NKG Copenhagen 5-8 September 2022

Effect of Icelandic hotspot on Mantle viscosity below Kangerlussuaq glacier in SE-Greenland

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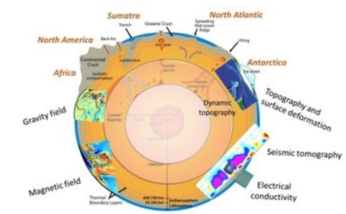
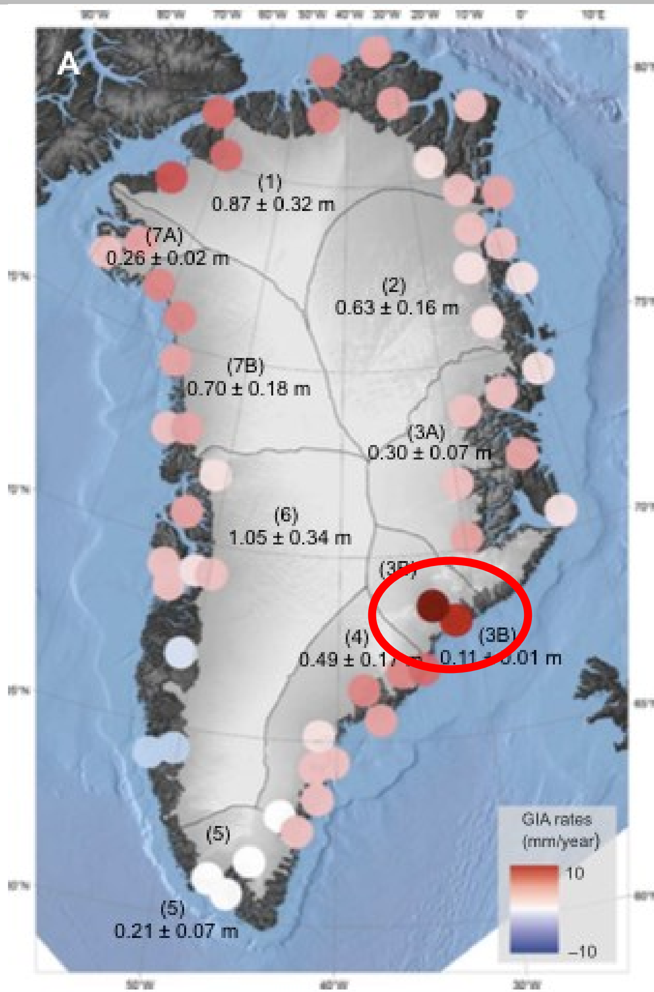
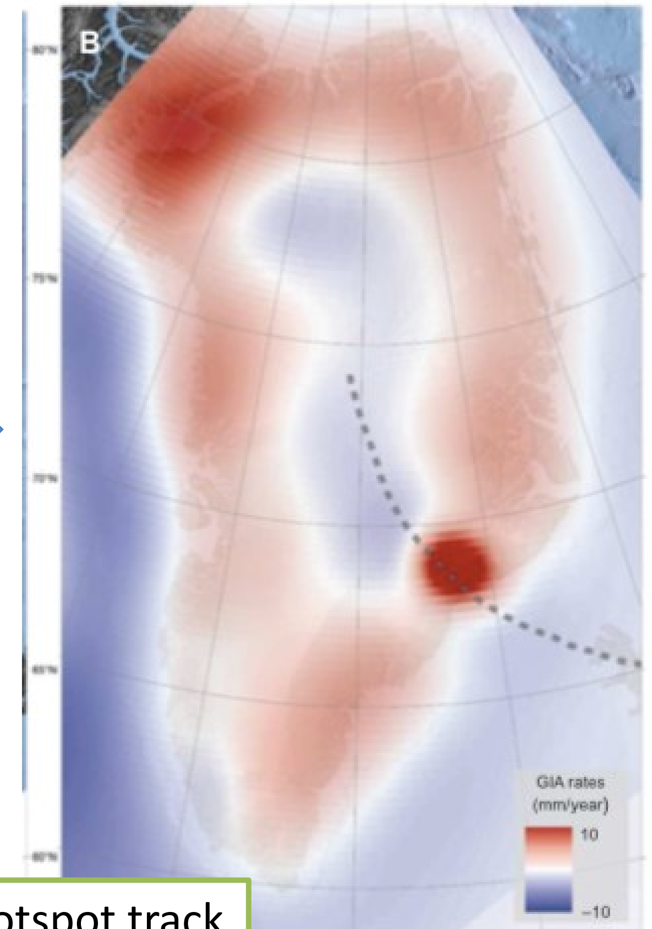


Projects:
ESA 3DEarth/GOCE+Greenland

Anomaly in GPS uplift residual in SE-Greenland

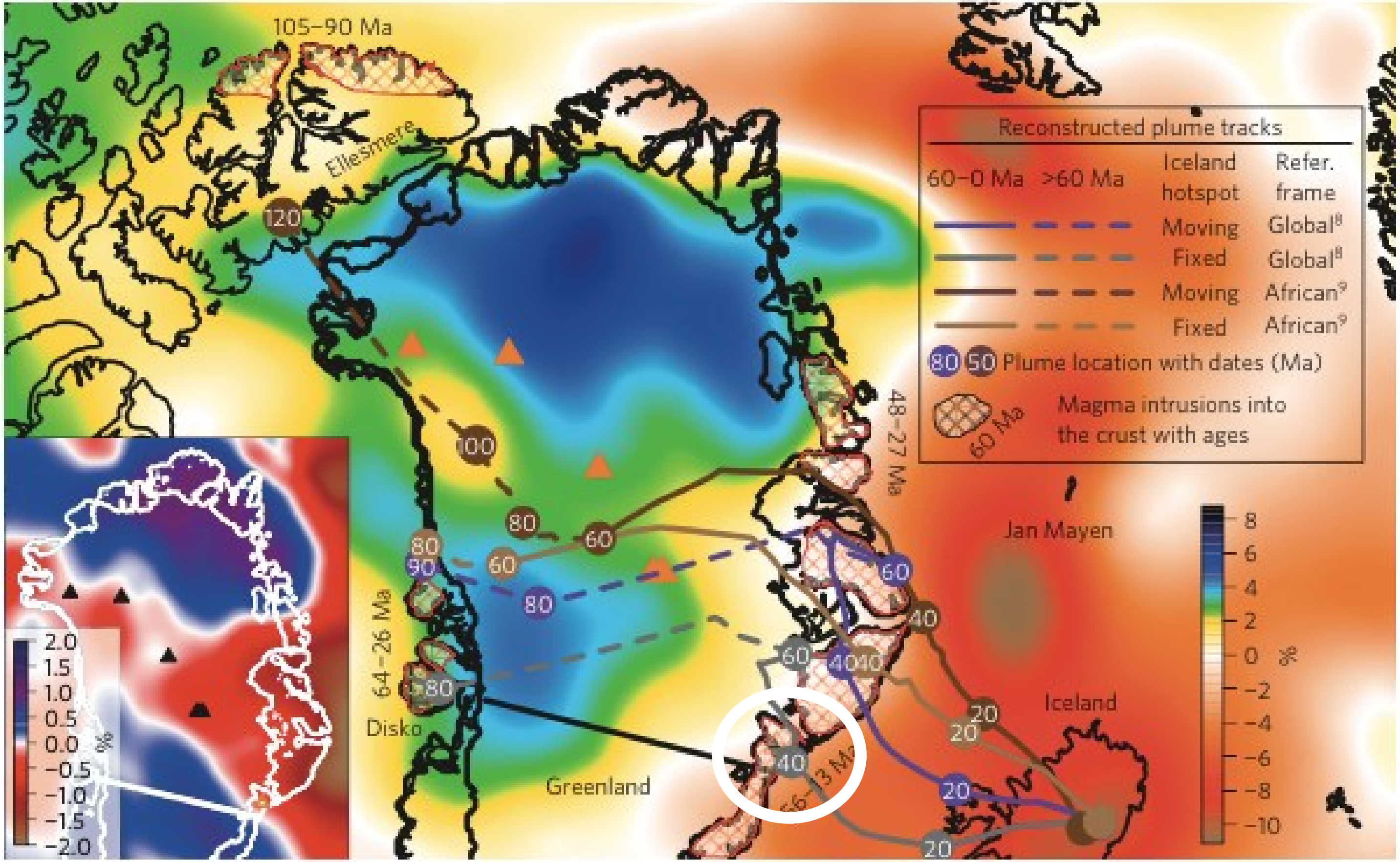
Khan et al. 2016





Hint of Hotspot track

Hotspot tracks



Rogozhina et al. 2016 - NatGeo

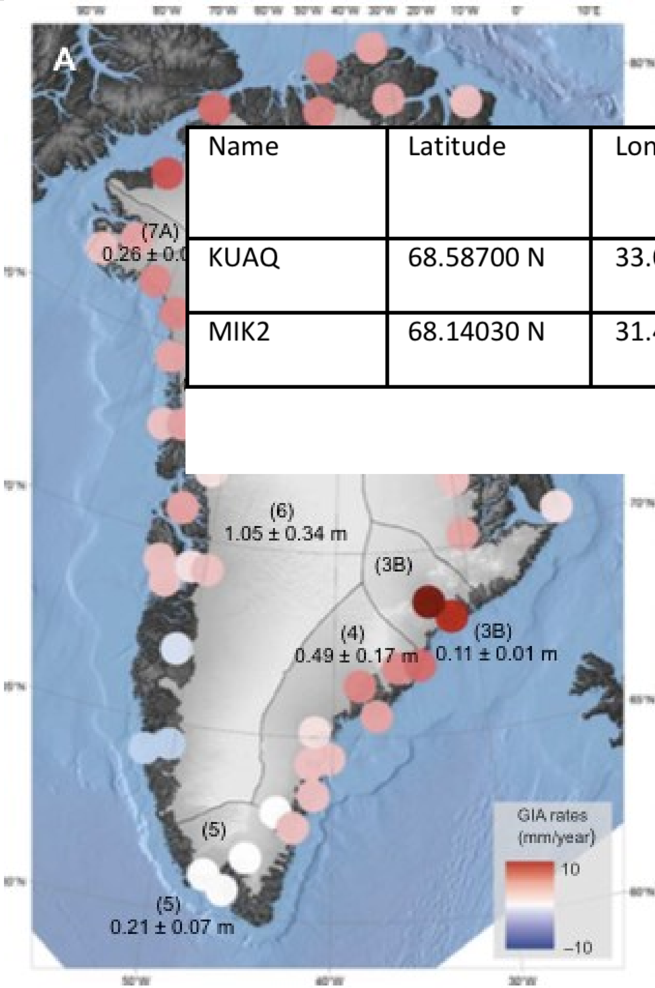
Motivations

1) There is a clear uplift anomaly in SE-Greenland detected by GNSS. More specifically two GPS nearby Kangerdlugssuaq glacier shows a residual uplift rate larger than the average in Greenland.

