Paper presented at the 31st EUREF Symposium held virtually from Zagreb, Croatia, June 1–3, 2022

National Report of Slovenia
to the EUREF 2022 Symposium in Zagreb

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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 2021–2022.

2 Terrestrial Reference Frame

A freeware tool (standalone desktop application) for time-dependent transformations between the Slovenian and international terrestrial reference frames has been made available (ITRS-SI 2021; Berk 2021). Six terrestrial reference frames are supported, i.e. the latest two Slovenian realizations of ETRS89:

- ETRS89/D17 which 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) and
- ETRS89/D96-17 – a 'hybrid' solution which is based on the ETRS89/D17 but attempts to keep changes of coordinates (as compared to the previous national realization of ETRS89) as small as possible (Berk et al. 2020); this new realization was officially implemented on 1st January 2020,

and the latest four releases of the ITRF:

- ITRF2000 which was in use between 2nd December 2001 and 4th November 2006,
- ITRF2005 which was in use between 5th November 2006 and 16th April 2011,
- ITRF2008 which was in use between 17th April 2011 and 28th January 2017, and
- ITRF2014 which has been in use since 29th January 2017.

The most common text formats (CSV, TXT, XYZ) are supported as well as the Bernese coordinate and velocity file formats (CRD+VEL).

There are three options for handling velocities (Fig. 1):

- zero velocities in ETRF2000 (i.e., assuming that the country is part of tectonically stable Europe),
- velocities taken from the input file (transformation of CORS stations with known velocities), or
- interpolated velocities based on a verified position/velocity dataset (velocity field modelling).

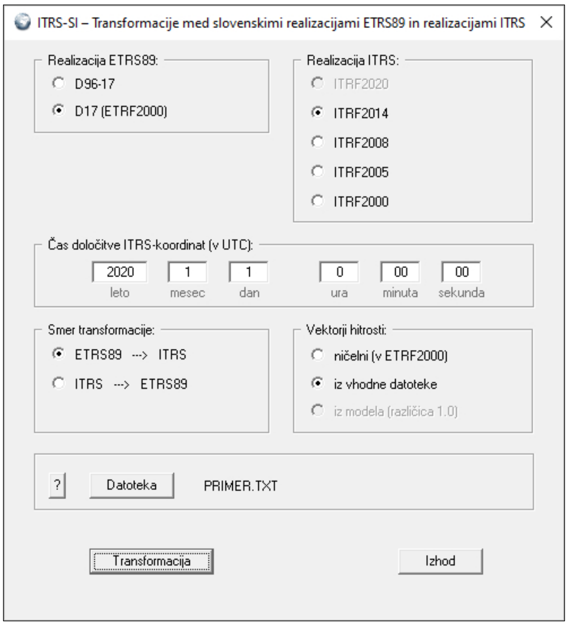

Figure 1: Dialog box of the ITRS-SI software.

The incorporation of the national geokinematic model into the transformation procedure in order to improve the accuracy of time-dependent transformations is in progress. The transformation procedure which takes into account the specificities of the ETRS89/D96-17 has been proposed (Berk and Medved 2021); it guarantees high accuracy and full reversibility of the supported time-dependent transformations. As for now, the velocity interpolation approach has been tested by using EPN stations only (Fig. 2) since the velocities of the Slovenian CORS networks still require some improvements and final verification.

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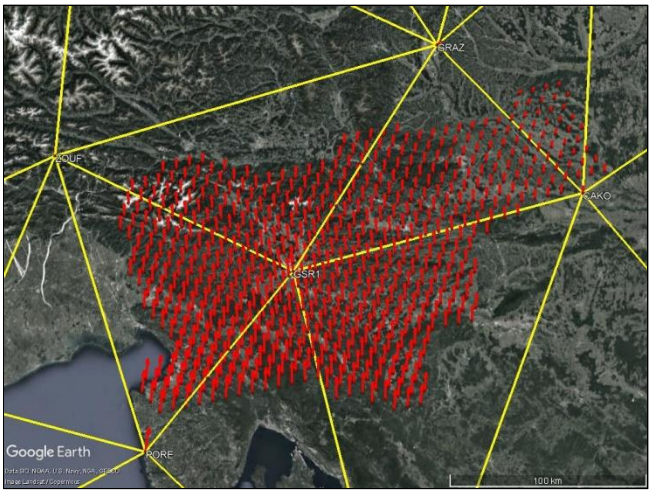

Figure 2: Velocity field interpolation.

