Processing of the NKG 2008 campaign

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Summary

The NKG 2008 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 is to improve and update the transformations from ITRF to the national ETRS 89 realizations in the area and to establish a common reference frame in the Nordic-Arctic region.

Totally 417 stations are included in the campaign covering the Nordic and Baltic area with a dense network and supplemented with a sparse network above the latitude of 60 degrees north.

The processing has been carried out as a distributed network with the Bernese Software ver. 5.0 with both absolute and relative antenna models. Selected solutions and sub-networks have also been computed with other softwares, GIPSY and GAMIT, but in this paper just the solutions with the Bernese software are presented. Different strategies for alignment to ITRF have been tested.

The campaign has been planned, measured and analysed within the frame of the NKG working group for Positioning and Reference Frames.

Introduction

The NKG 2008 campaign was observed exactly five years after the NKG 2003 campaign, in week 40 of the year. In this way the impact from seasonal variations should be about the same. Local seasonal variations due to e.g. monument instability is often also at a minimum during this time of the year (as well as in the spring).

The NKG 2003 campaign included 133 stations in the Nordic-Baltic area and in Greenland, Iceland and Svalbard. The final solution from this campaign was based on an average of solutions from Bernese, GAMIT/GLOBK and GIPSY and has a global connection to ITRF 2000 [Jivall, Lidberg, Nørbech, Weber 2005].

Three completely different processing strategies and connections to ITRF were performed for NKG 2003:

- Precise Point Positioning with JPL-products using GIPSY/OASISII
- Network solution with GAMIT combined with SCRIPPS global IGS-solutions for a global ITRF connection
- Network solution with the Bernese GPS software regionally connected to IGS cumulative solution.

The resulting coordinates of the different strategies agree for most stations within a few mm horizontally and 1 cm vertically.

The internal differences are even smaller with an rms of the differences between the individual solutions of 0.9, 1.2 and 2.5 mm for north, east and up. The processing in different softwares and at different analysis centres have given the final solution extra strength. Some errors were found in the comparison between the solutions and might not have been discovered if just one software at one centre had been used.

The result from the NKG 2003 campaign was used as a common reference frame in the transformations between ITRF 2000 and the national ETRS 89 realizations in Denmark, Finland, Norway and Sweden [Nørbech et.al. 2006]. Furthermore the final solution of the NKG 2003 was used to define updated ETRS 89 coordinates in Latvia and Lithuania [Jivall, Kaminskis, Parseliunas 2006].

The aim of NKG 2008 is to evaluate and update the transformations from ITRF to the national ETRS 89 realizations in the Nordic-Baltic area and to establish a common reference frame in the Nordic-Arctic region.

The Campaign

The NKG 2008 campaign was carried out from September 28th to October 4th 2008 (GPS-week 1499).

In the planning of the campaign we decided that it was up to each of the participating countries (Nordic and Baltic countries) to decide which stations to include. The main principle was to include national permanent stations operated by the national mapping agencies and campaign points used for the definition of the national ETRS 89 realization. The majority of the stations are permanent. 31 campaign points were included in Denmark, Faroe Islands, Latvia, Lithuania and Norway. 39 additional IGS/EPN stations were added to give a better coverage of the solution in the Arctic area. In total the campaign included 417 stations – see figure 1.