2) Below the same area there is one of the possible Icelandic hotspot tracks.

3) That could indicate the presence of a low viscosity mantle and with this study we want to investigate that possibility and see if we can constrain the values of such viscosity

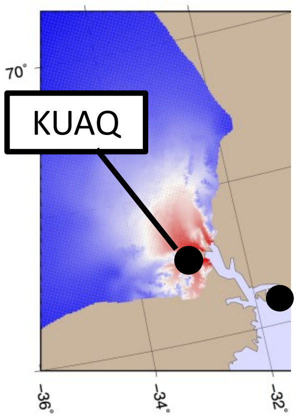
The residual GPS uplift rate

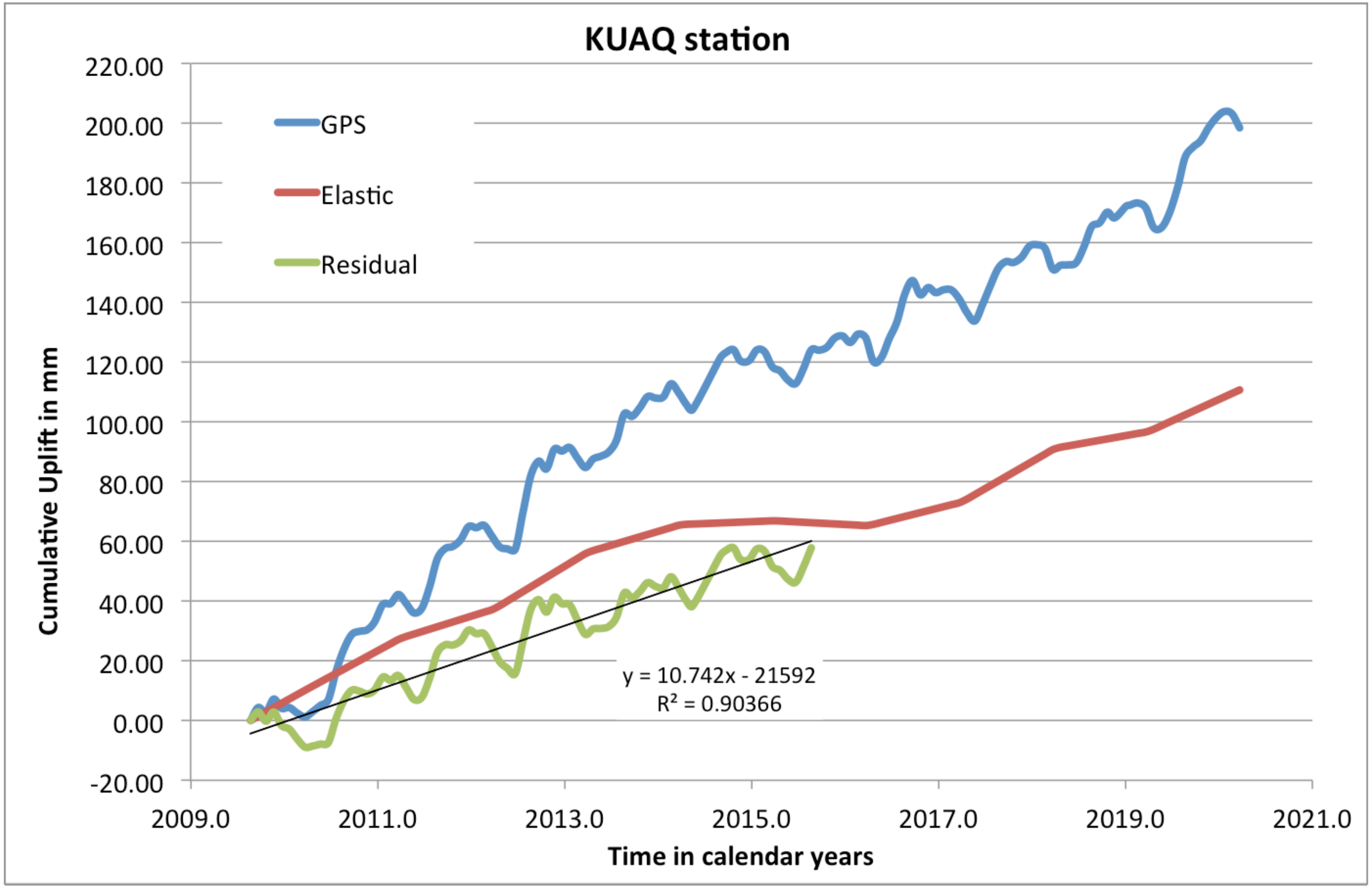


Name	Latitude	Longitude	t start	t end	Up rate (mm/year)	Elastic (mm/year)	GIA (mm/year)
KUAQ	68.58700 N	33.05270 W	2009.6	2015.6	23.8 ± 0.3	11.8 ± 1.3	12.0 ± 1.3
MIK2	68.14030 N	31.45180 W	2009.6	2015.6	15.4 ± 0.2	5.1 ± 0.1	10.3 ± 0.2

