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Research of the Horizontal Crustal Motions, Based on GPS Data for the Territory of Bulgaria and the Balkans (7093)

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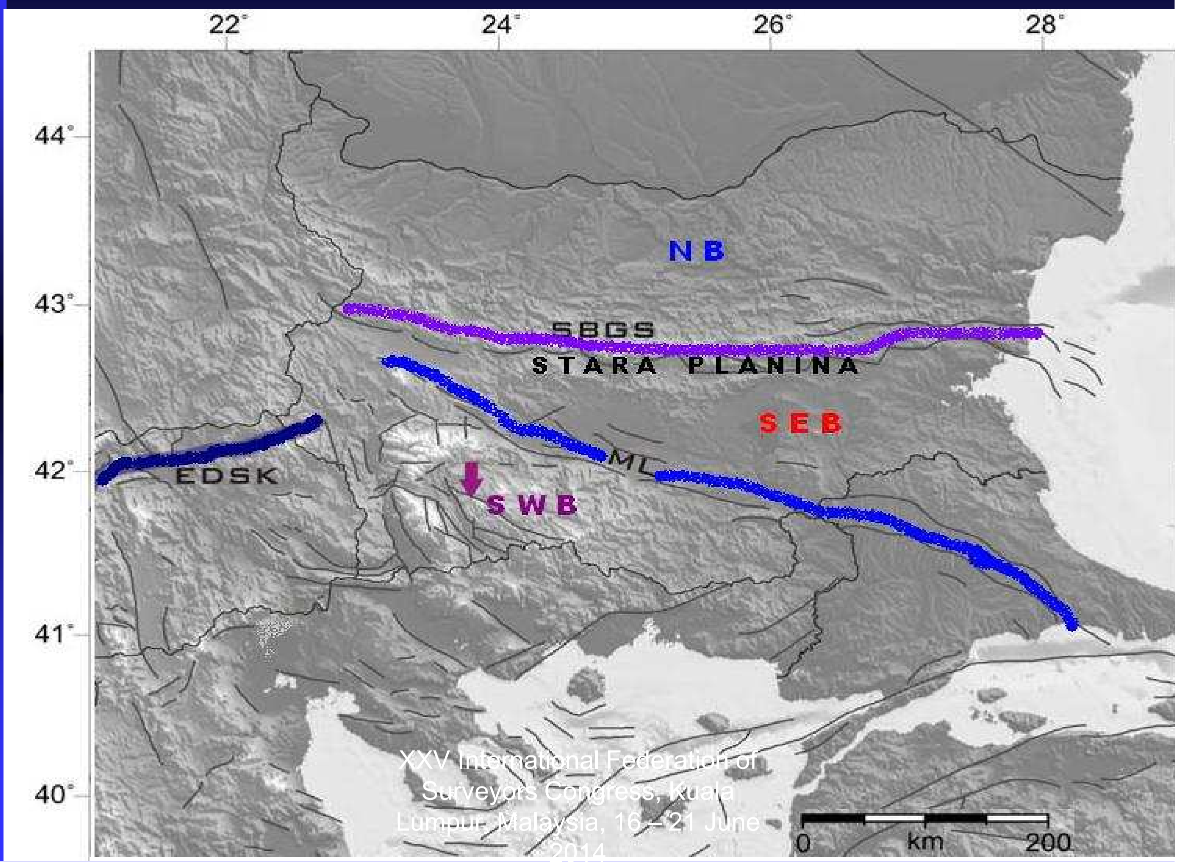
SUMMARY

- The present study is focused on the used GPS data from free available GNSS stations on the territory of the Balkans.
- Applying velocities and respective coordinates of the stations estimated from GPS data processing, it is possible to estimate the rotation Euler vector by Least Squares Method.
- For determination of Euler parameters I accepts a set of GPS stations as stable.
- Several different rotation poles have been estimated in order to test the proposed kinematics model for Bulgaria.
- The presented velocity gradient clearly indicates the increase of the motion from north to south.
- The GPS derived velocity field from GPS stations covering the territory of Bulgaria has been analysed and discussed in the context of tectonic block models.
- This paper covers an important topic, where GPS data has now been collected for enough years to be able to be used for reviewing plate movements.
- The main purpose of this work is to estimate and infer coordinates and velocity vectors of a set of stations, and to determine rotation parameters, using GPS data.

