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ON THE GEODYNAMICS IN LATVIA

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ABSTRACT

This paper discusses the research work done in Institute of Geodesy and Geoinformation, University of Latvia, and Department of Geomatics, Riga Technical Univesity, devoted to the geodynamics in Latvia: national geoid model computation, using different methods and data sets, in order to improve its precision; analysis of LatPos and EUPOS®-Riga GNSS permanent station observation data time series for time period of 5 years; development of digital zenith camera for vertical deflection determination.

1. INTRODUCTION

The coming Galileo and current GOCE achievements are highly promising for broadening the applications of GNSS technologies and various studies of environment using precise point positioning static and real time kinematic methods. For high precision normal height determination purposes more requirements for detailed geoid model are arising.

The work on European Space Agency project "EUPOS® contribution to GOCE mission" (Id: 4307) at the Institute of Geodesy and Geoinformation is continuing since 2010. During the last years the research was devoted to several issues related to the geodynamics in Latvia:

- attempts to improve the precision of the national geoid model using different input data, different global and regional Earth gravity field models and 2 different software packages. Geoid height reference surface for Latvia of the precision of RMS 1.6 cm was obtained;
- the analysis of the GNSS permanent station observation data time series and station displacements affected by Earth tides for period of 5 years;
- the success of development of digital zenith camera for vertical deflection determination and application for geoid model improvement.

2. NATIONAL GEOID MODEL

The current precision of LV'98 - the gravimetric geoid model of Latvia reaches 6-8 cm. The model was created by Dr. J. Kaminskis with the use of digitised gravimetric measurement data available on USSR era maps and the method used in the software developed in Denmark - GRAVSOFT. 15 years have passed since the creation of LV'98 and there is a necessity for a more accurate geoid model to enable a prompt determination of normal height with the use of GNSS coordinate determination methods.

The results of recent research on Earth's gravitational field conducted by NASA and ESA have yielded new models of Earth's global gravity field. Both the data from gravity satellite missions (GRACE, GOCE etc.) as well as data from the gravimetric measurement performed on Earth's surface have been used for creation of national geoid models. A significant contribution to the performance of gravimetric measurements have been provided by the Latvian Geospatial Information Agency (LGIA), nevertheless a significant amount of further measurements is required and geoid improvements at LGIA have not yet been implemented.

In this study two geoid computation methods were used for national geoid model computation – KTH method and DFHRS method.

The geoid calculation method by KTH was developed at the Royal Institute of Technology (KTH) in Stockholm and it is based on a modified version of Stoke's formula [14, 15, 16, 17].

The objective of this work was to calculate the geoid model for the territory of Latvia and Riga region using the KTH method and available garvimetric data and most recent and reliable Global Geopotential Model (GGM) data. Firstly experimental gravimetric geoid computations were made using digitised free air anomaly data from the USSR era and data from EGM2008 - global Earth's gravitational field model. Second part of work was done using recent gravimetric measurements of Latvian Geospatial Information Agency for the region of Riga and EGM2008 data as well as data from GO_CONS_GCF_2_DIR_R4 - Earth's gravitational field model obtained by GOCE satellite [3]. The obtained geoid models were then compared with Latvian gravimetric geoid model LV'98 [8]. Appropriate transformation was applied to the Riga region geoid models because the global geopotential models are not fitted to the national height system.

