## 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 2011.

### 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 document

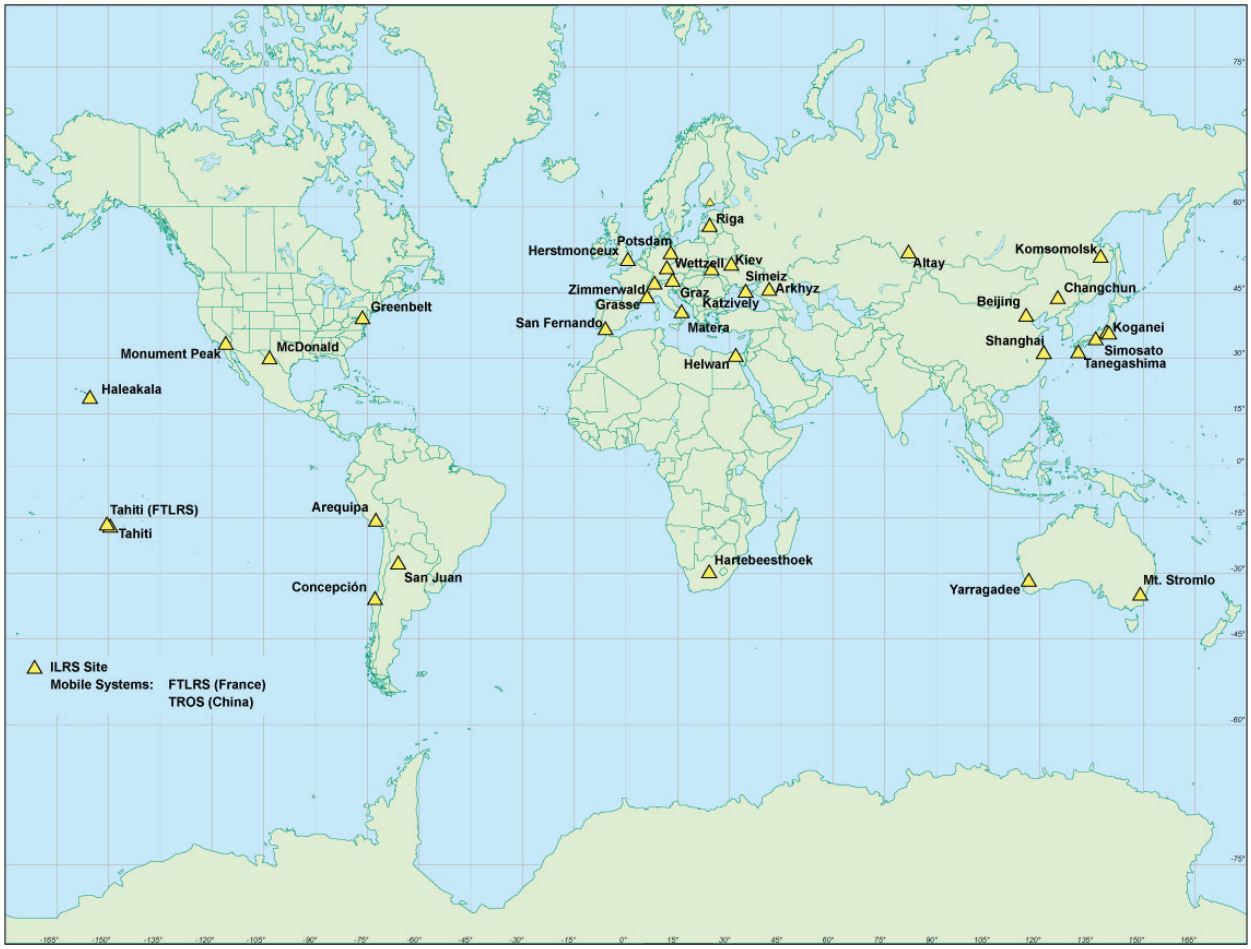


*Fig. 1: The global network of SLR stations (status early 2012).*

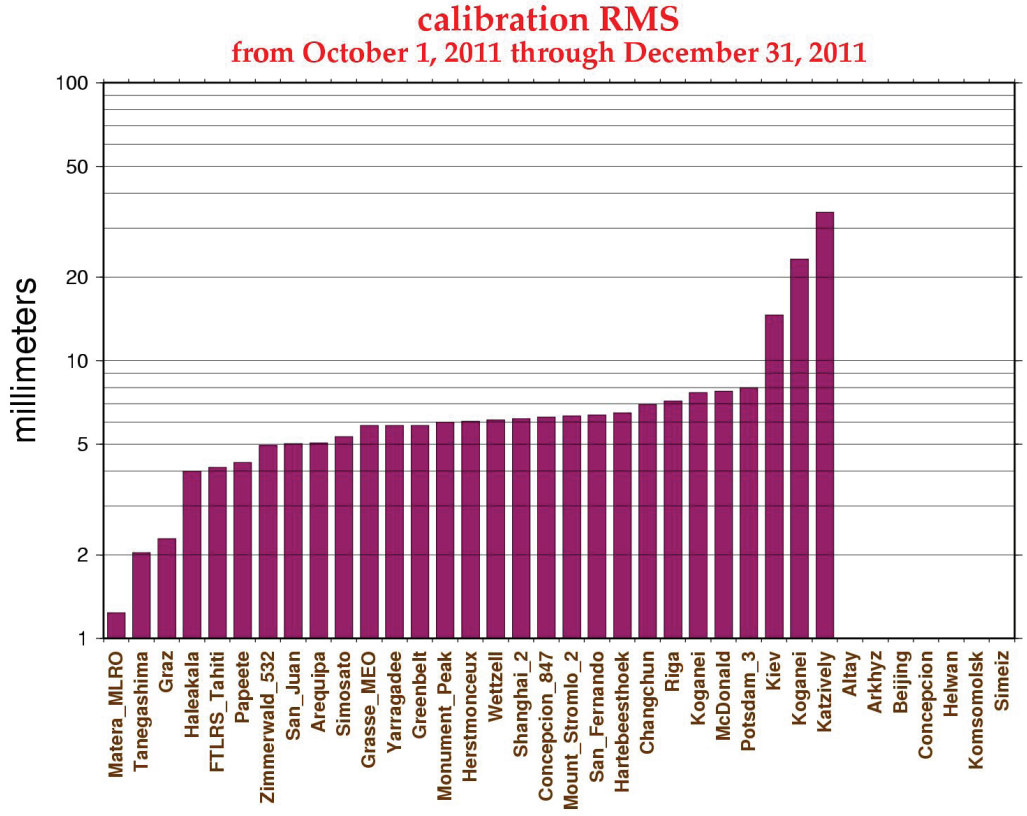


*Fig. 2: The global network of SLR stations (status early 2012).*

and several stations 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. Near the end of the year the Russian agencies indicated an interest in contributing a significant number of new, high repetition rate systems, most of which are located in areas void of coverage at the moment, and three of which are co-located with VLBI systems that are part of the IVS network for a long time now (Badary Zelenchukskaya, and Svetloe). These sites will have to be validated before they can become part of the ILRS network, early next year, however,

