to appear in Proceedings of the IX HOTINE-MARUSSI SYMPOSIUM, Rome, 18-22 June, 2018
(International Association of Geodesy Symposia, Springer 2019)

Impacts of the LARES and LARES-2 satellite missions on the SLR terrestrial reference frame

Rolf König · Susanne Glaser · Ignazio Ciufolini · Antonio Paolozzi

Received: date / Accepted: date

Abstract LARES, an Italian satellite launched in 2012, and its successor LARES-2 approved by the Italian Space Agency, aim at the precise measurement of frame dragging predicted by General Relativity and other tests of fundamental physics. Both satellites are equipped with Laser retro-reflectors for Satellite Laser Ranging (SLR). Both satellites are also the most dense particles ever placed in an orbit around the Earth thus being nearly undisturbed by nuisance forces as atmospheric drag or solar radiation pressure. They are therefore ideally suited to contribute to the terrestrial reference frame (TRF). At GFZ we have implemented a tool to realistically simulate observations of all four space-geodetic techniques and to generate a TRF from that. Here we augment the LAGEOS based SLR simulation by LARES and LARES-2 simulations. It turns out that LARES and LARES-2, alone or in combination, can not deliver TRFs that meet the quality of the LAGEOS based TRF. However once the LARES are combined with the LAGEOS satellites the formal errors of the estimated ground station coordinates and velocities and the co-estimated Earth Rotation Parameters are considerably reduced. The improvement is beyond what is expected from error propagation due to the increased number of observations. Also importantly, the improvement concerns in particular origin and scale of the TRF of about 25 % w.r.t. the LAGEOS- combined TRF. Also we find that co-estimation of weekly average range biases for all stations does not change the resulting TRFs in this simulation scenario free of systematic errors.

Keywords LARES · LARES-2 · LAGEOS · LAGEOS-2 · Terrestrial Reference Frame

R. König
German Research Centre for Geosciences GFZ
c/o DLR Oberpfaffenhofen
82234 Wessling
Germany
Tel.: +49-8153-9083214
Fax: +49-8153-9083202
E-mail: koenigr@gfz-potsdam.de

S. Glaser
German Research Centre for Geosciences GFZ
Telegrafenberg
14473 Potsdam
Germany

I. Ciufolini
Università del Salento
Lecce
Italy

A. Paolozzi
Sapienza Università di Roma
Roma
Italy

1 Introduction

The project GGOS-SIM (Schuh et al., 2015) resulted in a powerful tool that enables the simulation of the space-geodetic techniques Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) in order to test various effects on the Terrestrial Reference Frame (TRF). The requirements set by the Global Geodetic Observing System (GGOS) on accuracy and stability of the TRF are 1 mm and 0.1 mm/yr (Gross et al., 2009). In a first attempt, the observations of the 2008 to 2014 (inlcusive) ground networks of all the space-geodetic techniques have been simulated close to reality. Eventally the individual techniques are evaluated for the derivation of technique-specific and combined TRFs. The simulation of VLBI observations and VLBI-only TRFs is described in Glaser et al. (2016). The combination of the VLBI and SLR techniques based on so-called global and local ties and the extension of the global VLBI network by new stations is discussed in Glaser et al. (2017). The extension by new stations in case of SLR is discussed in Otsubo et al. (2016), Kehm et al. (2018) and Glaser et al. (2019). The impact of different local tie scenarios on the combined GPS, SLR, and VLBI TRF was investigated in Glaser et al. (2018). Simulations of LARES and LARES-2 regarding their main purpose to test General Relativity were performed by e.g. Ciufolini et al. (2013) and Ciufolini et al. (2017b)

For recent global TRFs, f.i. the ITRF2014 (Altamimi et al., 2016), SLR provides the fundamental datum parameters origin and, together with VLBI, the scale. The input from SLR to the ITRF2014 is provided by the analysis and combination centers of the International Laser Ranging Service (ILRS, Pearlman et al. (2002)) where the solution is mainly based on LAGEOS and LAGEOS-2 observations. Also involved are observations to the ETALON and ETALON-2 satellites, however their amount is so small that they hardly play any role. Therefore the GGOS-SIM SLR base is composed of LAGEOS mission data only. Currently the Analysis Standing Committee (ASC) of the ILRS has pilot projects on the way to also include LARES observations for the contribution to the next generation ITRF.

