International Laser Ranging Service

INTERNATIONAL LASER RANGING SERVICE 2009–2010 REPORT

NASA/TP 2013-217507

INTERNATIONAL LASER RANGING SERVICE

2009–2010 REPORT

June 2012

Edited by C. Noll and M. Pearlman

NASA/TP 2013-217507

The NASA STI Program Office … in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (443) 757-5803
- Telephone the NASA Access Help Desk at (443) 757-5802
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076

INTERNATIONAL LASER RANGING SERVICE

2009–2010

REPORT

June 2012

Edited by C. Noll and M. Pearlman

Goddard Space Flight Center
Greenbelt, MD 20771

NASA/TP 2013-217507

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 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

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*

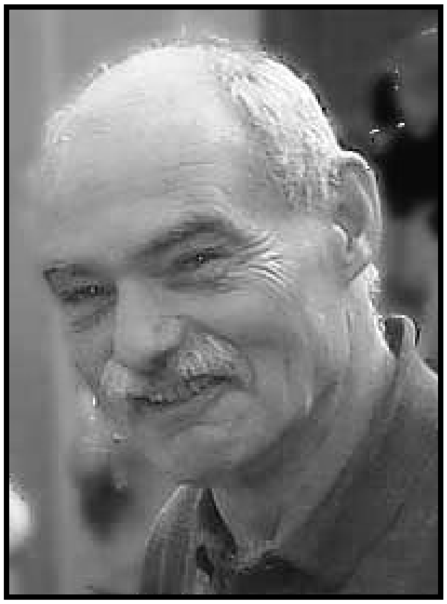
A complete list of ILRS associates can be found on the ILRS Web site at
http://ilrs.gsfc.nasa.gov/about/membership/associates.html

ACKNOWLEDGEMENT

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

TABLE OF CONTENTS

Dedication



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.

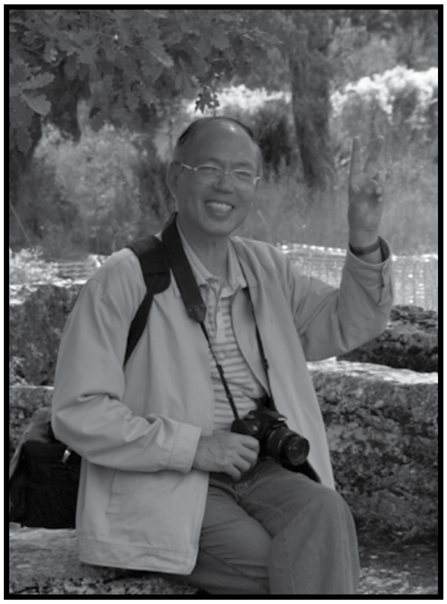
Parallel to all his SLR activities, Wolfgang was involved in the GPS analysis of data from the stations in the SIRGAS (Geocentric Reference System of the Americas) network since June 1996. He was responsible for the SIRGAS RNAAC, the Regional Network Analysis Center for South America, and has combined 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

Section 1
Science Report

SECTION 1

SCIENCE REPORT

Steve Klosko/SGT

INTRODUCTION

SLR and the Future of Geodesy

"A middle-aged rocky planet, Earth offers a wondrous combination of interconnected systems. From its molten core below to the ionosphere above, planetary layers interact dynamically, moving constantly, affecting climate and environment, and impacting life of all forms on the planet. Quantifying these changes is essential to understanding the underlying processes well enough to identify their root causes and to anticipate and respond to future changes. Precise global geodesy is an essential tool to capture these changes".

Precise Geodetic Infrastructure: National Requirements for a Shared Resource
Committee on the National Requirements for Precision Geodetic Infrastructure; Committee on Seismology and Geodynamics; National Research Council, ISBN: 0-309-15812-5, (2010)

To improve our four-dimensional understanding of the Earth system and the insights derived from recovery of like geophysical parameters in planetary settings, it is essential to recognize the limitations we currently face and the steps needed to improve them. Fundamentally these challenges center on acquiring the measurements needed to directly measure the state and sustainability of the Earth and its environmental systems, establish reference frames that retain mm-levels of accuracy over decadal time frames, and leverage insights gained from the study of terrestrial-like bodies in comparison with Earth.

The broad challenges for space geodesy and geodynamics will likely intensify despite the great progress geodesy has made in delivering key climate related trends. Geodesy has isolated many important phenomena related to the health, state, and sustainability of the Earth's environment like global sea level rise and precise measurements of ice sheet mass loss. These demands are driven by the need for greater modeling understanding, complexity, and detail. For example, while global sea level rise and active zone tectonic motions are now being captured at the sub-cm level over societal relevant time scales, their utility especially within the context of predictive climate and/or tectonic models demand continued improvement in solution error assessment, and much greater understanding and insight into the constituent parts of the signal being captured. We are currently focused on capturing remarkable and unprecedented sources of mass flux, defining stable reference frames, and developing an integrated and interdependent understanding of the Earth's system in four dimensions at increasingly detailed but ever longer timescales scales. With many new sensors, we are improving our understanding of the geosphere and its interaction with the hydrosphere and atmosphere. Observations from space and suborbital platforms are also essential for defining the framework and providing observational resources for making measurements of some of the key manifestations of these natural and anthropogenic impacts. Geodetic investigations will continue to make significant contributions to a wide span of geoscience disciplines. This is a result of the wide recognition that geodesy and geodetic methods are powerful for isolating critical signals across a broad range of observational investigations.

SLR TECHNIQUE

The SLR technique offers one of the best ways to unambiguously position a satellite in near Earth orbit.

The SLR network is sparse and only capable of directly tracking a satellite 10% or so of the time. Thereby, the passive, spherical, and dense satellites designed exclusively as range targets, have this level of data available for precision OD. The easy to model shape and high density of these objects mitigates to a large extent un-modelable non-conservative forces needed for accurate OD and orbits at the 1 to 2m level have been achieved on these SLR-only satellites like LAGEOS and Starlette.

There are a significant number of active satellites with varied shapes and attitude control laws, which are tracked by SLR along with DORIS and/or GPS. For these satellites there are near global networks proving tracking in combination with SLR. With SLR contributing to these combination solutions, the combination of these data have yielded the first sub-cm orbits in the radial direction.

Whether used alone or with a mix of other tracking systems, the overall unique characteristics of the SLR systems include:

- Simple range measurement
- A space segment is passive
- Simple refraction model with far reduced sensitivity to propagation delay arising from water vapor
- Night/Day Operation
- Near real-time global data availability
- Satellite altitudes from 300 km to synchronous satellites, and the Moon
- Short laser pulse widths (30 - 50 ps) to improved return pulse definition

The most important of these characteristics requires re-visitation given current and future accuracy requirements. A level of improvement is needed for all tracking technologies, but here we will only explore SLR. These shortcomings must be overcome to achieve the goals of a stable and highly accurate Terrestrial Reference Frame and the precise navigation of SLR sites within it.

<u>Simple range measurement with passive space segment</u>: While it is true that SLR produces an unambiguous range measurement, there are many models and translational links needed to produce a range between the satellite center of mass (CoM) and the optical axis of the ground laser system. The complexity of this task depends on the complexity of the satellite form, active fuel expenditures which move the CoM with respect to the retro-reflectors, the complexity of the return pulse (e.g. how many corner cubes are illuminated simultaneously as capture in a far field diffractive model, and for really complex satellites like TOPEX, thermal behavior, like warping of its large solar array, which causes cm level changes in CoM. mm-level accuracy will require much better understanding of the satellite's thermal behavior which is a real challenge given these objects are already on orbit and not accessible for direct thermal distortion measurements. In addition a significant improvement in range calibration is needed either for sites using external calibration targets measured pre and post a pass in multiple directions, or for systems with internal calibration capabilities. Currently these modeling error sources are at the 5mm to 1.5cm range. For SLR we form normal points, which very effectively reduce range noise to the 1-2 mm level for the high precision stations, but these systematic sources of error remain.
Lastly, a survey tie is needed to locate the laser optical axis with respect to the brass survey marker located on the site pad to tie multiple site occupations to a single reference point.

<u>Simple refraction model with far reduced sensitivity to propagation delay arising from water vapor</u>: Most of today's SLR systems use meteorological data acquired by the site. These measurements are inadequate to capture the full characteristics of the surrounding water vapor. In the case of the atmospheric delay, more sophisticated models (Pavlis et al, (2009), and VLBI-developed approaches which take into account horizontal gradients and azimuthal dependencies (especially at coastal sites) are being developed to improve SLR analyses. For SLR,

refraction biases are not solved for but use of atmospheric sounding data assimilated in global atmospheric circulation models has been shown to yield significant improvements in SLR solutions (Hulley and Pavlis, 2007). Approaches like these, perhaps tested using two color systems, are needed to improve SLR refraction modeling capabilities

TERRESTRIAL REFERENCE FRAME

The NRC report on **Precise Geodetic Infrastructure**: **National Requirements for a Shared Resource** recommended; "the United States …should invest in maintaining and improving the geodetic infrastructure, through upgrades in network design and construction, modernization of current observing systems, deployment of improved multi-technique observing capabilities, and funding opportunities for research, analysis, and education in global geodesy". The resulting integrated ITRF is envisioned to provide the services and products shown in Figure 1-1.

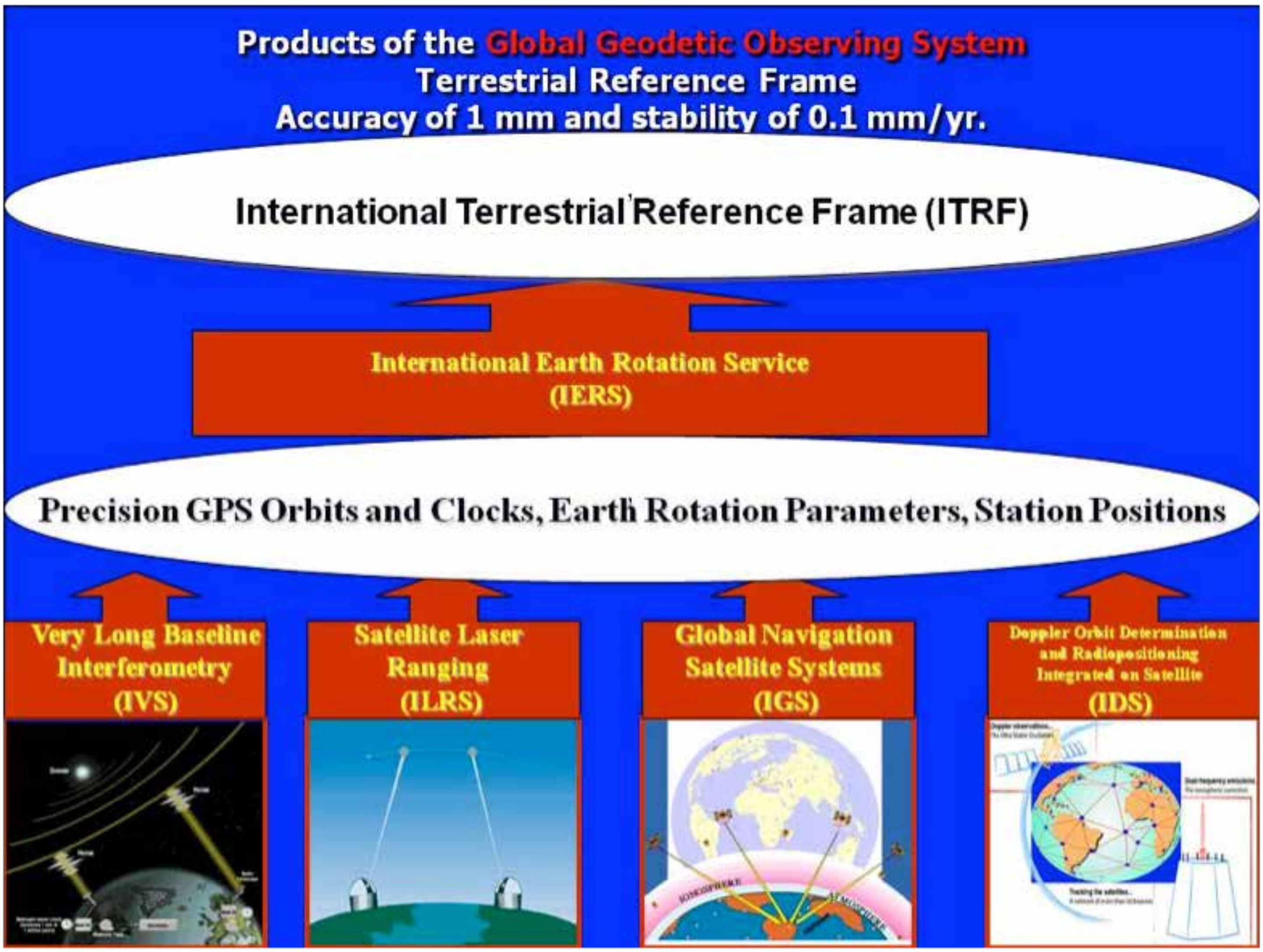


Figure 1-1. Products and services offered by contemplated future ITRF implementations.

This recommendation is made with the knowledge that the underlying VLBI and SLR networks have infrastructures that are old, hard to maintain, and are at risk of significant downtime due to their fragility. The sites used to anchor the ITRF must significantly upgrade through the deployment of the latest geodetic technologies, much better survey ties between instruments, and much improve monitoring of local surface motions through the use of absolute gravity meters.

The ITRF that we are seeking has characteristics that exceed all current capabilities of the current networks. A list of the objectives follows;

- An accurate, stable set of station positions and velocities needed for tracking and interpreting data acquired by flight missions and multiple sensors;
- ITRF should be accurate to 1 mm and stable to a 0.1 mm/yr,
- Static geoid should be accurate to 1 mm and stable to a 0.1 mm/yr.

These are goals given in GGOS plan developed by Plag and Pearlman (2009). Should these goals be met, the ITRF would:

- Be the stable foundation for all space-based and ground-based metric observations;
- Meet the need to establish and maintain the global space geodetic networks;
- Provide network measurements that are:
  - precise, continuous, robust, reliable, geographically well distributed
  - balanced over the continents and oceans
  - interconnected using highly accurate surveys between the different observing techniques

And the ITRF will support the following products:

- Hyper stable Terrestrial Reference Frame (Center of Mass and Scale)
- Sub- 0.1 mm/y monitoring of Plate Tectonics and Crustal Deformation
- Static and Time-varying Gravity Field
- Earth Orientation and Rotation (Polar Motion, length of day)
- Orbits and Calibration of Altimetry Missions (Oceans, Ice)

LASER RANGING DEVELOPMENTS

SLR technology is under a continual state of improvement driven by the Global Geodetic Observing System and the high accuracy and data yield requirements for the evolution of the reference frame. SLR development efforts are divided between those aimed at making the stations easier to maintain, and others looking to improve tracking performance. Major upgrades, implementations, and new concepts include:

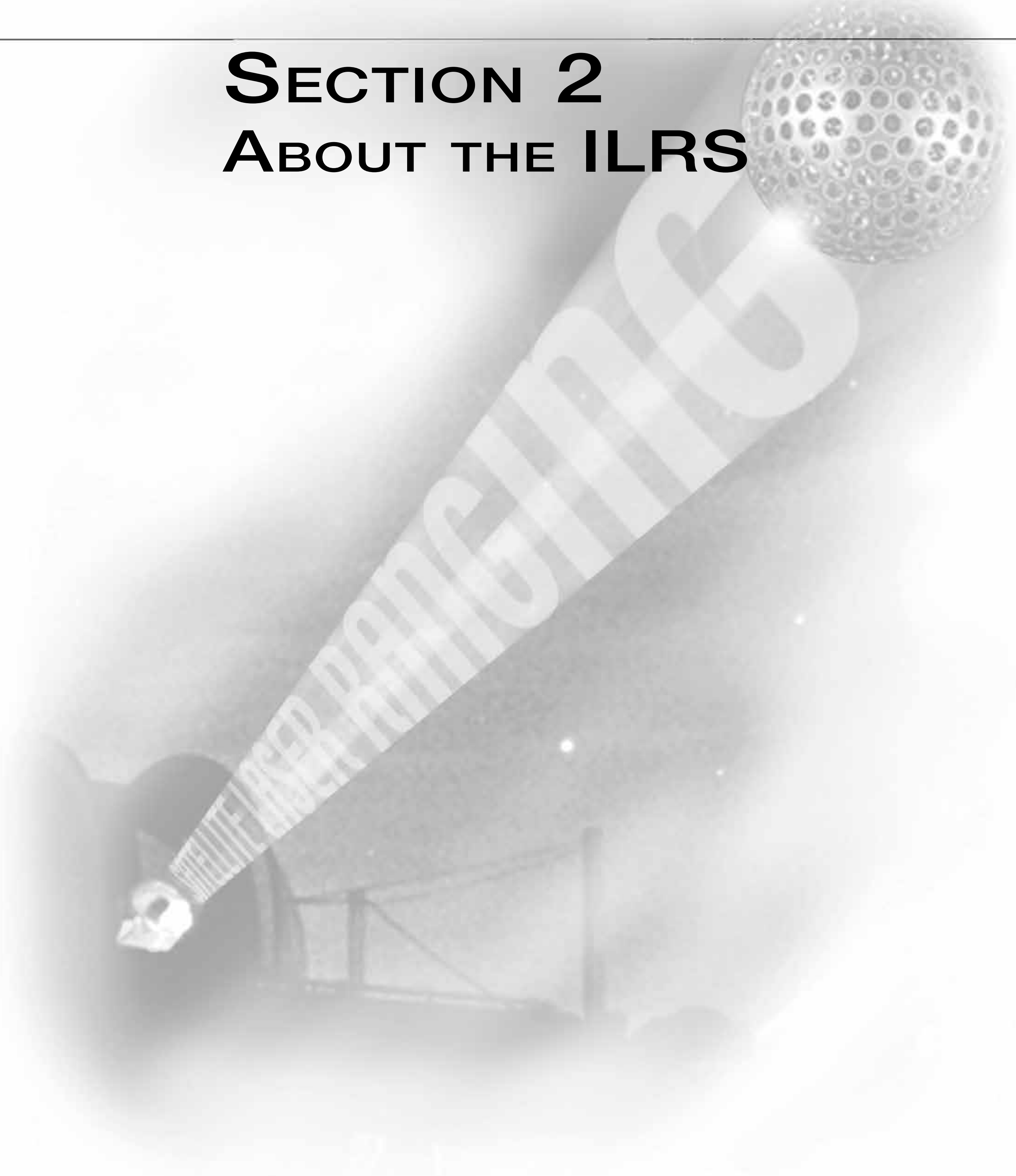
- High repetition rate lasers (0.1 – 2 kHz) to improve data yield and more rapid pass interleaving;
- Event timers with near-ps resolution for higher range resolution;
- Automation and autonomous operations to reduce manpower and permit operations during non-manned shifts;
- Two wavelength experiments to test refraction models;
- Testing of eye-safe concepts;
- Improvements in the design of retroreflector arrays for GNSS and synchronous satellites to increase data yield;
- Experiment aimed at demonstrating optical transponders for interplanetary ranging;
- LRO-LR one-way ranging to the Lunar Reconnaissance Orbiter;

Many groups are participating in upgrades and developments. NASA has focused on developing a new generation of systems, which may lead to a prototype for some replication. Many of these items will be discussed on the Section on Emerging Technologies.

Several new stations are being built and will help improve the global distribution of the SLR network. In particular we note the new stations underway in Russia and Korea.

Strong interest continues in Lunar ranging with new design in retroreflectors and the transponders for the lunar surface.

Section 2
About the ILRS



SECTION 2

ABOUT THE ILRS

Michael Pearlman/CfA

THE MISSION OF THE ILRS

The International Laser Ranging Service (ILRS) organizes and coordinates Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) to support programs in geodetic, geophysical, and lunar research activities and provides the International Earth Rotation Service (IERS) with products important to the maintenance of an accurate International Terrestrial Reference Frame (ITRF). This reference frame provides the stability through which systematic measurements of the Earth can be made over thousands of kilometers, decades of time, and evolution of measurement technology. The Service provides precision ephemerides to support active Earth sensing missions and is now preparing to support extraterrestrial missions with optical transponders. The ILRS is one of the technique services of the International Association of Geodesy (IAG).

THE ROLE OF THE ILRS

The International Laser Ranging Service (ILRS):

- coordinates activities for the international network of SLR stations;
- develops the standards and specifications necessary for product consistency;
- develops the priorities and tracking strategies required to maximize network efficiency;
- collects, merges, analyzes, archives and distributes satellite and lunar laser ranging data to satisfy user needs;
- provides quality control and engineering diagnostics to the global network;
- works with new satellite missions in the design and building of retroreflector targets to maximize data quality and quantity;
- works with science programs to optimize scientific data yield; and
- encourages the application of new technologies to enhance the quality, quantity, and cost effectiveness of its data products;

ILRS Data Products

Official Submission to the IERS

- Weekly solutions for station coordinates and Earth Orientation Parameters (EOPs) for the derivation of scale (Gm) and time-varying Earth Center of Mass for the ITRF

Other User Products

- Static and time-varying coefficients of the Earth's gravity field
- Accurate satellite ephemerides for POD and validation of altimetry, relativity, and satellite dynamics
- Backup POD for other missions
- Lunar ephemeris for relativity studies and lunar libration for lunar interior studies

THE STRUCTURE OF THE ILRS

The ILRS is composed of the following components, shown in Figures 2-1 and 2-2:

- Forty Satellite Ranging Stations that provide ranging data on an hourly basis and two Lunar Ranging Stations;
- Three Operations Centers that collect and verify the satellite data and provide the Stations with sustaining engineering, communications links, and other support;
- Two Global Data Centers that receive and archive data and supporting information from the Operations Centers and provide these data to the Analysis Centers; and receive and archive ILRS scientific data products from the Analysis Centers and provide them to the users;
- Two Combination Centers that prepare the ILRS weekly data product for the IERS; six SLR Analysis Centers that provide the input solutions to the Combination Centers for the data product process, eighteen Associate Analysis Centers that provide specialized SLR products to the users community and provide a second level of data quality assurance in the network; and four Lunar Analysis Centers that provide lunar data products;
- Five ILRS Working Groups that provide technical expertise and help formulate policy;
- ILRS Central Bureau that is responsible for the daily coordination and management of ILRS activities including communications and information transfer, monitoring and promoting compliance with ILRS network standards, monitoring network operations and quality assurance, maintaining documentation and databases, and organizing meetings and workshops
- Governing Board which is responsible for general direction, defining official ILRS policy and products, determining satellite-tracking priorities, developing standards and procedures, and interacting with other services and organizations

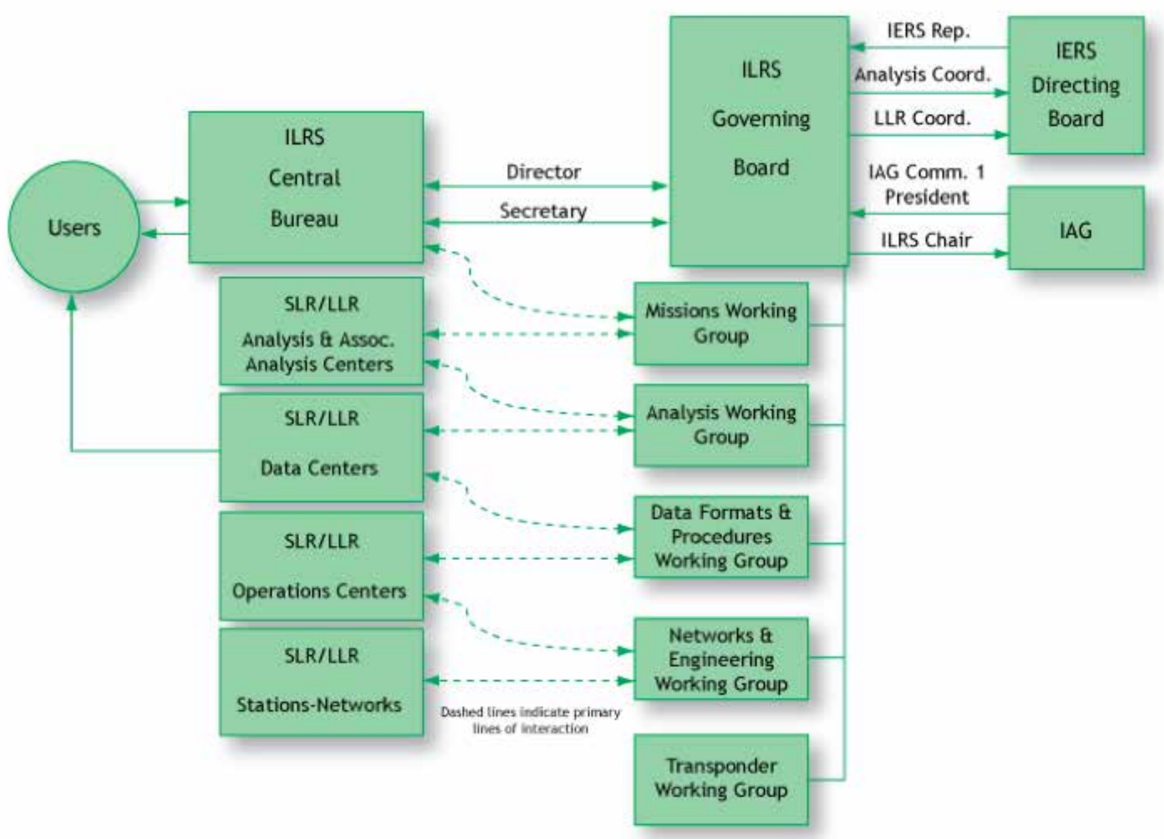


Figure 2-1. ILRS Organization

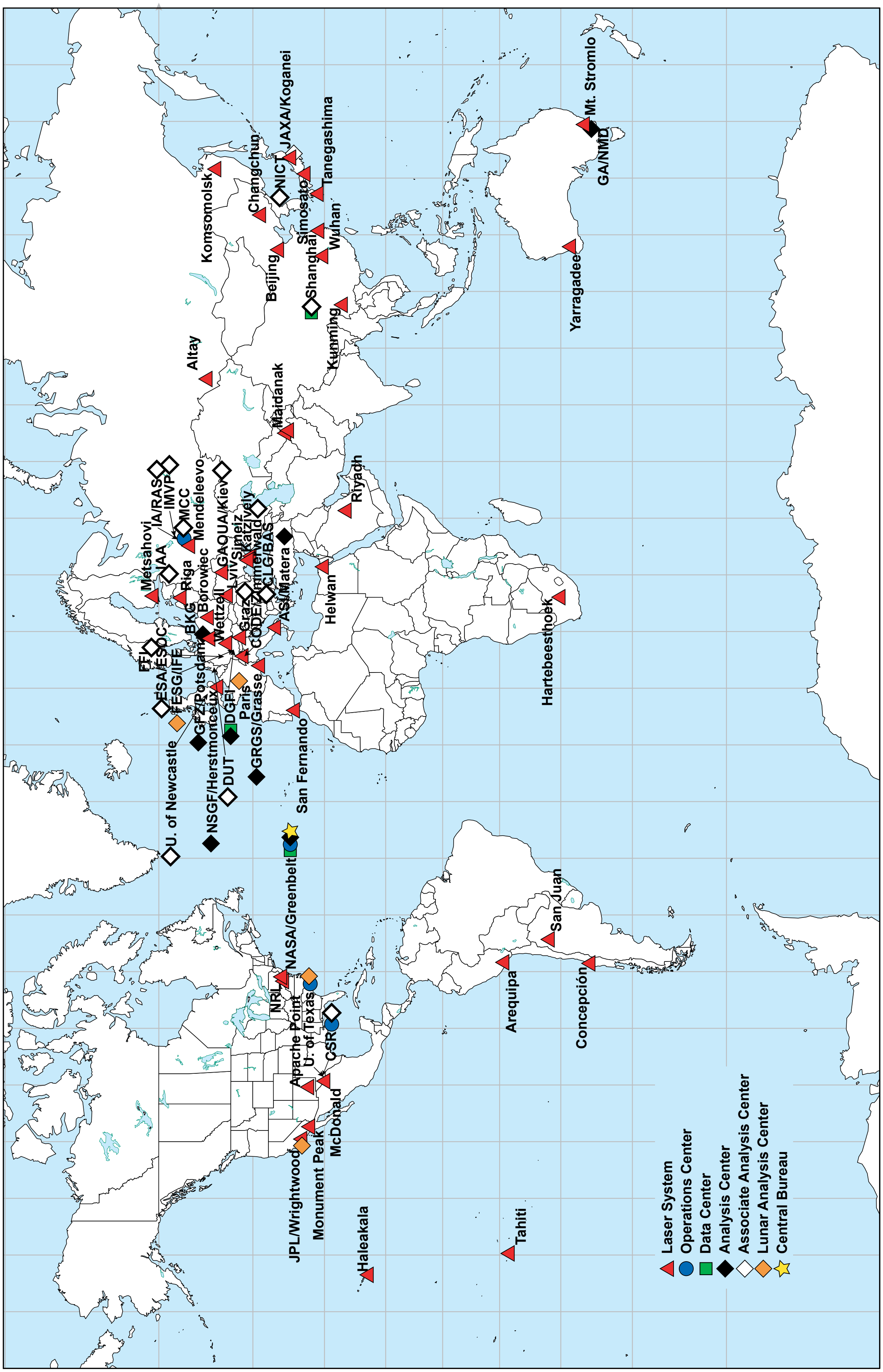


Figure 2-2. Components of the ILRS in 2009-2010.

ILRS GOVERNING BOARD

Name: Zuheir Altamimi

Position: Ex-Officio, President of IAG Commission 1

Affiliation: Institut Géographique National, France

Name: Jan McGarry

Position: NASA Network Representative

Affiliation: NASA Goddard Space Flight Center, USA

Name: Graham Appleby

Position: Chairman and At-Large Representative

Affiliation: Natural Environmental Research Center (NERC) Space Geodesy Facility (NSGF), UK

Name: Horst Müller

Position: Data Center Representative (replacing W. Seemueller in 11/2010)

Affiliation: Deutsches Geodätisches Forschungsinstitut (DGFI), Germany

Name: Giuseppe Bianco

Position: EUROLAS Network Representative

Affiliation: Agenzia Spaciale Italiana (ASI), Italy

Name: Jürgen Müller

Position: Lunar Representative

Affiliation: U. of Hannover/Institut für Erdmessung (IFE), Germany

Name: David Carter

Position: NASA Network Representative

Affiliation: NASA Goddard Space Flight Center, USA

Name: Carey Noll

Position: Ex-Officio, Secretary, ILRS Central Bureau

Affiliation: NASA Goddard Space Flight Center, USA

ILRS GOVERNING BOARD (CONTINUED)

Name: Yang Fumin

Position: WPLTN Network Representative

Affiliation: Shanghai Observatory, China

Name: Erricos Pavlis

Position: Analysis Center Representative

Affiliation: Joint Center for Earth Systems Technology (JCET) and Goddard Space Flight Center (GSFC), USA

Name: Ramesh Govind

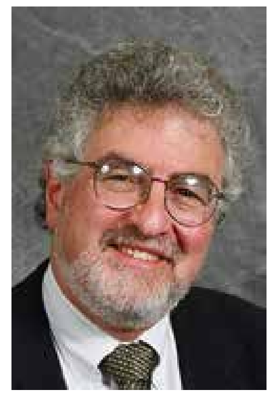
Position: WPLTN Network Representative

Affiliation: Geoscience Australia, Australia

Name: Michael Pearlman

Position: Ex-Officio, Director, ILRS Central Bureau

Affiliation: Harvard-Smithsonian Center for Astrophysics (CfA), USA



Name: Georg Kirchner

Position: At Large Representative

Affiliation: Austrian Academy of Sciences, Austria

Name: Francis Pierron

Position: EUROLAS Network Representative

Affiliation: Observatoire de la Cote d'Azur, France

Name: Vincenza Luceri

Position: Analysis Center Representative

Affiliation: e-GEOS S.p.A., Italy

Name: Bob Schutz

Position: IERS Representative to ILRS

Affiliation: Center for Space Research (CSR), University of Texas, USA

ILRS CENTRAL BUREAU

The Central Bureau, CB, is responsible for the daily coordination and management of the ILRS in a manner consistent with the directives and policies established by the Governing Board. The primary functions of the CB are to facilitate communications and information transfer within the ILRS and between the ILRS and the external scientific community, coordinate ILRS activities, maintain a list of satellites approved for tracking support and their priorities, promote compliance to ILRS network standards, monitor network operations and quality assurance of data, maintain ILRS documentation and databases, produce reports as required, and organize meetings and workshops.

The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, including standards/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions.

The CB operates the communication center for the ILRS. It maintains a hierarchy of documents and reports, both hard copy and electronic, including network information, standards, newsletters, electronic bulletin board, directories, summaries of ILRS performance and products, and an Annual Report.

In summary, the Central Bureau performs a long-term coordination and communication role to ensure that ILRS participants contribute to the Service in a consistent and continuous manner and that they adhere to ILRS standards.

SECTION 3
ILRS NETWORK

Section 3

ILRS Network

SATELLITE LASER RANGING (SLR)

Michael Pearlman/CfA, Graham Appleby/NSGF, Scott Wettzell/HTSI

The satellite laser ranging network as of December 31, 2010 as shown in Figure 3-1, includes 42 stations in 23 countries. Stations designated as operational meet the minimum ILRS qualification for data quantity and quality as specified by the ILRS (*http://ilrs.gsfc.nasa.gov/network/system_performance/global_report_cards/index.html*). A dozen stations dominated the network output, with the Yarragadee, Mt. Stromlo, Changchun, Zimmerwald, Matera, Graz, Herstmonceux, and Monument Peak were the strongest overall performers for this period. However the improved performance in the stations at San Fernando, the new Grasse (MEO), Potsdam, and Shanghai are also noted. A number of stations including Wettzell, Haleakala, Greenbelt, Hartebeesthoek and Arequipa were down or had subdued operations due to system repairs and upgrades.

Figure 3-1. ILRS tracking network in 2009-2010.

The ILRS welcomes the new station (ALTL 1879) at Altay Optic-Laser Center (AOLC) administered by the Institute for Precision Instrument Engineering (IPIE). This station fills a very large gap in central Asia. Other stations that have resumed operations include Simosato, which resumed operations in January 2009 after replacement of the telescope and laser control unit, and Komsomolsk after a telescope replacement. The new MEO station replaced the legacy station at Grasse for both SLR and LLR as the 3 year refurbishment was completed and the station qualified as an operational station.

Several stations implemented kilohertz ranging during this period. The Beijing (7249) station returned to operation in August 2010 after telescope servo repairs and kHz laser upgrades. In October 2010, the Shanghai system was again in operation with a kHz laser and new event timer, and meets the qualification for an operational station.

The TIGO system in Concepcion, Chile resumed two-color ranging with its Ti:Sapphire laser system after operations being limited to the near-infra-red for almost two years. Since August 2009, the station has been sending both optical 847 nm and infrared wavelengths 423.5 nm up to LAGEOS altitudes; the “primary product” is still the data in the near-infra-red. The magnitude 8.8 Chilean earthquake on February 27, 2010 disrupted operation, but the stations resumed operations on April 28. We congratulate the station crew on a remarkable recovery.

The NASA stations were configured for additional 10 Hz operation for low orbit satellites to increase data yield and improve satellite interleaving capability. The Yarragadee station added a hydrogen maser frequency reference source from the new VLBI station to be co-located at the site. The NASA Next Generation SLR (NGSLR) at GGAO is now routinely supporting one-way LRO-LR ranging at GSFC.

This period also saw a number of stations with prolonged downtime and quarantine after a repair. The Greenbelt station was down from April to November 2010 to check safety systems and revise engineering procedures. Hartebeesthoek and Tahiti were also down for periods of time with system repair issues.

In July 2009, the Wettzell SLR station WLRS was back on the air after a long repair period involving the system detectors, laser and calibration stability issues.

The Japanese stations at Tanegashima (GMSL 7358) and Koganei CRL (KOGC 7308) had problems with the their Telescope and mount systems.

The Borowiec station has been off-line since March 2010 with several laser problems. The station in Lviv has also been off the air since December 2009 with laser problems.

The station in Riyadh remains down while KACST develops a plan for refurbishment. Johan Bernhardt has moved from Hartebeesthoek to Riyadh to help lead the station.

Increased emphasis has been given to station change reporting, with a new status table available online at http://ilrs.gsfc.nasa.gov/stations/station_upgrades.html.

This is important to the data analysts, as subtle data anomalies have to be tracked to their origin. It is preferred to account for such events before the data is incorporated into operational products.

LUNAR LASER RANGING (LLR)

Jürgen Müller/IfE

During three U.S. American Apollo missions (11, 14, and 15) and two unmanned Soviet missions (Luna 17 and Luna 21), retro-reflectors were deployed near the landing sites between 1969 and 1973 (Figure 3-2). The LLR experiment has continuously provided range data for about 41 years, generating about 17000 normal points (Figure 3-3, left). The main benefit of this space geodetic technique is the determination of a host of parameters describing lunar ephemeris, lunar physics, the Moon's interior, various reference frames, Earth orientation parameters and the Earth-Moon dynamics [3, 5]. LLR has also become one of the strongest tools for testing Einstein's theory of general relativity in the solar system; no violations of general relativity have been found so far [1, 2, 4, 5]. However, the basis for all scientific analyses is more high quality data from a well-distributed global LLR network.

From all of the ILRS observatories (nearly 40), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (LLR) to retro-reflector arrays on the surface of the Moon (Figure 3-4). The McDonald Observatory in Texas, USA, the Apache Point Observatory, New Mexico, USA, and the Observatoire de la Côte d' Azur, France are the only currently operational LLR sites. The latter has undergone renovation since late 2004, and returned to action in September 2009. The McDonald observatory has major problems to get further LLR tracking funded. Although no system upgrade could be made in the past years, lunar tracking could be continued at a certain level. The most recent site with lunar capability at the Apache Point Observatory, New Mexico, USA, is equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A new set of data from APOLLO was released in 2011 with a total of ~940 normal points. The data are now available in the newly adopted ILRS CRD data format through a reformatting effort at the McDonald Observatory. The measurement statistics of the major lunar observatories between 1970 and early 2011 is shown in Figure 3-3 (right).

Also other modern stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station, Italy in 2010, but all of them suffer from technical problems or funding restrictions. The Wettzell observatory, Germany, plans to resume lunar tracking by end of 2011. The Australian station at Mt. Stromlo is expected to join this group in the future, and there are plans for establishing lunar capability at the South African site of Hartebeesthoek.

Current LLR data is collected, archived and distributed under the auspices of ILRS. All former and current LLR data is electronically accessible through the EDC in Munich (*http://ilrs.gsfc.nasa.gov/network/site_procedures/station_upgrade_status.html*), Germany and the CDDIS in Greenbelt, Maryland (*ftp://cddis.gsfc.nasa.gov/*).

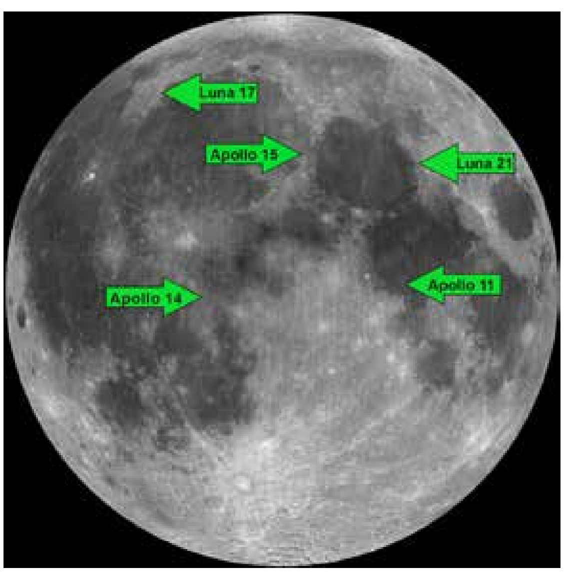


Figure 3-2. Retro-reflector sites on the Moon

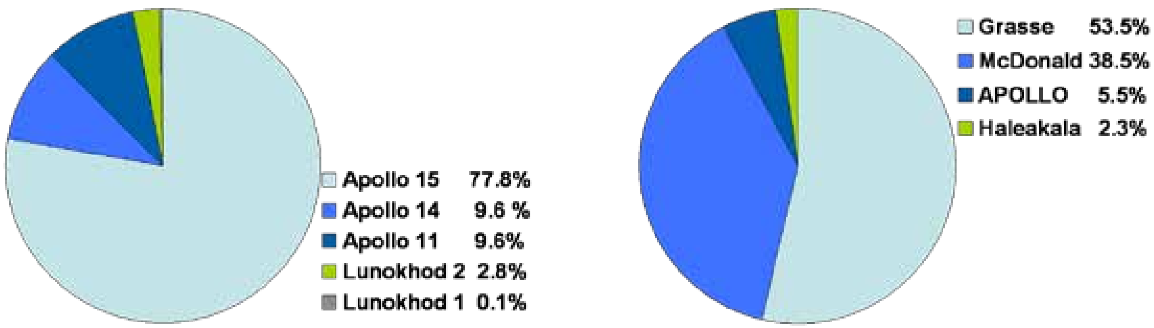


Figure 3-3. Measurement statistics of the retro-reflector arrays on the lunar surface (left), and of the major lunar observatories (right)

Figure 3-4. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future. The green arrows indicate active stations, the green-grey arrows the possible future stations and the grey arrows the former stations

References

[1] Hofmann, F., Müller, J., Biskupek, L.: Lunar laser ranging test of the Nordtvedt parameter and a possible variation of the gravitational constant. Astronomy and Astrophysics, Vol. 522, No. L5, 2010, doi: 10.1051/0004-6361/201015659.

[2] Müller, J., Williams, J. G., Threshed, S. G. (2008). Lunar Laser Ranging Contributions to Relativity and Geodesy. In Lasers, Clocks and Drag-Free Control: Exploration of Relativistic Gravity in Space, ed. H. Dittus, C. Lämmerzahl, & S. G. Turyshev, Astrophysics and Space Science Library, 349, 457-472.

[3] Shelus, P. J. (2001). Lunar Laser Ranging: Glorious Past And A Bright Future. Surveys in Geophysics, 22, 517-535.

[4] Soffel, M., Klioner, S., Müller, J., Biskupek, L. (2008). Gravito-Magnetism and LLR. Phys. Rev. D, 78, 024033.

[5] Williams, J. G., Turyshev, S. G., Boggs, D. H. (2009). Lunar Laser Ranging Tests of the Equivalence Principle with the Earth and Moon. Int. J. Mod. Phys. D, 18, 1129-1175.

NETWORK PERFORMANCE

Network Performance Report Cards are issued quarterly by the ILRS Central Bureau. These reports tabulate the previous 12 months of data quality, quantity, and operational compliance by station and can be found along with established guidelines for station performance on the ILRS website at:

http://ilrs.gsfc.nasa.gov/network/system_performance/global_report_cards/index.html

The ILRS Central Bureau uses these report cards to review stations performance and to maintain lists of the best performing stations which are tabulated at:

http://ilrs.gsfc.nasa.gov/network/system_performance/station_classification/index.html

As shown in Figures 3-5 through 3-8, network data yield has been fairly constant over the last few years, attributed mainly to the large number of systems that have spent time under maintenance and upgrade. We anticipate strong increase over the next several years as the stations come back into operation and additional satellites are added to the roster. In particular, with the planned increase in the number of GNSS satellites with arrays meeting the ILRS Standard, there should be considerable improvement in GNSS tracking performance.

As can be seen in Figures 3-6, -7, and -8, station data yield performance falls into three categories. About a quarter of the stations are very prolific, far exceeding the ILRS criteria for an operational station. Another quarter of the stations are performing satisfactorily with some caveats on LAGEOS tracking. These two categories of stations are having a major impact on the development of the reference frame and POD. Some of the stations on the lower half are recovering from engineering activities and will hopefully experience improved operations in 2011.

A fair number of the stations are starting to take data on GNSS satellites. More effort is need to refine individual stations procedures to improve performance.

Figure 3-8 tabulates the number of minutes of tracking during this 2-year reporting period. Out of a total of about a million minutes possible, Yarragadee and Zimmerwald are doing remarkably well. With the advent of more automated systems that should expand operating hours, the network has tremendous potential that is yet to be realized.

Almost all of the stations are meeting the 2 cm normal point RMS threshold, with about 80% operating below the cm level (see Figure 3-9). Several of the stations are working down at the 2-3 mm precision level which approaches the GGOS requirements. The implementation of the KHz lasers with shorter pulse widths and improved detectors should increase the number of stations with such performance.

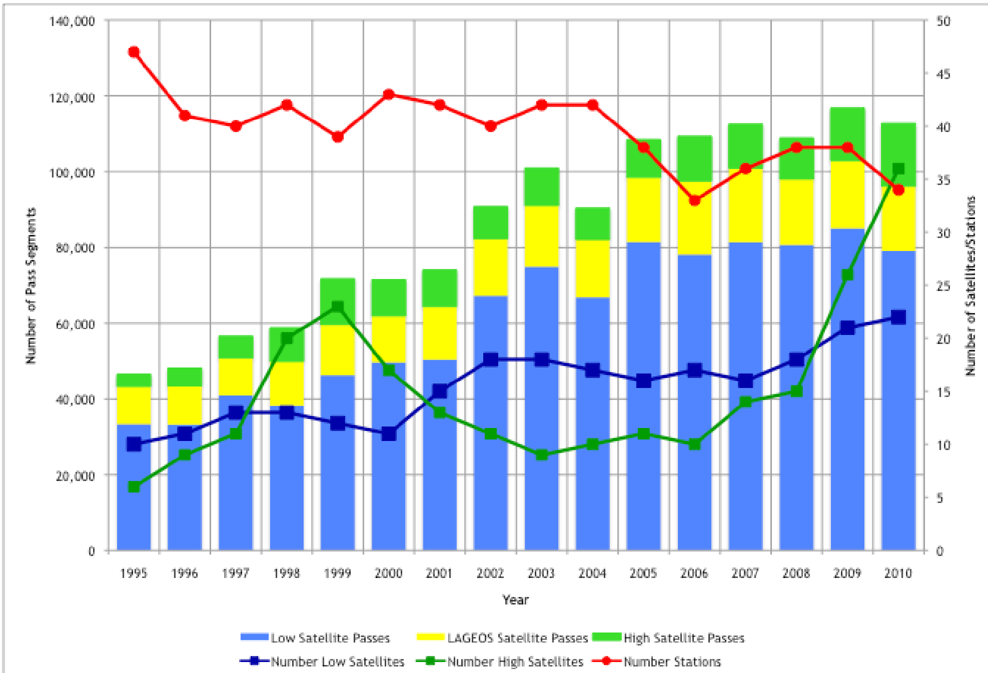


Figure 3-5. Network data yield continues to increase with the reopening of stations after repair and upgrading, improved network proficiency, and additional satellites mainly at GNSS altitude.

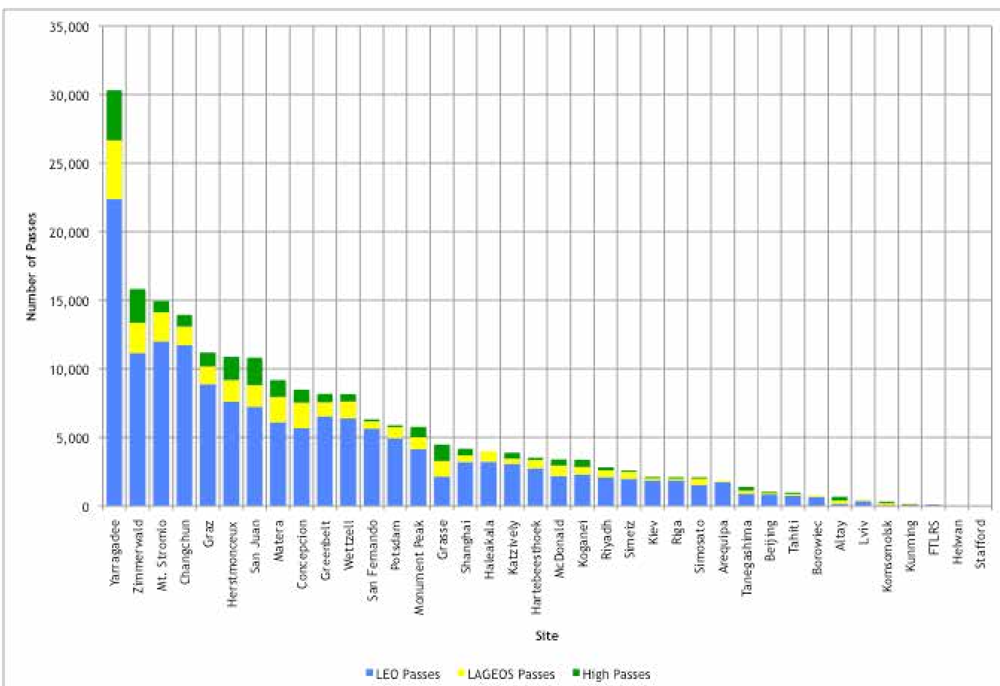


Figure 3-6. Number of passes tracked from January 2009 through December 2010

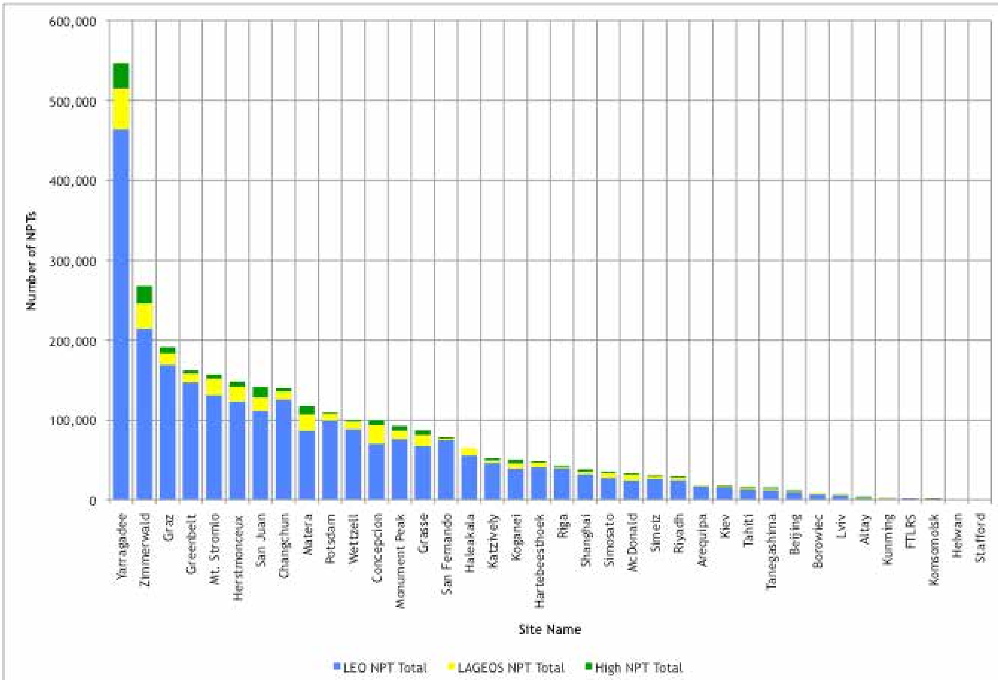


Figure 3-7. Number of normal points from January 2009 through December 2010.

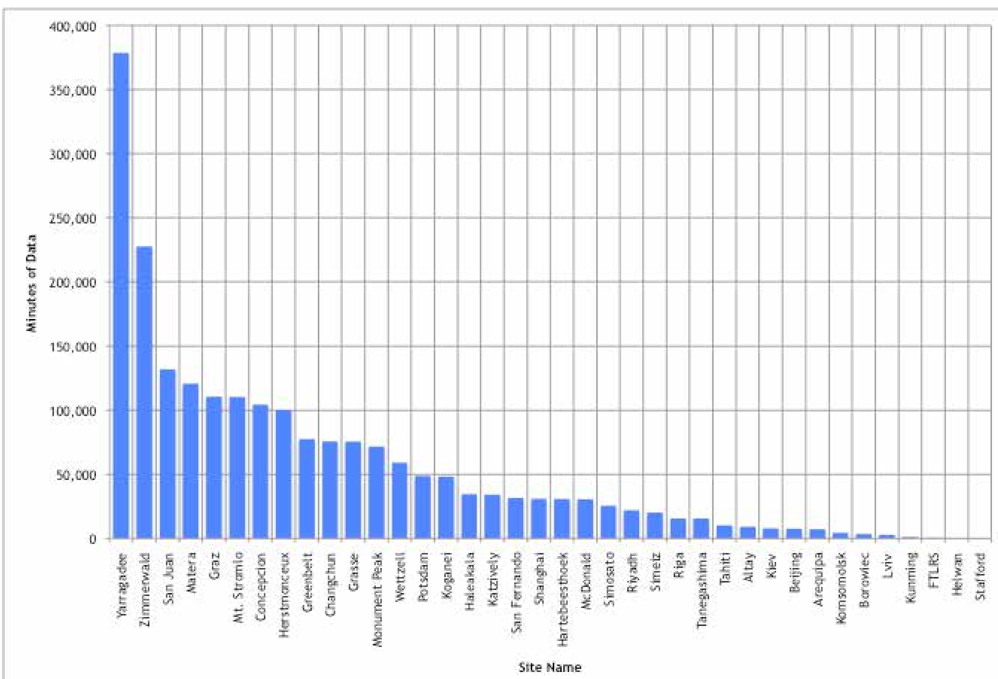


Figure 3-8. Number of minutes of data from January 2009 through December 2010.

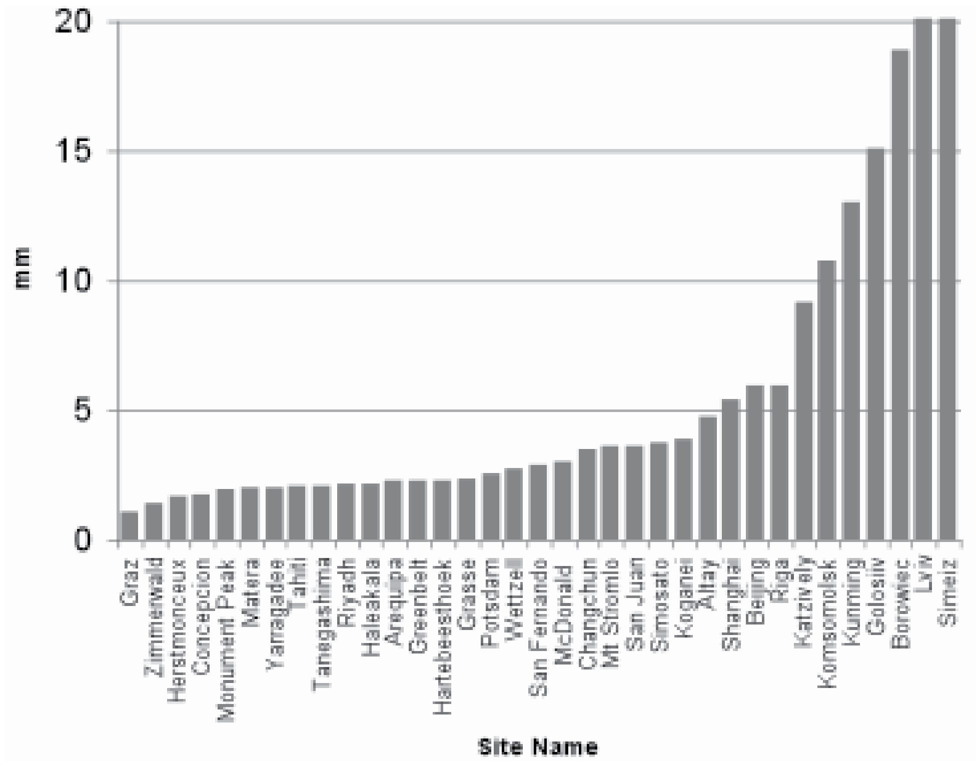


Figure 3-9. Average normal point precision in mm from January 2007 through December 2008 as calculated by Hitotsubatshi University, Japan

SITE SURVEYS AND CO-LOCATION SITES

Zuheir Altamimi/IGN and Michael Pearlman/CfA

The Terrestrial Reference Frame (ITRF) is the means by which we connect measurements over space, time and evolving technologies. Space may be ten thousand kilometers. Time will be decades and probably generations. Evolving technologies are the changes in the ground systems and the satellites that will happen as measurement capabilities improve. If we are going to see change in the Earth and its environment, we need the long-term stability of the reference frame. The reference frame should have and accuracy of 1 mm and a stability of 0.1 mm/year to satisfy the GGOS requirements.

Satellite Laser Ranging (SLR) is one of the fundamental geodetic techniques (along with GNSS, VLBI, and DORIS) that define and maintain the ITRF. Each technique is fundamentally different; each has its own unique strengths and its own systematic errors. We can exploit the strengths and mitigate the systematic errors through the co-location of space techniques (SLR, GNSS, VLBI, and DORIS) at common sites. This is an essential part in our achievement of the high–accuracy Terrestrial Reference Frame.

The very existence of the ITRF relies on the availability and quality of local ties among instruments at co-location sites as well as the number and distribution of these sites over the globe. A co-location site is defined by the fact that two or more space geodesy instruments are occupying simultaneously or subsequently very close locations, for which intersystem vectors have been accurately determined.

Intersystem-vectors or "site ties" among instruments at co-location sites are an essential, but often unappreciated component in the development of the reference frame. These vectors are a combination of (1) ground surveys between accessible points on or near each instrument and (2) an extrapolation to the reference points that maybe imbedded inside an instrument or at a point outside an instrument.

Ground surveys are very precisely surveyed in three dimensions using classical surveys and/or the GNSS technique. Classical surveys are usually direction angles, distances, and spirit leveling measurements between instrument reference points or geodetic markers. Adjustments of local surveys are performed by national geodetic agencies operating space geodesy instruments to provide differential coordinates (local ties) connecting the co-located instruments.

Extrapolations to the reference points are estimated through iterative ground-based survey procedures, engineering modeling, and vendor specifications. This component is obviously the most susceptible to error and the most in need of innovative approaches.

The value of mm level measurements across intercontinental distances can be lost through missing or inaccurate local ties, inconsistencies in ground survey techniques, poor survey control network geometry and monumentation, improper analysis of survey data, and lack of proper documentation.

Current Status of the Co-location Sites

The VLBI and SLR networks each include sites. The DORIS network is more homogeneous and includes 56 sites. The IGS GNSS network contains more than 440 permanent sites. In the worldwide currently operating Space Geodesy Network, 59 sites host two observing techniques (SLR, GNSS, VLBI, and/or DORIS); 17 sites have three, and only two sites have four, as illustrated by Figure 3-10.

The status of site co-locations with SLR is shown in Table 3-1 and Figure 3-10. There are currently only three SLR sites operating with SLR, GNSS, VLBI, and DORIS (one fully operational in 2010), and ten SLR sites operating with GNSS and VLBI. Seven are co-located with DORIS. All of the SLR sites in the ILRS operational network are co-located with GNSS; six of the other participating SLR stations do not have GNSS. The distribution of these co-located sites is not well placed and in some cases operations of one or more of the techniques is marginal. Local surveys are also an issue at nine of the SLR co-located sites.

Co-location of techniques and measurement and monitoring of local inter-technique vectors to the mm level must continue to be a high priority with the SLR network. Figure 3-10 shows all SLR and VLBI stations operated in 2010 where most of them are co-located with GPS. It also shows the current GPS and DORIS co-locations.

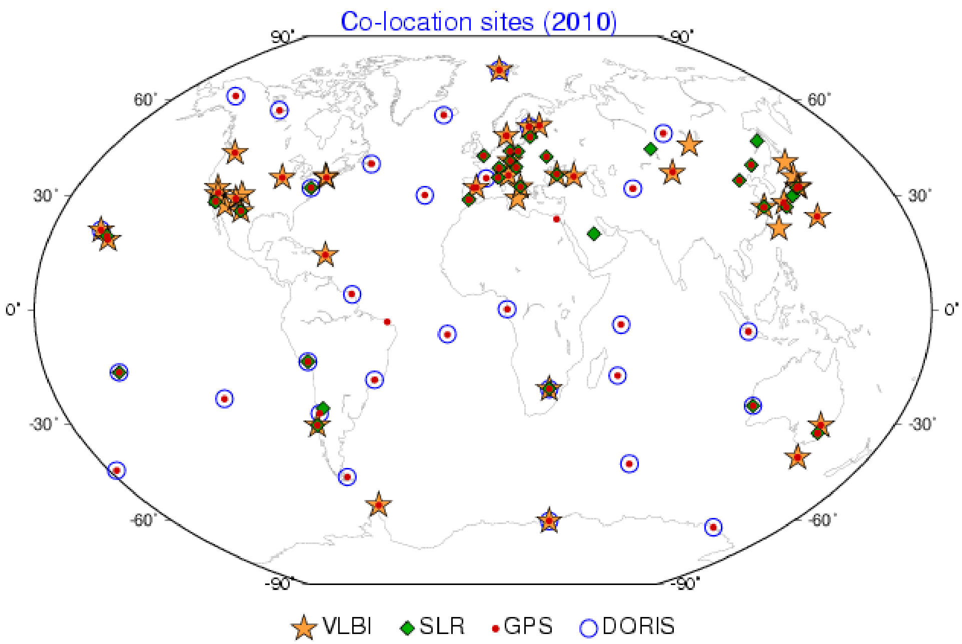


Figure 3-10. Current status of SLR, VLBI, DORIS, and GNSS co-locations (2010).

New Surveys

During this period, The Institut Géographique National (IGN), France conducted a complete survey of the Herstmonceux site, comprising two techniques: SLR and GNSS.

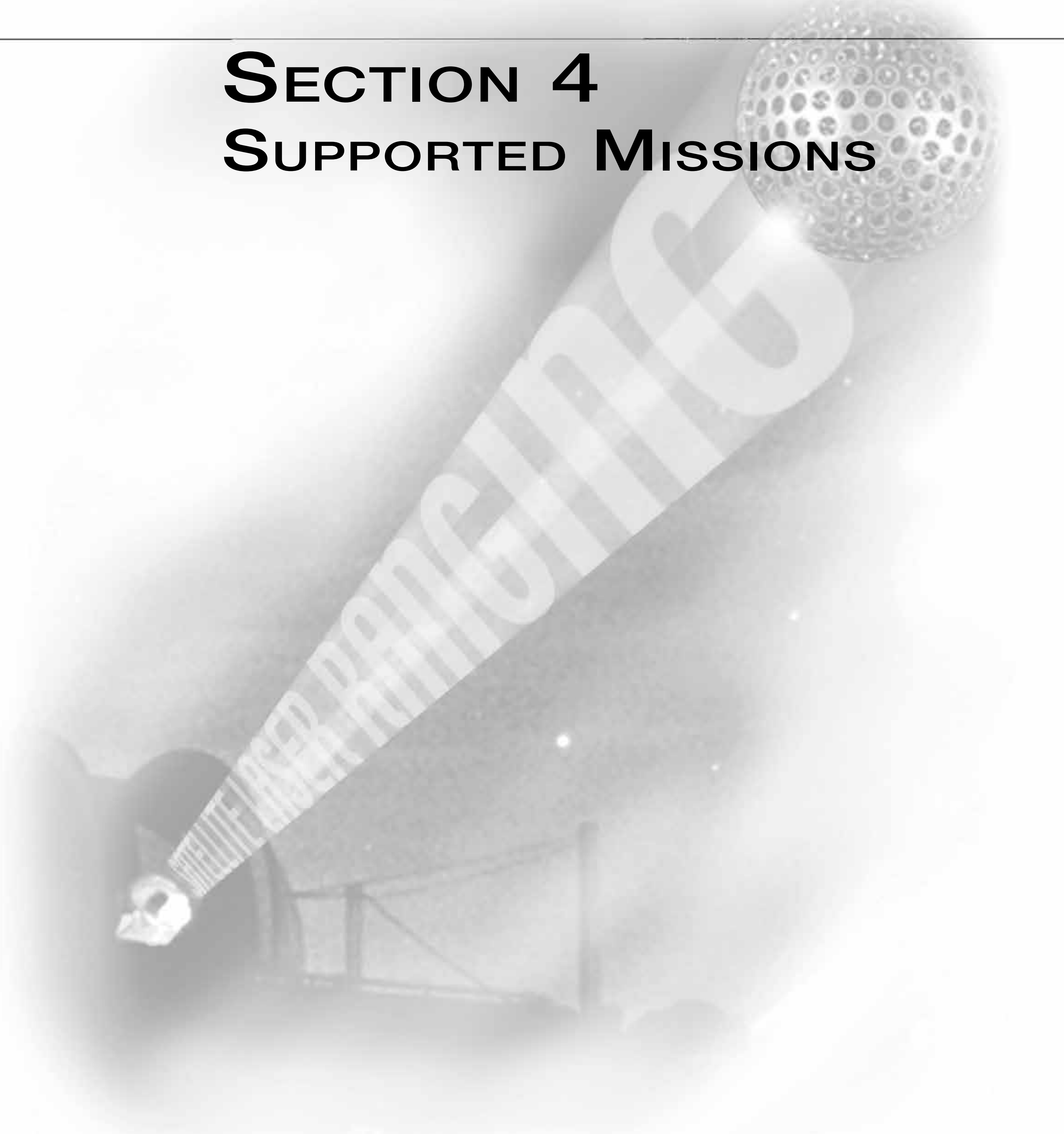
The adjustment of this survey is accomplished, including final report and SINEX file, which are available at the ITRF website *http://itrf.ensg.ign.fr/.*

Table 3.1. Space Techniques Co-Located with SLR (2009-2010)

Site Name	Country	GNSS	VLBI	DORIS	Gravimeter
Altay	Russia				
Arequipa	Peru	X		X	
Beijing	China	X			X
Borowiec	Poland	X			X
Changchun*	China	X			
Concepción	Chile	X	X		X
Grasse	France	X			X
Graz	Austria	X			X
Greenbelt, MD	USA	X	X	X	
Haleakala, HI	USA	X			
Hartebeesthoek	South Africa	X	X	X	
Helwan*	Egypt	X2			
Herstmonceux	UK	X			X
Katzively	Ukraine				
Kiev	Ukraine	X			
Koganei	Japan	X	X		
Komsomolsk	Russia				
Kunming*	China	X			X
Lviv*	Ukraine	X			
Maidanak	Russia				
Matera	Italy	X	X		X
McDonald, TX	USA	X	X		
Mendeleevo	Russia	X			
Metsahovi	Finland	X	X	X	X
Monument Peak, CA	USA	X		X	
Mount Stromlo	Australia	X		X	X
Potsdam	Germany	X			X
Riga	Latvia	X			X
Riyadh*	Saudi Arabia	X			
San Fernando	Spain	X			
San Juan	Chile				
Shanghai	China	X	X		
Simeiz*	Ukraine	X	X		
Simosato	Japan	X			
Stafford, VA	USA				
Tahiti	F. Polynesia	X		X	
Tanegashima*	Japan	X			
Wettzell	Germany	X	X		X
Wuhan	China	X		X	X
Yarragadee	Australia	X		X	
Zimmerwald	Switzerland	X			X
Totals:	41	35	10	9	15

Notes: * indicates missing tie

SECTION 4
SUPPORTED MISSIONS



SECTION 4

SUPPORTED MISSIONS

Graham Appleby/SGF, Scott Wettzell/HTSI/

CURRENT MISSIONS

The During 2009-2010, the ILRS supported 44 artificial satellite missions including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions. Missions were added to the ILRS tracking roster as new satellites were launched and as new requirements were adopted (see Figure 4-1). Ten missions were added to the roster during that period (see Table 4-1). The stations with lunar capability also tracked the lunar reflectors, one of which was rediscovered on the lunar surface after being lost for many years.

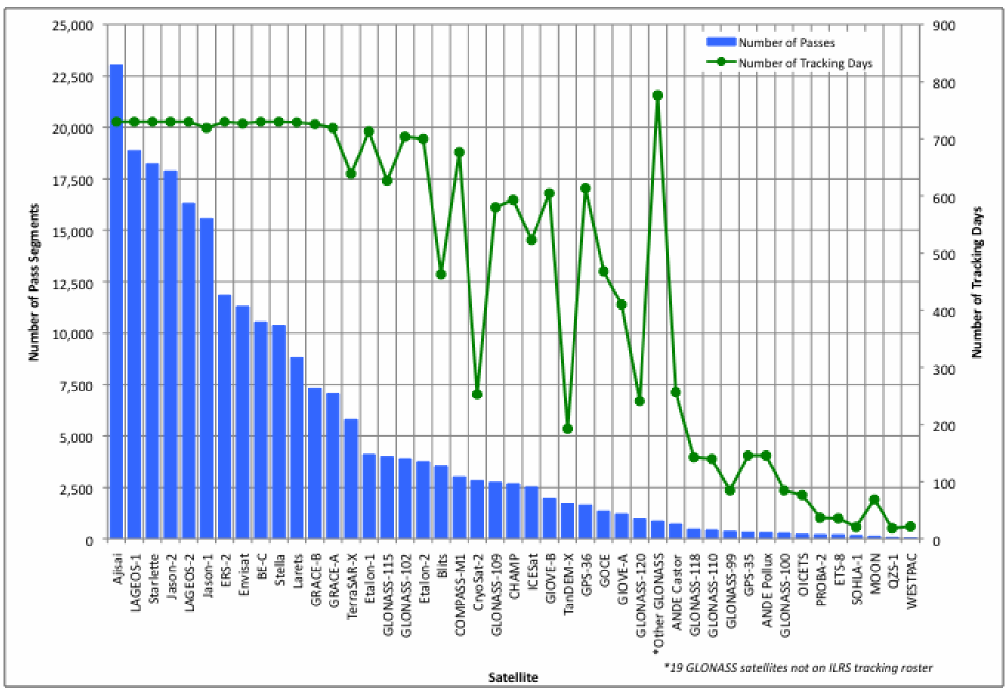


Figure 4-1. SLR tracking totals for 2009-2010.

The NASA Lunar Reconnaissance Orbiter (LRO) spacecraft and its laser altimeter brought one-way transponder ranging to a large subset of the ILRS network in support of precise orbit determination in lunar orbit. The network continued to support the GLONASS constellation; GLONASS-100 was added to the schedule in July 2009; GLONASS-115 replaced GLONASS-99 in March 2009; GLONASS-120 replaced GLONASS-109 in April 2010. During 2010 a few stations started experimental tracking of as many of the full GLONASS constellation as they could manage within their tracking schedules. It is likely that LR support for GNSS satellites will continue to increase, with the imminent launch of the first satellites that will ultimately constitute the European Galileo GNSS.

MISSIONS COMPLETED IN 2009-2010

The two satellites of the Atmospheric Neutral Density Experiment (ANDE) re-entered Earth's atmosphere during 2010 after a successful year-long mission.

The CHAllenging Mini-satellite Payload (CHAMP), launched on July 15, 2000, re-entered Earth's atmosphere on September 20, 2010. The dedicated low-orbit gravity field mission can be considered a pioneer for such missions, pre-dating GRACE and GOCE and leading the way to the development of very high precision gravity field models that are of value to many branches of geophysics.

During 2009, the Ice, Cloud and land Elevation Satellite (ICESat) came to the end of its mission to determine the mass balance of the polar ice sheets and their contributions to global sea level change. Since its launch in 2003, the mission provided multi-year elevation data as well as cloud property information, especially for stratospheric clouds common over polar areas. Some ten stations of the ILRS network whose procedures had been rigorously approved by the mission to avoid potential laser damage to its onboard detector tracked it on a regular basis.

After three years success, laser tracking support of the Engineering Test Satellite (ETS-8) from the WPLTN sub-network of the ILRS ceased during 2009. ETS-8 is in geosynchronous orbit and is a test of satellite-based positional augmentation of GPS navigation. The Australian SLR stations carried out some interesting return-rate experiments and polarization studies.

The JAXA Optical Inter-orbit Communications Engineering Test Satellite (OICETS) is a demonstration from LEO of optical communications with the ESA geostationary Advanced Relay and Technology MISsion (ARTEMIS). Laser tracking, the primary source of POD, ceased in September 2009 when the mission came to an end.

NEW MISSIONS IN 2009-2010

Table 4-1. New Missions Supported by the ILRS in 2009-2010

Mission	Launch	Altitude (km)	Sponsor	Application	ILRS Mission Support Requirement
SOHLA-1	Jan 23, 2009	666	JAXA (Japan)	Technology Development	POD, calibration of GPS
GOCE	March 17, 2009	295	ESA (Europe)	Gravity field and Ocean circulation	POD and instrument calibration
LRO	June 17, 2009	Lunar orbit	NASA (US)	Lunar studies	POD in lunar orbit
ANDE	July 30, 2009	350	NRL (US)	Atmospheric Modeling	POD
BLITS	Sept 17, 2009	832	IPIE (Russia)	Test of retroreflector technology	POD
PROBA-2	Nov 2, 2009	700 - 800	ESA (Europe)	Technology Development, solar studies	POD

CryoSat-2	April 8, 2010	720	ESA (Europe)	Sea-ice thickness and ice-sheet surface elevation	Altimeter calibration and satellite POD
TanDEM-X	June 21, 2010	514	DLR, GFZ, EADS-Astrium, Infoterra (Germany)	Global Digital Elevation Model	POD
QZS-1	Sept 11. 2010	32,000 – 40,000	JAXA (Japan)	Navigation, position, timing	POD

SOHLA-1

Figure 4-2 SOHLA-1 satellite (courtesy of JAXA)

SOHLA-1 (Figure 4-2) is a technical demonstration satellite developed by local small and medium-sized enterprises in Japan with technical support from the Japan Aerospace Exploration Agency (JAXA) and Osaka Prefecture University. The main objective of SOHLA-1 is to develop and demonstrate a variety of technologies for small satellites. One example is a VHF lightning impulse system. SLR was used for the calibration of GPS-based satellite positioning. The micro GPS receiver used in this mission has been developed by JAXA based on COTS automobile navigation technology. SLR tracking was scheduled for short campaigns of several weeks at a time as required, from March 2009 until the end of the mission in February 2010. More information is available at *http://god.tksc.jaxa.jp/sohla/sohla.html*.

Gravity field and steady-state Ocean Circulation Explorer (GOCE)

Figure 4-3. GOCE satellite (courtesy of ESA)

GOCE is an ESA mission dedicated to measuring the Earth's gravity field and modeling the geoid with extremely high accuracy and spatial resolution. It is the first Earth Explorer Core mission to be developed as part of ESA's Living Planet Program, and was launched into a very low orbit on March 17, 2009. The satellite (shown in Figure 4-3) consists of a single rigid octagonal spacecraft, approximately 5 m long and 1 m in diameter with fixed solar wings and no moving parts. The main objectives of the mission are to: (1) determine the gravity-field anomalies with an accuracy of 1 mGal (where 1 mGal = 10-5 m/s2), (2) determine the geoid with an accuracy of 1-2 cm, and (3) achieve the above at a spatial resolution better than 100 km. Mission instrumentation includes: a gravity radiometer, a 12-channel GPS receiver, and a standard compact laser retroreflector array. The mission, at an altitude of 250 km, is now mapping the Earth's gravity field with unprecedented precision, giving access to the most accurate model of the geoid ever produced (see for example *http://www.esa.int/esaCP/SEM1AK6UPLG_index_0.html*)

Lunar Reconnaissance Orbiter (LRO)

Figure 4-4. LRO spacecraft (courtesy of NASA)

The Lunar Reconnaissance Orbiter (Figure 4-4) is the first mission of NASA's Robotic Lunar Exploration Program (RLEP). The LRO mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon. The mission was launched on June 17, 2009 and is planned to take measurements of the Moon for at least two years. The LRO Laser Ranging (LR) system uses one-way range measurements from laser ranging stations on the Earth to LRO to determine LRO position at sub-meter level with respect to Earth and the center of the Moon (on the lunar near-side or whenever possible). The LR aspect of the mission will allow for the determination of a more precise orbit than possible with S-band tracking data alone. The flight system consists of a receiver telescope, which captures the uplinked laser signal and a fiber optic cable, which routes it to the LOLA instrument. The LOLA instrument captures the time of the laser signal, records that information and provides it to the onboard LRO data system for storage and/or transmittal to the ground through the RF link. This process is used to drive a near-real time display via a web-link to the tracking station(s) in order to inform the operator on the level of ranging success throughout each pass, thus allowing pointing corrections, etc., to be made if required. Currently some ten ILRS stations regularly support this mission through being scheduled to cover specific passes. More information is available at *http://lrolr.gsfc.nasa.gov/index.html*.

The Atmospheric Neutral Density Experiment (ANDE)

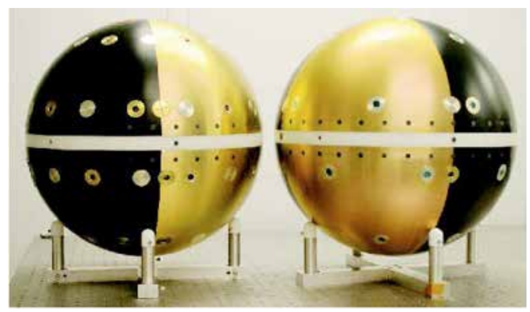


Figure 4-5. ANDE spheres (courtesy of NRL)

ANDE is a mission flown by the US Naval Research Laboratory to monitor the thermospheric neutral density at an altitude of 350km. The two satellites of the mission were launched from the Space Shuttle on July 20, 2009 and measured the density and composition of the low Earth orbit atmosphere while being tracked from the ground to better predict the movement and decay of objects in orbit.

The two spherical microsatellites, the ANDE Active spacecraft (Castor) and the ANDE Passive spacecraft (Pollux) (shown in Figure 4-5) are each fitted with retroreflectors. The satellites are identical in size (diameter of 19 inches), but have different masses, and were tracked by the ILRS network as well as the Space Surveillance Network (SSN). The spheres were in lead-trail 400 km, 51 degree inclination orbits. Scientific objectives include measurements of total atmospheric density for orbit determination and collision avoidance, validation of fundamental theories on air drag modeling, and establishing a method to validate neutral/ion density and composition derived from on-board sensors. ANDE Pollux re-entered the Earth's atmosphere shortly after its last observation by the SSN on March 28, 2010, and ANDE Castor re-entered on August 18, 2010.

Ball Lens in The Space (BLITS)

The BLITS retroreflector satellite (Figure 4-6) was developed and manufactured by the Science Research Institute for Precision Instrument Engineering (IPIE). BLITS was launched on September 17, 2009 and has been tracked by most of the ILRS network ever since. The purpose of the mission is experimental verification of the spherical glass retroreflector satellite concept as well as obtaining SLR data for solutions to scientific problems in geophysics, geodynamics, and relativity by millimeter and sub-millimeter accuracy SLR measurements.

The BLITS consists of two outer hemispheres made of a low-refraction-index glass (πκ6 type) and an inner ball lens made of a high-refraction-index glass (TΦ105 type). The ball lens radius is 53.52 mm; the total radius of the spherical retroreflector is 85.16 mm. The hemispheres are glued over the ball lens; the external surface of one hemisphere is covered with an aluminum coating protected by a varnish layer. All spherical surfaces are concentric. The satellite total mass is 7.53 kg. The "target error" (uncertainty of reflection center relative to the CoM position) is less than 0.1 mm, and the Earth's magnetic field does not affect the satellite orbit and spin parameters. SLR is the only source of POD information. This lack of target "signature" means that the single-shot range precision for most stations approaches that of their target-board ranging.

