Results of the EUREF Serbia 2010 Campaign

Z. Veljkovic, S. Lazic
Republic Geodetic Authorty of Republic of Serbia, bul. Vojvode Misica 39, 11000 Beograd, Serbia
L. Jivall
Lantmäteriet, 801 82 Gävle, Sweden

Abstract. The current realization of ETRS 89 in Republic of Serbia dates back to 1998, when the EUREF Balkan`98 campaigns were realized. Coordinate set in use in Serbia is in ITRF 96 epoch 1998.7, i.e. the coordinates transformed to ETRS 89 had not been used in Serbia. The coordinate set in ITRF 96 is based on the campaign realized in 1998. ITRF 96 has been used for GNSS related works. The official national reference frame is based on triangulation. The reference frame presented in this report will replace the current official reference frame.

In the summer of 2010 Republic Geodetic Authority of Republic of Serbia realized new campaign as extension of EUREF. The campaign included 20 EPN stations, 48 stations from national permanent networks (Serbia, Macedonia, Bulgaria and Hungary) and 19 field points. Observation period was 5 weeks. Calculations and analyses were performed in Bernese GPS Software version 5.0 by RGA.

EUREF campaign in Serbia 2010 was validated as extension of EUREF on Class B level at the meeting of Technical Working Group of EUREF in November 2010 in Lisbon and presented at the EUREF symposia in Chisinau, Moldova in May 2011.

Key words. European Terrestrial Reference System (ETRS), European Terrestrial Reference Frame (ETRF), European Reference Frame (EUREF), EUREF campaign

1. Introduction

The GPS measuring campaign, aiming at densification of EUREF on the territory of the Republic of Serbia, was realized simultaneously with the campaign in Former Yugoslav Republic of Macedonia. Measurements in the territory of the Republic of Serbia were performed by the professionals from the Republic Geodetic Authority.

Processing of all measurements was performed in the Republic Geodetic Authority. In parallel, results were processed by Lantmäteriet, including tests of various data processing strategies. Results of said tests had been studied in detail to obtain a final solution at the end.

For the datum definition, points in EPN had been used, i.e. exclusively the points declared as A class points, which brings up guaranteed accuracy of 1 cm in ETRS 89 coordinate system with coordinate velocities established with 1 mm annual accuracy, for each given epoch. 20 EPN-stations were selected, closest to the Republic of Serbia, which also meet said condition. However, the definition of the geodetic datum had used only 18 of those points, since geodetic equipment had been changed on two points, with notified shifts in the coordinates. Measurements from those two points were included in adjustment.

2. Campaign description

The campaign included 87 points, 20 EPN stations, 48 national permanent network points (Serbia, Macedonia, Bulgaria and Hungary) and 19 points of classic geodetic networks, namely 6 points originating from Serbian part of Balkan 98 campaign and 6 points of SREF (Serbian Reference Frame) network and 7 points established within Macedonian EUREF campaign in 1996.

Measurement interval was 5 weeks, from August 1st, 2010 (213th day of year, GPS week/day 1595/0) to September 4th, 2010 (247th day of year, GPS week/day 1599/6). Measurement interval on points in the field was 3-5 days in 24-hours sessions in 1597 GPS week. The exception was point E803 in Macedonia, for which there are measurements that were discarded due to poor quality, so this point participates in final solution with only two days of observations.

