



Lantmäteriet
Lantmäteriverket - National Land Survey
S - 801 82 GÄVLE · SWEDEN

Tekniska skrifter - Professional Papers

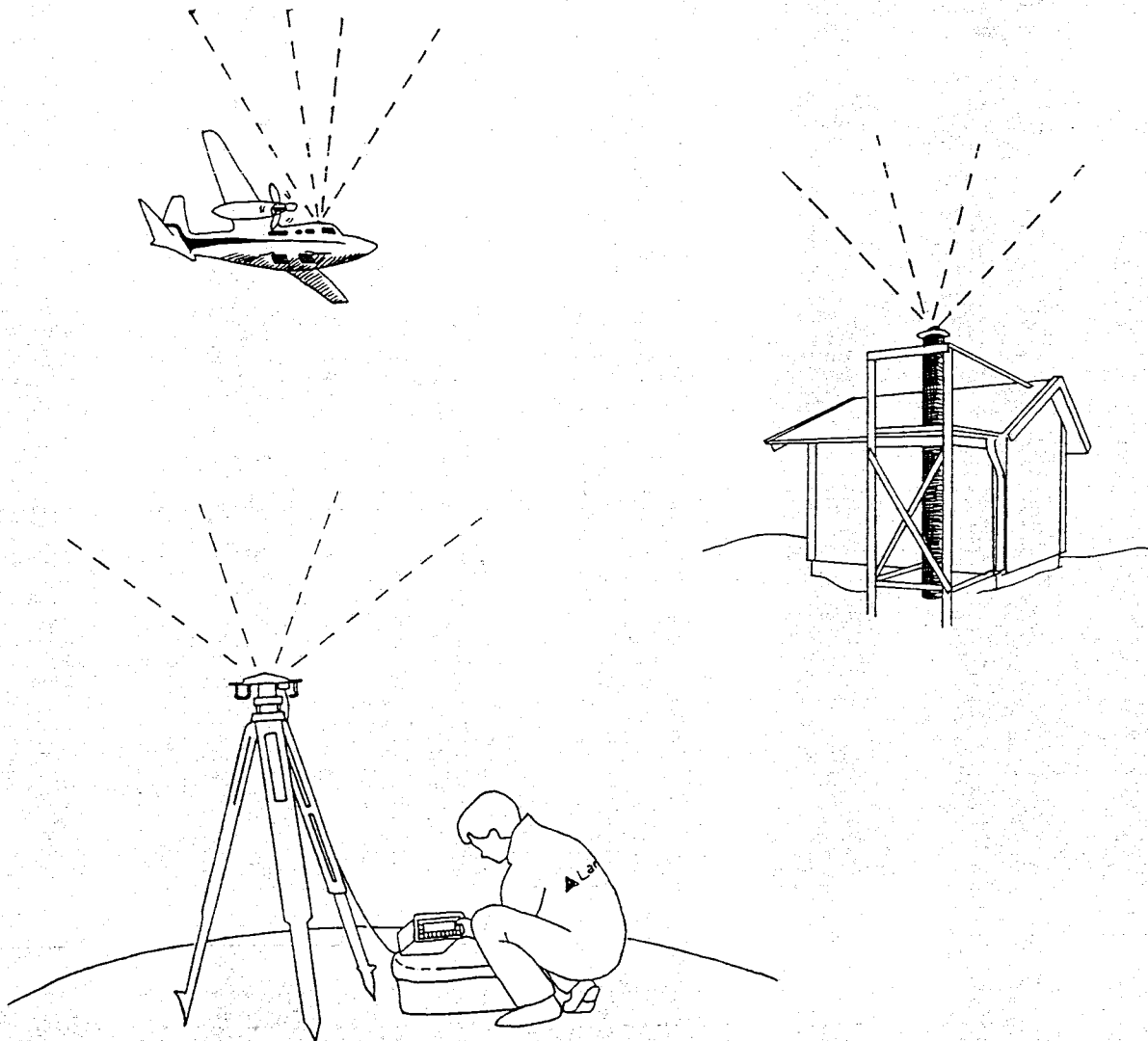
LMV-RAPPORT 1992:14

ISSN 0280-5731

SOME SWEDISH GPS ACTIVITIES 1991

Geodetic Control Surveying, Aerial Photography and a Swedish DGPS network

by Gunnar Hedling, Lotti Jivall, Bo Jonsson and Jonas Andreasson



Gävle 1992

National Land Survey of Sweden - Professional Papers in Geodesy

- 1985:7 Becker J-M: The Swedish Experience with Motorized Levelling - New Techniques and Tests.
- 1986:1 Persson C-G: SUKK - A Computer Program for Graphic Presentation of Precision and Reliability of Horizontal Geodetic Networks.
- 1986:2 Persson C-G: Swedish Experience of Wall-Mounted Targets.
- 1986:4 Ekman M: A Reinvestigation of the World's Second Longest Series of Sea Level Observations: Stockholm 1774 - 1984.
- 1986:6 Ekman M: Apparent Land Uplift at 20 Sea Level Stations in Sweden 1895 - 1984.
- 1986:7 Becker J-M & Lithén T: Nivellement indirect
1986:8 motorisé & technique motorisée XYZ en Suede. /
Motorized Trigonometric Levelling (MTL) &
Motorized XYZ Technique (MXYZ) in Sweden.
- 1988:16 Haller L Å & Ekman M: The Fundamental Gravity Network of Sweden.
- 1988:23 Becker J-M, Lithén T, Nordquist A: Experience of Motorized Trigonometric Levelling (MTL) - A Comparison with other Techniques.
- 1988:26 Ekman M: The Impact of Geodynamic Phenomena on Systems for Height and Gravity.
- 1990:8 Becker J-M: The Swedish Experience with the ISS Uliss 30 - Results from Tests and Pilot Projects.
- 1990:10 Hedling G, Jivall L, Jonsson B: Results and Experiences from GPS Measurements 1987-1990 - SVENAV-87, Local Control Networks and Dual-frequency Measurements.
- 1990:11 Jonsson B & Jivall L: Experiences from Kinematic GPS Measurements.
- 1991:15 Becker J-M & Andersson B: Evaluation of NA 2000 - A New Digital Level.
- 1991:22 Jivall L: GPS Computations and Analyses for Geodetic Control Networks.
- 1992:10 Ekman M: On the Effect of Local Masses on the Geoid (In Swedish with Summary in English).



Titel

SOME SWEDISH GPS ACTIVITIES 1991

- geodetic control surveying, aerial photography and a swedish DGPS network

by Gunnar Hedling, Lotti Jivall, Bo Jonsson and Jonas Andreasson

Huvudinnehåll

Some papers which describe GPS activities in Sweden during 1991 are collected in this professional paper. The following papers are included:

- GPS for Geodetic Control Surveying in Sweden. 6th International Geodetic Symposium on Satellite Positioning, Ohio 1992.
- Experiences from Navigation and Positioning with GPS in Aerial Photography. 6th International Geodetic Symposium on Satellite Positioning, Ohio 1992.
- Status of a Swedish DGPS network. First International Symposium Real Time Differential Applications of the Global Positioning System, Braunschweig 1991.

LDOK

Kg Satellitgeodesi

Beställs hos

Lantmäteriverket
Blankettförrådet
801 82 GÄVLE

Allmänna Förlaget

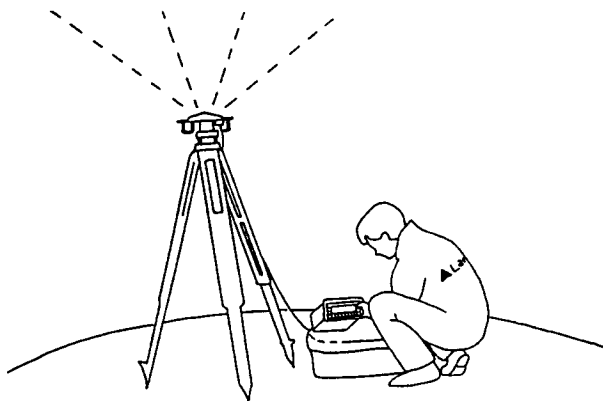


TABLE OF CONTENTS

Introduktion

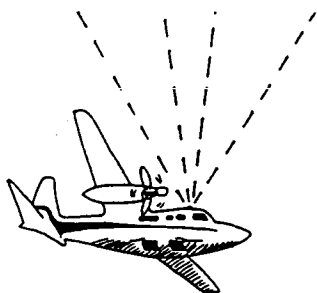
GPS for Geodetic Control Surveying

A:1 (10)



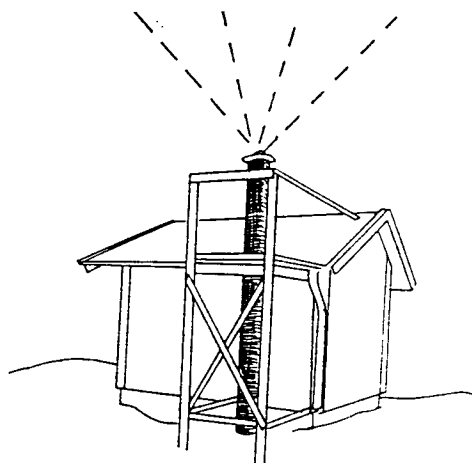
Experiences from Navigation and Positioning in Aerial Photography

B:1 (11)



Status of a Swedish DGPS Network

C:1 (16)



INTRODUCTION

In Sweden GPS is used by routine for geodetic control surveying and navigation in aerial photography.

The geodetic control surveying comprises local densification of the national primary horizontal network in cities and villages, control networks (mainly horizontal) for road and railway building, and control for photogrammetry and inertial positioning. The baseline lengths range from 0.5 to 20 km and the accuracy of the control networks is around 5 mm + 1-2 ppm (1 sigma) in the horizontal components.

With the growing interest for GPS a need for some sort of guidelines for GPS positioning has arisen. The paper "GPS for Geodetic Control Surveying in Sweden" presents the methods used in different phases of GPS control Surveys, with accent on the network planning, computation and analysis.

The goals for the use of the GPS technique in aerial photography at the National Land Survey (NLS) are the following:

- to give information to the pilot about the position of the aircraft with respect to the planned photostrip i. e. to navigate
- to enable automatic exposures to be made in preselected positions
- to determine the position of the aerial camera at the time of the exposure.

Today (June 1992) GPS equipment is mounted in the two aircrafts, which are used for aerial photography. GPS is used for navigation and automatic exposures in preselected positions.

The paper "Experiences from Navigation and Positioning with GPS in Aerial Photography" gives an overview of the GPS-equipment and the PC-program for navigation and automatic exposures. Experiences and results from the use of GPS in the aerial photography application are also shown.

Some Swedish test reference stations for GPS are operational since the end of 1991. These would have the purpose of:

- acting as high-precision control points for Swedish users
- providing differential messages for broadcasting for realtime users
- monitoring the integrity of the GPS-system
- acting as fiducial stations in very high precision networks.

The paper "Status of a DGPS network" shows practical results and experiences from tests with reference stations for GPS. The possibilities to establish a national DGPS network are also discussed in this paper.

Abstract	A:1 (10)
1. Introduction	A:1 (10)
2. Network Planning	A:1 (10)
2.1 Principles	A:2 (10)
2.2 Formulae	A:3 (10)
2.3 The planning method	A:3 (10)
3. Computation and analysis	A:4 (10)
3.1 Initial coordinates	A:6 (10)
3.2 Adjustment of GPS observations	A:6 (10)
3.3 Controls within and between sessions	A:7 (10)
3.4 Network adjustment	A:8 (10)
3.5 Connection to a supreme network	A:9 (10)
4. Concluding remarks	A:10 (10)
References	A:10 (10)
A Solution of the planning task	A:10 (10)

GPS for Geodetic Control Surveying in Sweden

by

Lotti Jivall
Division of Geodetic Research
National Land Survey of Sweden
S - 801 82 Gävle
SWEDEN

tel: +46 26 153740

fax: +46 26 106232

Abstract

The National Land Survey of Sweden has been using GPS by routine for geodetic control surveying since 1989. This use of GPS comprises local densification of the national primary horizontal network in cities and villages, control networks (mainly horizontal) for road and railway building, and control for photogrammetry and inertial positioning. The baseline lengths range from 0.5 to 20 km and the accuracy of the control networks is around 5 mm + 1-2 ppm (1 sigma) in the horizontal components. L1 measurements are used and the processing is based on single baseline processing.

Methods and strategies for planning, observing, data processing, and analysis have in the course of time been developed from experiences of the GPS control surveys. At present, work is going on with a guide for GPS positioning in Sweden, where those methods and strategies are further developed and documented. This paper is based on the work with these guide-lines and presents the methods used in the different phases of GPS control surveys, with the accent on the network planning and the computation and analysis.

1. Introduction

The way the GPS technique is used and spread in a country depends on the general geodetic situation there. In Sweden, the national primary network with interstation distances of around 10 km (in 70% of the country), measured by trilateration (1967-82), has a relative accuracy of 1-2 ppm (1 sigma). A densification of this network all over the country has not and will not be made since large areas of Sweden is sparsely populated. The responsibility for establishing local control networks for municipalities, and connecting them to the national coordinate system, is with the local authorities, who still do not use GPS themselves. GPS is, however, an excellent technique for this task and is often used on a consulting basis. In the case of railway building, where the accuracy demands are high and the extension of a project is great, GPS really has come in the right time for the improvement of railways for the high speed trains.

The National Land Survey of Sweden (NLS), as well as 2-3 private companies, use GPS for control surveying.

NLS has one GPS team, moving around all over the country and working in winter as well as summer. The persons in the team are sometimes exchanged. The team mostly consists of three persons: one responsible for the network planning, computation and analysis, as well as for the logistics; the other two responsible for the field work, including measurements, rising of masts etc. Six receivers (single frequency) are usually used, and often people who know the place well are put at our disposal.

The processing is made each day or night after the observations in order to see if any remeasurements are needed. The area is not left before one has achieved the requested quality of the network. All computations up to the final result are performed "in the field" and are then sent to the office for documentation and delivery.

