3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2015.

Network

The network of SLR/LLR stations (Figure 1), under the aegis of the ILRS, has been subject to change over the years. In 2015 the network further expanded with the addition of several new sites, most of them deployed by Russia, in support of their GLONASS tracking network. 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. Examination of the tracking over the past year indicates that while the tracking of targets increased by ~10% and the number of tracking sites decreased by ~10%, the

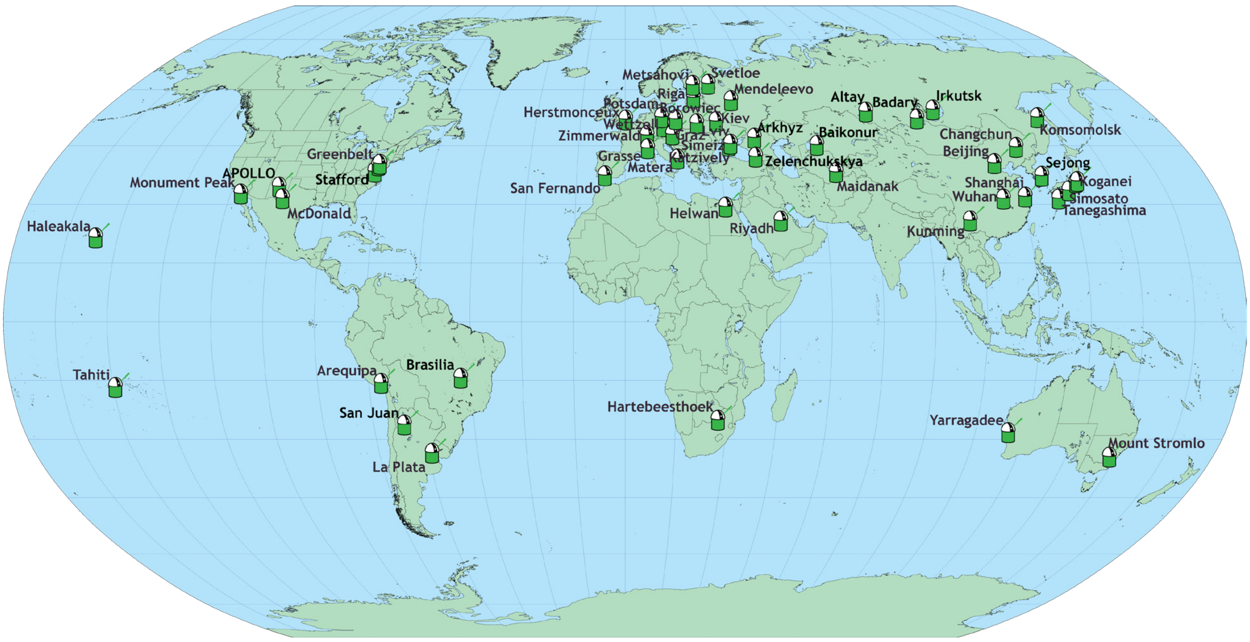


Fig. 1: The global network of SLR stations (status early 2016).

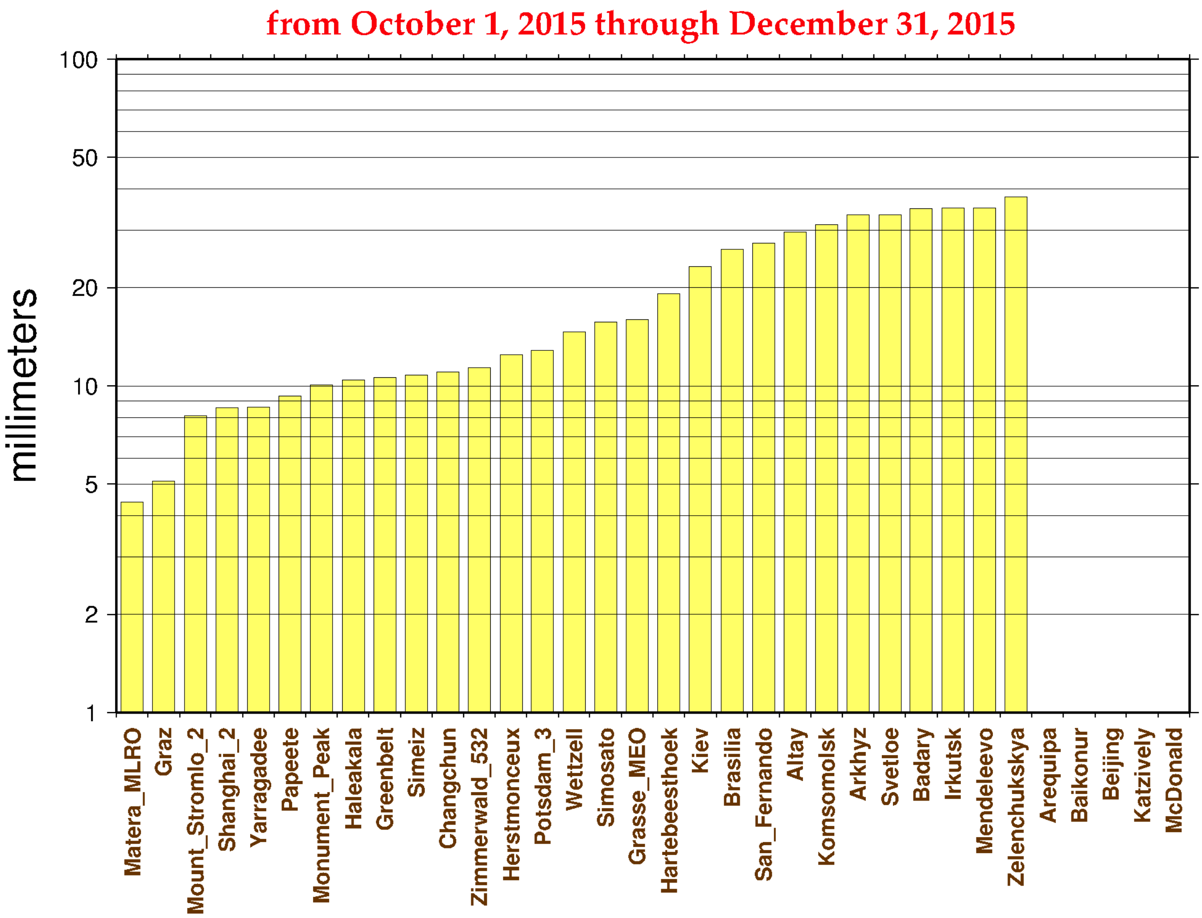


Fig. 2: Performance of the global network of SLR stations on LAGEOS (last quarter of 2015).