In the following the GGOS-SIM base of LAGEOS and LAGEOS-2 SLR simulated observations is augmented by simulated observations to the satellites LARES and LARES-2. With the augmented data base we evaluate their impact on the resulting TRF with a particular view on origin and scale.

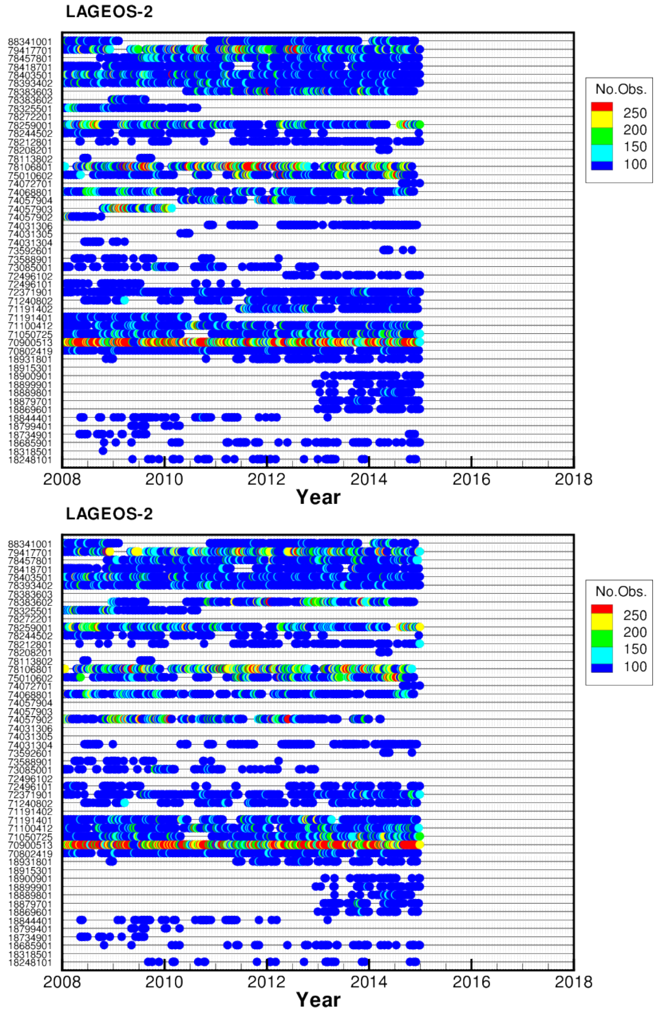

Fig. 1 Timely distribution and number of observations for LAGEOS-2, (top) for the real data, (bottom) for the simulated data

2 The Satellite Missions and Data Used

The characteristics of the satellite missions involved here are listed in Tab. 1. Where the LAGEOS satellites have been designed for geophysical applications, the LARES satellites serve the measurement of frame-dragging, a phenomenon predicted by General Relativity (GR) (Ciufolini et al., 2017a). However both objectives can be assigned to each mission due to the cannon ball shape of the satellites and their favorable area-to-mass ratio minimizing nuisance forces, e.g. solar radiation pressure. Indeed LARES obeys the lowest value of area-to-mass ratio, making it the densest object ever sent into orbit and therefore makes it together with the large eccentricity of the orbit a nearly ideal particle for testing effects of GR (Paolozzi et al., 2015).

For GGOS-SIM the LAGEOS and LAGEOS-2 SLR observations are simulated close to reality in terms of time of operation of a station, and in terms of number and accuracy. For this the real SLR observations of 51 ground stations were analyzed first. The simulations followed then assuming no systematic errors, just white noise, with no leaps in the coordinate time series. Fig. 1 shows the number of observations for each station for each arc over the analysis period for the real and the simulated data at the example of LAGEOS-2. Slight differences can be found where stations observing in reality with different eccentricities (and therefore with different occupation numbers) are simulated as one site only. Also one station with very few passes was left out.