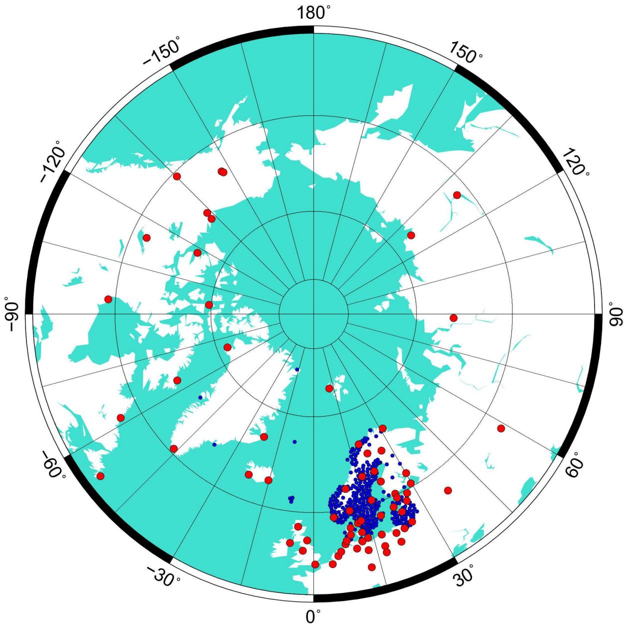

Fig. 1. *Stations included in the NKG 2008 campaign. Red dots are IGS or EPN-stations and the blue dots are national stations, both permanent and campaign points.*

The quality of all RINEX-files was checked with the program teqc from UNAVCO, as well as the consistency between the RINEX-headers and the log-files. Norway, Sweden and Estonia made the quality check of their own observations. Finland checked the files from Finland, Latvia and Lithuania, and Denmark the files from Denmark, Greenland and the Faroe Islands. Nothing extraordinary was discovered during the tests with teqc. Just that a few stations lacked full observations for all days. The check of the log-files resulted in some corrections to the RINEX-headers and/or log-files. All RINEX-files, log-files and also results from the processing, both final and intermediate working materials are available (with limited access) at an ftp-server at Kort og Matrikelstyrelsen (KMS) in Denmark.

Strategy for Processing

Following the experiences from the NKG 2003 campaign the original ambition was to process the full campaign with different softwares and by different analysis centres in order to detect possible strange behaviour of stations or bugs in any of the softwares.

But besides such extraordinary features, the results from the NKG 2003 campaign showed that the different softwares revealed quite similar results. The largest differences originate from the different connections to ITRF.

With this in mind and limited resources for processing, we decided to calculate one main solution of the full network with the Bernese Software. To share the work load, the network was divided into three sub-networks (see figure 2):

- Baltic part, 71 stations processed by Priit Pihlak
- Norwegian and Atlantic part, 116 stations processed by Oddvar Tangen
- Swedish, Finnish and Danish part, 190 stations processed by Lotti Jivall

The three sub-networks were tied together by a back-bone of 70 IGS/EPN-stations. This backbone was first processed by each analysis centre to check that all centres produced the same results on the same data, which was achieved after some iteration and changing of processing options.

Several different solutions were produced for each sub-network (and the back-bone):

- Absolute antenna models and relative antenna models
- Different elevation cut-off angles: 3°, 10°, 25°

The final solution is based on absolute antenna models and 3° cut-off and following the “Guidelines for EPN Analysis Centers” [EPN Coordination Group 2010].

The 10° solution with relative antenna models corresponds to the final solution of the NKG 2003 campaign and to EPN-solutions before GPS-week 1400 as well as to the national realizations of ETRS 89 in the Nordic and Baltic countries.

The 25° solution is a test solution used for a so called elevation cut-off test, where this solution is compared to the 3° or 10° solution. In such a test deficiencies in the used antenna models could be discovered.

Characteristics for the final solution can be found in table 1.

Table 1. *Characteristics for the final solution.*

Orbits	Final IGS
EOPs	Final IGS
Ocean tide loading	FES2004
Antenna models	Absolute, individual when available, some converted from relative to absolute
Strategy for baselines	OBSMAX
Ambiguity resolution	QIF, 10° cut-off
Troposphere modelling	• Saastamoinen apriori with dry Niell mapping function • Zenit path delay estimated every hour using wet Niell mapping function • Daily Troposphere gradients estimated
Ionosphere modelling	Ionosphere free linear combination except for QIF ambiguity resolution where the CODE global ionosphere models are used

In addition to the Bernese solutions, parts of the network were also processed with GIPSY, both by Shfaqat Abbas Khan, Danish Space Centre, and Gunstein Dalane, Statens Kartverk in Norway. A draft solution with GAMIT was also processed by Martin Lidberg. These additional solutions are not presented in this paper.