annual data yield of the network is nearly identical to that of the prior year (Table 1 and Figure 7). NASA is moving forward with the deployment of the first next generation Space Geodesy SLR systems (SGSLRs) at McDonald Obs., Texas, to be followed by the one at Mt. Haleakala, Hawaii. Russia's expansion and upgrade of their network continues, with new deployment of a system in co-location with MOBLAS 6 at Hartebeesthoek, South Africa. All sites will be co-located with GNSS systems primarily intended to tie the GLONASS monitoring network with that of the 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 2015 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 & 2 and LARES, and the High Earth Orbiters (HEO), GPS, GLONASS, ETALON, GIOVE-A/B, Galileo, BeiDou, IRNSS and the Moon.

Of all the active ILRS observatories (~36), very few are technically equipped to track retro-reflector arrays on the surface of the

3.4.2 International Laser Ranging Service (ILRS)

Table 1: ILRS Network Tracking Statistics for 2015.

Site Name	Station	Number of Pass Segments			
		Low	LAGEOS	High	Grand
Altay	1879	244	323	1,974	2,541
Apache Point	7045	0	0	190	190
Arequipa	7403	2,250	332	0	2,582
Arkhyz	1886	331	309	1,317	1,957
Badary	1890	2,762	571	427	3,760
Baikonur	1887	23	193	343	559
Beijing	7249	640	224	648	1,512
Brasilia	7407	8	292	906	1,206
Changchun	7237	9,260	2,180	7,386	18,826
Grasse	7845	360	308	178	846
Graz	7839	3,689	1,146	3,420	8,255
Greenbelt	7105	6,069	1,847	1,990	9,906
Haleakala	7119	1,178	596	0	1,774
Hartebeesthoek	7501	2,374	1,000	790	4,164
Herstmonceux	7840	3,330	1,242	3,143	7,715
Irkutsk	1891	83	289	670	1,042
Katzively	1893	1,346	290	0	1,636
Kiev	1824	783	215	4	1,002
Komsomolsk	1868	73	216	1,586	1,875
Matera	7941	3,068	2,128	3,568	8,764
McDonald	7080	400	203	145	748
Mendeleevo	1874	84	102	312	498
Monument Peak	7110	5,545	1,423	1,449	8,417
Mount Stromlo	7825	6,666	2,018	3,069	11,753
Potsdam	7841	2,786	711	366	3,863
San Fernando	7824	2,579	308	54	2,941
Shanghai	7821	1,414	405	1,631	3,450
Simeiz	1873	1,188	364	131	1,683
Simosato	7838	961	398	24	1,383
Svetloe	1888	1,006	685	537	2,228
Tahiti	7124	741	337	542	1,620
Wettzell	7827	134	57	172	363
Wettzell	8834	2,484	541	2,416	5,441
Yarragadee	7090	18,534	4,526	8,651	31,711
Zelenchukskaya	1889	544	301	690	1,535
Zimmerwald	7810	4,038	1,211	2,866	8,115
Totals:	36 stations	86,975	27,291	51,595	165,861

Moon or spacecraft orbiting around the Moon. In 2015, three Lunar Laser Ranging (LLR) sites regularly collected ranging data to the Moon: The Observatoire de la Côte d' Azur, France (249 normal points, NP), the APOLLO site in New Mexico, USA (236 NP) and the Matera Laser Ranging station in Italy (22 NP). Additionally in 2015, the McDonald Observatory in Texas, USA, returned with (only) 2 successful lunar tracks after one year without any lunar measurements. One has to await the further development of LLR capabilities at McDonald in the near future. These numbers still do not contain quite new measurements carried out in infrared at the French site. And also not all APOLLO data might be available in the archive, yet.

The measurement statistics of 2015 (Figure 3) shows that about one half of all LLR data have been collected at the French MeO site near Grasse and almost one half at APOLLO. Figure 4 illustrates the statistics for the observed retro-reflectors, where a much better coverage of all reflectors could be achieved in the past years. Nevertheless, most of the data have been obtained

