

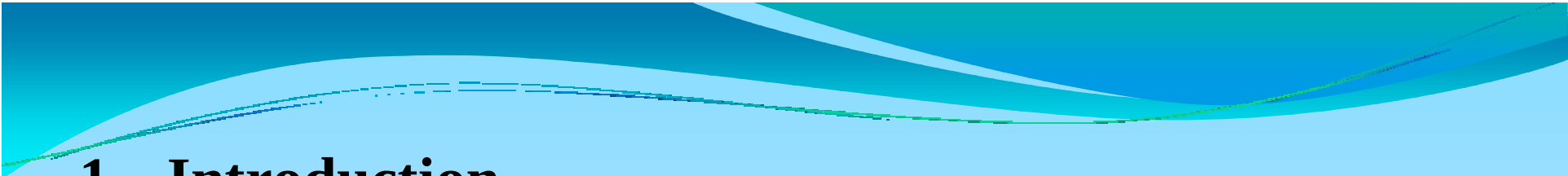


GMES OPERATIONAL CAPACITY WORKSHOP

**MARCH 25-26, 2010 in SOFIA,
BULGARIA**

GEODYNAMICS OF CENTRAL AND EASTERN EUROPE, BALKAN PENINSULA AND BULGARIA

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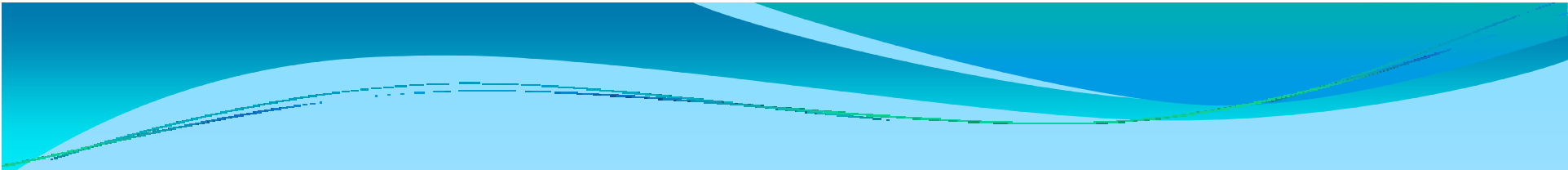
1. Introduction

Information about the physical, chemical and biological systems of the planet is collected - within the initiative of the European Community for monitoring of the Earth – Global Monitoring for Environment and Security (GMES).

Geodynamics – its elements are a part of this information.

- Its multilateral aspects of manifestation are subject of independent purposeful intensive investigations especially in recent time.
- By great scientific and practical importance of geodynamic investigations
- 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.

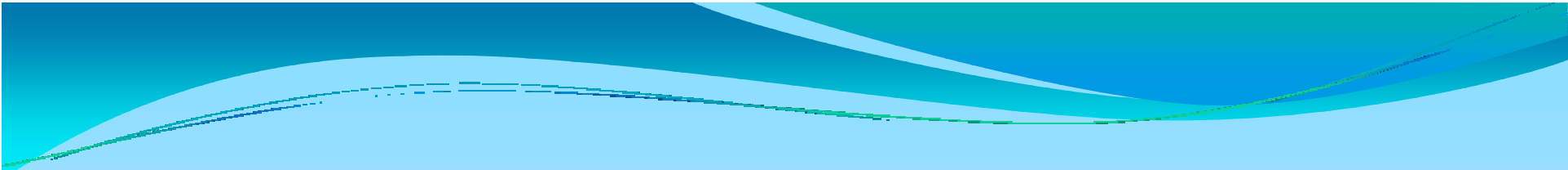
In this aspect the advanced scientific and practical achievements are very important.



➤ 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 scheduled for the next 5 years.

➤ 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.

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- Regional studies are deriving the crustal motion and strain patterns for particular areas .
 - For the combination of with other space and terrestrial techniques a uniform and homogeneous (re)processing of all data according to the latest models and the derivation of the related products for position time series and the derivation of a numerical velocity gradient tensor field solution for the Central European platform is required.
 - Dense data in the combination with other geodetic data on Earth surface change 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 multidisciplinary projects.**

Main questions are:

- 1.Determination of recent tectonic displacement rates in the central part of the Central and southern parts of the European Platform,**
- 2.Their separation from glacial isostatic adjustments as well as environmental and manmade 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.

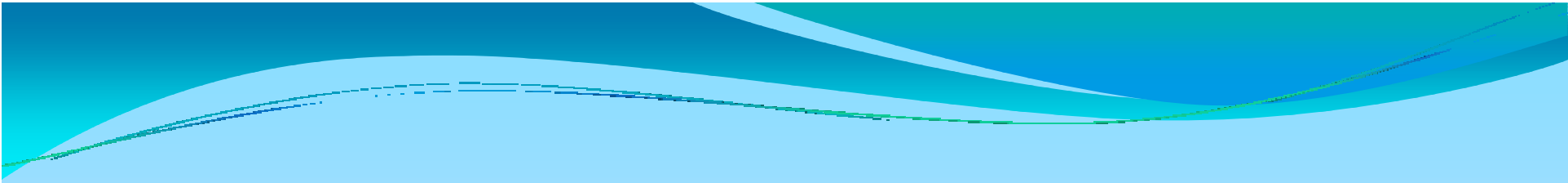
Many international projects are already realized, for example the GNSS infrastructure implemented by the EU FP 6 project **CERGOP-2** in the framework of the Consortium for **Central European GPS Geodynamic Reference Network (CEGRN)** and the others are in the process of realization.

Solutions and results are presented here from the cooperation within the framework of EC related to

- **regional collaboration in the Central and Eastern Europe (CEE)**
- **the Balkan Peninsula** as a whole
- **particular countries and specially in Bulgaria.**

It is a good example for fruitful cooperation with a particular importance.

The results reported here 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.



2. General information about the investigations of the global geodynamics in the context of Central and Eastern Europe (CEE) and the Balkan Peninsula (BP)

The transition zone between the African and Eurasian Plate at the Balkan Peninsula is the most active one in the Europe concerning seismicity and tectonic movements (*Figure 1*).

