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Processing of the NKG 2003 GPS Campaign

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LANTMÄTERIET

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Processing of the NKG 2003 GPS Campaign

1 Introduction

The Nordic countries have implemented national realizations of ETRS 89. Depending on when the realizations were made and on which ITRF the realizations are based, there are differences between the realizations up to a few cm. The national realizations have already been introduced to the users and will not be replaced. There are however situations were a common reference frame could be useful, e.g. for the Nordic Position Service which is under development. A common reference frame could also act as a link for transformations between the different national realizations and between the realizations and ITRF.

Resolution No 3 of the 14th General Meeting of NKG recommends the development of a unified ETRS 89 reference frame on the cm level for the Nordic area and of formulas for transformation from such a reference frame to the national realizations of ETRS 89, as well as the transformation from ITRF to the unified ETRS 89 reference frame."

The NKG working group for Positioning and Reference frames was given the task to develop such a common Nordic reference frame and transformation formulas. The chairman of this working group, Per Knudsen at DNSC[1], is leading the activity.

A working group meeting was held in Gävle in June 2003 to plan and organize the work.

GPS observations for the NKG 2003 GPS campaign were carried out from September 28th to October 4th, 2003 as a co-operation between members of NKG and the Baltic Countries. The observation campaign and data quality assurance were coordinated by Finn Bo Madsen at KMS[2]/DNSC.

The campaign has been processed by four analysis centres, using three different softwares:

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[1] Danish National Space Centre

[2] Kort og Matrikelstyrelsen, Denmark

- NMA[3], Torbjørn Nørbech, GIPSY/OASIS II
- OSO[4], Martin Lidberg, GAMIT/GLOBK
- LMV[5], Lotti Jivall, Bernese version 5.0
- KMS (Kort og Matrikelstyrelsen, Denmark), Mette Weber /Henrik Rønnest, Bernese version 4.2

The processing was coordinated by Lotti Jivall at LMV, Sweden, who also is responsible for calculating the final combined solution.

The last part of the project is the development of transformation strategies and formulas. This work is lead by Torbjørn Nørbech at NMA, Norway.

This report documents the processing of the campaign.

[3] Norweigian Mapping Authority

[4] Onsala Space Observatory, Sweden

[5] Lantmäteriet, Sweden

2 The campaign

GPS observations for the NKG 2003 GPS campaign were carried out from September 28th to October 4th, 2003 (day 271 to 277, GPS-week 1238). The observation campaign was co-ordinated by Finn Bo Madsen at KMS, Denmark.

Stations from Denmark, Estonia, Finland, Greenland, Iceland, Latvia, Lithuania, Norway and Sweden – finally 133 stations – participated in the campaign – see figure 1 and 2.

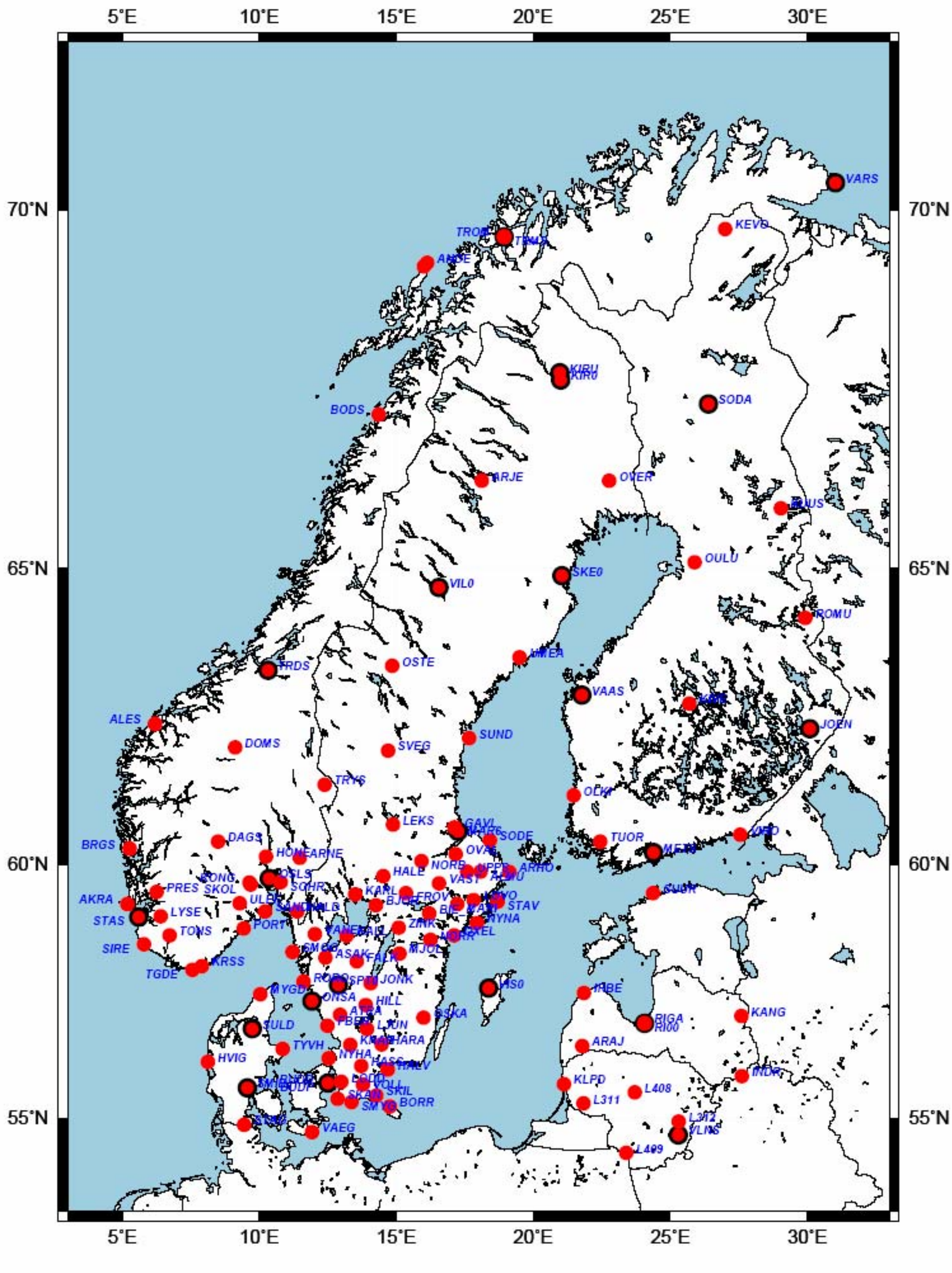

Figure 1: Stations in the Nordic-Baltic part of the NKG 2003 campaign.

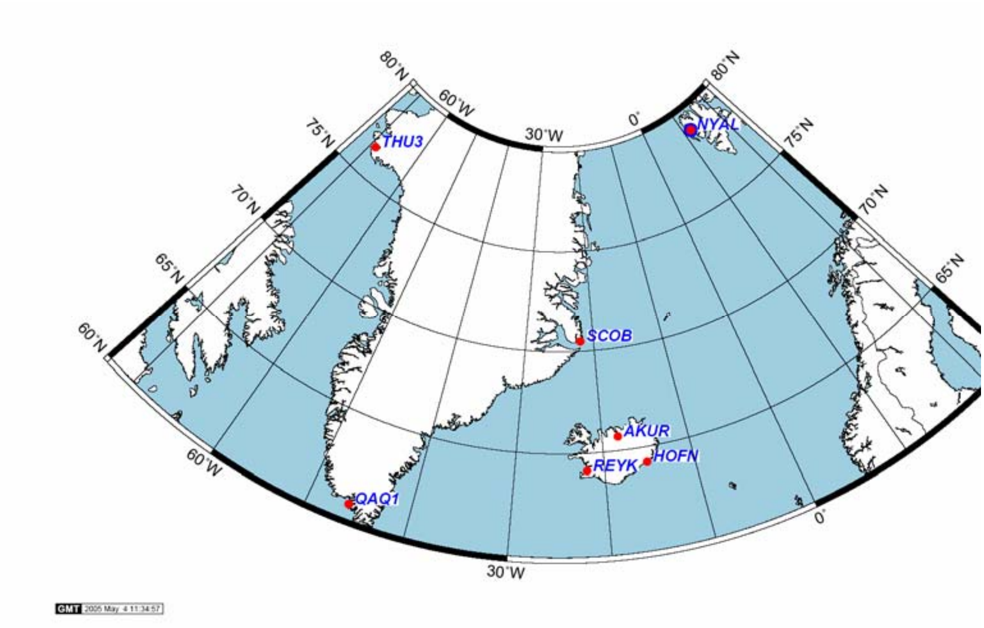

Figure 2: Stations in the Atlantic part of the NKG 2003 campaign.

Table 1 contains names, sorted by country, for all the observing locations found. Most of the GPS sites are permanent. Non-permanent stations have been written under a line.

Data and sitelog information for all stations have been transferred to an ftp-server (ftp2.kms.dk) at KMS in Copenhagen.

The RINEX-files and site log files were checked for quality, completeness and correctness by Henrik Rønnest at KMS. This quality control is documented in a special Data Validation Report.

The station characteristics (antenna, receiver and eccentricities) are found in appendix A.

The Lithuanian colleagues noticed problems with one of their stations (L311). To be sure to have this station included in the resulting coordinate set from the campaign, this station was observed for 5 extra days (292-296), ten days after the campaign together with the Lithuanian stations VLNS and KLPD.

Table 1: Stations included in the NKG 2003 GPS Campaign.

Denmark	TUOR	--------	PRES	FROV	OSTE
BUDP	VIRO	L311	SAND	GAVL	OVAL
SMID	VAAS	L312	SIRE	HALE	OVER
SULD		L408	SKOL	HALV	OXEL
--------	**Greenland**	L409	SOHR	HARA	RORO
BORR	QAQ1		STAS	HASS	SKAN
BUDD	SCOB	**Norway**	TGDE	HILL	SKE0
HVIG	THU3	AKRA	TONS	JONK	SKIL
MYGD		ALES	TRDS	KALL	SMOG
STAG	**Iceland**	ANDE	TRMS	KARL	SMYG
TYVH	AKUR	ANDO	TRO1	KIR0	SODE
VAEG	HOFN	ARNE	TROM	KIRU	SPT0
	REYK	BODS	TRYS	KNAR	STAV
Estonia		BRGS	ULEF	LEKS	SUND
SUUR	**Latvia**	DAGS	VARS	LJUN	SVEG
	IRBE	DOMS		LODD	UMEA
Finland	RIGA	HALD	**Sweden**	LOVO	UPPS
JOEN	--------	HONE	ALMU	MAR6	VANE
KEVO	ARAJ	KONG	ARHO	MARI	VAST
KIVE	INDR	KRSS	ARJE	MJOL	VIL0
KUUS	KANG	LYSE	ASAK	NORB	VIS0
METS	RI00	NALS	ATRA	NORR	VOLL
OLKI		NYA1	BIE_	NYHA	ZINK
OULU	**Lithuania**	NYAL	BJOR	NYNA	
ROMU	KLPD	OSLS	FALK	ONSA	
SODA	VLNS	PORT	FBER	OSKA	

3 Guidelines for the Processing

3.1 Introduction

Martin Lidberg and Lotti Jivall were assigned the task to propose guidelines for the processing of the NKG 2003 campaign. A draft was written in January 2004 and distributed to the analysis centres. The document was never finally published. During the processing some of the guidelines were changed, mainly concerning division into sub-networks and the connection to ITRF. The guidelines in this section are updated with those changes.

Guidelines are proposed for the following areas:

- the troposphere,
- ocean tide loading,
- atmospheric loading,
- orbits,
- other processing options,
- possible sub-network division
- connecting the campaign network to ITRF2000,

3.2 General strategy

At the meeting in Gävle in June 2003 of the working group for positioning and reference frames it was concluded that it would be a good idea to process the GPS campaign using the different software packages available within the group. These are:

- the Bernese GPS processing software
- GIPSY/OASIS II
- GAMIT/GLOBK

As a general philosophy for computing a GPS campaign using different software packages, we have concluded that each software package should be used together with the recommended settings for the respective software. Using this approach we will be able to check for possible differences in the result not only depending on the programs used, but also due to differences in processing strategy.

No attempt is therefore done to fully harmonise the processing strategy. We have rather tried to document how the programs are commonly used and if possible explain and compare differences.

Just for a few (but important) parameters, common recommendations were set: elevation cut-off = 10°, elevation dependent weighting of the observations, ocean tide loading corrections using the FES 99 model (values from Onsala provided for the stations in the campaign), and no atmospheric loading correction.

3.3 The Troposphere

See appendix A for a theoretical background.

3.3.1 Proposal

For handling the troposphere it is proposed to use the settings recommended for the particular software.

3.3.2 The Bernese GPS software Version 4.2

In the manual for Bernese v 4.2 (pg 191) it is recommended to estimate the total zenith delay together with the use of the dry Niell mapping function (Niell 1996).

In previous versions of the software it was recommended to use an apriori model for the delay and to estimate only the *corrections* to this model. But because the mapping functions included in these models (e.g. Saastamoinen or Hopefield) is not the best anymore, this is no longer the recommendation.

According to “Guidelines for EPN analysis” (http://www.epncb.oma.be/guidelines/guidelines_analysis_centres.html) the recommendation is to estimate hourly troposphere parameters. The estimated parameters are valid for the time period (t_i to t_{i+1}). The troposphere modelling may thus be considered as a step function (Bernese GPS software Version 4.2 documentation).

Since the objective of this campaign is to get a common co-ordinate set, the tropospheric parameters are just a bi-product, it is allowed to increase the interval for the tropospheric parameters to hold down the number of unknowns.

3.3.3 The Bernese GPS software Version 5.0

The recommendations for the troposphere handling have been changed for this new version (according to the help function in the program).

It is recommended to model the hydrostatic (dry) component of the tropospheric path delay using the Saastamoinen model with 'dry' Niell mapping function to obtain troposphere slant path delay values. The wet part is estimated as troposphere zenith path delay corrections using the 'wet' Niell mapping function.

In addition to this horizontal gradient parameters should be estimated using the tilting-function – one set for 24 hours – to model azimuthal asymmetries.

3.3.4 GAMIT

In GAMIT the troposphere delay is divided into its dry and wet components.

The zenith dry delay is determined from a model, and the estimated deviation from this model is considered to be the wet delay. An apriori value for zenith wet delay is determined from a model. To convert the zenith dry delay and the estimated wet delay to delay at a particular elevation, separate mapping functions for the dry and wet delay are applied.

According to the GAMIT documentation the proposed models and parameters to use is Saastamoinen model for dry and wet zenith delay, the Niell dry and wet mapping functions, and a sea level pressure of 1013.25 mbar, temperature of 20°C, and 50% relative humidity.

3.3.5 GIPSY

The handling of troposphere in GIPSY is principally very similar to GAMIT. A value for the zenith hydrostatic delay is achieved from an apriori model, and a value for the wet zenith delay is determined during parameter estimation. An apriori value for the wet zenith delay of 0.10m is used. Unfortunately, the apriori model for the hydrostatic zenith delay is not known for the authors.

The Niell (1996) are the current choice of hydrostatic and wet mapping functions.

3.3.6 Short comparison of the different approaches for handling of troposphere between the software

The "error" in modelling of the troposphere done by the Bernese version 4.2 approach is to model the complete tropospheric delay using the dry Niell mapping function. Therefore the wet part of the tropospheric delay is modelled with "wrong" mapping function (the dry and not the wet mapping function). If the wet part of the zenith tropospheric delay is considered to be less than 25 cm (extreme value), the amount of tropospheric zenith delay that is not optimally modelled is 25 cm. A typical value is at the level of 10 cm at mid to high latitudes.

The "error" in modelling done while using the Bernese version 5.0, GAMIT or GIPSY approach, is that the value for the hydrostatic delay is achieved from an a priori model and variations from the actual hydrostatic delay is thus modelled using wrong mapping function (the wet and not the dry mapping function). The correct value for the hydrostatic delay can be computed accurately from measured air pressure using (7) and (8) in appendix.

A simple check of the RINEX m-files from Metsähovi at noon during year 2003 give a (minimum, mean and maximum) value of (970, 1005, 1034) hPa. The variation is thus –35 to +30 hPa. Applying this variation to the typical sea level pressure of 1013.25 hPa and computing hydrostatic delay for Onsala following eq. (7) and (8) of the appendix, gives the results presented in Table 1.

Table 2: Hydrostatic delay computed for Onsala (latitude 57.2°, ellipsoidal height 45m) following equation (7) and (8) of the Appendix.

Air pressure at Sea level (hPa)	Hydrostatic delay (hd) in (m)	Deviation from a priori hd in (m)	Comment
1013.25	2.288		Normal pressure
1043.25	2.355	+0.067	+ 30 hPa
978.25	2.208	-0.080	-35 hPa
1083	2.445	+0.157	Siberia 1969 *
870	1.964	-0.324	Philippines 1969 *
1064	2.402	+0.114	Kalmar, Sweden, 1907*

(* Source: http://www.aftonbladet.se/vss/vader/story/0,2789,328755,00.html , and Eva Brokhøj, SMHI, Gefle Dagblad 2003-11-06).

From table 2 it can be concluded that the hydrostatic delay deviate from its a priori value by less than 10 cm except for extreme events. This is thus the miss modelling introduced in the GIPSY and GAMIT approach.

Comparing the tropospheric modelling in the Bernese version 4.2 and Bernese version 5.0, GIPSY or GAMIT software it may be concluded that modelling errors would be expected to be slightly smaller in the Bernese version 5.0, GIPSY or GAMIT approach.

3.4 Ocean tide loading

It is proposed to model the ocean tide loading in the processing. Hans-Georg Scherneck, OSO, has generously offered the help to compute ocean tide loading parameters for all stations included in our campaign.

The primary recommendation model for our project is to use FES99, or GOT00 as a second choice. The differences in the result of our GPS campaign due to different models for Ocean tide loading would however be very small in our area, especially while computing 24 h sessions (Scherneck, personal communication).

For Bernese users some active steps are needed to include ocean tide loading parameters.

In the GAMIT distribution, ocean loading parameters from the OSCR4.0 model are available for a list of IGS stations, and a grid is available for interpolation of parameters for other new stations. However, the grid and model are not at the latest state-of-the-art standard anymore. Therefore it is proposed to use the new parameters according to FES99 for all stations included in the campaign.

Ocean tide loading parameters are commonly included in processing using GIPSY. How new parameter values are included is however not investigated in this paper.

See (http://www.oso.chalmers.se/~hgs/README.html) for more information on ocean tide loading.

3.5 Atmospheric loading

The variation in load from the atmosphere on the earth crust, due to variation in air pressure, will cause displacements of the crust in the vertical as well as the horizontal components. A rough look at the time series of displacements for Metsähovi available at Hans-Georg Schernecks home page (see link below) indicate a magnitude of vertical displacements at the 1 cm level with maximum values at 2 cm. Horizontal displacements are usually below a few mm.

The magnitude the atmospheric loading displacements could motivate the inclusion of corrections for this effect. A brief look at the air pressure data from Metsähovi give a minimum and maximum value of 990 and 1007 hPa respectively, that can be compared to the mean value for year 2003 of 1005 hPa. It may also be expected that the air pressure variation is fairly regular within the area of interest for our campaign (this likely for high pressure, while the variation is usually more irregularly for low pressures). So, if our campaign is connected to ITRF2000 using stations within or close to the Nordic/Baltic region it can be justified to neglect the atmospheric loading.

Conclusion: For the time being is it not recommended to include corrections for atmospheric loading.

More information is available at
(http://www.oso.chalmers.se/~hgs/apload.html).

3.6 Orbits

As already decided at the meeting in Gävle in June 2003 of the working group for positioning and reference frames, IGS final orbits and the corresponding earth orientation parameters should be used.

This is not applicable for the GIPSY since orbits and satellite clocks corresponding to the models in GIPSY have to be used for the PPP solution. Normally products from JPL are used. JPL is one of the IGS analysis centres.

3.7 Other Processing Options

As decided at the meeting in Gävle in June 2003, the elevation-cut-off angle should be set to 10° and elevation dependent weighting should be applied.

It is recommended to make an optional solution with a higher cut-off angle, e.g. 25° (or make an elevation dependency study in some other way). A large elevation dependency is an indication of shortcomings of the used antenna model, i.e. the used antenna model does not describe the real antenna and its environment perfectly, which leads to uncertainty in the estimated co-ordinates, especially the height component.

3.8 Possible Sub-networks

During the discussions before writing the guidelines we anticipated that the stations in Greenland and Iceland would have a negative impact on the central Nordic-Baltic part in network solutions. The recommendation for network solutions was therefore to divide the network in two parts - the central Nordic-Baltic part and the Atlantic (Greenland- Island-Svalbard) part. When processing the data it turned out that this was not a problem.

There might however be other reasons for dividing the network into sub-networks, e.g. limitations in number of stations processed simultaneously. No special recommendations for how this sub-division should be made are given here.

3.8.1 Bernese

There are no hard coded limitations of the network size (number of stations), the declarations for the variables could be edited by the user and the software re-compiled. Though, the memory size of the computer might set limitations. It is quite common to divide large regional networks into clusters, where the clusters just are connected with one baseline to each other.

3.8.2 GIPSY

The precise point positioning (PPP) strategy applied using GIPSY implies that stations are computed on a per point basis. Therefore the discussion on networks and sub-networks are not applicable.

There is also possible to perform ambiguity fixed solutions using the GIPSY software. This kind of solution is however be based on double differences and then we are back to some kind of network solution. For our project there will be no attempt to resolve ambiguities to integers in the GIPSY solution.

3.8.3 GAMIT/GLOBK

In the version (compilation) of GAMIT available to the Onsala group at the moment, there is a limitation of 45 stations that can be processed simultaneously. Therefore some division into sub-networks will be needed. The different sub-networks will then be merged using the GLOBK part of the software. Division of the computation into sub-networks is usually not considered as a critical issue for GAMIT/GLOBK users. Let's assume this is true also for the NKG 2003 campaign.

For the GAMIT processing is proposed to compute a "backbone" including most EPN stations within and close to the area of interest. The all stations within each country are processed including some stations in neighbouring countries to get the relations of close by stations and maybe improve the overlap. Sweden with more than 45 stations may be divided by geography in a north-south part, or by function in "original stable SWEPOS" and "additional new roof-mounted network RTK-stations".

3.9 Connecting / constraining to ITRF 2000

The connection to ITRF 2000 could either be done as a global connection, where globally distributed stations are used for the connection, or as a local/regional connection just connecting to stations in the region. The latter one is most commonly used for ETRS 89 realizations.

A global constraint may be considered most correct (on a general level) when connecting to a global reference frame, while local/regional constraints may reduce influence from effects common or similar to stations in the area of interest (e.g. atmospheric loading).

Independent of the choice of a global or regional connection, the stations for the connection must have reliable ITRF 2000 coordinates, i.e. if extrapolated the coordinates must be based on long and reliable time series.

Many of the EPN-stations are included in the IERS ITRF 2000-solution, but the estimated velocities of the non-IGS-stations are not good enough considering that the co-ordinates will be extrapolated almost 4 years to the epoch of the campaign. The conclusion is that just IGS-stations should be considered for the (direct) constraint.

Stations with shifts that not have been taken into account in the IERS ITRF 2000 solution should not be used, e.g. ONSA, which had a height shift when the radome was replaced February 1st 1999.

Furthermore, the constrained stations should be chosen in such a way that (major) extrapolation is avoided.

3.9.1 GIPSY

The GIPSY PPP strategy result first in a "no-fiducial" solution and in the next step a transformation (7-parameter) to ITRF2000 is performed. While using satellite position and clock information from JPL, the transformation to ITRF2000 are usually based on some 20 globally distributed stations. The selection of the stations is made by JPL as they provide the transformation files.

3.9.2 GAMIT/GLOBK

The daily solutions of the local campaign computed using GAMIT will be merged using GLOBK with daily global solutions of IGS stations fetched from SOPAC. The result will be daily solutions of our campaign, constrained to ITRF2000 using a set of global stations. The selection of stations used for the constraint is made by the user. While examining the daily repeatability etc. a local connection to ITRF2000 may be considered.

3.9.3 The Bernese GPS software

In the Bernese Software the alignment to a reference system is performed either by constraining, fixing or fitting a number of stations to known co-ordinates in the desired reference frame. This means, in any case, that a certain minimum number of stations with reference co-ordinates, covering the area to avoid extrapolation, have to be included in the solution.

3.9.3.1 Daily and Combined solutions

First daily solutions are processed, for these we recommended to make minimum constrained adjustments. In Bernese version 4.2 one station could be constrained and in version 5.0 we recommend to a use minimum constraint with no-translation condition. Normal equations are saved.

The daily solutions are then combined to a campaign solution by minimum constraint with no translation condition. .

As the possibilities to make minimum constrained solutions are better in version 5.0 we decided to use this version for the final combination for both the KMS and LMV solution.

3.9.3.2 Selection of stations and coordinates for the constraint

Different strategies for selection of stations and coordinates for the constraint to ITRF are possible. Here some alternatives:

1. The standard way used by Bernese users of connecting a network solution to ITRF, is to directly use the ITRF solution published by IERS including coordinates and velocities. The coordinates are extrapolated to the epoch of the campaign using the velocities. However for this campaign not enough stations with good coordinates in ITRF 2000 are included in the network, thus this alternative was not used. Note that the extrapolation of the coordinates to the campaign is almost 4 years.
2. In the draft of the guidelines (January 2004) a coordinate set in ITRF 2000 for the EPN stations in the Nordic Baltic part was proposed for the constraint (NORDBALT.CRD). This was based on 5 weekly solutions of the EPN network densifying the IERS ITRF 2000 solution. This strategy was used for the computation of SWEREF 99, the Swedish ETRS 89 realization.
3. Strategy number 2 did not solve the connection of the Atlantic part (Greenland-Island-Svalbard). A similar approach for this part (or the whole network) would imply the use of IGS solutions. The IGS produces cumulative solutions including all weekly solutions from 1996-01-01 up to the current week. These solutions include coordinates in a reference epoch and velocities, which are connected to ITRF 2000 using some 90 stations over the globe constrained to the IERS ITRF 2000 values.

Note that all three above mentioned strategies are regional connections to ITRF, which imply that common mode errors in the network are reduced.

For this campaign we recommend to use alternative 3, i.e. using the IGS cumulative solution.

3.10 Antenna models

The guidelines did not include anything on which antenna models should be used. However, usually relative antenna models from IGS have been used, occasionally supplemented with models from NGS. For the Bernese processing (KMS, LMV) the NGS model has only been used for the antenna type ASH701008.01B. For the GAMIT processing (OSO), NGS models have been used also for the antenna types ASH701073.1, ASH701945C_M, and ASH 701945E_M. For the site L312 the IGS antenna model ASH700228 NOTCH has been used in the GAMIT processing. In the GIPSY processing (NMA) NGS antenna models have been used for several antennas (ASH700228D, ASH700936A_M (=B_M, D_M, E), ASH701008.01B, ASH701073.1, ASH701933B_M, ASH701945B_M (=C_M), ASH701945E_M, TRM22020.00+GP and TRM29659.00).

The radome codes were not considered except for "SNOW" in the GIPSY (NMA) processing.

The used antenna models are presented in appendix B.

4 NMA, GIPSY/OASIS II

Truong-An Phong processed a preliminary solution of Norway and Sweden under supervision of Torbjørn Nørbech in the beginning of 2004. During Truong-an Phong's stay at NMA, they did also start to look into the transformation part of the project.

Torbjørn Nørbech carried out a new preliminary solution of all 133 stations during November 2004.

A final solution was carried out February 2005.

4.1 Characteristics of the processing

- RINEX-files from directory "ready" at the KMS ftp server,

  30 sec. epoch interval. The additional observations in Lithuania (L311, VLNS and KLPD, day 292-296) have also been included in the processing.
- Fiducial free Precise Point Positioning solution for all 133 stations, 5 min. epoch interval.
- JPL satellite clock corrections (yyyy-mm-dd_nf.tdp and yyyy-mm-dd_nf.tdpc), orbits (yyyy-mm-dd_nf.eci) and earth orientation parameters (yyyy-mm-ddtpeo_nf.nml).
- Local tie information is taken from RINEX file header
- Antenna type information is taken from RINEX file header
- Antenna characteristics information from the antenna file ant_info.003, including both IGS and NGS models – see appendix B.
- Ocean loading coefficients from http://www.oso.chalmers.se/~loading/
- Float,L3 solution (no ambiguity resolution)
- 10 deg elevation cut-off
- The fiducial free solutions are then transformed with so called JPL products X-files (yymmmdd.itrf00.x) to ITRF 2000. The X-files contain 7 parameters parameters for a Helmert transformation. The parameters are determined daily by JPL from a global fit on 65-70 IGS stations. So this is a global connection to ITRF 2000.
- Finally the daily transformed solutions are combined to a weekly solution/solution for the campaign. This combination is performed as a least square adjustment of the daily transformed PPP solutions weighted by their corresponding co-variance information.

4.2 Results

The internal estimated standard deviations (from the covariance matrix of the least square adjustment) on the combined solution of seven days are:

Sx: max 1.7 mm, min 0.5 mm, average of 0.6 mm

Sy: max 1.8 mm, min 0.4 mm, average of 0.5 mm

Sz: max 2.9 mm, min 0.7 mm, average of 1.0 mm

The standard deviations for each station have been plotted in appendix D.

4.3 Problems

Some modifications of the RINEX files where necessary because GIPSY is not quite RINEX compatible. All COMMENT lines after END OF HEADER line had to be removed. If the file contain GLONASS observations they have to be removed.

RINEX file IRBE2740.03o was empty.

The stations L311, L312, L408,L409 have a variations from one day to another of local tie values during the observation period. L311, L312 and L409 have maximum 1mm, L409 have maximum 2 mm. These variations are compensated for.

Antenna type information in the RINEX file header does not always correspond to the antenna type in the IGS antenna file ant_info.003. Antenna type information filed shall consist of 20 characters. In some RINEX file headers, position 16-20, in the antenna type field contain the additional characters NONE, OSOD, DUTD, or SCIS. These are radome codes and do not appear in the IGS antenna file. These antennas are interpreted as antennas without these radomes.

Problems with processing of the Swedish stations

GAVL/273, NYHA/271, OSKA/271, OVAL/271, SKIL/271, SODE/271, UMEA/271, VAST/271, ZINK/274.

Lotti Jivall told us that all the doy 271 RINEX files have been manually edited, due to some problems. She had no explanation for the stations GAVL/273 and ZINK/274 except that the ZINK/274 had ”large position change” in the s-file.

