2023-06-12
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NATIONAL REPORT

National Report of Sweden to the EUREF 2023 Symposium

– Geodetic Activities at Lantmäteriet

1. Introduction

Lantmäteriet, the Swedish mapping, cadastral and land registration authority, is responsible for the national geodetic infrastructure. The work is based on the geodetic strategic plan (Lantmäteriet, 2018) and some of the main activities in the field of geodetic reference frames are

- the operation and development of SWEPOS™, the Swedish national network of permanent reference stations for GNSS, as well as SWEPOS-based services,
- contributions of SWEPOS data to international initiatives such as EPN, EPOS and IGS as well as international analyses of GNSS data,
- the implementation and sustainability of the Swedish national reference frame SWEREF 99 and the national height system RH 2000 (ETRS89 and EVRS realisations respectively), and
- improvements of Swedish geoid models.

2. Contributions from Lantmäteriet to EPN

The number of SWEPOS stations included in EPN is 28. Seven of the original SWEPOS stations have been included since the very beginning of EPN. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0).

The other 21 stations are represented by an additional monument located at the original SWEPOS stations. The latest one, SPT7 in Borås, was included in EPN in June 2022. Daily and hourly data are delivered for all stations, while real-time data are delivered from 13 stations.

Lantmäteriet operates the NKG EPN AC on behalf of the Nordic Geodetic Commission (NKG). The NKG AC contributes with final weekly and daily solutions, as well as rapid daily solutions, using the Bernese GNSS Software. The EPN sub-network processed by the NKG AC consists of 104 reference stations (May 2023) concentrated to northern Europe.

During the last months, the efforts have been put into the switch to IGS20 and Bernese GNSS Software version 5.4. The deliveries of final daily and weekly solutions are back to normal schedule since April, after the exchange of software. The rapid daily solutions were switched to version 5.4 of the Bernese GNSS Software from GPS week 2259 (23 April, 2023).

Lantmäteriet is leading the EPN Deformation Models working group and has computed and published the first EUREF velocity model EuVeM2022; see section 10.

3. EPN-related GNSS Analysis

The NKG GNSS Analysis Centre (Nordic Geodetic Commission, 2023) was chaired by Lantmäteriet until May 2022, when the responsibility was taken over by the Finnish Geospatial Research Institute. The project aims at a dense velocity field in the Nordic and Baltic area. Consistent and combined solutions are produced based on national processing using the Bernese GNSS Software, following the EPN analysis guidelines.

A second reprocessing of the full NKG network including all Nordic and Baltic countries is under planning and will be consistent with EPN Repro3. The weekly solutions from the earlier reprocessing (Lahtinen et al., 2019) and the continued operational solutions has contributed to the EPN densification project until late 2022. Preparations for the switch to IGS20 and Bernese GNSS Software version 5.4 are now ongoing, and contributions will be resumed as soon as the switch is completed.

Lantmäteriet is one of the analysis centres in E-GVAP, as the Nordic GNSS Analysis Centre, performing data processing for approximately 750 GNSS stations mainly in Sweden, Finland, Norway and Denmark (Lindskog et al., 2017). Since October 2022, 29 stations from Estonia were also included. Two near real-time (NRT) ZTD products, i.e., NGA1 and NGA2, are currently provided. Both products are obtained from the Bernese GNSS Software version 5.2 using a network solution. The NGA1 product is updated every hour while the NGA2 product is updated every 15 minutes. Due to the limited access to real-time data, the NGA2 product is currently only provided for all Swedish stations, 3 Norwegian and 18 Finnish stations.

We have calculated a cumulative solution including almost all SWEPOS stations. This solution was done with the CATREF software and is based on weekly solutions for the SWEPOS network 2005–2022. It includes 646 stations. For this work, an algorithm for detection of breaks and outliers in the time series was developed. The solution contains estimated positions, velocities, and annual variations for all stations. When comparing the velocities to the NKG_RF17 velocity model (Häkli et al., 2019; Häkli et al, 2023), we find a good agreement for most stations. Larger differences were only found at stations with known local motions, e.g., due to mining.

We have also implemented and investigated a method called global alignment. For a regional solution, e.g., the EPN solution, the accuracy of the estimated coordinates can be lower at the edges of the region. This is especially true if there are no datum stations close to an edge. One possible solution to this issue is to combine the regional solution with a global one, thus allowing the datum to be realised with stations over a larger area, perhaps even globally. We have tested the method by aligning the NKG EPN solutions to the CODE global solution and found that the method works well.

4. SWEPOS – the National Network of Permanent Reference Stations for GNSS

SWEPOS is the Swedish national network of permanent GNSS stations operated by Lantmäteriet; see the SWEPOS website.

The purposes of SWEPOS are

- providing single- and dual-frequency data for relative GNSS measurements,
- providing DGNSS corrections and RTK data for distribution to real-time users,
- acting as the continuously monitored foundation of SWEREF 99,
- providing data for geophysical research and for meteorological applications,
- monitoring the integrity of the GNSS systems.