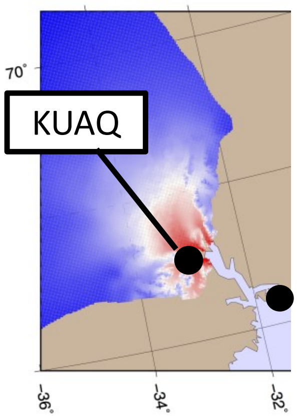
Khan et al. 2016

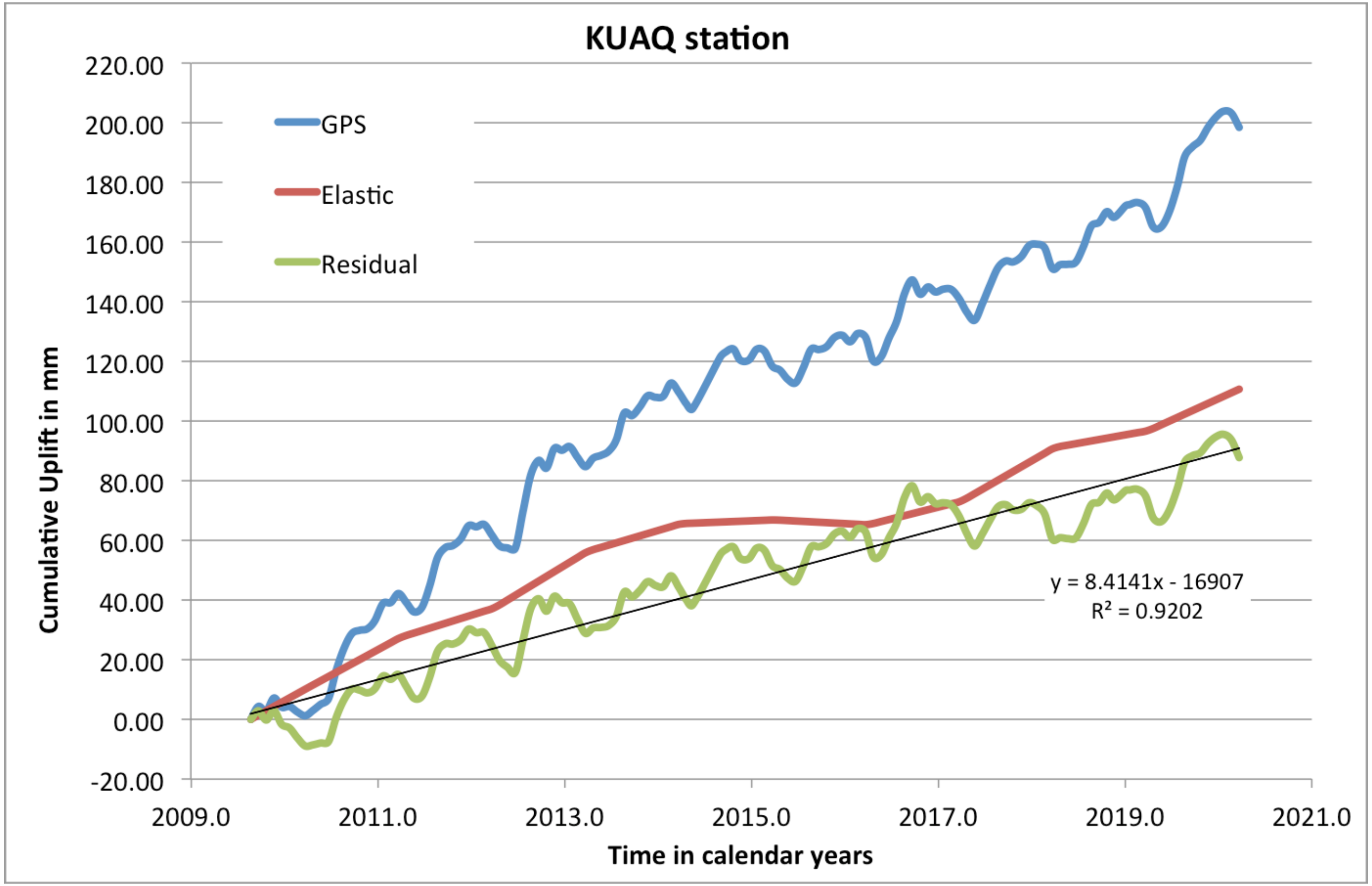
GPS time series



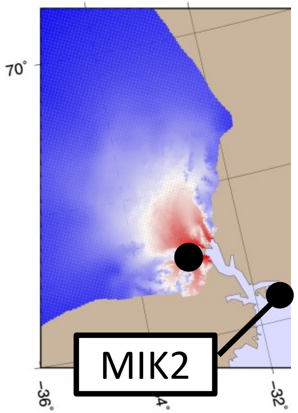


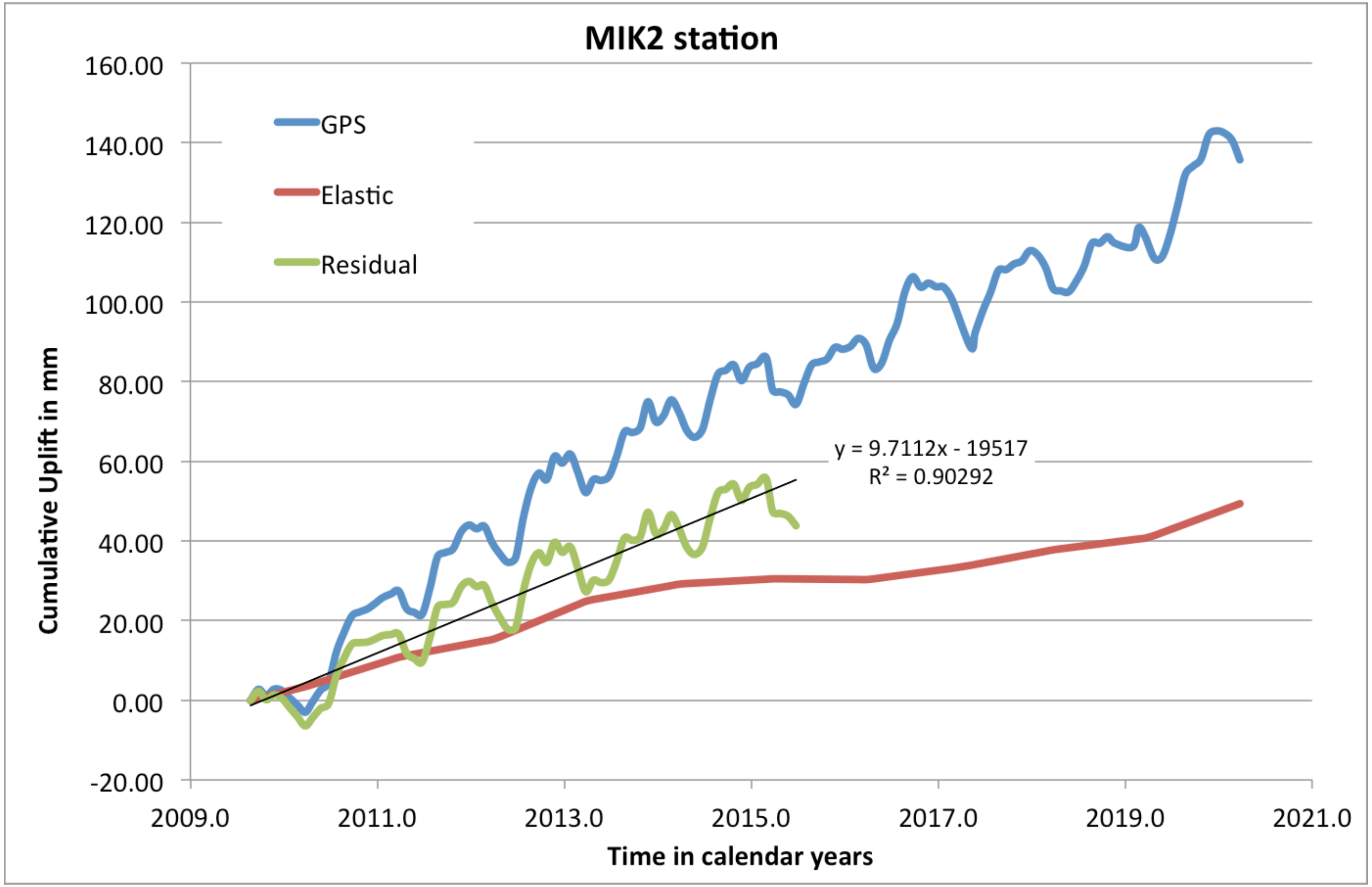
GPS time series



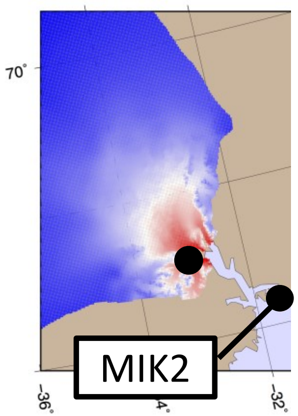


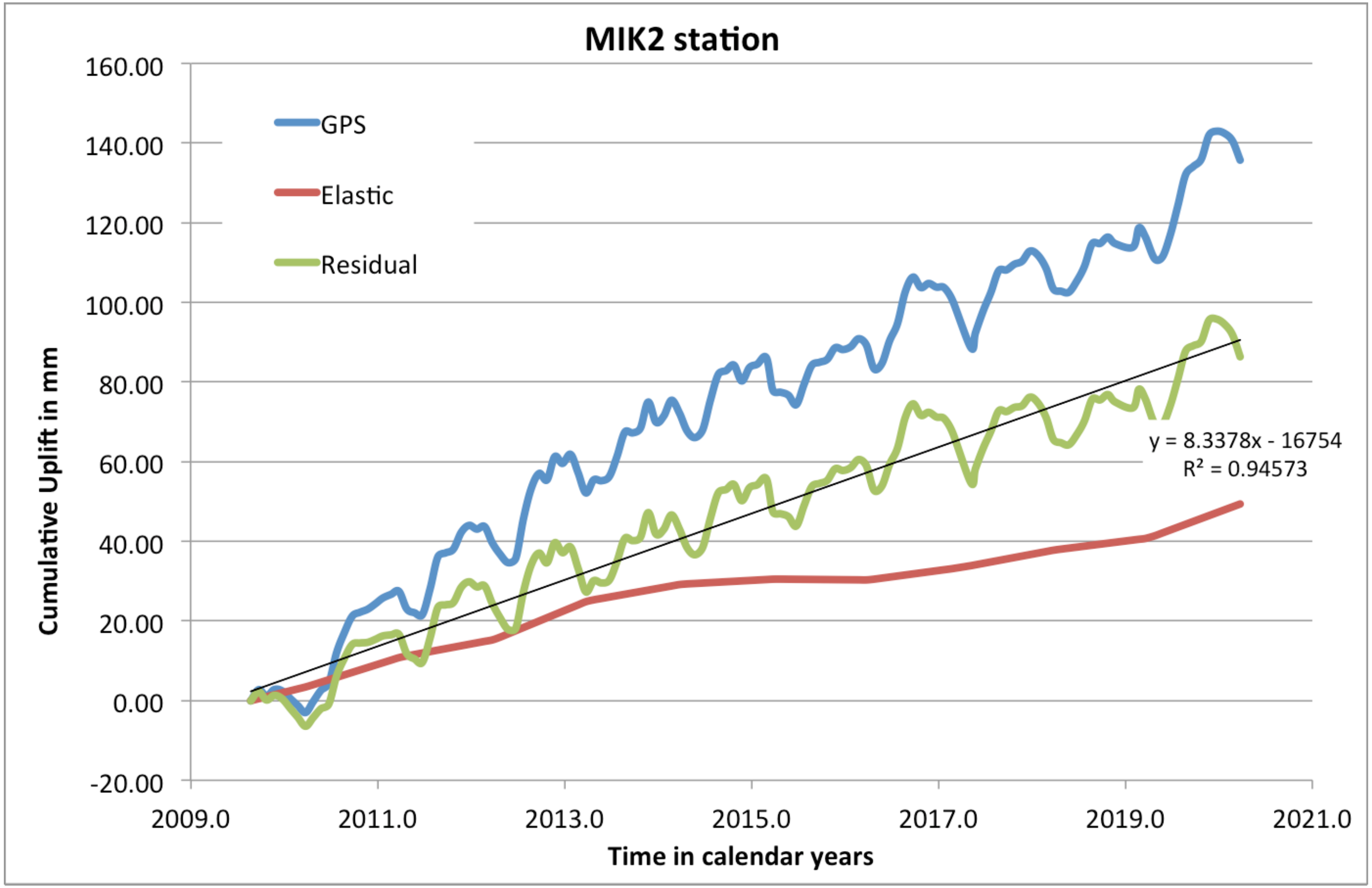
GPS time series



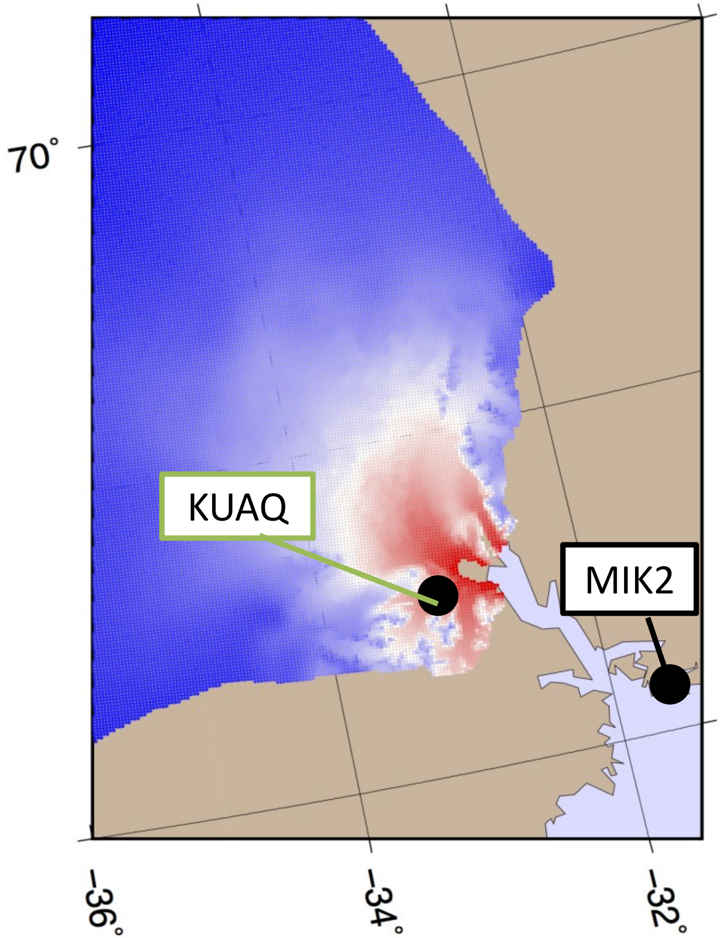


GPS time series





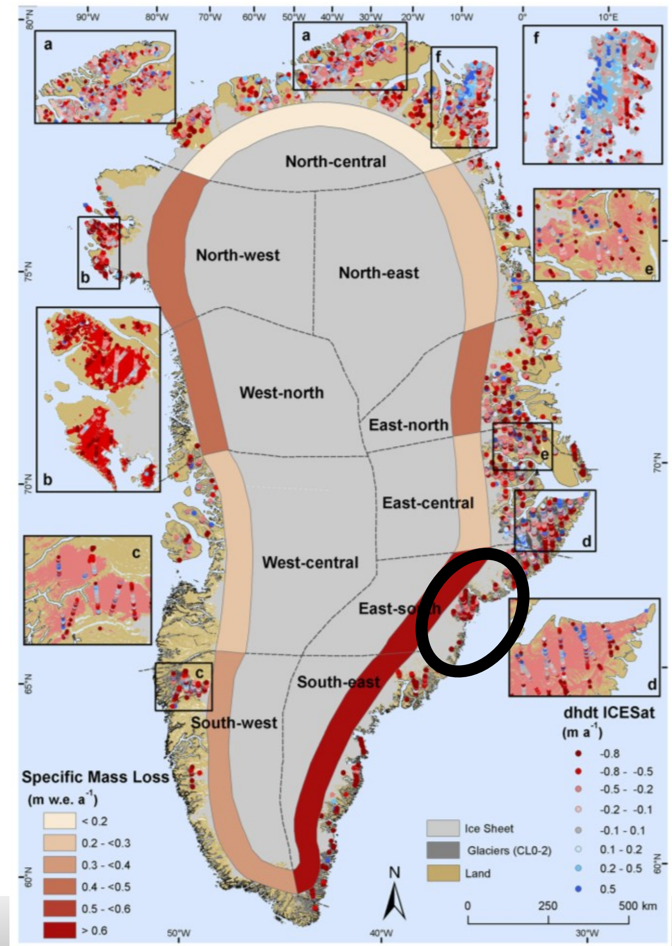
Peripheral Glaciers



From ESA Glaciers CCI

Non-continuous observations (IceSat1 period)

