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THREE SEASONAL BEHAVIOUR OF THE BALKAN PENINSULA GNSS PERMANENT STATIONS FROM GPS SOLUTIONS

Keranka Vassileva

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Abstract

Geodynamic investigations on the territory of the Balkan Peninsula within five years were outlined by using state-of-art space technologies. GPS data on 29 GNSS (Global Navigation Satellite Systems) free available permanent stations from 2006 till 2010 were used. One week yearly data sets within each of the three seasons – winter, spring and summer were processed with the Bernese software, version 5.0 in the international terrestrial reference frame ITRF2005. Station velocity vectors were estimated from combined solutions of the particular seasons. Seasonal results were compared and behaviour of the stations was studied. Analysis of the obtained horizontal station velocity vectors relative to the Eurasia plate shows smooth, undisturbed linear trend of movement. Dominant linear motion is the behaviour of the majority of the stations within the three seasons.

Key words: geodynamic investigations, GNSS permanent stations, velocity vectors

Introduction. On the territory of Central and Eastern Europe several important active tectonic zones are localized – the Adriatic Microplate, the Balkan Peninsula and Dinarides, the Carpathian Arc, the Eastern Alps and the Pannonian basin. The territory of the Balkan Peninsula is one of the most active geodynamic regions of Europe, especially the territory of Bulgaria [9]. It is a very interesting area for many earth sciences, especially after several earthquakes which have recently occurred. The very powerful geodetic space technologies are reliable tools for investigation of the earth crust movements. Recently, a number of GNSS permanent stations have been set up on the territory of all Balkan countries and their behaviour is of great interest. Data of these stations have been used for accomplishment of different kinds of geodynamic investigations [1, 4–7, 11–14] and their number is constantly increasing.

The main focus of this work is an investigation of the behaviour of the permanent GNSS stations within three seasons. It is a continuation of previous investigations already published. These studies comprise winter time [14, 15], spring time [15] and summer time [16]. Here station velocity vectors obtained in different seasons are compared and station movements have been analyzed.

Seasonal solutions. The geodynamic investigations were accomplished by using GPS data from all free available GNSS permanent stations on the territory of the Balkan Peninsula (BP) within the time between 2006 and 2010. The stations are equipped with different types of receivers and antennas and for some of them the receiver or antenna has been changed within the period of the investigation. The number of stations was increased during the period of study from 10 in 2006 up to 29 in 2010. The location of the Balkan Peninsula permanent stations involved is shown in Fig. 1.

By reason of comparability data from the same weeks of the respective season of the involved years were used. GPS weekly data of all years have been processed with the Bernese Software, Version 5.0. The same general input parameters of all weekly solutions have been used and the same IGS (International GNSS Service) stations (GLSV, GRAZ, ISTA, MATE, PENC, POLV, SOFI, WTZR, ZIMM) have been included for datum definition in all combined solutions. Geocentric Cartesian station coordinate estimations have been obtained in the system ITRF2005 at the respective observation epoch. Station velocity vectors have been estimated in ITRF2005 from combined solutions of the particular seasons.

Winter solution. GPS weekly data from four years – 2006, 2007, 2008 and 2009 of 18 GNSS stations were processed and analyzed in January.

The average root mean squared (RMS) errors of station coordinates from the weekly solutions in the particular years are shown in Table 1.

The results from Table 1 show very good station accuracy achieved during processing of one week winter data.

