Station Calibration of the Berlin GNSS Reference Stations (1)

Campaign to Analyse Multi-Stage Site Calibration

Gerhard Wübbena, Martin Schmitz, Gerald Boettcher, Gerd Rosenthal, Lars Schwarz

Abstract

A major error source for precise GNSS applications are station dependent errors, which consists mainly of antenna and multipath effects. The different characteristics of the error components can be effectively used to develop procedures to separate the effects. Consequently, different optimized correction or modelling options are possible. A multi-stage site calibration approach has been developed for multi-path effects on GNSS sites. The approach determined elevation and azimuth dependent corrections based on observable residuals (EAR) as well as variance component estimates (VCE) for each individual station.

The muti-stage approach is applied and investigated for the Berlin reference stations within a cooperative campaign between Senate Department for Urban Development and Environment Berlin and Geo++. Over several weeks in August 2012 data for a an in-situ station calibration of near-field (CaNF) has been collected on four Berlin reference stations. EAR-VCE models are obtained, which can be applied to GNSS data. Goal is an improvement of the operational RTK services in Berlin.

In a station analysis, the magnitude and impact of near-field effects for the Berlin reference stations are presented. The impact of the near-field effects is demonstrated for a short baseline by applying the EAR-VCE models. Further steps in the campaign are proposed.

Introduction

Currently, the multipath effects are a major limiting factor for GNSS applications. For a rover site, it is the user's responsibility to handle such errors. For reference stations, the provider or the GNSS RTK service has to account for these effects. The provider can to some extend consider multipath effects while choosing an adequate station design and locations. However, generally the GNSS application software has to provide sophisticated modelling options to account for such effects.

It has been proposed by Wübbena et al (2006a, 2006b) to separate station dependent errors dS into antenna phase variations (PCV) and two different types of multipath MP, namely the multipath near-field and multipath far-field components:

$$dS = \mathbf{PCV} + MP_{\mathbf{near\text{-}field}} + MP_{\mathbf{far\text{-}field}}$$

The justification for a near-field and far-field multipath term are their different properties, which allow different strategies to account for them. The following table gives an overview of station dependent errors and their basic characteristics and treatments (see also Wübbena et al. 2006a, 2011).

Goal of the station calibration is the analysis of the site's near-field multipath and the actual determination of single station near-field multipath models. The model can be applied in the GNSS processing to improve the network performance as well as the performance of rovers utilizing the different network services.

Table: Different treatment of station dependent errors

	Error	Characteristic	Treatment
Antenna	PCV	elevation and azimuth dependent PCV	calibration of PCV using robot
Multipath	MPnear-field	long-periodic, systematic effect, bias, close reflectors	calibration of near-field effects using robot/in-situ station calibration
	MPfar-field	short-periodic, systematic effect, remote reflectors	averaging over time, absolute station calibration or weighting (CN0), sidereal differences (GPS only)
Station Uncertainty		unstable underground, setup, monumentation	analysis of time series

Multi-Stage Site Calibration

Geo++ developed and analysed different approaches and methods to determine, handle and correct near-field effects. The approaches separate the near-field multipath for a single station from antenna PCV and far-field multipath. The impact from any other station involved in the processing is eliminated or greatly reduced. The different approaches can be combined and therefore allow scalable and flexible applications.

#1 NF+PCVCa: Near-**F**ield Antenna **PCV Ca**libration
The difference between a standard antenna calibration (PCV) and a calibration with a representative mock-up of the setup/mounting is an explicit determination of the near-field impact on an antenna. It is not always possible to resemble the site setup in all its complexity in such a near-field calibration. But even in the case of remaining differences to the actual setup conditions, it generally gives a representative and good approximation (e.g. Schmitz et al. 2008).

#2 CaNF: In-situ Station **Ca**libration of **N**ear-**F**ield with Calibrated Equipment
Over short distances several calibrated station setups are operated at a reference station site to access the GNSS observable. The station setups are free of near-field using #1 NF+PCVCa and with low far-field impact. Phase and code corrections for the original observable (e.g. L1, L2) as well as weighting schemes for near-field multipath are derived from a combined processing for the reference site. The approach uses redundancy to obtain e.g. the complete GNSS visibility of the reference station (e.g. Wübbena et al. 2011).

#3 CoNF: **Co**mpensation of **N**ear-**F**ield Effects
In RTK-networks the L0 residuals are the primary signal for near-field corrections. The original observable L1, L2 and L5 are not fully accessible due to non-distinguishable ionospheric effects. Therefore the method is termed compensation. Nevertheless, the basic concept of the CaNF calibration can be applied: elevation and azimuth dependent non-differenced ionospheric free signal residuals (EAR) are used to determine correction models and weighting schemes. A EAR-VCE model is estimated for each individual station in the network (e.g. Wübbena et al. 2012).

#4 Combination of Approaches
A flexible strategy is the combination and integration of the different methods. The #2 CaNF method uses already the method #1 NF+PCVCa. Also the combination of #2 CaNF and #3 CoNF is possible.

