3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of SLR/LLR missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2012.

Network

The network of SLR/LLR stations (Figure 1), under the aegis of the ILRS, has been subject to change over the years. From a technical perspective, the quality of the observations has improved drastically during the past decade. The single-shot precision of an average station today is better than 10 mm (for the best stations this number is a few millimeters, Figure 2). The absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing significantly better. Most of the stations deliver normal points with a precision of 1 mm, a firm requirement for the GGOS-era network as outlined in the GGOS2020 docu-

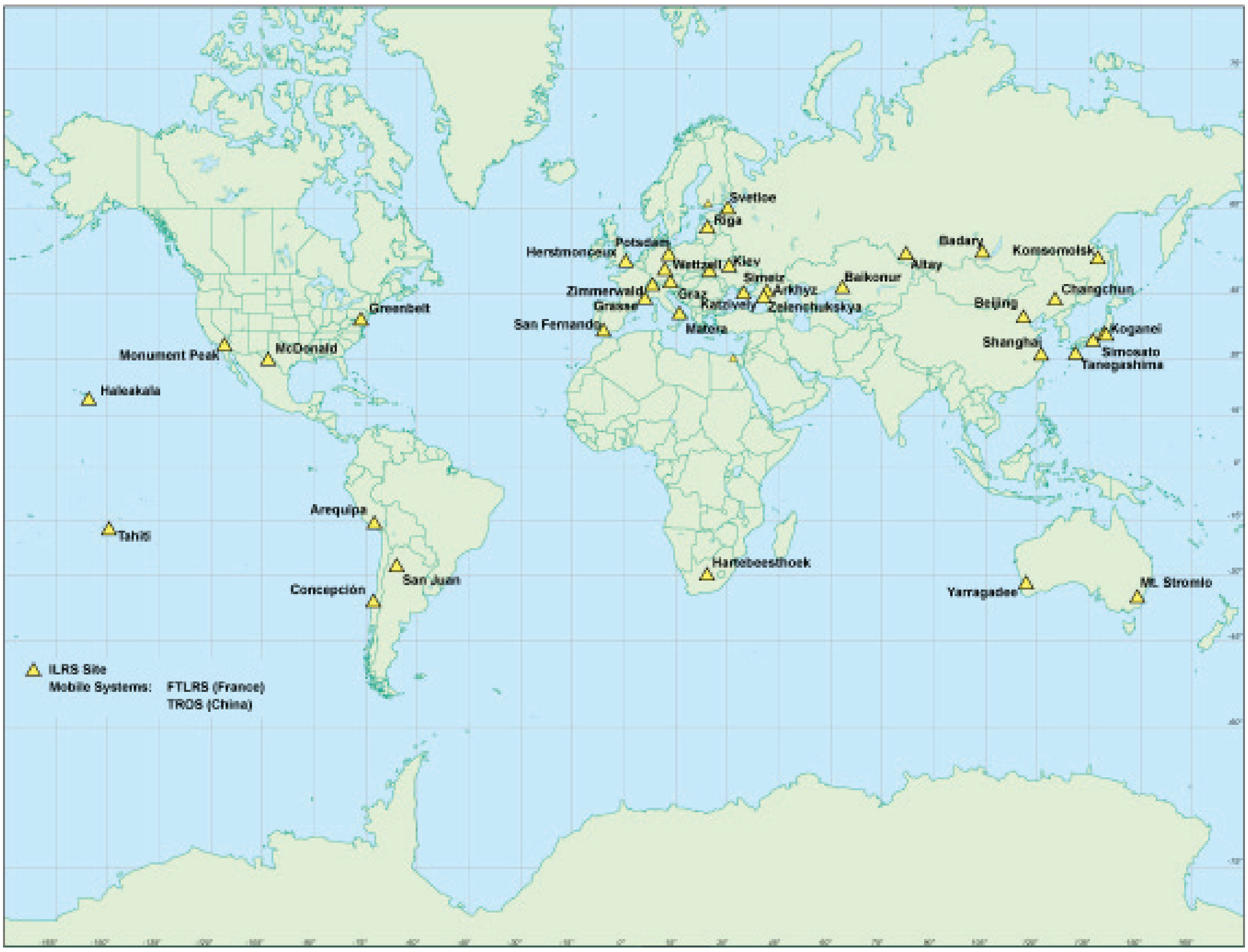

Fig. 1: The global network of SLR stations (status early 2013).

