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Investigation of Geodynamics of Central and Eastern Europe, Balkan Peninsula and Bulgaria

3.1 Introduction

Within the initiative of the European Community for monitoring of the Earth **–** Global Monitoring for Environment and Security (GMES) information about the physical, chemical and biological systems of the planet is collected. Among them are the elements of the geodynamics. However, its multilateral aspects of manifestation are subject of independent purposeful intensive investigations especially in recent time. On the one hand it is determined by the great scientific and practical importance of these investigations and on the other hand – by the direct and very often negative or adverse effect of the hazardous geodynamic processes and the necessity of their multilateral study and finding of methods and measures for reaction and prevention. In this aspect, the advanced scientific and practical achievements are very important. GNSS (Global Navigation Satellite Systems) and InSAR (Interferometric Synthetic Aperture Radar) are presently the main sensors of the Earth's surface deformation. This trend will be strengthened in the next decade because of the ongoing modernization of the Global Positioning System (GPS) and the deployment of GLONASS, GALILEO and other GNSS systems. Similarly, the launch of several new SAR sensors is now schedule for the next 5 years, such as SENTINEL-1. Presently GNSS can monitor the Earth's surface deformation in global Reference Frames like the ITRF 2005 and GPS velocity fields today can monitor site motions at a level of 0.5 mm/yr for the horizontal and 1 mm/yr in the vertical component. Regional studies are deriving the crustal motion and strain patterns for particular areas, like [Nocquet and Calais, 2003], [Caporali et al, 2008]. The strain rates can be resolved at the nanostrain or 1 ppb (10^{-9}) level, provided long enough time series are available. In all present studies, the vertical rates, essential for monitoring the present day status of the lithosphere, are deteriorated due to imperfect modeling. For the combination with other space and terrestrial techniques a uniform and homogeneous (re-)processing of all data according to the latest models is required. The derivation of the related products for position time series and the derivation of a numerical velocity gradient tensor field solution (i.e., spatial variations of horizontal strain rate tensor components and rotation rates) for the Central European platform are required, too. Dense data in the combination with other geodetic data on Earth-surface change, like InSAR and levelling will provide more insight to the present state of change of our environment.

Future projects in the frame of GMES therefore have to aim at an integrated approach of all techniques and multi-disciplinary projects. By this, the determination of strain rates and vertical rates can be extended to the monitoring of hazards and regional or local deformation regimes. Therefore, systematic effects, like periodic or episodic motion and the individual characterization of region may be separated. Main questions are the determination of recent tectonic displacement rates in the central part of the Central and southern parts of the European Platform, their separation from glacial-isostatic adjustments as well as environmental and anthropogenic effects. A major scientific question is how to combine multiple methods with different temporal and spatial resolutions to receive a single homogeneous product with information from the scale of tectonic plates to a fault or a landslide. InSAR and GNSS time series will allow the identification of surface and mass changes and in combination with spatial gravimetry data, a complete picture on the changing Earth can be obtained.

Many international projects are already realized, for example, the GNSS infrastructure implemented by the EU FP 6 project CERGOP-2 in the framework of the Consortium for Central European GPS Geodynamic Reference Network (CEGRN) and the others are in the process of realization. Solutions and results are presented here from the cooperation within the framework of EC related to the regional collaboration in the Central and Eastern Europe (CEE) and in the Balkan Peninsula (BP) as a whole and in particular countries and specially in Bulgaria. It is a good example for fruitful cooperation with a particular importance. The results reported in this study are therefore a step in the direction to the global monitoring of the system Earth and have to be continued in the future GMES framework.

3.2 General information about the investigations of the global geodynamics in the context of Central and Eastern Europe and the Balkan Peninsula

The transition zone between the African and Eurasian Plate at the Balkan Peninsula (BP) is the most active one in Europe concerning seismicity and tectonic movements (Figure 45).

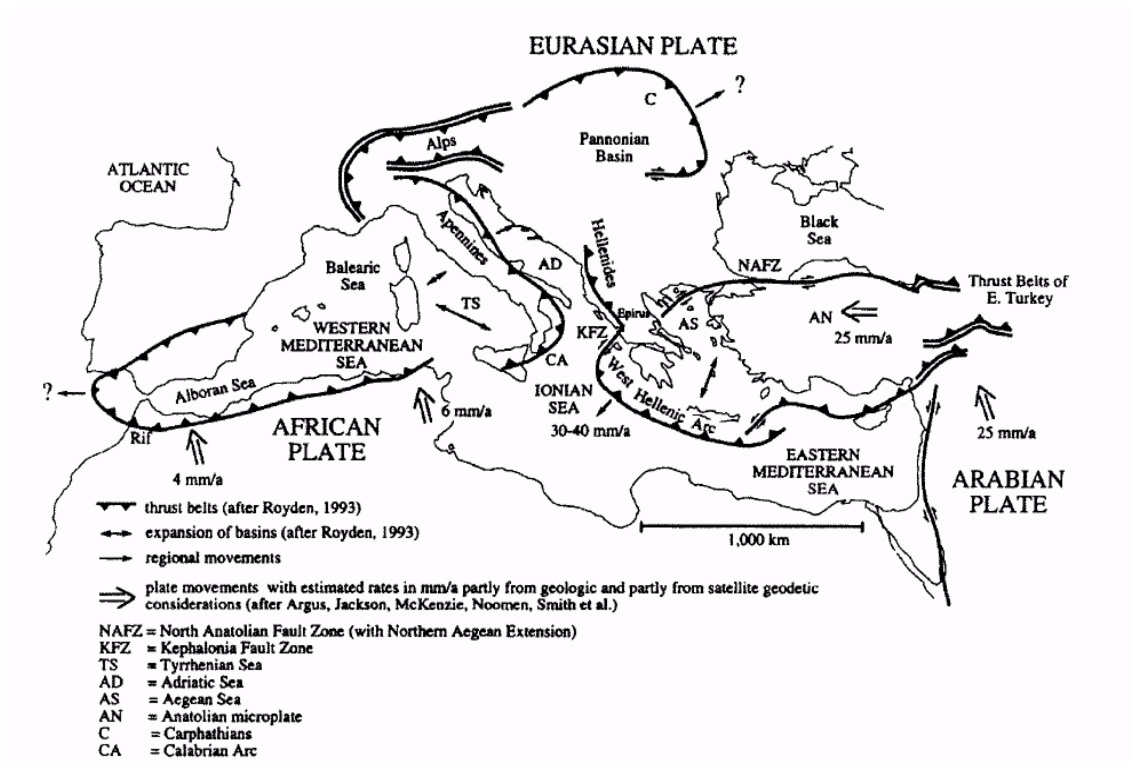

Figure 45. Simplified sketch of main tectonic plates and sub-plates in the Mediterranean area [Plag et al, 1998]