The new ITRS-SI software has been used for testing some free online post-processing positioning services, e.g.:

- AUSPOS Online GPS Processing Service, provided by the Australian Government, Geoscience Australia (https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos),
- CSRS-PPP Online Positioning Service, provided by the Government of Canada, Natural Resources Canada (https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos), and
- CenterPoint RTX Post-Processing Service, provided by Trimble Navigation, Ltd. (https://trimblertx.com).

All these services are global. The AUSPOS service is based on Bernese GNSS software; the network datum is defined with the minimum constraint solution by using 15 nearest IGS stations as reference frame stations. The other two services are based on PPP. All three services provide final coordinates in the ITRF2014 at the epoch of observations.

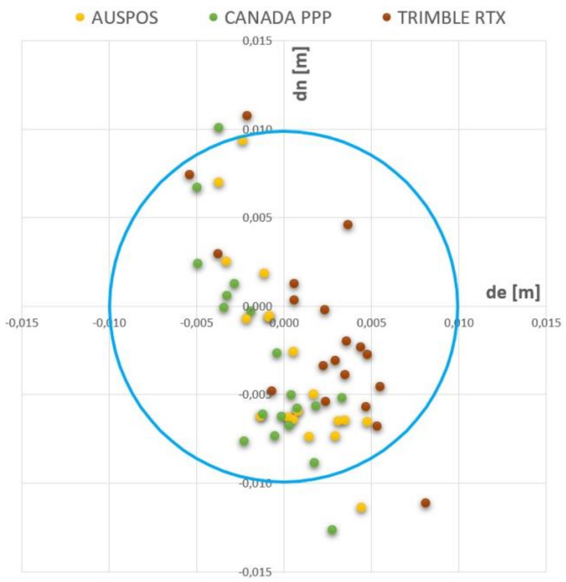

Figure 3: Coordinate differences between the official ETRS89/ D96-17 coordinates in the Slovenian CORS networks and coordinates derived from the AUSPOS (in orange), CSRS-PPP (in green), and TRIMBLE RTX services (in brown); daily RINEX data from 3rd November 2021 are used.

By using the above mentioned online post-processing positioning services and the ITRS-SI software for transformation into the ETRS89/D96-17, the horizontal coordinate accuracy close to 1 cm is achieved for daily RINEX data (Fig. 3). The reference epoch of the current Slovenian realization of ETRS89 is 2016.75 and some GNSS stations have a bit larger difference also due to the recent equipment changes.

Further improvement of the results is expected after the implementation of the national geokinematic model into our transformation solution which should minimize the impact of local tectonics to the accuracy of the time-dependent transformation between the Slovenian and international terrestrial reference frames.

First tests of the Trimble RTX (real-time PPP) service have also been performed. The initialization is fast, and the coordinate repeatability seems to be comparable to GBAS services. However, global settings (ITRF2014 + UTM-33N) should be used and the transformation to the ETRS89/ D96-17 should be performed in the office due to the specific character of the ETRS89/D96-17.

3 National GNSS Networks

The Slovenian Combined Geodetic Network (so-called Zero-Order Geodetic Network) includes 10 GNSS stations set up at six locations. Three of these stations were proposed for new EPN stations in August 2021 (Fig. 4). All three locations have double GNSS stations; the stations installed on the eastern side of each pillar are proposed, i.e.:

- ARA2 (Areh east) near St. Areh's Church, Frajhajm (village) in the Municipality of Slovenska Bistrica,
- KDA2 (Korada east) on the top of Mt. Korada, Zapotok (village) in the Municipality of Kanal ob Soči, and
- PZA2 (Prilozje east) at the Prilozje Sport Airfield, Boginja Vas (village) in the Municipality of Metlika.

Figure 4: Locations of the existing (orange circles) and new EPN stations (blue diamonds).

All three new GNSS stations were officially included to EPN on 23rd January 2022. They are equipped with Leica GR25/GR30 receivers, Leica LEIAR20-LEIM antennas with absolute individual calibrations, Vaisala WXT 520 micro weather stations, and Leica Nivel 210 precision inclination sensors. The data are sent to two EPN Data Centres (BEV and BKG); the stations are included to the sub-networks of four EPN Analysis Centres (BEV, RGA, SGO, and UPA).

In addition to the Zero-Order Geodetic Network we have a national GBAS network called SIGNAL Network which consists of 16 GNSS stations in Slovenia and 14 GNSS stations in the neighbouring countries (Fig. 5).

