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Adjustment of vertical crustal movement network on the basis of last three leveling campaigns in Poland

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Abstract. On the base of leveling data, three maps of vertical crustal movements were developed (Wyrzykowski, 1971; Wyrzykowski, 1985a; Kowalczyk, 2006a). Also two maps of vertical crustal movements were created (Wyrzykowski 1990, Kowalczyk, Rapiński 2011). In the above mentioned elaborations, the vertical crustal movements were calculated from two subsequent first order leveling campaigns. To include more data, results of all four leveling campaigns in Poland were accumulated and digitalized. One, unified database was developed on the basis of collected and unified data set of unadjusted observations (Kowalczyk, Bednarczyk, 2009; Kowalczyk, Bednarczyk, Kowalczyk, 2011). First trials of common use of three first order leveling campaigns were performed in 2008 (Kowalczyk, 2008). Though the available leveling data was not complete. The goal of this paper is to describe a trial of common adjustment of relative vertical crustal movements on the basis of three first order leveling campaigns in Poland.

1 Introduction

In the territory of Poland, first vertical crustal movements were calculated in late fifties. This work resulted with three maps of vertical crustal movements speed (Wyrzykowski 1971, Wyrzykowski 1985a, Kowalczyk 2006a). For the first elaboration of vertical crustal movements in Poland in 1960, common leveling lines from 1952-1958 (I and II order) and 1926 – 1937 (Ist order) were used. These lines did not create closed loops (Niewiarowski and Wyrzykowski

1961). The method used for the vertical crustal movement speed determination was based on comparison of heights of two common points of two adjusted networks in reference to the same point. The height of reference point was assumed to be zero (Niewiarowski and Wyrzykowski, 1961).

Second and third determination of vertical crustal movements were based on larger data set, different methods of vertical speed calculations were used. Detailed description of these elaborations can be found in (Kowalczyk, 2006b).

Maps mentioned in the above paragraph were created as analog maps and mathematical model (Kowalczyk, 2006b). Vertical crustal movements in the territory of Poland were depicted as isolines. Another way to depict these movements is a map of gradients calculated for each line with regard to it's direction. So far two maps of vertical crustal movements speed gradients were developed in Poland (Wyrzykowski, 1990; Kowalczyk and Rapiński, 2011).

After compare of each elaboration, the non-uniform character of data was observed. There was a variety of instruments used, reference points, corrections etc. (Kowalczyk 2006b), therefore leveling data was collected and unified. To complete this task one common database for all three leveling campaigns was designed and developed. (Kowalczyk Bednarczyk 2009, Kowalczyk Bednarczyk Kowalczyk 2011). First trials of common use of three first order leveling campaigns were performed in 2008 (Kowalczyk 2008). Though the available leveling data was not complete. The goal of this paper is to describe a trial of common adjustment of relative vertical crustal movements on the basis of three first order leveling campaigns in Poland.

1.1 Brief history of leveling campaigns in Poland

Data from four first order leveling campaigns are available in Poland. First campaign was performed from 1926 to 1937, second from 1953 to 1958, third from 1974 to 1982 and fourth 1997 to 2003. Data from campaigns first and second are stored as paper catalogs. Data from third campaign is in the form of paper catalog and ASCII

Table 1. *Characteristics of leveling campaigns in Poland (Wyrzykowski, 1988; Łyszkowicz and Leonczyk 2005)*

	Campaigns			
	1	2	3	4
Campaign epoch	1926-1937	1953-1958	1974-1982	1997-2003
Total line length [km]	10 046	10 200	17 015	17 516.42
Number of lines	121	116	371	382
Number of sections	5 907	8 820	15 827	16 150
Number of loops	36	23	135	138
Corrections	Scale, normal ortometrhic	Scale, normal Molodenski	Scale, thermic, lunisolar, normal Molodenski	Calibration, thermic, normal Molodenski, lunisolar
Reference level	Normall-Null	Kronstadt	Kronstadt	Kronstadt
Gravimetric system	—	Potsdam	Potsdam	Potsdam
Accuracy	±1.04	± 0.78	± 0.84	± 0.88

text files. Latest, fourth campaign is stored as a digital database. Characteristics of each campaign is presented in Table 1.

