On the Determination of Antenna Phase Center Corrections in a Multi-GNSS Multi-Frequency Approach

Tobias Kersten and Steffen Schön

Institut für Erdmessung | Leibniz Universität Hannover

Leibniz Universität Hannover

Introduction

The accuracy of user positions estimated by Precise Point Positioning (PPP) techniques depends - among others - on a consistent Phase Center Correction (PCC) model. Different investigations and modernizations of the space segment and the correction models can be noticed. Parallel to the introduction of the new International Terrestrial Reference Frame ITRF2008, by the IERS in May 2010, the model for the widely used antenna correction igs05.atx in the well known ANTEX format is updated starting with GPS Week 1632 by a new one, called igs08.atx. This new file satisfies the need of Multi-GNSS constellation antenna corrections, which are demanded by a broader community.

The GNSS modernization process includes the successful launch of a GPS II-F satellite (PRN25) with the first operational L5 signal, a second one will be launched in June this year. In the near future new GLONASS-K satellites will be launched, supporting the transmission of the new L3 signal as well as interoperable acquisition methods (CDMA additional to FDMA) on this signal. Consequently, for high-end applications based on carrier phase measurements, like PPP, a set of consistent absolute phase center corrections (PCC) is necessary.

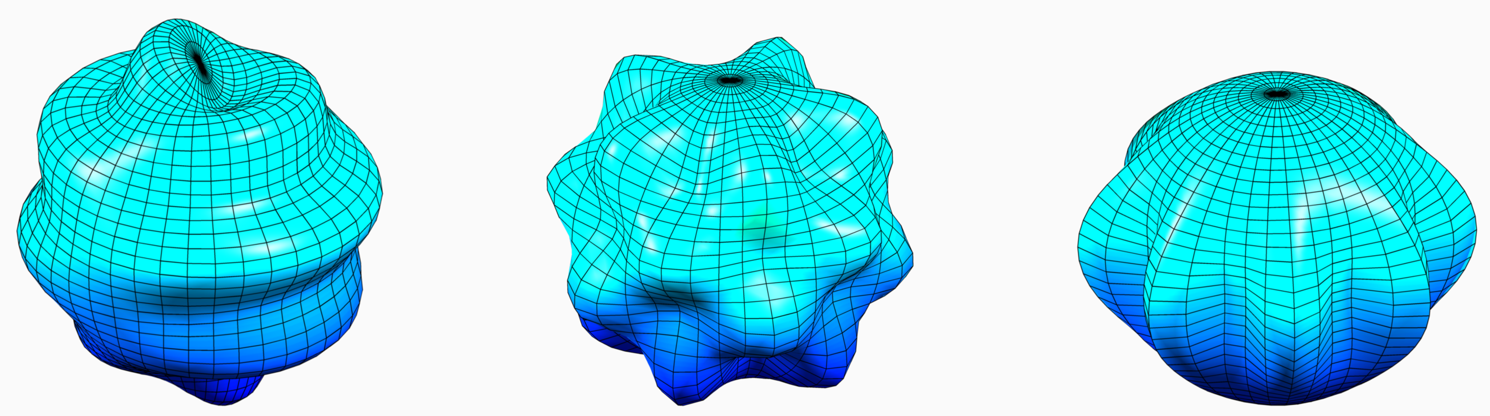
Modeling antenna receiver PCC

Antenna PCC are the consistent set of a mean Phase Center Offset (PCO) and associated variations (PCV). In this contribution the mathematical tool of spherical harmonics is used in a sense of a best fit curve for a precise approximation of the real-valued spherical function $PCC(\alpha, z)$, band limited to degree n and order m:.

$$PCC(\alpha, z) = \sum_{n=0}^{n_{Max}} \sum_{m=0}^{m=n} \{A_{nm}\bar{R}_{nm}(\alpha, z) + B_{nm}\bar{S}_{nm}(\alpha, z)\} \qquad (1)$$

$$\begin{Bmatrix} \bar{R}_{nm}(\alpha, z) \\ \bar{S}_{nm}(\alpha, z) \end{Bmatrix} = \begin{Bmatrix} \cos(m\alpha) \\ \sin(m\alpha) \end{Bmatrix} N_{nm} P_{nm}(\cos z)$$

The unknown coefficients A_{nm} and B_{nm} were estimated by least squares method. To avoid numerical instabilities within the linear adjustment fully normalized harmonics $\bar{R}_{nm}(\alpha, z)$, $\bar{S}_{nm}(\alpha, z)$ were used. They are derived by the normalization matrix N_{nm} and the associated Legendre Polynoms $P_{nm}(\cos z)$.