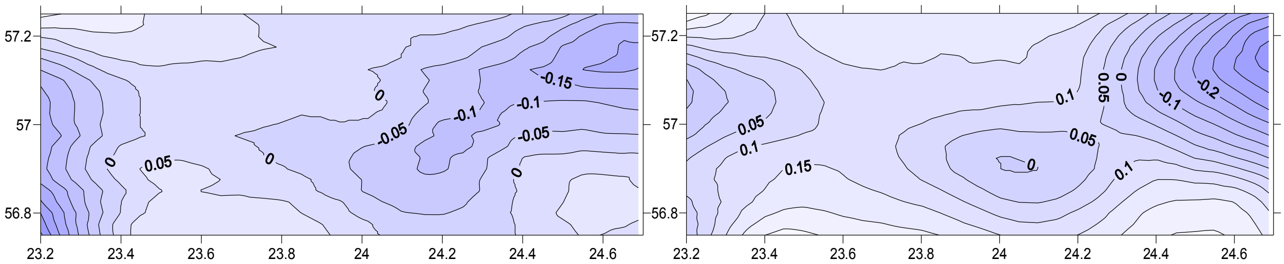


Figure 1. LV'98 and KTH GO_CONS_GCF_2_DIR_R geoid height comparison (left) and LV'98 and KTH EGM2008 geoid height comparison for solutions in the region of Riga (right) [m]

Several versions of Latvian geoid model were computed with different maximum spherical harmonics degrees of the GGM coefficients and spherical integration radius values using digitised free air anomaly data from the USSR era and data from EGM2008 by KTH-Geolab software. To evaluate precision of obtained geoid models, comparison with Latvian geoid model LV'98 was carried out. Relatively best result was obtained using EGM2008 spherical harmonics coefficients up to degree 360 and spherical integration radius 0.1 degree.

For the Riga region the best results were achieved using GO_CONS_GCF_2_DIR_R4 model with spherical harmonics coefficients up to degree 260 and spherical integration radius 0.1 degree. The mean square error for the geoid model in the region of Riga obtained using GO_CONS_GCF_2_DIR_R4, according to 21 GNSS/levelling data points in Riga region is equal to 5 cm. Comparison with Latvian geoid model LV'98 was also performed and is shown in Fig. 1.

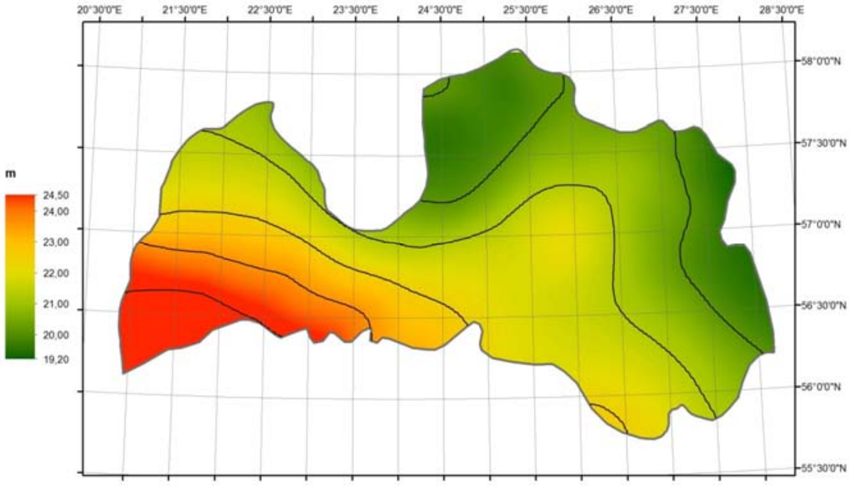


Figure 2. DFHRS geoid height reference surface for the territory of Latvia [m]

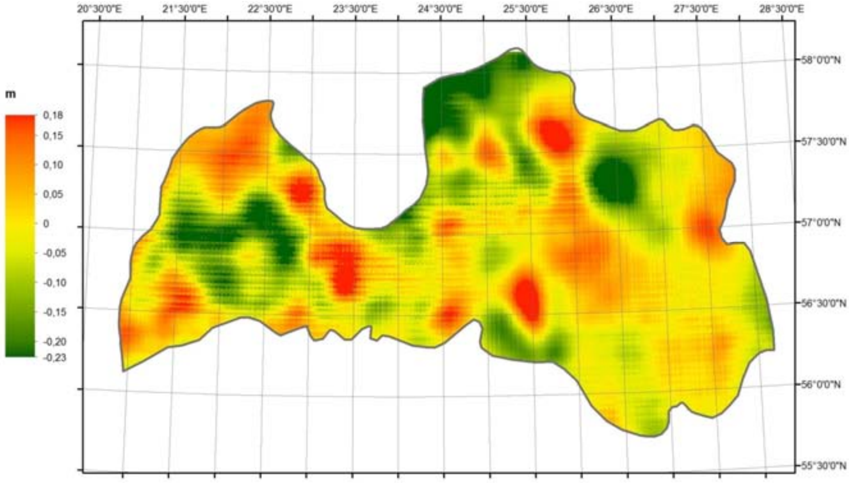


Figure 3. LV'98 and DFHRS geoid solution height comparison [m]

