S E S 2 0 1 2
Eighth Scientific Conference with International Participation
SPACE, ECOLOGY, SAFETY
4 – 6 December 2012, Sofia, Bulgaria

STUDY OF THE MOVEMENTS OF GNSS PERMANENT STATIONS ON THE BALKAN PENINSULA IN AUTUMN TIME

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Abstract: *Autumn behaviour of all free available GNSS permanent stations on the territory of the Balkan Peninsula has been studied. GPS data from seven days in five years have been processed with the Bernese software, version 5.0 and obtained estimated station coordinates from individual solutions have been analyzed. Velocity station estimations have been obtained from combined solution of all five normal equations. They have been analyzed and compared with results from other solutions. Some conclusions and suggestion have been done.*

ИЗСЛЕДВАНЕ НА ДВИЖЕНИЕТО НА GNSS ПЕРМАНЕНТНИ СТАНЦИИ НА БАЛКАНСКИЯ ПОЛУОСТРОВ ПРЕЗ ЕСЕНТА

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1. General

The present study is focused on the investigation of the behaviour of the available permanent GNSS stations on the territory of the Balkan Peninsula (BP) in autumn time. GPS data for this region in the other three seasons (winter, spring, summer) have been already processed and analyzed [1, 10, 11, 12]. This is the last seasonal study of the investigation of the four season's station behaviour of this region. GPS weekly data from free available GNSS stations on the territory of the Balkans have been involved. They cover the time span within five years – 2006, 2007, 2008, 2009 and 2010.
Particular year solutions have been combined and station velocity estimations have been obtained using Bernese software, version 5.0. Results have been compared and analyzed.
Locations of the IGS and EPN permanent stations used in data processing are shown in *Figure 1* and locations of the Balkan Peninsula permanent stations are shown in *Figure 2*. The number of Balkan Peninsula permanent stations was increased during this five year's period up to forty one in 2010.

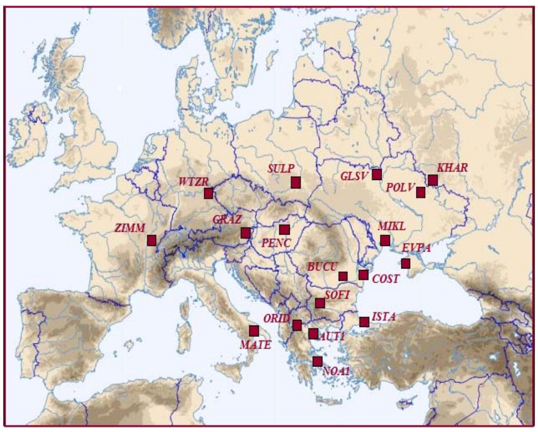

Fig.1. IGS/EPN Permanent Stations involved in this study

Fig. 2. Balkan Peninsula Permanent Stations involved

The stations are equipped with different types of receivers and antennas as for several stations the receiver or antenna equipment has been changed within this period. Seven observation sessions of 24-hours time length have been created in each year. Data from all available satellites above the horizon (3^o) have been used.

2. GPS data processing and analysis of individual year solutions

GPS data in all five periods have been processed with the Bernese Software, Version 5.0. The same general input parameters of all weekly solutions have been used for the reason of compatibility. Standard adjustment procedure of the software has been applied. Geocentric Cartesian station coordinate estimations have been obtained in the system ITRF2005 at the respective observation epoch. All five years weekly normal equations have been combined by using the program ADDNEQ2 and final results – station velocity estimations have been obtained.
The total number of participated stations was increased from 20 in 2006 up to 41 in 2010. Eight Balkan Peninsula stations participated only in one year - BURG, DRAG, LOVE, MONT, NIS_, SHUM, STAR, YUND as they are very yang stations, which started operating in 2009. Seven stations – DUTH, KUST, NVRK, PAZA, PAT0, SAND and SOFA participated only in two years. Six up to ten reference IGS stations have been used for datum definition. The station coordinates have been obtained in each of the five years from combined processing of the respective seven daily normal equations in ITRF2005, respective observation epoch 200x.77.

2.1. 2006 Data processing and analysis

Seven parameters Helmert transformation have been applied for assessment of the quality and precision of datum definition of the respective network. The residuals from transformations between input ITRF station coordinates and their estimated coordinates in 2006 from this study
are presented in *Table 1* in local system (North, East, Up).

