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## GLOBAL TECTONIC PLATE MOTIONS FROM SLR DATA PROCESSING

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### ABSTRACT

Various global and arc-dependent parameters are estimated by analyzing Satellite Laser Ranging (SLR) data of the geodynamic satellites Lageos 1 for the period April 1984 – December 2011 and Lageos 2 for the period January 1993 – December 2011. The SLR data are collected from 113 globally distributed stations and are processed and analyzed with SLRP (Satellite Laser Ranging Processor) software developed in the Department of Geodesy of the National Institute of Geophysics, Geodesy and Geography. The estimated global parameters include coordinates of all tracking stations and velocities of 98 of them. The site velocities are used to determine the motion of the global tectonic plates applying the Euler's model. The angular velocities and the rotation poles of Eurasian, North American, South American, African, Australian and Pacific plates are determined and compared with other solutions.

### 1. Introduction

The Earth shape is changing permanently due to the motion of the Earth's crust. The interpretation of observed motion needs a Terrestrial Reference Frame (ITRF), which provides a set of coordinates of some Earth's surface points. It can be used to measure plate tectonics, regional subsidence and loading. Nowadays, four main geodetic techniques are used to compute accurate coordinates: the GPS, VLBI, SLR, and DORIS. Since the tracking

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instruments are evolving and the available data increases with time, the ITRF is permanently being improved. 13 realizations of the ITRS were set up from 1988, the latest is the ITRF2014. All these realizations include station positions and velocities and they model secular Earth's crust changes.

The Satellite Laser Ranging (SLR) is one of the most accurate present-day space techniques for determination of the absolute geocentric coordinates of the tracking sites and their motion with respect to the geocenter, determination of the Earth's gravity time variations, absolute vertical motions monitoring, etc.

The site's velocities obtained in this paper are used to determine the motion of the global tectonic plates applying the Euler's model. The angular velocities and the rotation poles of Eurasian, North American, South American, African, Australian and Pacific plates are determined.

## 2. Method and Model from Estimation of Euler Rotation Pole Parameters

Plate tectonics is a uniting concept in Earth Sciences, first put forward in the mid 1960's building on the idea of Continental Drift. Plates move relative to each other. To describe their motion on the surface of a spherical Earth, one needs to use Euler fixed point theorem.

The most general displacement of a rigid body over the surface of a sphere can be regarded as a rotation about a suitable axis which passes through the centre of that sphere. Thus all plate motions can be described by a rotation axis, which passes through the centre of the Earth and cuts the surface at two points, called the poles of rotation (see Fig. 1).

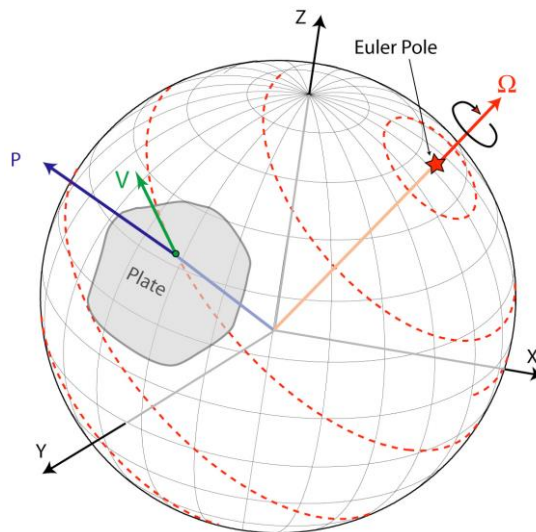


Figure 1. Describing motions on a sphere and Euler Poles

The motion of “plates” (spherical caps) on a sphere can be described by a pole of rotation (lat, lon), also called Euler pole and an angular velocity (usually in units of deg/My). Pole of rotation and angular velocity are equivalent to a 3-component angular rotation vector ( $\Omega$ ) in a Cartesian geocentric frame.

These can be determined in a number of ways including from direct measurements using satellite laser ranging, (SLR) or very-long baseline interferometry (VLBR), which uses the signal from quasars and terrestrial radio telescopes as receivers and GNSS observation.

