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CHANGING THE NATIONAL HEIGHT SYSTEM AND GEOID MODEL IN LATVIA

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Abstract. According to the decision of IAG Reference Frame Sub-commission for Europe (EUREF) the EVRF2007 solution as the vertical reference has to be deployed in EU countries.The new height system *LAS-2000,5* had been enacted as the European Vertical Reference System's *EVRF2007* realization in Latvia and the new geoid model LV'14 had been introduced by Latvian authority Latvian Geospatial Information Agency. However, the appreciation of the quality of quasi-geoid model LV'14 is rather contradictious among the users in Latvia. The independent estimate and comparison of the two Latvian geoid models developed till now has been performed by the Institute of Geodesy and Geoinformatics. Previous geoid model LV98 which was developed for *Baltic-1977* height system almost 20 years ago is outdated now. Preparatory actions described in order to fulfil the task of comparison the geoids in two different height systems. The equations and transformation parameters are presented in this article for the normal height conversion from *Baltic-1977* height system to the Latvian realization named *LAS-2000,5*. The comparison is performed of both Latvian quasi-geoid models – the new one LV'14 and previous LV98. The quality of both models estimated by controlling the geoid heights at the properly densified GNSS/levelling network sites. The distribution of discrepancies in comparison with normal distribution $N(x,\mu,\sigma)$ is depicted in corresponding figures. For LV'14 quasi-geoid model the standard deviation of discrepancies is 3.2 cm, 75% of discrepancies $x \le 3.2$ cm. For LV98 quasi-geoid model the standard deviation of discrepancies is 4.7 cm, 80% of discrepancies $x \le 6$ cm. Without doubt, the newly developed LV'14 quasi-geoid model is of higher quality.

Keywords: quasi-geoid determination, EVRF2007, LV'14, LV98, GPS/levelling network densification, ETRS89.

Introduction

The IAG Reference Frame Sub-commission for Europe (EUREF) has adopted the EVRF2007 solution as the vertical reference for pan-European geo-information (EVRF2007 2008). The implementation of this height system is under development in many countries (Sacher, Liebsch 2015). "New set of transformation parameters (to compute the normal heights from Baltic Height System to EVRF2007) was estimated in Estonia" (Kollo *et al.* 2015). "In August 20, 2014 Lithuania government issued the Decision No 791 to introduce in Lithuania new height system LAS07. The new height system coincides with European Vertical Reference Frame 2007" (Paršeliūnas *et al.* 2015).

Since December 1, 2014 a new height system *LAS-2000,5* had been enacted by Latvian Geospatial Information Agency (LGIA) as an *EVRF2007* realization in Latvia (Aleksejenko 2014; Liepins 2015; Liepiņš 2015). According to the EUREF Resolution (*EUREF2007*, 2008) the levelling data of epoch 2000.0 have to be used for the *EVRF2007* national realizations. The Latvian first order levelling was carried out in time span 2000–2011 and, consequently, the Latvian national levelling network had been aligned to the epoch 2000.5

(Aleksejenko 2014; Liepiņš 2015). The request to modify the national geoid model arisen as well and the new quasi-geoid model LV'14 had been developed by LGIA (Liepiņš 2015) which is used in surveying now instead of previous geoid model LV98. Currently, the development of the Baltic Rail Project in Latvia is in progress at a stage of the rail trace planning and placement dispute (Rail Baltic 2014). The land surveying and topographic mapping activities for railroad construction in Latvia will commence soon. GNSS applied measuring and navigation technologies are crucial for all of the engineering processes and therefore the need for high quality quasi-geoid model is very important. Up to now the appreciation of the quality of quasi-geoid model LV'14 is rather contradictious among the users (Vallis *et al.* 2015). Obviously, any quality estimation and improvements applied now are beneficial for various future applications.

1. Densification of the GNSS/levelling network for geoid control

High precision homogeneous GNSS/levelling network is required in order to achieve the reliable geoid fitting, testing and control quality. The attempt to develop such a network has been performed at the Institute of Geodesy and Geoinformatics (GGI) for the control of the mentioned above Latvian geoid models. The GNSS careful static measurement 4 hour sessions were carried out in order to significantly densify the GNSS/levelling network for test area of Eastern part of Latvia covering Latgale, Vidzeme and partly Zemgale regions. The measurements were performed at the 114 benchmarks of the first order levelling network and at the 40 sites of the second order levelling network. Ellipsoidal heights of both the current day measured GNSS/levelling point(s) and LatPos network stations (Zvirgzds 2005) were computed in ITRF08 system using Bernese 5.2 software (Dach *et al.* 2007) and IGS/EPN reference network data. In order to avoid both the GNSS measuring discrepancies and national network's local deformations on the current day the results of LatPos station coordinates are used for Helmert transformation parameter determination for the measured in corresponding date GNSS/levelling point coordinate transformation ETRS89 of fixed epoch 2015.0, similarly, like it is applied in RTK survrying in Latvian LKS92 coordinate system.

