GEODESY AND CARTOGRAPHY
Vol. 62, No 2, 2013, pp. 101-111

DOI: 10.2478/geocart-2013-0012

LC phase bias investigation of ASG-EUPOS stations

Andrzej Araszkiewicz, Karolina Szafranek

Military University of Technology
Faculty of Civil Engineering and Geodesy,
Centre of Applied Geomatics
2 Gen. S. Kaliskiego St., 00-908 Warsaw, Poland
email: aaraszkiewicz@wat.edu.pl; kszafranek@wat.edu.pl

Received: 13 March2013 / Accepted: 12 November 2013

Abstract: Monitoring of permanent stations that make up the reference frame is an integral part of the geodesists work. Selection of reference stations is based on analysis of parameters characterizing them (hardware, coordinates' stability, mounting, location). In this paper, we took into account phase residual as an indicator of unmodelled signal. Phase residuals were computed based on ASG-EUPOS and EPN observation processing. The results show the connection between the method of mounting the antenna and the residuals. We have reviewed multipath effect at ASG-EUPOS stations, and chosen those which are characterized by the highest value of phase residual. The results show that LC phase residual is a good factor to characterize site's solutions' reliability. For majority of sites RMS values were less than 10 mm. Modulations associated with multipath effect were observed for few ASG-EUPOS sites only. Phase residuals are distributed specifically for sites, which antennas are mounted on pillars (more common for EPN sites). For majority of analysed sites phase residual distribution was similar for different days and did not depend directly on atmosphere condition.

Keywords: ASG-EUPOS, multipath, residual phase bias, GPS time series

1. Introduction

Multipath is, among others, a factor causing systematic errors in the GPS observations (Axelrad et al., 1996; Clark, 1992). Multipath occurs when the GPS signals reaches at an antenna through reflections from nearby buildings, other objects or just the ground. Multipath effect can be minimized trough careful selection of antenna model and radomes (Dong et al., 2002), antenna mounting (Elosegui et al., 1995) and also proper processing strategy (e.g. using higher elevation cut-off angle). However, complete elimination of errors due to this phenomenon is not possible. There is a number of papers related to the impact of multipath effect on changes in the coordinates in annual (Ray et al., 2007), seasonal (Larson et al., 2008) or sub-daily (Penna et al., 2007) periods. According to (Kraus, 1988; Balanis, 2005) the surrounding space of an antenna may be divided into three zones: reactive near field (nearest the antenna), radiating near field and far field. Multipath effects in the first two were described e.g. by Dilssner et al. (2008) and King and Watson (2012). All these works prove that the multipath effect and antenna patterns, which are associated with them, have a very significant impact not only on the scattering signals, but they can also cause systematic errors in long-term time series, and thus may affect the determination of reference station coordinates (Dilssner et al. 2008) and velocity (Steigenberger et al., 2009). In this paper the phase residual values for stations of the Polish GBAS system ASG-EUPOS (Bosy et al., 2007) were analysed. ASG-EUPOS is a network of permanent GNSS stations, which according to the Regulation of the Polish Minister of Administration and Digitization of February 14, 2012 serves as the fundamental geodetic network in Poland. According to the model of multipath effect described by Elosegui (1995) and extended T. A. Herring model presented by King and Watson (2012) reflective effects can be seen as a modulation of phase residual ($\delta\phi_L$) in a function of the elevation angle (ε). As demonstrated in the work by Goebell and King (2011) this effect should be visible, depending on the position of the reflective medium, also in the azimuthally asymmetry. The Herring model assumed that multipath is caused by reflector located below the GPS antenna (at some height, H).

$$\delta\phi_L = \frac{\lambda}{2\pi}\left(\tan^{-1}\frac{asin\left[4\pi\frac{H}{\lambda}\sin\varepsilon\right]}{g_d + asin\left[4\pi\frac{H}{\lambda}\sin\varepsilon\right]}\right) \tag{1}$$

It takes into account antenna gain pattern for direct (g_d) and reflected signal (g_r) and also amplitude (a) of the reflected signal for specific surface roughness (S):

$$a = Sg_r\left(\frac{n_1\cos z - \sqrt{n_2^2 - (n_1\sin z)^2}}{n_1\cos z + \sqrt{n_2^2 - (n_1\sin z)^2}}\right) \tag{2}$$

The aim of this study was to examine the occurrence of this effect on ASG-EUPOS and selected EPN (EUREF Permanent Network) stations.