Therefore, the study of geodynamics and geokinematics of this region is very important for understanding natural hazards, like earthquakes, tsunamis, and volcanic activity. From geology it is known that the transition zone consists of several tectonic parts with different behavior, like the Adriatic Microplate, the Aegaean Plate, the Antaolian Plate and others. Apart from the seismic information, new methods of very accurate positioning by satellites like GPS allow to study crustal deformations at the surface at the millimeter level. Starting with the late nineteen eighties with laser and GNSS campaign measurements twenty years after a geokinematic model was computed for the region between the Hellenic Arc and Northern Greece and Anatolia [Reilinger et al, 2006]. The tectonic units can be described by abrupt changes in the velocity fields generated from the movements of the different epoch stations. Using a block model approach the associated kinematic energy can be compared to the energy released during earthquakes, which is somehow related. With the more frequent usage of GNSS permanent stations, more detailed studies can be done revealing more features [Stangl and Bruyninx, 2006]. For example, time series of coordinates of permanent stations show significant offsets after an earthquake in the neighborhood [Hollenstein, 2007]. With yearly velocities between 10 and 30 mm, accurate results can be achieved in the Hellenic region in short time. Farther north in the Balkan Peninsula the movements relative to the Eurasian Plate become much smaller in the range of 1-5 mm/year which are more complicate to detect and to interpret. These intra-plate movements at the Balkan Peninsula are the main object of research of the long-term project CERGOP (Central European Regional Geodynamic Project), covering the region between the Baltic and the Mediterranean Sea. Starting in 1994 CEGRN campaigns at well-determined sites try to deliver a picture of the movements in Central and Eastern Europe and the Balkan Peninsula. A network of permanent stations in that region is added to monitor the movements permanently.

3.3 Geodynamic investigations of CEE

The CERGOP networks have been adjusted to form consistent time series of the stations and to derive station velocities [Hefty et al, 2009], Figure 46 and Figure 47).

The general difficulties for deriving a velocity field for geodynamic investigation are the limited coverage of observations in time and space and the separation of local deviations from the general picture. As can be clearly seen in the figures there are empty spaces because of missing participation of some countries. Campaigns as well as permanent sites need a sufficient sequence of observations to derive accurate velocities. A minimum of three occupations for campaign sites is requested which means an occupation time of at least 2-3 years, for CEGRN sites presently 4-6 years [Stangl et al, 2008a,b]. Permanent sites require at least two years of observations to avoid misinterpretation by seasonal effects and potential local disturbances. The Istrian sites in Figure 46 show the problem of short occupation leading to high velocities, which are not reliable. The very high velocities of the sites CLUJ and DEVA in Romania (Figure 46 and Figure 47) are well determined, but were found to experience heavy local movements associated with the mining activities there. When these two stations are neglected, both figures show two velocity provinces in Southeast Europe which differ significantly from the general horizontal rotation of the Eurasian Plate. Around the Adriatic Sea the stations move generally to the North by 3-5 mm/year which is caused by the Adriatic Microplate. South of the Carpathians a transition zones seem to be pulled south with a small rotation focused at Bulgaria by 2-3 mm/year [Aichhorn et al, 2008]. Lack of observations in the region of the Dinarides inhibits to draw accurate boundaries inside the Balkan Peninsula. Combination of velocity fields from various sources leads to a slightly better picture [Caporali et al, 2007; 2008; 2009], but the interior of the Balkan Peninsula is still largely uncovered by observations.

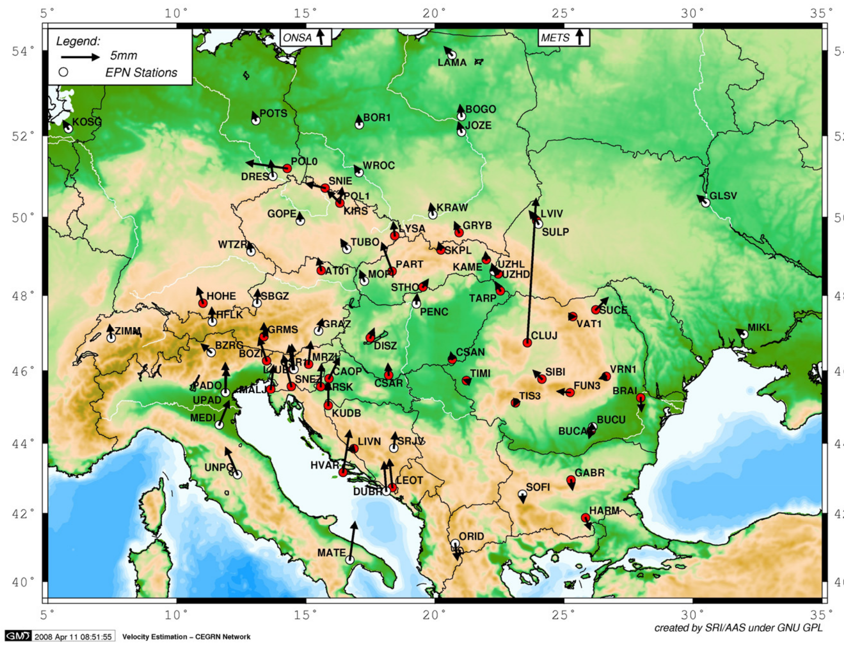

Figure 46. Horizontal velocity estimations from reprocessed time series of CEGRN campaigns 1994-2007

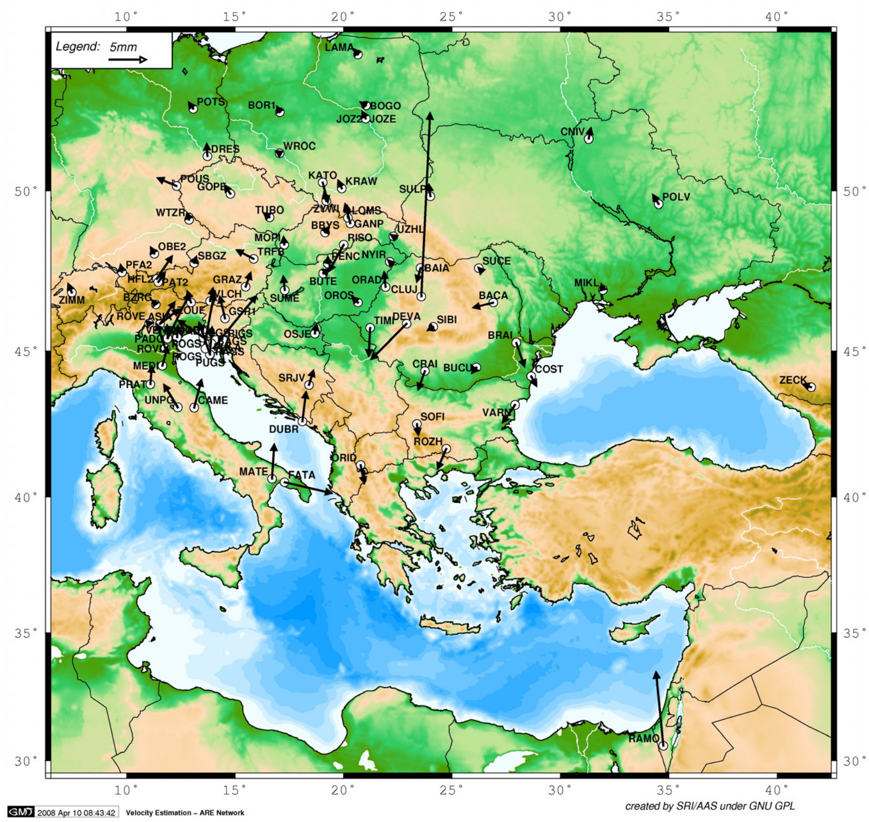

Figure 47. Horizontal velocity estimations from cumulated weekly time series of CERGOP permanent sites 1999-2008

