5.1.1. GEODYNAMICS OF THE BALKAN PENINSULA - GEODETIC INVESTIGATIONS

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5.1.1.1. Introduction

Between Paleogene and Eocene the structure of the Balkan Peninsula developed. The Dinarides and Hellenides in the West built the boundaries to the Adriatic Microplate. The Carpathians, Balkan mountains and Rhodopides surrounded the Moesian Platform. The Pontides of the same type separated from the Anatolian microplate. The Peninsula therefore can be viewed as a boundary zone between Eurasia, Africa and some microplates as a whole. Recent relative tectonic movements should be expected to be maximal at the boundary or transition zones which means along the Eastern Adriatic coast and in Greece. However, intraplate motions should also be detectable. Geological records and catalogues of earthquakes show that there are major active faults which cause surface movements. Because surface movements can be measured by satellite techniques, recently mainly by GPS, one can relate those movements to plate tectonics. It should also be mentioned that other techniques like SAR and gravity measurements may give valuable contributions to geodynamics. One could also add tide gauge measurements and levelling which have a history of decades. It is well known that plate tectonics are mainly described by interpreting lateral movements at the surface, resulting in 20-30 mm/year of the whole continent. The vertical movements overall should not exceed 2 mm/year. Given the short time of measurements since 1990 the lateral movements measured by GPS and other techniques are considered as linear. The usual way to present velocities is therefore a vector in a tangential system (latitude, longitude) plus a line pointing down or up to depict the vertical movement. This is in contrast to geologists who prefer Eulerian poles and angles. The following chapters will give a short overview about the availability of permanent GPS stations of the Balkan Peninsula and their results with respect to movements measured in this area.

5.1.1.2. GPS permanent stations

The total amount of permanent GPS stations in the region is not known it might be more than 50. Without open access they are useless for any international geophysical project even they are operating for a long time. End of 2005 the stations in Fig. 5.1.1.1 are available from the services IGS, EPN and some national institutions, mainly co-operating within the EU project CERGOP2/Environment. The time span goes from more than 10 years down to few weeks, depending on the year of construction or on the time of first opening to a broader community. All of them follow international standards concerning monumentation, equipment and data providing for high precision GPS networks. Data are used by weekly adjustments. The results can be checked against the official results of IGS and EPN. It is also easy to add the network to that ones of IGS and EUREF because also the same standards of adjustment are used. There are also epochs measurements in the region, most of the international ones have been performed under the umbrella of CERGOP (CERGOP1 and CERGOP2). Permanent sites have the main advantage, apart from the much larger amount of data, that blunders and seasonal variations can be detected and in most cases separated from the geophysical signal of station movements. Also those movements can be split up into periodic movements which are local and a perennial signal which can be correlated to

plate tectonics. If there are continuous results throughout one year station velocities estimated from permanent stations should be reasonable (but still not recommended) whereas two campaigns separated by one year might give very doubtful results.

