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The Compatibility of SWEPOS-data with GPS-Equipment Available on the market

Petra Ammenberg and Kristina Hansson

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PREFACE

SWEPOS is an experimental network of reference stations for GPS. Data from the SWEPOS-stations can be used for many different applications for example navigation and cadastral surveying. SWEPOS-data can be retrieved via Internet or a BBS in the recommended standardised format RINEX (Receiver INdependent EXchange).

The purpose of our diploma work is to investigate the compatibility of SWEPOS-data with GPS-equipment available on the market for static processing of dual frequency data.

The diploma work was carried out at the Geodetic Research Division (FoU Geodesi) at the National Land Survey of Sweden (Lantmäteriverket - LMV) in Gävle. It included planning, field measurements, calculations and analyses of the results from the measurements.

We would like to take this opportunity to thank all personnel at the Geodetic Research Division, especially Lotti Jivall who has been our instructor and Örjan Zackrisson who has helped us with our practical computer problems.

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Petra Ammenberg　　　　Kristina Hansson

Sammanfattning

Syftet med examensarbetet var att ta reda på om den data som levereras från SWEPOS-nätet, i RINEX-format, är kompatibel med de tillgängliga GPS-utrustningar som finns på marknaden. Den här undersökningen är gjord med avseende på statisk efterbearbetning av tvåfrekvens-data. Det bör här poängteras att syftet med arbetet inte är att undersöka noggrannheten hos de olika utrustningarna/programvarorna.

Följande utrustningar och programvaror har testats:

Mottagare	Mjukvara
Ashtech Z-12	PRISM II
Geotracer 2200	GeotracerGPS 2.20
Leica SR399	SKI 2.0 (1.09)
Trimble 4000SSE	GPSurvey 2.00
Topcon SII	TurboSurvey

Statiska mätningar gjordes i två 24-timmars perioder. Vi försökte inte göra mätningarna under identisk satellitgeometri, men eftersom vi mätte i 24 timmar blev alla möjliga satellit-konfigurationer ändå representerade.

Först beräknades hela dygnen var för sig. På grund av störningar i SWEPOS-driften kunde vissa dygn inte beräknas, vilket innebar att vi i vissa fall bara erhöll resultat från ett dygn. I de fall där det fanns två dygn att välja mellan valde vi det som hade det bästa resultatet med avseende på förbättringarna till baslinjerna från baslinjeberäkningen. I nästa steg delade vi upp de utvalda dygnen i två-timmars sessioner och gjorde nya beräkningar.

För att kunna säga något om det resultat vi erhållit gjordes också en referensmätning på samma punkt som med de testade utrustningarna. I denna mätning användes en Ashtech Z-12 mottagare och en Dorne Margolin (chokering) antenn. Valet av denna utrustning beror på att det är denna utrustningskombination som används på SWEPOS-stationerna. Beräkningarna av referensmätningen gjordes i Bern-programmet.

Om den data som levereras från SWEPOS-stationerna, i RINEX-format, är felfri är den kompatibel med Geotracer/GeoGPS, Trimble/GPSurvey och Topcon/TurboSurvey.

Informationen i manualen om Topcon-antennens elektriska centrum är felaktig. Detta orsakade ett höjdfel på ca 4 cm. En korrigering av detta värde skulle förbättra höjdresultatet avsevärt.

SWEPOS-data i RINEX-format är idag inte kompatibel med PRISM.

Leicas mjukvara SKI är känslig för kombinationen av ostabila mottagarklockor och blandade mottagare. Med blandade mottagare avses i detta fall att mottagarna kommer från olika tillverkare.

Abstract

The purpose of our diploma work was to investigate the compatibility of RINEX-data from the SWEPOS-network with the GPS equipment available on the market today and if they could use the data correctly. The test only deals with static post processing of dual frequency data. It is important to note here that the purpose is not to investigate the accuracy of the different equipment.

The following equipment and software has been tested:

Receiver	Software
Ashtech Z-12	PRISM II
Geotracer 2200	GeotracerGPS 2.20
Leica SR399	SKI 2.0 (1.09)
Trimble 4000SSE	GPSurvey 2.00
Topcon SII	TurboSurvey

Static measurements were made during two 24-hour periods. We did not try to make the observations under identical satellite geometry, but since the measurements lasted for a full 24-hour period all possible satellite configurations were represented.

At first all 24-hour periods were calculated. Due to disturbances in the SWEPOS-data some periods could not be calculated, which meant that we sometimes only got results from one 24-hour period. In those cases we had two 24-hour periods to choose between, we chose the period that had the best results referring to the baseline residuals, from the baseline processing. In the next step we divided the selected 24-hour periods into two-hour sessions and made new calculations.

To be able to form an opinion about the results we obtained, a reference measurement was made on the same point as with the tested equipment. For this measurement an Ashtech Z-12 receiver and a Dorne Margolin chokering antenna was used. The choice of this equipment is based on the fact that you should use the same receiver and antenna as on the SWEPOS stations to achieve the best result possible. The calculation of the reference measurement was done using the Bernese software.

If the data, in RINEX-format, delivered from the SWEPOS-stations is correct, it is compatible with Geotracer/GeoGPS, Trimble/GPSurvey and Topcon/TurboSurvey.

The information in the manual about the electrical centre of the Topcon antenna is wrong. This caused a height error of about four centimetres. A correction of this value would improve the height result considerably.

Today SWEPOS-data, in RINEX-format, is not compatible with PRISM.

The Leica software, SKI, is sensitive to the combination of unstable receiver clocks and mixed receivers. Mixed receivers means that the receivers are made by different manufacturers.

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APPENDICES

1 INTRODUCTION

The purpose of our diploma work was to investigate the compatibility of RINEX-data from the SWEPOS-network with the GPS receivers, antennas and processing software available on the market today and if they could use the data correctly. The use of SWEPOS for accurate positioning (cm-level) has until now not been commonly spread. It is mainly NLS who has used SWEPOS for this application and they either use the raw Ashtech-data from SWEPOS in combination with Ashtech field measurements or use the RINEX-format in the Bernese software. In order to get this technique more spread, it is important to test the compatibility of SWEPOS-data with the dual frequency GPS-equipment available on the market. In this way possible problems could be localized and further on solved, either in the SWEPOS-concept or on the manufacturer's side.

When mixing receivers and antennas there are two critical things that has to be considered, the data format and the difference between the phase centre and the physical centre of the antenna. Most software could handle the recommended standard format RINEX, but a problem is that the RINEX-format just tells how a record should look like, not which records should be present. This means that a certain RINEX-format from one software not necessarily is computable with an other software. The exact location of the phase centre (some antenna types have different phase centres for L1 and L2, and it varies with the elevation and azimuth to the satellites) is not interesting when using the same type of antenna, but when mixing antennas it is crucial. Especially the height component is hard to determine.

The equipment that we have been testing are presented in table 1.1

Receiver	Software
Ashtech Z-12	PRISM II
Geotracer 2200	GeotracerGPS 2.20
Leica SR399	SKI 2.0 (1.09)
Trimble 4000SSE	GPSurvey 2.00
Topcon SII	TurboSurvey

Table 1.1 Tested receivers and software.

With each equipment we have determined the position of a point on the roof of NLS in Gävle, using the four closest SWEPOS-stations Mårtsbo, Leksand, Sveg and Sundsvall as references. The purpose of the test was not to investigate the accuracy of different receivers/antennas/software, just to test the compatibility and see that reasonably good results were achieved (coordinates with a standard error of one centimetre in the horizontal position and a little bit higher in the vertical). To get reference coordinates calculated for the same point, observations were made using a Dorne Margolin antenna (chokering) and an Ashtech receiver which is the same equipment as used on the SWEPOS-stations. These reference coordinates are expected to be considerably better than the ones from the tested equipment in table 1.1. Therefor, the reference coordinates are regarded as known in the evaluation of the results (cf. 3.3)

1.1 Delimitation of the problem area

For each observation session, the receiver and the antenna used together were from the same manufacturer. We never mixed antennas and receivers from different manufacturers and we were only interested in processing the observation data with the software that each manufacturer provided for their own receiver. This investigation does just deal with static processing of dual frequency measurements i. e. not code alone and not kinematics.