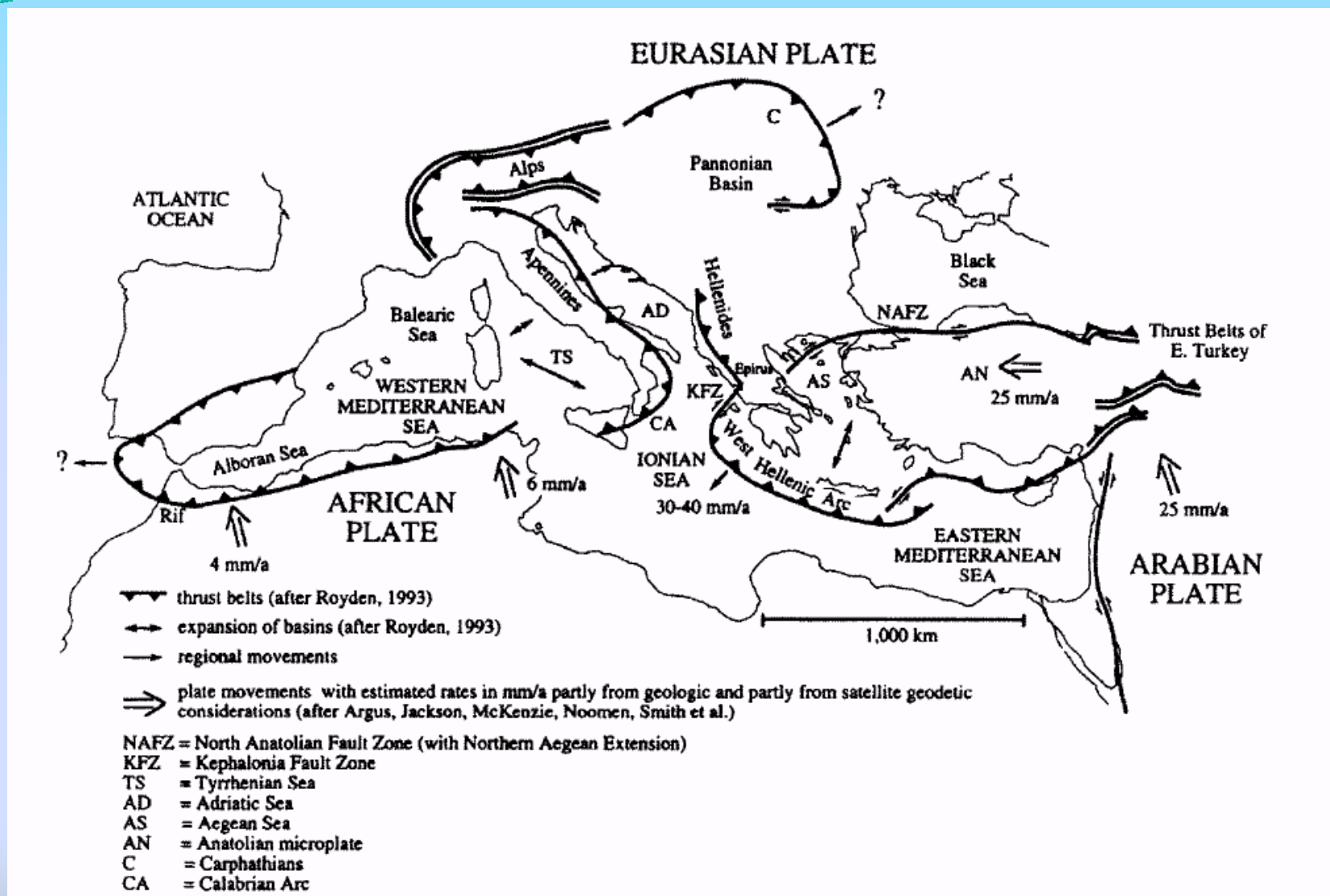


Figure 1. Simplified sketch of main tectonic plates and sub-plates in the Mediterranean area (Plag et al., 1998)

Therefore the study of **geodynamics** and **geokinematics** of this region is very important for understanding **natural hazards**, like **earthquakes, tsunamis and volcanic activity**.

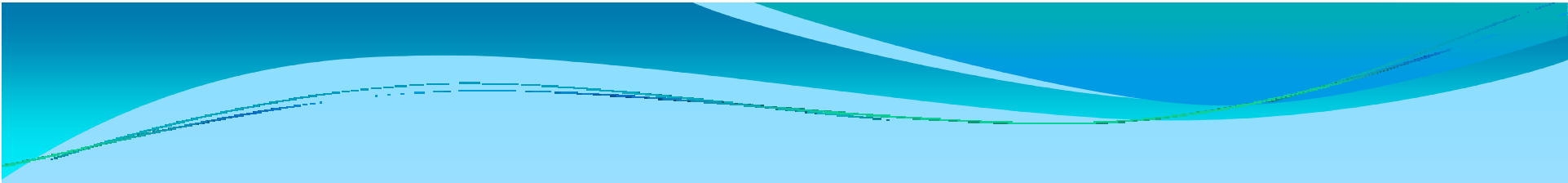
❑ The transition zone consists of several tectonic parts with different behaviour, like the **Adriatic Microplate**, the **Aegean Plate**, the **Antaolian Plate** and others.

❑ Apart from the **seismic information** new methods of very accurate positioning by satellites like **GNSS** allow to study crustal deformations at the surface at the millimetre level.

❑ The **tectonic units** can be described by abrupt changes in the velocity fields generated from the movements of the different epoch stations.

❑ With the more frequent usage of **GNSS permanent stations** more detailed studies can be done revealing more features.

❑ With yearly velocities between 10 and 30 mm accurate results can be achieved in the Hellenic region in short time.



These intraplate 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. Geodynamic investigations of CEE

The CERGOP networks have been adjusted to form consistent time series of the stations and to derive station velocities (*Figure 2 and Figure. 3*).

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.

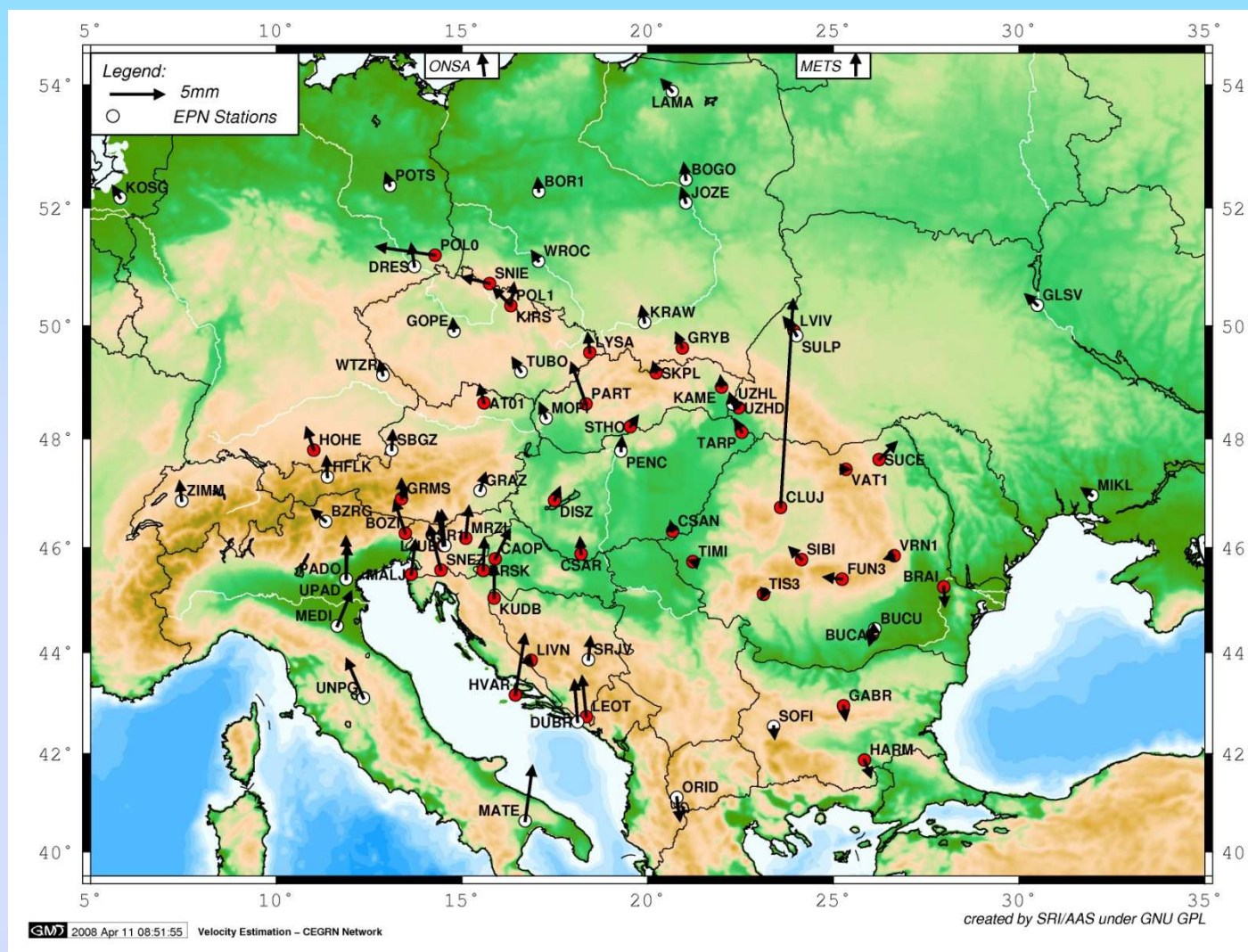


Figure 2. Horizontal velocity estimations from reprocessed time series of CEGRN campaigns 1994-2007

