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. The following summarizes the status and developments in 2007.

Network

The network of SLR/LLR stations, 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. At this moment, the single-shot precision of an average station is better than 10 mm (the best stations go well below that number). Also, the absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing better. The geometry of the SLR network has been a point of concern over the years. However, as of 2006 the layout of

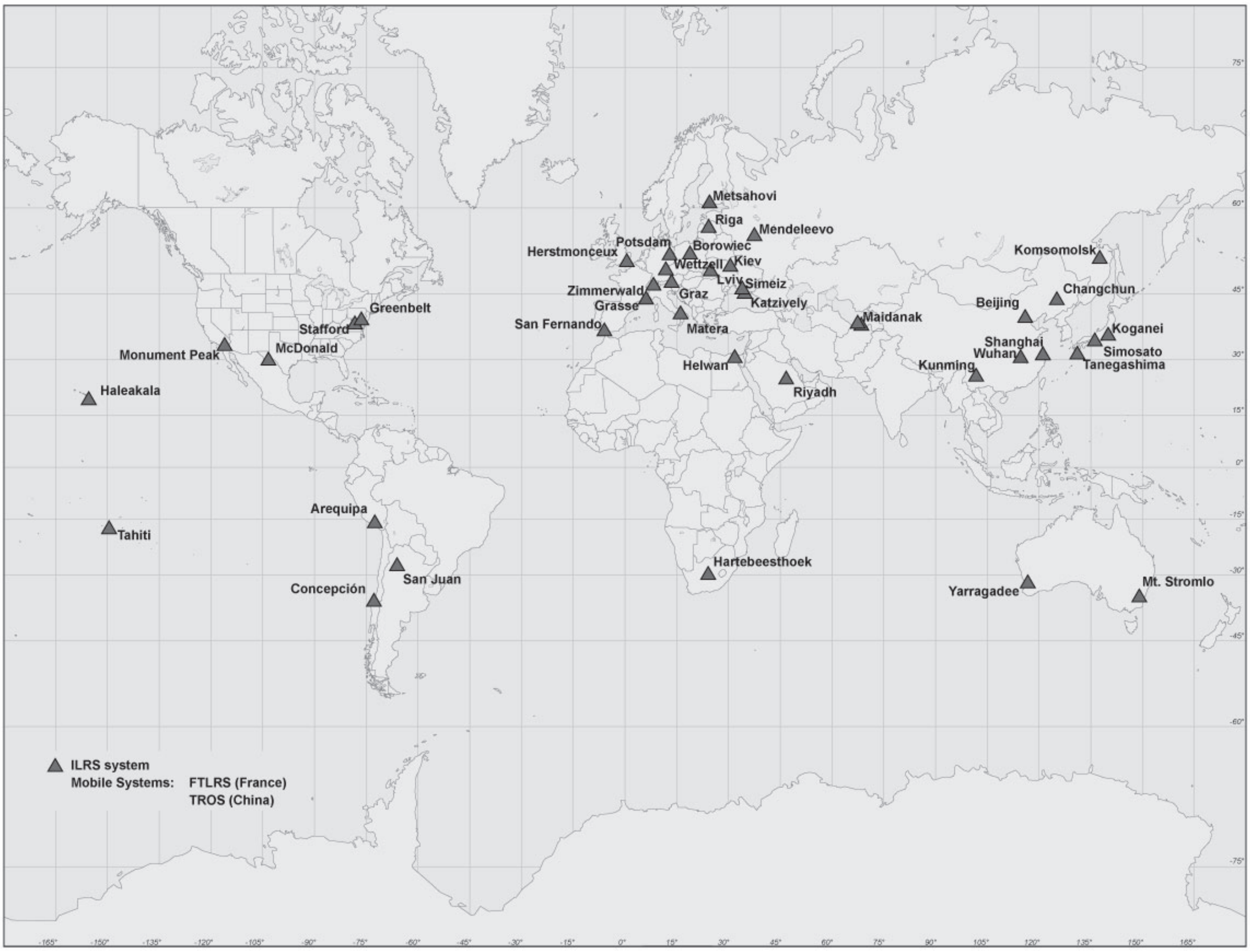

Fig. 1: The global network of SLR stations (status early 2008).

