National Report of Sweden

NKG geoid WG meeting

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Summary of Swedish geoid activities

- Updated GNSS/levelling observations.
- New gravimetric quasigeoid model KTH08 computed in cooperation between Lantmäteriet and KTH.
- New quasigeoid model (height correction model) SWEN08_RH2000 based on KTH08 and the updated GNSS/levelling observations were released in early 2009.
- Comparison of KTH08 and EGM2008.
- Comparison of SWEN08_RH2000 and FIN2005N00 along the border.
- Work started to improve the Swedish gravity networks and systems as well as the gravity data (today ice measurements started in the lake Vänern.)
- KTH: Two PhDs in Physical Geodesy during 2009 (Prosper Ulotu and Mehdi Eshagh)
- KTH: On-going research concerning estimation of crustal thickness based on different isostatic hypotheses.
- KTH: Geoid school in Istanbul, Turkey Sept. 20-24.
  More information from Lars Sjöberg; see http://www.infra.kth.se/geo/events.html

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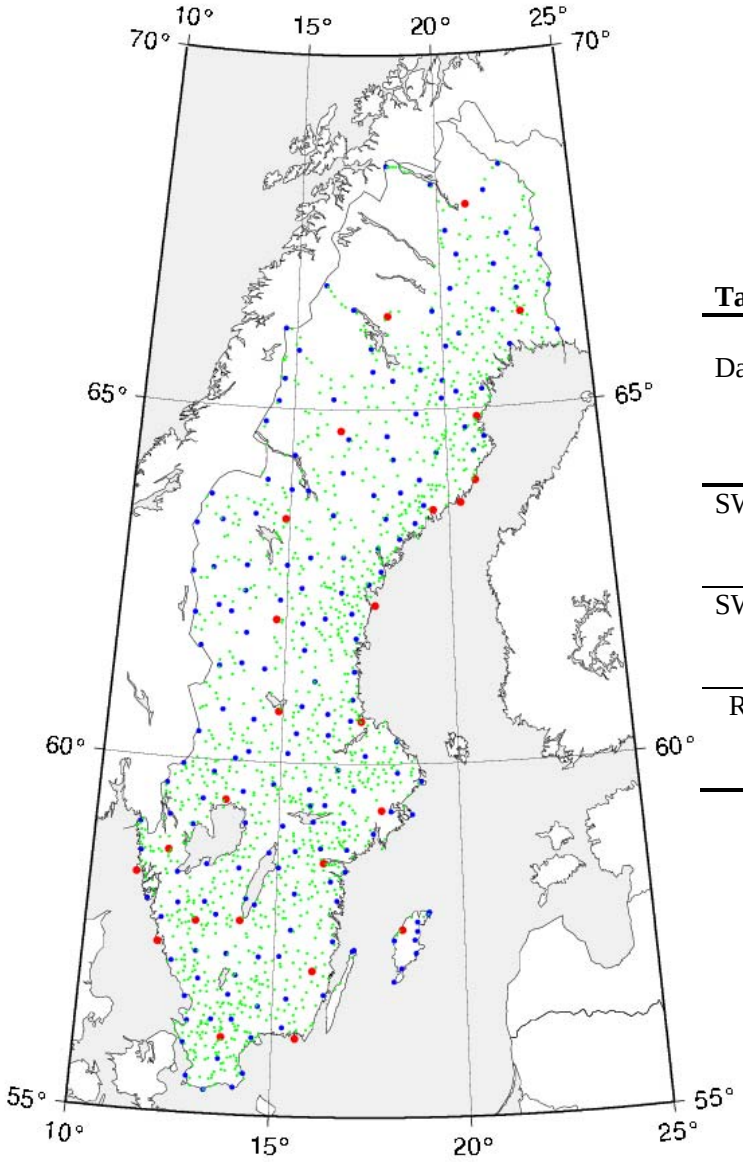

Updated GNSS/levelling

Tab.1. *The GNSS/Levelling observations and their approximate standard errors.*

Data set	#	Short description	Appr. standard errors (mm)		
			GNSS height	Normal height	Height anomaly
SWEPOS	25	Permanent GPS stations whose coordinates define SWEREF 99 (Jivall 2001)	5-10	5-10	7-14
SWEREF	181	Determined relative to SWEPOS using 48 hours of obs, DM T antennas and the Bernese software	10-20	5-10	11-22
RIX 95	1364	Densification of the above stations using static GPS with 0.5-1.0 hours of obs. per session. Network adjustment	15-30	5-10	16-32
	1570				

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Computation of KTH08

The Least squares modification of Stokes' formula (stochastic kernel modification) with additive corrections (LSMSA approach, KTH method, etc)

- The height anomaly is computed as

$$\zeta = \frac{R}{4\pi\gamma}\iint_{\sigma_0} S^M(\psi)\Delta g\, d\sigma + \frac{R}{2\gamma}\sum_{n=2}^{M}\left(s_n + Q_n^M\right)\Delta g_n^{GGM} +$$
$$\delta\zeta_{DWC} + \delta\zeta_{ATM} + \delta\zeta_{ELL}$$

$S^M(\psi)$ is the modified Stokes' function chosen according to Sjöberg (1991).

$\delta\zeta_{DWC}$ includes analytical continuation to point-level of both the gravity anomalies (Moritz 1980) and the spherical harmonic expansion; cf. Sjöberg (2003) and Ågren (2004).