After finishing the calculation process there are several possibilities to improve the achieved result. You can for example disable satellites or change the elevation angle, but we made no such improvements at all. The only time we disabled any satellites was when it was impossible to get any reasonable results, for example in the case with Geotracer when one baseline in one session could not be used in the adjustment, because of its bad solution.

We made no transformations to the national horizontal and vertical datum. The comparisons were done in SWEREF 93 [13].

1.2 Work by others

Tests of GPS-equipment are very time dependent since the development in this area is exceeding very rapidly. Tests similar to our were made two years ago at NLS but the software have changed since then. The results from these tests have not been published.
A lot of antenna tests have been made i.e. Schupler [15].

During our diploma work we had contacts with other Leica users using SWEPOS that experienced similar problems as we did during our calculations (see 4.3).

2 SWEPOS

2.1 SWEPOS - a short introduction

SWEPOS is a Swedish network of 21 permanent reference stations for GPS which has been established by the National Land Survey of Sweden, Onsala Space Observatory and the project "GPS resources in Northern Sweden". The network (App. 1) is today in an experimental stage, but is expected to become operational during the first six months of 1997. SWEPOS-data are already useful for production purposes though. In this section SWEPOS is briefly presented. For a more thorough description the reader is advised to consult Hedling and Jonsson (1995) [7] and [10].

2.1.1 The stations

All SWEPOS stations are equipped with two GPS-receivers. Either two Ashtech Z-XII receivers or one Ashteh Z-XII and one TurboRogue receiver. All receivers collect data with 15 seconds epoch intervals and 10 degrees elevation mask (except for the TurboRogue receiver in Onsala, which uses 30 secs epoch intervals). Some of the stations are equipped with external atomic clocks. The antennas are placed on top of three metre high concrete pillars that are heated electrically to a constant temperature of 15 degrees Celsius to avoid deformation because of differences in temperature. Every pillar is surrounded by a small precision network marked with steel bolts in the bedrock. These are used to monitor movements of the pillars. All antennas are of type Dorne Margolin. For high-precision positioning the best result is achieved when using the same antenna type for the unknown point.

2.1.2 The control centre

The management of SWEPOS is carried out from the control centre at NLS in Gävle. The observation data is automatically transferred to this centre where a RINEX-conversion and a quality control is done. For post-processing all the SWEPOS-data, that is code- and carrier phase data, is available in the recommended standardised format RINEX (Receiver INdependent EXchange) via Internet (SWEPOS-FTP) or SWEPOS-BBS.
The RINEX-files contains the following observations:

- Ashtech : L1, L2, C1, P1, P2, D1 and D2.
- TurboRogue : L1, L2, C1, P2 and D1.

L1 (L2): carrier phase measurements on L1 (L2)
C1 : C/A - code measurements
P1 (P2): P - code measurements on L1 (L2)
D1 (D2): Doppler measurements on L1 (L2)

Postcomputed ephemeris are also available through SWEPOS-BBS or SWEPOS-FTP, in the standardized format SP3. If your software requires another format, transformation programs between different formats (SP3, SP1, EF18 and ECF2) are available.

2.1.3 Reference systems for SWEPOS

The positions of the SWEPOS-stations are determined in the referencesystem SWEREF 93 [13]. SWEREF 93 is a reference system which is very well connected to both ITRF 89 and EUREF 89, but has a better coverage in Sweden. EUREF 89 (European Reference Frame 1989) is an expansion of the global ITRF 89 (IERS Terrestrial Reference Frame 1989) and includes five points in Sweden. SWEREF 93 coincides within a metre with WGS 84 and has a well established relation with the national horizontal and vertical reference systems RT 90 and RH 70. In this investigation, no transformation of the SWEPOS-stations position is necessary since we are using broadcast ephemeris and the uncertainty of broadcast ephemeris is larger than the difference between SWEREF 93 and WGS 84.

2.1.4 Applications

The purpose of SWEPOS is to supply a number of users with data from the GPS-satellites for different applications. An important application for SWEPOS has been to act as high-precision control points for the new geodetic reference system, SWEREF 93. Other applications are for example real-time positioning for navigation, data capture for GIS (Geographical Information Systems), studies of crustal movements and cadastral surveying [1], [4], [5],[16].

SWEPOS-data can be used for either postprocessing or real-time measurements. Using the post-processing option a position accuracy on the centimetre level can be achieved with an observation time of a few hours. This requires a dual frequency receiver, that the receiving conditions are good and that you have a good post processing software [11].

2.1.5 Problems

At some stations a phenomenon called "ghost-satellites" can be observed. Leksand is one of these stations. The phenomenon appears when a satellite, at a high elevation angle, with a very strong signal occupies two channels in the receiver. At one of the channels it transmits a signal that is identified as coming from one of the satellites that are below the horizon, but with its own elevation angle and azimuth. If you look at a plot of the orbit of the satellite below the horizon, it looks as if it is following the same orbit as the high satellite with strong signal. This effect has recently been discovered and reported to Ashtech Inc. Sunnyvale, but the reason can still not be properly explained. So far there exists no documentation concerning this problem.

Another problem has been the radomes that protects the antennas from snow, rain and birds etc. These radomes are not homogeneous and are different on the stations. When solving for tropospheric parameters the height determination has been affected. These radomes were present at three of the stations (Leksand, Sveg and Sundsvall) during our tests. Recently a new type of radome has been developed that does not have this effect on the heights.

Another thing that might cause problems to some of the processing software is the unstable receiver clock in the Ashtech receiver in combination with the RINEX-converter (ASRINEXO, ASRINEXN from the university of Bern) which is used for the SWEPOS-data. The Ashtech receiver clock is quite unstable but it corrects itself when the clock error exceeds 1 msec (see fig 2.1). The RINEX-converter used in SWEPOS however, recomputes the time and observations in order to get a continuous clock (see fig 2.2). This means that the clock error will be quite big at the end of a session.

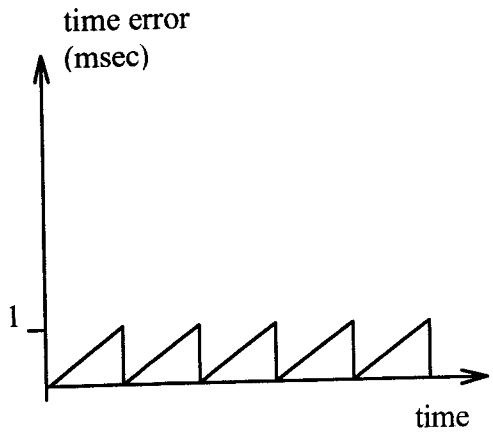

Fig. 2.1 Ashtech receiver time

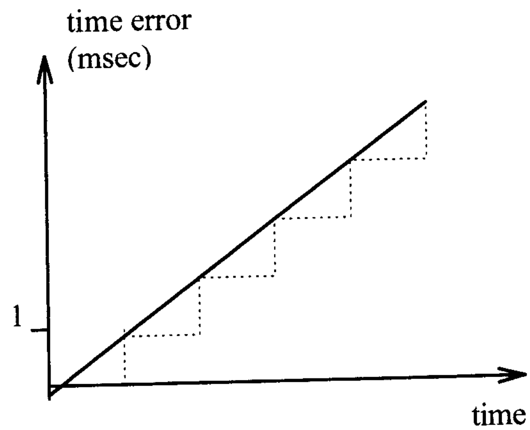

Fig. 2.2 Ashtech receiver time converted to RINEX

3 METHODS

3.1 Data aquisition and preparation

The point for which we have determined the position was situated on a pillar on the roof of NLS in Gävle (see fig. 3.1). At the top of the pillar there was a steel plate with a diameter of about 34 cm where a tribrach was mounted.

Fig. 3.1 The roof point with the Geotracer equipment.

Static measurements were carried out during two 24-hour periods with each GPS-equipment to increase our chances of getting complete data, even if some kind of interuption would occur in one of the periods. For this application a minimum elevation angle of 15 degrees and an epoch interval of 15 seconds were used. We did not try to make the observations under identical satellite geometry, but since the measurements lasted for a full 24-hour period all possible satellite configurations were represented. Because of the different storing capacity of the receivers some sessions only lasted for about 23 hours.
Each 24-hour period was divided into two-hour sessions, because two hours is the recommended observation time if you want to connect your measurement to the SWEPOS-network. The division into two-hour sessions is based on empirical studies made on the calculations of the daily collected measurements on NLS from the SWEPOS-stations. Two-hour sessions give much better results than one-hour sessions [6].

