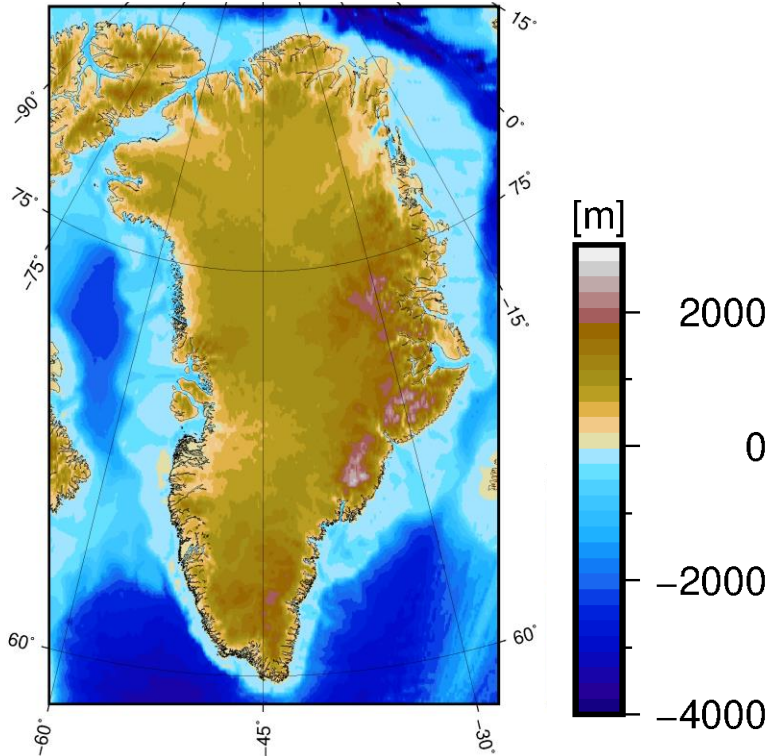
Method

- geophysical-petrological modelling with LitMod3D (Fullea et al. 2009)
 - modelling is done in a self-consistent thermodynamic framework
 - mantle density & velocities are defined by their geochemical composition
 - LAB depth is defined as 1315 °C isotherm
 - the models are adjusted to reproduce the observed topography & gravity as well as the GHF estimates
 - range from topography to 400 km depth
- the LAB depth controls the thermal field
 - we adjusted the LAB depth to reproduce the GHF
 - the Moho depth was adjusted to minimize the residual for the isostatic elevation and the vertical gravity gradient V_{uu}

LitMod3D

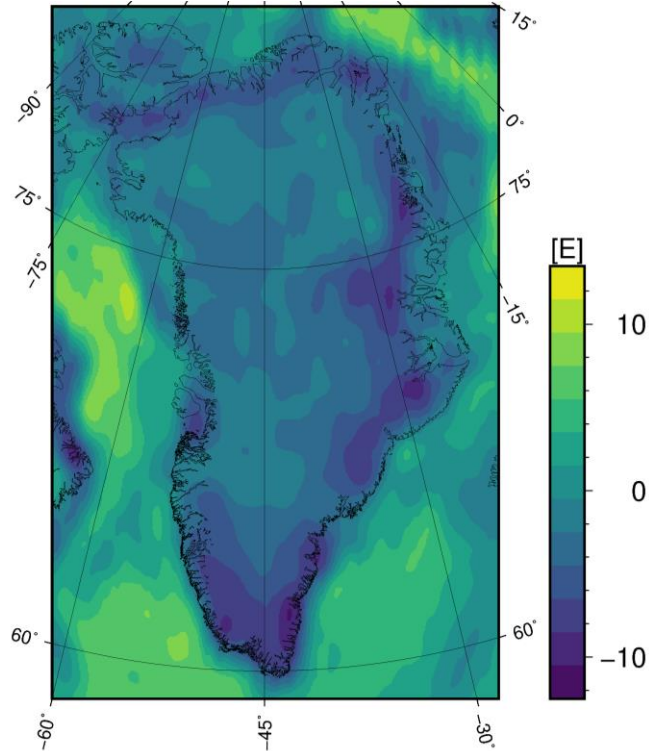


Equivalent Topography



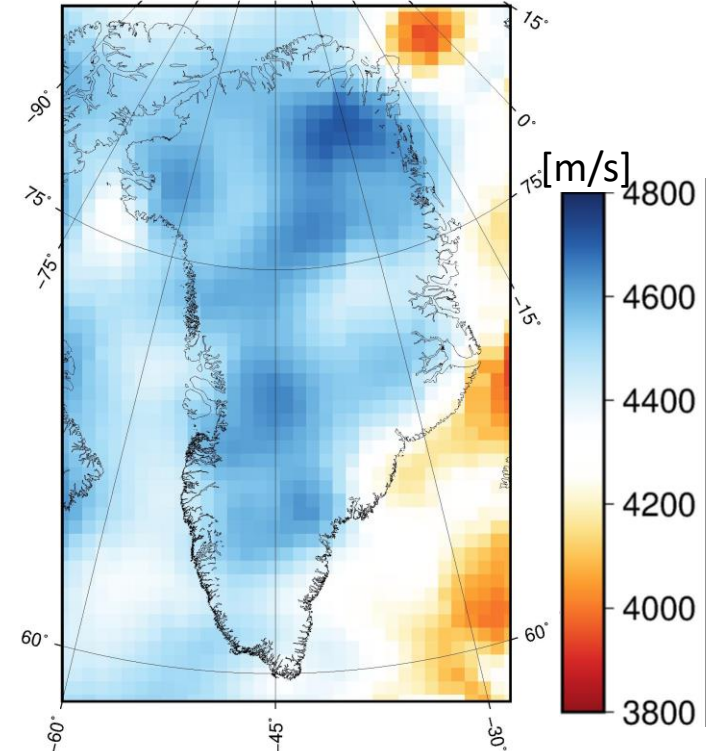
- loading effect of the ice is converted to bedrock elevation
- combination of Bedmachine v3 (Morlighem et al. 2017) and Etopo1 (Amante & Eakins 2009)