Table 1

Daily repeatability of the weekly solutions

Year	RMS of weekly solution		
	North [mm]	East [mm]	Up [mm]
2006	1.2	1.5	2.3
2007	0.8	0.8	3.0
2008	1.3	0.9	2.8
2009	1.1	1.1	3.8

Estimation of station velocities, their analysis and comparison was accomplished. Estimated ITRF2005 velocities of BP stations and their inner errors were obtained as follows: in North component V_{North} – within $1.0 \div 13.0$ mm/yr and rms – within $0.1 \div 0.2$ mm/yr; in East component V_{Easth} – within $8.0 \div 24.9$ mm/yr and rms – within $0.1 \div 0.2$ mm/yr; in Up component V_{Up} – within $-4.4 \div 5.0$ mm/yr and rms – within $0.2 \div 0.6$ mm/yr. The obtained estimations of the velocity vectors are consistent with the ITRF2005/EPN/CEGRN velocity estimations within 1–2 mm in all three components V_X, V_Y, V_Z. These results are in good agreement with the obtained velocity estimations in Hefti et. al. [5] as well.

Spring solution. GPS weekly data from four years – 2006, 2007, 2008 and 2009 of 21 GNSS stations were processed and analyzed in April [15].

The average root mean squared (RMS) errors of station coordinates from the weekly solutions in the particular years are shown in Table 2.

The results from Table 2 show very good station accuracy achieved in processing of one week spring data.

Estimated ITRF2005 velocities of BP stations and their inner errors are obtained as follows: in North component V_{North} – within $2.5 \div 13.0$ mm/yr and rms – within $0.1 \div 0.2$ mm/yr; in East component V_{Easth} – within $6.5 \div 24.8$ mm/yr and rms – within $0.1 \div 0.2$ mm/yr; in Up component V_{Up} – within $-4.9 \div 6.0$ mm/yr and rms – within $0.1 \div 0.4$ mm/yr. The spring velocity estimations obtained from all four years were compared with the results from ITRF2005/EPN/CEGRN annual solutions. Comparison of the velocity estimations of the Balkan Peninsula stations shows differences within $0.1 \div 2.5$ mm with some exceptions. Higher discrepancies for some stations can be explained with different reference stations used for datum definition, with shorter observation time span (only two years) and also with a number of equipment alterations and subsequent offsets.

Summer solution. GPS one week data of 29 GNSS stations on the territory of the Balkans have been used. They cover a time span within five years – 2006, 2007, 2008, 2009 and 2010 in July. Individual year solutions were combined and station velocity estimations were obtained. Results were compared and analyzed [16].

Table 2

Daily repeatability of the weekly solutions

Year	RMS of weekly solution		
	North [mm]	East [mm]	Up [mm]
2006	1.6	1.8	5.1
2007	1.1	1.0	3.0
2008	1.5	1.8	4.4
2009	1.2	1.7	4.7

Table 3

Daily repeatability of the weekly solutions

Year	RMS of weekly solution		
	North [mm]	East [mm]	Up [mm]
2006	2.0	3.0	7.5
2007	1.3	1.5	4.7
2008	1.7	1.3	4.3
2009	1.4	1.7	5.3
2010	1.9	1.7	5.0

Daily repeatability shows a very good accuracy of station coordinates achieved in all years (Table 3).

All possible three-years-combinations of the obtained weekly solutions in 2006, 2007, 2008, 2009 and 2010 have been processed and station velocity estimations were obtained in the system ITRF2005. Comparison of the velocity estimations from all three-year solutions and total five-year solution in all components for the Balkan Peninsula stations are shown in Fig. 2.

Velocity estimations 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 and equipment alterations. Only for stations LEMN, PRKV and VLSM the differences are higher although their results are from four years.

Estimated ITRF2005 velocities of BP stations and their inner errors were obtained as follows: in North component V_{North} – within $4.2 \div 17.0$ mm/yr and rms – within $0.1 \div 0.3$ mm/yr; in East component V_{Easth} – within $6.7 \div 25.0$ mm/yr and rms – within $0.1 \div 0.2$ mm/yr; in Up component V_{Up} – within $-5.2 \div 4.9$ mm/yr and rms – within $0.2 \div 0.6$ mm/yr.

