



ILRS: Current Status and Future Trends

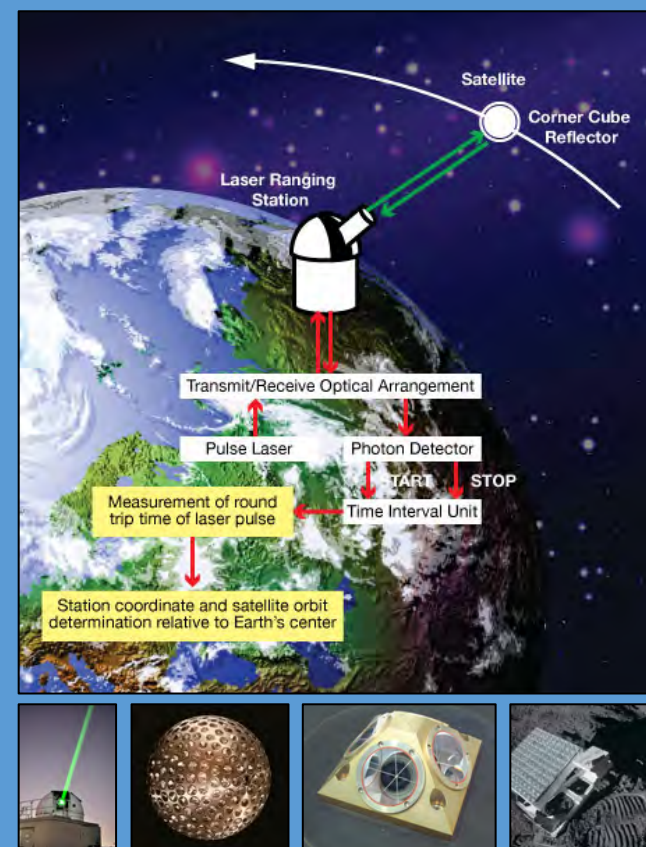
Michael Pearlman
Carey Noll
ILRS Central Bureau

Unified Analysis Workshop
October 03, 2019
Paris, France

Outline

- Introduction
- SLR overview
- Current trends
- Network
- Mission support
- Infrastructure
- Conclusion

- Satellite Laser Ranging and Lunar Laser Ranging
- Space Segment:
 - ◆ Satellites equipped with corner cube reflectors
 - ◆ 100+ satellites (including the Moon)
- Ground Segment:
 - ◆ Short-pulse laser transmitter
 - ◆ ~40 sites tracking
- Observable:
 - ◆ Two-way range measurement to the satellite
- Characteristics:
 - ◆ Passive space segment
 - ◆ “Simple” range measurement
 - ◆ Only optical system in the space geodetic complex




SLR: satellite laser ranging



- Satellite Laser Ranging directly measures the range between the ground station and the satellite using very short laser pulses, corrected for refraction, satellite center of mass, and the internal delay of the ranging machine.

$$R = \Delta t \times c/2 - R_{\text{atm}} + R_{\text{c/m}} + R_{\text{cal}}$$

- State of the art is sub millimeter precision average measurements (normal points) with centimeter level accuracies
- SLR systems can track satellites from 300 km to 22,000+ km in day & night; some track the arrays on the Moon
- Each station tracks independently but a network of stations can be scheduled together (set priorities) to optimize tracking
- Requires only a passive retroreflector on the satellite



*Unambiguous centimeter accuracy orbits
Long-term stable time series*

SLR science and applications










- Measurements
 - ◆ Precision orbit determination (POD)
 - ◆ Time series of station positions and velocity
- Products
 - ◆ Terrestrial reference frame (center of mass and scale)
 - ◆ Improve understanding of the dynamics and modeling of GNSS orbits (one of our major users)
 - ◆ Calibration and validation of ocean and ice altimetry missions
 - ◆ Static and time-varying gravity field (low order/degree terms)
 - ◆ Plate tectonics and crustal deformation
 - ◆ Earth orientation and rotation (polar motion, length of day)
 - ◆ Total Earth mass distribution
 - ◆ Space science – satellite dynamics, etc.
 - ◆ Relativity and lunar science

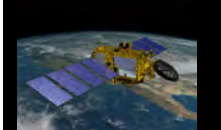
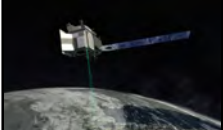
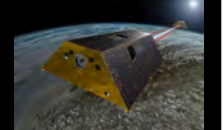
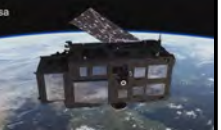