$\delta\zeta_{ATM}$ is the atmospheric correction (Sjöberg and Nahavandchi 2000).

$\delta\zeta_{ELL}$ is the ellipsoidal correction (Sjöberg 2004).

Practical steps in the computation

- Collection and choice of Data
  - Surface and air gravity observations from the NKG-database.
  - GGM02C extended with EGM 96 from degree 201 to 360.
  - Swedish photogrammetric DEM with 100mx100m resolution.
    The Scandinavian DEM from the NKG 2004 computation (sdem2004.01).
    SRTM30plus to extend the model to the south.
- Gridding of the surface gravity anomalies
  - The gravity anomalies are first reduced for the long-wavelength effect from the GGM and the high-frequency effect from the topography
    (RTM reduction)
  - Gross error detection.
  - The residual gravity anomaly is gridded using Kriging/Collocation, 15 km corr. length. Comparatively dense grid used (0.01°x0.02°).
  - The reduced effects are finally restored.
- Geoid heights in a regular grid are finally estimated using the above theory. Haagman's 1D-FFT to evaluate Stokes' integral.

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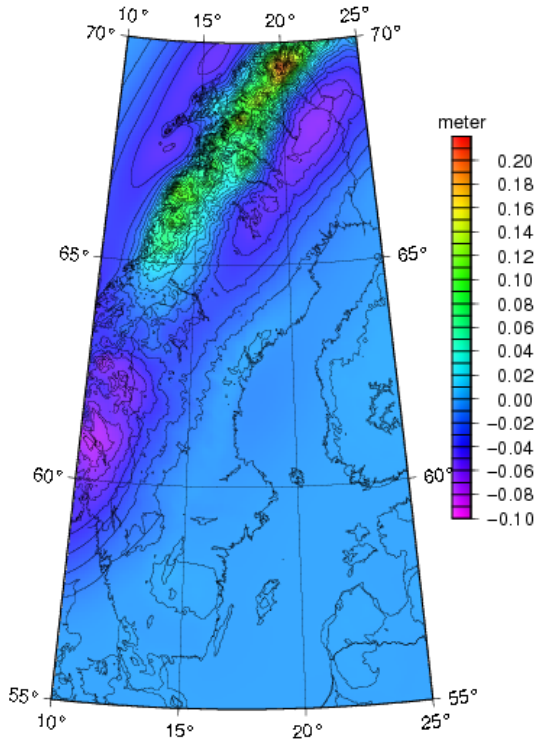
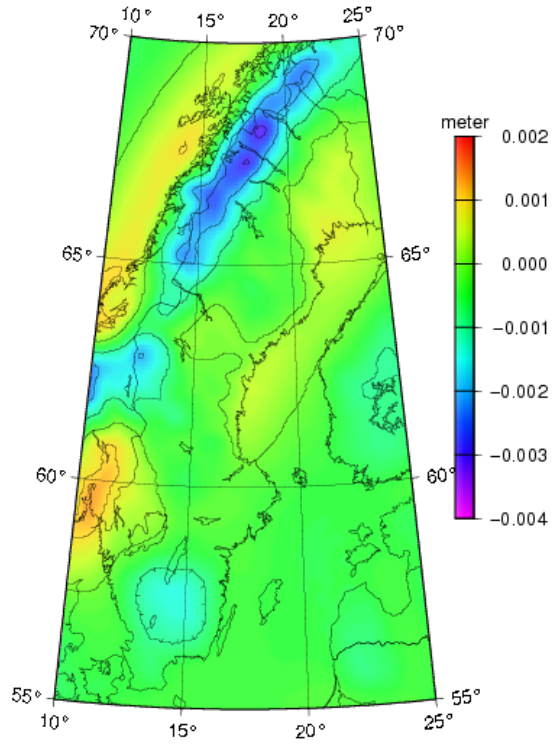
Additive corrections