Figure 4-6. BLITS satellite (courtesy of IPIE)

The PRoject for OnBoard Autonomy-2 (PROBA-2)

Figure 4-7. PROBA-2 satellite (courtesy of ESA)

PROBA is a series of technology demonstration missions of the European Space Agency. PROBA-2, the second satellite in the series and shown in Figure 4-7, was successfully launched on November 2, 2009 from the Plesetsk Cosmodrome in Russia and continues ESA's validation of new spacecraft technologies while also carrying a scientific payload. The objectives of PROBA are in-orbit demonstration and evaluation of (1) new hardware and software spacecraft technologies, (2) systems for onboard operational autonomy, and (3) instruments for Earth observation and space environment measurements. PROBA-2 carries solar observation instruments, plasma measurement instruments, a GPS receiver, and an SLR retroreflector array. GPS provides POD, validated using SLR from a two-week ILRS campaign in March-April 2010. The spacecraft continues to provide solar science data. For further information see: *http://www.esa.int/esaMI/Proba/SEMJJ5ZVNUF_0.html.*

CryoSat-2

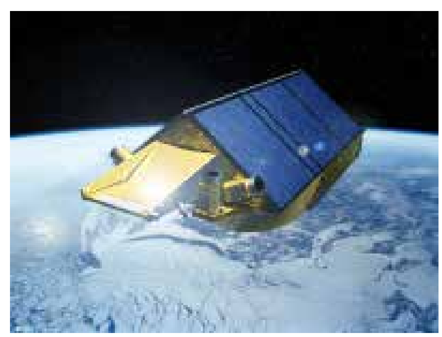


Figure 4-8. CryoSat-2 (courtesy of ESA)

A mission to measure change in the cryosphere, CryoSat-2 (Figure 4-8), was launched on April 8, 2010 into a non Sun-synchronous polar orbit 720km above the Earth. It is measuring the thickness of sea-ice and the surface elevation of ice sheets in both Northern and Southern hemispheres. For this, it uses an advanced radar altimeter combined with precise orbit determination. In addition, CryoSat-2's ocean measurements are being exploited by the French space agency CNES to provide global ocean observation products in near-real time. Understanding sea-surface currents is important for marine industries and protecting ocean environments. POD is carried out by the onboard DORIS system, with calibration of the altimeter and independent support for POD being supplied by ILRS SLR observations. More information is available at: *http://www.esa.int/esaLP/SEM54JVX7YG_LPcryosat_0.html.*

TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X)

TanDEM-X was launched on June 21, 2010. The goal of the TanDEM-X mission is to generate a high-accuracy global Digital Elevation Model (DEM). This goal is being achieved through TanDEM-X flying in a close (separation 250-500m) tandem orbit configuration with TerraSAR-X (Figure 4-9). Like TerraSAR-X, the satellite also carries the experimental Tracking, Occultation and Ranging (TOR) package provided by GFZ. TOR consists of a two-frequency CHAMP-type GPS receiver and a CHAMP Laser Retro-Reflector (LRR), giving access to high-precision orbit determination and inter-satellite interferometric baseline vector information. The mission's objectives are generation of DEM (e.g., for hydrology), along-track interferometry (e.g., for measurement of ocean currents), and bi-static applications (e.g., polarmetric SAR interferometry). More information is available at: *http://www.dlr.de/hr/en/desktopdefault.aspx/tabid-2317/3669_read-5488/.*

Figure 4-9. TanDEM-X and TerraSAR-X in close formation (DLR)

Quasi-Zenith-Satellite-1 (QZS-1)

The Quasi-Zenith Satellite System (QZSS) is a Japanese regional satellite navigation program planned to serve East Asia and Oceania. The first satellite of a two-stage deployment, QZS-1 (shown in Figure 4-10), was launched from the Tanegashima Space Center into a slightly elliptical geosynchronous orbit on September 11, 2010 for technical validation and demonstration of several applications.

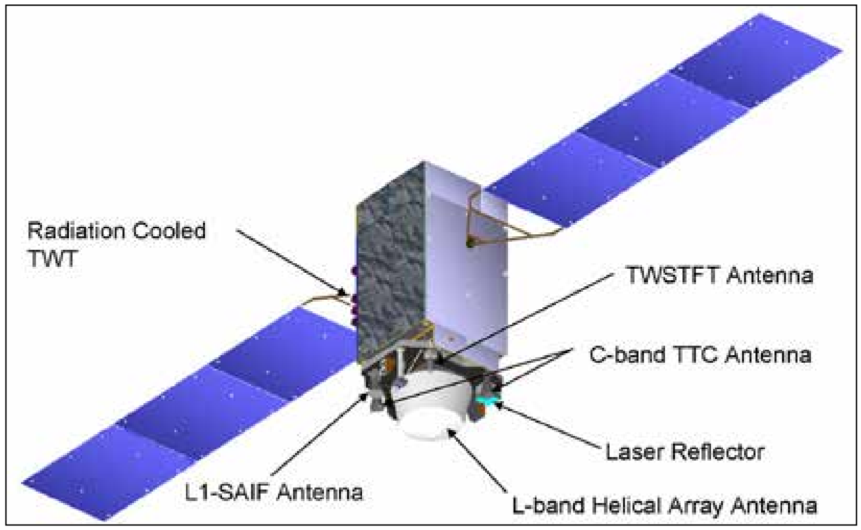


Figure 4-10. QZS-1 (courtesy of JAXA)

Ultimately, QZSS will be a three-satellite constellation where each satellite orbits in a different orbital plane such that at least one satellite is in place near the zenith over Japan at all times. The system will have complete interoperability with GPS, with JAXA and related research institutes managing the technology development and augmentation from QZSS. SLR tracking on QZS-1 is necessary in order to estimate navigation data biases and to evaluate the accuracy of orbit determination, which has a goal of several tens of centimeters. ILRS stations in the Western Pacific Laser Tracking Network routinely track QZS-1, mostly during the night. For additional information see: *http://www.jaxa.jp/projects/sat/qzss/index_e.html.*

FUTURE MISSIONS

A number of new missions requiring SLR support for POD and instrument calibration and validation are scheduled for launch over the next few years. All the satellites shown in Table 4-2 have sought and been granted tracking approval by the ILRS Governing Board.

Note: Requests for new mission support by the ILRS should be submitted via the online request form on the ILRS website at *http://ilrs.gsfc.nasa.gov/missions/mission_support/index.html*. Requests are reviewed by the ILRS Missions Working Group for suitability and then vetted by the ILRS Governing Board. Mission sponsors must supply precise details of the on-board characteristics of the retroreflector arrays as part of their Mission Support Request at the above link.

Table 4-2. Upcoming Missions Approved for ILRS SLR Support During 2009-10

Mission	Launch	Altitude (km)	Sponsor	Application	ILRS Mission Support Requirement
RadioAstron	Mid-2011	500-350,000	Lavochkin Association, Russia	Astrophysics	Episodic tracking sessions
KOMPSAT-5	2012	550	Korea Aerospace Research Institute (KARI)	SAR for Earth observation	Routine in support of GPS-based POD
SARAL	2012	800	CNES and Indian Space Research Organisation (ISRO)	Sea Surface	Routine for POD in support of DORIS

RadioAstron

The RadioAstron project (Figure 4-11, the Spectr-R project) is an international collaborative mission to launch a free flying satellite carrying a 10-meter radio telescope in high apogee (~350,000 km) orbit around the Earth. The aim of the mission is to use the space telescope to conduct interferometer observations in conjunction with the global ground radio telescope network in order to obtain images, coordinates, motions and evolution of angular structure of different radio emitting objects in the Universe with an extraordinary high angular resolution. Laser tracking to the 100-cube onboard array, most likely only possible from Lunar-capable SLR stations, will be important for the mission goals and be used to support the construction by RadioAstron of a high-precision celestial coordinate frame and a test of General Relativity by means of precision redshift measurements.

Figure 4-11. RadioAstron (courtesy Lebedev Physical Institute, Moscow, Russia)

KOMPSAT-5

The KOMPSAT-5 satellite (Figure 4-12) will carry out from low Earth orbit all-weather day/night monitoring of the Korean peninsula. The primary mission of the KOMPSAT-5 system is to provide high resolution mode SAR images of 1 meter resolution, standard mode SAR images of 3 meter resolution and wide swath mode SAR images of 20 meter resolution with viewing conditions of the incidence angle of 45 degrees using the COSI (COrea SAR Instrument) payload, for meeting GOLDEN mission objectives. GOLDEN stands for GIS, Ocean and Land management, Disaster and Environmental monitoring.
The secondary mission of KOMPSAT-5 is to generate atmospheric sounding profiles and support radio occultation science using AOPOD (atmospheric occultation and precision orbit determination). The secondary payload is composed of a dual frequency GPS receiver and a four-cube GFZ laser retroreflector array, identical to that flown on CHAMP and GRACE.

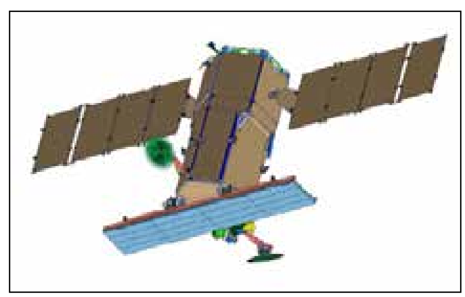


Figure 4-12. KOMPSAT-5 (courtesy of KARI)

SARAL

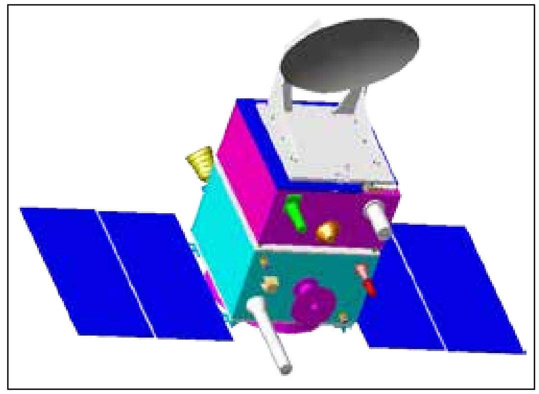


Figure 4-13. SARAL (courtesy of AVISO)

Satellite with ARgos and ALtika (SARAL) is a cooperative mission between CNES and the Indian Space Research Organization (ISRO) The mission (Figure 4-13) is complementary to Jason-2 and will provide observations of ice, rain, coastal zones, and wave heights. SARAL results from the common interests of CNES and ISRO in studying the oceans from space using altimetry and providing maximum use of ARGOS (Advanced Research and Global Observation Satellite), a joint NOAA CNES data collection system. The main mission objectives of SARAL are to create precise, repetitive global measurements of sea surface height, wave heights, and wind speed, ensure continuity of the altimetry service currently available from Envisat and Jason-1/-2 and to contribute to global ocean and climate studies to build a global ocean observing system. Instrumentation includes a CNES altimeter/radiometer (AltiKa), a DORIS system, a nine-cube laser reflector array built by CNESS and the ARGOS system. POD will be achieved by DORIS, with SLR providing strong tracking information to complement DORIS and by providing a unique and unambiguous verification of the absolute radial orbit accuracy.

Section 5
Operations

SECTION 5

OPERATIONS

Carey Noll/NASA GSFC, Michael Pearlman, CfA, Randy Ricklefs/CSR

ILRS CENTRAL BUREAU COORDINATION

The ILRS Central Bureau was responsible for the daily coordination and management of the ILRS activities including communication and information transfer, monitoring and promoting compliance with ILRS network standards, monitoring network operations and quality assurance, maintaining documentation and data bases, and organizing meetings and workshops. The Central Bureau worked with new missions in preparation for launch, orbital acquisition and assessment of tracking performance, organized the meetings of the Governing Board and issued the meeting notes, documented and assigned action items and monitored progress toward their completions, and met monthly at GSFC and issued meeting notes.

Aside from daily operations and routine monitoring of network and data performance, the Central Bureau also oversaw or participated in the following activities:

- Implementation of the CRD data format for improved range precision and extended range;
- Implementation of restricted tracking procedures for tracking optically vulnerable satellites;
- Update of the ILRS website to include additional charts on network performance, new procedures, and updated forms for new missions and retroreflector specification information;
- Harmonization for data procedures between CDDIS and EDC including a quarantine and verification procedure for new stations or stations returning to operation after major repairs of upgrades;
- Update of the prediction process for improvement in the tracking of satellites in very low orbits;
- Provision of letters of support for stations as required;
- Improved normal point definition for high repetition rate systems to improve data yield;
- Implementation of the new Retroreflector Standard for GNSS satellites for improved GNSS data yield and day light operations;
- Program organization of the 17th International Laser Ranging Workshop in Bad Koetzting to be held in 2011.

The Central Bureau staff also participated in all of the Working Groups and Task Forces.

DATA CENTER DEVELOPMENTS

The ILRS introduced the Consolidated Ranging Data (CRD) format during 2008. CRD provides a flexible, extensible format for ILRS full-rate, sampled engineering, and normal point data. The new format will accommodate new missions, e.g., transponder experiments, and station capabilities such as high-repetition rate lasers. The data centers began support of CRD tests by creating directories and updating data flow procedures. The complete transfer to the CRD format is scheduled for mid 2011.

The ILRS continues to improve data throughput. Data from the field stations are now submitted hourly and made available immediately through the data centers for rapid access by the user community and prediction providers. With this faster submission of data, better quality predictions are available more frequently and prediction quality assessment is available in near real-time.

The ILRS Data Center at the Crustal Dynamics Data Information System (CDDIS)

Introduction

Since 1982, the Crustal Dynamics Data Information System (CDDIS) has supported the archive and distribution of geodetic data products acquired by NASA as well as national and international programs. These data include GNSS (Global Navigation Satellite System), SLR and LLR (Satellite and Lunar Laser Ranging), VLBI (Very Long Baseline Interferometry) and DORIS (Doppler Orbitography and Radiolocation Integrated by Satellite). The CDDIS data system and its archive supports several of the operational services within the International Association of Geodesy (IAG) and its project the Global Geodetic Observing System (GGOS), including the ILRS, the International GNSS Service (IGS), the International VLBI Service for Geodesy and Astrometry (IVS), the International DORIS Service (IDS), and the International Earth Rotation Service (IERS).

CDDIS Operations

The update process for the CDDIS archive process can be divided into several structural components allowing for efficient and secure processing: deposit, operations, download, and archive support.

Deposit: Suppliers of content for the archive (e.g., network tracking data from operational centers, products from analysis centers, etc.) transfer their data and product files to the CDDIS deposit or "incoming" disk location using ftp. These incoming accounts have limited privileges allowing users to only deposit files. In a few cases, the CDDIS will retrieve files for the archive from data/product sources. All suppliers access a server dedicated to receipt of incoming files.

Operations: All processing of incoming files takes place in the CDDIS operations area, which is accessible to internal users only. Software scans the deposit directories on pre-determined schedules dependent upon the type of incoming files and copies the files to temporary locations where their contents are validated for readability and integrity (format and content) and metadata are extracted and loaded into a relational database. Valid files are moved to the CDDIS archive.

Download: The CDDIS public archive is openly accessible to the scientific community through anonymous ftp and the web (future enhancements will permit http access to the CDDIS archive). It is the repository for all valid files provided by the operational/regional/global data centers, analysis centers, and analysis center coordinators. The structure of the archive follows conventions established within the services and thus is data type (i.e., GNSS, SLR, VLBI, or DORIS) dependent. All users access a separate computer system dedicated to serving files from the archive's disk farm.

Archive Support: A final portion of the CDDIS archive update process is devoted to utilizing extracted metadata to maintain supporting information, particularly files summarizing the contents of the download area, statistics on the timeliness of the incoming files, etc.

Computer System Upgrade

On June 21, 2010 the CDDIS transitioned operations to a new distributed server environment. This new configuration allows for efficient and timely processing of incoming files as well as enhanced system security by separating user/archive functions. Distinct servers handle incoming data and product files (server cddisin.gsfc.nasa.gov), outgoing ftp and http requests (server cddis.gsfc.nasa.gov), and archive operations to the RAID storage. Servers handle load balancing on incoming queries for files to host cddis.gsfc.nasa.gov.

The archive server manages the RAID storage and its connections to the incoming and outgoing servers. Each server has a "hot spare" which can take over operations should a failure occur with the prime server. Additional RAID storage has been installed to bring the total available storage for the CDDIS archive to nearly 16 Tbytes, plus additional internal storage for processing and database applications. The CDDIS archive increases in size by approximately 1 Tbyte/year; the existing storage will accommodate the archive requirements for the near future. The CDDIS computer system also includes a secondary server for daily backup of the archive. Furthermore, two additional servers and RAID arrays will be set up in the next few months at another GSFC location to provide a complete backup server environment should access to the primary systems be disabled.

In addition to computer hardware changes, the CDDIS replaced its internal database management software (Oracle) with MySQL. This change required modification to database schemas, supporting software, and report queries.

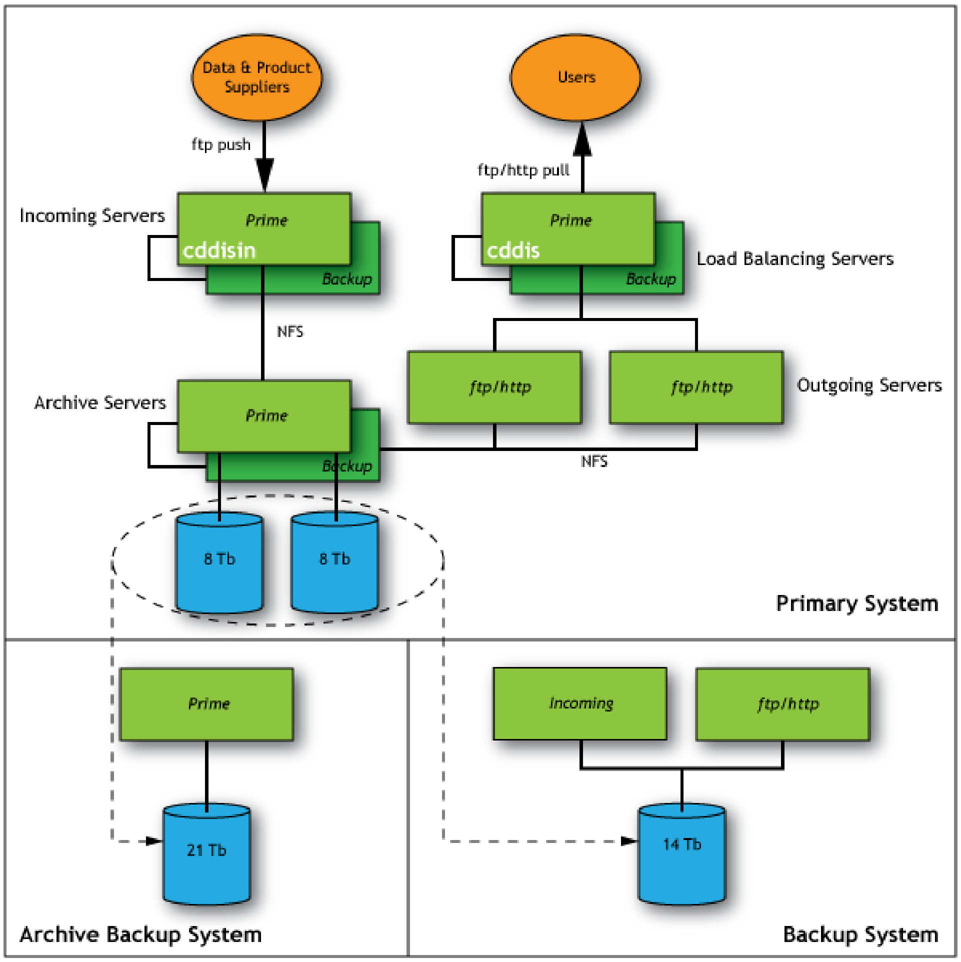


Figure 5-1. New CDDIS System Architecture.

Contact

Carey Noll
Code 690.1
NASA GSFC
Greenbelt, MD 20771
USA

E-mail: Carey.Noll@nasa.gov
Phone: 301-614-6542
Fax: 301-614-6015

Automated Data Management of SLR Data and Products at the EUROLAS Data Center (EDC)

Christian Schwatke/Deutsches Geodätisches Forschungsinstitut (DGFI)

Introduction

The DGFI operates the EUROLAS Data Center (EDC) since 1994. The main task is to assure that the SLR data and products are available for the stations, analysis centers, combination centers, prediction providers and users. In addition to the data center, the EDC runs an ILRS Operation Center. Tasks of the Operation Center are to quality check and validate SLR observations (both normal point and full-rate data sets) for format errors. In addition, prediction products must be checked by the Operation Center.

System Architecture

The continuously uploading and downloading of data and products by stations, analysis centers, combination centers, prediction providers, and users to the EDC requires an operational system which has as few as possible outages. To achieve this objective the system architecture has been changed.

In the past there was only one operational system available at the EDC. The data holdings were then backed up to an internal server.

The system architecture has been upgraded, making two identical, mirrored systems available. The address of the FTP is *ftp://edc.dgfi.badw.de.* The user will be directed automatically to one of the FTP servers. By using techniques such as port forwarding the failing of individual services (FTP, WWW) can be handled by redirecting requests to different servers. This procedure minimizes the downtime of the EDC.

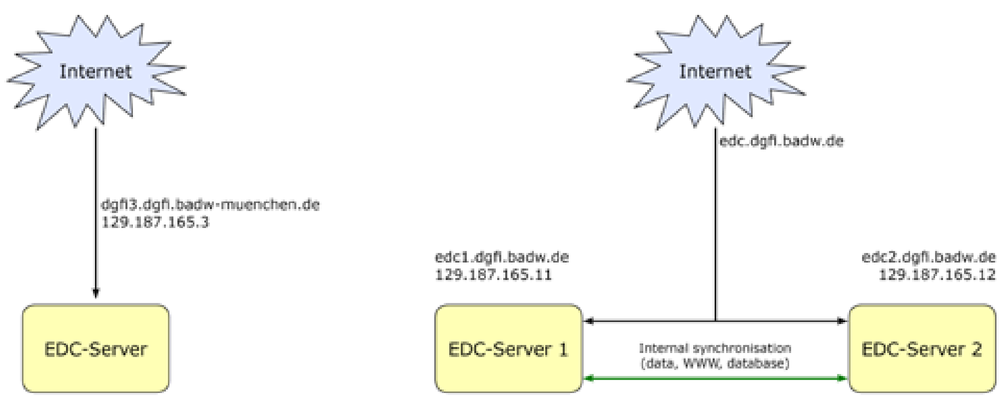


Figure 5-2: Past and current system architecture

Data Flow of EDC within the ILRS

Recently, data exchange within the ILRS infrastructure has become more important, particularly the data transfer between the data centers EDC and CDDIS has changed. Generation of sub-daily predictions for low Earth orbiting (LEO) satellites, such as GRACE, GOCE and others, are necessary. An additional hourly data exchange of data, in the new Consolidated Laser Ranging Data (CRD) format, and predictions, in the Consolidated Prediction Format (CPF), has been realized.

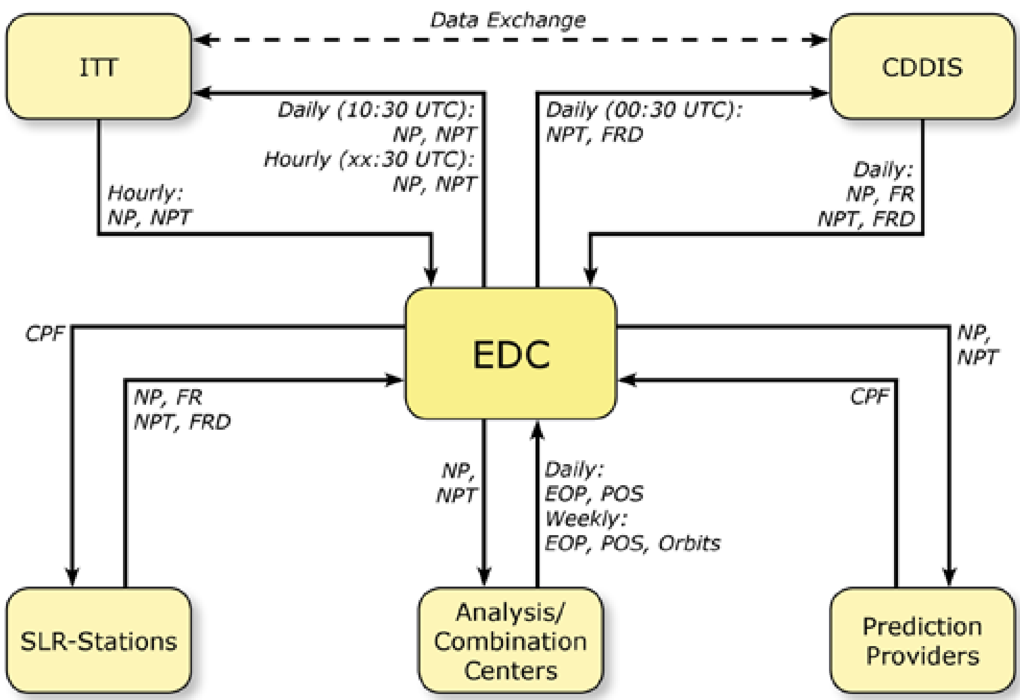


Figure 5-3: Data Flow of EDC within the ILRS

The data flow in the ILRS begins at the SLR-stations, which send normal point and full-rate data sets to the Operations Centers (OCs) located at EDC and NASA. The OCs check all incoming SLR observations. All valid normal point data sets are sent to the NASA Operations Center on an hourly basis. Additionally, a daily file is send to the NASA OC at 10:30 UTC. Independently from NASA, EDC sends daily files with normal point and full-rate data sets to CDDIS at 00:00 UTC. Conversely, the EDC receives hourly normal points from the NASA OC and daily normal point and full-rate data sets from CDDIS.

All SLR observations are available to the ILRS community through the FTP server of the EDC (ftp://edc.dgfi.badw.de). Normal points are used by the Analysis and Combination Centers for the estimation of EOPs, station positions, and orbits. Normal points are also used by Prediction Centers to estimate predictions of satellites. All of these products are also delivered to the EDC and are available on FTP. Additionally, predictions are forwarded via mail to SLR stations.

Data Management at the EDC

The EDC changes the procedure of managing SLR data and products with the introduction of the new Consolidated Laser Ranging Data (CRD) format, the Consolidated Prediction Format (CPF) and the change to a hourly data exchange.

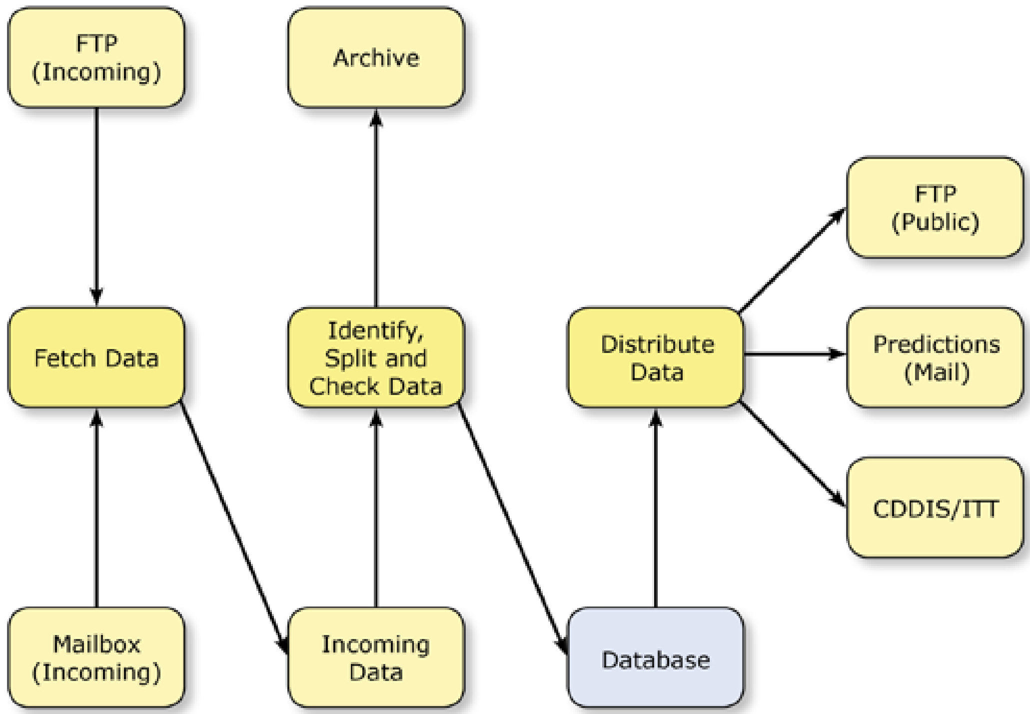


Figure 5-4: Data flow at the EDC

At the EDC, all types of SLR data sets are delivered by mail or ftp. The first step in the data flow is to fetch all data sets from the ftp and mailbox and move them into an incoming folder. Afterwards, a type-identification (NPT, NP, FRD, FR, CPF, etc) occurs. The original data set will be kept untouched with the original timestamp in an archive. Within the Operation Center all data sets are checked to detect format errors. If erroneous data are found, the station manager will be informed to correct them. Multi pass files are split into single pass files. Every single pass file is then saved as a new data set in the database. Each normal point and full-rate data set can be identified by satellite ID, station ID, start date of measurement, end date of measurement, and version. Predictions can be identified by satellite ID, provider, start date, and end date.

The last step in the data flow at the EDC is the distribution of data. All valid data sets are published via FTP. Additionally, CPF predictions are sent to stations as timely as possible after submission. Finally, the data exchange between EDC, the NASA OC, and the CDDIS is executed as described previously.

ILRS Mailing Lists

The EDC maintains the following mailing lists within the ILRS:

- SLR-Mail (*http://slrmail.dgfi.badw.de*)
- SLR-Report (*http://slreport.dgfi.badw.de*)
- Urgent-Mail *(http://urgent.dgfi.badw.de*)
- Rapid Service Mail (http://rapidservicemail.dgfi.badw.de)

SLR-Mail is used to communicate a message to the full ILRS membership (ILRS associates and correspondents). The SLR-Reports are usually computer-generated reports to communicate a periodic status report to interested parties, which are suitable for automated processing. The Urgent-Mail informs station operators about upcoming satellite maneuvers, urgent modification of satellite priorities, etc. The Rapid Service Mail informs stations and analysis centers about detected errors in SLR observations.

Prior to 2011, all mailing lists were managed through scripts. They operated in a semi-automated fashion and required special tags for message handling. A transition to the open source software "Mailman" software was made in 2011. The mailing lists now work automatically and do not require any special tags for processing.

EDC Website

The EDC has redesigned their website (*http://edc.dgfi.badw.de*). This website provides near real time access to the data flow at the EDC. The current status of incoming normal point and full-rate data and predictions are available. If erroneous data sets were submitted, information about the error is available. Statistics about the normal points, full-rate data, and prediction data holdings are also available.

Figure 5-5: Website of EDC

Contact

Christian Schwatke
E-mail: schwatke@dgfi.badw.de
Deutsches Geodätisches Forschungsinstitut (DGFI)
Alfons-Goppel-Str. 11
80539 München, Germany

INFRASTRUCTURE SUPPORT

New CRD Format

Randy Ricklefs/U. Texas at Austin/CSR

Due to the one-way laser ranging support of the Lunar Reconnaissance Orbiter (LRO) mission, and the growing number of stations with lasers firing at a kilohertz rate, the Data Formats and Procedures Working Group has rewritten the formats for the ILRS full-rate, normal point, and sampled engineering data types. The older formats do not allow for many of the fields or field sizes required for ranging to transponders. In addition, the current full-rate format is too cumbersome for the amount of data produced by kilohertz laser ranging. The new format encompasses all three data types for SLR, LLR, and transponder targets. The Consolidated Laser Ranging Data (CRD) format uses the same building block approach as the Consolidated Prediction Format (CPF), which allows modularity, flexibility, and expandability. Since the CRD format is considerably more complicated than the old formats, a process was developed by which the ILRS Operations Centers (OCs) at EDC and NASA/HTSI and the AWG would validate CRD normal points from each station. Once a station's data are validated, the station normally submits data only in the CRD format. As of the end of 2010, 29 stations were sending normal point to the OCs in the CRD format, with 25 having passed the validation tests. At the same time, many stations were producing full-rate data in the CRD format. To assist in implementing the new format, sample code is provided on the ILRS website.

Satellite Predictions

There are now ten centers that provide SLR predictions on a regular basis (see Table 5-1).

Table 5-1. Satellite Prediction Providers (as of December 2010)

Center	Interval	Satellites
CNES	Daily	Jason
CODE	Daily	GLONASS, GOCE, GPS
ESOC	Daily	CryoSat-2, Envisat, ERS-2, GIOVE, GOCE
FDF	Daily	LRO
GFZ	Sub-daily	GRACE, CHAMP, TerraSAR-X
HTSI	Daily	Ajisai, BE-C, BLITS, COMPASS-M1, CryoSat-2, Envisat, ERS-2, Etalon, GIOVE, GLONASS, GPS, Jason, LAGEOS, LARETS, Starlette, Stella
JAXA	Daily	Ajisai, LAGEOS, QZS
MCC	Daily	BLITS, LARETS
NSGF	Daily	Ajisai, BE-C, Envisat, ERS-2, Etalon, Jason, LAGEOS, LARETS, Starlette, Stella
SAO	Sub-weekly	COMPASS-M1
UTX	Daily	Moon

The Consolidated laser ranging Prediction Format (CPF) is used within the ILRS for ranging to Earth satellites and the Moon, and for transponder ranging to planets and interplanetary spacecraft. In the process of developing the format, sample software was developed to allow standardizing prediction interpolators used at the stations. Since 2006, the tracking of very low Earth orbit satellites has increased significantly with the sub-daily distribution of the new, high quality CPF predictions. Many stations have also been able to range to the Lunar Reconnaissance Orbiter, the first target in lunar orbit and the first one-way transponder mission to be tracked.

The ILRS is encouraging stations to use the mission-provided or -sanctioned predictions for satellites where they are available. Some of the recent missions have periodic maneuvers or drag compensation capability, and some also have GPS data from on-board receivers to enhance the SLR predictions. Since the missions have the most up-to-date information of this type, they are in the best position to keep predictions current and accurate.

Satellite Priorities

The ILRS tries to order its tracking priorities (shown in Table 5-2) to maximize the utility to the users of ILRS data. Nominally tracking priorities decrease with increasing orbital altitude and increasing orbital inclination (at a given altitude). Priorities for some satellites are then increased to intensify support for active missions (such as altimetry), special campaigns (such as satellite in eclipsing orbit), and post-launch intensive tracking campaigns. Some slight reordering may then be given missions with increased importance to the analysis community. Some tandem missions (e.g., GRACE-A and -B) may be tracked on alternate passes at the request of the sponsor. Stations may also adjust priorities to accommodate local conditions such as system capabilities, weather, and special program interests.

Table 5-2. Satellite and Lunar Tracking Priorities (as of December 2010)

Satellite Priorities					
Priority	**Satellite**	**Sponsor**	**Altitude (km)**	**Inclination (degrees)**	**Comments**
1	GOCE	ESA	295	96.7	
2	GRACE-A/B	GFZ, JPL	485-500	89	Tandem mission

3	CryoSat-2	ESA	720	92	
4	TanDEM-X	Infoterra/DLR/ GFZ/CSR	514	98	Tandem with TerraSAR-X
5	TerraSAR-X	Infoterra/DLR/ GFZ/CSR	514	97.44	Tandem with TanDEM-X
6	Envisat	ESA	796	98.6	Tandem mission with ERS-2
7	ERS-2	ESA	800	98.6	Tandem mission with Envisat
8	BLITS	Russia	832	98.77	
9	Jason-1	NASA, CNES	1,350	66.0	Tandem mission with Jason-2
10	Jason-2	NASA, CNES, Eumetsat, NOAA	1,336	66.0	Tandem mission with Jason-2
11	Larets	IPIE	691	98.2	
12	Starlette	CNES	815-1,100	49.8	
13	Stella	CNES	815	98.6	
14	Ajisai	JAXA	1,485	50	
15	LAGEOS-2	ASI, NASA	5,625	52.6	
16	LAGEOS-1	NASA	5,850	109.8	
17	QZS-1	JAXA	32,000-40,000	45	WPLTN tracking only
18	BE-C	NASA	950-1,300	41	
19	Etalon-1	Russian Federation	19,100	65.3	
20	Etalon-2	Russian Federation	19,100	65.2	
21	COMPASS-M1	China	21,500	55.5	
22	GLONASS-115	Russian Federation	19,400	65	Replaced GLONASS-99 (31-Mar-2009)
23	GLONASS-120	Russian Federation	19,400	65	Replaced GLONASS-109 (06-Apr-2010)
24	GLONASS-102	Russian Federation	19,400	65	Replaced GLONASS-89 (04-May-2007)
25	GPS-36	U.S. DoD	20,100	55.0	
26	GIOVE-A	ESA	29,601	56	
27	GIOVE-B	ESA	23,916	56	
28	GLONASS-109	Russian Federation	19,400	65	
29	GLONASS-110	Russian Federation	19,400	65	
30	GLONASS-118	Russian Federation	19,400	65	

Lunar Priorities			
Priority	Retroreflector Array	Sponsor	Altitude (km)
1	Apollo 15	NASA	356,400
2	Apollo 11	NASA	356,400
3	Apollo 14	NASA	356,400
4	Luna 21	Russian Federation	356,400
5	Luna 17	Russian Federation	356,400

Tracking priorities are formally reviewed semi-annually by the ILRS Governing Board. Updates are made as necessary. The Central Bureau communicates these updates to the ILRS stations.

Restricted Tracking on Vulnerable Satellites

Randy Ricklefs/U. Texas at Austin/CSR

During the last few years, network procedures have been implemented to protect satellites that are vulnerable to laser radiation. Satellites such as ICESat and ALOS have optical sensors aboard that could be damaged. Restricted satellite missions may opt to request one, two, or all of the possible restrictions for their mission, but the numbers 1 and 6 below are required procedures. The procedures include:

- predictions are sent to only participating (qualified) stations;
- stations are restricted to a maximum ranging elevation to protect fixed nadir pointing sensor(s);
- missions provide allowable pass segment files to carefully define tracking and non-tracking periods;
- stations are constrained by a mission-provided, Web-accessible GO/NO-GO flag which allows immediate (within 5 minutes) cessation of all network tracking of the target;
- stations can also be constrained to a mission-defined maximum power delivered to the spacecraft; and
- participation is limited to trusted stations that have demonstrated the ability to handle the restrictions (from 2-5 above) required by the mission.

A questionnaire regarding each station's ability to handle these various restrictions was circulated in 2009, with 31 stations responding. A total of 15 stations had the capability of handling all but the power restrictions. At that time, only 2 stations had automatic power control, although more could accomplish control manually. Another 10 were planning to add at least some of these capabilities, often on an as-needed basis. The latest information by station can be viewed through the Stations section of the ILRS website at *http://ilrs.gsfc.nasa.gov/network/stations/index.html*. Regardless of these findings, each mission requiring tracking restrictions should plan and conduct tests of their chosen sub-network with a non-restricted satellite.

During this period ICESat and LRO used the GO/NO-GO flag. ICESat also imposed elevation restrictions, and LRO required a power level restriction. Both provided predictions to a select sub-network.

Improved Normal Point Formulation Strategy

Peter Dunn

The original Herstmonceux normal point definition specifies a standard normal point interval (SNPI) for each satellite based on altitude. Normal points start and stop at prescribed times and the normal point epoch is taken as the epoch of the central point in the normal point full rate (FR) population. This definition was adopted based on our then current firing rates of 5 – 10 Hz.

As SLR systems move to higher repetitions rates (0.1 – 2 KHz) and more automation we need to revisit the definition of our normal points or at least make a provision for those systems that performance could be greatly enhanced with more flexibility. In particular, systems with higher repetition rates can use shorter normal point intervals, greatly improving satellite interleaving capability. In addition, stations in dense regions of the network (e.g. Europe, China, etc) may be requested to range differently from stations in sparse regions (South Africa, Tahiti, etc) to some satellites to enhance coverage. Stations in dense regions may be asked to share coverage on some satellites while those in sparse may have to time share among satellites more efficiently.

GGOS sets a goal of 1mm precision from the best performing systems. Normal points from each stations should be structured to extract the maximum amount of information that a station can provide; so structure will depend upon laser pulse repetition rate, pulse width, system noise, receiver characteristics, target signature, etc.

A Normal Point Study Group has been established to recommend modifications to the Herstmonceux procedure to better optimize our ranging resources. The over riding theme however is that it be as uncomplicated as possible.

The work of the Study Group is still underway, but a procedure being considered is the following:

1. A Normal Point is completed when either 1000 valid FR points have been taken, or the SNPI has been reach, whichever comes first;
2. If a station achieves 1000 valid FR points in less that the SNPI, it can move on to another satellite;
3. If the full SNPI has been required to populate the normal point, ranging can continue on the current satellite or another satellite;
4. A station should not return to Satellite 1 until at least the SNPI has elapsed;
5. New normal points can start at any time;
6. The epoch of the normal point is that of a central FR data point in the normal point population.

When the Study Group deliberations have been completed, the procedure will be released to the Analysis Working Group for assessment

SECTION 6
ANALYSIS REPORT

SECTION 6

ANALYSIS REPORT

Erricos Pavlis/GEST/UMBC and Cinzia Luceri/e-GEOS S.p.A.

INTRODUCTION

The ILRS is an official Technique Service in the International Earth Rotation and Reference Frame Service (IERS). To fully exploit the unique aspects of the SLR observations, the ILRS Analysis Working Group (AWG) addresses various issues of SLR products, such as quality control, the estimated parameter group, the satellite data to be used, and format definition/use, optimization, and (the development of) an official combination product on the basis of the individual AC contributions. Additional products being considered are evaluated through a number of so-called pilot projects, with several initiated during the past few years, some of them successfully completed and others still ongoing. This contribution to the ILRS Report presents an update on the status and the results of these efforts. General information on AWG activities, membership and more detailed information on the pilot projects can be found on the relevant Internet pages (*http://ilrs.gsfc.nasa.gov/science/awg/index.html*).

Activities in 2009 and 2010

The ILRS AWG met on four occasions during the period covered in this report. AWG meetings are planned to take place on dates close to major geophysical meetings (AGU/EGU) or other (ILRS) venues, in order both to maximize AWG members' attendance and to also encourage interaction with other scientists. The 22nd AWG meeting was held April 24, from 09:00-18:00, during the spring EGU meeting in Vienna, Austria. The brief, half-day 23rd meeting followed at the end of the Fall ILRS Technical Workshop in Metsovo, Greece, on September 19, 2009. In 2010, the 24th AWG meeting was held on May 8 during the spring EGU meeting in Vienna, Austria. The 25th and final AWG meeting for this period was held October 1 in Paris, France. Details on these meetings along with the presentations from the participating groups can be found online at the ILRS web site:
http://ilrs.gsfc.nasa.gov/science/awg/awgActivities/index.html
In addition to these, several members of the AWG participated with presentations and contributions to several position papers in the Unified Analysis Workshop of the Global Geodetic Observing System (GGOS), in December 2009, in San Francisco, CA.

The main activity of the AWG is the development of a unique, best-possible (in terms of quality) analysis product that can be used by the widest possible science community, e.g. station position and EOP. An official solution for station coordinates and daily EOPs is generated by the Analysis Centers (AC) and Combination Centers (CC) on a weekly basis, and submitted to the IERS as an official ILRS contribution. These weekly results depend on high-quality laser range observations to LAGEOS, LAGEOS-2 and to the two Etalon satellites, and the ILRS network is encouraged to support this valuable work, ideally by tracking these satellites day and night, seven days a week. Two different products are distributed each week: a loose constrained estimation of coordinates and EOP and an EOP solution, derived from the previous product, fully constrained to an ITRF. The development of these products goes back to the very first days of the ILRS AWG. The currently operational products and the adopted analysis scheme were agreed upon by the AWG and run continuously in an operational mode since 2003.

In addition to the operational products, the main topics that the AWG focused on during this period were the generation of the ILRS contribution for the development of the ITRF2008 and the evaluation of the ITRF2008. From our experience during the development of ITRF2005 we had surmised that a significant improvement in future analyses would come from the improved handling of systematic errors, whether due to station problems or associated with the target satellites. In that vein the AWG started out to collect, evaluate and document all known or suspected systematic errors for all sites contributing to ITRF2008. A parallel effort was also initiated to improve the modeling of the center-of-mass (CoM) correction for each of our targets, considering the actual operational characteristics of the tracking sites.

During the reporting period, eight different ACs support the operational activities and provide products routinely: ASI, BKG, DGFI, GA, GFZ, GRGS, JCET and NSGF. ILRS has also adopted two official CCs, the primary hosted by ASI and the back-up center at DGFI. These two CCs are responsible for combining the input solutions, and the delivery of the quality-checked and combined ILRS product to IERS. In preparing the weekly combination of the individual solutions, these combination centers follow a strict timeline and have to make sure that the products are of the highest possible quality. Official weekly ILRS products from the two combination centers are available in SINEX format each Wednesday at CDDIS and EDC. All ACs are encouraged to improve the quality of their contributions further. During 2009-2010 ESA/ESOC applied as candidate AC and started undergoing the certification process.

The systematic error documentation effort led to a complete and accurate set of corrections that were adopted and used by all ACs and are now published on the ILRS web pages for use by all SLR data users in the future, in order to ensure the best and most consistent results for any application. The compilation is called the "Data Handling File" and it is put in a SINEX-like format that is machine-readable and allows the automatic use of the information in any analysis environment. It represents a living document that SLR data analysts should interrogate routinely, as it is updated by the AWG:
*http://ilrs.dgfi.badw.de/data_handling/ILRS_Data_Handling_File.sn*x

On the target characterization side, the Task Force that was formed to investigate the subject in 2008 worked diligently to produce initially two tables that listed the range of the applicable corrections for the two LAGEOS and two Etalon arrays for the current configuration of the tracking systems. Since our analysis covers several decades, from 1983 to present, it was agreed that additional work is required to generate a tool that will make available the appropriate correction for each system and any time period our analysis covers. Once this tool becomes available, the AWG will validate it and eventually adopt it for our standard analysis products. For now, the SLR data users who require higher level of accuracy than the one a fixed CoM correction provides, are directed to use the results of this group as they appear online at:

http://ilrs.gsfc.nasa.gov/network/site_information/nsgf_iCoM_LAGEOScorrections.html
http://ilrs.gsfc.nasa.gov/network/site_information/nsgf_iCoM_ETALONcorrections.html

To improve the usefulness of the time series of combination solutions and the ancillary products, thus improve its prospects for future utilization (reliability of resulting velocities, results on historical SLR stations, etc.), the ILRS AWG agreed to extend the period covered by these solutions for our contribution to ITRF2008. The products were submitted to IERS for ITRF2008, in mid-2009, following preliminary analysis of our initial submission (later in 2008), taking into account the feedback from ITRS. The release of ITRF2008 in late 2010 followed a brief period of evaluation of candidate solutions submitted by the two ITRS Combination Centers (IGN/Paris and DGFI/Munich). Figure 6-1 shows the origin and scale components for the contributed products over the period (1983 – 2009).

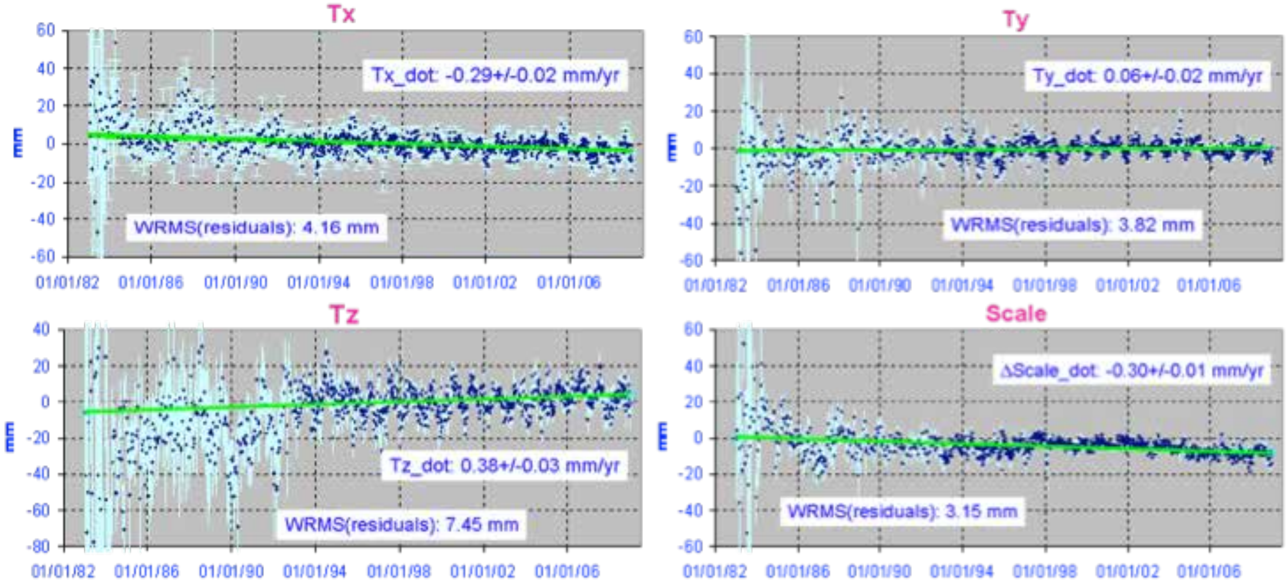


Figure 6-1: Time-series of X, Y, and Z offsets and scale factor of the ILRS-A official combination origin with respect to the reference ITRF (SLRF2005) origin (proxy for "geocenter" variations) and scale as observed by SLR (1983.0 – 2009.0).

IERS/ITRS uses the SLR solutions to exclusively determine the origin of the new ITRF2008 solution. Unlike the previous solution ITRF2005, the scale for the 2008 realization was determined through the combination of the SLR and VLBI contributions, similar to the way that was traditionally done in the past.

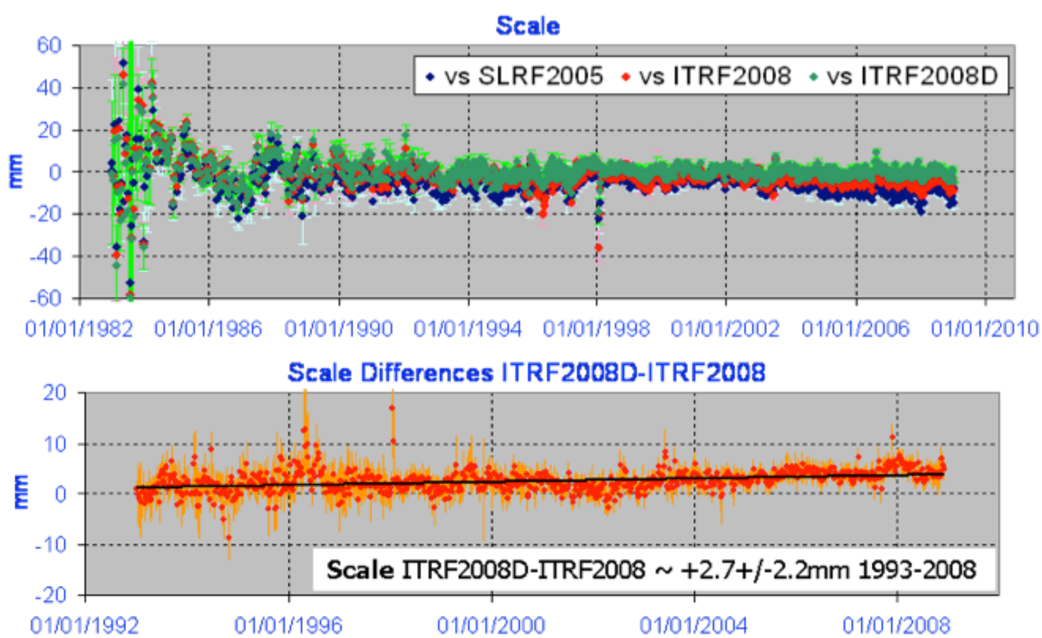


Figure 6-2: Time-series of scale factor variations as observed by SLR (1983.0 – 2009.0) compared to the two candidate ITRF2008 combinations. Note that there is no longer a trend on the SLR scale, especially when compared to ITRF2008D. The two candidate solutions differ by 0.4 ppb/y over 1993-2008.

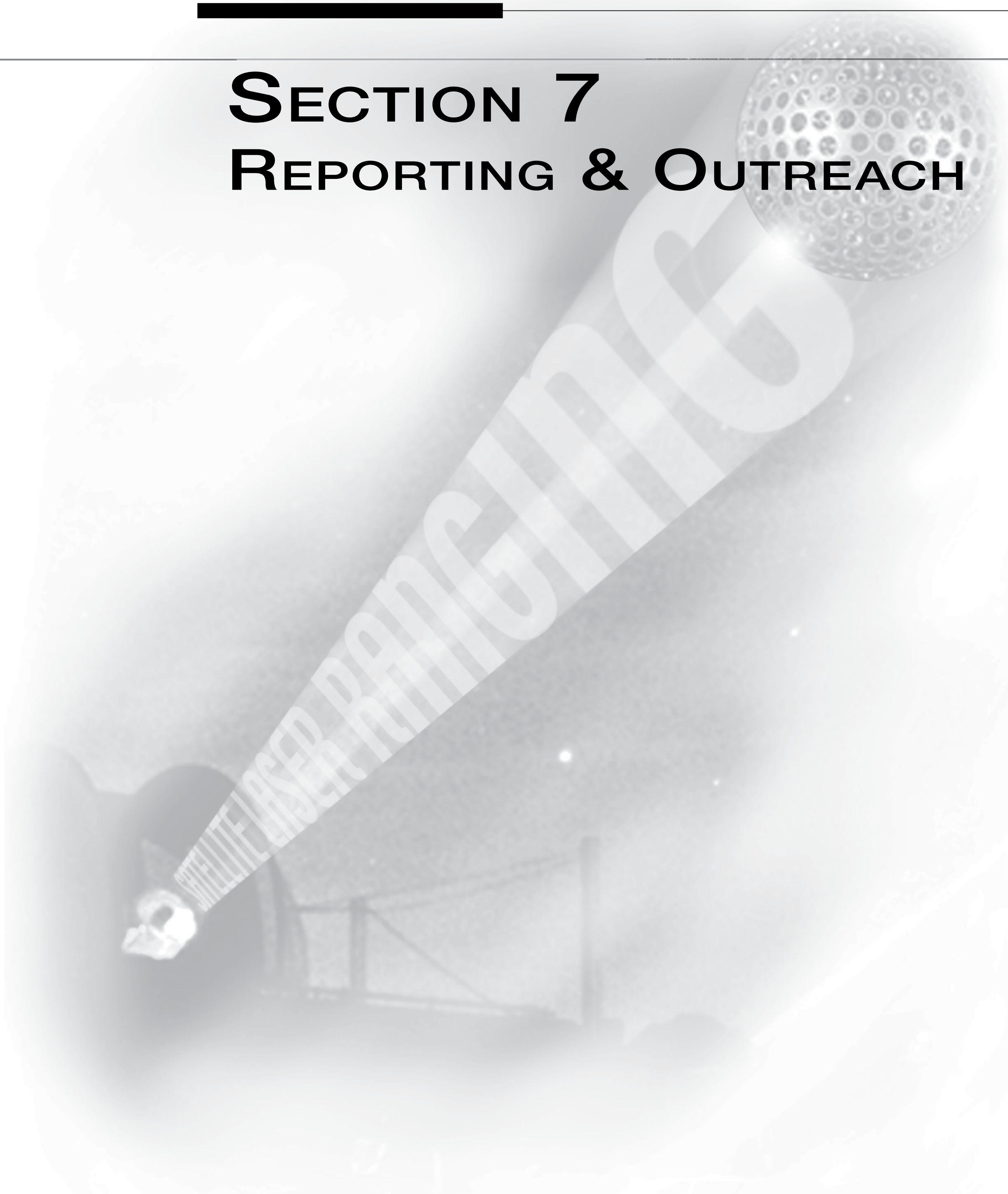
The AWG has also supported ILRS investigations for the harmonization of the two data centers, the optimization of the tracking of the increasing number of GNSS satellites, and the redefinition of the normal points, made necessary with the recent proliferation of high repetition rate systems. All of these investigations are currently ongoing and any decisions will be reported through the usual ILRS communication channels in due time.

The AWG is for some time now considering the expansion of its list of weekly products to fill a void in the area of routinely available precise orbits for the primary SLR targets, i.e., the two LAGEOS and two Etalon satellites. At present this is only a pilot project, however, it is expected that by next year these products will be delivered routinely on a weekly basis. In order to fulfill the need of NEOS for as "fresh" as possible EOP information, the ILRS AWG developed the "daily" product, based on a 7-day arc sliding by one day each day. The results of this analysis were made available to NEOS within two days from the last observation in the analysis, and efforts are underway to further decrease the latency period. By the end of 2010 almost all ACs were able to contribute to the new product. It was further decided that when all ACs have demonstrated this capability, this product should become the official operational product (replacing the weekly one), while the weekly one will be further enhanced with additional modeling improvements that are first to be tested through dedicated Pilot Projects. These include atmospheric loading and gravity variations, and the estimation of a set of low-degree harmonics. The weekly product will thus be the one to contribute to the future ITRF realizations, since IERS is moving in the direction of adopting the same modeling enhancements for all contributed products. It is anticipated that the weekly product will be the "definitive" ILRS product, although it will be available with some additional latency due to the delayed availability of some of the required models.

In the spring of 2010 Dr. Rainer Kelm of DGFI who was in charge of the back-up combination center for the ILRS, retired. DGFI was not able to replace him and suspended the support of that activity, although Dr. Kelm continued the process until a solution was found. After some discussions with the Director of DGFI, it was agreed that JCET could take over the activity once the DGFI software were ported and implemented successfully at JCET. The activity ran in parallel at the two centers during the summer of 2010 and Dr. Kelm visited JCET in September for a brief introduction to the software and a hand-over of the operations to JCET. As of December of 2010, the ILRS-B combination product has been generated at JCET with a smooth transition and no loss of data. The ILRS AWG and JCET in particular, would like to thank Dr. Kelm for his dedication to the support of its activities and for being always available to provide valuable guidance during the transition period.

The AWG has also worked on the improvement of the quality control (QC) process from various semi real-time analyses. In an effort to provide station personnel with improved QC results, it has looked into the development of direct communication channels between the QC centers and the station managers.

SECTION 7
REPORTING & OUTREACH



SECTION 7

REPORTING & OUTREACH

Carey Noll/NASA GSF

WEBSITE DEVELOPMENTS

The ILRS website, *http://ilrs.gsfc.nasa.gov*, is the central source of information for all aspects of the service. The website provides information on the organization and operation of ILRS and descriptions of ILRS components, data, and products. Furthermore, the website provides an entry point to the archive of these data and products available through the data centers. Links are provided to extensive information on the ILRS network stations including performance assessments and data quality evaluations. Descriptions of supported satellite missions (current, future, and past) are provided to aid in station acquisition and data analysis. The current format for the ILRS website has been in use since the early years of the service. Starting in 2010, the ILRS Central Bureau began efforts to redesign the look and feel for the website. The update will allow for a review of the contents, ensuring information is current and useful. Figure 7-1 shows an early mockup of the new design.

Figure 7-1. Prototype design for new ILRS website

STATION REPORTING

Station Performance Report Cards

The ILRS performance "report cards" are issued quarterly by the ILRS Central Bureau (CB). These reports are issued every three months and tabulate the previous 12 months of data quality, quantity, and operational compliance by station. The statistics are presented in one set of tables (one for artificial satellites and a second for lunar reflectors) by station and sorted by total passes in descending order (Figure 7-2). Plots of data volume (passes, normal points, minutes of data) and RMS (LAGEOS, Starlette, calibration) are created from this information and available on the report card website. A second table (Figure 7-3) summarizes independent assessments of station performance (see example in Figure 7-4) from several of the ILRS analysis/associate analysis centers (DGFI, JCET, Hitotsubatshi University, MCC, SAO). The report cards are available on the ILRS website at *http://ilrs.gsfc.nasa.gov/network/system_performance/global_report_cards/index.html.*

Site Information		Data Volume									Data Quality		
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Location	Station Number	LEO pass Tot	LAGEOS pass Tot	High pass Tot	Total passes	LEO NP Total	LAGEOS NP Total	High NP Total	Total NP	Minutes of Data	Cal. RMS	Star RMS	LAG RMS
Baseline		1000	400	100	1500								
Yarragadee	7090	11953	2223	2186	16362	236962	26114	18803	281879	209049	5.0	8.0	8.8
Mount_Stromlo_2	7825	6265	1060	485	7810	66889	10274	2776	79939	56370	3.7	3.5	6.2
Changchun	7237	6537	811	441	7789	67535	6138	2094	75767	42094	5.5	10.3	13.5
Zimmerwald_532	7810	5130	1006	1098	7234	90674	13628	10025	114327	102063	12.1	7.8	10.4
Matera_MLRO	7941	4255	1256	972	6483	59463	14239	8220	81922	88781	.9	2.9	4.6
Graz	7839	4768	669	546	5983	89395	7803	4493	101691	61561	2.0	4.3	5.1
Herstmonceux	7840	3858	753	1246	5857	60912	8723	4483	74118	56157	5.7	9.6	14.6
San_Juan	7406	2741	481	777	3999	41758	5285	5742	52785	51593	6.2	8.8	8.7
Monument_Peak	7110	2646	544	448	3638	48952	6563	3238	58753	42894	4.8	9.3	10.2
San_Fernando	7824	2719	287	44	3050	33551	1378	154	35083	13651	6.5	13.6	17.5
Grasse_MEO	7845	1514	654	867	3035	48092	7400	4165	59657	48139	5.1	15.2	13.6
Potsdam_3	7841	2336	387	58	2781	46361	4123	440	50924	22528	13.0	13.7	17.7

Figure 7-2. Table 1 of the ILRS Report Card for the fourth quarter of 2010

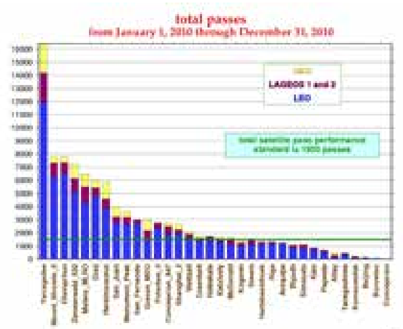
Site Information		DGFI Orbital Analysis				Hitotsubashi Univ. Orbital Analysis				JCET Orbital Analysis				MCC Orbital Analysis				SHAO Orbital Analysis			
Station Location	Station Number	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP	LAG NP RMS (mm)	short term (mm)	long term (mm)	% good LAG. NP
Baseline		**10.0**	**20.0**	**20.0**	**95**	**10.0**	**20.0**	**20.0**	**95**	**10.0**	**20.0**	**20.0**	**95**	**10.0**	**20.0**	**20.0**	**95**	**10.0**	**20.0**	**20.0**	**95**
Yarragadee	7090	4.1	23.4	3.4	100.0	2.2	9.0	3.7	100.0	5.2	30.5	5.0	99.8	2.8	13.8	4.2	97.5	2.3	11.3	3.4	96.1
Mount_Stromlo_2	7825	5.2	21.5	4.3	99.8	4.0	12.0	2.9	100.0	5.3	28.6	3.7	98.6	3.7	14.6	2.8	96.8	2.5	10.3	3.7	94.8
Changchun	7237	6.3	25.1	7.4	99.5	3.9	21.0	7.3	99.4	6.5	32.9	4.9	96.1	3.9	21.0	8.5	97.0	1.7	23.3	4.3	95.3
Zimmerwald_532	7810	2.8	15.7	3.2	99.9	1.4	8.9	2.1	99.9	3.5	21.2	3.6	99.8	2.7	10.1	2.8	98.3	0.9	9.4	2.0	95.0
Matera_MLRO	7941	2.8	20.4	2.8	99.8	1.7	10.7	3.9	99.9	3.5	25.4	3.5	99.5	2.5	17.1	4.3	99.2	2.1	28.5	3.9	98.8
Graz	7839	3.1	16.6	3.3	100.0	1.3	8.5	3.3	100.0	3.7	25.7	21.6	100.0	2.3	8.3	3.1	98.7	1.2	7.0	2.8	95.4
Herstmonceux	7840	3.3	16.5	3.2	100.0	2.0	8.5	2.1	100.0	3.6	23.0	3.1	99.7	2.5	11.0	2.4	98.3	1.3	7.3	1.6	94.5
San_Juan	7406	5.7	52.0	29.6	98.5	3.2	55.6	26.9	99.4	8.0	52.8	26.5	96.8	4.8	18.5	12.0	97.1				
Monument_Peak	7110	3.5	24.4	4.9	99.9	1.5	13.9	2.4	99.9	6.4	33.5	4.8	98.0	1.9	14.1	3.0	99.0	1.2	14.8	3.2	96.8
San_Fernando	7824	4.6	24.5	7.0	100.0	3.0	16.3	7.9	99.6	3.9	29.7	8.1	99.5	2.9	11.4	12.1	95.5				
Grasse_MEO	7845	4.0	17.9	6.0	100.0	2.3	13.0	6.4	99.9	3.7	26.4	5.3	99.1	3.0	9.8	4.4	97.5	1.8	13.2	5.1	95.9

Figure 7-3. Table 2 of the ILRS Report Card for the fourth quarter of 2010

```
Author: Toshimichi Otsubo, Hitotsubashi University
#
# @contact t.otsubo@srv.cc.hit-u.ac.jp (Toshimichi Otsubo)
# @website http://geo.science.hit-u.ac.jp/slr/bias/
# @version 0.15 (2005/02/23)
# @createdAt    2011/01/12 00:20:25
#
# each line contains:
#   sat            = 4-char satellite name
#   site           = 4-char site name (CDP ID)
#   date/time      = pass starting time
#   dur            = pass duration (min)
#   rb             = estimated range bias (mm) with 1-sigma error
#   tb             = estimated time bias (microsec) with 1-sigma error
#   prec           = post-fit scattering rms (mm)
#   bad/total      = number of bad/total normal-points
#   rms            = single-shot rms (mm)
#   pres/temp/humi = pressure (hPa), temperature (K) and humidity (%)
#   sdelay         = applied system delay (mm)
#   shft           = system delay shift (mm)
#   rms            = calibration single-shot rms (mm)
#   cfg            = system configuration flag; SCH and SCI
#   r              = data release flag
#   wlen           = laser wavelength (nm)
#
#  1824 = KIEV
# sat site       date  time dur    rb mm    error         tb us     error     prec bad total  rms   pres  temp hum  sdelay shft   rms cfg r wlen
ERS2 1824 2010/12/29 19:58   5    -165 (      3 )  -------.- ( ----.- )      1   1 /   4   13  995.6 264.6  85   30800    0    12 2 2 0  532
JAS2 1824 2010/12/29 22:28   5     108 (     36 )  -------.- ( ----.- )      6   1 /   4   16  995.6 263.6  85   30800    0    12 2 2 0  532
JASN 1824 2010/12/29 23:29   8     368 ( ----- )  -------.- ( ----.- )      0   1 /   2   30  995.6 263.6  83   30767    0    11 2 2 0  532
STRL 1824 2010/12/29 23:44   2  ------ ( ----- )  -------.- ( ----.- ) -----   2 /   3   54  995.6 263.6  83   30767    0    11 2 2 0  532
GL09 1824 2010/12/30 01:08   7     132 (    364 )  -------.- ( ----.- )     63   0 /   3   24  995.6 263.2  81   30840  146     8 2 2 0  532
STRL 1824 2010/12/30 01:35   3      -7 (      4 )  -------.- ( ----.- )      1   1 /   4   28  995.6 263.5  81   30913    0     6 2 2 0  532
STRL 1824 2010/12/30 03:25   1    -107 (     50 )  -------.- ( ----.- )     11   0 /   3   20  995.6 263.7  80   30913    0     6 2 2 0  532
#
#  1873 = SIMEIS
# sat site       date  time dur    rb mm    error         tb us     error     prec bad total  rms   pres  temp hum  sdelay shft   rms cfg r wlen
JAS2 1873 2011/01/05 15:20   7    -135 (    175 )      290.9 (   65.5 )     94   1 /  25   38  982.4 271.4  79   11043    0     0 0 1 0  532
JASN 1873 2011/01/05 16:22   9     -83 (    159 )      283.2 (   70.8 )     71   0 /  24   26  982.8 271.2  83   11043    0     0 0 1 0  532
LAG2 1873 2011/01/05 16:35  14     -97 (     89 )      322.4 (  129.2 )     65   0 /   9   40  982.7 271.1  84   11043    0     0 0 1 0  532
LAG1 1873 2011/01/05 17:45  18      36 (    336 )      215.1 (  202.2 )     94   0 /  10   56  982.8 270.4  89   11043    0     0 0 1 0  532
STRL 1873 2011/01/07 02:24   2    1461 (    225 )  -------.- ( ----.- )     50   0 /   5   57  983.0 271.5  86   11043    0     0 0 1 0  532
LAG2 1873 2011/01/07 16:39  25    -133 (     89 )      229.2 (  100.4 )     56   0 /   9   42  984.0 273.3  52   11049    0     0 0 1 0  532
LAG1 1873 2011/01/07 18:41   9    -425 (    934 )      494.8 (  556.9 )     65   0 /   6   37  983.9 272.9  32   11049    0     0 0 1 0  532
GL09 1873 2011/01/07 23:48  54     -71 (     63 )       92.0 (  458.7 )     91   0 /   7   58  984.0 272.0  57   11049    0     0 0 1 0  532
```

Figure 7-4. Example of weekly station bias report from Hitotsubashi University.

Example plots from the last 2010 report card are shown in Figure 7-5-a, -b, and -c.



7-5a. Total passes for 2010q4 report card

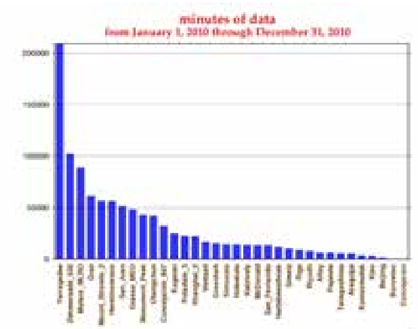


Figure 7-5b. Minutes of data for 20104 report card

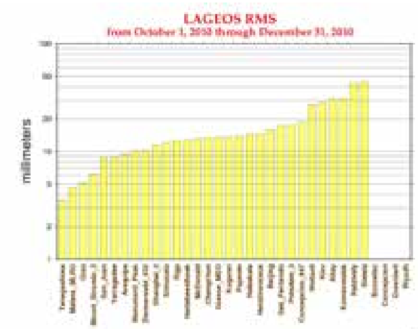


Figure 7-5c. LAGEOS RMS for 2010q4 report card

The report card is used to assess the performance of the stations in the ILRS network. The Central Bureau maintains lists of the operational and associate stations, classified according to the results posted in the ILRS report cards. Performance guidelines, defined on the ILRS website, cover yearly data quantity (number of passes), data quality (normal point precision and short and long term bias stability) and operational compliance factors (timely data delivery, correct data formatting, required station documentation). Current operational vs. associate status can be viewed on the ILRS website at*: http://ilrs.gsfc.nasa.gov/network/.*

Station Specific Performance Charts

To further aid analysis by station operators and users, the ILRS Central Bureau generates data plots summarizing station performance and environmental parameters. These plots, created for each active station in the network, are accessible through the “Lageos Performance tab in the Stations Section on the ILRS website. These plots summarize station performance on LAGEOS including data RMS, calibration RMS, system delay, observations per normal point, and full-rate observations per pass. For each parameter, two plots are generated, one covering the last year and a second showing the information from 2000 to the present. Examples of these plots for selected stations in the network are shown in Figure 7-6.

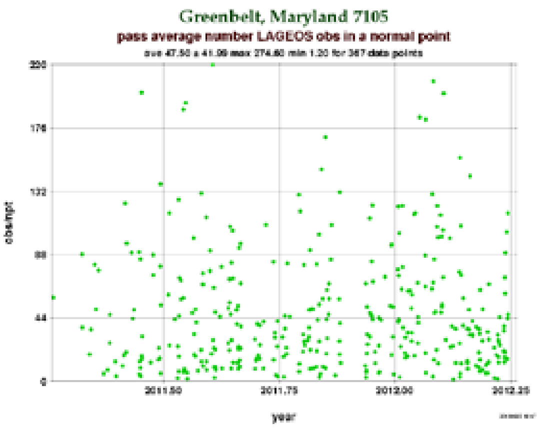


Figure 7-6a. Average number of LAGEOS observations per normal point at Goddard MOBLAS-7 for the past year

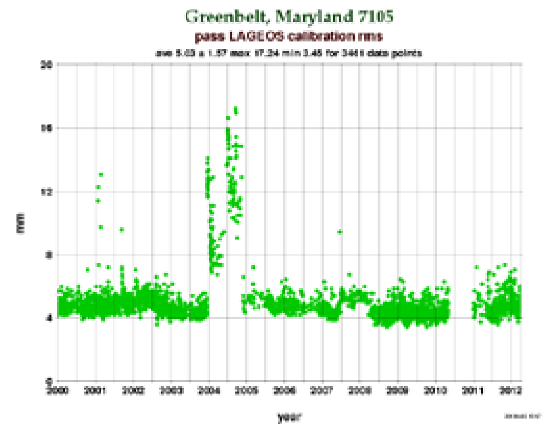


Figure 7-6b. Average LAGEOS pass RMS at Goddard MOBLAS-7 for the past ten years

The “Satellite Data Info” tab shows a table of plots providing statistics on all currently tracked satellites as a function of time; full-rate observations per normal point and normal point rms are also computed as a function of range and time. Examples of these satellite plots for a selected station in the network are shown in Figure 7-7. These plots are also accessible through the Satellite Missions section of the ILRS website (organized by mission, matrix of all stations tracking mission).

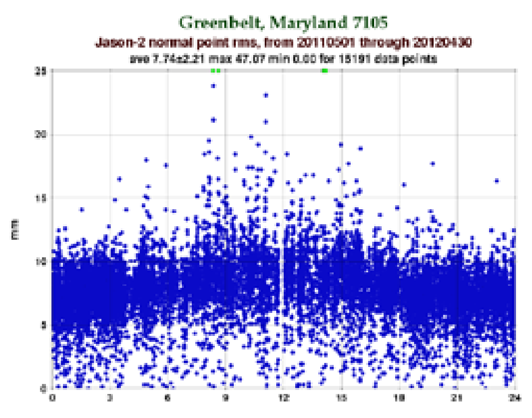


Figure 7-7a. Jason-2 normal point RMS at Goddard MOBLAS-7 (as a function of local time) for the past year

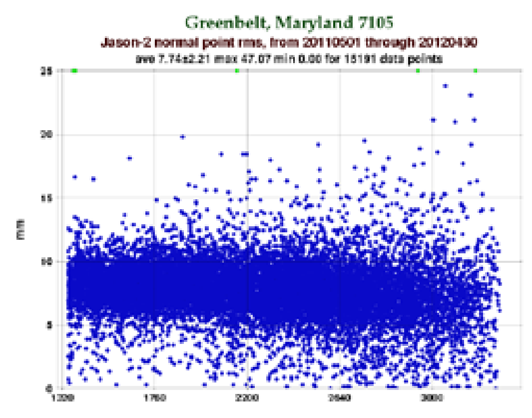


Figure 7-7b. Jason-2 normal point RMS at Goddard MOBLAS-7 (as a function of range) for the past year

The "Meteorological Data" tab presents plots of environmental parameters: temperature, humidity, and pressure; plots spanning the last year and since 2000 are also created for this category. Examples of these met data plots are shown in Figure 7-8.

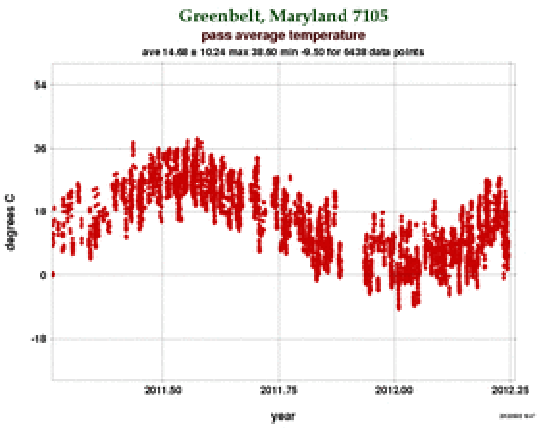


Figure 7-8a. Average temperature at Goddard MOBLAS-7 for the past year

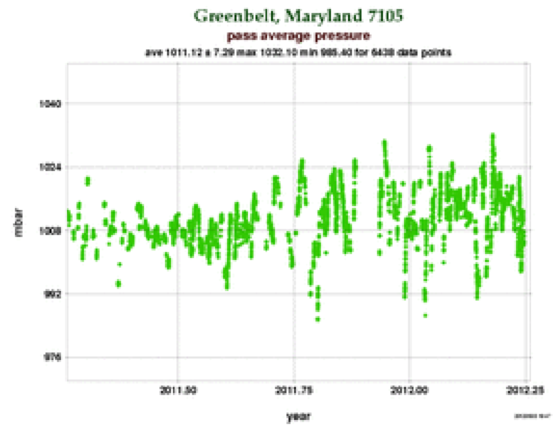


Figure 7-8b. Average pressure at Goddard MOBLAS-7 for the past year

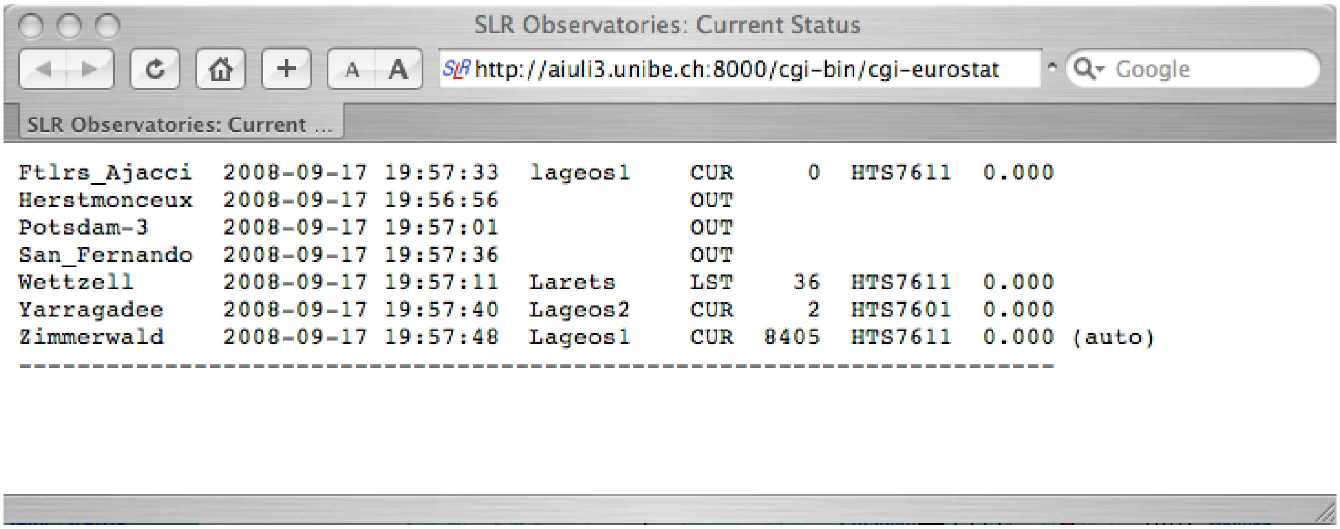
Real-Time Daily Station Status Reports

Station status information is available on a daily and near-real time basis through the EUROSTAT utility. These reports allow the ILRS community to quickly view the status of the stations in the tracking network. ILRS stations can automatically upload status information to EUROSTAT (maintained by the Astronomical Institute of the University of Berne, AIUB) that is then used to generate an overview of the current activities of the tracking stations. The real-time report (Figure 7-9) shows actual station operations at that point in time. The daily report (Figure 7-10) provides a one-line entry per day showing if stations are currently staffed, operational, off-shift, off-line because of system problems, etc. The ILRS encourages all stations in the network to participate in the daily and, if possible, real-time exchange of status information so that experience can be shared in a timeframe to help performance other stations.

http://aiuli3.unibe.ch:8000/slr/daystatus.y08

DOY	Date	BURF	CONL	FTLR	GRZL	HERL	MATM	MDOL	POT3	POTS	SFEL	TEST	WETL	YARL	ZIML
261	17-Sep-2008		OUT	OPER	OPER	OPER	OPER		OPER		OUT		OPER	OPER	OPER
260	16-Sep-2008		OUT	OPER	OPER	OPER	OUT	OPER	OPER		OPER		OPER	OPER	DOWN
259	15-Sep-2008		OUT	OPER	OUT	OPER	OPER		OPER		OPER		OPER	OPER	DOWN
258	14-Sep-2008			OPER	OUT	OPER			OUT		OPER		OPER	OPER	DOWN
257	13-Sep-2008			OPER	OUT	OPER	OPER		OPER		OPER		OPER	OPER	DOWN
256	12-Sep-2008			OPER	OPER	OPER	OPER		OPER		OPER		OPER	OPER	DOWN
255	11-Sep-2008			OPER		OPER	OPER		OPER		OPER		OPER	OPER	OPER
254	10-Sep-2008					OPER	OPER		OPER		OPER		OPER	OPER	OPER
253	09-Sep-2008					OPER	OPER		OPER		OPER		OPER	OPER	OPER
252	08-Sep-2008		OUT			OPER	OPER		OPER		OPER		OPER	OPER	OPER
251	07-Sep-2008					OUT	OPER		OPER				OPER	OPER	OPER

Figure 7-9. EUROSTAT real-time station status report.



Ftlrs_Ajacci	2008-09-17	19:57:33	lageos1	CUR	0	HTS7611	0.000	
Herstmonceux	2008-09-17	19:56:56		OUT				
Potsdam-3	2008-09-17	19:57:01		OUT				
San_Fernando	2008-09-17	19:57:36		OUT				
Wettzell	2008-09-17	19:57:11	Larets	LST	36	HTS7611	0.000	
Yarragadee	2008-09-17	19:57:40	Lageos2	CUR	2	HTS7601	0.000	
Zimmerwald	2008-09-17	19:57:48	Lageos1	CUR	8405	HTS7611	0.000	(auto)

Figure 7-10. Daily station status report (for Sept. 17, 2008).

PUBLICATIONS

2007-2008 Report

The 2007-2008 ILRS Report was issued and can be viewed on the ILRS website (*http://ilrs.gsfc.nasa.gov/about/reports/annualrpts/ilrsreport_2007.html*).
The bi-annual publication provides summary reports for all components of the ILRS.

