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International Laser Ranging Service

Recent Progress and Plans for Improvement of ILRS Infrastructure and Data Product Delivery

Michael Pearlman/Center for Astrophysics
Carey Noll/NASA GSFC, Erricos Pavlis/UMBC, Toshimichi Otsubo/Hitotsubashi U., Jean-Marie Torre/OCA, Georg Kirchner/OEAW, Ulrich Schreiber/TUM

with contributions from

Arttu Raja-Halli/FGI, Jan McGarry/NASA GSFC, Mikhail Sadovnilov/RPC PSI, Michael Steindorfer/OEAW, Zhang Zhongping/SHAO

Outline

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- Some highlights
- Network
- Missions
- Analysis
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- Infrastructure
- Conclusion

2020 EGU General Assembly

Acknowledgement

The Governing Board and Central Bureau of the ILRS want to thank those individuals who continue to support all aspects of the Service during these difficult times due to the COVID-19 pandemic. Your continued efforts allow the ILRS to continue to operationally support our global user community.

In particular, we want to express our appreciation to the efforts of the staff and supporting agencies of the global SLR stations who continue to maintain their active operations.

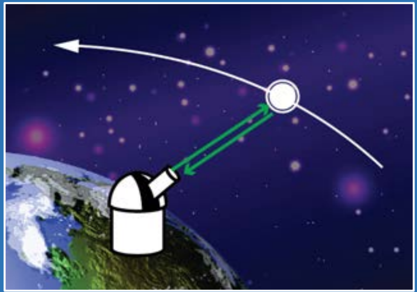
The ILRS mission

- Laser ranging activities are organized under the 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).*

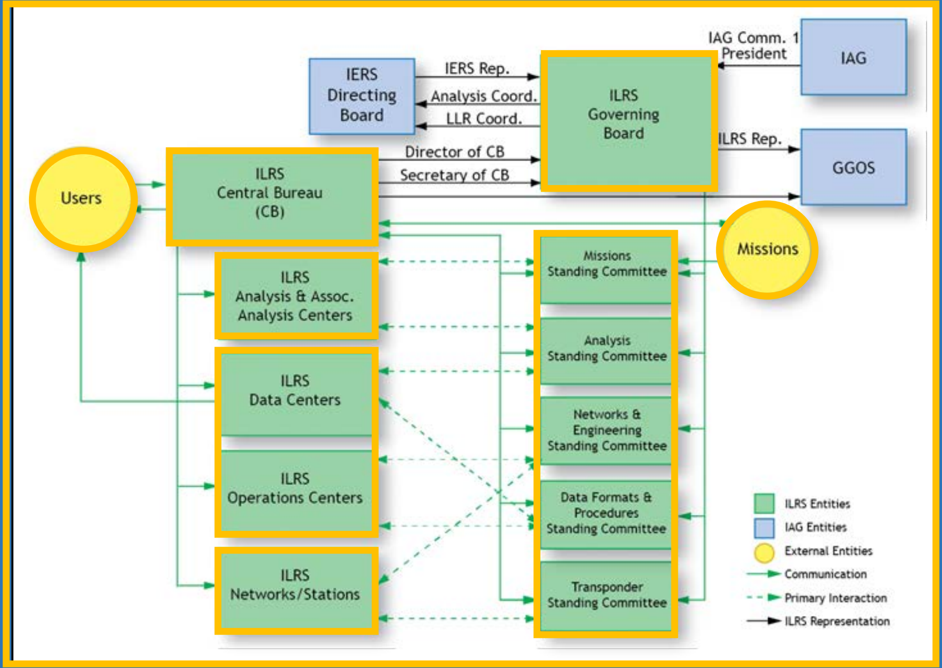
ILRS: overview

- The ILRS provides laser ranging data and products on an operational basis to geodesy analysts as well as a broader scientific community
- ILRS is one of four services within the International Association for Geodesy (IAG) supporting space geodesy
- IAG established these services to facilitate international cooperation and scientific research
  - Networks
  - Data centers
  - Analysis groups
- Services perform successful operations through cooperation of many international organizations, leveraging their respective resources to all levels of service functionality



ILRS: large community participation

- Operation through cooperation of organizations leveraging resources to all levels of service functionality
- Components:
  - Network: 40+ stations
  - Data Centers:
    - 2 Operations Centers
    - 2 Data Archive Centers
  - Analysis Centers:
    - 7 Analysis Centers
    - 2 Combination Centers
    - 21 Associate Analysis Centers
    - 6 Lunar Analysis Centers
  - Standing Committees: 5
  - Central Bureau: 25+ members
  - Governing Board: 18 members
  - Membership
    - Associates: 400+
    - Organizations: 110+
    - Countries: 30+
    - Correspondents: 200+
  - Supporting:
    - Users: 1000's
    - Missions: 110+



