

Change in Ice Loading, Vertical Land Motion and Coastal Sea Level



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Photo: Christian Helledie ©, NIRAS

Vertical Land Motion

– important for coastlines in Northern Europe

The **solid earth is moving** because of **present-day ice changes** - even thousands of kilometers away from the ice change.

What does it mean for coastlines Northern Europe?



Elastic deformation from Arctic ice loading changes

Geophysical Research Letters

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Vertical Land Motion From Present-Day Deglaciation in the Wider Arctic

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SECTIONS



TOOLS



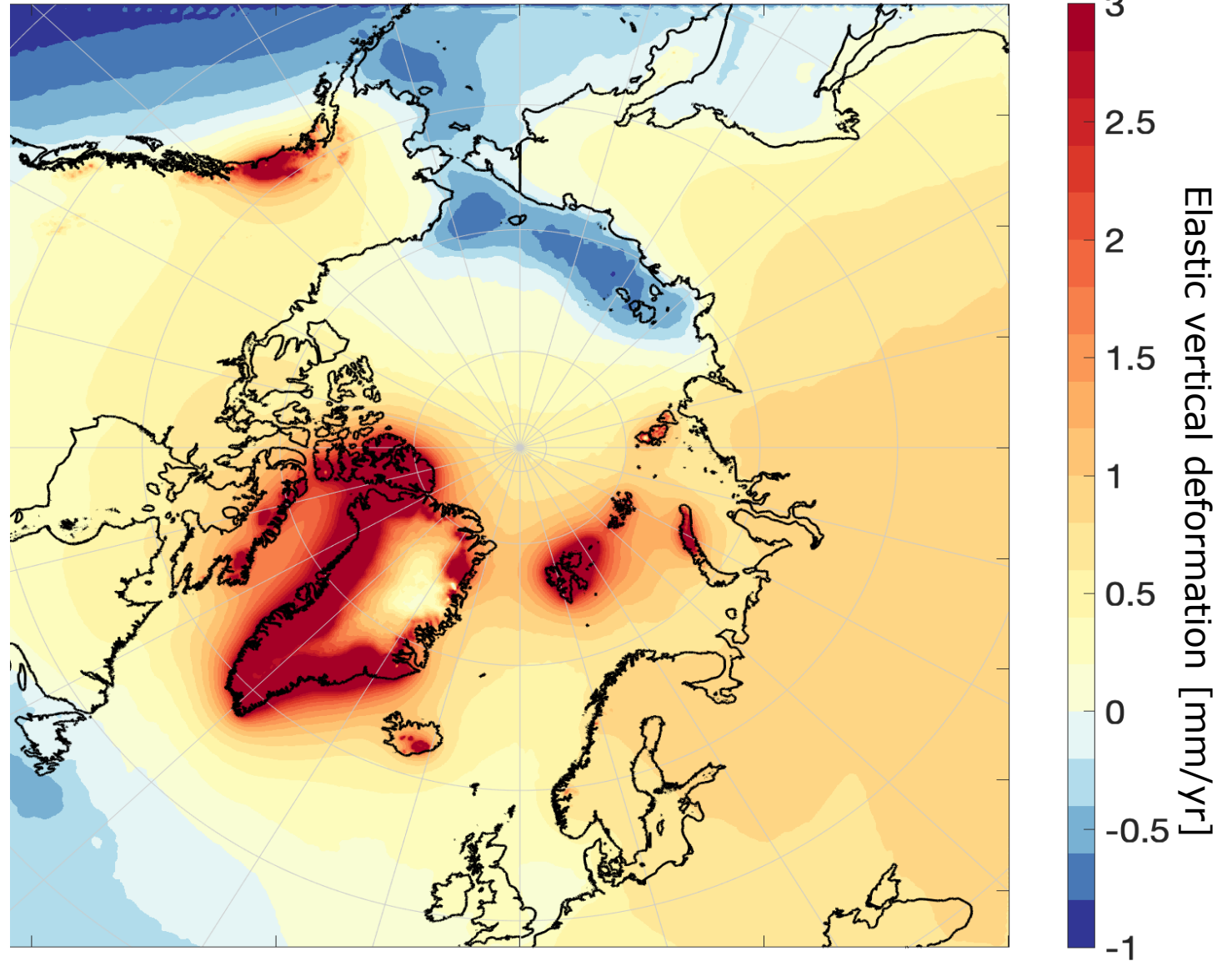
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Abstract

Vertical land motion (VLM) from past and ongoing glacial changes can amplify or mitigate ongoing relative sea level change. We present a high-resolution VLM model for the wider Arctic, that includes both present-day ice loading (PDIL) and glacial isostatic adjustment (GIA). The study shows that the nonlinear elastic uplift from PDIL is significant ($0.5\text{--}1\text{ mm yr}^{-1}$) in most of the wider Arctic and exceeds GIA at 15 of 54 Arctic GNSS sites, including sites in nonglaciated areas of the North Sea region and the east coast of North America. Thereby the sea level change from PDIL (1.85 mm yr^{-1}) is significantly mitigated from VLM caused by PDIL. The combined VLM model was consistent with measured VLM at 85% of the GNSS sites ($R = 0.77$) and outperformed a GIA-only model ($R = 0.64$). Deviations from GNSS-measured VLM can be attributed to local circumstances causing VLM.

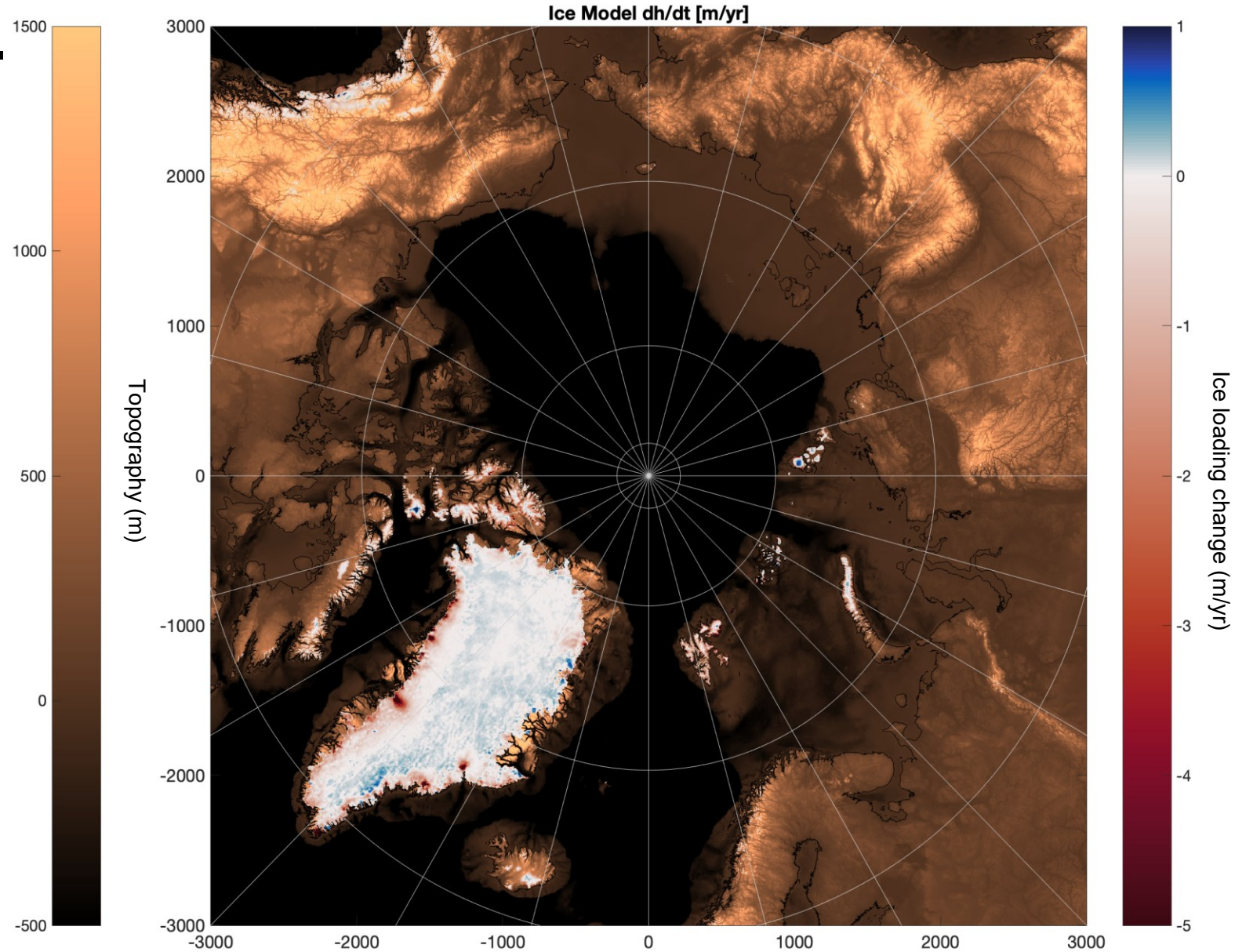
Data at: data.dtu.dk

Search for 'Arctic Vertical Land Motion'



Ice loading changes - Arctic

Yearly 5x5 km resolution
from 1997-2017.