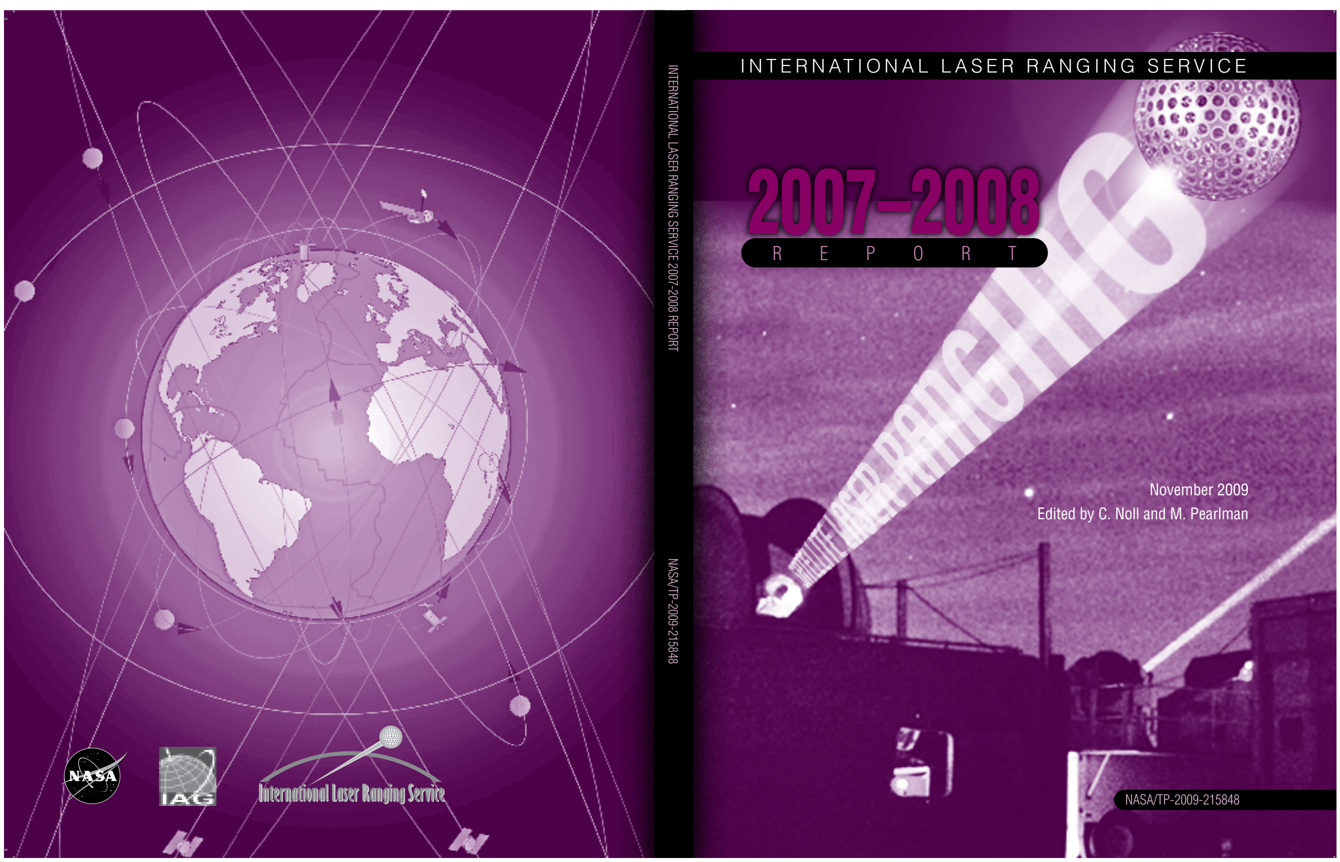


Figure 7-11. The 2007-2008 ILRS Report Cover

SECTION 8
WORKING GROUP REPORTS

SECTION 8

WORKING GROUP REPORTS

The ILRS Governing Board established several permanent (Standing) or temporary (Ad-Hoc) Working Groups to carry out the business of the ILRS. . Standing Working Groups carry out continuously evolving business of the ILRS. Ad-Hoc Working Groups are appointed to work special investigations or tasks of a temporary nature. Currently, the ILRS has five standing Working Groups: Analysis, Data Formats and Procedures, Missions, Networks and Engineering, and Transponder. The Working Groups are intended to provide the expertise to make technical decisions and to plan programmatic courses of action and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau.

ANALYSIS WORKING GROUP (AWG)

Erricos C. Pavlis/Goddard Earth Science and Technology Center, Cinzia Luceri/e-GEOS, Centro di Geodesia Spaziale "G. Colombo"

Official ILRS Analysis Products

The main activity of the Analysis Working Group during the 2009 - 2010 period was the routine generation of the official daily and weekly products. With the development of ITRF2008 in progress, the AWG planned and executed a complete reanalysis of ILRS data used for ITRF2008 and covering the period 1983 to early 2009. The ILRS contribution was submitted in mid-2009. Following the release of the candidate ITRF2008 solutions the AWG evaluated them during the designated period prior to the final acceptance in October 2010.

Pilot Projects

The AWG approach to the development of new products includes the execution of Pilot Projects (PP) during which the new products are tested and the ACs refine their processing and operational approach. The first step in most cases is the harmonization of the capabilities of all AC software to bring them to the same state of readiness for the execution of the planned PP.

During the 2009-2010 period, the Orbital Product PP was initiated and the ACs initiated software upgrade work required for the implementation of the new site and time dependent CoM corrections for the LAGEOS and Etalon satellites. The delivery of additional future products which also require the extension of the standard capabilities for some of the utilized software was discussed and various ACs initiated the required work to be able to eventually deliver low degree harmonic estimates along with the "pos+eop" product, as well as the incorporation of advanced modeling of time-varying gravity signals due atmospheric circulation, atmospheric loading at the tracking sites, etc.

Validation of CRD Format Implementation

The newly developed CRD format will soon replace the old "CSTG" format for increased precision, data characterization and quality control. Before the actual adoption of the new format, the ILRS decided on a strict validation of the newly implemented format for each station of the network. The role of the AWG in the process is to assure that the same data delivered by each station in both formats describe exactly the same orbit for the target. Once the new format implementation was checked by the Operational Centers for any syntax errors, the next step was the validation of data by the AWG. Several ACs checked the format compliance and then insured that there were no systematic differences between the data in the two formats. Once the entire network is validated the ILRS will adopt the new format and the use of the CSTG format will be discontinued. In anticipation of this change, the AWG underwent a test-run using the new format to ensure that each of the ACs is ready to use the new format.

AWG Meetings

The AWG tries to meet at a minimum twice a year, typically one meeting associated with the EGU meeting in the spring, and a second meeting, usually in the summer, autumn or fall, associated with either an ILRS International Laser Workshop, an ILRS Technical Workshop or some other meeting where a large number of ILRS Analysts are likely to participate. The 22nd AWG meeting was held April 24, from 09:00-18:00, at the EGU meeting in Vienna, Austria. The brief, half-day 23rd meeting followed at the end of the Fall ILRS Technical Workshop in Metsovo, Greece, on September 19, 2009. In 2010, the 24th AWG meeting was held on May 8 during the EGU meeting in Vienna, Austria. The 25th and final AWG meeting for this period was held on October 1 in Paris, France. Several members of the AWG participated with presentations and contributions to several position papers in the Unified Analysis Workshop of the Global Geodetic Observing System (GGOS), in December 2009, in San Francisco, CA.

Other Activities

The AWG is also responsible for the re-certification of stations that return to operations after a lengthy down time or a major upgrade. Similarly, when new stations are applying for acceptance into the ILRS network, the AWG is responsible for the validation of their data quality and the characterization of their performance. The 2009-2010 period saw several of both cases, when sites returned to operations after earthquake events, major upgrades or simply new sites joined the ILRS.

Other activities of the AGWG include the evaluation of new models for various components of the dynamical and measurement models used in the reduction of the data, the adaptation of new standards as directed by the IERS, and the support of the organization of ILRS meetings.

Contact

Dr. Erricos C. Pavlis (AWG Chair)
Goddard Earth Science and Technology Center,
University of Maryland, BC & NASA Goddard
1000 Hilltop Circle, TRC #182
Baltimore, MD
USA

Phone: 512-471-8121
Fax: 512-471-3570
E-mail: ricklefs@csr.utexas.edu

Dr. Vincenza Luceri (AWG Co-Chair)
e-GEOS S.p.A.
Centro di Geodesia Spaziale "G. Colombo"
P.O. Box ADP
75100 Matera,
ITALY

Phone: +39-0835-377231
Fax: +39-06-40999961
E-mail: cinzia.luceri@e-geos.it

DATA FORMATS AND PROCEDURES WORKING GROUP (DFPWG)

Randy Ricklefs/CSR

The Working Group's major activities during 2009 and 2010 were implementing the new Consolidated laser Ranging Data format (CRD), surveying the ILRS stations regarding implementation of satellite tracking restrictions, and several data handling issues. Unfortunately, at the end of this period, the Chairman of the Working Group, Wolfgang Seemueller passed away after an extended illness.

CRD Format Implementation

The CRD format was developed to provide a way to capture higher precision, higher volume, and better documented data than the old "CSTG" format. Validation of data in the new format from each of the stations was an important issue, with the Operations Centers (OCs), Analysis Working Group (AWG), and several ILRS Analysis centers (ACs) performing this service. Validation consists of checking for format compliance and then insuring that there are no systematic differences between data in the old and new format for each station. At the beginning of the period, only 1 station was validated; at the end there were 25.

Restricted Tracking

It has become important for laser ranging stations to handle restrictions placed on satellite tracking by their mission operators, generally with the purpose of preventing damage to on-board sensors. Because of several missions, there have been requirements for a maximum tracking elevation, tracking only certain segments of a pass, or suspending tracking for sustained periods (through the so-called go/no-go files). During this period, yet another restriction, on power delivered to the satellite, was added due to Lunar Reconnaissance Orbiter (LRO) requirements. Although a certain subset of stations is used to track these missions, it is important that the ILRS know which stations are ready to help with these special missions. To this end, a survey was conducted of stations and their implementation of the restrictions. The results are on the ILRS website.

Other Activities

Several issues have dealt with the ILRS Operations and Data Centers. When a new laser ranging station opens, or an existing station undergoes upgrades or is simply off-line for many months, the station's data must be quarantined until the Analysis Working Group has insured there are no unexpected changes or biases in the data. Making the quarantine process more systematic and automated has progressed during this period. With the new CRD format, there has been an effort to insure that both the EDC and NASA Operations Centers use similar data quality checking. Similarly, it has been a goal to make the data directories the same on the EDC and NASA Data Centers for the new format, to ease data users' access and minimize confusion.

Much of the Working Group's effort, from implementing the CRD format, surveying tracking restrictions, and handling data issues are all works in progress, and all have involved the tireless support of the members, the ILRS Central Bureau, the Operations Centers, the Data Centers, and the Analysis Working Group.

Contact

Horst Müller (DFPWG Chair)
Deutsches Geodätisches Forschungsinstitute
Alfons-Goppel-Straße 11
D-80539 München
GERMANY

E-mail: mueller@dgfi.badw.de
Voice: +49-89-23031-1277
Fax: +49-89-23031-1240

Randall Ricklefs (DFPWG Co-Chair)
University of Texas at Austin/CSR
3925 Braker Lane, Suite 200
Austin, TX
USA

Phone: 512-471-8121
Fax: 512-471-3570
E-mail: ricklefs@csr.utexas.edu

MISSIONS WORKING GROUP (MWG)

Graham Appleby/SGF

Introduction

The ILRS Missions Working Group (MWG) is tasked with managing and carrying out the review of new missions that seek laser ranging support from the ILRS. The MWG membership comprises some twenty ILRS associates who represent a wide spectrum of technical, scientific and tracking network expertise. The chairs of the Analysis, Network and Engineering, Signal Processing, and Data Formats and Procedures Working Groups are ex-officio members of the MWG, as are representatives from the NASA, WPLTN, and Eurolas tracking sub-networks, and from the ILRS Central Bureau (CB).

New Mission Support

Ideally at least a year ahead of launch, the mission will download the Mission Support Request form from the ILRS website at *http://ilrs.gsfc.nasa.gov/docs/2011/ilrsmsr_1106.pdf* and, once completed, submit it to the CB. The chair and co-chair of the MWG then circulate it, if necessary with some accompanying explanation and a deadline for responses, to the MWG membership. A full email-discussion of the mission request is encouraged, with a view to understanding the mission-specific need for very precise tracking, the nature of perhaps intensive tracking campaigns and whether or not the mission has made adequate provision for the protection from laser light of any onboard sensitive detectors. Also very important to document before launch is a full description of the physical characteristics of the retro-reflector array and its 3D location on the satellite; metric information not recorded before launch is unlikely to be determinable afterwards. Once the MWG members have come to a decision on the suitability of the mission for ILRS support, often after some specific issues have been raised with the mission, a recommendation is made to the ILRS Governing Board (GB). The CB then deals directly with the mission to ensure that predictions will be made available on a daily basis to the stations and that, for instance, any go/no-go issues are dealt with.

During the reporting period three new missions (as detailed in Section 4) were reviewed by the MWG. RadioAstron is a very ambitious astrophysics and relativity mission that takes the VLBI technique into space with a satellite in a highly-elliptical orbit of perigee 500km and apogee at a lunar distance of 350,000km. KOMPSAT-5 is a LEO SAR Earth-observation mission and SARAL is a LEO oceanography mission. The MWG recommended to the ILRS GB that in each of these cases tracking and data-handling support should be given.

Meetings

Given the nature of the tasks of the MWG, email is the most appropriate communication forum to deal with new support requests, and the willingness of the membership to engage in the review process is key to the procedure and gratefully acknowledged. However, on occasion, the opportunity is taken to hold short working group meetings in conjunction with ILRS workshops or science assemblies such as the EGU or AGU. During the reporting period, an MWG meeting was held during the 2009 September ILRS Technical Workshop on SLR Tracking of GNSS Constellations in Metsovo, Greece. Discussed was the membership of the MWG and it was agreed that the chairs of the other ILRS Working Groups should contribute to the evaluation process, consulting their members if appropriate. Future such opportunities for short meetings will be taken as they arise.

Contact

Graham Appleby (MWG Chair)
NERC Space Geodesy Facility
Herstmonceux Castle
Hailsham, East Sussex
UNITED KINGDOM

Voice: 44-0-1487-772477
Fax: 44-0-1487-773467
E-mail: graham.appleby@nerc.ac.uk

Scott Wetzel (MWG Co-Chair)
Honeywell Technology Solutions, Inc. (HTSI)
Goddard Corporate Park
7515 Mission Drive
Lanham, MD 20706
USA

Voice: 301-805-3987
Fax: 301-805-3974
E-mail: scott.wetzel@honeywell.com

NETWORKS AND ENGINEERING WORKING GROUP (NEWG)

Georg Kirchner/Austrian Academy of Sciences

Laser Beam Divergence Determination in SLR Stations

Especially with regard to calculations of energy density on the satellite (detector safety) and retro reflector link calculations, the knowledge of actual laser beam divergence becomes more important; to get at least some basic idea, the stations were asked to describe their methods and procedures to determine this value. Conclusion/Summary:

None of the SLR systems really measures the actual (far field) laser divergence (in the sense of getting a number); all systems apply some method rather to minimize the laser beam divergence (which is obviously the basic requirement for an SLR station).

In monostatic systems, usually 2 CCR on the spider of the secondary mirror are used to adjust for minimum divergence; bistatic systems are minimizing divergence - in a less scientific approach - by offset pointing to HEO satellites and correlating it with return rates (works okay to adjust for minimum divergence, gives at least a rough idea of the number); and by observing backscatter images of the laser beam. Measuring diameters of laser beam at a few km distances is not really suitable to get correct values (no far field). Nobody is using some of the standard methods (e.g., *http://www.uslasercorp.com/envoy/diverge.html).*

There have been suggestions to measure laser beam divergence via the onboard device of T2L2; however, this would include atmospheric seeing influence, thus limiting the accuracy to at least the actual seeing values; might work for stations with acceptable seeing values.

Other main activities of the NEWG included assisting existing (China) and new stations (Korea, Metsahövi) in design, technique, hardware/software, operational issues etc; especially close cooperation was with Korea: A new transportable SLR station has been built by KASI, and should start with first tests at the end of 2011; several visits by the Korean contacts at Graz and other SLR stations (from few weeks to few months each); tests/verification of calibration circuits, etc. were very helpful.

Contact

Dr. Georg Kirchner (NEWG Chair)	Phone: 43-316-873-4651
Space Research Institute	Fax: 43-316-873-4656
Austrian Academy of Sciences	E-mail: Georg.Kirchner@oeaw.ac.at
Lustbuhelstrasse 46	Web: http://www.iwf.oeaw.ac.at
A-8042 Graz	
AUSTRIA	

Matthew Wilkinson (NEWG Co-Chair)	Phone: 44-0-1323-833888
NERC Space Geodesy Facility	Fax: 44-0-1323-833929
Herstmonceux Castle	E-mail: matwi@nerc.ac.uk
Hailsham, East Sussex	
UNITED KINGDOM	

SIGNAL PROCESSING WORKING GROUP (SPWG)

Toshimichi Otsubo /Hitotsubashi University

Introduction

Retroreflector array is the prime component in the space segment of satellite laser ranging technique, and is the prime subject of research for the ILRS Signal Processing Working Group. It was organized in 1999 originally for studying the measurement accuracy degradation due to the pulse-spread effect of return signal. This group has been tightly linked with other working groups, and it has extended the study coverage in these years as described below.

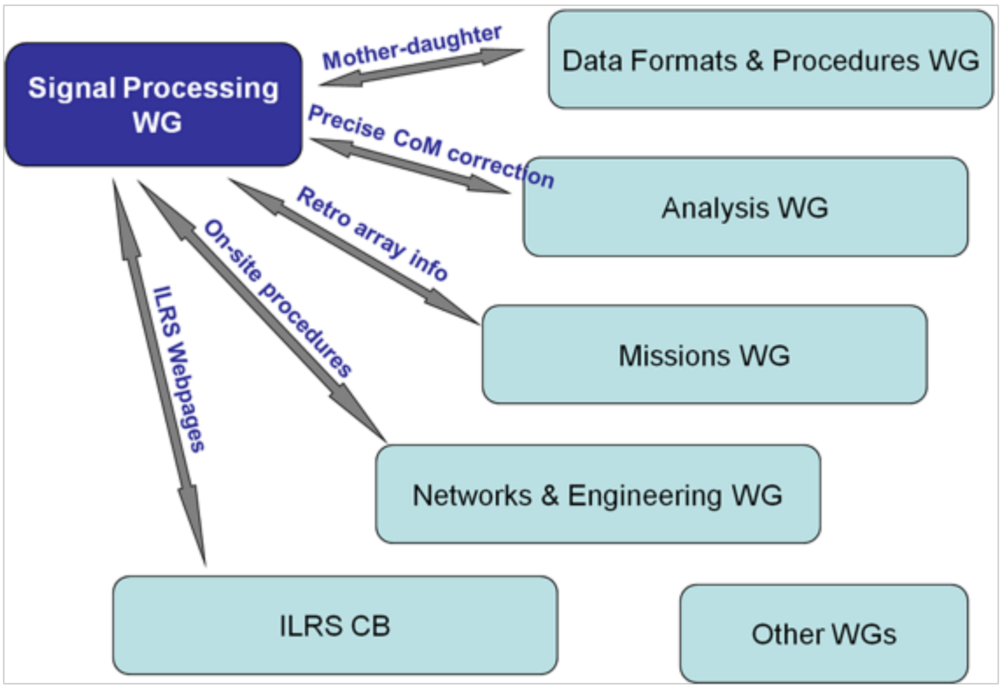


Figure 8-1. SPWG process.

System-Dependent and Intensity-Dependent Center-of-Mass Correction

SLR measurements ideally deliver the absolute two-way measurement between the ground station and the centre-of-mass (CoM) of the satellite. However, an intensity dependence has been proposed and detected in the actual laser ranging data. The post-fit residual data were sorted by the number of single-shot returns per normal point bin, which should be strongly related with the signal intensity reaching the detector. If the detection signal intensity varies, and if the detection timing is dependent on it, there will be intensity dependent bias. The so-called target signature effect, which is now the major error source of laser ranging technique, can reach 4 to 5 cm for Ajisai and 1 cm for LAGEOS, and as previous target signature studies predicted, strong signals make the range measurements shorter when compared to weak return signals. This intensity-dependent effect is detected in the SLR data of a number of stations by looking into the residuals of precise orbit determination analyses. The effect for Ajisai is the largest in most cases, but a number of stations show a significant trend (mostly negative) even for LAGEOS.

A recent effort has been completed to model the station-dependent satellite signature effect for the LAGEOS and Etalon satellites. The previously-published (Otsubo and Appleby, JGR, 2003) results on CoM corrections as a function of detection system, processing technique and return signal strength were used to determine a range of possible CoM corrections for each tracking station that has been active since the early 1980s. The ILRS station log files were used to determine date-dependent station hardware and software configurations, and a table of appropriate CoM corrections was developed. In many cases, such as when the log files indicate that the station does not control the return rate, the range of possible CoM values is large, perhaps up to 10mm, but it is felt that, on average, a better representation of the true CoM correction is being made when these results are implemented. It is anticipated that this work will be extended to include Ajisai and Starlette/Stella.

Laboratory Simulation of Thermal Behavior of Retroreflectors

It is important to optimize the design of the space segment to work efficiently. A ground support equipment facility to characterize retroreflectors in accurate laboratory-simulated space conditions has been developed at INFN/LNF, Italy, which is called "Satellite/lunar laser ranging Characterization Facility" (SCF). It can measure the optical far field diffraction pattern (FFDP) and the temperature distribution of retroreflectors under realistic thermal control and attitude conditions of retroreflectors in orbit, illuminated by high-fidelity a solar simulator. Infrared cameras are also equipped to monitor the thermal response. The retroreflectors for future GNSS satellites and LAGEOS engineering model has been actually examined using this facility, and the measured FFDP results were compared with computer-simulated FFDP. This so-called SCF-Test is described in detail in Dell'Agnello, et al., Adv. Space Res., 2011.

Determination of Spin Parameters and Orientation-Dependent Center-of-Mass Correction

One of "spin-off" studies utilizing the target signature effect is the determination of spin parameter of laser ranging targets. The complicated arrangement of the Ajisai retroreflectors and the kHz laser ranging observations has made it possible to determine its spin axis orientation as well as its spin rate. The precise spin parameter determination reveals that the spin parameters of Ajisai vary secularly and periodically, and that the periodical component is correlated with its orbital plane with respect to the sun.

The retroreflector arrays carried on Envisat, ERS-2, GRACE-A, and -B, had been recognized as signature-free targets, but a kHz data residual analysis shows clear variations up to 5 mm. This fact suggests their CoM corrections should be modeled to be dependent on their orientation parameters in an orbit analysis stage. In addition, in order to improve the ranging precision with the future satellites, this working group will also strive to minimize or zeorise the target signature effect, together with Missions Working Group.

Contact

Toshimichi Otsubo
Hitotsubashi University
East Bldg, 2-1 Naka, Kunitachi
Tokyo 186-8601
JAPAN

Phone: 81-42-580-8939
Fax: 81-42-580-8939
E-mail: t.otsubo@r.hit-u.ac.jp
Web:http://geo.science.hit-u.ac.jp/

TRANSPONDER WORKING GROUP (TWG)

Ulrich Schreiber/TU Munich

Activities within the Transponder Working Group (TWG) for 2009-2010 are summarized below.

Lunar Reconnaissance Orbiter Laser Ranging (LRO-LR)

Jan McGarry/NASA GSFC, John Degnan/Sigma Space, Inc.

The Lunar Reconnaissance Orbiter (LRO) spacecraft was launched in June 2009, and is currently in a 50 km lunar orbit above the Moon. A move to an elliptical 200 km x 30 km orbit is expected in late 2011, and the mission is expected to continue at least through 2012. Among the instruments is the Lunar Orbiter Laser Altimeter (LOLA), which uses 5 laser altimetry channels to map the lunar surface. A Diffractive Optical element (DOE) is used to generate 5 laser beamlets from a single transmitter firing at 28 Hz. One of the altimeter channels does double-duty as a receiver for the altimeter beam and to detect laser pulses from Earth. The science goals of the Earth-based Laser Ranging (LR) experiments include a more precise orbit determination than can be acquired from the available microwave tracking and an improved lunar gravity field. The LR signals are collected by a one-inch aperture telescope mounted on the S-band microwave tracking and communications antenna and transferred by fiber optics to the LOLA receiver. In order to be seen and recorded by LOLA, the Earth based pulses must arrive within an 8 msec period within the roughly 36 msec period between laser pulses. Unlike two-way laser transponders, the success of this one-way technique requires continuous synchronization of the ground-based and spaceborne clocks. LRO-LR represents the first operational use of laser ranging to a satellite in orbit about an extraterrestrial body, and, as of the 17th International Workshop on Laser Ranging in May 2011, over 1070 hours of laser ranging (LR) data had been obtained from 10 participating ILRS stations. Occasional simultaneous LR data from multiple ILRS stations is also being used to obtain geometric spacecraft position solutions. A low data rate lasercom demonstration spelling out “LRO-LR” in the Observed Minus Calculated (OMC) range data was presented, and plans for other lasercom and global time transfer experiments are in progress.

Time Transfer by Laser Link (T2L2)

Etienne Samain, Jean-Marie Torre/OCA

T2L2 (Time Transfer by Laser Link), developed by both CNES and OCA permits the synchronization of remote ultra-stable clocks over intercontinental distances. The principle is derived from laser telemetry technology with dedicated space equipment deigned to record the arrival times of laser pulses at the satellite. Using laser pulses instead of radio frequency signals, T2L2 provides laser links between distant clocks allowing time transfer with a stability of a few picoseconds and accuracy better than 100 ps.

The T2L2 space instrument on board the satellite Jason 2 has been in operation since June 2008. After a six-month period devoted to the characterization and the calibration of the system, the mission has been operational since January 2009. Several campaigns were done to demonstrate both the ultimate time accuracy and time stability capabilities. The main results of these campaigns are:

- Time accuracy in collocation: better than 50 ps
- Phase carrier GPS – T2L2 comparison: limited by the GPS noise
- Ground – space time transfer stability: better than 10 ps @ 10 s

Some important work has been done to accurately compare T2L2 with microwave time transfer GPS and Two-Way Satellite Time and Frequency Transfer (TWSTFT). These comparisons are based on laser station calibrations with a dedicated T2L2 calibration station designed to accurately set the optical reference of the laser station within the pulse per second (PPS) reference of the time and frequency laboratory.

European Laser Time Transfer Experiment (ELT)

Ulrich Schreiber/TU Munich, Ivan Prochazka/TU Prague, Anja Schlicht, Pierre Lauber/TU Munich

The European Laser Time Transfer Experiment (ELT) was proposed to support the (Atomic Clock Ensemble in Space (ACES) Mission, which aims at operating high precision atomic clocks in a micro-g environment. The objective of this proposal is to augment the two-way microwave time and frequency transfer with an optical counterpart. In order to reduce the requirements on the space segment hardware, the microwave link and the laser time transfer link share essential parts of the event timing hardware. The ELT space segment consists of a corner cube assembly similar to the design used for the Champ satellite and an avalanche photodiode detector in Geiger mode (SPAD). Therefore the ranging measurements support the time transfer mission with both two-way and one-way ranging. The proposal was accepted by ESA and is currently under development. The Engineering Model of the space segment detector is under construction and evaluation in the Czech Republic. The ELT data center is under development at the Technical University of Munich in Germany. A call for participation and the application of mission support for the Missions Working Group is in preparation.

Gravity, Einstein's Theory, and Exploration of the Martian Moons' Environment (GETEMME)

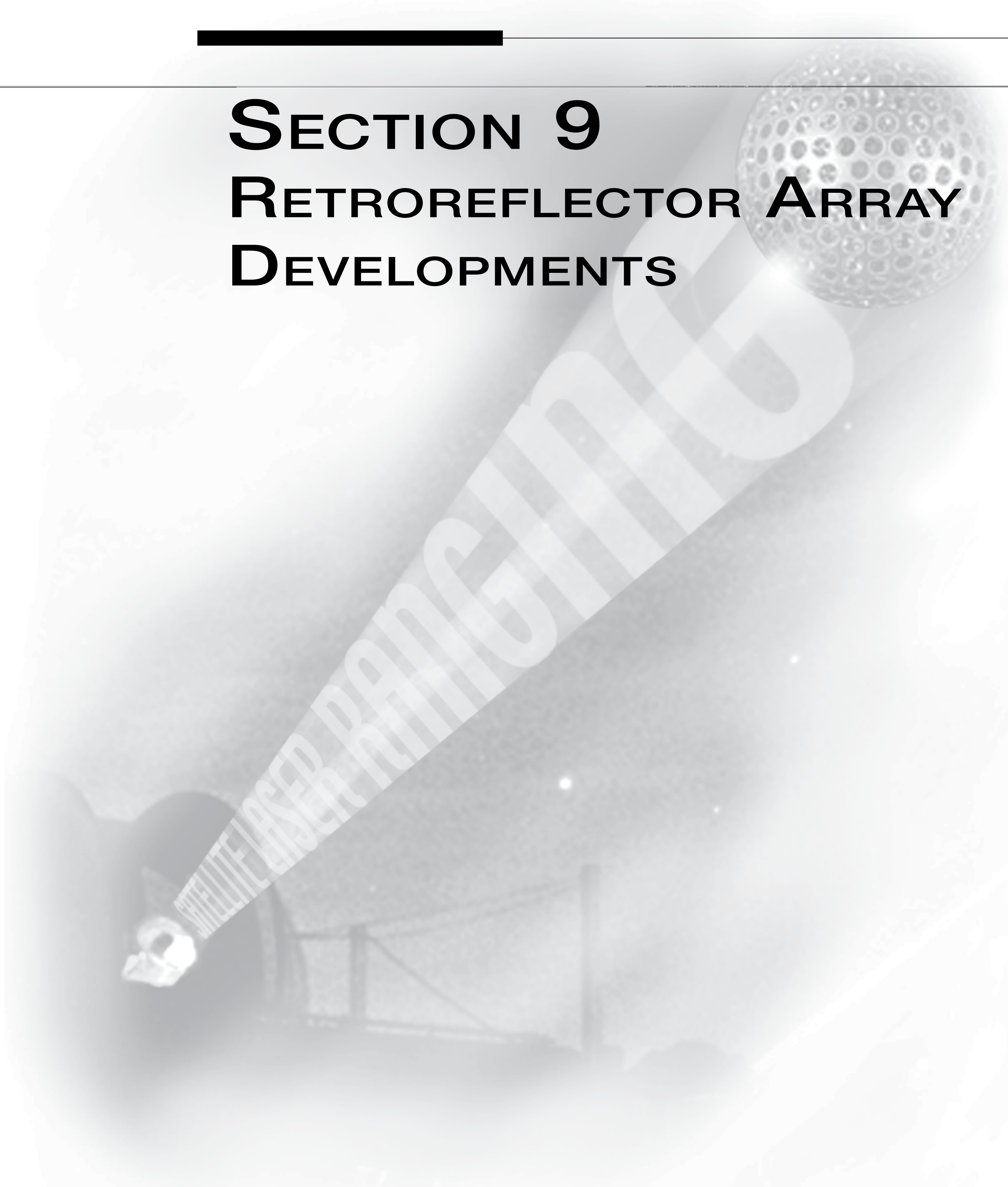
Juergen Oberst/DLR, Ulrich Schreiber/TU Munich

This mission proposal was submitted to the ESA Cosmic Vision Program with a proposed launch date of 2020 or 2021. The objectives of the mission were to use laser transponder technology to study the dynamic parameters of the Mars satellite system (satellite orbit and rotation models) and to improve the accuracy of key Fundamental Physics parameters, such as the Post-Newtonian beta-parameter, time-rate changes in the Gravitational constant G, and the Lense-Thirring effect. This can be achieved by ranging to the Martian moons Phobos and Deimos from a Mars orbit. At the same time, two-way asynchronous transponder techniques between Earth and Mars can be used to improve the orbit estimations of the Mars orbiter. A number of preliminary studies were carried out in support of this proposal. At this stage, the mission proposal has not been accepted.

Contact

Ulrich Schreiber (TWG Chair) Fundamentalstation Wettzell Technische Universitaet Muenchen D-93444 Koetzting GERMANY	Phone: 49-9941-603113 E-mail: ulrich.schreiber@bv.tu-muenchen.de
John Degnan (TWG Co-Chair) Sigma Space Corporation 4801 Forbes Blvd. D-93444 Lanham, MD 20706 USA	Phone: 301-552-6300x121 Fax: 301-577-9466 E-mail: john.degnan@sigmaspace.com
Jan McGarry (TWG Co-Chair) NASA GSFC Code 694 Greenbelt, MD 20771 USA	Phone: 301-614-5867 Fax: 301-614-6015 E-mail: jan.mcgarry@nasa.gov

SECTION 9
RETROREFLECTOR ARRAY DEVELOPMENTS



Section 9

Retroreflector Array Developments

Simone Dell'Agnello/INFN

INTRODUCTION

The Laboratori Nazionali di Frascati (LNF) dell'INFN has established a new test laboratory facility and test procedure to characterize and model the detailed thermal behavior and optical performance of cube corner laser retroreflectors (CCRs) for retroreflector satellites, with particular emphasis on GNSS. The tests are performed in laboratory-simulated space conditions, with a dedicated clean room of class 10000 or better are supporting programs at NASA, ESA and ASI. The laboratory is located at the INFN-LNF facility in Frascati, Italy, near Rome. The key experimental innovation is the concurrent measurement and modelling of the optical Far Field Diffraction Pattern (FFDP) and the temperature distribution of retroreflector payloads under thermal conditions produced with a close-match solar simulator. The apparatus includes infrared cameras for non-invasive thermometry, thermal control and real-time payload movement to simulate satellite orientation on orbit with respect to solar illumination and laser interrogation beams. Aside from measurements, the characterization program includes integrated thermal and optical modelling of the retroreflectors tuned to the test procedures.

These capabilities provide unique pre-launch performance validation of the space segment of LLR/SLR (Lunar/Satellite Laser Ranging) and allow for retroreflector design optimization to maximize ranging efficiency and signal-to-noise conditions in daylight. Results from tests and analyses performed on flight and prototype CCR payloads are presented in references [1][2][3][4][5] and summarized below. Between 2009 and 2010, INFN-LNF, in collaboration with international space agencies and institutions, was requested to SCF-Test, different kind of Laser Retroreflector Arrays (LRAs), whose applications span from fundamental physics to space geodesy to GNSS to R&D models. In the following we briefly describe such tests and their results.

Tests of a LAGEOS engineering model

The LAGEOS satellites are the standard ILRS targets for the reference frame and geodynamics studies. The LAGEOS-1 and -2 satellites are covered with 426 uncoated CCRs over a spherical surface, and were conceived to provide a long-term (many decades or even generations) stable reference in space. Uncoated CCR's with properly insulated mounting were used to minimize thermal degradation, significantly increase optical performance, and avoid the possibility of long-term degradation due to back-coating failure. In 2009, ILFN tested an engineering model (sector) of the LAGEOS satellite provided by NASA; the model, an aluminum spherical cap of the whole satellite, is shown in Figure 9-1 inside the test facility. The engineering model has a base diameter of 380 mm, a weight of 1.5 kg, and is equipped with 37 uncoated CCRs of good optical quality. The CCRs have a front face aperture of 1.5", mounted inside a cavity with the same scheme used on the lunar Apollo arrays.

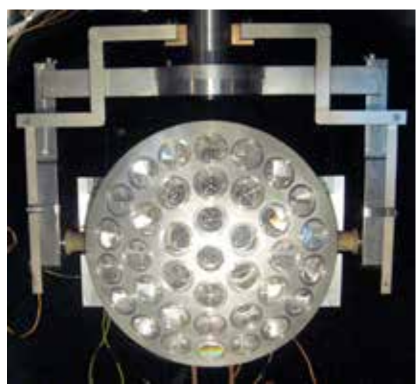


Figure 9-1. LAGEOS sector inside the SCF cryostat

Prior to the test of the sector, all of the 37 CCRs were tested in air, with measurements of the Far Field Diffraction Pattern (FFDP) in each of the three possible orientations (physical edge vertical), to verify their adherence to the original design specifications (angles between reflecting surface of 90°+ (1.25±0.5)”).

For the tests, the sector was placed inside the chamber on a rotation+tilt positioning platform with an interface copper plate. Temperature sensors recorded the temperature distribution, while the IR camera measured CCRs front face temperatures.

Measurements were performed in several conditions.

1. With the Sector held at 300 K we placed the polar CCR inside it’s housing with two different torque screws of the Aluminum retainer rings: 0.135 Nm (LAGEOS nominal value) and 0.2 Nm.
2. With the screw torque of the polar CCR, as defined above, set at 0.2 Nm we maintained the Sector at three different temperatures: 280K, 300K and 320K.

Concurrent optical and thermal measurements were performed only on the polar CCR, while full thermal analysis was performed also on the first and second CCR rings of the Sector. The output of the thermal analysis was the thermal relaxation time of the CCR, τ_{CCR}, based on IR measurements of the variation of the CCRs front face temperature. These values decreased as the temperature of the Aluminum, hence of the CCR, increased, following the expression:

$$\frac{\tau_1}{\tau_2} \propto \left(\frac{T_2}{T_1}\right)^3$$

Figure 9-2 shows instead the outcome of the optical FFDP measurements, comparing the different types of tests performed. In these plots we analyzed the variation of the intensity at 35 μrad (~the velocity aberration of LAGEOS). An increase on the screw torque from its nominal value decreases the intensity of the FFDP in the SUN OFF phase. An increase in the temperature of the Aluminum decreases the intensity of the FFDP in the SUN OFF phase.

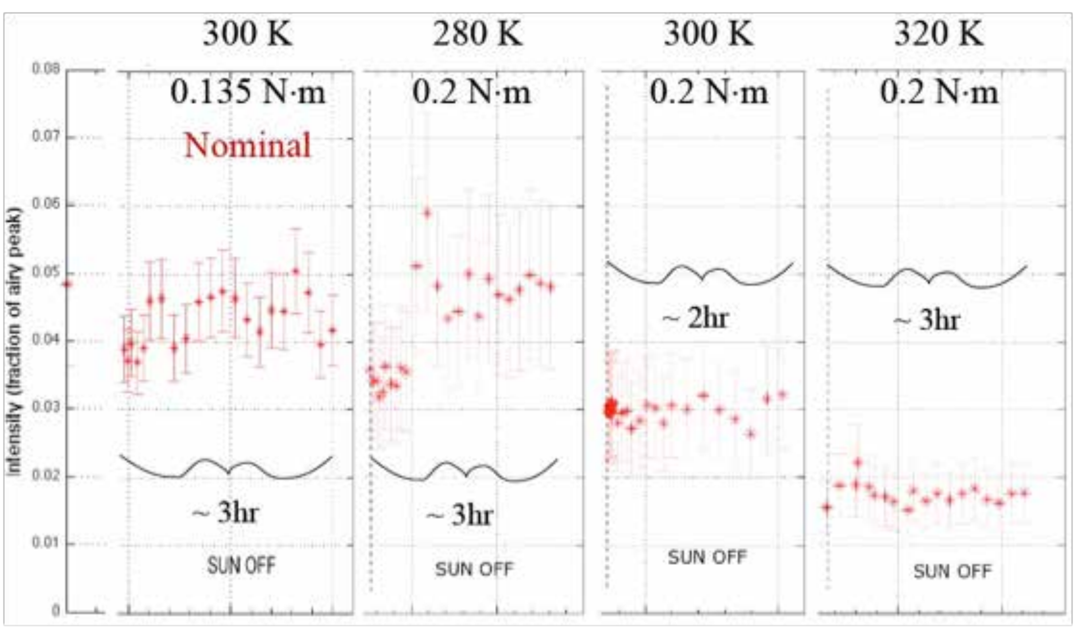


Figure 9-2. FFDP Intensity variation during LAGEOS Sector measurements. Relative error on intensity is ±10%.

Test of a NASA Hollow Retroreflector Prototype

Hollow CCRs are being considered for several applications. A NASA prototype hollow retroreflector was tested at ILFN in 2010 [2]. This prototype was built from three Pyrex faces, with a metal reflecting surface coating of optical quality. Joints between the surfaces are made with stycast cast glue for space applications. The unit is then supported, at the bottom, by an Invar foot, screwed to one of the faces (see Figure 9-3) was held inside the test facility with an Aluminum housing, with the Invar foot in thermal contact with the Aluminum. The housing was built in order to simulate the presence of other CCRs, around the sample under test, in a hypothetical array. The CCR was positioned with one physical edge, the one opposite to the face linked with the Invar foot, horizontal with respect to the cryostat. A platinum probe was placed on each of the three reflecting surfaces, giving information on the overall temperature of each of the reflecting surfaces. The housing was controlled in temperature at 300K with a Peltier cell on the back of the Aluminum base. The test was performed with the Sun Simulator beam parallel to the CCR symmetry axis. Thermal analysis of the τ_{CCR} showed significantly low values, due to the reduced dimension, and a significant perturbation introduced by the thermal link induced between the housing and the CCR. This effect, shown in Figure 9-4, caused a temperature difference between the faces. The effect on the FFDP was a large variation of the intensity (here analyzed at the central peak) as shown in Figure 9-4.

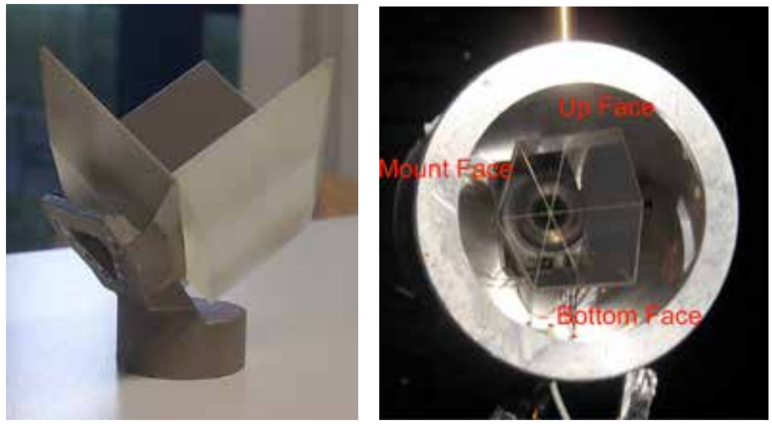


Figure 9-3. The NASA-GSFC hollow retroreflector. (right) CCR in its test configuration

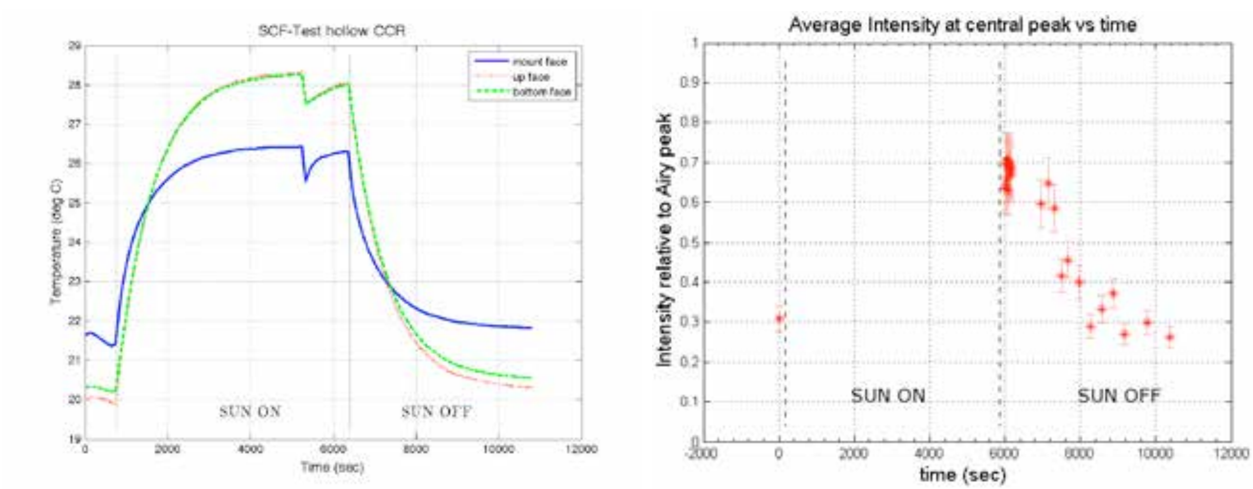


Figure 9-4. (Left) SCF-Test of the Hollow CCR. Drop in temperature at the end of heating phase due to quick turn in front of laser to set up subsequent FFDP acquisition. (Right) Intensity variation of FFDP at the central peak during the SCF-Test. Relative error on intensity is ±10%.

Test of a Galileo-IOV Prototype Retroreflector

In June 2010 INFN proceeded with a series of test requested by ESA on a prototype CCR of the upcoming IOV satellites of the Galileo constellation. The measurements were undertaken to analyze the thermal and optical properties of the CCR, which is an uncoated prism made of Suprasil 311 with a height of 23.3 mm. Its front face is the result of the intersection of a circle of 43 mm diameter with an equilateral triangle with edge length of ~ 114 mm (see Figure 9-5). The front face has an inscribed circle of 33 mm diameter. To compensate for the velocity aberration, three Dihedral Angle Offsets (DAO) of 0.8 arcsec are introduced in the angles between the faces. The CCR was then inserted in an Aluminum housing.

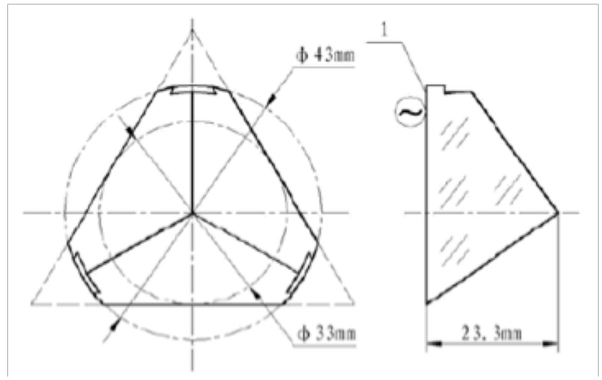


Figure 9-5. (Left) Galileo-IOV CCR tested at LNF. (Right) Drawing of the CCR.

The CCR was installed inside an aluminum enclosure to replicate the condition of a CCR inside the array, surrounded by other CCR housings. The aluminum housing was suspended from the payload support/positioning system so it could be rotated around the vertical direction. The first test performed on this CCR was the measurement of τ_{CCR}, at the temperatures of 310 K and 370 K of the external Al housing. Data taken with the IR camera (front face temperature) were fitted exponentially to extract the information of the characteristic heating time. These data showed a surprisingly short time constant compared with the previous measurements performed on solid cubes of similar volume with back coating. For the aluminum-coated CCRs of GPS/GLONASS/GIOVE satellites the relaxation time was of the order of ~ 1000 sec while for the engineering prototype of LAGEOS, described earlier, the measured τ_{CCR} was thousand of seconds. Moreover τ_{CCR} increases from 310K to 370K by ~30% while simulations indicate a decrease 1/T3, in case of a dominant radiative heating exchange between the CCR and its housing cavity. The difference in behavior could be caused by non-perfect isolation of the CCR with its housing during subsequent conductive heating exchange. This test was performed with the solar simulator beam orthogonal to the CCR front face; however it is crucial to test different incidence angles. Depending on the orientation of the CCR with respect to the solar simulator beam, there are cases in which total internal reflection is broken (breakthrough) and rays pass through the CCR, heating the internal surfaces of the housing. For uncoated CCRs this occurs when a light ray is tilted with respect to the symmetry axis above 17°. During its movement in orbit, the CCR experiences different solar inclination angles. For this reason the tests included simulations of Galileo critical orbits whose angular momentum is orthogonal to Sun-Earth direction. For this particular orbit the inclination vector of solar rays lies on a plane, and the orientation with respect to the CCR front face changes from -90° to +90°.

These conditions are reproduced in the laboratory by rotating the LRA inside the chamber at discrete angle steps for the proper orbital period. Galileo satellites have a quasi-circular orbit with a semi-major axis of ~29600 Km, which corresponds to an orbital period of ~14 hrs. The in-chamber simulation extended over half of the orbit period, from the moment in which sun rays rose above CCR front face until they disappeared on the other side, corresponding to a period of ~7 hrs (a schematic view of the test procedure is in Figure 9-6 left). A detailed description of the test can be found in [3].

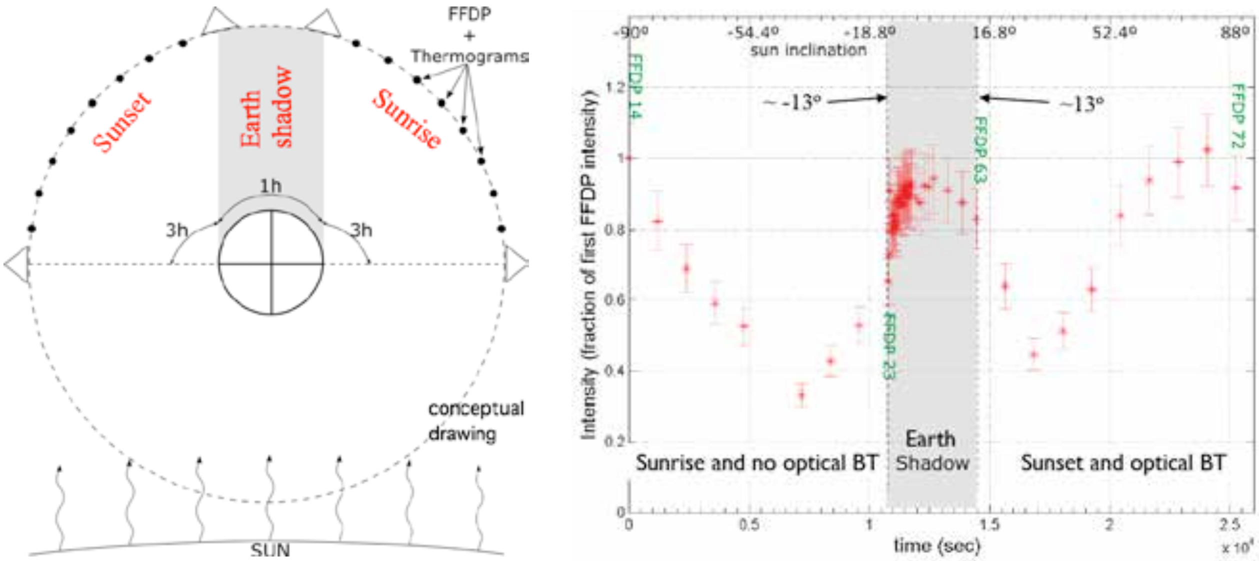


Figure 9-6. (Left) Galileo GCO conceptual drawing. (Right) FFDP average intensity, relative to the first FFDP, of the IOV CCR during the GCO at 24 μrad

The retroreflector was positioned inside the chamber with a circular aluminum plate behind it, in order to simulate the presence of the satellite behind the LRA, thereby shielding the rear side of the housing from cold deep space. Heater tape on the back of the aluminum plate controlled its temperature for initial starting conditions for each measurement run. Tests showed degradation in the range of 25% in optical performance over the exposure cycle as compared to as large as 87% with the old GPS/GLONASS/GIOVE ones CCR's. Averaging over the entire orbit, the CCR average intensity at 24 μrad velocity aberration would have a degradation of ~ 35%. The prototype IOV CCR shows the expected FFDP degradation due to optical breakthrough during sunset; for almost symmetric sun inclinations during sunrise, there is no thermal optical breakthrough. Thermal breakthrough could be due to a CCR mounting scheme with relatively large thermal conductance, as the tests described earlier seemed to point out.

Test of the LLRRA-21/MoonLIGHT Retroreflector

Measurement were performed on a 100 mm CCR [4] being studies as a lunar target. The CCR was installed inside the cryostat with its housing attached to the rotation system. FFDP measurements were performed using a laser beam smaller than the CCR front face. In simulated space environment, the CCR was heated with the solar simulator, with the beam orthogonal to the CCR. The irradiation of the Sun was then simulated at lower elevations, so the CCR was rotated from 30 degrees clockwise to 30 degrees counterclockwise with respect to the solar simulator. There was a total internal reflection breakthrough situation only in one direction. Figure 9-8 shows how the temperature difference from the front face to the tip varies and how the FFDP changes during the different thermal phases. This depicts the expected thermal distortion of the return beam to the Earth as the solar aspect and exposure changes.

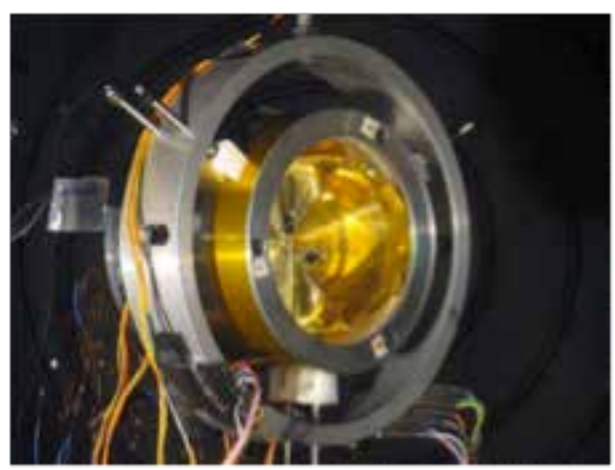


Figure 9-7. MoonLIGHT CCR inside the SCF cryostat

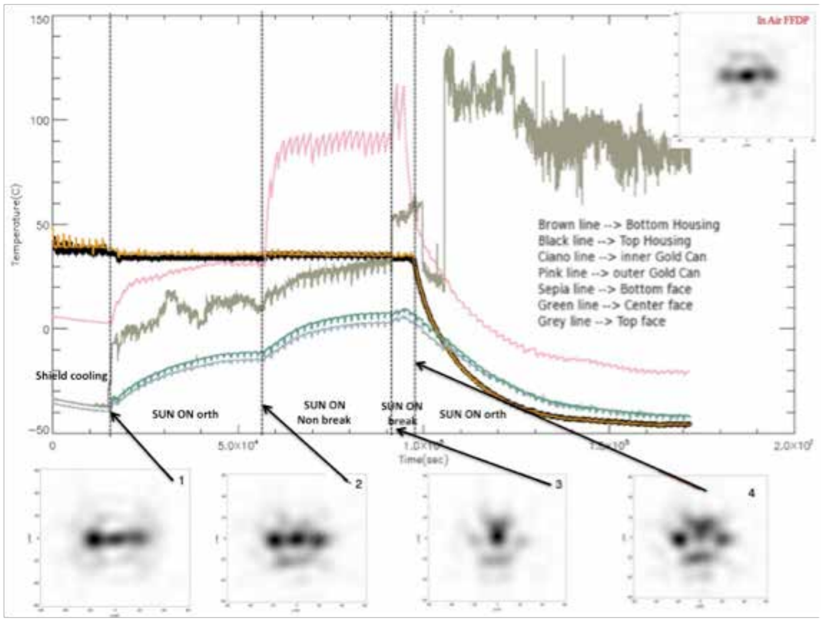


Figure 9-8. Temperature variations of the housing parts and relative FFDP

References

[1] S. Dell'Agnello, et al., Creation of the new industry-standard space test of laser retroreflectors for the GNSS and LAGEOS, Adv. in Space Res. 47, 822-842.

[2] Boni, et al., World first SCF-Test of the NASA-GSFC LAGEOS Sector and Hollow Retroreflector, 17th International Laser Ranging Workshop, Bad Koetzing (Germany), 2011.

[3] S. Dell'Agnello et al., ETRUSCO-2: an ASI-INFN Project of Technological Development and SCF-Test of GNSS Retroreflector Arrays, 3rd Int. Colloquium- Galileo Science, Copenhagen, Sept 2011.

[4] S. Dell'Agnello, et al., Isothermal FFDP-Test and SCF-Test of Flight-quality Uncoated Cube Corner Laser Retroreflectors, 17th International Laser Ranging Workshop, Bad Koetzing (Germany), 2011.

[5] D. Currie, S. Dell'Agnello, G. Delle Monache (2011). A Lunar Laser Ranging Retroreflector Array for the 21st Century. Acta Astron. 68, 667–680.

SECTION 10
EMERGING TECHNOLOGIES

SECTION 10

EMERGING TECHNOLOGIES

John Degnan/Sigma Space Corporation

INTRODUCTION

This report is largely, but not exclusively, based on the technical papers presented at the 17th International Workshop on Laser Ranging, held in Bad Koetzting, Germany in May 2011. The report also draws on material from external sources. It is not intended as a review of all that was presented, since the online presentations and manuscripts do that adequately. Instead, it is a subjective attempt to organize, summarize and comment on the key technology trends and highlights (hardware only) and to tie key engineering activities into an overall perspective.

KILOHERTZ PHOTON-COUNTING SYSTEMS

The number of kilohertz photon counting systems continues to grow worldwide with new stations in China [Zhang et al, 2011], Korea [Lim et al, 2011], and Finland [Halli et al, 2011].

Chinese colleagues reported on progress at the Kunming SLR station where night ranging to LAGEOS and LEO satellites has been routine and some daylight operations to LEOs has been achieved [Li et al, 2011]. The Kunming station is somewhat unique among kHz stations because of its large 1.2 meter telescope aperture, which is shared by the transmitter and receiver, and a rotating mechanical transmit/receive switch (shutter) which generates a nominal 1003 Hz synchronization pulse, protects the SPAD detector from laser backscatter, and allows the satellite returns to reach the receiver. Comparable upgrades have been implemented at the other Chinese stations, and additional technical and performance details on the Changchun kHz station were presented in several posters [see for example, Liu et al, 2011].

Austrian researchers from the Graz station [Kirchner et al, 2011] have been investigating, both theoretically and experimentally, the feasibility of operating at laser repetition rates greater than 2 kHz, e.g. 10 kHz. The principal barrier is a lower SNR at higher rates due to reduced laser pulse energies and increased solar, SPAD, and laser backscatter noise from the atmosphere. Their early results suggest that the number of satellite returns per second at 10 kHz increases for LEOs, is only marginally higher for LAGEOS, and remains largely unchanged for HEOs. The data increase is greatest at satellite PCA.

COMPONENTS

Detectors

Czech researchers [Prochaska et al, 2011] reported on a number of improvements which included a new SPAD detector designed for multi-kHz operations having a 3.5x lower dark count rate, faster rise and fall times under 150 psec, and reaching sub-mm stability in a few tens of nanoseconds. They also described a new APD start detector and discriminator providing a fast NIM output and a fall time of less than 100 psec.

Precision Timing

Czech colleagues [Prochazka et al, 2011] also reported on a "sub-picosecond" timer based on SAW filter excitation. Their device exhibited only + 4 fsec instability over a 3 hour period. They also discussed the advantages of new low temperature drift cables, such as the Phase Track 210 and LDF50, for achieving high timing stability in the absence of tight active temperature controls. Stability is less than 50 fsec/oK/m or a factor of 100 better than standard coaxial cable.

Latvian researchers reported that their latest Event Timer, Model A033-ET, has been commercially available since 2010 with 10 units delivered as of the Workshop [Artyukh et al, 2011a]. Single shot RMS resolution is in the 2.5 to 3 psec range with a temperature stability less than 0.5 psec/oC and a dead time of 50 nsec. The devices are suitable for both conventional and kHz systems. Current development efforts are focused on: (1) increased stability via temperature compensation and fast and robust calibration; (2) a more compact design and faster operational speeds via integration of all digital functions into one FPGA, use of higher clock frequencies and high speed interfaces (USB3, PCle, Ethernet 1G, etc.); and (3) more user friendly interfaces [Artyukh et al, 2011b].

Laser Transmitters

Picosecond, Kilohertz Lasers

Representatives from High-Q lasers (Austria) and Innolas (Germany) provided a summary of their current offerings in sub-nanosecond lasers [Schmidt et al, 2011]. The laser diode-pumped High-Q picoregen HE produces a highly stable 3.2/1.7 mJ per pulse at 1064/532 nm at a 1 kHz rate. The diode-pumped Spitlite Pico produces 12/6 mJ per 8 psec pulse at 1064/532 nm at a 1 kHz rate. At 2 kHz, the output energies are approximately halved and more than doubled when operated at 100 Hz.

NASA researchers described a nominal 1 mJ laser (non-eyesafe) operating at 2 kHz and 532 nm which uses a regenerative amplifier seeded by a Bragg-reflected short pulse diode laser emitting at the nominal Nd;YAG wavelength of 1064 nm. The laser is compact relative to commercial systems having comparable characteristics and is being tested in NASA's Next Generation Satellite Laser Ranging (NGSLR) system to enhance NGSLR tracking of GNSS satellites [McGarry et al, 2011]. The pulsewidth can be changed through the use of different diode seeders. The difficulties encountered when tracking GNSS satellites and possible means to overcome them were enumerated by the Herstmonceaux group [Wilkinsonson, 2011]. Recent successes in tracking very high altitude satellites during the day with the new 1 m aperture COMPASS SLR system were described by Chinese colleagues at the Shanghai Observatory [Zhang et al, 2011].

Chinese and Korean researchers have installed kHz lasers built by Photonics Industries in the United States [Zhang et al, 2011]. Their RG series of kHz picosecond lasers, introduced in 2010, produce 25 to 50 psec pulses with energies up to 3 mJ at 532 nm.

MULTI-WAVELENGTH RANGING

After a several year hiatus on multi-wavelength ranging activities and atmospheric refraction modeling, there appeared to be greatly renewed interest in the subject at the Bad Kotzting Workshop, where four relevant papers were presented. Atmospheric errors above 20 degrees elevation were deemed to be at the sub-cm level when the Mendez-Pavlis model is used [Reipl and Pavlis, 2011]. The authors also reported on an effort to take into account horizontal gradients via a Refraction Server, which uses 3D ray tracing and global atmospheric grid data. The only kHz two-color system, SOS-W, is scheduled to be completed by the end of 2011 and will use a 1 kHz, dual wavelength (849.8 nm and 424.9), SESAM mode-locked, Ti:Sapphire laser generating pulsewidths of 40 psec and energies of 1.5 mJ . Favored satellites for two-color measurements are Starlette and Stella due to their near-single cube response and sufficient link to track down to 14 degrees elevation.

Austrian colleagues have proposed an expanded atmospheric refraction model which adds ray curvature and water vapor effects to the usual dispersion contribution [Wijaya et al, 2011]. The authors further conclude that the required accuracy for dual wavelength SLR measurements of atmospheric refraction far exceeds the current state-of-the art. Australian researchers (Greene et al, 2011) disagree with the latter assessment and have proposed a four beam, 100 Hz, dual wavelength system which they believe is presently capable of absolute range accuracies of 3 mm with 1 mm possible in the near future.

The German/Chilean TIGO/SLR team reported on long term two color ranging and calibration activities at Concepcion using a 100 Hz, ultrashort pulse (30 psec), frequency doubled Ti:Sapphire laser oscillator/regenerative amplifier operating at 847 and 423.5 nm.

LUNAR AND INTERPLANETARY RANGING

Lunar Laser Ranging (LLR)

Following a brief review of the history of LLR and it's impact on our knowledge of the Earth/Moon gravity field interaction and general relativity [Muller, 2011], the status of the 3.5 meter APOLLO LLR system was reviewed along with recent discoveries [Murphy, 2011]. In addition to substantially outpacing all previous data collection rates, APOLLO can range during Full Moon, routinely achieves few mm precisions, and often records multiphoton returns from the lunar reflectors. Experimental results to date produce greater than 15 mm residuals when compared to theory and suggest that several few mm physical effects must be incorporated into current LLR model. An order of magnitude reduction in signal strength from expectations has been largely blamed on retroreflector degradation due to dust.

Japanese colleagues have introduced a 10 W, nanosecond pulse, 2 kHz laser into their 1.5 m aperture station at Koganei in preparation for future high power LLR experiments [Kunimori and Ohi, 2011].

Interplanetary Laser Transponders

Transponder experiments carried out to date or in the proposal stage were summarized at the opening of the transponder session [Degnan, 2011]. Both two-way and one-way experiment configurations were discussed. It was concluded that the physical size, weight, and accuracy of future interplanetary transponder experiments will benefit greatly from current SLR photon-counting technologies, such as:

- Multi-kHz, low energy, ultrashort pulse lasers (10 to 300 psec)
- Single photon sensitivity, picosecond resolution, photon-counting receivers
- Automated transmitter point ahead and receiver pointing correction via photon-counting quadrant detectors (e.g. NASA's NGSLR).

German colleagues at the Wettzell SLR station summarized the results of their AltiDemon transponder simulation experiment [Schreiber et al, 2011] fashioned after a simulation concept presented at an earlier workshop and later published [Degnan, 2006, 2007].

German and French representatives discussed a failed proposal to the ESA Cosmic Vision Program for a transponder mission to Mars labeled GETEMEE (Gravity, Einstein's Theory, and Exploration of the Martian Moons' Environment). The experiment targeted Mars and its moons, Deimos and Phobos. If approved, the onboard laser, derived from the ESA Mercury Bepi-Colombo Laser Altimeter effort, would have made altimetric measurements to the lunar surfaces and participated in two-way Earth-Mars transponder measurements.

Lunar Reconnaissance Orbiter (LRO)

NASA representatives [McGarry et al, 2011] described results from the first operational one-way laser transponder mission. Ten SLR stations in the ILRS network have ranged to NASA's Lunar Reconnaissance Orbiter (LRO) in orbit about the Moon, accumulating about 1078 hours of data before the Bad Koetzting Workshop in May 2011. The light was received by a 2.5 cm lens mounted to the microwave antenna used to communicate with Earth and then transferred by fiber to one of 5 receiver channels of the Lunar Orbiter Laser Altimeter (LOLA) which in turn recorded the time of arrival in the spacecraft time reference. The LR data was used to determine the onboard clock drift rate and aging with the ultimate goal of a more accurate lunar orbit [Mao et al, 2011]. In many instances, multiple stations (up to 4) ranged to LRO simultaneously thereby permitting attempts at geometric solutions for spacecraft position. A limited number of two-way transponder experiments were performed using the LOLA transmitter to range to an Earth station.

LASER TIME TRANSFER

French researchers reported on results obtained from the L2T2 experiment, which was launched on Jason 2 in June 2008 [Pierron, 2011]. Seven European and two Japanese stations participated in the second international campaign from June to October 2010. Time comparisons were conducted between a variety of ground-based ultrastable atomic clocks including rubidium, cesium, hydrogen masers, and fountain. Global performance was better than 100 psec over 1 minute of ranging.

Russian colleagues reported on experiments involving three SLR stations (located in Moscow, Altai, and Komsomolsk-on Amur), designed to synchronize onboard GLONASS clocks with ground-based standards [Moshkov et al, 2011]. They expect an order of magnitude improvement relative to the standard RF time transfer technique.

European researchers reported on a new space mission scheduled for 2014, the European Laser Timing Experiment, in which time transfer, at the few picosecond level, would occur between Earth ground stations and Atomic Clock Ensemble in Space (ACES) via both microwave and laser techniques [Schlict et al, 2011]. The experiments would test new generations of atomic clocks including a cesium fountain clock (PHARAO) and an active hydrogen maser (SHM). Fundamental physics applications would include gravitational red-shift, drift in the fine structure constant, and the anisotropy of light. Czech researchers provided a poster presentation on the photon-counting. [Kodet et al, 2011].

REFERENCES

Artyukh, Yu., Bespal'ko, V. Boole, E. and Vedin, V., "Event timer A033-ET: current state and typical performance characteristics", Proc. 17th International Workshop on Laser Ranging, Bad Kotzting, Germany, May 16-20, 2011.

Artyukh, Yu., Bespal'ko, V. Boole, E. and Vedin, V., "Main directions of Riga Event Timer development and current results", Ibid, 2011b.

Degnan, J., " Simulating Interplanetary Transponder and Laser Communications Experiments via Dual Station Ranging to SLR Satellites", Proc. 15th International Workshop on Laser Ranging, Canberra, Australia, October 16-20, 2006.

Degnan, J., "Asynchronous Laser Transponders: A New Tool for Improved Fundamental Physics Experiments", Int. J. Modern Physics D, 16, pp. 2137-2150, 2007.

Greene, B., Smith, C., Gao, Y., Sang, J., Luck, J., and Alsahhaf, N., "Multiple wavelength correction for atmospheric refraction" , Proc. 17th International Workshop on Laser Ranging, Bad Kotzting, Germany, May 16-20, 2011.

Hafner, M., Avendano, M., Bravo, M., Fernandez, A., Guaitao, C., Mora, V., and Reipl, S., "Multi-Colour Activities at TIGO-SLR", Ibid, 2011.

Kirchner, G., Koidl, F., and Iqbal, F., "Pushing Graz SLR from 2 kHz to 10 kHz repetition rate", Ibid, 2011.

Kodet, J., Prochazka, I., Blazej, J., and Brinek, J., "Construction progress in the photon-counting detector for the European Laser Timing Experiment", Ibid, 2011.

Li, Z., Fu, H., He, S., Zheng, X., Li, R., Li, Y., Zhai, D. and Xiong, Y., "Co-optical path kHz SLR at Kunming Station", Ibid, 2011.

Lim, H-C, Park, E., Seo, Y-K, Bang, S-C, Yu, S-Y, Lee, J-Y, Kim, K-D, Nah, J., Jang, J-G, Jang, B-H, Jong- Uk, "Status and Progress of Korean SLR Program, ARGO", Ibid, 2011.

Liu ,C., Han, X., Song, Q., Fan, C., and Zhang, Z. "Progress in kHz SLR and daylight tracking at Changchun station", Ibid ,2011.

Mao, D. et al, "Laser Ranging Experiment on Lunar Reconnaissance Orbiter: Timing Determination and Orbit Constraints" , Ibid, 2011.

McGarry, J., Varghese, T., Zagwodzki, T. , Degnan, J. , Cheek, J. , Donovan, H., Patterson, D., Clarke, C.., Coyle D.B, Poulios, D , "Improvements at NASA's NGSLR in support of GNSS ranging", Ibid, 2011.

Moshkov, V., Sadovnikov, M., Fedotav, A., and Shargorodsky, V., "Experimental laser system for monitoring of GLONASS time/frequency synchronization", Ibid, 2011.

Muller, J. , "Lunar laser ranging – introductory remarks", Ibid, 2011.

Murphy, T., "Apollo", Ibid, 2011.

Oberst, J., Lainey, V., and Le Poncin-Lafitte, C., "GETEMME– A mission to explore the Martian satellite system and the fundamentals of solar system physics", Ibid , 2011.

Pierron, F., "Laser Time Transfer Experiment 2010", Ibid, 2011.

Prochazka, I., Kodet, J., Blazej, J., and Panek, P., "New technologies for sub-millimeter laser ranging", Ibid, 2011.

Raja-Halli, A. , Näränen, J. , Lapushka, K. , Arsov, K. , and Poutanen, M., "Recent upgrades of the Metsähovi SLR telescope", Ibid, 2011.

Reipl, S. and Pavlis, E,, "Refraction modeling and remote sensing approach", Ibid, 2011.

Schlicht, A., Schreiber, U., and Prochazka, I., "The European Laser Timing Experiment and Timing Centre", Ibid, 2011.Schmidt, M., Graf, N., Huber, H., Kelnberger, R., and Aus derAu, J., "High energy picoseconds laser systems between 10 Hz and 2 kHz for next-generation laser ranging", Ibid, 2011.

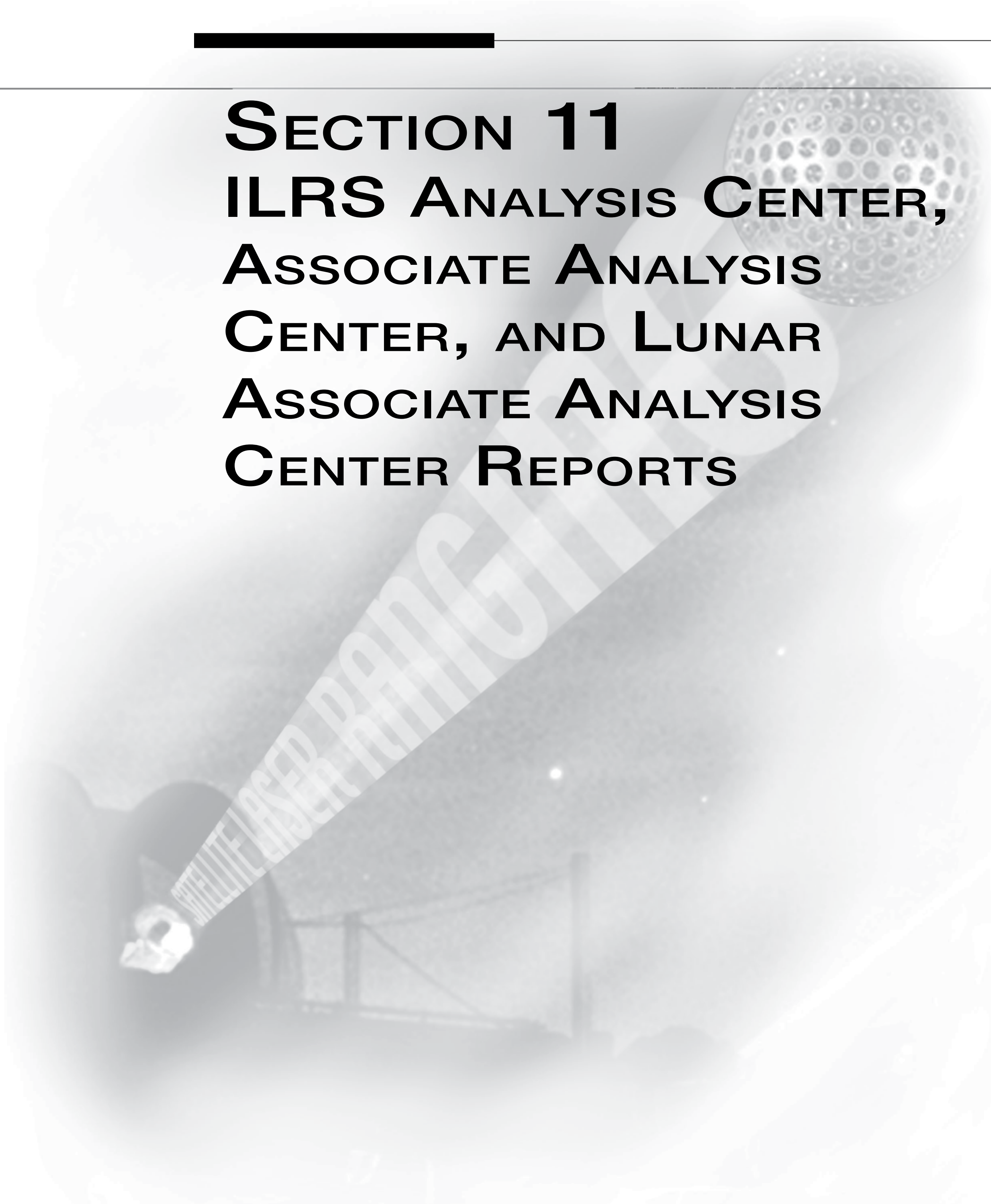
Schreiber, U., Lauber, P., Schlicht, A., Prochazka, I., Eckl J., Herold, G., and Michaelis, H., "Simulation of Two-Way Laser Transponder Links: The Wettzell Experience", Ibid, 2011.

Wijaya, D., Brunner, F., Bohm, J., and Schuh, H., "Atmospheric range correction for two-frequency SLR measurements", Ibid, 2011.

Zhang, Z. , Yang, F.., Zhang, H., Meng, W., Wu, Z., Chen W., Chen J. and Prochazka, I. "The achievements of the dedicated Compass SLR system with 1m aperture telescope: GEO satellite daylight tracking and Laser Time Transfer (LTT)", Ibid, 2011.

Zhang, Z., Wu Z., Zhang H., Chen J. , Li P., Meng W., and Yang F., "Progress in kHz SLR and laser

Section 11
ILRS Analysis Center, Associate Analysis Center, and Lunar Associate Analysis Center Reports



SECTION 11

ILRS ANALYSIS CENTER, ASSOCIATE ANALYSIS CENTER, AND LUNAR ASSOCIATE ANALYSIS CENTER REPORTS

ILRS ANALYSIS CENTER REPORTS

Eight centers have been qualified as ILRS Analysis Centers. These centers are required to provide weekly submissions of Earth orientation parameters and station coordinates that are included in the production of the official ILRS combination product. The Analysis Centers are appointed based on their demonstrated performance in both the rigor of their analyses and the punctuality with which their weekly solutions have been submitted to the ILRS Combination Centers.

Italian Space Agency/Space Geodesy Center "G. Colombo" (ASI/CGS)

Giuseppe Bianco/Agenzia Spaziale Italiana, Centro di Geodesia Spaziale, Matera, Italy, Vincenza Luceri/e-GEOS S.p.A., Centro di Geodesia Spaziale, Matera, Italy, Cecelia Sciarretta/e-GEOS S.p.A., Roma, Italy

Introduction

The ASI Space Geodesy Center "G. Colombo" (CGS) has contributed to ILRS since the beginning of the Service activities both as a fundamental station and analysis center. The SLR data analysis activities at the ASI/CGS started in the 80's and, since then, have been focused primarily on global, extended solutions in support of the reference frame maintenance. Due to the multi-technique nature of the CGS mission, space geodetic technique combination methods and applications are a top priority objective of the data analysis activities performed at the center.

The ILRS Governing Board recognized the center's continuous and rigorous contribution and appointed the ASI/CGS as one of the official ILRS Analysis Centers (ACs) when the ILRS AC structure was finalized (2004). In June 2004 the Center was selected by the International Laser Ranging Service (ILRS) as its primary Official Combination Center (CC) for station coordinates and Earth Orientation Parameters.

Information on the CGS and some of the analysis results are available at the CGS WWW server GeoDAF (Geodetic Data Archiving Facility, *http://geodaf.mt.asi.it*).

ILRS Analysis Center

In the year 2009-2010, the ASI/CGS has been deeply involved in the ILRS activities, mainly in support of the reference frame maintenance and under the coordination of the Analysis Working Group.
The center's main contributions were:

- Pos+EOP products:
  - √ weekly submission of loose coordinate/EOP solutions estimated using LAGEOS and Etalon data and following the project requirements. The product is the ASI/CGS input to the official ILRS combined SSC/EOP product.
  - √ daily submission of loose coordinate/EOP solutions estimated using LAGEOS and Etalon data and following the AWG requirements. The product is the ASI/CGS input to the official ILRS combined EOP product that is still in a pre-operative phase.satellites are distributed weekly, as requested by the AWG, in the same loose reference frame of the SSC/EOPs as input to the combination.
- Contribution to ITRF2008: the time series of weekly loose solutions, from 1983.0 to 2009.0, with estimated site coordinates and EOPs and obtained using LAGEOS and Etalon data, has been submitted as ASI/CGS input to the ILRS combination for the generation of ITRF2008. Each weekly solution has followed the AWG guidelines, bias included.
- "Station qualification": ASI/CGS is one of the ACs designated by the AWG to validate the data from new or upgraded sites or after an earthquake.
- "CRD validation": ASI/CGS is one of the ACs designated by the AWG to validate the data submitted by the station in the new CRD format.
- "Bias monitoring": a routine activity is carried out to compute data corrections whenever the biases are not reported by the station, in close contact with the station engineers.

ILRS Primary Combination Center

In 2009, the ASI-CGS combination activities, within the ILRS frame, were focused on the preparation of the long-term contribution to the ITRF2008, issued on August 2009. The official ILRS solution, ILRSA, spans a long period (more than 25 years) and has been obtained with a direct combination of the loose constrained solutions provided, as final version, in the late Spring 2009 by seven official ILRS ACs (ASI, DGFI, GA, GFZ, GRGS, JCET, NSGF), each one following strict standards agreed upon within the ILRS Analysis Working Group. The remarkable coherence of the contributing ILRS AC series makes the final combined estimates very accurate; the main components (linear trend and small amplitude annual periodic term) of the derived origin and scale time series are very neat. During 2010, ITRF2008 validation and assessment activities took place and the results discussed inside and outside the ILRS context.

Besides the ITRF2008 contribution activity, the center's routine contribution as ILRS Combination Center were:

- Pos+EOP Products:
  - √ weekly submission of the ILRS official solution (ILRSA) derived from the combination of individual contributing SLR solutions based on the observations to Lageos 1-2 and Etalon 1-2 satellites. The ILRSA solutions contain weekly coordinates of the worldwide SLR tracking network and daily EOPs (xpole, ypole, LOD), ITRF-framed for IERS Bulletin B and EOPC04
  - √ daily submission of the combined coordinate/EOP solutions computed using the individual AC contribution. The final product will contain daily EOPs, ITRF-framed with a constant, minimum latency of two days and is still in a pre-operative phase.

Periodic evaluation of the submitted solutions as well as of the final official products were presented at the ILRS AWG meeting to support ACs data analysis activities.

Non - ILRS activities in 2009-2010

The ASI/CGS analysis activities extend beyond the accomplishment of its role within ILRS and were addressed in the following main application fields.

