Station Calibration of the SWEPOS™ Network

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Summary

Site-dependent effects are important and limiting factors in high-accuracy GNSS positioning. Electrical coupling between the antenna and its near-field environment changes the characteristics of the antenna from what has been determined in e.g. absolute robot calibration.

Lantmäteriet, the Swedish Mapping, Cadastral and Land Registry Authority, has started in-situ station calibration of its permanent reference stations, SWEPOS™. The 21 fundamental stations, which are defining the national realization of ETRS89 – SWEREF 99 – have very long time-series and most of the antennas have not been changed since the stations were established. We currently foresee a risk that the antennas will break down, since they are getting quite old. Thus we would like to investigate the SWEPOS stations and their environment before it is too late. The observations can be used to estimate the biases introduced in computed parameters. Another approach is to model the site-dependent effects, which could be used as corrections when computing positions and troposphere parameters.

Initial tests were performed in 2008. The station calibration campaigns started in 2009 and have continued in 2010.

It can be seen from the results so far, that the GPS heights of the pillars systematically seems to be too low by approximately 10 mm. Tests with and without microwave absorbing material on the benchmark set ups also indicate that the height biases of the SWEPOS stations primarily are caused by the pillars and the antenna mounting.

Introduction

Site-dependent effects are important and limiting factors in high-accuracy GNSS positioning. Electrical coupling between the antenna and its near-field environment changes the characteristics of the antenna from what has been determined in e.g. absolute robot calibration.

The 21 fundamental SWEPOS™ stations, which are defining the national realization of ETRS89 – SWEREF 99 – have very long time-series and most of the antennas have not been changed since the stations were established. We currently foresee a risk that the antennas will break down, since they are getting quite old. Thus we would like to investigate the SWEPOS stations and their environment before it is too late. The observations can be used to estimate the biases introduced in computed parameters.

Another approach is to model the site-dependent effects, which could be used as corrections when computing positions and troposphere parameters. This could involve determining of the electrical centre of the GNSS antenna, as well as the PCV (phase centre variations) when the antenna is installed at a SWEPOS station.

Earlier studies (Granström, 2006) have shown that there are significant site-dependent effects on the SWEPOS stations. The effects are similar in many stations, but they are not identical, which implies that station calibration taking environmental effects into account is essential.

Carrier phase multipath and antenna coupling effects introduce biases to estimated parameters, e.g. coordinates and troposphere parameters. The magnitude of the bias is dependent on the environment near the antenna but also on the processing strategy including used frequency, elevation cut-off angle and antenna models.

This initial study is focused on the investigation of the possible bias of the height determination in SWEREF 99:

- Is there a significant bias in the height estimation of the SWEPOS stations?
- Do all SWEPOS stations show the same behaviour?
- Is there a difference in the bias between a SWEPOS station and a normal field setup?

The SWEREF 99 coordinates of the SWEPOS stations – as well as the network densifications – have been calculated with the Bernese software using ionosphere-free linear combination, relative antenna models, 15 degrees cut-off angle with solving for troposphere parameters.

SWEREF 99 has been densified with some 300 field points using normal setups with tripods and there is a program for repeated observations of these field points every six years. The processing strategy for the densification was initially identical to the one used in the SWEREF 99 campaign, but it has been slightly updated for the repeated observations, concerning elevation cut-off angle (10 degrees) and solving for troposphere parameters using the Niell (1996) mapping function. Tests indicated that the systematic effects on the computed coordinates due to this update were negligible and that the precision was improved.

The antenna setup including radome and pillar top has been changed only on a few stations since the SWEREF 99 campaign was observed in the summer 1999.

On one of the stations the microwave absorbing material Eccosorb® has been mounted around and beneath the antenna in order to reduce the effect of multipath and other site-dependent effects. This change introduced a change in computed coordinates (mainly height) in the order of 1 cm in the SWEREF type of processing, which gives an indication of the level of bias that could be expected in height estimation due to the site-dependent effects on the SWEPOS stations.

Surveying

The same setup is used for the calibration of all SWEPOS stations. So far, seven of the 21 fundamental SWEPOS stations have been surveyed and the analysis is underway. Another three stations have been surveyed but are not yet processed. All of the fundamental SWEPOS stations will not be calibrated, as extensive clearing of trees would be necessary.

The 21 fundamental SWEPOS stations have their antennas mounted on concrete pillars, surrounded by a number of benchmarks. Local surveys including the pillars and the benchmarks to monitor the monument stability have been done several times over the years.

