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Preface

This 2002 volume is the third published Annual Report for the International Laser Ranging Service (ILRS). With this year's report, we have chosen a different format, concentrating on achievements and work in progress rather than ILRS organizational elements. The 2002 ILRS Annual Report is structured as follows:

- Section 1, ILRS Organization, reviews the service and its role in space geodesy.
- Section 2, ILRS Tracking Network, provides the current status and recent performance statistics of the international stations supporting the ILRS and offers a perspective on site surveys and system collocations. An update on field engineering activities is also provided
- Section 3, ILRS Missions and Campaigns, gives information about many of the current and future missions supported by the ILRS.
- Section 4, Infrastructure, details recent activities tackled by the ILRS Central Bureau, including web site improvements and data center developments.
- Section 5, Tracking Procedures and Data Flow, discusses satellite predictions, ILRS tracking priorities, recent developments in the area of dynamic priorities, and the flow of on-site normal points and full-rate data.
- Section 6, Emerging Technologies, includes information about high repletion rate lasers and systems, detectors, timers and frequency standards, multi-wavelength ranging, and other hardware that will help advance the accuracy and automation of laser ranging systems. Also included are new applications for the SLR technique.
- Section 7, Analysis Pilot Projects, reviews the recent developments in the ILRS Analysis Working Group including the three pilot projects begun in 2002, Computation of Stations Positions and EOPs, Orbits, and Software Benchmarking.
- Section 8, Modeling, discusses recent advancements in refraction modeling and satellite center of mass corrections.
- Section 9, Science Coordination, examines the ILRS role in the ITRF, its synergy with the other geodetic techniques, and some interesting applications for both SLR and LLR.
- Section 10, Meetings and Reports, reviews ILRS-related meetings in 2002 and reports issued by the service.
- Section 11, Bibliography, lists some of the papers and presentations about SLR and LLR science and technology made during 2002.
- Section 12, ILRS Information, lists organizations participating in the ILRS and defines various acronyms used in this annual report.

This annual report is also available through the ILRS web site at URL http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrsar_2002.html.

Acknowledgements

The editors would like to acknowledge the essential contributions from our ILRS colleagues to this 2002 edition of the ILRS Annual Report. We would also like to thank John Hazen of RITSS for his design of the cover art and layout for the report.

Challenges For SLR

In The Realization of The Terrestrial Reference Frame, Modelling of The Earth's Gravity Field, Earth Rotation And Geodynamics, Positioning And Applications

The International Association of Geodesy (IAG) installed its new structure during the XXIII IUGG General Assembly in Sapporo Japan, July 2003. It consists of Services and Commissions at the same hierarchic level, namely the IAG Services

- International Earth Rotation Service (IERS),
- International GPS Service (IGS),
- International Laser Ranging Service (ILRS),
- International VLBI Service (IVS),
- International DORIS Service (IDS),
- International Gravimetric Bureau (BGI),
- International Geoid Service (IGeS),
- International Center for Earth Tides (ICET),
- International Gravity Field Service (IGFS) to combine BGI, IGeS and ICET,
- Permanent Service for Mean Sea Level (PSMSL),
- International Bureau of Weights and Measures (BIPM, Time Section),
- IAG Bibliographic Service (IBS),

and the IAG Commissions,

- Commission 1 Reference Frames,
- Commission 2 Gravity Field,
- Commission 3 Earth Rotation and Geodynamics,
- Commission 4 Positioning and Applications.

Furthermore there are three Inter-commission Committees (ICC)

- Inter-commission Committee on Planetary Geodesy,
- Inter-commission Committee on Geodetic Standards,
- Inter-commission Committee on Theory,

and the IAG Project

- Integrated Global Geodetic Observing System (IGGOS)

as well as the IAG

- Communication and Outreach Branch (www.iag-aig.org).

The role of SLR within the services will be quite clear to the readers of this article. It is reported in detail within the present annual report of the ILRS. There are, however, also great challenges for the scientific use of SLR within the Commissions. While the Services concentrate on the generation of products and related investigations, the Commissions deal with fundamental research in the corresponding fields. This includes in particular the basic study of

benefits and shortcomings of the individual geodetic techniques as well as its consistent combination for geodetic parameter estimation (e.g., time dependent position, orientation and gravity field parameters). SLR plays a major role in this research which shall be highlighted in the following.

IAG Commission 1 is divided into four sub-commissions (SC), namely

- SC1.1 Coordination of Space Techniques,
- SC1.2 Global Reference Frames,
- SC1.3 Regional Reference Frames,
- SC1.4 Interaction of Celestial and Terrestrial Reference Frames.

Sub-commission 1.1 will study, as its major objectives, the systematic effects of or between space geodetic techniques, develop common modelling standards and processing strategies, compare and combine orbits derived from different techniques, explore and develop innovative combination aspects and establish methods to validate the combination results. In cooperation with Commissions 2 and 3 as well as IGGOS there is a Working Group to study the interaction and consistency between terrestrial reference frame, Earth rotation, and gravity field. SLR is an extremely important component in these investigations due to its direct link to all three parameter groups.

Sub-commission 1.2 has the primary objectives of the definition and fundamental study of the realization aspects of global terrestrial reference frames. This includes the analysis of the specific contributions of individual techniques to the datum realization, the methodology of an optimum combination, and the definition of common standards for all techniques. SLR is indispensable for realizing the origin of the global terrestrial reference frame due to its direct connection to the Earth's centre of mass. SC1.2 will also deal with the implementation of the concept of Global Geodetic Observatories where general problems of the connection between different techniques' observing systems (including SLR) at co-location sites will be studied.

Sub-commission 1.3 will, among others, develop specifications for the definition and realization of regional reference frames, including vertical datums, coordinate the activities of regional sub-commissions focusing on exchange and sharing of expertise and results, and assist the countries to redefine and modernize their national geodetic systems, compatible with the ITRF. Due to its long history of observations and the resulting reliability of station coordinates and velocities, SLR observatories are very important for the establishment of regional reference frames. This holds in particular for the vertical component (heights).

Sub-commission 1.4 will deal with theoretical aspects of the relation between celestial and terrestrial reference frames. One major topic is the realization of the inertial reference frame needed for satellite orbit computations. A Working Group on satellite gravity theory will study, in cooperation with the ICC on theory, in particular the satellite dynamics in the quasi-inertial reference system which can be done in a best way using the precise SLR observations.

IAG Commission 2 has also got a structure of four sub-commissions. These are

- SC2.1 Gravimetry and Gravity Networks,
- SC2.2 Spatial and Temporal Gravity Field and Geoid Modelling,
- SC2.3 Dedicated Satellite Gravity Mapping Missions,
- SC2.4 Regional Geoid Determination.

SLR is mainly involved in Sub-commission 2.3 with its activities focussing on the generation of the best static and temporal global gravity models based on observations by space-borne techniques. Laser ranging to the satellites of the gravity missions, at present CHAMP and GRACE, in the future also GOCE, provides precise absolute distances between the ground-based tracking stations and the satellites which enable the most accurate orbit determination. This is necessary for comparing, validating and calibrating the orbits generated from other techniques. The combination of SLR with the GPS high-low mode of satellite-to-satellite tracking (SST) allows a significantly improved modelling of the orbits.

Besides the direct use of laser ranging for orbit determination of the gravity mission satellites, SLR will also contribute to the gravity field modelling by means of the tracking of other satellites such as LAGEOS-1 and -2. The combination of these long time series of tracking data with the modern SST data will stabilize in particular the long wavelength components of the gravity field and their secular and long-period time variations.

IAG Commission 3 comprises three sub-commissions:

- SC3.1 Earth Tides,
- SC3.2 Crustal Deformation,
- SC3.3 Geophysical Fluids.

SLR will provide major input for Sub-commission 3.2, the objectives of which comprise the study of tectonic motions including plate deformation, postglacial rebound, and local crustal deformations, in particular in coastal regions to model sea-level fluctuations in correlation with vertical crustal movements. The long time series of SLR station positions will allow a detailed long-term modelling of these motions and deformations. More than 20 years of precise positioning will enable us to separate linear, periodic and episodic point movements, a fundamental issue in crustal deformation research. Due to the high precision of the radial component in SLR positioning, it will be indispensable for monitoring height variations in a global scale.

