J. Geod. Sci. 2018; 8:34–42

DE GRUYTER

Research Article

Open Access

Sonja Lahtinen*, Häkli Pasi, Lotti Jivall, Christina Kempe, Karin Kollo, Ksenija Kosenko, Priit Pihlak, Dalia Prizginiene, Oddvar Tangen, Mette Weber, Eimuntas Paršeliūnas, Rimvydas Baniulis, and Karolis Galinauskas

First results of the Nordic and Baltic GNSS Analysis Centre

https://doi.org/10.1515/jogs-2018-0005
Received August 1, 2017; accepted December 21, 2017

Abstract: The Nordic Geodetic Commission (NKG) has launched a joint NKG GNSS Analysis Centre that aims to routinely produce high quality GNSS solutions for the common needs of the NKG and the Nordic and Baltic countries. A consistent and densified velocity field is needed for the constraining of the glacial isostatic adjustment (GIA) modelling that is a key component of maintaining the national reference frame realisations in the area. We described the methods of the NKG GNSS Analysis Centre including the defined processing setup for the local analysis centres (LAC) and for the combination centres. We analysed the results of the first 2.5 years (2014.5-2016). The results showed that different subnets were consistent with the combined solution within 1–2 mm level. We observed the so called network effect affecting our reference frame alignment. However, the accuracy of the reference frame alignment was on a few millimetre level in the area of the main interest (Nordic and Baltic countries). The NKG GNSS AC was declared fully operational in April 2017.

Keywords: Bernese GNSS Software; Combination of GNSS solutions; Glacial isostatic adjustment; Nordic Geodetic Comission

1 Introduction

The Nordic Geodetic Commission (NKG) has been the venue of the exchange of geodetic views and experiences within the Nordic and Baltic countries for a long time. The glacial isostatic adjustment (GIA) in the Fennoscandian area and its effects on the reference frames is one of the main topics that challenge us. The most accurate GNSS data processing is carried out in the global frames, but the spatial data is still mostly presented in the national frames. The knowledge of the GIA can significantly improve the accuracies of the coordinate transformations from global systems to the national realisations [1, 2]. On the other hand, the GNSS derived station velocities are important constraints for the GIA modelling [3].

To fulfil the common reference frame related needs in the Nordic and Baltic area, GNSS processing has been carried out within the NKG for a long time. The NKG has been contributing to the final products of the EUREF Permanent GNSS Network (EPN) since the start of the EPN in 1996 as one of its analysis centres. The network consists of the EPN stations from the Nordic and Baltic countries, but it is too sparse for many reference frame related works. Two large GPS campaigns, NKG2003 [4] and NKG2008 [5], have been organised to produce common reference frames for the NKG projects and to develop transformations from global to national frames. These campaigns included both permanent stations and passive geodetic markers defining the national ETRS89 realisations, and the processing was carried out as a co-operation between several national analysis centres.

The GNSS velocity estimation has been conducted under the project Baseline Inferences for Fennoscandian Rebound, Sea-level, and Tectonics (BIFROST) during several decades and latest results were reported in [6]. A partly densified velocity field has been published later [7], but in both solutions most of the Baltic area as well as Iceland and the Arctic area were not represented. Both the GIA modelling and the reference frames would benefit from consistent and densified GNSS solutions for the whole

---

***Corresponding Author: Sonja Lahtinen:** Finnish Geospatial Research Institute, National Land Survey of Finland Kirkkonummi, Finland, E-mail: sonja.lahtinen@nls.fi
Häkli Pasi: Finnish Geospatial Research Institute, National Land Survey of Finland Kirkkonummi, Finland
Lotti Jivall, Christina Kempe: Lantmäteriet, Sweden
Karin Kollo, Priit Pihlak: Estonian Land Board, Estonia
Ksenija Kosenko: Latvian Geospatial Information Agency, Latvia
Dalia Prizginiene: National Land Survey of Iceland, Iceland
Oddvar Tangen: Norwegian Mapping Authority, Norway
Mette Weber: Agency for Data Supply and Efficiency, Denmark
Eimuntas Paršeliūnas, Rimvydas Baniulis, Karolis Galinauskas: Vilnius Gediminas Technical University, Lithuania

area. For example [8] has theoretically analysed optimal places for GNSS stations in Fennoscandian area to improve the GIA modelling. More stations were suggested to Baltic countries, central Norway and especially to north-western Russia.

The growing need for a consistent and densified GNSS velocity field over the Nordic and Baltic countries and the resolution (No. 8) of the NKG General Assembly in 2010 [9] resulted in the development of the NKG GNSS Analysis Centre (AC) that was started in spring 2012 [10]. The distributed analysis enables dense network coverage with reasonable workload for the participants. On the other hand it requires coordination and commitment to be able to produce consistent solutions. In this paper we describe the methods of the NKG GNSS AC and analyse the results of our combined solutions for the first two and half years.

