**The 9th International Conference "ENVIRONMENTAL ENGINEERING"**
22–23 May 2014, Vilnius, Lithuania
SELECTED PAPERS
eISSN 2029-7092 / eISBN 978-609-457-640-9
Available online at *http://enviro.vgtu.lt*

Section: Technologies of Geodesy and Cadastre

# The analysis of the selected data from Polish Active Geodetic Network stations with the view on creating a model of vertical crustal movements

Kamil Kowalczyk[a], Janusz Bogusz[b], Mariusz Figurski[c]

[a]*Faculty of Geodesy and Land Management, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland*
[b, c] *Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland*

**Abstract**

Up to now, the maps and models of the vertical crustal movements on the territory of Poland were created on the basis of data from 1st class precise levelling. Apart from levelling data, the vertical movements can be determined using satellite data. The present system of reference network has been operating in Poland for 6 years. It enables the determination of the model of vertical crustal movements on Polishterritory on the basis of satellite data. The high credibility of levelling data is evaluated by a number of control procedures and statistical evaluation before and after adjustment, as well as during the measurement activities. The type of stabilisation allows for certainty as well (secular points, buildings of a specific stability, ground survey markers, above ground survey markers). Reference stations, due to the fact that they require an open horizon, are located on high buildings. The choice is conditioned by a number of factors. Moreover, the very structure of a station may influence the final result. The specificity – advantage or disadvantage – of satellite measuring is a permanent observation of the height changes recorded by a reference stations. All changes are recorded, even the slight ones that are not related to the dynamic changes of the Earth's crust. The purpose of this article is to evaluate the measuring data, being the periodic (diurnal) changes of the height between the chosen stations of the ASG-EUPOS system. The evaluation was conducted with the use of statistical methods.

**Keywords:** ASG-EUPOS; vertical crustal movements; statistical tests.

## 1. Introduction

The maps and models of vertical crustal movements in the area of Poland have been so far developed on the basis of the data from precise first-order levelling. Height differencesbetween nodal points of two repeated levelling campaigns were used as data. In 2012, attempts were conducted to adjustthe data from three precise levelling campaigns [1]. On the basis of the tests [1], the precise levelling campaign from 1947–1955 was excluded from the preparations of the model of vertical crustal movements within the Polish territory. The determination of the model of the vertical crustal movements can be based not only on the levelling and tide gauge [2] data, but also on satellite data [3, 4, 5] and interferometry [6]. The combined data was used to create the European Vertical Reference System [7]. In order to unify the data to a common epoch the land uplift model NKG2005LU [8] was utilised. A combination of solutions was used in this model, as presented in [9, 10].

Having various time series and a dense network of permanent stations (~60 km), one can employ the movements calculated between the particular stations to determine the model of vertical crustal movements. On the basis of these movements, one can conduct the process of adjustmentof the network by assigning them properly chosen weight functions.

The above approach requires a well-prepared and reliable research material. Various periods when the stations are operational, external conditions and other unidentified factors influence the quality of the data [11].

The purpose of this article is to evaluate the measuring data from North-Eastern part of Poland (Fig. 1), being the periodic (diurnal) changes of ellipsoidal heights between the chosen stations of the ASG-EUPOS network. The evaluation was conducted with the use of statistical methods. Moreover, not adjusted vertical movement between the chosen station was determined with the use of linear trend. Their standard deviation was calculated and the results were analysed.

Corresponding author: Kamil Kowalczyk. E-mail address: kamil.kowalczyk@uwm.edu.pl
http://dx.doi.org/10.3846/enviro.2014.221