3.4 Geodynamic investigations of BP

The territory of Balkan Peninsula is characterized by active geodynamics. It is the most active region in Central and Eastern Europe in geodynamical respect. A number of hazardous geodynamic processes of endogenic (earthquakes, contemporary movements of the Earth's crust, mud volcanoes) and exogenic origin (natural and technogenic), including landslides, abrasion, erosion, subsidence, collapse, rockfalls, mud-stone flows, deformations caused by mine workings, karst, etc., are observed in the area.

The tectonics on the Balkan Peninsula is determined by the fold structures of the Alpine-Himalayan orogen. The territory of the peninsula had been subjected to older orogeneses too. The Alpine-Himalayan orogen itself, which builds the three big South-European peninsulas and the greater part of Middle Europe, is bilateral. Its northern branch is represented by the Alps, the Carpathians, and the Balkanides and is called the Carpathian one. The southern branch, called the Dinarian, comprises the real Dinarides and the Hellanides. Both branches are equally well expressed and are in close contact on the Balkan Peninsula.

At present the space of the Balkan Peninsula falls within the zone of collision between three large plates – Euroasian, African and Arabian, which are themselves divided in smaller ones (Figure 45).

The geostructural situation and the geological evolution represent a substantial element of the general situation of relatively high seismicity in the region. The present-day geodynamics of the Balkan region is controlled by the active tectonic processes in the Eastern Mediterranean (Figure 48).

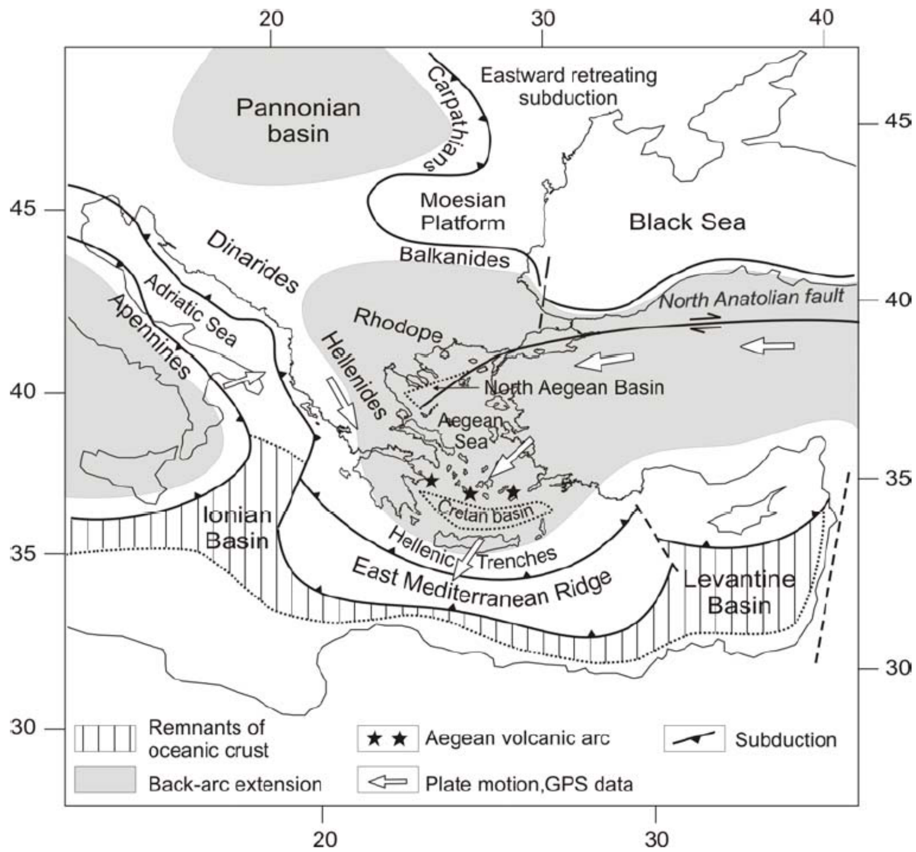

Figure 48. Active processes in the Eastern Mediterranean (based on [Carminati et al, 2004])

There exists a subduction of the Adriatic (Apulian) microplate beneath the Dinarides, a subduction of oceanic Ionian and Levantine lithosphere under the Hellenic arc-and-trench system and a collision between Eurasia and Arabia with related westward escape of Anatolia along the North Anatolian dextral strike-slip fault.

The Balkan Peninsula was a subject of study in a special working group of the international project – Central European Regional Geodynamic Project (CERGOP 2). The investigations performed are based on the GNSS campaign observations, operation of GNSS permanent and epoch stations, data processing, interdisciplinary geodynamic analysis and interpretation.

Except geophysical methods, recently GNSS have been widely applied for precise determination of earth crust movements in the region. The permanent GNSS stations are extensively increased.

3.4.1 Investigations of the particular Balkan countries

A concise review of the tectonic setting for each BP country is outlined. Detail information can be found in the Monograph "Geodynamics of the Balkan Peninsula" [Milev and Dabovski, 2006].

From the geological standpoint, **Albania** belongs to the Dinarides, the southern branch of the Alpine folded belt. The Dinarides are separated into two: the Dinarides and the Hellenides. The Dinarides pass into the Hellenides in Albania, most of the country being encompassed by them.

The Aegean (Hellenic) Arc, visible in the southern part of the Hellenides, is situated between the Arabic-Africa/Eurasia collision to the east and the Adriatic collision to the west.

The neotectonic zonation of Albania is based on tectonic regime and types of deformations, which occurred. Four large neotectonic units have been recognized, each of them based on the sense, intensity and chronology of vertical movements. The external margin of the fold and thrust belt in Albania and its surroundings was thrust on Adria microplate, partly over Apulian platform and partly over Albanian Basin.

The area of **Bosnia and Herzegovina** is included in the middle parts of the Dinaridic Mountain System and it is positioned between Apulia (Adriatic Microplate) in the south and the Panonian and South Tisia, respectively. It is located NE from active compressional geotectonic contact between the Adriatic mass and the Dinarides. The Adriatic mass, as part of Africa, is impressed between Apennines and Dinarides along strike-slip active faults.

According to the activities during the last 100 years, the Bosnia and Herzegovina was divided into 5 seismogenic zones and 57 potential seismoactive structures. Their lengths are between 6 km to 40 km. Based on analysis of tectonic data it is concluded that the stronger seismic activity occurs at the boundaries of geotectonic units (directions NW-SE), then along the longitudinal dislocation (directions NW-SE), at the intersections of transversal faults (directions NE-SW and N-S). In the year 2000 the National Offices for Surveying and Mapping in Bosnia and Herzegovina set up a GPS network comprised of about 30 stations.