2. Data and processing strategy

For the analysis of phase residuals ASG-EUPOS and EPN stations were used. Observations from 110 (EPN) stations were processed for the period of 01.01.2012–02.06.2012 (GPS WEEKS from 1669 to 1690) and 130 (ASG-EUPOS) stations for the period of 15.07.2012–11.08.2012 (GPS WEEKS 1697-1700). Most of the ASG-EUPOS stations are equipped with the same type of antenna: TRM41249.00 TZGD (Fig. 1). Observations were processed with the GAMIT/GLOBK software package v. 10.4 (King et al., 2010) in a BASELINE mode, in which the orbits are fixed. IGS final orbits and absolute antenna models igs08_1682.atx were used for processing. For troposphere modelling the GPT model was applied with Global Mapping Function (Böhm et al., 2006). The troposphere zenith delay parameters were estimated once per hour. Observations from low elevation satellites were eliminated by using elevation cut-off angle of 10 degrees. Melbourne-Wübbena widelane combination was used to resolve double-differenced ambiguities. The processing was done in three sub-networks (about 40 stations each) in daily intervals. As an observable the double differenced ionosphere-free linear combination (LC) was used. For the analysis one-way phase residuals have been computed by estimating the satellite and station clocks every 30 seconds. The average phase residuals for each pair satellite – station were estimated.

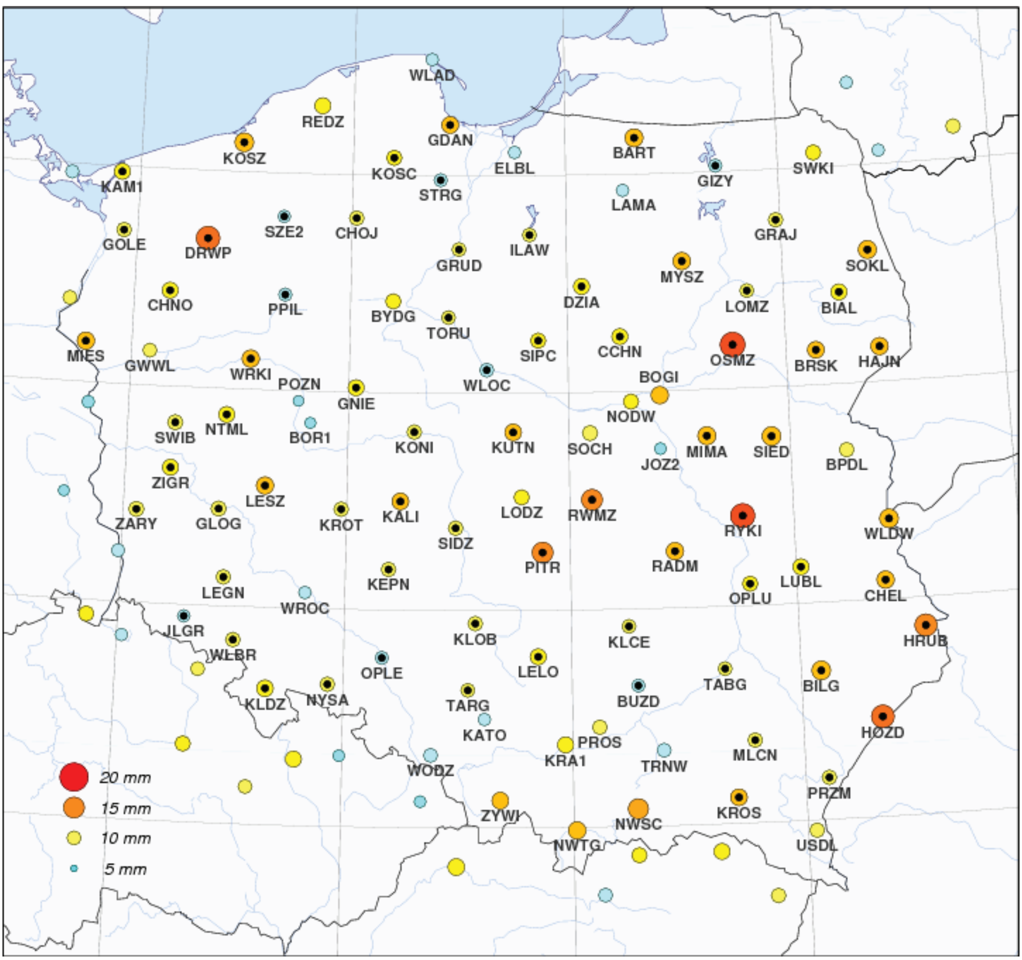

Fig. 1. LC residual phase for ASG-EUPOS stations: average value of RMS for the analyzed period (15.07.2012 – 11.08.2012). Trimble Zephyr Geodetic w/Radome (TRM41249.00 TZGD) antenna marked by black dots

3. LC phase residual on ASG-EUPOS stations

The one-way phase residuals were basis for the further analysis. The average value of root-mean-square (RMS) scatter of postfit LC phase residuals for station per day was calculated. The mean value of RMS for the analysed period is presented in figure 1. This values represent the quality of the processed observations. For the most stations the value of RMS did not exceed 10 mm (Fig. 1).