IAG Commission 4 is composed of five sub-commissions:

- SC4.1 Multi-sensor Systems,
- SC4.2 Applications of Geodesy in Engineering,
- SC4.3 GNSS Measurement of the Atmosphere,
- SC4.4 Applications of Satellite and Airborne Imaging Systems,
- SC4.5 Next Generation of Real-Time Kinematic Positioning.

SLR will enter here indirectly by contributing to the realization of the reference frames for the – mainly GPS-based – positioning and application.

As one may see from this incomplete listing, SLR is involved in nearly all fields of geodetic research within IAG. It is a basis for global geometric and gravimetric reference systems and for geodynamic studies. The cooperation between the IAG Services, among those the ILRS, and the Commissions is a fundamental requirement for the scientific work of IAG to the benefit of the international scientific community and society.

Hermann Drewes
President of IAG Commission 1

Chairman's Remarks

I am pleased to present to our ILRS Associates our fourth Annual Report covering ILRS activities in the year 2002. Previous reports are also available as hard copy from the Central Bureau or online at the ILRS website.

The International Laser Ranging Service (ILRS) was created on 22 September 1998 at the 11th International Workshop on Laser Ranging in Deggendorf, Germany. The Central Bureau (CB) was established at the NASA Goddard Space Flight Center. In July 1999, the ILRS became an IAG Service joining the International GPS Service (IGS) and the newly created International VLBI Service (IVS), with close ties to the International Earth Rotation Service (IERS).

2002 has been another year of increased productivity for the network. Several new and exciting missions were added to the tracking roster, including Jason, Meteor-3M, Reflector, Envisat, and GRACE. The new TIGO site at Concepción became operational, several systems underwent substantial upgrade or total replacement, and one station (Zimmerwald) started to regularly submit data collected in two wavelengths.

One of last year's highlights was the 13th International Workshop on Laser Ranging, October 7-11, 2002, held in Washington, D.C, which again attracted a large number of international participants active or interested in satellite and lunar laser ranging. We were sorry to learn, however, that due to recently increased security procedures in the United States several scientists were unable to obtain the necessary travel documentation in time for the workshop and were unable to attend.

Data flow has been substantially expedited. The data from most stations are now available to the user within one to two hours. Sub-daily predictions and on-line near real-time time bias functions have had a very positive impact on operations.

In support of the ILRS Governing Board, the Working Groups (WGs) have provided the expertise necessary to make technical decisions, to plan programmatic courses of action, and to review and approve material for the ILRS knowledge databases. The ILRS WGs continue to attract talented people who have contributed greatly to the success of these efforts. The Missions WG is developing procedures to dynamically adjust tracking priorities. The WG also continues to work with new missions and campaign sponsors to develop and finalize tracking plans and to establish recommended tracking priorities. The Data Formats and Procedures WG has been reviewing existing formats and procedures, rectifying anomalies, providing standardized documentation through the website, and setting up study subgroups and teams to deal with more complicated or interdisciplinary issues, such as the development of improved atmospheric refraction correction models. The Networks and Engineering WG has developed a new comprehensive web-based facility for reviewing station performance, implemented a new on-line capability to update predictions in near real-time, and continued the development of the ILRS technology database. The Analysis WG has been working with the ILRS

Analysis Centers to develop a unified set of analysis products presented in the internationally accepted SINEX format. Three associated pilot programs are underway to assess differences among analysis products from the different centers. The Signal Processing Ad-Hoc WG continued to work on improved center-of-mass corrections and signal processing techniques for SLR satellites with the intent of documenting these on the ILRS website for user access. More detailed information on the activities of the Working Groups and the Central Bureau can be found elsewhere in this volume and on the ILRS website. ILRS Associates who wish to volunteer their time or ideas in support of any of these organizations are encouraged to contact the Central Bureau or the appropriate WG Coordinator.

John Degnan, chairman of the former IAG sub-commission for SLR/LLR and first chairman of the ILRS Governing Board, retired from active duty at NASA at the end of 2002. The new Governing Board elected at its October meeting the signatory as its new chairman. I would like to thank John for his long and intensive engagement in laser ranging activities. The successful transition from the former sub-commission to the new International Laser Ranging Service can be directly attributed to John's leadership.

My special thanks go to the team of the NASA-sponsored Central Bureau, operating under the direction of Michael Pearlman, for the continuous coordination of the activities of the global network. An obvious outcome of this activity is the mere existence of this annual report.

Werner Gurtner
ILRS Governing Board Chairperson
Astronomical Institute of Berne
Berne, Switzerland

Section 1

ILRS Organization

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 ILRS is one of the technique services of the International Association of Geodesy (IAG).

The Role of the 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

- Scale (Gm) and time-varying Earth Center of Mass for the ITRF
- Static and time-varying coefficients of the Earth's gravity field
- Earth orientation: polar motion and length of day
- Long-term time history of three dimensional station positions
- Accurate satellite ephemerides for POD and validation of altimetry, relativity, and satellite dynamics
- Backup POD for other missions

The Structure of the ILRS (Figure 1-1)

- Forty Tracking Stations that provide ranging data on an hourly basis;
- 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;

continued on page 16


NRL
Greenbelt
JPL
U. of Texas
Monument Peak
CSR
McDonald
Haleakala
Tahiti
Arequipa
Concepción
Laser System
Operations Center
Data Center
Analysis Center
Associate Analysis Center
Lunar Analysis Center
Central Bureau
* Station Pending
-165°
-150°
-135°
-120°
-105°
-90°
-75°
-60°
-45°
-30°

ILRS Map


FFI
ESA/ESOC
Newcastle U
FESG/IFE
GFZ/Potsdam
ERC/Herstmonceux
DGFI
Paris
CERGA/Grasse
Cagliari
San Fernando
AIUB/Zimmerwald
BKG
Borowiec
Wettzell
Graz
Metsahovi
IAA
Riga
IA/RAS
IMVP
MCC
Mendeleevo
GAOUA/Kiev
Simeiz
Katzively
CLG/BAS
ASI/Mate
Helwan
Riyadh
Maidanak
Komsomolsk
Changchun
Beijing
CRL
NASDA
Simosato
Tokyo
Wuhan
Shanghai
Kunming
Hartebeesthoek
Yarragadee
Mt. Stromlo
GA/NMD
Mobile Systems: FTLRS-1 (France)
TIGO (Germany)
TROS (China)
-30°
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0°
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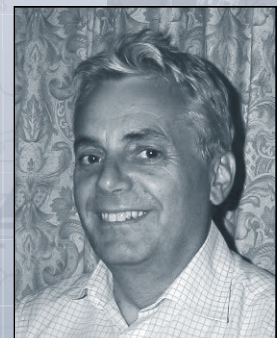
120°
135°
150°
165°