The method of digital finite element height reference surface (DFHRS) was developed at the University of Applied Sciences in Karlsruhe, Germany [5]. This method is based on an adjustment of highly accurate global and gravimetric geoid models to the local height system represented by the set of GNSS/levelling data.

European gravimetric geoid model of EGG97 was used as input data in the calculations of Latvian geoid height reference surface. 102 data points of GNSS/levelling were used in order to define the system. Most of the fitting points are located within territory of Latvia, 3 points in Estonia and 17 points in Lithuania [4].

The resulting geoid model is presented on Fig. 2. For the quality control of obtained geoid height reference surface result, it was tested using the same 102 GPS/levelling points which were used during DFHRS computation. Residual RMS of 1.6 cm for Latvian geoid HRS was obtained. The same RMS appears for LV'98 geoid model, however the minimum and maximum values are larger than those in DFHRS solution. For comparison between LV'98 model and DFHRS solution (Fig. 3), minimum difference is –25.7 cm, maximum: 21.1 cm, RMS: 5.8 cm.

3. GNSS STATION TIME SERIES ANALYSIS

In the frame of EUPOS® regional development project two GNSS station networks have been established in Latvia – LatPos [18] and EUPOS®-Riga [1], which have been continuously operating since 2006.

Time series of EUPOS®-Riga and LatPos station coordinates have been analysed for the observation period from the year 2008 to 2012 inclusive. The data growing amplitude and periodic variations were identified in the Up component.

Latvian GNSS station Up-differences have been increasing until a maximum in the fall of 2012, which might be caused by increasing solar activity. At the same time the number of sunspots has been rising with variability in ionospheric delays [7].

To demonstrate oscillations in the coordinate time series the autocorrelation and spectral density functions have been used.

For example, observations from one of the EUPOS®-Riga network stations have been used. It is LUNI station, which is located in Riga city centre. Fig. 4 illustrates LUNI station Up-differences with respect to the mean position for the year 2010. It is seen that there is a periodic tendency in the time series. Observed series can be characterised as a quasi-periodic series.

The autocorrelation function gives a visual picture of the way in which the dependence in the series damps out with the lag or separation k between points in the series. The sample autocorrelation function is defined by Eq. 1:

$$r(\mathrm{k}) = \frac{c(\mathrm{k})}{c(0)}, \qquad (1)$$

where $c(0)$ is the variance and $c(\mathrm{k})$ is the autocovariance function, which can be estimated by Eq. 2:

$$c(\mathrm{k}) = \frac{1}{\mathrm{N}} \sum_{t=1}^{N-k} (\mathrm{x}_{\mathrm{t}} - \bar{\mathrm{x}})(\mathrm{x}_{\mathrm{t+k}} - \bar{\mathrm{x}}), \qquad (2)$$

where $\bar{\mathrm{x}}$ is the mean of the observed time series [6].