By May 2023 SWEPOS consisted of totally 479 stations, of which 58 are of a higher class, the so-called class A, and the remaining 421 stations are of class B, see Figure 1. This means that five class A stations and 15 class B stations have been established since the EUREF Symposium in 2022. The main purposes of the newly established stations are positioning solutions for large-scale construction projects and monitoring of ground deformation in the vicinity of mines.

Figure 1: Sveg is one of the SWEPOS class A stations. It has an old monument (established in 1993) as well as an additional monument (2011). Right: Gustavsberg is a SWEPOS class B station with a roof mounted GNSS antenna established mainly for network RTK purposes.

The class A stations are monumented on bedrock and have redundant equipment for GNSS observations, communications, power supply etc. Class B stations are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as the class A stations (dual-frequency multi-GNSS receivers with choke ring antennas), but with somewhat less redundancy.

Five of the original 21 SWEPOS stations (Onsala, Mårtsbo, Visby, Borås and Kiruna) are included in the IGS network, as well as three of the additional monuments with newer steel grid masts (ONS1, MAR7 and KIR8).

4.1 Exchange of Antennas of the SWEPOS Fundamental Stations

Between 1992 and 1996, 21 fundamental stations were established in the SWEPOS network. These pillars have been used as the carrier of the Swedish national reference frame (SWEREF 99) since then. The pillars were originally equipped with Dorne Margolin choke ring antennas, of either Allen Osborne (AOAD) or Ashtech manufacture.

To modernise the network, truss masts were established at the same sites between 2011 and 2012. The masts were equipped with modern and individually calibrated Leica 3D choke ring antennas with belonging radomes (LEIAR25.R3, LEIT). These were capable of tracking all new GNSS signals. The goal was to switch the carrier of SWEREF 99 from the pillar-based to the mast-based network after some years, but this has still not been implemented.

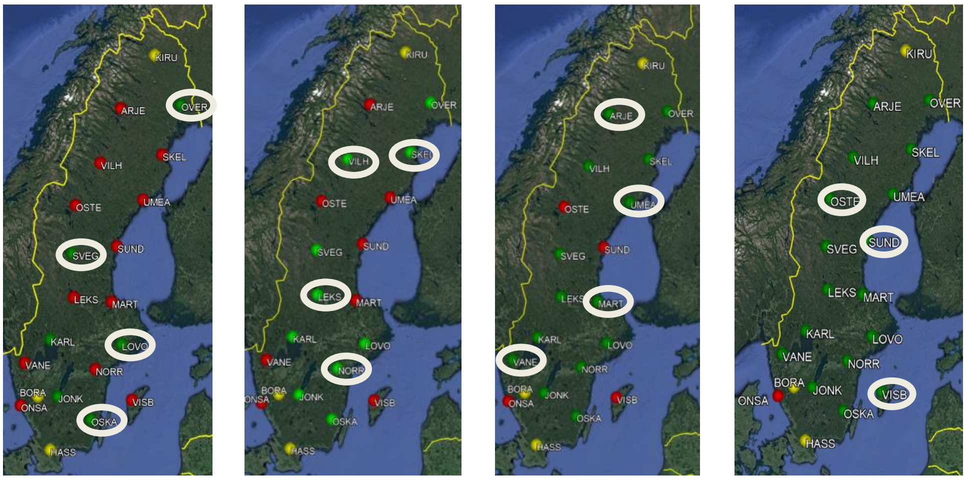
In 2021 we started to exchange antennas at some pillar stations, even though they were still working. In 2021 the use of individually calibrated antennas was highly recommended by EPN. Many of the antennas at the SWEPOS pillars were pretty old and most of them were not individually calibrated. Eight of the 21 antennas (the Ashtech antennas) could not track all signals (e.g., GPS L5 and Galileo). Another eight antennas (the AOAD antennas) were more sensitive to noise compared to modern antennas.

Therefore, in order to calibrate the old antennas at the other stations, before they stopped working, we decided to exchange the antennas in a more structured way. (Lilje et al., 2023a)

We wanted to change to individually multi-GNSS calibrated antennas. We decided to use antennas we already had, which were some Javad antennas (mainly JAVRINGANT_DM), which were sent for calibration.

We decided not to change more than four antennas at the same time, and these four antennas should be well distributed all over Sweden (see Figure 2). The plan was to do the final exchanges in spring 2023 but these exchanges have been postponed until autumn this year.

Figure 2: Antenna exchanges from left to right: autumn 2021, spring 2022, autumn 2022 and spring/autumn 2023.



When the masts at the SWEPOS fundamental stations were installed in 2011–2012, the idea was to switch from the pillar-based network to the mast-based network (to more modern and calibrated antennas), but we experienced some problems with the masts, e.g., lower rates of resolved integer ambiguities for the mast-based network compared to the pillar-based network. We have also had lichen growing on the Leica radomes (see Figure 3) and snow accumulates easier on the Leica radomes than on our OSOD radomes.

Figure 3: Radome with lichen.

Figure 4: LEIAR25.R3 antenna.

In the autumn 2022 we started to think about what we could do to resolve some of the problems with the masts, which all are EPN stations. In autumn 2022 the use of individually calibrated antennas was not required any longer for EPN stations, but type mean calibrations are needed.