Table 1 Characteristics of the SLR missions.

Satellite	Launch (year)	Altitude (km)	Eccentricity	Inclination (deg)	Area-to-Mass Ratio (m^2/kg)
LAGEOS	1976	5,900	0.004	109.8	0.000695
LAGEOS-2	1992	5,800	0.014	52.6	0.000697
LARES	2012	1,440	0.001	69.5	0.000269
LARES-2	2019 - 2020	5,900	0.001	70.2	0.000269

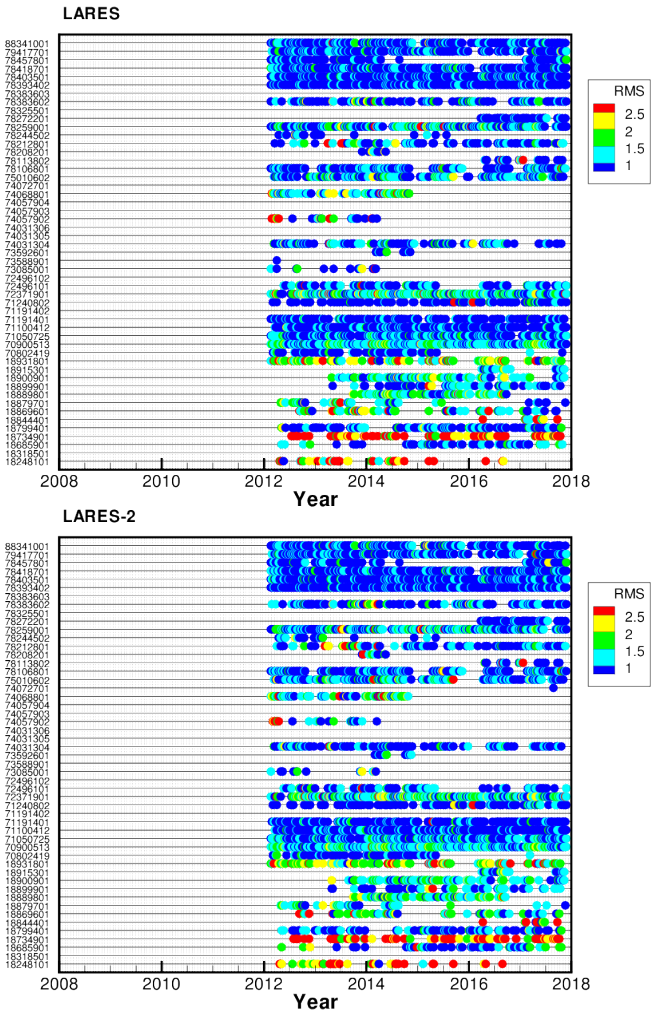

Fig. 2 Timely distribution and accuracy of the simulated observations for LARES and LARES-2

LARES has been tracked by SLR since its launch in 2012, therefore the simulations are as in case of the LAGEOS satellites simulated close to reality in terms of time of operations, and number and accuracy of the observations. Fig. 2 shows the orbital fits for each station for each arc at the example of LARES and LARES-2 in the simulation. It has to be noted that the observation period of LARES starts due to its launch in 2012 only which yields an overlap with the LAGEOS analysis period of three years only. In order to get a longer analysis period to properly solve for the velocities of new stations in the evolving network, the analysis for LARES is prolonged to 2017 (inclusive). LARES-2 is not yet in orbit, however already approved as mission by the Italian Space Agency (Agenzia Spaziale Italiana - ASI) and scheduled for a launch around 2019 to 2020. The simulation of the LARES-2 observations follows the real world scenario of LARES in the years 2012 to 2017 in terms of time of operations, and number and accuracy of observed ranges. Potentially the number of LARES-2 observations could be higher than that of LARES due to its higher orbital altitude. In fact, in spite of the expected much lower intensity of laser returns from LARES-2 with respect to LARES, the coverage for a higher altitude satellite is more favourable (see Fig. 3). For the simulations however the geometry will not suffer as the observations are distributed over the respective arcs.

