Geo++® White Paper

Comparison and Analysis of BLOCK II/IIA Offsets from Antenna Field Calibrations

Gerhard Wübbena, Martin Schmitz
Geo++ Gesellschaft für satellitengestützte geodätische und
navigatorische Technologien mbH
D-30827 Garbsen, Germany
www.geopp.de

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Introduction

A BLOCK II/IIA qualification antenna, which is identical to the flight antennas has been calibrated in two different antenna field calibrations.

In 2000, a relative field calibration of the BLOCK II/IIA antenna by Mader, Czopek (2001) analyzed the validity of phase offsets for the GPS transmitting antenna, which were based on theoretically computed offsets and was used for all satellites. Satellites passing through the zenith-pointed beam of the BLOCK II/IIA antenna provided by Boeing were observed. Several days of observing provided enough multiple satellite occurrences in the beam to obtain a good estimate of the L1 and L2 phase center offsets but insufficient data to compute the PCV.

In 2007, an absolute antenna field calibration of the same BLOCK II/IIA was carried out by Wübbena et al. (2007). The absolute GNSS antenna calibration system consisting of the Geo++ GNSMART software and a robot was used. The robot enables observations in different antenna orientations. In particular azimuth dependent PCV can be reliably and accurately determined due to optimized coverage of the antenna's hemisphere. L1 and L2 phase variations from several real-time calibrations were combined to provide L1, L2 offsets and PCV.

The general problem while comparing only offsets is discussed and the height offsets obtained from the two different calibrations are compared. Offsets from other research groups are also addressed.

Absolute and Relative Antenna Calibration

Calibration methods differ with respect to methodology. In the following the specific relative field calibrations used by Mader, Czopek (2001) and the absolute field calibration used by Wübbena et al. (2007) are discussed. For the relative and absolute BLOCK II/IIA field calibration there are two major differences

- multipath
- coverage

The absolute antenna calibration with robot was developed to eliminate multipath and to get calibration results completely independent from a reference antenna or station. The rotations and tilts of the calibration antenna give a homogeneous coverage of the antenna

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hemisphere.

Multipath may be present for the reference antenna and the BLOCK II/IIA in the relative calibration. The narrow reception beam is of advantage to avoid multipath, but both procedures use also the side lobes of the satellite antenna. The robot calibration will have reduces multipath errors for the BLOCK II/IIA.

The relative field calibration of the BLOCK II/IIA was a static setup. The coverage of the antenna is defined by the satellite tracks passing through the reception beam. Therefore only some areas of the antenna are covered by observations. Depending on the geographic latitude no observation are available for the northern hole. In contrast, the robot moves and inclines the satellite antenna to get an optimal coverage with observation data for the complete reception area.

Comparing Mean Offsets

A GNSS antenna is completely described by a set of consistent offsets and phase variations (PCV). Looking only at offsets is an approximation of the antenna model, which can lead to significant differences between calibrations or computations. The horizontal offsets are generally derived from antenna calibrations in an absolute sense and can be reproduced by different methods with sufficient accuracy. The height offsets, however, is determined not always directly in an absolute sense and is very sensitive. The determination of the height offsets depends on

- calibration procedure (absolute or relative method)
- elevation mask (negative elevation)
- distribution of data on the antenna hemisphere (northern hole)
- minimum condition for computing the height offset
- accuracy (less compared to horizontal offsets or PCV)

Therefore, comparing height offsets is not a rigorous method. The height offsets only represents a very limited and not precisely defined mean value of the PCV. A rigorous comparison is only possible while reducing the PCV to an identical antenna reference point (sum of offset and PCV) or comparing only PCV.

Offset differences have been investigated and analyzed for GPS antennas using absolute robot calibration, different relative calibration procedures/softwares and chamber calibration in several campaigns in Germany since 1999 (Antenna Workshops 1999-2006). The issue of comparing offsets has been worked out while doing benchmarks of the same antennas.

Comparison of BLOCK II/IIA Height Offsets

Despite the qualification of height offsets, Tab. 1 shows several different height offset computations based on the absolute antenna calibration with robot presented in Wübbena et al. (2007). The computations use the real-time results from the calibration. A standard spherical harmonics expansion of degree and order (8, 5) was selected for modeling PCV and the offset computations work currently with a step size of 5° on the spherical harmonic model.