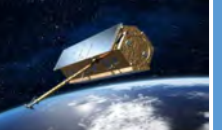
SLR satellite constellation: examples




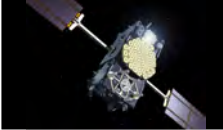




Geodetic

							
Satellite	LAGEOS-1	LAGEOS-2	LARES	Etalon-1/-2	Ajisai	Starlette	Stella
Inclination	109.8°	52.6°	69.5°	64.9°	50°	50°	98.6°
Perigee (km)	5,860	5,620	1,460	19,120	1,490	810	800

LEO

							
Satellite	Jason-3	ICESat-2	GRACE-FO	Sentinel-3A/-3B	SWARM	SARAL	TerraSAR-X
Inclination	66°	92°	89°	98.65°	92°	98.55°	97.44°
Perigee (km)	1,336	496	500	814.5	720	814	514

HEO/ GNSS

						
Constellation	GLONASS	Galileo	BeiDou	QZSS	IRNSS	GPS-III (future)
Inclination	65°	56°	55.5°	45°	29°	55°
Perigee (km)	19,140	23,220	42,161	32,00	42,164	~12,550

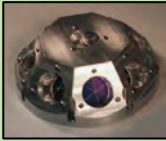
Retroreflector arrays



- Arrays for GNSS satellites
 - ◆ “ILRS Standard Specification for GNSS Satellites”: effective area of 100 million square meters
 - ◆ Adaptation of the GNSS standard to synchronous satellites (e.g., IRNSS, BeiDou, QZSS)
 - ◆ Improved station quality may allow lower quality, less expensive corner cubes to be used
 - ◆ Investigation of specialized designs for increase cross-section
- Arrays for LEO satellites
 - ◆ “Pyramid” type arrays (e.g., Lomonosov) are lightweight, inexpensive, and have the required accuracy (0.5 mm)
 - ◆ Common use of the GFZ array, nearly COTS
 - ◆ Particular design depends upon the satellites altitude and tracking requirement
- Geodetic satellites
 - ◆ New array designs for LEO spherical satellites to reduce cost and improve performance
 - ◆ BLITS-M type satellites have minimal target error
- Large cornercubes (lunar ranging)
- Hollow cubes for LLR



BeiDou



Jason



GRACE

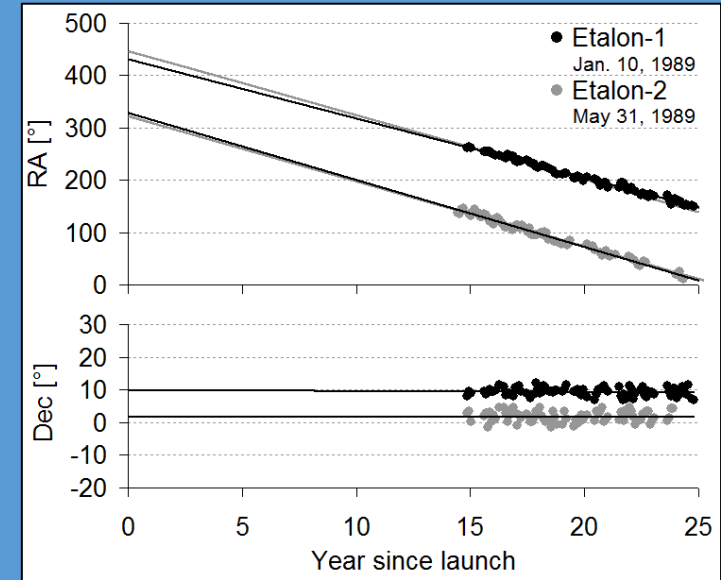
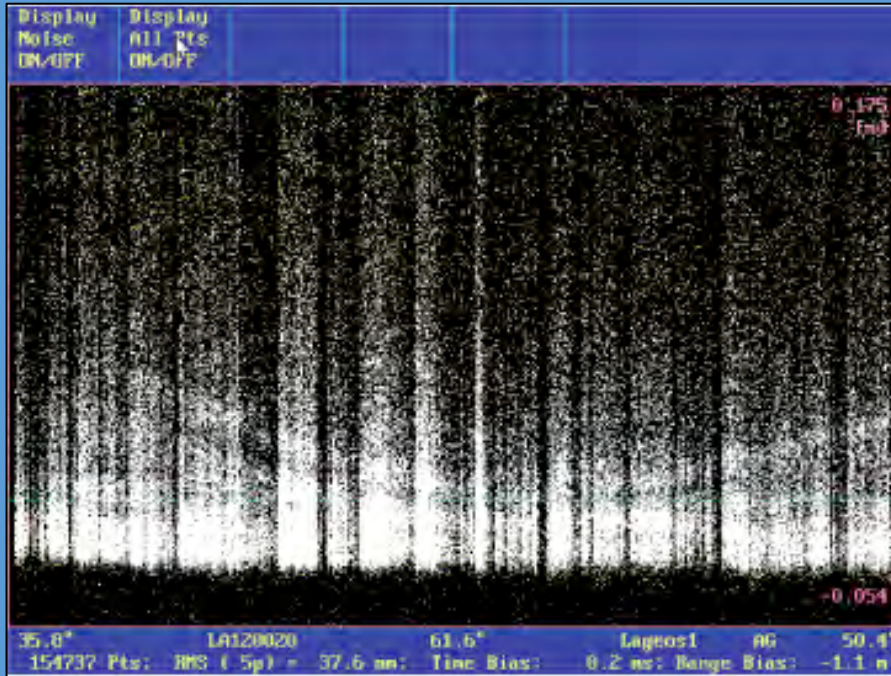