As the start time for each 24-hour measurement varies, it is not relevant to compare for example session 1/Leica with session 1/Topcon. Since we wanted to divide the best of our two 24-hour periods, referring to the baseline residuals from the baseline processing, into two-hour sessions we had to process both periods to be able to select one of them.

3.2 Processing of data

For our calculations we have used a Dell OptiPlex XL 590 with a 90 MHz pentium processor.

3.2.1 Processing strategy

Our intention was to connect the measurements to the four closest SWEPOS-stations. We wanted to compute all baselines (see fig. 3.2) using broadcast ephemeris with the software that each manufacturer provided for their receiver.

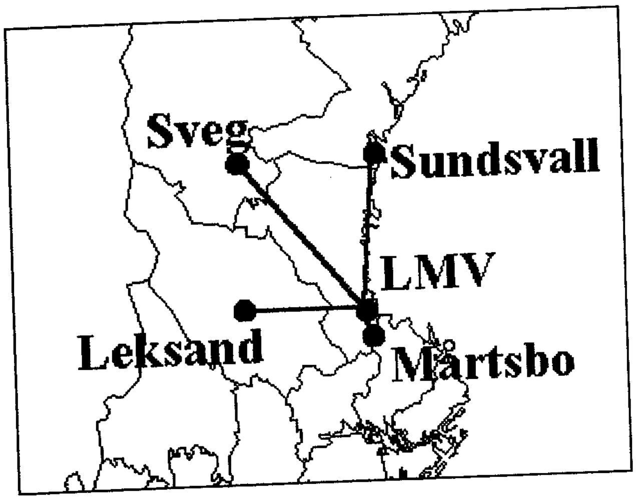

Fig. 3.2 Baselines to be computed.

We also wanted to use the ionosphere free linear combination, L3, as the final solution, which is a linear combination of the L1- and L2- frequencies (see fig. 3.3) [8].

$$\Phi_{L3} = \Phi_{L2} - \frac{f_{L2}}{f_{L1}} \Phi_{L2}$$

Fig. 3.3 The carrier phase for the L3 signal.

In both the baseline processing and the adjustment we followed the recommendations given in a part of "Guidelines for connecting cadastral surveys to the national datum" [2] (connection towards four SWEPOS stations), with the exception that we made no efforts to recover or improve baseline results by operator intervention. Only when the results far exceeded reasonable values we disabled bad satellites or increased the elevation angle.

During the adjustment the suggested weighting factors 25 mm northing, 25 mm easting and 55 mm up [2] were used for the long baselines (> 20 km) and the guidelines given in [9] were used for short baselines. In the below stated formulas and in the rest of the report x, y and h refers to northing, easting and up . In this study x, y and h is in a local system with origo coinciding with the point to be measured, that is with the roof point at NLS.

The antenna height was set to zero in the receiver during the observation. The correct antenna height were added in the software before processing.

Summary of the processing strategy:

1. Preparation of the files for the chosen time intervals (sessions).

2. RINEX-conversion
   * The SWEPOS-data in RINEX-format were to be converted to the actual format for processing.

3. Baseline processing
   * Use of broadcast ephemeris.
   * Only process the baselines between the SWEPOS-stations and the roof point, not between the SWEPOS-stations.
   * Attempt to fix ambiguities.
   * No estimation of tropospheric parameters.
   * Use of the ionosphere free linear combination, L3, as the final solution.

4. Network adjustment
   * All four SWEPOS-stations fixed during the network adjustment.
   * The suggested weighting factors 25 mm northing, 25 mm easting and 55 mm up [2] were used for the long baselines (> 20 km) and the guidelines given in HMK-Geodesi:GPS [9] were used for short baselines.

   Every deviation from the above stated processing strategy is accounted for in chapter four, in each section respectively.

3.3 Statistical algorithms used for the evaluation of the result

To be able to evaluate the result, reference coordinates were computed with the Bernese software from observations made with an Ashtech receiver and a Dorne Margolin antenna during two different 24-hour sessions with a time span of 5 days. The Dorne Margolin antenna, which is a chokering antenna, is more accurate than the ones to be tested(no chokering groundplane) [3], [12]. It is also the same antenna type as is used at the reference stations (no mixing of antennas). Besides this, a well tested and reliable processing strategy is used in the Bernese Software. All this means that the reference coordinates can be regarded as considerably better determined than the ones obtained from the equipment under evaluation. This justifies the assumption that the reference coordinates are regarded as known. One has to be aware, though, that there are problems with estimating tropospheric zenith parameters. It is suspected that the radomes at the SWEPOS stations interfere with this estimation, which results in errors in the height component. For the moment, this problem is not solved, but is further evaluated at the NLS.

To summarize: In the tests the reference coordinates are regarded as known. This assumption is well justified for the horizontal coordinates, but is more questionable for the height component.

Our intention was to calculate an estimated standard error for the above mentioned reference measurement and for the measurements made with the different equipment. Knowing this it is possible to calculate a standard error for the difference between the reference measurement and the other measurements. With respect to this we would consider SWEPOS-data as compatible with the tested equipment if the divergence was within the 95 % confidence interval. But after finishing the evaluation of the results we discovered that the divergence of the result between the sessions was so small, so it was difficult to estimate the accuracy of each of the five equipment. Therefor we had to base our analysis on other grounds (see below).

The results presented in the tables that will follow later on focuses on the coordinate difference and the difference of the baseline length towards Mårtsbo for each session compared to the reference value. As the baseline towards Mårtsbo is the shortest one it will influence the adjusted coordinates more than the other baselines, at least when it is possible to use the suggested weighting strategy.

The results have been calculated as follows:

- The deviations from the reference coordinates, which are assumed to be known (cf. above).

$$\Delta x = x_{obs} - x_{ref}$$
$$\Delta y = y_{obs} - y_{ref}$$
$$\Delta h = h_{obs} - h_{ref}$$

- The RMS for the two-hour sessions.

$$RMS_x = \sqrt{\frac{\sum (x_{obs} - x_{ref})^2}{n}} \quad (mm)$$

- The standard deviation for the two-hour sessions.

$$\sigma_x = \sqrt{\frac{\sum (x_{obs} - \bar{x})^2}{n-1}}$$

where

$$\bar{x} = \frac{\sum x_{obs}}{n}$$

- Difference from the baseline towards Mårtsbo.

$$\Delta d = d_{obs} - d_{ref}$$

- The average difference from the reference baseline towards Mårtsbo for the two-hour sessions .

$$\Delta \bar{d} = \bar{d} - d_{ref}$$

4 THE PROCESSING AND RESULTS

4.1 Ashtech - PRISM

The purpose of this section is not to make a detailed description of PRISM. For a more thorough description the reader is advised to consult the belonging manuals [17], [18], [19], [20] and [21].

4.1.1 RINEX-conversion

Conversion of RINEX-data caused "time tag mismatch" during Baseline processing i.e. the time tag of the observations differed too much between the receivers so the software was not able to combine them. When trying to find out the reason for this message a comparison between the converted SWEPOS RINEX-file and the rawdata-file were done. This showed major discrepancies between the two files (See App 2). The discrepancies depends on the unstable receiver clocks in combination with the RINEX-converter used by SWEPOS (cf. 2.1.5). This means that the type of SWEPOS-data we have today is not compatible with PRISM. Because of this phenomenon Ashtech rawdata were used instead.

4.1.2 Baseline processing

All file preparations, as joining and cutting files, could be made inside PRISM. The Ashtech rawdata file is divided in epochs that are numbered from the beginning of the file. To be able to calculate the desired epochs you have to know the start and stop time for the session expressed in GPS seconds. All four SWEPOS-stations could be used as references.
For the calculations of the baselines we used the widelane technique. This technique provides the facility to obtain an ionosphere-free, ambiguities-fixed solution. As mentioned above broadcast ephemeris were used, but it is also possible to use precise ephemeris. PRISM requires the standard format ECF2. The distance to the phase centre has to be encountered in the antenna height, otherwise this value is neglected in the process.
One of the advantages with Baseline processing in PRISM is that it is possible to select a desired set of baselines for processing. The Baseline processing takes approximately two hours for a 24 hour session consisting of four baselines.