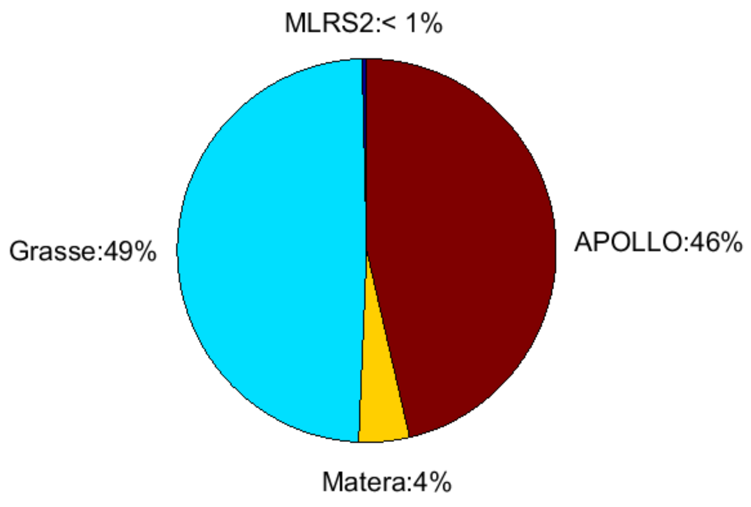


Fig. 3: Observatory statistics in 2015

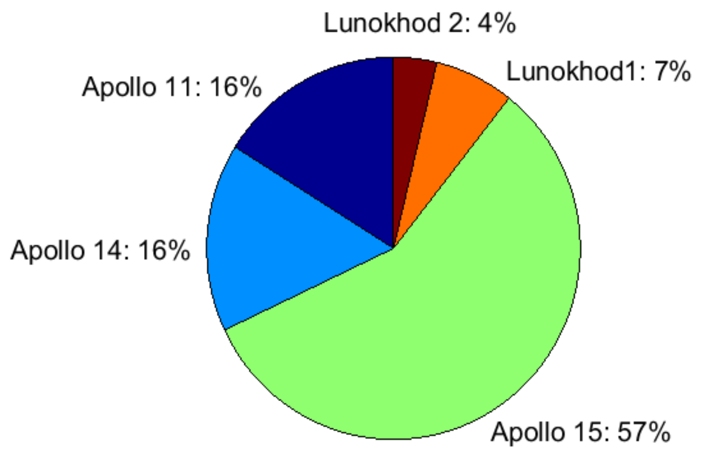


Fig. 4: Retro-reflector statistics in 2015

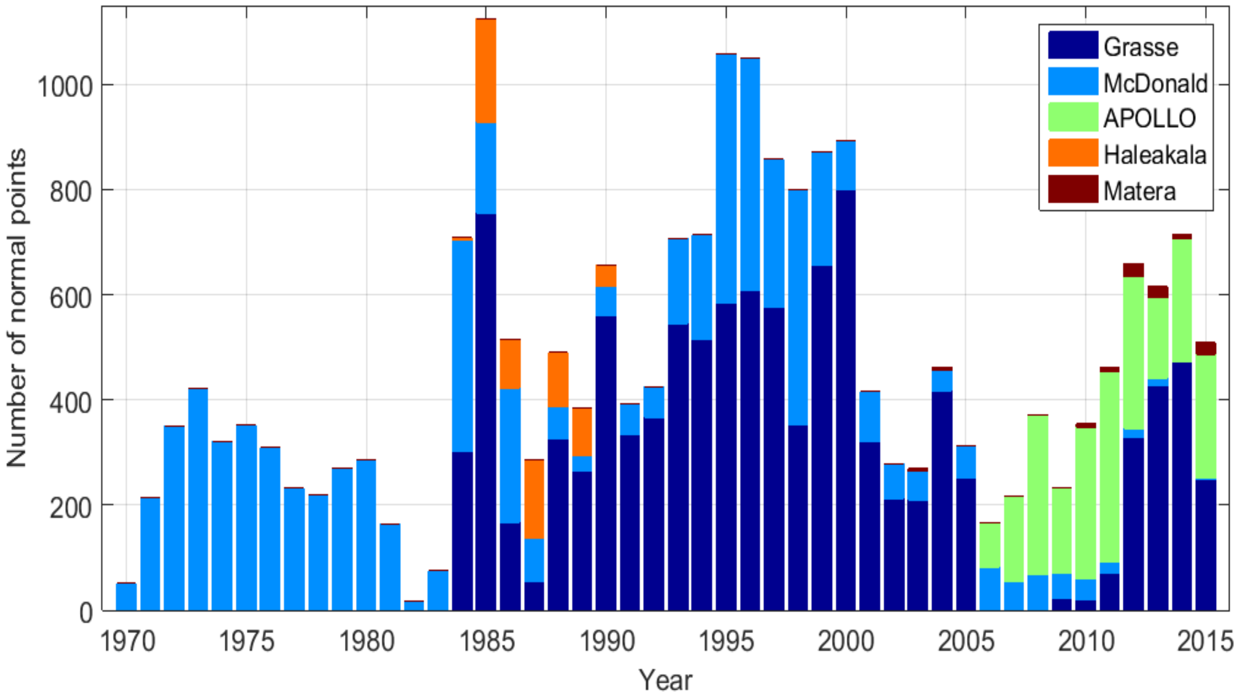


Fig. 5: Data yield of the global LLR network of stations (up to 2015). Note the increasingly significant contribution of Grasse's MeO system upon its return to operations in 2011.

by tracking the big Apollo 15 reflector (57%). Figure 5 shows the entire LLR data set from 1970 to 2015 indicating the amount of data collected by each of the active LLR sites in each year. It is more than 21,000 normal points in total. After several years with less LLR NP, one has reached quite a good level of more than 600 NP per year in the previous years, but a little bit less, about 500 NP, in 2015.

LLR data analysis is carried out by a few 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. In the last years, the National Institute for Nuclear Physics (INFN), Frascati, Italy, and the Graduate University for Advanced Studies (SOKENDAI), Japan, increased their activities to analyze LLR data.

One general objective of LLR analysis is to achieve mm level of accuracy; today it is still at the cm level (see Figure 6). The various analysis centers are eager to improve their various algorithmic codes, which is a difficult task. Recent activities also comprise simulations to show the potential benefit of improved tracking from further observatories and/or to new reflectors. These activities are aiming for a better science output, as LLR belongs to the best tools to support lunar science, to study the Earth–Moon dynamics and to test General Relativity in the solar system.