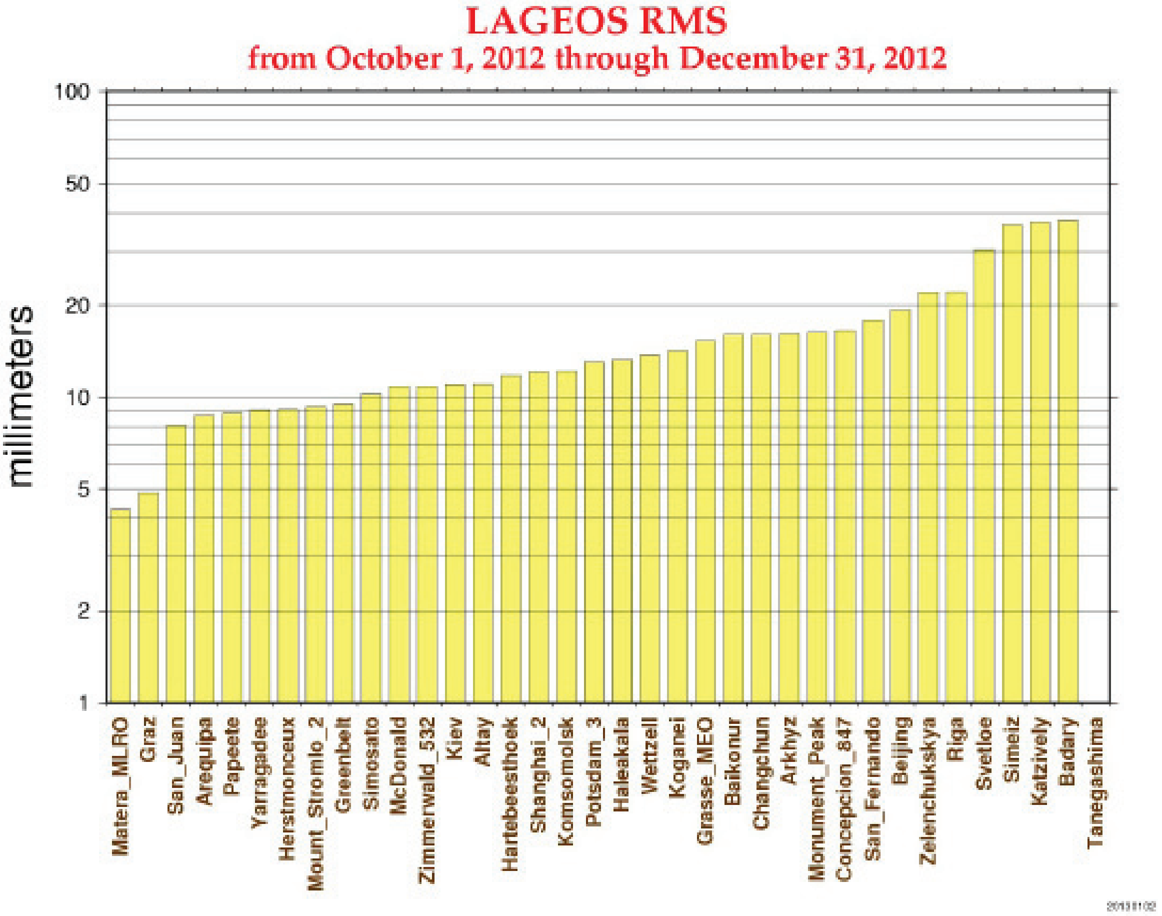

Fig. 2: Performance of the global network of SLR stations on LAGEOS (status end of 2012).

ment and several stations (6) have upgraded to high repetition rate systems to meet such requirements. NASA's next generation SLR system is in the final stages of development, demonstrating successful tracking of LEO to HEO targets at night and in daylight. The switching to high repetition rate systems at a number of sites has increased productivity and improved data quality. This evolution of the network led to the need for a revision of the definition of the way SLR normal points (NP) are constructed. A task force worked on an improved NP definition that increases productivity. The new rule allows for collection of many more data on various targets when automated pass interleaving is exercised. This is achieved by limiting inactivity for high repetition rate systems that meet the NP precision requirement long before they exhaust the time interval that is assigned for the target being tracked. So far a limited number of stations have implemented the new approach. Since the beginning of the year three new Russian sites started contributing data. These sites are located in areas void of coverage up to this time, and they are co-located with VLBI systems that are part of the IVS network for a long time now (Badary, Zelenchuks-

Table 1: ILRS Network Tracking Statistics for 2012.

