Preliminary new horizontal velocity model for Sweden and the Nordic area by transforming the new optimized GIA model

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(with assistance from many dear colleagues)

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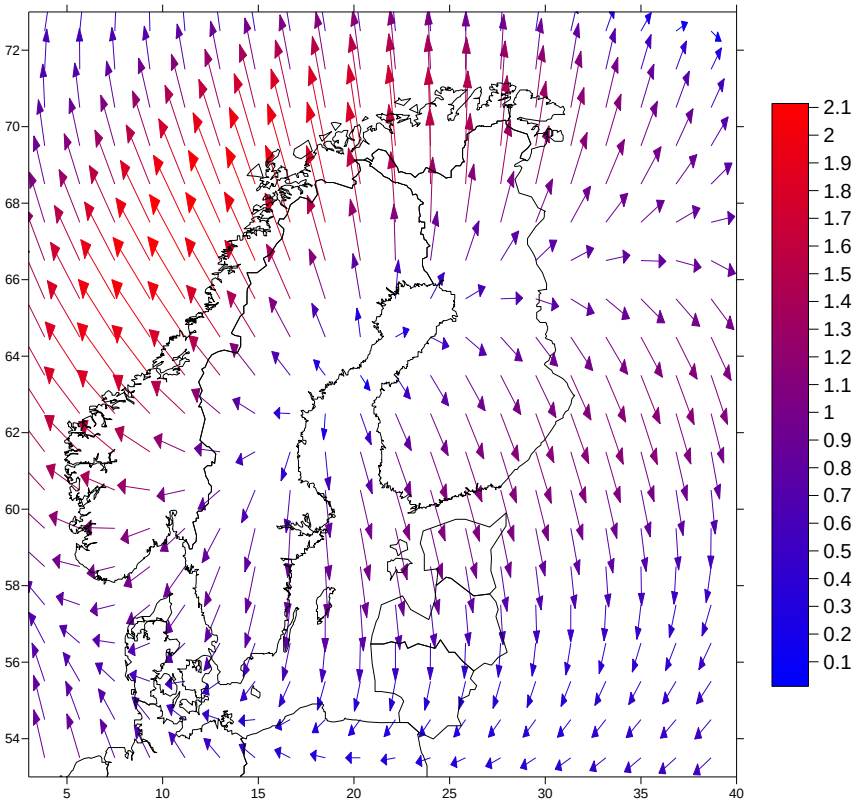
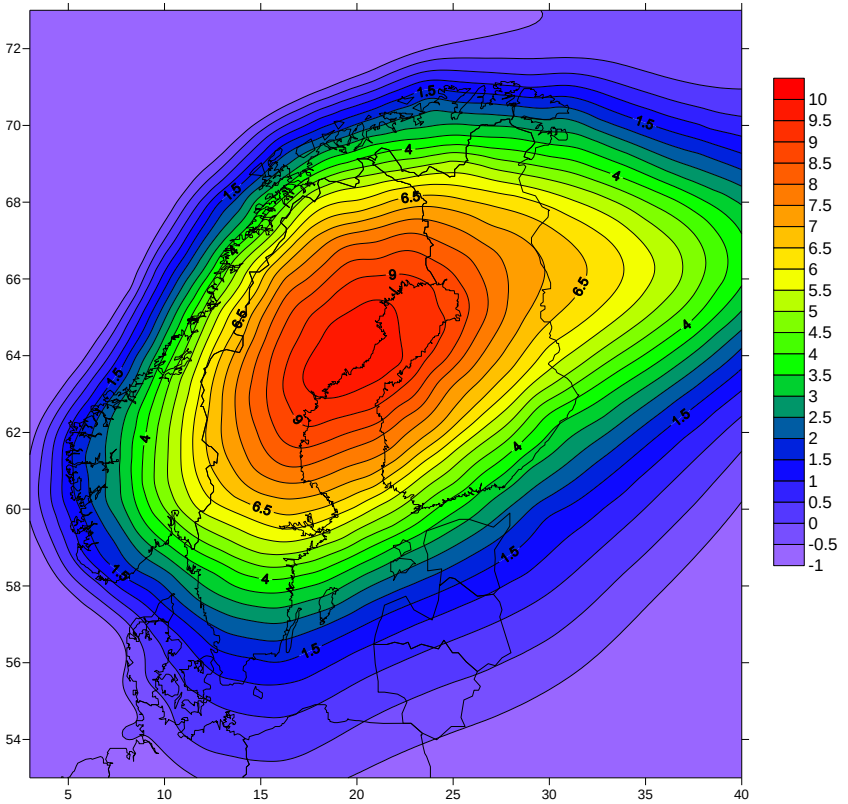
The NKG_RF03vel velocity model

- has been in use for more than 10 years..



Horizontal (0 to 2 mm/yr):
The GIA model in Milne et al. (2001) transformed to the GPS-velocities in Lidberg (2007).



Vertical (-1 to 10 mm/yr):
The NKG2005LU_ABS model
Based on: tide gauges, repeated levelling, and GPS. (Ågren & Svensson 2007)

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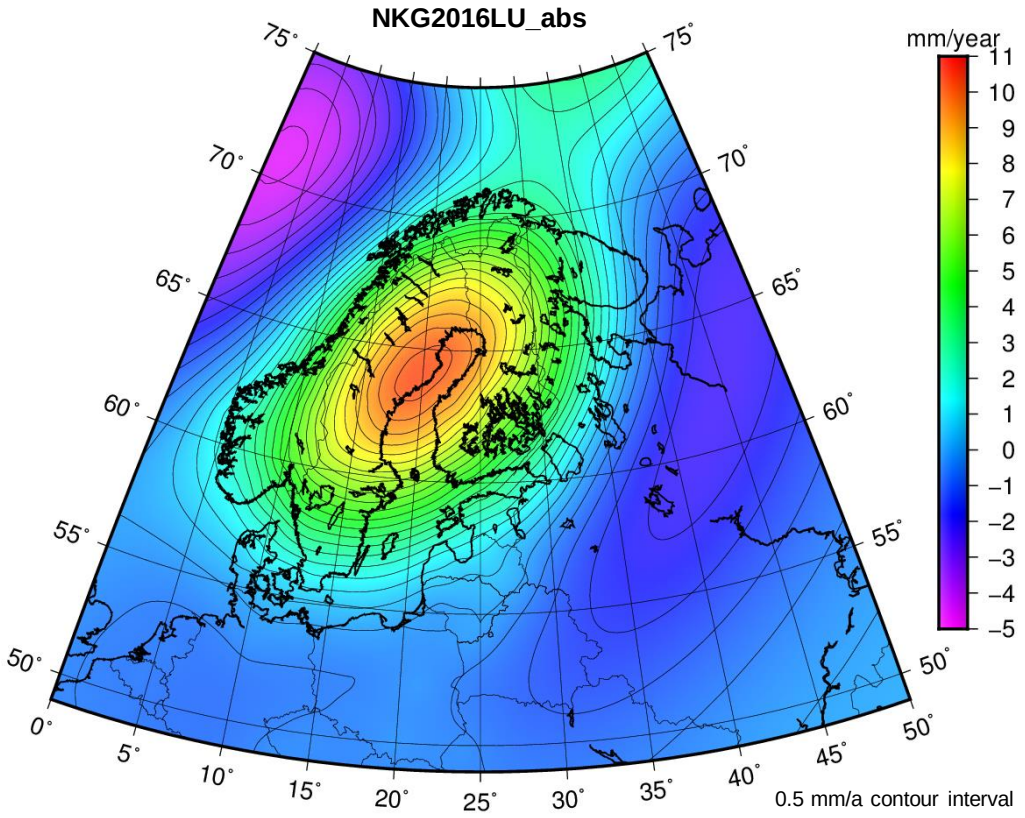
New Land uplift model NKG2016LU

