Magnetotelluric Constraints on Upper Mantle Viscosity Structure and Basal Melt Beneath the Greenland Ice Sheet

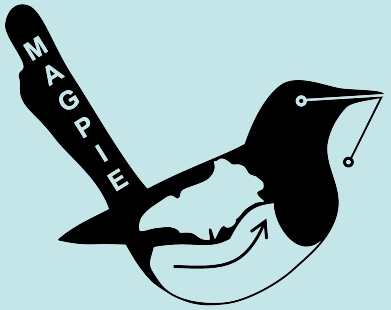
Clinton P. Conrad[1] Kate Selway[2] Maaike Weerdesteijn[1]
Silje Smith-Johnsen[3] Kerim Nisancioglu[3] Nanna B. Karlsson[4]

[1] Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Norway
[2] Department of Earth and Planetary Sciences, Macquarie Univeristy, Australia
[3] Bjerknes Centre for Climate Research, University of Bergen, Norway
[4] National Geological Survey of Denmark and Greenland, Denmark

The MAGPIE Project

Magnetotelluric Analysis for Greenland & Postglacial Isostatic Evolution

An international research project to constrain glacial isostatic adjustment (GIA) processes in Greenland.



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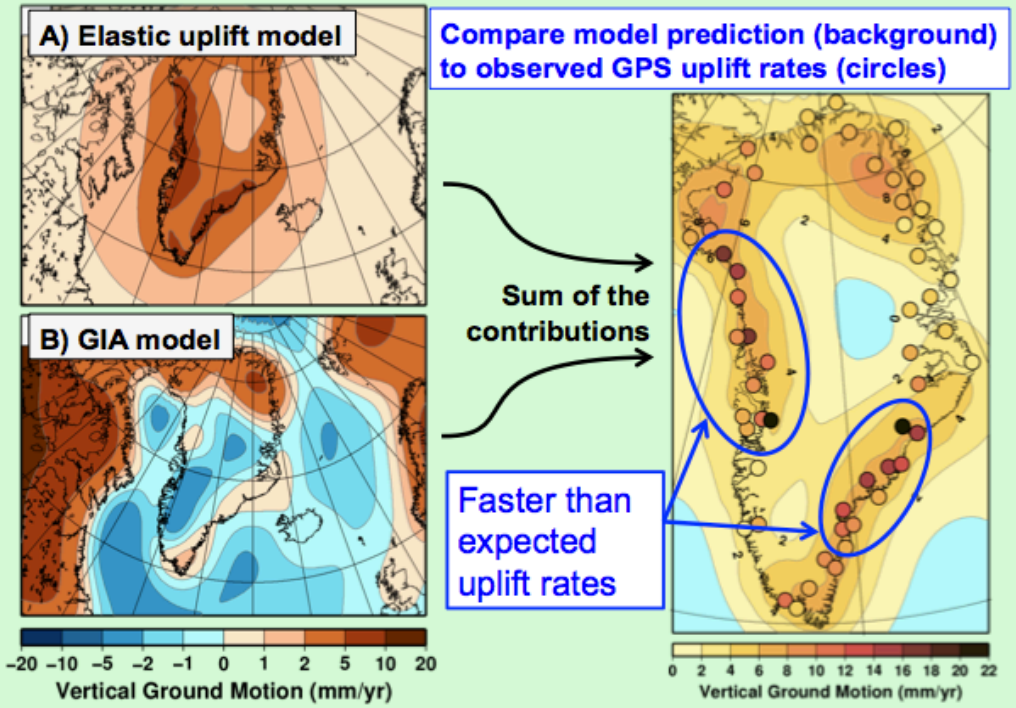
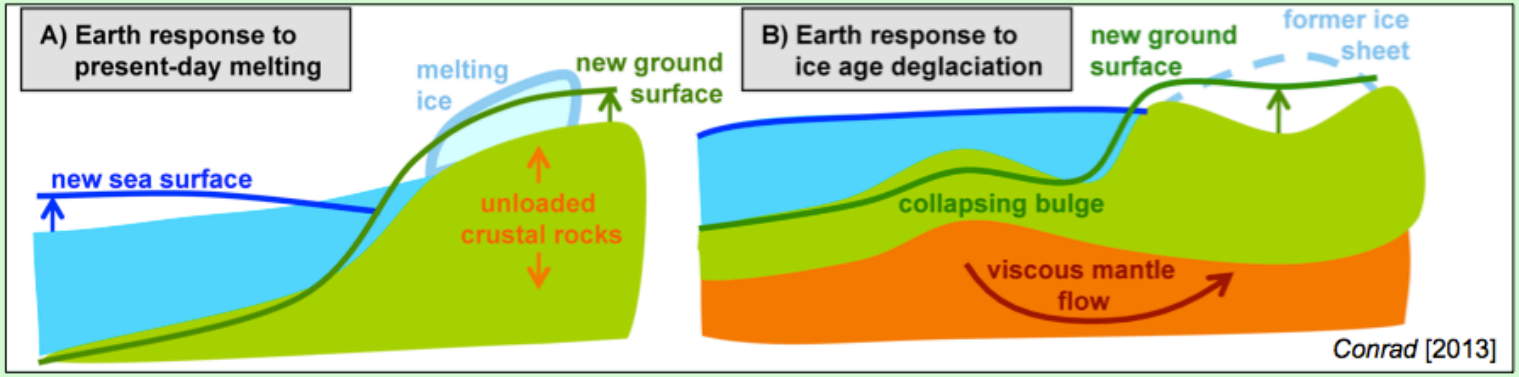
Introduction