- International Terrestrial Reference System (ITRS) maintenance:
  - √ production of IERS oriented products (global SSC/SSV and EOP time series) regularly performed as ASI/CGS operational EOP series: 1-day estimated EOP, from LAGEOS and Etalon data, are available at the IERS website

  ftp://hpiers.obspm.fr/iers/series/operational/;
  - √ generation of the multi-year solution ASI10L01, from LAGEOS-1 and -2 data (1983-2010). Global network SSC/SSV and 3-day EOP (x, y, LOD) are the main parameters estimated in this solution and available under request.
- EOP excitation functions: production of the geodetic excitation functions from the ASI/CGS estimated EOP values for IERS (at present SLR only; the current use of CGS VLBI and GPS EOP is also under testing) to make them available on the ASI geodetic web site (http://geodaf.mt.asi.it): the daily geodetic excitation functions are produced every Tuesday along with the operational weekly SLR solution, staked and compared whenever possible with the atmospheric excitation functions from the IERS SBAAM, under the IB and non-IB assumption, including the "wind" term;
- Geodetic solution combination: realization, implementation and testing of combination algorithms for the optimal merging of global inter- and intra-technique solutions and of regional (e.g. Mediterranean) solutions to densify tectonic information in crucial areas;
  - √ Once a year, ASI-CGS produces a combined velocity solution for the Mediterranean area using its original single-technique velocity solutions (SLR, VLBI and GPS) that cover the whole data span acquired by the three co-located systems from the beginning of acquisitions in Matera.
    The ASIMed solution (http://geodaf.mt.asi.it/html_old/ASImed/ASImed_06.html) gives a detailed picture of the residual velocity field in the area, profiting of the dense permanent GPS coverage. The semiannual updating profits of the improvements in the velocity field information as geodetic sites become stable in terms of their data acquisition history.

Future Plans

Most of the current activities will continue, with particular attention to the ILRS and IERS oriented products. Deeper investigations will be directed to the low degree geopotential zonals.

References

Luceri V., C. Sciarretta, G. Bianco, G. Appleby "The measurement bias effects in the ILRS product for ITRF", EGU 2009 meeting, 14-19 April 2009, Wien

Sciarretta C., V. Luceri, R. Lanotte, G. Bianco "Operational production of Geodetic Excitation Functions", (EGU 2009 meeting, 14-19 April, Wien

Luceri V., C. Sciarretta, G. Bianco "The measurement bias effects in the ILRS product for ITRF", (VII Hotine Marussi Symposium, 6-10 July 2009, Roma

Sciarretta C., V. Luceri, E. C. Pavlis, G. Bianco "The ILRS combined solution as contribution to the ITRF maintenance", VII Hotine Marussi Symposium, 6-10 July 2009, Roma

Sciarretta C., V. Luceri, G. Bianco "TRF maintenance at the ILRS Combination Center ASI/CGS", () IAG 2009, 31 august – 4 September 2009, Buenos Aires

Sciarretta C., V. Luceri, G. Bianco "The ASI/CGS contribution to the ITRF maintenance: the ILRSA solution", ITW on SLR GNSS Tracking, 14-18 September 2009, Metsovo, Greece

Sciarretta C., V. Luceri, E. C. Pavlis, G. Bianco "ILRS EOP Times Series", IERS workshop on EOP Combination and Prediction, 19-21 October 2009, Warsaw, Poland,

Sciarretta C., V. Luceri, R. Lanotte, G. Bianco "Operational production of Geodetic Excitation Functions from EOP estimated values at ASI-CGS", IERS Workshop on EOP Combination and Prediction, 19 – 21 October 2009, Warsaw, Poland

Luceri V., C. Sciarretta, G. Bianco "Measurement bias estimation and modelling – Data QC", GGOS Unified Analysis Workshop, 11-12 December 2009, San Francisco

Sciarretta C., V. Luceri, G. Bianco "Combination strategies for ILRS products", GGOS Unified Analysis Workshop, December 11-12, 2009, San Francisco, Ca, USA

Sciarretta C., V. Luceri, G. Bianco "Analysis of ILRS contribution to ITRF2008: Origin and Scale parameters", EGU 2010, 3 – 7 May, 2010, Wien

Sciarretta C., V. Luceri, G. Bianco "ILRSA & ITRF2008P", IERS Directing Board, 1 May 2010, Wien, Austria

Sciarretta C. , V. Luceri, R. Lanotte, C. Ferraro, R. Pacione, G. Bianco, F. Vespe "Velocity Field in Mediterranean Area from ASI-CGS GPS, SLR and VLBI Solutions; the ASIMed Solution", 15th General Assembly of WEGENER, September 2010, Istanbul

Sciarretta C., V. Luceri, G. Bianco "Small trends and oscillations in the 25 year ILRS geocenter and scale time series", IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), October 2010, Marne-la-Valle , France

Contacts

Dr. Giuseppe Bianco Agenzia Spaziale Italiana (ASI) Centro di Geodesia Spaziale C.da Terlecchia, 75100 Matera ITALY	Voice: +39-0835-377209 Fax: +39-0835-339005 E-mail: giuseppe.bianco@asi.it
Dr. Vincenza Luceri e-GEOS S.p.A. Centro di Geodesia Spaziale C.da Terlecchia, 75100 Matera ITALY	Voice: +39-0835-377231 Fax: +39-06-40999961 E-mail: cinzia.luceri@e-geos.it
Dr. Cecilia Sciarretta e-GEOS S.p.A. Via Cannizzaro 71, 00156 Rome ITALY	Voice: +39-06-40793864 Fax: +39-06-40999636 E-mail: cecilia.sciarretta@e-geos.it

Bundesamt für Kartographie und Geodäsie (BKG)

Bernd Richter, Maria Mareyen/BKG

From autumn 2009 to spring 2010 the necessary program code developments for the benchmark routine (i.e., for the weekly solution modus) was developed. The data files were prepared according to ILRS instructions (data corrections, handling, station eccentricities, etc.). The benchmark solution set was then generated with the Bernese Software was submitted to the ILRS.

On May 15th, 2010, BKG received confirmation that these benchmark solutions were accepted by the ILRS. In June 2010, the daily and weekly LAGEOS-only-solutions (based on the Bernese software) were uploaded to the ILRS (in addition to the ongoing official BKG Utopia solution) as next benchmark task. As of July 1st, 2010, BKG officially submits daily and weekly ILRS solutions generated by the Bernese Software.

The figures below illustrate the performance of the Bernese software in the BKG solution.

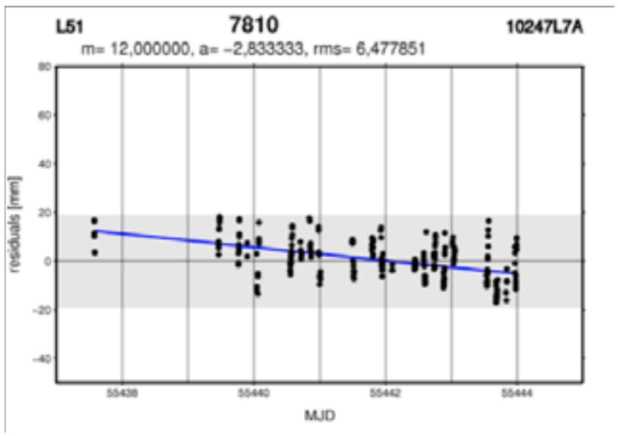


Figure 11-1. Data screening: station 7810, Zimmerwald, week 100904; LAGEOS-1 residuals "o-c" in the course of a week

The work on the Bernese software (BSW) continued with the implementation of the new CRD observation data format and the augmentation of the Etalon satellites. BKG began submitting LAGEOS and Etalon solutions in January 2011. The implementation of SLR data analysis into the Bernese software was performed at the Astronomical Institute of the University of Bern (AIUB). At BKG, the program had to be adapted to the BKG environment. Many tools had to be developed to ensure the automatic modus and a fast analysis of the solutions. As a next step, the reprocessing modus must be fully implemented in the BSW.

The first time series of weekly solutions (from 2006 to present) has been processed. This time series includes data before and after the 2010 earthquake in Concepcion, Chile, that shifted the station westward for three meters.

Figures 11-2 a,b,c. Weekly time series residuals resp. transformations of selected parameters estimated by the ILRS Analysis Centers and compared with respect to the ilrsa combined solution.

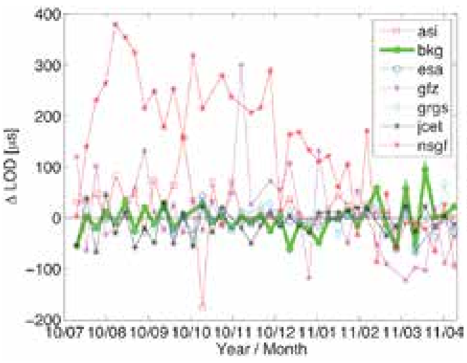


Figure 11-2a: Weighted Mean of "Length of Day" residuals

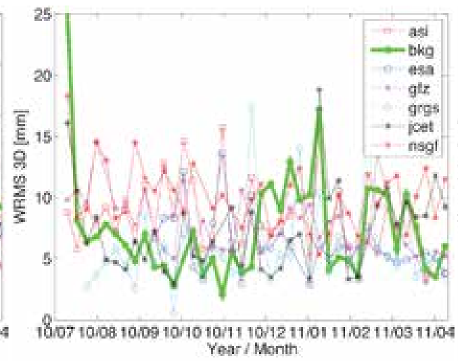


Figure 11-2b: Weighted Root Mean Square of "3D coordinate" residuals

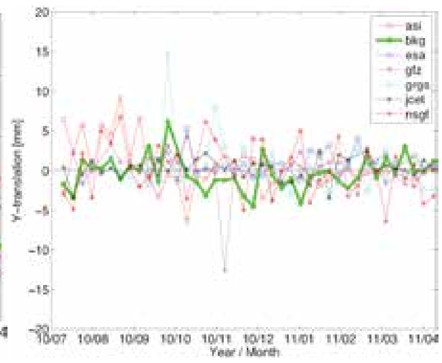


Figure 11-2c: "Y component of the translation vector"

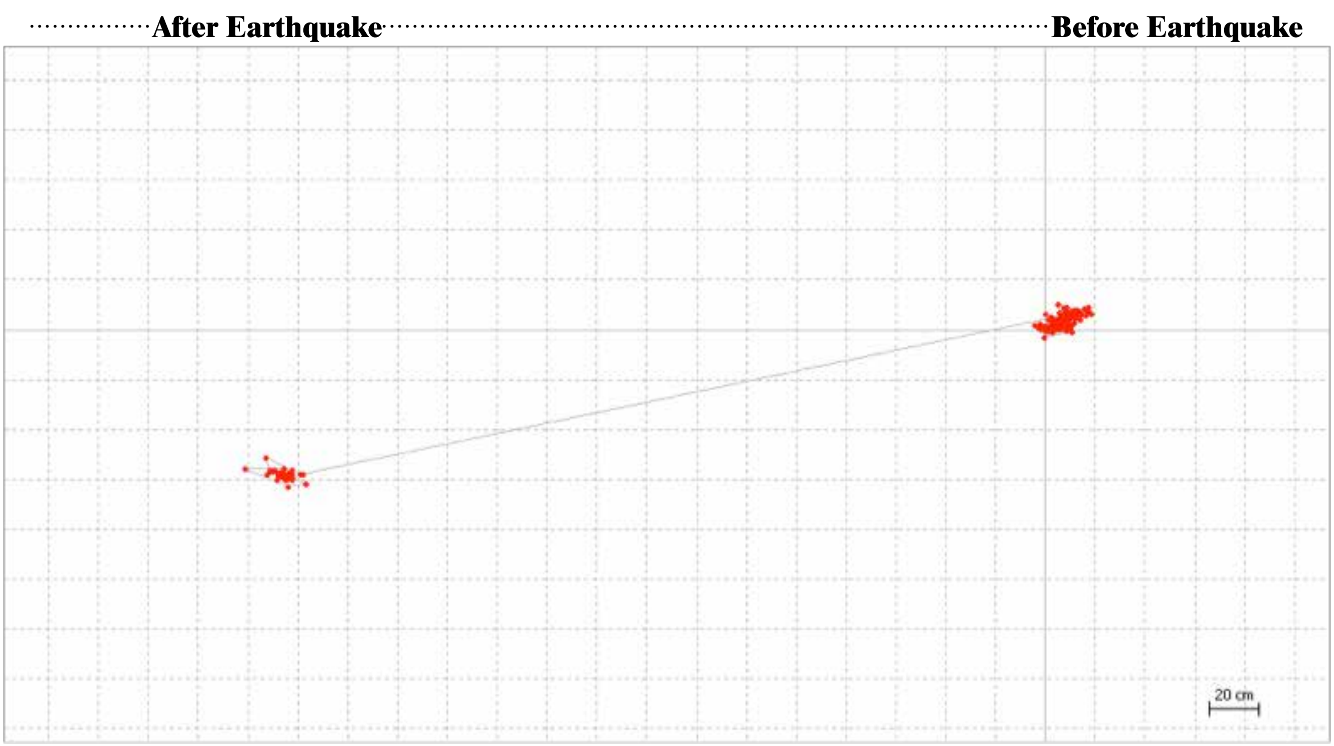


Figure 11-3: Groundtrack (ΔE, ΔN) of Stations Positions of the station Concepcion (Chile) 7405_SLR

Contact

Dr. Bernd Richter
Voice: 49-69-6333273
E-mail: richter@iers.org

Maria Mareyen
BKG
Richard Strauss-Allee 11
D-60598 Frankfurt/Main 70
GERMANY
E-mail: maria.mareyen@bkg.bund.de
Fax: 49-69-6333425

Deutsches Geodätisches Forschungsinstitute (DGFI)

Horst Müller, Mathis Bloßfeld, Detlef Angermann/DGFI

Introduction

DGFI routinely processes, on a weekly basis, station positions, Earth orientation parameters (EOP) and satellite orbits from SLR observations to the LAGEOS and Etalon satellites. For the validation of SLR tracking data we generate a daily report on biases, estimated from LAGEOS and Etalon observations. Finally the backup solution for the combined SLR time series was computed at the DGFI ILRS Backup Combination Center, until November 2010. Other activities are the qualification of new or returning SLR stations and the processing of SLR observations for an epoch combination of station coordinates, EOPs and low degree harmonics.

ILRS Analysis Center

As an ILRS Analysis Center DGFI processes on a weekly operational basis SLR data to LAGEOS-1/-2 and Etalon-1/-2 and provide loosely constrained solutions (SINEX files) with station positions and Earth orientation parameters (x-pole, y-pole and length of day) to the Data Centers at CDDIS and EDC. This processing is accomplished with the DGFI software package DOGS version 5.0. Additionally orbits to these satellites are routinely processed and delivered. The weekly solutions and orbits are available from: *http://ilrs.dgfi.badw.de*. Operation was deferred in July 2010 until a small problem in the estimation of the LOD parameter could be identified and solved.

During the automatic processing, a number of quality checks are performed, one is the computation of pass dependent range and time biases. These values sorted by satellite and week are available from the DGFI web server: *http://ilrs.dgfi.badw.de/quality/weekly_biases/*. Until June 7, 2011, we provided the biases with respect to SLRF2005 coordinates for all station and passes, since then we switched to SLRF2008.

DGFI has agreed to maintain a list with station discontinuities and data handling, which will be distributed to all analysts through the data centers of CDDIS and EDC. Together with ASI and GRGS, DGFI does the station qualification for new and returning tracking stations.

ILRS Combination Center

DGFI, as the official ILRS Backup Combination Center, has stopped operation in November 2010 due to manpower problems, caused by the retirement of R. Kelm. All combination software has been transferred to JCET to continue the work.

ILRS/AWG Rapid Service Mail

To keep stations informed on possible problems the quick-look analysis centers used to inform the stations as soon as they detected anomalies in the tracking data. To unify these activities a new service was initiated during the 17th International Workshop on Laser Ranging. This new ILRS/AWG Rapid Service Mail will have the following header and will be send to the affected station and a mailing list archive at EDC:

```
********************************************************************************
ILRS/AWG Rapid Service Mail (HITU) 7249 -1 m range bias        Message No.0001
********************************************************************************
```

Including the analysis center, which has issued the messages, presently HITU (Hitotsubashi University, Japan) and DGFI, a brief description of the error and an incrementing number. The message body will contain a detailed description of the problem if necessary.

SLR Solution for an Inter-Technique Combination with GPS and VLBI

For a project within the research group "Earth rotation and global dynamic processes", funded by the German Research Foundation (DFG), DGFI provides a SLR solution for the combination with GPS and VLBI. The goal of this project is to estimate the Earth's geometry (station coordinates) together with the Earth's orientation (pole coordinates, UT1-UTC) and the Earth's gravity field (spherical harmonics up to degree and order two).

For a global geodetic reference frame derived from various geodetic space techniques, SLR is the primary technique to realize the origin and contributes together with VLBI to determine the scale of the frame. Additionally SLR has also the potential to estimate the low degree spherical harmonics of the Earth's gravity field. The combined adjustment of gravity field parameters of degree and order two together with Earth Rotation Parameters (ERPs) and the orbital elements is a big effort. Especially the correlations of C20 with UT1-UTC and the rate of the ascending node make it difficult to estimate all the parameters within one adjustment.

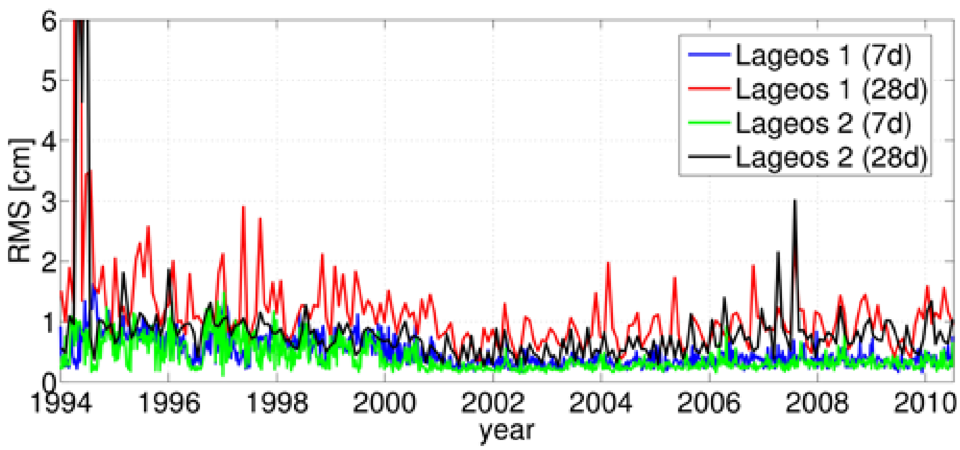


Figure 11-4: Orbit fits of LAGEOS-1 and -2 for the different arc lengths (weekly/4-weekly)

To compute the RMS values only observations of the official ILRS core stations are considered. The mean orbital fits of the weekly solutions are 50 percent smaller than the orbit fits for the 4-weekly solutions. In both solutions, we additionally set up empirical accelerations to stabilize the estimated orbit (see Table 11-1).

Table 11-1: Estimated Parameters of the SLR Solution

PARAMETER	TEMPORAL RESOLUTION (arc length: weekly/4-weekly)
station coordinates (X,Y,Z)	1 per arc (+ bias if necessary)
pole coordinates (x,y), UT1-UTC	piece wise linear polygon at 0h epochs (8 per arc)
spherical harmonics d/o 2	1 per arc
keplerian Elements	1 per arc (starting element)
factor for solar radiation pressure	3 per arc (start, mid, end of arc)
empirical acceleration (along-track), once-per-revolution	1 per arc (sine-/cosine term)
empirical acceleration (along-track), offset	3 per arc (start, mid, end of arc)
empirical acceleration (cross-track), once-per-revolution	1 per arc (sine-/cosine-term)

Gravity Field Parameters

In our SLR solutions we fix C00 to one and C10, C11, S11 to zero in order to guarantee a stable scale and origin over time. The gravity field parameters of degree and order two are estimated by using observations to LAGEOS-1 and -2. The different inclinations ensure that the correlations of C20, UT1-UTC and the rate of the ascending node are reduced to a mean value of 0.3.

The parameters cover a time span of about 16.5 years, from 1994 to 2010.5. Figure 11-5 shows the gained C20 coefficients with two different time resolutions. The red curve represents the coefficients, which were derived from a solution with an arc length of seven days whereas the blue curve shows the coefficients for a 28-day arc length. For comparison, the Center for Space Research (CSR) solution with monthly mean values between 2002 and 2010.5 is also displayed (green). In all three solutions there is a clear seasonal variation and a small linear trend. The a priori solution (dotted straight line) is the GGM02S gravity field (as recommended by the ILRS). The DGFI solutions contain observations to LAGEOS-1 and -2 whereas the CSR solution contains additional observations to Stella, Starlette and Ajisai.

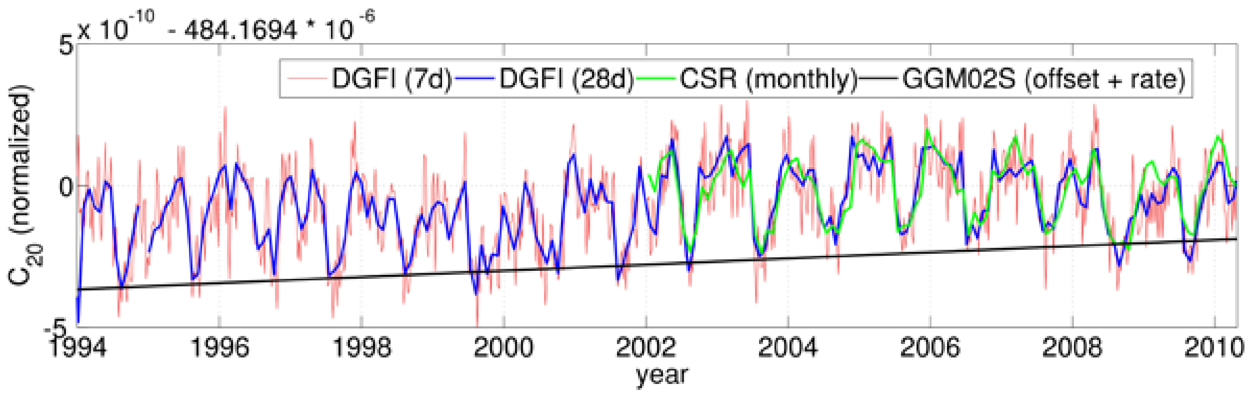


Figure 11-5: Estimated normalized coefficients with different temporal resolution (weekly/4-weekly)

Earth Rotation Parameters (ERPs)

Together with the gravity field parameters the SLR solution contains the ERPs. At the moment we are investigating especially the estimated UT1-UTC values. The high correlations between C20 and ERPs falsify the estimated UT1-UTC parameters significantly. If the gained UT1-UTC values are accumulated over the 16.5 years we see a mean trend w.r.t. the IERS 08 C04 time series of about -3.6 ms/y.

Empirical Accelerations

Another important aspect in the combined adjustment are the non-gravitational forces acting on the LAGEOS satellites. To get a stable orbit, we additionally set up empirical accelerations in along-track and cross-track direction, which are estimated once per revolution. Especially the sine-term of the cross-track acceleration is very sensitive to changes in UT1-UTC or C20.

Future Plans

Our SLR analysis software, called DOGS, is able to separate the dynamic pole of the gravity field and the geometrical pole of the station network. In the near future we want to investigate the temporal behavior of the differences of these two poles. Therefore we will set up two different solution types. Solution A contains the dynamic pole without a priori information whereas the geometric pole is fixed to its a priori values. In solution B the geometric pole is estimated and the dynamic pole is fixed to its a priori values.

Another task is to include observations to Etalon-1 and -2 in the solution in order to further decorrelate the parameters.

References

Angermann D., Drewes H., Gerstl M., Meisel B., Seitz M.: ITRS Combination Center at DGFI. IERS Annual Report 2007, Bundesamt für Kartographie und Geodäsie, Frankfurt a.M., 2009

Angermann D., Drewes H., Gerstl M., Krügel M., Meisel B.: DGFI combination methodology for ITRF2005 computation. In: Drewes, H. (Ed.): Geodetic Reference Frames, IAG Symposia, Vol. 134, 11-16, 2009

Angermann D., Drewes H., Gerstl M., Meisel B., Seitz M., Thaller D.: GGOS-D Global Terrestrial Reference Frame. In: Flechtner F., Gruber T., Güntner A., Mandea A., Rothacher M., Schöne T., Wickert J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, Springer, 2010

Kelm R. : Rigorous variance component estimation. In: weekly intra-technique and inter-technique combination for global rerrestrial reference frames. Springer, IAG Symposia, Vol. 134, 39-44, doi: 10.1007/978-3-642-00860-3_6, 2009, 2009

Müller H., Angermann D.: The International Terrestrial Reference Frame-Latest Developments. Proceedings of the 16th International Workshop on Laser Ranging, Poznan, Poland,Vol.1, 27-34, 2009

Contact

Horst Müller
Deutsches Geodätisches Forschungsinstitute
Alfons-Goppel-Straße 11
D-80539 München
GERMANY

E-mail: mueller@dgfi.badw.de
Voice: +49-89-23031-1277
Fax: +49-89-23031-1240

European Space Operation Center (ESOC)

Rene Zandbergen, Dirk Kuijper, Michiel Otten, Tim Springer/ESA/ESOC

Introduction

One of the tasks of the Navigation Support Office of the European Space Operation Center (ESOC) is to provide high-precision restituted orbit data for ESA's Earth Observation missions (ERS-2, Envisat). This orbit data are used, among others, to assist in the calibration and validation of the altimeter instrument and data processing techniques. To achieve this, SLR data for ERS-2 and Envisat are processed on a daily basis, together with other instrument data for the two missions. Furthermore, we are generating precise orbit solutions for the GIOVE-A and GIOVE–B spacecraft since continuous reliable SLR tracking became available in June 2006 and May 2008 respectively.

In addition to this activity, ESOC is the prime prediction center responsible for the delivery of predictions for the ERS-2, Envisat, GOCE, GIOVE-A, and GIOVE-B spacecraft. These predictions are disseminated to all SLR stations using the standard ILRS CPF prediction format and exchange mechanisms. These activities include predictions over orbit maintenance maneuvers for ERS-2, Envisat and GOCE, which are planned by and executed at ESOC.

Current Activities

All orbit solutions and related products are generated using a common software package (NAPEOS) and are generated automatically. The orbit solutions for ERS-2 and Envisat consist of 7-day arcs with varying timeliness of availability, depending on the mission. For ERS-2 the solution is generated with a delay of six days to allow collection of all SLR tracking data. For Envisat the final precise orbit solution has a typical delay of around 4-6 weeks depending on when the DORIS Doppler data become available.

For ERS-2, since the failure of the last onboard tape recorder in August 2003, the SLR tracking data have become the sole means to generate routinely precise orbit solutions. This process has been running very reliably for the last seven years thanks to the consistent tracking support provided by the ILRS community.

For Envisat, two different precise orbit solutions are generated. The first solution is a fast-delivery solution, which uses the SLR data together with the fast-delivery altimetry data. This solution is used to support the operational activities of Envisat and is also used to monitor the long-term performance of the Envisat altimeter. The second (and final) precise solution for Envisat is generated when the DORIS Doppler data for Envisat become available and is used to monitor the SLR and DORIS Doppler data performance.

For GIOVE-A and GIOVE-B, precise orbit solutions based on SLR tracking data have been generated since June 2006 and May 2008 respectively. These precise orbits have also been the basis for the orbit predictions as provided to the ILRS community. The precise orbit solutions have been used in studies inside the Galileo project to validate the orbit solutions based on the microwave data, to validate the microwave data, and to study the behavior of the GIOVE-A and GIOVE-B onboard clocks.

New and Future Developments

In September 2010 ESA was officially accepted as a full Analysis Center of the ILRS and contributor to the weekly SINEX solutions. ESA also contributes to the daily SINEX solutions, which are generated since November 2010. For these solutions, all available ILRS tracking data of the LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2 satellites are used. Both the weekly and the daily solutions are based on a 7-day arc for all four satellites. The daily solutions are generated at 17:00 UTC every day using all the data available at that time for the previous seven days. The weekly solutions are generated on Tuesday, i.e., three days after the end of the week for which the solution is computed.

For 2011, we are looking forward to the ILRS tracking data from the first two real GALILEO satellites. The GALILEO In Orbit Validation (IOV) phase will be a very interesting and exiting period for us and we hope the ILRS will contribute with a significant amount of tracking data from the GALILEO satellites.

Contacts

Rene Zandbergen (Navigation Support Office)
ESA/ESOC, Robert-Bosch-Strasse 5
D-64293 Darmstadt
GERMANY

Voice: +49-6151-902236
Fax: +49-6151-903129
E-mail: Rene.Zandbergen@esa.int

Michiel Otten
ESA/ESOC, Robert-Bosch-Strasse 5
D-64293 Darmstadt
GERMANY

Voice: +49 6151 902523
Fax: +49 6151 903129
E-mail: Michiel.Otten@esa.int

Geoscience Australia (GA)

Ramesh Govind/Geoscience Australia

Introduction

During the period 2009 through 2010, the main focus of the Geoscience Australia Analysis Center has been on the daily and weekly ILRS SINEX submissions and the contribution to the ITRF2008. The GA AC routinely processes LAGEOS-1, LAGEOS-2, Etalon-1, Etalon-2, Stella, Starlette, GIOVE-A, GLONASS, Envisat and Jason-2 data for satellite orbit determination, station coordinates, Earth Orientation Parameters, station performance monitoring and developing a long-term time series of the low-degree and order spherical harmonic coefficients of the Earth's gravity field. In addition, weekly orbit ephemeris files for the LAGEOS and Etalon satellites, in the standard SP3C format, are produced and submitted as part of the weekly contribution.

Key Accomplishments -- Analysis Activities during 2009-2010:

- Routine daily and weekly solutions comprising LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2 data for the respective ILRS product.
- As a contribution to the definition of the ITRF2008, weekly SINEX solutions were provided for the period 1983 – 2008; as per the requirements of the ILRS AWG (mid-2009)
- Stella and Starlette data for the period beginning 1993 to end 2010 were processed to study the contribution of these satellites to the definition of the ITRF. This study, together with monitoring station performance during this period, is continuing. A publication for the Journal of Geodesy, SLR Special Issue is in preparation.
- The potential of GNSS SLR observations to contribute to the definition of ITRF and to determine other geodetic products (such as EOPs) was presented in Govind (2009). All observed SLR data for the GLONASS constellation and GIOVE satellites for the period 1999 – 2009 (a total of 12 satellites over 10 years) were processed for this study.
- SLR data to Envisat and Jason-2 are routinely used as a quality check of their DORIS determined orbits. The SLR data to these satellites, for the period July 2002 – July 2010 and July 2008 – July 2010 for Envisat and Jason-2 respectively, were further used to estimate the DORIS system time biases for these satellites. The time bias results were presented by Govind et al. (2010a).
- The dynamically and geometrically determined geocenter estimates from the Geoscience Australia computation for the ITRF2008 submission were compared to the ILRSA combined solution. These were further compared to the DORIS determined dynamic and geometric estimates for these parameters from the Geoscience Australia computations for the DORIS contribution to the ITRF2008. These results are presented in Govind et al. (2010b).

Current Activities

Since the completion and implementation of the ITRF2008 for ILRS products, focus is now on:

- Continue the study of the potential of Starlette and Stella to contribute of to the ITRF definition.
- Quality checks of DORIS orbit products using SLR observations for Envisat, Jason-2, and Cryosat-2 – and estimating DORIS system time biases.

Related Publications

During the period 2009-2010 the following presentations were made:

Govind, R. (2009): “An assessment of the value of SLR observations to GNSS for terrestrial reference frame definition”, ILRS Workshop on SLR tracking to GNSS, Metsovo, Greece.

Govind, R., Lemoine, F.G., Chinn, D. and N. Zelensky (2010a): “DORIS time system bias: Envisat-1 and Jason-2”, presented at IDS Workshop, October 2010, Lisbon.

Govind, R., Lemoine, F.G., Valette, J-J., Chinn, D. and N. Zelensky (2010b): “DORIS Geodesy: A dynamic determination of geocenter location, Journal Advances in Space Research, doi:10.1016/j.asr.2010.08.25.

Contact

Dr. Ramesh Govind
Senior Research Scientist, Earth Monitoring Group
Geoscience Australia
PO Box 378
Canberra, ACT 2601
AUSTRALIA

Voice: 61 2 624 99033
Fax: 61 2 624 99929
E-mail: Ramesh.Govind@ga.gov.au

Helmholtz Centre Potsdam GeoForschungsZentrum German Research Centre for Geosciences (GFZ)

Rolf König, Hans Karl Neumayer, Franz-Heinrich Massmann, Sergei Rudenko, Krzysztof Snopek, Helmut Storr, Margarita Vei/GFZ

Key accomplishments

GFZ's orbit prediction system has been developed in the reporting period to a fully automated and redundant system: data acquisition and processing runs simultaneously at two facilities, one in Oberpfaffenhofen and one in Potsdam. Hence, it became robust against network and hardware failures.

Key challenges

The network proposed the new CRD format for the ranging data in order to deal with modern requirements. GFZ's Earth Parameter and Orbit System (EPOS) software was upgraded to directly read in the new format. With this feature the station validation process has been supported.

Products

Orbit Predictions for CHAMP, GRACE-A and -B, TerraSAR-X and TanDEM-X

GFZ is producing orbit predictions in two formats: Consolidated Prediction Format (CPF) and Twoline Elements (TLE). The orbit predictions are available from the CDDIS and the EDC.

The CHAMP mission ended on September 19th, 2010, with the burn-up of the satellite in the atmosphere. Since then GFZ provides orbit predictions for a total of four Low Earth Orbiters, i.e. GRACE-A and -B, TerraSAR-X and TanDEM-X. The predictions are updated as soon as new on-board GPS navigation solutions are available, approximately once per revolution or each 1.5 hours. These short turn-around times are made possible by receiving the satellite data at our Northern S-band station in Ny Alesund on Spitsbergen. Dissemination of the predictions to the network however is triggered 2-3 times per day only driven by accuracy requirements. The accuracy of the predicted orbits is permanently monitored. We assume an error margin of 10 ms in time bias, which should allow successful daylight tracking. Figure 11-6 shows for GRACE-A the 10-ms success rate 12 h after releasing the predictions. The success rate exceeds regularly 80% what justifies the present dissemination frequency policy.

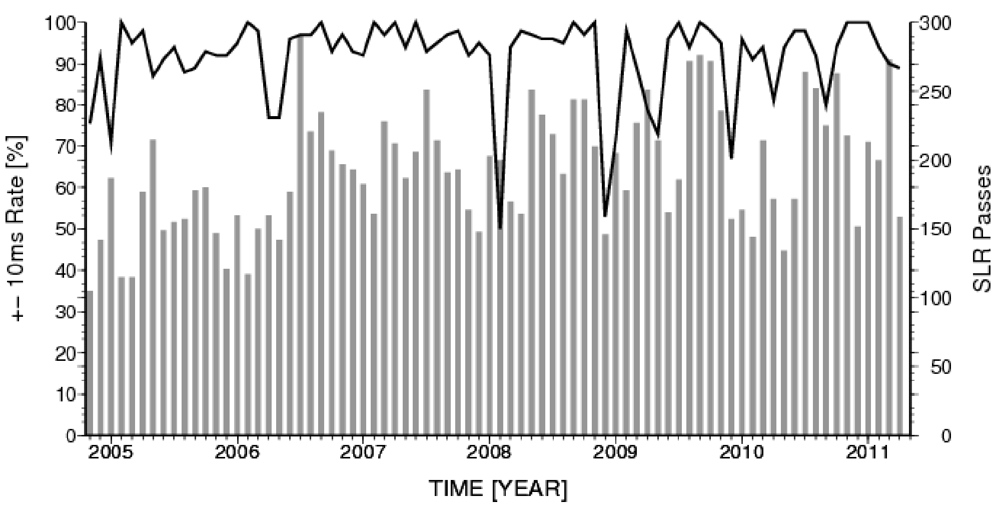


Figure 11-6. 10 ms success rate for GRACE-A (solid line) for a time advance of 12 h, together with SLR passes gathered in the network (gray columns)

POS&EOP Products

Daily and weekly POS&EOP products have been operationally provided in version v20 until May 2009, after that in version 23 following a new recommendation for station biases. Normal equations of these solutions are available in form of SINEX data from the CDDIS and EDC.

Data Handling File

The Data Handling File released by the Analysis Working Group has iteratively been monitored and updated. The Data Handling File can be accessed at the ILRS web page *http://ilrs.dgfi.badw.de/data_handling/ILRS_Data_Handling_File.snx.*

Contribution to ITRF2008

LAGEOS-1/-2 data have been reprocessed from 1983 onwards for the AC contribution to the ITRF 2008 in version v23. Normal equations of these solutions are available in form of SINEX files from the CDDIS and EDC.

Atmospheric loading and gravitational variations for 2008-2009

Files for deformation modeling at the sites and for variations of gravity due to short-term atmospheric mass movements, both consistent with GRACE standards, have been provided for test purposes to the ILRS AWG.

Other activities of the GFZ AAC include:

- Preliminary and precise orbits of ERS-2 have been calculated regularly under ESA contract
- Quality control of ERS-2 SLR data and generation and distribution of ERS-2, GRACE-A, GRACE-B, TDX and TSX Quick-Look Reports

Reprocessing of ERS-1 and ERS-2 Orbits

New precise homogeneous orbits of the European Remote Sensing Satellites ERS-1 (from August 1991 till July 1996) and ERS-2 (from May 1995 till July 2003) were derived at GFZ within the European Space Agency (ESA) project “Reprocessing of Altimeter Products for ERS (REAPER)”. The orbits were computed in the LPOD2005 reference frame (Zelensky et al., 2008) using satellite laser ranging (SLR), Precise Range and Range-Rate Equipment (PRARE) and single satellite altimetry crossover data, the most precise, consistent models available and mainly corresponding to the IERS Conventions 2003 (McCarthy et al., 2004). They show significant improvements (Figure 11-7), as compared to the German Processing and Archiving Facility (D-PAF) standards orbits, and can be used in a wide range of altimetric, Interferometric Synthetic Aperture Radar (InSAR) and other applications (Rudenko et al., 2010, Sch÷ne et al., 2010). The orbits are available via anonymous ftp at ftp://dgn6.esoc.esa.int/reaper/.

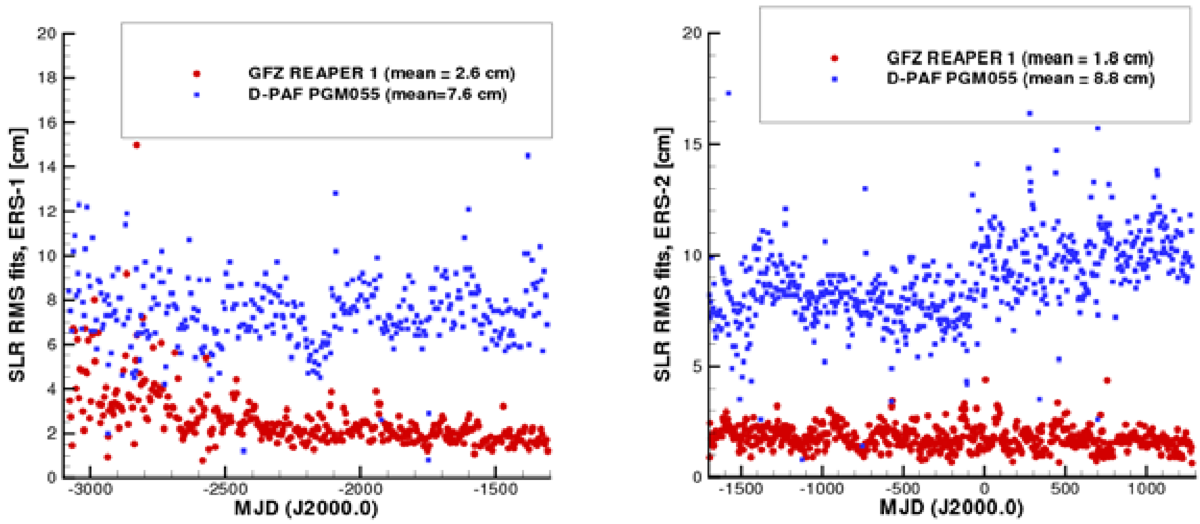


Figure 11-7a and b. Improvements in SLR RMS fits of ERS-1 (left) and ERS-2 (right) GFZ REAPER orbits as compared to D-PAF ones.

References

Zelensky, N., F. Lemoine, D. Rowlands, S. Luthcke, D. Chinn, J. Beall, B. Beckley, S. Klosko, P. Willis, V. Luceri (2008) Sub-centimeter SLR precision with the SLRF2005/LPOD2005 network, 16th International Workshop On Laser Ranging, Poznan Poland, Oct. 13-17, 2008, pp. 215-222.

McCarthy, D. and Petit, G. (2004) IERS Conventions (2003). IERS Technical Note 32. Verlag des Bundesamts f^{h}r Kartographie und GeodΣsie, Frankfurt am Main, 2004, 127 p.

Publications/Presentations

Ciufolini, I., Paolozzi, A., Pavlis, E.C., Ries, J.C., Koenig, R., Matzner, R.A., Sindoni, G., Neumayer, H.: Towards a One Percent Measurement of Frame Dragging by Spin with Satellite Laser Ranging to LAGEOS, LAGEOS 2 and LARES and GRACE Gravity Models.Space Science Reviews, DOI 10.1007/s11214-009-9585-7, Springer, online, 2009

Ciufolini, I., Pavlis, E.C., Ries, J., Koenig, R., Sindoni, G., Paolozzi, A., Neumayer, H.: Gravitomagnetism and Its Measurement with Laser Ranging to the LAGEOS Satellites and GRACE Earth Gravity Models. in: Ciufolini, I., Matzner, R.A. (Eds.): General Relativity and John Archibald Wheeler, DOI 10.1007/978-90-481-3735-0, Springer, Dordrecht, Heidelberg, London, New York, pp. 371-434, 2010

Ciufolini, I., Paolozzi, A., Pavlis, E., Ries, J., Koenig, R., Matzner, R., Sindoni, G.: The LARES Space Experiment: LARES Orbit, Error Analysis and Satellite Structure. in: Ciufolini, I., Matzner, R.A. (Eds.): General Relativity and John Archibald Wheeler, DOI 10.1007/978-90-481-3735-0, Springer, Dordrecht, Heidelberg, London, New York, pp. 467-492, 2010

Foerste, Ch., Stubenvoll, R., Koenig, R., Raimondo, J.-C., Flechtner, F., Barthelmes, F., Kusche, J., Dahle, Ch., Neumayer, H., Biancale, R., Lemoine, J.-M., Bruinsma, S.: Evaluation of EGM2008 by comparison with other recent global gravity field models. Newton's Bulletin, Issue N.4, pp. 26-37, 2009

Koenig, R., Koenig, D., Neumayer, K.H.: Station Coordinates and Low Degree Harmonics with Daily Resolution from a GPS/CHAMP Integrated Solution and with Weekly Resolution from a LAGEOS-only Solution. in: Drewes, H. (Ed.), Geodetic Reference Frames, IAG Symposium, Munich, Germany, 9-14 October 2006, pp. 31-38, Springer, Berlin, Heidelberg, 2009

Koenig, R., Vei, M.: A 25 Years Long Reference Frame Time Series from LAGEOS. EGU General Assembly 2009, Abstracts & Programme, Abstract No. EGU2009-5030, 2009

Michalak, G., Koenig, R.: Near-real time satellite orbit determination for GPS radio occultation with CHAMP and GRACE. In: Flechtner, F., Gruber, T., Guentner, A., Mandea, M., Rothacher, M., Schoene, T., Wickert, J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, DOI 10.1007/978-3-642-10228-8, Springer, Berlin, Heidelberg, pp. 443-454, 2010

Michalak, G., Koenig, R.: Rapid Science Orbits for CHAMP and GRACE Radio Occultation Data Analysis. In: Flechtner, F., Gruber, T., Guentner, A., Mandea, M., Rothacher, M., Schoene, T., Wickert, J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, DOI 10.1007/978-3-642-10228-8, Springer, Berlin, Heidelberg, pp. 67-77, 2010

Rudenko, S., Raimondo, J.-C., Schoene, T., Anderssohn, J., Massmann, F.-H.: The benefits of new improved orbits of ERS satellites for altimetry and InSAR applications. Proceedings ESA Living Planet Symposium, Bergen, Norway, 28 June - 2 July 2010, ESA SP-686, December 2010, 2010

Schoene, T., Esselborn, S., Rudenko, S., Raimondo, J.-C.: Radar Altimetry Derived Sea Level Anomalies - The Benefit of New Orbits and Harmonization. - In: Flechtner, F., Gruber, T., Guentner, A., Mandea, M., Rothacher, M., Schoene, T., Wickert, J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, Springer, 317-324. DOI: 10.1007/978-3-642-10228-8_25, 2010.

Snopek, K., Grunwaldt, L., Koenig, R.: Challenges of the TerraSAR-X/TanDEM-X formation. Proceedings, 16th International Workshop on Laser Ranging, Poznan, Poland, 2008, http://cddis.gsfc.nasa.gov/lw16, 2009.

Snopek, K., Koenig, D., Koenig, R.: Orbit Predictions for CHAMP and GRACE. In: Flechtner, F., Gruber, T., Guentner, A., Mandea, M., Rothacher, M., Schoene, T., Wickert, J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, DOI 10.1007/978-3-642-10228-8, Springer, Berlin, Heidelberg, pp. 59-66, 2010

Steigenberger, P., Artz, T., Boeckmann, S., Kelm, R., Koenig, R., Meisel, B., Mueller, H., Nothnagel, A., Rudenko, S., Tesmer, V., Thaller, D.: GGOS-D Consistent, High-Accuracy Technique-Specific Solutions. In: Flechtner, F., Gruber, T., Guentner, A., Mandea, M., Rothacher, M., Schoene, T., Wickert, J. (Eds.), System Earth via Geodetic-Geophysical Space Techniques, DOI 10.1007/978-3-642-10228-8, Springer, Berlin, Heidelberg, pp. 545-554, 2010

Future Plans

Future activities for the GFZ Analysis Center include:

- Analysis of historical LAGEOS tracking data back to 1976
- Analysis of LAGEOS long arcs
- Operational generation of POS&EOP QC reports
- Rigorous combination of space-geodetic data on the observation level

Contact

Dr. Rolf Koenig
GFZ German Research Centre for Geosciences
Dep. 1: Geodesy and Remote Sensing
c/o DLR Oberpfaffenhofen
D-82234 Wessling
GERMANY

Voice: 49-8153-28-1353
Fax: 49-8153-28-1735
E-mail: rolf.koenig@gfz-potsdam.de

Groupe de Recherche en Geodesie Spatiale (GRGS)

Florent Deleflie/OCA/GRGS, David Coulot/IGN

The staff of the GRGS ILRS Analysis Center are (alphabetical order): Dr Pascal Bonnefond (OCA/GRGS), Dr David Coulot(IGN/GRGS), Dr. Florent Deleflie (IMCCE-OP/GRGS),Dr Pierre Exertier (OCA/GRGS), Olivier Laurain (OCA/GRGS), Dr Jean-Michel Lemoine (CNES/GRGS), Franck Reinquin (CNES/GRGS), Xiaoni Wang (OCA/GRGS).

Operational Activities

1. ILRS weekly products: solution sent to ILRS data centers on a weekly basis. SINEX files contain EOP, station coordinates.
2. ILRS daily products: solution sent to ILRS data centers on a daily basis. SINEX files contain EOP, station coordinates.
3. Planned developments: Optimization of the combination between different dynamical configurations, time series of degree 2 gravity field coefficients, range bias, on an operational basis.

Analysis/Reanalysis Activities

1. Analysis/reanalysis for ILRS: comparisons between "operational" solutions and "long term" solutions. Comparisons between the various versions of the ITRF2008 realizations. Participation on the various activities of the AWG of the ILRS (including validation of the CRD format implementation).
2. Analysis for GRGS (combination center): GRGS-OCA is in charge of a complete reanalysis of SLR data (2005-present), for all geodetic satellites (especially LAGEOS-1 and -2, but other satellites as well, Starlette and Stella in particular), with a force model accounting for all loading effects. GRGS aims at providing a global solution for EOP, and station coordinates, thanks to a combination of individual solutions based on SLR, GNSS, VLBI, or DORIS data.
3. Daily analysis of T2L2 (Time Transfer by Laser Link) data.
4. Other activities: orbit determination and validation for various satellites: Jason-1, Jason-2, GPS-35, GPS-36, GIOVE-A, GIOVE-B.
5. Planned developments: time series of gravity field coefficients, on an operational point of view (degree 2 to degree 5), on a weekly basis.

Methodological Activities:

1. Methodological activities concerning orbit modeling: empirical forces modeling, non-gravitational forces modeling (LAGEOS-1 and -2), correlation with gravity field and EOP coefficients.
2. Methodological activities concerning time and range bias: optimization of the de-correlation of the parameters.
3. Methodological activities concerning statistics and estimation methods: optimization of the combination between different dynamical configurations, comparisons of results obtained from merely "geometrical" approaches, and merely "dynamical" approaches.
4. Genetic algorithms for geodesy
5. Planned developments: time transfer equations.

Fields of Interest

- Earth rotation, and its gravity field
- Station coordinates, range bias, terrestrial reference frame
- Fundamental physics
- Orbit determination and validation
- Motion of the Moon

Contact

Dr. Pierre Exertier	Voice: +33-(0)4 39 40 53 82
	E-mail: Pierre.Exertier@obs-azur.fr
Florent Deleflie	Voice: +33-(0)4 93 40 53 81
	E-mail: florent.deleflie@obs-azur.fr
OCA/GEMINI	Fax: +33-(0)4 93 40 53 33
Avenue Nicolas Copernic	
06130 Grasse	
FRANCE	

Joint Center for Earth Systems Technology/Goddard Space Flight Center (JCET/GSFC)

Erricos C. Pavlis, Magdalena Kuzmicz-Cieslak, Peter Hinkey, and Keith Evans/JCET

Introduction

The JCET/GSFC AC is presently the coordinating AC for the activities of the ILRS AWG. JCET participated in all AWG-related ILRS activities during the period 2009-10. During this reporting period, JCET has taken over from DGFI the responsibility of operating the back-up combination center for ILRS.

Background

The activities of JCET are primarily focused on the analysis of SLR data from LAGEOS, LAGEOS-2, Etalon-1 and -12, as required for the generation of the official ILRS products. The products supported are weekly station positions (and velocities for the multi-year solutions) and the Earth Orientation Parameters, x_p, y_p, and LOD at daily intervals. A similar product that is generated daily with a one-day shift of the 7-day arc start/stop dates is also produced in a Pilot Project mode. This product is intended to become eventually the operational ILRS product that will address amongst other needs of the community, the IERS Rapid Service need for as fresh estimates of EOP parameters as possible, from multiple techniques. In anticipation of a future ILRS product, we also form on a weekly basis a cumulative solution that is based on the entire set of analyzed data from 1993 to present. The weekly sets of normal equations are also used to derive a weekly resolution series of "*geocenter*" offsets from the adopted origin of the reference frame, defined by the multi-year solution.

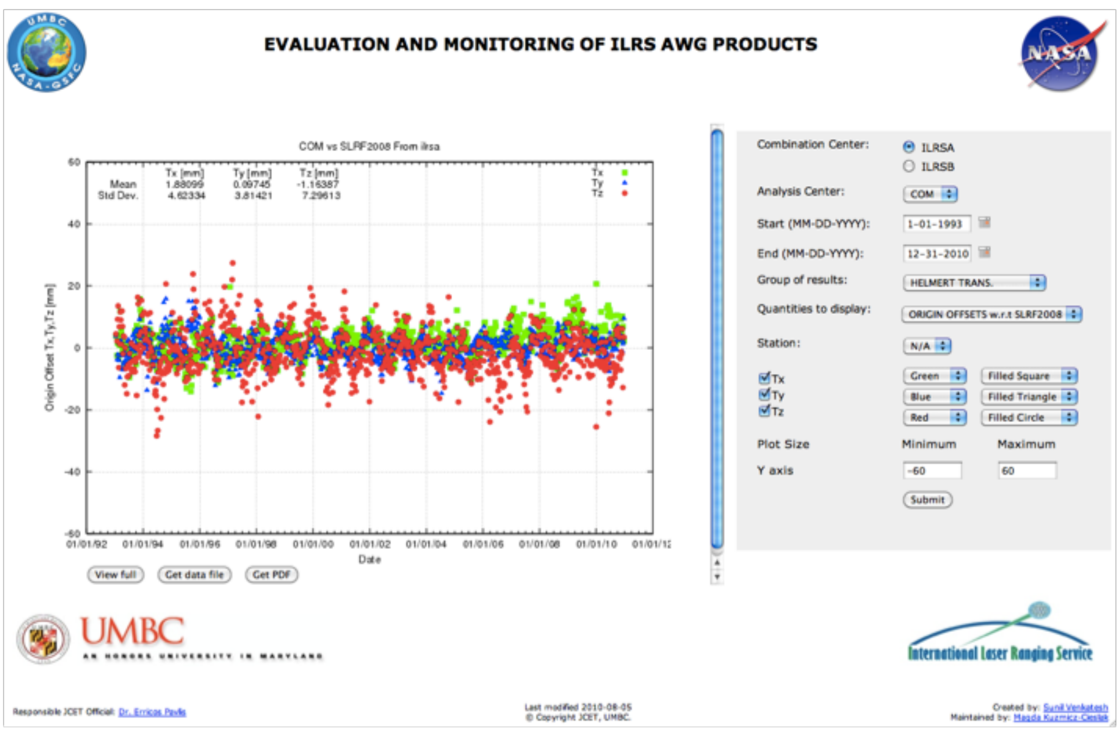


Figure 11-8. Example of JCET's "Evaluation and Monitoring of ILRS AWG Products" page displaying the origin offsets of the weekly combination series ILRS-A with respect to the a priori ITRF.

Facilities/Systems

The operational products are now developed on two systems in parallel, to ensure that we do not miss any deadlines due to hardware problems or other outages. A Linux cluster at UMBC is currently the primary server, while everything runs in parallel on NASA Ames' Pleiades super-cluster. The availability of two servers facilitates also the production of multiple versions of the products in parallel, when we are required to test changes in the modeling or enhancements with the use of ancillary information.

Current Activities

The generation of weekly and daily solutions as a contribution to the IERS/ITRF and the monitoring of episodic and seasonal variations in the definition of the geocenter with respect to the origin of the conventional reference frame continued in 2009-2010. One of the major activities this period was the generation of the final contribution for the development of ITRF2008 and the subsequent evaluation and validation of the candidate ITRF2008 realizations. The ILRS provided ITRF with the official combination product for the data span 1983 to early 2009 in mid-2009. JCET participated in the selection process for the ITRF2008, including relevant presentations at the dedicated IAG Symposium REFAG 2010. In parallel to the operational product generation and the work for ITRF2008, the JCET group made a significant effort to revamp and enhance the product evaluation and monitoring web sites that we maintain for the ILRS community. Over the past two years we redesigned our web portal that allows users to visualize the individual AC contributions as well as the two official ILRS combination product contributions and generate statistics of the series over periods of interest. It can still be accessed from: *http://geodesy.jcet.umbc.edu/ILRS_QCQA*. Figure 11-8 shows an example displaying the weekly solution origin offsets with respect to the underlying a priori TRF.

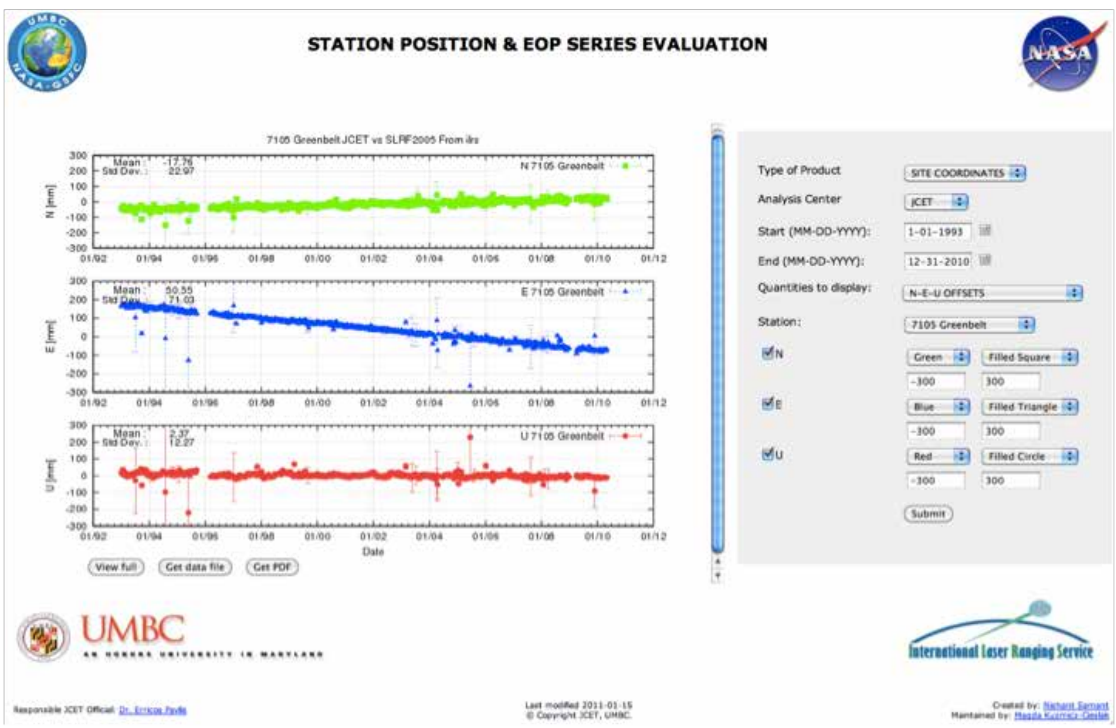


Figure 11-9. Example of JCET's addition to the ILRS AWG Products Visualization page, displaying the weekly series of N-E-U offsets for GGAO, Greenbelt, MD, from the JCET AC contributions with respect to the a priori ITRF.

The new system allows the selection of the type of quantity to be visualized, the AC/CC from which we will obtain the input series, the start/stop times over which to display the series and generate the statistics, and gives the user some flexibility in selecting the parameters for the graphics to be generated. The user has also the possibility to view the graphics in full scale, download a PDF version of the graphics or download the actual data used to generate the graphics. The original JCET system visualized the weekly residuals only with respect to the weekly a priori. It has now been extended to allow the visualization of the weekly solution with respect to the standard epoch positions of the adopted TRF (2005.0 at the moment):

http://geodesy.jcet.umbc.edu/ILRS_POS+EOP/

This extension allows the user to see the trends that the weekly solutions sense at each site in either a Cartesian (X-Y-Z) or a local (N-E-U) frame. From the same page, one can also obtain a comparison of the contributed EOP series to the underlying standard a priori series (IERS Bulletin A). Figure 11-9 shows an example with sample plots of coordinate variations in the North-East-Up directions for the SLR site at GGAO, Greenbelt, MD.

The AWG has over this time period focused on the mitigation of systematic errors in the process of SLR data reduction. One of the sources for such errors has long been identified as the assignment of practically a constant center-of-mass (CoM) offset correction to each target, with little regard to the tracking system involved and the mode in which this operates. In fact, a unique value was used for all systems except for the Herstmonceux system that has been operating in single photon mode at all times. In order to generate the appropriate corrections for each site and each time period when data are available, it is necessary to have information on the configuration and operation mode of that site. This information is of course available in the corresponding files submitted periodically by all sites. JCET generated a database where all of these files were uploaded and the information could be obtained for each site and for each of the parameters of interest.

In a similar manner, the ILRS data base for the site logs was used as input in a process that gleaned all of the required information from each text file and catalogued them in a spreadsheet that is now maintained and updated periodically, as new site logs are added or updated in the ILRS data base. The spreadsheet with the historical information comprises one set of information useful in developing the time series of CoM offsets for each ILRS system, while the spreadsheet that catalogues all items present in each site log text file is useful for the users of the current data, who want to understand in depth the characteristics of each system whose data they are analyzing. Both spreadsheets can be accessed from the same location in the CDDIS system, where the individual site logs are kept:

f*tp://cddis.gsfc.nasa.gov/pub/slr/slrlog/site_log_book.xlsm and*
ftp://cddis.gsfc.nasa.gov/pub/slr/slrlog/site_log_book_full.xlsm

The configuration database can be accessed via the web from the following link:

http://geodesy.jcet.umbc.edu/sch_sci_query/

The collection of these pages will be placed under a single portal for the JCET AC/CC, which is currently under construction. When completed in a few months, the portal will provide access to all of these pages including help and instructions with examples of how they should be used.

In recent years the ILRS community identified the control of systematic errors and their resolution as one of the most important focus areas. Several groups within ILRS provide Quality Control (QC) statistics for the network on a routine basis and they summarize their results in daily, weekly or biweekly reports made available by email or the web. Most of these reports are collected and archived at CDDIS. Having access to these over several years and from various providers offers great opportunities in the study of persistent problems at our sites. Recognizing this, JCET has generated a tool that can digest all of the available QC reports and generate a database from which the user can create visualizations of all of the reported quantities and all of the supported satellites. This tool can be installed on Unix, Linux, Windows and Apple platforms with great ease. It is currently under test and evaluation mode, however, it should be available for distribution through the ILRS web pages in the coming year.

An example of the graphical user interface with the results of a particular query is displayed in Figure 11-10. A similar tool was made available many years ago from the Graz group, however, that was limited to the reports available from CSR (not any longer) and operated only on Windows platforms.

In addition to coordinating the AWG, JCET is also responsible for conducting the software benchmarking process for candidate ACs aspiring to join the ILRS, as well as current ACs that undergo major software changes. During 2009-2010 we successfully completed the certification of the ESA/ESOC group and the re-certification of the BKG AC that exchanged the originally used software (CSR's Utopia) with a new version of the Bernese software that was extended by AIUB to handle laser range data. The addition of the new ESA AC has greatly strengthened the AWG operational products and allows for a more robust editing with nine independent submissions now routinely available.

With the retirement of Dr. Rainer Kelm in 2010 and after discussions with DGFI, JCET, after months of parallel operations, has taken over the responsibility of the back-up combination center for the ILRS. The DGFI combination software was ported, tested and validated at JCET in mid-2010. After a brief period of parallel processing at both centers, Dr. Rainer Kelm visited JCET in September 2010 and introduced the use of the new s/w to our group. Following that, JCET has officially produced the ILRS-B combination product starting in December 2010.

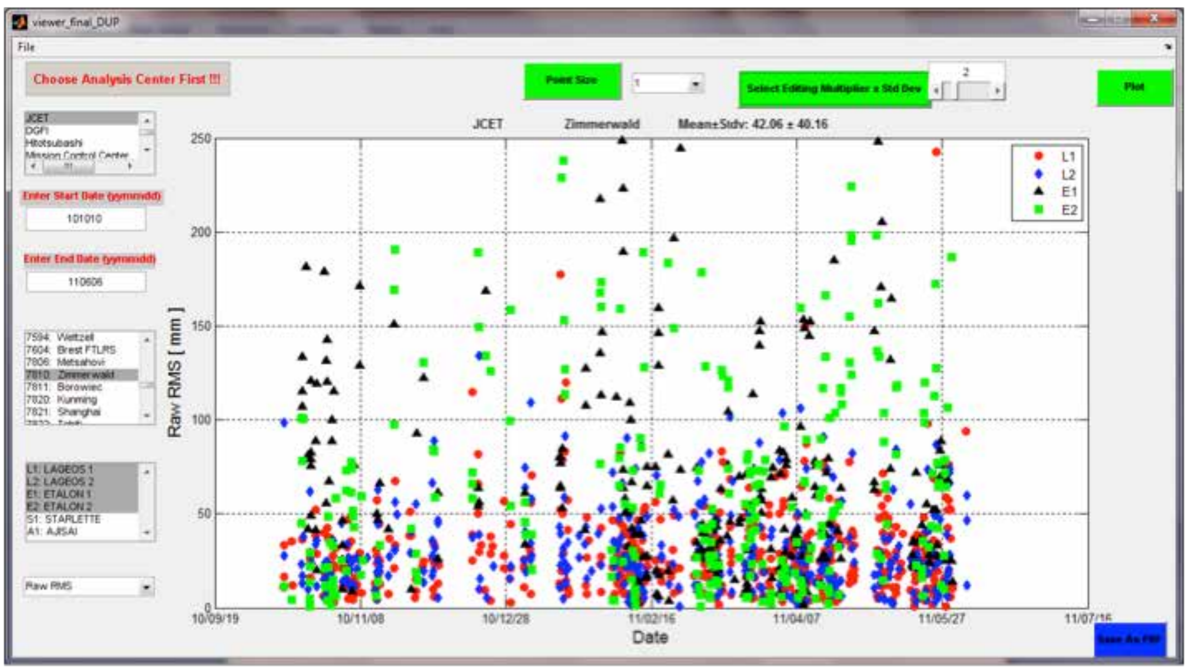


Figure 11-10. Example of JCET's QC Viewer GUI that allows users interested in the performance of ILRS sites to examine their statistics based on all available QC reports over any period of time that these are available for and for all satellites which are present in these reports.

The ILRS in its quest for higher accuracy has encouraged the design of new targets that promise a minimal signature. Along these lines, the BLITS (Ball Lens In The Space) retroreflector satellite has been developed and manufactured by the FSUE IPIE in accordance with the Federal Space Program of Russia and in agreement between the Federal Space Agency of Russia and the ILRS. The satellite was launched in Sept. of 2009 with the unique property of an aspect independent CoM correction and a very precisely defined correction prior to launch. For over a year the adopted value was about 197 mm, it was recently pointed out by R. Neubert that the value was based on erroneous refractive indices for the material of which the BLITS reflector is constructed and the CoM has been recently revised upwards to about 210 mm. JCET has consistently analyzed the data collected since the launch and over the 2009-2010 period the analysis indicates that the data can be fit to about 10 mm

RMS over the usual 7-day arcs (Figure 11-11). A new reanalysis using the corrected CoM is in progress.

The JCET group is part of the GGOS Bureau for Networks, Communications and Infrastructure and in this capacity it is involved in a number of GGOS related activities that support the design of the future Space Geodesy Network to support GGOS science products. One of the areas where we a lot attention was given over this period is the support of future navigation constellations with SLR tracking. In anticipation of a large number of candidate targets in the coming decade, JCET organized a focused Technical Workshop that brought together the SLR community with the future "customers", where information were exchanged and ideas were put forward on all aspects of the operations that will be required in a few years in order to provide the GNSS community with the required support. The workshop took place in Metsovo, Greece, in September of 2009.

As a co-PI on a proposal to the International Space Science Institute, Bern, Switzerland, with the title "Theory and Model for the New Generation of the Lunar Laser Ranging Data", JCET participated with presentations and panel discussions in the inaugural workshop hosted by ISSI on February 16-19, 2010. The interaction with the LLR community was mutually beneficial as it became apparent very quickly that a lot of the ILRS and in particular the AWG resources could greatly enhance the activities of these groups and improve their products. The plan for the next two annual workshops is to improve the ties of the LLR community and engage them in the activities of the AWG, which they are naturally part of.

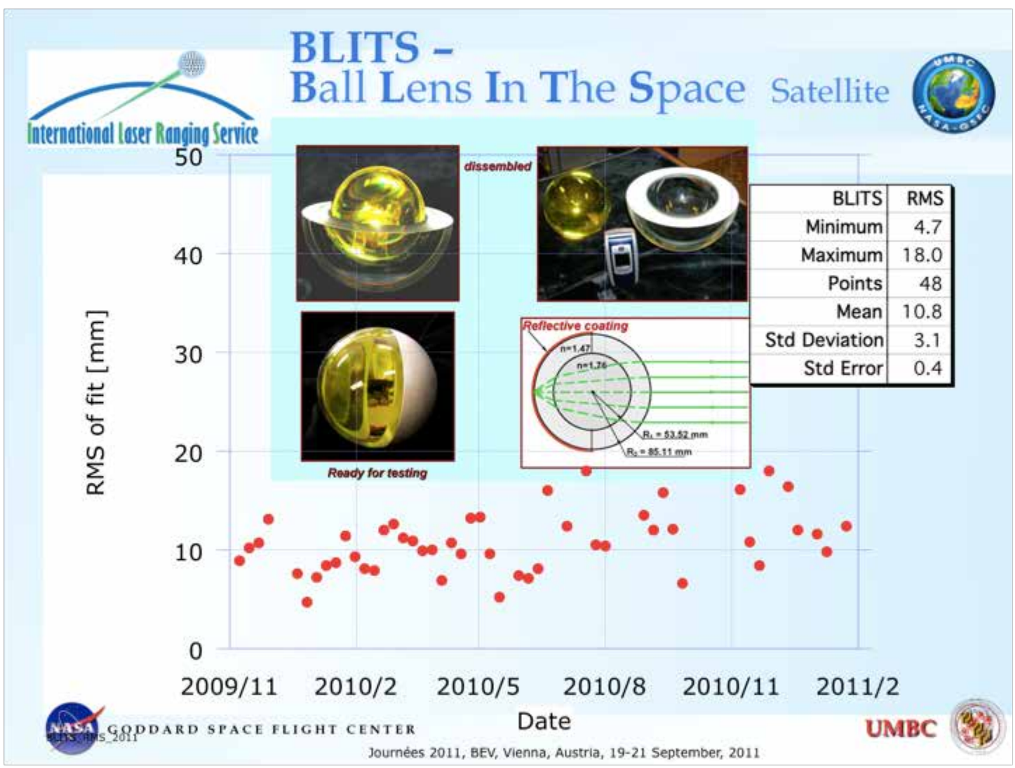


Figure 11-11. JCET's orbital fits of BLITS 7-day arcs over 2009 – 2010 using the original CoM correction.

As the U.S. PI for the Italian Space Agency's (ASI) mission LARES, JCET continued to support the project with simulations and modeling studies in anticipation of a launch that for a long time was set for the end of 2010 (eventually a successful launch occurred on Feb. 13, 2012). The successful launch of the mission will primarily provide data to improve the results of the joint relativistic experiment and measurement of the GR-predicted Lense-Thirring effect or "frame-dragging". At the same time though LARES will be the third cannonball satellite in a stable orbit, complementing LAGEOS-1 and -2 in the generation of official ILRS products. JCET along with the team members from GSFC, USNO and the University of Texas at Austin will evaluate the initial data and develop an optimal dynamical model before the inclusion in the official analysis products.

Future Plans

ILRS-related activities will continue, with emphasis now placed on the completion of simulation studies that will provide guidelines in the design of the future geodetic network to support the accuracy goals of the GGOS initiative and the optimal deployment of the NASA-contributed systems. A number of very important Pilot Projects for the AWG need to be planned and executed in the coming years before the development process for the next ITRF is initiated. These will include the finalization of a site and time dependent CoM model for the cannonball satellites supporting the ITRF, evaluation of the modeling improvement from the inclusion of higher resolution time-varying gravitational signals (e.g. from atmospheric circulation), the application at the observation level of atmospheric loading at the tracking sites, the validation of new products such as definitive orbits, gravitational harmonics for the low degrees of the gravity model, etc. Finally, with the adoption of such modeling enhancements, we will revisit the question of incorporating additional cannonball targets in much lower orbits, previously excluded due to environmental modeling limitations.

References (2009-2010)

Publications

Ciufolini, I., A. Paolozzi and E.C. Pavlis, (2009), “Status of the LARES Experiment for Accurate Measurements of Earth Gravitomagnetism”, in Proceedings of 16th Int. Laser Workshop, pp. 129-130, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Ciufolini, I., E. C. Pavlis, et al., (2010), “Gravitomagnetism and Its Measurement with Laser Ranging to the LAGEOS Satellites and GRACE Earth Gravity Models”, in General Relativity and John Archibald Wheeler, Ciufolini and Matzner (eds.), 2006 Erice Summer School Lectures, Astrophysics and Space Science Library, Vol. 367, pp. 371-434, DOI 10.1007/978-90-481-3735-0_1, Springer.

Ciufolini, I., A. Paolozzi, E. C. Pavlis, et al., (2010), “The LARES Space Experiment: LARES Orbit, Error Analysis and Satellite Structure”, in General Relativity and John Archibald Wheeler, Ciufolini and Matzner (eds.), 2006 Erice Summer School Lectures, Astrophysics and Space Science Library, Vol. 367, pp. 467-492, DOI 10.1007/978-90-481-3735-0_1, Springer.

Ciufolini, I., A. Paolozzi, E.C. Pavlis, J. Ries, R. König, R. A. Matzner, G. Sindoni, and H. Neumayer, (2009), “Towards a One Percent Measurement of Frame Dragging by Spin with Satellite Laser Ranging to LAGEOS, LAGEOS 2 and LARES and GRACE Gravity Models”, Space Science Reviews, 148, 1-4, pp. 71–104, 10.1007/s11214-009-9585-7, Springer, The Netherlands.

Kuzmicz-Cieslak, M. and E. C. Pavlis, (2009), “Implementing the new ILRS CRD data format”, in Proceedings of 16th Int. Laser Workshop, pp. 478-482, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Pavlis E. C. and Magdalena Kuzmicz-Cieslak, (2009), “Geocenter Motion: Causes and Modeling Approaches”, in Proceedings of 16th Int. Laser Workshop, pp. 16-26, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Pavlis, E. C. et al., (2009), “The goals, achievements, and tools of modern geodesy”, in GGOS2020: The Global Geodetic Observing System, H.- P. Plag and M. Pearlman(eds.) Chapter 2, pp. 24-62, GGOS/IAG, Springer-Verlag, New York.

Pavlis, E. C., Magdalena Kuzmicz-Cieslak and P. M. Hinkey, (2009), “Improved Modeling Approaches Towards the mm SLR”, in Proceedings of 16th Int. Laser Workshop, pp. 233-240, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Pavlis, E. C. and Magdalena Kuzmicz-Cieslak (2009), “SLR and the Next Generation Global Geodetic Networks”, in Proceedings of 16th Int. Laser Workshop, pp. 183-189, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Pearlman, M., C. Noll, J. McGarry, W. Gurtner, E. Pavlis, (2009), “The International Laser Ranging Service”, AOGS 2007, Adv. Geosciences, 13, pp. 129-153, World Scientific.

Ricklefs, R. L., C. Noll, J. Horvath, O. Brogdon, and E. C. Pavlis, (2009), "Implementing the Consolidated Laser Ranging Data (CRD) Format throughout the ILRS Network", in Proceedings of 16th Int. Laser Workshop, pp. 596-602, S. Schillack (ed.), Space Research Center, Polish Academy of Sciences, Warszawa, Poland.

Sciarretta, C., V. Luceri, E. C. Pavlis, and G. Bianco, (2010), "The ILRS EOP Time Series", Artificial Satellites, Vol. 45, No. 2, DOI: 10.2478/v10018-010-0004-9.

Willis, P., J.C. Ries, N.P. Zelensky, L. Soudarin, H. Fagard, E. C. Pavlis, and F.G. Lemoine, (2009), "DPOD2005 : An extension of ITRF2005 for Precise Orbit Determination", Advances in Space Res., 44 pp.535–544, Elsevier, The Netherlands, doi:10.1016/j.asr.2009.04.018.

Conference Presentations

Appleby, G. M., G. Kirchner, J. McGarry, T. Murphy, Carey Noll, E. C. Pavlis, M. Pearlman, and F. Pierron (2010), "Current Trends in Satellite Laser Ranging", Abstract G14B-05 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

LaBrecque, J., Pavlis, E. C., Magdalena Kuzmicz-Cieslak, P. M. Hinkey, Y. Bar-Sever, and D. Kuang (2010), "GPS-III Laser Ranging CONOPS Design", IFOR Geodetic Requirements WG Meeting, Rosslyn, VA, January 14, 2010.

Pavlis, E. C., M. Kuzmicz-Cieslak and N. Wolford (2010), "Accuracy of SLR Observations and Stability of its Analysis Products", Abstract G53A-01 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Pavlis, E. C., I. Ciufolini, G. Sindoni, P. M. Hinkey and N. Wolford (2010), "Investigation of GRACE Product Applications in SLR Analysis for the ITRF and the LARES Mission", GRACE Science Team Meeting, Potsdam, Germany, 11-12, Nov. 2010.

Pavlis, E. C. (2010), "ITRF2008: ILRS Support For Optimal SLR POD", 2010 Ocean Surface Topography Science Team (OST-ST) Meeting, Lisbon, Portugal, 18 – 22 October 2010.

Pavlis, E. C. (2010), SLR Contribution to ITRF: Accuracy and Stability Assessment, IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), 4-8 October 2010, Paris, France.

Pavlis, E. C., Magdalena Kuzmicz-Cieslak and P. M. Hinkey, (2010), "Improved SLR Data Analysis: Towards the mm SLR", Geophysical Research Abstracts, Vol. 12, EGU2010-11407, EGU2010-11407, EGU 2010, Vienna, Austria, 2 – 7 May 2010.

Pavlis, E. C., Magdalena Kuzmicz-Cieslak and P. M. Hinkey, (2010), "Contribution of SLR Tracking of GNSS Constellations to Future ITRF", Geophysical Research Abstracts, Vol. 12, EGU2010-11446, EGU2010-11446, EGU 2010, Vienna, Austria, 2 – 7 May 2010.

Pavlis, E. C., (2010), "Earth's gravity field models for testing general relativity", 1st Workshop on "Theory and Model for the New Generation of the Lunar Laser Ranging Data", ISSI, Bern, Switzerland 16-19 February, 2010.

Pavlis, E. C., V. Luceri, C. Sciarretta, R. Kelm, (2009), "The ILRS Reanalysis 1983 – 2009 Contributed to ITRF2008", Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract G11B-0629.

Pavlis, E. C., I. Ciufolini, G. Sindoni and P. M. Hinkey, (2009), "GRACE Support of SLR Analysis for LARES and the ITRF", GRACE Science Team Meeting, Austin, TX, Nov. 5-6, 2009.

Pavlis, E. C., Magdalena Kuzmicz-Cieslak and P. M. Hinkey, (2009), "Contributions of Future SLR Networks to the Development of ITRF", ILRS Tech. Workshop on SLR Tracking of GNSS Constellations, Metsovo, Greece, Sept. 14-19, 2009, http://cddis.gsfc.nasa.gov/metsovo/.

Pavlis, E. C., Magdalena Kuzmicz-Cieslak, J.-P. Boy and P. M. Hinkey, (2009), "Improved modeling approaches towards the mm SLR", Geophysical Research Abstracts, Vol. 11, EGU2009-6584, EGU2009-6584, EGU 2009, Vienna, Austria, 19 – 24 April 2009.

Pavlis, E. C., V. Luceri, C. Sciarretta, R. Kelm, (2009), "The ILRS Contribution to ITRF2008", Geophysical Research Abstracts, Vol. 11, EGU2009-6564, EGU2009-6564, EGU 2009, Vienna, Austria, 19 – 24 April 2009.

Pavlis, E. C, M. Kuzmicz-Cieslak and P. M. Hinkey (2009), "SLR Tracking of GNSS Constellations: A Marriage Made in Heaven", presented at the IAG 2009 Scientific Assembly "Geodesy for Planet Earth", Aug. 31-Sept. 4, 2009, Buenos Aires, Argentina.

Pavlis, E. C, J. C. Ries, D. S. MacMillan, M. Kuzmicz-Cieslak, C. Ma, and D. D. Rowlands (2009), "Global Geodetic Networks for GGOS Science Support", presented at the IAG 2009 Scientific Assembly "Geodesy for Planet Earth", Aug. 31-Sept. 4, 2009, Buenos Aires, Argentina.

Pavlis, E. C, V. Luceri, C. Sciarretta and R. Kelm (2009), "The ILRS Contribution to ITRF2008", presented at the IAG 2009 Scientific Assembly "Geodesy for Planet Earth", Aug. 31-Sept. 4, 2009, Buenos Aires, Argentina.

Pearlman, M., E. C. Pavlis, Z. Altamimi and C. Noll (2010), "Establishing a Modern Ground Network for Space Geodesy Applications", Abstract G14B-04 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Pearlman, M., E. C. Pavlis, Z. Altamimi and C. Noll, (2010), "Establishing a Modern Ground Network for Space Geodesy Applications", Eos Trans. AGU, 91(26), Meet. Am. Suppl., Abstract G12A-04, presented at the Meeting of the Americas August 09 - 13, 2010, Foz do Iguassu, Brazil.

Pearlman, M., G. M. Appleby, G. Kirchner, J. McGarry, T. Murphy, Carey Noll, E. C. Pavlis, and F. Pierron, (2010), "Current Trends in Satellite Laser Ranging", Eos Trans. AGU, 91(26), Meet. Am. Suppl., Abstract G13C-07, presented at the Meeting of the Americas August 09 - 13, 2010, Foz do Iguassu, Brazil.

Pearlman, M., E. C. Pavlis, Z. Altamimi and C. Noll, "The GGOS Bureau on Networks and Communication", presented at the IAG 2009 Scientific Assembly "Geodesy for Planet Earth", Aug. 31-Sept. 4, 2009, Buenos Aires, Argentina.