Name: Graham Appleby

Position: Analysis Center Representative

Affiliation: Natural Environment Research Council (NERC), UK

Name: Ben Greene

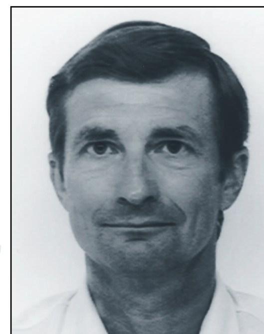
Position: WPLTN Network Representative

Affiliation: EOS PTy. Ltd, Australia

Name: Giuseppe Bianco

Position: EUROLAS Network Representative

Affiliation : Agenzia Spaciale Italiana (ASI), Italy



Name: Werner Gurtner

Position: Chairman and EUROLAS Network Representative

Affiliation: University of Berne, Switzerland

Name: David Carter

Position: NASA Network Representative

Affiliation : NASA Goddard Space Flight Center, USA

Name: Georg Kirchner

Position: At Large Representative

Affiliation: Austrian Academy of Sciences, Austria

Name: Herman Drewes

Position: Ex-Officio, President of IAG Commission 1

Affiliation: Deutsches Geodätisches ForschungsInstitut, Germany

Name: Hiroo Kunimori

Position: WPLTN Network Representative

Affiliation: Communications Research Laboratory, Japan

ILRS Governing Board

Name: Jan McGarry

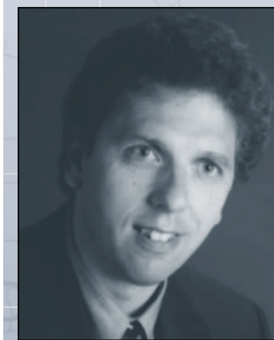
Position: NASA Network Representative

Affiliation : NASA Goddard Space Flight Center, USA

Name: Ulrich Schreiber

Position: At-Large Representative

Affiliation: Technische Universitaet Muenchen, Germany



Name: Carey Noll

Position: Ex-Officio, Secretary ILRS Central Bureau

Affiliation: NASA Goddard Space Flight Center, USA

Name: Bob Schutz

Position: IERS Representative to ILRS

Affiliation: University of Texas, USA

Name: Ron Noomen

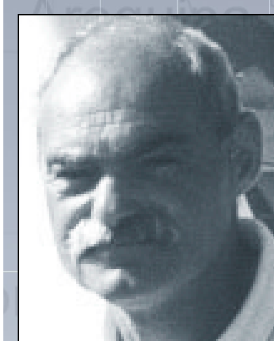
Position: Analysis Center Representative

Affiliation: Delft University of Technology, The Netherlands

Name: Wolfgang Seemueller

Position: Data Center Representative

Affiliation: Deutsches Geodätisches ForschungsInstitut, Germany



Name: Michael Pearlman

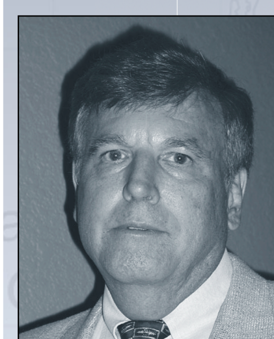
Position: Ex-Officio, Director, ILRS Central Bureau

Affiliation : Harvard-Smithsonian Center for Astrophysics, USA

Name: Peter Shelus

Position: Lunar Representative

Affiliation: University of Texas, USA



continued from page 11

- Three Analysis Centers and twelve Associate Analysis Centers that support the ITRF and routinely produce data products for the user community and provide a second level of data quality assurance in the network;
- 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

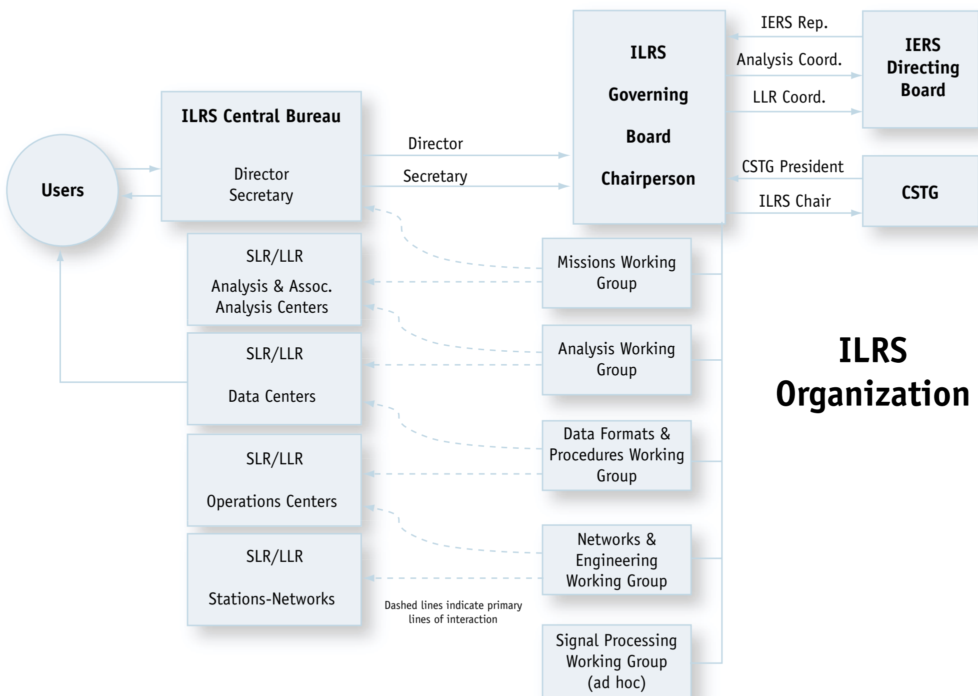


Figure 1-1. The ILRS Organization was estabished in 1998.

ILRS Information and Outreach

The ILRS Central Bureau maintains a comprehensive web site as the primary vehicle for the distribution of information within the ILRS community. The site, which can be accessed at: http://ilrs.gsfc.nasa.gov is also available at mirrored sites at the Communications Research Laboratory (CRL) in Tokyo and the European Data Center (EDC) in Munich.

Section 2 ILRS Tracking Network

Paul Stevens/ HTSI

Michael Pearlman/ CfA

ILRS Network

SLR activities continued to expand in 2002. Historically, the SLR network has been strong in the U.S., Europe, and Australia, but weak in other areas of the world. Over the past several years, priority has been placed on expanding geographic coverage, with particular emphasis on the Southern Hemisphere. A number of new stations have been added through international partnerships. In 2002, a number of very important improvements have been made. The map of the network is shown in Figure 2-1.

The new station in Concepción, Chile, established by the BKG (Germany) and a Chilean University consortium, is now operational with the BKG multi-technique Totally Integrated Geodetic Observatory (TIGO). With SLR, VLBI, GPS, and absolute gravimeter, the TIGO, now provides the first Fundamental Station in South America. A joint Chinese-Argentine SLR station at the San Juan Observatory in western Argentina is under development with SLR equipment furnished by the Beijing Astronomical Observatory. Unfortunately, a catastrophic forest fire destroyed the Mount Stromlo site in Australia and much of the surrounding area in early 2003. Reconstruction is in the planning stages with hopes that the station will be back in operation by early 2004. A program to improve the performance of MOBLAS-8 in Papeete, Tahiti was established in 2002 by NASA, CNES, and the University of French Polynesia.

The new state-of-the-art Matera Laser Ranging Observatory (MLRO) with both SLR and lunar ranging capability became operational with very impressive performance. Coupled with the on-site VLBI and GPS, the Matera station has now significantly improved its role as a European Fundamental Station. Several other systems in Europe have initiated upgrades or total replacement. Significant among these efforts is the Graz (Austria) two kHz laser upgrade that will, upon completion, provide substantially increased satellite return rates. The new Zimmerwald, Switzerland system, along with Concepción, started two wavelength operations in 2002 to help support atmospheric dispersion studies along with improved ranging. The new Potsdam (Germany) SLR station became operational, replacing the older system that had been in operation for more than eleven years. In the Ukraine, a new site established by the Astronomical Observatory of the Ivan Franko National University of Lviv, began operations at Lviv. The French Transportable Laser Ranging System (FTLRS) was operated from January 2002 to September 2002 at the Ajaccio, Corsica, the system's first occupation outside the Grasse Observatory in its new configuration. In 2003 it will be moved to Chania, Crete.

The performance of the Mt. Haleakala system improved significantly during 2002 with the completion of the long-awaited mount refurbishment. Work continued on the Apache Point Observatory Lunar Laser-ranging Operation (APOLLO), a next generation lunar laser system being developed in New Mexico, USA. Work also continues on the NASA SLR2000 prototype with field test planned for spring 2004.

An upgraded SLR station at the Communications Research Laboratory (CRL) in Tokyo also became operational. The new Global and High Accuracy Trajectory determination System (GUTS) SLR system continued development by NASDA for deployment at Tanegashima.

In Shanghai, a new site is being built outside the city for relocation of the SLR system sometime in 2004. A Chinese mobile SLR station built by the Chinese Academy of Surveying and Mapping in Beijing has occupied a site Urumqi, as part of a national geodetic program.

Figure 2-1. The ILRS Tracking Network has been strengthened significantly in the Southern Hemisphere.

