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 2013.

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 and quantity 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. Nearly all stations deliver normal points with a precision of 1 mm or better, a firm requirement for the GGOS-era network as outlined in the GGOS2020 document and several stations have upgraded to high repetition rate systems to meet such requirements. NASA's next generation SLR system (NGSLR) was finally completed and delivered, 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

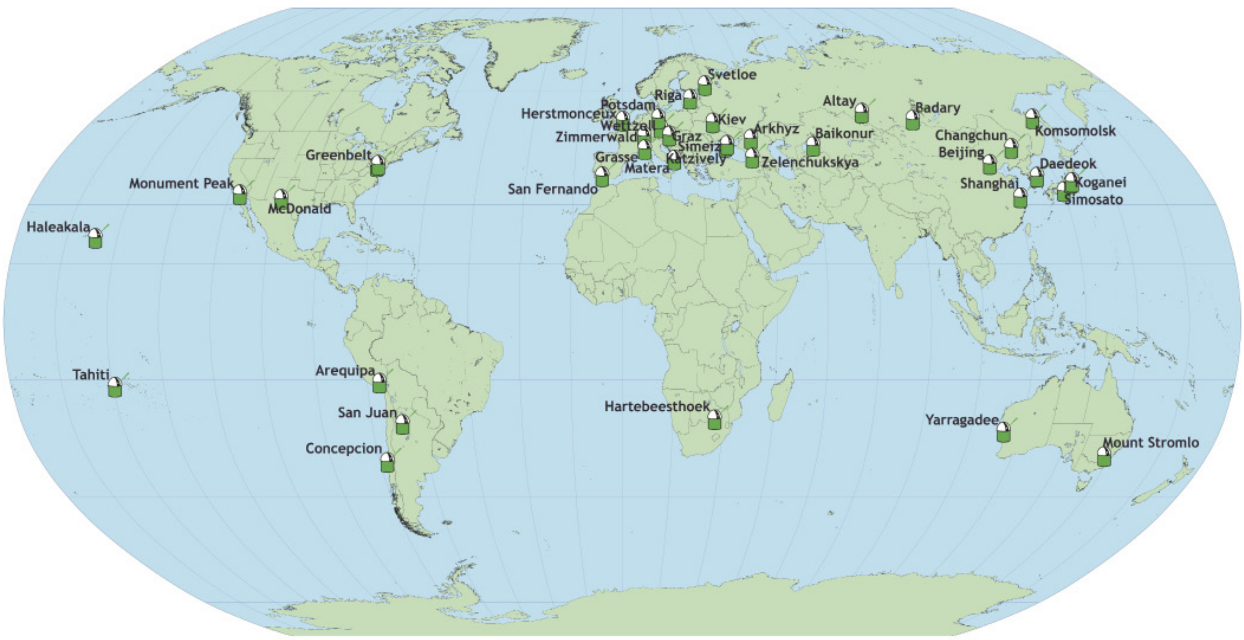

Fig. 1: The global network of SLR stations (status early 2014).

