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Data Article

The Central European GNSS Research Network (CEGRN) dataset

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A R T I C L E I N F O

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A B S T R A C T

The Central European GNSS Research Network (CEGRN) collects GNSS data since 1994 from contributors which today include 42 Institutions in 33 Countries. CEGRN returns a dataset of co-ordinates and velocities computed according to international standards and the most recent processing procedures and recommendations. We provide a dataset of 1229 positions and velocities resulting from 3 or more repetitions of coordinate measurements of each site over 4 or more years. The velocity data result from a combination of eight multiyear, partially overlapping networks, using 234 stations of class A of the European Permanent Network (EPN) for alignment to the 'European Fixed' ETRF2000 Reference Frame. The rms (root mean square) of the 8 individual contributions to the combined solution, after a 7 − parameter Helmert transformation, is less than 5 mm in the observation period 1996–2017. This combined CEGRN network maintains the origin coincident with that of the ETRF2000 reference frame to

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within 1.8 mm rms for the entire period of analysis. The mean positions and velocities of common EPN Class A and CEGRN stations differ by 0.0 ± 1.1, 0.5 ± 1.0 and 0.1 ± 2.7 mm for the coordinates and 0.06 ± 0.13, -0.07 ± 0.12, 0.38 ± 0.28 mm/yr for the velocities respectively for the North, East and Up components at epoch 2010.0.

Specifications Table

Subject area	*Geophysics*
More specific subject area	*High quality Positions Velocity Field for the CEGRN stations*
Type of data	*ASCII files (some in standard RINEX and SINEX format)*
How data was acquired	*Raw data were collected by GNSS permanent stations located throughout Central Europe. Different Analysis Centers (AC) that are responsible of such GNSS stations provide the observations in standard RINEX format.* *On the other hand, some ACs provide GNSS already computed data, following strict guidelines, in standard SINEX format for a later stacking of all the different results into a single solution.*
Data format	*a) Standard SINEX files: normal equations of already processed observation files.* *b) ASCII files for the results: positions and velocities.*
Experimental factors	*All the normal equations provided by the different Analysis Centers have been stacked in two steps:* *A. Stack all the normal equations of each AC to get AC-wise cumulative solutions (positions + velocities).* *B. Stack the resulting multiyear combined normal equations to get the unique CEGRN multiyear solution and dataset.*
Experimental features	*The combination of multiyear solutions (positions + velocities) to get a unique combined solution is experimental.*
Data source location	*Positions and velocity dataset covers Central Europe.*
Data accessibility	*Data in different formats are provided under request to the general public. However, data are regularly provided to several EUREF Working Groups (*http://www.epncb.oma.be/_organisation/WG*): European Dense Velocities Working Group (Chair: E. Brockmann), EPN Densification Working Group (Chair: A. Kenyeres), Deformation Models Working Group (Chair: M. Lidberg).* *The direct link to the public repository where the dataset is hosted is at the University of Padova:* *CEGRN website:* http://cegrn.cisas.unipd.it *Velocity dataset (ASCII):* http://cegrn.cisas.unipd.it/CEGRN/network/CEG_tableVEL.htm *SINEX cumulative solution (positions, velocities and full variance-covariances matrix):* http://147.162.183.197/SNXCEG/SNX/SNXCEG_MCV.SNX.gz
Related research article	*A. Caporali, J. Zurutuza, M. Bertocco, M. Ischchenko, O. Khoda (2019): "Present Day Geokinematics of Central Europe". Journal of Geodynamics.* https://doi.org/10.1016/j.jog.2019.101652.

Value of the Data

- The dataset is very valuable for geodetic and geophysical studies in central Europe. Crustal deformation studies as well as strain analysis can benefit from the data provided.
- The dataset can be used to validate densification networks or networks being computed by other research groups, at either the national or regional level.
- Three Working Groups within the EUREF community (http://www.epncb.oma.be/_organisation/WG/) are already using the dataset:
  - Deformation Models, chaired by M. Lidberg.
  - EPN Densification, chaired by A. Kenyeyeres.
  - European Dense Velocities Working, chaired by E. Brockmann.
- Because the data cover full central Europe and the network is very dense, the dataset can be used for any scale and by any geophysical/geodetic research based on velocity fields: either taking the full set or a subset of the dataset.
- The dataset is fully INSPIRE compliant: the results are given in ETRF2000.
- Moreover, the dataset can embed new network/velocity solutions so that these will be aligned to the ETRF2000 frame.

- We provide a very dense dataset of accurate positions and velocities, based on GNSS data that cover the whole central Europe and span for more than 20 years.
- The results are aligned to the ETRF2000 frame and are crucial to better understand the geological structures in central Europe.
- It is our intention to add more solutions to our dataset, so that the dataset will be under permanent upgrading.
- We fill a gap in Central Europe, where the available information (positions and velocities) was lacking in very specific areas, such as Serbia, Bosnia and Herzegovina and Romania.
- This dataset will help researchers of different study areas to improve our knowledge on the very complex geological structures in Central Europe.

1. Data

At present, the CEGRN dataset consists of 1229 different sites covering Central Europe (Fig. 1) from Lithuania to the Republic of North Macedonia and from Switzerland to Ukraine. The dataset, from raw data files to final velocities, are made available to the relevant Working Groups of the EUREF ('European Dense Velocities', 'EPN Densification' and 'Deformation Models') for validation and comparison with independent analyses. The number of sites available in the dataset for each CEGRN campaign since 1996–2017 is provided in Table 1, whereas in Fig. 2 we show the geographical distribution of the CEGRN dataset (positions available at: http://cegrn.cisas.unipd.it/CEGRN/network/CEG_tableVEL.htm). In Fig. 3 we show how the analysis of the different campaigns is carried out, whereas in Fig. 4 we show the time span, number of sites and rms of the individual contributions wrt the combined solution. Table 2 shows the Helmert parameters between the individual contributions and the dataset. The estimated velocities are shown in Figs. 5 and 6 (horizontal and vertical velocities respectively). Fig. 7 shows the velocity profiles that deserve further research and Figs. 8 and 9 zoom into particular areas of interest covered by the dataset. Tables 3 and 4 show the Helmert parameters for the positions and velocities respectively for the Class A sites (release C1980).

