

The Fennoscandian Land Uplift Gravity Lines

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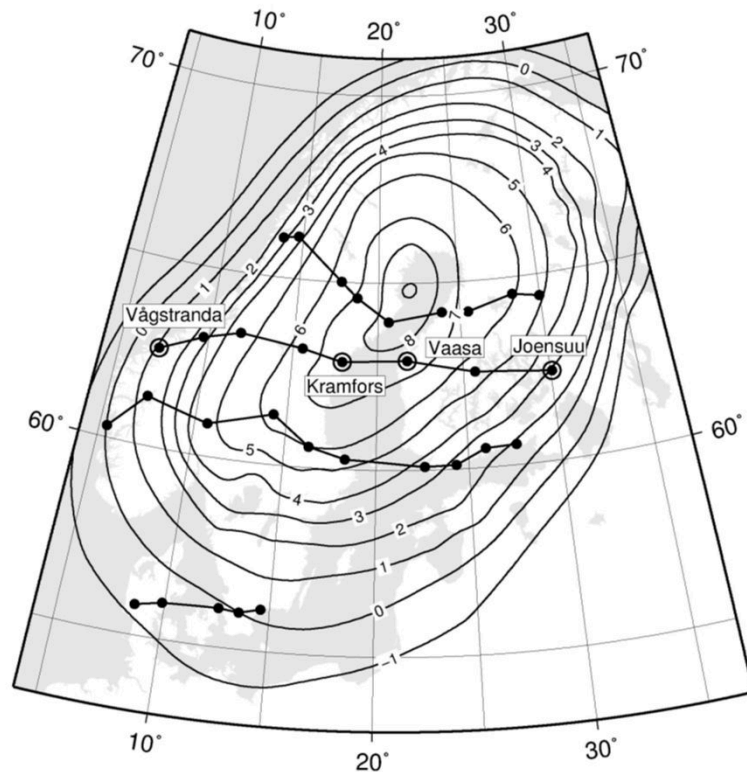
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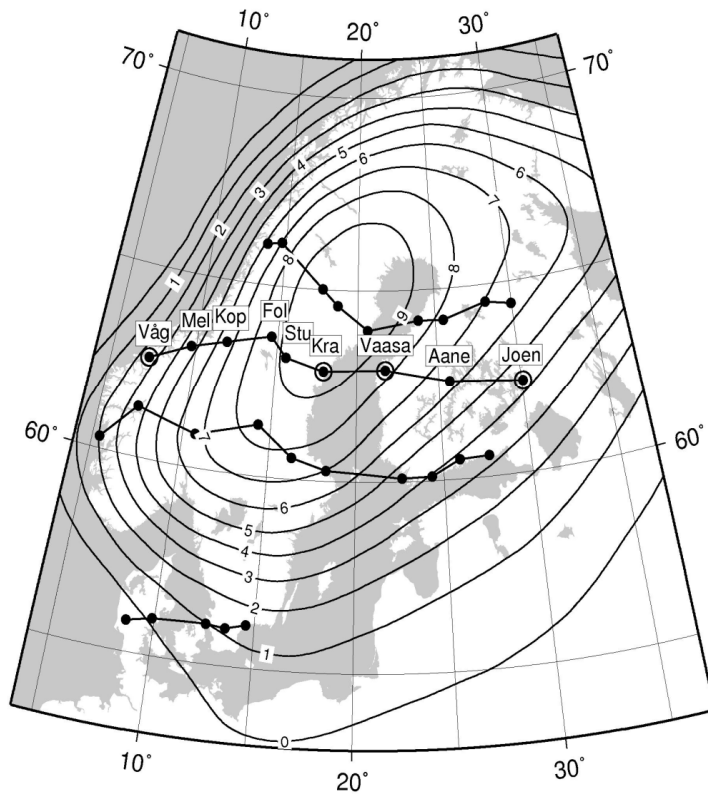
What are the Fennoscandian Land Uplift Gravity Lines?



Land uplift isobases by Ekman (1996)

- They are 4 approximately E-W profiles of outdoor gravity stations, measured using LaCoste & Romberg relative gravimeters
- Line along 63°N started in Finland by Aimo Kiviniemi (FGI) in 1966
- Continued 1967 to Sweden and Norway by Lennart Pettersson and Lars Åke Haller (LMV)
- Norway (Bjørn Geirr Harsson and Åge Midtsundstad, NGO/SK) joined 1972
- International (not only Nordic) participation, from 10 institutions
- Line along 65°N, first measurement in 1975
- Line along 61°N, first measurement in 1976
- Line along 56°N (Denmark- Sweden) first measured in 1977
- Coordinated by the NKG Working Group for Geodynamics