1.2 Types of vertical crustal movements

There is more then one definition of the vertical crustal movements. The simplest definition is that if a certain benchmark is stable (it's height in time is constant), then the vertical movements derived in the reference to this point it is called a relative movement. If this movement is derived in reference to the mean sea level, then it is a "observed" movement (Kakkuri, 1987):

$$v_0 = v_r + v_m \tag{1}$$

where: v_m - tide gauges vertical movement, v_r - relative movement.

If eustatic movements will be included in the model, the movement is called "leveling movements"

$$v = v_0 + v_e \tag{2}$$

where: v_e - eustatic movement. In the Baltic sea basin, expected eustatic movement varies from 0.8 to 1.1 mm/y (Ekman, 1986; Lisitzin 1974).

Including the geoid change in time one will obtain the "absolute movement" The geoid change rate is about ten times smaller then the relative movement (Sjőberg 1982):

$$v = v_0 + v_e \quad (3)$$

where: v_g - geoid change.

1.3 Historical vertical movement models

First attempt to determine the vertical crustal movements in Poland was in the late fifties. It resulted in two maps of vertical crustal movements (Wyrzykowski, 1971, 1985). First order leveling data from first (1926-1937) and second (1952 - 1958) campaigns were used for the first map, and data from second and third (1974-1982) campaign for second map.

First model was developed with approximate method in 1971 (Fig. 1). The difference between adjusted heights of nodal benchmarks from two campaigns was divided by the time span resulting in approximate vertical movement. The map was plotted manually with linear interpolation of vertical movements. The first class benchmark in Toruń was taken as a reference "zero" point.

Second model was finished in 1985 (Fig. 2.) (Wyrzykowski 1985). The model was derived in two steps. In the first step relative vertical movements were calculated from the leveling data corrected with comparation correction. In the second step the vertical crustal movements network was adjusted with fixed tide gauges in Świnoujście , Kołobrzeg , Ustka , Łeba , Władysławowo , Hel and Gdansk. As for the first map, the linear interpolation was used in the plotting process.

In 2006 the new vertical crustal movements map (Fig. 3.) was created with use of modern technology (Kowalczyk 2006a). Data from third (1974-1982) and fourth leveling campaign (1999-2003) was used. Raw leveling data was used to perform the vertical crustal