4.1.3 Adjustment

PRISM was the only software with the possibility to attach different weighting factors according to the length of the baseline before the adjustment, as mentioned in 3.2.1.
If the final solution is fixed but with a ratio of fixed ambiguities close to 95%, it is wise to check if this solution really is used in the adjustment process, because sometimes the software chooses the float solution instead.

4.1.4 Result

SWEPOS-data, in RINEX-format, is not compatible with PRISM (cf. 4.1.1) Therefor the calculation is based on Ashtech raw data. The results of this calculation indicates that PRISM is not suitable for calculations of long sessions because the accuracy will be degraded. This statement is based on the fact that the deviations | Δx | , | Δy | and | Δh | from the reference coordinates for the 24-hour session is much larger than the same deviations of the average calculated from the two-hour sessions. It is worth noting though that even if this deviation is larger for PRISM than for the other software the result is still within reasonable limits (2-3 cm).

Diff. from reference coordinates				Diff from ref baseline towards Mårtsbo
Session	**Δx**	**Δy**	**Δh**	
24 hours	-0,034	0,022	0,032	0,001
S1	0,021	0,026	-0,012	-0,002
S2	0,005	0,006	0,002	-0,003
S3	0,005	0,017	0,001	-0,010
S4	0,022	0,018	-0,024	-0,002
S5	0,014	0,017	-0,016	0,005
S6	0,000	0,009	-0,009	0,001
S7	0,014	0,048	-0,009	-0,002
S8	0,023	0,018	-0,009	0,001
S9	0,013	0,029	-0,008	-0,005
S10	0,003	0,015	-0,005	-0,003
S11	0,008	-0,004	-0,006	0,007
S12	0,007	0,006	-0,027	0,000
Std. dev.	σ_x 0,008	σ_y 0,013	σ_h 0,008	σ_d 0,004
RMS	x 0,014	y 0,021	h 0,013	d 0,004
Diff. of average from ref point	$\|\Delta x\|$ 0,011	$\|\Delta y\|$ 0,017	$\|\Delta h\|$ 0,012	$\Delta\bar{d}$ -0,001

Table 4.1 Ashtech. The deviation from the reference coordinates for different sessions and RMS, average and standard deviation for the two-hour sessions.

4.2 Geotracer -GeoGPS

The purpose of this section is not to make a detailed description of GeoGPS. For a more thorough description the reader is advised to consult the belonging manuals [23].

4.2.1 RINEX-conversion

No problems with the RINEX-conversion.

4.2.2 Baseline processing

Before starting the measurement you have to indicate which antenna type you are using. This will give the processing software information about what phase centre offsets to use. Information about the phase centre offsets for the different antennas can be retrieved from the GPS.INI file. The antenna height is measured to the ground plane of the antenna. GeoGPS offers no possibility to join or cut RINEX-files nor to cut observation files. To make these operations CCRINEXO.exe and CCRINEXN.exe from the Bernese software were used. When processing the two-hour sessions we used the windowing function of the software, which means that we defined the session to be processed using start and stop time. Our calculations are based on broadcast ephemeris but it is possible to use precise ephemeris as well. GeoGPS supports the standard format SP3 developed at the University in Bern, which is an ASCII-format. The baseline processing takes approximately 16 minutes for a 24 hour session consisting of four baselines.

4.2.3 Adjustment

It is possible to define your own weighting factors, but you have no possibility to attach different factors to different baselines with respect to the length of the baseline. If you don't define your own weighting factors, by default, the software uses the 3x3 variance-covariance matrix from the baseline process. As it was impossible to follow our intended weighting strategy we used the default weighting.

4.2.4 Result

SWEPOS-data is compatible with GeoGPS.
The Geotracer coordinates deviates very little from the reference coordinates. The calculations show no significant difference between the 24-hour session and the average of the two-hour sessions. In sessions 8 and 9 one satellite was deleted during baseline processing because it caused *one* very bad baseline solution. Still, the deviations are larger in these specific sessions compered with the other ones. Maybe the solution would have been better if one more satellite had been deleted, but as we had decided from the beginning that we would only disable satellites when the results exceeded reasonable values this was out of the scoop of our investigation.

Diff. from reference coordinates				Diff from ref baseline towards Mårtsbo
Session	**Δx**	**Δy**	**Δh**	
24 hours	0,000	0,005	-0,016	-0,002
S1	0,002	0,005	-0,006	-0,003
S2	0,000	0,005	-0,007	-0,005
S3	-0,004	0,003	0,001	-0,006
S4	-0,007	0,007	-0,028	-0,008
S5	-0,001	0,003	-0,017	0,000
S6	0,003	0,001	-0,008	-0,001
S7	0,000	0,002	-0,008	0,000
S8	0,015	0,003	0,003	0,006
S9	0,009	0,000	-0,027	0,007
S10	0,004	0,000	-0,026	0,004
S11	-0,001	0,008	-0,024	-0,003
S12	0,011	0,008	-0,016	0,005
Std. dev.	σ_x 0,0061	σ_y 0,0027	σ_h 0,011	σ_d 0,0047
RMS	x 0,007	y 0,005	h 0,017	d 0,005
Diff. of average from ref. point	$\lvert\Delta \bar{x}\rvert$ 0,003	$\lvert\Delta \bar{y}\rvert$ 0,004	$\lvert\Delta \bar{h}\rvert$ 0,014	$\Delta \bar{d}$ 0,000

Table 4.2 <u>Geotracer.</u> The deviation from the reference coordinates for different sessions and RMS, average and standard deviation for the two-hour sessions.

4.3 Leica - SKI

The purpose of this section is not to make a detailed description of SKI. For a more thorough description the reader is advised to consult the belonging manuals [14], [24], [25] and [26].

4.3.1 RINEX-conversion

No problems with RINEX-conversion.

4.3.2 Baseline processing

SKI offers no possibility to join or cut RINEX-files nor to cut observation files. To join and cut the RINEX-files we used CCRINEXO.exe and CCRINEXN.exe from the Bernese software. To process the two-hour sessions we used the software's windowing-function. This means that you can define the session to be processed using start and stop time.

SKI Version 1.09
At first nothing seemed to work, it was impossible to make any calculations what so ever. After several attempts we found that it was impossible to process sessions longer than six hours for the short baseline (< 20 km) and to get a fixed solution we had to set the session time to three hours. By reading "Guidelines on Processing RINEX Data with SKI" [14] we found out that SKI is not recommended when processing data from mixed receivers because the Leica receiver clock is much more stable than for example the clock in an Ashtech receiver. When we decreased the session time to one hour we were able to process all baselines except for the one towards Leksand. The reason to this is, as mentioned above, that the receiver clock at Leksand is not as stable as the ones on the other three reference stations or the one in the Leica receiver. The Leksand station was at the time the only station not equipped with an external atomic clock. To be able to calculate the Leksand-baseline we increased the clock offset and the clock synchronisation parameters to 2000 microseconds instead of one that had been used for the other baselines. These parameters can be changed in the *baseline processing menu* under *configuration-parameters-more.*

SKI Version 2.0
This SKI version was not as sensitive for processing mixed receivers as version 1.09, so using this version we managed to process the whole 24 hour session successfully if the clock offset and synchronisation were set to 2000 microseconds, if not, the above mentioned problems towards Leksand remained. It was possible to enter the antenna height and the distance to the phase centre manually. The distance to the antenna phase centre is the same for both L1 and L2. It was also possible to choose your own set of baselines by telling the program which stations that were reference stations. Our calculations are based on broadcast ephemeris, but it is possible to use precise ephemeris as well. SKI supports the standard format for precise ephemeris developed at the University in Bern called SP3, which is an ASCII-format.

4.3.3 Adjustment

It was not possible to apply the weighting strategy mentioned in 3.2.1 using SKI. The software offers a few different weighting strategies but you can not attach different weighting factors to different baselines. Therefor the default weighting of the software was used.

