AdriaArray Workshop 2024

Sofia University "St. Kliment Ohridski", Sofia, Bulgaria

12 – 15 March 2024

An overview of the studies of the earth's crust movements on the territory of Bulgaria and the Balkan Peninsula with GNSS

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OUTLINES

- Introduction
- GPS data processing
- Station velocity estimations
- Kinematic plate model
- Deformation analysis by applying Finite Elements Method in Space
- Discussion

INTRODUCTION

- The territory of the Balkan Peninsula is well known as a very active tectonic zone.
- Various geophysical, geological and geodetic methods and approaches have been applied to study and interpret the recent active earth crust movements of the region (*Burchfield et al. 2006, Kotzev et al.200, Matev 2011, Reilinger et al.2010, Stangl, Mitterschiffthaler, 2015*).
- Recently the advanced space geodetic techniques and methods are used to understand better the long-term geological and geophysical processes.
- The monitoring of crust movements by using GPS observations from campaigns and permanent stations of the territory of Central and Eastern Europe started in 1994 with the long-term project CERGOP1 (Central European Regional Geodynamic Project) and later on (2002) CERGOP 2/Environment (*Milev, G., Dabovski, 2006*), twice sponsored by European Commission, and **although already finished the geodynamic investigations continue nowadays**.
- The present study concerns the results from the processing of open access GPS data of GNSS stations in Balkan Peninsula.

GPS DATA PROCESSING

Seasonal behavior of the Balkan Peninsula GNSS permanent stations

- 3 seasons from weekly solutions of 2006,2007,2008,2009, 2010 data
- 18 up to 29 permanent GPS stations (*Vassileva, 2013*)
- Estimated velocities in North and East components of all combinations show very good agreement.
- In Up component discrepancies are about 2 mm and they can be considered mostly as impact of local phenomena.
- Analysis of the obtained horizontal station velocity vectors relative to the Eurasia plate shows smooth, undisturbed linear trend of movement.

Figure 1. Horizontal velocity vectors of BP stations for summer time with respect to the stable Eurasia

GPS DATA PROCESSING

- 31 GNSS permanent stations covered the territory of the study:
- 15 – in Bulgaria as12 of them belong to the *BULiPOS* reference network, which is the Bulgarian segment of the *European Determination Positioning System*) system and service.
- 4 stations are located in Romania,
- 10 - in northern Greece,
- 1 – in Macedonia
- 1 - in north-east Turkey.

and

- 11 IGS GNSS permanent stations (8 of them are used for datum definition).

Figure 2. BP and IGS GNSS permanent stations involved

GPS DATA PROCESSING

- One week data from each year are used from all six years – 2011, 2012, 2013, 2014, 2015 and 2016.
- The data are processed with Bernese software, Version 5.0 in coordinate system ITRF2008.
- Obtained normal equations from data processing of each year have been combined in Addneq2 program of the Bernese software.
- Finally, the estimated station coordinates (*X, Y, Z*) and station velocity components (V_X, V_Y, V_Z) of all stations have been obtained by applying the least squares method with minimum constraint conditions for coordinates and velocities of 8 selected reference IGS stations in the system ITRF2008, referred to epoch 2005.0.

STATION VELOCITY ESTIMATIONS

- The ETRF horizontal station velocity vectors in ETRF2000 have been derived for presentation of the local movements of the stations.
- The obtained horizontal station velocities vary from 0,3mm/yr up to 8,0mm/yr.
- The movements in southern Romania, station KNJA in Serbia, northern Bulgaria (Moesia platform), in southwestern and in central-southern Bulgaria show movements with directions to the south and to the south-west.
- Stations in northern Greece and station *Orid* in Macedonia are moving slightly to south-east.