The problem was however overcome by using the program ”clockprep” in the GIPSY software package to identify problems and then do manual deleting of some data. We discovered no regular pattern, but did some data deleting until GIPSY was running properly.

We have to emphasize that this manual editing is only done on one of seven days for the actual stations. The total amount of data was not dramatically reduces, except for the station ZINK/274 which was reduced by 60%.

5 OSO, GAMIT/GLOBK

Martin Lidberg processed the campaign during the summer 2004. Some antenna model errors were found, which were corrected in a new preliminary solution delivered in November 2004. The final solution was processed and delivered in February 2005, where incorrect handled horizontal GPS antenna eccentricities have been corrected.

5.1 Characteristics of the processing

- GPS observations (RINEX data) are processed using GAMIT up to so called “quasi-observations” including relative station position, satellite orbits and their co-variances.
- Network solution divided into 7 sub-networks with many common stations. Additional EPN and IGS stations added to the network.
- Double differences
- Ambiguity resolution
- 10° elevation cut off
- Saastamoinen a priori troposphere model
- troposphere zenith delay parameters estimated every 2nd hour (piece-wise-linear)
- daily gradient parameters estimated
- the Niell mapping function
- a priori orbits from SOPAC
- Solving for orbit corrections
- “Quasi observations” from the 7 sub networks of the stations in the current campaign processed using GAMIT are combined with “quasi observations” of global/regional networks of IGS stations (from SCRIPPS) are combined using GLOBK.
- The connection to ITRF 2000 is done in the combination (stabilization) with the global quasi observations. 39 “good” IGS stations globally distributed are constrained to IERS ITRF 2000 when solving for daily Helmert parameters (3 translations, 3 rotations and a scale). This is a global connection to ITRF.
- IGS antenna models except for the antenna types ASH701008.01B, ASH701073.1, ASH701945C_M, and ASH

701945E_M. For the site L312 the IGS antenna model ASH700228 NOTCH has been used. See further appendix B.

5.2 Results, problems e.t.c.

Daily repeatability and position standard error for the GAMIT/GLOBK solution is shown in Appendix E, where the position standard error is computed as $s = \sqrt{(1/n) \cdot \left\{\sum v^2 /(n-1)\right\}}$.

The standard errors are usually below 1 mm in north and east components, and below 2 mm in the vertical component. Exceptions are DOMS (e 1.5 mm), IRBE (u 4 mm), KONG (n & e 1.5 mm), L311, L312, L409 (u 4 mm) and QAQ1 (u 3mm).

The success rate of the resolved ambiguities are not presented in the result reports from GAMIT, so it is not known if the fixed solutions really are fixed solutions, some baselines might be mainly (closer to) float solutions.

In the results of the GAMIT processing, the stations BRGS, HALD, KONG and SAND get phase observation residuals exceeding 10 mm which are above the usually considered acceptable level.

For the station BRGS, the daily repeatability is satisfactory in this solution. However, the east component may get bad repeatability depending on GPS processing strategy and choice of stations included in the GAMIT computation. Therefore, there are indications of possible problems in the GPS data collection at the station BRGS.

(In the preliminary solution submitted in November 2004, there were some errors in the east component of some stations due to a known bug concerning handling of horizontal antenna eccentricities in the used version of GAMIT, which was not recognised by the operator. This mistake is now corrected.)

6 LMV, Bernese ver 5.0

A preliminary processing was carried out during November 2004 using version 5.0 of the Bernese Software by Lotti Jivall. Some improvements concerning exclusion of stations and replacement of the BRGS fixed solution with a float solution was carried out in February 2005.

6.1 Characteristics of the processing

- RINEX-files from directory "ready" at the KMS ftp. Final solution just containing GPS week 1238 (day 271-277).
- Network solution, full network 133 stations
- Double differences, baselines formed with OBSMAX strategy (maximizing the number of observations)
- ambiguity fixing (QIF)
- Orbits, EOPs and Satellite clocks from IGS
- P1-P2 and P1-C1 code biases from CODE
- Global ionosphere model from CODE
- Ocean tide loading FES 99 from Onsala
- Relative antenna models from IGS + NGS model for antenna ASH701008.01B – see appendix B.
- Saastamoinen apriori troposphere model (hydrostatic part) with dry Niell mapping function
- Estimating ZTD using wet Niell mapping function (2 h intervall)
- Horizontal gradient parameters: tilting (24 h interval)
- 10 deg cut off , elevation dependent weighting
- Data files shorter than 12 hours were rejected
- ITRF coordinates from IGS cumulative solution (up to week 1294) used for connection to ITRF, which was done through minimum constrained adjustment with no translation condition. This is a regional constraint to ITRF.
- (Alternative connection to the EPN based ITRF was also performed)

6.2 Results, problems e.t.c.

6.2.1 Quality of daily solutions

The daily solutions of the full network were of good quality, rms = 1-1.1 mm, average rate of resolved ambiguities per day vary between 86% and 89%. The worst individual ambiguity resolution was the baseline HOFN-SCOB with 65% resolved ambiguities day 277.

The following observations were rejected because of less than 12 hours with good observations per day: MYGD day 271, IRBE, SKOL and VLNS day 272 and finally SKOL day 273. UMEA had problems with the single point positioning (determination of receiver clock correction) day 271 and was also rejected. (The same problem as was found with GIPSY/OASIS II. It should be noted that UMEA did not show any problems that day in the ordinary SWEPOS processing, which is performed with the Bernese version 4.2.)

The daily repeatability expressed in rms values are up to 2-3 mm for the north component, up to 1 mm for the east component (except for station BRGS which had an rms of 3 mm) and up to 6 mm for the up component (except for L311, L312, L409 and QAQ1 which had rms of 11-13 mm in the up-component. L311 and L409 were excluded day 273 and QAQ1 day 271 reducing the rms values to 5-7 mm for these stations.

Position standard errors, computed as $s = \sqrt{(1/n) \cdot \left\{\sum v^2 /(n-1)\right\}}$, i.e. same formula as used for the presentation of the OSO solution, are presented in appendix F.

6.2.2 Comparison between fixed and float solution

The combined float and fixed solutions were compared to each other to see if there were any possible erroneous fixed solutions. The differences are normally below 5 mm in the horizontal components, but BRGS is an outlier with 23 mm difference in the east component – see appendix F. The float solution of BRGS has a better agreement with the GIPSY and GAMIT solutions as well as with the long time series (5 years) of GAMIT solutions processed by Martin Lidberg. The float solution for BRGS was considered to be more reliable. Float solutions are in general noisier than fixed solutions. For this network the average rms values of the 7 days were 1, 1, 3 mm (north, east and up) for the fixed solution and 2, 3, 12 mm for the float solution. This means that just use the combined float solution (for all stations) because of the problems with BRGS is not a very good idea. We decided just to replace the fixed solution of BRGS by the float solution at this station after a Helmert fit to the 5 closest stations (ALES, DOMS, DAGS, PRES and AKRA).

6.2.3 Elevation cut-off test

An elevation cut-off test was performed by comparing the final 10°-solution with a 25°-test solution. This test indicates that the station ANDO is less accurate in height, which might be caused by the used antenna model (AOAD/M_T) not perfectly modelling the antenna and its environment at this station. Also the stations ARNE, SPT0, ARAJ, KONG, DOMS, NYA1, KUUS and L312 and have somewhat larger differences between the two solutions than normal – see appendix F.

6.3 Connection to ITRF 2000

The connection of the final solution of LMV was made using the IGS cumulative solution. The cumulative solution up to GPS week 1294 was used, i.e. the latest solution available when the processing was carried out. This was chosen to get the best velocities for the calculation of the coordinates at epoch of the campaign.

Eleven stations from the campaign are included in the cumulative IGS solution of week 1294. Two of them are twin stations, TROM/TRO1 and NYAL/NYA1 so just one for each site was chosen for the constraint (TROM and NYAL). REYK and QAQ1 were also excluded from the constraint as they did not fit so well.

The final LMV solution is a combined minimum constraint solution of the seven days with no translation condition to the seven remaining IGS stations.

The rms in the Helmert fittings were 3.1 and 1.5 mm for the 3-parameter fit and the 6-parameterfit respectively on the seven remaining stations. The improvement with 6 parameters show that there are some tilt in the GPS-solution which probably depends on systematic effects in un-modelled errors – see appendix F.

As a test the GPS solution was also fitted to the EPN based ITRF for the Nordic-Baltic part. This fit resulted in an rms of 1.8 mm and 1.5 mm for the 3-parameter and 6-parameter fit respectively.

The two different ITRF connections (IGS cumulative solution and the "EPN based" ITRF, respectively) have a systematic difference of 0, 1 and 5 mm for the north, east and up-component respectively.

6.4 Additional Lithuanian data

The Lithuanian colleagues noticed problems with one of their stations (L311). To be sure to have this station included in the resulting coordinate set from the campaign, this station was observed for 5 extra days (292-296), ten days after the campaign together with the Lithuanian stations VLNS and KLPD.

First, it could be noted that when processing the campaign, the station L311 turned out to be of the same quality as the other Lithuanian stations (though some data were missing for the first days).

To further check the station L311, the extra observations were processed and compared to the campaign solution. In this processing the EPN stations RIGA and VIS0 were added. The differences to the combined solution of the campaign (the LMV solution) are found in table 3. Both a direct comparison between the additional data and the LMV solution and a comparison of the LMV solution with and without the additional data (i.e. the corrections to the LMV solution if the additional data were added to the solution) are presented.

Table 3: Differences at L311. The left column contains the differences between the additional data and the LMV solution. The right column contains the differences between the LMV solution with and without the additional data

	extra-gw1238	gw1238+extra-gw1238
N (mm)	0.6	0.3
E (mm)	0.7	0.4
U (mm)	5.9	1.5

The differences between the campaign solution and the combined solution of the campaign and extra data were below 1 mm in the horizontal and 2 mm in the vertical component at the station L311. This comparison shows that we could be confident with the coordinates for L311 of the original campaign.

7 KMS, Bernese ver 4.2

7.1 Preliminary processing and re-processing

A first preliminary processing was carried out by Henrik Rønnest during the spring 2004 using the Bernese version 4.2. The network was processed in two parts, one Nordic-Baltic part and one Atlantic part (Greenland, Iceland and Svalbard). During this processing he noticed problems with some of the Swedish RINEX-files for the first day of the week. The Bernese was not able to convert the files because of wrong information in the header on the time for the first observation. The headers were corrected and then there was no problem. Files with corrected headers were up-loaded to the KMS-ftp under the subdirectory ready/Sweden_corrected_headers. The wrong headers seem not to have been a problem for GAMIT and GIPSY.

Henrik's solution for the Nordic-Baltic part was delivered in summer 2004. Lotti Jivall noticed problems with some antenna models and the coordinates used for the constraint. This was further investigated by Mette Weber. Seven antenna models were wrong affecting 33 stations and 47 baselines in the Nordic-Baltic part. Mette did a re-processing of the Nordic-Baltic part just before the meeting in Hønefoss (30/11-1/12 2004). As the time was short, the re-processing was just carried out for the affected baselines and just from the ambiguity resolution step.

In the Atlantic part of the network there were no problems with the antenna models and the solution estimated by Henrik during spring 2004 was combined with the re-processed solution for the Nordic-Baltic part forming a solution for the whole network. This solution was determined in January 2005.

7.2 Characteristics of the processing

- Network solution in six clusters; four clusters in the Nordic-Baltic part and two clusters in the Atlantic part (clusters connected with one baseline)
- Double differences, baselines formed to get the shortest distances. The same baseline definition for all days.
- Ambiguity fixing (QIF)
- Orbits, EOP's and Satellite clocks from IGS
- Calculated own regional ionosphere model (used for ambiguity resolution)

- Ocean tide loading FES 99 from Onsala
- Relative antenna models from IGS + NGS model antennas not present in the IGS-file. See appendix B.
- No a priori troposphere model
- Estimating ZTD using dry Niell mapping function
- 10 deg cut off, elevation dependent weighting
- ITRF coordinates from IGS cumulative solution (up to week 1294) used for connection to ITRF

7.3 Network solution in clusters

The network was divided into six clusters A to F due to the capacity of the machine. The Nordic-Baltic part consists of cluster A to D, and the Atlantic part consists of cluster E and F. In principle the entire network was formed in a first step and afterwards divided into clusters. Therefore there will only be one baseline connecting the clusters. The network configuration is the same for each day. The Nordic-Baltic part is shown in figure 3 and the Atlantic part is shown in figure 4.

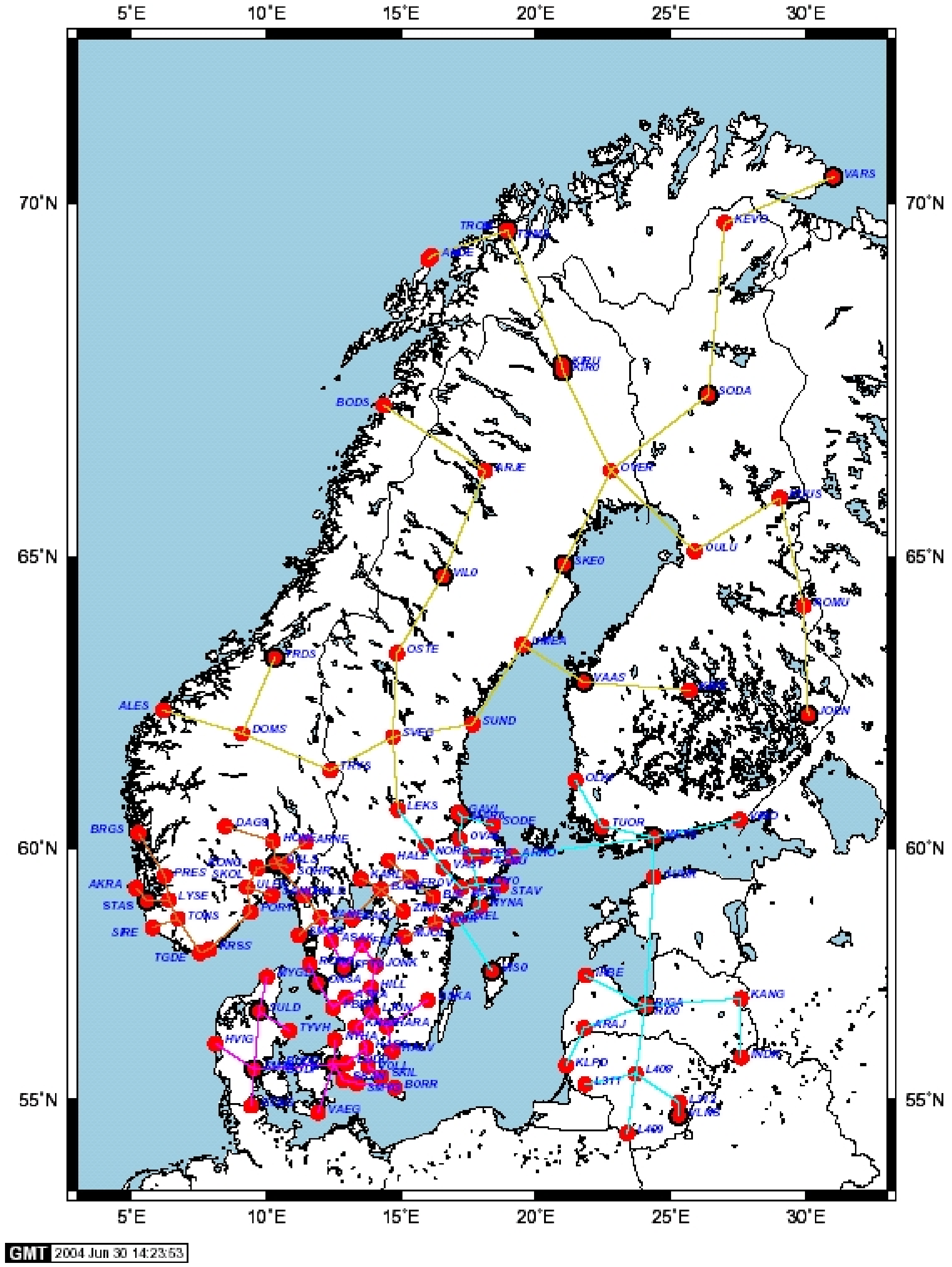

Figure 3: Cluster A (pink baselines), cluster B (red baselines), cluster C (yellow baselines) and cluster D (blue baselines)

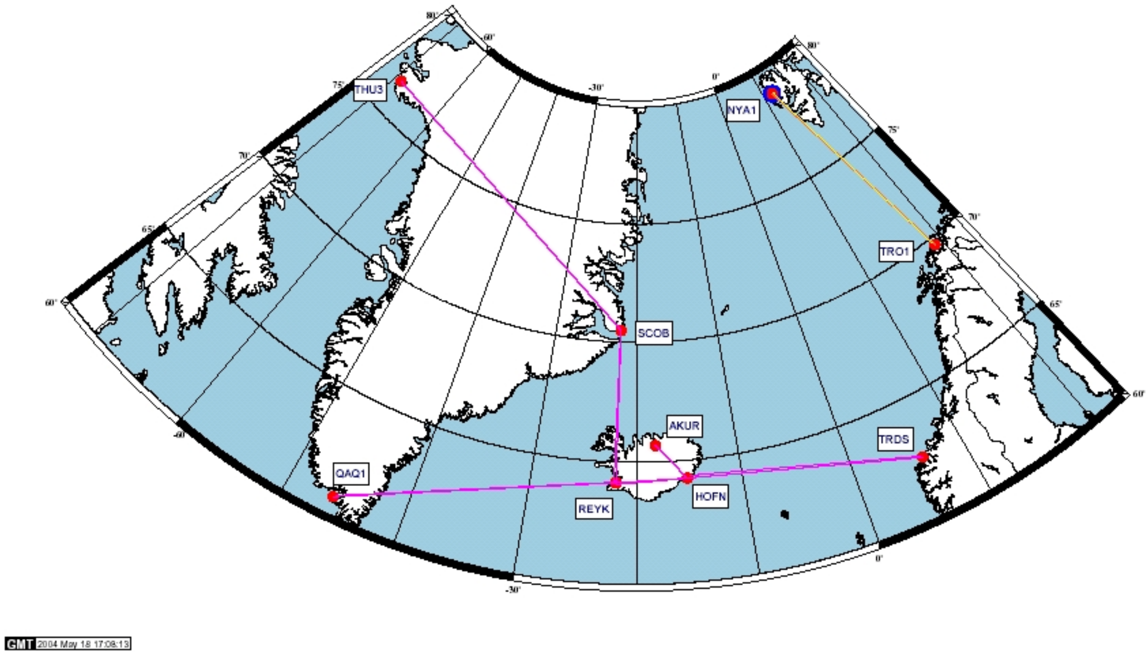

Figure 4: Cluster E (pink baselines) and cluster F (yellow baselines)

During the processing one station in each cluster was constrained: BUDP (A), OSLS (B), SKE0 (C), METS (D), HOFN (E) and NYAL (F). The normal equations for each day were formed by combining the normal equations from all clusters as shown in figure 3. In each 1-day NEQ these 6 stations were constrained. In the last step when forming the 7-day solution for the entire network selected IGS stations were constrained. This last step was not performed by KMS as explained in the next section.

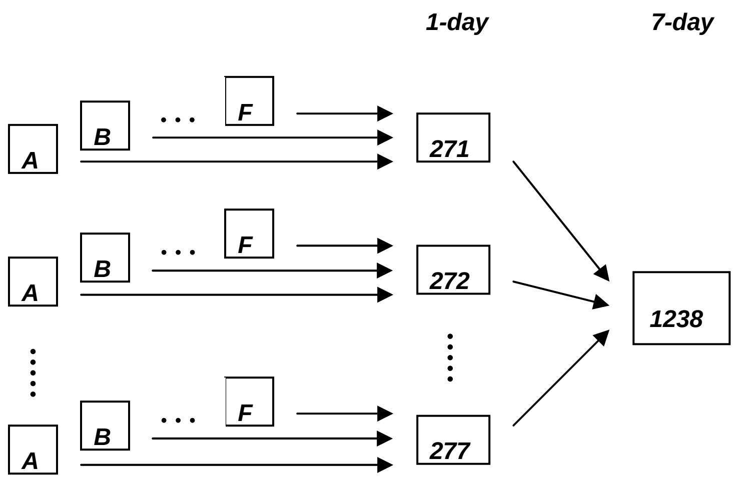

Figure 5: Combination of normal equations from each cluster

7.4 Processing problems

Some stations had to be rejected for some sessions due to bad data quality or missing data. The following stations and sessions were rejected during the preliminary processing:

- RINEX-files from directory "ready" at the KMS ftp, INDR day 274 and 276 (Lotti had the same problem first but solved it by deleting a wrong "extra site info" and the observations before that)
- L312, L408, L409 day 273, missing observations
- GAVl day 276, problems with the triple difference solution
- SODE day 274, problems with the triple difference solution
- VLNS day 273, connecting baseline missing
- SKIL day 271, problems with the triple difference solution
- L311 day 271, missing observations
- QAQ1 day 271, excluded from 1-day NEQ due to high repeatability

During the re-processing the wrong antenna models were corrected. The corrections were in the order of 1-2 cm for the antenna phase centre offsets for L1 and L2. These corrections resulted in a change in the coordinates of 2-4 cm in X and Y and 8 cm in Z for the affected stations. Therefore the a priori coordinates were updated for these stations before the re-processing from the ambiguity resolution step.

The constrained coordinates in the preliminary solution were wrong. During re-processing the correct coordinates were introduced in the final step with ADDNEQ as fixed coordinates. In Bernese version 4.2 it is not possible to produce a constrained solution at a new set of coordinates with ADDNEQ. The correct coordinates have to be introduced at the beginning of the processing, which was not possible because the re-processing was only performed from the ambiguity resolution step and only for some baselines. In Bernese version 5.0 it is possible to introduce new constrained coordinates in the final step with ADDNEQ and therefore KMS provided Lotti with the 1-day NEQ-files from the KMS solution and she performed the last step of the KMS solution.

7.5 Connection to ITRF 2000

Lotti made a minimum constrained ITRF 2000 solution from the KMS NEQ-files in the same way as for the LMV solution using Bernese version 5.0. The condition of the minimum constrained solution was no translation to seven IGS-stations (METS ONSA KIRU TROM THU3 NYAL HOFN) in the IGS cumulative solution of GPS week 1294. This connection to ITRF could be considered as a regional connection.

7.6 Results

The results were evaluated in terms of the ambiguity resolution and the rms of repeatability. The ambiguity resolution in per cent for each baseline is shown in appendix G. The values are an average of all 7 days. The baselines are sorted according to increasing baseline length, which is also shown. The average ambiguity resolution for all baselines and all days is 66%.

The ambiguity resolution for most of the baselines is rather low; 31 baselines (i.e. 23%) have a resolution less than 60% and only 12 baselines (i.e. 9%) have a resolution of 80% or more. Generally the long baselines in the Atlantic part have the lowest ambiguity resolution of less than 50%.

Compared to the Bernese ver. 5.0 solution from LMV, KMS has a lower ambiguity resolution. Lotti and Mette made a few comparisons of some parameter settings in MAUPRP and the differences in these settings can maybe explain some of the differences in ambiguity resolution (generally more ambiguities are set up in the KMS solution, but more ambiguities are not resolved). Nevertheless, the LMV and the KMS solution seem to agree well.

The daily repeatability expressed in rms values are up to 2-3 mm for both the north and east components and up to 9 mm for the up component.

Position standard errors, computed as $s = \sqrt{(1/n) \cdot \left\{\sum v^2 /(n-1)\right\}}$, i.e. same formula as used for the presentation of the OSO and LMV solutions, are presented in appendix G.

8 Comparison of the solutions from the four different analysis centres

8.1 Direct comparison of the solutions

The solutions from the different analysis centres were compared to each other. As mentioned before we have problems (related to ambiguity fixing) with the east component of the station BRGS. In the LMV solution BRGS was replaced by a float solution, since the difference between fixed and float solution was too big (23 mm in the east component) and the float solution was considered to be more reliable. In the comparison of fixed and float solutions in the KMS solution, the problems with BRGS were not so clear so the station was kept in a first comparison. It turned out that the KMS solution of BRGS differed c:a 20 mm in the east component, so BRGS was excluded from the KMS solution in the further comparisons and combinations. Results from the comparison of the four solutions (after excluding KMS BRGS) are presented in appendix H as a plot of residuals from the average value at each station.

The solutions agree for most stations within ±3 mm in the horizontal components and within ±10 mm for the vertical. RMS values computed on all the differences in north, east and up are 1.4, 1.5 and 4.7 mm respectively. There are however shifts between the solutions, e.g. OSO is c:a 2-3 mm south-east of the other solutions and LMV and KMS are c:a 5-10 mm below OSO and NMA. The reason for the shifts is that the connection to ITRF has been done in different ways. The OSO and NMA solutions are both global connections to ITRF while the LMV and KMS solutions are regional. Another difference is that the OSO and NMA solutions are aligned to ITRF 2000 by solving for 7 parameters and the LMV and KMS solutions are aligned just with a translation.

A graphical presentation with respect to the position is found in appendix I. The ITRF 2000 coordinates of each analysis centre have been transformed to UTM zone 33 before comparison and plotting. Some systematic effects besides the shifts between the solutions could be seen, see e.g. the comparison between OSO and KMS.

8.2 Harmonizing the solutions

In order to better detect outliers and get an impression of the internal consistency between the solutions, we decided to harmonize/align the solutions to each other or a common coordinate set.

First all four solutions where fitted to common coordinate sets with different number of parameters. The IGS-realizations of ITRF 2000 where used as common coordinate sets, both the weekly IGS-solution (GPS-week 1238) and the cumulative IGS-solution containing solutions up to GPS-week 1294. (Both solutions are connected to IERS ITRF 2000 and not IGS 2000.) The result of the fits is to be found in appendix J.

It could be noted that the RMS for the fits with 7 parameters are on the same level for all four solutions. The fits of the KMS and LMV solutions are improved quite a lot when a scale and rotations are solved for. The KMS and LMV scales are c:a 2 ppb. The improvement is not so large for the NMA and OSO solutions, since they already estimated these parameters, though on a daily basis.

The four solutions of the Nordic campaign were also fitted to each other – see appendix K.

The two Bernese solutions (KMS and LMV) do of course agree best with each other, but the agreement between KMS/LMV and OSO is not much worse. The RMS for the fits between KMS/LMV and NMA is a little bit higher (but still nothing to worry about). NMA has its best agreement with OSO.

Regarding the translations between the solutions, LMV and NMA differ c:a 1 cm in height . KMS and OSO are in the middle. The OSO solution differs c:a 2 mm in the north component and a little bit less for the east component in comparison to the other solutions.

As the regional connection of the two Bernese solutions (LMV and KMS) could be questioned (which stations should be used for the fit (there are some problems with some IGS stations on Greenland and Island)?, which coordinates? solving for scale and rotations? e.t.c.), we decided to let the two global solutions (OSO and NMA) decide the connection to ITRF 2000.

An average of the OSO and NMA coordinates was calculated for each station (and component). All four solutions were then transformed to this averaged coordinate set with a 7-parameter transformation.

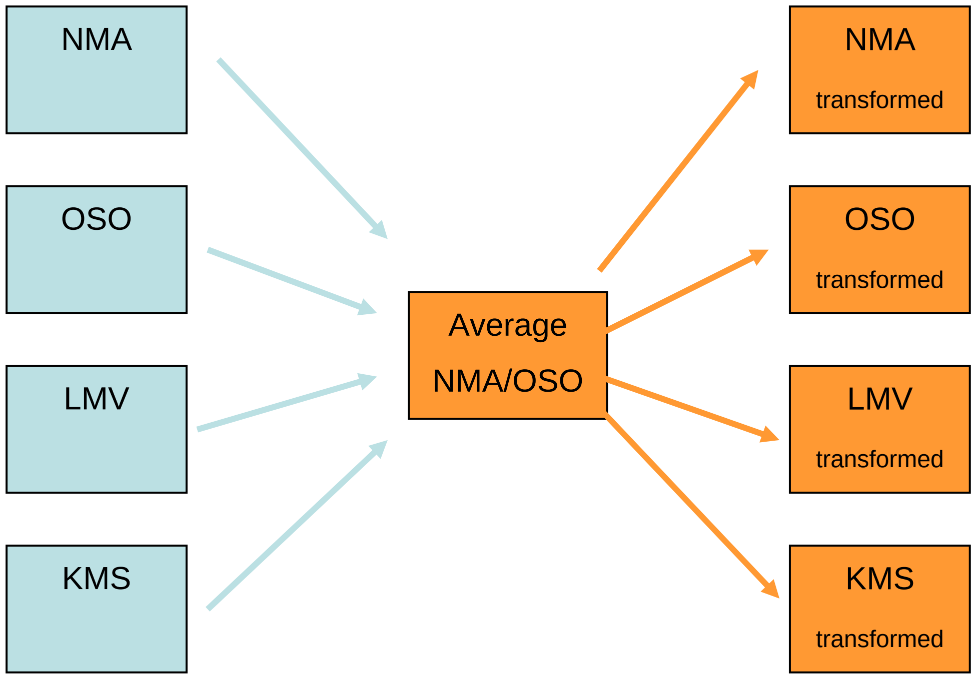

Figure 6: Harmonization of the solutions.

8.3 Comparison after harmonization

The four solutions transformed to the averaged NMA/OSO solution were compared to each other. Residuals from mean are presented in appendix L and M. (Appendix M contains a graphical presentation with respect to the geographical position, after transformation to UTM zone 33.)

The differences are after this harmonization generally very small and the systematic effects seen before have (almost) disappeared. (Some small systematic effects in height are left.) The RMS values of all differences in each component are 0.9, 1.2 and 2.5 mm (north, east and up), which should be compared to the corresponding values before harmonization (1.4, 1.5 and 4.7 mm). Especially in height there is a large improvement. Just 7%, 17% and 11 % of the stations have residuals larger than 2 mm in the north , 2 mm in east and 5 mm in up, respectively.

In table 4 residuals larger than 3 mm in north and east and 6 mm in up are presented. The limits are just chosen to get a reasonable number of residuals to present. Even the largest residuals are not really much to bother about. We think that we have been able to correct/handle the real outliers, which were found when the preliminary solutions from November 2004 were compared.

