The 2002 NKG GNSMART/GPSNet Test Campaign

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LANTMÄTERIET

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1 Abstract

Within the work of the NKG (Nordic Geodetic Commission) project Nordic Positioning Service, a test campaign with GPS and Network RTK was carried out in October-November 2002 at Lantmäteriet (National Land Survey of Sweden), Gävle, Sweden. The campaign included two Network RTK softwares, GNSMART from Geo++ and GPSNet from Trimble. As reference stations for the measurements, stations in the Swedish network of permanent reference stations, SWEPOS™, were used. Three different brands of GPS receivers were used as rover receivers, Javad, Leica and Trimble.

The measurements for the test campaign were performed in a test area that consists of seven points, situated at the distances 200 m, 4 km, 10 km, 17 km, 22 km, 28 km and 36 km from the nearest reference station. From the beginning the campaign was planned for week 41 in 2002, but due to installation problems the measurements started first in week 44. During this week, the test measurements were limited to measurements with Javad and Trimble. Leica was tested more intensively in week 45-46 instead.

Due to the reason that the Leica equipment was available for a longer period, more measurements were done with Leica than with Javad and Trimble. Specific for the Trimble receiver used for measurements with GNSMART was also that it could not interpret the RTCM-message 59 as expected (RTCM-message 59 is not a standard format), contributing to that the measurements on long baselines for the combination Trimble-GNSMART were not done in a proper way. All false fixed solutions for the Trimble with GNSMART have because of this been removed.

The coordinates for all test measurements have been compared with coordinates calculated from static measurements, which were considered as true values. In respect to the true coordinates, totally, 67 % of the measurements with GNSMART were within 21 mm (horizontal) and 35 mm (vertical) and with GPSNet they were within 20 mm (horizontal) and 24 mm (vertical). The 95 % values were for GNSMART 47 mm (horizontal) and 98 mm (vertical) and for GPSNet they were 50 mm (horizontal) and 64 mm (vertical). The initialisation times for both float and fixed solutions were also examined.

For the GNSMART measurements, the vertical deviations for Leica and Javad were a few centimetres systematically too low. This leads to a degradation of the vertical values above for GNSMART. An explanation could be that the antenna models for GNSMART have not modelled the antennas in a correct way. Finally the conclusion from this test campaign is that there is no big difference in accuracy or initialisation times between the two network RTK softwares.

A small test campaign with GNSMART in a more sparse network has also been carried out. The results from this test campaign are comparable with or a bit worse than the results from the actual test campaign described above. A big difference with the sparse network is however that it takes longer time to get a fixed solution and that it also is more difficult to get a fixed solution at all.

2 Background

A test campaign with GPS and network RTK was carried out in October-November 2002 at Lantmäteriet (National Land Survey of Sweden), Gävle, Sweden. The campaign was planned within the NKG (Nordic Geodetic Commission) project Nordic Positioning Service and the work was performed by Lantmäteriet in collaboration with Kort & Matrikelstyrelsen in Denmark (KMS) and the Norwegian Mapping Authority (SK). NKG is an association of geodesists from Denmark, Finland, Iceland, Norway and Sweden. The purpose of NKG is to be a body for a fruitful Nordic co-operation in the field of geodesy and close related issues (Jonsson et. al, 2002a).

As reference stations for the measurements, stations in the Swedish SWEPOS™ network of permanent reference stations (Hedling et. al, 2001) were used. The network has several purposes, where three ongoing production projects with network RTK (Jonsson et. al, 2002b) are one. The test campaign included two network RTK softwares, GNSMART from Geo++ and GPSNet from Trimble.

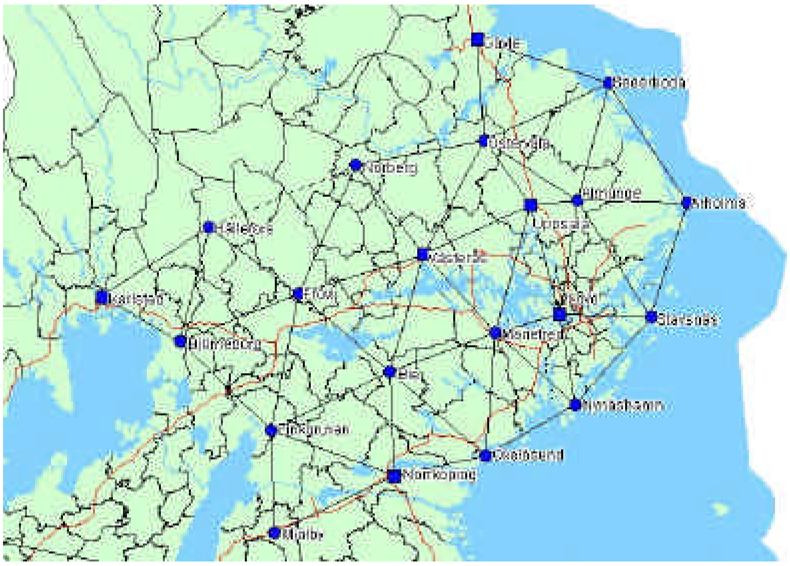

Figure 2.1: *Network for one of the ongoing production projects with network RTK in the SWEPOS™ network of permanent reference stations.*

3 The SWEPOS network

Since July 1st 1998 the Swedish network of permanent reference stations (SWEPOS), see figure 3.1, is operational in IOC mode, i.e. for positioning in real-time on the metre level and by post-processing on the centimetre level. Positioning in real time on the centimetre level is today (May 2003) possible in regional parts of Sweden.

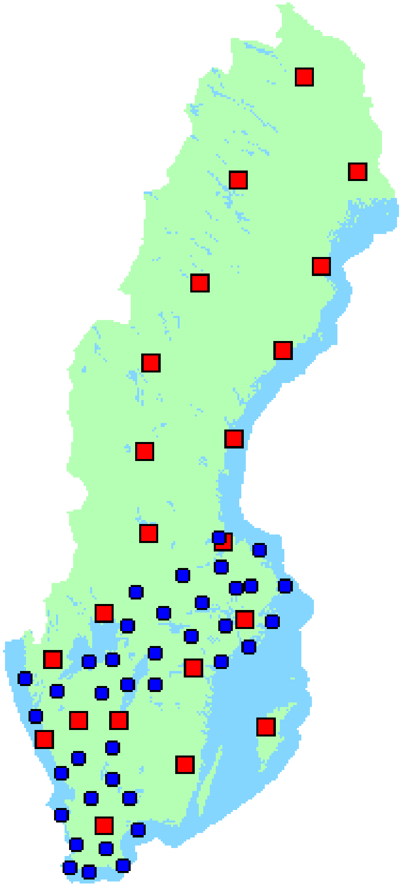

Figure 3.1: *The SWEPOS network of permanent reference stations May 2003 (squares are complete SWEPOS stations and dots are simplified ones).*

Figure 3.2: *The SWEPOS station Överkalix*

The purposes of SWEPOS are to:

- Provide single- and dual-frequency data for relative GPS measurements.
- Provide DGPS corrections and RTK data for broadcasting to real time users.
- Act as the continuously monitored foundation of the Swedish geodetic reference frame (SWEREF 99).
- Provide data for geophysical research.
- Monitor the integrity of the GPS system.

Figure 3.3: *Interior of a complete SWEPOS station.*

Figure 3.4: *The simplified SWEPOS station Västerås.*

The same 21 stations that SWEPOS consisted of when it became operational in IOC mode are still in operation. These stations are complete stations, i.e. they are monumented on bedrock and have redundant equipment for GNSS observations, communications, power supply etc. They are also connected to the national horizontal network and the national precise levelling network by precise levelling. Six SWEPOS stations are included in the EUREF Permanent Network (EPN) and five are included in the International GPS Service for Geodynamics (IGS) network.

Today (in May 2003) SWEPOS also includes 36 simplified stations, which mainly are located on the top of buildings and with less redundant equipment than the complete stations. The simplified SWEPOS stations are mainly used for regional network RTK services (Jonsson et. al, 2002b).

3.1 SWEPOS services

Quality checked SWEPOS data for post-processing has been available on a WWW/FTP server in RINEX format for a long time. In October 2000 an automated post processing service, based on the Bernese software, was introduced at **www.swepos.com**, the SWEPOS web page (Kempe & Jivall, 2002). This service has grown in popularity, making it possible for GPS users to automatically determine his position with centimetre accuracy using only one GPS receiver and data from the SWEPOS network.

The DGPS service EPOS is using correction data from SWEPOS since the service started in December 1994. The service is using the RDS channel on the FM radio network for the distribution and is from December 2001 operated by Cartesia Informationsteknik AB. SWEPOS also contributes to the DGPS correction data distributed by the company OmniSTAR.

To investigate the conditions for regional services for real-time positioning on the centimetre level, three pre-study projects with network RTK have been carried out during the period 1999-2001. The projects were carried out with Lantmäteriet, Onsala Space Observatory, local authorities, government agencies and private consulting firms as partners.

Based on the results from the pre-studies, three prototype regional positioning services have been launched as one-year projects during 2002. Position Stockholm-Mälaren-2 (figure 2.1) was in operation on February 7th and it has been followed by the two other projects, SKAN-RTK-2 and VÄST-RTK. The services are using GPSNet as network RTK software and GSM as distribution channel. The aims of these services are to evaluate and improve the Network RTK techniques and to carry out production work. The projects have been or will be prolonged to December 2003 and the intention is to provide regional services on a regular basis after that.

In the Nordic co-operation Nordic Positioning Service, steps towards a Nordic positioning service have been taken. One of these steps is the test campaign described in this report with the two working network RTK softwares.

4 Briefly about GNSMART and GPSNet

4.1 GNSMART

GNSMART stands for GNSS State Monitoring and Representation Technique. In this campaign GNSMART worked with virtual stations and multi-station solutions, which means that a virtual station is created quite close to the rover and that all stations in the network contribute to calculate the position of the rover receiver. In this campaign all the 21 SWEPOS stations in the Stockholm-Mälardalen-2 net were used (see figure 2.1).

For more information about the technique behind the software, see: http://www.geopp.de.

4.2 GPSNet

The used version of GPSNet was 1.61. This version works with virtual stations and triangles, which means that a virtual station is created at the initial absolute position and data from three stations contributes to calculate the position of the rover receiver. In this campaign the SWEPOS stations Gävle, Söderboda and Östervåla in the Stockholm-Mälardalen-2 net were used (see figure 5.1).

For more information about the technique behind the software, see: http://www.gpsnet.dk/VRSteknik_int.php.

5 The test area

In September 2002 Andreas Engfeldt got the mission to find about 6 to 8 test points in the Gävle – Söderboda – Östervåla triangle (see figure 2.1), at different distances from the nearest reference station. First of all three points, which were included in a test campaign with single station RTK (performed in 1999) were chosen. These points have the distances 4, 10 and 22 km from the nearest reference station. Also a point in the middle of the triangle, which was marked for a diploma work (Persson & Brynte, 2002), was immediately chosen. The distance to that point is 36 km from the nearest reference station. After points of view from Denmark, a point 200 metre from the reference station Gävle also was chosen. At last two ideal places, at 17 and 28 km from the nearest reference station, were reconnaitred. At those places new points were marked. All seven points (1-7) are firmly marked in bedrock or large stones and are situated at the distances 200 m, 4 km, 10 km, 17 km, 22 km, 28 km and 36 km from the nearest reference station in the SWEPOS™ network (see figure 5.1).

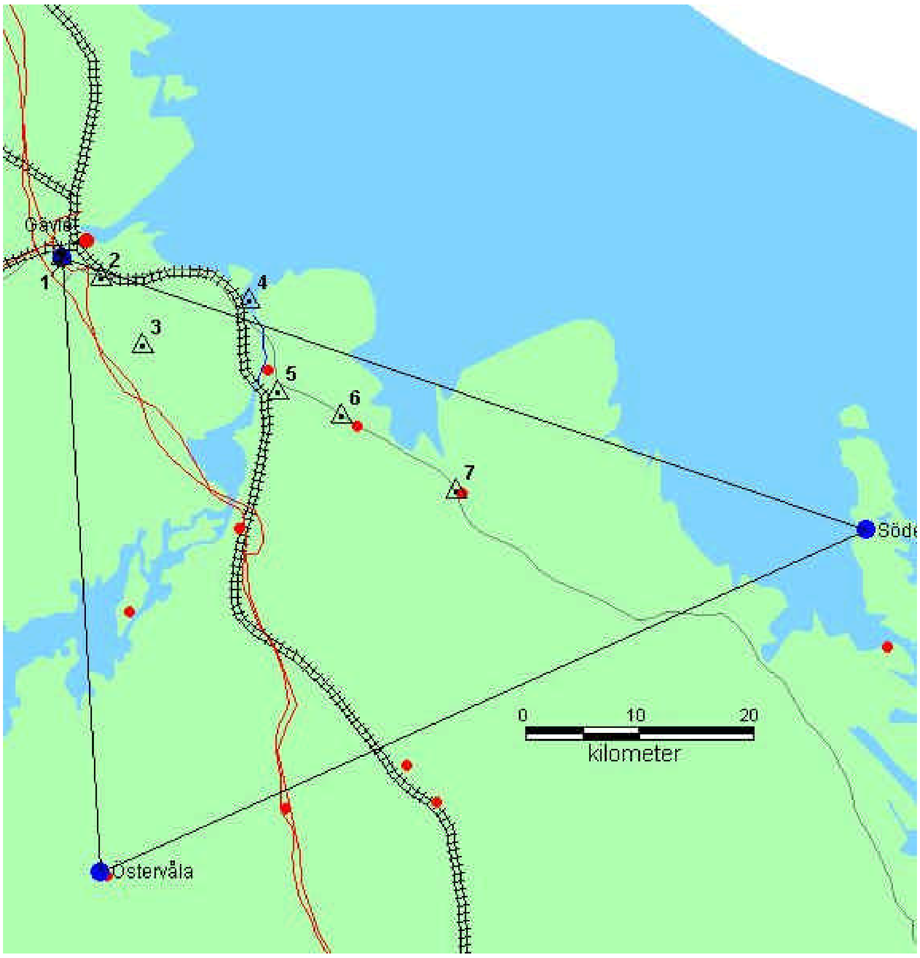

Figure 5.1: *The test area and the three nearest reference stations.*

In order to get accurate coordinates, all seven points were measured by static GPS, where tripods and calibrated tribrachs were used. The computed coordinates were considered as true coordinates during the test campaign. Dorne Margolin antennas together with either Leica or Ashtech receivers were used for the static measurements. The seven points were all measured twice, in three hour long sessions, by either Dan Norin or Christina Lilje. The coordinates were calculated in the reference frame SWEREF 99 as a mean value from the results from the two different sessions. The web-based Automated Processing Service at Lantmäteriet (Kempe & Jivall, 2002), which automatically processes the RINEX file in the Bernese software together with observation files from the nearest SWEPOS stations, was used. SWEREF 99 was in 2000 adopted by EUREF as an ETRS 89 realisation in Sweden (Jivall & Lidberg, 2000).

6 Test measurements and test procedures

It has been essential to use a procedure for the test measurements that gives:

- Independent data sets
- A good comparison between the two network RTK softwares

Three different brands of GPS receivers were used for the test measurements in the test area, namely Javad, Leica and Trimble. They were operated with standard RTK equipment with respect to GPS antennas, plumbing poles with bi-pods etc. For the distribution of data from SWEPOS™ control centre in Gävle, GSM modems were used.

All data have been collected in SWEREF 99 and all comparisons have been made between horizontal coordinates and ellipsoidal heights. All measurements with one specific equipment, have been performed independent from each other, i.e. travelling from one station to another, station set up, dial up, initialisation and measurement.

To be able to compare the different network RTK softwares, two GPS receivers of the same brand have been connected to the same GPS antenna by an antenna splitter. The antenna was mounted on a plumbing pole with a bi-pod, which was carefully levelled. Two persons then started the receivers and simultaneously called up two different modems (the two different network RTK softwares) and recorded the time for initialisation. When both the receivers had got a fixed solution, then the points were measured simultaneously as well. On every point ten independent measurements were carried out forming one data set, where power was turned off in between every single measurement. Measurements were carried out in all kind of conditions concerning satellite availability etc.

Initialisation times (both for float and for fixed solutions), DOP-values, number of satellites and internal accuracy values were recorded manually. Coordinates in SWEREF 99 for the fixed solutions with point numbers were recorded on the memory card of the GPS receivers or in a field computer. The measurements were terminated and no observations were recorded if a fixed solution was not attained within five minutes. The elevation mask was set to 13 degrees for all the equipment.

6.1 What happened during the field work

During September 2002 the GNSMART software from Geo++ should have been installed at Lantmäteriet. The installation was performed directly from Geo++ in Germany and took much longer time than expected. In the beginning we had planned to perform the test campaign in week 41 (October 7-11), but because of the delays with the installation of GNSMART we had to change the week for the test campaign to week 44 instead.

The GPSNet software from Trimble is already used in the network RTK projects in Sweden. In this campaign we didn't make any special arrangements for the GPSNet connection, we used the ISDN rooter which is running for the project Position Stockholm-Mälaren-2. But for the GNSMART software, we had to use separate modems for the connection. The installation of GNSMART was done in a way that every brand of GPS receivers should have its specific antenna model. This was implemented by making different configurations for three modems, which meant that every GPS receiver brand got a specific telephone number to use.

First on Thursday in week 43, it was possible to get a good solution out of it. Andreas Engfeldt then tested the Leica equipment, at a place about 100 meters away from the reference station Gävle, for all the three different phone numbers, and a fixed solution was established on all of the numbers. This meant that the campaign could start in week 44 as planned.

On Monday in week 44, Jan Nielsen (KMS), Louise Holm Warming (KMS) and Gro Grinde (SK) arrived in Gävle to take part in this GNSMART/GPSNet test campaign. Because of lack of Swedish resources that particular week, only Andreas Engfeldt could take part from Lantmäteriet. This means that only Javad and Trimble were tested during the week. Leica was tested more intensively by Lantmäteriet in week 45 and 46 instead.

The used equipment was:

- one Javad Legacy receiver from KMS in Denmark
- one Javad Legacy receiver from SK in Norway
- one Trimble 5700 receiver from KMS in Denmark
- one Trimble 5700 receiver borrowed from Trimble Sweden
- one Leica SR530 receiver from Lantmäteriet in Sweden
- one Leica SR530 receiver borrowed from the University of Gävle

For Javad the antenna JavadLegAnt was used, for Trimble the antenna Zephyr was used and for Leica the antenna AT502 was used. All GSM cards were Swedish and used the telephone operator Telia's net.

In spite of that the Leica equipment worked together with all the modems, the other brands did not do that. In the end of Day 1, we finally got the Trimble equipment to work with one of the modems. The strange thing was that it only worked with the modem that first was configured for Leica. After we found out that, we switched the configuration for the modems so that the old Leica modem now became a new Trimble modem. And the Leica receiver still worked with all of the modems, so it was no problem making the old Trimble modem a new Leica modem. Also the Javad modem seemed to work in the end of Day 1. But next morning it didn't. So Jan and Gro could start to make test measurements with Javad first in the end of Day 2.

In the beginning of Day 2 there were still problems for Andreas and Louise with the Trimble receiver for GNSMART. One connection in a row worked out fine, but after that the modem must be re-configured. This means that it took more than double the time to perform one data set. Around noon this procedure was no longer needed, because this error was reported to Geo++ and from Germany something in the configuration was changed, which made the whole thing work.

During Day 3 and Day 4 it looked like everything proceeded well in field, but it wasn't with the GNSMART software and the Trimble receiver. That particular receiver could namely not use the RTCM-message 59, which contributed to that almost all of the fixed solutions at the points 3-7 for the combination Trimble-GNSMART were false fixed solutions. Notice that all these false fixed solutions have been removed from the results. After Day 2, the Trimble solutions were stored on a computer, and a comparison was made between some of the measurements on point 2 with the different softwares. Also one of the measurements on another point, which happened to be point 3, was compared. Unfortunately the compared measurement on point 3 with GNSMART happened to be one of the very few which was not a false solution. This means that the problem was not discovered before the test campaign was finished.