Two main questions when carrying through a GPS survey are:

- What strategy should be used for the network planning?
- How are the computations and analyses of the data to be made?

Below, our approaches to these questions are outlined.

2. Network planning

The planning strategy is developed for networks with an areal extension and is described in more detail (in Swedish) by Lithén & Persson (1991).

2.1 Principles

The planning strategy is based on the following three principles:

1. All stations are treated in the same way - no matter if they are known or unknown.
2. Only the non-trivial baselines are treated in the planning.
3. The network is built up of quadrangles formed by non-trivial baselines.

The reason for the first principle is that we are using relative - not absolute - measurements and that we want a well-determined relation between known and unknown stations. Furthermore it makes it possible to check the known stations.

The second principle is an effect of the network giving the impression of being too strong if all combinations of baselines are used. (The total number of baselines in one session measured with r receivers is $r(r-1)/2$, while the number of non-trivial baselines is $r-1$.)

The third principle implies for large networks that the number of degrees of freedom is equal to the number of unknowns - an old rule of thumb for conventional networks.

2.2 Formulae

The following formulae are valid for the ideal network configuration, a quadratic network consisting of squares formed by non-trivial baselines (see figure 1).

- Given the number of stations (p , for points) in the network and the number of receivers (r) that are to be used, the number of required sessions will be

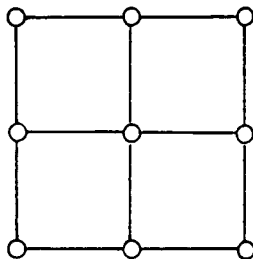
$$s = 2(p-p^2)/(r-1), \text{ which is rounded to the nearest higher integer.}$$

- The total number of non-trivial baselines in the network is then given by

$$b = s(r-1)$$

- The number of quadrangles is obtained from the approximate formula

$$q = b - p + 1$$



$$\begin{aligned} p &= 9 \\ r &= 4 \\ s &= 2(9-3)/(4-1) = 4 \\ b &= 4(4-1) = 12 \\ q &= 12 - 9 + 1 = 4 \end{aligned}$$

Figure 1. The ideal network configuration with 9 stations, measured by 4 receivers. In practice the squares turn into more irregular quadrangles and the network becomes less symmetric.

2.3 The planning method

First the network is constructed with q quadrangles formed by b baselines, as in figure 1. After that, sessions are placed into the network so that every baseline forms a non-trivial baseline in a session. The sessions can be formed in different ways depending on how many receivers that are available - figure 2 gives some examples.

Connecting adjacent stations with the sessions and having at least two common stations between the sessions implies a high local accuracy and an efficient measuring strategy. Figure 3 shows session planings of the network in figure 1, using different numbers of receivers.

After some training with this method it is often easier and faster to make the session planning directly.

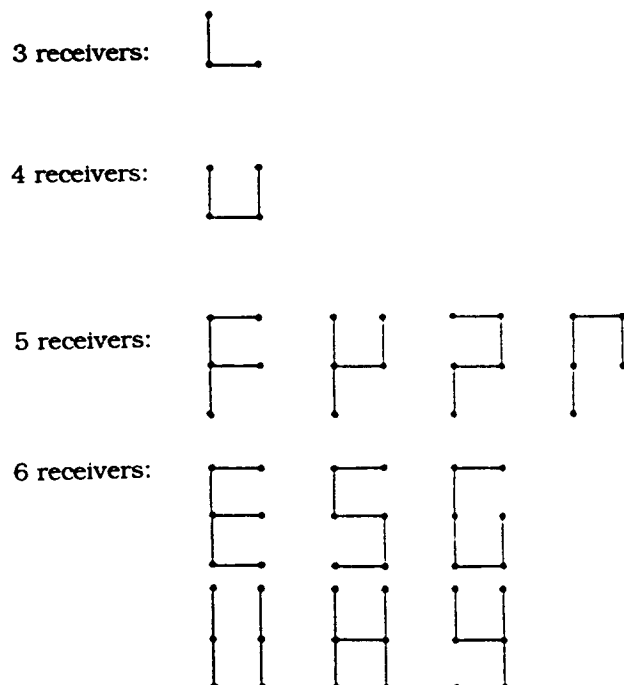


Figure 2. Non-trivial baselines in sessions with different numbers of receivers.

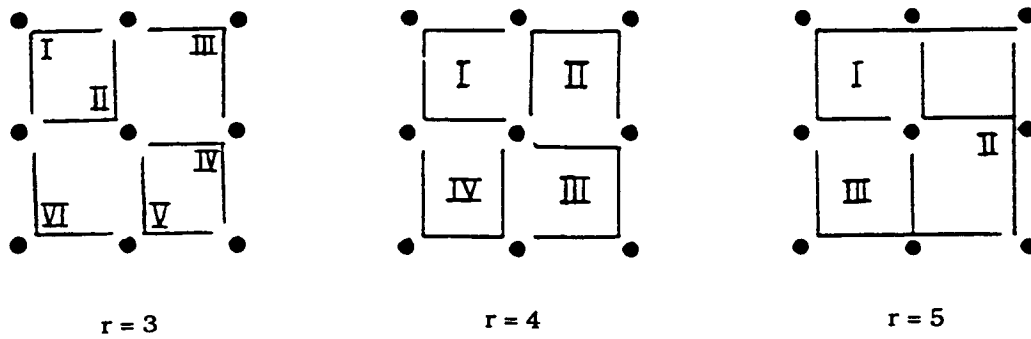


Figure 3. Session plannings with different numbers of receivers (r).

It should be noted that there are mostly more than one good solution to a planning task, especially when the network consists of more stations and is less symmetric than the one in our example.

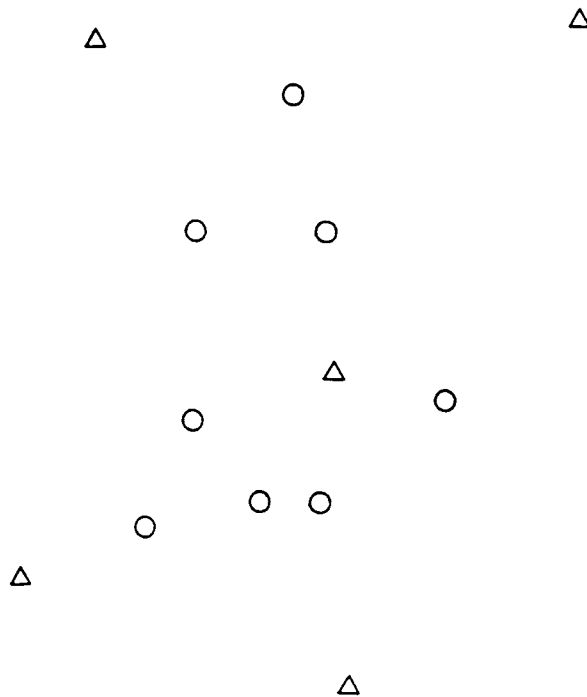


Figure 4. Try the planning method yourself! An example of a solution with 4 receivers is given at the end of this paper.

3. Computation and analysis

This chapter deals with computation and analysis of control surveying with single frequency measurements. There is no classification into different accuracy standards. Control surveying is to serve many different purposes, also future purposes unknown today. Therefore the accuracy is to be as high as possible using ordinary methods. Guide-lines and criteria have been determined with respect to the capability of the present technique. The basis has been computations of control networks made by the National Land Survey of Sweden during 1990 and 1991. The process chart in figure 5 shows the main steps of the computational process. A detailed treatment of the computation and analysis of GPS data is given by Jivall (1991).

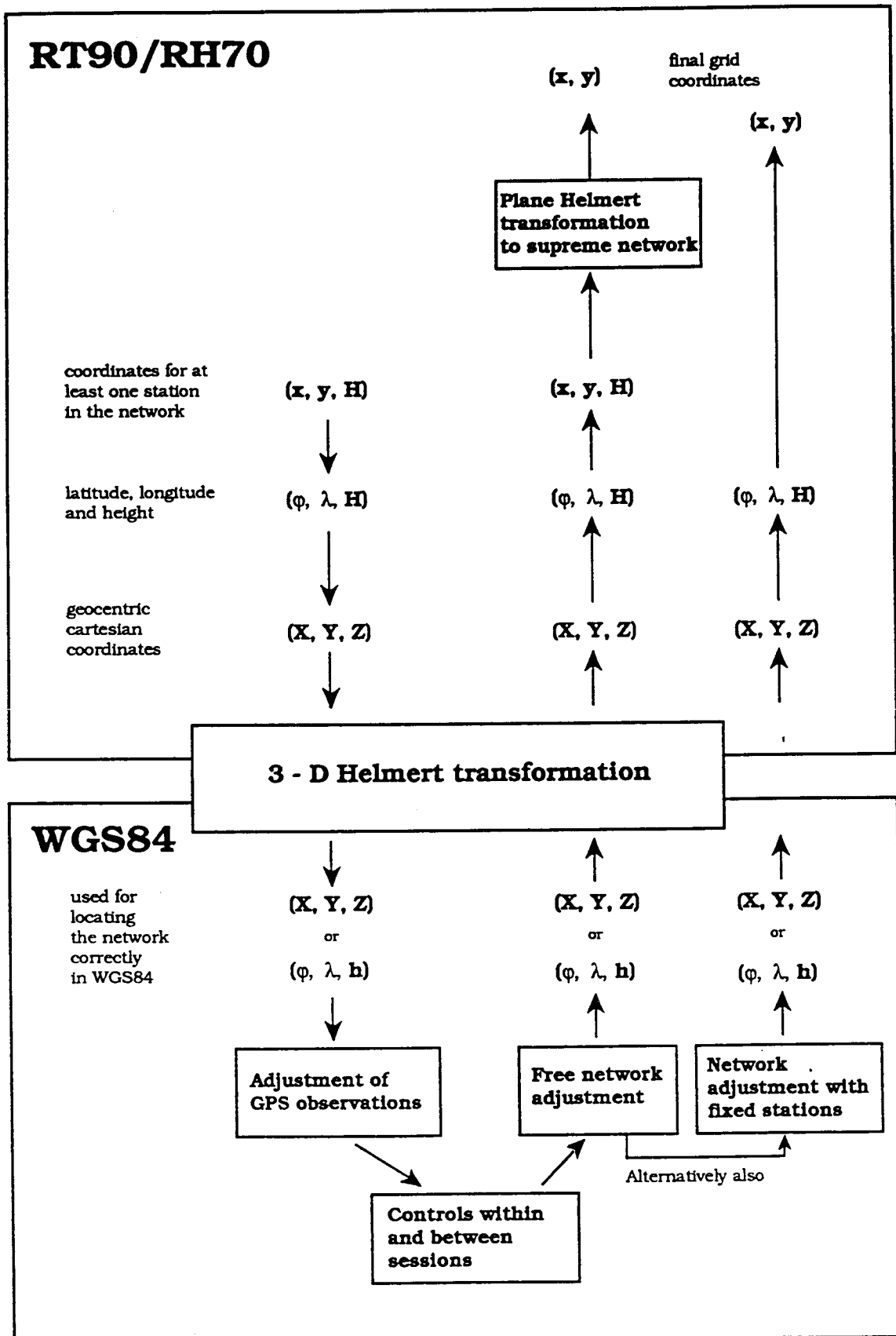


Figure 5. Process chart for computation of horizontal coordinates with GPS. RT90 and RH70 are the Swedish national coordinate and height systems, respectively.

3.1 Initial coordinates

It is necessary to have good initial coordinates in WGS84 for a starting point in the network in order to avoid systematic effects or bad results in the adjustment of GPS observations. It is recommended to get the initial coordinates by a transformation from the national coordinate and height systems. Hence one should plan the measurements in such a way that at least one station with coordinates known in the national systems is included in the measurements of the first day. Even more important than the absolute position itself is that all computations in a network are performed in the same absolute position.

3.2 Adjustment of GPS observations

The guide-lines and criteria given here are based on our experiences with the GPPS-software from Ashtech, but we have also made a comparison between GPPS and the software of Trimble, TRIMVEC-PLUS. Both programs use double-differences and determine the ambiguities through a statistical test before they are held fixed in a so-called fix solution. The same guide-lines are valid for both programs but there are different sets of criteria.

3.2.1 Guide-lines

- For the computation of a session or a baseline one needs at least one hour of observations with at least four simultaneous satellites (the time depends on the software, the baseline length and the satellite configuration).
- Normally, use Broadcast Ephemeris. When computing long baselines with high demands for accuracy, Precise Ephemeris should be used. The introduction of SA (Selective Availability) might raise new demands.
- The adjustment of GPS observations must be made in a correct absolute position as explained in the previous section.
- Normally, use a standard atmosphere for tropospheric corrections.
- For control surveys only fix solutions are allowed.
- Only solutions fulfilling the criteria below should be treated in the network adjustment.
- When using baseline programs, all baselines (also the trivial ones) must be computed. This is a primitive way to take care of the correlations between baselines.
- When using multi-station programs, it is recommendable to define (calculate double-differences for) the same baselines as those included in the planning of the network.

3.2.2 Criteria

PARAMETER	GPPS		TRIMVEC-PLUS	
	0 - 10 km	10 - 30 km	0 - 10 km	10 - 30 km
Baseline length:	0 - 10 km	10 - 30 km	0 - 10 km	10 - 30 km
1.Ambiguities	< 0.20 cycles	< 0.25 cycles	<0.25 cycles	<0.30 cycles
2.Test ratio	> 3	> 2	>3	>2
3.RMS-fix	<0.08 cycles	<0.10 cycles	<0.06 cycles	<0.07 cycles
4.Diff float-fix	< 5 cm	< 7 cm	<5 cm	<7 cm

Table 1. Criteria for the adjustment of GPS observations in GPPS and TRIMVEC-PLUS.

