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Forsmark site investigation

GPS deformation measurements in Forsmark

Annual report 2007

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Caliterra HB

May 2008

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Keywords: GPS, Deformation, AP PF 400-05-056, Forsmark.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

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Abstract

The objective is to identify possible movements in the bedrock within and outside the candidate area in Forsmark for a repository of spent nuclear fuel. Seven thermally and physically stable stations were built in the Forsmark area in the autumn of 2005. Stations were established within a 10-kilometer radius. The stations were placed in three different geologic areas: NE of the Singö zone, within the candidate area and SW of the Forsmark zone.

Stations consist of a stainless steel rod fixed in the bedrock on which the GPS antenna mounts. Each station has dedicated GPS equipment only used at that site. Sets consist of a GPS receiver collecting raw GPS data and a choke ring antenna linked to the receiver using a coaxial cable. The receivers and antennas are dual frequency high precision geodetic grade.

During each campaign the GPS receiver saves reading every second for the duration of the five days campaign. The antennas remains mounted on the stations during the entire project (3 year) while all other equipment is in place at the station only during the campaigns. The measurements will also be related to the SWEPOS network stations Lovö, Uppsala and Mårtsbo that are defined as stations with stable fundamentals by the National Land Survey of Sweden (Lantmäteriet). There will be fifteen campaigns in total. This report describes the first ten campaigns from November 2005 to October 2007.

Optimization of the data processing depends on the properties of the entire three-year data set. Our objective in this report is to establish the data quality. We divided the data in 24-hour periods with each period processed separately in the Bernese post processing software. We analyze the residuals to conclude that the data is of the expected quality. The entire three-year data set is needed to reveal any motion.

Sammanfattning

Målet med projektet är en kartering av eventuella millimetersmå rörelser i berggrunden kring SKB:s platsundersökningsområde i Forsmark. Under hösten 2005 etablerades totalt sju stationer inom en radie på 10 kilometer från platsundersökningsområdet. Stationerna placerades för att täcka tre tektoniska områden: NÖ om Singö zonen, inom kandidatområdet och SV om Forsmark zonen.

Stationerna består av en metallstav fixerad i berget på vilken en GPS-antenn sitter fastmonterad. Varje station har en egen dedicerad GPS-utrustning bestående av en GPS-mottagare och en separat choke-ring antenn. Både mottagaren och antennen är av geodetisk kvalitet.

Under varje kampanj finns utrustningen på stationen under totalt fem dygn. Utrustning sparar data varje sekund under de fem dagarna. Antennen sitter kvar på en och samma station under hela mätperioden på tre år. Resten av utrustningen placeras ut vid varje kampanj. Det lokala nätverket utökas med närbelägna SWEPOS stationer. Vi använder oss endast av SWEPOS stationer som har definierats av Lantmäteriet som stationer med stabila fundament. Dessa stationer är Lovö, Uppsala och Mårtsbo. Denna rapport behandlar de tio första kampanjerna som utfördes under perioden november 2005 till oktober 2007

Optimeringen av dataprocesseringen beror på data från hela 3-års perioden. Vårt mål med denna delrapport är att beskriva kvaliteten på data. Data delas upp i segment om 24 timmar vardera och beräknas separat från varandra i analysprogrammet Bernese. Vi analyserar residualer för att fastlägga att datat har förväntad kvalitet. Data från hela treårs perioden behövs för att kunna definiera eventuella rörelser i berggrunden.

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1 Introduction

This document reports data obtained from GPS deformation measurements in Forsmark, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-05-056. The project is carried out according to the SKB MD 133.003 (SKB, internal document).

Base stations were established in three geologically separate blocks. Geologists at SKB selected a set of possible GPS station placement areas, based on geological considerations. These were evaluated for suitability to high precision GPS measurements, and seven sites were selected within these areas accounting for GPS sky visibility, nearby manmade or natural reflectors and the ability to firmly anchor a station to the bedrock. Seven stations were built on the selected sites in August 2005 and their positions surveyed. Figure 1-1 gives an overview of station placement. Dual frequency (L1 and L2 bands) GPS code- and carrier-phase raw data were collected and evaluated for quality. The data was stored for use in the final deformation evaluations. This was repeated in ten five-day campaigns between November 2005 and October 2007. The first six campaigns are already reported in /1/.

The data was in general found to be of good quality, although during the first three campaigns data from one station may not have been as good as from the other six due to nearby vegetation. A new station was therefore built in May 2006 prior to the fourth campaign as an alternate site with better GPS sky. Data was successfully collected on all eight stations during the following campaigns. All original results are stored in the primary database Sicada and are traceable by the activity plan number.

