TIDAL PARAMETERS AS A TOOL FOR THE DETERMINATION OF THE COORDINATES OF THE SLR STATIONS

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ABSTRACT: One of the primary objectives of satellite geodesy is the determination of coordinates of the satellite laser ranging (SLR) stations. This task is conducted by using laser ranging techniques. The main goal of the current study was to assess the influence of using varied values of the tidal parameters (Love h_2 and Shida l_2 numbers) on the determination of the positions of chosen SLR stations. The obtained results are presented for coordinates determination conducted for six SLR stations: Mt Stromlo (no. 7825, Australia), Matera (no. 7941, Italy), Grasse (no. 7845, France), McDonald (no. 7080, USA), Arequipa (no. 7403, Peru) and Beijing (no. 7249, China). The analysis covers SLR data for 2 satellites (LAGEOS1 and LAGEOS2), which were observed for 10 consecutive years (from 2008 to 2018). The analysis was performed using the ITRF2014 reference frame in two scenarios of calculations. In scenario 1, the SLR stations coordinates were calculated using the nominal values as per the International Earth Rotation and Reference System Service (IERS) standards recommendation of the Love/Shida numbers: $h_2 = 0.6078$, $l_2 = 0.0847$. In scenario 2, the coordinates were estimated using the harnessing values of the Love/Shida numbers ($h_2 = 0.6140$ and $l_2 = 0.0876$), which were proposed by authors in a previous publication. The effect of the application of different values of the Love/Shida numbers for the determination of SLR stations coordinates was scrutinized.

Keywords: Love/Shida numbers, Satellite Laser Ranging, SLR stations, ITRF2014, tidal parameters

INTRODUCTION

Before this study, the research team conducted research programmes (Rutkowska and Jagoda, 2012; Jagoda and Rutkowska, 2013; Jagoda et al., 2016) focused on the determination of tidal parameters h_2 and l_2 (Love and Shida numbers, respectively) based on satellite laser ranging (SLR) data. Parameter h_2 describes the ratio of radial displacements of earth's mass to static tide heights. Parameter l_2 is associated with the horizontal displacements (Melchior 1982). Radial displacements are larger by an order of magnitude in comparison with the horizontal displacements. As stated by Rutkowska and Jagoda (2015), the values of the Love number h and Shida number l ranges from 0 to 1 for the elastic body. The shape of the earth alters in response to changes in the tide-generating potential. The tidal displacement of the earth's mass causes the oscillations of stations' positions. This oscillations influence the distance

between the satellite and the laser system. The phenomenon wields significant impact on the SLR observation equation (1) (McCarthy et al., 1999) and, subsequently, on the accuracy of the calculated solution.

$$(O_i - C_i) = -\sum_{j=1}^n \frac{\partial C_i}{\partial \varepsilon_j} d\varepsilon_j + dO_i \quad (1)$$

where

i and j are the numbers of measurements and adjusted parameters,

$d\varepsilon_j$ is the corrections to the j th parameter (e.g. a station's coordinates),

dO_i is the error of observation.

It should be taken into account when the determination of positions of stations is needed with the accuracy of a few millimetres. Keeping all above facts in mind, an attempt was made to survey the influence of harnessing varied values of the Love/Shida numbers (h_2 , l_2) on computing coordinates of the SLR stations in the ITRF2014 (Altamimi et al., 2016). Moreover, the tides generate dynamic satellite perturbations alongside a displacement of a station's ground positions. The displacement of a station's ground position induced by tides is depicted by equation (2) proposed by McCarthy et al. (1999):

$$\Delta \vec{r} = \sum_{j=2}^3 \left[\frac{GM_j}{GM_{Earth}} \frac{r^4}{R_j^3} \right] \left\{ [3l_2 (\hat{R}_j \hat{r})] \hat{R}_j + \left[3 \left(\frac{h_2}{2} - l_2 \right) (\hat{R}_j \hat{r})^2 - \frac{h_2}{2} \right] \hat{r} \right\} \quad (2)$$

where

GM_j , GM_{Earth} are the centric gravitational constant for the moon or the sun ($j = 2$ or $j = 3$)

and earth,

h_2 and l_2 are the nominal second degree of the Love and Shida numbers,

R_j is the geocentric distance,

$\hat{R}_j$ is the unit vector from the geocenter to the moon or the sun,

$\hat{r}$ is the unit vector from the geocenter to the station,

r is the magnitude of $\hat{r}$.

