CONSIDERATIONS ON ADVANCED GNSS DATA PROCESSING TECHNIQUES

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***Abstract**: The development of GNSS permanent stations networks at national or regional level has led to the need to integrate them into European and international networks. This involves calculating the coordinates of GNSS antennas in ETRF and ITRF systems with high precision, and this can only be achieved by performing observation compensation calculations with scientific GNSS data processing software. In this context, the certification of the coordinates of the antennas of the stations in the National GNSS Network by the European specialized forum, at EUREF – EPN, represents the last step to be taken, in order to fully integrate the Romanian Position Determination System – ROMPOS into the European network.*

***Keywords:** GNSS; ETRF; ITRF; Bernese GNSS Software; EUREF – EPN*

1. Introduction

The Romanian Position Determination System – ROMPOS was officially launched into production in September 2008, having at that time as basic infrastructure a network of 48 GNSS permanent stations, uniformly distributed throughout the national territory.

Over the years, the National Network of Permanent GNSS Stations has undergone a continuous process of modernization and expansion, and today it consists of 82 GNSS permanent stations on the territory of Romania and 20 stations operated by neighboring countries in the border area with Romania, namely Hungary, Ukraine, the Republic of Moldova and Bulgaria (countries with which cross - border GNSS data exchange agreements have been concluded). The current configuration of the ROMPOS network is shown in the Figure 1.

In this context, it should be noted that the national GNSS network was processed inhomogeneously, in accordance with the installation steps and using commercial software for this purpose.

The objectives of the block reprocessing of the National Network of GNSS Permanent Stations are, on the one hand, to increase the quality of the physical, ITRF coordinates of the permanent GNSS stations and, on the other hand, to complete the process of integrating the National GNSS Network into the European EUREF-EPN network, by approving by this forum the documentation on the calculation of coordinates in the ETRF system.