1. Ambiguities: The values for ambiguities refer to deviations from integers.
2. Test ratio: The test ratio is the quotient between the variance of the second best and the best solutions, respectively, where the difference between the solutions consists of one or a few ambiguities being fixed at other integers. A high ratio implies that the correct ambiguities have been chosen in the best solution.
3. RMS fix: The criteria are given for fix solutions since these are the ones to be used in control surveying. Also the RMS difference between the float and fix solutions should be checked; a large increase in RMS indicates that incorrect ambiguities might have been used.
4. Diff float-fix: The values refer to maximum differences in each component (N, E, U or X, Y, Z) between the float and fix solutions.

3.3 Controls within and between sessions

Controls within sessions are made either by multi-station adjustment or by separate network adjustments for each session. Controls between sessions are made through comparisons of double-measured baselines or computations of loop misclosures.

Below, error limits are given that are found empirically from double-measured baselines between 100 m and 20 km. Standard errors for each component have been estimated in a local system (northing, easting, up); from these the error limits have then been derived. For the error limits we employ the approach with a *warning limit* at two sigma (2σ) and a *rejection limit* at three sigma (3σ) for one-dimensional quantities, and a corresponding approach in two and three dimensions (σ = standard deviation). Baselines having differences larger than the warning limit shall be checked (input and adjustment of GPS observations) and, if necessary, corrected. If no error is found the baseline is kept provided the differences are below the rejection limit, otherwise it is omitted.

DOUBLE-MEASURED BASELINES				LOOP MISCLOSURES				
$D = a + bl$ D = limit for difference in mm between double-measured baselines a = constant in mm b = constant in mm/km l = length in km				$D = (cn + dL)/(n)^{1/2}$ D = limit for loop misclosure in mm c = constant in mm d = constant in mm/km n = number of baselines in loop L = total length in km				
Warning limit		Rejection limit		Warning limit		Rejection limit		
a	b	a	b	c	d	c	d	
N	10	2	15	3	8	1.6	11	2.4
E	6	2	9	3	5	1.6	7	2.4
U	20	3.4	30	5.1	15	2.7	22	4.1
2-D	11	2.6	15	3.6	8	2.1	11	2.9
3-D	23	4.3	30	5.6	17	3.4	22	4.6

Table 2. Constants of error limits for double-measured baselines and loop misclosures.

3.4 Network adjustment

The baseline components (from baseline programs) or the coordinate sets for each session (from multi station programs) are adjusted to form a unified, free network in WGS84.

The weighting can be made either according to standard weighting or according to the internal standard errors from the adjustment of GPS observations. In the latter case the standard errors should be rescaled to agree, as much as possible, with the standard weighting given below (valid for single frequency measurements up to 20 km):

$$\begin{aligned}\sigma N &= 5 \text{ mm} + 0.7 \text{ ppm} \\ \sigma E &= 5 \text{ mm} + 0.7 \text{ ppm} \\ \sigma U &= 8 \text{ mm} + 1.2 \text{ ppm}\end{aligned}$$

The network adjustment can be analysed with the help of the following quantities:

- standard errors of unit weight
- residuals/standardized residuals
- station standard errors.

The *standard error of unit weight* should be close to 1 if the weighting is correct. The neglect of correlations between baselines yields, however, a slightly lower standard error. If all combinations of baselines are adjusted, without regard to the correlations, one can expect a standard error of unit weight of about 0.9.

The *residuals* give in absolute figures (even if the scale of the weighting would be wrong) estimates of the discrepancies in the network. The residuals are, therefore, one of the most important measures of accuracy.

Standardized residuals are residuals divided by their respective standard errors. Large standardized residuals may indicate gross errors. On the analogy of the error limits for double-measured baselines we put the *warning and rejection limits for the standardized residuals to two and three, respectively*; i.e. the limits (tolerances) for the residuals are 2σ and 3σ . Here we presuppose that the standardized residuals are calculated with the *a priori standard errors* of the residuals. If the *a posteriori* standard error is used the error limits have to be divided by the standard error of unit weight.

Baselines with standardized residuals above the warning limit shall be investigated and, if possible, corrected. If no error is found the baseline is kept but down-weighted, provided the standardized residual is below the rejection limit; otherwise it is omitted.

Changes like down-weighting and rejection shall be made for one unit at a time, namely the one with the largest standardized residual. A unit could here be a baseline, a station or a session depending on what type of error that has caused the high residuals.

Relative station standard errors may give information about low accuracy stations in the network. To make the interpretation correct the internal weighting must be correct. The station standard errors do not tell anything, however, about the controllability of the network. Therefore, a graphic presentation of the network with down-weighted baselines marked is an important complement.

If all combinations of baselines have been included in the network adjustment the station standard errors must be rescaled to become more realistic. These then have to be multiplied by the factor $(\text{total \# baselines} / \text{\# non-trivial baselines})^{1/2}$.

3.5 Connection to a supreme network

The coordinates from the network adjustment are transformed to horizontal coordinates (grid coordinates) in an approximate national system. The actual connection to the coordinate system in question is made by means of a plane Helmert transformation. This is the most usual method. The scale in the Helmert transformation will on the average turn out to be 1-3 ppm (GPS too small) if the ionosphere is not considered in the adjustment of GPS observations.

Alternatively, this Helmert transformation is considered a check only, and a final connection is made with a network adjustment where the latitudes and longitudes in WGS84 of the connection stations are held fixed. In case the Helmert transformation has yielded a significant scale and rotation, these parameters may be solved for in the network adjustment. The WGS84 coordinates are obtained by transformation and are, after the network adjustment, reverted into the original coordinate system by transformation. It is, thereby, important that the two transformations really are the inverses of each other!

4. Concluding remarks

GPS has during the last years become a quite commonly used technique for geodetic control surveying in Sweden, although the number of GPS surveyors actually performing the GPS measurements still are few. With the growing interest for GPS, a need for some sort of guide for GPS positioning has arisen. The guide is awaited not only by GPS surveyors but also among the ones who buy GPS services, since they need to know which demands they should put on the GPS surveyors.

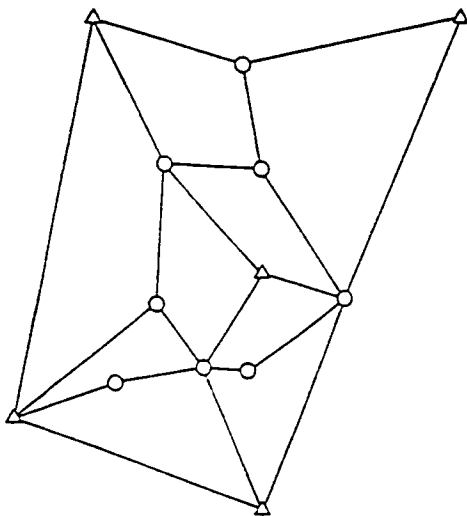
The outlines of planning and computation above are extracted from the work with such a guide, partly published in Jivall (1991) and Lithén & Persson (1991). The guide will include a lot of other things as well, but the main parts will be those discussed above.

The work with the guide will be going on during 1992 and it would be very useful for me to take part of your reflections and comments on the two parts outlined in this paper and to get ideas from similiar works in other countries.

References

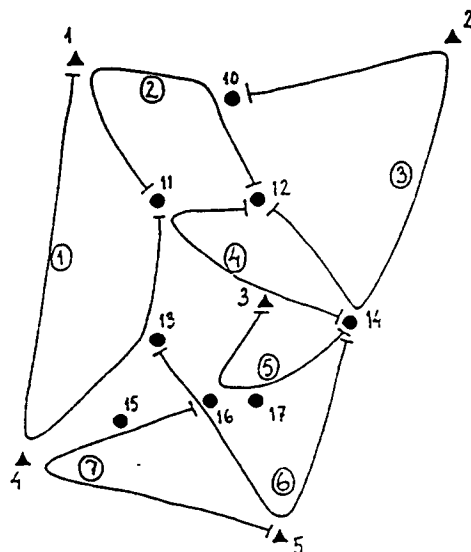
Jivall L 1991: GPS Computations and Analyses for Geodetic Control Networks, National Land Survey of Sweden, Professional Papers 1991:18.
 Lithén T, Persson C-G 1991: Planering av GPS-nät. National Land Survey of Sweden, Professional Papers 1991:8.

A solution of the planning task in figure 4.



$$p = 13$$

$$r = 4$$



$$s = 2(13 - 13^{1/2}) / (4 - 1) = 6.26 \rightarrow 7$$

$$b = 7 \quad 3 = 21$$

$$q = 21 - 13 + 1 = 9$$

EXPERIENCES FROM NAVIGATION AND POSITIONING WITH GPS IN AERIAL PHOTOGRAPHY

B

Abstract	B:1 (11)
1. Introduction	B:1 (11)
2. GPS-equipment and observation methods	B:2 (11)
3. Photogrammetric test field	B:4 (11)
4. The 1989 aerial photo experiment	B:5 (11)
4.1 GPS observations	B:5 (11)
4.2 Computation of the GPS observation data	B:5 (11)
4.3 Photogrammetric evaluation	B:6 (11)
4.4 Results	B:6 (11)
4.5 Summary of the 1989 experiences	B:8 (11)
5. The 1990 aerial photo experiment	B:8 (11)
5.1 Accomplishment of the experiment	B:8 (11)
5.2 Computation of the GPS observation data	B:9 (11)
5.3 Results	B:10 (11)
6. Concluding remarks	B:11 (11)
7. Acknowledgements	B:11 (11)
8. References	B:11 (11)

EXPERIENCES FROM NAVIGATION AND POSITIONING WITH GPS IN AERIAL PHOTOGRAPHY

Bo Jonsson and Jonas Andreasson
National Land Survey of Sweden
S-801 82 Gävle, Sweden
tel ++46 26 153000
fax ++46 26 106232

ABSTRACT

The goals for the use of the GPS-technique in aerial photography at the National Land Survey (NLS) are the following:

- to give information to the pilot about the position of the aircraft with respect to the planned photostrip i. e. to navigate
- to enable automatic exposures to be made in preselected positions
- to determine the position of the airborne camera at the time of the exposure

In 1989 and 1990 experiments were carried out with Ashtech receivers in order to get experiences of the GPS-technique in aerial photography and to get a notion of the capability of GPS in this application. A PC-program for navigation was developed. The GPS-equipment has been mounted in one of the aircrafts during the air photo season in 1991 and has been used periodically in the production work.

This paper will give an overview of the GPS-equipment and the PC-program for navigation and automatic exposures. Experiences and results from the use of GPS in the aerial photography application will also be shown.

1. INTRODUCTION

It is an advantage for many types of map production lines if the aerial photos can be exposed in preselected positions. If the positions of the exposures are recorded, they can be used for production overviews and records for aerial photos.

An accurate determination of the aerial camera at the time of the exposure, e. g. decimeter accuracy at the flying altitude 500 meters, should decrease the ground control for the photogrammetry.

In september 1989, July 1990 and September 1990 GPS experiments were performed at an established photogrammetric test field at Rörberg airport 15 km west of Gävle. The goals for the use of the GPS-techniques in these experiments were the following:

- to give information to the pilot about the position of the aircraft with respect to the planned photo strip i.e. to navigate
- enable automatic exposures to be made in preselected positions
- to determine the position of the airborne camera at the time of the exposure.



Figure 1. The Cessna aircraft with installed camera and GPS equipment.

Ashtech LXII GPS receivers and an Ashtech GPPS post- processing software package were used. The airborne camera which was used was a Zeiss-Jena LMK, which in the 1989 experiment was installed in a small Cessna aircraft, with a flying velocity of 180 km/h (50 m/s), see figure 1. The flying altitude was 500 meters. In the 1990 experiments a Gulf Stream Commander 840 aircraft was used. The flying altitude was 500 meters for the positioning of the aerial camera and 4600, 2000 and 500 meters for the navigation experiment.

2. GPS-EQUIPMENT AND OBSERVATION METHODS

The Ashtech LXII receiver fulfills all the requirements for airborne photogrammetry, i. e. the following requirements:

- up-date rate for positions and measurements should be 1 second or less
- real time output of velocity and time-tagged position
- an output of 1 pulse per second timing signal
- a possibility to record the time of the exposure is desirable
- time tagged positions, raw carrier phase observations, intergrated doppler and pseudo ranges should be recorded in an internal memory in the receiver or on a connected PC

- simultaneous observations of at least 6 satellites
- carrier tracking in high dynamics (0,5 g - 4 g).

The configuration of the equipment which was used in the 1989 experiment is shown in figure 2. Because of a delay in the delivery of the option "photogrammetry camera input" to the Ashtech receiver, two PCs were used in this experiment, one for navigation and steering of exposures (navigation PC) and the other for the recording of the times of the exposures. Before the flight, the coordinates of the preselected positions for the exposures were entered into the navigation PC and the clock in the PC was synchronized with the timing signal from the GPS receiver. During the flight the GPS receiver transmits time-tagged positions and velocities every second to the navigation PC, which activates an exposure when the aircraft reaches the preselected position. The navigation PC also provides information to the pilot about the position of the aircraft with respect to the planned photo strip and about the predicted time for the exposure. In the future this information will probably be entered into the auto pilot of the aircraft. The PC card for the recording of the times of the exposures was replaced in the 1990 experiment by the photogrammetry camera input option to the Ashtech receiver, see figure 3.

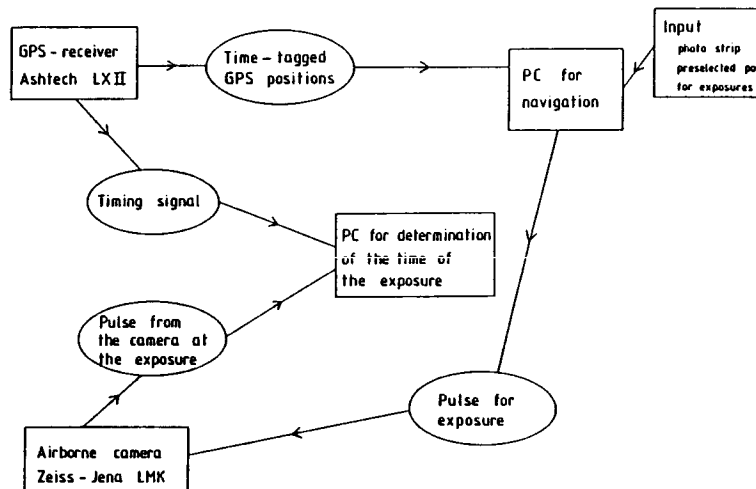


Figure 2. Functional diagram for the equipment in the 1989 experiment.