1. MOTIVATION AND OBJECTIVE

The planet earth is continuously changing in time. The gravitational effect of the sun and moon on the earth's surface induces tides. They create variations in the earth's mass distribution as well as displacement of the ground stations' positions. One of the key objectives of the satellite geodesy is the determination of the SLR stations coordinates from the SLR data. Over the years, it has been proven by multiple research teams (Rutkowska et al., 1995; Schillak, 2003; Lejba and Schillak, 2011) that the values of the determined coordinates and precision of the determination are influenced by different factors. The most frequently pointed factors by research teams are utilized coordinate system, population of the stations used for measurements, quantity of the measurements and their quality, data harnessed for the assessments of the orbital arcs and the locations of the stations and the selection of stations used for defining the orbit.

The principal objective of this study was to assess the influence of harnessing different values of the Love h_2 and Shida l_2 numbers on the determination of the coordinates of the selected SLR stations.

2. METHOD

The conducted study was based on the satellite laser data of two satellites: LAGEOS1 and LAGEOS2. The data were recorded by the SLR stations global network from 1 January 2008 to 1 January 2018. The sequence of the adjustment procedure is shown in Figure 1. The LAGEOS orbits were computed using the 11th order predictor–corrector Cowell’s method. In this way, the satellite equations of motion were numerically embedded in rectangular coordinates. The method in question was described in depth by McCarthy et al. (1999). The forces that disarrange the orbits of satellites were designed with the highest possible accuracy. The GEODYN II software (McCarthy et al., 1999) was used for calculations associated with applying the forces and constants model by recommendation of IERS Conventions 2010 (Petit and Luzum, 2010) and by ILRS Analysis Centers (Pearlman et al., 2002) (see Fig. 1). The data of LAGEOS1 and LAGEOS2 were taken from the Crustal Dynamics Data Information System (CDDIS) of the ILRS. Sourced data were in the form of 2-minute normal points. It had to be divided into 7-day arcs with half day overlaps between successive arcs.

The achieved solution enables the estimation of the Root Mean Square error (RMS) of the post-fit residuals at the initial epoch of arc. The authors achieved the following values of the RMS of the post-fit residuals: RMS LAGEOS1 = 12 mm, RMS LAGEOS2 = 10 mm (on an average for all the 7-day arcs). During the iterative process of orbit correction convergence in accordance with the formula $\{RMS(m) - RMS(m-1)\} < 0.01cm$ (see Fig. 1), the coordinates (X , Y and Z) of the following SLR stations were estimated in the ITRF2014 system: Mt Stromlo (7825, Australia), Matera (7941, Italy), Grasse (7845, France), McDonald (7080, USA), Arequipa (7403, Peru) and Beijing (7249, China). One has to keep in mind that equation (1) was created to be solved by the Bayesian least squares method (McCarthy et al., 1999). The coordinates were determined for both LAGEOS satellites separately for each station. The location of the stations is shown in Figure 2.

The analysis was executed in two scenarios of calculations for the adjustment of the coordinates of the SLR stations in ITRF2014. In scenario 1, the adjustment was calculated using the nominal values of the Love/Shida numbers: $h_2 = 0.6078$ and $l_2 = 0.0847$ (Petit and Luzum 2010). In scenario 2, the adjustment was calculated using the values of the Love/Shida numbers as per the estimation by Jagoda et al. (2016): $h_2 = 0.6140$ and $l_2 = 0.0876$. Subsequently, the impact of the values of changes in the Love/Shida numbers on the stations’ positions computation was scrutinized.

Fig. 1. The procedure for adjusting the coordinates of the SLR stations.

Fig. 2. Location of the SLR stations.

3. RESULTS AND DISCUSSION

The results of the estimated coordinates of the stations are summarized in Table 1. In the first column, the ID number of an SLR station is provided. In the second column, the coordinates X , Y and Z in ITRF2014 reference frame (Altamimi et al. 2016) are listed. Columns 3 and 4 present the results of the obtained coordinates and standard deviations of the components X , Y and Z in two scenarios: applying the nominal values of h_2 and l_2 given in the IERS Conventions (Petit and Luzum 2010) and using values of h_2 and l_2 estimated by Jagoda et al. (2016). The last column presents the differences between scenario 1 and scenario 2.

