The NKG 2008 GPS campaign – transformation results

Martin Lidberg[1], Pasi Häkli[2], Karsten Engsager[3,4], Torbjørn Nørbech[5], Priit Pihlak[6]

1) Lantmäteriet – the Swedish mapping, cadastral and land information authority
SE-801 82 Gävle, Sweden. e-mail: martin.lidberg@lm.se
2) The Finnish Geodetic Institute
3) National Space Institute at the Technical University of Denmark
4) Kort og Matrikelstyrelsen (National Survey and Cadastre, Denmark)
5) Statens Kartverk (Norwegian Mapping Authority)
6) Estonian Land Board, Estonia

Abstract

The Nordic countries have implemented national realizations of ETRS89. Depending on when the realizations were made and on which ITRF the realizations are based, there are differences between the realizations up to a few cm. The national realizations have already been introduced to the users and will not be replaced.

The NKG 2008 GPS campaign was carried out from September 28th to October 4th 2008 as a follow up of the NKG 2003 campaign. The aim of the campaign was to establish a common reference frame in the Nordic-Arctic region and to improve and update the transformations from ITRF to the national ETRS 89 realisations in the area.

The ETRS89 is described including how it is realised and how intraplate deformations may be considered. Finally results from comparisons and transformations between the NKG 2008 campaign and the national realisations of ETRS89 is presented.

1. Introduction

The Nordic countries have implemented national realisations of the ETRS89. Depending on when the realizations were made and which ITRF the realization are based on, there are differences between the realizations of up to a few cm. The national realizations have already been introduced to the users and will not be replaced. There are however situations were a common reference frame could be useful, e.g. for possible common positioning services in the Nordic/Baltic area, or as a link for transformations between the different national realizations, or between the national realizations and ITRF.

Such a common Nordic/Baltic reference frame was observed in 2003 and developed within the NKG working group for Positioning and Reference Frames (Jivall et al. 2006). This frame, denoted NKG_RF03, was used to develop transformations between the common frame and the national realisations of ETRS89 (Nørbech et al. 2006). In 2008 a second common reference frame was observed and developed (Jivall et al 2010). There were several reasons to carry out the 2008 campaign. Among the most important were the introduction of absolute calibrated phase centre variation models for GNSS antennas in GNSS analysis, and the release of ITRF2005.

The purpose of this paper is to compare the NKG_RF03 and the result of the NKG 2008 campaign, and to make some preliminary tests regarding transformations between national realisations of ETRS89 and the new frame.

2. About ETRS89

The foundation for the development of a uniform high accuracy European Reference Frame (ETRS89 and its realisations) was established when IAG formed the new sub-commission EUREF, and CERCO formed the Working

Table 1. *National ETRS89 realisations in the Nordic countries and Estonia. (e.g. Mäkinen et al. 2003,)*

Country	Denmark	Estonia	Finland	Norway	Sweden
System/campaign	EUREF-DK94	EUREF-EST97	EUREF-FIN	EUREF-NOR94 EUREF-NOR95 EUREF-NOR96	SWEREF 99
Internal epoch	1994-09-15	1997.56	1997.0	Appr. 1995.0	1999.5
Based on ITRF	ITRF92	ITRF96	ITRF96	ITRF93	ITRF97
Published in	Frankhauser and Gurtner (1995)	Rudja (1999)	Ollikainen et al. (2000)	Kristiansen and Harson (1999)	Jivall and Lidberg (2000)

Note: Latvia and Lithuania have based their national realisations of ETRS89 on the NKG_RF03.

Group VIII on geodesy in 1987. The background was the growing need for geoinformation data in a uniform geodetic reference system for many applications, e.g. surveying, navigation, transportation, and logistics. Important actors were e.g. the car industry and EUROCONTROL (the European Organisation for the Safety of Air Navigation). This forced the survey agencies in Europe to establish a uniform reference frame. The result was the development of the European Terrestrial Reference System 89 (ETRS89) (Adam et al. 2000).

ETRS89 has also been recognised at the European authority level e.g. through the "Inspire Architecture and Standards Position Paper" (Inspire 2010), where it is stated that ETRS89 should be used where allowed, with respect to accuracy limits, and together with EVRF2000 for expressing practical (gravity related) heights.