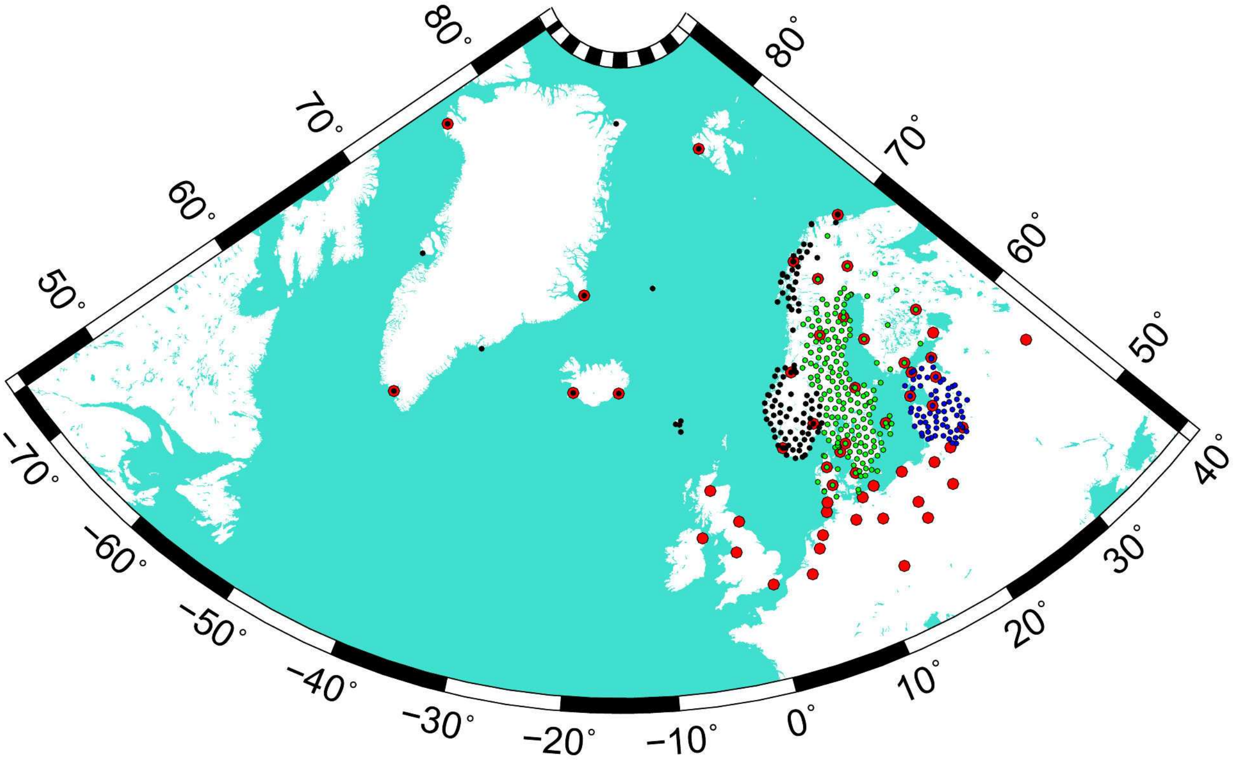

Fig. 2. *Stations included in the NKG 2008 campaign, divided into three sub-networks and the backbone. Red dots are the backbone with IGS/EPN-stations, the black stations were processed by Oddvar Tangen, the green by Lotti Jivall and the blue by Priit Pihlak.*

Processing of the sub-networks

Baltic sub-network

The baltic block consists of 16 stations from Estonia, 24 stations from Latvia and 31 stations from Lithuania. The six EPN stations RIGA, VLNS, SUUR, KURE, TORA and TOIL were used as fiducial stations for the connection to the backbone. Most of the stations are permanent, just the stations KANG, INDR, VENT and ARAJ in Latvia and L409, L408, L311 and L312 in Lithuania were campaign points.

The daily repeatability was studied and revealed no real outliers but the following stations had an rms greater than 5 mm in the height component for the 3° solution with absolute antenna models:

INDR -5.2 mm, L311 -7.3 mm, MUST -6.9 mm, TELS -8.9 mm.