Additionally, for 120 sites the measuring results were obtained from LGIA. Those GNSS measurements were performed in time span 2010–2014 and the results in LKS-92 framework were computed. However, the difference between LatPos station coordinates in ETRS89 and LKS92 frameworks correspondingly has achieved the notable values (Balodis *et al.* 2015; Kenyeres *et al.* 2015a, 2015b). In order to avoid discrepancies all the LGIA performed GNSS measuring results are reduced to the ETRS89 to date 2015.0. Therefore the total number of GNSS/levelling points increased up to 274 points with an average space between the GPS/levelling points of about 10 km.

2. Transformation parameters of the geoid in *BAS-77* height system to *LAS-2000,5*

The Baltic height system *BAS-77* (in Latvian) was used in Latvia till December 1, 2014. *BAS-77* was introduced in former Soviet Union. The transformation formula (1) for a height H_B of the single point (ϕ, λ, H_B) to height H_L in the new Latvian height system *LAS-2000,5* and set of values of transformation parameters $\{\phi_0, \lambda_0, a_1, a_2, a_3\}$ is given by M. Kaļinka (Kaļinka 2015):

$$H_L = H_B + a_1 + a_2 M_0 \left(\phi - \phi_0\right) + a_3 N_0 \left(\lambda - \lambda_0\right)\cos\phi, \quad (1)$$

where

$P_0\left(\phi_0 \lambda_0\right)$ – origin for the height transformation in Latvia with geodetic latitude and longitude of GRS80 ellipsoid;

ϕ_0 = 56° 58' 0.0000", in radians 0.994 255 897;

λ_0 = 24° 53' 0.0000", in radians 0.434 296 096;

a_1 = 1.4 9392 900 367 864 E^{-1} m (displacement in vertical direction);

a_2 = 7.99 066 182 789 555 E–8 m (displacement along meridian);

a_3 = – 9.48 289 473 646 151 m (displacement along prime vertical);

N_0 – the radius of curvature of the prime vertical for the point P_0;

M_0 – the radius of curvature in the meridian for the point P_0.

The geodetic coordinate values ϕ, λ in Equation (1) are used in radians.

The formulas for M_0 and N_0 can be found in other sources, for example (Clych 2006):

$$N_0 = \frac{a}{\sqrt{\left(1 - e^2 \sin^2 \phi_0\right)}}, \quad (2)$$

$$M_0 = \frac{N_0\left(1 - e^2\right)}{1 - e^2 \sin^2 \phi_0}, \quad (3)$$

wher a – semimajor axis of GRS80 ellipsoid, e – eccentricity.

The Equation (1) is modified in order to make the transformation of the geoid model LV98 from height system *BAS-77* to height system *LAS-2000,5.*

$$G_L = G_B - a_1 - a_2 M_0 \left(\phi - \phi_0\right) - a_3 N_0 \left(\lambda - \lambda_0\right)\cos\phi, \quad (4)$$

where geoid height $G_B \in$ *BAS-77* system and height $G_L \in$ *LAS-2000,5* system.

3. Comparison of geoid models LV 98 and LV'14

The geoid model LV98 was developed by Dr Janis Kaminskis (Kaminskis 2010) and this geoid model had been used by Latvian land surveyors and geodesists since 1998. The quasi-geoid model LV'14 has been developed by LGIA (Liepiņš 2015) recently and it is used in Latvia now. The data from the EGM2008 global geopotential model was used as a framework for LV'14 quasi-geoid modelling while the data from the EGM96 global geopotential model was used for LV98 quasi-geoid modelling. The LV98 model was developed on the basis of digitized gravity anomalies from Soviet gravity maps while LV'14 developed on the basis of real gravity measurements performed by LGIA personnel.

The height values from LV98 quasi-geoid grid file in *BAS-77* height system were converted into *LAS-2000,5* system using Equation (4) in order to make available the comparison with LV'14. The comparison results of both models is depicted in Figure 1.

Then the measured results of 272 (2 points were excluded due to outliers) GNSS/levelling control points were applied for comparison of normal height values resulted from both geoid models. Unfortunately, the area of this data set cover just Eastern part of Latvia. It doesn't cover the Western part of Latvia.

