A Review of the ILRS Station Validation Procedures and Recent Performance

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Abstract: The ILRS implements a procedure to verify the performance of new stations or stations that have undergone significant changes or repairs. With these procedures, the station data are withheld from public dissemination and analyzed by the Analysis Standing Committee (ASC) prior to release to the community and use in operational solutions for the International Terrestrial Reference Frame (ITRF). As currently formulated, the procedure requires that the stations to obtain 20 acceptable passes per satellite for LAGEOS-1, LAGEOS-2, LARES-2 and LARES, with a minimum of five normal points per satellite pass. The rationale for selecting these geodetic satellites as validation targets is first that this provides direct information on how the station will perform in its primary ILRS function, to contribute to the ITRF. The second indirect advantage is the validation procedure is simplified since these are passive spherical satellites that are straightforward to model. With certain exceptions for weather or other local considerations, the geodetic satellites passes should be obtained within a 60-day sliding window. The quarantined data are analyzed to determine the station precision and the magnitude of the biases that might be present in the ranging system. Since the amended procedures were implemented earlier this year (2024), they have been applied to the new stations of Tsukuba (7306), Yebes (7817), and to Mt. Stromlo (7825) which underwent a major system repair and upgrade. We describe the quarantine procedure, and report the results obtained in the primary ranging channels for these stations (532 nm for Tsukuba and Mt. Stromlo; 1064 nm for Yebes). We review the stations' performance in the ITRF SINEX solutions since the station data were released to the ASC and the scientific community by the ILRS data centers, in comparison to the other stations of the ILRS present in these routine solutions.

ILRS Station Qualification & Quarantine:

What: **When a new station applies to join the ILRS tracking network, or under special circumstances when an existing station has a long lapse in data delivery, or has undergone major changes, the station must undergo a "data validation" process in order to assess the quality of its data and to ensure that the overall performance of the station meets the ILRS Standards.**

When: (1) New stations; (2) Stations undergoing major changes to the ranging system; (3) Stations that have not submitted data for more than 90 days.

Why: **The purpose is to ensure that the station produces reliable data for users and for inclusion in ILRS products, especially for contribution to the International Terrestrial Reference Frame (ITRF).**

How:

→ The stations whose data are being validated are asked to submit **at least** 20 passes of data to each of the following geodetic satellites, **LAGEOS-1, LAGEOS-2, LARES-2 and LARES**, nominally within a 60-day period (*exceptions can be made for special circumstances*). Stations should consider that the QC process might edit out some passes due to editing or removal of spurious data. **So, submitting more than the minimum number (*20 passes per satellite*) is a really good idea.**

→ **Stations should obtain more than five normal points per pass,** in order that the mean data precision and mean bias can be computed and to allow that spurious data might be edited.

→ The station SLR data are held in a special folder at the Eurolas Data Center (EDC) to be retrieved only by the members of the Analysis Standing Committee (ASC).

Who:

(1) **The station must inform the ILRS CB of any major changes, or repairs to the laser ranging system, and send the data it collects to the EDC.**

(2) **ASC-designated analysts:** F. G. Lemoine (*NASA GSFC*); M. Kuzmicz-Cielak (*JCET/UMBC*); A. Belli (*SSAI*), V. Husson (*Perraton*) **conduct the qualification analyses**;

(3) **The ILRS secretary** (C. Carabajal, *SSAI*) sends out the official announcements regarding successful completion of the validation requirements.

(4). **The EDC** (C. Schwatke, *DGFI-TUM*) releases the with-held data to the public repositories and directories at the EDC and the NASA CDDIS.

Background models:
SLRF2020 coordinates if available, **latest ILRS-approved target-signature model**; Station coordinates may be adjusted if warranted using the available station data.

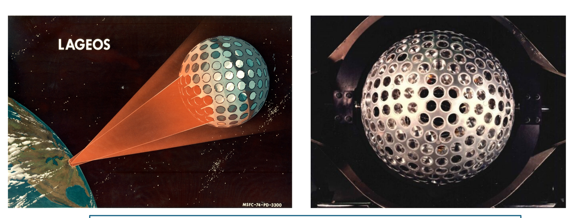
POD Software:
NASA Precise Orbit Determination and Geodetic Parameter Estimation Program (GEODYN).