One more thing was not done completely satisfying, the height was not measured properly for the Javad equipment at the points 2, 3 and 5. Those points have small holes in the middle of the marker, and the antenna poles was stuck into the hole. For the Trimble (and later also for the Leica) equipment it was measured how deep into the hole the top of the pole got. For the Javad equipment it wasn't. Instead this has been estimated as an average of how deep the Trimble pole got into the holes of the points with holes. This was performed in the same period and the antenna poles were quite equal, so the contribution to the measured error in height should not be larger than 5 mm.

In week 45 and 46, Andreas Engfeldt, Daniel Johansson, Christina Lilje, Andreas Nilsson, Dan Norin, Peter Wiklund and Tina Kempe (all from Lantmäteriet) performed the Leica measurements. The influence from activities in the ionosphere and troposphere was much larger in these weeks, especially on the last measure day, the 14th of November, when Andreas N and Tina were out for six hours and only got four fixed solutions during those hours. Three of those also happened to be false fixed solutions, so they are removed from the results.

Together with the false fixed solutions for the combination Trimble-GNSMART as mentioned above, only false fixed solutions, which were considered as false fixed solutions out in the field are withdrawn from the results. For example, two of those occurred at point 3 with GNSMART and Leica. At that time GPSNet was working fine and GNSMART was behaving very strangely due to problems at the SWEPOS control centre. So when we finally got fixed solutions we didn't trust it and after a comparison in the field with the GPSNet solutions, and later also with a second GNSMART solution, we could already then exclude those two measurements.

In the beginning it was meant that three data sets with every GPS receiver brand and every network RTK software should be measured (one data set = 10 independent measurements, see above). But in the end, the number of performed data sets by the different brands of GPS receivers and network RTK softwares are listed in table 6.1.

Point	Javad		Leica		Trimble	
	GNSMART	GPSNet	GNSMART	GPSNet	GNSMART	GPSNet
1	2	2	2	2	3	2
2	2	2	4	4	3	3
3	1	1	4	4	3	3
4	2	2	4	4	3	2
5	2	2	3	3	3	3
6	2	2	4	4	3	3
7	2	2	4	4	3	3

Table 6.1: *Number of data sets performed by the different GPS receiver brands and network RTK softwares.*

In table 6.2 the number of observations recorded at the points with the different brands of GPS receivers and network RTK softwares are shown. For measurements performed without difficulties, the number of observations should be ten for each data set.

Point	Javad		Leica		Trimble	
	GNSMART	GPSNet	GNSMART	GPSNet	GNSMART	GPSNet
1	19	18	20	18	29	20
2	17	16	40	40	28	29
3	10	10	29	39	1	27
4	20	17	38	36	2	18
5	20	15	23	19	0	30
6	11	13	26	23	2	27
7	20	20	23	24	1	29

Table 6.2: *Number of observations recorded at the points with the different brands of GPS receivers and network RTK softwares.*

Looking at table 6.1 and 6.2, it feels necessary to point out that one data set for Leica with GNSMART at point 3 was completely rubbish, as well as one of the data sets at both point 6 and 7 for Leica with both the softwares.

7 Results

The results from the GNSMART/GPSNet test campaign are shown in table 7.1-7-6 and all results are given by the formula:

Measured value – Known value

Due to the problems with the combination Trimble-GNSMART described in chapter 6.1 (se also table 6.2), where only a few observations could be done on point 3-7, these results are shown separately.

		GNSMART, 67%	GNSMART, 95%	GPSNet, 67%	GPSNet, 95%
Javad	horizontal [mm]	19	34	19	42
	vertical [mm]	36	63	22	40
	time to float [s]	27	29	25	27
	time to fix [s]	36	174	36	180
Leica	horizontal [mm]	24	51	20	47
	vertical [mm]	39	103	28	66
	time to float [s]	29	33	34	35
	time to fix [s]	54	245	49	208
Trimble	horizontal [mm]			18	35
	vertical [mm]			18	50
	time to float [s]			43	50
	time to fix [s]			70	173

Table 7.1: *The results from the GNSMART/GPSNet test campaign without the results for the combination Trimble-GNSMART, due to that there are only a few observations on points 3-7 for this combination.*

		GNSMART, 67%	GNSMART, 95%	GPSNet, 67%	GPSNet, 95%
Trimble	horizontal [mm]	13	25		
	vertical [mm]	17	24		
	time to float [s]	45	65		
	time to fix [s]	69	113		

Table 7.2: *The results from the GNSMART/GPSNet test campaign for the combination Trimble-GNSMART, where there are only a few observations on points 3-7.*

		GNSMART, 67%	GNSMART, 95%	GPSNet, 67%	GPSNet, 95%
Totally	horizontal [mm]	21	47	20	50
	vertical [mm]	35	98	24	64
	time to float [s]	29	46	35	47
	time to fix [s]	59	210	60	193

Table 7.3: *The total results from the GNSMART/GPSNet test campaign.*

The coordinates in SWEREF 99 for all measurements in all data sets were compared with the true values. Table 7.1-7.3 shows the horizontal and vertical deviations and also the initialisation times for the measurements with Leica, Javad, Trimble and Totally. The tables include the measurements with both GNSMART and GPSNet. Notice that all solutions with a bigger deviation than 2 decimetres have been considered as outliers and have been removed from tables 7.1-7.6. Totally there were 9 outliers with GNSMART (excluding the Trimble GNSMART combination, which includes many false fix solutions, because of the lack of RTCM message 59) and 9 outliers with GPSNet. This means that the total number of observations which are used for the tables 7.1-7.6 are 370 with GNSMART and 479 with GPSNet.

		GNSMART latitude	GNSMART longitude	GNSMART height	GPSNet latitude	GPSNet longitude	GPSNet height
Javad	Std [mm]	14	12	25	15	14	21
	RMS [mm]	14	13	34	16	14	21
	Mean [mm]	0	-5	-24	5	-4	4
Leica	Std [mm]	20	21	41	20	17	31
	RMS [mm]	21	21	50	20	17	33
	Mean [mm]	-4	3	-28	0	-2	-11
Trimble	Std [mm]				19	10	26
	RMS [mm]				19	10	26
	Mean [mm]				4	-2	2

Table 7.4: *The standard deviations and the RMS-values from the GNSMART/GPSNet test campaign, without the results for the combination Trimble-GNSMART due to that there are only a few observations on points 3-7 for this combination.*

		GNSMART latitude	GNSMART longitude	GNSMART height	GPSNet latitude	GPSNet longitude	GPSNet height
Trimble	Std [mm]	11	6	11			
	RMS [mm]	11	6	15			
	Mean [mm]	3	-2	11			

Table 7.5: *The standard deviations and the RMS-values from the GNSMART/GPSNet test campaign for the combination Trimble-GNSMART, where there are only a few observations on points 3-7.*

		GNSMART latitude	GNSMART longitude	GNSMART height	GPSNet latitude	GPSNet longitude	GPSNet height
Totally	Std [mm]	17	17	36	19	14	28
	RMS [mm]	18	17	41	19	14	28
	Mean [mm]	-2	0	-20	2	-2	-3

Table 7.6: *The total standard deviations the RMS-values from the GNSMART/GPSNet test campaign.*

Table 7.4-7.6 show the different standard deviations for the receiver brands for the latitude, longitude and vertically. The results from the Trimble-GNSMART combination (table 7.2 and 7.5) can be taken with a bit of salt (see chapter 6.1 and table 6.2).

Graphs showing details about the results can be found in appendix A.

8 Small test campaign with GNSMART in a sparse network

To see which results can be obtained with network RTK and GNSMART in a network with longer distances between the reference stations than normal, a small test campaign with GNSMART was performed during five days in December 2002-January 2003.

As reference stations for this small test campaign, the SWEPOS™ stations used for the production project with network RTK called Position Stockholm-Mälaren-2 were used (figure 2.1). To make the network more sparse, seven stations were excluded, namely Östervåla, Almunge, Västerås, Lovö, Nynäshamn, Norrköping and Björneborg (figure 8.1).

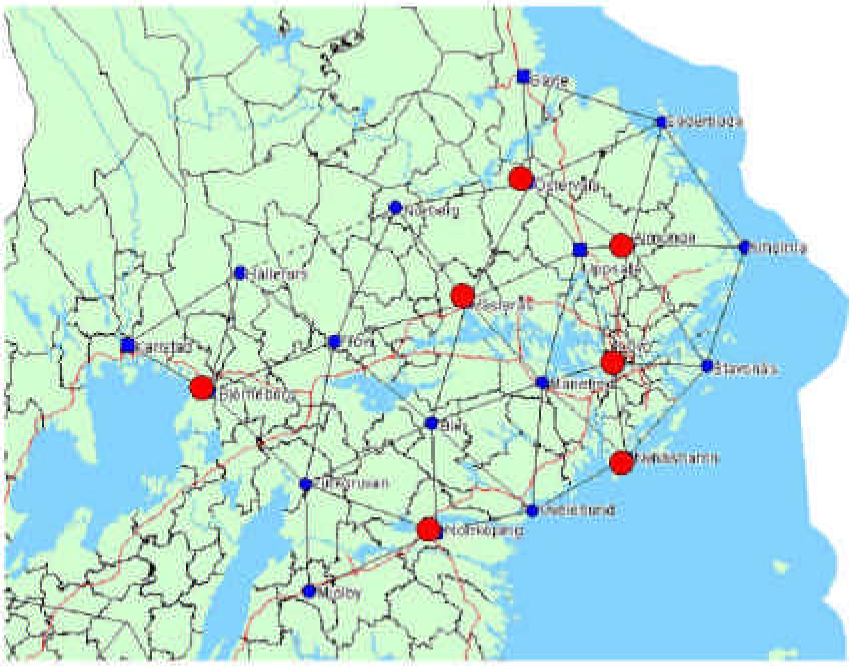

Figure 8.1: *The network used for the small test campaign in a sparse network. Reference stations marked with a large dot were excluded.*

8.1 The test area

The test area consists of four points (A-D), between Uppsala and Västerås. There are accurate coordinates in SWEREF 99 for all four points and these coordinates have been considered as true coordinates during the test campaign. The points have been measured with static GPS in the ongoing project RIX 95, which among others has the aim to densify the national horizontal geodetic control network in Sweden (Andersson, 2002). Point A is situated south-west of Uppsala, point D in Västerås and point B and C are in between. All four points are firmly marked in bedrock or in large stones and are situated at the distances 7 km, 31 km, 42 km, and 56 km from the nearest reference station in the sparse network. Some distances between reference stations around the four points are 96 km (Norberg-Uppsala), 115 km (Norberg-Mariefred) and 108 km (Frövi-Mariefred).

8.2 Test measurements and test procedures

One brand of GPS receiver was used for the test measurements in the test area, Leica SR 530 together with the AT502 antenna. A tripod was used to set up and carefully level the equipment over the points. For the distribution of data from SWEPOS™ control centre in Gävle, a GSM modem was used.

All data have been collected in SWEREF 99 and all comparisons have been made between plane coordinates and ellipsoidal heights. On every point four to ten independent measurements were carried out forming one data set, where power was turned off between every single measurement. A number of data sets have been carried out, but during three of them, data from the reference station Bie was not used due to that a wrong receiver type was indicated. This made the network during this period even more sparse than planned. Measurements were performed in all kind of conditions concerning satellite availability etc. and were carried out by Dan Norin from Lantmäteriet.

Initialisation times (both for float and fixed solutions) were recorded and written down manually. DOP-values, number of satellites, internal accuracy values and coordinates in SWEREF 99 for the fixed solutions with point numbers were recorded on the memory card of the GPS receiver. The measurements were terminated and no observations were recorded if a fixed solution was not attained within six or slightly more than six minutes. The elevation mask was set to 13 degrees.

In tables 8.1 and 8.2 the number of performed data sets and the number of observations at the different points are listed. It is also shown how many of the observations that were fixed or float solutions.

Point	Distance (km)	Data sets	Observations	Fixed solutions	Float solutions
A	7	1	7	6	1
B	31	3	18	3	15
C	42	1	10	6	4
D	56	1	4	0	4
	Totally	6	39	15	24

Table 8.1: *Number of data sets and observations performed in the network* ***with*** *the reference station Bie. Distance indicates the distance to the nearest reference station.*

Point	Distance (km)	Data sets	Observations	Fixed solutions	Float solutions
A	7	0	-	-	-
B	31	1	10	1	9
C	42	1	8	3	5
D	56	1	7	1	6
	Totally	3	25	5	20

Table 8.2: *Number of data sets and observations performed in the network* ***without*** *the reference station Bie. Distance indicates the distance to the nearest reference station.*

8.3 Results

		67%	95%	Mean value	Standard d.	RMS
With Bie	horizontal [mm]	28	45	-	-	-
	latitude [mm]	-	-	-3	19	18
	longitude [mm]	-	-	-13	14	19
	vertical [mm]	70	107	-57	33	65
	time to float [s]	29	32	-	-	-
	time to fix [s]	158	369	-	-	-
Without Bie	horizontal [mm]	63	129	-	-	-
	latitude [mm]	-	-	49	35	58
	longitude [mm]	-	-	50	38	61
	vertical [mm]	149	208	48	154	145
	time to float [s]	29	30	-	-	-
	time to fix [s]	70	123	-	-	-

Table 8.3: *The results from the small GNSMART test campaign in a sparse network.*

The coordinates in SWEREF 99 for all observations with fixed solutions in all data sets were compared with the true values. Table 8.3 shows the horizontal and vertical deviations and also the initialisation times for the measurements. The table is divided in two parts, one for the observations performed in the network with the reference station Bie and one for the observations performed in the network without it.

Furthermore the mean values, standard deviations and RMS-values for latitude, longitude and height are listed. Graphs showing details about the results can be found in appendix A (graph 35-42).

9 Conclusions

9.1 Conclusions for the GNSMART/GPSNet test campaign

From table 7.1 and 7.3 we can make the conclusion that there is no big difference in accuracy or initialisation times between the two network RTK softwares in our test area. One difference that could be noticed in the field was that GNSMART in general used one more satellite than GPSNet, although GPS receivers of the same brand were connected to the same GPS antenna.

The mean values in table 7.4 and 7.5 shows that the vertical deviations for measurements with GNSMART together with Leica and Javad are systematically too low and that the vertical deviations for measurements together with Trimble are slightly systematically too high. This can also be noticed in graph 8, 10, 12, 14, 16, 18 and 20 in Appendix A Probably the antenna models for GNSMART have not modelled the antennas in a correct way. This leads to a degradation of the vertical values for GNSMART in table 7.1-7.6.

When comparing the results for the different brands of GPS receivers, some values for Leica are higher than for Trimble and Javad. Especially since the atmospheric activity was much higher during the period when the Leica measurements were performed, it is however not possible to say that there are any differences between the different brands of GPS receivers.

9.2 Conclusions for the sparse network

The number of observations performed in the test campaign in a sparse network with GNSMART and a Leica receiver is not large, which makes it difficult to draw any certain conclusions. The results in table 8.3 shows however that it takes a long time to get a fixed solution, if you will get one at all. This is especially clear in the case with the network without the reference station Bie. Two of the five days when the measurements took place coincided however with high ionospheric activities and during these days it was more difficult to get fixed solutions than during the other days.

If you finally get a fixed solution it is usually quite acceptable in the case with the network where the reference station Bie was included. The horizontal values in table 8.3 are comparable with the values for the actual test campaign in table 7.1-7.6. The vertical values are a bit worse and here we also have the same height problem with systematically too low height values. This problem can be seen by the high vertical mean value (-57 mm) and the rather low vertical standard deviation (33 mm) and can also be noticed in graphs 36, 38, 40 and 42 in appendix A.

The few fixed solutions that were attained in the case with the network without the reference station Bie were however rather bad. They could sometimes be seen as false fixed solutions.

