Finnish Permanent GNSS Network, FinnRef

Hannu KOIVULA, Antti LAAKSONEN, Sonja LAHTINEN, Jaakko KUOKKANEN and Simo MARILA, Finland

Key words: GNSS, Reference Systems, NRTK, DGNSS, Open Data

SUMMARY

The National Land Survey of Finland (NLS) operates a nation-wide GNSS network of 20 stations. All stations, equipped with individually calibrated choke ring antennas and GNSS-receivers, track 1 Hz data from GPS, Glonass, Galileo, Beidou and SBAS. The data are streamed to the processing center of the NLS, where error modeling takes place. DGNSS corrections are transmitted through an IP network using NTRIP protocol and RTCM standards. The RINEX data of all the stations are stored for post processing purposes. Both DGNSS correction and RINEX data are freely available open data.

The Finnish Geospatial Research Institute (FGI), the research unit of the NLS, maintains the coordinate system of Finland, the national ETRS89 realization EUREF-FIN. The time series of daily RINEX data are analyzed for monitoring the deformations of the EUREF-FIN. The frame is mainly deformed due to the postglacial rebound and plate tectonics. Due to the crustal deformation the relation between ITRF (International Terrestrial Reference Frame) and EUREF-FIN is not accurately known without constant monitoring. The FGI can open any GNSS data, including NRTK (Network RTK) corrections for educational, development and research purposes.

The NRTK service will be improved so that it fulfills the internal surveying needs of the NLS. For this purpose the NLS has initiated a project for 2017-2019 to densify FinnRef with 20-30 new GNSS stations. Starting 2019 the FinnRef reference stations will be used as base stations for aerial survey work and the NRTK service by 400 NLS surveyors for RTK.

FinnRef, with 40-50 stations, will be the highest order network of the Finnish coordinate system. All FinnRef stations will be connected to the precise levelling network. The height is further transferred to the ARP of the GNSS antenna by tachymeter with sub mm accuracy. These data together with an accurate geoid model may offer means for accurately maintaining the height system in the future. Concrete pillars will be constructed for absolute gravity measurements at a selection of the FinnRef stations. They will in the future serve as first order gravity network.

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1. INTRODUCTION

The original Finnish Permanent GPS network Finnref was built between 1991 and 1996 by the Finnish Geodetic Institute. It consisted of 13 permanent GPS stations. The network was created to provide a basis for a new national reference frame that would have good connections to international frames. The new national frame was to be consistent with satellite positioning that was becoming an important tool for surveying. Another main task for the network was to observe crustal movements at the GPS stations. This offered, for the first time, a nearly real-time tool for monitoring deformations of the reference system.

The Finnish official reference frame EUREF-FIN is the national realization of the ETRS89 (European Terrestrial Reference System). EUREF-FIN is defined by the coordinates of the 12 FinnRef stations and 100 first order survey markers that were measured as field campaigns in 1996-1997.

The Ministry of Agriculture and Forestry granted funding for renewing the FinnRef network in 2012-2013. The current network consists of 20 GNSS stations and 4 GPS stations. The network offers also open RINEX data and an open DGNSS service with 0.5 m accuracy.

In the beginning of 2015 the Finnish Geodetic Institute was merged into the National Land Survey of Finland (NLS). The Finnish Geodetic Institute continued as a research unit of the NLS under a new name: Finnish Geospatial Research Institute (FGI). In this paper we explain how operations of FinnRef and the related positioning service are organized in the NLS since the merge.

In Section 2 we explain the roles and responsibilities of different units of NLS related to FinnRef. In section 3 we give the current status of the network, its primary use and the open positioning service. In section 4 we explain how the data is available for education, research and development and give as an example the Aurora project that is a test platform for autonomous vehicles in Finnish Lapland. In section 5 we give future perspectives of the network.

2. FINNREF AS PART OF THE NATIONAL LAND SURVEY

The National Land Survey of Finland maintains the cadaster, i.e. registers containing information on e.g. mortgages, registrations of property rights and other property information. The NLS also conducts research and its application as well as data and information system development.