There are often stations which are not easily accessible or not suited for an in-situ calibrations of type #2 CaNF. Therefore the method to determine corrections and weighting schemes to compensate near-field effects from a network of reference stations has been developed. One central task of #3 CoNF method is to separate individual near-field effects of one station and reducing correlation with any other station while using a network of stations. Sufficient redundancy in the network utilizes the compensation of near-field for all network stations. The combination with methods #2 CaNF, however, can in addition constrain the separation of effects. The original observable L1, L2 and L5 can in this case be distinguished from the ionospheric effect in a #3 CoNF approach.

Table: Different Approaches to Determine Near-Field Effects of a Reference Station

#	Approach	Method
1	explicit determination	robot-based antenna calibration (since 2002) **NF+PCVCa** (e.g. Schmitz et al. 2008)
2	determine near-field correction and weighting from L1 & L2 residuals	in-situ station calibration with calibrated, multipath free equipment (# 1) – **CaNF** (Wübbena et al. 2011)
3	determine near-field correction and weighting from L0 residuals in redundant setups	in-situ station calibration/ NF compensation within a network of GNSS reference stations - **CoNF**
4	combination of approaches	use of some in-situ calibrated stations (# 2) and apply it to constrain # 3 - **CNF**

CaNF: In-situ Station Calibration of Near-Field with Calibrated Equipment

NF+PCVCa: Near-Field Antenna PCV Calibration

CaNF: Near-Field with Calibrated Equipment (two setups at Wittenau)

CaNF: In-situ Station Calibration (Wilmersdorf)

CaNF: First Stage of the Berlin`s Reference Station Calibrations

The first stage of the Berlin`s reference station calibrations is the #2 CaNF method. One key issue for an in-situ station calibration are nearfield free stations, which are operated for the site analysis on a short baseline. A near-field free station requires optimal control of near-field effects and PCV. This is achieved using as an antenna mount of the near-field free stations an optimized copy of the robot top and its setup.

In addition a high and slim setup (refer to picture setup Wittenau) on a pole (~ 3 m) is used to reduce any far-field multipath beforehand. Over short distances no impact from atmospheric or orbit errors is anticipated. A redundant setup with three near-field free stations has beenused, which covers the complete GNSS visibility of the reference station. In addition sophisticated GNSS receivers with coupled clocks are used. In case, the original receiver of the reference station is substituted through an in-situ calibration receiver using an antenna splitter to access the coupled clock. The complete setup and system design is transportable, flexible, scalable and easy to use (Wübbena et al. 2011).

The four Berlin stations Berlin-Wilmersdorf (0896), Berlin-Wilmersdorf (E896) eccentric station, Berlin-Wittenau (0897) and Berlin-Grünau (0898) were calibrated in late August 2012. Common data parameters are 1 Hz data rate, 0° cut-off and at about 48 h data.

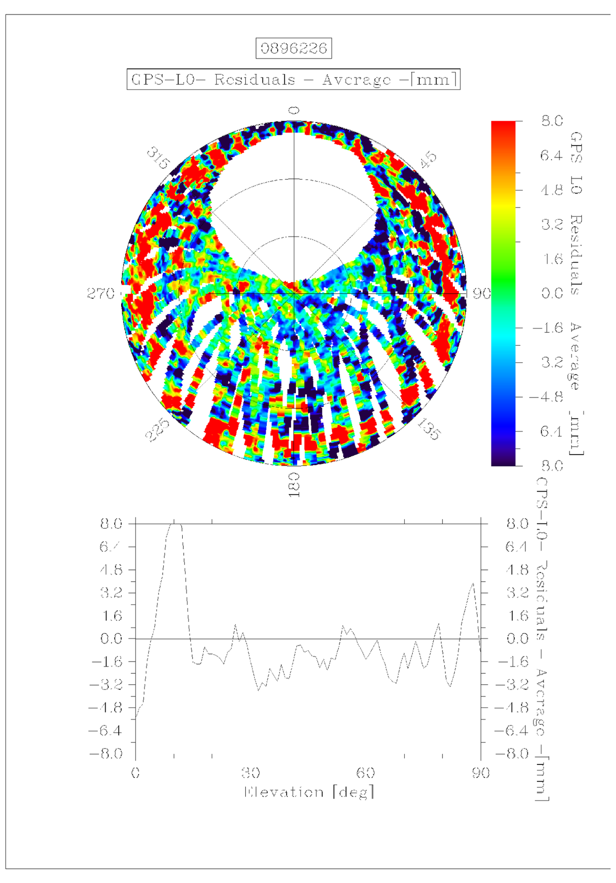
NF Analysis of Berlin's Reference Stations