Vertical land motion in Greenland is caused by two processes:

A. Earth's elastic response to present-day deglaciation
B. Earth's glacial isostatic (GIA) response to past deglaciation

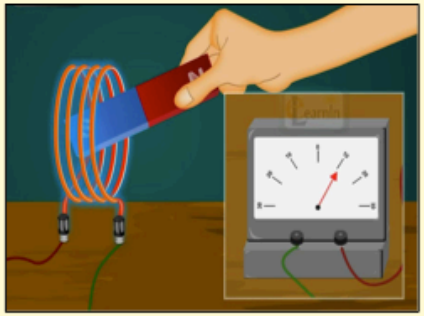
Both processes are operating in Greenland today. To estimate present melting using the elastic response (A), we need to remove the GIA response (B). GIA in Greenland is poorly constrained due to lack of knowledge of viscosity heterogeneity in the upper mantle.

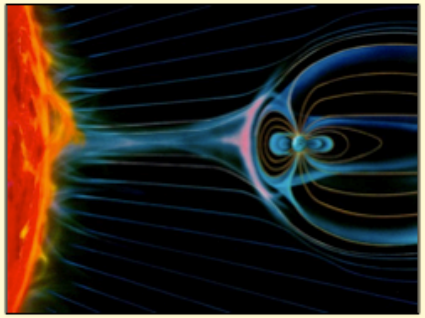


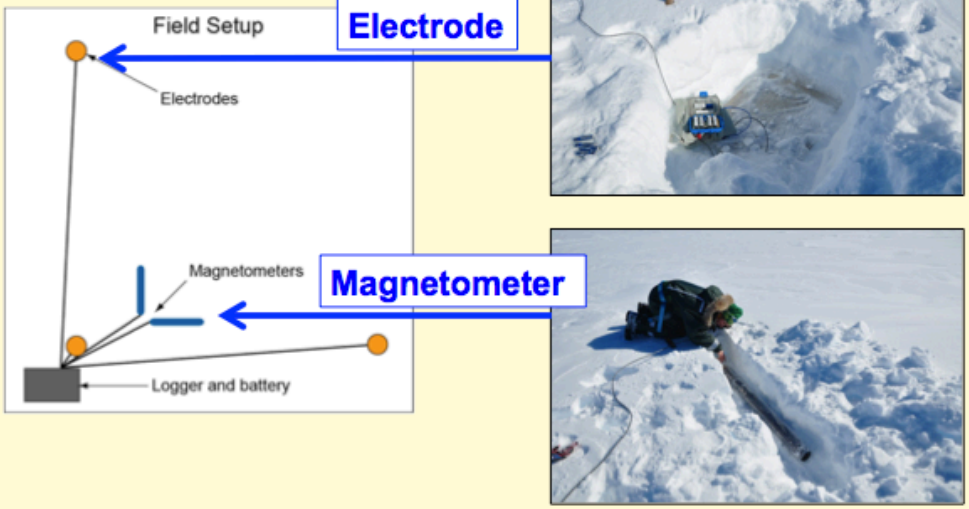


Using Magnetotellurics to infer Upper Mantle Viscosity Heterogeneity

Magnetotellurics (MT) is an electromagnetic method that can constrain electric conductivity variations at depth. The method uses lightning and solar wind as a varying electromagnetic source (right) that produces