International Laser Ranging Service (ILRS)

https://doi.org/10.82507/iag-gh2024_ilrs

Chair of the Governing Board: Stephen Merkowitz (USA)
Director of the Central Bureau: Michael Pearlman (USA)

ILRS website - http://ilrs.gsfc.nasa.gov/

1 Introduction

The International Laser Ranging Service (ILRS) is an established space geodetic Service of the IAG and a key contributor to the GGOS. The primary objective of the ILRS is to support – through Satellite and Lunar Laser Ranging data and related products – geodetic, geophysical and other scientific research activities, as well as product development for the International Earth Rotation and Reference Systems Service (IERS), important for the maintenance of an accurate and stable International Terrestrial Reference Frame (ITRF). The Service also develops and maintains the necessary standards/specifications and encourages international adherence to its conventions.

Satellite Laser Ranging (SLR) was established in the mid-1960s, with early ground system developments by NASA, SAO, and CNES. Early US and French satellites provided laser targets that were used mainly for inter-comparison with other satellite tracking systems, refinement of orbit determination techniques, and as input to the development of ground station fiducial networks and global gravity field models. Early SLR brought the results of orbit determination and station positions to the meter level of accuracy. The SLR network was expanded in the 1970s and 1980s as other groups built and deployed systems, and technological improvements began the evolution toward the decimeter and centimeter accuracy. Since 1976, the main geodetic target has been LAGEOS, subsequently joined by LAGEOS-2 (as well as Etalon-1 and -2) in 1992 and LARES in 2012, providing the backbone of the SLR technique's contribution to the realization of the ITRF. LARES-2 was later launched in 2022. Lunar Laser Ranging (LLR) tracking activity began in 1969 after the deployment of the first retroreflector array on the surface of the Moon by the Apollo 11 astronauts.

Tracking campaigns were initially organized through COSPAR (Committee on Space Research) and through the SLR/LLR Sub-commission on the Coordination of Space Techniques for Geodesy and Geodynamics (CSTG). With strong encouragement from the President of the CSTG, the Sub-commission Steering Committee undertook the formation of the ILRS in April 1998, following a similar initiative that had brought the GPS (now GNSS) community under the International Service IGS, in 1993.

The ILRS is a major component of GGOS, providing observations that contribute to the determination of the three fundamental geodetic observables and their variations, i.e., the Earth's shape, its gravity field and its rotational motion in space. The ILRS continues delivering fundamental inputs to the ITRF. Currently, more than 40 stations in the ILRS network track over 150 satellites in LEO, MEO, GNSS orbits. Some stations in the ILRS network support lunar ranging, with plans to extend ranging to interplanetary missions with optical transponders.

On the current path toward mm accuracy, SLR and LLR practitioners are now building new systems and upgrading old ones to improve the ground system performance using higher pulse repetition rates (0.1 – 100 kHz) for faster data acquisition. Smaller, faster slewing telescopes are being built for more rapid target acquisition and pass interleaving. Capabilities to ranging from Low Earth Orbiting (LEO) satellites to the Earth navigation satellites are being added. More accurate pointing allows for greater link efficiency; narrower laser pulse widths allow for greater precision. New detection systems permit greater ranging accuracy. Greater temporal, spatial, and spectral filtering improve signal to noise conditions. Increased automation should enhance operational economy (24/7) and greater temporal coverage. Modular construction and more off-the-shelf components should lead to reduced fabrication/operations/maintenance cost.

Over the next few years, considerable expansion to the ILRS network is anticipated (see Table 1). However, significant geographic gaps will still exist in Africa, South America, Oceania, and Antarctica.

2 Mission

The ILRS collects, merges, analyzes, archives and distributes SLR and LLR observation data sets of sufficient accuracy to satisfy the GGOS objectives of a wide range of scientific, engineering, and operational applications and experimentation. The basic observable is the precise time-of-flight of an ultra-short laser pulse to and from a retroreflector-equipped satellite (round-trip measurement). These data sets are used by the ILRS to generate a number of fundamental added value products, including but not limited to:

- Centimeter-accurate satellite ephemerides;
- Earth orientation parameters (polar motion and length of day);
- Three-dimensional coordinates and velocities of the ILRS tracking stations;

Table 1. Future ILRS network developments (*Status of the IPIE Stations uncertain due to political situation)