Other aspects: We have learned that it is useful to examine other aspects of the data (e.g. system delays vs time; verifying with independent software how the normal points are processed; checking the barometer (pressure) values with independent models such as VMF3o).

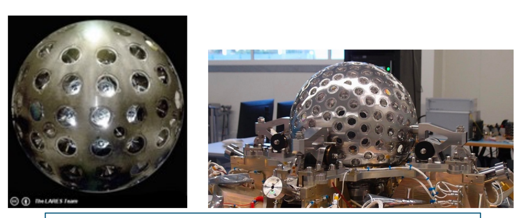
Feedback & Communication: An important aspect is to provide feedback to the station rapidly and regularly. Equally important is for the station to keep the ILRS informed of any station-related or data-related issues, especially while the station undergoes validation. **A reminder: Stations should update the history and site logs as necessary following any changes in the laser ranging system.**

For more information:
https://ilrs.gsfc.nasa.gov/network/site_procedures/quarantine_procedure.html

Acknowledgement: E.C. Pavlis (UMBC/JCET, retired) for conducting the station validation process until November 2023.



LAGEOS illustrations, courtesy NASA.



LARES, LARES-2 Images, courtesy ASI.

23rd International Workshop on Laser Ranging (IWLR), October 20-26, 2024 Kunming, China

2024 ILRS Station Quarantine Status

Stations validated so far in 2024

Tsukuba, TKBL (credit: JAXA)

Mt. Stromlo, STL3

Yebes, YEBL (credit: Yebes station)

Station	Status
Tsukuba (TKBL, 7306)	✓ Validated @ 532nm, 03/28/2024.
Mt. Stromlo (STL3, 7825)	✓ Validated @ 532nm, 08/16/2024.
Yebes (YEBL, 7817)	✓ Validated @ 1064nm 10/07/2024. **(New station for the ILRS network!)**

⚠ *Stations undergoing major repairs or changes*

Station	Status (*as of Oct. 9, 2024*)
Zimmerwald (ZIML, 7810)	Currently repairing laser.
Wettzell (SOSW, 7827)	Repaired azimuth drive, resumed tracking on 17-Jul-2024 but has not tracked since 1-Aug-2024 because of issues with their laser chiller.
San Fernando (SFEL, 7824)	The site has tracked with their new mount; control software; and updated event timer. (*see status report at the ILRS2024 Kunming workshop*).

⚠ *Other stations in quarantine*

Station	Status (*as of Oct. 9, 2024*)
Sejong (SEJL, 7394)	Needs a new laser.

Challenges

Multi-wavelength ranging: **The QC process currently only considers that the station ranges at one principal wavelength, but increasingly stations have the ability to range at multiple wavelengths (*e.g. 532 nm & 1064 nm for Izaña (7701), Tsukuba (7306) and Yebes (7817)*).**
Having a QC process that demands twice the number of passes (for both wavelengths) **presents a burden for the station, who would like to start normal operations as quickly as possible. Yet, from the perspective of the ASC, the two wavelengths represent independent ranging channels that need to be validated.**

Verification of NP computations: **The station-dependent Center-of-Mass (CoM) model for the geodetic satellites requires that the mode of Normal Point (NP) computation reported in the site log be verified in practice.** *For example, using a leading edge filter vs. a 2.2 sigma edit criterion systematically changes the NP ranges by a several mm.*

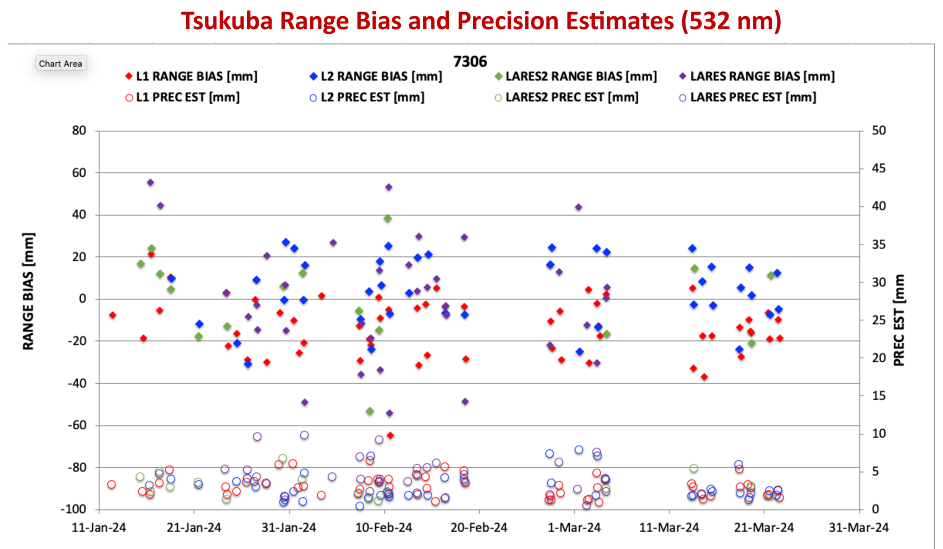
Verification of Ancillary information: **A model such as *VMF3o* should be used to verify measurements of station barometric pressure in the SLR data stream from the station.**