Table 1. 7-parameters Helmert transformation between input IGS station coordinates and their estimated coordinates in 2006 from this study

Residuals – 2006 [*mm*]							
Station Name	*North*	*East*	*Up*	Station Name	*North*	*East*	*Up*
BUCU	-0,8	2,1	-11,8	PENC	-3,9	2,3	3,7
GLSV	-2,3	-0,7	2,7	POLV	-3,2	0,2	5,7
GRAZ	0,3	-1,0	-2,5	SOFI	-0,4	-0,2	0,9
ISTA	-0,9	4,7	-6,8	WTZR	1,3	1,6	2,5
MATE	2,3	-3,7	-1,8	ZIMM	0.1	1.2	-2.6
RMS Component	3,4	2,0	5,0				

Results from the transformation show a very good consistence within 0,1 ÷ 4,7 mm in North and East components and 0,9 ÷ 6,8 mm in Up component. Only station BUCU in Up component shows a little higher value.
The achieved accuracy of estimated station coordinates is obtained from comparison of the respective seven daily solutions (daily repeatability). All daily solutions have been compared to the combined solution and the root mean square errors (RMS) of station coordinates have been obtained. Daily repeatability and the RMS's of station positions from the weekly solution are shown in *Figure 3*.

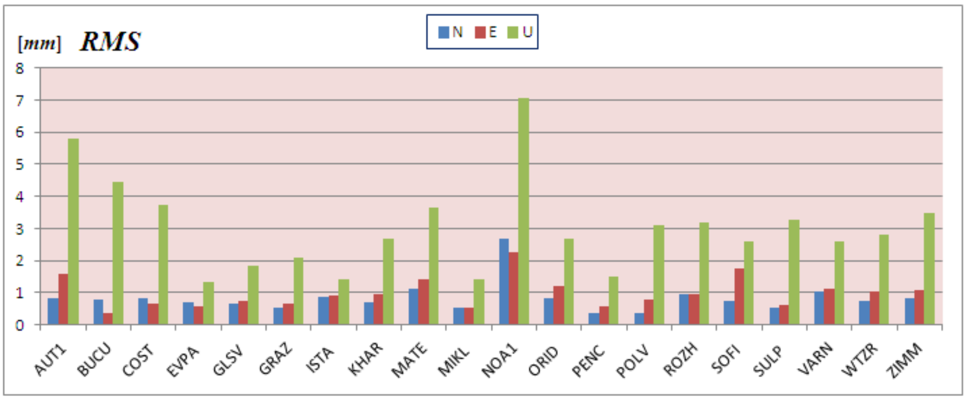

Fig. 3. Daily repeatability of the 2006 weekly solution

The results in *Figure 3* show very good accuracy of station coordinates achieved within – 0,3 ÷ 2,7 mm in North and East components and 1,3 ÷ 5,8 mm in Up component, except station NOA1 in North component – 7,0 mm.

2.2. 2007 Data processing and analysis

Seven parameters Helmert transformation have been applied for assessment of the quality and precision of datum definition of the respective network. The residuals from transformations between input ITRF station coordinates and their estimated coordinates in 2007 from this study are presented in *Table 2* in local system (North, East, Up).

Table 2. 7-parameters Helmert transformation between input IGS station coordinates and their estimated coordinates in 2007 from this study

Residuals – 2007 [*mm*]							
Station Name	*North*	*East*	*Up*	Station Name	*North*	*East*	*Up*
BUCU	-2,7	1,6	-16,0	PENC	-1,9	0,6	29,5
GLSV	-4,3	-1,1	1,1	POLV	-4,6	1,0	3,5
GRAZ	0,6	-0,1	1,1	SOFI	-1,7	1,8	1,9
ISTA	-	-	-	WTZR	2,7	2,2	0,1
MATE	1,5	-3,2	-2,0	ZIMM	0.5	-1.9	-0.2
RMS Component	6,3	1,6	5,0				

The results from the transformation show a very good consistence within 0,5 ÷ 4,6 mm in North and East components and 0,1 ÷ 5,0 mm in Up component. Station BUCU shows in Up component a little higher value. Station PENC has obtained a high value in Up component. A probable reason could be the change of the antenna/receiver type and introduced estimated offset not taken into account here. By this reason PENC has not been included in the set of reference stations defining the datum.
The achieved accuracy of estimated station coordinates is obtained from comparison of the seven daily solutions (daily repeatability). All daily solutions for each year have been compared to the combined solution and the root mean square errors (RMS) of station coordinates have been obtained. Daily repeatability and the RMS's of station positions from the weekly solutions are shown in *Figure 4*.

