The Brazilian GNSS antenna calibration station: technical results and achievements of a cooperation between Brazil and Germany

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Abstract
This paper presents technical outcomes of the Brazilian Calibration Station for GNSS Antennas at Universidade Federal do Paraná – BCAL/UFPR – since its establishment in 2007. As a result of a scientific and technological cooperation with the Geodetic Institute of the University Karlsruhe (TH) resp. Karlsruhe Institute of Technology, the Baseline Calibration Station provides an infrastructure for geodetic measurements to determine precise model parameters for GNSS receiver antennas.

1 Introduction

Taking into account the behavior of GPS/GNSS antenna models is of great importance in relative and absolute positioning applications, especially when millimeter precision is required for applications such as the monitoring of engineering structures or for GNSS attitude determination. To fully meet the precision requirements of such applications, a reliable and precise model for the individual behavior of sending and receiving GNSS antennas has to be taken into account.

While satellite antenna models and type-specific receiver antenna models are provided, for example, by the IGS (International GNSS Service, www.igs.org), individual receiver antennas have to be determined during calibration procedures. Within this framework, the BCAL/UFPR station was designed to be the first infrastructure aiming at the calibration of GNSS receiver antennas in South America (Freiberger Junior, 2007). It was established at the Federal University of Paraná (Curitiba, Brasil) in close cooperation with the Geodetic Institute (GIK) of the University Karlsruhe (TH) resp. the Karlsruhe Institute of Technology (KIT). This contribution reviews the close and long-term cooperation in the field of GNSS antenna calibration, in which German and Brazilian researchers collaborated successfully. Facts related to this fruitful cooperation can be found in Krueger and Centeno (2018) as well as in the final PROBRAL report (PROBRAL, 2012).

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2 Fundamentals

Incoming signals from GNSS satellites are referred to the so-called electrical antenna phase center, a point on the receiving patch elements inside the GNSS antenna, which necessarily doesn't coincide with the geometric center of the receiver antenna. In addition, the GNSS (phase) measurements have to be related to a physically known point (antenna reference point, ARP), for instance on the bottom of the antenna to link the measurements to the physical reference point (e. g., marker).

The position of the antenna phase center is not constant, but depends on the direction (azimuth resp. elevation angle) of the incoming signal. To model the behavior of the antenna, the phase center is defined as the so-called apparent source of radiation and differences to an ideal antenna are determined during the calibration procedure. The antenna model consists of frequency-dependent 3D values of the mean phase center offset (PCO) and the phase center variations (PCV), which describe the variations of the mean phase center. The neglecting of this antenna characteristic can cause errors at the centimeter level depending on antenna type and data processing strategy. Figure 2.1 shows the antenna model where the signal path is described by the azimuth α and elevation β in the antenna coordinate system.

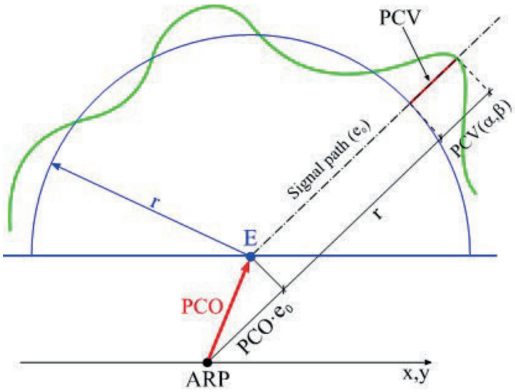

Figure 2.1: Antenna phase center properties.

The range $d(\alpha, \beta)$ is the desired correction:

$$d(\alpha, \beta) = r + \mathrm{PCO} \cdot e_0(\alpha, \beta) + \mathrm{PCV}(\alpha, \beta) + \varepsilon, \quad (2.1)$$

where the term e_0 is the unit vector in the direction α and β of the satellite, r is the error-free behavior of an ideal source of radiation and ε corresponds to the noise of the observation. Because PCV can reach values up to 20 mm it is necessary to use the full antenna model consisting of PCO with related PCV if highest accuracy is required.

3 Initial investigations on GNSS antenna calibration

In the framework of the close cooperation between UFPR and KIT various research was carried out jointly. Therefore, between 2004 and 2009 Brazilian researchers visited Germany and German researchers traveled to Brazil. All work was focusing on the establishment of the first antenna calibration infrastructure of South America. This section gives insight in scientific work, which was carried out under the umbrella of a PROBRAL funded project (PROBRAL, 2012).

Among the known calibration procedures – relative field calibration (Bilich and Mader, 2010), absolute calibration in anechoic chamber (Campbell et al., 2004) and absolute field calibration (Wübbena et al., 1997) – the absolute field method provides absolute values that are independent from a reference antenna (Rothacher, 2001). Within the relative procedure both antennas are mounted close together on stable monuments (e. g., pillars) with precisely known coordinates. The calibration is based on the analysis of single or double difference residuals with the elevation- and sometimes azimuth-dependent PCV model using e.g. polynomial or spherical harmonics. Applying the relative field calibration method, individual absolute antenna parameters are obtained with considerably low equipment costs and less complex tasks to fulfill in comparison to the absolute process, when one absolute calibrated antenna is used as reference antenna.