Coordinate estimation: **New stations likely need new coordinates, which are estimated from available data. If possible, another a priori ITRF2020 station velocity is used** (*from SLR preferably or from a nearby GNSS station*). **A geodetically measured site tie** (*if available*) **can allow us to verify the estimated coordinates.**

Results for Tsukuba (TKBL, 7306)

Background: **(1) Tsukuba had originally been validated and accepted into the ILRS network in June 2023. Unfortunately a system malfunction interrupted system operations and laser ranging did not resume in earnest until early 2024. (2) We used the default values of the geodetic satellite CoM:** *245.4 mm (L1); 244.8 mm (L2); 130.2 mm (Lares); 174.0 mm (LR2).* **(3) We tested new coordinates provided by *M. Bloßfeld* (*DGFI*) to account for possible station displacement after the Jan. 1, 2024 Noto earthquake. Nearby GNSS stations showed a possible displacement of 5-10 mm as a result of the earthquake.**

Tsukuba Range Bias and Precision Estimates (532 nm)



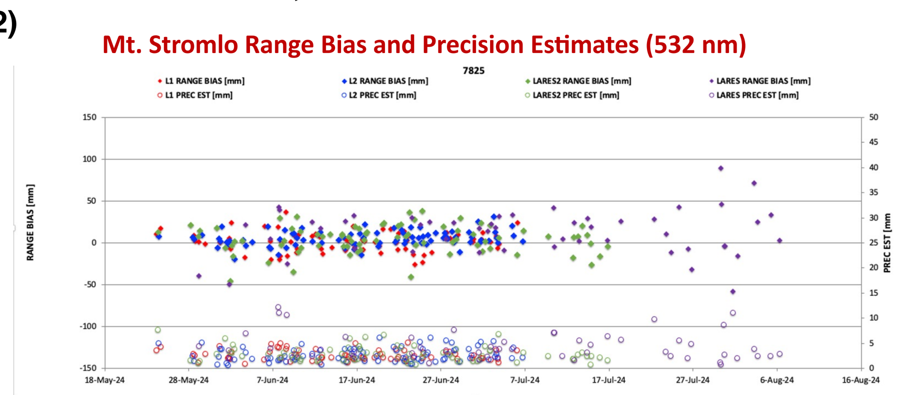
TKBL (7306) Analysis Comparison, SLRF2020 vs. DGFI (*new*) coordinates

Satellite	SLRF2020 (a priori)			DGFI_estimate		
	N	Precision (mm)	Range bias (mm)	N	Precision (mm)	Range bias (mm)
Lageos-1	43	3.2 ± 1.5	-11.7 ± 15.7	48	2.3 ± 1.0	-10.1 ± 10.2
Lageos-2	30	3.1 ± 2.1	3.0 ± 18.3	30	2.8 ± 1.4	-5.9 ± 12.6
LARES-2	13	3.0 ± 1.6	-0.5 ± 23.3	13	2.6 ± 1.6	-2.4 ± 17.8
LARES	33	4.5 ± 2.3	0.7 ± 26.3	32	4.4 ± 2.2	-0.3 ± 23.0

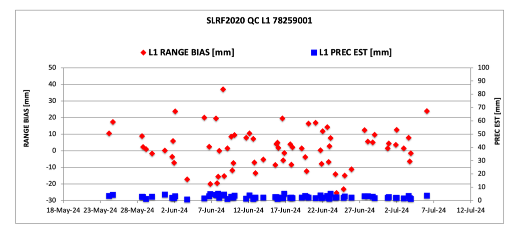
Results for Mt. Stromlo (STL3, 7825)