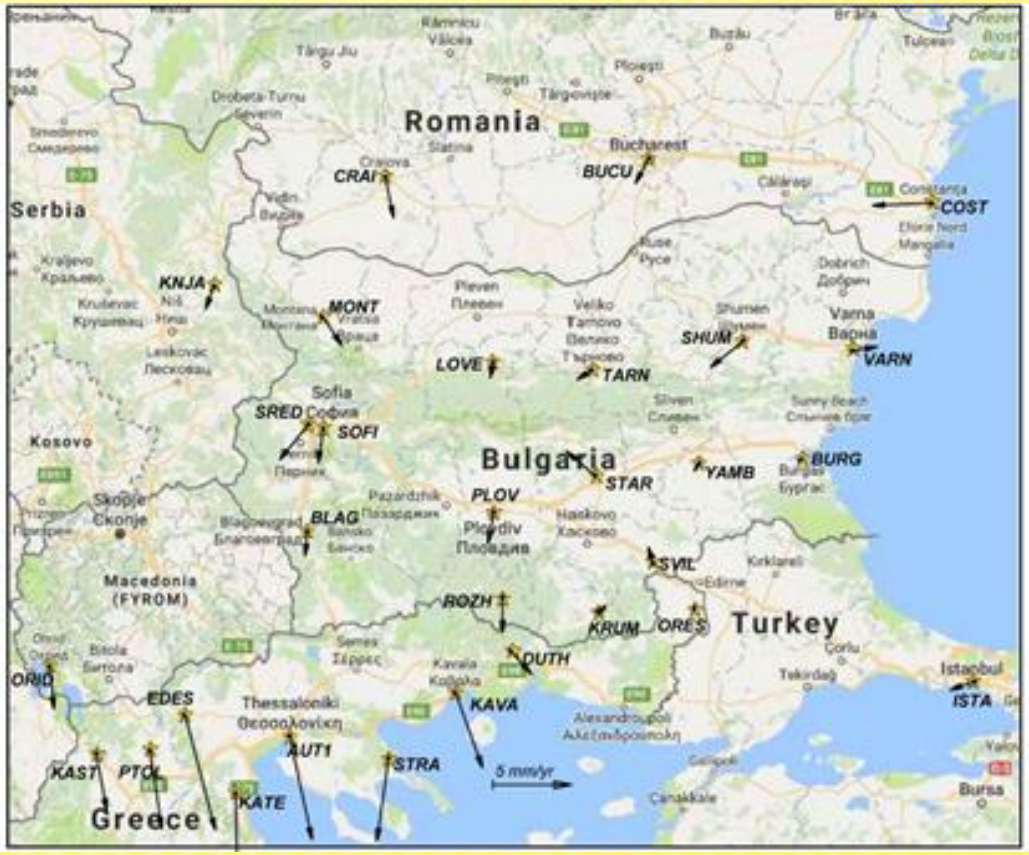


Fig. 3. ETRF2000 horizontal velocity vectors of BP GNSS permanent stations

STATION VELOCITY ESTIMATIONS

Directions of movements of stations *Yamb*, *Star*, *Plov*, *Rozh*, *Krum, Ores*, *Svil* show a counterclockwise rotation of the southeastern Rhodopes and the Maritsa basin (*Figure 4*), which corresponds well to the tectonic setting of the Maritsa fault zone (*Figure 5*) defined as a strike-slip zone in (*Gerdjikov, Georgiev, 2006*)

along the northern margin of the Rhodopes.

Fig. 4. Movements in East Rhodopes and the Maritsa fault zone

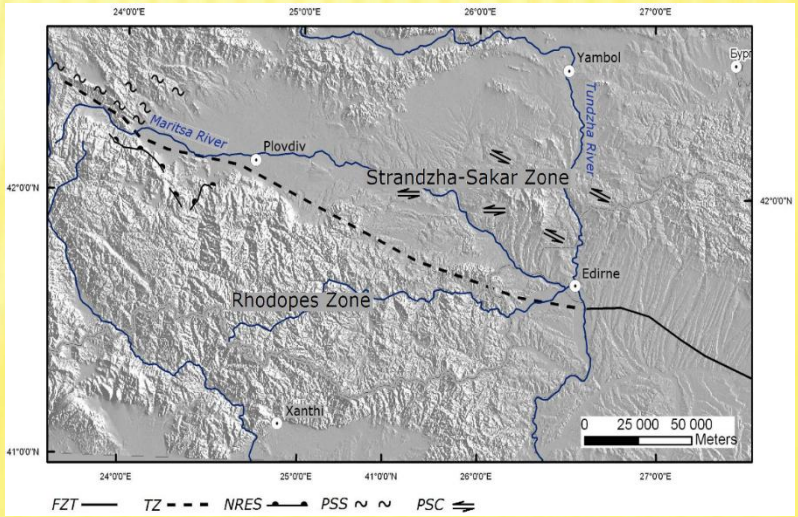


Fig. 5. Maritsa strike-slip zone (after Gerdjikov, Georgiev, 2006)

KINEMATIC PLATE MODEL

The kinematic plate model of a tectonic plate can be presented by six parameters: Euler rotation vector Ω (Ω_X, Ω_Y, Ω_Z) and Euler pole (φ, λ, Ω).

$$\vec{V} = \vec{\Omega} \times \vec{P}$$

After estimation of the Euler rotation vector Ω (Ω_X, Ω_Y, Ω_Z) it is possible to calculate the Euler pole (φ, λ, Ω).

