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MULTIPATH AT THE SWEPOS STATIONS
EVALUATION OF ECCOSORB, A MICROWAVE ABSORBING MATERIAL

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PREFACE

This report is divided in two parts. The first part of this work was to survey the occurrence of multipath at the SWEPOS stations. At those stations where signs of multipath were found, possible sources of the multipath are searched for. The second part of the work was to evaluate a microwave absorbing material called Eccosorb and investigate if it could reduce the multipath effect.

This diploma work was carried out at the Geodetic Research Division at the National Land Survey of Sweden in Gävle. It includes field measurements, processing of GPS data and analysis of the results.

We would like to thank the people at the Geodetic Research Division and especially the personnel at the SWEPOS control centre for supplying us with data and support at any time.

Thanks also to Lotti Jivall and Jonas Ågren for help with the antenna calibration.

A great thank to our instructor Gunnar Hedling for his support and for answering our questions.

Examiner is Bo Malmström, University of Gävle/Sandviken

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ABSTRACT

Multipath is the phenomena whereby a signal travels from a transmitter to a receiver via multiple paths due to reflection and diffraction. This phenomena appears even at the SWEPOS stations that are situated in locations where almost no reflecting objects around the antenna exists. SWEPOS is a Swedish national network of reference stations for GPS. The observations at those stations should be as good as possible and all error sources should therefore be eliminated or reduced.

This report contains two main parts, one where the multipath at the SWEPOS stations will be examined and another where a microwave absorbing material will be evaluated.

Observing the signal to noise ratios for the code on L1 and L2 with a program ,BSHOW, does the first part. By studying the graphs, an understanding for where multipath exist is obtained. A very simple characteristic of multipath are sinusoidal graph periodicity on the S/N graph. By using BSHOW presence of multipath is found. The program also presents the actual skytrack of the satellite, and with this information the direction of the source of the multipath signal can be detected. The elevation of the satellite is also given in the program.

The second part consists of an evaluation of a microwave absorbing material, Eccosorb, mounted underneath and around the antenna. By using this material the presence of multipath is hopefully reduced. Two different designs are tested, one with a plate of Eccosorb beneath the antenna and a second one with a ring of Eccosorb around the antenna added to the first design. By analysing the result from the observations with these two designs, and comparing them with observations from an antenna without Eccosorb, conclusions could be made.

The result from the first part of the work shows that multipath exists at almost all SWEPOS stations. Some stations have more signs of multipath than others do. The major source of multipath seems to be the ground around the antenna. A height of the disturbing object below the antenna could be calculated from the

period of the sinusoidal disturbances on the signal to noise graph. On most stations these heights coincided with the antenna pillar height, but on some stations these computed heights hinted that roofs near the antenna where the sources of the multipath.

The result from the second part showed that no major decreases were seen due to the microwave absorbing material, Eccosorb, mounted on the antenna. It was only small deviations seen but no significant differences.

SAMMANFATTNING

Flervägsfel är ett fenomen som uppkommer vid utbredning av radiovågor. Detta inkluderar även GPS signaler. Fenomenet förekommer när radiosignalen reflekteras mot ett objekt strax innan signalen når antennen. Dessa problem uppkommer även på SWEPOS stationerna som är belägna på platser där det knappt finns några reflekterande objekt. SWEPOS är ett Svenskt referensnät för GPS mätning. Observationerna på dessa stationer bör vara så bra som möjligt och alla felkällor bör därför bli eliminerade eller dämpade.

Denna rapport består av två delar. Den första delen utreder förekomsten av flervägsfel på SWEPOS stationerna och i den andra delen utvärderas ett mikrovågsabsorberande material.

I den första delen används BSHOW för att undersöka S/N värdet för C/A coden. Genom att studera det grafiska resultatet kan man få reda på var flervägsfel förekommer. Karakteristiken för flervägsfel är en sinusformad kurva. Programmet visar också i vilken azimuth den aktuella satelliten befinner sig. Med hjälp av detta får man fram i vilken riktning som flervägsfelen uppkommer. Man erhåller även satellitens elevation från programmet.

Den andra delen innefattar en utvärdering av ett mikrovågsabsorberande material, Eccosorb, påsatt i två olika konstillationer på antennen. Genom att använda detta material på antennen så minimeras förhoppningsvis flervägsfelen. Två olika konstillationer är testade, en med en platta av Eccosorb placerad under antennen, den andra genom att även sätta på en ring av Eccosorb runt chokeringarna. Genom att analysera resultaten av dessa två fall och jämföra dem med resultat från en antenn utan Eccosorb kan man få ut om Eccosorb förbättrar eller försämrar flervägsfelens inverkan.

Resultatet av den första delen visar att flervägsfel förekommer på nästan alla SWEPOS stationer. Förekomsterna varierar mellan stationerna, en del har mer än andra. Den största felkällan verkar dock vara marken runt omkring antennen. Genom att räkna ut det vertikala avståndet mellan *antenn - reflektor* så får man i de

flesta fall en höjd som är lik den vertikala höjden mellan *antenn – mark*. Det var endast på några få stationer som någon annan felkälla var orsaken.

Resultaten från den andra delen visar att inga nämnvärda förbättringar erhölls då Eccosorb var påsatt på antennen. Endast små avvikelser kunde ses men inga signifikanta skillnader.

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1INTRODUCTION

1.1 Overview

SWEPOS is a Swedish national network for GPS with 21 permanent reference stations located all over Sweden. SWEPOS is operated by the National Land Survey of Sweden (NLS).

The data collected from the SWEPOS stations are used for different tasks e.g. post-processing applications and real time applications. To achieve sufficient accuracy, possible error sources must be minimised. Multipath is one of those error sources that are known to disturb GPS measurements.

The aim with this report is to do a survey of the multipath at the SWEPOS stations and to study if the microwave absorbing material, Eccosorb ANW-77, reduces the multipath error.

The survey of the multipath will try to locate the origin of the multipath at every SWEPOS station. This will be done by analysing data from the SWEPOS stations in the software BSHOW, Vis-A-Vis and TEQC.

The evaluation of Eccosorb will be done by analysing data with and without the material on the antenna. Eccosorb will be mounted in two different ways on the antenna.

- A plate of Eccosorb beneath the antenna.
- A plate beneath and a ring of Eccosorb around the antenna.

The data from those two designs will be studied with help of the program TEQC. Base line calculations between Mårtsbo and Leksand will be done for further tests of Eccosorb and an antenna calibration will also be carried out to determine the antenna characteristics when Eccosorb is mounted on it.

1.2 SWEPOS

This experimental survey is made over the 21 SWEPOS stations located all over Sweden. But what is SWEPOS?

SWEPOS is a Swedish network of reference stations for GPS and the history about it is to be seen in the late eighties. In 1990 the idea of a reference net with GPS was originally presented in the report ”Geodesi 90” (1990) by NLS, Onsala space observatory and the project "GPS resources in Northen Sweden. During 1991 and 1992, after some planning and reconnaissance, six stations became operational and 14 more were established in the summer of 1993. A description of the developement of the network can be found in Hedling and Jonsson (1995).

Today (1998) the system consists of 21 stations and three more are planned to be operational during this winter (Västerås, Malmö and Göteborg). The stations are evenly spread over the country from Hässleholm to Kiruna with about 200 km between themselves. At the present time a project called CICERON is under development. This project aims to use the SWEPOS stations as reference stations when performing RTK-measuring.

The SWEPOS stations are established in a good way for GPS measurements, which means that they often stands on the top of a hill or a small mountain. The effect of this is that they can have a good view to many satellites down to low elevations (~ 5 degrees) in almost every azimuth. Although the circumstances are good at the paper the stations still suffers from different sources of noise and disturbances. Multipath, for instance, is one error source which put a limit for the accuracy at the stations.

1.2.1 The stations

Every station has a Dorne Margolin antenna placed on a concrete pillar. The pillar, which is about three meters of height, is electrically heated to about 15 degrees. This is to prevent movements of the pillar due to large temperature shifts. Close to the antenna a small cabin is situated which contains GPS receivers and other equipment for communication with the control centre. Ashtech Z-XII receivers are used. These are dual frequency receivers that can handle L1 C/A, L1 P-code, L2 P-code, L1 and L2 full wave carrier. Today only GPS data is collected but in the near future there will be tests of collecting GLONASS as well. With GLONASS the number of trackable satellites will increase.

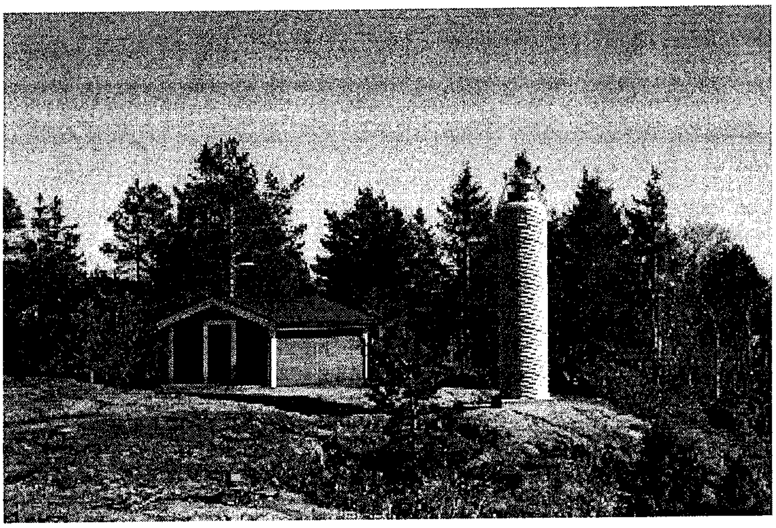


Fig 1.1 Karlstad SWEPOS station

1.2.2 The Control centre

The control centre for SWEPOS is located in Gävle at NLS. The raw data, dual frequency code, carrier phase observations and RTCM messages from the stations are transferred to the control centre through leased telephone lines bit connection. Each station is connected through one 64 kbit connection and a backup 19.2 kbit connection. An older system, which is working in parallel with the new one, uses ordinary dial-up telephone lines. Today this old system only covers about three quarters of the stations and will be phased out in a nearby future. After the rawdata has been collected at the control centre it is converted to RINEX using TEQC (see 1.5.2). Both RINEX and rawdata is stored on DLT tapes for backup. Less than an hour after the data has been received at the station the user easily can reach it through FTP from the control centre. Both raw data and RINEX are available through FTP.

The DGPS corrections passing through the control centre goes through an integrity monitor for quality check (see Hedling G. and Jonsson B. 1996).

1.3 Multipath

Multipath is an error that occurs when the antenna is located near reflecting surfaces. What happens is that the satellite signals are reflected before they arrive at the antenna. Direct signal and reflected signal are then both received at the antenna. Different surfaces can cause this reflection but the major ones are the ground or isolated, discrete objects near the antenna. Multipath will affect both the carrier phase and pseudorange measurements, but its size is much larger for the pseudorange measurements.

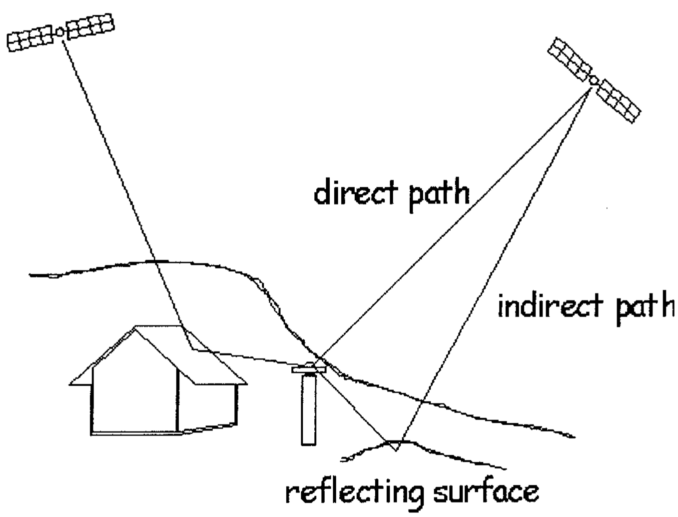


Fig 1.2 Multipath effect

The satellite signal will always travel a longer path when multipath occurs, see figure 1.2. This leads to measurement errors in the receiver, which is trying to measure a direct path length to the satellite. By comparing the reflected signal with the direct signal, a phase difference can be obtained which is proportional to the difference of the path length.

The effect of multipath on carrier phases can be estimated by the following considerations, B. Hofmann-Wellenhof et al (1997). The direct and indirect signals will interfere at the antenna centre (fig. 1.2). This can be expressed as

$a\cos\varphi$ direct signal (1.1)

$\beta\, a\cos(\beta+\Delta\varphi)$ indirect signal (1.2)

Where a is the amplitude and φ is the phase of the direct signal. β is the damping factor that reduces the indirect signal. The phase of the indirect signal is delayed by the phase shift $\Delta\varphi$ which is a function of the geometric configuration. The superposition of the signals is represented by

$$a\cos\varphi+\beta\, a\cos(\varphi+\Delta\varphi) \tag{1.3}$$

this can be rewritten as

$$a\cos\varphi+\beta\, a\cos\varphi\cos\Delta\varphi-\beta\, a\sin\varphi\sin\Delta\varphi \tag{1.4}$$

which can be rearranged to

$$(1+\beta\cos\Delta\varphi)a\cos\varphi-(\beta\sin\Delta\varphi)a\sin\varphi \tag{1.5}$$

This resultant signal may be represented in the form

$$\beta_M\, a\cos(\varphi+\Delta\varphi_M) \tag{1.6}$$

where the subscript M indicates multipath. By applying trigonometric formulas one get

$$(\beta_M\cos\Delta\varphi_M)a\cos\varphi-(\beta_M\sin\Delta\varphi_M)a\sin\varphi \tag{1.7}$$

By comparing the coefficients for $a\sin\varphi$ and $a\cos\varphi$ of equations

(1.5) and (1.7) the following relations are reached

$$\begin{aligned}\beta_M\sin\Delta\varphi_M &= \beta\sin\Delta\varphi\\ \beta_M\cos\Delta\varphi_M &= 1+\beta\cos\Delta\varphi\end{aligned} \tag{1.8}$$

which represents the two equations for the quantities β_M and $\Delta\varphi_M$. An explicit expression for β_M follows by squaring and adding the two equations. Thus,

$$\beta_M=\sqrt{1+\beta^2+2\beta\cos\Delta\varphi} \tag{1.9}$$

is obtained. An explicit expression for $\Delta\varphi_M$ follows by dividing the two equations in (1.8). Thus,

$$\tan\Delta\varphi_M = \frac{\beta\sin\Delta\varphi}{1+\beta\cos\Delta\varphi} \qquad (1.10)$$

is the solution.