2 Methods

2.1 Local analysis centres and networks

The NKG GNSS AC network currently consists of eight subnets processed by the NKG local analysis centres (LAC) and of the EPN subnet solution of the NKG as the common backbone. The NKG LACs include all Nordic and Baltic countries (Table 1). Mainly due to the data policy and workload, the main principle is that each LAC (country) processes its own stations. The advantage of this decision is that the stations are processed in most cases by the station operators who have good knowledge of the station quality and status. Furthermore, there is no need for GNSS data servers. The disadvantage is that national (non-EPN) stations are processed only by one LAC without redundancy.

As the main goal of the NKG GNSS AC is a homogeneous velocity field over the Nordic-Baltic region, the national subnets were designed by selecting a set of stable and well-performing stations with reasonable national coverage. Additionally, each subnet includes at least five IGS or EPN stations for the reference frame alignment, and at least six stations common with the NKG-EPN solution to obtain a strong connection to the backbone network. Otherwise the (sub)network design is a sum of many practical issues. For example, the NKG-EPN backbone network has not been specifically designed for this project as it is an operative EPN solution, and that is why it includes a few stations with a remote location in respect to the Nordic and Baltic area (Figure 1). The operational solution includes 272 stations in total and the number of stations and sites by each LAC is listed in Table 1 (situation in February 2017, including fiducial stations). Station refers to a unique geodetic marker, whereas site describes a geographical area with possibility of several geodetic markers, e.g. co-located stations.

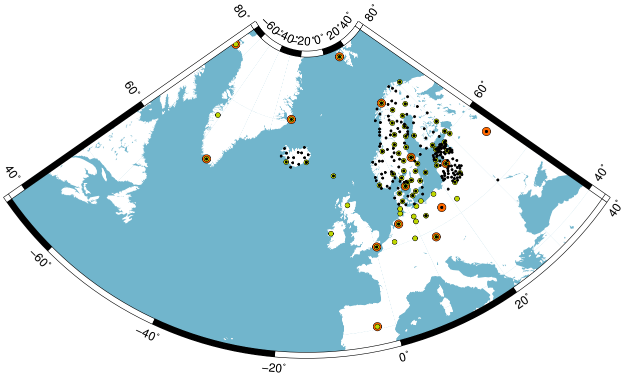

Figure 1: The NKG GNSS AC network (situation of GPS week 1934 / Feb 2017). Green circles represent the EPN NKG backbone network and the black dots stations processed by the LACs. The IGb08 reference stations are shown as orange circles.

2.2 Producing consistent LAC solutions

The main principle in the development of the processing strategy has been to follow the EPN guidelines for its ACs [11] and to take the advantage of the existing standard processing procedures. In that way we could achieve consistency with the EPN products and possibility to contribute to e.g. the EPN densification projects. We selected the Bernese GNSS Software [12] for the processing, because it fulfilled our requirements for high precision double-difference GNSS processing and it was available to all LACs.

We process GPS+GLONASS solutions with three different cut-off angles: 3°, 10° and 25°. The last one is mostly for detecting badly behaving stations by comparing it with the standard 3° solutions. We use final satellite orbits, earth orientation parameters and ionosphere models from the Center for Orbit Determination in Europe (CODE) [13]. Each LAC defines an independent set of baselines using the best fitting approach for its network, typically maximising the number of observations for the baselines. Additionally, subnet solutions have been improved by forcing some baselines to remote stations to strengthen the connections.

We solve the ambiguities using either the Quasi-Ionosphere-Free (QIF) strategy or by the advanced approach (different strategies for different baseline lengths

Table 1: Summary of the contributing LACs and their subnets (situation of GPS week 1934 / Feb 2017).

LAC id	Country	No. of stations (sites)	Other information
DK	Denmark	25 (22)	since GPS week 1861 (9/2015)
EST	Estonia	58 (56)	
FGI	Finland	49 (44)	
ISS	Iceland	22 (22)	
LAT	Latvia	20 (20)	
LIT	Lithuania	40 (40)	since GPS week 1934 (2/2017)
LM	Sweden	84 (63)	
SK	Norway	47 (45)	
ENG	Sweden	76 (68)	NKG-EPN backbone solution

with overlap) provided by the software [12]. Our pre-study with the NKG-EPN network showed that the ambiguity resolution was improved by roughly ten percent units for GPS and one percent unit for GLONASS by using the advanced approach, but its effect on the daily repeatability of station coordinates was only one percent improvement. However, computing time may increase significantly with the advanced strategy depending on the hardware. As a consequence and from the combination point-of-view, both options were considered equal and therefore the decision of the ambiguity strategy was left to the LACs to be based on e.g. available processing resources.