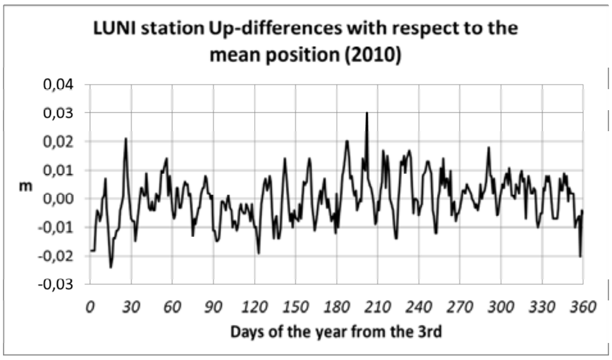


Figure 4. LUNI station coordinate changes in the Up-component of the year 2010

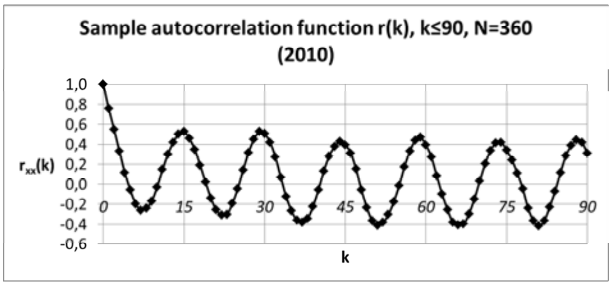


Figure 5. Sample autocorrelation function for LUNI station Up-differences of the year 2010

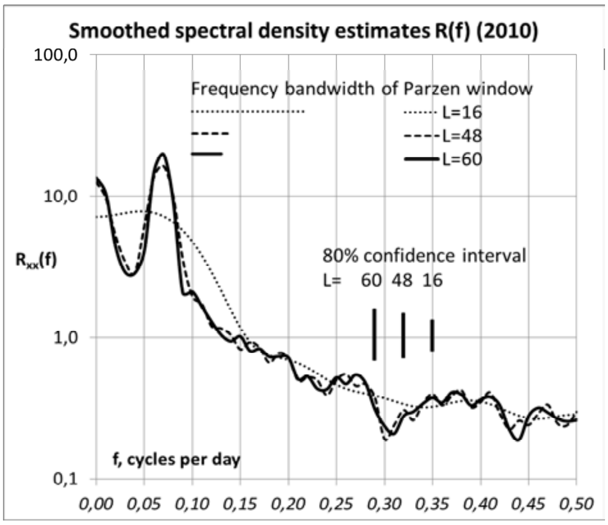


Figure 6. Smoothed spectral density estimates for LUNI station Up-differences of the year 2010

The autocorrelation function for LUNI station Up-differences, shown in Fig. 5 as a sample autocorrelation function obtained until 90th lag, reflects the periodic behaviour and consists of a sine wave with a period of about 14 days, which doesn't damp out.

The corresponding spectrum (see Fig. 6) has a peak at the frequency f = 0.07 cycles per day. Since the process is not truly periodic, the spectrum is not concentrated at the single frequency, but instead is spread over all frequencies. Most of the power, however, is near the frequency f = 0.07 cycles per day.

The reason of periodic behaviour in time series is not yet understood, but such oscillating data resemble displacements due to mass transfers at the Earth's surface caused by the tide effect.

For example, it was selected 80-day observation interval with Latvian GNSS station data post-processing results in the Up component (see Fig. 7), and were obtained theoretical estimates of the solid Earth tide caused vertical displacements in the territory of Riga for the same observation time interval (see Fig. 8).

Solid Earth tide Up components have been computed applying the program 'solid'. It implements the conventions described in Section 7.1.2 of the IERS Conventions (2003) [10] and does not implement ocean loading, atmospheric loading or deformation due to polar motion [11].

Comparing these two charts (Fig. 7 and Fig. 8) some coherence can be observed between extreme values of the vertical displacements at the EUPOS®-Riga and LatPos stations and tidal wave distribution.

As well as GNSS station time series for the first 80 days of the year 2010 have outstanding Up-differences for stations JEKA (orange curve), LODE (blue), SIGU (violet), BALV (green) and especially marked outliers for station VALM (light green).

These extreme values are observed after time of highest tidal waves during selected time interval as can be seen comparing curves of Fig. 7 and Fig. 8. It might be one of the reasons of mentioned outstanding Up-differences. Moreover, there are relatively unfavourable local engineering-geological conditions in the territory of Latvia – unconsolidated soil and high groundwater level, which increase the Earth's surface oscillations due to resonance effect [12].

After analysing coordinate series of all Latvian GNSS stations for period of 5 years, the daily observation standard deviations have been calculated with a 95 % confidence level: σ = ±1 cm in horizontal plane and σ = ±3 cm in the Up component. It means that, although there are relatively high-amplitude periodic variations in the time series, the accuracy of daily station positions is few times smaller.

