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DEVELOPMENT OF THE GEODYNAMIC INVESTIGATIONS IN CENTRAL AND EASTERN EUROPE

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Abstract

Results from geodynamic investigations of the region, which are accomplished after the 1st GMES (Global Monitoring for Environment and Security) Workshop in Sofia, 2010 and some new generalizations and conclusions are presented in this paper. Local densification, reprocessing, dense networks, analysis, long time spans for intraplate anomalies, horizontal velocities of the CERGOP (Central European Regional Geodynamic Project) network of permanent stations, horizontal velocities of the combined CERGOP network of permanent stations within Central and Eastern Europe and Monitoring Oriental Network (MON) are outlined.

1. General

The geodynamic investigations are an important component of the environmental and hazardous geodynamic phenomena investigations. In this respect regional geodynamic investigations have recently acquired a particular importance. Such a project was a regional CERGOP 2 Project that covered the geodynamic investigations [1] of Central and Eastern Europe and in particular the ones in Balkan Peninsula with special attention to the territory of Bulgaria. Results from these investigations were reported at the GMES Workshop in Sofia, 2010. Although the Project is financially finalized on the 5the EC Framework Program the investigations and the activity of the Participants in it are still going on including the regular measurements and data processing of CEGRN (Central European GPS Geodynamic Reference Network) network and annual meetings during the EGU (European Geosciences Union) Assembly in Vienna. Moreover neighbouring regions of Central and Eastern Europe and Monitoring Oriental Network have been associated and wider spectrum of problems, which include except GNSS (Global Navigation Satellite Systems) networks of EUREF (European Referents Frame), CEGRN and partly of EUPOS (European Position determination System) also local densification, reprocessing, dense networks, analysis, long time spans for intraplate anomalies, horizontal velocities. The result of these investigations presented in this work give the possibility to confirm the acquired geodynamic picture of the regions of interest and to profound the geodynamic investigations as a whole.

Furthermore these presented activities and the development of GMES activities enable a close collaboration and integration of the regional investigations.

2. Investigations in Central and Eastern Europe (CEE)

Results from the scientific analysis of GPS derived velocities are shown in Figure 1.

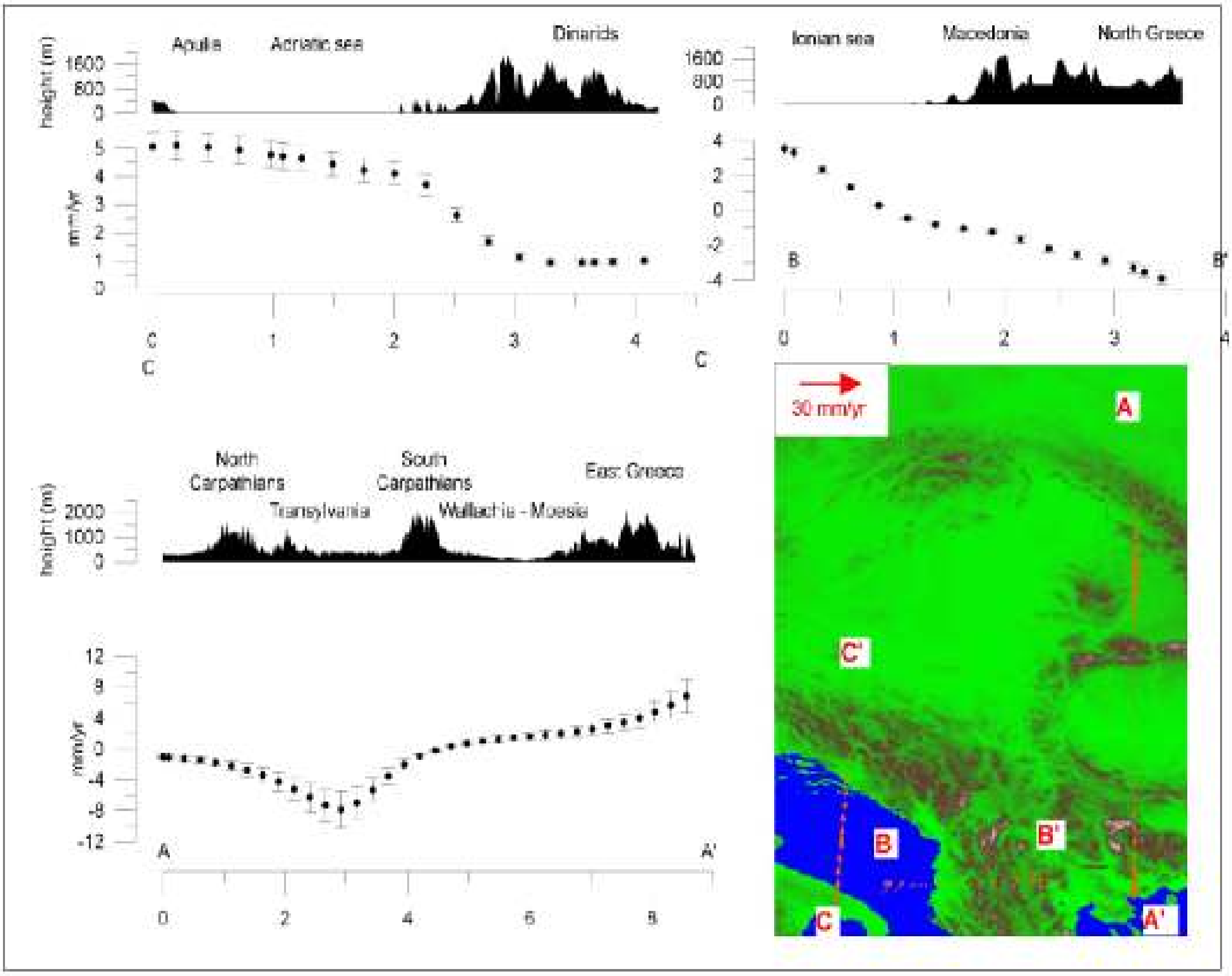

Figure 1. GPS velocity analysis in CEE

Profile AA' represents deformation rate from Northern Carpathians to Transylvania (compression) to East Greece (extension), through Moesia and Wallachia. Profile BB' represents the dextral strike slip across Albania and profile CC' represents the convergence of Apulia towards the Dinarids. The obtained results from the scientific investigation and analysis show that the CEGRN velocity field provides a regionally detailed picture of the surface deformation in seismically active areas of Central Europe and Balkans [3].

The interpretation of the Apuseni Mountains as a flexural bulge of the thin Pannonian lithosphere is presented in Figure 2.