The damping factor β can vary between 0 and 1. Where $\beta=0$ means that no reflected signal or multipath exist. If you substitute $\beta=0$ into (1.9) and (1.10) $\beta_M=1$ and $\Delta\varphi_M=0$ will be received, which means that the resultant signal is identical to the direct signal. $\beta=1$ gives the strongest possible reflection. By substituting this value into (1.9) and (1.10) following equations are received:

$$\beta_M = \sqrt{2(1+\cos\Delta\varphi)} = 2\cos\frac{\Delta\varphi}{2} \qquad (1.11)$$

and

$$\tan\Delta\varphi_M = \frac{\sin\Delta\varphi}{1+\cos\Delta\varphi} = \tan\frac{\Delta\varphi}{2} \qquad (1.12)$$

yielding

$$\Delta\varphi_M = \frac{1}{2}\Delta\varphi .$$

If the reflector is horizontal, for example the ground, the phase shift, $\Delta\varphi$, can be expressed as a function of the extra pathlength Δs.

$$\Delta\varphi = \frac{1}{\lambda}\Delta s = \frac{2h}{\lambda}\sin E \qquad (1.13)$$

$\Delta\varphi$ can be obtained where the phase shift is expressed in cycles. h is the vertical distance between the antenna and the ground and E is the elevation of the satellite, cf. fig. 2.1. Multipath is periodic because the elevation varies with time. The frequency of multipath is expressed as

$$f = \frac{d(\Delta\varphi)}{dt} = \frac{2h}{\lambda}\cos E\frac{dE}{dt} . \qquad (1.14)$$

From this formula different factors can be read out about the frequency, (Y. Georgiadou et. al, (1987):

- f is inversely proportional to the carrier wavelength
- f is proportional to the perpendicular distance, h, of the antenna centre from the reflector
- f is proportional to the cosine of the elevation E of the satellite above the reflector plane
- f is proportional to the rate of change of the elevation of the satellite above the reflector plane

The multipath influence can also be estimated by using a combination of L1, L2 code and carrier phase measurements. Troposphere, clock errors and relativistic effects affect both code and carrier phases measurements by the same amount, because they are frequency independent. Ionospheric refraction and multipath are frequency dependent so by using ionosphere-free code ranges and carrier phases and forming corresponding differences, all expected effects except for multipath will be cancelled.

1.4 Eccosorb

One possible way to reduce the effect of multipath is by using a microwave absorbing material attached to the antenna. P. Elósegui et al. (1995) has showed that a microwave absorbing material can have a positive effect on the multipath. In this paper it is found that the error due to scattering could be reduced by placing microwave absorbing material between the antenna and the concrete pillar, although not eliminated.

The microwave absorbing material that was used by Elósegui et al. is Eccosorb, a product from Emerson & Cuming microwave products. Eccosorb is a collection of different absorbers made for different purposes e.g. improvement of the antenna pattern and reducing undesirable reflections.

The type used in this project is called Eccosorb AN-W 77. This material can be achieved in six different thicknesses reaching from 6 to 114 mm. The number 77 stand for the thickness of the material and equals 57 mm in this case.

Eccosorb AN-W 77 absorbs radiowaves at frequencies above 1,2 GHz and is therefore suited for this purpose since the GPS frequencies are 1575.42 MHz and 1227.60 MHz for L1 respectively L2.

Eccosorb AN-W 77 consists of flexible open cell foam covered with olive green fuel and hydraulic fluid resistant nylon fabric. It is easy to cut to a suitable shape with a good tool like a sharp knife. See appendix 1.

1.5 Software

In this survey different software have been used depending on the task. Most of them are small and written for DOS. Short descriptions for all software are listed below.

1.5.1 BSHOW

BSHOW is written by Markku Poutanen of the Geodetic Institute in Finland. This program runs in DOS and is just 120 kb of size. However, although it is a small program it suits its purpose well. The input data is rawdata from a GPS receiver, tests have been made with Ashtech Z-12 and Ashtech Survey, and the program handles the data well.

BSHOW visualises the content of an Ashtech rawdata file. Number of epochs and positions computed in the receiver are displayed. The most important feature is that it visualises an individual satellites skytrack in a polar skyplot (See fig 3.1). S/N ratio of the C/A, P1 and P2-codes are plotted against epoch number. Cycle-slips and 1ms clockjumps are also indicated in the diagram.

1.5.2 TEQC

TEQC is a freeware program developed by Lou Estey at UNAVCO, University NAVSTAR Consortium, in Boulder Colorado,. TEQC stands for Translate, Edit, Quality Check and runs on a variety of platforms, PC, UNIX and different.

TEQC's primary function is to analyse a RINEX file but it can also produce RINEX from rawdata. TEQC can handle data from several different manufactures e.g. Trimble, Allen Osborne, Ashtech, Leica and Marconi. In this project Ashtech receivers have been used. After translating the files to RINEX a quality check has been done. This check will compute a number of figures related to the quality of the data. (See appendix 6)

1.5.3 Vis-A-Vis

This program is a module in the larger program Ashtech Office Suite. With this submodule a specific satellites elevation and azimuth at any time can be computed. The only necessary input is an almanac file. This has been used to calculate the vertical height of the multipath source (2.1.2).

2 THEORY AND METHOD

2.1 A survey over the 21 SWEPOS reference-stations

The purpose of this part is to survey multipath at the SWEPOS stations. It is also noticed where there is more noise than average. The data that has been used is in three-hour blocks from an Ashtech Z-XII receiver.

2.1.1 Performance

The data that are used are from two full days, 85 and 86 in GPS week 950 (26 and 27 march 1998). The data comes in blocks of three-hour sessions from the SWEPOS stations, which leads to 16 sessions of data per station.

From the S/N ratio the strength of the signal is possible to see. If the S/N ratio is a smooth line with a high value the signal is good and rather free from noise. However if the S/N ratio has a lower value and more jagged appearance, the signal is not as good as the earlier situation. Disturbing objects can be e.g. buildings, trees, vegetation and other things that can interrupt the signal. At lower elevations the antenna is exposed to multipath signals. A way to find out when this happens is to look at the S/N ratio in BSHOW.

When there are "normal" disturbances the S/N ratio shifts in an unsystematic way without any signs of continuity. However, sometimes the signal tends to get to a sinusoidal shape for several periods. This is a sign of possible multipath. The periods of these waves are often between four to six minutes depending on how high above the reflecting area the antenna stands. BSHOW also shows in which azimuth the satellite is heading. With knowledge of the azimuth of the satellite, the actual terrain around the actual site can be checked for possible obstructions that could disturb the signal. Several photos of each SWEPOS stations have been studied to get a picture of the surroundings of the pillars.

After studying data files of the S/N plots for one station for a while you normally notice some recurring circumstances. Sometimes the indications for multipath are weak or uncertain, but if the indications reappear in the same direction for several satellites, multipath probably exists in that direction. The indications for regular noise appear in a similar manner, although noise is easier to find. The basic rule is that lower altitudes generate more noise. However normally both noise and multipath indication appears first at 20 degrees and increases at lower elevations.

2.1.2 Calculating the vertical distance between antenna - reflector

From the sinusoidal waveform of the multipath in BSHOW it is possible to calculate the period of the multipath, $t = \frac{1}{f}$. With the knowledge of the period, frequency for L1, L2 and formula (1.14), the approximately vertical height of the reflecting object can be calculated.

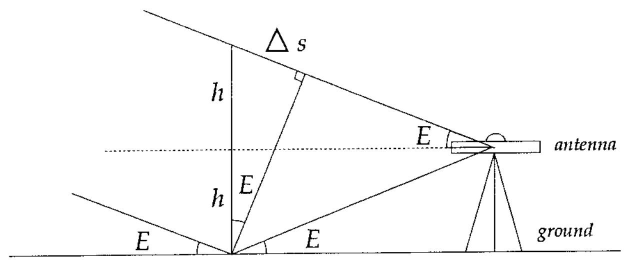


Fig 2.1. Geometry of multipath

$$f = \frac{2h}{\lambda} \cos E \frac{dE}{dt} \quad \Rightarrow \quad h = \frac{f \cdot \lambda}{2 \cdot \cos E \cdot \frac{dE}{dt}}$$

$f = \textit{frequency of the multipath}$

$h = \textit{vertical height, antenna} - \textit{reflecting surface}$

$\lambda = \textit{frequency of } L1, L2$

$E = \textit{elevation of the satellite}$

$\frac{dE}{dt} = \textit{satellite velocity in mrad per second}$

The $\frac{dE}{dt}$ computed with help of the program Vis-A-Vis and an almanac file. With Vis-A-Vis you can compute the elevation for a special satellite at any time. The time-period with severe multipath can be found with BSHOW. With knowledge about the difference in elevation between two times the angular velocity of the SV's can be calculated for that specific time.

The frequencies for L1 and L2 are,

- L1 = 1575.42 MHz
- L2 = 1227.60 MHz

An example of calculating the height h with data from Arjeplog station.

SV number = 21

$t = 360\,s \Rightarrow f = \frac{1}{360}$

$\lambda_{L1} = 0.19m$

$\lambda_{L2} = 0.24m$

E = 12 degrees

$\frac{dE}{dt} = 0.0873\ \textit{mrad per second}$

$$h_{L1} = \frac{\frac{1}{360} \cdot 0.19}{2 \cdot \cos 12 \cdot 0.0873} = 3.09\ m \qquad h_{L2} = \frac{\frac{1}{360} \cdot 0.24}{2 \cdot \cos 12 \cdot 0.0873} = 3.90m$$

For an Ashtech Z-12 height differences can be calculated only with help of the L1 S/N ratio, since the Z-tracking technique results in that the L1-"P-code" S/N ratio and the L2 "P-code" S/N ratio are dependent and almost identical (R.E. Dwyer, Ashtech, personal comment).

2.2 Evaluation of Eccosorb

The tests with Eccosorb AN-W 77 were performed on the SWEPOS station in Mårtsbo, Gävle. That station was used for analysing the effect of Eccosorb by comparing observation data with and without Eccosorb. The same station was also used for the antenna calibration.

Two different designs with Eccosorb were tested.

- A single plate of Eccosorb attached under the antenna, approximately thickness of 80mm (fig.2.2)
- A single plate under the antenna plus one ring of Eccosorb around the antenna (fig. 2.3)

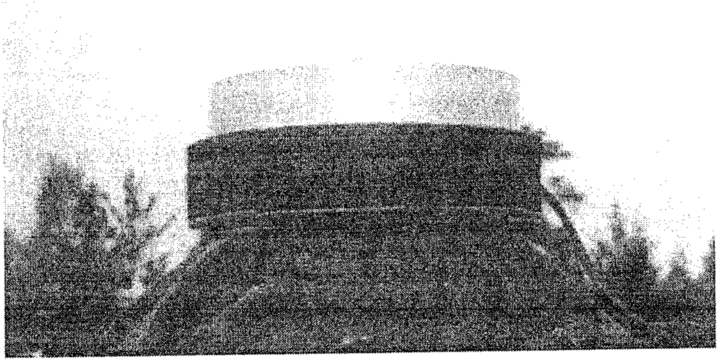


Fig 2.2 Eccosorb beneath the antenna

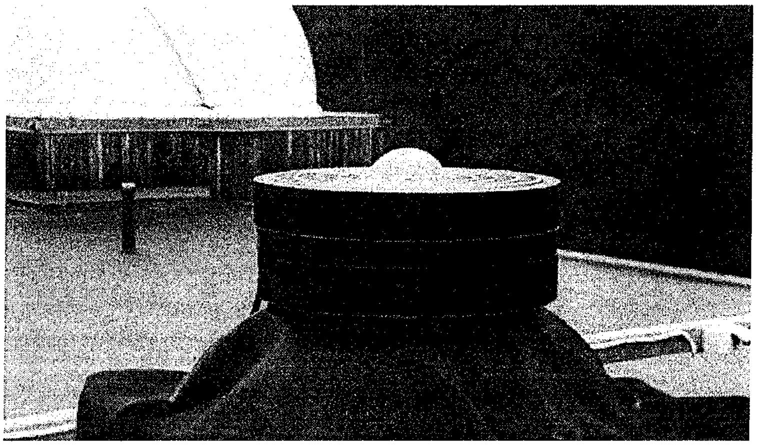


Fig 2.3 Eccosorb beneath and around the choke-rings

For a detailed drawing how the sheets were cut, see Appendix 1.

The plates of Eccosorb were carefully placed directly under the antenna. Data were then collected for two weeks. Later (see table 2.1) a ring of Eccosorb were added to the antenna and data were collected for two more weeks. Data for the antenna without Eccosorb were taken from the SWEPOS archive. Data for the receiver was the following: S/N: 700734 B 01833, Firmware: 1G00, Option: D-12MX

GPS day	Date	Events
93	April 3	Eccosorb beneath antenna
114	April 24	Eccosorb added around chokerings
149	May 29	Eccosorb removed from around chokerings

Table 2.1 Dates for the different designs of Eccosorb on the antenna

2.2.1 Statistical evaluation with data from TEQC

Data for the two different designs with Eccosorb were collected for fourteen days and then compared with data collected for the antenna without Eccosorb. The collected data were used for a quality check in TEQC (chap. 1.5.2). Before a quality check can be done the data must be translated from binary format to RINEX format. This is also done in the program TEQC.

The parameters MP1 and MP2 from the quality check are used in this study. These parameters stands for code multipath plus receiver and system noise, MP1 for L1 and MP2 for L2. How the MP values are calculated are shown in chapter 2.2.1.1

Mean values for MP1 and MP2 in elevation dependent classes are also computed by TEQC. The data for the three different designs of the antenna were analysed separately and then compared.