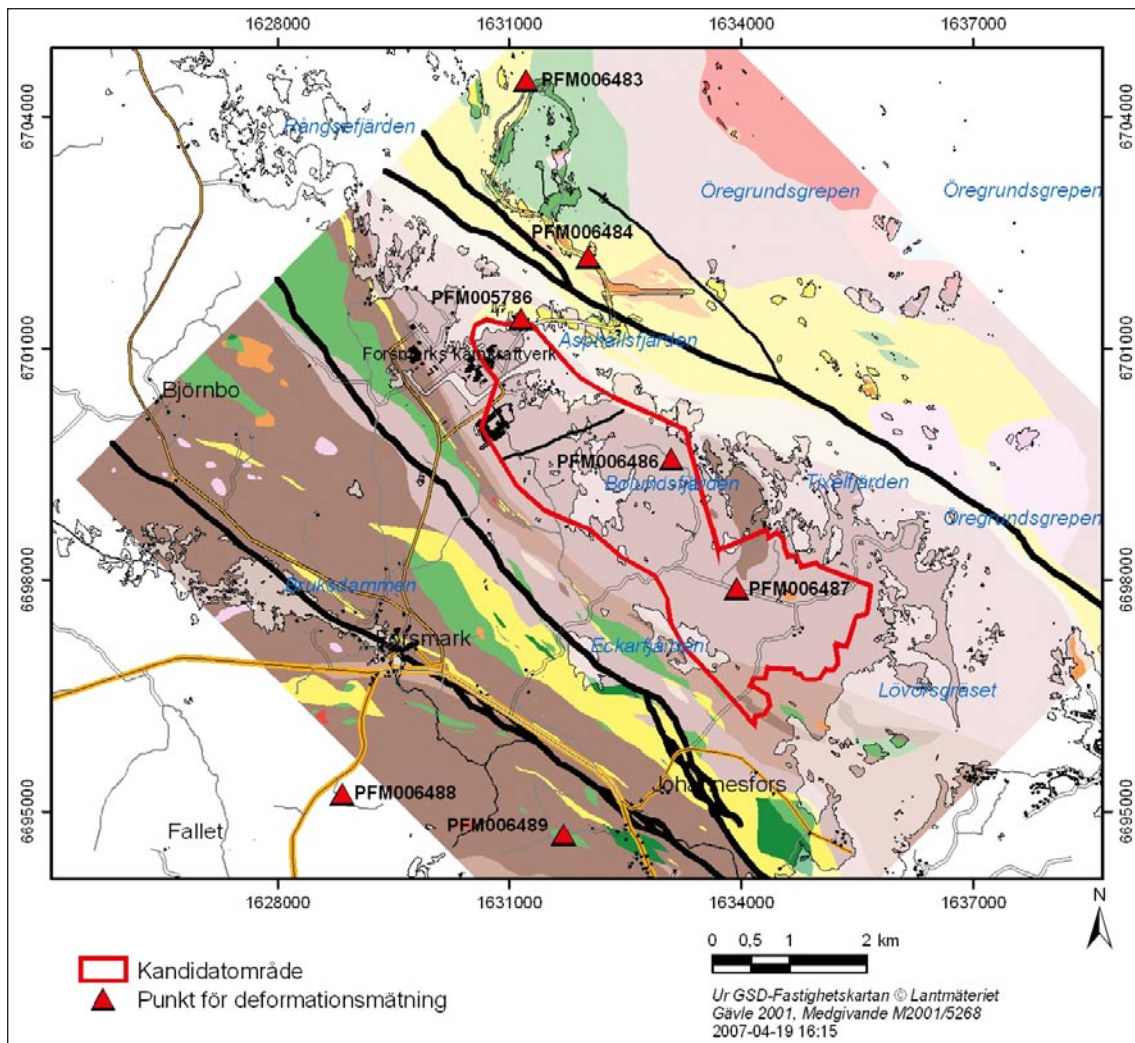


Figure 1-1. General overview over the Forsmark site investigation area with marked station locations and the candidate area outlined in red. The three stations PFM005786, PFM006486 and PFM006487 are located inside the tectonic lens in the investigation area. The stations PFM006483-PFM006484 are located NE of the Singö zone, and the stations PFM006488-PFM006489 are located SW of the Forsmark zone.