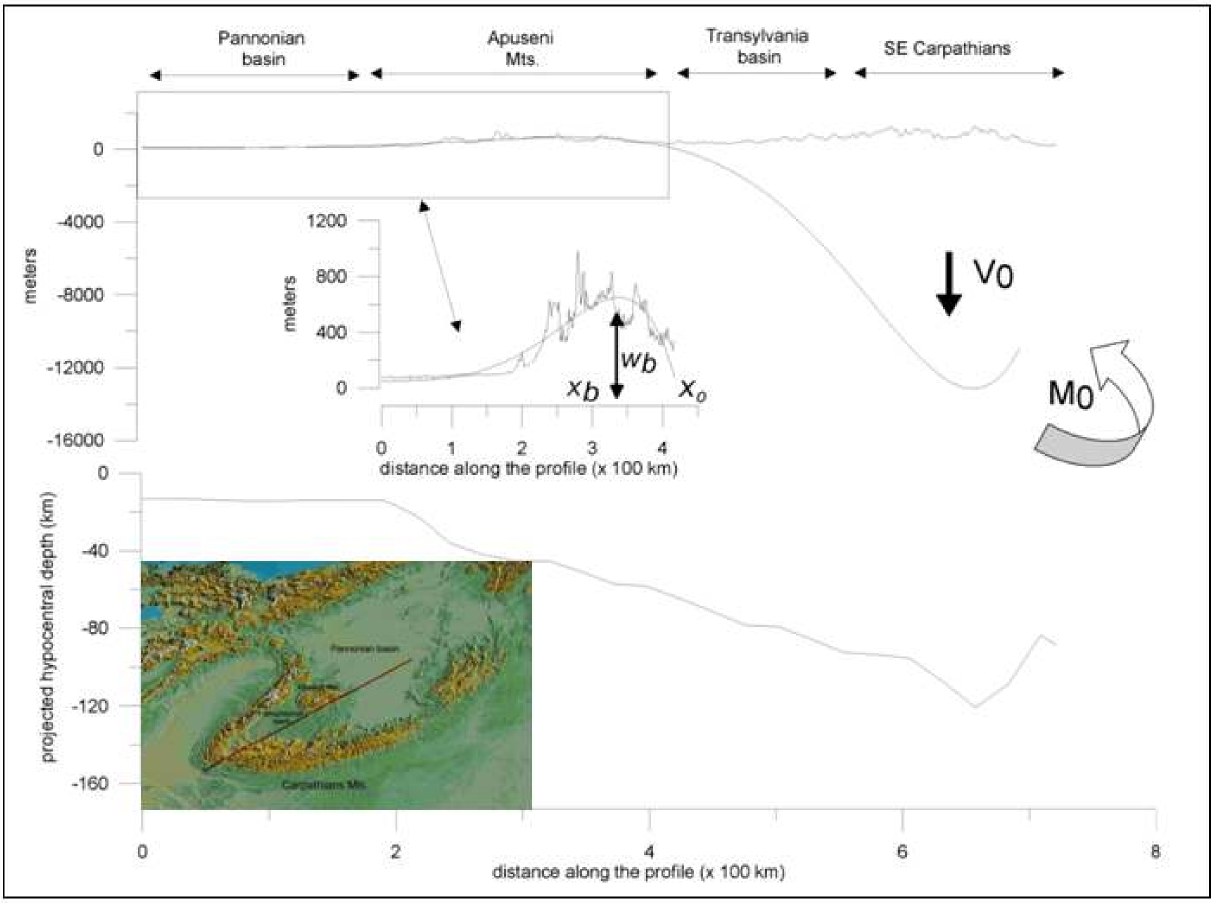

Figure 2. Interpretation of the Apuseni mts. as a flexural bulge of the thin Pannonian lithosphere

From the interpretation can be suggested that [2]:

- If the Pannonian lithosphere is allowed to bend under a load and torque localized beneath the SE Carpathians, then the location x_b and height w_b of the Apuseni mountains coincides with the flexural bulge.
- Temporal changes in the vertical shear force V_0 or bending moment M_0 should be visible as a variable strain on the surface of the Apuseni, measurable by GPS.

The outcomes from the local and regional scale monitoring can be summarized as follows:

- Natural Hazards and man-made constructions endanger infrastructure and society
- Examples are flooding, land-slides, opening of previously unknown caverns, soil instabilities due to previous use as landfill, mining, faulting etc.
- To monitor the environment and smallest motions a dense network of CORS (Continuously Operating Reference Stations) is required.
- These can be used in combination with space-borne SAR and DINSAR techniques for monitoring

An example of regional scale monitoring is the German Federal Network SAPOS-Hessen (Figure 3). Its data from the last eight years have been re-processed according to the latest IGS standards. The homogeneous re-processing of the dense network of CORS in the latest ITRF frame allows the detection of the small intra-plate deformations and local anomalous height and positioning changes. (The Data for SAPOS Hessen were kindly made available by the Hessisches Landesamt für Bodenmanagement und Geoinformation, the provision is kindly acknowledged).