To reduce snow accumulation and growing lichen we decided to change to OSOS radomes, but no type calibrations existed for the combination of LEIAR25 and OSOS.

To obtain a type mean calibration we decided to send five LEIAR25.R3/ OSOS antennas and radomes for calibration. Therefore we had to exchange antennas at three stations, since we only had two spare antennas available. After receiving the type mean calibration the idea was to exchange just the radomes at the other stations. But – meanwhile we have developed and tested an antenna heater, with very promising results. (Lilje et al., 2023b)

Therefore we now consider changing to other antennas (TPSCR.G5) with attached antenna heaters at some of the northern stations (north of Leksand and Mårtsbo/Gävle).

5. SWEPOS Services

SWEPOS provides real-time services of metre-level uncertainty (DGNSS) and centimetre-level uncertainty (Network RTK), as well as data for post-processing in RINEX format. An automated post-processing service, based on the Bernese GNSS Software, is also available.

Good coverage of the Network RTK service has been obtained in border areas and along the coasts through exchange of data from permanent GNSS stations between the Nordic countries. Several stations operated by the Norwegian Mapping Authority and the Danish Agency for Data Supply and Infrastructure are included in the service together with stations from private operators in Norway, Denmark, and Finland as well as Sweden.

The Network RTK service has, in June 2023, approximately 9800 subscriptions, which means some 1700 additional users since the EUREF Symposium in 2022. Lantmäteriet also has cooperation agreements with seven international GNSS service providers using data from SWEPOS stations for their services. This is done to increase the use of SWEPOS data as well as optimising the benefits of the geodetic infrastructure.

The real-time services utilise Trimble Pivot Platform GNSS Infrastructure Software and are operating in virtual reference station mode. The Network RTK service distributes data for GPS, Glonass and Galileo as well as GPS L5 and L2C signals using RTCM MSM. The plan is to include BeiDou during 2023.

5.1 Development of an Updated SWEPOS Post-processing Service

SWEPOS offers an online GNSS Post Processing Service, which calculates precise coordinates in the SWEREF 99 national reference frame. This service uses static GNSS data to calculate double-differenced coordinates for a single user point, using data from nearby SWEPOS stations. The service was initially developed in 2000 and was updated in 2015. However, a recent feasibility study identified some limitations with the current service. For example, it relies on outdated RINEX 2 version and uses old third-party software like TEQC (Estey & Meertens, 1999). The study also highlighted the need for improvements, such as support for RINEX 3, an easier-to-develop application, and better error handling to reduce the support workload. As a result, a new GNSS Post Processing Service is being built from scratch. Once released, it will support all RINEX versions from 2.x to 4.x. In addition to the existing services provided by the current system, including a nationwide service based on SWEPOS reference stations and project-adapted services for large infrastructure projects, the new service will offer additional features. These features include the ability to order a comprehensive RINEX data quality control report, improved validation of user provided RINEX files, more detailed reporting, support for multi-GNSS, and improved reference network selection based on geometry. The new service is being developed with the latest software technology and architecture, using a modular structure and an improved error handling system. Data quality checking within the new service will be using an in-house QC software called SWEPOSQC and G-Nut/Anubis (Vaclavovic & Dousa, 2016). Coordinate calculations will make use of the Bernese GNSS Software version 5.4.

5.2 Development of Swepos data Quality Monitoring

SWEPOS performs various activities to ensure the quality and reliability of GNSS data. This includes continuous monitoring of data quality and station coordinates in near real-time, daily, and long-term. As part of these efforts, SWEPOS has developed a system to check the quality of data in near real-time and detect any disturbances in the GNSS signals that may be caused by various sources (Abraha et al., 2023). By doing this, SWEPOS can identify any unusual or problematic patterns that may affect the quality of the data. This system uses hourly RINEX files and monitors the signal levels of GPS, GLONASS, Galileo, and BeiDou frequencies. If a disturbance is detected, a disturbance status map is generated, and an alert is sent to a dedicated team within SWEPOS to further investigate the issue and find a solution. This system has proven successful in identifying critical disturbances at several SWEPOS stations.