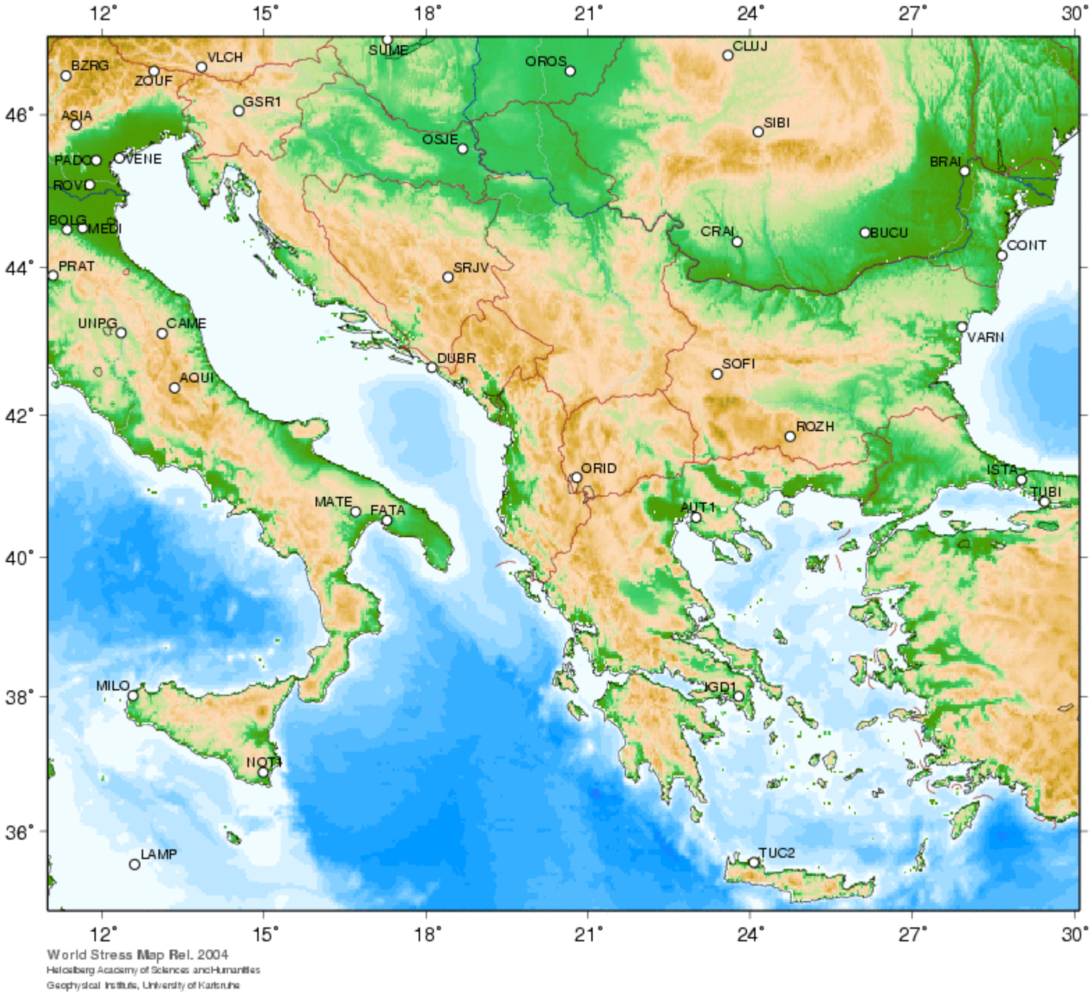

Fig. 5.1.1.1. Distribution of GPS permanent sites over the Balkan Peninsula (End of 2005)

It can be clearly seen that the stations in Fig. 5.1.1.1. are not distributed to cover all tectonic units and to monitor boundary zones. The overall density is too sparse to form groups of stations for one unit. It would be desirable to have at least two to three stations to find common movements which might be representative for a tectonic unit. From the log sheets of the station it follows also that most stations are on buildings which are founded at alluvial sediments and not on bedrock. However, the longer a time series continues the better the trend can be interpreted as a tectonic movement than that of a building. Because buildings are rarely sliding one can also discern between (geodynamic) lateral and (probably local) vertical movements. Fig. 5.1.1.2 is an example for the station SOFI (Sofia) where one easily can detect several periodic and non-periodic movements but one trend for each component, even in the vertical one. A list of all permanent stations which contribute to IGS, EPN or CERGOP2 is given in Table 5.1.1.1. Some neighbouring stations which are not at the Balkan Peninsula are added for comparisons in the next chapter.