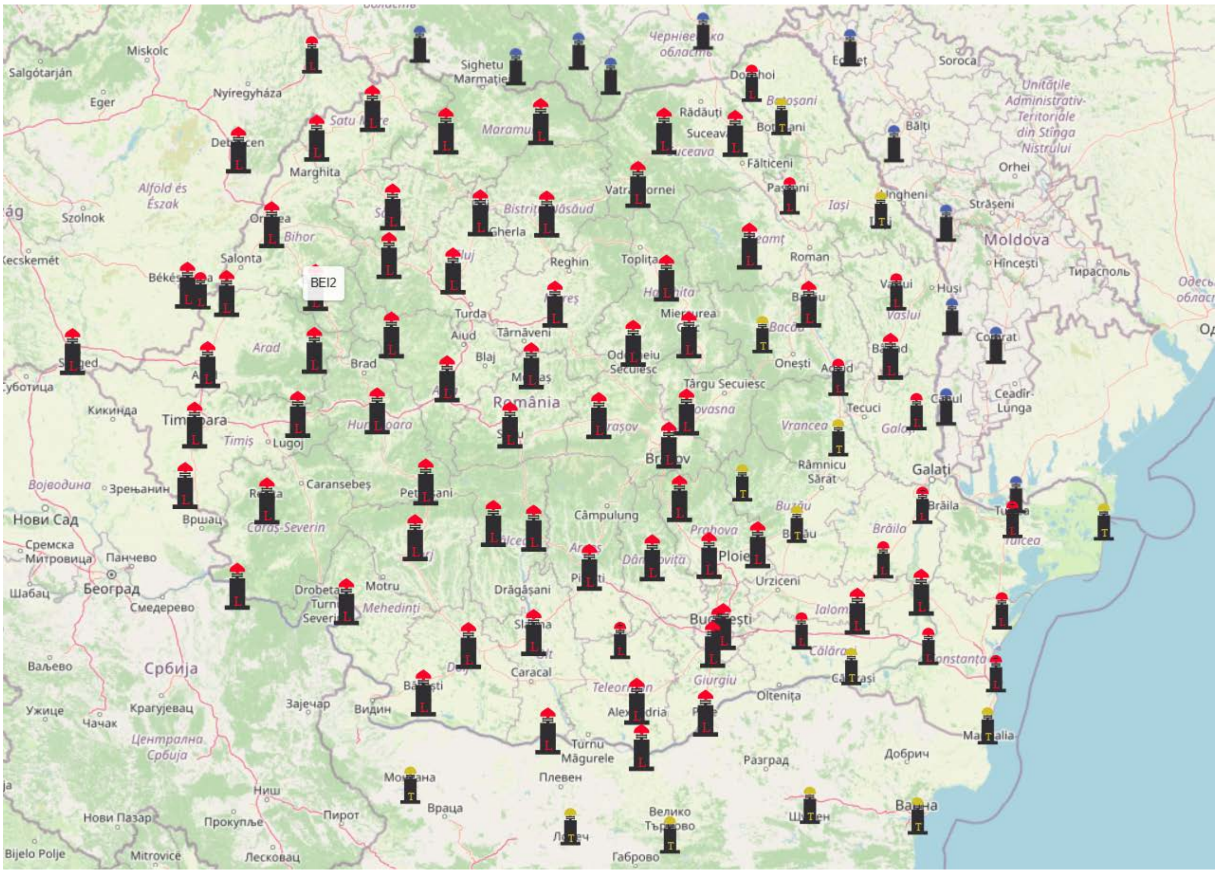

Fig. 1 – Current ROMPOS network configuration [1]

2. Materials and Methods

2.1. Brief description of ITRF and ETRF systems

The GNSS permanent stations networks, regardless of the scale at which they are established, respectively global, regional or national, are also used for the creation, maintenance and development of densification solutions of different reference networks (reference frame solutions) [2]. Regional solutions are based on outputs of global reference networks (such as ITRFyyyyy) and national networks are connected to either global or regional reference networks. The quality and reliability of the GNSS permanent stations belonging to the reference networks, which are currently in use, are therefore essential elements in order to obtain the best solutions [3].

Of the 82 stations of RN-SGP, the Bucharest station (BUCU) belongs to the IGS network, contributing to the realization of the ITRFyyyy global reference network, and 4 stations, respectively Bacău (BACA), Baia Mare (BAIA), Constanta (COST) and Deva (DEVA) belong to the European EPN network, contributing to the achievement of the ETRFyy European reference network, in the form of various achievements of ETRS89

Figure 2 shows the ITRF2014 network, the reference stations being represented separately, depending on the technology used to determine the coordinates [3].

Thus, it should be noted that for the antennas of the GNSS permanent stations in the ROMPOS network, two types of coordinates were determined:

1) Physical coordinates, in ITRF2014 system, to the 2019.08.01 00:00:00 reference epoch [1]. They directly influence the fixing time of user solutions performing real-time GNSS determinations (RTK);

2) Official coordinates, in European ETRF2000 system, to the 2007 reference epoch.