What is ETRS89?

The IAG Subcommision for the European Reference Frame (EUREF) , following its Resolution 1 adopted in Firenze meeting in 1990, recommends that the terrestrial reference system to be adopted by EUREF will be coincident with ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate. It will be named European Terrestrial Reference System 89 (ETRS89).

(http://etrs89.ensg.ign.fr/ , sited 2011-04-29)

Realisation of ETRS89

According to its definition the ETRS89 is coincident with the ITRS (International Terrestrial Reference System) at the Epoch 1989.0 and fixed to the stable part of the Eurasia tectonic plate (e.g. Boucher & Altamimi, 1992).

The principal formula for the transformation is given in eq. (1) below. X^E is position in ETRS89, X^I_{YY} is position in ITRF$_{YY}$.

The skew symmetric rotational matrix includes the rotation rates of the Eurasian plate and describes the plate tectonic motion of Eurasia in ITRS. It take care of the plate tectonic motion from 1989 to the epoch of observation t_c (it rotates back from location at epoch of observation t_c, to the plate tectonic epoch of 1989). The knowledge of the rotation of the Eurasian plate has been improved during the years, and therefore the values used have also changed.

The translation T_{YY} is a computational effect due to different stations, observations, techniques, models, etc. between the different realizations of ITRS (different ITRF$_{YY}$).

$$X^E(t_c) = X^I_{YY}(t_c) + T_{YY} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0) \qquad (1)$$

ETRF2000 as conventional frame for ETRS89

Small (typical <1cm) shifts has been visible in position time series of EPN-stations, due to different ITRFs used for the realization of ETRS89 (ETRS89 raw time series) (Lidberg et al. 2009).

Therefore EUREF has adopted the ETRF2000 as the conventional frame for realisations of ETRS89 (resolution no 2 from the symposium in Gävle 2010). See Figure 1.

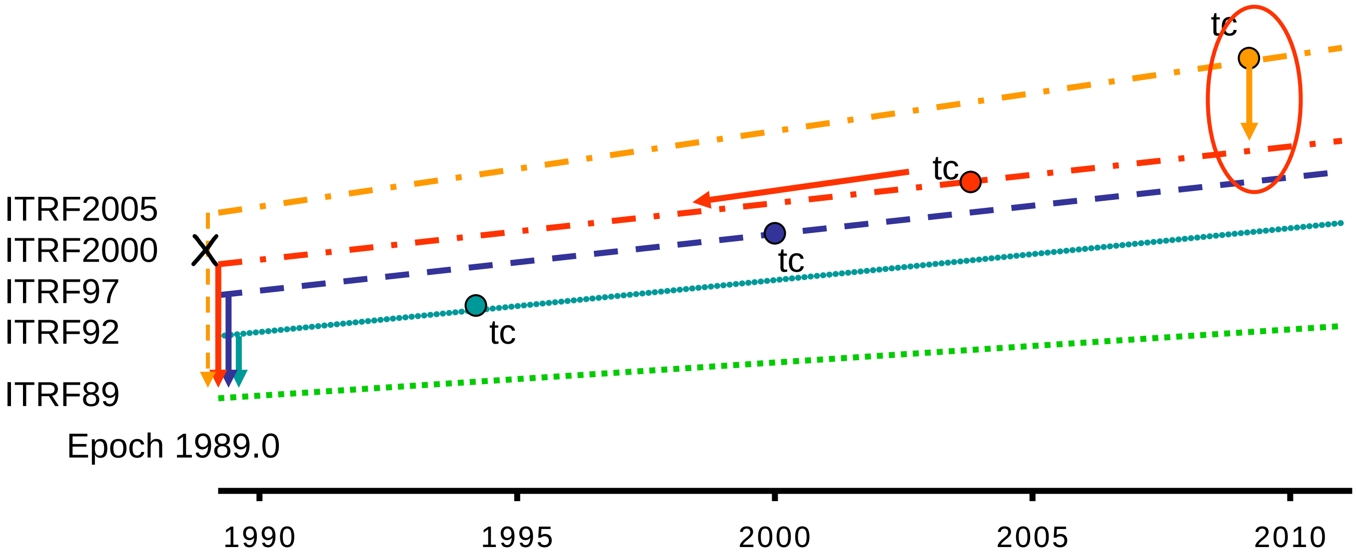


Figure 1. *ETRF2000 has been adopted as the conventional reference frame for ETRS89. This imply that an observed position in ITRF$_{YY}$ should first be transformed to ITRF2000 at epoch of observation, and then converted to ETRS89 (transformed to ETRF2000).*

