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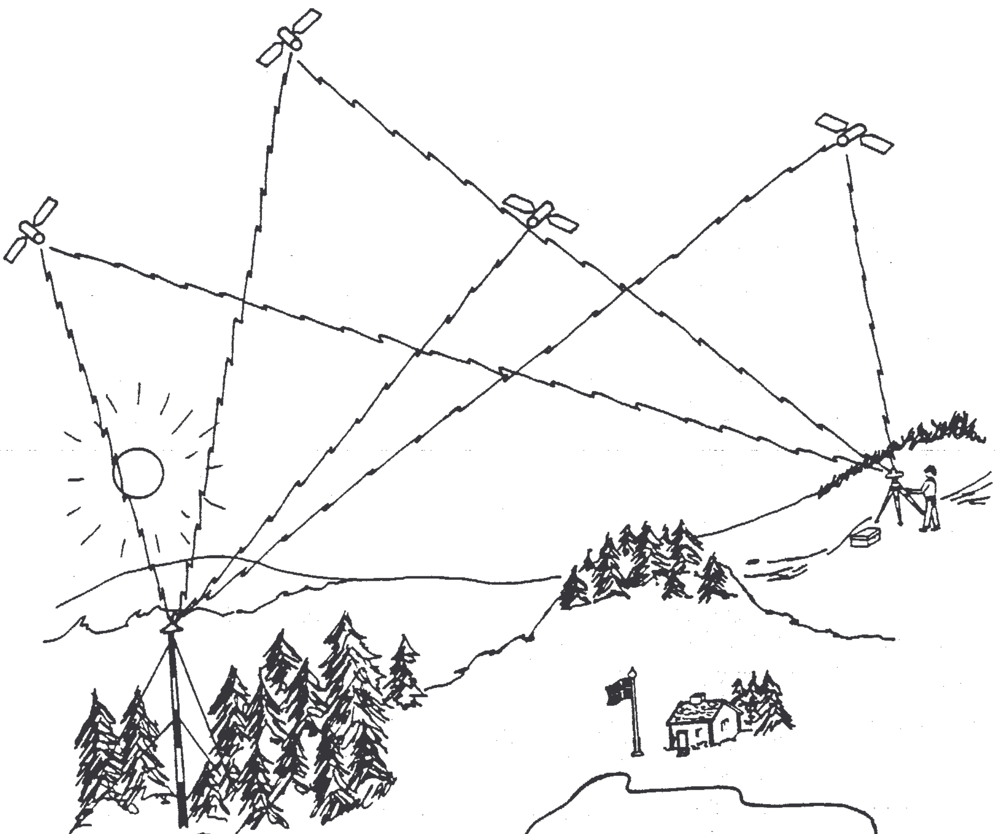
RESULTS AND EXPERIENCES FROM GPS MEASUREMENTS 1987 - 1990

— SVENAV -87, local control networks and dual - frequency measurements

by Gunnar Hedling, Ann-Charlotte Jivall and Bo Jonsson



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RESULTS AND EXPERIENCES FROM GPS MEASUREMENTS 1987 - 1990.

- SVENAV-87, local control networks and dual-frequency measurements

by Gunnar Hedling, Ann-Charlotte Jivall and Bo Jonsson

Huvudinnehåll

Some papers which describe experiences and results from GPS measurements carried out during the years 1987 - 1990 are collected in this professional paper. The following papers are included:

- THE SWEDISH GPS CAMPAIGN SVENAV 87. 5th International Geodetic Symposium on Satellite Positioning, Las Cruces 1989.

- ESTABLISHMENT OF LOCAL CONTROL NETWORKS WITH GPS. FIG XIX international congress, Helsinki 1990.

- RESULTS FROM STATIC DUAL-FREQUENCY GPS MEASUREMENTS - A STATUS REPORT. Nordic Geodetic Commission, 11th General Meeting, Copenhagen 1990.

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INTRODUCTION

The GPS campaign SVENAV-87 was carried out in November 1987. GPS observations were performed on eight stations in the test network by members of the Swedish GPS users group with three Texas TI4100 and three Wild-Magnavox WM101 receivers. We want to thank the the Danish Geodetic Institute and the Norwegian Mapping Authority for putting their Texas receivers to our disposal. The purpose of the campaign was to create a data set consisting of observations from both TI4100 and WM101 for studies with the Bernese GPS software package. The paper THE SWEDISH GPS CAMPAIGN SVENAV-87 in section A of this report describes the campaign.

During the years 1987 and 1988 NLS gathered experiences from GPS measurements and developed methods for the establishment of local control networks. Today the GPS techniques is routinely used for the establishment of local control networks. The use of the GPS technique for establishing local control networks are discussed in the paper ESTABLISHMENT OF LOCAL CONTROL NETWORKS WITH GPS in section B of this report.

The GPS equipment at NLS consists (june 1990) of seven Ashtech LXII L1-receivers, three Ashtech LDXII L1/L2-receivers and one Wild-Magnavox WM102 L1/L2-receiver. We are using the equipment both for geodetic production projects and for research projects. One of the Ashtech L1/L2-receivers will be installed at our observatory, Mårtsbo for one year following February 1990. For geodetic production projects we are using the Ashtech GPPS software package, the adjustment programme GeoLab from GEOsurv Inc and our own coordinate transformation programmes. We have installed the Bernese software version 3.0 on our PR1ME minicomputer for research purposes. The Wild-Magnavox PC-programme PoPS is used for evalution of WM102-data.

Some tests with dual frequency GPS measurements have been performed in order to investigate the possibilities to reduce the effect of the increasing ionospheric activity. The paper RESULTS FROM STATIC DUAL-FREQUENCY GPS MEASUREMENTS - A STATUS REPORT in section C of this report gives a description of these tests.

The possibility to use the GPS techniques in air photogrammetry is also very interesting for NLS air photo activity and we made a test in September 1989 in order to get some practical experiences. The photogrammetric experiment is described in NLS Professional Papers 1990: 11.

THE SWEDISH GPS CAMPAIGN SVENAV-87

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THE SWEDISH GPS CAMPAIGN SVENAV 87

GUNNAR HEDLING, ANN-CHARLOTTE JIVALL AND BO JONSSON
NATIONAL LAND SURVEY OF SWEDEN
S-80182 GÄVLE, SWEDEN

SUMMARY

The Swedish GPS users group has established a test network for GPS measurements with baseline lengths in the interval 0.5 - 1200 km.Between the 17th and 20th of November 1987 GPS observations were performed at 8 stations in this network by members of the GPS users group with three Texas TI4100 and three Wild-Magnavox WM101 instruments.
The purposes of the campaign were the following:

- -to create a data set consisting of observations from both TI4100 and WM101,
- -to study the GPS techniques for long baselines,
- -to study orbit relaxation,
- -to study the repeatability of GPS-observations,
- -to study ionosphere modelling.

The observation data have been processed with the Bernese GPS Software and the WM program PoPS. A comparison of the results of SVENAV 87 with earlier GPS results in the test network is also given.

INTRODUCTION

In February 1985 an informal Swedish GPS users group was established in order to promote cooperation and information exchange. At present the group has members from the National Land Survey, National Road Administration, Swedish Hydrographic Department, National Telecommunications Administration, Royal Institute of Technology, Onsala Space Observatory, University of Uppsala, Lund Institute of Technology, Swedish Association of Local Authorities and the military authorities.

The Swedish GPS users group has established a test network for GPS measurements with baselines in the interval 0.5 - 1200 km. The aim of the test network is that all Swedish tests of GPS receivers shall, if possible, be carried out in this network according to a specified schedule in order to facilitate comparisons of the tests and the receivers.

During 1986 GPS observations were made in the test network with Trimble 4000S, Texas TI 4100 and Wild-Magnavox WM101 receivers. The goal of these GPS observations was to test the receivers in typical Swedish environments and to compare the obtained results from the GPS measurements with those from conventional terrestrial methods.

Three Wild-Magnavox WM101 were purchased in June 1987. In September 1987 NLS gathered experiences from the establishment of local control networks with GPS techniques. The Wild-Magnavox post-processing software PoPS was used for the calculations.

During November 1987 the GPS campaign SVENAV 87 was carried out. The purposes of the campaign were:

- to create a data set consisting of observations from both TI4100 and WM101
- to study the GPS techniques for long baselines
- to study orbit relaxion
- to study the repeatability of GPS observations
- to study ionosphere modelling.

GPS MEASUREMENTS

The SVENAV 87 campaign was a collaboration project between the Royal Institute of Technology, University of Uppsala, Onsala Space Observatory, National Road Administration and the National Land Survey (NLS) who coordinated the measurements.

In November 1987 four days of GPS observations were made using 3 TI 4100 and 3 WM101 GPS receivers. Two TI 4100's were supplied by the Danish Geodetic Institute and one by the Norwegian Mapping Authority. The network, see figure 1, consists of an outer triangle with the TI receivers (approx. baseline lengths 400, 950 and 1200 km),which were stationary during the whole campaign and an inner network with WM101 receivers (the baselines here are in the range 40 to 230 km long). Two more sites, Hille and Västerbo, close to Gävle were also occupied during the campaign. These are not shown on the map and not presented in the results in this paper.

The observation window in Sweden starts at about 1 a.m. and lasts till 5 a.m. (local time) at this time of the year .
A map and the observation scheme for the whole campaign can be found in figure 1 and table 1.
As can be seen from the observation schedule our goal was to get several days of data on the stations at the ends of the long baselines, that is to get long continuous sessions of observations for the long baselines.These plans became upset by satellite 11 (PRN code) being declared as unhealthy after one hour of observations on the 17th of November. Unfortunately the WM101 automatically stops tracking a satellite which have the status message set to unhealthy unless you force it to go on tracking. On the other hand the TI 4100 does not react on the status message from the satellite. Therefore the WM101 and the TI 4100 stations don't have more than three satellites in common for most of the 17th.

TABLE 1

Observation periods for SVENAV 87

Station \ Date	17 Nov	18 Nov	19 Nov	20 Nov
TI 4100 stations				
Lovö (Stockholm) (Old observatory of NLS)	X	X		X
Onsala (Göteborg) (Onsala Space Observatory)	X	X	X	X
Kiruna (Institute of Space physics)	X	X	X	X
WM101 stations				
Mårtsbo (Gävle) (Observatory of NLS)	X	X		X
Mårtens Klack		X	X	
Vårdkasberget	X	X	X	X
Västerbo	X			X
Hille			X	

This makes it difficult to get enough single differences for the TI 4100 to WM101 baseline on that day. Other problems were a couple of long interupptions and two big freqency jumps in the TI receiver oscillator at Lovö.

All these problems forced us to divide our daily session into two sessions on all days except for the 20th of November when it was divided into three sessions.

Weather observations where taken at the WM101 stations for the trophosphere correction. For the TI 4100 stations ,which are all within some kilometers distance from weather stations, data from these were used.

DATA PROCESSING

For the processing of the data we have used the Bernese GPS Software version 3.0. Since the standard navigation software for the TI receivers was used, the observations were sampled during preprocessing to get 1 observation every 30 sec.