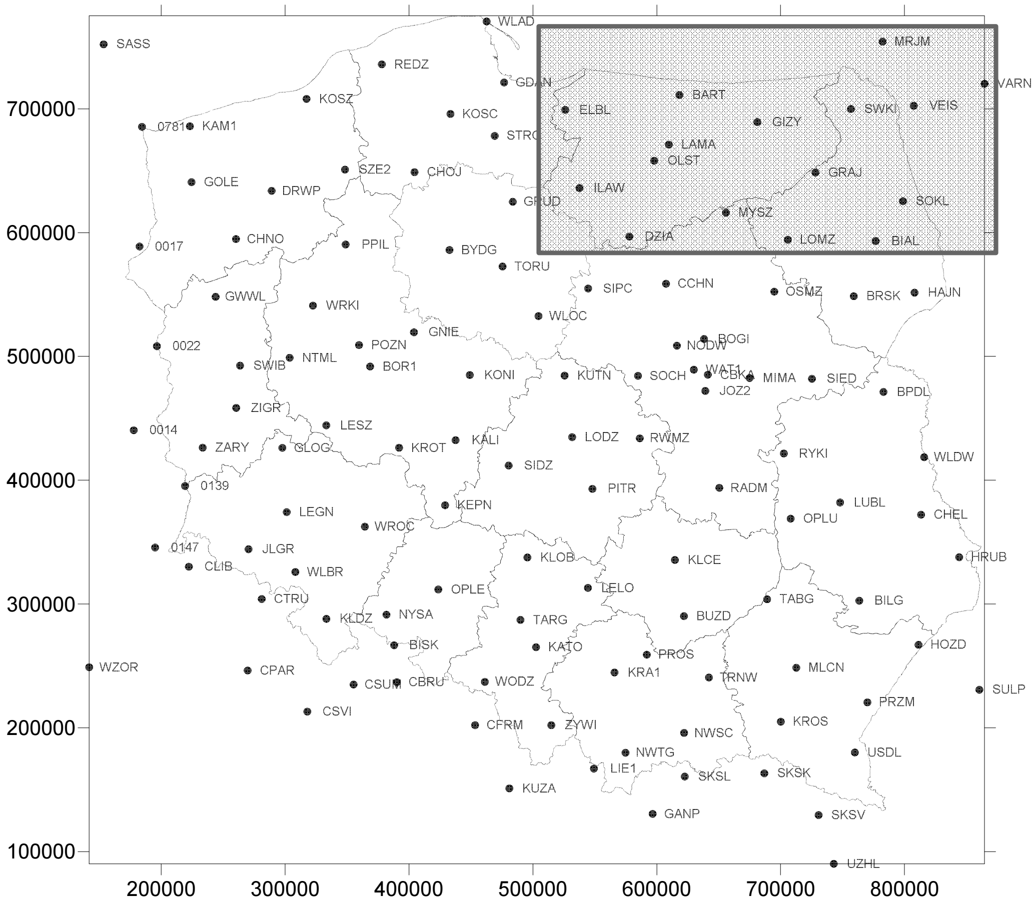



Fig. 1. Layout of ASG-EUPOS stationsin Poland (rectangle – analyzed area)

## 2. Research material

The research material consists of the diurnal height differences from 35 ASG-EUPOS stations determined in the Military University of Technology EPN Local Analysis Centre (MUT LAC) using Bernese 5.0 software [12]. The height differences were calculated between the stations of the neighbouring countries (Russia and Lithuania) as well. The connections of permanent stations for calculating the height differences were chosen with the use of Delaunay triangulation [13] (Fig. 2).