Site Name	Type	Agency	Timeframe
La Plata, Argentina	Upgraded core site	BKG, Germany	2024 – 2025
San Juan, Argentina	Upgraded SLR system	NAOC, China	2024 – 2025
Metsähovi, Finland	New SLR system	FGI, Finland	2024 – 2025
Greenbelt, MD, USA	Replacement core site	NASA, USA	2024 – 2024
Haleakala, HI, USA	Replacement core site	NASA, USA	2024 – 2026
McDonald, TX, USA	Replacement core site	NASA, USA	2024 – 2025
Ny Ålesund, Norway	New core site	NMA, Norway and NASA, USA	2024 – 2025
Ensenada, Mexico*	New SLR site	IPIE, Russia	2024 – 2026
Java, Indonesia*	New SLR site	IPIE, Russia	2024 – 2026
Gran Canaria, Spain*	New SLR in core site	IPIE, Russia	2024 – 2026
Tahiti, French Polynesia*	New SLR system	IPIE, Russia	2024 – 2026
Mt Abu, India	New SLR site	ISRO, India	2025 – 2026
Ponmundi, India	New SLR site	ISRO, India	2025 – 2026
Ishioka, Japan	New SLR site	Hitotsubashi U., NAOJ and U. Tokyo, Japan	2024
Yebes, Spain	New SLR site	IGS, Spain	2024
Irkutsk (Tochka)	New SLR site	VNIIFTRI, Russia	2025 – 2026
Mendeleevo (Tochka)	New SLR site	VNIIFTRI, Russia	2025 – 2026

- Time-varying geocenter coordinates;
- Static and time-varying coefficients of Earth's gravity field;
- Fundamental physical constants;
- Lunar ephemerides and librations;
- Lunar orientation parameters.

3 Products

The most important aspects of the SLR and LLR observations are the absolute accuracy as well as the long and stable time history at a number of sites. Accuracy approaches the level of a few mm for modern stations; time histories can be 40 years or more on some satellites (e.g., LAGEOS, Starlette, Beacon), and now 54 years on the Moon. Since the inception of the service, the ILRS has put the generation of official analysis products high on its agenda. Official submissions to the IERS include weekly solutions for station coordinates and Earth Orientation Parameters submitted daily. Additionally, some of the ILRS Analysis Centers submit estimates of GM and time-varying geocenter motion to the IERS Global Geophysical Fluids Center. Other user products include static and time-varying coefficients of Earth's gravity field, accurate satellite ephemerides for POD and validation of altimetry, relativity, and satellite dynamics, backup POD for other missions, and lunar ephemeris for relativity studies and lunar libration for lunar interior studies.

The products of the Analysis, Lunar Analysis, and Associate Analysis Centers are made available to the scientific community through the two Global Data Centers:

- Crustal Dynamics Data Information System (CDDIS) at NASA's Goddard Space Flight Center, Greenbelt, MD, USA;
- European Data Center (EDC), at DGFI-TUM, Munich, Germany.

The high accuracy of SLR/LLR data products supports many scientific, engineering, and operational applications including:

- Realization and maintenance of the ITRF;
- Access to Earth's center of mass relative to the global network and its time variations (geocenter);
- Monitoring three-dimensional deformations of the solid Earth;
- Monitoring Earth rotation variations and polar motion;
- Monitoring the long wavelength static and dynamic components of Earth's gravity field;
- Supporting, via precise ranging to altimeter satellites, the monitoring of variations in the topography of the liquid and solid Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, vegetation canopies, etc.);
- Calibration and validation of Global Navigation Satellite Systems (e.g., GPS, GLONASS, Galileo, Bei-Dou, and DORIS);
- Picosecond global time transfer experiments;
- Determination of non-conservative forces acting on satellites;
- Determination of satellite attitude;
- Astro-dynamic observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant;
- Gravitational and general relativistic tests, including Einstein's frame-dragging, Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant G;
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k2), and free librations and stimulating mechanisms;
- Solar System ties to the International Celestial Reference Frame (ICRF);
- Realization and maintenance of the Mean Earth and Principal Axis lunar reference frames;
- Tracking of space debris.

4 Structure

The ILRS structure includes the following permanent components:

- Tracking Station Network;
- Operations Centers;
- Global Data Centers;
- Analysis, Lunar Analysis, Associate Analysis, and Combination Centers;
- Governing Board;

- Central Bureau;
- Specialized Standing Committees: Analysis, Missions, Networks and Engineering, Data Formats and Procedures, and LLR and Transponders;
- Specialized Study Groups, including Space Debris Tracking.

