RECENT TECTONIC PLATE MOTIONS OF THE CARPATHIAN-BALKAN REGION AND THE SURROUNDING AREA FROM SATELLITE LASER RANGING

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Abstract: The Satellite Laser Ranging (SLR) geodetic solution for the plate motion of Carpathian-Balkan Region and the neighbourhood areas is based on the analysis of observations of the geodynamic satellites Lageos 1 (Laser GEOdynamic Satellite) covering the period April 1984 – December 2000, and Lageos 2 for the period January 1993 - December 2000. Tectonic motion results and comparisons with data from earthquake fault-plane solutions are discussed.

Key words: Satellite Laser Ranging, Plate Motion, Carpathian-Balkan Region.

The data

The presented global solution is obtained by analyzing the laser ranging data to Lageos 1 and Lageos 2 satellites. The total number of laser ranging data are 1 407 896, 1 378 277 of them are three minutes normal points and 29 619 are single shots. About a million are the observations of Lageos 1 and 400 000 of Lageos 2. The observations are made from 94 laser sites with global coverage: 48 of them lie on the Eurasian plate, 22 – on the North America plate, 5 – on the South America plate, 6 – on the African plate, 4 – on the Australian plate, 7 – on the Pacific plate, 1 – on the Nazca plate and 1 on the Anatolian plate. Permanent stations are 37 and mobile – 57.

Dynamic and geometric models used in processing

The data reduction and analysis of the observations are made by the orbital dynamic and estimation software SLRP (Satellite Laser Ranging Processor), developed at the Central Laboratory of Geodesy (CLG), (Kotzev and Georgiev, 1990; Georgiev and Kotzev, 1993). The dynamic and geometric models used in the processing are described in Table 1. These models follow almost exactly the IERS Standards (1996). The global Terrestrial

Reference Frame (TRF) is realized by fixing the latitude of Haleakala (7210) and longitude and latitude of Greenbelt (7105) and Matera (7939) laser sites at their ITRF97 values and using the a priory Earth Orientation Parameters (EOP) values from the International Earth Rotation Service (IERS) Bulletin B. For the last day of each month (orbital arc) the UTC-UT1 values are fixed to their IERS Bulletin B values due to full correlation between satellite node and UT1. The time evolution of coordinate system is constrained by adopting the ITRF97 rates for Haleakala (7210) and Greenbelt (7105) sites.

The choice of these stations lies on their continuous and homogeneous tracking data history. They are located on the two of major continental plates and their ITRF97 velocities are in a very good agreement with the geological NUVEL1A NNR model (DeMetz et al., 1994). The scale of the TRF is determined by the priory value of the Earth's gravitational constant and this parameter is also solved for.

Table 1. Reference frames, constants and models used in the solution

Celestial reference frame:	
Nature:	dynamical - Lageos 1 and Lageos 2
Definition of the orientation:	by fixing each month the last day UTC-UT1 values at IERS Bulletin B.
Terrestrial reference frame:	SSC ITRF97
Velocity of light:	299 792 458 m/s
GM	3.986004418 10^{14} m^3/s^2
Permanent tidal correction:	applied
Definition of origin:	geocentric
Definition of orientation:	by fixing the latitude of Haleakala (7210) and longitude and latitude of Greenbelt (7105) and Matera (7939) at their ITRF97 values
Reference epoch:	1997.0
Tectonic plate model:	ITRF97 velocity field
Constraint for time evolution:	by adopting the ITRF97 rates for Haleakala (7210) and Greenbelt (7105)
Earth orientation:	a-priori IERS Bulletin B values
A priori precession model:	IAU(1976)
A priori nutation model:	IAU(1980) and dPsi and dEpsilon corrections from IERS Bulletin B
Short period tidal variations in x, y, UT1:	tidal variations in UT1 caused by zonal tides with periods up to 35 days not modeled

The estimated parameters in our solution are listed in Table 2.

Table 2: Estimated parameters

Dynamical frame:	orbital state vector every month; along track acceleration twice per arc; solar radiation pressure coefficient twice per arc;
Terrestrial frame:	X_0, Y_0, Z_0, X_{DOT}, Y_{DOT}, Z_{DOT};
Earth orientation:	x, y, UT1 every day;
Others:	geogravitational parameter GM_0; selected set of 11 geopotential coefficients, including C_{20}; selected ocean loading parameters; station's range biases (fixing 7939); station's time biases (fixing 7939).