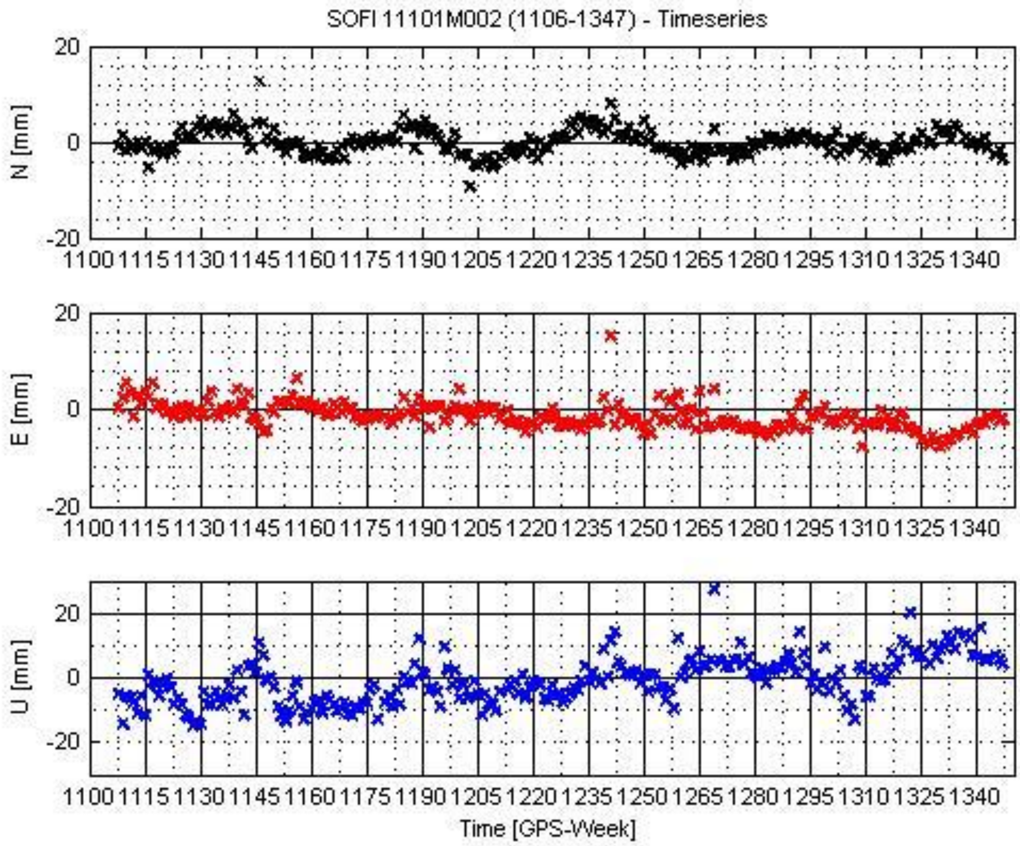

Fig. 5.1.1.2. Time series of SOFI within the ARE/CERGOP network of OLG (Minimum constraint)

Table 5.1.1.1. Permanent GPS stations at the Balkan Peninsula plus some neighbouring ones

STATION	NAME	COUNTRY	DATA SINCE	MONUMENT	POSSIBLE TECTONIC UNIT
AUT1	Thessalonike	Greece	2005	Building	Dinarides
BRAI	Braila	Romania		Building	Moesian Platform
BUCU	Bucuresti	Romania	1999	Building	Moesian Platform
CLUJ	Cluj	Romania		Building	Carpathians
CONT	Constanta	Romania		Building	Moesian Platform
CRAI	Craiova	Romania		Building	Moesian Platform
DUBR	Dubrovnik	Croatia	2000	Building	Adriatic Microplate
GSR1	Ljubljana	Slovenia	2000	Building	Julian Alps
IGD1	Athens	Greece	2004	Building	Hellenides
ISTA	Istanbul	Turkey	1999	Building	Rhodopides
MIKL	Mikolayev	Ukraine	2001	Building	East European Platform
ORID	Ohrid	FYROM	2000	Pillar	Dinarides
OROS	Oroshaza	Hungary	2001	Building	Pannonian Basin
OSJE	Osijek	Croatia	2000	Building	Pannonian Basin
ROZH	Rozhen Observatory	Bulgaria	2005	Building	Rhodopides
SIBI	Sibiu	Romania		Building	Carpathians
SOFI	Sofia	Bulgaria	1997	Building	Rhodopides
SRJV	Sarajevo	Bosnia-H.	1999	Building	Dinarides
TUBI	Gebce	Turkey	1998	Pillar	Pontides
TUC2	Chania	Greece	2004	Pillar	Hellenic Arc
VARN	Varna	Bulgaria	2005	Building	Moesian Platform

5.1.1.3. Station velocities

Usually the daily results of the adjustment of permanent stations are combined to one solution for each GPS week. These weekly results are used to study the long term behaviour of a station and to compute station velocities. As already mentioned the station velocity is estimated as constant throughout the years. Outliers and jumps, mainly caused by a change of the equipment, are eliminated where they could be detected. The reference frame should be chosen in such a way that the results become comparable to other investigations. As ITRF2000 is widely used and accepted as the hitherto most precise 3D-system it is convenient to choose it as the reference. Regional sub-networks take a subset of the stations preferring "trusted" stations with a long time series to align their reference to ITRF2000. For not introducing biases into new stations the method "minimum constraint" is used where the values of the reference stations are

not fixed (Altamimi, 2004). The results in Table 5.1.1.2. of EPN and OLG are based on that method. EPN uses the stations BOGO, BOR1, GRAZ, JOZE, KOSG, MATE, METS, ONSA, POTS, VILL and ZIMM whereas OLG chose GRAZ, MATE, POTS and ZIMM only because of the smaller extent of its network. However, the alignment of both to ITRF2000 and to each other should be good enough to not distort the results in a significant way. One can see at the common stations that the North component of EPN and OLG are very similar while the East component of OLG is always smaller by 1-2 mm/year than the corresponding EPN one. The most plausible explanation is the very small West-East extension of the OLG alignment (about 1 000 km ZIMM-GRAZ) against the pan-European set of EPN. Concerning the Up component the station values of BRAI, CONT and SIBI were left intentionally in Table 5.1.1.2 to show how short time series give unrealistic values. The other OLG values are quite similar to the EPN ones given the estimated r.m.s. of about 0.5mm/year. Because the error estimation from the Software seems always to be too optimistic the velocities of a longer time series (3-10 years) can be expected to be accurate to 0.2-0.5 mm/year against the computed ones of 0.01-0.1 mm/year. The NNR-NUVEL1A velocities derived from geology and older observations show a well known bias to the ITRF2000 values (Altamimi, 2002, Kierulf et al., 2003) because of the rotational pole difference between ITRF2000 and the NUVEL model.