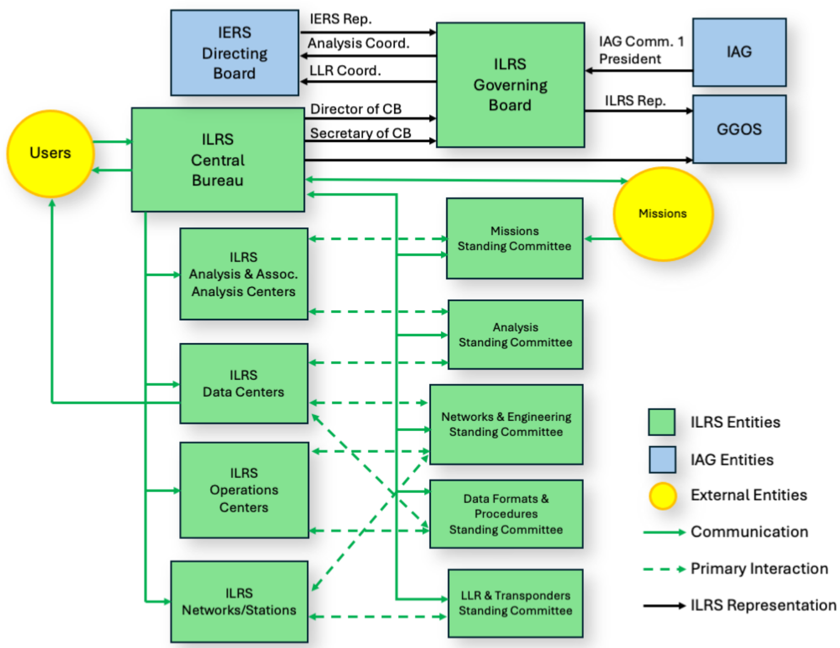

Fig. 1. ILRS Organization and relationship with IAG, IERS and GGOS

Governing Board (2023-2024)

The ILRS Governing Board (GB) is responsible for the general directions in which the ILRS is providing its services. It defines the official ILRS products, decides upon the satellites to be included in the ILRS tracking list, accepts standards and procedures prepared and proposed by the individual bodies of the ILRS, and ensures, through its Chair, contact with other services and organizations. The GB exercises general control over the activities of the ILRS including modifications to the organization that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and theory.

Most GB decisions are to be made by consensus or by a simple majority vote of the members, provided that there is a quorum consisting of at least ten GB members.

Changes in the ILRS ToR and the Chair can be made by a 2/3 majority of the GB members, i.e., by twelve or more votes.

- Stephen Merkowitz; appointed, NASA Network Repr.; Chair
- Michael Pearlman; ex-officio, Director Central Bureau
- Claudia Carabajal; ex-officio, Secretary Central Bureau
- Urs Hugentobler; ex-officio, President IAG Commission 1
- Daniela Thaller; appointed, IERS Repr.
- Sven Bauer; appointed, EUROLAS Network Repr.
- José Rodríguez; appointed, EUROLAS Network Repr.
- James Bennett; appointed, WPLTN Network Repr.
- Zhang Zhongping; appointed, WPLTN Network Repr.
- Evan Hoffman; appointed, NASA Network Repr.
- Vincenza Luceri; elected, Analysis Center Repr.
- Mathis Blossfeld; elected, Analysis Center Repr.
- Justine Woo; elected, Data Center Repr.
- Clément Courde; elected, LLR Repr.
- Christian Schwatke; elected, Member-at-Large
- Matthew Wilkinson; elected, Member-at-Large
- Takehiro Matsumoto; Board appointed member
- Randall Carman; Board appointed member

Central Bureau

The Central Bureau (CB) is responsible for the daily coordination and management of the ILRS in a manner consistent with the directives and policies established by the GB. The primary functions of the CB are to facilitate communications and information transfer within the Service and between the ILRS and the external scientific community, coordinate ILRS activities, maintain a list of satellites approved for tracking support and their priorities, promote compliance to ILRS network standards, monitor network operations and quality assurance of data, maintain ILRS documentation, website and databases, produce reports as required, and organize meetings and workshops. The responsibilities and activities of the CB may be distributed between different groups and organizations according to written agreements and charters.

Although the Chair of the GB is the official ILRS representative to external organizations, the CB, along with the directives, is responsible for the day-to-day liaison with such organizations.

The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, such as standards/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions. The CB operates the communication center for the ILRS. It produces and/or maintains a hierarchy of documents and reports, in both hard copy and electronic form, including network information, standards, newsletters, electronic bulletin board, directories, summaries of ILRS performance and products, and biannual reports summarizing the status of the Service.

The CB may propose to the GB names of individuals to be considered by the ILRS Associates for election as Members-at-Large on the GB to help ensure the proper representation of important contributing organizations.

