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Velocity Fields of the Latvian CORS Station Daily Coordinates for 2012–2017

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Abstract

The objective of this study is to obtain horizontal and vertical velocity fields of the continuously operating reference stations (CORS) in Latvia covering a six-year time period: years 2012–2017. The velocities of the Latvian CORS were previously obtained for the period 2012–2015.

The raw observation data have been collected from the Latvian CORS of two permanent GNSS networks: LatPos (26 stations in 2018) and EUPOS®-Riga (5 stations). Bernese GNSS Software V5.2 was used in the double-difference mode to obtain daily solutions. 9 IGS/EPN reference stations in the reference frame IGb08 were used to compute the coordinates of the Latvian CORS. Obtained daily solutions are transformed to ETRF2000.

The horizontal and vertical velocities of the daily solutions were computed for all LatPos and EUPOS®-Riga stations for the years 2012–2017 applying Tsview software. Outlier detection, offset identification, trend, seasonal variation, and uncertainty estimation was performed using it. Thereafter, the obtained velocity fields were compared to the models NKG_RF03vel and NKG2016LU_abs and the previous solution (2012–2015).

The solution for the years 2012–2017 confirms the effect of the Fennoscandian rebound in the territory of Latvia. The research will be continued by extending the length of the time series and improving the solutions.

Keywords: GNSS time series, Latvian CORS velocities, postglacial land uplift

1 Introduction

Latvia is located in an area that is exposed to ongoing relaxation of the Earth in response to the past ice mass loss, i.e., Glacial Isostatic Adjustment (GIA). The effect rates up to ∼10 mm/yr in the vertical direction in northern Scandinavia (*Steffen and Wu*, 2011; *Poutanen and Steffen*, 2014). In this study, a comparison of the results derived from the analysis of Latvian GNSS time series, which reveal the effect of the Fennoscandian rebound in the territory of Latvia, with the data retrieved from the deformation models NKG_RF03vel and NKG2016LU_abs is presented.

In Latvia, there are two continuously operating reference station (CORS) networks – LatPos and EUPOS®-Riga. The time series of CORS positions of both these networks are calculated at the Institute of Geodesy and Geoinformatics of the University of Latvia (*Balodis et al.*, 2016).

The velocities of LatPos and EUPOS®-Riga stations have been obtained for a period of six years: 2012–2017. The Latvian CORS velocities were previously computed by *Haritonova* (2016) for a period of four years: 2012–2015. Both solutions are presented in this study.

Velocities, however, were not computed for new stations: VALK introduced in 2015, VAIN – in 2016, and KUL2 – in 2017.

2 *Data processing*

The Latvian CORS coordinate time series have been computed for the six-year period from 2012 to 2017 by applying *Bernese GNSS Software V5.2* (*Dach et al*., 2015) in a double-difference mode. The final CODE precise orbits, Earth orientation and clock products, along with the CODE final ionosphere product, were used for GNSS data processing. The dry Global Mapping Function was used as the a priori troposphere model, while zenith path delay parameters were estimated using the wet Global Mapping Function; a cut-off elevation angle of 3° was selected. The positions of all stations were corrected for both solid Earth tide effect (*Petit and Luzum*, 2010), and ocean tide loading (FES2004 ocean tide model was selected). 9 IGS/EPN stations: BOR1 (Poland), GLSV (Ukraine), JOEN (Finland), LAMA (Poland), MAR6 (Sweden), ONSA (Sweden), PULK (Russia), RIGA (Latvia), VLNS (Lithuania), with the minimum constrained coordinates and velocities were used as fiducial stations in the reference frame IGb08. These stations belong to the EPN network as A-class stations (with the exception of GLSV site since 2015) (*Kenyeres*, 2009). According to *Bruyninx et al.* (2013), only A-class stations are suitable as fiducial stations for the densification of the ETRS89.

The same data processing strategy has been implemented for the four-year solution (2012–2015). Only GPS observations for both the four and six-year solutions (2012–2015 and 2012–2017) were used until 2015, commencing with the first day of the year when the combined processing of GPS and GLONASS was applied.

Obtained daily solutions have been transformed to ETRF2000 using ITRF2008-to-ETRF2000 one-step transformation with 14 transformation parameters according to *Boucher and Altamimi* (2011).