The geometrical distribution of the observations can be seen in Fig. 3 where the footprints of all observations in the analysis periods are sampled for number of occurence in 1x1 degree bins over the Earth's surface. It becomes clear that large parts of the orbit of LARES are not covered with observations. But LARES-2 covers about the same geographical area as LAGEOS due to its identical orbital altitude and its inclination supplementary to that of LAGEOS delimiting the geographical distribution towards Northern and Southern latitudes the same way.

3 Precise Orbit Determination

Before starting the simulations, Precise Orbit Determination (POD) of real LAGEOS, LAGEOS-2, and LARES observations was performed. For this we rely on our orbit and Earth system parameter estimation software EPOS-OC (Zhu et al., 2004). EPOS-OC uses the dynamic approach, based on modelling the forces acting on the satellite. The highly non-linear problem is solved by differential parameter improvement minimizing the residuals of the observations in the least squares sense. Most of the adopted dynamic and geometric models, and the measurement systematic corrections follow the IERS conventions 2010 (Petit and Luzum, 2010), some particular choices are given in Tab. 2.

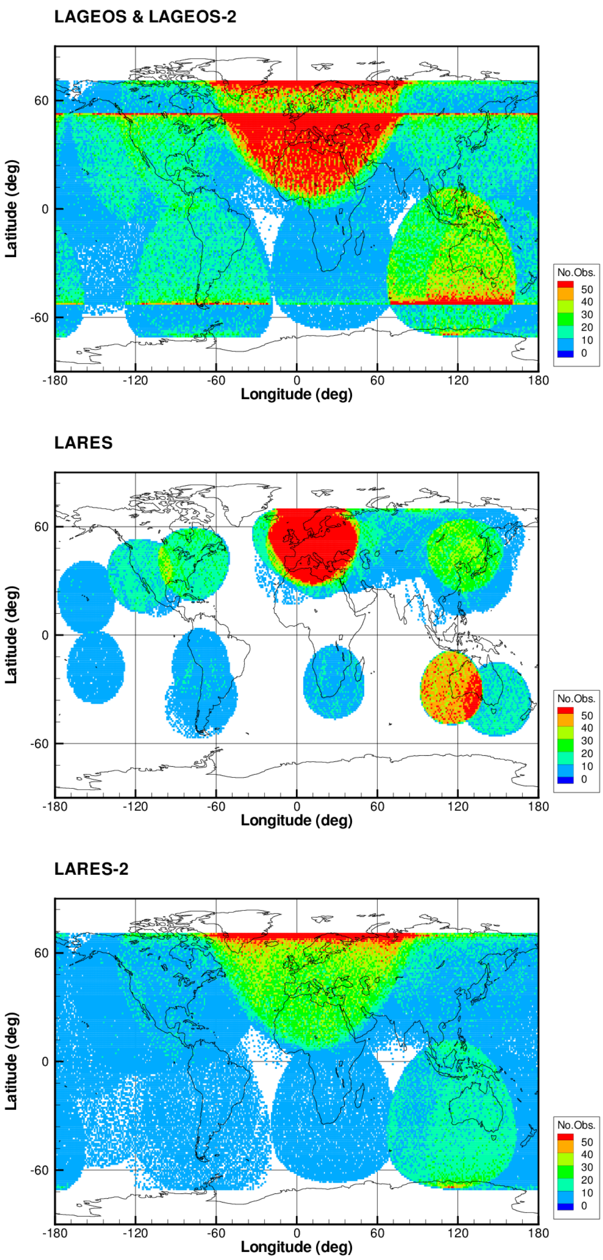

Fig. 3 Location and number of the simulated observations

Processing is conducted in seven day arcs. Modelling and parametrization for the LAGEOS satellites is chosen according to GFZ's SLR contribution to the generation of the ITRF2008. The modelling for LARES is identical, however slight differences in parametrization are applied to account for its different response to errors of the gravity field model. The parametrizations are summarized in Tab. 3.