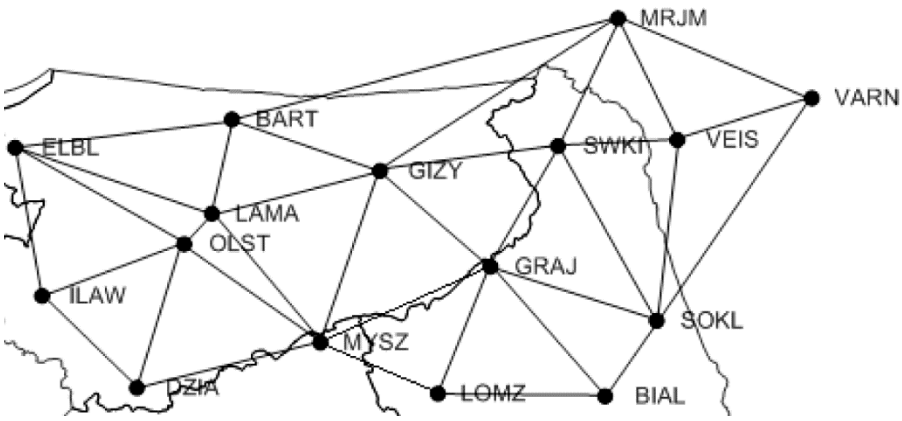
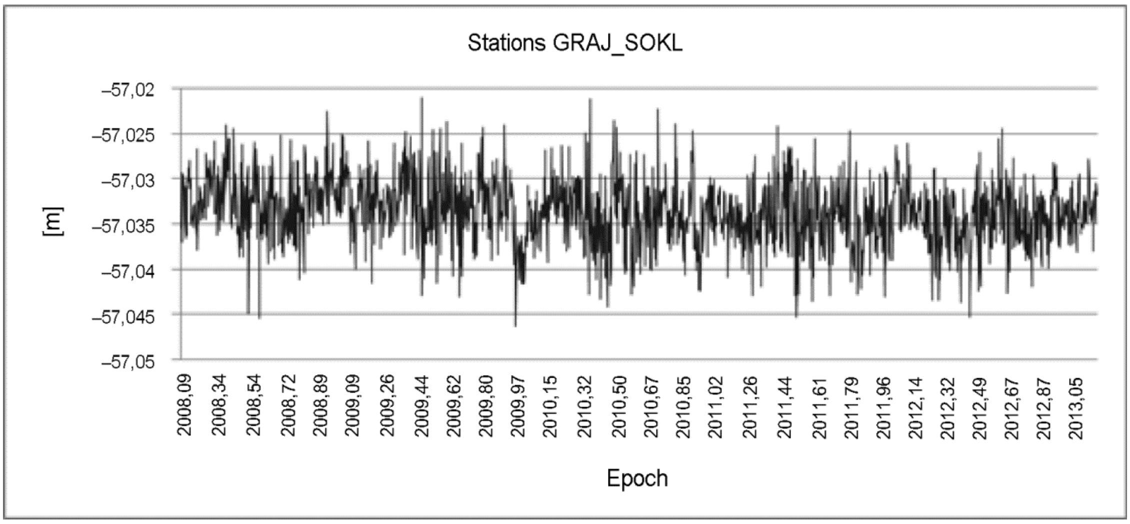
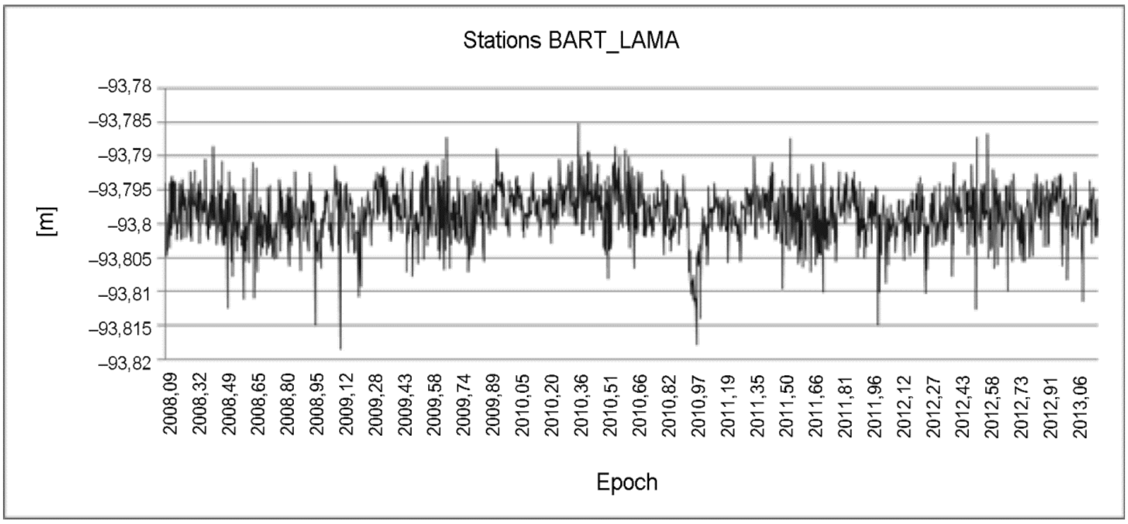



Fig. 2. The connections of the ASG-EUPOS stations with the use of Delaunay triangulation (North-Eastern part of Poland)

The calculated height differences were compiled in the files as time series (Fig. 3). Prior to the analysis, outliers influencing the standard deviation were eliminated from the research material using 3σ criterion. The data from the measurement epochs featured by major variations from the general characteristics of the series was eliminated.




a)




b)

Fig. 3. A sample of the data: the height differences between ASG EUPOS stations (stations: a) GRAJ_SOKLand b) BART_LAMA)

The research material was characterised by a large number of measurement epochs for each defined pair (vector) of permanent stations (Fig. 4).