We had two options for the troposphere modelling: either the Global Mapping Function (GMF) [14] or the Vienna Mapping Function (VMF1) [15]. The former is a fully empirical model, while the latter is based on direct ray tracing through a numerical weather model covering the time of observation. Our study [16] showed an average of 0.4 mm improvement for the repeatability of the height component for VMF1 compared to GMF, corresponding to 8–10 % improvement. However, maximum daily differences between VMF1 and GMF reached 6 mm in horizontal and 14 mm in vertical, which was considered too large difference between subnets to be combined. Based on this study, the VMF1 was selected to be used in all LAC solutions. However, due to a bug of the VMF1 implementation in the Bernese GNSS Software [17], roughly the first year of operative solutions was processed using GMF in the results of this paper. This period will be processed later with the VMF1 in the NKG reprocessing of the GNSS data history.

The subnets are aligned to the latest IGS solution (IGb08 until January 2017 and IGS14 since that) using minimum constraints (no-net-translation (NNT) condition) on the IGS station coordinates at the observation epoch. The NNT condition is recommended for the regional networks by the Bernese manual [12]. It ensures that the barycentre of the estimated coordinates coincides with the a priori coordinates while the fixed satellite orbits define the orientation of the network. Each LAC excludes badly behaving stations in daily and weekly solutions, e.g. stations with largely deviating coordinates or very high rms. The stations with receiver or antenna changes affecting daily and weekly solutions are also excluded. Snow accumulation on the antennas or radomes is typical for the northern stations causing deviating solutions, but these will be treated later in the time series analysis. The output of each LAC is normal equation formatted daily and weekly SINEX (Solution Independent Exchange Format) files.

We verified the consistency of the LAC solutions with a test setup of all GPS+GLONASS stations of the NKG-EPN subnet (35 EPN stations). Each LAC processed one week of data (GPS week 1682). After some iteration all LACs could produce practically identical solutions.

2.3 Combination of the LAC solutions

There are two combination centres in the NKG GNSS AC (Table 2). The NKL solution is computed using the ADDNEQ2 program of the Bernese GNSS Software and the NKF solution is produced using the CATREF software [18]. Both solutions are aligned to the latest IGS solution (IGb08 until January 2017) using the same set of reference stations (see Figure 1). The reference frame has been realised based on the recommendations of each software. The analysis of the performance and differences of the NKL and NKF reference frame realisation follows in Ch. 3.3.

The NKL (ADDNEQ2) combination starts with the normal equations (without constraints) of the LAC solutions. The reference frame is realised by using the NNT method that is used for the LAC solutions (Ch. 2.2). Constraining of all seven parameters (translations, rotations and scale) or a subset of them could be possible, but in our case (regional network) the NNT condition is recommended by the software developers [12]. Furthermore, some earlier experiences and tests have shown deviating results with other constraints for regional networks and thus supporting the recommendation.

The NKF (CATREF) combination routine first solves the normal equations of each LAC to loosely constraint SINEX solutions (covariance format). Thereafter the solutions are combined using minimum constraints over all seven parameters (translations, rotations and scale). The LAC solutions are weighted by the variance factor of the preliminary combination.

Before the combination we check the subnet solutions to ensure the consistency of the SINEX metadata with station information files (receiver/antenna types and numbers) and IGS/EPN antenna calibrations values. Based on our experiences of the fit of the LAC solutions, a minimum criteria for outliers has been set to 5 and 10 mm (horizontally and vertically respectively). The outliers are verified by checking the repeatability of the station coordinates within the LAC's solutions and by checking the Helmert fit of the LAC solution to the backbone solution. These minimum limits are rather loose aiming to exclude only gross errors and to achieve more realistic uncertainties.

3 Results

We have analysed the results of the combined solutions from the start of the operational phase (June, 2014) until the end of December, 2016. The results shown in sections 3.1 and 3.2 are from the NKL solution with three degree cut-off angle. Other solutions (NKF and 10° cut-off angles) are quite similar and not presented here except for some intercomparisons.

3.1 Consistency of LAC solutions

We compared LAC solutions to the combined solution to investigate the consistency of different subnets. In general, the subnets agree very well: the rms of the Helmert transformation between each LAC solution and the combined solution is mainly below 1 mm (Figure 2). The DK has shorter time span as they started submitting operational solutions later (see Table 1).

The subnet location has an effect on the fit. The LM (Sweden) subnet located in the middle of the area has the lowest rms and the ISS (Iceland) subnet located at the outer edge of the network has the largest rms especially for the first one and half years. Part of the difference can be explained by longer baselines in ISS network but this is also quite typical of regional networks. But in the end, the results show that different subnets are consistent with the combined solution within 1–2 mm level that can be considered very good agreement.

Also a small decrease of RMS can be seen in some solutions (ENG, FGI, LM, SK) at epoch 2015.7 due to the change of the troposphere model (from GMF to VMF1). This is visible for the standard solution with three degree cut-off angle but greatly diminished with 10 degree solutions. Besides our study in [16], also this shows that VMF1 is working better for low elevations.