As it is known, the kinematic plate model of each tectonic plate can be presented by three parameters: Euler rotation vector  $\Omega$  ( $\Omega_x, \Omega_y, \Omega_z$ ), or Euler pole ( $\varphi, \lambda, \Omega$ ). The relationship between unknown Euler parameters and Cartesian geocentric coordinates ( $X, Y, Z$ ) and station velocity components ( $V_x, V_y, V_z$ ) is applied. The unknown Euler parameters are obtained by applying the Least Squares method using obtained ITRF2000 coordinates and velocities of SLR stations. SLR velocity vectors are modeled:

$$\begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = \begin{bmatrix} 0 & -\Omega_Z & \Omega_Y \\ \Omega_Z & 0 & -\Omega_X \\ -\Omega_Y & \Omega_X & 0 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad (1)$$

where  $X, Y, Z$  are the Cartesian geocentric coordinates of the SLR station,  $V_x, V_y, V_z$  are the coordinate components of the velocity vector at that station, and  $\Omega$  ( $\Omega_x, \Omega_y, \Omega_z$ ) is the rotation vector defining the motion of the plate carrying the station.

After estimating Euler rotation vector  $\Omega$  ( $\Omega_x, \Omega_y, \Omega_z$ ) it is possible to calculate the Euler pole ( $\varphi, \lambda, \Omega$ ).

$$\lambda = \arctan\left(\frac{\Omega_Y}{\Omega_X}\right); \quad (2)$$

$$\varphi = \arctan\left(\frac{\Omega_Z}{\sqrt{\Omega_X^2 + \Omega_Y^2}}\right); \quad (3)$$

$$\Omega = \sqrt{\Omega_X^2 + \Omega_Y^2 + \Omega_Z^2}. \quad (4)$$

Various variants of Euler rotation vectors and Euler poles are estimated by combining velocity vectors of different stations to obtain information about the motion of potential plates. For all plates values of the estimated Euler pole ( $\varphi, \lambda, \Omega$ ) are obtained [1].

### 3. SLRP4.2 Software for Satellite Laser Ranging Processing and Analysis

The SLRP v4.2 software package, developed in the Department of Geodesy, consists of two modules – a dynamic orbital module for determining the satellite's orbit, obtaining the partial derivatives of the solved for parameters and compiling the observation equations. Apart from all the necessary information for the evaluation of the parameters – observation epoch, observation station code and number, coordinates and velocities of the satellite, etc., the observation equations contain the geometric and dynamic partials of the estimated parameters [4], which are:

Geometric:

- coordinates and velocities of observation stations;
- systematic time and range biases time;
- Earth Orientation Parameters (EOP) – pole coordinates and UT1-UTC.

And dynamic:

- the initial conditions (coordinates and velocities) of the satellite for the respective orbital arc;
- coefficients of the geopotential (zonal, sectorial and tesseraural);
- the constituents of the Earth and Ocean tides;
- the numbers of Love and Shida;
- the geogravitational parameter (GM) and Moon's and Sun's gravitational parameters;
- dynamic coefficients of orbital motion of the satellite – empirical acceleration in the direction of orbit, radial acceleration and solar pressure.

The parameter evaluation module compiles, based on observational equations, the normal matrices for the respective orbital arc. Measurement processing and analysis take place in two stages. The first one produces estimates of the known orbital arcs, usually the monthly orbital arcs for the Lageos 1 and 2 satellites. The second stage involves eliminating the arc dependent parameters and obtaining a multi-year global solution. In this case, these are the coordinates and the velocities of the tracking stations.

#### 4. Global Station Velocity Solution

Various global and arc-dependent parameters, with total number 46180, are estimated by analyzing more than 2.3 million Satellite Laser Ranging (SLR) observations of the geodynamic satellites Lageos 1 for the period April 1984 – December 2011 and Lageos 2 for the period January 1993 – December 2011. The SLR data are collected from 113 globally distributed stations and are processed and analyzed with SLRP (Satellite Laser Ranging Processor) software developed in the Department of Geodesy of the National Institute of Geophysics, Geodesy and Geography [3 ÷ 5]. The estimated global parameters include coordinates of all tracking stations and velocities of 98 of them (see Fig. 2).