10 References

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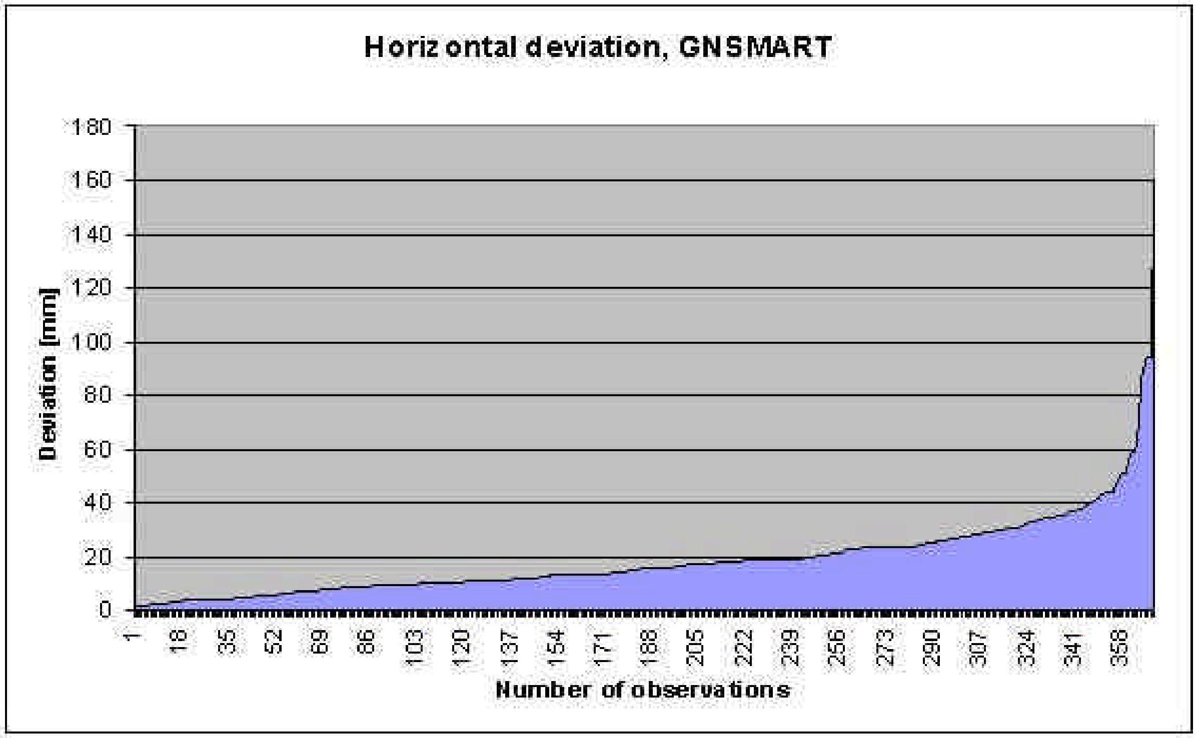
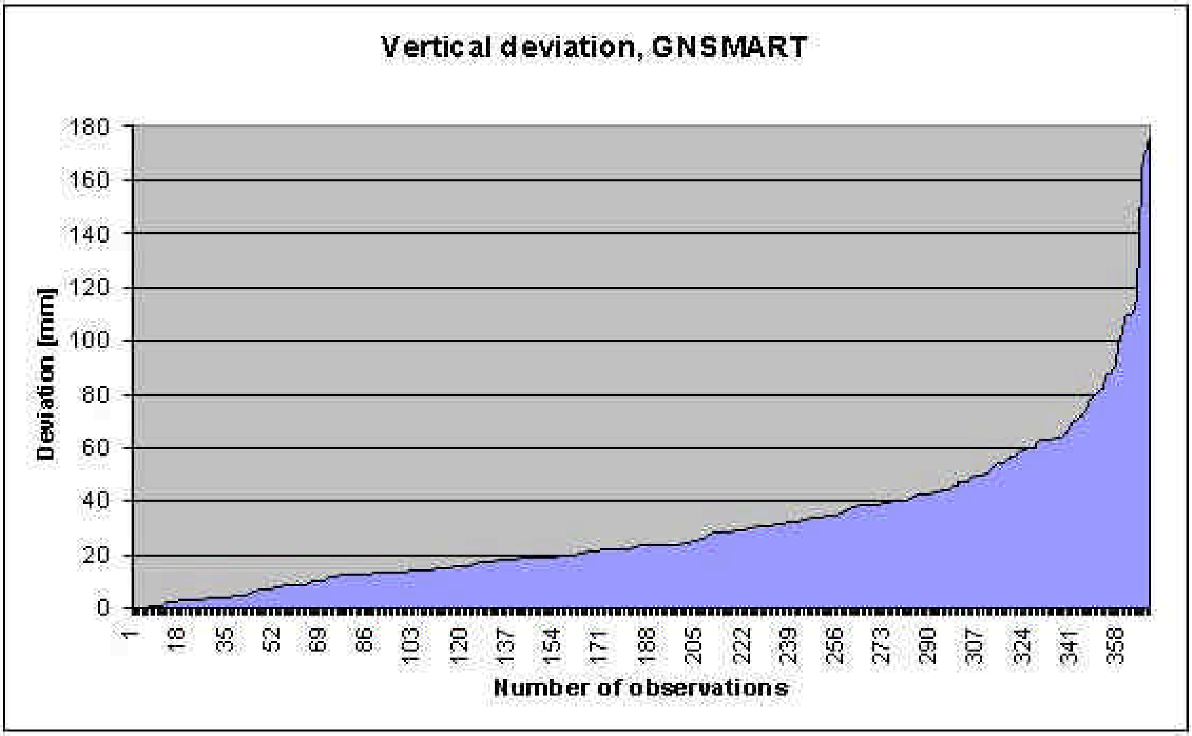
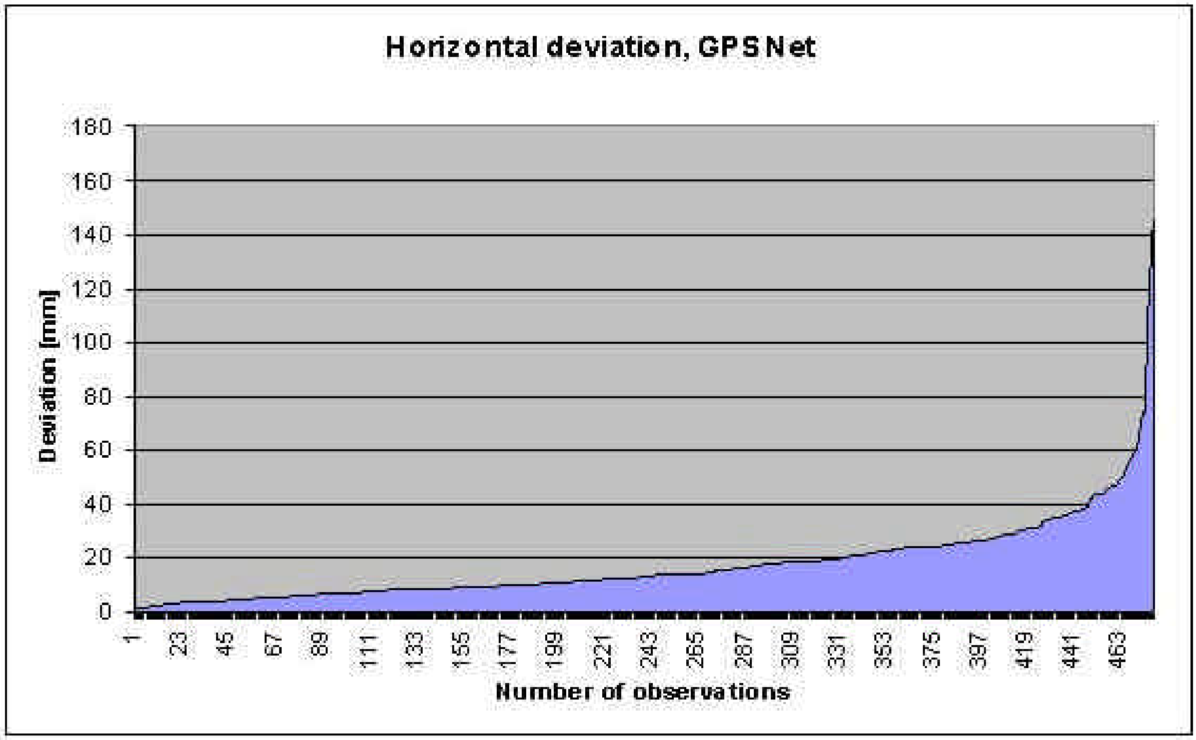
Appendix A Graphs



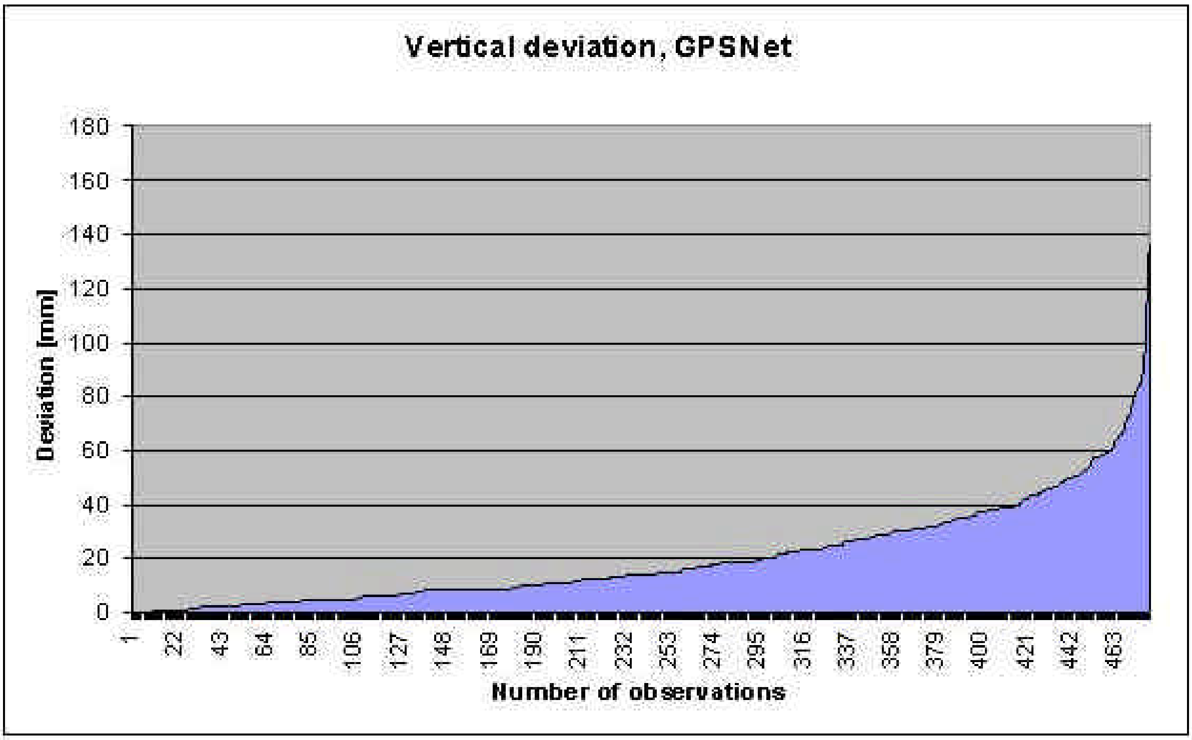
Graph 1: *The horizontal deviation for GNSMART. All the values are sorted.*



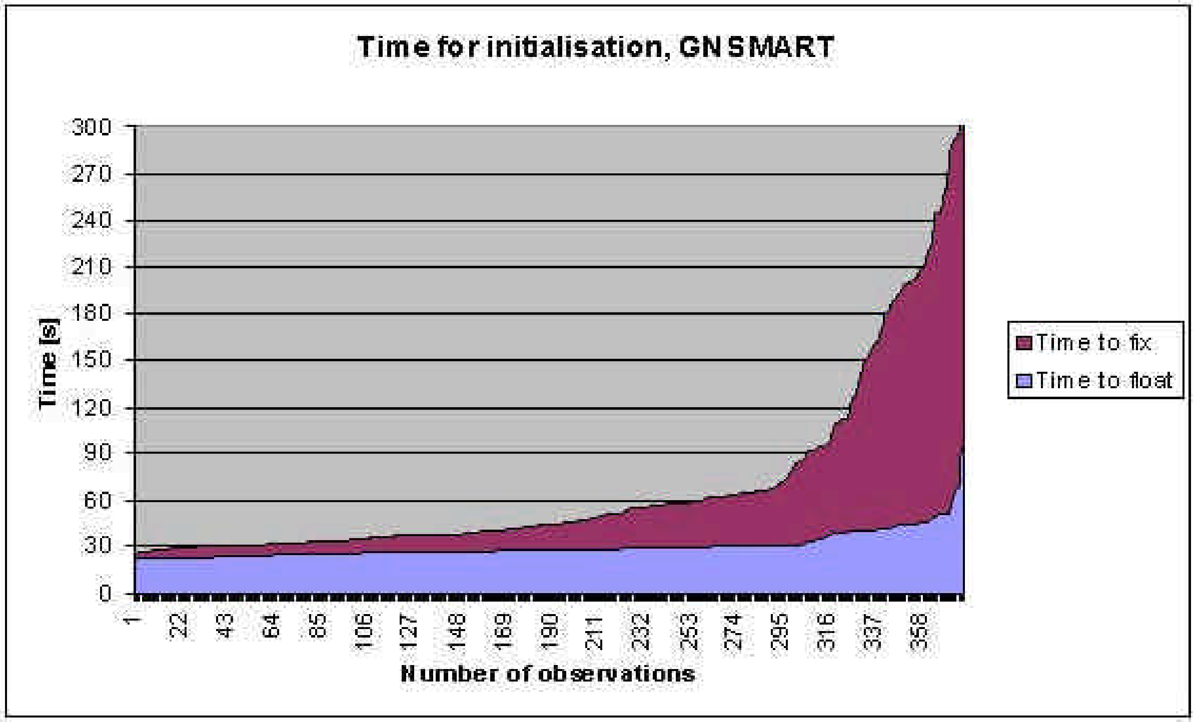
Graph 2: *The vertical deviation for GNSMART. All the values are sorted.*



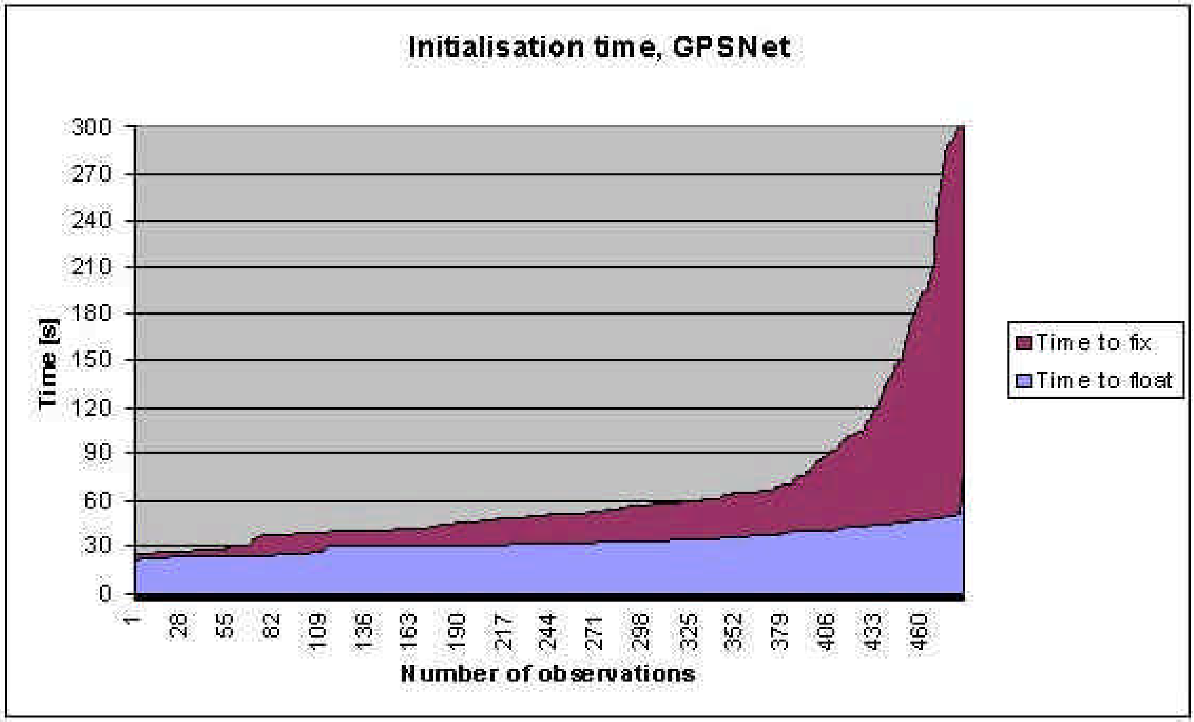
Graph 3: *The horizontal deviation for GPSNet. All the values are sorted*



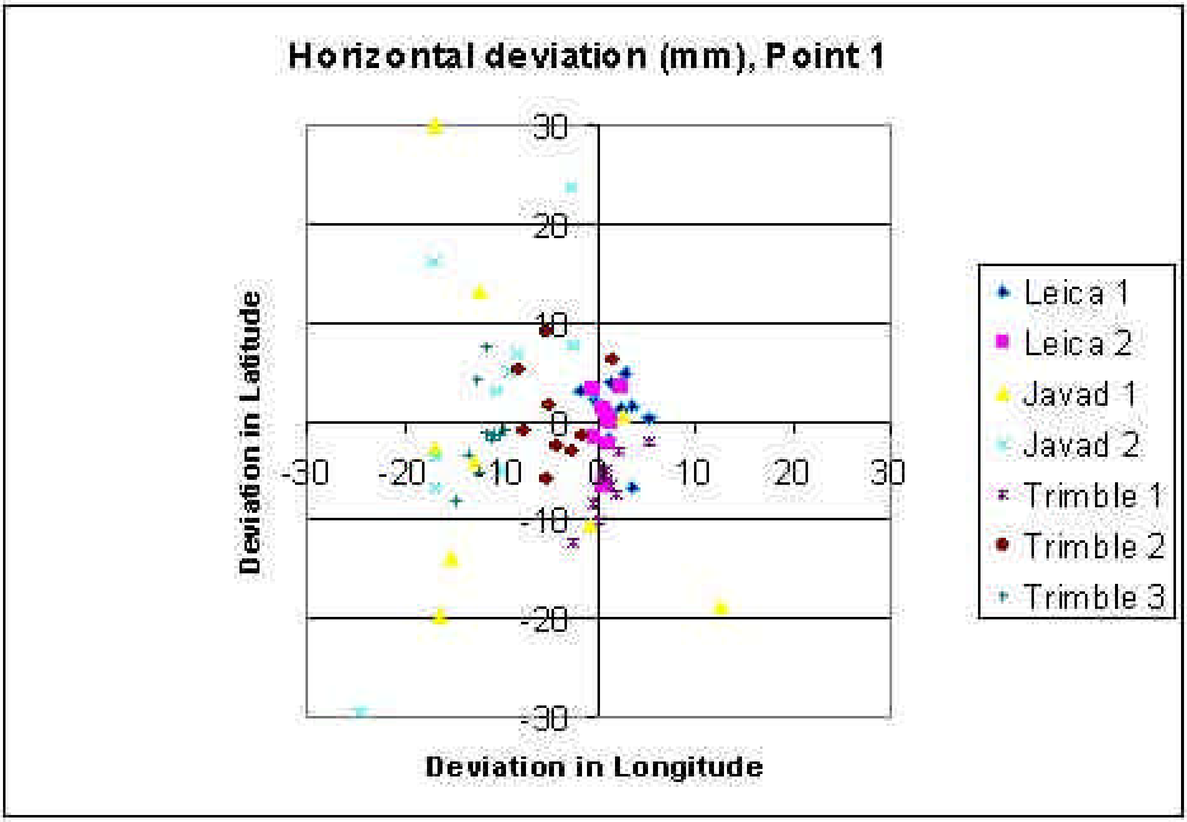
Graph 4: *The vertical deviation for GPSNet. All the values are sorted*



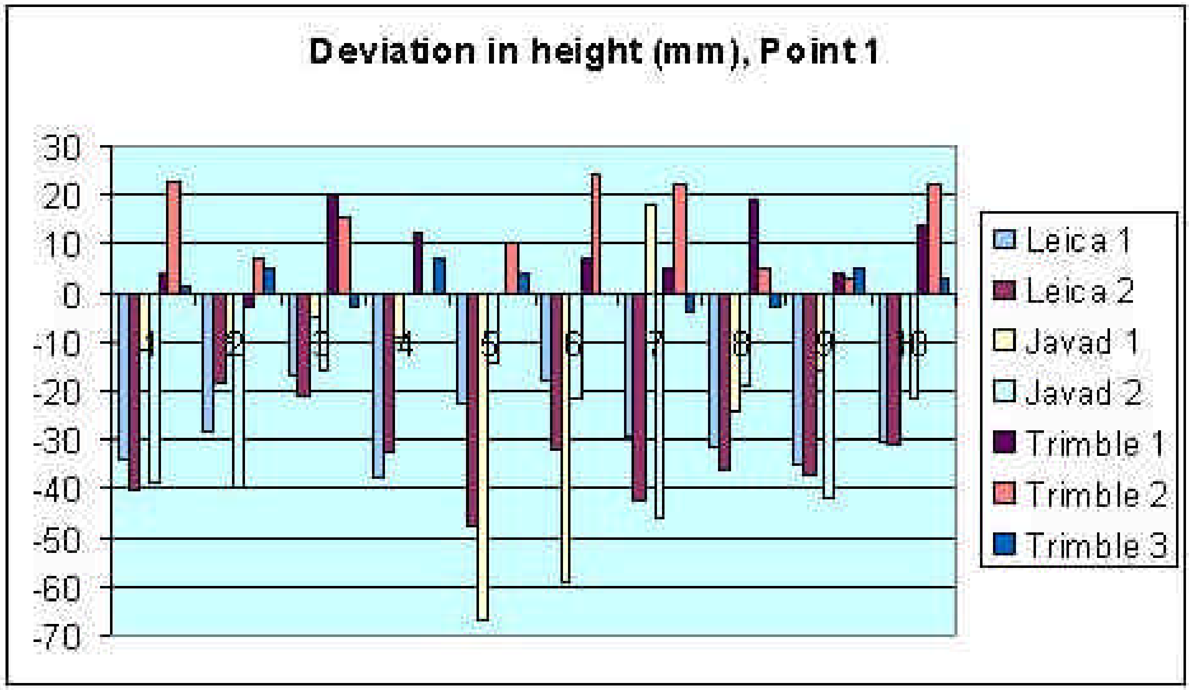
Graph 5: *The initialisation times for GNSMART. Both time to float solution and time to fixed solution is shown. All the values are sorted*