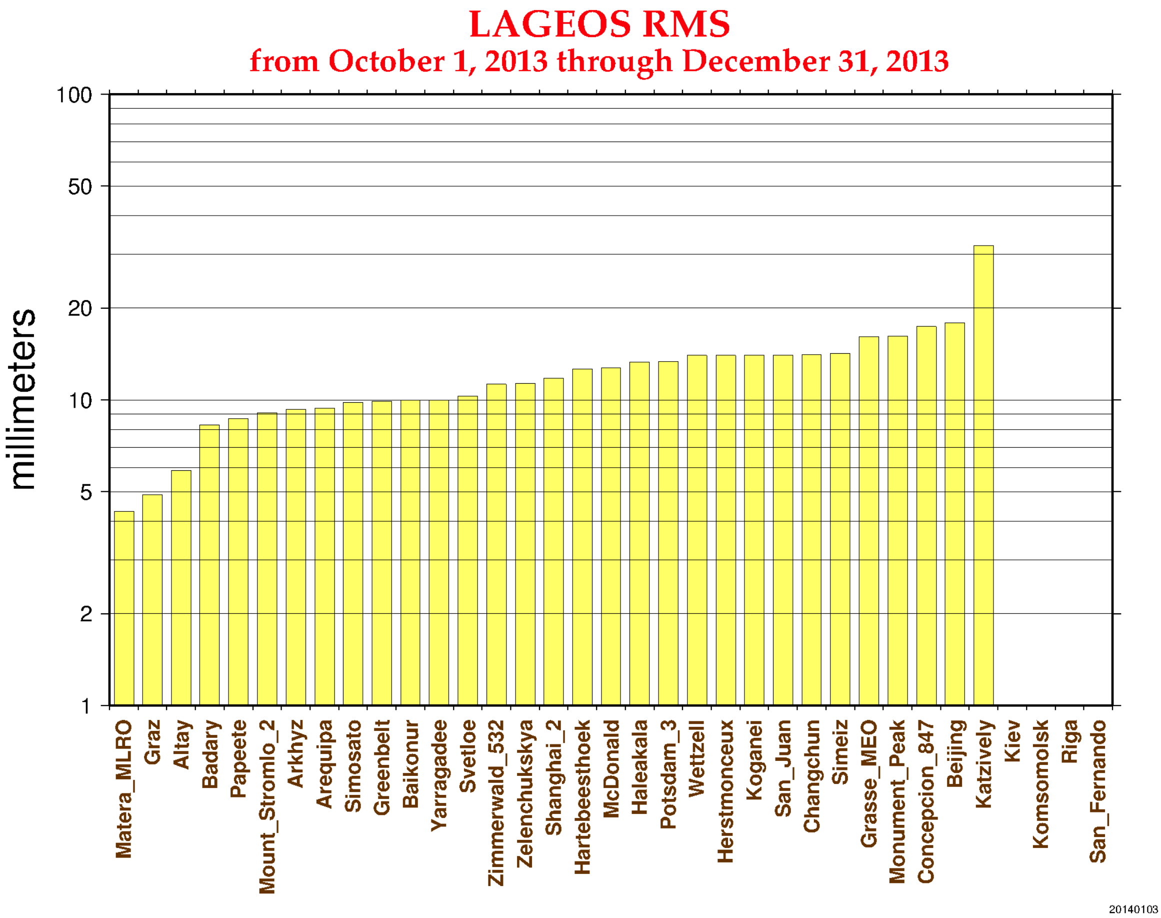

Fig. 2: Performance of the global network of SLR stations on LAGEOS (status end of 2013).

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. Russia has embarked on a program to deploy several new SLR sites around the world in addition to the expansion and upgrade of their network within the country. The first sites will be located in areas void of coverage up to this time, and they will be co-located with GNSS systems primarily intended to tie the GLONASS monitoring network with that of SLR. This addition will eventually improve tremendously the tie between the SLR- and GNSS-, VLBI-implied frames.

Statistics of the SLR data collected as pass segments during the calendar year 2013 are summarized in Table 1. For each of the contributing stations the tracked passes are broken down in three categories of target orbits: Low Earth Orbiters (LEO), LAGEOS 1 &

Table 1: ILRS Network Tracking Statistics for 2013.