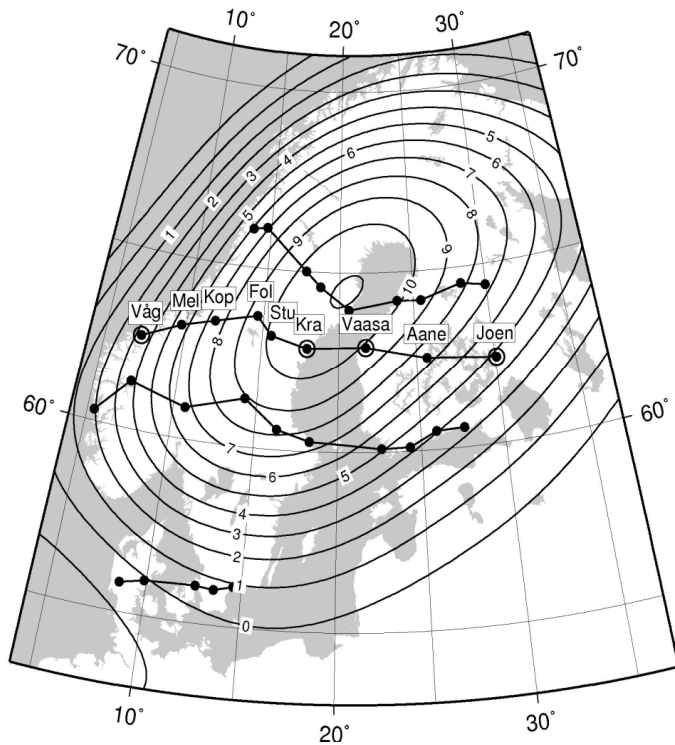
What is the purpose?



Land uplift isobases by Lambeck (1998)

- To observe the change in surface gravity to the Postglacial Rebound PGR
- This was already very early formulated in terms of two extreme hypotheses
- “Free-air”: for height change δh the gravity change δg corresponds to the free air gradient $\partial\gamma/\partial h$
- $\delta g / \delta h = -0.31 \mu\text{Gal}/\text{mm}$
- i.e., no mass compensation; the free-air gravity anomaly is unchanged
- “Bouguer”: there is a mass compensation corresponding to the density of the upper mantle
- $\delta g / \delta h \doteq -0.16 \mu\text{Gal}/\text{mm}$

Why relative gravimeters?



Land uplift isobases by Milne et al. (2004)

- In 1966 absolute gravimeters were rare; for physics laboratories only
- the Hammond-Faller free-fall absolute gravimeter (50 μGal accuracy) was used to measure 8 stations in 1968-1969
- they formed the basis of the International Gravity Standardization Net IGSN71
- LaCoste & Romberg relative gravimeters were available on loan from the (predecessor of) the Defence Mapping Agency (US)
- and had nominal accuracy of 10 μGal
- and in microgravimetry much better

Experimental setup



- Only quite small gravity differences could be accurately measured
- Stations had to be cleverly reconnoitered
- Line 63° had gravity differences of the order of 1 mGal, later lines some tenths of mGal
- Smoothed surfaces of bedrock with a marker for height reference
- Expedition with 1-2 observers and 2-5 gravimeters travels on the line (or on a part of it) in a car 3-5 times to and fro
- about 4 weeks needed to measure a complete line

Ekman and Mäkinen (GJI 1996)

Geophys. J. Int. (1996) **126**, 229–234

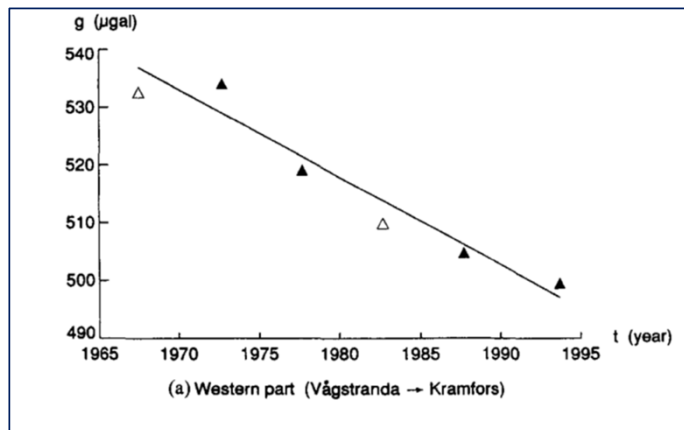
Recent postglacial rebound, gravity change and mantle flow in Fennoscandia

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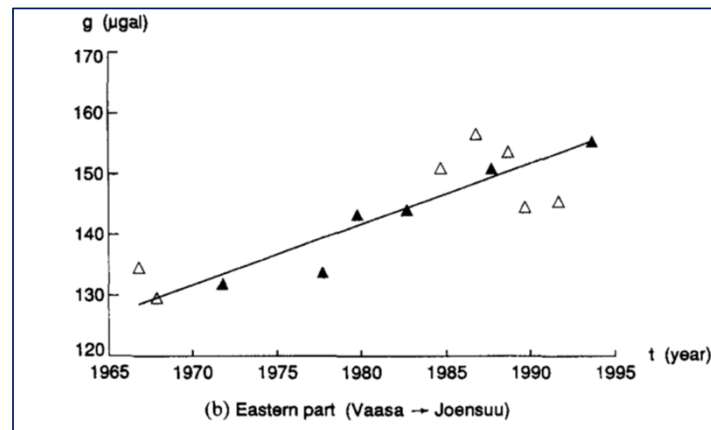
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Western part