(a) degree 8 order 0 (b) degree 8 order 5 (c) degree 8 order 8

Fig. 1: Accumulated spherical harmonics for different band limitations. The representation in (a) is used for an elevation dependent representation of PCC while (b) shows the traditional representation within the Hannover concept of field calibration. In (c) a full model of spherical harmonics is depicted.

Observables

Between subsequent epochs $(t_\iota, t_{\iota-1})$ the orientation and inclination of the antenna is changed to derive GNSS system and frequency dependent absolute PCC, independent from any reference antenna.

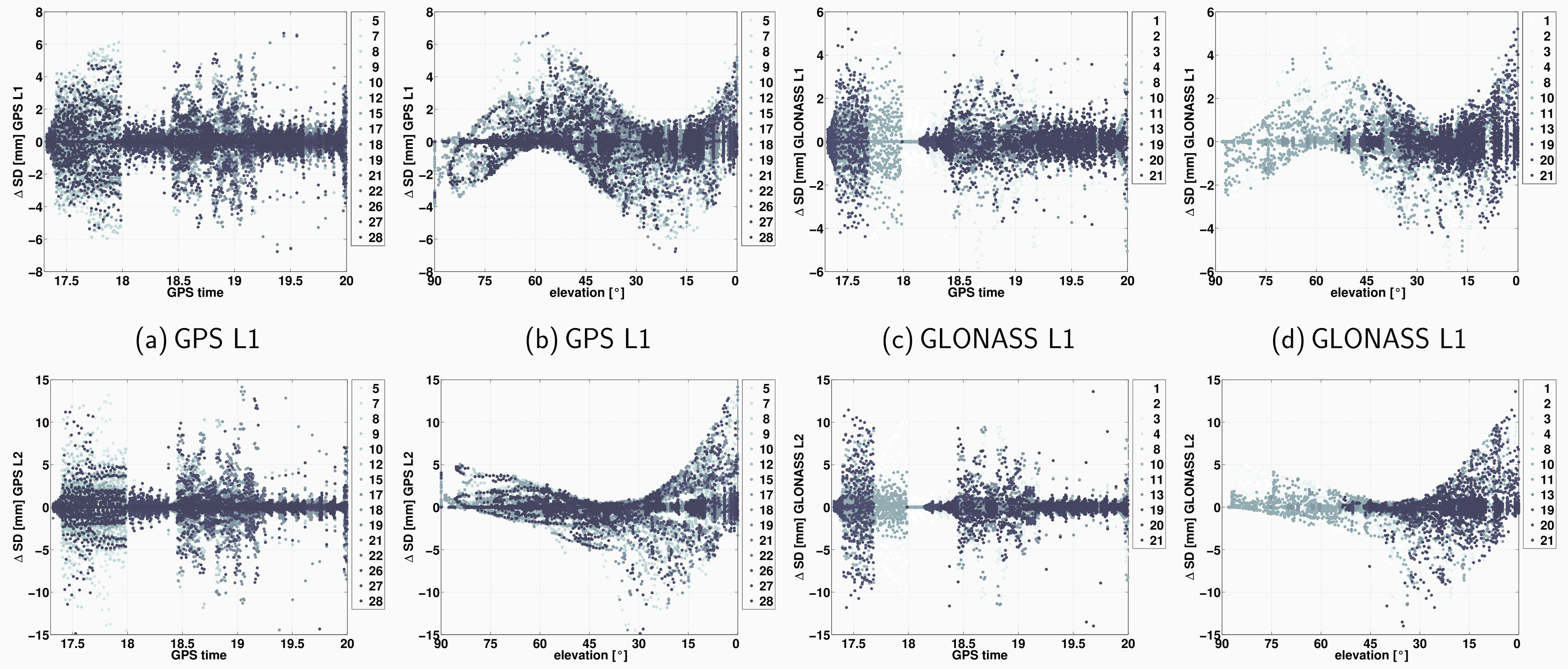
$$\Delta SD = PCC(t_\iota) - PCC(t_{\iota-1}) + \delta_{t_{AB}}(t_\iota, t_{\iota-1}) \qquad (2)$$

The usage of time differenced single differences on a short baseline ($\approx$ 8 m) requires an accurate estimattion model of the relative receiver clock offset $\delta_{t_{AB}}(t_\iota, t_{\iota-1})$ since clocks in station A and B are not aligned to each other and a significant impact on the estimated coefficients can be expected.