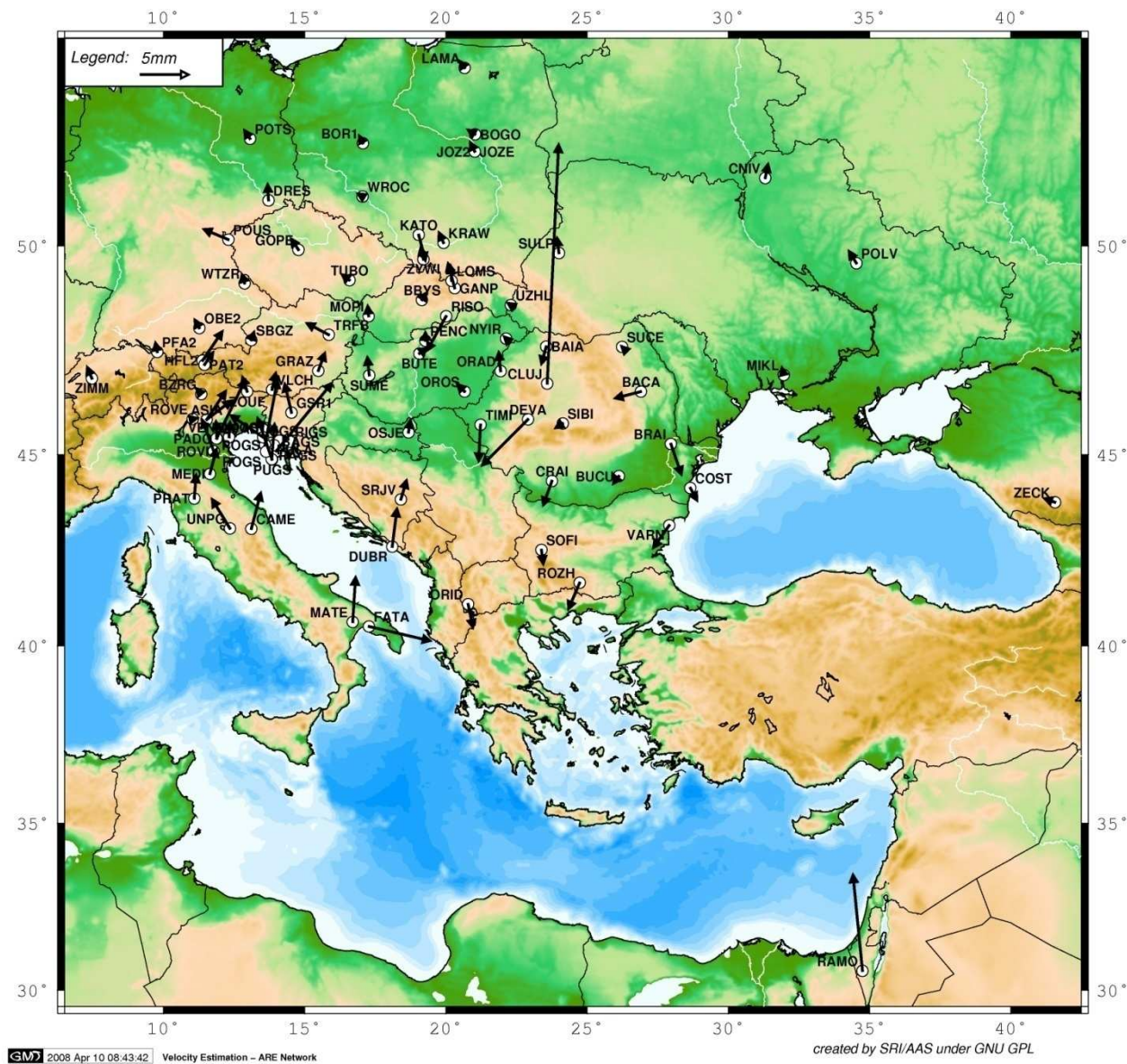
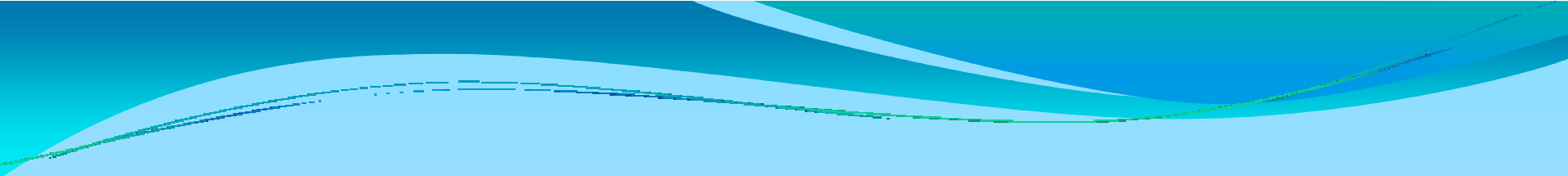


Figure 3. Horizontal velocity estimations from cumulated weekly time series of CERGOP permanent sites 1999-2008



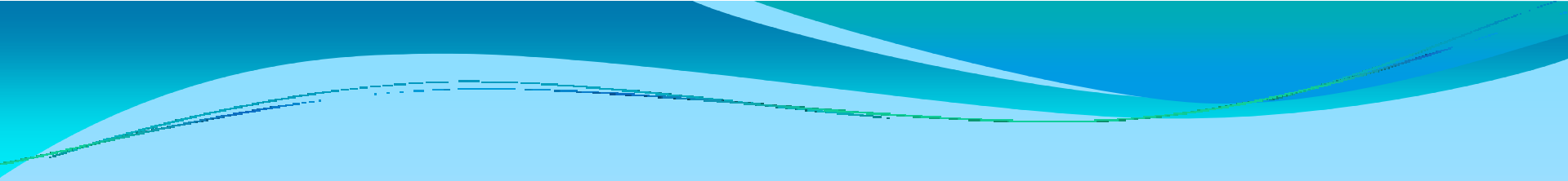
As can be clearly seen in the figures there are empty spaces because of missing participation of some countries.

❑ 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.

❑ Permanent sites require at least two years of observations to avoid misinterpretation by seasonal effects and potential local disturbances.

❑ Around the Adriatic Sea the stations move generally to the North by 3-5 mm/year which is caused by the Adriatic Microplate.

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- ☐ South of the Carpathians a transition zones seem to be pulled south with a small rotation focused at Bulgaria by 2-3 mm/year.
 - ☐ 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 but the interior of the Balkan Peninsula is still largely uncovered by observations.

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.

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.

The present-day geodynamics of the Balkan region is controlled by the active tectonic processes in the Eastern Mediterranean (*Figure 4*).

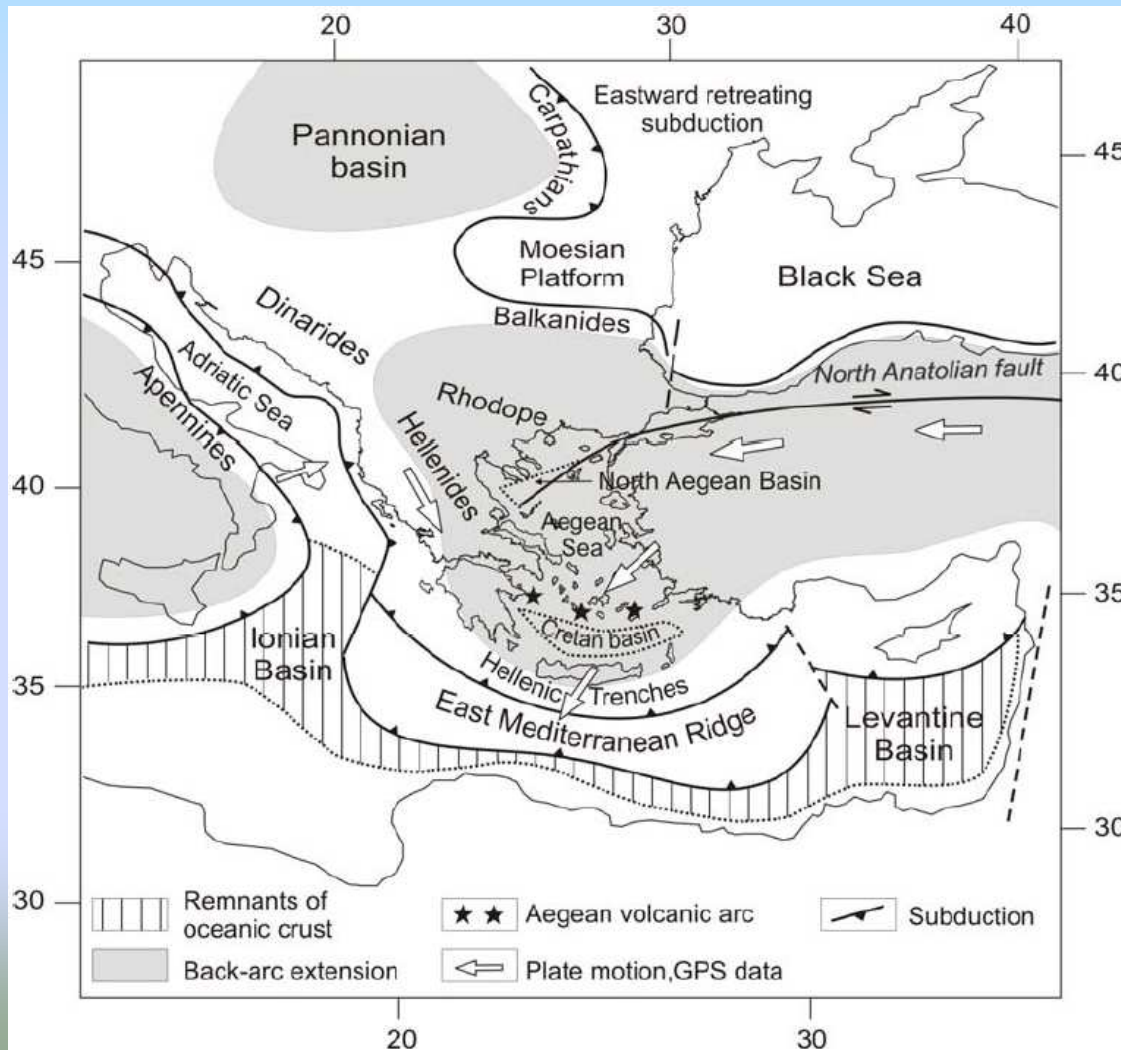
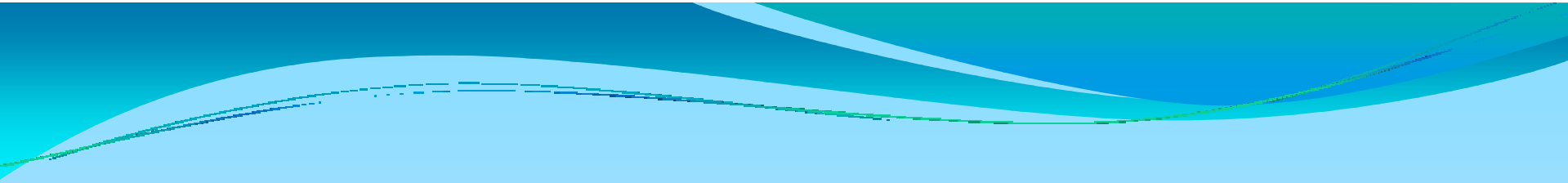


