NKG2016LU, an improved postglacial land uplift model over the Nordic-Baltic region

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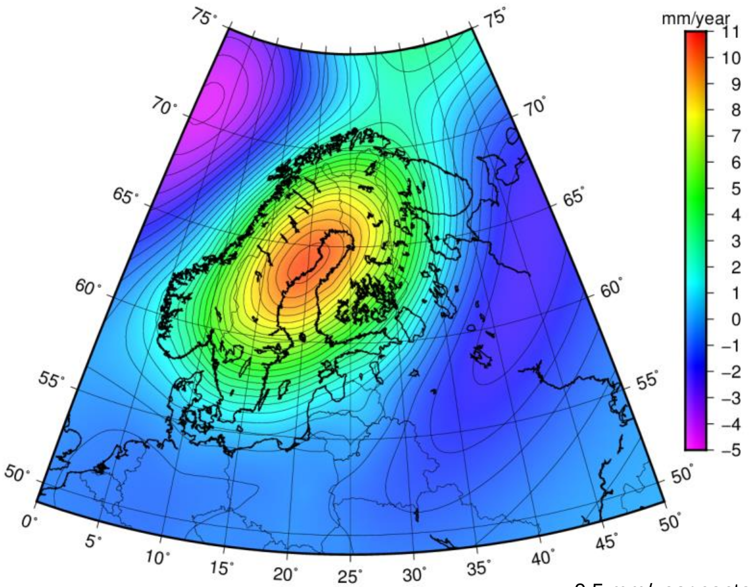
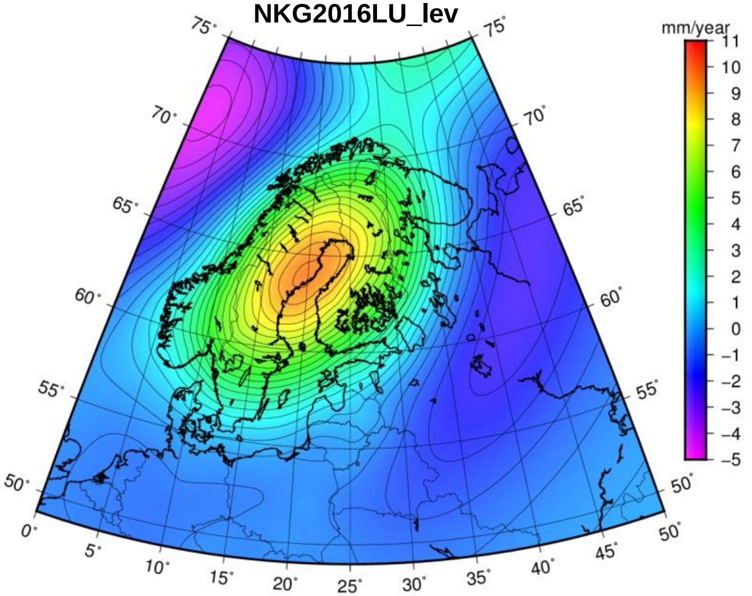
Summary

NKG2016LU_abs



0.5 mm/year contour interval

NKG2016LU_lev



- **NKG2016LU** is a semi-empirical land uplift model computed in Nordic-Baltic cooperation in the NKG Working Group of Geoid and Height Systems.
- The model gives the vertical land uplift rate in two different ways (**Unit: mm/year**),
  - **NKG2016LU_abs**: Absolute land uplift in ITRF2008 (i.e. relative to the Earth's centre of mass)
  - **NKG2016LU_lev**: Levelled land uplift, i.e. uplift relative to the geoid.
- No apparent model (i.e. uplift relative to Mean Sea Level over a certain time period) is released for the time being.
  - Due to the (accelerating) contemporary climate-related sea level rise (caused by temperature increase, present day ice melting, etc.), the apparent land uplift is **not** equal to the levelled land uplift.
- NKG2016LU has been computed based on
  - An **empirical land uplift model** computed by Olav Vestøl based on geodetic observations (GNSS time series from BIFROST and NKG levelling, **no** tide gauges used)
  - The preliminary geophysical GIA model **NKG2016GIA_prel0306** computed by Steffen et al. (2016) in the NKG WG of Geodynamics.

Contents

Introduction

- An **empirical land uplift model** is computed directly from the observations using a mathematical method, like for instance least squares collocation. (In Ågren and Svensson, 2007, this type of model is called "mathematical model")
- A **geophysical GIA model** is computed in a geophysically meaningful way based on an Earth model, an ice melting history, etc. (GIA=Glacial Isostatic Adjustment).
- A **semi-empirical land uplift model** is a combination of an empirical model and a geophysical GIA model.
- The previous official semi-empirical postglacial land uplift model **NKG2005LU** was originally computed for the adjustment of the Baltic Levelling Ring (Vestøl 2007; Ågren and Svensson 2007).
- NKG2005LU was based on an empirical model computed from GNSS, levelling and tide gauges, which was then combined with the geophysical GIA model of Lambeck et al. (1998b) as described in Ågren and Svensson (2007).
- In 2011, the NKG WG of Geoid and Height System started a new project to compute an improved version of NKG2005LU with Olav Vestøl as project leader. **NKG2016LU is the final result of this project**.
- In 2013, NKG under the leadership of Holger Steffen started to develop and compute GIA models. This activity, which involves more or less all GIA-modellers in the Nordic-Baltic countries, has an active cooperation with Lev Tarasov regarding the construction and tuning of ice models.

  The preliminary version **NKG2016GIA_prel0306** (Steffen et al. 2016) is used for NKG2016LU.

Overview of the computation strategy

- An **empirical model** is first computed by least squares collocation with unknown parameters based on GNSS velocities and (repeated) levelling. This gives the **absolute** land uplift rates in ITRF2008. (See Vestøl 2007, for details about the mathematical concept.)
- The empirical estimates in **the observation points** with estimated standard errors are then combined with the **GIA model** NKG2016GIA_prel0306 using the following **remove-compute-restore** technique:
  - The GIA model is first removed from the empirical model in the observation points
  - Least Squares Collocation (LSC) is applied to model the differences from the GIA model (residual surface). A first order Gauss Markov covariance function with correlation length 150 km used (chosen based on covariance analysis). The estimated standard errors above are applied for the observations.
  - The residual surface grid is finally restored to the GIA model to obtain the final land uplift grid NKG2016LU_abs.

$$\dot{h}^{\text{grid}}_{\text{NKG2016LU\_abs}} = \dot{h}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}} + \overbrace{LSC\left\{\dot{h}^{\text{obs. points}}_{\text{empirical\_abs}} - \dot{h}^{\text{obs. points}}_{\text{NKG2016GIA\_prel0306}}\right\}}^{\text{Residual surface (grid)}}$$

- The **levelled** uplift (relative to the geoid) is then computed by subtracting the **GIA model geoid rise** according to

$$\dot{H}^{\text{grid}}_{\text{NKG2016LU\_lev}} = \dot{h}^{\text{grid}}_{\text{NKG2016LU\_abs}} - \dot{N}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}}$$

The (strictly) empirical model

Basic concepts for the empirical model

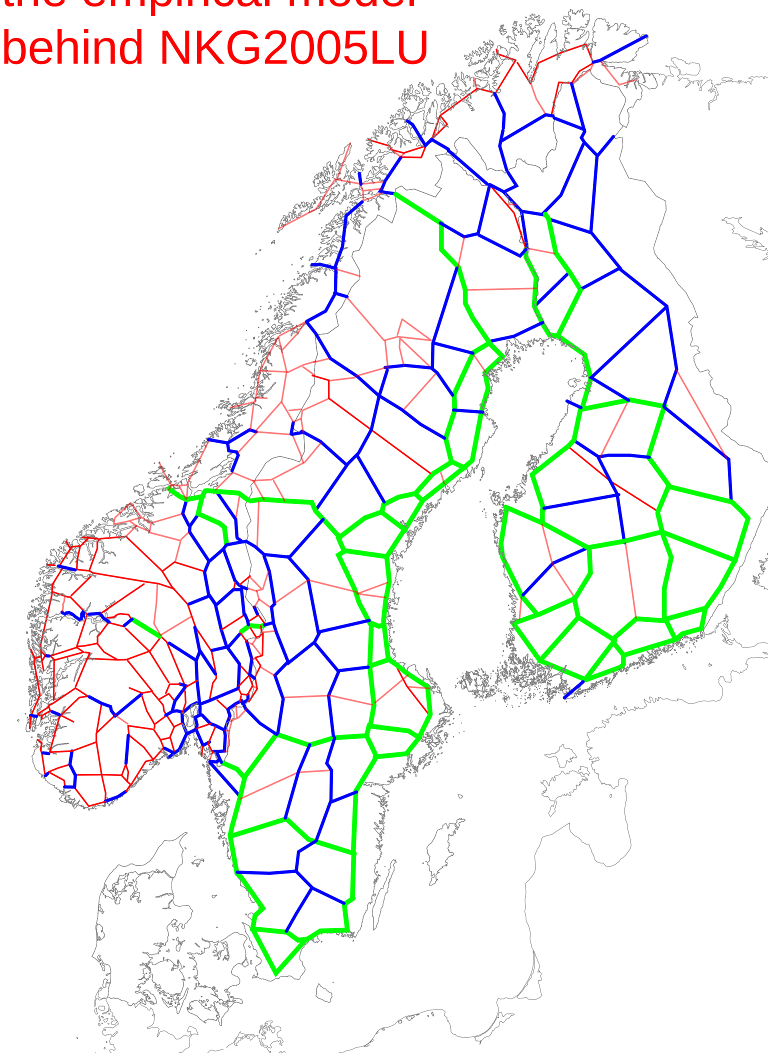
- **Geodetic observations** alone are used to calculate the **absolute** land uplift in ITRF2008. The following observations are used:
  - GNSS (vertical) velocities in CORS, from the BIFROST 2015/16 calculation processed in GAMIT/GLOBK. Finalised in March 1, 2016; an updated version of Kierulf et al. (2014).
  - Levelling from all the Nordic countries (except Iceland) and from all the Baltic countries.
- **Least squares collocation with unknown parameters** to estimate the absolute uplift in the observation points. (Separate gridding algorithm utilised by Vestøl, but this one is not utilised for NKG2016LU)
- **Trend surface** consisting of a 5th degree polynomial. Least squares collocation to estimate an additional **signal** (=difference from trend surface). A first order Gauss Markov covariance function with halved correlation after 40 km and variance (3 cm/year)^2 is selected for this latter part of the solution.
- The **geoid rise** is needed to relate the levelling and GNSS observations. This quantity is now taken directly from the GIA model (see below).
  - This means that the empirical model is actually not strictly empirical (but almost!)
  - However, almost the same empirical absolute land uplift values are obtained when solving for a scale factor to describe the geoid rise, (below ~0.1 mm/year everywhere).
  - This means that in practice the empirical model can be regarded as a strictly empirical model.

Geodetic observations in 2016 compared to in 2005

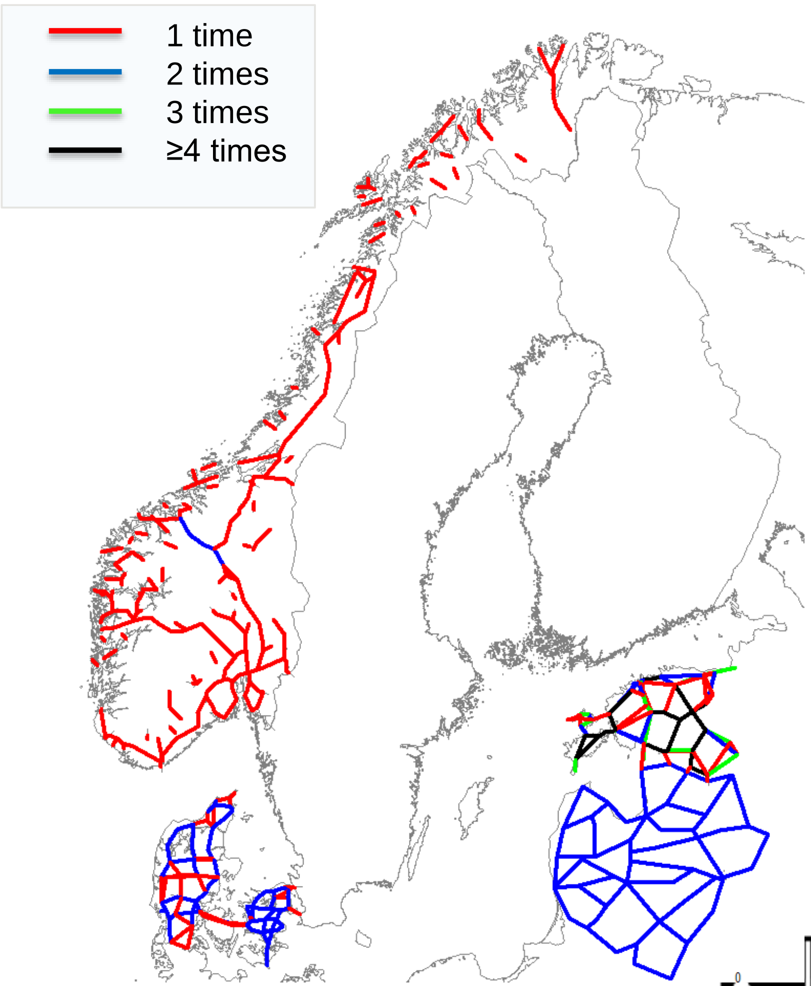
- More levelling
  - Denmark: 1. and 3. levelling
  - Latvia: 1. and 2. levelling
  - Estonia: Several; see next slide.
  - Lithuania: 1. and 2. levelling
  - Norway: Lines after 2005 + Railway obs.
- New GNSS dataset
  - More stations
  - Longer time series
- Tide gauge data excluded in NKG2016LU