3 *Latvian CORS time series and velocity fields*

Tsview software has been used for the time series analysis of the new solution (2012–2017). Written in Matlab, this software complements the GAMIT/GLOBK software package (*Herring*, 2003). Station coordinate files were prepared for the processing using program Samla that was written in Fortran by Gunstein Dalane and edited by Lotti Jivall.

Outliers were removed using the 3σ criterion, as well as more evident periods of bad data, usually occurring during the winter time (*Kenyeres and Bruyninx*, 2009), were excluded from the time series. Additionally, the time series were aligned from shifts that occurred due to GNSS antenna or receiver change as well as the introduction of GLONASS observations in 2015. An offset break caused due to the antenna change was also added for station BALV (2014), due to the receiver change – BAUS (2013) and

PLSM (2013). It is important to observe that not all stations were affected equally due to the introduction of GLONASS, an offset break was added for ALUK, BAUS, DAGD, IRBE, JEK1, KREI, LUNI, LVRD, OJAR, PREI, REZ1, SALP, SLD1, TALS, TKMS, VAIV and VANG (2015.01.01.). For other stations, an offset was at the sub-millimetre level. Offset breaks due to unknown reasons were added for KUL1 (2013) and LODE (2013 and 2014).

Observations of some stations do not cover the entire six-year period: KUL1 was operating till September of 2016, whereas TKMS has been operating since the beginning of 2013. 50–75% of the data were missing in 2015 and 2016 for the station RIGA, that was used as a fiducial station. Due to the possible velocity change, station SALP data for the year 2012 and station SLD1 data for the year 2016 were excluded from the solution.

After preparation of the time series, velocities, annual and semi-annual components and their standard uncertainties were estimated. The most pronounced annual variations are observable at the following stations: PREI, SLD1 (East), PLSM, REZ1, SIGU (North), KREI, LUNI, VANG (Up), MAZS and SALP (all components). The station MAZS should be mentioned in particular – the antenna installation of this station differs from others. It has been fixed on 8 m long post, which does not provide an appropriate base for geodynamic studies.

The uncertainties in Tsview are calculated using the sigmas of the coordinate estimates in the time series as well as the statistical properties of the time series residuals with either white or correlated noise assumptions (*Herring*, 2003). A time-correlated noise model is used in this study in order to estimate the parameter uncertainties. With this model, under the assumption that the noise process is a first order Gauss Markov process, a correlation time of the residuals for each coordinate component is estimated by computing the rate of increase in the chi-squared-per-degree of freedom over increasingly longer time intervals (*Herring*, 2003).

The station horizontal and vertical velocities obtained from the daily solutions for both four and six-year observation periods are illustrated in Figure 1 and Figure 2, respectively. The horizontal velocities are expressed in the ETRF2000 frame and the velocities for Up component – in the ITRF2008. Computed velocities of station MAZS are not depicted here due to its outlying nature. Additionally, horizontal velocities from the deformation model *NKG_RF03vel* and velocities for Up component from the model *NKG2016LU_abs* are depicted with blue vectors in these figures.

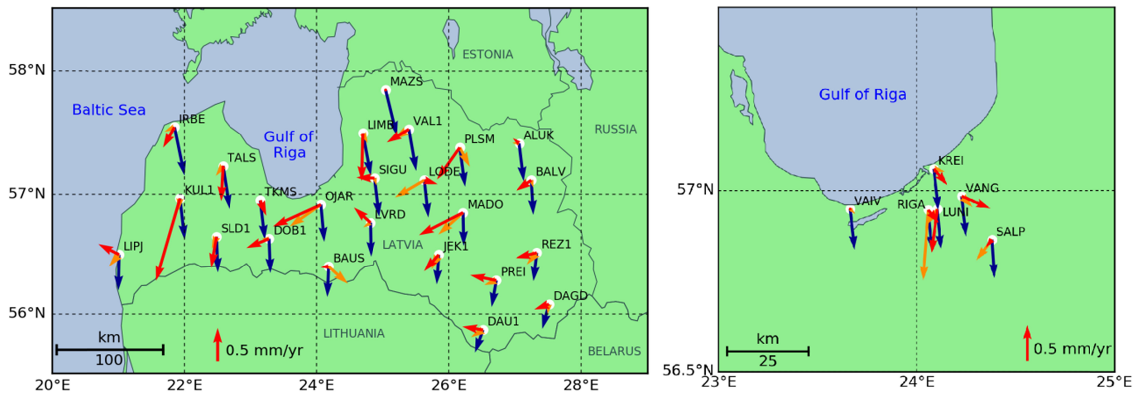

Fig. 1. LatPos (left), EUPOS®-Riga and RIGA (EPN) station (right) horizontal velocities from the daily solutions: 2012–2017 (red) and 2012–2015 (yellow); horizontal velocities from the model *NKG_RF03vel* (blue).

