INTERNATIONAL LASER RANGING SERVICE

2007–2008

R E P O R T

November 2009

Edited by C. Noll and M. Pearlman

Goddard Space Flight Center
Greenbelt, MD 20771

NASA/TP-2010-215848

Available From:

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

PREFACE

This 2007-2008 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. The 2007-2008 ILRS report is structured as follows

- Section 1 – ILRS Organization, reviews the service and its role in space geodesy.
- Section 2 – ILRS Tracking 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 3 – ILRS Missions and Campaigns, gives information about many of the current and future missions supported by the ILRS.
- Section 4 – Infrastructure, details recent activities tackled by the ILRS Central Bureau, including Web site improvements and data center developments.
- Section 5 – Tracking Procedures and Data Flow, discusses 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 – 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 7 – Analysis Activities, reviews the recent developments in the ILRS Analysis Working Group and plans for future products.
- Section 8 – Modeling, discusses recent advancements in refraction modeling and satellite center of mass corrections.
- Section 9 – 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 10 – Meetings and Reports, reviews ILRS-related meetings in 2007-2008 and reports issued by the service over that period.
- Section 11 – Bibliography, lists some of the papers and presentations about SLR and LLR science and technology made during 2007-2008.
- Section 12 – AC, AAC and Lunar AAC Reports, presents individual summaries from ILRS analysis, associate analysis, and lunar associate analysis centers.
- Section 13 – Station Reports, includes information received from the stations contributing to the ILRS network.
- Appendix – ILRS Information, lists organizations participating in the ILRS and defines acronyms used in this report.

This report is also available through the ILRS Web site at URL *http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrsreport_2007.html.*

For further information, contact the ILRS Central Bureau:

Carey Noll
Secretary, ILRS Central Bureau
NASA Goddard Space Flight Center
Code 690.1
Greenbelt, MD 20771
USA
Carey.Noll@nasa.gov

Michael Pearlman
Director, ILRS Central Bureau
Harvard/Smithsonian Center for Astrophysics
60 Garden Street
Cambridge, MA 02138
USA
mpearlman@cfa.harvard.edu

ILRS Web site: *http://ilrs.gsfc.nasa.gov*

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

ACKNOWLEDGEMENT

The editors would like to acknowledge the essential contributions from our ILRS colleagues to this 2007-2008 edition of the ILRS report.

Table Of Contents

Dedication

Professor Dr. Werner Gurtner, 1949-2009
Astronomical Institute of Bern, Switzerland

It is with deep sadness that the ILRS community learned of the death of Prof. Dr. Werner Gurtner from cancer on October 24, 2009 shortly after his sixtieth birthday.

Werner Gurtner completed his studies in Surveying Engineering in 1973 at the Institute of Geodesy and Photogrammetry of the ETH in Zurich, Switzerland. From 1974 to 1979 he was a research assistant and Ph.D. candidate with Prof. Max Schuerer, who was a lecturer at the ETH in addition to his position as director of the AIUB. Werner's Ph.D. thesis, partly written in Bern, resulted in a well-known reference, the "Geoid of Switzerland" using astrometric observations.

Werner started his official employment with the AIUB in January 1980. As early as 1978, at the ETH, he started work on the new Zimmerwald observatory, dedicated to Satellite Laser Ranging (SLR) and in 1987 he became the director of the Zimmerwald Fundamental Observatory. Between 1992 and 1996 he led the AIUB team, which planned and realized the new SLR and astrometry telescope in Zimmerwald. In collaboration with the Canton of Bern, the University of Bern, the Swiss National Science Foundation, and the Swiss Federal Office of Topography, the one-meter combined SLR and astrometry telescope was deployed at Zimmerwald and became one of the essential pillars of the International Laser Ranging Service (ILRS). With this same energy, Werner organized the upgrade of the observatory during 2005-2008. This upgrade included a new laser capable of performing dual-color measurements as well as supporting future one-way ranging and transponder experiments. The Zimmerwald Observatory as established by Werner is recognized now as one of the foremost stations in the global space geodesy community from the scientific, technical, and administrative points of view.

During the 1980's Werner also worked on the team that successfully developed what would eventually be known as the Bernese GPS Software package. In the 1990's, he was one of the key persons in the development of the International GNSS Service (IGS). His contributions related to IGS data transfer and information dissemination were of great importance and at least in part responsible for the worldwide acceptance of the IGS. The Receiver INdependent EXchange (RINEX) format, which he initiated and coined to a great extent, became a standard as the platform for exchanging GNSS data in both science and engineering applications. Werner continued to work on enhancements to RINEX until very recently. The global acceptance of RINEX in both the science and receiver technology communities is a tribute to Werner's foresight.

