INTERNATIONAL LASER RANGING SERVICE (ILRS)

E. C. Pavlis[1], M. R. Pearlman[2], C. E. Noll[3], G. Appleby[4], J. Müller[5]

[4] *Joint Center for Earth Systems Technology, UMBC and NASA GSFC, Baltimore, MD 21250, USA*
[2] *Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA USA 02138, USA*
[3] *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[4] *NERC Space Geodesy Facility, Herstmonceux Castle, Hailsham, East Sussex, BN27 1RN, UK*
[5] *University of Hannover/Institut für Erdmessung, Hannover, GERMANY*

CONTRIBUTIONS OF THE ILRS

The ILRS was organized as one of the IAG measurement services in 1998. The service collects, merges, analyzes, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets to satisfy the objectives of scientific, engineering, and operational applications and programs. The basic observables are the precise two-way time-of-flight of an ultrashort laser pulse to a retroreflector array on a satellite or the Moon and the one-way time of flight to a space borne receiver (transponder). These data sets are made available to the community and are also used by the ILRS to generate fundamental data products, including: accurate satellite ephemerides, Earth orientation parameters, three-dimensional coordinates and velocities of the ILRS tracking stations, time-varying geocenter coordinates, static and time-varying coefficients of the Earth's gravity field, fundamental physical constants, lunar ephemerides and librations, and lunar orientation parameters. The ILRS generates a standard weekly product of station positions and Earth orientation for submission to the IERS, and produces LAGEOS combination solutions for maintenance of the International Terrestrial Reference Frame (ITRF). The ILRS participates in the Global Geodetic Observing System (GGOS) organized under the IAG.

ORGANIZATION AND ROLE OF THE ILRS

The ILRS accomplishes its mission through the following permanent components:

- Tracking Stations and Subnetworks
- Operations Centers
- Global and Regional Data Centers
- Analysis and Associate Analysis Centers
- Central Bureau

The ILRS Tracking Stations range to a constellation of Earth satellites, the Moon, a lunar satellite, and eventually interplanetary spacecraft with state-of-the-art laser ranging systems and transmit their data on an hourly basis to an Operations or Data Center. Stations are expected to meet ILRS data accuracy, quantity, and timeliness standards; their data must be regularly and continuously analyzed by at least one Analysis or mission-specific Associate Analysis Center. Each Tracking Station is typically associated with one of the three regional subnetworks: National Aeronautics and Space Administration (NASA), EUROpean LASer Network (EUROLAS), or the Western Pacific Laser Tracking Network (WPLTN). Many of the stations are now involved with one-way transponder and time transfer activities.

Operations Centers collect and merge the data from the tracking sites, provide initial quality checks, reformat and compress the data if necessary, maintain a local archive of the tracking data, and relay the data to a Data Center. Operational Centers may also provide the Tracking Stations with sustaining engineering, communications links, and other technical support. Tracking Stations may perform part or all of the tasks of an Operational Center themselves.

Global Data Centers are the primary interfaces between the Tracking Stations and the Analysis Centers and outside users. They receive and archive ranging data and supporting information from the Operations and Regional Data Centers, and provide these data on-line to the Analysis Centers. The Data Centers also receive and archive ILRS scientific data products from the Analysis Centers and provide these products on-line to users. Regional Data Centers reduce traffic on electronic networks and provide a local data archive.

Analysis Centers retrieve data from the archives and process them to produce the official ILRS products. They are committed to follow designated standards and produce data products on a routine basis for delivery to the Global Data Centers and the IERS. Analysis Centers routinely process the global LAGEOS-1 and LAGEOS-2 data and compute weekly solutions of station positions and Earth orientation for combination and submission to the IERS. Analysis Centers also provide a second level of data quality assurance in the network. Analysis and Associate Analysis Centers produce station coordinates and velocities, geocenter coordinates, time-varying gravity field measurements, fundamental constants, satellite predictions, precision orbits for special-purpose satellites, regional geodetic measurements, and data products of a mission-specific nature. Associate Analysis Centers are also encouraged to perform quality control functions through the direct comparison of Analysis Center products and the creation of "combined" solutions using data from other space geodetic techniques. Based on the longest observation time series of all space geodetic techniques, lunar laser ranging (LLR) analysis centers provide results for several dynamic parameters in the Earth-Moon system, e.g., orbital and libration parameters, reflector and station coordinates, and lunar physics quantities. Moreover, LLR is sensitive to nutation/precession, Earth rotation UT0, and polar motion. Also a variety of relativistic features are studied, like the strong equivalence principle, variation of the gravitational constant, metric or preferred-frame effects.

CENTRAL BUREAU

The ILRS Central Bureau (CB) is responsible for the daily coordination and management of ILRS activities. It facilitates communications and information transfer and promotes compliance with ILRS network standards. The CB monitors network operations and quality assurance of the data, maintains all ILRS documentation and databases, and organizes meetings and workshops. In order to strengthen the ILRS interface with the scientific community, a Science Coordinator and an Analysis Coordinator within the CB take a proactive role to enhance dialogue, to promote SLR goals and capabilities, and to educate and advise the ILRS entities on current and future science requirements related to SLR. The Science Coordinator leads efforts to ensure that ILRS data products meet the needs of the scientific community and that there is easy online access to published material relevant to SLR science and technology objectives.

The Central Bureau has been actively providing new facilities to expedite communication and performance review, and adding to the technical and scientific database. The Central Bureau maintains the ILRS website, *http://ilrs.gsfc.nasa.gov*, as the primary vehicle for the distribution of information within the ILRS community. The website features details on the ILRS, the satellites and campaigns, individual

SLR station characteristics, a scientific and technical bibliography on SLR and its applications, current activities of the Governing Board, Working Groups, and Central Bureau, meeting minutes and reports (including annual reports), tracking plans, and more. Reports and charts are available on the Station Information pages to monitor station and network performance and as a means of providing engineering insight and as a tool for operational planning. Station operators, analysts, and other ILRS groups can view these reports and plots to quickly ascertain how individual stations are performing as well as how the overall network is supporting the various missions. Detailed information on satellites supported by the ILRS is also available on the ILRS website, organized by mission.

