Paper presented at the 30th EUREF Symposium held virtually from Ljubljana, Slovenia, May 26–28, 2021

National Report of Slovenia
to the EUREF 2021 Symposium in Ljubljana

Klemen MEDVED[1], Sandi BERK[1], Jurij REŽEK[1], Niko FABIANI[2],
Mihaela TRIGLAV ČEKADA[2], Božo KOLER[3], Tilen URBANČIČ[3], Klemen RITLOP[3],
Miran KUHAR[3], Polona PAVLOVČIČ PREŠEREN[3], Oskar STERLE[3], Bojan STOPAR[3]

1 Introduction

This report is a short review of activities related to national geodetic reference frames, CORS networks and activities related to EUREF in Slovenia for the period 2019–2021.

2 Terrestrial Reference Frame

The EUREF Slovenia 2016 GNSS campaign solution was presented at the EUREF symposium in Amsterdam (Berk et al. 2018) and accepted by the EUREF GB as Class B standard (EUREF 2018, Resolution No. 3). This solution includes:

- 8 Slovenian passive GNSS sites (included also in the previous EUREF campaigns), which are the old first-order triangulation points,
- 2 Croatian passive GNSS sites (included also in the previous EUREF campaigns),
- all 16 SIGNAL network stations, including EPN station GSR1 (Ljubljana), and
- all 6 zero-order combined geodetic network stations.

Afterwards, the complete campaign computation was performed (Berk et al. 2019). This final campaign solution follows the same processing strategy as those accepted by the EUREF GB but includes all collected data from all sites included – a total of 117 sites (48 passive and 69 active GNSS stations) and 80 consecutive daily sessions.

The new realization of ETRS89 based on the EUREF Slovenia 2016 GNSS campaign is an extension of ETRS89 in Slovenia, which is referred to as ETRS89/D17 (the mean epoch is 2016.75 and the frame of realization is IGb08/ETRF2000). The official Slovenian realization, which is based on the combined solution of the EUREF GPS campaigns in years 1994–1996, is referred to as ETRS89/D96 or D96 EUREF (the mean epoch is 1995.55 and the frame of realization is ITRF96/ETRF96).

Unfortunately, the horizontal (projected) coordinate differences (∆e, ∆n) between both realizations (D17 and D96) reach up to 76 mm (Berk 2020). Furthermore, the analysis of the coordinates used for the SIGNAL network stations showed they should actually be considered its own realization, e.g. referred to as D96 SIGNAL, since they are based on the so-called Mini EUREF 2007 GPS campaign (the mean epoch is 2007.26 and the frame of realization is ITRF2005/ETRF96). Namely, the horizontal coordinate differences (∆e, ∆n) between these two realizations reach up to 48 mm (Berk 2020).

A pragmatic approach is chosen to solve the situation described above. Instead of a direct implementation of the new realization of ETRS89 (D17), a 'hybrid' solution is implemented. All three realizations (i.e. D96 EUREF, D96 SIGNAL, and D17) are taken into account. This new solution, referred to as ETRS89/D96-17, attempts to keep changes of coordinates as small as possible but eliminates inconsistencies due to different epochs and frames of realizations as well as distortions in GNSS networks caused by the changes in physical space in the two-decade period.

D96-17 coordinates are determined with a 6-parameter (rigid) transformation from D17 right into the middle between D96 EUREF and D96 SIGNAL realizations (Berk et al. 2020). In this way the corrections of coordinates (from both previous realizations into D96-17) reach up to 24 mm for horizontal (projected) coordinates (e, n) and up to 10 mm for ellipsoidal heights (h). This can be tolerated by the cadastral community without transformation of coordinates of spatial datasets.

The new realization of ETRS89 (D96-17) was officially implemented on 1st January 2020 with the change of coordinates of GNSS stations in the SIGNAL network. All fundamental geodetic network coordinates will also be updated according to their origin – either by network re-adjustment or by transformation.

A freeware tool for coordinate transformations is also available (ETRS89-SI 2020; Berk 2020), which performs coordinate transformations between the four realizations of ETRS89 in Slovenia (Figure 1):

- D96 EUREF,
- D96 SIGNAL,
- D17, and
- D96-17.