ETRF (European Terrestrial Reference Frame) horizontal velocity vectors as representative characteristics of the station behaviour were obtained for all three seasons by using ETRF components of the Eurasia plate rotation pole to the obtained ITRF velocity vectors [2]. The obtained velocity estimations agree very well with the results from other investigations [1, 3, 5, 10]. The main direction of the movement of all Bulgarian stations is south-east and it is in agreement with other investigations in this region [8, 10]. Only velocity vectors of station DRAG show different direction in summer solution. The main direction of the movement of the majority of the Greek stations is south-west and for some stations (LEMN, PRKV, ATAL, NOA1, PAT0, RLSO) the velocities raise to 20–30 mm/y and they also agree with the results from other investigations [1, 3, 10].

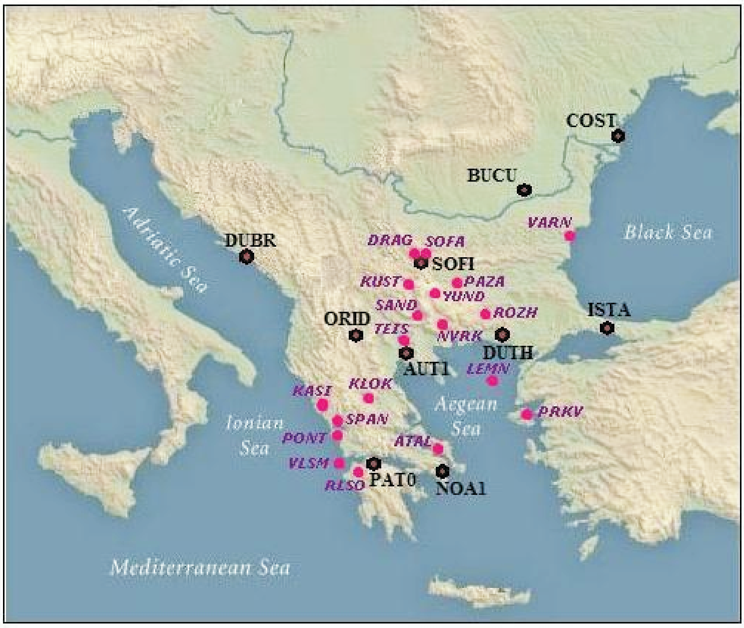

Fig. 1. Location of the Balkan Peninsula GNSS permanent stations involved

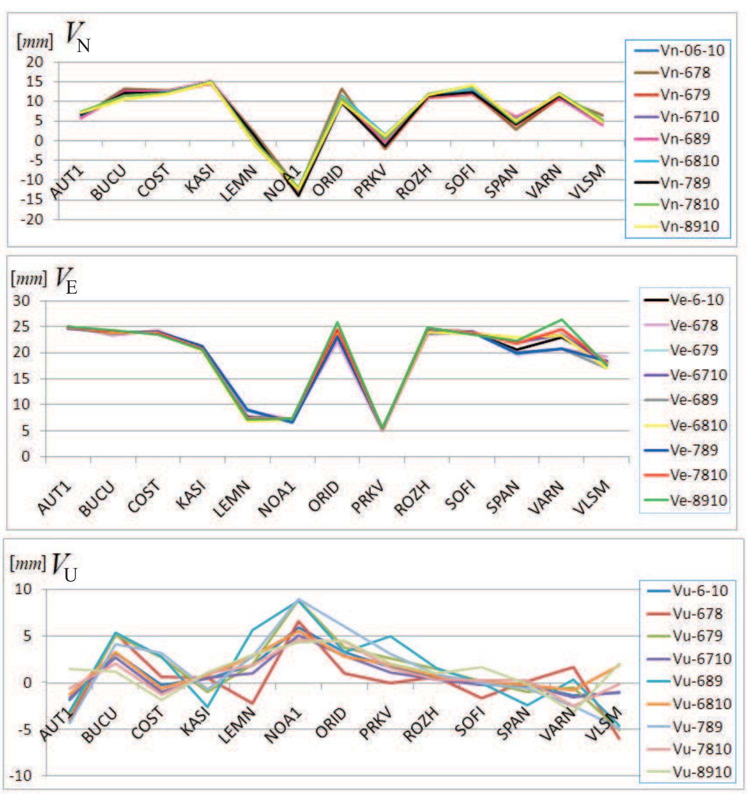

Fig. 2. BP velocity estimations from this study in North, East and Up components

Fig. 3. Horizontal velocity vectors of BP stations for the three seasons with respect to the stable Eurasia

