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Coordinate Analysis of Latvian CORS Stations

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Abstract. This paper considers the origin of Latvian Coordinate System LKS-92 definition which was based on two GNSS campaigns in 1992 and 2003. There are two continuously operating reference networks in Latvia: LatPos and EUPOS®-Riga. GNSS stations of these networks have fixed coordinate values in LKS-92. At the Institute of Geodesy and Geoinformatics of the University of Latvia both LatPos and EUPOS®-Riga station daily coordinate values are calculated. The coordinate differences between epochs 1989.0 and 2018.5 were obtained for LatPos and EUPOS®-Riga stations, expressed in ITRF14. ITRF reflects the motion of Eurasian plate in global frame of the Earth and ETRF89 system reflects the intraplate motion. Mean yearly coordinate components in ETRF89 were analysed. Comparison of LatPos and EUPOS®-Riga station coordinate components in ETRF89, LKS-92 and ETRF2000 coordinate systems was performed. Future of Latvian coordinate system LKS-92 is discussed.

Keywords: ETRF89, GNSS, ITRF2014, LKS-92.

1. Introduction

The Latvian land reform has been performed by fixing real estate boundaries in the framework of LKS-92 coordinate system which is declared as an ETRS89 realization in Latvia. The coordinates for Baltic countries: Estonia, Latvia and Lithuania, were determined by the State Land services of Nordic countries for 4 former triangulation points of each Baltic country within the NKG (Nordic Geodetic Commission) GPS campaign 1992. The Nordic countries kindly performed GPS observations without charge by applying GPS receivers served by their staff. The coordinate computation of 4 points for each Baltic country was performed as well (Madsen and Madsen, 1992). The reference network densification in Latvia was performed by Latvian State Land Service and new coordinate system was named LKS-92. Another NKG GPS campaign was performed in 2003, in which geodesists of the Baltic countries took part as well. The updated version of the coordinates for the previous 4 points in each country was obtained (Jivall et al., 2007).

The continuously operating GNSS reference system (CORS) named LatPos was established in 2006/2007 and since that time the LKS-92 coordinates of LatPos stations are used as a reference points in all GNSS measurements in land surveying. In Riga city the EUPOS$^{®}$-Riga CORS network was established with a state required coordinates referenced in LKS-92. For LatPos network stations, the LKS-92 coordinate values were determined by Latvian State Land Service in 2007 and they were updated by Latvian Geospatial Information Agency (LGIA) in the end of year 2011. Coordinate values are declared by Latvian authority LGIA and the fixed values are used unchanged in land surveying up to now (Aleksejenko et al., 2014).

Independently from LGIA, both LatPos and EUPOS$^{®}$-Riga station coordinates are calculated by the Institute of Geodesy and Geoinformatics (GGI) since the very beginning of 2007. The SINEX weekly solutions are regularly transferred to EPN densification Analysis Centre (Bruyninx et al., 2018), where they are applied for the European Permanent GNSS Network (EPN) densification and European velocity field calculations (Bruynix et al., 2017), as well as European Plate Observing System (EPOS). Mainly 9 IGS/EPN stations surrounding Latvia were used in GGI solutions as fiducial stations with the minimum constrained coordinates and velocities. The Bernese GNSS software package (Dach et al., 2015) and internationally used GNSS observation reduction parameters are applied. The validity of results in global European framework are regularly controlled by EPN densification Analysis Centre.

It is worth to mention that numerical values of solution results are different in relation to the applied coordinate system: either ITRFyy, ETRFyy, LKS-92, or any other coordinate system. By “yy” the year of reference system’s realization is denoted with regard of coordinates of Earth pole, Earth coordinate system origin, scale and various Earth rotation parameters. The monitoring of Earth Terrestrial Reference Systems is very complicated task, which is analysed by obtaining regular observations of many international observation and analysis services – International GNSS Service (IGS), International Laser Ranging Service (ILRS), International Earth Rotation Service (IERS), International Very Long Baseline Interferometry Service (IVS), International DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) Service (IDS). The shape of the Planet Earth is continuously changing due to the plate tectonics, earthquakes, eruption of volcanoes, dynamical processes caused by hurricanes, ocean and sea variations, as well as phenomena of outer space. ITRF is computed by worldwide distributed institutions under the International Association of Geodesy (IAG) based on the data mainly provided by four internationally supported space geodetic techniques (GNSS, SLR, VLBI and DORIS) and regularly updated post-seismic deformations (Altamimi et al., 2016).