The results of POD of all satellites based on real and simulated data are compared in Tab. 4. The numbers confirm the similarity of the simulations with reality.

Table 2 Models for POD.

Type	Model
Gravity model	EIGEN-6C
ERPs	IERS C04 08
	Bizouard and Gambis (2011)
Ephemeries	JPL421
Solar radiation	Cannon ball
Albedo	Heurtel
Ocean tides	Not modelled
Ocean pole tides	Desai (2002)
Coordinates	SLRF2008
Ocean loading	Chalmers feat. FES2004
Atmospheric loading	Not applied
Troposphere	Mendes and Pavlis (2004)

4 Terrestrial Reference Frame

After verifying the simulated observations in POD, the simulated observations are further processed to yield weekly normal equations containing position and velocity parameters of the ground network and ERPs. The weekly normal equations are then accumulated to yield one normal equation for LARES and one for LARES-2. From these normal equations, TRFs are generated for LARES and LARES-2 separately and for the combination of both. Eventually the LARES and LARES-2 normal equations are added to the LAGEOS- combined solution either one by one or in combination. Tab. 5 compiles the mean percentages of improvement of the formal errors for positions and velocities of the stations, and of the ERPs, i.e. the two polar motions and the Length-of-Day (LOD) parameter, w.r.t. the LAGEOS-combined solution. The improvement expected from error propagation due to the increased number of observations are also given in the last column denoted by "Exp.".

The LARES-only and the LARES-2-only TRFs do not meet the expected precision of the station position and ERP parameters, so does not the LARES-combined TRF featuring a number of observations comparable to that of the LAGEOS combination due to a less favourable geometry. On the other hand the station velocities from the LARES solutions exhibit the expected precision meaning that geometry does not play that role here. At a profit the improvement of the LAGEOS-combined TRF by adding LARES and LARES-2 can be seen in pronounced smaller formal errors of the estimated positions and velocities of the ground stations. This improvement goes beyond the expectation due to the increased number of observations and can be attributed to a better observation geometry in case of the positions, the station velocities benefit from the longer analysis period. The increase in precision of the estimated ERPs however stays behind expectation and is

Table 3 Parametrization.

Type	LAGEOS	LARES
Initial states	6/arc	6/arc
Albedo global scaling factor	1/arc	1/arc
Atmosph. drag global scaling factor	—	1/arc
Empirical accelerations	1 const. acc./4d in T 1cpr/4d in T	1 const. acc./4d in T 1cpr/4d in T
ERPs	xp, yp, LOD /d	xp, yp, LOD /d
Coordinates	X, Y, Z /station/arc	X, Y, Z /station/arc
Velocities	$\dot{X}$ $\dot{Y}$, $\dot{Z}$ /station/arc	$\dot{X}$ $\dot{Y}$, $\dot{Z}$ /station/arc

Table 4 Orbital fits.

Satellite	Real Data		Simulated Data	
	RMS (cm)	No.	RMS (cm)	No.
LAGEOS	0.88	528,742	0.86	529,600
LAGEOS-2	0.91	468,869	0.89	469,994
LARES	1.23	476,270	1.20	477,505
LARES-2	—	——-	1.20	474,453

owned to the small overlap of three years only between the analysis periods of the LAGEOS and LARES satellites.

Table 5 Improvement of formal errors w.r.t. LAGEOS- combined (LC)

Satellite	Pos. (%)	Vel. (%)	ERPs (%)	Exp. (%)
LARES	-95	-38	-143	-45
LARES-2	-103	-43	-149	-46
LARES+LARES-2	-37	3	-64	-2
LC+LARES	38	53	10	18
LC+LARES-2	36	51	9	18
LC+LARES+LARES-2	43	57	16	28

The improvement of the TRF in its defining parameters origin and scale is computed according to the approach by Sillard and Boucher (2001) where the variance-covariance matrix of the solution is divided into a datum dependent part and an independent one. The dependent part shows the reference system effect in the standard deviations of the Helmert parameters. As SLR provides origin and scale in international TRF solutions where the space-geodetic techniques are combined, we compile in Tab. 6 the improvement of origin and scale w.r.t. the LAGEOS-combined solution of the LARES-only, the LARES-2-only, and of the LARES-combined TRF and the impact of the addition of LARES or LARES-2 or of both to the LAGEOS- combined solution.