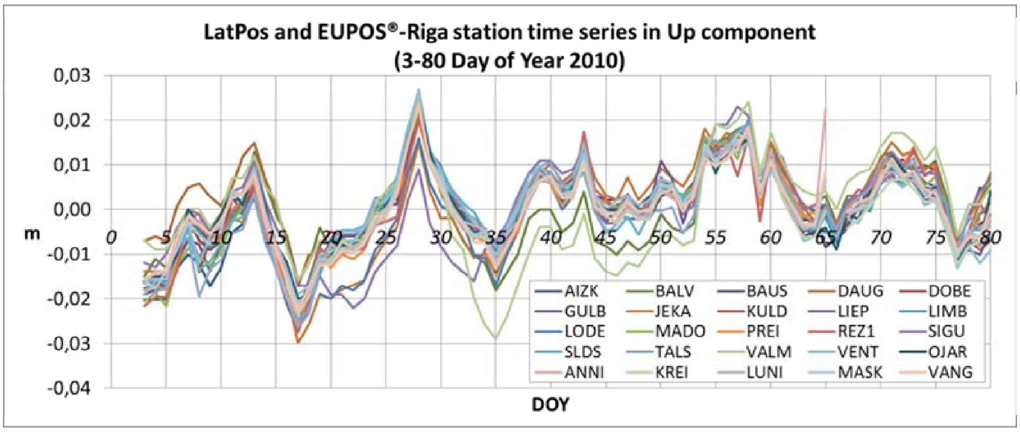


Figure 7. Outstanding values in the Up component of stations JEKA, LODE, SIGU, BALV and VALM (LatPos stations)

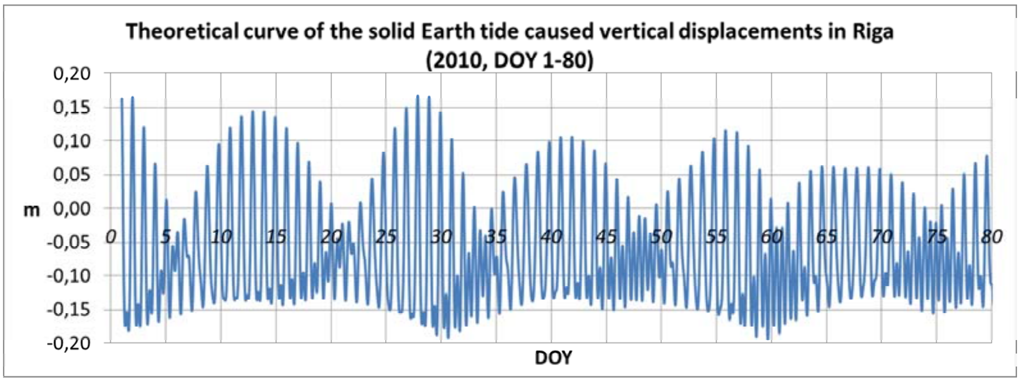


Figure 8. Theoretical solid Earth tide caused vertical displacements in Riga obtained by the program 'solid'