The NMA solution has the largest noise and thus most of the "large" residuals. The Lithuanian stations L311 and L312 have the largest residuals in height. These stations have a quite bad repeatability in the individual solutions and e.g. in the Bernese solutions one day was excluded for L311, which might explain why we get discrepancies between the different solutions. Other differences are that different antenna models have been used for the ASH700228D antenna at L312 and that the NMA solution contains also the additional data for L311 (but according to section 6.4 the impact of these extra data is negligible).

Table 4: The largest residuals between the harmonized solutions.

Sol/comp	Station	Residual (mm)
NMA-N	L312	5,3
NMA-N	AKUR	-3,7
NMA-E	DOMS	5,2
LMV-E	KONG	4
KMS-E	KONG	3,9
NMA-E	SUUR	3,2
NMA-E	OVER	3,1
OSO-E	KRSS	-3,1
NMA-U	L312	-15,5
LMV-U	L312	11,4
NMA-U	L311	-10,1
NMA-U	ARAJ	-9,4
NMA-U	VIRO	9,3
NMA-U	QAQ1	9,1
NMA-U	RI00	-8,7
KMS-U	NALS	8,4
NMA-U	JOEN	8,1
KMS-U	KONG	-8
KMS-U	NYAL	7,9
NMA-U	KUUS	7,6
KMS-U	L312	7,5
NMA-U	KONG	6,9
NMA-U	ROMU	6,7
LMV-U	VIRO	-6,4
KMS-U	ARAJ	6,4
LMV-U	KUUS	-6,1
KMS-U	NYA1	6,1

9 Combined solution

The final combined solution of the NKG 2003 campaign is the average of the four harmonized solutions – see figure 7.

Using the harmonized solutions, instead of the original solutions, for an average is motivated by the fact that the agreement between the solutions is improved after harmonization. The Hemert-fits in appendix 3 and 4 do also show that there are significant scales and rotations between the different solutions.

The choice of letting the NMA and OSO solutions define the connection to ITRF means further that we have a pure global connection to ITRF. If we should have used the Bernese solutions with regional connections as well, we would have got a mixture of global and a regional connection.

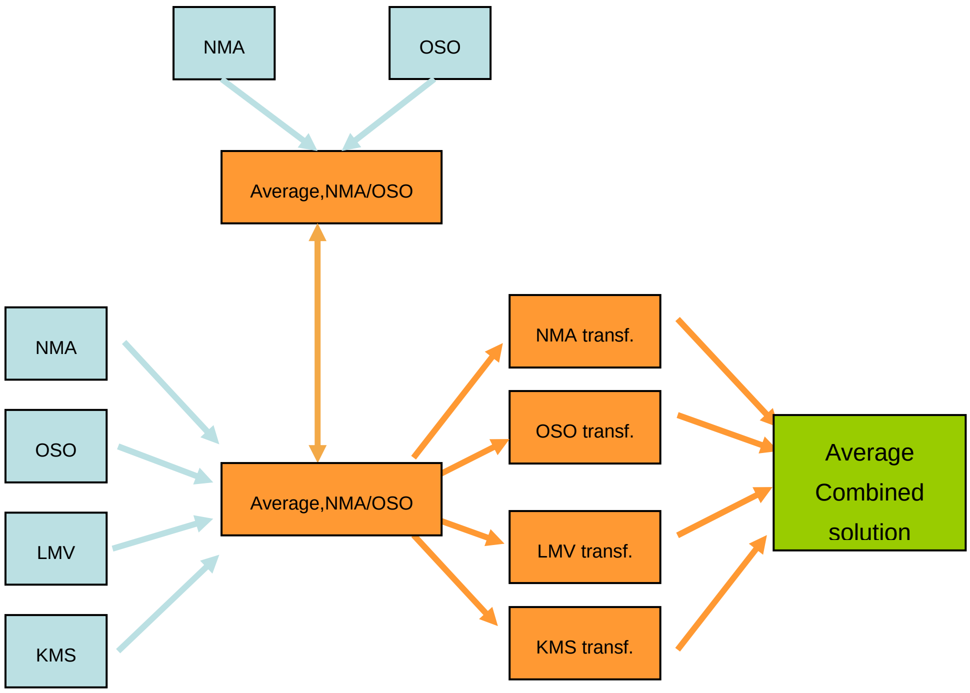

Figure 7: Calculation of the combined solution. 7-parameter transformations have been used for the transformation to the averaged NMA/OSO-solution.

Final combined coordinates in ITRF 2000 epoch 2003.75 are given both expressed as geocentric Cartesian coordinates and geodetic coordinates in appendix N. RMS values of the differences between the harmonized solutions and the combined solution (for the north, east and up-components) are given in appendix O.

The RMS values have been computed with the following formula for each component:

$$RMS = \sqrt{\frac{\sum v^2}{4}}$$

Note that this not could be interpreted as the standard error of the final combined coordinates. These values do just reflect the discrepancies between the four solutions and remember that the solutions basically are based on the same data (just a few stations/days have been treated differently). The RMS values are therefore much lower than the real accuracy, but they are included here to get an impression of the relation between the accuracy of different stations.

The real accuracy depends on the following components:

- Accuracy of the ITRF connection
- Systematic effects depending on un-modelled errors or wrong models
- Random errors, noise in the solutions

The accuracy of the ITRF connection could be estimated to a few mm in the horizontal components and 1 cm in height based on the direct comparison between the different solutions.

Neglected systematic effects, e.g. air pressure, might contribute to the relative uncertainty of maybe a few mm in the horizontal and half to one cm in the height component (left after the ITRF connection). Shortcomings in the used antenna models could add errors of up to a few cm. This type of error could mainly be expected for non choke ring antennas. In the performed elevation cut-off tests a few stations with possible antenna model problems were identified – see section 6.2.3.

The random errors in the solutions are reflected in the estimated standard errors/rms from repeatability of the four individual solutions – see section 4 - 7 and corresponding appendices - and in the comparison of the four harmonized solutions (see e.g. RMS values in appendix O).

Considering the estimations in the error components above, an estimation of the real accuracy would be 0.5-1 cm in the horizontal components and 1-2 cm in the vertical on 95% level for the main part of the stations. ANDO, L311 and L312 might be less accurate in height.

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A. Station characteristics

Station	Antenna	Receiver	*H*	*E*	*N*
Denmark					
BORR	ASH701945B_M	JPS LEGACY	0.1390	0.0000	0.0000
BUDD	ASH701945B_M	ASHTECH UZ-12	0.8701	0.0000	0.0000
BUDP	ASH701941.B	ASHTECH UZ-12	0.0000	0.0000	0.0000
HVIG	ASH701941.2	JPS LEGACY	0.7564	0.0000	0.0000
MYGD	ASH701945B_M	JPS LEGACY	0.1393	0.0000	0.0000
SMID	ASH701941.B	ASHTECH UZ-12	0.0000	0.0000	0.0000
STAG	ASH700936B_M	JPS LEGACY	0.1258	0.0000	0.0000
SULD	ASH701941.B	ASHTECH UZ-12	0.0000	0.0000	0.0000
TYVH	ASH701941.B	JPS LEGACY	0.1360	0.0000	0.0000
VAEG	ASH700936B_M	JPS LEGACY	0.1339	0.0000	0.0000
Estonia					
SUUR	AOAD/M_T	ASHTECH Z-XII3	0.0000	0.0000	0.0000
Finland					
JOEN	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
KEVO	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
KIVE	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
KUUS	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
METS	AOAD/M_B	ASHTECH Z-XII3	0.0000	0.0000	0.0000
OLKI	AOAD/M_T	ASHTECH Z-XII3	0.0000	0.0000	0.0000
OULU	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
ROMU	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
SODA	AOAD/M_T	ASHTECH Z-XII3	0.0000	0.0000	0.0000
TUOR	AOAD/M_T	ASHTECH Z-XII3	0.0000	0.0000	0.0000
VIRO	AOAD/M_T	ASHTECH Z-XII3	0.0000	0.0000	0.0000
VAAS	ASH700936A_M	ASHTECH Z-XII3	0.0000	0.0000	0.0000
Greenland					
QAQ1	ASH701941.B	ASHTECH UZ-12	0.1206	0.0000	0.0000

SCOB	TRM29659.00	TRIMBLE 4000SSI	0.0000	0.0000	0.0000
THU3	ASH701073.1	ASHTECH UZ-12	0.1002	0.0000	0.0000
Island					
AKUR	TRM29659.00	TRIMBLE 4700	0.0550	0.0000	0.0000
HOFN	TRM29659.00	TRIMBLE 4000SSI	0.0510	0.0000	0.0000
REYK	AOAD/M_T	AOA SNR-8000 ACT	0.0555	0.0000	0.0000
Latvia					
ARAJ	TRM33429.00+GP	TRIMBLE 4700	1.5561	0.0000	0.0000
INDR	TRM33429.00+GP	TRIMBLE 4700	1.5759	0.0000	0.0000
IRBE	ASH700936D_M	TRIMBLE 4000SSE	5.1115	0.0000	0.0000
KANG	TRM33429.00+GP	TRIMBLE 4700	1.4089	0.0000	0.0000
RI00	TRM22020.00+GP	TRIMBLE 4000SSE	1.3633	0.0000	0.0000
RIGA	ASH700936D_M	ROGUE SNR-8000	0.0850	0.0000	0.0000
Lithuania					
KLPD	ASH700936E	ASHTECH Z-XII3	0.0000	0.0000	0.0000
L311	ASH701008.01B	ASHTECH UZ-12	1.7701*	0.0000	0.0000
L312	ASH700228D	ASHTECH Z-XII3	1.6511*	0.0000	0.0000
L408	ASH701008.01B	ASHTECH UZ-12	1.6763*	0.0000	0.0000
L409	ASH701008.01B	ASHTECH UZ-12	1.7498**	0.0000	0.0000
VLNS	ASH700936A_M	ASHTECH Z-XII3	0.0730	0.0000	0.0000
Norway					
AKRA	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
ALES	TRM29659.00	TRIMBLE MS750	5.5360	0.0050	-0.0010
ANDE	AOAD/M_T	ROGUE SNR-800	0.0000	0.0000	0.0000
ANDO	AOAD/M_T	AOA BENCHMARK ACT	3.1650	0.0000	0.0000
ARNE	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
BODS	TRM29659.00	TRIMBLE MS750	5.5000	-0.0020	0.0080
BRGS	TRM29659.00	TRIMBLE MS750	5.5120	-0.0030	-0.0100
DAGS	TRM33429.00+GP	TRIMBLE MS750	0.0000	0.0000	0.0000
DOMS	TRM29659.00	TRIMBLE MS750	0.0000	0.0000	0.0000

* The antenna height at L311, L312, L408 and L409 differed from day to day ao an average is used instead.

HALD	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
HONE	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
KONG	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
KRSS	TRM29659.00	TRIMBLE MS750	5.5050	-0.0130	-0.0010
LYSE	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
NALS	ASH701073.1	TRIMBLE 4000SSI	0.0000	0.0000	0.0000
NYA1	ASH701073.1	AOA BENCHMARK ACT	0.0000	0.0000	0.0000
NYAL	AOAD/M_B	AOA BENCHMARK ACT	5.2160	-0.0010	0.0040
OSLS	TRM29659.00	TRIMBLE MS750	5.4960	0.0130	0.0170
PORT	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
PRES	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
SAND	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
SIRE	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
SKOL	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
SOHR	TRM41249.00	TRIMBLE MS750	0.0000	0.0000	0.0000
STAS	TRM29659.00	TRIMBLE MS750	5.5590	-0.0050	-0.0020
TGDE	AOAD/M_T	AOA SNR-12 ACT	0.0000	0.0000	0.0000
TONS	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
TRDS	TRM29659.00	TRIMBLE MS750	5.5460	0.0070	0.0180
TRMS	ASH701073.1	TRIMBLE MS750	0.0100	0.0000	0.0000
TRO1	ASH701073.1	AOA BENCHMARK ACT	0.0000	0.0000	0.0000
TROM	AOAD/M_B	AOA BENCHMARK ACT	2.4750	0.0000	0.0000
TRYS	TRM29659.00	TRIMBLE MS750	5.5700	0.0010	-0.0040
ULEF	TPSCR3_GGD	JPS LEGACY	0.0000	0.0000	0.0000
VARS	TRM29659.00	TRIMBLE MS750	5.5120	0.0170	0.0060
Sweden					
ARHO	ASH701945C_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
ARJE	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
ASAK	ASH701946.3	JPS E_GGD	0.0710	0.0000	0.0000
ATRA	ASH701946.3	JPS E_GGD	0.0710	0.0000	0.0000
BIE_	ASH701945C_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
BJOR	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000

FALK	ASH701945C_M	JPS E_GGD	0.0710	0.0000	0.0000
FBER	ASH700936D_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
FROV	ASH701941.B	ASHTECH Z-XII3	0.0710	0.0000	0.0000
GAVL	ASH701933B_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
HALE	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
HALV	ASH701945C_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
HARA	ASH700936D_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
HASS	AOAD/M_T	ASHTECH UZ-12	0.0710	0.0000	0.0000
HILL	ASH701946.3	JPS E_GGD	0.0710	0.0000	0.0000
JONK	ASH701073.1	JPS E_GGD	0.0710	0.0000	0.0000
KALL	ASH701945B_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
KARL	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
KIR0	AOAD/M_T	JPS E_GGD	0.0710	0.0000	0.0000
KIRU	ASH701945C_M	ASHTECH UZ-12	0.0620	0.0000	0.0000
KNAR	ASH701946.3	ASHTECH UZ-12	0.0710	0.0000	0.0000
LEKS	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
LJUN	ASH701946.3	JPS E_GGD	0.0710	0.0000	0.0000
LODD	ASH701946.3	ASHTECH UZ-12	0.0710	0.0000	0.0000
LOVO	ASH700936D_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
MAR6	AOAD/M_T	JPS LEGACY	0.0710	0.0000	0.0000
MARI	ASH701073.1	ASHTECH Z-XII3	0.0710	0.0000	0.0000
MJOL	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
NORB	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
NORR	ASH700936D_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
NYHA	ASH701946.3	ASHTECH UZ-12	0.0710	0.0000	0.0000
NYNA	ASH701945B_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
ONSA	AOAD/M_B	JPS LEGACY	0.9950	0.0000	0.0000
OSKA	ASH700936D_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
OSTE	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
OVAL	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
OVER	ASH700936D_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
OXEL	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000

RORO	ASH700936E	JPS E_GGD	0.0710	0.0000	0.0000
SKAN	ASH701945C_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
SKE0	AOAD/M_T	JPS E_GGD	0.0710	0.0000	0.0000
SKIL	ASH701945E_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
SMOG	ASH700936E	JPS E_GGD	0.0710	0.0000	0.0000
SMYG	ASH701945C_M	ASHTECH UZ-12	0.0710	0.0000	0.0000
SODE	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000
SPT0	AOAD/M_T	JPS LEGACY	0.0710	0.0000	0.0000
STAV	ASH701946.3	ASHTECH Z-XII3	0.0710	0.0000	0.0000
SUND	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
SVEG	ASH701946.3	ASHTECH Z-XII3	0.0710	0.0000	0.0000
UMEA	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
UPPS	ASH701941.B	ASHTECH Z-XII3	0.0710	0.0000	0.0000
VANE	AOAD/M_T	JPS E_GGD	0.0710	0.0000	0.0000
VAST	ASH700936E	ASHTECH UZ-12	0.0710	0.0000	0.0000
VIL0	AOAD/M_T	ASHTECH Z-XII3	0.0710	0.0000	0.0000
VIS0	AOAD/M_T	JPS E_GGD	0.0710	0.0000	0.0000
VOLL	ASH701946.3	ASHTECH UZ-12	0.0710	0.0000	0.0000
ZINK	ASH701945C_M	ASHTECH Z-XII3	0.0710	0.0000	0.0000

B. Used antenna models

Bernese software (LMV and KMS)

(Format of antenna file: Bernese version 4.2)

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RECEIVER ANTENNA PHASE CENTER OFFSETS AND VARIATIONS                   29-AUG-00
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RECEIVER TYPE          ANTENNA S/N  FREQ  PHASE CENTER OFFSETS (M)           ELEVATION
DEPENDENCE OF PHASE CENTER (MM)
ANTENNA  TYPE          FROM    TO    L*    NORTH    EAST     UP    FMT   90 85 80 75 70 65 60
55 50 45 40 35 30 25 20 15 10 05 00
********************  ****** ******   *   **.**** **.**** **.****   *    ** ** ** ** ** ** **
** ** ** ** ** ** ** ** ** ** ** **

*                          0 999999   1    0.0000  0.0000  0.0780   0
AOAD/M_B                              2    0.0000  0.0000  0.0960

*                          0 999999   1    0.0000  0.0000  0.1100   0
AOAD/M_T                              2    0.0000  0.0000  0.1280

*                          0 999999   1    0.0005  0.0003  0.0799   2
ASH700228D                            2   -0.0012  0.0008  0.0792

ASH700228 NOTCH (used by GAMIT, see below)

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH700936A_M                          2    0.0000  0.0000  0.1280

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH700936B_M                          2    0.0000  0.0000  0.1280

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH700936D_M                          2    0.0000  0.0000  0.1280

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH700936E                            2    0.0000  0.0000  0.1280

*                          0 999999   1   -0.0007  0.0007  0.0832   2
ASH701008.01B   NGS!                  2    0.0015 -0.0020  0.0617

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH701073.1                           2    0.0000  0.0000  0.1280

ASH701073.1   NGS! (used by GAMIT, see below)

*                          0 999999   1    0.0000  0.0000  0.1100   0
ASH701933B_M                          2    0.0000  0.0000  0.1280

*                          0 999999   1   -0.0002  0.0001  0.1080   2
ASH701941.2                           2   -0.0003  0.0002  0.1267

*                          0 999999   1   -0.0002  0.0001  0.1080   2
ASH701941.B                           2   -0.0003  0.0002  0.1267
```

```
*                         0 999999   1    0.0000  0.0000  0.1100   0
ASH701945B_M                         2    0.0000  0.0000  0.1280

*                         0 999999   1    0.0000  0.0000  0.1100   0
ASH701945C_M                         2    0.0000  0.0000  0.1280

ASH701945C_M   NGS! (used by GAMIT, see below)

*                         0 999999   1    0.0000  0.0000  0.1100   0
ASH701945E_M                         2    0.0000  0.0000  0.1280

ASH701945E_M   NGS! (used by GAMIT, see below)

*                         0 999999   1    0.0006  0.0008  0.1098   2
ASH701946.3                          2    0.0007  0.0014  0.1284

*                         0 999999   1    0.0001  0.0000  0.0805   2
TPSCR3_GGD                           2    0.0007  0.0008  0.1035

*                         0 999999   1    0.0015 -0.0012  0.0751   2
TRM22020.00+GP                       2   -0.0011  0.0017  0.0692

*                         0 999999   1    0.0000  0.0000  0.1100   0
TRM29659.00                          2    0.0000  0.0000  0.1280

*                         0 999999   1   -0.0002  0.0012  0.0740   2
TRM33429.00+GP                       2    0.0006  0.0009  0.0703

*                         0 999999   1    0.0003  0.0005  0.0714   2
TRM41249.00                          2   -0.0004  0.0001  0.0682




FORMAT INDICATOR:
  FMT=0 :  ONLY PHASE CENTER OFFSETS ARE USED
  FMT=1 :  ZENITH DEPENDENT CORRECTIONS GIVEN TO THE RIGHT OF THE OFFSET
           VALUES ARE USED
  FMT=2 :  PHASE CENTER MAPS OR SPHERICAL HARMONICS ARE USED (ZENITH/AZIMUTH
           DEPENDENT)

ANTENNA PHASE CENTER OFFSETS MEASURED FROM ANTENNA REFERENCE POINT (ARP)
TO THE MEAN L1/L2 PHASE CENTER.



PHASE CENTER MAPS AND/OR COEFFICIENTS OF SPHERICAL HARMONICS IN MILLIMETERS:
---------------------------------------------------------------------------

TYPE 1 :  ELEVATION/AZIMUTH GRID
TYPE 2 :  SPHERICAL HARMONICS COEFFICIENTS (UNNORMALIZED)
TYPE 3 :  SPHERICAL HARMONICS COEFFICIENTS (NORMALIZED)

D(Z)   :  ZENITH  TABULAR INTERVAL (DEGREES)
D(A)   :  AZIMUTH TABULAR INTERVAL (DEGREES)
N(Z)   :  DEGREE OF SPHERICAL HARMONICS DEVELOPMENT
N(A)   :  ORDER  OF SPHERICAL HARMONICS DEVELOPMENT
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```
RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    ASH700228D                0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   0.10   0.50   1.20   1.80   2.10   2.10   2.40   3.00   3.30   3.00   2.80
2.60   2.30   1.50   0.70   0.90   0.90   0.90
L2   0   0.00   0.40   1.10   1.50   1.60   1.80   2.20   2.30   2.10   2.00   1.90   1.70
1.50   1.80   2.40   1.60  -1.80  -1.80  -1.80

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    ASH701008.01B   NGS!      0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   0.70   2.00   3.60   5.30   7.00   8.40   9.40  10.10  10.20   9.90   9.00
7.80   6.30   4.50   2.70   1.00   0.00   0.00
L2   0   0.00  -2.00  -3.50  -4.70  -5.60  -6.30  -6.80  -7.10  -7.20  -7.20  -7.00  -6.60  -
6.00  -5.10  -3.90  -2.30  -0.30   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    ASH701941.2               0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00  -0.30  -0.50  -0.50  -0.40  -0.30  -0.20  -0.10   0.00   0.10   0.10   0.00
0.00  -0.10  -0.20  -0.20  -0.20   0.00   0.00
L2   0   0.00  -2.20  -3.30  -3.50  -3.30  -2.90  -2.50  -2.20  -2.10  -2.20  -2.50  -2.90  -
3.20  -3.20  -2.70  -1.30   1.30   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    ASH701941.B               0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00  -0.30  -0.50  -0.50  -0.40  -0.30  -0.20  -0.10   0.00   0.10   0.10   0.00
0.00  -0.10  -0.20  -0.20  -0.20   0.00   0.00
L2   0   0.00  -2.20  -3.30  -3.50  -3.30  -2.90  -2.50  -2.20  -2.10  -2.20  -2.50  -2.90  -
3.20  -3.20  -2.70  -1.30   1.30   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    ASH701946.3               0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00  -0.10  -0.20  -0.20  -0.10  -0.10   0.00   0.10   0.20   0.20   0.20   0.20
0.30   0.20   0.20   0.10   0.10   0.00   0.00
L2   0   0.00  -0.20  -0.30  -0.30  -0.30  -0.30  -0.30  -0.30  -0.20  -0.20  -0.20  -0.30  -
0.30  -0.30  -0.20  -0.20   0.00   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    TPSCR3_GGD                0 999999    1      5  360
```

```
    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   0.80   1.30   1.60   1.70   1.80   1.80   1.80   1.80   1.80   1.90   2.00
2.00   1.80   1.50   0.90  -0.10   0.00   0.00
L2   0   0.00  -0.50  -0.50  -0.20   0.20   0.70   1.10   1.50   1.80   1.80   1.70   1.50
1.10   0.70   0.20  -0.10  -0.30   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    TRM22020.00+GP            0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   1.80   4.60   8.10  11.70  14.50  16.10  16.90  16.90  16.20  14.90  13.40
11.90  10.40   9.00   7.90   8.20   8.20   8.20
L2   0   0.00   0.30   0.90   1.80   3.00   4.10   4.90   5.40   5.60   5.60   5.30   4.50
3.60   2.80   2.10   1.20   0.10   0.10   0.10

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    TRM33429.00+GP            0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   3.90   7.60  11.10  14.10  16.50  18.30  19.20  19.50  19.10  18.10  16.60
14.90  13.00  11.50  10.40  10.20   0.00   0.00
L2   0   0.00   0.60   1.40   2.40   3.40   4.40   5.10   5.60   5.80   5.70   5.30   4.70
3.90   3.00   2.10   1.40   0.90   0.00   0.00

RECEIVER TYPE        ANTENNA TYPE         FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
*                    TRM41249.00               0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55
60     65     70     75     80     85     90
L1   0   0.00   0.60   1.40   2.30   3.20   4.10   4.90   5.60   6.10   6.40   6.40   6.10
5.50   4.50   3.10   1.30  -0.90   0.00   0.00
L2   0   0.00  -0.50  -0.60  -0.50  -0.20   0.10   0.50   0.80   1.00   1.10   1.00   0.90
0.60   0.20  -0.20  -0.60  -0.80   0.00   0.00
```

Different models used in the GAMIT processing (OSO):

The GAMIT (v10.0) format is used in order to avoid mistakes in translation to the BERNESE format

```
# ANTYP freq   Up   North   East      Model        azinc elinc sign
# Elev ang 0    05    10    15    20    25    30    35    40    45    50    55    60    65
70    75    80    85    90

ASH700228 NOTCH

ASHP12  L1   80.8   -0.2   -1.0  I1_IGS01         360    05    1.0  ASHTECH 700228.D NOTCH
         0.0   0.0  -2.0  -0.3   1.0   1.8   2.4   2.8   3.0   3.1   3.0   2.9   2.6   2.4
2.1   1.7   1.3   0.7   0.0
         0.0   0.0  -2.0  -0.3   1.0   1.8   2.4   2.8   3.0   3.1   3.0   2.9   2.6   2.4
2.1   1.7   1.3   0.7   0.0
 ASHP12  L2   77.8   -1.9    3.8  I1_IGS01         360    05    1.0  ASHTECH 700228.D NOTCH
```

```
        0.0   0.0  -2.3  -3.0  -3.1  -2.9  -2.5  -2.1  -1.8  -1.6  -1.5  -1.7  -2.0  -2.3  -
2.6  -2.8  -2.5  -1.7   0.0
        0.0   0.0  -2.3  -3.0  -3.1  -2.9  -2.5  -2.1  -1.8  -1.6  -1.5  -1.7  -2.0  -2.3  -
2.6  -2.8  -2.5  -1.7   0.0

ASH701073.1 NGS

ASHGG1  L1  108.9    1.4   -1.0  N3_NGS03         360     5    1.0  ASH701073.1
GPS/GLONASS,REV.3,chokerings             NGS (  0) 00/04/20
        0.0   0.0   0.8   0.9   1.0   0.9   0.9   0.8   0.7   0.7   0.7   0.8   0.8   0.9
0.9   0.9   0.8   0.5   0.0
        0.0   0.0   0.8   0.9   1.0   0.9   0.9   0.8   0.7   0.7   0.7   0.8   0.8   0.9
0.9   0.9   0.8   0.5   0.0
 ASHGG1  L2  127.4    1.0    0.5  N3_NGS03         360     5    1.0  ASH701073.1
GPS/GLONASS,REV.3,chokerings             NGS (  0) 00/04/20
        0.0   0.0   0.1   0.3   0.4   0.5   0.5   0.4   0.4   0.4   0.4   0.4   0.5   0.5
0.5   0.5   0.4   0.3   0.0
        0.0   0.0   0.1   0.3   0.4   0.5   0.5   0.4   0.4   0.4   0.4   0.4   0.5   0.5
0.5   0.5   0.4   0.3   0.0

ASH701945C_M NGS

ATDM1C  L1  109.0    0.5    0.3  N3_NGS03         360     5    1.0  ASH701945C_M         D/M
element,REV.C,chokerings             NGS (  2) 00/04/20
        0.0   0.0   0.1   0.3   0.3   0.3   0.3   0.3   0.2   0.2   0.1   0.1   0.1   0.1
0.0   0.1   0.1   0.0   0.0
        0.0   0.0   0.1   0.3   0.3   0.3   0.3   0.3   0.2   0.2   0.1   0.1   0.1   0.1
0.0   0.1   0.1   0.0   0.0
 ATDM1C  L2  127.9    0.3    1.2  N3_NGS03         360     5    1.0  ASH701945C_M         D/M
element,REV.C,chokerings             NGS (  2) 00/04/20
        0.0   0.0   0.0  -0.1  -0.2  -0.2  -0.2  -0.3  -0.2  -0.2  -0.1  -0.1  -0.1  -0.1  -
0.1  -0.1  -0.1  -0.1   0.0
        0.0   0.0   0.0  -0.1  -0.2  -0.2  -0.2  -0.3  -0.2  -0.2  -0.1  -0.1  -0.1  -0.1  -
0.1  -0.1  -0.1  -0.1   0.0

ASH701945E_M NGS

ATDM1E  L1  109.0    0.5    0.3  N3_NGS03         360     5    1.0  ASH701945E_M         D/M
element,REV.C,chokerings             NGS (  2) 00/04/20
        0.0   0.0   0.1   0.3   0.3   0.3   0.3   0.3   0.2   0.2   0.1   0.1   0.1   0.1
0.0   0.1   0.1   0.0   0.0
        0.0   0.0   0.1   0.3   0.3   0.3   0.3   0.3   0.2   0.2   0.1   0.1   0.1   0.1
0.0   0.1   0.1   0.0   0.0
 ATDM1E  L2  127.9    0.3    1.2  N3_NGS03         360     5    1.0  ASH701945E_M         D/M
element,REV.C,chokerings             NGS (  2) 00/04/20
        0.0   0.0   0.0  -0.1  -0.2  -0.2  -0.2  -0.3  -0.2  -0.2  -0.1  -0.1  -0.1  -0.1  -
0.1  -0.1  -0.1  -0.1   0.0
        0.0   0.0   0.0  -0.1  -0.2  -0.2  -0.2  -0.3  -0.2  -0.2  -0.1  -0.1  -0.1  -0.1  -
0.1  -0.1  -0.1  -0.1   0.0
```

GIPSY processing (NMA):

```
<ant_info.003>                                                          <CBL-04/08/31=157>

ANTENNA ID        DESCRIPTION                  DATA SOURCE (# OF TESTS) YR/MO/DY
                                                                       |AVE = # in average
 [north]  [ east]  [  up ]                                             | L1 Offset (mm)
 [90]  [85]  [80]  [75]  [70]  [65]  [60]  [55]  [50]  [45]  | L1 Phase at
 [40]  [35]  [30]  [25]  [20]  [15]  [10]  [ 5]  [ 0]        | Elevation (mm)
 [north]  [ east]  [  up ]                                             | L2 Offset (mm)
 [90]  [85]  [80]  [75]  [70]  [65]  [60]  [55]  [50]  [45]  | L2 Phase at
 [40]  [35]  [30]  [25]  [20]  [15]  [10]  [ 5]  [ 0]        | Elevation (mm)