The highest LC phase residuals occurred at stations: DRWP, OSMZ, RYKI, HOZD, HRUB, where the values of RMS from the analysed period was over 15 mm (Fig. 1). These stations also have one of the most scattered time series from the entire network, as shown on figure 3 (e.g. ASG-EUPOS, 2013). Such high values of residuals were obtained for the whole observation period: for wet and dry days. This is a proof that for this particular case, high values of residuals do not depend directly on atmosphere state and troposphere delay. They can be related with electromagnetic

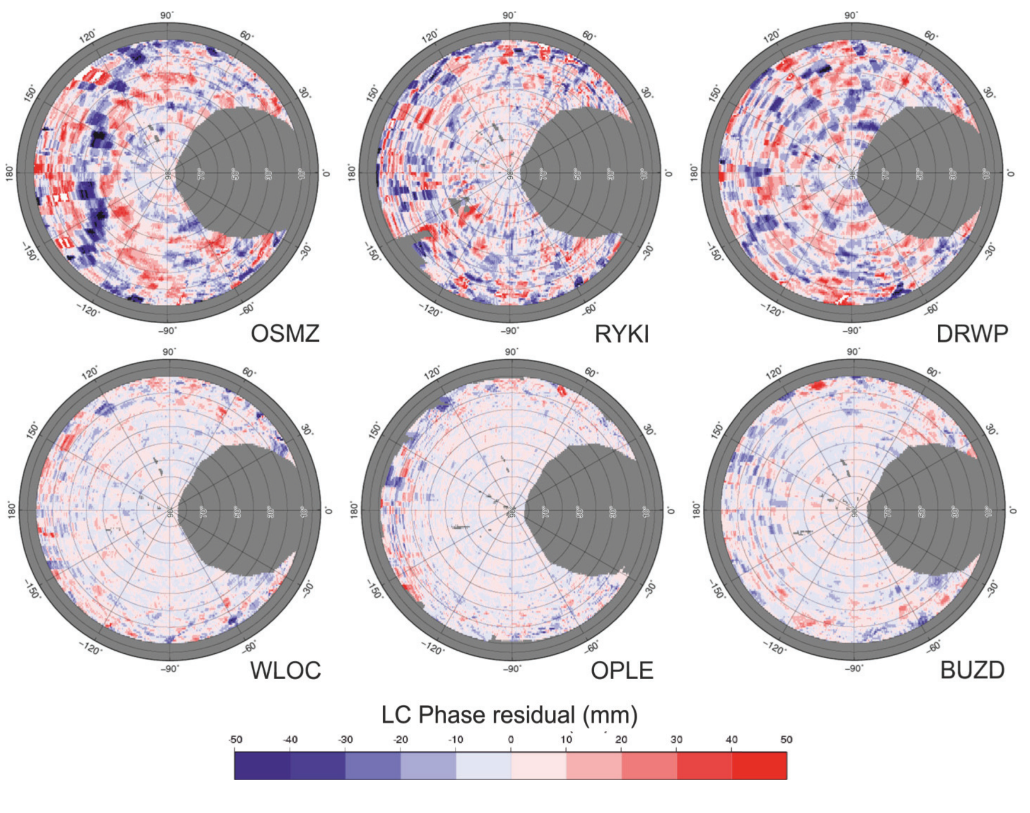

Fig. 2. Sky plots for GPS LC phase residuals for the worst (OSMZ – 18.3 mm, RYKI – 16.6 mm, DRWP – 16.5 mm) and good (WLOC – 9.6 mm, OPLE – 8.6 mm, BUZD – 8.9 mm) ASG-EUPOS stations on 09.08.2012. Values presents the RMS (scatters) of the LC residuals. All presented stations are located on the buildings

field anomalies in the near surroundings of the antenna, because high residual values occur across the whole sky (Fig. 2). For the rest of stations RMS do not exceed 10 mm (example stations on Figure 2); the highest values were obtained for low elevation angles, because biases caused by different phenomena (troposphere, multipath) can be observed mainly there.