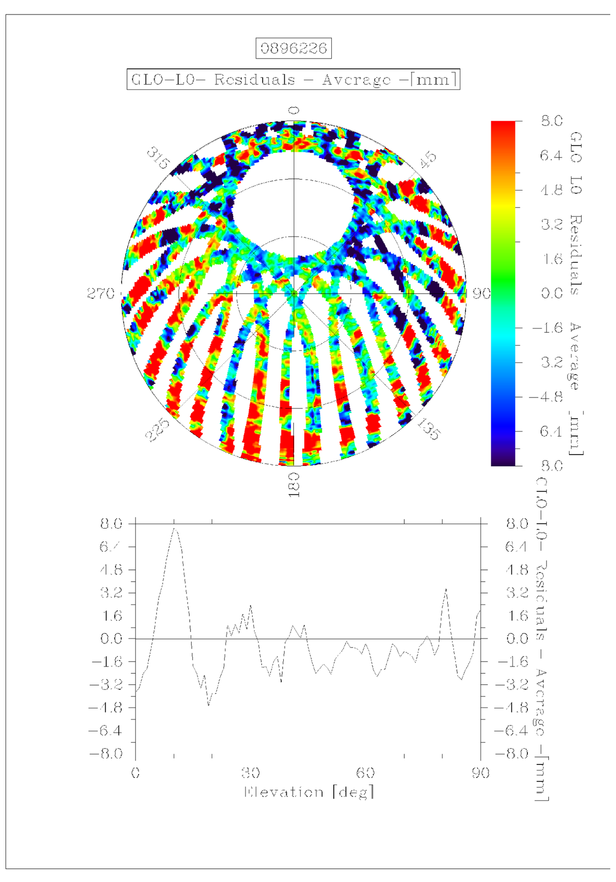
The residual analysis for the reference stations uses the original phase and code observable as well as carrier-to-noise observable (CN0) for GPS and GLONASS as input. The system is extendable to all future signals and GNSS systems. The residuals are processed as function of azimuth and elevation. The analysis software derives range corrections and a weighting scheme for the the observable (EAR-VCE model).

Although the residuals of the original signals are obtained, the ionospheric free linear combination GPS L0 and GLONASS L0 residuals are shown. There are basically no obstructions at the horizon, but prominent pattern are recognized. The patterns correlate with tri-brach, horizontal planes underneath the mount and general patterns due to the roof depending on the height above roof top. The height changes the frequency and the phase of the pattern. Remarkable is, that even roof edges, railings, lightning protection and other constructions show up in the residual plots, which are further away than 1 m.

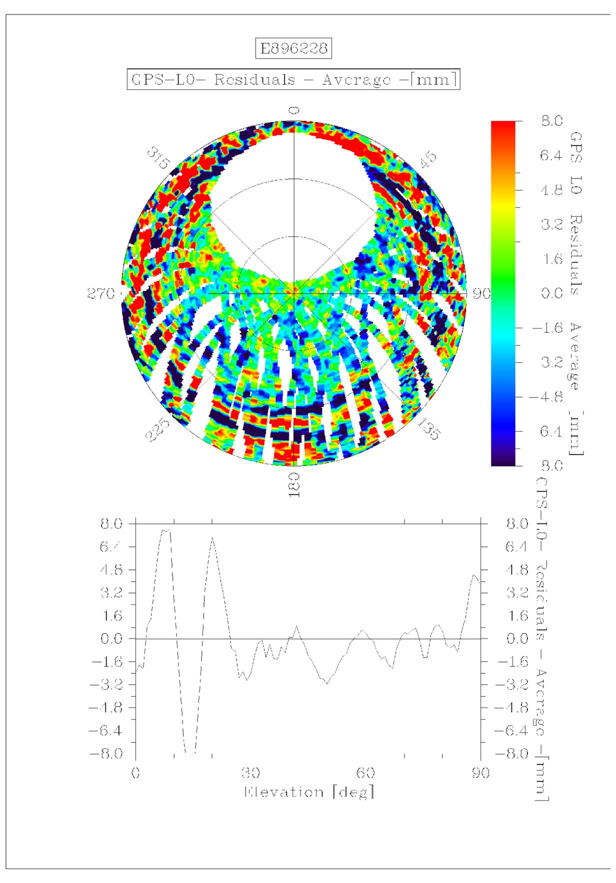
The magnitude of residual changes is up to 2 cm and more over small elevation ranges. GPS and GLONASS show independently well correlated results. The North direction is indicated by a green arrow in the station photos.