BeiDou



Lunar

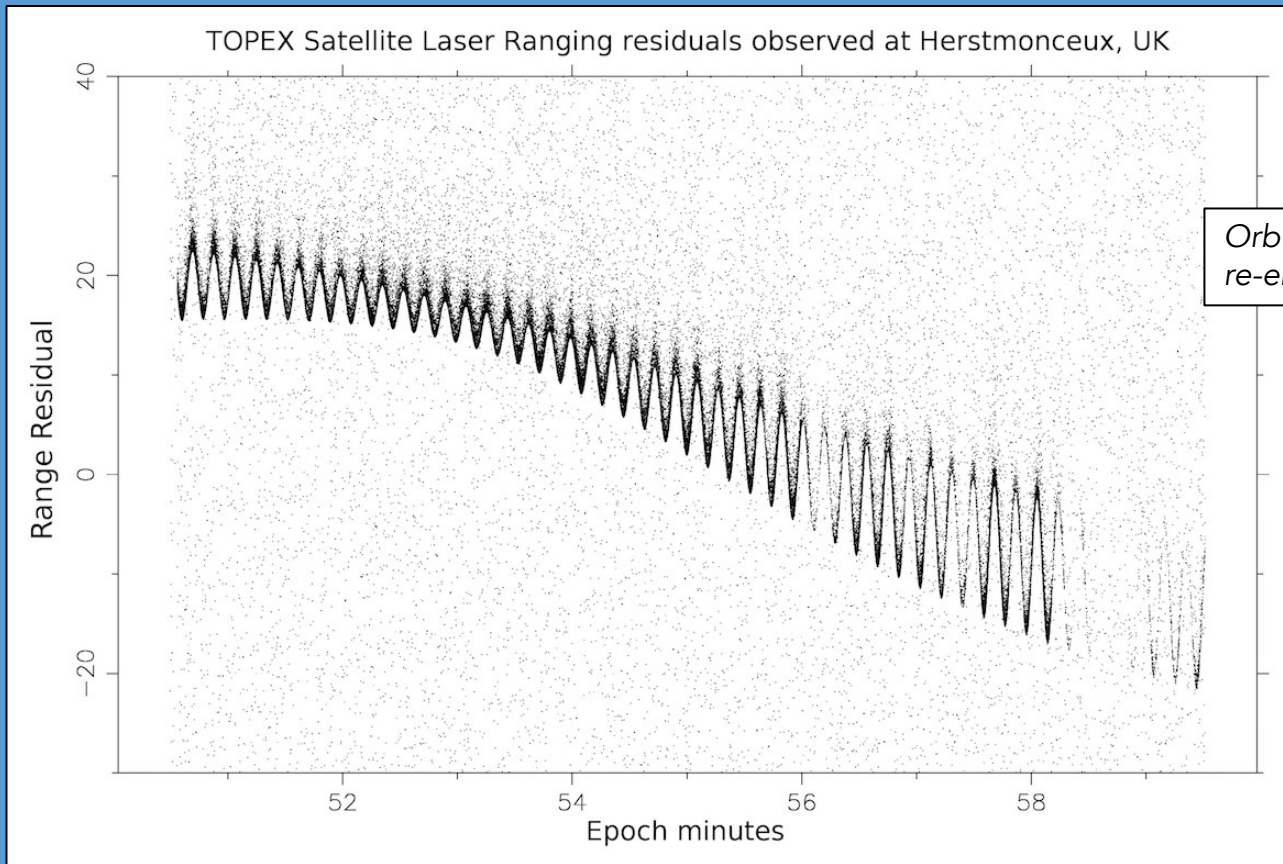
High repetition-rate systems



- High repetition rate, short pulse lasers allow us to see retroreflector array details