Figure 4. Active processes in the Eastern Mediterranean



❑ 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.

4.1. Investigations of the particular Balkan countries

Detail information can be found in the Monograph “Geodynamics of the Balkan Peninsula” - Milev, Dabovski., 2006.

- Albania**
- Bosnia and Herzegovina,**
- Greece,**
- Macedonia,**
- Romania,**
- Serbia and Montenegro,**
- Slovenia,**
- Turkey.**

4.2. Generalized investigations and results

4.2.1. 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 5*) of the CEGRN subnetwork covering Balkan Peninsula has been studied and analyzed.**

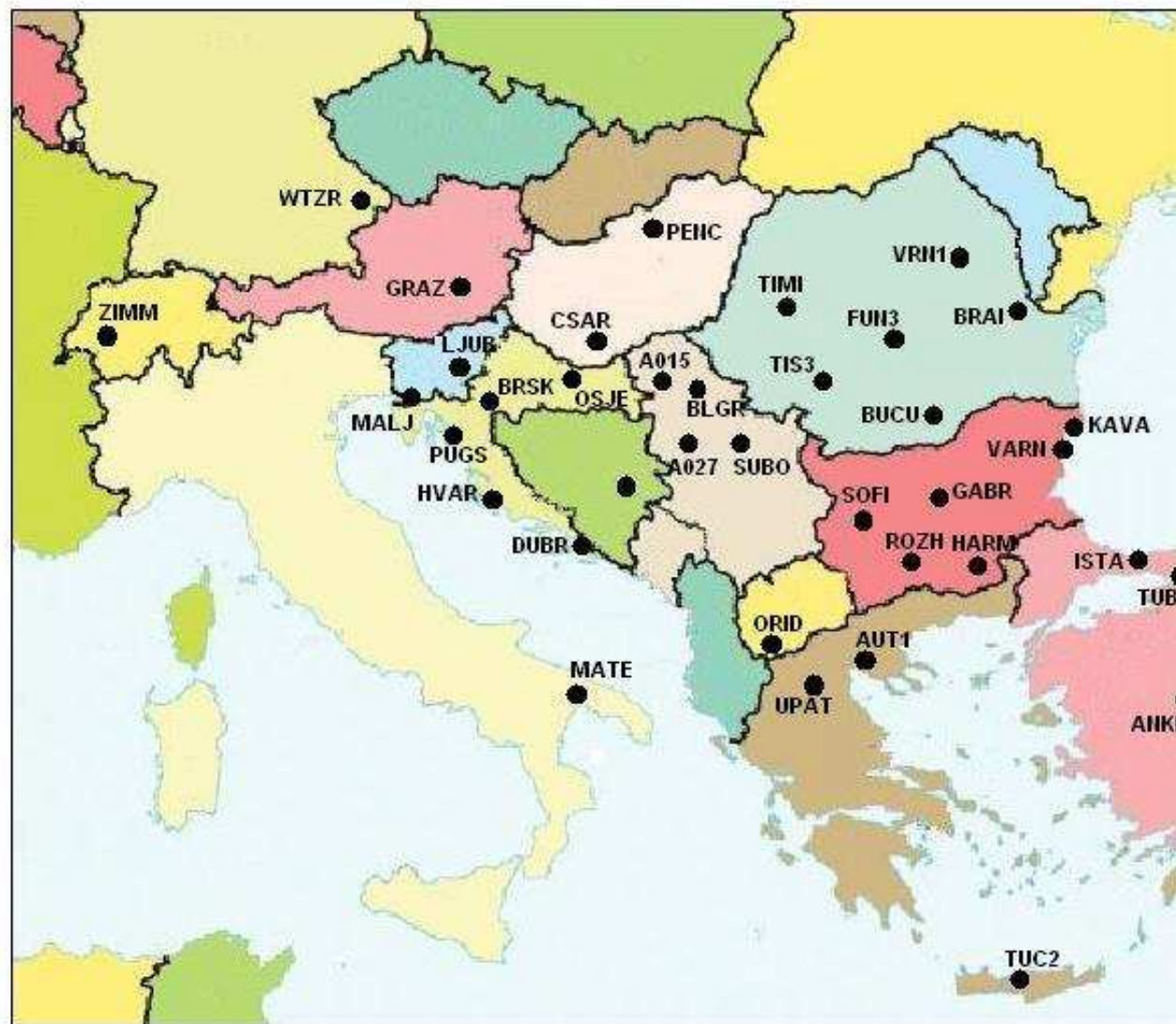
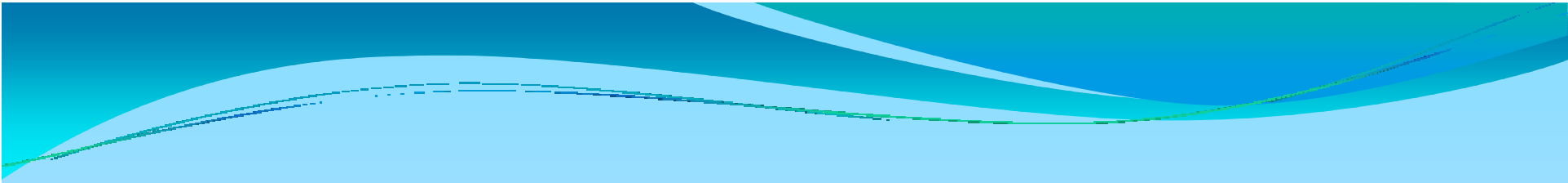


Figure 5. Balkan Peninsula CEGRN subnetwork stations

Observation data from different GPS CEGRN measurement campaigns concerning the Balkan Peninsula stations have been involved.

Data processings have 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 obtained.
- 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 subnetwork have been done.



The latest investigations covered the period 2007-2009.