The LARES-only and the LARES-2-only TRFs can not compete with the LAGEOS-combined TRF in terms of origin and scale definition. The LARES-combined TRF shows just a slight degradation in origin but a large deficiency in scale. The latter one might come from the relatively low altitude of LARES coming along with smaller ranges between the ground stations and the satellite and therefore resulting in less favorable ratios between the observed ranges and their errors. However once the LARES and LARES-2 observations are combined with the LAGEOS-combined solution, indeed considerable improvements of up to 29 % can be expected for the core contribution of SLR to the TRF, i.e. origin and scale.

Table 6 Improvement in origin and scale w.r.t. LAGEOS-combined (LC)

Satellite	Tx (%)	Ty (%)	Tz (%)	Scale (%)
LARES	-79	-73	-46	-157
LARES-2	-79	-71	-72	-140
LARES+LARES-2	-19	-15	-5	-68
LC+LARES	12	13	21	4
LC+LARES-2	12	14	14	5
LC+LARES+LARES-2	23	24	29	10

Apart from the improvements in the stochastic characteristics of the estimated station positions and velocities, the question arises whether adding of LARES and LARES-2 to the TRF solution leads to any systematic changes of the TRF. Therefore 14-parameter Helmert transformations are carried out where the LAGEOS+LARES, LAGEOS+LARES-2, and LAGEOS+LARES+LARES-2 TRFs are transformed w.r.t. the LAGEOS- combined TRF. All Helmert parameters are in the sub-millimeter range and are statistically not significant. This means that the addition of the new missions to the LAGEOS- combined TRF does not lead to a systematic change in the definition of the TRF.

5 On the Estimation of Range Biases

Appleby et al. (2016) advertised to estimate weekly average range biases for all SLR stations in the network in order to reduce the scale difference between SLR and very long baseline interferometry (VLBI) in the recent ITRFs. In preparation of the next generation ITRF the ILRS is running a pilot project where the estimation of range biases is analyzed. Here we follow these recommendations and estimate range biases besides station positions and velocities and ERPs for all solution types. The range biases are set up per station per satellite per arc (week) and endowed with an a priori sigma of 1 m. From all solutions with range biases being estimated adjacent TRFs are generated that can be compared to their counterparts with no range biases estimated. The comparison is done via 14-parameter Helmert transformations, the results are compiled in Tab. 7.

In all cases, i.e. LAGEOS-combined, LARES-only, LARES-2-only, and LAGEOS-combined plus LARES plus LARES-2, all Helmert parameters turn out with values for translations, rotations and scale and their derivatives below statistical significance. This means that estimation of range biases as described does not lead to a change of the TRF. In particular one should take note that the scale is not destroyed by estimating range biases in this simulation scenario where no systematic errors have been introduced a priori. In the real world, where systematic errors can not be ruled out, the conclusion might be different. To find out if systematic errors would change the above findings, extensive analyzes will be needed that are beyond the scope of this paper and are left therefore for future studies.

Table 7 14-Parameter Helmert transformations between solutions with range biases being estimated yes and no