In the elevation cut-off test (3°-25°) of the solutions with absolute antenna models the following stations had differences in the height component greater than 20 mm:

BALV 30.2 mm, KLPD 20.4 mm, OJAR -31.4 mm, ARAJ -22.3 mm.

Corresponding elevation cut-off test for the solutions with relative antenna models resulted in the following stations with differences greater than 20 mm: RIGA 20 mm, SUUR 20.2 mm, MVEE -20.4 mm, BALV 20.8 mm, OJAR -33.7 mm, ARAJ -27.2 mm.

In the comparison to the NKG 2003 campaign some discrepancies were found – see table 2.

Table 2. *Large differencies between the solutions from NKG2003 and NKG2008 for the Baltic sub-network.*

Station	dN (mm)	dE(mm)	dU(mm)
ARAJ	-9.4	1.3	-6.3
IRBE	-3.3	-3.6	-149.4
L311	5.5	-0.2	-44.9
L312	-14.5	4.4	-35.6
SUUR	-13.6	8.7	-9.2

The large differences at ARAJ coluld be explained by bad centuring, the marker is a cross on a stone. For IRBE it was possible to remeasure the vertical setup. The corrected setup is 5.161 m which was corrected in the final solution of NKG 2008. The shift at SUUR could be explained by the antenna change on 20.11.2007 from AOAD/M_T to LEIAT504GG and also a receiver change from ASHTECH Z-XII3 to LEICA GRX1200GGPRO. For the large differences in height at L311 and L312 we still have no explanation.

Norweigian + Atlantic sub-network

Norway, Iceland, Greenland, Faroe Islands and Svalbard were included in this sub solution. The number of stations was 106, and in addition 10 stations from the backbone were included. The processing was divided into two clusters because of the large number of stations.

Most of the stations are permanent GNSS stations except for 11 campaign points (brass screw on bedrock) in Norway and 5 campaign points (bolt on bedrock) in Faroe Islands.

The daily repeatability was in general quite good, rms 0-2.5 mm in north and east, and 2-6 mm in height. Two exceptions from this, FI06 is diverging 11.7 mm up, 6 mm north on day 274. LONC is diverging 17.6 mm up on day 272, both with absolute antenna model, 3° cut-off.

The elevation cut-off test with absolute antenna models indicates problems for the stations in table 3.

***Table 3**. Outliers in elevation-cut-off test in Norweigian-Atlantic solution.*

Country	Station	3°-25°
Norway	ANDO, FLOC, PREC, ROSC,LYSC	25-40 mm up
Greenland	NORD, QAQ1, KULU	25-50 mm up 20-40 mm east
Svalbard	NYA1	33 mm up

These are all permanent stations, future studies of time series are going to tell more about the quality.

On most of the permanent stations in Norway (mainland) the antennas have been changed in the period between the NKG 2003 and NKG 2008 campaigns. The reason for this was to include also GLONASS into the RTK (Cpos) service. Unfortunately this has been done without individual calibration of the antennas.

There are just 14 stations in Norway with unchanged antennas since the NKG 2003 campaign, eight of them with new names, old name in brackets: ANDO, DAGS, DOMS, TGDE, TROM , TRYS, AKRC(akra), HFSS (hone), PORC (port), PREC(pres), SIRC(sire), SKOC(skol), TONC(tons) and ULEC(ulef). The stations ANDO and DOMS have new reference points (other excentricities). The 11 campaign points were not present in the NKG 2003 campaign.

Swedish-Danish-Finnish sub-network

This sub-network consists of 190 stations including 14 EPN/IGS-stations in the backbone. All stations except 7 stations in Denmark (BORR, BUDD, HVIG, MYGD, STAG, TYVH, VAEG) are permanent. The processing of the network solution was divided into three clusters with maximum 70 stations in each.