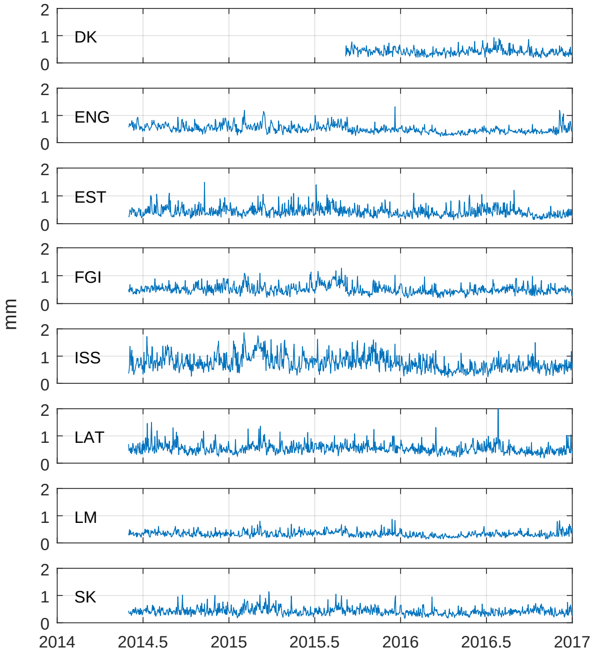

Figure 2: RMS of Helmert (translations only) between each daily 3 deg LAC solution and the combined solution.

3.2 Internal accuracy of the combined solution

We analysed the internal accuracy of the combined solution on the coordinate level using 34 stations processed by at least three LACs (including the NKG-EPN backbone solution). Additionally, 26 stations have been processed by two LACs that are not considered in the following results. They are mainly stations in Greenland and Sweden and

Table 2: Summary of the combination centres and software in use.

Centre id	Country	Software	MC used over	MC possibilities
NKL	Sweden	ADDNEQ2/Bernese GNSS Software	3 translations	all 7 parameters
NKF	Finland	CATREF	all 7 parameters: 3 translations, 3 rotations and scale	all 7 parameters and their time derivatives

* mc = minimum constraint

included in one LAC solution in addition to the NKG-EPN backbone.

The daily rms of the station coordinates (compared to the combined coordinates) was on average below 0.7 mm horizontally and below 2.5 mm vertically. The Figure 3 shows examples of the daily variation at two stations. The MAR6 station, located in the middle of the network, has one of the smallest variations (mean 0.4 mm in horizontal and 1.0 mm in vertical), but also the weakest station NYA1, located in northern edge of the network, is on an acceptable level (mean 0.8 mm in horizontal and 2.4 mm in vertical). The spatial correlation as growing rms from the barycentre of the network can be seen for other stations as well, see Figure 4. This is typical for minimum constraint approach for regional networks, see e.g. [20].

The Figure 4 also shows the station results regarding to the number of the LAC solutions. It is evident that some stations are pronounced in the LAC solutions as they are the IGS stations used for the reference frame alignment. However, the distribution of stations in the LAC solutions is reasonable and the results show that it has no clear correlation on accuracy. The daily rms for the stations processed by 6–8 LACs are not among the smallest rms. Hence, the accuracy is more correlated with the station location in the network. The Figure 4 explains also the higher Helmert rms of ISS solution (Figure 2). There is only one station processed by three or more LACs in Iceland or Greenland area making the connection weaker to the combined network.

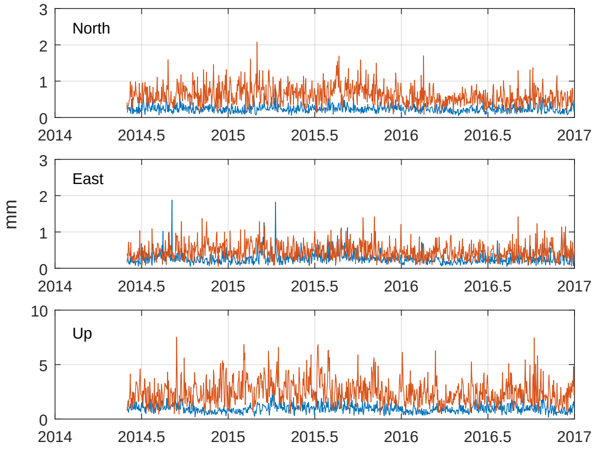

Figure 3: Example of the rms of station coordinates from the combination: MAR6 (blue) and NYA1 (red), processed by seven and five LACs, respectively (see locations in the Figure 4).