Contact

Dr. Erricos C. Pavlis
Goddard Earth Sciences and Technology Center, (GEST/UMBC)
University of Maryland, Baltimore County
1000 Hilltop Circle
TRC #182
Baltimore, MD 21250
USA

Voice: (410) 455-5832
Fax: (410) 455-5868
E-mail: epavlis@UMBC.edu

Natural Environment Research Council (NERC) Space Geodesy Facility (NSGF)

Graham Appleby, Matthew Wilkinson, Christopher Potter, and Vicki Smith/NERC

Overview

This report covers laser-ranging-related analysis work carried out by the UK Natural Environment Research Council Space Geodesy Facility (SGF Herstmonceux) ILRS Analysis Center (AC). The primary output of the AC is a daily station-coordinate and Earth orientation parameter solution using seven-day arcs fitted simultaneously to ILRS range observations of the two LAGEOS and two Etalon geodetic satellites. In common with the other ILRS ACs, the daily solutions are delivered to the ILRS Data Centers and thence to the Combination Centers in the form of loosely-constrained SINEX files, the seven-day arcs beginning nine days before the day of solution. A single geocentric station coordinate is computed at the mid-epoch of the laser data for each of the approximately 20 contributing stations. Mid-day daily Xpole, Ypole and Length-of-Day solutions are included, and for some stations a LAGEOS and or an Etalon range bias is solved-for. From mid-2011, all the ILRS ACs are using the ITRF2008 release for a-priori station coordinates as well as the corresponding IERS daily ITRF2008 a-priori EOP series.

In addition to this work, the SGF AC continues to generate back-up daily satellite orbital predictions in CPF form for most of the geodetic and some of the EO satellites, and to carry out daily web-based global QC solutions of the four primary geodetic satellites LAGEOS and Etalon, with station coordinates fixed to their ITRF2008 values. Further, the availability of laser range, GPS and absolute gravity data from the same site, plus the ability to analyse each data set, continues to open up some exciting opportunities for research, especially into vertical signals at this important site. Support data in the form of high-time-resolution water table depth measurements are also available continuously from 1996 to date, and have been used in some recent investigations (Appleby, et al, 2010).

Local inter-technique high-precision leveling work was begun on a regular basis in 2010, and is discussed in more detail in the SGF Station Report elsewhere in this ILRS Annual Report. Also discussed in that Station Report is SGF's testing of potential ranging support for the whole GLONASS constellation in addition to the ILRS minimum of four or five satellites, and to support that particular work the SGF carried out an in-orbit assessment of the efficiencies of the different retro-arrays carried on the laser-ranged orbiting GNSS constellations. This work estimated return efficiencies using three years of full-rate data from five ILRS stations that regularly track all the GNSS constellations as well as the Etalon satellites. The conclusion is that the uncoated cubes carried by the COMPASS-M1 vehicle are the most reflective currently in GNSS-type orbits (Wilkinson and Appleby, 2011).

Contribution Solution to ITRF2008

During the period, in common with the other ACs, several solution runs were carried out for the period 1983 to 2009 for eventual combination to form the ILRS contribution to ITRF2008. For the early period, when only the LAGEOS was available, the solutions were for 15-day arcs with EOPs solved every three days. From the 1992 data, when LAGEOS-2 was launched, the now-standard 7-day arcs, with daily EOP solutions were begun and also included the often-sparse data sets from the two Etalon satellites, which were launched in 1989. During this work, coordinated by the Analysis Working Group and discussed at AWG meetings, it became clear that since the inception of the SGF site in early 1983 with a single-shot precision of 35mm, several periods existed when significant range bias was apparent. As well as an analysis solution to determine the epochs and magnitudes of the effects (Luceri, 2009, 2010, presentations at AWG meetings) a thorough investigation was carried out by SGF into systematic effects of the early Maryland event timer and later series of Stanford counters prior to the introduction in 2007 February of the very-high accuracy event timer. This work was reported at the ILRS Workshop in Poznan, Poland (Appleby, et al, 2010) and a correction time-series was developed, as well as for several other stations, by the AWG. The SGF 15- and 7-day solutions themselves are in general noisier than those of most of the other ACs, and an on-going investigation suggests that the treatment of outliers and potential bias may be the cause. Consideration is now being given to include atmospheric loading in the SATAN software.

Centers-of-mass (CoM) Corrections

Detailed work was undertaken to produce tables of CoM corrections for the LAGEOS and Etalon satellites for all stations from the early 1980s until the present. It is recognized that both the hardware and the data-processing practices at stations can change over time as each station is upgraded, and the impact of such changes on the correct CoM value must be assessed. The ILRS site-logs were extracted and scripts written to track these hardware and processing changes, and the earlier published work by Otsubo and Appleby (JGR, 2003) was used to estimate the CoM values. It is recognised and repeated again that if laser returns are allowed to occur at variable signal strengths for a given station, then this fact will cause uncertainty in the corresponding CoM values; the tabular values are accompanied by an estimate of the uncertainty in the given station and time-dependent mean CoM values, which for certain configurations can reach 10mm.

Site-Stability from GPS Analysis

Analysis of the short baselines between the SGF GPS sites and analysis of regional and global short baselines was presented at the IAG REFAG2010 Symposium in October 2010 in France, and a paper has been peer-reviewed for inclusion in the proceedings (Wilkinson et al, 2011). Baselines calculated using GAMIT between the HERS, HERT and UK Ordnance Survey HERO sites reveal the presence of ~1mm near-annual variations in each component, as is the case for other baselines at other geodetic sites, that were analyzed as part of this work. The precise leveling that is being carried out may also give some clues as to the origins of these variations, at least in the vertical components.

Elastic LiDAR

A LiDAR system has been built and is used routinely to monitor atmospheric transparency at the SGF site, as an aid to expectations for laser ranging. As was well publicized, in April 2010 the Icelandic volcano Eyjafjallajo Nkull erupted, sending a plume of volcanic dust and ash up into the atmosphere over most of the European continent. The SGF began LiDAR observations a day before the ash cloud was expected to arrive over the South East of England and then routinely every hour as requested by the UK Met Office. Many observations showed increased backscatter due to the ash and dust particles at variable heights and thickness. The data showed that there were reflective layers of material, most likely ash particles from the volcano, at heights of from 1.1 to 1.6 km. Smooth curves fitted to the data above the ash, from 2-3 km, showed that at those heights there were no further aerosol layers and that atmospheric density decreased as expected exponentially with height. A publication is in preparation.

Publications

In-Orbit Assessment of Laser Retro-Reflector Efficiency Onboard High Orbiting Satellites; Wilkinson, M., Appleby, G.M. (2011, available online 15 April 2011), Advances in Space Research, http://dx.doi.org/10.1016/j.asr.2011.04.008

Monitoring site stability at SGF Herstmonceux. Wilkinson, M., Appleby, G.M., Sherwood R. (2011, accepted). Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010)

Comparison of height anomalies determined from SLR, absolute gravimetry and GPS with high frequency borehole data at Herstmonceux. Appleby, G.M., Smith, V., Wilkinson, M., Ziebart, M., Williams, S.D. (2010). Gravity, Geoid and Earth Observation, International Association of Geodesy Symposia, 135(1):107-113, DOI:10.1007/978-3-642-10634-7_15.

Attempts to separate apparent observational range bias from true geodetic signals. Appleby, G.M., Wilkinson, M., Luceri, V., Gibbs, P., Smith, V. (2010). In ‘Schilliak, S (Ed.), Proceedings of the 16th International Workshop on Laser Ranging, Poznan, Poland.

Current Trends in Satellite laser Ranging. Appleby, G.M., Kirchner, G., McGarry, J.,

Murphy, T., Noll, C., Pavlis, E.C., Pearlman, M., Pierron, F. (2010). EOS AGU, December 2010, presentation (abstract)

Further Improvements in Understanding Subtle Systematic Effects in Laser Ranging Observations Appleby, G.M., Otsubo, T., Luceri, V. EGU Abstracts G2.1, 2011

Contact

Graham Appleby
NERC Space Geodesy Facility
Herstmonceux Castle
Hailsham, East Sussex
UNITED KINGDOM

Voice: 44-0-1487-772477
Fax: 44-0-1487-773467
E-mail: graham.appleby@nerc.ac.uk

ILRS ASSOCIATE ANALYSIS CENTER REPORTS

Associate Analysis Centers are organizations that produce special products, such as satellite predictions, time bias information, precise orbits for special-purpose satellites, station coordinates and velocities within a certain geographic region, or scientific data products of a mission-specific nature.

Center for Orbit Determination in Europe (CODE)

Daniela Thaller/Astronomical Institute, University of Bern, Switzerland

Introduction

The Center for Orbit Determination in Europe (CODE) is a joint venture of the Astronomical Institute of the University of Bern (AIUB), the Swiss Federal Office of Topography (swisstopo), the Federal Agency of Cartography and Geodesy of Germany (BKG) and the Institute of Astronomical and Physical Geodesy of the Technische Universität München (IAPG/TUM). The activities as an Associated Analysis Center of the ILRS are located at AIUB.

Two types of activities are done for the ILRS:

- Provide predictions for the GPS and GLONASS satellites tracked by the ILRS;
- Provide daily SLR quick-look reports for GPS and GLONASS satellites.

Predictions for GPS and GLONASS Satellites

CODE acts also as an Analysis Center of the International GNSS Service (IGS). Since 2003, a rigorous combined analysis of the GPS and GLONASS microwave measurements is carried out for the final, rapid and ultra-rapid product line of the IGS. From these combined GPS/GLONASS rapid orbits predictions for those satellites tracked by the ILRS are derived and provided to the ILRS in the Consolidated Prediction Format (CPF).

Two GPS satellites and all GLONASS satellites carry retro-reflector arrays. The ILRS included the two GPS satellites and a sub-set of GLONASS satellites in its official tracking scenario. Unfortunately, one of the GPS satellites (i.e., GPS-35) stopped its operation in 2009.

As there are tracking capacities left at most of the stations, the ILRS decided in summer 2010 to increase the number of GLONASS satellites to be tracked from three to six. The sub-set of six GLONASS satellites was chosen in that way, that two satellites per orbital plane are tracked by the SLR sites. The GPS and GLONASS satellites included in the ILRS tracking scenario during 2009-2010 is summarized in Table 11-2.

CODE Quick-Look Reports

CODE includes all SLR observations to the GPS and GLONASS satellites from the last six days in the SLR-GNSS quick-look reports. The residuals are computed between the SLR measurements and the expected observation based on the SLRF2005 station coordinates, and the GNSS microwave–derived orbits and Earth rotation parameters (ERPs) determined at CODE for the IGS. Parameters are not estimated. The GNSS orbits of the last two days result from the rapid GNSS analysis, whereas the orbits of the earlier four days are taken from CODE’s final GNSS analysis. A description of the models used in the GNSS data analysis at CODE can be found at: *http://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn*. The summary of the quick-look analysis is divided per station, per satellite and per day. It contains the mean residual, the RMS and the number of observations. The reports are distributed every day via e-mail.

Table 11-2: GPS and GLONASS satellites included in the official ILRS tracking scenario.

System	PRN	SVN	ILRS name	Begin of SLR tracking during 2009-2010	End of SLR tracking during 2009-2010
GPS	05	35	gps-35	-	08-June-2009
GPS	06	36	gps-36	-	-
GLONASS	15	716	glonass-102	-	-
GLONASS	24	713	glonass-99	-	31-March-2009
GLONASS	08	729	glonass-115	03-April-2009	-
GLONASS	11	723	glonass-109	-	07- April- 2010
GLONASS	23	732	glonass-120	08-April-2010	-
GLONASS	05	734	glonass-118	05-September-2010	-
GLONASS	11	723	glonass-109	05-September-2010	-
GLONASS	18	724	glonass-110	05-September-2010	-

Scientific Analysis

The SLR tracking of GNSS satellites allows it to combine SLR range and GNSS microwave data using satellite co-locations instead of co-located ground stations (i.e., by applying local ties). By using the GNSS satellites as co-location the scale provided by SLR may be transferred into the microwave-based GNSS network. As a consequence, the satellite antenna offsets (SAO) of the microwave transmitting antennas can be estimated without fixing the scale of the GNSS ground network to any a priori scale, and the resulting SAO values are consistent to the SLR scale. In addition, the resulting station coordinates of co-located GNSS-SLR sites can be used as an independent validation of the local ties derived from terrestrial measurements.

The feasibility and the advantages of a combined GNSS-SLR analysis using satellite co-locations are shown in Thaller et al. (2011).

References

Thaller, D., R. Dach, M. Seitz, G. Beutler, M. Mareyen, and B. Richter (2011): Combination of GNSS and SLR observations using satellite co-locations. J Geod, Vol. 85(5), pp. 257-272, doi: 10.1007/s00190-010-0433-z.

Contact

Dr. Daniela Thaller
Astronomical Institute, University of Bern
Sidlerstrasse 5
CH-3012 Bern
SWITZERLAND

Voice: +41-31-631-3802
Fax: +41-31-631-3869
E-mail: thaller@aiub.unibe.ch

The University of Texas Center for Space Research (CSR)

John Ries, Minkang Cheng, Richard Eanes/UTCSR

Introduction

In addition to contributing to the SLR data acquisition through its operations at the McDonald Laser Ranging Station (MLRS), the Center for Space Research routinely analyzes the tracking data for several geodetic satellites in support of data quality assessment, reference frame evaluation, tests of General Relativity, and monitoring long-wavelength geopotential variations and geocenter motion.

Geocenter Motion

We continue to monitor the variations in the geocenter location, since this represents both possible systematic drifts in the terrestrial frame as well as seasonal mass transport within the Earth system at the longest length scale. In this analysis, geocenter motion is defined consistently with the IERS Conventions as the vector from the origin of the ITRF network to the instantaneous center of mass of the entire Earth. In Figure 11-12, we show an estimate of the geocenter motion obtained from SLR tracking to LAGEOS-1/-2 from late 1992 through 2009. The network is held fixed to SLRF2005/LPOD2005, and the geocenter motion vector is estimated every 60 days (this and other geocenter time series are available at ftp://ftp.csr.utexas.edu/pub/slr/geocenter). The annual variations determined from the various CSR series agree well in both amplitude and phase with other observations from SLR, GPS, GPS global inversion (using GPS, GRACE and ocean bottom pressure models), a number of geophysical model predictions, and various combinations of these, as shown in Table 11-3.

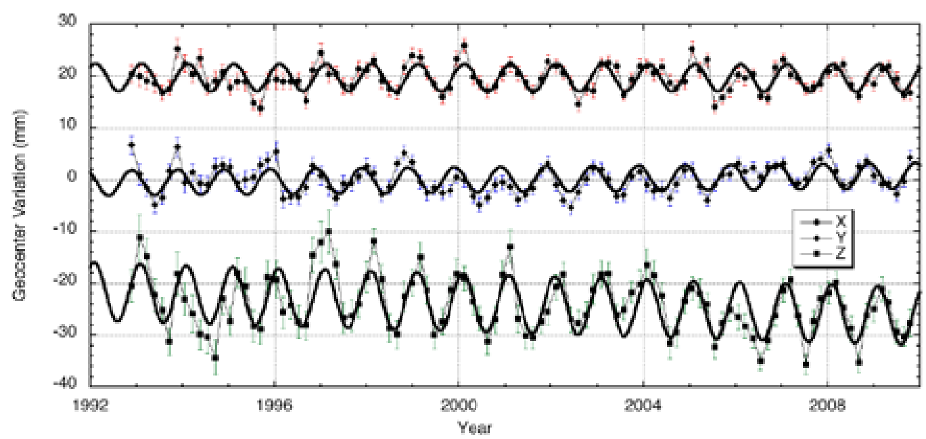


Figure 11-12. Geocenter variations estimated every 60 days from LAGEOS-1/-2. X and Z have had 20 mm added and subtracted, respectively. The fit curve is a bias, slope and annual term. A small slope of -0.3 mm/y is observed in Z.

Table 11-3. Estimates of annual amplitude (mm) and phase (deg) from CSR compared to the mean of 31 geodetic and geophysical model estimates. The amplitude and phase are defined by amp*cos(ωt-phase), where t is years past January 1 and ω is the annual frequency.

Case	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)
Sixty-day estimates from L1/L2	2.7	42	2.5	324	5.6	32
Monthly estimates from 5 satellites	2.9	46	2.6	322	4.1	43
Weekly estimates from 5 satellites	2.7	43	2.8	326	5.2	33
Mean of geodetic and model estimates	2.3	37	2.6	325	3.6	31
Standard deviation of estimates	0.6	13	0.6	14	1.0	17

Seasonal and Long-period Variations of the Earth's Gravity Field

We have extended the long-term variations in J2, shown in Figure 11-13, by analysis of the SLR data from multiple geodetic satellites over the past 34 years. In addition to the secular change induced primarily by post-glacial rebound and the annual variations, large fluctuations are correlated with the strong ENSO events of 1986-1991 and 1996-2002. There is also an apparent deceleration in the long-term drift that is likely attributable to accelerated ice melting in the arctic regions.

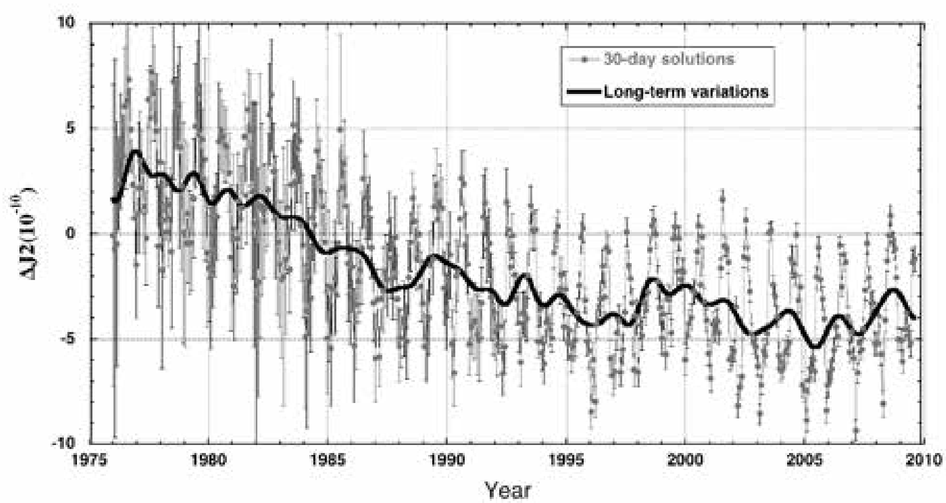


Figure 11-13. Monthly estimates showing the seasonal and long-term variations in J2.

In addition to this long-term analysis, monthly estimates of the degree-2 geopotential harmonics have been estimated from five satellites covering the GRACE mission period of 2002 to the present (available at ftp://ftp.csr.utexas.edu/pub/slr/degree_2). This analysis uses the same background modeling as used for Release 04 of the GRACE processing at CSR, and it is the source of the replacement values of C20 provided in GRACE Technical Note 05 [ftp://podaac-ftp.jpl.nasa.gov/allData/grace/docs]. In Figures 12-14 and 12-15, the SLR-based estimates for C21/S21 and C22/S22 are compared to those obtained from the GRACE mission. The estimates for C21/S21 show a clear change in direction over the last several years, again likely due to accelerated ice mass loss in the arctic regions affecting the orientation of the Earth's figure axis. The seasonal signal in C21 and C22 tends to be smaller, but the agreement between the series is still good. The large seasonal signal in S21 and S22 demonstrates more clearly the strong correlation between the SLR and GRACE estimates.

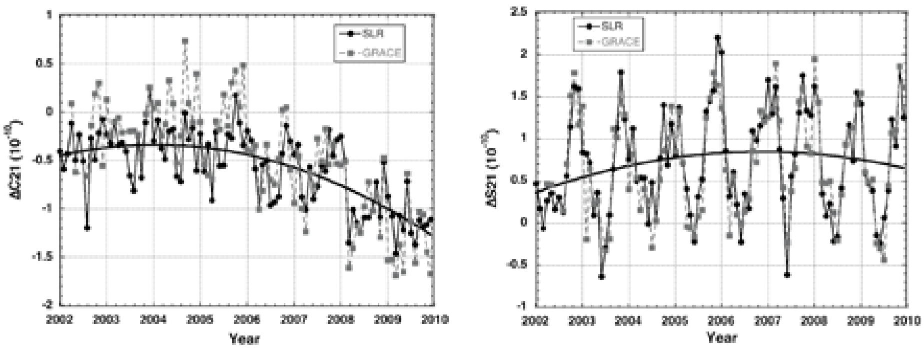


Figure 11-14. Monthly estimates of C21 and S21 from SLR and GRACE (a reference value has been removed). A quadratic fit to the time series is also shown to highlight the departure from the more linear motion observed in the past.

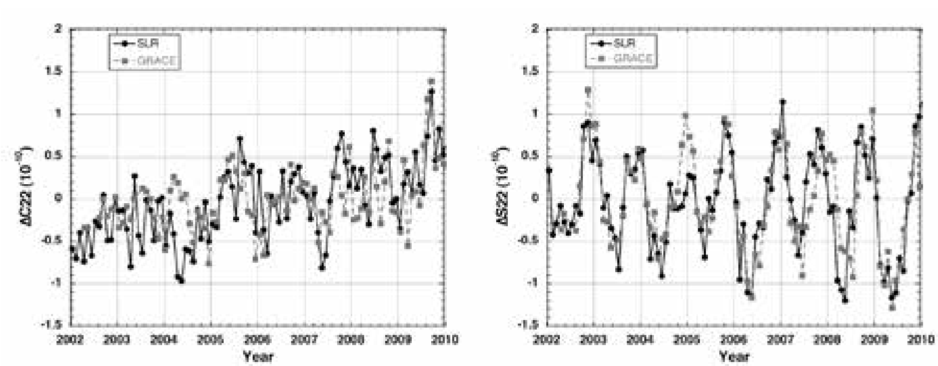


Figure 11-15. Monthly estimates of C22 and S22 from SLR and GRACE (a reference value has been removed).

Future Plans

We plan to continue the analysis of the low-degree gravity variations and geocenter from SLR. A particular emphasis is to see how well the long-wavelength gravity variations can be monitored during the expected gap between GRACE and any follow-on mission. We will evaluate the performance of the new ITRF2008 solution and, if necessary, provide the equivalent of LPOD2005 for production orbit determination. We look forward to the planned launch of the LARES satellite, in order to evaluate its contribution to tests of General Relativity and to the determination of the low-degree gravity variations.

Analysis Working Group Members

John Ries, Minkang Cheng, Richard Eanes, Bob Schutz

References

Cheng, M.K., J.C. Ries, and B.D. Tapley (2011) Variations of the Earth's Figure Axis from Satellite Laser Ranging and GRACE, J. Geophys. Res., 116, B01409, 2011, DOI:10.1029/2010JB000850.

Cheng, M.K., J.C. Ries, and B.D. Tapley (2010) Geocenter Variations from Analysis of SLR Data, to appear in proc. of IAG Commission 1 Symposium 2010, Reference Frames for Applications in Geosciences (REFAG2010), Marne-La-Vallée, France, 4-8 October 2010.

Cheng, M.K., J.C. Ries, and B.D. Tapley (2010) SLR Contributions to GRACE Science Applications, presented at GRACE Science Team Meeting 2010, Potsdam, Germany, 11-12 November 2010.

Ciufolini, I., A. Paolozzi, E. Pavlis, J. Ries, R. Koenig, R. Matzner, and G. Sindoni (2010) Gravitomagnetism and Its Measurement with Laser Ranging to the LAGEOS Satellites and GRACE Earth Gravity Models, General Relativity and John Archibald Wheeler, Astrophysics and Space Science Library 367, I. Ciufolini and R.A. Matzner (eds.), pp. 371-434, DOI 10.1007/978-90-481-3735-0_17, Springer.

Ries, J.C. (2009) Laser Ranging to GNSS / LPOD2005, International Technical Laser Workshop on SLR Tracking of GNSS Constellations, Metsovo, Greece, 14-19 September 2009.

Ries, J.C. (2009) Satellite Laser Ranging and Relativity, presented at the First International LARES Workshop, Rome, 3-4 July 2009.

Ries, J.C. (2009) General Relativity in Satellite Laser Ranging (2009) presented at IAU Symposium 261, Relativity in Fundamental Astronomy: Dynamics, Reference Frames and Data Analysis, Virginia Beach, VA, April 27-May 1, 2009.

Contacts

Dr. John C. Ries
The University of Texas at Austin
Center for Space Research
Mail Code R1000
Austin, TX 78712
USA

E-mail: ries@csr.utexas.edu
Fax: 01-512-471-7486
Fax: 01-512-232-2443
Web: http://www.csr.utexas.edu

Delft University of Technology (DUT)

E.J.O. Schrama, P.N.A.M. Visser, J. van den IJssel/DUT

Introduction

The group of Astrodynamics and Space Missions (AS) at Delft University of Technology (DUT) is involved in several precise orbit determination (POD) projects. Amongst these are CryoSat-2, REAPER ('Reprocessing of Altimeter Products for ERS') and GOCE HPF (High Level Processing Facility).

CryoSat-2

CryoSat-2 was successfully launched on April 8, 2010 to map the cryosphere with an advanced microwave altimeter system. The mission goal is to observe the freeboard of sea ice and the topography of ice sheets for a nominal period of three years. Precision orbit determination of CryoSat-2 relies on DORIS and SLR tracking. DUT uses the NASA/GSFC developed GEODYN software for this purpose. DUT has used data from up to 22 ILRS tracking stations, and presently gets an rms of fits of 1.5 to 2.0 cm. The 10-second DORIS range-rate data is obtained through the IDS, from up to 50 beacons; the rms of fit is 0.4 to 0.5 mm/s. Within the framework of a study contract with ESA to validate the CryoSat-2 orbit and altimeter performance, DUT conducted an inter-comparison with the orbit products produced by CNES (Toulouse, France) where an agreement of the radial component of the CryoSat-2 orbit of 1.5 to 1.6 cm is found. Presently the low-resolution mode altimeter accuracy over the oceans is around 10 cm rms; in this case DUT relies on its radar altimeter data base which retains sea level profile data of all operational and historic satellite altimeter missions.

REAPER

For the ESA European Remote Sensing satellites 1 and 2 (ERS-1/2), new orbit solutions have been computed using the latest standards and conventions. Especially, the availability of improved global gravity field models from the GRACE mission has resulted in more precise orbit solutions. The availability of SLR is indispensible for producing high-quality orbit solutions: only for ERS-2 and only for part of its mission lifetime, the possibility exists to add data collected by the Precise Range and Range-Rate equipment (PRARE). The period covered in the REAPER project is 3 August 1991 – 8 July 1996 for ERS-1, and 3 May 1995 – 4 July 2003 for ERS-2. The orbits are computed with the GEODYN software (version 0712), kindly provided by NASA/GSFC.

It is anticipated that the REAPER project will be extended with the production of ERS-2 orbit solutions until the end of its mission lifetime, i.e. covering July 2003-July 2011. SLR data have already been collected for this time frame, have been pre-processed and have been used in preliminary ERS-2 orbit solutions. SLR statistics for these preliminary solutions are listed in Table 11-4. The values are rather high due to a relaxed parameterization, i.e., relatively few orbit dynamic parameters are estimated.

Table 11-4. Mean and RMS-of-fit of SLR observations for ERS-2 preliminary orbit solutions covering 2009 and 2010. Observations with a residual larger than 3.5 times the RMS-of-fit were eliminated (a few %).

ILRS Station #	Number of Observations	Mean (cm)	RMS (cm)	ILRS Station #	Number of Observations	Mean (cm)	RMS (cm)
1824	2796	0.00	4.26	7501	4806	-0.20	5.66
1831	770	3.72	7.87	7810	22063	-0.01	8.09
1884	8797	2.11	4.07	7811	1773	-0.50	2.81
1893	4700	-1.17	4.51	7820	88	0.76	5.12
7080	2360	-0.01	1.55	7821	3121	0.00	3.92
7090	46194	1.11	7.53	7824	8763	-0.01	2.75
7105	12664	-0.98	9.83	7825	14862	0.24	6.39
7110	8015	0.11	3.52	7831	6	1.40	1.73
7119	7518	-0.09	11.59	7832	3612	0.61	3.30
7124	2002	1.06	7.00	7838	4348	1.01	8.60
7237	12806	-0.72	5.76	7839	20630	0.00	3.02
7249	1353	0.00	1.48	7840	13840	-0.01	3.65
7308	3055	-0.04	5.58	7841	15260	-0.78	2.72
7358	1233	6.61	12.68	7845	3324	0.00	9.98
7402	3194	-0.19	17.05	7941	8744	-0.43	4.60
7405	6362	0.03	5.22	8834	9194	-0.00	1.85
7406	13478	-0.59	6.31				

GOCE HPF

For the ESA Gravity Field and steady-state Ocean Circulation Explorer (GOCE), launched in March 2009, quick-look (less than one-day latency) orbit solutions are produced with the GEODYN (version 0302) and GHOST software from the DLR German Space Operations Center (GSOC). These orbits are validated by comparison with independent SLR observations. SLR statistics are listed in Table 11-5 for the GEODYN GOCE quick-look orbit solutions covering 2009 - 2010. It has to be noted that for final orbit solutions (only computed for a limited period by AS), the RMS-of-fit is typically of the order of 2-3 cm.

SLR observations are used for validating AS orbit solutions for the German CHAMP and U.S. GRACE satellites as well. However, orbit solutions for the 2009-2010 time period have yet to be computed.

Publications

E.J.O. Schrama, P.N.A.M. Visser, M.C. Naeije, (2011) Cryosat-2 precision orbit determination with DORIS and satellite laser ranging, validation with the SIRAL LRM data, Contribution to proceedings of the CryoSat Validation Workshop 2011, 1–3 February 2011 Frascati, Italy, ESA SP-693.

M. Naeije, E. Schrama, and R. Scharroo, (2011) Calibration and validation of Cryosat-2 low resolution mode data, Contribution to proceedings of the CryoSat Validation Workshop 2011, 1–3 February 2011 Frascati, Italy, ESA SP-693.

Table 11-5. Mean and RMS-of-fit of SLR observations for GOCE quick-look orbit solutions covering 2009 and 2010. Passes with an RMS-of-fit above 15 cm were eliminated (a few %).

ILRS Station #	Number of Observations	Mean (cm)	RMS (cm)	ILRS Station #	Number of Observations	Mean (cm)	RMS (cm)
1884	399	1.26	4.44	7406	106	-2.54	4.49
1893	247	-1.93	5.23	7501	61	-2.87	5.97
7090	5628	-1.37	5.30	7810	1402	-2.59	4.37
7105	1023	-2.19	5.35	7821	73	-5.54	8.05
7110	519	-0.80	4.58	7824	641	-1.63	4.45
7119	15	-4.77	4.86	7825	131	-2.04	4.36
7237	1291	-0.84	6.14	7839	2531	-1.58	4.71
7249	22	-1.71	7.40	7840	608	-2.40	4.31
7308	66	-2.49	9.09	7841	756	-3.50	5.26
7403	56	-3.14	4.82	7941	65	-3.19	3.73
7405	5	-1.48	1.51				

Contacts

Ron Noomen E-mail: R.Noomen@tudelft.nl
Ernst Schrama E-mail: E.J.O.Schrama@tudelft.nl
Pieter Visser E-mail: P.N.A.M.Visser@tudelft.nl
Delft University of Technology
Faculty of Aerospace Engineering
Kluyverweg 1
2629 HS Delft
THE NETHERLANDS

Forsvarets Forskningsinstitutt (FFI)

Per Helge Andersen/FFI

Introduction

FFI has during the last 29 years developed a software package called GEOSAT for the combined analysis of VLBI, GNSS (GPS, GLONASS, Galileo), SLR, space-borne gradiometry, altimetry and other types of satellite tracking data (DORIS, PRARE). The observations are combined at the observation level with a consistent model and consistent analysis strategies. With this procedure, the time-evolution of the common multi-technique parameters (for example EOP, geocenter, troposphere, or clock parameters) are treated consistently across the techniques. This is not the case when the techniques are combined "rigorously" at the normal equation level. The data processing is automated except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GNSS, and SLR observations the data are processed in arcs of 24 hours defined by the duration of the VLBI session. The result of each analyzed arc is a state vector of estimated parameter corrections at the last epoch of observation and a Square Root Information Filter array (SRIF) containing parameter variances and correlations for the same epoch. The individual arc results are combined into a multi-year global solution using a Combined Square Root Information Filter and Smoother program called CSRIFS. With the CSRIFS program any parameter can either be treated as a constant or a stochastic parameter between the arcs. The estimation of multi-day stochastic parameters is possible and extensively used in the analyses.

Activities

In 2008 we completed the development and validation of a new version of the GEOSAT software (called GEOSAT_2010). This version can be used for routine processing of space geodesy observations and tracking data towards spacecraft in the solar system.

For SLR applications GEOSAT_2010 produces monthly residuals for LAGEOS-1 and -2 of 7-9 mm. Only solve-for parameters are orbital elements, one-cycle-per-rev parameters, and monthly range biases. The station coordinates and velocities were fixed to ITRF2005.

The dynamical model of GEOSAT has been re-evaluated. GPS orbits derived with GEOSAT are consistent with IGS combined GPS orbits to 2 cm, with high quality GRACE orbits to 4 mm, and with GOCE orbits to 10 mm. It has been demonstrated that errors in the EGM2008 model results in orbital errors of approximately 20 cm for the GOCE satellite (approximately 250 km altitude).

FFI and Statens Kartverk (SK) started a close cooperation in 2009 in order to extend GEOSAT for analysis of space-borne gravity/accelerometry observations f ex from GRACE and GOCE. In addition, the altimetry part of GEOSAT has been modernized and a script-based production line for altimetry processing is established. The GEOSAT team consists of Per Helge Andersen (FFI), Eirik Mysen (SK, gravity/accelerometry), Kristian Breilid (SK, altimetry), and Halfdan Pascal Kierulf (SK, VLBI).

The inclusion of space-borne gravity in GEOSAT is completed and the software is presently being tested against real GOCE-observations. The residuals are as reported by others indicating that the implementation has been successful.

The altimetry production line has been used to generate sea surface level rates as a function of latitude and longitude using data from TOPEX, Jason I and Jason II. European altimeter satellites are being included right now. In the future GEOSAT-derived orbits, consistent across tracking techniques, will be used to produce the same type of information.

Statens Kartverk is presently in a process with the goal to become an IVS full Analysis Center. It will use GEOSAT for the analysis of VLBI observations. The status is that the results with GEOSAT differ from the other IVS analysis centers by a few mm or less. Statens Kartverk was recently accepted as an Associate Analysis center for IVS.

Future Plans

GEOSAT will be extended to be able to analyze GNSS data onboard LEO-satellites (GOCE, GRACE, altimeter satellites). A KBR analysis capability will be included in GEOSAT. The DORIS capability of GEOSAT has not been used for many years and will be modernized.

Acknowledgement

Per Helge Andersen's work over the last two years has been financed by Statens Kartverk. It's contributions are greatly appreciated!

Contact

Dr. Per Helge Andersen
FFI, Division III
P.O. Box 25
N-2007 Kjeller
NORWAY

Voice: 47-63-807407
Fax: 47-63-807212
E-mail: per-helge.andersen@ffi.no

Main Astronomical Observatory of the National Academy of Sciences of Ukraine (GAOUA)

Vasyl Choliy/Main Astronomical Observatory of the National Academy of Sciences of Ukraine

Introduction

AAC Main Astronomical Observatory Ukrainian Academy of Sciences consists of two parts. These are

1. the analysis center, managed by Dr. Vasyl Choliy
2. GLSL laser ranging station, managed by Dr. Mykhailo Medvedskiy

Prof. Yaroslav Yatskiv is the Observatory director and Head of Space Geodynamics division.

Scientific Results

In 2099-2010, the AAC in MAO continues its work on implementation and testing of the next generation of satellite data processing software, Juliette/KG++. Unfortunately, the software is still in the state of testing so we are able to only produce some testing level results. They cannot be understood as final results but only as preliminary solutions.

Our plans includes finalizing the software to a productive level and restoring the permanent activities in the AAC to generate our SLR EOP series. We plan to include low Earth orbiting satellites in our processing methodology.

Contact

Dr. Vasyl Choliy
Main Astronomical Observatory of the NAS of Ukraine
Akademika Zabolotnoho Str., 27
Kiev, UKRAINE, 03680

E-mail: Choliy.Vasyl@gmail.com

Hitotsubashi University

Toshimichi Otsubo and Mihoko Kobayashi/Hitotsubatshi University (HIT-U)

Introduction

Since 2007, Hitotsubashi University has regularly contributed to the ILRS analysis activities mainly with the "multi-satellite analysis report" that had been taken over from NICT. We have also taken the statistics called "hit rate" on the data production performance of the ILRS tracking stations.

Multi-Satellite Analysis Report

The daily quality check analysis has been automatically run and the bias analysis report has been issued in a daily basis. The main software engine is Java-based 'concerto v4' originally developed at NICT. We currently analyze as many as 16 satellites' data every day although some satellites are sometimes dropped from the analysis report when the quality or quantity is not sufficient. The report is being issued and uploaded around 9-11h JST (=0-2h UT) every day. The URL is: http://geo.science.hit-u.ac.jp/slr/bias where the daily reports from 2005 are all archived. We have been actively exchanged the result in the reports with the ILRS tracking stations especially when we (or sometimes a station) detect a series of anomalous data.

New Statistics "Hit rate"

We have worked up simple, but new statistics, called "hit rate", that is the ratio of successful ranging observations with respect to all possible observations, above 20 degrees of elevation. Ideally the hit rate should be 100 % which means the satellite is tracked every time it flies over the station, but in reality it is often hampered by the weather condition, the observer resource, the telescope time, etc. In order to calculate the hit rate, the observable passes are first counted based upon the CPF prediction data, and the tracking data are then matched. Figure 11-16 shows the hit rates for "Starlette and Stella" (top) and "LAGEOS-1 and LAGEOS-2" (bottom) in 2009 and 2010 for the most productive 20 stations. The solid bars indicates pass-based hit rate, and the gray bars indicates normal-point-based hit rate. For instance, it can be read that Yarragadee is the only station, which has actually tracked more than half of the observation opportunity. More detailed investigation and discussion are presented at 17th International Workshop on Laser Ranging in May 2011.

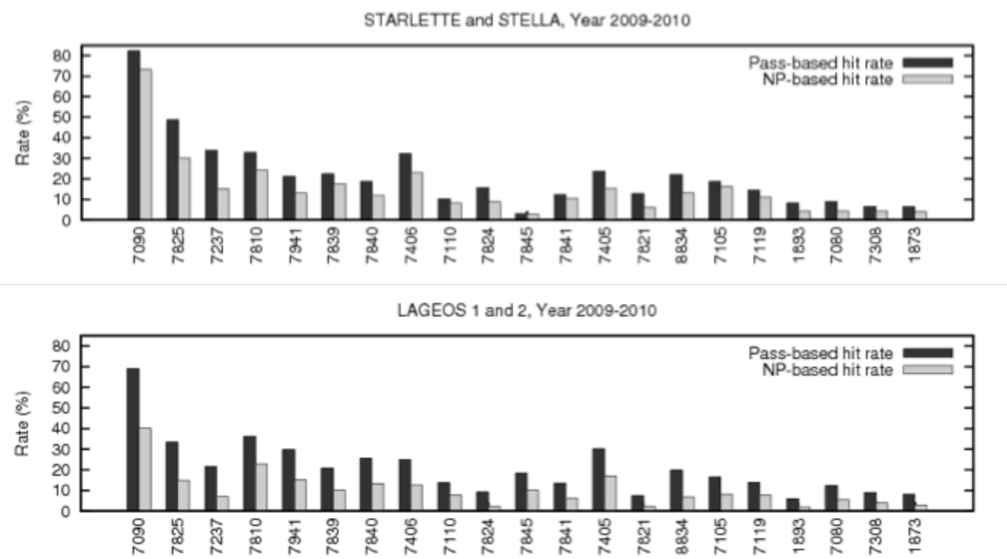


Figure 11-16. Hit rate of ILRS stations in 2009-2010. Top: Starlette and Stella. Bottom: LAGEOS-1 and LAGEOS-2.

Future Plan for 2011-12

We are currently developing the new version "5" of our own analysis software "concerto", in collaboration with NICT and JAXA. It is named "c5++" as we newly adopted C++ language. It is designed to be able to combine multiple types of geodetic/tracking data from the observation level, and to offer the best physical models such as IERS Conventions 2010.

Contact

Toshimichi Otsubo
Hitotsubashi University
East Bldg, 2-1 Naka, Kunitachi
Tokyo 186-8601
JAPAN

E-mail: t.otsubo@r.hit-u.ac.jp
Voice: 81-42-580-8939
Fax: 81-42-580-8939
Web: http://geo.science.hit-u.ac.jp/

Information-Analytical Center (IAC)

Vladimir Glotov/Information-Analytical Center

Introduction

The Information-Analytical Center (IAC) of Coordinate-Time and Navigation Service (previously know as MCC) has been involved in SLR data analysis since 1990. IAC has continued determination of Earth Orientation Parameters (EOPs) and SLR network quality control, the studies to use SLR measurements of GLONASS satellites to check the quality of the available microwave-based orbital solutions, and support of the Russian SLR network and Russian SLR missions (Larets, BLITS, etc.).

Facilities/systems

The IAC SLR analysis group utilizes two of its own PC-oriented software packages in routine activities: STARK and STARK-AUTO&STARK-SYSTEM (SLR, GPS/GLONASS "phases" and code navigation data processing in the near-automatic regime).

Current Activities

Weekly EOP Estimation and SLR Network Quality Control

The IAC started routine determination of EOP in cooperation with the IERS in 1993. Based on SLR data from the LAGEOS-1 and -2 satellites, IAC (MCC) EOP estimations are sent to the Central and Rapid IERS Bureaus. Plots are available at http://maia.usno.navy.mil/plots.html.

In 1996, the IAC (MCC) started a regular service of assessing performance of the SLR stations. All LAGEOS-1 and -2 data are analyzed to obtain values of time and range biases and RMS. The routine service requires two levels of data filtering: automatically excluding outliers and problem sessions and manually checking and correcting the results. Since 2008 we send the analysis reports for the SLR Report publication daily.

The IAC also serves as the Operation Center of the Russian SLR network, handling the following stations: Altay, Komsomolsk, Arkhyz (new station) and Baikonour (tested station).

The IAC SLR analysis group also provides satellite prediction files in the Consolidated Prediction Format for the Russian SLR missions (Larets and BLITS now).

GLONASS Orbit Determination and Verification

The global products from the IGS GLONASS activities should facilitate the use of combined GLONASS and GPS observations and analysis results for the civil scientific and engineering applications in the frame of the prototype Global Navigation Satellite System (GNSS). Particularly, there are many civil applications where navigation data from GPS are not enough for the complete analysis. From this point of view it is important to calibrate the geodetic base, the navigation signals accuracy etc. for the GLONASS system as good as possible. SLR data are the source of calibration data for the ephemeris determination, the international geodetic base providing and accuracy factor improving for GNSS etc.

The IAC has contributed to the International GNSS Service (IGS) by providing precise orbits based on SLR observations for those GLONASS satellites that are observed by the ILRS network. These independent orbits help to validate and evaluate precise orbits computed by Analysis Centers from the IGS tracking network observations. Since 1995, the IAC has permanently supported orbit determination of GLONASS satellites based on SLR data. Orbits for GLONASS satellites (in SP3 format) are regularly sent to the CDDIS for the determination of the final orbits based mainly on the GLONASS “phase” data.

Future Plans

The IAC will continue its ILRS-related activities through the routine processing and analysis of SLR data and as the Operation Center of the Russian SLR network.

Contact

Vladimir Glotov (coordinator)	Email: vladimir.glotov@mcc.rsa.ru
Vladimir Mitrikas (main expert)	Email: vladimir.mitrikas@mcc.rsa.ru
Sergey Revnivych (administrative support)	Email: sergey.revnivych@mcc.rsa.ru

Information-Analytical Center (IAC)
of Coordinate-Time and Navigation Service
4 Pionerskaya Street
Korolyov, Moscow Region 141070
RUSSIA

Japan Aerospace Exploration Agency (JAXA)

Anne Mori, Shinichi Nakamura, Ryo Nakamura/Flight Dynamics Division, JAXA

Introduction

One of the tasks of the JAXA Associate Analysis Center is to provide the precise orbit determination for Ajisai, LAGEOS-1, and LAGEOS-2. In addition, JAXA performed the clock synchronization experiments until 2010 using ETS-8, a geostationary satellite launched in December 2006. QZS-1 was launched in Sep. 2010 and QZS-1 tracking campaign has been performing since December 2010.

Current Activities

- Processing SLR tracking data of AJISAI, LAGEOS-1, and LAGEOS-2.
- Generating CPF predictions for the above satellites.
- Analyzing the data obtained from ETS-8. The analysis shows that the accuracy of orbit determination and time synchronization has achieved within approximately 20m (RMS) and 10 nsec.
- Performing QZS-1 tracking campaign. QZS-1 was launched in Sep. 2010.

Current Satellite Missions

ETS- 8

JAXA has carried out High Accuracy Clock (HAC) Experiment, one of the main experiments of Engineering Test Satellite-8 (ETS-8), for verification of global navigation satellite technologies. The experiment consists of management of onboard atomic clocks, satellites' precise orbit and clock estimation and satellite positioning with Global Positioning System (GPS) satellites and ETS-8. ETS-8 carries a cesium clock and can transmit navigation signals similar to GPS signals in L band and S band. The ETS-8's navigation signals are received by four Satellite Monitor Stations (SMSs). Navigation observations collected by the SMSs are sent to the Master Control Station in JAXA Tsukuba Space Center in real time, processed and used for orbit and clock estimation of ETS-8. In order to evaluate results of the precise orbit and clock estimations, another means of precise ranging such as Satellite Laser Ranging (SLR) is quite usable. Therefore, ETS-8 carries a laser retro reflector array. JAXA requested the candidate stations of WPLTN (Mt. Stromlo, Yarragadee, Koganei, Changchun, and Beijing station) to range ETS-8 once every two weeks.

Precise orbit and clock estimation experiments were performed for several times. The orbit estimation periods for each experiment were approximately 24 hours during a free flight of ETS-8. The orbits of ETS-8 estimated by navigation observations coincided with ones estimated by SLR measurements (collected with cooperation from ILRS network, especially the candidate stations of WPLTN) within the accuracy of 20m in any cases. The ETS-8's clock offsets were successfully estimated within the accuracy of 10 nanoseconds, evaluated by dispersions of estimated clock offsets except the first order drift. [2][3]

QZS-1

The QZSS (Quasi-Zenith Satellites System) is a constellation of several identical satellites, with at least one satellite positioned near zenith over Japan anytime, and its first one QZS-1 was launched in Sep. 2010. Users can receive the communication and positioning signals from QZSS near zenith direction without obstruction in urban and mountainous area. Due to this advantage, people in moving vehicles and using mobile phones can speak and send/receive high quality content without interference. In addition, the system, used together with a GPS, will provide much more accurate positioning information than with GPS alone. The system is aimed at improving availability of GPS signals for relevant users via QZSS, which is equipped with instruments capable of generating and transmitting signals compatible with modernized GPS signals. SLR ranging data from QZS are essential for these missions in order to transmit precise orbit ephemeris through a navigation message similar to GPS. JAXA performed QZS-1 tracking campaign in Dec. 2010 with the cooperation of the candidate stations, such as Koganei station, Yarragadee station, Mt. Stromlo station, Changchun station, Beijing station and Shanghai station. JAXA requested these stations to range QZS-1 6 times a day.

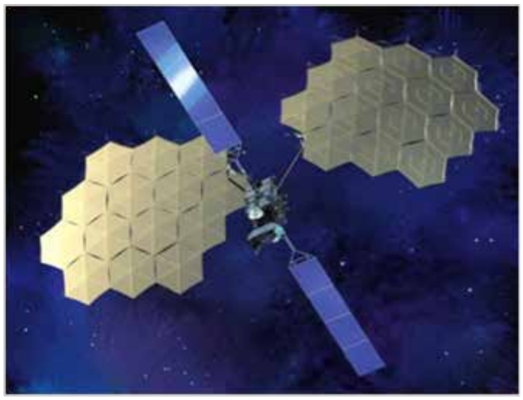


Figure 11-17. ETS-8 satellite.

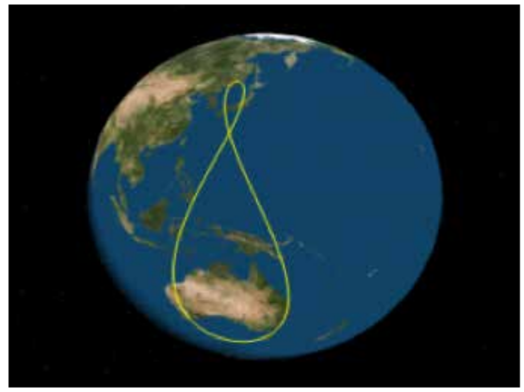


Figure 11-18. The QZSS constellation

References

[1] ETS-8 Tracking Standard http://god.tksc.jaxa.jp/

[2] R. Nakamura, et al, ETS-VIII precise orbit and clock estimation experiments, Proceedings of ION GNSS, 2010

[3] T. Inoue, et al, Precise Orbit and Clock Estimation Experiment Using Geostationary Satellite, ETS-VIII, Proceedings of ENC GNSS, 2010

Contacts

Shinichi Nakamura — Phone: +81-29-868-4798
Ryo Nakamura — Phone: +81-29-868-7031
Anne Mori — Phone: +81-29-868-7062
JAXA — Fax: +81-29-868-2990
Flight Dynamics Division
Consolidated Space Tracking and Data Acquisition Department
JAXA
JAPAN

National Institute of Information and Communications Technology (NICT)

Tadahiro Gotoh, Toshihiro Kubo'oka, Tetsuhara Fuse/NICT

Activities in 2009-2010

Between 2009 and 2010, we mainly contributed to the development of a time keeping system for the quasi zenith satellite (QZS). Since NICT is responsible for keeping Japan Standard Time, we have developed a precise time transfer system between the QZS master and slave Earth stations to link UTC(NICT). We also developed a new ranging system for geosynchronous satellites. In this system, the distance between a satellite and a ground station is measured by the correlation of real up-link and down-link communication signals. This passive system can enlarge bandwidth for ranging signals, which increases measurement accuracy, without a decrease in transponder bandwidth for communication services.

Future Plans from 2011 to 2012

NICT plans to carry laser communication equipment on a small low earth orbiter in the near future. For this satellite, we are going to develop a new orbit determination system, which determines a position of the satellite relative to background stars on images obtained with optical telescopes. In addition, we are discussing a lunar laser ranging system for the Japan Moon lander mission, SELENE-2, which is a follow-on mission to Kaguya (SELENE). If the LLR system is selected as an on-board instrument of SELENE-2 in 2011, a test ground station will be built in the headquarters of NICT in Tokyo.

Publications/Presentations

T. Kubo'oka, S. Kawase, and S. Taniguchi, "Orbit determination of geosynchronous satellite using passive ranging system," IEICE Technical Report, SANE2010-99(2010-10), pp.185-189, 2010.

H. Takiguchi, T. Gotoh, T. Otsubo, "Development of the estimation service of the Earth's surface fluid load effects for space geodetic techniques," AGU Fall Meeting, G51C-0694, San Francisco, CA, USA, 2010.

Contacts

Tadahiro Gotoh
NICT
4-2-1 Nukui-Kita
Koganei, Tokyo, 184-8795
JAPAN

Phone: 81 42 327 6850
Fax: 81 42 327 6664
E-Mail: tara@nict.go.jp

Toshihiro Kubo'oka
Tetsuharu Fuse
NICT
893-1 Hirai
Kashima, Ibaraki 324-8501
JAPAN

E-Mail: tkubooka@nict.go.jp
E-Mail: tetsu.fuse@nict.go.jp
Phone: 81 299 84 7181
Fax: 81 299 84 7160

National Institute of Geophysics, Geodesy and Geography (NIGGG, formerly CLG/BAS)

Ivan Georgiev, Department of Geodesy, National Institute of Geophysics, Geodesy and Geography at Bulgarian Academy of Sciences

Introduction/Data Products Provided

The Department of Geodesy (formerly the Central Laboratory of Geodesy) at the National Institute of Geophysics, Geodesy and Geography (NIGGG), Bulgarian Academy of Sciences (BAS), continues to make yearly global geodetic SLR solutions, coordinates (SSC) and velocities (SSV) and Earth Orientation Parameters (EOP) since 1993 . The analysis is performed by the Satellite Laser Ranging Processor (SLRP), a satellite orbit determination and parameter estimation software package developed at the Department of Geodesy. Information about the new National Institute can be found at http://www.niggg.bas.bg/.

The following data products are available from LAGEOS-1 and LAGEOS-2 tracking data analysis at the Department of Geodesy Associate Analysis Center:

1. Global SLR solutions, station coordinates and velocities and EOP;
2. Geogravitational parameter GM and selected set of geopotential coefficients and ocean loading parameters;
3. Low degree zonal rates;
4. Global tectonic plate motion;
5. Range- and time-biases for the SLR tracking stations.

Current Activities

1. Reprocessing SLR tracking data of LAGEOS-1 and LAGEOS-2 with the last software version SLRP 5.2;
2. Research activities of the low degree zonal drifts of the geopotential, geocenter variations and SLR reference frame;
3. Global tectonic motion with emphasize for the Mediterranean;
4. Processing SLR data from Etalon and GPS-35 and GPS-36 satellites.

Future Plans

1. GLONASS orbit determination and parameter estimation from SLR tracking data.

Contact

Prof. Ivan Georgiev
Department of Geodesy, National Institute of
Geophysics, Geodesy and Geography
Acad. G. Bonchev Str. Bl. 1
Sofia 1113
BULGARIA

Phone: + 359 2 979 2453
Fax: + 359 2 872 08 41
E-mail: ivan@bas.bg

Shanghai Astronomical Observatory (SHAO)

Xiaoya Wang, Xiaogong Hu, Yuanlan Zhu, Weijing Qu, Bin Wu/SHAO

Introduction

The ILRS Associate Analysis Center at the Shanghai Astronomical Observatory (SHAO) has performed SLR quick-look data processing for LAGEOS-1/2 and provided weekly quick-look analysis reports to the ILRS since 1999. SHAO has finished the automated SLR data processing and will provide daily quick-look analysis reports and weekly SLR SINEX solutions. In addition, SHAO has continued the precise orbit determination for COMPASS satellites by SLR and microwave observations and evaluated their orbit accuracy. Our AAC has also assessed methods to improve the orbit accuracy. We have also studied the determination of Earth orientation parameters (EOPs).

Facilities/Systems

The Shanghai SLR associate analysis group utilizes the SHODE-I and COMPASS software packages developed by SHAO in routine activities. We have modified some models according to IERS 2010 conventions.

Current Activities

Weekly Quick-look Data Analysis

SHAO has operated our weekly quick-look data analysis for the global SLR network quality control (QC) and LAGEOS-1/2 orbits. During 2010, we updated some models according to the ILRS 2010 standard and also adopted the new ground-system dependent CoM corrections published on the ILRS website. The typical rms-of-fit values can be reduced 0.4 mm for LAGEOS-1/2 and 0.6 mm for Etalon-1/2 after using the new corrections. SHAO will provide daily quick-look data analysis reports including range and time biases and residuals through our website.

Range and Time Biases Comparison

We compare our range and time biases from 2007 to 2011 with the estimates from DGFI and Hitotsubashi University (HIT-U). The range biases from analysis centers are consistent for most SLR sites. The time biases from different analysis centers show no significant difference. But to individual sites we have found incorrect site coordinates can generate incorrect range biases especially when the site coordinates and EOP are fixed.

COMPASS Orbit Determination and Verification

COMPASS/Beidou continues its constellation disposition. Up until now, the project has launched seven operational satellites. SHAO has continued to study the COMPASS orbit determination and its verification. We have also started studying new correction models such as a solar radiation model and a ground-system dependent CoM correction model for COMPASS.

Weekly SLR SINEX EOP and Coordinate Solutions

SHAO has performed a weekly loose SLR SINEX EOP and coordinate solutions test of five years of SLR data. We are now updating the models of our COMPASS analysis software according to the IERS 2010 conventions and will then reanalyze the SLR data.

Future Plans

SHAO will continue our current activities through the routine processing and analysis of SLR data. Firstly, SHAO will finish the update of two software packages according to IERS 2010 conventions and reanalyze the SLR data. Secondly, all results will be available from the SHAO webserver very soon. Thirdly, SHAO will change our current weekly quick-look data analysis into daily reports. Fourthly, SHAO will provide loosely SLR SINEX EOP and coordinate solutions on a weekly basis. Finally, we will try to provide a long time series of EOP, station coordinates and velocities, low order gravity field, and geocenter variation solutions.

Contact

Dr. Xiaoya Wang
E-mail: wxy@shao.ac.cn
Phone: 86-21-64386191-296

Dr. Xiaogong Hu
E-mail: hxg@shao.ac.cn
Phone: 86-21-64386191-216
Shanghai Astronomical Observatory
Chinese Academy of Sciences
80 Nandan Road
Shanghai 200030
CHINA

ILRS LUNAR ASSOCIATE ANALYSIS CENTER REPORTS

Lunar Associate Analysis Centers process normal point data from the Lunar Laser Ranging (LLR) stations and generate a variety of scientific products including precise lunar ephemerides, librations, and orientation parameters which provide insights into the composition and internal makeup of the Moon, its interaction with the Earth, tests of General Relativity, and Solar System ties to the International Celestial Reference Frame.

Institut Fuer Erdmessung/Forschungseinrichtung Satellitengeodaesie (IFE/FESG)

Jürgen Müller, Liliane Biskupek, Franz Hofmann/IfE, Ulrich Schreiber/Geodetic Observatory Wettzell, Dieter Egger/FESG

Recent Activities

The update of the analysis program includes the implementation of the atmospheric light time delay according to Mendes et al. (2002) and Mendes & Pavlis (2004). Measurements from the Italian Matera station and to the re-discovered Lunokhod 1 reflector can now be analyzed.

In the ephemeris calculation, the treatment of the asteroids was extended. In a first step up, to 16 asteroids can be included in the equations of motion. The lunar interior is modeled according to Williams et al. (2001) and Hinderer et al. (1982). Concerning the gravity field models of Earth and Moon, the software was updated using the coefficients from EGM2008 model for the Earth and the LP165P model for the Moon.

The global analysis was extended for a direct estimation of Earth rotation parameters. In contrast to the daily decomposition method, possible correlations to parameters in the Earth-Moon system can now be determined in the global analysis. The pole coordinates xP, yP and ΔUT can be estimated for relevant time spans.

For a better integration of the highly accurate APOLLO (Apache Point Observatory Lunar Laser-ranging Operation, New Mexico, USA) data, the stochastic model for the relative weighting of the normal points from the sites is now supported by a variance component estimation.

Concerning the determination of relativistic quantities, a study related to a possible violation of the equivalence principle, parameterized by the Nordtvedt parameter , and to the constancy of the gravitational constant was carried out. The Nordtvedt parameter was determined with an accuracy of 5.2 x 10-4 and the possible time-variation of the gravitational constant with an accuracy of 4.0 x 10-13 yr-1, see Hofmann et al. (2010). This improved the previous IfE results by a factor of 2.

Ongoing Activities and Future Plans

The ongoing and future activities include work on the effects of the gravity field expansion for mm accurate LLR analysis, an extension of the asteroid modeling as well as further model refinements concerning the lunar interior and Earth orientation.

Acknowledgement

We like to thank the Center of Quantum Engineering and Space-Time Research (QUEST) for funding Franz Hofmann as well as the DFG, the German Research Foundation, which funded Liliane Biskupek within the research unit FOR584 “Earth rotation and global dynamic processes”. We would also like to thank the International Space Science Institute (ISSI) in Bern for supporting this research.

Publications

Biskupek, L., Müller, J.: Lunar Laser Ranging and Earth Orientation. Proceedings of the "Journees 2008 Systemes de reference spatio-temporels", M. Soffel and N. Capitaine (eds.), Lohrmann-Observatorium and Observatoire de Paris, p. 182-185, 2009.

Biskupek, L., Müller, J., Hofmann, F.: Determination of nutation coefficients from Lunar Laser Ranging. In: Geodesy for Planet Earth, eds. Kenyon, S., Pacino, M.C. and Marti, U., IAG Symposia Series, Vol. 136, Springer, 2011.

Hofmann, F., Müller, J., Biskupek, L.: Lunar laser ranging test of the Nordtvedt parameter and a possible variation of the gravitational constant. Astronomy and Astrophysics, 522, L5, 2010.

Müller, J.: Lunar Laser Ranging – A Science Tool for Geodesy and General Relativity. Proceedings of the 16th International Workshop on Laser Ranging, Oct. 13-17, 2008, Poznan, Poland, ed. by S. Schillak, Space Research Centre, Polish Academy of Sciences, Vol. 1, p. 100, 2009.

Müller, J., Murphy, T.: Lunar and Interplanetary Laser Ranging – Session Summary. Proceedings of the 16th International Workshop on Laser Ranging, Oct. 13-17, 2008, Poznan, Poland, ed. by S. Schillak, Space Research Centre, Polish Academy of Sciences, Vol. 1, p. 253, 2009.

Müller, J., Biskupek, L., Oberst, J., Schreiber, U.: Contribution of Lunar Laser Ranging to Realise Geodetic Reference Systems. In: Geodetic Reference Frames, ed. by H.Drewes, IAG Symposia, Vol. 134, Springer, 55-59, 2009.

Pavlis, E., Müller, J.: International Laser Ranging Service (ILRS). IERS Annual Report 2007, ed. by W. Dick and B. Richter, BKG, 38-49, 2009.

References

Hinderer, J., Legros, H., Amalvict, M., 1982: A search for Chandler and nearly diurnal free wobbles using Liouville equations. Geophysical Journal International, 71, 303-332.

Williams, J.G. et al., 2001: Lunar rotational dissipation in solid body and molten core. JGR, 106, 27933-27968.

Mendes, V.B. et al., 2002: Improved mapping functions for atmospheric refraction correction in SLR. GRL, 29(10), 1414.

Mendes, V.B., Pavlis, E.C., 2004: High-accuracy zenith delay prediction at optical wavelengths. GRL, 31, L14602.

Contact

Prof. Dr.-Ing. Jürgen Müller	Voice:	++49 (0) 511-762 3362
	Email:	mueller@ife.uni-hannover.de
Dipl.-Ing. Liliane Biskupek	Voice:	++49 (0) 511-762 5784
	Email:	biskupek@ife.uni-hannover.de
Dipl.-Ing. Franz Hofmann	Voice:	++49 (0) 511-762 5783
Leibniz Universität Hannover	Email:	hofmann@ife.uni-hannover.de
Institut für Erdmessung		
Schneiderberg 50		
30167 Hannover		
GERMANY		

Dr.rer.nat Dieter Egger	Voice:	+49 (0)89 289 231 83
Forschungseinrichtung Satellitengeodäsie	Email:	dieter.egger@bv.tum.de
Technische Universität München		
Arcisstr. 21		
80333 München		
GERMANY		

Apl. Prof. Dr. Ulrich Schreiber	Voice:	+49 (0) 9941 603113
Bundesamt für Kartographie und Geodäsie	Email:	schreiber@fs.wettzell.de
Geodätisches Observatorium Wettzell		
Sackenrieder Straße 25		
D-93444 Bad Kötzting		
GERMANY		

Jet Propulsion Laboratory (JPL)

James G. Williams, Dale H. Boggs, Slava G. Turyshev, Jean O. Dickey, J. Todd Ratcliff/JPL

Analysis and Science Activities 2009-2010

JPL's Lunar Laser Ranging (LLR) data analysis has fit the operational data sets from the McDonald, Observatoire de la Côte d'Azur (Grasse) and Apache Point Observatory sites plus historical data from Haleakala Observatory. A night of ranges from Matera is also included. 17,474 normal points have been processed from 1970 through October 2010. 239 ranges were during 2009 and 263 during 2010. Retroreflector arrays include Apollo's 11, 14, and 15 and Lunokhods 1 and 2. For 2009-2010, 56% of the ranges are from the largest array, Apollo 15, while 5% of the ranges are from Lunokhod 2, the most difficult target.

The computer code for lunar laser ranging data analysis continues to evolve. The model for perturbations from Earth tides has been upgraded. UT0 and variation of latitude solutions have been made for a 40 yr LLR data span .

Standard solution parameters now include ranging station coordinates and motions, Earth orientation, lunar orbit, tidal acceleration, GM of Earth+Moon, lunar orientation, Love numbers, tidal Qs, dissipation at and flattening of the lunar fluid-core/solid-mantle boundary (CMB), mantle moment differences, gravity coefficients and retroreflector array positions. In addition, solutions were made for any equivalence principle violation (related to PPN beta and gamma), dG/dt, geodetic precession and scale change. Gravitational physics results are in agreement with general relativity.

Aided by the identification of Lunokhod 1 on pictures from Lunar Reconnaissance Orbiter, the Apache Point Observatory ranged the formerly lost retroreflector. Tom Murphy of APO reports that this retroreflector gives a strong signal during local night. 31 ranges have been processed giving a good position on the Moon. Positions of all five retroreflectors were used to calibrate lunar altimetry (Fok et al., 2011).

Lunar free librations were studied with Nicolas Rambaux of IMCCE (Rambaux and Williams, 2011). The 2.9 yr longitude and 74.6 yr wobble modes are strongly detected; the 81 yr precession in space is two orders-of-magnitude weaker. The free core nutation is not large enough to be certain. There must be a source of stimulation for the free libration modes.

Looking to future laser ranging activities, a corner cube design for future lunar landers was investigated. Lunar science results with future lunar landers were simulated with H. Noda of NAOJ. We also investigated transponders for future laser ranging to the Moon, Mars and Phobos (Murphy et al., 2009; Turyshev et al., 2010).

The recommended JPL orbit and physical libration ephemeris for the Moon is DE421. A description is given by Williams et al. (2008). DE421 is publicly available in two formats via ftp: *ftp://ssd.jpl.nasa.gov/pub/eph/planets/ascii/de421* and *ftp://ssd.jpl.nasa.gov/pub/eph/planets/bsp.*

Papers

J. G. Williams, D. H. Boggs and W. M. Folkner, DE421 Lunar Orbit, Physical Librations, and Surface Coordinates, JPL IOM 335-JW,DB,WF-20080314-001, March 14, 2008.

J. G. Williams, S. G. Turyshev, and D. H. Boggs, Lunar Laser Ranging Tests of the Equivalence Principle with the Earth and Moon, Int. J. of Modern Physics D, 18 (7), 1129-1175, doi:10.1142/S021827180901500X, 2009.

T. W. Murphy, Jr., W. Farr, W. M. Folkner, A. R. Girerd, H. Hemmati, S. G. Turyshev, J. G. Williams, and J. J. Degnan, Testing Fundamental Gravity via Laser Ranging to Phobos, in proceedings of 16th Int. Workshop on Laser Ranging, ed. Stanislaw Schillak, 675-681, 2009. http://www.astro.amu.edu.pl/ILRS_Workshop_2008/index.php

J. G. Williams and D. H. Boggs, Lunar Core and Mantle. What Does LLR See?, in proceedings of 16th International Workshop on Laser Ranging, ed. Stanislaw Schillak, 101-120, 2009. http://www.astro.amu.edu.pl/ILRS_Workshop_2008/index.php

S. G. Turyshev, W. Farr, W. M. Folkner, A. R. Girerd, H. Hemmati, T. W. Murphy, Jr., J. G. Williams, and J. J. Degnan, Advancing tests of relativistic gravity via laser ranging to Phobos, Experimental Astronomy, v 28, issue 2, 209, doi:10.1007/s10686-010-9199-9, 2010.

N. Rambaux and J. G. Williams, The Moon's physical librations and determination of their free modes, Celestial Mechanics and Dynamical Astronomy, 109, 85-100, (online version with tables Oct 26, 2010), doi:10.1007/s10569-010-9314-2, 2011.

H. S. Fok, C. K. Shum, Y. Yi, H. Araki, J. Ping, J. G. Williams, G. Fotopoulos, H. Noda, S. Goossens, Q. Huang, Y. Ishihara, K. Matsumoto, J. Oberst, and S. Sasaki, Accuracy assessment of lunar topography models, Earth, Planets and Space, 63, 15-23, doi:10.5047/eps.2010.08.005, 2011.

Abstracts

J. G. Williams, D. H. Boggs, and J. T. Ratcliff, A Larger Lunar Core?, abstract #1452 of the Lunar and Planetary Science Conference XXXX, March 23-27, 2009.

N. Rambaux and J. G. Williams, A new determination of the normal modes of the Moon's libration, Division on Dynamical Astronomy meeting, Virginia Beach, VA, May 2-5, 2009, Bull. Amer. Astron. Soc., 41, #2, 907, 2009.

J. G. Williams, D. H. Boggs, and J. T. Ratcliff, Lunar Fluid Core Moment, abstract #2336 of the Lunar and Planetary Science Conference XXXXI, The Woodlands, TX, March 1-5, 2010.

J. G. Williams, D. H. Boggs, and H. Noda, Exploring the Lunar Interior with Tides, Gravity and Orientation, abstract 21.10, 42nd DPS meeting, Pasadena, CA, Oct 3-8, 2010, Bull. Amer. Astron. Soc., 42, #4, 987, 2010.

Contacts

James G. Williams	E-mail: James.G.Williams@jpl.nasa.gov Phone: (818) 354-6466
Dale H. Boggs	E-mail: Dale.H.Boggs@jpl.nasa.gov Phone: (818) 354-1630
Slava G. Turyshev	E-mail: Slava.G.Turyshev@jpl.nasa.gov Phone: (818) 393-2600
Jean O. Dickey	E-mail: Jean.O.Dickey@jpl.nasa.gov Phone: (818) 354-3235
J. Todd Ratcliff	E-mail: James.T.Ratcliff@jpl.nasa.gov Phone: (818) 354-0204

Jet Propulsion Laboratory
Mail Stop 238-600
4800 Oak Grove Drive
Pasadena, CA 91109-8099
USA
FAX: (818) 393-4965

Paris Observatory Lunar Analysis Center (POLAC)

Sébastien Bouquillon, Jean Chapront, Gérard Francou, Wassila Zerhouni/Observatoire de Paris (SyRTE)

The lunar analysis center POLAC is located at SyRTE laboratory of Observatoire de Paris, France. It works in cooperation with the laser ranging team of the Observatoire de la Côte d'Azur (GRGS analysis center) and with the two IERS centers based at the Observatoire de Paris (EOP and ICRS centers).

During these last two years, we proceeded with the improvement of the POLAC reduction model of LLR observations. In particular, we increased the period of validity of the lunar libration model and we fitted the reduction model by taking into account additional data of the Apache Point observations (2006-2010) and the MeO observations (2009-2010).

Simultaneously, Wassila Zerhouni, a doctoral student under the direction of Nicole Capitaine, continued studying the link between the dynamical celestial reference frame realized by LLR and the kinematic celestial reference frame determined by VLBI. In particular, she modified the POLAC reduction model to determine corrections to the celestial pole coordinates and then compared them with the ones obtained from VLBI observations. She defended her doctoral thesis in January 2010.

Lastly, we developed a new web interface for the preparation and the validation of lunar laser ranging observations (http://polac.obspm.fr/PaV/). With this interface, distant LLR observers are able to run some POLAC tools. These tools allow them to compute the predictions of geocentric and topocentric coordinates of lunar targets (as retro-reflectors or craters) and predictions of round-trip times of laser-pulses between terrestrial stations and lunar retro-reflectors (an ftp-repository is also available with already computed predictions for all the lunar target for 3 days since the current date 0h). These tools also allow LLR observers to compute the residuals between their own LLR observations and the POLAC reduction model by running our computer code on the POLAC server with their data (this last tools is also available by e-mail).

```
Normal Points : 00942
Valid         : 00942
Wrong (***)   : 00000     Limit:      1.000 m

R0 Apollo 11  : 00176     Bias:       0.014 m       0.091 ns     St.dev.:       0.051 m      0.341 ns
R1 Lunokhod 1 : 00029     Bias:       0.000 m      -0.001 ns     St.dev.:       0.027 m      0.181 ns
R2 Apollo 14  : 00180     Bias:       0.026 m       0.175 ns     St.dev.:       0.048 m      0.323 ns
R3 Apollo 15  : 00506     Bias:      -0.008 m      -0.051 ns     St.dev.:       0.049 m      0.325 ns
R4 Lunokhod 2 : 00051     Bias:       0.006 m       0.043 ns     St.dev.:       0.054 m      0.360 ns
   Global     : 00942     Bias:       0.004 m       0.026 ns     St.dev.:       0.051 m      0.339 ns
```

Figure 11-19. The POLAC web interface screen shot for the 942 Apache Point LLR observations (2006-2010): for each retro-reflector, the bias and the standard deviation of residuals for distances (in meter) and for round-trip times of laser-pulses (in nanosecond).

References

C. Barache, S. Bouquillon, T. Carlucci, F. Deleflie, D. Feraudy, G. Francou, H. Manche, E. Samain, J.-M. Torre, 2010, "Web Interface for Lunar Laser Ranging Observations", Journées.2010 - Systèmes de référence spatio-temporels, Paris, France, N. Capitaine et al. (eds.).

H. Manche, A. Fienga, J. Laskar, M. Gastineau, S. Bouquillon, G. Francou, P. Kuchynka, 2010, "LLR residuals of the latest INPOP solution and constraints on post-Newtonian parameters", Journées.2010 - Systèmes de référence spatio-temporels, Paris, France, N. Capitaine et al. (eds.).

S. Bouquillon, 2010, "A Review of the ELP semi-analytical solution for the orbital motion of the Moon", ISSI-Working Group of S. Kopeikin, Bern, Switzerland.

W. Zerhouni, N. Capitaine, 2010, "Celestial pole offsets from lunar laser ranging and comparison with VLBI", ISSI-Working Group of S. Kopeikin, Bern, Switzerland.

W. Zerhouni, 2010, "Systèmes de référence et rotation de la Terre : apport de la télémétrie Laser sur la Lune", Thesis, Observatoire de Paris, France.

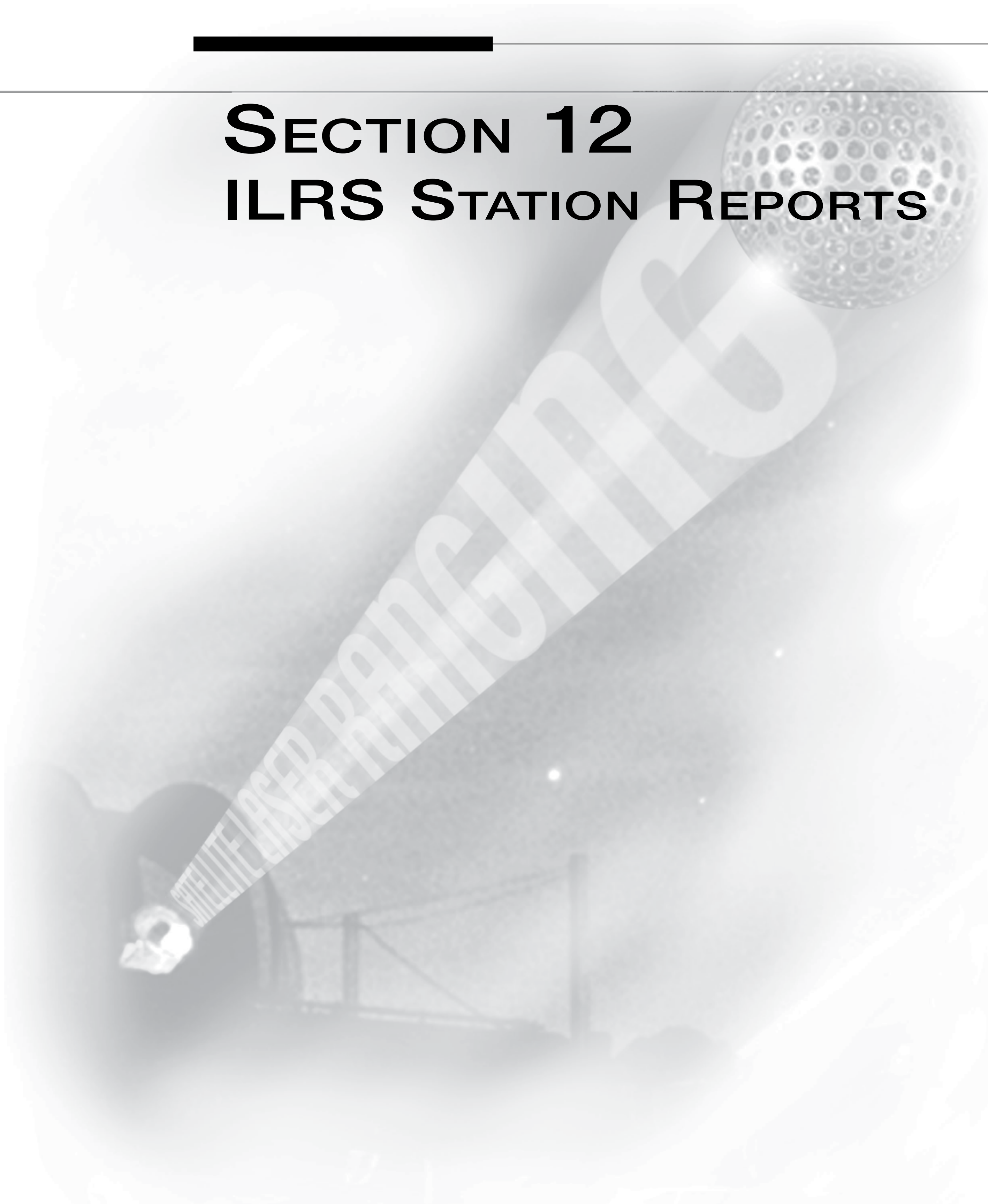
W. Zerhouni, N. Capitaine, 2009, "Celestial pole offsets from lunar laser ranging and comparison with VLBI", Astron. Astrophys., 507, 1687.

Contact

POLAC
Observatoire de Paris (SYRTE)
61 avenue de l'observatoire
75014 Paris
FRANCE

E-mail : polac.contact@obspm.fr

SECTION 12
ILRS STATION REPORTS



SECTION 12

ILRS STATION REPORTS

Arequipa, Peru

Raul Yanyachi/Universidad Nacional de San Agustin

Figure 12-1. TLRS-3 NASA Station in Arequipa, volcano Misti in the background.

The TLRS-3 NASA station located in Arequipa Peru continued operations during 2009 and 2010.

Station Upgrades and Problems/Repairs

In January 2009, a telescope mount vibration in elevation continued due to tachometer problems affecting/restricting the SLR tracking. This problem became significantly worse by the end of April. At the end of July, Dennis McCollums (HTSI) changed the elevation tachometer. A problem with the delay originated by the bad signal of 10 MHz that coming from Distribution Amplifier HP-5087 was fixed. Due to PMT failure there was no tracking from October to December. Changed the control unit card in CU-401 and replaced 5A fuses in the PU-420. The T/R Switch failed intermittently.

In January 8-22, 2010 Dennis McCollums again visited the station performing the following engineering activities:

- Investigated and minimized reflection in the receiver optics
- Installed new Photek PMT318 and NSR PS350 high voltage power supply
- Realigned laser in lower table and verified position of rod in the oscillator, replaced oscillator lamps, wave plate, 69.910Mhz AML, pockels cell, and SHG.
- Fixed T/R switch position, balanced arm by making holes, replaced the complement of the sensor hall in the arm with one having a magnetic feature.
- Assembled one T/R switch motor using spare parts and achieved stable T/R switch function.
- Performed and verified complete Ceolostat alignment.
- Completed boresite and verified the reflections on the receiver optics under different tracking conditions; results were nominal

- Initially set PMT at 3200 volts, but had much noise and finally we tracked at 2900 volts.
- Completed TIU optimization, stability and Minico test; twice blew 5A fuse in the PU-420.
- A connection in the discriminator TC-494 was bad, awaited a new one with cables.
- Installed the calibrated MET-3.
- Replaced STBY switch in the switch chassis.

In February 2010, the track ball failure in elevation was cleaned. The mount occasionally is oscillating in azimuth during nighttime operations. We installed a new processor computer (Dell Precision 380). In March 2010, the track ball failure in azimuth was cleaned. The mount continues nighttime oscillation in azimuth on occasion. The laser was realigned laser and we performed a boresite. Blown 5A fuses in the PU-420 forced us to adjust the T/R switch and change the motor. The system obtained a low quantity of returns from January to March due the cloudy weather. A small telescope mount vibration in azimuth was due to tachometer problems during May to August. By September the tracking improved due to clear skies. We also replaced the azimuth tachometer.

Dennis McCollums returned to the station in October 2010, performing the following work with station staff:

- Started tracking with 3000V PMT.
- Started tracking LAGEOS satellites in high priority. Although the station had more returns from these satellites, clouds inhibited the tracking. Passes in clockwis direction had more returns than those in counterclockwise direction.
- Replaced T/R switch motor with one we received, but it was bad.
- Replaced 5A fuse twice in PU-420.
- Replaced amp lamps and put new separators in the amp head.
- Transmit filter failure, adjusted the screws.
- OAM had error in the sattrk program, and gave error 41, checked the 24V power supply - changed 2A fuse and the problem fixed.
- Trackball cleaned and replaced.
- Fuse in the card E-120 trackball modified.
- Put cover for protection on corner cube B, was painted black.
- The rms was variable due unstable cable or startdiode.
- Replaced AML, amplifier rod, SHG and T/R switch motor.
- The dome failed due to insufficient tire pressure.
- The rms was variable due unstable cable or photodiode.

Station Operations

In 2009, Arequipa operated using two shifts (16 hours) per day, five days a week. Three shift operations (24 hour coverage) for five days a week began in March 2010.

TLRS-3 tracks low orbit satellite during the day and night with good results. Mid-altitude orbiting satellites such as LAGEOS-1/-2 have better results during nighttime operations. TLRS-3 does not track high orbit satellites.