The first CEGRN campaign was in mid-June 1994. However, those data and the 1995 data are unusable due to inconsistencies in the observation logsheets: mainly incorrect antenna models and

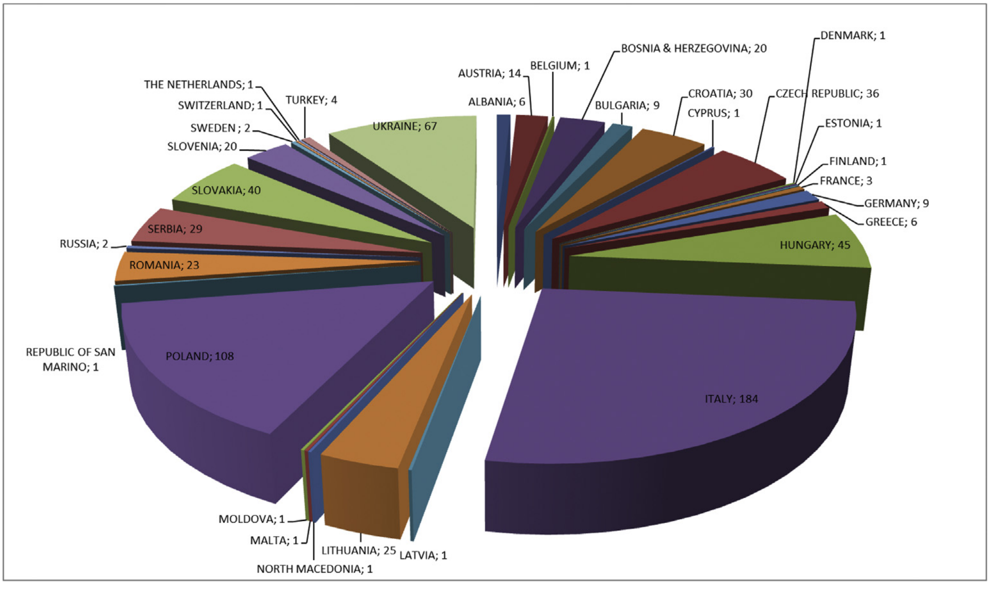

Fig. 1. The 33 Countries and number of sites in the CEGRN Cumulative solution (1996–2017).

Table 1
List of the CEGRN campaigns (1996–2017).

Campaign	From	To	Number of sites
CEGRN 1996	1996-06-10	1996-06-15	51
CEGRN 1997	1997-06-04	1997-06-10	44
CEGRN 1999	1999-06-14	1999-06-19	62
CEGRN 2001	2001-06-17	2001-06-23	57
CEGRN 2003	2003-06-16	2003-06-21	77
CEGRN 2005	2005-06-20	2005-06-25	106
CEGRN 2007	2007-06-18	2007-06-23	95
CEGRN 2009	2009-06-22	2009-06-27	85
CEGRN 2011	2011-06-20	2011-06-25	89
CEGRN 2013	2013-06-16	2013-06-22	178
CEGRN 2015	2015-06-14	2015-06-20	184
CEGRN 2017	2017-06-11	2017-06-17	1104

eccentricities. Therefore, the first CEGRN campaign considered is 1996. In 1997 it was decided to schedule the campaigns each 2 years, in mid-June, starting in 1997.

It is remarkable that the number of sites in 2017 is about 6 times the 2015 campaign. The reason for such increase is that we combined in that 2017 campaign observation files (standard RINEX [1]) with normal equation files (standard SINEX [2]). On the other hand, several new Agencies joined the CEGRN efforts in 2017.

2. Experimental design, materials, and methods

2.1. Experimental design

The Central European GNSS Research Network (CEGRN) consortium has its origin in the framework of the project called CERGOP (Central European Research on Geodynamics Project) [3]. The CERGOP consisted originally of 11 countries of Central Europe: Austria, Croatia, the Czech Republic, Germany, Hungary, Italy, Romania, Poland, Slovakia, Slovenia, and Ukraine. In 1998, Albania, Bosnia and Herzegovina and Bulgaria joined the CERGOP. These countries agreed to organize the CEGRN consortium to operate, maintain and develop the CEGRN GNSS network for reference frame definition and to study the geokinematic processes in Central Europe. The resulting positions and velocities, coordinate time series and supporting data are made available through the CEGRN website (http://cegrn.cisas.unipd.it).

The main objective of the CEGRN network is the monitoring of present day crustal surface deformations in Central Europe. The results of the first phase (1994–1997) were presented by Refs. [4,5]. The main study areas cover the Adriatic Microplate, the Balkans and Dinarides, the Carpathians, the Eastern Alps and the Pannonian Basin, being all of them active tectonic zones. The long term project is running since 1994 and was sponsored twice by EU projects: CERGOP-1 and CERGOP-2 (Environment Central European Geodynamics Project, funded by the European Union from 2003 to 2006) under the 5th Framework Programme ([6,7]).

In 2011 a Memorandum of Understanding [8] between the Regional Reference Frame Sub-Commission for Europe (EUREF, www.euref.eu; [9]) and the CEGRN based on the ETRS89 implementation and densification of the velocity field, both of common interest, was signed at the 2011 EUREF Symposium of Chisinau, Moldova.

In 2014 the 10 weekly campaigns (1996–2013) observed within the CEGRN activities were processed following the EUREF's guidelines for densification [10] and using repro2 products for non-IGb08 products. The resulting ten SINEX files were stacked in a combined solution. This solution was validated by the EUREF Technical Working Group ([11,12]).