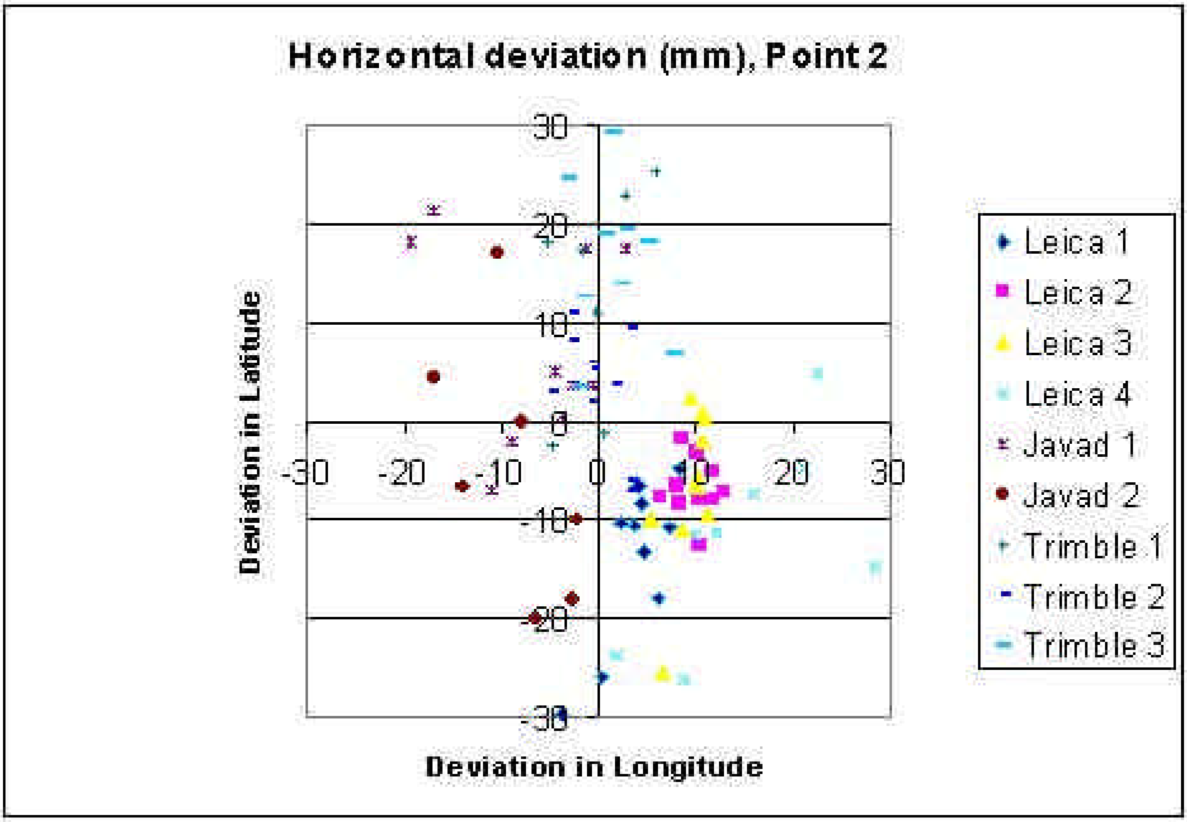
Graph 6: *The initialisation times for GPSNet. Both time to float solution and time to fixed solution is shown. All the values are sorted*



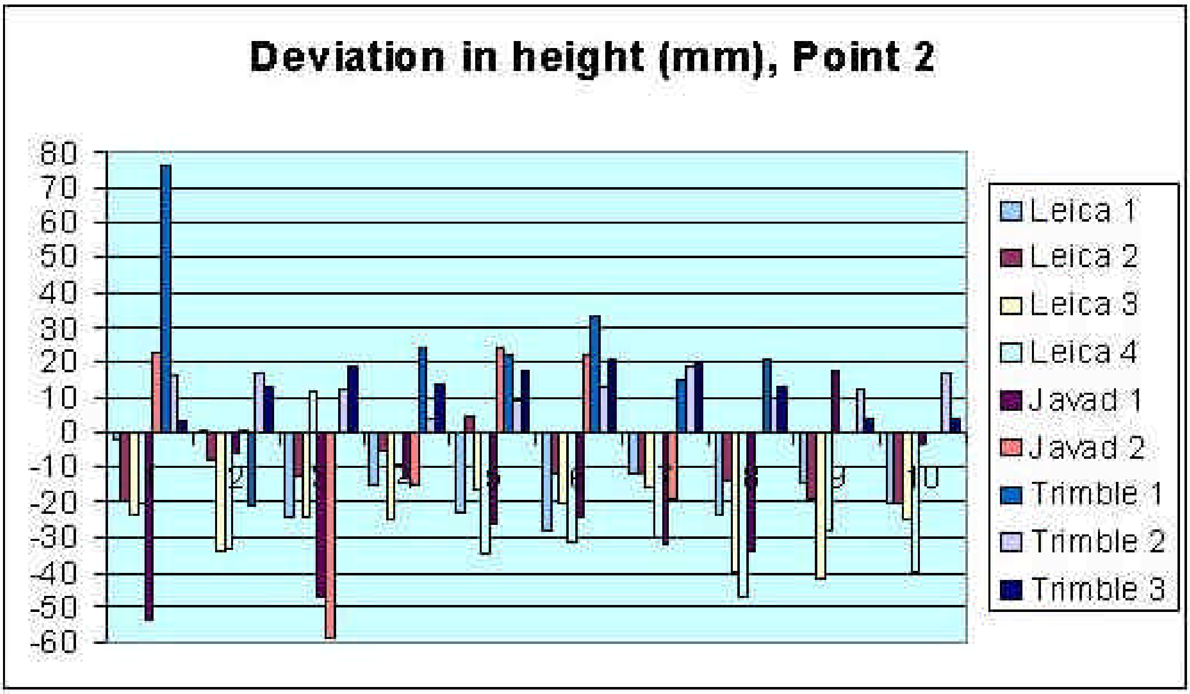
Graph 7: *The horizontal deviation at point 1 for GNSMART.*



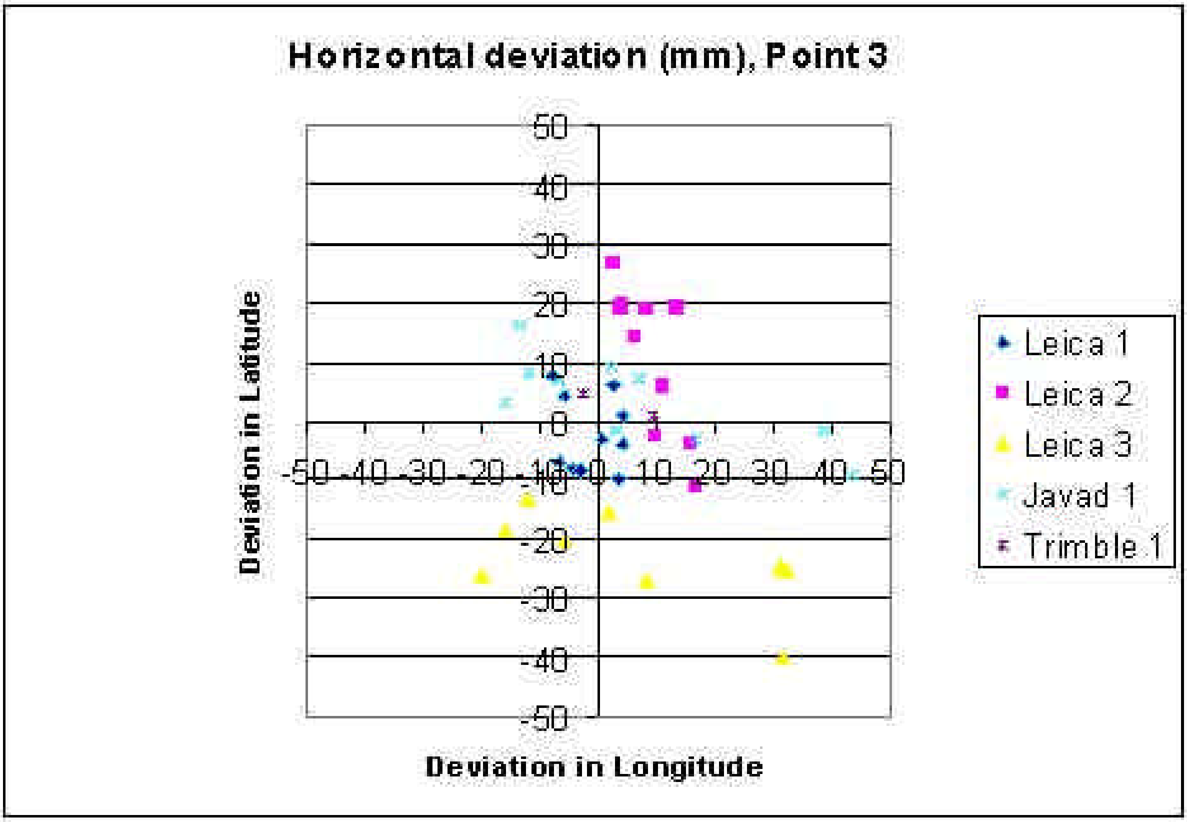
Graph 8: *The deviation in height at point 1 for GNSMART.*



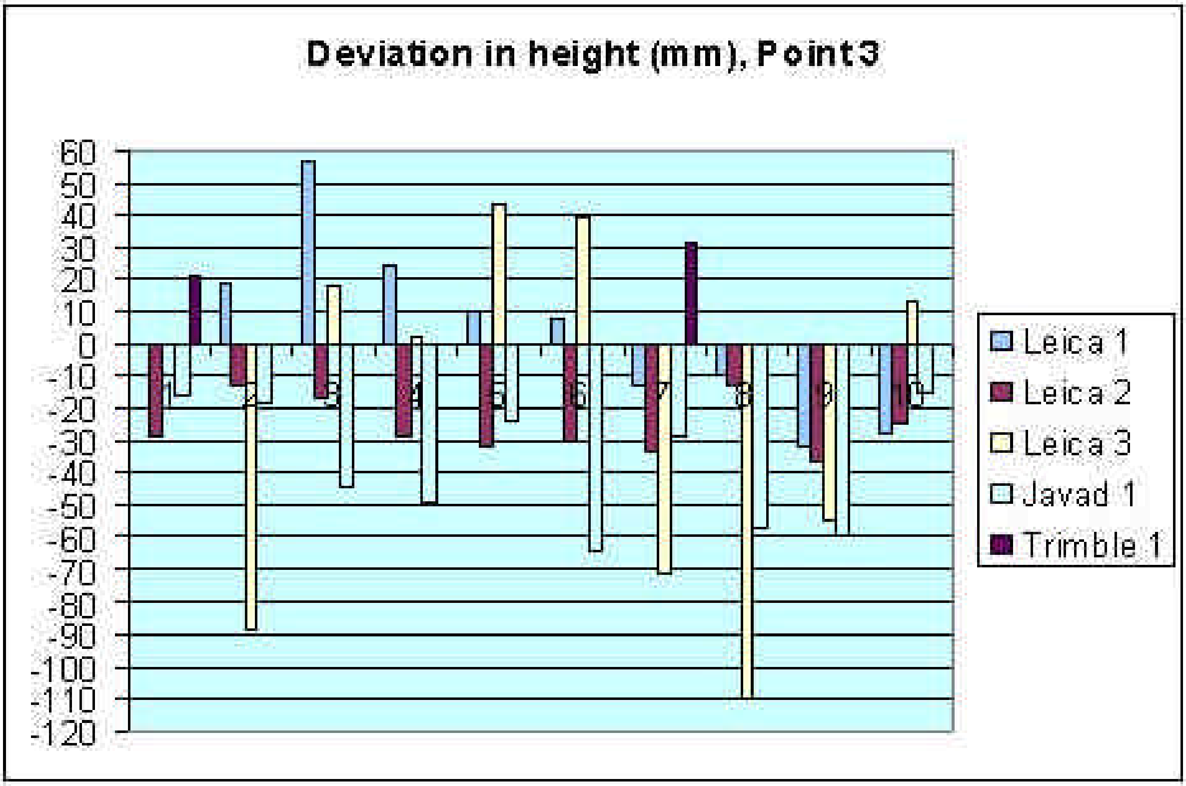
Graph 9: *The horizontal deviation at point 2 for GNSMART.*



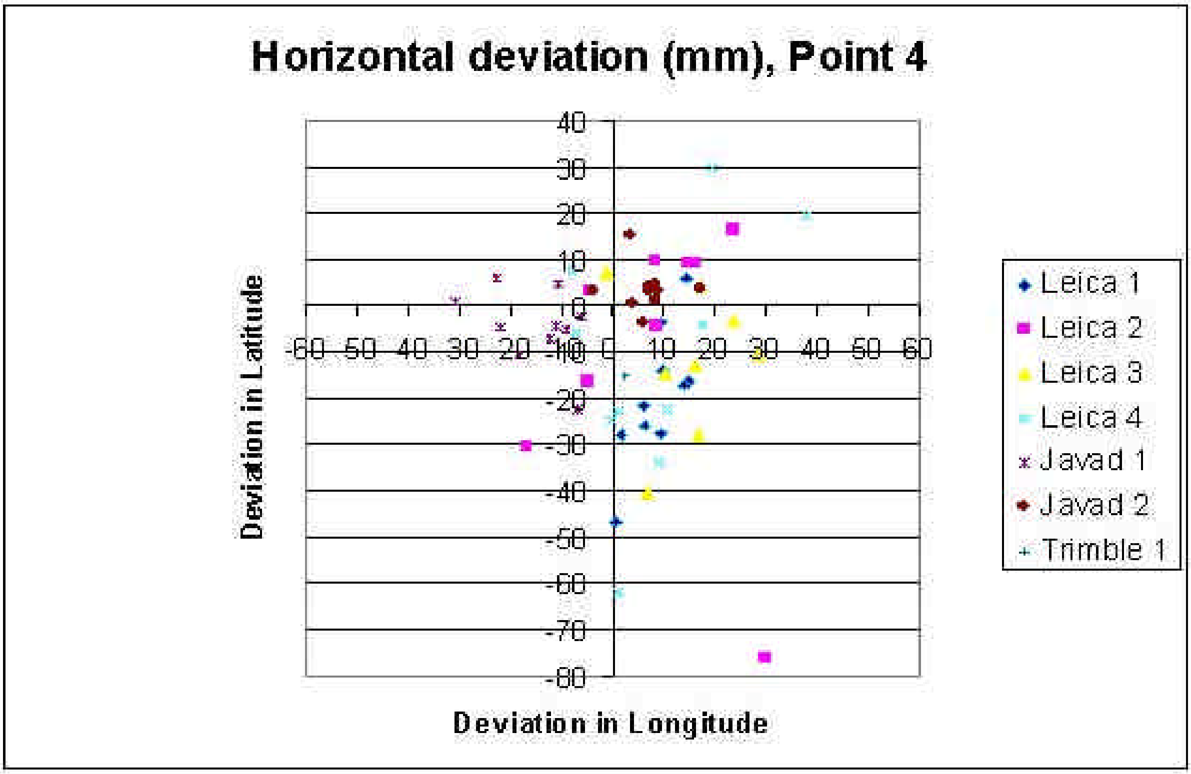
Graph 10: *The deviation in height at point 2 for GNSMART.*



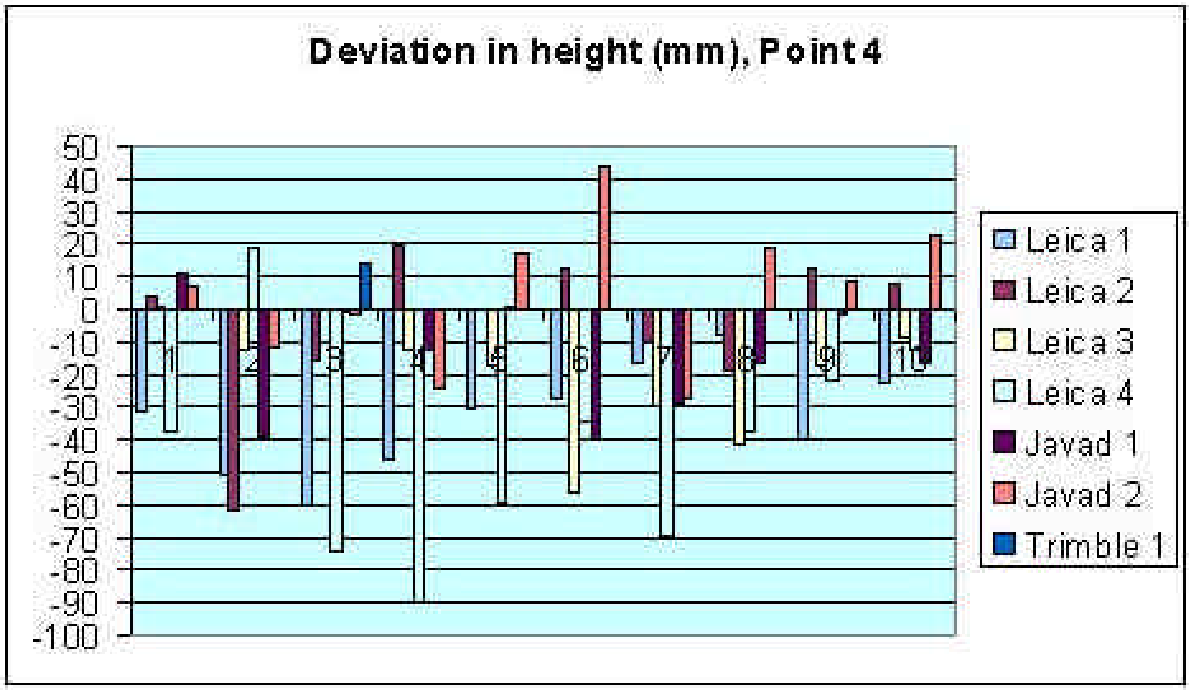
Graph 11: *The horizontal deviation at point 3 for GNSMART.*



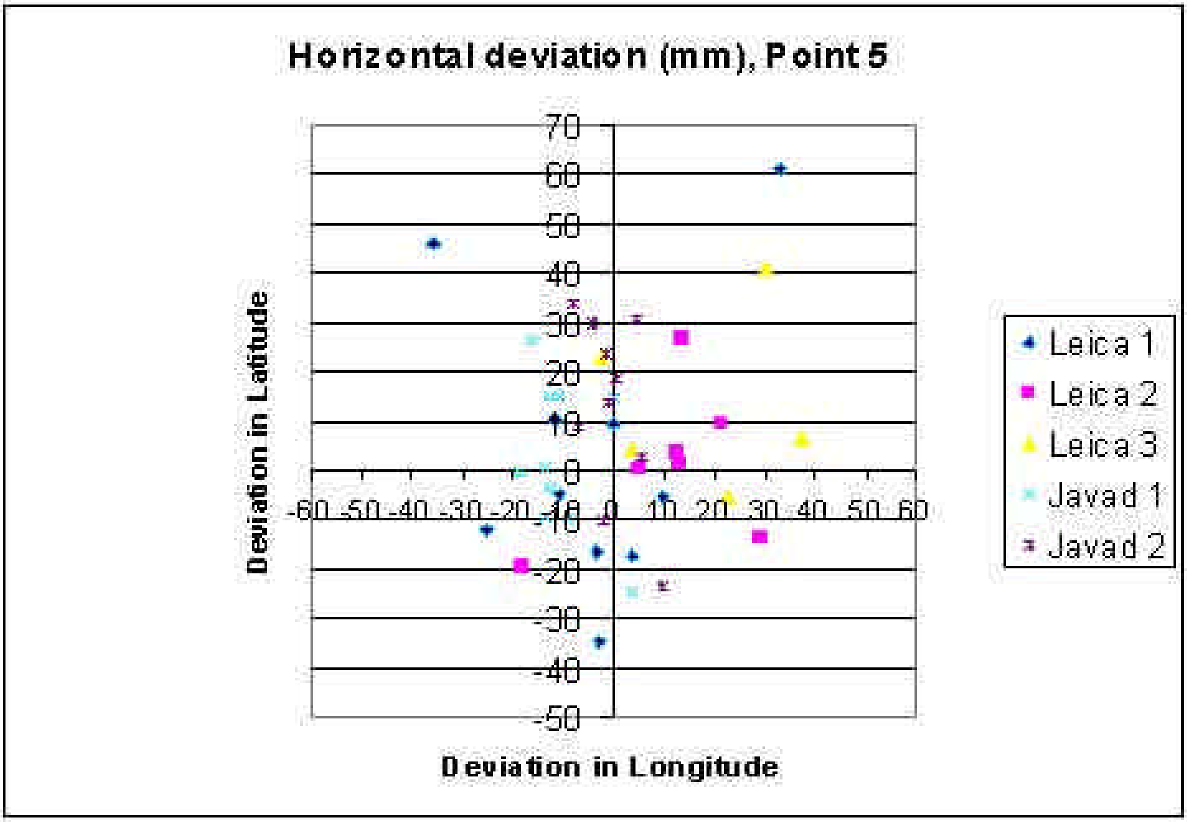
Graph 12: *The deviation in height at point 3 for GNSMART.*