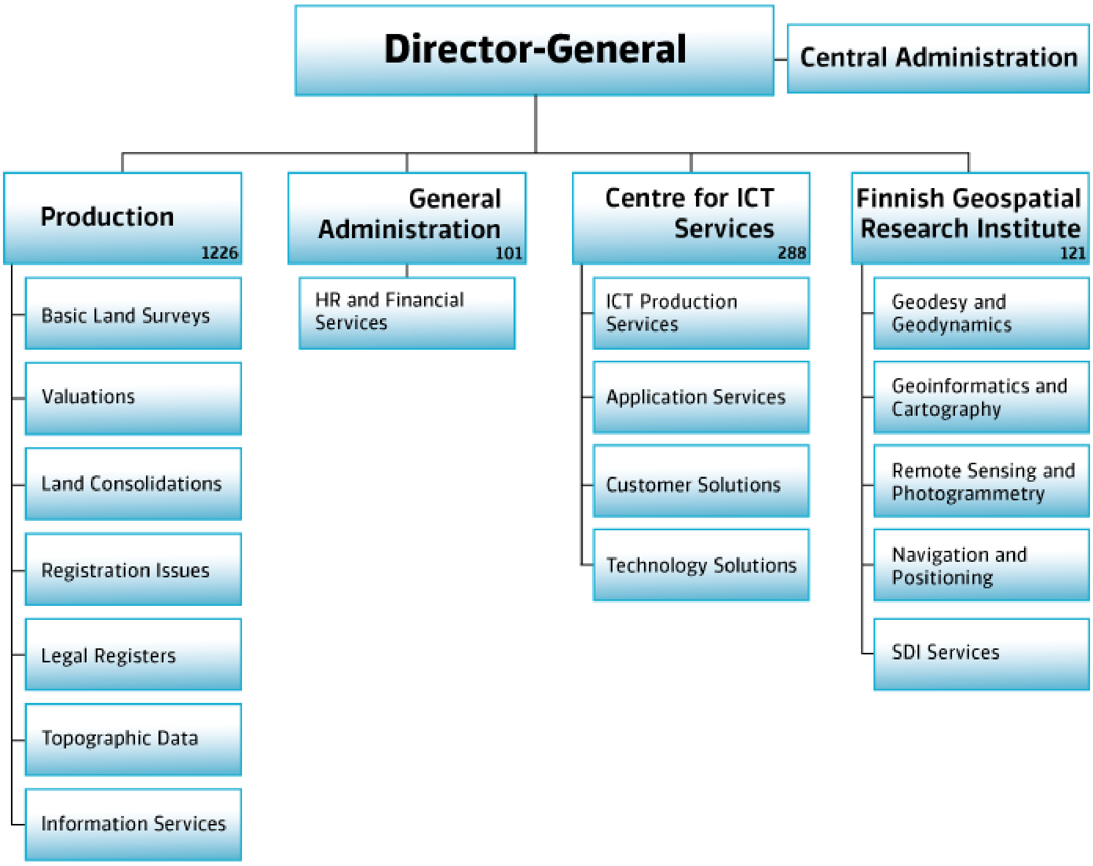

Figure 1. *Organization of the National Land Survey of Finland (Jan-1-2017).*

The NLS has offices in tens of different locations across Finland. The number of employees is nearly 2,000. The organization (shown in Figure 1) consists of a central administration and four operative units (Production, General Administration, Centre for ICT Services and the Finnish Geospatial Research Institute (FGI)).

The FGI is responsible for developing and maintaining the Finnish coordinate and height systems. The task is a basic duty of the department of Geodesy and Geodynamics (FGI-GG). Other units of the NLS support the task with field work etc. The FGI-GG defines the installations and hardware used at the permanent GNSS stations and takes care of the international connections to IGS, EPN and NKG. Any fundamental changes at a FinnRef station should be authorized by the FGI-GG. The FGI-GG processes daily coordinates of the FinnRef stations and monitors the deformation of national reference frame. FGI-GG also creates the transformations between GNSS and national reference frames. All departments of the FGI also perform research related to coordinates and GNSS. The FGI decides all data usage issues related to research and development.