2. Latvia in International and European Terrestrial Reference Systems (ITRS and ETRS)

Daily coordinates of LatPos and EUPOS$^{®}$-Riga continuously operating reference stations (CORS) are computed in GGI. The sets of Cartesian {X, Y, Z} coordinates are converted into sets of mapping grid coordinates: Northing, Easting and ellipsoidal height or Up component, denoted by {X, Y, h}.

The ITRF coordinate system was continuously updated and various versions were used in GGI computations according to the recommendations of IAG Regional Reference Frame sub-commission for Europe (EUREF): IGS05, IGS08, IGb08 and IGS14. In Europe it is recommended by EU to use in all the national mapping tasks the ETRS89 coordinate system which is defined for Eurasian tectonic plate. However, in recent years it is recommended by EUREF (Altamimi, 2018) to adopt the ETRF2000 as a conventional frame of the ETRS89.

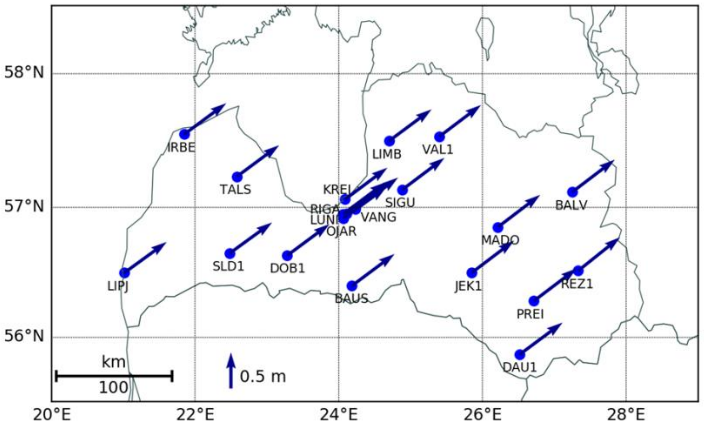

Fig.1. Latvian CORS differences regarding to GNSS observations in ITRF14 system epoch 1989.0 and 2018.5

The differences of the plane coordinate values of Latvian CORS in ITRF14 system for the time span from 1989.0 to 2018.5 depicted in Fig.1. As ITRF89 and ETRF89 completely coincide at 1989.0 epoch the observations from 2007.5 have been expressed also at 1989.0 and transformed to ITRF14 system for correct comparison (the difference between ITRF14 and ITRF89 is approximately 5 cm).

The time series of GNSS observations would be consistent if any changes of receivers and antennas haven't occurred. From the very beginning at 2006/2007 just 11 station antennas were continuously operating at the same sites without movement: BAUS, KREI, LIMB, LUNI, MADO, OJAR, PREI, SIGU, TALS, VANG, RIGA. Both antenna and receiver of IGS/EPN station RIGA were changed in 2007 and 2013; antenna was placed at the same place. For OJAR station both the antenna and receiver have been changed as well: antenna changed in 2010 and receiver changed in 2012 and 2018. BAUS antenna was changed in 2013. LUNI receiver was changed in 2018. For station PREI receiver was changed in 2011 and twice in 2014. For station TALS receiver was changed in 2010. The antennas were moved in 8 cities in the following cases: VENT and IRBE; DAUG and DAU1; DOBE and DOB1, JEKA and JEK1, LIEP and LIPJ, REZE and REZ1, SALD and SLD1, VALM and VAL1.

In global ITRF system was determined that all the stations moved about 57 cm in direction of 53°. This exposes the Latvia motion on the surface of global Earth. In Fig.2 the coordinate differences are shown according the values in the system ETRS89 which is reduced on the Eurasian plate. The coordinate differences in ETRF89 are just about 3 cm which are expressed at 2007.5 and 2018.5, correspondingly. The ETRS89 is theoretically defined system, ETRF89 means the practical realization of the system.

In Fig.2 the differences of the plane coordinate values of Latvian CORS in ETRF89 system are shown for the same time span from 1989.0 to 2018.5.

The mean values of displacement vector modules and direction in position between 2018.5 and 2007.5 are demonstrated in Table 1. ITRF reflects the motion of Eurasian plate in global figure of the Earth. The result in ETRF89 system reflects the intraplate motion.

