INTERNATIONAL LASER RANGING SERVICE

2009–2010

R E P O R T

June 2012

Edited by C. Noll and M. Pearlman

Goddard Space Flight Center
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PREFACE

This 2009-2010 volume is the sixth published report for the International Laser Ranging Service (ILRS). This edition once again concentrates on achievements and work in progress rather than ILRS organizational elements. This latest edition of the ILRS report is structured as follows:

- Section 1 – Science Report examines the ILRS role in the ITRF, its synergy with the other geodetic techniques, and some interesting applications for both SLR and LLR.
- Section 2 – About the ILRS, reviews the service, its mission, structure, and role in space geodesy.
- Section 3 – ILRS Network, provides the current status and recent performance statistics of the international stations supporting the ILRS and offers a perspective on site surveys and system co-locations. An update on field engineering activities is also provided.
- Section 4 – Supported Missions, gives information about many of the current and future missions supported by the ILRS.
- Section 5 – Operations, discusses data center developments, satellite predictions, ILRS tracking priorities, recent developments in the area of dynamic priorities, and the flow of on-site normal points and full-rate data.
- Section 6 – Analysis Activities, reviews the recent developments in the ILRS Analysis Working Group including the three pilot projects begun in 2002, Computation of Station Positions and EOPs, Orbits, and Software Benchmarking.
- Section 7 – Reporting and Outreach, reviews website development, station performance reporting, and ILRS-related publications.
- Section 8 – Working Group Reports, details the status of the ILRS Working Groups, recent accomplishments, and future plans.
- Section 9 – Retroreflector Array Developments, includes ILRS standards in the area, performance modeling activities, and studies on future arrays.
- Section 10 – Emerging Technologies, includes information about high repetition rate lasers and systems, detectors, timers and frequency standards, multi-wavelength ranging, and other hardware that will help advance the accuracy and automation of laser ranging systems. Also included are new applications for the SLR technique.
- Section 11 – AC, AAC and Lunar AAC Reports, presents individual summaries from ILRS analysis, associate analysis, and lunar associate analysis centers.
- Section 12 – Station Reports, includes information received from the stations contributing to the ILRS network.
- Section 13 – Meeting Summaries, reviews ILRS-related meetings in 2009-2010 and reports issued by the service over that period.
- Section 14 – Bibliography, lists some of the papers and presentations about SLR and LLR science and technology made during 2009-2010.
- Appendix – ILRS Information, lists organizations participating in the ILRS and defines acronyms used in this report.

This report is also available through the ILRS website at URL
http://ilrs.gsfc.nasa.gov/about/reports/annualrpts/ilrsreport_2009.html

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A complete list of ILRS associates can be found on the ILRS Web site at
http://ilrs.gsfc.nasa.gov/about/membership/associates.html

ACKNOWLEDGEMENT

The editors would like to acknowledge the essential contributions from our ILRS colleagues to this 2009-2010 edition of the ILRS report.

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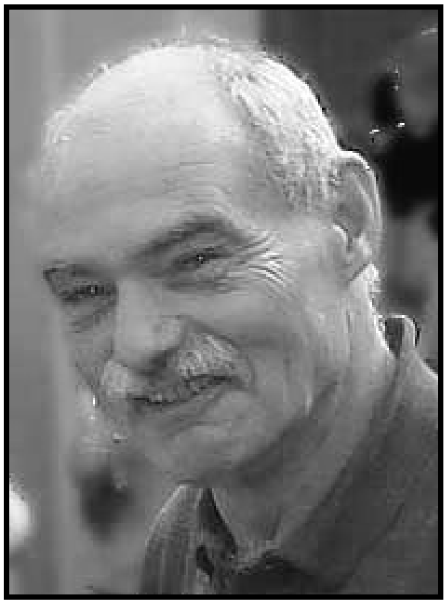


Wolfgang Seemueller (946-2010)
DGFI Munich

WOLFGANG SEEMUELLER (1946-2010)

The ILRS community sadly suffered another loss in 2010. Wolfgang Seemueller, head of the EUROLAS Data Center at the "Deutsches Geodätisches Forschungsinstitut", DGFI, in Munich, Germany, died from cancer on November 11, 2010 at the age of 64.

Wolfgang studied Physics and Surveying Engineering at the Technical University in Munich from 1968 to 1977. In the following years, until 1981, he was a research assistant at the Technical University of Munich and joined DGFI in March 1981. From the beginning, his interest was focused on the problems of data management and archiving. He reorganized the data stored at DGFI, particularly the SLR data, into new structures.