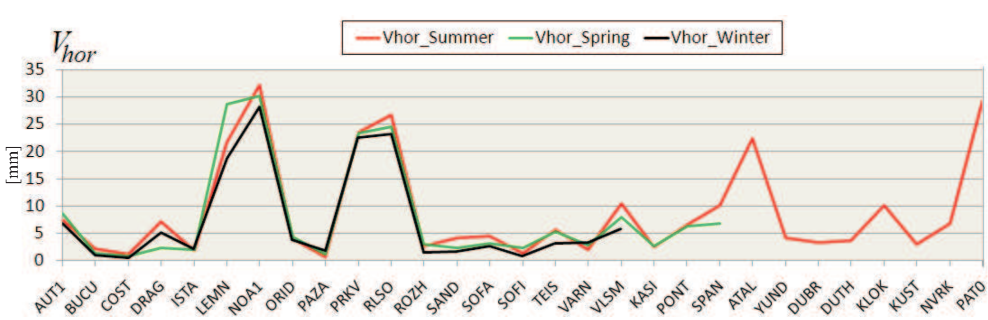

Fig. 4. Horizontal velocity vectors of BP stations in winter, spring and summer time

Analysis of three seasonal solutions. The total number of participating stations increased from 17 in 2006 up to 40 (including IGS/EPN stations) in 2010. 29 of them are located on the territory of the Balkan Peninsula.

ETRF horizontal velocity vectors of BP stations obtained for all three seasons are shown in Fig. 3 (yellow – winter velocities, purple – spring velocities, green – summer velocities).

For most of the stations the magnitude and direction of the velocity vectors within the three seasons are kept the same (Fig. 4).

The consistency of seasonal estimates of horizontal vectors is better than $0.2 \div 0.4$ mm/yr for stations with small movements. Accepting that significant periodical seasonal variations are usually local phenomena with respect to the antenna monumentation, multipath and troposphere effects, it can be assumed that there is no significant impact of the seasonal variations on stations behaviour and their movements are smooth and undisturbed within the period of investigation. Differences about $2.5 \div 3.0$ mm/yr are obtained for stations with larger movements of about $23 \div 32$ mm/yr (NOA1, LEMN, RLSO). Higher differences are obtained for stations with shorter time span of observations within the season – only two years (DRAG, SAND, SOFA, TEIS) and that is why the differences cannot be assumed as a result from seasonal variations. Several stations are very young (ATAL, DUTH, KLOK, NVRK, PAT0) and their velocities are estimated only from processing of summer data. That is why these results are not reliable.

Conclusion. Geodynamic investigations have been accomplished on the basis of GPS data of all free available GNSS permanent stations on the territory of the Balkan Peninsula within the time of five years in winter, spring and summer seasons. The obtained velocity estimations agree very well with the velocities from ITRF2005 annual solutions within the particular seasons with some exceptions. Individual seasonal results were compared and analyzed and station behaviour was studied. Analysis of the obtained horizontal station velocity vectors relative to the Eurasia plate shows smooth, undisturbed linear trend of movement. Dominant linear motion is the behaviour of the majority of the stations within the three seasons. This is the reason to assume that there is no significant seasonal impact on the station movements. The results obtained form a useful basis for further applications in geodynamic and seasonal effects analyses.

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National Institute of Geophysics, Geodesy and Geography
Bulgarian Academy of Sciences
Acad. G. Bonchev Str., Bl. 3
1113 Sofia, Bulgaria
e-mail: Keranka.vassileva@gmail.com