Bolch et al. 2013



Modeled time series for outer glaciers

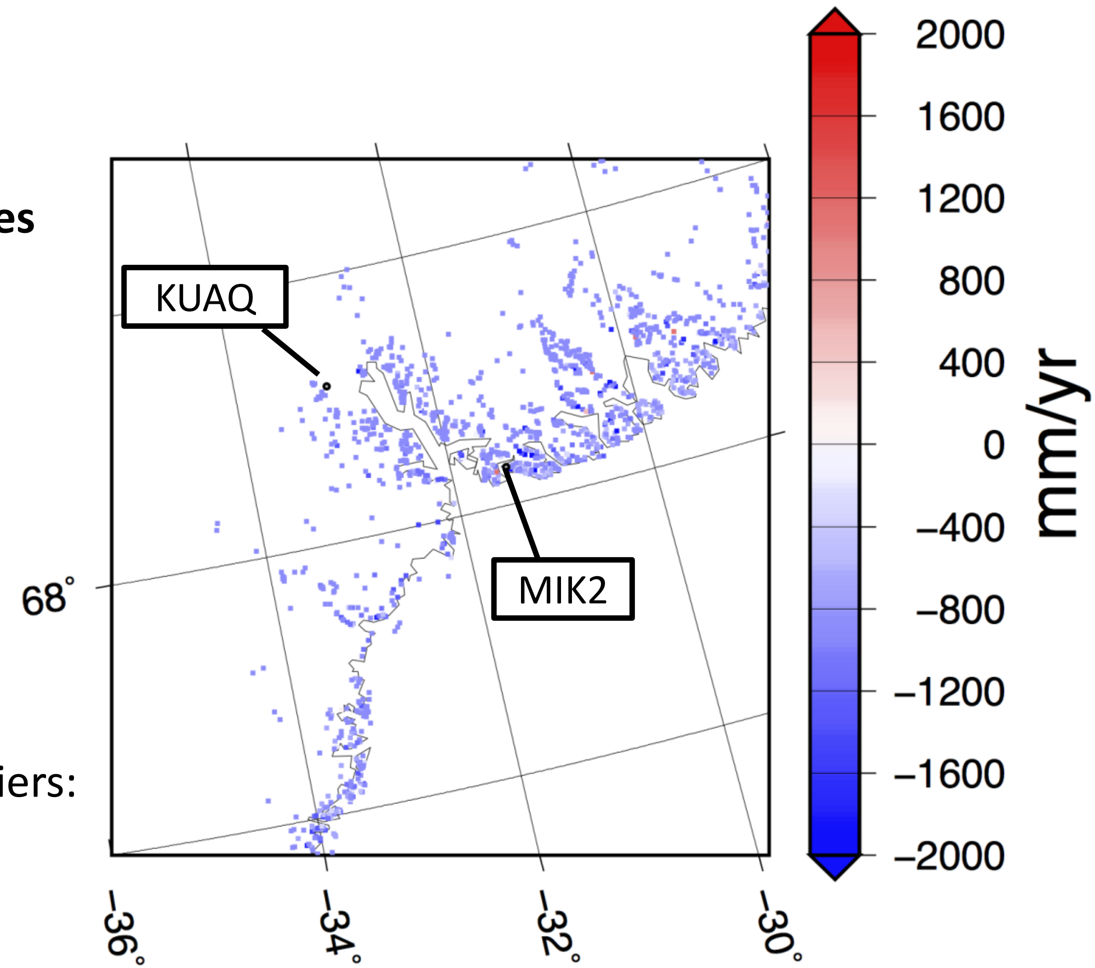
Full resolution version of the Global glacier model (GGM, Marzeion et al. 2012) – Greenland glaciers. Time series from 1901 to 2017

Extracted Trend for the period 2007-2017

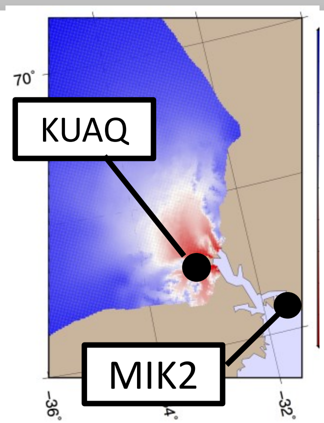
Average trend per glacier
-809.2 mm/yr (in water equivalent)

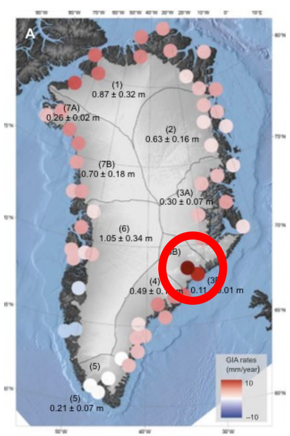
Elastic Contribution for Peripheral Glaciers:

KUAQ 2.39 mm/yr
MIK2 3.17 mm/yr



Elastic for Peripheral Glaciers





GPS uplift rates residual (Observed – Elastic)

KUAQ 12.0 +/- 1.3 mm/yr

MIK2 10.3 +/- 0.2 mm/yr

Elastic Contribution for Peripheral Glaciers

KUAQ 2.39 mm/yr

MIK2 3.17 mm/yr

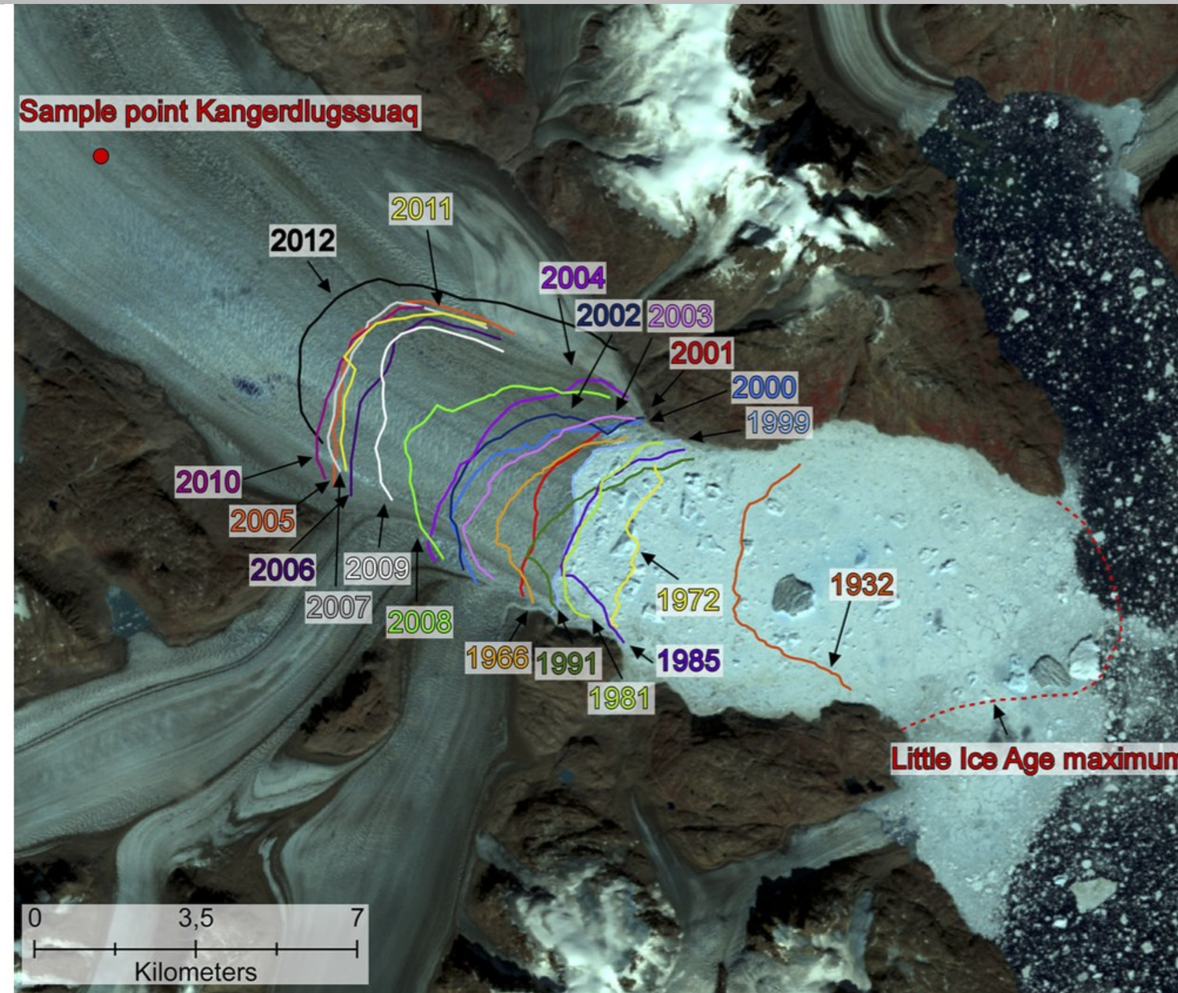
Name	Up rate (mm/yr)	Elastic (mm/yr)	GIA (mm/yr)	Elastic for GGM (mm/yr)	**Revised GIA (mm/yr)**
KUAQ	23.8 ± 0.3	11.8 ± 1.3	12.0 ± 1.3	2.39	**9.6 ± 1.3**
MIK2	15.4 ± 0.2	5.1 ± 0.1	10.3 ± 0.2	3.17	**7.13 ± 0.2**

Ice history in Kangerlugssuaq since Little Ice Age

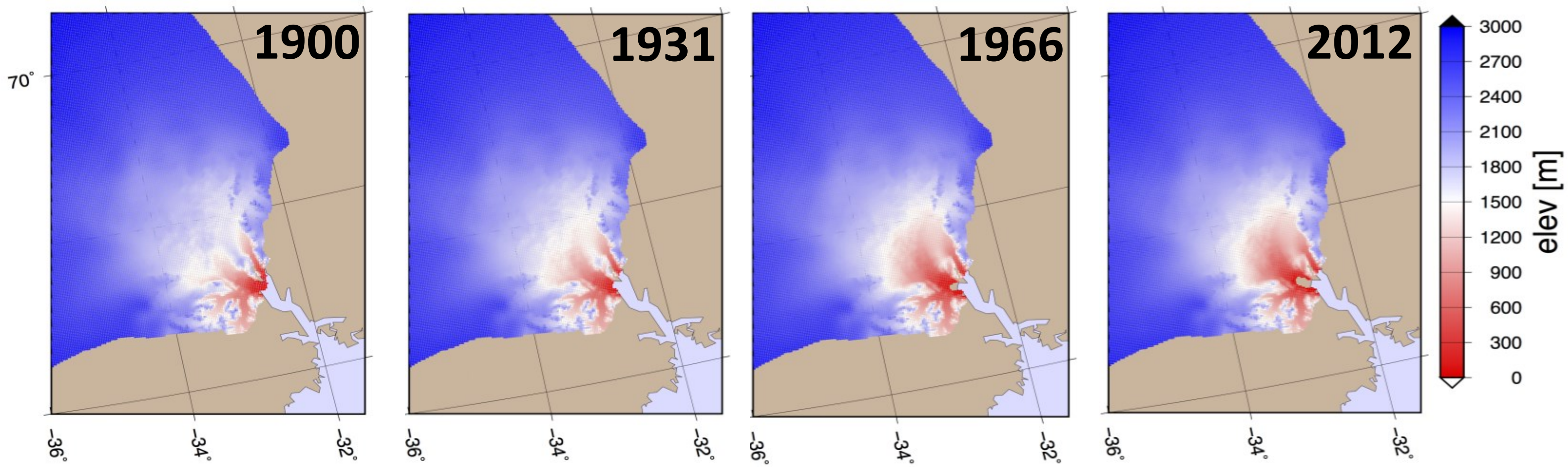
Khan et al. 2014

S. A. Khan, K. K. Kjeldsen, K. H. Kjær, S. Bevan, A. Luckman, A. Aschwanden, A. A. Bjørk, N. J. Korsgaard, J. E. Box, M. van den Broeke, T. M. van Dam, A. Fitzner, Glacier dynamics at Helheim and Kangerdlugssuaq glaciers, southeast Greenland, since the Little Ice Age. Cryosphere 8, 1497–1507 (2014).

