SWEPOS™ Automated Processing Service

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Abstract
SWEPOS™ is a multi-purpose network of permanent reference stations in Sweden, supplying users with data for both real-time and post-processing on centimetre- to metre-level The Swedish national reference system SWEREF 99 is realised through SWEPOS.
In order to facilitate the use of SWEPOS for accurate static post-processing, an automated processing service has been developed. The service uses the Bernese GPS Software and Internet is used for the interface to the users. The service was introduced to the users in the autumn 2000.

This paper describes the system, presents results from test processing and gives a summary of the use of the service. Possibilities and prerequisites of including the service in the project “A Nordic Positioning Service” are also discussed.

The SWEPOS system
SWEPOS provides via an FTP server GPS observation data from the Swedish permanent reference stations in hourly and daily files and orbit information from CODE (Centre of Orbit Determination in Europe).

The purpose of SWEPOS Processing Service
The purpose of SWEPOS Processing Service is to facilitate for the user to do accurate static post-processing with use of SWEPOS data, for example as an alternative of using a standard post-processing software.

Some examples of applications can be surveying of single points – e.g. photogrammetric ground control, base stations for local RTK surveying – and connection of local networks to the national reference system.

User interface
The communication with the user is done via the Internet. The user’s GPS data must be in the RINEX (Receiver Independent Exchange format) version 2 standard format and it is uploaded to SWEPOS via ftp.

All information required for the computation must be included in the RINEX file header, i.e. marker name, antenna type, approximate co-ordinates, antenna height and any eccentricities. The file must contain static dual-frequency GPS observation data. Data must also be within the same 24-hour period.

The settings in the Bernese software assume a sampling interval of 30 seconds for the GPS observations. If data are sampled at a higher frequency, a reduction of data will take place, i.e. even data with sampling intervals of 5, 10 or 15 seconds is possible to use. 20-second sampling interval, on the other hand, will after the reduction result in a 60-second sampling interval.

The user’s RINEX file is then transferred to SWEPOS ftp server. Either there is a possibility to use the form on the web-site to transfer the file from the hard disk of the user, or the user can transfer the file in advance via ftp, using an ordinary ftp client.

When ordering a new job, a check of the RINEX file is done, to see that all necessary information is available in the file header. When the processing is finished, the text file containing the result is copied to the web-site and it is also sent via e-mail to the user.

System design
The post-processing service is built up of a number of different components (see figure 1). The communication with the user is done via the Internet and a web server handles the job queue and the files.

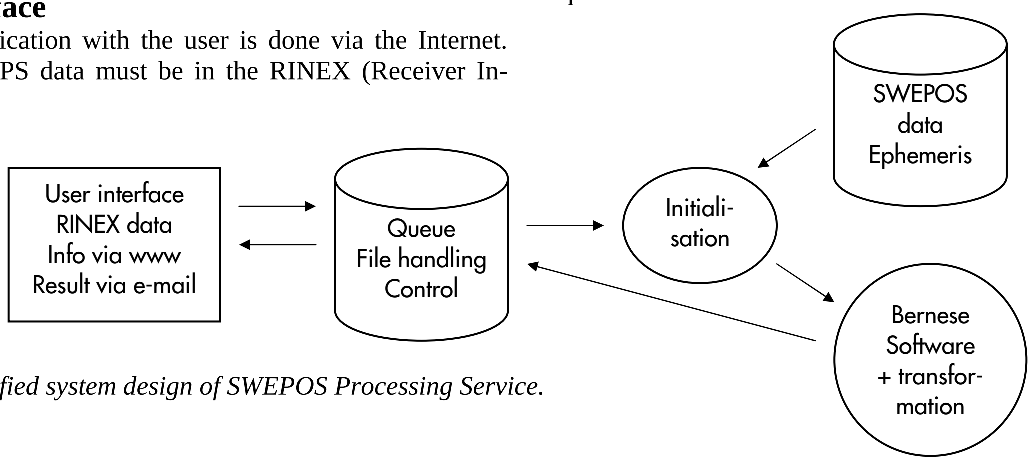

***Fig 1**. Simplified system design of SWEPOS Processing Service.*

The initialisation procedure puts together the proper SWEPOS data, ephemeris data etc, and prepares a script, that starts the processing. The Bernese GPS Software version 4.2 is used for the processing.