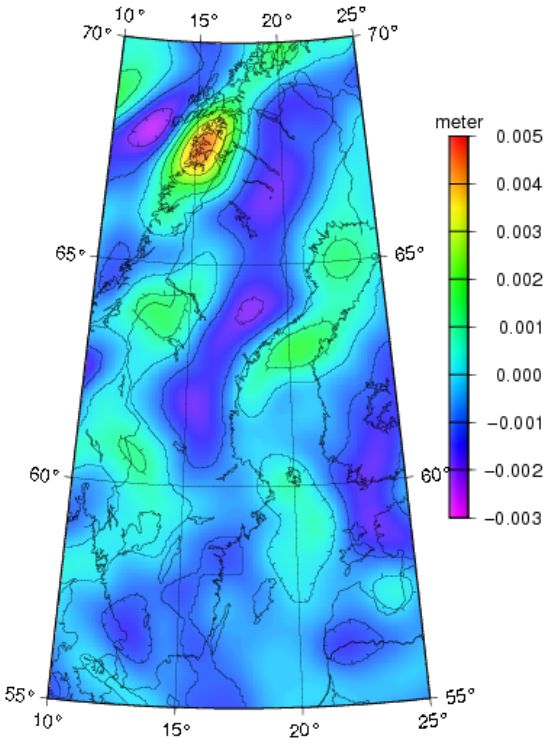
Downward Continuation Correction



Combined Atmospheric Correction



Ellipsoidal Correction



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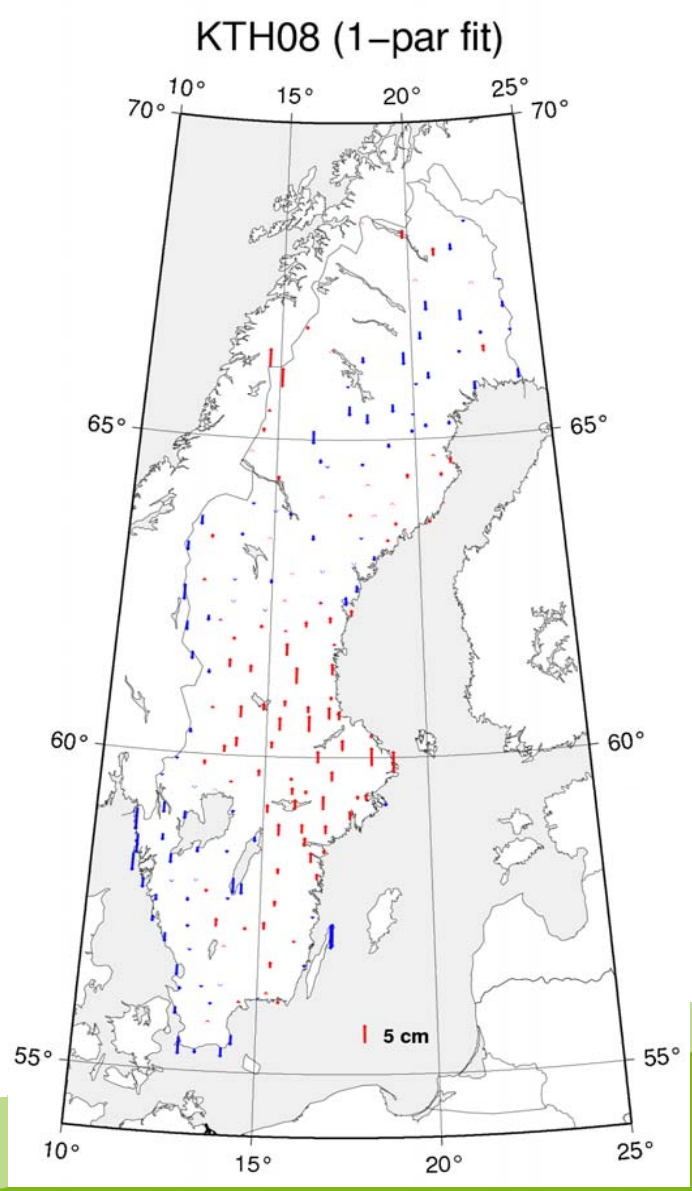
GNSS/levelling residuals for KTH08



- Statistics after fit (mm):

Model	# par	Min	Max	Mean	StdErr
KTH08	1	-66	60	0	22
	4	-73	68	0	20

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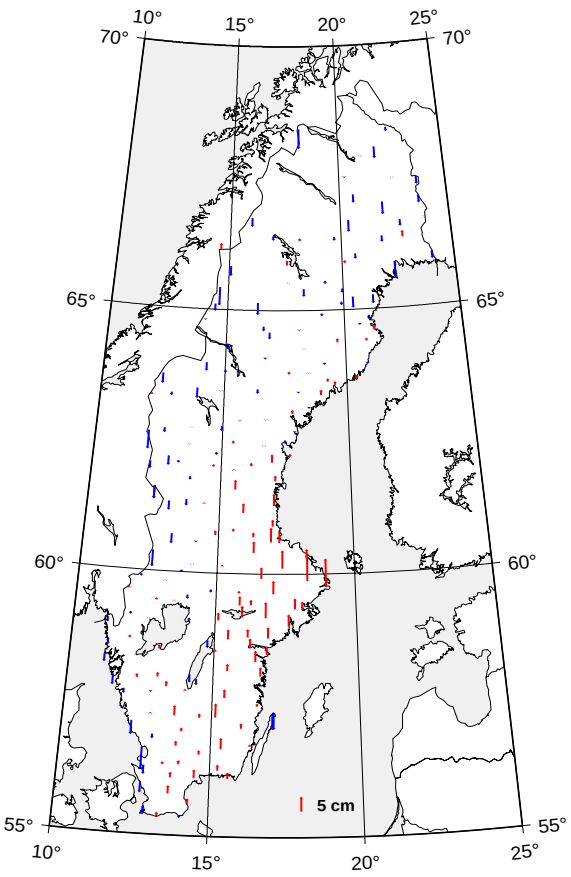
Final words on KTH08

- A new improved gravimetric quasigeoid model has been computed using the KTH method.
- The very good fit (RMS 2 cm) to GNSS/levelling indicates that the reference systems (SWEREF 99/RH 2000) **and** the gravimetric model are of high quality.
- Published in

  Ågren J, Sjöberg LE and Kiamehr R (2009) The New Gravimetric Quasigeoid Model KTH08 over Sweden. Journal of Applied Geodesy 3: 143-153.