[1] Surveying and Mapping Authority of the Republic of Slovenia, Zemljemerska ulica 12, SI-1000 Ljubljana, Slovenia
e-mails: {klemen.medved, sandi.berk, jurij.rezek}@gov.si

[2] Geodetic Institute of Slovenia, Jamova cesta 2, SI-1000 Ljubljana, Slovenia
e-mails: {niko.fabiani, mihaela.triglav}@gis.si

[3] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Jamova cesta 2, SI-1000 Ljubljana, Slovenia
e-mails: {bozo.koler, tilen.urbancic, klemen.ritlop, miran.kuhar, polona.pavlovcic-preseren, oskar.sterle, bojan.stopar}@fgg.uni-lj.si

Conversions between four coordinate systems are also available, i.e.:

- 3D Cartesian (X, Y, Z),
- geodetic (λ, φ, h) referred to GRS80 ellipsoid,
- compound – with TM projected coordinates (e, n) and ellipsoidal heights (h), and
- compound – with UTM projected coordinates (e, n) and ellipsoidal heights (h).

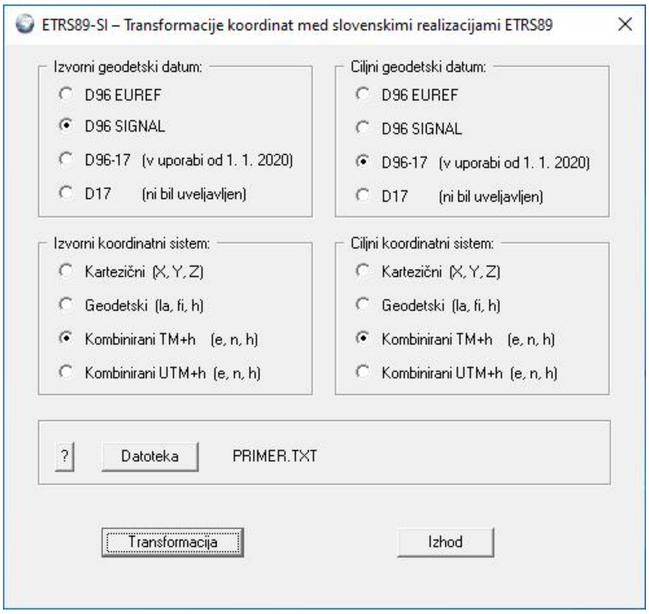

Figure 1: Dialog box of the ETRS89-SI program.

Various text formats (CSV, TXT, XYZ) are supported as well as the Bernese coordinate file format (CRD).

3 National GNSS Networks

There are two national CORS networks in Slovenia. The national Combined Geodetic Network – the so-called Zero-Order Network – consists of 10 GNSS stations set up at six locations; this network is operational since 2016 (Oven et al. 2019). The national GBAS Network (SIGNAL Network) consists of 16 GNSS stations in Slovenia and additional 14 GNSS stations in the neighbouring countries (Figure 2).

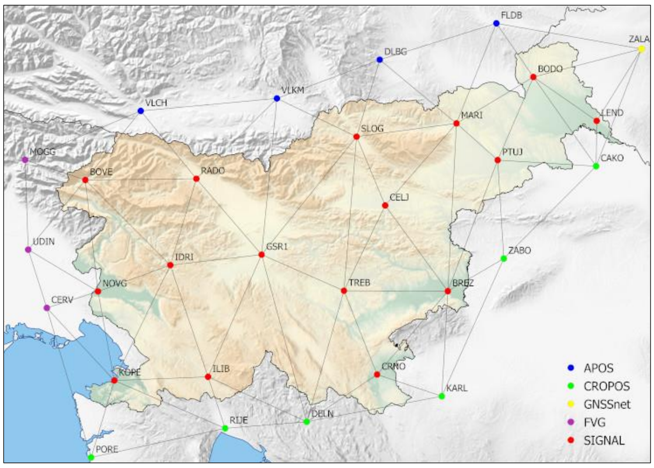

Figure 2: The SIGNAL network.

A few changes took place in the network since 2019:

- since the 1st January 2020, coordinates of the network stations have been replaced with new ETRS89/D96-17 coordinates (SIGNAL 2019);
- some of the stations of the SIGNAL network have been renamed, to make them compatible with their IERS DOMES names: BOVE → BOVC, BREZ → BRZC, CRNO → CRNM, MARI → MRBR, RADO → RDVL, TREB → TRBN (SIGNAL 2019);
- at the Lendava station (LEND), the coordinates changed due to renovation of the roof of the building the station is located on;
- the SIGNAL redundant system has been equipped with multi-GNSS capable software, currently running in its testing phase;
- in 2019 another archive for station data, derived directly from the GNSS receivers, was set up;
- a new station near the Koper (KOPE) station is being built;
- both national CORS networks have a new website.

