LARES-2 – Initial Results From NERC Space Geodesy Facility (SGF), Herstmonceux

**Andreja Susnik (1), Graham Appleby (2), Robert Sherwood (1),
Toby Shoobridge (1), Christopher Potter (1), Matthew Wilkinson (1), Victoria Smith (1), José Carlos Rodríguez (3)**

(1) British Geological Survey (BGS), Space Geodesy Facility (SGF), Herstmonceux, United Kingdom (andsni@bgs.ac.uk)
(2) Honorary Research Associate, BGS NSGF, United Kingdom
(3) Instituto Geografico Nacional, Observatorio de Yebes (IGN Yebes AAC), Spain

Abstract

An initial priority at Space Geodesy Facility (SGF), Herstmonceux following the launch of LARES-2 (LAser RElativity Satellite 2) was to obtain ranging data as soon as possible. The difficulty at this post-launch stage is very high due to the lack of the accurate predictions that are required to aid acquisition. Nevertheless within a few days SGF was one of the 5 stations that had managed to obtain precise data to the new satellite, using publicly available radar-based predictions, the so-called '2-line elements', with km-level accuracy. To enable the rest of the global network to join in making routine observation, especially during daytime, regular accurate predictions are required, based on recent data.

In this study we present the impact of adding the new target into the observing schedule and evaluate the quality of the predictions computed by the SGF. From the analysis point of view, we present the initial impact of adding observations from LARES-2 into our regular 7-day orbital fits.

1. Introduction

Laser range observations of the geodetic satellites are routinely used to contribute to efforts for the realisation of high precision global reference frames by computing station coordinates on a weekly basis and daily Earth Orientation Parameters (namely polar motion and length-of-day). Because of the high-precision inherent in laser ranging observations and the low area-to-mass ratio of the geodetic satellites, they are also attractive 'probes' for testing some of the predictions of General Relativity (GR). Relativistic frame-dragging, or Lense-Thirring precession, predicts that the plane of the orbit of a satellite will rotate by the tiny amount of 30 milli-arcsecond per year. To separate out this predicted relativistic effect on the orbital plane motion from the larger effect coming from the much improved, but still imperfectly known, Earth's gravity field (especially the long-wavelength terms relating to the polar flattening), ideally one would use two satellites whose orbital inclinations are such that the gravity-induced effects would cancel out, leaving the GR frame-dragging effect exposed.

Simple perturbed orbital theory shows that the C20-induced orbit plane motion is related to the cosine of the orbital inclination; hence two satellites whose orbital inclinations are supplements of each other would meet the required criteria. As a step towards using the SLR technique to measure the frame-dragging effect, the LAGEOS-2 satellite was launched by the National Aeronautics and Space Administration (NASA) and the Italian Space Agency (Agenzia Spaziale Italiana; ASI) in 1998. However, due to launch restrictions and the fact that its primary mission was to strengthen efforts to determine (together with LAGEOS observations) the terrestrial reference frame, the satellite was placed into its orbital position with far-from-ideal inclination. Nonetheless, an estimate of the Lense-Thirring effect was made, with an estimated uncertainty of 10% [0]. A later effort, that included observations from the LARES (Laser Relativity Satellite) satellite, launched in 2012, but again in a non-optimum orbit, reduced the level of uncertainty to 2% [0].

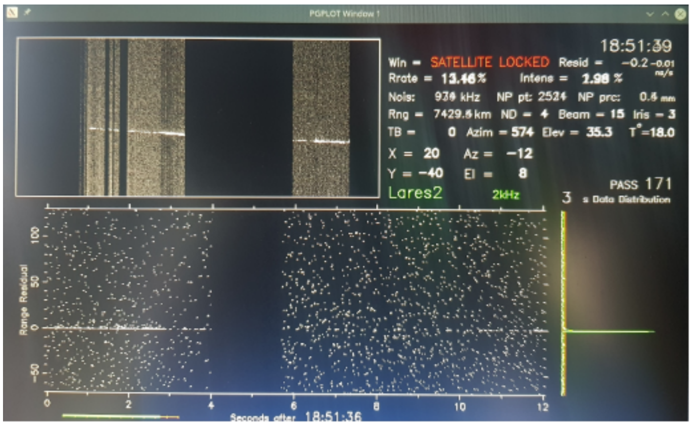
After many years of simulations and funding applications, the Italian Space Agency achieved the launch of LARES-2 from the European Space Agency (ESA) spaceport in Kourou on 13 July 2022 using a European Vega C rocket [0], placing it into an orbital altitude very close to LAGEOS at 5,890 km above the Earth. The inclination of LAGEOS's orbit is 109.84 degrees, with cos(I) = -0.3394, whereas the inclination of LARES-2 orbit is by design 70.16 degrees, with (I) = +0.3394, demonstrating a spectacularly good orbit placement of the satellite. This will provide an excellent opportunity to perform simultaneous analyses of observations coming from both satellites, thus enabling mitigation of the residual orbit-plane error due to the inevitably incomplete gravity field model and hence giving an opportunity to test the GR theory to very high precision [0].