The major role in geodynamics of Croatia belongs to the Adriatic microplate Dinnarides. Seismically the most active part is the coastal part of Croatia, especially its southernmost part. Two permanent GPS EUREF stations were installed on the territory of Croatia – Osijek and Dubrovnik. Several GPS campaigns were carried out. For monitoring the tectonic movements around Zagreb a local GPS networks is established. It is studied that the zone of Dinnarides delineated by the Alps in the north, the Adriatic in the southwest and the Pannonian basin in the northeast is seismically and tectonically very active area. GPS measurements yield very accurate displacements on regional or local level.

The area of western **Greece**, a seismically active region, exhibits substantial tectonic complexity mainly dominated by the counter clockwise motion of the Apulia microplate in the north and the active subduction of the front part of the African plate beneath Eurasia, in the south.

Monitoring of the displacements of the stations of the geodetic control network in the seismic zone of Volvi has been a task carried out for approximately 25 years. Starting 1994, the extended Volvi network was measured by GPS methods in five epochs (1994, 1995, 1996, 1997, and 2003). The analysis of the geodetic data shows that significant deformation occurred in the area until 1994. The highest rate of deformation observed after the 1978 earthquake (about 6 mm/year) is strongly correlated with it. Afterwards, GPS data show that there is a relaxation of the deforming body in general, with the exception of a few points.

The long-term seismicity in the **Macedonia-Bulgaria** border region has been critically considered. The revised picture suggests that the earthquake catastrophes in the region occur at intervals of 200 – 400 years on the average. Two peculiarities are marked as common to these series: tightening of the preceding seismic activity towards the location of forthcoming main shock and lack of strong aftershocks after coupling of the catastrophic events. The first GPS surveys in Macedonia were conducted in 1996. At that time, GPS observation on seven points was carried out in Macedonia and those points were merged with the global ITRF Network. During the conveyance of the GPS campaign in 1996, a permanent station in Ohrid was placed, as a point being part of the European GPS Network. At the beginning of 2004, large-scale GPS surveys were undertaken by which a larger number of points on the territory of R. Macedonia were encompassed.

Plate boundaries on the **Romanian** territory and their dynamics have been recently reviewed with special emphasize on the role played by the Black Sea opening. Short-distance large variations in the lithosphere thickness advocate for the presence of at least three plates/sub-plates in the area. East European plate (EEP), with a lithosphere thickness of more than 150 km, Intra-alpine micro-plate (IaP) with its 80-90 km lithosphere, and Moesian micro-plate (MoP), with 120-150 km lithosphere thickness, meets each other in the Vrancea unstable triple junction, where the asthenosphere was revealed at more than 250 km in depth.

The territory of **Serbia and Montenegro** was subject of complex geological investigations for different research and applied purposes. Reason for so significant interest is in very complex geological relationships and presence of geological formations at the area. At the territory of Serbia and Montenegro, the highest seismic activity is characteristic of Dinaridic seismogenous block (Montenegro and SW Serbia), with over 70% events.

The strong earthquakes caused by intensive tectonic processes, predominantly occurring in the coastal part of the territory, produce destructive effects in the form of landslides, avalanches, and soil liquefaction.

Although **Slovenia** is a small country, it lies in a tectonically very interesting area. Its territory is the meeting-point of three different geological units: Alpine, Dinaric and Pannonian. The larger part of Slovene territory, i.e. the northern and northwestern parts of the country, belongs to the Alpine region. The smaller, southern part of Slovenia with the Karst belongs to the Dinaric region, and the Pannonian massif is limited to the eastern part of the Prekmurje region.

Turkey is the country affected by several different faults such as Black Sea plate, Eurasian plate, Aegean plate, African Plate, Arab Plate, and Anatolian Plate. Due to this structure, almost 92% of the country is under the risk of earthquake. Most of the micro geodetic networks have been established for monitoring geodynamic activities on North Anatolian Fault (NAF). Turkish National Fundamental GPS Network (TUTGA) has been established in between 1997 and 1999 and some of the stations have been re-surveyed due to the earthquakes happened in 1999. The total number stations are 596, for each station 3D coordinates, and their associated velocities have been computed. The Turkish national permanent GPS network (TUSAGA) is still in establishment phase with its 16 operational stations of which data can be used.

3.4.2 Generalized investigations and results

- ✓ **GPS data processing**

An important indicator in geodynamical point of view is an eventual station movement of GNSS network stations. That concerns the permanent and epoch GNSS stations on the territory of the Balkan Peninsula. Determination of the size and direction of the vectors of movement, their analysis, and assessment is of significant importance for their further interpretation with a view to present the geodynamical picture of the region.

Geodynamical behavior of GNSS stations (Figure 49) of the CEGRN sub-network covering Balkan Peninsula has been studied and analyzed in number of papers. Data from different GPS CEGRN measurement campaigns concerning the Balkan Peninsula stations (permanent and epoch) have been involved.

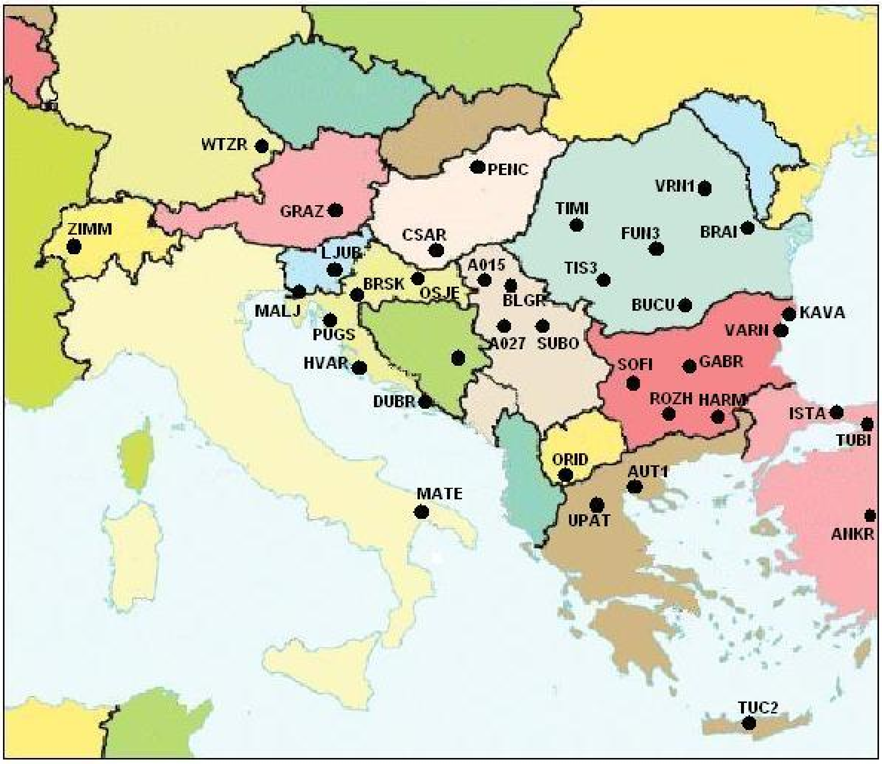

Figure 49. Balkan Peninsula CEGRN sub-network stations

Data processing has been accomplished with the scientific software Bernese Software, version 5.0. Before comparing and analyzing the most important from geodynamical point of view results, namely, velocity vectors the quality and reliability of station coordinate estimations obtained have been studied and analyzed.

