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Towards a 4D National Spatial Reference System
(National Report of Slovenia)

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Abstract

The territory of Slovenia with its western part situated at the Adriatic microplate is tectonically active. Surface deformations reach few millimeters per year which has an impact on the quality of the national spatial reference system. Static realizations of the system become out of date in a decade, and we are facing the challenge of how to introduce the fourth dimension (time) into the national spatial reference system. The main aspects to be considered are the quality of the reference system itself and the impact of the proposed solution on various spatial databases and services. In order to provide a conceptual framework of the future realization of the spatial reference system in Slovenia, we started the so-called SLO4D Project.

A Brief History

The first realization of ETRS89 in Slovenia is based on GPS campaigns in years 1994–1996. The combined solution with the mean epoch 1995.55 is referred to as the **ETRS89/D96**. The computation presented at the EUREF 2003 Symposium [1] was accepted as Class B standard (EUREF 2003 Resolution No. 1).

Passive GNSS sites for reference system realization

The second realization of ETRS89 is based on a GNSS campaign with the mean epoch 2016.75. The solution referred to as **ETRS89/D17** was presented at the EUREF 2018 Symposium [2]. It was also accepted as Class B standard (EUREF 2018 Resolution No. 3).

Due to substantial coordinate differences between both static realizations of ETRS89 in Slovenia (exceeding ***8 cm***), a pragmatic approach is employed that attempted to keep changes of coordinates as small as possible. This is achieved with a rigid (6-parameter) transformation from ETRS89/D17 into ETRS89/D96, which is based on carefully selected 56 GNSS sites included in both realizations. This solution is referred to as the **ETRS89/D96-17** and is used in Slovenia since 1st January 2020 [3].

Connection between ETRS89/D96-17 and ITRS

The transformation from a realization of ITRS (e.g., ITRF2020) at a given epoch (t) to ETRS89/D96-17 consists of four steps as follows [4]:

1. **ITRF2020**@t → **ITRF2020**@2016.75
2. **ITRF2020**@2016.75 → **ITRF2000**@2016.75
3. **ITRF2000**@2016.75 → **ETRF2000**@2016.75
4. **ETRF2000**@2016.75 (**ETRS89**/**D17**) → **ETRS89**/**D96-17**

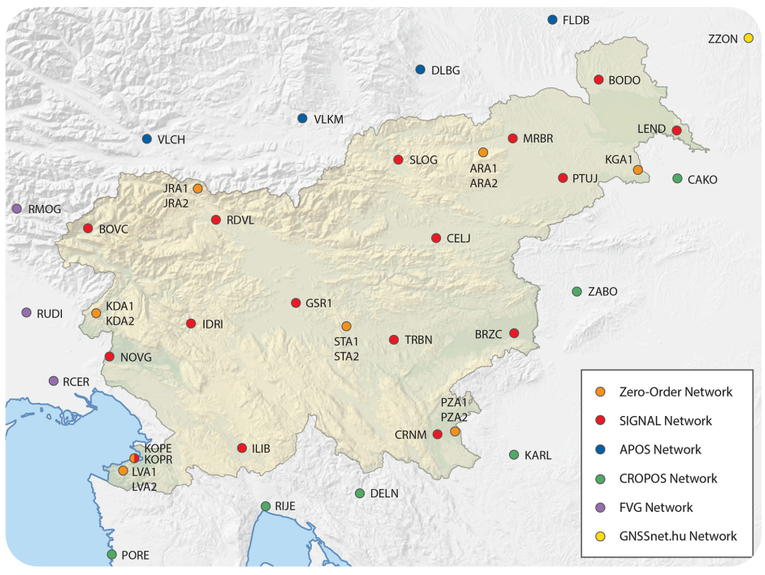
Step 1 requires estimated velocity that can be provided by a geokinematic model. Step 4 is a non-standard solution; a special reference frame for Slovenia (ETRS89-D96-17) is added to Trimble Coordinate System Database v2022.10 which is now supported by Trimble software solutions.

CORS Networks and Time Series Analysis

The first Slovenian permanent GNSS station dates back to the year 2000. Later on, two national CORS networks were built [5, 6]:

- **SIGNAL Network** (operational since 2006) and
- **Zero-Order Network** (operational since 2016).

At present, the SIGNAL Network consists of 16 GNSS stations and is expanded with 14 GNSS stations from neighbouring countries. The Zero-Order Network consists of 7 mostly twin stations (2 new stations in 2025). Four Slovenian GNSS stations are EPN stations: ARA2, GSR1, KDA2, and PZA2.



National CORS networks

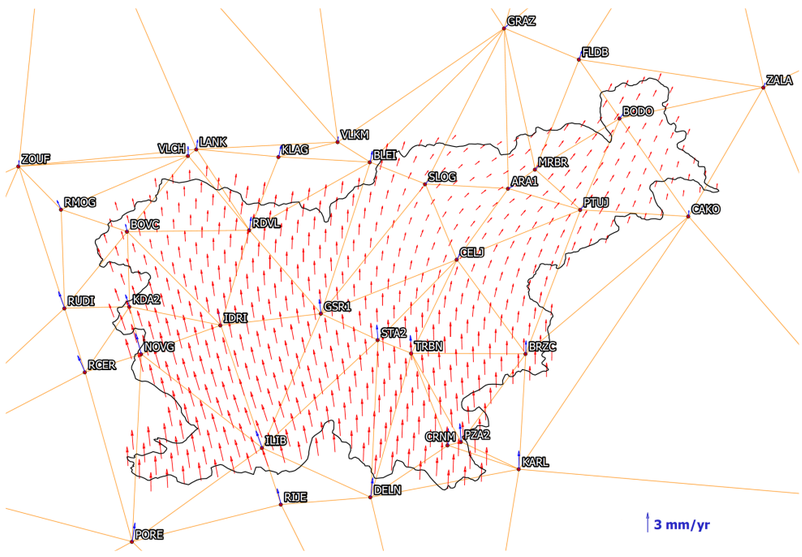
Trimble Pivot Platform and *Alberding Software* are used in operational and data centers to manage both national CORS networks. An analytical center was established in 2016. *Bernese GNSS Software* and a self-developed PPP software are used for daily coordinate time series analysis.

Tectonic Issues and National Geokinematic Model

Tectonics of the Adriatic region is not negligible. With respect to stable part of Europe, the country territory moves with velocities of up to ***few mm/yr*** which causes problems in a long-term maintenance of the national spatial reference system [7, 8].

A permanent activity of the analytical center [9] combined with a multidisciplinary research project [10] resulted in a preliminary national geokinematic model which is based on estimated velocities in the EPN and both national CORS networks.

A continuous 3D geodetic velocity field interpolation based on the ellipsoidal Earth model and Delaunay triangulation is developed [11] and implemented in a freeware tool for time-dependent coordinate transformation between ETRS89/D96-17 and international terrestrial reference frames [12]. Such transformation is needed to support PPP survey, precise navigation services etc.



A preliminary national geokinematic model, Hz part (ETRF2000)

The SLO4D Project and plans for the future

A project aiming to introduce the fourth dimension (time) to the national spatial reference system started in 2022 and is referred to as the **SLO4D Project**. The main project activities are:

- densification of the zero-order network,
- providing a national geokinematic model, v1.0,
- proposing a solution for a 4D national spatial reference system, and
- providing support for the users of this system.

The proposed solution will be implemented in the upcoming years. The main challenge of the project is how to appropriately handle tectonic issues without causing inconvenience to the users.

SLO4D

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