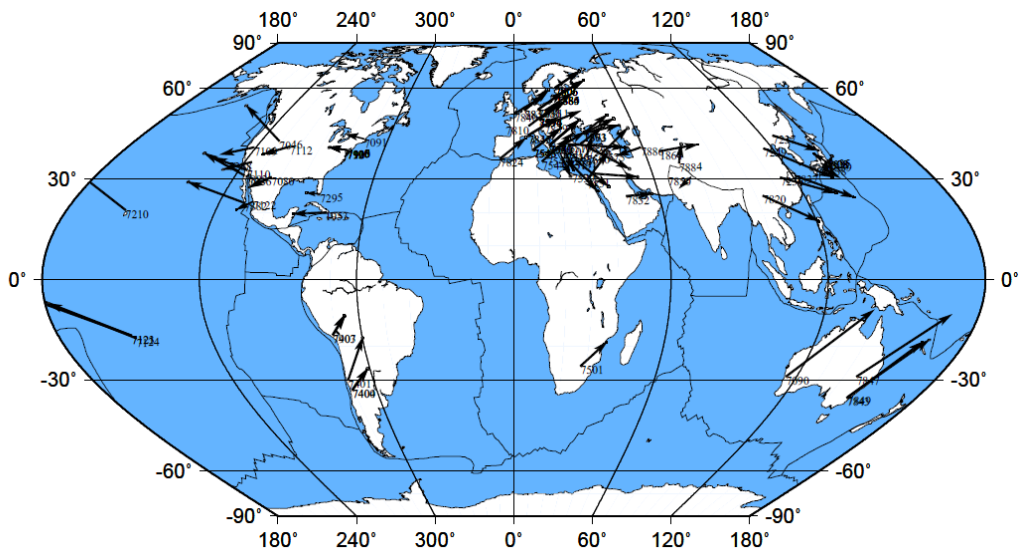


Figure 2. The Satellite Laser Ranging (SLR) site and horizontal velocities

## 5. Estimation of Euler Rotation Pole Parameters

The obtained velocities of SLR stations from around the world have been used. SLR stations are located on 8 different tectonic plates. The rotational components in the direction of the three axes are estimated. Locations of the Euler poles and of the vectors are determined.

The site velocities are used to determine the motion of the global tectonic plates applying the Euler's model. The angular velocities and the rotation poles of Eurasian, North American, South American, African, Australian and Pacific plates are determined (Table 1).

**Table 1. SLRP solution for Euler rotation vectors and Euler poles for all plates**

Name plate	$\Omega_x$ Mas/yr	$\Omega_y$ Mas/yr	$\Omega_z$ Mas/yr	$\varphi$	$\lambda$	$\Omega$ Mas/yr	Number of points
AFRC	-0.0883	-0.4359	0.5477	78.5886	-50.9430	0.7055	5
AUST	1.0756	0.9793	0.8412	42.3389	30.0540	1.6804	4
EURA	-0.0881	-0.4846	0.7667	79.6962	57.2826	0.9113	52
NOAM	-0.0383	-0.3167	-0.2317	83.1387	36.0099	0.3943	23
PCFC	-0.0723	0.8344	-1.5055	-85.0909	-60.9439	1.7228	7
SOAM	-0.1960	-0.8947	0.0767	77.6773	4.7914	0.9191	5

On NAZC plates measurements were taken from only one SLR station – *7097 EASTER ISLAND*, analogous to ARAB plate (*7832 – RIYADH*), the pole and the vector of rotation of these plates cannot be determined.

Comparisons have been made with the published models describing the movements of the “hard” Eurasia NUVEL-1A and EUREF [2]. Table 2 contains the relevant components of NNR-NUVEL-1A, EURASIA, EUREF (ITRF2000), REVEL2000.

**Table 2. Comparison of Eurasian plate components from different solutions [6, 7]**

Name model	$\Omega_x$ Mas/yr	$\Omega_y$ Mas/yr	$\Omega_z$ Mas/yr	$\lambda$	$\varphi$	$\Omega$ Mas/yr
REVEL2000	-0.103	-0.476	0.788	58.27	77.79	0.9266
NNR-NUVE-L1A	-0.202	-0.494	0.650	50.63	67.73	0.8413
EURASIA	-0.129	-0.494	0.732	55.10	75.36	0.8924
<b>SLRP</b>	<b>-0.0881</b>	<b>-0.4846</b>	<b>0.7667</b>	<b>57.28</b>	<b>79.69</b>	<b>0.9113</b>
EUREF	-0.081	-0.489	0.792	57.96	80.59	0.9343
Kraszewska et al., (2009)	-0.064	-0.458	0.6626	57.21	81.30	0.7869

Our estimates of the Eurasian rotations components (SLRP) are comparable and very close to the solution EUREF from ITRF2000 frame (Table 2). The small differences between the rotation pole parameters we have received and the EUREF model can be explained by the fact that EUREF rotations components are determined by combining data from several types of SLR, VLBI, DORIS and GPS satellite techniques.

## 6. Conclusion

The SLR data processing gives great opportunities to investigate the shape, size and dynamics of the Earth. These data consist of several millions high-accurate observations collected for more than 30 years time span. Our latest SLR solution by the program SLRP4.2 covers 27.5-year time span and determines more than 46 thousands unknown parameters; among them are the velocities of 98 laser stations. These laser stations are globally located over the Earth surface and they give possibility to determine the angular velocities and the rotation poles of Eurasian, North American, South American, African, Australian, and Pacific plates. Our solution to global tectonic plate motions is close to other available solutions.

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