		Number of Passes			
Site Name	**Station**	**Low**	**LAGEOS**	**High**	**Total**
Altay	1879	145	222	1,367	1,734
Apache Point	7045	0	0	151	151
Arequipa	7403	2,193	394	0	2,587
Arkhyz	1886	734	553	826	2,113
Badary	1890	904	258	101	1,263
Baikonur	1887	32	622	630	1,284
Beijing	7249	884	241	396	1,521
Changchun	7237	6,974	1,944	5,017	13,935
Concepcion	7405	936	413	76	1,425
Daejon	7359	357	179	195	731
Grasse	7845	1,080	703	1,376	3,159
Graz	7839	3,572	1,091	3,027	7,690
Greenbelt	7105	4,185	1,229	885	6,299
Haleakala	7119	1,380	576	0	1,956
Hartebeesthoek	7501	2,396	1,102	686	4,184
Herstmonceux	7840	2,547	1,028	1,874	5,449
Katzively	1893	1,274	345	41	1,660
Kiev	1824	1,061	336	81	1,478
Koganei	7308	194	154	189	537
Komsomolsk	1868	32	154	1,295	1,481
Kunming	7820	775	217	0	992
Matera	7941	3,494	1,951	1,898	7,343
McDonald	7080	871	492	224	1,587
Monument Peak	7110	3,707	1,084	973	5,764
Mount Stromlo	7825	6,244	1,532	1,136	8,912
Potsdam	7841	2,156	687	267	3,110
Riga	1884	356	10	0	366
San Fernando	7824	1,495	64	0	1,559
San Juan	7406	1,790	557	813	3,160
Shanghai	7821	1,625	556	1,363	3,544
Simeiz	1873	934	385	83	1,402
Simosato	7838	1,129	521	89	1,739
Svetloe	1888	206	118	25	349
Tahiti	7124	657	284	453	1,394
Wettzell	8834	3,683	1,126	3,204	8,013
Yarragadee	7090	13,769	3,577	7,173	24,519
Zelenchukskaya	1889	158	174	415	747
Zimmerwald	7810	4,542	1,669	3,595	9,806
Totals:	38	78,471	26,548	39,924	144,943

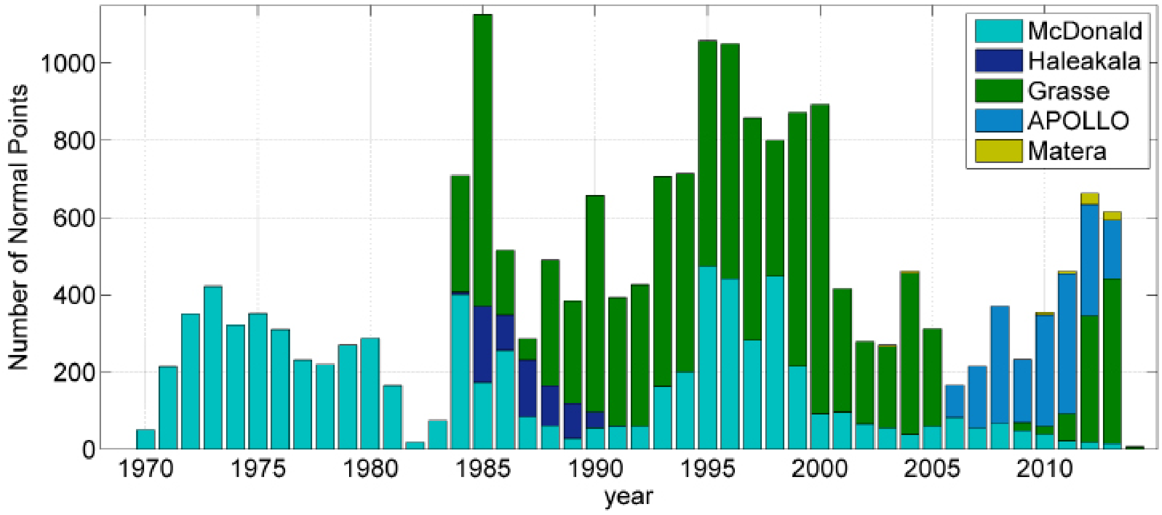

Fig. 3: Data yield of the global LLR network of stations (up to 2013). Note the increasingly significant contribution of Grasse's MeO system upon its return to operations.

2, and the High Earth Orbiters (HEO), GPS, GLONASS, ETALON, GIOVE-A/B, GALILEO, BeiDou, and the Moon.

Of all the active ILRS observatories (~38), very few are technically equipped to track retro-reflector arrays on the surface of the moon or spacecraft orbiting around the moon. In 2013, four active Lunar Laser Ranging (LLR) sites tracked the Moon: the McDonald Observatory in Texas, USA (generating 15 NP), the Observatoire de la Côte d' Azur, France (427 NP), the APOLLO site in New Mexico, USA (251 NP) and the Matera Laser Ranging station in Italy (22 NP). That means, almost 70% of the data have been collected at the French MeO site near Grasse and about one quarter of the data at the APOLLO site. Most of the data have been obtained by tracking the big Apollo 15 reflector (70%). Figure 3 shows the entire LLR data set 1970–2013, indicating the amount of data collected by each of the active LLR sites per year. It is more than 20,000 normal points in total. A steady increase of LLR NP in the last years is obvious. Additional data have been recovered through screening various archives and homogenizing the various data files maintained at individual institutions.