Ice loading changes - Arctic

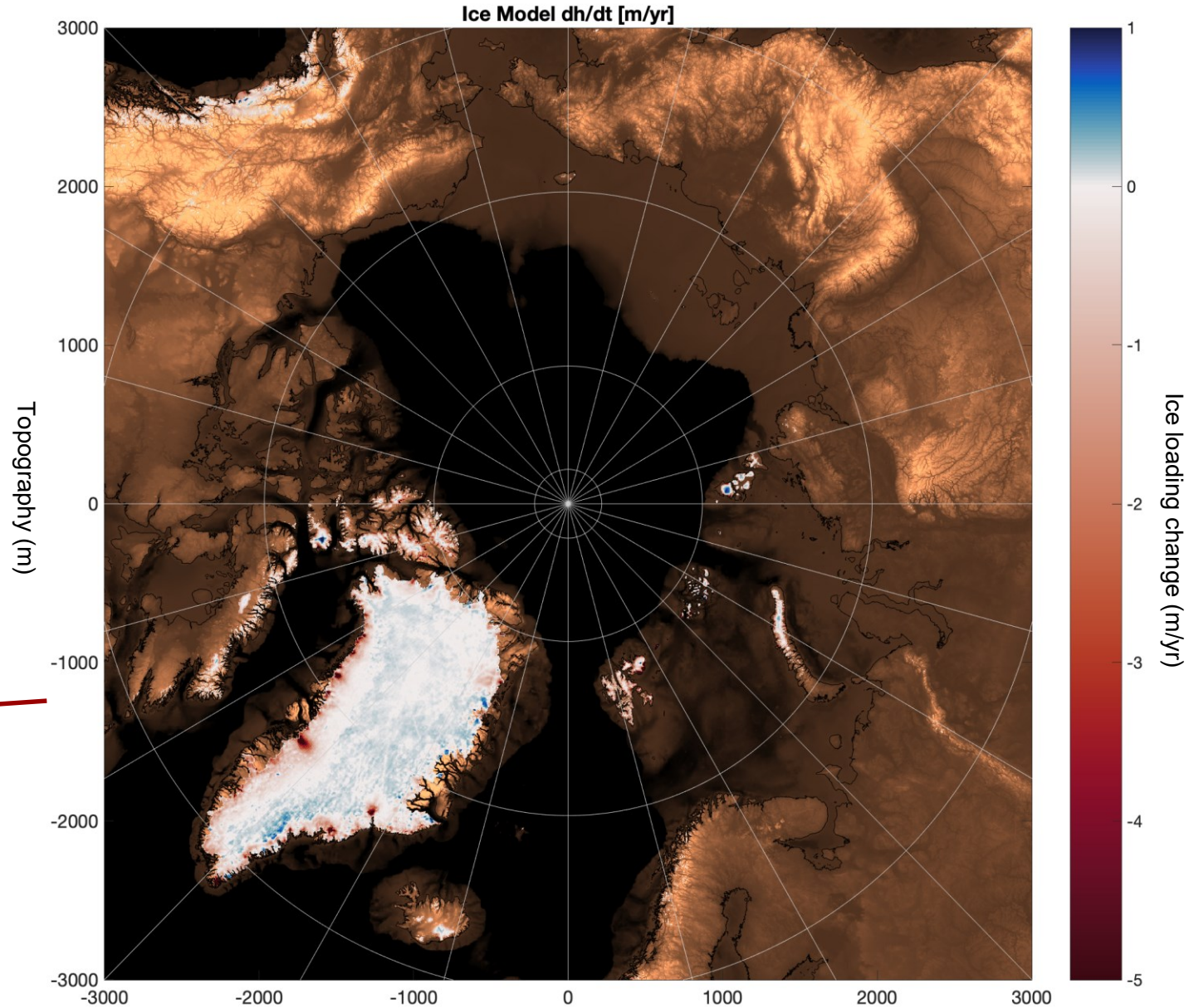
Yearly 5x5 km resolution
from 1997-2017.

Elastic Green's functions:

$$\begin{Bmatrix} u \\ v \\ \phi/g \end{Bmatrix}(\psi) = \frac{3\rho_i}{\rho_e} H \sum_{\ell=\ell_{min}}^{\ell=\ell_{max}} \begin{Bmatrix} h'_\ell \\ l'_\ell \\ 1+k'_\ell \end{Bmatrix} \frac{f_\ell(\alpha)}{2l+1} \begin{Bmatrix} 1 \\ \delta \\ 1 \end{Bmatrix} P_\ell(\cos \psi) \quad 0$$

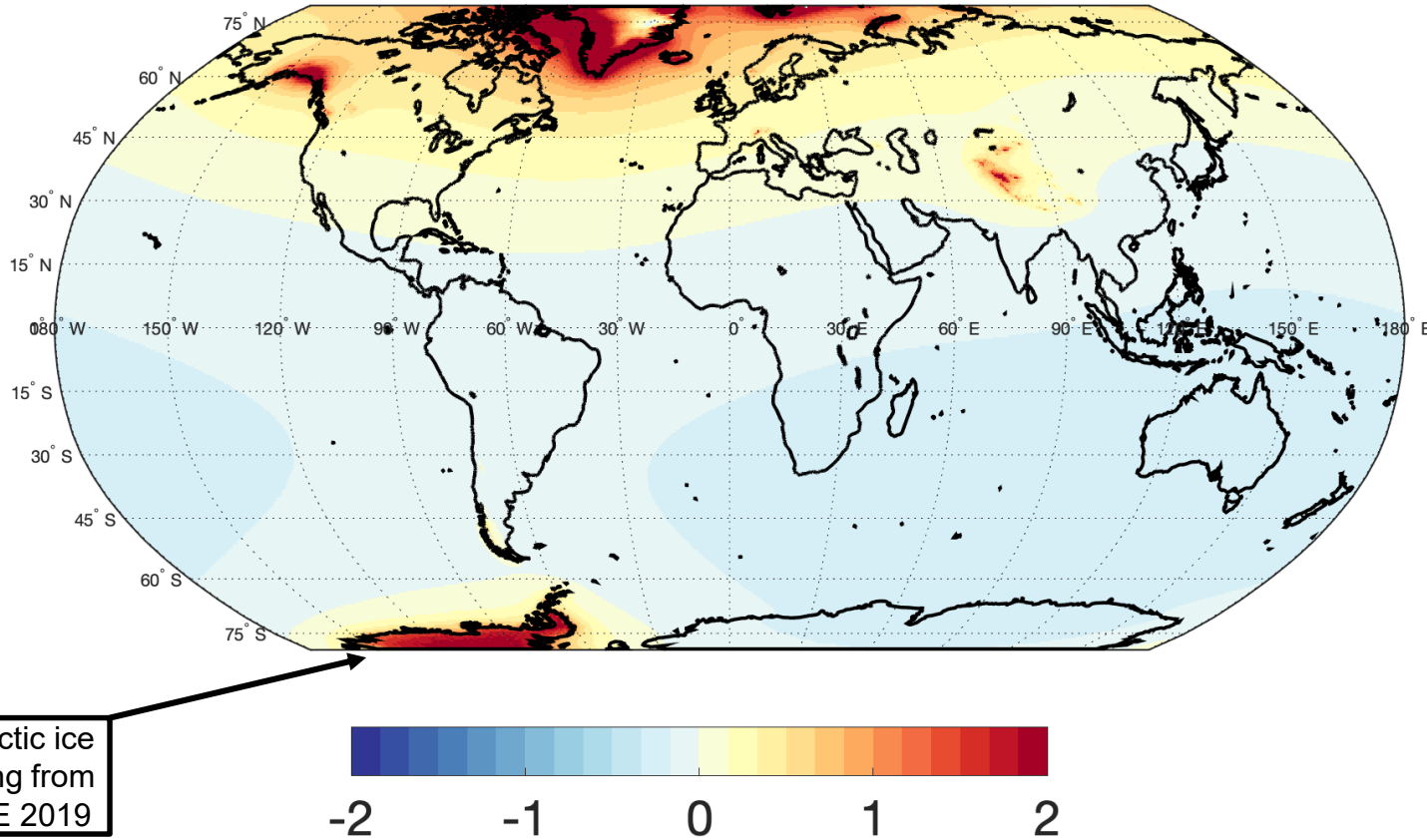
Adapted from Melini et al, 2015

u = vertical displacement
 v = horizontal displacement
 ϕ/g = geoid perturbation

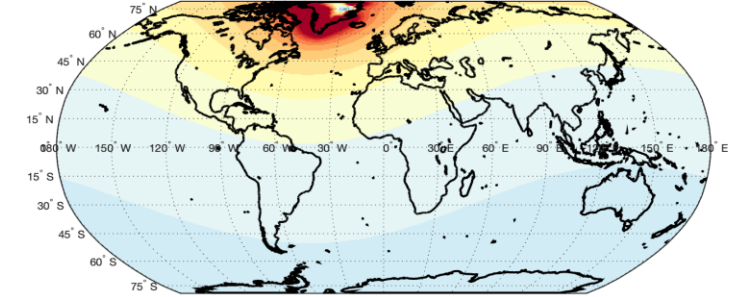


Global elastic deformation caused by present-day ice loading [mm/yr]

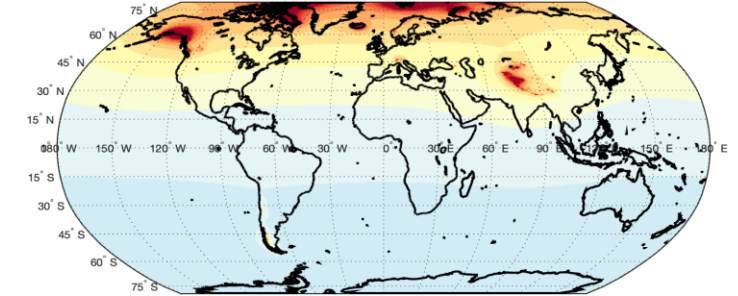
elastic VLM from all sources



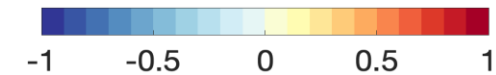
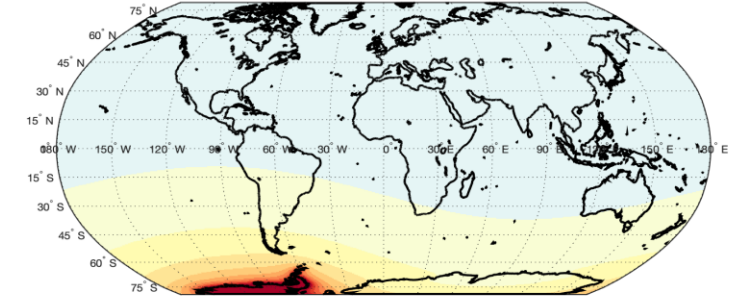
eVLM Greenland