- Semi-empirical land uplift model computed in Nordic-Baltic cooperation in the NKG Working Group of Geoid and Height Systems
- NKG2016LU has been computed based on
  - An **empirical land uplift model** computed by Olav Vestøl based on geodetic observations, i.e. levelling and **BIFROST GPS**
  - The preliminary geophysical GIA model N**KG2016GIA_prel0306** computed by Steffen et al. (2016) in the NKG WG of Geodynamics



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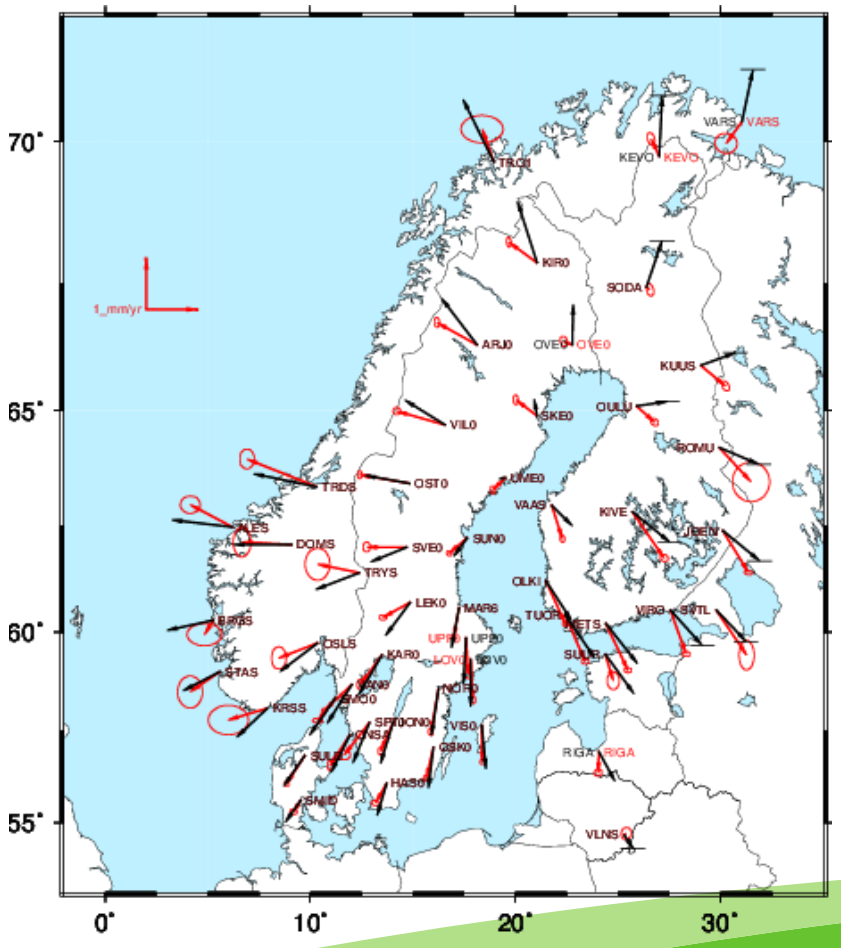
Evaluating station velocity results

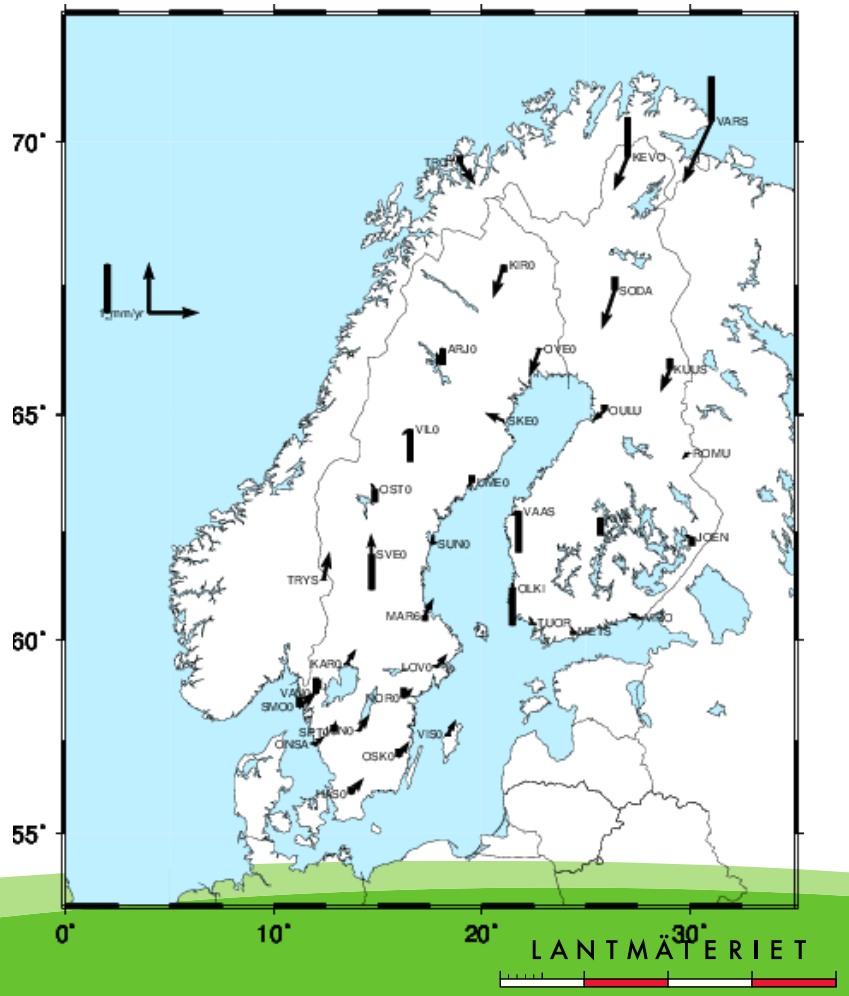
BIFROST Station velocities from GAMIT vs GIA model

RMS-p : 0.46 mm/yr (all sites)

GAMIT minus GIA model "best sites" : (0.4, 0.2, 0.4) (n,e,u) mm/yr std.