electric currents in conductive rocks at depth. By measuring the electric and magnetic fields simultaneously (below), MT analysis can place constraints on the conductivity of the crust and upper mantle.





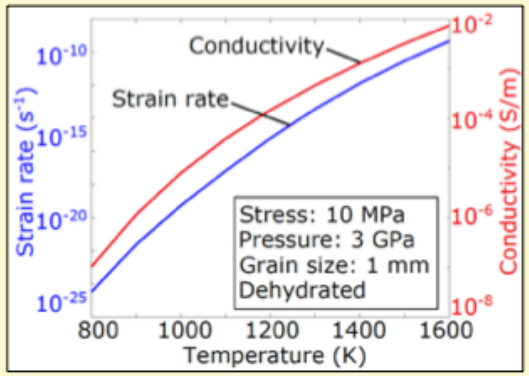


$$\sigma = AC_w^r \exp\left(\frac{-\Delta H}{RT}\right)$$

Dependence of electrical conductivity (σ) on temperature (T) and water content (C_W)

$$\dot{\varepsilon} = A\sigma^n d^{-p} C_w{}^r \exp(\alpha\varphi) \exp\left(\frac{-\Delta H}{RT}\right)$$

Dependence of strain rate on temperature (T) and water content (C_W)

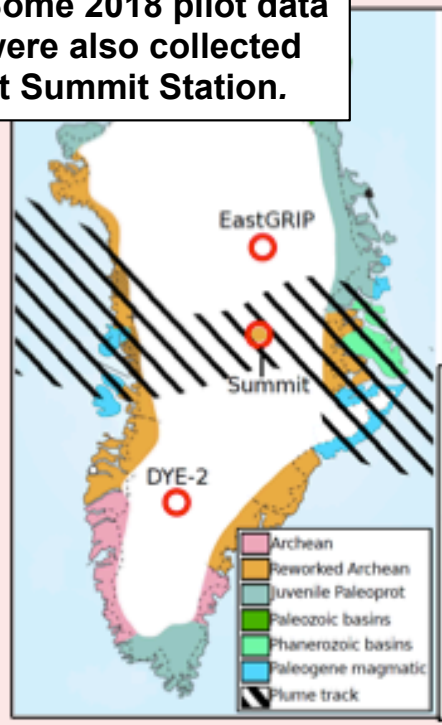


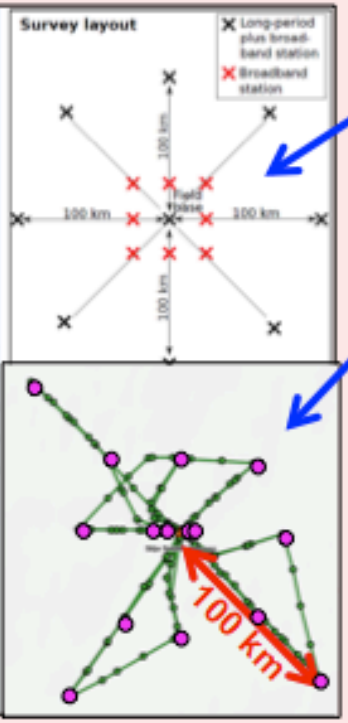
Similar dependences on temperature and water content mean that variations in viscosity can be inferred from constraints on electrical conductivity (from MT). [*Liu & Hasterok*, 2016; *Selway et al.*, 2020]