INTRODUCTION

- The territory of Bulgaria and particular the region of Balkan Peninsula characterizes with active tectonics and seismotectonics.
- Repeated GPS surveys in Bulgaria provide a direct measurement of current crustal motions. GPS surveys have been carried out in this region since 1996.
- The horizontal crustal movement have been studied by GPS analysis in (Burchfiel et al., 2006, Georgiev et al., 2013, Kotzev et al, 2008, Matev K., 2011).
- The region of South Bulgaria, especially Southwest Bulgaria and Rhodopes Mountains and Northern Greece is an active tectonic and seismotectonic area in the South Balkans with proved recent active tectonic structures and crustal motions.
- Based on these boundaries, geological structures and faults, I formed the contours of the blocks structure, in it research.
- The GPS velocity fields are estimated and they are used to estimate the block rotation motions.
- Blocks rotations are discussed in details by the study of GPS measurements, geology structural, and seismicity and paleomagnetic measurement, which contribute to more precise and clear determination of the transition zone.

Fig.1. Position fault from territory of Bulgaria and the part of Balkans, Southern Balkan Extensional Region (SBER) (Kotzev et al, 2008) and Maritza lineament (ML) (Georgiev I., (2009)



METHODS

- The velocity field of blocks can be determined by their relative displacement field of stable point groups. According to rigid kinematics theory and regarding the crust as a rigid body, we can establish kinematics model.
- Using the velocities, and the respective coordinates of the stations estimated by GPS, it is possible to estimate the rotation Euler vector in a Least Square adjustment. Using the very well known Euler theorem, the movement of blocks can be described by Euler vector, and the vector can be gotten from the linearized observation equation for one station (Perez et al., 2003):

$$\mathbf{V} = \Omega.\mathbf{X}\text{ , or} \tag{1}$$

$$\begin{bmatrix} v_i^x \\ v_i^y \\ v_i^z \end{bmatrix} = \begin{bmatrix} 0 & -\Omega_z & \Omega_y \\ \Omega_z & 0 & -\Omega_x \\ -\Omega_y & \Omega_x & 0 \end{bmatrix} . \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} \tag{2}$$

- It is also possible to write an observation equation similar to eq. (2) based on the spherical coordinates and so also north, east and vertical components in velocity. Because of the poor precision of GPS in vertical direction, we discard it and only use east velocity and north velocity to compute (Xu Caijun et al., 2000)

$$v_i^n = R.\sin\lambda_i.\Omega_x - R.\cos\lambda_i.\Omega_y \tag{3}$$

$$v_i^e = -R.\sin\varphi_i.\cos\lambda_i.\Omega_x - R.\sin\lambda_i.\sin\varphi_i.\Omega_y + R.\cos\varphi_i.\Omega_z$$

$$\Omega = \sqrt{\Omega_x^2 + \Omega_y^2 + \Omega_z^2} \tag{4}$$

$$\Phi = \arcsin\frac{\Omega_z}{\Omega}$$

$$\Lambda = \arctan\frac{\Omega_y}{\Omega_x}$$

R- mean radius of Earth.

Ω_x, Ω_y, Ω_z - angle velocity in coordinate axes X,Y,Z;

φ_i, λ_i - longitude and latitude of the point i

Euler vector parameters :

Ω is angle velocity

Φ, Λ are Euler polar coordinates.