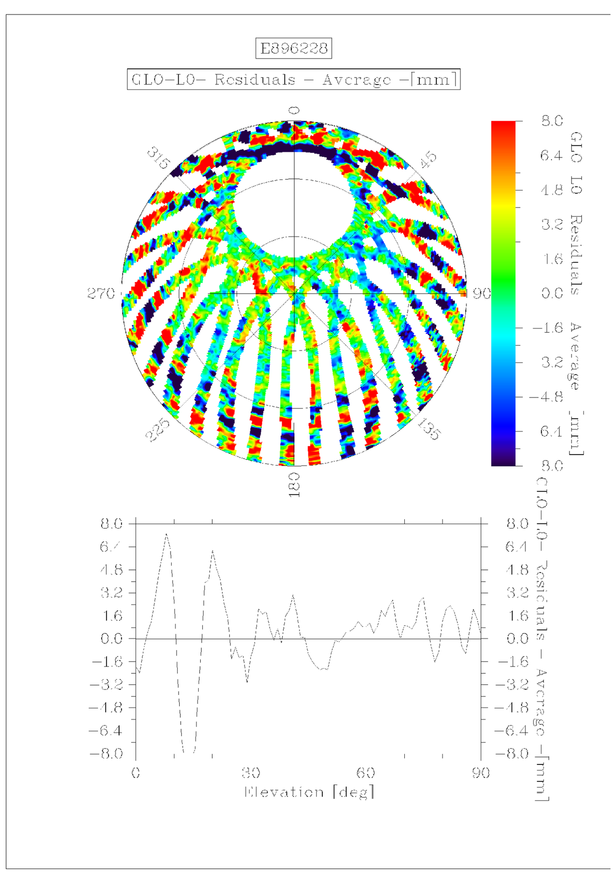
Berlin-Wilmersdorf (0896)





Berlin-Wilmersdorf (E896) eccentric station





Station Calibration of the Berlin GNSS Reference Stations (2)

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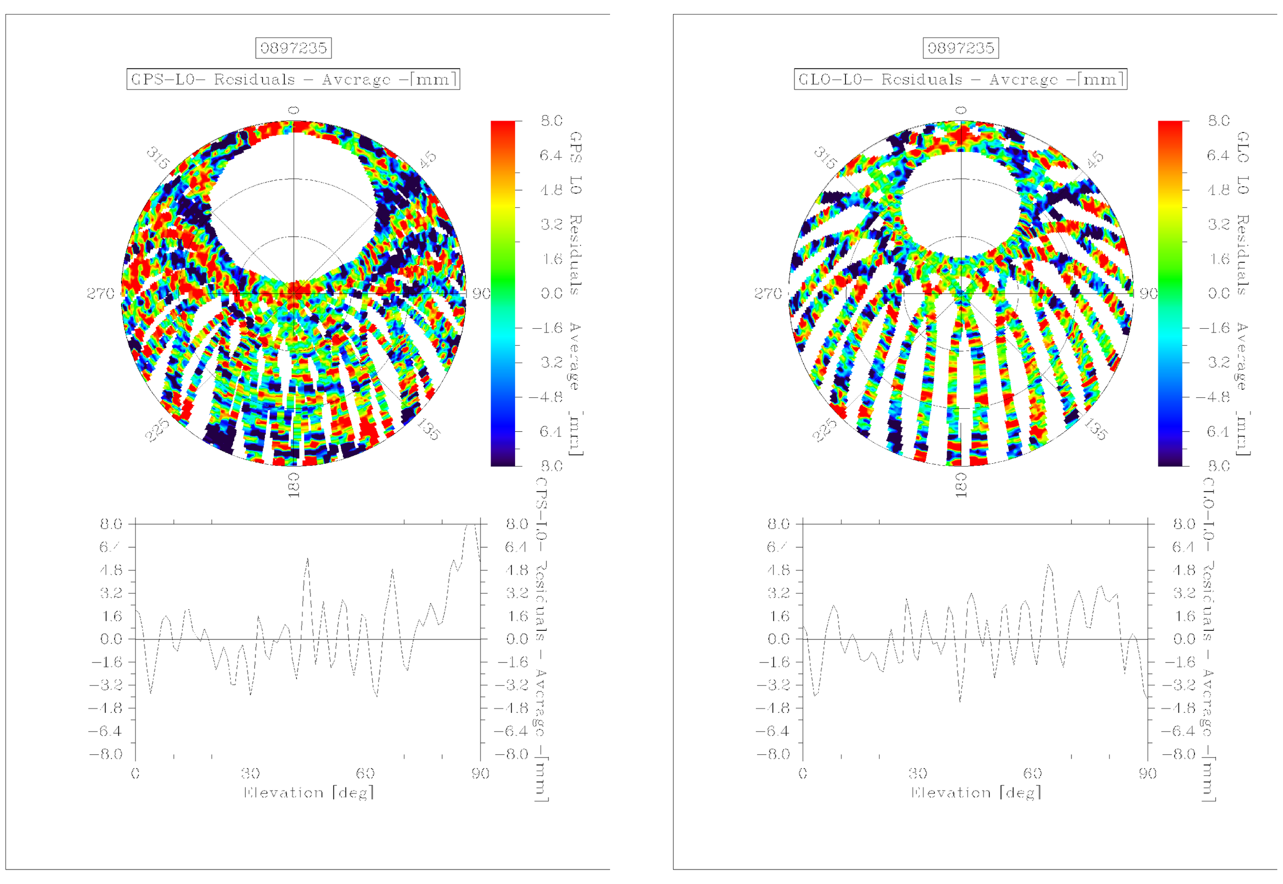
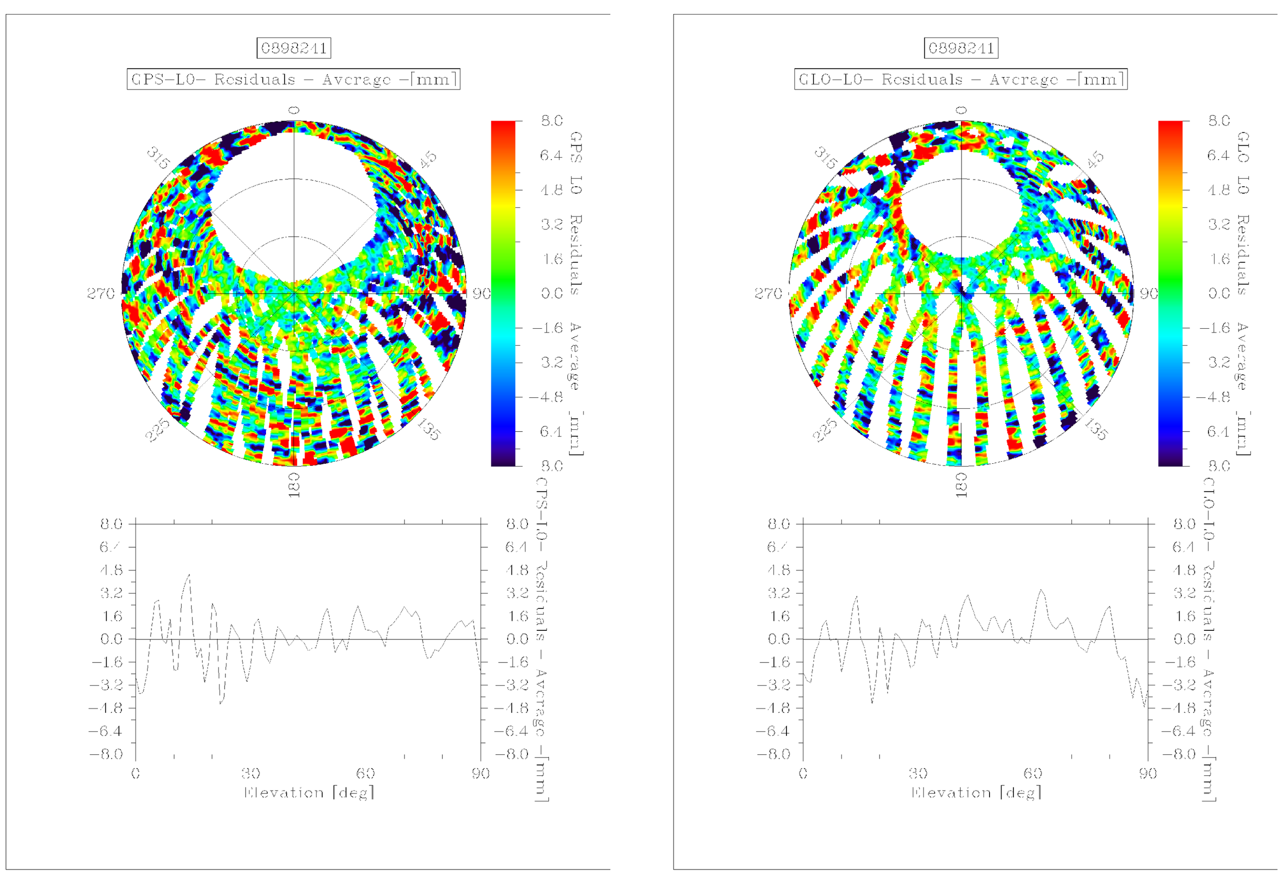
Berlin-Wittenau (0897)