Field Season 2019

During June of 2019 the MAGPIE team deployed 15 magnetotelluric (MT) stations within 100 km of EastGRIP station, which is situated on the Northeast Greenland Ice Stream. The station is positioned just north of the expected Iceland plume track.

Some 2018 pilot data were also collected at Summit Station.

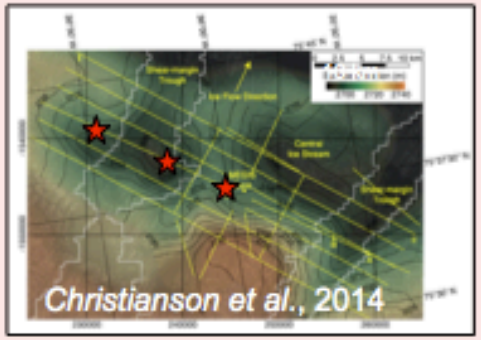


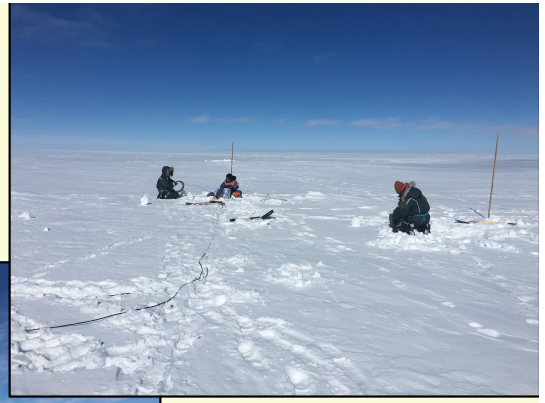


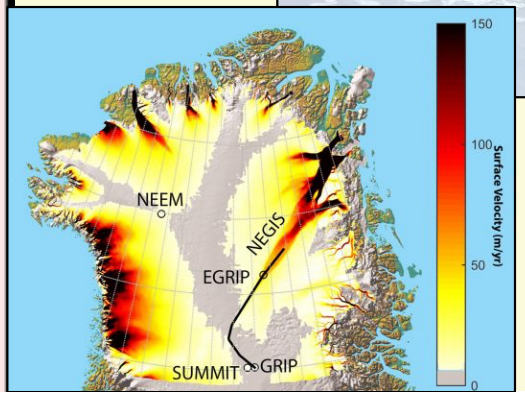
Optimal Survey

Actual Survey 2019

Cross-Stream Profile

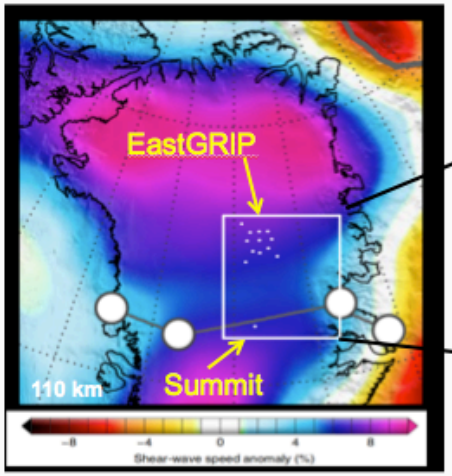


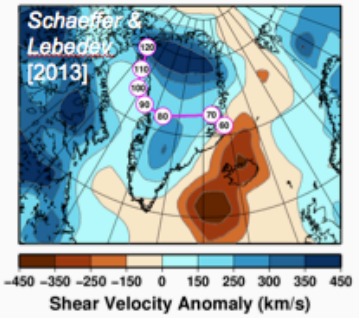




Preliminary Results

Greenland is thought to have passed over the Iceland plume 60-90 million years ago [*Steinberger et al.*, 2019], likely leaving a trail of heat and low viscosity behind it. Our survey is designed to look for this trail.