For the WM101 receivers a data-compression interval of 1 min was used. Then for the combined WM101-TI 4100 baselines a time-offset of 1 sec. between observations had to be accepted.

To model the troposphere we have used the Saastamoinen model. Usually an elevation cut-off angle of 15 degrees has been used.

The possibility to model the correlation between the double difference observations which exists in the Bernese GPS Software could not be used.

Instead only the correlation within baselines has been modelled.
As observables we used the ionosphere-free linear combination of L1 and L2 on the baselines between TI 4100 instruments for the rest L1 was used.
Due to the great number of sessions that had to be defined in order to obtain cycle slip free data sets of phase measurements, the number of ambiguity parameters that has to be estimated has grown. The task of ambiguity resolution thus becomes difficult. In our computations we only tried to solve the integer ambiguities on the short (40 km) baseline between Mårtsbo and Mårtens Klack. This leaves us with a heavy load of ambiguity parameters to solve for in the adjustment of the whole network.
The number of parameters in the final adjustment where; 15 station coordinates, 127 ambiguities and 7 orbital elements.

We also made a solution where we estimated the argument of latitude for each satellite. This is the orbital element that gives the position of the satellite in its orbit.
To arrive at a final solution we have used a simple analysis of the loss function which showed that the addition of 1 orbital element per satellite to the estimated parameters caused a significant decrease of the loss function. The orbital corrections also seemed reasonable,since we got larger corrections to the satellites with quartz or rubidium oscillators whereas the corrections to the satellites with cesium oscillators were very small.
We have also made some experiments with ionosphere modelling, so far these have been unsuccesful, maybe because there is very little ionosphere to model on a winter night in Sweden.

RESULTS

TABLE 2

Results without orbit parameters - Results with 1 orbit par/sat

Stations from	to	Receiver T=TI4100 W=WM101	Length (km)	Differences Dist (m)	ppm	azim (sec)	height (m)
Lovö	Onsala	T-T	407	-0.02	0.0	0.01	0.06
Lovö	Kiruna	"	956	0.08	0.1	0.04	-0.03
Onsala	Kiruna	"	1240	0.11	0.1	0.03	-0.09
Lovö	Mårtsbo	T-W	144	0.02	0.1	0.07	-0.01
Onsala	Mårtsbo	"	470	0.04	0.1	0.00	-0.08
Kiruna	Vårdkasb.	"	594	0.05	0.1	0.05	0.00
Mårtsbo	Mårtens K.	W-W	40	-0.01	-0.2	0.05	0.01
Mårtsbo	Vårdkasb.	"	228	0.01	0.0	0.02	0.02
Mårtens K.	Vårdkasb.	"	212	0.02	0.1	0.01	-0.03

First we made a comparison of the results with orbit relaxation (=final result) and the results without as shown in table 2. As you can see the differences between the two solutions are very small.

TABLE 3

Results for separate days - Final result

Stations from	to	Receiver T=TI4100 W=WM101	Length (km)	Differences Dist (m)	ppm	azim (sec)	height (m)
17 November:							
Lovö	Onsala	T-T	407	0.04	0.1	0.03	0.03
Lovö	Kiruna	"	956	-	-	-	-
Onsala	Kiruna	"	1240	0.33	0.3	0.10	-0.10
Lovö	Mårtsbo	T-W	144	-	-	-	-
Onsala	Mårtsbo	"	470	-0.47	-1.0	-0.17	0.33
Kiruna	Vårdkasb.	"	594	-	-	-	-
Mårtsbo	Mårtens K.	W-W	40	-	-	-	-
Mårtsbo	Vårdkasb.	"	228	0.07	0.3	-0.04	0.01
Mårtens K.	Vårdkasb.	"	212	-	-	-	-
18 November:							
Lovö	Onsala	T-T	407	0.11	0.2	0.00	0.23
Lovö	Kiruna	"	956	0.08	0.1	0.19	-0.02
Onsala	Kiruna	"	1240	-	-	-	-
Lovö	Mårtsbo	T-W	144	-0.07	-0.5	-0.25	0.11
Onsala	Mårtsbo	"	470	-	-	-	-
Kiruna	Vårdkasb.	"	594	-	-	-	-
Mårtsbo	Mårtens K.	W-W	40	0.01	0.2	0.00	0.05
Mårtsbo	Vårdkasb.	"	228	-0.06	-0.3	-0.11	0.04
Mårtens K.	Vårdkasb.	"	212	-	-	-	-
19 November:							
Lovö	Onsala	T-T	407	-	-	-	-
Lovö	Kiruna	"	956	-	-	-	-
Onsala	Kiruna	"	1240	0.26	0.2	-0.01	-0.38
Lovö	Mårtsbo	T-W	144	-	-	-	-
Onsala	Mårtsbo	"	470	-	-	-	-
Kiruna	Vårdkasb.	"	594	0.05	0.1	-0.22	-0.37
Mårtsbo	Mårtens K.	W-W	40	-	-	-	-
Mårtsbo	Vårdkasb.	"	228	-	-	-	-
Mårtens K.	Vårdkasb.	"	212	0.00	0.0	-0.03	0.05
20 November:							
Lovö	Onsala	T-T	407	0.05	0.1	0.06	0.07
Lovö	Kiruna	"	956	0.20	0.2	0.09	-0.18
Onsala	Kiruna	"	1240	-	-	-	-
Lovö	Mårtsbo	T-W	144	0.13	0.8	-0.30	-0.03
Onsala	Mårtsbo	"	470	-	-	-	-
Kiruna	Vårdkasb.	"	594	-	-	-	-
Mårtsbo	Mårtens K.	W-W	40	-	-	-	-
Mårtsbo	Vårdkasb.	"	228	0.13	0.6	0.05	0.04
Mårtens K.	Vårdkasb.	"	212	-	-	-	-

Secondly we made comparisons - see table 3 - of the final solution with solutions for each of the four days.
In these solutions we are using satellite orbits that have been calculated from broadcast ephemeris data from just one day, whereas in the final solution we used orbits that have been calculated with broadcast ephemeris from all four days of the campaign.
Note that only the baselines that were defined in the adjustments are shown in table 3.
Finally we have compared the results with terrestrial coordinates, in this case ED 87 coordinates that have been shifted into WGS 84 by a simple translation.

TABLE 4

Terrestrial coordinates - Final results

Stations from	to	Receiver T=TI4100 W=WM101	Length (km)	Differences Dist (m)	ppm	azim (sec)	height (m)
Lovö	Onsala	T-T	407	+0.46	+1.1	0.17	+0.66
Lovö	Kiruna	"	956	+1.10	+1.2	0.11	-0.35
Onsala	Kiruna	"	1240	+1.39	+1.1	0.09	-1.01
Lovö	Mårtsbo	T-W	144	+0.09	+0.6	-0.25	-0.11
Onsala	Mårtsbo	"	470	+0.27	+0.6	-0.09	-0.76
Kiruna	Vårdkasb.	"	594	+0.91	+1.5	0.24	+0.17
Mårtsbo	Mårtens K.	W-W	40	+0.04	+1.0	0.04	-0.14
Mårtsbo	Vårdkasb.	"	228	+0.20	+0.9	0.05	-0.06
Mårtens K.	Vårdkasb.	"	212	+0.19	+0.9	0.05	+0.09

We also added a 7-parameter transformation to ED 87 from the final solution, see table 5.

CONCLUDING REMARKS

The comparison between the final solution and the solutions for separate days shows that the repeatability of the GPS solutions is on the 1 ppm level. For the distances it seems to be well within the 1 ppm level, the azimuths are also good (note that 1 sec. of arc = 4.85 ppm) but as you can see in tables 3 and 4 the TI 4100 to WM101 baselines have rather big discrepancys in azimuth. This probably have more to do with the geometry of the network than with lacking 'compatibility' between TI 4100 and WM101 instruments.
From table 4 and the 7-parameter transformation between terrestial results and our final results one can see that there is a significant scale difference between them. The GPS results are shorter by a factor of 1 ppm. Otherwise there seems to be surprising accuracy in the terrestial network even on these distances.

TABLE 5

7-Parameter transformation between the final results and terrestrial results

Stations	Residuals in meters dlat	dlong	dh
Lovö	0.0628	-0.1397	0.1130
Onsala	0.0811	-0.1186	0.0795
Kiruna	0.1080	-0.1127	0.0486
Mårtsbo	-0.0639	0.0899	-0.0279
Mårtens Klack	-0.0845	0.1072	-0.2261
Vårdkasberget	-0.1035	0.1739	0.0129

rms of transformation	:	0.139 m		
translation in X	:	0.23	+-	0.06 m
translation in Y	:	0.07	+-	0.06 m
translation in Z	:	-0.06	+-	0.06 m
rotation around X-axis	:	-0.38	+-	0.13 "
rotation around Y-axis	:	-0.04	+-	0.05 "
rotation around Z-axis	:	0.13	+-	0.03 "
scale factor	:	1.11	+-	0.15 mm/km

Note that our results where obtained by very simple means; mixed single and double frequency receivers and a very straightforward processing strategy, e.g. no ambiguity resolution.

ACKNOWLEDGEMENTS

We want to thank the Danish Geodetic Institute and the Norwegian Mapping Authority who made the campaign possible by putting their TI 4100 instruments to our disposal.
We also want to thank Gerhard Beutler and the Berne group for guidance and advice on how to handle their program.

REFERENCES

Jonsson, B., (1986). GPS Observations with Trimble 4000S and Texas TI 4100 -Status Report September 1986. Proceedings of 10th General Meeting of the Nordic Geodetic Commission, Helsinki, Sept 1986, pp. 366-379.

Beutler, G., I. Bauersima, W. Gurtner, M. Rothacher, T. Schildknecht (1988). "Static Positioning with the Global Positioning System (GPS): State of the Art." Lecture Notes in Earth Sciences, Vol. 19, pp. 363-380.