Comparison of KTH08 and EGM2008

EGM2008, M=2190



KTH_080326

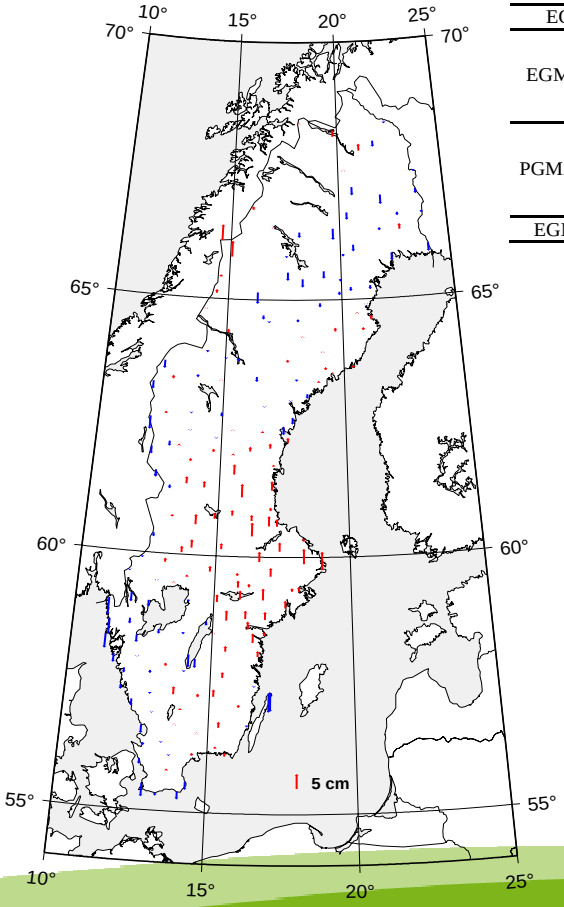


Table 2: Statistics for the GPS/levelling residuals after a **1-parameter** transformation/fit. Unit: m.

EGM	M	# gpslev	Min	Max	Mean	StdDev
EGM2008	2190	195	-0.074	0.095	0.000	0.027
	1440	195	-0.116	0.089	0.000	0.037
	720	195	-0.172	0.124	0.000	0.045
	360	195	-0.266	0.257	0.000	0.099
PGM2007A	2190	195	-0.248	0.085	0.000	0.039
	1440	195	-0.289	0.130	0.000	0.045
	720	195	-0.295	0.118	0.000	0.051
	360	195	-0.428	0.252	0.000	0.103
EGM 96	360	195	-0.376	0.509	0.000	0.172

- EGM2008 is almost as good as KTH08.
- Very similar results!

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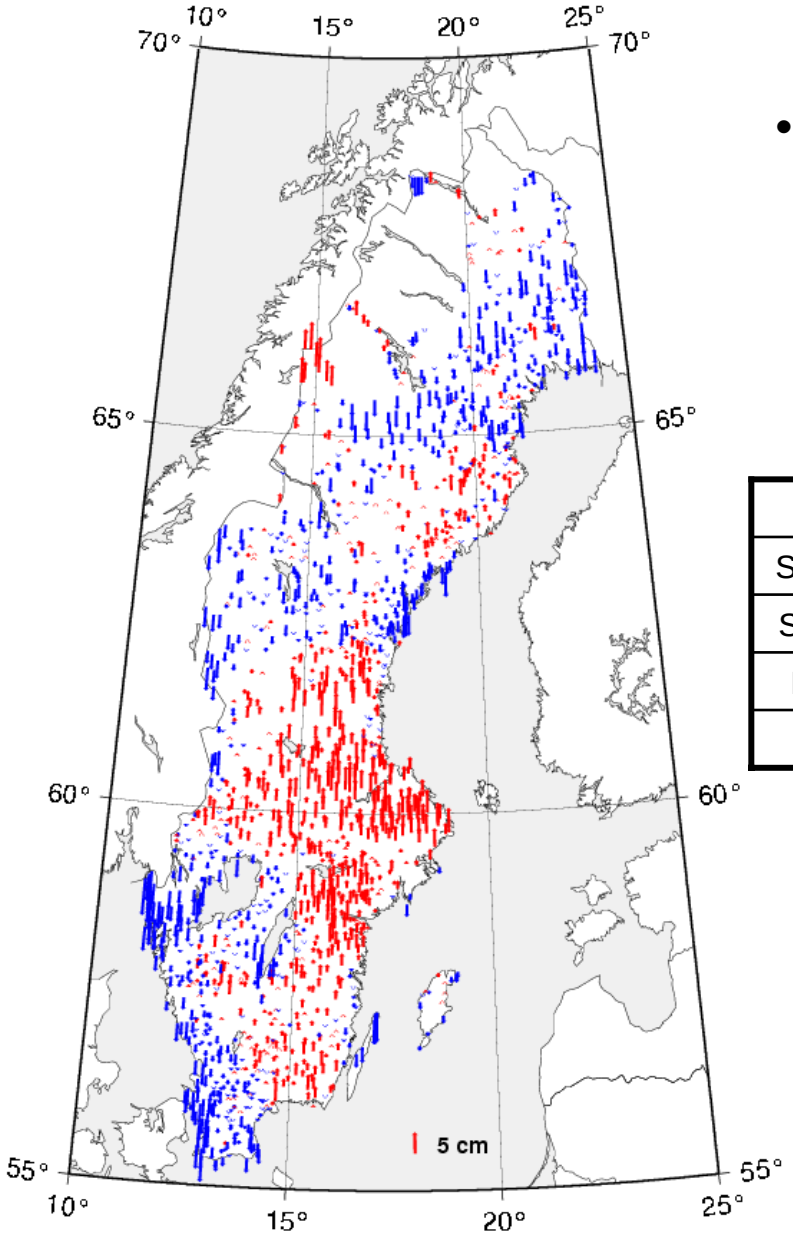
SWEN08_RH2000