Two different GNSS receivers are connected to the SWEPOS antenna during the station calibration – the “ordinary” SWEPOS receiver that is used for the daily operation, as well as a receiver especially set up for the calibration, utilising a multipath mitigation option.

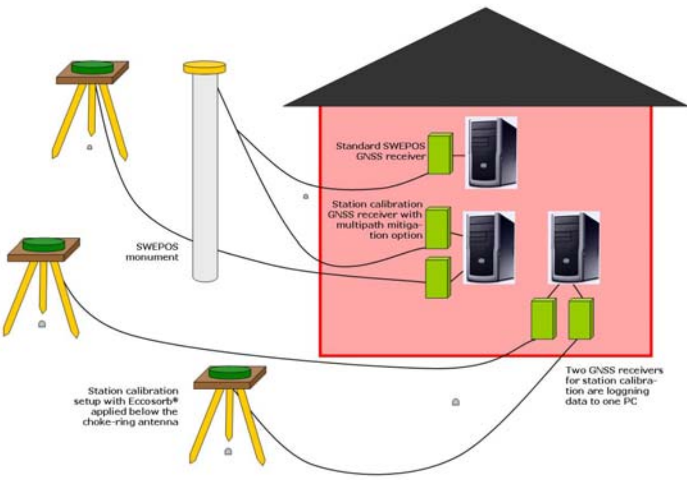

Fig. 1. *Principle sketch of the station calibration setup.*

Another three GNSS antennas and receivers are set up on a selection of the benchmarks surrounding the SWEPOS pillar, to be used as reference stations during the calibration. For these, microwave absorbing Eccosorb® plates are used to minimize the multipath (see figure 3). These GNSS receivers also utilise the multipath mitigation option.

The GNSS antennas used for the benchmark setups are all Javad JNSCR_C146-22-1 (Javad copy of AOAD/M_T), but the SWEPOS antenna is used as is.

Four different antenna types are in use at the seven SWEPOS stations processed so far – the Allen Osborne AOAD/M_T or three different Ashtech copies of AOAD/M_T.

All receivers are kept in the SWEPOS equipment cabin during the campaign. Data are logged to the computer connected to the receiver (1 second sampling rate), as well as to the internal receiver memory (5 second sampling rate) when possible. Each campaign lasts five (in some cases six) full 24-hour sessions.

GPS Processing

The size of the bias from site-dependent effects is affectted by the chosen processing strategy, including the used frequency, elevation cut-off angle and antenna models.

Four different processing strategies are used for the station calibration:

- Relative antenna models, using the “ordinary” SWEPOS GNSS receiver
- Relative antenna models, utilising the multipath mitigation GNSS receiver at the SWEPOS station
- Absolute antenna models, in combination with the “ordinary” SWEPOS GNSS receiver
- Absolute antenna model, using the multipath mitigation GNSS receiver at the SWEPOS station

In total, six Javad antennas have been used for the station calibration campaigns (except from the test campaigns in 2008, where also other antennas were used). Two of them have been calibrated by the NGS (National Geodetic Survey, USA) to get individual relative antenna models. For the other Javad antennas, the resulting relative type model is used. Four of the Javad antennas have been calibrated by Geo++, Germany, to obtain individual absolute antenna models. For the other Javad antennas, the resulting absolute type model is used.

Fig. 2. *Hässleholm, 2010. One of the bench¬mark setups. An Eccosorb plate is mounted directly beneath the choke-ring antenna. The GNSS receiver is kept in the SWEPOS equipment cabin during the campaign.*

Fig. 3. *Vänersborg, 2009. SWEPOS antenna monument, together with two benchmark setups. The SWEPOS equipment cabin can be seen in the background.*

The GNSS receivers are kept in the SWEPOS equipment cabin during the campaign. For the SWEPOS antennas, no individual antenna models are available and thus type models have been used for these antennas. The absolute antenna models are in some cases converted from relative antenna models, according to the same principles as for the EPN[1] processing. None of the used antenna models include the OSOD type radomes used at all SWEPOS pillars.

For this processing, only GPS observations have been used. The sampling rate for the processing is 15 seconds and the session duration is 24 hours.

The elevation cut-off angle is set to 10 degrees. Several solutions are produced for each processing alternative, i.e. L1 and L2 without estimation of troposphere parameters as well as L3 (ionosphere-free linear combination) with solving for troposphere parameters.