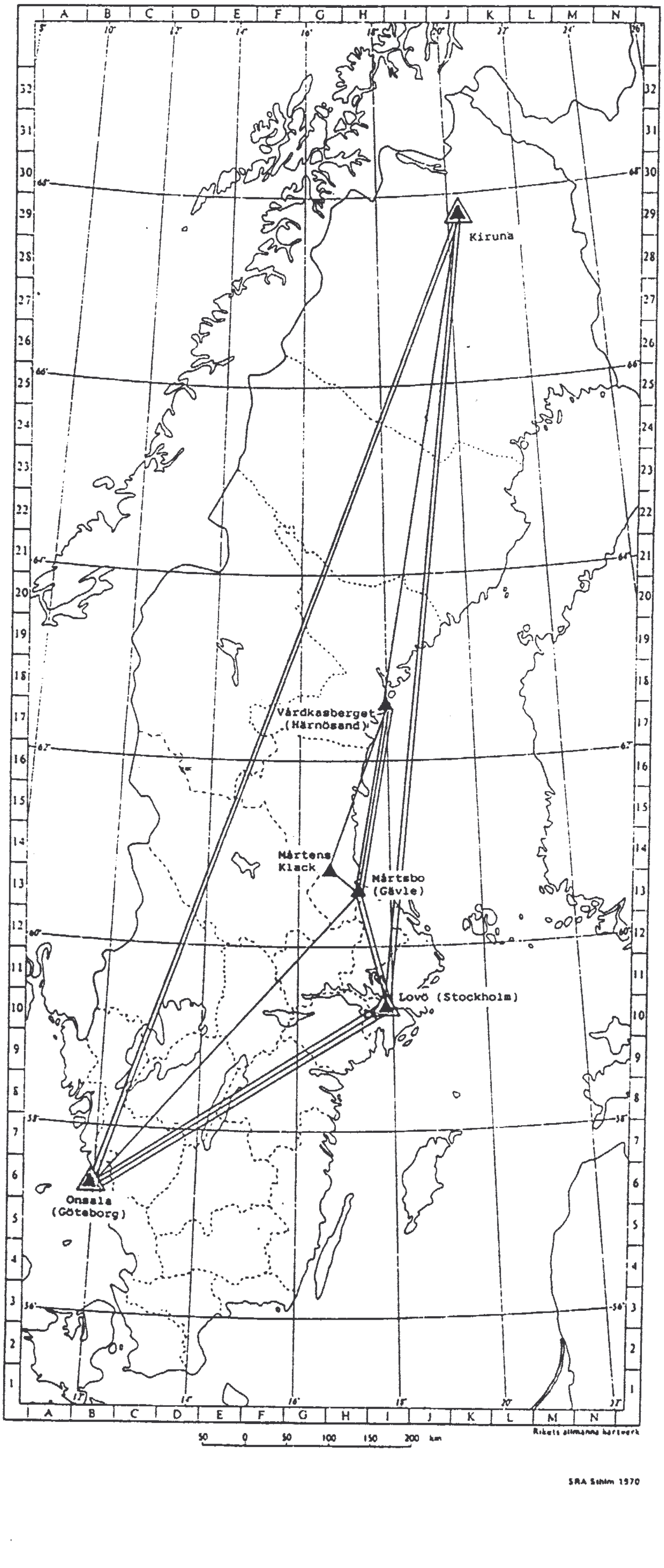

Figure 1

SVENAV 87 CAMPAIGN

17-20 NOVEMBER

△ - TI 4100 station

▲ - WM101 station

| - baseline defined one day

ESTABLISHMENT OF LOCAL CONTROL NETWORKS

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ESTABLISHMENT OF LOCAL CONTROL NETWORKS WITH GPS

A. Jivall, G. Hedling, B. Jonsson - Sweden

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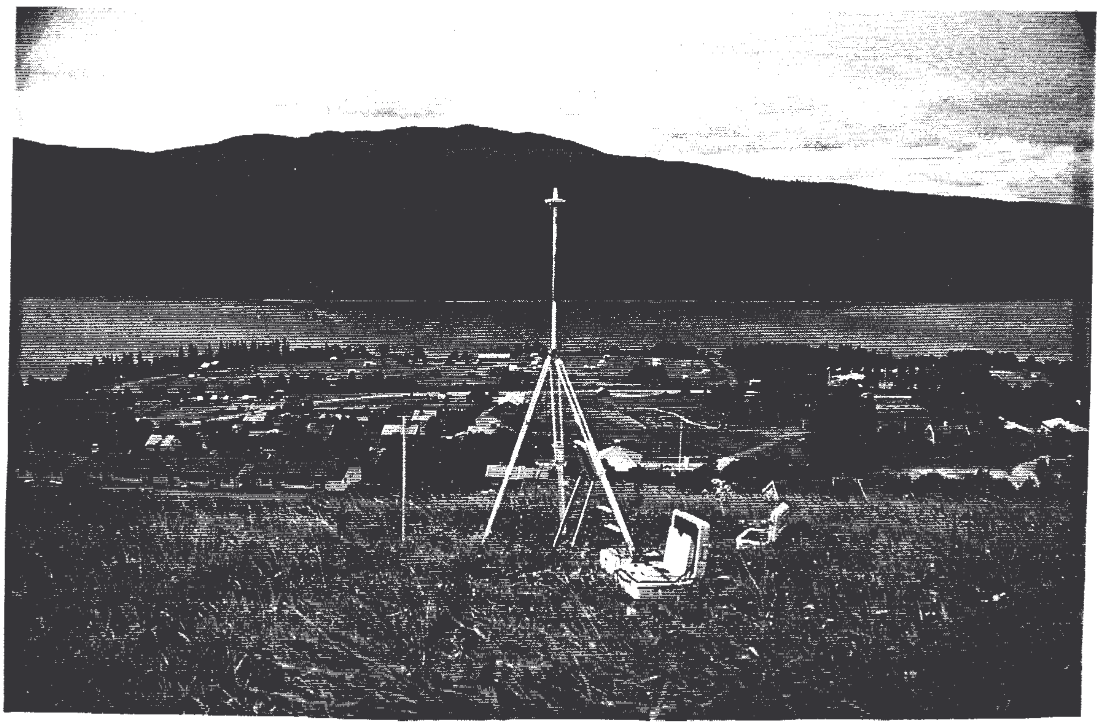
SUMMARY

During 1988 the National Land Survey of Sweden (NLS) has been using GPS for establishment of some local control networks (inter-station distances c. 1-3 km) connected to the Swedish Primary Network.

The capabilities of the GPS technique for establishing local control networks are discussed in this paper. A comparison between the GPS technique and conventional terrestrial methods is also made. Methods, results and experiences from GPS measurements along with a practical example of a local control network are shown.

The GPS observations have been performed with WM101 receivers and processed with PoPS ver. 2.01, running on an IBM-AT and with the Bernese GPS Software ver. 3.0, implemented on a Prime mini-computer.



GPS observations with WM101 in Åre. Renfjället in the background.

1. INTRODUCTION

In 1985 an informal Swedish GPS users group was formed in order to promote cooperation and information exchange in the field of GPS. Among its members were several university institutions and government agencies, such as the National Land Survey of Sweden (NLS). In June 1987 members of the GPS users group purchased three Wild Magnavox WM101 receivers. This year, and especially during the summer 1988, different pilot projects were carried out with these receivers in order to study methods for establishing local control networks. One of those projects is the subject of this paper. In 1989 NLS purchased 6 Ashtech L-XII receivers, 5 of which are now used for establishment of local control networks, control points for photogrammetry and inertial surveying etc.

2. GEODETICAL CONTROL NETWORKS - THE SITUATION IN SWEDEN

The last national triangulation or more adequately trilateration (1967-1982) resulted in a network with interstation distances of around 10 km (except for some areas in the north-west of the country) and a relative accuracy of 1-2 ppm. The primary stations are often situated on top of hills, and due to the rather flat and forested terrain in the greater part of Sweden portable towers and masts were used on many stations. In other words we have a high quality network, where a large number of stations are inaccessible or not very easy to use. A densification of this network all over the country has not been done since large areas of Sweden are sparsely populated. The responsibility for establishing local control networks for municipalities and connecting them to the national coordinate system lies with the local authorities. This task can be rather difficult and expensive with conventional terrestrial methods. In many cases towers and masts have to be built in order to get connections to the primary network. These facts have led to networks with different accuracies and many more or less local coordinate systems.

3. ESTABLISHMENT OF A LOCAL CONTROL NETWORK IN ÅRE AND DUVED

3.1 Description of the area

Åre and Duved are two villages with around 1300 inhabitants. They are situated in a valley with high mountains on both sides (c. 1000 m above the valley) and belong to the most popular places for winter sports in Sweden. In the last years the villages have expanded very quickly. This increases the need for a proper control network. The existing control network has an "unknown" quality and consists actually of two separate networks with no proper connection, either in between with the primary network. These circumstances have led to a decision to establish a new control network connected to the primary network.

3.2 A conventional approach

The primary stations are placed on the tops of surrounding mountains, which means that they are difficult to reach and sometimes hidden in clouds or fog. As can be seen in figure 1 there is no line of sight between the village and the adjacent primary stations. A conventional approach when establishing a local control network in the valley implies having points halfway down the mountains on both sides of the valley, where there is sight to the primary stations and to the village.

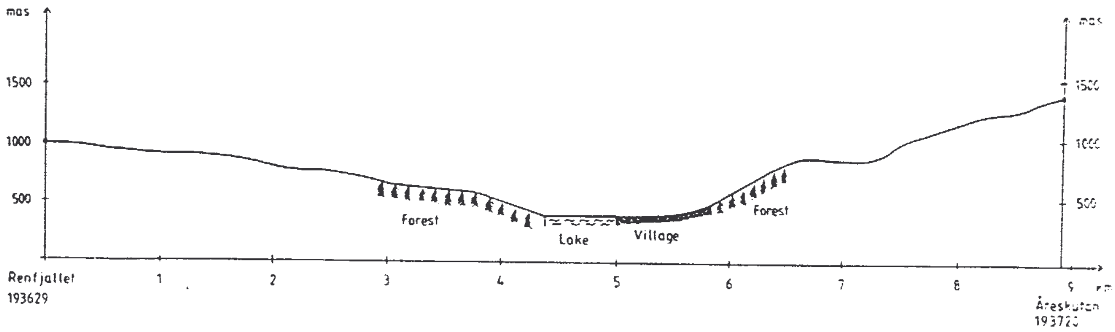


Figure 1. A vertical section across the valley.

3.3 The approach with GPS

The control network was established with GPS in a pilot project carried out in the summer 1988 in cooperation with local authorities.

With GPS the network solution looks a little bit different. Control points and new stations can be chosen with less constraints. The further densification of the network will be by traversing. Therefore, each station has to have line of sight to at least one other station in the network. Furthermore, the interstation distances should be long enough for good azimuths. The pairs should be close enough to keep down the number of points in the traverses. In this project some stations could, thanks the open terrain, use radio masts near two of the primary stations as back sights. 13 new stations were established along the valley with interstation distances of c. 1-3 km.

As control points 5 primary stations surrounding the new stations were chosen. The high and homogenious quality of the primary network makes it possible to skip some of the primary stations when connecting the network - see figure 2. Three of the control points had to be reached by helicopter.

3.4 GPS observations

We used the following principles for building a GPS network:

- The connection between adjacent stations should be observed.
- At least one common baseline between observation sessions.
- All new stations should be observed in at least two different sessions.
- All stations should be a part of a loop formed by non-trivial vectors.

For this project we had five WM101 receivers at our disposal. The observation interval, between 6 a.m. and 10 a.m., was divided into two sessions. Initially we planned to observe for four days; later this was changed to five days due to problems that occurred during the observations. The campaign took place 16-20 August 1988. In order to get free horizon over 15°-20° elevation, masts had to be built on two stations, and some of the other stations had 3-4 m high antenna setups. We used portable 9 m masts that could be erected quite easily. This project shows some examples of problems that could occur during GPS measurements. One of the receivers had power problems. Before we discovered how to get around this we lost a great part of the data. Another receiver didn't take any data at all for one day. Satellite 9 was set unhealthy as from the second day, which weakened the solutions. Fog and clouds in the valley made helicopter transportations impossible many days. These events explain the need for an additional observation day.