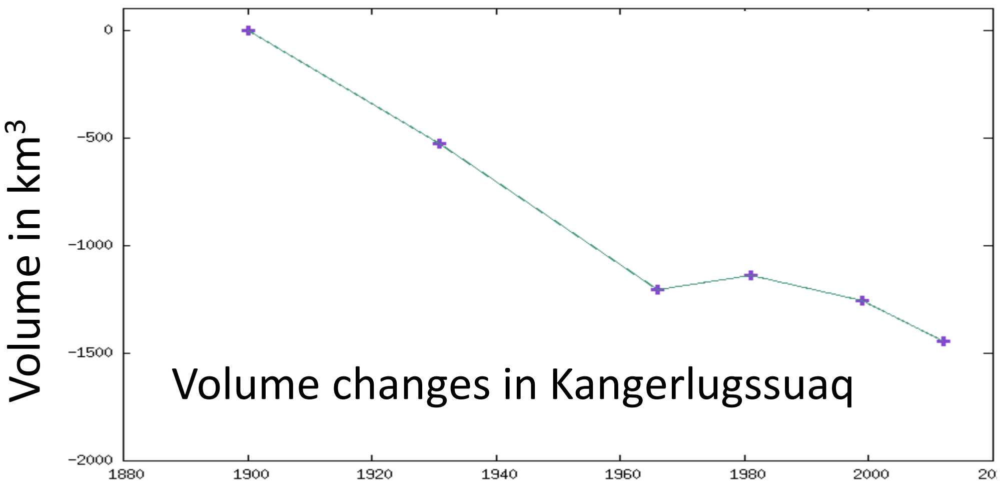
Frontal position of Kangerlugssuaq Glacier from:
Oblique aerial image (1932)
Corona satellite (1966)
Vertical aerial image (1972, 1981)
Landsat 5 TM (1985, 1991)
Landsat 7 ETM+ (1999-2012)

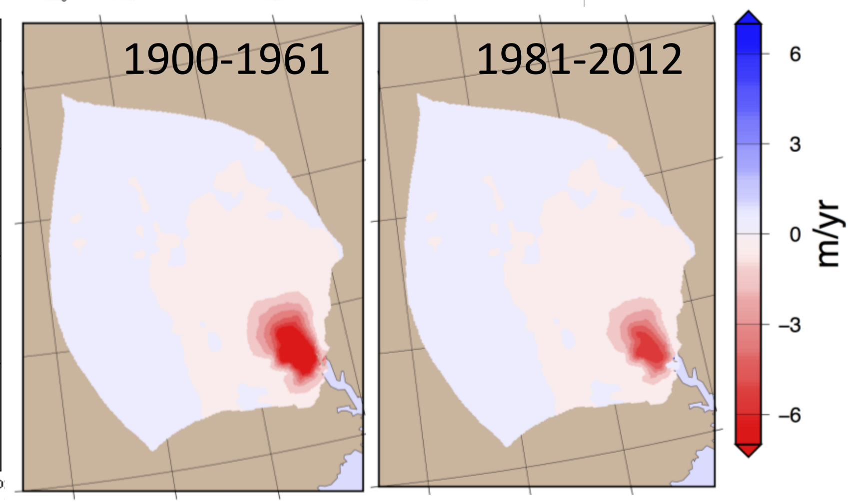


Estimate of ICE change since LIA

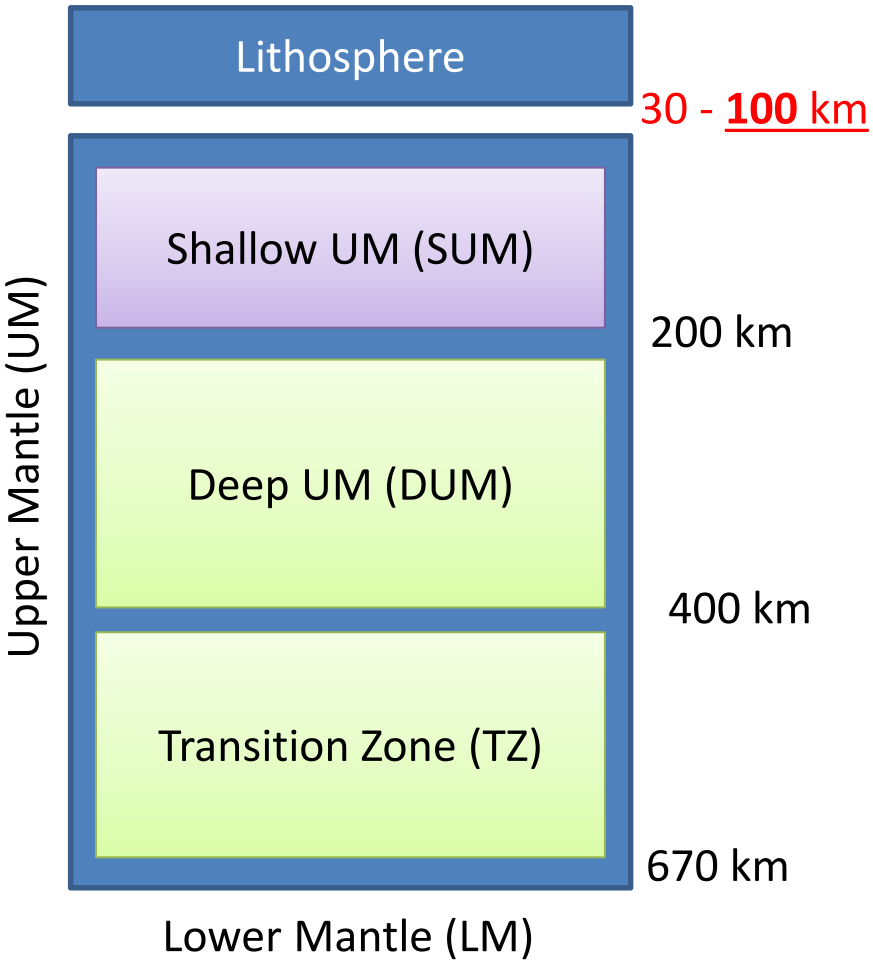


data from
Khan et al. 2014





The (low-viscosity) mantle structure



$\nu_{SUM} = \underline{10^{17} - }10^{21}$ Pa s

$\nu_{DUM} = \underline{10^{18} - }6.3x10^{21}$ Pa s

$\nu_{TZ} = \underline{6.3x10^{21} \text{ Pa s}}$

$\nu_{LM} = 2x10^{22}$ Pa s

3165 Earth models combinations of 3 parameters

The solid Earth model

1D viscoelastic compressible Earth model and software used in Barletta et al. 2018 as local approximation with a 5 layer viscoelastic Earth structure (in the previous slide).

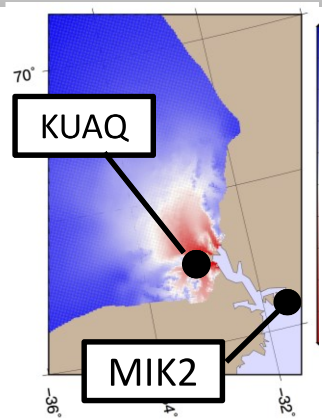
We use the software VE-CL0V3RS v3.6 to compute the elementary viscoelastic time-dependent Green's functions up to degree 1195 and thereafter we assume they do not change with time, so the trend is zero.

For each combination of Earth parameters we performed a temporal and spatial convolution with the ice history to compute uplift rate prediction as GPS sites. Such convolution is performed using the VE-HresV2 (Visco-Elastic High-Resolution technique for Earth deformations) software (Barletta et al. 2018 and 2006).

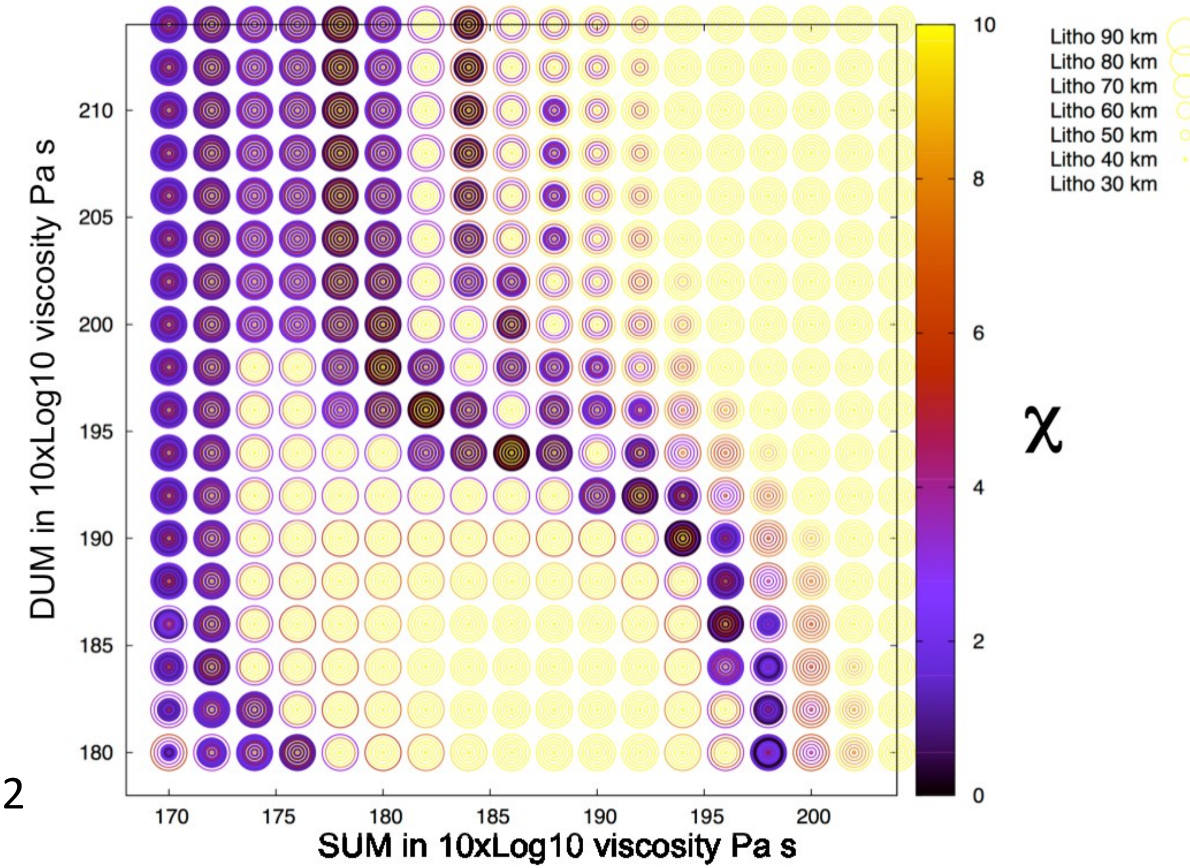
For the comparison between model prediction and GPS residual we use a simplified Chi test:

$$\bar{\chi}_k^2 = \frac{1}{N}\sum_{j=1}^{N}\left(\frac{oRES_j - U_k}{\sigma_{GPS_j}}\right)^2$$

