CONSIDERATIONS ON GNSS DATA ANALYSIS, ACCORDING TO EPN GUIDELINES

Vlad SORTA, PhD Eng., National Centre for Cartography, Romania, vlad.sorta@cartografie.ro
Mihaela–Simina PUIA, PhD Eng., National Centre for Cartography, Romania, mihaela.puia@cartografie.ro
Miluță FLUERAȘ, Eng., Head of Geodesy and ROMPOS Department, National Center for Cartography, Romania, miluta.flueras@cartografie.ro

***Abstract**: The development of GNSS reference networks at national and regional level has led to the need to integrate them into European and international networks. This involves the coordinate computation of GNSS antennas for the reference stations, both in ETRF and ITRF/IGS systems, ensuring a high precision and accuracy. This task can only be achieved by performing a rigorous data analysis using scientific software, designed for this purpose. In this context, the coordinates' certification by the European specialized forum, namely EPN, represents the last step to be taken, in order to fully integrate the Romanian Position Determination System – ROMPOS into the European network, according to the EPN Guidelines.*

***Keywords:** GNSS; EPN; IGS; Bernese GNSS Software*

1. Introduction

The Romanian Position Determination System – ROMPOS was officially launched in September 2008, having at that time a network of 48 GNSS reference stations as basic infrastructure. These were uniformly distributed throughout the national territory [12].

Over the years, the National Network of Permanent GNSS Stations has undergone a continuous process of modernization and expansion. Today it consists of 86 GNSS reference stations, covering the whole territory of Romania and, in addition, 20 more stations operated by neighbouring countries in the border area, namely Hungary, Ukraine, the Republic of Moldova and Bulgaria (countries with which cross - border GNSS data exchange agreements have been concluded). The Agreement with Serbia is being ratified also. 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 step by step, in an inhomogeneous approach, in accordance with the installation steps and using commercial software for this purpose.

The general purposes of reprocessing of the whole National GNSS Network are, on the one hand, to increase the quality of the physical, namely ITRF/IGS coordinates of the GNSS antennas [5] and, on the other hand, to complete the process of integrating the National GNSS Network into the European EUREF-EPN network [9], by approving the documentation regarding reprocessing it in a scientific approach, according to their Guidelines [3].

Fig. 1. Current ROMPOS network configuration

2. Materials and methods

2.1 Brief description of EPN Guidelines in the context of EPN-Repro3 campaign

The EUREF Permanent Network (EPN) analysis centres (ACs) switched to the IGS20 reference frame (based on ITRF2020) in GPS week 2238 (more specific from 27.11.2022). Before that, the global ACs conducted their 3rd reprocessing campaign in order to provide consistent products, which represent the input data for the ITRF2020/IGS20 computation. The ITRF2020 sites are shown in Figure 2.