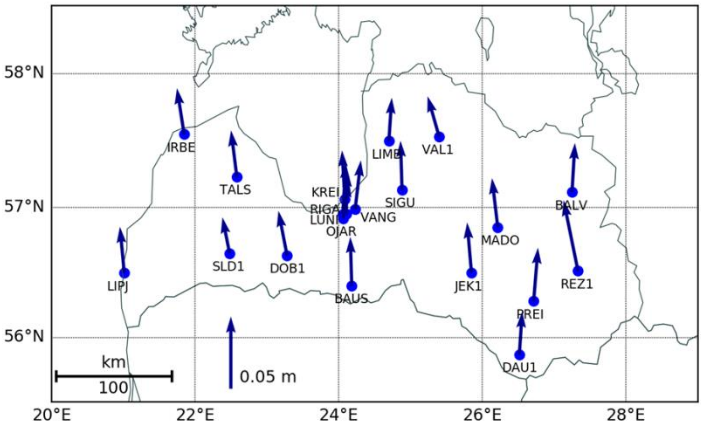

Fig.2. Latvian CORS differences regarding to GNSS observations in ETRF89 system epoch 1989.0 and 2018.5

Table 1. Comparison of the coordinate differences (m) expressed in ITRF14 and ETRF89 systems (1989.0-2018.5)

	ITRF14			ETRF89		
	Distance	Azimuth	Height	Distance	Azimuth	Height
Average	0,573	53,2°	0,003	0,033	-2,7°	0,003
STDV	0,008	0,6°	0,014	0,005	6,8°	0,013
Min	0,561	51,3°	-0,045	0,025	-15,9°	-0,035
Max	0,592	54,0°	0,014	0,050	8,7°	0,022

The height component differences are compared as well in Table 1. The average height differences in both systems – ITRF14 and ETRF89 system, correspondingly, is +3 mm.

ETRS89 is the official reference frame for all the EU countries, which is recommended to use for geodetic datum in land surveying and mapping. LKS-92 as an ETRS89 realization in Latvia has been confirmed by Latvian government. The individual calibration of each antenna has been recognized by EUREF as a very important for high precision positioning achievements. But just EUPOS®-Riga station antennas have been individually calibrated in Garbsen, Germany in 2006 and antenna calibration parameters are used for all the GGI solutions. No individual antenna calibration has been performed for LatPos station antennas. The Bernese v.5.0 software was used at the first period in GGI analysis and Bernese v.5.2 was used since it became available. EUREF recommended IGS05 frame to be used (2007-2011), IGS08 (2011-04-17 to 2012-10-06) and IGb08 (2012-10-07 to 2017-01-28) and IGS14 since 2017-01-28.

3. Horizontal coordinates in ETRF89, ETRF2000 and LKS92 systems

For all the above mentioned stations of LatPos and EUPOS®-Riga networks the time series of daily observations have been computed in GGI for the time span from 2007 up to 2018. In Fig.3 the differences of mean yearly Northing component in ETRF89 expressed at the epoch of corresponding middle of year are depicted by reducing them to ETRS89 expressed at each of those years (2007.5, 2008.5, … , 2018.5). Instead of theoretical ETRS89, further corresponding ETRF89 expressed at 2007.5, 2008.5, …, 2018.5 will be used in this article.