In summary, the CB performs a long-term coordination and communication role to ensure that ILRS participants contribute to the Service in a consistent and continuous manner and that they adhere to ILRS standards.

The CB Director and Secretary are ex-officio members of the GB (see above).

Specialized Standing Committees

The ILRS now uses the IAG standard term "Committee" for entities that focus on particular areas within the Service. The GB, at its discretion, can create or disband Committees. A Committee may be either permanent (Standing Committee) or temporary (Ad-Hoc Committee) in nature. Standing Committees carry out business of the ILRS for indefinite periods (more than 4 years). Occasionally, Ad-Hoc Committees are appointed to carry out special investigations or tasks of a temporary or interdisciplinary nature.

Actual information on these permanent components can be found on the ILRS website (http://ilrs.gsfc.nasa.gov/). From time to time, the ILRS also establishes temporary Study Groups to address timely topics.

5 Contacts

- Michael Pearlman; Director ILRS CB; mpearlman@cfa.harvard.edu
- Claudia Carabajal; Secretary ILRS CB; Claudia.Carabajal@nasa.gov
- Stephen Merkowitz; Chair ILRS GB; Stephen.M.Merkowitz@nasa.gov
- Cinzia Luceri; ILRS Analysis Coordinator; cinzia.luceri@e-geos.it
- Mathis Bloßfeld; ILRS Analysis Coordinator; mathis.blossfeld@tum.de

6 Publications, Meetings

The CB maintains a comprehensive website (http://ilrs.gsfc.nasa.gov) as the primary vehicle for the distribution of information within the ILRS community. Many ILRS and related publications and reports are accessible online through this website including:

- ILRS Terms of Reference;
- ILRS Standing Committee charters, members, reports;
- ILRS network description and status;
- ILRS satellite descriptions and tracking information;
- ILRS workshop/meeting reports and presentations;
- ILRS service reports;
- ILRS associates directory;
- ILRS organization and technical contacts;
- Science and engineering references and reports.

The ILRS sponsors International Workshops on Laser Ranging (IWLR) which are typically held every two years. In addition, it organizes focused technical or specialized workshops in years between the IWLR. The ILRS has created guidelines to plan these workshops and for the community to propose future workshops.

When the ILRS was not able to hold in person workshops, it has held virtual workshops to keep the community engaged, and posted materials presented on the website. During 2021, the virtual workshop included scientific sessions along with virtual stations tours (https://ilrs.gsfc.nasa.gov/ILRS_Virtual_World_Tour_2021/). In 2023, the virtual IWLR held sessions on i) Scientific Analysis of SLR Observations: Past, Current and Future Challenges and Possibilities; ii) New Technologies and Operations; iii) Lunar Laser Ranging and Transponders; iv) Missions and Applications and Space Debris (https://ilrs.gsfc.nasa.gov/lw23/Program/index.html). In October 2024, the 23rd IWLR will be held in Kunming, China (https://23rdworkshop.casconf.cn/). We hope to hold a specialized workshop in Arequipa, Peru in 2025.

Bibliography

[1] van Camp, M. and dos Santos, F. P. and Murböck, M. and Petit, G. and Müller, J., Eos, Transactions American Geophysical Union. **102** (2021). DOI 10.1029/2021EO210673

[2] GGOS, in *Global Geodetic Observing System*, ed. by H.P. Plag, M. Pearlman (Springer Berlin, Heidelberg, 2009). DOI 10.1007/978-3-642-02687-4

[3] Willis, P. and Lemoine, F.G. and Moreaux, G. and Soudarin, L. and Ferrage, P. and Ries, J. and Otten, M. and Saunier, J. and Noll, C. and Biancale, R. and Luzum, B., IAG Symposia Series **143**, 631 (2016). DOI 10.1007/1345_2015_164

[4] Johnston, G. and Riddell, A. and Hausler, G., in *Springer Handbook of Global Navigation Satellite Systems*, ed. by P.J.G. Teunissen, O. Montenbruck (Springer International Publishing, Cham, 2017), pp. 967–982. DOI 10.1007/978-3-319-42928-1

[5] Nothnagel, A. and Arzt, T. and Behrend, D. and Malkin, Z., Journal of Geodesy **91(7)**, 711–721 (2017). DOI 10.1007/s00190-016-0950-5

[6] S. Bonvalot, A. Briais, M. Kuhn, A. Peyrefitte, N. Vales, R. Biancale, G. Gabalda, G. Moreaux, F. Reinquin, M. Sarrailh, International Gravimetric Bureau (2012). DOI 10.18168/BGI.23. URL https://bgi.obs-mip.fr/catalogue?uuid=df2dab2d-a826-4776-b49f-61e8b284c409. 10.18168/BGI.23