Petra Ammenberg
Kristina Hansson

4.3.4 Result

The SKI software is sensitive to the combination of unstable receiver clocks and mixed receivers. If all SWEPOS stations were equipped with atomic clocks the problem with the SKI software would be eliminated. The SKI coordinates deviates about ±1-1,5 cm from the reference coordinates. The plane coordinates calculated with SKI showed no significant difference between the 24-hour session and the average of the two-hour sessions. The height though was much better determined in the 24-hour calculation. The baseline length towards Mårtsbo deviates much more from the reference baseline in the SKI calculation than in the other calculations. This indicates that SKI is not suitable to use while processing mixed receiver data.

Diff. from reference coordinates (m)				Diff from ref. baseline towards
Session	**Δx**	**Δy**	**Δh**	Mårtsbo **Δd**
24 hours	0,012	-0,014	-0,002	0,020
S1	0,006	-0,015	-0,026	0,017
S2	0,028	-0,030	0,002	0,044
S3	0,020	-0,027	-0,002	0,040
S4	0,016	-0,023	0,008	0,032
S5	0,010	-0,015	0,016	0,020
S6	-0,004	-0,007	-0,025	0,010
S7	0,007	-0,008	-0,025	0,011
S8	0,013	-0,006	-0,030	0,018
S9	0,010	-0,005	-0,023	0,013
S10	0,009	-0,010	-0,007	0,012
S11	0,002	-0,005	-0,019	0,006
S12	0,007	-0,008	-0,025	0,009
Std. dev.	σ_x 0,008	σ_y 0,008	σ_h 0,015	σ_d 0,012
RMS	x 0,013	y 0,016	h 0,020	d 0,023
Diff. of average from ref point	$\lvert\Delta x\rvert$ 0,010	$\lvert\Delta y\rvert$ 0,013	$\lvert\Delta h\rvert$ 0,012	$\Delta\bar{d}$ 0,019

Table 4.3 Leica. The deviation from the reference coordinates for different sessions and RMS, average and standard deviation for the two-hour sessions.

4.4 Topcon - TurboSurvey

The purpose of this section is not to make a detailed description of TurboSurvey. For a more thorough description the reader is advised to consult the belonging manuals [22] and [27].

4.4.1 RINEX-conversion

There was no need for RINEX conversion because this software operates directly on RINEX-data. The observation file was converted to RINEX before processing.

4.4.2 Baseline processing

If you indicate, in the receiver, that you are going to use slant heights, the software is supposed to know the offsets for L1 and L2 automaticlly. In our case the slant height was set to zero during the measurements which apparently got the effect that the software forgot all about antenna offsets because the distance to the phase centre had to be encountered in the antenna height manually, otherwise this value was neglected in the process (See App. 3.) .
TurboSurvey offers no possibility to cut or join files but as all files, both the SWEPOS-files and our own observation file, were in ASCII format the Brief editor could be used for these operations.
There was no possibility to choose your own set of baselines before processing. The options were to process all baseline combinations or to process them one by one.
As mentioned earlier our calculations are based on broadcast ephemeris, but it is possible to use precise ephemeris as well. TurboSurvey supports the standard format for precise ephemeris, developed at the University in Bern, called SP3.

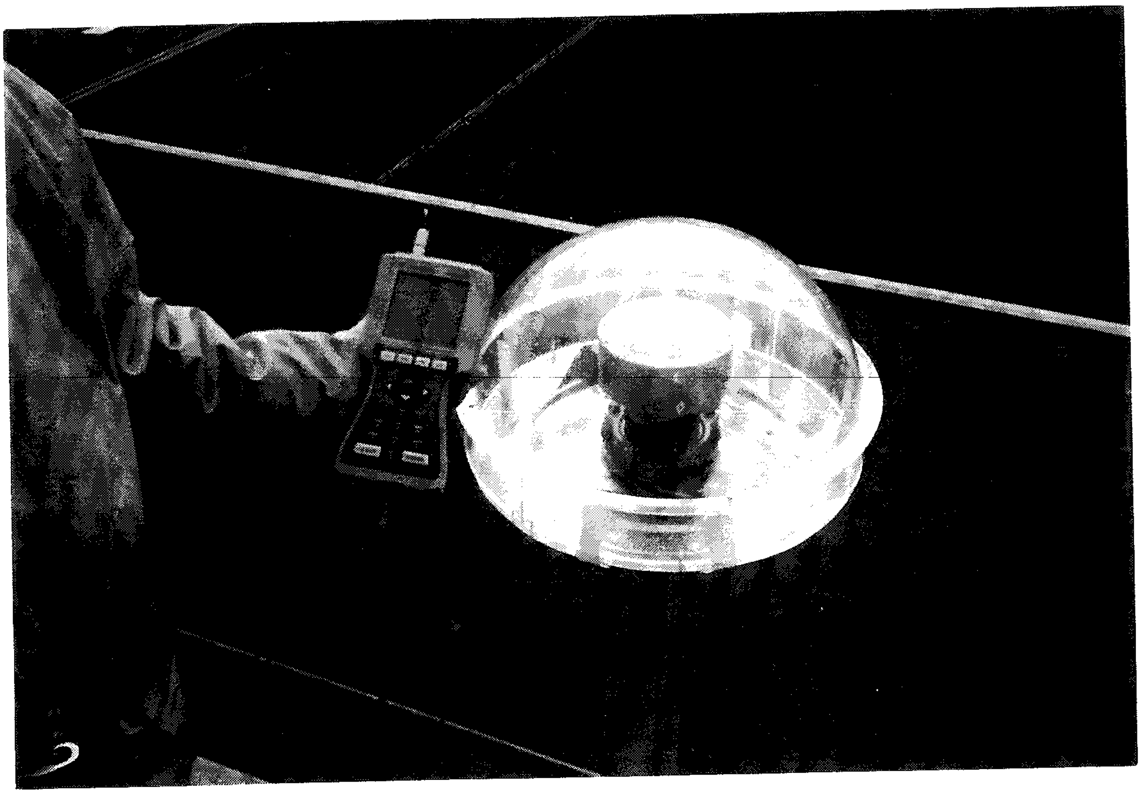

Fig. 4.1 The Topcon equipment.

Petra Ammenberg
Kristina Hansson

4.4.3 Adjustment

It was not possible to give the baselines different weights according to their length. The software uses the variance-covariance matrix from the baseline process.

4.4.4 Result

SWEPOS-data is compatible with TurboSurvey.
TurboSurvey produced plane coordinates that differed less than ± 1 cm from the reference coordinates with only one exception (x-coord. sess. 4). The heights on the other hand show a systematic error of about four centimetres. To check if the height error was caused by the software, TurboSurvey, calculations were made using the Bernese software. This gave the same height error which tells us that the information given in the manual about the electrical centre of the Topcon antenna is wrong. An independent test, made recently at Onsala Space Observatory, has shown similar discrepancies. The height error in the antenna eccentricity of the Topcon antenna will be determined in a field calibration at Onsala Space Observatory.
As with most other software there is no significant difference between the 24-hour solution and the two-hour solutions.

Diff. from reference coordinates				Diff from ref. baseline towards Mårtsbo
Session	Δx	Δy	Δh	
24 hours	0,001	0,002	0,042	-0,001
S1	-0,003	0,000	0,042	-0,005
S2	-0,006	0,003	0,052	-0,005
S3	-0,009	-0,001	0,027	-0,006
S4	0,013	-0,005	0,027	0,003
S5	0,003	0,002	0,050	-0,002
S6	0,000	0,000	0,038	-0,004
S7	0,007	0,000	0,038	0,003
S8	0,007	0,000	0,034	0,006
S9	0,002	0,002	0,051	-0,003
S10	0,006	0,009	0,046	-0,002
S11	0,004	0,003	0,061	-0,002
S12	-0,006	0,002	0,044	-0,007
Std. dev.	σ_x 0,0062	σ_y 0,0031	σ_h 0,0099	σ_d 0,0039
RMS	x 0,006	y 0,003	h 0,044	d 0,004
Diff. of average from ref point	$\lvert\Delta x\rvert$ 0,002	$\lvert\Delta y\rvert$ 0,0012	$\lvert\Delta h\rvert$ 0,043	$\Delta\bar{d}$ -0,002

Table 4.4 Topcon. The deviation from the reference coordinates for different sessions and RMS, average and standard deviation for the two-hour sessions.