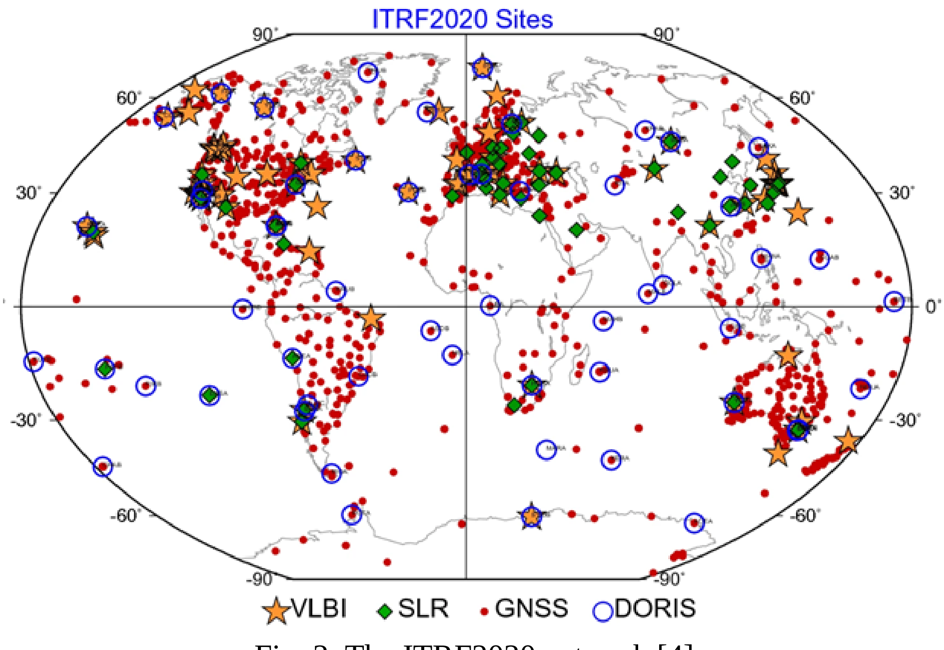

Fig. 2. The ITRF2020 network [4]

In this context, it was necessary to repeat the processing of the old data (from 1996), in order to obtain consistent products with the new reference frame, which has led to the new reprocessing campaign, namely EPN-Repro3. Regarding this campaign, the decision was to make it as consistent as possible with the operational EPN analysis in the IGS20 [10].

Basically, the standards for the EPN-Repro3 campaign are shown in the Table 1.

Table 1. Standards for EPN-Repro3 [7]

Reference frame	IGSR3~IGS20
GNSS observations to be used	GPS, GLONASS, Galileo
Orbits and ERPs for EPN-Repro3	Reprocessed products with GPS, GLONASS, and Galileo (e.g. COD, GFZ, ESA,…)
Ocean tide loading model	FES2014b
Product filenames	Long filenames according to new IGS convention [8]
Atmospheric mapping function	The Vienna mapping function VMF1* was suggested
Format of the troposphere products	Troposphere SINEX 2.0 (hourly products optimally given for the half hour and not for the full hour)
Atmospheric tidal Loading (ATL)	Atmospheric tidal loading will not be applied for the coming analysis of EPN operational and reprocessed products.

* It was actually used the VMF3 model, with a densified grid

Regarding the antenna calibration, it will be used the file epn_20_r3.atx, frozen on May 11th 2023 [7].

Also, the specific metadata file regarding the GNSS equipment is the EUREF54_R3.STA, which is a Bernese Station Information File, available at http://epncb.oma.be/ftp/station/general/EUREF54_R3.STA.

It has to be mentioned that, for those who are new to the EPN processing Guidelines and new to the Bernese GNSS Software 5.4 version (BSW 5.4), EPN has set up a so called benchmark campaign, in order to help ACs to make sure that the processing chain they set up is fine and in full agreement with the Guidelines. The involved data stems from 40 GNSS reference stations, covering most of the cases which can occur in the networks. The distribution of these stations is shown in the Figure 3.

By processing the datasets related to the year 2023 - 7 days (GPS week 2293) with BSW V.5.4, running the specific programs were obtained the coordinates in IGS20 system, at the 2015.01.01 00:00:00 reference epoch, according to EPN Guidelines, which were briefly described in the current subsection. It has to be mention that, the data processing has been run both manually and automatic, using the BPE (Bernese Processing Engine), specifically the Process Control File RNX2SNX.PCF.