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. A general objective is to achieve the mm level of accuracy for LLR data analysis, now still at the cm level. The four analysis centers cooperate to mutually improve the various codes. LLR remains one of the best tools to support lunar science and to test General Relativity in the solar

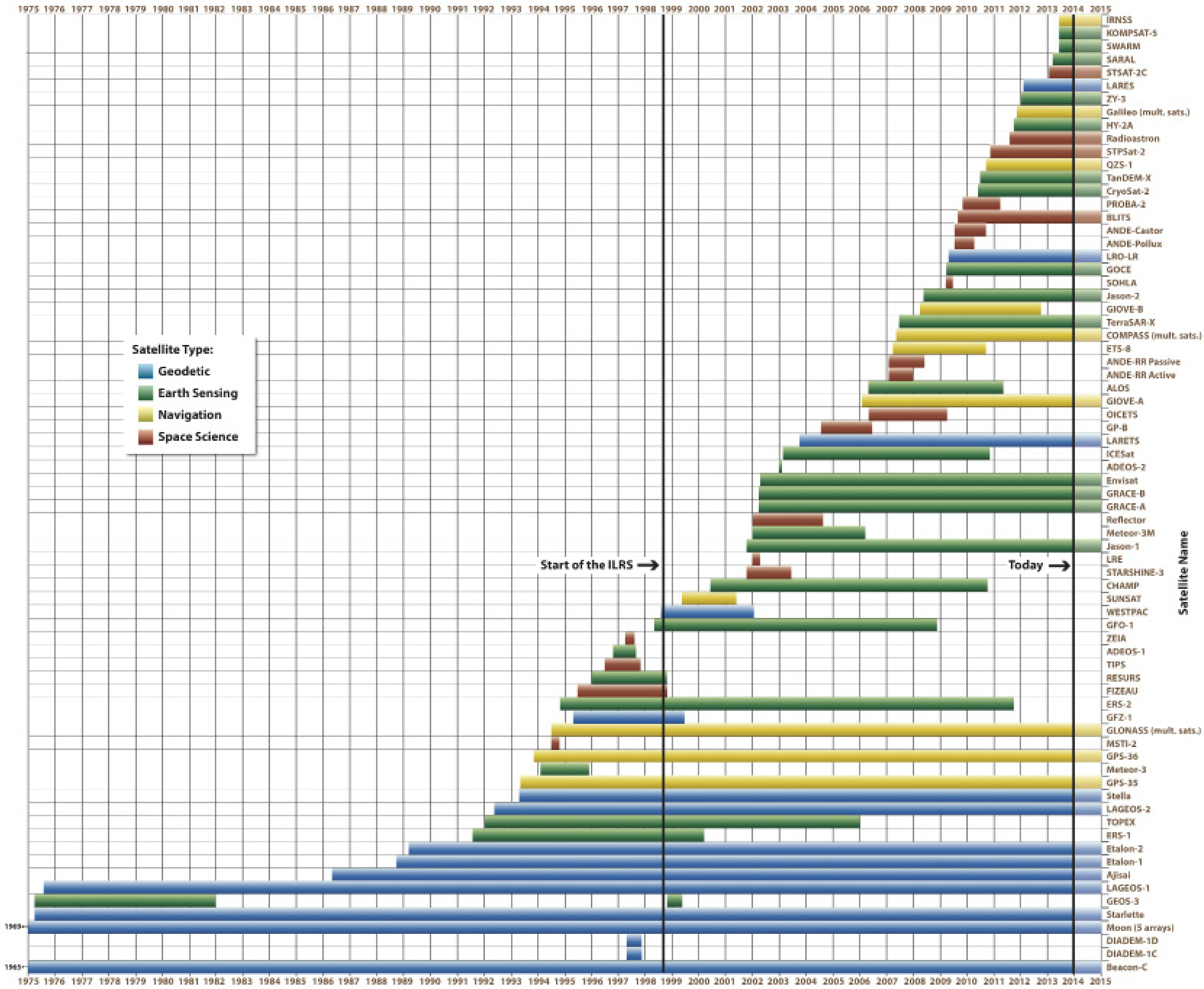

Fig. 4: The currently tracked SLR missions (status early 2014).

system, a fact presented at various conferences and in several papers of the LLR community. Recent activities also comprise comprehensive simulations to show the potential benefit of improved tracking from further observatories and/or to new reflectors.