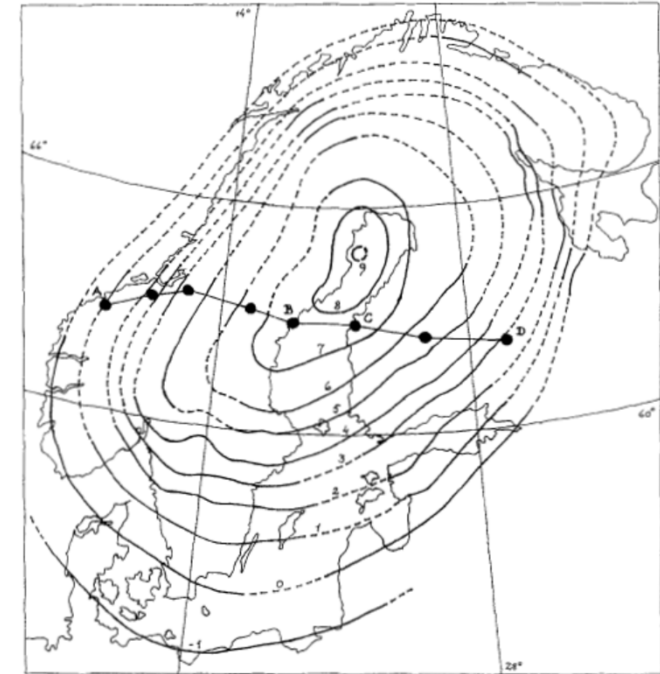


$$\dot{g} = -1.52 \pm 0.20 \mu\text{gal yr}^{-1}$$

Eastern part



$$\dot{g} = 1.00 \pm 0.14 \mu\text{gal yr}^{-1}$$



Ekman and Mäkinen (GJI 1996)

- Best estimate for the vertical velocity difference “Kramfors minus Vågstranda” from tide gauges

$$\dot{H} = 6.9 \pm 0.5 \text{ mm yr}^{-1}$$

- Best estimate for the vertical velocity difference “Joensuu minus Vaasa” from repeated precise levelling

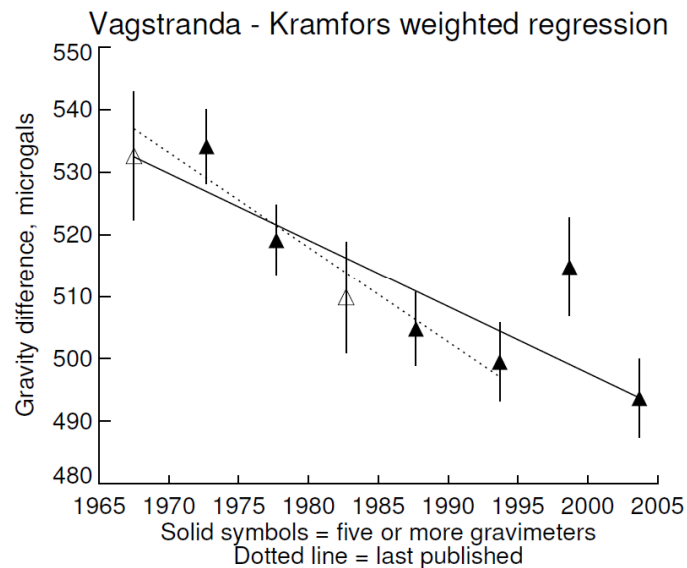
$$\dot{H} = -4.7 \pm 0.5 \text{ mm yr}^{-1}$$

leading to the ratio

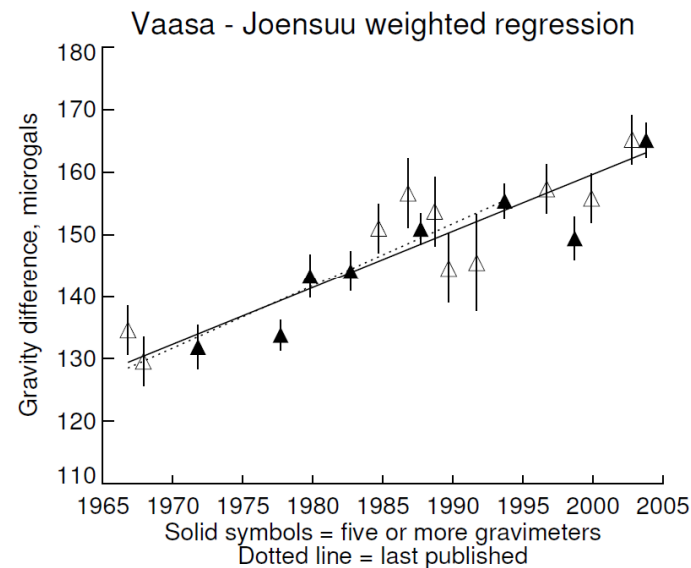
$$\dot{g}/\dot{h} = -0.204 \pm 0.058 \text{ } \mu\text{gal mm}^{-1} \quad (95 \text{ per cent}).$$