3. Model for intraplate velocities

To be able to keep coordinates stable in time, it is not only the plate tectonic motion and realization of different ITRFs that need to be considered, but also internal deformation within the Eurasian plate. These intraplate deformations are usually small, but in Fennoscandia the effect of the Glacial Isostatic Adjustment (GIA) amounts to ~1cm in the vertical and few mm/yr in the horizontal. While developing the NKG_RF03, also a velocity model was developed, NKG_RF03vel (Nørbech et al. 2006). See Figure 2.

In the preliminary evaluation of the NKG 2008 campaign we have used the NKG_RF03vel model in order to reduce for internal deformations when applicable. Correction for intraplate deformations from epoch of campaign to a certain reference epoch is described in equation 2.

Note that for the moment, it is not recommend by EUREF to reduce for intraplate deformations in the context of a GPS campaign. An important reason for this is that the knowledge of intraplate deformations within Europe is in general limited, and that an accepted “pan-European” model for the velocities is missing.

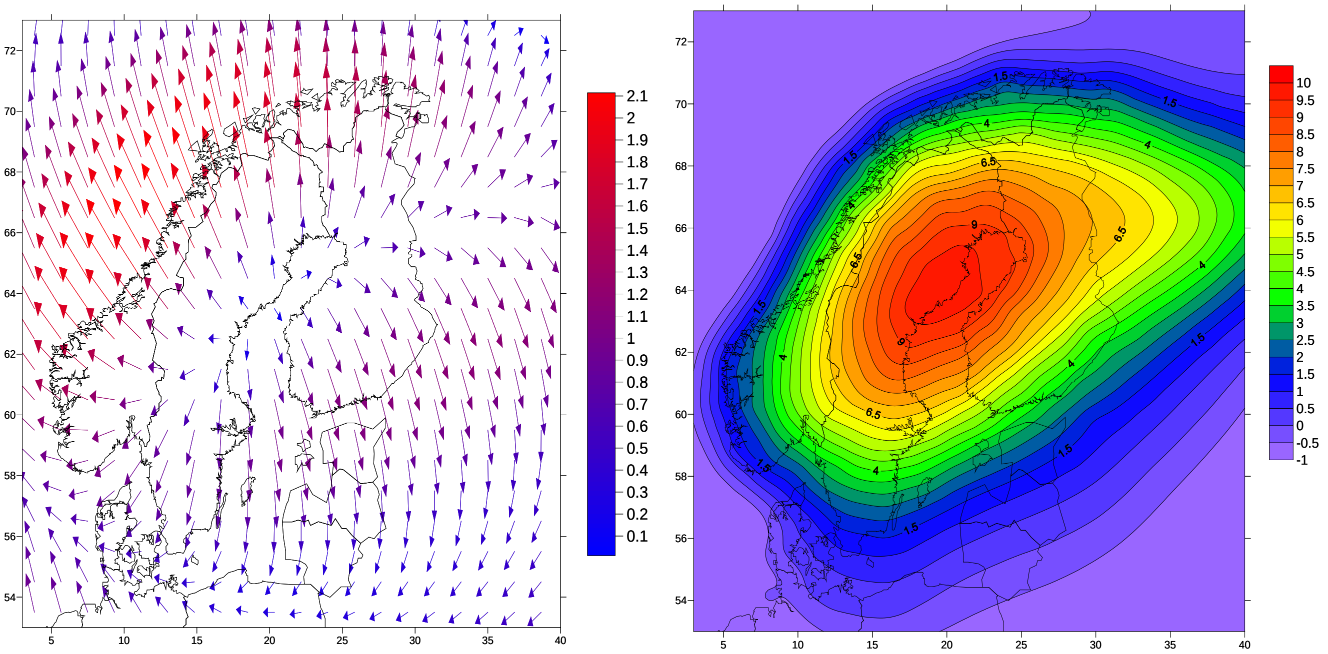


Figure 2. *The NKG_RF03vel velocity model. Reference for the horizontal velocity field (left) is “stable Eurasia” as defined by the ITRF2000 Euler pole for Eurasia. The vertical uplift rates are “absolute” values relative the earth centre of mass, also partly constrained to ITRF2000 (Nørbech et al. 2006, Vestøl 2006). Units: mm/year.*