2.2.1.1 Derivation of MP1 and MP2 equations

First define the psudorange measurements:

$$P_1 = R + I_1 + MP_1$$
$$P_2 = R + I_2 + MP_2 \qquad \text{(2.1 and 2.2)}$$

where:

$$P_1 = L_1 \ Pseudorange \ (m)$$
$$P_2 = L_2 \ Pseudorange \ (m)$$
$$R = Geometric \ range \ plus \ clock \ errors$$
$$I_1 = L_1 \ Ionospheric \ delay \ (m)$$
$$I_2 = L_2 \ Ionospheric \ delay \ (m)$$
$$MP_1 = P_1 \ multipath \ plus \ receiver \ and \ system \ noise$$
$$MP_2 = P_2 \ multipath \ plus \ receiver \ and \ system \ noise$$

Now define the phase measurements:

$$L_1 = R - I_1 + B_1 + mp_1$$
$$L_2 = R - I_2 + B_2 + mp_2 \qquad \text{(2.3 and 2.4)}$$

where:

$$L_1 = L_1 \ phase \ measurement \ (m)$$
$$L_2 = L_2 \ phase \ measurement \ (m)$$
$$B_1 = L_1 \ phase \ ambigity \ (Bias) \ (m)$$
$$B_2 = L_2 \ phase \ ambigity \ (Bias) \ (m)$$
$$mp_1 = L_1 \ phase \ multipath \ and \ noice \ MP_1 >> mp_1 \approx 0$$
$$mp_2 = L_2 \ phase \ multipath \ and \ noice \ MP_2 >> mp_2 \approx 0$$

Assuming that phase noise plus multipath is small in comparison with pseudorange noise plus multipath makes it neglectable. Further definitions:

$$\alpha \equiv \frac{I_2}{I_1} = \left(\frac{f_1}{f_2}\right)^2 \qquad (2.5)$$

where:

$$f_1 = L_1 \; frequency \; 154 \cdot 10.23 \; MHz$$
$$f_2 = L_2 \; frequency \; 122 \cdot 10.23 \; MHz$$

Find MP_1 by forming the appropriate linear combinations:

$$P_1 - L_1 = 2I_1 + MP_1 - B_1 \Rightarrow MP_1 - B_1 = P_1 - L_1 - 2I_1 \qquad (2.6)$$

$$L_1 - L_2 = I_2 - I_1 + B_1 - B_2 = I_1 \cdot (\alpha - 1) + B_1 - B_2 \qquad (2.7)$$

$$\Rightarrow 2I_1 = \frac{2}{\alpha - 1} \cdot (L_1 - L_2) + 2 \cdot \frac{(B_2 - B_1)}{\alpha - 1} \qquad (2.8)$$

Thus the following expression for MP_1 can be written:

$$MP_1 - B_1 = P_1 - L_1 - \frac{2}{\alpha - 1} \cdot (L_1 - L_2) - \frac{2}{\alpha - 1} \cdot (B_2 - B_1) \qquad (2.9)$$

or:

$$MP_1 - \left\{B_1 - \frac{2}{\alpha - 1} \cdot (B_2 - B_1)\right\} = P_1 - \left(\frac{2}{\alpha - 1} + 1\right) \cdot L_1 + \frac{2}{\alpha - 1} \cdot L_2 \qquad (2.10)$$

Where the second term on the left hand site is a constant. Since MP_1 is assumed to be zero-mean this constant can be computed by averaging over all values of MP_1 and then subtracting this average for the MP_1 values computed at each epoch. Thus the multipath (after the constant has been removed) can be written as:

$$MP_1 = P_1 - \left(\frac{2}{\alpha - 1} + 1\right) \cdot L_1 + \left(\frac{2}{\alpha - 1}\right) \cdot L_2 \qquad (2.11)$$

A very similar derivation for MP_2 yields:

$$MP_2 - \left\{B_2 - \frac{2\alpha}{\alpha - 1} \cdot (B_1 - B_2)\right\} = P_2 - L_2 - \frac{2\alpha}{\alpha - 1} \cdot (L_1 - L_2) \qquad (2.12)$$

or with rearranging some terms and removing the constant term caused by the phase biases then:

$$MP_2 = P_2 - \left(\frac{2\alpha}{\alpha - 1}\right) \cdot L_1 + \left(\frac{2\alpha}{\alpha - 1} - 1\right) \cdot L_2 \quad (2.13)$$

Equation (2.11) and (2.13) are the desired result and can be used to compute L_1 and L_2 pseudorange multipath. Using α=1.646944 one gets the equations:

$$MP_1 = P_1 - 4.0915 \cdot L_1 + 3.0915 \cdot L_2 \quad (2.14)$$

$$MP_2 = P_2 - 5.0915 \cdot L_1 + 4.0915 \cdot L_2 \quad (2.15)$$

2.2.2 Antenna calibration

There are two different methods to perform an antenna calibration (Rotacher M et.al.1996). One method is the anechoic chamber test where you measure the phase pattern of a single GPS antenna. The second method is the determination of phase centre corrections from processing GPS data taken on a short baseline. Those corrections are found by calibrating an antenna relative to another antenna. The latter of those methods were used in this survey.

The antenna at the SWEPOS station in Mårtsbo was calibrated relative to a Dorne Margolin T antenna located on SIB 1. The calibration was done when the SWEPOS station had the two different designs of Eccosorb (see chap. 2.2) mounted on the antenna and when no Eccosorb were on the antenna. The length of the baseline was approximately 50 metres.

Measurements were collected for three days for each of the three designs, see table 2.2, and were then processed using the Bernese GPS software package version 4.0. The calculations were performed by Lotti Jivall and Jonas Ågren at the Geodetic Research Division at the National Land Survey of Sweden in Gävle (see 3.2.1).

Ring+plate of Eccosorb				Without Eccosorb				Plate of Eccosorb		
114	115	116	117	118	119	120	121	149	150	151

Table 2.2 The GPS date (1998) when data were collected for the three different designs.

2.2.3 Elevation cut off test

The data that were collected from the antenna calibration were also used in an elevation cut off test. Information about the capture of data can be seen in table 2.2.

An elevation cut off test will show the errors that are dependent on the elevation limits. Those errors indicate how good or bad the antenna model is. The test will also, in this case, show if and how much the material Eccosorb affect the chosen calculation method. An ionosphere free linear combination is chosen as calculation method for this test. The test is done by performing calculations with different elevation limits (see 3.2.2).

3 PRACTICAL TESTS AND RESULTS

3.1 A survey of the 21 SWEPOS reference-stations

This section shows how the height of the disturbing surface relative to the antenna centre is calculated and how the orientation of the multipath source is determined. Short reports for every station are also presented here.

3.1.1 Calculating the vertical distance between antenna – reflector

When using BSHOW to analyse rawdata from a receiver a number of things are shown.

The first screen contains an absolute solution of the position of the receiver computed by averaging the positions in the rawdata file. This position can be displayed in either geocentric or in geodetic coordinates.

In the second screen, a graphical view of the rawdata is displayed (fig 3.1). In this every single satellites sky track during the timespan of the rawdata file can be seen. A graphical view of the S/N ratio over the time that the satellite was visible is also shown. It is this last information that has been used in this survey to locate possible multipath sources. By analysing how the S/N ratio shifts, signs of regularity can be seen. Regularity here means that the graph turns into a sinusoidal shape. However in some cases this can be difficult to see. Sometimes the difference between noise and multipath indication is small and it is hard to determine whether it is the one or the other. For every station two days (48 h) has been examined.

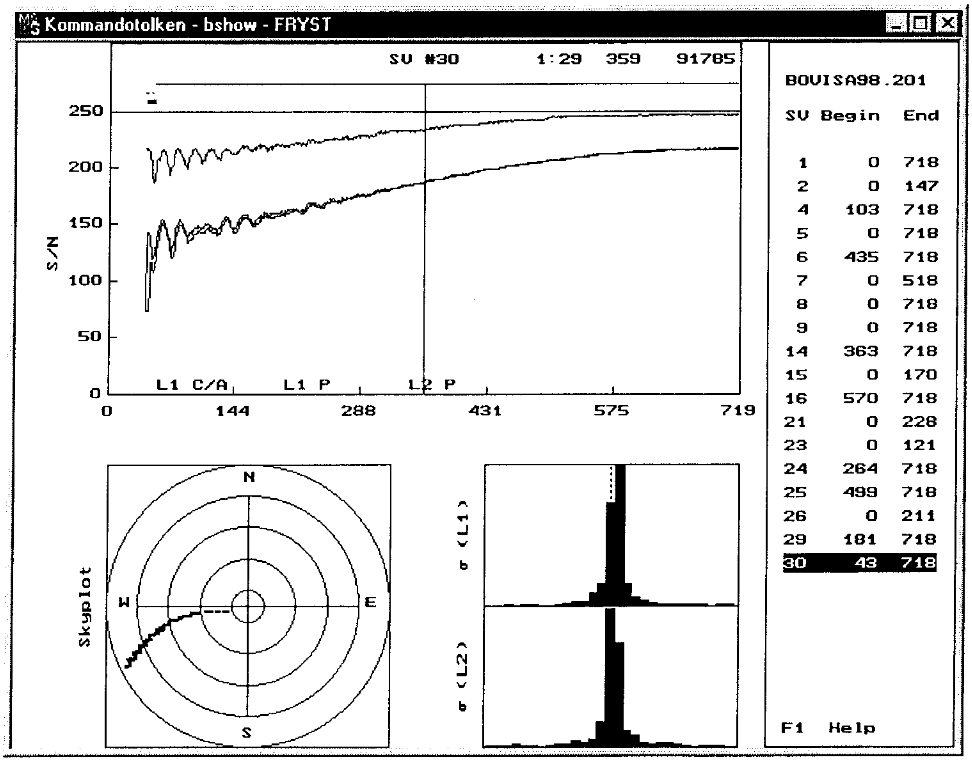


Fig 3.1 Screen captured from BSHOW

In fig 3.1 rawdata from the station in Visby is shown. This is a three hour session. In the right column of the figure all satellites that were visible during the session are listed with their SV numbers and their start and stop epoch. The whole file contains 720 epochs at 15 s interval. In the square in the lower left corner the highlighted satellite's orbit is shown. The bigger rectangle at the top contains the most useful information from our point of view. At the top the satellite PRN number is shown. In the diagram there are three graphs (but it sometimes looks like two). The single graph on top of the three shows the C/A code S/N, this has been used in this survey. The two lower ones shows the P-codes S/N for L1 and L2.

The fact that multipath is more common for low elevations is evident in this diagram. This satellite (PRN 30) has risen in the west/south-west and climbed to higher altitudes, heading north. When looking at the graph in the rectangle a sinusoidal line occur at the low elevations, this is a typical multipath sign.

In the graphical view there is a vertical line which can be moved to the left and right. With this tool, the period time for multipath can be measured. Together with this period of time and the knowledge of the actual satellites angular velocity, the height of the reflecting surface can be calculated.

The angular velocity of the satellite is computed with help of the program Vis-A-Vis. Lists of all satellites and their elevation at a specific time are shown in the program. These are calculated using a not to old GPS almanac file.

From BSHOW the actual time span when the multipath occurred can be found. By using the first and the last time in that time span and applying it to the Vis-a-Vis list, the elevation for the first and the last time is found.

With two elevations and a known time span the angular velocity is quite easy to calculate. This result is input in the height formula and a value for the vertical height is achieved. Because of the difference in frequency between L1 and L2 two different heights are received. See 2.1.2.

3.1.2 A survey of the multipath at the SWEPOS-stations

Two days were chosen for the survey: March 26 and 27 1998 or day 85 and 86 in GPS week 950. The same days were used for all stations. At several of the northern SWEPOS stations the ground was covered with snow during the survey.

A short report was written for every station. This report includes a hypothesis of what might be the error source and it also presents the calculated vertical distance to this possible source. The distances are calculated on both L1 and L2.

On most stations the calculated heights are approximately equally to the height of the pillar over the ground. This is an indication that the by far most common source of multipath is the ground on which the pillar stands. On some stations no definite error source can be found from the calculated heights. For those stations no error source is painted out.

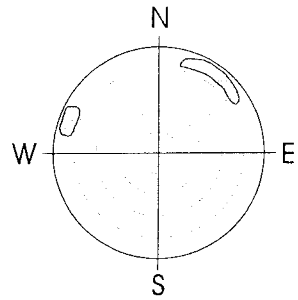
The location of the possible multipath source is shown graphically for every station. Grey area shows where the multipath indications appear on that specific station. The equidistance between the circles is 20 degrees except for the last interval from 80 to 90.

3.1.2.1 Arjeplog

This station is located on a hill surrounded by small spruce trees. In several directions this station is disturbed, especially on low elevations (~ 5 degrees). The noise is probably due to spruce trees near the station. Indications of multipath are only seen in the N NE and some in the W NW.

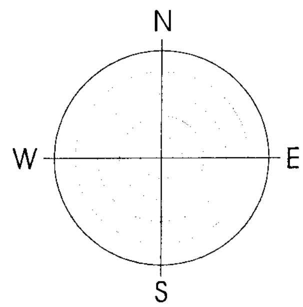
The calculated heights are:

Azimuth	280°	280°	20°
L1 (m)	3.1	3.2	3.0
L2 (m)	3.9	4.0	3.8



3.1.2.2 Borås

This station is located quite close to some buildings which disturbs the signals. In some azimuths the buildings completely prevents the satellite signals to reach the GPS-antenna. However, although there are a lot of signal interruptions, there are no clear indications of multipath. Therefore no heights are calculated.

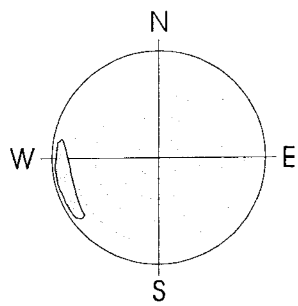


3.1.2.3 Hässleholm

This station is located on a small hill in a artillery range. Small vegetation partially surrounds the hill and bedrock can be seen around the antenna. In the west a few clear signs of multipath are visible. Also a number of indications are seen in the W SW. Some of the indications reaches up to twenty degrees above the horizon.

The calculated heights are:

Azimuth	260°	259°
L1 (m)	2.9	3.0
L2 (m)	3.7	3.8

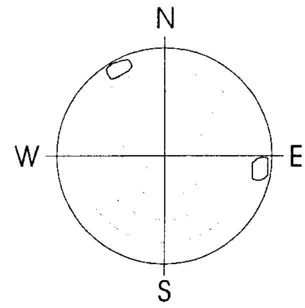


3.1.2.4 Jönköping

The pillar is located on bedrock in the open area close to the airport of Jönköping. No trees are in the vicinity that can disturb the signals. Clear indications of multipath are seen in the E SE direction, although not very much. Small indications in the south from a couple of satellites in different sessions are also noticed. But overall less indications of multipath than the average station. The pillar at this station is lower compared to the others. It is just about 1.0 m so the theory that the ground usually is the major source of multipath is a little weak here. However as said before the pillar stands on a little hill of rock and the terrain around the pillar is hilly with some rocks and grass. It is possible that the few multipath signals comes from a close rock that lies a little bit under the pillar. But as a summary this station does not have so much indications of multipath at all, so the ones showed here could maybe be neglected.