➤ **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 10 in 2007 up to 22 in 2009.**

➤ **All free available stations (*Figure 6*) on the territory of the Balkan Peninsula are used for study of their movement within the three years – 2007, 2008, 2009.**



**Number of Balkan
Peninsula
permanent stations**

in 2007 – 10 stations

in 2009 – 22 stations

**Figure 6. Balkan Peninsula
Permanent stations**

4.2.2. 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.

- **Combinations of two years give different results for most of the stations to some extent.**
- **That means 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 7*).
- For some of the stations greater differences between the velocity components have been obtained and an eventual reason like antenna changes can be assumed.

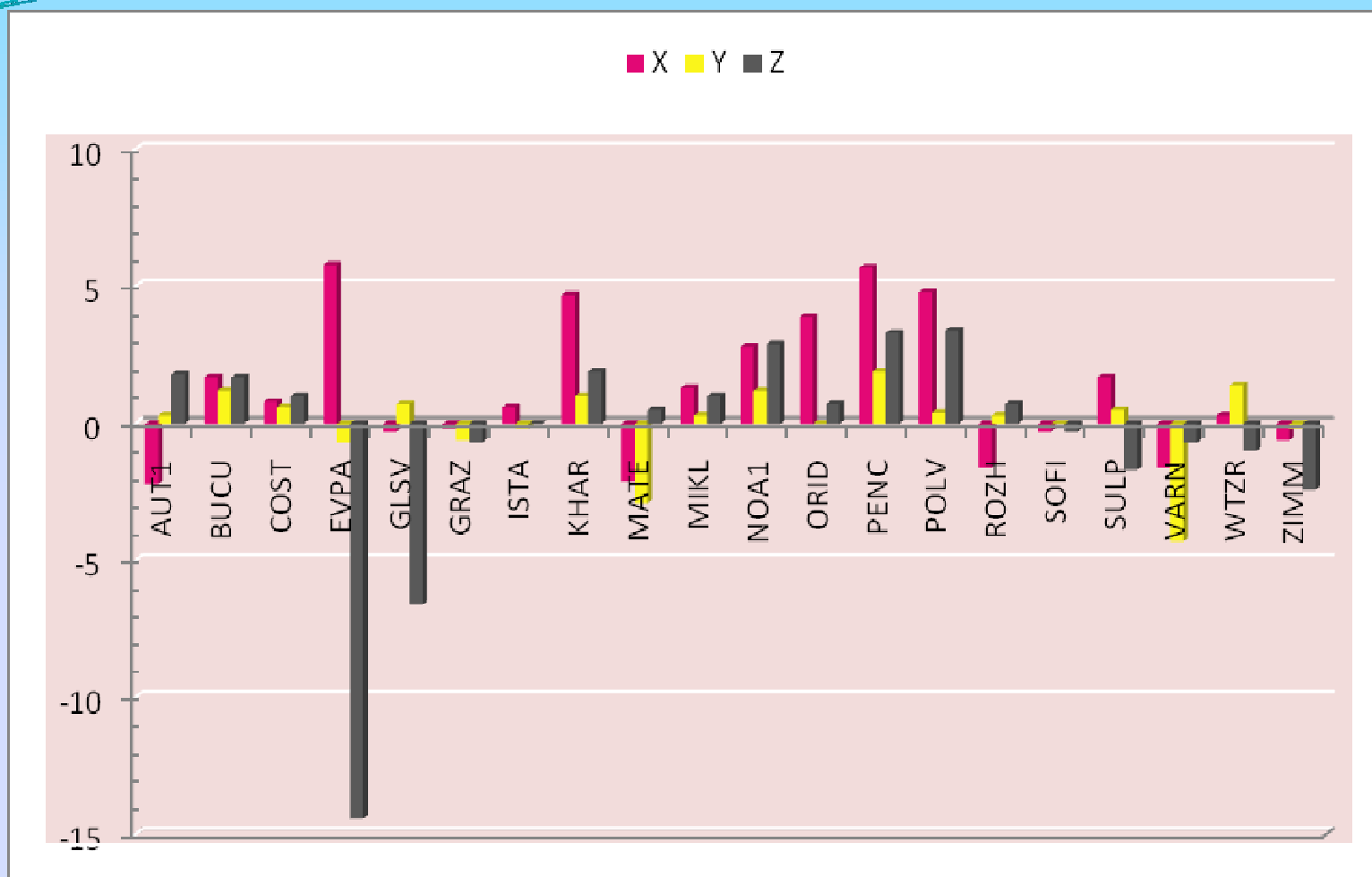
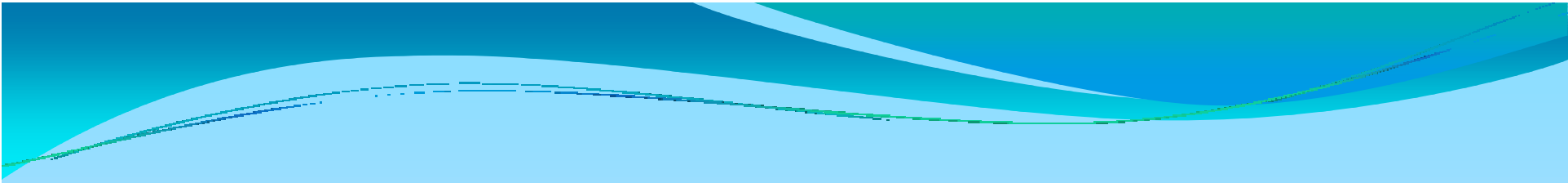


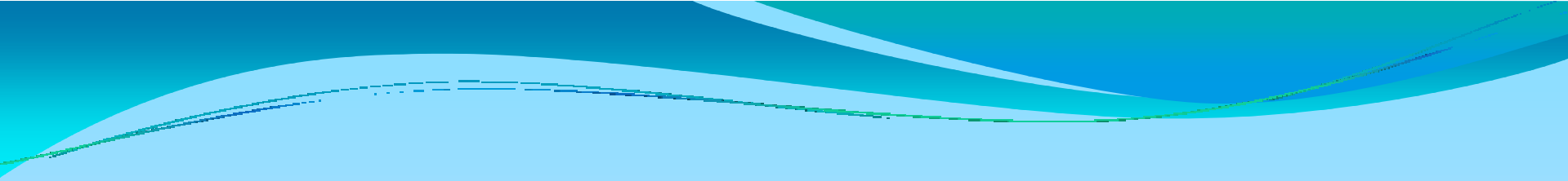
Figure 7. Station velocity differences between results of this study and estimations from IGS/EPN/CEGRN



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.

The main conclusions of the study which can be drawn 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.**



The above conclusions are very important in determination of velocity vectors of points from national networks and geodynamic networks.

It is suggested to be used for such points velocity estimations obtained from **processing of long term data of several years.**

Velocity vectors obtained are crucial for further analysis and interpretation and they should be reliable estimated.

Using these estimations by earth scientists is also important for further analysis and interpretation.

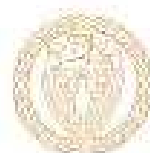
4.3. The Monograph “Geodynamics of the Balkan Peninsula”

The monograph 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.

POLITECHNIKA WARSZAWSKA

INSTYTUT GEODEZJI WYŻSZEJ I ASTRONOMII GEODEZYJNEJ

No. 5 (80), 2006



GEODYNAMICS OF THE BALKAN PENINSULA

Monograph

compiled in the frame of the Project CERGOP-2/Environment
(contributions of the Work Packages WP.10.1 and WP.10.6)

REPORTS ON GEODESY

WARSAW UNIVERSITY OF TECHNOLOGY

INSTITUTE OF GEODESY AND GEODETIC ASTRONOMY

Monograph structure is: (650 pages, contributions of 96 authors)

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

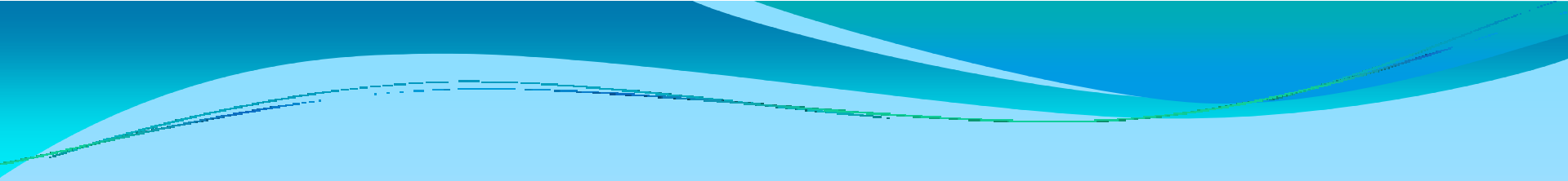
5. Generalized investigations

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

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- **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 is addressed to a broad range of specialists involved in the different Earth sciences and protection against natural disasters.**