The team at the British Geological Survey (BGS) Space Geodesy Facility, Herstmonceux (SGF), was excited to follow the launch of a new geodetic satellite in July 2022. The very prolific and mm-accurate laser ranging station, part of the International Laser Ranging Service (ILRS), immediately made plans to track LARES-2. The SGF ILRS Analysis Centre (AC) recognized the launch as a major new opportunity to strengthen its work on computing accurate global reference frame products and components of the Earth's gravity field. Nonetheless, an initial priority at SGF following the launch of LARES-2 was to obtain ranging data as soon as possible. The difficulty at this post-launch stage is very high due to the lack of accurate predictions that are required to aid acquisition. Nevertheless within a few days SGF was one of 5 stations that had managed to obtain precise data to the new satellite, using publicly available radar-based predictions with km-level accuracy.

2. Assessment of SGF LARES-2 predictions

To enable the rest of the ILRS global network in making routine observations, especially during daytime, regular and accurate predictions are required as they inform laser stations where to aim the telescope when conducting observations. Having imprecise predictions forces SLR stations/observers to spend more time on correcting the satellite pointing, hence directly impacting the number of collected observations [0][0]. Without this service the science benefits of the new target cannot be unlocked.

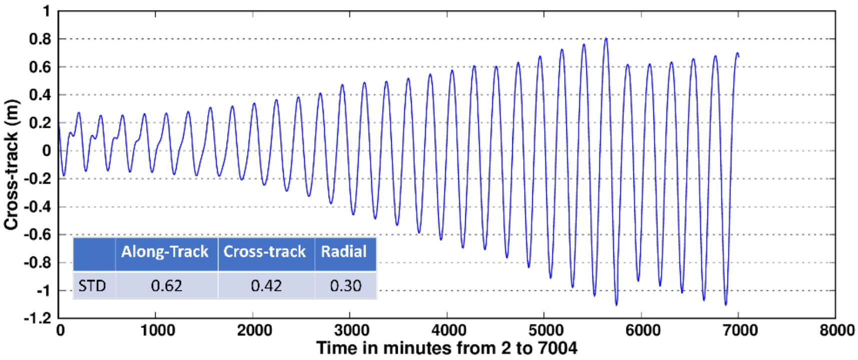
The predictions, which are based on recent data and generated automatically every day at Herstmonceux, use fits to four days of ILRS network range measurements to determine accurate orbital elements (state vector), which are then propagated a few days into the future. Orbit predictions are published in so-called Consolidated Prediction Format (CPF) – result of the work of the Prediction Format Study Group [0]. The high level of prediction accuracy that is achieved is shown in Figure 1 - a screenshot made during an observation of a daytime pass at Herstmonceux, where the solid white lines in the center of the plot windows show multiple range measurements from the satellite, amongst many sky-noise events. The mean value of this O-C (observed – computed) measurement time series, an estimate of prediction error, is a very modest +1 m.



18:51:39
Win = SATELLITE LOCKED Resid = −0.2 −0.01 ns/s
Rrate = 13.46% Intens = 2.98 %
Nois: 939 kHz NP pt: 2524 NP prc: 0.6 mm
Rng = 7429.6 km ND = 4 Beam = 15 Iris = 3
TB = 0 Azim = 574 Elev = 35.3 T°=18.0
X = 20 Az = −12
Y = −40 El = 8
Lares2 2kHz
PASS 171
3 s Data Distribution

Figure 1: Screenshot of daytime Lares-2 observations at Herstmonceux.

In addition to that, since October 2021 SGF is also providing to the community[1] fitted orbits as a by-product of its prediction service for all the cannonball geodetic targets, including LARES-2, in SP3c format. In order to assess the quality of these ‘rapid service’ ephemerides in SP3c format, a preliminary comparison with respect to the SGF LARES-2 precise orbits (see next section) for radial, along-track and cross-track components was carried out, see Figure 2.



	Along-Track	Cross-track	Radial
STD	0.62	0.42	0.30

Figure 2: Comparison between LARES-2 predictions in SP3c format and precise orbits for cross-track component. Additionally, STD values for along-track, cross-track and radial components are also shown.

From Figure 2, it can be seen that SGF LARES-2 predictions accuracy does not deteriorate significantly over time and is on the level of ~0.5 m for standard deviation for all three components.