2 Objective and scope

The objective of this project is to define possible movement (exceeding approximately 1 mm/year) in the bedrock in the Forsmark area. The study focuses on the Forsmark candidate site, an adjacent area to the NE separated by the Singö zone and an area to the SW, similarly separated by the Forsmark zone. Possible motion of these geologically separated areas will be related to the larger scale motion of the surrounding area using data from existing GPS stations operated by SWEPOS¹.

¹ SWEPOS is a national network of fixed GPS reference stations, operated by the National Land Survey of Sweden (Lantmäteriet).

3 Equipment

3.1 Description of equipment/interpretation tools

The surveying equipment used in this project is a set of carrier phase dual frequency geodetic grade GPS systems capable of yielding state-of-the-art accuracy. The GPS receiver is a Toughman, manufactured by DataGrid Inc. (see Appendix 1), customized with 128 Mb extended memory and improved temperature tolerance. All receiver functions are designed to the -40°C to $+70^{\circ}\text{C}$ temperature range, thus extending the interval indicated in the spec sheet in the appendix. The antennas are choke ring GPS L1 and L2 survey grade antenna of model AT2775-43 manufactured by AeroAntenna Technology Inc. (see Figure 3-1 and Appendix 1). Each station has the antenna permanently mounted on a mechanically and thermally stable fundament. To anchor the fundament every site was drilled with an 18 mm drill bit. A 25 cm long threaded 5/8-inch diameter metal rod was inserted in the holes to a depth 15 cm. The rod height above the ground is 10 to 12 cm. A two-component anchor paste curing totally after 24 hour was used. The station fundaments were built several weeks before the antennas were permanently mounted on them. All stations are equipped with the same model and version number hardware and software combination. The receiver mounted just below the antenna (also seen in Figure 3-1) is removed for safe storage between measurements.



Figure 3-1. Sample station with choke ring antenna and GPS receiver mounted to the lower left. The station in this picture is PFM006489 but all sites have identical hardware (and firmware). They are mounted on a short steel rod anchored in the rock for good mechanical and thermal stability. However the low mounts increases the demand on the GPS environment. The antenna radome and pin are designed to protect the active components of the antenna and discourage birds and other small animals from lodging on the antenna. A second cover provides additional protection between measurement campaigns.

Each receiver is marked and will be used on its dedicated station at each campaign. Each GPS receiver is equipped with internal power regulators and conditioners and can operate for up to 8 hours using internal batteries. An external power supply consisting of a lead acid battery/solar panel combination (not shown) extends this operating time practically indefinitely. The arrangement with power accumulated in two separate systems allows for reliable operation even at times when the temperature may dip below normal operating temperature for the lead acid batteries. All equipment is dedicated to this project and is not used for any other activity for the duration of the project. The Bernese post processing software package version 5.0, an advanced software for GPS-post processing developed by the astronomical institute of the University of Bern, Switzerland, is used for all data processing. Coordinate conversions from Earth-centered Earth-fixed Cartesian coordinates to the Swedish grid RT90-RHB70 coordinates was made in two steps. From Earth-centered coordinates to WGS 84 in Geotrans V2.2.3 by the US Army Topographic Engineering center (Geospatial Information Division and National Imagery and Mapping Agency Exploitation Tools Division). From WGS 84 to RT90 2.5 G V and RHB70 the transformation is made in G-trans 3.1, upgraded in 2007 to G-trans 3.6 by Lantmäteriet.

Calibration data for the antenna make and type phase centre is part of the processing software. Antennas are fixed in place to eliminate geometric errors related to antenna orientation and centering in the displacement data, thereby eliminating a significant potential error source and the corresponding need for calibration. The GPS receivers produce phase measurements in code phase and carrier phase. Since these all refer to a single clock (the GPS TCXO or Temperature Compensated Crystal Oscillators) the GPS receivers require no calibration. The data processing double difference technique eliminates any error due to clock differences from one receiver to another so also clock drift needs no calibration.

The largest remaining errors are probably related to site conditions. GPS station sites must have clear sky in all directions to as low on the horizon as is possible. Nearby electric conductors should be avoided. More detailed site studies with data gathering for a full 24-hours period may be used as acceptance tests in questionable locations. In our study one such site passed our initial study but did not yield as good data in subsequent campaigns presumably due to changes in nearby vegetation and or soil moisture. An alternative site has been established and data were subsequently collected on the original as well as new site. Since we perform displacement measurements rather than absolute position measurements, one may consider the comparison measurements to be calibrations in the sense that remaining differences are attributable to stochastic errors such as phase noise. A measure of the displacement should therefore be retrievable using standard statistical analysis methods.

Manufacturer's data sheets are presented in Appendix 1.