		Number of Passes			
Site Name	**Station**	**Low**	**LAGEOS**	**High**	**Total**
Altay	1879	173	259	630	1,062
Arequipa	7403	3,251	771	0	4,022
Arkhyz	1886	251	116	214	581
Badary	1890	496	213	65	774
Baikonur	1887	169	532	495	1,196
Beijing	7249	845	199	176	1,220
Changchun	7237	5,166	1,053	3,241	9,460
Concepcion	7405	1,763	852	367	2,982
Grasse	7845	885	568	882	2,335
Graz	7839	3,566	1,138	2,704	7,408
Greenbelt	7105	5,262	1,259	1,162	7,683
Haleakala	7119	2,170	1,023	0	3,193
Hartebeesthoek	7501	2,799	1,018	788	4,605
Herstmonceux	7840	3,018	1,056	1,777	5,851
Katzively	1893	1,666	460	340	2,466
Kiev	1824	733	192	43	968
Koganei	7308	425	203	367	995
Komsomolsk-Na-Amure	1868	33	161	420	614
Matera	7941	4,081	2,209	2,703	8,993
McDonald	7080	967	493	254	1,714
Monument Peak	7110	3,196	959	905	5,060
Mount Stromlo	7825	5,873	1,495	667	8,035
Potsdam	7841	2,678	774	313	3,765
Riga	1884	223	12	0	235
San Fernando	7824	2,719	259	7	2,985
San Juan	7406	2,787	1,131	1,385	5,303
Shanghai	7821	892	213	580	1,685
Simeiz	1873	870	381	80	1,331
Simosato	7838	1,069	562	130	1,761
Svetloe	1888	116	115	15	246
Tahiti	7124	506	211	126	843
Tanegashima	7358	125	15	13	153
Wettzell	8834	4,663	1,402	1,626	7,691
Yarragadee	7090	14,602	3,851	8,464	26,917
Zelenchukskaya	1889	177	126	411	714
Zimmerwald	7810	6,451	1,846	4,383	12,680
Totals:	36 stations	84,666	27,127	35,733	147,526

kaya, and Svetloe). By late 2012 the three sites were validated according to ILRS procedures and were accepted as operational sites of the ILRS network. This addition will eventually improve tremendously the tie between the SLR- and VLBI-implied frames, and since they all have GNSS receivers, the GNSS frame as well.

Statistics of the data collected as pass segments during the calendar year 2012 are summarized in Table 1. For each of the contributing stations the tracked passes are broken down in three categories of tracked targets: Low Earth Orbiters (LEO), LAGEOS 1 & 2, and the High Earth Orbiters (HEO), GPS, GLONASS, ETALON, GIOVE-A/B, GALILEO, and BeiDou satellites, part of the Chinese Navigation Constellation BeiDou (COMPASS).

Of all the active ILRS observatories (~35), very few are technically equipped to track retro-reflector arrays on the surface of the moon or spacecraft orbiting around the moon. The situation did actually improve in 2012, and the active Lunar Laser Ranging (LLR) sites were: the McDonald Observatory in Texas, USA (generating 17 NP), the Observatoire de la Côte d' Azur, France (351 NP), the APOLLO site in New Mexico, USA (201 NP) and the Matera Laser Ranging station in Italy (28 NP). The measurement statistics of 2012 (Figure 3) shows that about one third of the data have been collected at the APOLLO site, almost 60% of the data at the French MeO site near Grasse. Figure 4 illustrates the statistics for the observed reflectors, where – thanks to APOLLO and the upgraded French system – a much better coverage of all reflectors could be achieved than in the previous years. Figure 5 shows the entire LLR data set 1970–2012, indicating the amount of data collected by each of the active LLR sites in each year. It is about 17,700 normal points in total. A steady increase of LLR NP in the last years is obvious.