Werner helped the International Association of Geodesy (IAG) to develop essential structural elements related to space geodesy. He was a member of the very active EUREF Technical Working Group since 1992; he chaired this group from 1999 to 2003. He was not only a key person on the development of the IGS, but also, even to a much greater extent, for the development of the ILRS. Werner Gurtner was a member of the ILRS Governing Board since its inception in 1998 and served as Chair of the Board from 2002 to 2009. Before that time he chaired EUROLAS, an association of European SLR observatories. Werner was an important link between the various space geodesy communities, particularly the ILRS and IGS.

The Faculty of Sciences of the University of Bern acknowledged the achievements of this eminent engineer and scientist by awarding him the title of professor in 1999. Werner Gurtner will be remembered as competent collaborator, good friend and dear colleague.

The ILRS would like to dedicate this issue of the report series to the memory of our colleague, Professor Dr. Werner Gurtner, in grateful recognition of his many contributions to SLR and GNSS, the ILRS and the IGS, and the broader international space geodesy community. We all will miss our association and interactions with Werner.

Michael Pearlman, Harvard-Smithsonian Center for Astrophysics, USA
Gerhard Beutler, Astronomical Institute University of Bern, Switzerland

Introduction

THE INTERNATIONAL LASER RANGING SERVICE 2007-2008

In August, 1969, NASA convened a 10-day seminar at Williams College, Williamstown, Massachusetts. The seminar was chaired by William Kaula and attended by other visionaries in the emerging discipline of satellite geodesy. A report of the discussions and deliberations was produced: “The Terrestrial Environment: Solid Earth and Ocean Physics,” NASA CR-1579, April, 1970, which became known as “The Williamstown Report.”

It was an exciting time in August, 1969, with the first successful Apollo landing on the Moon in July and return of the Apollo-11 astronauts to Earth. The astronauts had deployed reflector arrays to enable studies of the lunar orbital and rotational motion with unprecedented accuracy using the new laser ranging technology, already demonstrated in 1964 with Earth satellites. In fact, initial laser returns from the Apollo-11 reflectors were obtained in August just before and during the Williamstown meeting.

The Williamstown Report acknowledged the importance of laser ranging: “There is no doubt that laser ranging will be a basic technique in any future system that requires maximum accuracy” (page 2-7). And indeed it is the case that laser ranging to artificial satellites and the Moon have been essential contributors to the science described in the Williamstown Report.

It was recognized very early that laser tracking of artificial satellites and the Moon would benefit from a global distribution of instruments, especially to support applications of the technique to investigate global phenomena, such as distribution of mass within the Earth (gravitational field) and three-dimensional motion of the Earth and Moon in space. With this recognition, the community organized itself, somewhat informally, to build a global network of SLR and LLR stations. This network of stations played key roles in the missions of several satellites, including satellites specifically designed to operate with laser ranging (such as the Laser Geodynamics Satellite, LAGEOS) and radar altimeter satellites that carried retroreflector arrays (such as GEOS-C, Seasat and TOPEX/Poseidon). The informal network was accomplished through the gracious collaboration of institutions and government agencies of several nations. This collaboration, which is now formalized into the International Laser Ranging Service, continues to provide key functions and services to the global geodetic and geophysical community. In the more than forty years that have elapsed since the first experiments on laser ranging to an artificial satellite (Beacon Explorer-B), the ILRS has matured into a global network that provides vital support to missions. The international collaboration has been crucial to the success and the sharing of the cost among the various institutions and agencies has been essential for the network growth.

The ILRS roots can be traced to the first laser ranging experiments on BE-B, but the ILRS now provides tracking support of numerous satellites and the list continues to grow. It is always a pleasure to acknowledge the many dedicated contributors to the ILRS. The tracking of the variety of satellites is not only much appreciated, it is essential for the scientific application (and in some cases, the technological applications) of those satellites.

Although the role of laser ranging has changed over the years, it is still the premier technique for aspects of the reference frame and for providing an absolute measure of accuracy. Today, SLR is used as the sole source of tracking on some satellites, such as LAGEOS and Starlette, but SLR also provides an essential role of validating the orbit determination based on other techniques, such as GPS.