The global solution consists of estimates for the geocentric coordinates of 94 and velocities of 60 laser sites; Love and Shida numbers; the Earth's gravity constant – GM; three zonal harmonic coefficients - - C_{20}, C_{30}, C_{40} and fourteen, from C_{21}, S_{21} to C_{42}, $S_{42,}$ tesseral and sectorial harmonic coefficients of the Earth's gravity field; coefficients of the ocean tides for diurnal waves Q1, O1, P1, K1, semi-diurnal waves N2, M2, S2, K2 and long periodic waves SSa, MM, MF. The number of unknown parameters in the simultaneously processing of the two satellites is 27 775 and the root mean square (rms) of the global solution is 6.9 cm.
The quality of the derived station coordinates and the solution as a whole is illustrated by the seven parametric transformation between our solution and the ITRF97 - Table 3.

Table 3. Sevent parametric transformation between global solution CLG(SSC) L 01 and ITRF97. The dimensions are marcsec and mm.

R_1 [marcsec]	**R_2** [marcsec]	**R_3** [marcsec]	**$S.10^{-9}$**	**T_1** [mm]	**T_2** [mm]	**T_3** [mm]
0.87	-1.06	0.71	3.6	-28	14	-16
±0.61	±0.64	±0.55	±2.3	±16	±15	±15

Results

The obtained velocities of the laser sites for the European and Mediterranean sites are shown on Figure 1. According to these results, the West and Central Europe – the "stable" part of the Eurasian plate, is moving northeastwards with an average velocity of 20-25 mm/y and no intraplate motion is detected. The Circum-Carpathian Area participates in this motion without major discrepancies. The north – northwestwards motion of the Arabian plate and its impact on the Anatolian plate is expressed with rotation of the velocity vectors towards west along the North Anatolian Fault System. The southern part of the Aegean plate is moving towards south-southwest, and this motion is explained by the process of subduction of the African beneath the Eurasian plate along the Hellenic Arc.