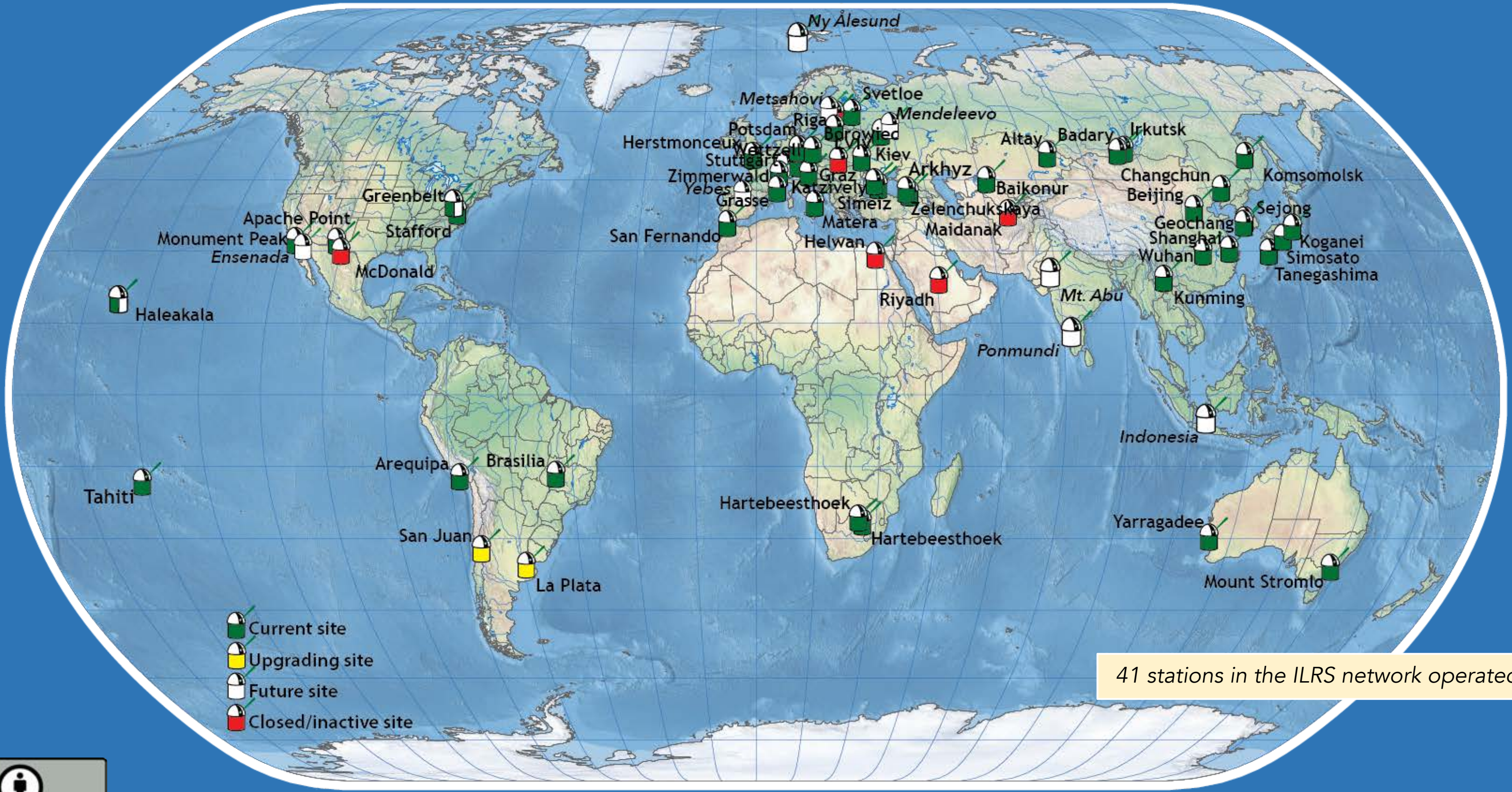
https://ilrs.gsfc.nasa.gov/about/organization/index.html

ILRS 2019 Technical Workshop

- ILRS organizes smaller, focused workshops in years between the International Workshops on Laser Ranging workshops
- The 2019 ILRS Technical Workshop held in Stuttgart, Germany, hosted by German Aerospace Center (DLR) in October 2019 with the theme "*Laser ranging: To improve economy, performance, and adoption for new applications*"
- Included one-day "SLR School" providing tutorials on SLR and the ILRS
- Over 150 attendees from 20 countries participated in 5-day workshop

https://cddis.nasa.gov/2019_Technical_Workshop/index.html

ILRS network



41 stations in the ILRS network operated in 2019

New NASA SGSLR stations: replacing MOBLAS/TLRS)