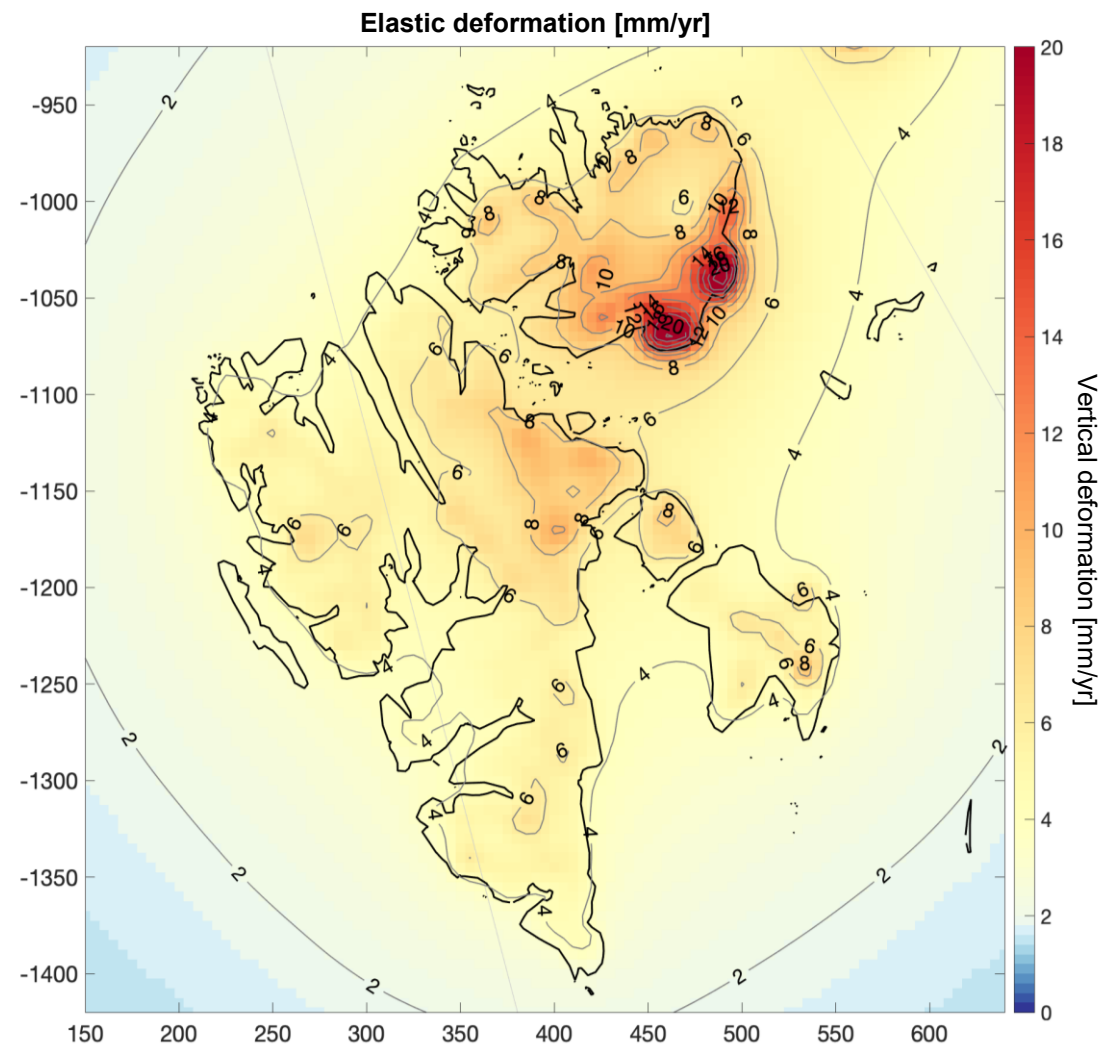
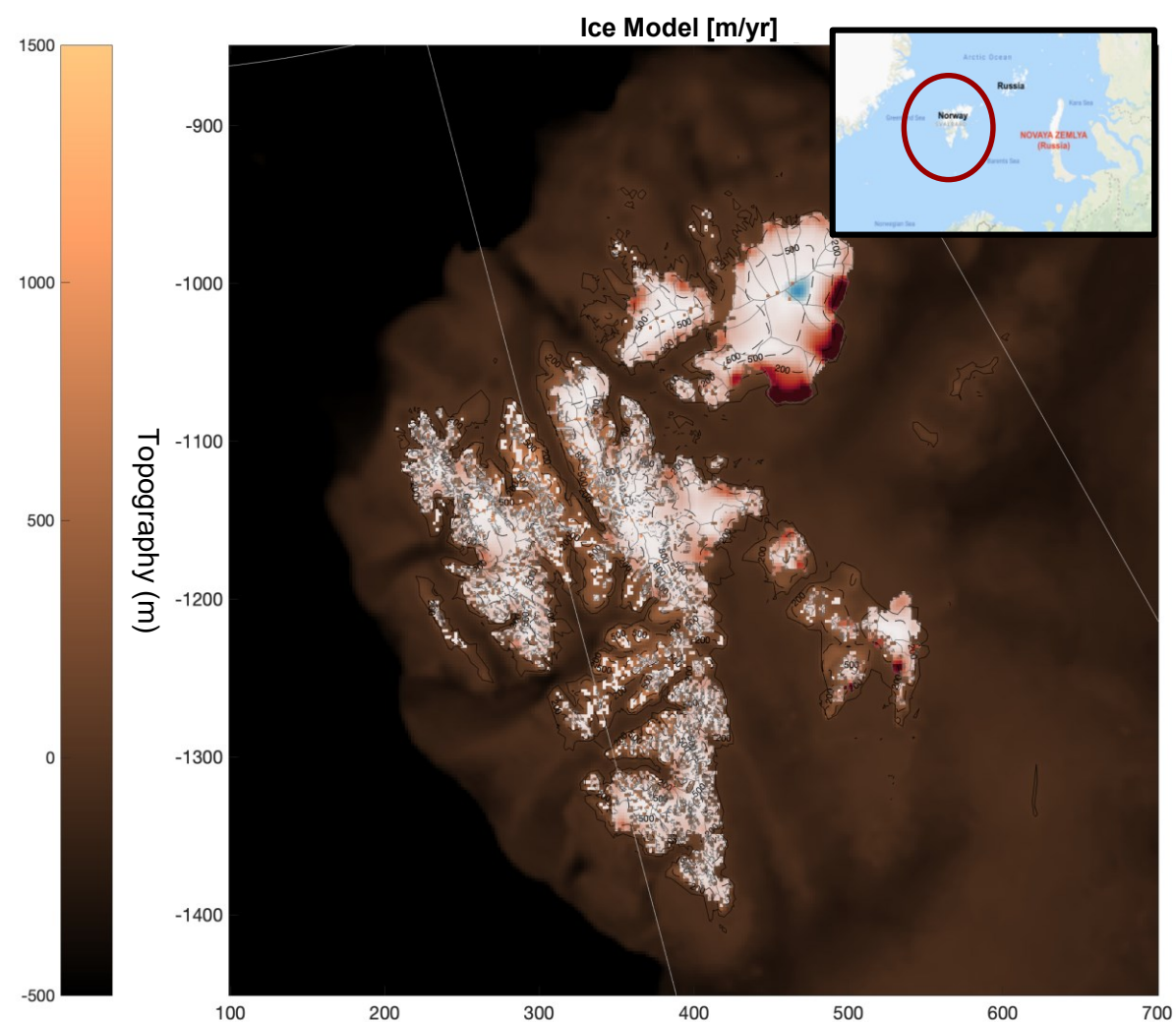
eVLM Glaciers