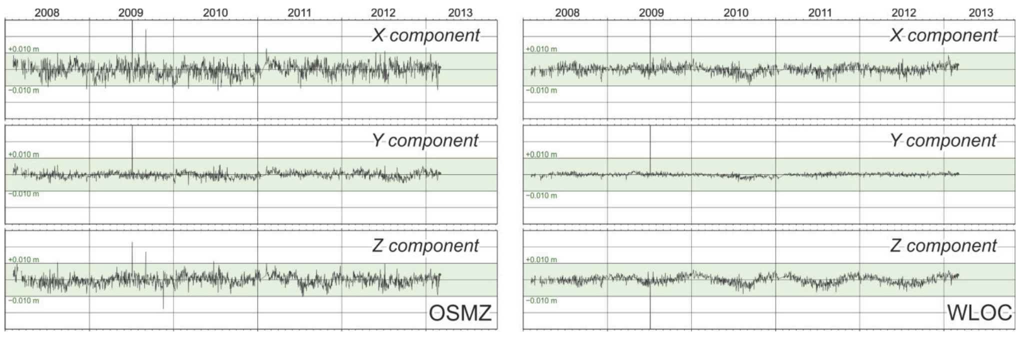

Fig. 3. Time series of coordinates of two exemplary stations: OSMZ (on the left) and WLOC (on the right). Graphs from the website dedicated to the project ASG+ (http://www.cgs.wat.edu.pl/ASG_PLUS/)

4. Multipath investigation

The following analysis took into account the influence of the multipath effect for ionosphere-free linear combination ($\delta\phi_L^{LC}$). According to papers (Elosegui et al., 1995; King and Watson, 2010) reflective influence can be seen as a modulation of phase residual for specified frequencies L1($\delta\phi_{L1}$) a d L2($\delta\phi_{L2}$). Due to the complex structure of the buildings' roofs (metal elements like masts or plates, concrete surfaces or even grit) it is hard to define a single refractive index for a particular station.

$$\delta\phi_L^{LC} = 2.5457 \cdot \delta\phi_{L1} + 1.5457 \cdot \delta\phi_{L2} \tag{3}$$

To compare the results obtained in presented studies Herring model with the values of the model parameters (G = 1.1, S = 0.3) presented by King and Watson (2010) was used. Refractive indexes (n_2) were matched to concrete and steel. As it can be seen it figure 4 small changes of reflection factor (n_2) do not affect significantly phase residuals. Height of the antenna above the reflective surface and factor S, which affects the signal diffusion are the most important here (King and Watson, 2010).

Among the EPN stations it can be easily distinguish which stations are characterized by the increased value of LC residual phase at low elevation angles (lower than 30°). These are mostly stations which antennas are mounted on pillars or on flat roofs. This effect is about 5-10 mm, which is less than in the Herring model. It should be in mind

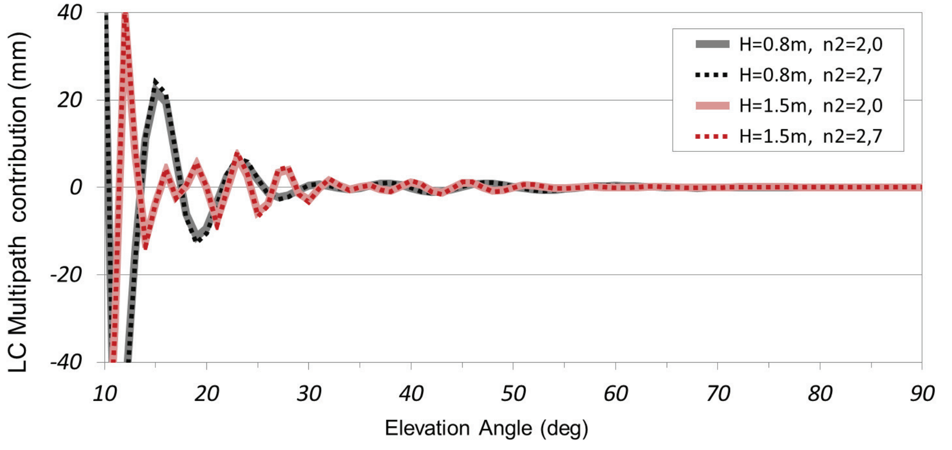

Fig. 4. Multipath contributions to LC phase based on T.A. Herring model with H = 0.8m and 1.5m, and various reflective medium: wet concrete (n_2 = 2.0) and steel (n_2 = 2.7)