GOVERNING BOARD

The Governing Board (GB) is responsible for the general direction of the service. It defines official ILRS policy and products, determines satellite-tracking priorities, develops standards and procedures, and interacts with other services and organizations. There are sixteen members of the Governing Board (GB) - three are ex-officio, seven are appointed, and six are elected by their peer groups (see Table 1). A new Board was installed in May 2011 at the 17th International Workshop on Laser Ranging in Bad Koetzting, Germany. We remember with sadness that over the past three years the ILRS has lost three of its founding colleagues: Werner Gurtner (Chair of the ILRS Governing Board from 2002-2009), Wolfgang Seemueller (Data Center representative from 1998-2010), and Yang Fumin (WPLTN representative for several years since 1998).

WORKING GROUPS

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG) carry out policy formulation for the ILRS. At its creation, the ILRS established four standing WGs: (1) Missions, (2) Data Formats and Procedures, (3) Networks and Engineering, (4) Analysis, and (5) Transponders for lunar and planetary ranging. The WGs are intended to provide the expertise necessary to make technical decisions, to plan programmatic courses of action, and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau. All GB members serve on at least one of the five WGs, led by a Coordinator and Deputy Coordinator (see Table 1). The WGs continue to attract talented people from the general ILRS membership who contributed greatly to the success of these efforts.

The Missions WG, with a set of evolving formal and standardized documentation, works with new satellite missions that seek approval for SLR observing support. The WG makes its recommendation based on whether such support is deemed necessary for the success of the mission and that the requested support is within the operational capabilities of the network. The WG also calls upon the expertise of the Analysis Working Group and Signal Processing Study Group to make a proper assessment during this process, and works with the new mission personnel and campaign sponsors to develop and finalize tracking plans and to establish recommended tracking priorities.

The Data Formats and Procedures WG completed the implementation of the Consolidated Prediction Format (CPF) for improved predictions on a much wider variety of laser ranging targets including (1) Earth-orbiting retroreflector satellites, (2) Lunar reflectors, (3) asynchronous and synchronous transponders. The new expanded format capability, with more complete modeling representation, removes the need for drag and special maneuver files as well as virtually all satellite time-bias corrections, a great benefit particularly on lower orbiting satellites. The working group also designed and implemented the Consolidated laser Ranging Data format (CRD), which accommodates full rate, sampled engineering, and normal point data types for artificial satellite, lunar, and now, one-way transponder ranging data. This format change was required to incorporate higher precision fire times for transponder ranging and to more efficiently represent full rate data from kHz laser-repetition-rate stations. It was designed to be flexible and expandable and to incorporate additional statistical and configuration data unavailable in the earlier formats. Implementation and validation of the CRD format is being monitored by the WG through a cooperative effort with the OCs, DCs, and AGs (organized through the Analysis WG). The Working Group has also coordinated the implementation of new features to support mission support restrictions for accommodate satellite vulnerability.

Table 1. ILRS Governing Board (as of May 2011)

Zuheir Altamimi	Ex-Officio, President of IAG Commission 1	France
Michael Pearlman	Ex-Officio, Director, ILRS Central Bureau	USA
Carey Noll	Ex-Officio, Secretary, ILRS Central Bureau	USA
Bob Schutz	Appointed, IERS Representative to ILRS	USA
Giuseppe Bianco	Appointed, EUROLAS	Italy
Francis Pierron	Appointed, EUROLAS	France
David Carter	Appointed, NASA	USA
Jan McGarry	Appointed, NASA	USA
Ramesh Govind	Appointed, WPLTN	Australia
Hiroo Kunimori	Appointed, WPLTN	Japan
Vincenza Luceri	Elected, Analysis Representative, Analysis Working Group Deputy Coordinator	Italy
Erricos C. Pavlis	Elected, Analysis Representative, Analysis Working Group Coordinator	USA
Horst Mueller	Elected, Data Centers Rep., Data Formats and Procedures WG Coordinator	Germany
Jürgen Müller	Elected, Lunar Representative	Germany
Graham Appleby	Elected, At-Large, Missions Working Group Coordinator	UK
Georg Kirchner	Elected, At-Large, Networks and Engineering Working Group Coordinator	Austria

The Networks and Engineering WG is assisting stations to upgrade to high repetition rate lasers and to implement some adaptations to the exiting normal point format to accommodate this high rate data. Software has been made available to the stations for on-site normal point data quality verification. Work continued on the bias problems with the Stanford SR620 counters, but laboratory calibrations did not prove to be sufficiently stable to reduce biases below the several cm level. The Signal Processing Study Group completed its modeling of the LAGEOS and Etalon retroreflector arrays and the AWG is now evaluating the new models. The Networks and Engineering WG is spearheading a number of engineering procedural studies for the improvement of network operations.

The Analysis WG completed its pilot projects to assess, document and resolve differences among analysis products from the Analysis and Associate Analysis Centers. Nine institutions have qualified as Analysis Centers; additional center has expressed interest. A Combination Center and a Backup Combination Center have been in operation since 2004. In June 2010, DGFI retired was no longer able to continue in its role as the Backup Center and the activity, and software and associated scripts were transferred to the JCET. The transfer process was completed in October 2010, and JCET has been producing the backup combination product since that time. The WG has developed and implemented the process to deliver LAGEOS and Etalon derived site positions and EOP to the IERS as required on a weekly basis. A 1983-

2008 reanalysis of the LAGEOS-1 and -2 and Etalon-1 and -2 data were provided to the IERS in support of the development of ITRF2008. Over the past three years an analogous daily product was developed, based on the data from the immediate prior seven days. This product is primarily for use by the IERS EOP Prediction Service at USNO, providing as fresh as possible SLR-derived EOP. Work is underway to add additional official ILRS products including precision orbits and certified data corrections, and the improvement of the underlying models. During the ILRS/AWG meetings LLR activities are also reviewed.