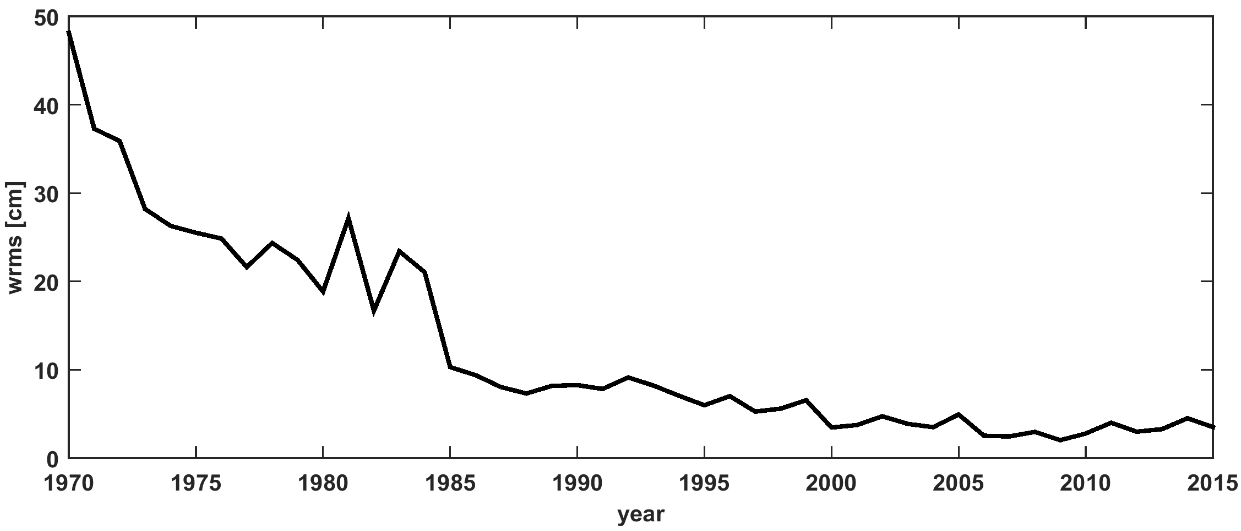


Fig. 6: LLR residuals, annual WRMS.

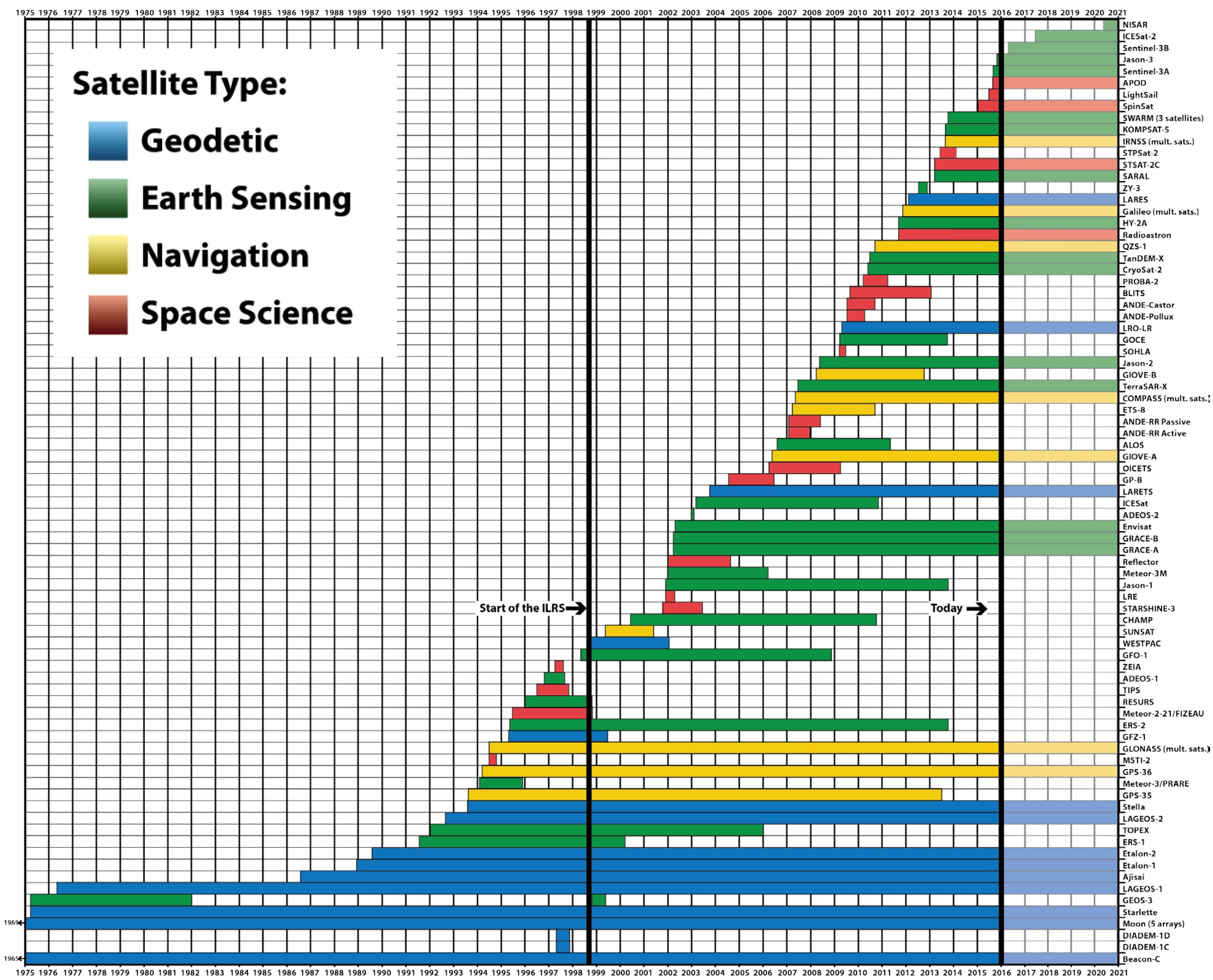


Fig. 7: The currently tracked SLR missions (status as of late 2015).