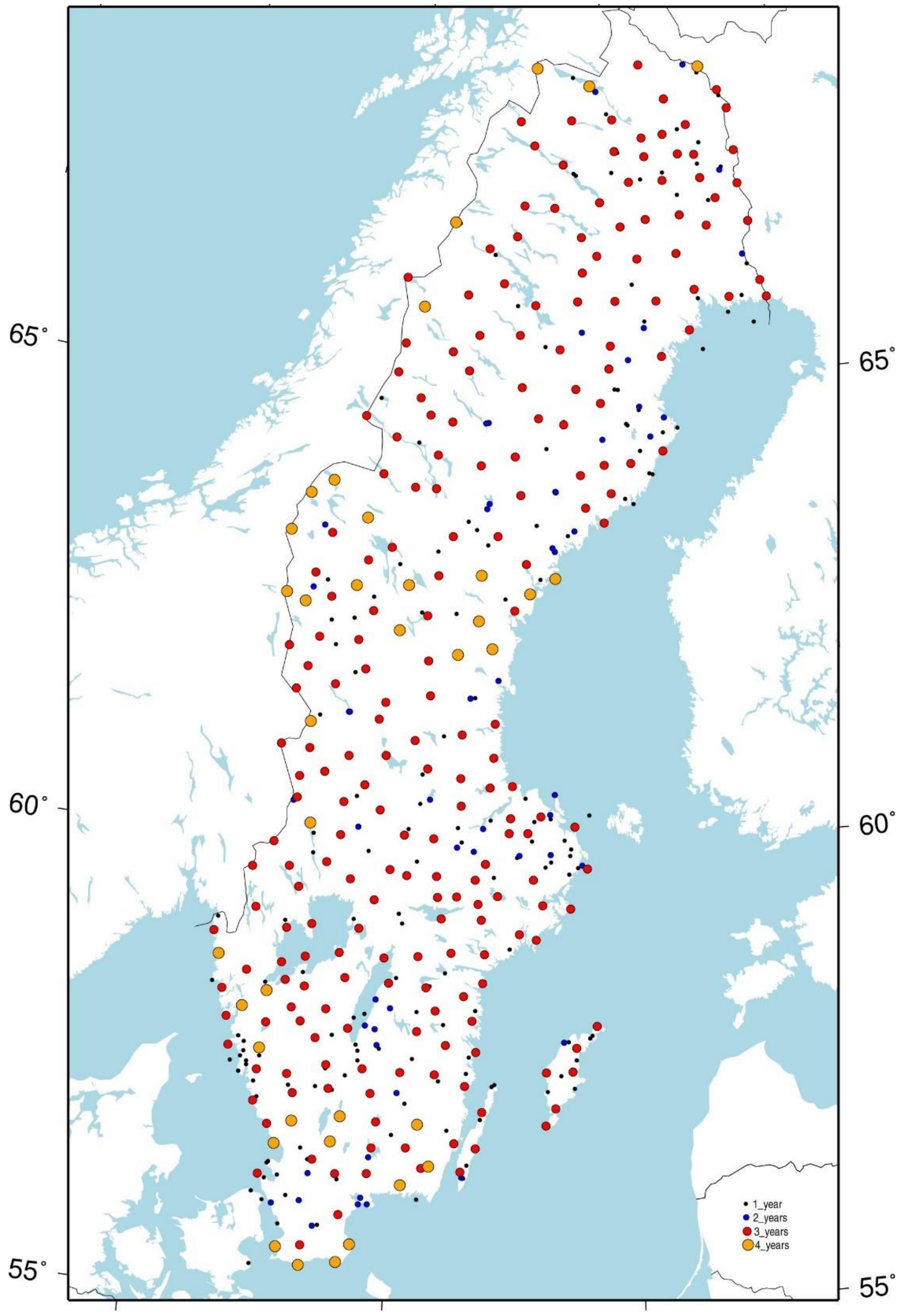
6. Reference Frame Management – SWEREF 99

SWEREF 99 was adopted by EUREF as the Swedish realisation of ETRS89 in 2000 (Jivall & Lidberg, 2000) and is used as the national geodetic reference frame since 2007. SWEREF 99 is defined using SWEPOS class A stations (see chapter 4) and equivalent stations in our neighbouring countries.

By defining SWEREF 99 by active reference stations we are exposed to rely on the positioning services of SWEPOS, like the Network RTK service. All alterations of equipment and software as well as movements at the reference stations will in the end affect the coordinates.

To be able to check all these alterations, approximately 300 nationally distributed passive so-called consolidation points (SWEREF 99 class 1) are used. Each year, 50 of them are remeasured with static GNSS following a yearly programme. A first aggregate analysis of the repeated measurements (24-hour observation sessions) has been conducted with the Bernese and GAMIT-GLOBK software packages (Jivall et al., 2022) (see Figure 5). The results shows that the SWEREF 99 coordinate determination is stable on the level of about 2 mm for the horizontal components and 6 mm in height (with 2×24 hours of observation), regardless of whether the original processing with different models in different time periods or results from a consistent reprocessing is used. About 10% of the points show significant trends, but we should be aware that the redundancy is very low with mainly just three observations.

Figure 5: Distribution of the SWEREF 99 class 1/consolidation points and number of measurements visualised by different size of coloured circles, for the period 1993–2020.



7. Maintenance of the National Levelling Network

The third precise levelling of the mainland of Sweden lasted 1979–2003, resulting in the new national height system RH 2000 in 2005 (Ågren et al., 2007).

Our assessment is that RH 2000 will be the national height system for many years to come and that it will be based on levelling. The reason is that the precision of height determination with GNSS (height above the ellipsoid) is not as accurate as the levelling technique. Therefore, the maintenance of the height control network needs to be continued for the foreseeable future.

Since the beginning of the 1990s, a systematic inventory and updating of the network is performed continuously. All benchmarks are visited but since benchmarks founded in bedrock and nodal points are more valuable for the perseverance of the network, destroyed points are replaced according to specific criteria. This approach ensures that a sufficient number of destroyed benchmarks are replaced, securing the sustainability of the network and at the same time keeping costs down.

When new height benchmarks are demarcated to replace destroyed benchmarks, the levelling of them is done through procurement procedures, which is also the situation for the re-measurements of the 300 consolidation points described in chapter 6.