3. Preliminary assessment of LARES-2 SLR solutions

Two analysis approaches for determining the initial impact of adding LARES-2 into our SLR processing were carried out. First, examining the RMS of post-fit residuals (Figure 3) and second comparing LARES-2 RMS of 7-day orbital fits with respect to LAGEOS 1/2 and Etalon 1/2 satellites (Figure 4).

To include LARES-2 into our processing software we have used an estimated Center of Mass value of 174 mm. For this preliminary analysis we have estimated range-biases together with station coordinates and Earth Rotation Parameters for all stations included in the processing; we note that this approach will absorb potential errors in our estimated CoM value for LARES-2, where no attempt has yet been made to account for

---

[1] https://cddis.nasa.gov/archive/slr/products/orbits/

known station-dependent differences in this crucial parameter.

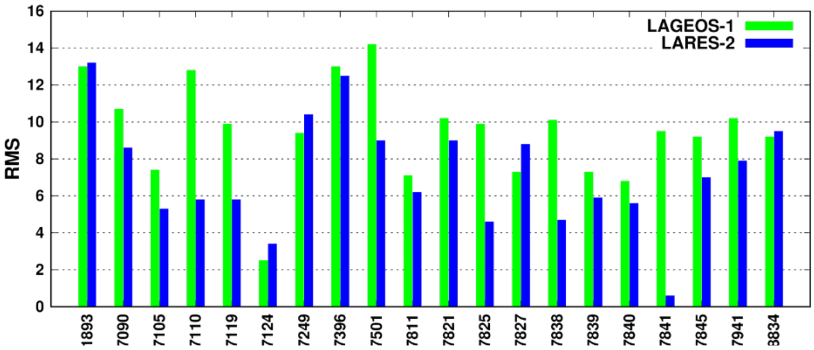


Figure 3: RMS values of post-fit range residuals for selected SLR stations.

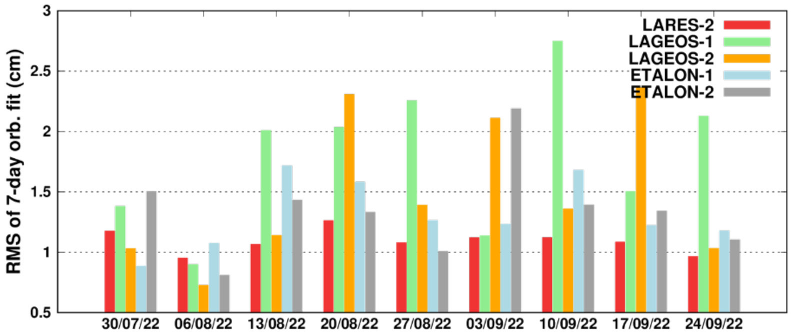


Figure 4: RMS values of 7-day orbital fits for period between 30/07/2022 – 24/09/2022.

As can be seen from Figure 4 and Figure 6, in terms of post-fit residuals and orbital fits, the quality of LARES-2 data is on the same level or even better than LAGEOS, providing preliminary evidence that it should be included into normal operational ILRS products.

4. Impact on the observing schedule

One of the questions that arose after the first successful tracking of LARES-2 was the extent to which adding such a high-priority target in a LAGEOS type orbit would affect the overall SLR observing. Time spent SLR observing at SGF is scheduled to fit with the satellite passes each day with local weather closely monitored to make the most of clear skies. Such observing schedule is presented in Figure 5, with LARES-2 pass shown in red color. Other satellite passes shown in Figure 5 are color grouped based on their ILRS tracking priority, e.g., LAGEOS, LAGEOS-2 with green color and GNSS in light blue.

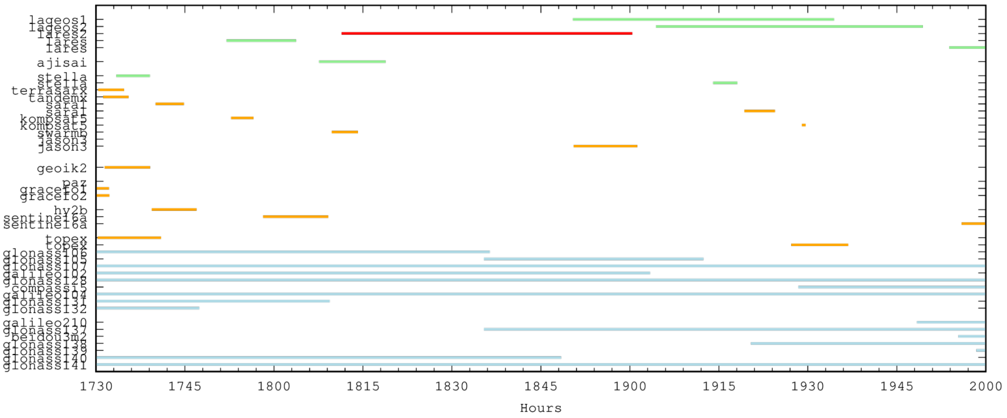


Figure 5: Observing schedule for 02 August 2022, with LARES-2 shown in red color.