References

Kersten, Tobias and Schön, Steffen (2010).
Towards Modelling Phase Center Variations for Multi-Frequency and Multi-GNSS. In 5th ESA Workshop on Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing.

Observations



(a) GPS L1 (b) GPS L1 (c) GLONASS L1 (d) GLONASS L1

(e) GPS L2 (f) GPS L2 (g) GLONASS L2 (h) GLONASS L2

Fig. 2: The subfigures above show time differenced single-differences with alternating antenna orientation for GPS (left column) as well as for GLONASS (right column) and on both frequencies L1 (top) and L2 (bottom), used within this process. The expected PCV pattern is clearly noticable by plotting ΔSD against the elevation angle in a topo-centric antenna system, since the illustration against time is not very meaningful.

Normal Equation Stacking

Subsequent epochs are correlated to each other. Thus normal equations (NEQ) per satellite j and frequency/system G are suitable to consider this. Different weight matrices **P** are applicable within the PCC estimation in one common model. The fully populated weight matrix yields a circular toeplitz structure and reflecting the correlation among the unknowns [Kersten and Schön, 2010].

$$\underset{[(2u+\nu)\times(2u+\nu)]}{\mathbf{N}^j_G} = \begin{bmatrix} \sum_j \mathbf{A}^{T\,j}_{G1}\mathbf{P}^j\mathbf{A}^j_{G1} & 0 & \sum_j \mathbf{A}^{T\,j}_{G1}\mathbf{P}^j\mathbf{B}^j_1 \\ 0 & \sum_j \mathbf{A}^{T\,j}_{G2}\mathbf{P}^j\mathbf{A}^j_{G2} & \sum_j \mathbf{A}^{T\,j}_{G2}\mathbf{P}^j\mathbf{B}^j_2 \\ \sum_j \mathbf{B}^{Tj}_1\mathbf{P}^j\mathbf{A}^j_{G1} & \sum_j \mathbf{B}^{Tj}_2\mathbf{P}^j\mathbf{A}^j_{G2} & \sum_j \mathbf{B}^{Tj}_1\mathbf{P}^j\mathbf{B}^j_1 + \sum_j \mathbf{B}^{Tj}_2\mathbf{P}^j\mathbf{B}^j_2 \end{bmatrix} \qquad (3)$$

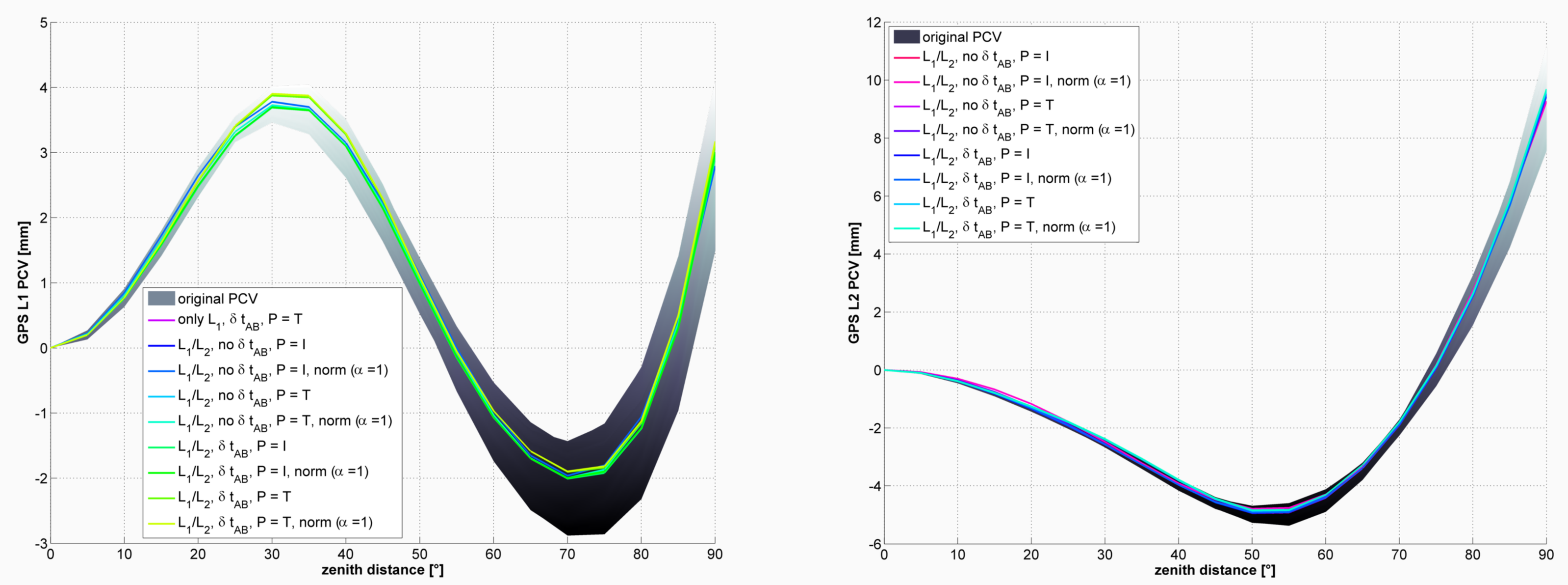
Since coefficients are affected by the receiver clock accumulated in **B**, the approach results in a NEQ system with the above mentioned dimensions of unknown u and epochs ν.