3.4.2 International Laser Ranging Service (ILRS)

Table 1: ILRS Network Tracking Statistics for 2007

Site Name	Station	Number of Passes			
		LEO	LAGEOS	HEO	Total
Arequipa	7403	2,074	218	0	2,292
Beijing	7249	1,713	339	152	2,204
Borowiec	7811	361	99	4	464
Burnie (FTLRS)	7370	167	4	0	171
Changchun	7237	4,373	774	542	5,689
Concepcion	7405	2,206	1,089	240	3,535
Graz	7839	4,813	825	529	6,167
Greenbelt	7105	1,831	321	69	2,221
Haleakala	7119	1,488	350	0	1,838
Hartebeesthoek	7501	1,535	304	35	1,874
Helwan	7831	54	0	0	54
Herstmonceux	7840	3,861	932	414	5,207
Katzively	1893	1,193	287	36	1,516
Kiev	1824	1	0	0	1
Koganei	7308	709	252	178	1,139
Kunming	7820	18	2	0	20
Lviv	1831	127	18	0	145
Maidanak	1864	509	216	141	866
Matera	7941	2,261	753	232	3,246
McDonald	7080	1,390	415	270	2,075
Monument Peak	7110	2,482	484	191	3,157
Mount Stromlo	7825	4,906	1,199	515	6,620
Potsdam	7841	1,725	304	0	2,029
Riga	1884	557	112	0	669
Riyadh	7832	3,783	975	659	5,417
San Fernando	7824	2,588	523	52	3,163
San Juan	7406	5,058	906	1,192	7,156
Shanghai	7821	968	53	3	1,024
Simeiz	1873	450	151	11	612
Simosato	7838	717	266	1	984
Stafford	7865	9	0	0	9
Tahiti	7124	19	0	0	19
Tanegashima	7358	240	70	69	379
Wettzell	8834	4,153	1,041	518	5,712
Yaragadee	7090	9,185	1,807	1,581	12,573
Zimmerwald	7810	5,973	1,219	727	7,919
Totals:	36 stations	73,497	16,308	8,361	98,166

the network has improved (cf. Figure 1), in part due to the reinstatement of some key-sites that were shut down in 2004. Although the network has been dominated traditionally by stations in the Northern Hemisphere, the Southern Hemisphere now contains a number of high-quality stations, that have come online recently or that have developed and proven themselves over the past few years. In French Polynesia, Tahiti is slowly coming back online; in South America, Arequipa, Peru has returned, whereas Concepcion and San Juan are in operational service with very significant contributions; in South Africa, Hartebeesthoek has proven itself to be a highly reliable, top-quality, productive station; and in Australia the Mt. Stromlo station is a role model for modern, autonomous operations. The contributions from stations in the Southern Hemisphere are of course complemented by the activities of Yarragadee, on the West coast of Australia. Yarragadee has been the number-one station in the network again. In 2007 it was joined by another high-yield system, the San Juan station in Argentina, to provide more uniform southern hemisphere tracking to all missions. Graz continued operations with the first 2 kHz system of the network, providing impressive "pictures" of the reflector arrays on geodetic satellites like the two LAGEOS. NASA's next generation SLR system (formerly known as SLR2000) is in the final stages of development, and it is expected to reach the production line by 2008. Several other stations acquired high repetition systems (e.g. Herstmonceux, UK, Zimmerwald, Switzerland) and these will soon be operational. Statistics of the data collected during the calendar year 2007 are summarized in Table 1, in terms of pass segments. 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).

From all of the ILRS observatories (>30), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (LLR) to the Moon (Figure 2). The McDonald Observatory in Texas, USA and Observatoire de la Côte d' Azur, France are the only currently operational LLR sites achieving a typical range precision of 18–25 mm. The latter has been actually undergoing renovation since late 2004, which leaves only one site currently operational over the past two years. A new site with lunar capability has been built at the Apache Point Observatory, New Mexico, USA, equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A new release of data from APOLLO was added to the first set of ~70 normal points, and a promise to soon make the data available in the newly adopted ILRS data format. The data look promising and comprise well over 50% of the 2007 yield.