GPS DATE

- Two different kinds of GPS networks are used to monitor and determine present-day displacements on the territory of Bulgaria and the Balkans.The networks include observation from permanent stations
- IGS (http://igscb.jpl.nasa.gov/),
- EPN sites (most of the IGS sites are part of EUREF),
- HemusNet permanent stations (http://www.hemus-net.org/)-
- HemusNet permanent GPS network was established in 2007 under international project “Science for Peace Program”, NATO: SFP 981881 (Monitoring Crustal deformation in West Central Bulgaria and Northern Greece using GPS). The aim of the project is to provide basic infrastructure in both Bulgaria and Northern Greece for navigation, surveying, science, engineering, and atmospheric sensing. The network contains 8 permanent stations that cover West-Central Bulgaria and Northern Greece.

- The second kind GPS data, who are used are campaigns measurements for the15 points of the precise BULREF network, adopted for officially realization of ETRS89 in Bulgaria.

- BULREF network The initial observations were carried out in two campaigns – 1992 and 1993 (Altiner Y. et al., 1996). Seven points from this network are officially accepted as extension of EUREF with accuracy class B. The points from the BULREF network were measured during the period 1993-2005, for the various projects and campaigns by several author's groups (Altiner et al., 1996, Kotzev V., et. al. 2001, Vasileva K. et. al. 2004, Georgiev I. et al. 2009).