Parameter	Value (mm)	St.Dev. (mm)	Deriv. (mm/a)	St.Dev. (mm/a)
LAGEOS-comb:				
Tx	-0.09	0.48	-0.30	0.30
Ty	-0.12	0.49	0.08	0.30
Tz	-0.29	0.47	-0.10	0.29
Rx	-0.09	0.59	-0.09	0.36
Ry	-0.16	0.58	-0.19	0.36
Rz	0.05	0.56	-0.02	0.35
Sc	-0.35	0.46	-0.21	0.29
LARES:				
Tx	-0.46	0.80	0.03	0.17
Ty	1.11	0.81	-0.25	0.17
Tz	-0.58	0.77	0.04	0.17
Rx	-0.20	0.97	0.02	0.21
Ry	0.00	0.95	0.02	0.20
Rz	0.59	0.93	-0.10	0.20
Sc	-0.58	0.77	0.19	0.17
LARES-2:				
Tx	-0.99	1.77	0.20	0.30
Ty	0.37	1.79	-0.20	0.30
Tz	0.11	1.71	-0.14	0.29
Rx	0.38	2.16	0.00	0.36
Ry	-1.04	2.10	0.15	0.35
Rz	0.15	2.05	-0.06	0.35
Sc	-1.78	1.70	0.29	0.29
LAGEOS-comb+LARES+LARES-2:				
Tx	0.12	0.19	-0.02	0.04
Ty	-0.08	0.19	0.04	0.04
Tz	-0.01	0.18	-0.01	0.04
Rx	0.26	0.23	-0.02	0.05
Ry	0.04	0.22	0.00	0.05
Rz	0.09	0.21	-0.03	0.05
Sc	-0.17	0.18	0.07	0.04

6 Summary and Conclusions

The project GGOS-SIM has provided a tool to simulate the space-geodetic techniques for the generation of global TRFs. Available are realistic, representative solutions for the years 2008 to 2014 where the SLR solutions are based on the LAGEOS and LAGEOS-2 missions. Here we simulated SLR observations to the LARES satellite over the years 2012 to 2017 following closely the analysis of the real world data. In addition we simulated SLR observations to the planned LARES-2 satellite relying on the LARES scenario in terms of accuracy and number of observations. It turns out that both LARES missions, either alone or in combination, can hardly compete with the LAGEOS combined TRF. However in combination with the LAGEOS they considerably improve the resulting coordinates and velocities of the SLR stations in terms of lower formal errors. The improvement is beyond what is expected from error propagation by the increased number of observations. The ERPs are also improved in the formal errors however at a lesser amount as in case of the coordinates because of the shorter overlap in the parameter space. Also origin and scale of the resulting TRFs are improved by about 25 % when the LAGEOS and LARES missions are combined. Systematic changes of the TRF defining parameters identified by 14-parameter Helmert transformations were not found when adding the LARES missions. An attempt was made to assess the effect of estimating weekly average range biases for all stations for all satellites besides station positions and velocites and EOPs. The resulting TRFs are statistically not different from their counterparts where the said range biases are not estimated.

Acknowledgements SLR data and a priori station coordinates are provided by the ILRS. EOPs are provided by IERS (IERS, 2018). I.C. and A.P. acknowledge ASI for supporting both LARES and LARES 2 missions under agreements No. 2015-021-R.0 and No. 2017-23-H.0 . The authors would like to thank two anonymous reviewers for their valuable comments on the manuscript.

References

Altamimi Z, Rebischung P, Métivier L, Collilieux X (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, J Geophys Res: Solid Earth, 121(8), https://doi.org/10.1002/2016JB013098

Appleby G, Rodriguez J, Altamimi Z (2016) Assessment of the accuracy of global geodetic satellite laser ranging observations and estimated impact on ITRF scale: estimation of systematic errors in LAGEOS observations 1993–2014, J Geod, 90:12, https://doi.org/10.1007/s00190-016-0929-2

Bizouard C, Gambis, D (2011) The combined solution C04 for Earth Orientation Parameters consistent with International Terrestrial Reference Frame 2008, http://hpiers.obspm.fr/iers/eop/eopc04/C04.guide.-pdf

Ciufolini I, Moreno Monge B, Paolozzi A, Koenig R, Sindoni G, Michalak G, Pavlis EC (2013) Monte Carlo simulations of the LARES space experiment to test General Relativity and fundamental physics, Classical and Quantum Gravity, 30:23, DOI 10.1088/0264-9381/30/23/235009