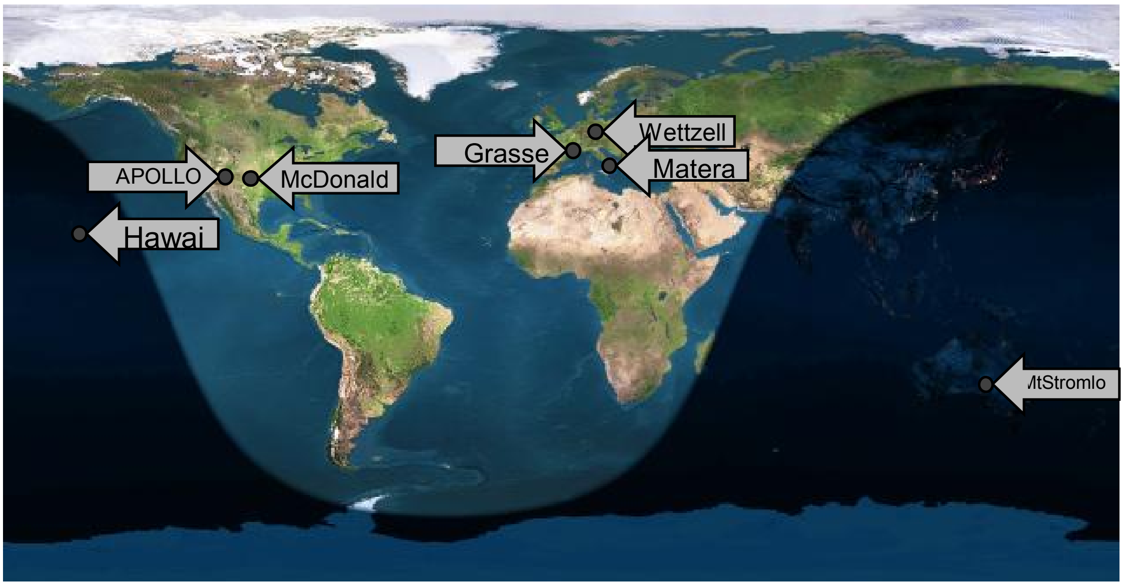

Fig. 2: The ILRS stations with lunar capability (status early 2008).

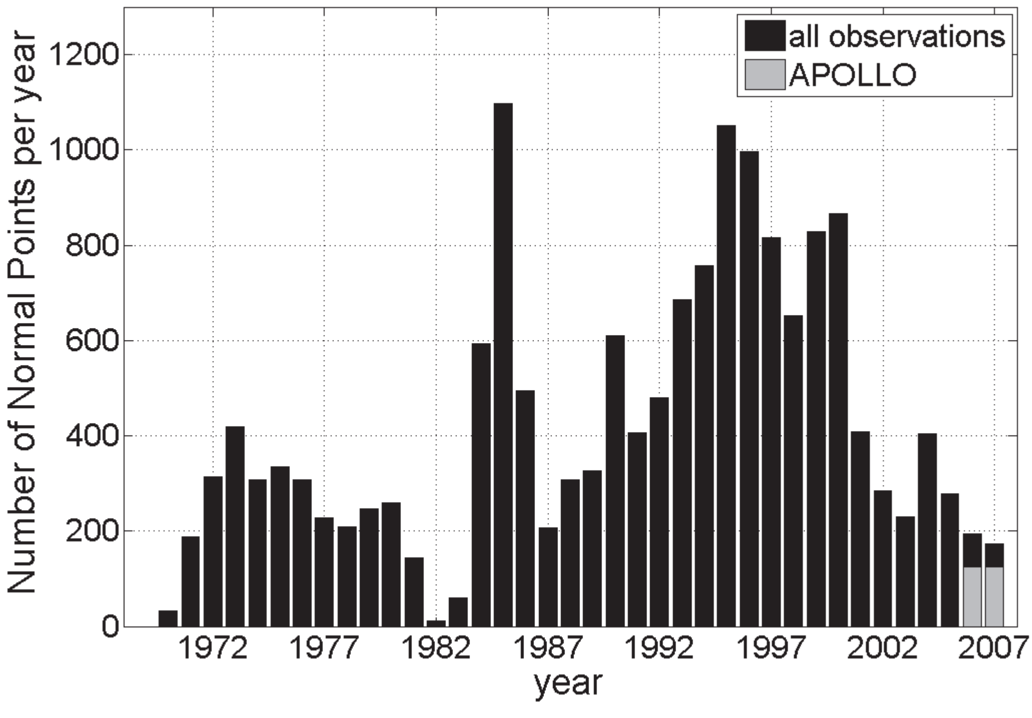

Fig. 3: The currently available LLR data set (status early 2008).

The Australian station at Mt. Stromlo is expected to join this group in the future, and there are plans for establishing a lunar capability at the South African site of Hartebeesthoek, once there is a new telescope installed. Today, the results from LLR are considered among the most important science return of the Apollo era. The lunar laser ranging experiment has continuously provided range data for over 38 years, generating about 16000 normal points (Figure 3).