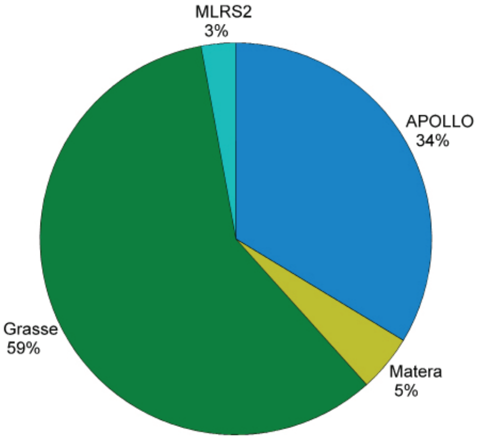

Fig. 3: Observatory statistics in 2012.

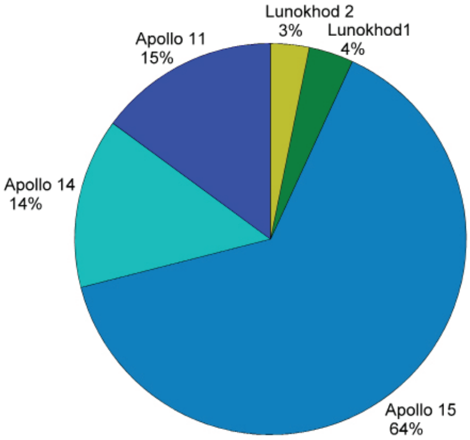

Fig. 4: Reflector statistics in 2012.

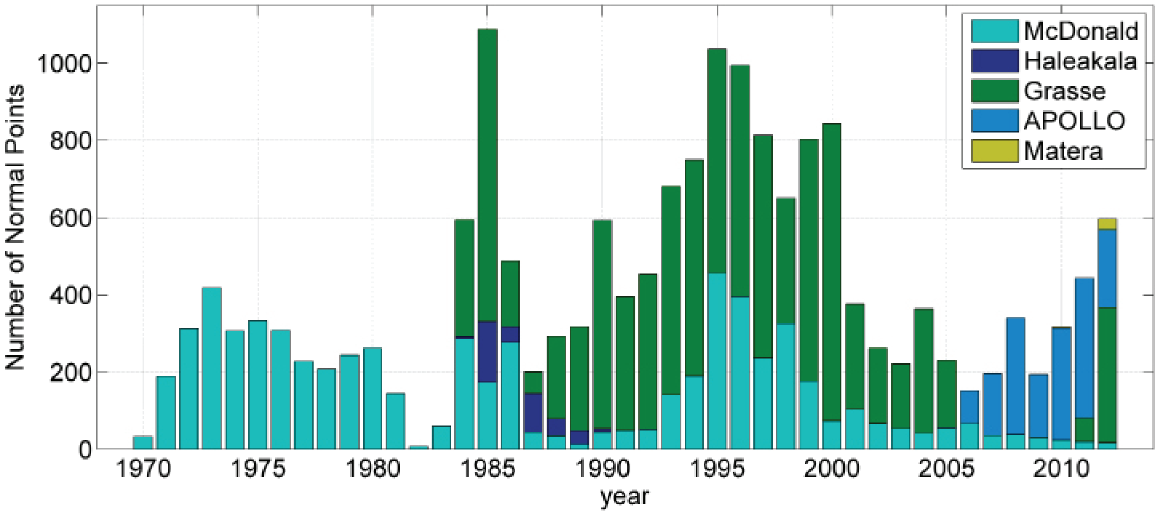

Fig. 5: Data yield of the global LLR network of stations (up to 2012). Note the significant contribution of Grasse's MeO system upon its return to operations.

LLR data analysis is mainly carried out by four major LLR analysis centers: Jet Propulsion Laboratory (JPL), Pasadena, USA; Center for Astrophysics (CfA), Cambridge, USA; Paris Observatory Lunar Analysis Center (POLAC), Paris, France; Institute of Geodesy (IfE), University of Hannover, Germany.