An in-house developed software – Gtrans – is used for the co-ordinate transformation of the obtained co-ordinates from the reference system of SWEPOS (SWEREF 99) to the national reference systems RT 90.and RH 70B.

Initialisation

The initialisation routine reads the starting and ending time, and approximate co-ordinates from the RINEX file header. Based on this information, the corresponding SWEPOS data from the five closest stations, current ephemeris and pole parameters are put together. The best available ephemeris data is selected (i.e. preferably official post-processed or rapidly post-processed ephemeris and in the second place predicted ephemeris). Ephemeris and pole parameters are produced at the Centre for Orbit Determination in Europe (CODE).

The data structure for the Bernese software is created. Some files will also be edited, e.g. a script that starts the Bernese software processing.

The Bernese Software

The GPS processing is done using the Bernese GPS Processing software version 4.2 that is developed at the University of Bern, Switzerland. An automated process, going through a number of steps, runs the software:

- The first step includes converting of data to the format of the Bernese software. Files will be reduced to 30-second sampling interval.
- Satellite orbits will then be determined from CODE ephemeris, where satellite positions every 15 minutes are given. Orbits are computed through numerical integration in the celestial system, after transformation from the terrestrial system. These orbits are then transformed back to the terrestrial system.
- Next step is determination of clock-corrections of the receiver. This is done epoch by epoch, through determination of the absolute position.
- Forming differences will then be done. Baselines are formed like a star from the point to be determined to the five SWEPOS stations.
- After that a solution of triple differences is done and cleaning of data, baseline by baseline, is carried out. Cycle-slips will be fixed and poor observation data will be excluded.
- Preliminary double difference solution (a float solution) is done to get better approximate co-ordinates for the point to be determined.
- Cycle ambiguities are then determined, baseline by baseline. The so-called QIF (Quasi Ionosphere-Free algorithm strategy) is used.
- The final solution is an ionosphere-free solution, with (partly) fixed cycle ambiguities. The cycle ambiguities that could be determined in a satisfactory way in the previous step will be fixed. Troposphere parameters (zenith delay) are decided in three-hour intervals. (If the observation time is one to three hours, one to two parameters per station will be determined, depending on starting and ending time.) The final solution is a multi-station solution, i.e. a simultaneous adjustment of the five baselines.
- A similarity transformation from the current ITRF epoch to SWEREF 99 based on the five used SWEPOS stations is done.
- For test purposes, a number of computations are also done: An ionosphere-free solution with a 25-degree elevation cut-off angle instead of a 15-degree cut-off angle, and the corresponding computation without troposphere parameters. A transformation of the final solution to the current ITRF is also done.

All computations are done in the actual ITRF. Not until the end, a transformation to SWEREF 99 is done.

Processing routine for short observation times

During the late summer of 2001, a further development of the post-processing service was done, to improve the computation for shorter observations than 30 minutes. The aim for the improvement was optimisation of determination of heights.
The post-processing service selects the proper routine on the basis of observation length, which means that the user does not have to think about which routine to use.

This adjusted routine differs from the 'standard' processing routine mainly as follows:

- 15-second sampling interval is used for GPS data instead of 30-second sampling interval.
- No troposphere parameters will be determined.
- No fix solution of cycle ambiguities is done.
- No correlation between baselines is used.
- (Some further test solutions are produced.)

The result of the processing of observations with short observation time is not as good as one could expect. The reason of this is mainly that the processing software itself is not developed for such short sessions.
This adapted routine was mainly developed for use in Lantmäteriet, but it was decided that it could be of use even for external users – i.e. the possibility is there, but it is not at the present excellent.

Transformation of the result

The software Gtrans, developed at Lantmäteriet, is used for the transformation of the final result from SWEREF 99 to RT 90 and RH 70B in the post-processing service.