4 Execution

4.1 General

Our first task was to evaluate a set of GPS station placement areas proposed by SKB for suitability as high precision GPS station sites. Station sites within the three areas proposed by SKB were selected accounting for GPS sky visibility, nearby manmade or natural reflectors and the ability to firmly anchor the station to the bedrock. Seven stations with mechanically and thermally stable fundaments were built in August 2005.

Dual frequency (L1 and L2) GPS code- and carrier-phase raw data were typically collected from these stations at 1-second interval in 4 to 4.5 days campaigns. The data collected during each campaign are processed in the Bernese post processing software package and evaluated for quality and self-consistency. The results including preliminary coordinates are presented in an "EG180 – Point surveying Session" file. Final optimization of the data processing depends on the total dataset so we view currently calculated positions as preliminary. Our aim is to collect data of known good quality in this phase of the investigation.

The data was successfully evaluated for quality and stored for use in the final deformation evaluations. This was repeated in ten campaigns between November 2005 and October 2007, see Table 4-1. The first six campaigns are already reported in /1/. However, quality checking also revealed that one station (PFM006485) might have produced data of lower quality than the other six during the first three campaigns. This is believed to be due to sky disturbances possibly due to nearby vegetation. An additional station (PFM005786) was established in May 2006 prior to the fourth campaign as an alternative site with better GPS sky view. Data was successfully collected on all eight stations during the following campaigns. All original results are stored in the primary databases (Sicada and/or GIS) and are traceable by the activity plan number.

Figure 1-1 shows a general overview of station placements within and outside the candidate area. Two stations were placed NE of the Singö zone. Two stations were established SW of the Forsmark zone and three stations in the candidate area.

A dedicated GPS set consisting of receiver and choke ring antenna is used at each of the seven stations during each measurement campaign. The antennas are permanently mounted to minimize mechanical errors (see Figure 3-1) while the GPS receivers and power supplies (lead-acid battery and solar panel combination) were securely stored between campaigns. A cover also protects each station between campaigns. After the cover is removed and the GPS with its power supply are deployed (only two cables to connect), the receiver is turned "on" and data is automatically stored in internal flash memory until they are retrieved at the end of the campaign. The equipment is then restored to its protected inter-campaign state and the data are processed and evaluated for quality.

The methods used in this project are in accordance with the method description SKB MD 133.003.

Table 4-1. Activity log listing all the activities at all the stations reported here.

Campaign	Idcode	Activity type code	Activity	Start date	Stop date
1	PFM006483	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006484	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006485	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006486	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006487	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006488	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	PFM006489	EG180	Point surveying	2005-11-02 00:00	2005-11-08 00:00
	2	PFM006483	EG180	Point surveying	2006-01-31 00:00
PFM006484		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
PFM006485		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
PFM006486		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
PFM006487		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
PFM006488		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
PFM006489		EG180	Point surveying	2006-01-31 00:00	2006-02-06 00:00
3		PFM006483	EG180	Point surveying	2006-03-07 00:00
	PFM006484	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	PFM006485	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	PFM006486	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	PFM006487	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	PFM006488	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	PFM006489	EG180	Point surveying	2006-03-07 00:00	2006-03-14 00:00
	4	PFM005786	EG180	Point surveying	2006-05-09 00:00
PFM006483		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006484		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006485		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006486		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006487		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006488		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
PFM006489		EG180	Point surveying	2006-05-09 00:00	2006-05-15 00:00
5	PFM005786	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006483	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006484	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006486	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006487	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006488	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
	PFM006489	EG180	Point surveying	2006-07-06 00:00	2006-07-10 00:00
6	PFM005786	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006483	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006484	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006485	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006486	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006487	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006488	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
	PFM006489	EG180	Point surveying	2006-09-13 00:00	2006-09-17 00:00
7	PFM005786	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
	PFM006483	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
	PFM006484	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00

Campaign	Idcode	Activity type code	Activity	Start date	Stop date
	PFM006486	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
	PFM006487	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
	PFM006488	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
	PFM006489	EG180	Point surveying	2007-01-18 00:00	2007-01-22 00:00
8	PFM005786	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006483	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006484	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006486	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006487	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006488	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
	PFM006489	EG180	Point surveying	2007-04-25 00:00	2007-04-29 00:00
9	PFM005786	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006483	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006484	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006486	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006487	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006488	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
	PFM006489	EG180	Point surveying	2007-07-09 00:00	2007-07-13 00:00
10	PFM005786	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006483	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006484	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006486	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006487	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006488	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00
	PFM006489	EG180	Point surveying	2007-10-25 00:00	2007-10-29 00:00

4.2 Preparations

A functional test was made on a standard site with well-known coordinates. All components were found to function properly.