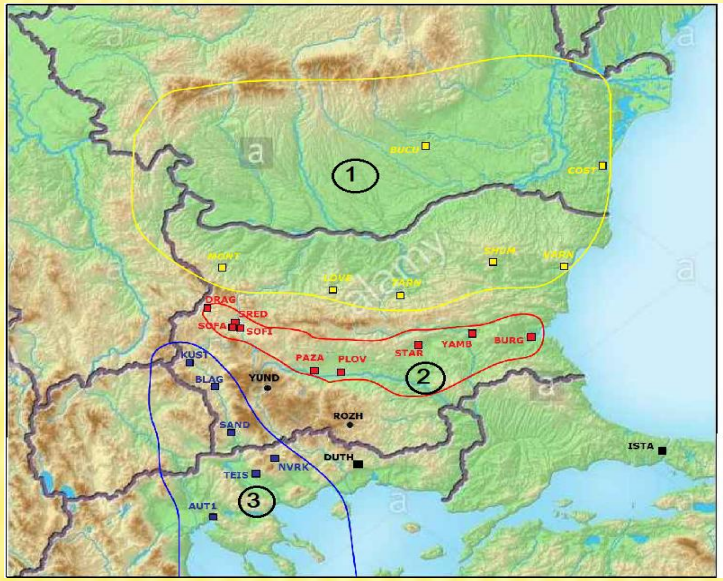


Fig. 6. Suggested potential microplates

1) Moesia plate
2) East Rhodopes and Maritsa basin
3) North Greece and south Macedonia

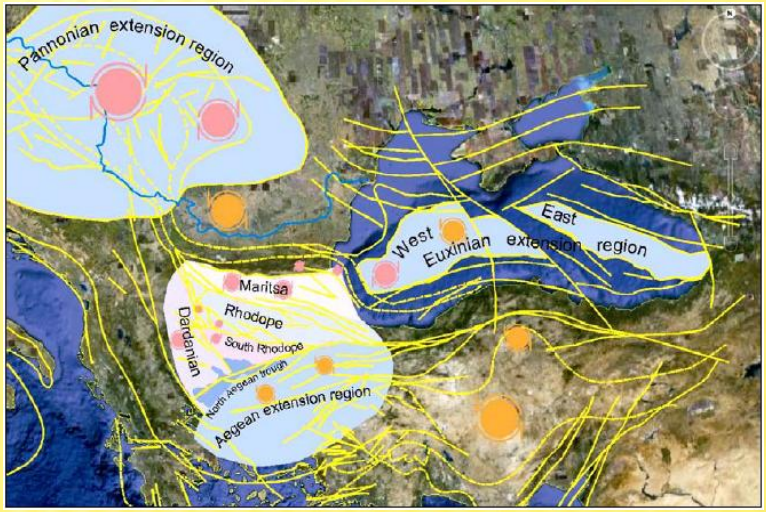


Fig. 7. Principle extensional areas and regional rotation patterns (after Zagorchev, 2011)

Principal faults – yellow,
Zone boundaries – dashed yellow

DEFORMATION ANALYSIS BY APPLYING FINITE ELEMENTS METHOD (FEM) IN SPACE

For the majority of studies the FEM is mainly used in the analysis of movements of stations, which are results from GNSS data processing in order to be obtained strain tensors and strain accumulation (*Bogusz et al. 2013, Deniz, Ozener 2010, Hu et al. 2004, Valev, Kastreva 2006*) in plane.

Since the Balkan Peninsula is large region, the method of finite elements is developed by the authors specifically for the space. More detail theory of the developed method can be found in (*Vassileva, Valev 2015*).

The ellipsoidal station coordinates $P(\varphi, \lambda, h)$ obtained from the GNSS data processing are input data used in FEM after stations projecting onto the ellipsoidal surface and their transformation into Cartesian station coordinates $P_0(X_0, Y_0, Z_0)$.