Network Performance

Network Performance Report Cards are issued quarterly by the ILRS Central Bureau. They tabulate the previous 12 months of data quality, quantity, and operational compliance by station and can be found on the ILRS web site. Guidelines for station performance have been established and are also tabulated on the ILRS web site. As shown in figures 2-2, 2-3, and 2-4, network data yield continues to increase as stations become more efficient, more satellites are added to the roster, and more stations join the network.

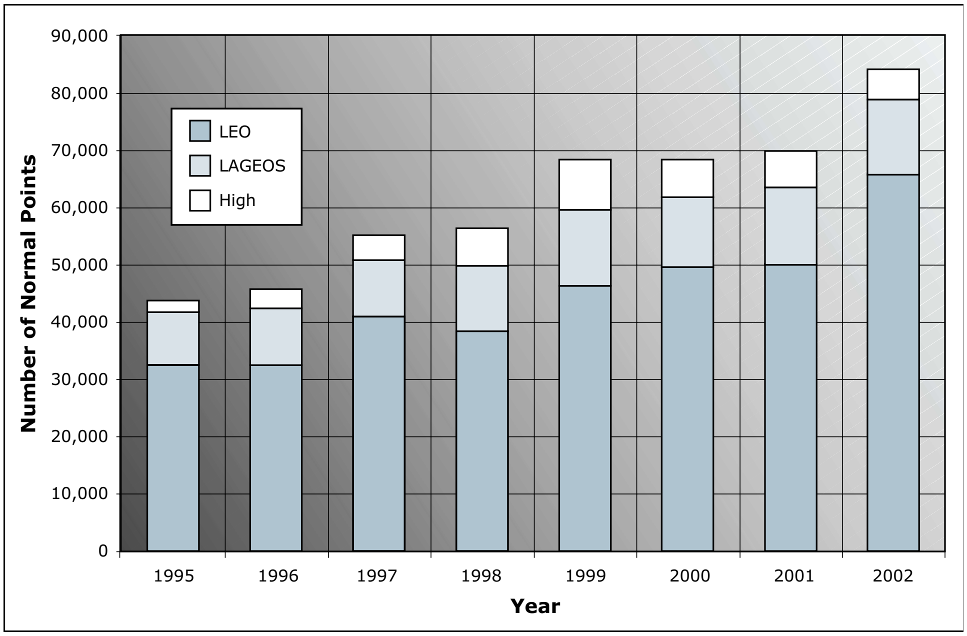


Figure 2-2. Network data yield continues to increase with improved automation and new satellites.

There is still a wide discrepancy in the data yield of the network stations. This may be in part due to weather conditions, level of automation, and funding support for operational personnel. Approximately half of the stations are now operating at the minimum data quantity level of 1500 passes per year. Some qualification will be adopted in 2003, to segregate stations with especially low performance into an Associate category.

All of the ILRS stations are now operating with normal point precisions of a few mm.

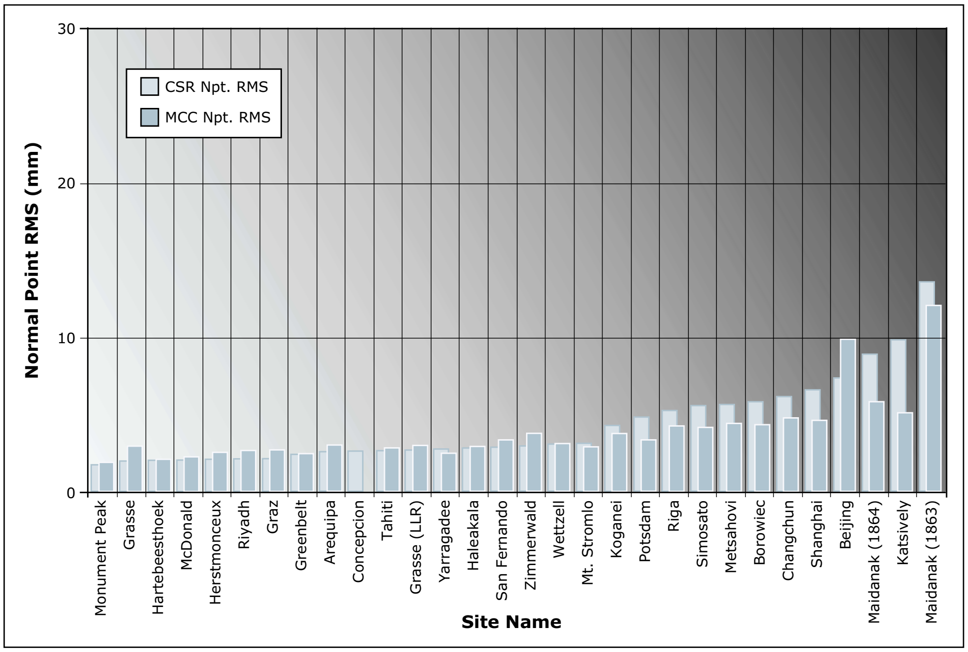


Figure 2-3. Nearly all ILRS Stations produce nornal points with rms values of a few mm.

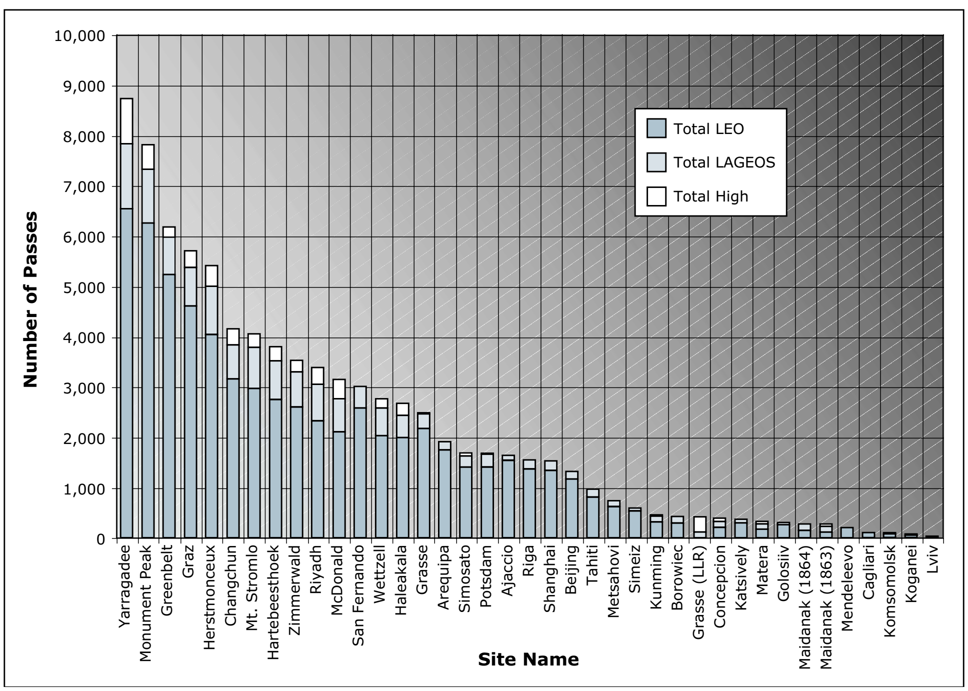


Figure 2-4. Approximately half of the ILRS Network stations now provide significant data yield. Others are in the process of upgrade or development.

Site Surveys and Collocations

Jim Long/ HTSI

Michael Pearlman/ CfA

Site surveys are a fundamental issue impacting the realization of the space geodetic reference frame, especially related to collocation of techniques needed for the TRF combination solution. The value of sub-centimeter measurement to the TRF can be lost through missing or inaccurate local ties, inconsistencies in the ground survey techniques used, poor survey control network geometry and monumentation, the improper analysis of survey data, the lack of documentation, and discrepancies between site survey and TRF results. Nearly all of the ILRS sites are collocated with GPS receivers and many are collocated with VLBI, DORIS, PRARE, and/or gravimeters (see Table 2-1). It is crucial to measure and monitor the local inter-technique vectors to the mm level in order to properly continue the measurements. The ISGN Sub-commission, under John Bosworth, made an assessment of the local survey status for each station in the SLR and VLBI networks; and developed an action plan with priority to critical sites.

