Estimation of the local tidal parameters h_2, l_2 for the Riga satellite laser ranging station based on LAGEOS data

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Abstract. The paper presents estimates of local tidal parameters (Love and Shida numbers) h_2, l_2 for the Riga (No. 18844401, Latvia) satellite laser ranging station based on LAGEOS-1 and LAGEOS-2 data for a period of 15 years (01.01.2004–01.01.2019). The adjusted values for $h_2 = 0.6891 \pm 0.0009$ and $l_2 = 0.1043 \pm 0.0004$ are discussed and compared with the nominal values of $h_2 = 0.6078$ and $l_2 = 0.0847$ given in International Earth Rotation and Reference Systems Service standards. The differences of the coordinates of the Riga station in International Terrestrial Reference Frame ITRF2014 evaluated using the nominal and adjusted values of the tidal parameters are 4.4 mm for the X component, 4.7 mm for the Y component and 6.9 mm for the Z component.

Key words: satellite laser ranging, tidal parameters, Love number, Shida number, ITRF2014, Riga station (No. 18844401).

INTRODUCTION

This paper is a continuation of the research into estimates and analysis of the tidal parameters (Love and Shida numbers) in the Baltic Sea region. The Earth's shape changes as a response to variations in the tide generating potential. The Love number h represents the ratio of the radial displacement of the element of mass of the elastic Earth to the corresponding displacement for the liquid Earth. For the real elastic body, $0 < h < 1$. The Shida number l represents the ratio of the transverse displacement of the element of mass of the crust to the displacement for the hypothetical liquid Earth. For the elastic Earth, $0 < l < 1$. The parameters h, l are thus a measure of the elastic response of the Earth to tidal stresses.

The redistribution of the ocean and solid Earth's mass due to tides induces dynamical perturbations of the location of the satellite and a displacement of the ground station. The displacement of the station caused by tides is described in terms of the tidal parameters h_2 and l_2 as follows (McCarthy et al. 1993):

$$\Delta X = \sum_{j=2}^{3} \left[\frac{GM_j}{GM_{Earth}} \frac{r^4}{R_j^3} \right] \left\{ \left[3l_2 \left(\hat{R}_j \hat{r} \right) \right] \overline{X}_j + \left[3 \left(\frac{h_2}{2} - l_2 \right) \left(\hat{R}_j \hat{r} \right)^2 - \frac{h_2}{2} \right] \overline{x}_{STA} \right\},$$

$$\Delta Y = \sum_{j=2}^{3} \left[\frac{GM_j}{GM_{Earth}} \frac{r^4}{R_j^3} \right] \left\{ \left[3l_2 \left(\hat{R}_j \hat{r} \right) \right] \overline{Y}_j + \left[3 \left(\frac{h_2}{2} - l_2 \right) \left(\hat{R}_j \hat{r} \right)^2 - \frac{h_2}{2} \right] \overline{y}_{STA} \right\}, \qquad (1)$$

$$\Delta Z = \sum_{j=2}^{3} \left[\frac{GM_j}{GM_{Earth}} \frac{r^4}{R_j^3} \right] \left\{ \left[3l_2 \left(\hat{R}_j \hat{r} \right) \right] \overline{Z}_j + \left[3 \left(\frac{h_2}{2} - l_2 \right) \left(\hat{R}_j \hat{r} \right)^2 - \frac{h_2}{2} \right] \overline{z}_{STA} \right\},$$

where GM_j, GM_{Earth} denote the centric gravitational constant for the Moon ($j = 2$) or the Sun ($j = 3$) and the centric gravitational constant for the Earth, respectively, $\hat{R}_j$ and R_j represent unit vectors

from the geocentre to the Moon or Sun and the geocentric distance, respectively, $(\overline{X}_j, \overline{Y}_j, \overline{Z}_j)$ and $(\overline{x}_{STA}, \overline{y}_{STA}, \overline{z}_{STA})$ are the Cartesian components of the unit vectors $\hat{R}_j$ and $\hat{r}$, respectively, $\hat{r}$ and r represent the unit vector from the geocentre to the station and the magnitude of that vector, respectively. The radial displacement is at its maximum when the Moon and the Sun are in conjunction or in opposition and $\hat{R}_j$ is parallel or anti-parallel to $\hat{r}$. The largest radial and transverse displacements due to the degree 2 tide need to be taken into consideration when an accuracy of few millimetres is desired in determining the stations' coordinates.