The positioning service is the responsibility of the Centre for ICT Services. Operational work, namely operating the open positioning service, is a task of the ICT production services. They guarantee that the service performs in a defined accuracy and reliability level. They also take care of the maintenance of the stations and data transfers from stations to the processing center and to the end users.

3. CURRENT STATUS OF FINNREF

3.1 Infrastructure

In 2012-2013 the FinnRef network was completely renewed [Koivula et al., 2012]. The new FinnRef consists of 20 permanent GNSS stations (Fig 2). All stations except SAVU and SODA are founded on bedrock. The stability of the bedrock was tested using a Scintrex CG5 gravimeter as a sensitive seismometer. The standard antenna platform, a 3-meter high steel grid mast, is narrowed from the top (see fig 2). In KEV2 and MET3 a similar, but 6-meter high, mast was used because of the obstacles around the antenna. The masts are anchored straight to the bedrock with screw bars. There are at least 3 survey markers around the mast. The stability of the mast is regularly monitored with respect to the survey markers using tachymeter and levelling instruments.

All antennas are JPL design Javad choke ring antennas with SCIGN radar domes (JAVRINGANT_DM SCIS) to prevent snow accumulating on the choke rings during the winter season. Radomes have an effect on the signal propagation and therefore they influence the estimated coordinates. There are also slight differences between antenna phase patterns even if though similar antennas are used. To minimize the uncertainty all antennas have been individually calibrated at Geo++ in Germany using a calibration robot [Wübbena et al., 2000]. Receivers are Javad Delta-G3T (JAVAD TRE_G3TH DELTA) and they track GPS, Glonass, Galileo, Beidou and SBAS with 1 Hz.

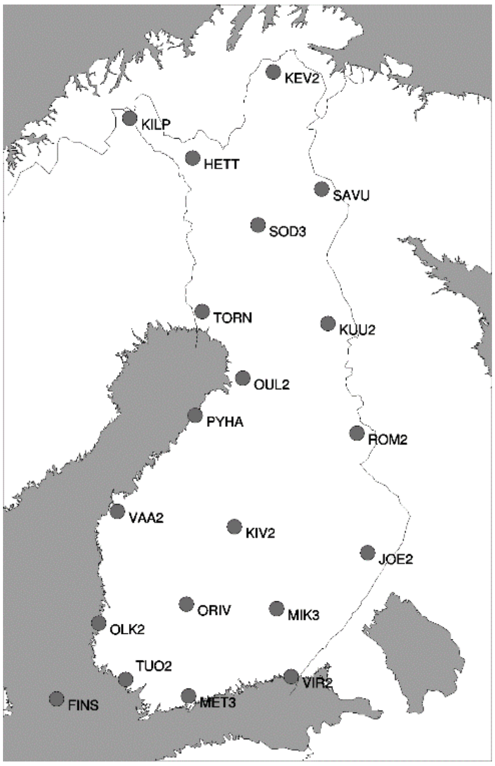

Figure 2. *FinnRef is a nation-wide network that consists of 20 continuously operating GNSS stations (left). On the right the TORN station is shown. The antenna is mounted on a 3 m height steel mast that is fixed to the bedrock. The top of the mast is narrowed to minimize reflections from the mast.*

Data connections are 3G/4G or fiber connections. For open data products the 1 Hz data are streamed to the GNSS analysis center of the NLS. At the analysis center the GNSMART software is used to perform real-time error analysis of FinnRef allowing us to provide DGNSS corrections for end users. For maintenance of the reference frame the hourly data with 30 s interval are ftp-pushed to the local data center of the FGI, where they are further archived and, in case of international stations, submitted to the data banks of IGS and EPN.