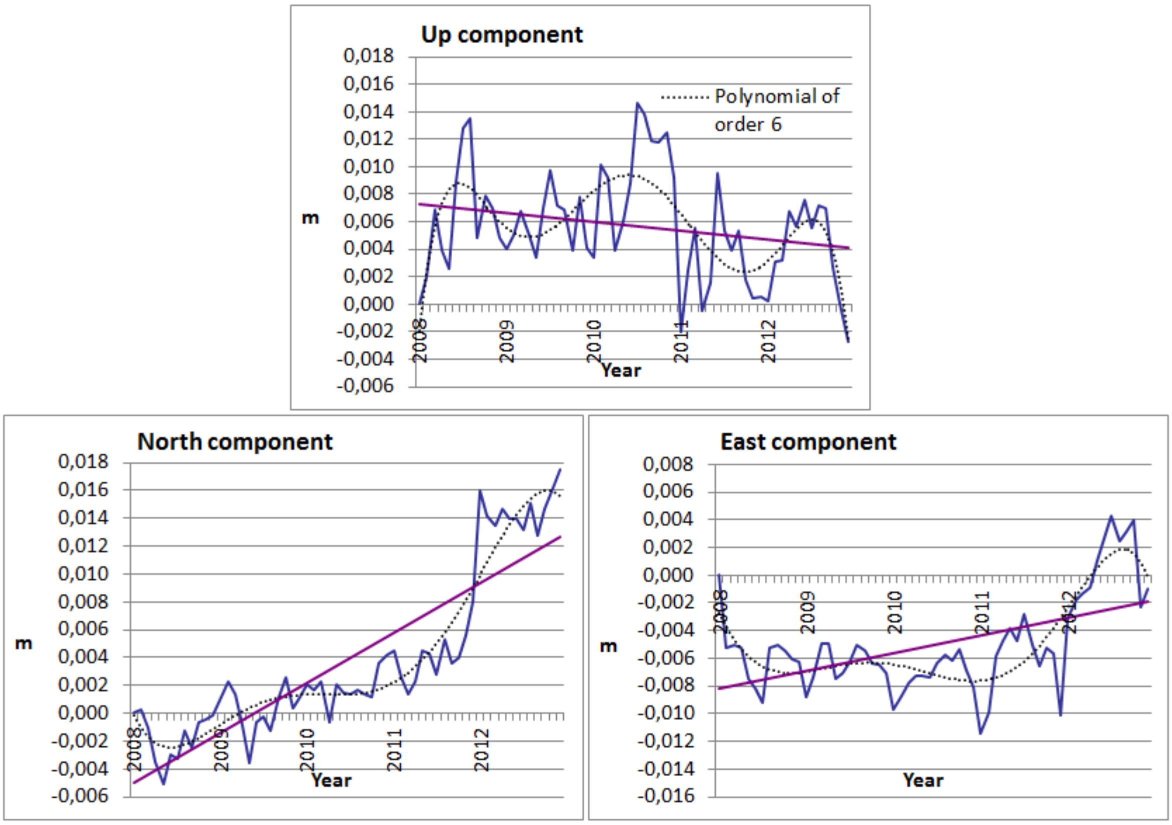


Figure 9. LUNI station monthly average changes for three coordinate components, years 2008-2012: (series – blue curve, linear trendline – violet, and polynomial of order 6 – black dotted line)

To demonstrate trends in the GNSS time series, also LUNI station data were used. In this case monthly average changes have been calculated with respect to the mean station position of the first observation month.

Fig. 9 represents LUNI station monthly average changes in three coordinate components for the observation period from the year 2008 to 2012. As well as linear trendline and polynomial of order 6 are shown for each component.

The results of GNSS data processing have been affected by switch to IGS08/igs08.atx at GPS week 1632 (17 April 2011), causing jumps in several time series [9].

North and East components, shown in Fig. 9, demonstrate a leap in their time series, which corresponds to the beginning of 2012. It is seen that positive shift is stronger marked in the North component series.

The linear trendline of LUNI station Up-differences illustrates the gradual decrease of station position. In this case, there is no clearly visible jump in the time series due to switching to IGS08/igs08.atx.

The corresponding information is mentioned in IGSMAIL-6354 [13]:

- The scale difference between IGS05 and IGS08 will cause a mean decrease of station heights by ~6 mm. The Z translation will accentuate this effect in the Southern hemisphere and attenuate it in the Northern hemisphere.
- The Z translation will also cause positive North shifts, especially at low latitudes.

4. DIGITAL ZENITH CAMERA

The goal of digital zenith camera project is to design a portable, cheap and robust instrument for vertical deflection determination. The project was started in 2010, a simple prototype camera has been built and an extensive test research carried out, looking for solutions and design elements which might present problems and should be improved [2]. In general, prototype camera properties were found close to expected. The most problematic aspect was mechanical stability of camera assembly. Effects of thermal deformations during observation sessions appeared to be a serious disturbing factor, changing relative orientation of tiltmeter and optical system. In prototype camera the main source of such deformation appeared to be tiltmeter fitting, also, as it turned out, main optical system suffered from thermal deformations, resulting in shifting of optical axis and introducing image distortions.