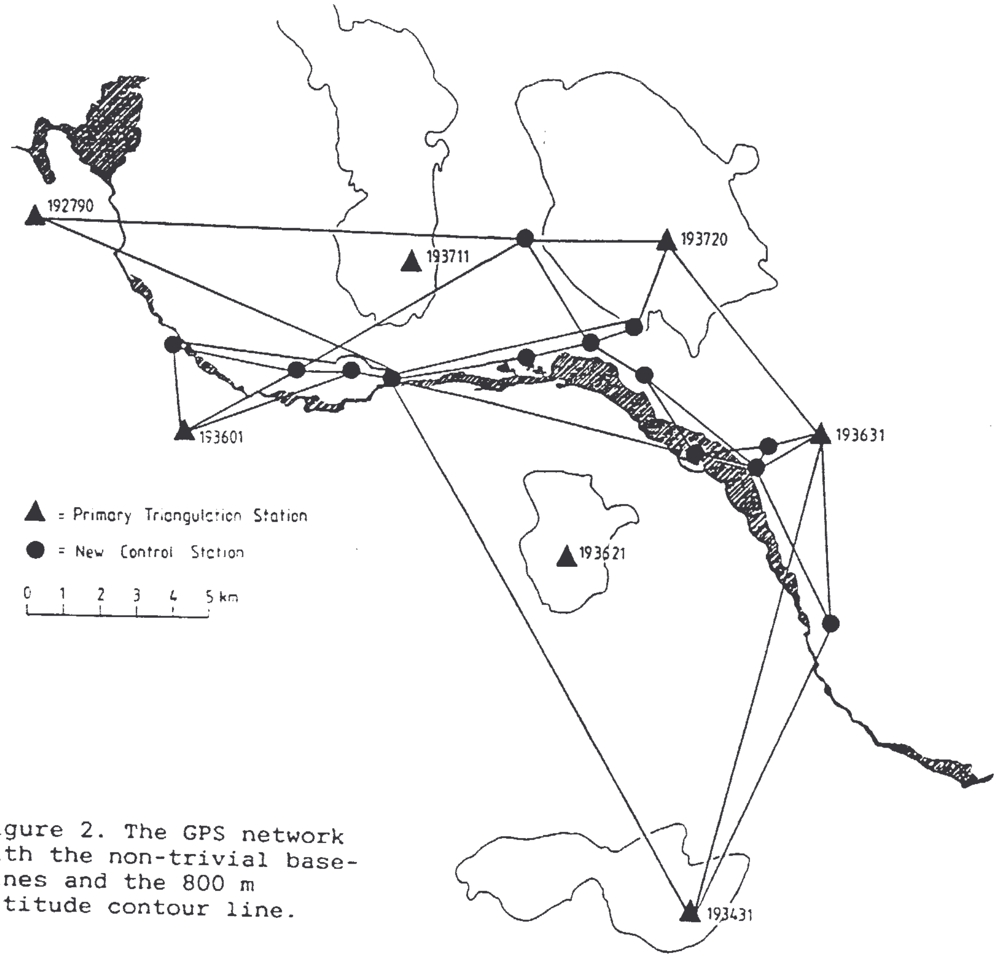


Figure 2. The GPS network with the non-trivial baselines and the 800 m altitude contour line.

3.5 Processing

The observation data were processed with PoPS ver. 2.02 (Post Processing Software) during the campaign in order to see if any remeasurements were needed. Each day was processed as one separate net, later on these separate nets were merged with the Geolab program. The data have finally been processed with the Bernese GPS Software ver. 3.0. Both programs use multistation adjustment and are based upon the same algorithms. One major difference is that the Bernese software has possibilities to adjust a network with many more stations than PoPS. However, there seems to be small differences in the final coordinates between the programs.

The elevation cut off angle was set to 20° because of the mountains. In the Bernese software there is no need to split the observing intervals into sessions as it is in PoPS, but considering the redundancy aspect we split them into two sessions. Loops were formed in order to search for gross errors, which resulted in detection of two antenna height errors and two bad baselines. The size of one of the antenna height errors was estimated in the Bernese software and turned out to be 25 cm, which is exactly the same length as the WM101 height hook constant!

The coordinates in WGS84 from the GPS adjustment was transformed in three steps into grid coordinates in the national system. The last step is a 4-parameter Helmert transformation with the primary stations as fitting points. This way is preferred to a 7-parameter transformation, where the less accurate heights of the primary stations can influence the horizontal coordinates.

3.6 Results

The loop misclosures give an indication of the internal accuracy of the GPS network. The result in table 1 shows that the accuracy is about the same in height as in the horizontal coordinates and that it is about 1-2 cm even on short baselines, which agrees with results we have obtained in other campaigns with WM101. The misclosures contain errors from both the GPS measurements and from the centering, except for the loops that are formed within one day, where there is only one antenna setup for each station. The one day loops have smaller errors in height and there are also some systematic effects in latitude and longitude between the first and second sessions, which probably depend on the weak satellite configuration. Except for antenna height errors, atmospherical differences between the days could be a reason for the larger height errors in loops with more than one day.

Horizontal distance (km)	Days	Height diff. (m)	$\Delta\varphi$ (m)	$\Delta\lambda$ (m)	Δh (m)
2	1	500	0.004	-0.002	-0.006
10	1	700	0.001	-0.006	-0.003
12	1	200	0.005	-0.026	-0.002
21	1	200	0.015	-0.030	0.000
30	1	500	0.017	-0.039	0.014
41	1	600	0.029	-0.002	-0.012
1	2	100	-0.002	0.025	-0.018
5	2	300	0.011	-0.006	-0.025
7	2	0	0.004	0.003	0.032
8	2	200	0.008	-0.008	-0.001
13	2	500	0.024	-0.013	0.006
15	2	300	0.008	0.028	0.026
19	2	300	-0.016	0.005	-0.007
21	2	0	0.006	0.008	-0.008
29	2	600	-0.013	-0.002	0.034
33	2	300	-0.028	0.009	-0.030
18	3	1000	-0.013	-0.005	0.062
		RMS	0.014	0.017	0.023

Table 1. Loop misclosures. The distance is the sum of vector distances in the loop and the height difference is the difference between the highest and lowest station.

The result from the 4-parameter Helmert transformation shows a good agreement between the GPS network and the primary network - see table 2. The scale is not significant and the rotation of 2 mgon is caused by a rotation between the WGS84 ellipsoid and the Bessel ellipsoid used in the Swedish datum.

Station	Residuals (m)	
192790	0.015	0.005
193431	0.008	0.009
193601	-0.009	-0.009
193631	-0.003	0.006
193720	-0.011	-0.012
Standard error 0.012 m Scale 0.7 ppm +- 0.5 ppm Rotation 1.91 mgon		

Table 2. 4-parameter Helmert transformation.

4. CONCLUDING REMARKS

GPS is an excellent technique to connect local control networks to the primary network. Towers don't have to be built, just masts in some cases. There is also no need to establish any intermediate points in order to reach the area of interest. New stations can be placed where they are needed for further measurements. This means that the total number of stations can be reduced with GPS in comparison to terrestrial methods.

GPS measurements can be carried out in any weather, an exception is when the transportations to the stations demand good weather. On the other hand, GPS measurements can be disturbed by magnetic storms, which now (1990) is a problem in Sweden, and by changes in the GPS system itself.

The field work with GPS has been reduced to starting and stopping the observations and to setting up and centering tripods and masts. More work has moved over to processing and analysis of the data. The only way to decide the quality of the data is to process it. Therefore it is important to make the processing more or less in parallel with the observations.

GPS has proved itself to be an effective technique for establishment of local control networks, although the system isn't fully built up yet. We have been using GPS for networks with down to 3 km between the point pairs. Further densification has been considered to be more efficient with conventional methods. Development of new methods with shorter observation time, such as the pseudo-kinematic method, better satellite configuration and cheaper receivers will further improve the effectivness of GPS measurements.

REFERENCES

Beutler G and others, Static Positioning with the Global Positioning System (GPS): State of the art. Proceedings of the International GPS-Workshop Darmstadt, April 1988.

Eliasson L, Reit B-G, RT90 - förbättrade koordinater på rikets triangelpunkter. Svensk Lantmäteritidskrift 1988:4.

C

RESULT FROM STATIC DUAL-FREQUENCY GPS MEASUREMENTS - A STATUS REPORT

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RESULTS FROM STATIC DUAL-FREQUENCY GPS MEASUREMENTS - A STATUS REPORT.

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ABSTRACT

At the National Land Survey of Sweden (NLS) GPS techniques are now used routinely for the establishment of local control networks (inter-station distances c. 1-3 km) connected to the Swedish Primary Triangulation Network. L1-receivers are used and in most cases they give good accuracies for baseline lengths up to 30 km. During 1989 ionospheric activity has increased, which for some days has resulted in unusable GPS measurements.

One possibility to minimize the effect of the ionospheric refraction is to perform observations on both the L1- and the L2-frequencies. The results from dual-frequency measurements, in the Swedish test network for GPS-observations around the NLS observatory at Mårtsbo southeast of Gävle, are discussed in this paper.

1. INTRODUCTION

During the time period 1987-1989 National Land Survey (NLS) developed methods for the use of GPS techniques in the establishment of local control networks (inter-station distances c. 1-3 km) connected to the Swedish Primary Triangulation Network (3). Since June 1989 GPS techniques are used routinely at NLS for this purpose.

We are using Ashtech LXII GPS receivers and an Ashtech GPPS post-processing software package combined with the 3-dimensional adjustment programme GeoLab from GEOsurv Inc. NLS has also implemented the Bernese GPS software ver. 3.0 on a Prime mini-computer. At present no conversion programme between the Ashtech observation data format and the standard format RINEX is available and therefore it has not been possible to compute the Ashtech data using the Bernese software.

In most cases the Ashtech L1-receivers give good accuracies for baseline lengths up to 30 km. During 1989 the ionospheric activity increased, which for some days resulted in unusable GPS measurements. One possibility to reduce the effects of high ionospheric activity in production work is to avoid measurements of baseline lengths above a few km when the activity level is high.