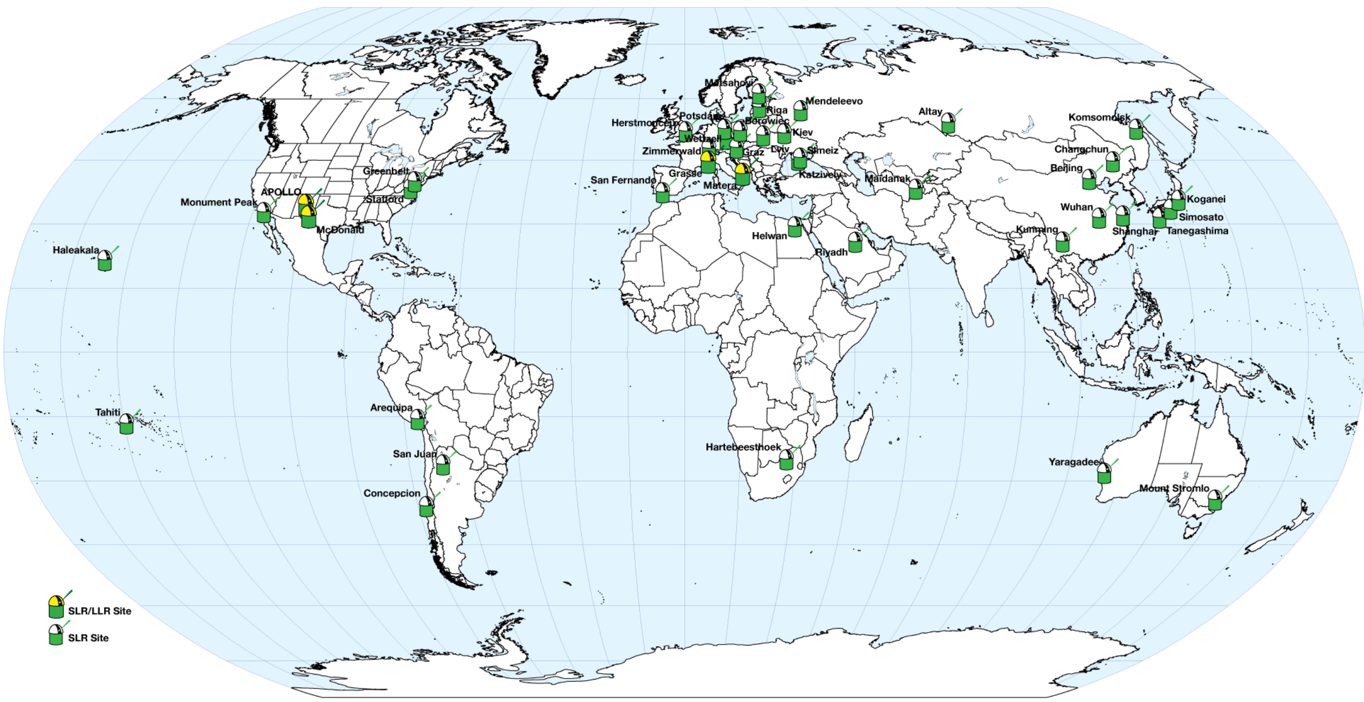

Figure 1. ILRS network (as of May 2011).

The Transponder Working Group has been involved in one-way ranging and time transfer programs. The first time transfer experiment T2L2 is under way on the satellite Jason-2; time transfer to an accuracy of 100 ps has been demonstrated with potential of greater accuracy as the data analysis continues. A second time transfer proposal (ELT) utilizing a laser link for the atomic clock ensemble in space (ACES) mission on the ISS has progressed to the point that it is ready to be accepted for the baseline design of ACES. The transponder working group also actively supports LRO, where one-way laser ranging from the ILRS Network is being used to improve the orbit calculations for the laser altimeter and surface positioning. Ground-based hardware simulations for planning and designing laser transponder operations at interplanetary distances have been successfully carried out within the frame of the Transponder Working Group. Results are promising and currently under review at "Planetary and Space Science". A BLITS type satellite at 1000 – 2000 km altitude could help this activity with its low satellite signature characteristics.

ILRS NETWORK

Satellite Laser Ranging (SLR) Network

The present ILRS network includes over forty stations in 23 countries (see Figure 1). Stations designated as operational have met the minimum ILRS qualification for data quantity and quality. Several stations dominated the network with the Yarragadee, Mt Stromlo, Zimmerwald, and Changchun stations being the strongest performers. From start-up in 2005, the San Juan station performance has been dramatic and is now second in performance to Yarragadee. There has also been noticeable improvement at Matera, Graz, Concepcion, Shanghai, Herstmonceux and Monument Peak. The improved orbital coverage over the

Pacific region should have a very fundamental impact on our ILRS data products. In addition to San Juan, the rest of the Chinese SLR network continues its very strong support for the ILRS network. The Riyadh station had been doing very well, but it is now down for major renovations. This station is very critical to the ILRS network because it is the only SLR station on the Arabian Peninsula. Data started flowing again from the Russian Stations, including the new station at Altay and most recently Arhiz. New stations are currently being installed in Zelenchukskaya and Irkutsk. The TIGO system in Concepción, Chile amazingly returned to operation within three months following the nearby magnitude 8 earthquake in February 2010. SLR data are again flowing from the new MEO station at Grasse, France; the French Transportable Laser System (FTLRS) conducted a campaign in Ajaccio, France in 2009 to support altimeter calibration and validation for Jason; other occupations were performed in Grasse and Paris, France. The station is now in Tahiti for a co-location with Moblas-8.

Several stations have moved to higher repetition rate lasers. In the spring of 2008, the Zimmerwald station introduced its new 100 Hz system and rapidly became one of the major data producers in the network. The Graz system continues its impressive performance with 2 kHz operations. A 2 kHz laser has been added to the Herstmonceux station; several Chinese stations have upgraded to 1 kHz systems and several other stations have similar upgrades underway. High repetition rate systems will be the model of the future with SLR; requirements to track many GNSS satellites coupled with the additional Geosynchronous and LEO satellites anticipated over the next several years will require the network stations to accumulate normal points much faster and rely more heavily on rapid interleaving.