- Status
  - Shelter completed, dome installed, lightning protection in place
  - Time and Frequency subsystem and system-wide UPS installed
  - Dome and gimbal, with a mass simulator for the telescope, is at Goddard SGSLR undergoing testing with the computers & software (currently on hold due to virus)
  - Mass simulator has a tertiary to provide light through the Coudé path to the optical bench below
  - Optical bench install started but had to stop due to precautions for virus
- Plan for completion
  - Initial star calibration testing and ground ranging will take place with the mass simulator
  - The first Gimbal and Telescope Assembly (GTA) is expected to be delivered to Goddard in the fall 2020
  - Integration & Testing (I&T) for all SGSLR systems will take place at Goddard
  - Collocation testing with NASA's legacy MOBLAS-7 system will occur after I&T and before the systems are deployed to their final locations


Gimbal and mass simulator


Riser

SGSLR: deployment 1 and 2

- McDonald Observatory
  - Integration & Testing (I&T) of SGSLR #1 will be performed at GGAO
  - Collocation testing of SGSLR #1 at Goddard will be performed with NASA's legacy MOBLAS-7 system providing for characterization of the SGSLR system as well as verifying the system performance requirements
  - A six month commissioning will follow deployment to McDonald Observatory after completing the Collocation Acceptance Review
- Ny-Ålesund, Norway
  - SGSLR #2 I&T will be performed at GGAO
  - Collocation testing of SGSLR #2 will also be performed at Goddard with NASA's legacy MOBLAS-7 system for the same reasons
  - A six month commissioning will follow deployment to Ny-Ålesund after completing the Collocation Acceptance Review


McDonald SGSLR facility


Ny-Ålesund SGSLR facility

RSLRN: plans

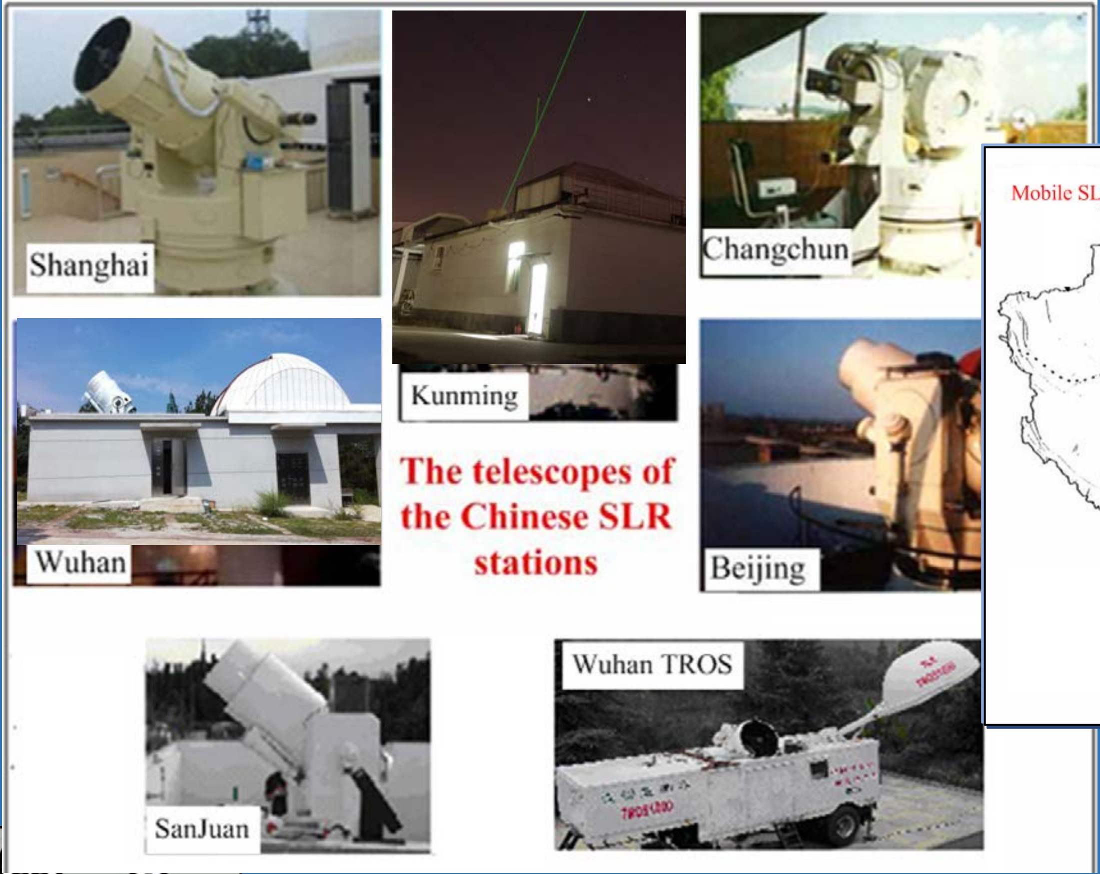
- Russian Space Laser Ranging Network (RSLRN) currently has 11 stations;
- New Tochka stations with co-located SLR systems underway;
- Expanding existing RSLRN with additional Tochka stations (2 co-located SLR) outside of Russia;