Berlin-Grünau (0898)



Verification and Demonstration

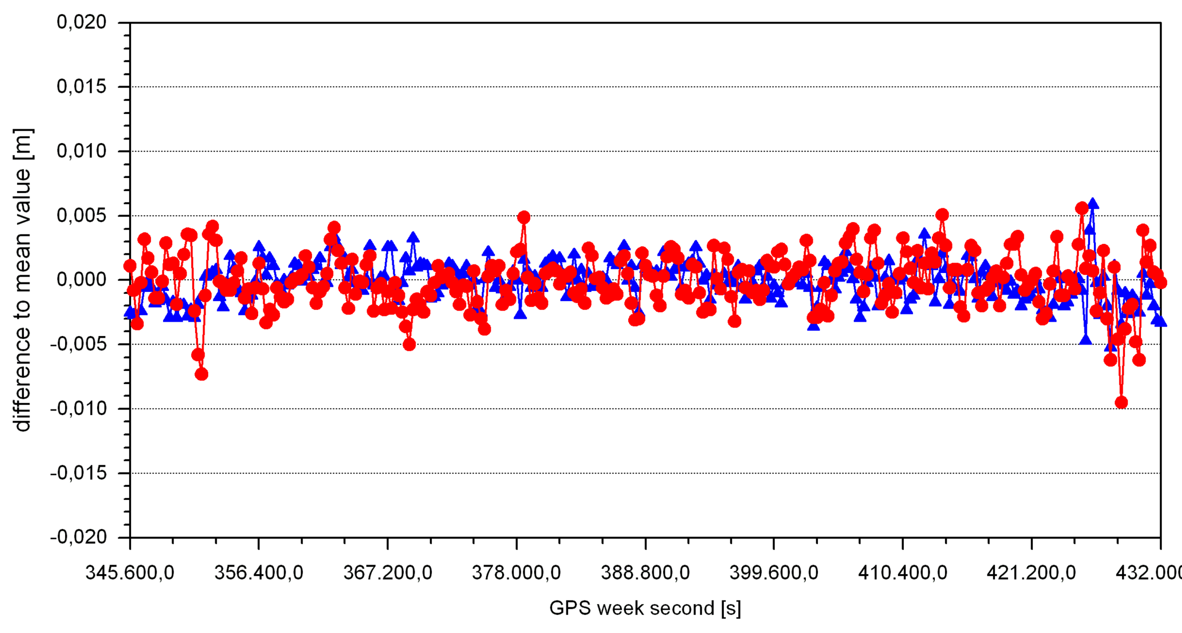
The EAR-VCE models obtained from the four single Berlin reference station calibration can be applied on actual data. The short baseline between the center station and eccentric station of Wilmersdorf has been selected, because over the short baseline of about 5m disturbing effects like distant dependent errors can be excluded efficiently. In addition a 24 h data from a day in October 2012 was used, which is independent from the actual GNSS calibration data. The application of the EAR-VCE models demonstrates the improvement and potential for reference stations and RTK services.