A number of stations using the Stanford Counter have experienced timing (range) errors in some cases as large as a centimeter. Calibration procedures have not been successful in addressing the problem, and time-dependent, empirical, range corrections have been made under the guidance of the Analysis WG. Several of these stations have now installed new epoch timing units – in particular the units now made by the University of Latvia. Additional stations have also moved to using SPAD detectors.

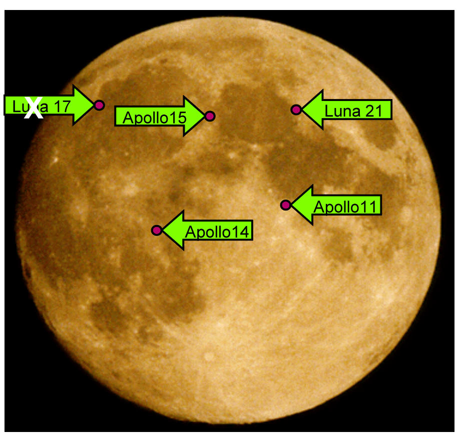

Figure 2. Retro-reflector sites on the Moon, Luna 17 had never been successfully tracked, until it was "rediscovered" from LRO images in 2010.

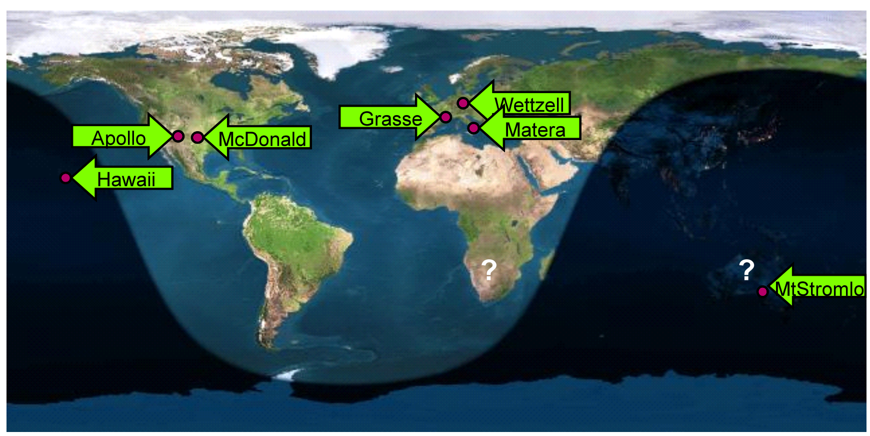

Figure 3. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future.

Lunar Laser Ranging (LLR) Network

During three U.S. American Apollo missions (11, 14, and 15) and two un-manned Soviet missions (Luna 17 and Luna 21), retro-reflectors were deployed near the landing sites between 1969 and 1973 (Figure 2). LLR ranging has continuously provided data for about 41 years, generating about 17000 normal points.

LLR is used to determination parameters describing lunar ephemeris, lunar physics, the Moon's interior, various reference frames, Earth orientation parameters and the Earth-Moon dynamics. LLR has also become one of the strongest tools for testing Einstein's theory of general relativity in the solar system; no violations of general relativity have been found so far. However, the basis for all scientific analyses is more high quality data from a well-distributed global LLR network.

From all of the ILRS observatories (nearly 40), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (Figure 3). The McDonald Observatory in Texas, USA, the Apache Point Observatory, New Mexico, USA, and the Observatoire de la Côte d' Azur, France are the only currently operational LLR sites. The latter returned to action in September 2009, after several years of renovation. The McDonald observatory has had major LLR funding problems, and as a result, LLR operations have recently slowed to a much reduced level. The new Apache Point Lunar Laser Observatory (APOLLO) in New Mexico, USA, became operational in 2005 and has since been by far the largest producer of lunar ranging data. Built with a 3.5 m telescope, the station is designed for mm accuracy ranging. A new set of data from APOLLO was released in 2011 with a total of ~940 normal points. The data are now available in the newly adopted ILRS CRD data format through a reformatting effort at the McDonald Observatory. The measurement statistics of the major lunar observatories between 1970 and 2011 is shown in Figure 4.

Other modern laser ranging stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station in Italy in 2010, but all of them suffer from technical problems or funding restrictions. The Wettzell observatory in Germany plans to resume lunar tracking by end of 2011. The Australian station at Mt. Stromlo is expected to participate in the future, and there are plans for establishing lunar capability at the South African site at Hartebeesthoek.

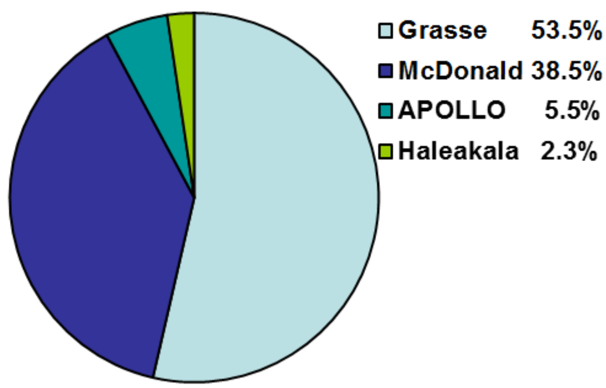

Figure 4. Measurement statistics of lunar observatories between 1970 and 2011

Current LLR data are collected, archived and distributed under the auspices of ILRS. All former and current LLR data are electronically accessible through the CDDIS in Greenbelt, Maryland.
At the Observatoire de Paris, an "assisting tool" (http://polac.obspm.fr/PaV) has been developed to support lunar tracking by providing predictions of future LLR observations as well as a validation of past LLR normal points.