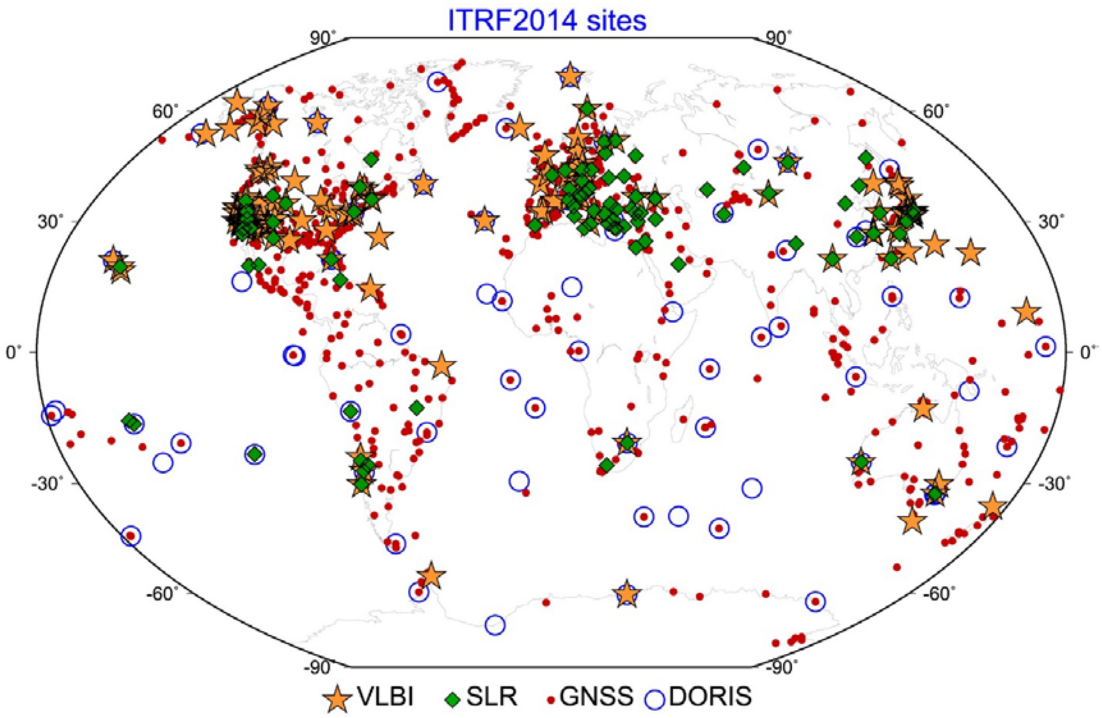

Fig. 2 – The ITRF2014 network [4]

2.2. GNSS data processing using Bernese scientific software, v. 5.2 (BSW 5.2) – methodology

2.2.1. General description of BSW 5.2

BSW 5.2 is a scientific software package designed to the highest quality standards for applications in the sphere of global navigation satellite systems (GNSS). It supports GPS and GLONASS constellations, and Galileo is declared experimental in version 5.

This software package is used by more than 700 universities and institutions worldwide, typical education and research users, government agencies responsible for operating high-precision GNSS networks, and commercial users developing applications that require a high degree of precision and reliability [5].

BSW 5.2 comprises more than 450000 lines of code, organized into approximately 1500 modules and presents the following main technical characteristics [6]:

- is platform-independent, supporting UNIX/Linux, Mac OS and MS-Windows operating systems;
- uses Perl as a scripting language;
- calculation programs are written in Fortran 90;
- Platform-independent GUI, developed in C++, using Qt4 libraries, which also supports remote mode;
- presents a clear directory structure, divided into 3 areas: program, user and data.

2.2.2. Processing method used

The general flow of data in Bernese can be summarized in the Figure 3.

Fig. 3 – General Data Flow in BSW 5.2 [6]

Before starting the actual processing of data, it is necessary to prepare them and transfer them from area where a local copy of all relevant input data for the GNSS (DATAPOOL) to the current campaign – directory with their subdirectories for all GNSS processing activities with the Bernese processing programs.

Subsequently, the a priori coordinates are generated, the pole information is prepared, the satellite orbit files are generated, the RINEX observation files in Bernese format are imported.

It should be mentioned that, for the calculation of coordinates in the ITRF2014 system subject to this case study, RINEX data from 10 days were used, corresponding to 2022 and 2023, in Daily format (one day), with a sampling rate of 30 seconds.

After completing these steps, the data is preprocessed, being necessary to run specific programs, as shown schematically in the Figure 4.