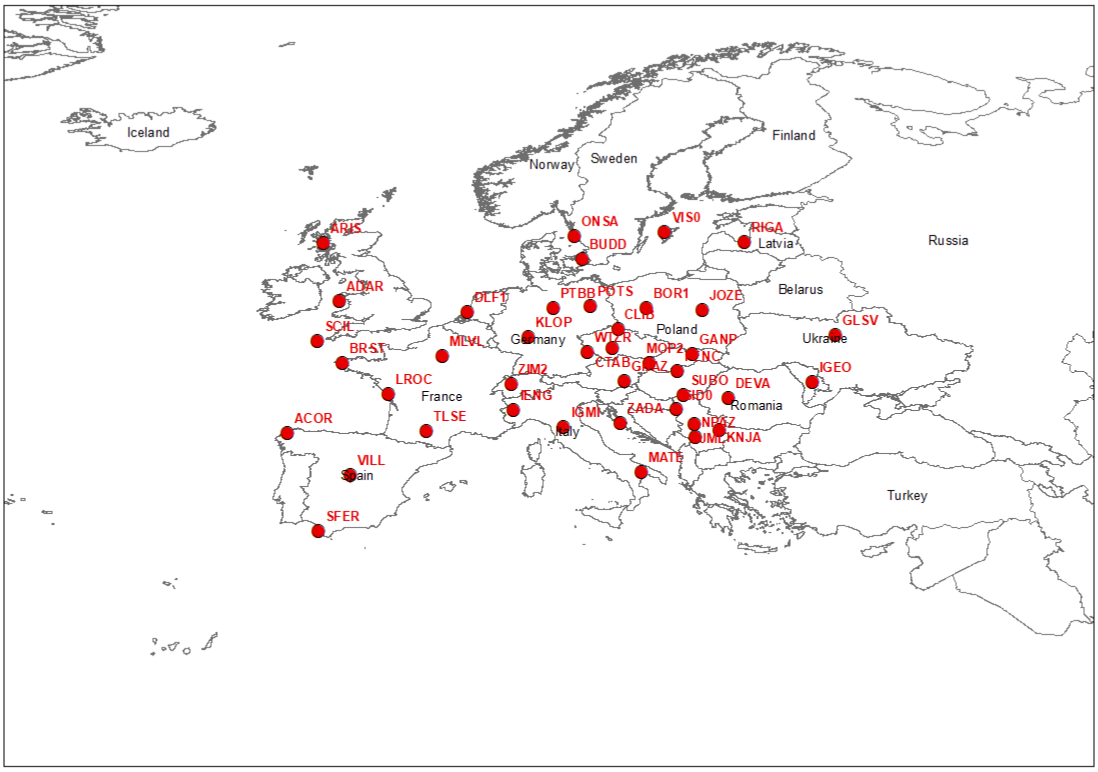

Fig. 3. EPN stations benchmark campaign

2.2 GNSS data processing using BSW 5.4 – methodology

2.2.1 General description of BSW 5.4

BSW 5.4 is a scientific software package designed to the highest quality standards for applications in the field of global navigation satellite systems (GNSS). It supports GPS, GLONASS, Galileo and BeiDou constellations.

This software package is used by more than 800 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 [11].

BSW 5.4 comprises more than 450000 lines of code, organized into approximately 1500 modules and presents the following main technical characteristics [1, 11]:

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

2.2.2 Processing method

The general data flow in Bernese can be summarized in the Figure 4.

Fig. 4. General Data Flow in BSW 5.4 [1, 2, 11]

Before starting the actual data processing, it is necessary to prepare and transfer them from area which contains a local copy of all relevant input data for the GNSS, namely 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 and the RINEX observation files in Bernese format are imported.

It should be mentioned that, for the coordinate computation in IGS20 system, subject to the current case study, RINEX data from 15 days were used, in Daily format (one day), with a sampling rate of 30 seconds.

After completing these steps, the data is pre-processed, being necessary to run specific programs, as shown schematically in the Figure 5.