The levelling network

Levelling data used for the empirical model behind NKG2005LU

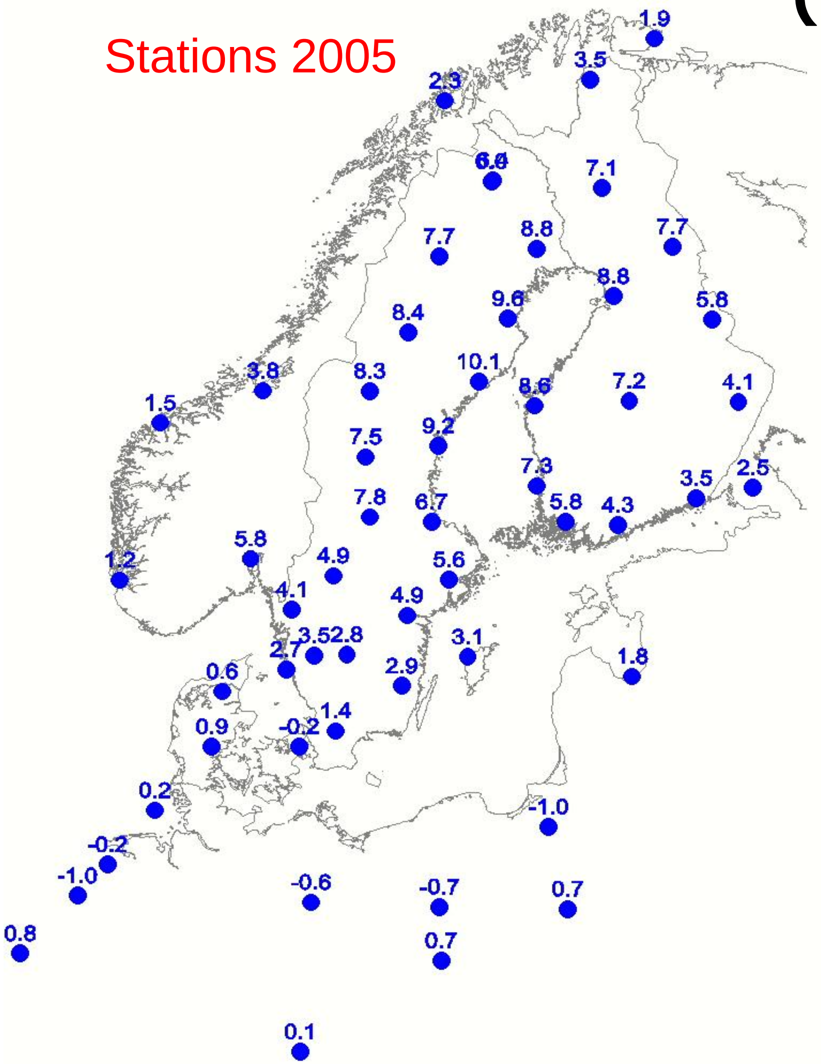


New data included since 2005



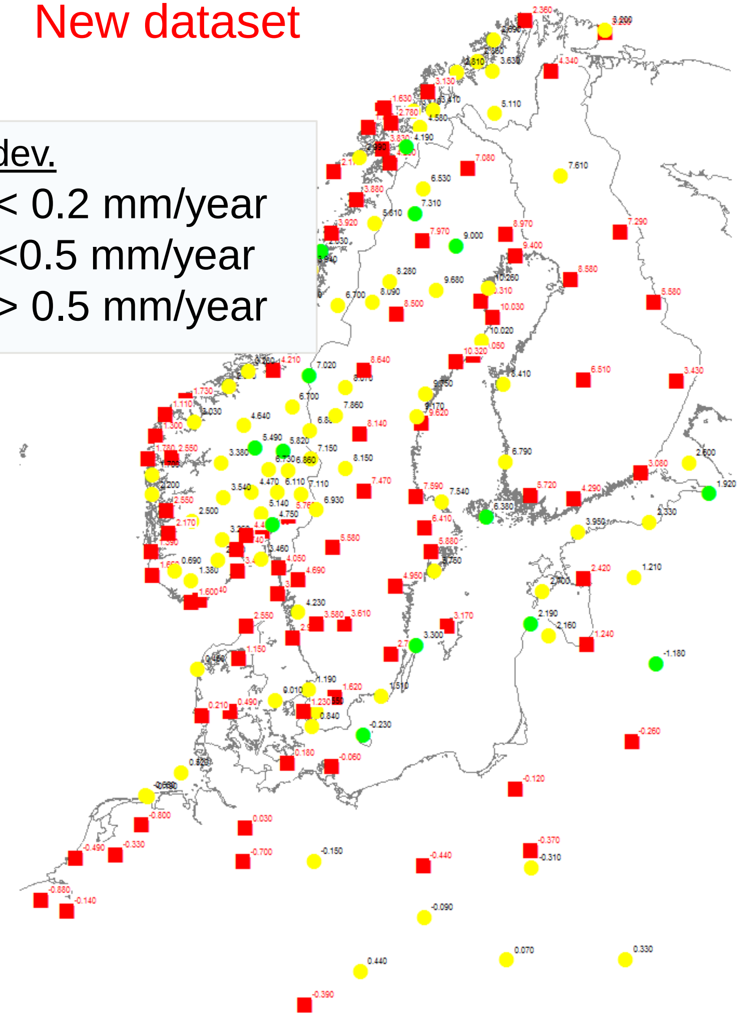
GNSS velocities in permanent reference stations (CORS)

Stations 2005



BIFROST solution presented in Lidberg (2004), later published in Lidberg et al. (2007)

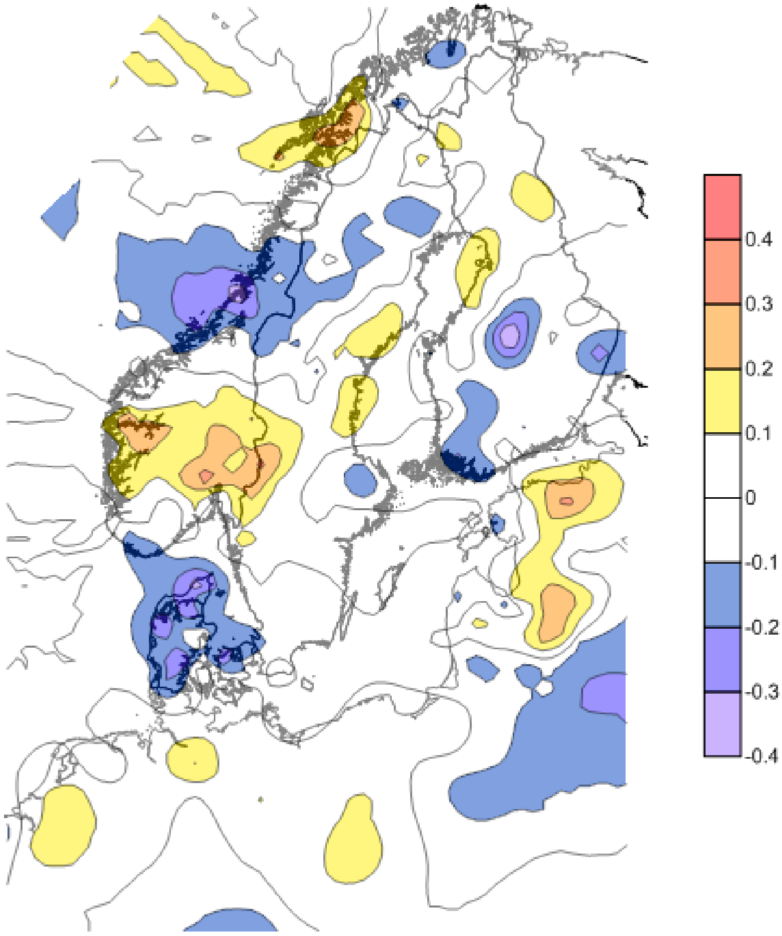
New dataset



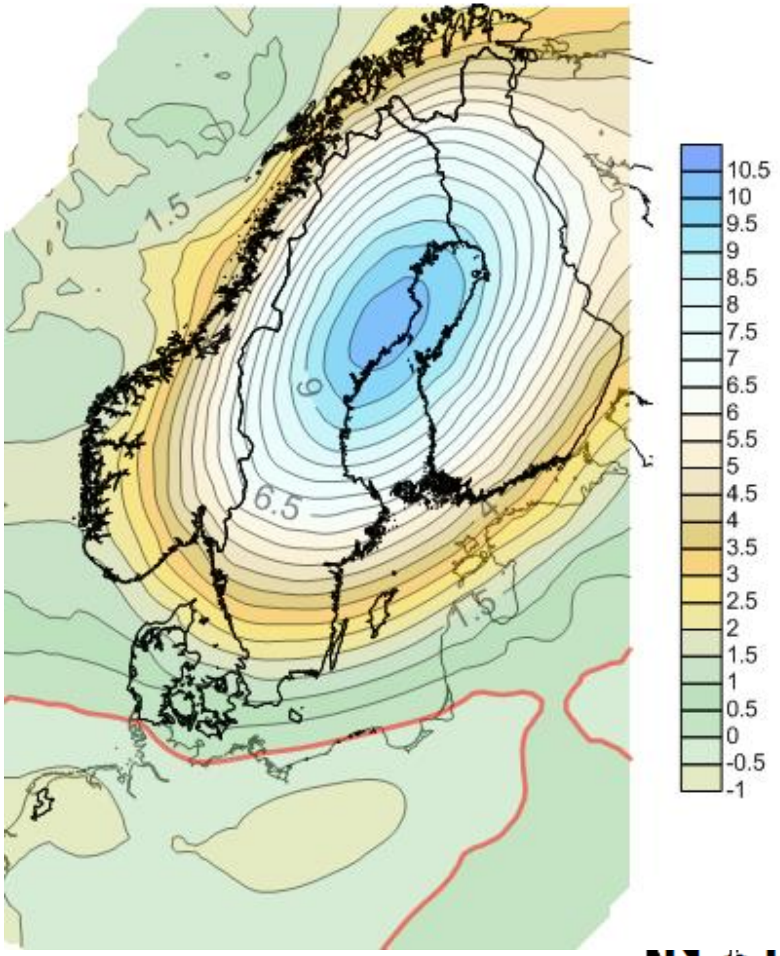
BIFROST 2015/16 calculation processed in GAMIT/GLOBK. Finalised March 1, 2016; an updated version of Kierulf et al. (2014).

The estimated signal

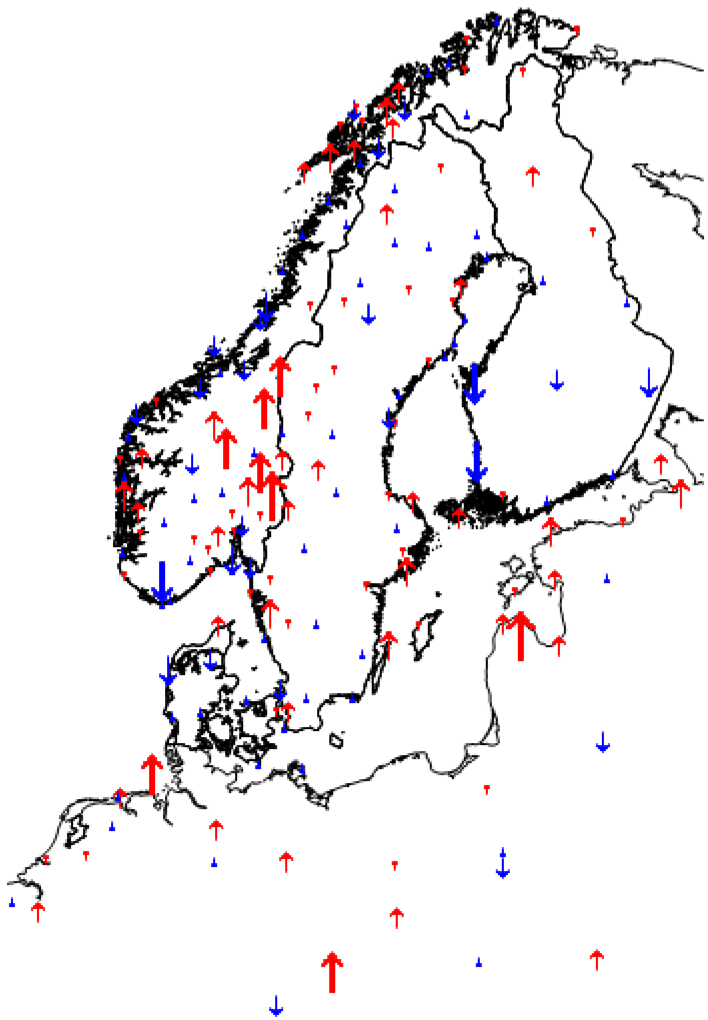
Signal estimated by least squares collocation (in the observation points, then gridded)



Purely empirical model (polynomial + signal) (absolute uplift in the observation points, then gridded)



GNSS rate residuals (difference between the BIFROST solution and the gridded empirical model)



Station	Residual	Outlier	T-value
Removed			
TEJH	-0.9		<2
LILC	1.3		<2
TNSC	-1.0		<2
HELC	1.0		<2
PREI	-1.4		<2
ROAC	-1.3	-1.2	4.9
DONC	-1.9	-1.8	2.1
Suspicious			
GESR	-0.2	-0.5	2.4
TRDS	-0.4	-0.6	2.6
VAAS	-0.9	-1.0	2.4

The removed observations are not shown.

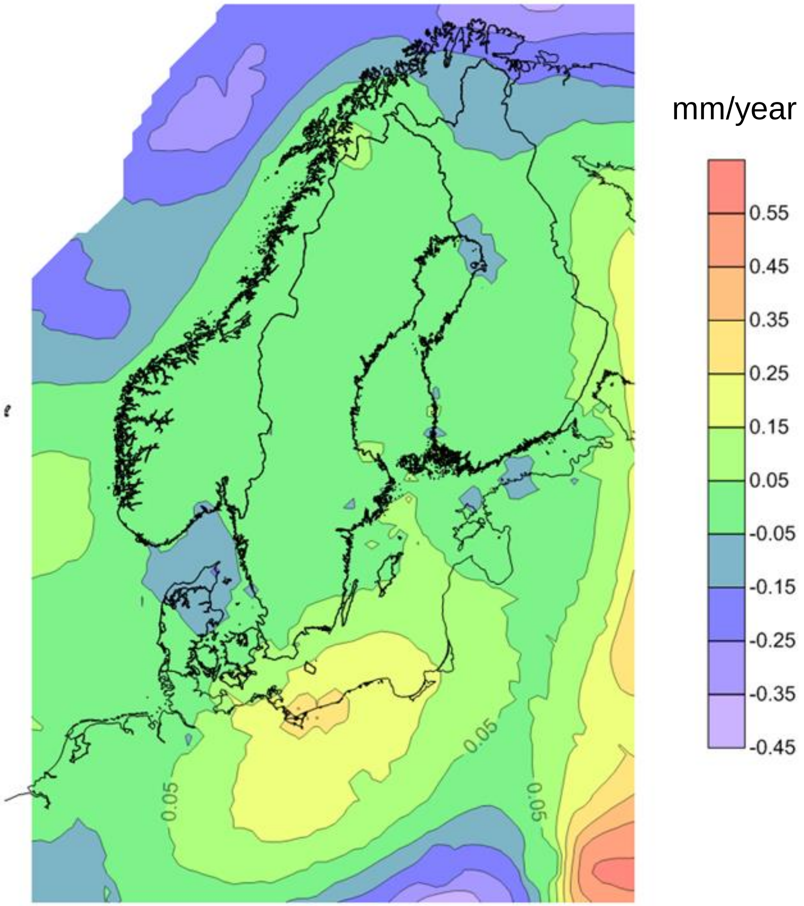
Levelling data - Some results

	Est. Accuracy (mm/km)			# outliers removed			Remark
	1.	2.	3.	1.	2.	3.	
Norway	2.4	1.4	1.3	2	6	7	1. is railway levelling.
Finland	1.3	0.9	0.8	1	0	1	
Sweden	3.0	1.4	1.1	0	7	2	
Denmark	1.4		0.9	0		0	
Estonia		0.9	0.4		21	1	*
Latvia		0.7	1.0		0	0	
Lithuania		0.6	1.4		1	1	

* Many obs. in 1. levelling removed due to sinking problems in Parnu.