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{t_r}^{ITRF\,2000} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{2003.75}^{ITRF\,2000} + (t_r - t_C)\begin{pmatrix} V_{X_{\mathrm{int}\,ra}} \\ V_{Y_{\mathrm{int}\,ra}} \\ V_{Z_{\mathrm{int}\,ra}} \end{pmatrix}_{NKG\_RF\,03vel}^{ITRF\,2000} \qquad (2)$$

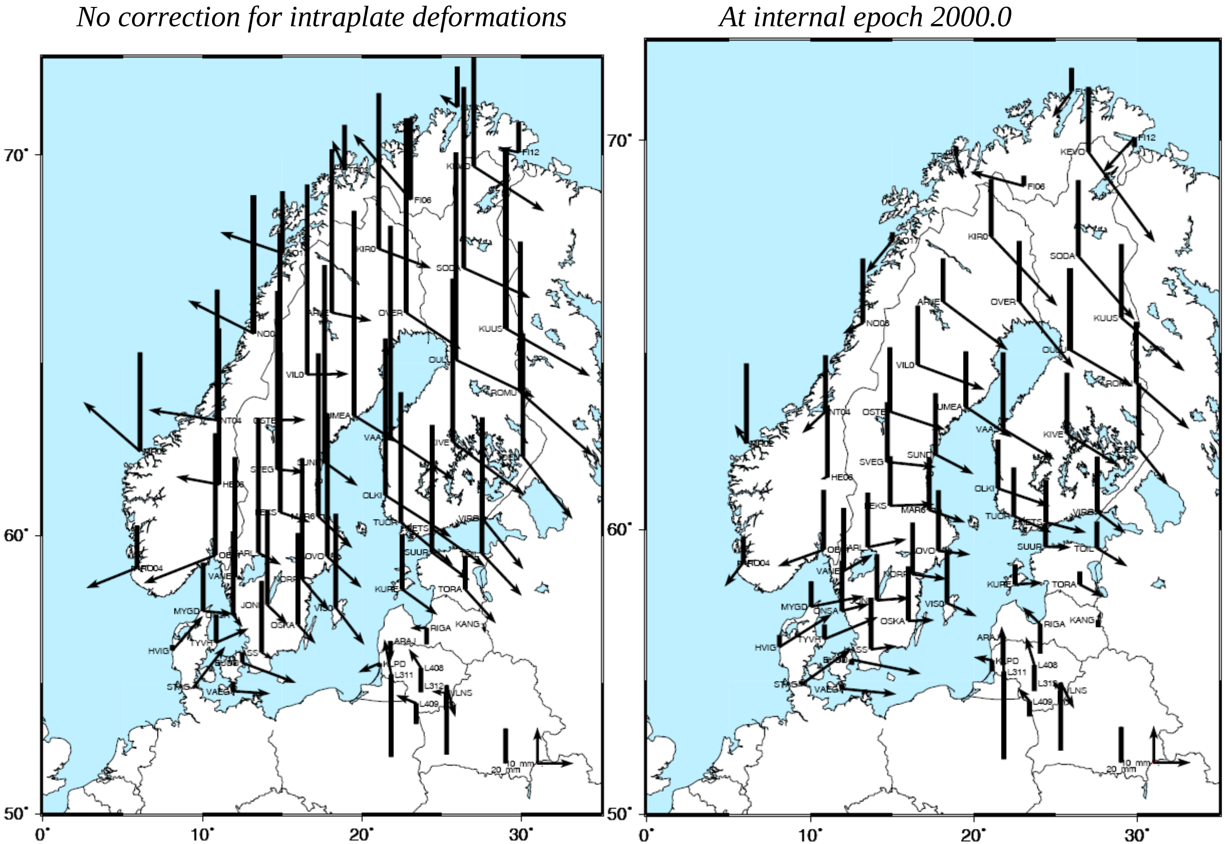
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}^{national\_ETRS89} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + (1+D)\begin{pmatrix} 1 & R_Z & -R_Y \\ -R_Z & 1 & R_X \\ R_Y & -R_X & 1 \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{t_r}^{ITRF\,2000} \qquad (3)$$