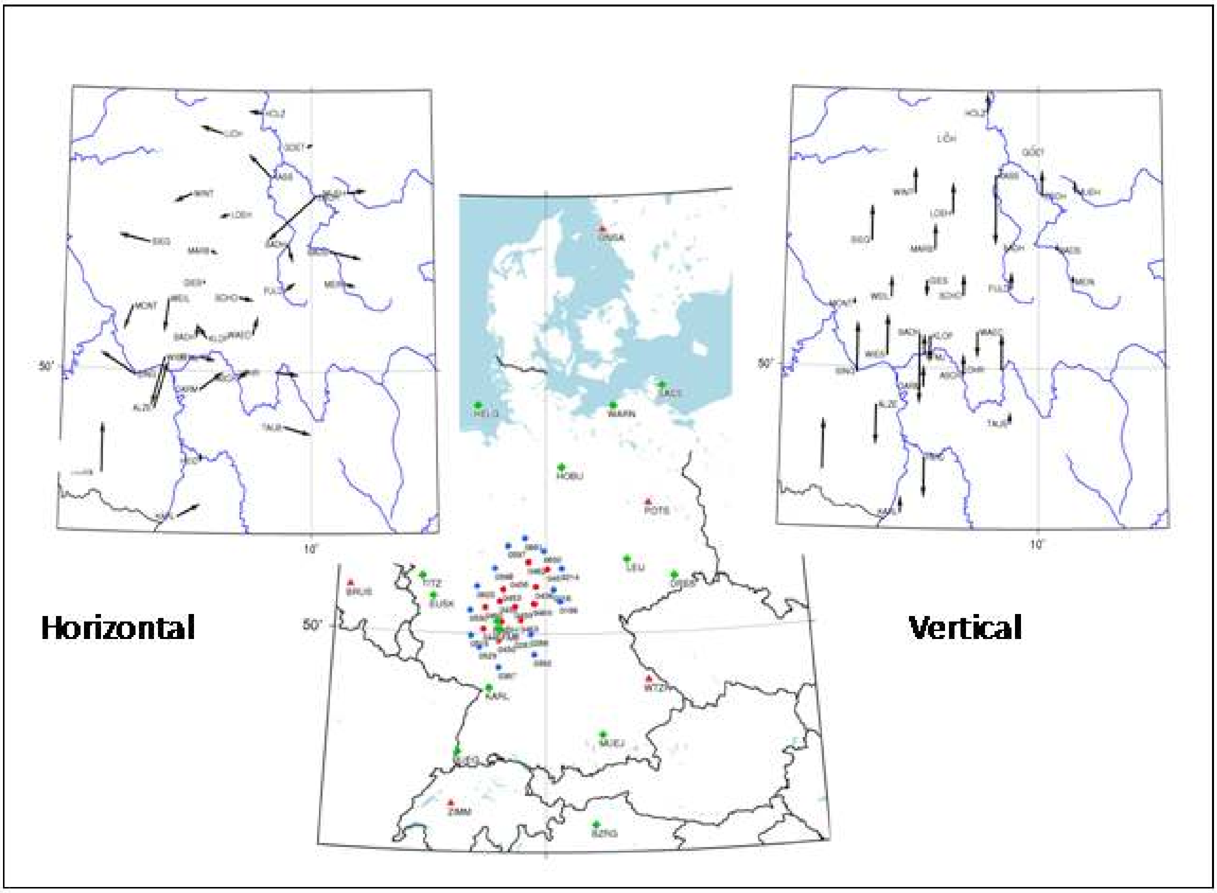

Figure 3. Horizontal and vertical station velocity vectors of the German Federal Network SAPOS-Hessen from re-processing

An example for long time span monitoring of a station behaviour concerns IGS/EPN station Brussels, it was used as reference frame station in the SAPOS re-processing. Figure 4 and Figure 5 show time series of the three velocity components – North, East and Up represent the behavior of the station during the time between January 2003 and January 2009.

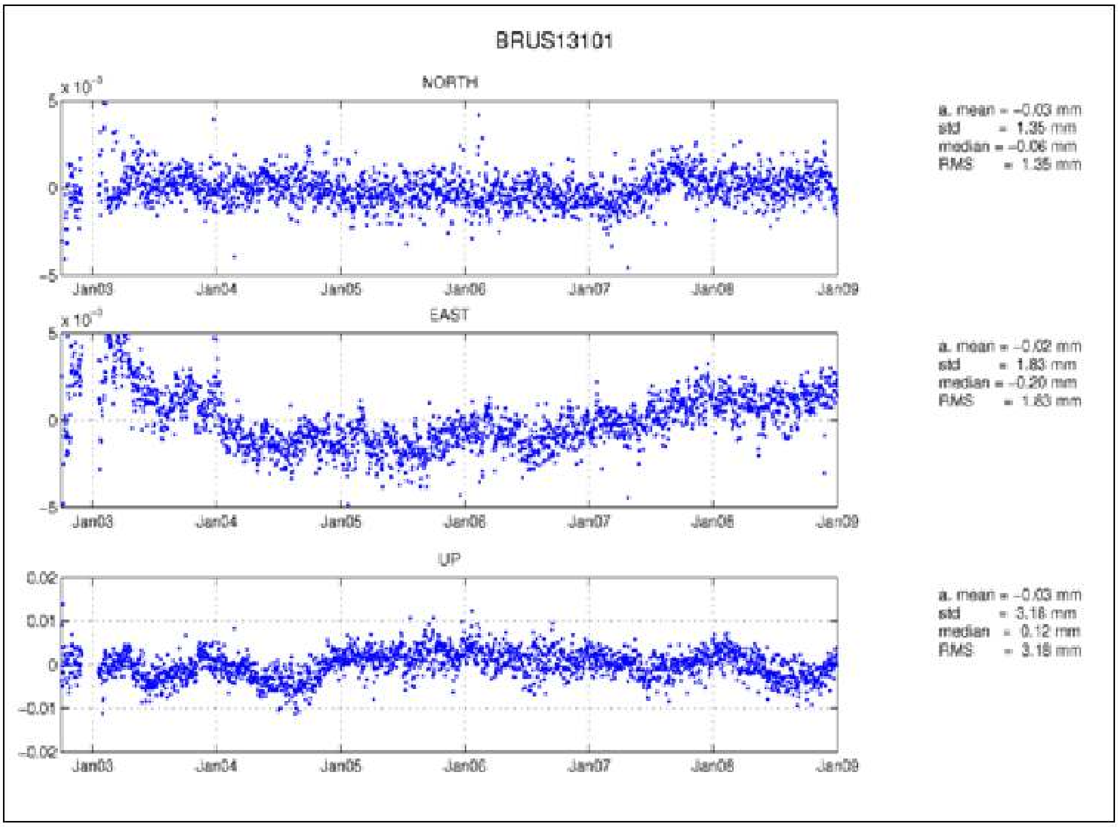

Figure 4. Time series of IGS/EPN station BRUS in North, East and Up components

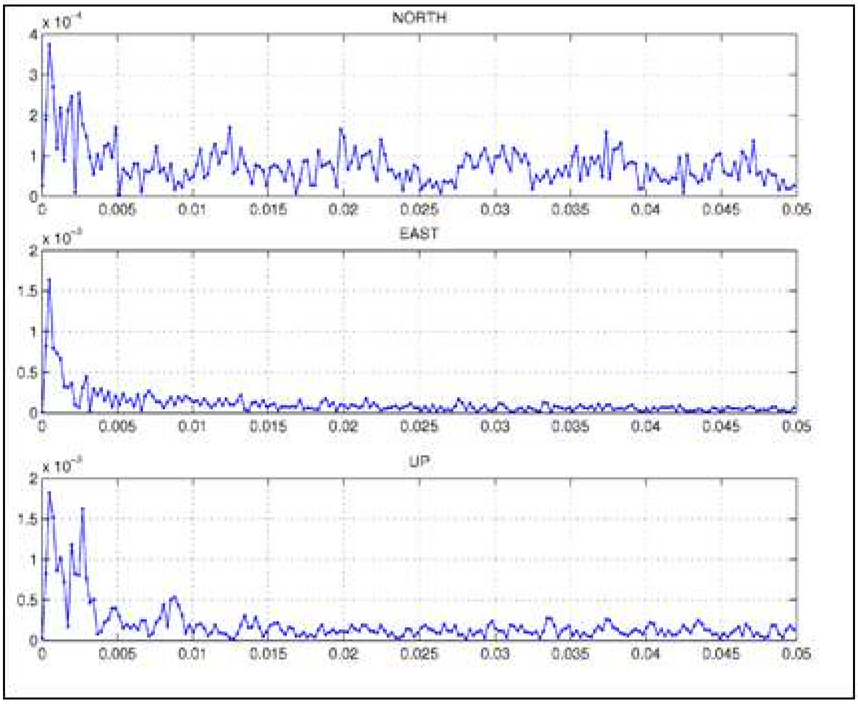

Figure 5. BRUS Power Spectrum, high frequency part of North, East and Up components

The reprocessing of GNSS data of BRUS over 8 years forces the idea that for the detection of changes in position and height at the mm-level long time series and re-processing according to the latest reference frames and IGS standards is required. Only long time series allow the separation of seasonal, equipment related or anomalous behavior of the station that are the basis for accurate modeling of climatologically or environmentally induced surface changes of the Earth.