Why not use tide gauges in the computation of the absolute uplift of the empirical model?

Difference of gridded empirical model computed with and without tide gauges (meters):

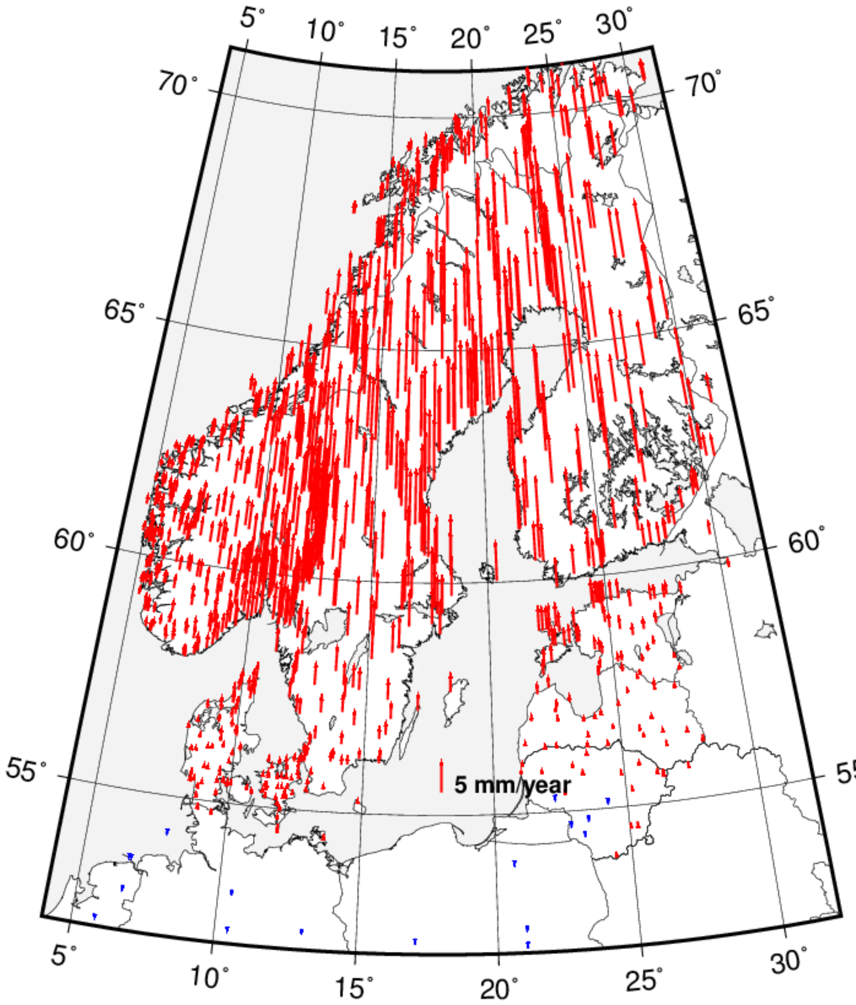


0.1 mm/year contour interval

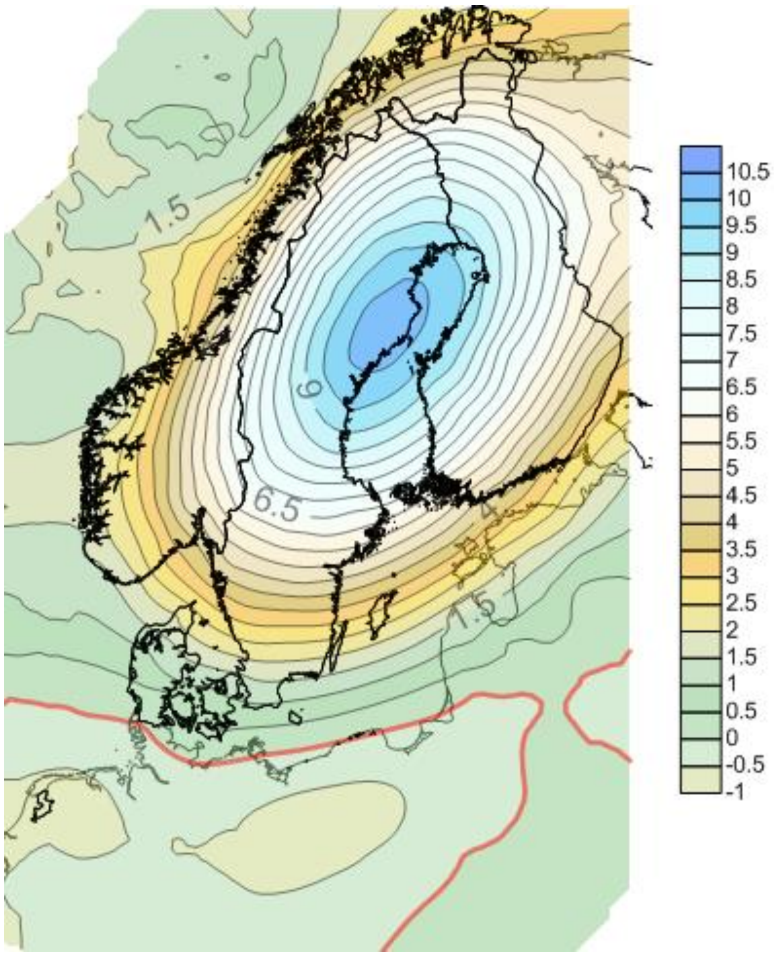
- Since there may be **spatial variations in the mean sea level rise**, it is difficult to separate this effect from the land uplift.
- There are also **temporal variations in the mean sea level rise**, making the separation even more difficult. The apparent uplift computed in the tide gauges will always refer to a certain time interval.
- Another advantage is that the final model **NKG2016LU_lev then becomes independent from tide gauge and sea level related information**.
- We can then learn something about climate related sea level changes by comparing NKG2016LU_lev with apparent uplift in tide gauges for a certain time period.
- The differences are overall small and almost negligible, except the northernmost part of Norway. (See figure to the left).

The empirical land uplift model

Absolute uplift in the observation points
(used for NKG2016LU)



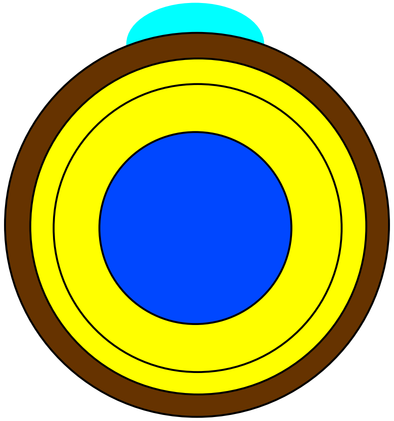
Gridded directly without underlying GIA model
(**not** used for NKG2016LU)



The underlying GIA model

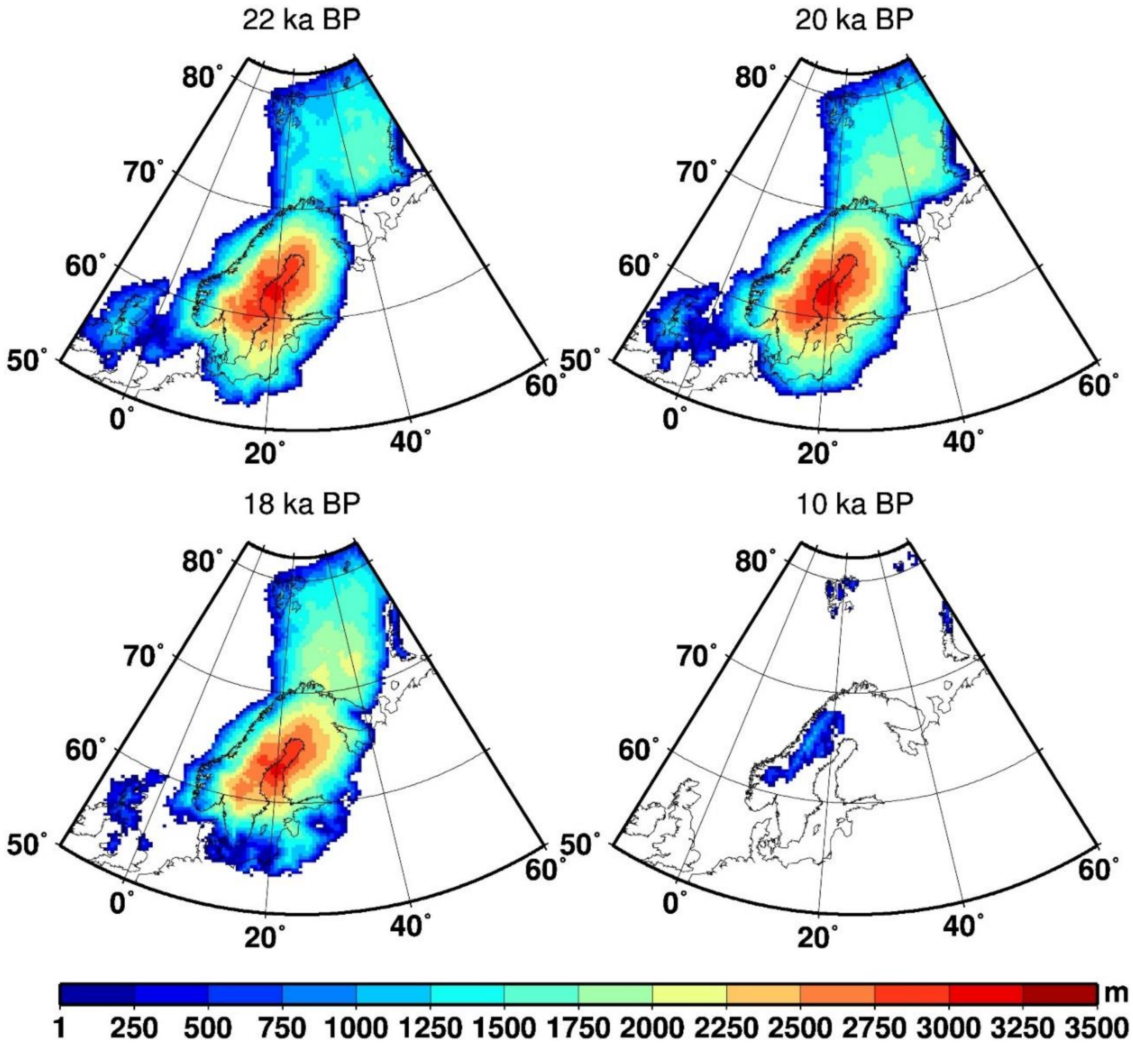
Method overview

- Viscoelastic normal-mode method, pseudo-spectral approach (Mitrovica et al. 1994; Mitrovica & Milne 1998), iterative procedure in the spectral domain, spherical harmonic expansion truncated at degree 192 (Steffen & Kaufmann 2005)
- Applying software ICEAGE (Kaufmann 2004)
- Spherically symmetric (1D), compressible, Maxwell-viscoelastic earth model
- Lithospheric thickness, upper and lower mantle viscosity as free parameter (so-called three-layer models); other model parameters as used in COST benchmark activity (Spada et al. 2011)
- Test of different ice models (see next slide)
- 1:1 or 4:1-weighted root-mean-square fitting of more than 11,000 GIA models (earth-ice model combinations) to uplift component of BIFROST 2015/16 GAMIT/GLOBK GNSS solution **and** Fennoscandian RSL data (see next but one slide)



$$\chi = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{o_i - p_i\left(a_j\right)}{\Delta o_i}\right)^2}$$

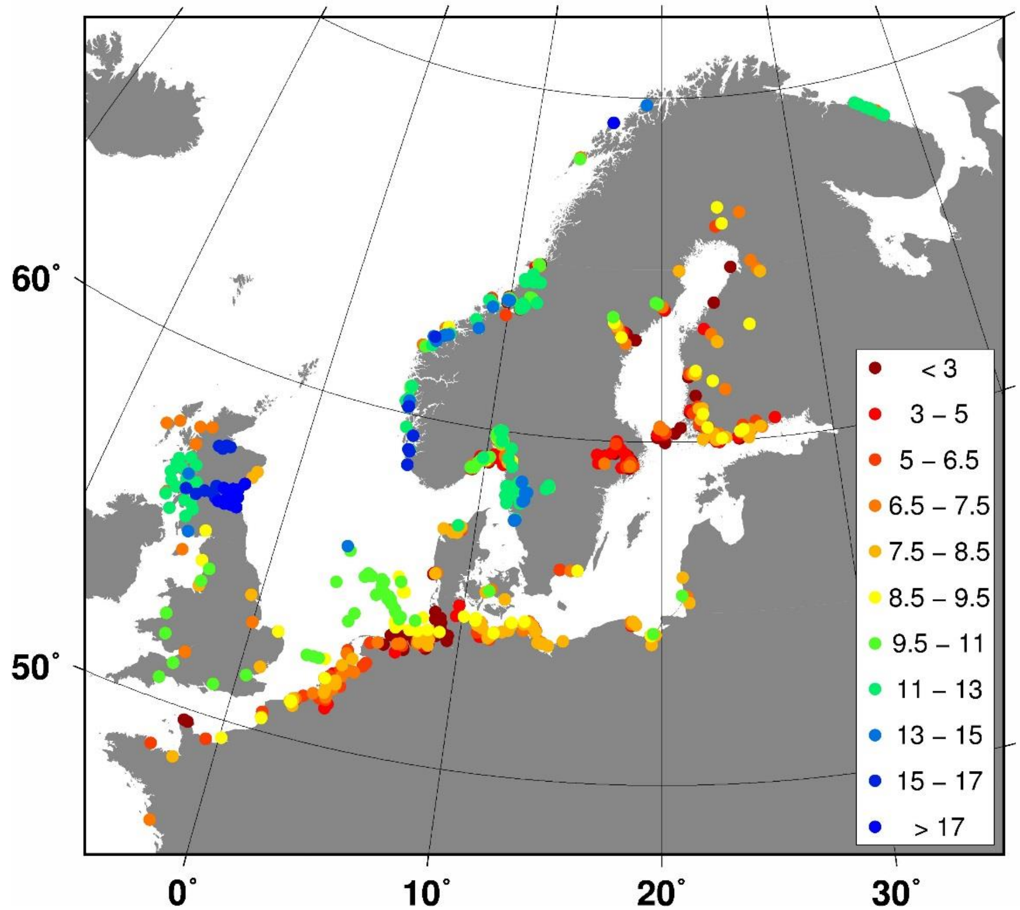
Best ice model GLAC-71340



- Glaciological Systems Model (GSM) results kindly provided by Lev Tarasov, Memorial University of Newfoundland, Canada, to NKG
- 3D thermo-mechanically coupled glaciological model calibrated against ice margin information, present-day uplift, relative sea-level records
- 39 ensemble parameters (the majority related to the climate forcing) subject to Bayesian calibration
- Calibration done with Peltier's VM5a earth model
- Takes uncertainties in the constraints into account → generates posterior probability distributions for past ice sheet evolution (Tarasov et al., 2012)
- Test of 25 different GLAC ice histories for Fennoscandia and Barents Sea
- Other parts of the world from ICE-5G (Peltier, 2004) and tuned to fit global sea-level equivalent; ICE-5G factor to be determined for each ice history
- Best model #71340 (thickness in meter for selected times shown left) determined by lowest misfit to observations