4. Comparing NKG2008 to official national realizations of ETRS89 and NKG_RF03

In this paper we have used the solution of the NKG 2008 campaign as described in Jivall et al. (2010). This solution is here denoted “NKG 2008 mc6” (minimum constrained solution with 6 parameters).

In Figure 3 is shown the residuals between NKG 2008 mc6 and the national realisations of ETRS89. To the left without any correction for internal deformations (the post glacial rebound, PGR, or Glacial Isostatic Adjustment, GIA), and to the right the 2008 campaign has been reduced to epoch 2000.0. It is worthwhile to note the improvements due to correcting for GIA. The plot to the right gives a fairly good picture of the level of agreement between the different national realisations of ETRS89. It also shows the difference in horizontal component between Norway and the other countries, but also that Norway agree better to the modern NKG 2008 campaign. The explanaition may partlly be found in the plate tectonic velocity model in ITRF92 which is used for the realisation in Norway (Lidberg et al. 2006).

In Figure 4 is shown the comparison between the NKG 2008 campaign and the NKG_RF03. To the left without handling intraplate deformations and to the right the 2008 campaign has been reduced to the epoch of the 2003 campaign. Note that this is just differences of coordinates without any fit between the two sets of coordinates! The good agreement with bias at the level of few mm must however partly be attributed to good luck in the reference frame realisation.



No correction for intraplate deformations

At internal epoch 2000.0

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Statistics of residuals (n,e,u) and (mm).
   RMS   :    9   12   68                   RMS  :     8   11   28
   Mean  :   -4    5   53                   Mean :    -3    7   19
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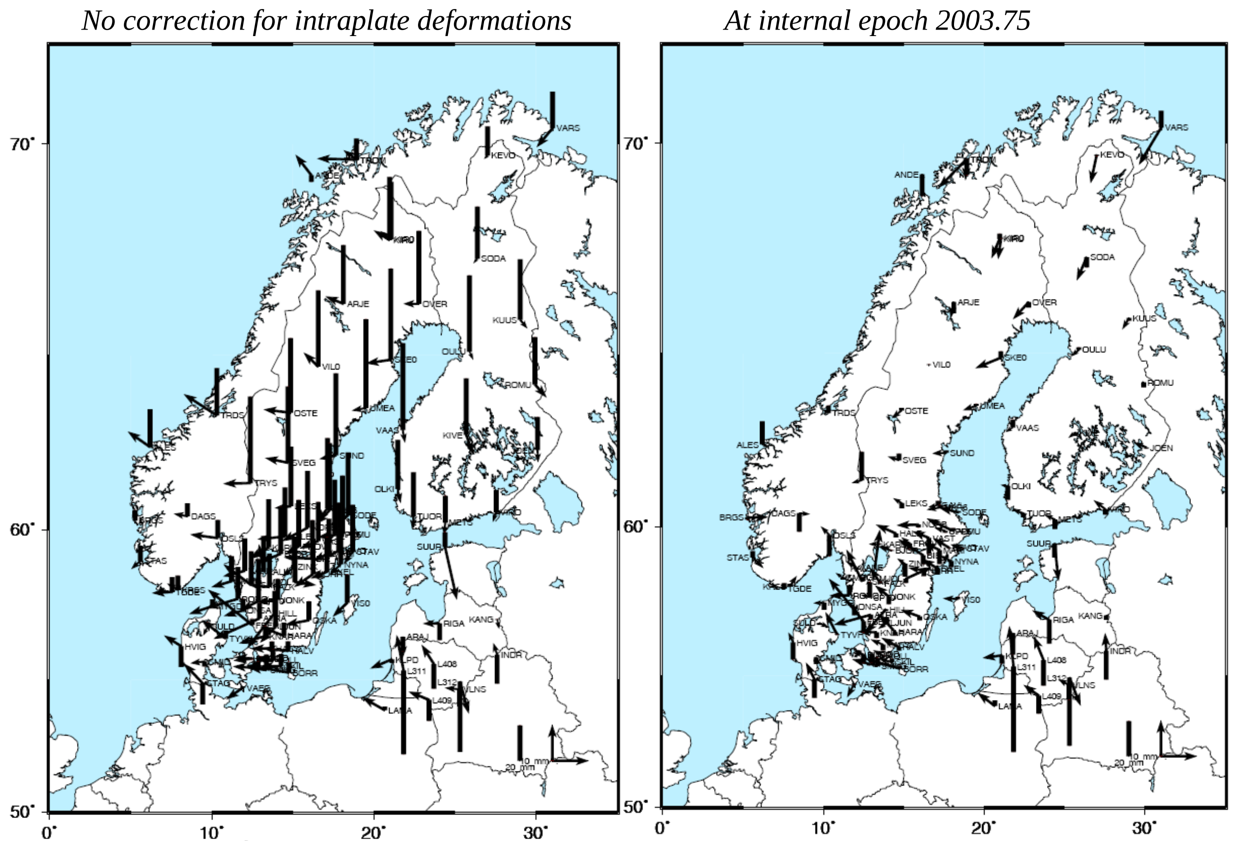
Figure 3. *Differences between NKG 2008 mc6 in ETRS89 and national realisations of ETRS89; Left:Without any corrections for intraplate deformations (NKG 2008 at epoch of observation, i.e. 2009.75, and national ETRS89 at their epoch of the national realisation). Right: NKG 2008 reduced to internal epoch of 2000.0 using the model.*