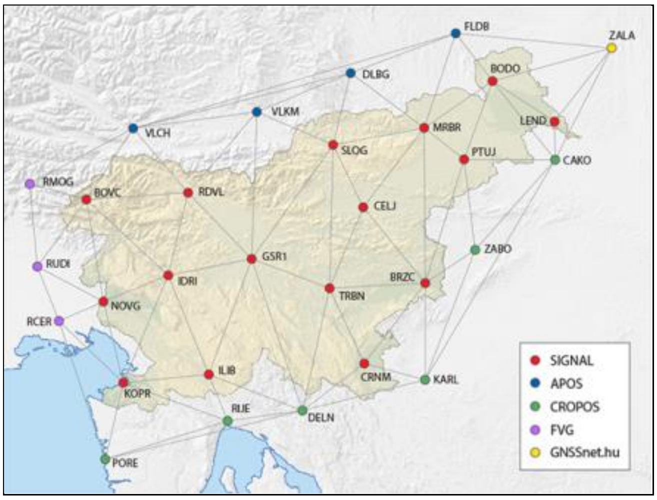

Figure 5: The new configuration of the SIGNAL Network.

The following changes of the network configuration were made in the last year:

- a new processing server for the redundant system and a new data server were installed;
- a new station in Koper (KOPR) was built in the vicinity of the old station (KOPE) and put in operation in April 2022;
- the new KOPR station replaced the previous KOPE station (found to be unstable) in the SIGNAL Network thus changing the network configuration;
- a major upgrade of the production version of the system was performed in April 2022, adding Galileo GNSS capabilities;
- the coordinates for the station in Celje (CELJ) were re-calculated and officially replaced due to larger diffe-rences detected after the antenna change in July 2020.

In the last year, the equipment changes (receivers+ antennas) were made at four SIGNAL stations – in Idrija (IDRI), Nova Gorica (NOVG), Koper (KOPR), and Ljubljana (GSR1).

4 Vertical Reference Frame

Some shorter levelling polygons in total distance of 40 km have been re-measured in order to improve the quality of levelling networks, mainly in urban areas.

Heights of the old trigonometric points (from II to IV order) have been systematically checked. Some gross errors are detected, and re-measurements of heights are performed by using GNSS levelling method.

The quality of GNSS levelling has been tested after implementing the new Slovenian height reference system to daily geodetic practice (e.g., Medved et al. 2021a); the new system is referred to as SVS2010/Koper. The corres-ponding new height reference surface, denoted as SLO_ VRP2016/Koper, was applied. By using RTK GNSS levelling technique, an average height difference of ~2 cm is obtained in the national height reference system (i.e., heights above sea level) for benchmarks in the Ljubljana city area (Kuhar et al. 2021).

The national Bouguer anomaly map was updated in 2021 (Fig. 6); the old map was a few decades old. Quite a few new gravimetric measurements as well as high quality digital terrain models were made available in recent years. The methodology and standards for creating gravity anomaly maps have also changed. Some gross errors detected in the set of old gravimetric data are now eliminated. The new Bouguer anomaly map is proven to be of a significantly better quality as compared to the old one (Medved et al. 2021b and 2022).

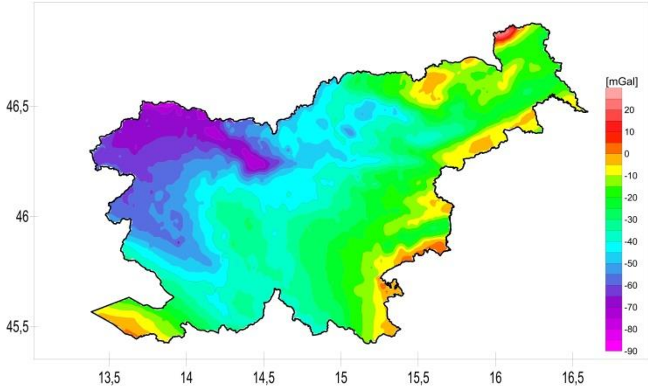

Figure 6: New complete Bouguer anomaly map of Slovenia.

5 Ongoing Research Projects

1) Geokinematic Model of Slovenian Territory

The activities in the SLOKIN project (Stopar et al. 2021) during the period of 2021/2022 were focused on the arrangement of the archive of available GNSS measure-ments in Slovenia from 1994 to the end of 2021. The archive includes the data from permanent GNSS stations in Slovenia also campaign GNSS measurements data in the duration of at least 48 hours. Besides the arrangement of GNSS measurements data and evaluation of its quality and completion, we put a lot of effort to arrange also metadata needed in future computations. We were able to obtain public data and data for some very important areas from private and state owned companies (Fig. 7).