Over the last years, the number of the CEGRN sites has grown considerably, as well as the contribution of the Analysis Centers. Fig. 1 shows the number of Countries (33) and the number of stations they contribute with in the cumulative CEGRN solution (1996–2017) spanning at least 4 years. Stations

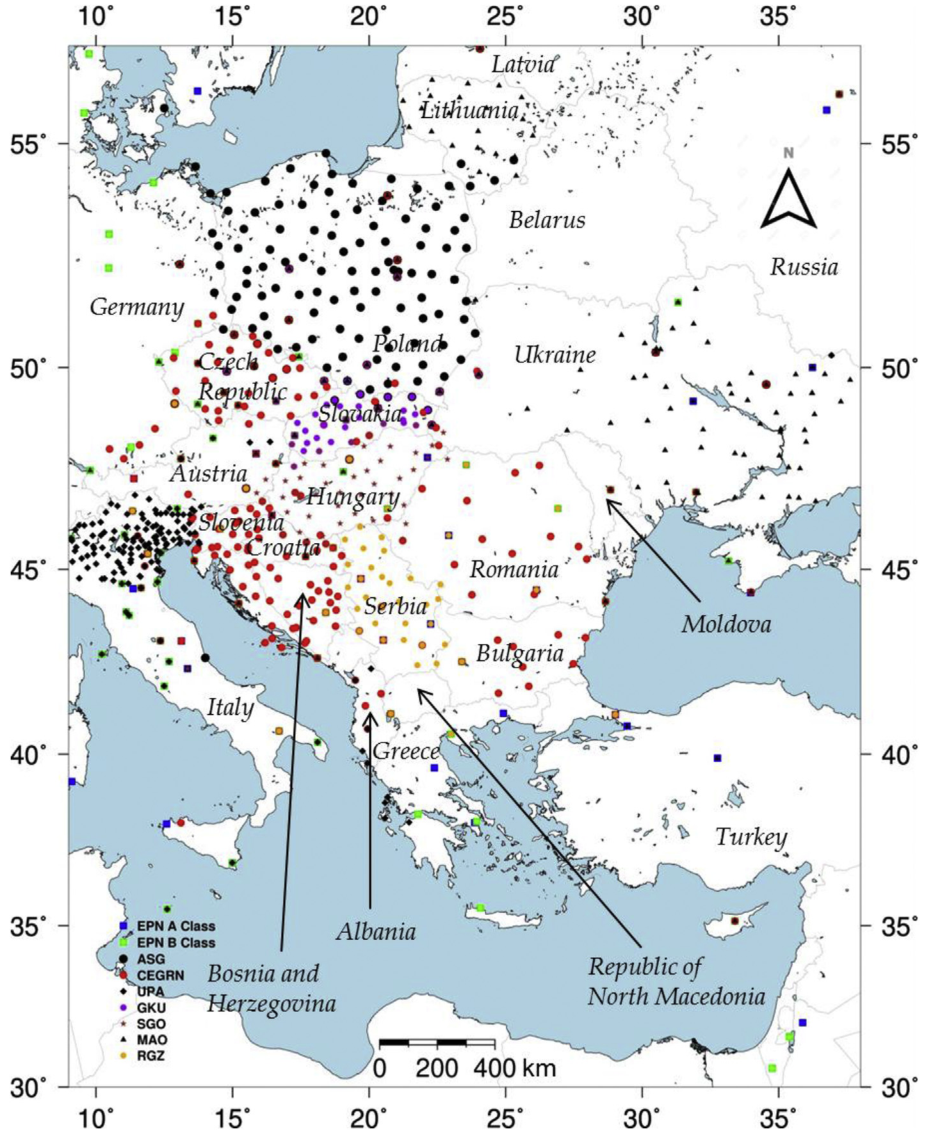

Fig. 2. CEGRN Network, sites with more than 4 years of data. EPN = *European Permanent Network*; ASG = *Glowny Urzad Geodezji i Kartografii*, Poland; GKU = *Geodetický a Kartografický Ústav*, Slovakia; MAO = Main Astronomical Observatory, National Academy of Sciences of Ukraine, Ukraine; RGZ = *Republicki geodetski zavod, Serbia*; SGO = Satellite Geodetic Observatory, Hungary; UPA = University of Padova, Italy. EPN A Class are used for frame alignment; EPN B Class are complementary sites not used for frame alignment. Mercator cylindrical projection is used (GRS80 ellipsoid).

entering the European Permanent Network cumulative solution (http://epncb.oma.be/_productsservices/coordinates/) are not included in this list but are included in the CEGRN densification analysis.

This paper presents the cumulative solution of the CEGRN network from 1996 to 2017 (Table 1) and (Fig. 2), as a densification of the European Permanent Network (EPN). We stack the adjusted normal

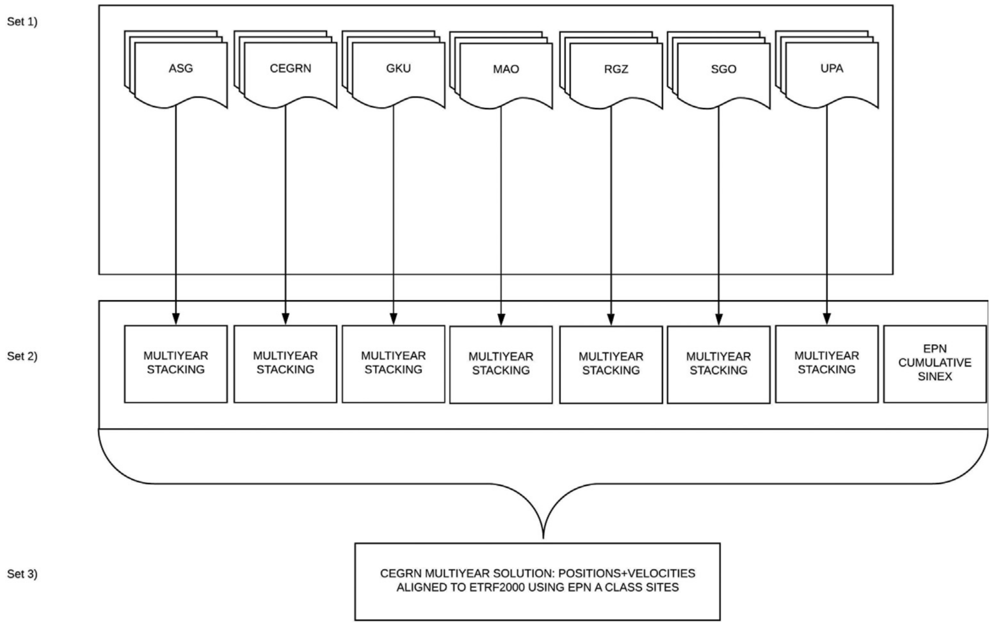

Fig. 3. CEGRN multiyear files processing flowchart: Set 1) refers to weekly normal equations of each of the eight subnetworks. Set 2) refers to the stacking of the normal equations to generate multiyear normal equations for each subnetwork. Set 3) refers to the stacking of the multiyear subnetworks to generate the multiyear CEGRN densification.