Figure 6 presents the horizontal velocities of the CERGOP network of permanent stations within Central and Eastern Europe. The analysis is done weekly according to the rules of the EUREF Permanent Network EPN. The time series starts around 2000 but is not yet reprocessed using consistent models. Non-EPN stations are provided by the CERGOP members.

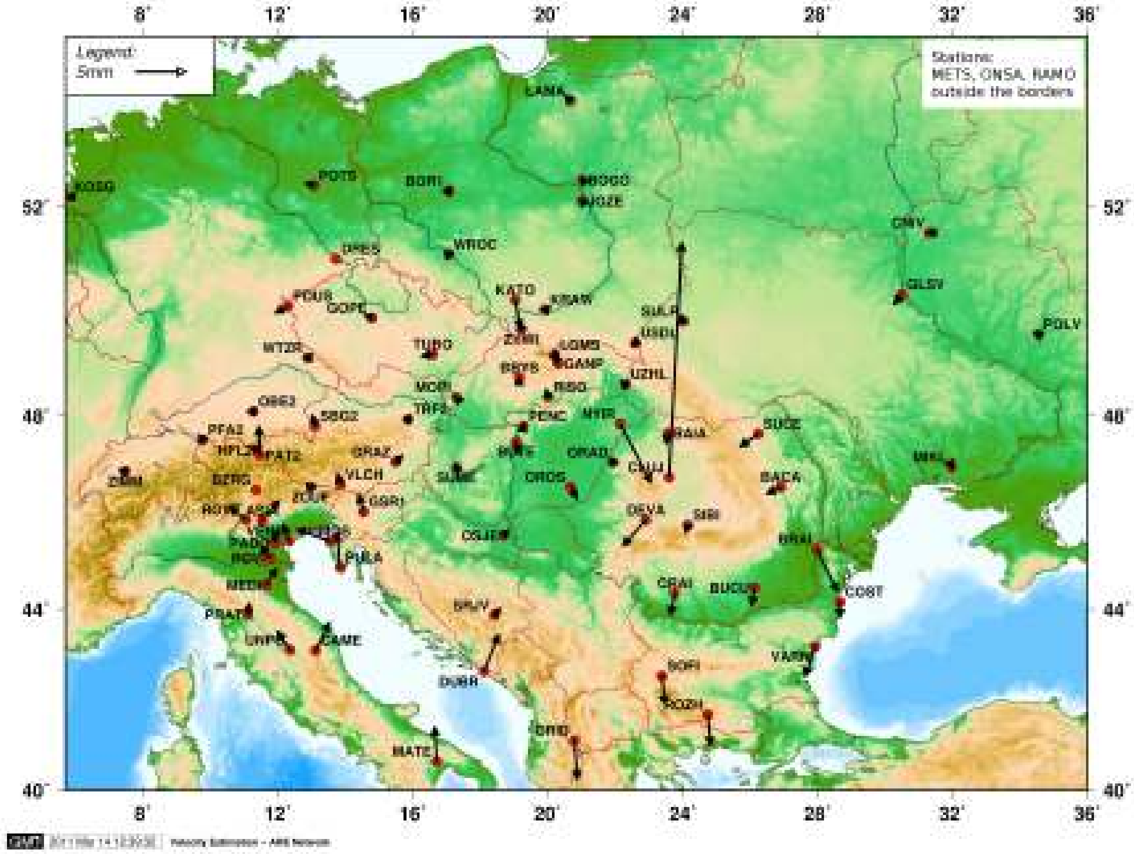

Figure 6. CEGRN horizontal station velocity vectors with respect to the stable Eurasia

Figure 7 presents the horizontal velocities of the combined CERGOP network of permanent stations within Central and Eastern Europe and MON, which extends into the Indian Ocean monitoring plate boundaries. Because of historical reasons the networks overlap in the southern Balkan region. At the about 10 identical points the difference of estimated velocities are between 0 and 1 mm/year, only the VARN velocities differ by 1-2 mm/year. The reason of these differences is the choice of different reference sites. All the analysis is done weekly according to the rules of the EUREF Permanent Network EPN. The time series start around 2000 but are not yet reprocessed using consistent models. Non-EPN stations are provided by CERGOP members and the Hemus-Net.