The control of the LV'14 model was performed by comparing the normal heights obtained from LV'14 model at the 272 sites of the set of GNSS/levelling points of *ETRS89* at epoch 2015.0 mentioned above. Obtained normal height values compared with normal heights in *LAS-2000.5* catalogue. The distribution of discrepancies in comparison with normal distribution $N(x, \mu, \sigma)$ is depicted in Figure 2. The standard deviation of discrepancies is 3.2 cm, 75% of discrepancies $x \leq 3.2$ cm. Skewness is normally distributed (0.003), kurtosis 3.9 tells on the height and sharpness of the relative to that of a standard bell curve.

The control of the LV98 model was performed by comparing the normal heights at the same 274 sites of GNSS/levelling points and compared with normal heights from *LAS-2000,5* catalogue as well. The distribution of discrepancies in comparison with normal distribution $N(x, \mu, \sigma)$ is depicted in Figure 3. The standard deviation of discrepancies is 4.7 cm, 80% of discrepancies $x \leq 6$ cm. Skewness is almost normally distributed (–0.15), kurtosis 2.5.

Conclusion

The formula for normal height conversion from Soviet time system *BAS-77* to *EVRF2007* system realization in Latvia named *LAS-2000,5* is presented.

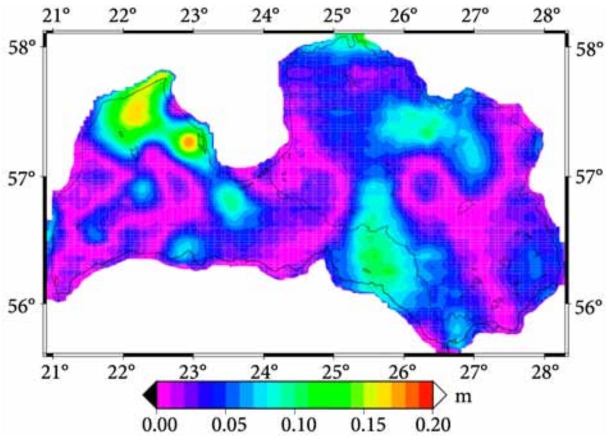

Fig. 1. Results of comparison of LV98 and LV'14 models (m)

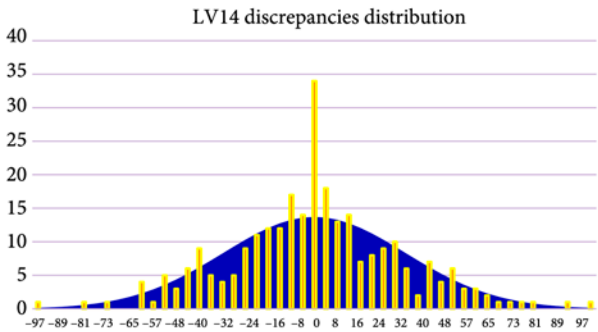

Fig. 2. The distribution histogram of the discrepancies of LV'14 (mm) and normality plot

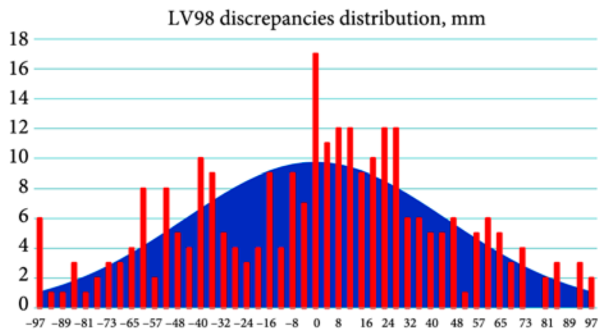

Fig. 3. The distribution histogram of the discrepancies of LV98 and normality plot from *LAS-2000.5* (mm)

Implicitly, the LV'14 quasi-geoid model is of higher quality than LV98. LV'14 has been developed 20 years after the LV98 on the basis of more advanced gravity measuring data and probably, of larger set and higher quality GNSS/levelling data.

The standard deviation of LV'14 in current research appears ±3.2 cm comparing with ±4.7 cm of LV98 where the shift of the error distribution plot is observed as well..

For LV'14 the discrepancies of 59% resulted ≤ 2 cm, 75% resulted ≤ 3.2 cm, 97% resulted ≤ 6 cm, while for LV98 38% resulted ≤ 2 cm, 54% resulted ≤ 3.2 cm, 82% resulted ≤ 6 cm.

Probably, the LGIA authors of LV14 quasigeoid model will improve the precision in near future by densifying and improving precision of the applied set of fitting points. Actually, the number of fitting points in test area for LV'14 were applied 3 times less comparing with current set of 274 control points.

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