No correction for intraplate deformations

At internal epoch 2003.75

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Statistics of residuals (n,e,u) and (mm).
   RMS   :    4    5   24                       RMS  :     4    4    8
   Mean  :   -5   -4   16                       Mean :     0   -3   -3
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Figure 4. *Differences between NKG 2008 mc6 in and NKG 2003 in ETRS89. Left:Without any corrections for intraplate deformations (NKG 2008 at epoch of observation, i.e. 2009.75, and NKG 2003 in epoch 2003.75. Right: NKG 2008 reduced to internal epoch of 2003.75 using the model.*

5. Transformations between national realisations and NKG2008

One important purpose of the NKG 2008 campaign was to develop transformation methods from “latest ITRF current epoch” to the national realisations of ETRS89. In order to test the expected level of uncertainty we have performed some preliminary transformations. We have used the 7 parameter Helmert transformation (Equation 3) and reduced the intraplate deformations to epoch 2000.0 and to epoch of the national realisation. The results are shown in Figure 5.

6. Some remarks

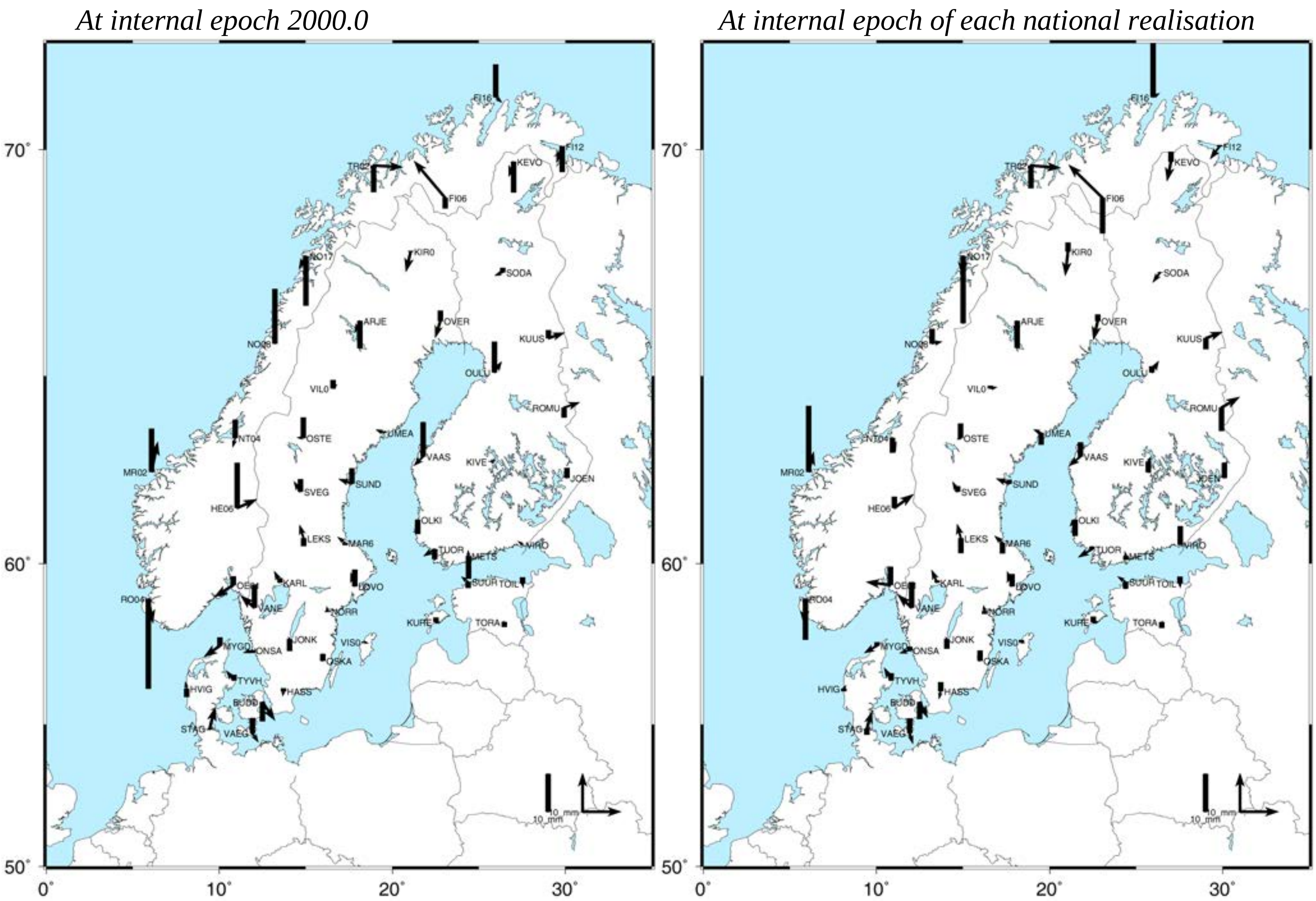
No values for the transformation parameters have been presented here – This will be a task for the new NKG working group Positioning, navigation and reference frames!

The NKG 2008 and the former NKG 2003 campaigns agree well also without a 7-parameter fit (but intraplate deformations considered). This indicates that the repeatability in the GNSS technology is good, but we do see that the reference frame realisation is an issue to be improved.