Expressions (1) contain the second-degree tidal parameters h_2 and l_2 which are known as Love and Shida numbers. According to International Earth Rotation and Reference Systems Service (IERS) Conventions (Petit & Luzum 2010), the nominal values of the tidal parameters for the second-degree tides are $h_2 = 0.6078$, $l_2 = 0.0847$. As for the second-degree tides (Eqs (1)) there are also tidal parameters for the spherical harmonics of higher orders. They have different numerical values, but their physical meaning is the same.

Rutkowska & Jagoda (2015), Jagoda & Rutkowska (2016) and Jagoda et al. (2017, 2018) presented estimates of global tidal parameters h_2, l_2, k_2, k_3. In this paper we present estimated values for the second-degree local tidal parameters h_2, l_2 for the Latvian satellite laser ranging (SLR) station Riga (No. 18844401, 56°56′54.7″ N, 24°03′32.6″ E) based on 15 years (1 January 2004 until 1 January 2019) of LAGEOS-1 and LAGEOS-2 data. The LAGEOS satellites experience a minimal amount of atmospheric drag and are less apt to be perturbed by short-wavelength impact of the Earth's gravitational field and tidal forces. Therefore data of these satellites provide adequate information regarding the tidal parameters and stations' positions (Pearlman et al. 2019). The Latvian station Riga is an important station for the SLR network. It is one of the easternmost European SLR stations.

MOTIVATION AND OBJECTIVE

Determining the positions of observation stations from the SLR data is one of the fundamental tasks of satellite geodesy. The process has to take into consideration also the tidal displacement of the observation stations. Equations (1) apply the global values of tidal parameters h_2 and l_2. Jagoda (2019) demonstrated that even a small change in the values of h_2 and l_2 impacts the estimates of coordinates X, Y, Z by 1–3 mm. As the Earth is not a homogeneous body, its reaction to tidal forces varies over the globe and thus tidal parameters will have different values for different locations as well.

With this in mind, an attempt is made in this paper to (i) determine the local values of tidal parameters from the SLR data of the Latvian Riga station and (ii) assess how their specific values impact the estimates of station's coordinates. We also evaluate the minimum and necessary time interval for an adequate estimate of the local values of the Love and Shida numbers and the associated errors.

METHODOLOGY

We used 15 years of LAGEOS-1 and LAGEOS-2 data to estimate the local values of the tidal parameters h_2, l_2 for the Latvian SLR station Riga. We also show how their specific values influence the estimates of the Riga station coordinates in the International Terrestrial Reference Frame (ITRF2014) system (Altamimi et al. 2016). The method of analysis consists of three stages: (i) estimation of the LAGEOS satellites' orbits, (ii) determination of the local values of tidal parameters and (iii) calculation of the coordinates of the Riga station.

All calculations were performed with the use of NASA GEODYN II software (McCarthy et al. 1993). The satellites' orbits, models of force and constants were estimated according to IERS Conventions (Petit & Luzum 2010) as well as in accordance with the International Laser Ranging Service (ILRS) applied by international computation centres. We employed the gravity field model GGM05S (Tapley et al. 2013)

using static terms through degree and order 60 and time-dependent terms $C_{(2,0)}$, $C_{(3,0)}$, $C_{(4,0)}$, $C_{(5,0)}$, $C_{(6,0)}$, $C_{(2,1)}$, $S_{(2,1)}$. The tidal forces were extracted from the Solid Earth tide model, Earth pole tidal model and Ocean pole tide model from the IERS Conventions 2010 (Petit & Luzum 2010). Atmospheric tidal loading is employed as recommended in Ray & Ponte (2003). Ocean tides are evaluated using the Finite Element Solution tide model FES2014 developed in 2014–2016 (Carrère et al. 2016).