The future for laser ranging is bright, with new technology and applications not envisioned by the Williamstown Report. The technology has emerged in the form of laser altimetry of the Earth, Moon, and Mars. And one-way ranging experiments are planned from the Earth to lunar satellites, for example. Once again, it is an exciting time as we watch these new technologies and applications move toward fruition. Nevertheless, we cannot neglect our core activities and responsibilities. We must continue to improve the instrumentation by lowering operating costs and improving accuracy. The laser ranging community continues to be a vibrant and innovative international collaboration of individuals and institutions, and on behalf of the community of users of laser ranging data, I offer the sincere thanks from the user community for your dedication to laser ranging.

I was asked the following questions some years ago: how long do we need to continue tracking LAGEOS? Have we already extracted all the information about the LAGEOS dynamics and various applications of LAGEOS that we can and therefore, there is no need to continue tracking? These are certainly thought provoking and valid questions. It is amazing to me, that after more than thirty years, LAGEOS and Starlette, for example, continue to be orbiting benchmarks. SLR now has the longest time history of high accuracy observations of artificial satellites. We are still learning about long-term satellite dynamics, i.e., orbit evolution, the reference frame and the environment in which the satellite moves. And these satellites and their applications still have a lot to teach us. As long as we continue to learn, I would argue that we should continue tracking such satellites. As of now, we continue to learn.

Bob E. Schutz
Austin, Texas
November 2, 2009

Chairman's Remarks

The bi-annual report is an opportunity for the ILRS to provide the community with the update on the Service activities, procedures and plans. The report also gives each of the ILRS entities the occasion to include news on recent activities and to bring us up to date on staff changes. The report also includes station performance information and activities underway that will improve performance in the future. This report period includes some rather fundamental changes and some new challenges for the ILRS.

Network data yield continues to increase. The stations in Arequipa and Haleakala are now operational and data yield on GNSS satellites has improved. Daylight tracking, particularly on the higher satellites is still a major issue on the higher satellites, but some of the stations have had success with daylight ranging on some of the GNSS satellites as technology has improved with the higher repetition rate lasers and tracking techniques have been refined. One disappointment during this period was discovery of small range biases, some being introduce by the Stanford Counter that have been installed in several stations. Calibration procedures provided some improvement, but this will not suffice as range accuracy requirements continue toward the mm level.

The Consolidated Prediction Format (CPF) has now been fully implemented, with commensurate improvement in prediction quality. The new Consolidated Range laser range Data format (CRD), that accommodates higher range accuracy and extended one-way and two-way ranging to planetary distances is being implemented as the new ILRS standard. It is already in use at several stations; full transition for the network is scheduled for early 2010.

A Laser Workshop was held in Grasse, France in September 2007. The Sixteenth Workshop on Laser Ranging was held in Poznan, Poland in November 2008. Both workshops included a week-long format covering analysis, ranging systems hardware and software, and retroreflector arrays provided a venue for scientists, analysts, and practitioners to meet and discuss technique issues and new ideas. The proceedings for both are accessible through the ILRS website. We thank the organizers and sponsors of both meetings, the Space Research Centre of the Polish Academy of Sciences and the Observatoire de la Cote D'Azure, for the their excellent arrangements and wonderful hospitality. The workshops were certainly highlights of this reporting period. The Seventeenth Workshop on Laser Ranging will be held in Concepcion, Chile in November 2010.

By the end of 2008, the ILRS community was assembling its data product for submission for the ITRF 2008. Eight analysis centers were preparing their solutions of time-dependent station positions for submission to the Combination Centers at the ASI and DGFI.

A number of new satellites were added to the ILRS roster during this period. TerraSAR-X, and Jason-2 (with the T2L2 timing experiment) are making fundamental contributions to Earth Science. Three new GNSS satellites were added during this period including GLONASS 115, GIOVE-B, and Compass- M1. Of particular note, both GLONASS 115 and Compass-M1 carried retroreflector arrays with uncoated cubes for improved array effective cross-section. The improvement in data yield was quite evident.

The ILRS continued its support the IAG's Global Geodetic Observing System (GGOS). The book, "Global Geodetic Observing System: Meeting the Requirements of a Global Society in a Changing World" with a number of contributions from the ILRS, has been published by Springer. To help support future space geodesy requirements, the ILRS has undertaken a simulation activity to help scope future network design.

I would like to thank all of our colleagues in the tracking network, at the Central Bureau, the analysis and data centers, those who undertook additional duties as working group chairs or members, for their continuous contribution to our Service. Special thanks of course to the agencies, institutions and foundations for their ongoing financial support of our activities.

Werner Gurtner
Chairman, ILRS Governing Board
Astronomical Institute
Bern, Switzerland
September 2009