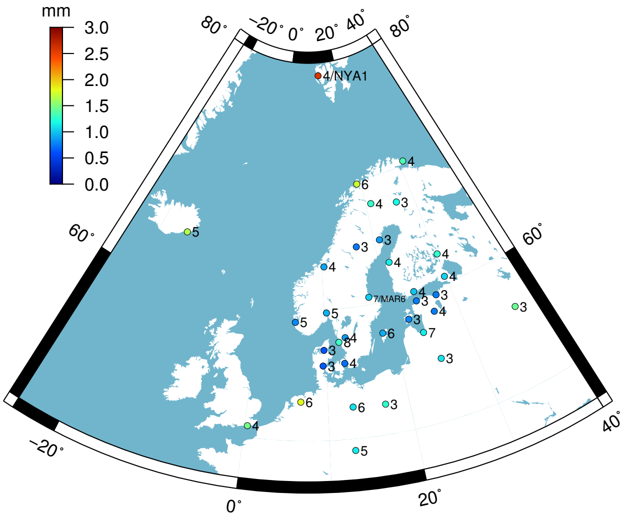

Figure 4: The mean of daily 3D rms at stations processed by at least three LACs (the number of LACs is shown next to the station).

3.3 Difference of the NKL and NKF solutions

We analysed the differences between the two combinations for each station from the daily solutions over the 2.5 years period. Horizontally the mean difference was below 2 mm for the whole area and below 1 mm for the region of main interest (the Nordic and Baltic countries), and vertically 5 and 3 mm, respectively (Figure 5). The standard deviations varied between 0.5–2.7 mm horizontally and 0.6–6.0 mm vertically depending on seasonal variations of the differences. The largest differences were linked to the stations locating e.g. on Greenland or Svalbard. These stations also have the largest seasonal effects especially in height component that is partly absorbed by the constrained scale parameter of the NKF solution and consequently seen also in the differences of these two solutions.

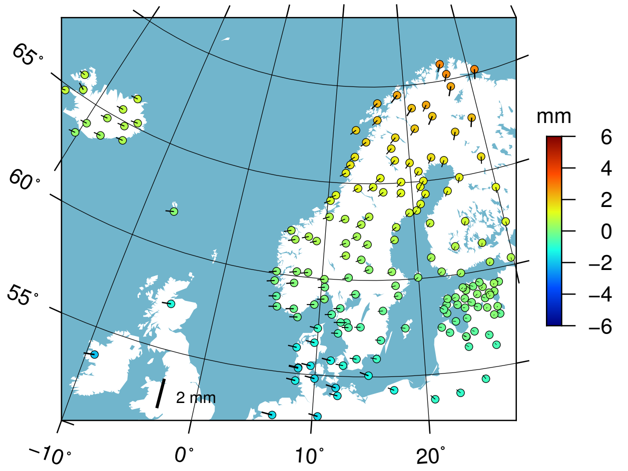

Figure 5: Mean coordinate differences between the NKL and the NKF combination for the main area of interest. The horizontal differences are shown by vectors and the vertical by coloured circles. Six stations have been excluded due to small amount of data.

The maximum daily differences were below 10 and 25 mm horizontally and vertically over the whole period. The results indicate that the NKL and NKF solutions agree sufficiently well to each other even if different number of transformation parameters has been used in constraining the solutions.

However, we see a small horizontal rotation between the solutions as well as a small latitude related dependency (North-South tilt) in the vertical coordinates. This is a typical example of network effect in a regional network (e.g. [19, 20]) and in this case caused by different parameters in the minimum constraint approach of the combined solutions. In order to demonstrate this, we computed an additional NNT solution with CATREF. Figure 6 shows that the differences between CATREF and ADDNEQ NNT solutions are negligible in most of the Fennoscandian region verifying the conclusion.

As we did not observe trends in the time series of daily differences, the differences will most likely not have much effect on the station velocities and only a small effect on the combined coordinate solution.

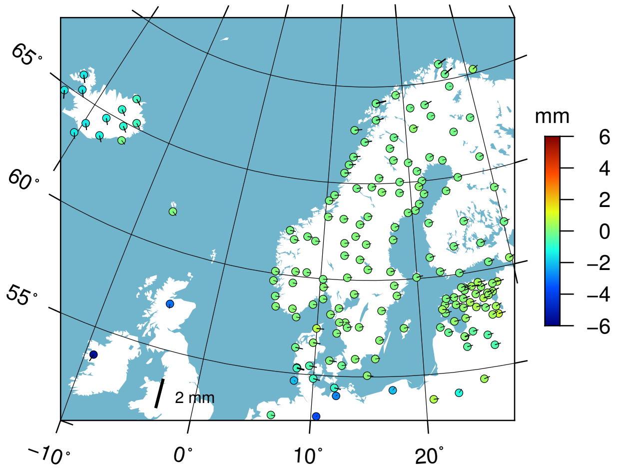

Figure 6: Mean coordinate differences between the NKL and the additional NNT solution with the CATREF.