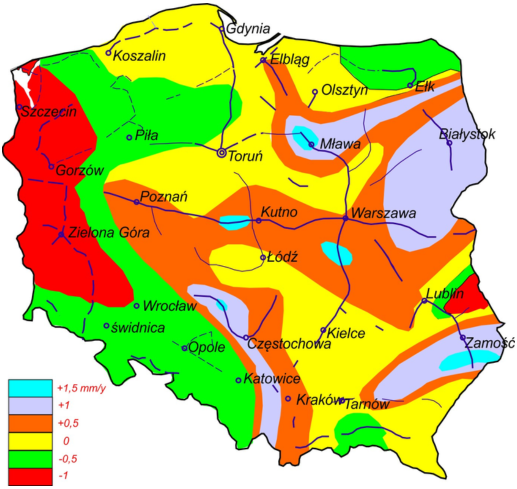

Figure 1. *First model vertical crustal movements in Poland (1971)*

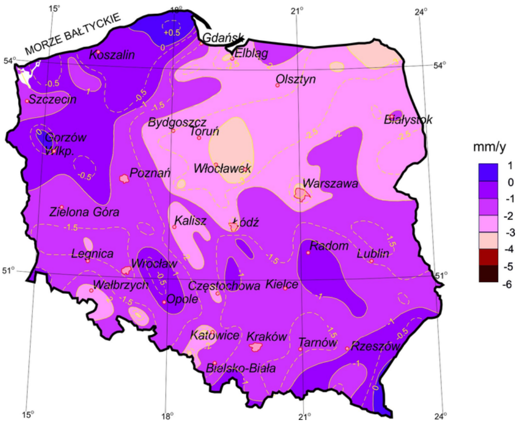

Figure 2. *Second model vertical crustal movements in Poland (1985)*

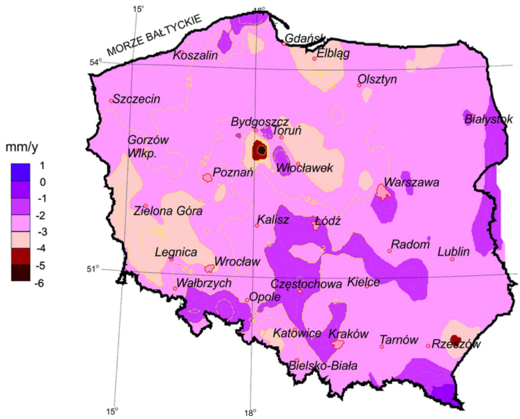

Figure 3. *Third model vertical crustal movements in Poland (2006)*

movements network adjustment. The adjustment was referenced to the Władysławowo tide gauge. Detailed description of this model can be found in Kowalczyk 2006a, Kowalczyk 2006b. To interpolate the movements, collocation method with Hirvonen function was used (Kowalczyk, 2006c). In 2010 different methods of interpolation of vertical crustal movements were compared (Kowalczyk, Rapiński and Mróz, 2010).

2 Data processing

2.1 Data preparation

In order to properly adjust the vertical crustal movements network, data from four campaigns had to be unified. Data from fourth campaign was stored in the Microsoft Access database. This data was imported into Microsoft Excel data sheet. Data from third campaign was stored in 376 ASCII text files. This data was also imported to Excel. Data from third and fourth campaigns was relatively easy to obtain and unify.

Data from first and second campaign, was stored in the archives as paper documentation. Until 1992 this archives were classified confidential. This documentation consists of typewrite catalogs of adjusted benchmark heights (this were available before 1992), handwrite paper calculation sheets, survey reports. First campaign contained 292 pages, second 568 pages. This data was digitalized in two steps:

Typewrite data was scanned and processed with OCR (Optical Character Recognition) software. This data was updated with unadjusted height differences.

Handwrite catalogs were rewritten into Microsoft Excel manually.

2.2 Identification of common benchmarks

Since the ID of benchmarks was not unified between campaigns, the unification had to be done manually. Between first and second campaign 137 common benchmarks were identified, 43 nodal points between second and third (with 2600 benchmarks). Between third and fourth campaign 235 common nodal points were identified (with 11000 benchmarks). The identification process was performed on the basis of point description, point number, pommel number, pommel type, number in line, geodetic coordinates.

2.3 Adjustment

Unification of data from all four leveling campaigns allowed to automatically readjust the vertical crustal movements network in Poland. Adjustment was performed in three scenarios:

- vertical crustal movements between campaigns two and three,
- vertical crustal movements between campaigns three and four,
- common adjustment of campaigns two, three and four.

Data from first campaign was neglected in the adjustment. The data from years 1929 - 1936 was very modest. Moreover, the borders of Poland changed after the second world war. Therefore first campaign does not overlap with second, third and fourth. Considering the equipment used in first campaign and various corrections applied to observations the first campaign was abandoned. It could be useful if data from former territory of Germany and Austro - Hungarian would be available. Also, in the first campaign, there is a lot of data from the current territory of Russia, Lithuania, Belarus and Ukraine.

In each scenario raw, unadjusted height differences were used to calculate the vertical movements. This were then adjusted using least squares method to obtain the vertical crustal movements network. Each observation used in the adjustment was calculated using the following formula:

$$v_i = \frac{\Delta h_{ij}}{\Delta T_{ij}} \tag{4}$$

where: v_i - vertical movement of the line, h_i, h_j - height difference in epoch i and j, ΔT- difference between epochs i and j expressed in decimal years.

The errors used for weighting the observations were calculated with assumption that the height differences are uncorrelated:

$$m_{v_i} = \sqrt{\frac{2L^2}{\Delta T_{ij}^2}} \tag{5}$$

where: L - line length in km, T - survey epoch in years, h - unadjusted height difference between start and end of leveling line, 0.5 - assumed maximum error of vertical movement.