The calculated heights are:

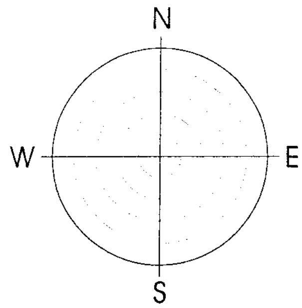
Azimuth	334°	105°	82°
L1 (m)	3.9	3.0	3.5
L2 (m)	5.0	3.7	4.5



3.1.2.5 Karlstad

This station is located on a hill surrounded by pine trees. The bedrock can clearly be seen close to the pillar and the house is located almost on the same level as the pillar.

The station has almost no indications of multipath, only small disturbances, hardly at medium size. No heights are calculated due to no good existing data of multipath.



3.1.2.6 Kiruna

This station is situated on a mountain with some medium sized spruces around. Several multipath indications are seen in the S SE direction, some signs are also found in N NE and in S. The calculated heights are here between 3.0 m to 3.2 m for L1 in all directions except NW. In the NW direction a height of 1.5 m is calculated for L1. The nearby roof of the cabin probably causes this.

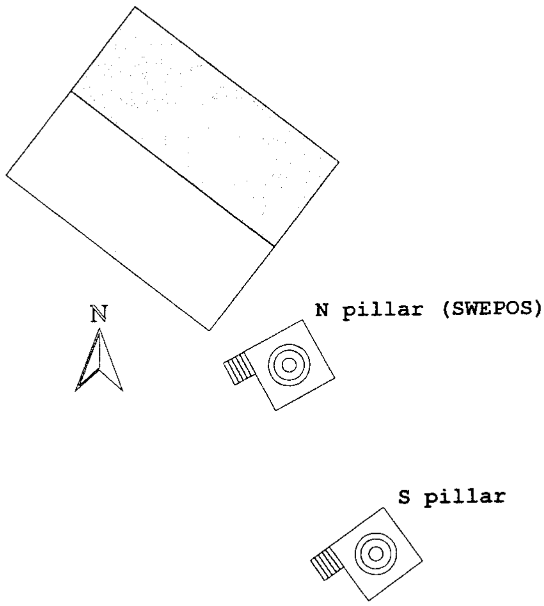
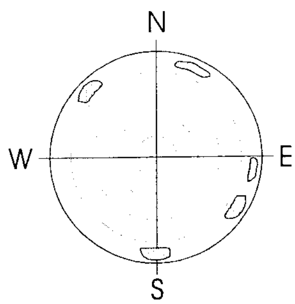


Fig 3.2 Sketch over Kiruna SWEPOS station

The calculated heights are:

Azimuth	24°	319°	170°
L1 (m)	3.0	1.5	3.2
L2 (m)	3.8	1.9	4.1

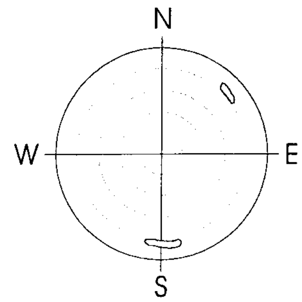


3.1.2.7 Leksand

This station is located on the top of a ski slope, surrounded by pine trees. A circular area of about 15 m radius around the pillar is cleared from trees. The bedrock is mostly covered with moss and low vegetation. Weak indications of multipath are seen in the south, most clearly about 20 degrees above the horizon though. At lower altitudes the signal becomes just noise. The northern area are more disturbed than a normal station but no signs of multipath.

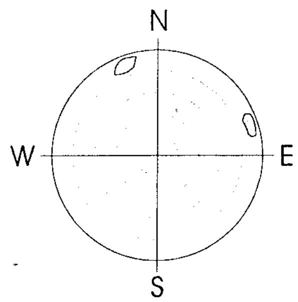
The calculated heights are:

Azimuth	178°	47°
L1 (m)	2.4	2.4
L2 (m)	3.1	3.0



3.1.2.8 Lovö

This station is located quite close to the capital of Sweden. Weak indications of multipath in the N NW and in E, a little more distinct in the north though. The noise and disturbances are a little bit stronger in the northern hemisphere. No heights calculated due to weak data.



3.1.2.9 Mårtsbo

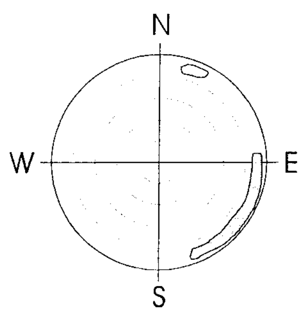
This station is situated 10 km outside Gävle at Mårtsbo Geodetic observatory". The pillar stands close to a rather big building compared to other SWEPOS stations. This station is used as an experimental testing place for the NLS. The pillar is high (~5.0 m) and is surrounded by a rail.

In the east to south area the multipath indications becomes very large. This is probably due to the flat roof on the nearby building.

As a summary this station has more clear signs of multipath than the average station.

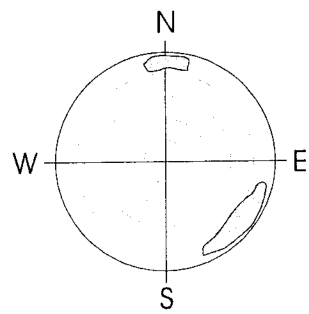
The calculated heights are:

Azimuth	104°	10°	131°
L1 (m)	1.4	5.3	1.4
L2 (m)	1.8	6.7	1.8



3.1.2.10 Norrköping

This station is situated in an open area close to Norrköpings airport. The ground consists of moss, rock and grass. Indications of multipath in the E SE direction are found, some of them even reach a little bit over 20 degrees. In the north there is some indications of multipath combined with usual distortion and signal interruption. Why the vertical distance differs so much in the last calculation is a little strange. One reason might be the large rocks around the pillar. This together with temporary circumstances can be a reason. Also keep in mind that the multipath wavelengths are decided with a human eye and some variations are natural.



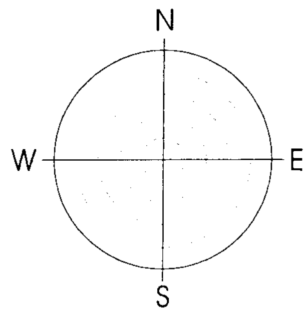
The calculated heights are:

Azimuth	114°	105°	13°
L1 (m)	3.1	3.1	6.1
L2 (m)	4.0	3.9	7.7

3.1.2.11 Onsala

Onsalas SWEPOS station is situated at Onsala Space Observatory, OSO. Due to this, many different buildings and constructions are located in the pillar's vicinity. One 20 meters circular telescope radom is located to the N NE of the SWEPOS antenna. This prevents the antenna to receive good satellite signals in that direction. Weak indications of multipath in the area between S and W without any continuity occur. Also some heavy noise in the N which probably is due to the constructions. Onsala differs from the other stations because it has a different construction of the pillar and it is only about one meter of height. Tests with Eccosorb have already been performed here and Eccosorb was mounted under/beside the antenna here already in Sept. 1994.

No heights have been determined here due to lack of multipath data.

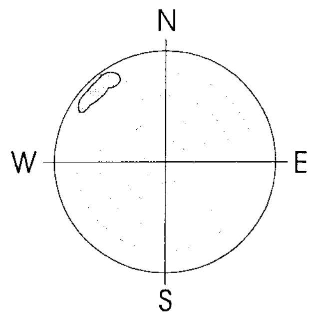


3.1.2.12 Oskarshamn

The pillar is situated on the top of a hill. In the vicinity of the pillar there are trees and the ground consists of flat bedrock. Indications of multipath are seen in the N NW direction and as usual on low elevations. However the signs of multipath does only appear here if the satellite is rising or sinking, not if it is only sniffing at low elevations in the horizon. Less indication than the average station.

The calculated heights are:

Azimuth	321°	327°	278°
L1 (m)	2.6	3.5	3.0
L2 (m)	3.2	4.4	3.7



3.1.2.13 Skellefteå

This station stands in an open area on a flat bedrock ground. No trees or other constructions are located in the nearby area, which can prevent the signal to reach the antenna. Clear indications of multipath are present in several directions though. In the W SW and in an area between E and SE there are clear multipath indications. Down in the S SE azimuths there are some strange signals (see the hatched area in the picture). The waveform is much flatter and with a longer wavelength here than usual. The sinusoidal also gets up to higher elevations than usual (~40 degrees). At this station the pillar with the antenna is located very close, (~0.5 m), north of the building (fig.3.3).

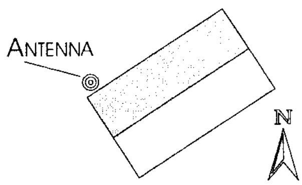
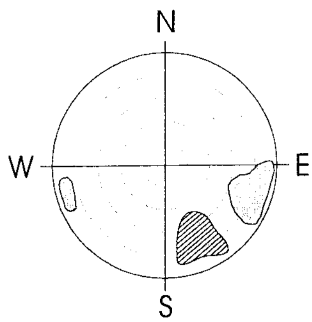


fig. 3.3 Sketch over Skellefteå SWEPOS station

It is no doubt that the roof reflects the signal from this direction, which is confirmed by the determined heights in that azimuth. However there are still "usual" multipath in the other two directions, W SW and E SE. The ground here consists of flat stones with grass between. It seems like these stones reflect the signal well.

The calculated heights are:

Azimuth	239°	142°	91°
L1 (m)	3.4	0.7	3.1
L2 (m)	4.2	0.9	4.0



3.1.2.14 Sundsvall

This station is located just a short distance from the sea and the surrounding ground consists of flat rocks. Here there are indications of multipath in an section between NW to NE.

Rather close in the NE direction there is a light hillside down a few meters with some bushes and grass (fig.3.4). This is probably the reason why the calculated height is bigger in this direction.

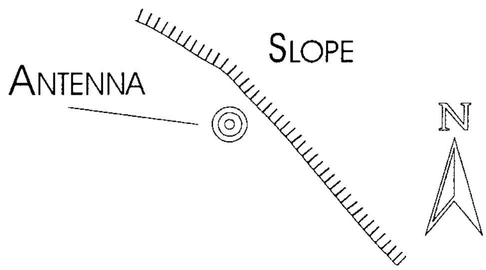
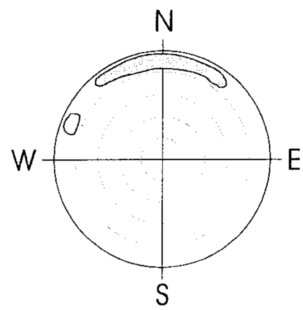


Fig. 3.4 The terrain around Sundsvall SWEPOS station

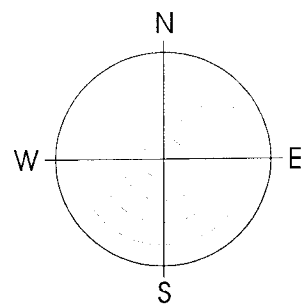
The calculated heights are:

Azimuth	297°	328°	26°
L1 (m)	2.7	3.0	4.0
L2 (m)	3.4	3.7	5.9



3.1.2.15 Sveg

Like Karlstad this station is almost completely spared from any kind of multipath and there are not much noise either. No heights are calculated due to no data.

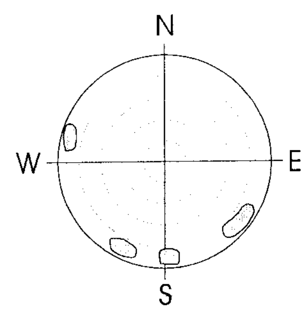


3.1.2.16 Umeå

The antenna stands on a hill of rock with spruce and pines below. There are not much indications of multipath here. Only a few in the south and east. Between SW to SE some scattered signs of multipath are found and there is also some indications in the east. The different results in the heights are probably due to the shifting ground.

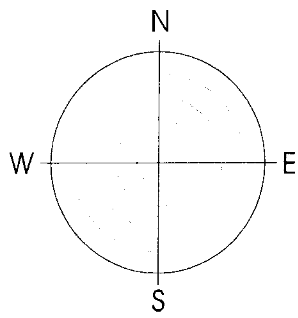
The calculated heights are:

Azimuth	260°	131°	156°
L1 (m)	2.9	4.3	3.1
L2 (m)	3.7	5.4	3.9



3.1.2.17 Vilhelmina

Like Karlstad and Sveg this station is spared from any kind of multipath and noise. No heights are calculated due to lack of data.

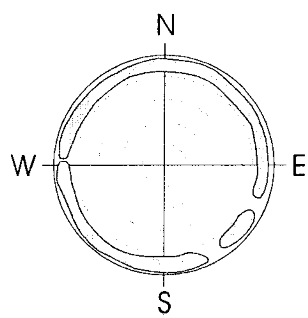


3.1.2.18 Visby

This station is located on Gotland. In the vicinity of the pillar the ground consists of very flat limestone temporally covered with grass. Very flat ground probably yields a very good reflector. Below 15 degrees this station has clear indications of multipath in almost all azimuths. It is quite obvious that the ground is the major source for reflection here.

The calculated heights are:

Azimuth	33°	118°	85°
L1 (m)	2.5	2.8	2.9
L2 (m)	3.1	3.5	3.7



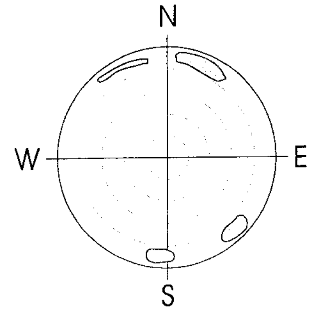
3.1.2.19 Vänersborg

The station is located on the top of a small hill with no obstructions in the neighbourhood. The ground is mostly covered with grass but the rock can be seen in some places. This station has strong noises mixed with multipath in an area between NW to E NE. The disturbances only appear on elevations lower than 15 degrees though.

There are also some signs in the south that could be multipath, these are rather weak however.

The calculated heights are:

Azimuth	197°	176°	148°
L1 (m)	4.2	2.7	3.6
L2 (m)	5.3	3.5	4.5

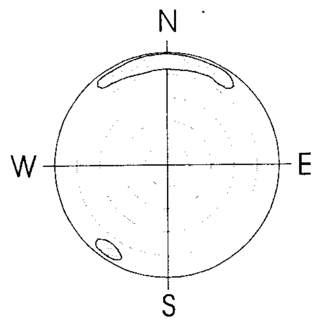


3.1.2.20 Östersund

This station stands in an open area and the ground is covered with soil and grass. Here there are indications of multipath in an area between NW and NE. The disturbances only appear on elevations lower than 15 degrees though. Like Vänersborg it seems like satellites with low orbits have more noise than satellites with a rising or sinking orbit.