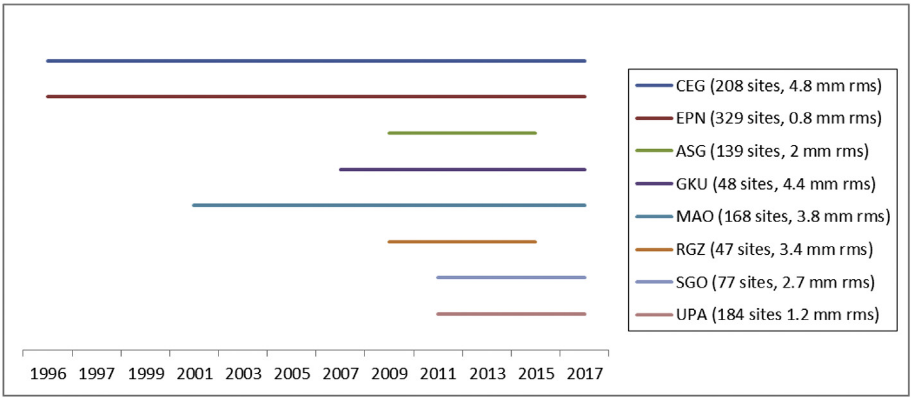

Fig. 4. Number of sites and rms of the subnetwork solution with respect to the combined solution and time span of the data made available by the eight contributing Analysis Centers for the multiyear CEGRN solution.

equations of eight European subnetworks in a combination scheme compliant with state of the art processing guidelines (Bruyninx et al., 2018). The main goal is to generate as rigorously as possible a very accurate set of positions and velocities to be used to study present day deformations at a regional scale in Central Europe (in press). As deformations can be very small, we have payed particular attention to the control of systematic errors coming from reference frame effects. Our experience combining and comparing results of the EPN, EPN Densification, CEGRN and the Italian GNSS Network, show that even if different Analysis Centers share the same processing standards, systematic

Table 2
Helmert transformation parameters of the individual solutions with respect to the combined CEGRN at epoch 2010.0. For each individual solution, the number of reference stations (Class A sites) is provided. Rms is the root mean square of the common coordinate differences at the reference epoch. TX, TY, TZ are the translations of the origin of each subnetwork relative to the combined network; likewise, RX, RY and RZ represents rotations about the X, Y and Z axis and scale is the scale difference, in parts per billion (ppb).

	Class A Sites	Rms (mm)	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)
EPN	234	0.8	−0.2	−0.3	0.1	0.0	0.0	0.0	0.0
CEG	50	4.8	−13.4	6.7	14.7	0.0	−0.6	0.2	−0.6
MAO	71	3.8	−0.5	−3.5	8.7	0.2	−0.2	−0.1	−0.7
GKU	15	4.4	16.7	−29.0	−2.5	0.6	0.4	−0.9	0.9
ASG	35	2.0	5.3	−17.4	7.1	0.5	0.0	−0.5	−0.2
RGZ	17	3.4	56.5	−44.7	−21.0	1.1	1.8	−1.1	−1.8
UPA	22	1.1	−3.0	3.0	6.2	0.0	−0.2	0.0	0.0
SGO	19	2.6	20.0	−7.4	−5.6	0.2	0.6	−0.3	−0.3

differences in the computed coordinates and velocities can result from network effects, length of the processing period and other reasons. Consequently, the velocities coming from the different Analysis Centers cannot be merged and an additional stacking with the removal of Helmert parameters is needed.

In Section 2 the data and analysis method are described. We use data at different levels of processing, from RINEX (raw data files from one site and one day) to normal equations in standard SINEX format (coordinates, variance covariance and a priori constraints for a subnetwork using typically one week of data) to multiyear SINEX, where weekly SINEX data are time-wise stacked to generate a multiyear solution for a specific subnetwork. We discuss how the individual contributions are validated and checked for mutual consistency, taking the EUREF Guidelines as a reference.

In Section 2.2 we describe the multiyear adjustment of subnetworks providing the desired velocities for sites with long enough tracking history. Particular attention is given to the alignment of the adjusted network to the backbone EPN in its C1980 realization, updated up to GPS week 1980 (December 17, 2017). The alignment of the cumulative CEGRN solution to the backbone cumulative EPN solution is achieved by a minimally constrained 14 parameter Helmert transformation, with the most reliable EPN stations (so called class A sites [13,14]) kept as reference for position and velocity. We conclude by providing mapped and numerical values of the computed velocities, which form the basis of further research [15].

2.2. Data and analysis method

2.2.1. Processing of the subnetworks

Our processing scheme foresees that all the contributing stations are provided with a machine readable log-sheet, to keep track of equipment and environmental changes. Because several sites (e.g. sites in common with the EPN) already have an IGS-style log-sheet (IGS is the acronym for International GNSS Service), a procedure was developed to generate the same type of log-sheet for all the remaining sites. The information contained in the SINEX or RINEX files is checked against the log-sheet of the involved GNSS sites. Updates of the log-sheet of a site may imply a discontinuity in the time series of its coordinates, which is handled with a solution number. The EPN solution number file for the EPN sites (ftp://ftp.epncb.oma.be/pub/station/coord/EPN/) was taken as basis and complemented with additional solution numbers for CEGRN sites, whenever appropriate.

The following Analysis Centers contributed to the CEGRN analysis (hereafter referred to as 'CEG') with weekly SINEX files computed according to the EPN Guidelines (http://epncb.oma.be/_documentation/guidelines/):

- ASG (*Glowny Urzad Geodezji i Kartografii*, Poland): solutions from 2009 to 2015.
- GKU (*Geodetický a Kartografický Ústav*, Slovakia): solutions from 2007 to 2017.
- MAO (Main Astronomical Observatory, National Academy of Sciences of Ukraine): solutions from 2001 to 2017.