- The new national Swedish (quasi)geoid model adapted to the reference systems SWEREF 99 and RH 2000.
- Computed by fitting KTH08 to the updated GNSS/levelling data set by means of a smooth residual surface.
- Published in

  Ågren J (2009): beskrivning av de nationella geoidmodellerna SWEN08_RH2000 och SWEN08_RH70. Reports in Geodesy and Geographic Information Systems, 2009:1, Gävle, Sweden.

  Download at http://www.lantmateriet.se/upload/filer/kartor/geodesi_gps_och_detaljmatning/Rapporter-Publikationer/LMV-rapporter/LMV-Rapport_2009_1.pdf
- See http://www.lantmateriet.se/templates/LMV_Page.aspx?id=4416

Residuals of KTH08



- The gravimetric model KTH08 have been corrected for the weighted mean of the differences from GNSS/levelling (1-parametertransformation)

Statistics for the residuals [m]:

Points	#	Min	Max	Mean	StdDev
SWEPOS	25	-0.056	0.021	-0.003	0.018
SWEREF	181	-0.071	0.057	-0.006	0.022
RIX 95	1364	-0.086	0.071	0.001	0.024
Alla	1570	-0.086	0.071	0.000	0.024

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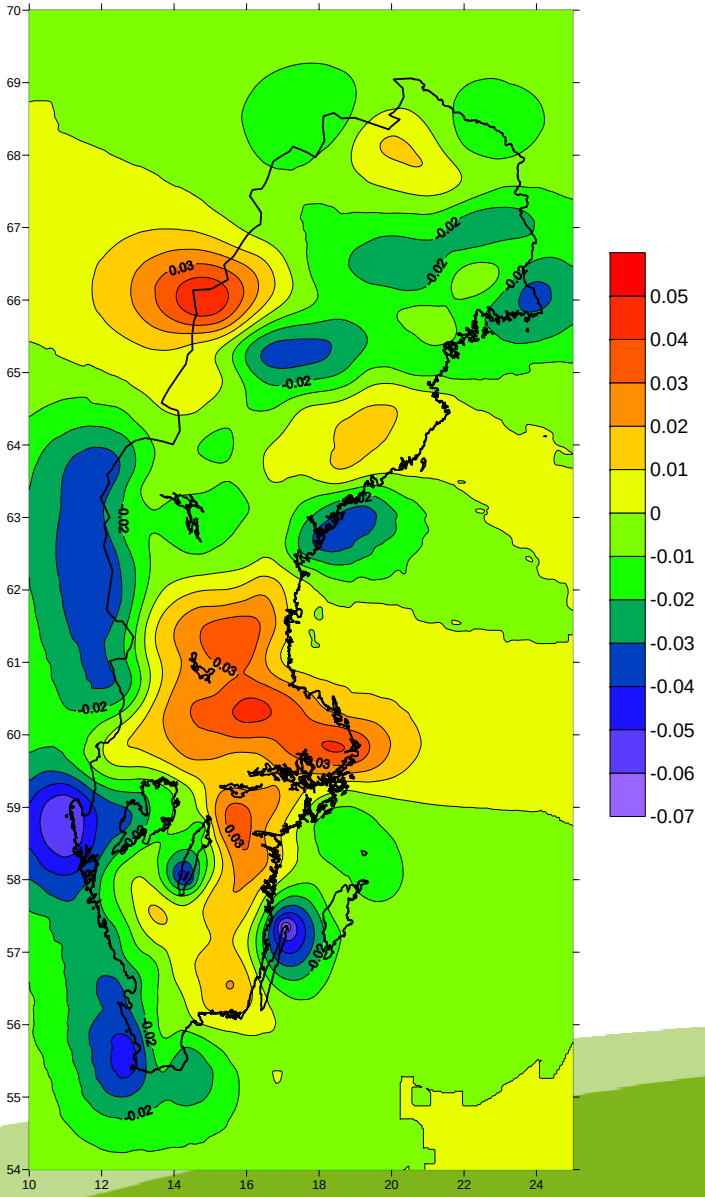
SWEN08_RH2000: Residual surface



- Collocation (GEOGRID) with the following apriori standard errors for the GNSS/ levelling observations:

Type	Apriori standard errors
SWEPOS	10 mm
SWEREF (50km)	14 mm
RIX 95	21 mm

- Covariance function (2nd order Gauss Markov) with 85 km correlation length chosen after covariance analysis of the residuals.