The calculated heights are:

Azimuth	26°	207°
L1 (m)	3.6	3.3
L2 (m)	4.5	4.2

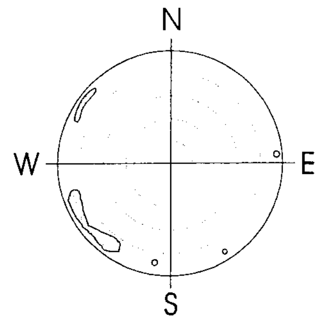


3.1.2.21 Överkalix

The pillar stands on rock, which is partly covered with moss and low vegetation. Indications of multipath are found in SW and in a minor section in NW, stronger though in the SW. There is also scattered signs of multipath at different locations, see picture below.

The calculated heights are:

Azimuth	244°	263°	165°
L1 (m)	2.5	1.9	2.2
L2 (m)	3.2	2.3	2.8



3.2 Evaluation of Eccosorb

An antenna calibration was performed to determine the antenna characteristics. Data were collected for the three designs with Eccosorb. This data were then used for both the antenna calibration and the cut off test.

The microwave absorbing material Eccosorb AN-W 77 were mounted on the antenna at the SWEPOS station in Mårtsbo in two different ways, see 2.2. The results from the observations with Eccosorb were then compared with results from an antenna without Eccosorb. Statistical evaluation with data from TEQC was made.

3.2.1 Antenna Calibration

The observations from three to four days of observations for everyone of the three different antenna designs were computed separately in the Bernese software version 4.0 by Lotti Jivall and Jonas Ågren, see Jivall (1998), (see 2.2.2).

When solving for elevation parameters small significant deviations could be seen between the three designs. Those deviations occur at elevations lower than 15 degrees. A more significant effect was that the standard deviation of the elevation parameters was smaller with Eccosorb than without.

It can be said from those results that the microwave absorbing material Eccosorb does not seem to effect the characteristics of the antenna in a major way. But it should be noted that those differences are increased when using an ionosphere-free combination.

3.2.2 Elevation cut off test

The result from the test, fig 3.5, shows that Eccosorb affects the height in a systematic way when using an ionosphere-free linear combination and also solving for troposphere parameters. The height error vary between – .004 mm at an elevation of 10 degrees to + 0.004 at an elevation of 25 degrees without Eccosorb. But when Eccosorb is added to the antenna, both designs, the height error rises from 0 at 10 degrees to + 0.017 at an elevation of 25 degrees.

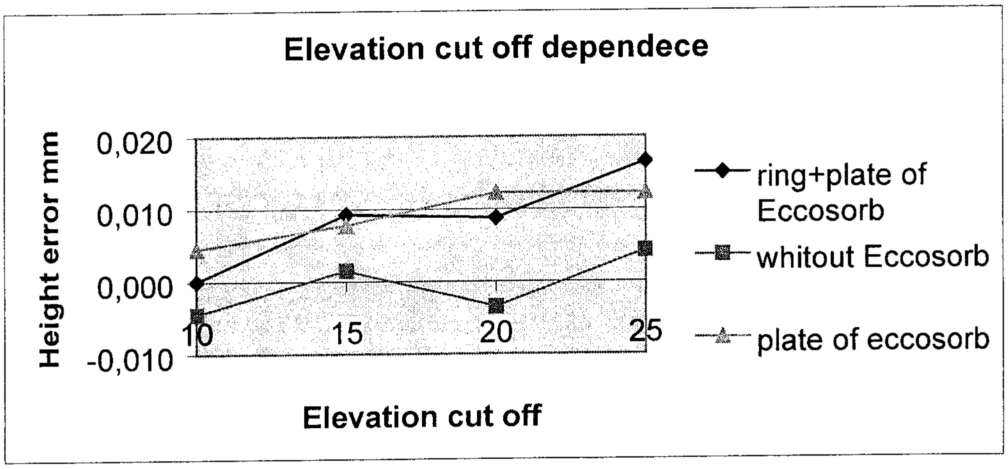


Fig 3.5 Result from elevation cut off test

No differences can be seen in this test depending on if Eccosorb is only beneath the antenna or if a ring around the choke rings is added.

When new points relative to SWEPOS, e.g. new SWEREF-points, are determined at NLS, an elevation mask of 15 degrees is used. This test indicates that there can be a systematic error of 5-10mm in the height component when Eccosorb is placed under the antenna.

3.2.3 Statistical evaluation with data from TEQC

MP1 and MP2 are indicators on how much code multipath there are on the L1 and L2 signals. A large number means more multipath than a smaller one. The MP1 and MP2 values from the full quality check in TEQC were used in the statistical tests. The MP1 and MP2 values were sorted in Excel after there elevation. For all three antenna designs (no Eccosorb, plate, plate + ring) mean values and standard deviations were calculated. The mean value and the standard deviation as a function of elevation can be seen in appendices 3, 4 and 5.

If the mean and standard deviations for the case without Eccosorb and the case with Eccosorb are compared, small improvements will be seen, however these are to small to be statistically significant. If the same thing is done for the case without Eccosorb and the case with plate and ring of Eccosorb, the mean of the MP is statistically larger. This means that the ring of Eccosorb around the antenna amplifies multipath instead of reducing it. In appendices 3, 4 and 5, notice that the MP values decrease as the elevation angle increase. This is because multipath most often occurs at low elevations. The figure only presents MP1 values but the same behaviour appears for MP2.

Confidence intervals were calculated to investigate if the improvement with Eccosorb were of significance. Those intervals were computed by applying the formula for confidence interval for the difference between two expected values where the standard deviation is unknown.

The formula for the confidence interval is

$$I_{m1-m2} = \left(\bar{x} - \bar{y} - t_{\alpha/2}(f) \cdot d\right), \left(\bar{x} - \bar{y} + t_{\alpha/2}(f) \cdot d\right)$$

where

$$d = s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \qquad Q_1 = \left(\bar{x} - x_i\right)^2 \qquad Q_2 = \left(\bar{y} - y_i\right)^2$$

$$s = \sqrt{\frac{Q_1 + Q_2}{(n_1 - 1) + (n_2 - 1)}}$$

The intervals were calculated for 95% confidence and as can be seen in the formula for the confidence interval the t-distribution is used.

The result with TEQC showed that only small improvements could be seen with Eccosorb beneath the antenna compared to a clean antenna. The antenna design with both plate and ring of Eccosorb had more multipath than the clean design.

By using the microwave absorbing material Eccosorb on the antenna small variations can be seen but no significance can be found that it really increases the accuracy.

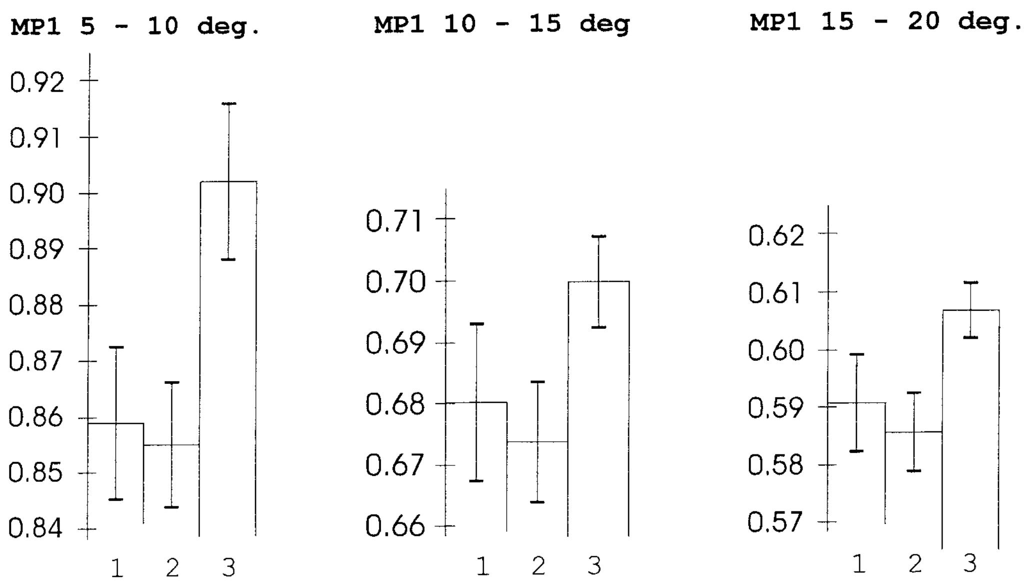


Fig. 3.6. MP1 values for the three first elevation intervals. The bars shows the mean values for the MP1 value over 14 days. The interval in each bar shows the standard deviation for 95% of the observations. Number: 1 = antenna without Eccosorb, 2 = plate of Eccosorb beneath the antenna, 3 = plate + ring of Eccosorb on the antenna.

4 DISCUSSION

4.1 Multipath at the SWEPOS reference-stations

As have been said before the reference stations are usually located in places that are near optimal for receiving satellite signals. Almost all stations are situated in the countryside where there are few obstacles with reflective surfaces but still multipath exist, more at some places, less at others.

At Mårtsbo and Skellefteå, where the pillar is situated close to the cabin, the roof clearly acts as a source of multipath errors. At Kiruna, where the pillar stands a couple of meters from the cabin, the roof is probably also a source of multipath errors. Karlstad, Sveg and Vilhelmina seems to be the most trouble free stations, in this survey, they have no traces of sinusoidal waves in the signal-to-noise diagrams.

In Borås and Onsala no clear traces of multipath are seen but there are some other types of disturbances instead. This is probably due to some huge objects in the close neighbourhood of these stations. Onsala has Eccosorb mounted under the antenna since September 1994.

The station in Visby, which lies on Gotland, an island in the Baltic Sea, shows really legible multipath almost around the whole horizon (3.1.2.18). The reason for this is probably that this station is surrounded by very flat ground and a flat surface is also a very good reflector.

The calculations of the vertical height *antenna – reflector* shows unanimous results with some exceptions. On almost every station where the heights have been calculated, the value has turned out to be equal to the vertical distance *antenna – ground.*

In Skellefteå (3.1.2.13) the antenna is placed close to its cabin. In the direction of the cabin the vertical distance between *antenna – reflector* roughly is the difference in height between *antenna – roof.* This shows that a nearby roof can reflect the satellite signal and cause multipath.

At Mårtsbo (3.1.2.9) the antenna once again is located close to a nearby building. Like in Skellefteå lower heights are computed for the observations in the direction of the building compared to other directions around the antenna. Once again the lower vertical heights are approximately the same as the height difference.

If a comparision is made between this survey and an older survey made by Lars Harrie in the winter 1995/1996, several similarities can be seen, see app.8. In this version an older version of the TEQC program from UNAVCO called QC (quality check) was used. Statistics for the MP1 and MP2 variables were computed from two months of data.

If assumption is made that a low MP value means low multipath at a station, this survey indicates that Jönköping, Onsala and Vilhelmina are good stations with low multipath. Note that Jönköping and Onsala are the two stations with low pillars (~1m), neither one had any serious indications of multipath in the survey made with BSHOW. Vilhelmina is also very a good station in both surveys so the result in both studies in many ways agree.

The bad MP values for the Vänersborg station are probably explained by a bad fibreglass radome that was used in Vänersborg 1995/1996.

4.2 Eccosorb

During the work and evaluation of Eccosorb (AN-W 77) different results has been achieved. It has been said in other reports (Elósegui et al. 1995) that this material improves the measurements. The result from our own experiments seems to show that the improvements are small.

Analysing the MP values from TEQC during 14 days for three alternative setups shows small improvements in the MP values for alternative two, just a plate beneath the antenna (fig. 3.6). Also the variation of the MP values becomes smaller with this alternative.

On alternative three, plate plus ring mounted around the antenna, the MP rises more than with no Eccosorb mounted under the antenna although the standard deviation becomes smaller also in this case. These results are the same for both MP1 and MP2. These small differences can only be seen on low elevations up to 20 degrees. On higher elevations the result becomes almost the same for the three alternatives.

An antenna calibration made with the Bernese GPS software version 4 indicated that the antenna characteristics where almost identical for the three alternatives.

On the other hand the result from the elevation cut off test showed that the height error increased when the material Eccosorb was added to the antenna. At ten degrees elevation mask the errors seems to be close to zero but at 15 degrees elevation mask the errors are between five and ten mm. 15 degrees is used as standard in SWEPOS densification. Why those two results shows opposite indications is difficult to explain. One reason might be that the data amount for the both tests are small.

Another way to improve the multipath situation on the SWEPOS stations could be to use GPS - receivers that filter out multipath internally. The new Ashtech receiver, Z-Surveyor, has improved satellite tracking algorithms buildt-in, especially at low elevations (ION - GPS-96 Garin et. al). A little test with this new receiver was performed. The result from this test indicated better values, but no further investigation is done in this report.

5 CONCLUSIONS

Multipath occurs at most of the SWEPOS stations.

The calculation of the vertical height *antenna - reflector* shows a unanimous result for almost every station. At most stations the distance is equal with the height of the pillar. This means that the ground is the main source for reflection. A nearby roof can also act as a source of multipath.

The results from the evaluation of the microwave absorbing material Eccosorb were different depending on the tests. A statistical investigation of the "multipath" observable MP1 and MP2 for three different designs of the Eccosorb plates showed that there were small improvements in the MP1/MP2 values when a plate of Eccosorb was placed beneath the antenna. In the antenna calibration the variation of the elevation-parameters between the days decreased with Eccosorb. These two results indicates that a large scale test with Eccosorb under the antenna at all SWEPOS stations for a longer time period could be of interest.

On the other hand the elevation cut off test showed that Eccosorb affects the height in a systematic way, an error of five to ten mm seems to occur when using a 15 degree elevation mask.

A possible conclusion is that either Eccosorb should be added to all the SWEPOS antennas or taken away completely from SWEPOS.