The daily repeatability was studied and revealed one outlier, the Swedish station HEDE for day 278, up-component diverging 25 mm in the 3° solution with absolute antenna models. No explanation was found but this station/session was excluded from the final solution. The rms values for all other stations were below 2.5 mm for the horizontal components and 5 mm for the height.

The elevation cut-off test (3°-25°) was performed both for the absolute and relative solutions. In case of absolute antenna models, the stations DEGE (34.5 mm), OLKI (23.5 mm) and VIRO (22.9 mm) have differences above 20 mm in height. OLKI and VIRO are equipped with DUTD radomes which have been neglected (no absolute calibration available). This is probably the reason for the large values. DEGE is equipped with ASH701945C_M without radome for which we have used a true absolute model. The reason for the height difference at DEGE is possible to be found in the environment near the antenna, site dependent effects.

In case of relative antenna models, DEGE is also diverging (32.2 mm) and VAAS (26.0 mm) and ESBH (24.9 mm). The SNOW radome on VAAS is neglected but the ASH701945E_M with SCIS radome has a calibration from NGS.

Also many of the Swedish sites have replaced antennas since the NKG 2003 campaign in order to better receive GLONASS and to be prepared for Galileo and the new L5-signal. Most of the fundamental SWEPOS-stations are however untouched (except SKE0 and SPT0).

Combination of the sub-networks

The three sub-networks and the backbone were combined using the Bernese program ADDNEQ2. As a test each sub-solution was fitted by a 3-parameter transformation (translations) to the corresponding backbone solution which showed agreement on a few mm-level – see table 4.

***Table 4**. RMS for 3-parameter Helmert-fit (translation) between solutions for the sub-networks and corresponding solution for the back-bone. A03 is the final solution based on absolute antenna models and 3° cut-off. Unit: mm.*

Solution type: Abs/rel, elev	Swe, DK, Fin #14	Norway + atlantic #10	Baltic #6
A03	1.0	1.4	4.4
A10	0.8	1.3	2.2
A25	1.8	2.5	1.4
R10	1.2	1.7	1.7

First, the combined solutions were produced by combining the four solutions of each type by using minimum constraint with no-translation condition on all fiducial stations to IGS05 (for the solutions with absolute antenna models) and to ITRF 2005 (for the solutions with relative antenna models).

Alignment to ITRF

Our experience from the NKG 2003 campaign was that the largest difference between individual solutions was the constraint to ITRF. We had regional and global constraints differing about 1 cm in height. In the use of the transformation formulas based on the NKG 2003 campaign, we experienced that there are regionally large differences between the official extrapolated IERS ITRF 2000 coordinates and the frame defined by NKG2003. This is quite natural but it gave rise to the question of what kind of alignment to ITRF we should use for NKG 2008. Should it be a global or regional constraint? Should we use the official IERS published coordinates or coordinates from updated cumulative solutions? What kind of constraints should be used? How about the consistency with absolute and relative antenna tables?

Which ITRF-solution to use?

In case of the NKG 2003 campaign it was quite obvious to align the solution to ITRF 2000, but the situation is more complicated for this campaign and there are several possible candidates of reference frames.

ITRF2005 solutions were the only available ones when the the NKG 2008 campaign was processed. The ITRF2008 solution was already released but there were no orbits in ITRF2008/IGS08. However, also with ITRF2005 there were some options to choose between. The "official" solution published by IERS has some disadvantages. These coordinates were obtained by using relative antenna tables while IGS05 (the IGS version of ITRF 2005 used for precise orbits) has been corrected to be compatible with absolute antenna tables. IERS ITRF2005 has also data only up to the end of 2005, so extrapolation of the coordinates would have been necessary to get coordinates to the epoch of NKG 2008.

Also, if using this solution and extrapolating the coordinates, several discontinuities after 2006.0 have occurred inducing jumps and thus forcing to exclude these stations from the list of fiducial stations (which was not long even in the beginning). So it was not convenient to use IERS ITRF2005. IGS05 instead could have been one option, but the main reasons not to use that were the same as in IERS ITRF2005 (and the network of fiducial stations was even more sparse).