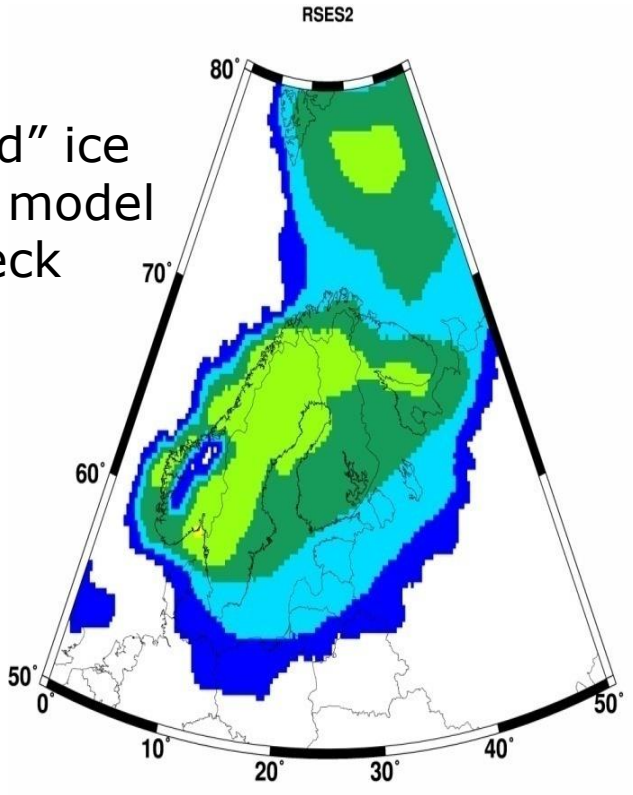
(after 6-par fit, applying rotation and translation rates)

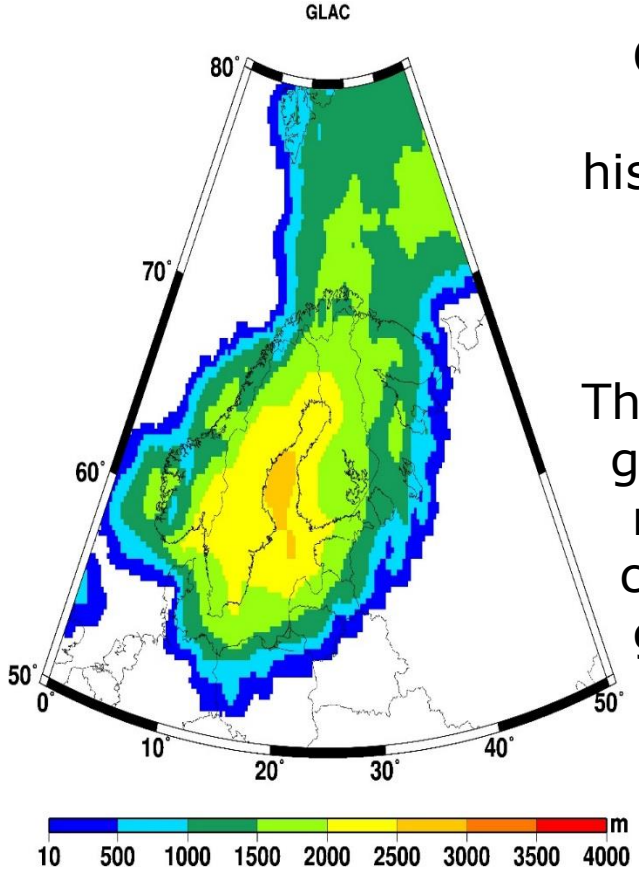




New Thermo-mechanical ice model examples at LGM

The ”old” ice history model (Lambeck 1998)





One of the ”new” ice history models from Lev Tarasov.

The ice history governed by models for climate and glaciology.