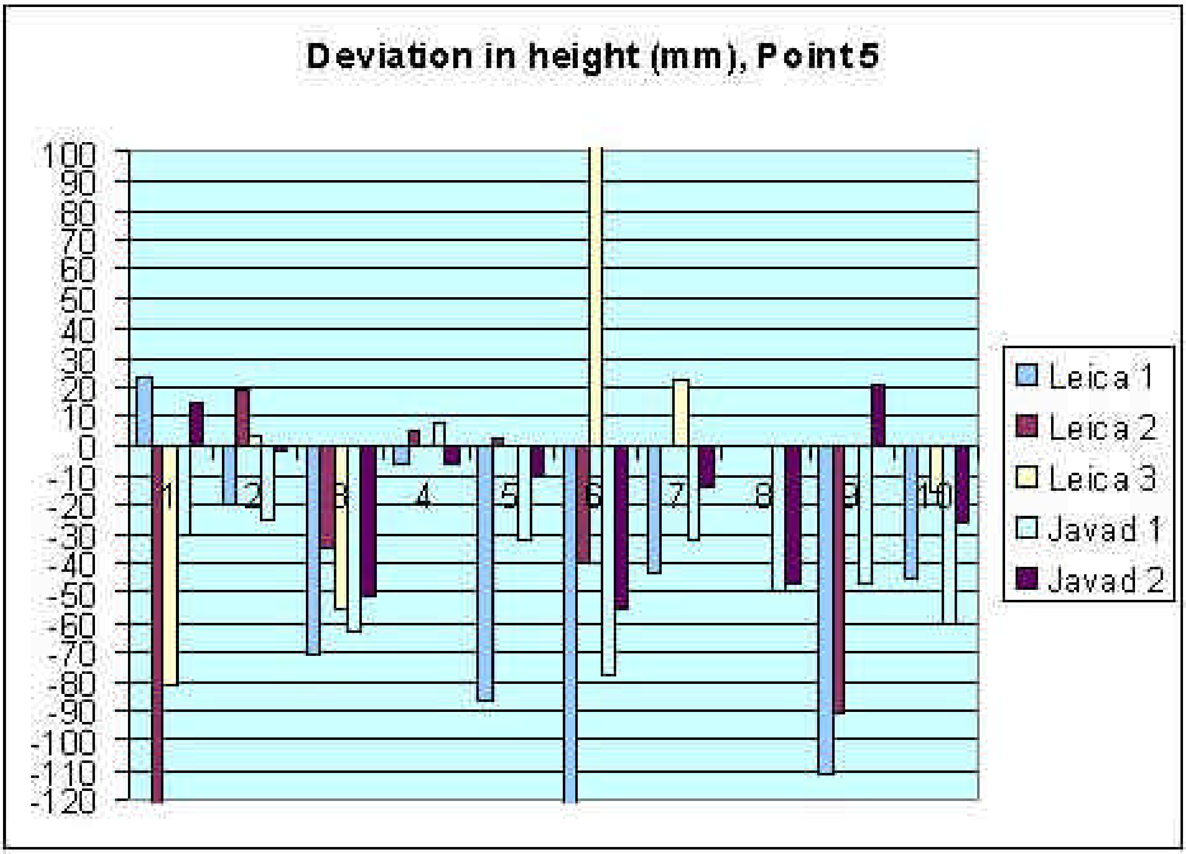
Graph 13: *The horizontal deviation at point 4 for GNSMART.*



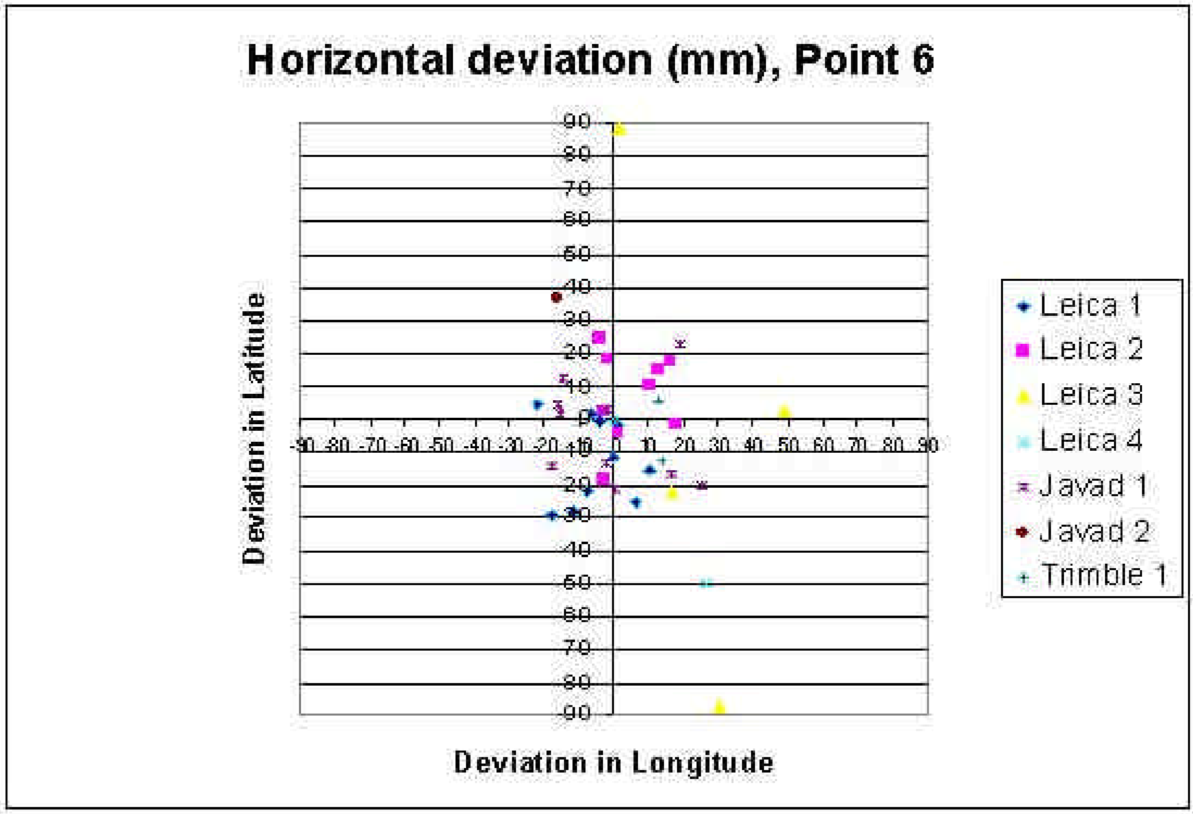
Graph 14: *The deviation in height at point 4 for GNSMART.*



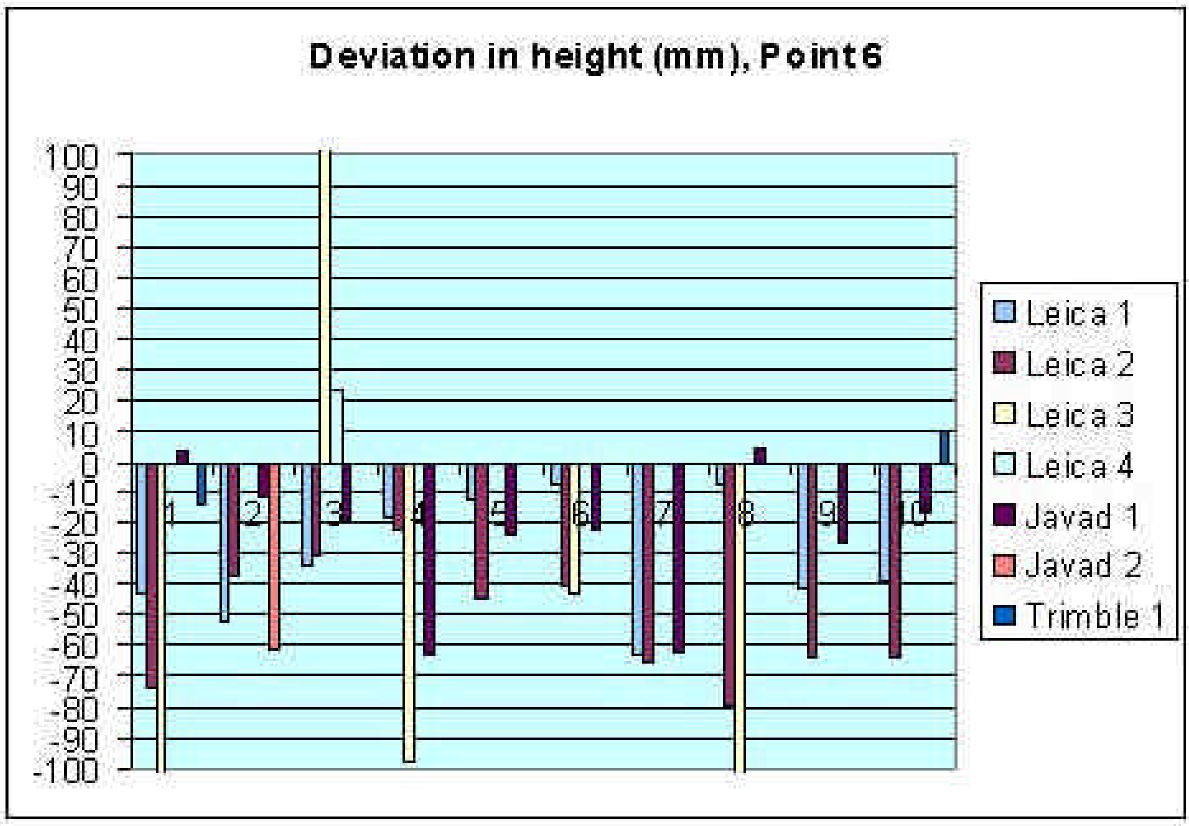
Graph 15: *The horizontal deviation at point 5 for GNSMART.*



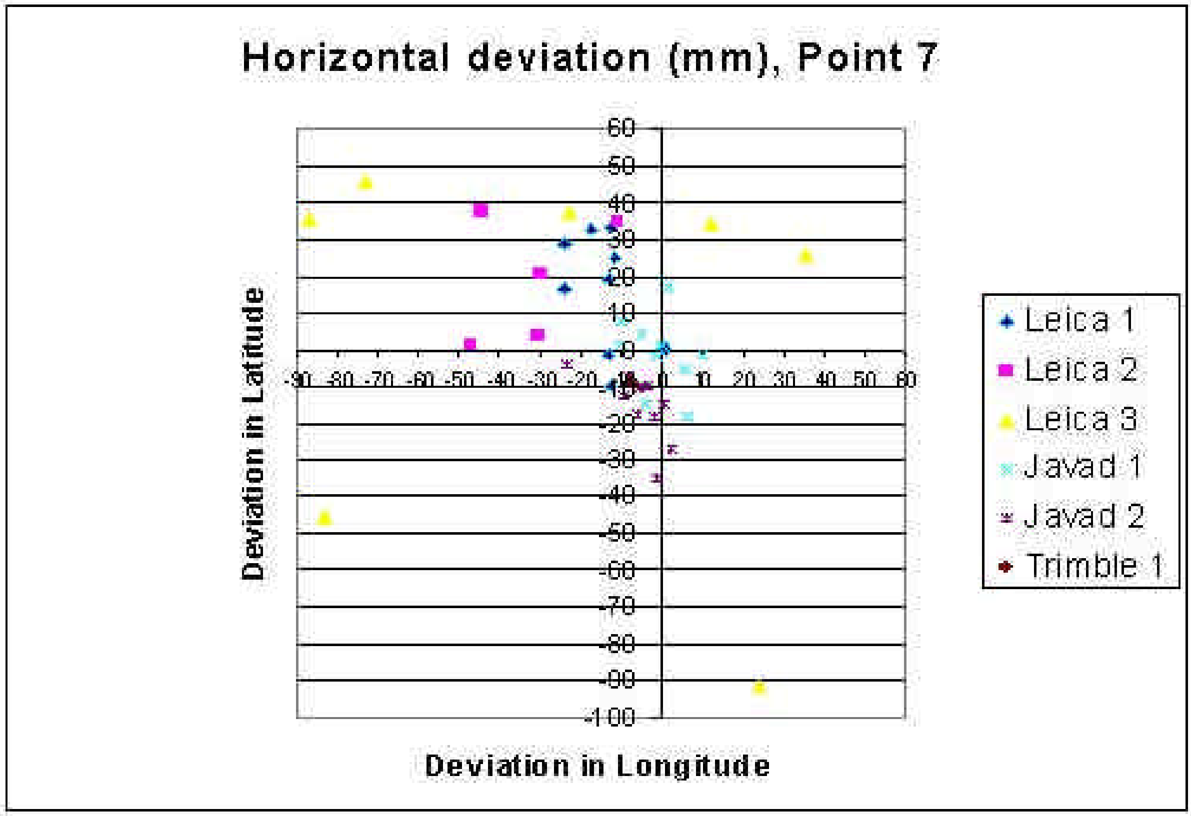
Graph 16: *The deviation in height at point 5 for GNSMART.*



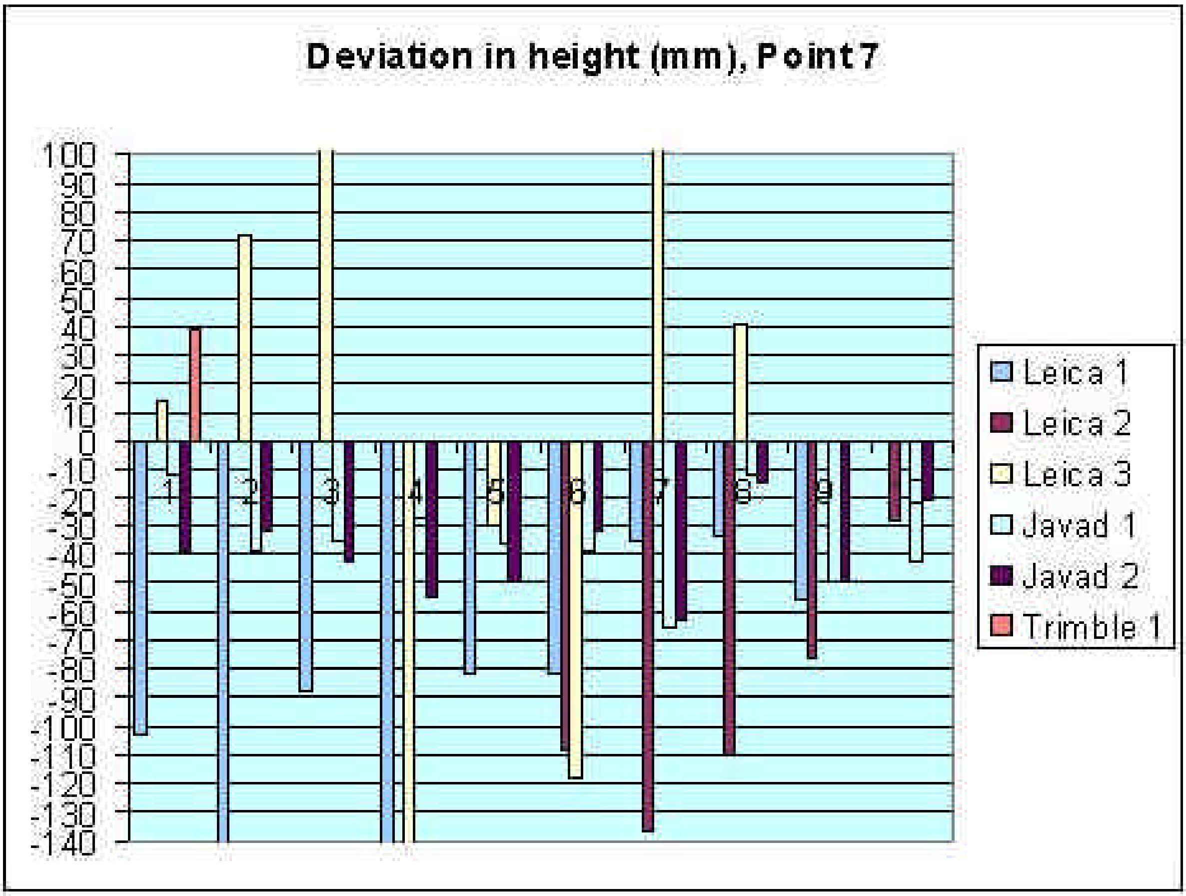
Graph 17: *The horizontal deviation at point 6 for GNSMART.*



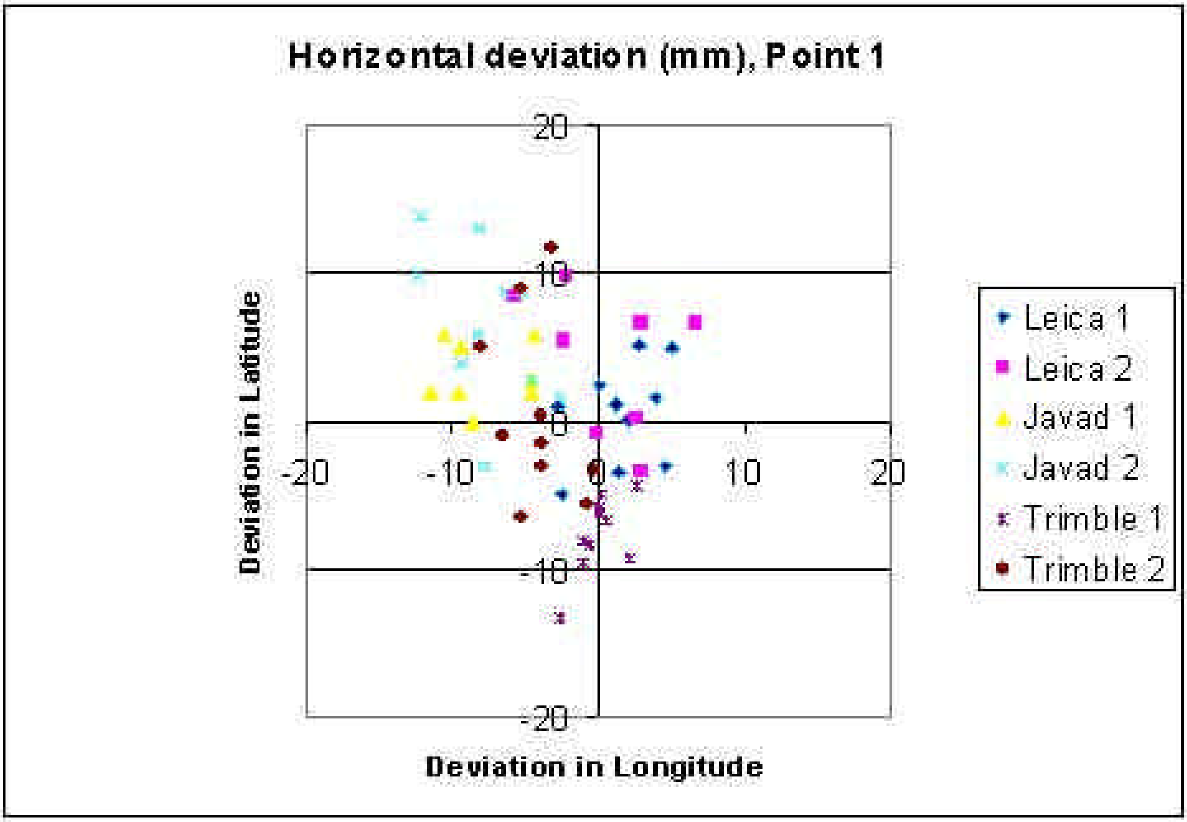
Graph 18: *The deviation in height at point 6 for GNSMART.*