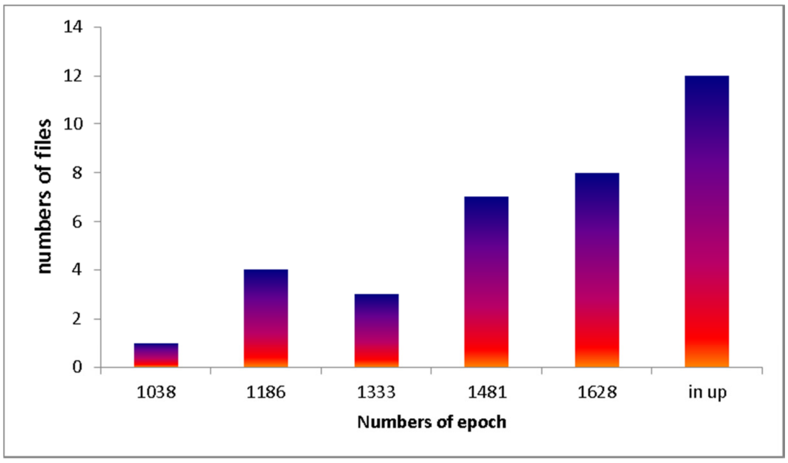



Fig. 4. The number of epochs in the particular pairs of ASG EUPOS stations

## 3. Statistical analyses and evaluation of the results

### *3.1. Standard deviation of the height differences*

A standard deviation of the sample was calculated for particular vectors. At first, the calculated standard deviation of the height differences at particular pairs (vectors) of permanent stations was analysed. In Fig. 5 the distribution of standard deviation for particular vectorsis presented.

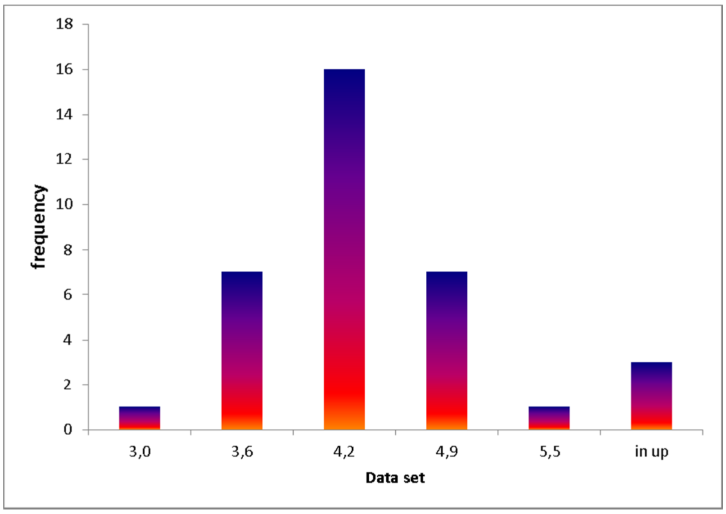
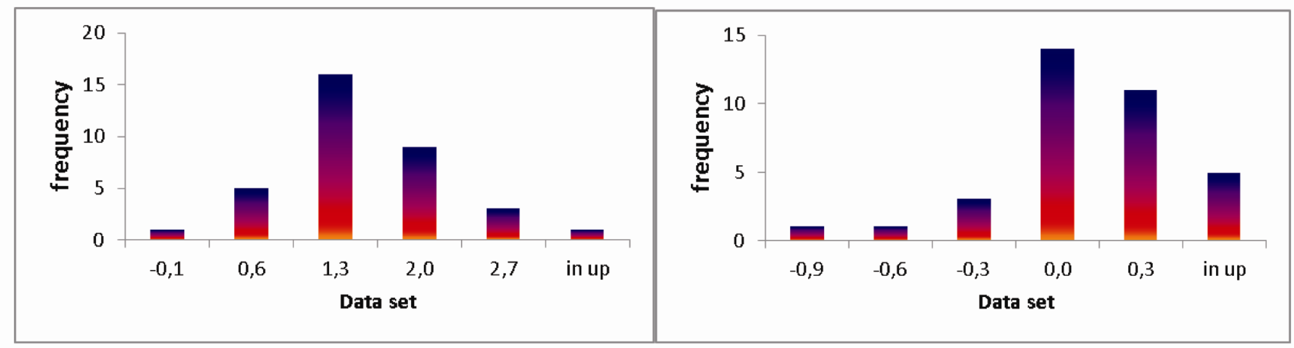