Together with the geological part of the project team we evaluated the GNSS data archive regarding the site distribution and its importance to get the proper insight into the geodynamics and recent tectonics in the area. During the spring of 2022, the geological part of the project team is performing field reconnaissance work on selected sites. We plan to perform repeated GNSS measurements to 10–15 GNSS sites in 2022.

Within the project, we obtained the very first and preliminary estimation of vertical velocities on Slovenian territory, based on repeated levelling measurements of the national levelling network of 1st order and some individual levelling polygons of high-quality levelling measurement data. The first period of levelling measurements ranged from 1947 to 2006 and the second one from 2003 to 2019. The time interval between first and repeated measurements spans from 11 to 67 years.

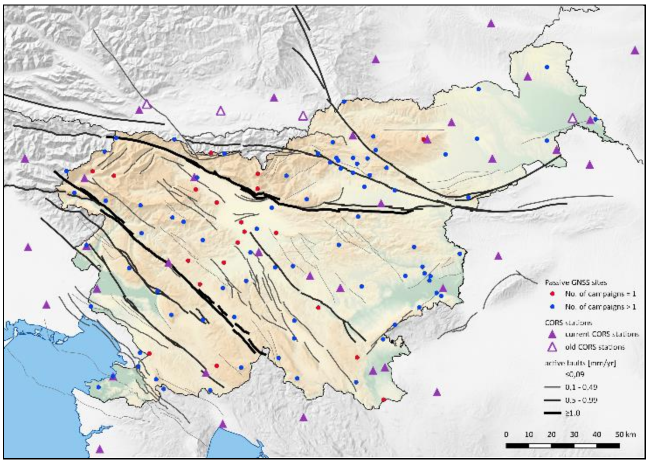

Figure 7: Spatial distribution of sites in the GNSS data archive of the project.

Based on repeated levelling measurements, which include 2168 km of leveling polygons of good and comparable accuracy ($\hat{\sigma}_0$ = 0.38 mm/km), we estimated vertical velocities of 1043 benchmarks range from –2.7 mm/year to +2.0 mm/year.

The above-mentioned results are still under consideration and are obtained on the basis of several different adjustment and velocity estimation procedures. Namely, we want to perform adjustment of the levelling measurements by taking into account the very long-time duration of both individual levelling measurements periods. We expect to present final results about vertical velocity distribution at the Slovenian territory in the next year.

2) Development of Research Infrastructure

We present here a status update on geodetic equipment, acquired in 2020 within the project RI-SI-EPOS – "Development of Research Infrastructure for the International Competitiveness of the Slovenian RDI Area" (Medved et al. 2021a). Five of six GNSS receivers are fully operational and integrated into the national CORS networks. Last receiver is used for stability and quality monitoring of the SIGNAL Network. Monitoring is done by RTK positioning using different SIGNAL Network RTK products. Positioning is done by the receiver's RTK engine while data logging and analysis is done by an in-house developed application (Fig. 8).

Trimble RTXNet processor with support for Galileo was added to the SIGNAL network for extensive internal testing. No major problems were found, and Galileo did not have any negative effects on the performance of RTK positioning. Therefore, RTK products with Galileo included will be launched for public use in 2022.

Leica Nova MS60 MultiStation is used for local stability monitoring of six national Combined Geodetic Network sites; their main purpose is high-quality long-term realization of national terrestrial reference frame.

Figure 8: FGG3 monitor – an application for QC monitoring of SIGNAL Network RTK products (data viewer).

3) Maintaining the National Reference Frame

Establishment and maintaining of national coordinate system of Slovenia in addition to several geodynamical researches on a basis of repeated or continuous GNSS surveys have shown slight but permanent geodynamical activity of territory of Slovenia. To determine magnitude and nature of this activity, processing of GNSS data from almost 100 permanent GNSS stations located on the continent of Europe is done for almost 5 years (Sterle et al. 2021). This includes all permanent GNSS stations from the SIGNAL and Combined Geodetic Networks in together with numerous GNSS stations from EPN in the vicinity of Slovenia and IGS stations from the whole Europe.

Processing of GNSS data is done on a daily basis with two independent software. The first one is Bernese GNSS Software and the other is gPPP, a GNSS processing software developed at Geodetic Department of UL FGG and is based on PPP principle. The first results of the processing are daily coordinates in ITRF; a high level of congruency is obtained for both solutions.