Due to the large condition number of the NEQ system a Tikhonov regularization with a parameter $\alpha > 0$ -among other - can be used to stabilize the inversion.

$$\|\mathbf{Ax} - \mathbf{l}\|_2^2 + \alpha\,\|\mathbf{x}\|_2^2 = \min$$

$$\left\|\tilde{\mathbf{A}}\mathbf{x} - \tilde{\mathbf{l}}\right\|_2^2 = \min, \quad \tilde{\mathbf{A}} = \begin{pmatrix} \mathbf{A} \\ \sqrt{\alpha}\mathbf{E} \end{pmatrix}, \quad \tilde{\mathbf{l}} = \begin{pmatrix} \mathbf{l} \\ \mathbf{0} \end{pmatrix}$$

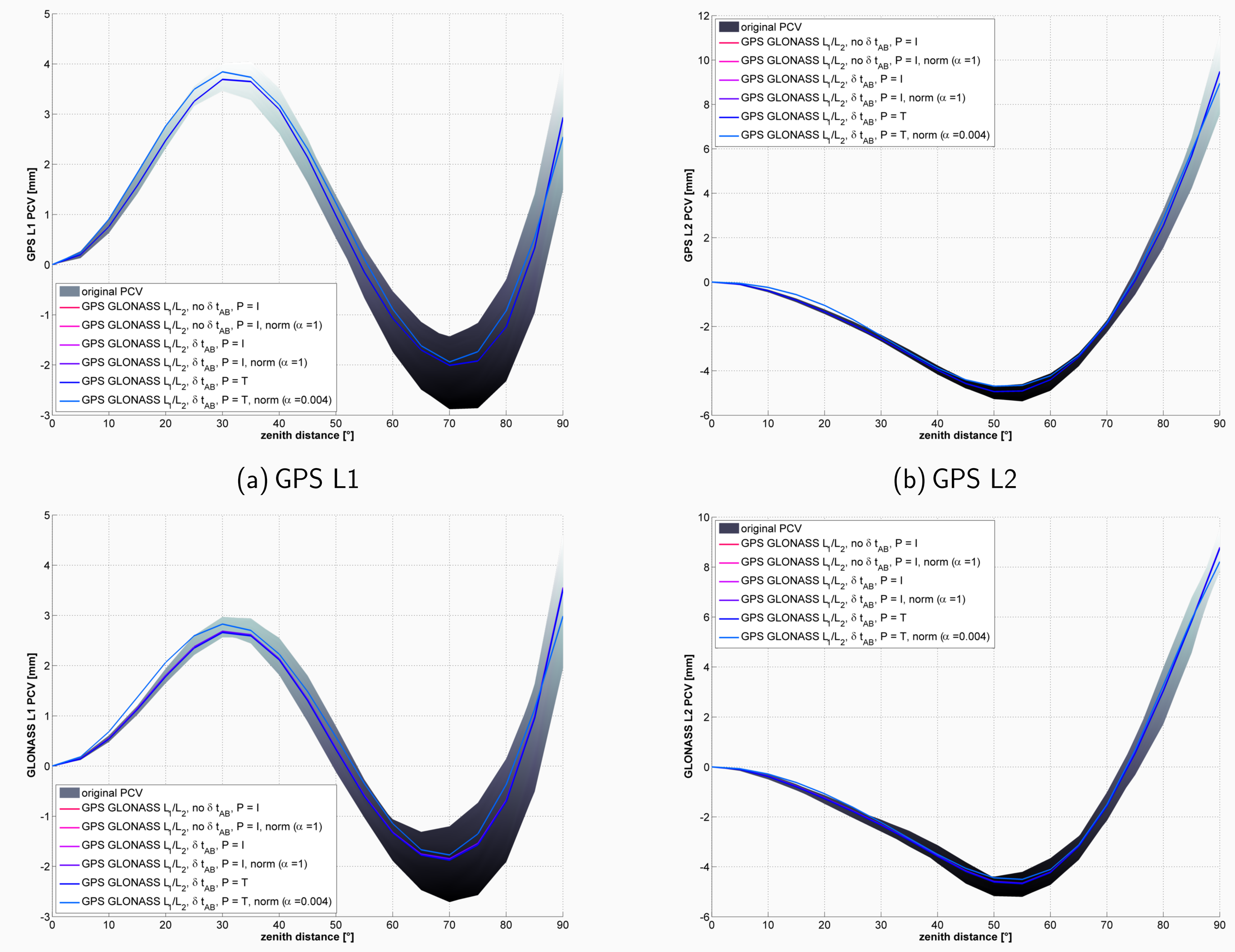
Multi-Frequency Approach



(a) GPS L1 (b) GPS L2

Fig. 3: Derived PCV pattern from estimated spherical harmonic coefficients for degree 8 and order 5. Different variants were processed to analyse the impact on the determinability of the unknown coefficients. Original PCV pattern is presented as projection of all azimuthal variations into the elevation plane. For different processing strategies only mean values are shown since the azimuthal pattern is similar within a magnitude of 0.20 - 0.25 mm.

Multi-Frequency Multi-GNSS Approach



(a) GPS L1 (b) GPS L2

(c) GLONASS L1 (d) GLONASS L2

Fig. 4: Derived PCV pattern from estimation of multi-GNSS and multi-frequency approach within one adjustment. The original PCV pattern projected into the elevation plane is depicted, mean values for derived pattern are shown for GPS (a,b) and GLONASS (c,d). The results for GPS equal the results presented in Figure 3. The gradients of elevation dependent pattern vary with the normalization of the complete model.

Discussion

- Determination of PCC parameters along with the differential receiver clock error as well as a fully weighted covariance matrix influence the unknowns within a magnitude of 10-15% and corresponds to variances in the PCV pattern of up to 0.2-0.25 mm but close below the precision of the method itself. This is caused by higher gradients in the elevation dependent pattern.