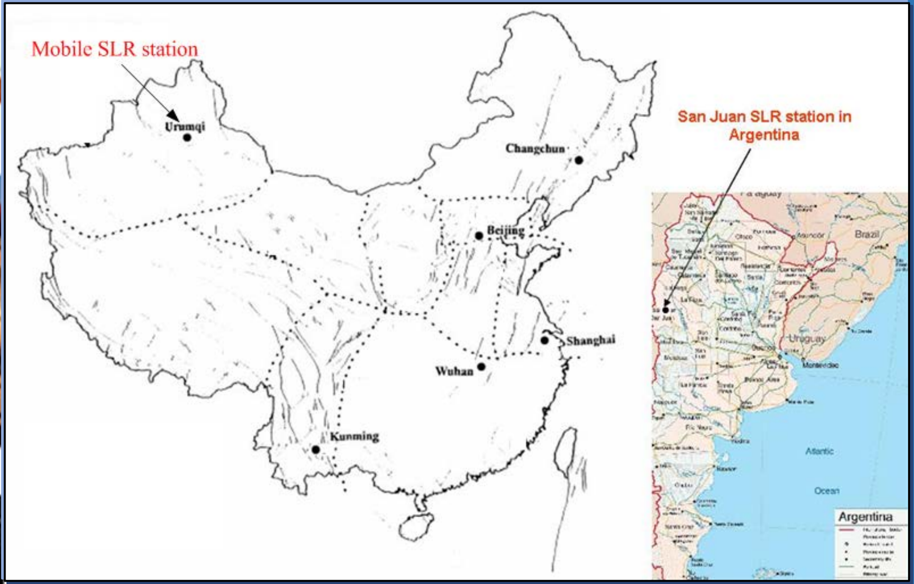
- Negotiations underway on sites in Tahiti, Gran Canaria, San Juan (Argentina), Java (Indonesia) and Ensenada (Mexico);
- Plans to co-locate some Tochka SLR with VLBI (Core Sites)

RSLRN: top priorities

- Increased data quality and quantity to support geodetic and geodynamical tasks, including those within the scope of ILRS and GGOS;
- Improved precision monitoring, verification and accuracy for geodetic and ephemeris/time data of GLONASS;
- Improved precision and estimation of accuracy of onboard and ground-based time scales using laser measurements on the GLONASS SC;
- Implementation
  - Deployment of new Tochka SLR systems;
  - Upgrade of current RSLRN stations;
  - Development of precision laser time transfer system through GLONASS;
  - Development of the onboard retroreflector systems with a sub-millimeter signature;
  - improvement of measuring data processing and analysis methods.

Chinese SLR network





Chinese SLR stations: status

ILRS

- Routine 1kHz SLR measurements at Shanghai, Changchun, Beijing, Kunming, to track ILRS satellites;
- Wuhan station with the aperture of 1 meter has transferred laser data to ILRS data center since Sep-2019;
- Improvements of Kunming station have significantly increased data yield;
- Mobile SLR system (TROS) with a 1 meter aperture is operating at the Xinjiang Observatory (Urumqi); data flowing since Sep. 19, 2019
- Upgrading of the San Juan station delayed again due to corona-virus;
- Shanghai station developing 100kHz rep. rate SLR technology;
- Plan to upgrade the Chinese SLR network to 2kHz by 2022.

The mobile SLR system (TROS) in Xinjiang Observatory (Urumqi)

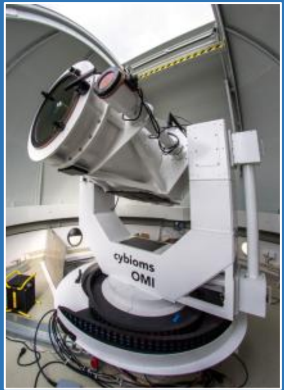
AGGO in La Plata, Argentina: update

- VLBI, GNSS, gravimetry (absolute and superconducting), time and frequency keeping, meteorological sensors, and hydrological measurements operational
- SLR in the process of modernization
- In January/February 2020 AGGO participated in absolute gravity measurements at the Patagonian icefields with FG5 and CG5
- Plans for 2020/2021:
  - Start SLR operation;
  - Installation of tide gauge, water vapor radiometer, and ceilometer;
  - Extension of solar power supply and improvements in the energy supply;
- Cooperation BKG-CONICET is under negotiation for the continuation of the shared operation of AGGO for next 10 years
- Lockdown due to the coronavirus resulted in temporary shutdown of the non-automated operation procedures of AGGO; operation will be resumed as soon as it is possible

