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National Report of Slovenia
to the EUREF 2023 Symposium in Gothenburg

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1 Introduction

This report is a short review of activities related to the national geodetic reference system, geodetic networks and activities related to EUREF in Slovenia for the period 2022–2023.

2 Terrestrial Reference Frame

Within the Recovery and Resilience Plan – a national programme of reforms and investments to mitigate the economic and social impact of the COVID-19 pandemic in Slovenia, a project referred to as the SLO4D – *Zeleni slovenski lokacijski okvir* (SLO4D Brochure, 2023) was started in 2022. One of the sub-projects covers activities of the national spatial reference system modernization which are intended:

1) to introduce the fourth dimension to the national spatial reference system (i.e., a time-dependent system) and
2) to establish a quality assurance system to support the national spatial reference system and its users.

The kick-off conference of the SLO4D project was held on 12th April 2023 (Fig. 1). The project activities will finish in 2026.

Figure 1: The SLO4D project kick-off conference

The tasks within the first sub-project activity (intended to implement a time-dependent spatial reference system) are:

- upgrading and densification of the existing national combined geodetic network – building up two new zero-order stations (2022–2024),
- purchase and installation of measuring and other equipment (2024–2026),
- providing a national geokinematic/deformation model (2024–2025), and
- implementing a four-dimensional national spatial reference system – via time-dependent coordinate transformations (2025–2026).

The motivation to start the SLO4D project is active geodynamics in the area – at least as compared with more central part of Europe (Fig. 2).

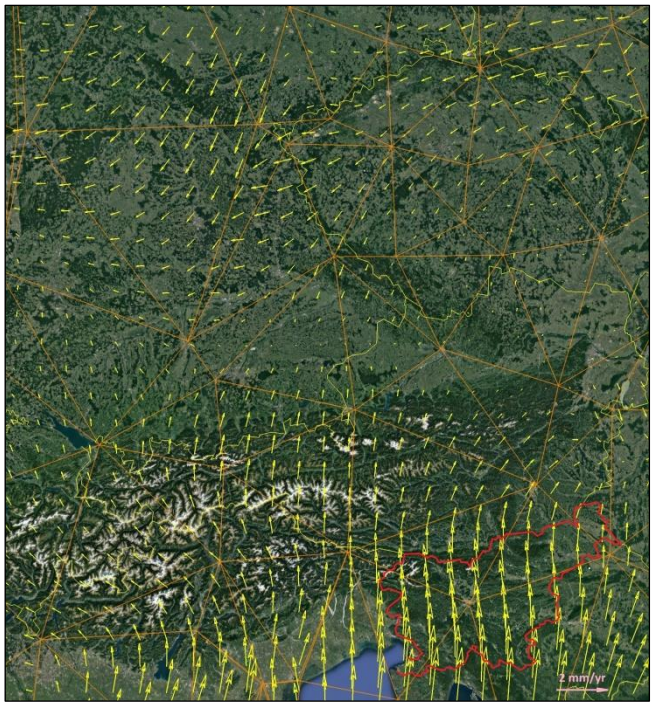

Figure 2: Horizontal velocity model in the ETRF2000 based on the EPN data

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The tasks within the second sub-project activity (focused on the quality of the national spatial reference system and user experience) are:

- establishing a system for quality control and quality assurance of the national spatial reference system (2024–2025) and
- establishing a system to support the users of the national spatial reference system (2025–2026).

The above-mentioned activities in the SLO4D project are carried out in close cooperation between the Surveying and Mapping Authority of the Republic of Slovenia, the Geodetic Institute of Slovenia, and the University of Ljubljana, Faculty of Civil and Geodetic Engineering. The analysis of the zero-order network and gathering the project documentation for its densification is in progress (Oven et al., 2022). The activities of the analytical centre for the national GNSS networks resulted in the first release of the velocity vectors for all Slovenian CORS networks (Sterle et al., 2023). Some extra effort was put into dealing with discontinuities in the GNSS time series in order to provide more reliable velocities (Figs. 3, 4).