3.2 Maintenance of the national reference frame

The official coordinate system of Finland is the ETRS89 realization called EUREF-FIN. It is defined by the coordinates of 100 first order benchmarks and the 12 original FinnRef stations [Ollikainen et al., 2000]. Four of these original GPS stations are also EPN (EUREF permanent GNSS network) stations. The new FinnRef stations have been proposed in December 2016 to the EPN and the data is already available at the EPN's regional data centres. The RTCM data will be provided as well. The inclusion of the densified FinnRef network to the EPN provides valuable data for the EUREF community eg. for intraplate deformation analysis.

The FGI contributes to the NKG's GNSS Analysis Centre by processing FinnRef as a sub-network. The analysis is done on a weekly basis using the Bernese software. This solution is the main tool to monitor deformations of the coordinate system. Long coordinate time series of the FinnRef stations offer reliable velocities of coordinates. These velocities are in a crucial role when coordinates are transferred from ITRF to EUREF-FIN. In order to fully utilize the old and new time-series of FinnRef we gathered overlapping data for roughly three years: 11/2013 (RINEX 2), 2/2014 (binary) - 11/2016 for non EPN-stations. All old EPN stations are still dual stations. Figure 3 shows an example of the time series of dual station VIRO/VIR2.

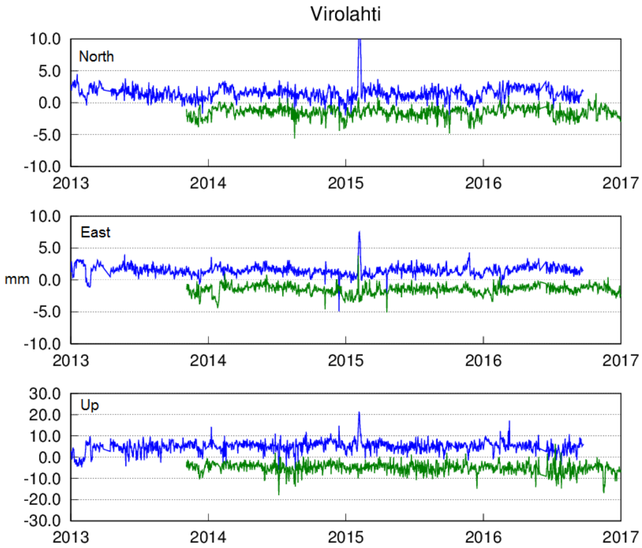

Figure 3. *The detrended time series of the Virolahti stations: VIRO (blue) and VIR2 (green) in mm. For clarity, the time series have been offset from each other 3 and 5 mm in horizontal and vertical, respectively.*

Figure 4. *Control measurements at the Joensuu GNSS stations. Tripods are on survey markers founded on bedrock. New FinnRef station JOE2 is in the front and old JOEN in the back.*

In order to guarantee that the coordinate time series relate to actual movements of the crust and not to the deformation of the mast, we regularly perform control surveys at the stations (Figure 4). All stations are surrounded by at least 3 survey markers. We use tachymeters to control the location of the GNSS antenna (where a miniprism can be attached to the antenna mounting screw as a reference point) with respect to the survey markers. The height difference between the survey markers are precise levelled as well.

The official transformation parameters provided by the IERS are not sufficient to accurately model intra-plate deformations or land uplift [Häkli and Koivula, 2012]. When transforming from ITRF to EUREF-FIN we take the intra-plate deformations between observation epochs into account using the NKG land uplift model, as discussed in detail in Häkli et al. (2016).

It is crucial that all the measurement in Finland are performed in the official EUREF-FIN frame. For this purpose Public recommendations on measuring control markers in EUREF-FIN have been published [JHS, 2017]. Traditionally all the coordinates are classified into different measurement classes. This is the case for EUREF-FIN coordinates as well. The highest class E1 includes the FinnRef stations and survey markers defining EUREF-FIN. Under that there are classes E2-E6. E2 and E3 are typically the highest classes of the municipalities and cities. Traditionally measurements in a certain class had to be tied to the closest benchmarks of the higher class. Our recommendation allows the use of permanent GNSS stations, having official E2 coordinates, instead of survey markers if certain measurement protocols are followed.