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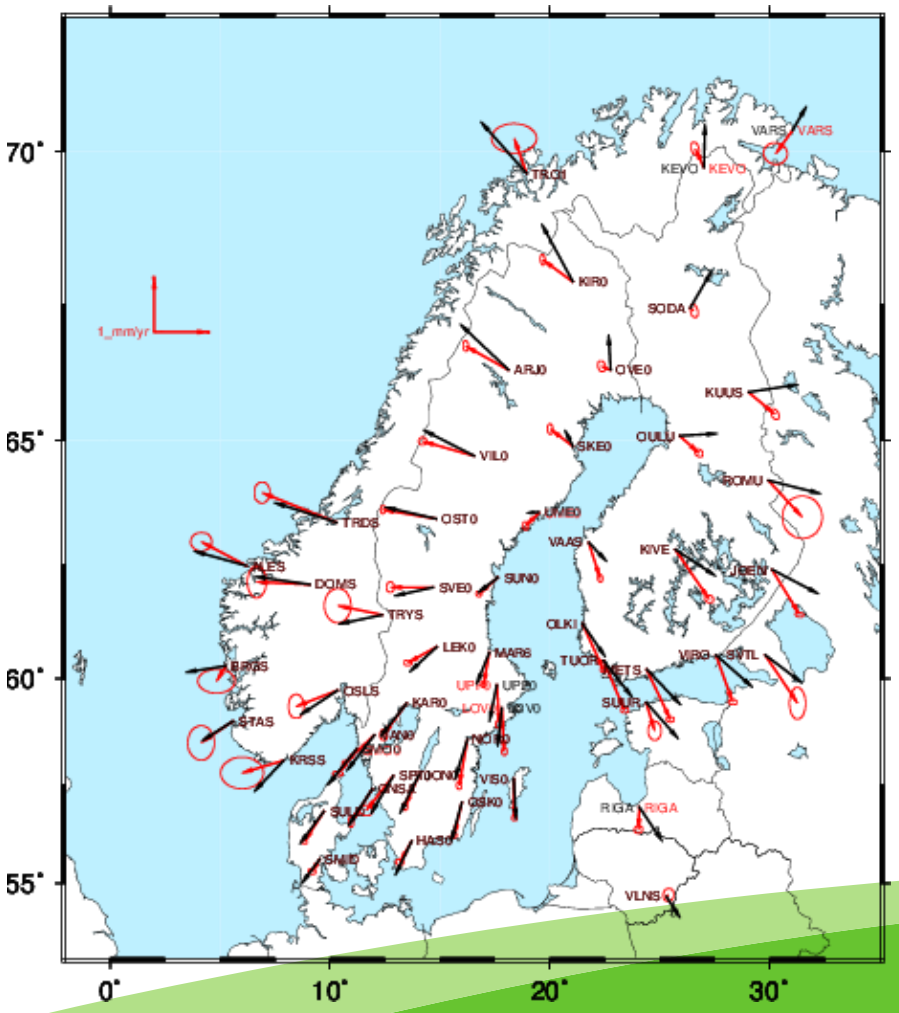
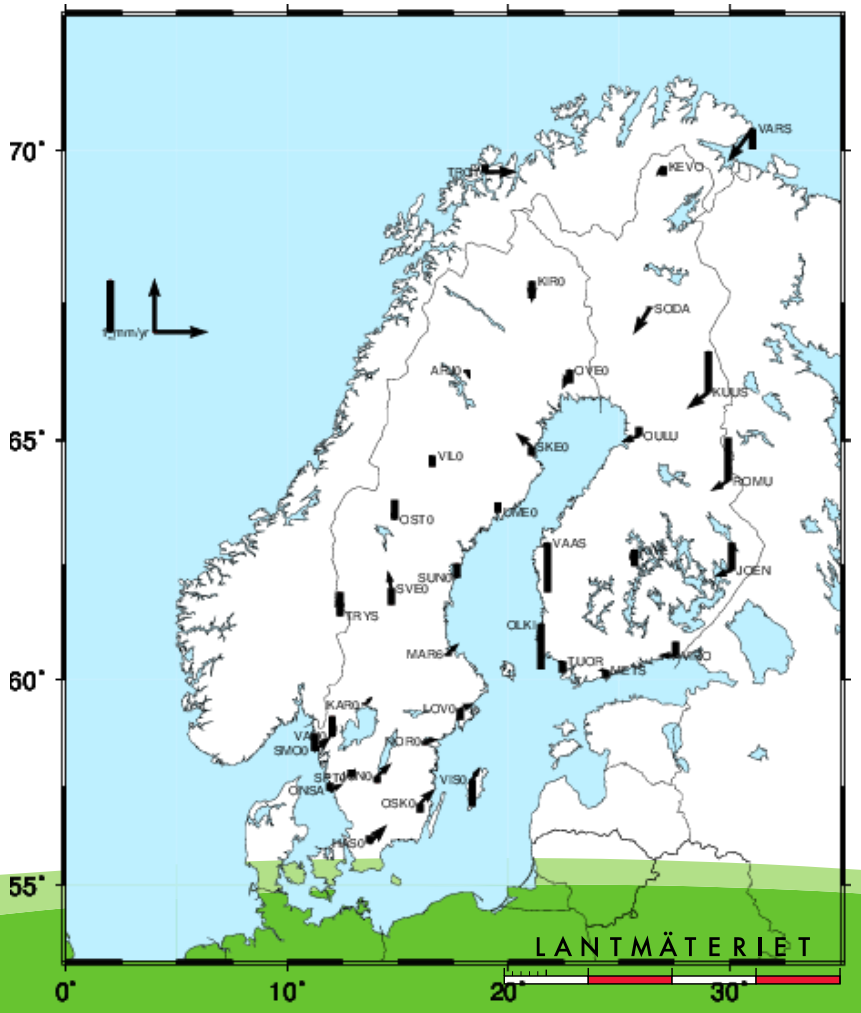
Evaluating station velocity results vs new ice model

GAMIT vs GIA model (new)
RMS-p : 0.39 mm/yr (all sites)



GAMIT minus GIA model (new)
"best sites" : (0.2, 0.2, 0.4)
(n,e,u) mm/yr std.
(after 6-par fit, applying rotation and translation rates)

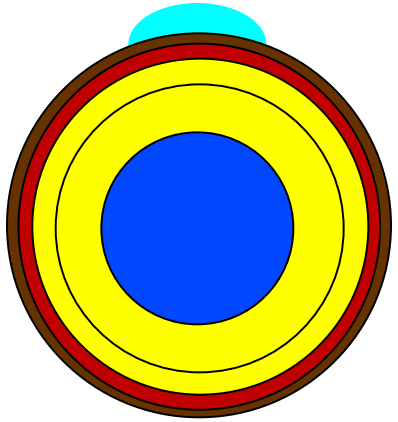


Content

- Background (done!)
- Choice of which GIA model from Holger Steffen to be used!
- Which geodetic reference frame should the selected GIA model be transformed to?
- We end up in using the GPS velocities from BIFROST as reference (version 2016-03-01), but which common points should be used for the transformation!
- Which parameters should we solve for in the transformation?
- Then transforming the grid from GIA-frame to the geodetic frame and compiling a product

