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Recent Progress and Plans for the ILRS

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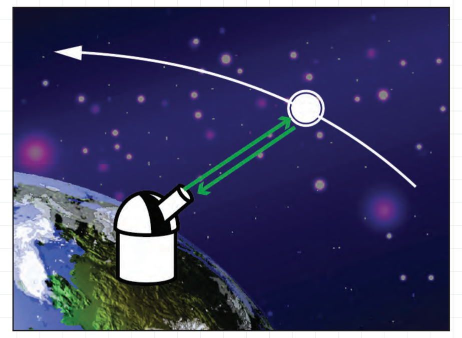
Abstract: The International Laser Ranging Service (ILRS) is improving its service through the deployment of new SLR ground stations, the adoption of new technologies in some of its legacy stations, the expansion of its roster of tracking missions, and the adoption of new procedures and tools to improve data quality and reliability. Laser ranging is embracing a wide range of new technologies, including lower energy, higher repetition rate (kHz) systems, single photon sensitive detectors, shorter pulse widths and normal point intervals for faster data acquisition and increased pass interleaving, automated to autonomous operation with remote access, and embedded software for real-time updates and decision making. The primary role of the ILRS is to support precision tracking of active missions such as those that provide ice and ocean altimetry observations, InSAR data, and measurements of the static and time-variable gravity field; enable precision measurements of Earth rotation parameters; and support space science and engineering. As an IAG Service, the ILRS supports the Global Geodetic Observing System (GGOS) and its primary product: the development of the ITRF and its maintenance. Support for the GNSS constellations (e.g. BeiDou, Galileo, GLONASS, GPS, QZSS and IRNSS) has increased dramatically in recent years; further expansion of the roster is anticipated when the new GPS III constellation is deployed over the next decade. Applications have expanded to include ground and space-time synchronization and asynchronous ranging for targets at extended range. Support provided for new missions from universities and research institutions has also increased over the past few years. A few stations continue lunar laser ranging activities and several others have begun lunar ranging on a test basis. About a dozen stations are active in debris tracking for studies of orbital dynamics and reentry predictions. New tools and procedures and a new Quality Control Board have been established to improve the quality of our data and products, and to expedite the resolution of engineering issues via rapid response reports to the stations. Work also continues on the design and building of improved retroreflector targets to maximize data quality and quantity. This poster will give an overview of activities underway within the Service, paths forward presently envisioned, and current issues and challenges.

Introduction



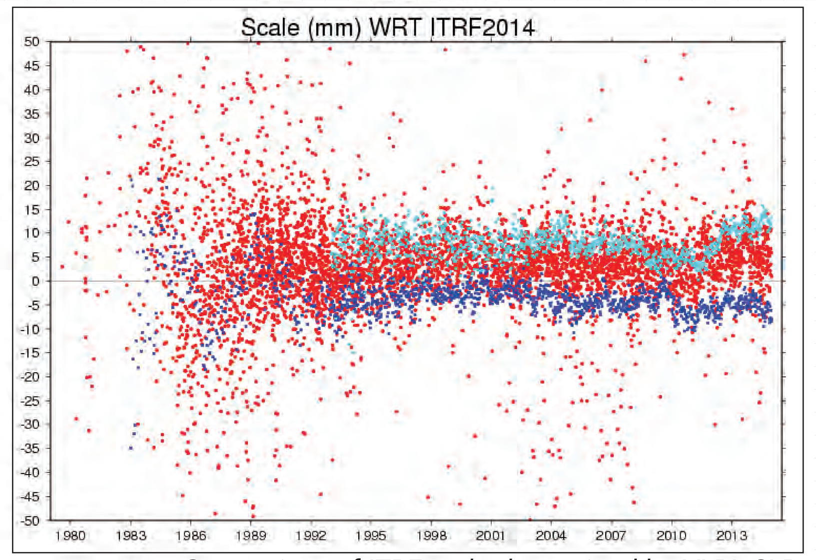
- In the era of the Global Geodetic Observing System (GGOS), high-quality multi-technique sites are crucial
- The space-observational services, the ILRS, IDS, IGS, and IVS together supply the data and products to meet the GGOS mission
- Major goals are determination and maintenance of the terrestrial reference frame and determination and monitoring of the Earth's gravity field and Earth orientation parameters (including polar motion, UT1, nutation, and precession)
- These goals are realized through:
  - Inter-technique site ties (core and co-location stations)
  - Combination of analysis products (site position, velocity, Earth orientation)
  - Tracking support for gravity missions
- Precise orbit determination is crucial for altimetry and other missions with scientific impact
- The addition of SLR to GNSS makes a very powerful tool to understand the orbital perturbations on the GNSS orbit.
- All SLR sites have co-located GNSS receivers capable of tracking multiple GNSS constellations; some are co-located with VLBI and DORIS
- In support of these objectives:
  - Laser ranging activities are organized under the aegis of International Laser Ranging Service (ILRS) which provides global satellite and lunar laser ranging data and their derived data products to support research in geodesy, geophysics, Lunar science, and fundamental physics. This includes data products that are fundamental to the International Terrestrial Reference Frame (ITRF), which is established and maintained by the International Earth Rotation and Reference Systems Service (IERS).
  - The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a member of the IAG's Global Geodetic Observing System (GGOS). The Services, under the umbrella of GGOS, provide the geodetic infrastructure necessary for monitoring global change in the Earth system (Beutler and Rummel, 2012).