The perturbations caused by the third bodies (the Moon, the Sun and the planets Venus, Mars and Jupiter) are taken from the Jet Propulsion Laboratory (JPL) Solar System Ephemeris DE405 (Folkner et al. 1994) and the numerical values for the nutation from the International Astronomical Union's IAU 2000A model (Petit & Luzum 2010). The reference frame (stations' coordinates and velocities) is ITRF2014 (Altamimi et al. 2016), Earth orientation parameters are from C04 series from the IERS, consistent with ITRF2014 (Bizouard et al. 2017). The subdaily pole model is IERS2000 (Petit & Luzum 2010); tropospheric delay is described by the Mendes–Pavlis model (Mendes & Pavlis 2004). Relativistic effects such as light time propagation correction and Schwarzschild orbit perturbation are employed according to IERS Conventions 2010 (Petit & Luzum 2010). For the satellite centre of mass correction, different values for particular SLR stations were obtained from ILRS tables (Pearlman et al. 2002). It was assumed that solar radiation pressure $C_R = 1.13$. The solution based on the above assumptions, corrections and force model makes it possible to estimate the satellite orbits with an accuracy of about 1 cm.

The LAGEOS-1 and LAGEOS-2 orbits were estimated using the data from the best ILRS stations (Nos 7080, 7090, 7838, 7811, 7839, 7105, 7110, 7501, 7840, 7237, 7941, 8834, 1893, 7406, 1868, 7821, 7841, 7825) in the ITRF2014 system (Altamimi et al. 2016) collected in the period from 1 January 2004 until 1 January 2019. The orbits were computed using the 11th-order predictor-corrector Cowell's method (McCarthy et al. 1993). The 15-year period of the LAGEOS-1 and LAGEOS-2 data was divided into monthly orbital arcs with half-day overlaps between the successive arcs. The observation arcs of the Riga station were selected for further calculations. The 15-year period in question contains 120 such arcs. The adjustment was performed using an iterative process with the convergence criterion in terms of the root mean square (RMS) deviation:

$$\{\text{RMS}(n) - \text{RMS}(n-1)\} < 0.01 \text{ cm}, \tag{2}$$

where n is the number of the current iteration. This solution makes it possible to calculate the RMS of the post-fit residuals at the initial epoch of an arc. The RMS values of the post-fit residuals are computed from the following expression (Rutkowska & Jagoda 2010):

$$\text{RMS of the post-fit residuals} = \frac{1}{n-1}\sqrt{\sum_{i=1}^{n}(O_i - C_i)^2},$$

where $O_i - C_i$ denotes the difference between the SLR observations and the computed distance from the station to the satellite. The performed analysis resulted in the following values of the post-fit residuals: RMS for LAGEOS-1 was 12 mm and RMS for LAGEOS-2 was 11 mm. These results reflect the average over all 30-day arcs.

The results of the iterative process of orbit correction according to Eq. (2) were used to calculate the local values of the tidal parameters h_2, l_2 for the Latvian SLR station Riga. This process was conducted on the basis of combined observations of SLR satellites LAGEOS-1 and LAGEOS-2 over the period of 15 years in question. The longest intervals in observation performance (due to the laser damage) occurred from May 2013 to March 2016 and from January to July 2012. In total, 7450 normal points of LAGEOS-1 and 4633 normal points of LAGEOS-2 satellites were used in the calculations. From this data set 120 combined LAGEOS-1 + LAGEOS-2 orbital arcs were generated.

The local values of the tidal parameters h_2, l_2 and the Riga station coordinates were calculated using the observation equation

$$O_i - C_i = -\left(\sum_{i=1}^{n} \frac{\partial \rho_i}{\partial \varepsilon} d\varepsilon_j + \frac{\partial \rho_i}{\partial h_2} dh_2 + \frac{\partial \rho_i}{\partial l_2} dl_2 \right) + dO_i, \qquad (3)$$

where i and j denote the number of measurements and adjusted parameters, respectively, $d\varepsilon_j$ are corrections for the satellite position, velocity and other unknowns connected with the satellite orbit and the station positions, velocities and range biases, dO_i is the error of observation associated with the ith measurement, dh_2 and dl_2 are corrections for the Love number h_2 and Shida number l_2, respectively. The priori values of $h_2 = 0.6078$ and $l_2 = 0.0847$ were taken from IERS Technical Note No. 36 (Petit & Luzum 2010). Equation (3) was solved by the Bayesian least-squares method (McCarthy et al. 1993). The partial derivaties $\partial \rho_i / \partial h_2$, $\partial \rho_i / \partial l_2$ in Eq. (3) are computed by differentiating Eqs (1).

The process of estimating the Love and Shida numbers h_2, l_2 was conducted using a sequential approach. In the first phase the tidal parameters were calculated separately for each orbital arc. The further steps consisted in adding arcs, one by one, resulting in a sequence of combinations arc 1 + arc 2, arc 1 + arc 2 + arc 3, arc 1 + arc 2 + arc 3 + arc 4, etc. For each resulting combination of arcs the Love and Shida numbers were calculated anew.