Equipment changes (receivers + antennas) were made at six SIGNAL stations: Lendava (LEND), Ptuj (PTUJ), Maribor (MRBR), Celje (CELJ), Ljubljana (GSR1), Ilirska Bistrica (ILIB) and one on the Combined Geodetic Network: Prilozje 2 (PZA2).

The impact of the Petrinja 2020 earthquake (Croatia) on the coordinates of stations in the SIGNAL network was examined with the estimation of kinematic baseline components set between the SIGNAL stations. Seismic surface waves were detected on practically all SIGNAL stations and needed approximately 70 seconds to pass Slovenian territory (Sterle et al. 2021).

A new passive GNSS control network has been established in Slovenia (Majcen 2020). It was created in order to:

- monitor the quality of the national CORS network products and services and
- verify the quality of methods and measurement equipment for GNSS positioning.

The network points are evenly spaced over the country (Figure 3). 58 points were stabilized on 44 locations.

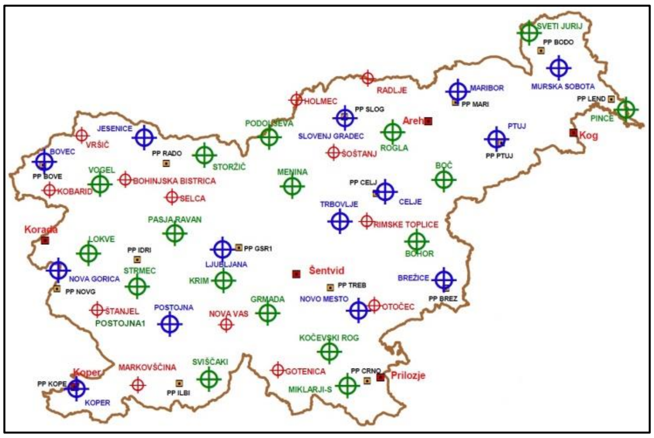

Figure 3: Passive GNSS control network of Slovenia;
sites with pairs of points are in blue and sites on hills are in green.

There are 14 locations with pairs of points creating calibration bases (Figure 4) to be used for testing RTK GNSS positioning according to the ISO 17123-8 standard. 17 points are located on hills (some of them at heights above 900 m) in order to check the quality of RTK GNSS heighting.

Figure 4: A pair of passive GNSS control points.

All new passive GNSS network points were determined from 24-hour static measurements in the D96-17 reference frame. The network points can be used by all surveyors. The coordinates and site descriptions are available from the web site of the Surveying and Mapping Authority (Portal Prostor 2021).

4 Vertical Reference Frame

As already reported, the new Slovenian height system, referred to as SVS2010, was implemented in daily geodetic practice (Medved et al. 2018, 2020a; Berk et al. 2019). A new “Technical Instruction for the Use of the New National Height System” was also prepared and published (Medved et al. 2020b). An on-line software called SiVis is available for transformation of heights determined by using GNSS technology (Figure 5). The heights referred to SVS2000 can be transformed into SVS2010 and vice versa (SIVIS 2019).

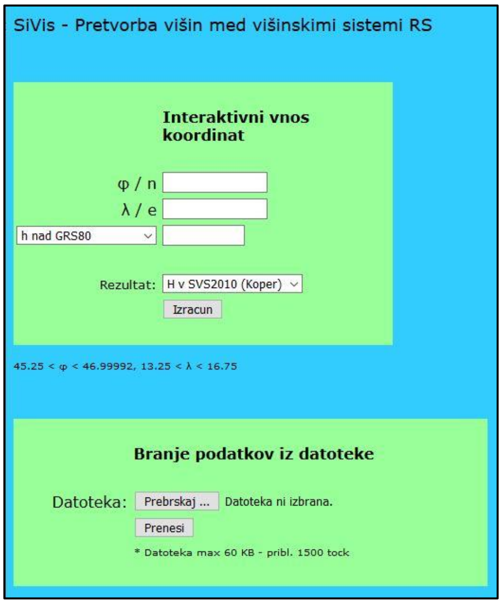

Figure 5: Dialog box of the SiVis program.

Some urban area levelling networks were also re-measured as their height quality was to low to recalculate them in the new national height system.