Current Trends

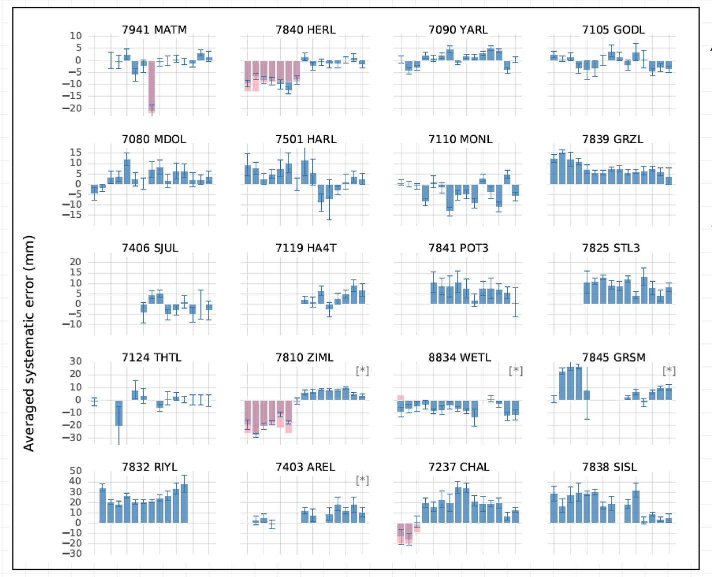
- SLR systems: lower energy, higher repetition rates (kHz)
- Single photon sensitive detectors (geodetic satellites)
- Shorter normal point intervals (take data more quickly) and faster slewing for increased pass interleaving
- Real-time data evaluation for real-time decision making
- Automated to autonomous operation with remote access
- Stations with two SLR systems to help address the workload (e.g., Hartebeesthoek)
- Environmental monitoring and awareness for instrument integrity and safety
- Real-time network communication and information sharing among stations
- Denser arrays with smaller cubes can reduce return signal RMS

SLR and the Reference Frame Scale

- Results for ITRF2014 (courtesy of Zuheir Altamimi, March 2016):
  - Persistent systematic difference in scales determined by SLR and VLBI
  - VLBI vs. SLR scale difference: 1.37 (± 0.10) ppb
  - Scale rate negligible
- At least part (about 50%) of the cause of the scale differences appears to be systematic issues (e.g., range biases) in the measurement data
- Other contributors might be site ties and an uneven global distribution of SLR tracking sites