There are also EPN densifications of ITRF 2005. The original EPN densification of IERS ITRF2005 [Kenyeres 2008] has the same draw-backs as the IERS ITRF2005 itself.

Since October 2009 the original EPN densification is regularly updated every 15 weeks based on cumulative combinations of the weekly EPN-solutions [EUREF 2009]. Station specific events (coordinate outliers and discontinuities, including the shift between relative and absolute antenna heights) are identified and taken into account. The latest EPN cumulative solution available when the final coordinates for NKG 2008 were determined was EPN_A_ITRF2005_C1570, i.e. a cumulative solution up to GPS-week 1570, well including the campaign-week 1499. When comparing the original EPN densification of IERS ITRF 2005 and EPN_A_ITRF2005_C1570, the discontinuities and extrapolation to the epoch of NKG2008 (=2008.75) and differences between relative and absolute antenna tables were clearly seen – see figure 3 and 4.

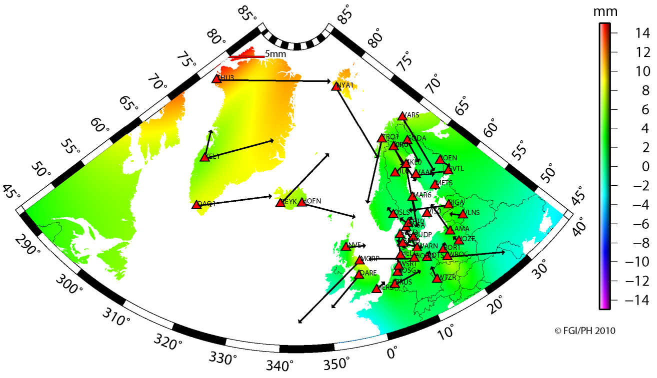

Fig. 3. Horizontal differences beween the EPN_A_ITRF2005_C1570 and the original EPN densification of IERS ITRF 2005 in the epoch of the NKG 2008 campaign.

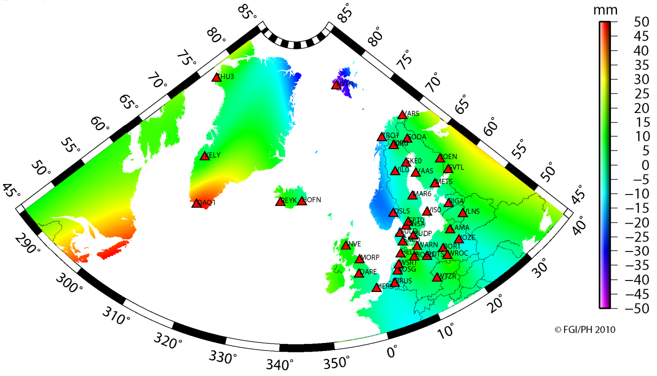

Fig. 4. Vertical differences beween the EPN_A_ITRF2005_C1570 and the original EPN densification of IERS ITRF 2005 in the epoch of the NKG 2008 campaign.

The conclusion was to use the EPN densification EPN_A_ITRF2005_C1570. When comparing this solution with ITRF2008, the difference was negligible (no extrapolation, no discontinuities). With the EPN ITRF2005 cumulative solution, coordinates need not to be extrapolated (and thus discontinuities do not interfere), they are obtained with absolute antenna tables same as the precise orbits and the network of fiducial stations is dense. And with this decision we followed also the guidelines given by EUREF for EUREF densifications [Bruyninx et.al. 2010]. A draw-back of this choice is that it is not suitable for the full network, but the area of interest for NKG (Nordic, Baltic, Greenland, Iceland, Faroe Islands and Svalbard) is covered by the EPN-solution.

Which type of constraint?

There are several different ways to constrain the GPS-solution to the reference coordinates of the fiducial stations. In the past tight (=fixed, sigma=10^{-10} m), removable (~fixed, sigma=10^{-5} m) and in some cases loose (free, sigma=~1m) constraints were used. In these methods constraints are applied directly to coordinates. At the moment, however, instead of these it is recommended (by e.g. EUREF) to use minimum constraints (MC). In the MC method the constraints are not applied to coordinates but to transformation parameters.