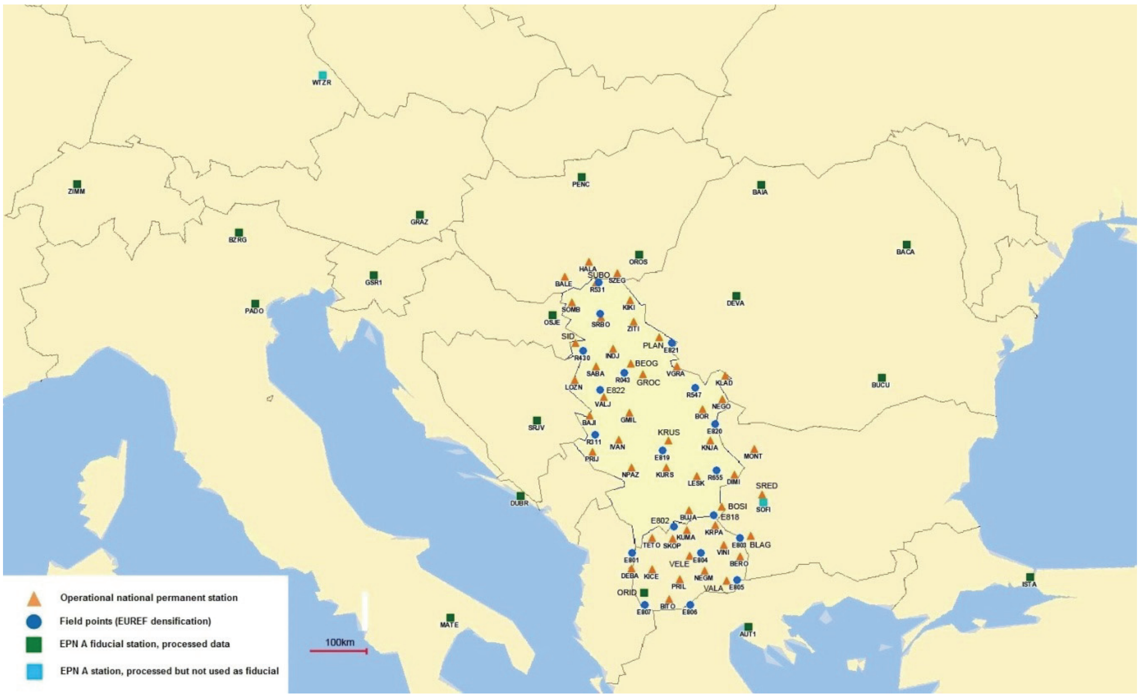

Figure 1 Spatial distribution of stations during EUREF Serbia 2010 campaign

Class A EPN stations had been used for definition of geodetic datum in ITRF 2005 reference frame. Coordinate of these EPN stations had been taken over from the last available cumulative solution, at the moment of calculation, in SINEX (Software Independent Exchange Format) format – EPN_A_ITRF2005_C1600.SNX. Spatial distribution of said stations can be seen in Figure 1.

3. The processing strategy

All data processing of the GPS measurements have been performed using the Bernese Software, version 5.0, Release 18-February-2010, fully congruent with the instructions for EPN analysis published by the EUREF Technical Work Group, which is available on the official EPN web portal, titled „*Guidelines for EPN Analysis Centers*“

External data were necessary to collect for the purpose of GPS measurement processing. Final precise GPS orbits, Earth rotation parameters and satellite clocks parameters were collected from IGS. CODE global ionosphere maps and differential code biases were used for the same purpose. Absolute antenna models for antenna phase center given in file epn_05_1604.atx previously converted to Bernese format were used for data processing. For describing ocean tide loading FES2004 model was used, without correction for Earth mass center movement in BLQ file format.

Each of the 35 daily sessions in the GPS weeks 1595 to 1599 were processed separately. Each daily solution generated a minimally constrained normal equation file. An elevation cut off angle of 3° and “cos z” elevation dependent weighting was used throughout the processing, except for the ambiguity resolution where 10° cut off angle was used and in a test solution with 25° cut off.

Summary of daily processing is given in Table 1.

3.1 Modeling Troposphere and Ionosphere and Resolving Phase Ambiguities

A simple troposphere strategy was implemented for programs CODSPP and MAUPRP (steps 7 and 10 in Table 1). Tropospheric refraction is modeled by using the Saastamoinen model in CODSPP. The Niell model is used in MAUPRP i.e., the Saastamoinen zenith path delay together with the Neill mapping functions (dry and wet).

In the double difference float solution using GPSEST (step 11 and 13 in Table 1), the Dry Niell a priori model was in combination with the estimation of the partial derivatives of the troposphere zenith path delay every second hour using the wet-Niell mapping function. The troposphere model from the double differences float solution was introduced in the QIF-ambiguity resolution (step 15). In the fixed ambiguity double differences solution (step 16) the Dry Niell a priori model was used in combination with estimation of troposphere zenith path delay parameters every hour and gradient parameters using the tilting model and 24 hours interval. Absolute and relative a priori constraints on the values of the tropospheric zenith path delay parameters were applied with a priori sigma of 5m for troposphere parameter estimations.