Missions

In 2015, a total of ~38 missions including the Moon (over 70 targets!) were being tracked by SLR/LLR (Figure 7). Of these, only about 1/3 are geodetic type targets (cannonball satellites), about one half are navigation satellites and the rest are mainly Earth Observation missions, along with a small number of experimental space science missions. In 2015 the steady increase of tracking multiple GNSS targets continued for a fifth year in a row and two dedicated tracking campaigns organized through the ILRS/GGOS LARGE Working Group (LAser Ranging to GNSS s/c Experiment), resulted in a further increase in data yield from such missions.

During 2015 the new missions that were launched are shown in Table 2. They were almost exclusively spacecraft of GNSS Constellations. PN-1 is an experimental mission that includes four spacecraft (1A through 1D) that form the APOD mission (Atmospheric density Detection and Precise Orbit Determination), an initiative of China's Beijing Aerospace Control Center (BACC) aiming at precise orbit determination and thermosphere density detection, designed and manufactured by DFH satellite Co. Ltd. APOD consists of one nano-satellite (PN-1A) with a mass of 15 kg and three identical pico-satellites (PN-1B, -1C,-1D) with a mass of 5 kg. There was one additional launch of an experimental mission in late May, 2015: LightSail-A (<http://ilrs.gsfc.nasa.gov/missions/satellite_missions/past_missions/lita_general.html>), which however had a very short lifetime due to its very low altitude that resulted in not being tracked by the network. A more advanced version of this spacecraft is scheduled for launch in late 2016.

Table 2: ILRS Supported Missions Launched or Initiating Tracking in 2015.

Satellite Name	Satellite ID	SIC Code	Satellite Catalog Number*	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	First Data Date
Galileo-202	1405002	7202	40129	9	300	17,000-26,210	~ 50	2015-Mar-17
Galileo-203	1501701	7203	40544	9	300	23,220	56 ± 2	2015-Mar-27
Galileo-204	1501702	7204	40545	9	300	23,220	56 ± 2	2015-Mar-27
IRNSS-1D	1501801	3304	40547	9	300	42,293	30.5	2015-Apr-24
COMPASS-MS1	1503702	2007	40749	9	300	21,528	55	2015-Jul-25
COMPASS-MS2	1503701	2008	40748	9	300	21,528	55	2015-Jul-25
COMPASS-IS1	1501901	2006	40549	9	300	35,786	55.5	2015-Sep-08
Galileo-205	1504501	7205	40889	9	300	23,220	56 ± 2	2015-Sep-11
Galileo-206	1504502	7206	40890	9	300	23,220	56 ± 2	2015-Sep-11
COMPASS-IS2	1505301	2010	40938	9	300	35,786	55.5	2015-Sep-29
PN-1	1504905	2203	40903	1	5	450-120	94.47	2015-Nov-11
Galileo-208	1507902	7208	41175	9	300	23,220	56 ± 2	2015-Dec-17
Galileo-209	1507901	7209	41174	9	300	23,220	56 ± 2	2015-Dec-17

** Formerly known as the NORAD Number.*

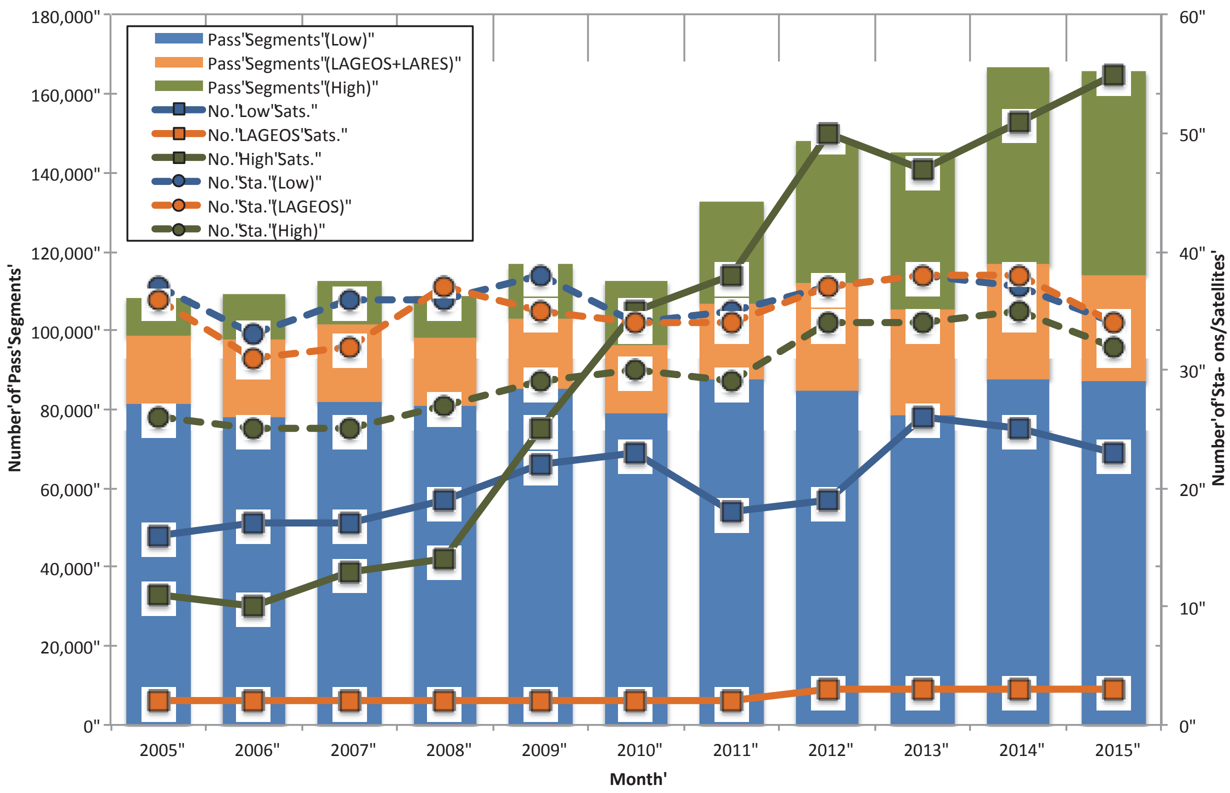


Fig. 8: ILRS network data yield by target type since 2005 (by end of 2015).