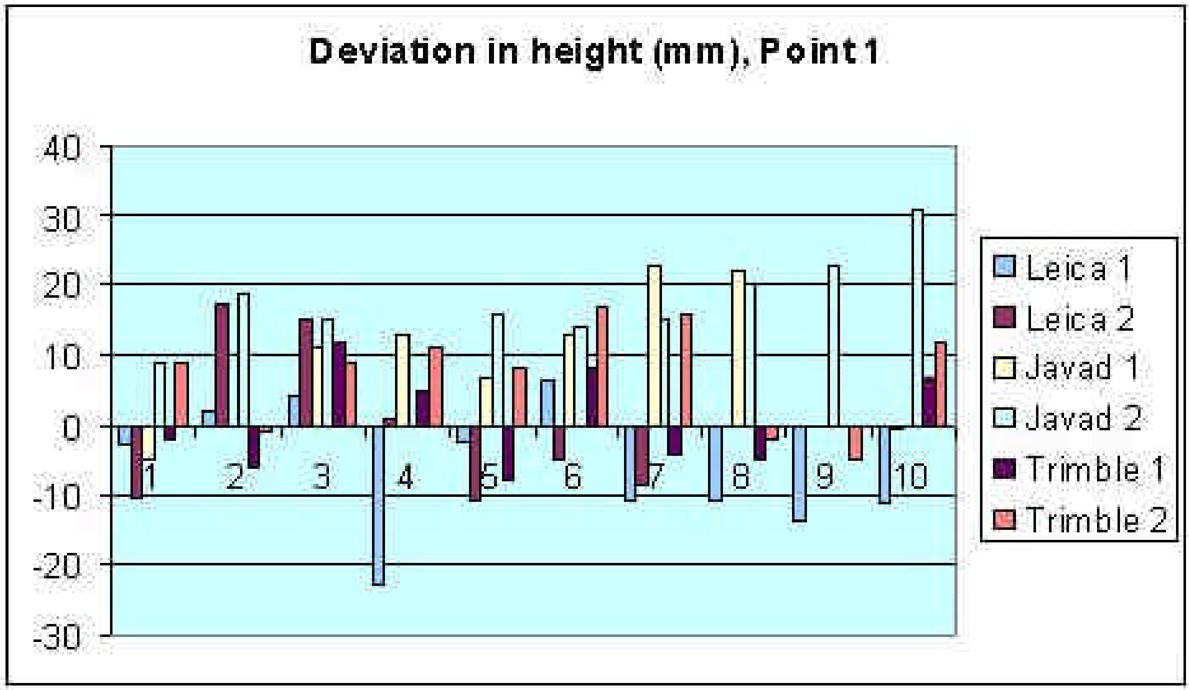
Graph 19: *The horizontal deviation at point 7 for GNSMART.*



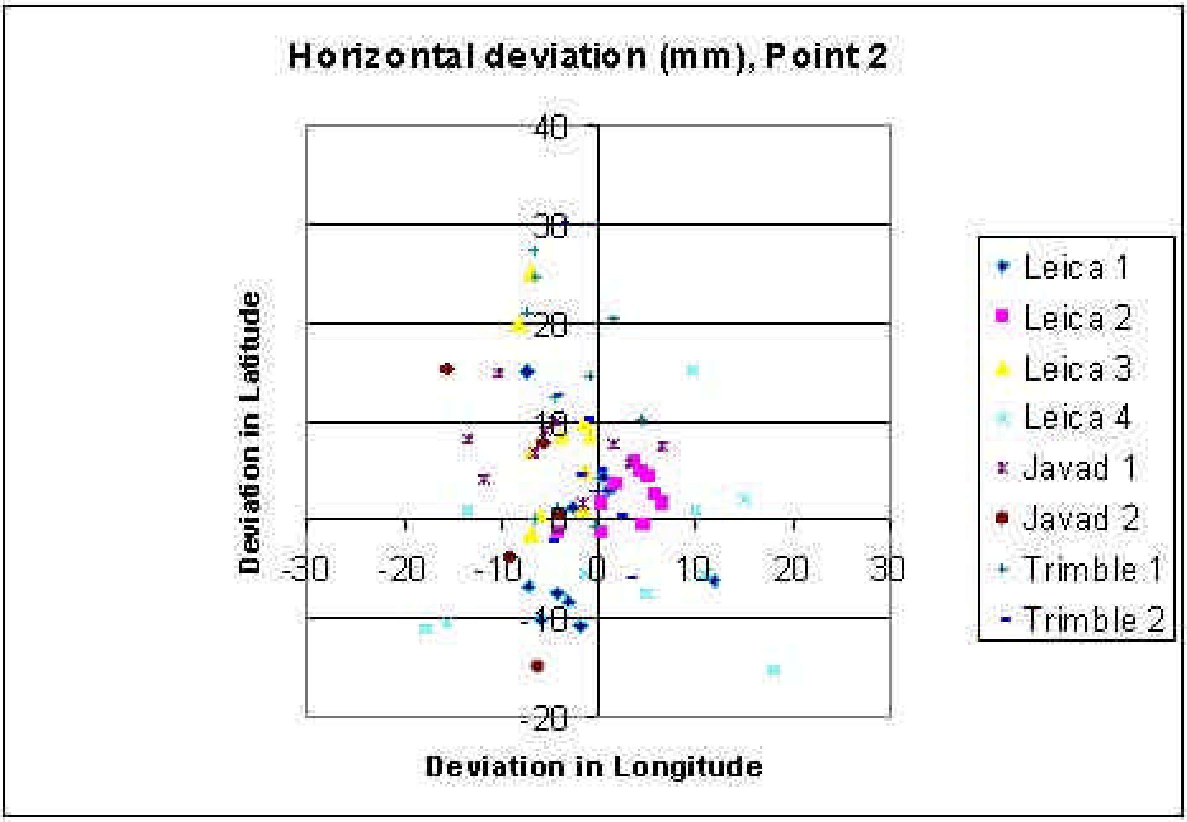
Graph 20: *The deviation in height at point 7 for GNSMART.*



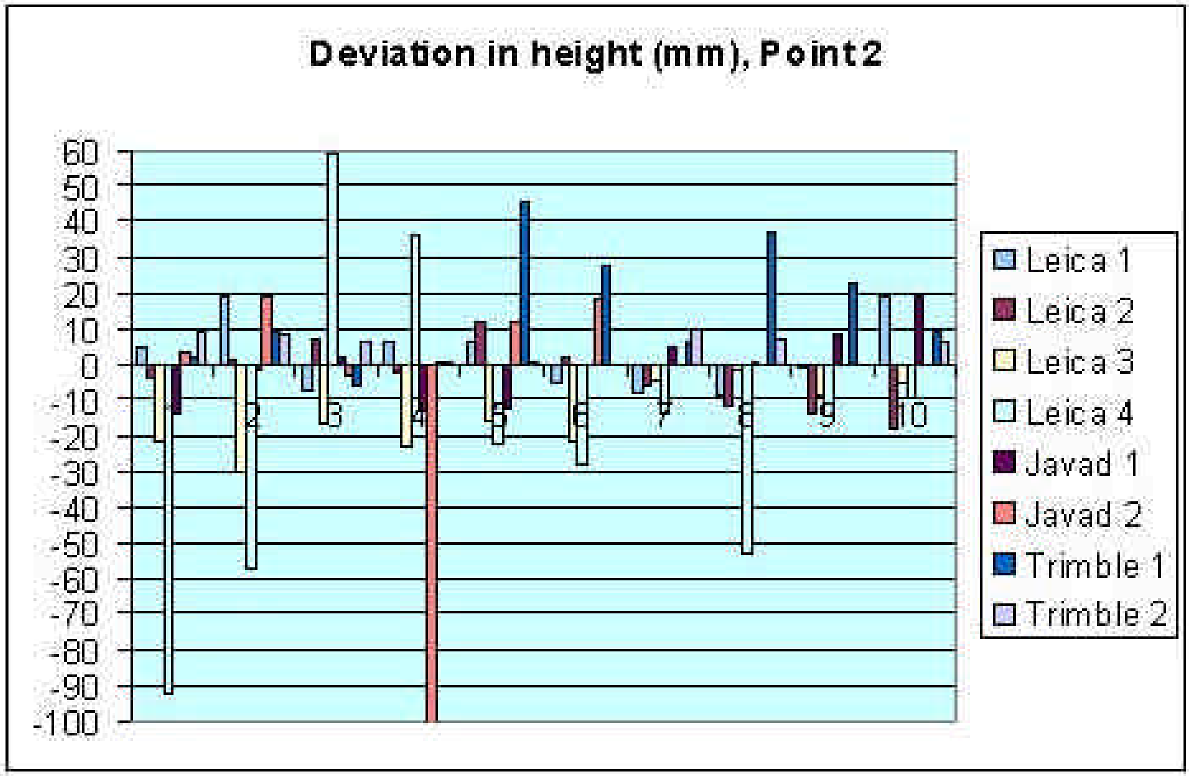
Graph 21: *The horizontal deviation at point 1 for GPSNet.*



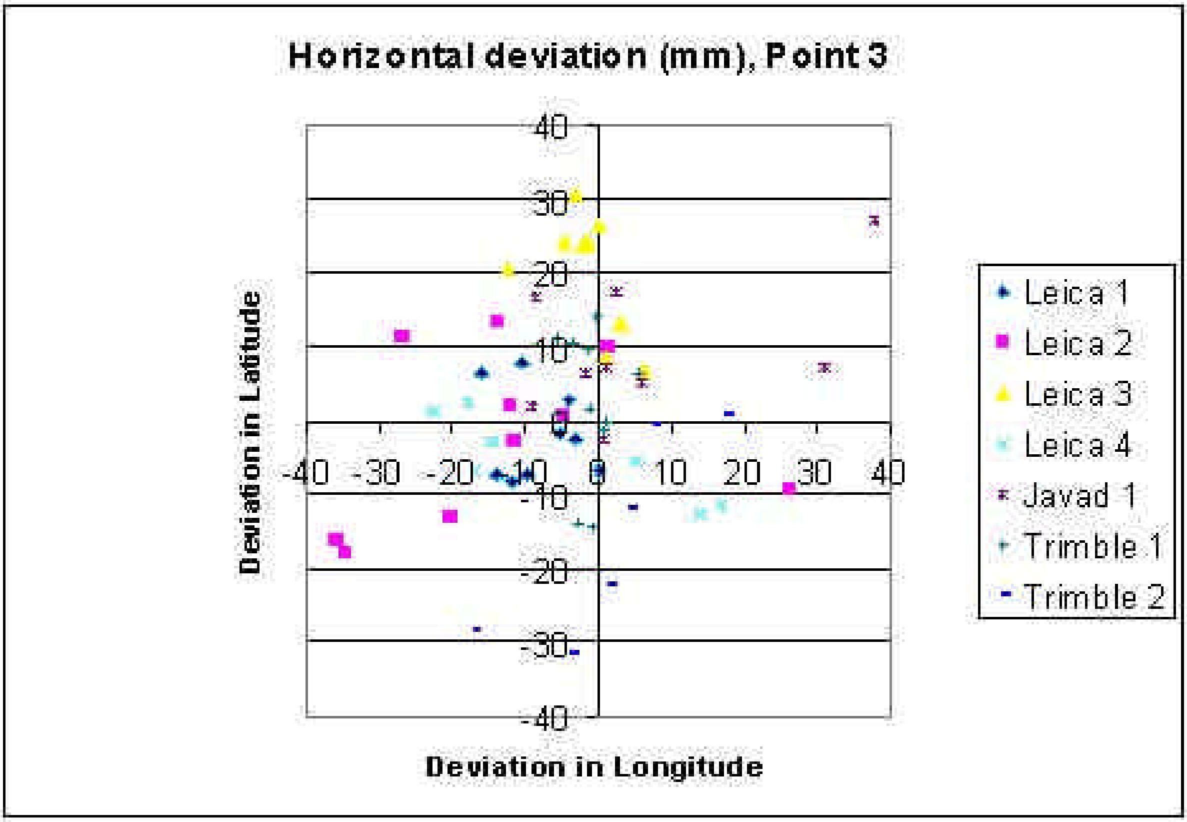
Graph 22: *The deviation in height at point 1 for GPSNet.*



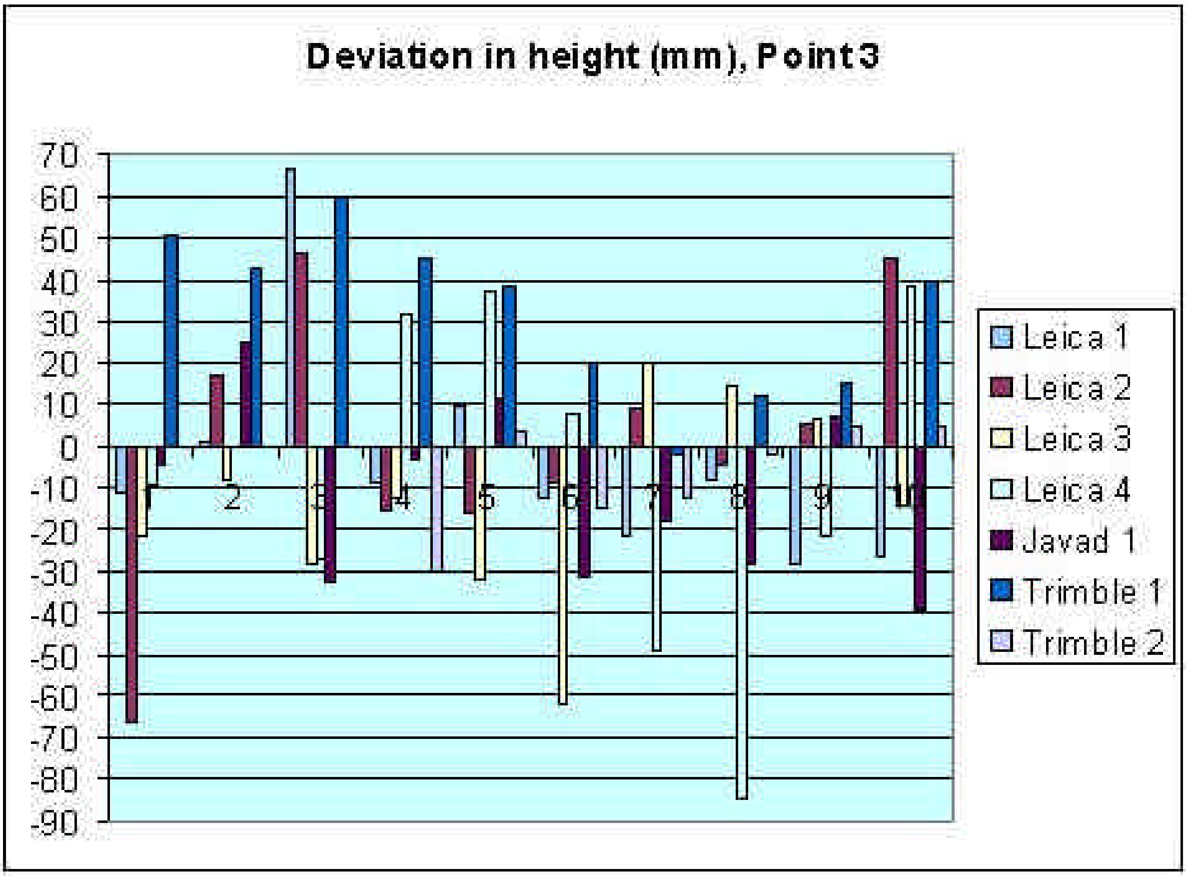
Graph 23: *The horizontal deviation at point 2 for GPSNet.*



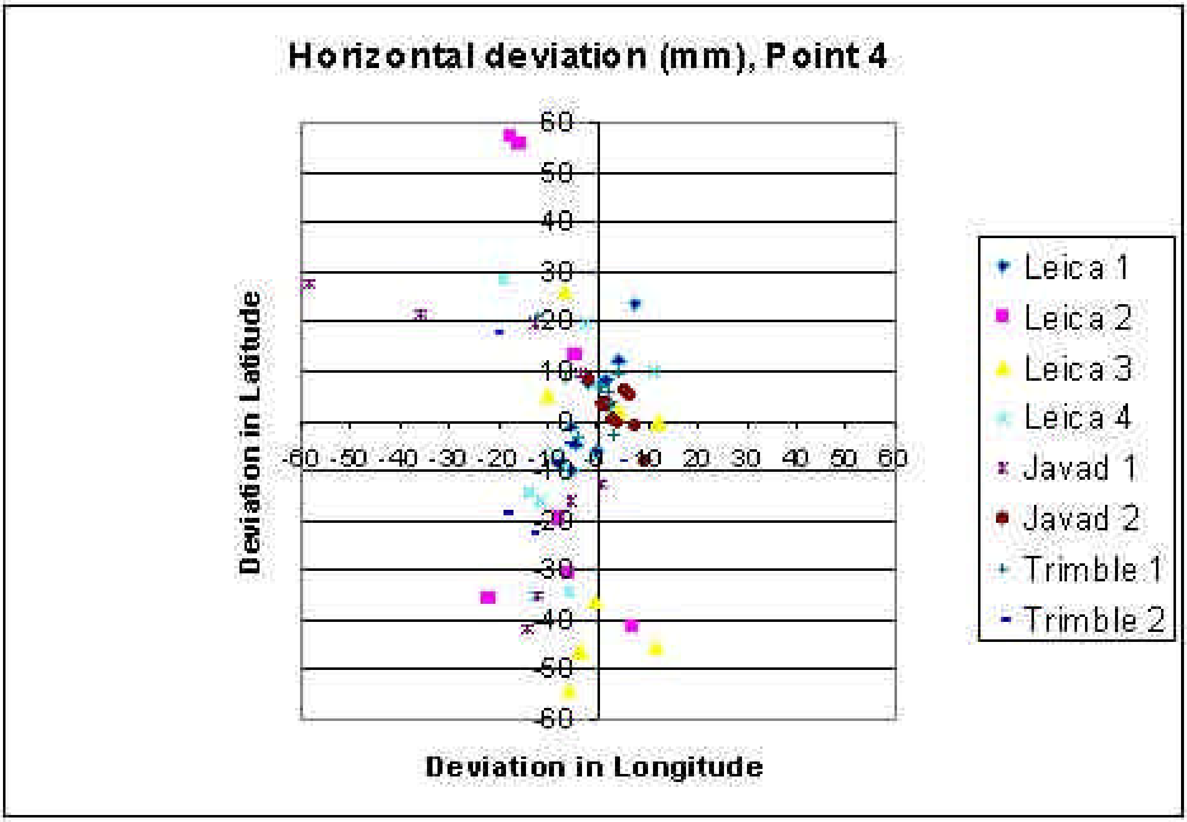
Graph 24: *The deviation in height at point 2 for GPSNet.*