4.3 Execution of field work

The technique used is briefly described below in connection to the results presented. For detailed descriptions the reader is referred to the method descriptions.

A network of GPS stations was established. GPS data collected in ten 5-day measurement campaigns spread out over the first two years. The antenna on every station remains on the station during the entire project. The GPS-systems and power supplies are deployed only during measurement campaigns.

Every station includes:

- One geodetic survey grade dual frequency receiver with 128 MB internal memory to store all data during the session.
- Choke ring geodetic survey grade dual frequency antenna.
- Cables, backup battery and solar panels.

Every GPS-system and related components is dedicated to its specific station for the duration of the 3-year investigation. The equipment is therefore used on the same location during the entire project and the choke ring antennas remain fixed on the stations during the entire project. This prevents errors caused by displacements or any asymmetries in the antennas. The GPS receivers are collected after a total of 120 hours of survey and the data is uploaded to a laptop/desktop computer for analysis and storage.

4.4 Data handling/post processing

Raw GPS data (code and carrier phase in the L1-band and carrier phase from the L2-band along with “housekeeping data” on satellite functions and the GPS receivers) are collected directly by onboard controllers sealed inside the GPS receiver box. The onboard controller stores data at 1-second intervals on a 128 MB internal and similarly sealed solid-state flash memory chip rated for “industrial” use.

After retrieval of the GPS receivers, their data is uploaded to a computer and processed for quality control using the Bernese software package. Coordinates are calculated for three separate 24-hour periods using the Bernese software and checked for consistency. Before processing the data we wait for precise ephemerides (trajectories of the satellites) to post process at the highest accuracy. The precise ephemerides are available approximately two weeks after the measurements. After the post processing a network adjustment is made with ADDNEQ routine in the software package where the known distance between the stations is used to increase the accuracy. The Stations in the network are related to three SWEPOS stations with stable fundamentals (see photography in Figure 4-2) Lovö, Uppsala, and Mårtsbo by including them in the network. The results are transformed from Earth-centered Earth-fixed Cartesian coordinates to the Swedish grid RT90-RHB70 coordinates in two steps: From Earth-centered coordinates to WGS 84 in Geotrans V2.2.3 by the Topographic Engineering Center at US Army Corps of Engineers and from WGS 84 to RT90 2.5 G V / RHB70 by G-TRANS version 3.1 from Lantmäteriet.

The results are entered in an “EG180 – Point surveying Session” file and delivered to the Sicada data base. All raw files and results are also saved both by SKB and Caliterra HB.

4.5 Analyses and interpretations

The Bernese software is advanced software for post processing of GPS-data, developed by the astronomical institute at the University of Bern, Switzerland. It performs ranging data differencing to minimize or eliminate the dominating ranging errors. This is a standard technique used in all high precision GPS work. The main difference between the Bernese software and other standard software packages is in the great control over processing parameters offered in the Bernese software suite along with academically credited and partly peer-reviewed methods and documentation. The great control over processing parameters allows the operator to optimize processing and retrieve information about error sources while the transparency allows proper statistical interpretation.

4.6 Nonconformities

There are no reported nonconformities. The project runs according to the activity plan and will be completed one year from now.



Figure 4-2. The SWEPOS reference station in Uppsala.

5 Results

Our aim is to determine if the data collected is of the expected quality. There are several ways to estimate quality. A discussion of this issue is found in /2/. With similar methods and conditions the findings in /2/ are probably the most relevant to this specific investigation. Most strikingly, the authors found that formal errors that are estimated as part of the Bernese post processing are optimistic. Instead they used the residuals from the arithmetic mean of coordinate positions as a more realistic “ground-trough” measure.

Our findings concerning error estimates are in agreement with /2/, and we therefore include deviations that are not accounted for in the formal errors reported by the Bernese software.

We use these residuals in the form of root mean square (RMS) deviations from the arithmetic mean coordinates as measures of the overall quality. Horizontal errors are significantly lower than errors in the vertical direction. We decided to compare the residual in three-dimensional (3D) space for compactness and as a quality measure of the entire data set. This measure is used to make a direct comparison between our results and those reported in /3/ to determine if the data sets are of similar quality.

In /2/ the authors discuss optimization of post processing and averaging. Figure 5-1 is compiled from residuals reported in /2/ after final processing, in which L1 ranging data only are used. These are therefore a measure of the quality of the data set after optimization of the processing. We have not settled on an optimization scheme, since we intend to use the same settings and averaging techniques at all epochs to avoid systematic bias. We therefore need to evaluate the full data set for optimization. Specifically there is a real possibility that ionospheric stability will degrade in coming years and may force reliance on L1/L2 data combinations despite the higher phase noise than in L1 alone. Averaging techniques may reduce the effect of the phase noise depending on ionospheric stability across a campaign.