Background: **(1) We used the followiing values of the geodetic satellite CoM:** *244.9 mm (L1); 244.1 mm (L2); 130.6 mm (Lares); 173.6 mm (Lares2);* **(2) The station provided an abundance of data at 532 nm with which to perform the validation; (3) We updated the time-variable gravity (TVG) model, and noticed an improvement in the precision obtained with Lares. The previous TVG model was a linear and annual fit to the GRACE+GRACE FO CSR RL06 monthly gravity models. For the new TVG model we used the most recent COST-G FSM Model and replaced the C_{20} and C_{30} values from the recent SLR solutions of Loomis et al. (*NASA GSFC*). The TVG improved the precision estimate on LARES and reduced the dispersion in the bias estimates for LARES, but had no effect on the results for the higher orbit satellites (LAGEOS-1,2, LARES-2)**

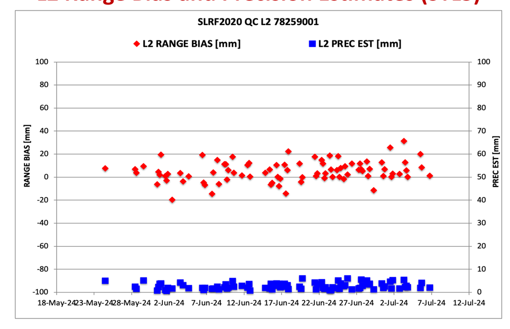
Mt. Stromlo Range Bias and Precision Estimates (532 nm)



L1 Range Bias and Precision Estimates (STL3)



L2 Range Bias and Precision Estimates (STL3)

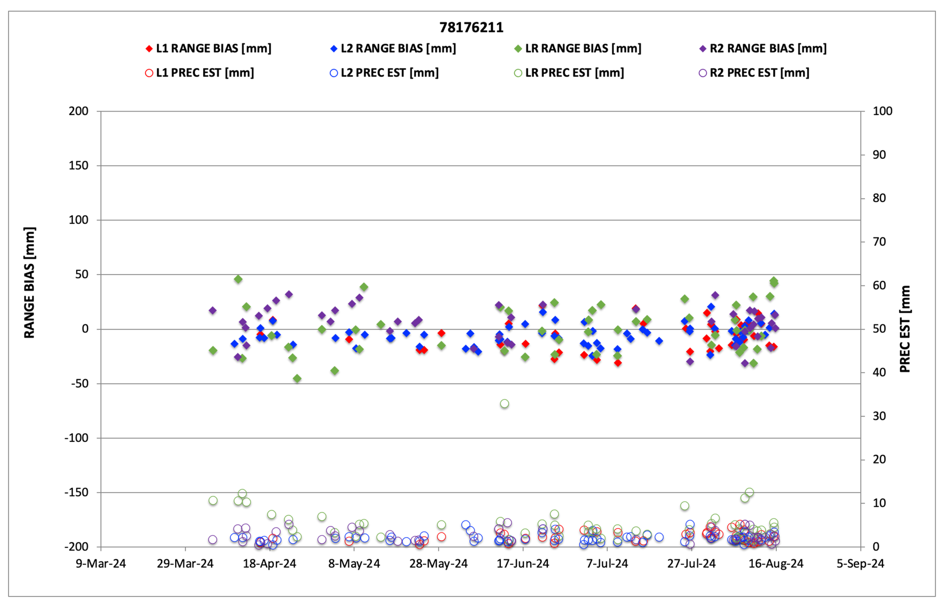


Satellite	SLRF2020 (previous TVG)			SLRF2020 (new TVG)		
	N	Precision (mm)	Range bias (mm)	N	Precision (mm)	Range bias (mm)
Lageos-1	72	2.6 ± 1.0	1.3 ± 12.1	72	2.6 ± 1.0	1.3 ± 12.1
Lageos-2	87	2.7 ± 1.4	5.1 ± 8.9	87	2.7 ± 1.4	5.1 ± 8.9
LARES-2	80	2.8 ± 1.4	4.4 ± 16.2	80	2.8 ± 1.4	4.4 ± 16.2
LARES	51	5.5 ± 3.9	13.0 ± 37.4	51	4.6 ± 2.8	13.0 ± 27.5