A Joint Service team with the IGN (Zuheir Altamimi), the IVS (Chopo Ma), the ILRS (Mike Pearlman), and the NASA/Survey Team (Jim Long) are building on this earlier activity. It appears that this effort will likely evolve into a working group under the IERS. Jim Long has developed and circulated a draft survey standards document and is running tutorial survey sessions at major meetings. A joint IGN/NASA team is making arrangements to visit some of the most critical sites to help with survey procedures and training. One objective is to expand this team into a larger international effort to help expedite the completion of the outstanding surveys, standardize the documentation and reporting, and make the results available in an on-line database in SINEX format. The old SLR system eccentricity database, which documents the offsets between the ground monumentation and the optical intersection of axes, was recently converted into the SINEX format for ease of use

Table 2-1. Collocation of Space Techniques is crucial to the establishment of an accurate Terrestrial Reference Frame.

Site Name	Country	GPS/ GLONASS	VLBI	DORIS	PRARE	Gravimeter
Arequipa	Peru	X		X		
Beijing	China	X				X
Borowiec	Poland	X				X
Cagliari	Italy	X				
Changchun	China					
Concepción	Chile	X	X		X	
Grasse (2)	France	X				X
Graz	Austria	X				X
Greenbelt	USA	X	X	X	X	
Haleakala	USA	X				
Hartebeesthoek	South Africa	X	X	X	X	
Helwan	Egypt					
Herstmonceux	UK	X				
Katzively	Ukraine					
Kiev	Ukraine	X				
Koganei	Japan	X	X			
Komsomolsk	Russia					
Kunming	China	X				X
Lviv	Ukraine	X				
Maidanak (2)	Uzbekistan					
Matera (MLRO)	Italy	X	X		X	
McDonald	USA	X	X			
Mendeleevo	Russia	X				
Metsahovi	Finland	X		X		X
Monument Peak	USA	X				
Mount Stromlo	Australia	X		X		X
Potsdam	Germany	X				
Riga	Latvia	X				X
Riyadh	Saudi Arabia					
San Fernando	Spain	X				
Shanghai	China	X	X			
Simeiz	Ukraine	X				
Simosato	Japan					
Tahiti	F. Polynesia	X		X	X	
Wettzell	Germany	X	X			X
Wuhan	China	X				X
Yarragadee	Australia	X		X		
Zimmerwald	Switzerland	X				X
Totals:	40	31	8	7	5	11

Philip Gibbs/ NERC

Field Engineering

Comparisons of SR620 Interval Timers

The non-linearity of the SR620 interval timer is a potential source of bias in the SLR system. Tests over extended periods of time have also shown that the SR620 non-linearities in each timer are stable and repeatable (see Figure 2-5).

At the Eurolas Workshop held at Herstmonceux in March 2002 the SR620 timers from several stations were brought together for comparison tests against a single SR620 timer (D unit at Herstmonceux). Comparison measurements were made over the full dynamic range required by SLR. Although these were not absolute calibrations, the D unit had been previously calibrated against (1) the Portable Picosecond Event Timer (PPET) unit developed by the Technical University of Prague (using Dessault timers), (2) an HP5370A Interval Timer at Herstmonceux and (3) two HP5370B Interval Timers at Herstmonceux

The tests at Herstmonceux included the SR620 timers from Borowiec (2 units) Graz, Herstmonceux (2 units), Potsdam, San Fernando, and Zimmerwald, and one of the Herstmonceux HP5370B counters. Extrapolating the results back to the PPET as the standard, the tests showed that with careful calibration, the SR620 measurements could be recovered over the full range to about 10 ps. Full details were given at the 13th Laser workshop in Washington at: http: //cddisa.gsfc.nasa.gov/lw13/docs/papers/ time_gibbs_1m.pdf.

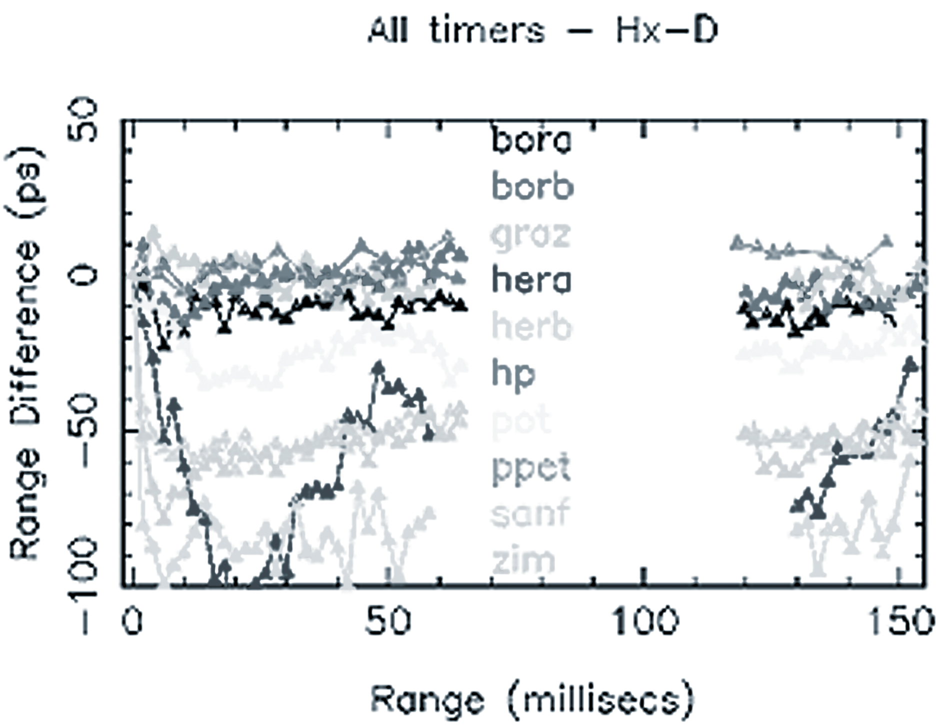


Figure 2-5. Non-Linearities in the SR620 Counters can now be calibrated to a few mm.

The Herstmonceux and Zimmerwald stations have implemented the corrections in on-site software processing. The range corrections have been provided to the user community for historical corrections. Since 2000, the Graz station has been using a Dessault event timer.

Comparisons of EUROLAS Station Barometers

SLR range measurements are also very susceptible to errors in barometric pressure readings. A one millibar error in pressure reading will introduce a 3 mm error in range at zenith. At the Eurolas workshop, it was agreed that a spare Druck DPI 141 barometer at Herstmonceux would be sent to each of the Eurolas stations for comparison checks. The test would also include a verification of the height correction from barometer position to telescope axis. Traveling barometer readings would to be taken next to the existing station barometer and next to the telescope axis. The difference would be interpreted as a height correction and would be compared with the height correction being used by the station.

All the stations within the European Economic Community were visited. The differences for each of the stations visited are given in Table 2-2 below.

Table 2-2. SLR range measurements are very susceptible to errors in barometric pressure readings, making accurate calibrations essential.

Station	Difference (mb)
Grasse SLR	0.09
Ajaccio	0.13
Grasse LLR	1.59
	0.14
Potsdam	0.06
Wettzell	0.30
Graz	0.55
Matera	0.30
Cagliari	–1.60
San Fernando	–0.03

Shortly after the tests, a new meteorology system installed at Graz confirmed the barometer error. As yet, no action has been taken at the Grasse LLR, but the offset has been posted on the ILRS web site for data users. The Cagliari SLR activity has since been closed. The height corrections being applied by all the stations were correct.

Plans have been made to visit the SLR stations at Zimmerwald and Borowiec.

Section 3 ILRS Missions and Campaigns

Scott Wetzel/ HTSI

Julie Horvath/ HTSI

Michael Pearlman/ CfA

Current Missions

During 2002, the ILRS supported 28 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions. The stations with lunar capability are also tracking the lunar reflectors. Missions are added to the ILRS tracking roster as new satellites are launched and as new requirements are adopted (see Figure 3-1). Missions for completed programs are deleted.