V_{uu}



- the vertical gravity gradient component from XGM2019 at 50 km height, corrected for topography, bathymetry and ice

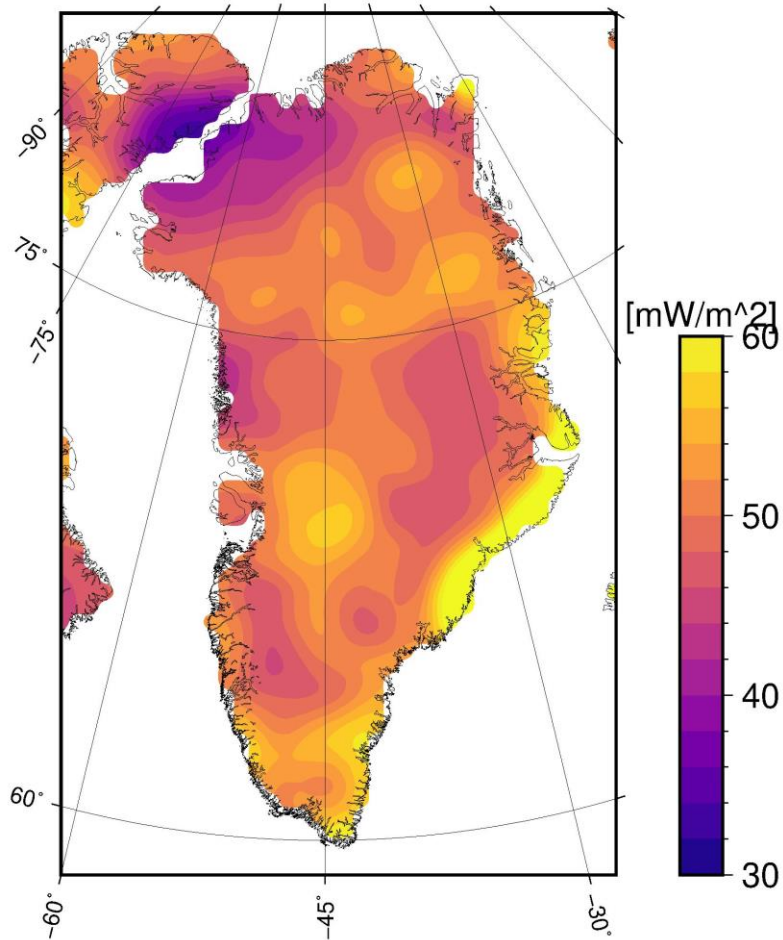
V_s at 80 km



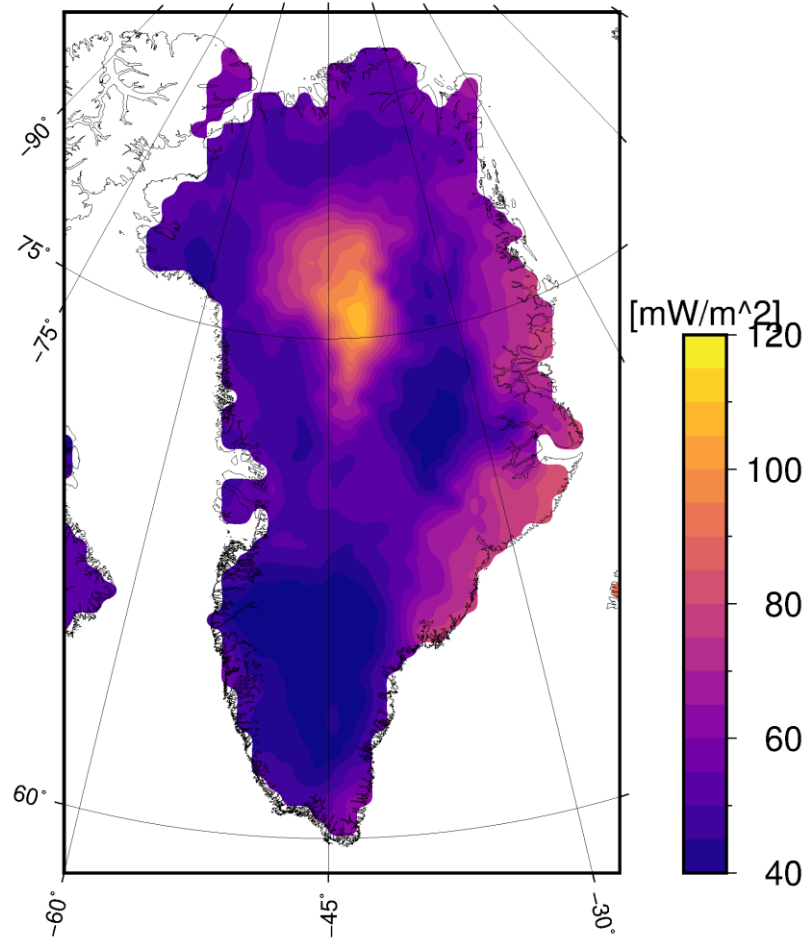
- the tomography model NAT2020 (Celli et al. in prep)