Test with corrected residual for both stations

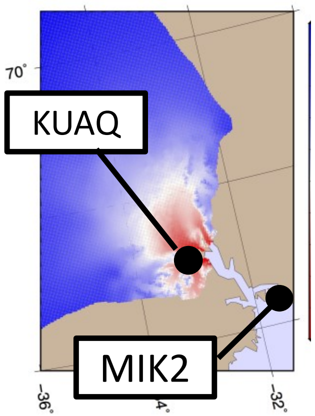


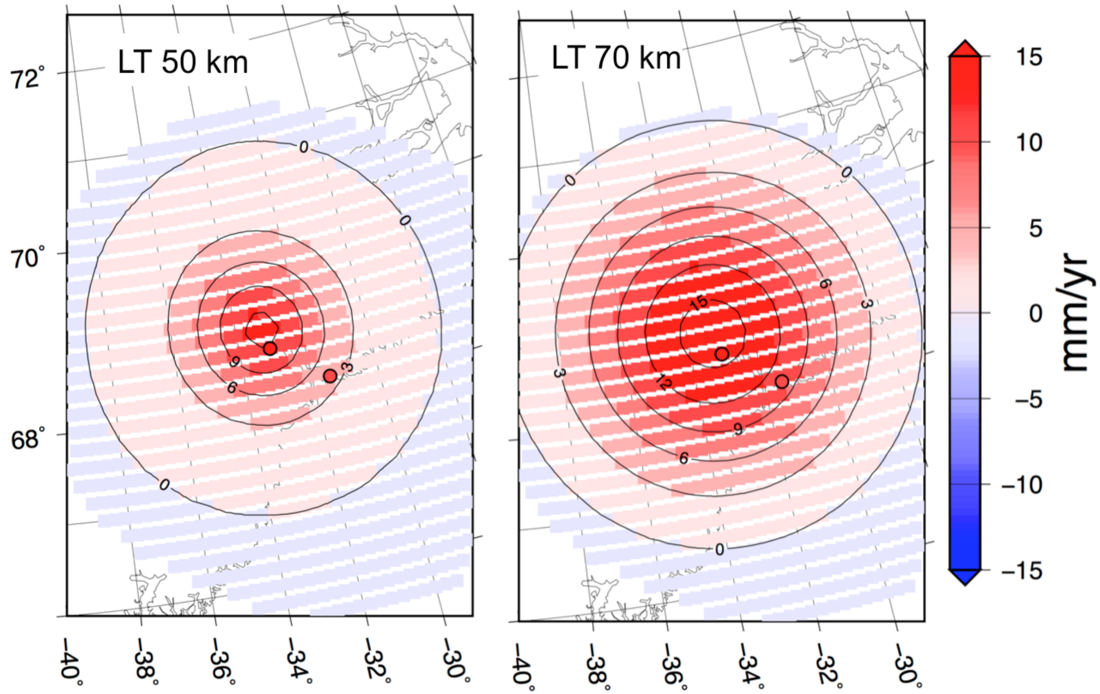
GPS residual – Elastic from Glaciers
KUAQ 9.60 +/- 1.3 mm/yr
MIK2 7.13 +/- 0.2 mm/yr



Solid circle for Chi<2

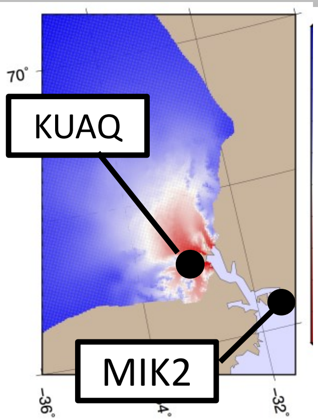
The spatial pattern

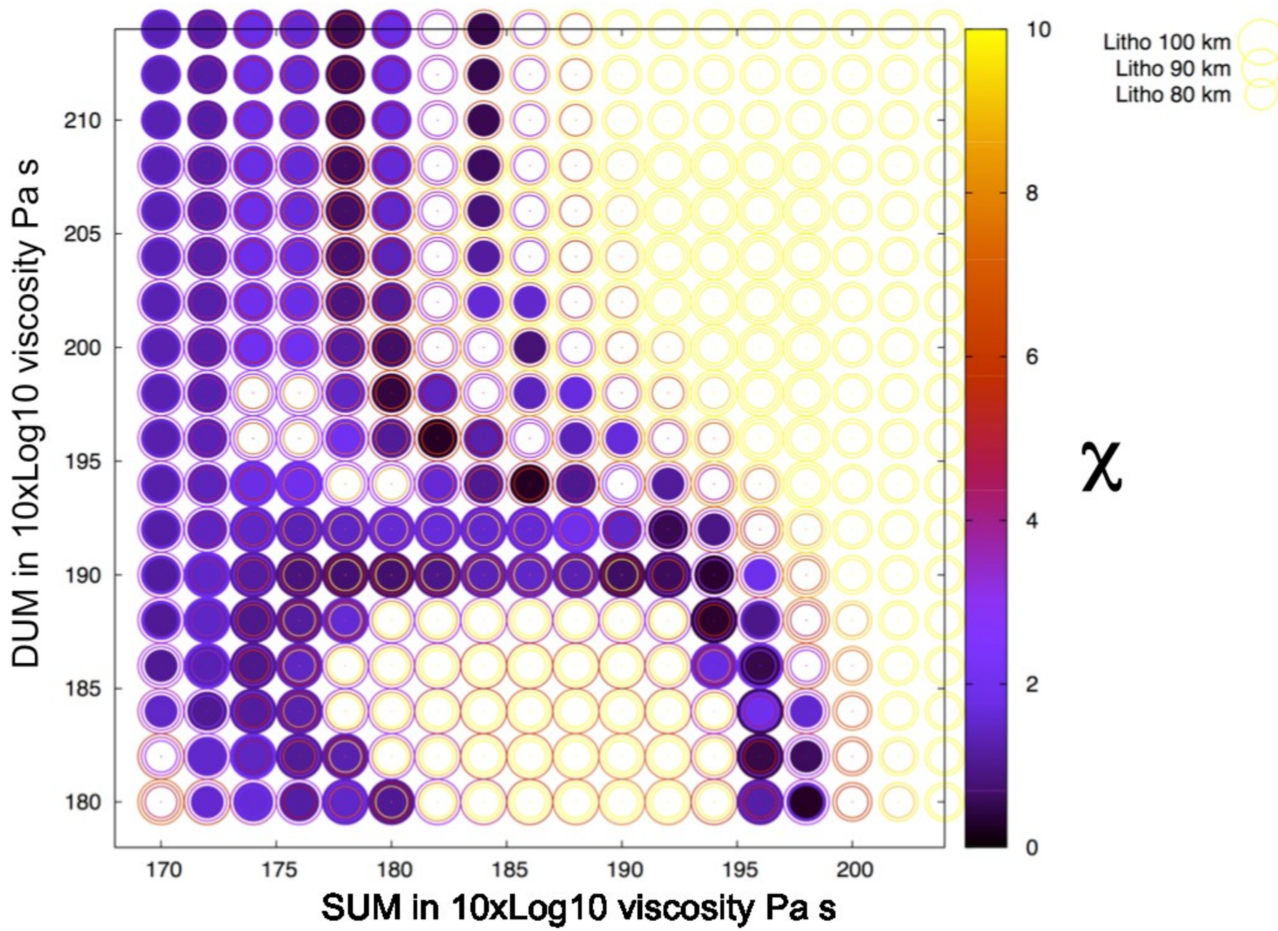




The GIA signal in this case is a very simple bell-shaped pattern with the maximum near KUAQ station and decreasing more or less rapidly (depending on LT) farther away. A thin lithosphere doesn't seem suitable because the modelled signal decreases too much when it reaches MIK2. Moreover, we have a larger error on KUAQ station, which means that the predictions of the model there can have a wider spread.