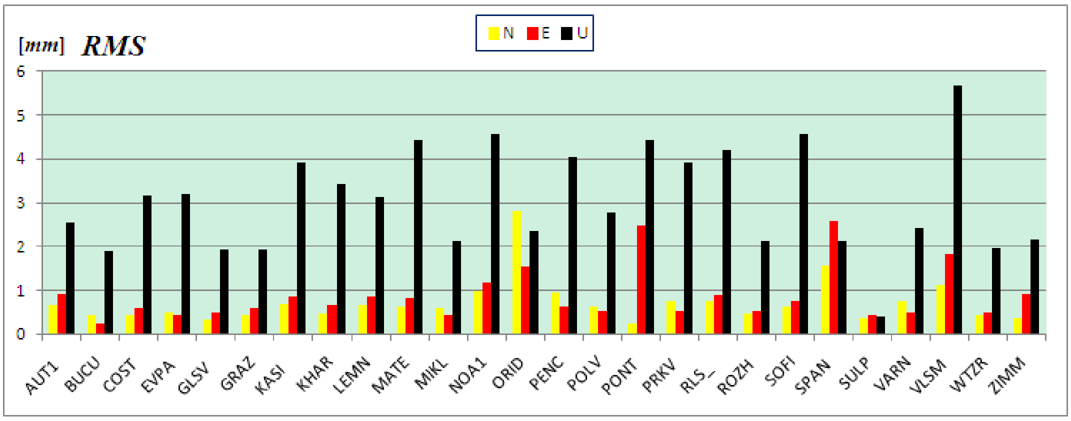

Fig. 4. Daily repeatability of the 2007 weekly solution

The results above show very good station coordinates accuracy achieved– 0,2 ÷ 2,8 mm in North and East components and 1,9 ÷ 5,7 mm in Up component.

2.3. 2008 Data processing and analysis

Seven parameters Helmert transformation have been applied for assessment of the quality and precision of datum definition of the network. The residuals from transformations between input ITRF station coordinates and their estimated coordinates in 2008 from this study are presented in *Table 3* in local system (North, East, Up).

Table 3. 7-parameters Helmert transformation between input IGS station coordinates and their estimated coordinates in 2008 from this study

Residuals – 2008 [*mm*]							
Station Name	*North*	*East*	*Up*	Station Name	*North*	*East*	*Up*
BUCU	-1.4	1.4	-16.3	PENC	-0.3	1.2	-10.5
GLSV	-2.6	-5.5	-5.2	POLV	-1.6	-1.1	-0.4
GRAZ	0.5	-0.8	-4.4	SOFI	-0.4	2.2	7.0
ISTA	-1.4	5.3	-2.4	WTZR	3.5	1.0	3.3
MATE	2.6	-2.0	-0.5	ZIMM	-0.6	-1.9	1.8
RMS Component	2.0	2.4	4.7				

The results from the transformation show a very good consistence within 0,3 ÷ 5,5 mm in North and East components and 0,4 ÷ 10,5 mm in Up component. Only station BUCU in Up component shows a little higher value. It was the reason this station not to be chosen as reference station.
The achieved accuracy of estimated station coordinates is obtained from comparison of the seven daily solutions (daily repeatability). All daily solutions have been compared to the combined solution and the root mean square errors (RMS) of station coordinates have been obtained. Daily repeatability and the RMS's of station positions from the weekly solution are shown in *Figure 5*.

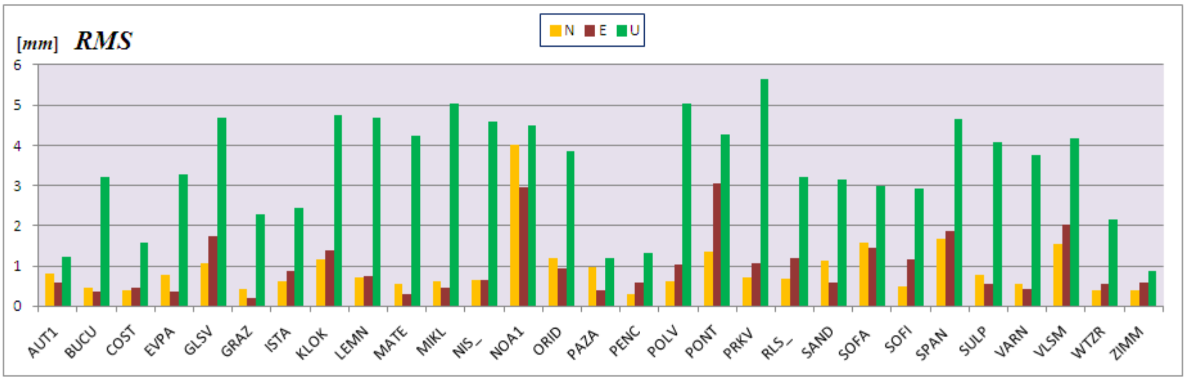

Fig. 5. Daily repeatability of the 2008 weekly solution

The results obtained show very good station coordinates accuracy achieved: 0,2 ÷ 4,0 mm in North and East components and 0,9 ÷ 5,6 mm in Up component.