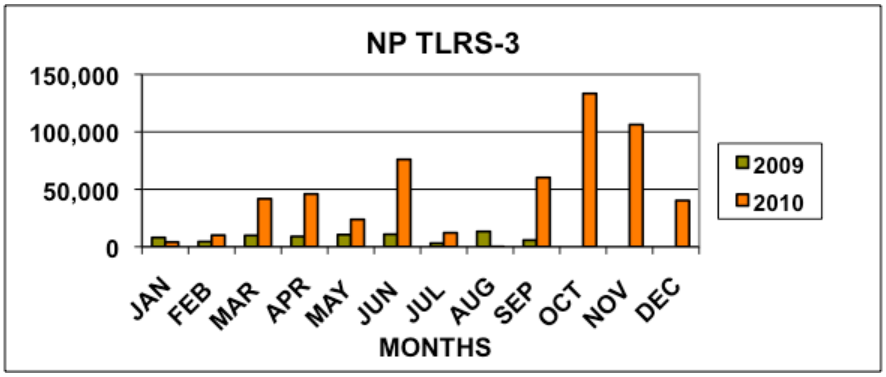


Figure 12-2. TLRS-3 normal point statistics for 2009 and 2010.

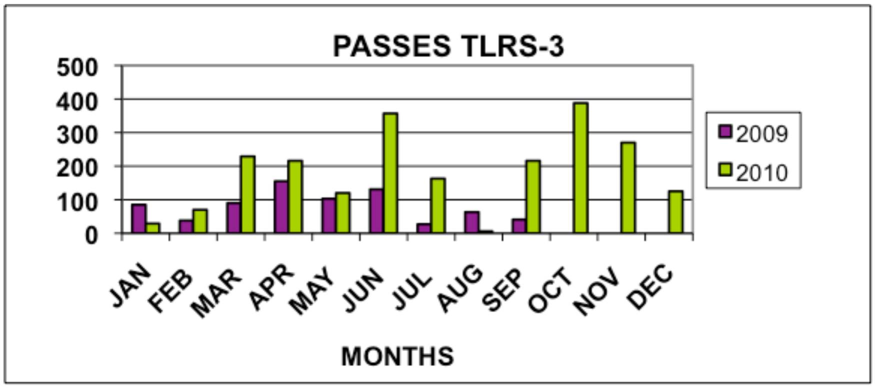


Figure 12-3. TLRS-3 pass statistics for 2009 and 2010.

Significant Events

In June 2009 David Carter, the NASA SLR Manager, Curtis Emerson, and Claudia Carabajal from GSFC visited Arequipa for discussions on the agreement between NASA and the National University of San Agustin. NASA personnel met with the Rector Dr. Valdemar Medina and Vice Rector Dr. Elisa Casta eda and visited the station for meetings with the station manager and supporting personnel.

Figure 12-4. David Carter, Curtis Emerson, Claudia Carabajal and TLRS-3 station crew during site visit in 2009.

July 1, 2009 commemorated the 50-year anniversary of the Arequipa SLR station. Initial tracking began using the Baker-Nunn Camera from 1950 until 1975 and continued with the Spacerays red laser until 1990. The current NASA TLRS-3 station has occupied the site since 1990. An anniversary ceremony was held to commemorate the event; attendees included the UNSA Vice rector Dr. Elisa Casta eda, current and former station personnel, and directors from the Institute Geophysical at UNSA. On July 13, a plaque was dedicated in memoriam to Dave

Hallenbeck who worked at the station since 1971, retired as station manager in 1998, and died of lung cancer in 1999.

In August 2009, Julio Marius from GSFC and his wife visited the station; he gave a presentation with Arequipa station manager at the IEEE Congress of Engineering Electronics INTERCON 2009 which was co-organized by UNSA. He was recognized by UNSA in a special ceremony and received a diploma and medal from UNSA's Rector. Marius also participated in interviews with local TV, radio, and newspapers. Staff from DLR and the Director of Geophysics Institute of Peru also visited the station. Many visitors from local schools and universities toured the TLRS-3, with presentations by station personnel.

Figure 12-5. UNSA Vice Rector Victor Linares, Rector Valdemar Medina, Vice Rector Elisa Castañeda and Julio Marius in ceremony of distinction.

Other Systems

UNAVCO sent a new computer (Acrosser) and Javad GPS receiver to Arequipa in June 2009; the receiver was sent back to UNAVCO in 2010 for repair. The CCD camera in the FPI Clemson experiment was replaced.

Personnel Changes

The crew at TLRS-3 consists of station manager Dr. Raul Yanyachi, senior operators Jorge Valverde and Manuel Yanyachi, and operator Mariano Gomez. Dante Corrales, Marco Higueras, and Kevynn Rodriguez continued training as operators. Janet Caceres is our administrative assistant and Wilberto Cañari serves as our maintenance assistant.

Contact

Dave McCormick (primary)
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Phone: 301-286-2354 (primary)
Phone: 301-377-2711 (secondary)
Fax: 301-286-0328
E-mail: David.R.McCormick@nasa.gov

David Carter
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Voice: 301-614-5966
Fax: 301-286-0328
E-mail: David.L.Carter@nasa.gov

Raul Yanyachi (station contact)
UNSA
Characato - Arequipa PERU

Phone: 51-54-448211
Fax: 51-54-448418
E-mail: raulpab1@hotmail.com

Beijing, China

Wang Tanqiang, Qu Feng/Chinese Academy of Surveying and Mapping (CASM)

KHz Ranging System Built, Tested and Observing

Work on the kHz ranging system built at the Beijing station began in January of 2010 and was completed in September of the same year. The system consists of two separate computers for tracking and data acquisition. A Latvia event timer A032-ET was used for the kHz measurements; it is connected to the data acquisition computer through a parallel port line. The two computers are linked by a serial port line; the main computer performs the satellite tracking and ranging control functions. Operators interface with the main computer and perform a majority of the ranging activities, such as tracking satellites, firing the laser, opening the range gate for the C-SPAD, making the computer clock synchronization to GPS time receiver, and aiming the laser beam at the satellites. The temperature control of the narrow band filter and the pin hole size control of the changeable diaphragm are also performed by the main computer. The diagram shown in Figure 12-6 shows the profile of the system.

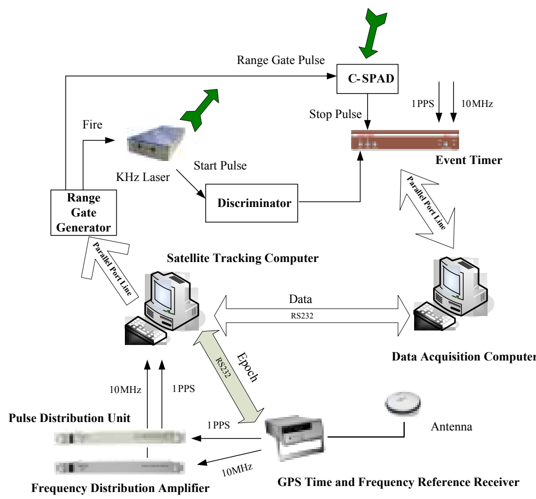


Figure 12-6. The Beijing station's kHz SLR system.

Daytime Tracking Tests

Daytime tracking tests were carried out in November and December of 2010; by the end of February of 2011 more than 100 daytime passes were obtained by the station. There was a lack of high satellite passes during these tests. Figures 12-7 and 12-8 show the daytime tracking results for the LAGEOS-2 satellite:

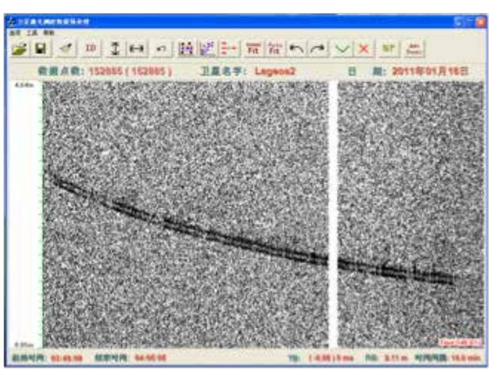


Figure 12-7. LAGEOS-2 daytime data pre-processing

Figure 12-8. LAGEOS-2 daytime tracking (11:49am-12:06am)

HQ Laser Operations

Equipment for upgrading the kHz laser ranging to an HQ kHz laser was ordered in 2008. The laser was delivered to the station on October 29, 2009 and after four days for installation and adjustments the system worked well. We used the laser for 1 kHz ranging and found it can produce a single pulse energy of 1.2 mj. The laser has high power stability (less than 1% RMS), a high pulse-to-pulse stability (not more than 1% RMS), and good beam quality (M2 < 1.5). Figure 12-9 shows the HQ laser system in the Beijing station, which has been operational since November 27, 2009.

Figure 12-9. The HQ laser installed at the Beijing SLR station.

Upgrading the Encoders and the Servos

The Renishaw angle encoders, imported from Britain, were installed in the SLR telescope mount both in azimuth and elevation, replacing the Round Inductosyn encoders. The azimuth encoder (model RESM20USA300) has a diameter of 300 mm and after 400 times subdivision the resolution ratio is 0.69 seconds of arc. The elevation encoder (model RESM20USA250) has a diameter of 250 mm and after 400 times subdivision the resolution ratio is 0.81 seconds of arc. A reading head (model SR050A) was installed for both angle encoders in azimuth and elevation. A subdivision box (model Si-NN-0400) was also installed and has a resolution of 50 nanometers.

For the servo systems we chose the DC Brush Servo Amplifier from Copley Controls Corporation of America as the drivers (type MOD 412); two separate systems were installed for the azimuth and elevation components. After the upgrading the tracking accuracy for both azimuth and elevation, we attained an RMS of 1 second of arc, an improvement from the 10 seconds of arc achieved with the original configuration. The new servo and encoder configuration is shown in Figure 12-10.

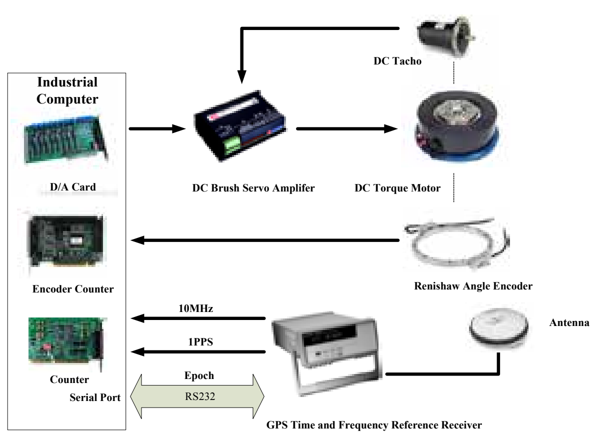


Figure 12-10. Schematic diagram of the servos and encoders.

The Range Gate Generator for kHz Measurement

The range gate generator was created on the base of FPGA (field programmable gate array) of the Xilinx Spartan3 series. The minimum control precision of the range gate is 5 nanoseconds and can be suitable for the kHz and daytime measurements. The elementary diagram for the range gate generator is shown in Figure 12-11.

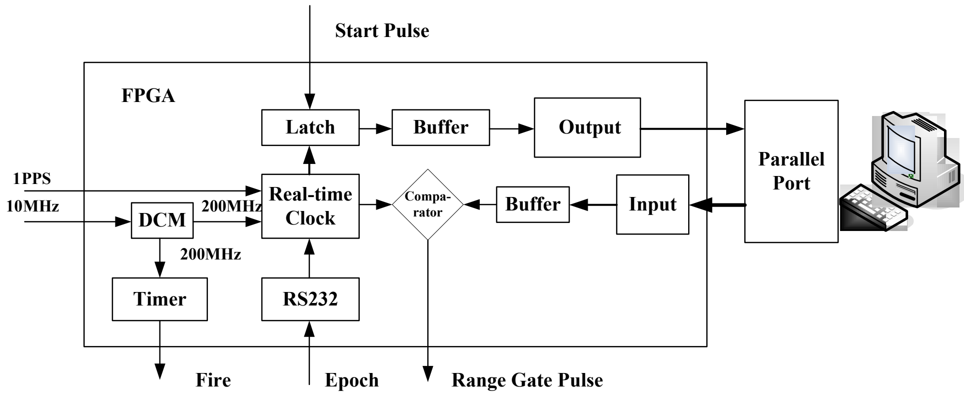


Figure 12-11. Elementary diagram for the range gate generator.

Contact

Prof. Qu Feng
Beijing Station
Chinese Academy of Surveying and Mapping (CASM)
16 Beitaiping Road
100039 Beijing
CHINA

Voice: +0086-10-88217725
Fax: +0086-10-68218654
E-mail: qufeng@casm.ac.cn

Borowiec, Poland

Stanislaw Schillak/ Space Research Centre, Polish Academy of Sciences

Introduction

The Borowiec SLR station activity in 2009-2010 was limited only to 2009 and the first quarter of 2009. The station is offline since 25 March 2010 because of damage of the laser heads due to near 20 years of the laser operation. An exchange of the heads is not possible due to lack of these spare parts. The upgrading of the laser to a new model is possible but up to now we have not sufficient funds for this operation.

Figure 12-12. The Borowiec SLR staff (left to right): Stanislaw Zapasnik, Stanislaw Schillak, Danuta Schillak, Piotr Michalek, Pawel Lejba (and dog "Niunius" – important at night-time).

Changes in the System During 2009

Several changes in the SLR system were introduced in 2009: installation of the A032-ET event timer (replacing the Stanford Time Interval Counter and shown in Figure 12-13), implementation of new software for the event timer operation, and application of the new SLR data format (Consolidated Laser Ranging Data Format). These changes enabled the participation of the Borowiec SLR station in the first campaign for the time scale comparison by laser technique (Oct. 05-25, 2009) – Time Transfer by Laser Link (T2L2). All time delays between the Borowiec master clock (Hydrogen Maser) and the SLR reference point were determined to an accuracy level of 100 ps. Unfortunately the laser pulse energy was too low due to laser head problems for detection of the signals on the Jason-2 satellite.

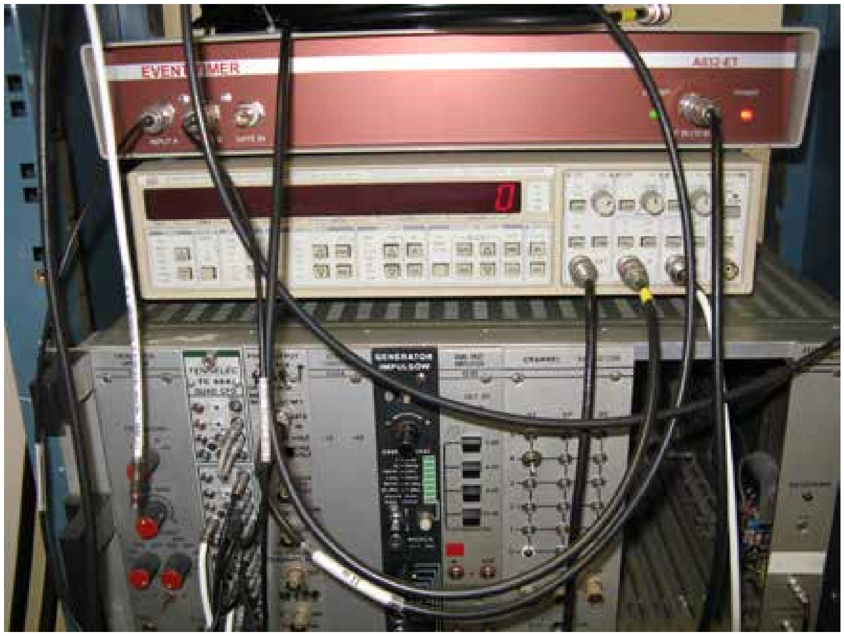


Figure 12-13. Riga Event Timer, below Time Interval Counter "Stanford".

Operations

During 2009 and 2010 the Borowiec SLR station produced, collected, and delivered 10,248 normal points to the scientific user community, tracking 803 passes on 18 satellites. The problems with the energy and stability of the laser pulses limited the number of satellite passes.

Future Plans

First of all, we need to upgrade of the laser to the new Continuum model as soon as possible. Further efforts will concentrate on the modernization of the second Borowiec telescope including the exchange of the driving system, engines, and angle encoders, which is expected to permit the realization of daylight tracking and more accurate tracking than can be performed with the present telescope.

Other Tasks

The Borowiec SLR Analysis Group continued orbital analysis of the SLR data, determining the positions and velocities of all co-located GPS and SLR stations during the period 1993.0-2009.0 (25 stations). The determination of the SLR station positions and velocities from the low Earth orbiting satellites, Starlette, Stella, and Ajisai, were continued with a new version of GEODYN-II (0909), new models, and parameters. The terrestrial reference frames ITRF2000, ITRF2005 and ITRF2008 for SLR stations were compared using five years of LAGEOS data (1999-2003).

In addition to the SLR system operation, the Borowiec site is a permanent IGS station (BOR1) operating with a Trimble NetRS receiver and high-quality time service equipped with two hydrogen masers and two cesium frequency standards HP-5071A, a 500 ps Time Transfer System TTS-4 (produced in the Borowiec Observatory) and two-way system with accuracy 200 ps for time scales comparison. Gravity measurements are made by an absolute gravimeter two times per year.

Figure 12-14. After 20 years, these laser heads do not properly function; the reflective cover inside is destroyed and it is dangerous for other laser elements.

Figure 12-15. Operators room.

Contact

Stanislaw Schillak
Space Research Centre,
Polish Academy of Sciences
Astrogeodynamic Observatory
Borowiec
ul. Drapalka 4
62-035 Kornik
POLAND

Voice: +48-61-8170-187
Fax: +48-61-8170-219
Email: sch@cbk.poznan.pl
Web: www.cbk.poznan.pl

Changchun, China

Xingwei Han, Cunbo Fan, Qingli Song,/National Astronomical Observatories, Changchun Observatory, CAS

The kHz SLR System in Changchun – Upgrades During 2009-2010

Changchun (station 7237) completed a kHz SLR system upgrade in July 2009 and achieved routine kHz SLR and daytime ranging.

kHz Ranging

We developed a new control system for our system and applied a kHz laser and an event timer.

1. kHz laser
   The RG30-L-532 series laser from Photonics Industries (USA) was installed in the ranging system. Obviously, the stability of laser has improved. The specification of the laser is as follows: 3mJ@532nm/1kHz/20ps, 0.4mrad divergence, pointing stability <10urad (typically 5urad). The typical lifetime of the pump diode exceeds 5000 hours. Since July 2009, Changchun has been using this laser at low power for more than 7140 hours, about 23 months, with an average use of 10 hours per day.

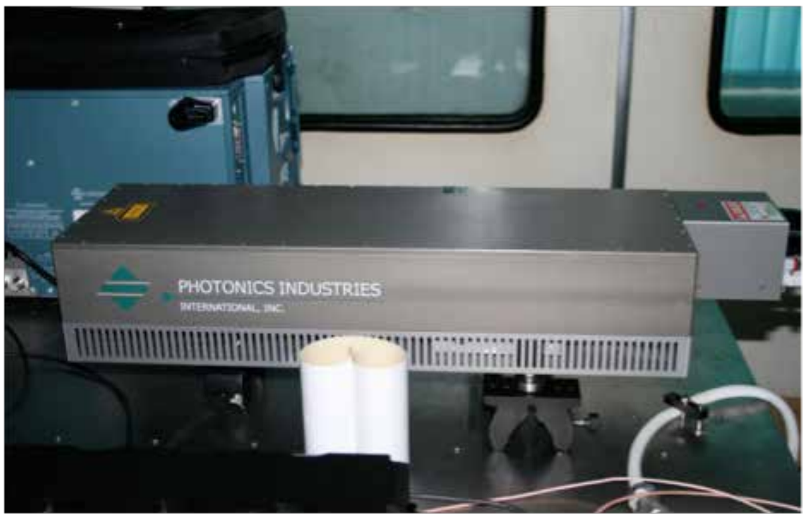


Figure 12-16. The photo of RG30-L-532 laser

2. Event timer
   The use of the A032-ET obtains epochs of laser firing with an accuracy to a few picoseconds.

3. Ranging control system
   For kHz ranging capability, we use a Windows PC to read the ET, drive telescope, control laser, indication data, display data, and archive data in kHz rates. We developed technology that consists of real-time data recognition, automatic gate, automatic range-gate and time-bias setting, a method for handling an enormous amount of data.

We developed a Range Gate Generator for our system, which generates range gate and laser fire, avoiding backscatter, with a precision of 10ns for kHz ranging.

Daylight Tracking

In order to reduce the background noise, an adjustable iris (0.5mm-7mm) is used in the receiving system. The smaller receiver field of view is 30 . The Narrow Band spectrum filter is also applied in the receiving system, and the center wavelength is 531.95nm, the bandwidth is 0.15nm, transmission>70%, work temperature is 23°C.

An experiment in the visibility of the kHz laser beam daylight has been accomplished. We tested a new sensitive camera, made in Germany and shown in Figure 12-17, for watching the laser beam. The camera uses technology that integrates backscatter to increase the signal/noise ratio, change exposure time, and image processing to obtain a clear and continuous image of the kHz laser beam.

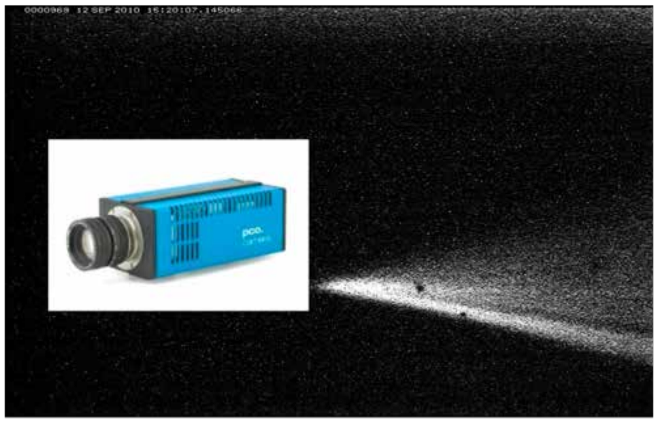


Figure 12-17. The PCO-1600 camera and laser beam imaging in daylight.

Routine Operations

In routine daylight tracking operations in Changchun, we need to scan for returns and save the previous bias for next pass.

From August 2009 through December 2010, during kHz ranging and daylight tracking, we have obtained about 12 thousand passes in total, including more than 33 hundred passes in daylight. Some days we are able to obtain 75 passes, including 34 pass in daylight.

Our data quality is good. Single shot precision is better than 13 mm for LAGEOS, and the normal point RMS is less than 1mm for LAGEOS. The Changchun SLR station is now one of the top three stations in the ILRS network.

Future Plans

In order to improve the capabilities of our SLR system, especially daylight ranging to HEOs, we plan to install a new near target for calibration, obtain kHz laser beam imaging in daylight, and research tracking stars in daylight to improve the telescope pointing accuracy.

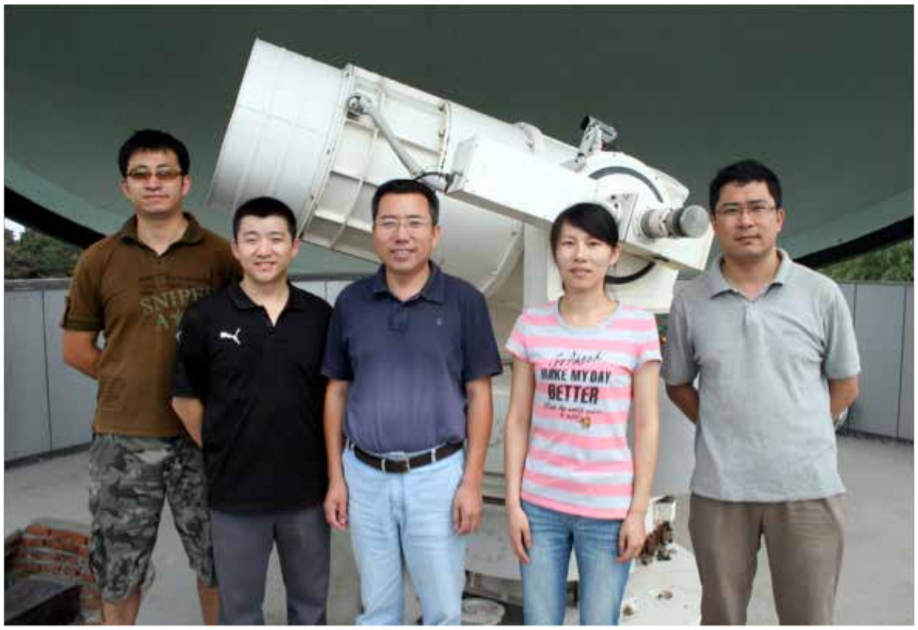


Figure 12-18. The Changchun SLR Station staff (left to right):
Zhang Haitao, Zhang Zi'ang, Liu Chengzhi, Song Qingli, Han Xingwei.

Contact

Cunbo Fan
Changchun Observatory
National Astronomical Observatories
Chinese Academy of Sciences
Jingyue Lake Changchun
130117, Jilin
CHINA

Voice: 86-431-84511337
E-mail: fancb@cho.ac.cn
Fax: 86-431-84512722

Concepción, Chile

Michael Häfner /BKG

During the report period of 2009-2010 the event that had by far the most serious impact on the operation of the SLR station of the Transportable Integrated Geodetic Observatory (TIGO) was the magnitude 8.8 earthquake on the night of February 27, 2010. It was the first time that a geodetic fundamental station was close to the epicenter of a major earthquake which was located off the coast of Maule, some 80 km distance NNW of the TIGO site. The entire observatory was displaced by roughly 3 meters in the WSW direction within only 30 seconds and the equipment was exposed to accelerations of up to 0.6 g. Although the containers in which TIGO-SLR equipment is housed were heavily shaken, only relatively little damage had to be repaired. Amongst the most serious problems were the overthrown optics table and dislocated telescope (see upper row of Figure 12-19). With collective effort of the TIGO-team and with the experience accumulated during previous maintenance work these damages could be rapidly resolved and preliminary operation could be resumed only six weeks after the earthquake. The SLR data obtained before and after the earthquake form an important contribution to the precise analysis of the post-seismic movement of the station (see Figure 12-19).

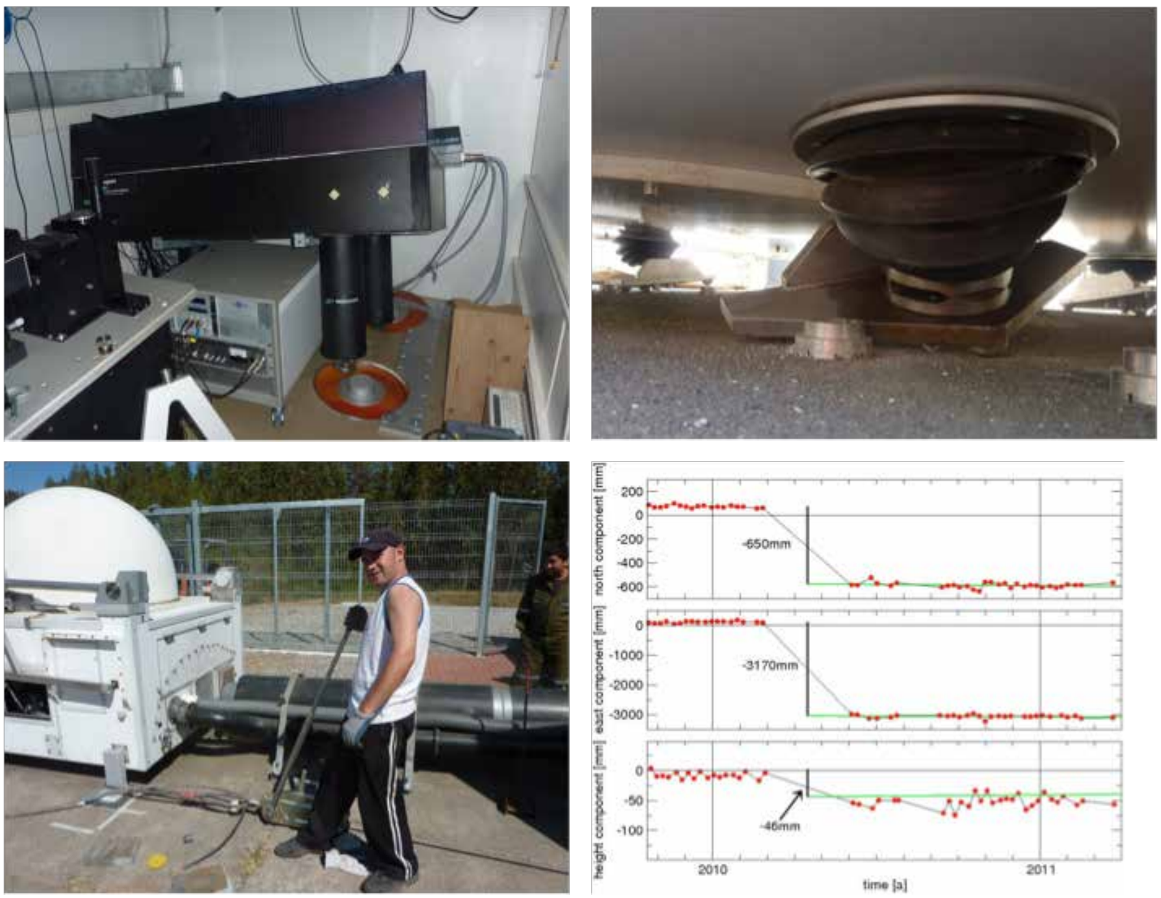


Figure 12-19: Photos taken after the earthquake of February 27, 2010. Upper left and right: Telescope and optics table overthrown by the shocks of the earthquake. Lower left: Coarse re-alignment of the telescope. Lower right: Displacement due to earthquake measured by TIGO-SLR.

Further important maintenance work that was carried out during the reporting period includes the on-site-repair of the pump laser's power supply after its deficiency in August 2010 and a thorough revision of the telescope's mechanics in February 2011. This fundamental maintenance was done with the outstanding expertise of former TIGO-SLR head of group Stefan Riepl and included the exchange of the azimuthal encoder

These events had an important impact on the measurement statistics of TIGO-SLR, which is also reflected in the monthly observation statistics plotted in Figure 12-20. After a new record year with roughly 5750 satellite passages measured in 2009 the first two months of 2010 continued in this direction with a new monthly record for the station of 828 satellite passages measured in January 2010. The challenges after the earthquake limited the productivity in 2010 and the number of measured satellite passages dropped to some 3150 in 2010. With the scheduled renewal of the pump laser in the second half of 2011 we expect to catch up to earlier performances in particular with respect to HEO satellites (GNSS and Etalon).

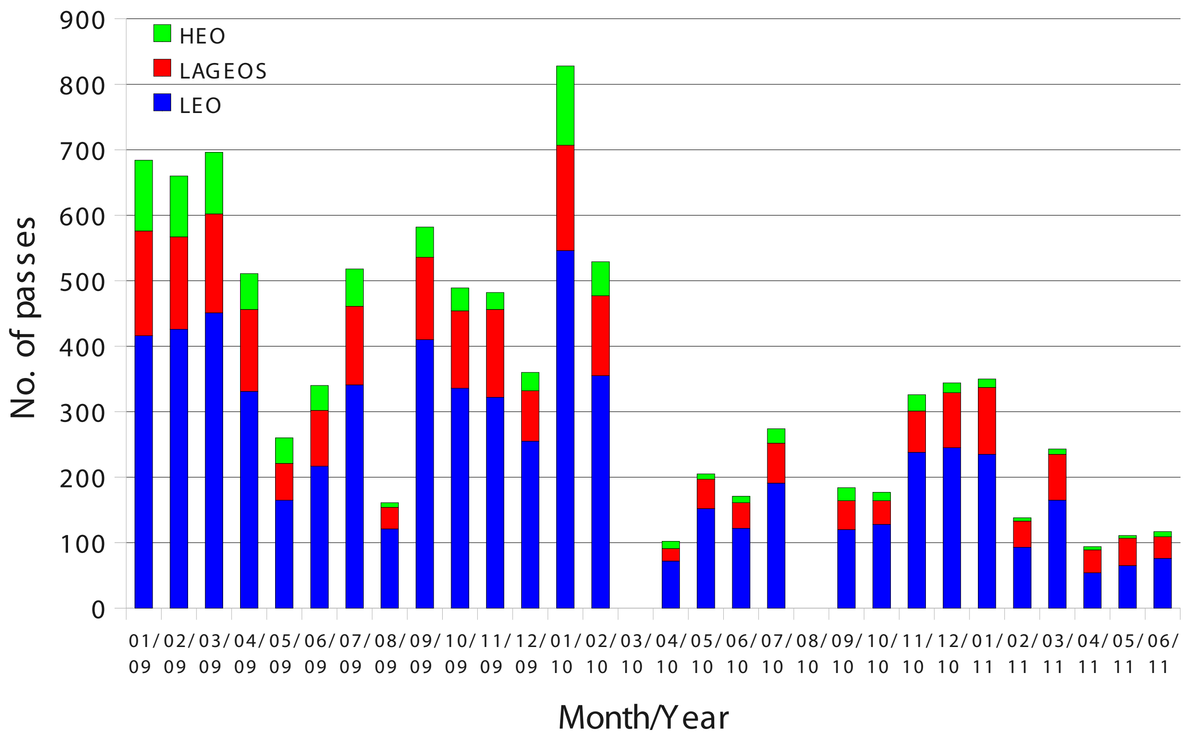


Figure 12-20: Number of passes per month from 2009 through June 2011. Note the effect of particular events on the overall statistics. Remaining deficiencies e.g., of the pump laser limit the measurements particularly of HEO satellites.

Regarding ongoing and future projects, most notably is the 2011 installation on the TIGO site of a three-wavelength tropospheric LIDAR system by the University of Concepción. This system initially aims at monitoring the aerosol concentration of the atmosphere at the TIGO site. Furthermore, automation of multi-color measurements of TIGO-SLR are planned and will be continuously integrated in the station's regular operation. Altogether a thorough analysis of atmospheric refraction effects is envisaged. With respect to the personnel structure the most significant change was the departure of the former head of the group Bernd Sierk in July 2010 and his replacement by Michael Häfner in November 2011.

Figure 12-21: The TIGO-SLR team (left to right, as of May 2011): Manuel Bravo, Maria-José Jerez, César Guaitiao, Víctor Mora, Ivo Fustos, Michael Häfner, Anatoli Poliak, and Marcos Avendaño (insets: Alejandro Fernández and former head of group Bernd Sierk).

Contact

Dr. Michael Häfner
Bundesamt fuer Kartographie und Geodäsie
Observatorio Geodesico TIGO
Universidad de Concepción
Concepción
Chile

Voice: +56-41-2207035
Fax: +56-41-2207031
E-mail: haefner@tigo.cl

FTLRS and Grasse, France

Francis Pierron/Observatoire de la Cote d'Azur

FTLRS laser staff: F. Pierron, D. Feraudy, M. Furia, M. Pierron, J.M.Torre, J.C. Poyard (IGN), M. Aimard, E. Samain
Scientists and associates for T2L2 campaigns: P. Guillemot, P. Exertier, P. Laurent, J. Achkar, D. Rovera

Paris Pre-Campaign for T2L2 Experiment (October/November 2009)

FTLRS was deployed for the first time in Paris for a two-month period in support of the time transfer project experiment with T2L2 on board equipment on Jason-2. This project is a collaboration between the Observatoire de la Côte d'Azur (France), CNES (French Space Agency) and the Observatoire de Paris. T2L2 is a two-way technique based on the timing of optical pulses emitted (and received) by a laser station and received by a space segment, as show in the formula below:

Figure 12-22. T2L2 reflector and receiver.

Ground: T_{start} T_{return}.................Space: T_{board}

From these three times the difference between the ground and space clock can be determined.

Second T2L2 International Campaign (June-August 2010)

Figure 12-23. FTLRS installed at the Paris Observatory.

Figure 12-24. Grasse MEO station.

Time transfer between Grasse/MEO system and Paris/FTLRS system

Figure 12-25. Transportable atomic fountain clock in Grasse developed and installed by the Observatoire de Paris group.

For the second time, FTLRS was installed on the roof of the Paris Observatory for a three-month period. The scientific purpose of this efficient campaign was to observe simultaneously as much as possible Jason-2 passes from Paris and Grasse in order to achieve very accurate time transfer. Both of these sites are equipped with atomic fountain clocks and hydrogen masers carefully calibrated for time comparisons.

Table 12-1. Preliminary Operational Results of the Campaign

Site	Passes with triplets	Passes with Triplets in Common View					
		Paris	Zimmerwald	Grasse	Matera	Wettzell	Simosato
Herstmonceux (GBR)	169	47	14	87	33	19	
Paris/FTLRS (FRA)	140		22	88	43	36	
Zimmerwald (CHE)	85			35	27	21	
Grasse (FRA)	350				77	58	
Matera (ITA)	190					38	
Wettzell (DEU)	167						
Koganei (JPN)	29						5
Simosato (JPN)	25						

Time Transfer Comparison: T2L2 and GPS and TW

- Atomic Fountain comparison
- T2L2-Microwave: inside 2 ns over 60 days
- Fountains give a frequency information; phase is integrated
- Global T2L2 performance: better than 100 ps over 1 minute of ranging

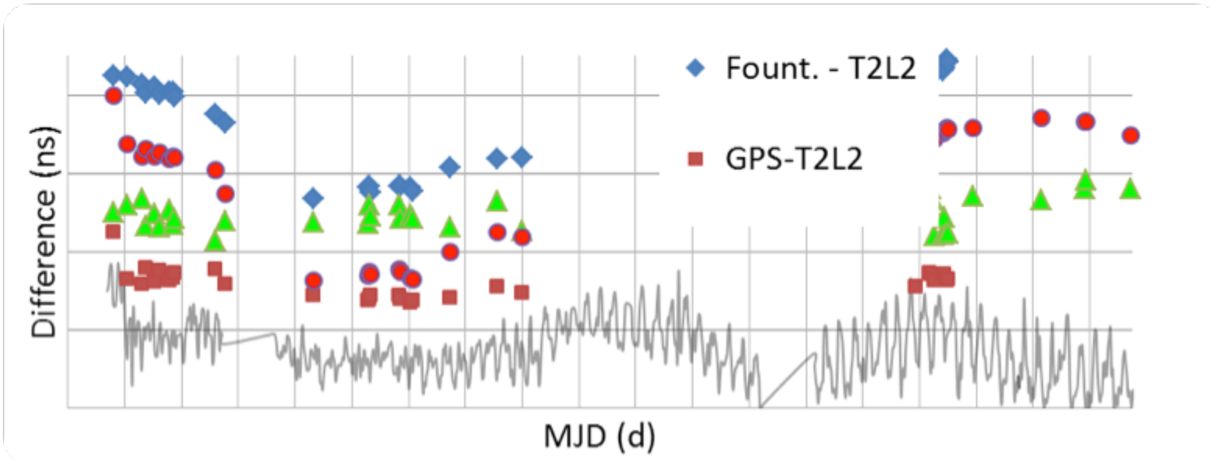


Figure 12-26. Global T2L2 performance.

Contact

Francis Pierron
Observatoire de la Côte d'Azur, CNES/GRGS
Avenue N. Copernic
06130 Grasse
FRANCE

Voice: 33 493405420
Fax: 33 493092614
E-mail: francis.pierron@obs-azur.fr

Graz, Austria

Georg Kirchner, Daniel Kucharski, Franz Koidl/Austrian Academy of Sciences

The kHz SLR System in Graz – Major Upgrades and Results during 2009 and 2010

During 2009 the implementation of our serial Bus was completed: Single BNC cables now connect major SLR station units with the PC, allowing software control of flip mirrors, filter settings, piezo drives in the mount, and also accepting observer command inputs. This configuration enables fast setting of multiple components via single key switches, or via software: A big benefit when tracking very low satellites like GOCE.

Mechanics, electronics and software now allow us to remove the wavelength filter for HEO satellites (LAGEOS and above) during nighttime operations. Because our narrow-bandwidth filter transmits only 35%, night ranging without this filter increases the return rate three times (Figure 12-27). For GLONASS satellites, this now results in passes with several 100.000 returns, with the potential capability for > 1 million returns per pass (forbearing pass switching). This capability might help for the planned Galileo satellites: All of them will be equipped with retro reflectors, and all of them will be at a distance of about 24,000 km, with corresponding low return rates.

The filter is also removed for the LAGEOS-1 and -2 satellites: besides getting more returns, here the fraction of multi-photon returns is also significantly increased, reducing satellite signature, and favoring our "leading edge post-processing method" developed last year.

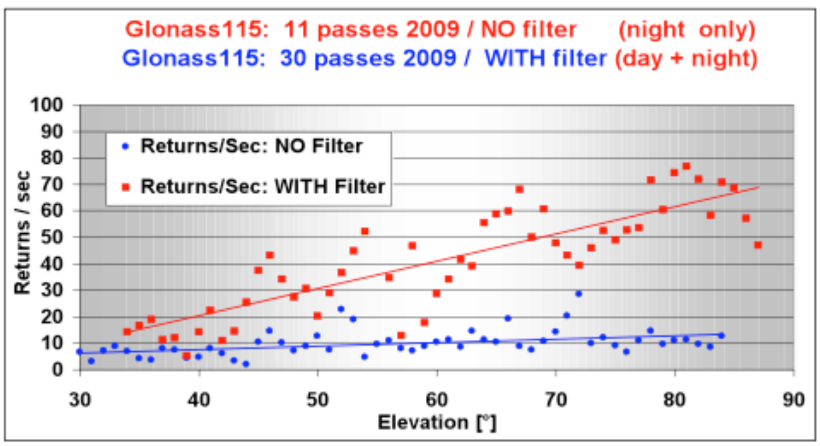


Figure 12-27: Increase of returns for distant satellites: 3 times more returns when filter is removed during night

For special satellites, like BLITS ("Ball Lens In The Space"), the filter is also removed: The relatively weak return signals (in spite of only about 830 km distance, due to its small retro cross section), can be increased, giving a rather constant RMS of 2.5 mm, allowing for significantly better spin parameter determinations (work was completed at the beginning of 2011).

Spin Parameter Determinations

The spin period of the Ajisai satellite for the last five years was determined with an accuracy of <0.005% (for the 2 s period, this is <100 µs), using the 2 kHz SLR data of Graz only. The spin period residuals calculated to an exponential trend function show a significant modulation (Figure 12-28/left: the blue dots); the grey line models a function which depends on the total solar irradiance (TSI) acting on Ajisai: The spin rate slow-down of Ajisai is slower if parts of the orbit are in Earth shadow and faster if in the sun (Yarkovsky-Schach effect).
Using Graz 2 kHz SLR data, we determined the spin axis precession of Ajisai (Figure 12-28/right). Ajisai's spin axis is almost parallel to Earth's spin axis, and it is synchronized with the right ascension of ascending node of the satellite orbit. The spin axis is precessing with a period of about 117 days, around a circle of 2.81 in

diameter.

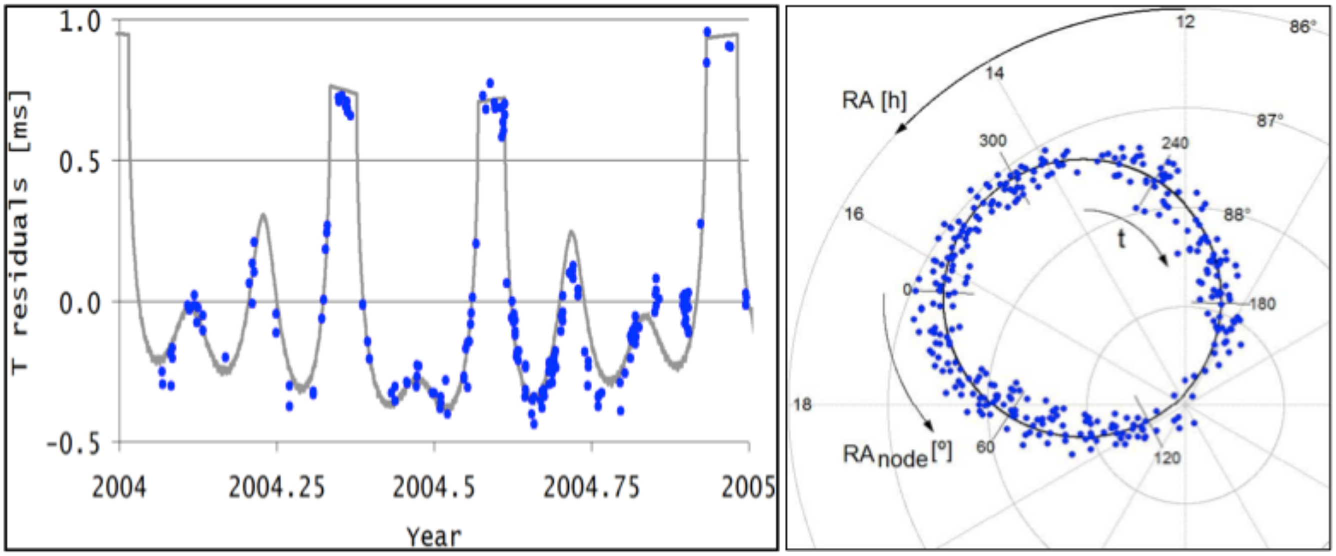


Figure 12-28/Left: Ajisai spin period residuals (blue dots) and the model function (grey line) which depends on TSI (Total Solar Irradiance) acting on Ajisai; plotted for the year 2004.

Figure 12-28/Right: Spin axis orientation (blue points) of Ajisai; determined from Graz 2 kHz SLR data, plotted in the inertial reference frame. The orientation of the spin axis follows t (time) direction, the right ascension of the ascending node (RAnode) is decreasing with time.

The Graz 2 kHz SLR system also measures the spin parameters of the nano-satellite BLITS (Ball Lens In The Space, launched September 2009). The objective of this pioneering mission is an experimental verification of the spherical glass retro-reflector concept. Analysis of the 2 kHz SLR measurements to BLITS shows that the spin period remains constant. However, the orientation of the spin axis is not constant in the inertial reference frame and follows the satellite's orbit.

Contact

Dr. Georg Kirchner
Space Research Institute
Austrian Academy of Sciences
Lustbuhelstrasse 46
A-8042 Graz
AUSTRIA

Phone: 43-316-873-4651
Fax: 43-316-873-4656
E-mail: Georg.Kirchner@oeaw.ac.at
Web: http://www.iwf.oeaw.ac.at

"There are 3 kinds of people: Those who can count, and those who can't ..."

Greenbelt MD (MOBLAS-7), USA

Dave McCormick, Curtis Emerson/NASA GSFC, Bob Stelmaszek/ITT, Thomas Varghese/Cybioms

Figure 12-29. MOBLAS-7 in Greenbelt, MD.

In 2009 and 2010, MOBLAS-7, located at the Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, Maryland, operations under the supervision of Maceo Blount. The station was able to track consistently in 2009 but was suspended for a significant portion of 2010 due to a radar error, violating FAA safety regulations.

In 2009, the station operations ran without many critical problems. Testing and simulation for Lunar Reconnaissance Orbiter (LRO) tracking began in April 2009. After successful testing, the station adjusted the operations schedule to 3 shifts/5 days per week and started LRO tracking at the end of June. MOBLAS-7 altered the laser repetition rate operate at 10 Hz for LRO tracking. A system delay drift was discovered on February 2010 in the ground test data and investigations lead to several changes in the wiring and the power supply of the laser. Cables that may have been causing delay issues were replaced and new connectors were purchased to further stabilize the system. In addition, the power supply was replaced to prevent it from causing power losses. After these changes the system delay drift over one hour period was less than 1mm.

Operator Robert Hicks retired in March 2010. The station, however, continued with a two-shift schedule with the help of William Weaver. Recently, two new staff members, Paul Beckwith and Tushar Ujla, have been added and are in training.

In March 2010, an error lead to a serious issue with the MOBLAS-7 radar and laser interlock system. All laser operations were temporarily halted for stations in the NASA network to ensure network safety. All stations except MOBLAS-7 were given permission to return to SLR operations on 05/07/2010. In order for MOBLAS-7 to perform tracking operations again it first had to undergo hazard analysis and receive NASA Safety and FAA concurrence for laser operations. Ranging operations resumed in November 2010 when the FAA was satisfied with the MOBLAS-7 safety systems and new procedures.

During the time that the laser was offline and non-operational, the station focused its efforts on ground ranging activities and attending to visitors. The station continued to perform ground testing on the universal counter units and the Laser Hazard Reduction System (LHRS). The LHRS upgrades included modifications made to the radar control card and the target determination logic. These modifications corrected a tuning error and an external triggering for multiple radar synchronization.

MOBLAS-7 hosted several tours in August 2010 for NASA management, NASA safety officials and FAA representatives, and NASA interns who were interested in learning more about the NASA SLR and LRO efforts. The staff also supported the GGAO public presentation during International Observe the Moon Day for the second year in a row. Over 100 visitors toured MOBLAS-7, with presentations given by Development Engineers and Station Operations personnel.

Contact

Dave McCormick (primary)
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Phone: 301-286-2354 (primary)
Phone: 301-377-2711 (secondary)
Fax: 301-286-0328
E-mail: David.R.McCormick@nasa.gov

Curtis Emerson (secondary)
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Phone: 301-286-7670 (primary)
Phone: 301-286-3065 (secondary)
Fax: 301-286-0328
E-mail: Curtis.M.Emerson@nasa.gov

Greenbelt MD (NGSLR), USA

Jan McGarry/NASA GSFC

Figure 12-30. NGSLR ranging to LRO orbiting the Moon.

NGSLR developers continued work on the system automation during the 2009-2010 time period while stabilizing the system performance and working toward a co-location with MOBLAS-7. The system continued to use the eyesafe Q-Peak laser with the 4-quadrant 12% QE detector until near the end of 2010, when the new 1 mJ in-house built laser and a single anode 40% QE Hammamatsu MCP-PMT detector were installed. The combination of the higher power laser and the higher QE detector are expected to permit daylight ranging to GNSS satellites. With the eyesafe laser and lower QE detector, the system had successfully tracked daylight LEO and LAGEOS satellites and nighttime GNSS.

NGSLR successfully performed 1-way ranging to LRO on its first attempt shortly after launch in June 2009 and has been successfully ranging to LRO ever since. Operational ranging to LRO coexists well with SLR R&D development since LRO-LR requires no receiver and each activity has its own separate laser. The lasers are easily swapped by insertion/removal of a mirror and a change of the start diode cable.

Figure 12-31. NGSLR staff (left to right): Howard Donovan, Tom Zadwodski, Scott Wetzel, Felipe Hall, Evan Hoffman, Tony Mann, Alice Nelson, Don Patterson, Jan McGarry, Tom Varghese, Bart Clarke, Julie Horvath, Randy Ricklefs, Jack Cheek, John Annen, John Degnan, Tony Mallama. Additional staff members: Peter Dunn, Mike Perry, Mark Torrence.

Contact

Jan McGarry
NASA GSFC
Code 694
Greenbelt, MD 20771
USA

Voice: 301-614-5867
Fax: 301-614-6015
E-mail: Jan.F.McGarry@nasa.gov

Haleakala HI, USA

Daniel O'Gara/University of Hawai`i Institute for Astronomy

The TLRS-4 system has completed two more years of successful laser ranging operations at Haleakala. Since the installation of TLRS-4 at Haleakala Observatories in 2007, we have benefitted from several system upgrades that had been installed previously in other NASA SLR stations.

Figure 12-32. TLRS-4 at Haleakala, Hawai`i

In the first quarter of 2009, testing of the new system controller computer was completed. This computer is responsible for the control of the electronic systems during tracking operations. The new computer hardware and software system gave us increased speed and a large increase in storage capacity.

Later in 2009 the hardware and software system that performs the onsite data analysis was upgraded. As with the controller computer, this was an update from early 1990's technology and provided a large increase in speed and data storage capacity.

The most significant upgrade during this 2-year period was completed in late July 2010. HTSI installed at TLRS-4 a newly configured laser system that incorporated a solid-state replacement for the flowing dye cell system. This new laser configuration makes use of a saturable crystal (Cr+4:YAG) as a Q-switch. The laser is extremely stable and requires very little daily maintenance or adjustments. We are also no longer handling hazardous chemicals that were used to dissolve the dye used in the flowing dye cell system.

The ability of the TLRS-4 system (0.28 meter telescope) to see laser reflections from a GNSS target was proven again during tests in April and May 2010. GLONASS-120 and -102 were tracked over 12 separate attempts with returns seen on the tracking oscilloscope on about half of the attempts. However, a problem with recording the data at 4 Hz has not been resolved. We are currently restricting our tracking to all targets up to LAGEOS altitude.

Work has continued on the Laser Traffic Control System (LTCS). When completed, this web based system will monitor all of the participating telescopes at Haleakala Observatories and prevent the TLRS-4 laser from interfering with their operations.

TLRS-4 maintains a two-shift operation that provides 7 day a week, day and night coverage. Since we do not have a radar on site, each shift consists of a system operator and a mount observer. The two teams have been with TLRS-4 since 2008. Our two system operators are Mr. Craig Foreman (Laser Technician and Observatory Foreman) and Mr. Jake Kamibayashi (Laser Ranging Technician). Our two mount observers are Ms. Rikki Kaia and Ms. Vivian Kamibayashi; Haleakala staff are shown in Figures 12-34 and -35.

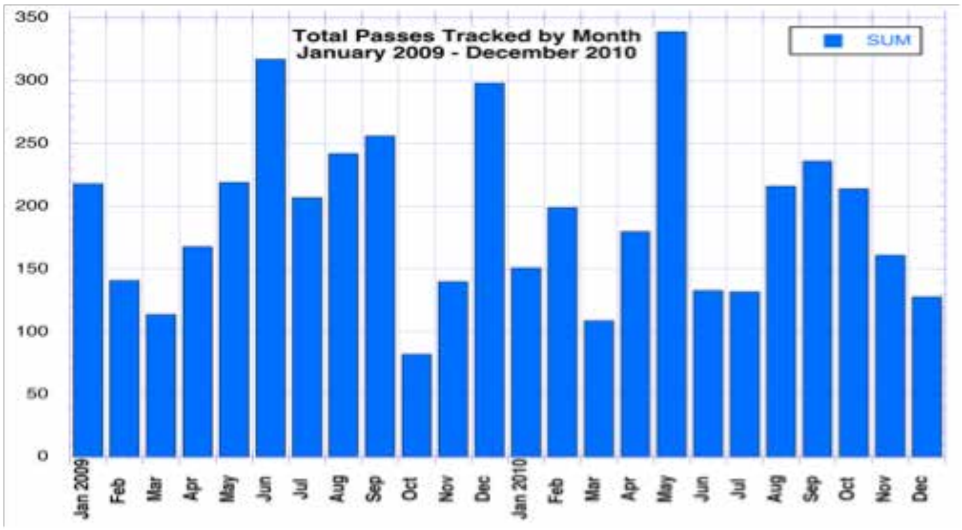


Figure 12-33. Total Passes/Pass Segments Tracked by Month (2009-2010)

Figure 12-34. Jake and Vivian Kamibayashi

Figure 12-35. Rikki Kaia, Dan O'Gara, Craig Foreman

Contact

Dan O'Gara
University of Hawaii Institute for Astronomy
34 Ohia Ku
Makawao, Hawaii, 96768
USA

Voice: 808-573-9505 (Office)
Voice: 808-870-3295 (Cell)
Fax: 808-573-9557
E-mail: ogara@ifa.hawaii.edu

Hartebeesthoek, South Africa

Ludwig Combrinck/HartRAO

The MOBLAS-6 satellite laser ranging system (Figure 12-36) was installed at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) during June 2000 in collaboration with NASA as part of the NASA SLR Network. Operations commenced in August 2000 and the site was inaugurated in November 2000.

Figure 12-36. MOBLAS-6, the telescope enclosure is in stow position.

Recent Activities

During the last 10 years, MOBLAS-6 and it's crew have supplied high quality satellite laser ranging data from Hartebeesthoek, South Africa. Several system failures and a spate of cloudy weather have reduced data volume during the last few years. Most of these issues have recently been addressed so that we expect a drastic improvement in data output. In addition, during the period of reporting, MOBLAS-6 was equipped to partake in ranging to the Lunar Reconnaissance Orbiter (LRO). First ranging results to LRO were achieved on December 6, 2009. To enable participation, HartRAO had to purchase a dedicated PC (Dell Precision Workstation T3400), a time interval card (Guidetech GT658), and serial card (Dual Serial Adapter, SIIG, Model #: JJ-P02012-S6). These were configured by NASA and shipped to HartRAO for installation. The configured equipment arrived in South Africa during the first week of September 2009.

System Upgrades

The processor computer was upgraded during early July 2009. New software was installed at the end of November 2009; the new version of the satellite tracking software has an Az-El Bias panel that uses the keyboard for biasing. Operators can use either the software for tracking via the keyboard or the digit switches for azimuth and elevation biasing. During October 2009 MOBLAS-6 suffered from a damaged oscillator head and this had to be replaced (inclusive of damaged associated parts, flashlamp ends, laser rod, etc.). All UPS batteries were replaced during mid-February 2010; these are typically replaced on a two-year cycle. At the end of November 2010, a rotary joint on the radar system failed, resulting in a short downtime, as safety could not be compromised. Don Patterson visited HartRAO from July 26 through August 11, 2010 to make repairs to MOBLAS-6's MPACS system. During August 2010, Tom Oldham revisited HartRAO to optimize the system (alignments and testing) for satellite tracking, to provide additional training, as required, to maintain optimal system performance and to verify ranging operations for the LRO satellite.

Figure 12-37. Willy Moralo and all other crew members received additional training during 2010. It is envisaged that at least two crew members will be sent to NASA for training during 2011 to enhance local maintenance and operating skills related to MOBLAS-6.

Recent upgrades (February 2011) also include a new laser table (Figures 12-38, -39), which was required due to movement of the optical components on the old table (which was delaminating), causing continual realignment and consequent down time. Thomas Oldham and the crew worked hard to get the new table installed, re-populated and also used the opportunity to do some training.

Personnel

MOBLAS-6 lost its manager to KACST at the end of January 2010. Johan Bernhard was one of the initial members of staff appointed during the installation and commissioning of MOBLAS-6 at HartRAO. The accumulated experience and know-how lost as a result of his departure adversely influenced operations. Appointment of a suitable replacement proved to be problematic and time consuming as major organizational restructuring was also in place. Willy Moralo was promoted to Operations Supervisor and Lusanda Ntsele was appointed as Technical Manager in October 2010. Current personnel complement is therefore:

- Ludwig Combrinck (Associate Director: Space Geodesy)
- Willy Moralo (Operations Supervisor)
- Lusanda Ntsele (Technical Manager)
- Klaas Ramaoka (SLR Operator)
- Tshepo Makate (SLR Operator)
- Sammy Tshefu (SLR Operator)

Figures 12-38 and -39. Lusanda Ntsele and Willy Moralo (left) assisted by Klaas Ramaoka and Sammy Tshefu (right) during the installation of the new laser table in MOBLAS-6.

New Developments

A new system (Figure 12-40) is being developed next door to MOBLAS-6 in collaboration with the Observatoire de la Côte d'Azur (OCA) and NASA. This equipment will be developed as a dual SLR and LLR capable system. The telescope (ex-OCA) has a one-meter mirror and will be refurbished at HartRAO. A new laser system with an expected output of 200 mJ, 200 ps pulse length at 532 nm will be constructed in collaboration with NASA.

Figure 12-40. The SLR/LLR telescope located in its newly built enclosure. This enclosure runs on three tracks. Adjacent to the enclosure is a modified 12-meter long shipping container which will house the control room, laser system and power supplies. It is planned to move the new SLR/LLR system to the semi-arid Karoo region, to a site close to Matjiesfontein where we are developing a new space geodesy and geophysics observatory.

Contacts

Dr. Ludwig Combrinck	E-mail: ludwig@hartrao.ac.za
Associate Director: Space Geodesy	
Lusanda Ntsele, Technical Manager, MOBLAS-6	E-mail: lusanda@hartrao.ac.za
Willy Moralo, Operations Supervisor	E-mail: willy@hartrao.ac.za
Hartebeesthoek Radio Astronomy Observatory	Voice: +27 12 301 3100
P.O. Box 443	Fax: +27 12 301 3300
Krugersdorp, 1740	Web: http://hartrao.ac.za
SOUTH AFRICA	

Helwan, Egypt

Makram Ibrahim/NRIAG

The Helwan satellite laser ranging station belongs to the space research laboratory of the National Research Institute of Astronomy and Geophysics (NRIAG). The station is operated under the cooperation between the NRIAG and the Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering (CTU - FNSPE).

Although the precision of the measurements of the Helwan SLR station is good, there is bad performance of the Helwan SLR station during the previous years, as the total number of passes observed during 2007, 2008, 2009 and 2010 are, 54, 21, 6 and 0 respectively. This level of performance is due to several reasons, one being the old Laser Radar Electronic unit (LRE), which was installed at the station 20 years ago. New equipment, such as the Laser Radar Control System (LRC), redesigned completely by Dr. Miroslav Cech, will be installed in the station during July or August 2011. It is expected to improve the performance of the Helwan SLR station in the near future.

Helwan SLR-Station Staff

- Associate Prof. Dr. Makram Ibrahim, the head of space science laboratory and the principal chief of the Helwans SLR station
- Dr. Khalil Ibrahim, head of solar and space science department.
- Mr. Hany Mahmoud, assistant researcher.
- Mr. Mahmoud Mostafa, assistant researcher engineer.
- Mr. Mohamed Yehya , specialist scientific
- Mr. Sami Fath-allah, technician

Figure 12-41. The Egyptian and Czech chiefs (from left to right)
Dr. Makram Ibrahim and Dr. Josef Blazej

Recent Equipment and Upgrades to the Helwan-SLR Station

A satellite laser radar system with full computer control based on minicomputer system HP 2100 has been operating in Helwan since 1981. From 1987 to 1989, an IBM-PC computer and special control electronics based on Z80 microprocessors were implemented in the laser radar system. The control system covers all important functions for satellite ranging and calibration: two axes mount control with stepper motors, range and epoch counter, laser trigger, HP-IB interface for HP5270 or Stanford SR620 counters, arming and gate control. A new servo motor control system was developed in 1994. In 2009, the laser radar control system was completely redesigned by Dr. Miroslav Cech. The new system is based on a powerful 80C188EB microprocessor operating with 1MB memory. Special circuits for range and epoch reading are included. The control system connected to the main station computer via fast RS232C interface based on 16550 chips. A second serial port is used for high accurate meteorological station MET-3. Two DC servomotors (for azimuth and elevation) are controlled in closed loop feedback. Special microchips HP HCTL-1100 are used. HCTL-1100 is a high performance, general purpose motion control IC. A very precise time interval counter (resolution 20 ps) HP5370B or Stanford SR620 is connected via HP-IB interface based on second generation of HP-IB micro controller Ines i7210. Firmware is written in C language and assembler and is very flexible. Furthermore, the firmware is compatible with the old LRCS system at the command level. The new control system will increase the reliability of the laser station.

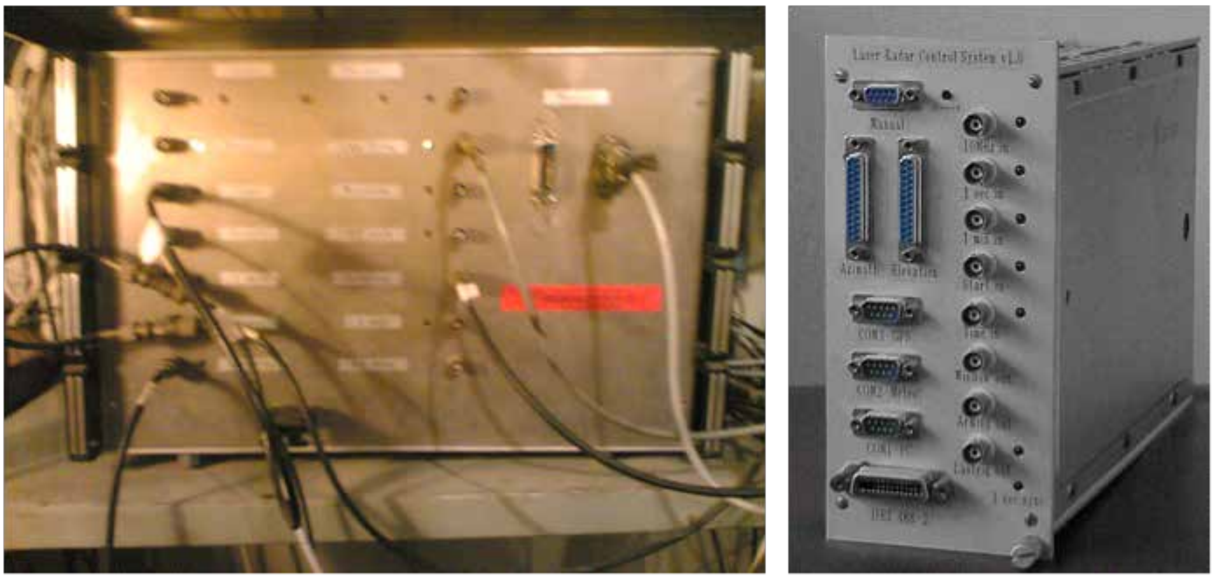


Figure 12-42. The old LRE (left) and the new LRC (right).

Future Plans

A Hamamatsu H6533 box with PMT tube 4998 has been used since 1998. The quantum efficiency of this PMT is 10 % at 532 nm and of normal gain equal 5.6 10^6. The mode of the PMT is single photoelectron detection. It consists of a PMT tube and high voltage (HV) with precise divider. The Tennelec TC 952A high voltage power supply with stable 2500 volts is used as a source for the PMT to obtain standard parameters. It is expected the change of that PMT in the near future, due to the long operating time of that PMT which in fact affect its sensitivity.

Contact

Dr. Makram Ibrahim
NRIAG
Space Science Laboratory
11421 Helwan, Cairo
EGYPT

Voice: +201 05799722
Fax: +202 25548020
E-mail: makram@nriag.sci.eg
E-mail: makikh@yahoo.com

Herstmonceux, UK

Graham Appleby, Philip Gibbs, Christopher Potter, Robert Sherwood, Toby Shoobridge, Vicki Smith, Matthew Wilkinson/ NSGF

Introduction

The SGF operates a dual laser SLR system comprised of a 12Hz, Nd:YAG, 20mJ, 100ps laser and a 2kHz, Nd:VAN, 0.4mJ, 10ps laser purchased from High Q Laser. Switching between the systems is achieved in less than 30 seconds and this requires separate calibrations. The SGF observer selects the laser best suited for each satellite, usually 12Hz for daytime GNSS and in poor sky conditions and kHz for greater precision and night tracking. The 12Hz system is run at 14Hz for synchronous detection at the LRO satellite orbiting the Moon. The kHz system has not performed as well as expected and it has thus proved to be of great benefit to have retained a dual-laser system. Investigations into the under-performance of the kHz system lead to a discovery that the dichroic mirror, internal to the telescope, was highly sensitive to polarization and it has been replaced. A study into the impact of the atmosphere on the SLR return signal strength was initiated with a system upgrade to LiDAR capability. In addition to the ILRS-supported subset of the GLONASS constellation, all GLONASS satellites are routinely tracked, with the extra ones being given a lower priority. This experiment appears to have had little negative impact on the overall productivity of the station.

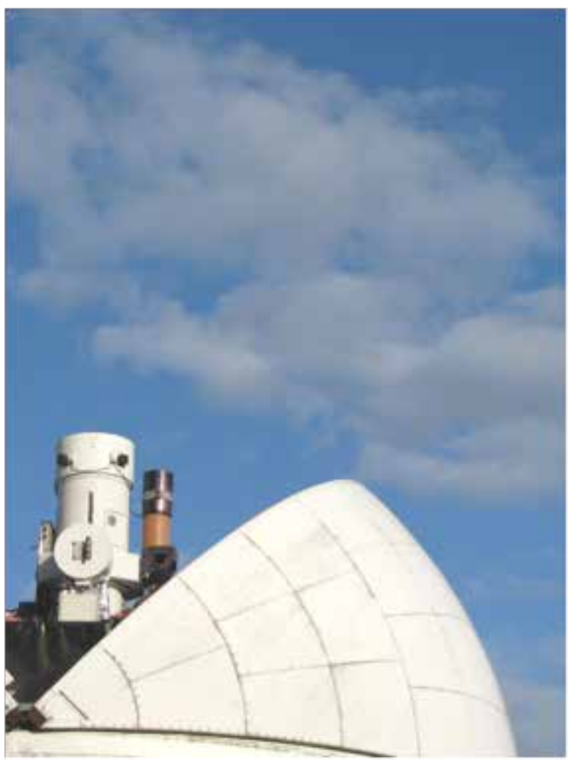
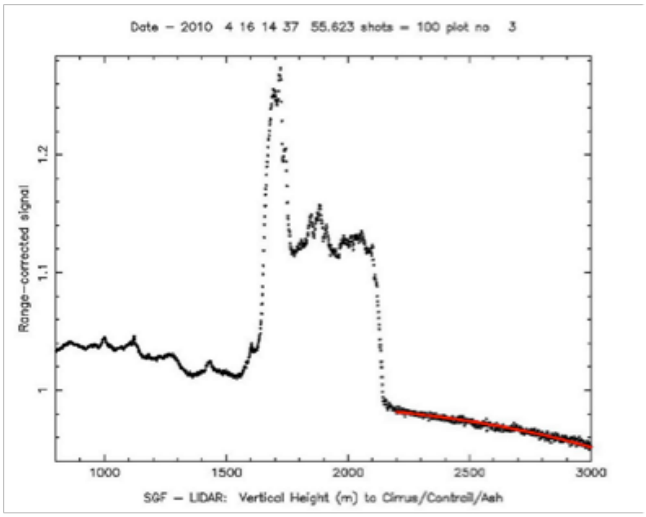


Figure 12-43. The SGF telescope and dome.

The SGF continued to operate a FG-5 absolute gravimeter on a weekly basis to measure local gravity and height change. In support of this, a lot of work in this period was focused on the stability of the SGF site, which is located on a bed of clay. This included short-baseline GPS analysis and the commencement of regular digital leveling to survey relative height changes between monuments around the site. Significant investment was made in the SGF with the acquisition and installation of an active Hydrogen Maser. This now provides epoch and frequency for the SLR system and drives the HERS GNSS receiver.

LiDAR

An elastic LiDAR observational capability was developed at the site to study different aspects of the atmosphere. This includes aircraft contrails, atmospheric transparency, particularly during ranging support of LRO and also included the tracking of the ash plume following the eruption of the Icelandic volcano Eyjafjallajökull in April 2010. The volcano sent a plume of dust and ash up into the atmosphere over most of the European continent. The SGF began LiDAR observations a day before the ash cloud was expected to arrive over the South East of England and continued them routinely as requested by the UK Met Office. Some observations showed increased backscatter due to the ash and dust particles at variable heights and thickness. The plot, above right, shows reflective layers of material, most likely ash particles from the volcano, at heights of from 1.1 to 1.6 km.



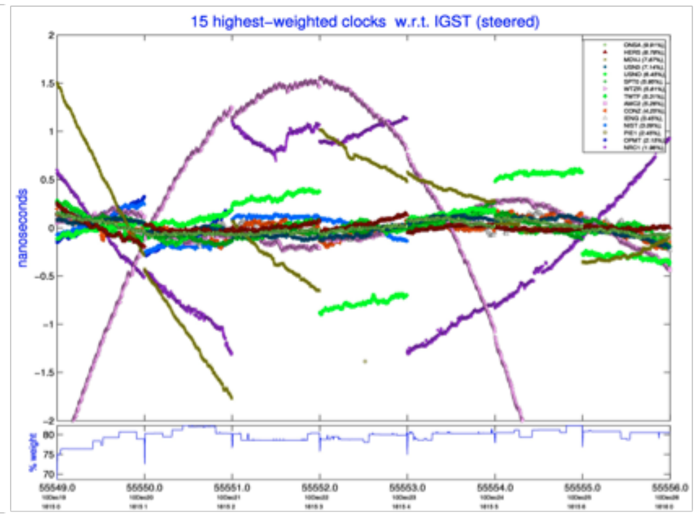


Figure 12-44. (left) A LiDAR backscatter profile through the atmosphere containing some volcanic ash.

Figure 12-45. (right) A weekly IGS clock comparison showing the new H-maser to be performing well.

Active Hydrogen Maser

An active hydrogen maser frequency source, an 'i-Maser', was installed at the beginning of 2010 in a dedicated air conditioned lab. The maser's performance and the environmental stability are continually monitored remotely. The frequency source from the i-Maser is now used to drive the HERS GNSS site, which was upgraded with a Septentrio receiver. This enables this site to contribute to the IGS timescale at relatively high weight, see plot right. The maser is performing very well and to specification.

Since May 2010 the maser one-second tick and 10MHz frequency have been used as the source for driving the SLR event timer. All measurements are therefore benefiting from the more stable frequency source, and time-tag epochs are no longer being steered to UTC(GPS). This provides maser-driven epochs for SGF ranging data, which is of particular interest to the LRO mission and to the T2L2 experiment on Jason-2.

Optical Studies, Dichroic Losses

A new dichroic mirror was installed and has properties ideal for the SLR system. The previous dichroic mirror had not been replaced for many years and was found to be degraded and highly polarization-sensitive. Below are the results of laser-bed tests for polarization-dependence for the old (left) and new (right) dichroic mirrors. Installation of the new dichroic led to an improvement in signal-return of more than 100%.

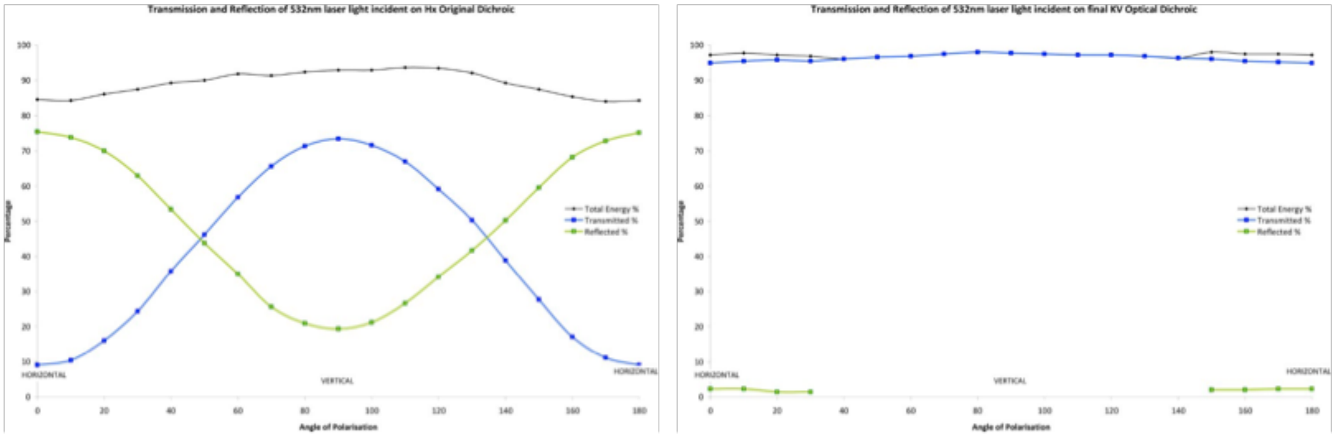


Figure 12-46. The old (left) and new (right) dichroic mirror tests for reflectance dependence on polarisation .

Monitoring Site Stability by GPS Baseline Analysis

To study the horizontal stability of the local site around the SGF, short GPS baselines were calculated using the GAMIT GPS analysis software. The HERS-HERT baseline, plotted right, can be determined to mm-level precision on a daily basis. The near-annual variation present in the baseline suggests a movement in one of the GNSS site monuments or an artifact inherent in the GPS analysis technique and this discovery is leading to further investigation into the local stability of the SGF site and monuments.

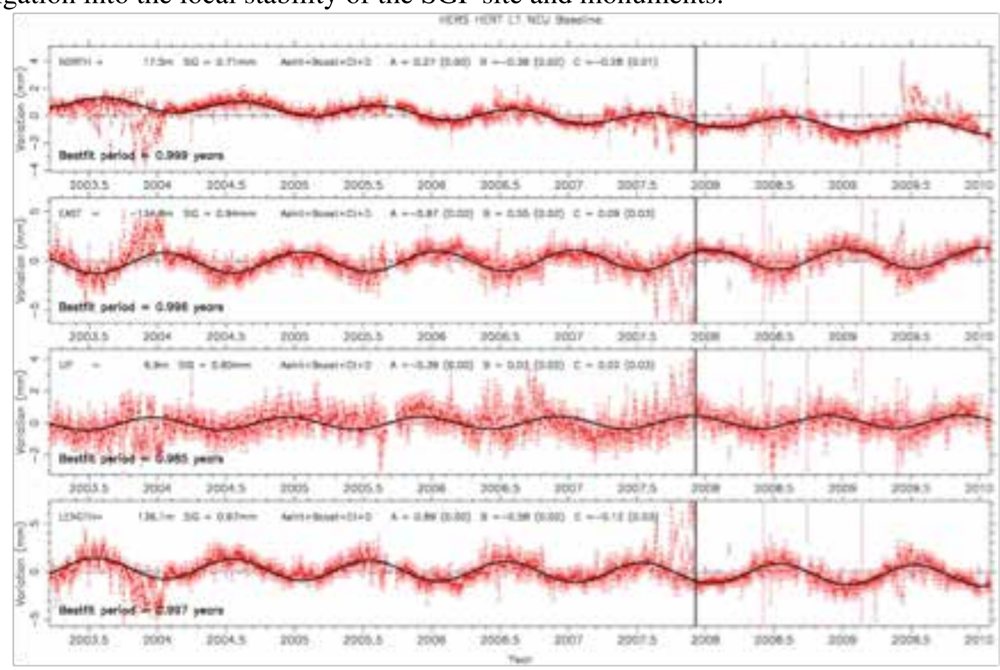


Figure 12-47. The components of the short baseline between HERS and HERT as determined using GAMIT.

Monitoring Site Stability by Digital Leveling

A campaign to monitor potential small differential height variations around the SGF site, particularly between the different technique monuments, began in 2010 using a Leica DNA03 digital level. The leveling run includes a gravimetry pier, three GNSS monuments, a UK Ordnance Survey pillar and an invar barcode strip permanently mounted on the SLR telescope pillar. The digital level can determine height changes to a precision of 0.3mm.

Figure 12-48. SGF team members performing a digital leveling run.

Fast Satellite Switching with kHz

The high repetition-rate laser allows 1mm normal point precision to be reached in a short time period, often less than the ILRS-recommended duration of a normal point. The SGF displays in real time the normal point precision and once a value of 1mm is reached the observer is free to consider other satellites in the schedule and switch, with the option of returning to the previous satellite later in its pass. This lead to a novel, experimental approach to SLR observing where only minimal time was spent on one satellite before switching to the next. The plot to the right shows an attempt to track a high number of coinciding satellite passes and to minimize the time spent on one satellite with efficient satellite switching. Working in this manner requires the observer to be closely aware of which satellites have recently been tracked and which satellites should be the next priority for SLR. It may be possible to automate some of this decision-making process.

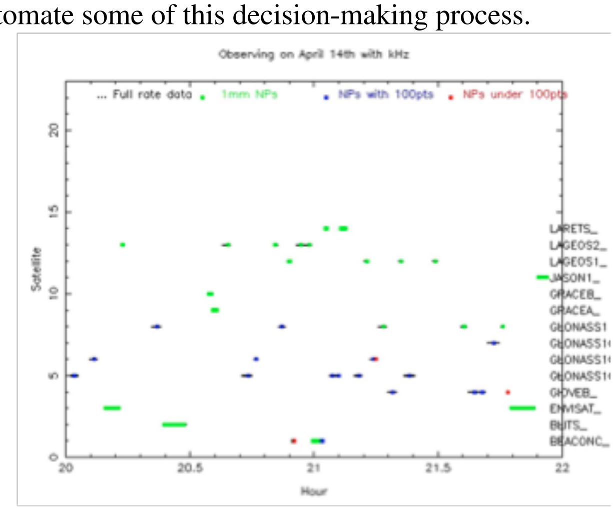


Figure 12-49. Fast switching between many satellites over 2 hours of SLR observing.

TerraSAR-X and TanDEM-X Simultaneous SLR Measurements

When TanDEM-X was positioned in close orbit to its partner mission TerraSAR-X, a technique was developed at the SGF to switch automatically between the two satellites at 10 second intervals. This is achieved through a combined single prediction and a shared data file. The observations from each satellite are then separated during data reduction, which is carried out on the individual satellites.