Missions

In 2013, a total of ~38 missions including the Moon (a total of over than 75 targets!) were being tracked by SLR/LLR (Figure 4). Of these, only about 1/3 are geodetic type targets (cannonball satellites), the rest are mainly Earth Observation missions and numerous navigation satellites, along with a small number of experimental space science missions. In 2013 the steady increase of tracking multiple GNSS targets continued for a third year in a row and given the inter-technique arrangements through the ILRS/GGOS LARGE Working Group (LAser Ranging to GNSS s/c Experiment), this trend is expected to persist and further increase in the coming years.

Table 2: ILRS Supported Missions Launched or Initiating Tracking in 2013.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	First Data Date
SARAL	1300901	3201	39086	3	15	814	98.55	2013-Mar-04
STSAT-2C	1300301	3804	39068	3	15	300-1500	80	2013-Mar-29
GLONASS-131	1301901	9131	39155	9	300	19,140	65	2013-May-23
Swarm-C	1306703	8009	39453	1	5	530	88.95	2013-Nov-25
Swarm-A	1306702	8007	39452	1	5	460	88.35	2013-Nov-26
Swarm-B	1306701	8008	39451	1	5	460	88.35	2013-Nov-27
IRNSS-1A	1303401	3301	39199	9	300	42,164	29	2013-Sep-05
KOMPSAT-5	1304201	3803	39227	1	5	550	97.6	2013-Sep-09

Table 3: ILRS missions that de-orbited or ceased being tracked in 2013

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	Last Data Date
BLITS	904907	5558	35871	5	30	832	98.77	3/5/13
STPSat-2	1006201	1075	37222	3	15	650	72	10/18/13
GOCE	901301	499	34602	1	5	295	96.7	11/2/13

During 2013 several new missions were launched as shown in Table 2. SWARM is a demanding Earth Observation mission with targets orbiting within a few seconds apart, requiring special tracking procedures and a quick target interleaving approach.

Similarly, Table 3 shows the few missions that were removed from the list of active missions and the missions that were de-orbited or ceased requiring SLR tracking in 2013.

Despite the small decrease on active stations in 2013 and a significant increase in tracked targets, the ILRS network has increased its productivity tremendously to keep the data yield at a similar level as in the recent years (Figure 5). 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.

Analysis and science

The Analysis Working Group (AWG) spent considerable effort in preparation for the complete data re-analysis in support of the development of ITRF2013. During the several AWG meetings in 2013, new models and processing approaches were developed, implemented tested and the participating ACs initiated the re-analysis process to meet the early 2014 delivery deadline to ITRS. Some of the new model improvements include better handling of systematic errors for the tracking systems, a detailed modeling