One general objective is to achieve the mm level of accuracy for LLR data analysis (e.g. Müller et al. 2012b). The four analysis centers have started a comparison initiative to mutually improve the various codes.

LLR remains one of the best tools to test General Relativity in the solar system. It allows for constraining gravitational physics parameters related to the strong equivalence principle, geodetic precession, preferred-frame effects, or the time variability of the gravitational constant, cf. Müller et al. (2012a), Murphy et al. (2012), Williams et al. (2012).

In 2012, the International Space Science Institute (ISSI) workshop series on "Theory and model for the new generation of the Lunar Laser Ranging data" has been finalized with a short spring meeting in Berne, Switzerland.

Missions

In 2012, a total of ~34 satellites (including the Moon) were being tracked by laser (Figure 6). Of these, only about 1/3 are geodetic type targets (cannonball satellites), the rest are mainly Earth Observation missions and navigation satellites, along with a small number of experimental space science missions. There were four successful launches in 2012, of satellites carrying LRAs, listed in Table 2, and three missions which were launched in previous years, initiated SLR tracking in 2012. The first two satellites are GLONASS spacecraft launched in 2011, which were tracked by ILRS for the first time in 2012. The next mission, LARES, is an

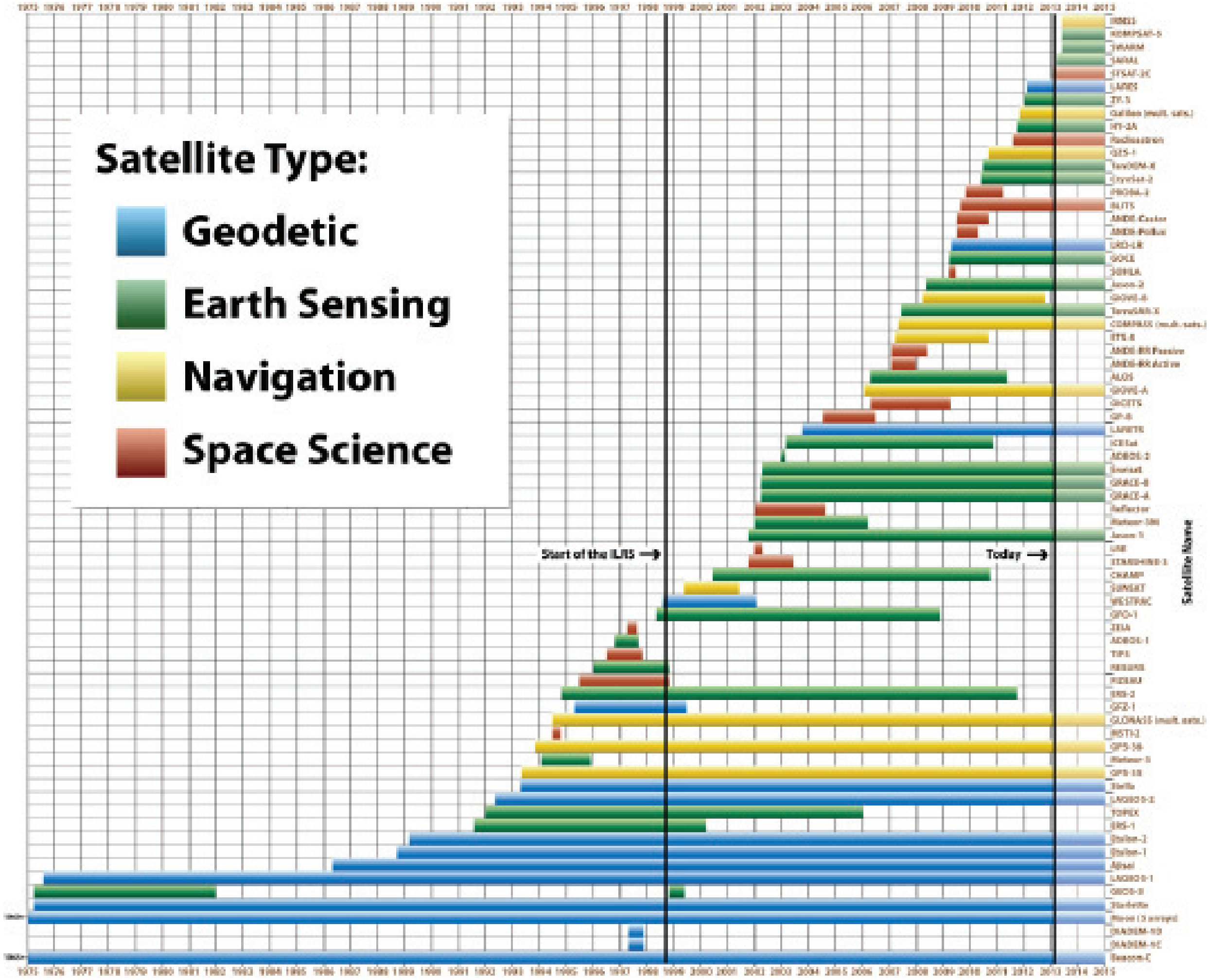

Fig. 6: The currently tracked SLR missions (status early 2013).