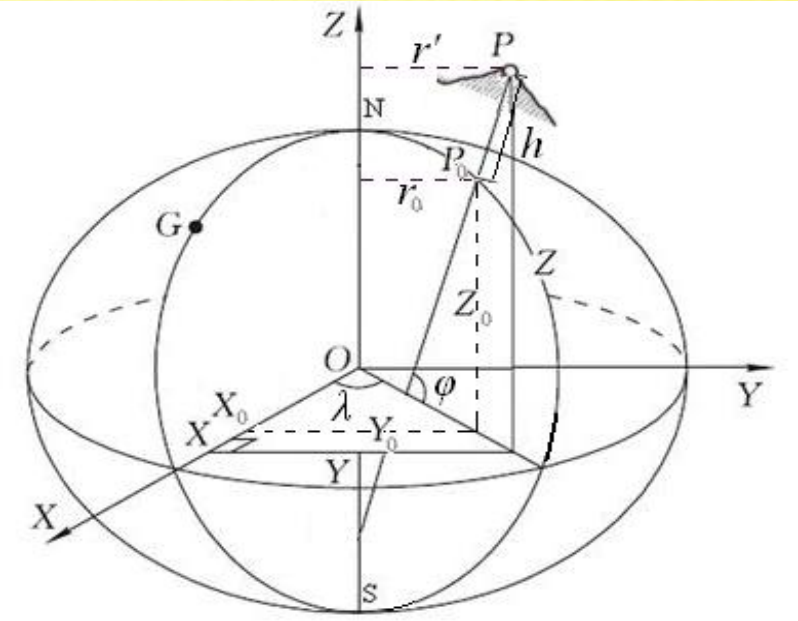


Fig. 8

Point P_0 must satisfy both the equation of meridian ellipse and the equation of the normal line through the point P (X, Y, Z) to this ellipse, namely

$$r_0^2 + Z_0^2(1+e'^2) = a^2$$

DEFORMATION ANALYSIS BY APPLYING FINITE ELEMENTS METHOD IN SPACE

After substitutions and some modifications, a 4th degree obtained equation is solved and Cartesian station coordinates (X_0, Y_0, Z_0) of point P_0 are obtained.

The ETRF2000 coordinates (X, Y, Z) of all stations in each year have been transformed into ellipsoidal station coordinates (φ, λ, h) and then they have been transformed according into Cartesian station coordinates (X_0, Y_0, Z_0) onto the ellipsoidal surface used. These station coordinates have been used for determination of the ellipsoidal chords (baselines) between projected stations onto the ellipsoidal surface.

The ellipsoidal chords form the triangle sides of every finite element in each year.

The final elements (triangles) have been configured approximately as equilateral triangles with approximately equal areas and not overlapping.

The linear deformations of the triangle sides and finally - principal deformations of each finite element (major and minor) and their directions are determined.

16 relatively uniform triangles have been configured.

DEFORMATION ANALYSIS BY APPLYING FINITE ELEMENTS METHOD IN SPACE

- Principal deformations of finite elements in the Moesia plate are dominantly of compression with northwest-southeast directions.
- The western part, close to the Bulgarian border and the south-east part show deformations of compression in directions northeast-southwest up to east-west.
- Principal deformations of the most west and south-west part of the Balkans covering the north and northwest Greece, south Macedonia, part of Serbia and south-west Bulgaria are of extension in all direction.