The transformation of the SWEREF 99 result to RT 90 and RH 70B is done by first applying the official transformation, which is described in Jivall, Lidberg, Lilje and Reit (2001). After that, a correction for the transformation residuals is done. Gtrans uses a linear interpolation i in triangles, based on the control points with known co-ordinates in SWEREF 99 as well as RT 90 and/or RH 70B.

Completion of the processing

When the Bernese software has finished the GPS processing, a follow-up routine similar to the initialisation routine, starts. The follow-up routine sends signals to the processing computer and to the queue, to allow next processing job in the queue to start.

It also compiles chosen parts of the result from the Bernese software, to form a text file consisting of a result, more easy to understand. This simplified result is then sent to the web server, to be presented to the user on the web site and also via e-mail to the user.

The result

The result is presented as a text file, on the web site as well as in an e-mail to the user. It consists of chosen parts of the result from the Bernese software processing:

- Job ID, date and time for processing.
- Name and e-mail address of the user.
- File name of the user's observation file, and marker name. Date and time for the observation.
- Antenna type and antenna height.
- SWEPOS stations used for processing, as well as control stations.
- The result from the quality check of data: Number of epochs and observations compared to the expected number, respectively.

The next section contains the co-ordinates for the point to be determined:

- SWEREF 99 co-ordinates.
- Planar co-ordinates (RT 90) and heights of the national height system (RH 70B).

The following section describes the quality of the processing:

- RMS per baseline and number of resolved ambiguities. The average RMS and number of resolved ambiguities are also given, as well as the RMS of the final fixed solution.
- RMS per component and the standard deviation of unit weight of the Helmert fit to SWEREF 99.

Guidelines for evaluation of the result

Some guidelines for evaluation of the post-processing result has been put together, based on limited testing.

The parameters which can be used for evaluation are the fraction of resolved ambiguities ("Amb Res"), the RMS of the multi-station solution ("RMS i slutlig fixlösning") and the standard deviation of unit weight ("Grundmedelfel") of the similarity transformation to SWEREF.

One- to three-hour observation sessions

The following guidelines can be used for one- to three-hour observation sessions, to identify a satisfactory result. In this case, 'a satisfactory result' means a standard deviation of approximately 1 centimetre per planar component and 1.5-2 centimetres in height for a Dorne Margolin T antenna, and somewhat higher for other antennas.

- The fraction of resolved ambiguities ("Amb Res") is more than 30 %.
- The RMS of the multi-station solution ("RMS i slutlig fixlösning") is less than 3 millimetres.
- The standard deviation of unit weight ("Grundmedelfel") of the Helmert fit is less than 10 millimetres.

Short observation sessions

For short observation sessions, the aim must be to get a result of decimetre or metre accuracy rather than of centimetre accuracy.

Some very limited tests have shown that the following accuracies can be expected, for sessions of…

- 5 min – better than 1 m
- 10 min – better than 0.5 m
- 15 min – better than 0.3 m
- 30 min – better than 0.2 m

Analysis of the results from the post-processing service

SWEPOS post-processing service is at present developed for observation times of at least one hour, but preferably two hours or more, to achieve centimetre accuracy.

All test computations are done with observation data from so-called SWEREF points in the RIX 95 project. This means that the points are very well suited for GPS surveying. For example, they have a rather clear sky view. Dual-frequency GPS receivers and Dorne Margolin T antennas have been used during 48-hour observing sessions. The results from these 48-hour observations have been used as known co-ordinates in the following comparisons.

The result is strongly dependent on the number of observations, and consequently also dependent on the length of the observation time. This can clearly be seen in figure 2.

There are some parameters to study to evaluate the quality of the result: the fraction of resolved ambiguities (the larger share fixed to an integer number, the better), RMS of the final multi-station solution (the smaller, the better) and the RMS of the transformation from ITRF to SWEREF.

The three-dimensional error – compared to the 48-hour solution, with an estimated standard deviation of 5 mm per planar component and 10-15 mm in height – has then been plotted as a function of these parameters.