The main scientific contributions of LLR are the determination of a host of parameters describing the lunar ephemeris, lunar physics, parameters associated with the Moon's interior, various reference frames and dynamics of the Earth-Moon system. LLR provides also tests of verification of metric theories of gravity and gravitational physics, such as the equivalence principle or temporal variation of the gravitational constant. Even with current technology, LLR is an extremely challenging measurement task. For more details about the ILRS network, see the ILRS Annual Report 2005–2006: <http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrsreport_2005.html>

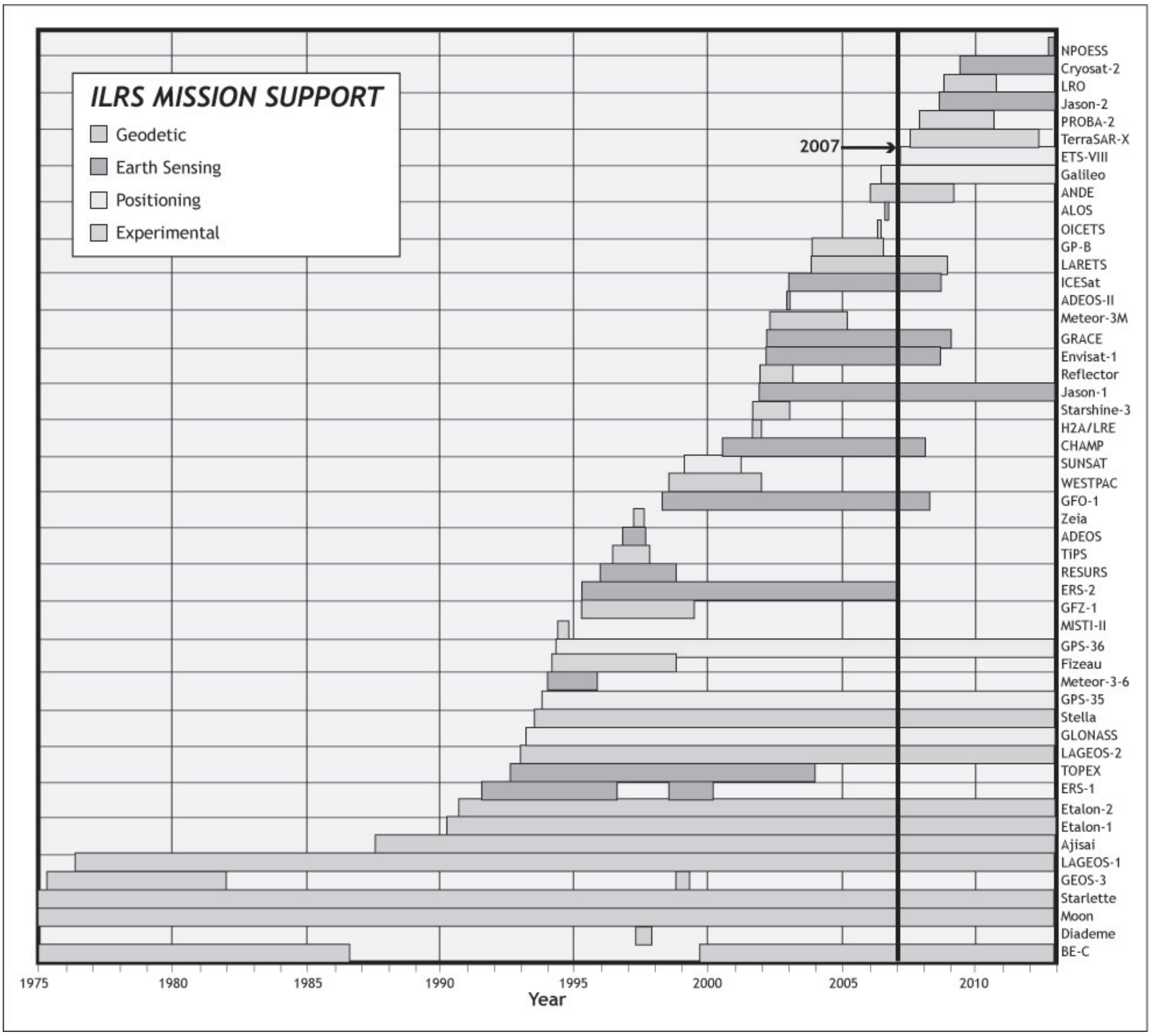

Fig. 4: The currently tracked SLR missions (status early 2008).