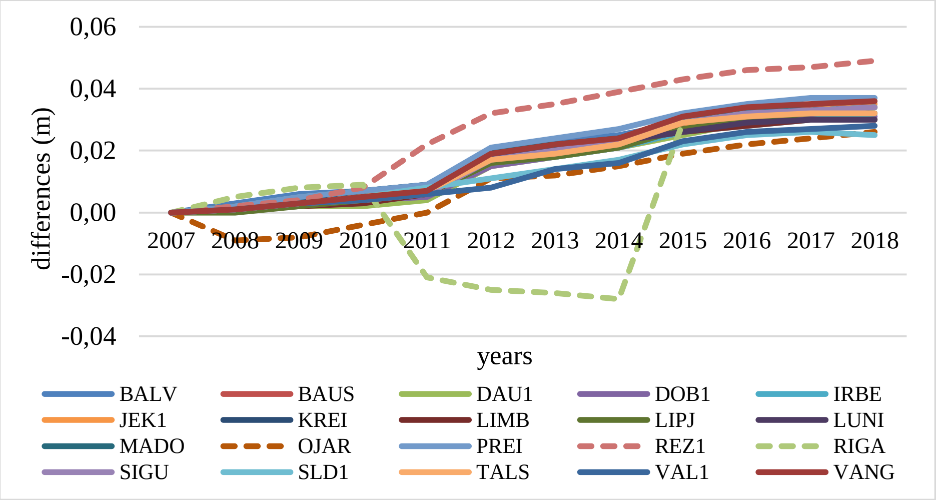

Fig.3. ETRF89 Northing component of Latvian CORS stations

IGS/EPN station RIGA position results (see Fig.3) appeared deformed in 2011 when the antenna calibration parameters in RINEX files changed. Just in 2015 RIGA results appears in line together with the other stations when the updated antenna calibration parameters were fixed. In Fig.3 the upper line depicts the REZ1 (Rezekne) station results, but OJAR station Northing component is seen as a lower line in years 2008-2011.

In order to compare GGI solution results and LKS-92 coordinates computed by Latvian State Land Service and Latvian Geospatial Information Agency (2011) correspondingly, the same Northing component of above mentioned station ETRF89 solutions (blue) and additionally the LKS92 Northing component differences between x∈LKS92 and x∈(ETRF89 expressed at 2007.5) (black) are depicted in Fig 4.

The official ETRF89 coordinates used in Latvia are maintained by Latvian Geospatial Information Agency (LGIA). LGIA defined national ETRS89 coordinates of RIGA station in Northing, Easting and Up (WEB1); in LKS-92 realization they are: RIGA x=311667.766, y= 503574.998, h= 34.730.

In Fig.4, Fig.6 and Fig.8 differences ({x,y,h}∈LKS92 – {x,y,h}∈(ETRF89 expressed at 2007.5)) depicted by black lines and correspondingly by blue lines the differences ({x,y,h}∈(ETRF89 expressed at 2018.5) – {x,y,h}∈(ETRF89 expressed at 2007.5, 2008.5, …, 2018.5)). In the same manner in Fig.6 the differences in Easting component are shown, in Fig.8 – in Up component. Similarly, by red lines depicted the corresponding values in ETRF2000 system. The lines of ETRF2000 obtained by repeatedly computing Bernese v.5.2 in IGb08 and IGS14 system and reducing to ETRF2000.

Typical precision of GGI computed Northing, Easting and Up components are: 0.001 m, 0.001 m and 0.004 m, correspondingly.

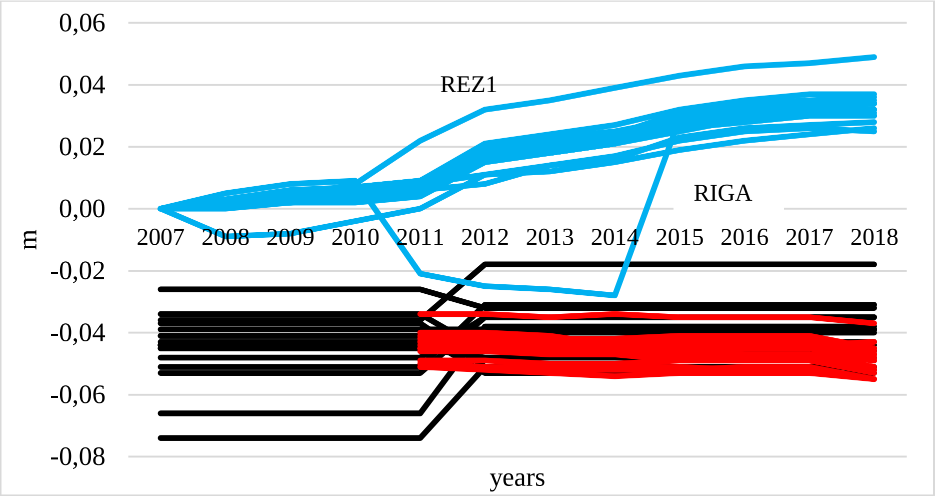

Fig.4. Comparison of LatPos station Northing component in ETRF89 (blue), LKS-92 (black) and ETRF2000 (red) coordinate systems

Fig.5 and Fig.7 show comparison of EUPOS®-Riga station Northing component and Easting component in ETRF89 and ETRF2000 coordinate systems, correspondingly.