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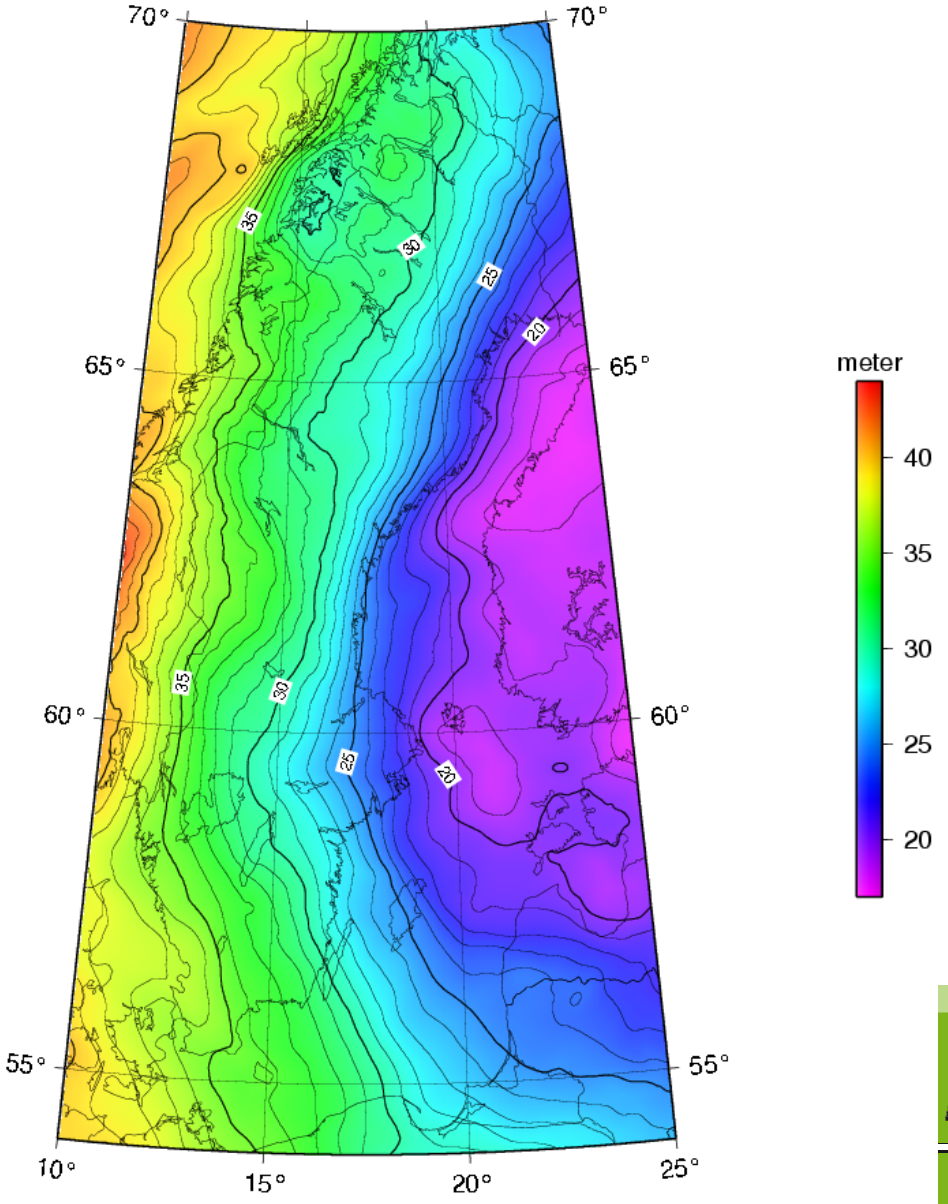
SWEN08_RH2000 =
KTH08 + corr. land uplift and perm. tide + shift + residual surface



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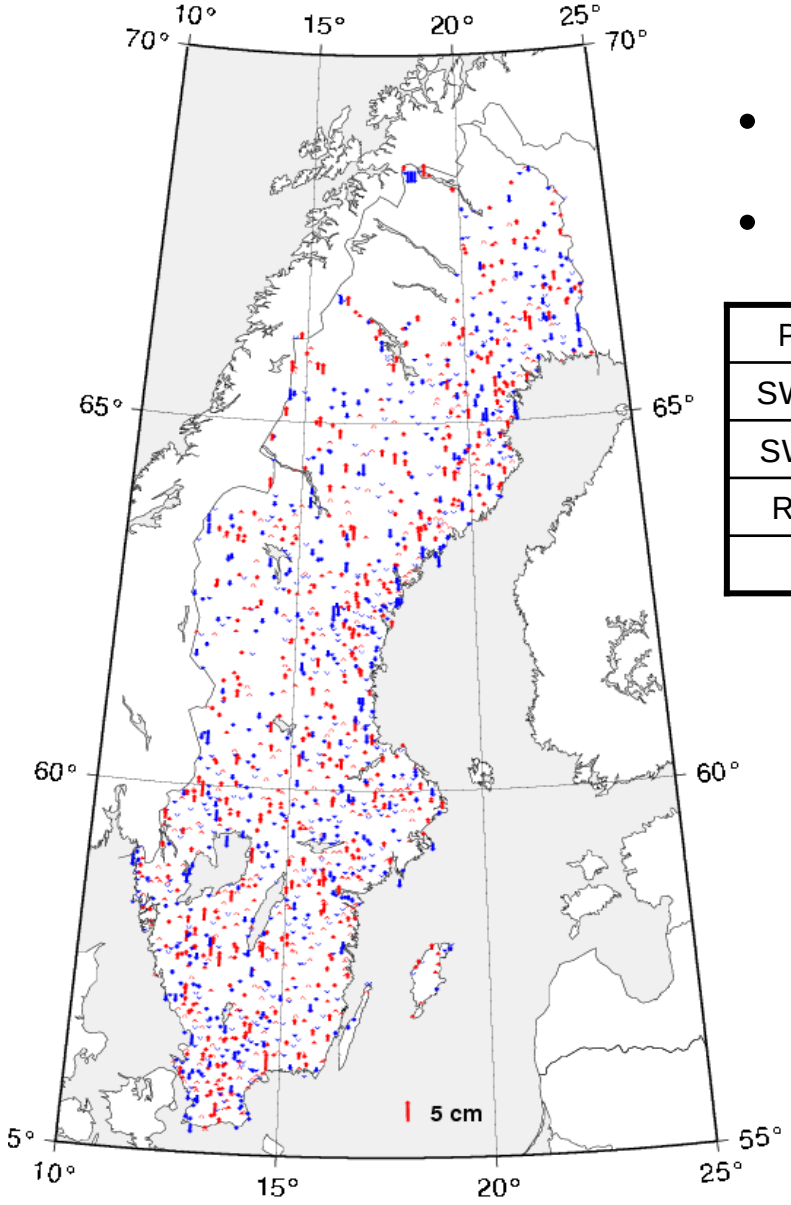
SWEN08_RH2000: Residuals