Latest publication 2005

Mäkinen et al, GGSM2004 Proceedings (Springer IAG series)



$$\dot{g} = -1.07 \pm 0.24 \text{ } \mu\text{gal/yr (W)}$$



$$\dot{g} = +0.91 \pm 0.09 \text{ } \mu\text{gal/yr (E)}$$

Much more $\dot{h}$ results were available, including CGPS on the Eastern side
 $\dot{g}/\dot{h}$ estimates were now -0.16 to -0.18 $\mu\text{Gal/mm}$ (Vaasa-Joensuu)

Afterwards

- 2003 was the last major campaign
- absolute-gravity (AG) measurements replaced the uplift lines
- larger signal and less work
- AG gravity differences at AG stations close to the uplift lines can be linked to the relative results

Now

- the uplift lines 1966-2003 provide an additional time window to gravity change, compared with absolute gravity
- absolute gravity time window:
 - 2003 onwards using FG5s
 - 1987–2002 JILAg-5 and sporadic FG5 from NOAA and BKG
- the NKG-WGGEO wants to rescue, reprocess and publish the relative data
- rescue: done
- reprocessing and publication in progress

Some items in reprocessing

- reconsider instrument attributes
- consider ocean tidal loading, especially at Norwegian coasts
- hydrological loading: availability and quality of models a problem (1966–), and correction might bias trends
- close-field hydrological attraction: estimate uncertainty contribution
- elastic effects from Greenland mass loss are small (– 2003)
- nontidal Baltic loading: straightforward to correct for but minor:

RMS variation of Baltic loading at selected stations 2008–2013, using calculation by Nordman et al. (2015), in μGal

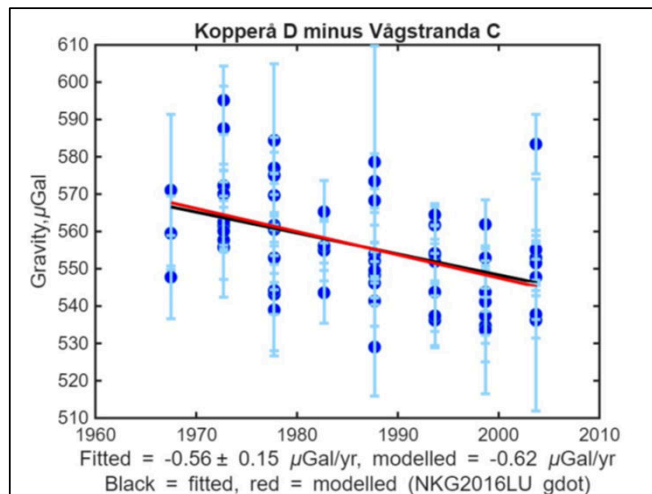
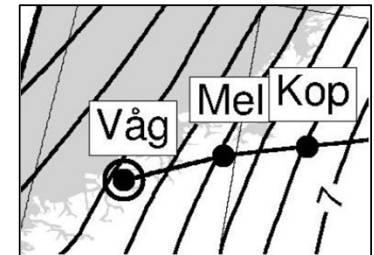
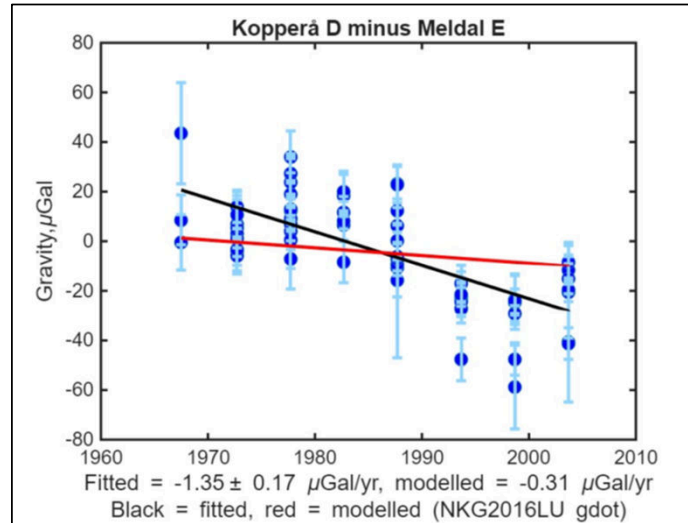
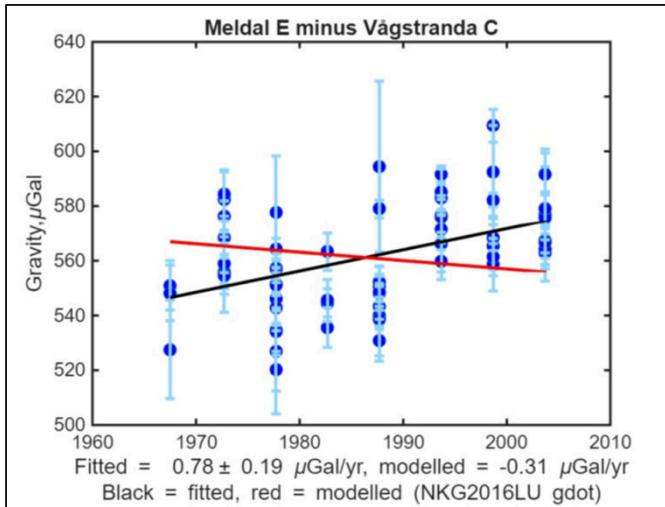
Stugun	Kramfors	Vaasa	Äänekoski	Joensuu
0.30	0.61	0.59	0.32	0.20