4.5 Trimble - GPSurvey

4.5.1 RINEX-conversion

RINEX-conversion with GPSurvey generally caused no problems. The only exception was that it was impossible to convert the Leksand-file for one of the days with good results. While examining the RINEX-file from the Leksand-station we found a strange gap in the data for one of the satellites. To be more precise satellite 24 had no L2-data (See App.4). Further investigations showed that the satellite in question was operating as a ghost-satellite (see 2.1.5) during the epochs with gaps.

4.5.2 Baseline processing

GPSurvey offers an opportunity to join RINEX-files but not to cut them. However, this could be done in an ordinary text editor provided that it can handle large files. An ordinary RINEX-file for a 24-hour period has a size of approximately 4 Mbytes. Since the measurements covered parts of two 24-hour periods, the files we were working with had a size of about 8 Mbytes. In this case the Brief-editor was used. The observation files could not be cut, instead the software has a windowing-function. This means that you can define the session to be processed using start and stop time. Our calculations are based on broadcast ephemeris, but it is possible to use precise ephemeris as well. GPSurvey supports the standard format for precise ephemeris developed at the University in Bern called SP3.

4.5.3 Adjustment

When finished processing, the baseline solution files for every session were stored elsewhere and the result files from the adjustment were renamed. This was necessary because otherwise the old baselines affected the new adjustment and the adjustment resultfiles were overwritten since they were not automatically stored under unique names. It was not possible to apply the weighting strategy mentioned in 3.2.1 using GPSurvey. The software offers a few different weighting strategies but you can not attach different weighting factors to different baselines. Therefor the default weighting of the software was used.

4.5.4 Result

As far as we know GPSurvey is the only software that has a slight problem with ghost satellites. The plane coordinates calculated with GPSurvey are good (RMS = 3 resp 6 mm), but the heights show a systematic error of approximately two centimetres.

Diff. from reference coordinates				Diff from ref. baseline towards Mårtsbo
Session	Δx	Δy	Δh	
24 hours	0,005	0,000	0,024	0,006
S1	0,004	0,000	0,027	0,003
S2	0,010	0,001	0,013	-0,001
S3	0,003	0,008	0,021	0,005
S4	0,011	0,002	0,013	0,014
S5	0,005	0,000	0,018	0,004
S6	0,011	-0,003	0,017	0,008
S7	0,001	0,003	0,017	0,007
S8	0,003	0,002	0,027	0,007
S9	-0,003	0,000	0,022	0,007
S10	0,010	0,000	0,022	0,009
Std. dev.	σ_x 0,005	σ_y 0,003	σ_h 0,005	σ_d 0,004
RMS	x 0,006	y 0,003	h 0,020	d 0,007
Diff. of average from ref. point	$\lvert\Delta\bar{x}\rvert$ 0,006	$\lvert\Delta\bar{y}\rvert$ 0,001	$\lvert\Delta\bar{h}\rvert$ 0,022	$\Delta\bar{d}$ 0,006

Table 4.5 <u>*Trimble*</u>*. The deviation from the reference coordinates for different sessions and RMS, average and standard deviation for the two-hour sessions.*

4.6 Summary of results

	$\lvert\Delta x\rvert_{24\text{-hour}}$ $\lvert\Delta y\rvert_{24\text{-hour}}$ $\lvert\Delta h\rvert_{24\text{-hour}}$ [m]	$\lvert\Delta x\rvert_{\text{two-hour}}$ $\lvert\Delta y\rvert_{\text{two-hour}}$ $\lvert\Delta h\rvert_{\text{two-hour}}$ [m]	Std. dev. $\sigma_{x\text{-eq}}$ $\sigma_{y\text{-eq}}$ $\sigma_{h\text{-eq}}$	RMS x y h	$\Delta\bar{d}$ (m)
Ashtech	0,034 0,022 0,032	0,011 0,017 0,012	0,008 0,013 0,008	0,014 0,021 0,013	-0,001
Geotracer	0,000 0,005 0,016	0,003 0,004 0,014	0,006 0,003 0,010	0,007 0,005 0,017	0,000
Leica	0,012 0,014 0,002	0,010 0,013 0,012	0,008 0,008 0,015	0,013 0,016 0,020	0,012
Topcon	0,001 0,002 0,042	0,002 0,001 0,043	0,006 0,003 0,010	0,006 0,003 0,044	-0,002
Trimble	0,005 0,000 0,024	0,006 0,001 0,022	0,005 0,003 0,005	0,006 0,003 0,020	0,006

In the table above and in the rest of the report x, y and h refers to northing, easting and up. In this study x, y and h is in a local system with origo coinciding with the point to be measured, that is with the roof point at NLS.

$\lvert\Delta\#\rvert_{24\text{-hour}}$ - Deviation from the reference coordinates for the 24-hour sessions
$\lvert\Delta\#\rvert_{\text{two-hour}}$ - Deviation from the reference coordinates for the average of the two-hour sessions
$\sigma_{\#\text{-eq}}$ - Standard deviation for the two-hour sessions
\# - x, y or h
RMS - root mean square for the two-hour sessions
$\Delta\bar{d}$ - The average difference from the reference point

Table 4.6

5 DISCUSSION

For the sake of the investigation it is important to notice that PRISM was not able to convert RINEX-data successfully. Eventually PRISM should have been excluded from this work. If the same problem had occurred with any other software we had not been able to make any kind of calculations at all, and the software would have been omitted. In the case of PRISM we had the opportunity to use rawdata, since all SWEPOS-stations are equipped with Ashtech receivers.

During the Leica measurement all our SWEPOS-stations, except for the one in Leksand, were equipped with external atomic clocks. The SKI software is sensitive to unstable receiver clocks, which caused problems in the calculation towards the Leksand station. SKI 1.09 was much more sensitive regarding this problem than SKI 2.0, which in the end meant that we had to change software version to be able to proceed with the calculations. The unstable clock in combination with the RINEX-converter caused problems also for PRISM as mentioned above. The RINEX-conversion caused no problems for the rest of the software.

With respect to the results it is interesting to note that the average of the two-hour sessions not necessarily coincides with the result from the 24-hour session. As an example we can look at the PRISM calculation where the 24-hour session is partly worse than the result from the two-hour session calculation. This means that the software's possibility to handle long sessions is important.

During the RINEX-conversion with GPSurvey we discovered for the first time that a ghost satellite could cause problems. In this case we could not proceed with our calculation, instead we had to restart on the other 24-hour period. It would have been interesting though, to investigate the ghost satellite problem more thoroughly. It is quite possible that ghost satellites has influenced other measurements too, even if we did not suspect anything at the time. The difference might be that in the other cases the ghost satellites have not caused any problems during RINEX-conversion, which means that it has been possible to eliminate the ghost satellite in a later stage, in connection to the calculation.

The problems discovered or confirmed in our test concerning the compatibility between SWEPOS and the GPS-equipment available on the market, caused by the SWEPOS-design (radomes, ghost satellites and unstable clocks), will be solved for before SWEPOS gets operational. The height error in the antenna eccentricity of the Topcon antenna will be determined in a field calibration at Onsala Space Observatory.

6 CONCLUSIONS

- When SWEPOS-data in RINEX-format is correct it is compatible with Geotracer/GeoGPS, Trimble/GPSurvey and Topcon/TurboSurvey. Today this type of SWEPOS-data is not compatible with PRISM.
- PRISM is not suitable for processing long sessions (24 h), because the accuracy will be degraded.
- As far as we know GPSurvey is the only software that has a slight problem with ghost satellites.
- The information in the manual about the electrical centre of the Topcon antenna is wrong. This incorrect information caused a height error of about four centimetres. A correction of this value would improve the height results essentially.
- The SKI software is sensitive to the combination of unstable receiver clocks and mixed receivers. If all SWEPOS stations were equipped with atomic clocks the problem with the SKI software would be eliminated.