- Same scale as above.
- Statistics for the residuals [m]:

Points	#	Min	Max	Mean	StdDev
SWEPOS	25	-0.018	0.023	-0.005	0.009
SWEREF	181	-0.021	0.019	-0.002	0.008
RIX 95	1364	-0.038	0.047	0.001	0.011
All	1570	-0.038	0.047	0.000	0.011

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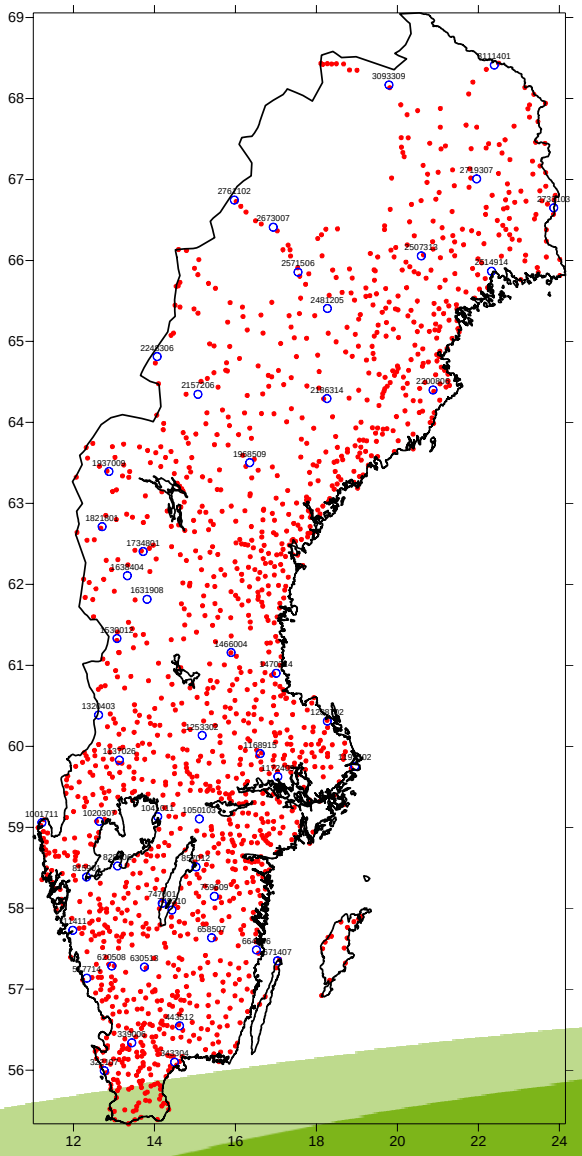
Evaluation in test points



- 51 new SWEREF-points were measured in 2007 on benchmarks in areas without GNSS/levelling (of this class).
- These 51 SWEREF stations are suitable to test the accuracy of SWEN08_RH2000 (comparatively independent).
- All the test points were first excluded and a similar model as SWEN08_RH2000 computed.
- Statistics for the differences in the test points (m):

#	Min	Max	Medel	Medelfel	RMS
51	-0.031	0.029	-0.004	0.013	0.013

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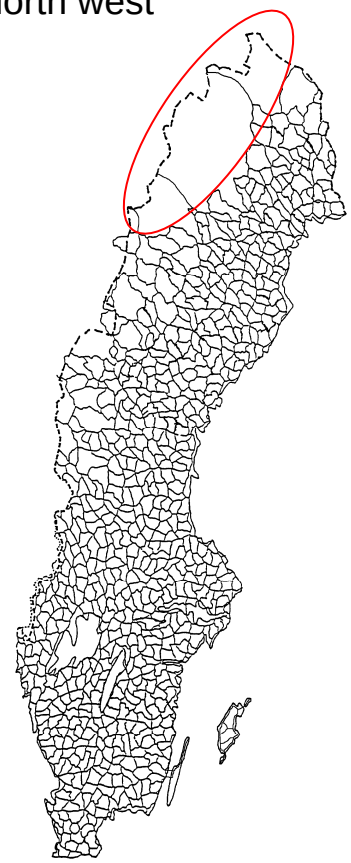
Accuracy for SWEN08_RH2000