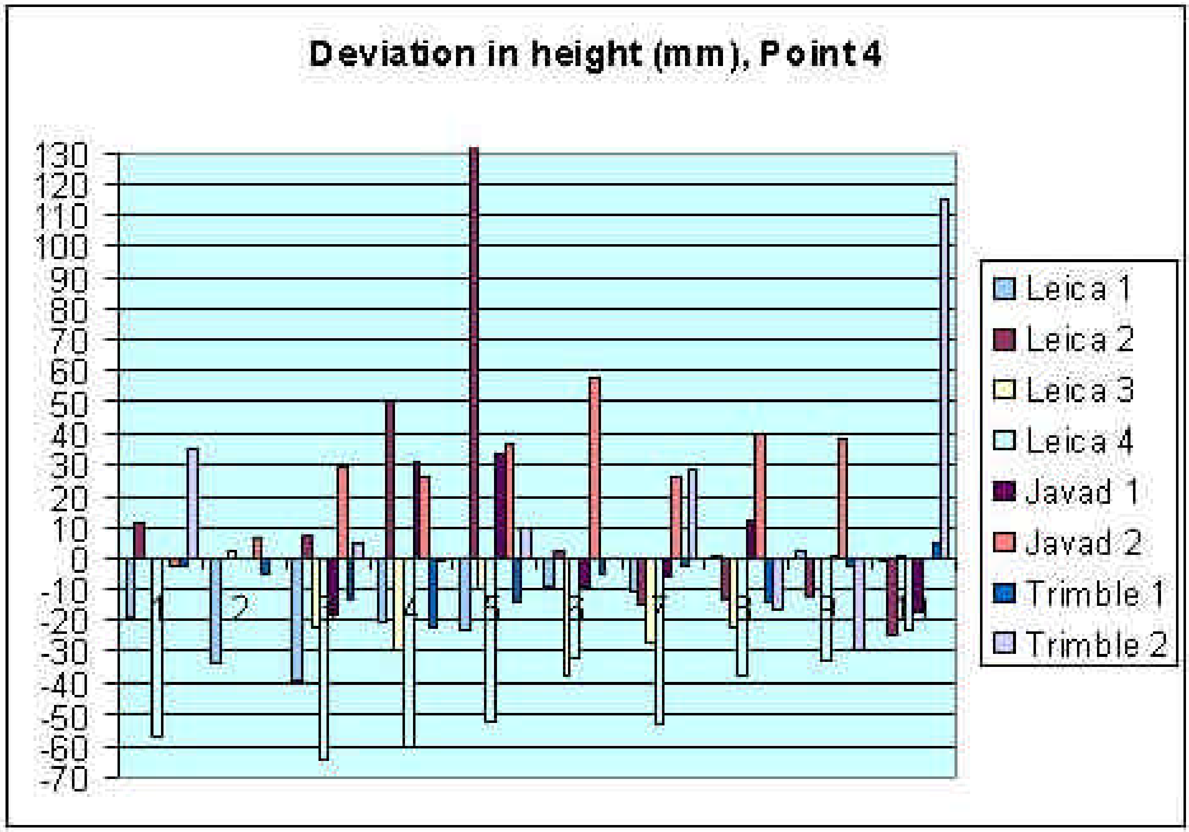
Graph 25: *The horizontal deviation at point 3 for GPSNet.*



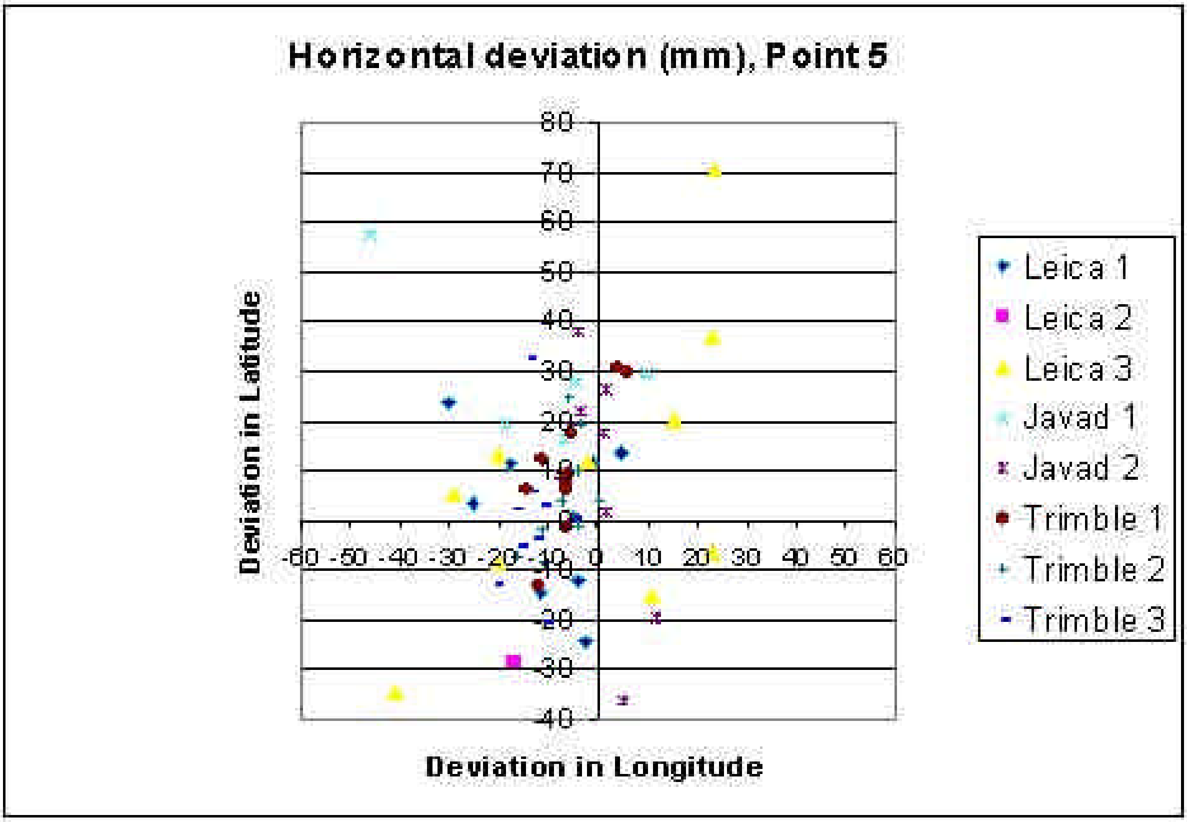
Graph 26: *The deviation in height at point 3 for GPSNet.*



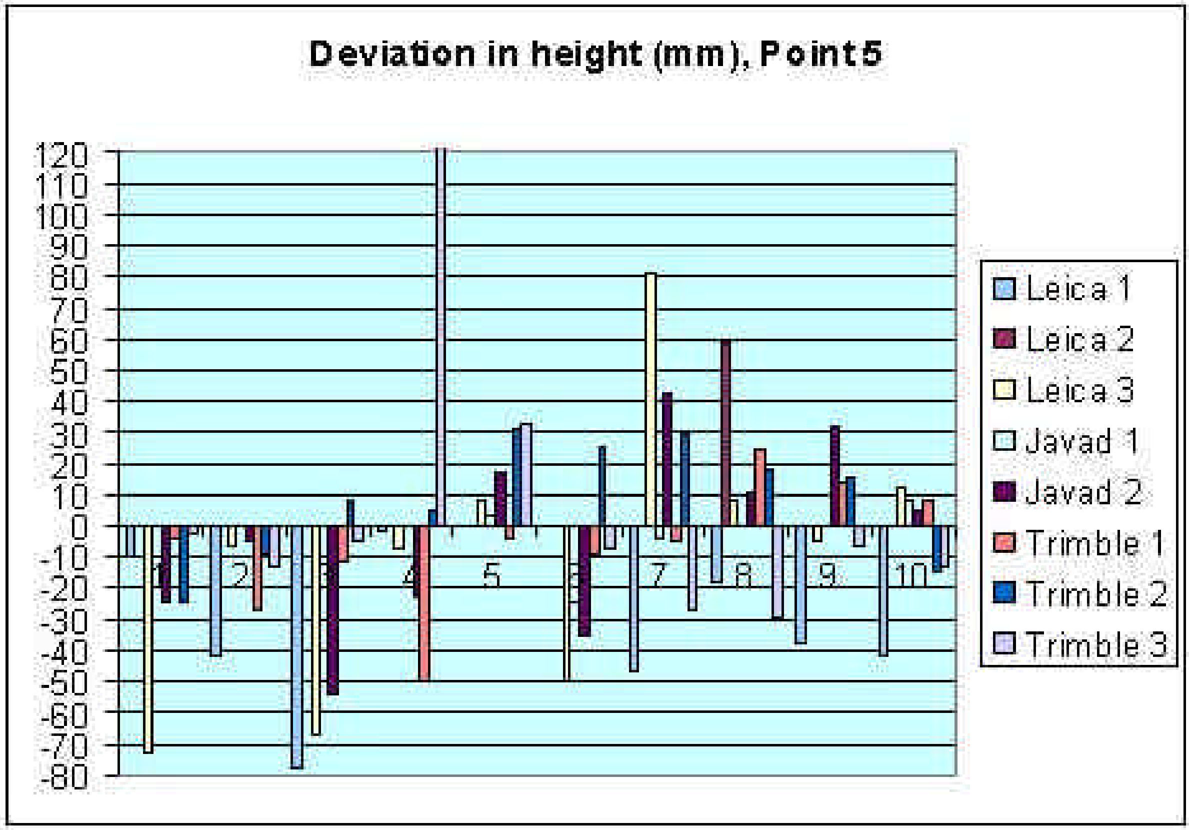
Graph 27: *The horizontal deviation at point 4 for GPSNet.*



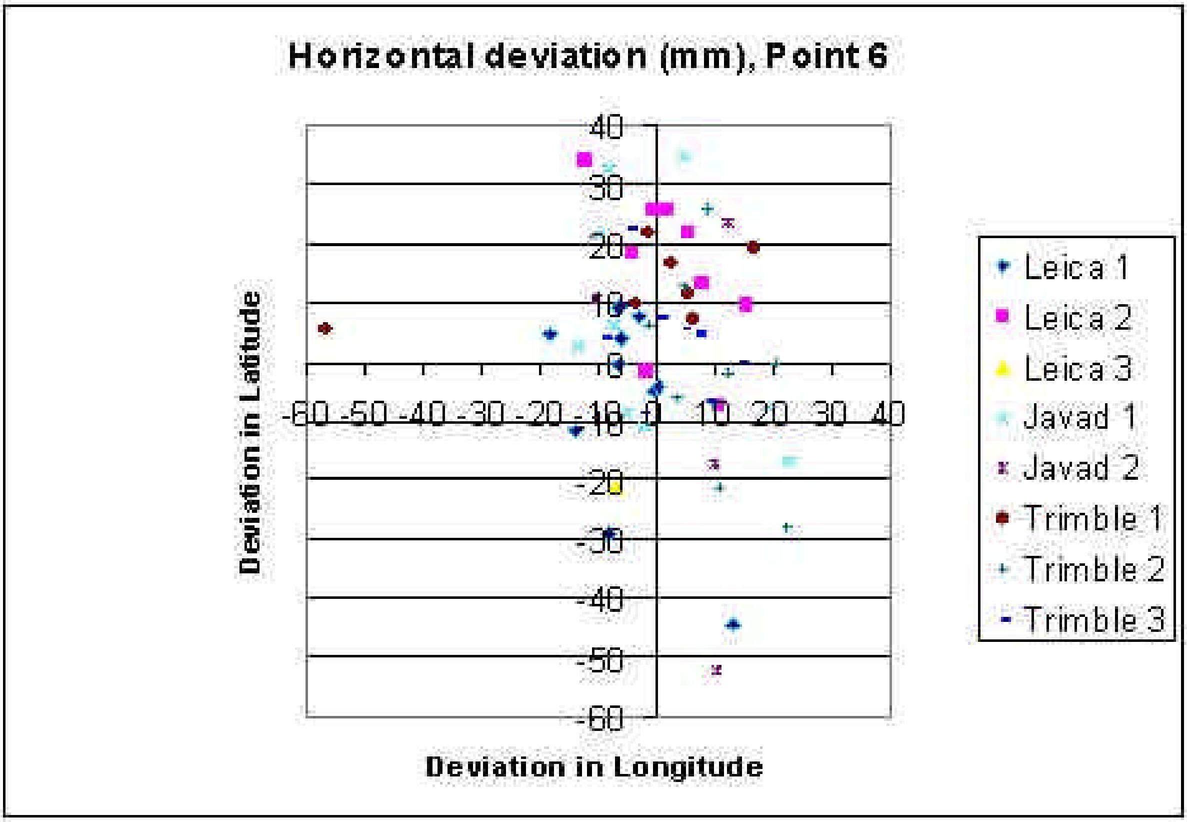
Graph 28: *The deviation in height at point 4 for GPSNet.*



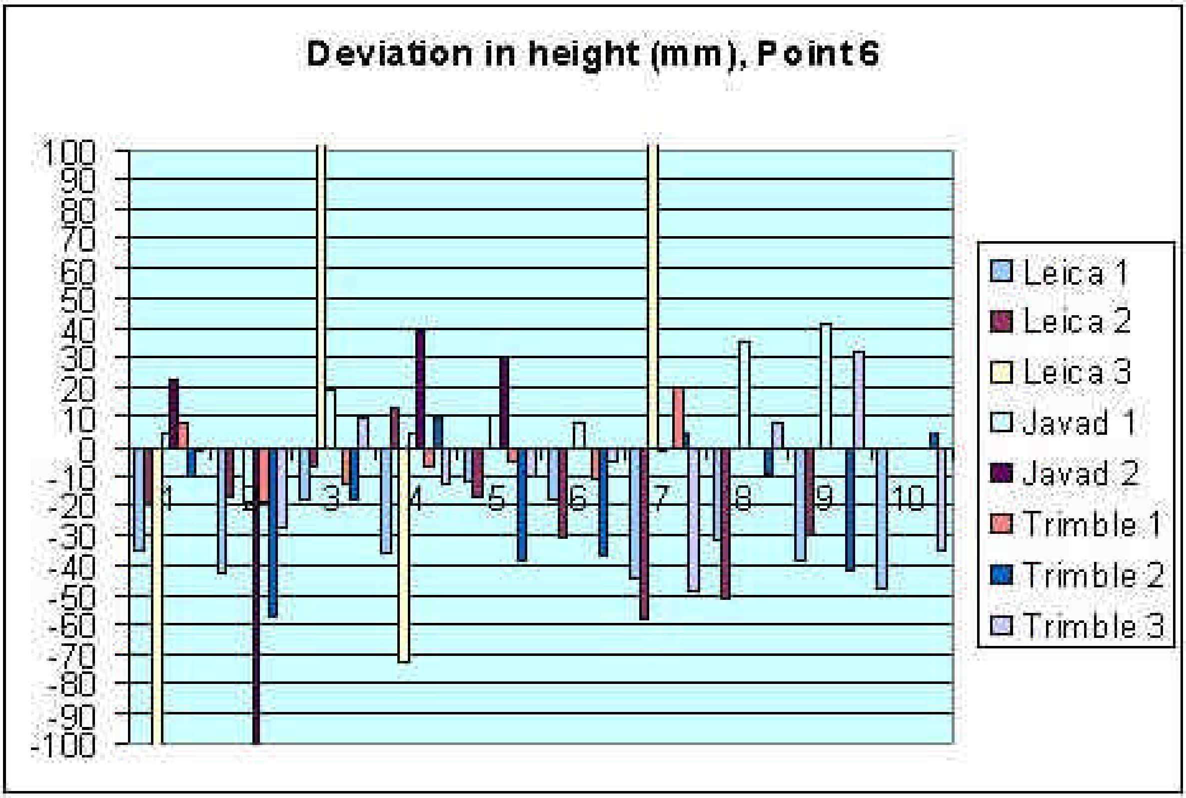
Graph 29: *The horizontal deviation at point 5 for GPSNet.*



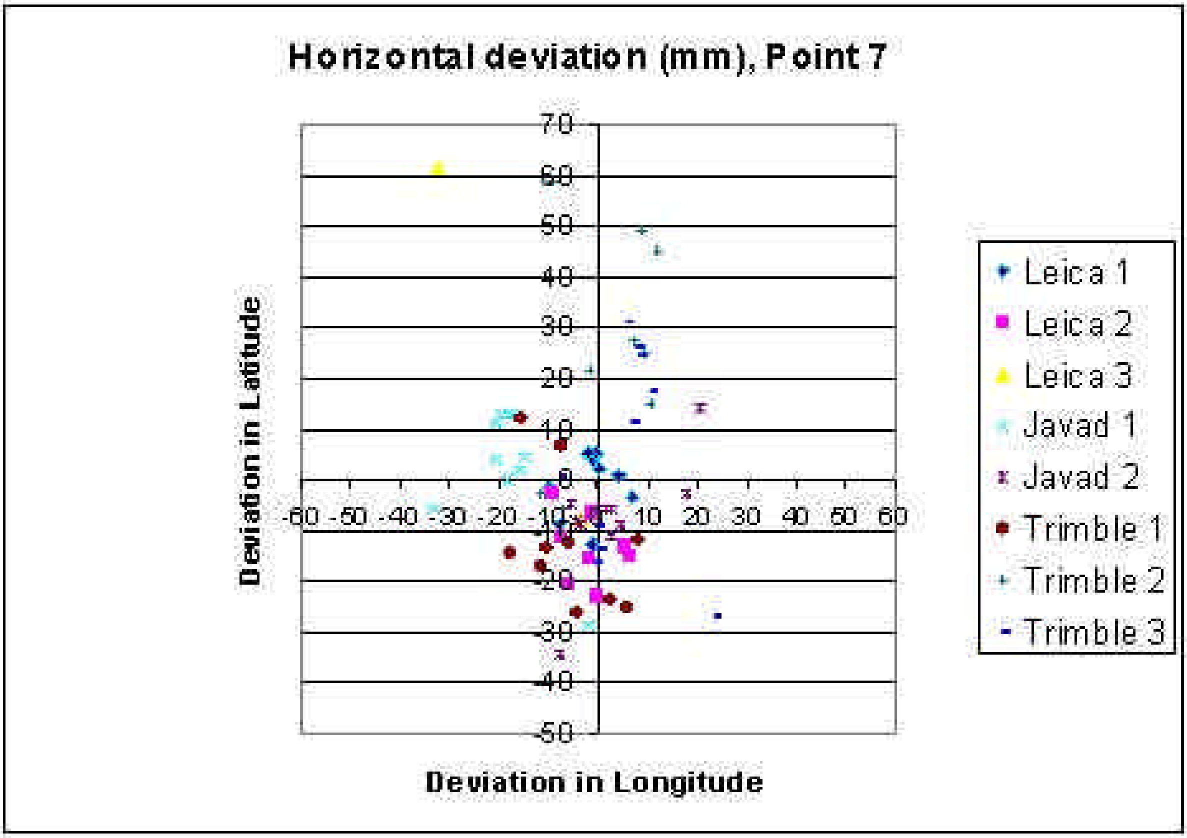
Graph 30: *The deviation in height at point 5 for GPSNet.*



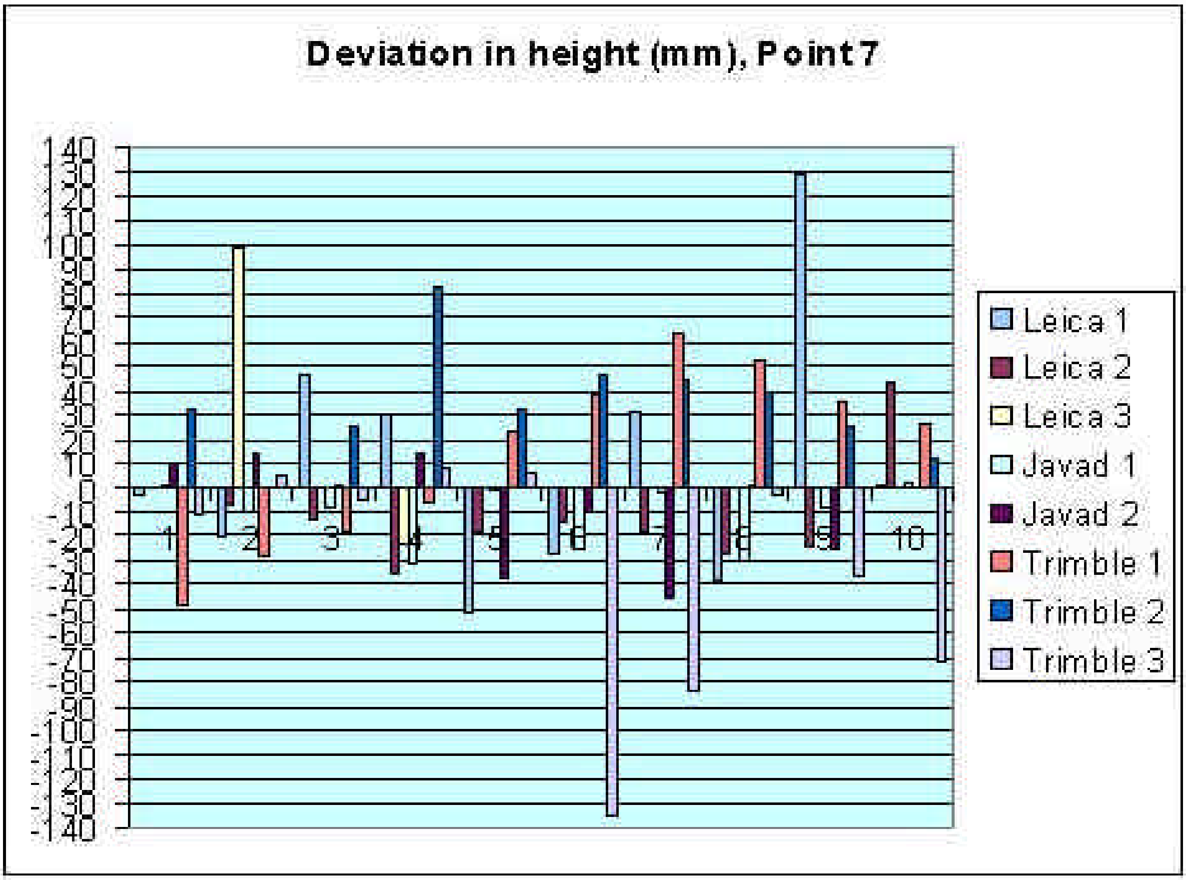
Graph 31: *The horizontal deviation at point 6 for GPSNet.*