Missions

In 2007, a total of ~30 satellites (including the Moon) were being tracked by laser (Figure 4). During 2007 the ILRS continued its effort to develop a standardized design for retrorefrector arrays on future missions. In early 2007 the first data were collected from JAXA's geostationary ETS-8, an experimental communications, timing and positioning satellite. After a successful tracking campaign for almost a year to the date, Naval Research Lab's (NRL) ANDE-RRA (Atmospheric Neutral Density Experiment Risk Reduction) mission re-entered the atmosphere on Christmas day of 2007. The other half of the mission, the passive spacecraft ANDE-RRP is not expected to follow until spring of 2008 or later. On June 15, 2007, the TerraSAR-X mission was launched and has been tracked by SLR since then. It carries an X-band SAR antenna, occultation GPS, a Laser Retroreflector Array (LRA), as well as a Laser Communication Terminal (LCT). All spacecraft, including the newcomers, are regularly tracked, following a set of dynamically adjusted priorities depending on mission and science demands.

Over the past year, ILRS prepared for several demanding new missions to be launched in the near future. One of them, the Lunar Reconnaissance Orbiter (LRO), carries multiple laser technology components: a laser altimeter (LOLA) for topographic mapping and a laser transponder for one-way laser ranging (LR). It is anticipated that a significant number of the ILRS sites will participate in tracking LRO-LR when launched in late 2008.

Analysis and science

SLR provides an extremely valuable and unique tool to relate (the center-of-mass of) satellites to reference points on Earth's surface with unprecedented absolute accuracy: sub-centimeter at present, for about a dozen core sites. Recognizing the importance of this work, ILRS has organized and coordinated its analysis efforts through an Analysis Working Group (AWG). The AWG added one more Analysis Center this year, the GRGS/OCA group, to increase the number of official Analysis Centers (ACs) from seven to eight. There are additionally, two Combination Centers (CCs) and several Associate Analysis Centers (AACs). The eight ACs are located at different institutes around the world: ASI/Italy, BKG/Germany, DGFI/Germany, GA/Australia, GFZ/Germany, GRGS/France, JCET/USA and NSGF/UK. ASI (primary) and DGFI (backup) are also hosting the two CCs responsible with the combination of the contributions of the ACs into a single official ILRS product, following quality checks of the individual contributions and a thorough evaluation of the result. The majority of the AACs focus on restricted data sets, usually associated with a particular mission or world region. A number of them offer a quality control service for the entire network yield on a weekly basis (available via SLR e-mail) which is summarized on a quarterly basis at <http://ilrs.gsfc.nasa.gov/stations/site_info/