A campaign of regional gravimetric survey was completed. The measurements at the northeastern part of the territory of Slovenia were completed last and after four years’ campaign the whole country is covered by gravimetric points in the 4×4 km grid (Figure 6). The coastal area is densified with a point in the 2×2 km grid. The new gravimetric data will be used to improve a future geoid model (Medved et al. 2019).

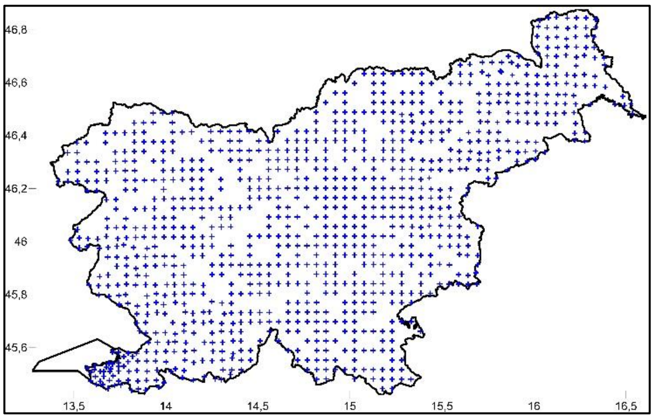

Figure 6: New regional gravimetric data, 4×4 km grid.

5 Ongoing Research Projects

1) Geokinematic Model of Slovenian Territory

In 2020 started a national research project called SLOKIN – Geokinematic Model of Slovenian Territory, which is led by the University of Ljubljana, Faculty of Civil and Geodetic Engineering, with participation of the University of Ljubljana, Faculty Natural Science and Technology, Geologic Survey of Slovenia, and Geodetic Institute of Slovenia. The aim of the project is to create the geokinematic model of active tectonic deformations in the territory of Slovenia, which is sitting in the north-eastern part of the collision zone between the Adriatic microplate and the Eurasian plate (Stopar et al. 2021). We will use repeated GNSS observations from about 50 points obtained in the time span of more than 20 years, and GNSS observations from the continuously operating national reference network called SIGNAL, comprising 15 stations with more then 15-year time series of data. We will additionally use the national high-quality levelling network which was measured in two campaigns within 30-year time span. Our dataset will be augmented with GNSS observations from continuously operating reference networks of neighboring countries and from EPN and IGS services. For control and verification, we will use interferometric analysis of ERS (1991 to 2003) and Sentinel-1 (from 2014 onward) radar satellite data covering our entire study area.

Geokinematic model will be used to create a model of active tectonic deformation. We will utilize various geological and geophysical data such as geological maps, the map of active faults of Slovenia that we produce and maintain as a public service, data about historical and instrumental seismicity, estimates of long-term fault-slip rates derived from tectonic geomorphology, and paleoseismological data about the past seismogenic activity of tectonic structures. Geokinematic model and derived products like the regional strain distribution map and velocity profiles will be used to identify active tectonic structures and to quantify their seismotectonic characteristics. Geological interpretation of the geokinematic model will be used to classify the region into areas according to the degree of tectonic activity and seismic risk.

2) Development of Research Infrastructure

Within the project called RI-SI-EPOS – "Development of Research Infrastructure for the International Competitiveness of the Slovenian RDI Area" in 2020 the University of Ljubljana, Faculty of Civil and Geodetic Engineering acquired a new research infrastructure, namely six high-end GNSS receivers, one tachymeter with laser scanner, one combined GNSS receiver and tachymeter and the Trimble RTXNet Processor software module with the support for Galileo, which is part of the Trimble Pivot Platform software that manages the national GNSS network (SIGNAL). Geodetic equipment is only one part of the newly acquired research infrastructure to be used at the field of geodesy, geology, seismology and for cooperation with the international community in the field of geosciences.

3) Reliability of Public GNSS Network

In the scope of a targeted research project (V2-1729) called "The Increase of Reliability of Public GNSS Network SIGNAL and Combined Zero Order Geodetic Network", lasting from 2018 to 2019, we have upgraded the methodology for improving the current procedures for management of both national GNSS networks. The stress of methodology development was on the improvement of operational reliability and quality control. We have to be aware that those systems are complex in terms of hardware and software maintenance and not all faults and problems can be detected and corrected immediately. Therefore, the methodology for its operational reliability checking and quality control has to be upgraded on regular basis by the new procedures and scientific findings (Ritlop et al. 2019).