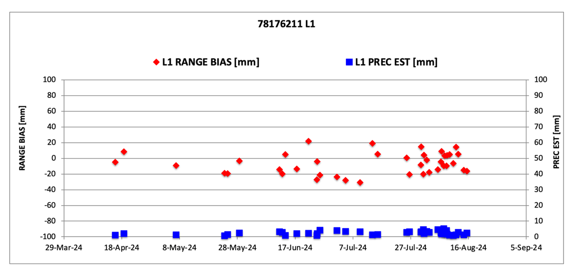
Results for Yebes (YEBL, 7817)

Background: **(1) We used the default value of the geodetic satellite CoM:** *245.4 mm (L1); 244.8 mm (L2); 130.2 mm (Lares); 174.0 mm (LR2).* **(2) The station provided data at both 532 nm and 1064 nm. We conducted the validation at 1064 nm, since it was only at that wavelength that the minimum 20-paas per satellite requirement was satisfied. Nonetheless, we show below the results for 532 nm, bearing in mind the statistics are not as robust, as only about 10 passes per satellite are available. (3) José Rodriguez (*IGN Spain*) provided an a priori estimate of the station coordinates. We tested these coordinates, and our own estimates. For now we prefer the IGN Spain coordinates. When we tested the adjusted coordinates, we noted an improved precision for L1, L2, LR2, but more strongly negative biases for L1, L2. Since this subject needs more study by the Analysis Standing Committee (ASC), preferably with more data, and dialogue with Yebes station, we prefer the a priori IGN coordinates for the time being. (4) We tested the coordinates and the performance of Yebes in v80 SINEX (weekly reference frame solutions) and find that the station performs satisfactorily and is ready to be included in routine daily and weekly solutions for the ITRF.**

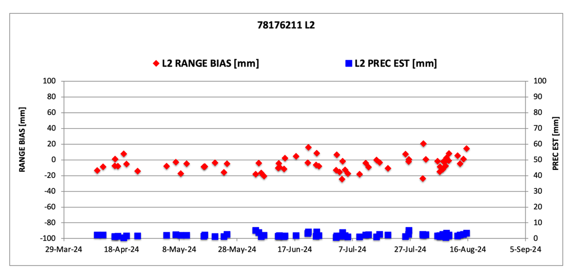
Yebes Range Bias and Precision Estimates (1064 nm)



L1 Range Bias and Precision Estimates (YEBL)



L2 Range Bias and Precision Estimates (YEBL)

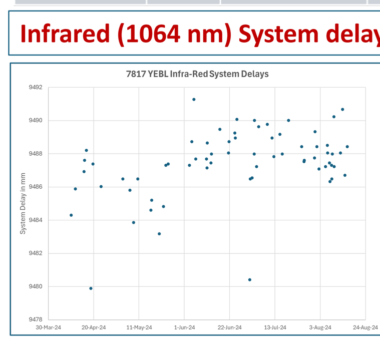


YEBL (7817) Coordinates Comparison, Apriori (*IGN Sp.*) vs. adjusted (*L1+L2 only*)

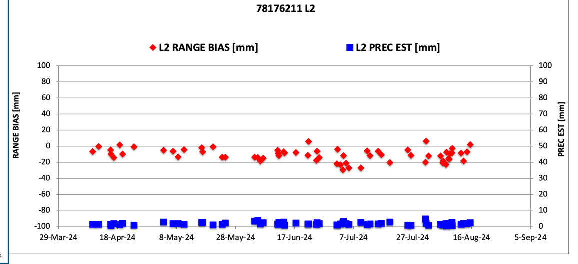
Satellite	SLRF2020. (IGN Spain *a priori* coordinates)			SLRF2020 (*Adj. coordinates 1064 nm data only, L1+L2 only*)		
	N	Precision (mm)	Range bias (mm)	N	Precision (mm)	Range bias (mm)
Lageos-1	40	2.4 ± 1.2	-5.3 ± 9.3	40	1.9 ± 0.8	-12.0 ± 8.0
Lageos-2	65	2.1 ± 1.0	-5.3 ± 9.3	64	1.7 ± 0.8	-10.9 ± 7.8
LARES-2	44	2.7 ± 1.5	5.3 ± 16.0	43	2.5 ± 1.5	-0.4 ± 14.9
LARES	50	5.6 ± 4.9	-0.2 ± 22.4	51	4.9 ± 4.8	-2.0 ± 23.2