Metsähovi, Finland: update

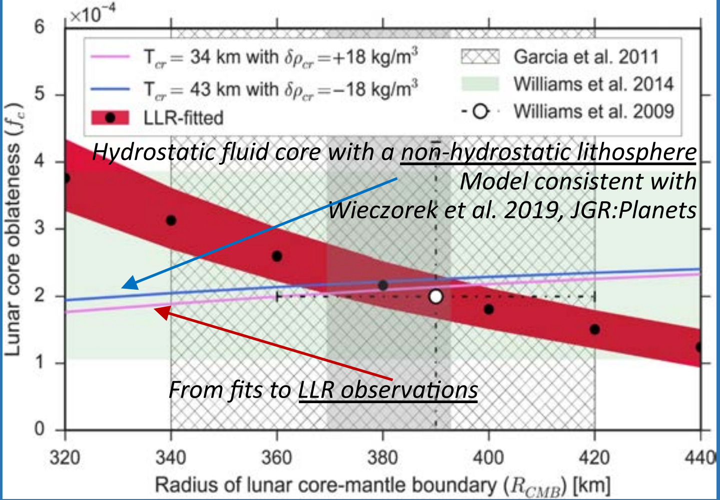
Metsähovi is a GGOS core site

- GNSS, SLR, DORIS, VGOS VLBI, superconducting + absolute gravity, environmental monitoring etc.
- Precise geodetic local tie measurements are a key focus
- VGOS VLBI: receiver first light achieved; antenna and signal chain integration and development during 2020
- SLR to a testing phase during winter 2020/2021 (global COVID-19 situation has caused major delays in the finalization)
- SLR key parameters
  - Laser package: 532nm, ~0.4mJ, ~12ps, 2kHz (looking for new 532+1064nm ps-laser)
  - Telescope: Bistatic 50cm RX/10cm TX + 15cm refractor, possibility for piggyback options
  - Detector package: C-SPAD
  - Accuracy/Precision: sub-centimeter (full-rate)
  - Dome: slit-type
  - Special features:
    - Aircraft safety (ADS-B, tracking camera, all sky camera, automatic cloud detection)
    - Indoor calibration, possibility for outdoor targets
    - Space debris laser ranging and light curve option in the future



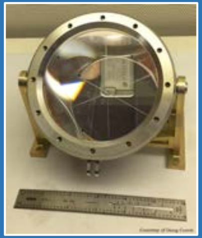
LLR activities

- Four operational LLR stations: APOLLO (USA), Grasse (France), Matera (Italy), and Wettzell (Germany)
- Seven active ILRS LLR analysis centers, focusing on different research topics: JPL (USA), CfA (USA), POLAC (France), IfE/U. Hannover (Germany), INFN (Italy), SOKENDAI (Japan), IAA RAS (Russia)
- Recent results: Geometry of a relaxed lunar fluid core from LLR