GHF models which are used as modelling targets

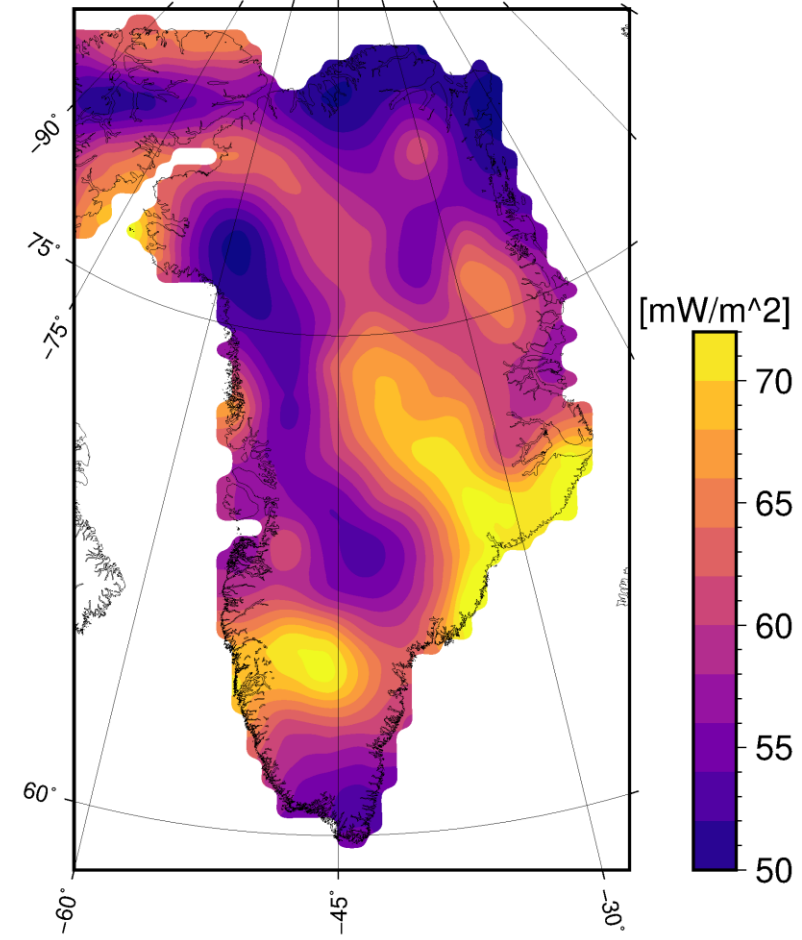
GHF from NAT2020



GHF Lösing

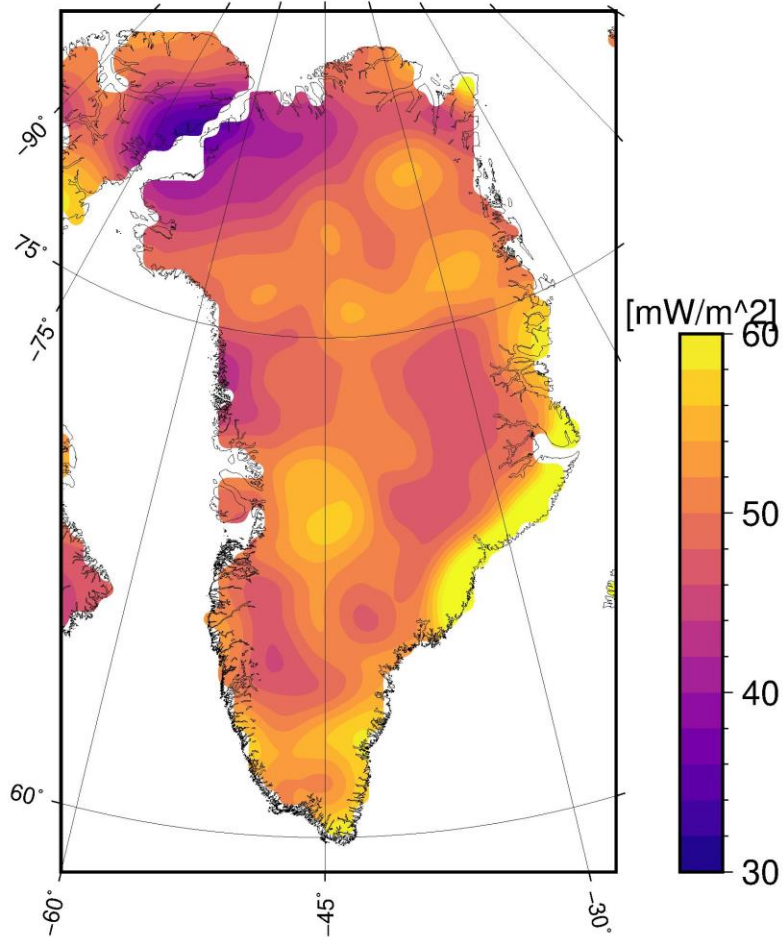


GHF Martos et al. 2018



please note the different colormap ranges

GHF from NAT2020



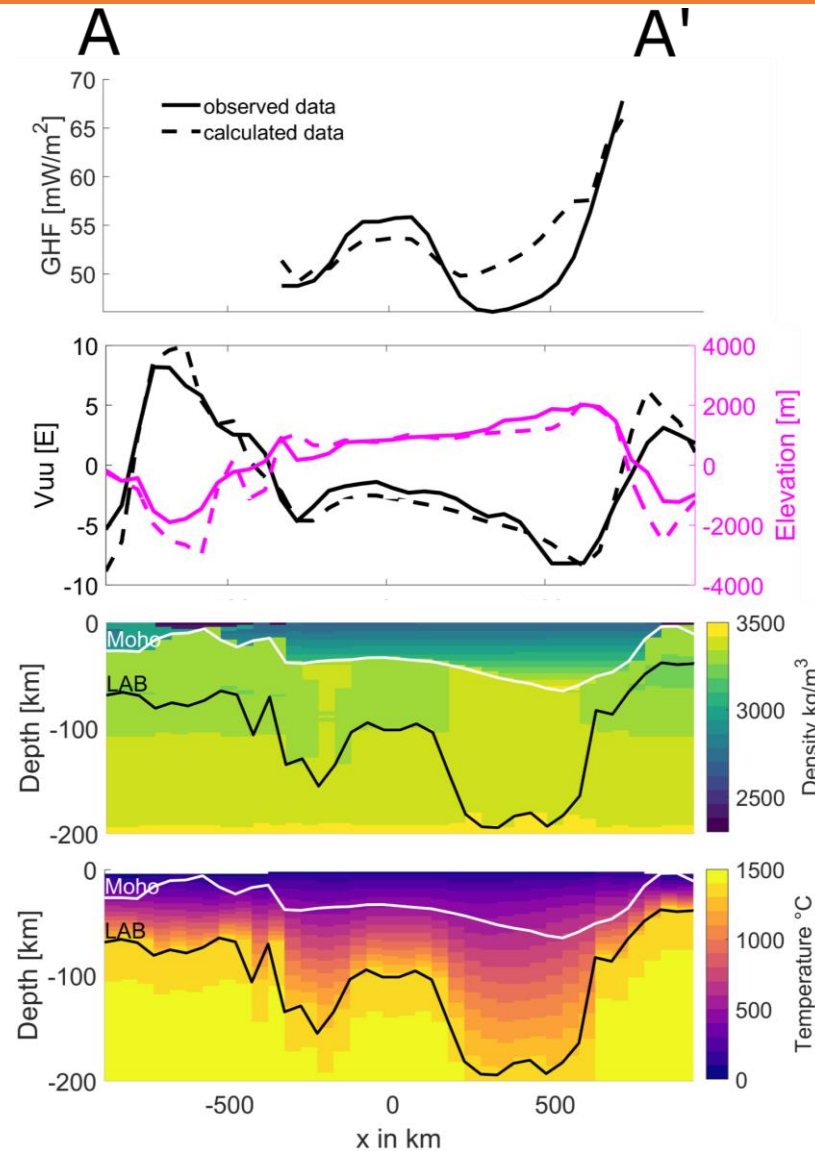
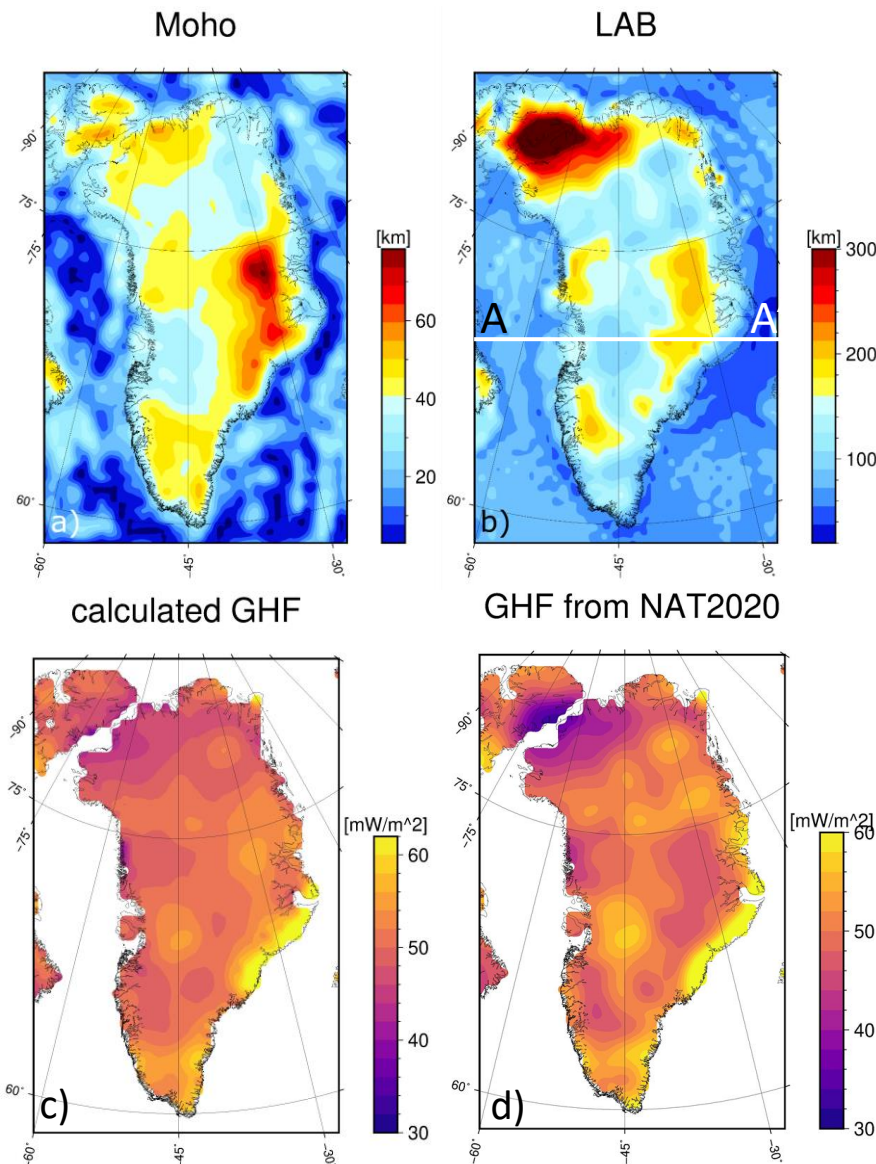
- GHF calculated from a comparison of the velocity structure in Greenland (NAT2020 tomography) with the velocity structure in the US
 - based on observed correlation between the shear wave velocities and the measured GHF in the US
 - calculate a similarity function S & take weighted mean of GHF values from best 0.5% of most similar points

$$S(r1, r2) = \frac{\int_{z=H+5}^{150 \text{ km}} (V1(z) - V2(z))^2 dz}{145 - H}$$

$r1, r2$... points in Greenland & the US
 H ... maximum Moho depth from $r1$ & $r2$
 z ... depth [$H+5$ km – 150 km]
 V .. shear wave velocity