Table 1 Summary of daily processing strategy

Step	Subroutine	Details
1	COOVEL	getting a priori coordinates; propagate coordinates with given velocity field to the epoch of observation
2	POLUPD	creating Bernese formatted ERP file from precise IGS ERP file
3	PRETAB	getting orbit and clock information in tabular files from IGS precise ephemeris and Bernese formatted ERP file (step 2)
4	ORBGEN	generating standard orbits file
5	RNXGRA	creating pseudo-graphics from RINEX observation file and rejection of bad files
6	RXOBV3	importing RINEX files into Bernese format, only for GPS observations
7	CODSPP	single point positioning for each station, using orbit and clock information from step 3.
8	CODXTR	bad station detection and removal from further processing
9	SNGDIF	creating single differences observation files using the OBSMAX strategy
10	MAUPRP	preprocessing single differences and marking of observations before cycle slip detection: elevation mask 3°, minimum time interval for continuous observation 361 seconds and max gap 181 seconds identification of data without cycle slips and in remaining data find if possible repair cycle slips
11	GPSEST	solving ambiguity float double differences solution with corrected cycle slips detected in step 10, clusters with three baselines troposphere estimation, saving normalized residuals, saving normal equations
12	RESRMS SATMRK	screening and marking high residuals from saved residuals in step 11.
13	GPSEST	the same as step 11, but input files have marked observations from step 12.
14	ADDNEQ2	Combining clusters from step 13, output preliminary coordinates and troposphere estimation
15	GPSEST	solving ambiguities with QIF strategy baseline by baseline
16	GPSEST	computing final loosely constrained network solution with ambiguities fixed from step 15, saving normal equations
17	ADDNEQ2	computing a minimal constraint solution on fiducial stations, troposphere estimates and troposphere SINEX files from normal equations saved in step 16, saving normal equations
18	HELMR1	verification of fiducial stations, iteration on step 17 if outliers exist
19	ADDNEQ2	size reduced NEQ information and SINEX generation
20	GPSEST	computing a test solution with ambiguities fixed from step 15, cut-off angle 25°
21	ADDNEQ2	the same as step 19 but for cut-off angle 25°
22	HELMR1	Elevation cut-off test for all stations, comparison between the 3° and 25° solutions from step 17 and 21, respectively

Ionosphere is not modeled. Ionosphere-free L3 linear combination of dual-band measurements was used in processing which nearly completely eliminates the ionospheric refraction effects in program GPSEST.

A priori coordinates for the ambiguity resolution are taken from step 14 in Table 1 (float double differences solution with marked outliers and corrected cycle slips).

Ambiguity resolution is done baseline by baseline (step 15 in Table 1). The QIF ambiguity resolution strategy was used to resolve L1 and L2 ambiguities without using the code measurements and with implemented CODE global ionosphere model. Cut-off angel used for this purpose was 10°.

3.2Elevation cut-off test

For testing purposes, a test solution with elevation mask 25° had also been calculated. This test solution is obtained by excluding measurements having an elevation angle under 25°. Such daily solutions with elevation mask of 25° are subsequently being combined in joint adjustment into single test solution. This test solution is then being compared with the final campaign solution, for which the elevation mask was 3°. A large difference between the two is an indication that there are shortcomings in the used antenna model, i.e. that the antenna model is not describing the real situation. Site dependent effects could be the reason for this. This test indicated significant differences on stations equipped with Trimble Zephyr (TRM39105.00 NONE) antennas, which is not the antenna for geodetic purpose.

3.3 Daily Network Solutions

Preliminary coordinates from float double differences solution with marked outliers and corrected cycle slips are taken as apriori coordinates in this step in processing. The mathematical correlations between the double-difference observations are handled correctly in processing baselines. Sampling interval was 180 seconds. Normal equations are saved for later use in the final combined solution of the campaign. The daily network solutions are minimal constrained on EPN class A stations.

The agreement with the reference coordinates were checked with a Helmert transformation and if the absolute value of correction exceeded 1 cm in horizontal position or 2 cm in vertical position, such station would be excluded from the list of fiducial sites and the procedure would be repeated.

3.4 Final Combined Network Solution

All of the 35 daily solutions were combined into a common adjustment using the program ADDNEQ2. Different types of minimal constraints to the ITRF 2005 reference coordinates in EPN_A_ITRF2005_C1600 were tested. For the final combined network solution just translation minimum constraints was imposed on the fiducial stations, as this is the recommendation for regional networks according to the Bernese manual.