ASI mission, designed at the Univ. of Rome "La Sapienza" and launched on ESA's VEGA rocket, in its maiden, demonstration launch from Kourou, French Guiana. LARES is a cannonball satellite similar to LAGEOS in design, however, it is made of a single piece of Tungsten alloy so that despite its smaller size (~36 cm diameter compared to 60 cm for LAGEOS), it has almost three times a smaller area-to-mass ratio, making it a perfect test particle even if in a lower than LAGEOS' orbit. The following three s/c, COMPASS-I3, COMPASS-G1, and COMPASS-I5, are part of the BeiDou/COMPASS Constellation, launched in prior years by China, however, tracking was requested only in 2012. COMPASS-M3 is another member of the BeiDou/COMPASS Constellation that was launched in 2012 and was tracked by the ILRS network since mid-2012. The last two satellites which were launched in 2012, are the second two of four operational satellites designed to validate the Galileo concept in both space and on Earth. This In-Orbit Validation (IOV) phase will be followed by additional satellite launches to reach Initial Operational Capability (IOC) by mid-decade.

During 2012 the ILRS ceased tracking COMPASS-M1, there were no other missions that were removed from the list of active missions and no missions were de-orbited over 2012.

Although the ILRS network has lost a number of stations since an all-time high in 2000 (red line in Figure 7), the productivity of

Table 2: ILRS Supported Missions Launched or Initiating Tracking in 2012.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	First Data Date
GLONASS-129	1106402	9129	37868	9	300	19,140	65	02-Jan-12
GLONASS-130	1107101	9130	37938	9	300	19,140	65	01-Jan-12
LARES	1200601	5987	38077	5	30	1,450	69.5	17-Feb-12
COMPASS-I3	1101301	2003	37384	9	300	42,161	55.5	27-Apr-12
COMPASS-G1	1000101	2002	36287	9	300	42,164	55.5	28-Apr-12
COMPASS-I5	1107301	2005	37948	9	300	42,161	55.5	6-Jul-12
COMPASS-M3	1201801	2004	38250	9	300	21,528	55	11-Jul-12
Galileo-103	1205501	7103	38857	9	300	23,220	56	7-Nov-12
Galileo-104	1205502	7104	38858	9	300	23,220	56	7-Nov-12