- follows method from Shen et al. 2020

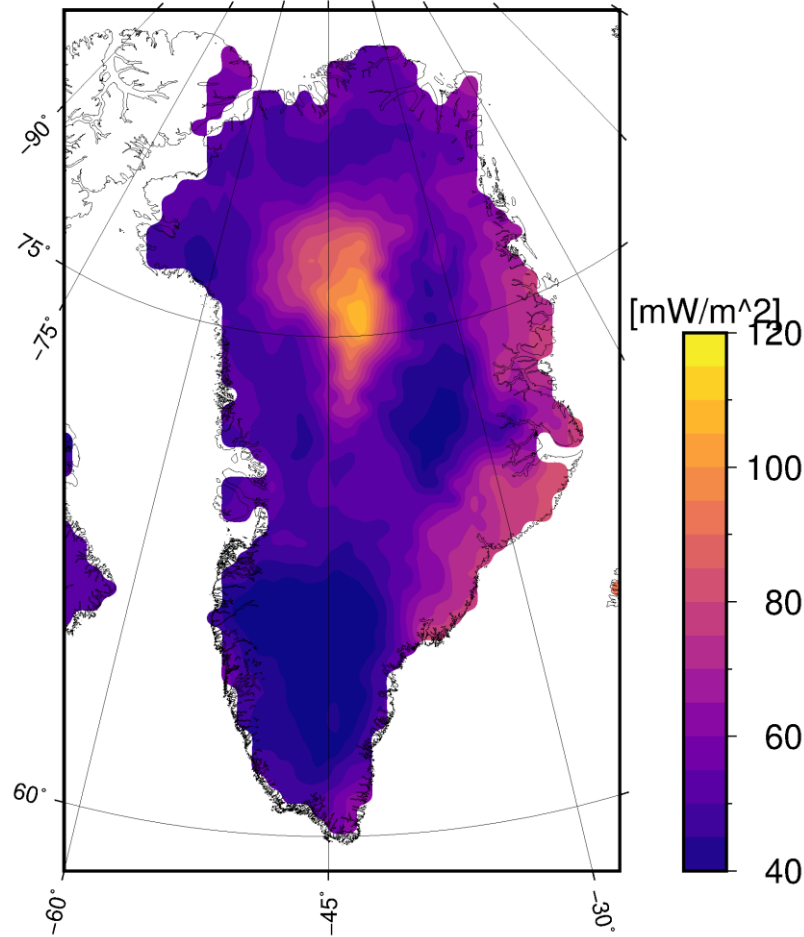
Reproduce GHF from NAT2020 – results



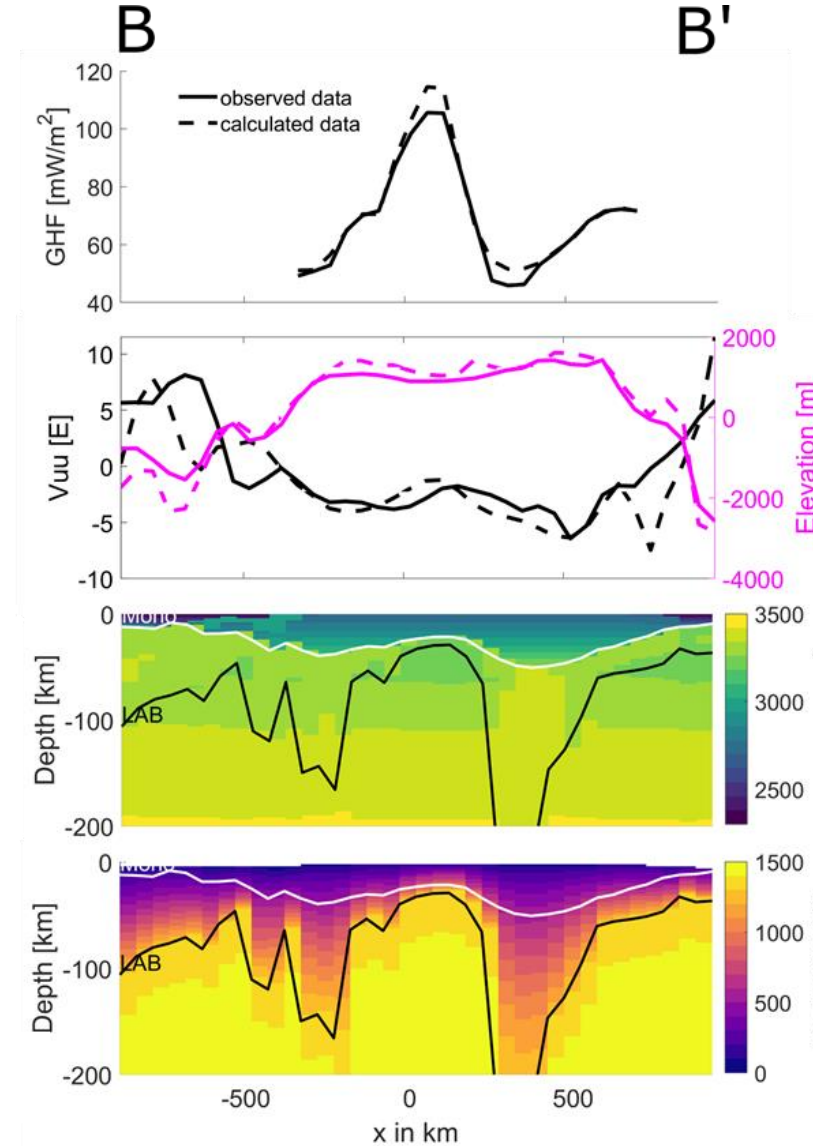
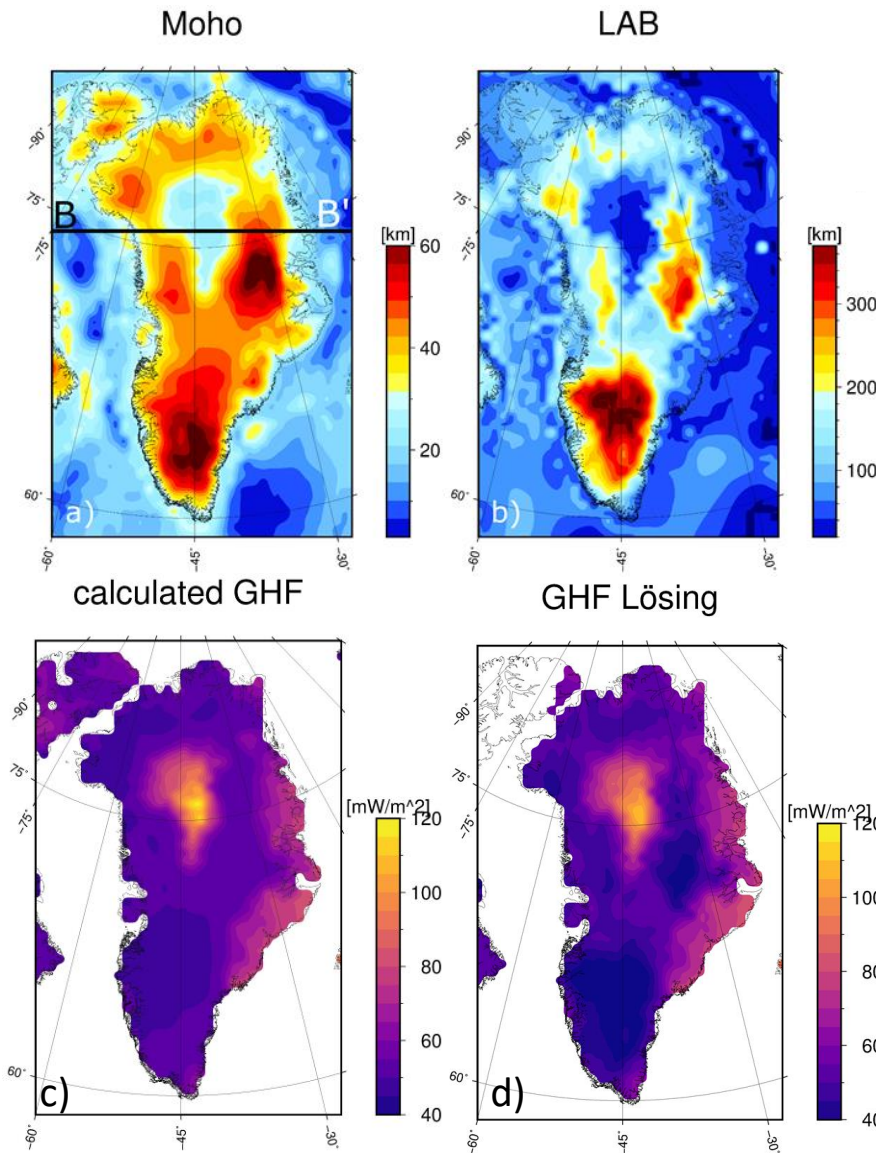
- coldest area in NW with 40 mW/m² → 340 km LAB depth, could be shallower with less radiogenic heat production in this area
- W-E cross-section shows the observed vs. the modelled GHF as well as V_{uu} and topography
- pattern of Moho and LAB depth are mostly similar (deep Moho depth in places with a deep LAB depth)