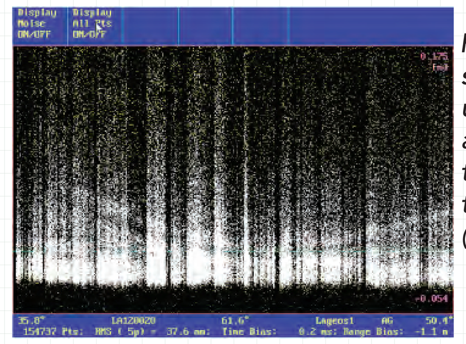
Comparison of ITRF scale determined by VLBI, SLR, and DORIS w.r.t. ITRF2014 *(Zuheir Altamimi)*



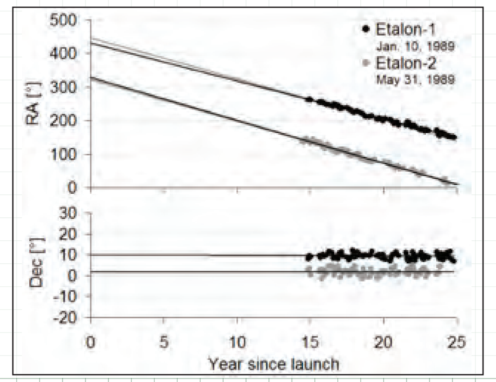
Annual station range biases estimated using long arc orbital analysis at Herstmonceux (Appleby, Rodriguez, Altimimi, JoG, 2016)

- ILRS activities underway within the ILRS Analysis Standing Committee:
  - Station systematics modeling
  - Center of mass correction on the geodetic satellites
  - Atmospheric loading; other loading effects, etc.
- So far, a reduction in the difference of about 50% (very promising) can be seen

SLR used to study Satellite Dynamics



High repetition rate, short pulse lasers allow us to see retroreflector array details as shown in this LAGEOS pass from the Graz Austria station (G. Kirchner)

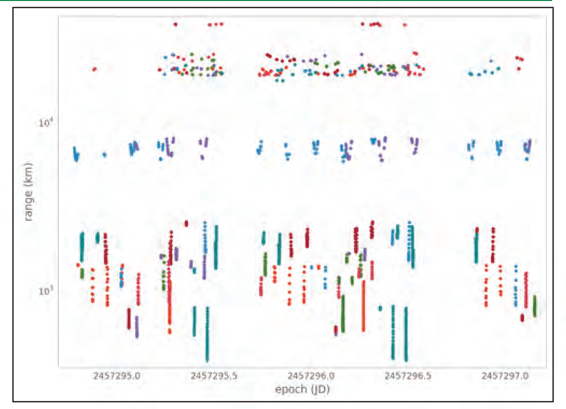


Tracking from high repetition-rate stations leading to impressive diagnostics of satellite attitude

Most of the geodetic spheres have had spin vectors measured as functions of time (from D. Kucharski et al., Etalon-1 and -2, ASR 2014)

Highlights: Network

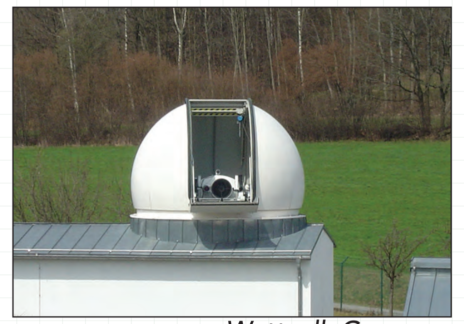
- New sites in the ILRS network in development:
  - BKG AGGO continuing setup at La Plata Observatory (Argentina)
  - Russia planning site installations in: Ensenada (Mexico), Java (Indonesia), Canary Islands (Spain)
  - NASA/NASA affiliated sites planned: McDonald, Haleakala (USA), and Ny-Ålesund (NMA, Norway)
  - New sites in process: Metsahovi (Finland), Mt. Abu and Ponmundi (India), and Yebes (Spain); others planned
  - Additional major upgrades underway at some stations: La Plata and San Juan (Argentina)
- However gaps in geographic coverage of the network remain
- First co-locations of Russian SLR systems with established station at Hartebeesthoek (South Africa) and Mendeleevo (Russia) to provide expanded tracking coverage; other planned