3.5 Transformation to ETRS89 System

After obtaining final combined solution, definite coordinates of all points had been transformed from campaign reference frame ITFR 2005 epoch 2010.631 to ETRS 89 reference system, which will be the new state reference system of the Republic of Serbia. For the purpose of harmonization of future ETRS 89 system implementation throughout the Europe, EUREF recommends that, instead using ETRF2005 reference frame, ETRF 2000 should be adopted as a standard frame for implementation of ETRS 89. Transformation of coordinates to ETRS 89 system were done in ETRF 2000 reference frame, epoch 2010.631 using service software available on EPN web page: http://www.epncb.oma.be/_dataproducts/coord_trans/

4. Results

4.1 Comparison of coordinates in the ITRF 2005

The estimated coordinates of EPN permanent stations from the final combined solution was compared with coordinates of EPN permanent stations from the last available cumulative solution EPN_A_ITRF2005_C1600.SNX. The differences are below 4 mm in all components and the RMS of the differences are 0.9, 1.6 and 1.9 mm for north, east and up, respectively. These differences in horizontal and vertical components are shown in Figures 2 and 3. The numerical values are given in Table 2.

Table 2 Coordinates differences for fiducial station from comparison in the ITRF 2005

Station	N	E	U
	[mm]	[mm]	[mm]
AUT1 12619M002	-0,2	-1,6	-1,5
BACA 11405M001	0,2	-1,4	1,9
BAIA 11406M001	0,2	-1,3	0,1
BUCU 11401M001	-0,2	-1,8	-1,6
BZRG 12751M001	-0,2	0,1	2,7
DEVA 11408M001	-0,6	-1,8	0,7
DUBR 11901M001	-1,7	2,2	0,2
GRAZ 11001M002	-1,3	2,0	3,0
GSR1 14501M001	0,1	0,6	0,5
ISTA 20807M001	1,7	1,2	-2,0
MATE 12734M008	0,7	3,5	-2,5
ORID 15601M001	0,2	-0,9	-2,3
OROS 11207M001	0,7	-1,1	0,7
OSJE 11902M001	-0,8	-1,4	-0,6
PADO 12750S001	0,6	0,2	1,2
PENC 11206M006	-0,2	-0,1	2,6
SRJV 11801S001	1,3	1,6	-3,5
ZIMM 14001M004	-0,8	0,9	-0,4
RMS / COMPONENT	**0,9**	**1,6**	**1,9**

4.2 Comparison of coordinates in the ETRS 89

The final ETRF2000 coordinates are compared with coordinates from campaign EUREF Balkan 98 transformed from ITRF96 epoch 1998-09-06 to ETRF2000 in the same epoch.

This comparison was done in the ETRF 2000 because, as we said above, the results from Balkan 98 campaign were never used in ETRS 89 in Serbia.

The new campaign agrees with previous one at the 20 mm level, except a shift in height of 4-5 cm.