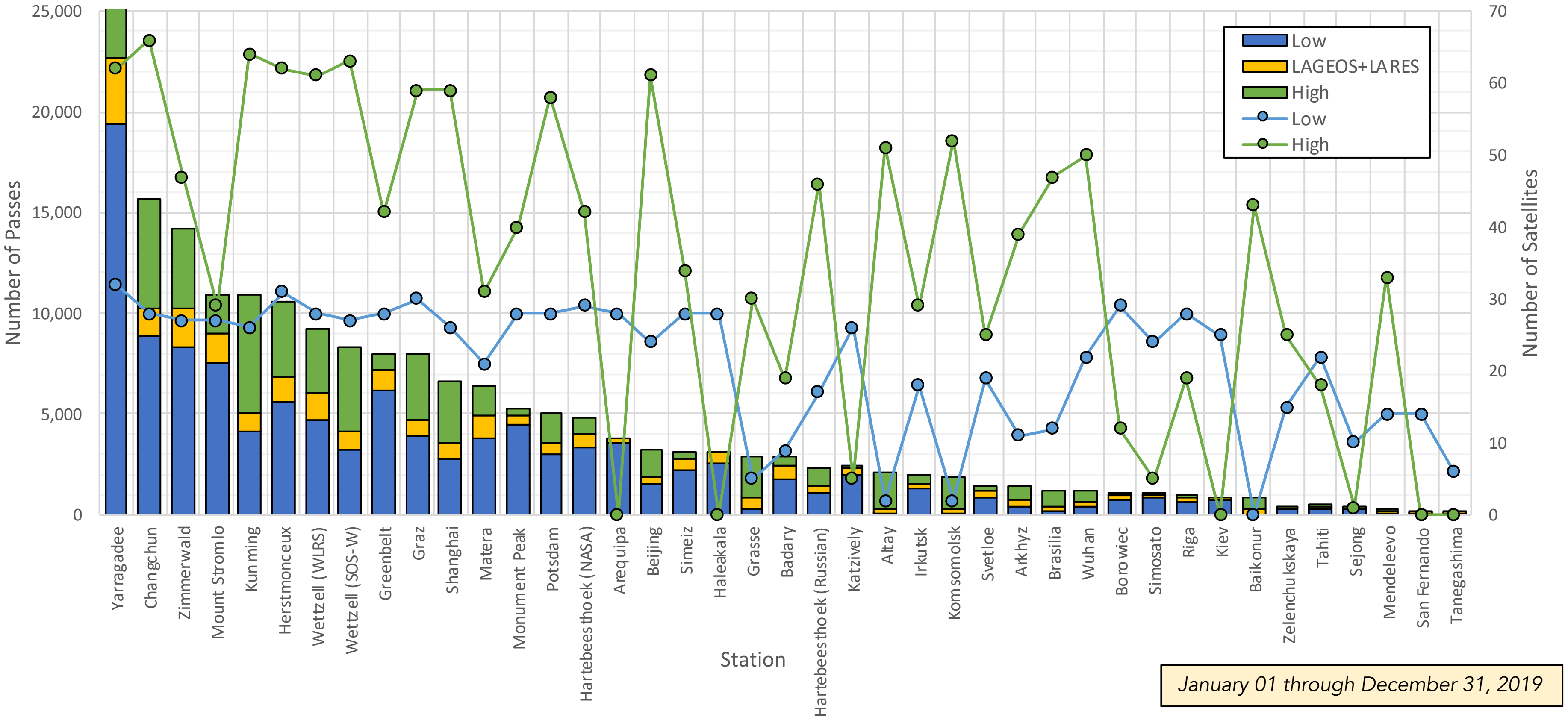


Hydrostatic fluid core model intersects observed fluid core oblateness

- Next Generation Lunar RetroReflector will improve ranging accuracy by a factor of 100; limits to the science with this improvement:
  - Ground station hardware and procedures
  - Modeling of horizontal gradients in the Earth's atmosphere
- Community currently organizing ILRS LLR focus group including science, analysis, and station colleagues; workshop planned for fall 2020

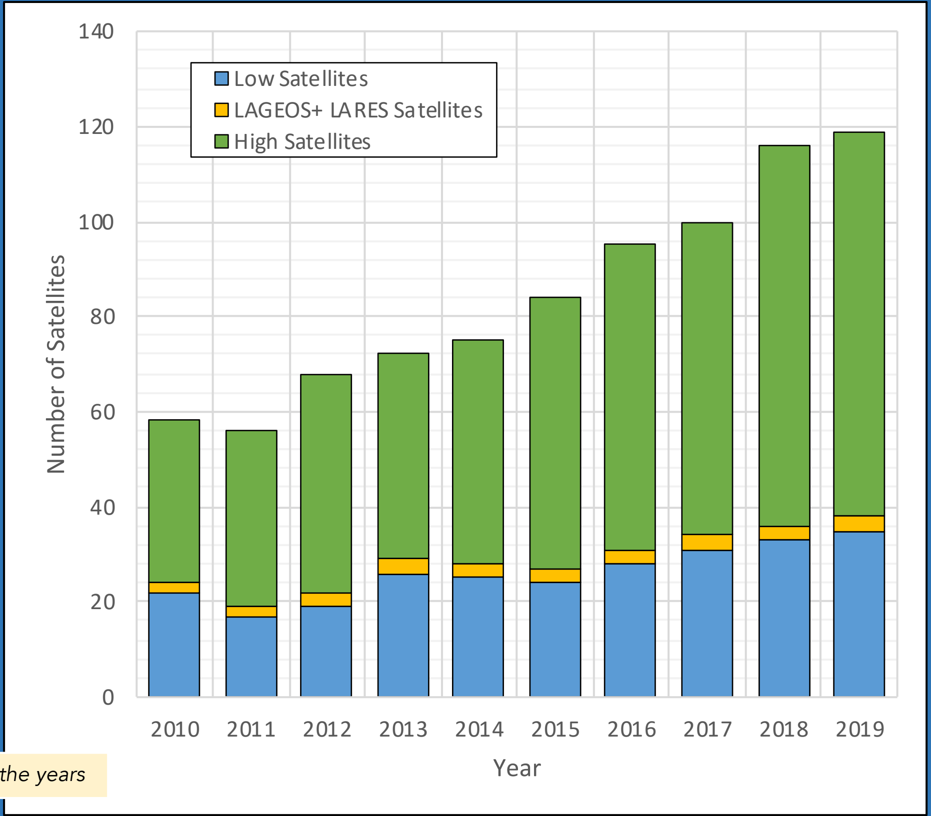


Station performance: 2019



Mission support

- Tracked 119 satellites in 2019
- Formulated new GNSS tracking strategy
- Held successfully 3-month Etalon campaign; stations collected more Etalon data overall and added geometry to data yield making a significant difference in ILRS EOP product
- Updated mission support request guidelines