3.4 Reference frame realisation

In order to produce accurate and consistent set of station coordinates in the preferred reference frame, the accuracy of the reference frame alignment is one of the key criteria for selection of the final solution. For validating it, we analysed the daily residuals of the coordinates of the reference stations after the minimum constraints (estimated vs. a priori coordinate differences) for both NKL and NKF solutions. In total, we had 14 IGb08 reference stations available. The mean residuals for the NKL solution were mostly below 2 mm horizontally and 6 mm vertically (Table 3, Figure 7). The NKF solution is slightly better due to the more parameters in minimum constraints decreasing network effect, but the parameters can be correlated for a regional network. Overall, the reference frame alignment is sufficiently good even though some effects of regional network are visible.

The Figure 8 shows examples of the residuals at two stations. The ONSA (Sweden) has small deviation and the NKL and NKF solutions are almost overlapping. The THU3 (Greenland) has one of the largest deviation, and seasonal variation can be seen especially in the east component of the NKL solution. The largest differences were at the Arctic stations (THU3, QAQ1 and NYA1) and at a remote station YEBE (Spain). The similar pattern has been reported in EUREF analysis reports implying outdating or increased uncertainties of the IGb08 at those stations and similar network effect, see e.g. [21]. Although systematically larger residuals were found at remote stations, it seems that these discrepancies do not have significant effect on the reference frame alignment at the central areas (Figure 7). Besides, the change to the newest IGS reference frame realisation (IGS14) will partly decrease the differences.

4 Discussion and Conclusions

We have developed the routines to a level that enables routinely produced consistent solutions within the Nordic and Baltic area. The first results from 2.5 years of operational

Table 3: Mean residuals of the NKL and NKF solutions and their standard deviations (mm).

	NKL			NKF		
	n	**e**	**u**	**n**	**e**	**u**
BOR1	-2.2 ± 2.0	−0.9 ± 1.1	−0.9 ± 4.1	−1.8 ± 1.5	−1.3 ± 1.0	0.5 ± 3.9
HERS	−0.4 ± 1.3	1.7 ± 1.4	−2.8 ± 4.8	0.6 ± 1.0	1.7 ± 1.3	−0.6 ± 4.0
MAR6	−0.5 ± 1.3	0.1 ± 1.5	0.0 ± 4.2	−0.1 ± 1.0	0.2 ± 1.4	−0.4 ± 4.0
MDVJ	0.1 ± 1.5	−1.9 ± 2.1	6.1 ± 10.5	−0.3 ± 1.3	−2.0 ± 1.9	5.9 ± 8.2
NYA1	1.8 ± 1.9	1.3 ± 1.2	−8.7 ± 6.4	2.6 ± 1.2	1.7 ± 1.2	−12.8 ± 4.6
ONSA	0.2 ± 1.2	0.1 ± 1.0	−1.6 ± 3.6	0.7 ± 0.9	0.1 ± 0.9	−1.2 ± 3.4
QAQ1	−0.2 ± 1.7	4.0 ± 2.1	0.1 ± 5.2	−0.4 ± 1.7	4.4 ± 1.6	0.0 ± 4.5
RIGA	−2.4 ± 1.1	0.7 ± 1.2	−2.8 ± 4.3	−2.2 ± 0.9	0.6 ± 1.0	−2.7 ± 4.0
SCOR	1.0 ± 1.5	−1.4 ± 1.8	−2.4 ± 5.3	1.4 ± 1.4	−1.6 ± 1.4	−4.3 ± 4.4
THU3	−1.6 ± 1.5	−0.7 ± 2.3	16.5 ± 8.3	−2.0 ± 1.5	−1.9 ± 1.3	12.0 ± 5.2
TRO1	−2.1 ± 1.5	−1.0 ± 1.2	3.3 ± 4.3	−1.7 ± 1.2	−0.5 ± 1.3	0.9 ± 4.2
WSRT	0.1 ± 1.2	−0.8 ± 0.9	−1.4 ± 4.6	0.8 ± 0.9	−0.9 ± 0.8	0.2 ± 3.8
WTZR	0.4 ± 1.5	0.1 ± 1.0	5.8 ± 4.9	1.2 ± 1.0	−0.3 ± 0.9	8.1 ± 3.8
YEBE	−0.1 ± 1.9	−0.2 ± 1.1	−10.8 ± 4.7	1.6 ± 1.8	−0.2 ± 1.4	−5.8 ± 3.7
rms	1.3	1.5	6.4	1.5	1.7	5.8

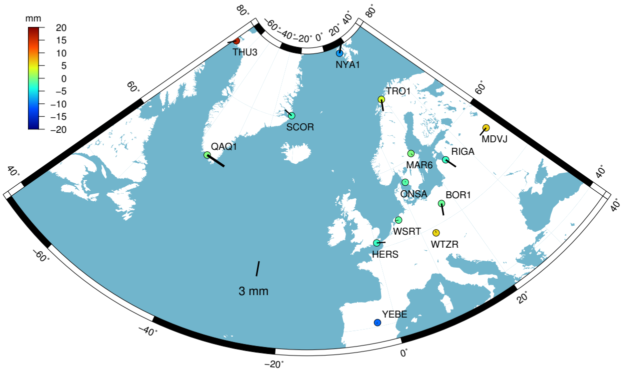

Figure 7: Mean residuals of the NKL solution. The horizontal differences are shown by vectors and the vertical by coloured circles.