Figure 5-2 and Figure 5-3 shows residuals in our data computed similarly as the residuals by /2/ shown in Figure 5-1, except that the processing and averaging of our data is not optimized. Figure 5-2 compiles the results from the first six campaigns, and Figure 5-3 for the four campaigns in 2007. Further, our results are based on all the data (including L1 and L2 combinations) as compact measures of overall data quality. We consider the results as a “worst case” processing and averaging, acknowledging that this leaves room for improvement.

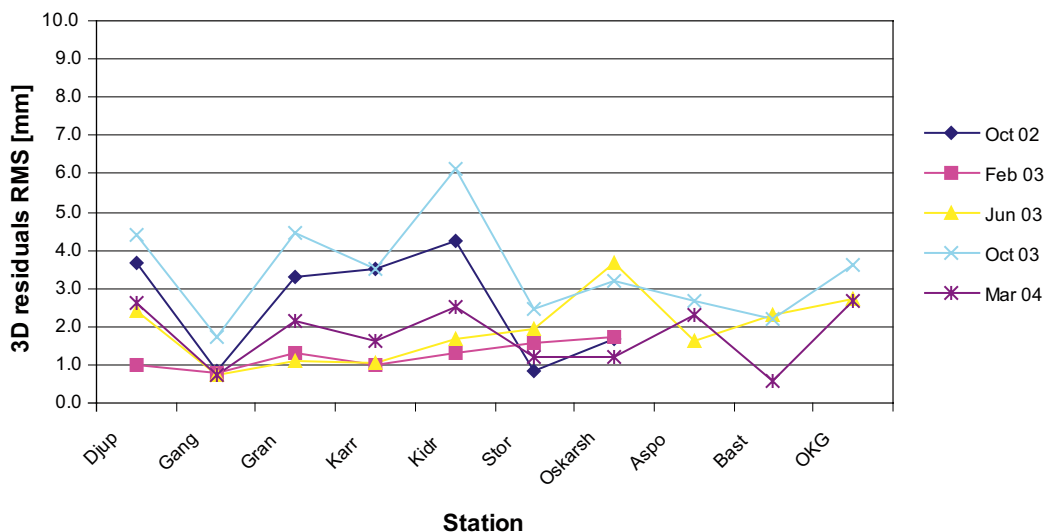


Figure 5-1. Residuals in three-dimensional space from the arithmetic mean solution compiled from a study at Oskarshamn /1/, based upon 24-hour simultaneous solutions.

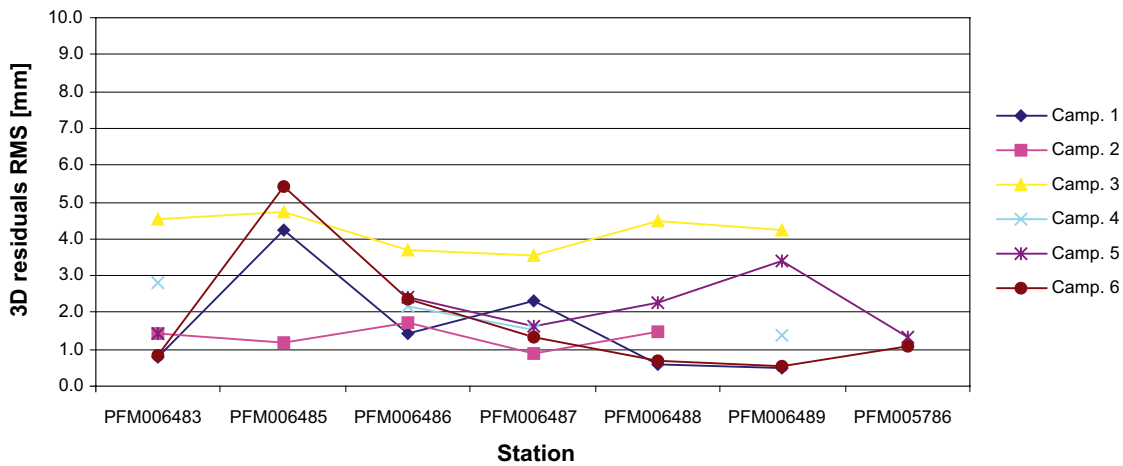


Figure 5-2. Residuals from the on-going study at Forsmark in three-dimensional space from the arithmetic mean solution from 24-hour simultaneous solutions for the data from the first six campaigns, reported in /1/.