2.4. 2009 Data processing and analysis

Seven parameters Helmert transformation have been applied for assessment of the quality and precision of datum definition of the network. The residuals from transformations between input ITRF station coordinates and their estimated coordinates in 2009 from this study are presented in *Table 4* in local system (North, East, Up).

Table 4. 7-parameters Helmert transformation between input IGS station coordinates and their estimated coordinates in 2009 from this study

Residuals – 2009 [*mm*]							
Station Name	*North*	*East*	*Up*	Station Name	*North*	*East*	*Up*
BUCU	0.4	-3.3	-23.5	PENC	-1.7	1.6	-17.7
GLSV	2.4	-7.0	4.9	POLV	-3.8	-3.0	-0.8
GRAZ	0.2	-0.5	-6.3	SOFI	-1.0	0.6	2.7
ISTA	-4.0	5.1	-1.8	WTZR	2.7	2.1	3.0
MATE	1.4	3.6	1.5	ZIMM	1.9	-2.4	-0.6
RMS Component	2.7	3.8	3.7				

The results from transformation show a very good consistence within 0,4 ÷ 5,1 mm in North and East components and 0,6 ÷ 6,3 mm in Up component. Only station BUCU in Up component shows very high value of 23,5 mm. The most probable reason is the change of the antenna/receiver type and the height of the antenna reference point (ARP) in 2009. For station PENC is obtained a higher value as well, probably due to the not included estimated offset. It was also the reason this station not to be chosen as reference station for datum definition.
The achieved accuracy of estimated station coordinates is obtained from comparison of the seven daily solutions (daily repeatability). All daily solutions have been compared to the combined solution and the root mean square errors (RMS) of station coordinates have been obtained. Daily repeatability and the RMS's of station positions from the weekly solutions are shown in *Figure 6*.

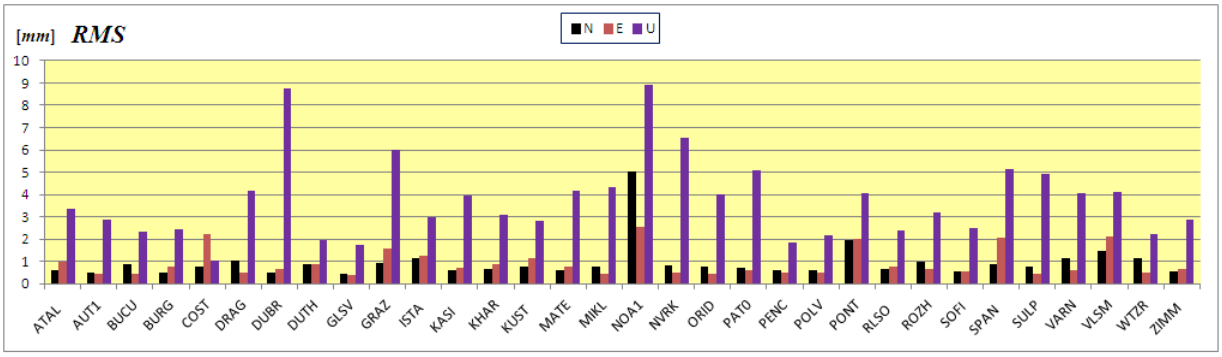

Fig. 6. Daily repeatability of the 2009 weekly solution

The results show very good station coordinates accuracy achieved– 0,6 ÷ 5,1 mm in North and East components and 0,6 ÷ 6,5 mm in Up component except stations DUBR and NOA1 in North component – about 9,0 mm.

2.5. 2010 Data processing and analysis

Seven parameters Helmert transformation have been applied for assessment of the quality and precision of datum definition of the network. The residuals from transformations between input ITRF station coordinates and their estimated coordinates in 2010 from this study are presented in *Table 5* in local system (North, East, Up).