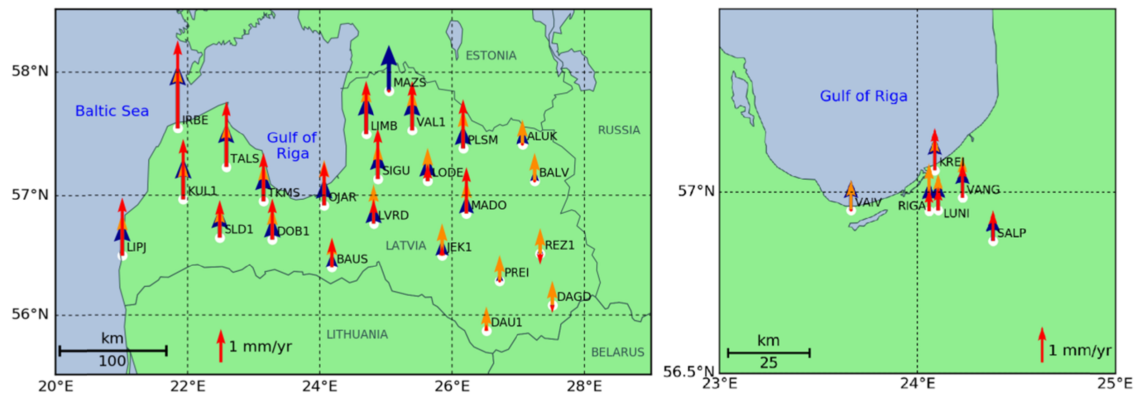

Fig. 2. LatPos (left), EUPOS®-Riga and RIGA (EPN) station (right) vertical velocities from the daily solutions: 2012–2017 (red) and 2012–2015 (yellow); vertical velocities from the model *NKG2016LU_abs* (blue).

The North- and East-components of the deformation model *NKG_RF03vel* originate from the GIA model presented in *Milne et al*. (2001). The velocity field from this model has been transformed to the GPS-derived velocity field in *Lidberg* (2004) (*Jivall*, 2014). Therefore, the horizontal velocity field describes the horizontal displacements relative to stable Eurasia as defined by the ITRF2000 as well as its rotation pole for Eurasia (*Altamimi et al*., 2003).

NKG2016LU denotes a semi-empirical land uplift model over the Nordic-Baltic region (*Vestøl et al*., 2016). Its computation is based on two models: an empirical land uplift model based on GNSS time series and levelling data, without tide gauge data, and preliminary geophysical GIA model (*Steffen et al*., 2016). In this study, *NKG2016LU_abs* – an absolute land uplift model in ITRF2008 has been used.

The results are summarized in Table 1. Velocity values of the four-year period (2012–2015) and six-year period (2012–2017) for North, East and Up components are given with the standard uncertainty values for the latest solution. The station velocities for Up component are given both in the ETRF2000 and ITRF2008 frame. Velocity values from the models *NKG_RF03vel* and *NKG2016LU_abs* for the given stations are also presented.

Table1. Latvian CORS velocities (mm/yr) in North, East and Up components obtained for the periods 2012–2015 and 2012–2017 with standard uncertainties of velocity (mm) (2012–2017); velocities from the deformation models *NKG_RF03vel* and *NKG2016LU_abs*. Largest uncertainties are marked in bold.