The most significant differences between scenario 1 and scenario 2 of the computation were obtained for the Z component (from 2.8 to 4.9 mm). The lowest discrepancy was observed for the 7845 (Grasse) and 7080 (McDonald) stations and was equal to 2.8 and 2.9 mm, respectively. The largest discrepancy was observed for the 7825 (Mt Stromlo) station and was equal to 4.9 mm. The standard result divergence for the Z component amounts to 3.5 mm. The differences of the computed values for the X component were within the range of 1.1–3.3 mm. The largest differences were observed in the case of 7249 (Beijing) and 7845 (Grasse) stations, which were 3.3 and 2.5 mm, respectively. The smallest differences of the computed values for the X component were achieved for 7941 (Matera) and 7080 (McDonald) stations, which were 1.1 and 1.4 mm, respectively. For the X component, the average difference was equal to 2.0 mm. As far as the Y coordinate is concerned, the difference between the obtained values was within the range of 1.6–4.1 mm. The lowest difference was observed for the 7845 (Grasse) station (1.6 mm). The largest difference was observed for the stations 7825 (Mt Stromlo) and 7403 (Arequipa), which was 4.1 and 4.0 mm, respectively. The standard discrepancy for the Y component amounts to 2.9 mm. When analysing the components X , Y and Z of specific stations, one can observe that the largest differences were obtained in the case of the Australian Mt Stromlo (7825) station (for Z and Y components). The smallest ones were those obtained for the Grasse (7845) station in France (for Z and Y components). The divergent results of the determined coordinates between scenario 1 and scenario 2 are not regular. They take on various values for particular coordinates X , Y and Z and specific stations. The coordinates of the stations in computation scenarios 1 and 2 were estimated based on the same data with the application of the same software and model of forces. Therefore, the single impact on the obtained coordinates was due to the influence of the application of different values of the Love h_2 and Shida l_2 numbers.

Due to a reasonably narrow period of time of observation the coordinates presented in this study cannot be used as the final stations' positions. The presented analysis should be considered as a demonstration of the impact of the used values of the Love/Shida numbers on the computed coordinates of stations in question. The carried out study demonstrates the fact that it constitutes still another factor that should be considered when stations' coordinates are being determined. This is the reason why the Love and Shida numbers ought to be subjected to regular determination. Only updated values should be used for calculating the positions of observation stations.

Table 1. Estimated values for the coordinates of the SLR stations in ITRF2014 reference frame.

ID number of the SLR station	X, Y, Z [m] ITRF2014	Estimated X, Y, Z [m]		Scenario 1 minus Scenario 2 [m]
		Using values of h_2, l_2 proposed in IERS Conventions (Petit and Luzum 2010)	Using values of h_2, l_2 estimated by Jagoda et al. (2016)	
		Scenario 1	Scenario 2	
78259001	-4467064.7778 2683034.8865 -3667007.3186	-4467064.7531 $\pm$ 0.0022 2683034.8620 $\pm$ 0.0014 -3667007.3346 $\pm$ 0.0014	-4467064.7508 $\pm$ 0.0022 2683034.8579 $\pm$ 0.0014 -3667007.3395 $\pm$ 0.0014	-0.0023 0.0041 0.0049
79417701	4641978.6171 1393067.7231 4133249.6227	4641978.6342 $\pm$ 0.0019 1393067.7088 $\pm$ 0.0013 4133249.6357 $\pm$ 0.0014	4641978.6331 $\pm$ 0.0019 1393067.7115 $\pm$ 0.0013 4133249.6320 $\pm$ 0.0014	-0.0011 -0.0027 0.0037
78457801	4581692.0031 556196.2728 4389355.2262	4581692.0294 $\pm$ 0.0023 556196.2601 $\pm$ 0.0015 4389355.2535 $\pm$ 0.0020	4581692.0269 $\pm$ 0.0023 556196.2617 $\pm$ 0.0015 4389355.2563 $\pm$ 0.0020	0.0025 -0.0016 -0.0028
70802419	-1330021.2329 -5328401.8419 3236480.7171	-1330021.2170 $\pm$ 0.0020 -5328401.8166 $\pm$ 0.0016 3236480.7329 $\pm$ 0.0015	-1330021.2184 $\pm$ 0.0020 -5328401.8194 $\pm$ 0.0016 3236480.7300 $\pm$ 0.0015	0.0014 0.0028 0.0029
74031306	1942808.2803 -5804069.6722 -1796915.2599	1942808.2579 $\pm$ 0.0018 -5804069.6878 $\pm$ 0.0019 -1796915.2343 $\pm$ 0.0017	1942808.2560 $\pm$ 0.0018 -5804069.6918 $\pm$ 0.0019 -1796915.2311 $\pm$ 0.0017	0.0019 0.0040 -0.0032
72496102	-2148760.7559 4426759.5584 4044509.6074	-2148760.7802 $\pm$ 0.0021 4426759.5411 $\pm$ 0.0022 4044509.6327 $\pm$ 0.0012	-2148760.7835 $\pm$ 0.0021 4426759.5435 $\pm$ 0.0022 4044509.6292 $\pm$ 0.0012	0.0033 -0.0024 0.0035

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