- Leading to impressive diagnostics of satellite attitude
 - ◆ Most of the geodetic spheres have had spin vectors measured as functions of time:
 - ◆ e.g., D. Kucharski et al, Etalon-1 and -2, ASR 2014

Space debris: TOPEX/Poseidon



The ILRS mission

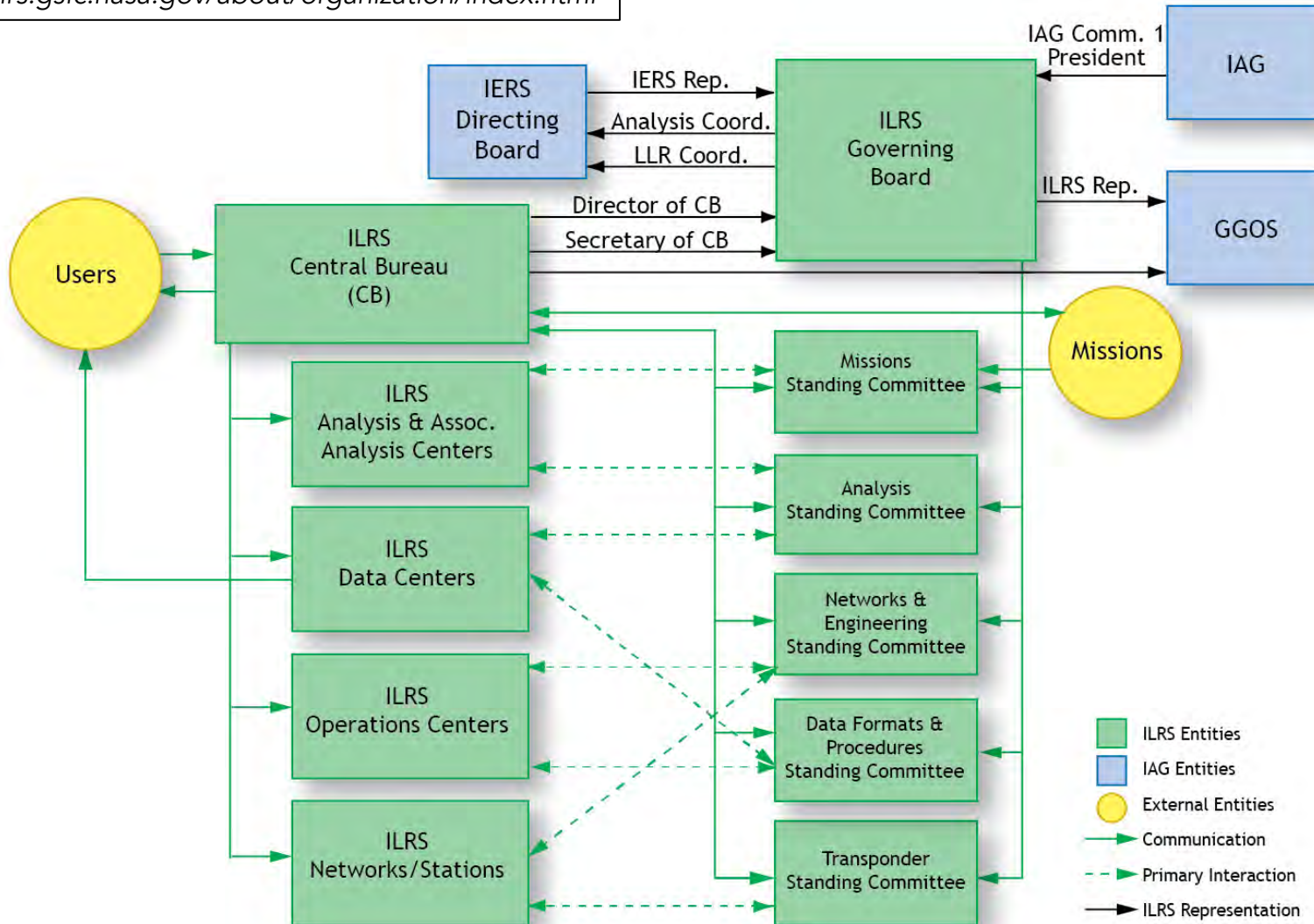


- Laser ranging activities are organized under the International Laser Ranging Service (ILRS) which provides global satellite and lunar laser ranging data and their derived data products to support research in geodesy, geophysics, Lunar science, and fundamental physics. This includes data products that 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 organization



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



Governing board: 2019-2020



- Ex-officio/appointed positions:

- ◆ Director of the Central Bureau – **Mike Pearlman**
- ◆ Secretary of the Central Bureau – **Carey Noll**
- ◆ Representative of IAG Commission 1 – **Urs Hugentobler**
- ◆ IERS Representative – **Daniela Thaller**