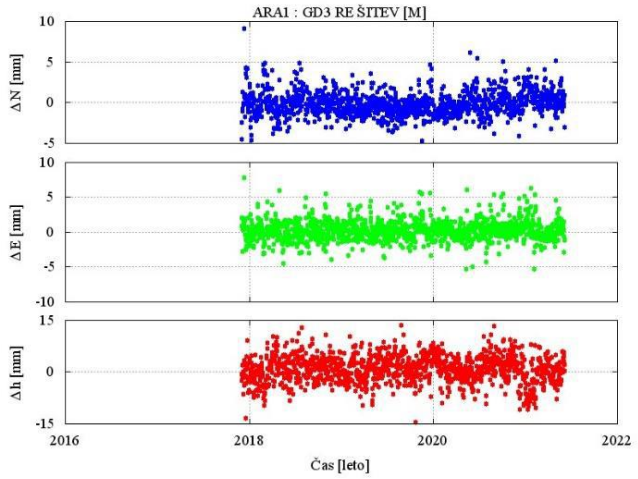

Figure 3: Position time series for the ARA1 station (Areh · west)

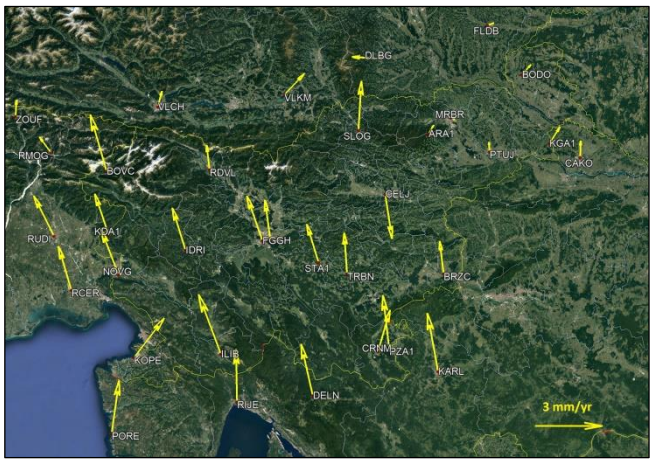

Figure 4: Horizontal velocities in the ETRF2000 for the Slovenian CORS networks

Within the ongoing activities to remove discontinuities from the time series, several other modifications in obtaining daily coordinates of reference stations were introduced in data processing. The first one was to reduce number of included permanent stations outside Slovenia and to rely on EPN products in greater extent. In the end, 19 reference stations with label C0 from EPN in the vicinity of Slovenia are used as datum points. The second improvement was to use multi-GNSS observations – beside GPS and GLONASS, Galileo observations are currently also processed. In the future, BDS will also be considered. Finally, in order to remove all discontinuities from the coordinate time series, EPN discontinuities for reference stations are adopted, whereas for Slovenian permanent stations, time series are analysed, and more than one position and velocity is estimated for each station if needed.

In order to densify the velocity data, 72-hour static GNSS measurements have been carried out at the network of geodynamic sites (Fig. 5) over a few-year period. Most of these sites date back to the first EUREF GPS campaigns in the years 1994–1996.

Figure 5: 72-hour static GNSS survey at the SOCE (Socerb) geodynamic site in October 2022

3 National GNSS Networks

The Slovenian Combined Geodetic Network – so-called Zero-Order Geodetic Network – consists of 10 GNSS stations which are set up at six locations. The following changes have been made in the last year:

- the obsolete Leica GRX1200 receiver on the STA1 (Šentvid pri Stični · west) station was replaced by a Leica GR10 receiver;
- due to the deactivation of the 3G mobile network in Slovenia, routers on all stations were replaced with 4G compatible models;
- Alberding GNSS Status Software was upgraded to the latest version;
- telecommunications in the data centre were upgraded to fibre optics.

The national GBAS network – the SIGNAL Network – consists of 16 GNSS stations in Slovenia and additional 14 GNSS stations in the neighbouring countries (Fig. 6). The following changes of the network configuration were made in the last year:

- due to the deactivation of the 3G mobile network in Slovenia, routers on all stations were replaced with 4G compatible models;

- the problem occurred in October 2022 due to a sudden limitation of bandwidth in the SIGNAL Network Analysis Center was solved;
- automated scripts to archive RINEX data directly from receivers (not TPP) and check data completeness were created;
- the receiver on the BRZC (Brežice) station was changed due to a hardware malfunction,
- the Trimble Pivot Platform software was upgraded to the latest version in May 2023 – testing is in progress on the redundant/backup system.