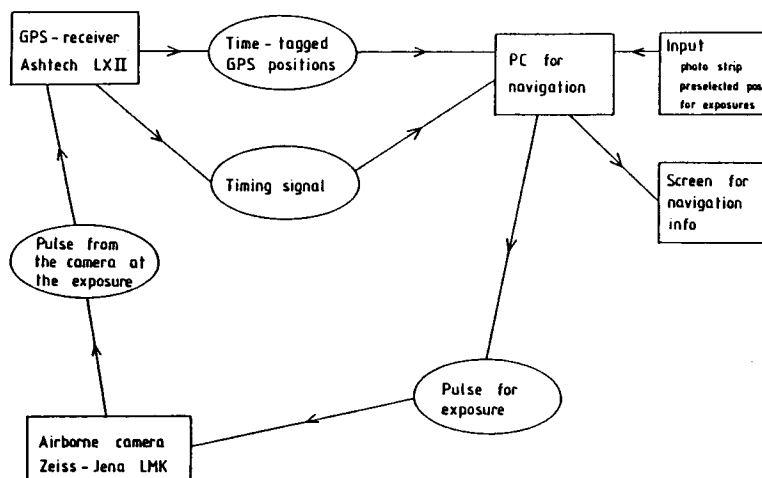


Figure 3. Functional diagram for the GPS-equipment in the 1990 experiment

The methods "relative carrier smoothed code" and "relative carrier phase" measurements were used for the positioning of the aircraft at the exposure and carrier smoothed code measurement for the navigation. The following observation data was recorded: time-tagged pseudo ranges, integrated doppler and carrier phase. The ambiguities were determined by relative static observations on a reference mark with a known position before the flight. Signal lock on at least four satellites, which are common for the reference stations and the mobile receiver, are necessary during the whole flight in order to be able to compute the position of the camera using Ashtech's software package.

The GPS antenna in the 1989 was experiment mounted on the aircraft in such a way that it was centered above the camera with an accuracy of a few centimeters during the photography. The camera was locked to the aircraft body during each photo strip. In the 1990 experiment the eccentricity between the phase center of the GPS antenna and the projection center of the camera was measured on the ground before the photographing. The direction of the the photo strips were used to get the actual eccentricity for each exposure. Also in this experiment the camera was locked to the aircraft body during each photo strip.

3. PHOTOGRAMMETRIC TEST FIELD

A photogrammetric test field, based on the test field for EDM instruments and theodolites at the Rörberg airport (3), was established, see figure 4. The ground control stations have been located for the flying altitude 500 meters. The ground control survey was connected to both the national triangulation network (RT R10) and the levelling network (RH70).

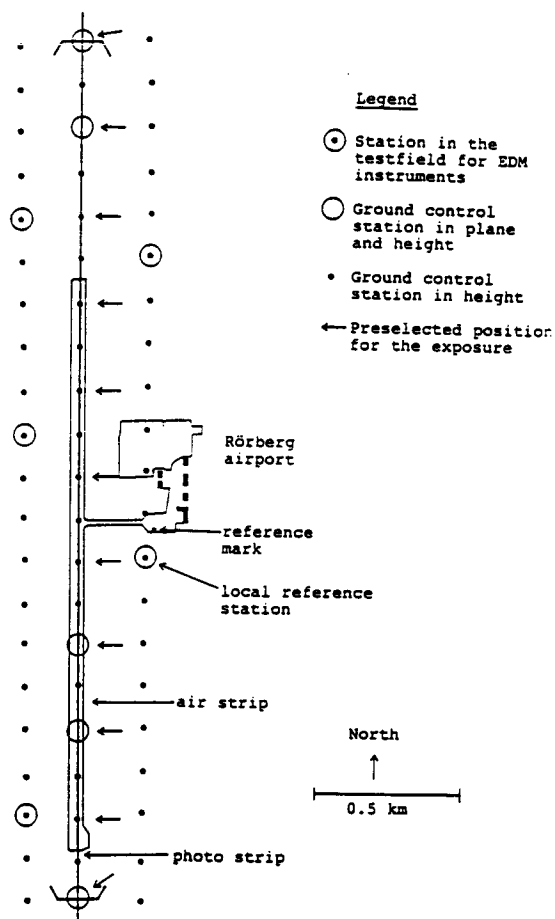


Figure 4. Photogrammetric test field at Rörberg airport.

4. THE 1989 AERIAL PHOTO EXPERIMENT

4.1 GPS observations

Beause of delays in the preparations of the experiment the photography could not take place until the end of September 1989. The satellites were close above the horizon early in the morning in September but the quality of the photos was satisfactory for an accurate photogrammetric determination of the coordinates of the airborne camera. We had problems with fog at sunrise, during some mornings.

One of the stations in the testfield for EDM instruments was used as a local reference station during the flight. A reference mark with a known position, close to the air strip was used for the determination of the ambiguities before take-off. The goal was to return to this reference mark after the flight with maintained signal lock on at least four satellites. However it was not possible to reach the reference mark after the landing without a number of cycle slips.

In order to maintain signal lock to satellites with low elevations (20-25 degrees) it was not possible to bank the aircraft in the turns between the photo strips which resulted in very wide turns and a lot of observation data. In our experiment we had 1 Mb of internal receiver memory available, which is sufficient for about 1 hour's observation of five satellites with one second between the observations.

The reception of the GPS signals was disturbed (cycle slips for all satellites) when the communication transmitter of the aircraft was used. It was no problem to use the receiver part of the communication equipment. Three strips were photographed and they are denoted strip 2, 3 and 4.

Five simultaneous satellites were available only during photo strip 2. During the photography of strips 2, 3 and 4 signal lock on at least four satellites was maintained both in the aircraft and at the reference station. But between the strips 2 and 3 only 3 common satellites were observed which, together with the fact that it was not possible to reach the reference mark after the landing with maintained signal lock, resulted in it being impossible to process the carrier phase measurements for the strips 3 and 4 using Ashtech's software package.

4.2 Computation of the GPS observation data

Time-tagged positions and velocities of the aircraft were recorded every second.

Recorded observation data have been processed using the programmes KINSRVY and PPDIFF from Ashtech. KINSRVY computes relative positions once a second from the carrier phase measurements and PPDIFF does the same from recorded pseudoranges and integrated doppler measurements.

The times of the computed GPS positions have been obtained from the conversion program between observation data in Ashtech format and the ARGO format. The position of the camera has been interpolated from the obtained relative GPS positions using the times of the exposures recorded by the PC card.

The GPS coordinates of the camera have then been provisionally transformed to the national coordinate system using the transformation formula between WGS84 and RT90, which has been developed for navigation purposes by NLS. Finally a local Helmert transformation has been performed using two transformation stations and a local connection to the national height system.

4.3. Photogrammetric evaluation

The goal for the photogrammetric evaluation was to determine the 3-dimensional position for the projection center of the camera at the exposure.

The evaluation has been carried out in two steps. In the first step a photogrammetric densification was carried out by aerial triangulation in each strip. Then the position for the projection center of the camera was determined in each photo using single point intersection. The accuracy of the obtained photogrammetric positions is in the order of 5 cm per coordinate (1 sigma).

4.4 Results

4.4.1 Exposures in preselected positions

Table 1. Comparisons between actual exposed and preselected positions (1989 experiment)

STRIP NO 2 (north to south)							STRIP NO 3 (south to north)						
Exp no	Int fac.	PDOP	Diff	Diff: exp pos - preselected pos (meters)			Exp no	Int fac.	PDOP	Diff	Diff: exp pos - preselected pos (meters)		
				dx	dy	dh					dx	dy	dh
14	5	0.5	3.4	-33.2	-48.1	-17.4	25	4	0.0	17.9	15.1	-72.0	-16.8
15	5	0.1	3.4	-45.5	-59.3	-18.2	26	4	0.1	17.6	24.9	-67.5	-14.0
16	5	0.5	3.4	-30.9	-64.2	-18.0	27	4	0.1	17.4	14.5	-56.2	-16.1
17	5	0.5	3.4	-32.4	-63.9	-18.2	28	4	0.4	17.2	19.2	-39.7	-18.1
18	5	0.6	3.4	-29.9	-53.7	-18.5	29	4	0.6	17.0	17.6	-25.9	-19.0
19	5	0.1	3.4	-43.0	-33.7	-17.7	30	4	0.1	16.8	33.0	-7.7	-21.4
20	5	0.0	3.4	-27.8	-8.3	-7.1	31	4	0.1	16.7	29.6	11.2	-23.6
21	5	0.2	3.4	-26.4	15.6	-18.1	32	4	0.1	16.5	19.5	27.8	-23.4
22	5	0.5	3.4	-32.9	18.7	-23.7	33	4	0.1	16.3	14.4	32.9	-21.7
23	5	0.7	3.4	-32.8	13.6	-23.1	34	4	0.4	16.2	19.8	31.5	-19.0
24	5	0.5	3.4	-30.9	15.4	-19.3	35	4	0.6	16.0	14.8	25.4	-14.9
Mean:				-33.2			Mean:				20.2		
Stand. dev.:				5.87			Stand. dev.:				6.36		

STRIP NO 4 (north to south)

Exp no	Int fac.	PDOP	Diff	Diff: exp pos - preselected pos (meters)		
				dx	dy	dh
36	4	0.0	9.2	-38.0	34.8	-6.4
37	4	0.0	9.1	-40.2	42.8	-4.6
38	4	0.0	9.1	-49.4	51.5	-5.4
39	4	0.3	9.0	-36.2	56.0	-4.2
40	4	0.6	9.0	-28.6	54.1	-3.0
41	4	0.5	8.9	-28.4	52.5	-2.0
42	4	0.6	8.9	-35.6	52.0	-1.9
43	4	0.5	8.9	-36.0	53.1	-2.2
44	4	0.3	8.8	-30.0	53.2	-2.2
45	4	0.3	8.8	-31.9	52.8	-1.3
46	4	0.1	8.7	-45.9	53.2	0.9
Mean:				-36.4		
Stand. dev.:				6.81		

The differences between the actual positions of the exposures and the preselected positions are shown for photo strips 2, 3 and 4 in table 1. dx denotes the difference along the photo strip, dy across the strip in the map projection plane and dh denotes the height difference.

The information from the navigation PC has been used very sparingly in this experiment because of shortage of time for instructions before the flight and the fact that there was no separate screen for the pilot. The navigation was principally performed in the following way: The navigator reported to the pilot on the position of the aircraft with respect to the planned photo strip using a standard navigation sight.

The shutter of the camera was opened by an electronic pulse which was sent from the navigation PC when the aircraft reached the preselected position of the exposure. Table 2 shows that the exposures were made 20-40 meters (ca. 0.5 seconds) too late and that the accuracy of an exposure at a preselected position was 6 meters (1 sigma) along the strip in this experiment. The SPS-concept is now implemented on the Block II-satellites which will degrade the accuracy in the future. The main part of the delay for the exposure can be explained by the fact that it was not possible to take into consideration the computation time in the GPS receiver. The position of the aircraft was tagged with the time for the arrival of the position data at the navigation PC.

4.4.2 Positioning of the camera

The differences between positions from relative carrier smoothed code measurements and photogrammetric positions of the camera are large (several meters) and are not shown in this report.

Table 2. Comparisons between relative carrier phase and photogrammetric positions (1989 experiment).

STRIP NO 2 (north to south)							
Exp no	Int fac.	PDOP	Diff: rel phase pos - photogrammetric pos (meters)	rel phase pos - photogrammetric pos (meters)			
				dx	dy	dh	
14	5	0.5	3.4	-0.059	0.144	-0.141	
15	5	0.1	3.4	-0.224	0.158	-0.185	
16	5	0.2	3.4	-0.230	0.228	-0.156	
17	5	0.5	3.4	-0.198	0.213	-0.196	
18	5	0.6	3.4	0.000	0.223	-0.182	
19	5	0.1	3.4	0.058	0.239	-0.139	
20	5	0.0	3.4	0.015	0.126	-0.098	
21	5	0.2	3.4	-0.249	-0.207	-0.189	
22	5	0.5	3.4	-0.232	0.048	-0.168	
23	5	0.7	3.4	-0.192	0.422	-0.203	
24	5	0.5	3.4	-0.130	0.452	-0.198	
Mean:-				0.131	0.186	0.169	
Stand. dev.:				0.114	0.177	0.032	

Comparisons between positions from relative carrier phase measurements and photogrammetric positions are shown for photo strip 2 in table 2. The agreement between the positions is about 0.15 meters per coordinate.

It was not possible to compute GPS-positions in strips 3 and 4 using the Ashtech processing software because of the cycle slip between the strips 2 and 3.

4.5 Summary of the 1989 experiences

The possibility to make automatic exposures in preselected positions was successfully demonstrated in the 1989 experiment. Further development of the program in the navigation PC is necessary if it shall be possible to use GPS as an efficient navigation system

Further experiments are required to demonstrate the possibilities to use GPS for the positioning of the camera at the time of the exposure.

5. THE 1990 AERIAL PHOTO EXPERIMENT

The goal for the 1990 aerial photo experiment was to improve the navigation PC programme and to get more experiences of the positioning of the camera at the time of the exposure

5.1 Accomplishment of the experiment

The 1990 experiment was performed with a Gulf Streamer Commander 840 aircraft with a flying velocity of 250 km/h (70 m/s) at the flying altitude 500 meters. Because of delays in the preparations the experiment was divided into two parts; positioning of the aerial camera in July 1990 and navigation in September 1990.