Any permanent GNSS station or network can obtain official E2 class coordinates using the E2-Service of the FGI. The owner of the permanent station or network agrees to transfer daily RINEX data to the FGI and as a return gets official EUREF-FIN coordinates for the station. The FGI monitors the quality of the E2 coordinates on a daily basis. If the station is unstable and/or there is too much deviation from the official coordinates the validity of the coordinates and the station will be ended.

3.3 Open Positioning Service and post processing data

The data from all FinnRef stations are streamed to the processing center of the NLS, where error modeling takes place. For this purpose the GNSMART software is used. DGNSS corrections are transmitted free of charge through the IP network using the NTRIP protocol and the RTCM 2.x standards. Currently we are transferring corrections for GPS and Glonass satellites only. It is possible to choose corrections from a desired GNSS station, the closest station or use a Network DGNSS solution where the correction is tailored for the user position taking into account the error modelling of the network. This mode guarantees the most homogenous solution over the country. Also the RINEX files from all the FinnRef stations are openly available. The RINEX data of 1 Hz is guaranteed to be available at least two months after the observations. Users can decide the time span and the observing interval of the downloaded data. For the most accurate use the individual calibration tables are also available.

Differential GNSS service performances have been investigated and published in Marila et al. 2016. Based on practical experiments performed with state-of-the-art geodetic receivers about 0.5 meter accuracy (horizontal even better) can be obtained in a good positioning environment with a static or even a moving platform (car in the tests). The distance from the FinnRef station has minor influence on the accuracy and the Network DGNSS performed slightly better compared to the nearest station corrections. In a challenging environment the positioning accuracy decreases providing most of the time still higher accuracy than with stand-alone GNSS. Relatively high availabilities of DGNSS corrected solutions were obtained in the tests. Breaks occurred mostly due to a very bad positioning environment (no satellites in view) or breaks in the internet connection via which the DGNSS corrections were obtained. Problems with the latter can be minimized by allowing the receiver to use eldering corrections during the breaks. Additionally, the Network RTK solution (open for research purpose only and used as a reference solution during the car tests) performed really well in good signal conditions.

Table 1. *Obtained accuracies in m (3d-error, 95 % percentile) under different conditions. *break in internet connection.*

	Stand-alone GNSS	**Network DGNSS**	**Network DGNSS Availability**
Site	**95 %**	**95 %**	**% of time**
Static			
FGI Headquarters	5.54	0.62	98.08 %*
FGI Headquarters (Forest)	7.33	3.39	100.00 %
Dynamic			
Field Road		0.69	99.38 %
High-/Motorway		4.36	97.29 %

4. OPEN DATA FOR EDUCATION, RESEARCH AND DEVELOPMENT

Section 3.2 described the data that is open for anybody to use. The FGI can provide open data or tailor a service for any educational, research or development purpose. We are able to provide data streams from the FinnRef stations and also Network RTK corrections. We can provide PRS, FKP and MAC corrections using RTCM 3.x formats. Our own preliminary studies indicate that in good observing conditions it is possible to reach 5 cm NRTK accuracy even if our network is really sparse (average distance between stations is 200 km).

FinnRef error modeling was successfully used in the P3-service project (https://p3-service.net/) financed by private companies and Tekes, the Finnish Funding Agency for Innovation. Our analysis center offered the error analysis of the FinnRef network as SSR corrections through the IP network in RTCM format. The corrections were utilized in prototype mobile phones that allowed access to raw code and phase data. Raw FinnRef data are also streamed to Kartverket in Norway to support their Ionosphere Scintellation studies (http://sesolstorm.kartverket.no/). Figure 5 shows an example of the tailored FinnRef network for research and development: The Aurora ecosystem in Finnish Lapland gives the opportunity to test new intelligent traffic solutions in extreme weather conditions. Aurora has a closed testing ground but in the future also the whole E8 road will be a test field.