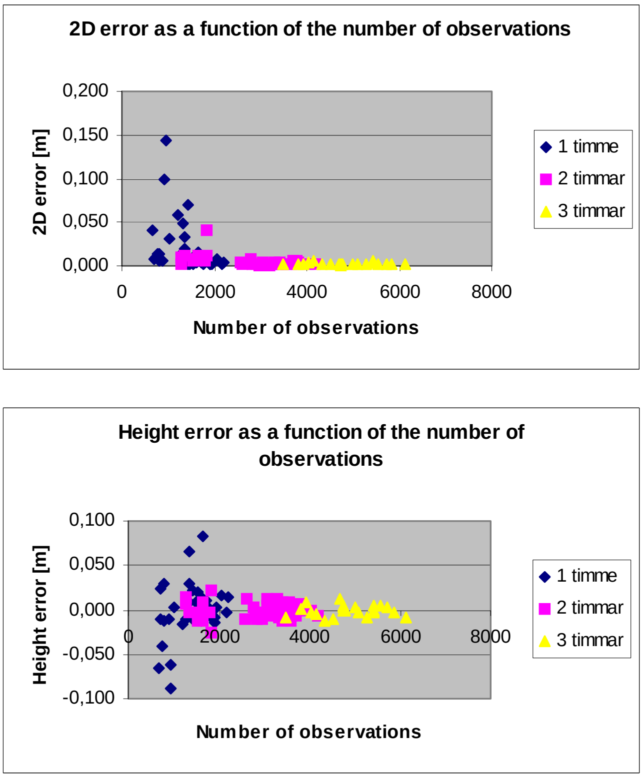

Fig 2. *2D error and height error as a function of the number of observations for all test computations, for observation sessions of one- to three hours.*

The obtained accuracy at 1-sigma level (expressed as a RMS – Root Mean Square) can be seen in table 1.
In figure 2, the errors are plotted as a function of the number of observations. Both from table 1 and figure 2, it can be read that the one-hour intervals end up with significantly worse results than the longer observation sessions.

Table 1. *RMS of one- to three-hour observation sessions. Unit: metres.*

	2D	*Height*	*3D*
RMS 1 hour [m]	*0,033*	*0,029*	*0,046*
RMS 2 hours	*0,008*	*0,009*	*0,012*
RMS 3 hours	*0,003*	*0,006*	*0,007*
RMS all	*0,022*	*0,019*	*0,030*

In figure 3 below, the different quality parameters and the results have been correlated, to find out which parameters that can provide good information about the result, and try to find threshold values of these parameters.