RSL (Relative Sea Level) observations

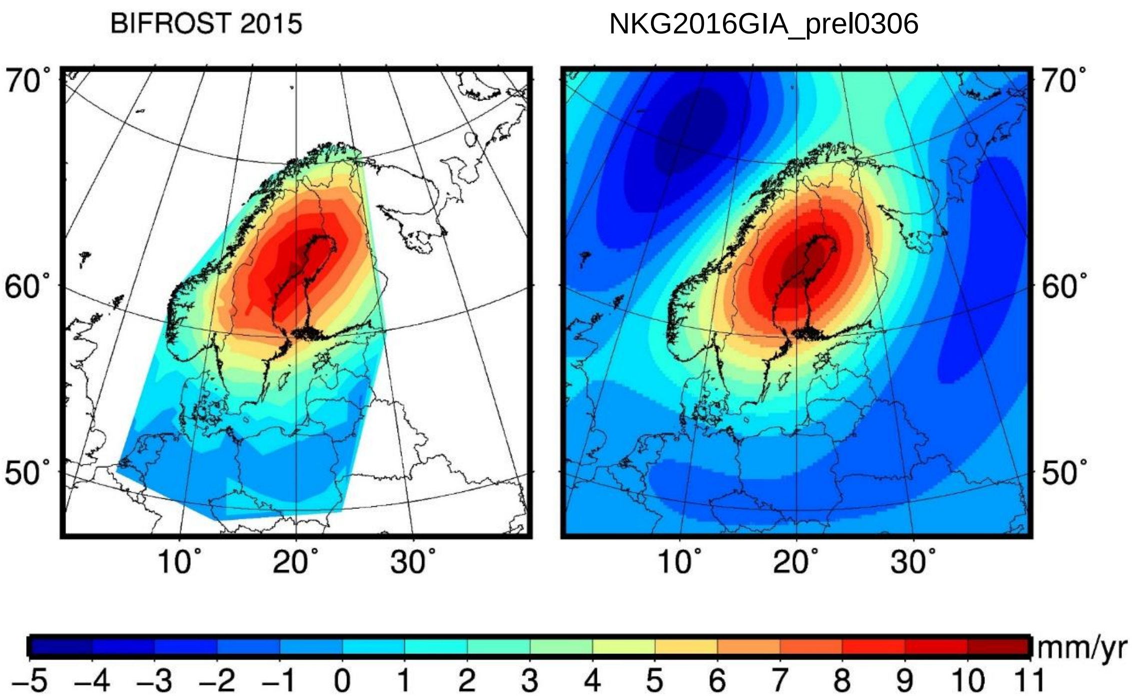
- Data from Lambeck et al. 1998a, Vink et al. 2007 and Steffen et al. 2014
- See picture of geographic distribution and age in ka BP (colored dots)
- Different RSL groupings to identify best GIA model:
  - Whole northern Europe
  - Central Baltic Sea
  - Peripheral Scandinavia
  - Baltic countries
  - Denmark
  - North Sea
  - Forebulge
  - Southwest of Tornquist Zone
  - (Not the British Isles)



(Steffen et al. 2014)

RSL observations in this connection are of the ancient sea level relative to land… and must not be mixed up with modern tide gauge records.

Best fitting model NKG2016GIA_prel0306 to GNSS and RSL observations



- Parameter: 160 km lith. thick., 7 x 10^{20} Pa s upper mantle visc., 7x10^{22} lower mantle visc.

Update 01/12/2016:

- **Model gives best overall fit (several regions) if also gravity information from absolute gravity (Gitlein 2009) and GRACE is included**
- **Model hits #3 and #9 if also 3D velocity field is taken into account**

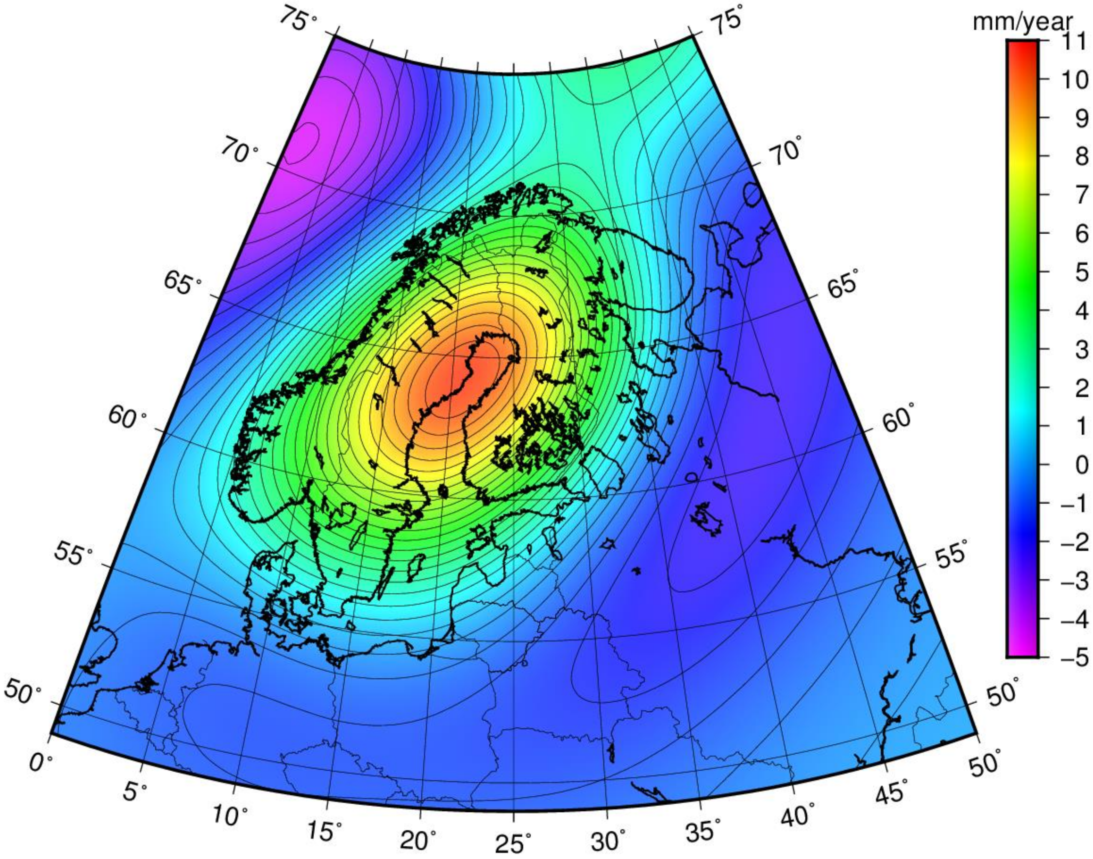
- Model gives best overall fit to GNSS uplift component and RSL data in *central Fennoscandia* (i.e. where the GNSS observed uplift is higher than 6 mm/year) with 1:1 weighing
- Model gives second-best overall fit to GNSS uplift component and RSL data in *central Fennoscandia* with 1:4 weighing.
- Model gives best fit to GNSS uplift component and RSL data in Fennoscandia with 1:1 weighing
- Model gives second-best fit to GNSS uplift component and RSL data in Fennoscandia with 1:4 weighing
- Model gives 30th-best fit to GNSS uplift component and RSL data in the Baltic countries with 1:1 weighing.
- Best-fitting models for regions SW of the Tornquist Suture Zone indicate thinner lithospheric thickness of about 100 km and a slightly lower upper mantle viscosity

Discussion of NKG2016GIA_prel0306

- Lithospheric thickness is higher than in previous studies (120-140 km) for Fennoscandia (though they applied different ice models), and also much higher than standard lithospheric thickness (90 km) used by Lev Tarasov
- Upper mantle viscosity fits to former results
- Detailed (side-by-side) comparison of results shows partly large differences for Ångermanälven RSL data and GNSS and RSL data for regions SW of the Tornquist Suture Zone including forebulge
- Fitting to gravity, stress and horizontal velocity has not been performed

- Future:
  - Weighted fit (ratio to be tested) to horizontal velocity data to use full information of the velocity field
  - Test of 4-layer models with an extra layer below the lithosphere to tune the 1D model towards good fit with horizontal velocities
  - Weighted fit (ratio to be tested) to both terrestrial and satellite gravity data
  - Use of geologic information such as dated activity of glacially induced faults to exclude model setups
  - Test with North and Baltic seas tide gauge data results (provided by University of Siegen)
  - Comparison to expanded RSL database (in cooperation with several partners in Europe)
  - Development of 3D spherical compressible Finite Element models with higher spatial resolution (0.5x0.5 degrees) with laterally varying lithospheric thicknesses and mantle viscosities (in cooperation with University of Hong Kong and Chinese Academy of Sciences Wuhan)

NKG2016GIA_prel0306 – vertical land uplift

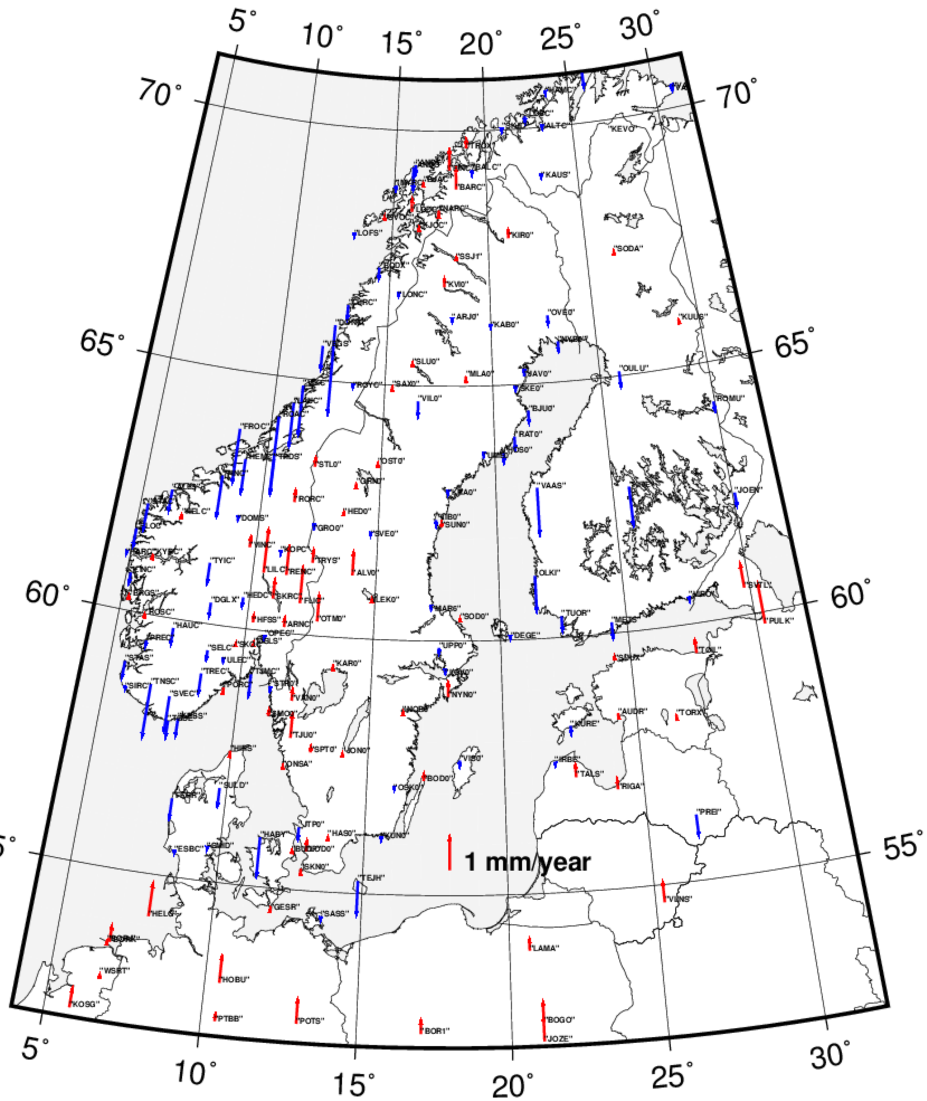


- Gridded vertical displacement rate
- Statistics:

#	313 x 301
Min	-4.55
Max	10.49
Mean	0.90
StdDev	3.22

- Contour interval: 0.5 mm/year

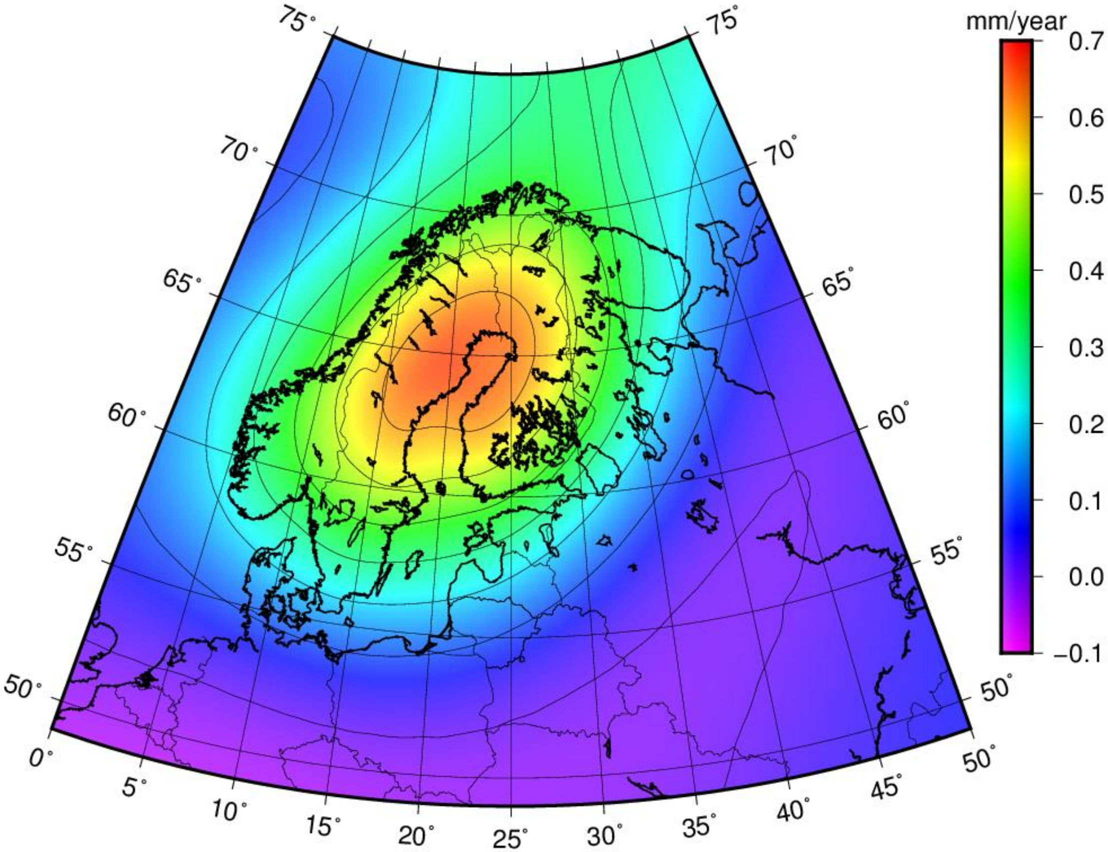
Difference between the BIFROST GNSS and NKG2016GIA_prel0306



- mm/year
- Statistics:

#	179
Min	-2.52
Max	1.51
Mean	-0.06
StdDev	0.61

NKG2016GIA_prel0306 – Geoid rise



- Gridded geoid change rate
- Statistics:

#	313 x 301
Min	-0.05
Max	0.66
Mean	0.21
StdDev	0.28

- Contour interval: 0.1 mm/year

Computation of the semi-empirical models NKG2016LU_abs and NKG2016LU_lev

Computation of NKG2016LU_abs and NKG2016LU_lev

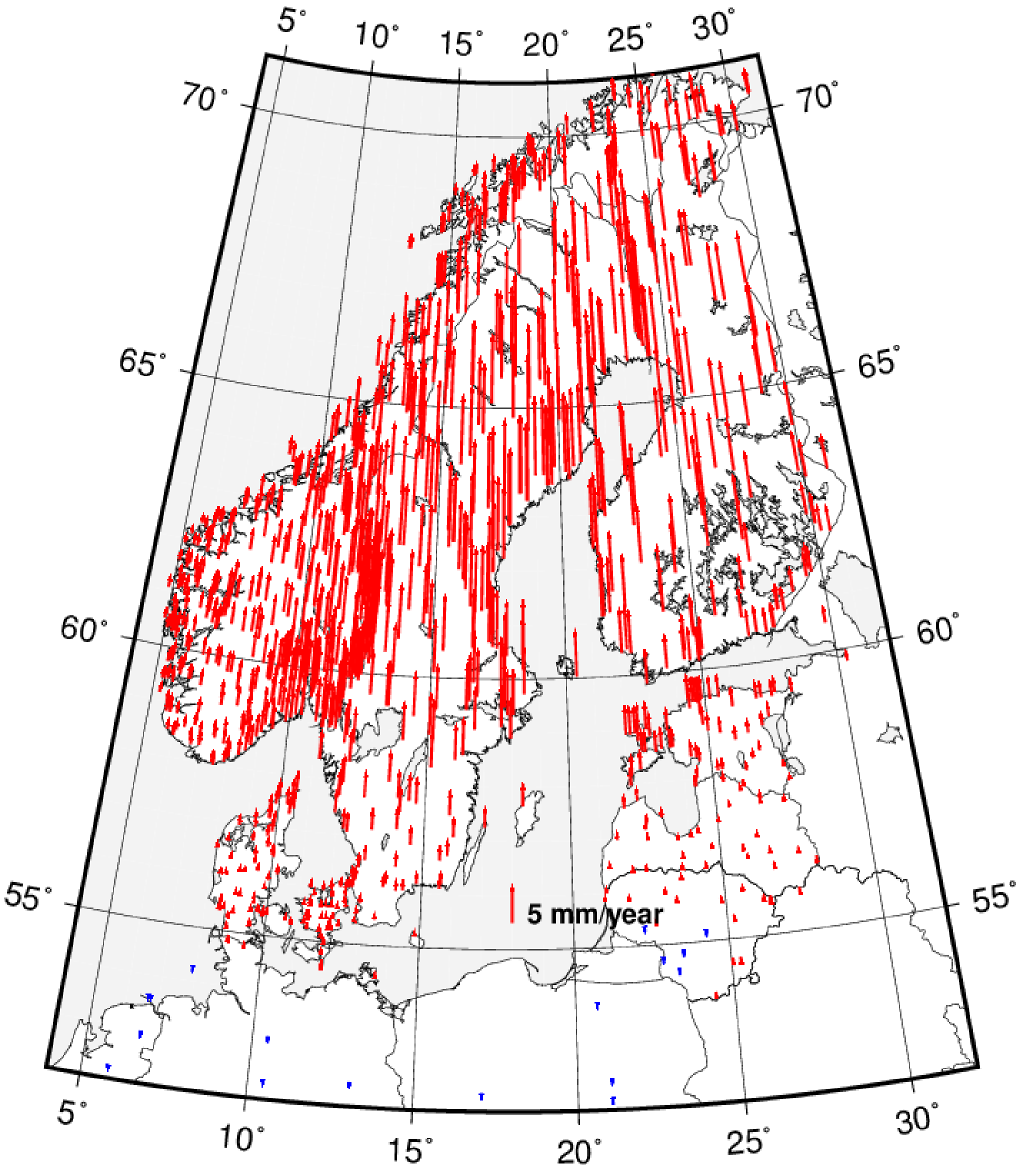
- The empirical estimates in **the observation points** and the estimated standard errors are then combined with the **GIA model** NKG2016GIA_prel0306 using the following **remove-compute-restore** technique:
  - The GIA model is first removed from the empirical model in the observation points
  - Least Squares Collocation (LSC) is applied to model the differences from the GIA model (residual surface). A first order Gauss Markov covariance function with correlation length 150 km used (chosen based on covariance analysis). The estimated standard errors above are applied for the observations.
  - The residual surface grid is finally restored to the GIA model to obtain the final land uplift grid NKG2016LU_abs,

$$\dot{h}^{\text{grid}}_{\text{NKG2016LU\_abs}} = \dot{h}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}} + \overbrace{LSC\left\{\dot{h}^{\text{obs. points}}_{\text{empirical\_abs}} - \dot{h}^{\text{obs. points}}_{\text{NKG2016GIA\_prel0306}}\right\}}^{\text{Residual surface (grid)}}$$

- The **levelled** uplift (relative to the geoid) is then computed by subtracting the **GIA model geoid rise** according to

$$\dot{H}^{\text{grid}}_{\text{NKG2016LU\_lev}} = \dot{h}^{\text{grid}}_{\text{NKG2016LU\_abs}} - \dot{N}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}}$$

Vestøl's strictly empirical model in the observation points

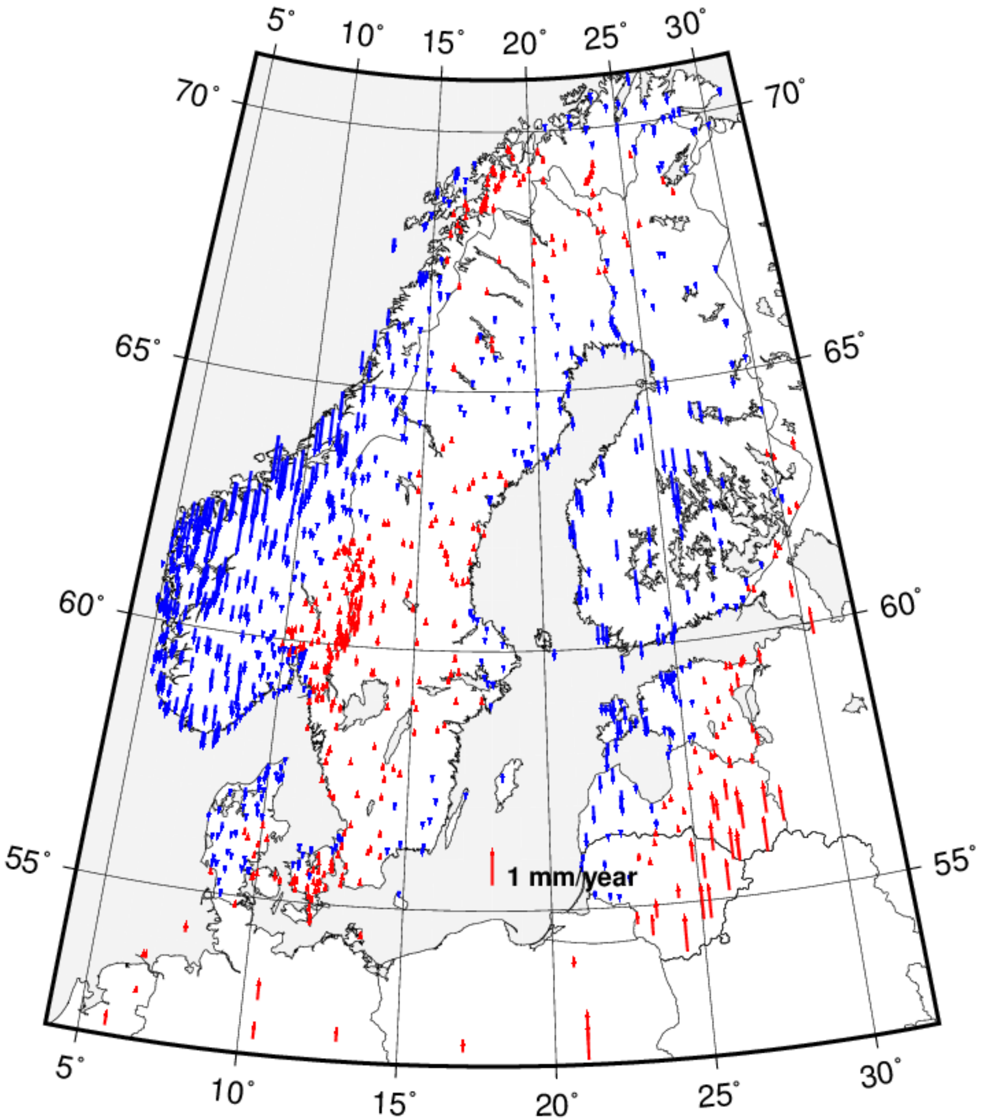


$$= \dot{h}^{\text{obs. points}}_{\text{empirical\_abs}}$$

- mm/year
- Statistics:

#	1111
Min	-0.75
Max	10.29
Mean	4.19
StdDev	2.71

Difference between the empirical model in the observation points and the GIA model

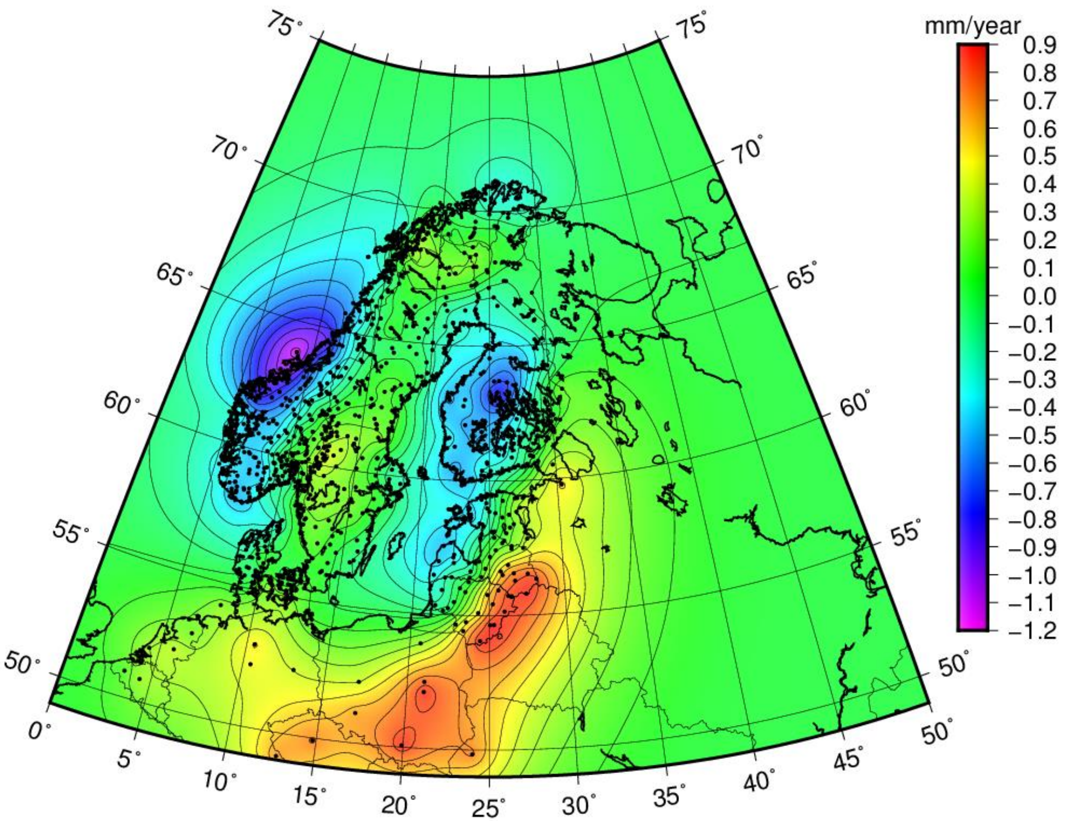


$$= \dot{h}^{\text{obs. points}}_{\text{empirical\_abs}} - \dot{h}^{\text{obs. points}}_{\text{NKG2016GIA\_prel0306}}$$

- mm/year
- Statistics:

#	1111
Min	-1.23
Max	1.24
Mean	-0.13
StdDev	0.34

Residual surface (gridded difference between the empirical model in the observation points and the GIA model)



$$\overbrace{= LSC\left\{\dot{h}^{\text{obs. points}}_{\text{empirical\_abs}} - \dot{h}^{\text{obs. points}}_{\text{NKG2016GIA\_prel0306}}\right\}}^{\text{Residual surface (grid)}}$$

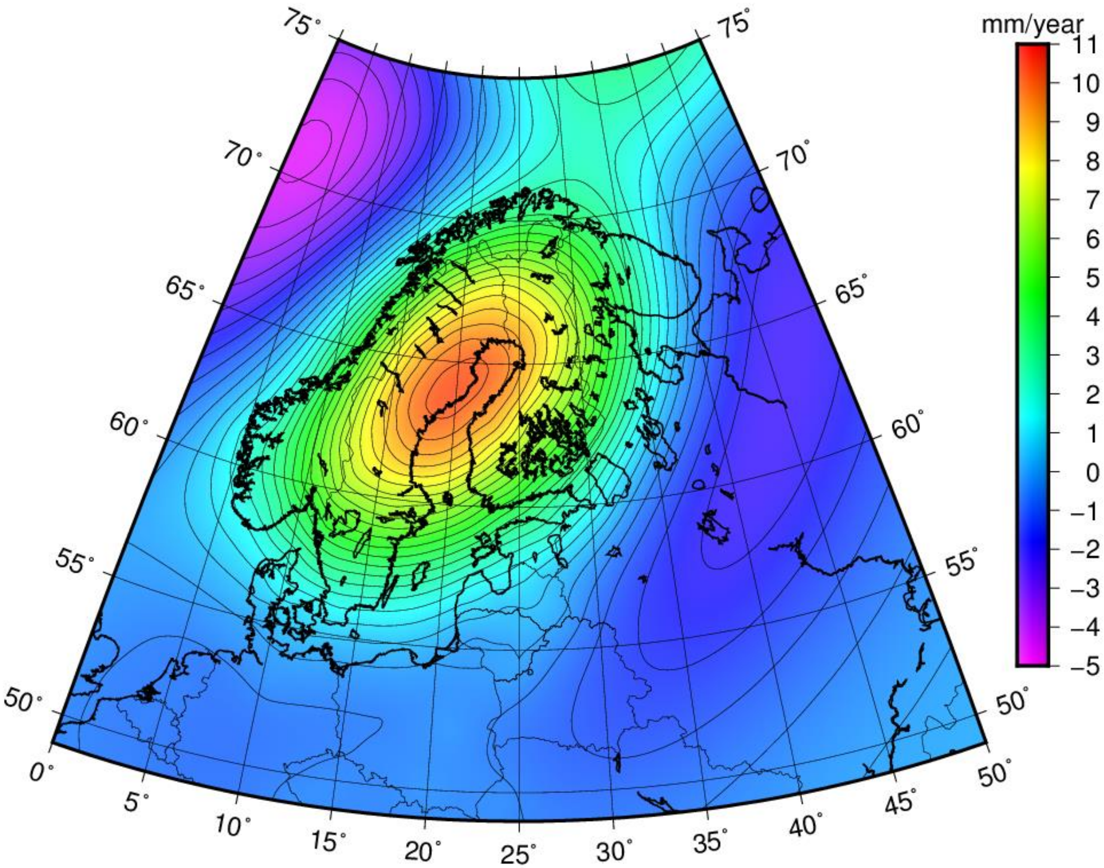
- Interpolation method: Least Squares Collocation (LSC). A first order Gauss Markov covariance function with correlation length 150 km used (chosen based on covariance analysis). The estimated standard errors above are applied for the observations.
- Statistics:

#	313 x 301
Min	-1.14
Max	0.88
Mean	0.00
StdDev	0.27

- Contour interval: 0.1 mm/year

NKG2016LU_abs

$$= \dot{h}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}} + \overbrace{LSC\left\{\dot{h}^{\text{obs. points}}_{\text{empirical\_abs}} - \dot{h}^{\text{obs. points}}_{\text{NKG2016GIA\_prel0306}}\right\}}^{\text{Residual surface (grid)}}$$

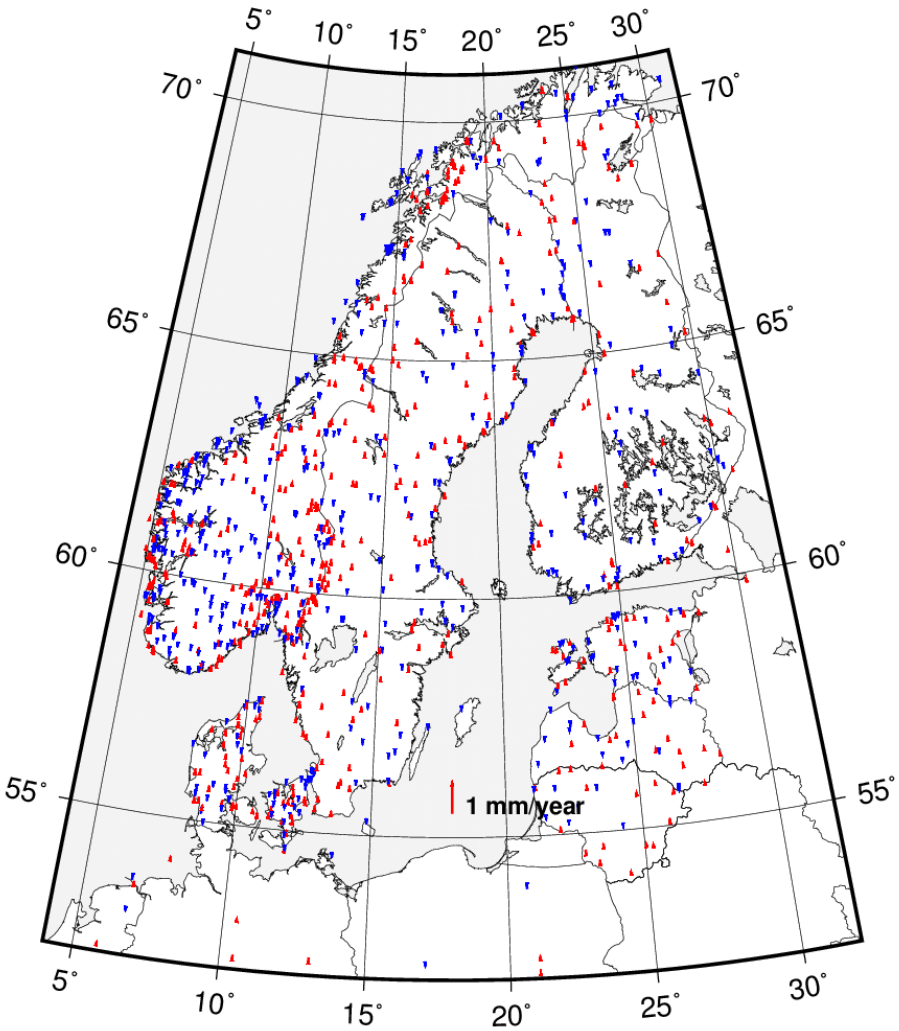


- Absolute land uplift in ITRF2008 (relative to the centre of mass)
- Statistics:

#	313 x 301
Min	-4.61
Max	10.29
Mean	0.90
StdDev	3.14

- Contour interval: 0.5 mm/year
- Should be used for the correction of GNSS or other space geodetic techniques.

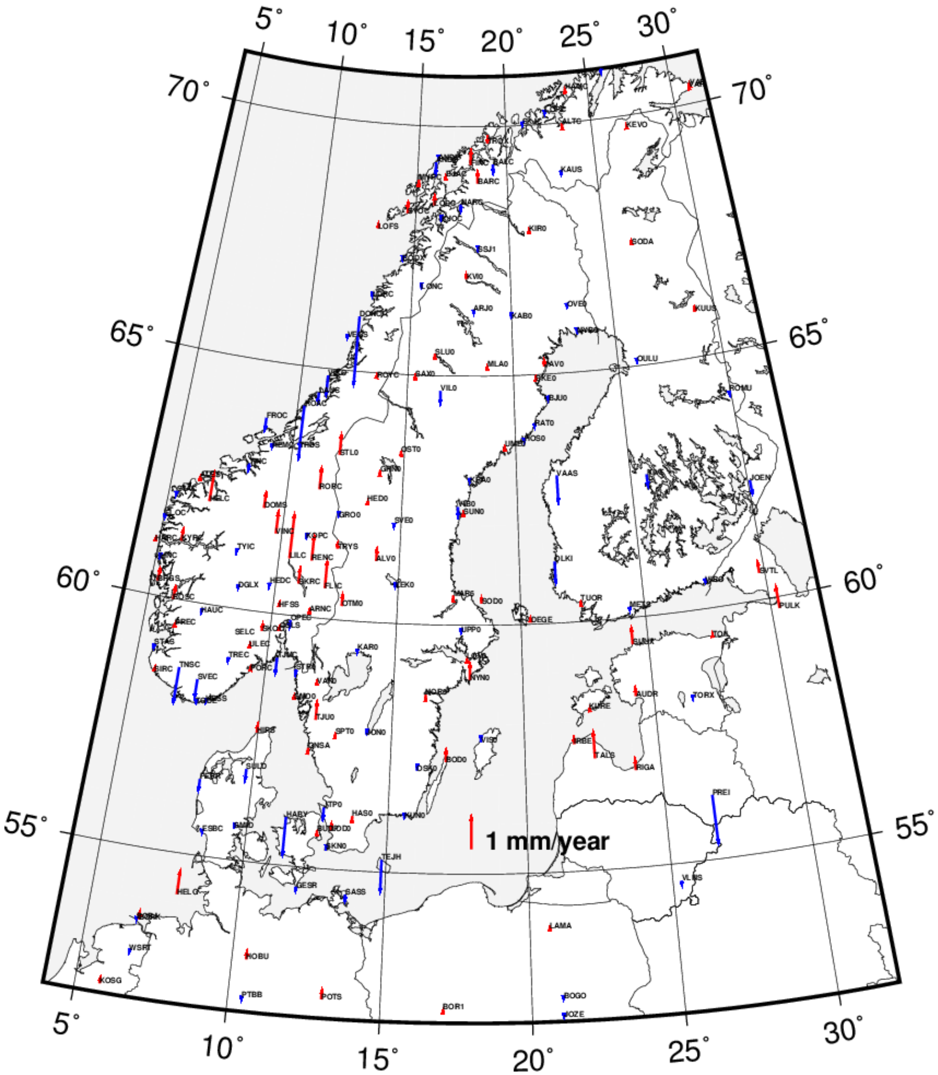
Residuals (i.e. difference between the empirical model in the observation points and NKG2016LU_abs)



- mm/year
- Statistics:

#	1111
Min	-0.15
Max	0.45
Mean	0.00
StdDev	0.04

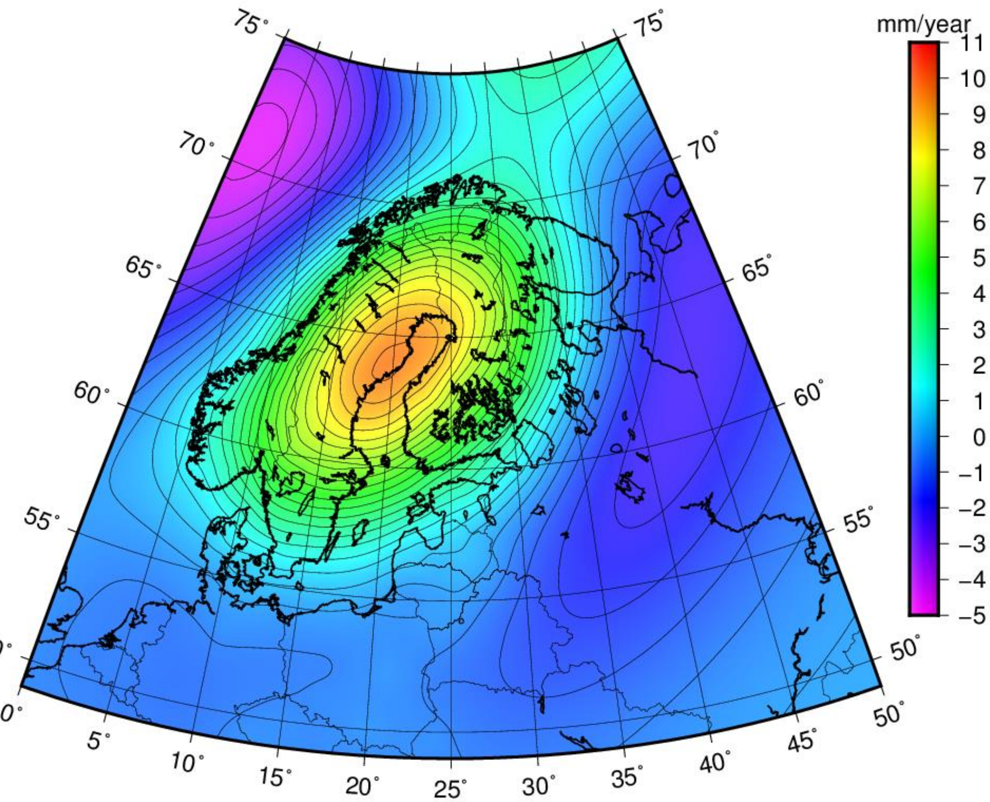
Difference between BIFROST GNSS and NKG2016LU_ABS



- mm/year
- Statistics:

#	179
Min	-2.00
Max	1.32
Mean	0.02
StdDev	0.42

NKG2016LU_lev



$$\dot{H}^{\text{grid}}_{\text{NKG2016LU\_lev}} = \dot{h}^{\text{grid}}_{\text{NKG2016LU\_abs}} - \dot{N}^{\text{grid}}_{\text{NKG2016GIA\_prel0306}}$$

- Levelled uplift = uplift relative to the geoid.
- The geoid is here interpreted as an equipotential surface that is still rising due to historical ice melting in the past, through Glacial Isostatic Adjustment…, but **not** due to contemporary climate related sea level changes (caused by temperature increase, present day ice melting, etc.)
- Statistics:

#	313 x 301
Min	-4.67
Max	9.63
Mean	0.69
StdDev	2.98

- Contour interval: 0.5 mm/year
- Can be used for epoch conversion of orthometric or normal heights in a vertical reference system.
- Can also be used as a basis to take care of the postglacial land uplift due to old historic deglaciations in sea level studies; see next paragraph.