An example of behaviour of prototype camera in static position for 1 hour with temperature drop about 5°C show almost linear drift of tiltmeter orientation (see Fig. 10), probably caused by both tilting of support surface, which was ordinary pavement, and deformation of instrument assembly.

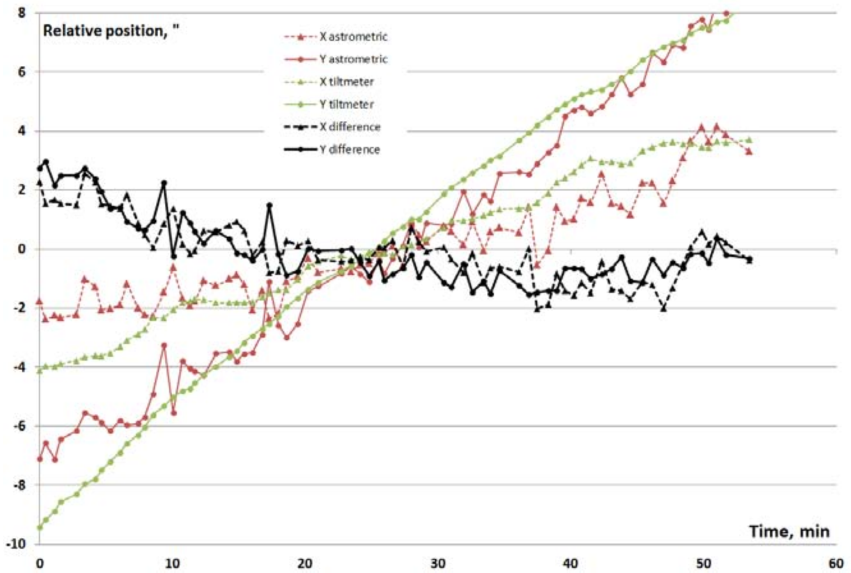
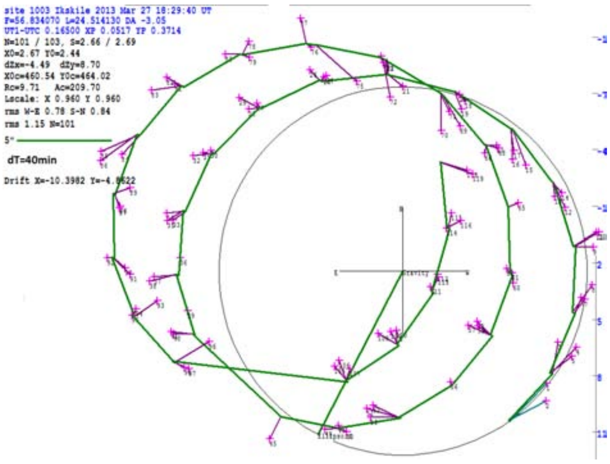


Figure 10. Drift of plumb line and ellipsoidal zenith positions and difference of them when instrument is in stationary position

Drift of astrometric zenith position, due to deformation of a faulty lens support element, is decidedly non-linear, so also difference of these directions, directly used for vertical deflection determination, suffers a non-linear drift. In such circumstances, only very short observation sessions or thermally stable environment would produce acceptable results. Performance of optical subsystem was relatively poor (as jumping of astrometric zenith position curve suggests) due to very few (3-10) reference stars per frame, caused by both "empty season" in zenith area and distorted star images.

Difference between directions to reference ellipsoid normal and plumb line in rotating imager coordinate system, where drift of relative component orientation has been almost linear during 40 minutes, is shown in Fig 11.