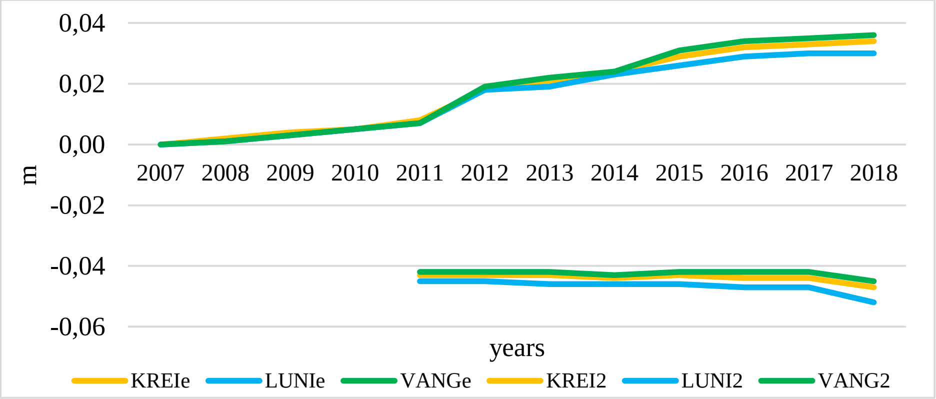

Fig.5. Comparison of EUPOS®-Riga station Northing component in ETRF89(e) and ETRF2000(2) coordinate systems

In Fig.6 the differences in Easting component are depicted. Upper blue line reflects the OJAR station differences, lower blue – REZ1, upper black in left side – DAU1.

Antenna calibration has been recognised very important. The antennas of EUPOS®-Riga stations KREI, LUNI and VANG has been calibrated individually in year 2006 in Geo++, Garbsen, Germany. The antennas were not moved or changed, and calibration parameters have been applied in GGI computations till now. The results of these three stations are most consistent in Riga.

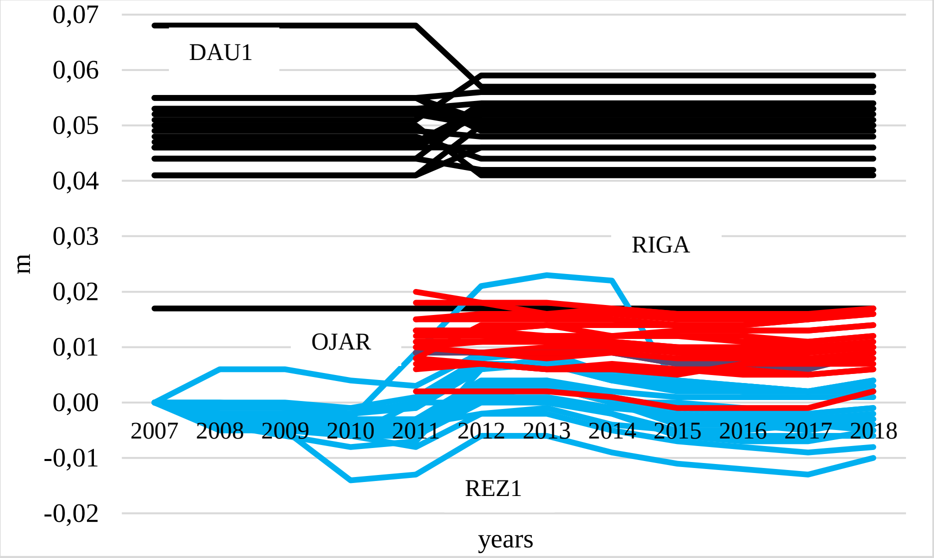

Fig.6. Comparison of LatPos station Easting component in ETRF89 (blue), LKS-92 (black) and ETRF2000 (red) coordinate systems