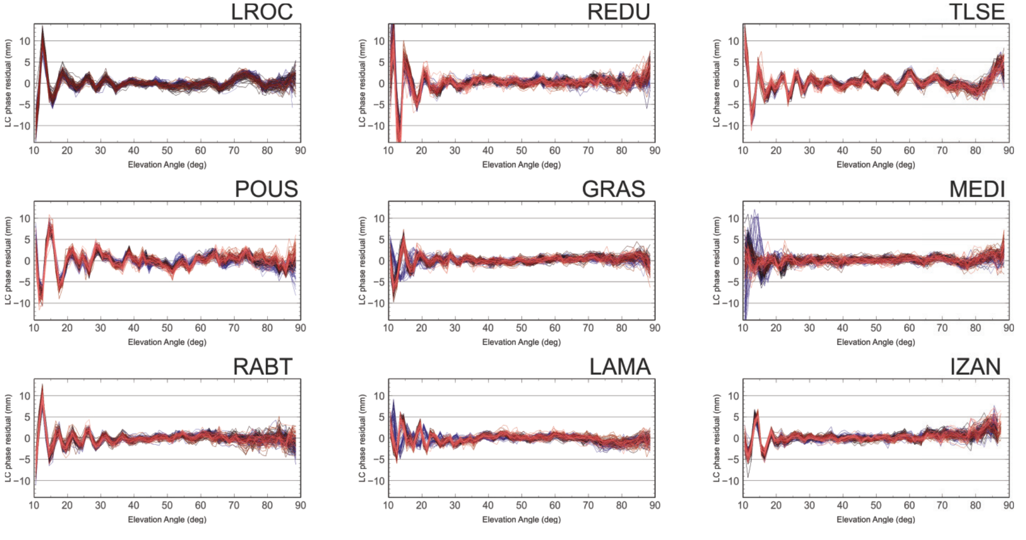

Fig. 5. LC phase biases for selected EPN stations, which multipath effect can be observed. Graphs shows results of each day in a different colour. Values was calculated as mean value from all observations for particular elevation angle. Red – first day, navy blue – last day

that model assumed an ideal conditions of reflection and reflection only. Graphs in figure 5 show this influence received from 154 days of observations.

For the majority of stations phase residuals distribution in a function of elevation angle does not change in time. Only for some stations (MEDI, GRAS, LAMA) change of distribution during spring can by observed. Stability of this parameter can be a proof that these changes are not resulted from troposphere state changes. Residuals for two collocated sites BOGI-BOGO and KIR0-KIRU were also investigated (Fig. 6). For each pair one antenna is mounted on the pillar (higher than 1m). For these antennas distribution of phase residuals was similar to the Herring multipath model (especially for KIRU station).

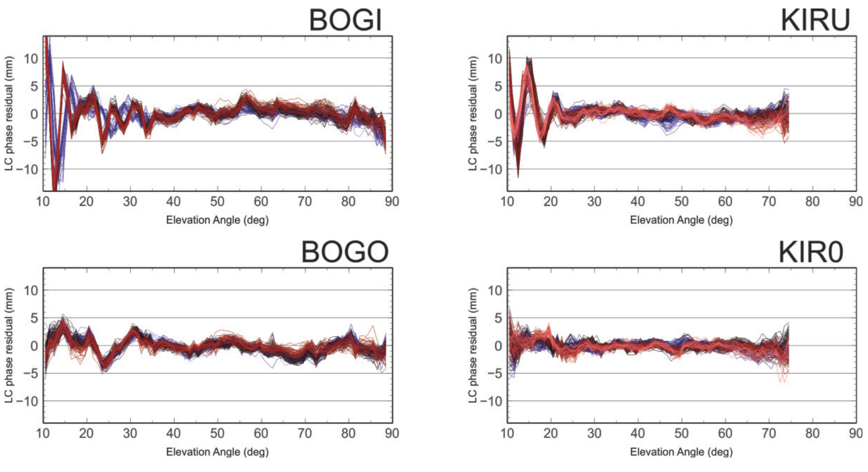

Fig. 6. LC phase biases for pairs of co-located stations (on the left BOGI and BOGO, on the right KIRU and KIR0). For the stations BOGI and KIRU (on top) an obvious ground reflection can be seen. Antennas of these stations are mounted on ~1m pillar. For stations BOGO (located on building 1m above tiled roof) and KIR0 (located on high concrete pillar close to the buildings' roof) this effect is not visible