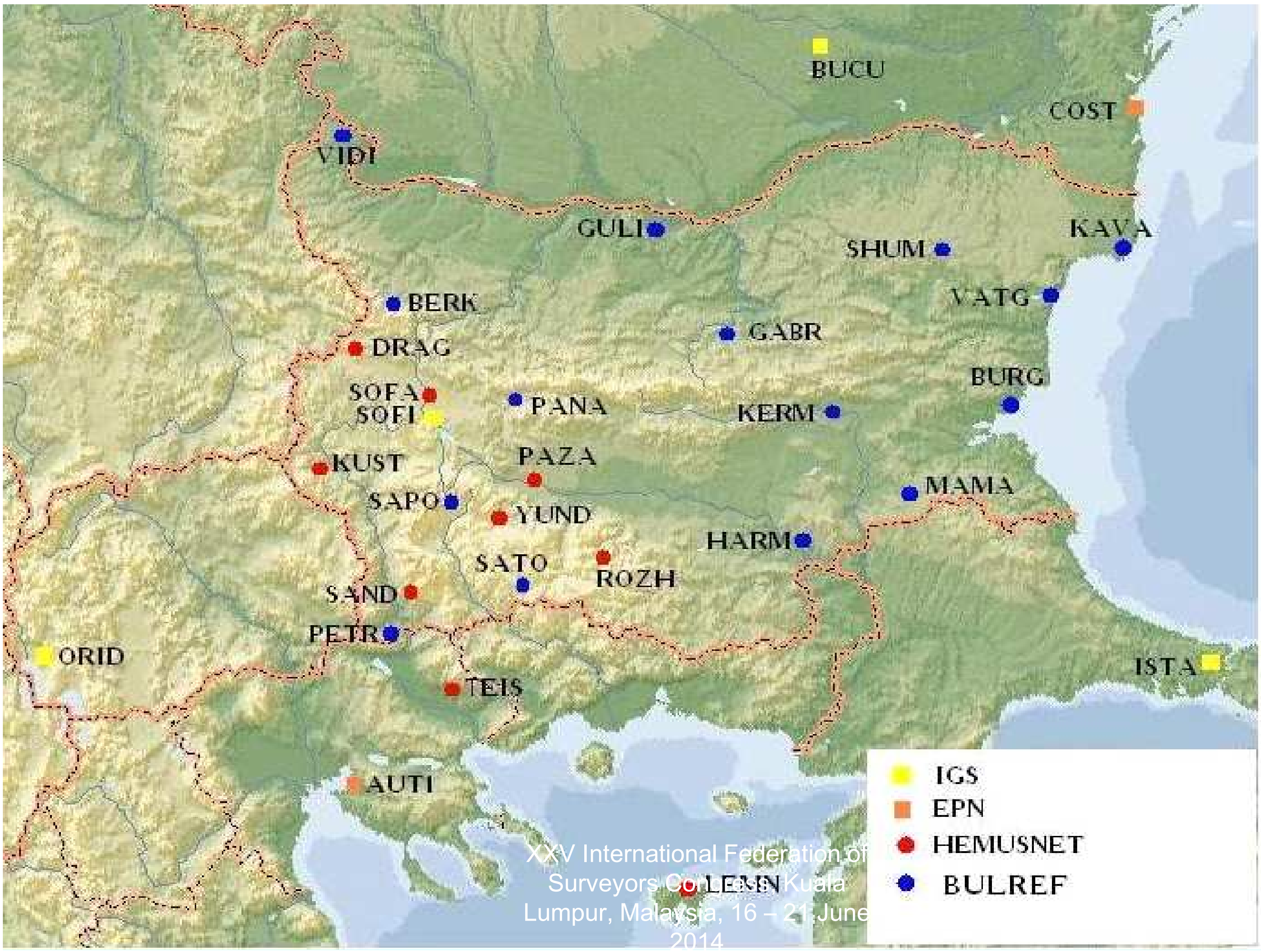


Table 1.
BULREF stations using in campaign processing

NAME	1992.7	1993.4	1996.74	1997.74	1998.74	2003.46	2005.0
PETR	X	X	X	X	X	X	X
HARM	X	X				X	X
GABR	X	X		X	X	X	X
VIDI	X	X				X	X
KAVA	X	X			X	X	X
SOFI	X	X	X	X	X	X	X
BURG	X	X		X	X	X	X
SAPA		X	X	X	X	X	X
SATO		X	X	X	X	X	X
GULI		X				X	X
SHUM		X		X		X	X
KERM		X				X	X
MAMA		X				X	X
BERK		X	X	X	X	X	X
PANA		X	X			X	X

- To estimate current displacements, we have used data for the 15 BULREF points. GPS measurements carried out in 1996, 1997, 1998 within the frames of international project with Massachusetts Institute of Technology (MIT) (Geodynamic settings of Bulgaria in the active and young Near East-Balkan geotectonic system) (Kotzev et. al. 2001).
- In epoch 2005.0 this 15 points are observation, adjustment and include of the National GPS network-based class system ETRF2000 (Georgiev I., et al. 2005).
- Stations were processed with the same software, in the one same coordinate system ETRF2000. For the local movements of the stations, which are more important for ours, ETRF horizontal velocity vectors have been obtained by applying ETRF components of the Eurasia plate rotation pole (Boucher, Altamimi, 2008) from the obtained ITRF2005 velocity vectors.
- Then they have been transformed into ETRF2000 (Atanasova M,. 2013a, . Atanasova M,. 2013b)

Table 2. GPS coordinates and velocities and their mean square errors with respect to the stable Eurasian