5. Geodynamics of Bulgaria

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.**
- **Over the past centuries, Bulgaria has experienced strong earthquakes. Some of the Europe's strongest earthquakes 20-th century occurred in Bulgaria.**

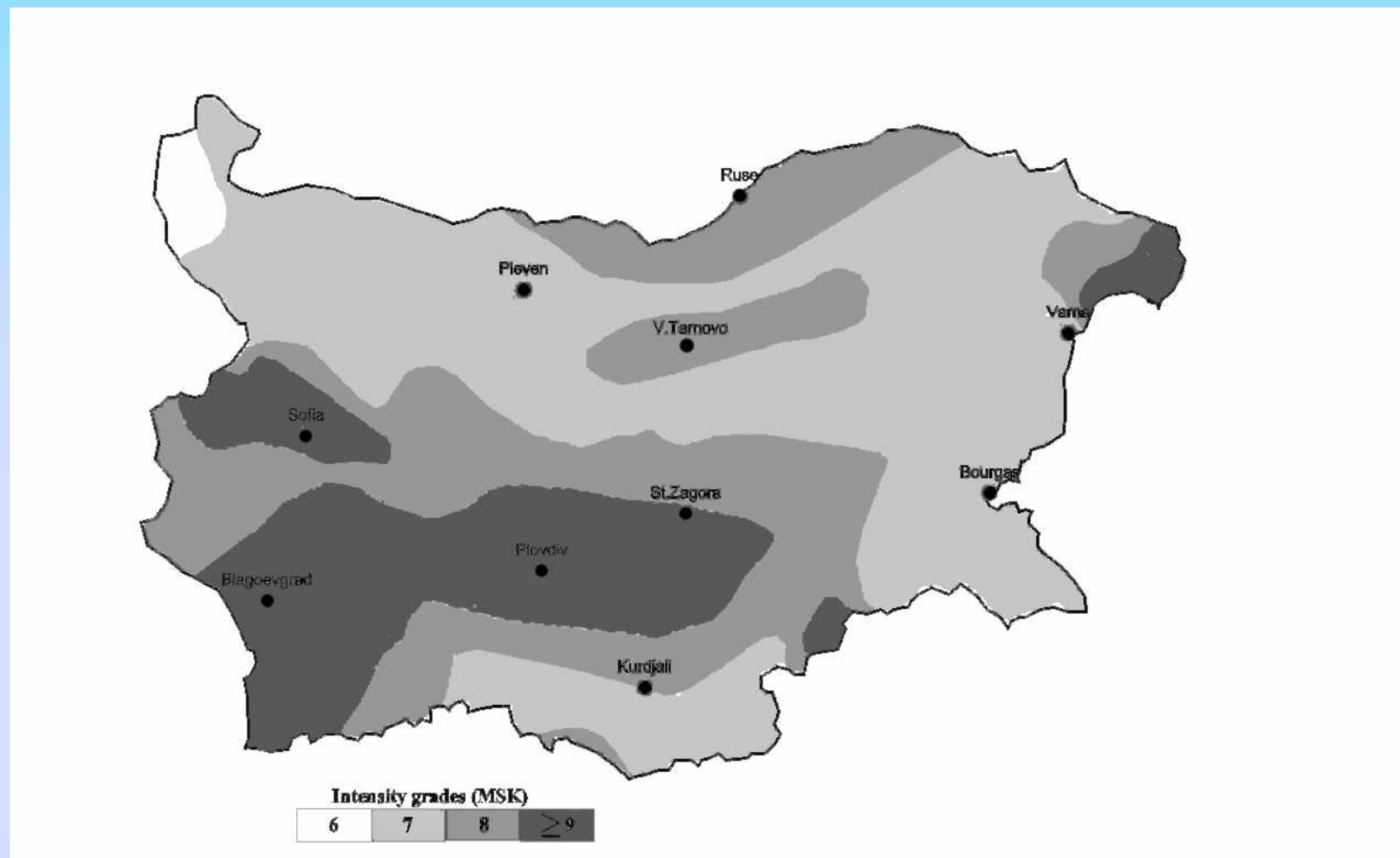
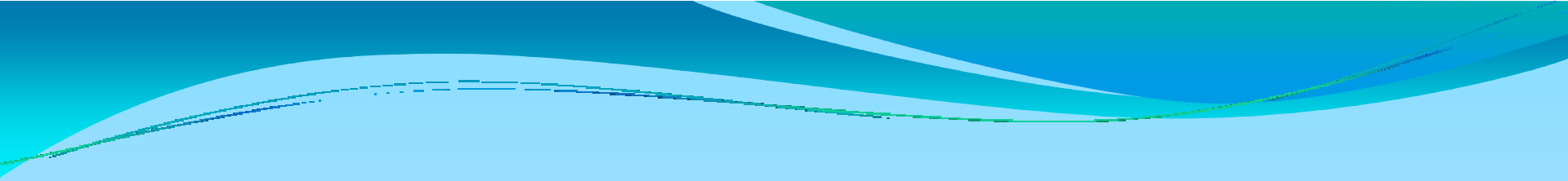


Figure 9. Hazard map for a 1000-year return period



The historical seismicity in Bulgaria has not been satisfactory covered by the existing information sources.

The supporting dataset quality has been improving in the course of time, although the data points' number has not been significantly changed.

The nowadays monitoring of the weak earthquakes in Bulgaria is based on a modern **National seismological network which was established in 1980.**

More than 15000 events recorded during the operation of this National network are located on the territory of Bulgaria and its close vicinity.

5.2. Geodetic measurements

First geodetic measurements for the territory of Bulgaria on the CERGOP project were carried out in 1996.

Four Bulgarian stations - SOFI, HARM, GABR, KAVA were involved in the CEGRN GPS campaigns (*Figure 10*).