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site 1003 Ikskile 2013 Mar 27 18:29:40 UT
F=56.834070 L=24.514130 DA -3.05
UT1-UTC 0.16500 XP 0.0517 YP 0.3714
N=101 / 103, S=2.66 / 2.69
X0=2.67 Y0=2.44
dZx=-4.49  dZy=8.70
X0c=460.54 Y0c=464.02
Rc=9.71   Ac=209.70
Lscale: X 0.960 Y 0.960
rms W-E 0.78 S-N 0.84
rms 1.15 N=101
```

```
Drift X=-10.3982 Y=-4.8622
```

Figure 11. Difference between directions to reference ellipsoid normal and tiltmeter axis in rotating coordinate system

In ideal circumstances measurements should make circle with radius of vertical deflection value (shown by thin black line). In reality, thermal deformations change tiltmeter axis direction relative to optical system, resulting in spiralling trajectory. If dependence of deformations on time is close to linear, evaluation of simple compensating drift model is possible.

Figure 12. New digital zenith camera design

Taking into account prototype camera test results, an improved camera design was made (Fig. 12). Precision support surface which turned out to be not flat enough in prototype camera (a few micron deformations resulted in rotation axis movement with up to 20 arc second amplitude), now is replaced by a simple, less accurate support, motorized computer-controlled leveling in each camera position before measurements will be used, ensuring that tiltmeter readings are always small and minimizing problems arising from tiltmeter scale and orientation uncertainty. It will also make pre-observation adjustment much easier; allow for bigger extent of automation. Camera will be equipped with wireless data transmission devices and on-board battery power source. Also in principle not necessary, possibility to use any turn position is kept – it provided excellent means to control camera properties.

5. CONCLUSIONS

With the use of KTH method for gravimetric geoid calculations for the territory of Latvia, initially using the digitised data of free air anomalies from USSR area and data of EGM2008, best result was obtained using spherical harmonics coefficients up to degree 360 and spherical integration radius 0.1 degree. The application of most recent gravimetric measurement data from the Latvian Geospatial Information Agency for the region of Riga and the data of EGM2008 yielded a geoid model for the region of Riga with a higher precision, its mean square error according to the GNSS/levelling point data was 7.5 cm. The use of most recent gravimetric measurement data and data from GOCE satellite GO_CONS_GCF_2_DIR_R4 revealed that the mean square error according to GNSS/levelling point data was 5 cm. Thus, in the region of Riga the compatibility of GO_CONS_GCF_2_DIR_R4 is better than that of EGM2008 model. It must be concluded that the quality of historical gravimetric data restrict one from calculating a high quality geoid but the density of actual gravimetric measurements accumulated by LGIA for Latvia as of yet is not sufficient.

Geoid height reference surface for Latvia of RMS 1.6 cm was obtained using DFHBF software. In case of poor coverage of fitting point data it is possible to change input parameters of DFHBF software to obtain better accuracy. High accuracy geoid height reference surface can be achieved by minimum number of observations (102 fitting points).

Time series of Latvian GNSS station coordinates have been analysed for the observation period from the year 2008 to 2012 inclusive. The data growing amplitude and periodic variations were identified in the Up component. Distinctive behaviour of EUPOS®-Riga and LatPos station coordinate changes was identified. Outstanding values are observed after time of highest tidal waves, which correlating with Latvian local engineering-geological conditions may increase the Earth's surface oscillations due to resonance effect. Deeper investigation and additional information are needed to understand such biases in the GNSS time series.

The results of GNSS data processing have been also affected by switch to IGS08/igs08.atx, causing leaps in time series.

The daily observation standard deviations of EUPOS®-Riga and LatPos permanent network stations have been calculated with a 95 % confidence level: $\sigma = \pm 1$ cm in horizontal plane and $\sigma = \pm 3$ cm in the Up component.

Currently the project of digital zenith camera and its control software for vertical deflection measurements is under development at the University of Latvia, Institute of Geodesy and Geoinformation. Taking into account prototype camera test results, an improved camera design is made. During the test observation sessions the most problematic aspect was mechanical stability of camera assembly. Effects of thermal deformations during observation sessions were changing relative orientation of tiltmeter and optical system. In such circumstances, very short observation sessions or thermally stable environment would produce acceptable results, also dependence of deformations on time is close to linear, so evaluation of simple compensating drift model is possible.

6. ACKNOWLEDGEMENT

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