- GHF from **machine learning** with xgboost
- uses a variety of features:
 - Moho depth
 - LAB depth
 - Topography
 - mean curvature (from gravity gradients)
 - Susceptibility
 - vertical magnetic field
 - tectonic regionalisation
 - distance to ridge, volcano, trench, transform fault & young rifts

GHF Lösung



Reproduce GHF machine learning Lösung – results

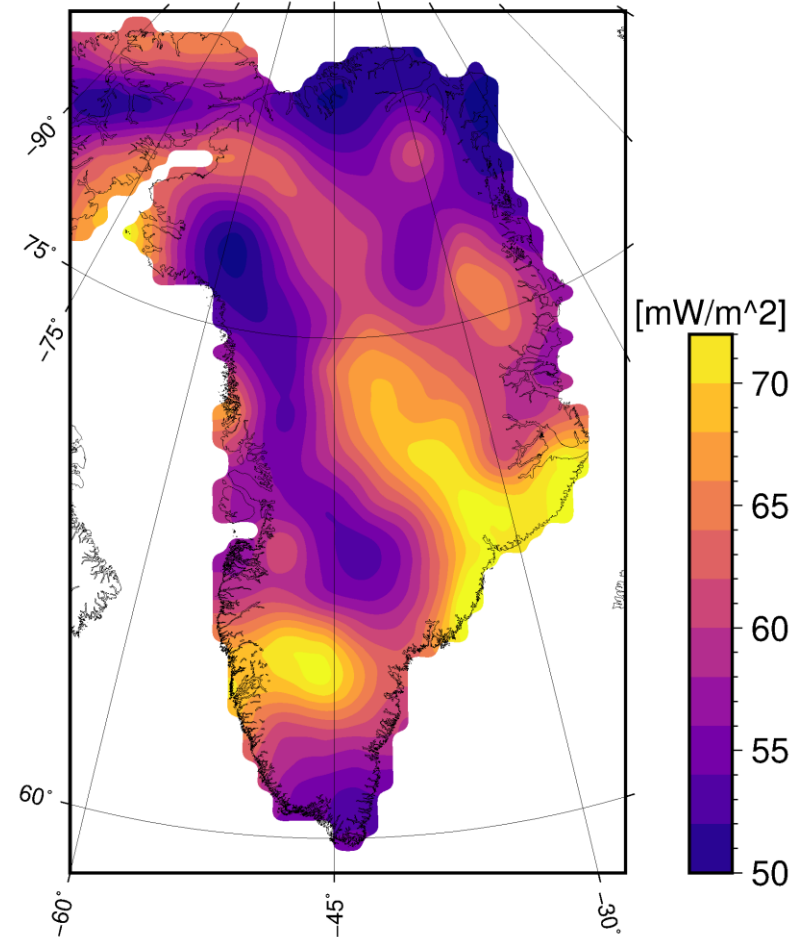


- high HF in central Greenland from NGRIP station → 60 km LAB depth
- thick lithosphere in south Greenland because of low GHF
- low HF values hard to model because we limit max. LAB depth
- cross-section shows steep LAB topography
- pattern of Moho and LAB depth are similar