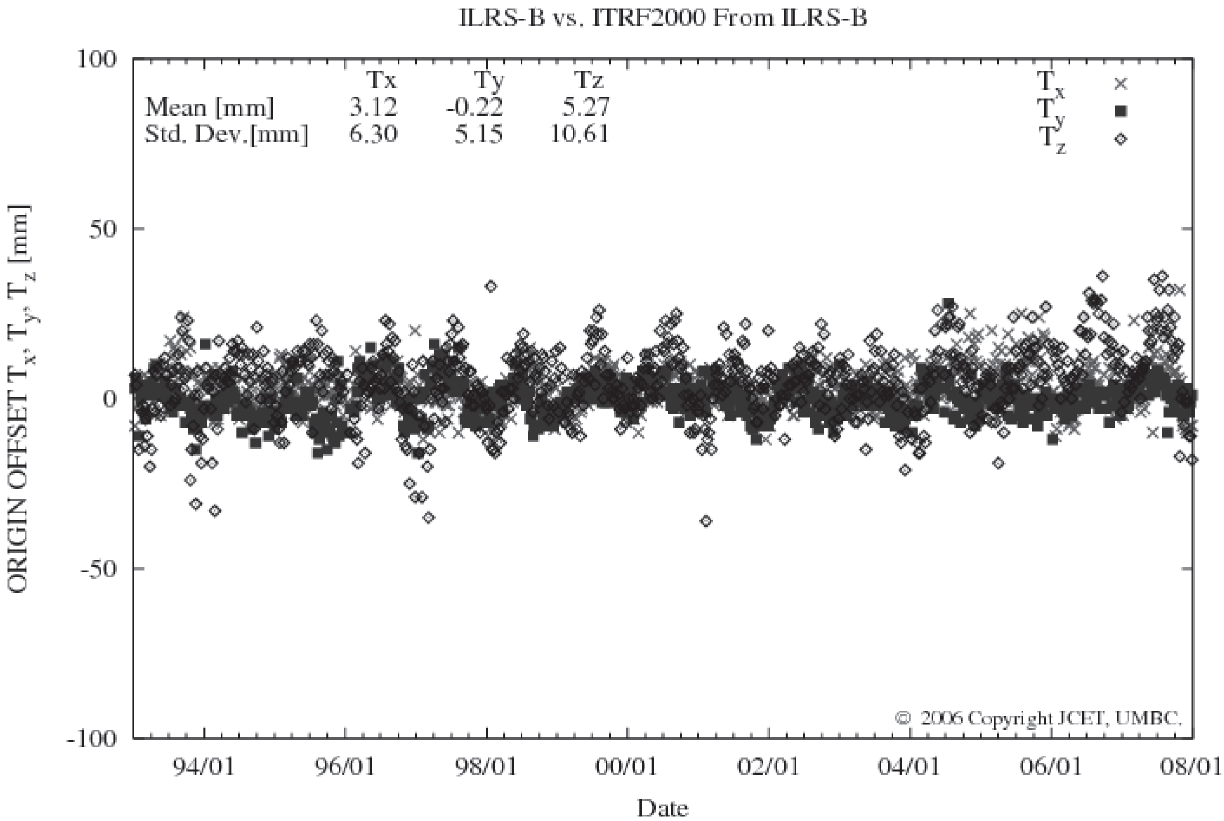

Fig. 5: Time-series of X, Y, and Z offsets of the ITRF2000 origin with respect to the weekly ILRS-B solutions' origin (proxy for "geocenter" variations) as observed by SLR (1993.0 – 2008.0).

global_report_cards/perf_2008q1_wLLR.html> (ILRS Quarterly Performance Reports).

During 2007, ILRS continued improving the models and procedures used in the analysis of the range data collected from the ILRS network. The improvements focused on the accurate determination of the target signature ("center of mass to effective reflection surface") and the accurate description of measurement biases for each system. A major effort in assessing current as well as historical data biases at all of the tracking sites resulted in the compilation of a data set used for the reanalysis of the data in 2007. Recognizing the importance of these issues, the ILRS established two task force groups dedicated to improving the target signature characterization and the communication between tracking stations and the analysts. Their effort will contribute to the timely and proper consideration of systematic biases. A first result is the characterization of the LAGEOS targets, the two satellites that by and large define the origin and scale of the ITRF series, with 1–2 mm accuracy for all of the ILRS network sites (Table 2). To put it in perspective, such accuracy limits the error on the scale definition of the ITRF at the level of 0.1–0.3 ppb.

Table 2: Site-dependent LAGEOS array corrections (CoM) and their accuracy

Site	Site	*Pulse-width*	*Detector*	*Regime*	*Processing*	*Calib.*	*LAGEOS*	*LAGEOS*
ID	*Name*	[ps]		*(single, few, multi)*	*level*	*sdt. error* [mm]	*std. error* [mm]	*CoM* [mm]
1873	Simeiz	350	PMT	No-CNTL	2.0 σ	60	70	248-244
1884	Riga	130	PMT	CNTL s→m	2.0 σ	10	15	252-248
7080	Mc Donald	200	MCP	CNTL s→m	3.0 σ	8.5	13	250-248
7090	Yaragadee	200	MCP	CNTL f→m	3.0 σ	4.5	10	250-248
7105	Greenbelt	200	MCP	CNTL f→m	3.0 σ	5	10	250-248
7110	Monument Pk.	200	MCP	CNTL f→m	3.0 σ	5	10	250-248
7124	Tahiti	200	MCP	CNTL f→m	3.0 σ	6	10	250-248
7237	Changchung	200	CSPAD	CNTL s→m	2.5 σ	10	15	250-245
7249	Beijing	200	CSPAD	No-CNTL, m	2.5 σ	8	15	255-247
7355	Urumqui	30	CSPAD	No-CNTL	2.5 σ	15	30	255-247
7405	Conception	200	CSPAD	CNTL s	2.5 σ	15	20	246-245
7501	Harteb.	200	PMT	CNTL f→m	3.0 σ	5	10	250-244
7806	Metsahovi	50	PMT	?	2.5 σ	15	17	254-248
7810	Zimmerwald	300	CSPAD	CNTL s→f	2.5 σ	20	23	246-244
7811	Borowiec	40	PMT	No-CNTL f	2.5 σ	16	23	256-250
7824	San Fernando	100	CSPAD	No-CNTL s→m	2.5 σ	30	25	252-246
7825	Stromlo	10	CSPAD	CNTL s→m	2.5 σ	4	10	257-247
7832	Riyadh	100	CSPAD	CNTL s→m	2.5 σ	10	15	252-246
7835	Grasse	50	CSPAD	CNTL s→m	2.5 σ	6	15	255-246
7836	Potsdam	35	PMT	CNTL s→m	2.5 σ	10	20	256-252
7838	Simosato	100	MCP	CNTL s→m	3.0 σ	20	40	252-248
7839	Graz	35	CSPAD	No-CNTL m	2.2 σ	3	9	255-250
7839	Graz kHz	10	CSPAD	No-CNTL s→f	2.2 σ	3	9	255-250?
7840	Herstmonceux	100	CSPAD	CNTL s	3.0 σ	6	15	246-244
7840	Hx kHz	10	CSPAD	CNTL s	-1.5,+2.5 σ	3	9	245
7841	Potsdam 3	50	PMT	CNTL s→f	2.5 σ	10	18	254-248
7941	Matera	40	MCP	No-CNTL m	3.0 σ	1	5	252-248
8834	Wettzell	80	MCP	No-CNTL f→m	2.5 σ	10	20	252-248