*Table 1: ILRS Network Tracking Statistics for 2011.*

| Site Name | Station | Number of Passes | | | Total |
|---|---|---|---|---|---|
| | | Low | LAGEOS | High | |
| Altay | 1879 | 214 | 243 | 773 | 1,230 |
| Arequipa | 7403 | 1,998 | 166 | 0 | 2,164 |
| Arkhyz | 1886 | 72 | 189 | 184 | 445 |
| Beijing | 7249 | 569 | 45 | 1 | 615 |
| Changchun | 7237 | 5,202 | 544 | 1,020 | 6,766 |
| Concepcion | 7405 | 1,049 | 573 | 111 | 1,733 |
| Grasse | 7845 | 877 | 550 | 764 | 2,191 |
| Graz | 7839 | 4,784 | 708 | 1,841 | 7,333 |
| Greenbelt | 7105 | 4,301 | 593 | 684 | 5,578 |
| Haleakala | 7119 | 1,654 | 493 | 0 | 2,147 |
| Hartebeesthoek | 7501 | 2,875 | 970 | 992 | 4,837 |
| Helwan | 7831 | 3 | 0 | 0 | 3 |
| Herstmonceux | 7840 | 3,931 | 760 | 1,673 | 6,364 |
| Katzively | 1893 | 1,449 | 244 | 213 | 1,906 |
| Kiev | 1824 | 935 | 165 | 89 | 1,189 |
| Koganei | 7308 | 439 | 169 | 356 | 964 |
| Koganei | 7328 | 129 | 34 | 0 | 163 |
| Komsomolsk-Na-Amure | 1868 | 59 | 135 | 439 | 633 |
| Matera | 7941 | 4,924 | 2,036 | 2,933 | 9,893 |
| McDonald | 7080 | 1,164 | 427 | 213 | 1,804 |
| Monument Peak | 7110 | 3,303 | 949 | 1,166 | 5,418 |
| Mount Stromlo | 7825 | 6,217 | 971 | 386 | 7,574 |
| Potsdam | 7841 | 2,217 | 331 | 86 | 2,634 |
| Riga | 1884 | 1,427 | 106 | 2 | 1,535 |
| San Fernando | 7824 | 1,674 | 185 | 19 | 1,878 |
| San Juan | 7406 | 2,794 | 608 | 831 | 4,233 |
| Shanghai | 7821 | 1,741 | 270 | 516 | 2,527 |
| Simeiz | 1873 | 1,143 | 308 | 10 | 1,461 |
| Simosato | 7838 | 1,233 | 431 | 124 | 1,788 |
| Tahiti | 7124 | 538 | 189 | 0 | 727 |
| Tahiti | 7822 | 96 | 50 | 0 | 146 |
| Tanegashima | 7358 | 274 | 33 | 107 | 414 |
| Wettzell | 8834 | 3,938 | 917 | 902 | 5,757 |
| Yarragadee | 7090 | 15,330 | 2,918 | 5,142 | 23,390 |
| Zimmerwald | 7810 | 9,152 | 1,732 | 4,489 | 15,373 |
| Totals: | 35 stations | 87,705 | 19,042 | 26,066 | 132,813 |

they will 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 2011 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) which include the GPS, GLONASS, ETALON and GIOVE-A/B satellites (GALILEO test s/c), as well as a number of recently launched Beidou satellites, part of the Chinese Navigation Constellation COMPASS/Beidou.

Of all the active ILRS observatories (35), only a few laser-ranging systems are technically equipped to track retro-reflector arrays on the surface of the Moon or spacecraft orbiting around the Moon, where the Lunar Reconnaissance Orbiter (LRO) could be tracked successfully by several SLR sites with one-way ranging. The active dedicated Lunar Laser Ranging (LLR) sites in 2011 were the following observatories: the McDonald Observatory in Texas, USA (generating 20 NP), the Observatoire de la Côte d' Azur, France (60 NP), the APOLLO site in New Mexico, USA (366 NP) and the Matera Laser Ranging station in Italy (3 NP). The German Geodetic Observatory at Wettzell is still working on its system hoping to soon join the LLR tracking network. The measurement statistics of 2011 (Figure 3) clearly shows that most of the data have been collected at the APOLLO site, that however needed a long time span for re-processing and calibration correction, before the data could be released by end of 2012.

Figure 4 illustrates the statistics for the observed reflectors, where – thanks to APOLLO – a much better coverage of all reflectors could be achieved than in the previous years. Figure 5 shows the entire LLR data set 1970–2011, indicating the amount of data collected by each of the active LLR sites in each year. It is about 17,200 normal points in total.