5.1.1 Positioning of the aerial camera.

Two of the stations in the testfield for EDM instruments were used as local reference stations while flying. A reference mark with a known position was used for the determination of the ambiguities before take-off. The GPS-receiver in the aircraft and the one on the reference station at the airport had 2Mb internal memory available. All three receivers had firmware for 0.5 seconds update rate.

On July 10th and 11th 1990 flyings were carried out during totally five observation sessions.

5.1.2 Navigation experiment

After further development of the program for the navigation PC a car test was carried out in August 1990.

During the time period 19 - 22 September 1990 the navigation software was tested at the flying altitudes 4600, 2000 and 600 meters. The possibility to make automatic exposures in preselected positions was successfully demonstrated. The screen pictures of the navigation PC are shown in the figures 5 and 6.

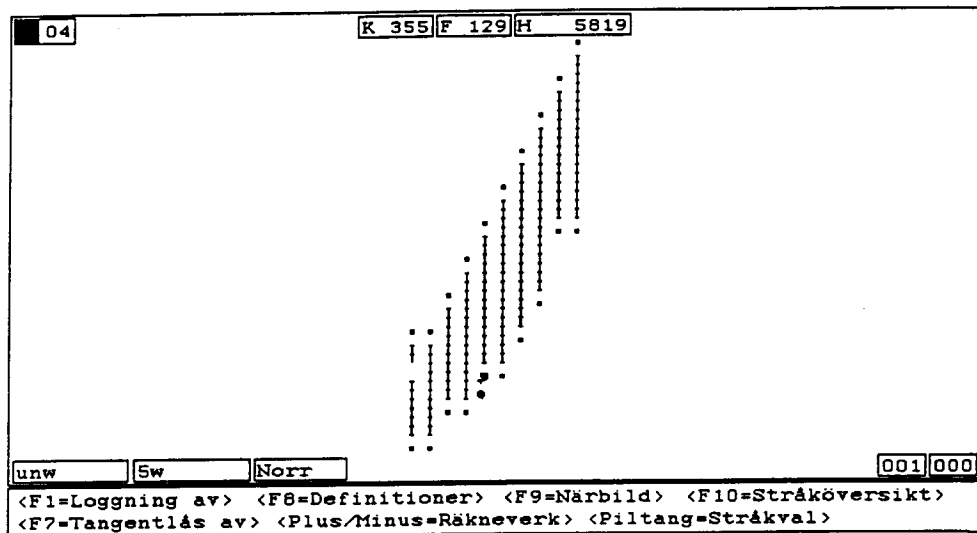


Figure 5. Screen picture: summary of photo strips.

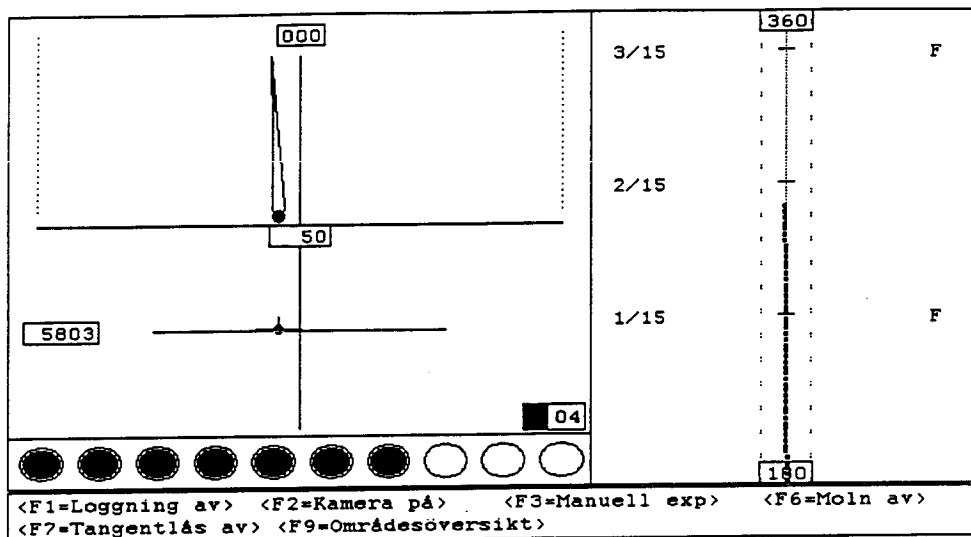


Figure 6. Screen picture: navigation information.

5.2 Computation of the GPS observation data

The recorded observation data has been processed using the Ashtech computation program KINSRVY, which computes a relative position from each carrier phase observation. The accuracy of the C/A-code measurements is degraded because of a fault in the Ashtech firmware and therefore it is not meaningful to use the pseudorange for the computation.

The times of the GPS-observations can be found in the observation data file which has been recorded internally in the GPS-receiver. The positions of the aerial camera at the times of the exposure have been interpolated from the positions which have been

computed with KINSRVY and the recorded times of the exposures. The positions of the fotogrammetric evaluation have been centered to the phase center of the GPS antenna based on the measured distance between the projection center of the camera and the GPS antenna and the direction of the photo strip.

5.3 Results

The differences between positions from relative carrier phase measurements and photogrammetric positions are shown for two strips in table 3. dx denotes the difference along the photo strip, dy across the strip in the map projection plane and dh denotes the height difference.

Systematic differences between the GPS positions and the photogrammetric ones can be found along the photo strip and in height. The differences along the photo strip have different signs related to the direction of the strip, which indicates that it can be a timing error causing this systematic effect. The observation data will be processed with other software packages in the future.

Table 3. Comparisons between relative carrier phase and photogrammetric positions (1990 experiment).

STRIP NO 192.011 (south to north)				STRIP NO 191.022 (north to south)						
Exp no	Int S	PDOP fac	Diff: rel phase pos - photogrammetric pos (meter)	Exp nr	Int S	PDOP fac	Diff: rel phase pos - photogrammetric pos (meters)	dx	dy	dh
			dx dy dh	1	5	0.3	5	0.33	0.05	-0.05
1	5	0.3	3	2	5	0.3	5	0.37	0.00	-0.11
2	5	0.4	3	3	5	0.4	5	0.22	0.04	-0.10
3	5	0.2	3	4	5	0.5	5	0.24	-0.06	-0.24
4	5	0.1	3	5	5	0.5	5	0.27	-0.05	-0.10
5	5	0.5	3	6	5	0.4	5	0.37	-0.12	-0.05
6	5	0.2	3	7	5	0.2	5	0.35	-0.05	-0.15
7	5	0.1	3	8	5	0.2	5	0.27	-0.04	-0.12
8	5	0.3	3	9	5	0.2	5	0.30	0.07	-0.17
9	5	0.3	3	10	5	0.1	5	0.17	0.01	-0.22
10	5	0.1	3	11	5	0.0	5	0.12	0.02	-0.34
11	5	0.2	3							
12	5	0.4	3							
Mean			-0.152 -0.008 -0.297	Mean:				0.274	-0.012	-0.150
Stand dev.			0.043 0.054 0.060	Stand dev:				0.082	0.057	0.088

In the last observation session on July 11th the up-date rate for the measurements was 0.5 seconds. GPS positions have been computed every second as well as every 0.5 second. The 0.5 second positions have also been interpolated from the 1 second positions. Differences between interpolated and computed positions are shown in table 4. The results indicate that the interpolation errors are neglectable in the experiment. It is of course desirable to have as small interpolation factors as possible.

The position of the aircraft GPS antenna was determined in the coordinate system of the EDM testfield by conventional geodetic methods before as well as after every flying. During each flight a number of strips were photographed. The position from one GPS observation at the reference mark after the landing has been computed and compared with the one from the geodetic measurements, see table 5. The results indicate that the computation technique has worked satisfactorily during this flight.

Table 4 Comparisons between interpolated positions from 1 second measurements and computed positions from 0.5 second measurements.

Time	Diff: interpolated pos - computed pos (meter)		
	latitude	longitude	height
8:09: 14.5	-0.018	-0.013	-0.074
20.5	-0.003	-0.015	-0.009
28.5	-0.009	-0.028	-0.033
37.5	-0.018	-0.045	-0.054

Table 5. Comparisons between GPS determined positions and terrestrially measured positions (after the landing).

	Diff: GPS pos - ter pos (meter)		
	latitude	longitude	height
GPS 1 sec	0.024	-0.045	-0.022
GPS ca 5 min	-0.018	-0.033	-0.026

6. CONCLUDING REMARKS

The possibilities to use GPS in aerial photography for navigation and automatic exposures in preselected positions were successfully demonstrated during the experiments in 1989 and 1990.

A GPS-equipment has been mounted in one of the aircrafts during the aerial photography season 1991 and has been used periodically in the production work. During the time period October - November 1991 GPS has been used in aerial photography for the Kuwait-Iraq boarder demarcation. An increased usage of GPS in the aerial photography season 1992 can be foreseen.

Further analyses of already recorded GPS-data and further experiments are necessary to demonstrate the possibilities to determine the position of the camera at the time of the exposure for use in photogrammetry.

7. ACKNOWLEDGEMENTS

Martin Lidberg, NLS, has performed the computations of the positions in the 1990 experiment.

8. REFERENCES

- (1) Haarstad I., Hals T.: GPS anvendt for flyfotogrammetri, GPS resultater, 16 mars 1989. IKU-rapport 89.036.
- (2) Hein G. W.: Precise kinematic GPS/INS positioning - a discussion on the applications in aerophotogrammetry, Universität der Bundeswehr, München.
- (3) Peterson I.: Testfield at the Rörberg airport, Nordic Geodetic Commission, 11th Meeting, Copenhagen 1990.
- (4) Ashtech XII GPPS, GPS Post-processing system (manual)

STATUS OF A SWEDISH DGPS NETWORK

C

Abstract	C:1 (16)
1. Introduction	C:1 (16)
2. Geodesy 90	C:2 (16)
3. IT4-GPS satellite navigation	C:3 (16)
4. The Swedish radio navigation plan	C:4 (16)
5. Experiences and results from studies of pseudorange corrections	C:4 (16)
5.1 The influence of time delay	C:5 (16)
5.2 Results	C:5 (16)
5.3 The influence of the distance	C:6 (16)
5.4 Results	C:7 (16)
6. The status of a Swedish GPS network-summary	C:7 (16)
7. Concluding remarks	C:8 (16)
8. References	C:8 (16)
Acknowledgement	C:8 (16)
Figure 1	C:9 (16)
2	C:10 (16)
3	C:11 (16)
4	C:12 (16)
5	C:13 (16)
6 a-c	C:14 (16)
6 d-f	C:15 (16)
6 g-h	C:16 (16)

Status of a Swedish DGPS network

Gunnar Hedling and Bo Jonsson
National Land Survey of Sweden
S-80182 Gävle, Sweden
tel ++46 26 153000
fax ++46 26 128400

ABSTRACT

In "Geodesy 90", a report on the future role of geodesy in Sweden - prepared by the National Land Survey of Sweden (NLS) - a sketch of a system of reference stations for GPS is made. These would have the purpose of :

- acting as high-precision control points for Swedish users.
- providing differential messages for broadcasting to realtime users.
- monitoring the integrity of the GPS system.
- acting as fiducial stations in very high-precision networks for some of the stations, is also feasible.

In the first phase, two test stations will be operational in 1991.

NLS is also a partner of the Swedish navigation project "IT-GPS Satellite Navigation", which among other things will prepare a proposal for a Swedish network of reference stations for DGPS.

Practical results and experiences from tests with reference stations for GPS are presented in this paper.

1. INTRODUCTION

The GPS activity in Sweden started in the field of geodetic positioning. In February 1985 an informal Swedish working group was formed in order to facilitate cooperation and exchange of information about GPS. The group had representatives from the Royal Institute of Technology in Stockholm, the National Land Survey (NLS), the National Road Administration, the Swedish Maritime Administration, Onsala Space Observatory, the University of Uppsala, The Lund Institute of Technology and the military authorities. A Swedish GPS test network around the NLS observatory Mårtsbo, 11 km southeast of Gävle was established by the group in the end of 1985.

A group of Swedish universities and the National Land Survey purchased three Wild-Magnavox WM101 receivers in 1987. Between 1987 and 1990 these receivers were used for pilot projects in different types of GPS applications. The receivers

were upgraded to dual-frequency WM102s in the beginning of 1989. There were only a few single-frequency navigation receivers (Magnavox MX4400, Trimble Tans etc.) in Sweden during this period.

The launch of the first Block II satellite in February 1989 and the arrival of a new generation of GPS receivers (Ashtech XII and Trimble 4000ST) made it possible to use the GPS technique by routine for geodetic measurements e.g. densification of the national triangulation network and establishment of local control networks. In the end of 1989 there were ten Ashtech LXII and about four Trimble 4000ST receivers in Sweden. The introduction of Magnavox MX4200 in 1990 on the Swedish market, increased the interest for navigation applications of GPS.

During 1989 the National Land Survey together with the geodesy community in Sweden carried out an investigation about the geodesy in the nineties. A report was prepared - Geodesy 90 - which contains a number of proposals for the geodetic activities in Sweden and the commission also suggests that the report should be considered as an action programme for geodesy in Sweden. In March 1990 the report was submitted to the Government. The proposals for and the status of the GPS activities can be found below.

In the middle of 1988 preparatory negotiations for a Swedish satellite navigation project started and in March 1989 the agreement for the project IT4-GPS Satellite Navigation was signed by the partners. The goal for this project is to get practical experiences from the use of the GPS technique in a variety of navigation applications and to prepare a proposal for a Swedish network of active control points for navigation. A status report for the project and some results from tests with reference stations are given below.

The Swedish Radio Navigation Board - an association of mainly government agencies and institutions which have an interest in radio navigation - has prepared a Swedish Radio Navigation Plan which was published in April 1991. In the plan a summary of available radio navigation systems and official future plans in the field are given.

2. GEODESY 90

The proposals for the geodetic activities, which are presented in the report, are based on interviews about future needs with municipalities, surveying and engineering companies and a number of government authorities.