In practice, some stations are very busy: several days of tracking at the Herstmonceux UK station (Graham Appleby)

In 2018, 39 stations in the ILRS network routinely tracking over 110 orbiting satellites and retroreflectors on the Moon

Greenbelt MD, USA (NASA)



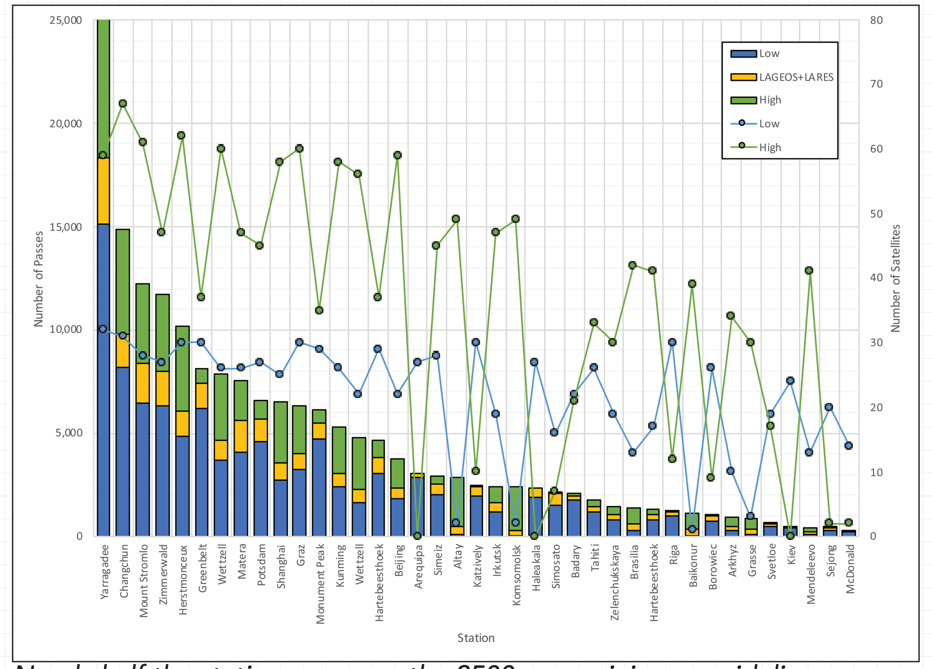
Wettzell, Germany (BKG and FESG)

Graz, Austria (Austrian Academy of Sciences)

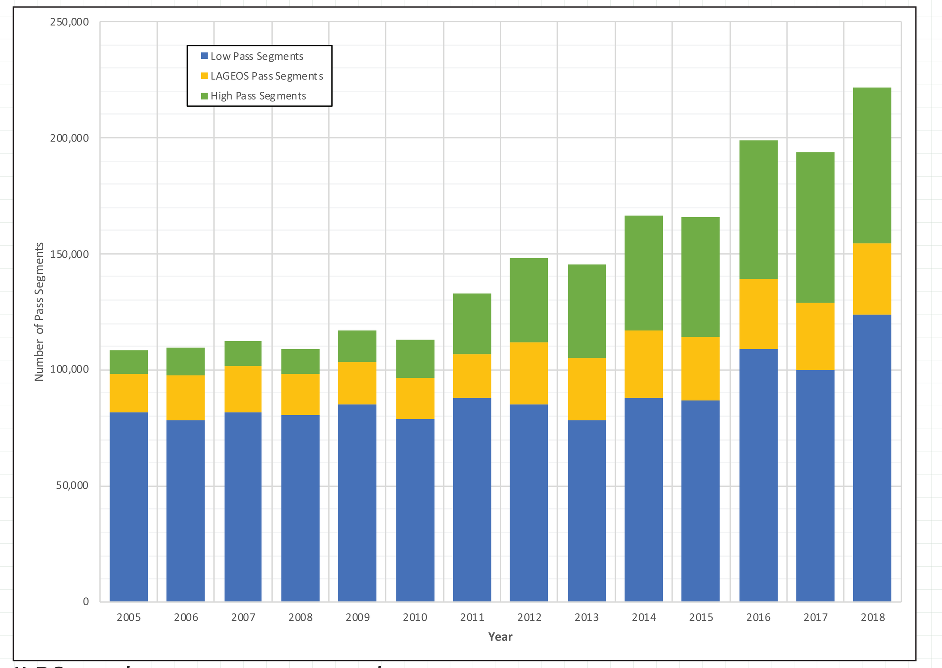
Haleakala HI, USA (NASA)