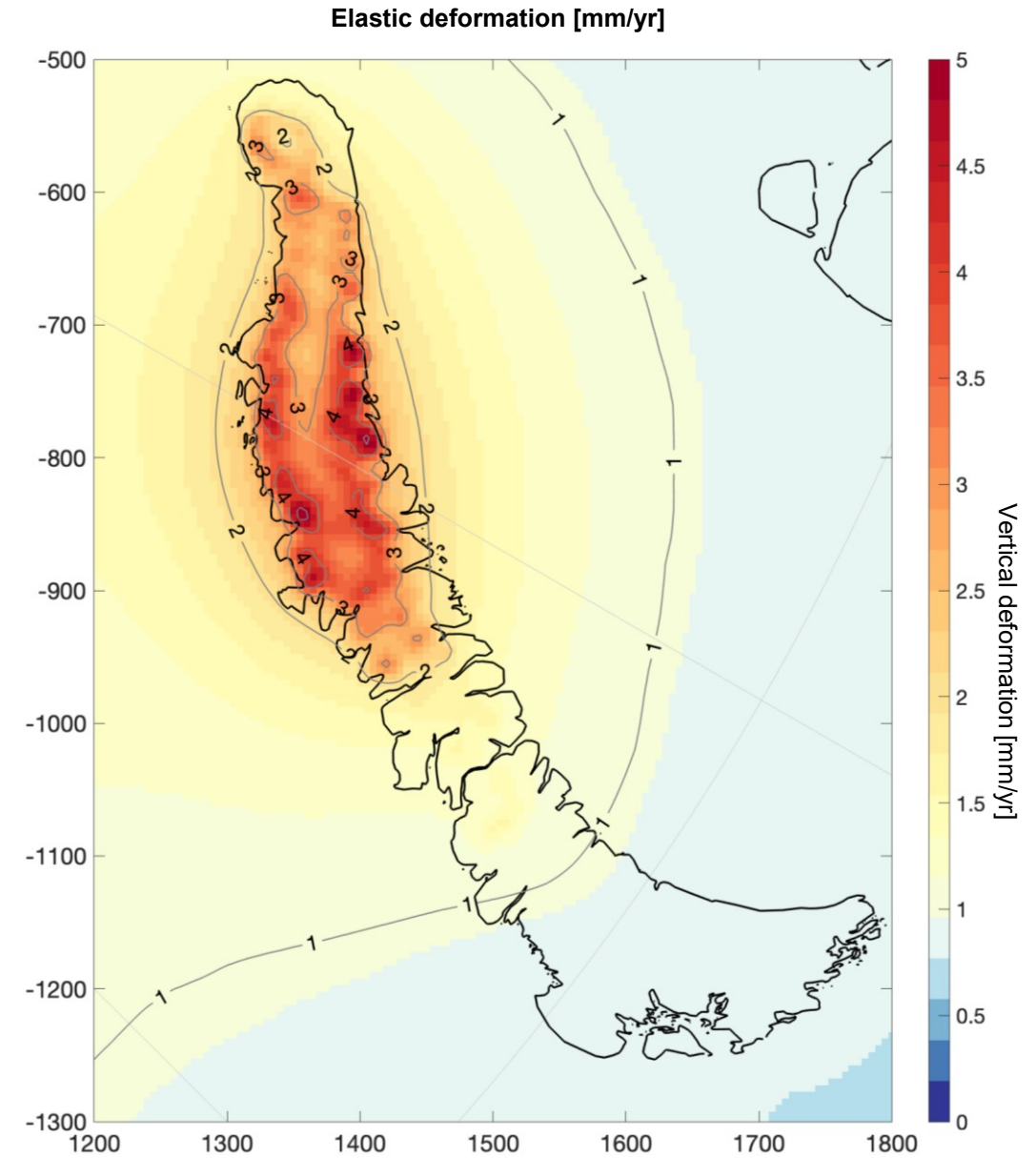
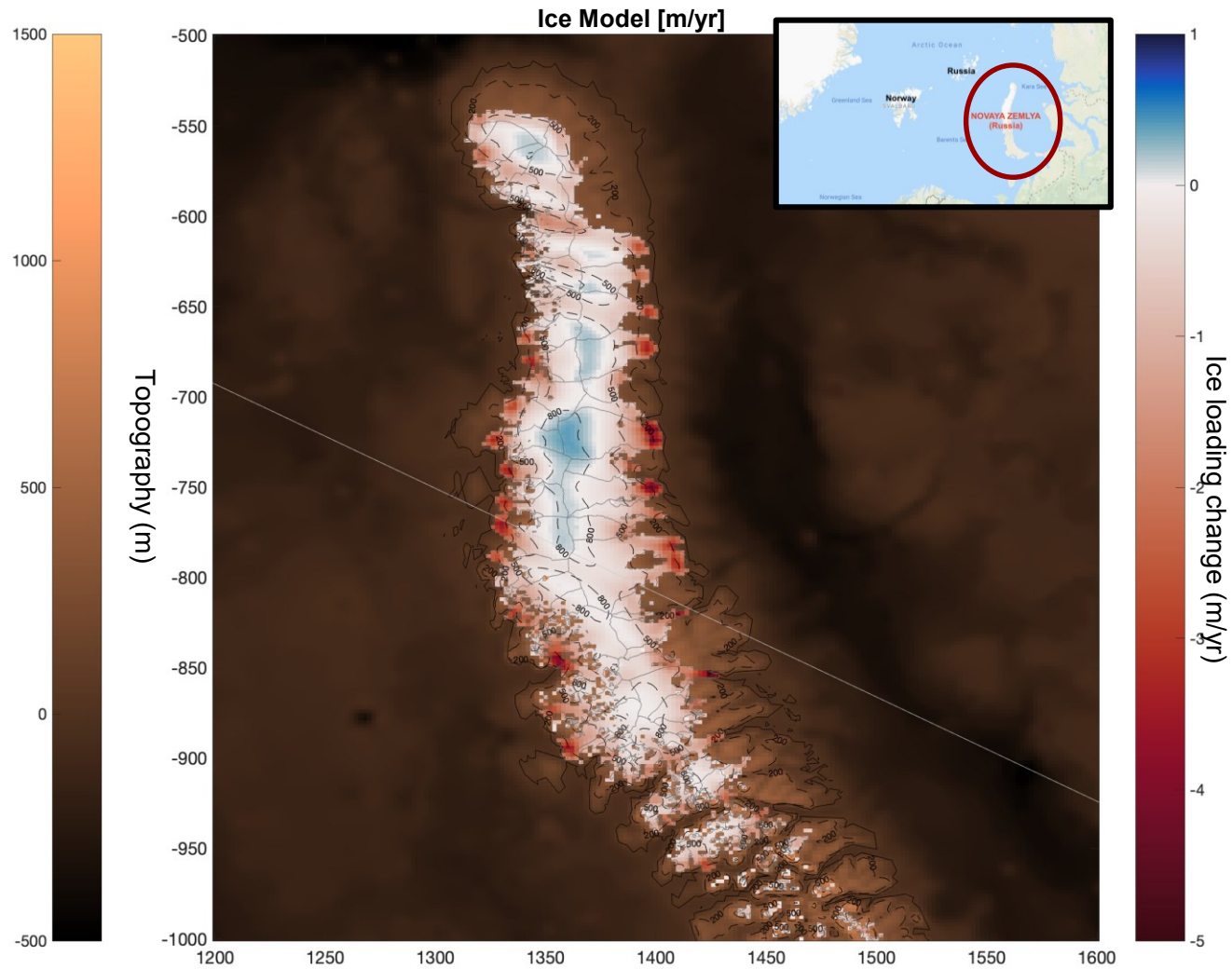
eVLM Antarctica