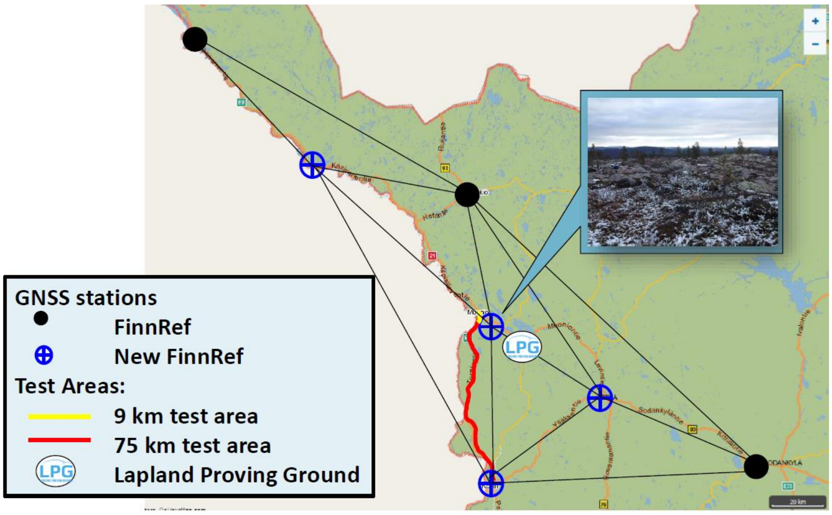

Figure 5: *Infrastructure that will provide GNSS correction data for intelligent traffic in Lapland.*

5. FUTURE PERSPECTIVES

5.1 Improving Positioning Service for the NLS internal use

Currently the NLS is operating the open DGNSS service and NRTK is reserved for research purposes only. The NRTK service will be improved so that it fulfills the internal surveying needs of the NLS. For this purpose the NLS has initiated a project for 2017-2019 to densify FinnRef with 20-30 new GNSS stations (Figure 6). At the same time the quality monitoring of the corrections and data will be improved. Starting 2019 the FinnRef reference stations will be used as base stations for aerial survey work and the NRTK service by 400 NLS surveyors for RTK.

When fully operational in 2019 the positioning service will be located at the Governmental Data Center. All the key components are made redundant and therefore the availability of the service is as high as it can get considering the hardware. Abilities to detect errors of the system in multiple levels are constantly monitored and being developed. In case of a software, data or hardware failure, appropriate measures for recovery have been thought through and are also constantly under development. The entire telecommunication network is built using secured 3G/4G or Fiber optic connections having SLA's (Service Level Agreement) with local ISP's (Internet Service Provider). The whole service architecture is designed as secure and scalable as possible taking into account possible future needs. The service is still under heavy development and all effort is put to secure the service and maintaining the required level of accuracy, continuity, integrity and availability in the RTK- and DGNSS-services.

The Ministry of Agriculture and Forestry has initiated a project that gives the Parliament of Finland a clarification of spatial data policies by the end of 2017. Typically these kind of clarifications may later lead to legislative changes and may have influence on the open data policy.

5.2 FinnRef as a coordinate, height and gravity reference network

The FGI is maintaining the coordinate, height and gravity reference networks in Finland. The new FinnRef will provide basis for all of them in the future. All new stations will be built as highest order reference stations (as described in section 3.1.). All of these techniques support each other and may give valuable information. For example a slowly growing forest may be seen on long GNSS time series as slow vertical velocity even if the station is not uplifting. Uplift models by repeated levellings or gravity observations may help to notice the anomalies.