4) Verification of Permanent GNSS Networks

To avoid the problems of inconsistency in determining coordinates at the level of detail by using different private GNSS stations, activities are undertaken to determine the appropriateness of using private GNSS stations for cadastral surveying. A conceptual model and methodology for the periodic verification of the quality of private GNSS stations and/or networks is being developed in order to gain better insight into the quality of the determination of the coordinates that will be included in the national databases.

5) Permanent Geodetic Marks

In the scope of a targeted research project (V2-1924) called "Permanent Geodetic Marks as a Basis for the High-Quality Performance of the Geodetic Profession" lasting from the end of 2019 to the beginning of 2021, we analysed still existing permanent geodetic marks from the era of classical geodesy: trigonometric, geodynamic, levelling, gravimetric and cadastral permanent signs. Their potential for modern surveying, cultural heritage and touristic usage was described. A conceptual model for new digital collection of important geodetic marks rated by all three perspectives was developed and a sample collection was made. Through interviews made with senior, experienced surveyors, we identified additional interesting geodetic marks, which have a great potential for cultural heritage preservation (Triglav Čekada and Jenko 2020).

Acknowledgement

Some of the activities presented in this report were realised within the research projects titled SLOKIN – "Geokinematic Model of Slovenian Territory" (J2-2489), "The Increase of Reliability of Public GNSS Network SIGNAL and Combined Zero Order Geodetic Network" (V2-1729), "Permanent Geodetic Marks as a Basis for the High-Quality Performance of the Geodetic Profession" (V2-1924), "Development of Methodology and System for Verification of GNSS Permanent Networks and Stations" (V2-1944), and within the research program "Geoinformation Infrastructure and Sustainable Spatial Development of Slovenia" (P2-0227), supported by the Slovenian Research Agency (ARRS). The RI-SI-EPOS project is co-financed by the Ministry of Education, Science and Sport of the Republic of Slovenia and by the European Union from the European Regional Development Fund (ERDF).

References

Berk, S. (2020). ETRS89-SI – a Freeware Tool for Coordinate Transformations between the Slovenian Realizations of ETRS89. *Geodetski Vestnik*, 64 (4), 594–602 (in Slovene), http://www.geodetski-vestnik.com/64/4/gv64-4_berk.pdf

Berk, S., Fabiani, N., Koler, B., Komadina, Ž., Kuhar, M., Medved, K., Oven, K., Pavlovčič Prešeren, P., Režek, J., Ritlop, K., Sterle, O., Stopar, B., Triglav Čekada, M. (2019). National Report of Slovenia to the EUREF 2019 Symposium in Tallinn. *Symposium of the IAG Reference Frame Subcommission for Europe (EUREF)*. Tallinn, Estonia, May 21–24, 2019, 6 p., http://www.euref.eu/symposia/2019Tallinn/Symposium2019-Tallinn.html

Berk, S., Sterle, O., Medved, K., Komadina, Ž., Stopar, B. (2018). Computation of the EUREF Slovenia 2016 GNSS Campaign. *Symposium of the IAG Reference Frame Subcommission for Europe (EUREF)*. Amsterdam, the Netherlands, May 30–June 1, 2018, 27 p. + appendices, http://www.euref.eu/symposia/2018Amsterdam/01-03-p-Berk.pdf

Berk, S., Sterle, O., Medved, K., Stopar, B. (2020). ETRS89/ D96-17 – a Result of the EUREF Slovenia 2016 GNSS Campaign. *Geodetski Vestnik*, 64 (1), 43–67 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2020.01.43-67

ETRS89-SI (2020). Program ETRS89-SI. Portal Prostor, Surveying and Mapping Authority of the Republic of Slovenia, https://www.e-prostor.gov.si/aplikacije/page/2/ or https://www.e-prostor.gov.si/fileadmin/DPKS/Transformacije_ETRS89/Aplikacije/ETRS89-SI.zip

EUREF (2018). EUREF 2018 Resolutions. *Symposium of the IAG Reference Frame Subcommission for Europe (EUREF)*. Amsterdam, the Netherlands, May 30–June 1, 2018, 4 p., http://www.euref.eu/symposia/2018Amsterdam/06-01-Resolutions-EUREF2018.pdf

MAJCEN, D. (2020). Creation of a Passive GNSS Control Network in Slovenia. *Geodetski Vestnik*, 64 (2), 169–181 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2020.02.169-181

MEDVED, K., BERK, S., FABIANI, N., KOLER, B., REŽEK, J., STERLE, O., STOPAR, B. (2018). National Report of Slovenia to the EUREF 2018 Symposium in Amsterdam. *Report on the Symposium of the IAG Reference Frame Subcommission for Europe (EUREF)*. Amsterdam, the Netherlands, May 30–June 1, 2018, 4 p., http://www.euref.eu/symposia/2018Amsterdam/05-21-p-Slovenia.pdf

MEDVED, K., BERK, S., KOLER, B., STERLE, O., STOPAR, B. (2020a). Coordinate Systems as a Basis for Good Decision Making in Physical Space. *Summaries of presentations at the 48th Slovenian Surveying Day*. Ljubljana, Slovenia, September 17, 2020, pp. 28–31.