ILRS TRACKING PRIORITIES AND MISSION SUPPORT

The ILRS is currently tracking 30 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions (see Table 2). The stations with lunar capability are also tracking the lunar reflectors. In response to tandem missions (e.g., GRACE-

A/-B) and general overlapping schedules, many stations are tracking satellites with interleaving procedures.

Table 2. ILRS Tracking Priorities (as of May 2011)

Satellite Priorities					
Priority	**Mission**	**Sponsor**	**Altitude (km)**	**Inclination (degrees)**	**Comments**
1	GOCE	ESA	295	96.7	
2	GRACE-A, -B	GFZ/JPL	485-500	89	Tandem mission
3	CryoSat-2	ESA	720	92	
4	TanDEM-X	Infoterra/DLR/ GFZ/CSR	514	98	Tandem with TerraSAR-X
5	TerraSAR-X	Infoterra/DLR/ GFZ/CSR	514	97.44	Tandem with TanDEM-x
6	Envisat	ESA	796	98.6	Tandem with ERS-2
7	ERS-2	ESA	800	98.6	Tandem with Envisat
8	BLITS	Russia	832	98.77	
9	Jason-1	NASA/CNES	1,350	66.0	Tandem with Jason-2
10	Jason-2	NASA, CNES, Eumetsat, NOAA	1,336	66.0	Tandem with Jason-1
11	Larets	IPIE	691	98.2	
12	Starlette	CNES	815-1,100	49.8	
13	Stella	CNES	815	98.6	
14	Ajisai	NASDA	1,485	50	
15	LAGEOS-2	ASI/NASA	5625	52.6	
16	LAGEOS-1	NASA	5850	109.8	
17	QZS-1	JAXA	32,000-40,000	45	WPLTN tracking only
18	Beacon-C	NASA	950-1,300	41	
19	Etalon-1	Russian Federation	19,100	65.3	
20	Etalon-2	Russian Federation	19,100	65.2	
21	COMPASS-M1	China	21,500	55.5	
22	GLONASS-115	Russian Federation	19,100	65	Replaced GLONASS-99 on 03/31/2009
23	GLONASS-125	Russian Federation	19,100	65	Replaced GLONASS-120 on 05/04/2011
24	GLONASS-102	Russian Federation	19,100	65	Replaced GLONASS-89 on 05/04/2007
25	GPS-36	US DoD	20,100	55.0	
26	GIOVE-A	ESA	29,601	56	
27	GIOVE-B	ESA	23,916	56	
28	GLONASS-109	Russian Federation	19,100	65	
29	GLONASS-110	Russian Federation	19,100	65	
30	GLONASS-118	Russian Federation	19,100	65	

Lunar Priorities

Priority	Retroreflector Array	Sponsor	Altitude (km)
1	Apollo 15	NASA	356,400
2	Apollo 11	NASA	356,400
3	Apollo 14	NASA	356,400
	Luna 21	Russian Federation	356,400
	Luna 17	Russian Federation	356,400

The ILRS assigns satellite priorities in an attempt to maximize data yield on the full satellite complex while at the same time placing greatest emphasis on the most immediate data needs. Priorities provide guidelines for the network stations, but stations may occasionally deviate from the priorities to support regional activities or national initiatives and to expand tracking coverage in regions with multiple stations. Tracking priorities are set by the Governing Board, based on application to the Central Bureau and recommendation of the Missions Working Group.

Missions are added to the ILRS tracking roster as new satellites are launched and as new requirements are adopted. Missions for completed programs are deleted from the ILRS (see Figure 5). New missions added during this reporting period included: ANDE, CryoSat-2, TanDEM-x, BLITS, QZS-1, and additional GLONASS satellites. The network continued to support the GLONASS program: GLONASS-125 replaced GLONASS-120 in May 2011. Three additional GLONASS satellites were added to the ILRS tracking list in September 2010 at the request of the Center for Orbit Determination (CODE). ANDE Castor and Pollux, NRL satellites that monitored the thermosphere neutral density, were tracked from August 2009 until March and April 2010 when the two satellites re-entered the Earth's atmosphere. PROBA-2, an ESA mission validating spacecraft technology concepts, has been tracked in campaign mode by the ILRS network in 2010 and 2011. CHAMP, launched in July 2000 re-entered Earth's atmosphere in September 2010.

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

At one time, the main task of the international SLR Network was the tracking of dedicated geodetic satellites (LAGEOS, Starlette, etc.). Although the ILRS has had requests to revive tracking on older satellites already in orbit (e.g., Beacon-C) to further refine the gravity field with improved accuracy laser data, new requests for tracking are now coming mainly for active satellites including those in the GNSS complexes. The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS website. The form provides the ILRS with the following information: a description of the mission objectives, mission requirements, responsible individuals and contact information, timeline, satellite subsystems, and details of the retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 3 along with their sponsors, intended application, and projected launch dates.