The SLR observations find their way into many cutting-edge science studies: reference frames (origin and scale), crustal deformation (relative motions), long wavelength static and time varying gravity field (direct inversion and/or calibration of solutions derived with other techniques), oceanography (sea-level change, tides), earth rotation (observation of relevant parameters), orbital mechanics (satellite motion), and fundamental physics (gravitational theory tests), to name a few. A number of these aspects will be highlighted below.

Some of the ILRS analysis products are of particular interest to IERS, either as input to Earth Orientation Parameter (EOPs) predictions or the development of the ITRF. In particular, SLR plays a uniquely important role in the definition of the origin of the ITRF and its scale. The laser technique provides unique information on the exact location of Earth's geocenter with respect to the tracking network (Figure 5) and along with VLBI, its absolute scale (Figure 6). Figures 5 and 6 display strong seasonal effects, but systematic effects are absent, except for a dip in Tz during 2006 (result of a known by now bias), and the trend in Tz (~ –1.8 mm/y), which is an error in ITRF2000 rather than in the current analysis. The root-mean-square (RMS) of the weekly X-Y-Z offsets and Δ-scale is 5.0 mm, 5.2 mm, 10.6 mm and 0.68 ppb, respectively, for the fifteen-year period. Similar statistics limited to the 2007 period are: 4 mm, 3 mm, 10 mm and 0.96 ppb.

Since 2003, the ILRS AWG maintains the above time-series of weekly solutions for station coordinates and EOPs: x-pole and y-pole and excess Length of Day (LOD). These solutions are based on SLR data taken on the satellites LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2. The organization (of generating these solutions) is such that the backup CC institute is able to take over the role of the primary institute at any time. The combinations were generated without interruptions during the past year on a weekly basis, and were available to IERS every Wednesday evening (UTC). From the "operational" point of view, the combination solutions are used for a variety of purposes: the IERS Combination Pilot Project, the IERS/NEOS Bulletin A, etc. From a less frequently updated product, they were vital in the development of the new ITRF every few years.

In order to fulfill the need of NEOS for as "fresh" as possible EOP information, the ILRS AWG decided in late 2007 to develop a new "daily" product, based on a 7-day arc sliding by one day each day. The results of this analysis are available to NEOS less than two days from the last observation in the analysis, and efforts are underway to further decrease the latency period. During 2007, three ACs (ASI, JCET and NSGF) contributed to the Pilot Project for this daily product. By the end of the year though two more ACs (BKG and GFZ) joined the group and it is expected that in 2008 more ACs will contribute. In 2008 NEOS will evaluate the new product and the ILRS will decide whether to evolve this PP into an official product (replacing the weekly one), or to discontinue it.

With the release of ITRF2005 in mid-2006, ILRS started preparing for the implementation of the "hybrid" version, the one scaled back to agree with SLR-implied scale (ITRF2005 SLR re-scaled). At the same time it was evident that a new reanalysis of the entire SLR data set would be necessary for the upcoming ITRFxx, so the AWG proceeded in the preparation of an intermediate TRF based primarily on ITRF2000 and ITRF2005SLR, to allow for a single consistent set of a priori positions and velocities in a single frame. This resulted in the SLRF2005 frame that was released in the fall of 2007 and starting Nov. 1, 2007, it has been adopted as the official ILRS frame to report the weekly products in. Since this frame encompasses all of the SLR sites that ever tracked in a single, accurate frame (ITRF2005SLR), ILRS posted this on the official website as the recommended frame for any SLR data analysis, including Precision Orbit Determination.