name	λ_i	φ_i	v^n	σ_{v^n}	v^e	σ_{v^e}	v	α
Block NB								
BUCU	26.1257	44.4639	-1.20	0.4	-0.12	0.4	1.20	185.71
VIDI	22.7334	44.0772	-1.00	0.4	-1.02	0.4	1.42	225.59
COST	28.4334	44.1639	-0.30	0.4	-0.20	0.4	0.36	213.70
BERK	23.1378	43.1095	-0.42	0.4	-0.83	0.4	0.93	243.19
SHUM	26.725	43.4878	-0.29	0.4	-0.81	0.5	0.86	250.33
GABR	25.2768	42.9629	-0.01	0.4	-0.13	0.4	0.13	265.64
GULI	24.6781	43.6029	-0.38	0.4	-0.55	0.4	0.66	235.38
KAVA	28.3734	43.4135	0.00	0.4	0.18	0.4	0.18	266.86
VATG	27.9093	43.1927	-1.95	0.4	0.89	0.5	2.14	155.45
Block SEB								
HARM	25.8463	41.8844	0.18	0.4	-0.12	0.4	0.21	146.29
KERM	26.3246	42.5185	0.10	0.4	-0.11	0.4	0.14	132.24
MAMA	26.7854	42.1041	-0.30	0.4	-0.25	0.4	0.39	219.82
PANA	24.1593	42.5947	-0.51	0.4	-0.13	0.4	0.52	165.69
PAZA	24.3400	42.2310	0.37	0.4	-0.54	0.4	0.65	124.39
BURG	27.4419	42.6664	-1.47	0.4	0.56	0.4	1.57	159.13
ISTA	29.0193	41.1044	-2.11	0.4	0.42	0.4	2.15	168.73
Block SWB								
SOFA	23.2685	42.6678	-1.81	0.4	0.70	0.4	1.94	158.84
SOFI	23.3947	42.5560	-1.97	0.4	0.30	0.5	1.99	171.33
DRAG	22.9335	42.9318	-1.70	0.4	1.82	0.4	2.49	133.02
KUST	22.7131	42.2837	-1.58	0.4	0.90	0.5	1.82	149.77
SAPA	23.2460	42.2817	-2.72	0.5	0.26	0.5	2.73	174.53
PETR	23.1247	41.4588	-3.71	0.5	0.61	0.5	3.76	170.65
SATO	23.9125	41.5981	-3.04	0.5	0.45	0.5	3.07	171.57
SAND	23.2678	41.5505	-2.82	0.4	-0.40	0.5	2.84	188.07
YUND	23.8538	42.0643	-2.06	0.4	0.28	0.4	2.07	172.25
ROGH	24.6872	41.6334	-2.47	0.4	0.31	0.5	2.48	172.84
ORID	20.7940	41.1273	-2.55	0.4	0.52	0.4	2.60	168.46
Northern Greece								
AUT1	23.0037	40.5668	-7.91	0.6	0.86	0.4	7.95	173.79
TEIS	23.5640	41.2476	-4.31	0.6	-8.20	0.5	9.30	208.08
LEMN	25.1805	39.8972	-11.7	0.5	-16.7	0.5	20.39	235.01

- The obtained velocity field of the Earth's crust is represented by 30 points in Bulgaria and encompassing the region. (Figure 2).The results show southward displacements between 0.5-3.8 mm/yr. GPS results give detailed information on the displacements. The presented velocity gradient clearly indicates the increase of the motion from north to south and reaches the Hellenic arc with values of up to 30mm/yr.
- The extensional zone passes through Central Bulgaria along an approximately east-west trend separating a northern region with insignificant motion relative to Eurasia from south-western region characterized by E-W extensional grabens and increasing southward velocities between 2 - 3mm/yr)
- Several different rotation poles covering different scale of areas have been tested to fit better with the observed velocities.
- By this reason two main sets are configured from all stations in Northern Bulgaria and two stations in Romania and respectively from all stations in Southern Bulgaria, Northern Greece and Northern Turkey and Macedonia.
- Using 9 GPS points I suggest a Block to name NB, which reaches the Stara Planina Mountain of south. On Figure 2 is shown proposed NB block (blu points) defined with Euler pole of rotation around
- First I want to find a large single block SB, which consists of stations only in southern Bulgaria, Northern Greece and Northern Turkey and Macedonia, calculating rotation pole using 21GPS stations
- The obtained misfits between the observed and model velocities are very big. The presented by the misfits results are not consistent with the proposed and clearly show that there is no rigid block which can perform the current displacement shown through our study as single stable block within such large area.