Shortly after the European Laser Stations (EUROLAS) Consortium was founded, Wolfgang joined the group to establish the new EUROLAS Data Center (EDC) since there was no common data management available at that time. Due to the reduced computer resources at DGFI he devoted a great portion of his time to create and run the operational data center for EUROLAS. Wolfgang dedicated all his heart and energy to this important task. His ideas to support the SLR community with rapid information on predictions, including time biases, and his effort to reduce the turn around time of data delivery are still in our memories. Since 1995 he also served as secretary of the EUROLAS Consortium and actively supported this group by setting up various infrastructure components including e-mail exploders.

Wolfgang was a member of the SLR/CSTG Steering Committee, which was responsible for the establishment of the International Laser Ranging Service in 1998. Since the start of the ILRS, Wolfgang served on the Governing Board as its Data Center Representative. The EDC became part of the ILRS as a Global Data Center, parallel to CDDIS. His friendly rapport with the station operators and his willingness to solve any problem concerning predictions or data earned him the respect of the ILRS community.

Because of his position at the EDC, Wolfgang was also a member of the Data Formats and Procedure Working Group of the ILRS, which he chaired from 2002 until his passing in 2010. The new CPF and CRD formats were formulated and applied under the direction of this working group during his tenure.

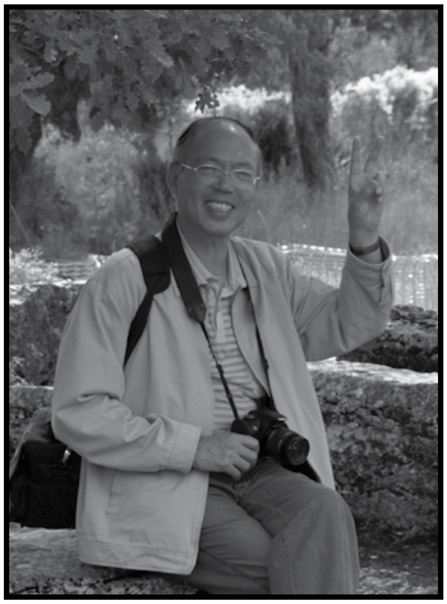
Parallel to all his SLR activities, Wolfgang was involved in the GPS analysis of data from the stations in the SIRGAS (Geocentric Reference System of the Americas) network since June 1996. He was responsible for the SIRGAS RNAAC, the Regional Network Analysis Center for South America, and has combined the weekly solutions for this network as well as various combined SIRGAS coordinate solutions that are basis for national networks of those countries.

Wolfgang Seemueller will be remembered as a competent member of the ILRS, a dear colleague, and a good friend.

The ILRS wishes to dedicate this issue of the ILRS annual report series to the memory of Wolfgang Seemueller in the grateful recognition of his contribution to the ILRS and the entire SLR community. He will be missed.

Horst Mueller, DGFI, Munich, Germany
Mike Pearlman, Harvard-Smithsonian Center for Astrophysics, USA

DEDICATION



Yang FuMin (1942-2011)
Shanghai Obs., China

YANG FUMIN (1942-2011)

I am honored to write this dedication on behalf of my longtime SLR colleague and friend, Professor Yang FuMin. I wish to express my gratitude to Yang's son, Jun, and to his SLR colleague in Shanghai, Zhang Zhongping, for filling in the gaps in my knowledge of Yang's life history and accomplishments.

Yang FuMin was born on 24 December 1942 in Chongqing City, China. His family later moved to the city of Guang-zhou in Guang-dong Province, where he spent his childhood years. In 1961, he began his studies at the Shanghai Astronomical Observatory and, in 1964, was the one of the Observatory's first Master's Degree candidates. Following his graduation in 1968, he carried out research on astrometry and celestial mechanics for the Chinese Academy of Sciences.

By 1971, Yang had become interested in SLR technology, and, from 1978 to 1985, he led the development of multiple generations of China's SLR stations and software for precision orbit determination. From 1985 to 1988, Yang was a Visiting Scholar in the Quantum Electronics Group at the University of Maryland College Park in the USA. The group was led by my Ph.D. thesis advisor, Professor Carroll Alley, who first introduced me to Yang. Shortly after I was appointed Deputy Manager of NASA's Crustal Dynamics Project in 1989, my wife and I were invited by Yang and Madame Ye to tour the Chinese SLR sites. It was during our first visit to China in 1991 that Yang invited us to their apartment in Shanghai, where we were introduced to his lovely and gracious wife, Hu Miaoying, and to their affable teenage son, Jun. Over the years, Yang and I continued to correspond. When Yang traveled to the USA, I often met with him in Washington DC and Adele and I were happy to have the opportunity to host him in our home.