This year we have started the planning of production tests of a fully digitised benchmark inventory process. The aim is to make the process more efficient by removing many of the analogue tasks and reduce the amount of paperwork such as printing benchmark descriptions and field maps.

8. Geoid Determination

According to Lantmäteriet's strategic plan (Lantmäteriet, 2018), an important goal is to compute a seamless geoid model of high accuracy that fulfils the needs of users both on land and at sea. The current Swedish national geoid model is SWEN17_RH2000, which has been computed by combining the Nordic NKG2015 gravimetric model with Swedish GNSS/levelling data.

Many activities are going on to improve the Swedish geoid model. The new gravity reference system/frame RG 2000 (see further chapter 9) was finalised in 2019. New Swedish detail gravity observations are continuously being collected using Scintrex CG5 to fill gaps or replace old data of lower quality. In 2022, the second largest lake in Sweden, Vättern, was measured with our marine gravimeter.

Lantmäteriet has also contributed with gravity observations and gravimetric geoid modelling to the BSCD2000 (Baltic Sea Chart Datum 2000, Schwabe et al., 2020). This will improve navigation and hydrographic surveying with GNSS-based methods and geoid model in the Baltic Sea. The geoid model will realise BSCD2000 in the Baltic Sea and connect to the national EVRS realisations on land. This work is now finalised under the umbrella of the Chart Datum Working Group of the Baltic Sea Hydrographic Commission.

In the last years, much work has been spent on improving and densifying the Swedish national GNSS/levelling dataset. The number of stations will increase from 185 to around 300 in 2023. The core of the new, updated dataset is the so-called SWEREF 99 class 1 points for which accurate levelled heights are available in RH 2000. A majority of these SWEREF 99 class 1 points are consolidation points that are redetermined every six years (see chapter 6). This makes it possible to detect and remove unstable points. Since 2019, the levelled normal heights of the GNSS/levelling points are also checked by relevelling relative to benchmarks in the national precise levelling network. During 2022, 29 points were checked.

The Swedish national GNSS/levelling dataset, consisting of 185 stations, was delivered in 2022 to the EUREF working group "European Unified Height Reference" and the ongoing work with the European Height Reference Surface, EHRS.

In 2020, an industrial PhD student was initiated at the University of Gävle in cooperation with Lantmäteriet. The main aim of this PhD project is to develop and investigate different methods for regional realisation of the International Height Reference System (IHRS) in Sweden and the Nordic/Baltic countries.

9. Gravity Activities

In Sweden 14 stations are revisited with Lantmäteriet's absolute gravimeter, FG5X-233, with an interval of approximately one to three years. Since 2007, FGX-233 also regularly participates in local, regional and international absolute gravity (AG) intercomparisons to keep track of possible biases.

In 2022, Lantmäteriet arranged, together with Onsala Space Observatory and the Finnish Geospatial Institute, an AG intercomparison at Onsala Space Observatory as a mission from the NKG. The intercomparison took place between May and July and gathered 15 different instruments of which 13 gave good results. The report is in preparation.

In autumn 2023, Lantmäteriet will participate in ICAG-2023, the international comparison for absolute gravimeters in Table Mountains, USA.

All Swedish absolute gravity stations for FG5 (also known as Class A points in the Swedish gravity reference frame RG 2000) are co-located with SWEPOS stations. Ratan, Skellefteå, Smögen, Visby and Onsala are furthermore co-located with tide gauges. Onsala is also co-located with VLBI telescopes and a superconducting gravimeter, which is annually calibrated with FG5X-233 AG observations.

Since 2021, all Lantmäteriet's detail gravity observations have got a gravity value in RG 2000, the new Swedish gravity reference frame (Engfeldt et al., 2019; Engfeldt, 2019), regardless of which origin the observations had. The quality of the older detail gravity observations is under investigation and more detail gravity observations will be performed during this year and the upcoming years where it is needed.

Lantmäteriet is also participating in the BalMarGrav project, co-funded by the European Union. The aim of this project is to improve the marine gravity data in the south-eastern part of the Baltic Sea. Our contribution in this project is to conduct a marine gravity campaign in Latvian waters together with the Latvian Geospatial Information Agency, the Latvian Coast Guard and Riga Technical University.