Combined solutions of different BP'CEGRN have been done and published in [Milev et al, 2005]. The estimated velocities from different combined solutions have been compared and analyzed. The problematic stations have been localized and some explanation for the problems within the respective CEGRN campaigns concerning Balkan Peninsula sub-network have been done.

Figure 50. Balkan Peninsula permanent stations

The latest investigations covered the period 2007-2009 [Vassileva, 2009a]. For more precise and detailed monitoring of the tectonic movements by GNSS, the number of the permanent GNSS stations in the region of Balkans is permanently increased. Within this period, they increased from ten in 2007, up to twenty-two in 2009.

All free available stations (Figure 50) on the territory of the Balkan Peninsula are used for study of their movement within three years – 2007, 2008, 2009.

GPS data of one week in each year and their combinations are processed. The obtained station velocity estimations have been analyzed and compared with other results.

✓ Analysis of velocity estimations

All possible combinations of the obtained weekly solutions in 2007, 2008 and 2009 have been processed and station velocity estimations have been obtained in system ITF2005 [Vassileva, 2009b]. Minimum constrained adjustments have been applied for all combinations using the same reference stations. All possible combinations of two years give different results for most of the stations to some extent. Comparison with the annual station velocity estimations of the IGS, EPN, and CEGRN results shows deviations, which are considerable for most of the stations. It confirms again the conclusion drawn in [Vassileva, 2009a] that two years solutions do not generate reliable results especially using two consecutive years.

Velocity estimations of IGS/EPN/CERGOP stations obtained are compared with those ones obtained from the respective IGS/EPN/CERGOP solutions and the differences are within 1-3 mm (Figure 51). For some of the stations greater differences between the velocity components have been obtained and an eventual reason like antenna changes has been assumed.

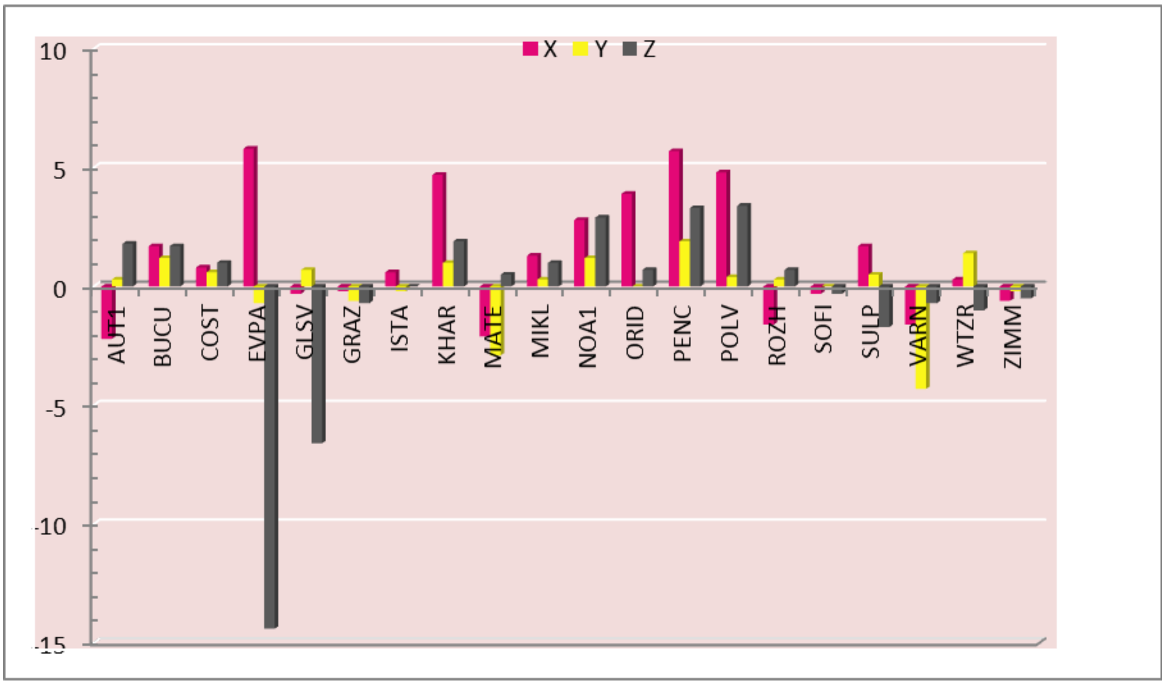

Figure 51. Station velocity differences between results of this study and estimations from IGS/EPN/CEGRN

Three years weekly data processing and their combined solution have been accomplished and the comparison of obtained results for the velocity estimations of most of the stations shows a good consistence. For some of them differences in the different components of the velocity vectors are higher and they are not acceptable. Conclusions, which can be drawn here, confirmed these ones drawn in [Vassileva, 2009a] and they are:

– velocity estimations obtained from two years data independently of the time interval between the years are not reliable and they should not be used;

- for obtaining reliable estimations of the velocity vectors of permanent stations GPS data from more than three years should be used;
- velocity estimations obtained from weekly data are not very reliable. For obtaining representative velocity vectors, it is advisable to be used annual data solutions.

These conclusions undoubtedly confirm the suggestion given in [Vassileva, 2009a] about determination of velocity vectors of national network reference points and geodynamic network points. The suggestion concerns involving of long term data of several years in obtaining of point velocity estimations for such a type of points. Velocity vectors obtained are crucial for further analysis and interpretation and they should be reliable estimated.

3.4.3 The monograph "Geodynamics of the Balkan Peninsula"

The monograph (Figure 52) is a result of the investigations carried out by the Work Group on Geodynamics of the Balkan Peninsula within the framework of the "Central European Regional Geodynamic Project – CERGOP-2" of the 5th Framework Program of the European Commission [Milev and Dabovski, 2006]).