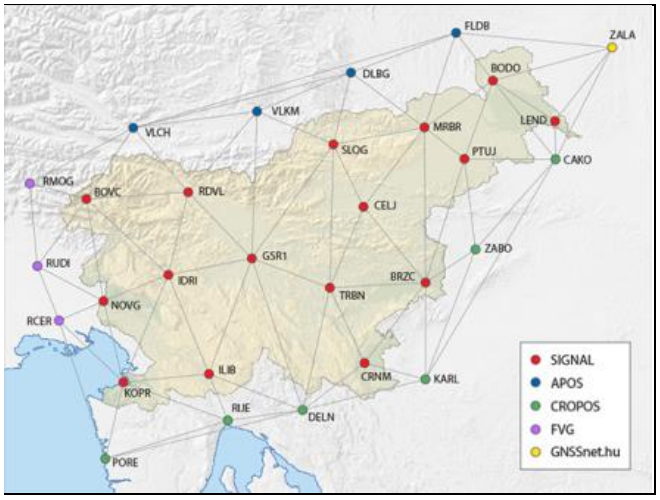

Figure 6: The configuration of the SIGNAL Network

4 Vertical Reference Frame

Works already mentioned in the previous national report (Medved et al., 2022) have continued. Some additional levelling polygons in total distance of ~70 km have been measured in order to improve the quality of the levelling networks. Also, some new GNSS/levelling points have been added and connected to the levelling and gravimetric networks in order to improve future geoid fitting. Periodical levelling network control of the Koper tide gauge is performed.

Development of the national height transformation model between SVS2000/Trieste and SVS2010/Koper is in progress. A case study for an area in eastern Slovenia was conducted (Koler et al., 2022). The aim of this activity is to determine an official transformation model and software for transformations between the old and new national height systems.

Research on the modelling of vertical gravity gradient based on geodetic and geophysical data has been conducted (Odalović et al., 2022; Medved, 2023).

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 new Slovenian height reference surface (SLO-VRP2016/Koper) was added to the geoid repository of the International Service for the Geoid (ISG Repository, 2023; Reguzzoni et al., 2021). This hybrid quasi-geoid model is licensed under CC BY 4.0 and can now be accessed via DOI (Omang and Medved, 2016).

In January 2023, two new compound coordinate systems for Slovenia were added to the EPSG Geodetic Parameter Dataset (EPSG Dataset, 2023; Berk and Medved, 2023):

- **EPSG 10245** … ETRS89-D96/φλ+SVS2010/H (EPSG 4765 + EPSG 8690) and
- **EPSG 10246** … ETRS89-D96/TM+SVS2010/H (EPSG 3794 + EPSG 8690).

The new coordinate reference systems are created from the official Slovenian horizontal and height reference systems. Two new transformations were also added:

- **EPSG 10247** … ETRS89-D96/φλh → SVS2010/H (EPSG 4883 → EPSG 8690) and
- **EPSG 10248** … ETRS89-D96/φλh → ETRS89-D96/φλ+SVS2010/H (EPSG 4883 → EPSG 10245)

The motivation to add compound coordinate reference systems into the EPSG Dataset is transition of spatial datasets from 2D datasets with heights as attributes to real 3D datasets, for example in the cadastre. Standardization of the compound coordinate reference systems at the international level is important to ensure the development of GIS software, applications, and web services supporting 3D datasets.

5 Ongoing Research Projects

1) Geokinematic Model of Slovenian Territory

The activities in the SLOKIN project (Stopar et al., 2022) during the period of 2022/2023 were focused on the performing GNSS measuring campaign on sites of geological importance. Based on the archive of GNSS data in Slovenia from 1994 on the expertise of the geological part of the project team, we evaluated app. 20 sites with in the past already performed GNSS observations and performed GNSS re-measurements in 2022 on 14 sites. (Fig 7). Besides the approximately 70 campaign GNSS sites, we have on our disposal data from 39 permanent GNSS sites as part of public (national) GNSS networks (SIGNAL and Combined Geodetic Network) with the 20 to 30 years of GNSS data history. For the national horizontal geokinematic model setting up we now have quite dense network of more than 100 stations and sites with the coordinate's time series already set up. In next few months we expect to set up a first draft of dense geokinematic model of Slovenian territory.