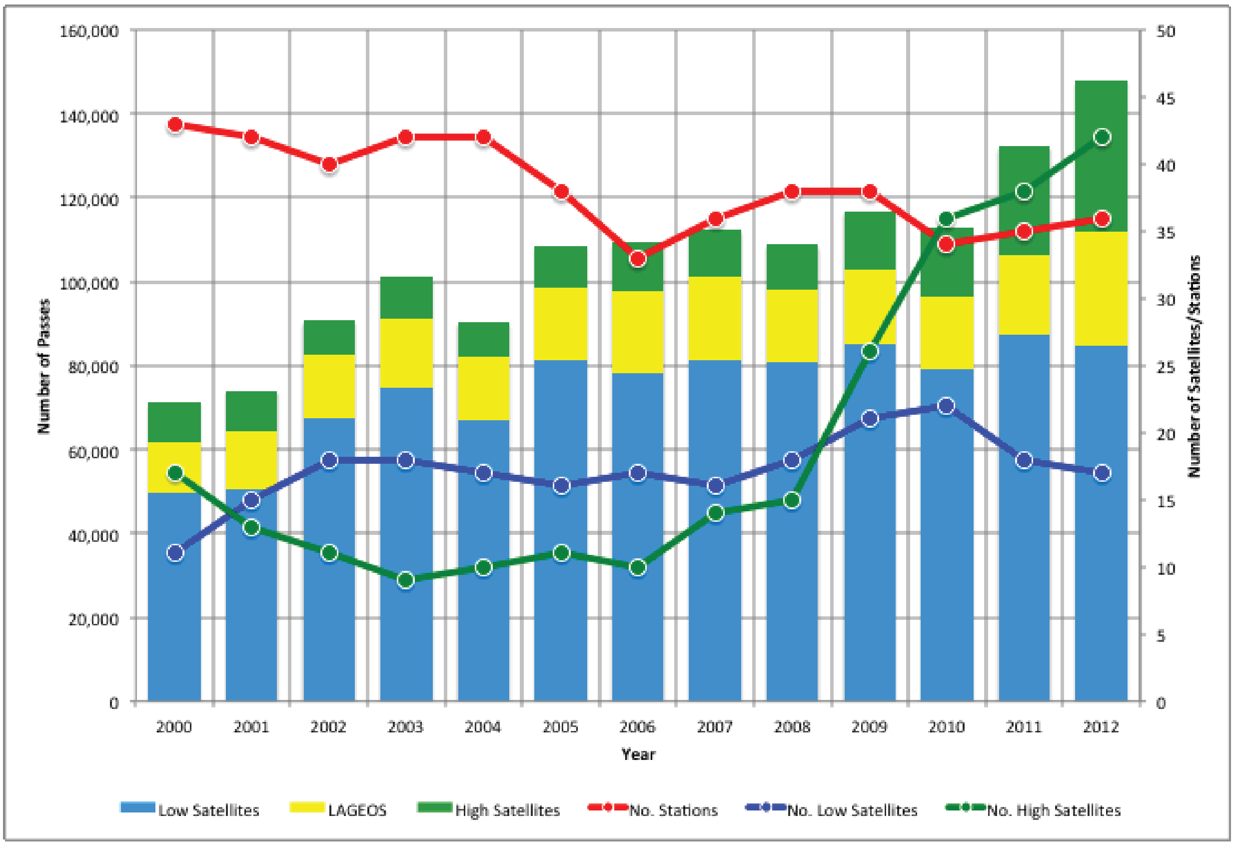

Fig. 7: ILRS network data yield over the past decade (status late 2012).

the remaining sites has increased tremendously to not only make up for that loss but rather double the data yield by 2012 (Figure 7). A major contributor in the recent years' data yield increase is the fact that several stations have started tracking all GLONASS satellites as of 2010. This resulted in tripling the number of HEO satellites tracked between 2008 and 2012 (note the green line in the graph of Figure 7). This demonstrates the ability of the current network to deal with such increases in the demand for tracking HEO orbits and indicates that with the expected system upgrades for the realization of the GGOS-era network, we should be in very good shape to deal with increasing demand for mission support.

The ILRS implemented the new data format (CRD) on May 1, 2012, after a long delay since the initial attempt at the end of 2010 beginning of 2011 due to Data Center issues that had to be resolved prior to this format switch. The delay was however quite beneficial for the ILRS, as the two DC emerged from this process as nearly mirror images of each other. This ensures in the future that users will find the same data at either DC at any time. As part of this improvement in data handling, EDC implemented also a very helpful website for visualization of metadata from their data base.

Another significant improvement of the ILRS resources is the accelerated development of a new website for the Service, a project that was under the aegis of the ILRS CB. The new website became operational in late 2012, during the Frascati workshop. There are several sections of the website which are still being improved and the entire website is maintained current through the efforts of the CB and the ILRS associates' comments and suggestions.