MEDVED, K., KOZMUS TRAJKOVSKI, K., BERK, S., STOPAR, B., KOLER, B. (2020b). Implementation of the New Slovenian Height System (SVS2010). *Geodetski Vestnik*, 64 (1), 33–42 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2020.01.33-42

MEDVED, K., KUHAR, M., KOLER B. (2019). Regional Gravimetric Survey of Central Slovenia. *Measurement*, 136, 395–404. https://doi.org/10.1016/j.measurement.2018.12.065

OVEN, K., RITLOP, K., TRIGLAV ČEKADA, M., PAVLOVČIČ PREŠEREN, P., STERLE, O., STOPAR, B. (2019). Establishment of the Slovenian Combined Geodetic Network and Its Operation Analysis for the Period 2016–2018. *Geodetski Vestnik*, 63 (4), 491–513 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2019.04.491-513

PORTAL PROSTOR (2021). Mreža kontrolnih GNSS-točk (in Slovene), https://www.e-prostor.gov.si/zbirke-prostorskih-podatkov/drzavni-prostorski-koordinatni-sistem/zbirka-podatkov-drzavnih-geodetskih-tock/#tab4-1643

RITLOP, K., FABIANI, N., OVEN, K., PAVLOVČIČ PREŠEREN, P., STERLE, O., STOPAR, B., TRIGLAV ČEKADA, M. (2019). Increase of Reliability of the SIGNAL and Zero-Order GNSS Networks. *Geodetski Vestnik*, 63 (4), 514–524 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2019.04.514-524

SIGNAL (2019). New Coordinates of Permanent Stations in the SIGNAL Network Based on the EUREF Slovenia 2016 GNSS Campaign. Surveying and Mapping Authority of the Republic of Slovenia and Geodetic Institute of Slovenia (in Slovene), https://gu-signal.si/wp-content/uploads/2020/06/Obvestilo_12_12_2019-EUREF_SVN_2016.pdf

SIVIS (2019). Program SIVIS. Portal Prostor, Surveying and Mapping Authority of the Republic of Slovenia, https://www.e-prostor.gov.si/aplikacije/ or http://sitranet.si/sivis.html

STERLE, O., HAMZA, V., RITLOP, K., STOPAR, B., PAVLOVČIČ PREŠEREN, P. (2021). Omrežje GNSS-postaj SIGNAL za spremljanje potresov: Primer potresa v Petrinji, december 2020 (SIGNAL GNSS Network for Monitoring Earthquakes: The Case of Petrinja Earthquake, December 2020). In: *Raziskave s področja geodezije in geofizike 2020*. Proceedings. Ljubljana, January 28, 2021, pp. 105–117 (in Slovene), http://fgg-web.fgg.uni-lj.si/SUGG/referati/2021/SZGG_2021_Sterle_in_dr.pdf

STOPAR, B., STERLE, O., RITLOP, K., PAVLOVČIČ PREŠEREN, P., KOLER, B., TRIGLAV ČEKADA, M., RADOVAN, D., FABIANI, N., JAMŠEK RUPNIK, P., ATANACKOV, J., BAVEC, M., VRABEC, M. (2021). Projekt SLOKIN – geokinematski model ozemlja Slovenije (SLOKIN Project – Geokinematic Model of Slovenian Territory). In: *Raziskave s področja geodezije in geofizike 2020*. Proceedings. Ljubljana, January 28, 2021, pp. 87–104 (in Slovene), http://fgg-web.fgg.uni-lj.si/SUGG/referati/2021/SZGG_2021_Stopar_in_dr.pdf

TRIGLAV ČEKADA, M., JENKO, M. (2020). Types of Trigonometric Points in Slovenia. *Geodetski Vestnik*, 64 (4), 469–488 (in Slovene), https://doi.org/10.15292/geodetski-vestnik.2020.04.469-488