	North comp. in ETRF2000				East comp. in ETRF2000				Up comp. in ETRF2000		Up comp. in ITRF2008			
Station	2012-2017	Uncertainty 2012-2017	2012-2015	NKG_RF03vel	2012-2017	Uncertainty 2012-2017	2012-2015	NKG_RF03vel	2012-2017	2012-2015	2012-2017	Uncertainty 2012-2017	2012-2015	NKG 2016LU_abs
ALUK	0.08	0.09	0.01	-0.57	-0.10	0.05	-0.11	0.07	-1.03	-0.22	-0.05	0.18	0.76	0.48
BALV	-0.16	0.06	-0.11	-0.52	-0.23	0.09	0.03	0.03	-0.97	-0.11	-0.01	**0.28**	0.85	0.34
BAUS	-0.01	0.05	-0.26	-0.46	-0.12	0.08	0.29	-0.02	-0.06	-0.04	0.89	0.13	0.91	0.46
DAGD	-0.08	**0.12**	-0.15	-0.37	-0.22	0.07	-0.02	-0.10	-1.19	-0.22	-0.24	**0.28**	0.73	0.02
DAU1	0.05	0.06	-0.11	-0.34	-0.31	0.03	-0.18	-0.12	-0.75	-0.22	0.20	0.13	0.73	0.15
DOB1	-0.14	0.02	0.00	-0.52	-0.34	0.04	-0.11	0.02	0.28	0.01	1.24	0.05	0.97	0.69
IRBE	-0.31	0.06	-0.07	-0.73	-0.17	0.06	-0.15	0.15	1.66	0.91	2.64	**0.31**	1.89	1.91
JEK1	-0.25	0.08	-0.22	-0.45	-0.22	0.05	-0.11	-0.03	-0.65	0.02	0.30	**0.20**	0.97	0.50
KREI	-0.23	0.06	-0.04	-0.58	0.19	**0.13**	0.15	0.06	0.22	-0.01	1.19	**0.31**	0.96	0.93
KUL1	-1.24	0.04	-0.18	-0.62	-0.36	0.07	-0.02	0.07	0.85	0.22	1.82	**0.29**	1.19	1.25
LIMB	-0.72	**0.11**	-0.15	-0.64	-0.02	0.05	0.07	0.12	0.63	0.51	1.61	0.11	1.49	1.19
LIPJ	0.16	0.09	-0.18	-0.54	-0.31	0.04	-0.15	-0.01	0.79	0.33	1.75	0.10	1.29	1.05
LODE	-0.06	**0.12**	-0.26	-0.56	0.20	0.05	-0.44	0.06	-0.45	0.03	0.52	0.16	1.00	0.76
LUNI	-0.62	0.07	-0.22	-0.56	-0.08	**0.19**	-0.15	0.05	-0.29	0.07	0.67	**0.20**	1.03	0.85
LVRD	0.23	0.09	-0.07	-0.51	-0.25	0.10	-0.11	0.01	-0.22	0.22	0.75	0.16	1.19	0.64
MADO	-0.34	0.07	-0.33	-0.50	-0.66	0.07	-0.37	0.01	0.43	0.04	1.39	0.12	1.00	0.56
MAZS	-2.69	**0.25**	-1.75	-0.69	0.33	0.07	-0.01	0.17	-0.20	0.33	0.78	0.13	1.31	1.38
OJAR	-0.33	**0.19**	-0.33	-0.56	-0.72	**0.23**	-0.47	0.05	0.33	0.40	1.30	**0.20**	1.37	0.83
PLSM	-0.48	0.06	-0.29	-0.59	-0.34	0.05	0.15	0.08	0.52	0.22	1.49	0.11	1.19	0.73
PREI	0.08	0.07	-0.07	-0.40	-0.39	0.08	-0.18	-0.07	-0.88	-0.15	0.07	0.15	0.80	0.28
REZ1	-0.08	**0.11**	-0.18	-0.43	-0.32	0.05	-0.15	-0.05	-1.28	-0.18	-0.33	**0.29**	0.77	0.21
RIGA	-0.19	0.06	-0.99	-0.56	0.15	0.09	-0.07	0.05	-0.34	0.37	0.63	0.11	1.34	0.85
SALP	-0.11	**0.11**	-0.29	-0.54	-0.09	0.05	-0.22	0.03	-0.11	-0.88	0.86	**0.27**	0.09	0.76
SIGU	0.01	0.04	-0.11	-0.58	-0.28	0.04	0.03	0.07	0.56	0.11	1.53	0.11	1.08	0.90
SLD1	-0.47	**0.11**	-0.18	-0.54	-0.08	**0.30**	-0.07	0.02	0.16	0.00	1.13	0.16	0.97	0.91
TALS	-0.53	0.08	-0.15	-0.65	-0.03	0.06	-0.11	0.10	1.01	0.40	1.98	0.17	1.37	1.34
TKMS	-0.23	0.10	-0.07	-0.59	0.09	0.06	0.04	0.07	0.49	0.18	1.46	0.06	1.15	0.96
VAIV	0.00	0.07	-0.07	-0.57	0.01	**0.11**	0.07	0.06	-0.95	-0.11	0.01	**0.26**	0.85	0.85
VAL1	-0.20	0.03	-0.15	-0.63	-0.33	0.04	-0.22	0.11	0.50	0.26	1.48	0.07	1.24	1.06
VANG	-0.17	0.06	-0.15	-0.56	0.40	0.07	0.15	0.06	-0.01	0.18	0.96	0.19	1.15	0.88