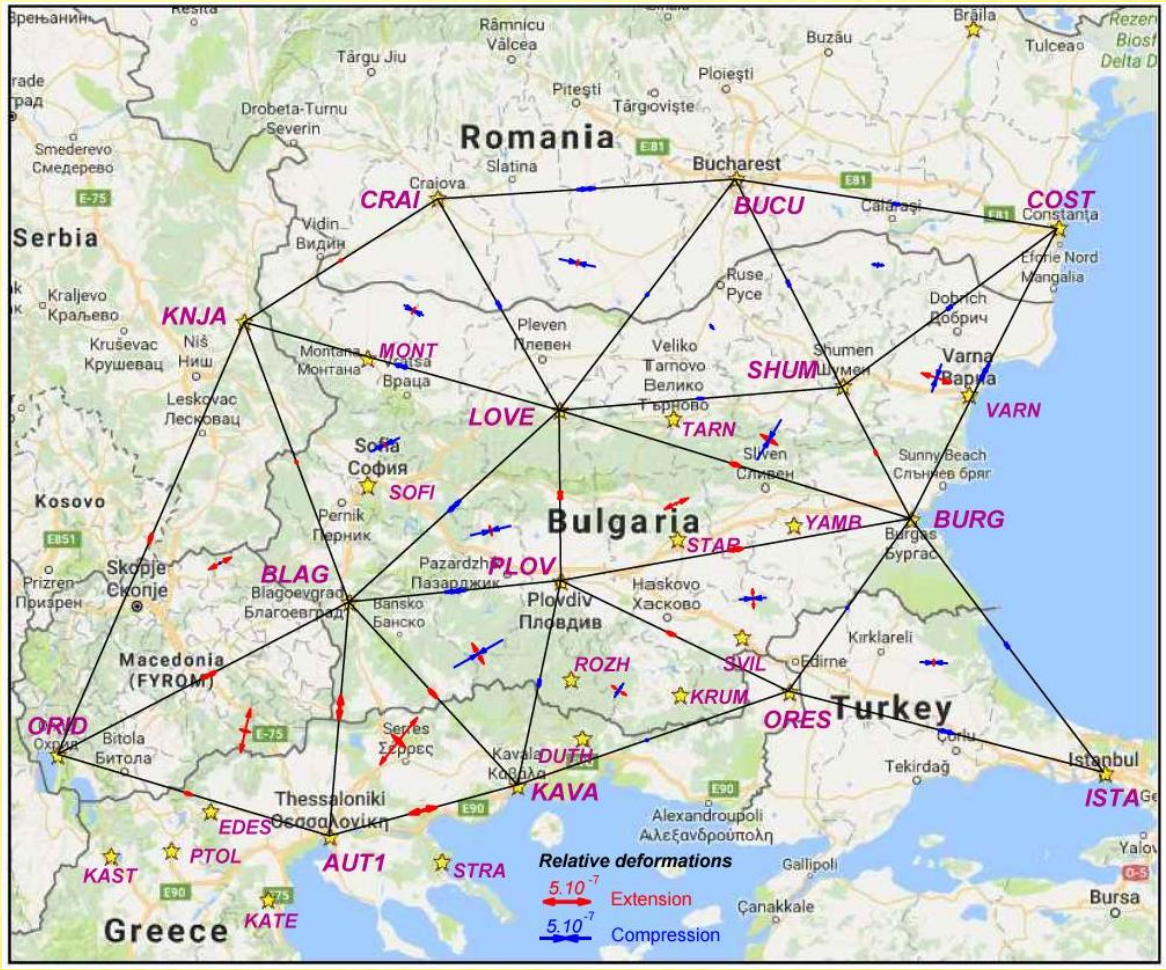
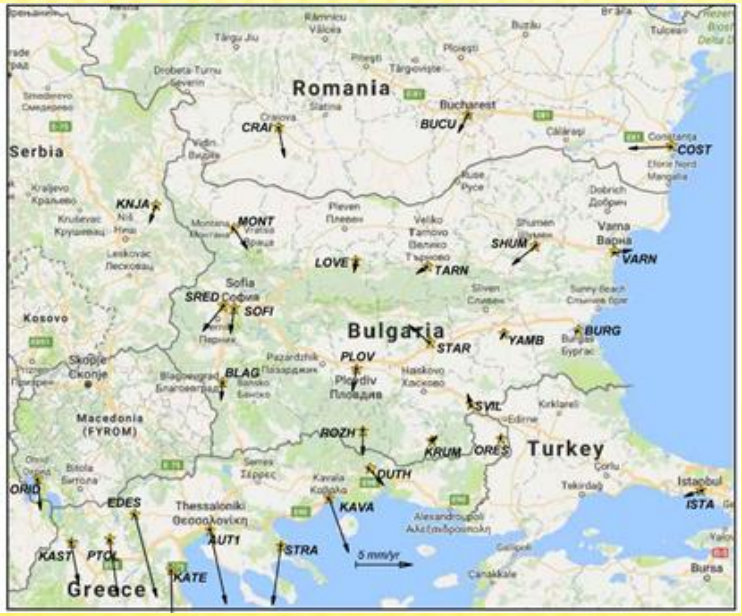