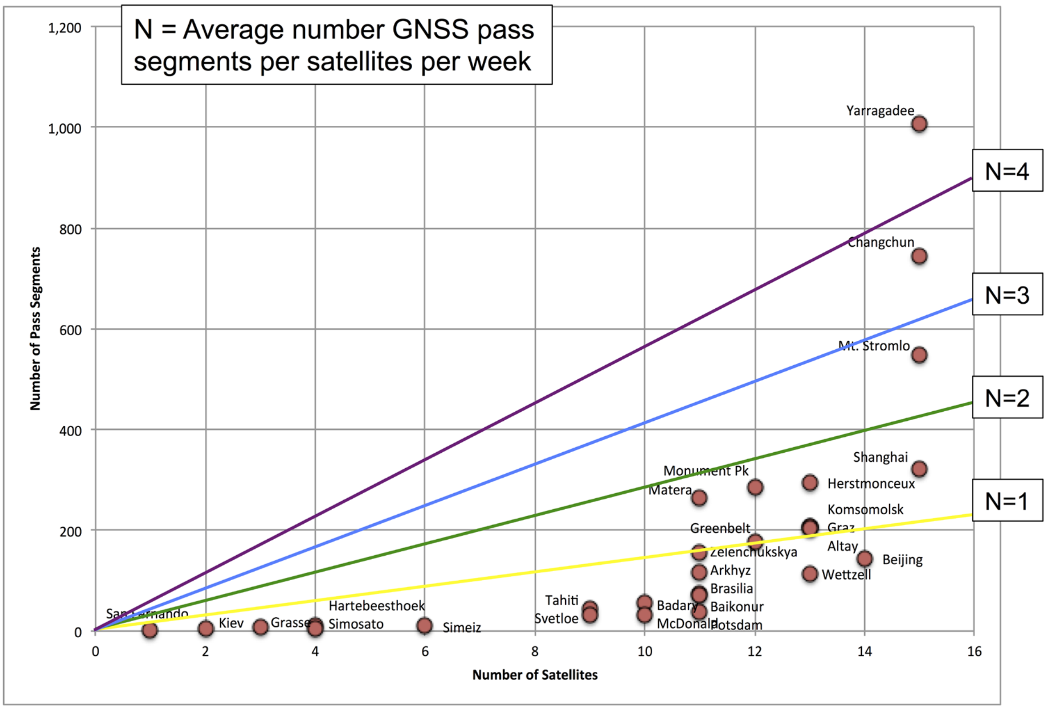
Despite the small decrease in active stations in 2015 and comparable increase in tracked targets, the ILRS network has increased its productivity tremendously to maintain the data yield (Figure 8). A major contributor in the recent years' data yield increase is the fact that several stations now track all GNSS satellites. The results of the second and third GNSS target tracking campaigns organized by the LARGE Working Group (November 2014 through October 2015) indicated that only a few sites were able to track significant number of passes on multiple targets during the second campaign and things improved dramatically during the third campaign (Fig. 9).

Analysis and science

The Analysis Working Group (AWG) delivered the final version of the ILRS contribution to ITRF2014 prior to the European Geosciences Union meeting in April 2015 (Figure 10). When the ITRS Center's preliminary result was released in the summer of 2015, the ILRS ACs evaluated the proposed ITRF2014P model and based on several ACs tests, a positive recommendation was submitted to the ITRS Center, in late October 2015, following the ILRS Technical Workshop in Matera, Italy. The new model shows significant improvements to the outdated ITRF2008, especially

Campaign 2

November 22, 2014 – February 28, 2015 (3 months/14 weeks/99 days)



Campaign 3

August 20 – October 16, 2015 (2 months/8 weeks/58 days)