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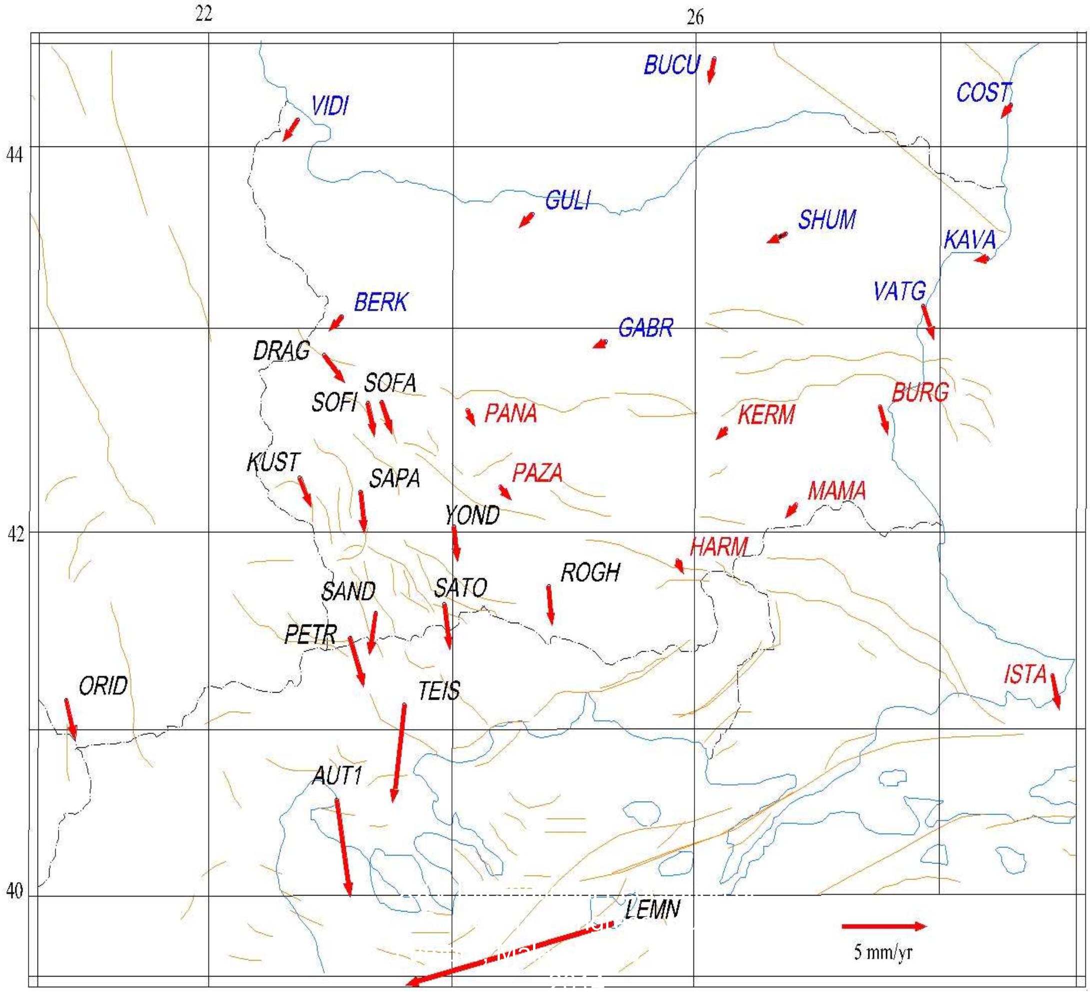

- I divided this large area into two small blocks and boundaries passes through Maritza lineament passing NW-SE. The block situated east of the Maritsa lineament is named SEB and its boundaries to the north is Stara planina Mountain and the Black Sea to the east. With 7 GPS stations (red points) located of SEB
- The region of Southwest Bulgaria (SWB) has the most pronounced tectonic and seismotectonic activity on the whole Bulgarian territory (Shanov et al. 2001).
- Using 10 GPS stations (black points) on areas in SWB and 2 GPS stations on NG territory, 1 GPS stations on territory Macedonia I estimated rotation pole. With those areas the obtained misfits results still do not provide good fitting.
- The misfits decrease with the decreasing the scale of blocks area.
- I indicated 2 blocks that present better fitting between observed and model vectors A set of 4 points (DRAG, SOFA, SOFI, KUST) are used to define a block corresponding to the observed velocities (SWB blok "SOFI") and a set of 7 points (PETR, SAND, SAPA, SATO YOND, ROGH, ORID) are used to define a block corresponding to the observed velocities (SWB block "PETR")
- The smaller on block size gives better fitting between observed and model velocities
- The estimated parameters of the rotation pole are listed in Table 3.
- These results obtained by analysis of GPS data set are in agreement with the obtained by result of other scientists (Georgiev et al., 2011, Matev K., 20111)

Figure 3. Schematic mapping of block structure SWB inferred from GPS results.