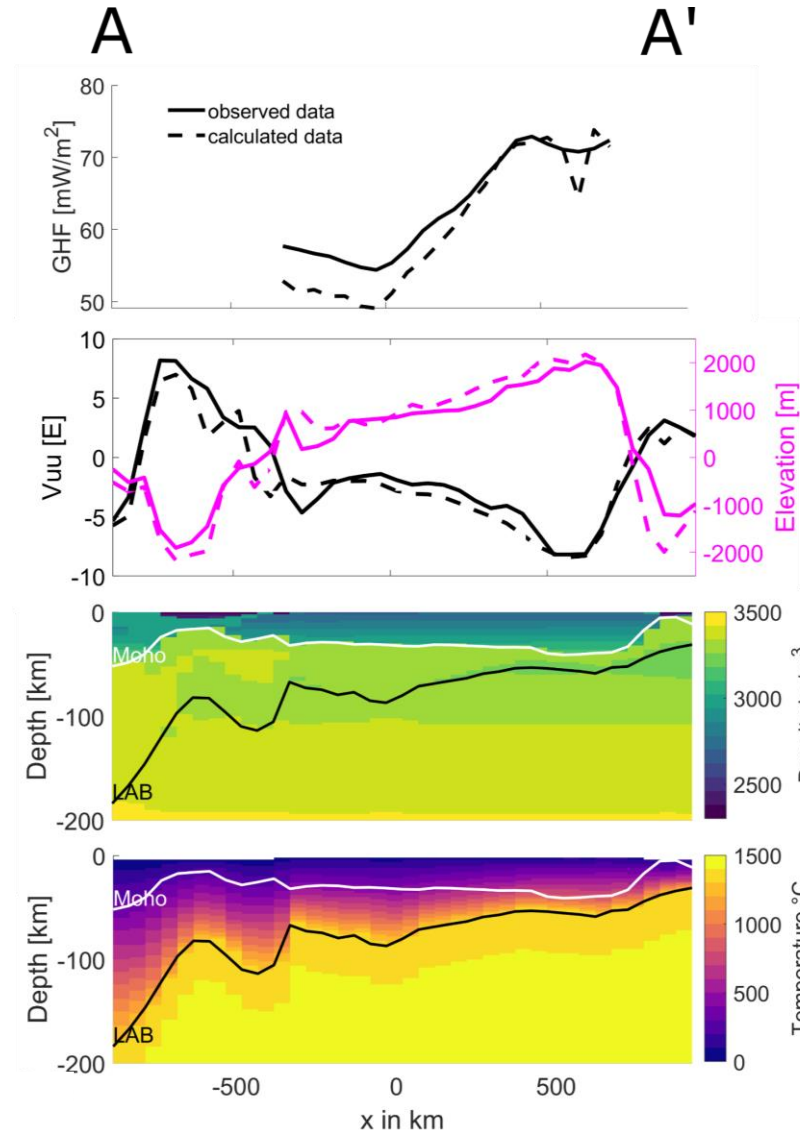
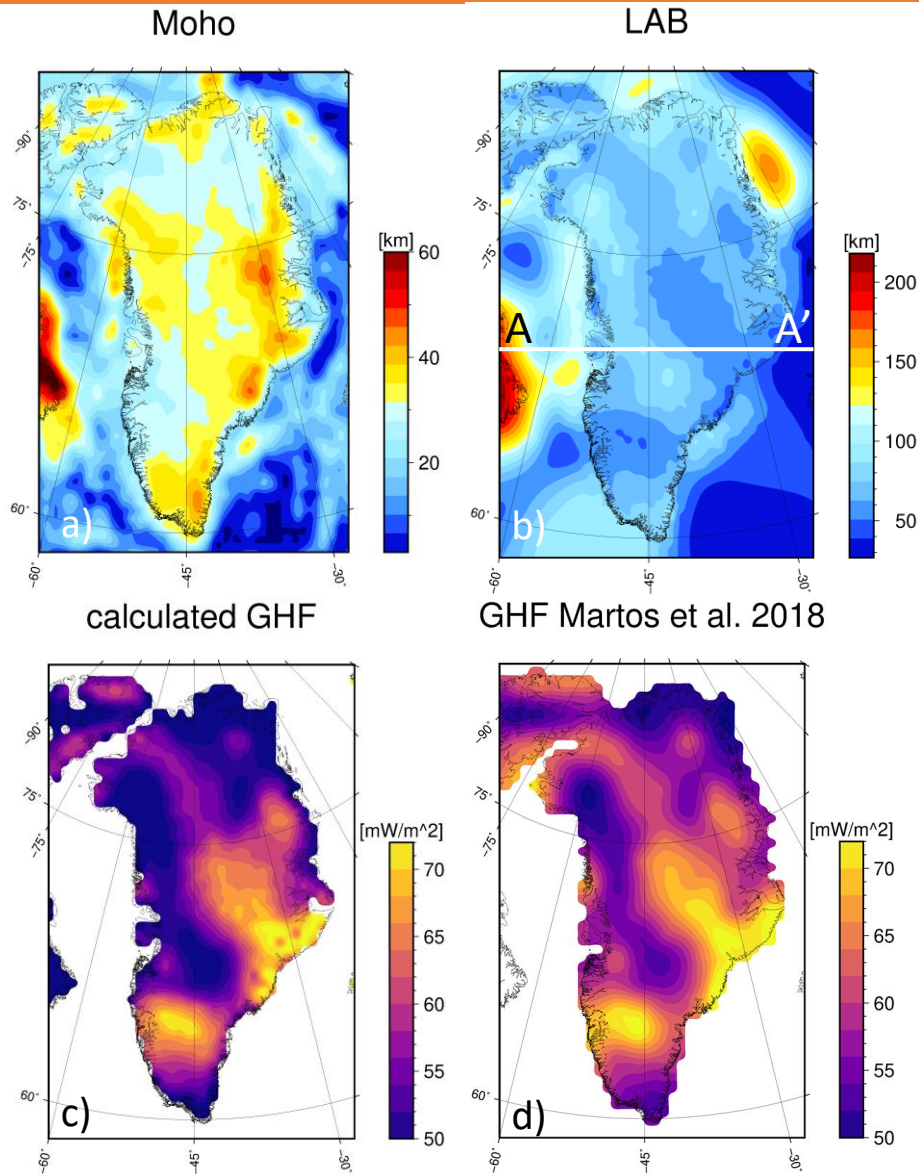
GHF from Martos et al. 2018

- estimation of the Curie depth with a spectral analysis of the World Digital Magnetic Anomaly Map2
- with the assumption that the Curie depth corresponds with the 580 °C isotherm :
 - calculation of the GHF with a thermal model