The next step was to determine the coordinates of the Riga SLR station from Eq. (3). The coordinates were evaluated using the procedure described in detail by Schillak (2004). The coordinates were determined for both LAGEOS satellites (LAGEOS-1 data + LAGEOS-2 data) assuming *a priori* the stations' coordinates as given in ITRF2014 (Altamimi et al. 2016). The precision of the resulting coordinates is defined by the mean standard deviation (Lejba & Schillak 2011)

$$\sigma = \sqrt{\frac{(\sigma_X)^2 + (\sigma_Y)^2 + (\sigma_Z)^2}{3}}, \qquad (4)$$

where $\sigma_X, \sigma_Y, \sigma_Z$ are standard deviations of the components X, Y, Z.

The adjustment of the Riga station coordinates was performed using two different procedures as described in the next paragraph.

RESULTS AND DISCUSSION

The Love and Shida numbers h_2 (Fig. 1) and l_2 (Fig. 2) determined in this research were analysed with respect to the accuracy of the outcome and convergence of the iterations to the final value (sometimes called the stability of determination). The stability was interpreted in terms of fluctuations of the successive iterations of h_2, l_2 for subsequent orbital arcs. After some time these fluctuations were comparable to or smaller than the formal error of the parameter in question. For better readability we present only the values obtained for blocks of five orbital arcs (arcs 1–5, arcs 1–10, arcs 1–15, ..., arcs 1–120). The nominal values of h_2, l_2 from Petit & Luzum (2010) are represented in these figures as the solid black line, while the local values of the Love and Shida numbers from our solution are shown by black diamonds.

The final values (for 120 orbital arcs) of the local tidal parameters for the Riga station are $h_2 = 0.6891 \pm 0.0009$ and $l_2 = 0.1043 \pm 0.0004$. The adjusted parameter h_2 reaches the level close to its final value after about 70 months (Fig. 1). This should therefore be considered the minimum interval necessary for the estimation of the local Love number h_2 for the Riga station. The adjusted parameter l_2 approximately approaches its final value after 80 months (Fig. 2), and this is the minimum interval necessary for the estimation of the local Shida number l_2 for the Riga station.