NONE                 NONE                                       NGS (  0) 99/10/04
       0.0       0.0       0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
       0.0       0.0       0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_B
        0.0       0.0      78.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
        0.0       0.0      96.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_B        NONE
        0.0       0.0      78.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
        0.0       0.0      96.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_B        OSOD
        0.0       0.0      78.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
        0.0       0.0      96.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_T
        0.0       0.0     110.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
        0.0       0.0     128.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_T        DUTD
        0.0       0.0     110.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
        0.0       0.0     128.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_T        NONE
        0.0       0.0     110.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
       0.0       0.0     128.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
AOAD/M_T        OSOD
       0.0       0.0     110.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
       0.0       0.0     128.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
ASH700228D
      -3.2        .1      84.2
     .0    .8   1.4   1.8   2.0   2.2   2.4   2.5   2.6   2.6
    2.6   2.3   1.9   1.2    .1  -1.6  -3.9    .0    .0
      -1.9       4.9      76.7
     .0  -1.0  -1.5  -1.6  -1.5  -1.3  -1.1  -1.0   -.9  -1.0
   -1.2  -1.4  -1.7  -2.0  -2.1  -1.9  -1.4    .0    .0
ASH700936A_M
       1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
       1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936A_M    SNOW
        .3       -.2     108.1
     .0   1.0   1.5   1.7   1.6   1.4   1.2    .9    .7    .6
     .7    .8   1.1   1.5   1.8   2.2   2.5    .0    .0
        .9        .5     125.6
     .0    .1    .3    .5    .6    .7    .8    .8    .7    .6
     .5    .4    .4    .4    .7   1.1   1.9    .0    .0
ASH700936B_M
       1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
       1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936D_M
       1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
       1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936D_M    NONE
       1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
       1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936D_M    OSOD
       1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
       1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936E
```

```
        1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
        1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH700936E      OSOD
        1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
        1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH701008.01B
        -.7        .7      83.2
     .0    .7   2.0   3.6   5.3   7.0   8.4   9.4  10.1  10.2
    9.9   9.0   7.8   6.3   4.5   2.7   1.0    .0    .0
        1.5      -2.0      61.7
     .0  -2.0  -3.5  -4.7  -5.6  -6.3  -6.8  -7.1  -7.2  -7.2
   -7.0  -6.6  -6.0  -5.1  -3.9  -2.3   -.3    .0    .0
ASH701073.1
        1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
        1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH701073.1     OSOD
        1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
        1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH701073.1     SCIS
        1.4      -1.0     108.9
     .0    .5    .8    .9    .9    .9    .8    .8    .7    .7
     .7    .8    .9    .9   1.0    .9    .8    .0    .0
        1.0        .5     127.4
     .0    .3    .4    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .5    .5    .4    .3    .1    .0    .0
ASH701933B_M    OSOD
        -.3       -.3     107.5
     .0   -.5   -.6   -.7   -.6   -.4   -.2   -.1    .1    .1
     .2    .1    .0    .0   -.1    .1    .3    .0    .0
        -.1       1.1     126.5
     .0  -2.3  -3.5  -3.8  -3.6  -3.2  -2.7  -2.4  -2.3  -2.4
   -2.7  -3.1  -3.4  -3.4  -2.9  -1.3   1.5    .0    .0
ASH701941.2
        -.2        .1     108.0
     .0   -.3   -.5   -.5   -.4   -.3   -.2   -.1    .0    .1
     .1    .0    .0   -.1   -.2   -.2   -.2    .0    .0
        -.3        .2     126.7
     .0  -2.2  -3.3  -3.5  -3.3  -2.9  -2.5  -2.2  -2.1  -2.2
   -2.5  -2.9  -3.2  -3.2  -2.7  -1.3   1.3    .0    .0
ASH701941.B
        -.2        .1     108.0
     .0   -.3   -.5   -.5   -.4   -.3   -.2   -.1    .0    .1
     .1    .0    .0   -.1   -.2   -.2   -.2    .0    .0
        -.3        .2     126.7
```

```
     .0  -2.2  -3.3  -3.5  -3.3  -2.9  -2.5  -2.2  -2.1  -2.2
   -2.5  -2.9  -3.2  -3.2  -2.7  -1.3   1.3    .0    .0
ASH701941.B     SCIS
        -.2        .1     108.0
     .0   -.3   -.5   -.5   -.4   -.3   -.2   -.1    .0    .1
     .1    .0    .0   -.1   -.2   -.2   -.2    .0    .0
        -.3        .2     126.7
     .0  -2.2  -3.3  -3.5  -3.3  -2.9  -2.5  -2.2  -2.1  -2.2
   -2.5  -2.9  -3.2  -3.2  -2.7  -1.3   1.3    .0    .0
ASH701941.B     OSOD
        -.2        .1     108.0
     .0   -.3   -.5   -.5   -.4   -.3   -.2   -.1    .0    .1
     .1    .0    .0   -.1   -.2   -.2   -.2    .0    .0
        -.3        .2     126.7
     .0  -2.2  -3.3  -3.5  -3.3  -2.9  -2.5  -2.2  -2.1  -2.2
   -2.5  -2.9  -3.2  -3.2  -2.7  -1.3   1.3    .0    .0
ASH701941.B     UNAV
        -.2        .1     108.0
     .0   -.3   -.5   -.5   -.4   -.3   -.2   -.1    .0    .1
     .1    .0    .0   -.1   -.2   -.2   -.2    .0    .0
        -.3        .2     126.7
     .0  -2.2  -3.3  -3.5  -3.3  -2.9  -2.5  -2.2  -2.1  -2.2
   -2.5  -2.9  -3.2  -3.2  -2.7  -1.3   1.3    .0    .0
ASH701945B_M
         .5        .3     109.0
     .0    .0    .1    .1    .0    .1    .1    .1    .1    .2
     .2    .3    .3    .3    .3    .3    .1    .0    .0
         .3       1.2     127.9
     .0   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.2
    -.2   -.3   -.2   -.2   -.2   -.1    .0    .0    .0
ASH701945B_M    OSOD
         .5        .3     109.0
     .0    .0    .1    .1    .0    .1    .1    .1    .1    .2
     .2    .3    .3    .3    .3    .3    .1    .0    .0
         .3       1.2     127.9
     .0   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.2
    -.2   -.3   -.2   -.2   -.2   -.1    .0    .0    .0
ASH701945C_M    OSOD
         .5        .3     109.0
     .0    .0    .1    .1    .0    .1    .1    .1    .1    .2
     .2    .3    .3    .3    .3    .3    .1    .0    .0
         .3       1.2     127.9
     .0   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.2
    -.2   -.3   -.2   -.2   -.2   -.1    .0    .0    .0
ASH701945C_M    SNOW
         .4        .8     109.3
     .0    .9   1.2   1.3   1.2    .9    .7    .4    .2    .0
     .1    .2    .4    .7   1.1   1.3   1.6    .0    .0
        -.2        .3     126.2
     .0   -.2   -.1   -.1    .0    .1    .1    .1    .1    .1
     .0   -.1   -.2   -.1    .1    .5   1.3    .0    .0
ASH701945E_M    OSOD
         .5        .3     109.0
     .0    .0    .1    .1    .0    .1    .1    .1    .1    .2
     .2    .3    .3    .3    .3    .3    .1    .0    .0
         .3       1.2     127.9
     .0   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.1   -.2
    -.2   -.3   -.2   -.2   -.2   -.1    .0    .0    .0
ASH701946.3     OSOD
         .6        .8     109.8
```