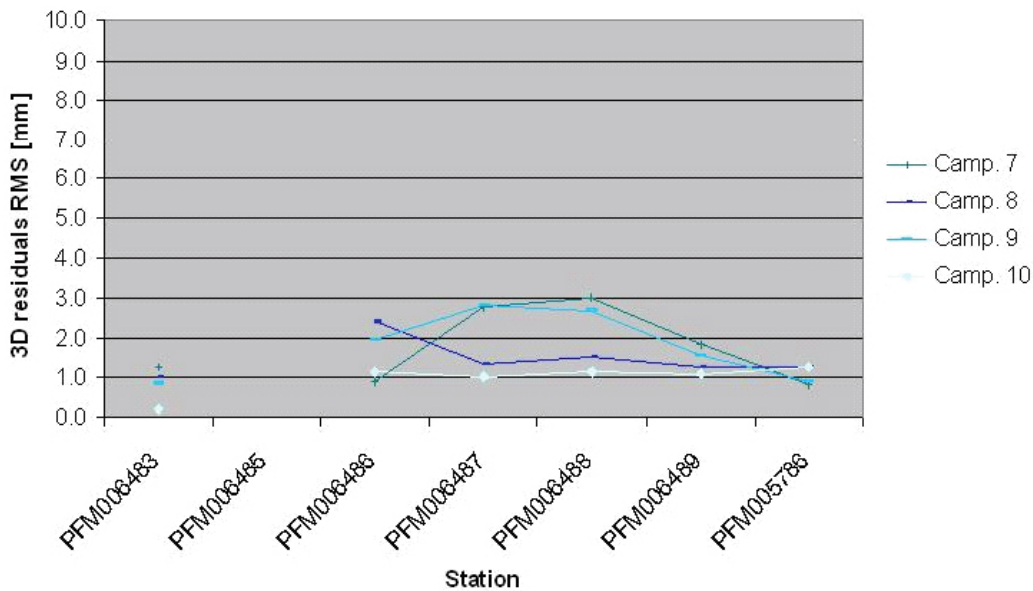


Figure 5-3. Residuals from the 2007 campaigns in Forsmark in three-dimensional space from the arithmetic mean solution from 24-hour simultaneous solutions for the data reported in this report.

We also note that we have a significantly larger data set for Forsmark (we captured one record per second, whereas the data reported in /2/ are collected every 15 seconds). With this larger data set we may want to use the median as a better estimate than the arithmetic mean, along with more advanced averaging with digital filters to reduce the effect of noise in the carrier phase determinations and to retrieve the wanted low frequency displacement terms. This may allow us to make better use of especially the L2 data.

Figure 5-2 and Figure 5-3 thus summarizes the quality of all data from the ten first campaigns, including L1 and L2 ranging using standard or default settings in the Bernese post processing software (no optimizations). No residuals are shown for the points PFM006485, PFM006488 and PFM006489 from campaign 4 due to the fact that the data collection time was shorter than for the other campaigns. This did not allow daily residuals to be computed similarly to /2/ for those locations. However, we note that residuals at the other locations are typical values. The overall conclusion is that the figure shows comparable residuals to those seen in Figure 5-1. We can therefore expect results of similar or better quality than in /2/, assuming that the data in the remaining time of the project are of the same quality as those for this the first two years.

6 Summary and discussions

A network of stable stations with good anchoring into the rock and good GPS sky was established in three tectonically different areas in Forsmark. The first and second year of data is found to be of good quality. Final processing will depend especially on the quality of the data obtained in the last year. We will therefore only settle on an optimized processing technique once the quality of the entire data set is known.

We may note that during this project the probability for solar activity affecting the ionosphere is expected to be low. However, significant solar activity can occur at any time during the solar cycle. It is therefore prudent not to settle on a processing optimization technique until the entire record has been collected and evaluated. However, it could be concluded (in Section 5) that the data quality from the two first years is good.

Even though the Sun is in a “quiet” phase sudden ionospheric disturbances, caused by solar outbursts, struck the Earth on December 6, 2006. In addition to disturbing the ionosphere, the disturbances produced what are possibly the strongest emissions ever observed at a frequency (1.4 GHz) near the L1 waveband used by GPS satellites. Dale Gary, director of Owens Valley Solar Array (OVSA), one of the leading research facilities for studies of the Sun’s impact upon earth, commented /4/:

“The Sun is supposed to be at the minimum phase of its 11-year cycle. Nevertheless, the disruption lasted more than an hour, produced a record amount of radio noise, and caused massive disruptions of Global Positioning Satellite (GPS) receivers world wide.”