Dedicated tests on relative GNSS antenna calibration were performed in the beginning of the PROBRAL project at GIK in cooperation with the ordnance survey of Baden-Württemberg investigating the phase center variability of several geodetic antenna models (Freiberger Junior et al., 2007, 2005b). The elevation-dependent PCV curves of seven individually calibrated TRM22020.00+GP antennas are shown in Figure 3.1 with the elevation angle on the horizontal axis and the PCV in millimeters on the vertical axis.

Azimuth- and elevation-dependent PCV for L1 and L2 frequencies were also analyzed (Figure 3.2). Based on these tests, further experiments with respect to affecting effects (e. g., multipath; Smyrnaios et al. (2013) were carried out, in order to gain valuable insights for the establishment of the BCAL/UFPR station. Representing these experiments, Fig. 3.2 shows near-field multipath effects (Balanis, 2005) in northern direction at approx. 20° – 30° elevation.

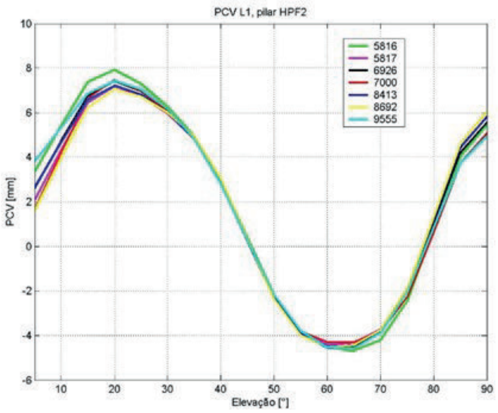

Figure 3.1: Elevation dependent L1-PCV-values of seven TRM22020.00+GP antennas.

In addition, tests were carried out at GIK quantifying the effects of multipath reducing equipment (e. g., ground plane, absorber material). In Fig. 3.3, the PCV-pattern of TRM22020.00 antenna is shown, when removing the ground plane. The peaks correspond to the antenna case characteristic of the receiver element.

4 Establishment of BCAL/UFPR – validation and calibration results

Before in 2006 two tubular pillars – named 1000 and 2000 – were built on the rooftop of the astronomical observatory of the Federal University of Paraná in Curitiba (Krueger et al., 2009) using appropriate material (e. g., multipath absorbing), initial tests on the BCAL/UFPR station were carried out focusing on the PCO estimation of GPS antennas (Freiberger Junior et al., 2005a). In addition, investigations related to GNSS data processing strategies (Knoch, 2007) and multipath effects were carried out by Schäfer (2007). This research was performed by two German exchange students. In 2009, a third pillar (no 3000) was established. Fig. 4.1 presents the resulting present-day build-up of the BCAL/UFPR station. Further insights into GNSS antenna calibration experiments are treated in the following sections. In addition to these GNSS-related work, a vertical monitoring network consisting of six control points (P1-P6) aiming at the stability of the astronomical observatory was established and repeatedly observed. Based on the evaluation of levelling campaigns vertical displacement rates were calculated, which prove the stability of the observatory (Euriques, 2016).

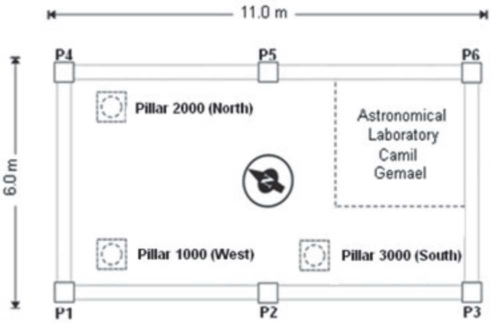

Figure 4.1: The BCAL/UFPR floor plan.

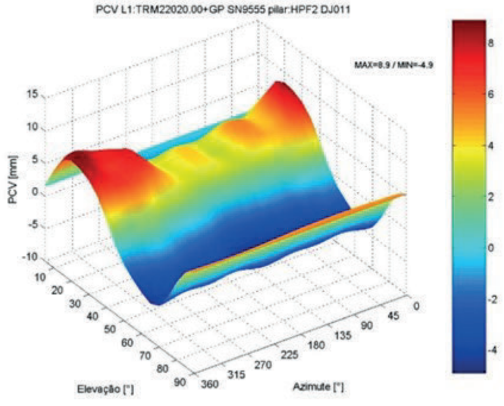

Figure 3.2: Example of azimuth- and elevation-dependent PCV-values.

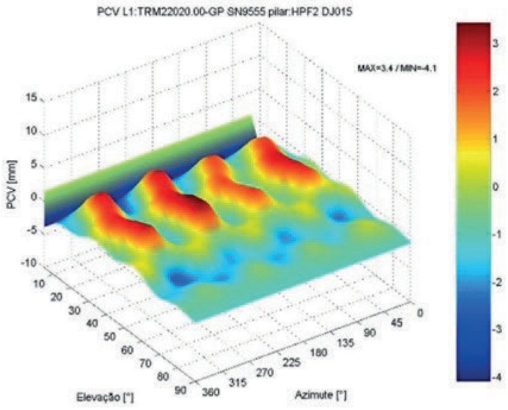

Figure 3.3: Example of azimuth- and elevation-dependent PCV-values of a TRM22020.00-GP antenna.