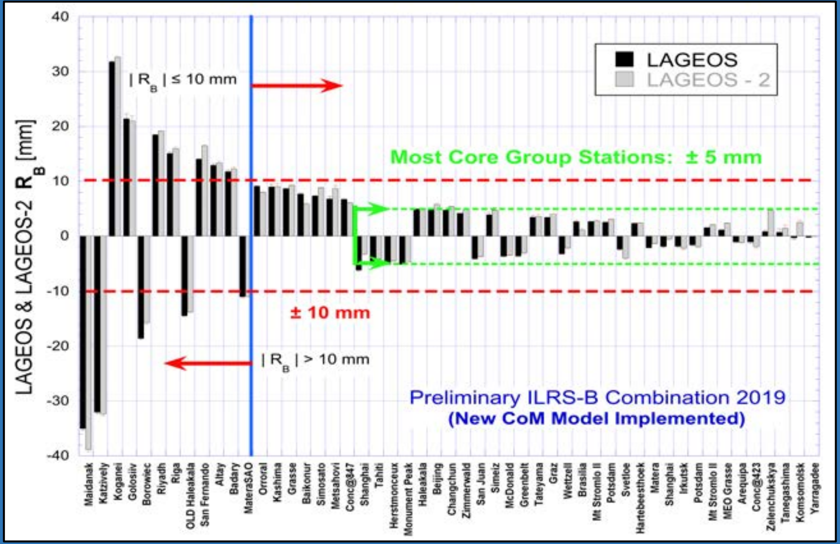


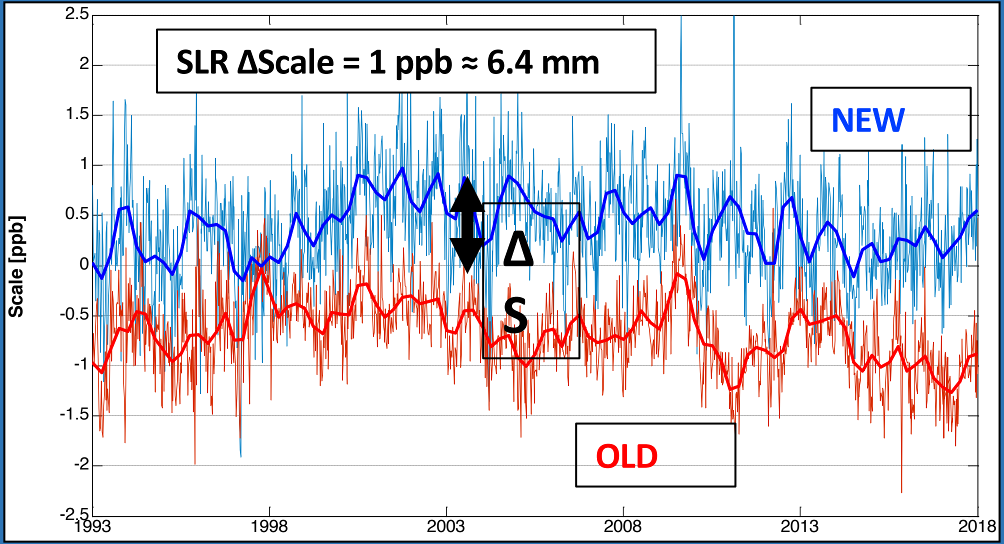
Number of satellites tracked over the years

Operations/infrastructure: developments

- Implemented web-based site log creation/update procedure;
- Implementing updated versions of CRD and CPF formats to (1) enhance prediction capability to support new missions (e.g., ELT, space debris) and (2) provide new information from the stations to improve data quality control;
- Enhanced QC procedures and harmonization between EDC and NASA operations centers for uniformity;
- Improved (daily) performance feedback to the stations;
- Holding meetings of ILRS Quality Control Board to examine data quality issues and procedures; currently focusing on pulse shape information and normal point formulation procedures;
- Implemented enhanced web-based data product displays for the users information;
- Accepted new ILRS Mirror Data Center at ESA/GSAC;
- Implemented data systematics modeling procedure within the Analysis Standing Committee to reveal and model data systematics;
- Created new procedure to expedite yet be more critical of new missions tracking support requests.