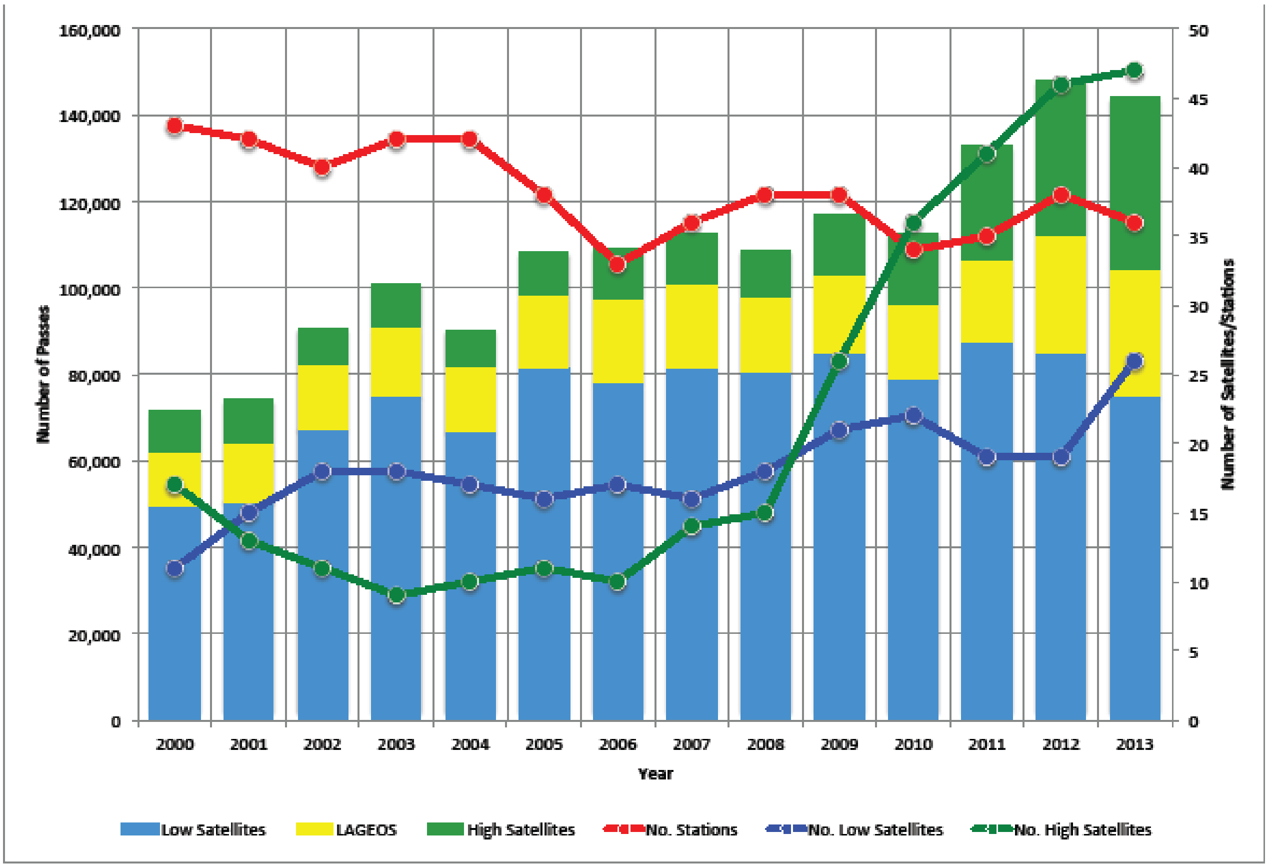

Fig. 5: ILRS network data yield over the past decade (status late 2013).

of time varying gravity to degree and order two, and a realistic modeling of the mean rotational pole used in the computation of the pole tide potential.

Several Pilot Projects (PP) will be completed after the ITRF2013 development process is completed.

Meetings

The ILRS held an international laser workshop in Fujiyoshida, Japan, November 11–15, with the title "Pursuing Ultimate Accuracy & Creating New Synergies", (ILW-18, <http://geo.science.hit-u.ac.jp/lw18>). The AWG held three meetings in 2013, one prior to the EGU General Assembly, on April 7 (<http://ilrs.gsfc.nasa.gov/docs/2013/Agenda_Spring2013_ILRS_AWGMeeting.pdf>, one prior to the IAG Scientific Assembly, in Potsdam, Germany, September 01 (http://ilrs.gsfc.nasa.gov/docs/2013/Draft_Agenda_Fall2013_ILRS_AWGMeeting.pdf), and one prior to the Fujiyoshida workshop, on November 9 (<http://ilrs.gsfc.nasa.gov/docs/2013/FINAL_Minutes_AWG_Fujiyoshida2013.pdf>). The ILRS Governing Board met once during 2013, during the Fujiyoshida workshop on November 14 (<http://ilrs.gsfc.nasa.gov/docs/2013/ILRSGB_minutes_20131114.pdf>).

Publications

An extensive publications list of interest to ILRS can be found at the ILRS website:

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

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