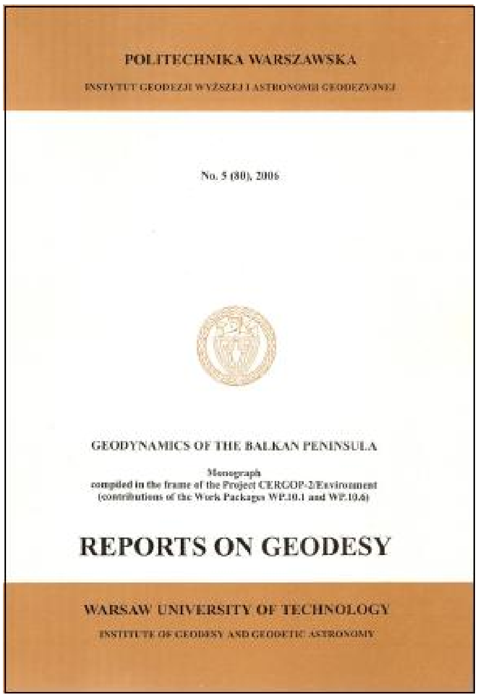

Figure 52. The monograph "Geodynamics of the Balkan Peninsula"

The monograph structure is:

1. Preface
2. Introduction
3. General data and prerequisites for the part of global geodynamics comprising BP
4. Geodynamic investigations in the single Balkan countries
   - 4.1. Seismological investigations
   - 4.2. Seismotectonic investigations
   - 4.3. Geological and geomorphologic investigations; engineering geodynamics
   - 4.4. Geodetic investigations
   - 4.5. Complex analysis and interpretation
   - 4.6. Views on BP geodynamics in the single countries
5. Generalized investigations
   - 5.1. Analysis and generalization of the results obtained from the GNSS – geodetic investigations
   - 5.2. Complex interpretation of the velocity and deformation vector field
   - 5.3. Generalized geodynamics of BP
6. Conclusion

A special attention is paid to the fight against the hazard geodynamic processes and to the registration and documentation of the effects of their impact, including creation of special geographic information systems.

The Monograph provides an accurate picture of the position and particular features of BP in the overall geodynamic picture of the Earth and the region. It comprises 650 pages, contributions of 96 authors. It is addressed to a broad range of specialists involved in the different Earth sciences and protection against natural disasters.

3.5 Geodynamics of Bulgaria

3.5.1 Tectonic setting

Bulgaria is situated in the eastern part of the Balkan Peninsula. The eastern part of the Balkan region comprises variable in type structural units differing in age, origin, tectonic style, and contemporary geodynamics.

The earthquake activity in Bulgaria is the most apparent manifestation of contemporary geodynamics on its territory [Christoskov et al, 2006]. Over the past centuries, Bulgaria has experienced strong earthquakes. Some of the Europe's strongest earthquakes 20-th century occurred in Bulgaria. The hazard map for a 1000-year return period is presented in Figure 53. The adopted Bulgarian building construction code is based on this hazard map.

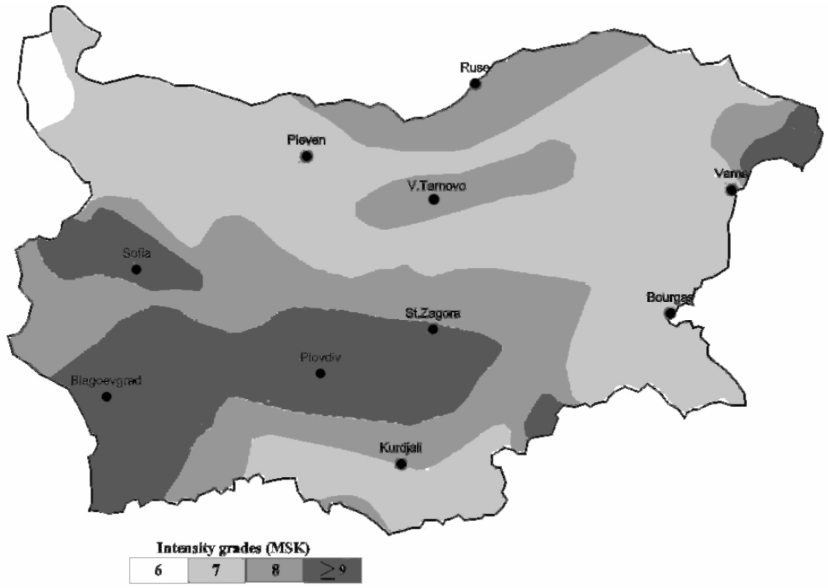

Figure 53. Hazard map for a 1000-year return period

The historical seismicity in Bulgaria has not been satisfactory covered by the existing information sources [Botev et al, 2006]. The supporting dataset quality has been improving in the course of time, although the data points' number has not been significantly changed.

After establishing (in 1891) Bulgarian Service for regular observing and documenting earthquakes felt in the country, the seismicity over its territory as well as seismic impacts from seismic zones around are known quite better. The nowadays monitoring of the weak earthquakes in Bulgaria is based on a modern National seismological network, which was established in 1980. More than 15 000 events recorded during the operation of this National network are located on the territory of Bulgaria and its close vicinity.

3.5.2 Geodetic measurements

First geodetic measurements for the territory of Bulgaria on the CERGOP project were carried out in 1996. Only two Bulgarian stations (SOFI, HARM) of the four planned stations (SOFI, HARM, GABR, KAVA) were involved in the CEGRN'96 and in the CEGRN'97 GPS campaigns (Figure 54).

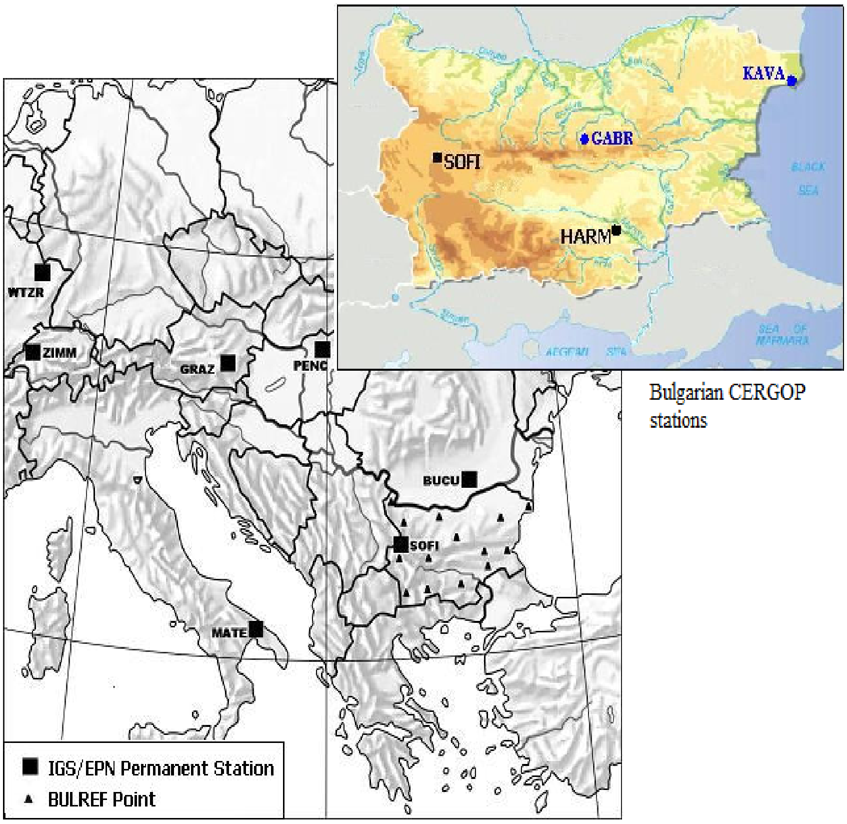

Figure 54. Bulgarian stations participated in CEGRN03 campaign

In the second stage of the project – CERGOP-2 during the CEGRN'03 GPS campaign Bulgaria participated with all 15 BULREF points as three of them were the CERGOP epoch stations – GABR, HARM, KAVA and one IGS/EPN permanent station – SOFI (Figure 54) [Milev and Vassileva, 2004]. The BULREF points were observed earlier in 1993 during the EUREF – BULREF GPS campaign and as a part of the WEGENER-MEDLAS geodynamic project. In the CEGRN'05 GPS campaign, the country was involved with one EPN/IGS permanent station (SOFI), two newly established CERGOP permanent stations (VARN, ROZH) and the three epoch stations (Figure 55).