In case of ASG-EUPOS stations the residuals are more scattered but only for a few of them LC phase residual distribution was similar to the Herring model. Only few of them are equipped with antenna mounted on pillars, they usually belong also to the EPN network (LAMA and BOGI in figures 5 and 6). In case of several stations (KAM1,NYSA, ZARY, SWIB, POZN, KALI, KUTN, PITR, RADM, TABG, BUZD, WLDW, BRSK, SIPC) it can be only presumed that the obtained modulation can be caused by multipath effect. This effect does not exceed 5 millimetres. Similar results were also obtained for a few associated stations (CSVI, CPAR, CLIB, SKSV). Figure 7 shows the LC phase residual from 28 days of observation.

For station KUTN modulations of phase residuals occur mainly for azimuths 240^{o}-330^{o} (Fig. 8), which refer to the direction of the building's roof (station is mounted on the edge of the roof). Similar, but smaller effect can be seen for station

LELO. These cases prove the observed effect is caused by multipath. Similarly as for EPN station, here the distribution of phase residuals does not change significantly for different days (Fig. 8).

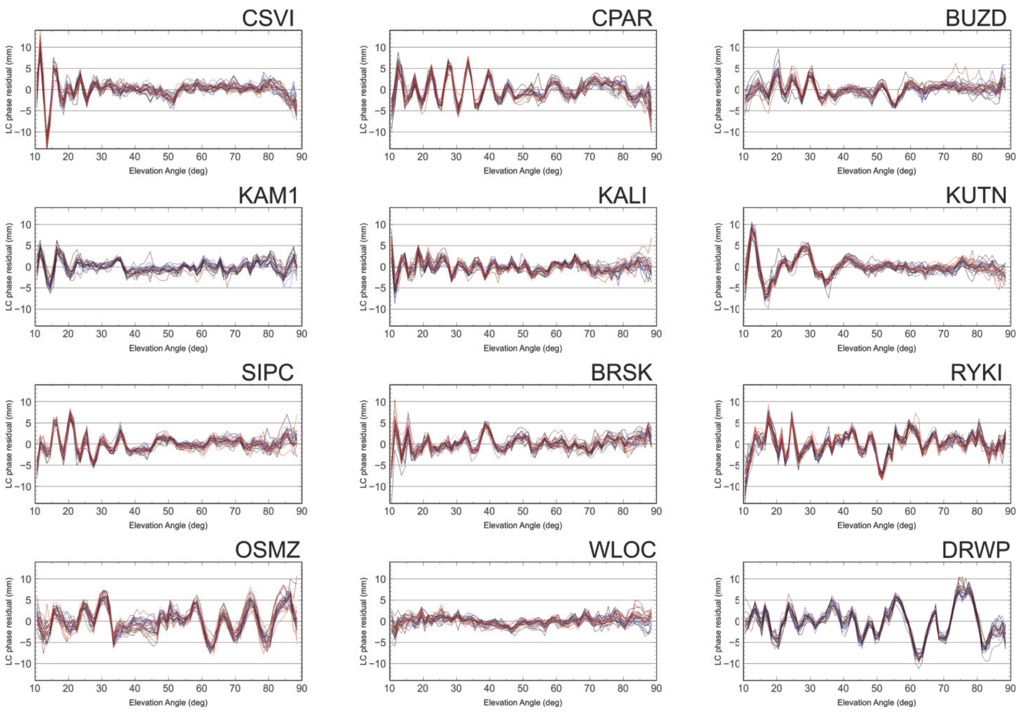

Fig. 7. LC phase biases for selected ASG-EUPOS and associated stations

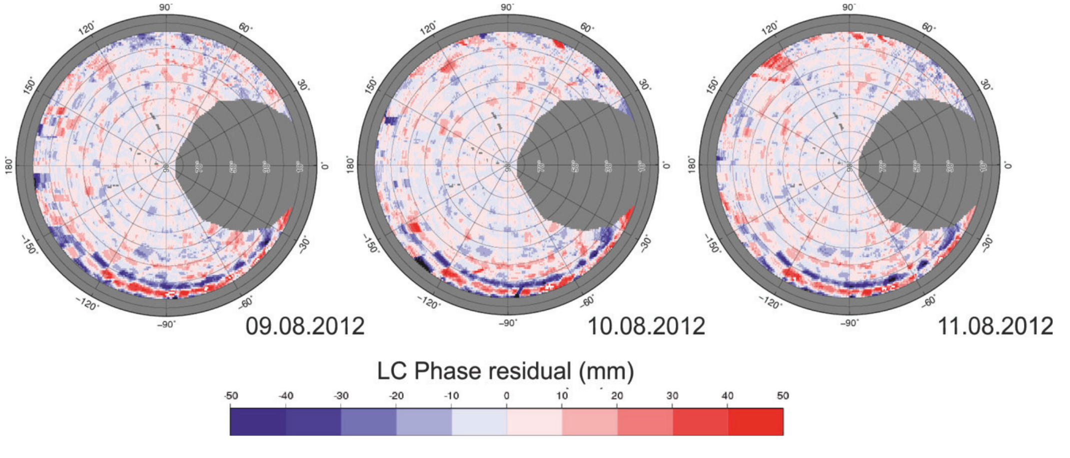

Fig. 8. Sky plots of the phase residuals at KUTN station for 3 consecutive days

5. Summary

The studies concerned analysis of iono-free LC residual phase on ASG-EUPOS and EPN stations. The average value of the LC phase residuals for Polish stations is around 10 mm. The highest values were obtained for three stations (DRWP, OSMZ, RYKI), which have also most scattered time series of the coordinates. As shown in this paper, for the most of the ASG-EUPOS stations there is no proof for multipath influence on phase observations. For some EPN stations, which antennas are mounted on pillars clear modulation characteristic for the GPS signal reflected from ground surface can by observed. This can be particularly seen when comparing the collocated stations: BOGO-BOGI or KIRU KIR0, where one of them is mounted on a low pillar. In this case, the modulation is 10 mm, as well for other stations mounted on pillars or flat roofs (e.g. TLSE, POUS, RABT).