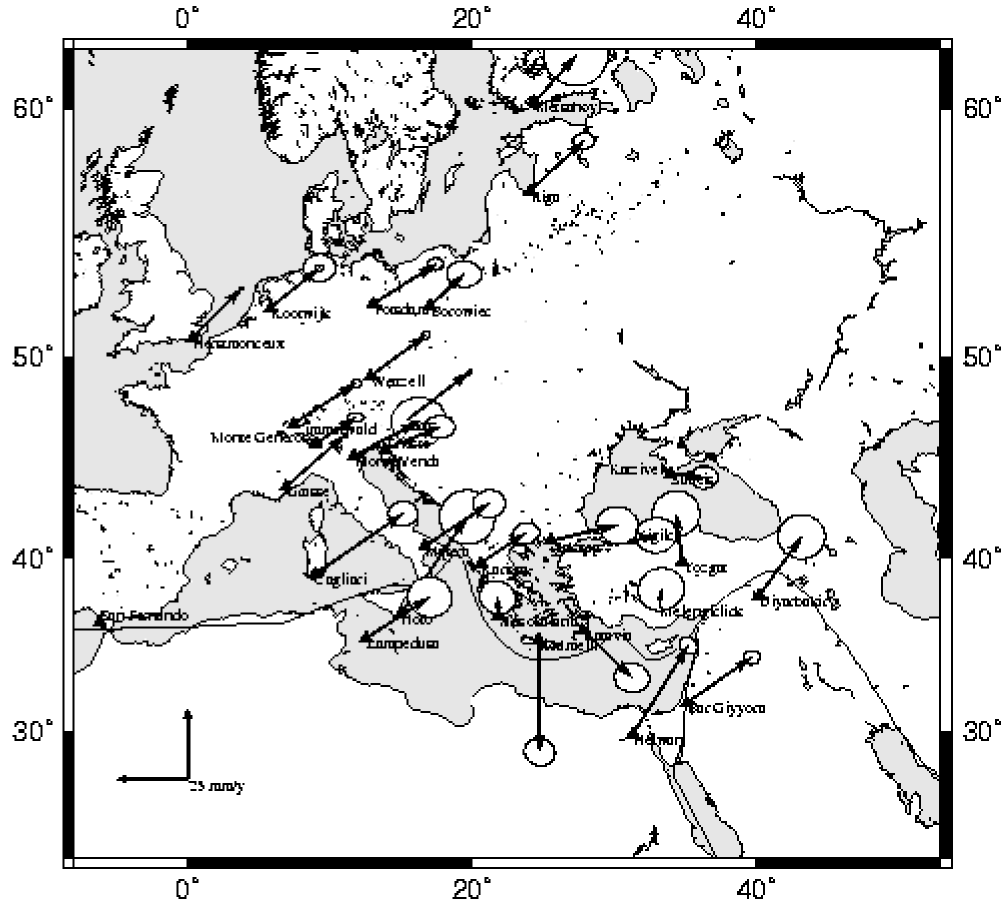

Fig. 1 Absolute motions of Europe, African and Anatolian according to SLR geodetic solution

The relative motion of the Carpathian-Balkan Region relative to Eurasia is practically zero (Fig. 2). Well expressed are the movements of Anatolian plate relatively westwards to Eurasia along the North Anatolian Fault System. The high strain capacity of the Anatolian plate on the structures of Eurasia is clearly underlined by its relative motion. This relative motion towards west and its transformation to well expressed southwards displacement with velocities higher than 30 mm/y in the Aegean denotes the complicated crustal and mantle processes of this part of Eurasia.

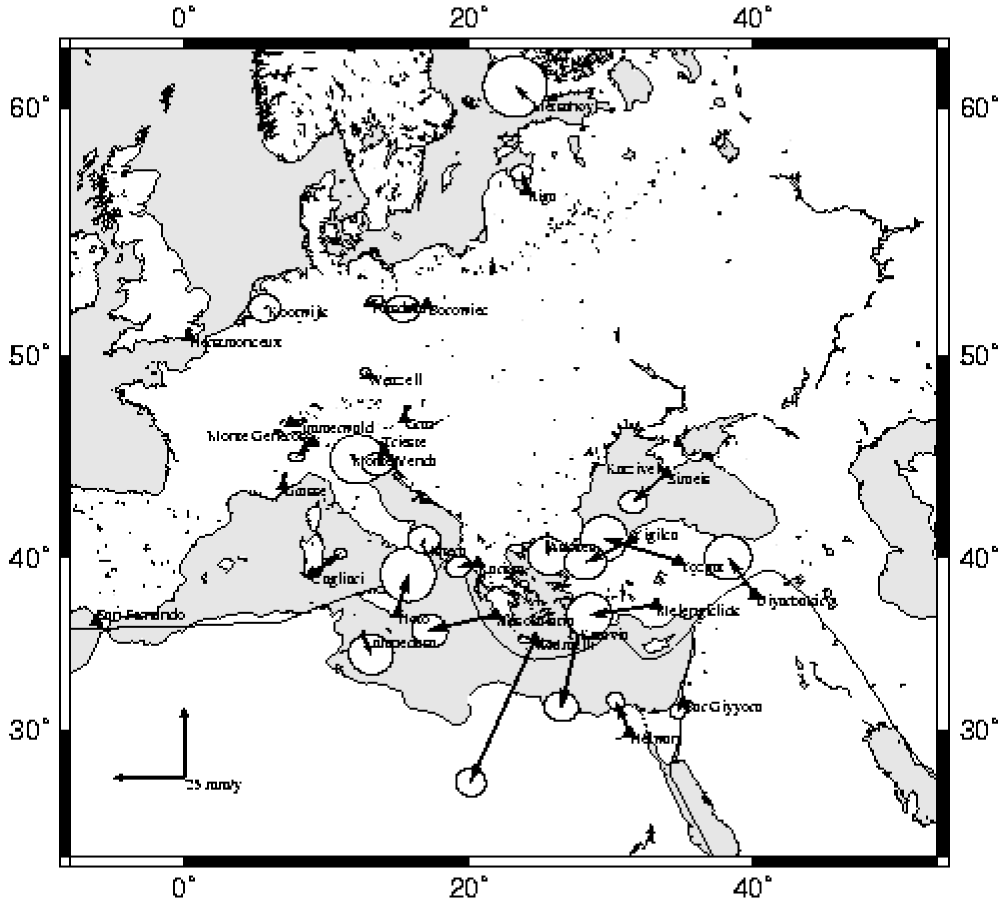

Fig. 2 Motions relative to Eurasia for the SLR stations around and in the Carpathian-Balkan Region