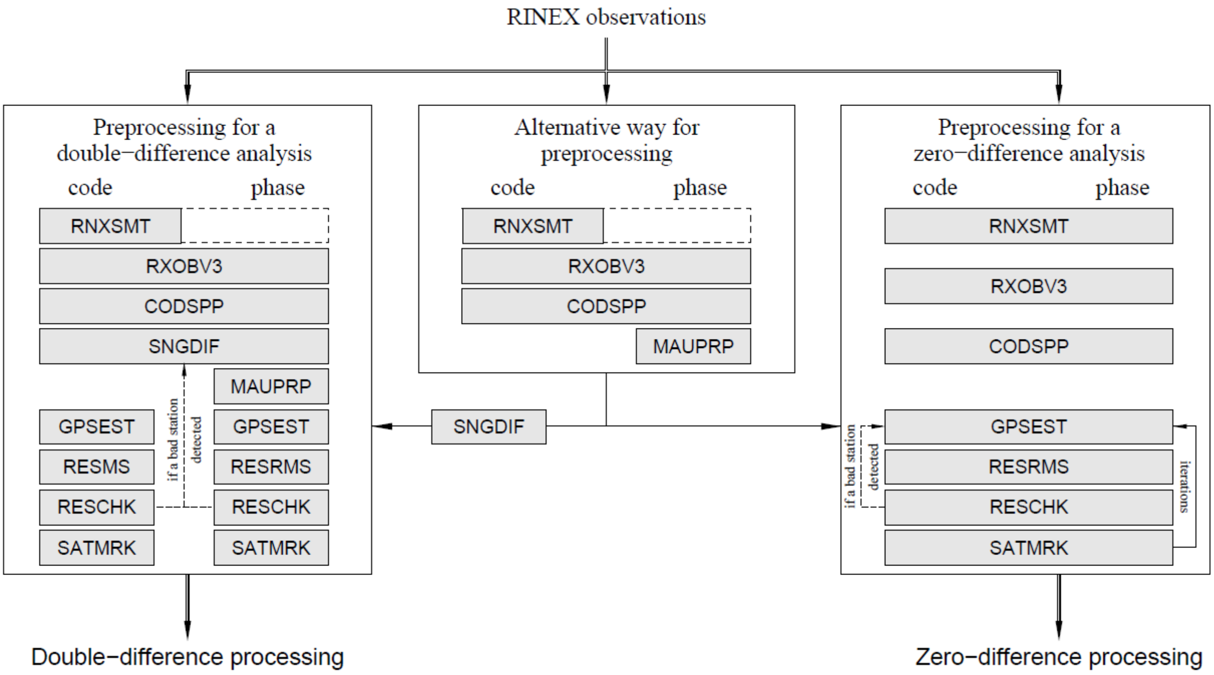

Fig. 5 – Data pre-processing [1]

In order to create the baselines corresponding to the phase observations, it was chosen the OBS-MAX strategy. In this case, bases shall be set up considering the number of common observations to the reference stations undergoing processing [2, 3]. From all possible combinations is chosen the basic set with the maximum number of common observations.

The data processing involve several steps, such as: synchronization of receiver clocks, baselines creation, pre-processing of baseline files using phase measurements, the generation of the first network solution, ambiguity resolution through Quasi Ionosphere - FREE-QIF strategy, computation of the final network solution, checking the fiducially Sites coordinates, checking the daily repeatability and finally the velocity field estimation.

3. Results

The correctness of the results and the software configuration were checked and confirmed by Analysis Coordinator of the EPN, based on the benchmark campaign. This allowed the transition to the next stage, namely that of testing the processing including data from the ROMPOS network, for a 15 days interval, between 19.07.2024 and 08.08.2024 (GPS days 207 - 221). ROMPOS and IGS stations are shown in the following figure (Fig. 6):