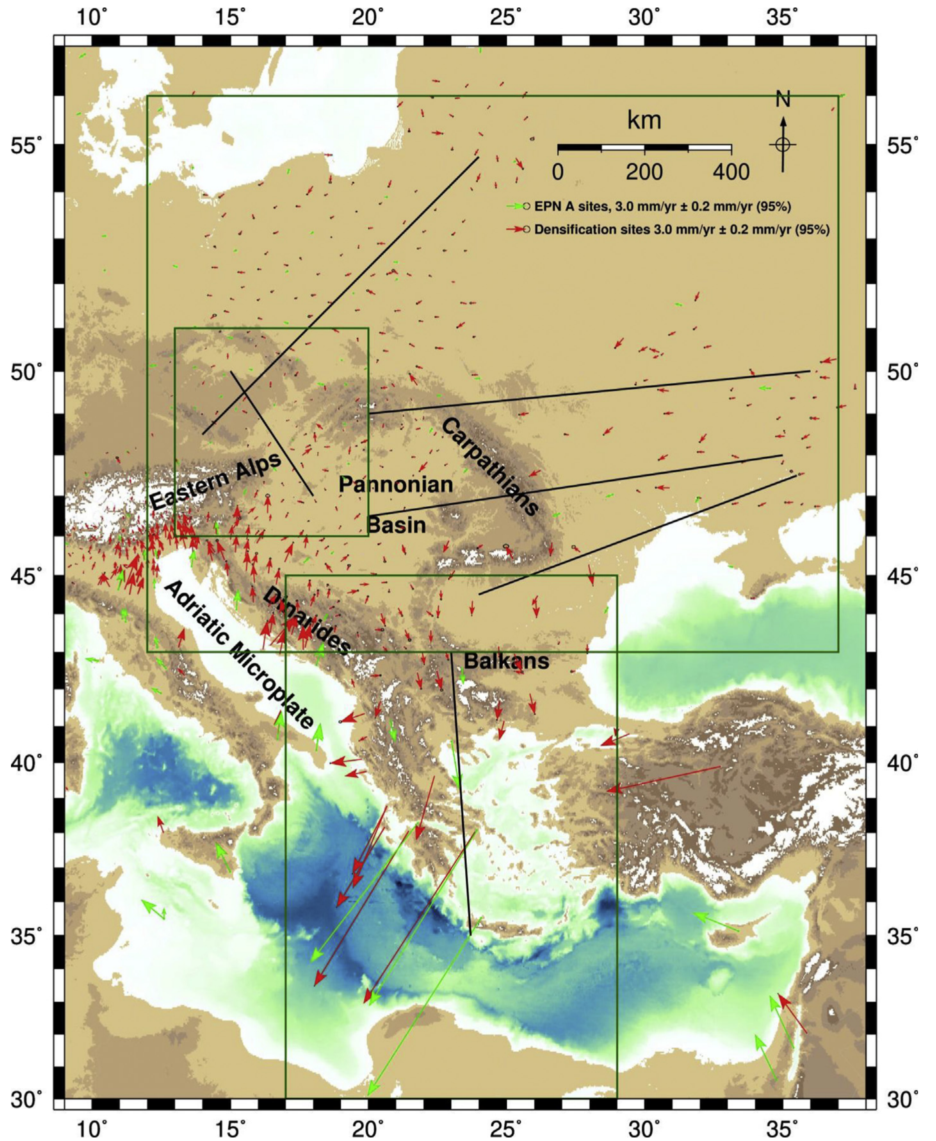

Fig. 5. Horizontal velocity map (ETRF2000) from the combination of the eight multiyear solutions. The dark green rectangles are areas of special interest studied in Part 2 of this work by interpolating the measured velocities to the six horizontal profiles (black lines). Mercator cylindrical projection is used (GRS80 ellipsoid).

- EPN (European Permanent Network): solutions from 1996 to 2018.
- RGZ (*Republicki geodetski zavod*, Serbia): solutions from 2009 to 2015.
- SGO (Satellite Geodetic Observatory, Hungary): solutions from 2011 to 2017.
- UPA (University of Padova, Italy): solutions from 2011 to 2017.

We have subdivided the available data into eight subnetworks, one for each Analysis Center (Fig. 3). For each subnetwork, weekly SINEX solutions have been assembled either by processing the daily RINEX