So far no local tidal parameters for the Riga station have been estimated. Also, such estimates have not been performed for other locations in Latvia. Hence the obtained results can only be compared with the nominal h_2, l_2 values and with other global estimates of these parameters. The estimated local values of h_2 and l_2 differ from their nominal values (Petit & Luzum 2010) by 0.0813 (about 14%) and 0.0196 (about 23%), respectively. Our estimates of h_2, l_2 also substantially differ from the global tidal parameters
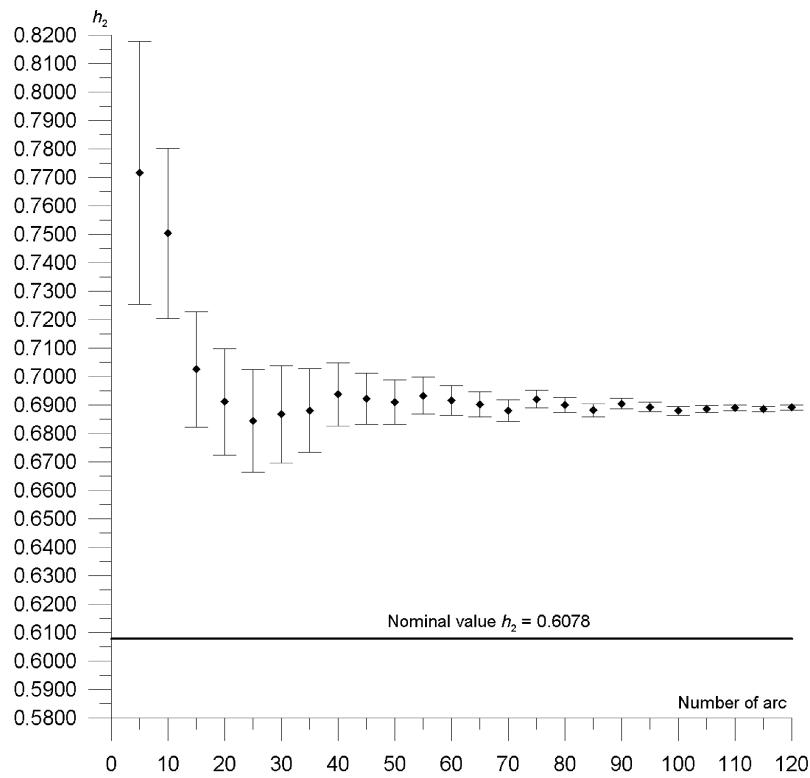
Fig. 1. The sequential solution for the local Love number h_2 for the Riga station estimated in the combined analysis based on data for LAGEOS-1 and LAGEOS-2. The final adjusted value (for 120 arcs) of the local Love number h_2 is 0.6891 ± 0.0009.
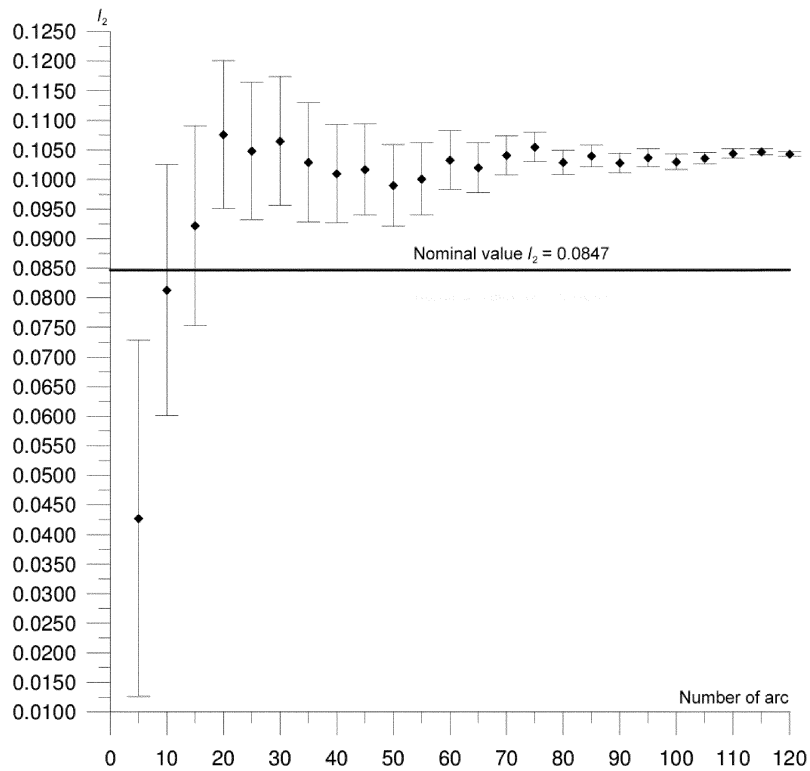
Fig. 2. The sequential solution for the local Shida number l_2 for the Riga station estimated in the combined analysis based on data for LAGEOS-1 and LAGEOS-2. The final adjusted value (for 120 arcs) of the local Shida number l_2 is 0.1043 ± 0.0004.

$h_2 = 0.6140 \pm 0.0005$, $l_2 = 0.0876 \pm 0.0002$ calculated in Jagoda et al. (2017). The difference for h_2 is approximately 12% (0.0751), for l_2 approximately 19% (0.0167). Unpublished estimates of local tidal parameters for the Polish Borowiec station (No. 7811) lead to the following values: $h_2 = 0.7308$, $l_2 = 0.1226$. Therefore, the obtained results differ significantly (approximately 6% for h_2 and 17% for l_2, respectively) from the values obtained for the Riga station.

The formal errors of the estimated values are ±0.0009 for h_2 and ±0.0004 for l_2. Therefore, the application of a long enough observation time interval makes it possible to calculate the local tidal parameters with an accuracy close to the accuracy of global parameters reached using the period of 2 years (Jagoda et al. 2017). Such high accuracy of the local tidal parameters is reached in our analysis by using 15 years of satellite data.

Figures 1 and 2 indicate that the formal error of the parameters h_2 and l_2 also reaches a very low level after involving approximately 70 and 80 months of orbital arcs into the calculations. These time scales coincide with the time after which fluctuations in the subsequent iterations of the parameters h_2 and l_2 also became very small. Therefore, the necessary time interval for reaching an adequate estimate of the local tidal parameters for the Riga station is about 7 years. This is much longer than in the case of global parameters (about 2 years; Jagoda et al. 2017).