Presented results are the first such analysis carried out for ASG-EUPOS stations. Preliminary results showed that the evaluation of the LC phase biases may be a useful method for stations monitoring. This also allows to assess the impact of the environmental effects on the accuracy of position determination. For few ASG-EUPOS stations (e.g. KAM1, KUTN, SIPC) the obtained phase residuals were constant in the analysed period, this may indicate the influence of the multipath effect. No significant relationship between this residuals and troposphere condition were observed. Analysis of observations from longer period will allow to define how changing environmental conditions (e.g. snow layer) affect the multipath and its impact on the phase observations of ASG-EUPOS stations. It will also eliminate the risky unreliable geophysical interpretation.

Acknowledgements

The research was found in part by the Polish Ministry of Science and Higher Education statutory activities (PBS 23 817) and the National Centre for Research and Development (project No. NR09-0010-10/2010). The GPS processing was performed on the cluster computer with HP Proliant DL380 servers belonging to Centre of Applied Geomatics at the Department of Civil Engineering and Geodesy, Military University of Technology. The analysis were carried out in cooperation with the HOGC (*Head Office of Geodesy* and Cartography in Poland) concerning ASG-EUPOS monitoring and providing QC of the observations. All figures are prepared using GMT open source package (Wessel and Smith 1991).

References

ASG-EUPOS. (2013). ASG-EUPOS, System description. Reference stations. http://www.asgeupos.pl/. Cited February 2012.

Axelrad, P., Comp C. J. & MacDoran P. F. (1996). SNR-based multipath error correction for GPS differential phase, *IEEE Trans. Aerosp. Electrion. Syst.,* 32(2), 650 – 660. DOI:10.1109/7.489508.

Balanis, C. A. (2005). *Antenna Theory: Analysis Design, 3rd ed.*. New York: John Wiley, Hoboken.

Bosy, J., Graszka, W. & Leoczyk, M., (2007). ASG-EUPOS. A Multifunctional Precise Satellite Positioning System in Poland, *European Journal of Navigation*, 5(4), 2–6.

Böhm, J., Niell A., Tregoning P. & Schuh H. (2006). Global mapping function (GMF): a new empirical mapping function based on numerical weather model data. *Geophysical Research Letters* 33, L07304. DOI:10.1029/2005GL025546.

Clark, T. (1992). GPS antennas: De-mystifying multipath. *NASA Goddard Internal Memorandum,* March 5*,* 1992.

Dilssner, F., Seeber G. Wubbena G. & Schmitz M. (2008). Impact of near-field effects on GNSS positions solutions. *Proceedings of the 21st International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2008)*, 16-19 September 2008 (pp. 612-624). Savannah, GA, USA: *Institute of Navigation.*

Dong, D., Fang P., Bock Y., Cheng M. K. & Miyazaki S. (2002). Anatomy of apparent seasonal variations from GPS-derived site position time series, *J. Geophys. Res.,* 107(B4), 2075. DOI:10.1029/2001JB00057.