Analysis and science

The Analysis Working Group (AWG), in an effort to accommodate the Pilot Project of the IERS/ITRS and the GGFC on "Non-tidal atmospheric loading corrections" at observation level, postponed its own similar PP and tried to provide GGFC with as many submissions from our ACs as it was possible in the tight timeline that was agreed during the 2011 UAW meeting in Zurich. For this GGFC PP the input data were requested to be the ones provided by GGFC, something that not all ACs were ready to make use of due to formatting and other issues. In the end, six ACs were able to participate in the first step, with more providing results at a much later stage. Initial examination of these submissions indicated that there was a varied success in the implementation of the corrections and left several questions unanswered. It was agreed to re-examine the submissions and compile a report to be presented and discussed during the coming year (EGU).

In regards to modeling improvement in SLR data analysis, the newly released target signature model of Appleby and Otsubo, a time dependent version of their original "center-of-mass" (CoM) offset correction for the LAGEOS and ETALON satellites, was put under test by all ACs. The newly proposed CoM model was to be validated by the end of the year and the AWG to determine the level of improvement in the final product from its implementation. Due to the slow response of several ACs, the results of these tests will likely be available not earlier than spring of 2013. The AWG will then adopt the new model and proceed with the execution of a number of Pilot Projects for testing new products such as orbital files, low degree harmonics, station-dependent systematics monitoring, inclusion of new targets in the analysis, e.g. LARES, Starlette, etc.

It is hoped that these PP will be completed in time to benefit the reprocessing effort of the entire data set from 1983 to present, in support of the development process of the next ITRF realization, ITRF2013. Based on the latest ITRS draft CfP, the Services who will participate in ITRF2013 should have their contributions ready by early 2014.

Meetings

The ILRS held an international technical workshop in Frascati, Italy, November 5–9, with the title “Satellite, Lunar and Planetary Laser Ranging: characterizing the space segment”, (ITLW-12). The Western Pacific Laser Tracking Network (WPLTN) held a Technical Workshop, “One-way and two-way SLR for GNSS co-located with RF techniques” (WPLTN-2012), on September 24–28, 2012, at St. Petersburg, Russia. The AWG held two meetings in 2012, one prior to the EGU General Assembly, on April 21, and one prior to the Frascati workshop, on November 3. Other meetings of direct interest to ILRS were the final meeting of the ISSI-sponsored study group “Theory and Model for the New Generation of the Lunar Laser Ranging Data”, in Bern Switzerland, March 22–23, 2012, and the “Second International LARES Science Workshop” in Rome, Italy, September 17–19, 2012. The ILRS Governing Board met twice during 2012, once during the EGU General Assembly, and a second time during the Frascati workshop. In 2012 the ILRS released its newly designed website, on the occasion of the Frascati workshop. Everyone was encouraged to visit the site and submit comments and suggestions to the ILRS CB and/or the relevant Working Groups.

Publications

Biskupek, L., Müller, J., Hofmann, F.: Determination of nutation coefficients from Lunar Laser Ranging. In: Geodesy for Planet Earth, eds. Kenyon, S., Pacino, M.C. and Marti, U., IAG Symposia Series, Vol. 136, Springer, p. 521–526, 2012.

Müller, J., Hofmann, F., Biskupek, L.: Testing various facets of the equivalence principle using Lunar Laser Ranging. Classical and quantum gravity, Vol. 29, 184006 (9pp), 2012a, doi:10.1088/0264-9381/29/18/184006

Müller, J., Hofmann, F., Fang, X., Biskupek, L.: Lunar Laser Ranging – recent activities at Institut für Erdmessung (IfE). Proceedings of the 17th International Workshop on Laser Ranging, May 16–30, 2011, Bad Kötzting, Germany, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Vol. 48, p. 227–231, 2012b.

Murphy, T., Adelberger, E., Battat, J., Hoyle, C., Johnson, N., McMillan, R., Stubbs, C., Swanson, H.: APOLLO: millimeter lunar laser ranging. Classical and quantum gravity, Vol. 29, 184005 (11pp), 2012, doi: 10.1088/0264-9381/29/18/184005

Williams, J.G., Turyshev, S., Boggs, D.: Lunar Laser Ranging Tests of the Equivalence Principle. Classical and quantum gravity, Vol. 29, 184004 (13pp), 2012, doi: 10.1088/0264-9381/29/18/184004

Additionally, an extensive publications list of interest to ILRS can be found at the ILRS website:

<http://ilrs.gsfc.nasa.gov/about/reports/biblio/bibliography.2012.html>

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