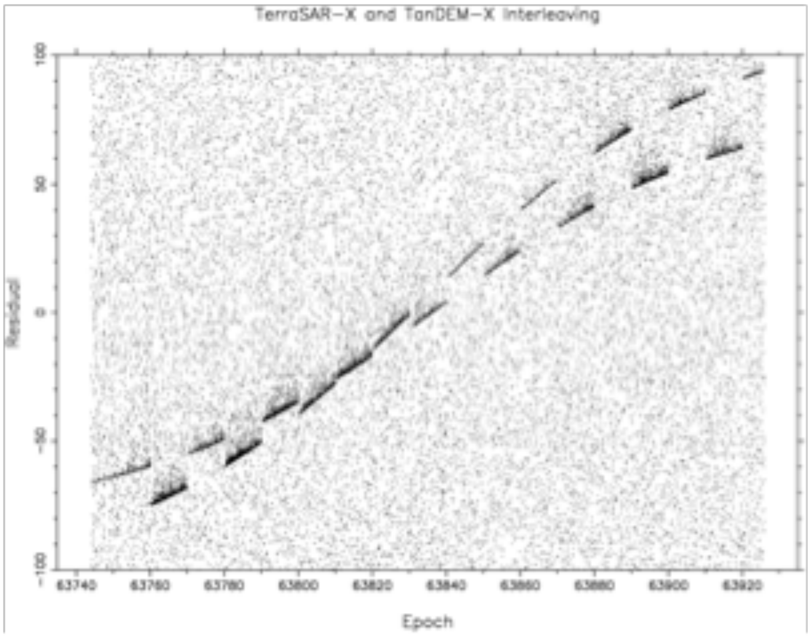


Figure 12-50. SLR returns from TerraSAR-X and TanDEM-X using the interleaving technique.

Acknowledgements

The continuing support for the work of SGF Herstmonceux by the Services and Facilities management team of the UK Natural Environment Research Council and by its Space Geodesy Facilities Steering Committee are gratefully acknowledged.

Contacts

Dr. Graham Appleby
Robert Sherwood
NERC Space Geodesy Facility
Herstmonceux Castle
Hailsham, East Sussex
BN27 1RN
UNITED KINGDOM

E-mail: gapp@nerc.ac.uk
E-mail: rshe@nerc.ac.uk
Voice: +44 (0)1323 833888
Fax: +44 (0)1323 833929
Web: http://sgf.rgo.ac.uk

Kiev, Ukraine

Mikhail Medvedsky, Viktor Pap/Agency Main Astronomical Observatory of NAS of Ukraine

Introduction

The Main Astronomical Observatory of Ukraine built the Kiev SLR station in 1985. Since April 1996, the station has performed routine satellite laser ranging operations and on January 22, 1999, the station began permanent laser tracking operations as part of the ILRS network. Today, most low-orbiting satellites as well as LAGEOS are tracked on routine basis. High-orbiting satellites, such as GPS, Etalon, and GIOVE, are not tracked due to the lack of required technical resources. However, since 2010, after improvements to the signal detection system and software, high-orbiting satellites have been tracked. Today, the station is ranging to all available satellites: both low- and high-orbiting targets. Four people work at the Kiev station; the system is operational 6 to 7 days per week, weather permitting. The station performs ranging activities at night in semiautomatic mode with only one operator.

Figure 12-51. Kiev telescope and station staff (left to right): Vitaliy Kostogryz, Michael Medvedsky, and Viktor Pap; the staff also includes chief engineer Juriy Glushchenko.

Figure 12-52. Station operations at night

Figure 12-53. The system's calibration target, placed in the observatory's main building.

Figure 12-54. The new laser system of our station, installed in 2008.
The laser unit (left) and power supply, control unit, laser cooling unit (right).

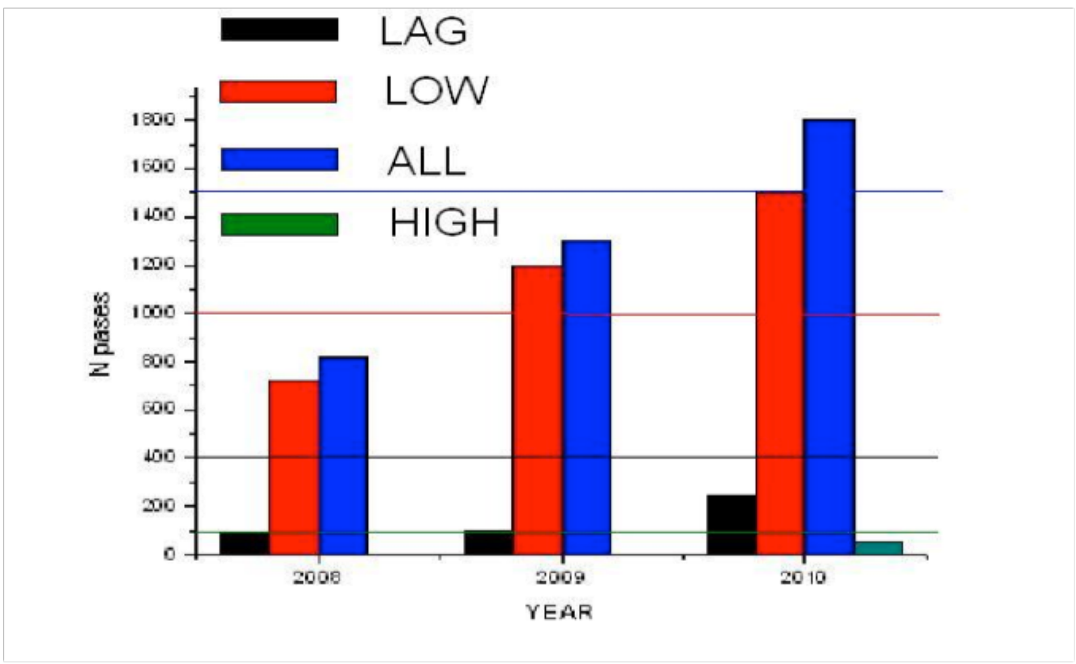


Figure 12-55. The number of passes satellite laser ranging in Kiev SLR station

System Upgrades

The station's hardware and software were upgraded at the end of 2010. A new PMT was installed; a new PMT pre-amplifier was also constructed and installed. The time-gate system has been adjusted for ranging to high-orbiting satellite. The dome of station was adjusted; the dome is now lighter and we have not experienced any problems during hard frost conditions. A CFD discriminator was adjusted and the single-shot RMS has improved to 2 cm at calibration and 2.5 cm during satellite ranging.

Future Plans

In the near future, the staff plans to develop a daylight ranging unit and plans to obtain a new time interval counter and PMT.

Contact

Dr. Mikhailo Medvedskij
Main Astronomical Observatory of NAS of Ukraine
Golosiiv, 03680 Kyiv-127
UKRAINE

E-mail: medved@mao.kiev.ua
Phone: +380-44-5264759

Kunming, China

Xiong Yaoheng, Zheng Xiangming, Fu Honglin, Li Yuqiang/National Astronomical Observatories, Yunnan Observatory, CAS

Introduction

Figure 12-56 shows the Kunming station's SLR system. The system was built to perform Satellite Laser Ranging (SLR) work in 1998, and has produced a series of valuable data for users who utilize these data for scientific research. The telescope was upgraded from 2003 to 2006, and resumed operations in 2007 with improved tracking capabilities. Before 2009, this system had a 1-10Hz ranging frequency.

Figure 12-56. Kunming SLR system

System Upgrades

Now the Kunming station has been upgraded to kHz frequencies, using a kHz laser (Figure 12-57) and a A033-ET (Figure 12-58), as well as other equipment. The Kunming SLR system has successfully obtained daylight ranging data in late October 2010.

Figure 12-57. Kunming's kHz laser

Figure 12-58. A033-ET with <5ps precision

Future Plans

It has not been easy to carry out high repeat frequency co-optical path SLR, and our experiment of realizing kHz co-optical path SLR at the Kunming station has completely proved this. However, at the same time, our experiment indicated that the co-optical path kHz satellite laser ranging technique could be fulfilled. Therefore, we will continue to carry out LLR experiments in this system in the upcoming months.

Contact

Li YuQiang
E- mail:lyq@mail.ynao.ac.cn
Voice: 86-871-3920403-805

Zheng XiangMing
E-mail: zhengxm@mail.ynao.ac.cn
Phone: 86-871-3920403-801

Yunnan Observatory
National Astronomical Observatories
Chinese Academy of Sciences
P. O. Box 110
Kunming 650011 Yunnan
CHINA
Fax: 86-871-3920599
Voice: 86-871-3920823

Lviv, Ukraine

Andriy Bilinsky, Yaroslav Blagodyr, Konstiantyn Martyniuk-Lototsky, Natalia Virun, Eva Vovchyk, Andriy Kurylo/ Astronomical Observatory of Ivan Franko National University of Lviv

Observation results

The Lviv SLR station acquired 457 passes (7,628 normal points) from 12 satellites during 2009-2010 (434 LEO satellites passes with a total of 7,444 normal points and 23 ≈ passes with a total of 184 normal points). The mean error of measurement data consist: the calibration on the ground-based target - 12.7 mm, the ranging on LEO satellite Starlette – 45.7mm, the ranging on geodetic satellite ç – 56.5mm.

Recent Developments

A small amount of SLR observations within the period 2009-2010 was due to several station systems failures: in the early 2009 the HDD of the main server (with the software for initial data for satellite tracking and SLR results pre-processing) failed; later the frequency standard failed and was subsequently repaired. In the end of 2009, the failure of the laser water-cooling system resulted in the destruction of the optical parts of the laser oscillator and intensifier. We are trying to repair and purchase the necessary parts for the laser, and hope to complete its repair by the end of 2011.

Nevertheless, we worked on SLR system improvements to satisfy ILRS requirements. The software for preliminary processing of observational results in full-rate and normal point format was modernized to support the new CRD data format. Our system is currently in the "OC Validated" stage.

For the purpose of improving the protection system of receiving channel of the telescope TPL-1M, a new shutter was developed and placed into the receiving path of telescope.

For preparation of SLR observations in late of 2010, the reserve set of main and secondary mirrors of the telescope were recovered through government financial support for the national property object. We also purchased an Agilent DSO6104L 1GHz oscilloscope through financial support of the rector of our University. This equipment allows us to test the Hamamatsu PMT and at last put it into operation.

Future Plans for System Improvements

By the end of 2011, we plan to finish the system repairs and obtain SLR results at first at the previous accuracy level, and next after changing the mirrors set and putting the Hamamatsu PMT into operation with improved accuracy. We also plan to continue updating the station software for restricted SLR tracking operations.

Contact

Yaroslav Blagodyr

Astronomical Observatory of
Ivan Franko National University of Lviv
St. Kyrylo i Mefodij, 8,
79005, Lviv
UKRAINE

E-mail: ja.blagod@gmail.com
slr1831@ukr.net
Voice: +380 32 2600393

Matera, Italy

Giuseppe Bianco/Agenzia Spaziale Italiana, Centro di Geodesia Spaziale "Giuseppe Colombo", Matera, Italy

During years 2009-2010 the MLRO (Matera Laser Ranging Observatory) has mostly been in routine, full time (24/7) operations. However, in 2009 MLRO experienced a significant 7-months down time due to severe problems to the telescope mount and controller which have been solved in September. In 2010 operations went much more smoothly, with twice as much data produced.
The tables and figures below summarize the weekly number of passes observed by MLRO in each year.

Table 12-2. 2009 pass summary: acquired/scheduled

Sat	acqu / sched [%]	acqu / sched [#]	sat NP [#]
HIGH	6.9	193/2794	2269
LOW	15.0	1951/12995	29109
LAGEOS	19.8	588/2977	7056

Table 12-3. 2010 pass summary: acquired/scheduled

Sat	acqu / sched [%]	acqu / sched [#]	sat NP [#]
HIGH	19.4	770/3976	8172
LOW	31.4	4226/13455	59373
LAGEOS	39.9	1228/3077	14123

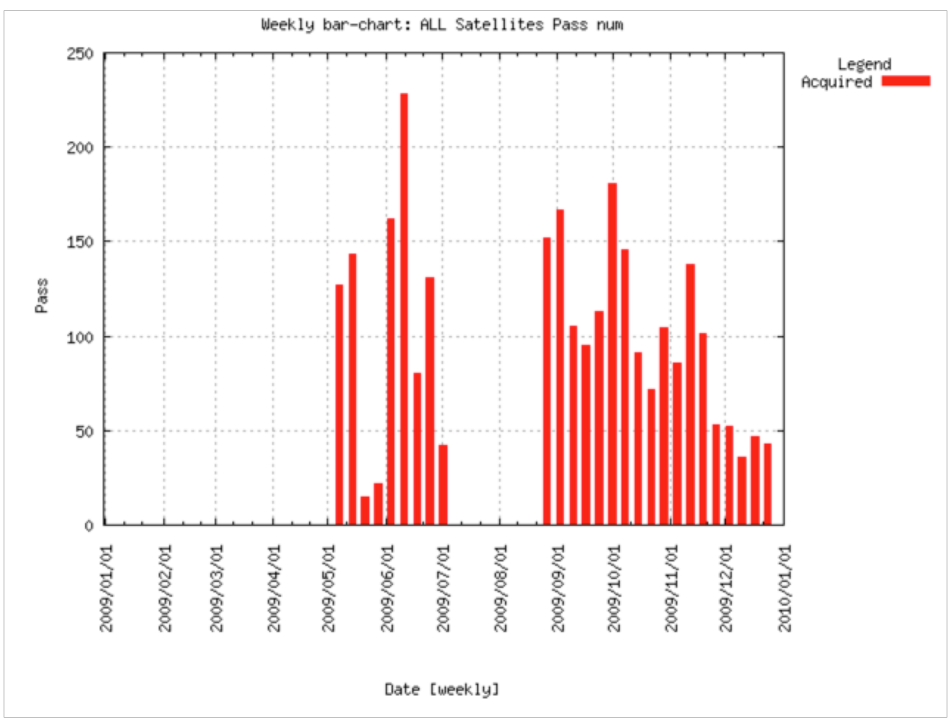


Figure 12-59. MLRO pass totals for 2009.

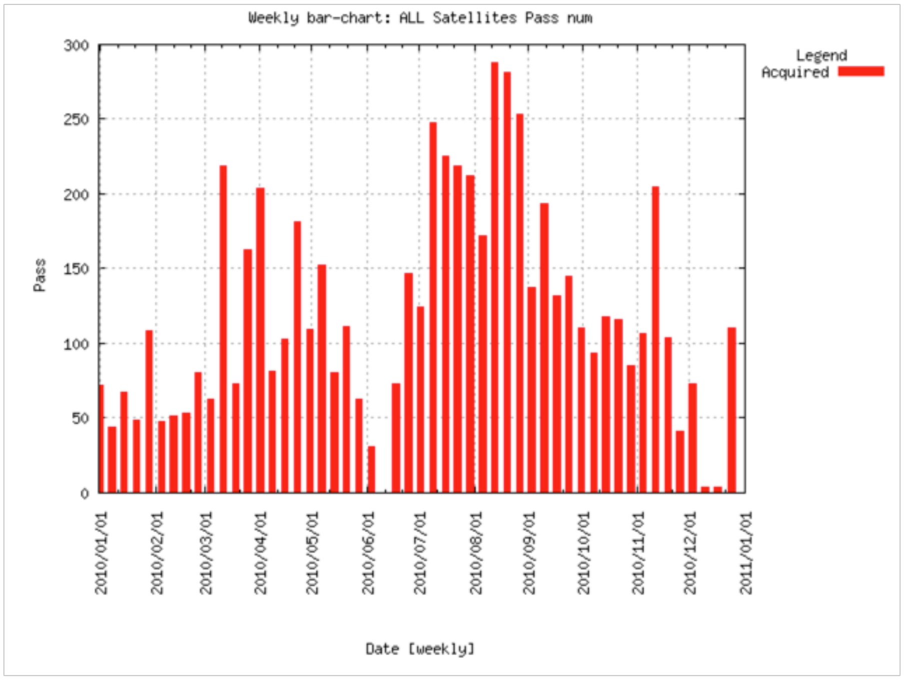


Figure 12-60. MLRO pass totals for 2010.

Contacts

Dr. Giuseppe Bianco
Agenzia Spaziale Italiana (ASI)
Centro di Geodesia Spaziale
C.da Terlecchia, 75100 Matera
ITALY

Voice: +39-0835-377209
Fax: +39-0835-339005
E-mail: giuseppe.bianco@asi.it

Dr. Vincenza Luceri
e-GEOS S.p.A.
Centro di Geodesia Spaziale
C.da Terlecchia, 75100 Matera
ITALY

Voice: +39-0835-377231
Fax: +39-06-40999961
E-mail: cinzia.luceri@telespazio.com

McDonald TX, USA

Peter J. Shelus, Jerry R. Wiant, Randall L Ricklefs, John C. Ries, Judit G. Ries/Center for Space Research and McDonald Observatory, University of Texas at Austin

The McDonald Laser Ranging Station (MLRS)

The McDonald Laser Ranging Station (MLRS) is located at McDonald Observatory in the Davis Mountains of west Texas, near the town of Fort Davis, TX (USA). In addition to ranging to artificial satellites (SLR), it is one of the very few stations that also performs laser ranging to the Moon (LLR). For the past several years, we have also been involved in the Lunar Reconnaissance Orbiter (LRO) program.

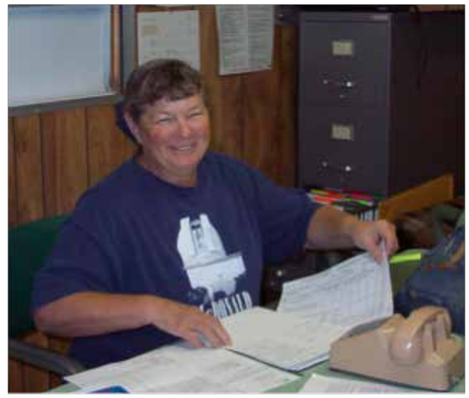
Figure 12-61. MLRS

Our support comes from an operations contract from the National Aeronautics and Space Administration (NASA). In the recent past, LLR support came from a research grant from the National Science Foundation (NSF).

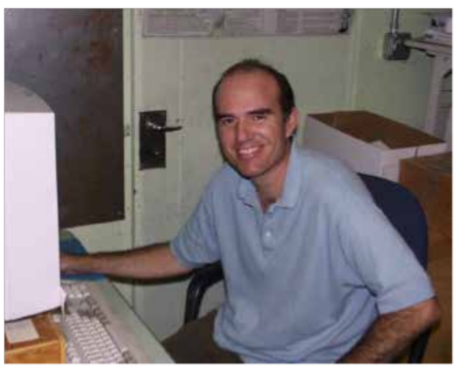
Dr. Peter J. Shelus is Project Manager. Mr. Jerry R. Wiant is Project Engineer and Mr. Randall L. Ricklefs is Software Manager. Dr. John Ries provides quality control for our SLR data. Dr. Judit Ries provides part-time logistical support for our LLR data product. Mr. Ken T. Harned and Mr. Anthony R. Garcia are observers. Ms. Rachel M. Green serves as a part-time Technical Assistant.

SLR

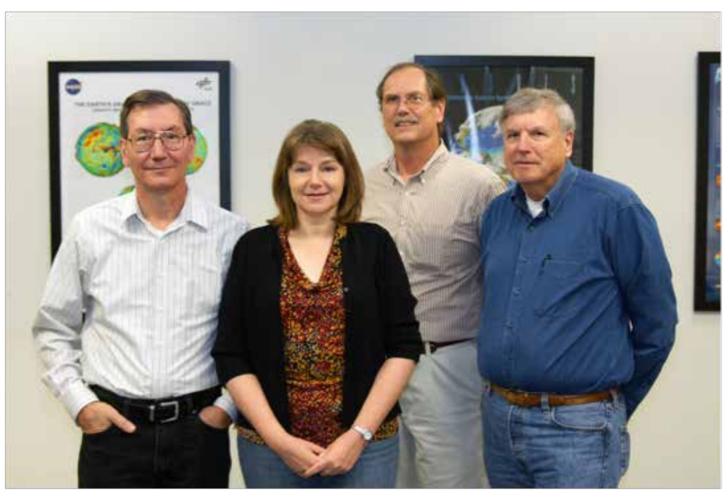
SLR data volume from the MLRS continues to be less than optimal, due to the reduction in manpower that has been forced by a sequence of funding cuts over the past several years.
In addition, the station is showing its age. The MLRS can do with upgrade and refurbishment. Day-to-day activity is directed toward keeping the station operational and in a data-gathering mode.

Jerry Wiant and Rachel Green




MLRS observers Anthony Garcia and Ken Harned



John Ries, Judit Ries, Randall Ricklefs and Peter Shelus

Figure 12-62. MLRS Staff

ICESat

Ranging to the ICESat target continued to the end of that very successful experiment. The MLRS was one of a handful of ILRS SLR stations that had been specially configured to range safely to ICESat. That satellite had a downward looking telescope that would have been irreparably damaged by inadvertent laser pulses from the ground.

LLR

Ranging to the Moon continues. The MLRS is one of only three laser stations that have been ranging to the moon during this report period. The LLR station at Apache Point, New Mexico is still not an official member of the ILRS, and its data are not yet in the CDDIS data archives. The French LLR station has just recently begun LLR operations after being down for several years for refurbishment and upgrade.

MLRS LLR data are available through the several data centers of the ILRS. The data are transmitted to the centers in near real-time, using standard ILRS formats. A Hamamatsu MCP has been made available by GSFC to the MLRS to replace the two Varian photomultiplier tubes that had been used over the past 25 years for LLR operations. Although not as sensitive as the Varian tubes and a bit noisier, it has allowed the continuation of LLR observations.

LRO-LR

The MLRS was designated as a ground station to participate in the LRO-LR project. Extensive work had been performed to get the station ready. LRO was launched in June 2009. We have been continuously working on the LRO target from October 2009 down to the current date. We are happy to say that the MLRS has been involved in a very good number of 2, 3 and 4 station simultaneous observing operations.

Data Quality Control

Regular SLR data processing and quality control is performed in Austin by John Ries. The analogous LLR tasks are performed by Judit Ries.

Contact

Dr. Peter Shelus (Austin)
University of Texas, Center for Space Research
3925 West Braker Lane, Suite 200
Austin, TX 78759-5321
USA

Voice: 1-512-471-7599
Fax: 1-512-471-3570
E-mail: pjs@csr.utexas.edu

Mr. Jerry R. Wiant (MLRS)
9 Lunar Cir
McDonald Obs., TX 78734
USA

Voice: 1-432-426-3668
E-mail: jrw@astro.as.utexas.edu

Metsähovi, Finland

K. Arsov, A. Raja-Halli, J. Näränen, M. Poutanen/Finnish Geodetic Institute, Finland

The Metsähovi research station was founded in the mid-1970s, and over the years it has become an essential part of the activities of the Finnish Geodetic Institute. The instrumentation of the station serves both the Institute's own research and the international scientific community. The following instruments are currently installed at the Metsähovi research station: satellite laser ranging (SLR), geodetic Very Long Baseline Interferometry (VLBI) in a co-operation with the Aalto University, GPS and GLONASS receivers, a DORIS beacon and a superconducting gravimeter. Absolute gravity is regularly measured in the gravimetric laboratory where the National reference point of gravity exists. There is also a seismometer of the University of Helsinki. Metsähovi is one of the few fundamental stations in the world where all major geodetic observing instruments are installed in the same site.

In 2006 a decision was made to purchase a modern kHz laser and a contract was made with the High Q Laser Production GmbH of Austria. The laser ordered is a diode-pumped Nd:VAN solid state laser with the pulse rate up to 2 kHz and the pulse energy > 0.5 mJ. The laser is of the same type what Graz and Herstmonceux are currently using.

At the same time, a major renovation of the 1 m Cassegrain-Mangin telescope was needed. It includes the replacement of the drive and control system as well as separation of outgoing and incoming signals. New encoder has been installed to the azimuth ring and, together with new motors, testing will start in summer 2011. The new optical solution for separating outgoing and incoming beam has been developed together with the University of Latvia in Riga and installing of the new system will start in summer 2011. With the new optics, the focal length of the telescope is reduced from the Coudé focus to the Cassegrain focus inside the telescope. Due to the reduced focal length we will lose some effective aperture, however considering the large aperture of the telescope this is acceptable. As the telescope has been disassembled, the primary mirror was recoated, the telescope mount has been leveled and a preliminary study has been made on how to best tie the telescope to the local reference frame. The aim is to install the new systems to the telescope during the year 2011 and to start testing the telescope in fall/winter 2011.

Parallel to that, work on new 2 kHz operational software is ongoing. It is tailored to our new equipment and is currently capable of dealing with 2 kHz observations frequency. Improvement in the filtering of residuals, automation in the range gate setting, time bias estimation and management as well as smart session planning is implemented. Laser control as well as telescope communication and steering are under development. Furthermore, a new FPGA based SLR controller is designed and programmed. It is implemented into our new SLR software and many time-critical tasks are incorporated into this controller. It is fully controlled by the SLR operational software. For the future a new post-processing software development is foreseen and is under planning currently.

Contact

Dr. Kirco Arsov
Finnish Geodetic Institute
Department of Geodesy and Geodynamics
P.O.Box 15
Geodeetinrinne 2
02431 Masala
Finland

Phone: +358-(0)9-2564995
Fax: +358-(0)9-2955 5200
E-mail: kirco.arsov@fgi.fi

Monument Peak CA, USA

David Carter/NASA GSFC, Julie Horvath and Scott Wetzel/HTSI
Dave McCormick, Curtis Emerson/NASA GSFC, Bob Stelmaszek/ITT, Thomas Varghese/Cybioms

Figure 12-63. MOBLAS-4 site at Monument Peak, CA

MOBLAS-4, located at Monument Peak in Mt. Laguna, California, has consistently provided SLR tracking for 27 years. During 2009 and 2010, the NASA-contractor operated station faced critical challenges and achieved great accomplishments. In February of 2010, MOBLAS-4 was able to track the Lunar Reconnaissance Orbiter (LRO) successfully and has since tracked it regularly. The tracking schedule was adjusted due to conducting three-way ranging efforts of LRO with NGSLR and McDonald Observatory (MLRS). In the fall of 2010, MOBLAS-4 completed the first simultaneous three-way ranging effort with NGSLR and MLRS and they proceeded to achieve further two-way and three-way ranging LRO missions.

In May 2009, the processor computer was upgraded, increasing the prediction and data processing times significantly. On February 4, 2010, the on-site DORIS activity was terminated due to an electromagnetic interference with a television tower adjacent to the site. MOBLAS-4 laser operations were temporarily suspended in April 2010 due to a laser safety infringement at NASA partner station MOBLAS-7 in Greenbelt, MD. After a thorough investigation and instated resolutions, laser operations resumed on May 7, 2010.

The most significant challenge overcome by MOBLAS-4 was due to the radar failure that occurred during the summer of 2007. The station operation schedule was reduced to one shift/five days a week and the usage of a mount observer was implemented. In June 2010, the failed radar unit was replaced with a unit that had previously been located at MOBLAS-7 in Greenbelt. The radar was leveled, boresighted, and successfully tested for aircraft detection. After extensive tests and verification, laser tracking operations utilizing the radar resumed on June 22, 2010, allowing the station to operate on a two shift schedule.

MOBLAS-4 is operated by Ronald Sebeny, station manager, and Theodore Doroski (shown in Figure 12-64 below). The station had the pleasure of hosting a tour for Dr. Tom Murphy and the AstroPhysics club from the University of San Diego in January 2009. The station was also able to assist Glen Sasagawa from University of California San Diego in a GPS-related project requiring GPS survey measurements. MOBLAS-4 continues to consistently track the priority satellites and remains a core ILRS station.

Figure 12-64. MOBLAS-4 staff (left to right): Ronald Sebeny and Theodore Doroski.

Contact

Dave McCormick (primary)
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Phone: 301-286-2354 (primary)
Phone: 301-377-2711 (secondary)
Fax: 301-286-0328
E-mail: David.R.McCormick@nasa.gov

Curtis Emerson (secondary)
NASA GSFC
Code 453
Greenbelt, MD 20771
USA

Phone: 301-286-7670 (primary)
Phone: 301-286-3065 (secondary)
Fax: 301-286-0328
E-mail: Curtis.M.Emerson@nasa.gov

Mount Stromlo, Australia

Chris Moore/EOS Space Systems Pty Limited, Gary Johnston/Geoscience Australia

The Mt. Stromlo Space Research Centre is a fundamental space geodesy site that currently consists of a high precision satellite laser ranging (SLR) station based on a 1m aperture telescope, and an experimental facility based on a 1.8m aperture telescope. The site is also supported by IGS GPS and IGLOS GLONASS receivers, IDS DORIS beacon, and a comprehensive local tie network.

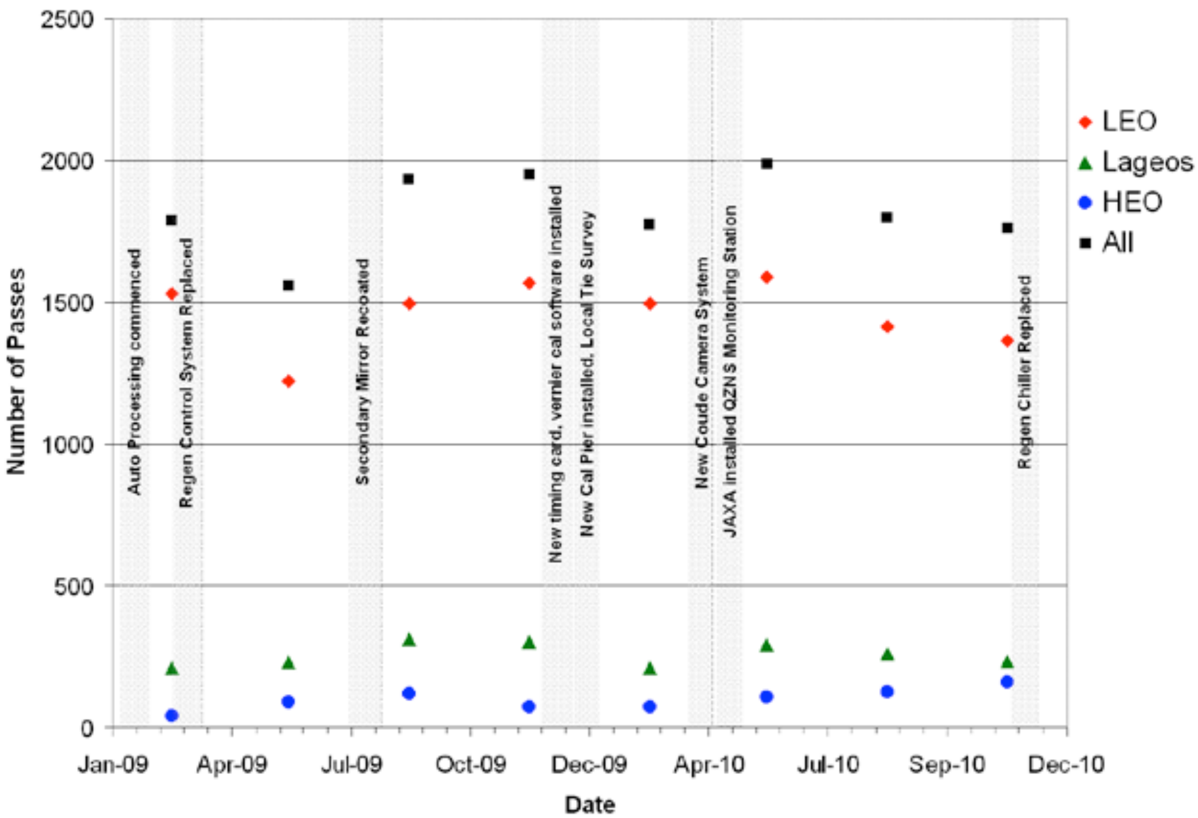


Figure 12-65. Productivity at Mt Stromlo during 2009-2010 with major events identified.

Mt. Stromlo SLR Station (STL3, 7825)

The Mt. Stromlo SLR station has now been operating continuously since December 2004 and continues to be one of the most productive SLR stations. Figure 12-65 shows the productivity that has been obtained over the period 2009 to 2010 in terms of low earth orbit (LEO), high earth orbit (HEO), and LAGEOS passes tracked.
This figure also shows a number of the major events that occurred at the station during this period. A major milestone was the transition to automated post processing early in 2009 that allowed more rapid publication of data products. The station is now routinely operated in an ‘unmanned’ mode without any significant loss of productivity. One operator provides supervisory and maintenance roles during normal business hours.
Since Q2 2010, Mt Stromlo station incorporates a new monitoring station to support tracking of the satellite constellation that will be part of the Japanese Space Agency’s Quasi Zenith Satellite System (QZSS).
Mt Stromlo Experimental Ranging Station (STRK, 7826)

The experimental facility continues to provide a research and development facility for visually tracking and ranging to space debris, the development of guide star and ablation lasers and other projects (see www.eos-aus.com for more information).

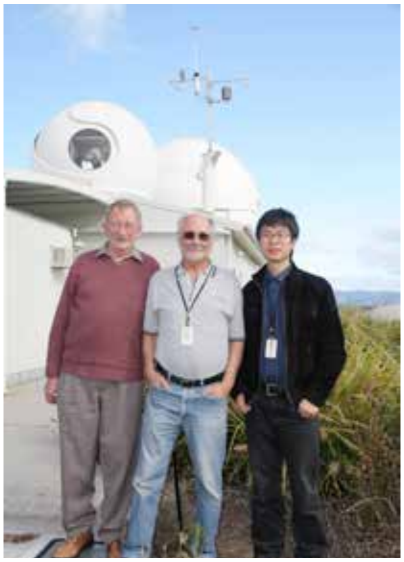


Figure 12-66. Mt. Stromlo SLR Station Manager Dr Chris Moore (C), consultant Dr John Luck (L) and operator Sihang Li (R).

GNSS

The two IGS sites at Mt Stromlo (STR1 and STR2) continue to provide a variety of GNSS data products, including a 1 Hz real-time data stream. A third GNSS antenna/receiver has been installed at the observatory on the northwest pillar. This new site STR3 is capable of tracking the Galileo satellites along with GPS and GLONASS, and is providing a 1 Hz real-time stream to the Cooperative Network for GIOVE Observation (CONGO) project Local Tie Survey

A full local tie survey was completed in 2009 including the connection to the 1.8m telescope and the new GPS mount. A report detailing the survey is in preparation.

Gravimetry

As part of the AuScope gravity program the Reynolds dome at Mt Stromlo has been refurbished into a dedicated absolute gravity comparison facility for four instruments. Commissioning of this facility has already begun. The super-conducting gravimeter continues to operate, with frequent calibration from AuScope's FG5 237 gravimeter. Continuing observations from this gravimeter extend the vertical gravity monitoring series at Mt Stromlo.

References

Woods, A. and R.E. Ruddick (2009): "The 2009 Mount Stromlo Local Tie Survey", Geoscience Australia (In preparation).

Contacts

Dr. Christopher Moore
EOS Space Systems Pty Limited
EOS Building, Mount Stromlo Observatory
Weston Creek, ACT 2611
AUSTRALIA

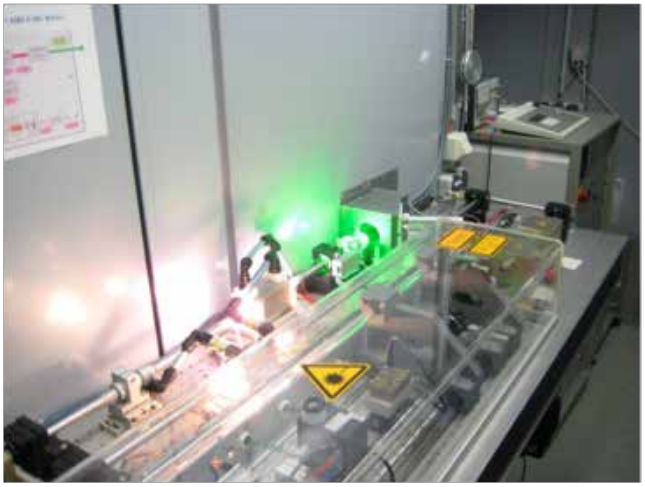
Voice: +61 2 6222-7979
Fax: +61 2 6287-2951
E-mail: cmoore@eos-aus.com

Ron Thompson
Group General Manager
Electro Optic Systems Pty Limited
Mount Stromlo Observatory
Weston Creek, ACT 2611
AUSTRALIA

Voice: + 61-2-6222-7999
Fax: + 61-2-6299-2853
E-mail: ronthompson@eos-aus.com

Potsdam, Germany

Ludwig Grunwaldt/GFZ Potsdam



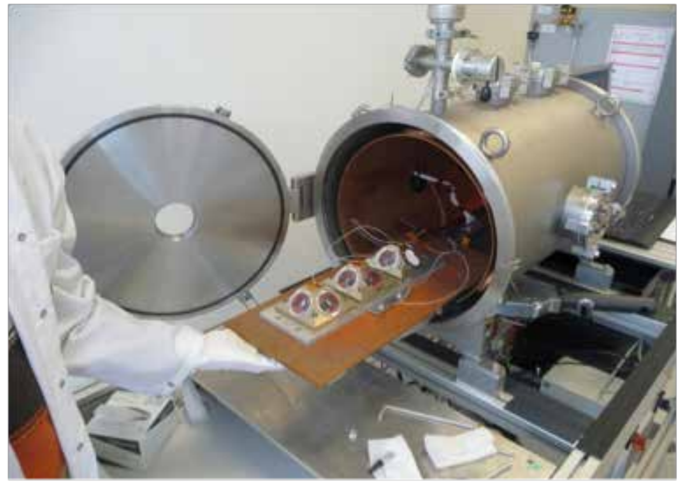


Figure 12-67: (left) Laser Transmitter of 7841
Figure 12-68: (right) LRR Arrays for Swarm Potsdam(Vacuum Test)

The system 7841 was maintained in standard operational conditions (with day- and nighttime tracking capabilities for LEOs and LAGEOS) during 2009 and 2010 and tracked a total of 3167 and 2780 passes, respectively. The higher number of passes in 2009 is mainly result of the unusually good sky conditions in spring of this year. While no substantial changes in hardware were performed, the tracking software was modified in a way to perform a fast switchover between TerraSAR-X and TanDEM-X during the close formation flight of both spacecraft. This is based on an idea by Philip Gibbs (NERC Herstmonceux).

Preparatory work for the system upgrade to kHz tracking capability was started in 2009 with the purchase and test of a Nd:YVO laser system. First indoor ranging tests demonstrated the readiness of the self-made range gate generator, which is based on the ARM-7 micro-controller.

Three low-signature laser retro reflector arrays of the CHAMP type were manufactured, tested and delivered for the ESA magnetometry mission Swarm and another one for the Spanish radar satellite PAZ. A feasibility study for a single large hollow laser retro reflector to be flown on GNSS satellites was performed and the encouraging results were reported during the ILRS workshop “SLR Tracking of GNSS Constellations” (Metsovo/Greece, September 2009. The main advantage of such a LRR is the absence of any target signature (pulse spreading) within the return signal as compared to extended multi-prism arrays, which are currently in use. This would allow for millimeter accuracy in laser ranging to satellites in the GNSS orbit by advanced SLR ground systems.

Contact

Dr. Ludwig Grunwaldt
GeoForschungsZentrum Potsdam
Telegrafenberg
D-14473 Potsdam
GERMANY

Voice: +49-331-2881733 (Office)
Voice: +49-331-2881164 (SLR station)
Fax: +49-331-2881732
E-mail: grun@gfz-potsdam.de

Riga, Latvia

Kazimirs Lapushka, Kalvis Salminsh/Astronomical Institute of University of Latvia, Yuri Artyukh/Institute of Electronics and Computer Science

Main Activities (2009-2010)

Routine tracking efforts in Riga include:

- During 2009 and 2010 a slight improvement in weather conditions was observed. In the year 2009 a total of 126 clear weather opportunities allowed the Riga SLR station to obtain 804 passes from 20 satellites, yielding a total of 954,093 data points and forming 19,378 normal points. See Table 12-5 for details.
- In the year 2010, 136 clear weather opportunities allowed the station to obtain 1,333 passes from 19 satellites, yielding a total of 949,744 data points and forming 25,062 normal points. See Table 12-5 for details.
- Main attention was concentrated on LAGEOS and LEO laser ranging. Sky conditions during the year and high signal energy losses in the telescope receiving channel seriously hampered a systematic laser ranging of the high-orbiting satellites.
- According to the satellite range bias analysis reports from Dr. Toshimichi Otsubo, Riga's calculated average per year range bias (ARB) for satellites LAGEOS-1 and -2 are as shown in Table 12-4.

Table 12-4. Average Range Bias for LAGEOS-1 and -2.

2009	LAGEOS-1	43 passes	ARB = -0.6 mm
	LAGEOS-2	49 passes	ARB = -26,7 mm
2010	LAGEOS-1	75 passes	ARB = -14.4 mm
	LAGEOS-2	57 passes	ARB = -10.2 mm

Telescope optical systems upgrade

During 2009, intensive efforts were undertaken to find an acceptable solution for a telescope transmit-receive channels separation. As mentioned in the station's ILRS report for 2007-2008, a "small blood" solution was only partially successful. Therefore significant changes in the construction of the receiver's channel optical system were designed during 2009 (see Figure 12-69. Manufacturing of new optical components and mechanical systems was made during year 2010. We are planning to test a new system in the summer of 2011.

The view of main peripheral hardware to laser telescope used during reported years is shown in Figure 12-70.

Software upgrade

The Riga SLR station is currently being upgraded with a new Windows-based data management, prediction, and on-site data processing software. The new software is designed as a client-server application for use at the station and as a 3-tier application to access part of the system functionality via WWW. Compared to the previous version, the prediction generation and on-site data processing workflow has been improved.

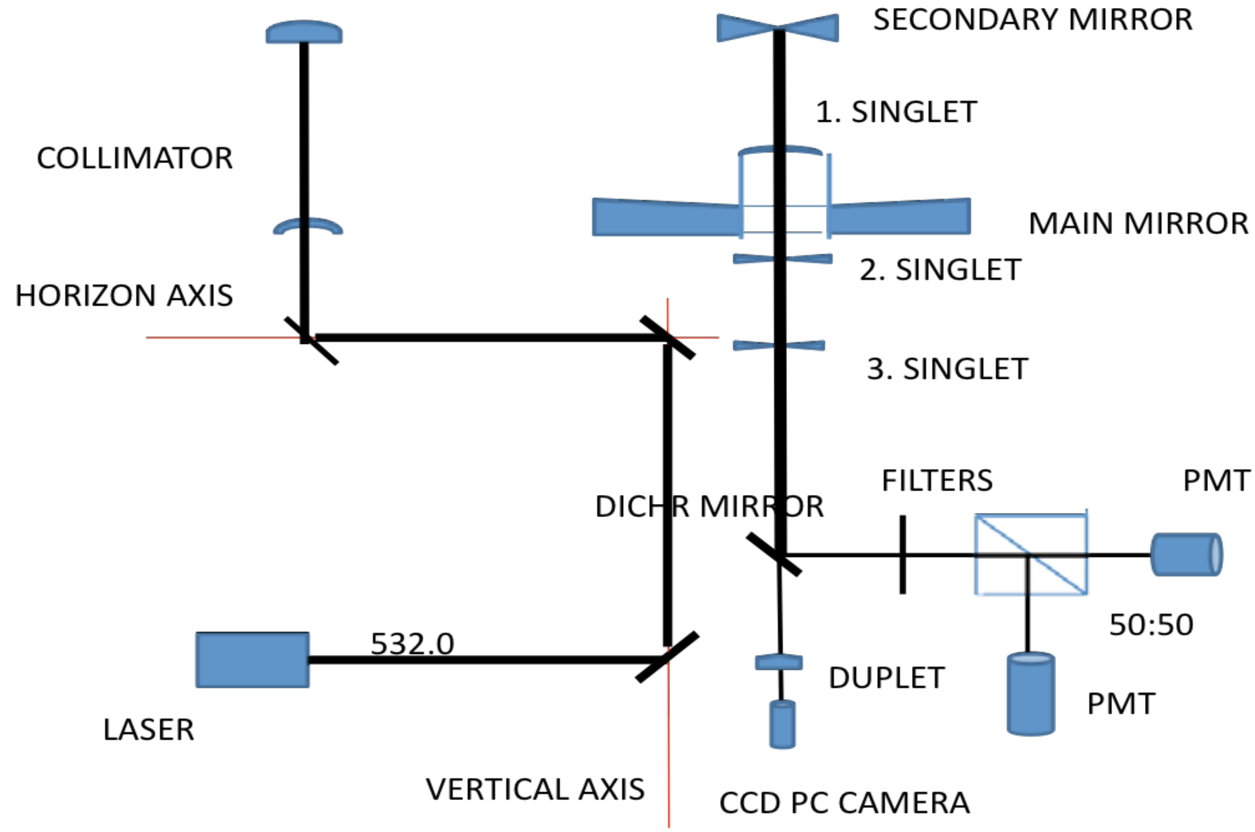


Figure 12-69. Laser telescope channels separation principle (not in scale)

Figure 12-70. Electronics for telescope drive and data registration left; "EKSPLA" Electro-optically Q-switched SBS-compressed Nd:YAG laser SL312 with pulse energy 120 mJ at 532 nm, pulse duration 150 ps (FWHM), pulse duration stability 10%, repetition rate 10 Hz, beam profile Hat Top, diameter 9 mm and divergence <0.5 mrad right.

Figure 12-71. Riga-1884 Station staff. From left: A.Meijers, K. Dzenis, K. Pujats, J. Sharkovskis, K. Salminsh, K. Lapushka

Event Timers group activities

The research group from IECS continued its activities in the area of Event Timer development. In particular, the Event Timer A033-ET has been developed as an advanced version of the previous model A032-ET, well known in SLR community. In terms of functionality and operation speed, the A033-ET and A032-ET are closely related instruments, but the new model differs by considerably improved precision of time measurement (~2 ps RMS). Since 2010 the A033-ET is commercially available.

Figure 12-72. Event Timer A033-ET

Generally the A033-ET performance meets the basic requirements of most SLR applications, potentially supporting millimeter ranging precision at a repetition rate of up to 3-5 kHz. Nevertheless, R&D activity directed to the further improvement of Riga Event Timers (such as their reliability, friendliness and hardware simplicity) continued.

Table 12-5. RIGA-1884, Years 2009-2010 Data Production

SATELLITE	2009		2010	
	#passes	#NPts	#passes	#NPts
AJISAI	57	1,138	107	1,911
ANDE-C	2	24	-	-
ANDE-P	1	11	-	-
BLITS	12	87	39	242
CHAMP	32	509	11	167
COMPASS-1M	1	12	-	-
CRYOSAT-2	-	-	95	1,660
ENVISAT	139	3,627	140	2,630
ERS-2	155	3,885	153	2,895
ETALON-1	2	19	4	36
GOCE	7	89	26	392
GRACE-A	18	559	68	1,483
GRACE-B	23	655	70	1,277
JASON-1	86	2853	153	4,057
JASON-2	94	2975	169	4,604
LAGEOS-1	43	610	75	744
LAGEOS-2	49	610	57	678
LARETS	-	-	38	254
STARLETTE	41	577	41	443
STELLA	15	162	41	406
SOHLA	4	43	-	-
TANDEM-X	-	-	19	468
TERRASARX	23	933	27	715
TOTAL:	804	19,378	1,333	25,062

Contact

Dr. Kazimirs Lapushka
Astronomical Institute of University of Latvia
Blw. Rainis 19
Riga, LV-1586
LATVIA
Voice: 371 67611984
E-mail: riglas@lanet.lv

Dr. Yuri Artyukh
Institute of Electronics and Computer Science
14 Dzerbenes Str., Riga, LV-1006
LATVIA
Voice: 371 67558184
E-mail: artyukh@edi.lv

San Fernando, Spain

Jorge Gárate, José Martín Dávila, Manuel Quijan, Luis M. Cortina/Real Instituto y Observatorio Armada

About 6,500 successful satellite passes were tracked by the Spanish San Fernando Naval Observatory Satellite Laser Ranging station (SFEL: 7824), from the beginning of 2009 to the end of 2010. About 78,000 normal points, corresponding to more than 5,000 LEO's, about 600 LAGEOS, and 150 high satellites passes, were delivered to the ILRS Data Centers. Data quality remained stable, about 15 millimeters for single shot rms, and 3 to 4 millimeters for the normal points rms over LAGEOS passes, in accordance with the SLR Global Performance Report Cards.

This observational effort is possible by the work of five permanent system operators who cover mainly the night tracking spans. We must also acknowledge the invaluable support of the San Fernando Naval Observatory technical staff, represented by other five civil technicians plus five Spanish Navy petty officers, who filled the observation time gaps. It should be also remarked that the technical team was completed in 2010, since a new engineer, Luis M. Cortina, joined us.

An important milestone was reached in July 2009. Since July 6th to 18th local ties between the SLR and the IGS permanent GPS antenna receiver reference marks were surveyed. Classical geodetic observations were made by a Spanish National Geographic Institute (Instituto Geografico Nacional de Espa a: IGNE) working team. Some other geodetic references located in the Observatory, as the second IGS Antenna Reference mark (ROAP) which was included in the IGS Time Transfer Experiment, were also integrated in the investigation.

The objective of the survey was to verify old values, modifying them as needed, and to complete the information linking not only these three reference points together but also linking them with other points to allow further reviewing: there are a number of survey monuments and pillars within the observatory to be used as reference marks for the local ties determination through terrestrial connections.

Local ties determination at ROA is actually complicated due to the situation of the main points. The SLR station is located inside the closed dome at the top of the Observatory main building while the intermediate reference marks are placed on the terrace. This configuration means that there are large height gradients, and it is also difficult to get a direct line of sight from the reference points located on the terrace to the SLR telescope reference point. Furthermore, to look for the telescope axis cross point is not an easy task due to the reduced dimensions of the SLR telescope dome. Lastly, a background of scattered buildings of very different heights and large trees that hinder the visual intermediate between them seem to be not the best scenario to ensure uncertainty improvements.

Regardless, surveying results were delivered as a contribution to the International Reference Frame Research Working Groups.

On January 1 2010, a new Research Action funded by the Spanish Government began. It is entitled "Satellite Laser Ranging Automation and accuracy improvement" ("Automatización y mejora de la precisión de las observaciones láser de satélites"). The objective of this action is to improve the satellite tracking accuracy, in particular laser observations on highest satellites. This objection should be obtained by improving the pointing ability when acting on the telescope mount movement controls. Furthermore, an automation increase has also been proposed.

Improvements in the telescope movement control should produce a better tracking stability. In such a way, tracking losses would be minimized. On the other hand, an increase of the system processes automation should produce a decreasing dead time span since the satellite is rising over the horizon, until the effective tracking begins. As a consequence, SLR station performance must be enhanced because it will obtain a larger number of returns, and a better accuracy in the tracking results.

A remarkable additional benefit from automation is to invest the ROA SLR station with tracking swap ability: GNSS and other HEO tracking lasts some hours, because the long time the satellite is over the station horizon. Usually some lower satellite flies over there as well. The HEO tracking might be interrupted to track a lower satellite. Once this tracking is over, the system should recover the higher satellite. In practice this means beginning a new acquisition procedure. Telescope pointing improvement, as well as increased automation, would make this swap procedure feasible.

The research action is on its way. The different options for the movement control system have been studied, and after a careful comparison process, new tools have been purchased. The implementation on the system is scheduled for the period 2011-12.

At the beginning of 2010, systematic errors in the pressure measurements associated with the satellite ranging were uncovered after the comparison of some different pressure time series obtained from different barometers installed at the observatory. Once the error law was calculated, it was delivered to the ILRS Analysis Centers. The problem was reported in the Data Formats and Procedures Working Group meeting in Vienna, on May 6, 2010.

In order to promote the San Fernando SLR activities, presentations were given at different Spanish Universities. For example, on March 24, 2009, the conference titled Satellite Laser Ranging was given at the Technical University of Madrid, and on June 22, 2009, a new presentation entitled San Fernando Naval contribution to Satellite Geodesy: SLR & CGPS was shown at the University of Zaragoza.

Contact

Jorge Garate
Real Instituto y Observatorio Armada
Sec. Geofísica, C. Cecilio Pujazón S/N
11110 San Fernando, Cádiz
SPAIN

Voice: 34-956-545595
Fax: 34-956-599366
E-mail: jgarate@roa.es

San Juan, Argentina

Weidong Liu, Zhiqiang Yin, Yanben Han /National Astronomical Observatories, CAS (NAOC); E. Actis, E. Alonso, R. Podesta, A. Pacheco/Observatorio Astronómico Félix Aguilar (OAFA) of the Facultad de Ciencias Exactas, Físicas y Naturales (FCEFN) of the Universidad Nacional de San Juan (UNSJ)

Introduction

The San Juan SLR station, which is working under the cooperation in astronomy between NAOC and UNSJ, has operated five years since the end of February 2006. The observations of the SLR station have made excellent contributions to the ILRS. These results are mainly from the efforts of the station staffs of NAOC and OAFA and the good weather of San Juan. In the end of 2009, the San Juan SLR station began to upgrade the SLR system for daylight and kHz tracking through the support of the project “Cooperation observation and research of SLR between China and Argentina”, and the SLR system upgrades will be completed in 2012. In July of 2009, the dean and vice-dean of the FCEFN and the director of OAFA of UNSJ visited NAOC at the invitation of the director of NAOC. Both sides reviewed the developments and achievements of the collaborations in astronomy in the past years, believe that the development of the cooperation will make more significant contributions to the development of astronomy in the world, and signed the cooperation agreement on SLR during 2010 to 2020 and the memorandum of understanding for cooperation on astronomical observation and research in the future.

Figure 12-73. Ceremony for signing agreements of cooperation on astronomy between NAOC and UNSJ.

Operations

The San Juan SLR system (station 7406) was maintained in good working condition and acquired 6,818 passes and 88,848 normal points on all SLR satellites during 2009. However, the station experienced some problems in 2010; examination and maintenance of the power supply of the observatory led to a halt in observations for over a month. A variety of equipment failures began to appear, the supply of dichloromethane encountered a serious problem, and bad weather conditions hampered laser ranging activities. These events caused a significant reduction in the observation days. The SLR equipment failures were solved in 2011 and the system is now experiencing normal operations. The observational results of the station during 2009 and 2010 are shown in Figures 12-74 and -75.

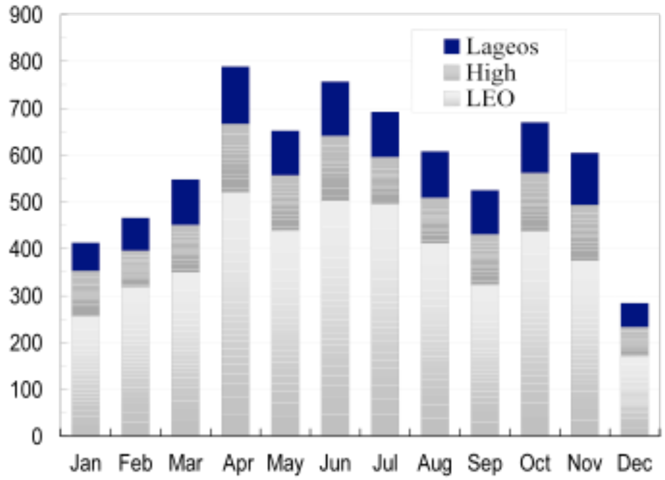


Figure 12-74. Number of passes per month in 2009

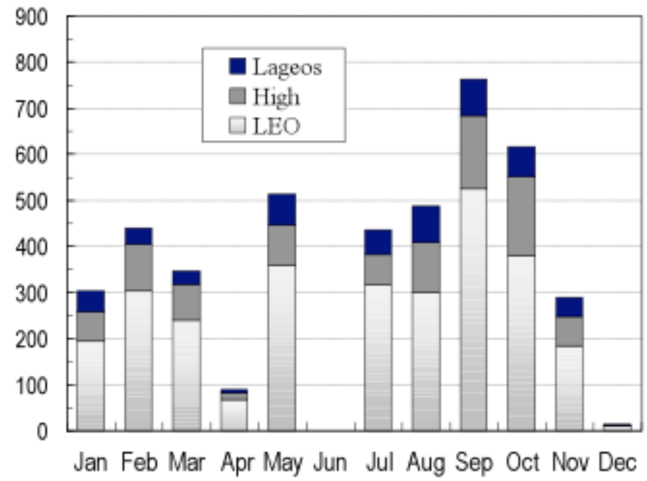


Figure 12-75. Number of passes per month in 2010

System Upgrades

In 2010, a company in China started to make a new kHz laser for the SLR system, and the laser should be completed in 2011. The laser will then be used for three-month trial observation at the Changchun station. Control and operating system upgrades are under development through cooperation between NAOC and the Changchun station. These upgrades include: an A033-ET event timer for kHz operations, a set of pulse distribution module (designed by the Graz station staff) for the start and C-SPAD stop pulse and their output represented by NIM logic Pulse for A033-ET, and a set of steel grating encoders to be used in place of the old AZ-EL inductosyns. The system integration and tests are being done through cooperation with the Changchun and Beijing stations. After completion of the system preparation, the equipment will be delivered to the San Juan station and the upgrades will be completed in 2012.

Future Developments at the San Juan Station

We plan to realize routine observation of kHz and daylight tracking in 2012. In the end of 2010, NAOC and UNSJ approved a 40-meter radio telescope cooperative project (VLBI). We hope the San Juan station will become an integrated observational station with SLR, GPS, and VLBI in the coming years.

Contacts

Prof. E. Actis
Prof. E. Alonso
Observatorio Astronómico Félix Aguilar
Benavídez 8175 – Oeste
5407 – Marquesado
San Juan
ARGENTINA

E-mail: actis2003@yahoo.com.ar
E-mail: esteralons@hotmail.com
Voice: +0054-264-4231467

Prof. Weidong Liu
Zhiqiang Yin,
You Zhao
Jinzeng Li
National Astronomical Observatories, CAS
A20 Datun Road
Chaoyang District
100012 Beijing
CHINA

E-mail: wdliu@bao.ac.cn
E-mail: yinzhq@bao.ac.cn
E-mail: youzhao@bao.ac.cn
E-mail: ljz@bao.ac.cn
Voice: +0086-10-64888730

Shanghai, China

Zhang Zhongping/Shanghai Astronomical Observatory, CAS

During 2009-2010, the Shanghai SLR station has continued to update the system for routine satellite tracking kHz repetition rate laser at nighttime and in daylight. Since October 2009 the station has been routinely performing with a kHz repetition rate at nighttime. In August 2010, daylight tracking with the kHz laser was successfully implemented to LEO satellites. Meanwhile, several laser ranging measuring experiments were also done, such as Pico-Event Timer measurements, uncooperative targets laser ranging, and dual SLR system ranging to satellites.

KHz SLR Measurement

The Shanghai SLR station obtained 1,526 and 2,658 passes in 2009 and 2010 respectively. The ability and stability of laser ranging observations were obviously improved after adopting the kHz SLR system. On August 14, 2010, the Shanghai SLR station firstly ranged to the Compass GEO/IGSO satellites with kHz repetition rate, 1W output power laser at the slope range of 3,8800 km and 3,6000 km respectively.

After realizing routine kHz SLR measurements at nighttime, the Shanghai station concentrated on kHz daylight laser tracking and in August 2010 obtained kHz laser returns from the LEO satellites in daylight. We have been updating the receiving system in order to range to LAGEOS and HEO satellites.

Pico-Event Timer

The Shanghai SLR station imported a new Pico-Event Timer from Czech Technical University in Prague with a resolution of less than 1 ps. Firstly we used the high precision event timer to measure the calibration and the precision (about 2 ps). In order to take full advantage of the high measuring precision, we are developing functions of the event timer to measure satellites in the kHz SLR system for millimeter precision laser ranging.

Uncooperative Targets Laser Ranging

In 2010, the Shanghai SLR station upgraded the experimental measuring system of uncooperative targets laser ranging by using the stable high power laser with the output power of 10W, improving the capability of servo-tracking, adopting Two Line Elements (TLE) prediction. Through the above upgrades, the measurement efficiency of the laser ranging system is obviously increased and the measuring maximum distance of targets is about 1,200km. We have gained support for further studies of un-cooperative space target ranging technology.

Dual SLR System Ranging to Satellites

Using two SLR systems with an aperture of 60 cm and 35 cm at the Shanghai SLR station simulates the ground terminal and the spacecraft terminal respectively to investigate one-way interplanetary laser ranging technology; the distance between the two measuring systems is about 70 m. The aperture of the 60 cm SLR system emits the laser pulse and the aperture of 35 cm telescope receives returns from satellites. The laser transmitting path to satellites is defined by the 60 cm aperture; the 35cm aperture defines the laser transmitted path to deep space terminals. The measurements for satellites with retro-reflector arrays were performed in December 2010 and received returns from Ajisai, LAGEOS, and Compass-M1; the simulated equivalent interplanetary distance reaches to Jupiter.

Onboard Laser Time Transfer Experiment

Shanghai Observatory has preformed the LTT (Laser Time Transfer) experiment between the Compass-M1 satellite and the ground station in 2007. In July 2010, another improved LTT payload onboard the Compass IGSO1 satellite was launched with an orbital altitude of 36,000 km. Based on the aforetime experiment, some improved technologies have been applied in the new LTT payloads, such as one gate mode adopted, two different FOV used, narrower filter etc. At the end of August 2010, the first measurement experiment was implemented successfully by using a one-meter laser ranging system; the clock difference between satellite and ground was obtained. Compared to the LTT experiment of the Compass-M1 satellite, the performances of the new LTT payload on Compass IGSO1 and the laser ranging system on the ground are more advanced. The LTT measurement was also performed much easier. Additional LTT experiments between satellite and ground, and time synchronization for different stations on the ground in the Chinese regions or beyond China will be carried out in future.

Figure 12-76. The members of Shanghai SLR station from left to right: Meng Wendong, Li Pu, Chen Juping, Zhang Haifeng, Qin Si, Shi Hailong, Cao Guangzhong, Wu Zhibo, Zhang Zhongping.

Figure 12-77. High power laser beams

Contact

Zhang Zhongping
Shanghai Astronomical Observatory
Chinese Academy of Sciences
80 Nandan Road
Shanghai 200030
CHINA

Voice: 86-21-64696290
E-mail: zzp@shao.ac.cn

Simeiz, Ukraine

A.I. Dmytrotsa, I.V. Artemov, D.I. Neyachenko, S.V. Filikov, U.A. Martyshin/SRI Crimean Astrophysical Observatory

Abstract

Unfortunately, we were unable to replace the old laser with a new unit as planned. However, the station continues to work in a stable fashion and the quantity of satellite's passes did not fall below 1000. Software upgrades for new formats (CPF and CRD) have been completed.

Figure 12-78. SLR-1873. General view.

Current Status

As we informed earlier, the basic our problem with the Simeiz laser ranging system is the old laser. The laser is constructed on an old element base with which we continue to have repair problems. Unfortunately, we could not replace the old laser with a new unit as previously planned. These problems were why we were unable to reach the ILRS required level of ranging of 1500 passes.

In 2010, we worked on a new model of the master generator with a shorter impulse [1]. This system has had a small improvement in our results. The station also uses a new external target for system calibration.

Current Goals

Modernization of the Simeiz SLR station proceeds:

- Repair, restore or change old laser transmitter.
- Modernization of optical schemes.
- Start implementation of the new time registration and gate generator.
- Continue processing GPS data with GAMIT/GLOBK.

System Configuration

Element	Description
Mount	Alt-Az. 1m mirror
Angular encoders	FARRAND controls, 0.4”
Time interval counter	SR620
PMT	H6533
Time & Freq standard	TC-74, sec. from GPS.
Laser	350 ps, 5Hz. (18 years old)
Software	GUI in JAVA, server in C++, low-level modules in C, Linux OS.
Ephemerides	CPF, (in F77)

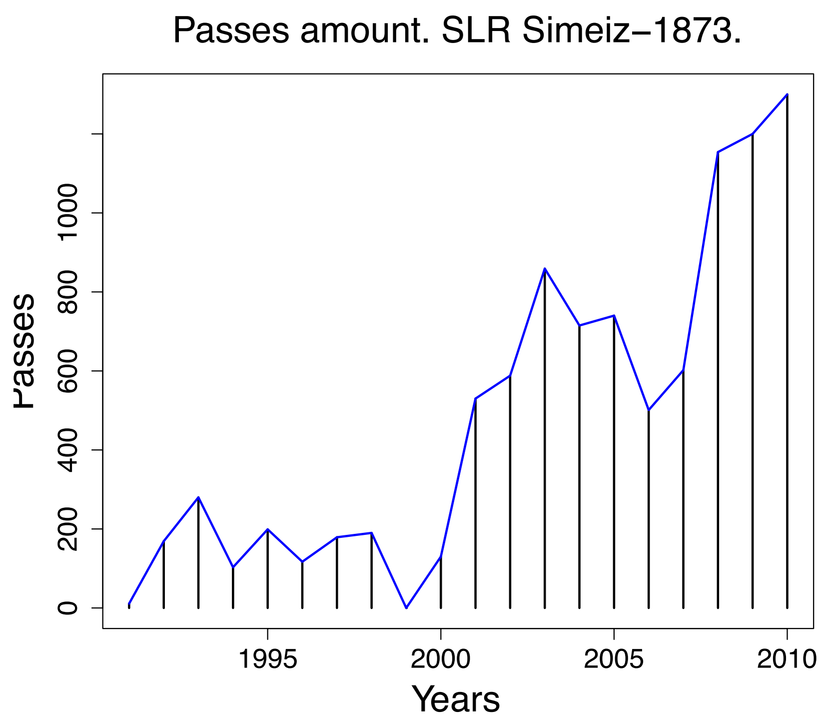


Figure 12-79. Amount of satellite laser ranging data from 1991 to 2010.

Historical dates

- Regular satellite laser ranging started in our observatory in 1976 as an INTERKOSMOS station with a laser system installed by K. Hamal on a KRIPTON telescope.
- In 1988 the Crimean Astrophysical Observatory installed a new station (near the old station).
- Co-locations with the IFAG (now BKG) MLTRS system were conducted in 1991.
- A modernization program was undertaken in 2000 under a CRDF grant.
- A permanent GPS receiver has been operating near "Simeiz-1873" since 2000.
- In 2004 the GPS receiver became an IGS site "GPS-CRAO".
- 2008 first year Simeiz obtained 1000 SLR passes per year.
- In 2009-2010 completed implement of new ILRS formats (CPF and CRD) in 2009-2010.
- In 2010, work on new master generator with shorter impulse.

References

И.В. Артемов , Д.И. Неяченко,, А.И. Дмитроца, С. Филиков, Ю. Мартышин Повышение эффективности сжатия импульса неодимового лазера.// Изв.Крымск.Астрофиз.Обсерв. - 2010 Рік.- Том.~106, No 1.-~С.~148-154.
(I.V. Artemov, D.I. Neyachenko, A.I. Dmytrotsa, S. Filikov, U. Martyshin Increase of efficiency of compression of an impulse of the laser.// Izv. Crimean Astrophys. Observ – 2010, Vol. 106, #1, P.148-154)

Contact

A.I. Dmytrotsa
SRI Crimean Astrophysical Observatory
Nauchny, Crimea, 334413
UKRAINE

Email: dmytrotsa@gmail.com
Email: simeiz@mail.ylt.crimea.com

Tahiti, French Polynesia

Jean-Pierre Barriot, Geodesy Observatory of Tahiti, University of French Polynesia

Figure 12-80. MOBLAS-8 at the Outumaoro University Campus, near Papeete, Tahiti

MOBLAS-8, located at the Outumaoro University Campus, near Papeete, Tahiti, has consistently provided SLR tracking from 1997, despite its remote location causing high operating costs (custom fees, electricity bill), and insufficient staffing.

Crew:

- Jean-Pierre Barriot (Head),
- Yannick Vota (technician)
- Laurent Mercier (technician)
- Youri Verschelle (technician)

Principal events 2009-2010:

- 2009:

- MPACS instability: from 03/03 to 06/03 (1 week)
- MPACS power supply failure: 26/03 (1 day)
- Dual power amplifier failure: from 31/03 to 19/11 (about 8 months)
- Trip of Dennis McCollums in October 2009 to fix the problem
- New laser chiller installation

- 2010:

- 5370A HP counter failure: from 11/02 to 09/03 (1 month)
- Air conditioning failure (oscillator and amplifier laser heads were wet because of the condensation): 26/03 (one day)
- Elevation power amplifier failure: from 07/04 to 12/04 (one week)
- 5370A HP counter failure: from 27/04 to 25/06 (2 months)
- Power amplifier failure: from 16/07 to 29/09 (2 months)
- Elevation pointing unstable: 26/10 (one day)

Contact

Jean-Pierre Barriot (primary)
OGT/UPF
BP 6570
Tahiti, Faaa 98702
FRENCH POLYNESIA

Voice: 689-803-814 (primary)
Voice: 689-290-659 (secondary)
Fax: 689-803-804
E-mail: jean-pierre.barriot@upf.pf

Yannick Vota (secondary)
OGT/UPF
BP 6570
Tahiti, Faaa 98702
FRENCH POLYNESIA

Voice: 689-710-707 (primary)
Voice: 689-241-443 (secondary)
Fax: 689-803-842
E-mail: yannick.vota@upf.pf

Tanegashima, Japan

Anne Mori, Shinichi Nakamura, Ryo Nakamura/Flight Dynamics Division, JAXA

Introduction

Japan Aerospace Exploration Agency's (JAXA) Satellite Laser Ranging system called "GUTS-SLR" (GMSL, Tanegashima), was completed in the spring of 2004. The GUTS-SLR is located in Tanegashima Island, where the Japanese launch site is also located. The GUTS-SLR is operated by remote control from the Tsukuba Space Center (TKSC), approximately 1100 km away from SLR station. Routine SLR operations began on September 1st, 2004.

Facilities/Systems

GUTS-SLR is capable of ranging to various satellites, from low-earth-orbiting satellites to geostationary satellites. The ranging accuracy of the GUTS-SLR system evaluated by single-shot RMS is less than 10 mm for the LAGEOS satellite and less than 20 mm for ETS-8 (JAXA geostationary satellite). The GUTS-SLR station is operated almost automatically according to the predetermined sequence. An operator only needs to turn on/off the initial power supply, manually operate the initial acquisition when the orbit prediction has an error, and perform maintenance on the system regularly. An operational plan for the whole GUTS system is organized by the Master Control and Operation Planning Subsystem called COPs. COPs also monitors operational conditions of each subsystem. In 2010, as part of the large-scale maintenances, the mirrors except the primary one were recoated. After the maintenances, the position of GUTS-SLR was precisely re-measured for the first time since the completion.

Figure 12-81. Tanegashima station

Current Activities

GUTS-SLR has tracked various satellites, from low-earth-orbiting satellites to geostationary satellites. GUTS-SLR successfully performed the campaign for High Accuracy Clock (HAC) Experiment, one of the main experiments of ETS-8, which was the first time for JAXA to successfully track a geostationary satellite using SLR. HAC experiments were finished in 2010. GUTS-SLR is now conducting the campaign for the QZS-1 launched in Sep. 2010.

Contacts

Shinichi Nakamura — E-mail: nakamura.shinichi@jaxa.jp
Ryo Nakamura — E-mail: nakamura.ryoh@jaxa.jp
Anne Mori — E-mail: morie.an@jaxa.jp
Voice: +81-50-3362-4798/7031/7062
Fax: +81-29-868-2990

Flight Dynamics Division
Consolidated Space Tracking
and Data Acquisition Department
JAXA
JAPAN

Wettzell, Germany

Guenther Herold, Pierre Lauber, Ulrich Schreiber/BKG

From 2009 onwards a number time of transfer experiments were carried out repeatedly in Wettzell. Apart from observing the Jason-2 satellite including the T2L2 package, developed by CNES and the Observatoire de Cot Azur (Grasse, France) a feasibility study for the European laser time transfer experiment on behalf of EADS/Astrium has been designed and built (Schreiber et al. 2010). Both concepts are based on a combination of two-way and one-way SLR. Standard SLR range measurements were taken at the Wettzell station and, using the satellite on-board clock, the epochs at the arrival of the laser pulses at the satellite were obtained. For this type of measurement, it was required that the new CRD format of the ILRS was implemented, because a resolution of the start epoch at the level of picoseconds is required. Using the combined SLR-data from both, the WLRS and the satellite signal arrival epoch measurements, clock offsets and drifts between the timescales can be calculated with high resolution. In order to perform a similar time transfer experiment on the International Space Station (ISS), a significant reduction of mass of the space segment was required. This was achieved by sharing the timer with the microwave time comparison link (TWSTFT) and by simplifying the detector concept. The engineering model of the space segment is currently under construction. Furthermore the WLRS contributed to the NASA Lunar Reconnaissance Orbiter (LRO) one-way ranging effort, following the formal acceptance as a ranging station by NASA.

In March 2009, a new detector (Photec PMT-MCP 210) was qualified for SLR operations and integrated into the WLRS. Its high quantum efficiency, at 532nm and increased bandwidth, promises improved ranging performance. Furthermore, together with the GM10-50B gating module, the installation could be simplified over the earlier setting. An Ortec 9327 discriminator performs the analog to digital conversion.

Improving the in-sky-safety of the WLRS was a major action item for 2009. The implementation of the Honeywell Laser Hazard Reduction System (LHRS) commenced in 2009 (Figure 12-82). Recently, we also integrated a secondary aircraft transponder receiver system as an additional safety system. Detected aircraft are plotted over a skyplot of satellite tracks in order to identify potential hazards. The top right corner of Figure 12-83 shows this feature.

Between November 2009 and July 2010 a major refurbishing of the WLRS telescope drives took place. Motors, encoders, hydraulics and control system software were replaced. The final tests showed encouraging operations of the WLRS. After resuming operations, developments for an improved T/R-switch started. WLRS currently cannot track very low altitude satellites because of limitations of the T/R system at repetition rates at or below 10Hz. By increasing the repetition rate to 20Hz this limitation can be overcome. The new T/R switch design is in an advanced state but still a work in progress. At the same time, a system to control the epoch of laser fire has been implemented.

Another ongoing project is the extension of the SLR control software towards an automatically tracking software package, which can handle both SLR systems in Wettzell. The advantages are easy portability to other SLR systems and the capability of handling up to 1kHz laser pulse repetition rates. A slightly adapted version that works on the WLRS (screenshot shown in Figure 12-83) is currently operational. The new system uses the CPF predictions, which already include the Earth orientation parameters (EOP). The new Consolidated Laser Ranging Data (CRD) format is now generated in both the old and new WLRS control system software.

Figure 12-82: Honeywell LHRS at WLRS

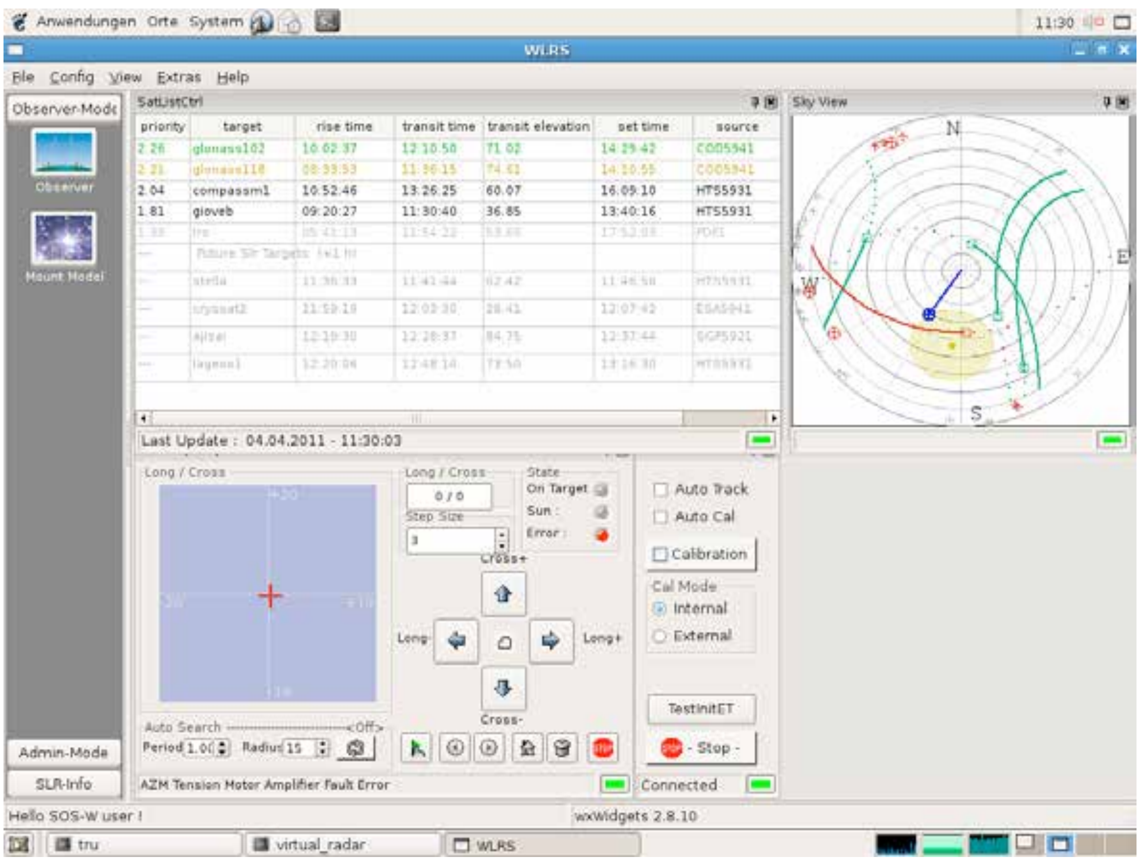


Figure 12-83. Screenshot of WLRS-software.

In the near future, the software upgrade will be used routinely. There are also efforts to resume the LLR measurements at a laser wavelength of 532 nm and the fundamental wavelength of 1064 nm.

References

Schreiber et al. 2010: K. U. Schreiber, I. Prochazka, P. Lauber, U. Hugentobler, W. Schäfer, L.Cacciapuoti, and R. Nasca, "Ground-Based Demonstration of the European Laser Timing (ELT) Experiment", IEEE TUFFC, 57, 3, 728 - 737, (2010)

Contact

Guenther Herold — E-mail: herold@fs.wettzell.de
Pierre Lauber — E-mail: lauber@fs.wettzell.de
Ulrich Schreiber — E-mail: ulrich.schreiber@bv.tu-muenchen.de
Bundesamt für Kartographie und Geodäsie
Fundamentalstation Wettzell
Sackenrieder Str. 25
D-93444 Kötzting
GERMANY

Yarragadee, Australia

Vince Noyes/EOS Space Systems Pty. Ltd.

General

A total of 13,957 passes were tracked during 2009 that produced 264,206 normal points and during 2010 this increased to 16,362 passes with 281,879 normal points. Yarragadee has continued to increase its data yield over the previous reporting period and maintain the top global position for total data collected.

New satellites successfully tracked during the report period included QZS-1, TanDEM-X, SOHLA-1, PROBA-2, ANDE Castor and Pollux, CryoSat-2, BLITS, GOCE, and LRO-LR.

Yarragadee staffing levels increased to eight when two new technicians joined us in May 2010 to support the growing aerospace precinct.

Figure 12-84. MOBLAS-5 SLR station staff: kneeling, left to right Peter, Bargewell and Vince Noyes; standing, left to right, Jack Paff, Brian Rubery, Randall Carmen, Dave Essers, John Colley; inset: Peter Thomas.

SLR System Upgrades

The laser and detection system was upgraded in June 2010. The upgrades included: a new laser table, a saturable absorber (to replace the dye cell system), a new laser chiller, and a new Photek MCP. The system was also upgraded in October 2009 to be capable of 10Hz ranging. The maser for VLBI came on-line in 2010 and became the prime 10 MHz reference for LRO-LR in May.

Geoscience Australia conducted a complete local tie survey mid July 2010.

Guest Equipment Upgrades

The 12m VLBI antenna was constructed in 2010 and most of the electronics installed.

Future Plans for the Site

The VLBI2010 installation nears completion and will be observing in the first half of 2011. The Midwest Space Communications Facility (of which the Yarragadee Geodetic Observatory is part) continues to grow and the newest ground station, which is owned and operated by the Swedish Space Corporation, will be operational in mid 2011.

Contacts

Vince Noyes
EOS Space Systems Pty Limited
P.O. Box 137
Dongara, Western Australia 6525
AUSTRALIA
E-mail: moblas@midwest.com.au

Ron Thompson
Electro Optic Systems Pty Limited
111 Canberra Avenue
Griffith ACT 2603
AUSTRALIA
Voice: + 61-2-6222-7999
Fax: + 61-2-6299-7687
E-mail: ronthompson@eos-aus.com

Zimmerwald, Switzerland

Adrian Jäggi, Martin Ploner, Johannes Utzinger, Marcel Prohaska, E. Pop, W. Gurtner/Astronomical Institute of Bern

In the 2009 and 2010 period the experiences with the 100 Hz Nd:YAG system installed in 2008 were consolidated for routine operations. The design of the system enables a high flexibility in the selection of the actual firing rate and epochs by adjusting the pulse rate between 90-110 Hz. An additional decimation may be achieved by means of a pockels cell. Together with pulse energies of about 8 mJ at 532 nm, synchronous operation in one-way laser ranging experiments to spaceborne optical transponders is possible. As the second non-US station, Zimmerwald successfully ranged to the Lunar Reconnaissance Orbiter (LRO) for the first time on 28 July 2009.

Figure 12-85 shows the number of observed satellite passes in the 2009 and 2010 period. Weeks with a top performance, e.g., between 6th and 12th September 2009 with a total of 396 observed satellite passes, demonstrate the outcome under optimal weather conditions. The gap from December 2009 to January 2010 was caused by a relatively long service intervention. Damaged optical parts of the laser system were replaced and parts of the control electronics had to be reconfigured.