The internal geometry agrees well between the NKG 2008 (and NKG 2003) campaign and the national realisations of ETRS89. This indicates that the results achieved some decade ago are still valid and very much useful also for the future. (However, maybe some more investigations could be useful for Norway.)

For the transformations between a common homogenous reference frame (NKG 2008 or NKG_RF03) to the national realisations of ETRS89, the standardized epoch of 2000.0 performs almost equally well as using the individual epochs for each country. This may be used to simplify the model for transformations.

Finally, we have in this investigation used the velocity model developed together with NKG_RF03. It seems that this model still performs well. However, some but some more recent GIA-based model do exist and could be tested in future work.



```
Statistics of residuals (n,e,u) and (mm).
   RMS  Dk:  3.5  2.4   3.0                    RMS  Dk:  3.0  1.8   2.7
        Ee:  0.7  1.0   1.4                         Ee:  0.8  1.2   1.6
        Fi:  1.8  2.2   4.9                         Fi:  2.4  2.4   3.4
        No:  4.7  4.1  11.4                         No:  4.3  4.4  10.7
        Se:  3.0  2.1   3.8                         Se:  3.5  2.1   4.0
```

Figure 5. *Residuals between NKG 2008 mc6 in ETRS89 and national realisations of ETRS89; Left: NKG 2008 reduced to internal epoch 2000.0 and a national 7-parameter fit. Right: NKG 2008 reduced to internal epoch of each national ETRS89 realisation and a national 7-parameter fit.*

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