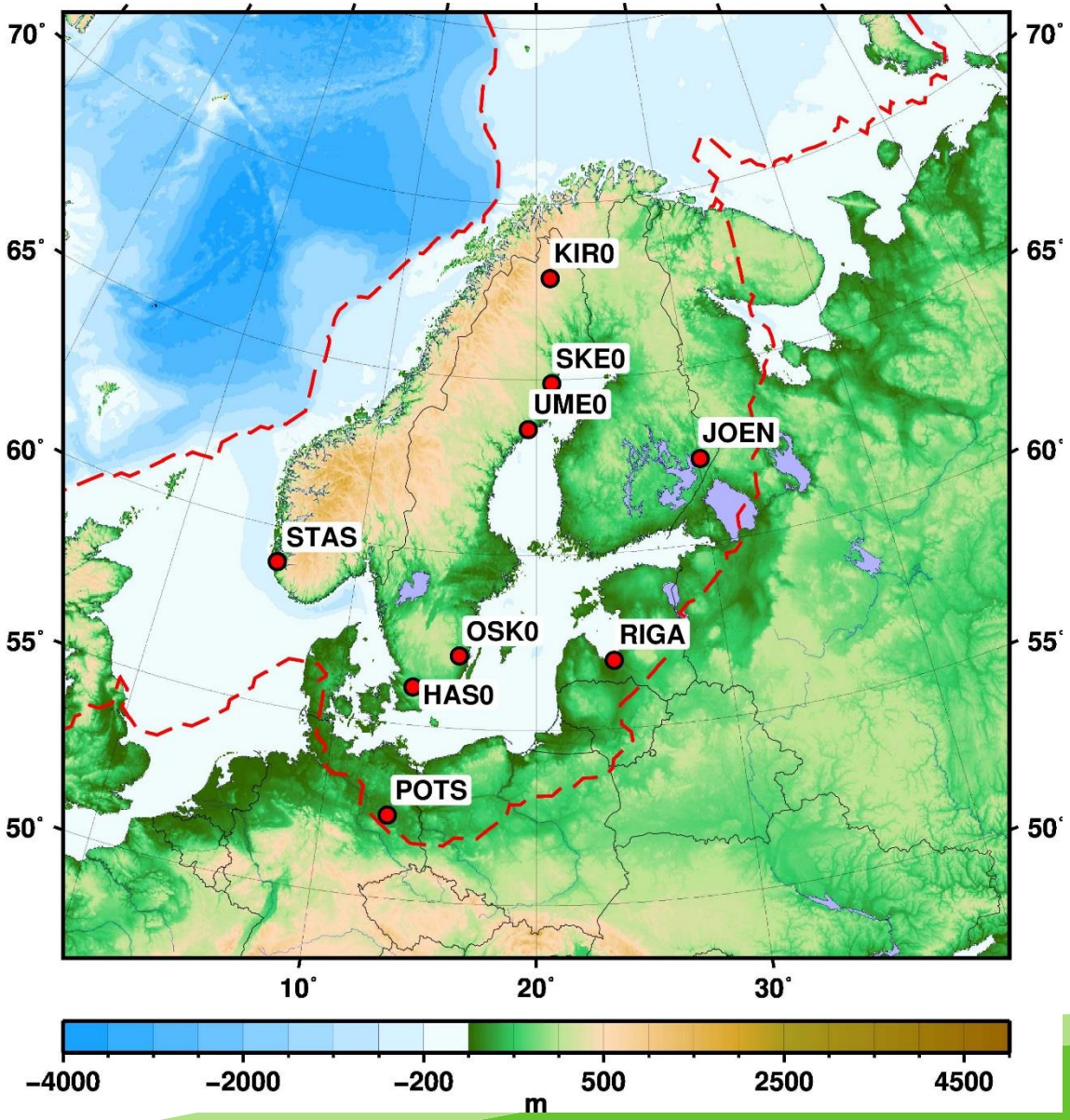
GIA modelling: Method overview

- 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, **sublithospheric,** upper and lower mantle viscosity as free parameter (so-called **four**-layer models); other model parameters as used in COST benchmark activity (Spada et al. 2011)
- Test of different ice models
- 1:1 or 4:1-weighted root-mean-square fitting of **quite many** GIA models (earth-ice model combinations) to **3D velocity field** of BIFROST 2015/16 GAMIT/GLOBK GNSS solution **and** Fennoscandian RSL data



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

Location of sieve test stations



Red dashed line: ice margin from GLAC71340 at 22 ka BP

25 different ice history models; 441 different earth models
=> ~11000 GIA models

Sieve test:
Models to be considered for further analysis should agree with GPS velocities in the selected stations "reasonable well"

Since GIA models are not in "geodetic reference frames", some transformations are needed.

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Choice of which GIA model from Holger to be used

- Out of “numerous” GIA models, From the “sieve-test” we got 6 models to choose among
- Criteria for selection: “best fit to the BIFROST solution”

But:

- Which stations from the BIFROST 2016-03-01 solution to use?
- How to do the comparison?

RMS of (mis-)fit, (n,e,u) mm/yr 1(2)

"all" 164 sites from the BIFROST solution

model1_to_BIFROST_164_R.veldiff:x RMS	:	0.33	0.25	0.95
model2_to_BIFROST_164_R.veldiff:x RMS	:	0.53	0.36	0.52
model3_to_BIFROST_164_R.veldiff:x RMS	**:**	**0.26**	**0.25**	**0.86**
model4_to_BIFROST_164_R.veldiff:x RMS	:	0.47	0.31	0.54
model5_to_BIFROST_164_R.veldiff:x RMS	:	0.44	0.32	0.70
model6_to_BIFROST_164_R.veldiff:x RMS	:	0.26	0.25	0.59

Selected 66 sites

model1_to_BIFROST_best_R.veldiff:x RMS	:	0.32	0.25	0.72
model2_to_BIFROST_best_R.veldiff:x RMS	:	0.49	0.38	0.46
model3_to_BIFROST_best_R.veldiff:x RMS	**:**	**0.22**	**0.21**	**0.76**
model4_to_BIFROST_best_R.veldiff:x RMS	:	0.45	0.30	0.47
model5_to_BIFROST_best_R.veldiff:x RMS	:	0.41	0.32	0.67
model6_to_BIFROST_best_R.veldiff:x RMS	:	0.23	0.21	0.54

33 sites in Sweden and Finland

model1_to_BIFROST_swefin_R.veldiff:x RMS	:	0.23	0.21	0.60
model2_to_BIFROST_swefin_R.veldiff:x RMS	:	0.45	0.34	0.43
model3_to_BIFROST_swefin_R.veldiff:x RMS	**:**	**0.13**	**0.14**	**0.70**
model4_to_BIFROST_swefin_R.veldiff:x RMS	:	0.38	0.24	0.50
model5_to_BIFROST_swefin_R.veldiff:x RMS	:	0.34	0.27	0.80
model6_to_BIFROST_swefin_R.veldiff:x RMS	:	0.12	0.15	0.54

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RMS of (mis-)fit, (n,e,u) mm/yr 2(2)

"all" 164 sites from the BIFROST solution

model1_to_BIFROST_164_TR.veldiff:x RMS	:	0.27	0.24	0.67
model2_to_BIFROST_164_TR.veldiff:x RMS	:	0.48	0.33	0.84
model3_to_BIFROST_164_TR.veldiff:x RMS	**:**	**0.27**	**0.24**	**0.52**
model4_to_BIFROST_164_TR.veldiff:x RMS	:	0.42	0.28	0.80
model5_to_BIFROST_164_TR.veldiff:x RMS	:	0.38	0.28	0.75
model6_to_BIFROST_164_TR.veldiff:x RMS	:	0.25	0.25	0.57