[7] G. Gabalda, S. Bonvalot. Mgl_quickview : Micro-g lacoste fg5/a10 results quick view (2023). DOI 10.18168/BGI.22. URL https://bgi.obs-mip.fr/catalogue?uuid=7cfb9b19-987f-4532-a042-d6c0df9cb7f6. 10.18168/BGI.22

[8] G. Gabalda, S. Bonvalot. Cg6tool : Scintrex gravity data processing (2024). DOI 10.18168/BGI.21. URL https://bgi.obs-mip.fr/catalogue?uuid=5c7699c7-c428-426e-b0a9-42764fc2998a. 10.18168/BGI.21

[9] H. Wziontek, S. Bonvalot, R. Falk, G. Gabalda, J. Mäkinen, V. Pálinkás, A. Rülke, L. Vitushkin, Journal of Geodesy **95**(1), 7 (2021). DOI 10.1007/s00190-020-01438-9. URL http://link.springer.com/10.1007/s00190-020-01438-9

[10] H. Wilmes, L. Vitushkin, V. Pálinkáš, R. Falk, H. Wziontek, S. Bonvalot, in *International Symposium on Earth and Environmental Sciences for Future Generations*, vol. 147, ed. by J.T. Freymueller, L. Sánchez (Springer International Publishing, Cham, 2016), pp. 25–29. DOI 10.1007/1345_2016_245. URL http://link.springer.com/10.1007/1345_2016_245. Series Title: International Association of Geodesy Symposia

[11] Y. Bidel, N. Zahzam, A. Bresson, C. Blanchard, A. Bonnin, J. Bernard, M. Cadoret, T.E. Jensen, R. Forsberg, C. Salaun, S. Lucas, M.F. Lequentrec-Lalancette, D. Rouxel, G. Gabalda, L. Seoane, D.T. Vu, S. Bruinsma, S. Bonvalot, Journal of Geophysical Research: Solid Earth **128**(4), e2022JB025921 (2023). DOI 10.1029/2022JB025921. URL https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022JB025921

[12] D.T. Vu, S. Bonvalot, L. Seoane, G. Gabalda, D. Remy, S. Bruinsma, Y. Bidel, A. Bresson, N. Zahzam, D. Rouxel, C. Salaün, M.F. Lalancette, R. Forsberg,

T. Jensen, O. Jamet, Journal of Geodesy **98**(4), 28 (2024). DOI 10.1007/s00190-024-01839-0. URL https://link.springer.com/10.1007/s00190-024-01839-0

[13] P. Zahorec, J. Papčo, R. Pašteka, M. Bielik, S. Bonvalot, C. Braitenberg, J. Ebbing, G. Gabriel, A. Gosar, A. Grand, H.J. Götze, G. Hetényi, N. Holzrichter, E. Kissling, U. Marti, B. Meurers, J. Mrlina, E. Nogová, A. Pastorutti, C. Salaun, M. Scarponi, J. Sebera, L. Seoane, P. Skiba, E. Szűcs, M. Varga, Earth System Science Data **13**(5), 2165 (2021). DOI 10.5194/essd-13-2165-2021. URL https://essd.copernicus.org/articles/13/2165/2021/

[14] D.T. Vu, S. Bruinsma, S. Bonvalot, Earth, Planets and Space **71**(1), 65 (2019). DOI 10.1186/s40623-019-1045-3. URL https://earth-planets-space.springeropen.com/articles/10.1186/s40623-019-1045-3

[15] D.T. Vu, S. Bruinsma, S. Bonvalot, D. Remy, G.S. Vergos, Remote Sensing **12**(5), 817 (2020). DOI 10.3390/rs12050817. URL https://www.mdpi.com/2072-4292/12/5/817

[16] D.T. Vu, S. Bonvalot, S. Bruinsma, L.K. Bui, Earth, Planets and Space **73**(1), 92 (2021). DOI 10.1186/s40623-021-01415-2. URL https://earth-planets-space.springeropen.com/articles/10.1186/s40623-021-01415-2

[17] Reguzzoni, M. and Carrion, D. and De Gaetani, C. I. and Albertella, A. and Rossi, L. and Sona, G. and Batsukh, K. and Toro Herrera, J. F. and Elger, K. and Barzaghi, R. and Sansó, F., Earth Syst. Sci. Data **13**, 1653 (2021). DOI 10.5194/essd-13-1653-2021