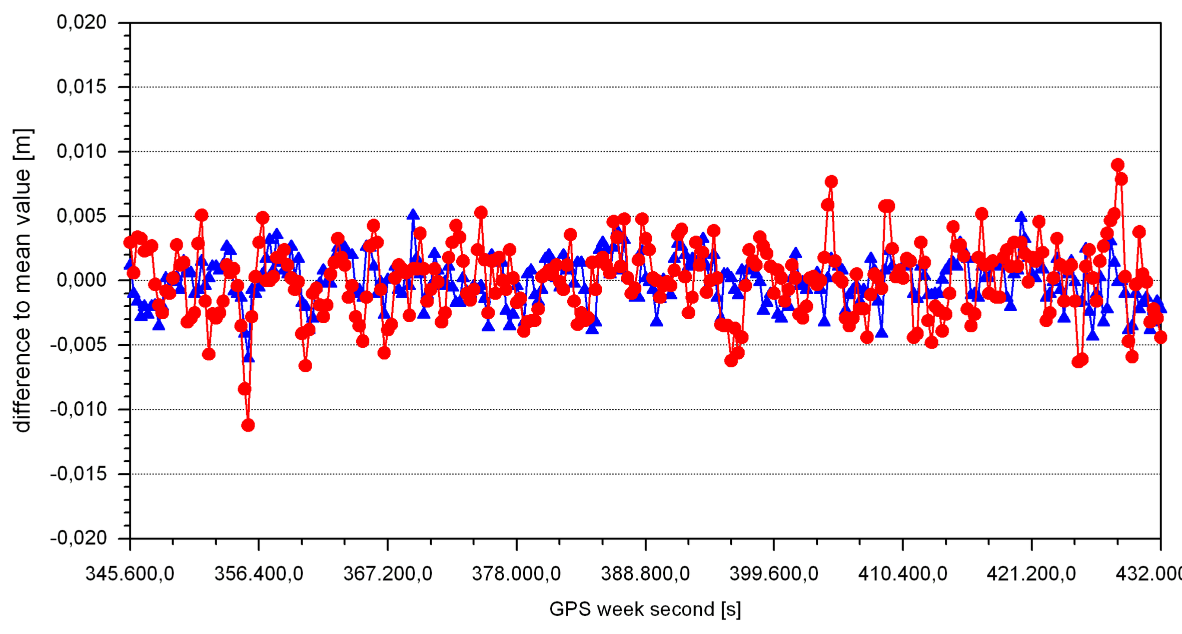
The center station 0896 was held fixed in the post-processing experiment. The coordinates of the eccentric stations E896 were estimated with different modelling options concerning integration time of the RTK solution and the tropospheric modelling. First, a filter reset for station E896 (e.g. ambiguities, coordinates, etc.) was executed every 5 minutes. The GNSS signal for the positioning corresponds to the ionospheric free linear combination L0 using both, GPS and GLONASS. The processing was repeated allowing for the estimation of a tropospheric scale factor. Furthermore, the integration time for the tropospheric model was extended using a reset every 15 minutes. The ambiguity resolution was always within 2 to 4 sec over the short baseline.