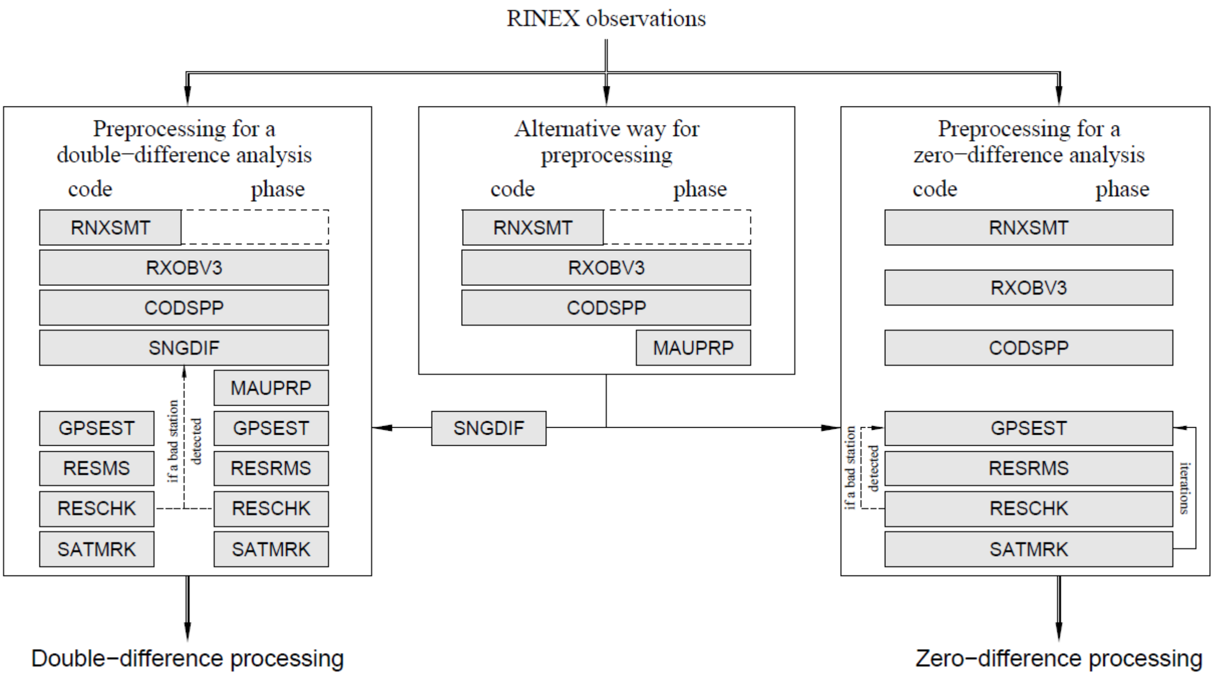

Fig. 4 Data preprocessing [6]

For phase observations, when creating the bases, the OBS-MAX strategy was chosen. In this case, bases shall be set up taking into account the number of observations common to the reference stations undergoing processing [7]. From all possible combinations, the basic set with the maximum number of common observations is chosen.

The data processing involved several steps such as: synchronization of receiver clocks, creation of bases, pre-processing of base files with phase measurements, following the generation of the first network solution, resolution of ambiguities using Quasi Ionosphere - FREE-QIF, determination of the final network solution, verification of Fiducial Sites coordinates, verification of daily repeatability, estimation of velocities.

3. Results and Discussion

The network to be processed includes 75 national stations: 1 IGS station (BUCU station), 4 EUREF stations (BAIA, BACA, COST and DEVA stations) and other 70 stations from the National Network of Permanent GNSS Stations - ROMPOS as well as other 15 stations from outside the country from the IGS network. Only IGS stations classified by EUREF as Class A have been included in the processing, which means that it can used as fiducial station for EUREF densifications [8].