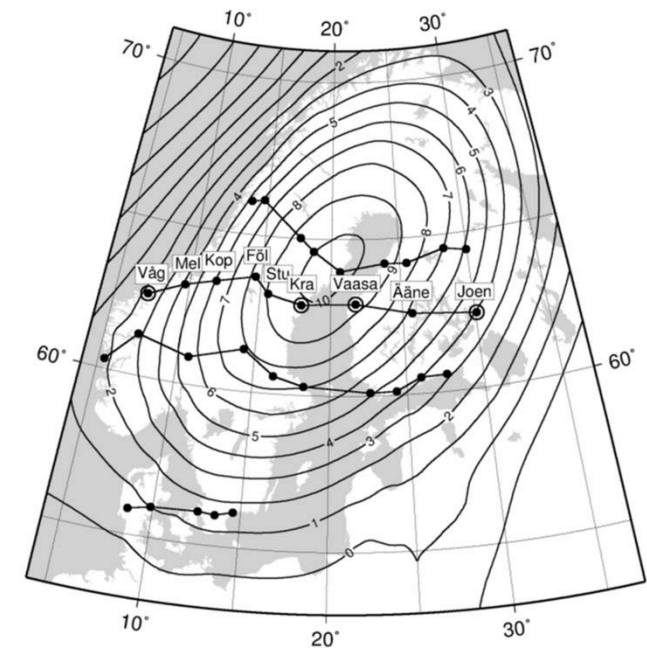
Further

- so far, all gravimeters have had equal weights
- in two or three cases only, poor instruments have been rejected, on the basis of obvious physical diagnostics
- investigate filtering and robust methods
- in the sequel we show the data at the 63°N line as-is, interval by interval
- the visual reference for observed gravity rates is the NKG2016_abs multiplied by $-0.163 \mu\text{Gal}/\text{mm}$, i.e. NKG2016_gdot
- the data points are results of individual gravimeters,
- consisting of 3-5 to and fro measurements
- the error bars are 1-sigma from drift elimination
- note the variable vertical scale!

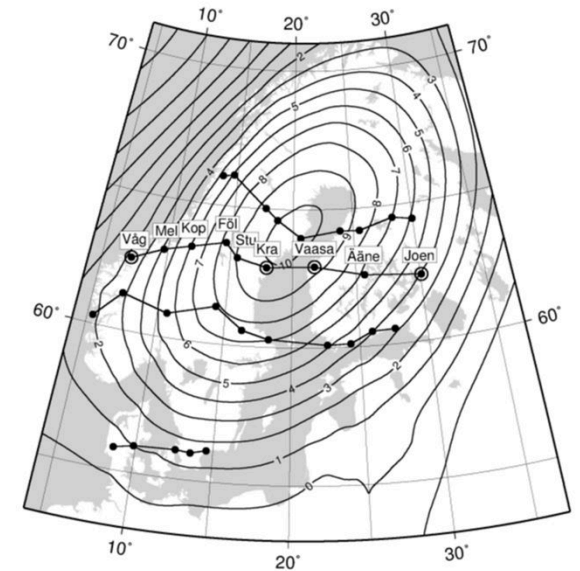
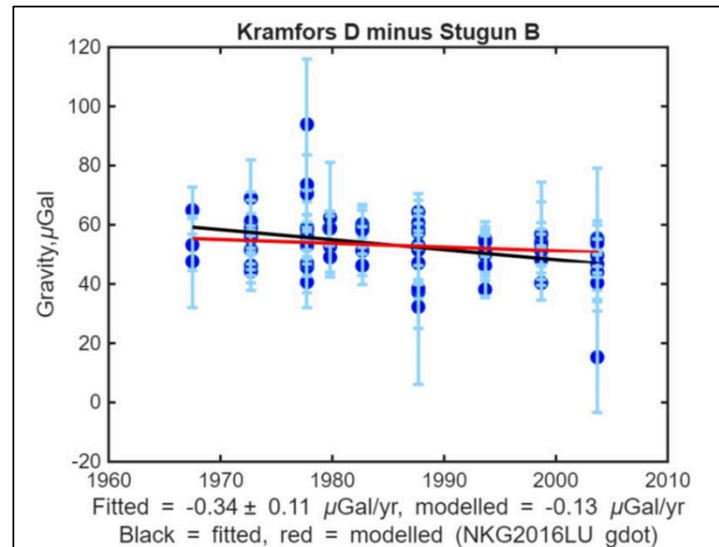
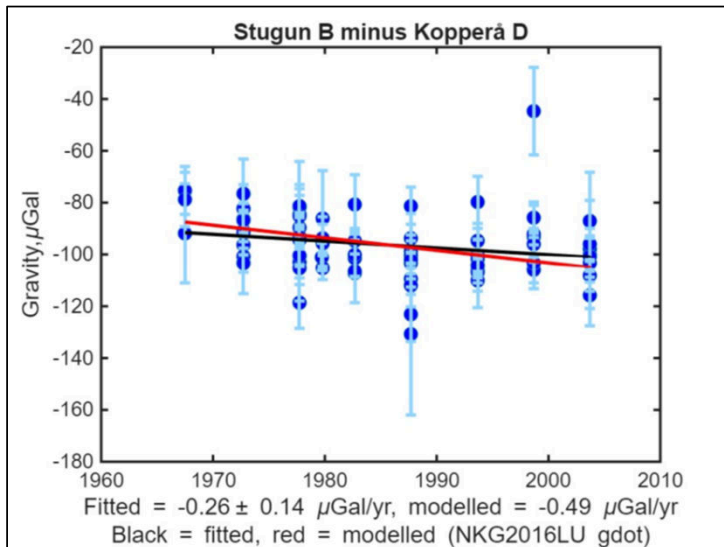
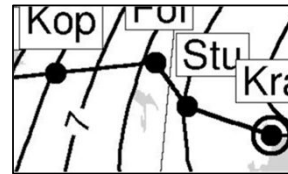
Vågstranda-Meldal-Kopperå