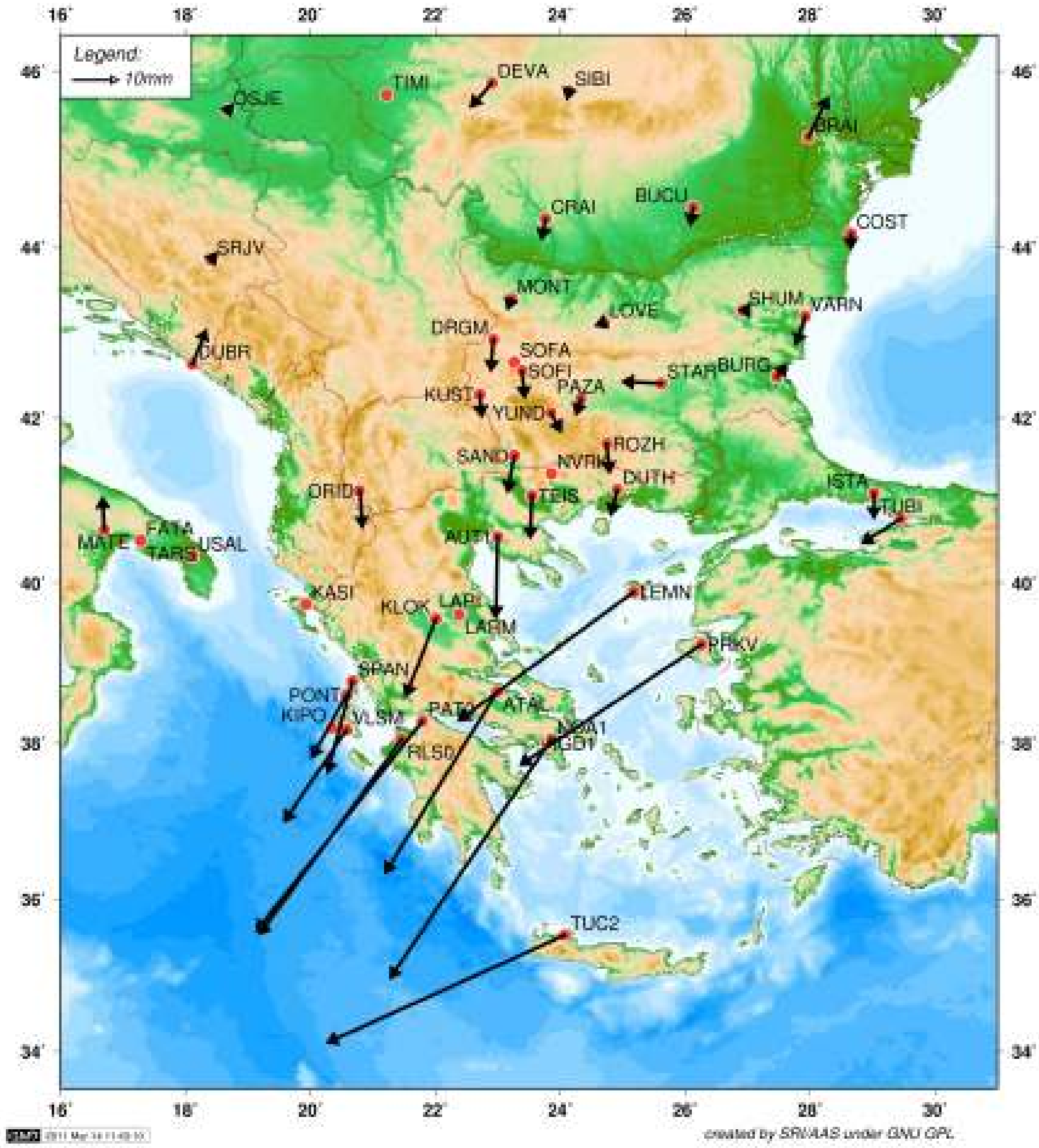

Figure 7. CEGRN and MON horizontal station velocity vectors with respect to the stable Eurasia

3. Investigations in Balkan Peninsula and Bulgaria

3.1. Investigations in Balkan Peninsula

The latest investigations of Balkan Peninsula (BP) geodynamic concern the seasonal behaviour of GNSS permanent stations on its territory (*Figure 8)*. Two season's data – winter and spring are processed and analyzed. GPS data of same winter weeks in January 2006, 2007, 2008 and 2009 have been processed with Bernese software, Version 5.0 [5, 6]. GPS data of the same spring weeks in April 2006, 2007, 2008 and 2009 have been processed [7] with the same software. Combined solution of two season's data has been accomplished and station velocity estimations have been obtained. They are compared with winter and spring station velocities and the results have been analyzed.

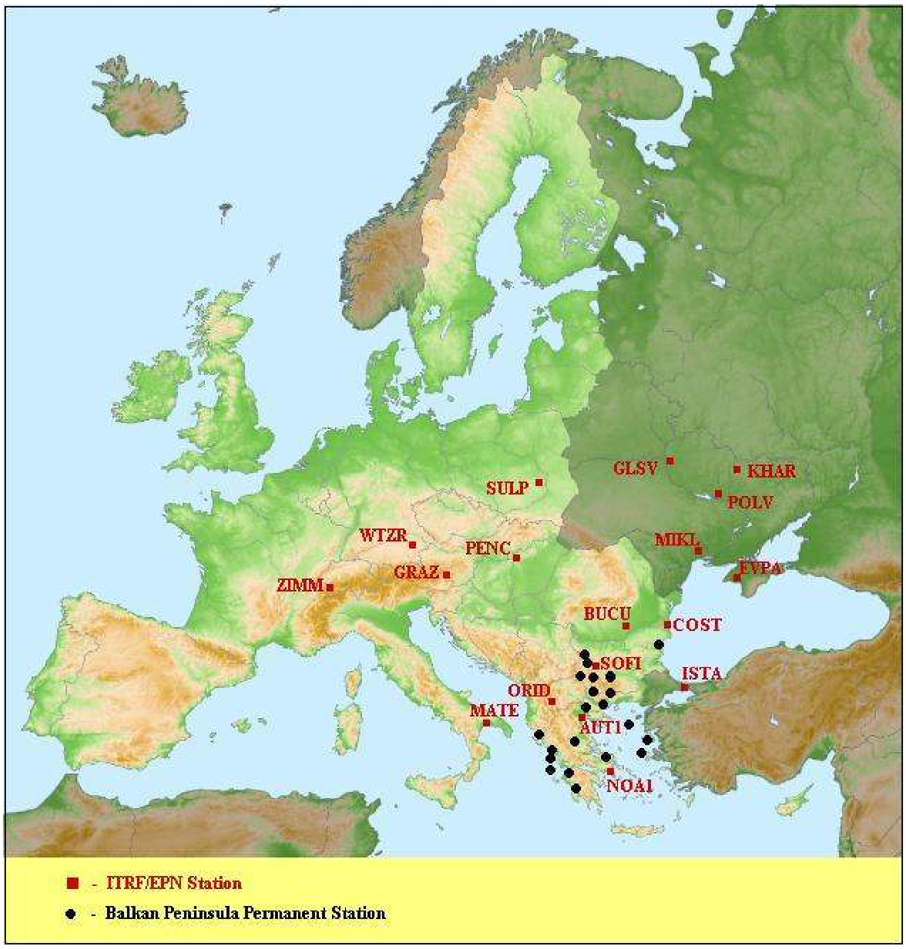

Figure 8. IERS/EPN and Balkan Peninsula permanent stations involved in this study

Within the period of interest the receiver and/or antenna types have been changed for several stations and for some stations the height of antenna reference point (ARP) have been also changed. Seven observation sessions of 24-hours time length have been created in each year. Data from all available satellites above the horizon (3^o) have been used.

For analyzing the behaviour of stations within the seasons of interest the combined seasonal velocity estimations are compared with the particular winter and spring estimations on one hand and on the other hand – winter estimations are compared with the obtained spring velocity estimations. By reason of compatibility the same IERS reference stations have been used for datum definition in all seasonal solutions by applying minimum constrained.
The results from all types of velocity comparisons – Winter&Spring – Winter, Winter&Spring – Spring, Winter – Spring and Winter&Spring – IERS/EPN/CERGOP in North component are shown in *Figure 9*.