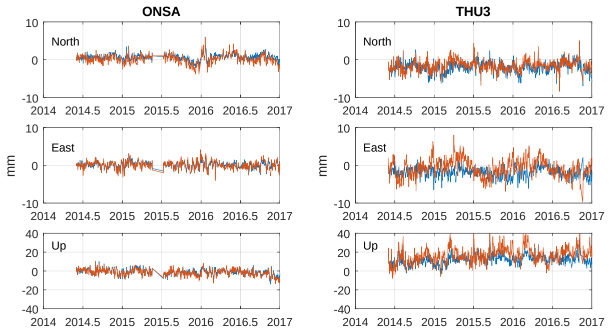

Figure 8: Example of coordinate residuals at ONSA (Sweden) and THU3 (Greenland) stations. The red lines represent the NKL solution and the blue one the NKF solution.

processing showed some effects from troposphere modelling and network design, but most observably the weaknesses of regional network by the reference frame realisation. In troposphere modelling the VMF1 was shown to be better over the GMF when processing data from low elevations. Based on this observation as well as the recommendation of the EPN, the VMF1 was chosen as the mapping function for troposphere modelling.

In network design, small differences were found in subnet results. The remote parts of the network suffer from slightly uneven distribution of common stations and more uncertain baselines. This can be improved by more homogeneous distribution of stations e.g. by including remote stations to other subnets, especially from Iceland area. However, longer baseline lengths and the challenging circumstances will still cause some heterogeneity to the results.

Most visible weakness is related to the network effect in the reference frame alignment. This was seen in combination results with different software and transformation parameters in minimum constraints. This could be minimized by changing to the global processing and constraining the network using optimal reference frame parameters (translations, rotations and scale). This would be a big change in processing routines and strategy and should be communicated thoroughly within the NKG GNSS AC before any conclusion. However, our main focus is in the Nordic and Baltic countries and on the other hand, the accuracy of the reference frame alignment in the focus area was already on a few millimetre level. This is sufficient for the purposes the NKG GNSS analysis centre was initially set up: dense velocity field for the Nordic and Baltic region and reference frame maintenance on the national level. Furthermore, the network can be later re-aligned to different reference frame realisations for specific purposes, e.g. time series analysis.

The developed routines and achieved knowledge are next utilised for the re-processing of the data history and combination of those solutions. The reprocessing will result in homogeneous time series of 10–20 years for most of the stations. Therefore it was not reasonable to focus on velocities in these first results. Time series analysis with some specific issues like snow accumulation on the antennas and plate tectonics in Iceland will be the next step after reprocessing with the goal being an NKG GNSS position and velocity solution with uncertainties for the region. The results will be of great benefit for maintaining the reference frames in the Nordic and Baltic countries, as well as for the geodynamics studies in the area.

This joint effort of NKG GNSS Analysis Centre has shown the strength of local analysis of the data. The analysis is not only based on numbers we receive from the software, but on in-depth knowledge of the sites as well. It also encourages faster actions in case of issues at the stations and in that way improves the quality of the output time series.

Acknowledgement: We thank all the members of the NKG Working Group of Reference Frames and other contributors for participating to this project. Especially we thank Danish Agency for Data Supply and Efficiency for hosting the FTP server for the needs of the NKG GNSS Analysis Centre. We are grateful for Zuheir Altamimi, Patrick Sillard and Claude Boucher for the CATREF software. The maps of this paper were generated using the Generic Mapping Tools (GMT) [22]. Finally we thank the reviewers for valuable comments and suggestions which have significantly improved the manuscript.

References

[1] P. Häkli, H. Koivula, Transforming ITRF Coordinates to National ETRS89 Realization in the Presence of Postglacial Rebound - Evaluation of Nordic Geodynamical Model in Finland. In: Kenyon S. et al. (Eds.), Geodesy for Planet Earth, International Association of Geodesy Symposia 136, Springer-Verlag Berlin Heidelberg, 77–86, doi: 10.1007/978-3-642-20338-1_10

[2] P. Häkli, M. Lidberg, L. Jivall, T. Nørbech, O. Tangen, M. Weber, et al., The NKG2008 GPS campaign – final transformation results and a new common Nordic reference frame, J. Geod. Sci. 6 (2016), 1–33, doi: https://doi.org/10.1515/jogs-2016-0001