The following proposals concerning GPS can be found in the Geodesy 90 report.

- the GPS technique shall be introduced in the Swedish surveying community in those applications where it is convenient from a technical and economical point of view.
- The National Land Survey is appointed a coordination responsibility for information and guidelines for the use of GPS in Sweden.

- a Swedish network of fifty reference points - not necessarily permanently equipped with GPS receivers - is established in order to facilitate densification of the national triangulation network and the connection of local control networks. The network of reference points will be connected both to the national triangulation network and the national levelling network.
- a test network of four active control points - permanently equipped with GPS receivers - is established as soon as possible in order to study the use of such a network for different applications and the routines for the operation of the network. Examples of possible applications for the Land Survey are connections to the national triangulation network of cadastral surveys and air photography/photogrammetry. GPS users will be invited to use data from the test network. A sketch of a network of active control stations are shown in figure 1.
- a geoid for Sweden should be developed as soon as possible, to make height determinations with moderate accuracy (decimeter level) possible using GPS.

As mentioned earlier the report and an application for extra funds for the test network of the four active control stations was submitted to the ministry in March 1990. In January this year the Government notified NLS that no funds had been voted. By changing the priority it will be possible to realize a test network of two active control stations.

The two active control stations, in Gävle and Stockholm, are planned to be in operation in November this year.

A bulletin board for GPS information is in operation since May this year. At present (Aug -91) we have thirty registered users.

3. IT4-GPS SATELLITE NAVIGATION

The object of the project is to get experiences of the GPS technique - in both autonomous and relative mode - in a number of different environments: cars, trucks, boats, aircrafts and to get a notion of the capabilities of GPS in these applications.

The partners of the project are the Defence Materiel Administration, the Telecommunications Administration, the National Land Survey, the National Maritime Administration, Ericsson Radio Systems, SAAB-SCANIA, Volvo and FFV Aerotech.

The experiments in the project are carried out by six working groups: cars, trucks, boats, aircrafts, reference stations and filtering and aiding of GPS. The field tests have been completed (Aug -91) in all the groups and final reports will be ready in the end of this year. The remaining activity in the project is to prepare a proposal for a network of active control stations including distribution channels for real-time users.

In the working group reference stations the goals have been to distribute pseudorange corrections for the experiments in the other groups, to run a complete reference station during a test period, see figure 2, and to investigate the validity of pseudorange corrections with respect to time and the distance from the reference station. A short summary of results from the study of pseudorange corrections will be given in this report.

The project is planned to be completed in February 1992

4. THE SWEDISH RADIO NAVIGATION PLAN

The Swedish Radio Navigation Board (Swedish acronym RNN) is an association of the following Swedish authorities and institutions: Naval Staff, Air Staff, Defence Materiel Administration - Naval Materiel Dept. and Air Materiel Dept., National Defence Research Establishment, Telecommunications Administration, Swedish State Railways, National Maritime Administration, Board of Civil Aviation, National Land Survey, National Road Administration, Swedish Coast Guard and Communicator AB. The main objective of RNN is to keep its member organizations informed about the evolution and progress in the various areas of radio navigation.

In June 1989 RNN appointed a working group, consisting of representatives from National Maritime Administration, Board of Civil Aviation, National Land Survey, Telecommunications Administration and National Defence Research Establishment, for the preparation of a Radio Navigation Plan. Following a detailed summary of existing radio navigation systems, the plans and policies of the government authorities are shown in the plan. In the field of GPS the following plans for a Swedish DGPS network can be found:

- Land: At the present there are no co-ordinated plans for the use of a DGPS network. Experimental work is going on. The National Land Survey plans to prepare a proposal for a DGPS network for geodetic positioning in 1993.
- Sea: The National Maritime Administration plans to establish a DGPS network covering the Swedish sea waters and some large lakes. The design of the network and a time table is not published yet. Experimental work is going on, see Bäckström.
- Air: No concrete plans for the use or establishment of a DGPS network.

5. EXPERIENCES AND RESULTS FROM STUDIES OF PSEUDORANGE CORRECTIONS

Some basic parameters of DGPS have been studied in the IT4-project, namely how the accuracy of the positions depend on:

- the delay of the pseudorange corrections
- the distance from the reference station.

The study have been divided into two parts. The first one consisted of studying the effects of delay and distance from the reference station using older GPS-data, collected by NLS, and a post-processing program. The second part consisted of two experiments that took place in May 1991, where the effects of delay and distance were studied directly.

5.1 The influence of time delay.

The influence of the time delay on DGPS was studied by introducing delays on the data link between the reference receiver sending pseudorange corrections and the receiver that was using these corrections.

Preliminary investigations with a post-processing program by which one could simulate delays of the pseudorange corrections, indicated that even long delays of up to 5 minutes had little influence on the accuracy of the positions. We therefore decided to study the following delays: 0, 1, 2, 3, 5, 7 and 10 minutes, a test session with autonomous GPS (no differential corrections) observations was also planned for comparison.

The tests were performed May 7-8 1991 at Mårtsbo, the observatory of NLS, see figure 3. The equipment consisted of 2 Ashtech L-XII's and 3 IBM PC kloner used for data-logging and for a delay-program. This program stores the differential correction messages, coming from the reference receiver, in a buffer and after a specified time transmits them to the other receiver. The test sessions consisted of 15 minutes of 1 second data, which means about 900 positions for each delay. The sessions were spread randomly over the interval between 8:30 and 12:30 (local time). This interval was chosen because it had low DOP values and at least 5 satellites visible during most of the time. According to the plans for the future constellation of GPS satellites this will be more or less a normal geometry for the measurements. The same schedule for the sessions was used on both days. This is not the best design for the experiment, two different schedules would have made the results less dependant on the satellite geometry during the individual sessions, but because of the time that was needed to fill the buffer for the long delays it was impossible to change the schedule.

5.2 Results

The results for the two days can be seen in figure 4. The radial mean and radial standard deviation for the horizontal errors are plotted as two adjacent bars, the left one for the mean and the right one for the standard deviation. These are plotted as functions of the delay with the results from the autonomous measurements to the left in the diagram. It can be seen in figure 4 that during both days, the results follow the same pattern. For delays up to 3 min the results seems to be very little influenced by the delay of the pseudorange corrections. After 5 min of delay both the radial mean and standard deviation exhibit a clear increase with the delay. An example of dependancy on satellite geometry also can be seen in figure 4 where the radial standard deviation for the 1 minute delay sessions on both days is bigger than the radial standard deviations for the 2 and 3 minute sessions. This is probably caused by the fact that the 1 minute session were taken mainly with 4 satellites and a higher DOP-value than the other sessions.

5.3 The influence of the distance.

To study the influence of distance from the reference station on DGPS, the following test was made. A reference station was established at the National Maritime Administration (Swedish acronym SJÖV) in Norrköping, this station sent pseudorange corrections via telephone modems to four stations, see figure 5, with GPS receivers located on different distances from the reference station.

Table 1

Station	Receiver	distance (km)
Norrköping	Ashtech L-XII	reference station
Stockholm	Trimble 4000RL MX4200D	135
Gävle	Ashtech L-XII MX4200D	232
Malmö	Ashtech L-XII MX4200D	385
Kiruna	Ashtech L-XII MX4200D	1053

As you can see this experiment also became a test of the compatibility of different receiver manufacturers implementations of the RTCM SC-104 protocol.

The test was conducted May 28-30 1991 with three daily sessions during the first two days and two sessions the third day: session A 9:00 - 10:30, B 11:15 - 12:30 and C 22:00 - 23:00. During the test sessions the positions from the receivers were sampled every 5 second.

The criteria for this choice of sessions were the same as in the delay test, but session C was chosen with the intention of detecting any influence from ionospheric disturbances on DGPS. According to forecasts from the Geological Survey of Canada the geomagnetic activity would be rather high during the test period.

Since we have come a long way from the earlier GPS receivers with simple code-solutions for the position, we will say something of the differences between the receivers used in the test.

- Ashtech XII receivers use a dual-ramp technique for the carrier-smoothing of the code. The position updates are computed independently of earlier updates (no filter).
- MX4200 receiver also use carrier-smoothed code measurements but for the position updates a Kalman- filter is used, the constants of the filter can be set for different kinds of operation (static, low, medium and high dynamics). During this test all the MX4200's were set for low dynamics.

- Trimble 4000RL use carrier-smoothed code and a Kalman-filter for the position updates. Since the differential software arrived on the second day of the test and we only had one Trimble receiver, we used the default settings.

This makes comparisons of positions difficult since the filtered positions (Magnavox and Trimble) probably will be less noisy compared with the non-filtered positions (Ashtech).

The execution of the test worked well considering that so many GPS receivers, spread all over Sweden, were involved. Some sessions failed and a couple of interruptions during the sessions had to be fixed manually.

5.4 Results.

The results are presented in the same way as the delay test, but this time the statistics is plotted as functions of the stations, which have been ordered with distance from the reference station, the leftmost bars are for the autonomous positions (no DGPS) of the reference station which are shown for comparison. The truth in this test to which the GPS positions have been compared are conventional terrestrial coordinates combined with doppler measurements. These will probably show some systematic effects on the stations on the outer edges of Sweden: Malmö and Kiruna.

The results of the test are given in figures 6 a-h, there is one diagram for each session. From figures 6 a-h it can be seen that the neither the radial means nor standard deviations show any tendency to grow with a greater distance from the reference station. We are very doubtful about the station in Kiruna which lies 1053 km's from the reference station! On all of the sessions except 29/5 session B the statistics doesn't look very different from the other stations.

Ashtech receivers give noisier positions than MX4200, but the accuracies seems to be the same. This can be seen on the stations that have both of these receivers: Gävle and Malmö. An explanation of this follows from the description above of the different types of position updates in Ashtech and Magnavox receivers.

The C sessions (22:00 to 23:00) that took place to detect signs of an active ionosphere doesn't differ from the other sessions, least of all the station in Kiruna, where the ionospheric activity was expected to be high.

6. THE STATUS OF A SWEDISH DGPS NETWORK - SUMMARY

At the present time there is a lot of tests with DGPS going on in Sweden. We are also following international DGPS projects with great interest. The conditions for a national DGPS network - co-ordinated as far as possible with Scandinavian, European and global DGPS networks - seems to be favourable because of a close technical collaboration between the responsible authorities and the GPS users. But still many technical problems need to be solved and the idea of having a fundamental network of active control stations which can deliver GPS data for

different categories of GPS users will be discussed thoroughly. A national network of active control stations can be used for the following purposes:

- acting as high-precision control points for Swedish users.
- providing differential messages for broadcasting to realtime users.
- monitoring the integrity of the GPS system.
- acting as fiducial stations in very high-precision networks, for some of the stations, is also feasible.

A proposal for a DGPS network will be prepared by the working group reference stations in the project IT4-GPS. The working group have representatives from the Maritime Administration, National Land Survey, Telecommunications Administration and FFV-Aerotech (military authorities). The proposal is planned to be ready in the end of 1991.

The National Land Survey, in collaboration with the geodetic GPS user community, plans to prepare a proposal for a DGPS network for geodetic positioning which will be ready in 1993. Efforts will be made already now to co-ordinate this proposal with DGPS networks for navigation purposes.

7. CONCLUDING REMARKS

Our tests indicate that the pseudorange corrections are usable at least 3 minutes after the moment that they have been computed and that they are usable at distances up to 1000 km from the reference station. The satellite geometry and the environment of the antenna have in many cases a larger influence on the accuracy of DGPS than the distance from the reference station and delays on the correction link.. This applies when using current generation C/A-code receivers with carrier-smoothed code measurement and there is no SA on.

This report deals with technical questions and the possibility to establish a national DGPS network. Other important questions are of course the operation and the financing of such a network. But our opinion is that the conditions for a co-ordinated widely supported proposal for a national DGPS network are favourable at the moment.

8. REFERENCES

- Geodesi 90. LMV-rapport 1990:1, 1990.
Svensk radionavigeringsplan 1991. Radionavigeringsnämnden, 1991.
Bäckström R, Enge P K, Tryggö B, Wilson S: Establishment of a Joint Governmental Differential Service for Marine Use in the Baltic Sea, to appear in Proceedings of ION GPS-91.

ACKNOWLEDGEMENT

The results in this paper are based on a co-operation by the members of the reference stations group in the project IT-GPS.