The values of horizontal displacements of Earth's masses resulting from tidal forces (as described by the Shida number) are much lower and more difficult to measure than radial displacements (as described by the Love number). Consequently, the relative error of the parameter l_2 remains rather big.

To investigate the influence of the use of the adjusted local tidal parameters on the determination of the Riga station coordinates in the ITRF2014 reference frame, we compared two options:
1. the adjustment of the Riga station coordinates in the ITRF2014 reference frame using the nominal values of the Love and Shida numbers $h_2 = 0.6078$ and $l_2 = 0.0847$ (Petit & Luzum 2010);
2. the adjustment of the Riga station coordinates in the ITRF2014 reference frame using the local values of the Love and Shida numbers estimated in this paper $h_2 = 0.6891$ and $l_2 = 0.1043$.

The results of these two approaches are presented in Table 1.

The largest discrepancy between the results following options 1 and 2 (0.0069 m) becomes evident for the Z component. The difference is smallest (0.0044 m) for the X component while the difference for the Y coordinate is –0.0047 m. Jagoda (2019) showed that the application of various values of the global h_2, l_2 tidal parameters to determine the coordinates of the SLR station leads to the following magnitudes of the maximal effect upon components of X, Y, Z, respectively: 3 mm (stations: Graz, No. 7839 and Wettzell, No. 8834), 3 mm (stations: Yarragadee, No. 7090 and Changchun, No. 7237) and 4 mm (stations: Yarragadee, No. 7090 and Monument Peak, No. 7110). The obtained mean discrepancies of X, Y, Z for the nine SLR stations used in the analysis of Jagoda (2019) were 2 mm, 2 mm and 3 mm, respectively. These values are less than a half compared to the ones obtained for the Riga station using the local values of h_2, l_2.

In conclusion, this paper presents the calculations of adjusted local tidal parameters h_2, l_2 for the Riga SLR station obtained from a common solution based on 15 years (2004–2018) of LAGEOS-1 and LAGEOS-2 data, and their influence on the determination of the Riga station coordinates in the ITRF2014 reference frame. Large discrepancies between the determined local tidal parameters for the Riga station and the widely used nominal values demonstrate the necessity of more exact estimates of the values of local tidal parameters and the practical importance of using such estimates in calculating coordinates of observation stations. More generally the highlighted discrepancies indicate a need for further research regarding other areas of the Earth's crust.

Table 1. Estimated values of the Riga station coordinates X, Y, Z and their standard deviations $\sigma_X, \sigma_Y, \sigma_Z$ (m) in the ITRF2014 system and of these coordinates estimated using options 1 and 2

ITRF2014 (Altamimi et al. 2016)	Option 1	Option 2	Option 1 minus option 2
3183895.6372	3183895.6244 ± 0.0027	3183895.6200 ± 0.0027	0.0044
1421497.2080	1421497.2178 ± 0.0021	1421497.2225 ± 0.0021	−0.0047
5322803.7926	5322803.7842 ± 0.0018	5322803.7773 ± 0.0018	0.0069

REFERENCES

Altamimi, Z., Rebischung, P., Métivier, L. & Collilieux, X. 2016. ITRF2014: a new release of the International Terrestrial Reference Frame modeling nonlinear station motions. *Journal of Geophysical Research*, **121**, 6109–6131.

Bizouard, C., Lambert, S., Becker, O. & Richard, J. Y. 2017. *Combined Solution C04 for Earth Rotation Parameters Consistent with International Terrestrial Reference Frame 2014*. IERS Earth Orientation Product Centre, Observatoire de Paris, France, 15 pp.

Carrère, L., Lyard, F., Cancet, M., Guillot, A. & Picot, N. 2016. Finite element solution FES 2014, a new tidal model – Validation results and perspectives for improvements. *Presentation at the ESA Living Planet Conference, Prague 2016.*

Folkner, W. M., Charlot, P., Finger, M. H., Williams, J. G., Sovers, O. J., Newhall, X. X. & Standish, E. M. Jr. 1994. Determination of the extragalactic-planetary frame tie from joint analysis of radio interferometric and lunar laser ranging measurements. *Astronomy and Astrophysics*, **287**, 279–289.