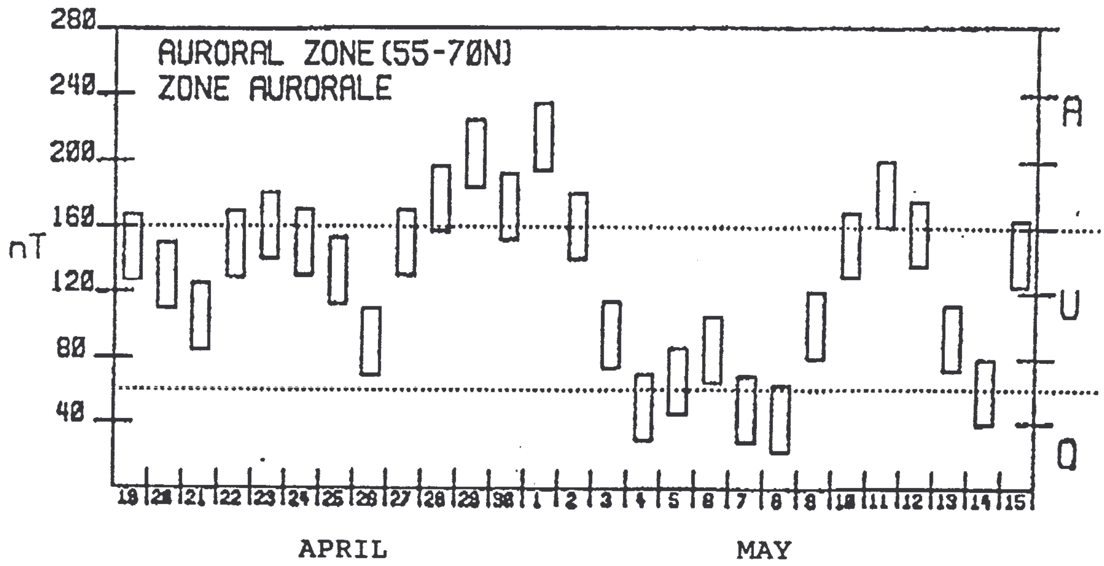


Figure 1. Forecasts from the Geological Survey of Canada for geomagnetic activity. Q, U and A represent quiet, unsettled and active levels of geomagnetic activity.

Forecasts for geomagnetic activity can be obtained from the Geological Survey of Canada, see figure 1. We have not investigated the reliability of these types of forecasts.

A well-known method to reduce the effects of ionospheric refraction for long baseline lengths (> 30 km), at quiet and perhaps unsettled levels of geomagnetic activity, is to carry out observations on both the L1- and L2-frequencies. It is not clear today if also the effects of high ionospheric activity will be reduced (or eliminated) with this method.

In December 1989 NLS received a delivery of 3 dual-frequency Ashtech LDXII receivers. Ashtech uses the codeless (squaring) technique for the L2-observations. The GPPS processing software is able to use the ionosphere-free linear combination of the L1- och L2-observations which in this paper is called the L3-observation.

2. GPS OBSERVATIONS

NLS carried out dual-frequency measurements during a total of 13 days in the time period January to March 1990 in the Swedish GPS test network around Gävle (4). The length of the observed baselines was in the interval 8-40 km. A summary of the observed baselines are shown in table 1.

The available observation interval was divided into three sessions during the time period 25 January - 17 February and into two sessions during the time period 18 February - 7 March. The satellite distribution is shown in appendix 1.

The level of the geomagnetic activity varied during the time period for the observations. According to information from the Swedish Institute of Space Physics, the Uppsala Division and the Lycksele observatory, the level of the geomagnetic activity was quiet ("normal") during 6 observation days and unsettled or active during 7 observation days.

3. COMPUTATION OF THE GPS-OBSERVATIONS

For each baseline a L1-solution was developed based on the carrier phase measurements on the L1-frequency and a L3-solution which is based on the ionosphere-free linear combination of the carrier phase measurements on the L1- and L2-frequencies using the Ashtech GPPS post-processing software. GPPS is a baseline programme, which uses the double difference technique and has an automatic routine for cycle slip fixing. In the float solution the ambiguities are estimated as parameters and in the fix solution they are fixed to integers for the L1-observations. No fix solution is computed for the L3-observations.

The quality of each baseline computation has been evaluated using the following factors:

- the decimal part of the ambiguity values
- the results of the test of the estimated integer values of the ambiguities
- the RMS values of the fix and float solutions
- the difference between the RMS values for the float and the fix solutions
- coordinate differences between the float and fix solutions
- geometric number (gives an indication of the satellite geometry)
- plots of the residuals of the double differences

The baseline vectors have been adjusted using a model which takes into consideration the correlations between different vector components within a baseline but not the correlation between baselines. Weights according to the estimates of the internal standard error of the GPS observations have been applied. Outlying observations have been down-weighted using the "Danish" method.

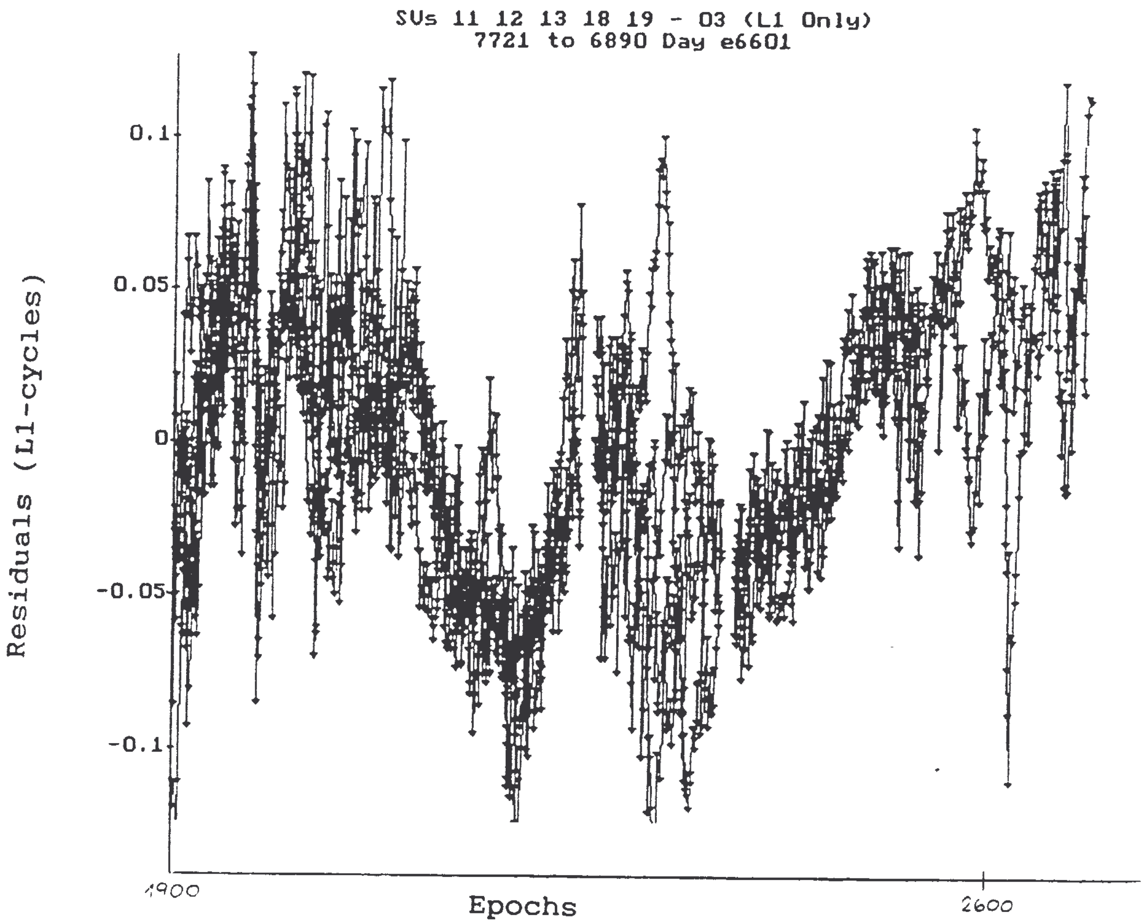
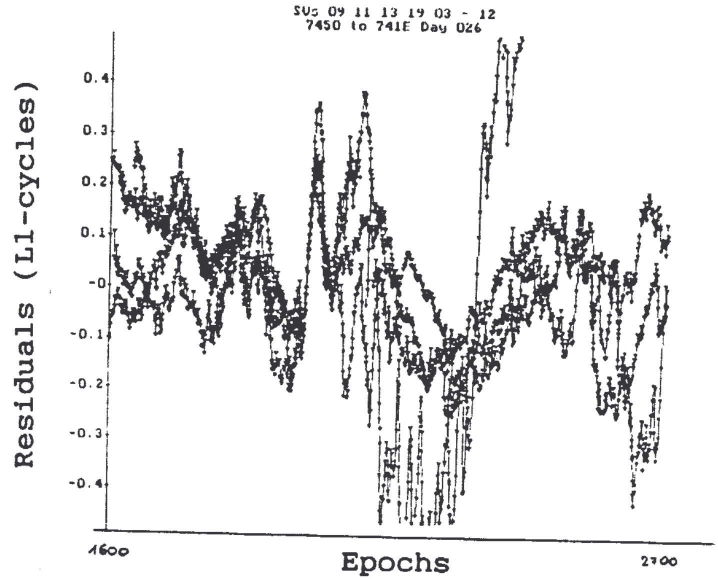


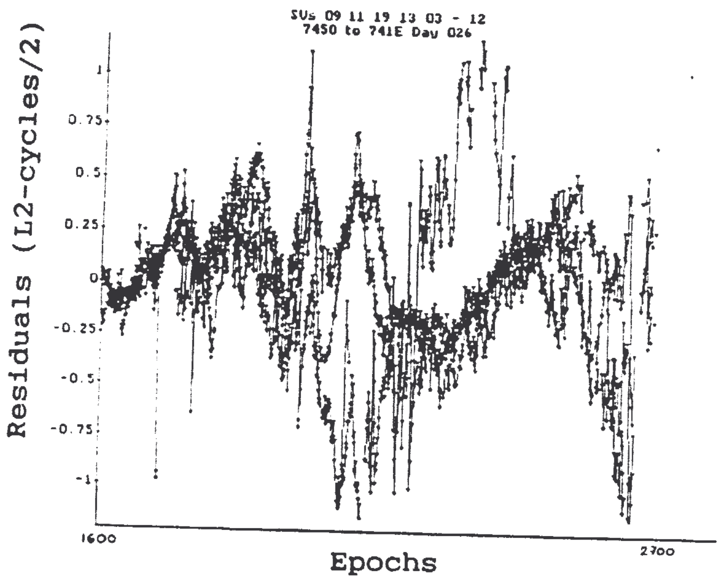
Diagram 1. Plot of double difference residuals for a "normal" L1-solution (baseline length 18 km)

4. RESULTS

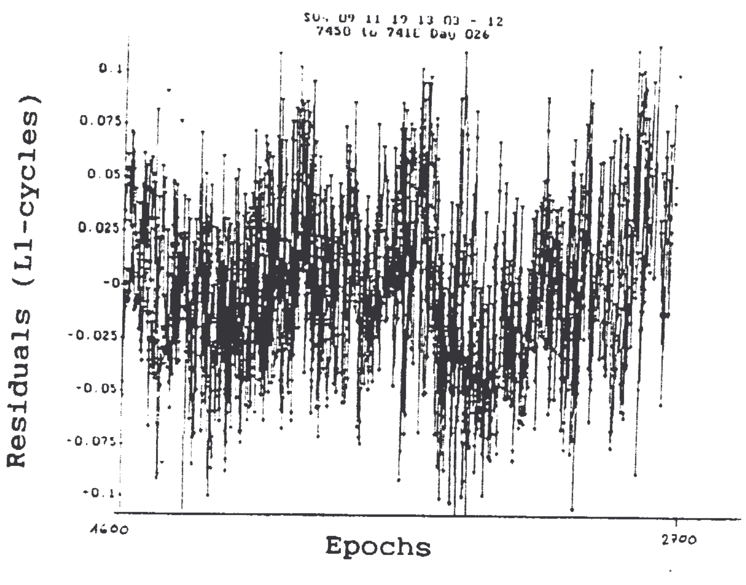
The quality of a baseline computation can be illustrated by plots of the double difference residuals. In diagram 1 the double difference residuals for a "normal" L1-solution are shown. The epoch interval is 10 seconds. In diagrams 2 and 3 it is shown that the effect of the ionospheric refraction in the L1- and L2-solutions can be removed in the ionosphere-free L3-solution.