Elósegui, P., Davis J. L., Jaldehag R. T. K, Johansson J. M., Niell A. E. & Shapiro I. I. (1995). Geodesy using the Global Positioning System: The effects of signal scattering on estimates of site position. *J. Geophys Res.,* 100(B6), 9921-9934. DOI:10.1029/95JB00868.

Goebell, S. & King. M. A. (2011). Effects of azimuthal multipath asymmetry on long GPS coordinate time series. *GPS Solutions,* 11, 287 – 297. DOI:10.1007/s10291-011-0227-7.

Herring, T.A., King R.W. & McClusky S.C. (2010). Introduction to GAMIT/GLOBK Release 10.4, *Massachusetts Institute of Technology Internal Report*, USA, 48 pp. (http://www-gpsg.mit.edu/~simon/gtgk/Intro_GG.pdf).

King, M. A., Watson C. S. (2010). Long GPS coordinate time series: multipath and geometry effects. *J. Geophys. Res.,* 115(B44403) 1-23. DOI:10.1029/2009JB006543.

King, R.W., Herring T.A., McClusky S.C. (2010). *Documentation for the GAMIT GPS analysis software 10.4.* Massachusetts Institute of Technology Internal Report, USA. (http://www-gpsg.mit.edu/~simon/gtgk/GAMIT_Ref.pdf)

Kraus J. D. (1988). *Antennas, 892 pp., McGraw-Hill, New York.*

Larson, K. M., Small E. E., Gutmann E., Bilich A., Axelrad P. & Braun J. (2008). Using GPS multipath to measure soil moisture fluctuation: Initial results. *GPS Solutions,* 12, 173-177. DOI:10.1007/s10291-007-0076-6.

Penna, N. T., King M. A. & Stewart M. P. (2007). GPS height time series: Short-period origins of spurious long-period signals. *J. Geophys. Res.,* 112(B0202). DOI:10.1029/2005JB004047.

Ray, J., Altamimi A., Collilieux X. & van Dam T. (2007). Anomalous harmonics in the spectra od GPS position estimates. *GPS Solutions,* 12(1), 55 – 64. DOI:10.1007/s10291-007-0067-7.

Steigenberger, P., Tesmer V., Schmid R., Rothacher M., Rülke A., Fritsche M. & Dietrich R. (2009). Effects of different antenna phase center models on GPS-derived reference frame. Geodetic Reference Frames: IAG Symposium, 9 – 14 October 2006, Munich, Germany,edited by H. Drewes, New York: Springer.

Wessel, P. & Smith W. H. F. (1991). Free software helps map and display data, *EOS Trans*. AGU, 72, 441.

Analiza odchyłek liniowej kombinacji obserwacji fazowych GPS na stacjach ASG-EUPOS

Andrzej Araszkiewicz, Karolina Szafranek

Wojskowa Akademia Techniczna
Wydział Inżynierii Lądowej i Geodezji
Centrum Geomatyki Stosowanej
Gen. S. Kaliskiego 2, 00-908 Warszawa, Polska
email: aaraszkiewicz@wat.edu.pl; kszafranek@wat.edu.pl

Streszczenie

Monitorowanie permanentnych stacji GPS/GNSS, które tworzą układ współrzędnych stanowi integralną część pracy geodetów. Wybór takich stacji bazuje na analizie parametrów, które charakteryzują jej jakość (mi.in. sprzęt, stabilność współrzędnych, lokalizacja i montaż anteny). W przedstawionej pracy przeanalizowano jeden z nich – odchyłki obserwacji fazowych. Wartości tych różnic obliczono dla stacji EPN oraz ASG-EUPOS z rozwiązań dobowych. Dla większości z analizowanych stacji średnia kwadratowa otrzymanych odchyłek nie przekraczała 10 mm. Wartość ta oraz sam rozkład odchyłek nie zmieniał się znacząco przy różnych warunkach atmosfery. Na podstawie otrzymanych odchyłek fazowych przeanalizowano wpływ wielotorowości na tych stacjach. Modulacje wartości odchyłek na niskich kątach elewacji, których jednym ze źródeł jest efekt wielotorowości otrzymano zaledwie na kilku stacjach ASG-EUPOS. Taka sytuacja miała miejsce głównie dla stacji, których anteny zamontowane są na słupach. Wyniki pokazały, że podejście wykorzystujące analizę odchyłek liniowej kombinacji obserwacji fazowych jest dobrą metodą do oceny pracy stacji.