- Elected positions:

- ◆ EUROLAS Network Representatives – **Pippo Bianco, Georg Kirchner**
- ◆ NASA Network Representatives – **Jan McGarry, Stephen Merkowitz**
- ◆ WPLTN Representatives – **James Bennett, Zhang Zhongping**
- ◆ Data Center Representative – **Christian Schwatke**
- ◆ LLR Representative – **Jean-Marie Torre**
- ◆ Analysis Representatives – **Cinzia Luceri, Erricos Pavlis**
- ◆ At-Large Representatives – **Toshi Otsubo (Chair), Matt Wilkinson**

- Appointed by the Governing Board:

- ◆ **Ulli Schreiber**
- ◆ **Krzysztof Sońnica**

*18 members serving on the
ILRS Governing Board which
took office on January 01, 2019*

International Workshops on Laser Ranging



- International Workshops on Laser Ranging typically held every two years
 - ◆ Program includes sessions on science, infrastructure, operations, technology, software, and mission design
 - ◆ Presentations, proceedings, summaries available on ILRS website
 - ◆ Clinics focus on small group interactions with station personnel
 - ◆ 21st International Workshop on Laser Ranging held in Canberra, Australia, November 2018
 - ◆ Theme: “Laser Ranging for Sustainable Millimeter Geoscience”

Number	Year	Location
1 st	1973	Lagonissi, Greece
2 nd	1975	Prague, Czechoslovakia
3 rd	1978	Lagonissi, Greece
4 th	1981	Austin, TX, USA
5 th	1984	Herstmonceux, UK
6 th	1986	Antibes, France
7 th	1989	Matera, Italy
8 th	1992	Annapolis, MD, USA
9 th	1994	Canberra, Australia
10 th	1996	Shanghai, China
11 th	1998	Deggendorf, Germany
12 th	2000	Matera, Italy
13 th	2002	Washington, D.C., USA
14 th	2004	San Fernando, Spain
15 th	2006	Canberra, Australia
16 th	2008	Poznan, Poland
17 th	2011	Bad Koetzing, Germany
18 th	2013	Fujiyoshida, Japan
19 th	2014	Annapolis, MD, USA
20 th	2016	Potsdam, Germany
21 st	2018	Canberra, Australia
22 nd	2020	Kunming, China



Over 150 participants in the 21st International Workshop on Laser Ranging, Canberra Australia
<https://cddis.nasa.gov/lw21/>

<https://ilrs.gsfc.nasa.gov/about/reports/workshop/index.html>

ILRS Technical Workshops



- ILRS also organizes smaller, focused workshops in years between the International Workshops on Laser Ranging
 - ◆ Next technical workshop will be held in Stuttgart, Germany, October 21-25, 2019
 - ◆ Theme: *“Laser ranging: To improve economy, performance, and adoption for new applications”*
 - ◆ 2019 workshop will be preceded by a one-day “SLR School” providing tutorials on SLR and the ILRS

Topic	Year	Location
SLR System Calibration Issues	September 1999	Florence, Italy
Working Toward the Full Potential of the SLR Capability	October 2003	Kötzing, Germany
Observations Toward mm Accuracy	October 2005	Eastbourne, UK
Challenges for Laser Ranging in the 21st Century	September 2007	Grasse, France
SLR Tracking of GNSS Constellations	September 2009	Metsovo, Greece
Satellite, Lunar and Planetary Laser Ranging: Characterizing the Space Segment	November 2012	Frascati, Italy
Network Performance and Future Expectations for ILRS Support of GNSS, Time Transfer, and Space Debris Tracking	October 2015	Matera, Italy
Improving ILRS Performance to Meet Future GGOS Requirements	October 2017	Riga, Latvia
Laser ranging: To improve economy, performance, and adoption for new applications	October 2019	Stuttgart, Germany

<https://ilrs.gsfc.nasa.gov/about/reports/workshop/index.html>

Journal of Geodesy Special Issue on Laser Ranging



30+ papers submitted;
18 papers published online;
4 papers in final review stage.