4.1 Influence of multipath effect on antenna calibration

Before starting experiments aiming at calibration procedures, GNSS measurements were carried out to evaluate the site multipath (Huinca, 2009). The main goal was to select pillars for the establishment of two reference antennas. GNSS dual-frequency data from four sites were analyzed using the WaSoft/Multipath software to perform specific analysis regarding multipath conditions. In addition to the three sites on the roof top of the astronomical laboratory, the nearby (distance approx. 50 m) IGS site UFPR was included. Figure 4.2 shows that all three pillars of the BCAL/UFPR station are slightly affected by multipath. Since pillar 2000 showed less impact of multipath, it was selected as the calibration site while pillars 1000 and 3000 were chosen as reference sites.

4.2 Development of calibration method and evaluation measurements

In order to validate GNSS antenna calibration procedures in accordance with international standards, experimental measurements were carried out starting in 2011 considering equipment and software aspects, especially. A LEIAX1202GG antenna was tested at site 2000. It was mounted on a software-controlled motorized device enabling axial rotation of the antenna on pre-defined azimuthal directions (Figure 4.3). This equipment guarantees good coverage for the whole antenna horizon and meets the needs of scientific experiments especially in GNSS antenna calibration (Frevert et al., 2003). Two absolute calibrated antenna models LEIAR25 and LEIAT504 were considered as redundant reference sites on pillars 1000 and 3000, respectively.

Calibration procedures of 24-hour measurements (tracking rate: 15 s) were performed using the Wasoft/Kalib software (Wanninger, 2009) to derive the calibration parameters PCO and PCV on L1 and L2 carriers as well as associated standard deviations. Later, this test antenna was calibrated at the Technical University of Dresden and also by the Geo++ Company in Hannover, the latter using absolute robot field calibration procedure (Wübbena et al., 1997). The comparison of these calibration results – considering in addition type-specific antenna calibration values published by the National Geodetic Survey (NGS) – proved the appropriateness of the calibration infrastructure. See Huinca et al. (2012, 2016) for details.

4.3 Repeatability of results

Various calibration procedures were performed using a LEIAX1202GG antenna, to check the repeatability of antenna products provided by the BCAL/UFPR station. Within these experiments different reference antennas (LEIAR25, LEIAT504) were used. In all cases the PCO-differences were less than 1 mm. A special focus was set on the comparison with respect to the NGS-values. It is important to emphasize that NGS parameters represent averages of antenna calibration procedure, too. These experiments demonstrated that the GNSS antenna calibration method of BCAL/UFPR is not significantly different to NGS-values.

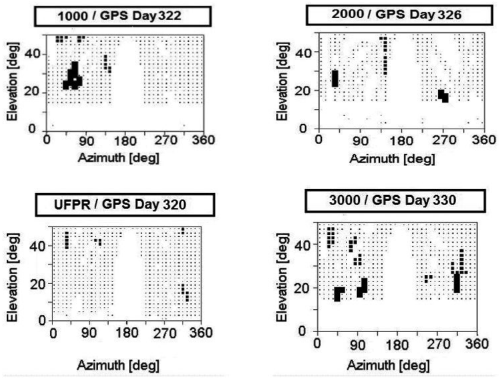

Figure 4.2: Multipath at pillars 1000, 2000 and 3000 resp. the CORS UFPR. No symbol: No data; dot: No Multipath; small square: Multipath/Standard deviation: 5 – 15 mm.

Figure 4.3: Motorized device (left) and reference antennas.

In addition to the LEIAX1202GG five Trimble Zephyr Geodetic II antennas (NGS code: TRM57971.00) were tested in November 2012 based on two consecutive 24 h sessions for each antenna. Analyzing horizontal PCO sets derived from two independent calibration procedures, no significant differences were observed (differences less than 1 mm).

Besides PCO-related analyses, elevation-dependent PCV were evaluated in detail. Since each PCV-set has its own matching PCO, it is required that all PCV-results are converted to a common PCO to enable valid comparison. See Freiberger Junior (2007) and Huinca (2014) for a detailed review of PCV-analyses. These two doctoral dissertations represent – besides other scientific output (e. g., approx. 90 contributions; Krueger and Heck (2012) – the tremendous success of the collaboration between UFPR and GIK.

5 Conclusions

This paper gave a descriptive overview on the works related to the establishment of GNSS antenna calibration at the BCAL/UFPR station, which was the aim of the scientific PROBRAL project between UFPR and GIK/KIT and started more than ten years ago. Another goal was to sensitize the South American GNSS community for site-specific effects (e. g., receiver antenna modelling, multipath). The results of the research and experiments carried out in Germany and Brazil collaboratively prove that the products derived at BCAL/UFPR are equivalent to products of renowned services (e. g., NGS).

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