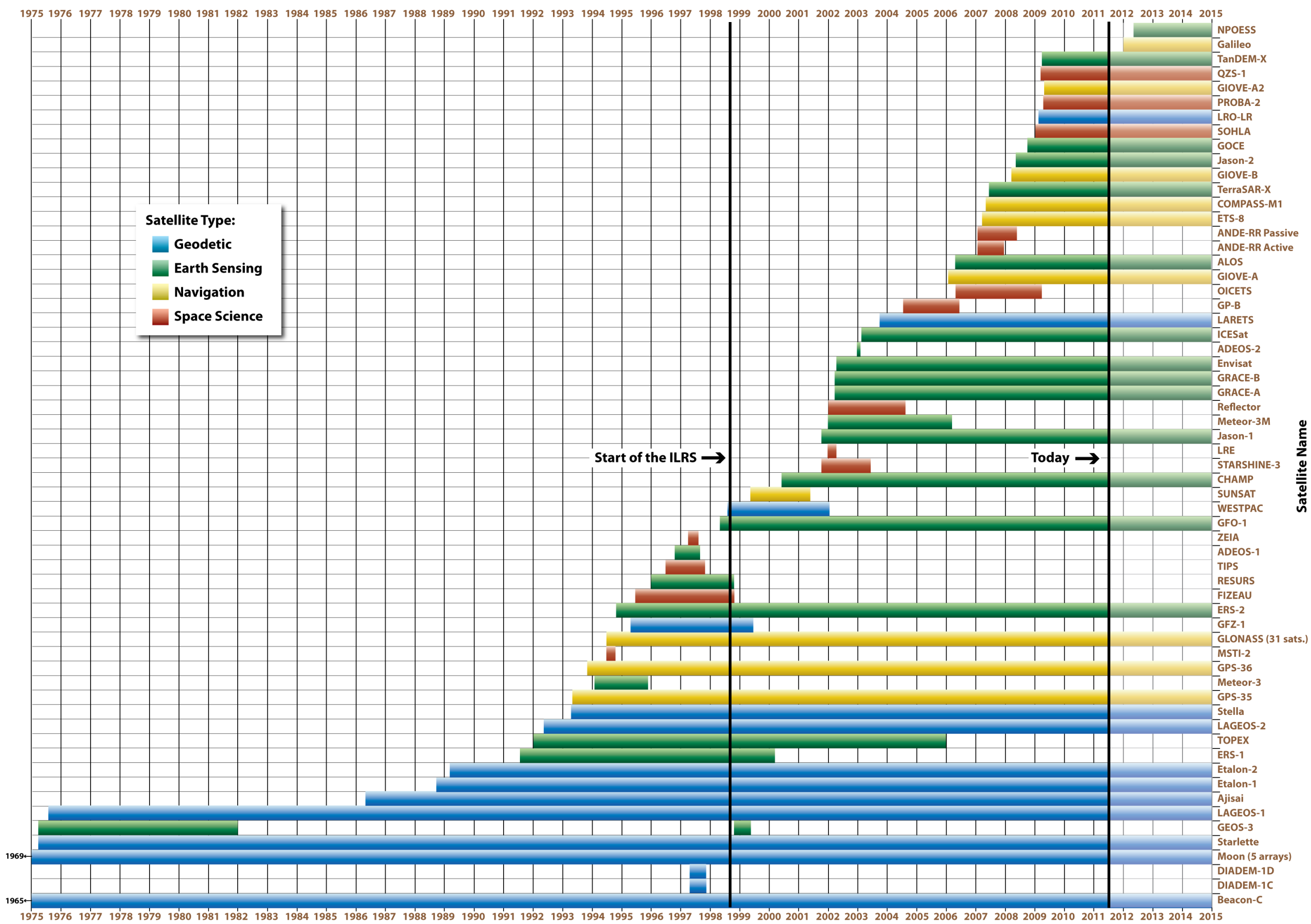

Figure 5. The past, current, and future tracking roster for the ILRS network.

Once tracking support is approved by the Governing Board, the Central Bureau works with the new missions to develop a Mission Support Plan detailing the level of tracking, the schedule, the points of contact, and the channels of communication. New missions normally receive very high priority during the acquisition and checkout phases and are then placed at a routine priority based on the satellite category and orbital parameters. After launch, reports with network tracking statistics and operational comments are issued weekly. The Central Bureau monitors progress to determine if adequate support is being provided. New mission sponsors (users) are requested to report at the ILRS meetings on the status of ongoing campaigns, including the responsiveness of the ILRS to their needs and on progress towards achieving the desired science or engineering results.

One interesting application for SLR is the tracking support of the Lunar Reconnaissance Orbiter (LRO), launched June 17, 2009. The LRO mission objective is to conduct investigations that are targeted to prepare for and support future exploration of the Moon. The LRO Laser Ranging (LR) system uses one-way range measurements from laser ranging stations on the Earth to LRO to determine LRO position at sub-meter level with respect to Earth and the center of the Moon (on the lunar near-side or whenever possible). The LR aspect of the mission allows for the determination of a more precise orbit than possible with S-band tracking data alone. The flight system consists of a receiver telescope, which captures the uplinked laser signal and a fiber optic cable, which routes it to the LOLA instrument. The LOLA instrument captures the arrival time of the laser signal records that information and provides it to the onboard LRO data system for storage and/or transmittal to the ground through the RF link. As of May 2011, ten stations have provided over 1,070 hours of one-way laser ranging data.

Table 3. Upcoming Missions (as of May 2011)

Mission	Sponsor	Planned Launch Date	Mission Duration (years)	Altitude (km)	Inclination (degrees)	Application
KOMPSAT-5	KARI	2011	5	550	97.6°	Earth observation
RadioAstron	Lavochkin Assoc., Russia	2011	5	500-350,000	51.4°	Interferometry
SARAL	CNES, ISRO	2011	5	814	98.55°	Altimetry, water surfaces
NPOESS	NOAA, NASA, DoD	2013	7	833	98.7°	Sea surface height

OFFICIAL ANALYSIS PRODUCTS

The ILRS products consist of SINEX files of weekly station coordinates and daily Earth Orientation Parameters (x-pole, y-pole and excess length-of-day, LOD) estimated from 7-day arcs. Two types of products are distributed each week: a loosely constrained estimation of coordinates and EOP and an EOP solution, derived from the previous one and constrained to an ITRF, currently ITRF2005S. Official ILRS Analysis Centers (AC) and Combination Centers (CC) generate these products with individual and combined solutions respectively. Both the individual and combined solutions follow strict standards agreed upon within the ILRS Analysis Working Group (AWG) to provide high quality products consistent with the IERS Conventions. This description refers to the status as of May 2011. Each official weekly ILRS solution is obtained through the combination of weekly solutions submitted by the official ILRS Analysis Centers:

ASI, Agenzia Spaziale Italiana
BKG, Bundesamt für Kartographie und Geodäsie
DGFI, Deutsches Geodätisches Forschungsinstitut
ESA, European Space Agency
GA, Geosciences Australia
GFZ, GeoForschungsZentrum Potsdam
GRGS, Observatoire de Cote d'Azur
JCET, Joint Center for Earth Systems Technology
NSGF, NERC Space Geodesy Facility

These ACs have been certified through a benchmark process developed by the AWG. The official Primary Combination Center (ASI) and the official Backup Combination Center (DGFI through 2010, JCET since 2011) follow strict timelines for these routinely provided products.