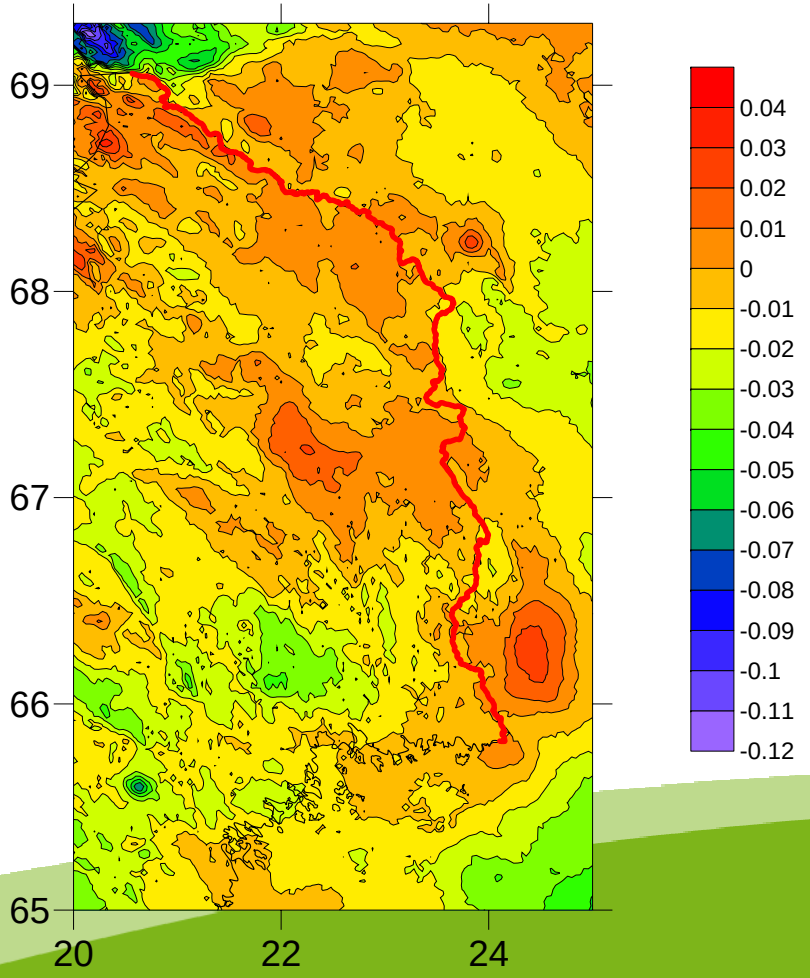
”The highest mountains to the north west”

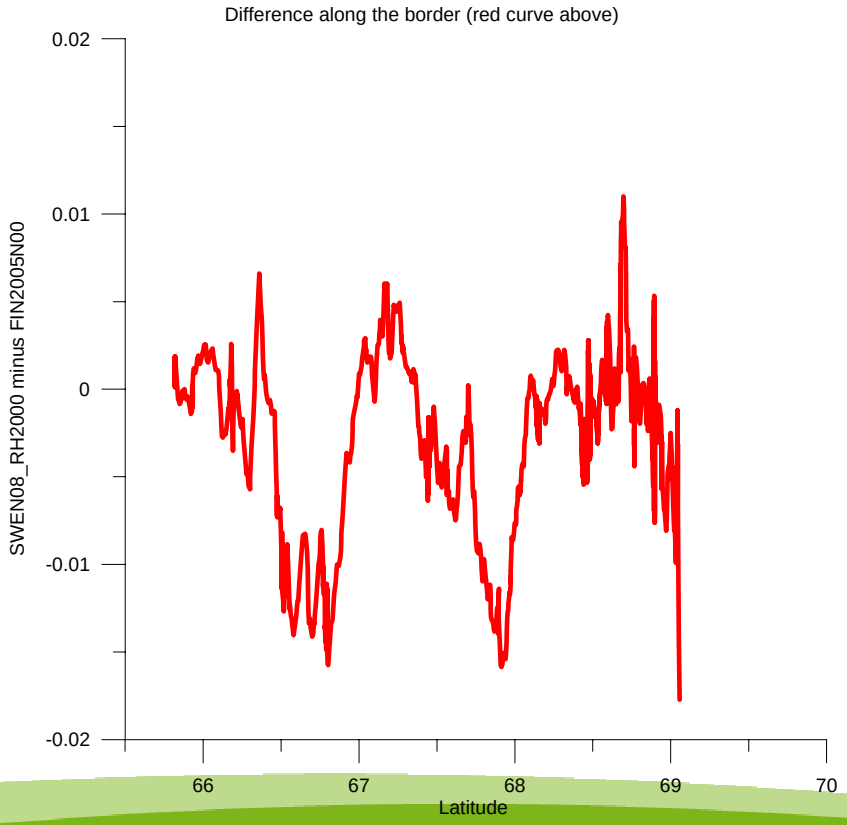


- *Standard error* for SWEN08_RH2000 is 10-15 mm on the main land (except for ”the highest mountains to the north west”; see figure)
- Standard error in ” highest mountains to the north west” and at sea I probably around 5-10 cm.

Comparison along the Swedish-Finnish border

SWEN08_RH2000 minus FIN2005N00





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