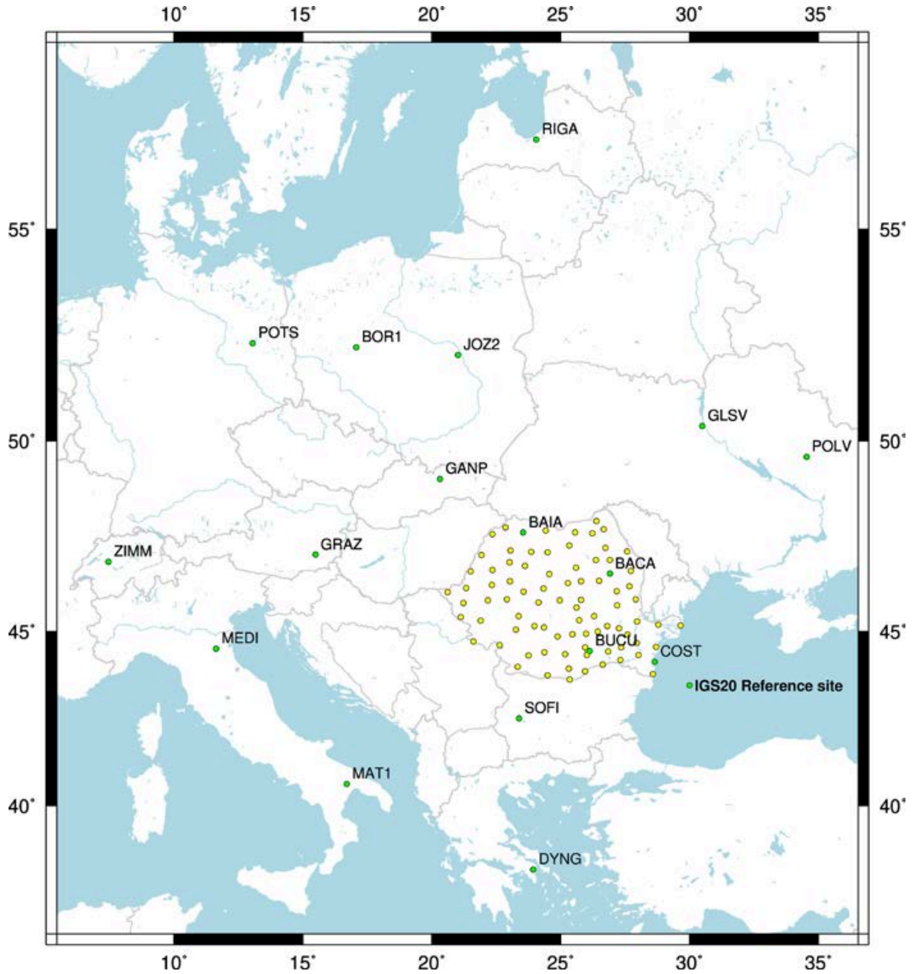

Fig. 6. ROMPOS test campaign (Photo credit Dr. Joaquin Zurutuza)

The IGS20 coordinates for some ROMPOS reference stations, obtained running RNX2SNX.PCF in BPE are shown in the Table 2.

Table 2. Cartesian IGS20 coordinates for some of the ROMPOS stations

ROMPOS IGS20 cumulative solution	**09-MAR-25 18:38**
LOCAL GEODETIC DATUM: IGS20	**EPOCH: 2024-08-01 12:00:00**

NO.	STATION	DOMES NO.	X [m]	Y [m]	Z [m]
1	ABIU	11410M001	4062652.289	1772082.145	4571465.744
2	ADJU	11409M001	3941186.880	2024566.934	4572709.484
3	ALXR	11411M001	4155947.004	1966872.529	4405767.919