```
     .0   -.1   -.2   -.2   -.1   -.1    .0    .1    .2    .2
     .2    .2    .3    .2    .2    .1    .1    .0    .0
         .7       1.4     128.4
     .0   -.2   -.3   -.3   -.3   -.3   -.3   -.3   -.2   -.2
    -.2   -.3   -.3   -.3   -.2   -.2    .0    .0    .0
TPSCR3_GGD
         .1        .0      80.5
     .0    .8   1.3   1.6   1.7   1.8   1.8   1.8   1.8   1.8
    1.9   2.0   2.0   1.8   1.5    .9   -.1    .0    .0
         .7        .8     103.5
     .0   -.5   -.5   -.2    .2    .7   1.1   1.5   1.8   1.8
    1.7   1.5   1.1    .7    .2   -.1   -.3    .0    .0
TRM22020.00+GP
        -.1       -.6      74.2
     .0   4.6   8.9  12.6  15.8  18.3  20.0  20.9  21.1  20.6
   19.5  18.1  16.3  14.5  13.0  12.0  11.8    .0    .0
        -.5       2.8      70.5
     .0    .3   1.0   1.9   2.8   3.6   4.3   4.8   5.1   5.0
    4.7   4.1   3.3   2.4   1.4    .5   -.1    .0    .0
TRM29659.00
        1.2        .5     109.8
     .0    .3    .5    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .4    .4    .5    .5    .4    .0    .0
        1.2        .6     128.0
     .0    .0    .0    .0    .0    .0    .1    .1    .0    .0
    -.1   -.1   -.1   -.1    .0    .2    .4    .0    .0
TRM29659.00     NONE
        1.2        .5     109.8
     .0    .3    .5    .5    .5    .5    .5    .4    .4    .4
     .4    .4    .4    .4    .5    .5    .4    .0    .0
        1.2        .6     128.0
     .0    .0    .0    .0    .0    .0    .1    .1    .0    .0
    -.1   -.1   -.1   -.1    .0    .2    .4    .0    .0
TRM33429.00+GP
        -.2       1.2      74.0
     .0   3.9   7.6  11.1  14.1  16.5  18.3  19.2  19.5  19.1
   18.1  16.6  14.9  13.0  11.5  10.4  10.2    .0    .0
         .6        .9      70.3
     .0    .6   1.4   2.4   3.4   4.4   5.1   5.6   5.8   5.7
    5.3   4.7   3.9   3.0   2.1   1.4    .9    .0    .0
TRM41249.00
         .3        .5      71.4
     .0    .6   1.4   2.3   3.2   4.1   4.9   5.6   6.1   6.4
    6.4   6.1   5.5   4.5   3.1   1.3   -.9    .0    .0
        -.4        .1      68.2
     .0   -.5   -.6   -.5   -.2    .1    .5    .8   1.0   1.1
    1.0    .9    .6    .2   -.2   -.6   -.8    .0    .0
```

C. Troposphere models

a. The Saastamoinen model for total zenith delay used in GAMIT

$$saaszd = 0.002277\left(p + \left(\frac{1255}{t_K} + 0.05\right)e\right) / \mathit{ffun}$$

where:

$$p = p_{SL}\left(\frac{t_K - \alpha \cdot h}{t_K}\right)^{\left(\frac{govrr}{\alpha}\right)}$$

$$e = rh \cdot 6.11 \cdot 10^{\left(\frac{7.5 \cdot t}{t + 273.16}\right)}$$

$$\mathit{ffun} = 1 - 0.00266 \cdot \cos(2 \cdot \varphi) - 0.00028 \cdot h$$

with:

p_{SL} = pressure at sea level in [mbar]

t = temperature i [°C]

t_K = temperature in [K]

φ = latitude

h = site geodetic height in [km]

$govrr$ = 34.1

α = 4.5

In the GAMIT processing, the a priori zenith delay is separated in its dry and wet components:

$$dry\_zenith\_delay = 0.002277\left(p + \left(\frac{1255}{t_K} + 0.05\right) \cdot 0.0\right) / \mathit{ffun}$$

$$wet\_zenith\_delay = 0.002277\left(0.0 + \left(\frac{1255}{t_K} + 0.05\right)e\right) / ffun$$

In the processing the dry part is kept fixed to its a priori value, while the wet part is estimated.

b. Theoretical background to troposphere (from Emardsson 1998)

Electromagnetic radio waves are affected in various ways while passing through the atmosphere from the satellites to the user receiver close to the surface of the earth (Emardsson 1998). Since the velocity of light varies between different media, the refractive index , *n*, is introduced:

$$n = c_0 / c \qquad (1)$$

where c_0 is the speed of light in vacuum and c is the speed of light in the media. The extra time needed for the signal to travel through the media compared to travel the same distance through vacuum can thus be written:

$$\delta t = \frac{1}{c_0}\int_S (n-1)ds \qquad (2)$$

where S is the actual travelled distance which deviates from a straight line due to the bending effect.

In processing GPS data collected close to the surface of the earth, the effects from the ionosphere and the troposphere is the most considered.

The troposphere is the lower part of the atmosphere, usually said to extend up to 10 km, but may vary from 8 km at the pole to 17 km at the equator (Geerts, B., Linacre, E., 1997). The mixing ratio between the different species, where nitrogen and oxygen is the main contributors, is fairly constant throughout the troposphere. An exception is water vapour which is varying between 0-4% volume mixing ratio with a typical value of 1% at ground level (Brasseur

1999). The Troposphere is electrically neutral and effects electromagnetic waves of different frequencies equally. We may introduce refractivity χ as $10^{-6}(n-1)$. A common expression for χ at frequencies below 10 GHz is

$$\chi = k_1 \frac{p_d}{T} Z_d^{-1} + k_2 \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1} \tag{3}$$

where p_d and e are partial pressure of the dry species and water vapour in mbar respectively, T is temperature in K, and Z_d and Z_w are compressibility factors for the dry air and water vapour. The terms in (3) can be rearranged as

$$\chi = k_1 \rho \frac{R}{M_d} + k_2^{'} \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1} \tag{4}$$

where ρ is the density of the atmosphere, R is the universal gas constant, M_d is the molar weight of dry air, and $k_2^{'} = k_2 - mk_1$ with m as the ratio of molar masses of water vapour and dry air. The coefficients k_1, $k_2^{'}$ and $k_3^{'}$ have been determined from laboratory experiments to 77.6 K(mbar)$^{-1}$, 70 K(mbar)$^{-1}$ and 3.7 K^2(mbar)$^{-1}$. By this rearrangement the refractivity can now be written as

$$\chi = \chi_h + \chi_w \tag{5}$$

where χ_h, the first term in (4) is called the hydrostatic refractivity and is only dependent on the total density and not on the wet/dry mixing ratio. By integrating according to (2) we get the total delay (in distance unit) from the neutral atmosphere as the sum of the hydrostatic and wet delay

$$l = l_h + l_w \tag{6}$$

where $l = c_0 \times \delta t$ have been used. The hydrostatic delay can be approximated using ground pressure measurements

$$l_h = (2.2768 \pm 0.0024)\frac{P}{f(\varphi, H)} \tag{7}$$

with

$$f(\varphi, H) = 1 - 0.00266\cos(2\beta) - 0.00028H \tag{8}$$

where l_h is the zenith hydrostatic delay in mm, P is the pressure in mbar, φ is the site latitudes in degrees, and H is the station height in km. The hydrostatic delay in zenith is typically around 2.3 m, while the wet delay is typically below 30 cm but is highly variable.

To relate the delay at a certain elevation angle above the horizon to the delay in zenith, it is common practise to use a mapping function

$$m(\varepsilon) = \frac{l(\varepsilon)}{l(90°)} \tag{9}$$

where ε is the elevation angle to the observed satellite. The approach assumes in principle a horizontally stratified atmosphere. The form of the mapping function is close to 1/sin(ε), at least for higher elevation angles.

c. References

Emardson, T.R., *Studies of Atmospheric Water Vapor Using the Global Positioning System,*
PhD thesis, Technical Report 339, School of Electrical and Computer Engineering, Chalmers University of Technology, 1998.

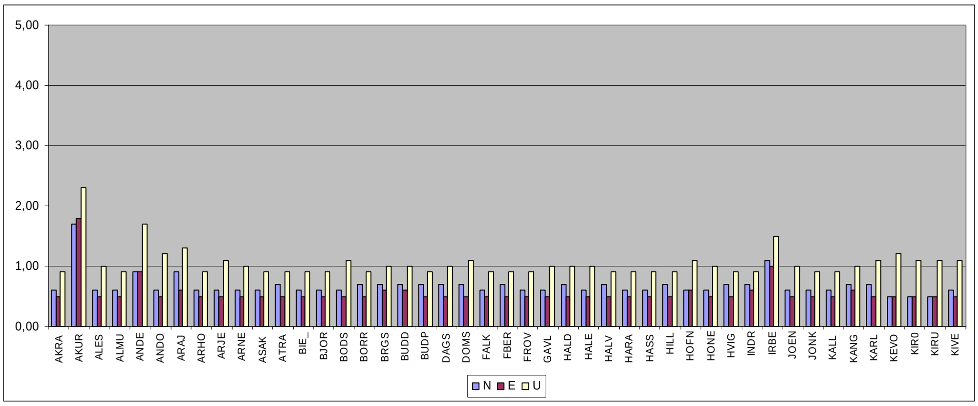
Geerts, B., Linacre, E., 1997 *Height of the tropopause*, http://www-das.uwyo.edu/~geerts/cwx/notes/chap01/tropo.html

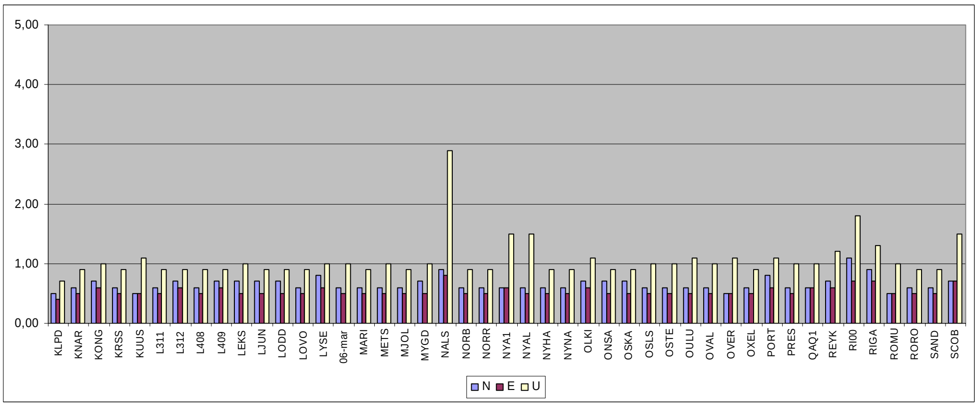
Houghton, John, T., *The Physics of the Atmospheres*, Cambridge, 1995.

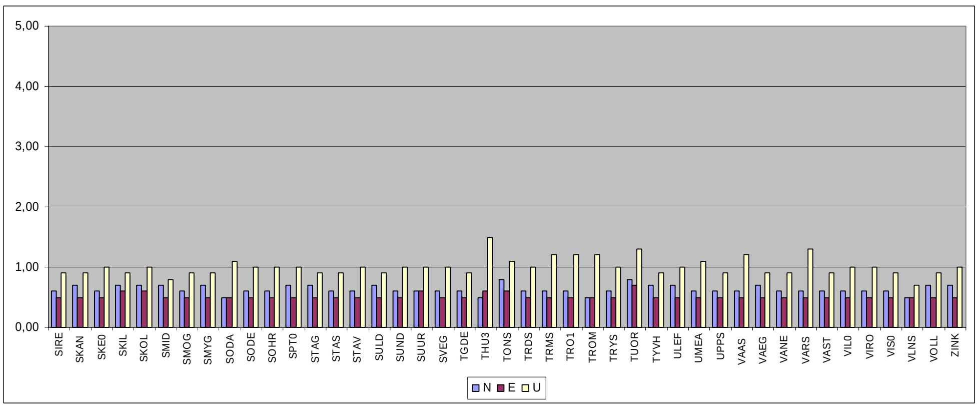
Brasseur, Guy, P., John J. Orlando, Geoffrey S., Tyndall, *Atmospheric Chemistry and Global Change,* Oxford University Press, New York, 1999.

D. The NMA solution - GIPSY/OASISII

Position standard errors

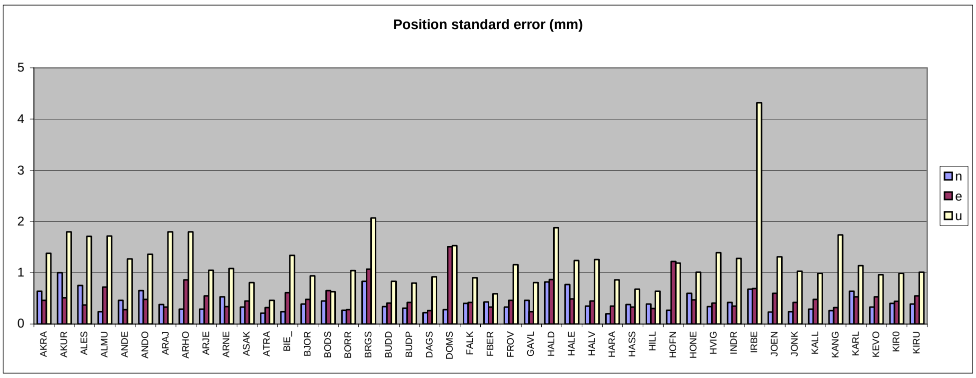


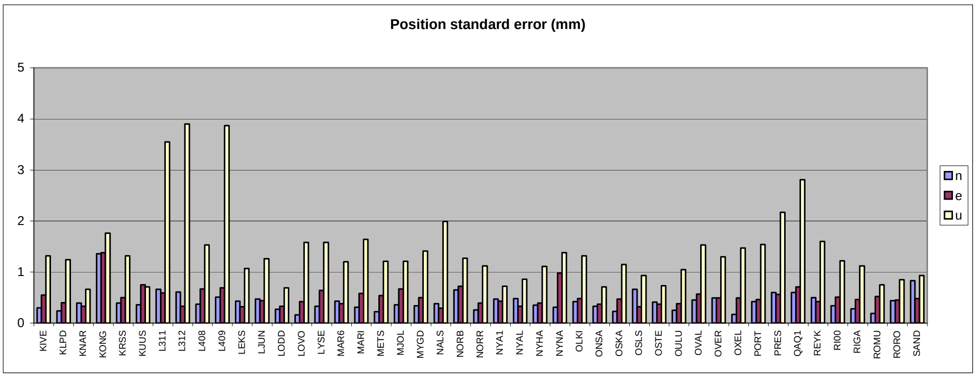


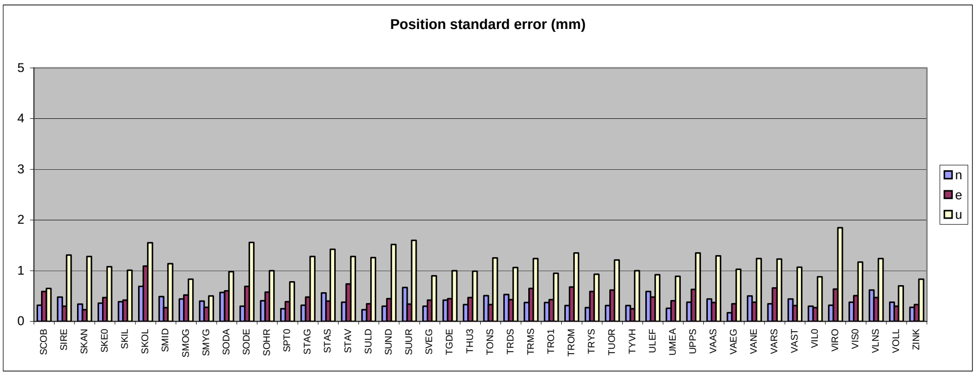


E. The OSO solution - GAMIT/GLOBK

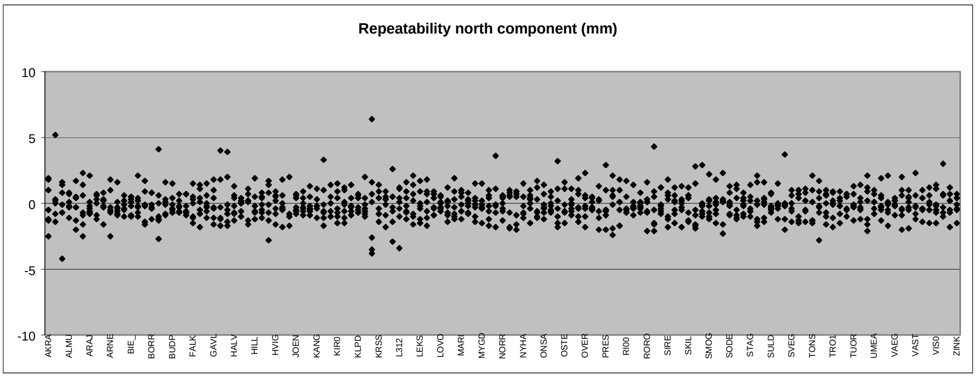
Position standard errors

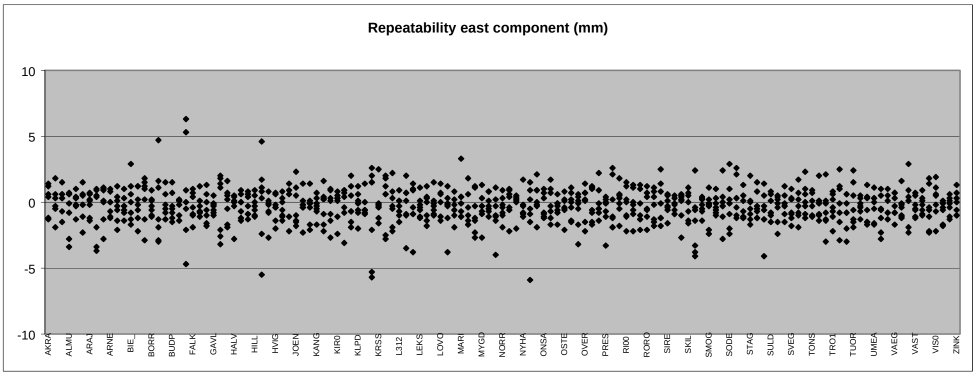


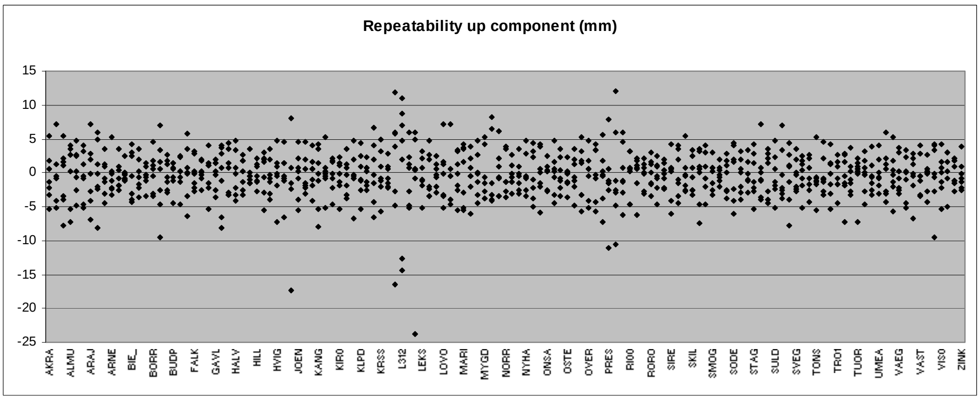




Daily repeatability

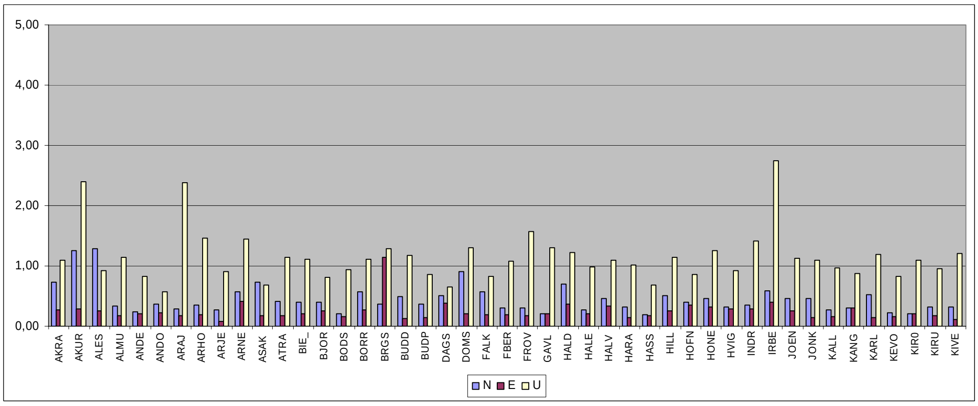


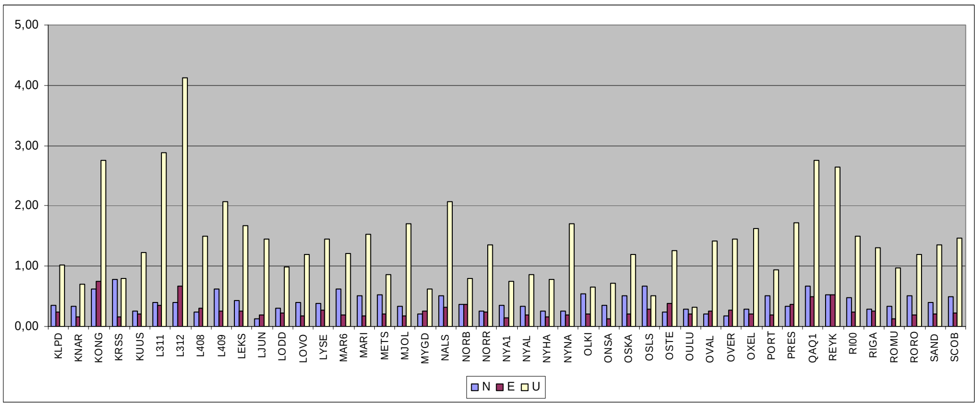


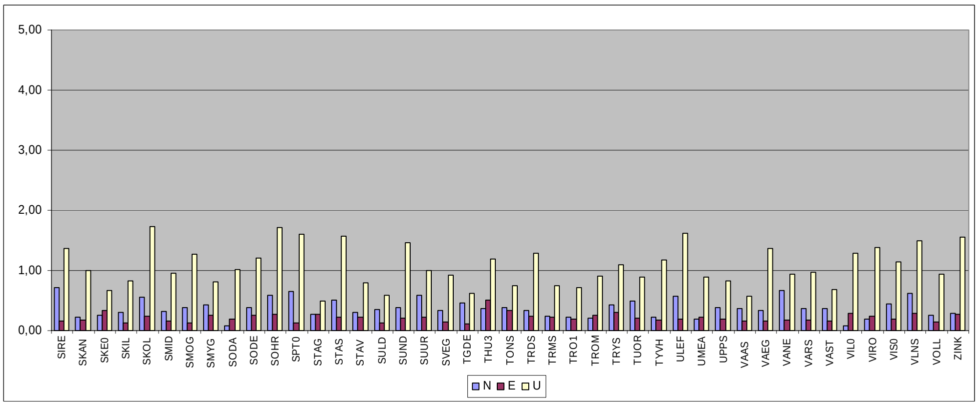


F. The LMV solution – Bernese ver 5.0

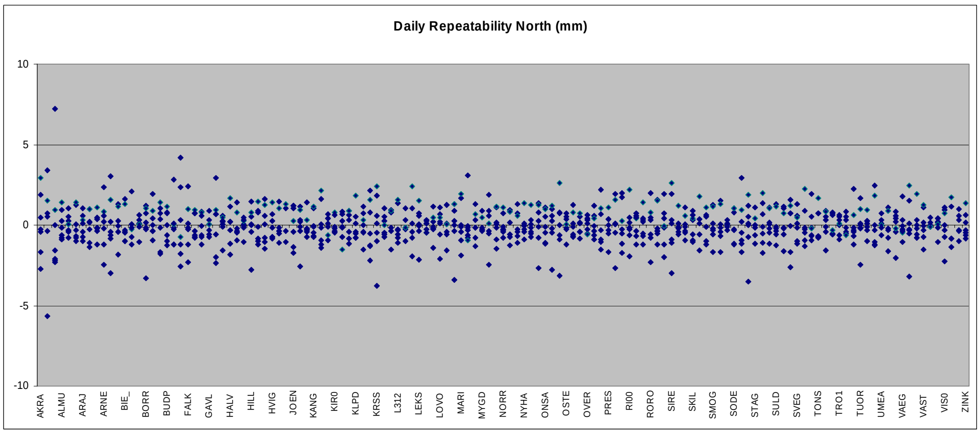
Position standard errors

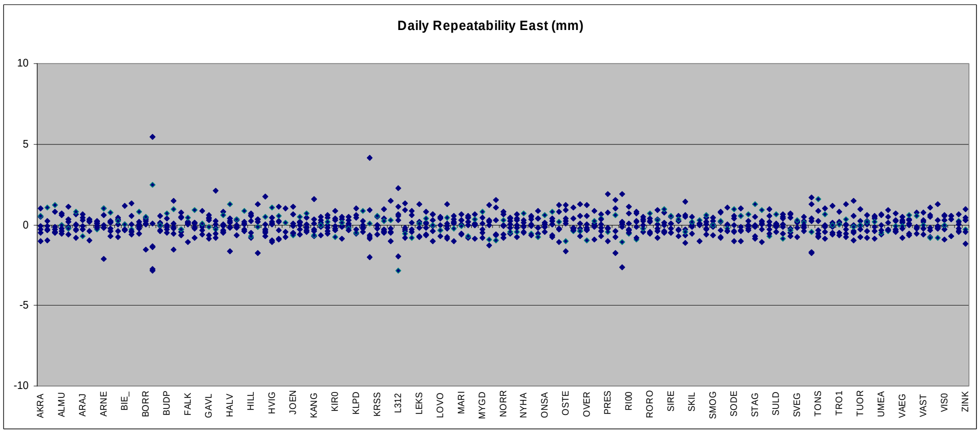


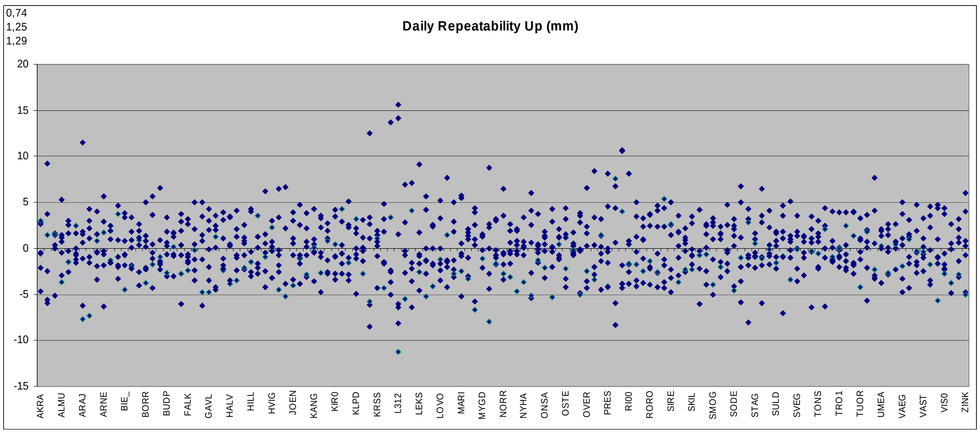




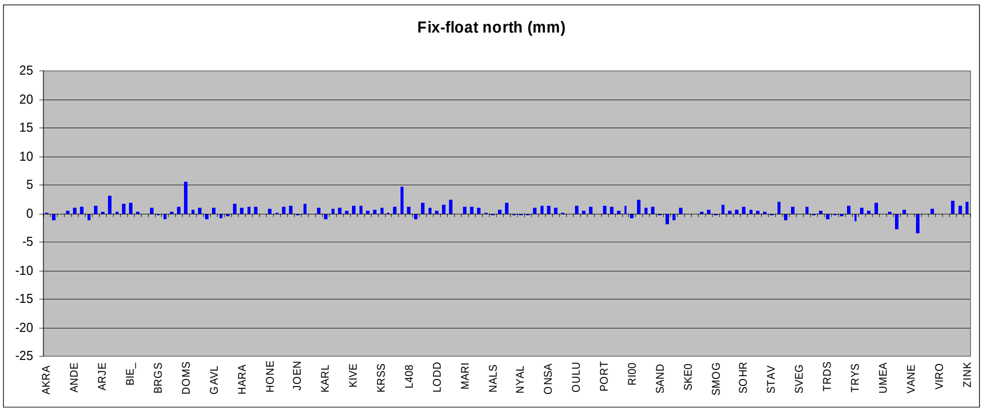
Daily repeatability