During 2002 several new satellites were added to the ILRS tracking roster as listed in Table 3-1.

Figure 3-1. New missions are added to the ILRS roster as new satellites are launched and new programs are adopted. Old missions are deleted as programs are completed.

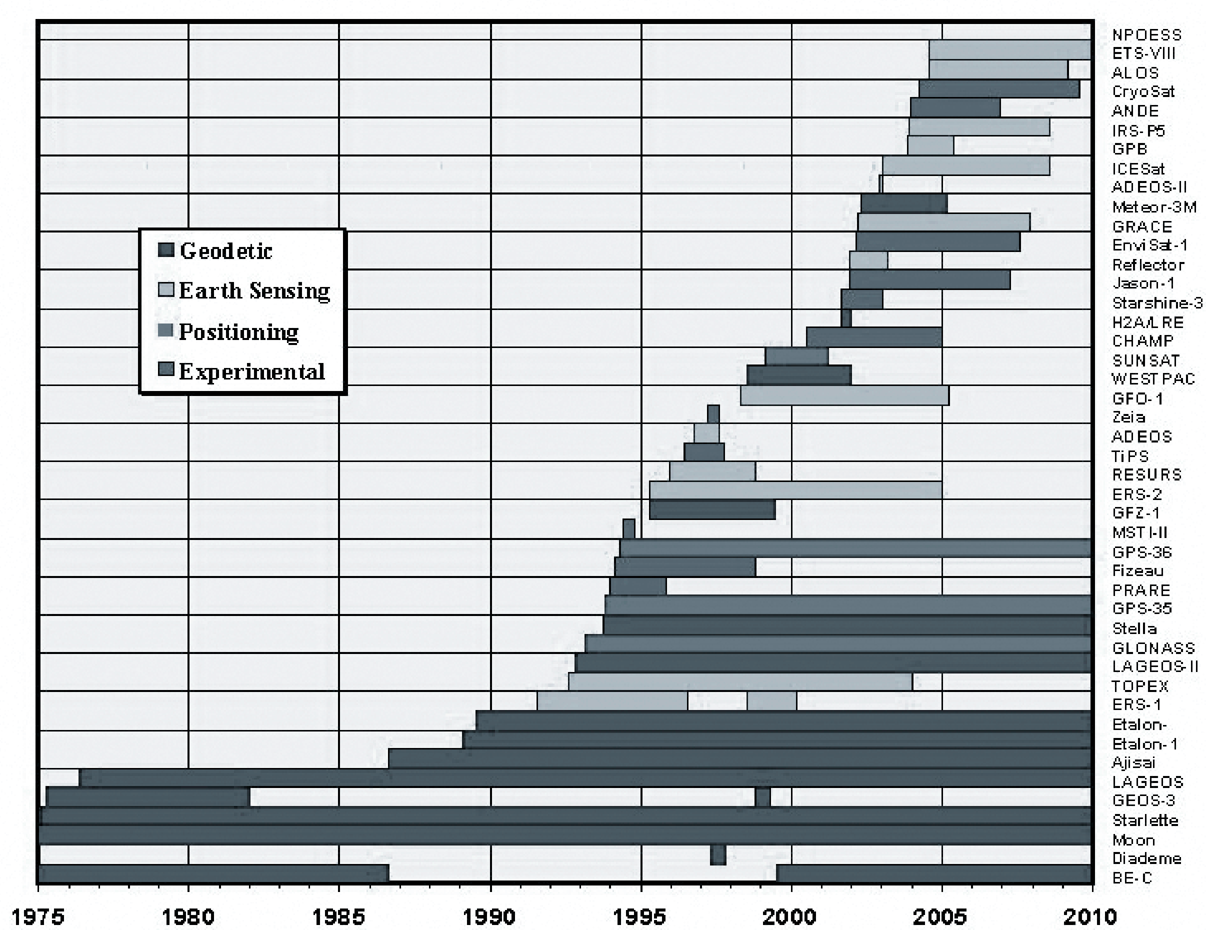


Table 3-1. New Missions in 2002

Mission	Launch	First Tracking	Sponsor	Application	Comments
Jason-1	07-Dec-01	10-Jan-02	NASA, CNES	Ocean surface altimetry	In tandem with TOPEX/Poseidon
Meteor-3M	10-Dec-01	01-May-02	NASA	Atmospheric constituents, test of Optical Luneberg Lens	POD after failure of radio tracking system
Reflector	10-Dec-01	20-Dec-01	IPIE	Spacecraft dynamics	One-year campaign
Envisat	01-Mar-02	10-Apr-02	ESA	Ocean surface altimetry	In tandem with ERS-2
GRACE-A/B	17-Mar-02	26-Mar-02	GFZ, NASA, CSR	Gravity field recovery	Separation of 30 seconds
ADEOS-2	14-Dec-02	14-Dec-02	NASDA	Microwave and optical sensing of the environment	One month of tracking by the network; limited tracking after launch with advance approval only

Some of the new missions were rather unique. The Russian Reflector satellite had retroreflectors over its nearly two meters length (see Figure 3-3). Differences in the laser return time-of-arrival (Figure 3-2) are being used to interpret the orientation and dynamics of the satellite. The Reflector tracking support will extend into early 2003.

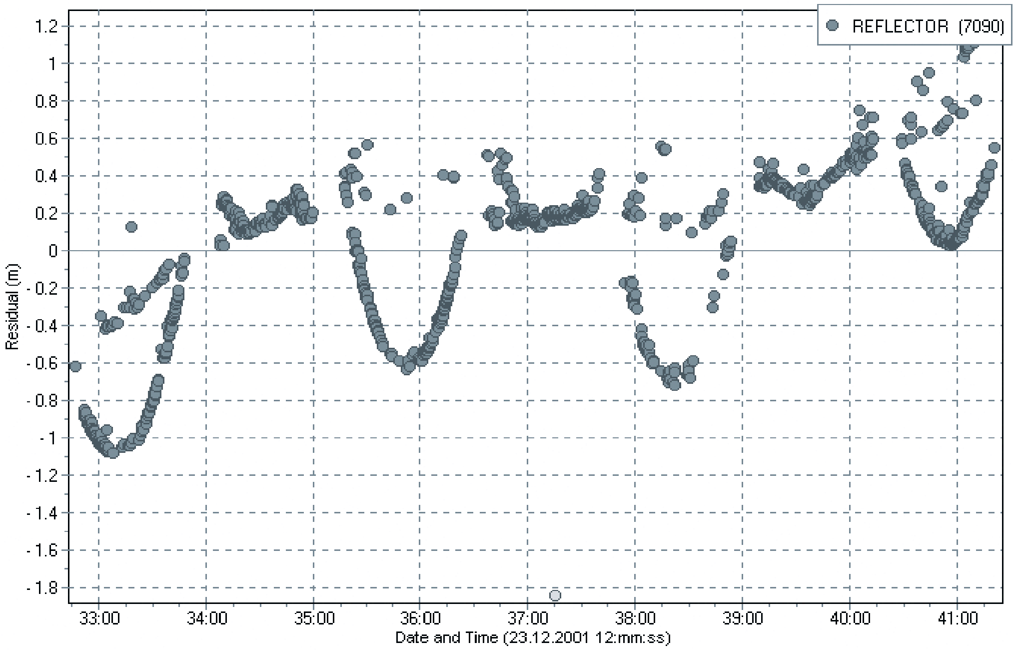
The Meteor-3M (Figure 3-4) satellite carried an Optical Luneberg Lens consisting of two concentric glass balls of different indices of refraction with one half covered with a reflective coating. Experiments were conducted on the lens to test it for future retroreflector designs. Although the tracking on Meteor-3M was planned as a six-week experiment, the immediate failure of the onboard GPS/GLONASS receiver following launch left the mission without routine tracking support for the on-board NASA Strategic Aerosol and Gas Experiment (SAGE) which is measuring the vertical structure of the atmosphere. After this failure, the ILRS approved routine SLR tracking for the mission.