FinnRef, with 40-50 stations, will be the highest order network of the Finnish coordinate system. The majority of the stations will be built on bedrock and their stability will be monitored. This dense reference network allows us to consider changing into an active definition of the reference frame. This would mean that the national reference frame would be defined by the permanent GNSS stations instead of a number of fixed benchmarks. Also the E2 class stations could be included in this definition if necessary. The network will also offer a dense velocity field for intra-plate deformation models. This will improve the accuracy of transformations from GNSS coordinates to the national realization. A dense active reference network gives us the possibility to aim for a fully dynamic time dependent reference frame in national measurements. However, deciding to do so means a major change in measurement guidelines, registers, GIS software etc.

All FinnRef stations will be connected to the precise levelling network (Figure 6). The survey markers of every FinnRef station will be precise levelled from the closest pair of stable first order precise levelling benchmarks. The height is further transferred to the ARP of the GNSS antenna by tachymeter with sub mm accuracy. By precise levelling we can offer official normal heights for the stations, long GNSS time series provide ellipsoidal heights and change rates with small uncertainties. These data together with an accurate geoid model may offer means for accurately maintaining the height system in the future. The major height related challenge in Finland is postglacial rebound, meaning that the land is uplifting between a few millimeters up to one centimeter per year.

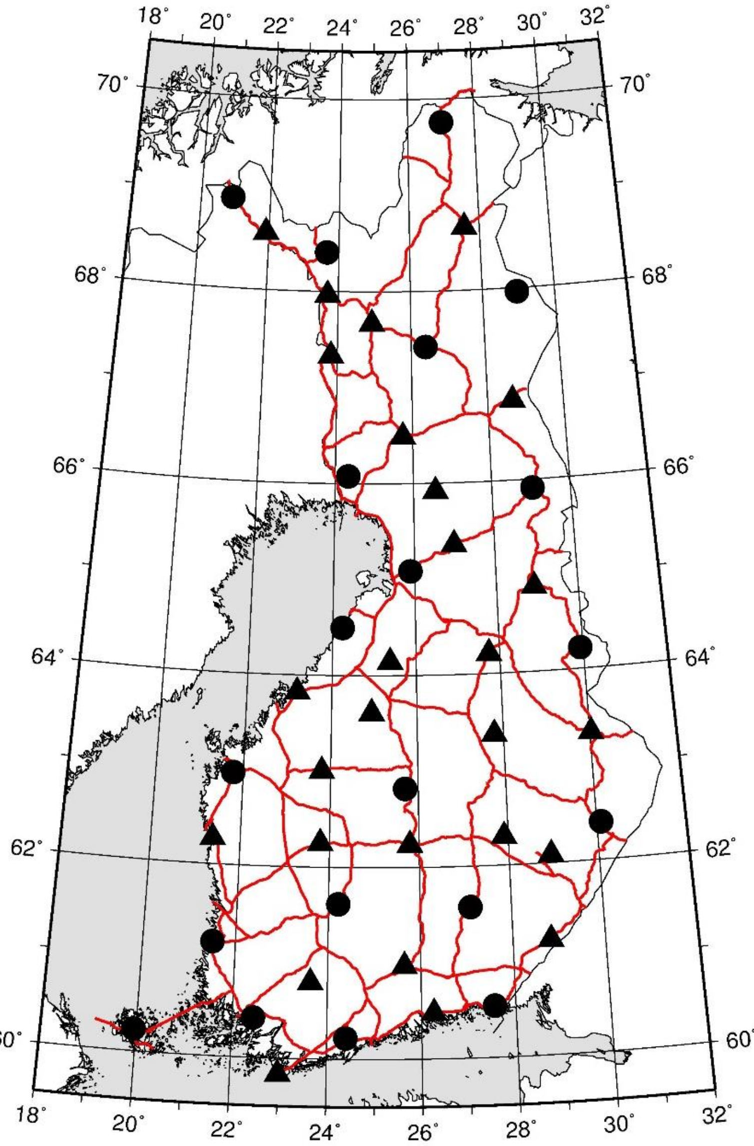

Figure 6. *All FinnRef stations will be connected to the precise levelling network (red lines). Current stations are shown with dots and planned stations with triangles. The final locations of the new stations will be decided in 2017-2018.*