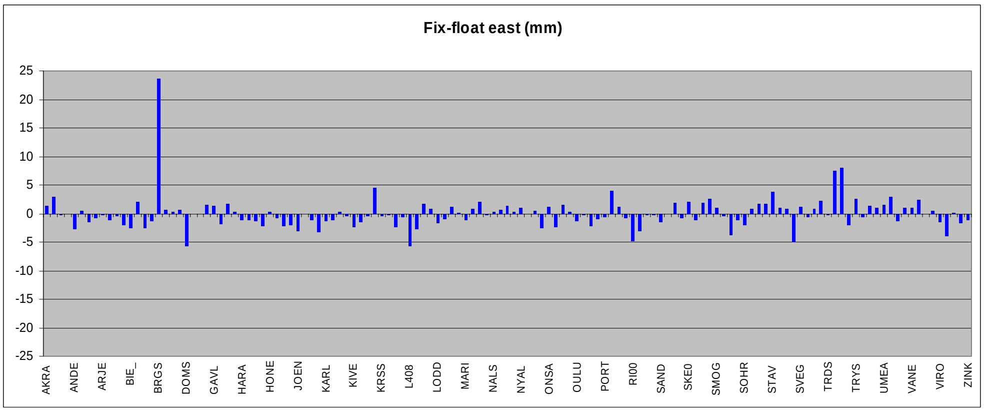


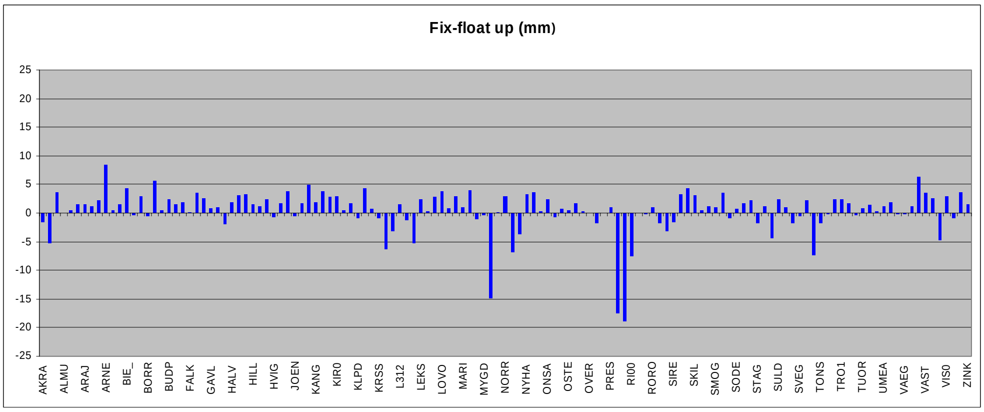




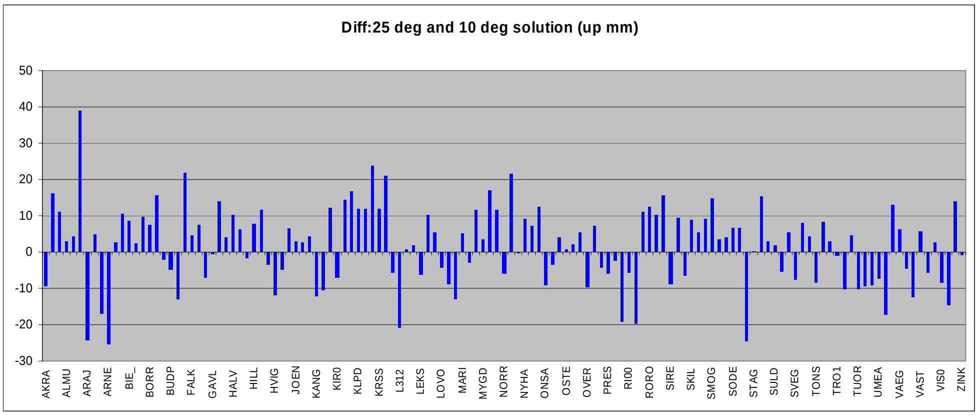
Fixed – float solution







Elevation cut-off test (25 deg – 10 deg)



Largest differences:

Station	Diff up (mm)
ANDO	38,9
ARNE	-25,5
SPT0	-24,7
ARAJ	-24,3
KONG	23,7
DOMS	21,9
NYA1	21,7
KUUS	21,1
L312	-20,9

Helmert transformations to ITRF 2000 (IGS cumulative solution (GPSWeek 1294)

3-parameter fit to IGS cumulative solution G1294
ep G1238, Unit:mm

STN	N	E	U	Not used
HOFN	-1.9	-1.7	1.5	
KIRU	-2.0	0.7	0.5	
METS	-1.6	1.1	-6.0	
NYA1	-2.7	0.3	6.3	*
NYAL	1.7	0.3	0.6	
ONSA	-0.9	0.6	-4.0	
QAQ1	1.6	-2.3	21.6	*
REYK	-0.9	-1.9	23.9	*
THU3	0.7	0.4	9.5	
TRO1	-1.8	0.5	3.0	*
TROM	-1.2	1.2	-0.2	
RMS	1.6	1.0	4.9	3.1

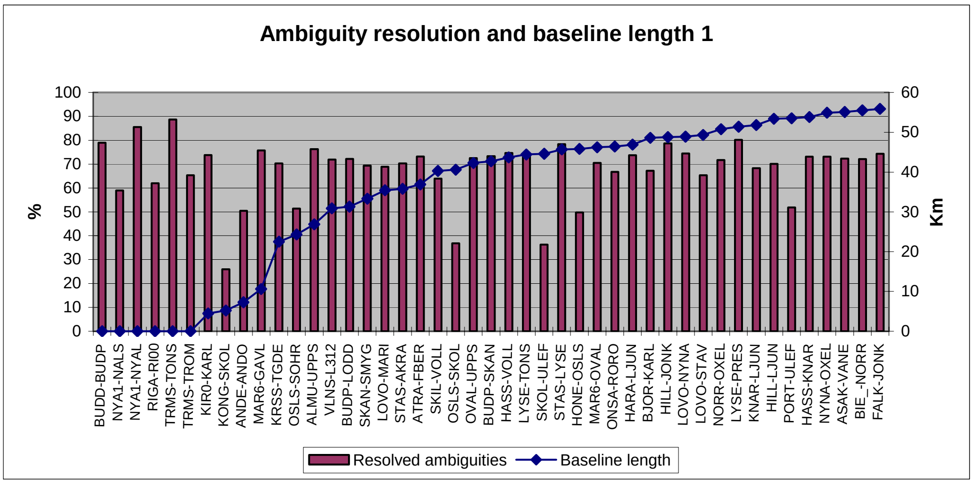
6-parameter fit to IGS cumulative solution G1294
ep G1238, Unit:mm

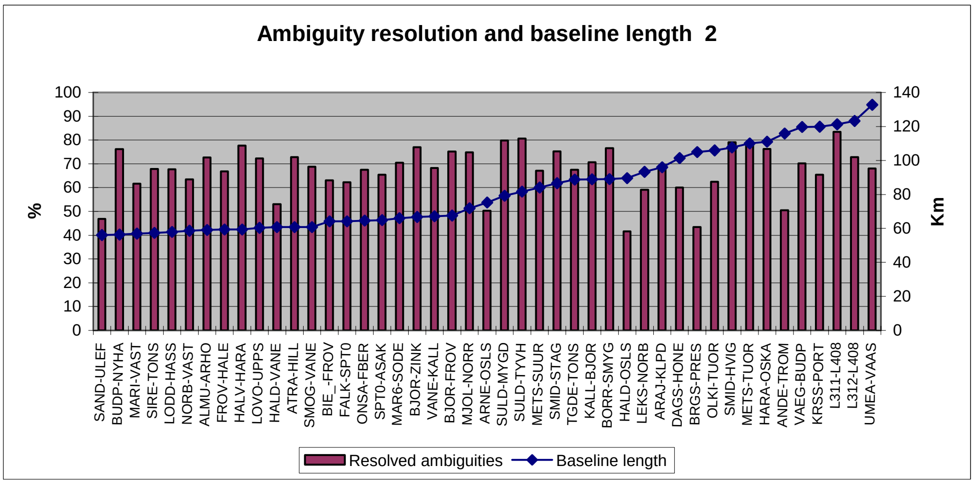
STN	N	E	U	Not used
HOFN	-2.1	-1.9	-0.1	
KIRU	-1.6	0.4	2.4	
METS	-0.6	0.7	-1.1	
NYA1	-2.1	0.1	4.0	*
NYAL	2.3	0.2	-1.8	
ONSA	0.0	0.7	0.3	
QAQ1	-0.5	-2.7	14.8	*
REYK	-1.4	-2.2	21.3	*
THU3	-0.2	-1.5	1.1	
TRO1	-1.4	0.2	4.1	*
TROM	-0.8	0.9	0.9	
RMS	1.5	1.1	1.4	1,5

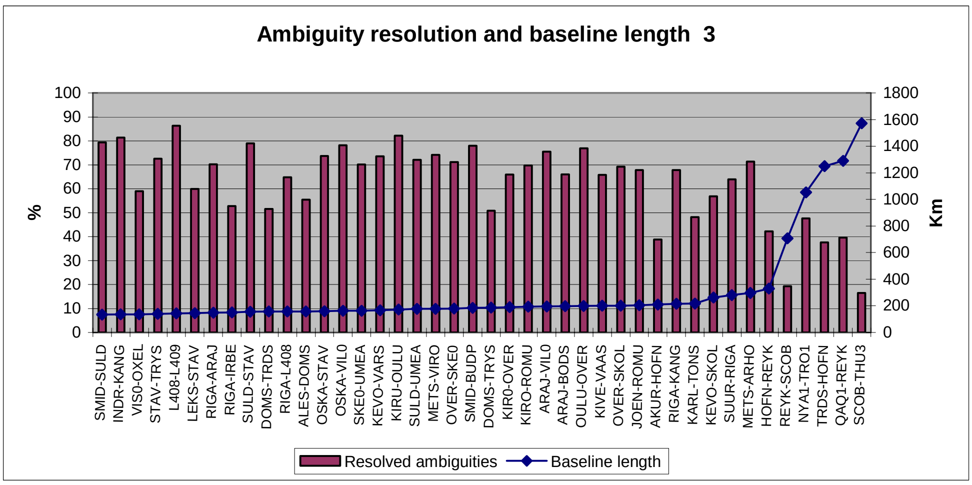
G. The KMS solution, Bernese ver 4.2

Ambiguity resolution and Baseline length.

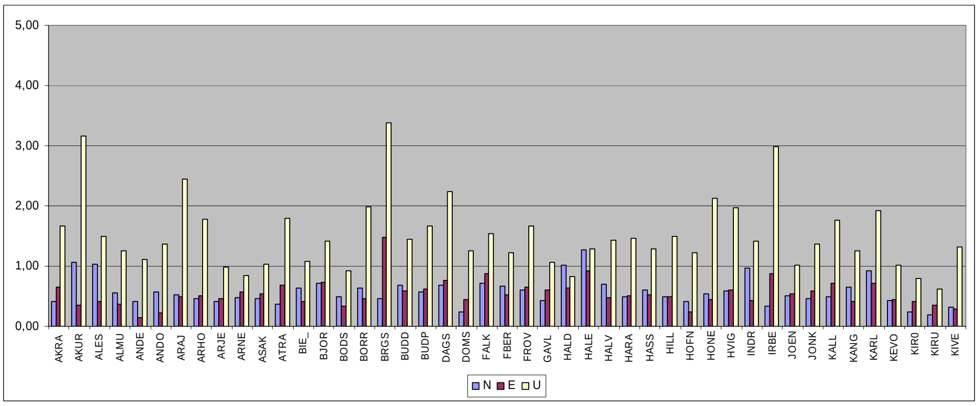
Resolved ambiguities in percent for each baseline. The values are an average of all 7 days.

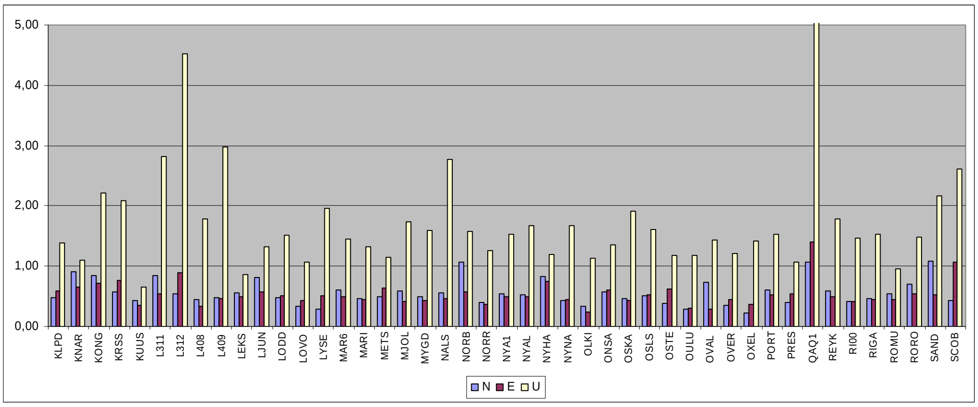


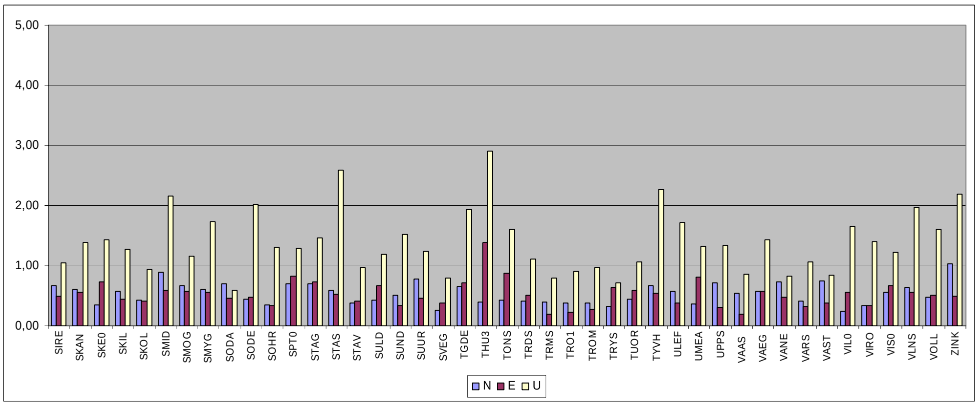




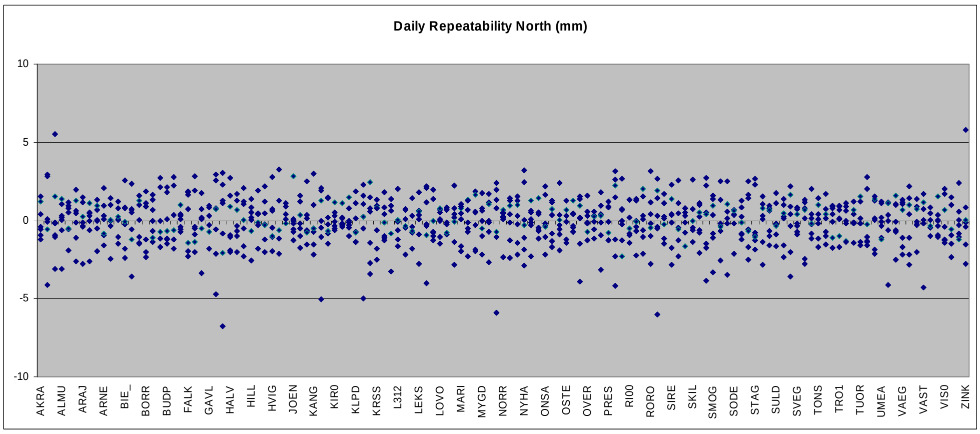
Position standard errors

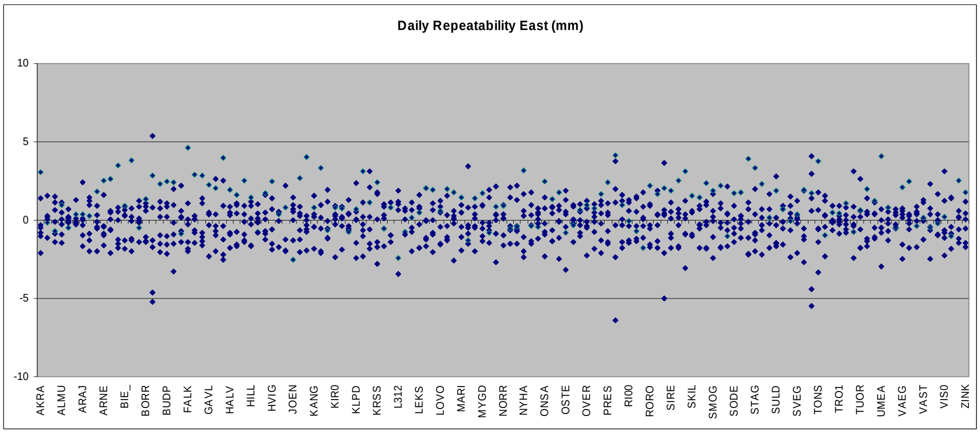


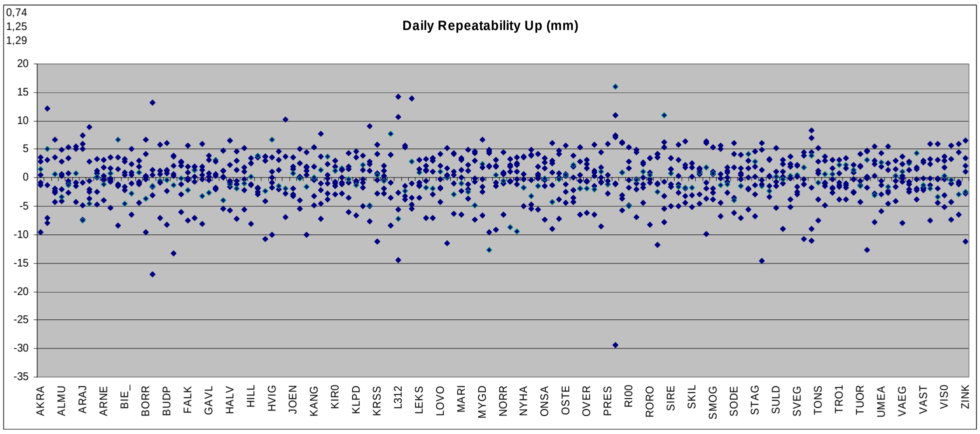




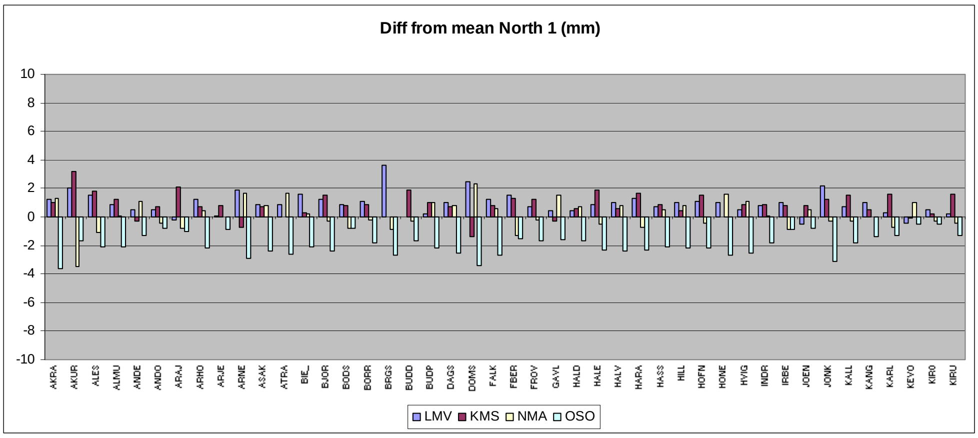
Daily repeatability

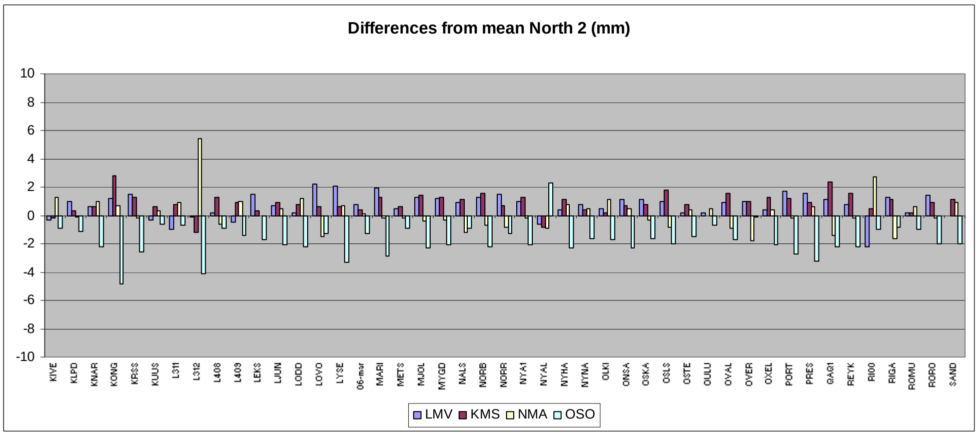


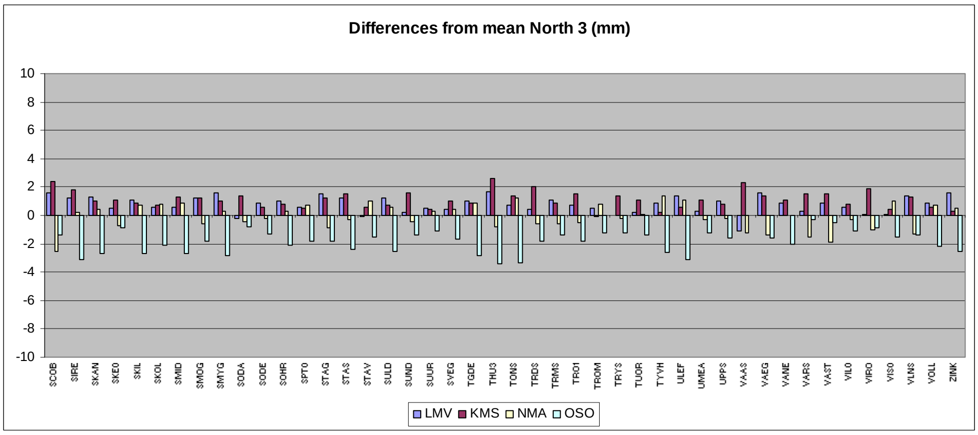


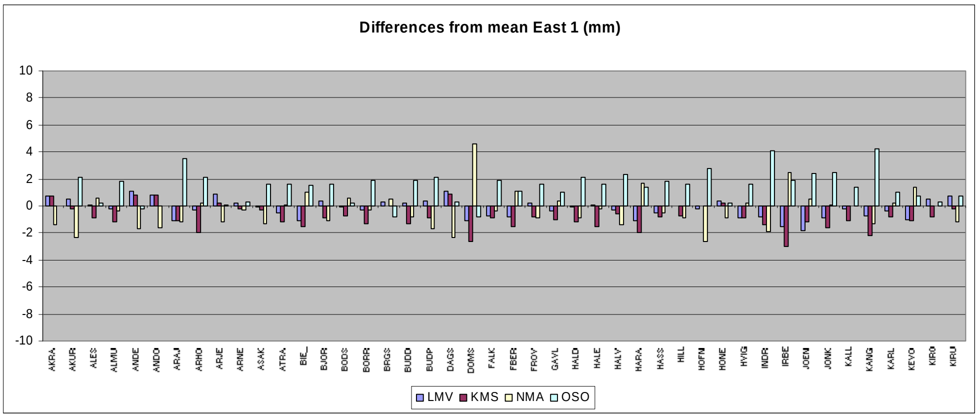


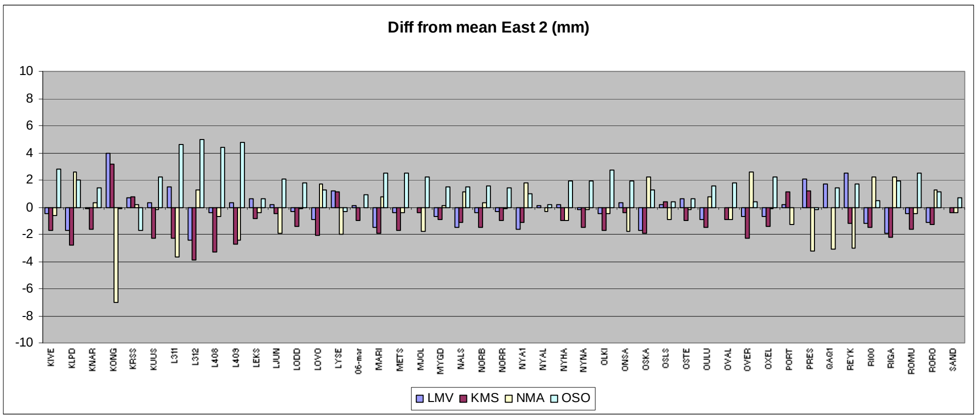
H. Direct comparison

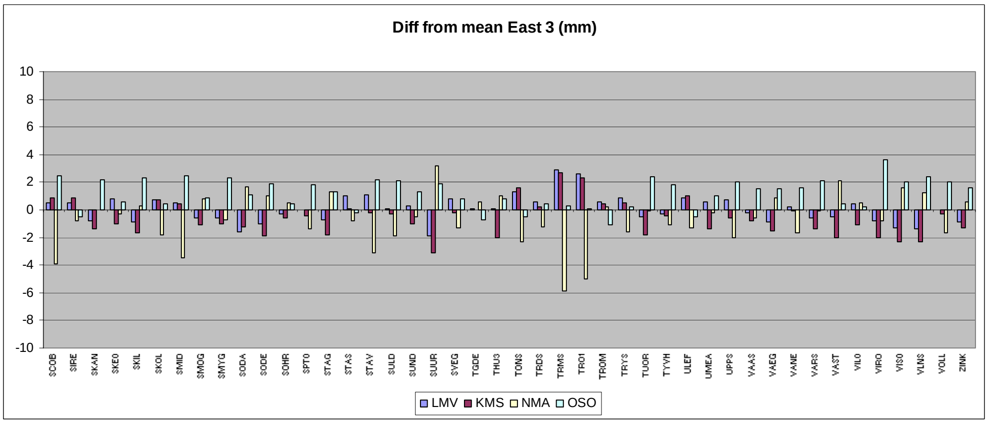


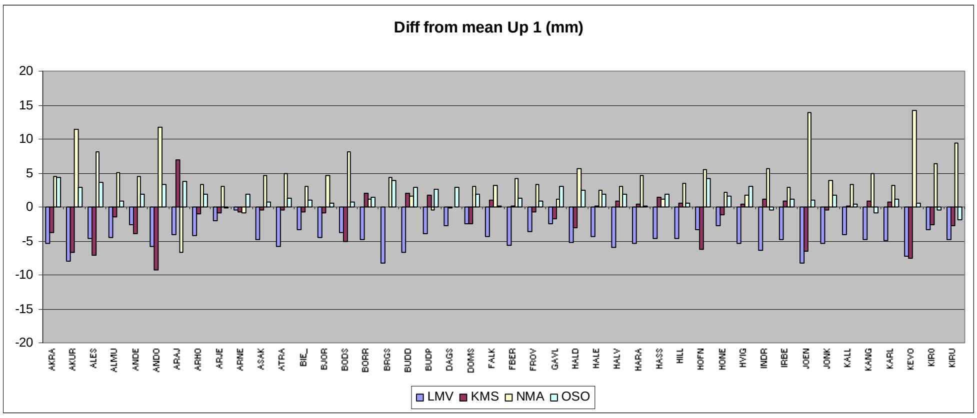


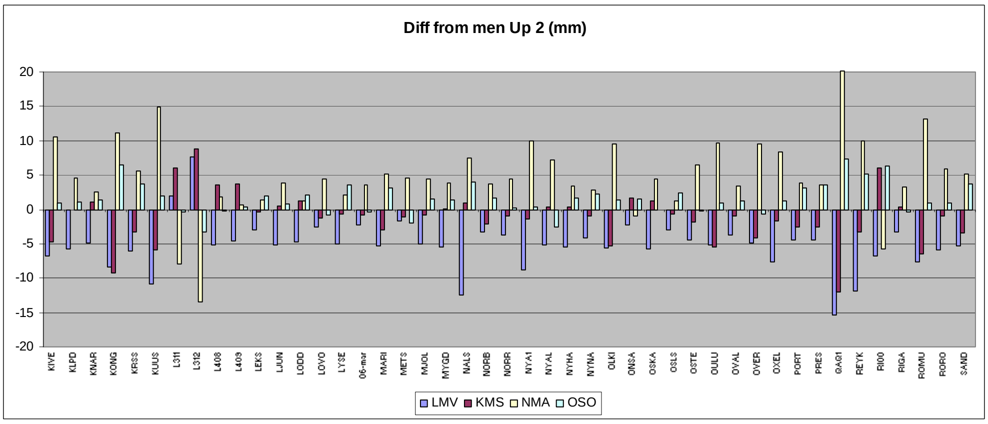


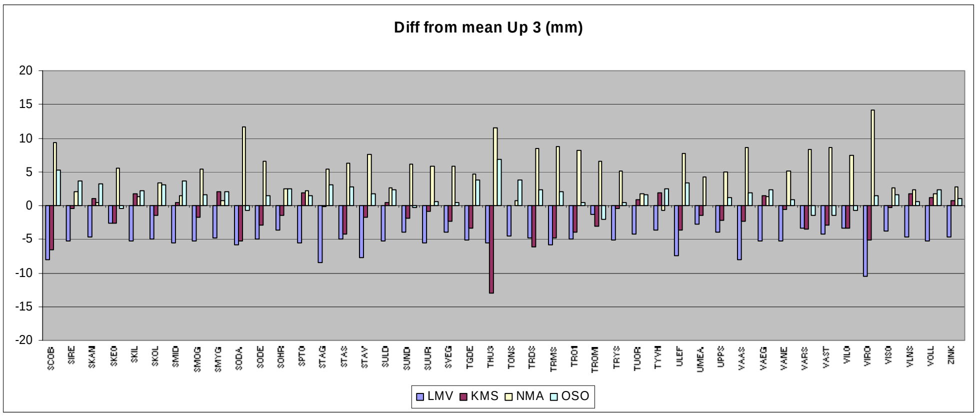

Differences from mean East 1 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
AKRA AKUR ALES ALMU ANDE ANDO ARAJ ARHO ARJE ARNE ASAK ATRA BIE_ BJOR BODS BORR BRGS BUDD BUDP DAGS DOMS FALK FBER FROY GAVL HALD HALE HALV HARA HASS HILL HOFN HONE HVIG INDR IRBE JOEN JONK KALL KANG KARL KEVO KIR0 KIRU
LMV KMS NMA OSO


Diff from mean East 2 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
KIVE KLPD KNAR KONG KRSS KUUS L311 L312 L408 L409 LEKS LJUN LODD LOVO LYSE 06-mar MARI METS MJOL MYGD NALS NORB NORR NYA1 NYAL NYHA NYNA OLKI ONSA OSKA OSLS OSTE OULU OVAL OVER OXEL PORT PRES QAQ1 REYK RI00 RIGA ROMU RORO SAND
LMV KMS NMA OSO


Diff from mean East 3 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
SCOB SIRE SKAN SKE0 SKIL SKOL SMID SMOG SMYG SODA SODE SOHR SPT0 STAG STAS STAV SULD SUND SUUR SVEG TGDE THU3 TONS TRDS TRMS TRO1 TROM TRYS TUOR TYVH ULEF UMEA UPPS VAAS VAEG VANE VARS VAST VIL0 VIRO VIS0 VLNS VOLL ZINK
LMV KMS NMA OSO

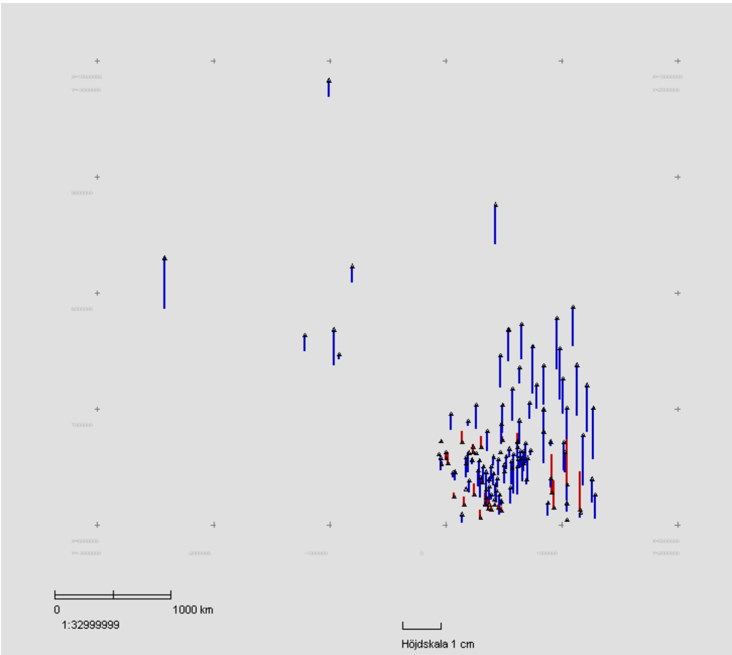

Diff from mean Up 1 (mm)
20
15
10
5
0
-5
-10
-15
-20
AKRA AKUR ALES ALMU ANDE ANDO ARAJ ARHO ARJE ARNE ASAK ATRA BIE_ BJOR BODS BORR BRGS BUDD BUDP DAGS DOMS FALK FBER FROV GAVL HALD HALE HALV HARA HASS HILL HOFN HONE HVIG INDR IRBE JOEN JONK KALL KANG KARL KEVO KIR0 KIRU
LMV KMS NMA OSO


Diff from men Up 2 (mm)
20
15
10
5
0
-5
-10
-15
-20
KIVE KLPD KNAR KONG KRSS KUUS L311 L312 L408 L409 LEKS LJUN LODD LOVO LYSE 06-mar MARI METS MJOL MYGD NALS NORB NORR NYA1 NYAL NYHA NYNA OLKI ONSA OSKA OSLS OSTE OULU OVAL OVER OXEL PORT PRES QAQ1 REYK RI00 RIGA ROMU RORO SAND
LMV KMS NMA OSO

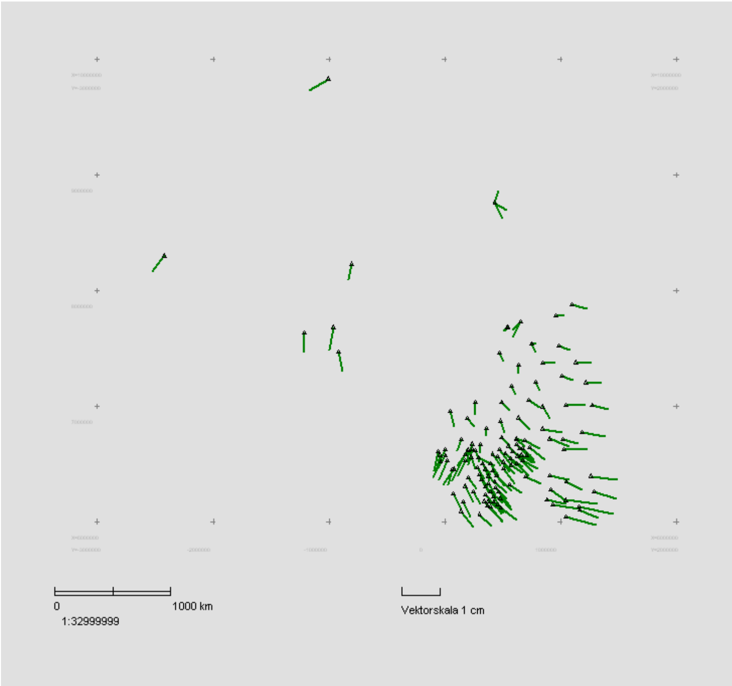

Diff from mean Up 3 (mm)
20
15
10
5
0
-5
-10
-15
-20
SCOB SIRE SKAN SKE0 SKIL SKOL SMID SMOG SMYG SODA SODE SOHR SPT0 STAG STAS STAV SULD SUND SUUR SVEG TGDE THU3 TONS TRDS TRMS TRO1 TROM TRYS TUOR TYVH ULEF UMEA UPPS VAAS VAEG VANE VARS VAST VIL0 VIRO VIS0 VLNS VOLL ZINK
LMV KMS NMA OSO

I. Comparison between solutions after transformation to UTM zone 33

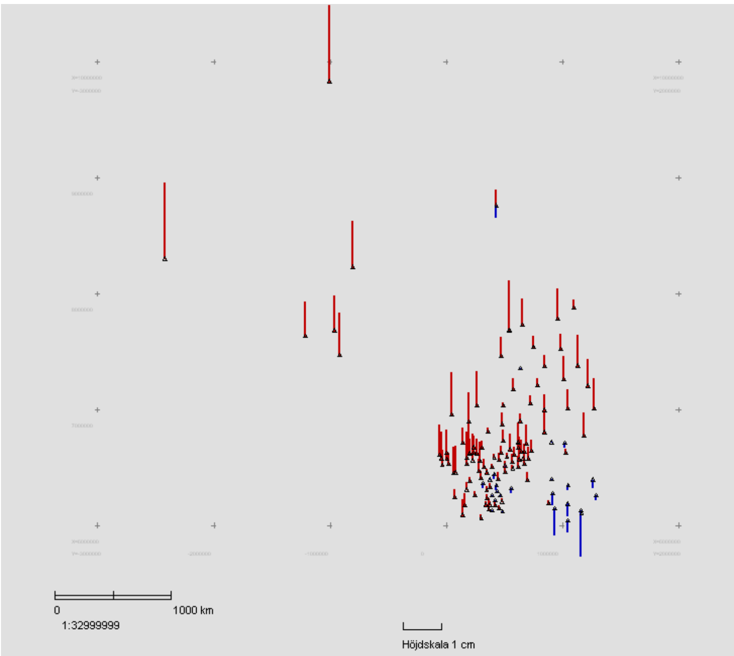
Figur I-1: OSO-NMA, horizontal differences.



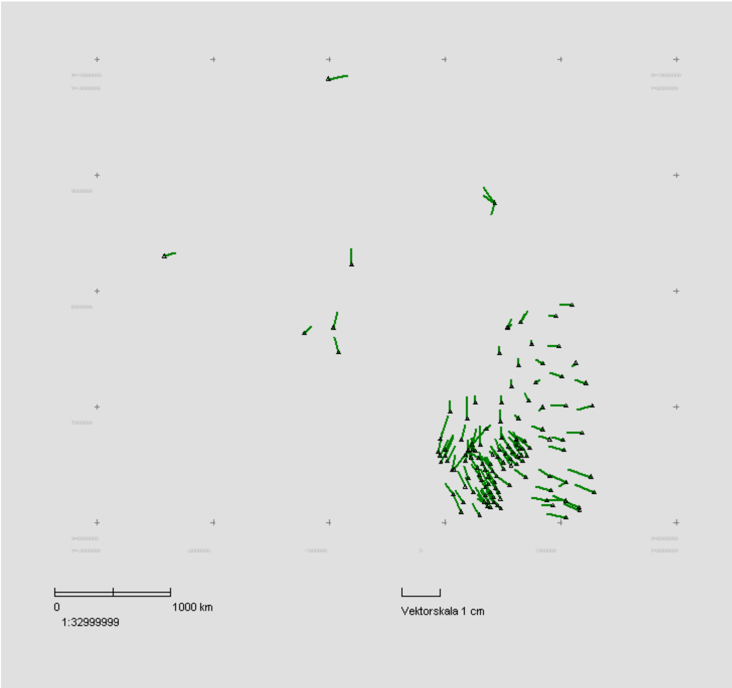
Figur I-2: OSO-NMA, vertical differences.



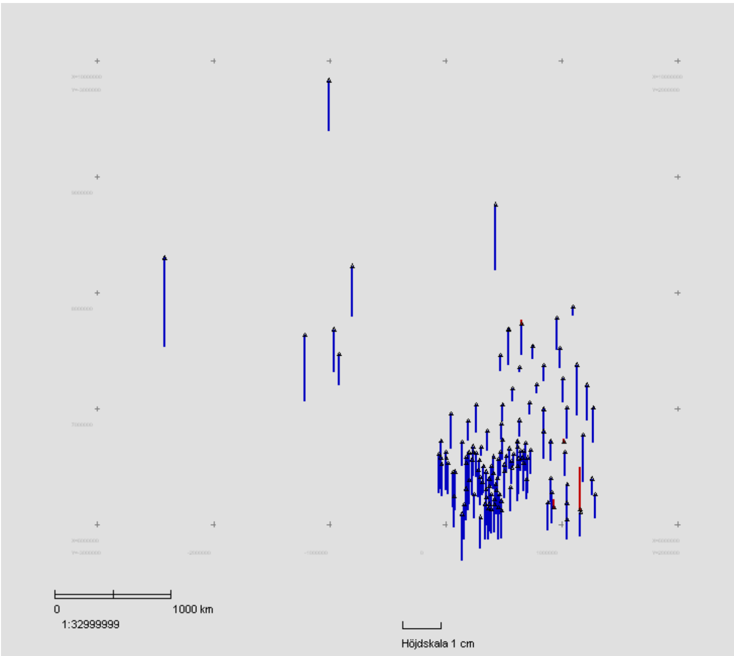
Figur I-3: OSO-KMS, horizontal differences.



Figur I-4: OSO-KMS, vertical differences.

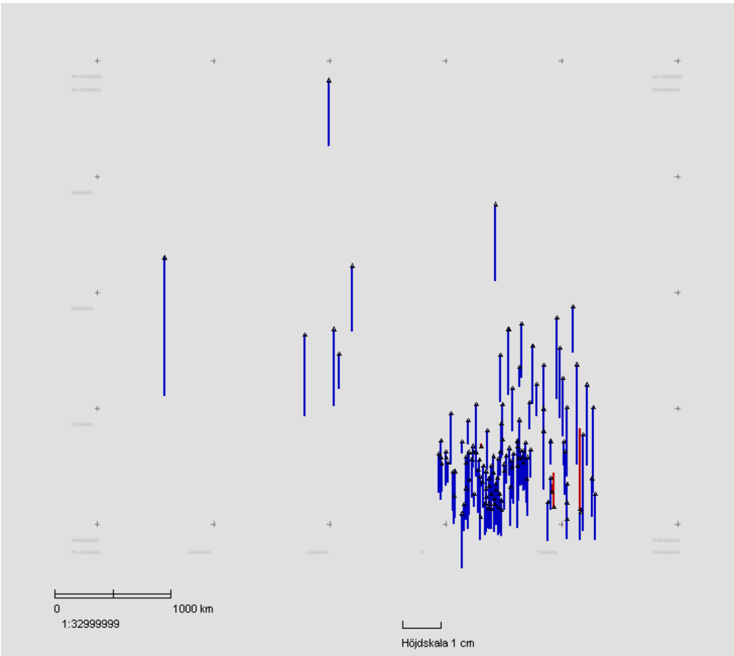


Figur I -5: OSO-LMV, horizontal differences.

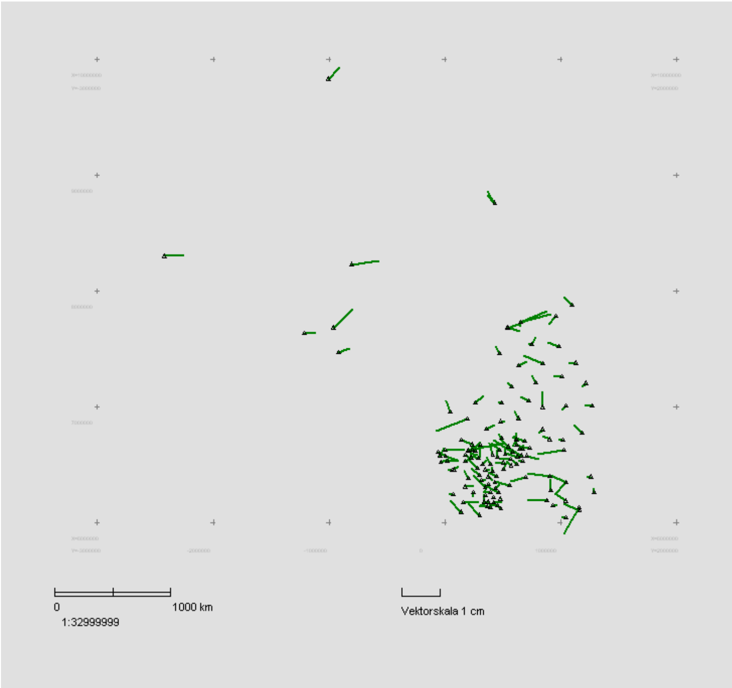


Figur I-6: OSO-LMV, vertical differences.

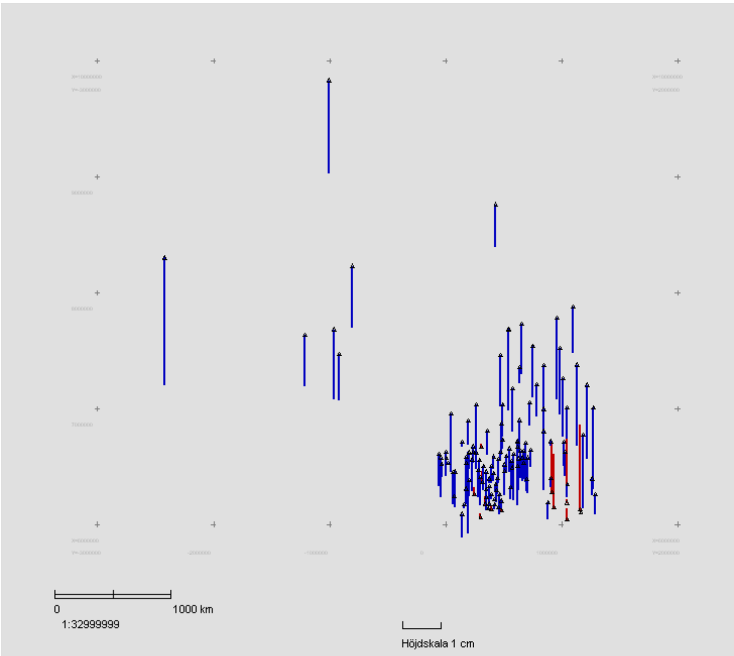
Figur I-7: LMV-NMA, horizontal differences.



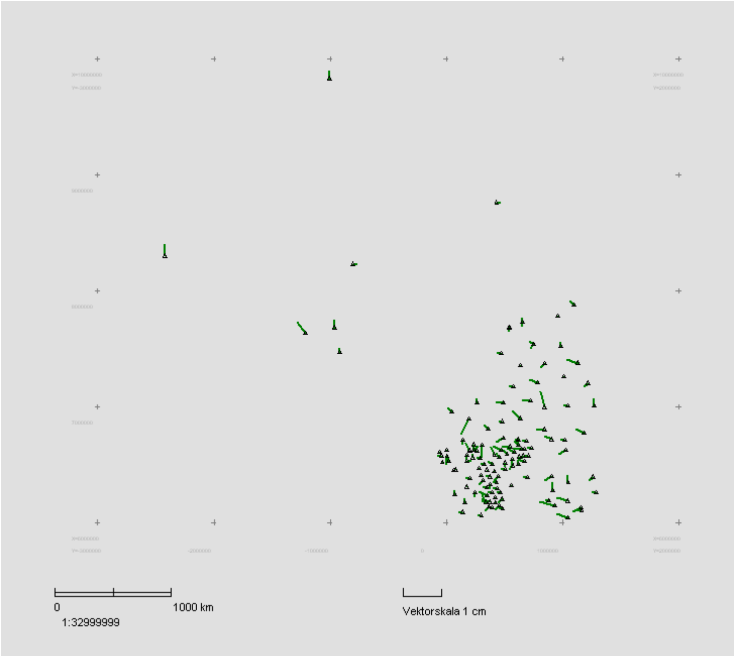
Figur I-8: LMV-NMA, vertical differences.



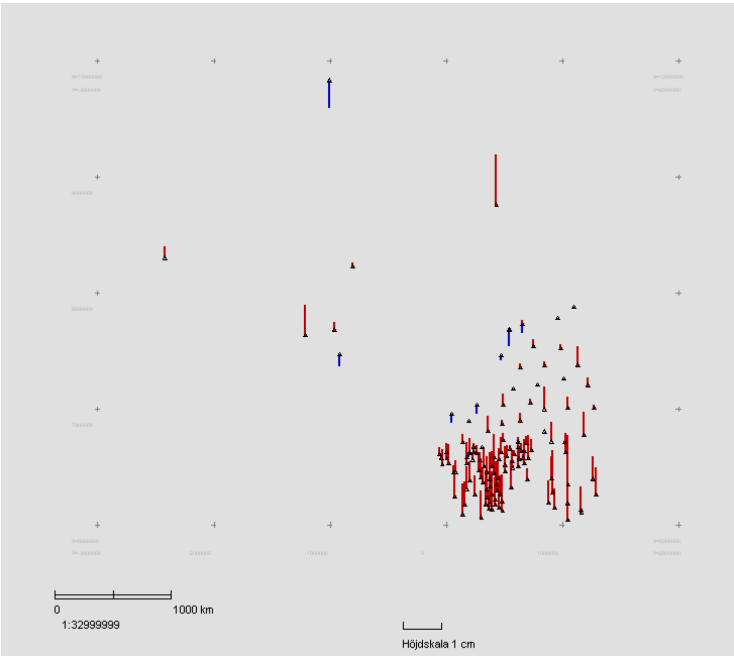
Figur I-9:KMS-NMA, horizontal differences.



Figur I-10: KMS-NMA, vertical differences.



Figur I-11:KMS-LMV, horizontal differences.



Figur I-12:KMS-LMV, vertical differences.

J. Helmert-fits to IGS realizations of ITRF 2000

Helmert to IGS weekly sol 1238 (in ITRF 2000)								
fitted on METS ONSA KIRU TROM THU3 NYAL HOFN QAQ1 REYK								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
NMA	3,3	3,2	2,9	2,8	-0,0011	0,6	1,4	-8,9
OSO	2,3	2,3	1,6	1,5	-0,0005	2,0	-0,7	-2,5
LMV	6,3	6,2	3,0	2,3	0,0021	0,4	-2,1	4,4
KMS	6,4	6,4	2,6	2,1	0,0018	0,0	-1,4	3,1

Helmert to IGS cumulative sol 1294 (in ITRF 2000)								
fitted on METS ONSA KIRU TROM THU3 NYAL HOFN QAQ1 REYK								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
NMA	3,4	3,2	3,4	3,2	-0,0015	0,2	2,1	-8,4
OSO	3,2	3,2	2,9	2,9	-0,0009	1,7	0,0	-2,1
LMV	6,4	6,4	3,9	3,7	0,0017	0,0	-1,4	4,8
KMS	6,3	6,3	3,1	2,9	0,0014	-0,4	-0,8	3,6

Helmert to IGS cumulative sol 1294 (in ITRF 2000)								
fitted on METS ONSA KIRU TROM THU3 NYAL HOFN (not QAQ1 and REYK)								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
NMA	2,2	2,1	1,9	1,8	-0,0009	0,0	1,6	-9,4
OSO	2,7	2,6	1,9	1,9	-0,0011	1,1	0,4	-3,5
LMV	3,1	3,0	1,5	1,3	0,0010	0,0	0,0	0,0
KMS	5,2	5,3	2,9	2,9	0,0010	0,0	0,0	0,0

Explanations:

# par	Parameters
3	translations
4	translations + scale
6	translations + rotations
7	translations + rotations + scale

The presented scale is taken from the 7-parameter transformation but it is almost in all cases identical to the scale in the 4-parameter transformation. dN, dE and dU are the translations in a topocentric system when solving for 3 parameters.

K. Helmert-fits between solutions

Helmert to NMA, sigma, unit mm, ppm								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
OSO	3,0	3,0	2,6	2,6	0,0000	2,2	-1,7	3,2
LMV	4,2	4,0	3,7	3,5	0,0028	-0,2	-0,5	9,5
KMS	4,7	4,6	3,8	3,7	0,0024	-0,2	0,2	6,0

Helmert to OSO, sigma, unit mm, ppm								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
LMV	2,8	2,5	2,5	2,1	0,0028	-2,4	1,2	6,3
KMS	3,1	2,9	2,4	2,1	0,0023	-2,4	1,9	2,8

Helmert to LMV, sigma, unit mm, ppm								
#par	3	4	6	7	Scale	dN	dE	dU
	RMS (mm)				ppm	Translations (mm)		
KMS	2,0	1,9	1,8	1,8	-0,0005	0,0	0,7	-3,5

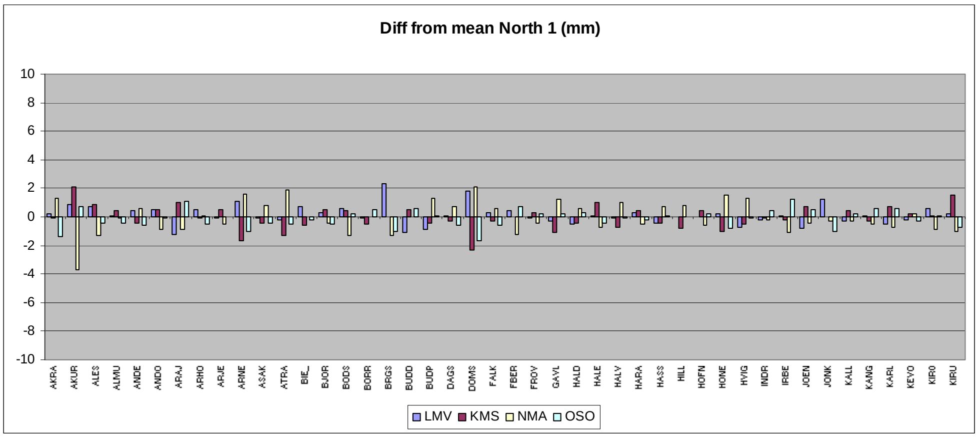
All 133 used as fitting points (except for KMS where BRGS is excluded).

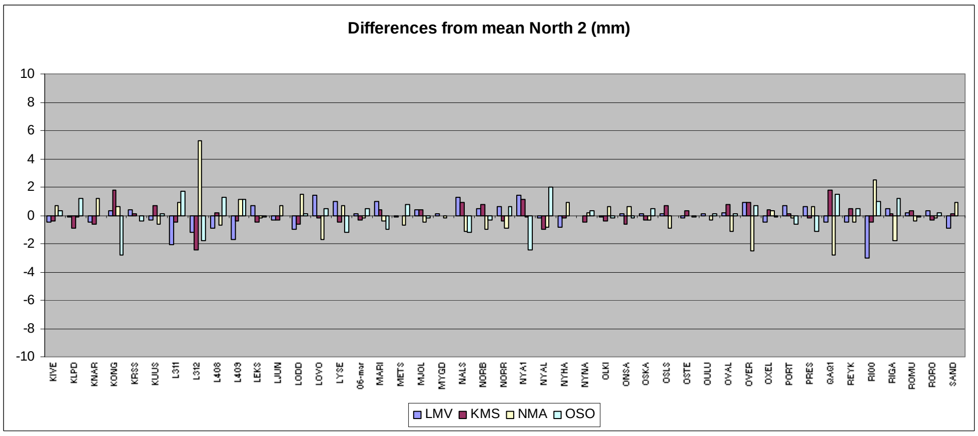
Explanations:

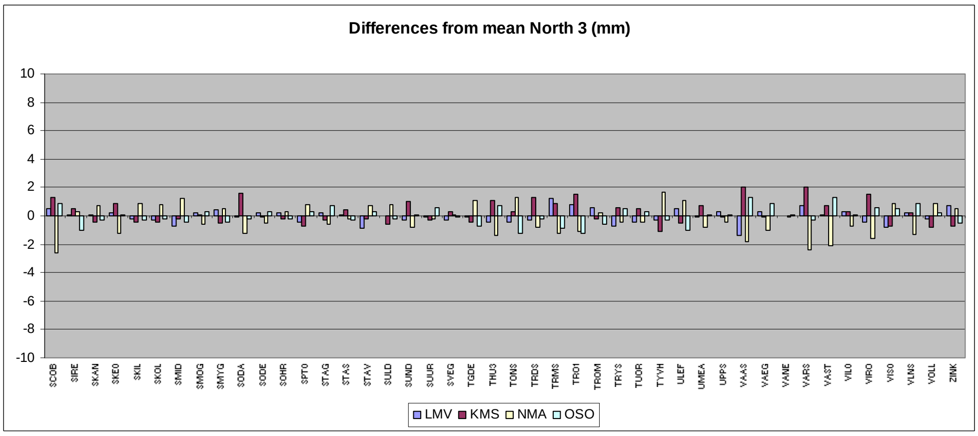
# par	Parameters
3	translations
4	translations + scale
6	translations + rotations
7	translations + rotations + scale

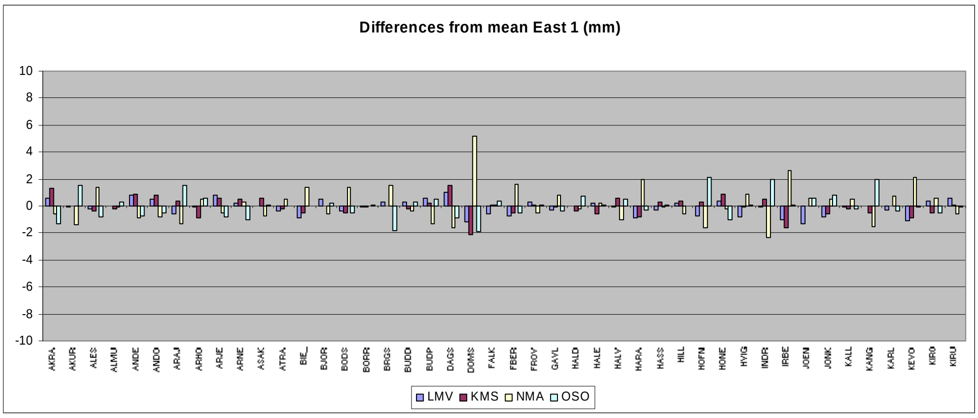
The presented scale is taken from the 7-parameter transformation but it is almost in all cases identical to the scale in the 4-parameter transformation. dN, dE and dU are the translations in a topocentric system when solving for 3 parameters.

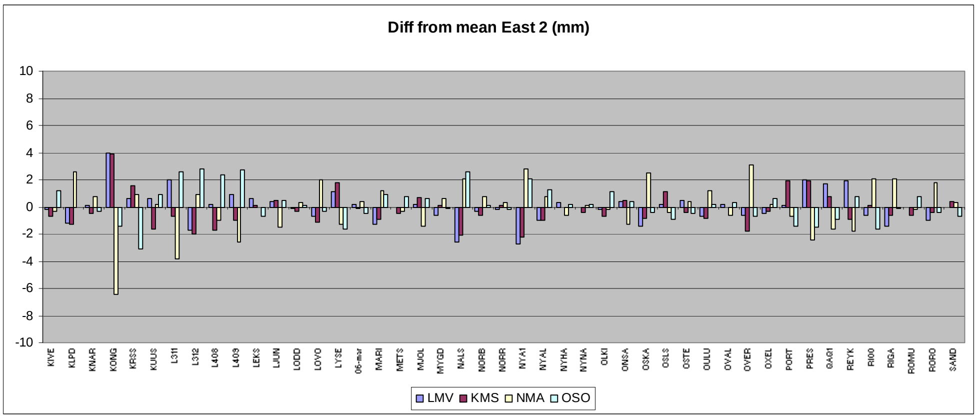
L. Comparison after harmonization

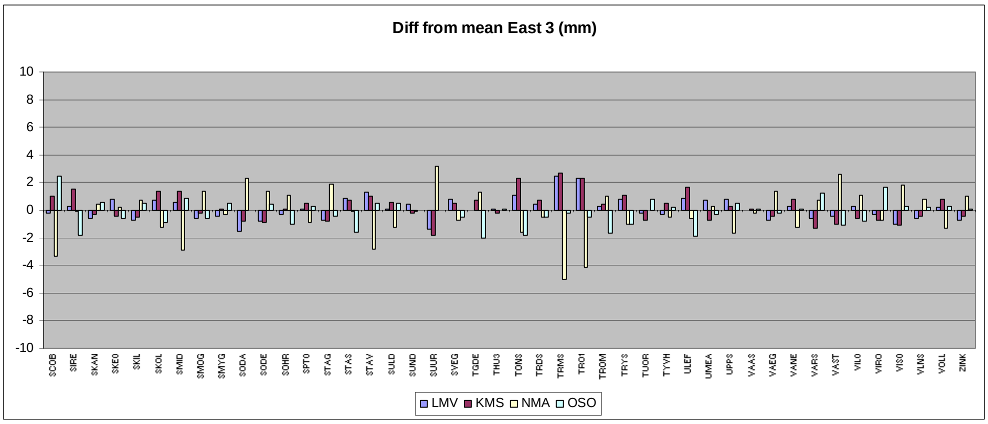


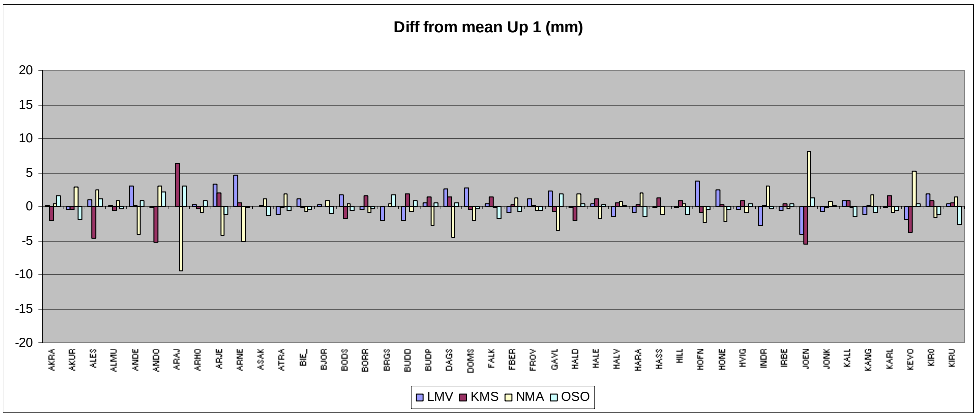


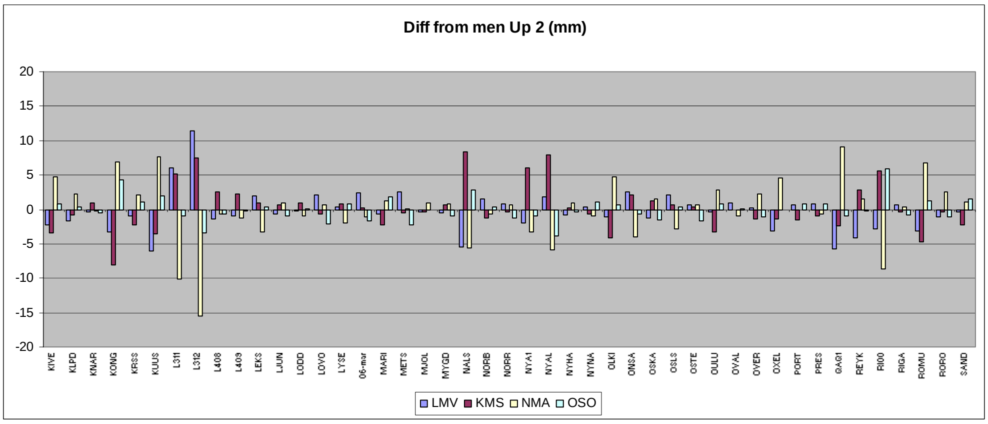


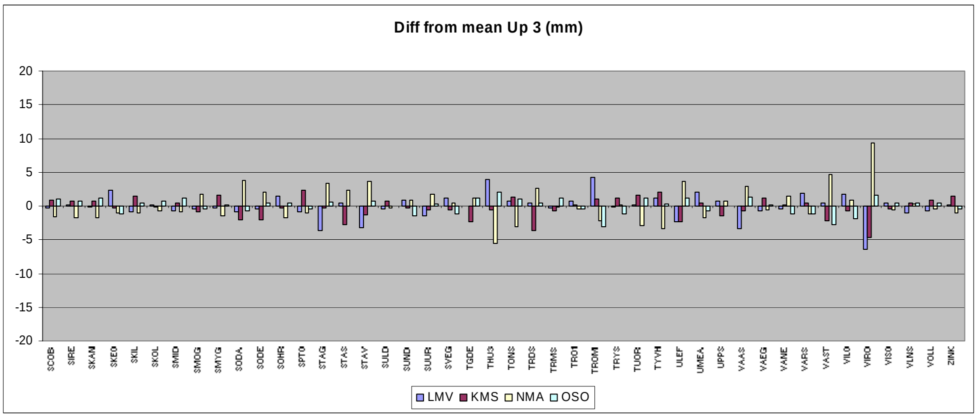

Differences from mean East 1 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
AKRA AKUR ALES ALMU ANDE ANDO ARAJ ARHO ARJE ARNE ASAK ATRA BIE_ BJOR BODS BORR BRGS BUDD BUDP DAGS DOMS FALK FBER FROY GAVL HALD HALE HALY HARA HASS HILL HOFN HONE HVIG INDR IRBE JOEN JONK KALL KANG KARL KEVO KIR0 KIRU
LMV KMS NMA OSO


Diff from mean East 2 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
KIVE KLPD KNAR KONG KRSS KUUS L311 L312 L408 L409 LEKS LJUN LODD LOVO LYSE 06-mar MARI METS MJOL MYGD NALS NORB NORR NYA1 NYAL NYHA NYNA OLKI ONSA OSKA OSLS OSTE OULU OVAL OVER OXEL PORT PRES QAQ1 REYK RI00 RIGA ROMU RORO SAND