Such disturbances cannot be reliably predicted with sufficient accuracy, but our campaigns are sufficiently long to allow collection of adequate data, even if a disturbance compromises a portion of the campaign.

References

- /1/ **Gustafson L, Ljungberg A, 2007.** GPS deformation measurements in Forsmark. Annual report 2006. SKB P-07-89, Svensk Kärnbränslehantering AB.
- /2/ **Sjöberg L E, Pan M, Asenjo E, 2004.** A deformation analysis of the Äspö GPS monitoring network from 2000 to 2004. SKB P-04-196, Svensk Kärnbränslehantering AB.
- /3/ **Sjöberg L E, Pan M, Asenjo E, 2002.** An analysis of the Äspö crustal motion-monitoring network observed by GPS in 2000, 2001 and 2002. SKB R-02-33, Svensk Kärnbränslehantering AB.
- /4/ **Weinstein S, 2006.** EurekAlert (New Jersey Institute of Technology)
URL: http://www.eurekalert.org/pub_releases/2006-12/njio-nsp121506.php

Specifications



AeroAntenna

Choke Ring Antenna AT2775-43

High-precision dual frequency choke ring GPS antenna

The choke ring antenna AT2775-43 from AeroAntenna is a high-quality dual frequency antenna with choke ring and radome, ideal for stationary long-time measurements.

Options

- Amplification (gain) ± 2 dB: 00 (passive), 12 dB (30 mA), 26 dB (60 mA), 36 dB (60 mA), others on request
- Input voltage: 00 (passive), 5 VDC, 5–18 VDC, others on request
- HF-connector: TNC female, BNC female, N-Type female, others on request
- with or without radome

Applications

- GPS Reference Stations
- GPS deformation monitoring

Specifications

- Frequency: $1,227 \pm 10$ MHz, $1,575 \pm 10$ MHz
- Polarization: right hand circular
- Axial ratio: max. 3 dB
- Noise figure: max. 2.5 dB
- Impedance: 50 Ohm
- VSWR: $< 2.0:1$
- Band rejection: 35 dB
- Finish: Polyurethan Enamel
- Choke Ring: Aluminium
- Designed to: DO-160

Dimensions and Consumption

- Dimensions in mm: $\varnothing 379.4 \times 150$ (without radome)
- Weight: max. 4,535 g
- Consumption: 60 mA.

Toughman Product Specifications

GPS Receiver:

- 28 parallel-channel GPS L1/L2 receiver
- 2 channels can be used for SBAS support of WAAS, EGNOS and MSAS
- Position update rate: 1 to 10 Hz
- Real time DGPS code phase, fallback to 2D/3D DGPS and L1/L2 standalone positioning modes
- Carrier phase post-processing
- Cold start: 120 seconds
- Warm start: 33 seconds
- Re-acquisition time: 1 second typical

Features:

- 32 MB Flash Memory non-volatile data storage
- 2 Serial input/output ports (configurable. NMEA 0183 compatible)
- 1 A/D Input +/- 5V 16 bit ADC
- Rechargeable Lithium-ion Polymer battery, 10 hours continuous operation
- Internal battery charger accepts 10 to 28 VDC
- Visual status indicators
 - Low Battery
 - Charging
 - Satellite Count
 - Valid Position
- Audio alarm for Invalid Position

Physical Characteristics:

- Powder coated aluminum enclosure
- Meets IP65 Rating
- Operating temperature: -20°C to 60°C
- Dimensions 20 cm x 8.5 cm x 3.5 cm (7 7/8" x 3 1/4" x 1 3/8")
- Weight: <800 grams (1 lb 5 oz)

Antenna:

- L1/L2, Geodetic Survey Grade
- Weight: <300 grams (10.5 oz)



Typical Accuracy:

- Real time differential
 - Dynamic (WAAS, EGNOS) 2 meter
- Post-processing
 - Static +/- 0.5 cm + 1ppm RMS
 - Dynamic
- RTK +/- 1 cm + 1ppm RMS (Accuracy will vary depending on baseline range of radio)*

GeoID Software:

- Windows Operating System
- Import and Export RINEX files
- Automatic and advanced post-processing
- Static and kinematic modes
- Imports data from data collectors
- GeoMapper Software

Optional Upgrades:

- Wireless Bluetooth Communications

* RTK performance is provided by optional DataGrid CSTRTK software run on an external PocketPC

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D9001

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