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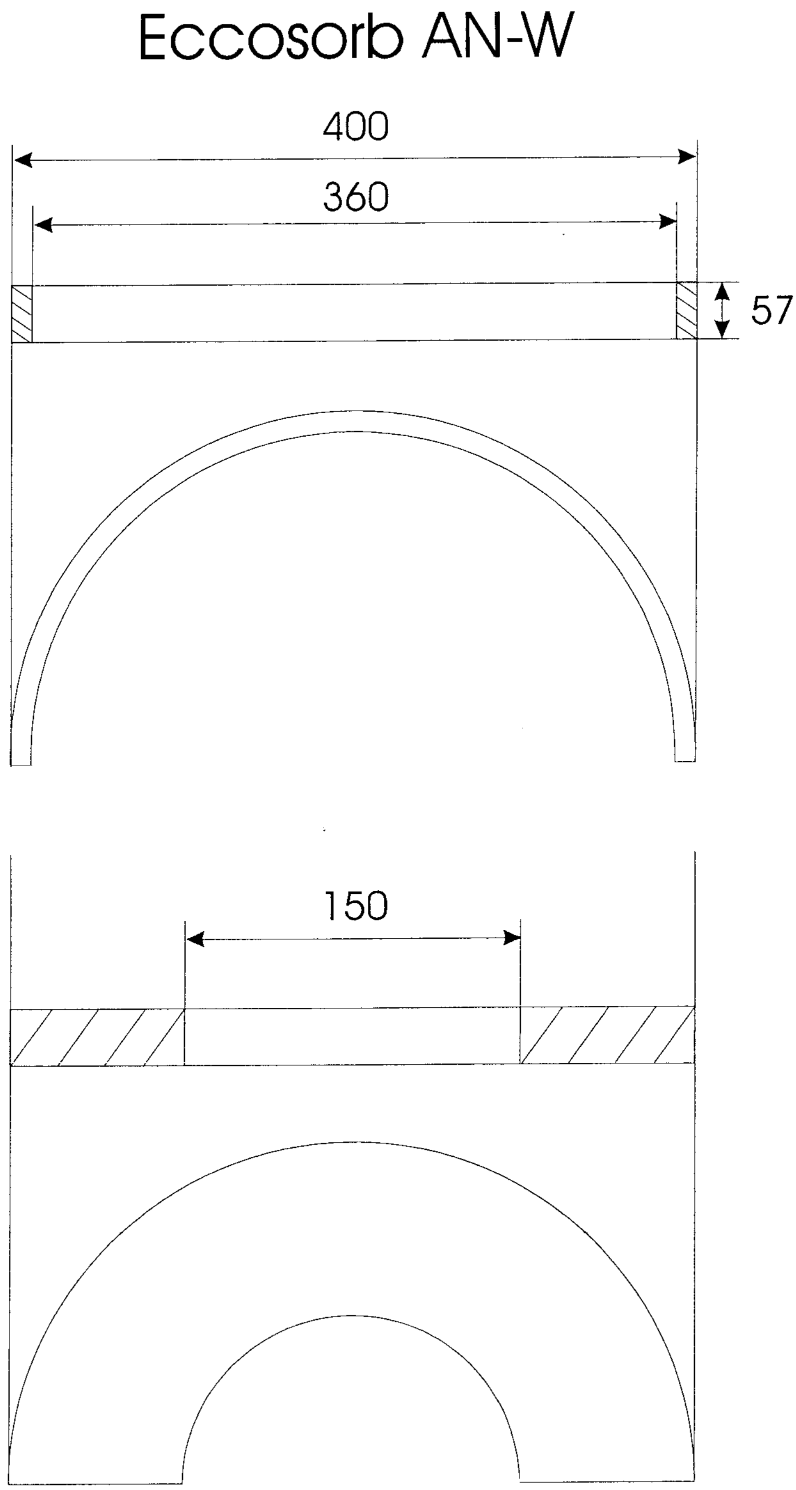
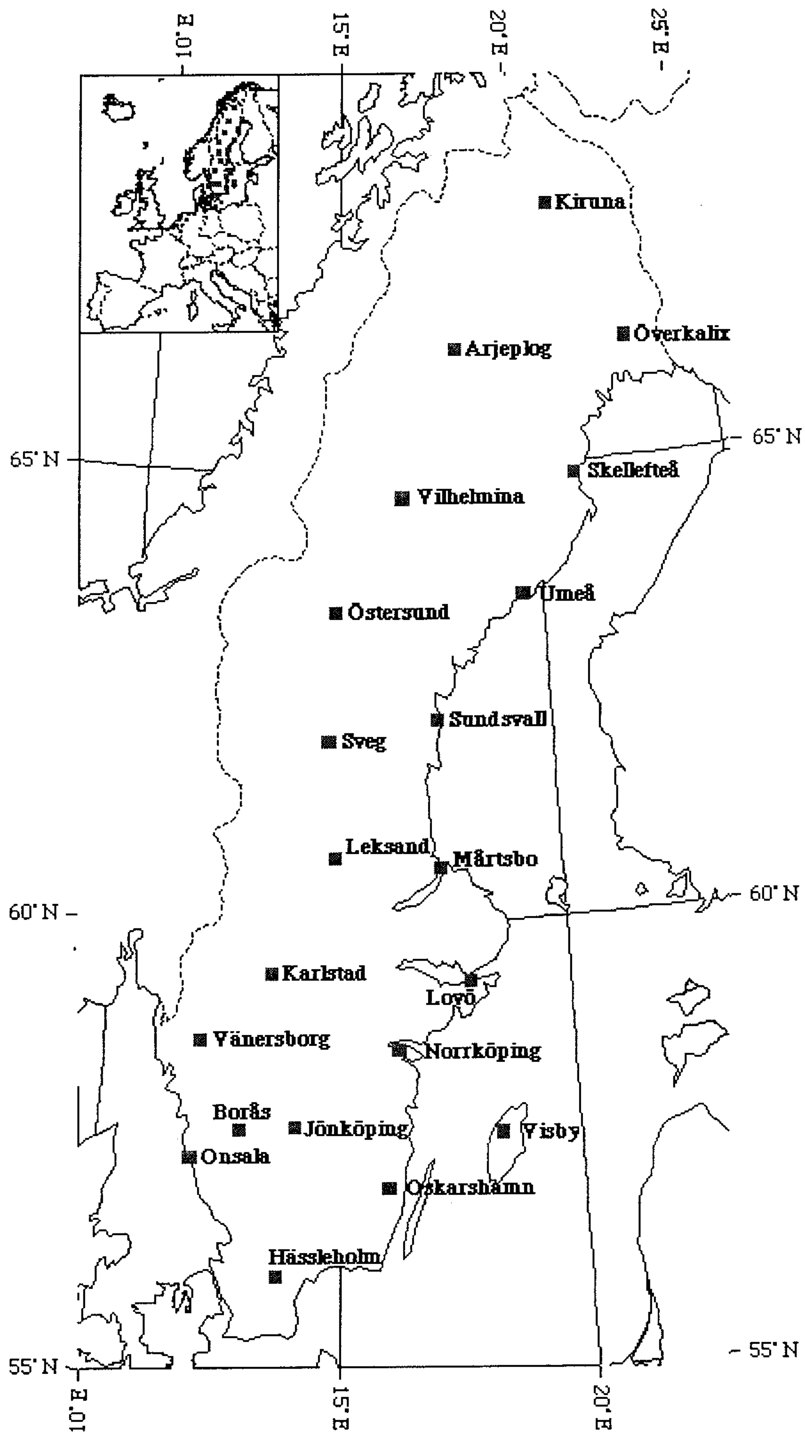
Appendix 1.
Drawing for the cutting of Eccosorb to fit the Dorne Margolin antenna.



Appendix 2. Map over SWEPOS.

SWEPOS Sites



Appendix 3.

Without Eccosorb

	Mean	Std
MP1	0,448450	0,014135
MP2	0,454273	0,020235

elev (deg)	MP1 Mean	MP1 Std	MP2 Mean	MP2 Std
85 - 90	0,000000	0,000000	0,000000	0,000000
80 - 85	0,128075	0,006075	0,123582	0,006371
75 - 80	0,138112	0,005262	0,131503	0,005380
70 - 75	0,161397	0,005119	0,142880	0,006261
65 - 70	0,166016	0,006638	0,154141	0,005385
60 - 65	0,161825	0,007618	0,164392	0,005505
55 - 60	0,174713	0,008222	0,176646	0,006197
50 - 55	0,193970	0,008978	0,197030	0,008637
45 - 50	0,221959	0,008738	0,231618	0,010589
40 - 45	0,256356	0,010618	0,265170	0,011114
35 - 40	0,312986	0,009475	0,313357	0,012770
30 - 35	0,377396	0,010538	0,384549	0,012181
25 - 30	0,470990	0,013136	0,479560	0,015137
20 - 25	0,546214	0,020415	0,533589	0,017474
15 - 20	0,590543	0,016834	0,605057	0,023428
10 - 15	0,680921	0,023961	0,700883	0,071905
5 - 10	0,858740	0,027227	0,967229	0,113639
0 - 5	1,226417	0,170760	1,372258	0,335783

Appendix 4.

Plate with Eccosorb

	Mean	Std
MP1	0,442131	0,011600
MP2	0,451299	0,013022

elev (deg)	MP1 Mean	MP1 Std	MP2 Mean	MP2 Std
85 - 90	0,000000	0,000000	0,000000	0,000000
80 - 85	0,121014	0,003769	0,125448	0,007157
75 - 80	0,134056	0,004066	0,132234	0,005649
70 - 75	0,157012	0,004485	0,138125	0,004069
65 - 70	0,162847	0,004688	0,152505	0,004736
60 - 65	0,158270	0,006956	0,161507	0,006371
55 - 60	0,177806	0,008535	0,175285	0,005178
50 - 55	0,191165	0,006214	0,196839	0,008593
45 - 50	0,213384	0,005331	0,228563	0,007059
40 - 45	0,253146	0,008960	0,259693	0,009805
35 - 40	0,305171	0,006711	0,310694	0,010264
30 - 35	0,367808	0,009905	0,383617	0,013384
25 - 30	0,458498	0,011283	0,485365	0,015694
20 - 25	0,535108	0,017841	0,542325	0,017136
15 - 20	0,587654	0,015848	0,607833	0,019202
10 - 15	0,674028	0,018935	0,677850	0,026913
5 - 10	0,855919	0,023999	0,942054	0,077553
0 - 5	1,218813	0,222538	1,484897	0,386275

Appendix 5.

Plate+Ring with Eccosorb

	Mean	Std
MP1	0,460462	0,005276
MP2	0,476897	0,005235

elev (deg)	MP1 Mean	MP1 Std	MP2 Mean	MP2 Std
85 - 90	0,000000	0,000000	0,000000	0,000000
80 - 85	0,127920	0,005128	0,134374	0,004784
75 - 80	0,138537	0,003350	0,141479	0,003819
70 - 75	0,160266	0,003291	0,146143	0,003303
65 - 70	0,169502	0,003969	0,158795	0,003241
60 - 65	0,170946	0,003070	0,170736	0,002748
55 - 60	0,185593	0,002635	0,187095	0,003608
50 - 55	0,203944	0,002782	0,209625	0,003933
45 - 50	0,228577	0,004202	0,248951	0,006161
40 - 45	0,269740	0,005445	0,277991	0,005260
35 - 40	0,312604	0,003608	0,339988	0,005506
30 - 35	0,385458	0,008240	0,405889	0,004535
25 - 30	0,478848	0,007802	0,508694	0,008245
20 - 25	0,560643	0,008246	0,566217	0,007760
15 - 20	0,607365	0,007670	0,647543	0,010294
10 - 15	0,700748	0,016244	0,714638	0,018371
5 - 10	0,908847	0,025667	1,027084	0,101945
0 - 5	1,387804	0,185697	1,343421	0,202156

Appendix 6. Quality file from TEQC, Kiruna GPS day 180

```
QC v3 by UNAVCO Summary File: 0KIR1800.98S Receiver type: ashtech z-xii3
     +-------------------------------------------------------------------+
 S  1| YYYYYYYYYYYY+                -YYYYYYYYYYYYY+                    |
 A  2|YYYYYY+                       IYYYYYYYYY+                IYYYYYYYYY|
 T  3|                    YYYYYYYYYYYYYYYY+                IYYYYYYYY+    |
 E  4|     -YYYYYYYYYYYY+                      -IYYYYYYYYYYYY+           |
 L  5| YYYYYYYYYYYYYYYYY+                   *IYYYYYYY+                  |
 L  6|          --YYYYYYYYYYYYYYY+                     -IYYYYYYY+        |
 I  7|YYYYYYYYYYY+                      YYYYYYYYYYYYYY+              IYY|
 T  8|YYYYYYYYYYYYYYYY+                -IYYYYYYYYY+                      |
 E  9|YYYYYYYYYYYYY+                  IYY---IY-                     IYYY|
   10|               RYYYYYYYYYY+                     IYYYYYYYYYYYYY+   |
   13|                   YYYYYYYYY+                  IYYYYYYYYYYYYYYYY+ |
   14|     YYYYYYYYY+                    YYYYYYYYYYYYYYYYY+             |
   15|YYYYYYYY+                       IYYYYYYYYYYYYYYY+               -I|
   16|        YYYYYYYYY+                      IYYYYYYYYYYYYYYYYY+        |
   17|                -YYYYYYYYYYYYYYY+                      YYYYYYYYYY+ |
   18|              YYYYYYYY+                     IYYYYYYYYYYYYYYYY+     |
   19|                    YYYYYYYYY+                  -YYYYYYYYYYYYYYYY+ |
   21|YYYYYYY+                IYYYYYYYYYYYYYYY+                      IYYY|
   22|              YYYYYYYYYYYYYYY+                  -IYYYYYYYYY+       |
   23|YYYYY+                  IYYYYYYYYYYYYYY+                    IYYYYYY|
   24|       -YYYYYYYYYYYYY+                       IYYYYYYYYYYYY+       |
   25|       YYYYYYYYYYYYYY+                 IYYYYYYYYYYYY+             |
   26|YYYYY+                  IYYYYYYYYYY+                    IYYYYYYYYYY|
   27|+                       YYYYYYYYY+                 -YYYYYYYYYYYYYYYY|
   29|    YYYYYYYYYYY+                  -IYYYYYYYYYYYYY+                 |
   30|    YYYYYYYYYYYYYYYYY+                     IYYYYYYY+               |
   31|+                       IYYYYYYYYYYYYYYY+                 *RYYYYYYYYY|
  CLK|                                                                   |
     +--------|--------|--------|--------|--------|--------|--------|-------+
      00:00                                                          23:59

Time of First Epoch in File (year,month,day,hour) :98   6  29   0: 0
Time of Last Epoch in File (year,month,day,hour)  :98   6  29  23:59
Observation Interval for File (in seconds)        :      15
Elevation cutoff for qc                           :       5
Total number of observations expected             :   56272
Total number of observations in file              :   54403
Total number of points deleted                    :     422
Data collection percentage                        :      97
RINEX vs qc point pos diff [Km]                   :    0.30
Average MP1                                       : 0.17395
Average MP2                                       : 0.18802
# of points for MP moving average                 :      50
Average clock drift [msec/hr]                     :   0.000
Average time between resets [min]                 :   0.000
Number of detected slips                          :      37
Observations per slip                             :    1470
    first epoch     last epoch     hrs   dt  #expt  #have  %   mp1   mp2   o/slp
SUM 98  6 29  0: 0 98  6 29 23:59 24.00  15  56272  54403  97  0.17  0.19   1470

Meaning of flags:
I slip detected on iono phase      S multipath slip MP1 and MP2
R multipath slip on MP1 only       P multipath slip on MP2 only
C clock reset / slip (optional)    G gap in data
- SV up but no data found          + SV data but below elev mask
. L1 C/A only no A/S               , L1 C/A only A/S
: L1 P only no A/S                 ; L1 P only A/S
~ L1 C/A L2 P no A/S               # L1 C/A L2 P A/S
* L1 P L2 P no A/S                 Y L1 P L2 P A/S
```

PM 1998-09-18

ECOSORBS inverkan på statisk GPS-mätning

Bakgrund

I samband med examensarbetet "Multipath at the SWEPOS-stations..." genomfört av Thor-Björn Andreasson och Linda Engman, testades ett microvågsabsorberande material - ECOSORB - för att minska flervägsfelen på SWEPOS-stationerna. Materialtet placerades på olika sätt kring Dorne-Margolin antennen på SWEPOS-stationen Mårtsbo. Som jämförelse användes mätningar utan ECOSORB.