LMV KMS NMA OSO


Diff from mean East 3 (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
SCOB SIRE SKAN SKE0 SKIL SKOL SMID SMOG SMYG SODA SODE SOHR SPT0 STAG STAS STAV SULD SUND SUUR SVEG TGDE THU3 TONS TRDS TRMS TRO1 TROM TRYS TUOR TYVH ULEF UMEA UPPS VAAS VAEG VANE VARS VAST VIL0 VIRO VIS0 VLNS VOLL ZINK
LMV KMS NMA OSO


Diff from mean Up 1 (mm)
20
15
10
5
0
-5
-10
-15
-20
AKRA AKUR ALES ALMU ANDE ANDO ARAJ ARHO ARJE ARNE ASAK ATRA BIE_ BJOR BODS BORR BRGS BUDD BUDP DAGS DOMS FALK FBER FROV GAVL HALD HALE HALV HARA HASS HILL HOFN HONE HVIG INDR IRBE JOEN JONK KALL KANG KARL KEVO KIR0 KIRU
LMV KMS NMA OSO


Diff from men Up 2 (mm)
20
15
10
5
0
-5
-10
-15
-20
KIVE KLPD KNAR KONG KRSS KUUS L311 L312 L408 L409 LEKS LJUN LODD LOVO LYSE 06-mar MARI METS MJOL MYGD NALS NORB NORR NYA1 NYAL NYHA NYNA OLKI ONSA OSKA OSLS OSTE OULU OVAL OVER OXEL PORT PRES QAQ1 REYK RI00 RIGA ROMU RORO SAND
LMV KMS NMA OSO


Diff from mean Up 3 (mm)
20
15
10
5
0
-5
-10
-15
-20
SCOB SIRE SKAN SKE0 SKIL SKOL SMID SMOG SMYG SODA SODE SOHR SPT0 STAG STAS STAV SULD SUND SUUR SVEG TGDE THU3 TONS TRDS TRMS TRO1 TROM TRYS TUOR TYVH ULEF UMEA UPPS VAAS VAEG VANE VARS VAST VIL0 VIRO VIS0 VLNS VOLL ZINK
LMV KMS NMA OSO

M. Comparison between harmonized solutions and combined solution after transformation to UTM zone 33.

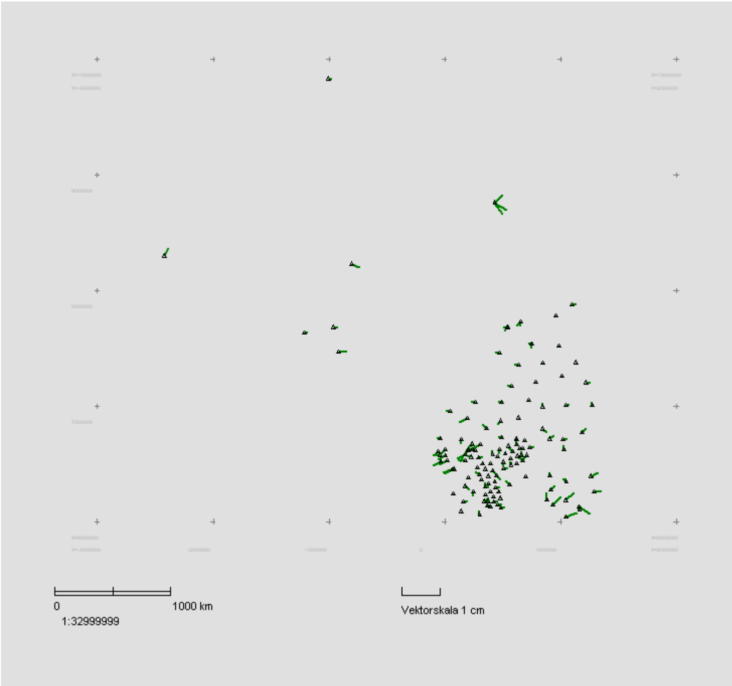


Figure M-1: OSO to combined solution, horizontal differences.

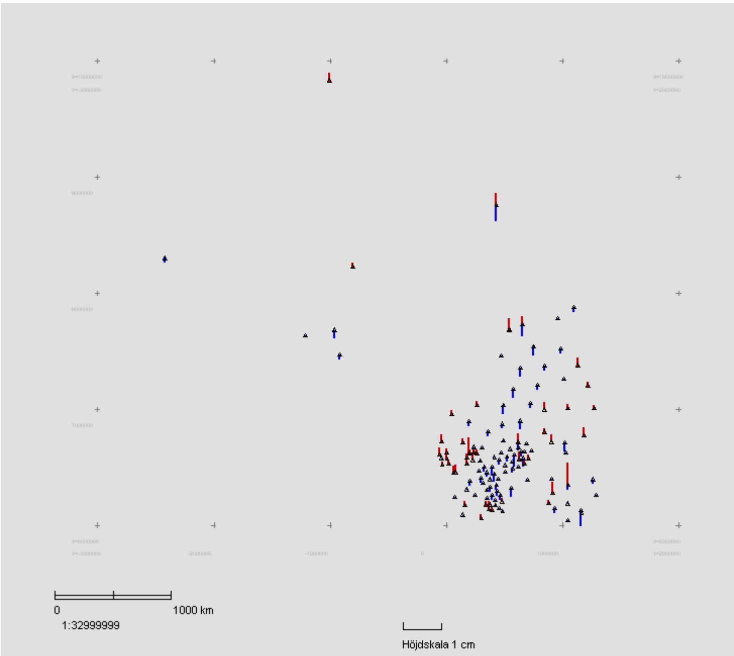


Figure M-2: OSO to combined solution, vertical differences.

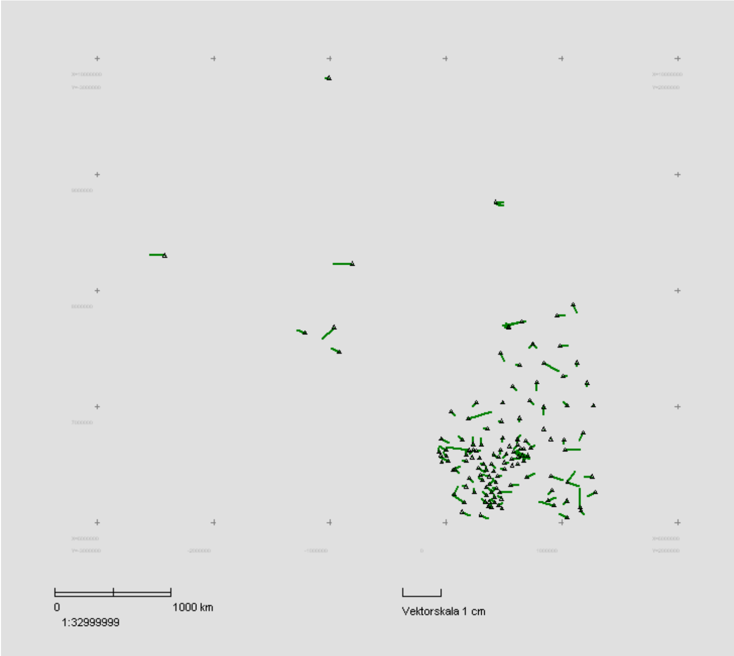


Figure M-3: NMA to combined solution, horizontal differences.

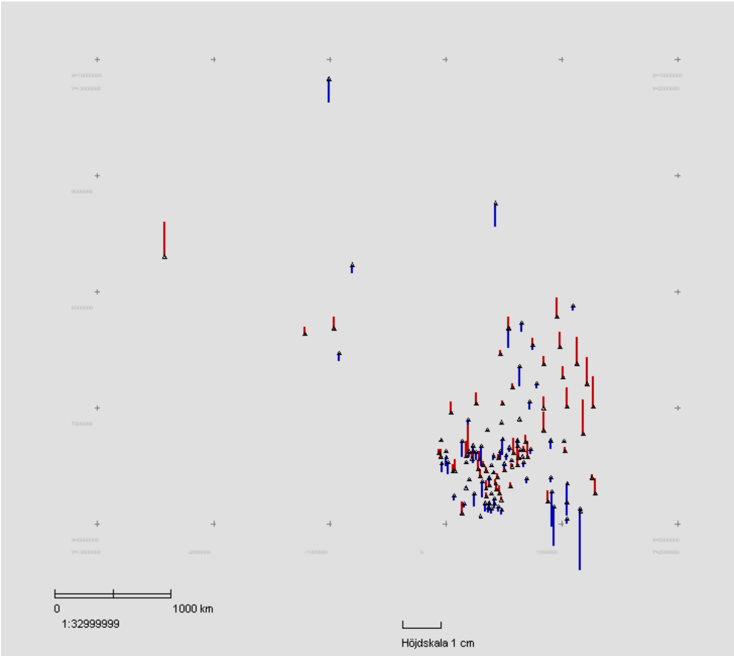


Figure M-4: NMA to combined solution, vertical differences.

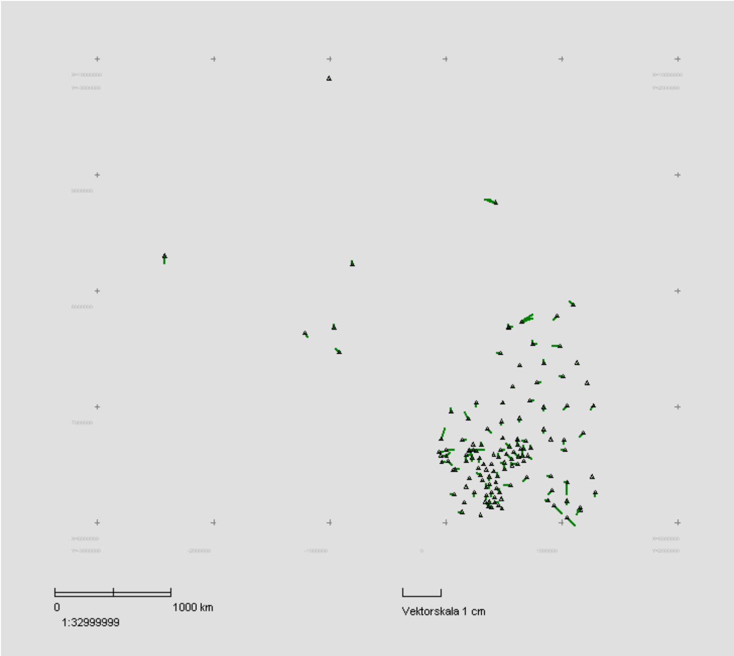


Figure M-5: LMV to combined solution, horizontal differences.

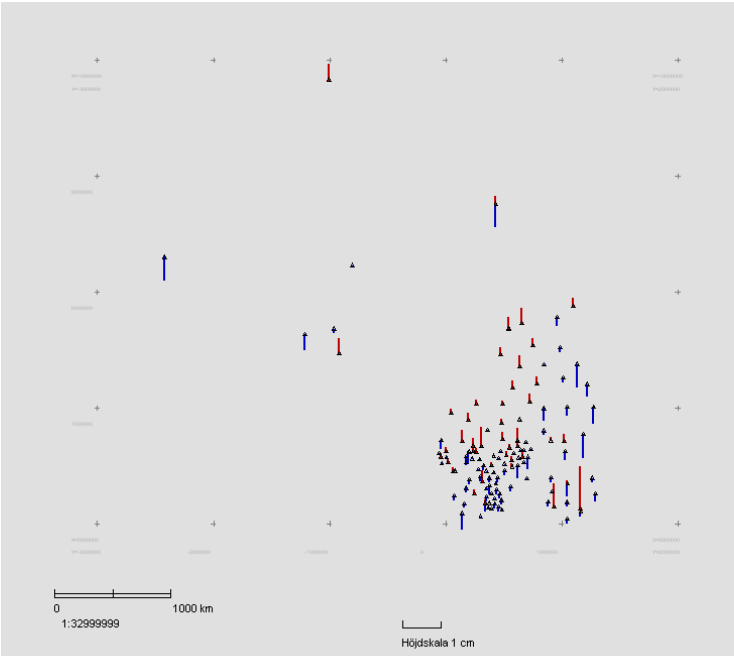


Figure M-6: LMV to combined solution, vertical differences.

Figure M-7: KMS to combined solution, horizontal differences.

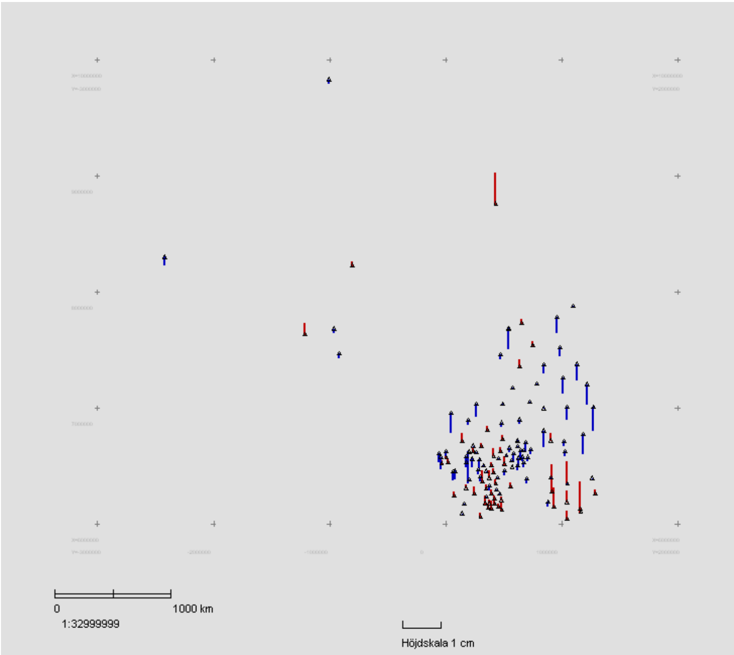


Figure M-8: KMS to combined solution, vertical differences.

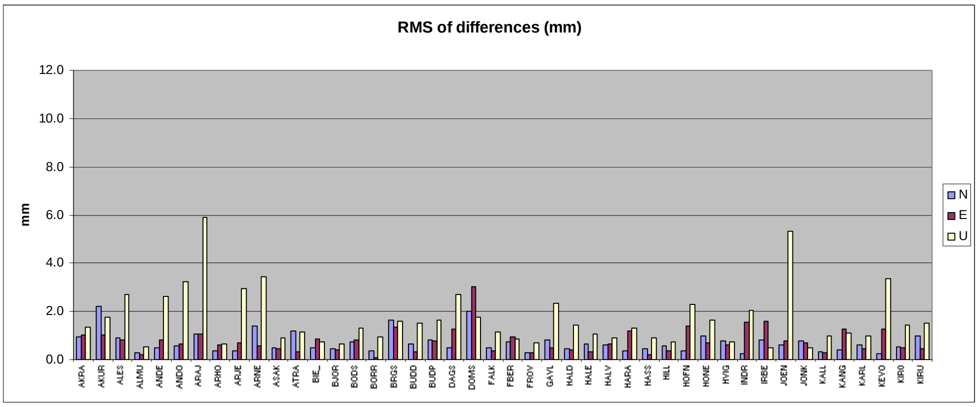
N. Final combined coordinates in ITRF 2000 epoch 2003.75

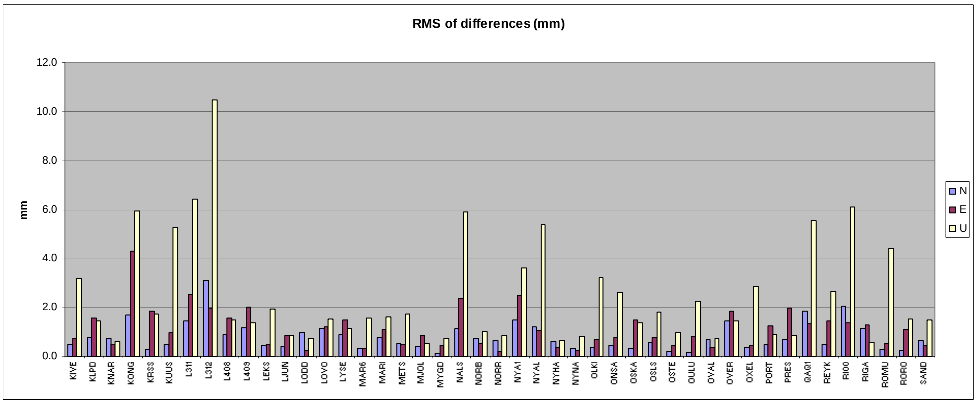
Station	X	Y	Z	Latitude			Longitude			h
AKRA	3254758.5874	295601.6128	5458918.8409	59	15	40.162546	5	11	21.997171	65.1172
AKUR	2502918.5717	-819166.9627	5789714.8936	65	41	7.527077	-18	7	20.928177	134.1588
ALES	2938027.3479	319096.3493	5633413.9555	62	28	34.980641	6	11	54.757201	189.8870
ALMU	3051686.9263	995723.6848	5493062.9845	59	51	58.665284	18	4	14.865394	56.6094
ANDE	2169480.9148	627616.8718	5944952.2349	69	19	33.806299	16	8	5.338510	44.2585
ANDO	2175764.8320	624247.8976	5943414.8317	69	16	42.143599	16	0	31.303832	410.6163
ARAJ	3277266.5876	1309685.8298	5295146.7568	56	29	36.592344	21	46	58.828475	208.5641
ARHO	3033319.5435	1051907.2736	5492748.4149	59	51	39.296362	19	7	32.655022	40.8546
ARJE	2441775.1562	799268.1815	5818729.3538	66	19	4.865846	18	7	29.513638	489.2236
ARNE	3121952.5970	633902.4445	5507296.4802	60	7	10.456920	11	28	39.675335	196.6044
ASAK	3286466.4641	723964.3668	5400051.7214	58	14	30.163506	12	25	23.080325	112.6673
ATRA	3382554.0630	777774.8477	5333332.8494	57	7	13.633050	12	56	57.640053	165.3756
BIE_	3154144.2738	917058.8568	5449043.1160	59	5	15.913277	16	12	41.923532	91.6453
BJOR	3169460.3481	805521.4644	5457845.8620	59	14	25.049725	14	15	35.523083	199.4249
BODS	2393811.6263	612747.7349	5860377.6599	67	16	30.158486	14	21	28.109270	50.8152
BORR	3523674.9150	928375.9673	5217378.7300	55	14	57.216280	14	45	36.663776	158.9460
BRGS	3155871.1642	290902.8634	5516573.5590	60	17	19.481129	5	15	59.563128	93.8190
BUDD	3513649.3528	778954.7377	5248201.9529	55	44	19.926687	12	29	59.856187	87.9557
BUDP	3513638.2818	778956.3810	5248216.4219	55	44	20.469399	12	30	0.085468	94.0294
DAGS	3122524.3628	466764.2060	5524286.5581	60	25	0.590496	8	30	6.449291	845.3651
DOMS	2957499.2597	474477.2292	5612998.1331	62	4	24.187291	9	6	51.853410	733.3466
FALK	3278189.6828	790418.5431	5395964.7976	58	10	11.776130	13	33	21.915732	259.9188
FBER	3408401.3181	755024.5572	5320097.1446	56	54	12.838713	12	29	25.399943	63.7055
FROV	3132396.4978	860615.4634	5470596.9011	59	27	59.749437	15	21	45.919430	83.0049
GAVL	2993586.6966	922761.7340	5537295.8504	60	40	0.409089	17	7	54.176227	55.3864
HALD	3216858.5498	647832.1092	5450991.3868	59	7	20.131135	11	23	10.683985	62.0599
HALE	3115217.6604	806835.8348	5488628.1283	59	47	3.675953	14	31	13.583395	234.5759
HALV	3456798.7196	906264.1963	5265352.9450	56	0	49.187975	14	41	25.945657	72.5524
HARA	3414100.0473	880514.9557	5297435.7386	56	31	50.548889	14	27	42.293419	211.8560
HASS	3464655.5746	845750.1366	5270271.6918	56	5	31.982963	13	43	5.076671	114.0576
HILL	3351528.4856	828634.3617	5345223.3891	57	19	1.178683	13	53	14.468955	212.4473
HOFN	2679689.9926	-727951.2438	5722789.2884	64	16	2.250331	-15	11	52.515360	82.6959
HONE	3132537.3405	566401.9816	5508615.1977	60	8	36.869260	10	14	56.617715	181.4228
HVIG	3523228.6414	502878.8676	5275213.1004	56	10	21.095560	8	7	23.151878	63.7218
INDR	3177703.5301	1662050.1151	5257080.3777	55	52	44.782764	27	36	40.107893	213.6405
IRBE	3183612.0641	1276706.6593	5359310.8632	57	33	15.905960	21	51	7.193165	40.6878
JOEN	2564139.1129	1486149.7560	5628951.4318	62	23	28.223771	30	5	46.169334	113.7375
JONK	3309991.5798	828932.2615	5370882.4564	57	44	43.705214	14	3	34.593751	260.4011
KALL	3237443.3561	758888.5786	5424620.9530	58	39	49.062907	13	11	33.010548	90.0978
KANG	3078174.9738	1608797.7677	5331767.6517	57	5	40.540959	27	35	37.200148	163.8297
KARL	3160763.0950	759160.3153	5469345.6926	59	26	38.476035	13	30	20.252058	114.3253
KEVO	1972158.1932	1005174.4726	5961798.7967	69	45	21.202191	27	0	25.711923	135.9368
KIR0	2248123.2150	865686.6698	5886425.7662	67	52	39.272419	21	3	36.863379	498.0413
KIRU	2251420.8155	862817.2074	5885476.6924	67	51	26.465067	20	58	6.408414	390.9694
KIVE	2632277.1946	1266957.4282	5651027.7075	62	49	11.544469	25	42	8.141467	216.3162
KLPD	3359228.1678	1297490.4662	5246690.3389	55	42	55.278148	21	7	7.983582	42.7483
KNAR	3431762.5836	812400.2727	5296793.0496	56	31	17.664428	13	19	6.366517	113.9577
KONG	3183811.0452	541144.9938	5481926.0674	59	39	54.535417	9	38	46.484938	227.1250

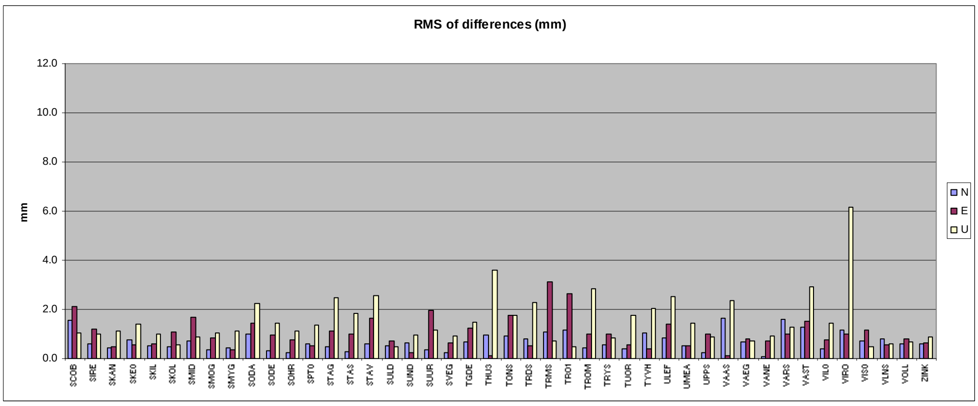
KRSS	3348185.8605	465041.0271	5390738.2783	58	4	57.701015	7	54	26.705198	147.7625
KUUS	2282711.4838	1267071.8685	5800215.8486	65	54	36.895566	29	2	0.524665	379.0288
L311	3376643.0337	1352769.9641	5221718.8865	55	19	6.745000	21	49	56.307880	92.5089
L312	3320254.0314	1570665.2038	5197158.2262	54	55	51.397915	25	19	0.331053	229.5558
L408	3311606.6354	1453968.8188	5236111.2744	55	32	44.819957	23	42	14.368025	138.3882
L409	3425867.8966	1482315.7191	5154672.4781	54	16	19.523500	23	23	50.379655	228.4209
LEKS	3022572.9212	802945.8092	5540684.1541	60	43	19.722679	14	52	37.228130	478.1607
LJUN	3394252.5769	842398.5075	5316209.5268	56	50	16.314606	13	56	17.744586	196.3137
LODD	3504242.4443	808744.1673	5249934.9603	55	46	0.998333	12	59	44.690783	56.3532
LOVO	3104219.1798	998384.1615	5463290.7027	59	20	16.089503	17	49	44.098099	79.6678
LYSE	3269683.9398	366420.5995	5446037.5801	59	1	56.428671	6	23	39.240264	287.7511
MAR6	2998189.4392	931451.7616	5533398.6671	60	35	42.517043	17	15	30.693975	75.4408
MARI	3121535.1963	967771.3826	5458911.7085	59	15	41.193561	17	13	30.125719	37.8463
METS	2892570.8188	1311843.4328	5512634.1289	60	13	2.899021	24	23	43.151544	94.6198
MJOL	3241110.5949	876032.9902	5404956.8641	58	19	29.257692	15	7	29.815966	159.8037
MYGD	3379477.5810	598261.6074	5358170.5416	57	32	2.783052	10	2	20.186148	127.9848
NALS	1202433.8622	252632.2796	6237772.5829	78	55	46.396648	11	51	55.111702	84.2328
NORB	3068753.8376	875354.2331	5504108.8792	60	3	45.048255	15	55	14.391427	176.1418
NORR	3199093.0510	932231.4694	5420322.6793	58	35	24.833333	16	14	46.977951	40.9732
NYA1	1202433.8628	252632.2800	6237772.5863	78	55	46.396648	11	51	55.111747	84.2362
NYAL	1202430.5512	252626.6990	6237767.6112	78	55	46.504705	11	51	54.309162	78.5111
NYHA	3467557.7777	771271.7438	5279655.2769	56	14	39.356434	12	32	23.575306	63.1279
NYNA	3141747.3916	1017435.9871	5438418.3499	58	54	10.706008	17	56	39.242533	66.0969
OLKI	2863210.0008	1126271.5364	5568267.3953	61	14	22.757464	21	28	21.642601	30.6062
ONSA	3370658.5718	711877.1220	5349786.9410	57	23	43.075111	11	55	31.861171	45.5824
OSKA	3341339.9149	957912.4884	5330003.4077	57	3	56.300787	15	59	48.516623	149.7999