In addition to operational products, solutions have been provided covering the period back to 1983. A new activity has been established to provide similar solutions on a daily basis, with a minimal 2-day delay, possibly even one day, primarily to provide IERS' NEOS center with robust EOP observations for their weekly predictions. The ILRS products are available, via ftp from the official ILRS Data Centers CDDIS/NASA Goddard (*ftp://cddis.gsfc.nasa.gov/*) and EDC/DGFI (*ftp://ftp.dgfi.badw-muenchen.de*).

ILRS Contribution to ITRF2008

The time series of weekly solutions from 1983 to the end of 2008, produced by the Primary Combination Center, was delivered to IERS/ITRS as an official ILRS contributed data set for ITRF2008. Several months of joint work within the ILRS AWG were devoted to the quality assessment of the contributed solutions from the ILRS ACs as well as the final combined solutions from the ILRS CCs. The preliminary version of the combined ILRS time series was submitted in April 2009, and through continuous interaction with the ITRS Combination Centers, revised versions were contributed through the summer, until a satisfactory combination was reached. Figures 6 and 7 show a summary and illustration of the origin and scale rate differences with respect to the old ITRF realization, ITRF2005S (actually the SLRF2005 frame, a derivative of ITRF2005, scaled for compliance to the SLR scale and merged with the ITRF2000 normal equations to cover all sites tracking in the early 80's which were not part of ITRF2005S.

Tx	Tx_dot mm/yr	σ_Tx_dot mm/yr	WRMS (res) mm	Ty	Ty_dot mm/yr	σ_Ty_dot mm/yr	WRMS (res) mm
asi	-0,35	0,02	5,37	asi	-0,12	0,02	4,50
dgfi	-0,57	0,03	6,27	dgfi	0,09	0,03	5,78
ga	0,05	0,02	4,18	ga	0,17	0,02	4,29
gfz	-0,49	0,03	5,46	gfz	0,11	0,02	4,98
grgs	-0,32	0,03	4,50	grgs	0,04	0,03	3,71
jcet	-0,18	0,02	4,19	jcet	0,10	0,02	3,99
nsgf	-0,41	0,03	6,70	nsgf	-0,08	0,03	7,26
C	**-0,29**	**0,02**	**4,16**	**C**	**0,06**	**0,02**	**3,82**
Tz	**Tz_dot mm/yr**	**σ_Tz_dot mm/yr**	**WRMS (res) mm**	**D_Sc**	**D_Sc_dot mm/yr**	**σ_D_Sc_dot mm/yr**	**WRMS (res) mm**
asi	0,24	0,06	10,38	asi	-0,31	0,02	4,26
dgfi	0,88	0,08	13,07	dgfi	-0,48	0,03	4,98
ga	0,83	0,04	8,58	ga	-0,22	0,01	3,64
gfz	0,36	0,06	10,89	gfz	-0,08	0,03	4,71
grgs	0,06	0,02	7,11	grgs	-0,46	0,02	3,34
jcet	0,25	0,04	8,32	jcet	-0,23	0,01	2,88
nsgf	0,11	0,08	14,06	nsgf	-0,62	0,03	6,00
C	**0,38**	**0,03**	**7,45**	**C**	**-0,30**	**0,01**	**3,15**

Figure 6. Origin offset rates of the weekly product from each AC and the combination (C) with respect to SLRF2005 (ITRF2005S): 1983-2009.

The new time series take advantage of improved modeling of systematic errors derived after an extensive AWG effort to explain all systematic differences from the previous ITRF and to account for all known engineering corrections. All this information have been compiled into a database that is now online in the form of a quasi-SINEX-formatted file, accessible from the ILRS web pages on "Data Corrections". The database is maintained with future releases indicated in the file with a "Release Date" for the benefit of all SLR data users. The description of the official contribution to ITRF2008 is available on the ILRS and ITRS web pages upon finalization and adoption of ITRF2008. In addition to ITRF2008, the ILRS AWG has compiled a companion TRF, SLRF2008, which will be accessible from the ILRS web pages and will replace SLRF2005. This TRF will be a "living" version of ITRF2008 in the sense that new sites will be incorporated as they come online, using ILRS-derived coordinates from the initial set of data they provide and improved at infrequent intervals to maintain the uniform quality of the data set.

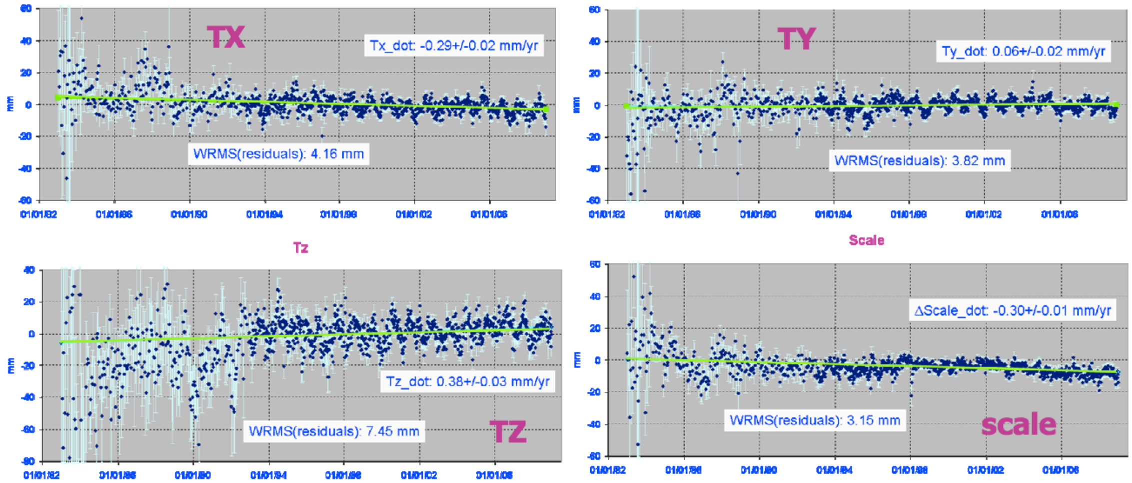

Figure 7. Origin and scale differences of the weekly combination product with respect to SLRF2005 (ITRF2005S): 1983–2009.