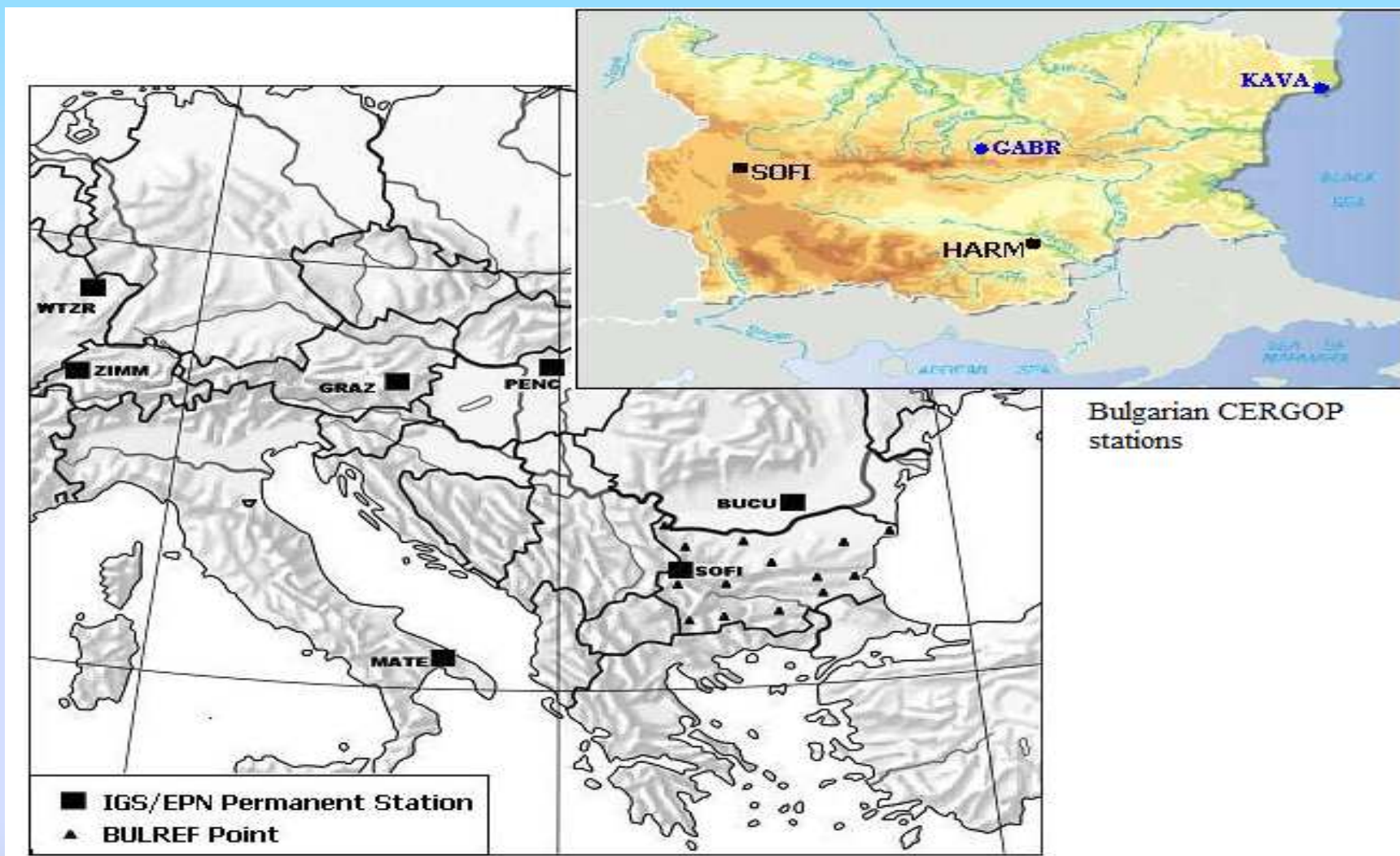


Figure 10. Bulgarian stations participated in CEGRN03 campaign

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 10*).

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 11*).



Figure 11. Bulgarian stations participated in CEGRN05 campaign

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.

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 12*.

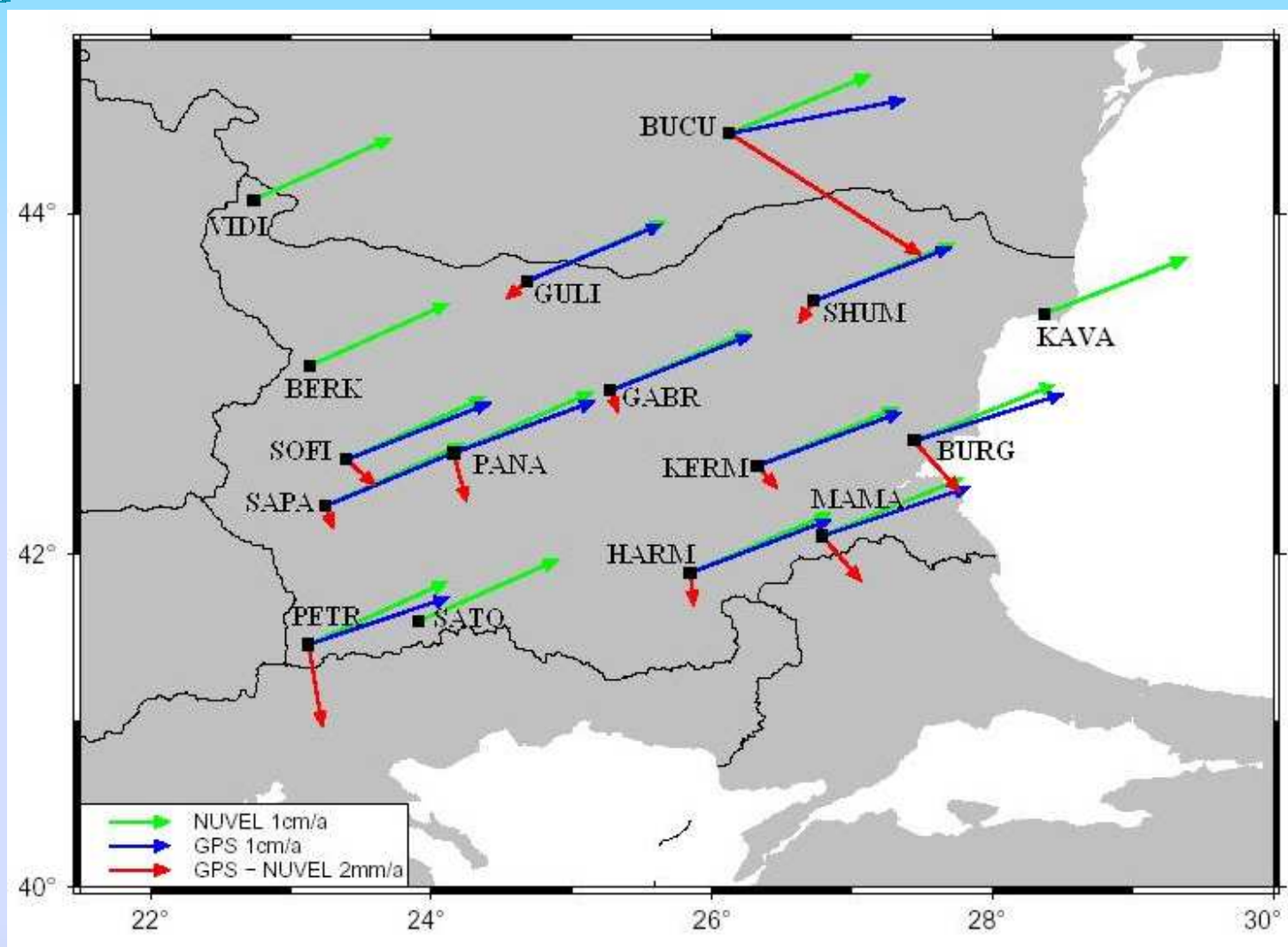
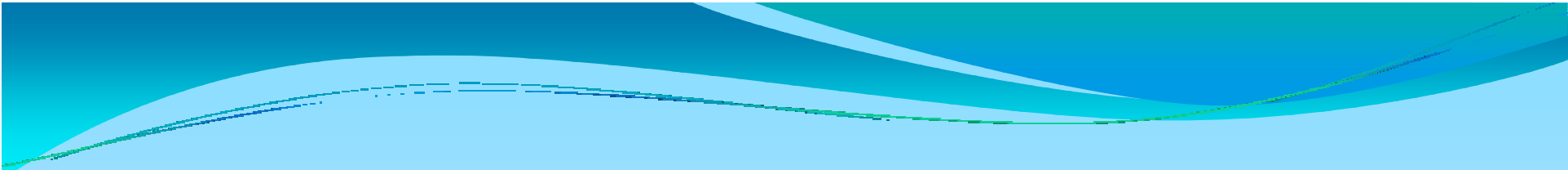


Figure 12. GPS and NNR-NUVEL1A velocity vectors of BULREF stations



❑ 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.

❑ Also 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 as well.

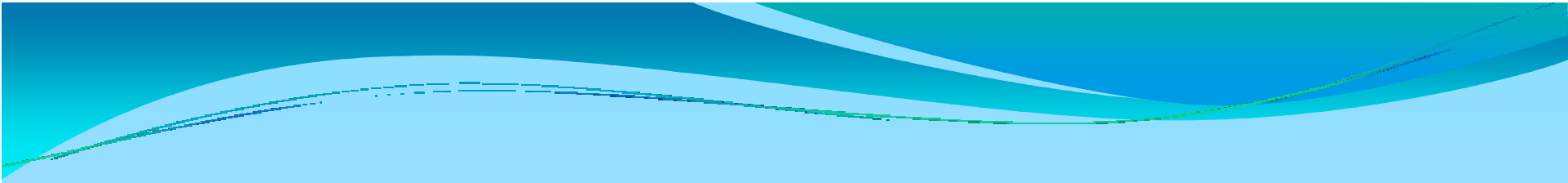
5.4. Permanent DGNSS networks

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 Intelligent 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.



- The establishment of the DGNSS network *BULiPOS* was carried out in 2007 and the number of active reference stations is 12 shown in *Figure 14*.

- The stations have been spread over the country evenly and 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.