NO.	STATION	DOMES NO.	X [m]	Y [m]	Z [m]
4	ARAD	11412M001	4121078.320	1610437.647	4578721.100
5	BACA	11405M001	3917524.614	1988524.418	4608585.795
6	BAIA	11406M001	3945839.435	1720428.593	4691082.904
7	BAIS	11413M001	4217904.550	1820055.523	4409956.813
8	BEI2	11414M002	4055361.490	1667396.486	4616703.678
…	…	…	…	…	…
85	TBUJ	11467M001	3931132.554	2082546.740	4555330.542
86	TIM1	11404M001	4153556.206	1613641.861	4548331.243
87	TJIU	11468M001	4146764.545	1783643.646	4491220.674
88	TLCA	11469M001	3946524.969	2169746.410	4501321.646
89	TRGV	11466M001	4084675.946	1945288.297	4481149.713
90	VAD2	11470M002	4048861.325	1950517.834	4511663.871
91	VAMO	11431M001	3883084.751	1858392.478	4691370.319
92	VASL	11472M001	3883224.792	2040866.173	4614626.328
93	VATR	11473M001	3915868.437	1854265.521	4666770.281
94	VISE	11474M001	3915083.740	1778571.866	4695502.573
95	VLC2	11471M002	4107642.067	1860279.885	4496108.869
96	ZALU	11475M001	3996326.991	1701430.169	4655459.607
97	ZERI	11432M001	4082340.726	1609507.840	4613352.166
98	ZIMM	14001M004	4331296.796	567556.230	4633134.161
99	ZIMN	18027M001	4176286.745	1979885.630	4380766.081

After the initial verification of the results by the EUREF Governing Board specialist, it were obtained very good values of mean repeatability, namely 0.85, 0.72, and 2.75 (NEU, respectively, in mm).

The alignment of the ROMPOS solution to the IGS20 is also very good, as shown in the following statistics (Table 3):

Table 3. The alignment of the ROMPOS solution to the IGS20 (represented as north, east and up components)

NUMBER	NAME	DOMES NO.	RESIDUALS (IN MM)		
			N	E	U
1	BACA	11405M001	-0.47	0.01	-2.62
2	BAIA	11406M001	0.26	0.22	-0.53
3	BOR1	12205M002	0.01	0.05	2.80
4	BUCU	11401M001	0.82	-2.19	-5.48
5	COST	11407M001	-0.39	0.68	-1.31
6	DYNG	12602M006	5.21	1.49	0.91
7	GANP	11515M001	-1.55	-0.42	3.44
8	GLSV	12356M001	-6.01	-2.48	-0.43
9	GRAZ	11001M002	0.81	0.36	-0.93

NUMBER	NAME	DOMES NO.	RESIDUALS (IN MM)		
			N	E	U
10	JOZ2	12204M002	-2.46	-0.19	1.62
11	MAT1	12734M009	1.52	1.10	-1.82
12	MEDI	12711M003	-0.03	2.49	-0.81
13	POLV	12336M001	0.06	-2.62	-1.45
14	POTS	14106M003	-0.20	0.11	1.70
15	RIGA	12302M002	-0.29	-0.16	4.51
16	SOFI	11101M002	0.62	1.00	-6.37
17	ZIMM	14001M004	1.18	1.17	3.87

RMS/COMPONENT	2.14	1.34	2.95
IQR	1.20	1.19	3.15
MEAN	-0.05	0.04	-0.17
MEDIAN	0.01	0.11	-0.53
MIN	-6.01	-2.62	-6.37
MAX	5.21	2.49	4.51

4. Conclusions

First of all, it should be mentioned that the BPE has been primarily designed for the processing automation for GNSS permanent networks. The BPE was rated many times as an extremely useful tool and has become a very important component of the Bernese GNSS Software. It should be noticed that, it is used since 1995 at the CODE AC for the routine processing of the global IGS network [1].

Based on the obtained results, we can conclude that the method used to process GNSS data (even the manually approach) is effective, strictly following the new IGS20 standards.

Taking into account the encouraging results obtained for the 15-day processing period and the need to periodically compute the coordinates of the reference stations [6], the National Centre for Cartography (NCC) will start soon the continuous data processing in the IGS20 system from its launch date, i.e. 27.11.2022 (GPS day 331). Also, as a large amount of data will be processed, we will be able to obtain reference station velocities in addition to the coordinates. These will allow extrapolation of coordinates to different epochs and will open the path for our institution to take part in various European projects, including related fields such as geodynamics.