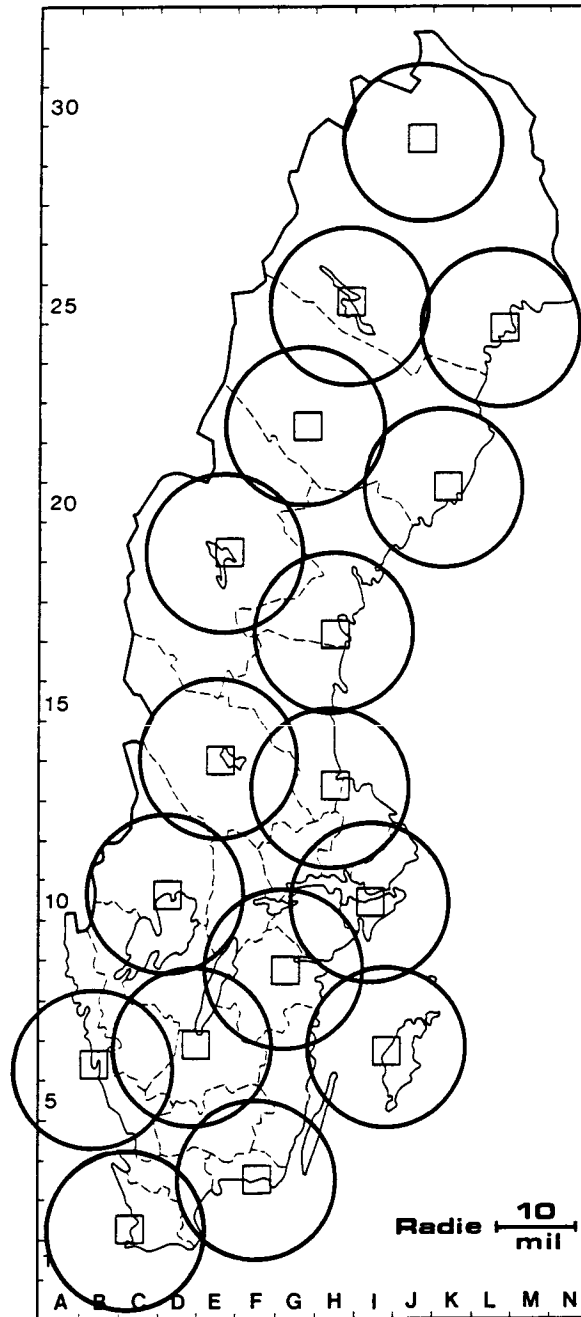


Figure 1. Sketch of a network of active control stations

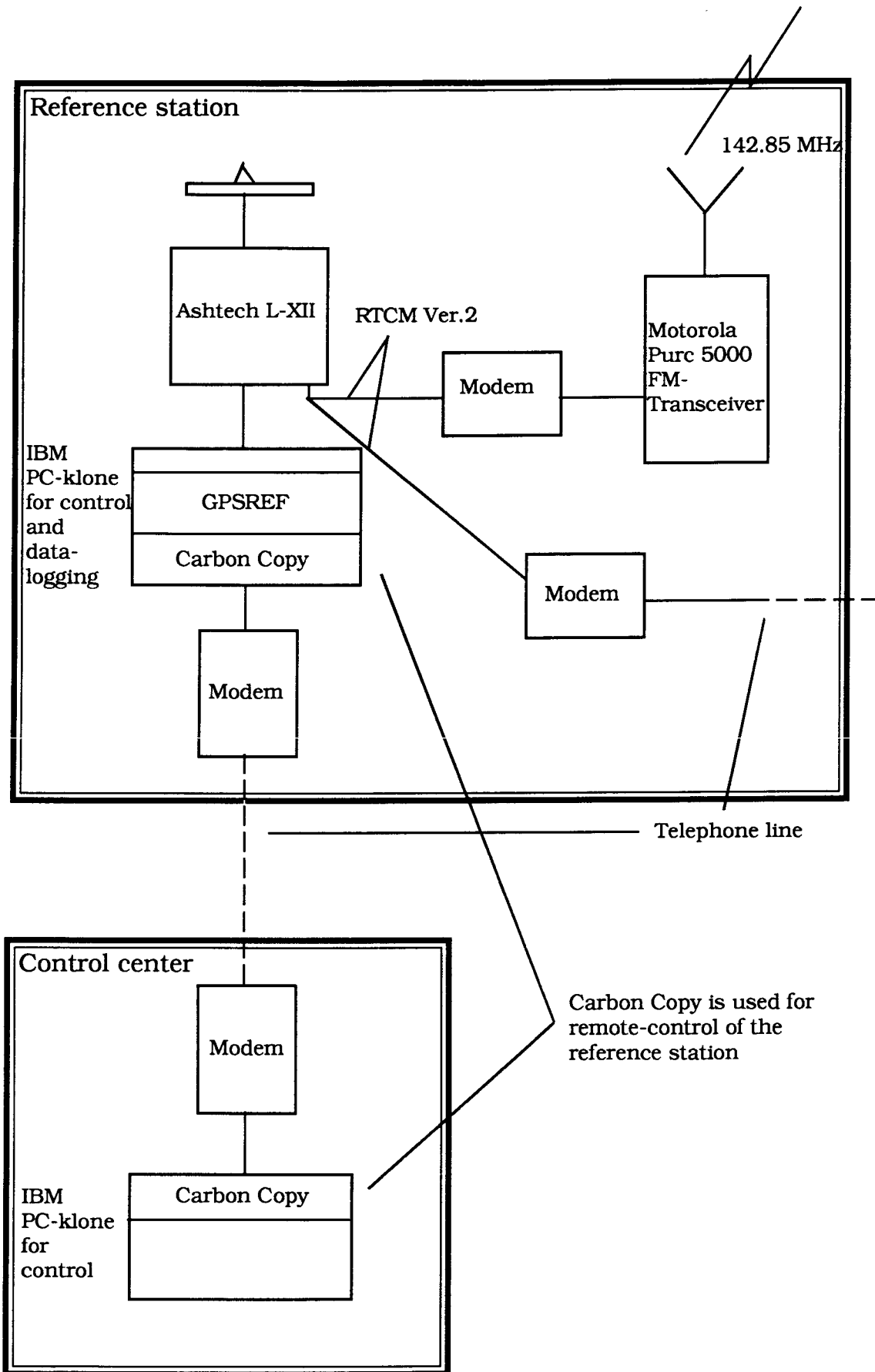


Figure 2. Diagram of the reference station in Gothenburg, Sweden, summer 1991

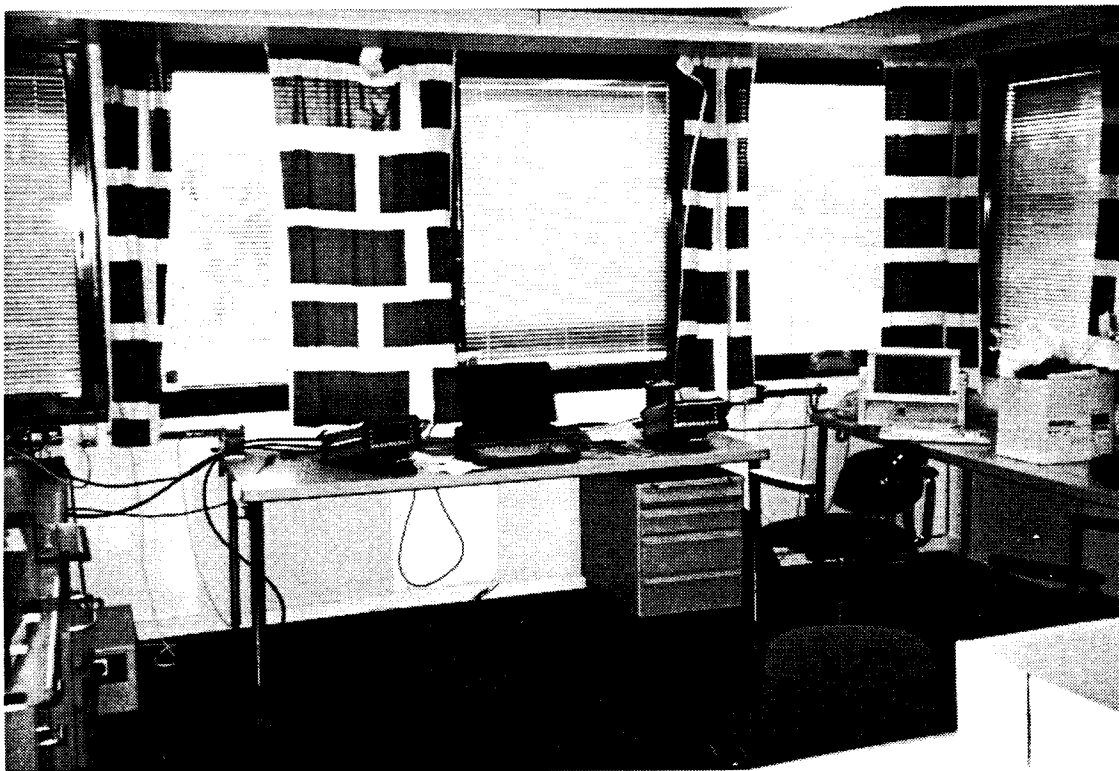
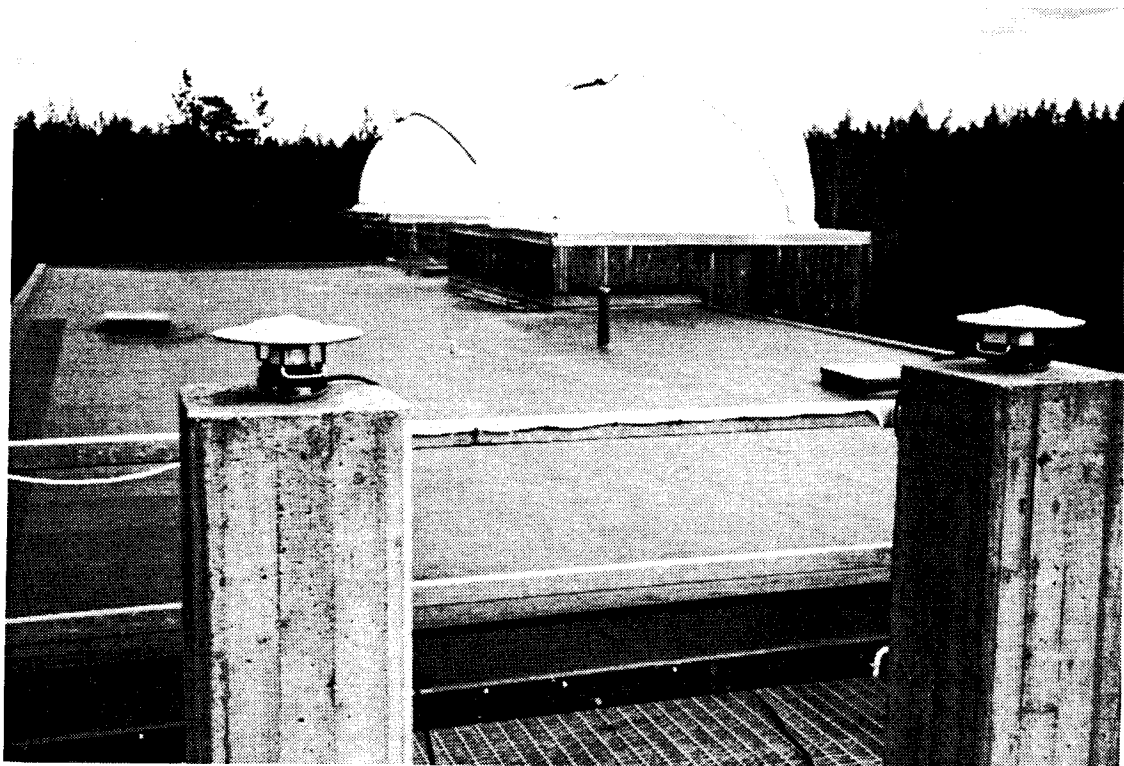
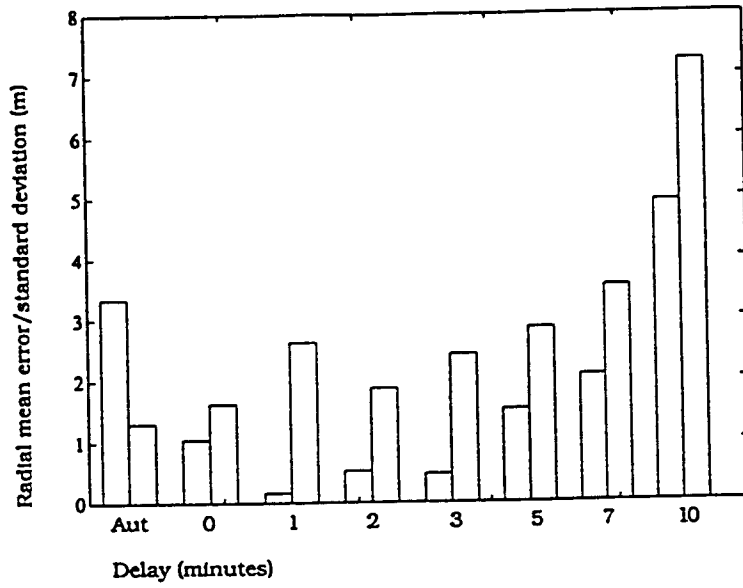


Figure 3. Arrangements at Mårtsbo Observatory for the test of time delays, May 7-8 1991

7/5



8/5

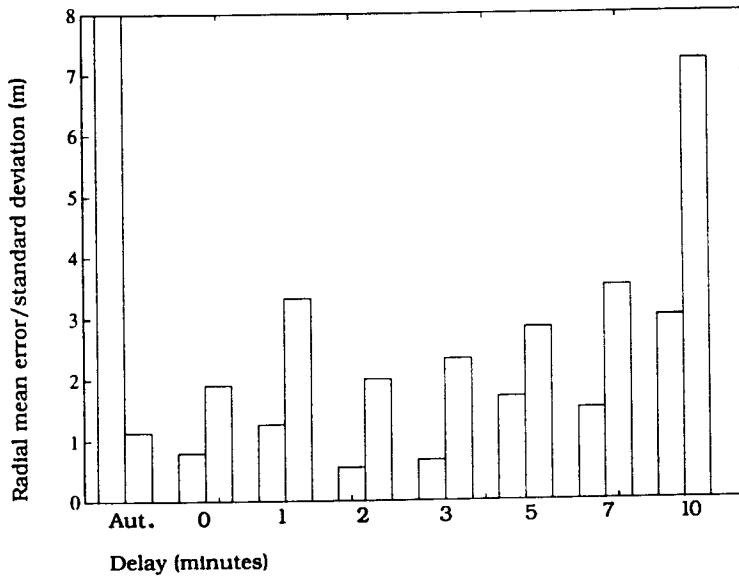


Figure 4. Radial mean error and standard deviation as functions of the time delay of pseudorange corrections