The station velocities of CLUJ, CRAI and VARN are not shown in Table 5.1.1.2. because the short time series provide unrealistic results worse than that ones of BRAI, CONT and SIBI. ROZH has no time series at all. The Greek stations AUT1, IGD1 and TUC2 are also short but they may show already some features which are already detected by campaigns (e.g. Hollenstein et al., 2006, Fig. 4., p. 41). This means that Central Greece and Crete are moving to the Southwest with more than 10 mm/year relative to the Eurasian Plate. In that case the tectonic movement is already larger than a potential error of 5 mm/year in the time series. A second case of geophysical interpretation is the values of DUBR. Compared to that ones of GSR1 and SRJV they are very similar, therefore DUBR cannot move with the Adriatic Microplate relative to the others with estimated 5-10 mm/year difference. As Fig. 5.1.1.3 shows the differences between the motion of the Eurasian Plate and the station velocities at all sites outside Greece are very small except a systematic part. One can deduce that intraplate motions at the Balkan Peninsula are at the 0-5 mm/year level.

5.1.1.4. Conclusions

GPS permanent stations give a valuable contribution to estimate crustal movements. Analysing their time series provide quick and accurate results within about three years at least down to the 1 mm/year level. The estimates derived from geology can be checked very easily at plate boundaries giving a picture of the actual geodynamics. Intraplate movements of smaller tectonic units can be detected also within a decade of observation. Because of the financial limitations permanent stations are usually not dedicated for long term investigations about geodynamics and are therefore not situated in an optimal way. The poor monumentation from the aspect of geodynamics is of minor concern. As was shown the older stations deliver velocities which can be representative for tectonic sub-units. Even the doubtful velocities from estimations of one year only can already contribute to investigations of boundary zones. The most interesting and fastest moving zones at the Balkan Peninsula are still poorly covered by permanent stations. The Eastern coast of the Adriatic Sea and almost all Greece are poorly covered with international stations. The situation could be improved very much if all larger campaigns and national permanent stations could be collected together,

checked and united. This could be done under the umbrella of international projects like WEGENER or CERGOP. Because the Balkan Peninsula is "divided" between both projects a new Balkan Geodynamic Consortium could be founded.

Table 5.1.1.2. Station velocities of Permanent GPS stations at the Balkan Peninsula

STATION	V_N EPN	V_E EPN	V_U EPN
	V_N OLG	V_E OLG	V_U OLG
	V_N NUVEL1A	V_E NUVEL1A	
AUT1 12619M002	---	---	---
	5.4	30.6	-4.9
	11.5	22.8	
BRAI	---	---	---
	5.4	27.8	-19.5
	10.5	23.1	
BUCU 11401M001	11.04	23.72	0.82
	11.1	22.2	-1.2
	10.9	23.0	
CONT	---	---	---
	10.2	16.8	-20.7
	10.4	23.3	
DUBR 11901M001	16.63	23.34	-2.66
	16.9	22.7	-3.4
	12.5	22.0	
GSR1 14501M001	16.24	21.45	-1.69
	16.3	22.2	0.6
	13.2	21.0	
IGD1 12605M001	---	---	---
	-10.3	5.2	-5.1
	11.4	23.1	
ISTA 20807M001	8.29	26.98	-0.32
	9.3	24.6	-0.2
	10.3	23.6	
MIKL 12335M001	11.16	23.74	-0.89
	10.7	21.8	-4.9

	9.6	23.5	
ORID 15601M001	10.20	24.72	0.00
	10.9	23.6	-1.2
	12.1	22.6	
OROS 11207M001	14.74	21.98	-3.12
	13.8	21.4	-3.0
	12.0	22.0	
OSJE 11902M001	14.00	22.80	-2.18
	13.8	22.1	-3.8
	12.4	21.8	
SIBI	---	---	---
	12.9	20.8	-17.4
	11.3	22.6	
SOFI 11101M002	10.87	24.23	-1.37
	11.2	22.3	-2.5
	11.5	22.8	
SRJV 11801S001	15.02	23.54	-1.64
	14.8	23.0	-1.8
	12.5	21.9	
TUBI 20806M001	7.91	24.50	-3.19
	9.4	21.6	-1.9
	10.2	23.6	
TUC2 12617M003	---	---	---
	-13.8	14.0	-2.9
	11.4	23.3	