Several of the missions involved tandem orbits. The GRACE-A and -B (Figure 3-5) satellites are two identical spacecraft positioned thirty seconds apart in a low orbiting configuration to measure intermediate and short wavelength structure of the gravity field using satellite to satellite tracking. GPS and SLR provide POD for the GRACE mission.

Jason-1 (Figure 3-6) is in a tandem orbit with TOPEX/Poseidon, originally separated by one minute in time, later moved into a six-minute separation. This configuration was adopted first to verify the Jason altimeter measurements and to then provide a wider swath of ocean topography. GPS and SLR provide POD and altimeter calibration and validation.

Envisat (Figure 3-7) is positioned in tandem orbit with ERS-2, separated by thirty minutes to provide periodic cross-validation for the altimeters and synthetic aperture radars on each of the satellites. The configuration is also being used to test INSAR concepts. DORIS and SLR provide POD for Envisat.

In December, the ILRS began a one-month tracking campaign in ADEOS-II (Figure 3-8) to help initialize the orbit of the satellite, prior to activating the optically sensitive global imager. After the campaign, a small number of stations will continue to track the satellite with very carefully controlled procedures to protect vulnerable onboard systems.



source Natalia Parkomenko

Figure 3-2. A distributed array of cornercubes on the Reflector Satellite is used to study spacecraft dynamiccs.

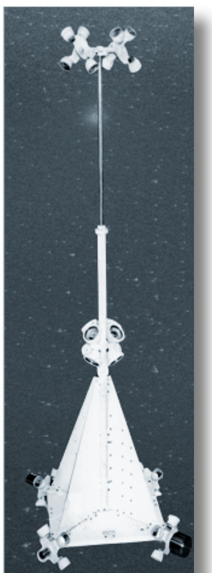


Figure 3-3. Reflector

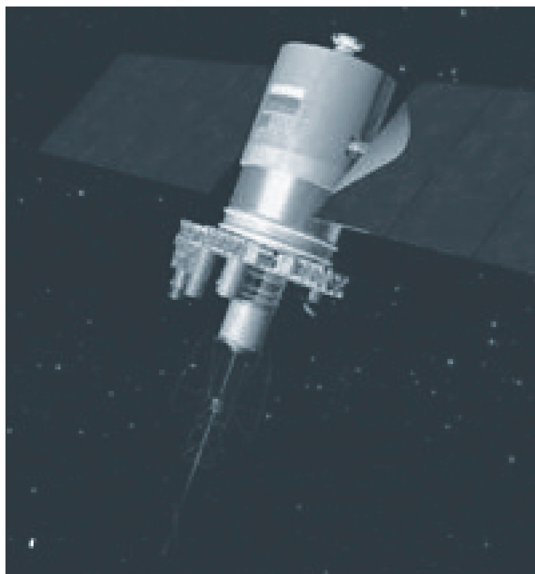


Figure 3-4. Meteor-3M

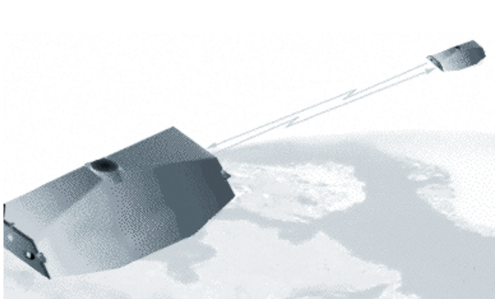


Figure 3-5. GRACE

In late October, tracking on the two Etalon satellites was elevated from campaign to regular status to support Earth orientation measurements, long wavelength gravity field recovery, and network quality control. The ILRS also continues to support the GPS and GLONASS missions for validation of the radio tracking systems.

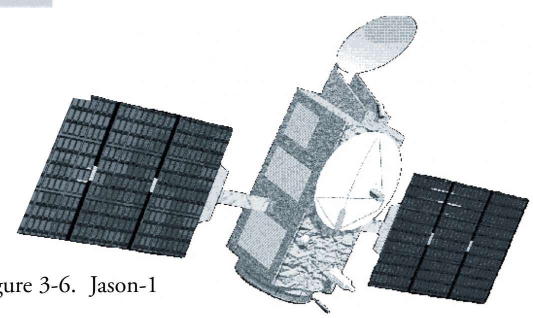


Figure 3-6. Jason-1

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS continues to encourage new missions with high precision orbit requirements to include retroreflectors. Retroreflectors are used as a fail-safe backup tracking system, for improvement of overall orbit precision, and for important intercomparison and calibration data for systems with onboard microwave navigation.

Figure 3-7. Envisat

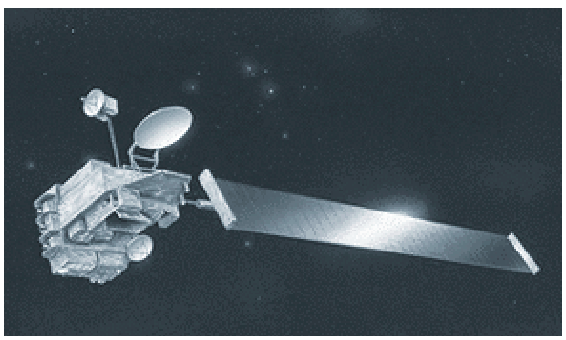


Figure 3-8. ADEOS-II

Future Missions

A number of new missions, showen in Table 3-2; requiring SLR support are scheduled for launch over the next two years. SLR will support POD and instrument calibration and validation for these missions.

Table 3-2. New missions are requesting SLR support for POD and instrument calibration and validation.

Mission	Sponsor	Scheduled Launch	Application
ICESat	NASA	January 2003	Altimetry satellite to study relative ice and ocean surface mass balance
GP-B	NASA, Stanford	November 2003	Check on theory of relativity through precise gyroscope measurements
STARSHINE-4/5	NRL, NASA, others	Mid 2004	Atmospheric drag measurements; student involvement to study atmospheric density
CryoSat	ESA	May 2004	Ice surface altimetry to study changes in ice thickness
ANDE	NRL	Late 2003	Digital communications transponder for amateur science
ALOS	NASDA	August 2003	Microwave and optical sensing of the environment
ETS-VII	NASDA	2004	Test of new geosynchronous satellite bus
NPOESS	NOAA, NASA, DoD	2013	Sea surface height

Section 4 Infrastructure

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Web site Developments

Enhancements to the ILRS web site continued in 2002. A re-engineered navigation scheme including bread crumbs and the re-formatting of each page using cascading style sheets gave the site a fresh and consistent look. Two new web applications were added: a news banner on the ILRS homepage and a template for satellite center of mass corrections. There were a number of minor content changes, but the most significant content addition was the information related to Timing Devices under the Engineering and Technology Section. The Timing Device pages included content on manufacturer specifications, BEST calibration and operational practices, error analysis, definition of key terms, and a complete timing related bibliography.

Even though not part of the main ILRS web site, a comprehensive web site in support of the 13th International Workshop on Laser Ranging was developed and deployed in 2002. This site included the daily session agendas, travel, lodging and registration information, conference photographs, session summaries, and links to workshop presentations, posters, and papers for the proceedings. The web site is accessible at http://cddisa.gsfc.nasa.gov/lw13.

ILRS Reporting

The Central Bureau continued to provide quarterly performance report cards in 2002. This report provides metrics with accompanying charts on ILRS network data quantity, data quality, and operational compliance. Analysis results from the MCC were added to those already included from the University of Texas to provide two independent assessments of station performance.

Sites were constantly reminded to review and update their Site and System Information Forms. These forms, commonly referred to as site logs, contain detailed site information (e.g., coordinates, contact information, collocation information, site identifiers, local survey ties, and system eccentricities), ranging machine sub-system configuration specifications (e.g., laser, telescope/mount, receiver, timing, meteorological devices, and data processing systems) along with system ranging capabilities.

Data Center Developments

Full-rate data

At the ILRS meetings held in conjunction with the Spring 2002 EGS General Assembly in Nice, the Network and Engineering Working Group requested that the data centers archive SLR full-rate data from the global network. Prior to this time, stations were to retain full-rate data on-site for one year; working group members feared that these data could be irretrievable and thus recommended a central archive. Although the data may not provide a real-time benefit, the data could be used in a historical sense to diagnose system issues.