L1-solution.



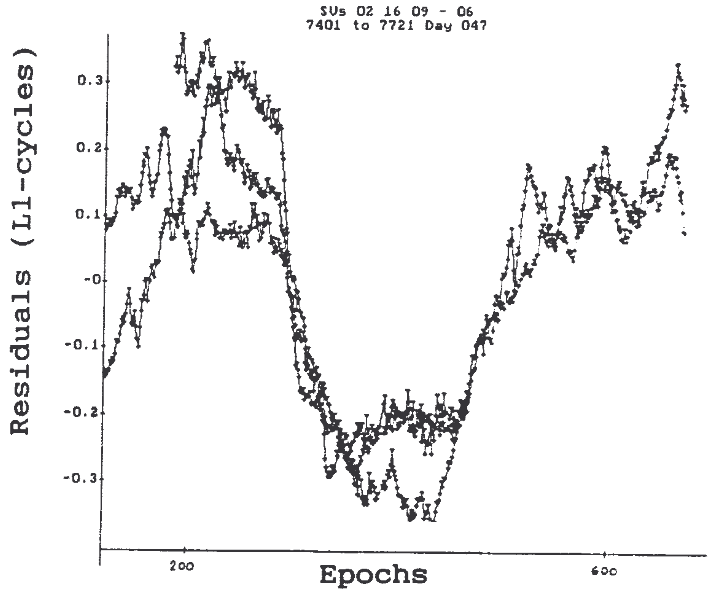
L2-solution.



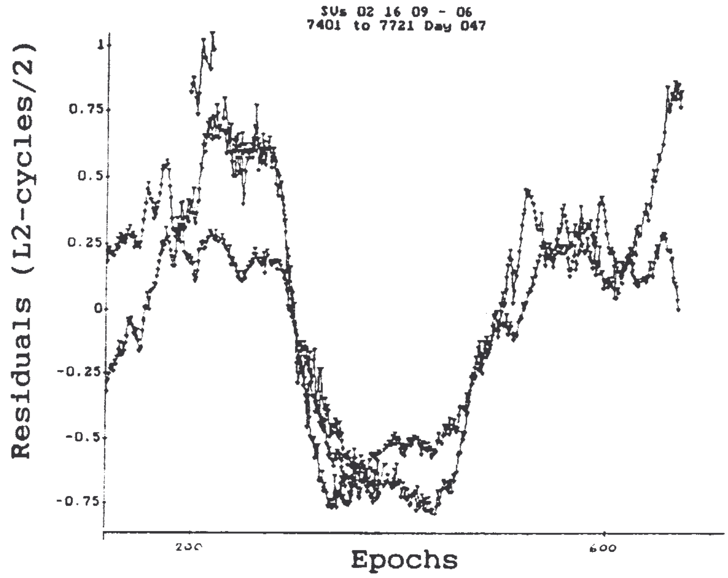
L3-solution.

Diagram 2.
Plot of double difference residuals for "noisy" solutions (Baseline length 15 km).

L1-solution.



L2-solution.



L3-solution.

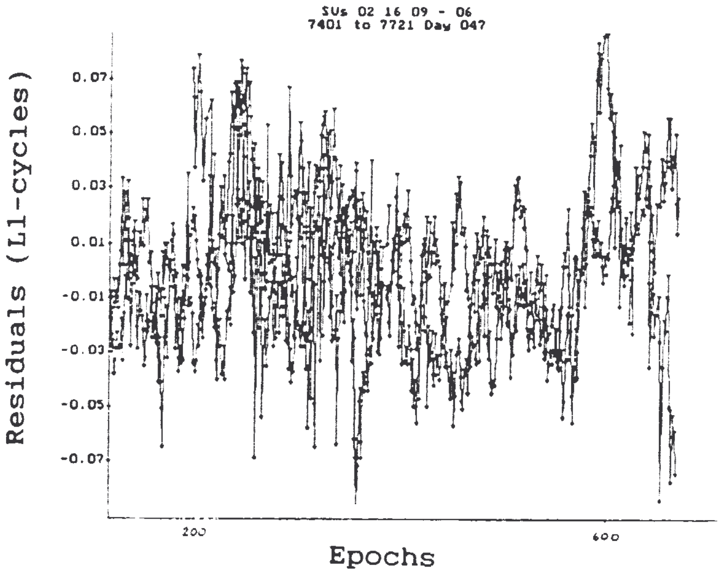


Diagram 3.
Plot of double difference residuals for solutions with systematic effects (Baseline length 19 km).

A summary of the baseline computations is shown in table 1. In the left columns of the table the quality of the computed baselines is shown. "OK" means that the solution is good, i. e. the above mentioned quality factors fulfill the criterions for a good baseline and "OK?" means that it is difficult to judge whether the solution is good or not. "sy" , "ni" or "-" means that it was not possible to obtain a good solution because of systematic effects, noisy data or any other reason.

Table 1. Summary of the evaluation of the quality of the computed baselines and comparisons between GPS-determined baseline lengths and terrestrial lengths.

Day sess	Base-line	Di km	Io ac	GPS-sol. L1-s.	GPS-sol. L3-s.	Length differences (GPS - terr.) L1-sol. meter	L1-sol. ppm	L3-sol. meter	L3-sol. ppm
025A	MBO-SVT	27	n	OK?	-	-0.028	-1.0		
B				OK?	-	-0.051	-1.9		
C				OK?	OK	-0.076	-2.8	-0.045	-1.6
026A	MBO-HVT	15	n	OK?	OK?	(-0.108	7.0)	-0.057	-3.7
B				-	-				
C				OK?	OK	-0.000	0.0	-0.041	-2.7
031A		34	n	sy+ni	-				
B				sy+ni	ni				
C				sy+ni	OK	No terrestrial info			
034B	HVT-SLG	12	n	-	OK?			-0.046	-3.9
C				OK	OK	0.002	0.2	-0.010	-0.8
064D	SLG-VBO	13	n	OK	OK?	-0.023	-1.8	(-0.171	-13.1)
E				-	OK			0.007	0.5
066D	HVT-NYH	11	n	OK	OK?	-0.008	-0.7	-0.024	-2.1
E				OK	OK	0.002	0.2	0.025	2.1
066D	HVT-MLK	29	n	OK	OK?	-0.063	-2.2	-0.037	-1.3
E				OK	OK	-0.038	-1.3	-0.019	-0.7
066D	NYH-MLK	18	n	OK	OK?	-0.056	-3.1	-0.013	-0.7
E				OK	OK	-0.041	-2.3	-0.060	-3.4
				MEAN:		-0.034	-1.5	-0.026	-1.5
				STAND DEV:		0.0262	1.11	0.0259	-1.77

Table 1. (cont.)

Day sess	Base-line	Di km	Io ac	GPS-sol. L1-s.	GPS-sol. L3-s.	Length differences (GPS - terr.) L1-sol. meter	L1-sol. ppm	L3-sol. meter	L3-sol. ppm
032A		30	y	sy	OK?	No terrestrial info			
B				sy	-				
C				sy+ni	OK	"	"	"	
035A	MBO-SLG	8	y	OK	-	-0.025	-3.0		
B				OK	-	-0.032	-3.9		
C				sy	ni				
047A	SVT-NYH	19	y	sy	OK			-0.032	-1.7
B				sy	-				
C				sy	OK			-0.013	-0.7
048B	SVT-HVT	26	y	sy+ni	-				
C				-	OK?			(-0.187	-7.2)
049D	MBO-SVT	27	y	OK?	OK	-0.067	-2.5	-0.072	-2.6
E				ni	OK			-0.058	-2.1
050D	MBO-SVT	27	y	sy+ni	OK			-0.050	-1.8
E				sy+ni	-				
065D	MBO-MLK	37	y	sy	sy				
E				sy	sy				
065D	MBO-VBO	16	y	sy	OK?			(0.157	9.8)
E				sy	OK			(-0.130	-8.1)
065D	MLK-VBO	40	y	sy	sy				
E				sy	sy				
				MEAN:		-0.041	-3.1	-0.045	-1.7

Legend:

Io ac = ionospheric activity
y = the level of the geomagnetic activity is unsettled or active according to information from the Swedish Institute of Space Physics
n = the level of the geomagnetic activity is quiet
OK = the solution fulfils the criterions for a good solution
\- = the solution does not fulfil the criterions for a good solution
sy = systematic effects is shown in the plots of the double difference residuals (no good solution)
ni = noise is shown in the plots of the double difference residuals (no good solution)

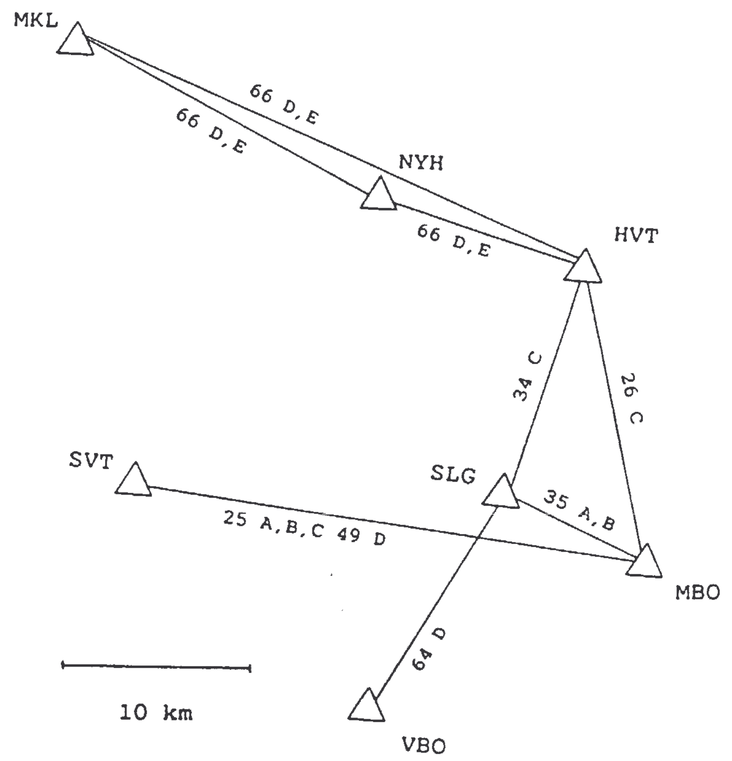


Figure 2. Good baselines in the L1-solution.