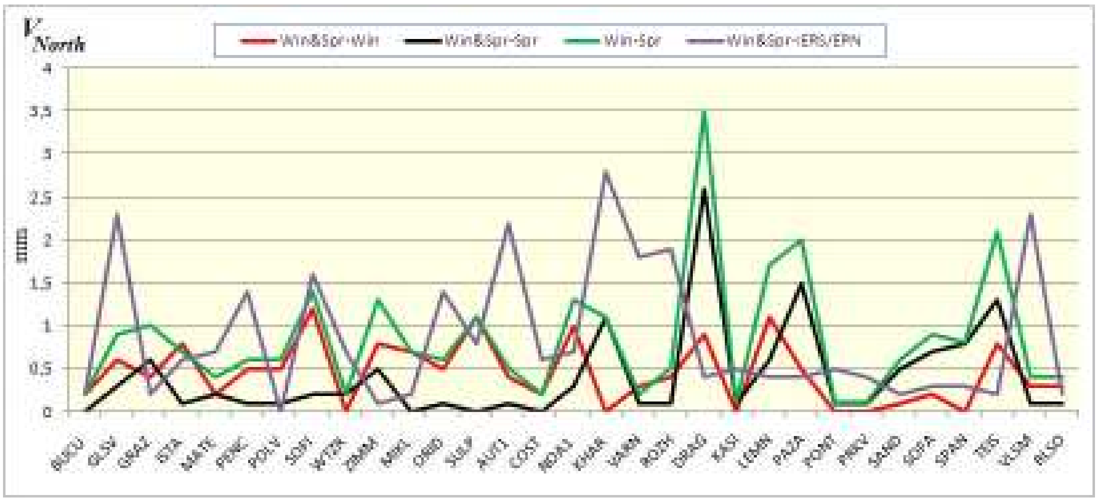

Figure 9. Velocity differences in North component

Nearly for all stations differences Winter&Spring – Spring in North component are very small – below 0,6mm and their movements can be considered as uniform during the analyzed time period. All other differences in this component, for all stations are below 2mm except some young Balkan Peninsula stations.

The results from all types of velocity comparisons in East component are shown in *Figure 10* for all participated stations.

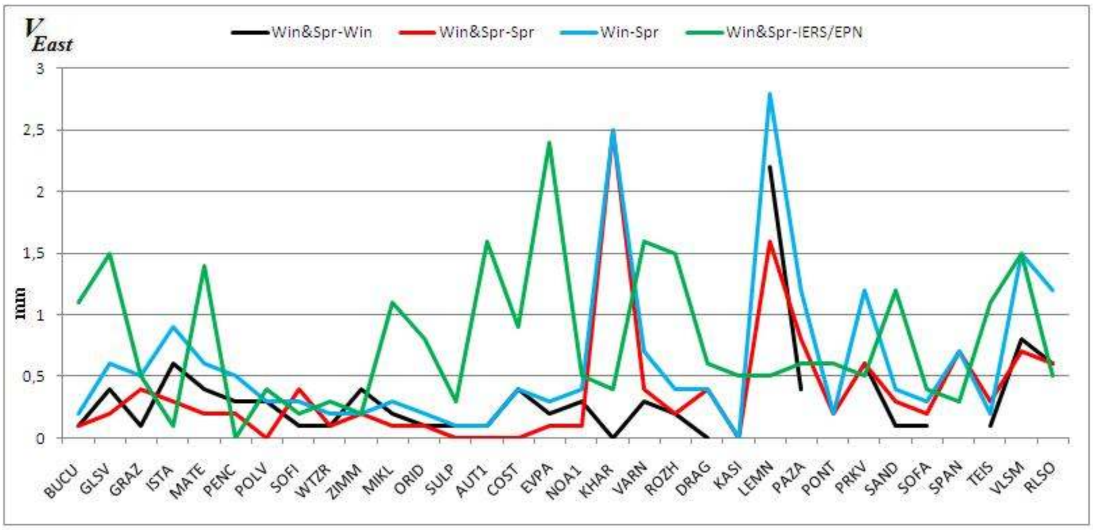

Figure 10. Velocity differences in East component

The highest value of velocity differences for all combinations is obtained pretty small - 1,5mm. EPN stations EVPA and KHAR and BP station LEMN show a little higher value – about 2,5mm which is result from the comparison of winter and spring estimations and from Winter&Spring – IERS/EPN/CERGOP velocity comparison. The smallest differences are determined almost for all stations in comparison of Winter&Spring and Winter solutions - below 0,5mm. So their movement during the analyzed time span can be considered as uniform. Nevertheless it should be taken into consideration that Winter&Spring solution produces average values for the investigated period on the base of accepted velocity model of the software. More adequate estimations for the stations behavior are the estimations obtained from separate winter and spring solutions which differ from each other with less than 1mm except a few stations.

As it is expected the highest differences are obtained in Up component for all combinations. The comparison results for all stations are shown in *Figure 11*. The problematic station EVPA shows difference of 7,4mm. Differences for BP station LEMN are too high - values of 28-37mm in the comparison of combined Winter&Spring solution with the particular Winter and Spring solutions. A reason for such behaviour is probably some offset in station height or seasonal change or presence of strong movement. For proving the movements of this station more and continuous data for a longer time interval should be involved to be obtained representative velocity results.