The offset computation was executed with different elevation masks from 30° to 80°. During the absolute antenna calibration observation over 30° elevation were used. The height offsets in Wübbena et al. (2007) are based on an elevation mask of 75°, which corresponds to the transmitting beam of the antenna generally seen on the ground.

The elevation mask used in the relative calibration by Mader, Czopek is 60°. From Tab. 1, the differences of the height offset are 4 cm for the 75° elevation mask and 16 cm for 60° elevation mask.

Obviously, the height offsets are significantly depending on the elevation mask. On the one hand, this depends on the small reception beam of the BLOCK II/IIA antenna, which makes a mean fit to the PCV residuals from a sphere difficult. The geometric conditions of the computation are very weak. On the other hand, the data distribution of the relative calibration has an severe impact. The results of have a limited coverage of the reception beam due to the static observations. Only tracks of satellites have been observed, which does not give a homogeneous coverage of the antenna. Therefore, the height offset is affected by the adjustment of PCV and the general distribution of observation data.

Looking at elevation dependent PCV, a change of PCV of 1.7 cm at 15° nadir angle causes a change in the height offset approximately 0.5 m. A change of 1 mm PCV still causes a change of 3 cm for the height offset. Hence, slight differences in the coverage of the antenna hemisphere (down to 60° elevation) will cause PCV differences transferring into height offset changes. This holds especially for PCV with azimuthal variations.

The data distribution causes difference for the estimated height offsets, which should be in theory best for the same elevation mask. Another indicator is the difference of L1 and L2 height offsets, which tend to be comparable for different calibration procedures having the same data distribution. The L1-L2 measure agrees better for the 60° elevation mask computation. However, individual observations of the side lobes of the BLOCK II/IIA antenna and the general data distribution can be easily attributed for such differences.

Computation	cut-off [°] elev/nadir	L1 Up [m]	L2 Up [m]	L0 Up [m]	L0 Up [m]	Std. L0 Up [m]	L1-L2 Up [m]
ARP		top GP	top GP	top GP	CM		
Wübbena et al.	75/15	+0.2687	-0.1882	+0.9748	+1.6931		+0.4568
Geo++	30/60	+0.3511	+0.0056	+0.8852	+1.6035		+0.3455
Geo++	60/30	+0.2983	-0.0135	+0.7804	+1.4987		+0.3119
Geo++	80/10	+0.2689	-0.2571	+1.0820	+1.8003		+0.5260
Mader, Czopek		+0.459	+0.149	+0.9382	+1.6563		+0.31

Tab. 1: Height offsets (5° step size) from absolute field calibration (Wübbena et al. 2007, Geo++) and relative field calibration (Mader, Czopek 2001)

In Fig. 1 the height offset has been computed for every 5 deg azimuthal direction. The offsets are computed by fitting the total PCV for the corresponding azimuth to give minimum RMS of the residual PCV. The published data with an elevation mask of 75° was used. Clearly, a range of the height offset for the ionospheric free linear combination L0 of 1.4 m is visible. The bars in Fig. 1 indicate the standard deviation of the height offset computation, i.e. the RMS of the fit. The accuracy of the height offsets computation is different than the PCV estimation obtained from the absolute antenna calibration system, which is well below 1 mm except for the horizon (Wübbena et al. 2000).