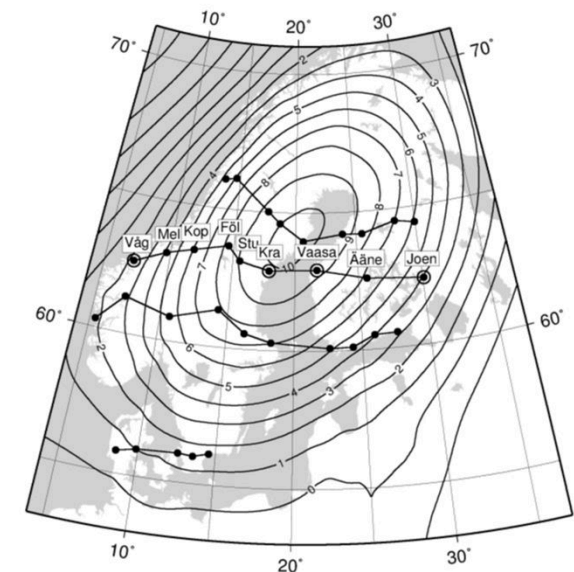
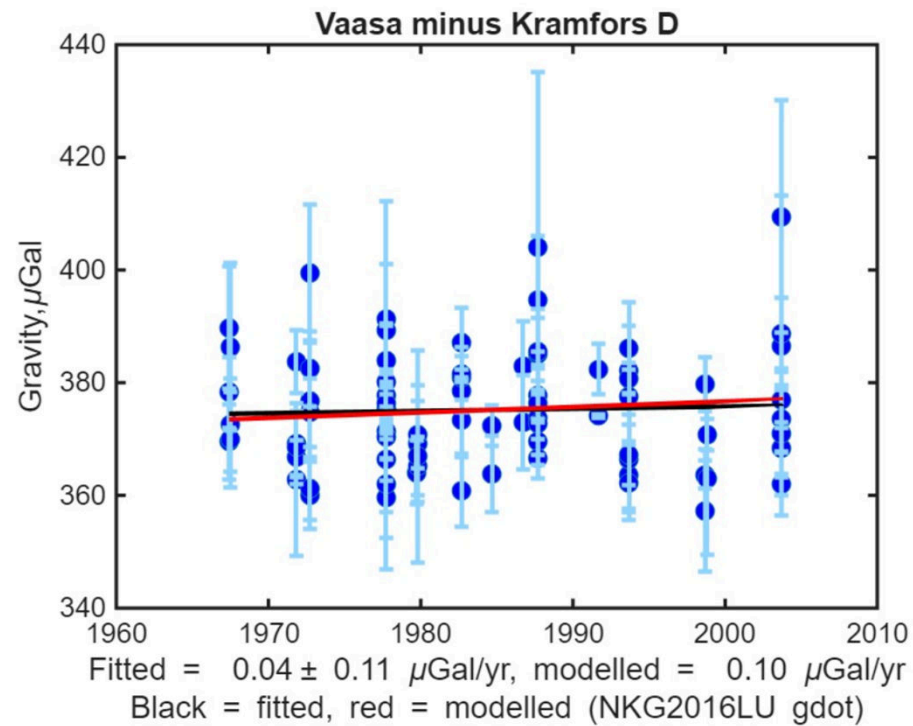
combined