7 ABBREVIATIONS

BBS - Bulletin Board System
ECF2, SP1, SP3, EF18 - standard formats for precise ephemeris
EUREF 89 - European reference frame 1989
FTP - File Transfer Protocol
HMK - Handbok till mätningskungörelsen
ITRF 89 - IERS Terrestrial Reference Frame 1989
LMV - Lantmäteriverket
NLS - National Land Survey
SWEREF 93 - Swedish reference frame 1993
RH 70 - Rikets höjdnät 1970
RINEX - Receiver INdependent EXcange
RMS - root mean square
RT 90 - Rikets triangelnät 1990
WGS 84 - World Geodetic System 1984

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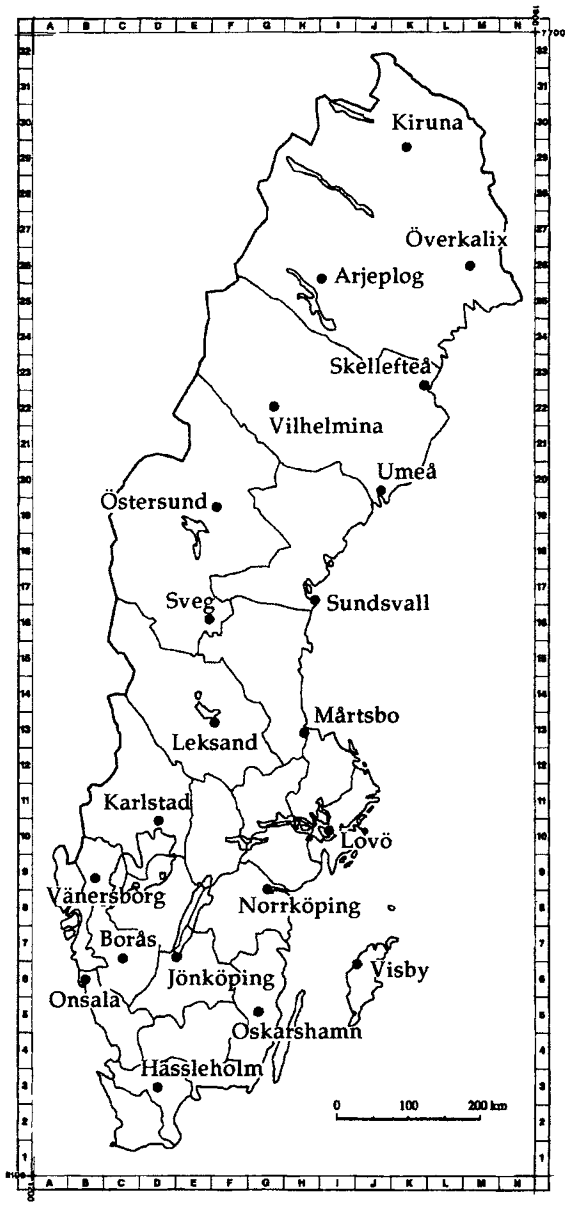
Kiruna
Överkalix
Arjeplog
Skellefteå
Vilhelmina
Umeå
Östersund
Sundsvall
Sveg
Mårtsbo
Leksand
Karlstad
Lovö
Vänersborg
Norrköping
Borås
Jönköping
Visby
Onsala
Oskarshamn
Hässleholm
0
100
200 km

SWEPOS

Extract from Asctech raw data file and the corresponding epoch converted from RINEX-file (SWEPOS) with rintoash.

```
RECORD = 1   RECEIVE TIME = 118800.000000
SV CH   WN G TXMTTIME  CDPHASE    DOPPL       CARRIER_PH   EL  AZ S/N  DTYPE
26  2    2 24 0.9246   22615257  32410545    -9366986.406 37 182 240   L1
        32 22 0.9246   22615260  32410551    -9366986.408         201   L1P
        32 22 0.9246   22615267  25255022    -7274554.526         201   L2P
23  3    2 24 0.9212   23619273  24155962    -8796080.596 22 264 229   L1
        32 22 0.9212   23619275  24155960    -8796080.600         175   L1P
        32 22 0.9212   23619281  18822851    -6367705.926         176   L2P
 7  4    2 24 0.9273   21793682  -8211330   -15955688.655 45 104 244   L1
        32 22 0.9273   21793685  -8211328   -15955688.657         210   L1P
        32 22 0.9273   21793692  -6398354   -12400754.040         210   L2P
 2  5    2 24 0.9226   23200521  31290885    -7948233.633 28  68 232   L1
        32 22 0.9226   23200522  31290887    -7948233.635         187   L1P
        32 22 0.9226   23200530  24382598    -6172072.368         186   L2P
 5  6    2 24 0.9206   23816869 -32700994    -6617127.491 20 228 223   L1
        32 22 0.9206   23816870 -32700987    -6617127.490         172   L1P
        32 22 0.9206   23816878 -25481236    -5133344.532         173   L2P
 9  7    2 24 0.9310   20676607  -7931279   -21248056.366 68 258   0   L1
        32 22 0.9310   20676609  -7931277   -21248056.366         230   L1P
        32 22 0.9310   20676615  -6180170   -16540685.551         231   L2P
15 11    2 24 0.9196   24089399  -2150690    -5527085.961 14  26 210   L1
        32 22 0.9196   24089401  -2150688    -5527085.956         155   L1P
        32 22 0.9196   24089411  -1675843    -3940385.320         157   L2P
2[illegible] 12    2 24 0.9219   23403447   2838428    -7592471.741 23 308 229   L1
        32 22 0.9219   23403450   2838425    -7592471.740         177   L1P
        32 22 0.9219   23403457   2211890    -5904301.348         179   L2P
SITE        NAVX              NAVY              NAVZ              NAVT
OLEK   3022583.665026    802954.367286    5540680.769045     135809.000000
PDOP      NAVXDOT           NAVYDOT           NAVZDOT           NAVTDOT
  2        -0.340            -0.374            -0.100           54.733017
```

```
RECORD = 1   RECEIVE TIME = 118799.997000
SV CH   WN G TXMTTIME  CDPHASE    DOPPL       CARRIER_PH   EL  AZ S/N  DTYPE
26 99    0 22 0.9246   21715880  32410549    -9366986.408 37 182 122   L1
        32 24 0.9246   21715883  32410549    -9366986.408         122   L1P
        32 22 0.9246   21715889  25255019    -7274554.526         122   L2P
23 99    0 22 0.9212   22719895  24155960    -8796080.600 22 264 122   L1
        32 24 0.9212   22719897  24155960    -8796080.600         122   L1P
        32 22 0.9212   22719904  18822850    -6367705.926         122   L2P
 7 99    0 22 0.9273   20894305  -8211330   -15955688.657 45 104 122   L1
        32 24 0.9273   20894307  -8211330   -15955688.657         122   L1P
        32 22 0.9273   20894315  -6398350   -12400754.040         122   L2P
 2 99    0 22 0.9226   22301143  31290889    -7948233.635 28  68 122   L1
        32 24 0.9226   22301145  31290889    -7948233.635         122   L1P
        32 22 0.9226   22301152  24382600    -6172072.368         122   L2P
 5 99    0 22 0.9206   22917491 -32700990    -6617127.490  0   0 122   L1
        32 22 0.9206   22917493 -32700990    -6617127.490         122   L1P
        32 22 0.9206   22917500 -25481239    -5133344.532         122   L2P
 9 99    0 22 0.9310   19777229  -7931280   -21248056.366 68 258 122   L1
        32 24 0.9310   19777232  -7931280   -21248056.366         122   L1P
        32 22 0.9310   19777238  -6180170   -16540685.551         122   L2P
15 99    0 22 0.9196   23190023  -2150689    -5527085.956 14  26 122   L1
        32 24 0.9196   23190025  -2150689    -5527085.956         122   L1P
        32 22 0.9196   23190034  -1675840    -3940385.320         122   L2P
2[illegible] 99    0 22 0.9219   22504070   2838430    -7592471.740  0   0 122   L1
        32 22 0.9219   22504072   2838430    -7592471.740         122   L1P
        32 22 0.9219   22504080   2211889    -5904301.348         122   L2P
SITE        NAVX              NAVY              NAVZ              NAVT
LEKS   3022567.597485    802960.486746    5540669.705563    -163996.231173
PDOP      NAVXDOT           NAVYDOT           NAVZDOT           NAVTDOT
  2        -0.067            -0.145            -0.052           54.903976
```