GHF Martos et al. 2018



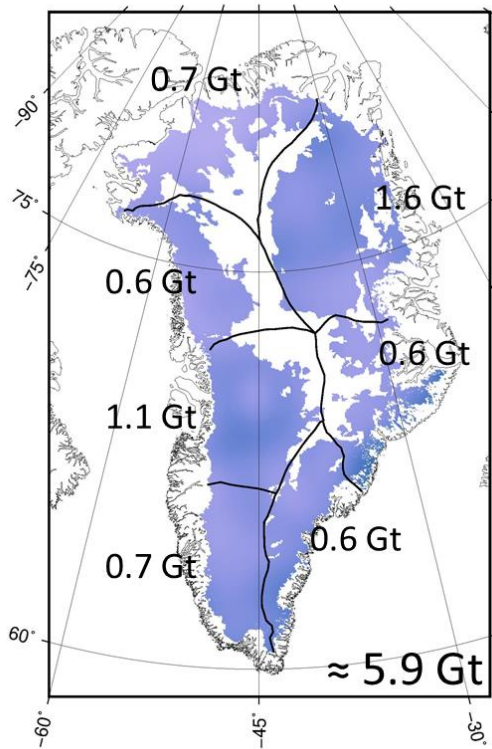
Reproduce Curie depth Martos et al. 2018 – results



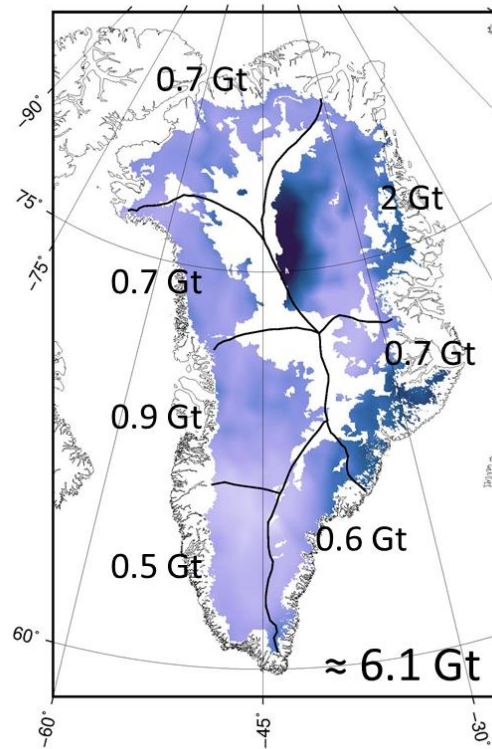
- shallow LAB depth in south & central east Greenland to generate high GHF values
- no high correlation between Moho and LAB depth → extremely thin SCLM in east Greenland
- LAB depths of 60 km for south Greenland are inconsistent with the cratonic age of the region

Basal melt rates according to the GHF models

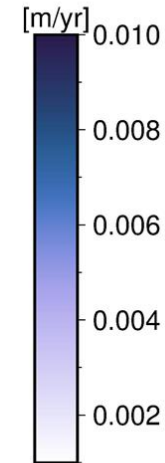
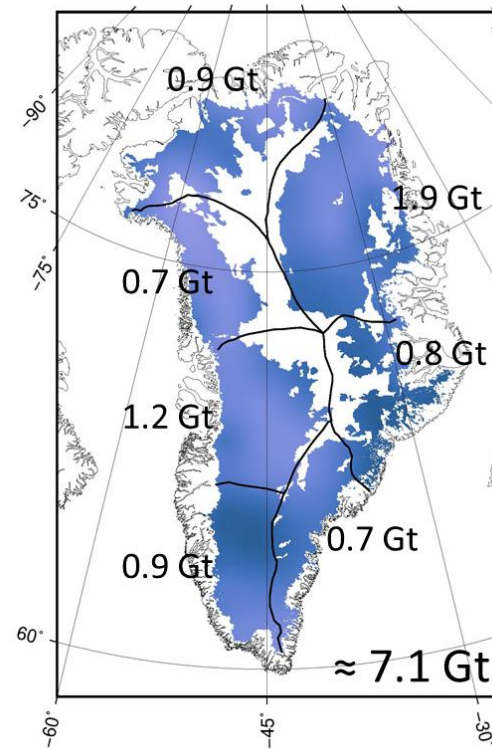
from tomography NAT2020



Lösing et al. in prep



Martos et al. 2018



- three contributions to the basal melt: friction heat, **geothermal heat flow** and viscous heat dissipation
- the total mass loss as well as the individual mass loss for the seven major drainage regions (according to White et al. 2016) depends on the GHF model
- areas considered as frozen at the bed – ice interface are blanked out (MacGregor et al. 2016, modified)

Discussion

- it is possible to build lithospheric models for all three GHF estimates, but:
 - the model to fit the GHF from Martos et al. 2018 has an uncommon shallow LBA depth and thin subcontinental lithospheric mantle
 - the model to fit the machine learning GHF exhibits an unusual steep LAB topography around the elevated heat flow which is caused by the North Grip station in central north Greenland
 - the one from the tomography model NAT2020 is the least controversial, the LAB and Moho depth are reasonable
- depending on the considered model the basal melt mass loss from GHF for one year in Greenland varies between 5.9 to 7.1 Gt with the assumption of a partly frozen ground and between 8.0 to 9.6 Gt without this assumption
- with a currently estimated complete mass loss of the Greenland ice sheet of 222 Gt per year (The IMBIE Team., Shepherd, A., Ivins, E. *et al.* 2020) it might not seem to be important which GHF model to choose for the total estimate of mass loss but depending on the pattern of GHF the local occurrence of basal melt changes which influences the behaviour of the ice sheet

Outlook & further reading

- we plan to further constrain the crustal parts of the model with airborne magnetic data and a joint inversion of gravity and magnetic data
- William Colgan and colleagues work on a new GHF database for Greenland, we will recalculate the GHF from machine learning with this new database and include local features for Greenland
- the paper from Karlsson et al. about the basal melt estimation for Greenland is available as preprint here: <https://eartharxiv.org/repository/view/151/> , their EGU presentation can be found here: <https://meetingorganizer.copernicus.org/EGU21/EGU21-7304.html>
- Lösing et al. work on GHF estimations with machine learning in Antarctica: <https://meetingorganizer.copernicus.org/EGU21/EGU21-5764.html>

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