Selected 66 sites

model1_to_BIFROST_best_TR.veldiff:x RMS	:	0.28	0.22	0.60
model2_to_BIFROST_best_TR.veldiff:x RMS	:	0.45	0.35	0.77
model3_to_BIFROST_best_TR.veldiff:x RMS	**:**	**0.23**	**0.20**	**0.43**
model4_to_BIFROST_best_TR.veldiff:x RMS	:	0.40	0.27	0.74
model5_to_BIFROST_best_TR.veldiff:x RMS	:	0.35	0.27	0.72
model6_to_BIFROST_best_TR.veldiff:x RMS	:	0.22	0.22	0.51

33 sites in Sweden and Finland

model1_to_BIFROST_swefin_TR.veldiff:x RMS	:	0.20	0.19	0.42
model2_to_BIFROST_swefin_TR.veldiff:x RMS	:	0.43	0.32	0.63
model3_to_BIFROST_swefin_TR.veldiff:x RMS	**:**	**0.15**	**0.13**	**0.31**
model4_to_BIFROST_swefin_TR.veldiff:x RMS	:	0.35	0.23	0.55
model5_to_BIFROST_swefin_TR.veldiff:x RMS	:	0.29	0.23	0.60
model6_to_BIFROST_swefin_TR.veldiff:x RMS	:	0.12	0.16	0.43

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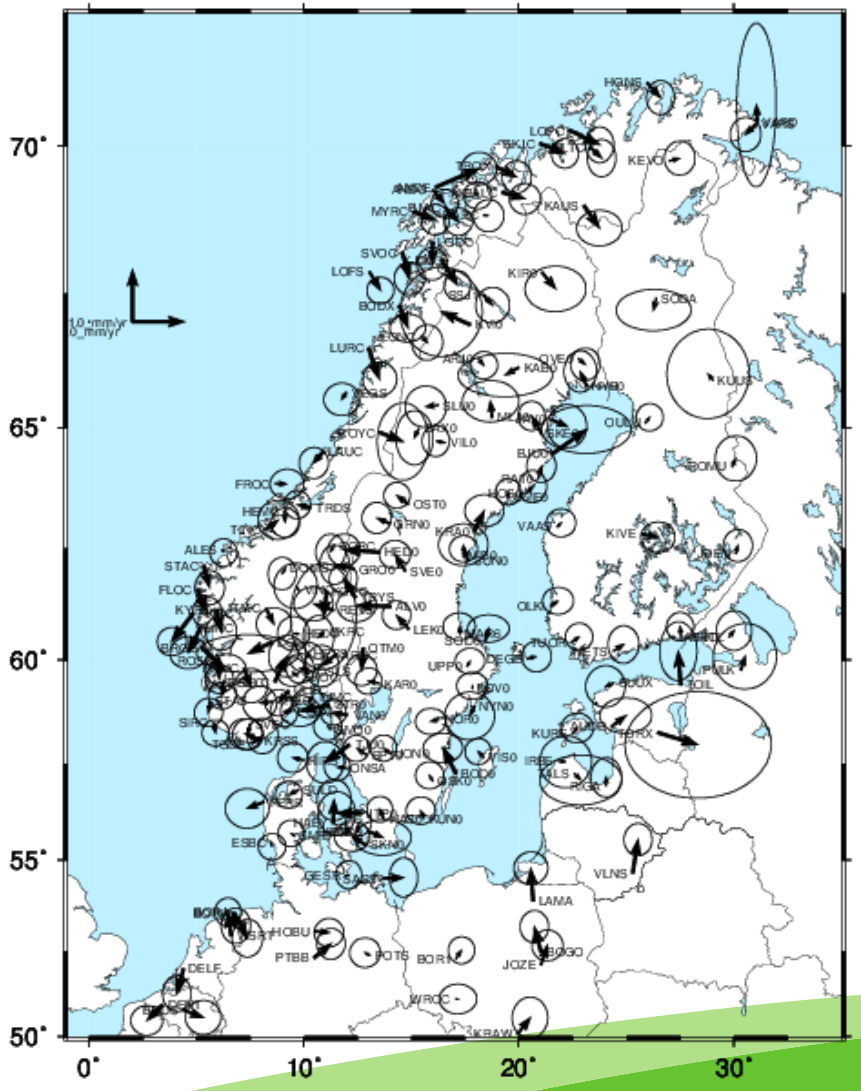
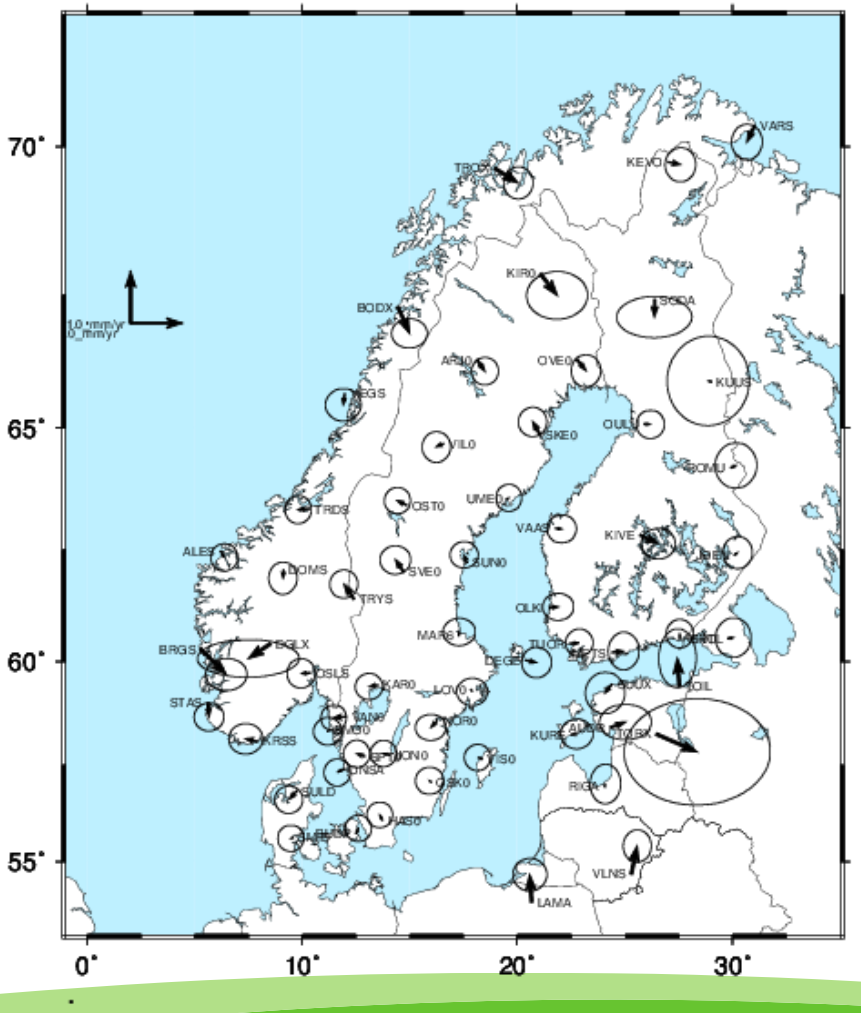
BIFROST & model 3 residual plots