10. Geodynamics

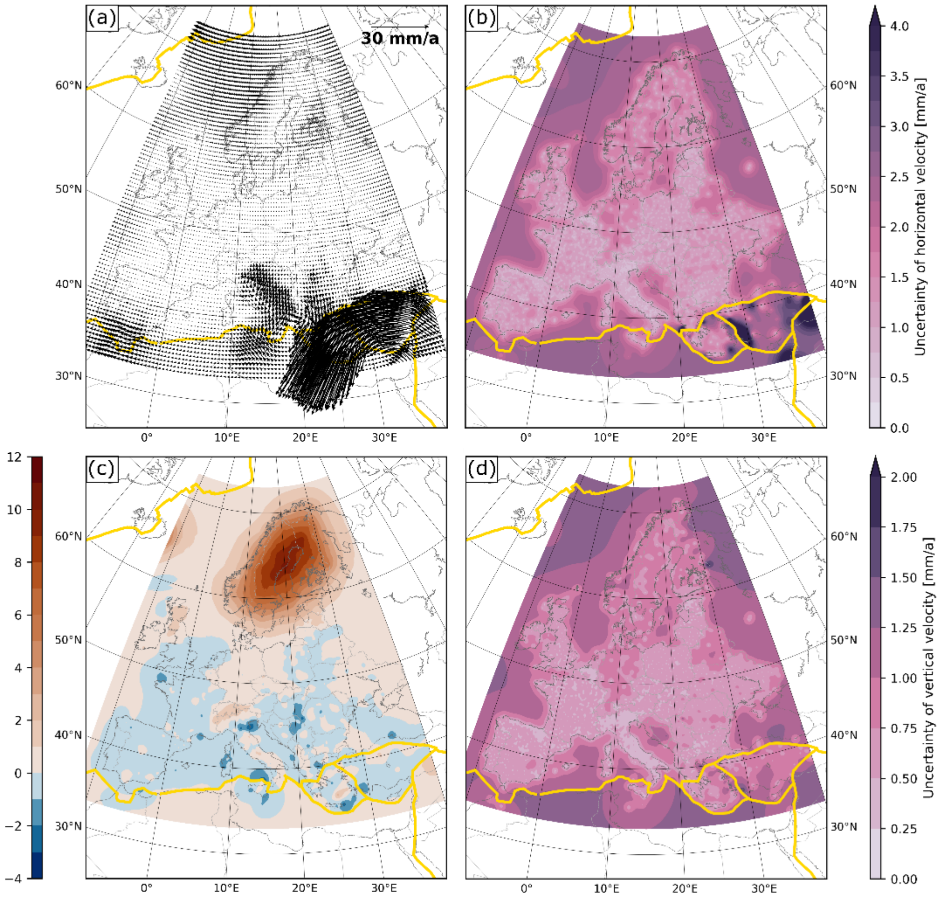
Studies of crustal deformation in Fennoscandia by means of continuous GNSS observations have been carried out within the BIFROST effort since more than three decades (Kierulf et al., 2021). The current BIFROST2022 reprocessing of GNSS data, a cooperation of NKG members and Poland, has commenced which will largely extend the number of stations (several 100s) and observation time span (1 January 2000 – 31 December 2022). Next to many planned processing related studies (e.g., software comparison, analysis of snow cover and non-tidal loading effects), the results will be used in the generation of revised official NKG land uplift and deformation models for northern and central Europe.

Lantmäteriet is involved in the EUREF effort on obtaining a high-resolution velocity model for Europe and adjacent areas. The first official EUREF velocity model EuVeM2022 (see Figure 6 below) using the densified EPND2150 velocity field, based on a new least-squares collocation method with moving variance and taking plate boundaries into account (Steffen et al. 2022), is officially released during the EUREF 2023 Symposium. The model is a high-resolution grid (0.1×0.1 degrees) providing uncertainties for each grid point. It is available in different formats and reference frames.

Lantmäteriet contributes to EPOS and is member of the Swedish consortium EPOS-Sweden, which is an infrastructure project supported by the Swedish Research Council. The generation of the strain-rate product has become Lantmäteriet's responsibility within EPOS (Fernandes et al., 2022). Lantmäteriet has meanwhile produced the second strain-rate grid for Europe (Lantmäteriet, 2023) which can be downloaded from the EPOS Data Portal.

Lantmäteriet further contributes with GIA modelling studies and data in different fields. Latest studies include the time-varying uplift in Svalbard (Kierulf et al., 2022), sea-level rise in Denmark (Colgan et al., 2022), glacially triggered earthquakes in north-eastern Germany (Pisarska-Jamroży et al., 2022), a new model for post-seismic deformation modelling (Nield et al., 2022), crustal structures in various places of Africa derived with gravimetry (Ghomsi et al., 2022a,b) and the determination of terrestrial water storage changes in the Tibetan Plateau (Xiang et al., 2022).

Figure 6: EuVeM2022 based on EPND2150 velocity field solution. Horizontal velocity field (a) in ETRF2000 and its associated uncertainties (b). Vertical velocity model (c) in IGS14 and its associated uncertainties in (d). Yellow lines in each subfigure show plate boundaries based on Bird (2003). The model can be downloaded from https://www.lantmateriet.se/geodata/geodesi/.



11. InSAR

The InSAR Sweden project which was the implementation of a nationwide ground motion service (GMS) for Sweden (2020–2022) was finished and the service is online now and publicly available via the web-based GMS service. The project was coordinated by the Swedish National Space Agency and is the result of processing of seven years of Sentinel-1 data acquired between 2015–2022) over Sweden. The service visualises the localisation of deformation in different parts of Sweden and includes the time series of displacements for ~1.5 billion measurement points. During the project and afterwards, Lantmäteriet contributed to the validation of the results and installation of radar corner reflectors co-located with SWEPOS stations to complement the geodetic infrastructure of Sweden with at least 20 passive corner reflectors. So far, different designs of the reflectors have been examined and 14 reflectors have been installed in different locations (see Figure 7). There is a preliminary technical report for the validation activity and installation of the corner reflectors by Nilfouroushan et al. (2023). The updated map and table for installations of the corner reflectors are shown below.