As a researcher, Yang published 70 papers and reports and, in 1992, was elected one of China's National Outstanding Experts and went on to win three national science prizes, six Shanghai prizes, among others. In 1995, he was elected Deputy Chairman of the Chinese Astronomical Society. He also served as a professor, doctoral thesis advisor, Deputy Director of the Shanghai Observatory, and Chair of the Shanghai Astronomical Society. Within the ILRS community, Yang served as a member of the ILRS Governing Board, Chairman of the WPLTN Executive Committee, and Chairman of 10th ILRS Workshop Scientific Committee. Perhaps most importantly, after nearly 40 years of Yang's leadership, the Chinese SLR stations now rank among the top performing stations in the world.

Within the past decade, Yang conducted research on uncooperative space targets and Laser Time Transfer (LTT). Using a 40W laser, laser returns from an uncooperative space target were first obtained by the Shanghai station on July 7, 2008. In 2007, an LTT experiment, between a ground-based hydrogen maser and space-qualified rubidium clocks on the Chinese Experimental Compass M1 Navigation satellite, successfully monitored the performance of Chinese-made atomic clocks onboard. Furthermore, in 2008, the high cross-section laser retro-reflector arrays (LRAs), also designed by Yang, were successfully tracked by the ILRS network.

Yang retired from the Observatory in November 2008, but continued to work with his SLR colleagues in China until his untimely death from heart disease on February 9, 2011. Yang FuMin will be remembered as a kind-hearted, hard-working, and soft-spoken consummate gentleman. He will long be missed by his family and his colleagues in the ILRS community. Rest in peace, my friend.

Dr. John Degnan, Chief Scientist, Sigma Space Corporation

INTRODUCTION

THE IMPORTANCE OF SATELLITE LASER RANGING TO THE INTERNATIONAL TERRESTRIAL REFERENCE FRAME

Since its inception, space geodesy has brought a new era of global measurements allowing us to quantify changes of the Earth system in space and time: Earth rotation, its gravity field and their irregularities, global and regional sea level variation, tectonic motion and deformation, post-glacial rebound, geocenter motion, large scale deformation due to Earthquakes, local subsidence and other ruptures and crustal dislocations. All these geosciences applications, together with precise satellite orbit determination and other practical applications in geo-information, fundamentally depend on the availability of a truly global reference system that only space geodesy is able realize.

Geodetic observations collected at stations with measurement systems of Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS) and Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS), are the main ingredients of the construction of the International Terrestrial Reference Frame (ITRF), recommended as a standard by the International Unions for Earth science applications. As the ITRF becomes widely used and needed, the science requirement becomes more demanding and stringent, aiming for a precise reference frame at the level of 1 mm and 0.1 mm/year stability over decades.

SLR is playing a major, yet a critical role in the ITRF definition, currently being the most precise satellite technique for realizing the physical center of mass of the whole Earth system, chosen as a natural origin for the ITRF. SLR, together with VLBI, contributes to the ITRF scale definition. These two physical parameters (origin and scale) are of fundamental importance in Earth science applications, such as the currently under-debate societal issue of how much sea level is rising due to ice sheet melting and its ramification with global warming and climate change.

An ITRF origin drift of 2 mm/year would cause an error of 0.3 mm/year in the estimated rate of global sea level rise as determined by satellite altimetry. This bias would be more amplified in the estimated regional sea level rise, and in particular at high latitudes, reaching up to 1.8 mm/year. An ITRF origin drift in the Z direction of 2 mm/year generates a change in the north velocity, as a function the cosine of the latitude (2 mm/year at the equator and zero at the pole), and a vertical velocity change as a function of the sine of the latitude (zero at the equator and +2 and -2 mm/year at the North and South poles, respectively). A scale drift of 0.1 ppb/year (10-9, or 6.3 mm/year at the equator) translates to a drift of 0.6 mm/year in the estimated rate of sea level rise, as determined by tide gauge records, and causes vertical velocity changes by the same amount. Such origin and scale drifts would be critical, not only for sea level rise investigation, but also for plate motion and Post Glacial Rebound estimates by space geodesy.

Our current assessment of the accuracy of the ITRF origin and scale (ITRF2008 results) is roughly 1 cm over the time span of the available observations. As we aim for a stable ITRF over decades, we still need to improve the reference frame by at least a factor of ten in order to meet the science requirement. As long as we need to improve the reference frame, we still need to continue tracking LAGEOS and other satellites, but we also need to upgrade the aging SLR and other technique ground instruments to new generation of observing systems.