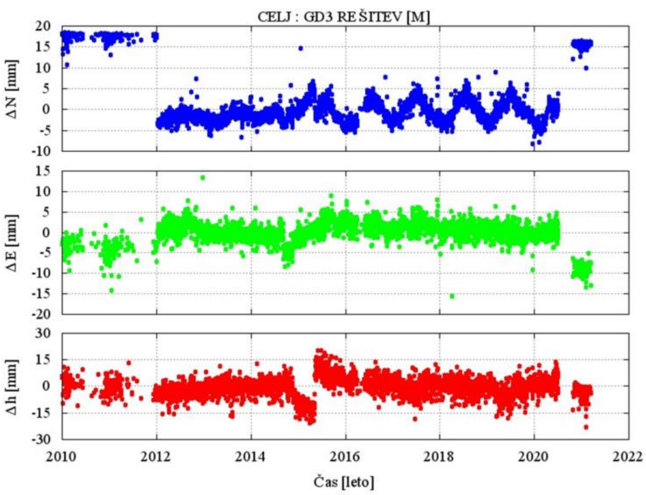

Figure 9: PPP time series of ITRF coordinates for the CELJ station with several discontinuities.

Due to much longer processing time within Bernese the results extend over 4 years, whereas in case of gPPP the results extend over 11 years of data. Due to long period of time, a significant effect of time series discontinuities on determined coordinates and more importantly on estimated velocity vectors is detected (Fig. 9).

Planed activities in the future are focused on constructing a framework to automatically detect and remove discontinuities from estimated daily coordinates in order to obtain reliable coordinates and velocity vectors.

4) Verification of Permanent GNSS Networks

In a targeted research project (V2-1944) titled "Development of methodology and system for verification of GNSS permanent networks and stations" a methodology was developed in order to assure positioning in a unique coordinate frame for national as well as private GNSS stations and networks (Pavlovčič Prešeren et al. 2021). Both national CORS networks (SIGNAL and Zero-Order Combined Geodetic Network) were established for geodetic positioning as well as for scientific purposes by the Surveying and Mapping Authority of the Republic of Slovenia and are maintained by the Geodetic Institute of Slovenia with a collaboration of the Geodetic Department of UL FGG. Coordinates of all stations from both CORS networks are determined in the national terrestrial reference frame ETRS89/D96-17 and represent its backbone.

However, there are also numerous permanent GNSS stations in Slovenia that are established by private companies for their positioning purposes as well as one private network, i.e., Geoservis SmartNet which is a part of the Leica's global SmartNet. Currently, there is no assurance that coordinates of those permanent stations are consistent with the national coordinate reference system and that positioning services based of these stations provides coordinates in the national coordinate reference system.

The purpose of the project is to develop a methodology for testing and verifying private permanent GNSS networks and stations to perform high quality positioning in the national coordinate reference system. The verification is done in four steps in order to assure:

- proper establishment of permanent GNSS stations focusing on selection of micro/macro locations, geological aspects of selected location, conditions for tracking GNSS signals, stabilization of geodetic point, selection of GNSS equipment etc.,
- high quality coordinate determination of all permanent GNSS stations in the national coordinate reference system that are valid for longer period of time,
- high quality positioning of geodetic points on a basis of permanent GNSS stations/networks in a single-station mode as well as within network products (VRS, MAC, iMAC …), and
- proper and transparent managing of GNSS data for dissemination in real time or for post-processing.

The quality of the positioning based on private GNSS networks/stations must not be worse than the quality of positioning based on the national permanent GNSS network (SIGNAL Network).

5) Permanent Geodetic Marks

Based on the results of the targeted research project (V2-1924) titled "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 (Triglav Čekada et al. 2021), where we analysed still existing permanent geodetic marks from the era of classical geodesy (trigonometric, geodynamic, levelling, gravimetric and cadastral permanent signs), the work continued with the preparation of initiatives for the inscription of selected geodetic marks in the Slovenian Cultural Heritage Register (https://www.gov.si/teme/register-kulturne-dediscine/). We started with the first-order trigonometric point at Krim, the origin of the coordinate system established for the major part of today's Slovenia at the beginning of 19th century (Oven and Škafar 2022).

The initiatives for the inscription of six cadastral municipality boundary marks from the Franciscean land cadastre surveying (1818–1819) in the Littoral (Primorska) region were also prepared (Fig. 10). Some of those boundary marks can be treated as anchors for the preservation of local memories (fairy tales). The work on the preparation of initiatives for inscription in the Slovenian Cultural Heritage Register is in progress.

Figure 10: Cadastral municipality boundary marks: Markovščina - Gradišče, Križen Drev, and Tri Kunfini.

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).

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