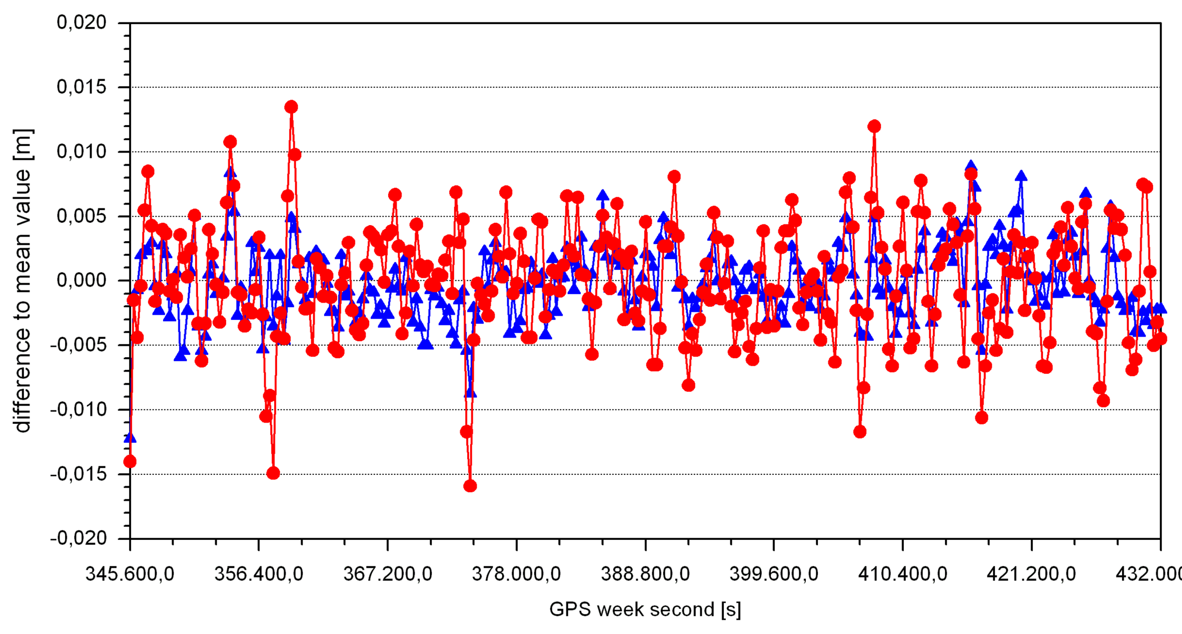
The coordinate estimation from the RTK positioning was analyzed and is depicted in the following diagrams. For the first experiment the impact of the EAR-VCE model is shown for the Easting, Northing and height component. For the other processings only the height component is depicted. The table shows the standard deviation of the different experiments from a mean coordinate value for all experiments and coordinate components.

The EAR-VCE corrections reveals a significant improvement in both, horizontal and height coordinate components. The distribution around the reference is smaller for the coordinate differences with EAR-VCE model applied. In actual GNSS network applications, the troposphere will generally be estimated, which magnifies the impact especially for the height components. This is obvious in the corresponding diagrams and the statistics given in the table. The magnitude of the improvement can amount to about 2-3 mm in horizontal components and about 5 mm in height.

static processing, re-initialization 5 minutes







Diagrams above: Short Baseline Experiment 0896-E896,
re-initilization every 5 min, top Easting, middle Northing, bottom height,
red line/dit **without** and **blue** line/triangle **with EAR-VCE** model

without EAR-VCE model			with EAR-VCE model			Stdev [m]
Easting	Northing	Height	Easting	Northing	Height	Remark
0.0021	0.0028	0.0045	0.0015	0.0018	0.0028	5 min reset
0.0020	0.0032	0.0090	0.0017	0.0022	0.0056	tropospheric scale – 5 min reset
0.0015	0.0025	0.0070	0.0015	0.0017	0.0041	tropospheric scale – 15 min reset

Table: Standard Deviation to Mean Coordinate in [m]

Summary

An in-situ calibration of CaNF type has been executed for the Berlin reference stations. The CaNF uses near-field free calibration equipment operated close to the actual reference station to determine elevation and azimuth dependent corrections and weighting (EAR-VCE) models. The EAR-VCE model can be applied in the GNSS processing to improve the network performance as well as the performance of rovers utilizing the different network services. The impact and potential of the EAR-VCE corrections has been demonstrated on a short baseline.