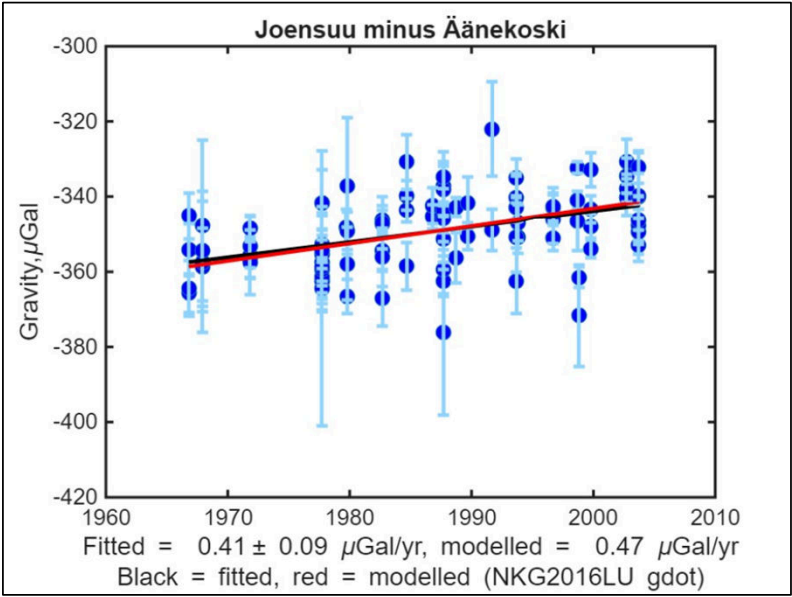
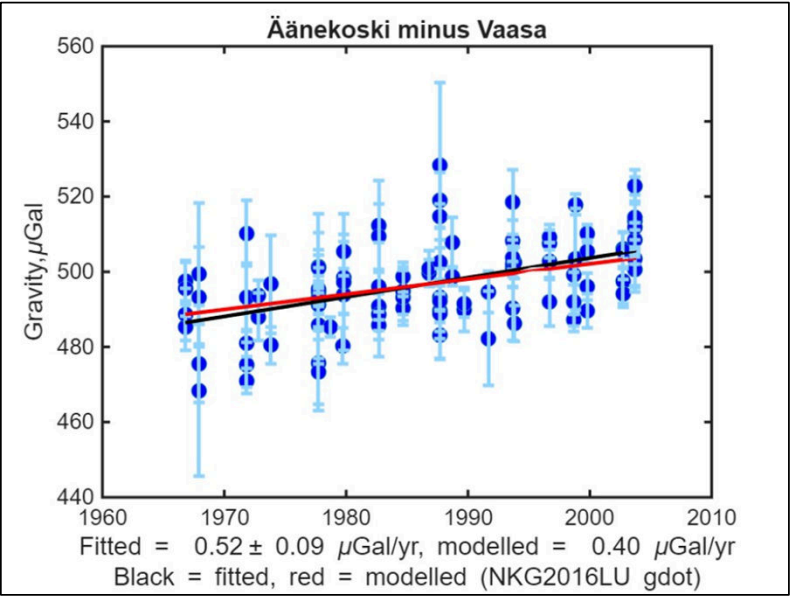
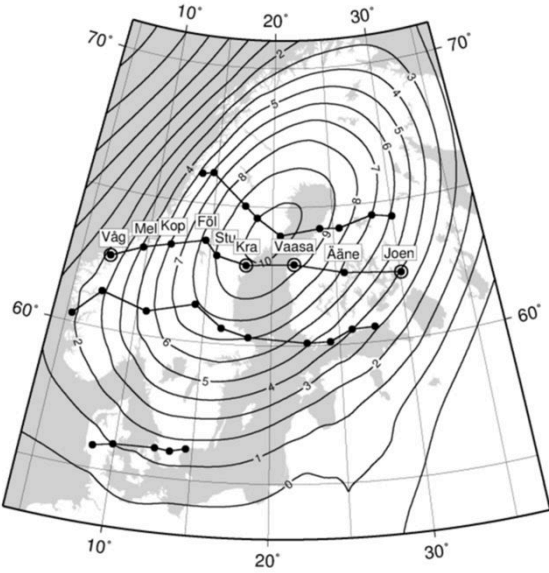
Kopperå-Stugun-Kramfors