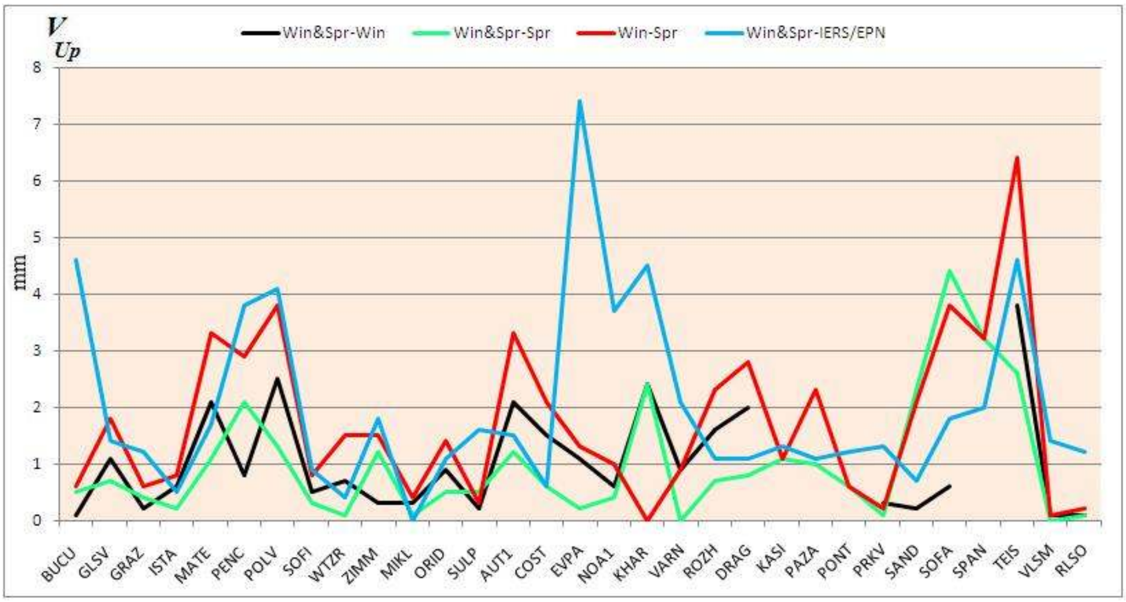

Figure 11. Velocity differences in Up component

The smoothest behaviour of the stations is determined in East component. The station velocity differences in all seasonal combinations are much closer to the differences obtained from comparison of combined seasonal solution Winter&Spring with IERS/EPN/CERGOP solutions. Except some stations the behaviour of all other stations in North component can be also determined as smooth one. It is not the case of differences in Up component.

3.2. Investigations in Bulgaria

The geodynamic investigations on the territory of Bulgaria are continued on the base of the united network of permanent CERGOP 2 stations enlarged with stations from the BULiPOS network of permanent stations (BULgarian intelligent POsition determination System), which is the national segment of the EUPOS network and system (EUropean POsition Determination System), and with stations from Leica network in Bulgaria. The new combined network of permanent stations and their connection with the permanent networks of the neighboring countries is shown in *Figure 12*. In this way at present the number of total stations of *BULiPOS* is 27 and number of neighboring stations is 12.

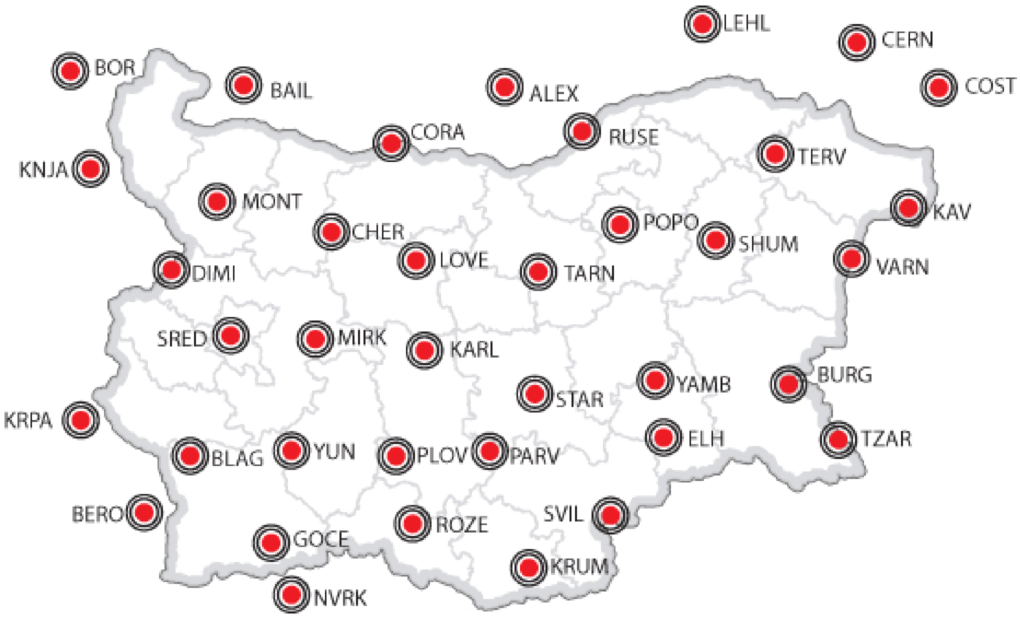

Figure 12. Present status of *BULiPOS - Leica* and its connection with the neighboring stations

From the start of operation of *BULiPOS* GNSS/DGNSS network in 2007 the number of permanent stations was increased from 5 up to 12 stations in 2009.

The coordinates of the stations are provided in reference system ETRS89 (*European Terrestrial Reference System 89*) more precisely in its realization ETRF2005. The coordinates are result from the adjustments of *BULiPOS* network GPS data in 2008, in system ITRF2005, epoch. The new data processing is based on GPS data in 2010, January 10-16. Seven observation sessions of 24-hours time length have been created. Data from all available satellites above the horizon (3^o) have been used.
The total number of participated stations is 31 – 14 ISG stations, 5 EPN stations and 12 *BULiPOS* stations. The station coordinates obtained from the combined processing of the seven daily normal equations are in ITRF2005, epoch 2010.03. Five reference stations have been used – ISTA, MATE, PENC, SOFI, ZIMM. All daily solutions have been compared to the combined solution and the root mean square errors of the stations have been obtained.

Seven parameters Helmert transformation have been accomplished for assessment of the quality and precision of datum definition of the network. The residuals in local system (North, East, Up) are presented in *Figure 13*.

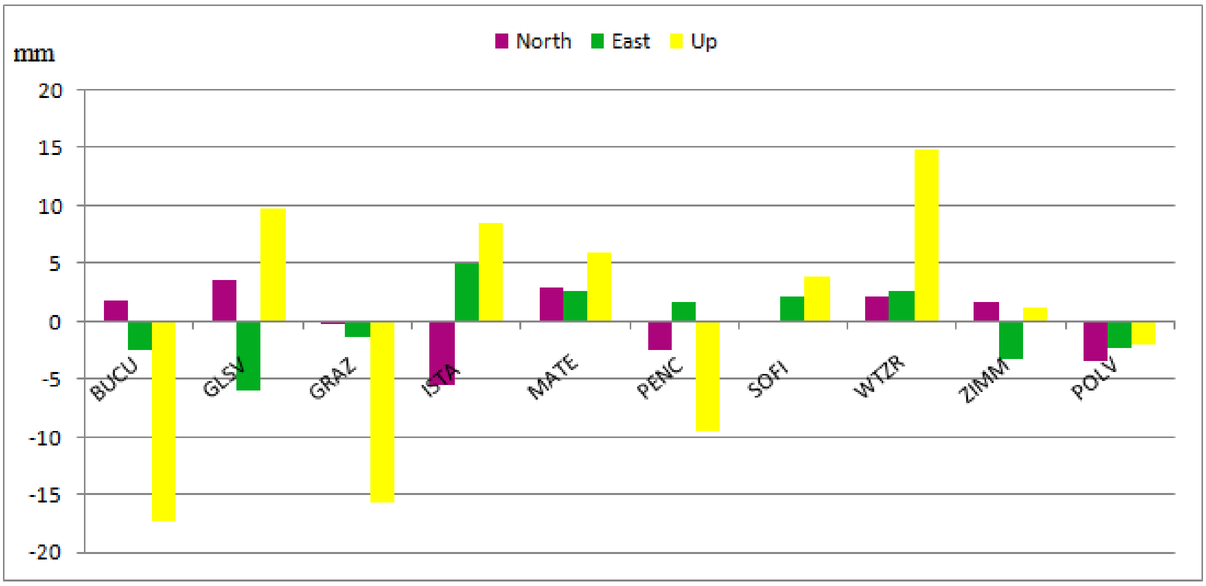

Figure 13. 7-parameter Helmert transformation between input IGS/EPN station coordinates and their estimated coordinates