Table 5. 7-parameters Helmert transformation between input IGS station coordinates and their estimated coordinates in 2010 from this study

Residuals – 2010 [*mm*]							
Station Name	*North*	*East*	*Up*	Station Name	*North*	*East*	*Up*
BUCU	1.3	-5.9	-17.0	PENC	-1.3	0.1	-7.1
GLSV	2.2	-7.5	5.6	POLV	-3.4	-1.8	-4.1
GRAZ	0.4	0.9	-1.1	SOFI	-3.3	1.6	2.4
ISTA	-3.7	5.5	-0.7	WTZR	4.1	-1.0	7.2
MATE	3.0	3.1	1.5	ZIMM	2.0	-1.0	-3.7
RMS Component	3.0	3.6	4.7				

The results from the transformation show a very good consistence within 0,4 ÷ 5,9 mm in North and East components and 0,7 ÷ 7,1 mm in Up component. Only station BUCU in Up component shows a higher value of 17 mm. The most probable reason is the change of the antenna/receiver type and the height of the antenna reference point (ARP) in 2009. It was also the reason this station not to be chosen as reference station.

The achieved accuracy of estimated station coordinates is obtained from comparison of the seven daily solutions (daily repeatability). All daily solutions have been compared to the combined solution and the root mean square errors (RMS) of station coordinates have been obtained. Daily repeatability and the RMS's of station positions from the weekly solution are shown in *Figure 7*.

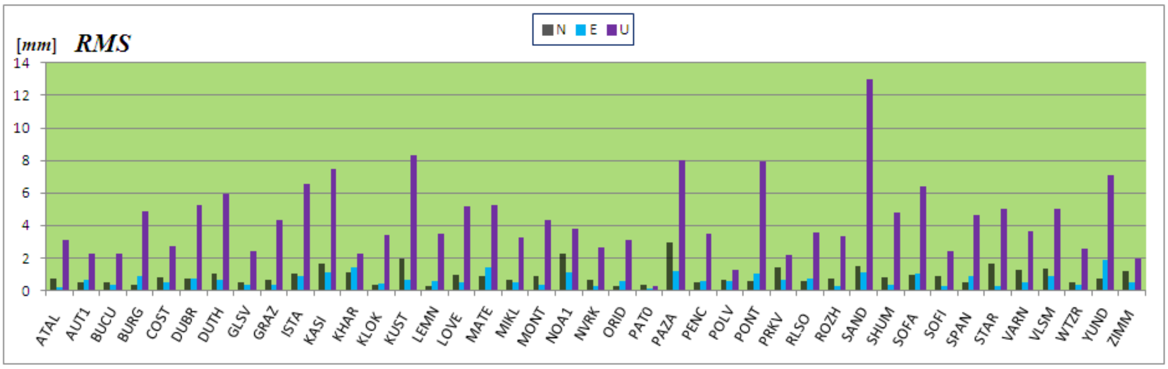

Fig. 7. Daily repeatability of the 2010 weekly solution

The results obtained show very good station coordinates accuracy achieved in all years – 0,4 ÷ 2,3 mm in North and East components and 2,7 ÷ 8,4 mm in Up component except station SAND in North component – 13,0 mm.

3. Analysis of results from five years combined solution

All one week normal equations in 2006, 2007, 2008 2009 and 2010 have been combined and processed with ADDNEQ2 program of Bernese software and station velocity estimations have been obtained in the system ITF2005. Minimum constrained adjustments have been applied using 8 IGS reference stations - GLSV, GRAZ, ISTA, MATE, POLV, SOFI, WTZR and ZIMM. Approximate velocity values for the new stations have been calculated from the NUVEL1A model and they have been introduced in the adjustment procedure for obtaining of the velocity estimations.
Five years autumn velocity estimations of IGS/EPN stations in North and East components obtained in this study compared with the results from EPN solution show a very good consistence (*Figure 8*). In Up component the results agree not quite good especially for stations DUBR, DUTH, EVPA, PENC and SULP.