För att testa ECOSORBs påverkan på statiska bärvågsmätningar samlades data samtidigt på SIB 1 (stativuppställning - inget ECOSORB). Mätningar insamlade för test av statisk bärvågsmätning framgår av tabell 1. Tre till fyra sessioner á 24 timmar finns för varje uppställning. Sessionerna börjar olika tid på dygnet, men det faktum att det är hela dygn gör att alla sessionerna innehåller samma satellitkonfigurationer. Eventuella avvikelser mellan sessionerna bör därför ej kunna härledas till skillnader i konfigurationen.

ECOSORB runtom + under				Utan ECOSORB				ECOSORB under		
114	115	116	117	118	119	120	121	149	150	151

Tabell 1: Sessioner (dagnummer 1998) med data samlade på SIB1 för tester av materialet ECOSORBs inverkanpå statisk bärvågsmätning.

Testets genomförande

Två tester genomfördes, dels en antennkalibrering, dels ett elevationsgränstest. Bern-programmet version 4.0 användes för beräkningarna.

LOTTI JIVALL
LF-DATA GEODESI-ENHETEN 802 82 GÄVLE
BESÖK: LANTMÄTERIGATAN 2 TEL: 026-63 37 40 FAX: 026-61 06 76
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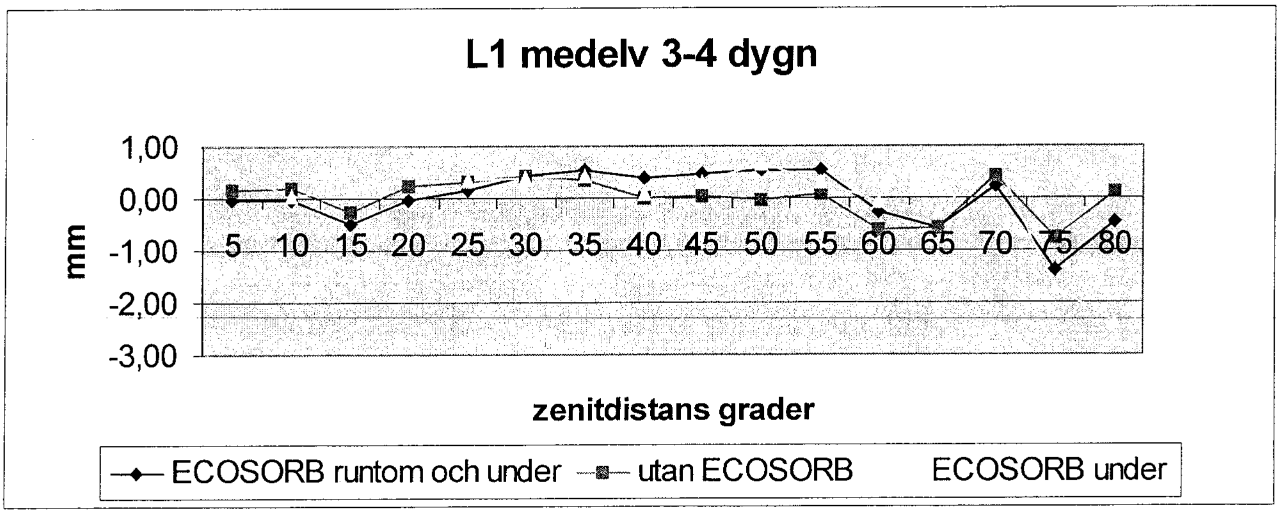
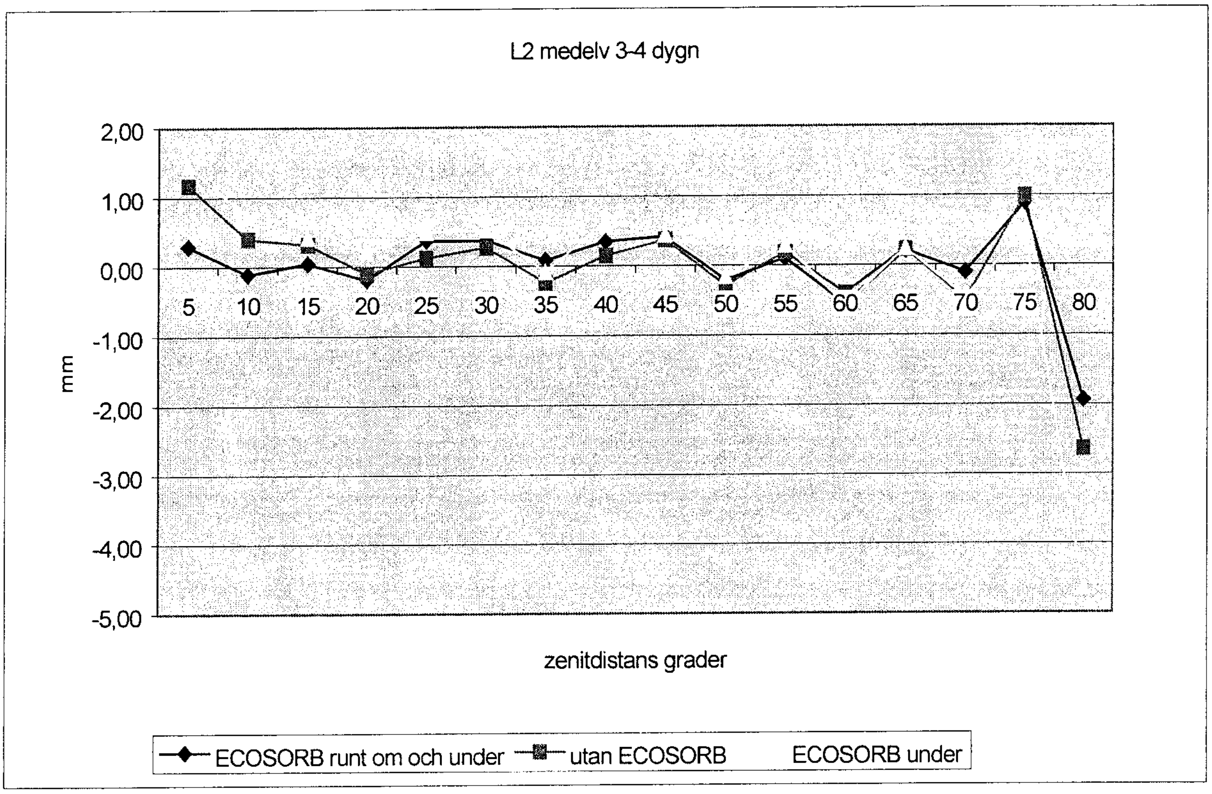
Antennkalibrering

Vid antennkalibreringen kalibrerades antennen på Mårtsbo (Dorne Margolin T med och utan ECOSORB) relativt en Dorne Margolin T-antenn på stativ på punkten SIB1, som ligger c:a 50 m från SWEPOS-pelaren i Mårtsbo. Först gjordes en bestämning av offset mellan antennerna. Någon signifikant skillnad kan inte konstateras ur dessa beräkningar (se bilaga 1). Därefter löstes elevationsberoende parametrar ut. För att inte eventuella centreringsfel i plan skulle påverka elevationsparameterarna löstes offset parametrar i plan ut samtidigt. Offset i höjd varken löstes ut eller sattes till det värde som bestämts i tidigare steg, vilket gör att elevationsparametrarna modellerar hela höjdavvikelsen. Avvikelserna redovisas i form av elevationsberoende parameterar numeriskt i bilaga 1 och grafiskt i figur 1 och 2. Antennmodellerna för de olika uppställningarna har väldigt små korrektioner och är dessutom mycket lika varandra. Korrektionen för 10 ° elevation (zenitdistans =80°) med ECOSORB under antennen avviker från de andra. Det är dock inte omöjligt att denna avvikelse beror på något annat än avvikande karaktäristik för den antennuppställningen, t.ex. andra mätförhållanden. Den ev. skillnaden är dessutom inte speciellt intressant eftersom en elevationsgräns på 15 ° normalt används vid statiska beräkningar.



Figur 1: Elevationsberoende parametrar för L1 från antennkalibrering. Korrektioner i mm som en funktion av zenitdistansen (90° - elevationen). Medelvärde av 3-4 dagar för respektive uppställning.



Figur 2: Elevationsberoende parametrar för L2 från antennkalibrering. Korrektioner i mm som en funktion av zenitdistansen (90° - elevationen).Medelvärde av 3-4 dagar för respektive uppställning.

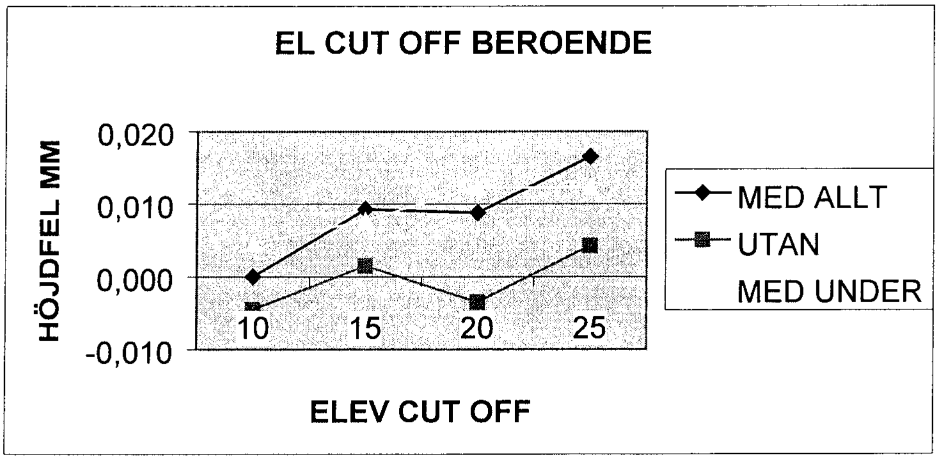
Även om skillnaderna är små skall man vara medveten om att dessa förstärks vid användning av jonosfärsfri linjärkombination. Vid bestämning av troposfärsparametrar tas dessutom omodellerade avviklser mellan antennerna upp och resulterar i höjdfel.

Elevationsgränstest

I ett elevationsgränstest utförs beräkningar med olika elevationsgränser (mätningar med lägre elevation tas ej med). Samma beräkningsmetod som vid noggrann efterberäkning mot SWEPOS användes, d.v.s. jonosfärsfri linjärkombination och bestämning av troposfärsparametrar.

Fel som är beroende av elevationsgränsen tyder på en dålig antennmodellering. Vidare visar det här testet om och i så fall hur stor systematisk effekt som ECOSORB ger vid ovan nämnda beräkningsmetod.

I figur 3 redovisas höjdfel (jämfört med avvägd höjd) för de olika uppställningarna. Numeriska resultat redovisas i bilaga 1.



Figur 3: Höjdfel vid olika elevationsgränser och med olika mycket ECOSORB, medelvärde av 3-4 dagar.

Detta test visar att ECOSORB ger en systematisk påverkan i höjd vid beräkningar med jonosfärsfri lösning och bestämning av troposfärsparametrar. Däremot verkar det inte vara någon skillnad om materialet endast är placerat under eller om det även finns runtom antennen. Vid noggrann positionsbestämning mot SWEPOS, t.ex. beräkning av SWEREF-punkter, används elevationsgränsen 15 °. Det här testet indikerar ett systmatiskt höjdfel på 5-10 mm på Mårtsbo vid den typen av beräkning. Detta är tillräckligt stort för att kunna ge en påverkan (om än mycket liten) på beräkningen av en nypunkt i SWEREF 93. (Anslutningen görs ju då normalt mot 6 stationer, en enstaka station får då inte så stor påverkan.)

Om resultaten från den här studien är relevant kan man förmodligen se ett hopp i tidsserierna på Mårtsbo. Risken finns att detta felaktigt tolkas som en hastighet.

Tidsseriestudier på SWEPOS

ECOSORBs äventyr på SWEPOS framgår av tabell 2.

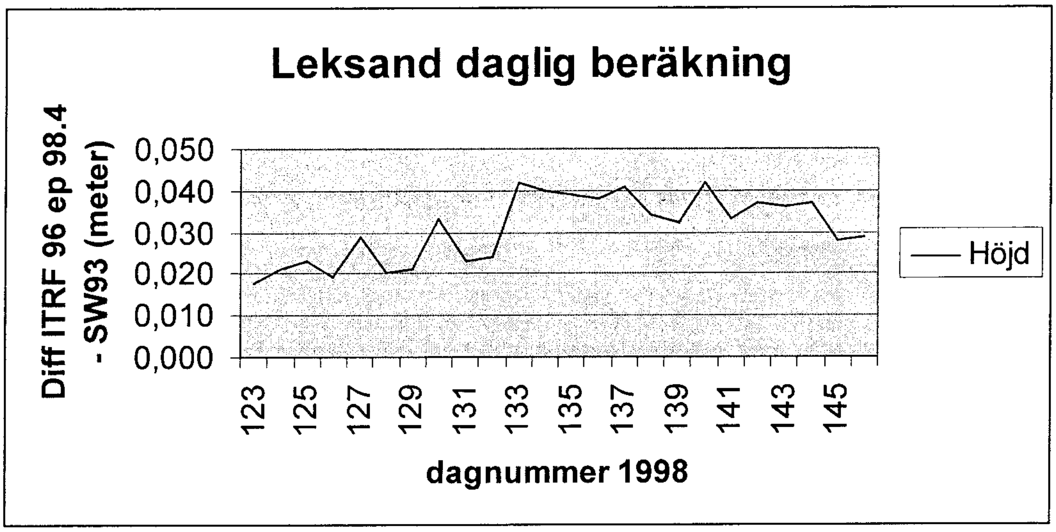
Datum	Dag	Tid	Förändring
98-04-03	93	10:30	ECOSORB under antennen på Mårtsbo
98-04-24	114	9:30	ECOSORB under och runtom antennen på Mårtsbo
98-04-28	118	19-21	ECOSORB togs bort på Mårtsbo
98-05-04	124	13:45	ECOSORB under och runtom antennen på Mårtsbo
98-05-12	132	12:00	ECOSORB under och runtom antennen på Leksand
98-05-29	149	15:10	ECOSORB under antennen på Mårtsbo
98-07-01	182	Ca 10	ECOSORB bort på Leksand

Tabell 2: Tidpunkter för av- och på-montering av ECOSORB på SWEPOS-stationerna.