<u>Extract from the Leksand RINEX-file during the Trimble measurement</u>

```
     2              OBSERVATION DATA                           RINEX VERSION / TY
*** Merged Obs file created by RINMERGE Version 1.01. ***      COMMENT
CCRINEXO V2.1.3 LH  LMV                 19APR96 16:15:33 GMTPGM / RUN BY / DAT
LMV                                                            OBSERVER / AGENCY
929                 ASHTECH Z-XII3      1F00                   REC # / TYPE / VER
223                 DORNE MARGOLIN T                           ANT # / TYPE
LEKS.0                                                         MARKER NAME
134698.0                                                       MARKER NUMBER
  3022573.1570    802945.6900   5540683.9510                   APPROX POSITION XY
        0.0000         0.0000        0.0000                    ANTENNA: DELTA H/E
-------------------------------------------------------------- COMMENT
Note: The above offsets are NOT corrected.                     COMMENT
-------------------------------------------------------------- COMMENT
     1     1     0                                             WAVELENGTH FACT L1
     5    L1    C1    P1    L2    P2                           # / TYPES OF OBSER
    15                                                         INTERVAL
  1996     4    11     0     0    0.000000                     TIME OF FIRST OBS
  1996     4    12    23    59   45.006000                     TIME OF LAST OBS
    24                                                         # OF SATELLITES
     1  3797  3797  3797  3792  3797                           PRN / # OF OBS
     2  3705  3705  3705  3705  3705                           PRN / # OF OBS
     4  3833  3833  3833  3833  3833                           PRN / # OF OBS
     5  3157  3157  3157  3157  3157                           PRN / # OF OBS
     6  3369  3369  3368  3366  3368                           PRN / # OF OBS
     7  3860  3860  3860  3860  3860                           PRN / # OF OBS
     9  3297  3297  3297  3297  3297                           PRN / # OF OBS
    14  3298  3298  3298  3298  3298                           PRN / # OF OBS
    15  3401  3401  3401  3401  3401                           PRN / # OF OBS
    16  3730  3730  3730  3730  3730                           PRN / # OF OBS
    17  3581  3581  3581  3581  3581                           PRN / # OF OBS
    18  3170  3170  3170  3170  3170                           PRN / # OF OBS
    19  3466  3466  3466  3466  3466                           PRN / # OF OBS
    20  3218  3218  3218  3218  3218                           PRN / # OF OBS
    21  3660  3660  3660  3660  3660                           PRN / # OF OBS
    22  3650  3650  3650  3643  3650                           PRN / # OF OBS
    23  3818  3818  3818  3818  3818                           PRN / # OF OBS
    24  3967  3968  3956  3426  3956                           PRN / # OF OBS
    25  3796  3796  3796  3796  3796                           PRN / # OF OBS
    26  3618  3618  3618  3618  3618                           PRN / # OF OBS
    27  3325  3325  3325  3325  3325                           PRN / # OF OBS
    28  3957  3962  3949  3454  3949                           PRN / # OF OBS
    29  3505  3505  3505  3505  3505                           PRN / # OF OBS
    31  3580  3580  3580  3577  3580                           PRN / # OF OBS
                                                               END OF HEADER
96  4 11 10 52 45.0020000  0 10  6 14  1 20 24  9  4  7  5 25
   4399855.48649  24907226.39700  24907228.74840  -3415909.69149  24907237.226
  -4693224.96049  25152443.89100  25152445.90540  -3492444.46749  25152453.393
 -11644784.88549  23013131.50300  23013133.67240  -9062299.78249  23013140.705
 -20743657.84149  21509321.97100  21509323.76540 -16142184.68249  21509330.852
  -5330989.51909  20799388.59700  20795008.46900                  20795023.199
  -5812888.04249  23508337.32200  23508339.82140  -4275599.61849  23508347.163
 -11389817.62949  23291466.71300  23291469.62640  -8865217.91449  23291476.279
   2838302.97749  25119521.58000  25119526.79840   2232767.38849  25119535.511
 -20878743.11049  20928308.33800  20928310.47840 -16246842.84649  20928317.014
  -2759872.81649  25324389.42700  25324390.68040  -1414310.67149  25324397.018
96  4 11 10 53  0.0020000  0 10  6 14  1 20 24  9  4  7  5 25
  -4450676.40049  24897555.62000  24897557.85940  -3455510.33849  24897566.348
  -4696135.49149  25151889.95700  25151891.97340  -3494712.42249  25151899.619
 -11627883.42349  23016347.71100  23016349.92040  -9049129.80749  23016356.951
 -20768610.26349  21504573.56500  21504575.46240 -16161628.12249  21504582.542
  -5337128.37309  20800693.84000  20793840.27900                  20793859.147
  -5757415.69049  23518893.35200  23518895.82940  -4232374.42849  23518903.187
 -11394936.52049  23290492.71200  23290495.58440  -8869206.65649  23290502.174
   2895659.01749  25130436.37600  25130441.27840   2277460.38249  25130449.888
```

Extract from the Topcon observation file

The first file extract is from our measurement, it contains no information about the original slant height, nor the line that confirms that the offset values and the radius values really are used in the process.

```
     2              OBSERVATION DATA    GPS                 RINEX VERSION / TY
TB2RNX              xxxxxxxxxxxx         96-05-09 15:00:02  PGM / RUN BY / DAT
Turbo SII rinex formatter Version: 96.1.5                   COMMENT
MODE : STATIC                                               COMMENT
                                                            COMMENT
OLMV                                                        MARKER NAME
KRI                                                         OBSERVER / AGENCY
662659328           TURBO SII           Production unit     REC # / TYPE / VER
662659328           TURBO SII                               ANT # / TYPE
  2993569.7557   922832.7109  5537422.2359                  APPROX POSITION XY
      0.0000       0.0000         0.0000                    ANTENNA: DELTA H/E
Turbo SII antenna radius(m)  :          0.0699              COMMENT
TurboRogue Choke ring radius(m)  :      0.1896              COMMENT
TurboRogue Choke ring offsets(m) L1: -0.0064  L2: 0.0198    COMMENT
Turbo SII antenna offsets(m)     L1:  0.0530  L2: 0.0510    COMMENT
     1     1                                                WAVELENGTH FACT L1
     5    C1     L1     L2     P1     P2                    # / TYPES OF OBSER
  1996     4     29      6     58    45.000000              TIME OF FIRST OBS
                                                            END OF HEADER
```

29/05/1996 10:18 4631268607 TOPCON SVENSKA AB SIDA 01

File: C:\TURBOMÄT\KBH\IVAN\0005.950 10/19/95, 15:00:08

```
     2              OBSERVATION DATA    GPS                 RINEX VERSION / TYPE
xxxxxxxxxxxx        xxxxxxxxx            95-10-19 13:05:40  PGM / RUN BY / DATE
Turbo SII rinex formatter Version: 95.5.19                  COMMENT
MODE : STATIC                                               COMMENT
S.HT                                                        COMMENT
2394                                                        MARKER NAME
IPM                 S.HT                                    OBSERVER / AGENCY
0                   Turbo SII           Production unit     REC # / TYPE / VERS
0                   Turbo SII                               ANT # / TYPE
  3520937.4497   787609.0442  5242029.9921                  APPROX POSITION XYZ
      1.6965       0.0000         0.0000                    ANTENNA: DELTA H/E/N
Original slant height(m) :     1.6450                       COMMENT
Turbo SII antenna radius(m) :            0.0699             COMMENT
TurboRogue Choke ring radius(m) :        0.1896             COMMENT
TurboRogue Choke ring offsets(m)  L1: -0.0064  L2: 0.0198   COMMENT
Turbo SII offsets(m)              L1:  0.0530  L2: 0.0510   COMMENT
urbo SII L1 offset and radius used                          COMMENT
     1     1                                                WAVELENGTH FACT L1/2
     5    C1     L1     L2     P1     P2                    # / TYPES OF OBSERV
  1995    10     18      8     51    0.000000               TIME OF FIRST OBS
                                                            END OF HEADER
```

3 4