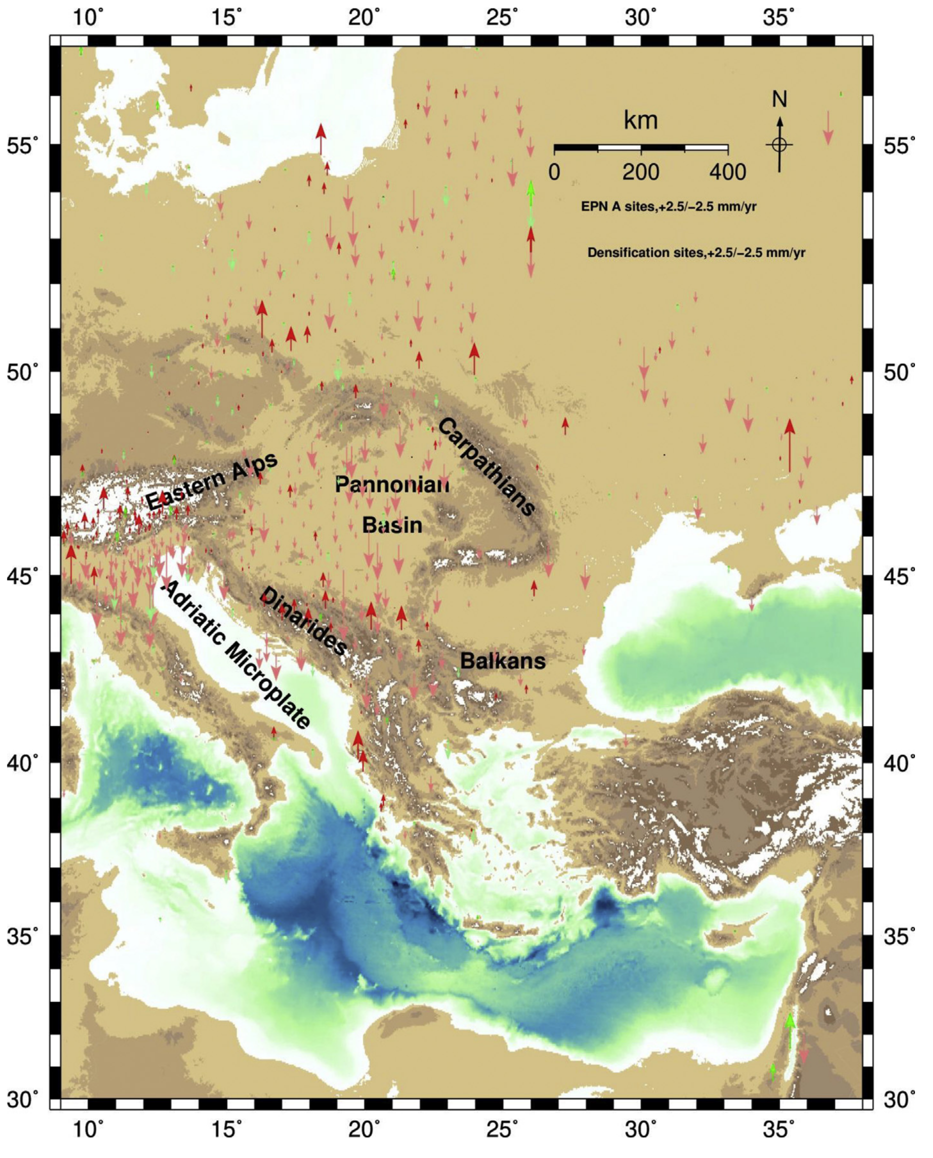

Fig. 6. Vertical velocity map (ETRF2000) from the combination of the eight multiyear solutions. Mercator cylindrical projection is used (GRS80 ellipsoid).

data or by stacking the daily SINEX files which were provided by the contributing Analysis Centers. The software used for the computation of the daily campaigns, based on RINEX observation files, as well as to compute the final combined solution is the Bernese GNSS Software v5.2 [16], hereafter BSW52. All the weekly SINEX data were generated consistently with the IGb08 orbits and antenna models.

The processing of the GNSS data for each subnetwork can be summarized as follows (Fig. 3):

1. Daily processing of the RINEX observations yields daily normal equation files.
2. Stacking of the daily normal equations into weekly for each CEGRN campaign. Minimum Constraints on the coordinates of fiducial stations (EPN Class A stations) are applied to invert the normal equations for later re-usability.

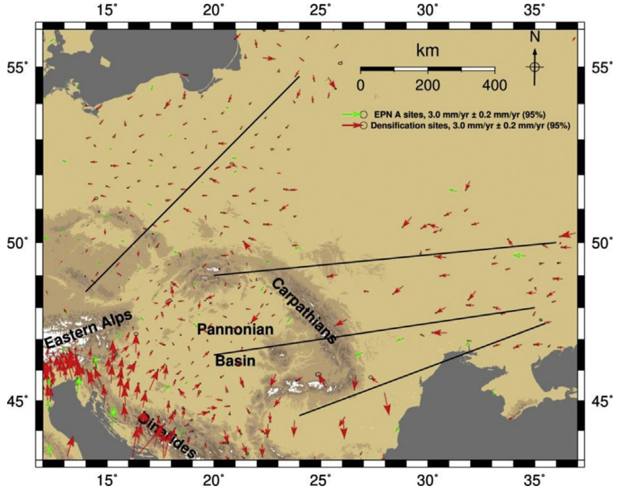

Fig. 7. Velocity profile covering the area of Poland from Lithuania to Austria, and velocity profiles from Ukraine towards Romania and the Carpathians. Mercator cylindrical projection is used (GRS80 ellipsoid). Velocity arrows are in ETRF2000.

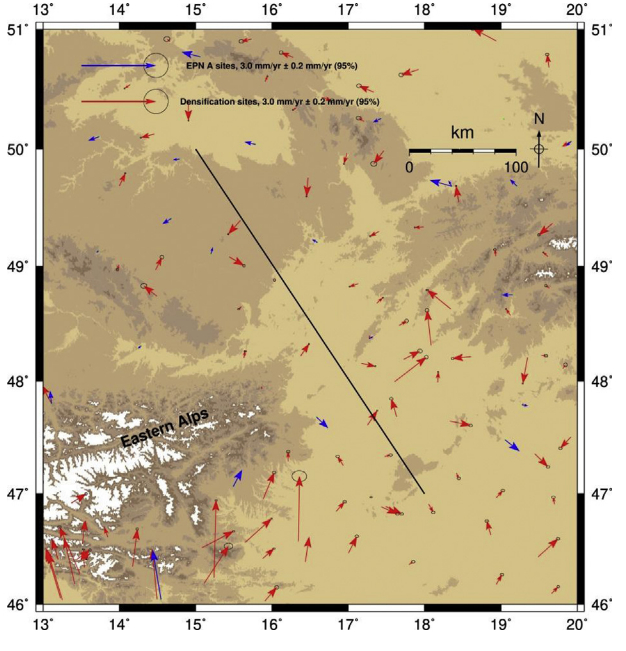

Fig. 8. Velocity profile covering the Pannonian basin, the Czech Republic and Hungary. Mercator cylindrical projection is used (GRS80 ellipsoid). Velocity arrows are in ETRF2000.

Details of the GNSS data processing are available in the Guidelines. GPS and GLONASS, if available, are considered and a sampling interval of 30 sec is used for the daily computations. The cutoff elevation was set to 3°. In case individual phase center (PCV) calibration values are available, they are included in the model. Solid Earth tidal displacements are corrected according to IERS 2010 Conventions. To correct