Arkhyz, Russia (OJC RPC PSI)

Network Performance



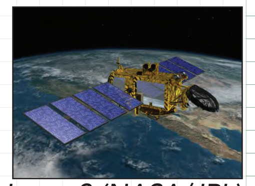
Nearly half the stations are near the 3500-pass minimum guideline
Large divergence in performance; many stations continue to have low performance and hence have little contribution to ILRS derived products which contribute to the ITRF
Low data yield in some cases due to station upgrades or technical issues



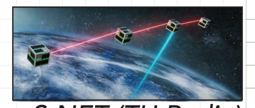
ILRS yearly pass segment totals
ILRS is on track for another year of increased data yield in 2018

Recent Developments in ILRS Mission Support

- The number of satellites on ILRS tracking roster continues to grow
- Missions and users want as much laser tracking data as possible
- Network routinely tracked 110+ satellites in 2018
- In 2018, ILRS approved 10+ new missions supporting altimetry, positioning, gravity, SAR, and experimental/engineering testing applications (e.g., cubesat tracking)
- An ever-increasing number of satellites that is particularly demanding are the expanding constellations of GNSS satellites
- Also complicating that picture are the different user requirements for SLR tracking data from GNSS satellites
- The ILRS, in consultation with the IGS and the International Committee on GNSS (ICG), is looking at different tracking strategies to try to provide better capability for GNSS while not compromising the other users
  - Approach will most likely include a combination of some routinely tracked satellite in each constellation and a pool of GNSS satellite for sampled tracking on an as available basis
  - The ILRS conducted two tracking campaigns in 2018 to test tracking strategies to improve temporal and spatial coverage of the GNSS constellations; reports available on ILRS website
  - More satellites coming with retroreflector arrays, e.g., planned for GPS-IIIF series
- Etalon tracking campaign proposed for early 2019 to evaluate increase role of Etalon data in computation of ILRS products contributing to the ITRF
- Other campaigns can be proposed to improve tracking on new missions
- ILRS supports missions requiring restrictions on SLR tracking of vulnerable satellites
  - Development takes considerable time, coordination, and interaction between CB, mission, and stations
  - Process requires implementation of detailed infrastructure and tracking scenarios
  - Recent restricted tracking missions: Sentinel-3 and ICESat-2

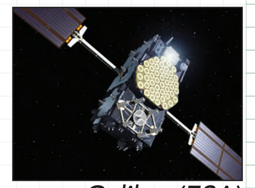


Jason-3 (NASA/JPL)



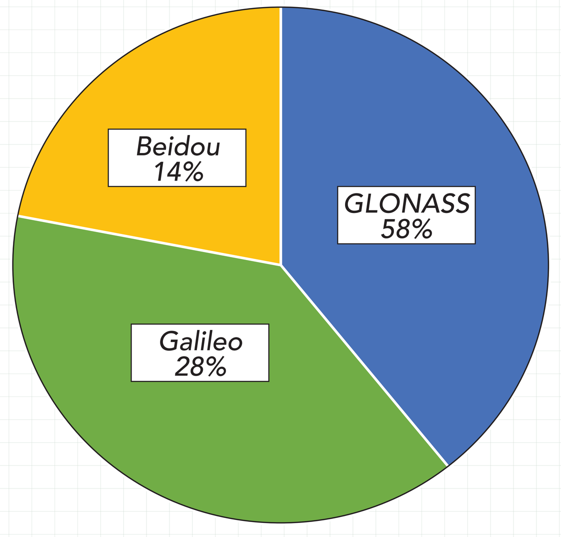
S-NET (TU Berlin)

LAGEOS-1 (NASA)