Jagoda, M. 2019. Influence of use of different values of tidal parameters h_2, l_2 on determination of coordinates of SLR stations. *Studia Geophysica et Geodaetica*, **63**, 71–82.

Jagoda, M. & Rutkowska, M. 2016. Estimation of the Love numbers: k_2, k_3 using SLR data of the LAGEOS1, LAGEOS2, STELLA and STARLETTE satellites. *Acta Geodaetica et Geophysica*, **51**, 493–504.

Jagoda, M., Rutkowska, M. & Kraszewska, K. 2017. The evaluation of time variability of tidal parameters h and l using SLR technique. *Acta Geodynamica et Geomaterialia*, **14**, 153–158.

Jagoda, M., Rutkowska, M., Kraszewska, K. & Suchocki, C. 2018. Time changes of the potential Love tidal parameters k_2 and k_3. *Studia Geophysica et Geodaetica*, **62**, 586–595.

Lejba, P. & Schillak, S. 2011. Determination of station positions and velocities from laser ranging observations to Ajisai, Starlette and Stella satellites. *Advances in Space Research*, **47**, 654–662.

McCarthy, J. J., Rowton, S., Moore, D., Pavlis, D. E., Luthcke, S. B. & Tsaoussi, L. S. 1993. *GEODYN II System Operation Manual*, Vols 1–5. STX System Corp. Lanham MD 20706, USA.

Mendes, V. B. & Pavlis, E. C. 2004. High-accuracy zenith delay prediction at optical wavelengths. *Geophysical Research Letters*, **31**, L14602.

Petit, G. & Luzum, B. (eds). 2010. *IERS Conventions (IERS Technical Note No. 36)*. Verlag des Bundesamts für Kartographie und Geodesie, Frankfurt am Main, 179 pp.

Pearlman, M. R., Degnan, J. J. & Bosworth, J. M. 2002. The International Laser Ranging Service. *Advances in Space Research*, **30**, 135–143.

Pearlman, M., Arnold, D., Davis, M., Barlier, F., Biancale, R., Vasiliev, V., Ciufolini, I., Paolozzi, A., Pavlis, E. C., Sośnica, K. & Bloßfeld, M. 2019. Laser geodetic satellites: a high-accuracy scientific tool. *Journal of Geodesy*, https://doi.org/10.1007/s00190-019-01228-y.

Ray, R. D. & Ponte, R. M. 2003. Barometric tides from ECMWF operational analyses. *Annales Geophysicae*, **21**, 1897–1910.

Rutkowska, M. & Jagoda, M. 2010. Estimation of the elastic Earth parameters (h_2, l_2) using SLR data. *Advances in Space Research*, **46**, 859–871.

Rutkowska, M. & Jagoda, M. 2015. SLR technique used for description of the Earth elasticity. *Artificial Satellites*, **50**, 127–141.

Schillak, S. 2004. Analysis of the process of the determination of station coordinates by satellite laser ranging based on results of the Borowiec SLR station in 1993.5-2000.5. Part 2: Determination of the station coordinates. *Artificial Satellites*, **39**, 265–287.

Tapley, B. D., Flechtner, F., Bettadpur, S. V. & Watkins, M. M. 2013. The status and future prospect for GRACE after the first decade. *American Geophysical Union, Fall Meeting 2013*, abstract G32A-01.

Maakoore loodete parameetrid Riia laserkaugusmõõtmiste jaamas LAGEOS-1 ja LAGEOS-2 satelliidiandmete põhjal

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On esitatud satelliitide LAGEOS-1 ja LAGEOS-2 laserkaugusmõõtmiste 15 aasta pikkusel andmestikul (2004–2019) põhinevad Love'i ning Shida arvude h_2, l_2 täpsustatud hinnangud Riia jaama (nr 18844401) jaoks. Need arvud peegeldavad maakoore reaktsiooni loodeid põhjustavaid jõude. Saadud hinnangud $h_2 = 0{,}6891 \pm 0{,}0009$ ja $l_2 = 0{,}1043 \pm 0{,}0004$ erinevad märgatavalt standardsetest väärtustest $h_2 = 0{,}6078$ ja $l_2 = 0{,}0847$. Uutel hinnangutel põhinevad Riia laserkaugusmõõtmiste jaama koordinaadid erinevad kasutusel olevatest 4,4 mm (X-koordinaat), 4,7 mm (Y-koordinaat) ja 6,9 mm (Z-koordinaat) võrra.