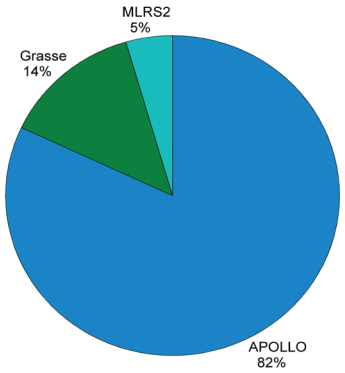


*Fig. 3: Observatory statistics in 2011.*

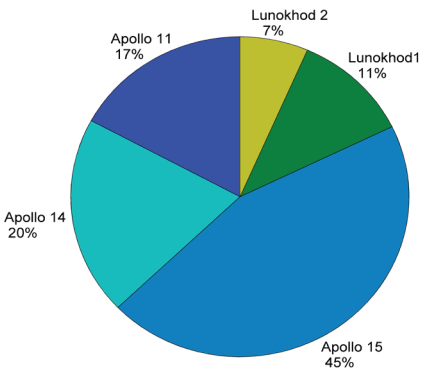


*Fig. 4: Reflector statistics in 2011.*

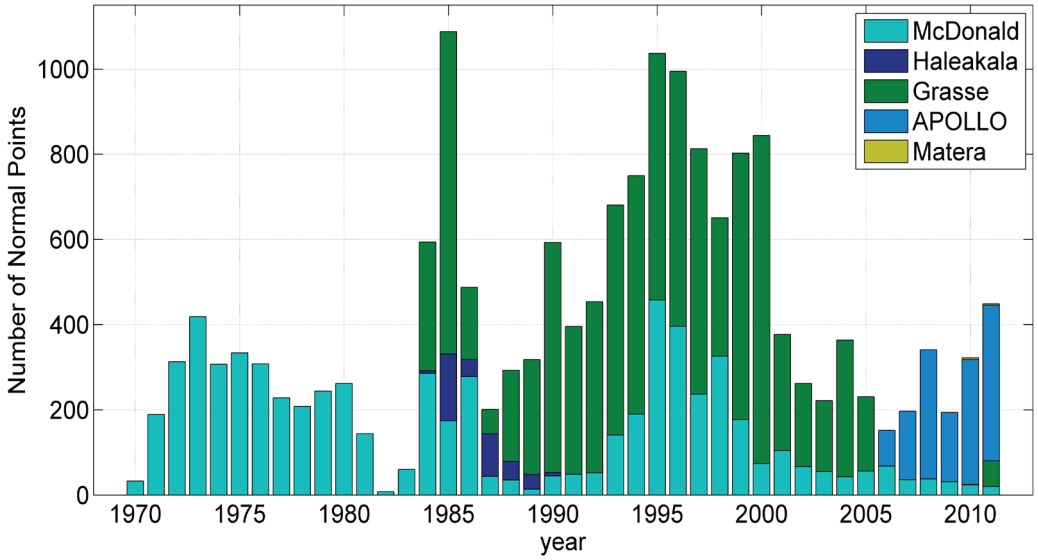


*Fig. 5: Data yield of the global LLR network of stations (up to 2011)*

The LLR results are considered among the most important science return of the Apollo era. To enable data analysis at the mm level of accuracy, all elements of the tracking process have to be modeled at appropriate (relativistic) approximation, i.e. the orbits of the major bodies of the solar system, the rotation and deformation of Earth and Moon, the signal propagation, but also the involved reference and time systems. This is mainly done 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.

By analysing the 42-year record of range data, LLR is 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. In 2011, the ISSI (International Space Science Institute) workshop series on “Theory and model for the new generation of the Lunar Laser Ranging data” has been continued with a spring meeting in Berne, Switzerland.

## Missions

In 2011, a total of ~38 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 twelve successful launches in 2011, of satellites carrying LRAs, listed in Table 2. The first one, COMPASS-I3 is a geostationary