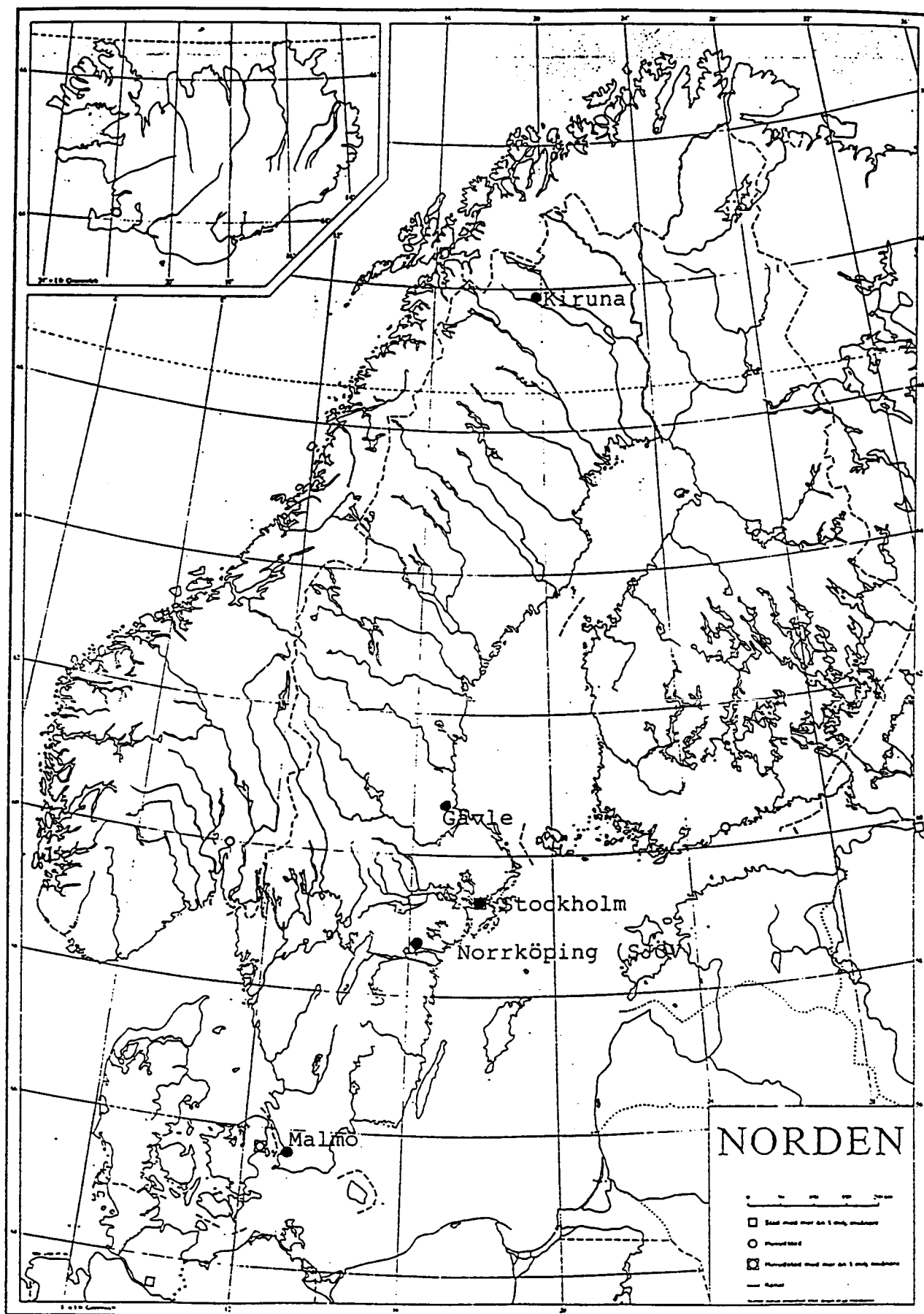


Figure 5. Map of locations during the test of distances to the reference station

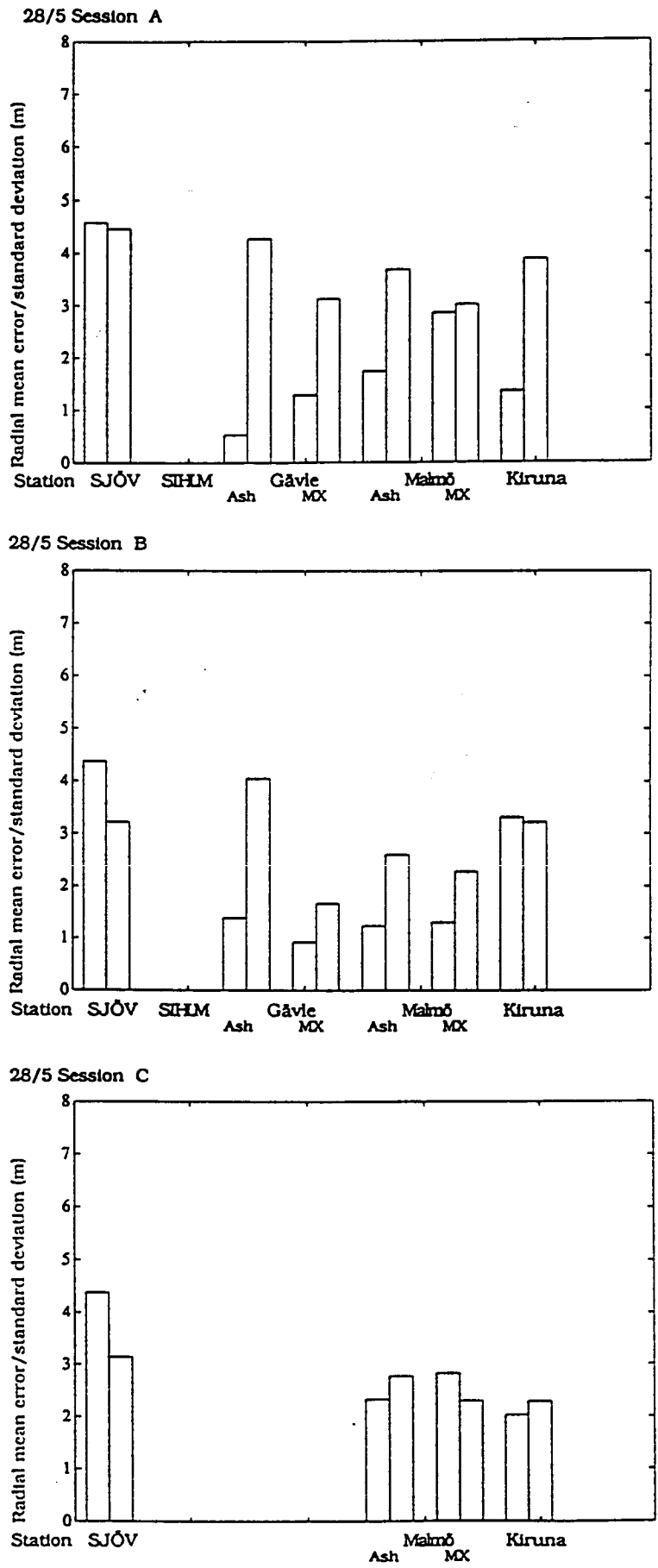
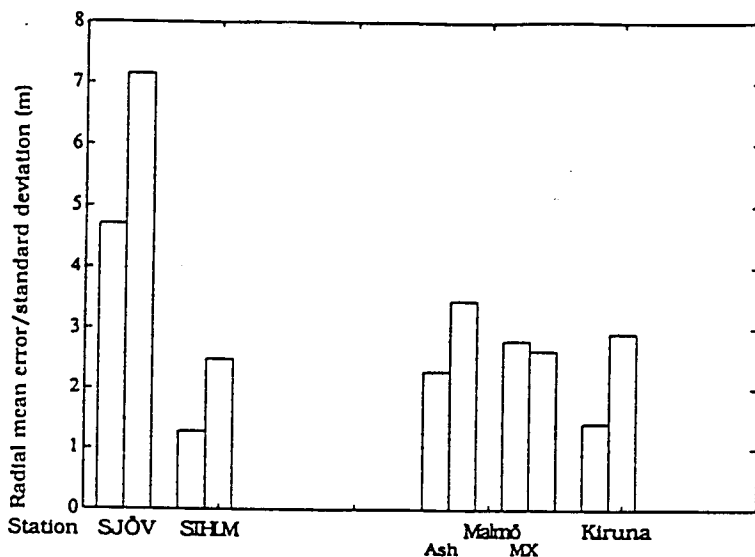
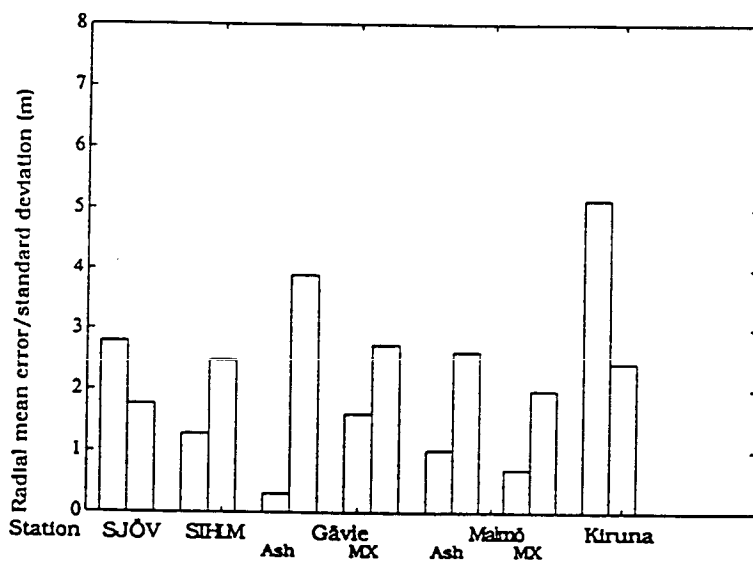


Figure 6 a-c. Radial mean error and standard deviation as functions of station, ordered with distance from the reference station

29/5 Session A



29/5 Session B



29/5 Session C

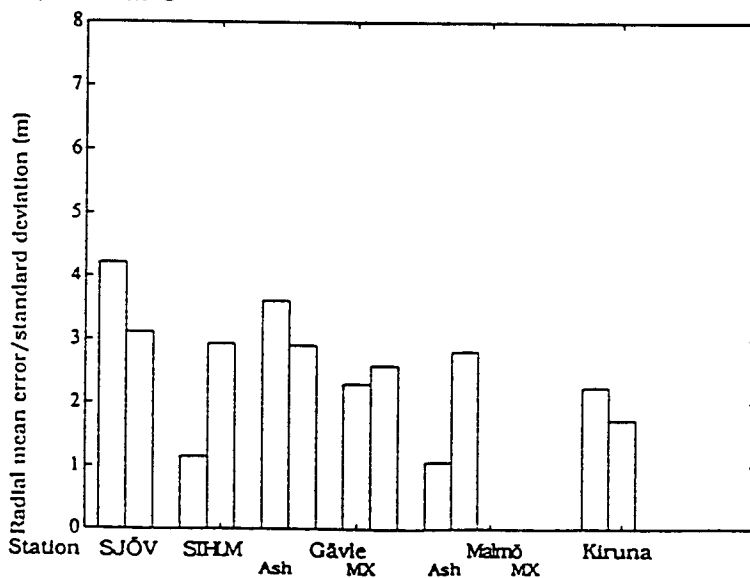


Figure 6 d-f. Radial mean error and standard deviation as functions of station, ordered with distance from the reference station

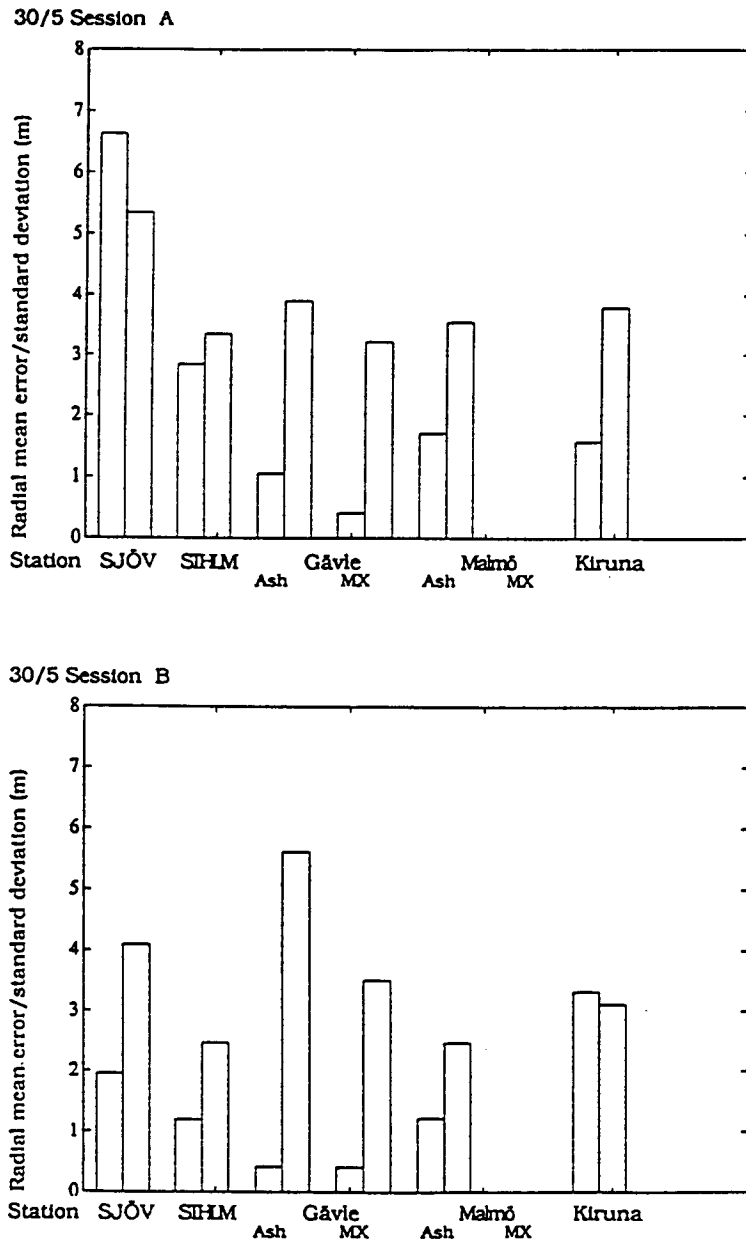


Figure 6 g-h. Radial mean error and standard deviation as functions of station, ordered with distance from the reference station