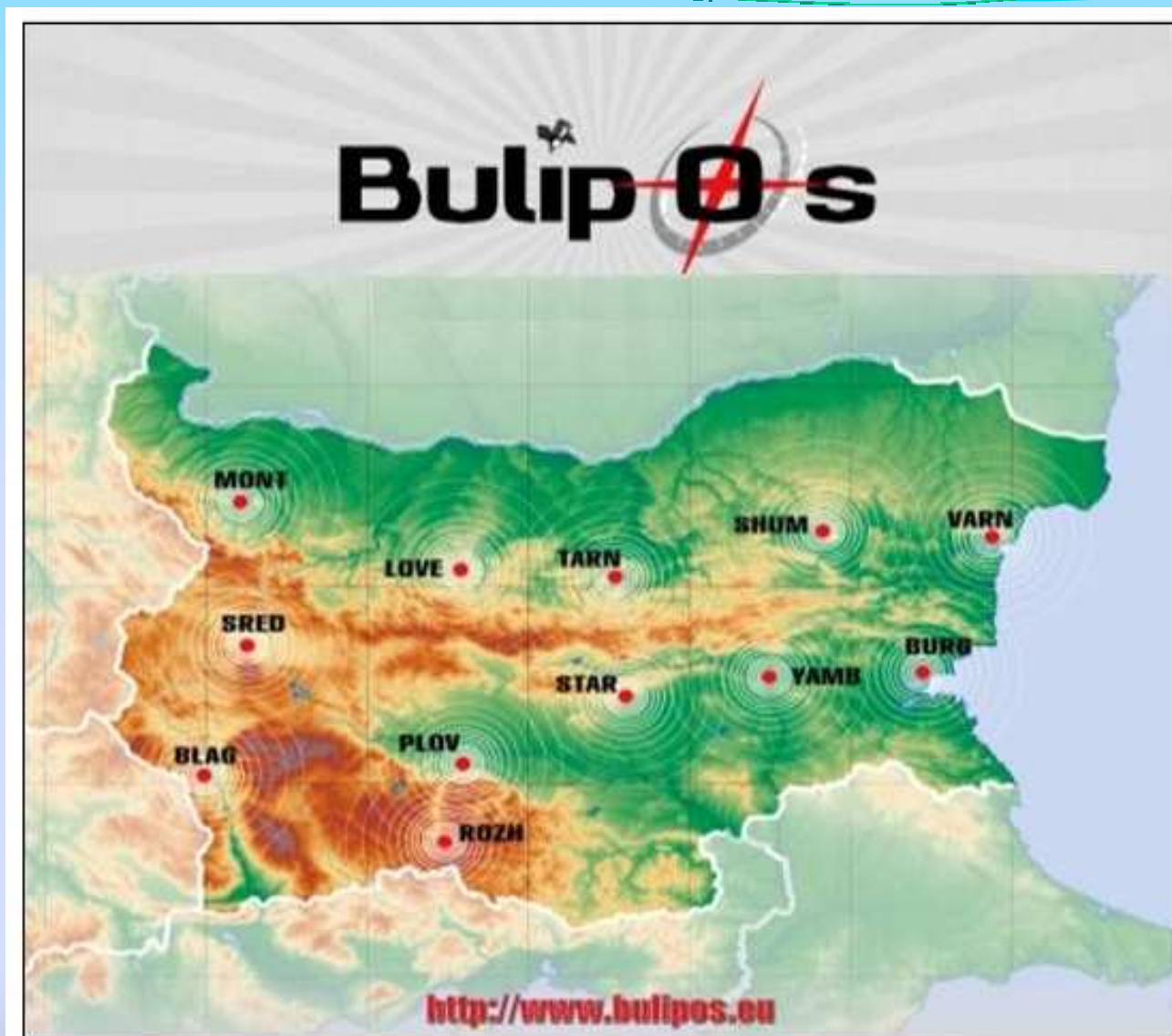


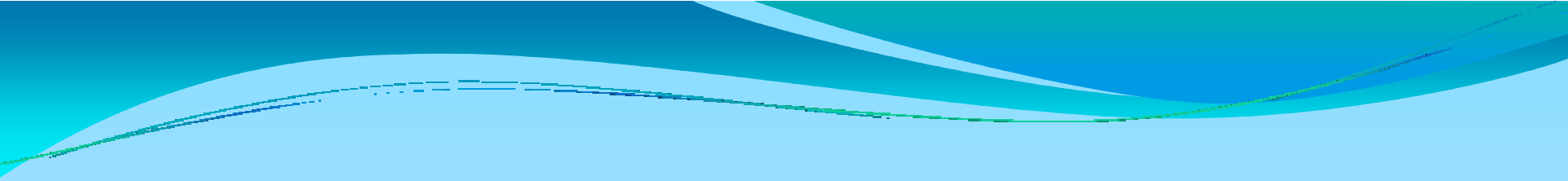
Figure 14. *BULiPOS* DGNSS stations

The *BULiPOS* is unified homogeneous reference network and system for determination of position and space orientation.

BULiPOS 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.

BULiPOS offers 4 types of services, depending on the required level of accuracy (from several meters to centimetres and millimetres) - **Real Time Kinematics, Precise Real Time, Virtual Station and Post Processing.**

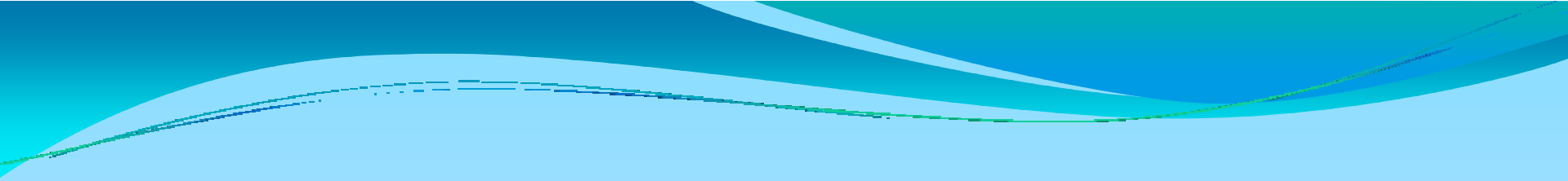


The *BULiPOS* stations BURG, LOVE, MONT, SHUM and TARN (*Figure 14*) have been included in the data processing of the CEGRN network and since 2009.

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

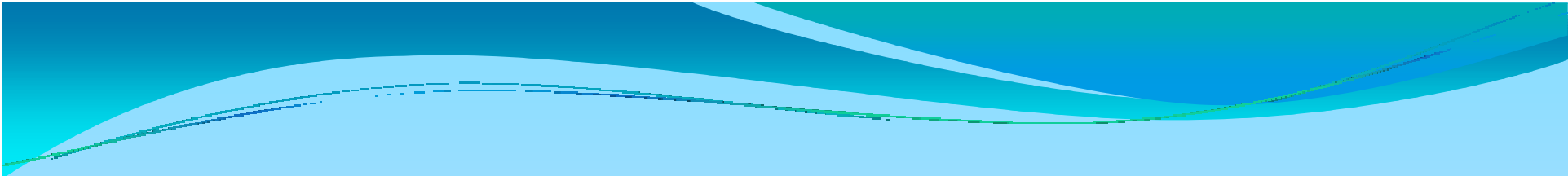
6. Conclusion

- ❖ 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 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.

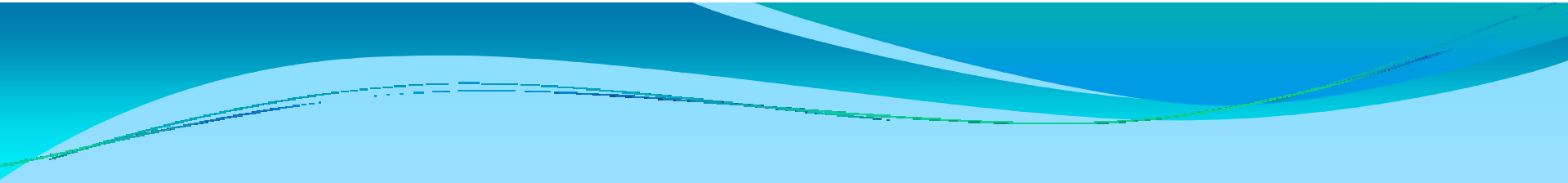


❖ They outlined the contemporary approach for regional and national investigations of this type and they can be used as an effective base for future measurements and studies in the region of the Balkan Peninsula, and in the particular countries of it.

❖ 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 (like *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.



**THANK YOU
FOR ATTENTION!**