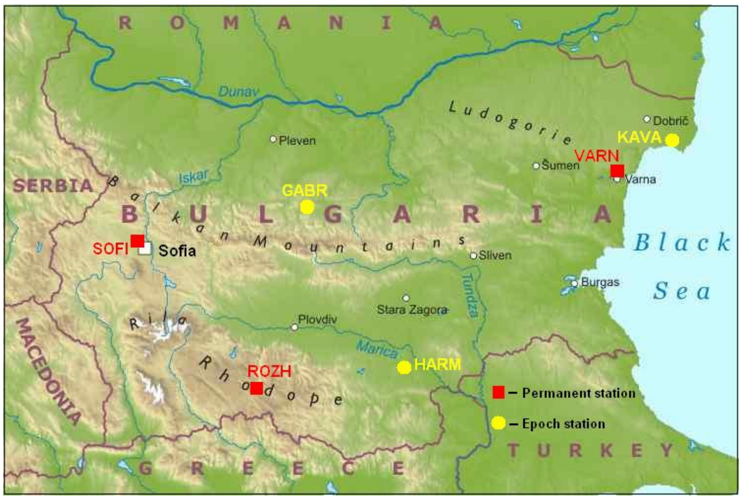

Figure 55. Bulgarian stations participated in CEGRN05 campaign

3.5.3 Geodetic investigations and analysis

For investigation of station movements GPS data of all 15 BULREF stations available in two campaigns – BULREF93 and CEGRN03/BULREF03 were processed with the Bernese GPS Software, version 4.2 [Milev and Vassileva, 2003; 2004], [Vassileva, 2004] regarding the accepted processing CERGOP principles. A combined processing of BULREF'93 and BULREF'03 was accomplished and estimations of the ITRF2000 coordinates for the mean epoch and station velocities were computed. The estimated GPS horizontal velocity vectors (blue), calculated NNR-NUVEL1A velocity vectors (green) and the obtained relative velocity vectors (red) are shown in the Figure 56.

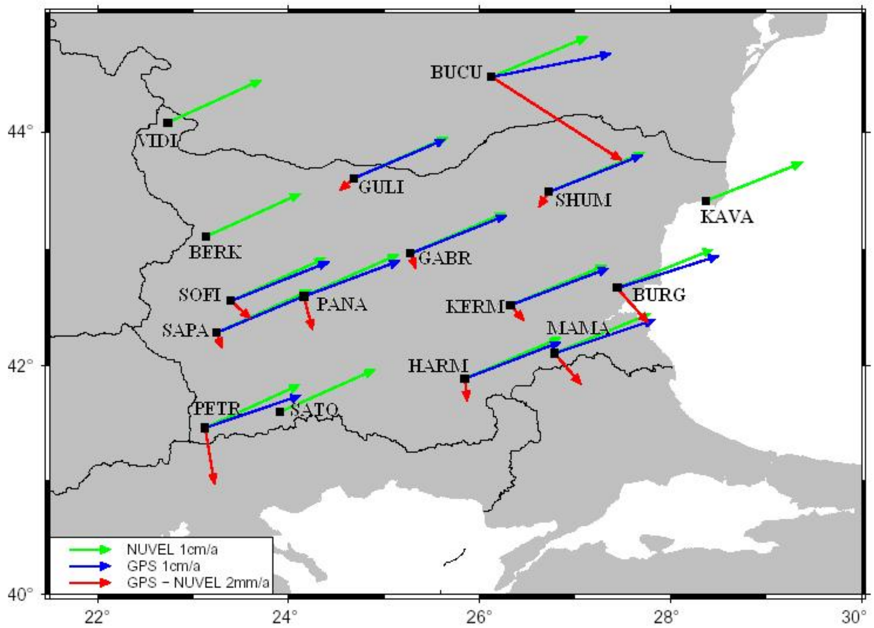

Figure 56. GPS and NNR-NUVEL1A velocity vectors of BULREF stations

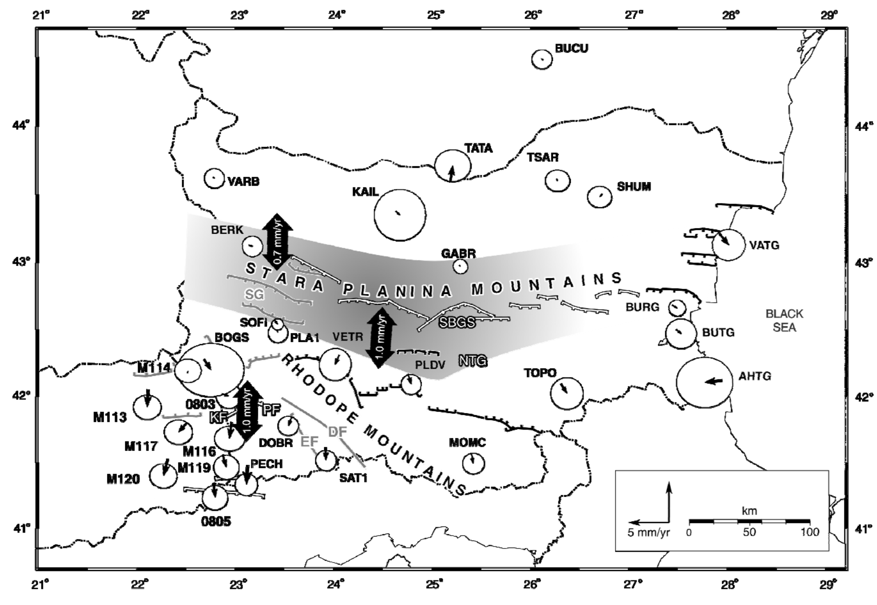

Figure 57. GPS station velocities in south-west Bulgaria

The velocity estimations obtained from the study show undisturbed behavior for all BULREF stations for the period of 10 years, period between the two campaigns. The values of station velocities are very similar and differences vary with an amount of maximum up to 2 mm in north component and in east component. In addition, the deviations to the NUVEL model velocities are in a reasonable size. This indicates that no unexpected jumps or outliers occurred in the behavior of stations during that time.