The ILRS: Approaching twenty years and planning for the future

Geodetic Satellites: A High Accuracy Positioning Tool

Satellite Laser Ranging to Low Earth Orbiters - Orbit and Network Validation

Version of a glass retroreflector satellite with a sub-millimeter "target error"

Laser and Radio Tracking for Planetary Science Missions - A Comparison

Assessment of the impact of one-way laser ranging on orbit determination of the Lunar Reconnaissance Orbiter

Overview of Applications of Satellite Laser Ranging and Laser Time Transfer in BeiDou Navigation Satellite System

Lunar Laser Ranging - A Tool for General Relativity, Lunar Geophysics and Earth Science

NASA's Satellite Laser Ranging Systems for the 21st Century

Time and laser ranging: A window of opportunity for geodesy, navigation and metrology

The Next Generation of Satellite Laser Ranging Systems

Rapid Response Quality Control Service for the Laser Ranging Tracking Network

Solar orbital thermo-optical characterization of an innovative GNSS retroreflector array

Operating two SLR Systems at the Geodetic Observatory Wettzell - from local survey to space ties

Future SLR station networks in the framework of simulated multi-technique terrestrial reference frames

Information Resources Supporting Scientific Research for the International Laser Ranging Service

Modernizing and Expanding the NASA Space Geodesy Network to Meet Future Geodetic Requirements

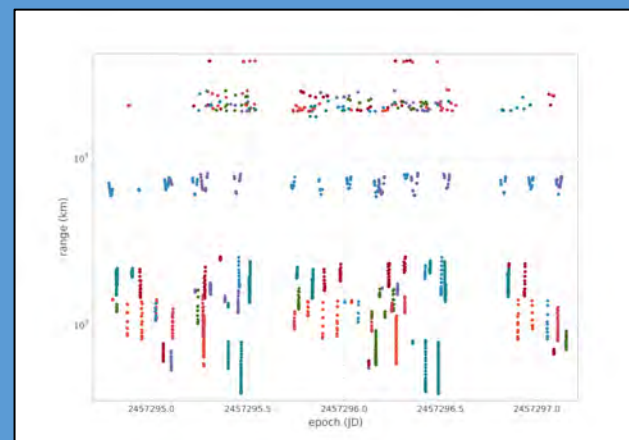
Time Bias Service: Analysis and Monitoring of Satellite Orbit Prediction Quality