The complexity of the processes around the Balkan Peninsula is manifested in the results from the earthquake fault-plane solutions (Fig. 3). The maximum stress axis orientation for the Arabian Plate according these solutions practically coincides with the detected movements from the SLR solutions. Those can not be postulated for the Aegean. The processes of subduction along the Hellenic Arc create different stress conditions at the different depths. The existing tectonic structures of the Earth’s crust additionally contribute for the reorientation of the regional strain. So, the fault-plane solutions of this area can not be compared with the results from the SLR geodetic solutions directly, without considering the 3 D geometry of the subduction zone along the Hellenic Arc.

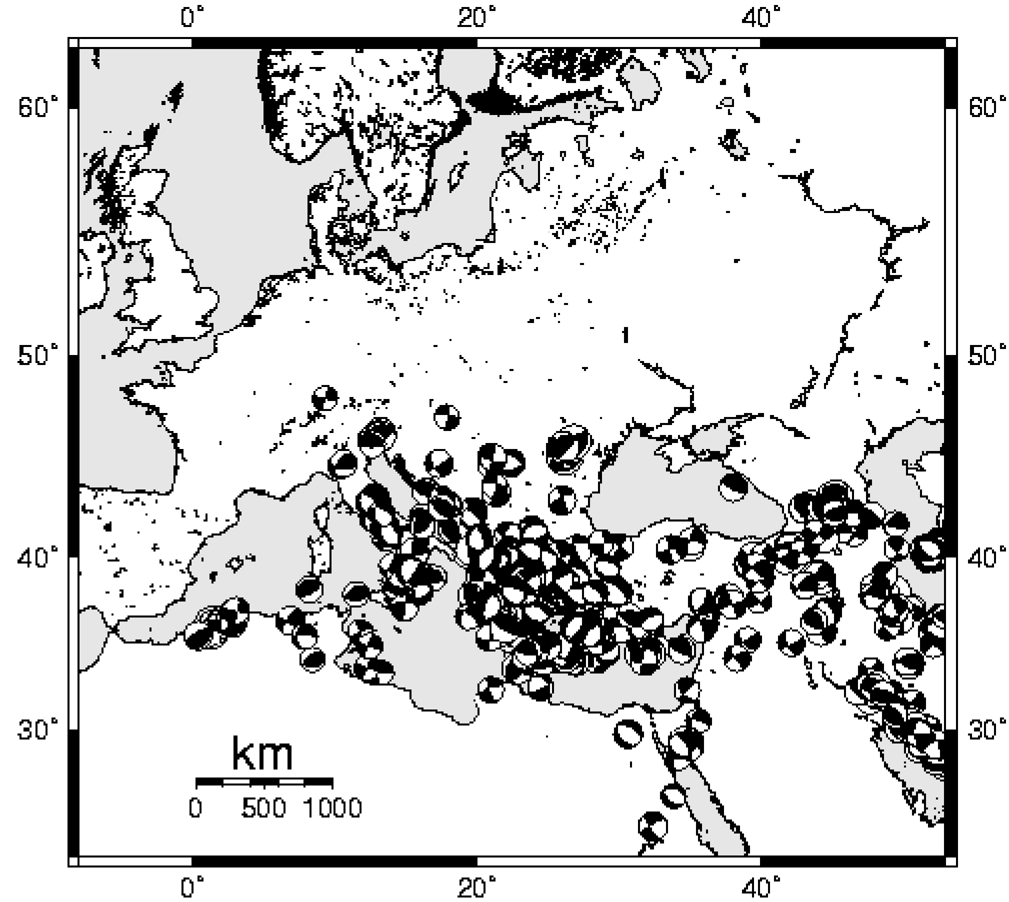

Figure 3: Fault-plane solutions from earthquakes (1977 to 2000) in the Eastern Mediterranean according to the Harvard catalogue.

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