The adjusted coordinates provided improved precision on L1, L2 in particular, but also on Lares & Lares2, so that is encouraging. However, whereas in the a priori the adjusted biases (for L1, L2) are statistically consistent with zero, after adjustment there is a clear negative bias, (for L1 and L2). In addition we see in the time history a break in the L2 bias history around June 1, 2024. This might be related to a change in the system delay @ 1064 nm(see below). This issue needs to be clarified by working with the station personnel.

Infrared (1064 nm) System delay



L2 Range Bias and Precision Estimates (YEBL) w. adjusted coordinates



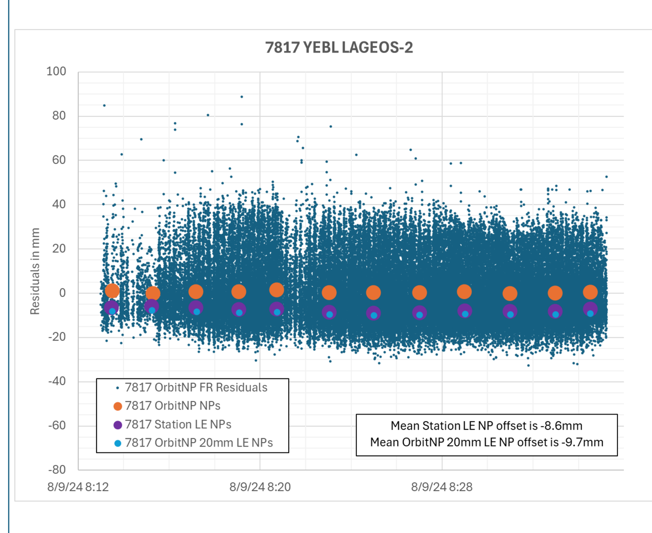
YEBL (7817) Performance Comparison, 1064 nm vs. 532 nm.

Satellite	SLRF2020. (1064 nm) (IGN Spain *a priori* coordinates)			SLRF2020. (532 nm) (IGN Spain *a priori* coordinates)		
	N	Precision (mm)	Range bias (mm)	N	Precision (mm)	Range bias (mm)
Lageos-1	40	2.4 ± 1.2	-5.3 ± 9.3	11	2.0 ± 0.9	14.2 ± 13.7
Lageos-2	65	2.1 ± 1.0	-5.3 ± 9.3	8	3.2 ± 1.9	5.9 ± 14.3
LARES-2	44	2.7 ± 1.5	5.3 ± 16.0	6	3.8 ± 2.1	2.2 ± 17.6
LARES	50	5.6 ± 4.9	-0.2 ± 22.4	5	4.1 ± 1.8	11.6 ± 7.8

While the results for the data at 532 nm are interesting, we need more data before we can draw any conclusions about the relative performance of ranging at 1064 nm vs. 532 nm for this station.

Analysis using OrbitNP with Yebes (7817) Data

Background: **The OrbitNP program (*from Matt Wilkinson, NERC Space Geodesy Facility, Herstmonceux U.K.*) was used to analyze the 7817 YEBL fullrate (FR) data. OrbitNP processes FullRate (FR) data and generates fullrate residuals and Normal Points (NPs). The FR residuals and generated NPs are written to text files. Then a time series is generated of the Orbit NP FR residuals is overlain with the OrbitNP-generated NPs, and the station-generated NPs.**



Results: **The figure at the left shows the OrbitNP 7817 FR residuals (small blue dots) based on the 'data' FR filter flag; OrbitNP-generated NPs from the same FR (orange circles); the station-generated NPs (purple circles); and the OrbitNP-generated NPs using a 20 mm Leading-Edge (LE) filter (small light blue circles).**

Based on this analysis we can conclude; the station-generated NPs were based on an ~20mm LE filter

We can also conclude that if a default Center of Mass (CoM) is applied in the range bias analysis, the 7817 NPs should appear to be biased short by several mm; assuming there are no other systematic errors and that we have accurate station coordinates.