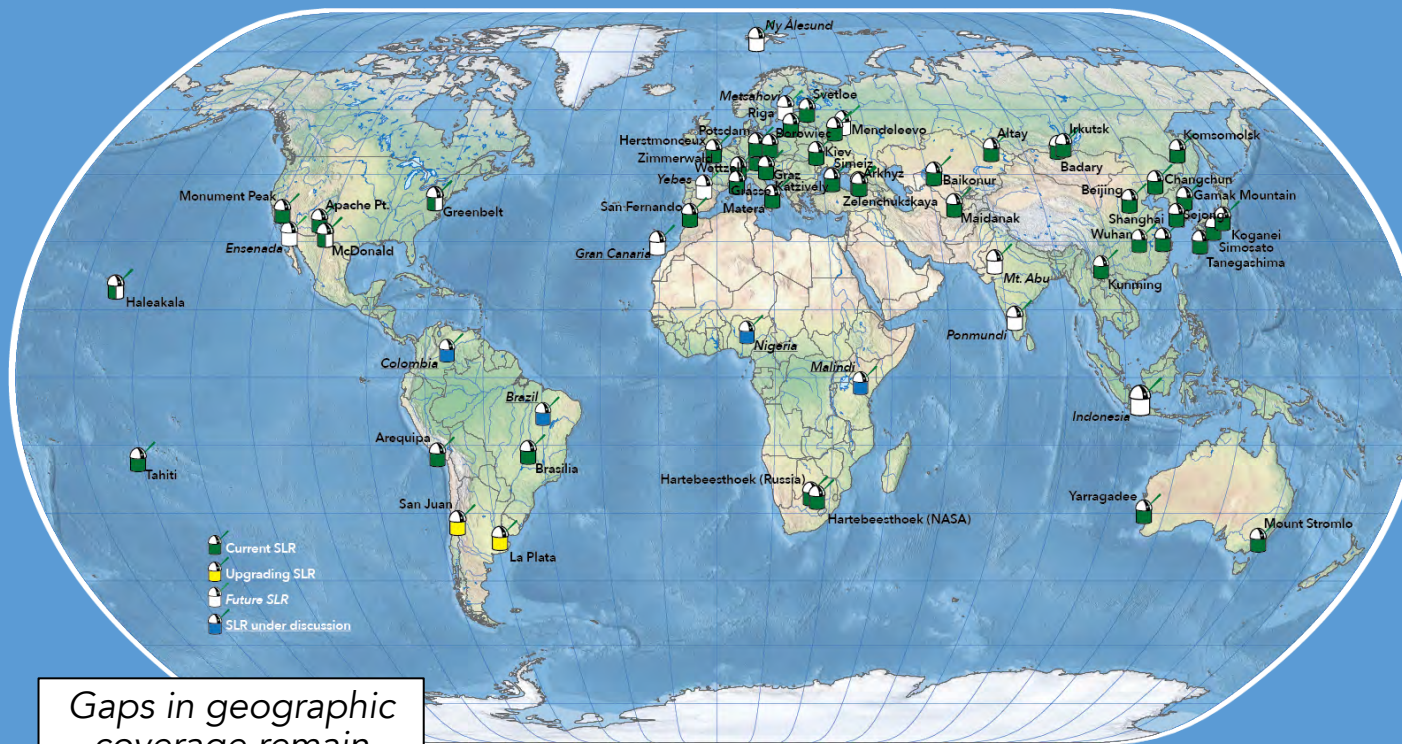


Current trends



- 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
- Interleaving of satellite passes
- 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





- BKG AGGO continuing setup at La Plata Observatory (Argentina)
- Russians implementing co-location concept in their own network to expand temporal coverage of satellites
- New stations underway:
 - Russia: Ensenada (Mexico), Java (Indonesia), Canary Islands (Spain)
 - NASA/NASA affiliated: McDonald, Halekala (USA), and Ny Ålesund (NMA, Norway)
 - Others: Metsahovi (Finland), Mt. Abu and Ponmudi (India), and Yebes (Spain)
- Upgrades underway at some stations

Station activity over the next few years



Site	Type	Agency	Time Frame
La Plata, Argentina	Upgraded core site	BKG, Germany	2019 – 2020
San Juan, Argentina	Upgraded SLR system	NAOC, China	2019 – 2020
Metsahovi, Finland	New SLR system	FGRI, Finland	2019 – 2020
Greenbelt, MD, USA	Replacement core site	NASA, USA	2019 – 2020
Haleakala, HI, USA	Replacement core site	NASA, USA	2019 – 2020
McDonald, TX, USA	Replacement core site	NASA, USA	2019 – 2020
Ny Ålesund, Norway	New core site	NMA, Norway/NASA, USA	2019 – 2020
Ensenada, Mexico	New SLR site	IPIE, Russian Federation	2020
Java, Indonesia	New SLR site	IPIE, Russian Federation	2020
Gran Canaria, Spain	New SLR in core site	IPIE, Russian Federation	2020
Mt Abu, India	New SLR site	ISRO, India	2019 – 2020
Ponmundi, India	New SLR site	ISRO, India	2019 – 2020
Yebeas, Spain	New SLR site	IGS, Spain	2022