164 sites, RMS n:0.26 e:0.25 mm/yr



66 sites, RMS n:0.22 e:0.21 mm/yr



Relative to NONE Input file : BIFROST_best_to_m3_R.veldif
Confidence interval : 95 ChiSquare / dof : 0.00 Formal Errors Scaled by 1.00
Fri Dec 2 01:10:23 CET 2016

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Target geodetic reference frame for the selected GIA model?

- Should be "stable Eurasia"
- Could be realized in different ways, e.g.:
  - ITRF2008, rotated using ITRF2008 Euler pole for Eurasia
  - ITRF2014, rotated using ITRF2014 Euler pole for Eurasia (ETRF2014)
  - ETRS89, realized through ETRF2000
  - Or model transformed to "zero velocity" at land uplift maximum, and areas outside the fore bulge.

Differences between BIFROST in IGb08 and ITRF2014

IGb08 vs ITRF2014

Bias:

vn:-0.06 ve:-0.15

rotated to Eurasia

Bias:

vn:-0.16 ve: 0.21 mm/yr

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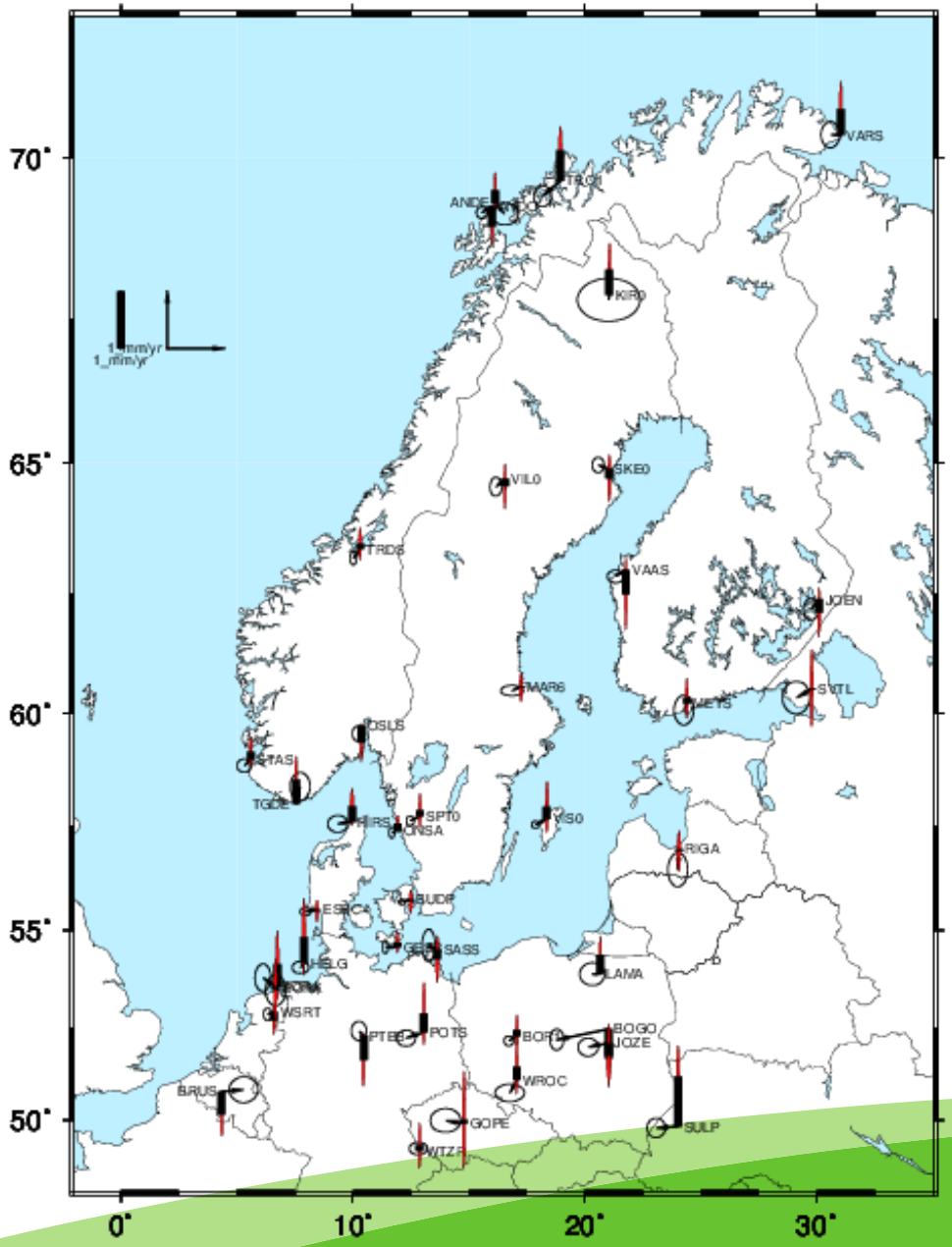
BIFROST IGb08 v.s. ITRF2014



BIFROST - ITRF2014
north east up (mm)
mean : -0.06 -0.15 0.06
Std : 0.12 0.19 0.30