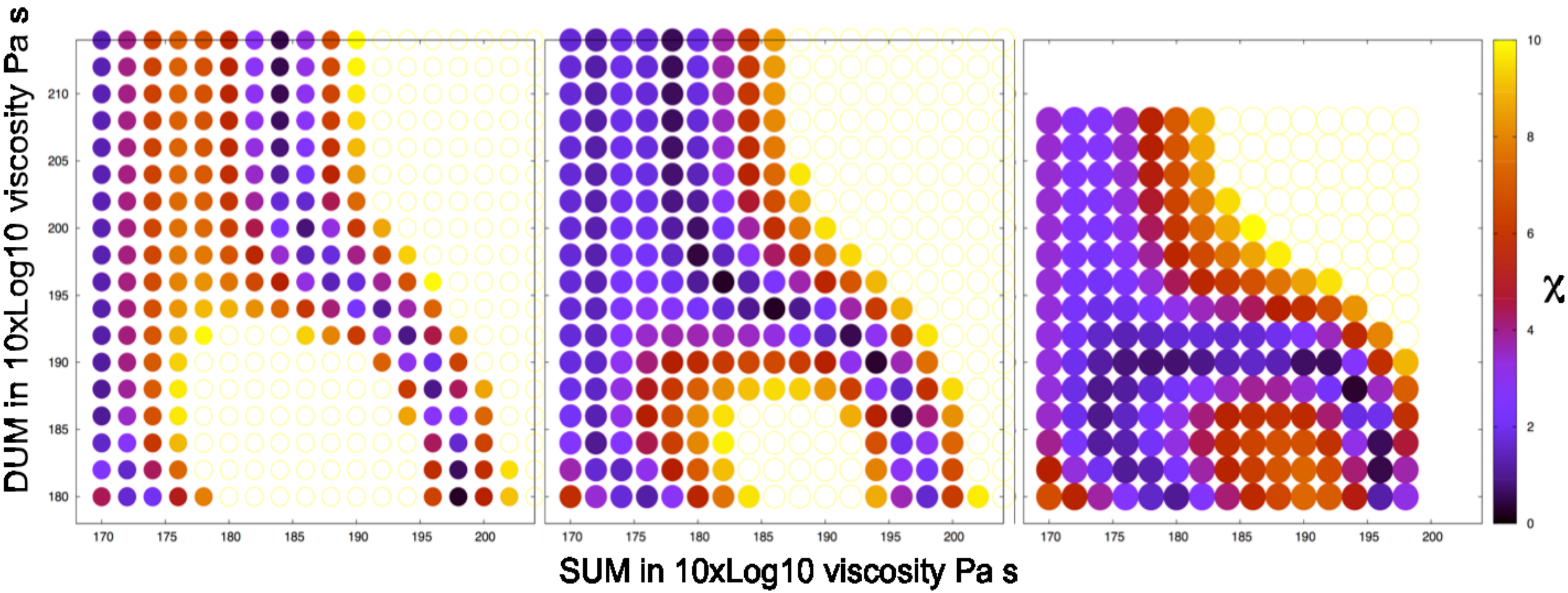
Test with corrected residual for both stations





Solid circle for $\chi<2$

Chi Test for 80 - 90 - 100 km lithosphere



Equally good models

4 regions for the viscosity

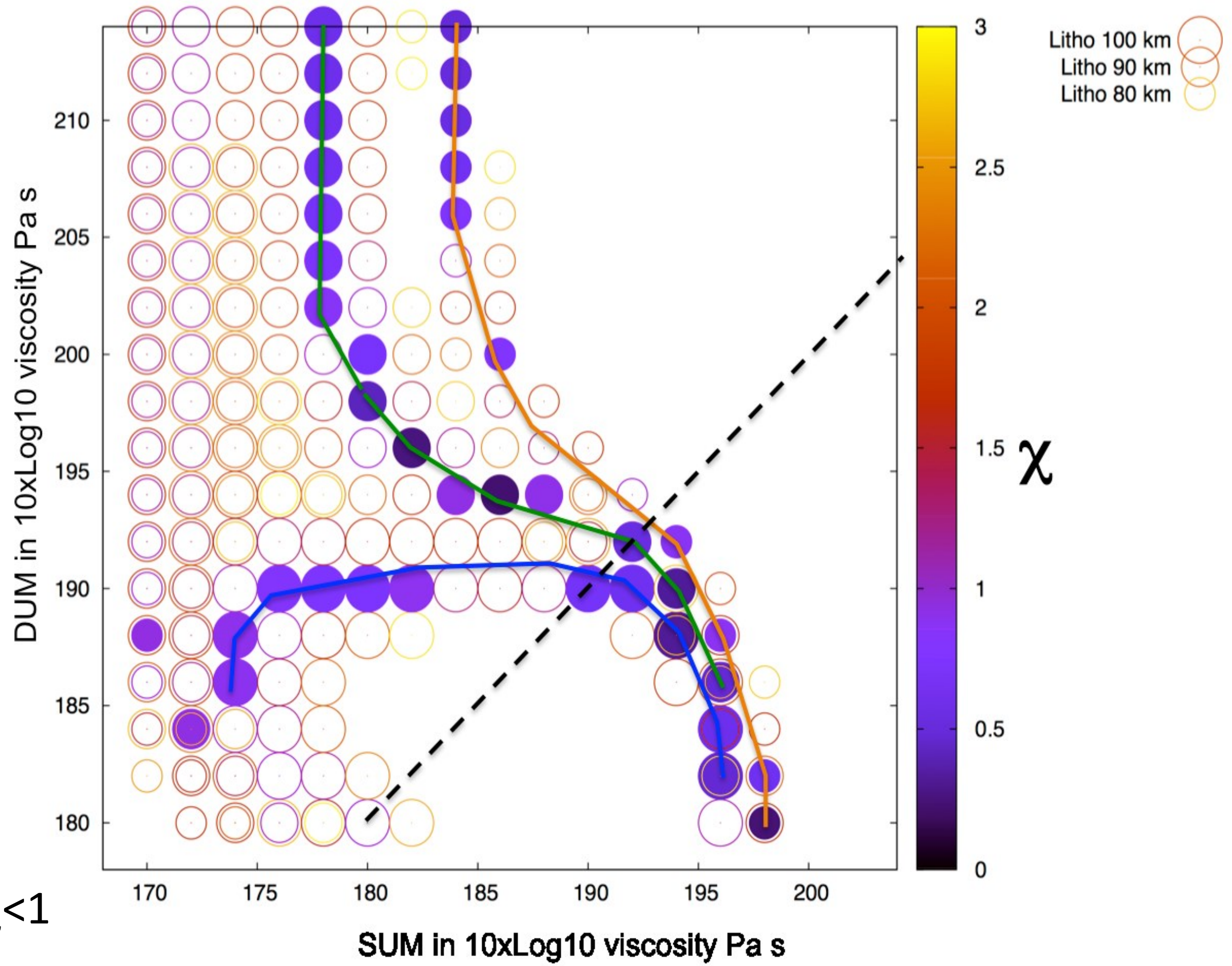
1. DUM > 10^{20} Pa s, very low viscosity SUM ($6.3x10^{17}$ - $2.5x10^{18}$ pa s), LT 90 - 80 km. The thicker the LT and the lower the SUM viscosity has to be. No good models are found for LT <70 km in this range of viscosities.

2. very low viscosity for both SUM (<184 10xLog10 Pa s) and DUM (< 10^{19} Pa s). LT=100 km is preferred.

3. very low viscosity DUM (< 10^{19} Pa s) and SUM around $4x10^{19}$ Pa s. LT, from 80 to 100 km, give equally good results.

4. Around DUM 195 and SUM 184 (10xLog10 Pa s) LT 90 km best models

Solid circle for χ<1



Equally good models

4 regions for the viscosity

1. DUM > 10^{20} Pa s, very low viscosity SUM (6.3×10^{17} - 2.5×10^{18} pa s), LT 90 - 80 km. The thicker the LT and the lower the SUM viscosity has to be. No good models are found for LT <70 km in this range of viscosities.
2. very low viscosity for both SUM (<184 10xLog10 Pa s) and DUM (< 10^{19} Pa s). LT=100 km is preferred.
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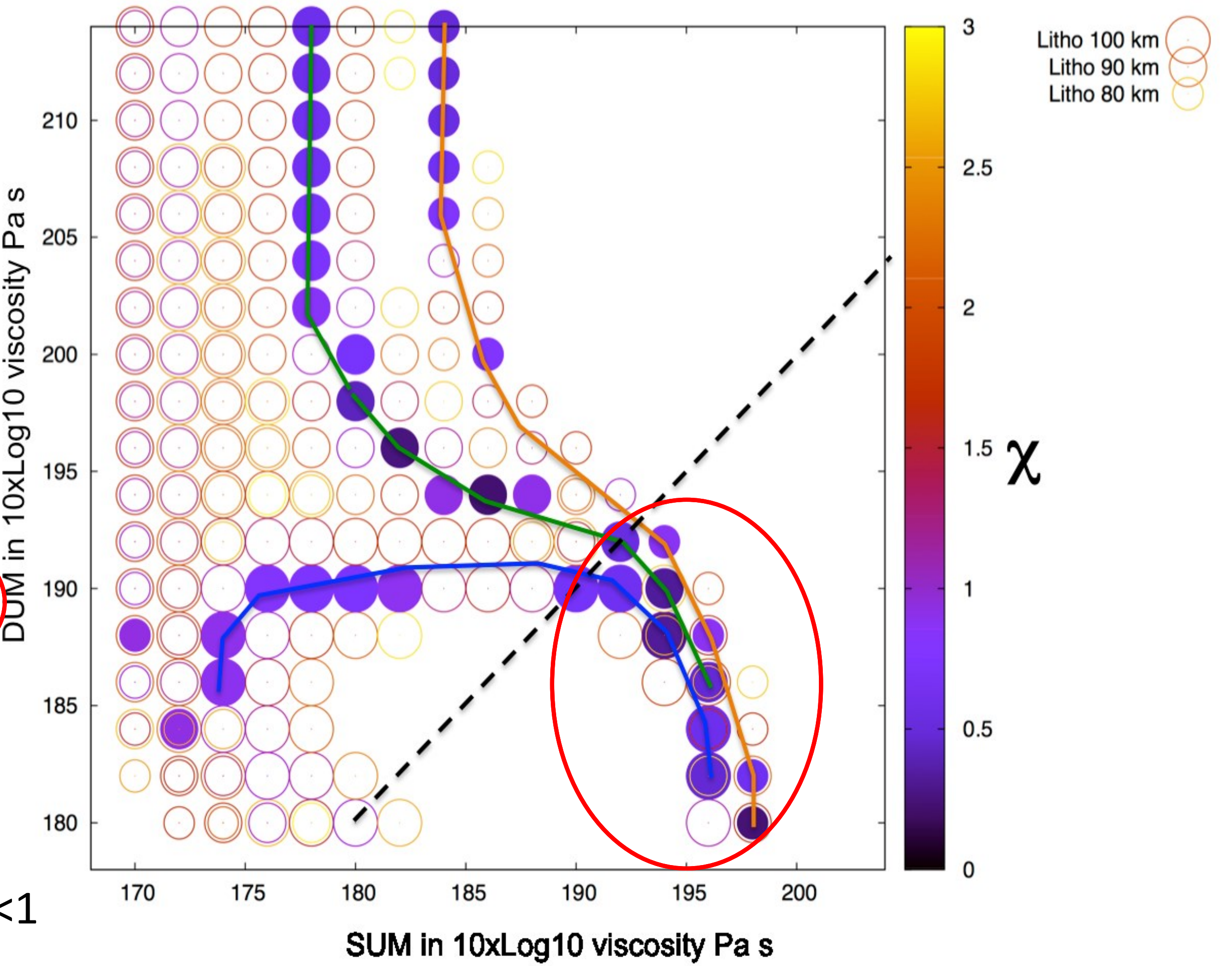
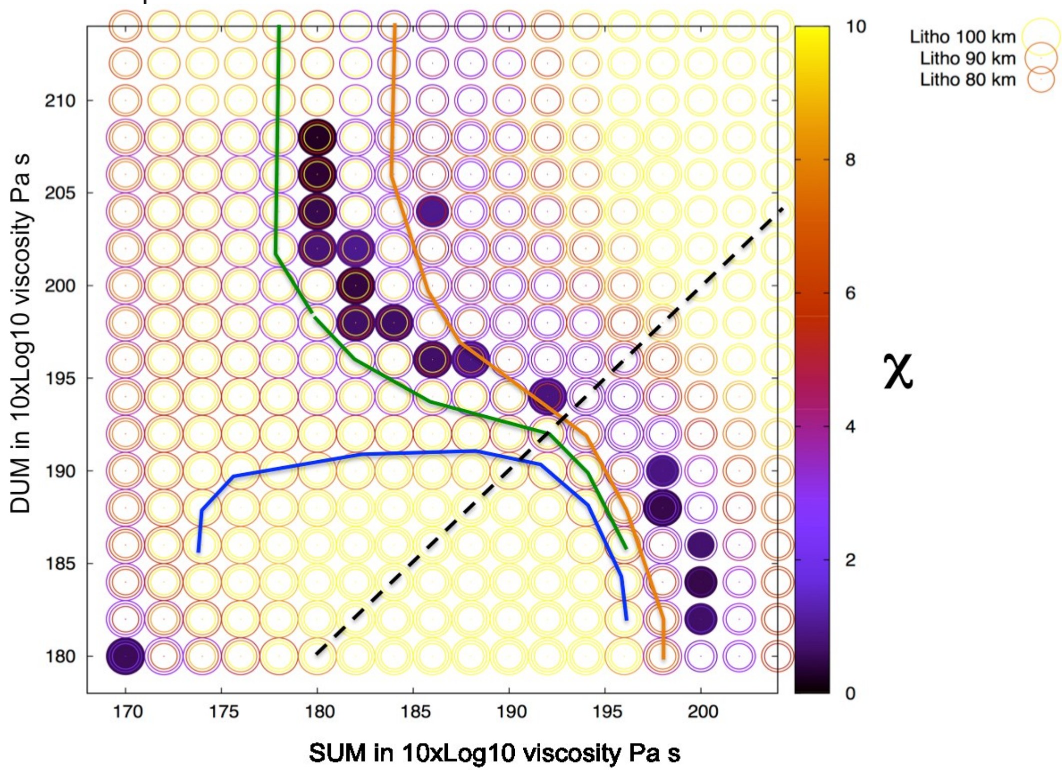