Comparisons of NKG2016LU_lev with observed apparent land uplift in tide gauges

Recommended strategy to convert the levelled uplift of NKG2016LU_lev to apparent land uplift

- **If** we had no contemporary climate-related sea level changes (due to temperature increase, present day ice melting, etc.), **then** the levelled uplift would be equal to the apparent uplift (i.e. land uplift relative to Mean Sea Level).
- However, now we do have such additional contemporary sea level changes. These changes are accelerating in time and varies (a little) with position.
- To get the apparent uplift for a certain time interval and area, the following procedure is recommended. (It means that NKG2016LU_lev is utilised to model that part of the apparent uplift that depends on old historical ice melting through Glacial Isostatic Adjustment. The remaining part, i.e. the additional contemporary sea level change, is estimated as a simple mean value.)
- The apparent uplift (i.e. uplift relative to Mean Sea Level over a certain time period) is first computed in all the tide gauges for the time interval and area in question,

$$\Rightarrow \dot{H}_{\text{app,year1-year2,i}}$$

- The additional contemporary relative sea level change, based on *n* tide gauges, is then computed as a (positive) constant, using

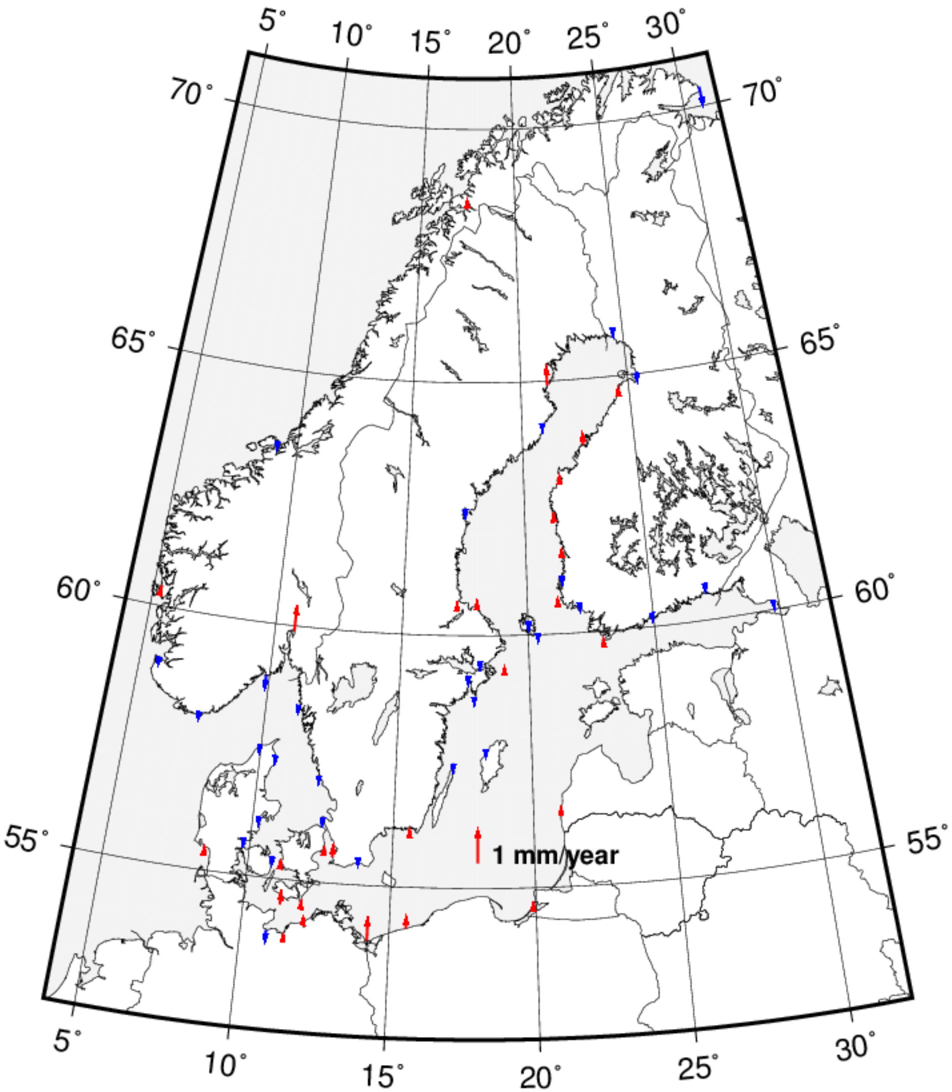
$$\Delta\dot{H}^{\text{constant}}_{\text{year1-year2}} = \frac{\sum_{i=1}^{n}\left(\dot{H}_{\text{NKG2016LU\_lev,i}} - \dot{H}_{\text{app,year1-year2,i}}\right)}{n}$$

- The apparent uplift for the area and time interval in question is then computed as,

$$\dot{H}_{\text{app,year1-year2}} = \dot{H}_{\text{NKG2016LU\_lev}} - \Delta\dot{H}^{\text{constant}}_{\text{year1-year2}}$$

- Neither an official apparent uplift model nor a reference time interval is recommended here. It is now up to others to convert NKG2016LU_lev to apparent uplift (for a specific purpose, time interval and area).
- See examples below.

Difference between apparent uplift in tide gauges and NKG2016LU_lev minus a constant (1)



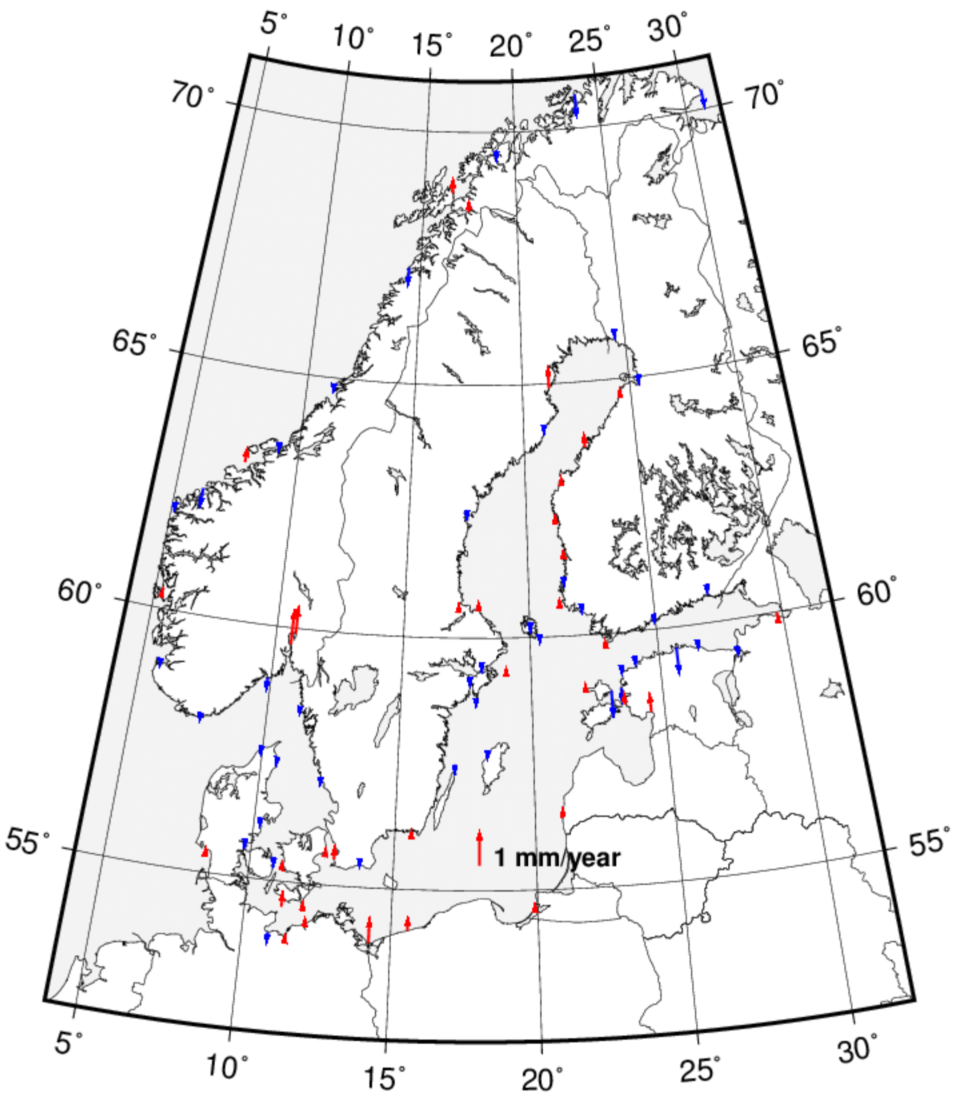
$$\dot{H}_{\text{app,1892-1991}} = \dot{H}_{\text{NKG2016LU\_lev}} - 1.29 \text{ mm/year}$$

- **Ekman (1996).**
- Time interval: 1892-1991
- Standard uncertainty estimated by Ekman (1989) to 0.2 mm/year
- Statistics (mm/year):

#	58
Min	-0.61
Max	0.75
Mean	0.00
StdDev	0.27

- Considering the accuracy estimation above and that NKG2016LU_lev has been computed completely without tide gauge information, this is a **very good agreement.**

Difference between apparent uplift in tide gauges and NKG2016LU_lev minus a constant (2)

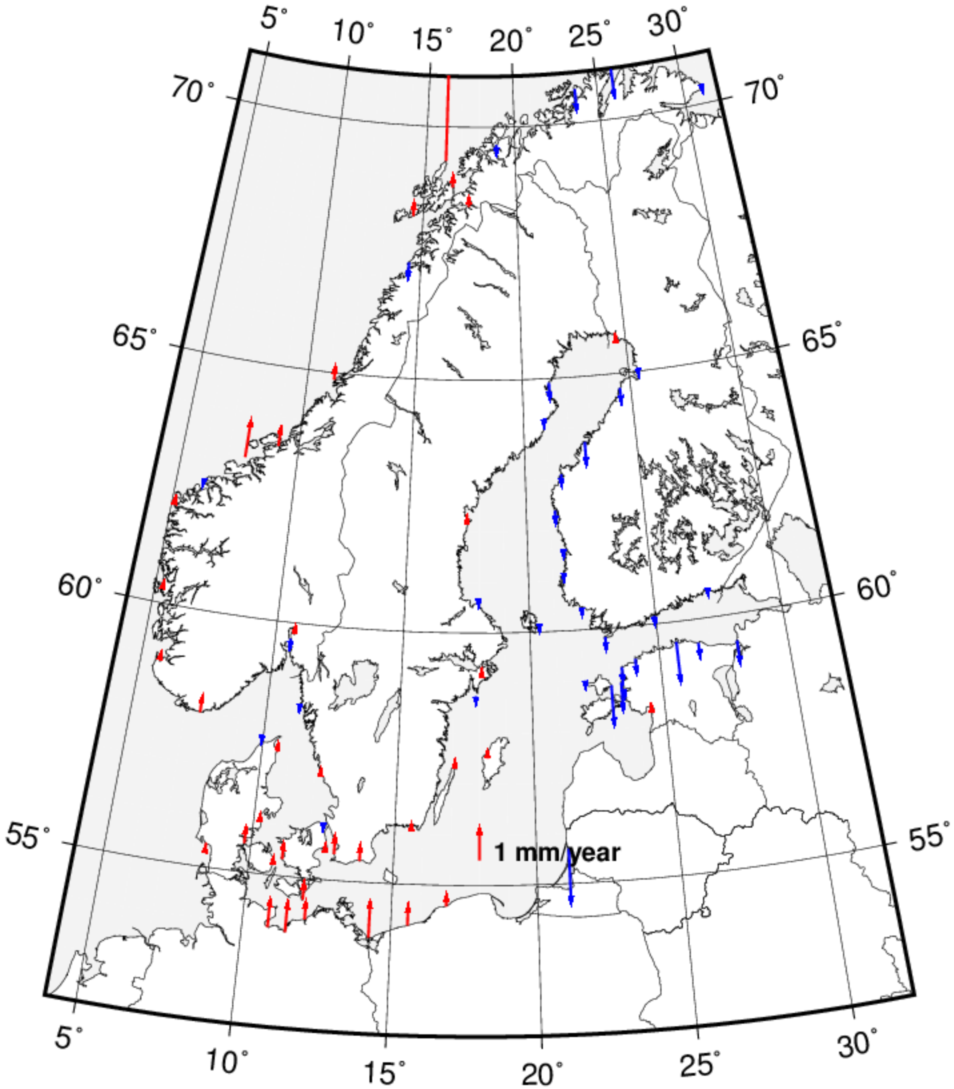


$$\dot{H}_{\text{app,1892-1991}} = \dot{H}_{\text{NKG2016LU\_lev}} - 1.32 \text{ mm/year}$$

- **Ekman (1996) and Norwegian/ Estonian** tide gauges with shorter time spans (converted to the Ekman interval 1892-1991).
- Time interval: **1892-1991**
- Statistics (mm/year):

#	77
Min	-0.79
Max	0.99
Mean	0.00
StdDev	0.35

Difference between apparent uplift in tide gauges and NKG2016LU_lev minus a constant (3)



$$\dot{H}_{\mathrm{app,1892\text{-}1991}} = \dot{H}_{\mathrm{NKG2016LU\_lev}} - 2.38\ \mathrm{mm/year}$$

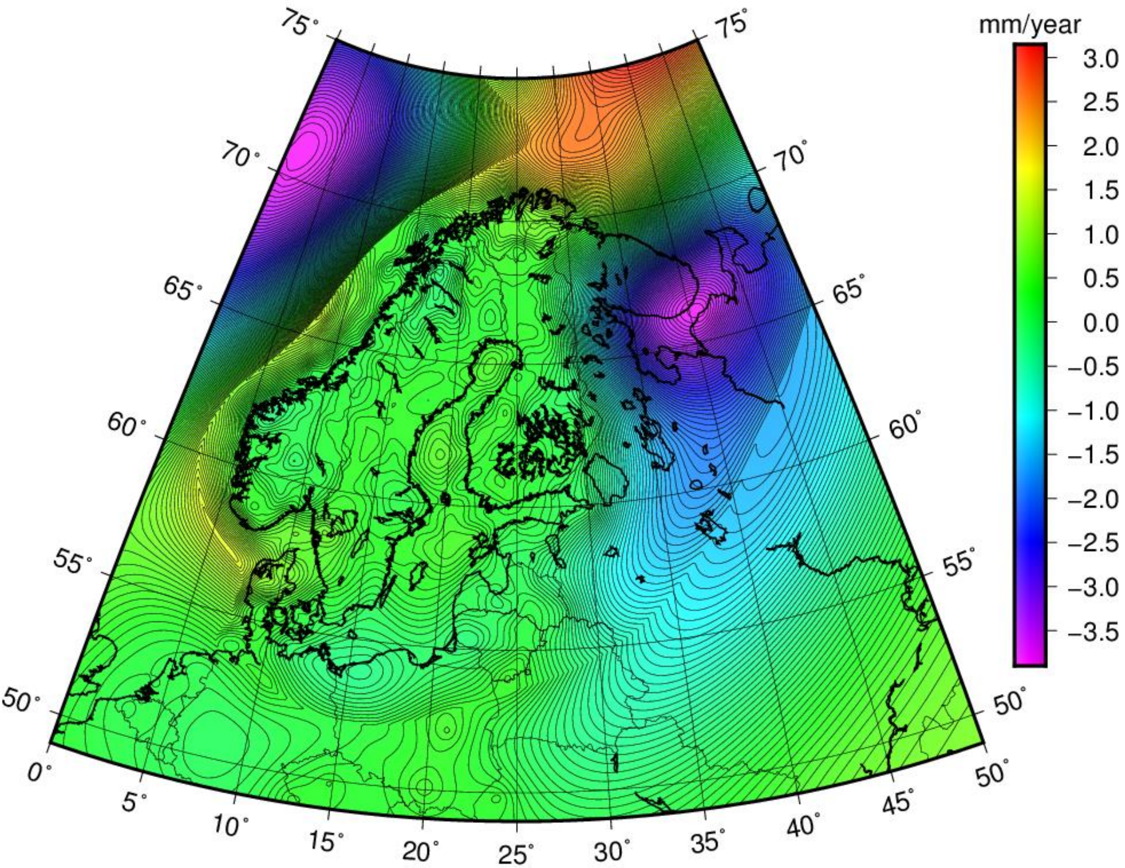
- **PSMSL**, preliminary apparent uplift values compiled by Olav Vestøl.
- Time interval: **1956-2012** (57 years)
- Statistics (mm/year):

#	71
Min	-1.62
Max	2.80
Mean	0.00
StdDev	0.63

- Some clearly systematic geographic differences. One very large outlier in northern Norway not removed.
- Deeper investigations needed.