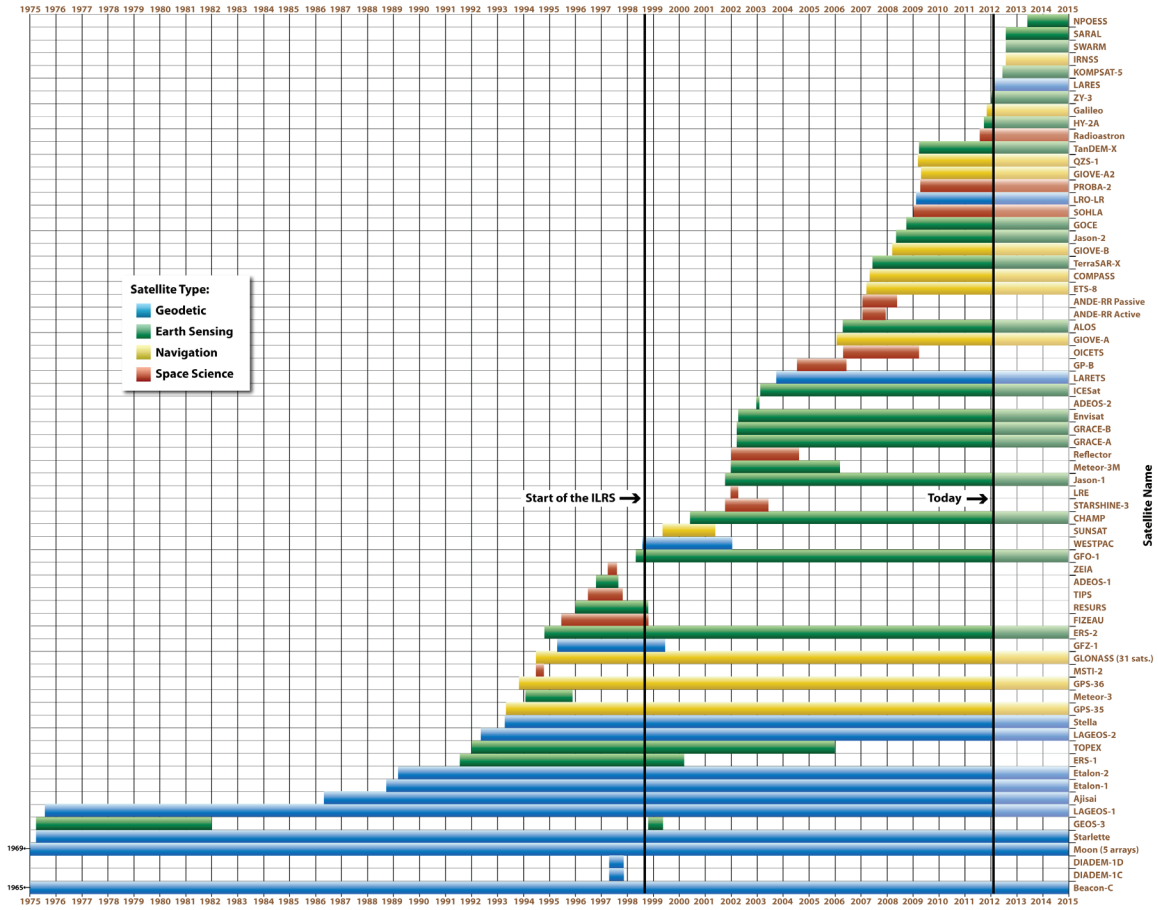


*Fig. 6: The currently tracked SLR missions (status early 2012).*

member of the COMPASS/Beidou Constellation, launched by China. RadioAstron is a mission of the Russian Academy of Sciences, carrying a large radio telescope into a challenging highly eccentric orbit, with a very low perigee and an apogee that is almost at the distance to the Moon. Tracking such a mission will be very challenging for the network and it is expected that only stations with lunar capability will be able to achieve that. The third mission is an oceanographic mission from China with a collaboration with the French space agency CNES. The next two satellites were launched together on 21 October 2011, they are the first 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. The following six satellites from Russia were put in four different launches. Six new GLONASS satellites, 125-130, completed the GLONASS Constellation, all of which carry improved LRAs. The group of GLONASS spacecraft tracked by ILRS was changed to substitute older spacecraft with the recently launched ones. Several ILRS

stations though have decided to increase the number of GLONASS satellites they track, in preparation of future requests for regular support of the complete constellation. The last entry of Table 2 corresponds to another geostationary member of the COMPASS/ Beidou Chinese navigation constellation that has accelerated the pace of populating their orbital slots in recent years.