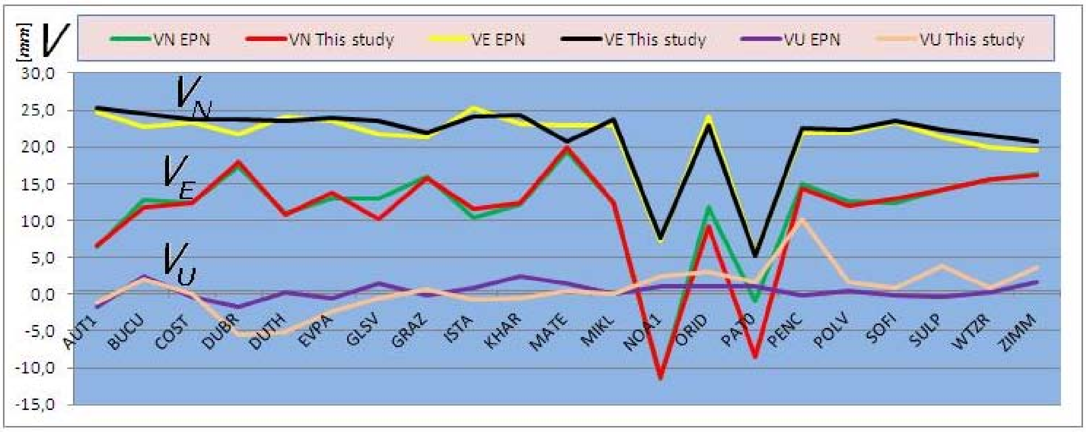

Fig. 8. Comparison of ITRF2005 station velocity components (*N, E, U*) obtained from EPN solution and from this study

The reason for higher differences for these stations could be explained with the antenna and/or receiver change during this period and for station BUCU – the change of the height of the antenna reference point (ARP) and different datum used in the adjustment process.

The ETRF horizontal velocity vectors are representative for the local station behaviour. They are obtained by using ETRF components of the Eurasia plate rotation pole [3] to the obtained from five years combined solution ITRF velocity vectors. The magnitude and directions of reduced to the stable Eurasia horizontal velocities of the Balkan Peninsula stations are shown in *Figure 9*.

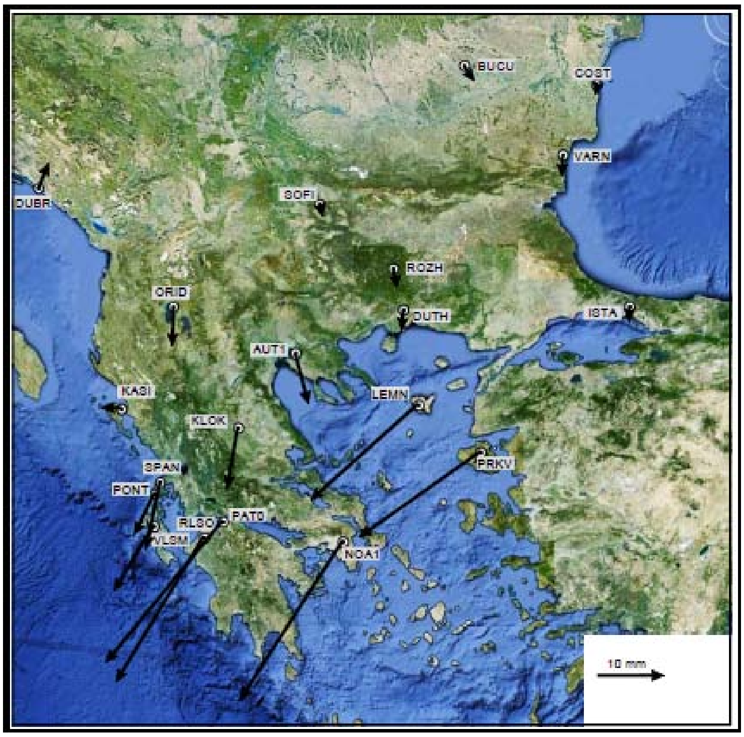

Fig. 9. Horizontal velocity vectors of BP stations relative to Eurasia plate

Velocity estimations have been estimated only for stations for which observations in three and more years have been available. The estimations agree very well with results from other investigations [2], [4], [5], [6], [7]. The main direction of the movement of all Bulgarian stations is south-east and it is in a good agreement with other investigations for this region [6], [9]. Velocity vectors of stations DRAG and VARN show different directions.

The main direction of the movement of the most Greek stations is south-west and they are also in a good agreement with results from other investigations [2], [5], [9].

4. Conclusion

Five years individual weekly data processing in autumn time, their combined solutions and analysis have been accomplished in this study.

The obtained results for the velocity estimations show an undisturbed linear behaviour of the Balkan Peninsula stations within the five year's autumn periods.

Their orientations and magnitudes are in good consistence with results from other investigations.

Very good agreement of the obtained velocity estimations with the EPN long term estimations has been obtained.

Important reason for higher discrepancies in comparison of velocity estimations obtained from different investigations is the different datum definitions used.

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