The results from the transformations show a good consistence except IGS stations BUCU, GRAZ and WTZR. These stations have higher values in Up component. By this reason these three stations are not selected for datum definition of the network as it was done in the most of the other cases.

Daily repeatability and the RMS of station positions from the weekly solution are shown in *Figure 14*.

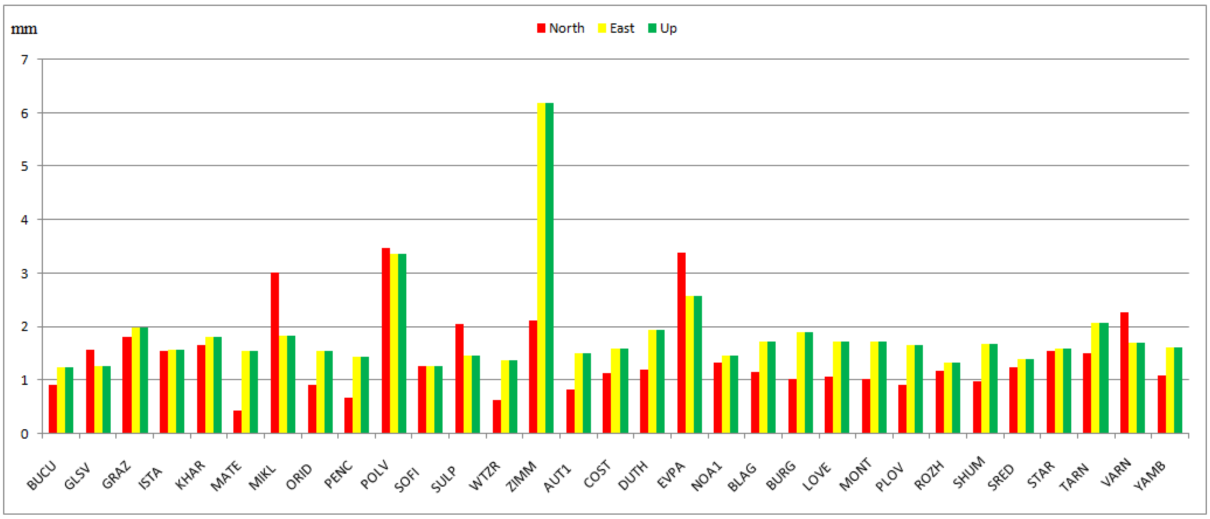

Figure 14. Daily repeatability of the weekly solution

The results above show very good station accuracy achieved – for the most of the stations between 1 - 2,5 mm.

The new results obtained could be used for further investigations of the monitoring of the *BULiPOS* stations behaviour

4. Generalization of the results and future activities

The obtained results up to now can be summarized in the following.

The reprocessing of GNSS data of BRUS over 8 years forces the idea that for the detection of changes in position and height at the mm-level long time series and re-processing according to the latest reference frames and IGS standards is required. Only long time series allow the separation of seasonal, equipment related or anomalous behavior of the station that are the basis for accurate modeling of climatologically or environmentally induced surface changes of the Earth.

From the interpretation of the Pannonian lithosphere can be suggested that

- If the Pannonian lithosphere is allowed to bend under a load and torque localized beneath the SE Carpathians, then the location x_b and height w_b of the Apuseni mountains coincides with the flexural bulge.

- Temporal changes in the vertical shear force V_0 or bending moment M_0 should be visible as a variable strain on the surface of the Apuseni, measurable by GPS.

The obtained results from the scientific investigation and analysis in Central and Eastern Europe show that the CEGRN velocity field provides a regionally detailed picture of the surface deformation in seismically active areas of Central Europe and Balkans.

The comparison of obtained results for the velocity estimations of most of the stations in Bulgarian territory shows a good consistence in North and East components between the seasons and it shows smooth station movements. For some of them differences are higher and they are not acceptable. It should be sought other reasons for this stations behaviour. As Up component is more sensitive to different impacts so the differences in velocity estimations obtained are higher and for the particular stations their values differ significantly as they correspond to the specific circumstances of the stations (station location, atmospheric changes etc.).

The new results obtained could be used for further investigations of the monitoring of the *BULiPOS* stations behaviour.

For the future activities it is important the following. There is a strong interest for the geodetic products resulting from the CEGRN campaigns, particularly because the data have been reprocessed in a state-of-the art mode, and extend over a very long lapse of time. There are new initiatives, also. One of them is a new COST action called TEGO 'Towards a European GNSS Observatory'. Further important initiative concerns the partnership with EUREF, and the possibility that the CEGRN solution is combined with the EPN long term solution. It is a new challenge, but it should be feasible because of the very similar standards adopted in processing. Once the combination is done, we will have a first good example of combination of solutions which will continue with other local networks. In this way the problem of densification of ETRF will be addressed very effectively.

EUPOS project, something in some sense similar to the Plate Boundary Observatory in the U.S., is looking for a homogeneous and consistent dense velocity field for application to geodynamics and seismicity. The theme of the dense velocity field is present also within the IAG. Also the way in which the ETRFxx coordinates of stations in national networks evolve relatively to the Eurasian rigid plate is related to the details of the 3d velocities. This is relevant to INSPIRE (Infrastructure for Spatial Information in Europe), and the obligation the EU Countries have to maintain ETRS89 standards.

5. Conclusions and suggestions

It can be summarized that the results of all investigations accomplished enable to confirm the acquired picture of the geodynamics of the region of interest and to enrich the geodynamic investigations of the region as a whole. It is necessary to more rigidly and strictly tighten and future activities and investigations on CERGOP, EUREF, EUPOS with the ones of GMES related to the investigated region. The combination of space borne and terrestrial sensing of the environment for an integrated interpretation of the manmade and natural changes will be a sound basis for a monitoring and protection of our geosphere.

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