Zuheir Altamimi
Institut Géographique National
President of IAG Commission 1 (2007-2011)
May 21, 2012

Chairman's Remarks

The period of time covered by this bi-annual ILRS Report is, in my opinion, a very exciting time to be involved in Satellite Laser Ranging and in Space Geodesy in general. The inclusion of the ILRS as a Service within the International Association of Geodesy's Global Geodetic Observing System (GGOS) brings us into firm scientific context alongside our sister Services, the IGS, IVS and IDS. With GGOS itself a sub-task within the Inter-governmental GEO (Group for Earth Observation), our work to support a wide range of geophysical investigations, many of them of direct interest to policy makers and the general public, has never had such a high profile.

Of course, along with that impact on such areas of interest as climate change, sea-level rise, etc., comes the responsibility to ensure that our underpinning observations and the products derived from them are of the highest possible quality. The GGOS goal is to realize a global reference frame of accuracy 1mm and stability 0.1mm y-1 [Gross, et al, in: The Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020, edited by H.-P. Plag and M. Pearlman, Springer, Berlin, 2009], so we cannot afford to take our eyes off the ball in terms of continuing efforts to drive down systematic errors in our calibration and satellite range measurements and to improve the models used in our analyses. My predecessor, the late and sadly missed Prof. Werner Gurtner, wrote in his introduction to the 2007-2008 ILRS Report that a disappointment during that period was the discovery of small but significant range errors detected at a number of stations that used a particular time-of-flight counter. Hopefully, with the evident migration at several stations to high-quality event timers to support high repetition ranging, such discoveries will become rare and of dwindling magnitude. But many stations continue to be in need of upgrade and the hope is that their responsible agencies will consider this as a matter of urgency. In some respects of course, such discoveries of range errors do show that a healthy dialogue is in place between the ILRS observing teams, technologists, and analysts such that there can be no hiding place for bad data.

The ILRS continues to increase its impact on a wide variety of new missions. Many hours of one-way tracking have been recorded by the mission from a subset of the ILRS network to NASA's Lunar Reconnaissance Orbiter (LRO), in orbit a few tens of km above the lunar surface. Very impressive and crucial to tracking success is the web-interface that gives observers near real-time feedback on whether or not their photons are being detected on board. The CNES/OCA Time Transfer by Laser Link (T2L2) project on board Jason-2 continues successfully with several tracking campaigns organized by the mission, including one involving the Observatoire de Paris and the French transportable laser ranging system. It was very exciting to see that, following very high resolution imaging from LRO that re-discovered on the surface of the Moon the long-lost Russian Lunokod-2 rover, the Apache Point Observatory LLR Operation obtained a strong series of returns from the vehicle. It is to be hoped that such high-profile work will re-invigorate this very valuable lunar component of the ILRS.
Future to-be supported missions include the Russian RadioAstron astrophysical VLBI satellite that will challenge even the Lunar-capable stations, the proposed highly-novel JPL mission, Geodetic Reference Antenna in Space (GRASP), that is set to revolutionize from orbit the accuracy with which stations' inter-technique ground ties can be determined and monitored for all the key geodetic systems, and the new ASI/ESA geodetic and relativity sphere LARES. More speculatively, but approved by the ILRS for transponder support, is the far-future international GETEMME mission to Mars and its two moons.

A very successful Technical Workshop on SLR Tracking of GNSS Constellations was held in Metsovo, Greece in September 2010. The meeting discussed many aspects of both the scientific advantages and practical issues surrounding the requirement for the ILRS network to track increasing numbers of GNSS satellites, including those from the GLONASS, COMPASS and emerging Galileo constellations, as well as plans for future GPS satellites. A follow-on Technical Workshop is to be held in Italy in late 2012. Events surrounding the planned 17th International Workshop on Laser Ranging in Concepcion Chile, served as a stark reminder of the forces that our geodetic observations seek to understand. The magnitude 8.8 earthquake that struck and caused extensive damage to the region in March 2010 prevented the University of Concepcion from hosting the workshop in late 2010. Our colleagues at the Wettzell station are to be thanked for offering at short notice to host the re-arranged workshop in Koetzting in May 2011.

From the many sections of this report it is clear that the ILRS continues as a vibrant, essential service with many new technological and analytical advances and new scientific applications. New missions that need precise tracking to underpin their scientific goals are always welcome to apply for support, and it is very encouraging that the network stations, operations, and data centers continue to cope with the increasing workload without any apparent negative impact on the more 'traditional' geodetic targets LAGEOS and Etalon that ensure that the ILRS continues to play an important role in fundamental geodesy.

Graham Appleby
ILRS Governing Board Chairman
NERC Space Geodesy Facility
United Kingdom