[3] H. Steffen, H and P. Wu, Glacial isostatic adjustment in Fennoscandia: A review of data and modeling, J. Geodyn., 52 (2011), 169–204, doi:10.1016/j.jog.2011.03.002

[4] L. Jivall, M. Lidberg, T. Nørbech, M Weber, Processing of the NKG2003 GPS Campaign. In P. Knudsen (Ed.), Proceedings of the 15th General Meeting of the Nordic Geodetic Commission (2006, Copenhagen, Denmark), DTU Space, 2008, 52–67

[5] L. Jivall, P. Häkli, P. Pihlak, O. Tangen, Processing of the NKG 2008 campaign. In S. Henriksen and A Jørgensen A. (Eds.), Proceedings of the 16th General Assembly of the Nordic Geodetic Commission (2010, Sundvolden, Norway), Norwegian Mapping Authority, 2013, 143–149

[6] M. Lidberg, J.M. Johansson, H.-G. Scherneck, G. A. Milne, Recent results based on continuous GPS observations of the GIA process in Fennoscandia from BIFROST, J. Geodyn. 50 (2010), 8–18, doi: 10.1016/j.jog.2009.11.010

[7] H. P. Kierulf, H. Steffen, M. J. R. Simpson, M. Lidberg, P. Wu, and H. Wang, A GPS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models, J. Geophys. Res. Solid Earth 119 (2014), 6613–6629, doi: 10.1002/2013JB010889.

[8] P. Wu, H. Steffen, H. S. Wang, Optimal locations for GPS measurements in North America and northern Europe for constraining Glacial Isostatic Adjustment, Geophys. J. Int 181 (2010), 653–664, doi:10.1111/j.1365-246X.2010.04545.x.

[9] S. Henriksen and A. Jørgensen A. (Eds.), NKG General Assembly, 2010. Proceedings of the 16th General Assembly of the Nordic Geodetic Commission (2010, Sundvolden, Norway), Norwegian Mapping Authority, 2013, 202–203.

[10] L. Jivall, T. Kempe, C. Lilje, S. Nyberg, P. Häkli, K. Kollo, et al., Report from the project NKG GNSS AC. In C. Kempe (Ed.), Proceedings of the NKG General Assembly (2014, Gothenburg, Sweden), Lantmäteriet, Sweden, 2016, 98-102.

[11] EPN, Guidelines for the EPN Analysis Centres, http://www.epncb.oma.be/_documentation/guidelines/guidelines_analysis_centres.pdf, cited 2017-05-22

[12] R. Dach, F. Andritsch, D. Arnold, S. Bertone, S. Fridez, P., Jäggi, A., et al., Bernese GNSS Software Version 5.2. Astronomical Institute, University of Bern, Switzerland, 2015

[13] R. Dach, S. Schaer, D. Arnold, L. Prange, D. Sidorov, A. Sušnik, et al., CODE final product series for the IGS. Published by Astronomical Institute, University of Bern, 2017. url: http://www.aiub.unibe.ch/download/CODE doi: 10.7892/boris.75876.2.

[14] J. Böhm, A. E. Niell, P. Tregoning, H. Schuh, The Global Mapping Function (GMF): A new empirical mapping function based on data from numerical weather model data, Geophys. Res. Lett. 33 (2006), L07304, doi: 10.1029/2003GL018984

[15] J. Böhm, B. Werl, H. Schuh, Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for Medium-Range Weather Forecasts operational analysis data. J. Geophys. Res. 111 (2006), B02406, doi: 10.1029/2005JB003629

[16] L. Jivall, Comparison of Vienna mapping Function (VMF1) and Global Mapping Function (GMF) for NKG GNSS AC. In C. Kempe (Ed.), Proceedings of the NKG General Assembly (2014, Gothenburg, Sweden), Lantmäteriet, Sweden, 2016, 132–136

[17] Bernese mail No. 339, ftp://ftp.unibe.ch/aiub/bswmail/bswmail.0339

[18] Z. Altamimi, P. Sillard, C. Boucher, CATREF Software: Combination and Analysis of Terrestrial Reference Frames, Institut Géographique National, Paris, France, 2006

[19] Z. Altamimi, Discussion on How to Express a Regional GPS Solution in the ITRF, EUREF Publication No. 12. (2003), 162-167. Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main, Germany, 2003

[20] J. Legrand, C. Bruyninx, EPN Reference Frame Alignment: Consistency of the Station Positions, EUREF 2008 Symposium (2008, Brussels, Belgium)

[21] EUREF mail No. 8900, EUREF Analysis Report for GPS week 1929, http://epncb.oma.be/ftp/mail/EUREF/eurefmail.8900

[22] P. Wessel, W. H. F. Smith, R. Scharroo, J. Luis, F. Wobbe, Generic Mapping Tools: Improved Version Released, EOS Trans. AGU, 94 (2013), 409-410, doi:10.1002/2013EO450001