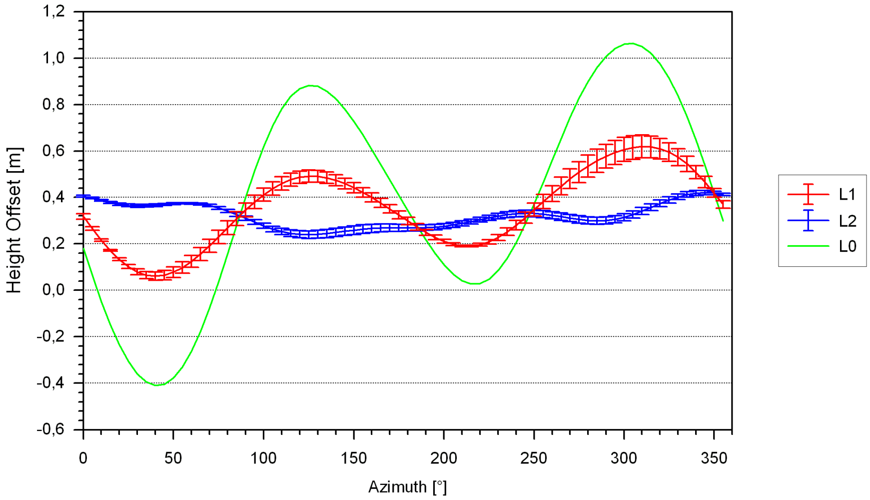

Fig. 1: Height offsets computed for different azimuth

Tab. 2 shows in addition height offsets determined by other research groups. See Bar-Sever et al. (2006) and Schmid et al. (2007) for details. The measure to the BLOCK II/IIA satellite's center of mass (CM) is 0.7183 m according to Mader, Czopek (2002), which has been used to reference different results to the same antenna reference point. Antenna reference point for the height (up) offset is top of the BLOCK II/IIA antenna groundplane (top GP) or center of mass. The differences between the height offsets of other research groups differ in the order of half a meter among each other and compared with the two field calibrations in Tab. 1.

Computation	cut-off [°] elev/nadir	L1 Up [m]	L2 Up [m]	L0 Up [m]	L0 Up [m]	Std. L0 Up [m]	L1-L2 Up [m]
ARP		top GP	top GP	top GP	CM		
IGS*		n/a	n/a	+1.6778	+2.396	0.156	n/a
JPL*		n/a	n/a	+1.2417	+1.96	0.05	n/a
NGA*		n/a	n/a	+0.2334	+0.9519		n/a

Tab. 2: Height offsets from other research groups

The variation of the height offset in Fig. 1 demonstrates the dependency on data distribution. Actually, we considered this dependency as one possible cause for the different satellite height offsets derived from global data or combination with LEO data by other research groups. This is underlined in the following discussion of azimuthal variations.

Comparison of BLOCK II/IIA Azimuthal PCV

The robot calibration of the BLOCK II/IIA antenna finds significant azimuthal variation especially for the L1 signal (Fig. 2), which average out in the computation of the pure elevation dependent PCV (Wübbena et al. 2007). The L1 PCV range from -8 mm to +6 mm and show two significant maximums. The L2 PCV (Fig. 3) pattern shows more maximums, but has a smaller magnitude with values from -4 mm to +2 mm.

Nevertheless, the PCV determined by the absolute robot calibration agree well with the L1 and L2 of the relative calibration residuals presented by Mader, Czopek. In Fig. 4 and Fig. 5 the phase

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*	IGS	International GNSS Service
	JPL	Jet Jet Propulsion Laboratory
	NGA	National Geospatial-Intelligence Agency

residuals for different elevations are depicted. Especially the L1 residuals show differences of about 20 mm for the same satellite tracked under same elevation (Fig. 4). Cause of the differences are azimuthal variations, which consequently support the PCV pattern determined by the absolute antenna calibration. The L2 PCV have less azimuthal variations: Less L2 residual differences for different azimuth and same elevation must be expected. The L2 residuals from the relative calibration in Fig. 5 support this as well as the general magnitude of the L2 PCV.

Although the relative field calibration could not determine PCV due to the complex design and small beam width, the results perfectly support the improved calibration results of the absolute field calibration.

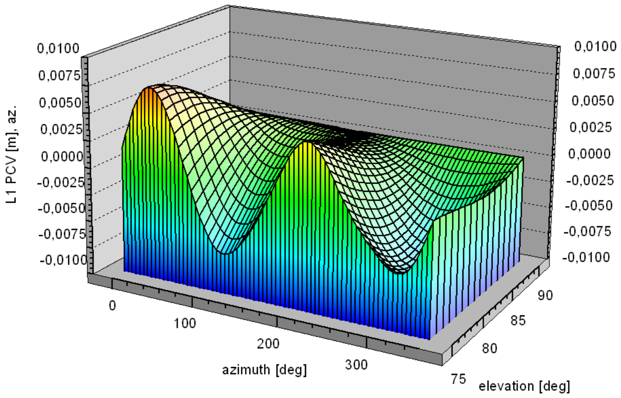


Fig. 2: L1 PCV [m], offset removed from absolute calibration Wübbena et al. (2007)