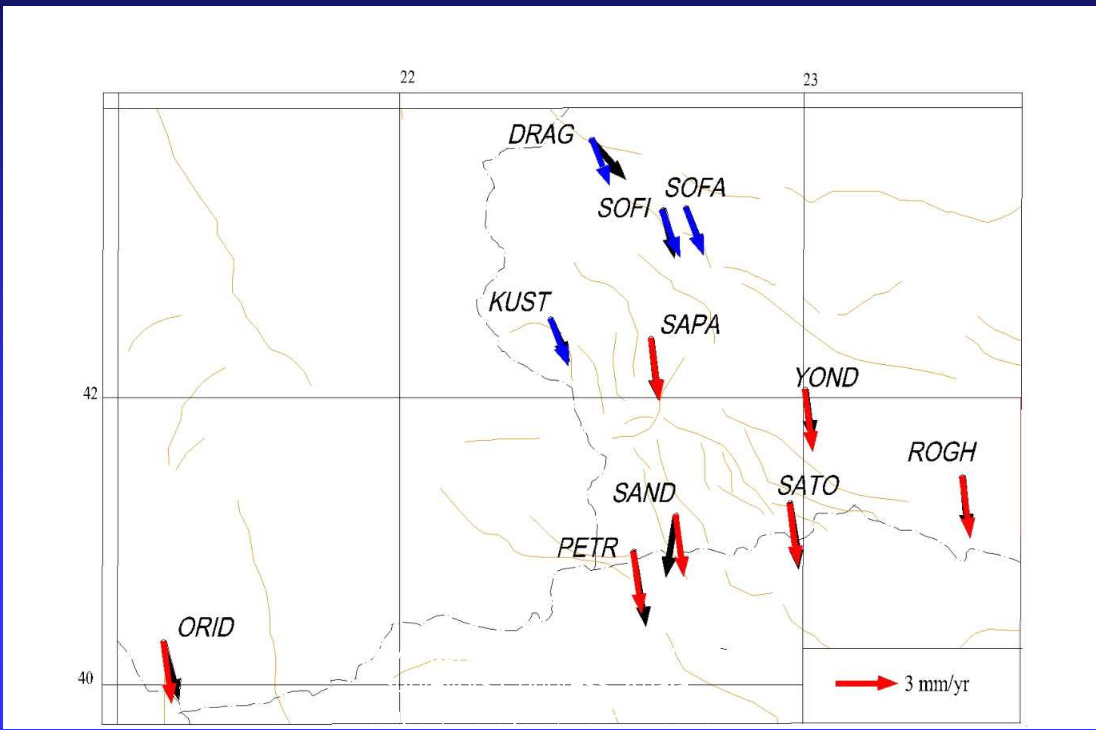

Table 3. Euler Parameters of Blocks deduced from the velocities

Name of Blocks	Euler Longtitude Λ ° E	Euler latitude Φ ° N	Ω °/Ma.
1.Northern Bulgaria - NB	31.57	39.00	0.138
2.Southern Bulgaria - SB	32.77	43.07	0.381
2.1 South-East - SEB	26.28	-43.03	0.438
2.2 South-West - SWB	11.13	-39.11	0.369
2.2.1. Block " SOFI"	19.13	-40.68	0.842
2.2.2. Block "PETR"	75.67	33.23	0.104

CONCLUSION

- The obtained velocities from the GPS data processing indicate an overall motion to the south.
- The results show an increasing rate from 1-1.5 mm/yr in Central-west Bulgaria to 10 mm/yr for the Northern Greece confirming the north-south extensional regime in the region.
- The horizontal velocities in North Bulgaria, confirm the suggestion that North Bulgarian territory is part of the Eurasian plate.
- Our results show that the Southwest Bulgaria do not belong to the Eurasian plate and seem to move the south with the velocities relative to Eurasia gradually increase in N-S direction from 1.5 mm/yr in western Bulgaria to 10mm/yr in the Northern Greece.

THANK YOU FOR YOUR ATTENTIION

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