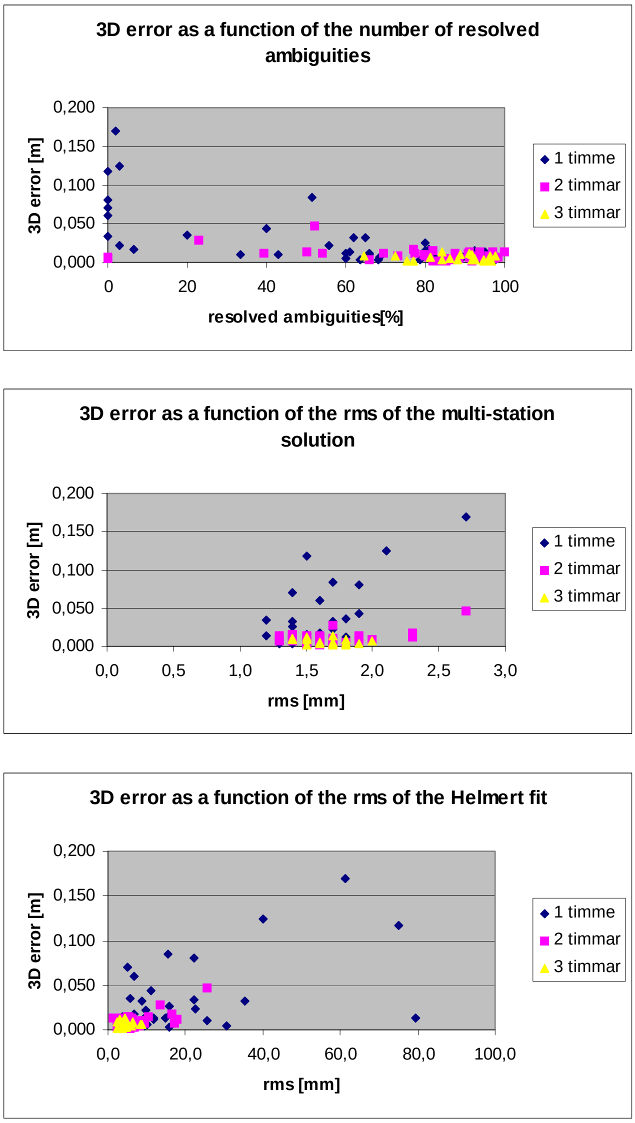

Fig 3. *3D error as a function of the fraction of resolved ambiguities, RMS of the multi-station solution and RMS of the similarity transformation to SWEREF 99, for observation sessions of one to three hours.*

From the diagrams it can be seen that the share of resolved ambiguities is a good measure of the quality. If more than half of the ambiguities have been resolved, a satisfactory position has also been achieved. Many of the one-hour observing sessions only have a small fraction of the ambiguities resolved, and all bad positions originate from the one-hour observation sessions. For occasional two-hour sessions, only smaller fractions of the ambiguities have been resolved but these still do have satisfactory positions. This confirms the rule that it is more important – but also more difficult – to resolve the ambiguities if the observation session is short.

RMS of the multi-station adjustment does not say much about the quality of the result. It has to be very low to eliminate the risk of accepting bad solutions. On the other hand, many satisfactory results would then be rejected.

From the RMS of the similarity transformation from ITRF to SWEREF 99 it can be read that if it is about 1 centimetre or less, the result is of centimetre accuracy.

User statistics

The SWEPOS post-processing service was introduced to the users during the autumn of 2000. It was considered to be in a test phase for about a year, and thus it was free of charge. Since mid-October 2001, the service is fully operational.

The user statistics presented include the period from autumn 2000 to the end of September 2002, i.e. both the test phase and the operational phase so far:

- External users
  - More than 1200 jobs
  - Approx. 70 users
- Geodetic Research Department
  - More than 1000 jobs

"External users" here include all users except the employees at the Geodetic Research Department at Lantmäteriet, i.e. also Metria and Cadastral Services of Lantmäteriet are included in the statistics for external users.

The user statistics from the Geodetic Research Department mainly consist of testing, trouble-shooting and demonstrations of the service, but also of processing of gravity measurements and preliminary positions of the SWEPOS stations.

Inclusion in "A Nordic Positioning Service"

The NKG project a Nordic Positioning Service comprises several sub-projects, one of them being A2, An automated computation service for post processing applications. The idea is to use the SWEPOS automated processing service as a base and extend it to the Nordic area and adjust it to requirements of all participating countries.

The advantages of a common Nordic processing service compared to the Swedish one, is first of all that it would work also in the other Nordic countries, but also that less extrapolation would be needed as also stations from neighbouring countries could be used.

Prerequisites for such a service are that data for all Nordic stations easily and uniformly could be reached and transformations to the national ETRS 89 realisations are available.

The development of a common Nordic ftp-server (subproject A1) will fulfil the first prerequisite.

Different options are available for the handling of reference systems and transformations. Assuming that the GPS-processing will be performed in current ITRF, the following two alternatives are possible:

1. The current ITRF co-ordinates are directly transformed to the national ETRS 89. The easiest and most robust alternative would be to make a similarity transformation to the national ETRS 89. This solution is used in the SWEPOS processing service. To use this alternative on a Nordic level, national ETRS 89 co-ordinates for each country have to be available also for stations in the neighbouring countries.
   Another alternative is to make a direct transformation using a velocity field to compensate for the epoch and a fixed transformation.

2. The current ITRF co-ordinates are first transformed to a common Nordic ETRS 89, using a velocity field and a fixed transformation. In the next step a transformation between the common Nordic ETRS 89 and the national ETRS 89 is performed, using fixed parameters.

A common ETRS 89-campaign would give a base for a common Nordic ETRS 89, national ETRS 89 co-ordinates in the neighbouring countries, as well as transformations between a common Nordic ETRS 89 and the national realisations.

References

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