3 Results

The network was adjusted using SNAP (Survey Network Adjustment Program) version 2.3.44 developed by Land Information New Zealand. Vertical velocities on leveling lines were adjusted. Resulting velocities for each point are relative to one fixed point. Fixed point was chosen in the central Poland and is common for all three leveling campaigns. The adjustment was performed in three scenarios. In these scenarios data from second and third, third and fourth, second and third and fourth campaigns was used

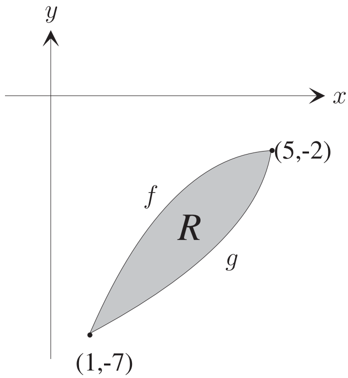

Figure 4. *Residuals of adjusted vertical crustal movements. a) scenario 2 and 3; b) scenario 3 and 4; c) scenario 2 and 3 and 4*

respectively. Total number of observations was 447, from which only 99 observations were from second – third campaigns.

3.1 Vertical movements in nodal points

Figure 4 depicts residuals of adjusted vertical crustal movements.

Analyzing Figure 4, it is clear that the largest value of residuals were obtained for the scenario 2-3 in the west and south part of Poland. In the remaining two scenarios large residuals exist rare in various places. Mean error of relative vertical crustal movements were:

- scenario 23 mean error at each point was smaller then 0.17 mm/year
- scenario 34 mean error at each point was smaller then 0.10 mm/year
- scenario 234 mean error at each point was smaller then 0.10 mm/year

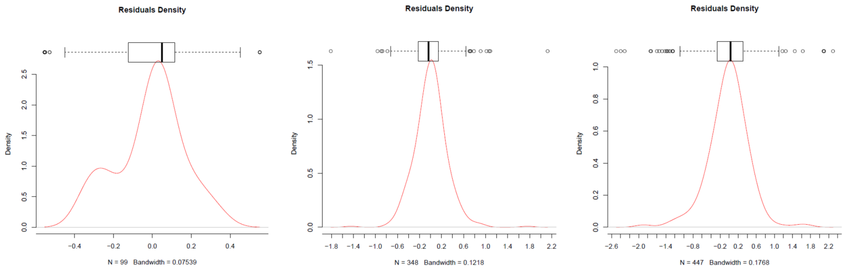

Figure 5. *Residual density distribution*

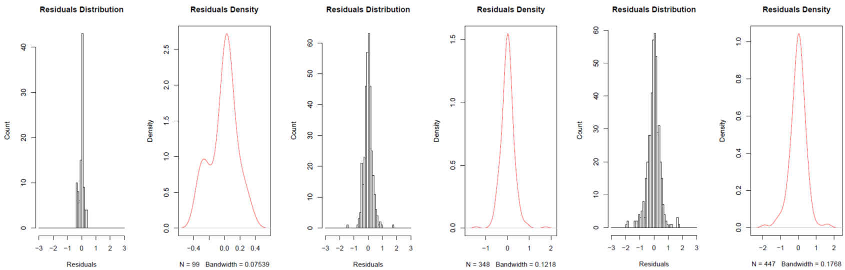

Figure 6. *Residual density plots and histograms*

3.2 Analysis of residuals distribution

Vertical velocities on each line between nodal points of leveling network were adjusted. Figure 5 depicts residuals distribution as a box plot along with corresponding density function.

Figure 5 shows a close to normal distribution in case of 2-3 and 2-3-4 scenarios. Only few points do not fulfill the criterion of triple mean error. The distribution of 2-3 is skewed, the criterion of triple mean error is not fulfilled by even less residuals.

To depict the residuals distribution histograms alongside with density plots are depicted in Figure 6.

4 Conclusions

Collected data form last three campaigns of first order leveling allowed common adjustment of vertical crustal movement velocities in the territory of Poland. The differences of unadjusted height differences between points from subsequent campaigns were used. Reference point was fixed in the center of Poland. Obtained values are relative movements. The adjustment was performed in three scenarios: using data from 2-3, 3-4 and 2-3-4 campaigns. Performed adjustment is a preliminary elaboration. Work on the adjustment will be continued. The main problem in data unification was identification of common points in all campaigns.

On the basis of performed adjustment, preliminary assessment of residual distribution and obtained mean errors it can be claimed that common adjustment of vertical movement velocities on the basis of three leveling campaigns is possible. The value of residuals must be investigated more in order to verify reasons for large residuals.

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