The current first order gravity network FOGN consists of 50 gravity points on accessible locations. Traditionally many of these points are locating on concrete or granite stairs in front of churches. These locations were considered to be safe from construction works of the urbanizing society. The points have been re-measured with an A10 absolute gravimeter in 2009-2010. Concrete pillars will be constructed for absolute gravity measurements at a selection of the FinnRef stations. Already today we have time series of absolute gravity measurements from 12 FinnRef stations with FG5. We intend to increase this number by six in order to study the influence of postglacial rebound to our gravity system.

6. CONCLUDING REMARKS

The Finnish Permanent GNSS network and its positioning services are operated together by two units of the National Land Survey. The Centre for ICT Services is responsible for the open services like the DGNSS-service, data transfers etc., while the research unit, Finnish Geospatial Research Institute FGI, concentrates on maintaining the reference frame and research work. Both units are working in close co-operation. The NLS project to improve NRTK services is strongly supported by the FGI with expertise and vision on future reference frames and services. In the near future the improved services will increase the possibilities of the NRTK users to obtain reliable accurate EUREF-FIN coordinates from the service that is maintained by the same organization that maintains the reference frame as well. The new densified FinnRef will bring the definitions of coordinate, height and gravity references to the same geographical location, giving a unique possibility to study phenomena that are common for all reference frames.

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BIOGRAPHICAL NOTES

Hannu Koivula is the head of the Reference Systems research group at the FGI. He received his M.Sc. (tech) degree in1994 (Helsinki University of Technology) and Lic. (tech) degree in 2007 (Aalto University), both majoring geodesy. He has 20 years of research experience in high accuracy GNSS applications and GNSS networks. He has studied the accuracy of GNSS applications and lately specialized in metrological traceability of GNSS measurements.

Antti Laaksonen received his Bachelor of Engineering in Telecommunications in 2011 from Lahti University of Applied Sciences. He has worked as an ICT Specialist at the Centre of ICT Services at the National Land Survey since 2015, before that in the Finnish Geospatial Research Institute since 2014. Currently his main responsibility is in development and maintenance of Finland's Positioning Service and FinnRef network. He also works as the hosting entity manager for Finland's EGNOS RIMS ground station. He is specialized in telecommunications and information technology architecture and is currently studying for a Master's degree in Business Informatics at Metropolia University of Applied Sciences.

Sonja Lahtinen is a research scientist at the Finnish Geospatial Research Institute (FGI), National Land Survey of Finland. She received her M.Sc. (Tech.) degree from Helsinki University of Technology, Finland, in 2009. She has been analysing the FinnRef data for the maintenance of national coordinate systems as well as operating the FinnRef positioning services.

Jaakko Kuokkanen received his Master of Science degree (Geodesy) in 2012 from Aalto University. He has worked as a Research Scientist at the Department of Geodesy and Geodynamics in the Finnish Geospatial Research Institute since 2011. He is specialized in Real Time Kinematic GNSS measurements and GNSS reference station networks.

Simo Marila received his Master of Science degree in 2011 from Aalto University, Finland. His main subject was geodesy. He works now as a Research Scientist at the Department of Geodesy and Geodynamics in the Finnish Geospatial Research Institute. He was involved in renewing the Finnish permanent GNSS network (called FinnRef) and his recent research work has been mainly related to the reliability and accuracy of GNSS positioning.

CONTACTS

Hannu Koivula[1], Antti Laaksonen[2], Sonja Lahtinen[1], Simo Marila[1], Jaakko Kuokkanen[1]
National Land Survey of Finland
[1]Finnish Geospatial Research Institute
[2]Centre for ICT Cervices
Geodeetinrinne 2
FI-02430 Masala
FINLAND
Email: firstname.lastname@maanmittauslaitos.fi