Ice loading changes - Svalbard



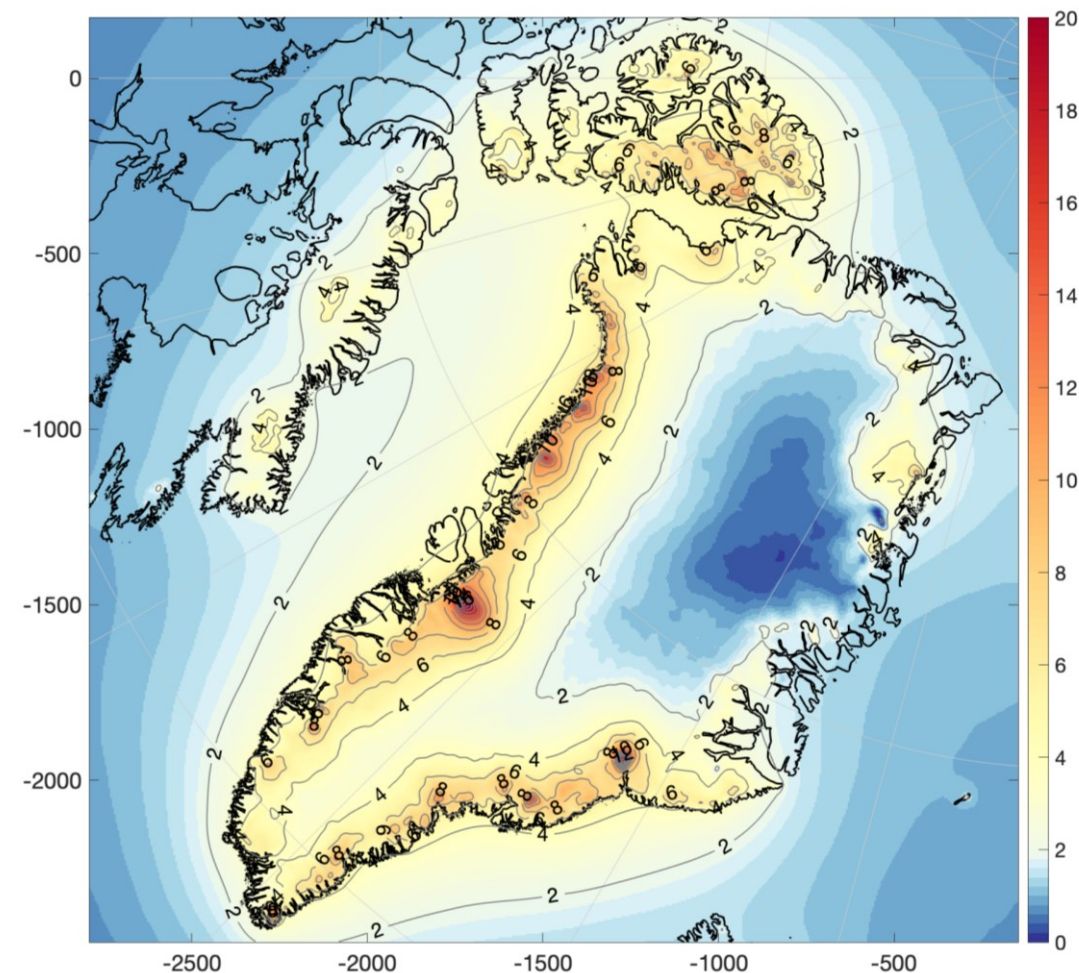
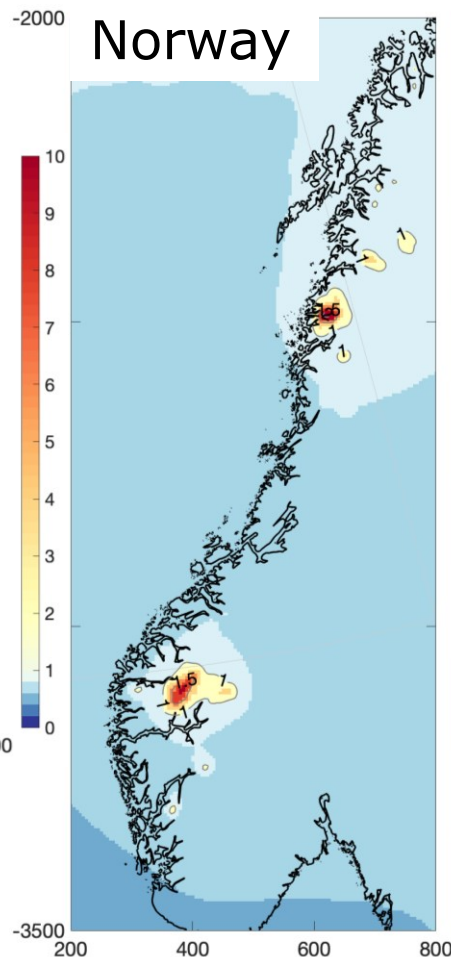
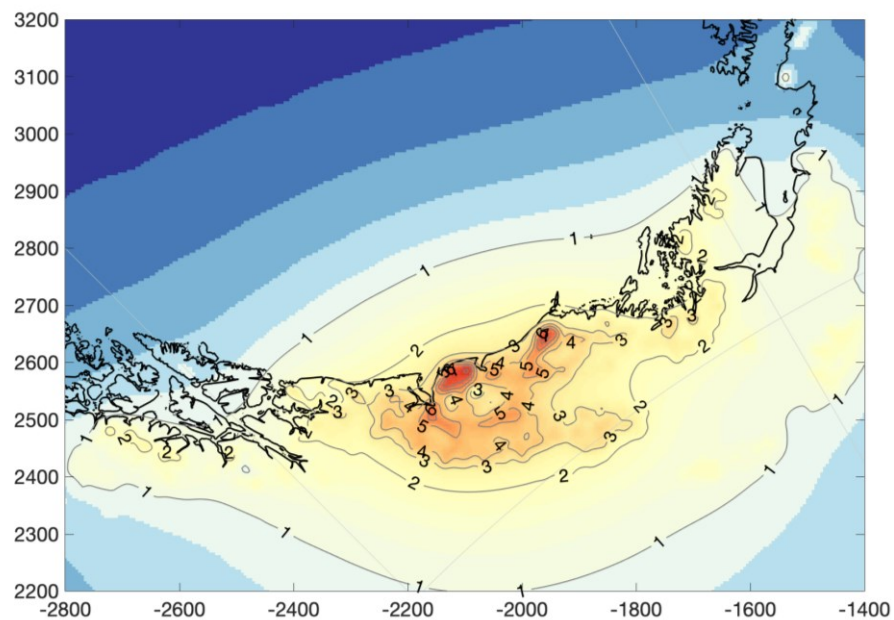
Ice loading changes – Novaya Zemlya



Elastic vertical deformation [mm/yr] – other examples

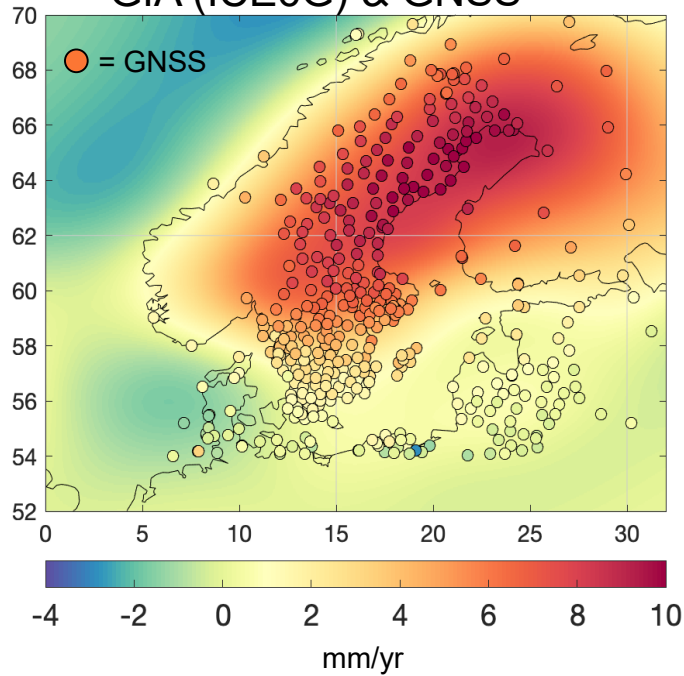
Greenland and North-East Canada

South Alaska



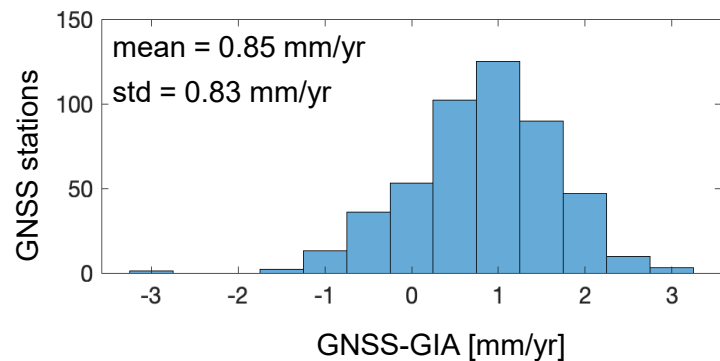
VLM in Scandinavia

GIA (ICE6G) & GNSS



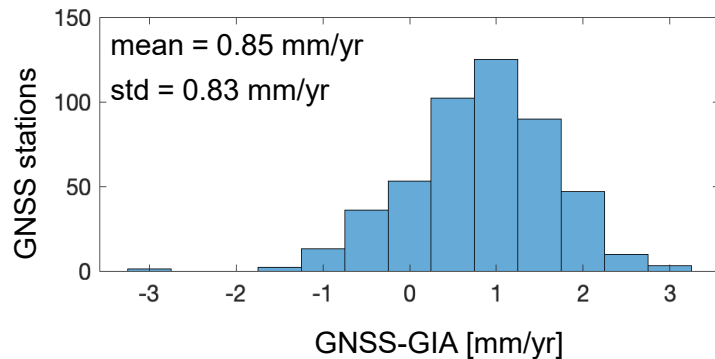
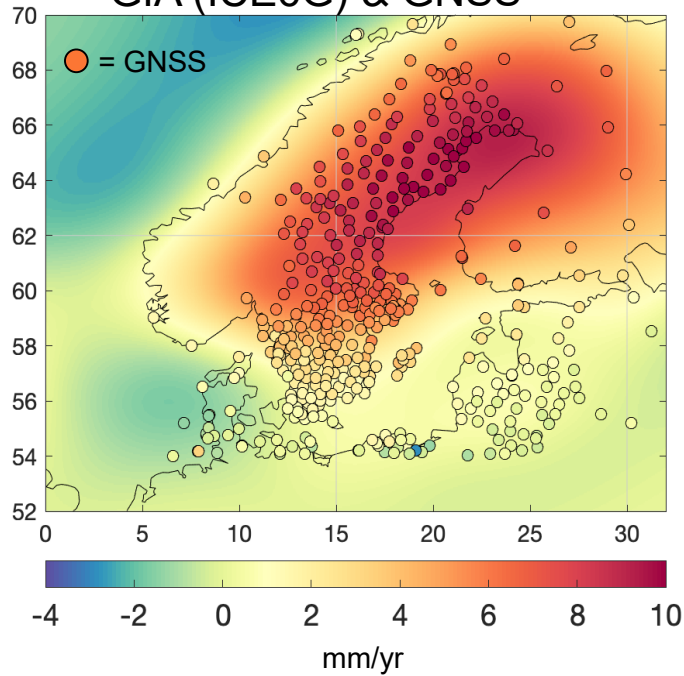
GNSS from MIDAS velocity fields from Nevada Geodetic Laboratory.

Stations with +5 years duration (N=483).