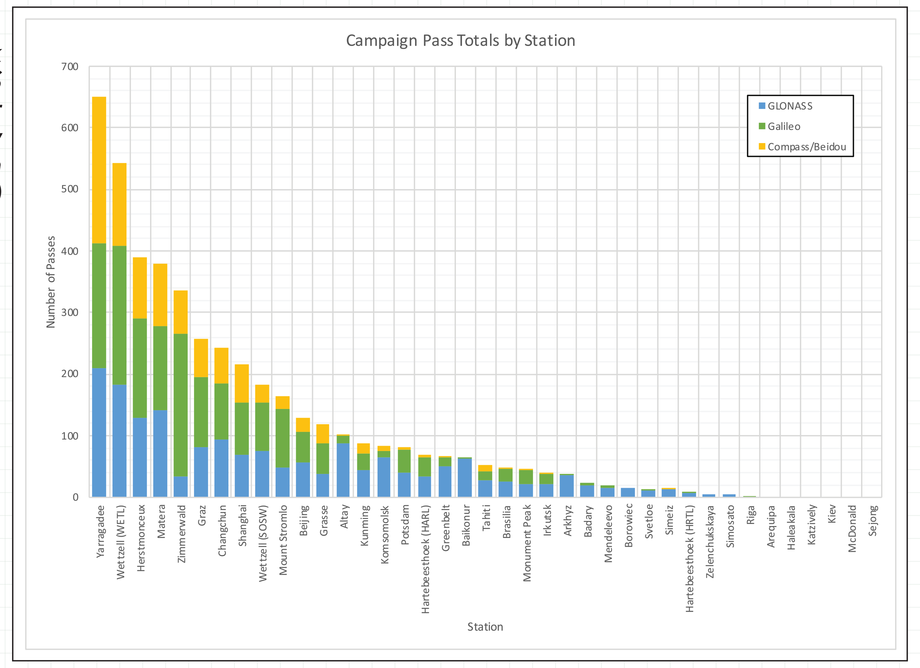


Galileo (ESA)

ILRS network tracking of GNSS satellites (number of passes) by station (09/2017-08/2018)

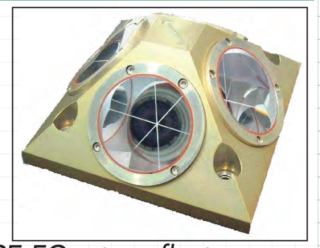


GNSS tracking by constellation for 2018 LARGE Campaign 2



Space Segment: Trends for Retroreflector Arrays

- Arrays need to accommodate velocity aberration
- Common use of the pyramid array (e.g., as developed by GFZ) is nearly COTS for LEO satellites; particular design depends upon the satellite's altitude and tracking requirement
- Issued ILRS standard specification for GNSS satellite arrays; specifies effective area of 100 million square m.; the retroreflector arrays for Galileo and Beidou comply with this specification
- Adaptation of this GNSS standard made for synchronous satellites
- Denser arrays with smaller cubes helps reduce return signal rms



GRACE-FO retroreflector array (GFZ Helmholtz Center, Potsdam)

Summary

- Challenging program with very important science and societal benefits
- Technologies are maturing and new technologies are on the horizon
- Global distribution of SLR stations is essential; success requires the enhanced networks, which will depend on partnerships
- Very large opportunity for participation in analysis and scientific research
- Need to engage young scientists and students
- Challenges:
  - Many geographic gaps, primarily in Latin America, Africa, and Oceania
  - Mix of new and old technologies in the network and varying levels of financial support
  - Lack of standardization in system hardware and operations
  - Local limitations: weather, personnel, budget, etc.
  - Data systematics issues
  - Number of target satellites continues to increase as new missions use SLR for orbit determination and other applications (100+ satellites)

For More Information

- For more information about the ILRS visit the ILRS website: *https://ilrs.gsfc.nasa.gov* or the document: Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The International Laser Ranging Service", Advances in Space Research, Vol. 30, No. 2, pp. 135-143, July 2002, DOI:10.1016/S0273-1177(02)00277-6.

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