This paper only presents the results for the L3 solution. The L3 solution is the most interesting one, as the environmental effects on height determination are considerable for this linear combination, and it also corresponds to the computation strategy used in the determination of new points in SWEREF 99

		Relative antenna model		Relative antenna model + multipath mitigation		Absolute antenna model		Absolute antenna model + multipath mitigation	
		Std.dev. translation	dh PP	Std.dev. translation	dh PP	Std.dev. translation	dh PP	Std.dev. translation	dh PP
HASS	RMS	1.3		1.3		1.5		1.5	
	Standard deviation		1.3		1.2		1.3		1.3
	Mean		-9.6		-6.3		-12.3		-8.9
	Std.dev. of mean		0.6		0.6		0.6		0.6
JONK	RMS	0.8		0.8		1.1		1.1	
	Standard deviation		3.0		2.8		2.9		2.8
	Mean		-10.6		-8.2		-13.7		-11.2
	Std.dev. of mean		1.3		1.3		1.3		1.3
LEKS	RMS	1.3		1.3		0.3		0.3	
	Standard deviation		1.1		1.0		1.1		1.0
	Mean		-12.5		-11.0		-18.9		-17.4
	Std.dev. of mean		0.5		0.4		0.5		0.4
NORR	RMS	1.0		1.0		1.4		1.4	
	Standard deviation		1.2		1.2		1.2		1.2
	Mean		-8.6		-9.1		-10.2		-10.7
	Std.dev. of mean		0.5		0.5		0.5		0.5
OSKA	RMS	0.5		0.6		0.7		0.7	
	Standard deviation		0.7		0.7		0.7		0.7
	Mean		-7.9		-4.6		-9.7		-6.4
	Std.dev. of mean		0.3		0.3		0.3		0.3
SUND	RMS	1.1		1.1		1.2		1.1	
	Standard deviation		2.8		2.8		2.8		2.7
	Mean		-10.8		-9.0		-12.5		-10.8
	Std.dev. of mean		1.1		1.1		1.1		1.1
VANE	RMS	1.5		1.6		2.2		2.3	
	Standard deviation		1.5		1.4		1.6		1.5
	Mean		-8.8		-6.8		-10.3		-8.3
	Std.dev. of mean		0.7		0.6		0.7		0.7

Table 1. *Statistics of the shift of the GPS heights to the "true" ellipsoidal heights of the benchmarks. "Std.dev. translation" is the standard deviation of the translation obtained. RMS is calculated from the five (or six) sessions of the station."dh PP" is the ellipsoidal height difference between the measured GPS height and the "true" height of the pillar plate. Mean values of the five (or six) sessions have been computed, as well as stan¬dard deviation of the differences and standard deviation of the mean value.*

[1] EUREF Permanent Network

Estimating the height bias

The SWEPOS station benchmarks are levelled from a Third Precise Levelling benchmark, resulting in RH 2000 heights. The RH 2000 height of the SWEPOS pillar plate is determined by trigonometric levelling in relation to the benchmarks.

The mentioned RH 2000 heights are converted to ellipsoidal heights using the national geoid model SWEN08_RH2000, to obtain "true" ellipsoidal heights. The ellipsoidal heights from the GPS processing are then shifted to fit the "true" ellipsoidal heights of the benchmarks. Finally, the shifted ellipsoidal height of the SWEPOS pillar plate is compared to the "true" ellipsoidal height stemming from the levelling; see table 1.

Discussion

It can be seen from the results above that the GPS heights of the pillars systematically are too low by approximately 10 mm, except for Leksand where the systematic difference is slightly larger.

There is also a difference between the use of relative and absolute antenna models; approximately 2 mm, which is more than expected when computing such short baselines. Leksand has a larger difference (circa 6 mm), but the cause of that has not been clarified.

During the surveying of Leksand, some snow fell. The antennas were cleared from snow, but it is not known exactly for how long there was snow on the antennas before it was cleared. This might of course have affected the result of the station calibration of Leksand, but it will be difficult to estimate the magnitude of this possible effect.

The use of the multipath mitigation receiver at the SWEPOS station gives a positive effect on the result. The multipath mitigation algorithms are mainly developed for code multipath and it was believed that the effect would be small for the near-field multipath on phase observations (Dilβner et al., 2008).

The 2008 calibrations were performed without Eccosorb on the benchmark setups. There are results only from one session each on two stations. A comparison of these data with the later calibrations, where Eccosorb was used, shows similar results, which means that the results here also are relevant for the height bias in SWEREF 99 between the defining pillars and the field points, determined in SWEREF 99.

This also indicates that the height biases of the SWEPOS stations above all are caused by the pillars and the antenna mounting. On one of the stations the microwave absorbing material Eccosorb has been mounted around and beneath the antenna, which introduced a change in computed coordinates (mainly height) in the order of 1 cm in the SWEREF type of processing, and thus confirms what can be seen in the station calibration results.

References

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