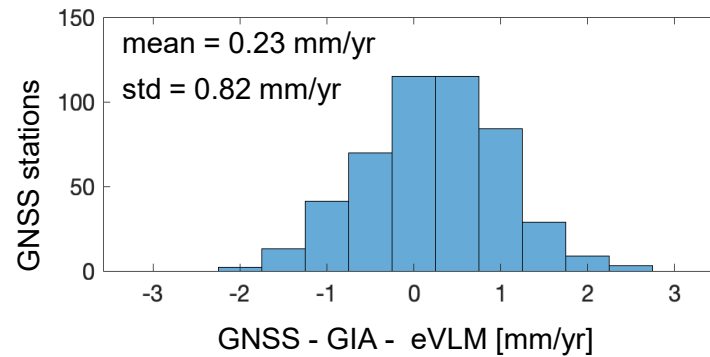
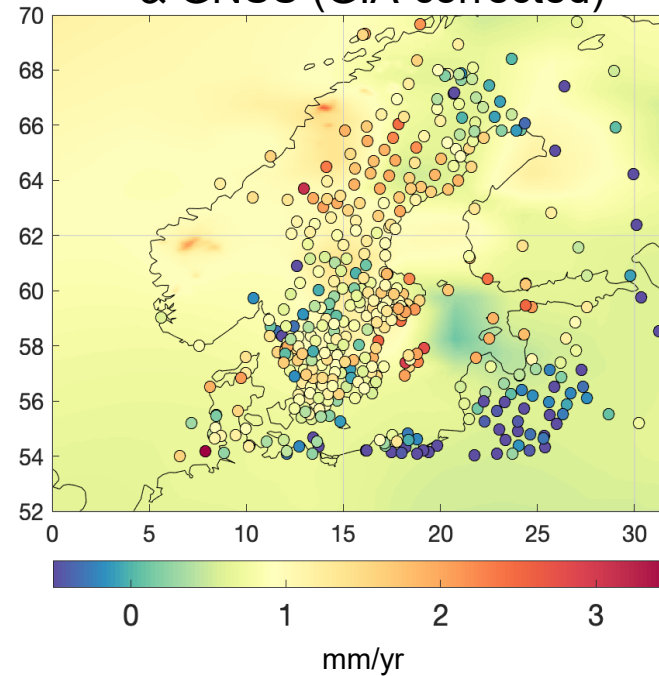


VLM in Scandinavia

GIA (ICE6G) & GNSS



elastic VLM from ice loading
+ terrestrial water storage
& GNSS (GIA-corrected)

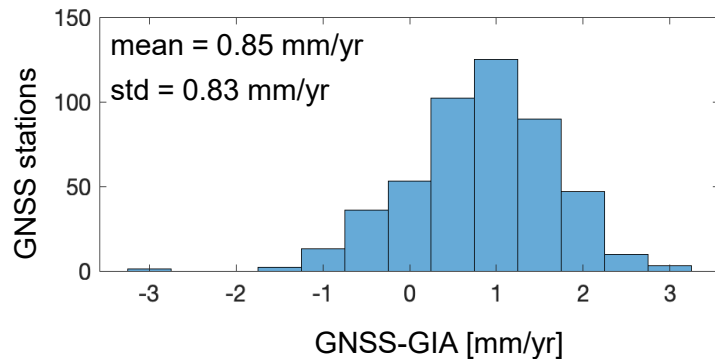
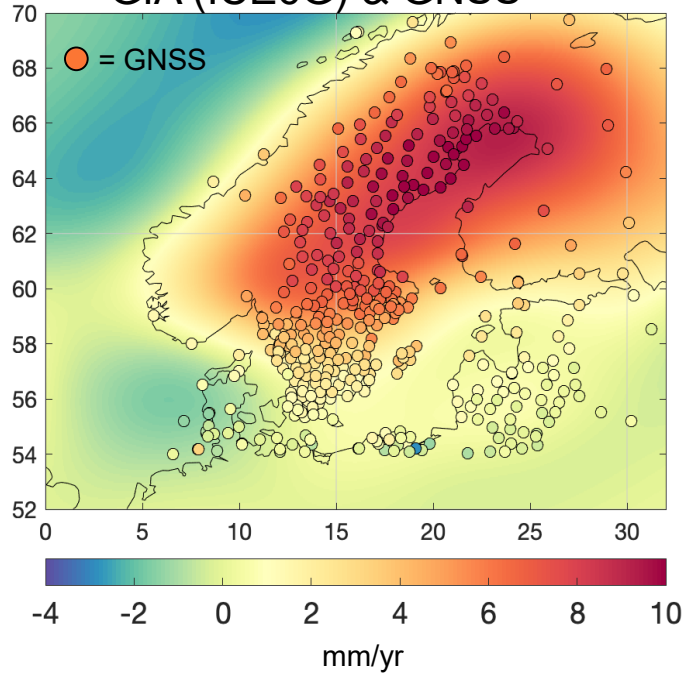


*Terrestrial Water Storage
from WaterGAP v2.2d
(Müller-Schmied et al,
2020)*

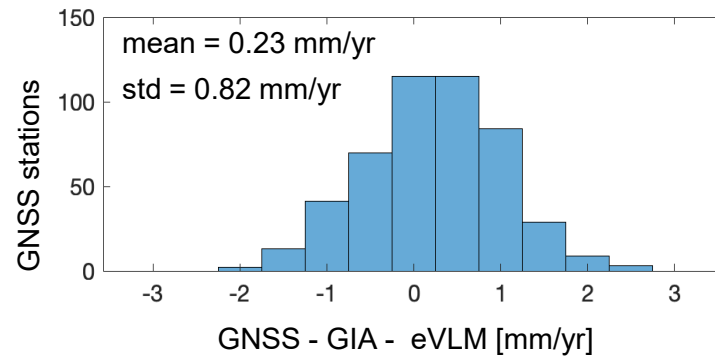
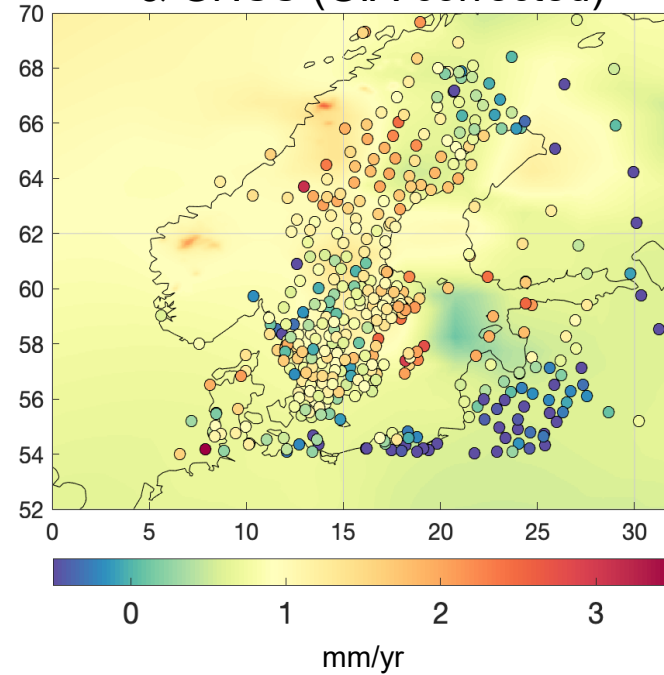
*VLM-model adjusted to
the time period of each
GNSS-station.*

VLM in Scandinavia

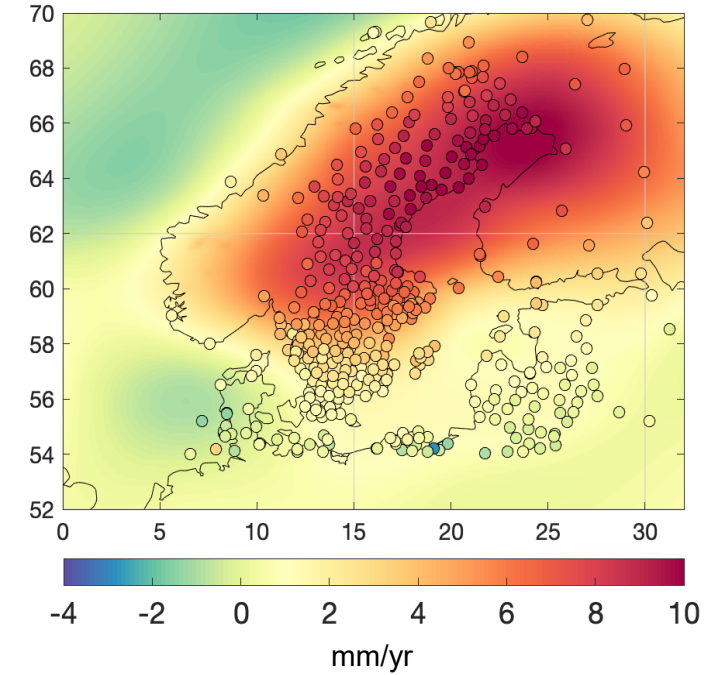
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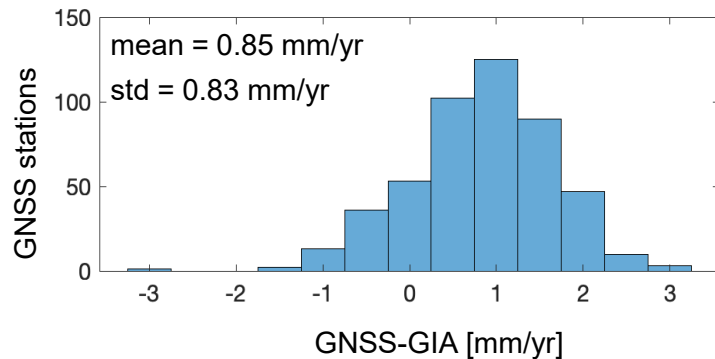
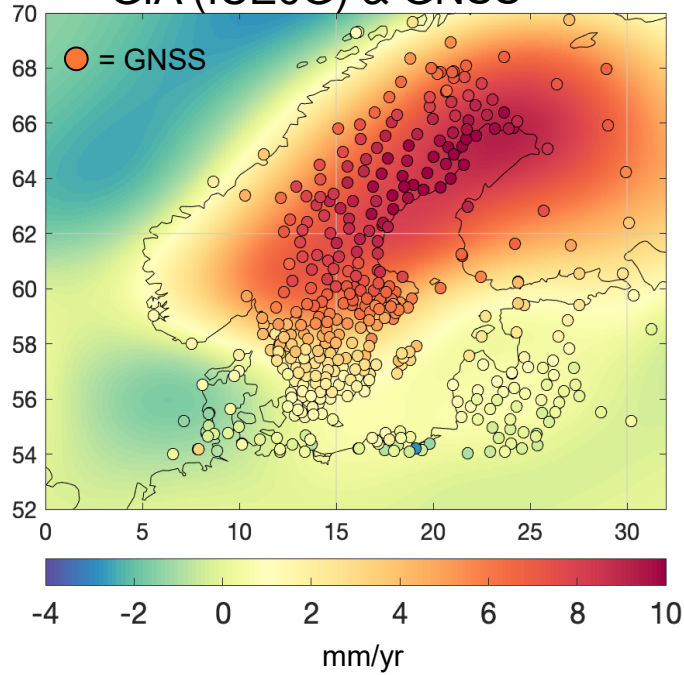
Combined VLM & GNSS