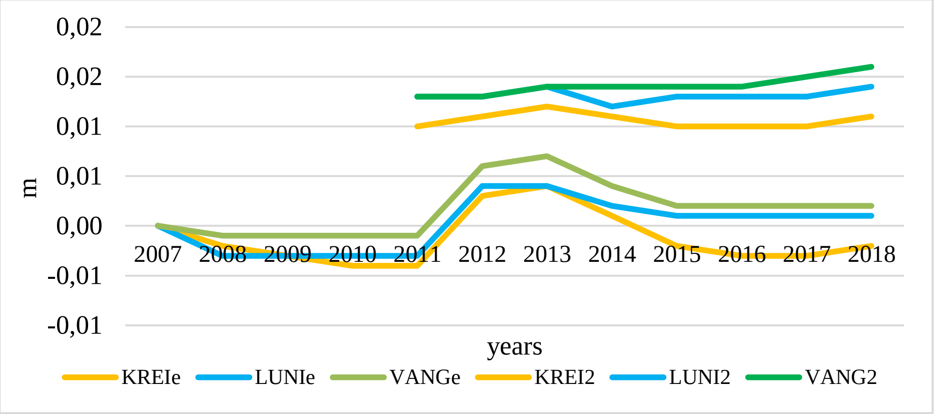

Fig.7. Comparison of EUPOS®-Riga station Easting component in ETRF89(e) and ETRF2000(2) coordinate systems

4. Up component in ETRF89, ETRF2000 and LKS92 systems

The systems ITRF14, ETRF89, ETRF2000 and LKS92 are based on the same datum. However, the corresponding system's realization in corresponding epochs and observation and reduction results are different.

In Fig.8 the Up component differences are plotted in the same manner as previously. Upper blue is OJAR station, upper black in left side JEK1, VENT and DOB1, lower black – REZ1.

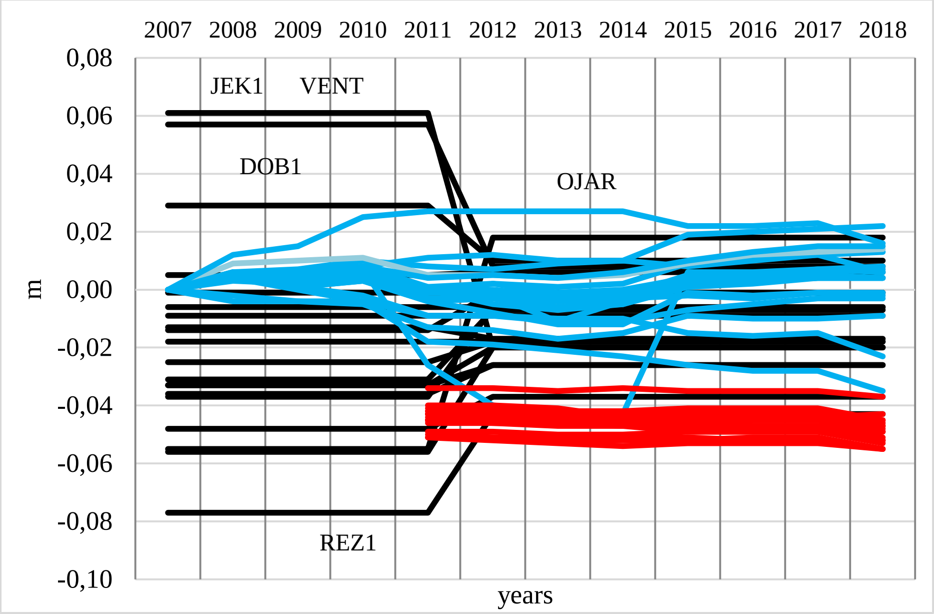

Fig.8. Comparison of LatPos station Up component in ETRF89 (blue), LK-S92 (black) and ETRF2000 (red) coordinate systems

In Fig.9 the Up component of CORS stations with most variable Up values in ETRF89 system are depicted and for the same stations repeatedly computed in IGb08 and IGS14 system and reduced to ETRF2000. Station domes (like IRBEe) with extension "e" belongs to ETRF89 and domes with extension "2" (like IRBE2) belongs to ETRF2000.

Fig.10 shows comparison of EUPOS$^{®}$-Riga station Up component in ETRF89 and ETRF2000 coordinate systems.

In Fig.11 the Up differences for the period of 7 years (year 2018 - year 2011) in ETRF89, ETRF2000 and ITRF14 coordinate systems are depicted, correspondingly. The histogram plot shows nearly similar values of Up differences in ETRF89 and ITRF14 systems. However, the view is quite different in ETRF2000 system, where all the Up differences are negative. Average value in ETRF2000 system is -4.4 mm while for both ITRF14 and ETRF89 systems the average value is +2.8 mm. The common differences are about 5 cm of absolute value. Up component decreases at 5 sites according to the ETRF89 solution (see Fig.8): IRBE, JEK1, OJAR, REZ1 and SLD1, except SLD1 for the ITRF14 solution. The most pronounced subsidence appears for REZ1 (-17 mm), JEK1 (-14 mm) and OJAR (-11 mm). At SLD1 ETRF89 and ITRF14 gives values with opposite sign. There should be observable a land uplift in the case of station IRBE, however, according to the used data the subsidence appears. The maximum values of uplift are in the case of station LIMB (14 mm), BALV (13 mm), DOB1 (11 mm) and TALS (11 mm).