As we mentioned in last year national report (Medved et al., 2022), we already set up a draft vertical geokinematic model on a basis of repeated levelling measurements. Our next goal in this respect is to combine vertical geokinematic models, determined on a basis of levelling and GNSS data and InSAR.

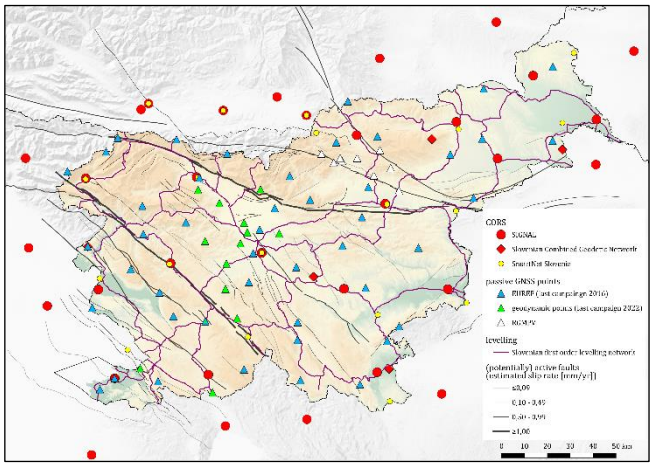

Figure 7: Spatial distribution of sites with the GNSS data

2) Project RI-SI-EPOS – Development of Research Infrastructure

Within the RI-SI-EPOS project, partners are purchasing scientific equipment for study and collection of scientific data from the field of geoscience. We present here a status update on geodetic equipment, acquired in 2020. Five of six GNSS receivers are fully operational and integrated into the national CORS networks SIGNAL and Zero-Order Combined Geodetic Network of Slovenia. The sixth GNSS receiver is used for quality monitoring of data and products 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.

GNSS data are exchanged with the international geoscience community, i.e., GNSS observation data from all Zero-Order GNSS stations are transmitted in real time to the EPOS.

3) Permanent Geodetic Marks

Based on the research project presented in the last year national report (Medved et al., 2022), we analysed different types of trigonometric marks and their preservation share in the Primorska region (Triglav Čekada et al., 2022a) and other regions (Triglav Čekada et al., 2022b). We 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/).

Two geodetic points have already been inscribed: the first-order trigonometric point at Krim (Oven, 2022) and trigonometric baseline points in Maribor. Additionally, 10 proposals for old cadastral municipality boundary marks from the Franciscean land cadastre surveying (1818–1819) in the Primorska region are still waiting to be inscribed (Triglav Čekada et al., 2022c).

In agreement with the local open air museum – the Rodik Mythical Park (https://mitski-park.eu/geodetske-tocke-v-mitskem-parku-rodik/), we added additional markers in nature to the old boundary stones of the cadastral municipalities and different types of trigonometric points (Fig. 8). Brochures named Geodetic Highlights intended for general public were prepared in Slovenian and English at this occasion as well (https://gis.si/en/geodetski-utrinki/).

Figure 8: Marking of boundary stones and trigonometric points in the Rodik Mythical Park

6 Other Activities

8th EUPOS® Council and Technical Meeting

The European Position Determination System (EUPOS, 2022) is an international non-profit initiative of public institutions providing GNSS augmentation services. Once a year, its members meet to discuss actual topics, share and exchange their experience, and plan further activities. The 8th EUPOS Council and Technical Meeting was held from 15th to 16th November 2022 in Ljubljana (Fig. 9) – hosted by the Surveying and Mapping Authority of the Republic of Slovenia (https://www.eupos2022.eu).

Figure 9: Participants of the EUPOS 2022 Meeting in Ljubljana

The topics raised at this year's technical meeting were: online GNSS post-processing services, GNSS-InSAR collocation, GNSS data in the light of the EU2019/1024 Directive on Open Data, and GNSS signal jamming and spoofing.

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