- Estimability of second frequency looks quite better, but this is because of smaller azimuthal variations. A combined consideration of clock modelling and fully weighted covariances yields the most accurate parameters. Figure 3 (a,b) shows that the smaller the azimuthal variations are, the better the performance of the estimation method is.
- The higher the number of parameters to be estimated, the higher the need for a normalization of NEQ system (cf. figure 4). Complete consideration of GPS and GLONASS as well as both frequency - combined with clock offset and ΔSD correlations - yield the physically most meaningful coefficients.
- We point out, that the unknown spherical harmonic coefficients are separable for each frequency as well as for each GNSS. The derived grid pattern shows no significant decrease of accuracy within a combined adjustment.

Conclusions and Further Steps

First experiments look comprising and it could be shown, that estimation of antenna PCC can be carried out by a multi-GNSS and multi-frequency approach. We also show a experimental environment for different PCC modelling within one adjustment model. Special care has to be taken with regard to the regularization of the NEQ system due to the large condition number.

Further work is concentrated on the development of an automated algorithm to determine PCC for new GNSS as well as Frequencies (Galileo, GPS L5, GLONASS L3) since we could show that multi processing is feasible in a common model.

Acknowledgement

The project is carried out by the German Aerospace Center (DLR) with the project label 50NA 0903 , funded by the Federal Ministry of Economics and Technology (BMWI), and based on a resolution by the German Bundestag.

Institut für Erdmessung
Schneiderberg 50
D-30167 Hannover

EGU General Assembly 2011 | Vienna | Austria
03. - 08. April 2011

Tobias Kersten
Steffen Schön
www.ife.uni-hannover.de
{kersten, schoen}@ife.uni-hannover.de