The Official ILRS Combination (ILRSA)

ASI produces the official ILRSA combination solution and it is routinely compared with the backup combined solution ILRSB produced by DGFI (by JCET since 2010) following a fundamentally different approach. Comparisons show a good agreement between the two solutions and absence of any systematic differences.

1. mean 3D wrms of the site coordinates residuals with respect to SLRF2005 (Table 4 and Figure 8);
2. mean differences of the translation and scale parameters with respect to SLRF2005 (Table 5);
3. EOP residuals with respect to EOP 05 C04 (Table 6) for the year 2008.

Table 4. 3D wrms of the site coordinates residuals w.r.t. SLRF2005

	ILRSA(mm)	
	1983-1993	1993-2008
All sites (mean)	52	10
Core sites (mean)	15	7

Table 5. Translation and scale differences between ILRSA and SLRF2005

	TX(mm)	**TY(mm)**	**TZ(mm)**	**Scale(mm)**
Weighted Mean	-2 ± 4	0 ± 4	0 ± 9	6 ± 4
WRMS	3	3	6	2

Table 6. EOP daily residuals with respect to EOPC04 for ILRSA

ILRSA	1983-1993		1993-2008	
	WMEAN	**WRMS**	**WMEAN**	**WRMS**
EOP-X (mas)	-0.058	0.468	-0.024	0.156
EOP-Y (mas)	-0.092	0.434	0.030	0.131
LOD (ms)	-0.012	0.061	0.001	0.024

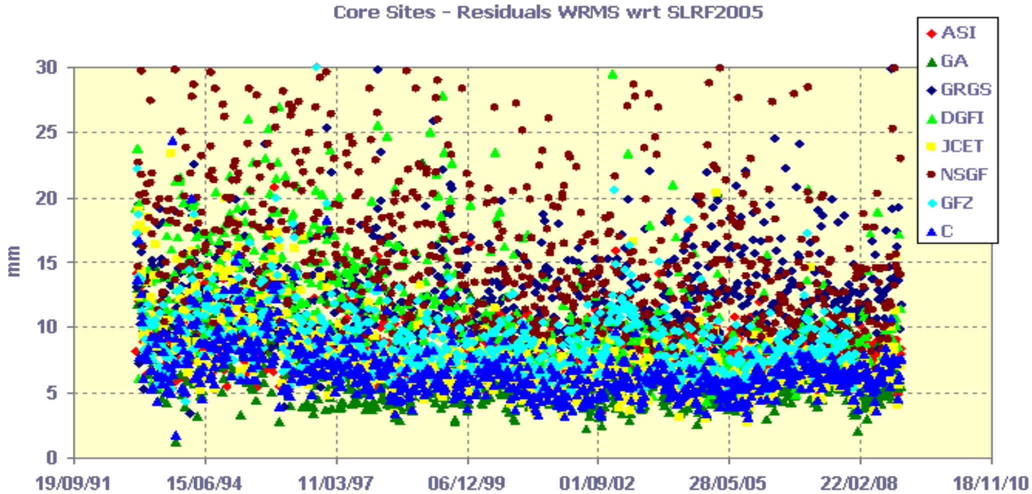

Figure 8. 3D wrms of the core site coordinates residuals with respect to SLRF2005.

The individual as well as the combinations of the ILRS ACs and CCs are monitored on a weekly basis with a graphical and a statistical presentation of these time series through a dedicated website hosted by the JCET AC at http://geodesy.jcet.umbc.edu/ILRS_QCQA/.

Table 7. Recent ILRS Meetings (as of May 2011)

Timeframe	Location	Meeting
September 2009	Metsovo, Greece	International Technical Laser Workshop on SLR Tracking of GNSS Constellation
December 2009	San Francisco CA, USA	ILRS Governing Board Meeting
May 2010	Vienna, Austria	ILRS Governing Board Meeting ILRS Working Group Meetings Analysis Working Group Meeting
May 2011	Bad Koetzting, Germany	17th International Workshop on Laser Ranging 15th ILRS General Assembly and WG Meetings ILRS Governing Board Meeting Analysis Working Group Meeting ILRS Working Group Meetings

MEETINGS AND REPORTS

The ILRS organizes regular meetings of the Governing Board and General Assembly; General Assemblies are open to all ILRS Associates and Correspondents. These meetings are typically held in conjunction with ILRS workshops, such as the fall technical workshops (oriented toward SLR practitioners) or the biannual International Workshop on Laser Ranging. A summary of recent and planned ILRS meetings is shown in Table 7. Detailed reports from past meetings can be found on the ILRS website.

ILRS Biannual Reports summarize activities within the service over the period since the previous release. They are available as hard copy from the CB or online at the ILRS website.

ILRS Analysis Center reports and inputs are used by the Central Bureau for review of station performance and to provide feedback to the stations when necessary. Special weekly reports on on-going campaigns are issued by email. The CB also generates quarterly Performance Report Cards and posts them on the ILRS website. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. These results include independent assessments of station performance from several of the ILRS analysis/associate analysis centers. The statistics are presented in tabular form by station and sorted by total passes in descending order. Plots of data volume (passes, normal points, and minutes of data) and RMS (LAGEOS, Starlette, calibration) are created from this information and available on the ILRS website. Plots, updated frequently, of multiple satellite normal point RMS and number of full-rate points per normal point as a function of local time and range have been added to the ILRS website station pages.