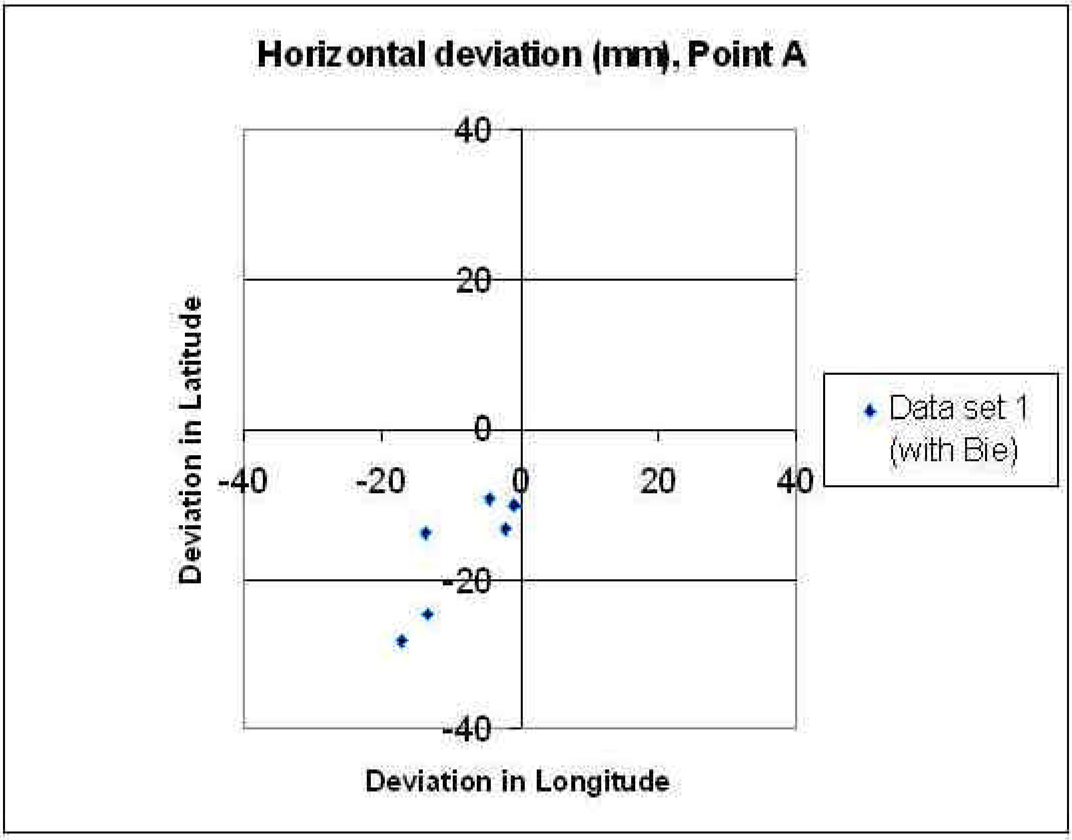
Graph 32: *The deviation in height at point 6 for GPSNet.*



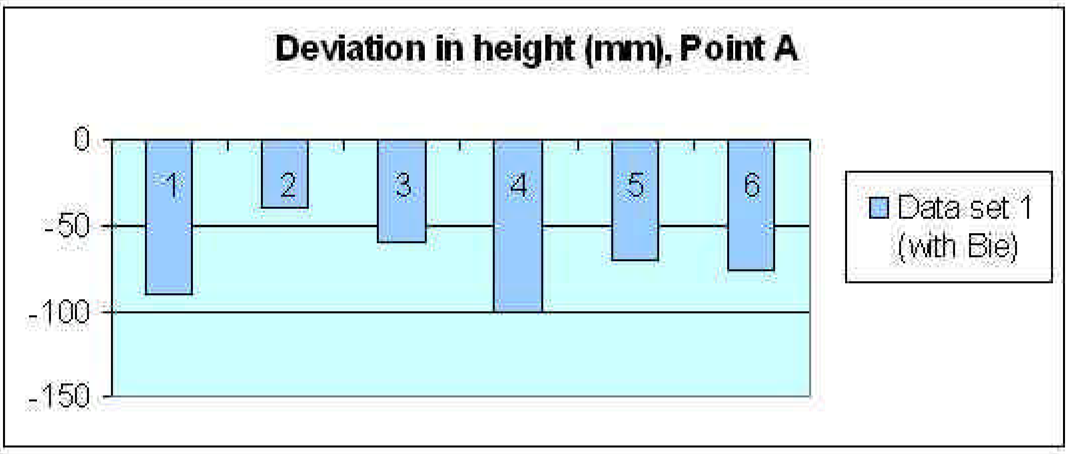
Graph 33: *The horizontal deviation at point 7 for GPSNet.*



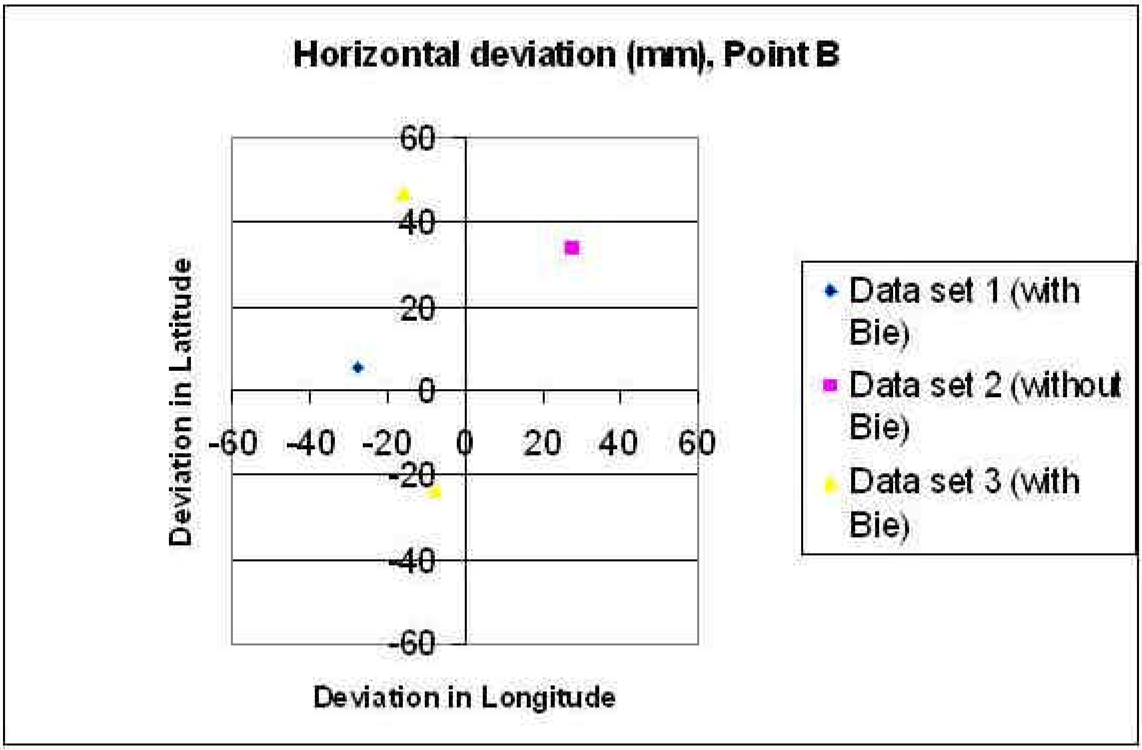
Graph 34: *The deviation in height at point 7 for GPSNet.*



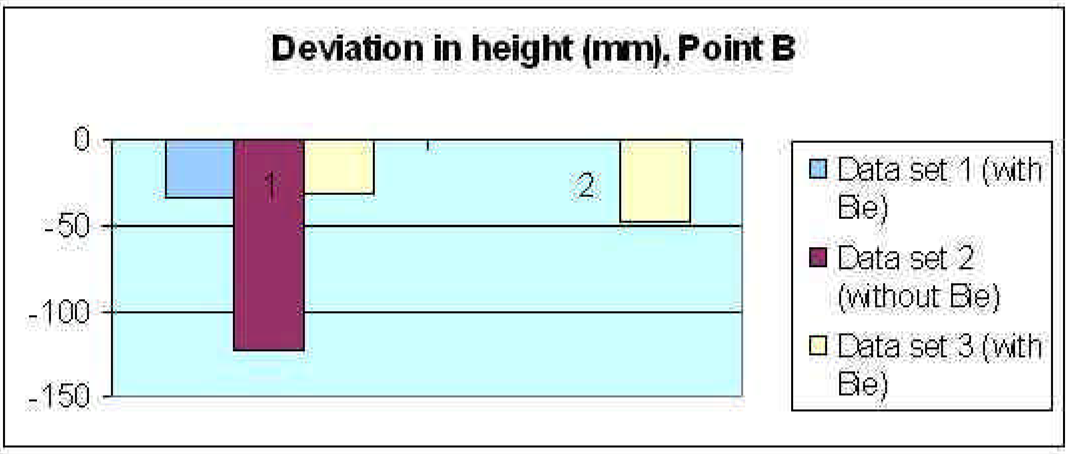
Graph 35: *The horizontal deviation at point A for the test campaign in a sparse network.*



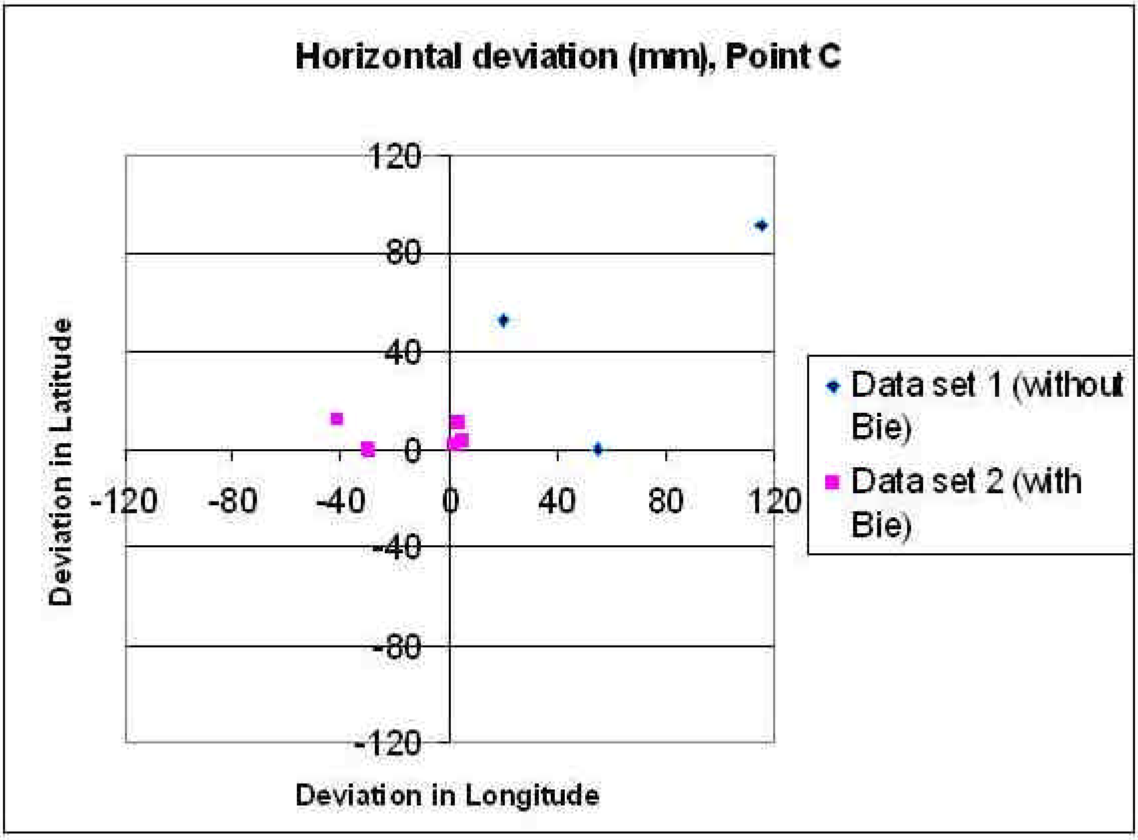
Graph 36: *The deviation in height at point A for the test campaign in a sparse network.*



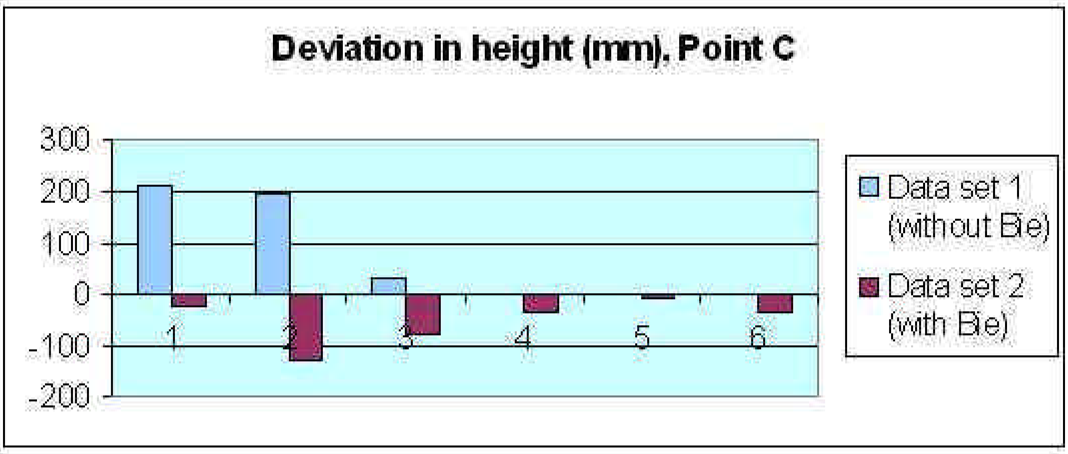
Graph 37: *The horizontal deviation at point B for the test campaign in a sparse network.*



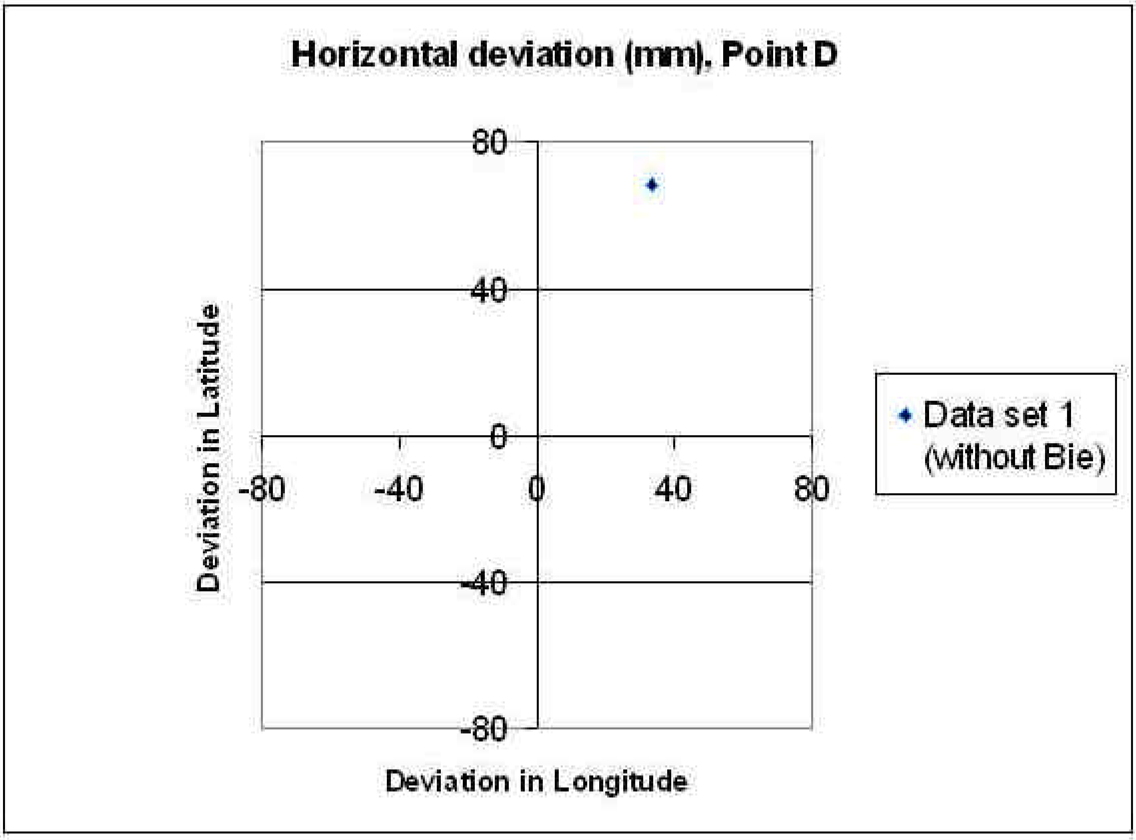
Graph 38: *The deviation in height at point B for the test campaign in a sparse network.*



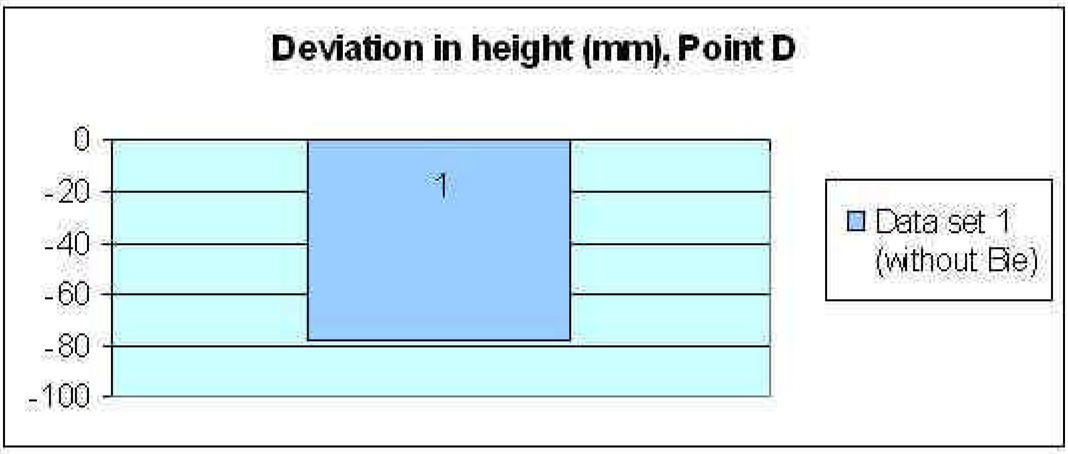
Graph 39: *The horizontal deviation at point C for the test campaign in a sparse network.*



Graph 40: *The deviation in height at point C for the test campaign in a sparse network.*



Graph 41: *The horizontal deviation at point D for the test campaign in a sparse network.*



Graph 42: *The deviation in height at point D for the test campaign in a sparse network.*

Appendix B Photo from the campaign

Photo 1: *Point 1, 200 m from the nearest reference station.*