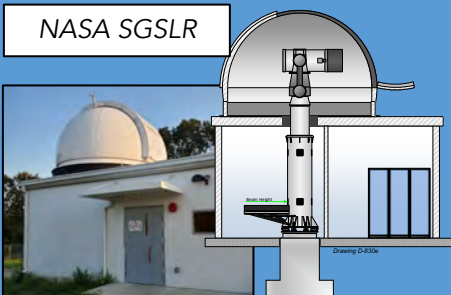
Tochka, Mendeleev, Russia



Sazhen-TM, Brasilia, Brazil



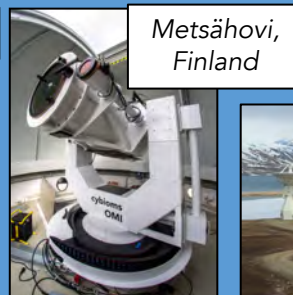
Wuhan, China



NASA SGSLR



ISRO, India



Metsähovi, Finland



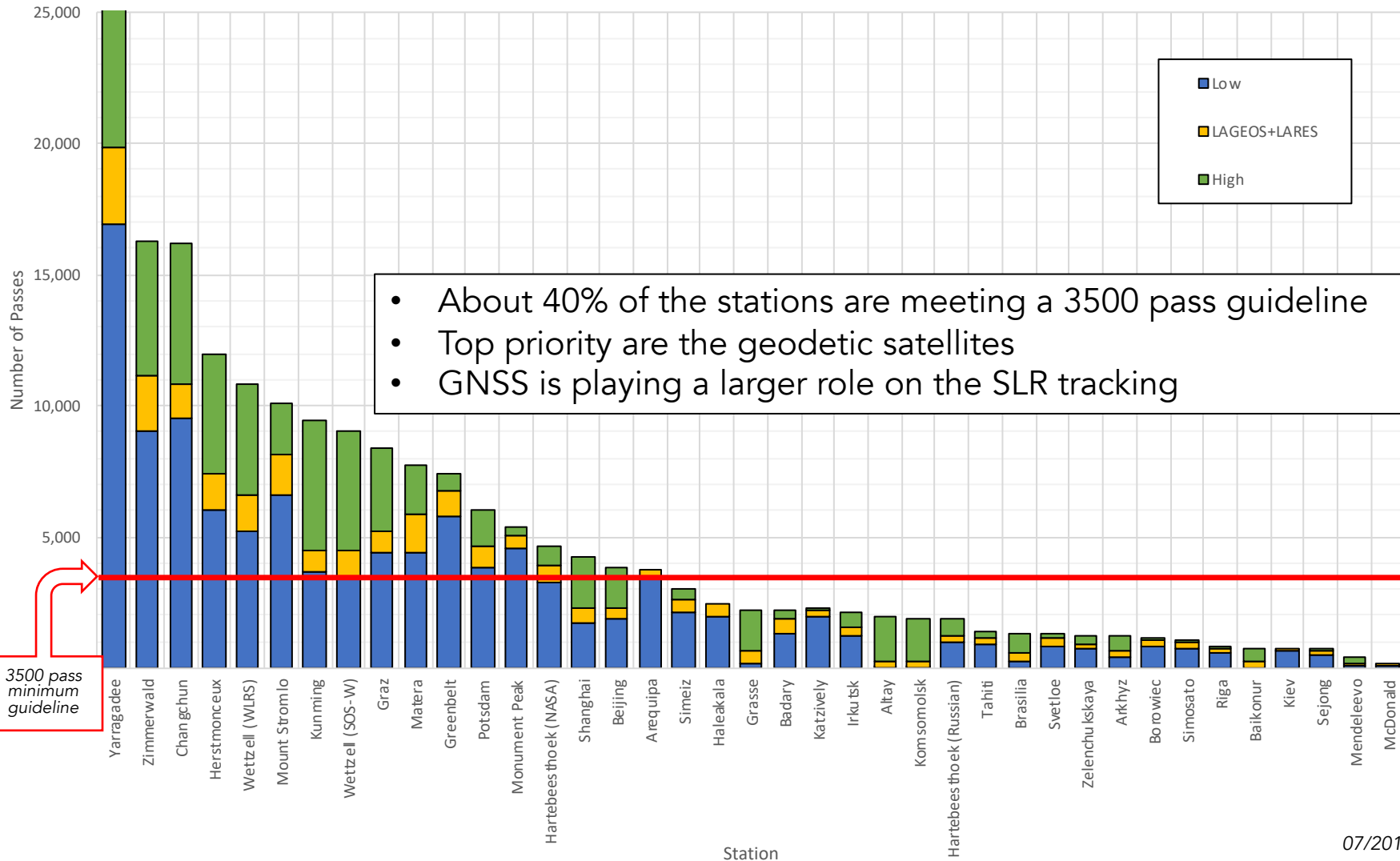
Ny Ålesund, Norway



San Juan, Argentina



Station performance: passes



07/2018-06/2019

Highlights: missions



- Network routinely tracked 110+ satellites in 2019
- Recent additions to the ILRS priority list:
 - ◆ S-NET (4 cubesats/testing inter-satellite communication)
 - ◆ Sentinel-3B (altimeter mission/restricted tracking)
 - ◆ GRACE-FO (2 satellites/gravity measurements)
 - ◆ PAZ (SAR mission)
 - ◆ ICESat-2 (laser altimetry mission/restricted tracking)
 - ◆ Beidou-3M (4 GNSS satellites)
 - ◆ GNSS (Galileo, GLONASS, IRNSS)
 - ◆ LightSail-2 (solar sail)
- Future missions:
 - ◆ Astrocass Precursor (2 cubesats/engineering testing)
 - ◆ Additional GNSS: BeiDou/Compass, Galileo, etc.
 - ◆ COSMIC-2, HY-2C, SWOT, NISAR
- More requests for restricted tracking, which is time consuming to implement



Analysis activities (ASC)



- Working on the development of the ITRF2020 series; production starts in late 2019
- Currently we are testing new models for gravity, tides, TVG, and target signature (CoM) models, and the inclusion of LARES data
- New operational approach to handling error sources in our current modeling standards
 - ◆ Allowance for estimation of systematic errors simultaneously with all other parameters to eliminate biases in station positions (mainly height)
 - ◆ Improved corrections in the current model for the Center of Mass (CoM) target signatures; such errors can affect the SLR-VLBI scale difference at the 0.25 ppb level
- Next steps
 - ◆ Low degree/low order gravity field terms (data product)
 - ◆ Include LARES satellite to the operational data products and ITRF2020
 - ◆ Add atmospheric loading to the operational data products (at the observation level)

Issues & challenges

- Many geographic gaps, primarily in Latin America, Africa, and Oceania
- Mix of new and old technologies, levels of financial support, weather
- 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 (110+ satellites)