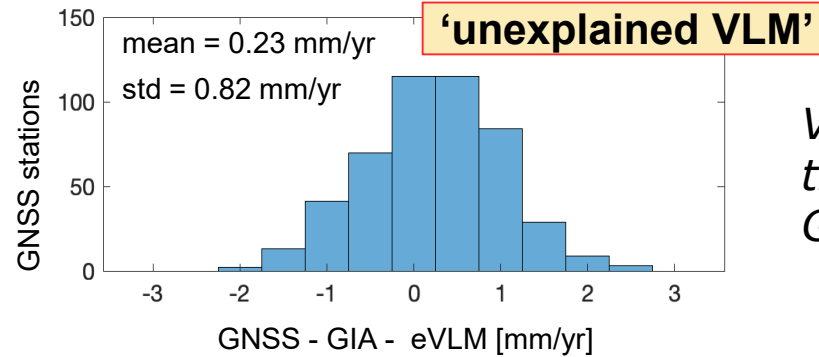
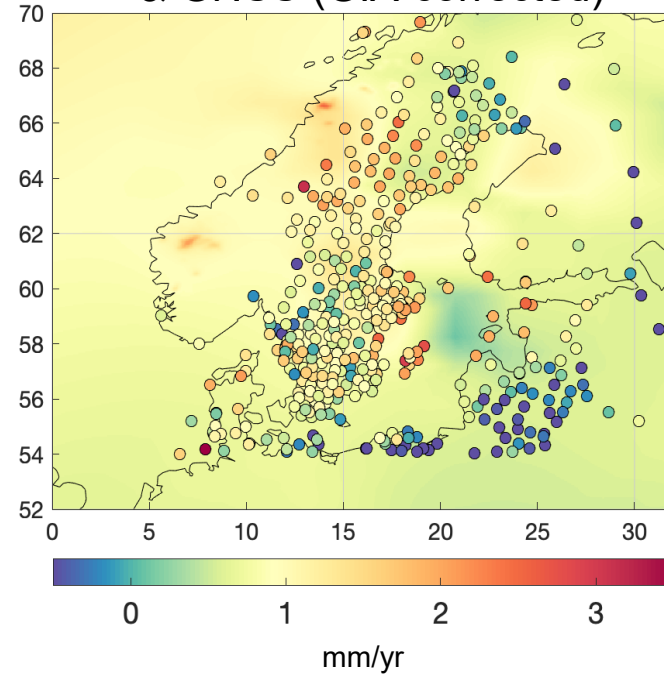
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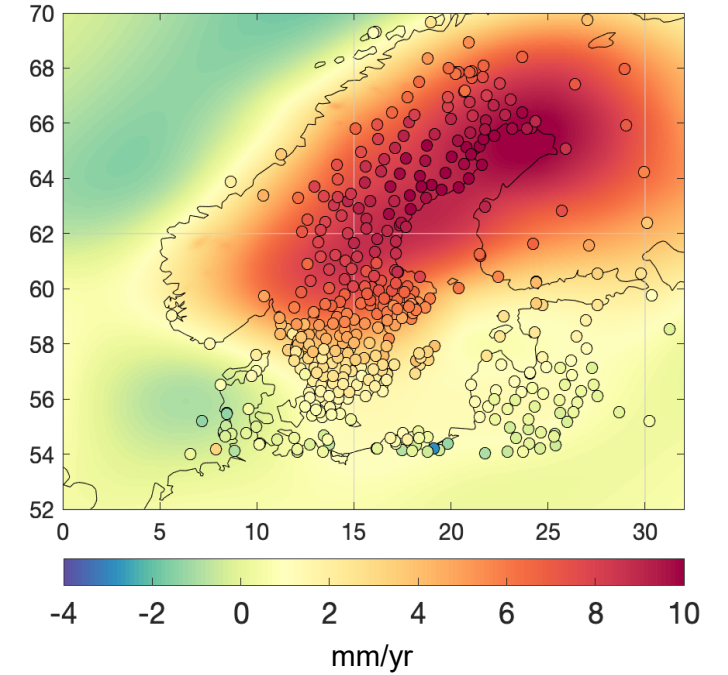
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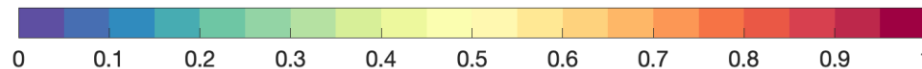
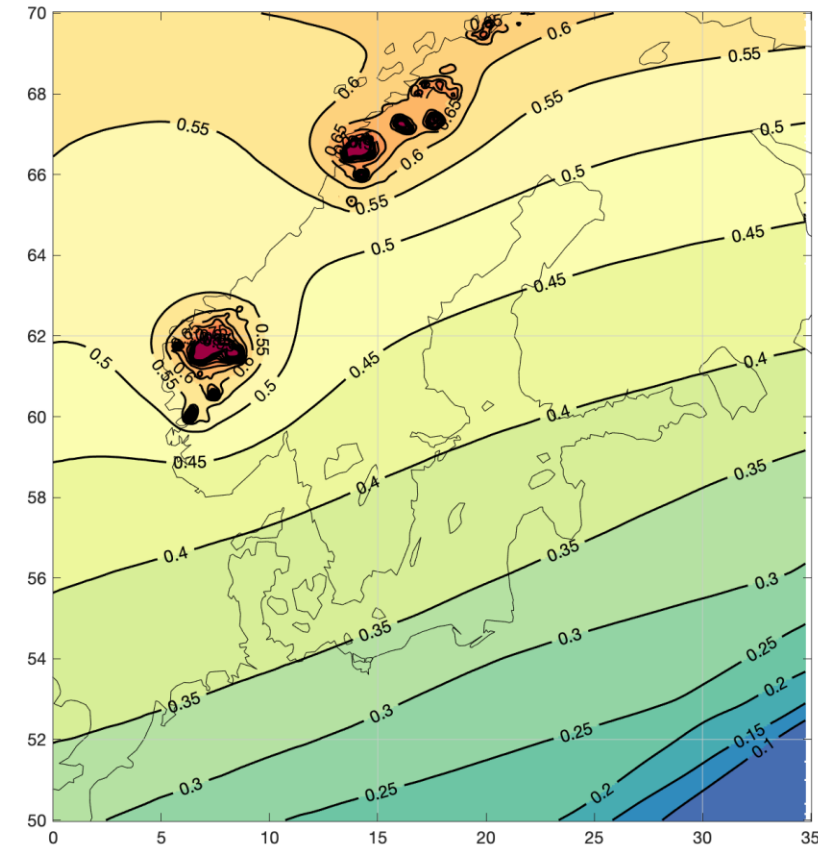
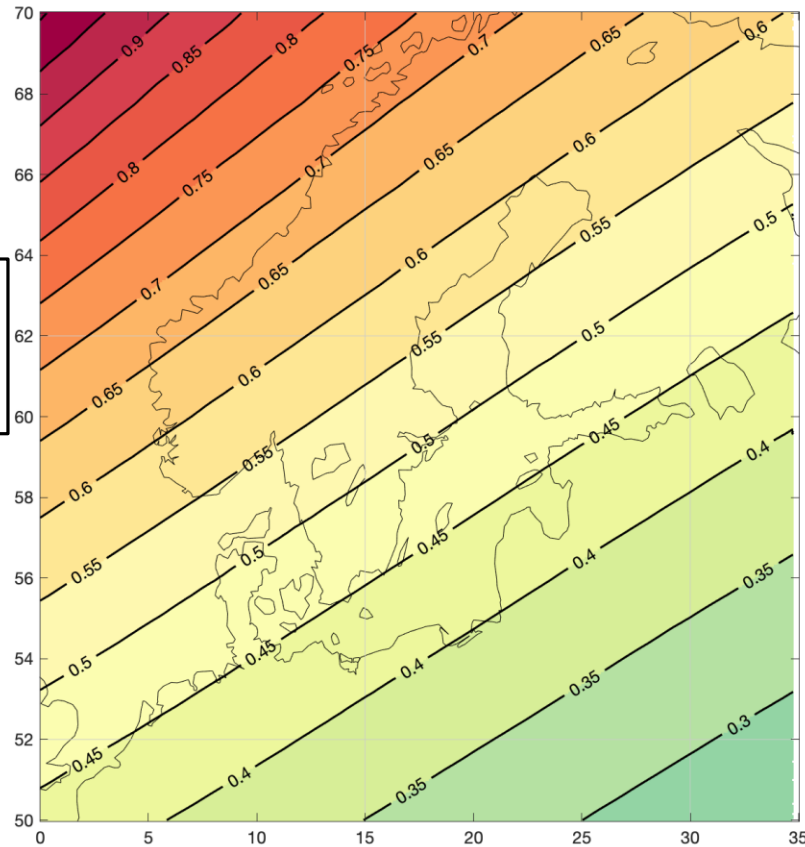
*VLM-model adjusted to
the time period of each
GNSS-station.*