Fig. 5. Histogram of the standard deviation of height differences for particular vectors

The calculated standard deviations of height differences at vectors vary from 3.0mm to over 6.2 mm. In order to verify the evaluation of the compatibility of the above distribution of the standard deviation of height differences at vectors, the values of kurtosis (Fig. 6a) and skewness (Fig. 6b) were calculated.




(a) (b)

Fig. 6. Histograms of pressure kurtosis (a) and skewness (b)

Within the analysed set, the value of kurtosis is negative only in one case. The values are less concentrated than in the normal distribution. Skewness does not exceed 1.0 sets. The distributions of errors does not show any significant skewness.

### *3.2. Linear trend and the standard deviation of the trend*

The linear trend of the height changesintime was calculated at particular vectors. Alongside, the standard deviation of this trend was computed, as well as correlation coefficient of the data to the trend was determined. The obtained values of the standard deviation of the linear trend are presented in Fig. 7.

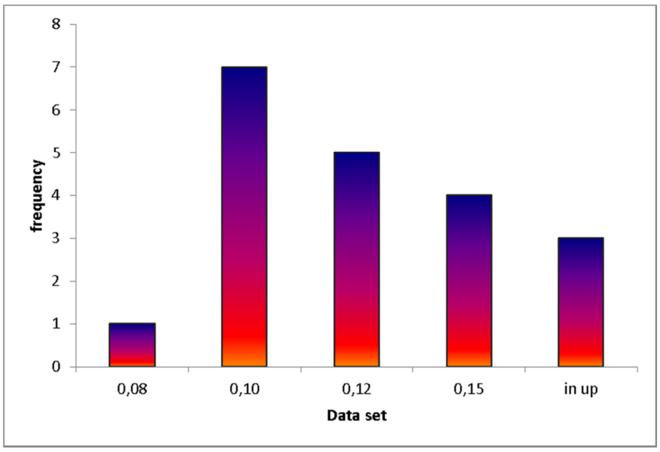



Fig. 7. Standard deviation [mm/y] of the trends at the vectors

### *3.3. Loop misclosures*

Another phase constituted the calculation of loops misclosure. Averagemisclosureis equal to ~0.3 mm/year, while maximum misclosureis equal to ~1.0 mm/year. The distribution of the loop misclosures is presented in Fig. 8.

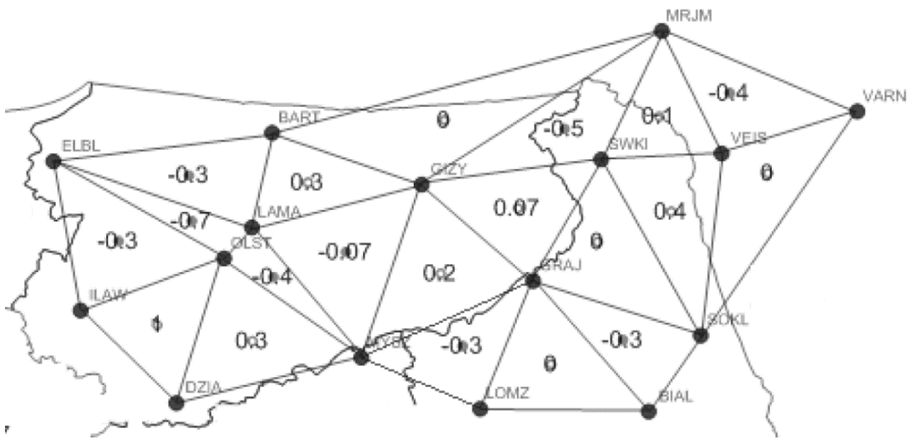



Fig. 8. Loops misclosure [mm/year]