Given the recommendations of specialists, in addition to ROMPOS, both the GNSS network of the National Research and Development Institute for Earth Physics - NIEP and MOLDPOS (the official GNSS network of the Republic of Moldova) will be included in the processing (see the figure below – Fig. 7).

Also, considering possible large amount of data, like years, the specialists of the National Centre for Cartography (NCC) analyse and consider also other automation possibilities, by realising specific routines, especially for downloading and preparation of the input data.

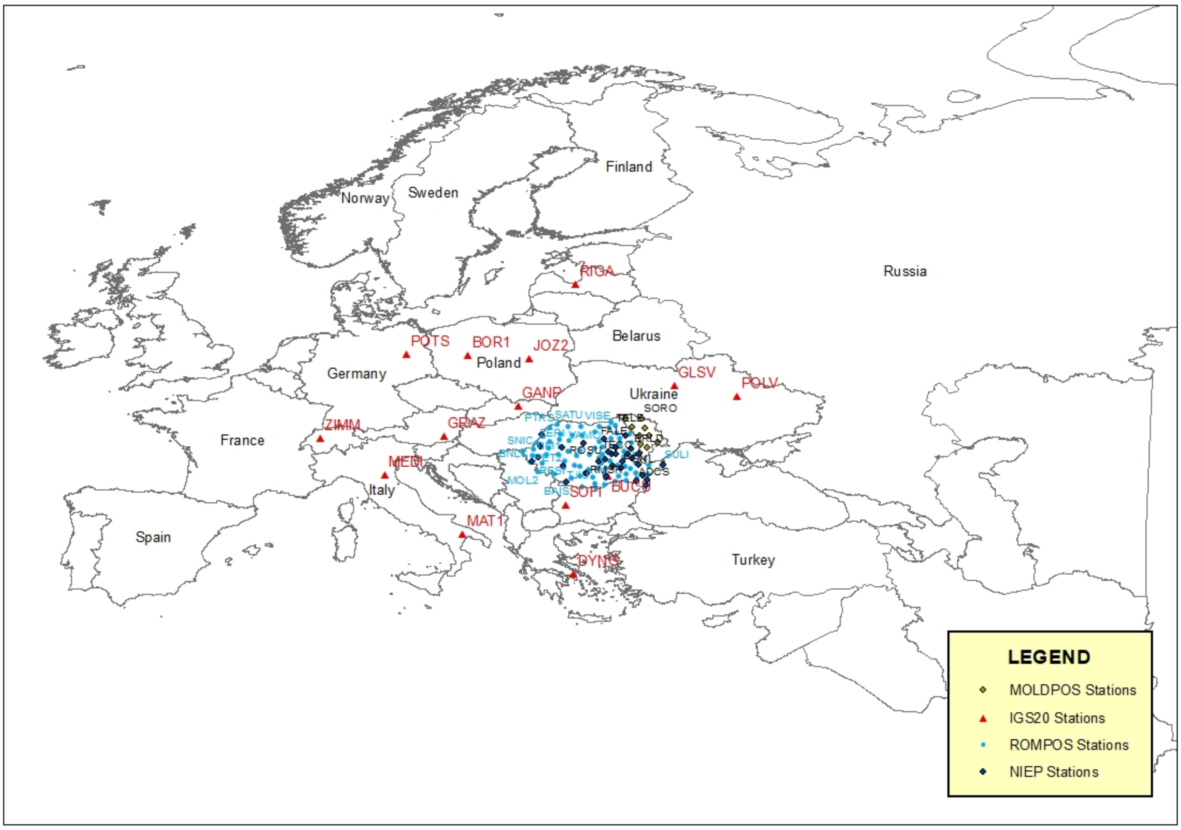

Fig. 7. Proposed reference stations for long term processing (all the three networks, namely ROMPOS, NIEP and MOLDPOS)

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