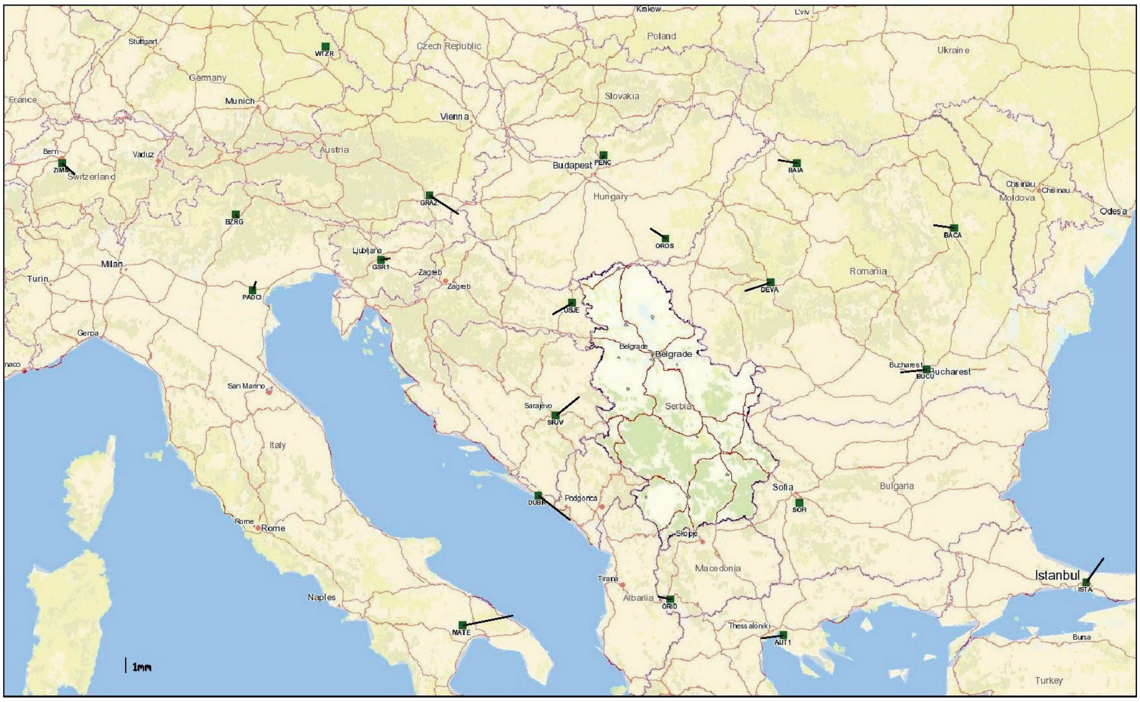

Figure 2 Differences of EPN permanent stations coordinate in latitude and longitude

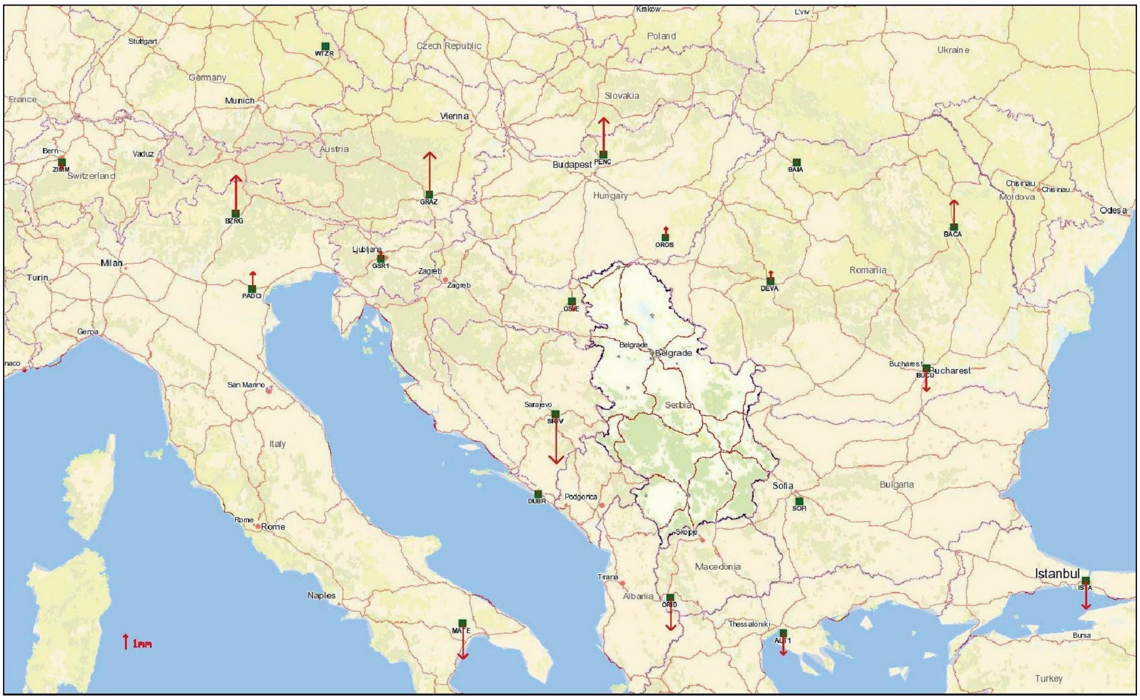

Figure 3 Differences of EPN permanent stations coordinate in height

5. Conclusion

The internal quality of the solution is around 1 to 2 mm in and N and E and around 3 to 5 in U. This quality level is estimated by daily coordinate repeatabilities.

The coordinate recoveries of fiducial stations indicate that ITRF2005 for EUREF Serbia 2010 is realized to around 2mm in all three components.

Results from elevation cut off test show different level of accuracy depending on antenna type used and site dependent effects. The stations with non geodetic antennas have lower level of accuracy.

Comparison with EUREF Balkan 98 campaign based on ITRF96 is at 20mm level compared in ETRF2000, except a shift in height of 4-5cm.

The EUREF campaign in Serbia 2010 was accepted as densification of European Reference Frame, categorized as class B.

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