## 4. Summary

The analysed material was heterogeneous. The researches aimed at the evaluation of its quality and at giving instructions to prepare material to create a model of vertical crustal movements in the area of Poland out of satellite data. The main criterion of the analysis was an a priori search for an answer to a question whether the analysed material (standard deviation) is consistent with the normal distribution. A number of statistical tools were used in order to achieve that. On the basis of the results of the calculations and analyses, one can claim that not the entire data at the chosen vectors has a symmetrical distribution of standard deviations. There are outliers within the sets (these were eliminated with the use of the 3σ criterion of post fit). Sudden, slight height changes were observed, the reason of which has not been established so far, at this stage of analysis.There are few deviations in loopsmisclosure.

## References

[1] Kowalczyk, K.; Rapiński, J. 2013. Evaluation of levelling data for use in vertical crustal movements model in Poland, *ActaGeodynamica et Geomaterialia* 10(3): 401–410. http://dx.doi.org/10.13168/AGG.2013.0039
[2] Sjöberg, L. E.; Fan, H. 1987. Experiences with the UNB land uplift modelling program using Swedish levelling and tide gauge data, *TritaGeod 1010*, Department of Geodesy, Royal Institute of Technology, Stockholm.
[3] Vestøl, O. 2007. Determination of Postglacial Land Uplift in Fennoscandia from Leveling, Tide-gauges and Continuous GPS Stations using Least Squares Collocation, *Journal of Geodesy* 80: 248–258. http://dx.doi.org/10.1007/s00190-006-0063-7
[4] Stępniak, K.; Baryła, R.; Wielgosz, P.; Kurpiński, G. 2013. Optimal data processing strategy in precise GPS leveling networks, *ActaGeodynamica et Geomaterialia* 10(4): 443–452. http://dx.doi.org/10.13168/AGG.2013.0044
[5] Kontny, B.; Bogusz, J. 2012. Models of vertical movements of the Earth crust surface in the area of Poland derived from leveling and GNSS data, *ActaGeodynamica et Geomaterialia* 9(3): 331–337.
[6] Heki, K. 1996. Horizontal and vertical ceustal movements from three-dimensional very long baseline interferometry kinematic reference frame: Implication for the reversal timescale revision, *Journal of Geophisical research* 101(B2): 3187–3198.

[7] Sacher, M.; Liebsch, G.; Ihde, J.; Mäkinen, J. 2008. EVRF07 as Realization of the European Vertical Reference System Presented, *in the Symposium of the IAG Sub-commission for Europe (EUREF) in Brussels, June 18–21, 2008.* Submitted to the proceedings.
[8] Ågren, J.; Svensson, R. 2007. Postglacial Land Uplift Model and System Definition for the New Swedish Height System RH 2000, *LMV-Rapport 2007* 4: 124. Gävle.
[9] Vestøl, O. 2005. Land uplift model, *Documentation – An empirical model based on levelling, tide gauges and GPS-rates*. January 2005.
[10] Lambeck, K.; Smither, C.; Ekman, M. 1998. Test of glacial rebound models for Fennoscandia based on instrumented sea- and lake-level records, *Geophys. J. Int*. 135: 375–387. http://dx.doi.org/10.1046/j.1365-246X.1998.00643.x
[11] Bogusz, J.; Figursk, I. M.; Kroszczyński, K.; Szafranek, K. 2011. Investigation of environmental influences to the precise GNNS solutions, *ActaGeodynamica et Geomaterialia* 81 (1): 5–15.
[12] Dach, R.; Hugentobler, U.; Fridez, S.; Meindl, M. (Eds.) 2007. *Bernese GPS software version 5.0*, Astonomical Institute, the University of Bern.
[13] Delaunay, B. 1934. Sur la sphere vide, *IzvestiaAkademiiNauk SSSR, Otdelenie Matematicheskikh I Estestvennykh Nauk* 7: 793–800.