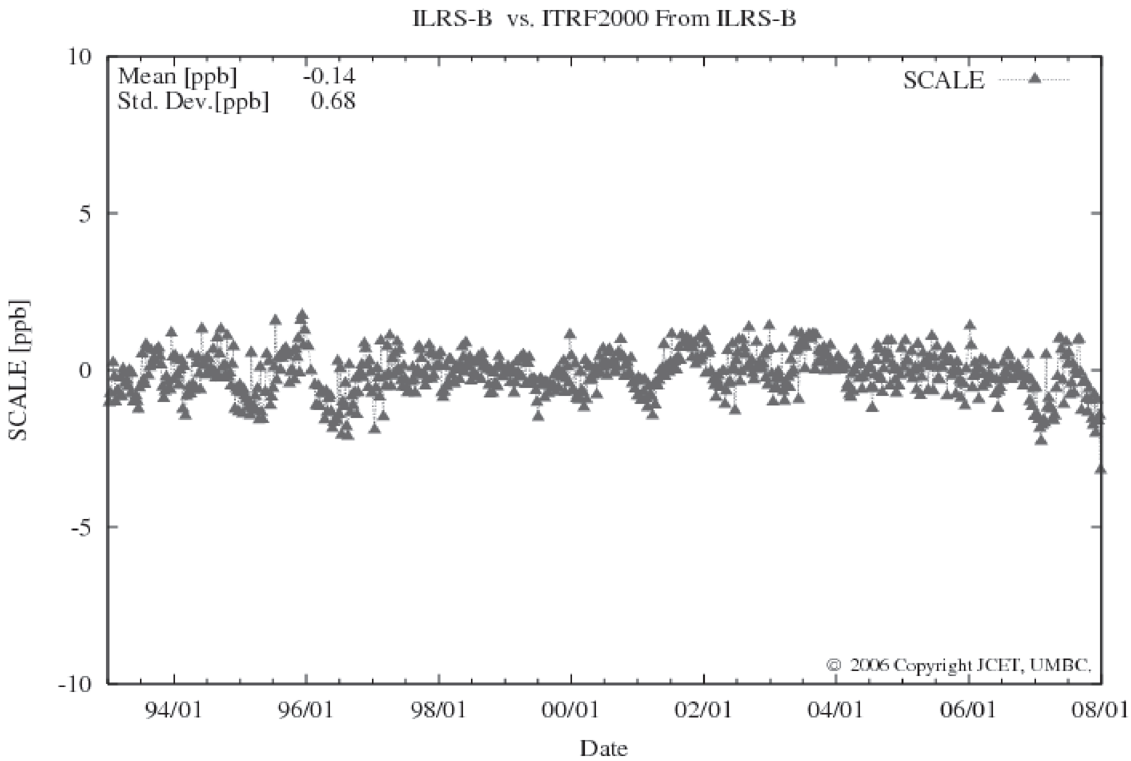

Fig. 6: Time-series of weekly solutions' difference in global scale from ITRF2000 as observed by SLR (1993.0 – 2008.0).

It is planned that in 2008, a new, completely and consistently reanalyzed series of official ILRS products will be available to IERS and the broader community, spanning at least the period September 1983 to end of 2007 (and beyond). However, recognizing the reduced number of satellites available (only LAGEOS) in the period 1983 to 1993, the geometry of the network, the quality of the observations and other aspects, the historical data reanalysis cannot be expected to result in data products that are of similar quality and resolution as what is being obtained from contemporary SLR observations. Nevertheless, this analysis effort will extend the timespan to nearly thirty years, and will provide valuable information on some of the most crucial elements of (understanding and describing) System Earth.

The weekly products are evaluated during their combination, and the results are archived and graphed each week by the JCET AC. Reports for the past weeks as well as the results for the current week for each of the contributing ACs and CCs are available to all via the World Wide Web at <http://geodesy.jcet.umbc.edu/ILRS_QCQA/>. When the reanalysis is completed, a new release with the evaluation of the new products will replace the current version of these reports (currently a mixed bag of ITRF2000 and SLRF2005 referenced results).

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