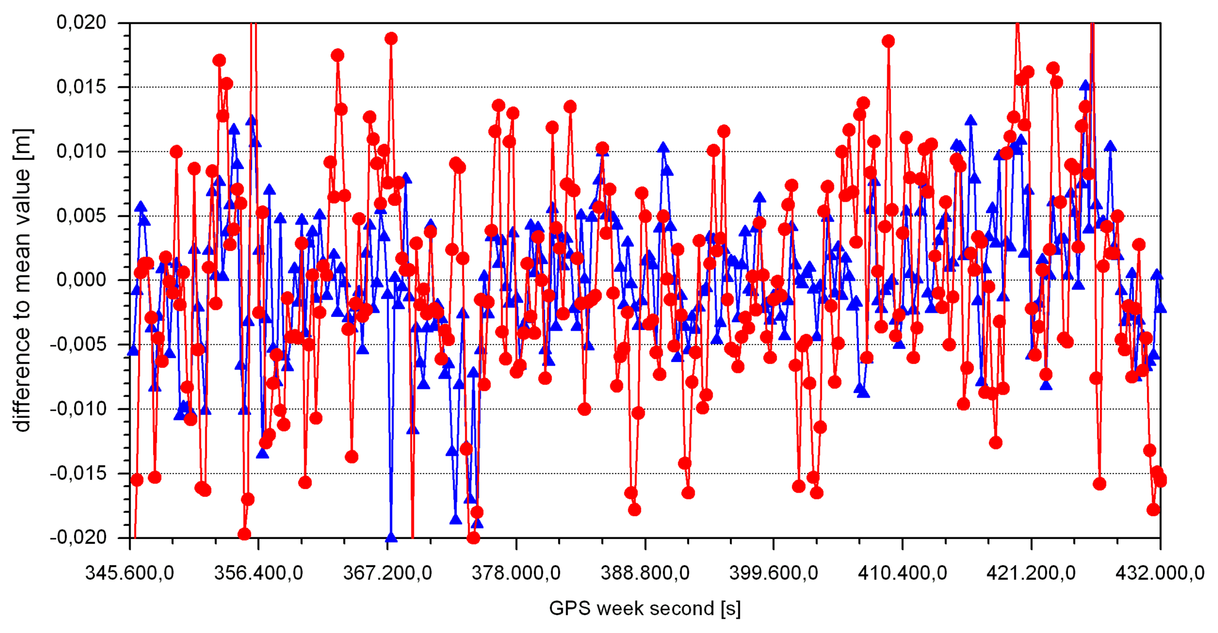
All addressed station calibration methods as well as in-situ station calibration equipment, analysis and processing software have been developed for operational use. The benefits of near-field station calibration are obvious: an improvement of accuracy and reliability for a variety of GNSS applications.

In a next step, the in-situ CaNF calibration of the Berlin reference stations will be used in a network with additional not calibrated GNSS reference stations. The analysis of the site's near-field multipath of the new reference station according to the CoNF method will be applied. The actual determination of single station near-field multipath can,however, then be constrained using the in-situ station calibration results of the Berlin reference stations.

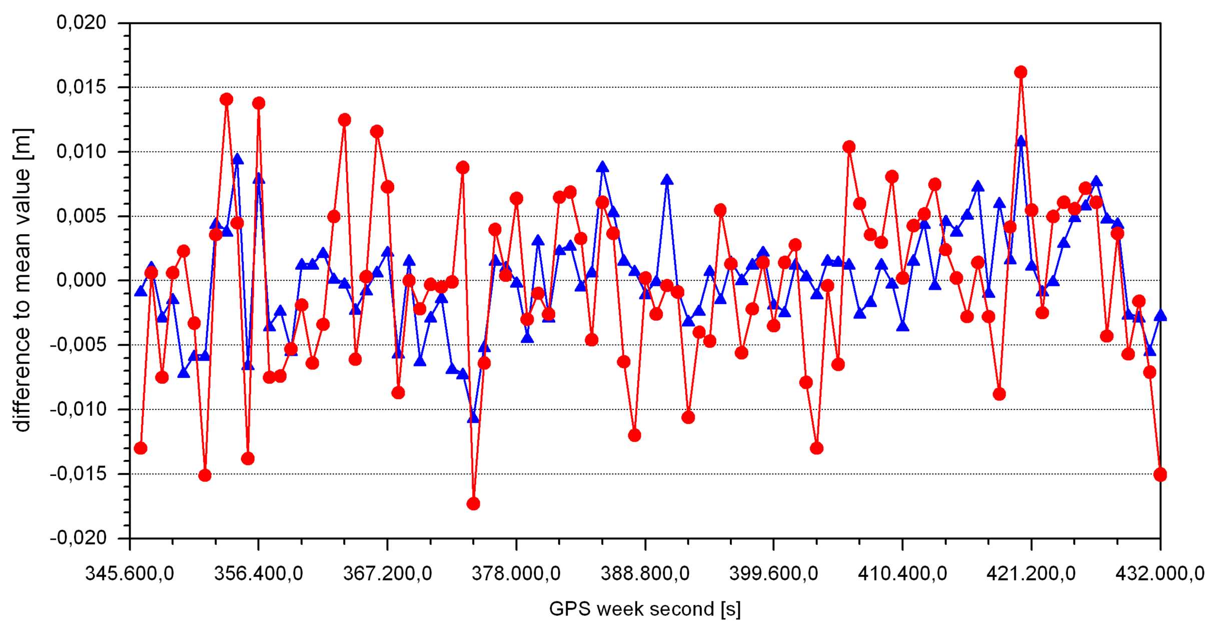
Further analysis and experiences with respect to e.g. environmental changes (e.g. weather condition) are meaningful.

Diagrams below: Short Baseline Experiment 0896-E896 with Troposphere,
with troposheric model, re-initilization every 5 min or 15 min; height component only,
red line/dit **without** and **blue** line/triangle **with EAR-VCE** model

static processing, re-initialization 5 minutes, with troposphere estimation



static processing, re-initialization 15 minutes, with troposphere estimation



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