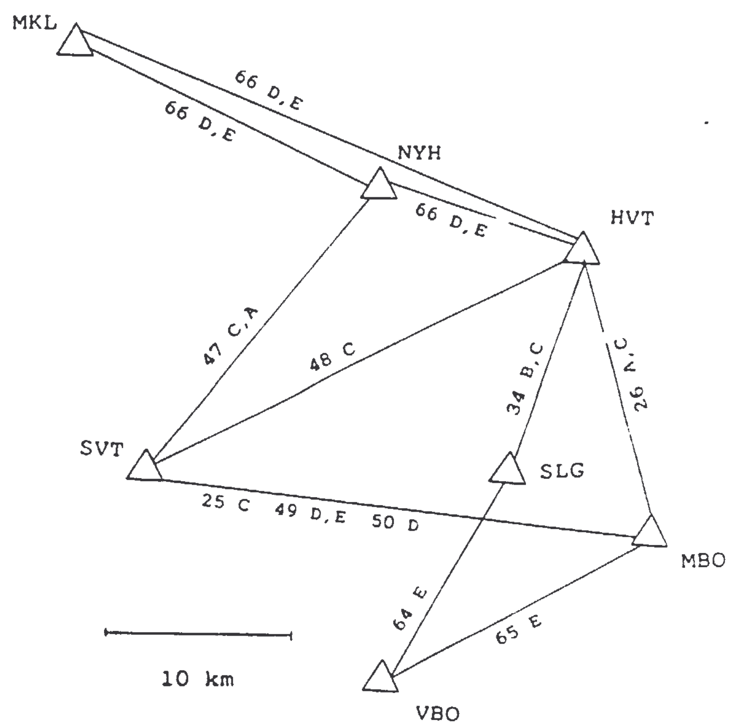


Figure 3. Good baselines in the L3-solution.

Table 2. Helmert transformations from the GPS coordinate system to the terrestrial system.

Site	L1-solution Transform. errors dx (meters)	L1-solution Transform. errors dy (meters)	L3-solution Transform. errors dx (meters)	L3-solution Transform. errors dy (meters)
MBO	0.005	-0.018	0.027	0.005
HVT	0.022	0.009	-0.003	0.000
SVT	-0.034	-0.004	-0.010	0.019
SLG	0.000	-0.003	0.001	-0.001
NYH	0.015	-0.001	0.015	0.010
MKL	0.000	0.023	-0.007	0.002
VBO	-0.006	-0.006	-0.024	-0.036

	L1-solution	L3-solution
Stand. error of unit weight:	0.017 meter/coord.	0.019 meter/coord.
Scale:	1.7 ppm +/- 0.4	2.0 ppm +/- 0.5
Rotation:	-0.15 +/- 0.09	-0.13 +/- 0.10

In the right columns of table 1 comparisons between GPS determined baseline lengths and terrestrial lengths are shown.

From the table it can be seen that the criterions for a good baseline measurement was realistic in this experiment. There was no obvious improvement in the the results when dual-frequency measurements were used at quiet levels of geomagnetic activity. At unsettled and active levels there was an improvement in the number of good solutions using dual-frequency measurements, but there were still many observed baselines which did not give good solutions.

The good baseline vectors of the L1- and L3-solutions were adjusted in two separate networks, see figures 2 and 3, using the GeoLab adjustment programme.

The GPS-coordinates were transformed into the local terrestrial coordinate system using a Helmert transformation. The transformation errors and parameters are shown in table 2. From the table it can be seen that there is no obvious difference in the quality of the L1- and L3-solutions in our experiment.

5. EXPERIENCES FROM COMPUTATIONS OF DUAL-FREQUENCY MEASUREMENTS

The observations on the L2-frequency are more sensitive to cycle slips because of the fact that the squaring technique decreases the signal-to-noise ratio and halve the wave length to 0.12 meters. It is also more difficult to repair cycle slips on the L2-frequency because of the short wavelength and difficulties in distinguishing between atmospheric disturbancies and cycle slips at low elevations. A minimum cut-off angle of 15 degrees is normally used for L1-observations, but a minimum angle of 25 degrees was used in the computations of the dual-frequency measurements in order to be able to repair the cycle slips. Manual repairs of slips have been carried out for some baselines. The increase of the cut-off angle to 25 degrees resulted sometimes in poor satellite geometry at the present satellite configuration and therefore the dual-frequency measurements require longer observation times than L1-observations.

Many of the factors for the evaluation of the L1-solution are based on the ambiguity resolution and comparisons between float and fix solutions. Since no fix solution is developed for the L3-observations it is necessary to to find other factors for the evaluation of the L3-solutions.

More favourable locations of the satellites in the future will improve the conditions for dual-frequency measurements. Another possibility may be to use the P-code for the L2-observations instead of the codeless technique.

6. FUTURE PLANS

The observation data of the dual-frequency measurements with the Ashtech receivers will be processed with the Bernese software as soon as the conversion programme between the Ashtech data format and RINEX-format is available.

The obtained results will be further evaluated and additional dual frequency measurements will be carried out in September this year.

7. CONCLUDING REMARKS

The experiences and results in this experiment indicate that the codeless dual-frequency technigue is not fully developed for routine production work, but the possibility to obtain good solutions during periods of high ionospheric activity increases with dual-frequency measurements.

8. REFERENCES

(1) Fredriksson K., Jivall A.-C.: Kinematisk och Pseudokinematisk GPS -ett alternativ till statisk GPS?, Svensk Lantmäteritidskrift 1990:1.

(2) Jivall A.-C.: Test av Trimble 4000ST och Ashtech LXII i det svenska testnätet för GPS, Svensk Lantmäteritidskrift 1990:1.

(3) Jivall A.-C., Hedling G., Jonsson B.,: Establishment of local control networks with GPS, FIG XIX international congress, Helsinki, Finland, June 1990.

(4) Jonsson B.: GPS observations with Trimble 4000S and Texas TI4100 -status report September 1986, Nordic Geodetic Commision 10th Meeting, Helsinki, 1986.

(5) Musman S.: Disruption of GPS observations by ionospheric disturbances, Proceedings of ION GPS-89, The second International Technical Meeting of the Satellite Division of the Institute of Navigation, Colorado Springs, 1989

(6) Ashtech XII GPPS, GPS Post-processing system (manual)

Session definition for day 025 - 048

Table 1

Satellite visibility for LAT: N60-35-42.00 LONG: E17-15-30.00 Alt: 0.000(m) MARTSBO
Date of Table: 22-FEB-90(Day 53) Date of Almanac: 02/16/90 Cut off Angle: 15 Min Visible Sats: 1

	Alm Ref	527	527	527	527	527	527	527	527	527	527	527	527
	SV Num	2	3	6	9	11	12	13	14	16	17	18	19
	UTC Time	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ
	14:15:00	41 65	¦	61 233	18 237	¦	¦	¦	¦	45 285	15:340	¦	¦
	14:25:00	38 60	¦	66 236	23 239	¦	¦	¦	¦	46 279	16 336	¦	¦
	14:35:00	35 57	¦	71 240	27 241	¦	¦	¦	¦	47 273	16 332	¦	¦
	14:45:00	31 54	¦	76 244	32 244	¦	¦	¦	¦	46 266	16 328	¦	¦
A	14:55:00	28 52	¦	81 251	36 247	¦	¦	¦	¦	45 260	16 324	¦	¦
	15:05:00	24 50	¦	86 270	41 250	¦	1:249	¦	¦	44 254	15:320	¦	¦
	15:15:00	20 48	¦	87 15	46 253	¦	5:251	¦	¦	41 248	14:316	¦	¦
	15:25:00	16 48	¦	83 51	51 256	¦	9:254	¦	¦	38 243	12:312	¦	¦
	15:35:00	12: 47	¦	78 60	56 260	¦	13:256	¦	¦	35 239	10:308	¦	¦
	15:45:00	8: 47	¦	73 66	61 263	0:137	17 259	¦	¦	32 235	8:305	¦	¦
	15:55:00	4: 47	¦	68 70	66 268	5:136	21 262	¦	¦	28 232	5:302	¦	¦
	16:05:00	0: 47	¦	63 73	71 273	9:134	26 264	¦	¦	24 229	2:299	¦	¦
	16:15:00	¦	¦	58 77	76 280	14:133	30 267	¦	¦	20 227	¦	¦	¦
	16:25:00	¦	¦	53 80	80 292	18 131	34 269	¦	¦	16 225	¦	¦	¦
B	16:35:00	¦	¦	49 83	85 319	22 130	39 272	¦	¦	12:223	¦	¦	¦
	16:45:00	¦	¦	44 86	85 23	27 128	43 275	¦	¦	8:221	¦	¦	¦
	16:55:00	¦	¦	39 89	82 62	31 125	48 278	¦	¦	4:219	¦	¦	0:278
	17:05:00	¦	¦	35 91	77 77	36 122	53 280	3:160	¦	0:217	¦	¦	4:279
	17:15:00	¦	¦	31 94	72 85	40 119	57 283	8:159	¦	¦	¦	¦	8:281
	17:25:00	¦	¦	26 97	68 91	44 115	62 286	12:159	¦	¦	¦	¦	12:282
	17:35:00	¦	¦	22 100	63 95	47 110	67 289	17 158	¦	¦	¦	¦	16 283
	17:45:00	¦	¦	18 102	58 99	50 104	72 291	22 157	¦	¦	¦	¦	20 285
	17:55:00	¦	¦	14:105	53 103	52 97	77 294	27 157	¦	¦	¦	¦	24 285
	18:05:00	¦	¦	10:108	48 106	54 89	82 298	32 155	¦	¦	¦	¦	28 286
	18:15:00	¦	¦	6:110	44 109	54 81	87 304	37 154	¦	¦	¦	3:332	33 287
	18:25:00	¦	4:180	2:113	39 112	54 72	88 109	42 152	¦	¦	¦	7:331	37 287
	18:35:00	¦	8:181	¦	34 115	52 65	83 120	47 150	¦	¦	¦	10:329	41 286
C	18:45:00	¦	13:181	¦	30 118	50 58	78 124	51 146	¦	¦	¦	14:328	45 285
	18:55:00	¦	17 182	¦	26 120	47 53	73 127	56 142	¦	¦	¦	17 325	50 284
	19:05:00	¦	22 182	¦	21 123	43 48	68 129	60 136	¦	¦	¦	20 323	54 281
	19:15:00	¦	27 182	¦	17 125	40 45	63 132	63 127	¦	¦	¦	23 320	58 278
	19:25:00	¦	32 183	¦	13:128	36 43	58 134	66 116	¦	¦	¦	25 316	61 272
	19:35:00	¦	37 183	¦	8:130	31 41	53 136	67 104	¦	¦	¦	28 312	64 265
	19:45:00	¦	42 184	¦	4:132	27 40	48 139	67 91	¦	¦	¦	29 308	66 255
	19:55:00	¦	47 184	¦	0:134	23 39	43 141	65 79	¦	¦	¦	30 303	68 244
	20:05:00	¦	53 183	¦	¦	18 39	39 143	62 70	¦	¦	¦	31 298	67 231
	20:15:00	¦	58 182	¦	¦	14: 39	34 145	58 63	2: 58	¦	¦	31 293	66 220
	20:25:00	¦	63 180	¦	¦	10: 39	29 146	54 58	4: 55	¦	¦	30 288	64 211
	20:35:00	¦	68 177	¦	¦	5: 40	24 148	50 55	7: 52	¦	¦	29 283	60 203
	20:45:00	¦	73 170	¦	¦	1: 41	20 150	45 53	9: 48	¦	¦	28 279	56 198
	20:55:00	¦	77 157	¦	¦	¦	15 151	41 52	11: 45	¦	¦	26 274	52 193