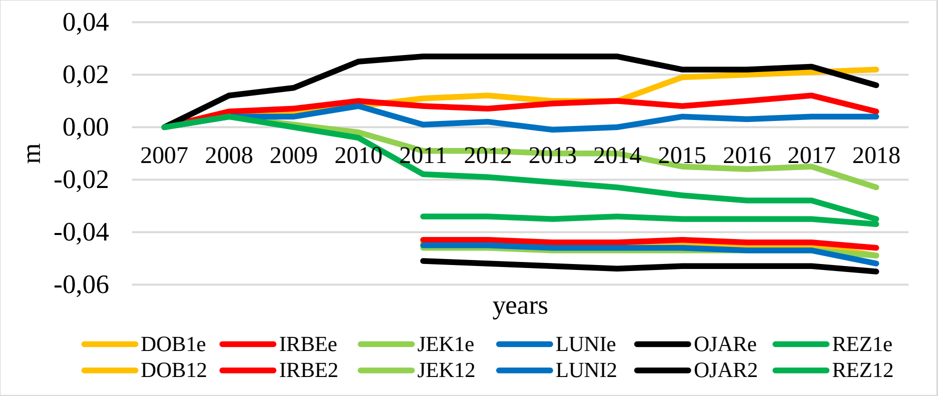

Fig.9. Up component of most unstable stations in ETRF89(e) and ETRF2000(2) coordinate systems

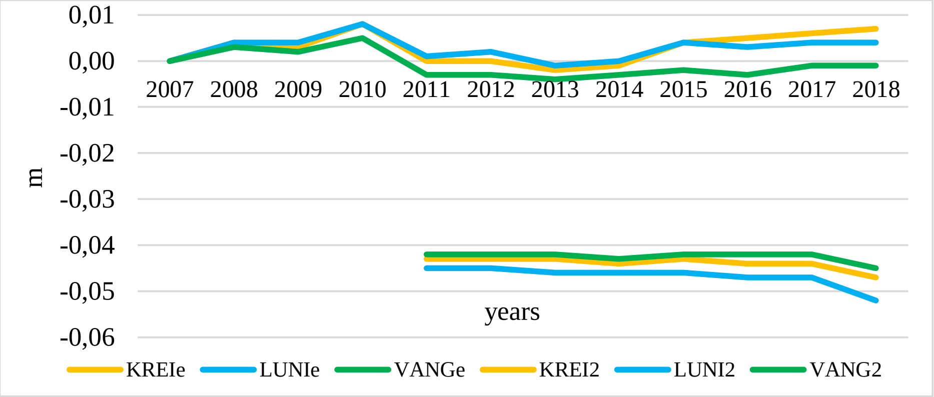

Fig.10. Comparison of EUPOS®-Riga station Up component in ETRF89(e) and ETRF2000(2) coordinate systems

It is worth to mention that the ellipsoidal height differences are exposed. However, the differences in normal height system are expected to be similar due to the expected stability of geoid surface in bounds of Latvia. There are no meaningful earthquakes in last century and no meaningful intraplate tectonic movements in the Latvia region.

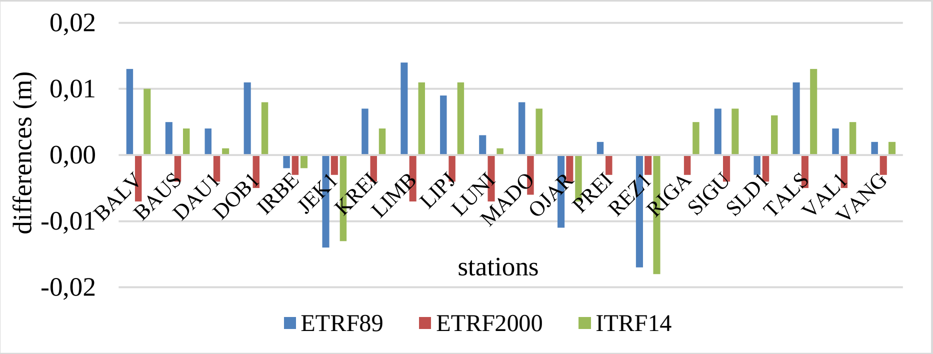

Fig.11. Up differences (year 2018 - year 2011) in ETRF89, ETRF2000 and ITRF14 coordinate system