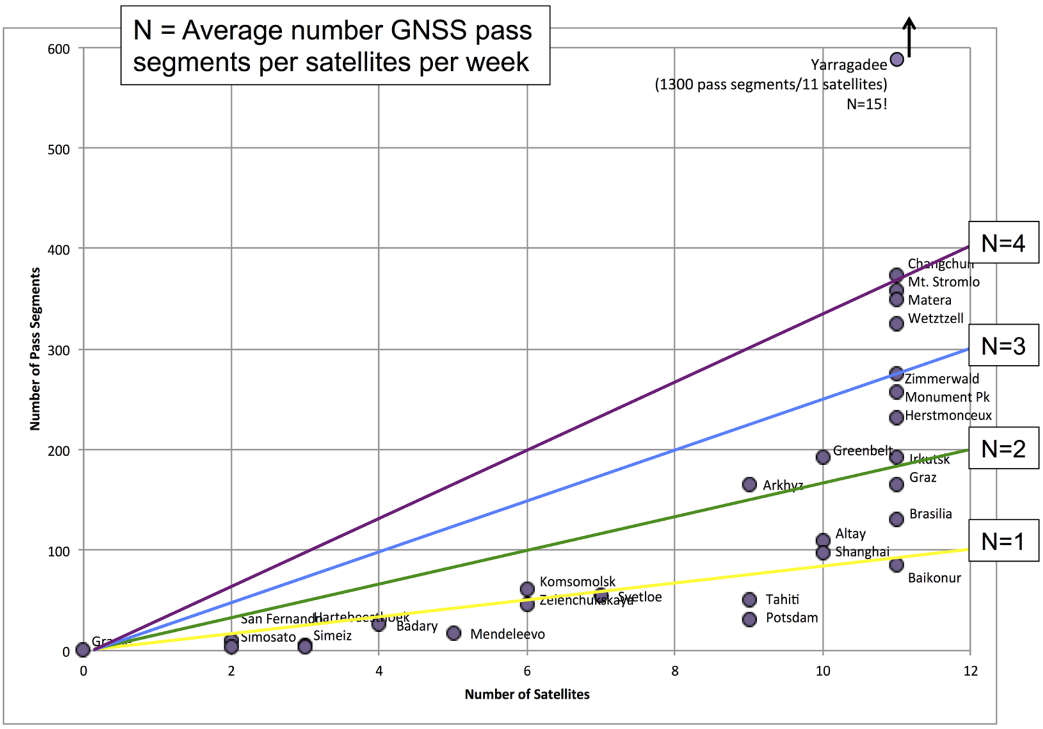


Fig. 9: Tracking data distribution statistics for the second (top) and third (bottom) GNSS target tracking campaigns (2015).

for a large number of newly established SLR sites. There are still some inter-technique issues with most prominent the scale inconsistency between SLR and VLBI. There are ongoing efforts now looking into this inconsistency from various points of view and it is hoped that a thorough review of both techniques in the coming year will lead to a resolution.

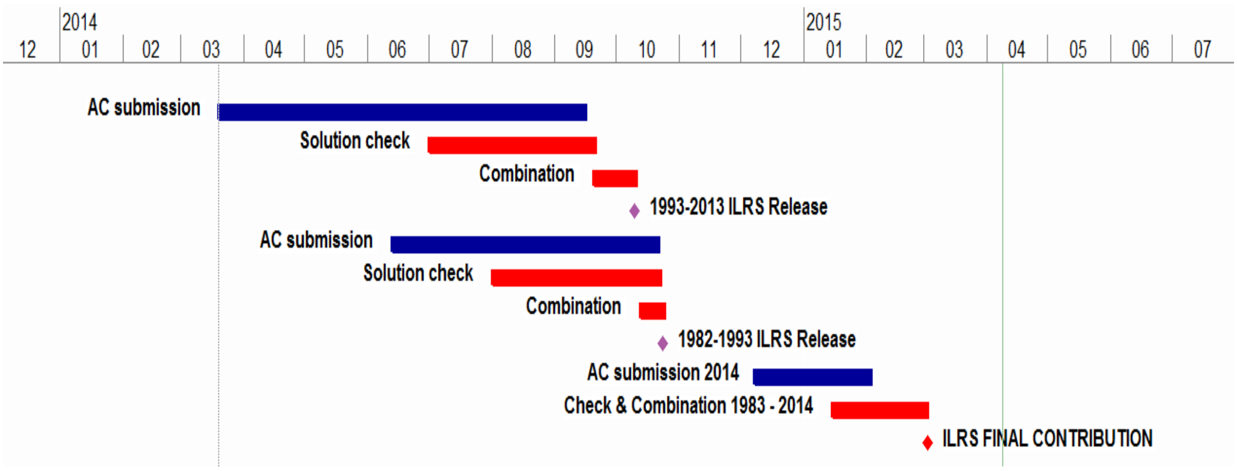


Fig. 10: The timeline of the official ILRS Analysis and Combination process for the development of the ILRS contribution to ITRF2014 based on the input of the ILRS ACs.

The final ITRF2014 model exhibits a very good quality in the definition of the origin (Fig. 11) and the scale of the SLR-only TRF, which were already described in presentations by the ILRS Analysis Working Group chairs (Luceri, V. et al., 2015, Pavlis, E. C. et al., 2015).

Meetings

In 2015 the ILRS Technical Workshop was held at the Casa Cava in Matera, Italy, October 26 – 30, co-sponsored by the Italian Space Agency (ASI) and the ILRS, to address:

1. Network performance on GNSS and present and future user expectations,
2. Present performance and future expectations for time transfer, and
3. Present performance and future expectations for space debris tracking.

The workshop was very well attended with over 100 participants and 50 oral presentations and over 15 posters. The AWG held two meetings in 2015, one during the EGU General Assembly, on April 16, and one prior to the Matera Workshop, on October 24 (<http://ilrs.gsfc.nasa.gov/science/awg/awgActivities/>). The ILRS Governing Board met once in 2015, prior to the Matera workshop