De dagliga SWEPOS-beräkningarna vid LMV startade först v 956, d.v.s. dag 123 1998. En tidseriestudie på Mårtbo ur våra beräkningar är därför inte möjlig utan att först beräkna ytterligare äldre veckor. Onsala Rymdobservatorium har dock utfört dagliga beräkningar sedan många år tillbaka.

Höjdkomponenten för Leksand kan dock studeras före och efter ECOSORB ur LMVs beräkningsmaterial. Beräkningarna är utförda som ett fritt nät med viktade koordinater (0.1 mm på varje komponent) på Onsala i ITRF 96 epok 1998.4. Jonosfärsfri linjärkombination, bestämning av troposfärsparametrar och elevationsgränsen 15° har använts. Se figur 4.

På grund av det långa avståndet till den "fasta punkten" (407 km) är bruset ganska högt, c:a 1 cm, i höjd. Trots det kan man (med lite god vilja?) i figur 4 se ett hopp på c:a 1 cm vid dag 133, d.v.s. den första hela dagen med ECOSORB. Numeriskt resultat finns i bilaga 1. Ett säkrare resultat kan erhållas genom att studera längre tidsserier, vilket som sagt finns på Onsala Rymdobservatorium.



Figur 4: Tidsserie på Leksand, ur dagliga SWEPOS-beräkningar.

Slutsatser

Både elevationsgränstestet på Mårtsbo och tidsserien på Leksand indikerar att ECOSORB ger en systematisk effekt på i storleksordningen 5-10 mm i höjd (punkten hamnar för högt) vid statisk bärvågsmätning, beräknad med jonosfärsfri linjärkombination och bestämning av troposfärsparametrar. Detta är mycket allvarligt! En jämförelse med Onsalas tidsserier för Mårtsbo och Leksand bör göras. Om dessa bekräftar resultatet av de här testerna bör ECOSORB tas bort.

Antennkalibrering -Offset

Offset från antennkalibrering av Mårtsbo, med ECOSORB runtom och under, utan och endast under. Observera att antennen har centrerats om mellan de olika uppställningarna (114-117, 118-121 och 149-151) och att den använda trefotens optiska lod var behäftat med parallax. Offsetvärdena i plan är därför inte relevanta.

SESSION		1140	1150	1160	1170	1180	1190	1200	1210	1490	1500	1510
L1	N	-0.0016	-0.0016	-0.0015	-0.0018	-0.0030	-0.0031	-0.0031	-0.0030	-0.0017	-0.0017	-0.0022
	E	0.0021	0.0021	0.0016	0.0019	0.0017	0.0017	0.0017	0.0017	0.0034	0.0040	0.0039
	U	-0.0007	-0.0008	-0.0008	-0.0007	-0.0006	-0.0005	-0.0007	-0.0004	-0.0010	-0.0009	-0.0015
L2	N	-0.0014	-0.0015	-0.0013	-0.0018	-0.0029	-0.0029	-0.0029	-0.0028	-0.0017	-0.0016	-0.0020
	E	0.0018	0.0018	0.0014	0.0016	0.0015	0.0016	0.0016	0.0015	0.0029	0.0035	0.0034
	U	0.0003	0.0002	0.0008	0.0007	0.0002	0.0001	0.0001	0.0008	-0.0007	-0.0007	-0.0004

Antennkalibrering - elevationsparametrar

Med ECCOSORB runtom och under

L1		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	1140	0,09	-0,11	-0,48	-0,1	0,04	0,33	0,44	0,44	0,42	0,62	0,44	-0,21	-0,67	0,31	-1,52	-0,03
	1150	-0,4	-0,02	-0,39	0,09	0,26	0,5	0,55	0,47	0,34	0,61	0,61	-0,21	-0,54	0,23	-1,35	-0,73
	1160	-0,14	0,17	-0,63	0,1	0,16	0,43	0,6	0,24	0,55	0,52	0,49	-0,27	-0,61	0,22	-1,3	-0,53
	1170	0,24	-0,15	-0,43	-0,17	0,13	0,4	0,52	0,42	0,61	0,37	0,58	-0,37	-0,54	0,22	-1,3	-0,53
MEDEL		-0,05	-0,03	-0,48	-0,02	0,15	0,42	0,53	0,39	0,48	0,53	0,53	-0,27	-0,59	0,25	-1,37	-0,46
STD DEV		0,28	0,14	0,11	0,14	0,09	0,07	0,07	0,10	0,12	0,12	0,08	0,08	0,06	0,04	0,10	0,30

Utan ECCOSORB

	1180	0,02	0,27	-0,24	0,17	0,36	0,47	0,17	0,11	0,15	-0,13	0,07	-0,65	-0,51	0,38	-0,91	0,28
	1190	0,24	-0,01	-0,11	0,27	0,4	0,38	0,39	0,03	0,06	0,06	0,11	-0,52	-0,54	0,58	-0,74	-0,61
	1200	0,57	0,2	-0,21	0,35	0,22	0,44	0,36	0,02	0,12	-0,04	0,06	-0,76	-0,56	0,5	-0,96	-0,32
	1210	-0,14	0,25	-0,52	0,18	0,19	0,34	0,41	-0,22	-0,11	-0,12	0,06	-0,55	-0,65	0,27	-0,4	1,04
MEDEL		0,17	0,18	-0,27	0,24	0,29	0,41	0,33	-0,02	0,06	-0,06	0,08	-0,62	-0,57	0,43	-0,75	0,10
STD DEV		0,31	0,13	0,18	0,08	0,10	0,06	0,11	0,14	0,12	0,09	0,02	0,11	0,06	0,14	0,25	0,73

Med ECOSORB under

	1490	0,81	0,16	0,08	0,67	0,21	0,25	0,31	-0,19	0,22	0,73	0,3	-0,1	-0,29	0,87	-1,77	-2,24
	1500	0,53	-0,2	0,25	0,48	0,41	0,35	0,35	0,05	0,25	0,58	0,34	-0,11	-0,28	0,78	-1,64	-2,15
	1510	0,23	0,2	0,12	0,6	0,46	0,54	0,6	0,34	0,48	0,68	0,25	-0,03	-0,27	0,42	-1,82	-2,81
MEDEL		0,52	0,05	0,15	0,58	0,36	0,38	0,42	0,07	0,32	0,66	0,30	-0,08	-0,28	0,69	-1,74	-2,40
STD DEV		0,29	0,22	0,09	0,10	0,13	0,15	0,16	0,27	0,14	0,08	0,05	0,04	0,01	0,24	0,09	0,36

Med ECCOSORB runtom och under

L2		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	1140	0,88	-0,18	0,12	-0,17	0,36	0,37	0,15	0,4	0,36	-0,21	-0,12	-0,57	0,01	-0,15	0,78	-2,03
	1150	0,26	-0,04	0,19	-0,1	0,5	0,45	0,27	0,43	0,29	-0,19	0,12	-0,66	0,21	-0,32	1	-2,39
	1160	-0,06	-0,03	-0,16	-0,13	0,23	0,28	-0,1	0,21	0,47	-0,18	0,18	-0,46	0,24	-0,05	1,04	-1,49
	1170	0,09	-0,21	0,02	-0,37	0,39	0,38	0,01	0,35	0,56	-0,26	0,23	-0,56	0,38	0,1	0,73	-1,85
MEDEL		0,29	-0,12	0,04	-0,19	0,37	0,37	0,08	0,35	0,42	-0,21	0,10	-0,56	0,21	-0,11	0,89	-1,94

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STD DEV		0,41	0,09	0,15	0,12	0,11	0,07	0,16	0,10	0,12	0,04	0,16	0,08	0,15	0,18	0,16	0,37
Utan ECCOSORB																	
	1180	0,61	0,57	0,36	-0,09	0,28	0,29	-0,36	0,27	0,46	-0,26	0,21	-0,38	0,15	-0,32	0,51	-2,3
	1190	1,7	0,16	0,49	-0,09	0,24	0,21	-0,2	0,19	0,33	-0,26	0,21	-0,42	0,18	-0,51	0,84	-3,06
	1200	1,6	0,49	0,39	-0,03	0,17	0,3	-0,17	0,26	0,46	-0,26	0,17	-0,49	0,33	-0,56	0,79	-3,44
	1210	0,75	0,37	0,02	-0,2	-0,2	0,27	-0,24	-0,14	0,24	-0,37	0,14	-0,31	0,26	-0,61	1,8	-1,77
MEDEL		1,17	0,40	0,32	-0,10	0,12	0,27	-0,24	0,15	0,37	-0,29	0,18	-0,40	0,23	-0,50	0,99	-2,64
STD DEV		0,56	0,18	0,20	0,07	0,22	0,04	0,08	0,19	0,11	0,06	0,03	0,08	0,08	0,13	0,56	0,75
Med ECOSORB under																	
	1490	1,81	0,76	0,29	0,41	0,5	0,62	-0,11	0,57	0,33	-0,12	0,34	-0,57	0,2	-0,36	0,3	-4,97
	1500	1,08	0,69	0,58	0,26	0,53	0,56	-0,08	0,67	0,46	-0,21	0,26	-0,56	0,15	-0,48	0,42	-4,34
	1510	1,49	0,72	0,4	-0,01	0,44	0,37	-0,07	0,66	0,55	-0,15	0,27	-0,61	0,37	-0,56	0,77	-4,64
MEDEL		1,46	0,72	0,42	0,22	0,49	0,52	-0,09	0,63	0,45	-0,16	0,29	-0,58	0,24	-0,47	0,50	-4,65
STD DEV		0,37	0,04	0,15	0,21	0,05	0,13	0,02	0,06	0,11	0,05	0,04	0,03	0,12	0,10	0,24	0,32

Elevationsgränstest

MART,6_F10_1140	6720630,409	1579635,414	44,970			
MART,6_F10_1150	6720630,409	1579635,414	44,970			
MART,6_F10_1160	6720630,409	1579635,413	44,970			
MART,6_F10_1170	6720630,409	1579635,414	44,970	6720630,409	1579635,414	44,970
MART,6_FIX_1140	6720630,409	1579635,414	44,980			
MART,6_FIX_1150	6720630,409	1579635,414	44,980			
MART,6_FIX_1160	6720630,409	1579635,414	44,978			
MART,6_FIX_1170	6720630,409	1579635,414	44,979	6720630,409	1579635,414	44,979
MART,6_F20_1140	6720630,409	1579635,414	44,979			
MART,6_F20_1150	6720630,409	1579635,414	44,978			
MART,6_F20_1160	6720630,409	1579635,414	44,978			
MART,6_F20_1170	6720630,409	1579635,414	44,980	6720630,409	1579635,414	44,979
MART,6_F25_1140	6720630,409	1579635,414	44,986			
MART,6_F25_1150	6720630,409	1579635,414	44,987			
MART,6_F25_1160	6720630,409	1579635,414	44,986			
MART,6_F25_1170	6720630,409	1579635,414	44,987	6720630,409	1579635,414	44,987
MART,6_F10_1180	6720630,408	1579635,413	44,965			
MART,6_F10_1190	6720630,408	1579635,413	44,967			
MART,6_F10_1200	6720630,408	1579635,413	44,965			
MART,6_F10_1210	6720630,408	1579635,413	44,965	6720630,408	1579635,413	44,966
MART,6_FIX_1180	6720630,407	1579635,414	44,972			
MART,6_FIX_1190	6720630,408	1579635,414	44,972			
MART,6_FIX_1200	6720630,408	1579635,414	44,971			
MART,6_FIX_1210	6720630,407	1579635,414	44,971	6720630,408	1579635,414	44,972
MART,6_F20_1180	6720630,408	1579635,413	44,967			
MART,6_F20_1190	6720630,408	1579635,414	44,967			
MART,6_F20_1200	6720630,407	1579635,414	44,966			
MART,6_F20_1210	6720630,408	1579635,414	44,966	6720630,408	1579635,414	44,967
MART,6_F25_1180	6720630,408	1579635,414	44,975			
MART,6_F25_1190	6720630,408	1579635,414	44,974			

MART,6_F25_1200	6720630,408	1579635,414	44,975			
MART,6_F25_1210	6720630,408	1579635,414	44,973	6720630,408	1579635,414	44,974
MART,6_FACIT	6720630,411	1579635,412	44,970			
MART,6_f10_149	6720630,410	1579635,416	44,972			
MART,6_f10_150	6720630,410	1579635,416	44,973			
MART,6_f10_151	6720630,409	1579635,416	44,971	6720630,410	1579635,416	44,972
MART,6_f15_149	6720630,409	1579635,416	44,977			
MART,6_f15_150	6720630,409	1579635,416	44,977			
MART,6_f15_151	6720630,408	1579635,416	44,976	6720630,409	1579635,416	44,977
MART,6_f20_149	6720630,409	1579635,416	44,970			
MART,6_f20_150	6720630,409	1579635,416	44,971			
MART,6_F20_151	6720630,408	1579635,416	44,970	6720630,409	1579635,416	44,970
MART,6_f25_149	6720630,409	1579635,416	44,975			
MART,6_f25_150	6720630,409	1579635,416	44,980			
MART,6_F25_151	6720630,408	1579635,416	44,976	6720630,409	1579635,416	44,977

Tidsserie- Leksand

dag	ΔN	ΔE	ΔH
123	0,179	0,089	0,018
124	0,182	0,087	0,021
125	0,178	0,093	0,023
126	0,182	0,091	0,019
127	0,180	0,091	0,029
128	0,185	0,089	0,020
129	0,185	0,092	0,021
130	0,182	0,092	0,033
131	0,181	0,093	0,023
132	0,180	0,092	0,024
133	0,181	0,091	0,042
134	0,182	0,090	0,040
135	0,182	0,092	0,039
136	0,182	0,092	0,038
137	0,187	0,090	0,041
138	0,180	0,090	0,034
139	0,185	0,090	0,032
140	0,181	0,094	0,042
141	0,183	0,092	0,033
142	0,183	0,090	0,037
143	0,183	0,091	0,036
144	0,184	0,093	0,037
145	0,186	0,094	0,028
146	0,187	0,095	0,029

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