Table 2 summarizes the statistical results of the comparison between estimated velocities of both solutions as well as the models *NKG_RF03vel* and *NKG2016LU_abs* (station MAZS was excluded from these comparisons).

Table 2. Mean, STDV and RMS of differences (mm/yr) between estimated velocities of both (2012–2017 and 2012–2015) solutions and the deformation models *NKG_RF03vel* (North, East) and *NKG2016LU_abs* (Up).

	Solution 2012-2017			Solution 2012-2015		
	NKG_RF03vel		NKG2016LU_abs	NKG_RF03vel		NKG2016LU_abs
	North	East	Up	North	East	Up
Mean	0.32	-0.20	0.17	0.36	-0.12	0.28
STDV	0.27	0.23	0.45	0.20	0.18	0.28
RMS	0.42	0.31	0.48	0.41	0.21	0.39

4 Conclusions

In this study, horizontal and vertical velocity fields of all CORS in Latvia were obtained for the six-year time period: 2012–2017. The Tsview software was used to prepare time series and estimate velocities, seasonal variations and uncertainties.

Similar to the solution 2012–2015 previously computed by *Haritonova* (2016), the solution 2012–2017 reveals the effect of the Fennoscandian rebound in the territory of Latvia. In both these solutions, the EUPOS®-Riga and LatPos station vertical velocity vectors have maximum values in the north-western part of Latvia and minimum values in the south-eastern part of the country. The highest velocity differences in Up component between the obtained results (2012–2017) and *NKG2016LU_abs* model have been observed in the north-western part of Latvia, up to 0.73 mm/yr at IRBE, as well as in the middle-eastern part of Latvia, up to 0.83 mm/yr at MADO. It is also noticed that the velocities of this new solution correspond better to the *NKG2016LU_abs* model values in the eastern part of Latvia. By contrast, the previous solution had higher vertical velocities there.

The horizontal velocities of the solution 2012–2015 are less pronounced as compared to the horizontal movements from the *NKG_RF03vel* model. While the new results have shown approximately the same order of magnitude of the vectors, however, the orientation is different.

LODE appears to exhibit different velocity behaviour than the closest stations. This could be due to two offset breaks in 2013 and 2014. Most of EUPOS®-Riga stations have larger than average uncertainties for Up component. For some of these stations, large uncertainties can be associated with monumentation problems. SALP having large annual variations could be influenced by local hydrological effects – it is located in close proximity to the hydroelectric power station. The large difference to RIGA can be explained with the missing data and short useful time series; in addition, it also indicates that the estimated uncertainties might be too optimistic.

From a statistical perspective, longer time series make the estimated velocities more precise. Additionally, different time series analysis methods, treatment of offsets and outliers, and seasonal variation estimation lead to different interpretation of the results. This explains the differences of velocities between the new solution (2012–2017) and the solution 2012–2015.

A deeper and more elaborative investigation of station site-specific effects and time series noise characteristics is necessitated. This research will be continued by extending the length of time series – reprocessing of the earlier data: 2007–2011 or even reprocessing up to the year 2014 using both GPS and GLONASS observations in order to avoid offsets due to GLONASS introduction, as well as testing other time series analysis software (e.g. CATS (*Williams*, 2008)).

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