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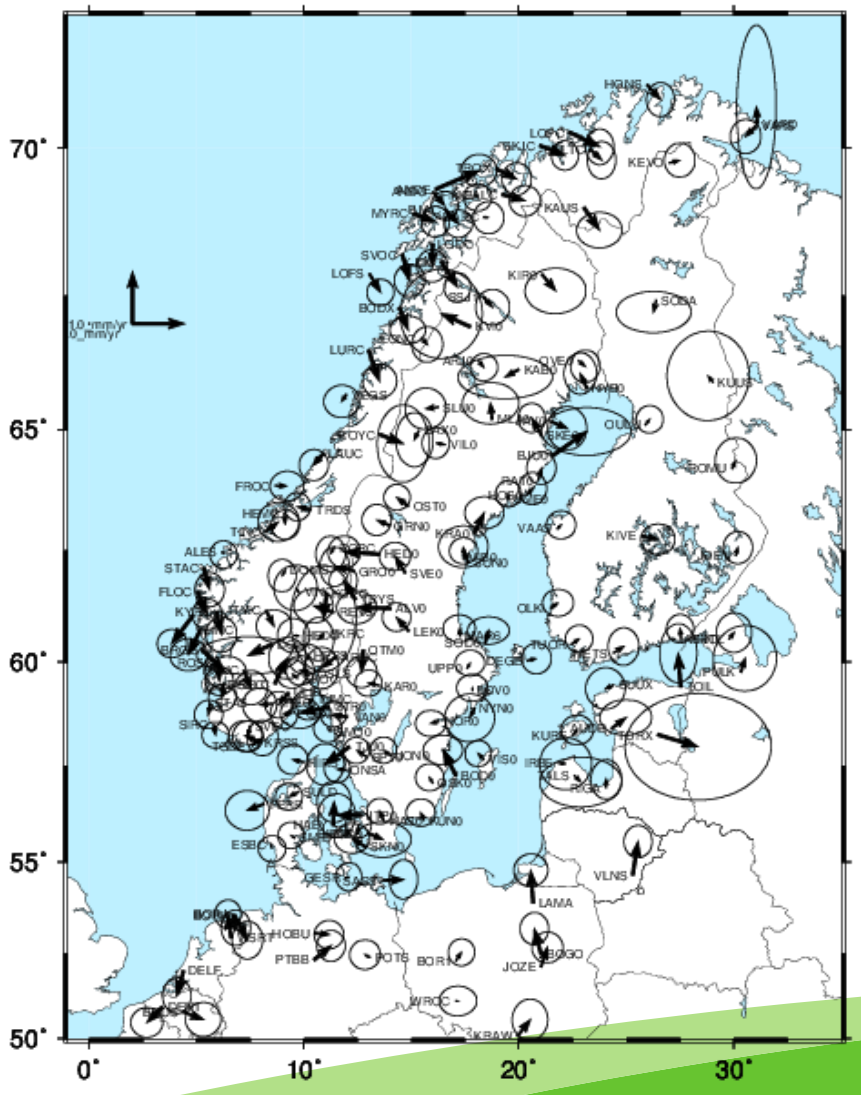
Some considerations

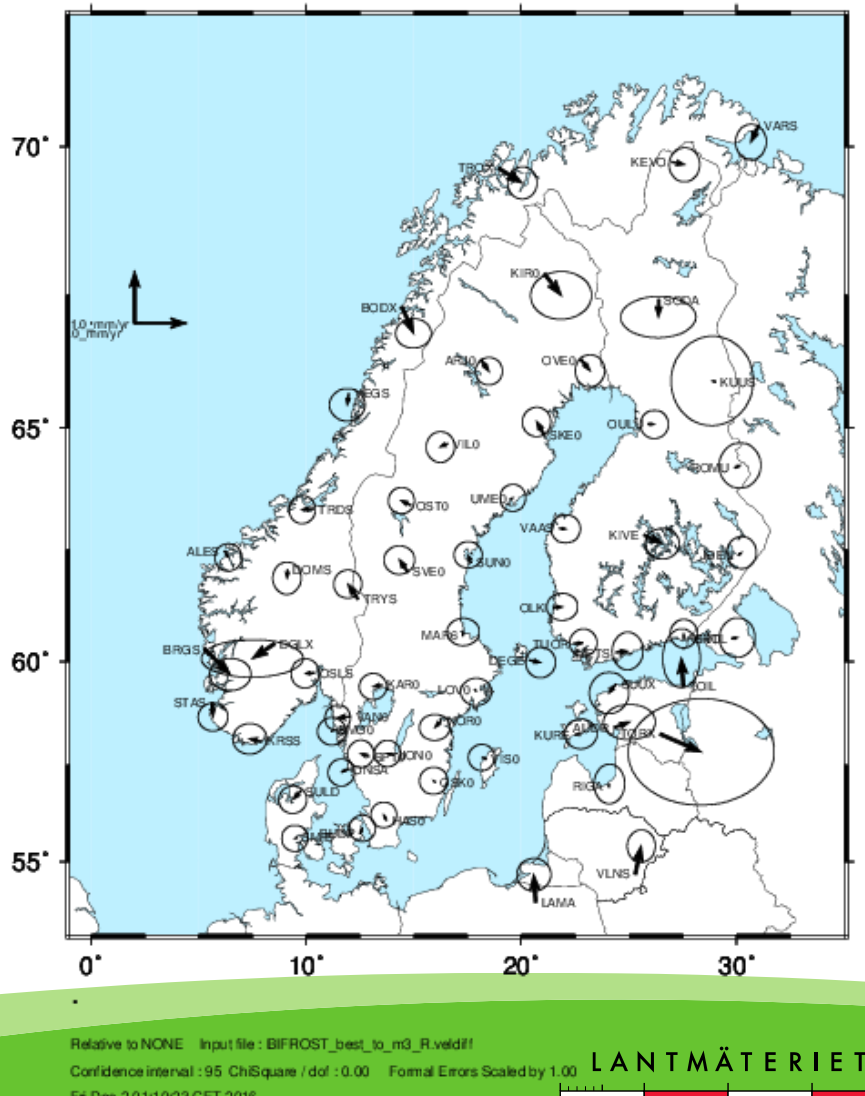
- NKG2016LU_ABS use IGb08
- It is “not too bad” if the horizontal velocities are consistent with the vertical velocities of a combined model
- ETRF2000 vertical velocities differ from ITRF2008
- Booth ETRF2000 and ETRF2014 is/will be available, and for ETRF2014, horizontal velocities will be “ITRF2014 with Eurasia rotation removed”
- And difference between “stable Eurasia” realized through ITRF2008 and ITRF2014 are at 0.2 mm/yr

=> BIFROST in IGb08 reduced using its rotation pole

Choice of common points, and parameters to solve for in transformation of the model

- Euler pole rotation using the 66 "good sites





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Fri Dec 2 01:10:23 CET 2016

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Check,

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=> lif87g5_71340l_on_Eura.dat

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