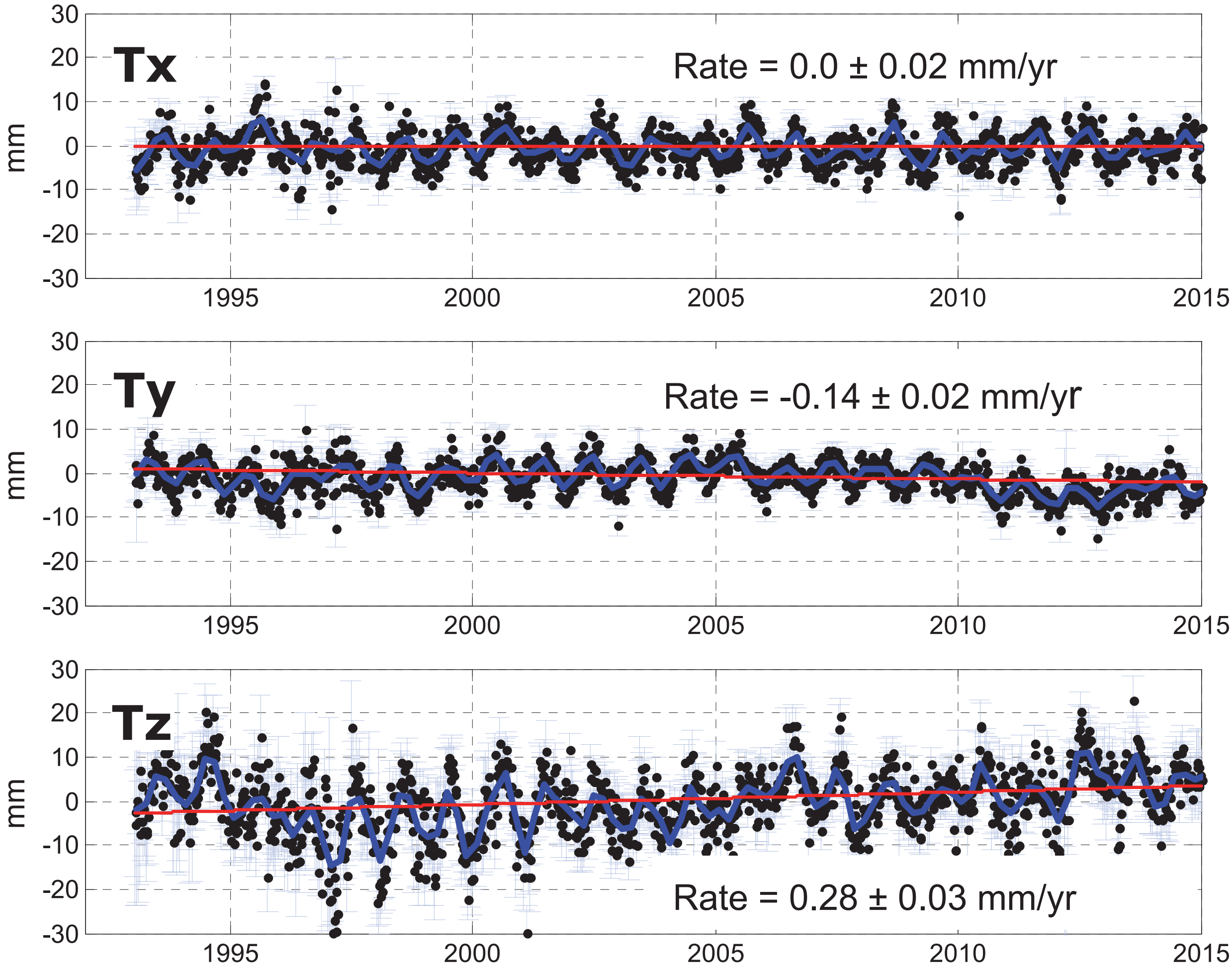


Fig. 11: The three components of the TRF origin implied by SLR from the official ILRS-A submission to ITRF2014.

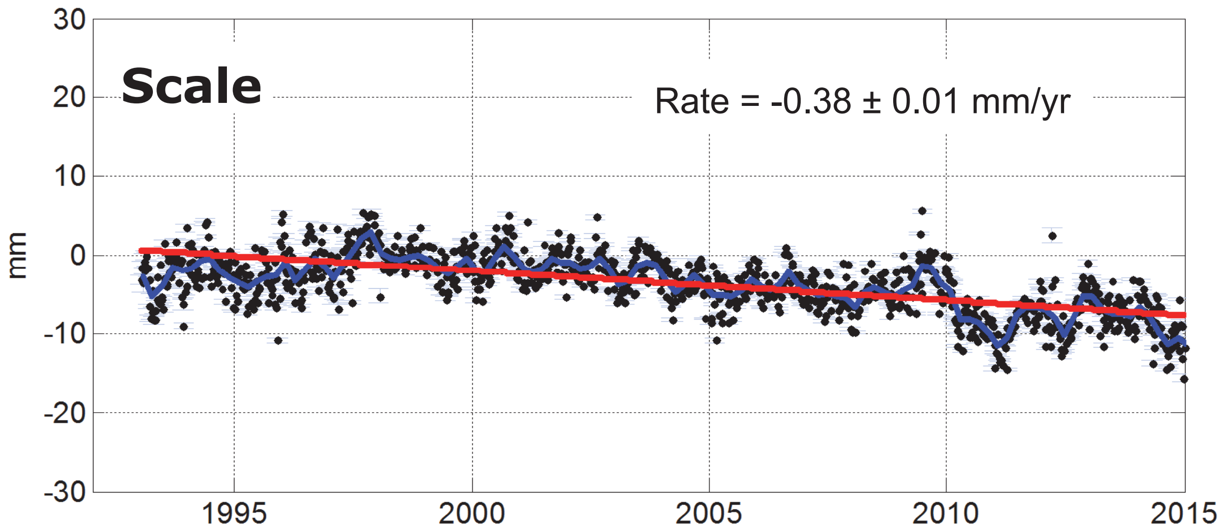


Fig. 12: Weekly variations of the scale of the SLR network with respect to ITRF2014.

on October 25 (<http://ilrs.gsfc.nasa.gov/about/organization/gov-board/gbmeeting_reports.html>). The ILRS will hold in 2016 the 20th International Workshop on Laser Ranging that will take place in Potsdam, Germany, co-hosted by GFZ (see <http://iwslr2016.gfz-potsdam.de/international-workshop-on-laser-ranging/>).

Publications

Access all the presentations, posters, and proceedings papers presented at the Technical ILW in Matera, Italy from the official ILRS page for the workshop:
<http://cddis.gsfc.nasa.gov/2015_Technical_Workshop/Program/>

An extensive publications list of interest to ILRS associates can be found at the ILRS website:
<http://ilrs.gsfc.nasa.gov/about/reports/biblio/bibliography.2015.html>

References

Luceri, V., E. C. Pavlis, B. Pace, M. Kuzmicz-Cieslak, D. König, G. Bianco, and K. Evans (2015) “The ILRS Contribution to the Development of the ITRF2014”, 2015 26th IUGG General Assembly, Prague, Czech Republic, June 22 – July 2, 2015.

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