Tight and removable constraints force the network/solution to the reference coordinates of the fiducial stations and this means that the coordinates of the fiducial stations do not change during the constraining/aligning the solution. However, these methods are not optimal if the fiducial coordinates are not good enough or if there is e.g. bad quality data or lacking of data at some (fiducial) station and thus – due to this – inaccuracies in the solution. If the constraints are applied directly to coordinates in such a case, this may distort the internal accuracy of the whole GPS-solution. But on the contrary, if the data quality is well-checked and the coordinates of the fiducial stations are accurate, tight or removable constraints may be a good choice. In this case the solution will be well-defined in the reference frame of the fiducial stations.

With minimum constraints the datum definition (reference frame alignment) is based on the whole network through transformation parameters instead of being directly based on single or a set of station coordinates. Minimum constraints are applied to 7 or 14 transformation parameters of the terrestrial reference frame, meaning translations, rotations and scale and in case of 14 parameters, their time evolution. However, the constraints can be applied also only to translations (no-net-translation, NNT), rotations (no-net-rotation, NNR) or scale and/or some combination of these. Using transformation parameters means that e.g. a single bad station do not affect to the whole network and the network/GPS-solution is not distorted since the similarity transformation preserves the geometry of the network. This ensures also optimum datum definition. However, this method allows the fiducial coordinates to change during the constraining (because the constraints are not applied to coordinates). Also this type of constraint is sensitive to station selection. Shifting or tilting of the network (called network effect) have been reported especially on regional solutions. Global coverage of fiducial stations improves the situation but this is not applicable to all solutions. An MC solution has to be verified by comparing the fiducial coordinates before and after constraining.

The best method has to be decided case-specifically. For small, regional or non-scientific networks it is probably best (safest) to choose removable constraints (tight constraints are not recommended anymore due to difficulties in removing them afterwards) in order to align the GPS-solution as good as possible to the desired Terrestrial Reference Frame (TRF). Minimum constraint is an option if it is desired to keep the internal geometry from the GPS-solution. For global networks or geodynamical studies it is better to use minimum constraints. Instead of the constraining method itself, it is probably more important to be able to align the solution as consistently as possible to the frame of the fiducial coordinates. This ensures that the resulting coordinates (or densification of the frame) are accessible also in the future.

The alignment of NKG 2008 to ITRF 2005

The NKG2008 campaign solution was constrained with several different strategies to the cumulative ITRF 2005 solution EPN_A_ITRF2005_C1570. Both removable and minimum constraints were tested. The Bernese recommendation to use MC but constrain only translations, led to up to 1 cm changes between the reference (original a priori) and estimated coordinates due to the constraining approach (compared at fiducial stations, see figures 5-6). The vertical residuals are also tilting in N-S direction (network effect). If residuals were not verified, we would have added unnecessary biases to the solution and thus degraded also the accuracy of our transformation for the future use (due to loose connection to the accurate cumulative EPN ITRF2005 solution). Adding constraints also to rotations (NNT+NNR) decreased the residuals mainly to below 5 mm at fiducial stations (see figures 7-8). The results are also pretty equal to those from removable constraints and the method fulfils also the criteria given in the EUREF guidelines [Bruyninx 2010]. Therefore this solution was chosen as the final one.

After finalizing the processing of the NKG 2008 campaign, and when the final coordinates already had been used for the transformation project, we did in another project discover that the minimum constrained solution with the Bernese Software using both no-net-translation and no-net-rotation conditions not is optimal. The existing rotation between the GPS-solution and the reference coordinates is just taken care of partially. A part of it just affects the fiducial sites in such a way that the coordinate recoveries on the fiducial stations decrease but the internal geometry of the GPS-solution is distorted. The distortion is similar to the effect when using removable constraints on the stations (but smaller). With another software, e.g. CATREF, it would probably have been possible to perform the minimum constraint with NNT+NNR without distorting the GPS-solution.