For study of the active tectonics in south-west Bulgaria, a number of local GPS measurements and data processing were carried out [Nakov et al, 2006]. The obtained stations velocities are shown in the Figure 57 are part from a velocity solution for about 80 GPS stations in the southern Balkan region [Burchfiel et al, 2006], [Kotzev et al, 2006].

3.5.4 Permanent DGNSS networks

At present for the purposes of many applications in the life on the territory of the country, the following DGNSS networks and systems are established or in process of establishment or operating in some extent: BULiPOS, NAVITEQ, Geonet of Zenith-GEO, Leica. The BULiPOS is the only system, which operates over the whole country within the EUPOS (EUropean POsition Determination System) as its Bulgarian segment.

BULiPOS (BULgarian Inteligent POSition determination System) is a DGNSS and a system of permanently operating reference stations for position determination and for space orientation, established and operating within the framework of EUPOS [Milev and Vassileva, 2009].

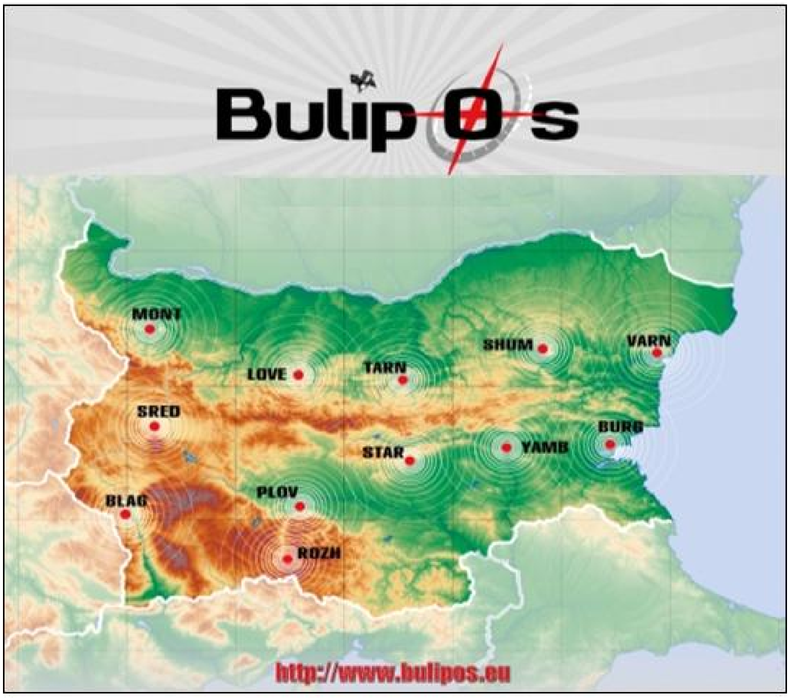

Figure 58. BULiPOS DGNSS stations

The establishment of the DGNSS network BULiPOS was carried out in 2007 [Milev et al, 2009]. The number of the established active reference stations is 12, shown in Figure 58. The stations have been spread over the country evenly, each of them covers an area of 70-100 km in radius, and thus the required DGNSS corrections can be provide with the necessary accuracy and reliability. DGNSS reference stations are multifunctional and they are established according to the respective international standards of EUPOS. The used software for processing and transmitting the differential corrections is Geo++® GNSMART professional.

The BULiPOS is unified homogeneous reference network and system for determination of position and space orientation. It is a high efficient system and meets the technical requirements for solving the problems of all fields of geodesy and cadastre and a variety of other applications in management, legal regulation, and economy of the country.

BULiPOS provides DGNSS corrections for position determination with high precision in real time as well as data for post processing within the territory of the country by the established network of active reference stations.

The coordinates of the stations are provided in reference system ETRS89 (European Terrestrial Reference System 89) more precisely in its realization ETRF2005.

BULiPOS provides, through various kinds of connections, additional information to correct data in the use of the Global satellite systems to determine the position – GPS and GLONASS. The variety of communication media (radio UKW / RDS), 2 m-band, GSM-mobile phone, Internet, Systems for data transfer) allows the transfer of data and accurate determination of location for diverse fields of application with different level of accuracy, from several meters to centimeters and millimeters. BULiPOS offers four types of services, depending on the required level of accuracy shown in Table 2.

Table 2. BULiPOS services

NAME	DESCRIPTION	ATTAINABLE ACCURACY	DATA FORMAT	TRANSFER	SATTELITE SYSTEM
BULiPOS PP	Post Processing	5 mm	RINEX	Internet	GPS+ GLONASS
BULiPOS VP	Virtual Station	5 mm	RINEX	Internet	GPS+ GLONASS
BULiPOS RT Precise	Precise Real Time	2 cm	RTCM2.3	CSD GPRS Internet	GPS+ GLONASS
BULiPOS RT	Real Time Kinematics	0.5 – 3.0 m	RTCM2.3(3.0)	CSD GPRS Internet	GPS+ GLONASS

The multifunctional BULiPOS network for position determination does not only replace a great part of the classical geodetic control network but it allows effective and economic favorable solutions in geodesy, photogrammetry, and other fields. Moreover, it proposes a possibility of position determination of moving objects to all who need to know their position in a fixed moment.

The BULiPOS stations BURG, LOVE, MONT, SHUM, and TARN (Figure 58) have been included in the data processing of the CEGRN network and since 2009.

Furthermore, BULiPOS, respectively DGNSS are actively used for different aspects of imaging and monitoring of the earth surface (aerial imaginary, laser scanning), investigation of different geodynamic processes, designing, etc.

3.6 Discussion

Decisions and results from the cooperation in the frame of EC related to the regional cooperation within the CEE and Balkan Peninsula as whole and particular countries of it is a good example of a fruitful cooperation with significant importance and it should further be developed and used.

The outlined in a large-scale measurements, data processing, investigations, generalizations, and interpretation of the geodynamic processes on the territory of the Balkan Peninsula, their manifestation and impact, the consequences, measures for their exploration and protection are grounded on the complex interdisciplinary basis within the Earth sciences and related fields. They are based on the use of modern systems, devices, instruments and methods, technologies, algorithms as well as the modern knowledge, algorithms and software to determine the present outlook and state of the different Earth sciences and they are reliable enough. They confirm, supplement, and enlarge the existing active geodynamic picture of the Balkan Peninsula and in particular this one for Bulgaria within the framework of the Central and Eastern Europe and the Mediterranean. They outlined the contemporary approach for regional and national investigations of this type and they can be used as an effective base for future measurements and studies in the region of the Balkan Peninsula, and in the particular countries of it.

The usage of GNSS observations for determining crustal intraplate movements in the Balkan Peninsula was successfully demonstrated by the CERGOP project. The missing gaps need to be filled by using time series of permanent stations, which are known to exist in the countries without present data. A data provision would help all countries to a better understanding of the geodynamics of the Balkan Peninsula.

Establishing and using the DGNSS (as BULiPOS a Bulgarian part of EUPOS) unified systems, based on the common standards will solve a great number of problems and applications including those ones required very high precision. Their multilateral possibilities and realized aspect of application in the countries are of great important as well. There is no doubt these are the systems of the present and the future useful for geodynamic the investigations and the GMES monitoring.