EPN: Derived from “CLEANED TIME SERIES” from the beginning until September 2005 (http://epncb.oma.be/_dataproducts/timeseries/series_sp).
OLG: Derived from Time Series of weekly results with minimum constraints
NUVEL1A: Derived from the rotation of the Eurasian Plate of the NUVEL1A model

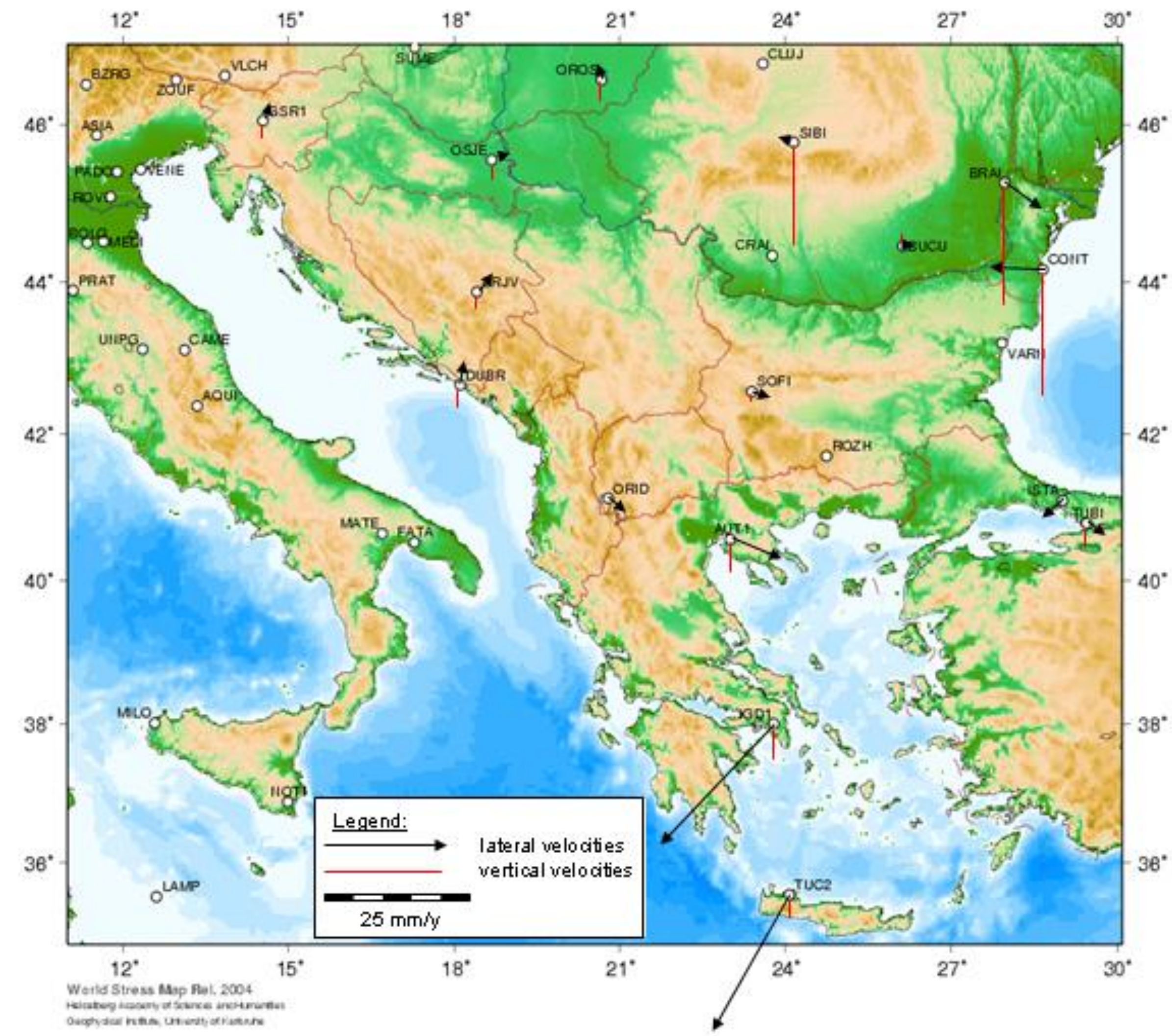

Fig. 5.1.1.3. Station velocities relative to the NUVEL1A velocities of the Eurasian Plate

5.1.1.5. References

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