Figure 9. Principal deformations, time span 2011-2016

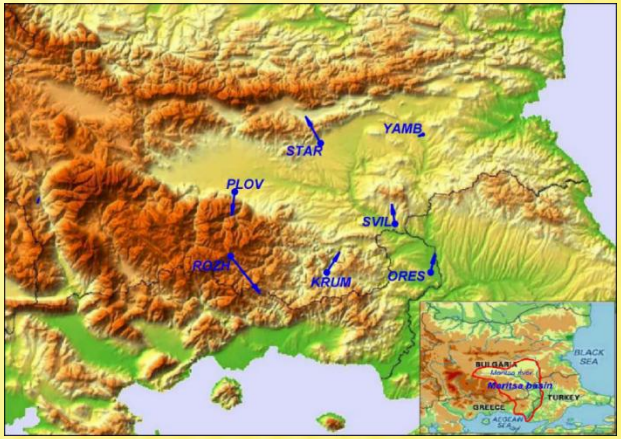
DISCUSSION

The clear transition boundary between the Moesia platform and the southern Bulgaria zone along the Balkan Mountains chain is not established, also an assumption of another study (*Stangl, 2011*).

The behaviour of the stations in northern Greece confirm the suggestion that they belong to the Aegean extensional zone.



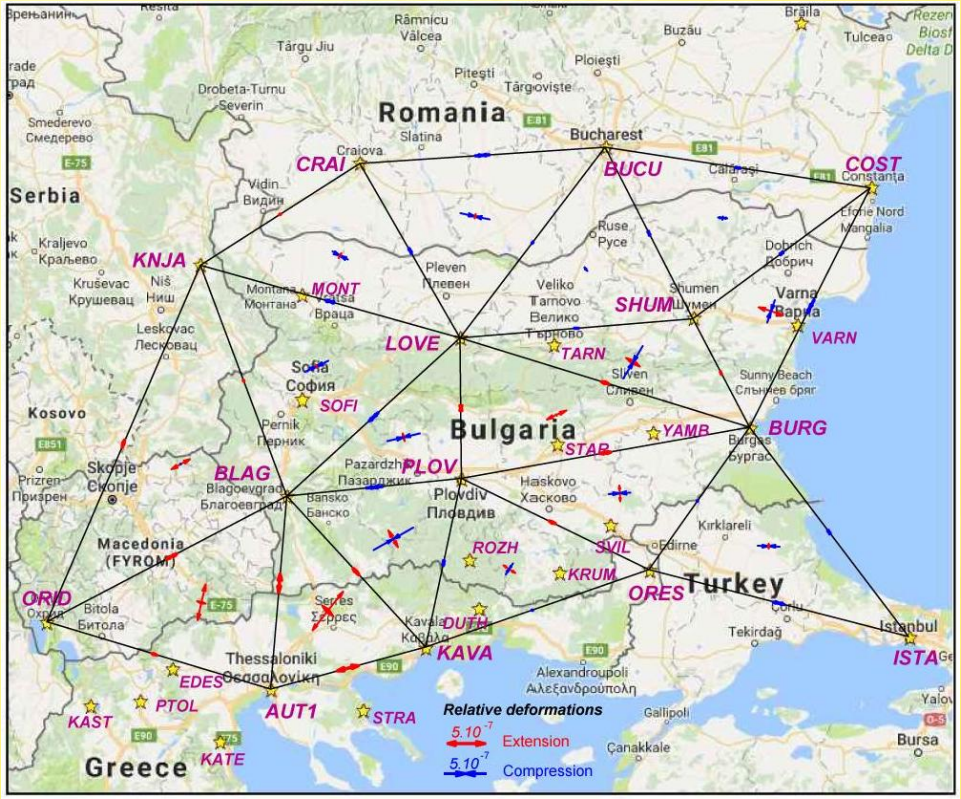
A counterclockwise rotation of the Maritsa zone is found, which is compatible to the tectonic setting of this area.



DISCUSSION

The finite elements method in space is applied for deformation analysis mostly of the central and southern territory of the Balkan Peninsula for the first time and it is an attempt to be applied another approach in surface geokinematics.

The suggested areas of extension and compression present a mathematical-geometrical interpretation of the movements of the Balkans region.
Further analysis is needed with use of more stations for configuring elements with shorter side lengths.



Thank you for the attention

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Acknowledgements

[1]We would like to thank the team of *IPOS Ltd.* for kindly provided us all necessary BULiPOS GNSS data for the processing.

[2]The scientific results are part of the work on the project: "Study of co-seismic deformations of the earth's crust for the territory of the Balkan Peninsula based on satellite data", financed by “Competition for financial support of basic research projects – 2023” of Bulgaria. Contract No. KP-06-N74/2 from 14.12.2023r