Present-day ice loading impact on coastlines in Scandinavia

Greenland (incl peripheral glaciers)
Global-mean sea level contribution = 0.84 mm/yr

Glaciers (expect Greenland)
Global-mean sea level contribution = 0.86 mm/yr

Ice loading
change from
2001-2020



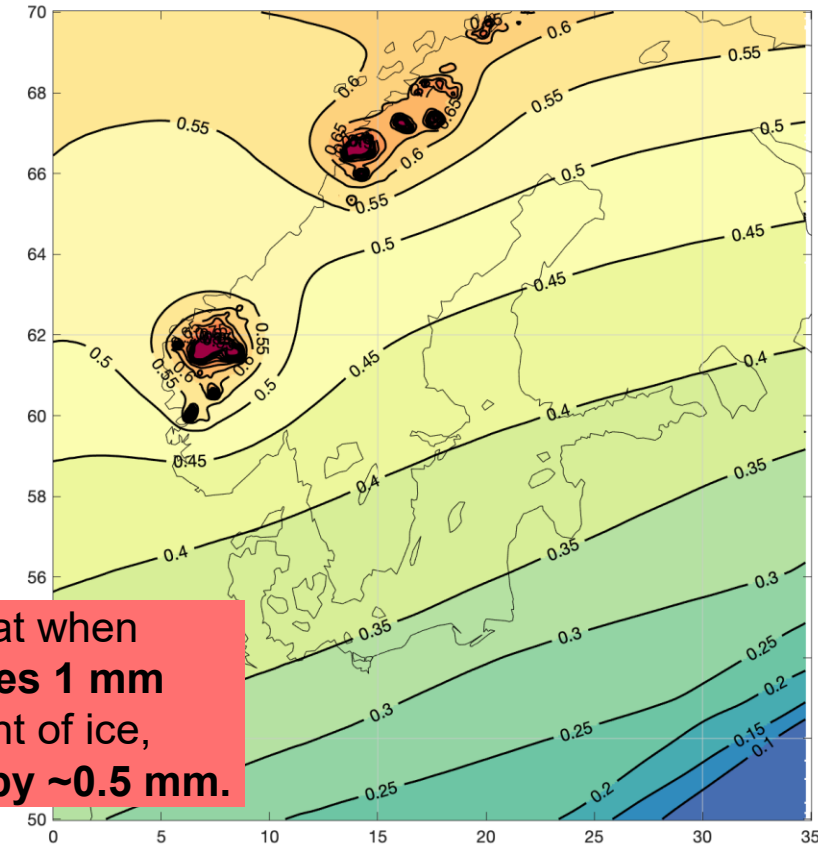
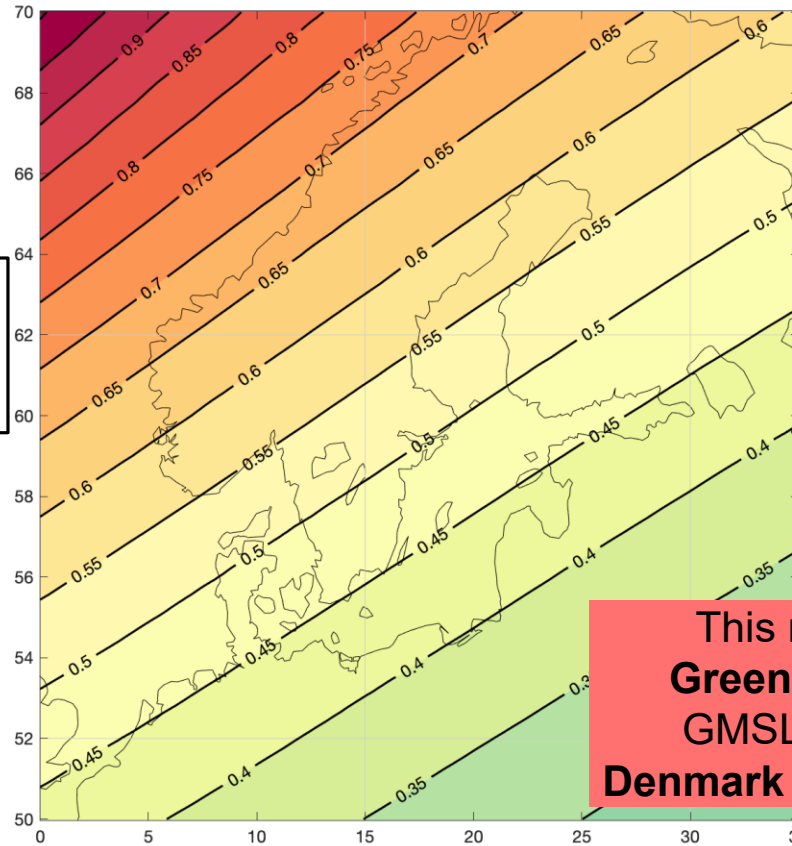
Mitigation fraction: VLM / GMSL contribution

Present-day ice loading impact on coastlines in Scandinavia

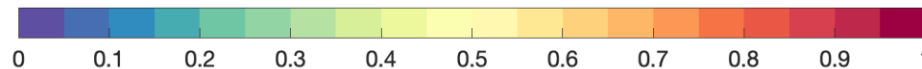
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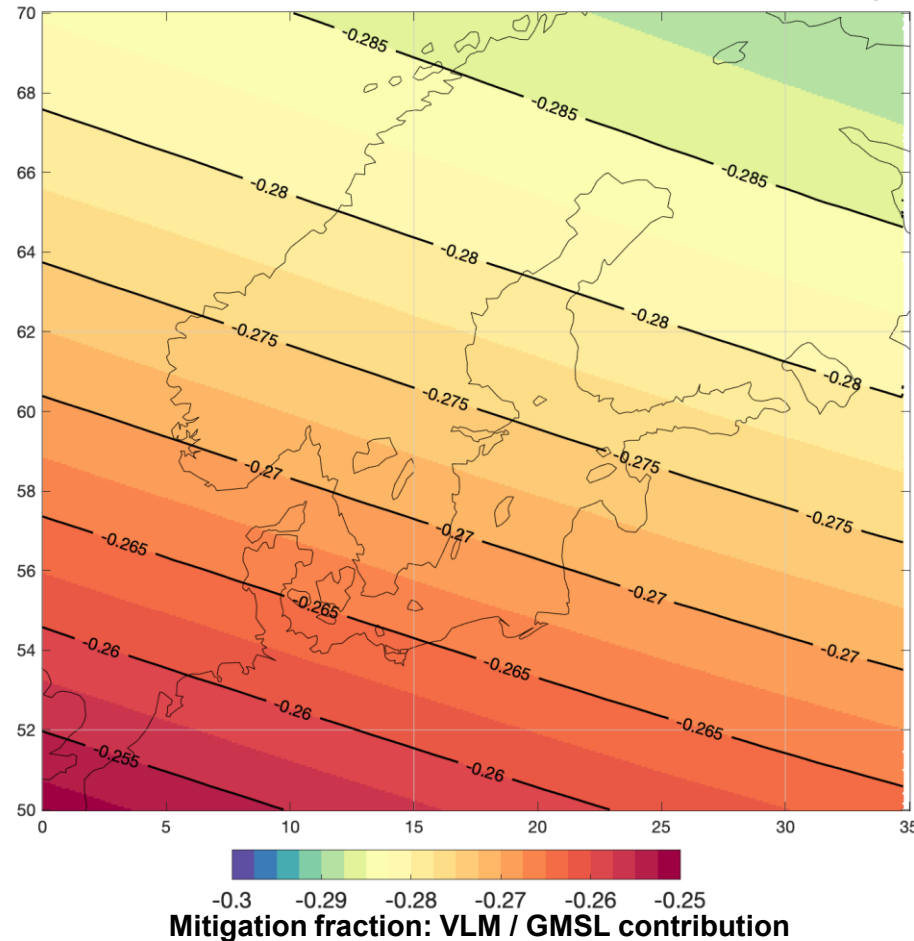
This means, that when
Greenland loses 1 mm
GMSL-equivalent of ice,
Denmark goes up by ~0.5 mm.



Mitigation fraction: VLM / GMSL contribution

Present-day ice loading impact on coastlines in Scandinavia

Antarctica
Global-mean sea level contribution = 0.39 mm/yr



Ice loading
change from
2001-2020

This means, that when **the Antarctic ice sheet loses 1 mm GMSL-equivalent of ice**, **Denmark goes DOWN by ~0.27 mm.**

Summary

- Understanding present-day change of 'far-field' VLM is important for coastal sea level projection.
- 45-75 % of Greenland ice loss is **mitigated** by uplift in Scandinavia. 35-60% for Glaciers.
- Sea level change from the Antarctic Ice Sheet is **amplified** due to subsidence!
- Significant 'unexplained' VLM. Unmodelled change in water storage, oil and sand extraction, large-scale construction etc. contributes to VLM.

Data:

Arctic VLM-model (5x5 km, ~2GB): data.dtu.dk Arctic Vertical Land Motion

MIDAS GNSS data (Blewitt et al., 2016): geodesy.unr.edu/velocities/midas.IGS14.txt

Reference paper:

Ludwigsen, C. A., Khan, S. A., Andersen, O. B., & Marzeion, B. (2020). Vertical land motion from present-day deglaciation in the wider Arctic. *Geophysical Research Letters*, 47, e2020GL088144. <https://doi.org/10.1029/2020GL088144>