Using the updated GPS uplift rates

Name	Updated GIA (mm/yr)	~Elastic for GGM (mm/yr)	*~Revised GIA (mm/yr)*	*difference in %*
KUAQ	8.41 ± 1.3	*2.39*	***6.01 ± 1.3****	***-37%***
MIK2	8.34 ± 0.2	*3.17*	***5.16 ± 0.2****	***-27%***

Clear shift of about 2 units of the SUM scale.
This corresponds to a 5% variation in the results upon a variation around 30% of the data.

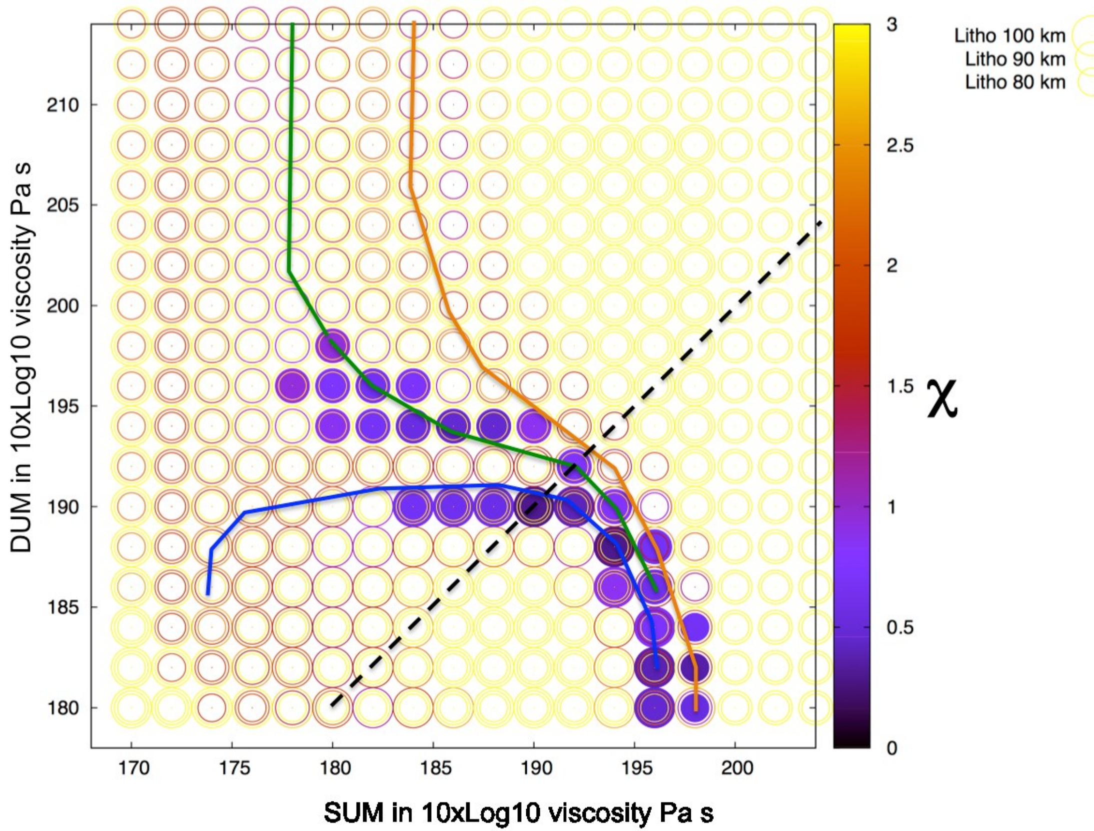
=> the pattern we found is quite stable



Using same weight for both GPS stations

fixed 0.5 mm/yr error (weight) for both GPS points

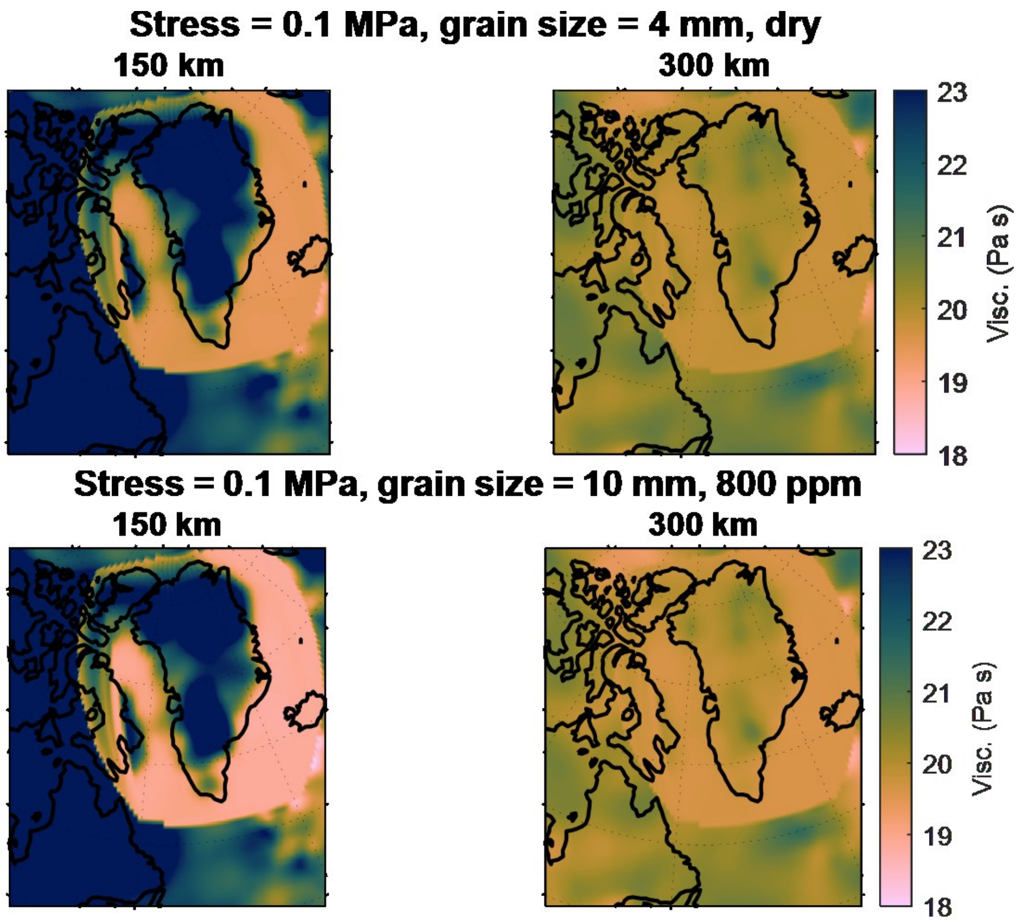
The best models have LT 100 and are in the region where SUM has slightly higher viscosity than DUM



3D viscosity maps

Viscosities calculated with a temperature model. The temperature model does not cover the entire domain.

A lower viscosity in the deeper upper mantle can be achieved if the grain size decreases with depth. Grain size reaches a minimum around 150 km, and then slowly increases to depth of 400 km or remains constant (Behn et al., 2009). Water content is not likely to increase with depth as there is no subduction that brings water to larger depth.



Conclusions

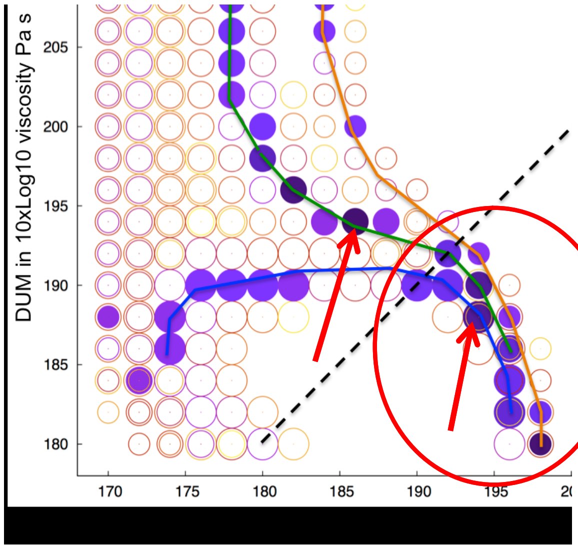
- With only two GPS time series and GIA modelling we can gain insight on both the lithospheric thickness and the viscosity structure below Kangerlussuaq region, overall indicating a strong compatibility with the presence of the hot spot track.

- Overall a rather thick lithosphere is preferred, i.e. between 90 and 100 km. This is compatible with a lithospheric thickness of about 20% less than the average of the rest of Greenland.

- The upper mantle most likely has a structure, i.e. it is not uniform. The overall upper mantle viscosity has to be quite low, however it is not well constrained which part of the upper mantle has to be low. Two well-fitting solution can be taken as reference: LT 90 km S186-D194 and LT 100 km S194-D188.

- The peculiar viscosity structure we find can also be explained with 3D viscosity maps calculated with more complex Earth models.

- **We verified the stability of our viscosity grid search** and we find that our conclusion about the upper mantle having low viscosity and a quite clear structure remains solid even if the GPS residual are about 30% different from what we used.



Thank you