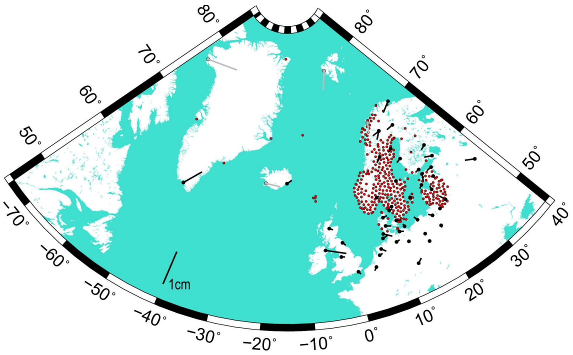

***Fig. 5**. Horizontal coordinate recoveries when using NNT minimum contraints to EPN_A_ITRF2005_C1570.*

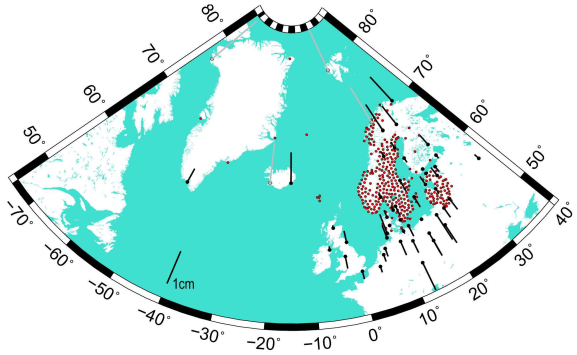

Fig. 6. Vertical coordinate recoveries when using NNT minimum contraints to EPN_A_ITRF2005_C1570.

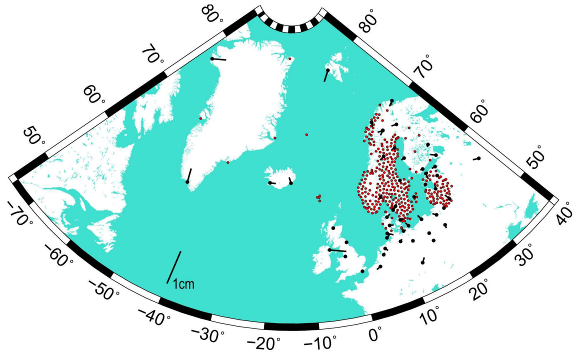

***Fig. 7**. Horizontal coordinate recoveries when using NNT+NNR minimum contraints to EPN_A_ITRF2005_C1570.*

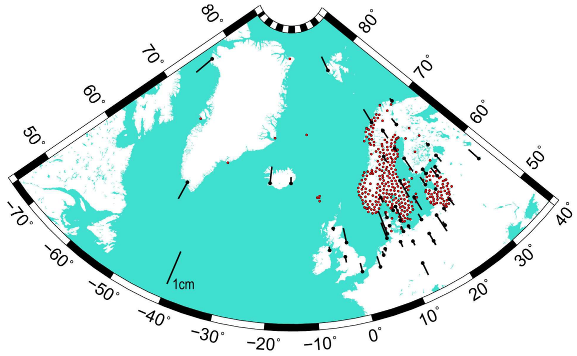

***Fig. 8**. Vertical coordinate recoveries when using NNT+NNR minimum contraints to EPN_A_ITRF2005_C1570.*

Conclusion

To sum up, the final solution of the NKG 2008 is a Bernese solution based on absolute antenna models and 3° cut-off. It has a regional connection to ITRF 2005 achieved through minimum constraints to the EPN cumulative solution EPN_A_ITRF2005_C1570 with no-net-translation and no-net-rotation conditions. The characteristics of the solution is however somewhat similar to a solution with removable contraints as the internal geometry has been affected – see above.

It would be interesting to test to calculate the minimum constrained solution with no-net-translation and no-net-rotation conditions in the CATREF-software.

In addition to the final solution also alternative combined solutions aligned to IERS ITRF 2005, IGS 05 and ITRF 2008 were computed. All solutions are available (with limited access) at the ftp-server at KMS.

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