Ciufolini I, Paolozzi A, Pavlis E C, Sindoni G, Koenig R, Ries J C, Matzner R, Gurzadyan V, Penrose R, Rubincam D, Paris C (2017a) A new laser-ranged satellite for General Relativity and space geodesy: I. An introduction to the LARES2 space experiment, EPJp, DOI 10.1140/epjp/i2017-11635-1

Ciufolini I, Pavlis EC, Sindoni G, Ries J C, Paolozzi A, Matzner R, Koenig R, Paris C (2017b) A new laser-ranged satellite for General Relativity and space geodesy: II. Monte Carlo simulations and covariance analyses of the LARES 2 experiment, EPJp, DOI 10.1140/epjp/i2017-11636-0

Desai S (2002) Observing the pole tide with satellite altimetry, J Geophys Res, 107(C11), DOI 10.1029/2001JC001224

Glaser S, Ampatzidis D, König R, Nilsson T, Heinkelmann R, Flechner F, Schuh H (2016) Simulation of VLBI Observations to Determine a Global TRF for GGOS, IAG Symposia Series, Springer Berlin Heidelberg, DOI 10.1007/1345_2016_256

Glaser S, König R, Ampatzidis D, Nilsson T, Heinkelmann R, Flechner F, Schuh H (2017) A Global Terrestrial Reference Frame from simulated VLBI and SLR data in view of GGOS, J Geod, DOI 10.1007/s00190-017-1021-2

Glaser S, König R, Neumayer KH, Nilsson T, Heinkelmann R, Flechtner F, Schuh H (2018) On the impact of local ties on the datum realization of global terrestrial reference frames, J Geod, https://doi.org/10.1007/s00190-018-1189-0

Glaser S, König R, Neumayer KH, Balidakis K, Schuh H (2019) Future SLR station networks in the framework of simulated multi-technique terrestrial reference frames, J Geod, https://doi.org/10.1007/s00190-019-01256-8

Gross R, Beutler G, Plag HP (2009) Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020, Springer Berlin Heidelberg, Berlin, Heidelberg, chap Integrated scientific and societal user requirements and functional specifications for the GGOS, pp 209-224. DOI 10.1007/978-3-642-02687-4n 7

IERS (2018) International Earth Rotation and Reference Systems Service web site. http://www.iers.org. Accessed 30 October 2018

Kehm A, Blossfeld M, Pavlis EC, Seitz F (2017) Future global SLR network evolution and its impact on the terrestrial reference frame, J Geod 92: 625. https://doi.org/10.1007/s00190-017-1083-1

Mendes VB, Pavlis EC (2004) High accuracy zenith delay prediction at optical wavelengths, Geophys Res Lett, 31, L14602, DOI 10.1029/2004GL020308

Otsubo T, Matsuo K, Aoyama Y, Yamamoto K, Hobiger T, Kubooka T, Sekido M (2016) Effective expansion of satellite laser ranging network to improve global geodetic parameters, Earth, Planets and Space, 68:65, DOI 10.1186/s40623-016-0447-8

Paolozzi A, Ciufolini I, Paris C, Sindoni G (2015) LARES: A New Satellite Specifically Designed for Testing General Relativity, International Journal of Aerospace Engineering, 2015, Article ID 341384, http://dx.doi.org/10.1155/2015/341384

Pearlman M R, Degnan J J, and Bosworth J M (2002) The International Laser Ranging Service. Adv Space Res, 30(2):135–143.

Petit G, Luzum B (2010) IERS Conventions (2010). Bundesamts f¨
furt am Main.

Schuh H, König R, Ampatzidis D, Glaser S, Flechner F, Heinkelmann R, NilssonT (2015) GGOS-SIM: Simulation of the Reference Frame for the Global Geodetic Observing System, In: van Dam T. (eds) REFAG 2014, International Association of Geodesy Symposia, 146, pp. 95-100, DOI:10.1007/1345_2015_217

Sillard P, Boucher C (2001) A review of algebraic constraints in terrestrial reference frame datum defini-

tion, J Geod, 75(2-3):63–73
Zhu S, Reigber Ch, König R (2004) Integrated adjustment of CHAMP, GRACE, and GPS data, J Geod, 78(1-2):103–108