Comparison with the old model (NKG2005LU)

Differences between NKG2016LU_abs and NKG2005LU_abs



- Old official model; cf. introduction (Vestøl 2007; Ågren et al. 2007).
- Different reference frames ITRF2008 vs ITRF2000)
- Statistics (mm/year):

#	313 x 301
Min	-3.89
Max	3.10
Mean	-0.25
StdDev	1.35

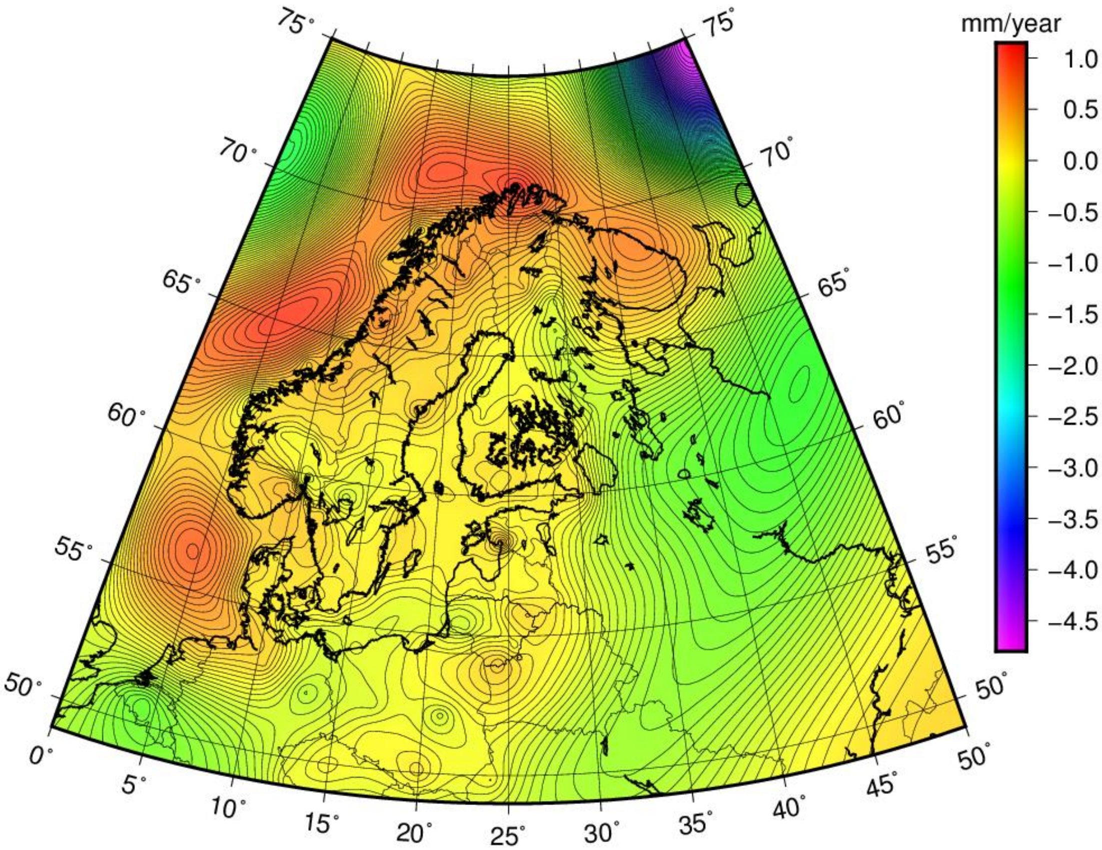
- Contour interval: 0.05 mm/year
- The strange "ridge" e.g. outside the west coast of Norway depends on that NKG2015LU was deliberately truncated to the apparent uplift -2 mm/year (smaller values set to this)
- The big deviation in the White Sea is due to different ice models.

Final words

- The semi-empirical land uplift model **NKG2016LU** is hereby released.
- The model gives the vertical land uplift rate in two different ways (**in mm/year**),
  - **NKG2016LU_abs**: Absolute land uplift in ITRF2008 (i.e. relative to the Earth's centre of mass)
  - **NKG2016LU_lev**: Levelled land uplift, i.e. uplift relative to the geoid.
- The NKG2016LU_abs and NKG2016LU_lev have been computed based on
  - An **empirical land uplift model** computed by Olav Vestøl (2016) based on geodetic observations (GNSS time series from BIFROST and NKG levelling, **no tide gauges used**)
  - The preliminary geophysical GIA model **NKG2016GIA_prel0306** computed by Steffen et al. (2016) in the NKG WG of Geodynamics
  - The geoid rise of this GIA model is used to transform between absolute and levelled uplift.
- No apparent model (i.e. uplift relative to Mean Sea Level over a certain time period) is released for the time being,
  - Due to the (accelerating) contemporary climate-related sea level rise (caused by temperature increase, present day ice melting, etc.), the apparent land uplift is **not** equal to the levelled land uplift.
  - If the **apparent uplift** is needed, then it is recommended to estimate a constant (for a certain time interval and for a certain geographical area) to subtract from NKG2016LU_lev. This is a qualified task that should be made with great care.

Extra slides

Differences between NKG2016LU_abs and NKG2014LU_test_abs

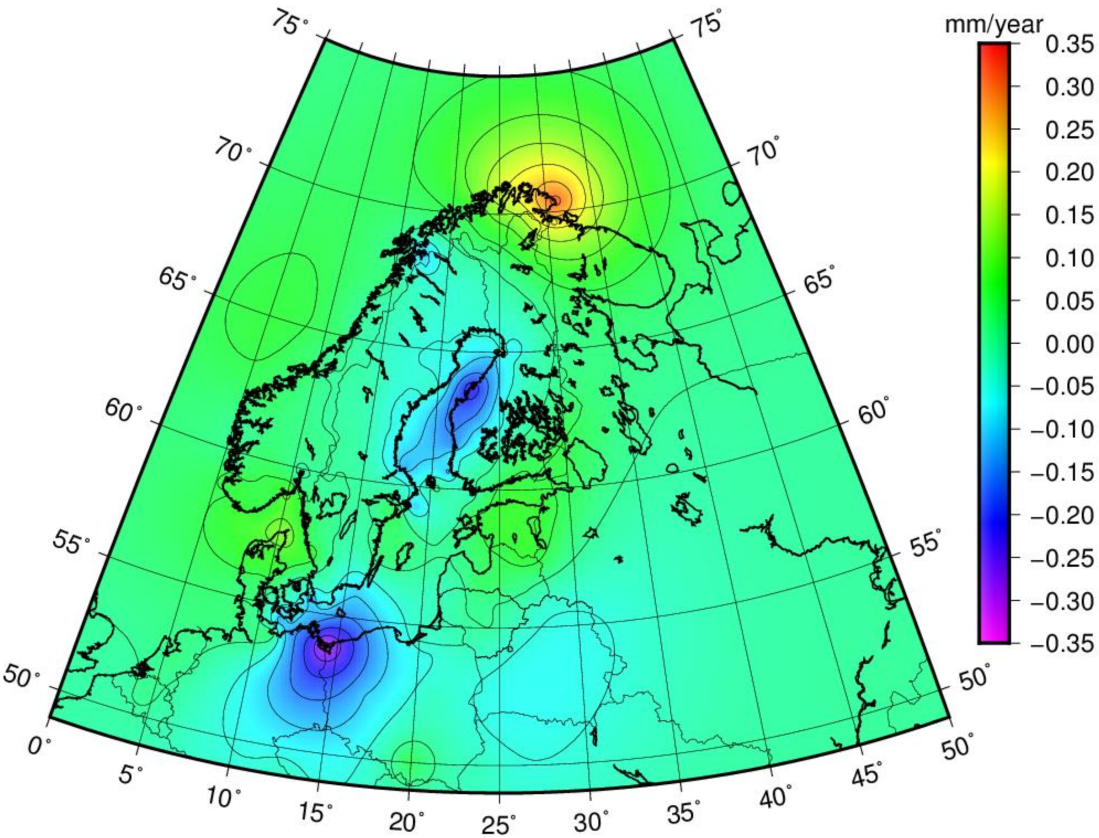


- The **NKG2014LU_test** model was computed to the NKG General Assembly 2014 (Vestøl 2014). It was then evaluated, but never released.
- NKG2014LU_test has been computed using
  - an earlier BIFROST GNSS solution,
  - A previous GIA model of Steffen et al. (2014)
  - Ekman + Norwegian tide gauges
  - no levelling from Lithuania
  - a scale factor model for the geoid rise.
  - …
- Statistics (mm/year):

#	313 x 301
Min	-4.76
Max	1.11
Mean	-0.19
StdDev	0.73

- Contour interval: 0.05 mm/year

Differences between NKG2016LU_abs and NKG2016LU_test_abs

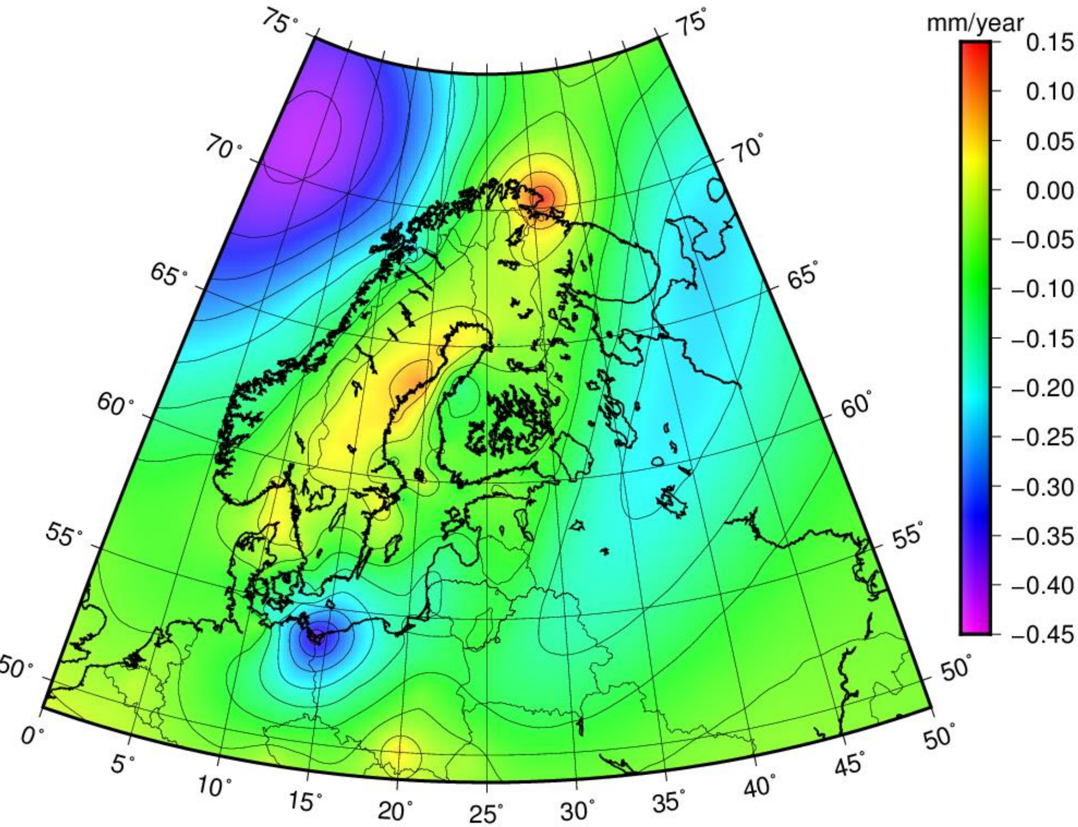


- **NKG2016LU_test_abs** was computed using
  - Also tide gauges (Ekman + short Norwegian and Estonian)
  - and a scale factor model for the geoid rise (to relate GNSS, levelling and tide gauges; cf. next slide).
- Otherwise everything exactly the same as for final NKG2016LU_abs.
- Statistics (mm/year):

#	313 x 301
Min	-0.31
Max	0.32
Mean	0.00
StdDev	0.06

- Contour interval: 0.05 mm/year

Differences between NKG2016LU_lev minus NKG2016LU_test_lev



- **NKG2016LU_test_lev** was computed using the linear scale factor relationship implicit in the **old type** model:

$$\dot{H}^{\mathrm{grid}}_{\mathrm{NKG2016LU\_test\_lev}} = \dot{h}^{\mathrm{grid}}_{\mathrm{NKG2016LU\_test\_abs}} \cdot \left(1 - \frac{1}{1.0810}\right)$$
$$= \dot{h}^{\mathrm{grid}}_{\mathrm{NKG2016LU\_test\_abs}} \cdot 0.9251$$

- Statistics (mm/year):

#	313 x 301
Min	-0.41
Max	0.15
Mean	-0.13
StdDev	0.10

- Contour interval: 0.05 mm/year

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