Table 1 Coordinates in ITRF2014 system, at the 2019.08.01 00:00:00 reference epoch, obtained by processing the datasets related to the years 2022 and 2023 - 10 days - BSW V.5.2 and differences from physical coordinates, in ITRF2014 system, at the 2019.08.01 00:00:00 reference epoch (ROMPOS)

	Coordinates in ITRF2014 system, at the 2019.08.01 00:00:00 reference epoch, obtained by processing the datasets for the years 2022 and 2023 - 10 days - BSW V.5.2			**Differences from physical coordinates, in the ITRF2014 system, at the 2019.08.01 00:00:00 reference epoch (ROMPOS)**			
Core ID	**X [m]**	**Y [m]**	**Z [m]**	**dX [m]**	**dY [m]**	**dZ [m]**	**3D**
ABIU	4062652.373	1772082.061	4571465.697	0.001	-0.001	0.001	0.002
ADJU	3941186.967	2024566.856	4572709.438	0.000	-0.002	-0.004	0.005
ALXR	4155947.080	1966872.436	4405767.871	0.002	-0.001	0.002	0.003
ARAD	4121078.404	1610437.567	4578721.055	0.001	-0.006	0.000	0.006
BACA	3917524.703	1988524.337	4608585.751	-0.001	-0.001	-0.004	0.004
…							
INSU	4009613.413	2096458.146	4480418.023	-0.005	-0.006	-0.008	0.011
ISTR	3991556.257	2186335.069	4453671.823	-0.003	-0.005	-0.001	0.006
LEHL	4069495.709	2060206.650	4443376.425	0.012	-0.005	-0.006	0.014
MEDS	4031960.261	1824470.921	4578054.295	-0.003	-0.004	-0.005	0.007
MNGL	4048453.773	2205462.249	4392860.214	0.002	0.004	0.003	0.005
MOLD	4219760.282	1672219.137	4466011.896	0.005	-0.007	0.002	0.009
…							
VLC2	4107642.138	1860279.808	4496108.822	0.008	-0.009	0.002	0.012
ZALU	3996327.070	1701430.085	4655459.562	0.005	0.000	-0.002	0.005
ZERI	4082340.813	1609507.756	4613352.129	-0.004	-0.003	-0.007	0.009

With the velocity values, the ITRF coordinates at the epoch of the observations were converted online to ITRF2014 coordinates at epoch 2019.08.01.

As a result of processing, coordinate sets were obtained for 75 GNSS permanent stations, which were compared with a priori GNSS permanent stations coordinates, determined in the ITRF2014 datum (2017.10.01) for the 2019.08.01 00:00:00 reference epoch, used by the ROMPOS system. The differences obtained are shown in the Table 1.

From the analysis of the obtained results it can be seen that the coordinate differences are in the order of millimeters, which is a verification of the processing method used.

4. Conclusions

Based on the obtained results, we can conclude that the method used to process GNSS data is applicable to relatively small amounts of data (10-15 days), especially for calculating the coordinates of reference stations.

For the processing of large amounts of data, in the order of years, to calculate speed fields, it is necessary to automate the process, using the BPE module (Bernese Processing Engine) and the specific scripts in BSW 5.2.

Also, in order to fully benefit from the multiconstellation capabilities of the new GNSS permanent stations (Leica GR 50 receivers, with AR20 LEIM antennas), it will be necessary to purchase the next version of the software, namely BSW 5.4, which allows data processing also from the satellites of the constellations Galileo and BeiDou, in RINEX 3 format.

Among the immediate perspectives in using BSW 5.2 / 5.4, we can see the calculation of the coordinates of GNSS permanent stations (including the newly installed ones) in ITRF2020 and ETRF2000 systems, and in the long term, the processing of the last 4 years of data using BPE, in order to obtain travel speeds and ensure NCC participation including in geodynamics projects, together with partner institutions.

The determination of the coordinates of ROMPOS GNSS permanent stations must be done periodically [9]. The use of scientific software is recommended due to the possibility to control and verify the processing steps, in order to obtain reliable results and to be validated by the EUREF committee.

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