*Table 2: ILRS Supported Missions Launched in 2011.*

| Satellite Name | Satellite ID | SIC Code | NORAD Number | NP Indicator | Bin Size (sec) | Altitude (Km) | Inclination (deg) | First Data Date |
|---|---|---|---|---|---|---|---|---|
| **COMPASS-I3** | 1101301 | 2003 | 37384 | 9 | 300 | 42,161 | 55.5 | 27-Apr-12 |
| **RadioAstron** | 1103701 | 5559 | 37755 | 6 | 60 | 500-350,000 | 51.4 | 22-Jan-12 |
| **HY-2A** | 1104301 | 2201 | 37781 | 5 | 30 | 971 | 99.35 | 2-Oct-11 |
| **Galileo-101** | 1106001 | 7101 | 37846 | 9 | 300 | 23,220 | 56 | 29-Nov-11 |
| **Galileo-102** | 1106002 | 7102 | 37847 | 9 | 300 | 23,220 | 56 | 29-Nov-11 |
| **GLONASS-125** | 1100901 | 9125 | 37372 | 9 | 300 | 19,140 | 65 | 9-Mar-11 |
| **GLONASS-126** | 1105501 | 9126 | 37829 | 9 | 300 | 19,140 | 65 | 15-Nov-11 |
| **GLONASS-127** | 1106403 | 9127 | 37869 | 9 | 300 | 19,140 | 65 | |
| **GLONASS-128** | 1106401 | 9128 | 37867 | 9 | 300 | 19,140 | 65 | |
| **GLONASS-129** | 1106402 | 9129 | 37868 | 9 | 300 | 19,140 | 65 | |
| **GLONASS-130** | 1107101 | 9130 | 37938 | 9 | 300 | 19,140 | 65 | 9-Mar-11 |
| **COMPASS-I5** | 1107301 | 2005 | 37948 | 9 | 300 | 42,161 | 55.5 | 6-Jul-12 |

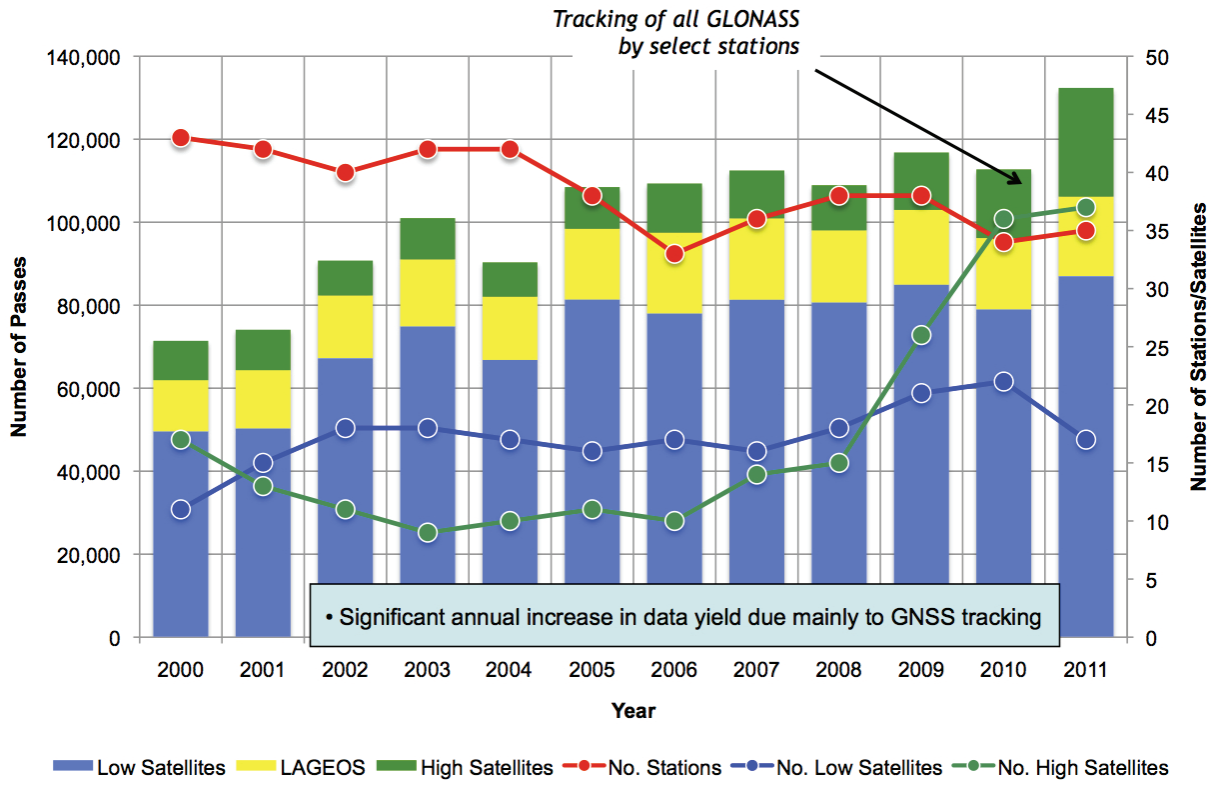


*Fig. 7: ILRS network data yield over the past decade (status late 2011).*

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 the remaining sites has increased tremendously to not only make up for that loss but rather nearly double the data yield by 2011 (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 more than doubling the number of HEO satellites tracked between 2008 and 2011 (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.