For purposes of this analysis, we have grouped SLR targets based on their type, e.g., geodetic, GNSS and LEO's. Firstly, we had a look into total number of satellite passes tracked over SGF, see Figure 6. In contrast to that Figure 7 presents the total of hours spent on observing SLR targets for two selected months in 2022.

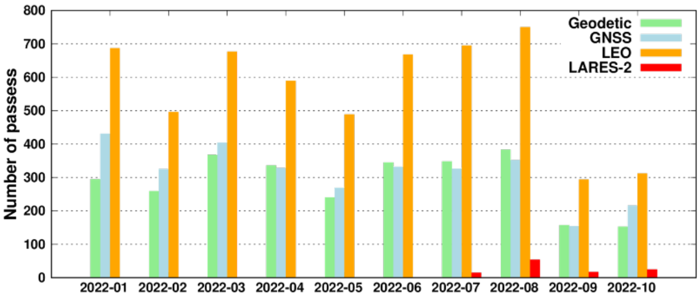


Figure 6: Number of satellite passes tracked at SGF for the period between January – October 2022.

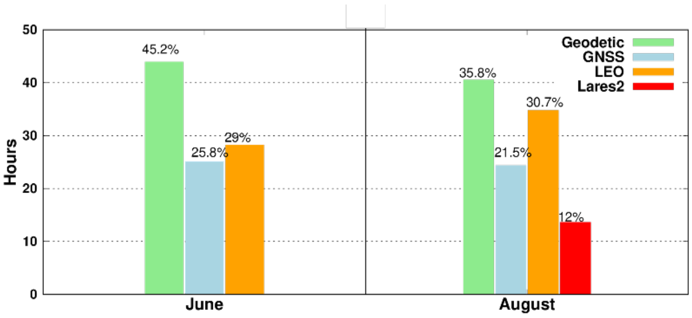


Figure 7: Total number of hours spent observing SLR targets for two selected months; left side June 2022 and one the right side for August 2022.

Looking at Figure 6, adding LARES-2 into observing schedule appears not to have impact on the total number of passes. On the other hand, it does have an impact on the total hours spent observing, see Figure 7. In particular it has a slight impact on time spent observing geodetic targets whereas very small to none on the LEO's and GNSS. Keeping in mind that monthly analysis does not depend only on observing schedule (Figure 5) but also highly on the weather conditions.

5. Conclusions

We have shown that SGF LARES-2 prediction accuracy does not deteriorate significantly over time and is on the level of ~0.5 m standard deviation for all three components. In terms of quality of LARES-2 solutions, initial results based on RMS values of post-fit range residuals and orbital fits show that they are on the same level as for LAGEOS or even better in some cases**.**

Adding LARES-2 into the observing schedule does not have a major impact on the total number of tracked passes; however, it does have an impact on the total hours spent observing, keeping in mind that monthly analysis depends on the particular observing schedule and on the weather conditions. For a proper analysis on how much of an impact adding such high-priority targets has, at least one year of data are required together with recorded weather conditions.

References

I. Ciufolini, and E.C. Pavlis, A confirmation of the general relativistic prediction of the Lense–Thirring effect. Nature **431**, 958–960, 2004. https://doi.org/10.1038/nature03007

I. Ciufolini, Paolozzi, A., Pavlis, E. C., Ries, J. C., Koenig, R., Matzner, R. A.. Towards a one percent measurement of frame dragging by spin with satellite laser ranging to LAGEOS, LAGEOS 2 and LARES and GRACE gravity models. Space Science Reviews, 148(1), 71-104, 2009. DOI: 10.1007/s11214-009-9585-7.

I. Ciufolini, et al., Disco-ball satellite will put Einstein’s theory to strictest test yet, 2022. https://www.nature.com/articles/d41586-022-02034-x

J. Najder and K. Sosnica. Quality of Orbit Predictions for Satellites tracked by SLR Stations. Remote Sens.,13, 1377, 2021. https://doi.org/10.3390/rs13071377

S. Bauer and J. Steinborn, J., Time bias service: Analysis and monitoring of satellite orbit prediction quality. J. Geod., 93, 2367–2377, 2019.