OSLS	3169981.9028	579956.7555	5485936.6695	59	44	11.712092	10	22	3.925258	221.5422
OSTE	2763885.2474	733247.4904	5682653.5420	63	26	34.057623	14	51	29.046746	490.0901
OULU	2423778.4672	1176553.8338	5761861.0191	65	5	11.506317	25	53	34.535813	88.8576
OVAL	3037697.4452	938862.3153	5510711.8425	60	10	58.642316	17	10	29.388550	81.8152
OVER	2368884.7404	994492.3224	5818478.3665	66	19	4.290500	22	46	24.145532	222.9736
OXEL	3177394.3820	977921.6621	5425008.4094	58	40	15.441066	17	6	25.352279	46.8192
PORT	3267084.8120	542580.9987	5432706.2499	58	48	13.928207	9	25	45.600089	63.6883
PRES	3227088.6670	353649.8215	5471909.9041	59	29	18.718022	6	15	14.282232	166.4434
QAQ1	2170942.1348	-2251829.9647	5539988.3259	60	42	54.947521	-46	2	51.944911	110.4130
REYK	2587384.3347	-1043033.5212	5716564.0159	64	8	19.622028	-21	57	19.747985	93.0254
RI00	3183914.0589	1421473.6508	5322796.8693	56	56	54.470984	24	3	30.965538	29.3703
RIGA	3183899.2311	1421478.4814	5322810.7950	56	56	55.030029	24	3	31.584060	34.7321
ROMU	2410839.1841	1388069.6051	5720515.3016	64	13	2.633043	29	55	54.128943	241.7122
RORO	3339312.1912	686422.8320	5372576.0238	57	46	37.037051	11	36	56.925641	51.3375
SAND	3228737.1194	582180.5439	5451381.2483	59	7	44.297174	10	13	16.667687	69.1965
SCOB	1982098.7615	-798842.3819	5989460.9759	70	29	6.843693	-21	57	3.030487	128.6601
SIRE	3323397.4067	336993.7003	5415278.0084	58	30	11.332457	5	47	24.081018	60.7412
SKAN	3537800.6052	807531.9492	5227707.7794	55	24	49.546891	12	51	28.598544	48.5894
SKE0	2534030.9116	975174.5562	5752078.5305	64	52	45.110128	21	2	53.843856	81.2760
SKIL	3511254.6709	893660.5319	5231575.3295	55	28	29.581761	14	16	45.689267	58.1286
SKOL	3187460.1361	543919.0213	5479516.0650	59	37	21.890422	9	41	1.931713	200.8681
SMID	3557911.2557	599176.6633	5242066.4356	55	38	26.322944	9	33	33.500665	122.8327
SMOG	3290543.5591	652615.2074	5406535.5696	58	21	12.471069	11	13	4.539838	45.2410
SMYG	3536512.2937	840549.8098	5223404.0052	55	20	44.521024	13	22	11.464728	50.1424
SODA	2200146.7036	1091638.3381	5866870.7880	67	25	15.093320	26	23	20.585324	299.8229
SODE	2993266.3958	996674.0302	5524712.0255	60	26	14.258303	18	24	58.739357	40.6700
SOHR	3172308.3354	603814.0171	5481968.1359	59	40	1.090794	10	46	36.166100	157.1570
SPT0	3328984.5532	761910.2482	5369033.6743	57	42	53.850377	12	53	28.855826	219.9590
STAG	3629048.0697	603765.6761	5192855.8322	54	51	55.046350	9	26	44.871500	107.8279

STAS	3275753.6501	321111.0210	5445042.0601	59	1	3.762503	5	35	55.045971	104.9091
STAV	3091410.6638	1045979.3692	5461608.2947	59	18	31.907169	18	41	35.729775	35.9610
SULD	3446394.2311	591713.1255	5316383.4430	56	50	30.333334	9	44	31.763396	120.7238
SUND	2838909.6615	903822.2116	5620660.4023	62	13	56.910531	17	39	35.596037	31.8545
SUUR	2959056.4001	1341058.5074	5470427.2905	59	27	48.885841	24	22	48.939380	84.3878
SVEG	2902494.8383	761455.9556	5609859.8784	62	1	2.688705	14	42	0.045826	491.2547
TGDE	3358080.9309	445364.8938	5386152.9195	58	0	22.955296	7	33	17.115036	45.8465
THU3	538093.5751	-1389088.0458	6180979.2342	76	32	13.370874	-68	49	30.128747	36.1128
TONS	3301576.3569	389093.1040	5425120.9079	58	40	18.850932	6	43	16.843288	114.2979
TRDS	2820170.8438	513486.0350	5678935.9228	63	22	16.980735	10	19	8.965119	317.7273
TRMS	2102928.4974	721619.4468	5958196.2416	69	39	45.784765	18	56	22.726281	138.0775
TRO1	2102928.5009	721619.4480	5958196.2509	69	39	45.784757	18	56	22.726281	138.0875
TROM	2102940.2233	721569.4457	5958192.1621	69	39	45.894457	18	56	17.985501	132.4668
TRYS	2987993.8613	655946.2118	5578690.2102	61	25	23.574380	12	22	53.696458	724.8430
TUOR	2917810.7826	1205222.7052	5523550.1084	60	24	57.056722	22	26	36.327098	60.6104
TYVH	3471138.4076	665488.5483	5291632.4792	56	26	16.774424	10	51	11.096034	88.7469
ULEF	3223773.3753	527002.8206	5459933.8030	59	16	41.076115	9	17	3.274375	125.3200
UMEA	2682407.6446	950396.0454	5688993.3082	63	34	41.300247	19	30	34.549591	54.5790
UPPS	3060037.7056	970123.0043	5492999.4098	59	51	54.540651	17	35	24.591261	57.1965
VAAS	2699864.3556	1078263.9918	5658064.8676	62	57	40.295035	21	46	14.289396	58.1255
VAEG	3612854.9835	763382.4428	5183133.8156	54	42	51.926954	11	55	51.201093	60.5552
VANE	3249408.0322	692758.0951	5426397.1326	58	41	35.258530	12	2	6.011876	169.7226
VARS	1844607.3153	1109719.1996	5983936.1431	70	20	10.942448	31	1	52.299045	174.8800
VAST	3097214.7217	921046.1324	5480693.5904	59	38	44.457217	16	33	40.910815	68.5528
VIL0	2620258.6177	779138.1343	5743799.4697	64	41	52.250636	16	33	35.750977	450.0173
VIRO	2788248.1976	1454873.4666	5530280.1810	60	32	19.682937	27	33	17.987572	36.9750
VIS0	3246470.2796	1077900.4966	5365278.0866	57	39	13.931083	18	22	2.340221	79.8217
VLNS	3343600.6532	1580417.7287	5179337.2871	54	39	11.313802	25	17	55.206790	240.8501
VOLL	3498678.0362	858203.7287	5245922.9922	55	42	6.565192	13	46	55.830832	141.3360
ZINK	3196313.2901	861751.7063	5433743.3811	58	49	9.704703	15	5	19.105467	231.2861

O. RMS values for the final combined coordinates in ITRF 2000 epoch 2003.75







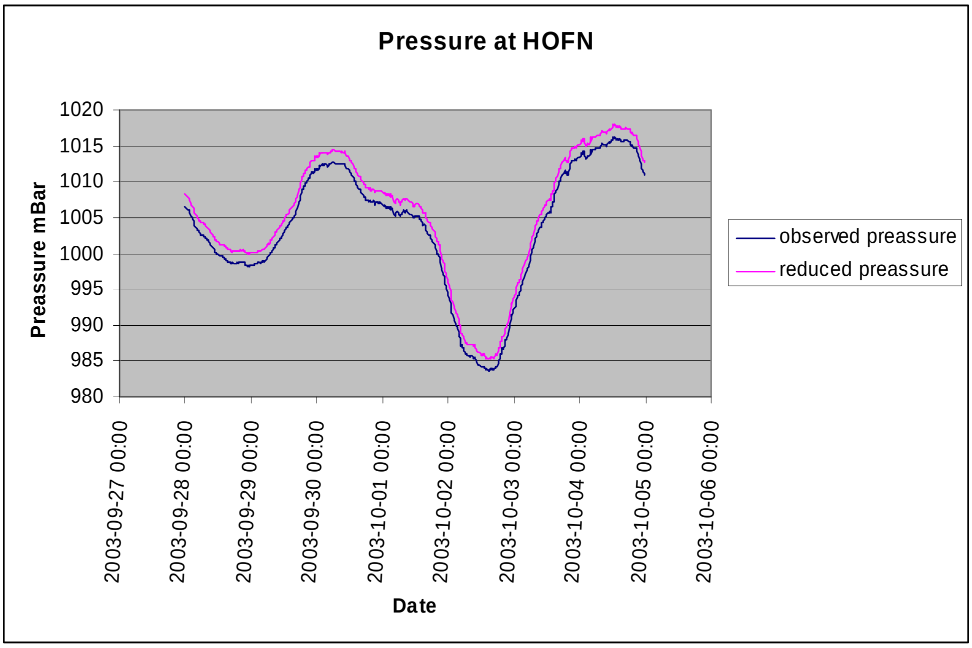
P. Atmospheric pressure

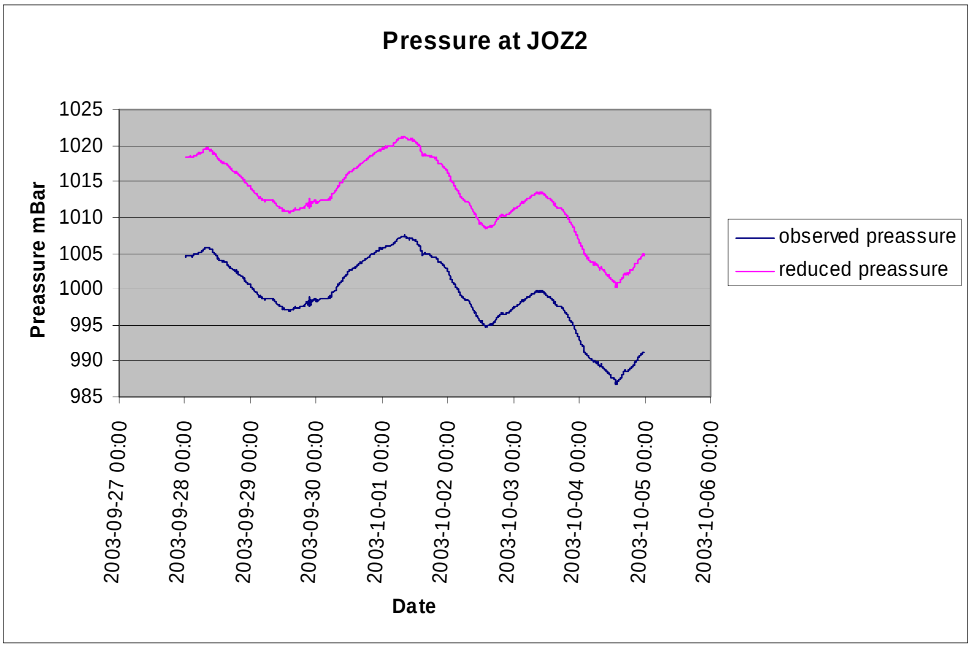
The pressure data from HOFN, JOZ2, METS, POTS and REYK are gathered from the IGS Met-files during the GPS week 1238.

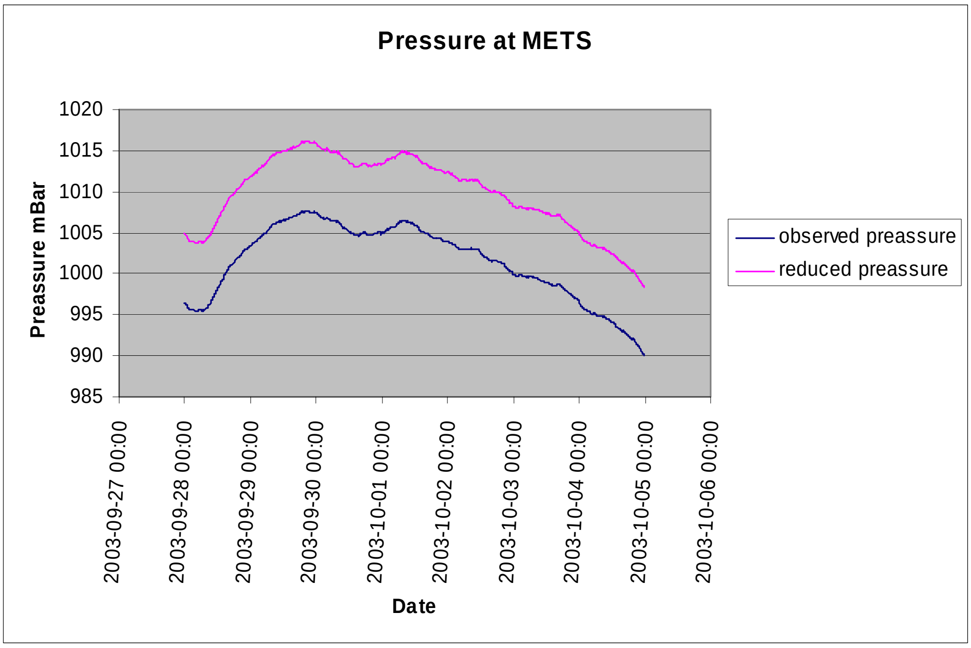
The observations have been reduced to MSL using the following formula:

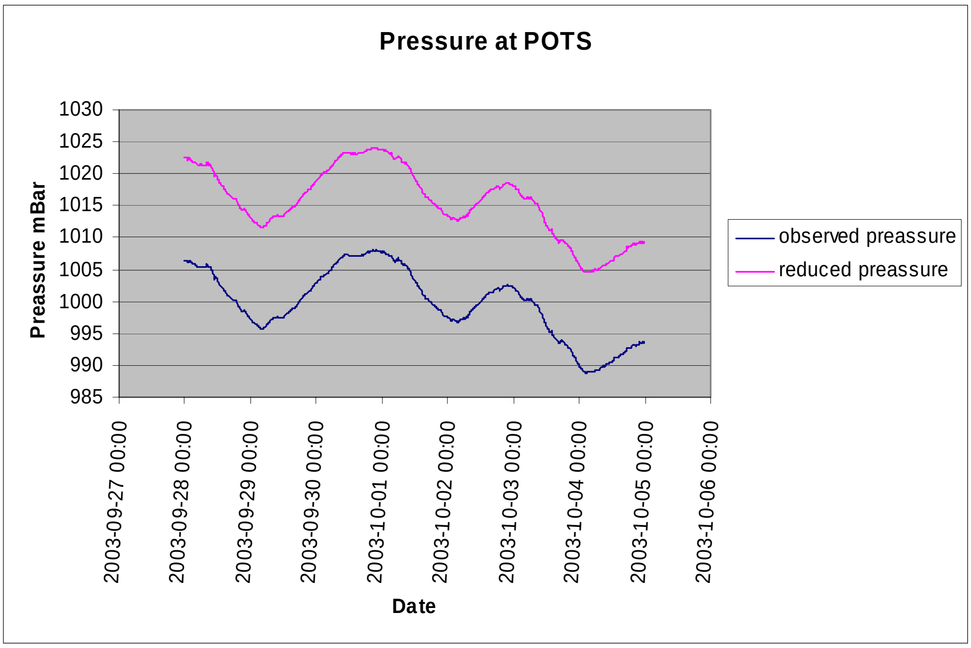
$$p_{MSL} = p_{OBS} /(1-0.0000226 * H)^{5.225}$$

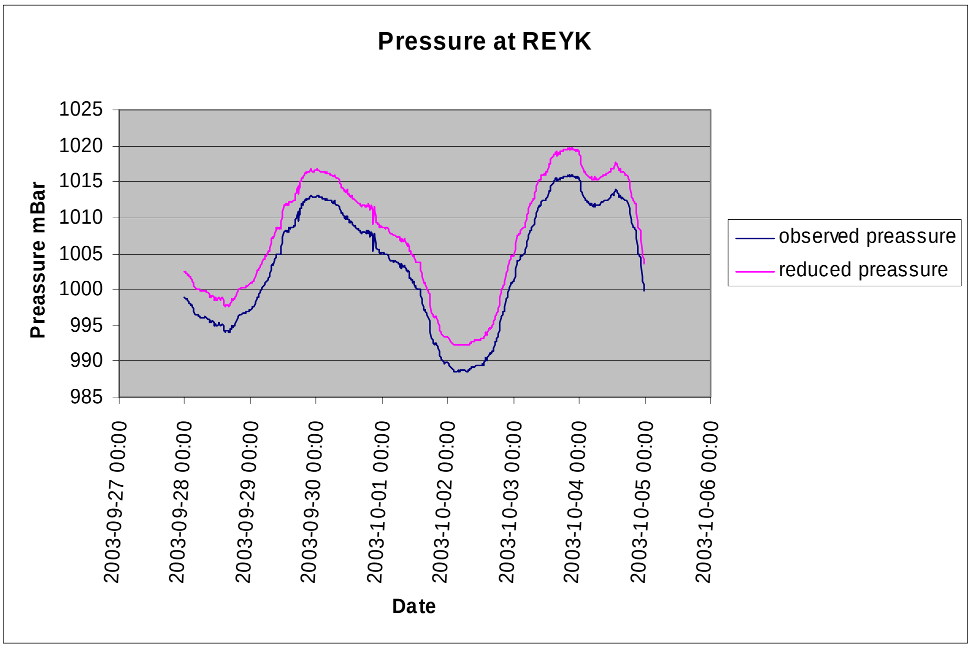
Used heights: HOFN 14.5m, JOZ2 115.3m, METS 70,6m, POTS 133.6m and REYK 22.7m (Ellipsoidal heights are taken directly from the Met files or from the logfiles, in the latter case adding height for antenna and difference for meteorological equipment. EGM geoidal heights are then subtracted to get MSL heights.)



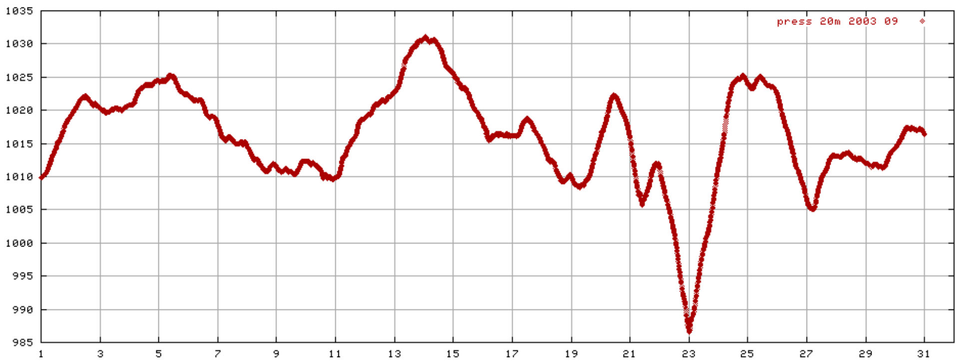

Pressure at JOZ2
Preassure mBar
1025
1020
1015
1010
1005
1000
995
990
985
2003-09-27 00:00
2003-09-28 00:00
2003-09-29 00:00
2003-09-30 00:00
2003-10-01 00:00
2003-10-02 00:00
2003-10-03 00:00
2003-10-04 00:00
2003-10-05 00:00
2003-10-06 00:00
Date
observed preassure
reduced preassure

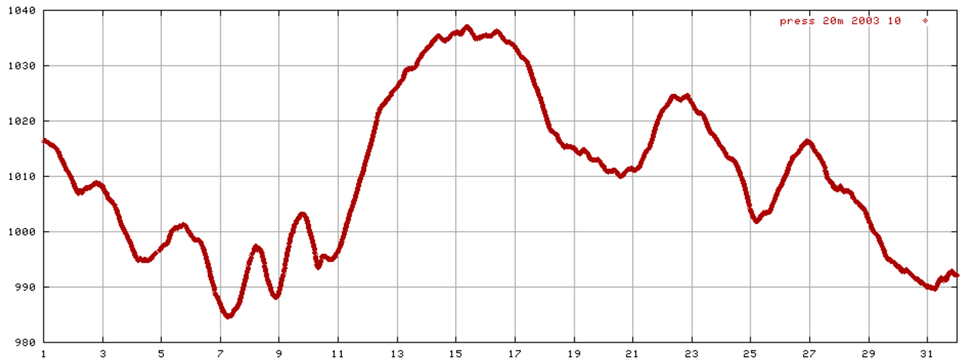

Pressure at METS
Preassure mBar
1020
1015
1010
1005
1000
995
990
985
2003-09-27 00:00
2003-09-28 00:00
2003-09-29 00:00
2003-09-30 00:00
2003-10-01 00:00
2003-10-02 00:00
2003-10-03 00:00
2003-10-04 00:00
2003-10-05 00:00
2003-10-06 00:00
Date
observed preassure
reduced preassure

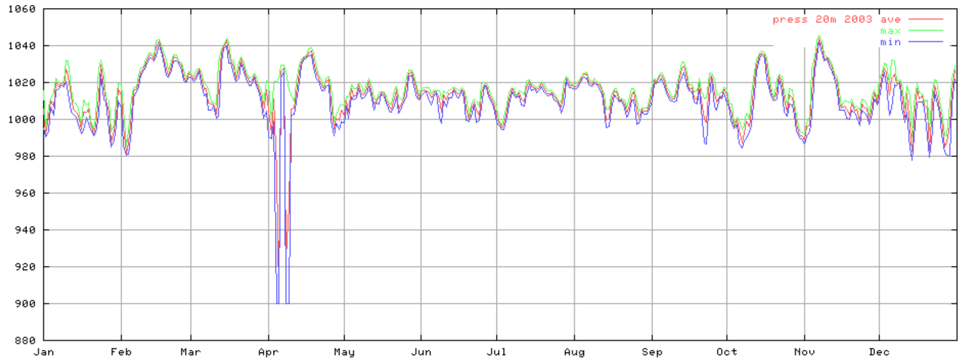




The data from ONSA has been received directly from Onsala Space Observatory.







HOFN/ REYK , ONSA/METS and POTS/JOZ2 do look similar between themselves but different to the other “pairs”. The pressure is a bit higher than normal in the south and lower in the north.

Reports in Geodesy and Geographical Information Systems from Lantmäteriet (the National Land Survey of Sweden)

2003:4 Engfeldt Andreas, Norin Dan, Nielsen Jan, Holm Warming Louise, Grinde Gro, Johansson Daniel, Lilje Christina, Nilsson Andreas, Wiklund Peter, Kempe Tina, Frisk Anders: The 2002 NKG GNSMART/GPSNet test campaign.

2003:8 Vejdeland Sofia & Dahlberg Liselotte: Tolkbarhet av GGD-objekt i bilder registrerade av olika sensorer.

2003:10 Engfeldt Andreas & Jivall Lotti: Så fungerar GNSS.

2003:11 Alm Malin & Munsin Anna-Stina: Traditionell RTK kontra nätverks-RTK – en noggrannhetsjämförelse.

2003:12 Jonsson Albert & Nordling Anders: Jämförelse av enkelstations-RTK och nätverks-RTK i Lantmäteriets testnät.

2004:1 Peterzon Martin: Distribution of GPS-data via Internet.

2004:4 Andersson Maria: Deformationer av fasta geometrier - en metodstudie.

2004:7 Valdimarsson Runar Gisli: Interpolationsmetoder för restfelshantering i höjdled vid höjdmätning med GPS.

2004:11 Kempe Christina: Väst-RTK – nätverks-RTK i produktionstest i västra Sverige.

2004:12 Johansson Daniel: SKAN-RTK – 2 – nätverks-RTK i produktionstest i södra Sverige.

2004:13 Wiklund Peter: ”Position Stockholm-Mälaren – 2” – nätverks-RTK i produktionstest.

2004:16 Andersson Therese & Torngren Julia: Traditionell RTK och nätverks-RTK – en jämförelsestudie.

2005:3 Ahrenberg Magnus & Olofsson Andreas: En noggrannhetsjämförelse mellan Nätverks-RTK och Nätverks-DGPS

2005:4 Jämtnäs Lars & Ahlm Linda: Fältstudie av Internet-distribuerad nätverks-RTK

2005:5 Engfeldt Andreas (ed.) Network RTK in northern and central Europe.

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