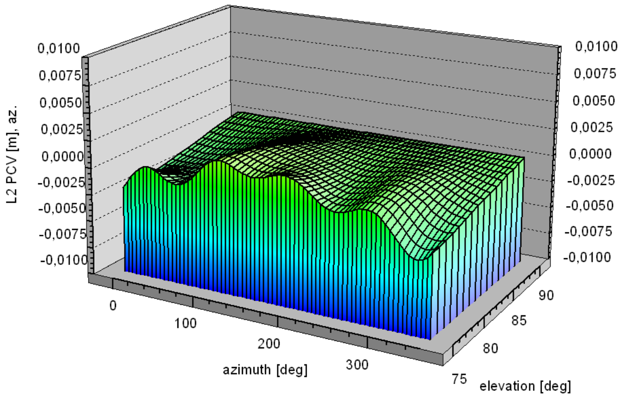
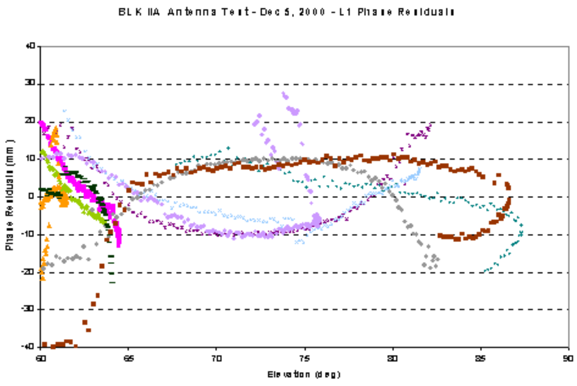
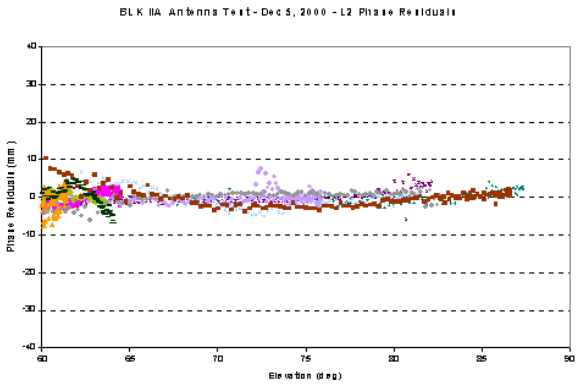


Fig. 3: L2 PCV [m], offset removed from absolute calibration Wübbena et al. (2007)



The L1 phase residuals have a pronounced asymmetry, but at the level of a few cm. This antenna will be re-tuned and then tested again.

Fig. 4: L1 residuals [mm] from relative calibration in from Mader (2000)



The L2 phase residuals do not show the asymmetry seen for the L1 residuals. There is no significant phase curvature across the beam.

Fig. 5: L2 residuals [mm] from relative calibration from Mader (2000)

Discussion and Summary

The restricted properties of antenna height offsets must be considered, while comparing height offsets from different calibration procedures. This is once again more severe for the BLOCK II/IIA GPS satellite antenna with its small transmitting/reception beam.

Differences in the height offsets have to be expected, because only a consistent set of offsets and complete elevation and azimuth dependent PCV can describe an antenna completely. But the magnitude of differences must be analyzed and justified. It has been shown, that already slight differences in the data distribution used for the height offset estimation can cause differences in the order of half a meter or even more.

Therefore, the agreement of the absolute and the relative field calibration of the qualification BLOCK II/IIA antenna of about 4 cm is considered as very good. Although no PCV were estimated in the relative field calibration, the residuals clearly verify the magnitude and the presence of azimuthal PCV variations for the BLOCK II/IIA antenna.

The demonstrated impact of data distribution in combination with the azimuthal PCV variations of the BLOCK II/IIA GPS satellite antenna can serve as explanation for existing large differences between the individual results of satellite antenna height offsets. In this case, global data based satellite offset and PCV estimations might be limited and calibration of satellite antennas before launch is recommended.

The absolute and relative field calibration give consistent results at an expected level of agreement while interpreting all information.

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