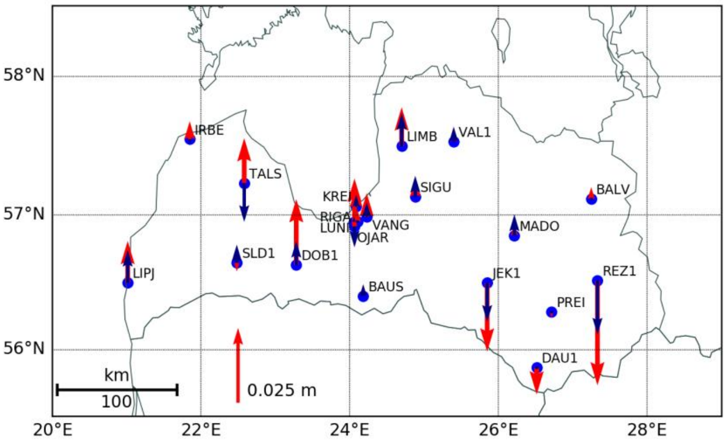

Fig.12. Ellipsoidal height changes (year 2018 - year 2011) according to ETRF89 solution (red vectors) and ITRF14 solution (blue vectors)

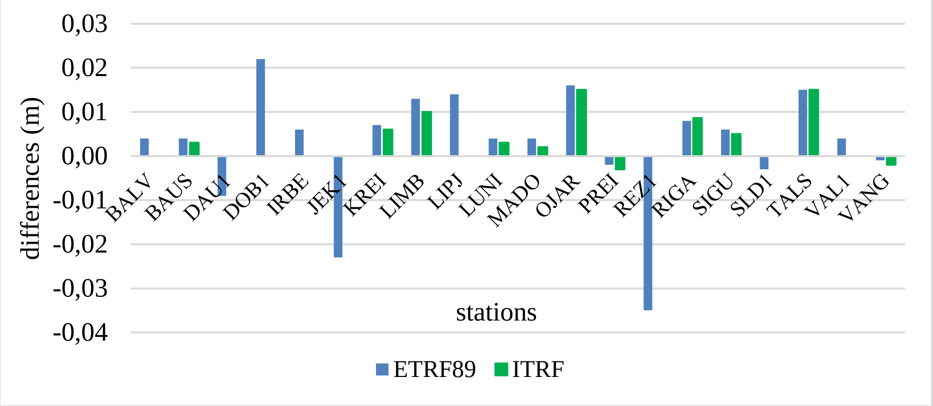

Fig.13. Up differences (year 2018 - year 2007) in ETRF89 and ITRF coordinate system

In histogram of Fig.13 the differences are shown for 11-year period for 20 stations in ETRF89 system and for 11 stations in ITRF system. The GNSS receivers were moved to the other places in Daugavpils, Dobele, Jekabpils, Liepaja, Rezekne, Saldus and Valmiera. The receiver from Ventspils was moved to Irbene. It was assumed that coordinate velocities are the same for sites which are not far away from each other and the Up differences were calculated in ETRF89 system. The ITRF values were calculated only for those stations which were not moved.

In Fig.12 ETRF89 reflects the same which is exposed in Fig.8 and Fig.9. The most subsidence is observed in JEK1 and REZ1.

5. Discussion on the future of Latvian coordinate system

The decision in future to use the Latvian LKS-92 coordinate system is the duty of Latvian authority - the Latvian Geospatial Information Agency. LatPos reference stations represent the main source of reference coordinate information for land surveying, cadastre and mapping. Will LKS-92 coordinate system be approached to ETRS89, ETRF2000 or ETRF14, or to some of most advanced ETRF coordinate system versions? Will it be continued to use LKS-92 system in Latvia – it is a question to Latvian land surveying and mapping community. In Estonia the coordinates and velocities are given both in ITRF14 and ERTS89 coordinate systems (Kollo et al., 2019). This study is preliminary and it should be continued by detailed estimation of Latvian CORS coordinates and velocities and their statistical noise properties.

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