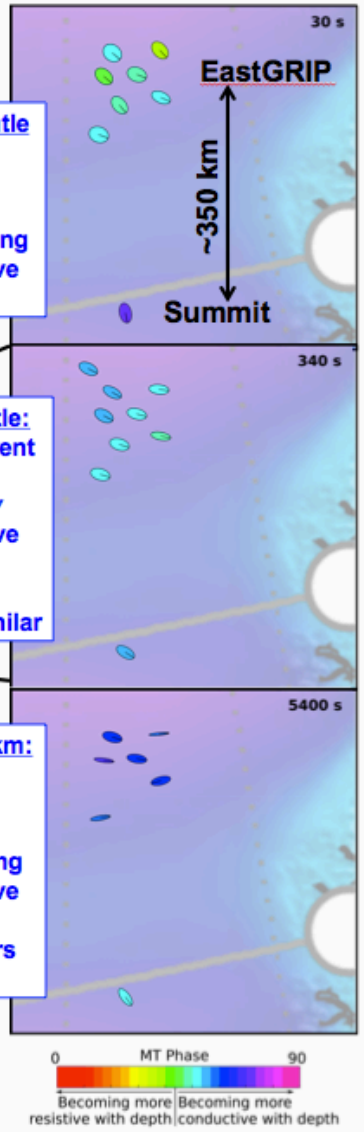


Approximate depth range & interpretation ↓

Crust - top of mantle
- NE-SW current orientation at EastGRIP
- Summit is getting more conductive with depth

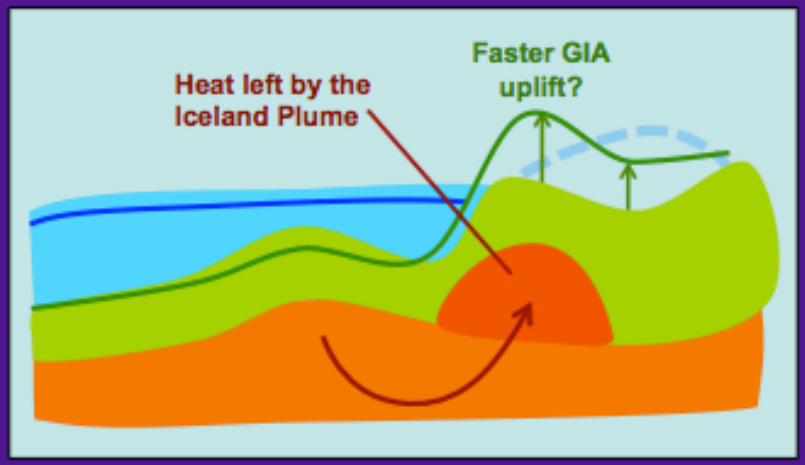
Lithospheric Mantle:
- WNW-ESE current orientation
- Getting *slightly* more conductive with depth
- EastGRIP and Summit are similar

Several hundred km:
- East-West orientation at EastGRIP
- EastGRIP getting more conductive with depth
- EastGRIP differs from Summit



Summary

- Our goal is to use MT to constrain lateral viscosity variations within and beneath the Greenland lithosphere
- The MAGPIE team performed a magnetotelluric (MT) survey in northeast Greenland in Summer 2019.
- Preliminary MT results suggest deep variations that may be associated with the Iceland Plume track.
- Constraints on viscosity variations can improve models for Glacial Isostatic Adjustment (GIA).



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