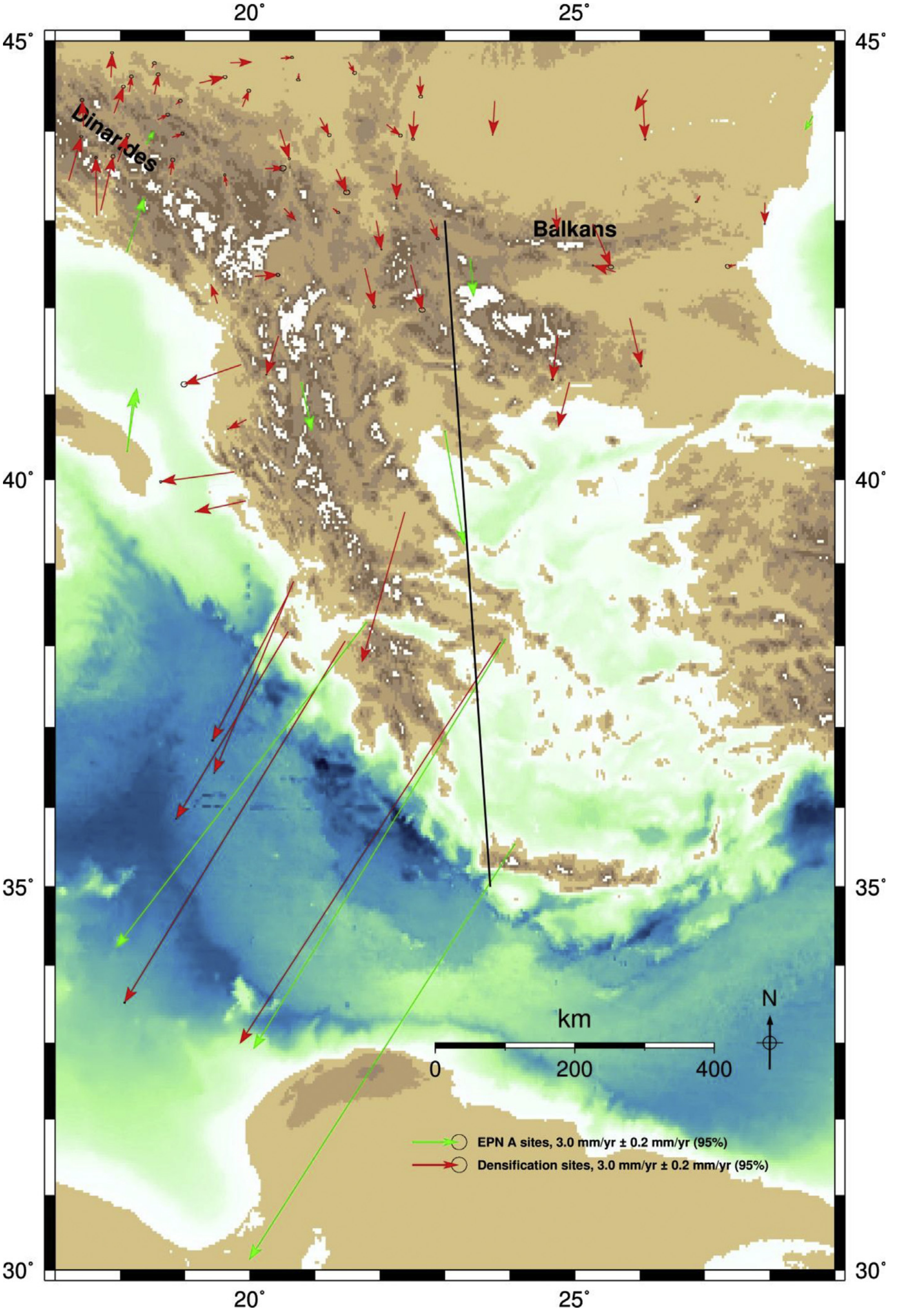

Fig. 9. Area covering the Balkans and Greece. Mercator cylindrical projection is used (GRS80 ellipsoid). Velocity arrows in ETRF2000.

Table 3
Helmert Parameters (only translations) between the computed values (CEGRN 1996–2017) and the nominal values (C1980) of the EPN class A sites, at epoch 2010.0. RMS is the root mean square difference in the coordinates of the 234 Class A sites (690 if solution numbers are considered) after the Helmert Transformation at the reference epoch 2010.0.

RMS (mm)	TX (mm)	TY (mm)	TZ (mm)
1.8	−1.17 ± 0.07	−1.60 ± 0.07	−2.05 ± 0.07

Table 4
Statistic of the residuals, after applying the Helmert Parameters in Table 3, between the CEGRN multiyear adjustment (CEGRN 1996–2017) presented in this paper and the nominal values (C1980) of the 234 EPN class A sites (690 if solution numbers are considered), at epoch 2010.0, for position and velocities.

N (mm)	E (mm)	Up (mm)	Vn (mm/yr)	Ve (mm/yr)	VUp (mm/yr)
0.0 ± 1.1	0.5 ± 1.0	0.1 ± 2.7	0.06 ± 0.13	−0.07 ± 0.12	0.38 ± 0.28

ocean loading effects we used the FES2004 coefficients, whereas atmospheric loading is corrected for each site using coefficients computed by the BSW52 (program GRDS1S2, using IERS2010 standards) from a gridded model.

The tropospheric refraction was modelled using an elevation dependent weight and the global mapping function ‘GMF dry’ mapping function as a priori values. Zenith Tropospheric Delays (ZTD) were estimated using ‘wet’ GMF and the azimuthal asymmetries were modelled using the CHENHER gradient estimation model [16]. The ionospheric effect was removed by the “iono-free” linear combination of L1 and L2 carrier phases. The CODE's (Center for Orbit Determination in Europe) ionospheric data were used to compute the 2nd and 3rd order ionospheric corrections.

2.2.2. Cumulative solutions of the individual networks

In section 2.1 we summarized how the RINEX files are processed on a daily basis to produce a weekly solution (Fig. 3) for each of the eight regional subnetworks. Then, we stack the weekly solutions and compute the cumulative solution of each of the eight subnetworks with the ADDNEQ2 program (BSW52). ADDNEQ2 is an advanced tool that can manipulate and combine, by least squares, normal equations. A number of different options are allowed and the following files are have been used as input:

- Weekly normal equation files.
- Discontinuity file: from EPN C1980, from the CEGRN analysis centers, log-sheets and time series inspection (http://147.162.183.197/CEG/).
- Datum definition for Minimum Constraints (No Net Translation) in both position and velocity: EPN A class sites EPN C1980.

Velocities of densification sites are solved for if four or more years of data are available. The result is eight sets of position and velocities, with a number of sites in common among the different networks. These sets are not useable as such, because each network refers to its own realization of the ETRF2000 Reference Frame. To realize a unique frame in which the coordinates and velocities are defined in a consistent manner we need a further step consisting of a stacking of the eight multiyear networks, imposing again the same minimum constraints on the position and velocities of the reference, Class A EPN stations. This is discussed in the next section. The different solutions available cover a different time span (Fig. 4). The sum of the contributing sites (1200) is slightly smaller than the number of velocities (1229) because for some EPN Class A sites used as reference different velocities are specified for the time span 1996–2017.

2.2.3. CEGRN cumulative solution: velocity field estimation

Once all the multi-year cumulative solutions are available from each Analysis Center they are combined into the cumulative CEGRN solution using the ADDNEQ2 module of the BSW52. The stacking of the eight normal equations is made imposing Minimal Constraints on positions and velocities of class A reference sites of the EPN and solving for a full set of 7 Helmert parameters.

In Table 2 we show the Helmert parameters between each individual subnetwork solution and the combined one.