Figure 7: Left: The photos show the double back flipped squared type of corner reflectors installed in Sveg (top) and Östersund (bottom). Right: The map shows the locations of the electronic corner reflectors (ECR) and passive reflectors (CR) which are co-located with permanent GNSS stations.

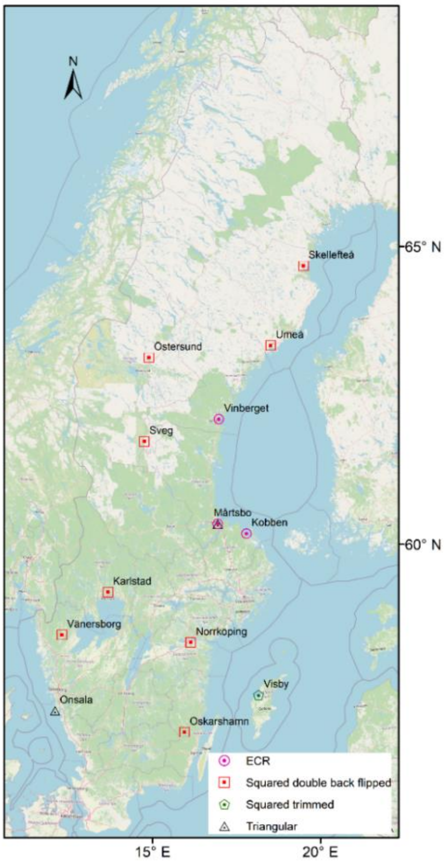


Table 1: Installed corner reflectors and transponders (ECRs) in different locations in Sweden (coordinates are given in SWEREF 99).

ID	Latitude	Longitude	Location	Passive/ Active	Date of Installation	Type	Orientation
ECR01	60.5951	17.2585	Mårtsbo	Active	7-Jan-2020	Electronic transponder	Asc and Desc
ECR02	60.4099	18.2303	Kobben	Active	1-Jun-2020	Electronic transponder	Asc and Desc
ECR03	62.3739	17.4279	Vinberget	Active	1-Oct-2020	Electronic transponder	Asc and Desc
CR01	57.3949	11.922	Onsala	Passive	1-Jun-2021	Triangular	Asc
CR02	57.395	11.9222	Onsala	Passive	10-Sep-2021	Triangular	Desc
CR03	60.5946	17.2596	Mårtsbo	Passive	14-Sep-2021	Triangular	Asc
CR04	58.59	16.2451	Norrköping	Passive	4-Nov-2021	Double back flipped squared	Asc and Desc
CR05	57.654	18.3671	Visby	Passive	11-May-2022	Squared trimmed	Desc
CR06	57.654	18.3671	Visby	Passive	11-May-2022	Squared trimmed	Asc
CR07	62.0173	14.7	Sveg	Passive	14-Jun-2022	Double back flipped squared	Asc and Desc
CR08	63.4427	14.8579	Östersund	Passive	1-Sep-2022	Double back flipped squared	Asc and Desc
CR09	63.5781	19.5096	Umeå	Passive	21-Oct-2022	Double back flipped squared	Asc and Desc
CR10	64.8792	21.0485	Skellefteå	Passive	23-Oct-2022	Double back flipped squared	Asc and Desc

ID	Latitude	Longitude	Location	Passive/ Active	Date of Installation	Type	Orientation
CR11	59.4441	13.5056	Karlstad	Passive	10-May-2023	Double back flipped squared	Asc and Desc
CR12	58.6931	12.035	Vänersborg	Passive	12-May-2023	Double back flipped squared	Asc and Desc
CR13	57.0656	15.9968	Oskarshamn	Passive	13-May-2023	Double back flipped squared	Asc and Desc

12. Other Activities

12.1 Guidelines for Mapping and Surveying

The regulatory documents for Lantmäteriet states that one of its responsibilities is to contribute to efficient and standardised surveying and mapping in Sweden. One of the means to accomplish this is through a series of best practice guidelines called HMK (a Swedish acronym roughly translated as "Guidelines for mapping and surveying").

HMK covers a wide variety of methods for geodata capture (e.g., laser scanning, aerial photography, geodetic surveying), and includes recommendations for professional surveyors as well as potential clients that need to specify such services.

The HMK guidelines are reviewed by a stakeholder reference group on an annual basis and are published as new versions in case of major revisions. As of 2023, geodesy and geodetic applications were covered in the following HMK guidelines:

- Geodetic infrastructure in Sweden
- Control surveying
- Terrestrial detail surveying
- GNSS/RTK detail surveying
- Terrestrial laserscanning
- Survey markers

All HMK guidelines are published online, free of charge. The guidelines are also supplemented by online self-study courses and technical literature that cover topics related to HMK more in-depth.

12.2 "Reference Network in the Air"

The project "Reference Network in the Air" (in Swedish: Stomnät i luften 2.0) is a research and innovation project initiated by the Swedish Transport Administration and is based on earlier research concerning positioning systems for large-scale construction projects (Trafikverket, 2011). The aim of this project is, through 13 sub-activities, to secure that the Swedish Transport Administration uses a modern, robust and future-proof geodetic infrastructure for positioning based on GNSS technique.