An area of concern for the entire community was the change of hands of the operations for the NASA network during early 2011. It turns out that this change came at some cost, primarily in the prompt data flow of the collected data. This however gave the ILRS an incentive to pursue a more systematic overhaul of the data flow and the archival of the data at its two Data Centers (DC), CDDIS at Goddard SFC, Greenbelt and EDC at DGFI, München. The harmonization of the two DCs caused severe delays in the implementation plan of the new data format (CRD), with the initial attempt at the end of 2010 beginning of 2011 to be aborted and a quick return to the old format. 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 will ensure 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 is under the aegis of the ILRS CB. The new website is expected to become operational for user comments sometime in 2012. At the Kötzting workshop all WGs were encouraged to work on the updating of their pages for inclusion in the new website.

### Analysis and science

The Analysis Working Group (AWG) concentrated on the integration of ITRF2008 within the system maintained by ILRS for all sites that hosted SLR tracking at any time in the past. The new TRF, titled "SLRF2008", was released in mid-2011, at the AWG meeting in Kötzting, Germany, for evaluation and validation by the Analysis Centers (AC). At the same time, the AWG decided to improve the feedback of the QC services provided by a number of ACs to the stations, by instituting a new type of official ILRS email, the "Rapid Service Mail". Use of this tool will ensure that anomalies observed

by any of the participating ACs will be communicated immediately to the entire group and the station(s) involved, in a brief message indicating the nature of the observed anomaly. It is expected that the stations will respond with an explanation, if available, or indicate that they will undertake measures to resolve the anomaly and report back to the AWG when the issue has been resolved.

In regards to modeling improvement of the SLR data, the task force on target signature released a new, time dependent version of their "center-of-mass" (CoM) offset correction for the LAGEOS and ETALON satellites. This new version is no longer in tabular form and comprises a data base that requires regular updates and a s/w package that users can use to interrogate the data base. Based on the mode in which a site operated at different times, the CoM offset can be quite different for each target, a difference that has a range in some cases as much as 10 mm. This is a huge variation given that the goal for the accuracy of the ITRF is at or below the 1 mm, with 0.1 mm/y stability! The newly proposed CoM model was put to test in an AWG Pilot Project (PP) to validate the model and determine the level of improvement in the final product. Results are expected in early 2012.

The ILRS AC members of the AWG begun to look into the ability of their s/w to model the application of atmospheric corrections in the calculated station positions and on the orbit. This is in anticipation of an ITRS request that was discussed during the second AWG meeting in Zürich, Switzerland and the IERS Unified Analysis Workshop in the same venue. The ITRS expressed an interest in testing the application of the atmospheric corrections at the level of the contributions of the Services rather at the observation level, so a PP that would compare the final results from these two approaches seemed a reasonable approach. The ITRS indicated that they would work together with the IERS/GGFC to formulate the proposed PP to the Technique Services.

## Meetings

The ILRS held three meetings in 2011. The 17th International Workshop on Laser Ranging was held in Bad Kötzting, Germany, May 16–20, 2011. This workshop was originally intended to take place in Concepcion, Chile, however, the disastrous earthquake of 2010 forced a change of plans. A Governing Board (GB) meeting was held during the workshop. In acknowledgement of the loss of two of our closest associates over the past year, Dr. W. Seemüller and Dr. Y. Fumin, the GB recognized their contribution to the success of the ILRS with two plaques that were sent to their families. A brief meeting of the AWG also followed the end of the workshop, where plans were made for the agenda of the subsequent AWG meeting that took place in Zürich, Switzerland, on September 15, 2011 in conjunction with the IERS Unified Ana-

lysis Workshop. A second GB meeting took place during the Fall AGU on Tuesday, December 6, 2011. During this meeting Carey Noll gave a demonstration of the new ILRS website at the stage it reached at that time. Everyone was encouraged to visit the site and submit commends and suggestions to the ILRS CB.

## Publications

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