Table 2 shows that the coordinates and velocities of individual subnetworks are defined in reference frames which are offset in origin and rotated relative to each other and, hence, to the combined Reference Frame. The reference EPN solution has instead a negligible offset or rotation relative to our combination solution, demonstrating that our combined network and the reference EPN network are very well aligned in origin, orientation and scale. The removal of systematic translations in origin, rotations and scale by a Helmert transformation is such that the coordinates and velocities of all the GNSS sites are defined in a unique reference frame.

The estimated velocities are shown in Fig. 5 (horizontal velocities) and Fig. 6 (vertical velocities). Fig. 7 shows the velocity profiles that deserve further research [15]. Figs. 8 and 9 zoom into particular areas of interest which are studied in Ref. [15].

2.3. Validation of the reference frame, of the coordinates and velocities

This section is devoted to verify that the estimated coordinates and velocities resulting from the combination of the eight subnetworks (see Table 2) comply with the state − of −the art standards for maximum accuracy. Following the Guidelines for EPN densification we validate our results based on two criteria: a) the alignment of the CEGRN reference frame to the ETRF2000 frame of the EPN stations is validated by means of a 3 translations Helmert parameter transformation; b) the mean and rms of the differences between CEGRN computed and EPN Class A sites is evaluated for both positions and velocities.

To prove the alignment of the CEGRN reference frame to the ETRF2000 frame of the EPN stations the values of a Helmert 3D (only translations) of the adjusted coordinates with respect the published values at their reference epoch (2010.0) are shown in Table 3. Minimum constraints are imposed, as above.

To demonstrate the mean and rms of the differences between CEGRN computed and EPN Class A sites, Table 4 gives the summary of the accepted EPN A class residuals (CEGRN multiyear adjustment vs EPN published values at epoch 2010.0) after applying the Helmert Parameters (3 translations) described in Table 3.

The Guidelines for EPN densification (Bruyninx et al., 2018) state that the frame alignment is properly accomplished when the agreement in coordinates and velocities is within 10 mm and 0.5 mm/yr respectively, for every component. Tables 3 and 4 demonstrate that these criteria are fulfilled for the CEGRN multiyear densification.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] RINEX format (latest: 3.03) (visited on 2019/03/11), ftp://igs.org/pub/data/format/rinex303.pdf.
[2] SINEX format. https://www.iers.org/IERS/EN/Organization/AnalysisCoordinator/SinexFormat/sinex.html, 2019.
[3] I. Fejes, A. Kenyeres, The central Europe regional geodynamic project (CERGOP), in: Proc. 1st Turkish Int. Symp. On Deformations. Sept. 5–9, 1994, 1994, p. 991. Istanbul, Turkey.
[4] Grenerczy Gy, A. Kenyeres, I. Fejes, Present crustal movement and strain distribution in Central Europe inferred from GPS measurements, J. Geophys. Res 105 (B9) (2000) 21,835–21,846.
[5] G. Stangl, Deficits of CEGRN solutions and time series. Reports on Geodesy No. 1(64), 2003, in: Proceedings of the EGS-AGU-EUG G17 Symposium "Geodetic and Geodynamic Programmes of the CEI (Central European Initiative)" Nice, France 6 – 11 April 2003, 2003, pp. 29–32 (visited on 2019/03/11). http://slideplayer.com/slide/9617645/.
[6] I. Fejes, Consortium for Central European GPS Geodynamic Reference Network (CEGRN):concept, Objectives and Organization. EGS XXVII. General Assembly, Nice, France, 2002, 2002, pp. 15–21. Reports on Geodesy No. 1(61).
[7] I. Fejes, P. Pesec, CERGOP-2/Environment – a challenge for the next 3 years, Rep. Geodesy 1 (64) (2003) 13–22 (visited on 2019/03/11), https://www.researchgate.net/publication/252405409_CERGOP-2Environment_-_A_challenge_for_the_next_3_years.

[8] Memorandum of Understanding between EUREF and CEGRN, Chisinau (Moldova) (visited on 2019/03/11), http://www.euref.eu/documentation/MoU/2011_5%20MoU%20EUREF-CEGRN.pdf, 2011.
[9] C. Bruyninx, The EUREF Permanent Network: a multi-disciplinary network serving surveyors as well as scientists, Geo-informatics 7 (2004) 32–35.
[10] C. Bruyninx, Z. Altamimi, A. Caporali, A. Kenyeres, M. Lidberg, G. Stangl, J.A. Torres, Guidelines for EUREF Densifications (visited on 2019/03/11), http://epncb.oma.be/_documentation/guidelines/Guidelines_for_EUREF_Densifications.pdf, 2018.
[11] A. Caporali, M. Barlik, M. Becker, L. Gerhatova, G. Grenerczy, J. Hefty, D. Medak, G. Milev, M. Mojzes, M. Mulic, T. Rus, J. Simek, G. Stangl, G. Virag, J. Zurutuza, A contribution to ETRS89 in central Europe: results from the CEGRN activity. EUREF 2015 Symposium lepzig, Germany (2015) 3–5 (June).
[12] EUREF 2015 Resolutions, June. Resolution No. 2, in: EUREF 2015 Symposium Lepzig, Germany, 2015, pp. 3–5 (visited on 2019/03/11), http://www.euref.eu/symposia/2015Leipzig/07-01-ResolutionsEUREF2015.pdf.
[13] A. Kenyeres, Categorization of Permanent GNSS Reference Stations (visited on 2019/03/11), http://www.epncb.oma.be/_productsservices/coordinates/kenyeres_2010.pdf, 2010.
[14] A. Kenyeres, The Implementation of IGS08 in the EPN ETRS89 Maintenance Products (visited on 2019/03/11), ftp://epncb.oma.be/pub/station/coord/EPN/IGS08_densification_V4.pdf, 2012.
[15] A. Caporali, J. Zurutuza, M. Bertocco, M. Ishchenko, O. Khoda, Present day geokinematics of central Europe, J. Geodyn. (2019), https://doi.org/10.1016/j.jog.2019.101652.
[16] R. Dach, S. Lutz, P Fridez P Walser (Eds.), Bernese GNSS Software Version 5.2. User Manual, Astronomical Institute, Universtiy of Bern, Bern Open Publishing, 2015, https://doi.org/10.7892/boris.72297. ISBN: 978-3-906813-05-9.