Lantmäteriet is, together with the KTH Royal Institute of Technology and RISE Research Institutes of Sweden, a major partner of this project and involved in most of the activities. The Swedish Transport Administration is also contributing.

The project started in 2019 and was finished in the end of 2022. The project reports will be published in mid-2023.

12.3 Monitoring of EGNOS

Lantmäteriet is one of the partners in the EGNOS Service Performance Monitoring Support (SPMS) project and participates in the work package of local position performance assessment. Lantmäteriet's objective is to monitor the position obtained by SWEPOS class A stations in Överkalix and Visby using EGNOS corrections. The safety of life analysis of the data is done by Lantmäteriet. At the end of each quarter, we perform the following tasks:

- Daily monitoring and assessment of the availability of the data and the processing.
- Quality check and analysis of the results.
- Prepare quarterly reports.

The SPMS project was successfully finished in September 2022. The proposal to a new project, named as Galileo and EGNOS Monitoring of Performances (GEMOP), has been granted by EUSPA. Lantmäteriet will continuously participate in GEMOP project undertaking the same tasks. The new project is expected to start in July 2023.

12.4 DINPAS

DINPAS – Digital Infrastructure Enabling Accurate Positioning for Autonomous Systems – is an R&D project funded by Vinnova, Sweden's innovation agency. The aim of the DINPAS project is to evaluate the requirements of future autonomous airports in terms of reliable, precise positioning as well as scalability to large numbers of devices, to benefit the next generation of industrial digital solutions. The targeted implementation, including software for generating corrections, 3GPP-based delivery, and navigation device, will be used for evaluating relevant performance.

Lantmäteriet's contribution to the project comprises implementing a new software for generation of GNSS corrections based on the State Space Representation (SSR) technique, which was completed during spring 2023. The SSR corrections are based on data from the SWEPOS stations, and different configurations of reference stations as input for generation of corrections are under investigation. Positioning with the SSR technique is also evaluated and compared to OSR (Observation Space Representation) in both static and dynamic conditions. In the dynamic tests, a total station, positioned relative to a local reference network, is used for tracking a moving drone equipped with a prism. The position from the GNSS receiver on board the drone is then compared to the position obtained from the total station measurements.

The project started in October 2021 and will run until September 2023. Involved partners are RISE, AstaZero, Combitech, Ericsson, IBG, Katla Aero, Lantmäteriet, Telia and u-blox.

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Acronyms and Abbreviations

Table 2: Explanations of acronyms and abbreviations used in the report, in alphabetical order.

Acronym or abbreviation	Explanation
3GPP	3rd Generation Partnership Project
AC	Analysis Centre
AG	Absolute Gravity
BIFROST	Baseline Inferences for Fennoscandian Rebound Observations Sea level and Tectonics
BSCD	Baltic Sea Chart Datum
CODE	Centre for Orbit Determination in Europe
CR	Corner Reflector
DGNSS	Differential GNSS
DINPAS	Digital Infrastructure Enabling Accurate Positioning for Autonomous Systems
ECR	Electronic Corner Reflector
E-GVAP	The EUMETNET GNSS water vapour programme
EGNOS	European Geostationary Navigation Overlay Service
EHRS	European Height Reference Surface
EPN	EUREF Permanent GNSS Network
EPND	EPN Densification
EPOS	European Plate Observing System
EPOS-SP	EPOS Sustainability Phase
ETRS	European Terrestrial Reference System
EUSPA	European Union Agency for the Space Programme
EVRS	European Vertical Reference System
FAMOS	Finalising Surveys for the Baltic Motorways of the Sea
GEMOP	Galileo and EGNOS Monitoring of Performances
GIA	Glacial Isostatic Adjustment
GMS	Ground Motion Service

Acronym or abbreviation	**Explanation**
GNSS	Global Navigation Satellite Systems
GPS	Global Navigation System
HMK	Guidelines for mapping and surveying (Swedish: *Handbok i mät- och kartfrågor*)
IBG	Independent Business Group
ICAG	International Comparison of Absolute Gravimeters
IGS	International GNSS Service
IHRS	International Height Reference System
InSAR	Interferometric Synthetic Aperture Radar
KTH	Royal Institute of technology (Swedish: *Kungliga Tekniska högskolan*)
MSM	Multiple Signal Message
NGAA	Nordic GNSS Analysis Centre [for E-GVAP]
NKG	Nordic Geodetic Commission (Swedish: *Nordiska kommissionen för geodesi*)
NRT	Near Real-Time
OSR	Observation Space Representation
OSOD	Onsala Space Observatory Dome
OSOS	Onsala Space Observatory Dome, Short model
QC	Quality check
R&D	Research and Development
RINEX	Receiver Independent Exchange format
RISE	Research Institutes of Sweden
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SAR	Synthetic Aperture Radar
SPMS	Service Performance Monitoring Support
SSR	State Space Representation

Acronym or abbreviation	**Explanation**
VLBI	Very Long Baseline Interferometry
ZTD	Zenith Total Delay