Improved ILRS modeling: VLBI-SLR scale difference ~0.23 ppb

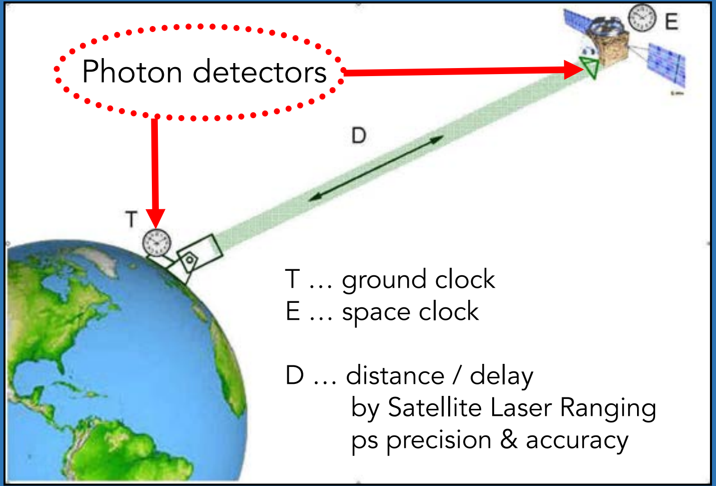




- Systematic re-analysis of LAGEOS-1 & -2 and Etalon-1 & -2 data (1993-2019) produced a preliminary set of persistent long-term biases at the most active SLR stations.
- When these biases are implemented in the reprocessing for the development of the SLR contribution to ITRF2020, they reduce the VLBI-SLR scale discrepancy to ~0.23 ± 0.10 ppb.

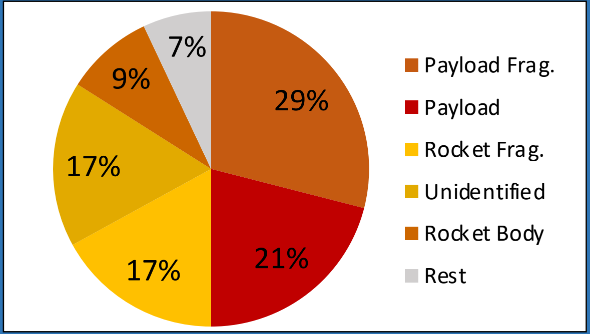
Controlling signal delays by optical 2-way link stabilization

- Space geodesy has progressed to the point where systematic measurement errors become the largest residual error source.
- The most prominent contribution comes from internal instrumental time delays, which are not captured by the system calibration.
- A limited bandwidth, variable electrical ground potential fluctuations, temperature fluctuations of electronic devices for relevant timing functions and phase noise are the most prominent contributors.
- Optical 2-way time and frequency transfer is the most promising way to overcome this problem, because delays are actively controlled.
- Active control of the internal system delays improves the long-term system stability of VLBI, SLR and GNSS.



Space debris laser ranging: overview

- Numbers:
  - 5450 rocket lauches since 1957
  - 5000 satellites (1950 active)
  - 34 000 objects > 10 cm, 900 000 objects > 1 cm
  - > 20 000 objects monitored / Space Surveillance Networks
- Sources:
  - Rocket parts, payload, break ups, fragmentation, anti-satellite weapons, collisions
- Risks:
  - Velocity: 7 kilometers / second; large potential impact energy
  - Even mm-sized particle are a threat to active satellite
  - Orbit needs to be known as good as possible
- Space debris laser ranging:
  - Laser pulses (16 Watt, 200 Hz, 80mJ) sent to uncooperative targets > $0.5m^2$
  - Diffuse reflection of laser detected, time of flight (distance) measured
  - Single shot accuracy of approx. 1 meter



Space debris laser ranging: Recent research and technology

- <u>Daylight</u> space debris laser ranging:
  - Inaccurate orbit predictions -> corrections necessary -> center target in FoV
  - Solution: Visualization of space debris during daytime
  - 2019 realized for the first time at IWF in Graz (up to 39° sun elevation)
- Multistatic space debris laser ranging
  - One (active) station sends out laser pulses
  - Pulses detected by multiple (passive) laser stations -> improved orbit
- Stare and Chase within a single pass
  - Space debris laser ranging without any a-priori knowledge of orbit
  - Pointing determination -> initial orbit determination -> space debris laser ranging
- Attitude determination
  - SLR -> high repetition rate and depth information
  - Unique method to determination rotation axis
  - Importance to future removal missions

SLR in the next 10 years

- Modular design; extended use of COTS -> significant cost reduction
- Standard SLR stations or e.g., miniSLR station (Stuttgart concept)
- Would allow a denser SLR network / more stations
- Routine [sub-] mm SLR with 100 kHz to 1 MHz, up to GEOs
- One 10 ps laser used regularly for space debris laser ranging (20-40 W)
- SLR at 532 and / or 1064 nm
- Simultaneous light curve recording for attitude / motion
- Automatic / autonomous operation (with some minimum human backup)
- Add-ons, like LIDAR for cloud detection; atmosphere recording etc.

Issues & challenges

- Many geographic gaps, primarily in Latin America, Africa, and Oceania
- Mix of new and old technologies and levels of financial support
- Lack of standardization in system hardware and operations
- Data quality issues (efforts underway to detect and reduce systematics)
- Number of target satellites continues to increase as new missions use SLR for orbit determination and other applications (100+ satellites)
    - Need to implement more effective tracking strategies
    - Need to be more selective on the targets
    - Need to conduct periodic community surveys to understand user requirements