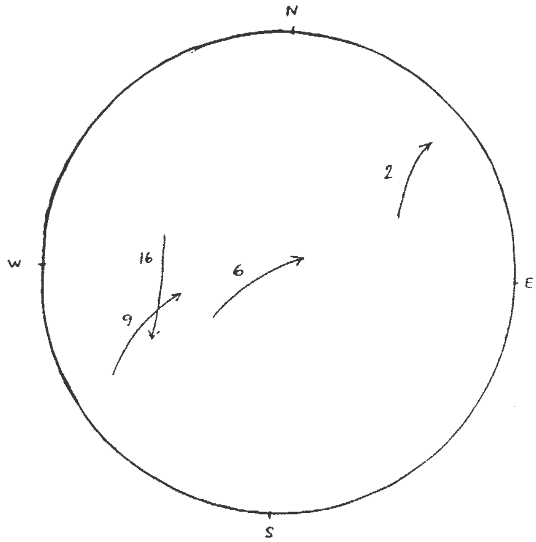
Session definition for day 049 - 066

Table 1

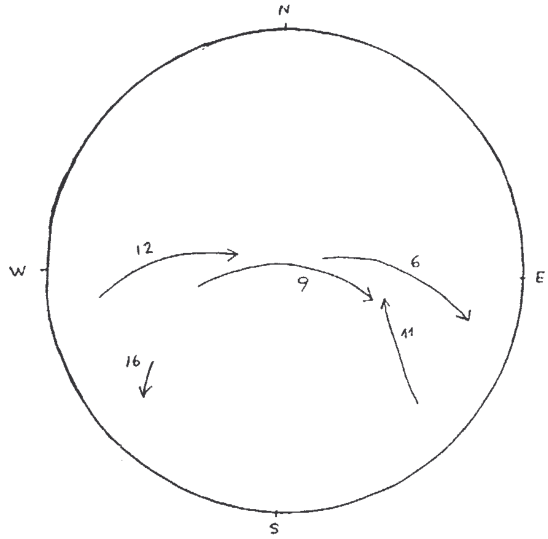
Satellite visibility for LAT: N60-35-42.00 LONG: E17-15-30.00 Alt: 0.000(m) MARTSBO
Date of Table: 22-FEB-90(Day 53) Date of Almanac: 02/16/90 Cut off Angle: 15 Min Visible Sats: 1

	Alm Ref	527	527	527	527	527	527	527	527	527	527	527	527
	SV Num	2	3	6	9	11	12	13	14	16	17	18	19
	UTC Time	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ	EL AZ
	14:15:00	41 65	¦	61 233	18 237	¦	¦	¦	¦	45 285	15:340	¦	¦
	14:25:00	38 60	¦	66 236	23 239	¦	¦	¦	¦	46 279	16 336	¦	¦
	14:35:00	35 57	¦	71 240	27 241	¦	¦	¦	¦	47 273	16 332	¦	¦
	14:45:00	31 54	¦	76 244	32 244	¦	¦	¦	¦	46 266	16 328	¦	¦
	14:55:00	28 52	¦	81 251	36 247	¦	¦	¦	¦	45 260	16 324	¦	¦
	15:05:00	24 50	¦	86 270	41 250	¦	1:249	¦	¦	44 254	15:320	¦	¦
	15:15:00	20 48	¦	87 15	46 253	¦	5:251	¦	¦	41 248	14:316	¦	¦
	15:25:00	16 48	¦	83 51	51 256	¦	9:254	¦	¦	38 243	12:312	¦	¦
	15:35:00	12: 47	¦	78 60	56 260	¦	13:256	¦	¦	35 239	10:308	¦	¦
	15:45:00	8: 47	¦	73 66	61 263	0:137	17 259	¦	¦	32 235	8:305	¦	¦
	15:55:00	4: 47	¦	68 70	66 268	5:136	21 262	¦	¦	28 232	5:302	¦	¦
	16:05:00	0: 47	¦	63 73	71 273	9:134	26 264	¦	¦	24 229	2:299	¦	¦
	16:15:00	¦	¦	58 77	76 280	14:133	30 267	¦	¦	20 227	¦	¦	¦
D	16:25:00	¦	¦	53 80	80 292	18 131	34 269	¦	¦	16 225	¦	¦	¦
	16:35:00	¦	¦	49 83	85 319	22 130	39 272	¦	¦	12:223	¦	¦	¦
	16:45:00	¦	¦	44 86	85 23	27 128	43 275	¦	¦	8:221	¦	¦	¦
	16:55:00	¦	¦	39 89	82 62	31 125	48 278	¦	¦	4:219	¦	¦	0:278
	17:05:00	¦	¦	35 91	77 77	36 122	53 280	3:160	¦	0:217	¦	¦	4:279
	17:15:00	¦	¦	31 94	72 85	40 119	57 283	8:159	¦	¦	¦	¦	8:281
	17:25:00	¦	¦	26 97	68 91	44 115	62 286	12:159	¦	¦	¦	¦	12:282
	17:35:00	¦	¦	22 100	63 95	47 110	67 289	17 158	¦	¦	¦	¦	16 283
	17:45:00	¦	¦	18 102	58 99	50 104	72 291	22 157	¦	¦	¦	¦	20 285
	17:55:00	¦	¦	14:105	53 103	52 97	77 294	27 157	¦	¦	¦	¦	24 285
	18:05:00	¦	¦	10:108	48 106	54 89	82 298	32 155	¦	¦	¦	¦	28 286
	18:15:00	¦	¦	6:110	44 109	54 81	87 304	37 154	¦	¦	¦	3:332	33 287
	18:25:00	¦	4:180	2:113	39 112	54 72	88 109	42 152	¦	¦	¦	7:331	37 287
	18:35:00	¦	8:181	¦	34 115	52 65	83 120	47 150	¦	¦	¦	10:329	41 286
	18:45:00	¦	13:181	¦	30 118	50 58	78 124	51 146	¦	¦	¦	14:328	45 285
	18:55:00	¦	17 182	¦	26 120	47 53	73 127	56 142	¦	¦	¦	17 325	50 284
	19:05:00	¦	22 182	¦	21 123	43 48	68 129	60 136	¦	¦	¦	20 323	54 281
	19:15:00	¦	27 182	¦	17 125	40 45	63 132	63 127	¦	¦	¦	23 320	58 278
E	19:25:00	¦	32 183	¦	13:128	36 43	58 134	66 116	¦	¦	¦	25 316	61 272
	19:35:00	¦	37 183	¦	8:130	31 41	53 136	67 104	¦	¦	¦	28 312	64 265
	19:45:00	¦	42 184	¦	4:132	27 40	48 139	67 91	¦	¦	¦	29 308	66 255
	19:55:00	¦	47 184	¦	0:134	23 39	43 141	65 79	¦	¦	¦	30 303	68 244
	20:05:00	¦	53 183	¦	¦	18 39	39 143	62 70	¦	¦	¦	31 298	67 231
	20:15:00	¦	58 182	¦	¦	14: 39	34 145	58 63	2: 58	¦	¦	31 293	66 220
	20:25:00	¦	63 180	¦	¦	10: 39	29 146	54 58	4: 55	¦	¦	30 288	64 211
	20:35:00	¦	68 177	¦	¦	5: 40	24 148	50 55	7: 52	¦	¦	29 283	60 203
	20:45:00	¦	73 170	¦	¦	1: 41	20 150	45 53	9: 48	¦	¦	28 279	56 198
	20:55:00	¦	77 157	¦	¦	¦	15 151	41 52	11: 45	¦	¦	26 274	52 193

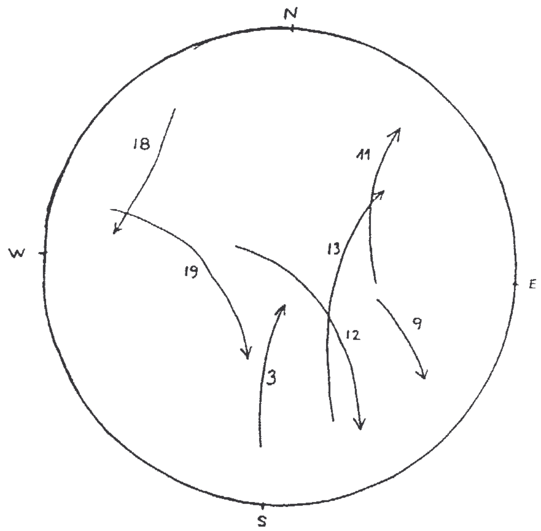
Satellite visibility polar map



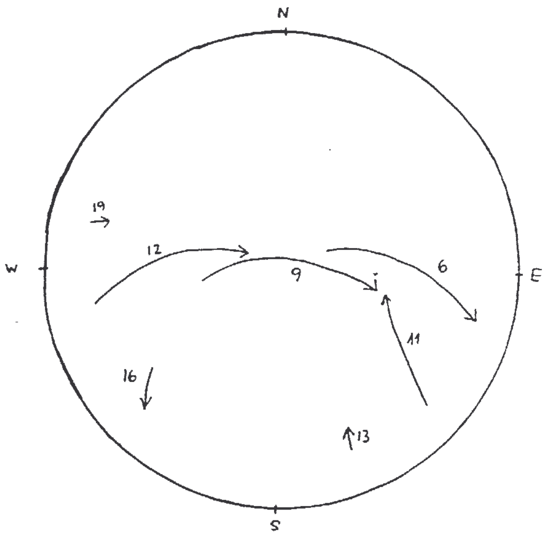
Session A



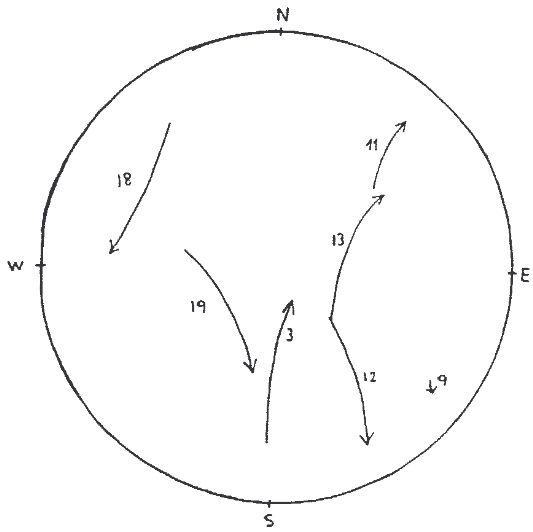
Session B



Session C



Session D



Session E