Kramfors-Vaasa



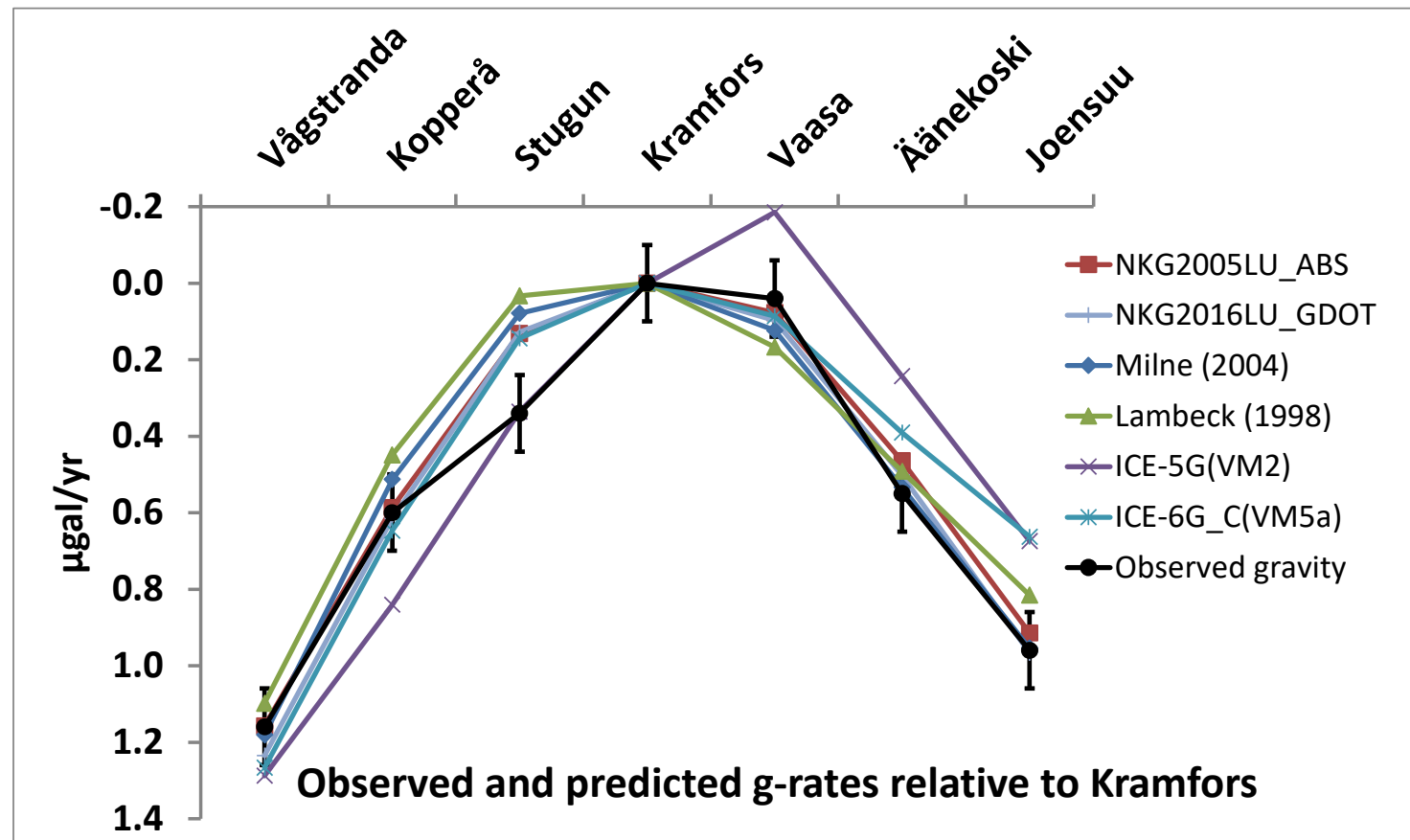
Vaasa-Äänekoski-Joensuu



Comparison directly with GIA models

- Instead of looking at ratios $\delta g_{\dot{}}/\delta h_{\dot{}}$ we can compare $\delta g_{\dot{}}$ results directly with models
- GIA modellers do not always publish $g_{\dot{}}$ predictions
- but for a large class of GIA models, it is adequate to do $g_{\dot{}}_{\text{predicted}} = k \cdot h_{\dot{}}_{\text{predicted}}$
- where k depends on the size of the deglaciation
- we use $k = -0.163 \text{ } \mu\text{Gal}/\text{mm}$ from Olsson et al (GJI 2019)
- include NKG2006LU_ABS and NKG2016_GDOT in comparison

Vertical rates
predicted from the
different models
were multiplied by
 $-0.163 \mu\text{Gal}/\text{mm}$ to
obtain predicted
gravity



Model	Std. dev. μgal/yr	Normed Chi-square
NKG2005LU_ABS	0.08	0.67
NKG2016LU_GDOT	0.10	0.91
Milne (2004)	0.11	1.22
Lambeck (1998)	0.14	1.84
ICE-5G (VM2)	0.21	4.53
ICE-6G_C (VM5a)	0.15	2.31

- Discrepancy between observed and predicted gravity differences
- The model graphs that were presented relative to Kramfors in the previous slide were shifted vertically to obtain best fit to observed gravity
- Std. dev. is the RMS fitting error.
- The normed Chi-square was calculated using 0.14 μGal/yr as the standard uncertainty for observed gravity differences, and ignoring model uncertainty

Thank you!