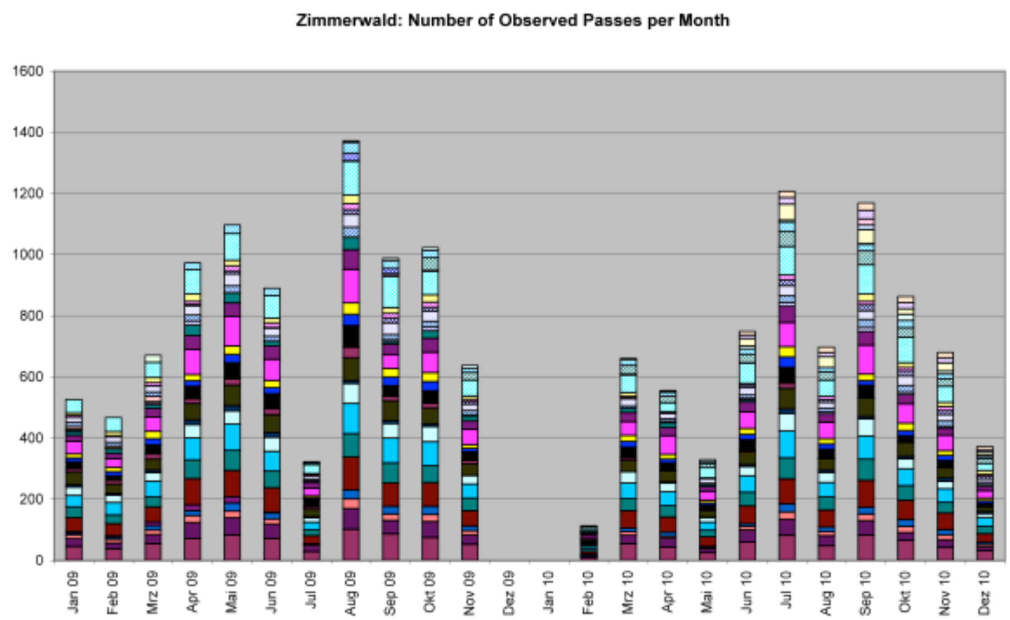


Figure 12-85: Number of observed passes per month in the 2009 and 2010 period.

Zimmerwald significantly contributed to new and advanced concepts and procedures within the ILRS, e.g.,

- one-way ranging to the LRO satellite in synchronous mode
- regular tracking of all satellites at high orbital altitudes, e.g., all GLONASS satellites according to the ILRS priority list
- regular tracking of satellites at very low orbital altitudes, e.g., the GOCE satellite, which was tracked by Zimmerwald as the first European station

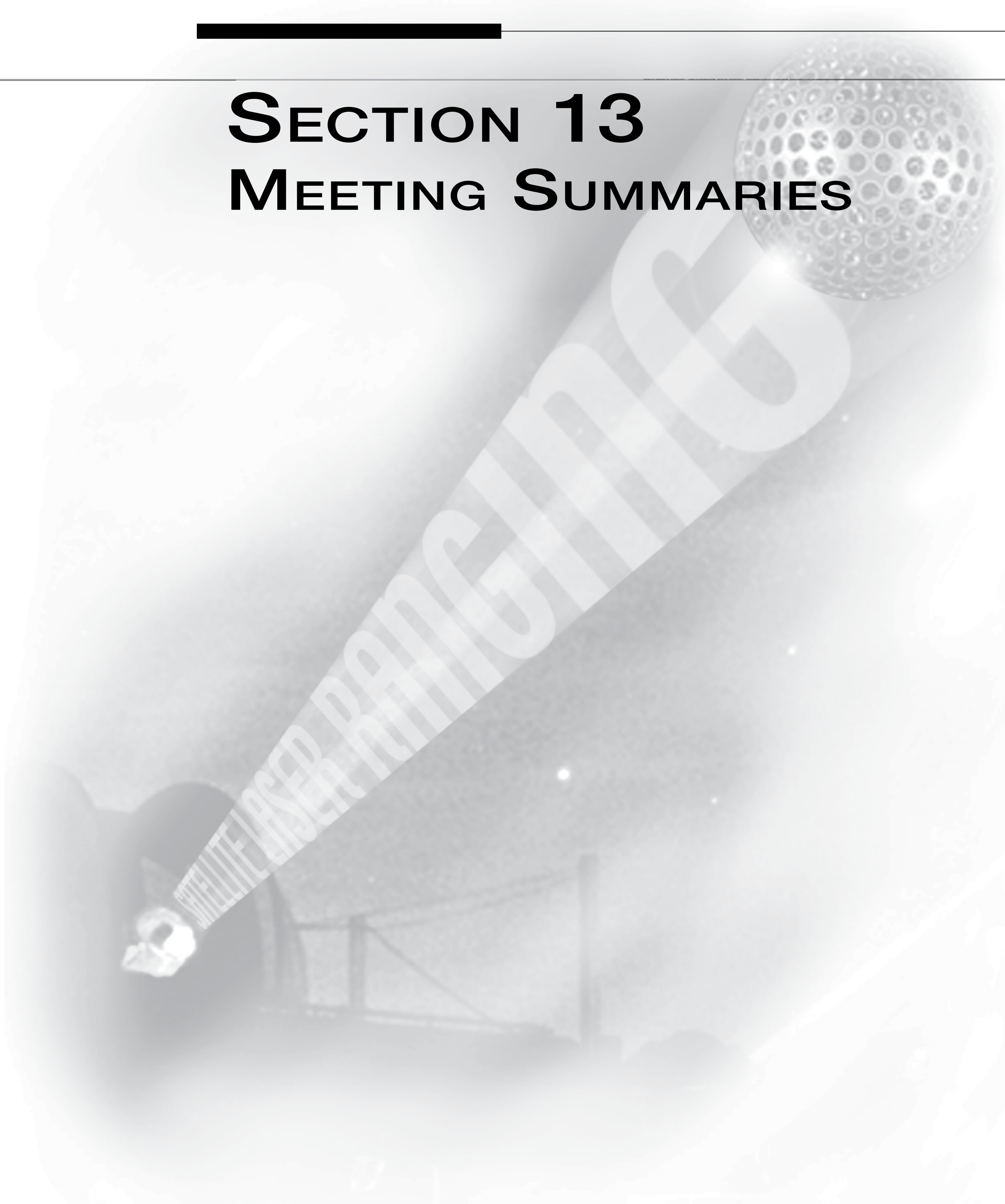
The maintenance and operation of the satellite laser ranging facility are performed and supported by the Astronomical Institute of the University of Bern (AIUB), the Federal Office of Topography (swisstopo), the Swiss National Science Foundation (SNF), and the Swiss Academy of Sciences (sc|nat).

Contact

Adrian Jäggi
Astronomical Institute
University of Bern
Sidlerstrasse 5
CH-3012 Bern
SWITZERLAND

E-mail: adrian.jaeggi@aiub.unibe.ch

SECTION 13
MEETING SUMMARIES



SECTION 13

MEETING SUMMARIES

Carey Noll/NASA GSFC

The ILRS Central Bureau organizes meetings of the ILRS Governing Board (typically two times per year) and ILRS General Assemblies (once per year). General Assembly Meetings provide updates on the status of the ILRS. Reports from past ILRS-related meetings can be found at *http://ilrs.gsfc.nasa.gov/about/reports/meeting_reports.html.*

ILRS 2009 Fall Workshop

Erricos Pavlis/UMBC

The ILRS 2009 Fall Workshop was held in Metsovo Greece on September 14-19, 2009. The workshop was organized by the ILRS and the National Technical University of Athens, Greece (NTUA). Information about the workshop, summary information, and links to presentations can be found on the workshop website: http://cddis.gsfc.nasa.gov/metsovo/index.html.

The 2009 International Laser Ranging Service (ILRS) Technical Workshop addressed a very timely issue: the tracking of current and future Global Navigation Satellite Systems (GNSS) constellations with Satellite Laser Ranging (SLR). The workshop brought together experts from the SLR and GNSS communities to discuss all aspects of the theme, focusing primarily on the science benefits, while also tackling problems arising from the large number of GNSS clients and the finite resources available to the ILRS. We summarize herein the most important findings, conclusions and recommendations.

The meeting stressed that there is great synergism between the two techniques and that these synergies should be fully exploited to the benefit of the larger community, in particular the communities of space geodesy and Earth science. What is now required is to understand the requirements of each of the GNSS constellations and then to optimize SLR and GNSS resources to maximize the benefit to all.

The combined list of benefits to both techniques, space geodesy, and to the broader community of users in general, can be summarized in the following:

- SLR tracking of the GNSS satellites allows to connect the ILRS/SLR and IGS/GNSS reference frames in space (using “space ties”);
- Validation and calibration of the GNSS orbit quality, passing SLR tracking through GNSS-based orbits and by comparison of GNSS orbits to independently determined orbits from SLR tracking;
- Improvement of GNSS-based results by combining SLR and GNSS data at the observation level;
- Improvement in the determination of the SLR contribution to the terrestrial reference frame by including laser ranging to GNSS satellites along with that to lower satellites (e.g. LAGEOS);
- Improved scale contribution to International Terrestrial Reference Frame (ITRF) from improved GM estimates based on SLR tracking of GNSS satellites (and indirect improvement of lower orbits as well, e.g. for LAGEOS);
- Improving the orbits of LEO satellites with onboard sensors like radar and laser altimeters, sounders, SAR, InSAR, etc.

The presentations of the GNSS operators indicated that there is already a great effort on interoperability of these constellations for the benefit of society. It remains o be seen if these operators will rise to the occasion and we will see an equally enthusiastic harmonization of their relationship to the SLR community, signing up to the requirements and ensuring a uniform treatment for all GNSS constellations. This can only increase the benefits to all parties and keep the cost and effort of the SLR community as low as possible.

From the GNSS point of view, the most important requirements on SLR are:

- Continuous SLR tracking of all GNSS targets, or as network capacity permits, using optimized scenarios that ultimately rely on the combined use of the two techniques;
- GNSS operators should follow strictly the ILRS recommendations for laser reflector array (LRA) designs to meet network requirements for best data yield;
- The SLR community should document unambiguously and maintain a publicly accessible data base of all known system biases for the ILRS network, past and future, with clear documentation even for non-SLR users;
- Extensive and timely (even near real-time) support of GNSS constellations, especially during the initial deployment phase and their "in-orbit validation" phases for models, hardware, software, operations, etc. ILRS Workshop Summary Series

From the ILRS point of view, important requirements are:

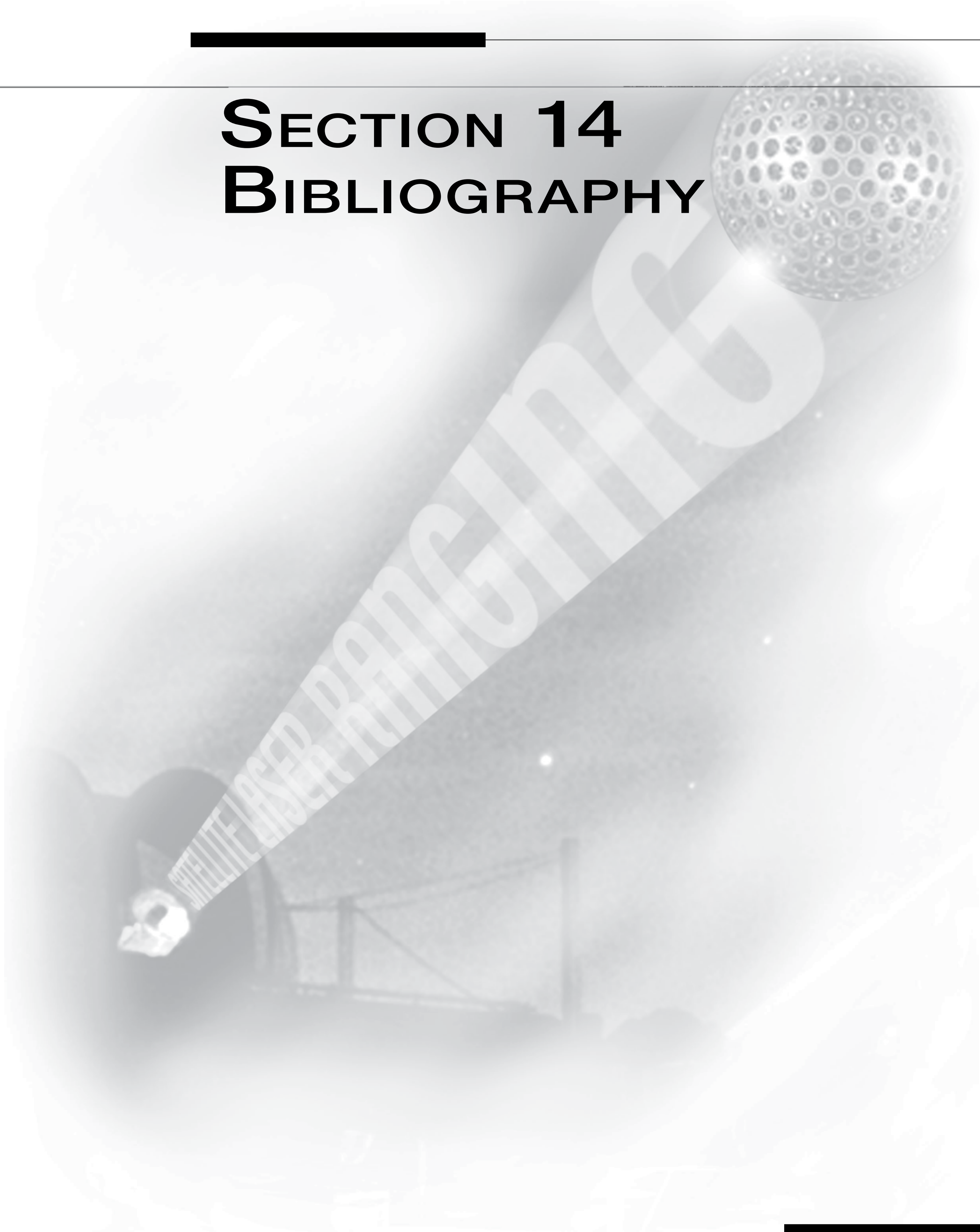
- All of the GNSS operators should adhere to the adopted ILRS standard for the laser reflector arrays (LRA), so that ILRS can assure uniform tracking capability throughout its network and at all times and conditions;
- An accurate calibration of all LRA designs prior to launch with a goal of a measurement of the vector to the center of gravity of the spacecraft to within a few millimeters (1-3 mm) and continuous monitoring of any changes while in orbit, due to fuel expenditure, attitude changes, etc. ;
- A precise description of the spacecraft attitude routine while in orbit and during periods of SLR tracking in particular;
- The ILRS must work with the separate GNSS constellation communities to develop a practical strategy to satisfy both the tracking requirements of the constellations and those for the development of the terrestrial reference frame;
- The ILRS should continue the simulation activity on GNSS satellites in order to quantify trade-offs among competing options

An overarching requirement is that the GNSS and SLR communities work together to facilitate communications so that planning can be done well in advance of any new GNSS deployments to exploit best the combination of techniques.

Future Workshops

The 17th International Workshop on Laser Ranging was proposed to take place in Concepcion Chile in January 2011. However, due to the impact of the magnitude 8 earthquake in the area in February 2010, the organizers proposed to move the location of the workshop to Bad Kötzting, Germany. The workshop will be held in May 2011 and will be sponsored by the Bundesamt fuer Kartographie und Geodaesie (BKG), which includes the Geodetic Observatory Wettzell and TIGO, the Research Group Satellite Geodesy of the Technische Universitaet Muenchen and the ILRS

SECTION 14
BIBLIOGRAPHY



Section 14

Bibliography

Mark Torrence/SGT, Inc.

Abbondanza, C., Altamimi, Z., Sarti, P., Negusini, M., Vittuari, L. (2009). Local effects of redundant terrestrial and GPS-based tie vectors in ITRF-like combinations. Journal of Geodesy, 83(11), 1031-1040. DOI: 10.1007/s00190-009-0321-6.

Afraimovich, E.L., E.I. Astafyeva, V.V. Demyanov, I.F. Gamayunov (2009), Mid-latitude amplitude scintillation of GPS signals and GPS performance slips (2009), Advances in Space Research, Volume 43, Issue 6, 16 March 2009, Pages 964-972, ISSN 0273-1177, DOI: 10.1016/j.asr.2008.09.015.

Alberti, M., Debbie Biscaro (2009), Height variation detection in polar regions from ICESat satellite altimetry, Computers & Geosciences, Volume 36, Issue 1, January 2010, Pages 1-9, ISSN 0098-3004, DOI: 10.1016/j.cageo.2009.07.002.

Altamimi, Z., Collilieux, X. (2009). IGS contribution to the ITRF. Journal of Geodesy, 83(3-4), 375-383. DOI: 10.1007/s00190-008-0294-x.

Altamimi, Z., Xavier Collilieux (2010), Quality Assessment of the IDS Contribution to ITRF2008, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1500-1509, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.03.010.

Angermann, D., Manuela Seitz, Hermann Drewes (2010), Analysis of the DORIS contributions to ITRF2008, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1633-1647, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.07.018.

Angermann, D., Seitz, M., Drewes, H. (2010). Analysis of the DORIS contributions to ITRF2008. Advances in Space Research, 46(12), 1633-1647. DOI: 10.1016/j.asr.2010.07.018.

Angermann, Detlef, Manuela Seitz, Hermann Drewes, Analysis of the DORIS contributions to ITRF2008, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1633-1647, ISSN 0273-1177, 10.1016/j.asr.2010.07.018.

Artz, T., Bockmann, S., Nothnagel, A., Steigenberger, P. (2010). Subdiurnal variations in the earth's rotation from continuous very long baseline interferometry campaigns. Journal of Geophysical Research, 115(B5) DOI: 10.1029/2009JB006834.

Auriol, A., C. Tourain (2010), DORIS system: The new age, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1484-1496, ISSN 0273-1177, 10.1016/j.asr.2010.05.015.

Battat, J. B. R., Stubbs, C. W., Swanson, H. E., Murphy, T. W., Adelberger, E. G., Gillespie, B. (2009). The apache point observatory lunar laser-ranging operation (APOLLO): Two years of millimeter-precision measurements of the earth-moon range. Publications of the Astronomical Society of the Pacific, 121(875), 29-40. DOI: 10.1086/596748.

Bernhardt, P.A., Carl L. Siefring (2009), Low-latitude ionospheric scintillations and total electron content obtained with the CITRIS instrument on STPSat1 using radio transmissions from DORIS ground beacons, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1535-1540, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.12.001.

Bessissi, Z., Mekki Terbeche, Boualem Ghezali (2009), Wavelet application to the time series analysis of DORIS station coordinates, Comptes Rendus Geosciences, Volume 341, Issue 6, June 2009, Pages 446-461, ISSN 1631-0713, DOI: 10.1016/j.crte.2009.03.010.

Beutler, G., Jaeggi, A., Mervart, L., Meyer, U. (2010). The celestial mechanics approach: Theoretical foundations. Journal of Geodesy, 84(10), 605-624. DOI: 10.1007/s00190-010-0401-7.

Beutler, G., Moore, A. W., Mueller, I. I. (2009). The international global navigation satellite systems service (IGS): Development and achievements. Journal of Geodesy, 83(3-4), 297-307. DOI: 10.1007/s00190-008-0268-z.

Bezdek, A., (2010). Calibration of accelerometers aboard GRACE satellites by comparison with POD-based nongravitational accelerations, Journal of Geodynamics, Volume 50, Issue 5, December 2010, Pages 410-423, ISSN 0264-3707, DOI: 10.1016/j.jog.2010.05.001.

Bezdek, A., Jaroslav Klokocnik, Jan Kostelecky, Rune Floberghagen, Christian Gruber, (2009), Simulation of free fall and resonances in the GOCE mission, Journal of Geodynamics, Volume 48, Issue 1, July 2009, Pages 47-53, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.01.007.

Bock, H., Jaeggi, A., Dach, R., Schaer, S., Beutler, G., (2009). GPS single-frequency orbit determination for low Earth orbiting satellites, Advances in Space Research, Volume 43, Issue 5, 2 March 2009, Pages 783-791, ISSN 0273-1177, DOI: 10.1016/j.asr.2008.12.003.

Bock, Olivier, Pascal Willis, Maite Lacarra, Pierre Bosser, (2010). An inter-comparison of zenith tropospheric delays derived from DORIS and GPS data, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1648-1660, ISSN 0273-1177, 10.1016/j.asr.2010.05.018.

Bockmann, S., Artz, T., Nothnagel, A. (2010). VLBI terrestrial reference frame contributions to ITRF2008. Journal of Geodesy, 84(3), 201-219. DOI: 10.1007/s00190-009-0357-7.

Boomkamp, H. (2010). Global GPS reference frame solutions of unlimited size. Advances in Space Research, 46(2), 136-143. DOI: 10.1016/j.asr.2010.02.015.

Bortoluzzi, D., B. Foulon, C. Garcia Marirrodriga, D. Lamarre, (2010). Object injection in geodesic conditions: In-flight and on-ground testing issues, Advances in Space Research, Volume 45, Issue 11, 1 June 2010, Pages 1358-1379, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.01.023.

Bruinsma, S., Jean-Michel Lemoine, Richard Biancale, Nicole Vales, (2010). CNES/GRGS 10-day gravity field models (release 2) and their evaluation, Advances in Space Research, Volume 45, Issue 4, 15 February 2010, Pages 587-601, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.10.012.

Brzezinski, A., Richter, B., Schuh, H., Ma, C., Dehant, V., Defraigne, P., (2010). Commission 19: Rotation of the Earth. Proceedings of the International Astronomical Union, 6(T27B), 130-139. DOI: 10.1017/S1743921310004898.

Campbell, J., Axel Nothnagel, (2010). Intra-plate deformation in west-central Europe, Journal of Geodynamics, Volume 49, Issues 3-4, WEGENER 2008 - Proceedings of the 14th General Assembly of Wegener, WEGENER 2008, April 2010, Pages 130-140, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.10.004.

Capitaine, N. (2009). Models and nomenclature in earth rotation. Proceedings of the International Astronomical Union, 5(S261), 69-78. DOI: 10.1017/S1743921309990172.

Capitaine, N., Mathews, P. M., Dehant, V., Wallace, P. T., Lambert, S. B. (2009). On the IAU 2000/2006 precession nutation and comparison with other models and VLBI observations. Celestial Mechanics and Dynamical Astronomy, 103(2), 179-190. DOI: 10.1007/s10569-008-9179-9.

Capozziello, S., De Laurentis, M., Garufi, F., Milano, L. (2009). Relativistic orbits with gravitomagnetic corrections. Physica Scripta, 79, 025901. DOI: 10.1088/0031-8949/79/02/025901.

Catalao, J., M.J. Sevilla, (2009). Mapping the geoid for Iberia and the Macaronesian Islands using multi-sensor gravity data and the GRACE geopotential model, Journal of Geodynamics, Volume 48, Issue 1, July 2009, Pages 6-15, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.03.001.

Cazenave, A., Chen, J. (2010). Time-variable gravity from space and present-day mass redistribution in the Earth system. Earth and Planetary Science Letters, 298(3), 263-274. DOI: 10.1016/j.epsl.2010.07.035.

Chen, J. L., Wilson, C. R., Seo, K. (2009). S2 tide aliasing in GRACE time-variable gravity solutions. Journal of Geodesy, 83(7), 679-687. DOI: 10.1007/s00190-008-0282-1.

Choi, E.-J., Jae-Cheol Yoon, Byoung-Sun Lee, Sang-Young Park, Kyu-Hong Choi, (2010). Onboard orbit determination using GPS observations based on the unscented Kalman filter, Advances in Space Research, Volume 46, Issue 11, 1 December 2010, Pages 1440-1450, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.07.022.

Christian Bizouard, L Seoane. (2010). Atmospheric and oceanic forcing of the rapid polar motion. Journal of Geodesy, 84(1), 19-30. DOI: 10.1007/s00190-009-0341-2.

Ciufolini, I., Paolozzi, A., Pavlis, E. C., Ries, J. C., Koenig, R., Matzner, R. A., (2009). Towards a one percent measurement of frame dragging by spin with satellite laser ranging to LAGEOS, LAGEOS 2 and LARES and GRACE gravity models. Space Science Reviews, 148(1), 71-104. DOI: 10.1007/s11214-009-9585-7.

Collilieux, X., Altamimi, Z., Coulot, D., van Dam, T., Ray, J. (2010). Impact of loading effects on determination of the international terrestrial reference frame. Advances in Space Research, 45(1), 144-154. DOI: 10.1016/j.asr.2009.08.024.

Collilieux, X., Z. Altamimi, J. Ray, T. van Dam, X. Wu. (2009). Effect of the satellite laser ranging network distribution on geocenter motion estimation. Journal of Geophysical Research - Solid Earth, 114(B4), B04402. DOI: 10.1029/2008JB005727.

Combrinck, L. (2009). The MOBLAS-6 satellite laser ranging station at hartebeesthoek, south africa; technology and data applications. 4, IV-161-IV-164. DOI: 10.1109/IGARSS.2009.5417347.

Combrinck, L. (2010). Satellite laser ranging. (pp. 301-338). Berlin, Heidelberg: Springer Berlin Heidelberg. DOI: 10.1007/978-3-642-11741-1_9.

Coulot, D., Pollet, A., Collilieux, X., Berio, P. (2010). Global optimization of core station networks for space geodesy: Application to the referencing of the SLR EOP with respect to ITRF. Journal of Geodesy, 84(1), 31-50. DOI: 10.1007/s00190-009-0342-1.

Crossley, D., Hinderer, J. (2009). A review of the GGP network and scientific challenges. Journal of Geodynamics, 48(3), 299-304. DOI: 10.1016/j.jog.2009.09.019.

Dehant, V., S. Le Maistre, A. Rivoldini, M. Yseboodt, P. Rosenblatt, T. Van Hoolst, M. Mitrovic, O. Karatekin, J.C. Marty, A. Chicarro, (2010). Revealing Mars' deep interior: Future geodesy missions using radio links between landers, orbiters, and the Earth, Planetary and Space Science, In Press, Corrected Proof, Available online 9 April 2010, ISSN 0032-0633, DOI: 10.1016/j.pss.2010.03.014.

Dong-ju, P., Bin, W. (2009). The effect of GPS ephemeris on the accuracy of precise orbit determination of LEO satellite-borne GPS. Chinese Astronomy and Astrophysics, 33(2), 206-216. DOI: 10.1016/j.chinastron.2009.03.007.

Dow, J. M., Neilan, R. E., Rizos, C. (2009). The international GNSS service in a changing landscape of global navigation satellite systems. Journal of Geodesy, 83(3-4), 191-198. DOI: 10.1007/s00190-008-0300-3.

Eshagh, M., Lars E. Sjoberg, (2009). Atmospheric effects on satellite gravity gradiometry data, Journal of Geodynamics, Volume 47, Issue 1, January 2009, Pages 9-19, ISSN 0264-3707, DOI: 10.1016/j.jog.2008.06.001.

Eshagh, M., (2010). Least-squares modification of extended Stokes' formula and its second-order radial derivative for validation of satellite gravity gradiometry data, Journal of Geodynamics, Volume 49, Issue 2, March 2010, Pages 92-104, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.11.003.

Exertier, P., Etienne Samain, Pascal Bonnefond, Philippe Guillemot, (2010). Status of the T2L2/Jason2 Experiment, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1559-1565, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.06.028.

Exertier, P., Samain, E., Bonnefond, P., Guillemot, P. (2010). Status of the T2L2/Jason2 experiment. Advances in Space Research, 46(12), 1559-1565. DOI: 10.1016/j.asr.2010.06.028.

Exertier, Pierre, Etienne Samain, Pascal Bonnefond, Philippe Guillemot, (2010). Status of the T2L2/Jason2 Experiment, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1559-1565, ISSN 0273-1177, 10.1016/j.asr.2010.06.028.

Felix W. Landerer, Jean O. Dickey, Andreas Guentner. (2010). Terrestrial water budget of the eurasian pan-arctic from GRACE satellite measurements during 2003-2009. Journal of Geophysical Research. Atmospheres, 115(23) DOI: 10.1029/2010JD014584.

Ferland, R., Piraszewski, M. (2009). The IGS-combined station coordinates, earth rotation parameters and apparent geocenter. Journal of Geodesy, 83(3-4), 385-392. DOI: 10.1007/s00190-008-0295-9.

Fritsche, M., Dietrich, R., R lke, A., Rothacher, M., Steigenberger, P. (2010). Low-degree earth deformation from reprocessed GPS observations. GPS Solutions, 14(2), 165-175. DOI: 10.1007/s10291-009-0130-7.

Gambis, D., Bizouard, C. (2009). Monitoring UT1 from astro-geodetic techniques at the EOP center of the IERS. Proceedings of the International Astronomical Union, 5(H15), 207-208. DOI: 10.1017/S1743921310008781.

Giorgi, G., Peter J.G. Teunissen, Sandra Verhagen, Peter J. Buist, (2010). Testing a new multivariate GNSS carrier phase attitude determination method for remote sensing platforms, Advances in Space Research, Volume 46, Issue 2, GNSS Remote Sensing-1, 15 July 2010, Pages 118-129, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.02.023.

Gobinddass, M. L., Willis, P., de Viron, O., Sibthorpe, A., Zelensky, N. P., Ries, J. C., Diament, M. (2009). Systematic biases in DORIS-derived geocenter time series related to solar radiation pressure mis-modeling. Journal of Geodesy, 83(9), 849-858. DOI: 10.1007/s00190-009-0303-8.

Gobinddass, M., Willis, P., Menvielle, M., Diament, M. (2010). Refining DORIS atmospheric drag estimation in preparation of ITRF2008. Advances in Space Research, 46(12), 1566-1577. DOI: 10.1016/j.asr.2010.04.004.

Gobinddass, M.L., Willis, P., Viron, O. de, Sibthorpee, A., Zelensky, N.P., Ries, J.C., Ferland, R., Bar-Sever, Y., Diament., M., Lemoine, F.G., (2009). Improving DORIS geocenter time series using an empirical rescaling of solar radiation pressure models, Advances in Space Research, Volume 44, Issue 11, 1 December 2009, Pages 1279-1287, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.08.004.

Govind, R., J.J. Valette, F.G. Lemoine, (2010). A DORIS determination of the absolute velocities of the Sorsdal and Mellor glaciers in Antarctica, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1523-1534, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.02.011.

Govind, R., Lemoine, F.G., Valette, J.J., Chinn, D., Zelensky, N. (2010). DORIS geodesy: A dynamic determination of geocentre location. Advances in Space Research, 46(12), 1593-1605. DOI: 10.1016/j.asr.2010.08.025.

Gross, R. S. (2009). Ocean tidal effects on earth rotation. Journal of Geodynamics, 48(3), 219-225. DOI: 10.1016/j.jog.2009.09.016.

Han, S., Ray, R. D., Luthcke, S. B. (2010). One centimeter-level observations of diurnal ocean tides from global monthly mean time-variable gravity fields. Journal of Geodesy, 84(12), 715-729. DOI: 10.1007/s00190-010-0405-3.

Hausleitner, W., Kirchner, G., Krauss, S., Weingrill, J., Pail, R., Goiginger, H., Rieser, D. (2010). Improved kHz-SLR tracking techniques and orbit quality analysis for LEO missions. Advances in Space Research, 45(6), 721-732. DOI: 10.1016/j.asr.2009.11.016.

Helleputte, T. V., Doornbos, E., Visser, P. (2009). CHAMP and GRACE accelerometer calibration by GPS-based orbit determination. Advances in Space Research, 43(12), 1890-1896. DOI: 10.1016/j.asr.2009.02.017.

Hilgen, F.J., (2010). Astronomical dating in the 19th century, Earth-Science Reviews, Yamamoto, K., Yoichi Fukuda, Koichiro Doi, Interpretation of GIA and ice-sheet mass trends over Antarctica using GRACE and ICESat data as a constraint to GIA models, Tectonophysics, In Press, Corrected Proof, Available online 26 November 2010, ISSN 0040-1951, DOI: 10.1016/j.tecto.2010.11.010.

Hwang, C., Tseng, T., Lin, T., Svehla, D., Schreiner, B. (2009). Precise orbit determination for the FORMOSAT-3/COSMIC satellite mission using GPS. Journal of Geodesy, 83(5), 477-489. DOI: 10.1007/s00190-008-0256-3.

Iorio, L. (2009). An assessment of the systematic uncertainty in present and future tests of the lense-thirring effect with Satellite laser ranging. Space Science Reviews, 148(1), 363-381. DOI: 10.1007/s11214-008-9478-1.

Iorio, L. (2009). Towards a 1% measurement of the lense-thirring effect with LARES? Advances in Space Research, 43(7), 1148-1157. DOI: 10.1016/j.asr.2008.10.016.

Iorio, L. (2010). How accurate is the cancelation of the first even zonal harmonic of the geopotential in the present and future LAGEOS-based lense-thirring tests? DOI: 10.1007/s10714-011-1151-4.

Jayles, C., J.P. Chauveau, F. Rozo, (2010). DORIS/Jason-2: Better than 10 cm on-board orbits available for Near-Real-Time Altimetry, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1497-1512, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.04.030.

Jianguo, Y., Ping Jinsong, Li Fei, Cao Jianfeng, Huang Qian, Fung Lihe, (2010). Chang'E-1 Precision orbit determination and lunar gravity field solution, Advances in Space Research, Volume 46, Issue 1, 1 July 2010, Pages 50-57, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.03.002.

Jin, S., Attila Komjathy, (2010). GNSS reflectometry and remote sensing: New objectives and results, Advances in Space Research, Volume 46, Issue 2, GNSS Remote Sensing-1, 15 July 2010, Pages 111-117, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.01.014.

Jin, S., O.F. Luo, J. Cho, (2009). Systematic errors between VLBI and GPS precipitable water vapor estimations from 5-year co-located measurements, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 71, Issue 2, February 2009, Pages 264-272, ISSN 1364-6826, DOI: 10.1016/j.jastp.2008.11.018.

Kang, Z., Tapley, B., Chen, J., Ries, J., Bettadpur, S. (2009). Geocenter variations derived from GPS tracking of the GRACE satellites. Journal of Geodesy, 83(10), 895-901. DOI: 10.1007/s00190-009-0307-4.

Kierulf, H.P., Bjorn Ragnvald Pettersen, Daniel S. MacMillan, Pascal Willis, (2009). The kinematics of Ny-Alesund from space geodetic data, Journal of Geodynamics, Volume 48, Issue 1, July 2009, Pages 37-46, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.05.002.

King, M. A., Mendes Cerveira, P. J., Penna, N., Riva, R. E. M., Steigenberger, P., van Dam, T., (2010). Improved constraints on models of glacial isostatic adjustment: A review of the contribution of ground-based geodetic observations. Surveys in Geophysics, 31(5), 465-507. DOI: 10.1007/s10712-010-9100-4.

Kirchner, G., Kucharski, D., Cristea, E., (2009). Gravity probe-B: New methods to determine spin parameters from kHz SLR data. IEEE Transactions on Geoscience and Remote Sensing, 47(1), 370-375. DOI: 10.1109/TGRS.2008.2002770.

Palamartchouk, Kirill. (2010). Apparent geocenter oscillations in global navigation satellite systems solutions caused by the ionospheric effect of second order. Journal of Geophysical Research. Solid Earth, 115(B3) DOI: 10.1029/2008JB006099.

Kotsakis, C. (2009). A study on the reference frame consistency in recent earth gravitational models. Journal of Geodesy, 83(1), 31-50. DOI: 10.1007/s00190-008-0227-8.

Kucharski, D., Kirchner, G., Koidl, F., Cristea, E. (2009). 10 years of LAGEOS-1 and 15 years of LAGEOS-2 spin period determination from SLR data. Advances in Space Research, 43(12), 1926-1930. DOI: 10.1016/j.asr.2009.01.019.

Kucharski, D., Kirchner, G., Otsubo, T., Koidl, F. (2009). 22 years of AJISAI spin period determination from standard SLR and kHz SLR data. Advances in Space Research, 44(5), 621-626. DOI: 10.1016/j.asr.2009.05.007.

Kucharski, D., Kirchner, G., Otsubo, T., Koidl, F. (2010). The impact of solar irradiance on AJISAI's spin period measured by the graz 2-kHz SLR system. IEEE Transactions on Geoscience and Remote Sensing, 48(3), 1629-1633. DOI: 10.1109/TGRS.2009.2031229.

Kucharski, D., Otsubo, T., Kirchner, G., Koidl, F. (2010). Spin axis orientation of ajisai determined from graz 2 kHz SLR data. Advances in Space Research, 46(3), 251-256. DOI: 10.1016/j.asr.2010.03.029.

Kusche, J., Schmidt, R., Petrovic, S., Rietbroek, R. (2009). Decorrelated GRACE time-variable gravity solutions by GFZ, and their validation using a hydrological model. Journal of Geodesy, 83(10), 903-913. DOI: 10.1007/s00190-009-0308-3.

Kuzin, S. P., Tatevian, S. K., Valeev, S. G., Fashutdinova, V. A. (2010). Studies of the geocenter motion using 16-years DORIS data. Advances in Space Research, 46(10), 1292-1298. DOI: 10.1016/j.asr.2010.06.038.

Lavallee, D. A., Moore, P., Clarke, P. J., Petrie, E. J., van Dam, T., King, M. A. (2010). J2: An evaluation of new estimates from GPS, GRACE, and load models compared to SLR. Geophysical Research Letters, 37(22) DOI: 10.1029/2010GL045229.

Le Bail, K., Lemoine, F. G., Chinn, D. S. (2010). GSFC DORIS contribution to ITRF2008. Advances in Space Research, 45(12), 1481-1499. DOI: 10.1016/j.asr.2010.01.030.

Lee, J., Kim, Y., Lee, K., Lee, S. (2010). Time-of-flight measurement with femtosecond light pulses. Nature Photonics, 4(10), 716-720. DOI: 10.1038/nphoton.2010.175.

Lemoine, F.G., N.P. Zelensky, D.S. Chinn, D.E. Pavlis, D.D. Rowlands, B.D. Beckley, S.B. Luthcke, P. Willis, M. Ziebart, A. Sibthorpe, J.P. Boy, V. Luceri, (2010) Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1513-1540, ISSN 0273-1177, 10.1016/j.asr.2010.05.007.

Lidberg, M., Jan M. Johansson, Hans-Georg Scherneck, Glenn A. Milne, (2010). Recent results based on continuous GPS observations of the GIA process in Fennoscandia from BIFROST, Journal of Geodynamics, Volume 50, Issue 1, Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas (DynaQlim) -- Understanding the Glacial Isostatic Adjustment, July 2010, Pages 8-18, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.11.010.

Magruder, L. A., Ricklefs, R. L., Silverberg, E. C., Horstman, M. F., Suleman, M. A., Schutz, B. E. (2010). ICESat geolocation validation using airborne photography. IEEE Transactions on Geoscience and Remote Sensing, 48(6), 2758-2766. DOI: 10.1109/TGRS.2010.2040831.

Mallama, A., Chris Stockdale, Bruce A. Krobusek, Peter Nelson, (2010). Assessment of the resonant perturbation errors in Galilean satellite ephemerides using precisely measured eclipse times, Icarus, Volume 210, Issue 1, November 2010, Pages 346-357, ISSN 0019-1035, DOI: 10.1016/j.icarus.2010.06.007.

Mercier, F., Cerri, L., Berthias, J. (2010). Jason-2 DORIS phase measurement processing. Advances in Space Research, 45(12), 1441-1454. DOI: 10.1016/j.asr.2009.12.002.

Metivier, L., Marianne Greff-Lefftz, Zuheir Altamimi, (2010). On secular geocenter motion: The impact of climate changes, Earth and Planetary Science Letters, Volume 296, Issues 3-4, 1 August 2010, Pages 360-366, ISSN 0012-821X, DOI: 10.1016/j.epsl.2010.05.021.

Montenbruck, O., Garcia-Fernandez, M., Yoon, Y., Schn, S., Jaeggi, A. (2009). Antenna phase center calibration for precise positioning of LEO satellites. GPS Solutions, 13(1), 23-34. DOI: 10.1007/s10291-008-0094-z.

Mtivier, L., Greff-Lefftz, M., Altamimi, Z. (2010). On secular geocenter motion: The impact of climate changes. Earth and Planetary Science Letters, 296(3), 360-366. DOI: 10.1016/j.epsl.2010.05.021.

Murphy Jr, T. W. (2009). Lunar ranging, gravitomagnetism, and APOLLO. Space Science Reviews, 148(1), 217-223. DOI: 10.1007/s11214-009-9491-z.

Neumeyer, J., Uwe Schafer, Jens Kremer, Hartmut Pflug, Guochang Xu, (2009). Derivation of gravity anomalies from airborne gravimeter and IMU recordings--Validation with regional analytic models using ground and satellite gravity data, Journal of Geodynamics, Volume 47, Issue 4, April 2009, Pages 191-200, ISSN 0264-3707, DOI: 10.1016/j.jog.2008.08.001.

Noll, C. E. (2010). The crustal dynamics data information system: A resource to support scientific analysis using space geodesy. Advances in Space Research, 45(12), 1421-1440. DOI: 10.1016/j.asr.2010.01.018.

Otsubo, T., Kunimori, H., Noda, H., Hanada, H. (2010). Simulation of optical response of retroreflectors for future lunar laser ranging. Advances in Space Research, 45(6), 733-740. DOI: 10.1016/j.asr.2009.12.003.

Otten, M., Claudia Flohrer, Tim Springer, John Dow, (2010). DORIS processing at the European Space Operations Centre, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1606-1613, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.04.024.

Ozener, H., Esen Arpat, Semih Ergintav, Asli Dogru, Rahsan Cakmak, Bulent Turgut, Ugur Dogan, (2010). Kinematics of the eastern part of the North Anatolian Fault Zone, Journal of Geodynamics, Volume 49, Issues 3-4, WEGENER 2008 - Proceedings of the 14th General Assembly of Wegener, WEGENER 2008, April 2010, Pages 141-150, ISSN 0264-3707, DOI: 10.1016/j.jog.2010.01.003.

Pan, X., Zhou, H. (2009). The data depth-weight-kernel estimation of the model error of satellite orbit determination. Chinese Astronomy and Astrophysics, 33(3), 293-304. DOI: 10.1016/j.chinastron.2009.07.004.

Peltier, W.R., (2009). Closure of the budget of global sea level rise over the GRACE era: the importance and magnitudes of the required corrections for global glacial isostatic adjustment, Quaternary Science Reviews, Volume 28, Issues 17-18, Quaternary Ice Sheet-Ocean Interactions and Landscape Responses, August 2009, Pages 1658-1674, ISSN 0277-3791, DOI: 10.1016/j.quascirev.2009.04.004.

Petit, G. (2009). Relativity in the IERS conventions. Proceedings of the International Astronomical Union, 5(S261), 16-21. DOI: 10.1017/S1743921309990093.

Prange, L., Jaeggi, A., Dach, R., Bock, H., Beutler, G., Mervart, L. (2010). AIUB-CHAMP02S: The influence of GNSS model changes on gravity field recovery using spaceborne GPS. Advances in Space Research, 45(2), 215-224. DOI: 10.1016/j.asr.2009.09.020.

Raj, X.J., Ram Krishan Sharma, (2009). Prediction of satellite orbits contraction due to diurnally varying oblate atmosphere and altitude-dependent scale height using KS canonical elements, Planetary and Space Science, Volume 57, Issue 11, September 2009, Pages 1312-1320, ISSN 0032-0633, DOI: 10.1016/j.pss.2009.05.007.

Ray, R.D., B.D. Beckley, F.G. Lemoine, (2010). Vertical crustal motion derived from satellite altimetry and tide gauges, and comparisons with DORIS measurements, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1510-1522, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.02.020.

Rietbroek, R., Brunnabend, S., Dahle, C., Kusche, J., Flechtner, F., Schrter, J., Timmermann, R. (2009). Changes in total ocean mass derived from GRACE, GPS, and ocean modeling with weekly resolution. Journal of Geophysical Research, 114(C11) DOI: 10.1029/2009JC005449.

Riva, R. E. M., Schutz, B. E., Gunter, B. C., Urban, T. J., Vermeersen, B. L. A., Lindenbergh, R. C., (2009). Glacial isostatic adjustment over antarctica from combined ICESat and GRACE satellite data. Earth and Planetary Science Letters, 288(3), 516-523. DOI: 10.1016/j.epsl.2009.10.013.

Rummel, R. (2010). The interdisciplinary role of space geodesy Revisited. Journal of Geodynamics, 49(3), 112-115. DOI: 10.1016/j.jog.2009.10.006.

Rutkowska, M., Jagoda, M. (2010). Estimation of the elastic earth parameters (h 2, l 2) using SLR data. Advances in Space Research, 46(7), 859-871. DOI: 10.1016/j.asr.2010.04.010.

Rutkowska, M., Jagoda, M. (2010). Estimation of the elastic earth parameters using the SLR LAGEOS 1 and LAGEOS 2 data. Acta Geophysica, 58(4), 705-716. DOI: 10.2478/s11600-009-0062-1.

Scheeres, D.J., C.M. Hartzell, P. Sanchez, M. Swift, (2010). Scaling forces to asteroid surfaces: The role of cohesion, Icarus, Volume 210, Issue 2, December 2010, Pages 968-984, ISSN 0019-1035, DOI: 10.1016/j.icarus.2010.07.009.

Schiller, S., Ferrari, G., Poli, N., Lusanna, L., Klein, H., Margolis, H., (2009). Einstein gravity Explorera medium-class fundamental physics mission. Experimental Astronomy, 23(2), 573-610. DOI: 10.1007/s10686-008-9126-5.

Schreiber, K. U., Hiener, M., Holzapfel, B., Michaelis, H., Brandl, N., Haufe, K., (2009). Altimetry and transponder ground simulation experiment. Planetary and Space Science, 57(12), 1485-1490. DOI: 10.1016/j.pss.2009.07.016.

Schreiber, K. U., Prochazka, I., Lauber, P., Hugentobler, U., Schaefer, W., Cacciapuoti, L., Nasca, R. (2010). Ground-based demonstration of the european laser timing (ELT) experiment. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 57(3), 728-737. DOI: 10.1109/TUFFC.2010.1471.

Shi, C., Y. Lou, H. Zhang, Q. Zhao, J. Geng, R. Wang, R. Fang, J. Liu, (2010). Seismic deformation of the Mw 8.0 Wenchuan earthquake from high-rate GPS observations, Advances in Space Research, Volume 46, Issue 2, GNSS Remote Sensing-1, 15 July 2010, Pages 228-235, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.03.006.

Shuanggen Jin, Don P. Chambers, Byron D. Tapley. (2010). Hydrological and oceanic effects on polar motion from GRACE and models. Journal of Geophysical Research. Solid Earth, 115(B02) DOI: 10.1029/2009JB006635.

Smith, David E., Thomas H. Duxbury, Oded Aharonson, Paul G. Lucey, Mark S. Robinson, Olivier S. Barnouin, (2010). Initial observations from the lunar orbiter laser altimeter (LOLA). Geophysical Research Letters, 37(18) DOI: 10.1029/2010GL043751.

Smylie, D. E., Zuberi, M. (2009). Free and forced polar motion and modern observations of the chandler wobble. Journal of Geodynamics, 48(3), 226-229. DOI: 10.1016/j.jog.2009.09.028.

Steffen, H., Svetozar Petrovic, Jurgen Muller, Roland Schmidt, Johann Wunsch, Franz Barthelmes, Jurgen Kusche, (2009). Significance of secular trends of mass variations determined from GRACE solutions, Journal of Geodynamics, Volume 48, Issues 3-5, New Challenges in Earth's Dynamics - Proceedings of the 16th International Symposium on Earth Tides, December 2009, Pages 157-165, ISSN 0264-3707, DOI: 10.1016/j.jog.2009.09.029.

Steffen, H., Olga Gitlein, Heiner Denker, Jurgen Muller, Ludger Timmen, (2009). Present rate of uplift in Fennoscandia from GRACE and absolute gravimetry, Tectonophysics, Volume 474, Issues 1-2, TOPO-EUROPE: The Geoscience of coupled Deep Earth-surface processes, 1 September 2009, Pages 69-77, ISSN 0040-1951, DOI: 10.1016/j.tecto.2009.01.012.

Steigenberger, P., Manuela Seitz, Sarah Bockmann, Volker Tesmer, Urs Hugentobler, (2010). Precision and accuracy of GPS-derived station displacements, Physics and Chemistry of the Earth, Parts A/B/C, In Press, Corrected Proof, Available online 2 August 2010, ISSN 1474-7065, DOI: 10.1016/j.pce.2010.07.035.

Steigenberger, P., Rothacher, M., Fritsche, M., R lke, A., Dietrich, R. (2009). Quality of reprocessed GPS satellite orbits. Journal of Geodesy, 83(3-4), 241-248. DOI: 10.1007/s00190-008-0228-7.

Stepanek, P., Jan Dousa, Vratislav Filler, Urs Hugentobler, (2010). DORIS data analysis at Geodetic Observatory Pecny using single-satellite and multi-satellite geodetic solutions, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1578-1592, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.04.015.

Swann, W. C., Nenadovic, L. (2009). Rapid and precise absolute distance measurements at long range. Nature Photonics, 3(6), 351-356. DOI: 10.1038/nphoton.2009.94.

Tesmer, V., Steigenberger, P., Rothacher, M., Boehm, J., Meisel, B. (2009). Annual deformation signals from homogeneously reprocessed VLBI and GPS height time series. Journal of Geodesy, 83(10), 973-988. DOI: 10.1007/s00190-009-0316-3.

Valette, J., Lemoine, F. G., Ferrage, P., Yaya, P., Altamimi, Z., Willis, P., Soudarin, L. (2010). IDS contribution to ITRF2008. Advances in Space Research, 46(12), 1614-1632. DOI: 10.1016/j.asr.2010.05.029.

van Barneveld, P.W.L., O. Montenbruck, P.N.A.M. Visser, (2009). Epochwise prediction of GPS single differenced ionospheric delays of formation flying spacecraft, Advances in Space Research, Volume 44, Issue 9, 2 November 2009, Pages 987-1001, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.07.006.

van den IJssel, J., Pieter Visser, (2010). Performance of GPS-based accelerometry: A simulation experiment, Advances in Space Research, Volume 45, Issue 2, 15 January 2010, Pages 225-238, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.09.012.

Vermeersen, L. L. A., Schotman, H. H. A. (2009). Constraints on glacial isostatic adjustment from GOCE and sea level data. Pure and Applied Geophysics, 166(8-9), 1261-1281. DOI: 10.1007/s00024-004-0503-3.

Visser, P. N. A. M., van den IJssel, J., Van Helleputte, T., Bock, H., Jaeggi, A., Beutler, G., (2009). Orbit determination for the GOCE satellite. Advances in Space Research, 43(5), 760-768. DOI: 10.1016/j.asr.2008.09.016.

Vtpnek, Petr, Jan Dousa, Vratislav Filler, Urs Hugentobler, (2010). DORIS data analysis at Geodetic Observatory Pecny using single-satellite and multi-satellite geodetic solutions, Advances in Space Research, Volume 46, Issue 12, 15 December 2010, Pages 1578-1592, ISSN 0273-1177, 10.1016/j.asr.2010.04.015.

Wang, R., J. Liu, Q.M. Zhang, (2009). Propagation errors analysis of TLE data, Advances in Space Research, Volume 43, Issue 7, 1 April 2009, Pages 1065-1069, ISSN 0273-1177, DOI: 10.1016/j.asr.2008.11.017.

Wang, X., Wang, S., Rhee, H., Eichler, H. J., Meister, S., Riesbeck, T., Chen, J. (2010). LD end pumped, actively mode locked and passively Q-switched nd:YAP laser at 1341 nm. Optics Communications, 283(4), 570-573. DOI: 10.1016/j.optcom.2009.10.089.

Wei, Z., Hou-Tse, H., Min, Z., Mei-Juan, Y. (2009). Accurate and rapid error estimation on global gravitational field from current GRACE and future GRACE follow-on missions. Chinese Physics B, 18, 3597. DOI: 10.1088/1674-1056/18/8/077.

Willis, P. (2010). DORIS: Precise orbit determination and applications to the earth sciences. Advances in Space Research, 46(12), 1483-1483. DOI: 10.1016/j.asr.2010.07.013.

Willis, P., Boucher, C., Fagard, H., Garayt, B., Gobinddass, M. (2010). Contributions of the french institut g ographique national (IGN) to the international DORIS service. Advances in Space Research, 45(12), 1470-1480. DOI: 10.1016/j.asr.2009.09.019.

Willis, P., Herve Fagard, Pascale Ferrage, Frank G. Lemoine, Carey E. Noll, Ron Noomen, Michiel Otten, John C. Ries, Markus Rothacher, Laurent Soudarin, Gilles Tavernier, Jean-Jacques Valette, (2010), The International DORIS Service (IDS): Toward maturity, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1408-1420, ISSN 0273-1177, DOI: 10.1016/j.asr.2009.11.018.

Willis, P., (2010). Preface, DORIS: Precise orbit determination and applications to the Earth sciences, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Page 1483, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.07.013.

Willis, P., Ries, J. C., Zelensky, N. P., Soudarin, L., Fagard, H., Pavlis, E. C., Lemoine, F. G. (2009). DPOD2005: An extension of ITRF2005 for precise orbit determination. Advances in Space Research, 44(5), 535-544. DOI: 10.1016/j.asr.2009.04.018.

Wooden, W., Luzum, B., Stamatakos, N. (2009). Current status and future directions of the IERS RS/PC predictions of UT1. Proceedings of the International Astronomical Union, 5(H15), 218-218. DOI: 10.1017/S1743921310008872.

Worden, P., Mester, J. (2009). Satellite test of the equivalence principle uncertainty analysis. Space Science Reviews, 148(1), 489-499. DOI: 10.1007/s11214-009-9568-8.

Xie, Y., Kopeikin, S. (2010). Post-newtonian reference frames for advanced theory of the lunar motion and for a new generation of lunar laser ranging. Acta Physica Slovaca. Reviews and Tutorials, 60(4), 393-495. DOI: 10.2478/v10155-010-0004-0.

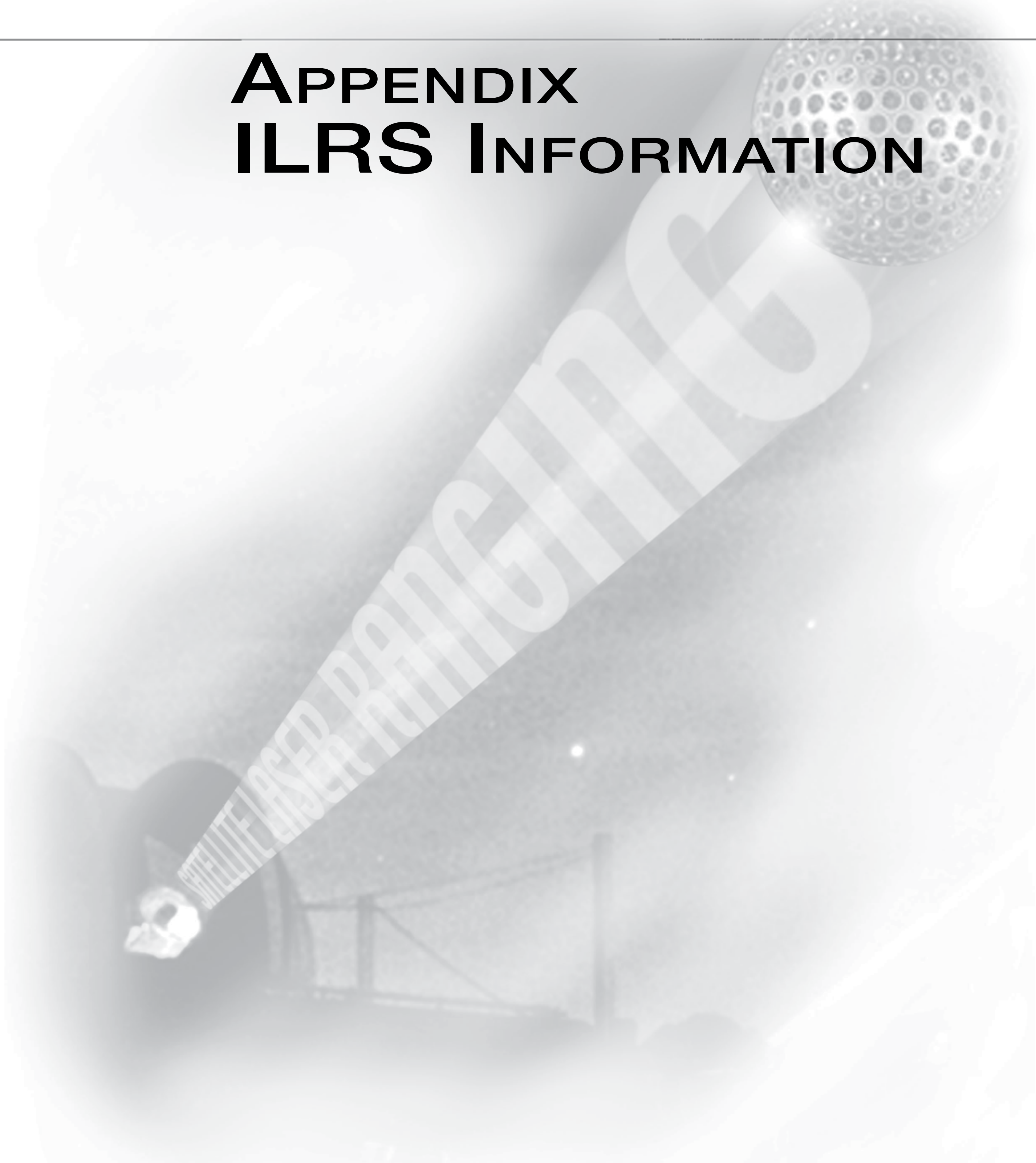
Yaya, P., C. Tourain, (2010). Impact of DORIS ground antennas environment on their radio signal quality, Advances in Space Research, Volume 45, Issue 12, DORIS: Scientific Applications in Geodesy and Geodynamics, 15 June 2010, Pages 1455-1469, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.01.031.

Zelensky, N.P., Frank G. Lemoine, Marek Ziebart, Ant Sibthorpe, Pascal Willis, Brian D. Beckley, Steven M. Klosko, Douglas S. Chinn, David D. Rowlands, Scott B. Luthcke, Despina E. Pavlis, Vincenza Luceri, (2010), DORIS/SLR POD modeling improvements for Jason-1 and Jason-2, Advances in Space Research, Volume 46, Issue 12, DORIS: Precise Orbit Determination and Applications to Earth Sciences, 15 December 2010, Pages 1541-1558, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.05.008.

Zhigui Kang, Byron Tapley, Jianli Chen, John Ries, Srinivas Bettadpur. (2009). Geocenter variations derived from GPS tracking of the GRACE satellites. Journal of Geodesy, 83(10), 895-901. DOI: 10.1007/s00190-009-0307-4.

Zuber, M. T., Ott, M. N., Ramos-Izquierdo, L. A., Rowlands, D. D., Torrence, M. H., Zagwodzki, T. W., (2010). The lunar reconnaissance orbiter laser ranging investigation. Space Science Reviews, 150(1-4), 63-80. DOI: 10.1007/s11214-009-9511-z.

Appendix
ILRS Information



Appendix

ILRS Information

ILRS Contributing Organizations

Agency	Country
Observatorio Astronómico Félix Aguilar (OAFA) of the Facultad de Ciencias Exactas, Físicas y Naturales (FCEFN) of the Universidad Nacional de San Juan (UNSJ)	Argentina
Geoscience Australia (GA)	Australia
EOS Space Systems Pty. Ltd.	Australia
Austrian Academy of Sciences	Austria
National Institute of Geophysics, Geodesy and Geography (NIGGG, formerly CLG/BAS)	Bulgaria
Observatorio Geodetico TIGO, Universidad de Concepción	Chile
Academia Sinica	China
Chinese Academy of Surveying and Mapping (CASM)	China
Institute of Seismology, China Seismological Bureau	China
National Astronomical Observatories of China (NAOC), Chinese Academy of Sciences (CAS)	China
Shanghai Astronomical Observatory (SHAO)	China
State Seismological Bureau	China
Yunnan Observatory	China
Technical University of Prague	Czech Republic
National Research Institute of Astronomy and Geophysics (NRIAG)	Egypt
Finnish Geodetic Institute	Finland
Groupe de Recherche en Geodesie Spatiale (GRGS)	France
Observatoire de la Côte d'Azur/Center d'Etudes et de Recherches Géodynamiques et Astrométrie (OCA/CERGA)	France
Observatoire de Paris	France
Tahiti Geodetic Observatory, University of French Polynesia (UFP)	French Polynesia
Bundesamt für Kartographie und Geodäsie (BKG)	Germany
Deutsches Geodätisches ForschungsInstitut (DGFI)	Germany
European Space Agency/European Space Operation Center (ESA/ESOC)	Germany
Institut fuer Erdmessung/Forschungseinrichting SatellitenGeodasie (IFE/FESG)	Germany
Helmholtz Centre Potsdam GeoForschungsZentrum German Research Centre for Geosciences (GFZ)	Germany
Italian Space Agency (ASI)	Italy
Hitotsubashi University	Japan
Hydrographic Department/Japan Coast Guard	Japan

ILRS Contributing Organizations continued

Japan Aerospace Exploration Agency (JAXA)	Japan
National Institute of Information and Communications Technology (NICT)	Japan
Astronomical Observatory, University of Latvia	Latvia
Delft University of Technology (DUT)	The Netherlands
Forsvarets ForskningsInstitutt (FFI)	Norway
Universidad Nacional de San Augustin (UNSA)	Peru
Space Research Center of the Polish Academy of Sciences (PAS)	Poland
Information-Analytical Center (IAC)	Russia
Institute of Applied Astronomy (IAA)	Russia
Institute of Astronomy of the Russian Academy of Sciences (INASAN)	Russia
Institute of Metrology for Time and Space (IMVP)	Russia
Russian Space Agency (RSA)	Russia
Space Research Institute (SRI) for Precision Instrument Engineering	Russia
King Abdulaziz City for Science and Technology (KACST)	Saudi Arabia
Hartebeesthoek Radio Astronomy Observatory (HartRAO)	South Africa
Real Instituto y Observatorio de la Armada	Spain
Astronomical Institute, University of Berne (AIUB)	Switzerland
Astronomical Observatory of the Ivan Franko National University of Lviv	Ukraine
Crimean Astronomical Observatory	Ukraine
Lebedev Physical Institute in the Crimea	Ukraine
Main Astronomical Observatory (MAO) of the National Academy of Sciences of Ukraine (GAOUA)	Ukraine
Natural Environment Research Council (NERC)	United Kingdom
University of Newcastle Upon Tyne	United Kingdom
Harvard-Smithsonian Center for Astrophysics	USA
Jet Propulsion Laboratory (JPL)	USA
Joint Center for Earth System Technology (JCET), University of Maryland, Baltimore County	USA
National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC)	USA
Naval Research Laboratory (NRL)	USA
University of Hawaii	USA
University of Texas at Austin	USA
University of Texas, Center for Space Research (CSR)	USA

List of Acronyms

AAC	Associate Analysis Center
AC	Analysis Center
ACES	Atomic Clock Ensemble in Space
ACT	Australian Capital Territory
ADEOS	Advanced Earth Observing Satellite
AG	Absolute Gravimeter
AGU	American Geophysical Union
AIUB	Astronomical Institute of Berne (Switzerland)
AltiKa	Altimeter Ka-band
ANDE	Atmospheric Neutral Density Experiment (USA)
ANDE-RR	Atmospheric Neutral Density Experiment Risk Reduction (USA)
AOLC	Altay Optic-Laser Center
AOPOD	Atmospheric Occultation and Precision Orbit Determination
APD	Avalanche Photodiodes
APOLLO	Apache Point Observatory Lunar Laser-ranging Operation (USA)
ARB	Average Range Bias
ARTEMIS	Advanced Relay And Technology Mission
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic
AWG	Analysis Working Group
Az-El	Azimuth-Elevation

◆ ◆ ◆

BAS	Bulgarian Academy of Sciences
BE-C	Beacon Explorer C
BELA	BepiColombo Laser Altimeter
BIPM	International Bureau of Weights and Measures
BLITS	Ball Lens In The Space
BKG	Bundesamt für Kartographie und Geodäsie (Germany)
BSW	Bernese Software

◆ ◆ ◆

Cal/Val	Calibration/Validation
CAS	Chinese Academy of Sciences
CASM	Chinese Academy of Surveying and Mapping
CB	Central Bureau
CC	Combination Center
CCD	Charge-Coupled Device
CCR	Corner Cube Reflector
CCTV	Close Circuit Television
CDDIS	Crustal Dynamics Data Information System (USA)
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astrométrie (France)
CfA	Center for Astrophysics (USA)
CFD	Constant Fraction Discriminator
CGS	Centro di Geodesia Spaziale (Italy)
CHAMP	CHAllenging Mini-Satellite Payload
CLG	Central Laboratory for Geodesy (Bulgaria)

CLS	Collecte, Localisation, Satellites (France)
CNES	Centre National d'Etudes Spatiales (France)
CODE	Center for Orbit Determination in Europe
CoM	Center of Mass
CONGO	Cooperative Network for GIOVE Observation
COPs	Control Operation Planning Subsystem (Japan)
COSI	COrea SAR Instrument
COSPAR	Committee on Space Research
COTS	Commercial Off The Shelf
CPF	Consolidated Prediction Format
CPP	Combination Pilot Project
CRD	Consolidated Laser Ranging Data format
CRDF	Civilian Research and Development Foundation
CRL	Communications Research Laboratory (Japan)
Cr:YAG	Crystal Yttrium Aluminum Garnet
C-SPAD	Compensated Single Photoelectron Avalanche Detector
CSR	Center for Space Research (USA)
CSRIFS	Combined Square Root Information Filter and Smoother (Finland)
CSTG	International Coordination of Space Techniques for Geodesy and Geodynamics
CTU	Czech Technical University (Czech Republic)

◆ ◆ ◆

DEM	Digital Elevation Model
DEOS	Department of Earth Observation (The Netherlands)
DFPWG	Data Formats and Procedures Working Group
DGFI	Deutsches Geodätisches ForschungsInstitut (Germany)
DAO	Dihedral Angle Offsets
DLR	German Aerospace Center
DoD	Department of Defense (USA)
DOGS	DGFI software
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPSSL	Diode Pumped Solid State Laser
DTOF	Differential Time of Flight
DUT	Delft University of Technology (The Netherlands)

◆ ◆ ◆

EDC	EUROLAS Data Center (Germany)
EGU	European Geophysical Union
ELT	European Laser Time Transfer Experiment
ENSO	El Ni o-Southern Oscillation
EO	Earth Observation
EOP	Earth Orientation Parameter
EOS	Earth Observing System (USA)
EOS	Electro Optical Systems (USA)
EOST	EOS Technologies, Inc. (Australia)
ERP	Earth Rotation Parameter
ERS	European Remote Sensing Satellite
Er:YAG	Erbium Yttrium Aluminum Garnet
ESA	European Space Agency

ESOC	ESA Space Operations Center
ET	Event Timer
ETS	Engineering Test Satellite
EU	European Union
EUREF	IAG Reference Frame Sub-Commission for Europe
EUROLAS	European Laser Consortium

◆ ◆ ◆

FAA	Federal Aviation Administration (USA)
FCEFN	Facultad de Ciencias Exactas, Físicas y Naturales (Argentina)
FDF	Flight Dynamics Facility (USA)
FESG	Forschungseinrichting Satellitengeodäsie (Research Facility for Space Geodesy, Germany)
FFDP	Far Field Diffraction Pattern
FFI	Forsvarets ForskningsInstitutt (Norwegian Defense Research Establishment)
FOV	Field Of View
FPGA	Field Programmable Gate Array
FR	Full-Rate
FRD	Full-Rate Data
FTLRS	French Transportable Laser Ranging System
FTP	File Transfer Protocol

◆ ◆ ◆

GA	Geoscience Australia
GAOUA	Main Astronomical Observatory of the National Academy of Sciences of Ukraine
GB	Gigabyte
GeoDAF	Geodetical Data Archive Facility (Italy)
GEO	Group on Earth Observations
GEOS	Geodetic and Earth Orbiting Satellite
GEOSS	Global Earth Observation System of Systems
GEST	Goddard Earth Sciences and Technology Center (USA)
GETEMME	Gravity, Einstein’s Theory, and Exploration of the Martian Moons’ Environment
GFO	GEOSAT Follow-On (USA)
GFZ	GeoForschungsZentrum (Germany)
GGAO	Goddard Geophysical and Astronomical Observatory (USA)
GGOS	Global Geodetic Observing System
GIA	Glacial Isostatic Adjustment
GIOVE	Galileo in Orbit Validation Experiment
GIS	Geographic Information System
GLAS	Geoscience Laser Altimeter System (USA)
GLONASS	Global Navigation Satellite System
GLONASS	Global’naya Navigatsionnay Sputnikovaya Sistema
GM	Gravitational Constant
GNSS	Global Navigation Satellite System
GOCE	Gravity Field and Steady-state Ocean Circulation Explorer
GOLDEN	GIS, Ocean and Land management, Disaster and Environmental monitoring
GP-B	Gravity Probe B
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GRGS	Groupe de Recherches de Geodesie Speciale (France)

GSFC	Goddard Space Flight Center (USA)
GSOC	German Space Operations Center
GSTB	Galileo System Test Bed
GUTS	Global and High Accuracy Trajectory Determination System

◆ ◆ ◆

H2A/LRE	Laser Ranging Experiment
HAC	High Accuracy Clock
HartRAO	Hartebeesthoek Radio Astronomy Observatory (South Africa)
HDD	Hard Disk Drive
HEO	High Earth Orbiter
Hit-U	Hitotsubatshi University (Japan)
HOLLAS	Haleakala Laser Station (USA)
HP	Hewlett-Packard
HPWREN	High Performance Wireless Research and Educational Network (USA)
HTSI	Honeywell Technology Solutions, Inc. (USA)
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
HxET	Herstmonceux Event Timer

◆ ◆ ◆

IAA	Institute of Applied Astronomy (Russia)
IAC	Information-Analytical Center (Russia)
IAG	International Association of Geodesy
IAPG/TUM	Institute of Astronomical and Physical Geodesy of the Technische Universität München (Germany)
IAPSO	International Association for the Physical Sciences of the Oceans
IA/RAS	Institute of Astronomy/Russian Academy of Sciences
IAU	International Astronomical Union
ICCD	Intensified Charged Coupled Device
ICESat	Ice Cloud and Land Elevation Satellite
ICET	International Center for Earth Tides
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IDS	International DORIS Service
IEEE	Institute of Electrical and Electronics Engineers
IERS	International Earth Rotation and Reference Systems Service
IFE	Institut für Erdmessung (Germany)
IGeS	International Geoid Service
IGFS	International Gravity Field Service
IGGOS	Integrated Global Geodetic Observing System
IGLOS	International GLONASS Service
IGN	Institut Geographique National (France)
IGNE	Instituto Geografico Nacional de Espa a (Spain)
IGOS	Integrated Global Observing Strategy
IGS	International GNSS Service
ILRS	International Laser Ranging Service
ILRSA	ILRS A solution
ILRSB	ILRS B solution
IMVP	Institute of Metrology for Time and Space (Russia)

INASAN	Institute of Astronomy of the Russian Academy of Sciences
INFN	Istituto Nazionale di Fisica Nucleare (Italy)
INGV	Istituto Nazionale di Geofisica (Italy)
InSAR	Interferometric Synthetic Aperture Radar
IOV	In Orbit Validation
IPIE	Science Research Institute for Precision Instrument Engineering (Russia)
IR	Infrared
IRS	Indian Research Satellite
IRV	Inter-Range Vector
ISGN	Integrated Space Geodetic Network
ISRO	Indian Space Research Organization
ISS	International Space Station
ISTRAC	ISRO Telemetry Tracking and Command Network (India)
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
IVS	International VLBI Service for Geodesy and Astrometry

◆ ◆ ◆

JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology (USA)
JGM	Joint Gravity Model
JGR	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory (USA)

◆ ◆ ◆

KACST	King Abdulaziz City for Science and Technology (Saudi Arabia)
KARI	Korea Aerospace Research Institute
kHz	Kilohertz
KOMPSAT	Korea Multi-Purpose Satellite

◆ ◆ ◆

LAGEOS	LAser GEOdynamics Satellite
LAREG	Laboratoire de Recherches en Géodésie (France)
LARES	Laser Relativity Satellite
LEO	Low Earth Orbit
LLR	Lunar Laser Ranging
LNF	Laboratori Nazionali di Frascati (Italy)
LNU	Lviv National University (Ukraine)
LOD	Length Of Day
LOLA	Lunar Orbiter Laser Altimeter
LR	Laser Ranging
LRC	Laser Radar Control
LRA	Laser Retroreflector Array
LRE	Laser Retroreflector Experiment
LRO	Lunar Reconnaissance Orbiter
LRO-LR	Lunar Reconnaissance Orbiter Laser Ranging
LRRA	Laser Retro Reflector Array

LTT	Laser Time Transfer
LURE	LUnar Ranging Experiment

◆ ◆ ◆

MAO	Main Astronomical Observatory (Ukraine)
MCC	Mission Control Center (Russia)
MCP	Micro Channel Plate
MeO	Meteorology and Optics (France)
MEO	Medium Earth Orbit
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MGS	Mars Global Surveyor
MHz	Megahertz
MLA	Mars Laser Altimeter
MLRO	Matera Laser Ranging Observatory (Italy)
MLRS	McDonald Laser Ranging System (USA)
MOBLAS	MOBile LASer Ranging System
MOLA	Mars Orbiter Laser Altimeter
MoonLIGHT	Moon Laser Instrumentation for General relativity High- Accuracy Tests
MPACS	Mount Positioning and Control Subsystem
MSTA	Ministry of Science and Technology of Argentina
MSTC	Ministry of Science and Technology of China
MWG	Missions Working Group

◆ ◆ ◆

NAO	National Astronomical Observatories (China)
NAOC	National Astronomical Observatories of Chinese Academy of Sciences
NAS	National Academy of Sciences (Ukraine)
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency (Japan)
NASU	National Academy of Sciences of Ukraine
NCEP	National Centers for Environmental Prediction (USA)
NCL	University of Newcastle Upon Tyne (UK)
NCST	Naval Center for Space Technology (USA)
Nd:YAG	Neodymium Yttrium Aluminum Garnet
Nd:YLF	Neodymium: Yttrium Lithium Fluoride
Nd:YVO	Neodymium-doped yttrium orthovanadate
NEAR	Near Earth Asteroid Rendezvous
NEOS	National Earth Orientation Service (USA)
NERC	Natural Environment Research Council (UK)
NEWG	Networks and Engineering Working Group
NGA	National Geospatial-Intelligence Agency (USA)
NGSLR	Next Generation Satellite Laser Ranging system (USA)
NICT	National Institute of Information and Communications Technology (Japan)
NIGGG	National Institute of Geophysics, Geodesy and Geography
NIM	Nuclear Instrumentation Measurement
NOAA	National Oceanic and Atmospheric Administration (USA)
NP	Normal Point
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPT	Normal Point

NRC	National Research Council (USA)
NRIAG	National Research Institute of Astronomy and Geophysics (Egypt)
NRL	Naval Research Laboratory (USA)
NSF	National Science Foundation (USA)
NSGF	NERC Space Geodesy Facility (UK)
NTUA	National Technical University of Athens (Greece)
NUSJA	National University of San Juan of Argentina

◆ ◆ ◆

OAFA	Observatorio Astronómico Félix Aguilar (Argentina)
OC	Operations Center
OCA	Observatoire de la Côte d'Azur (France)
OGT	Observatoire Géodésique de Tahiti (French Polynesia)
OICETS	Optical Inter-orbit Communications Engineering Test Satellite (Japan)
OSTM	Ocean Surface Topography Mission

◆ ◆ ◆

PALSAR	Phased Array L-band Synthetic Aperture Radar (Japan)
PAS	Polish Academy of Sciences
PCA	Point of Closest Approach
PCIe	Peripheral Component Interconnect Express
PDF	Portable Document Format
PHARAO	Projet d'Horloge Atomique par Refroidessement d'Atome en Orbite (France)
PMSL	Permanent Service for Mean Sea Level
PMT	Photo Multiplier Tube
POD	Precision Orbit Determination
POE	Precise Orbit Ephemerides
POLAC	Paris Observatory Lunar Analysis Center (France)
PP	Pilot Project
PPET	Portable Pico-Second Event Timer
PPS	Part Per Second
PRARE	Precise Range and Range-rate Equipment
PROBA	Project for On-Board Autonomy

◆ ◆ ◆

QC	Quality Control
Q/C	Quality Control
QLNP	Quick-Look Normal Point
QUEST	Quantum Engineering and Space-Time Research (Germany)
QZS	Quasi-Zenith Satellite (Japan)
QZSS	Quasi-Zenith Satellite System (Japan)

◆ ◆ ◆

R&D	Research and Development
RAS	Russian Academy of Sciences
REAPER	Reprocessing of Altimeter Products for ERS (Germany)
RG	Red-Green laser

RINEX	Receiver Independent Exchange format
RIS	Reflector In Space
RLEP	Robotic Lunar Exploration Program (USA)
RMS	Root Mean Square
RNAAC	Regional Network Associate Analysis Center
ROA	Real Instituto y Observatorio de la Armada (Spain)
RRA	Retro Reflector Array
RSA	Russian Space Agency
RSG	Refraction Study Group

◆ ◆ ◆

SALRO	Saudi Arabian Laser Ranging Observatory
SARAL	Satellite with ARgos and ALtiKa
SAO	Shanghai Astronomical Observatory (China)
SAO	Smithsonian Astrophysical Observatory (USA)
SAR	Synthetic Aperture Radar
SCF	Satellite/lunar laser ranging Characterization Facility (Italy)
SCF	System Configuration File
SELENE	Selenological and Engineering Explorer
SGF	Space Geodesy Facility (UK)
SGT	Stinger Ghaffarian Technologies, Inc. (USA)
SHAO	Shanghai Astronomical Observatory (China)
SHM	Space Hydrogen Maser
SINEX	Software Independent Exchange Format
SIRAL	SAR/Inteferometric Radar Altimeter
SIRGAS	Sistema de Referencia Geocéntrico para las Américas (Geocentric Reference System for the Americas)
SK	Statens Kartverk
SLR	Satellite Laser Ranging
SLRP	Satellite Laser Ranging Processor
SMS	Satellite Monitor Station (Japan)
SNPI	STandard Normal Point Interval
SNR	Signal-to-Noise Ratio
SOD	Site Occupation Designator
SOS-W	Satellite Observing System-Wettzell (Germany)
SP3	Standard Product 3 (satellite orbit format)
SPAD	Single Photoelectron Avalanche Detector
SPIE	International Society for Optical Engineering
SPWG	Signal Processing Working Group
SRI	Space Research Institute (Russia)
SRIF	Square Root Information Filter
SSC	Set of Station Coordinates
SSV	Set of Station Velocities
SSN	Space Surveillance Network (USA)
SST	Satellite-to-Satellite Tracking

◆ ◆ ◆

T2L2	Time Transfer by Laser Link
TanDEM	TerraSAR-X add-on for Digital Elevation Measurement
TC	Timer and Counter
TCE	Time Compare Equipment
TDC	Time-to-Digital Converter
TIGO	Transportable Integrated Geodetic Observatory
TIRV	Tuned Inter-Range Vector
Ti:Sap	Titanium Sapphire
Ti:Sapphire	Titanium Sapphire
TIU	Time Interval Unit
TKSC	Tskuba Space Center (Japan)
TLE	Two Line Element
TLRS	Transportable Laser Ranging System
TOF	Time-Of-Flight
TOPEX	Ocean TOPography Experiment
ToR	Terms of Reference
TOR	Tracking, Occultation and Ranging
T/P	TOPEX/Poseidon
T/R	Transmit/Receive
TRF	Terrestrial Reference Frame
TROS	TRansportable Observation Station
TROS	Transportable Range Observation System
TTS	Triple Threshold Screening
TUM	Technische Universität München (Germany)
TUP	Technical University of Prague (Czech Republic)
TWG	Transponder Working Group
TWSTFT	Two-Way Satellite Time and Frequency Transfer

◆ ◆ ◆

UCSD	University of California San Diego (USA)
UFP	Université de la Polynésie Française (French Polynesia)
UK	United Kingdom
UMBC	University of Maryland Baltimore County (USA)
UNAVCO	University NAVSTAR Consortium
UNESCO	United Nations Education, Scientific and Cultural Organization
UNSA	Universidad Nacional de San Augustin (Peru)
UNSJ	Universidad Nacional de San Juan (Argentina)
UPF	University of French Polynesia
UPS	Uninterruptible Power Supply
URL	Uniform Resource Locator
USA	United States of America
USB	Universal Serial Bus
USNO	U.S. Naval Observatory
UT	University of Texas
UTC	Universal Coordinated Time
UTX	University of Texas
UV	Ultraviolet

VLBI	Very Long Baseline Interferometry

◆ ◆ ◆

WESTPAC	Western Pacific Laser Tracking Network Satellite
WG	Working Group
WLRS	Wettzell Laser Ranging System (Germany)
WPLTN	Western Pacific Laser Tracking Network
YAG	Yttrium Aluminum Garnet
Yt:YAG	Ytterbium Yttrium Aluminum Garnet

◆ ◆ ◆

ZD	Zenith Delay