The initial request included the archiving of calibration data along with satellite data; subsequent discussions dropped this requirement. Furthermore, recent missions (e.g., LRE, Reflector) have asked for full-rate data; analysts also believed these data should be retained to verify unusual signatures found in the normal point data. In the fall 2002, a request was issued to the ILRS stations to forward all full-rate data to the operational data centers on a daily basis, one file per satellite per day. The files are then archived at the global data centers in special daily subdirectories by satellite, station, and day of data. The CDDIS has established procedures, similar to those created for normal point data, to maintain monthly satellite files of full-rate data based upon these daily files. The flow of SLR full-rate data was set to commence on March 31, 2003. Additional details on the full-rate data procedures and archive can be found at http://ilrs.gsfc.nasa.gov/products_formats_procedures/fullrate/index.html.

Dual wavelength data

In 2002, both ILRS global data centers implemented procedures to effectively archive data from two wavelength laser systems. Prior to that time, data archiving software did not distinguish incoming passes based on wavelength; therefore passes with an identical satellite, station, and timestamp were rejected as duplicate data. Software was modified at the CDDIS and EDC to examine the wavelength used, in addition to other pass parameters, to ensure all data were properly archived.

Data integrity checks

As part of its operational data center responsibilities, EDC implemented further data integrity checks on all incoming SLR normal point data in 2002. The software now tests for valid values for seconds, surface pressure, temperature, and humidity, checks for modifications to the release flag, and validates the number of digits in the data record and the checksum. The ILRS operational data center at NASA/HTSI implemented similar data integrity software prior to 2002.

Section 5 Tracking Procedures and Data Flow

Julie Horvath/ HTSI

Tracking Priorities

The ILRS tries to order its tracking priorities (shown in Table 5-1) to maximize the utility for data users. Nominally tracking priorities decrease with increasing orbital altitude and increasing orbital inclination (at a given altitude). Priorities of some satellites are then increased to intensify support for active missions (such as altimetry), special campaigns (such as IGLOS), and post-launch intensive tracking campaigns. Some slight reordering may then be given to 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.

Table 5-1. Satellite Tracking priorities nominally decrease with increasing orbital altitude and increasing orbital inclination. Priorities are then adjusted to intensify support for the most important missions.

Priority	Satellite	Sponsor	Altitude (Km)	Inclination	Comments
1	GRACE-A/B	GFZ	500	89.0	Tandem orbit (30 sec. apart)
2	CHAMP	GFZ	429 - 474	87.3	
3	ADEOS-II	NASDA	800	98.6	Campaign through mid January 2003.
4	GFO-1	US Navy	790	108.0	SLR tracking only
5	Envisat	ESA	800	98.6	Tandem orbit with ERS-2 (30 min. apart)
6	ERS-2	ESA	800	98.6	
7	Jason	NASA/CNES	1,350	66.0	Tandem orbit with TOPEX (originally 1 min apart)
8	TOPEX/Poseidon	NASA/CNES	1,350	66.0	
9	Starlette	CNES	815 - 1,100	49.8	
10	Stella	CNES	815	98.6	
11	Meteor-3M	ROSAVIA-COSMOS	1,020	99.6	SLR tracking only
12	Reflector	ROSAVIA-COSMOS	1,020	99.6	Campaign through mid-January 2003
13	Beacon-C	NASA	950 - 1,300	41.0	
14	Ajisai	NASDA	1,485	50.0	
15	LAGEOS-2	ASI/NASA	5,625	52.6	
16	LAGEOS-1	NASA	5,850	109.8	
17	Etalon-1	Russian Federation	19,100	65.3	
18	Etalon-2	Russian Federation	19,100	65.2	
19	GLONASS-86	Russian Federation	19,100	65.0	Support for IGLOS
20	GLONASS-87	Russian Federation	19,100	65.0	Support for IGLOS
21	GLONASS-84	Russian Federation	19,100	65.0	Support for IGLOS
22	GPS-35	US DoD	20,100	54.2	
23	GPS-36	US DoD	20,100	55.0	
Priority	**Lunar Targets**	**Sponsor**			
1	Apollo 15	NASA			
2	Apollo 11	NASA			
3	Apollo 14	NASA			
4	Luna 21	Russian Federation			

Stations may also adjust priorities to accommodate local conditions such as system capabilities, weather, and special program interests.

Tracking priorities are formally reviewed semi-annually at the ILRS General Assembly Meetings. Updates are made as necessary at the discretion of the Governing Board. The Central Bureau communicates these updates to the ILRS stations.

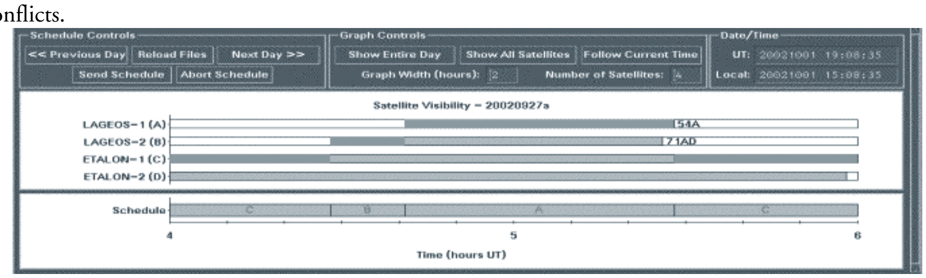
Dynamic Priorities

As the number of satellites tracked by the SLR network increases, the ILRS is considering options for setting priorities dynamically, taking into consideration any imbalance of data that may have resulted in an abundance of data on some satellites and a dearth on others. This may be partially the result of unavoidable conditions; but it may also be exacerbated by strict adherence to the priority list and lack of immediate knowledge on data flow from the rest of the international network. Several stations in close proximity may also be tracking one satellite, while other satellites go untracked.

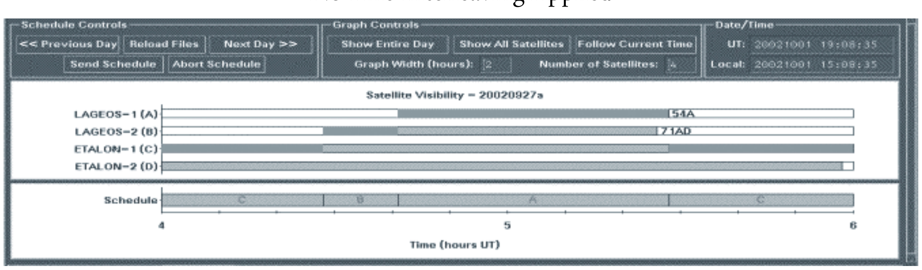
One option being considered is a daily or sub daily update from the Central Bureau on tracking imbalances to help make local scheduling decisions. This scheme would be based on previously tracked data, and would be updated through the AIUB automated prediction server. A second option includes preset data guidelines for changing local priorities.

In October 2002 at the 13th International Workshop on Laser Ranging in Washington, D.C., HTSI presented an “Intelligent Scheduler”, based on the current scheduling software developed for the Matera Laser Ranging Observatory. The software features dynamic prioritizing of satellites by satellite position, amount of recently tracked data, and/or unique station criteria. The software also features several optimizations, such as the fine interleaving optimization feature graphically displayed in Figure 5-1 below.

Figure 5-1. Careful scheduling permits stations to interleave satellite passes thereby minimizing the losses due to conflicts.



No Fine Interleaving Applied



Fine Interleaving Applied

Data Flow

During the past two years, the ILRS has addressed very important challenges that have improved the SLR satellite acquisition and satellite data quantity. 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 near real-time. The tracking on very low Earth orbit satellites has been significantly improved through the sub-daily issue of predictions, drag functions, and the real-time exchange of time bias information.

Predictions

There are now six centers that provide SLR predictions on a regular basis (see Table 5-2.) Quality assessments of the all of the predictions are available 24 hours a day/7 days a week on the AIUB near-real-time Time Bias Server. The NERC Space Geodesy Facility group at Herstmonceux is automatically and frequently collecting normal point data to compute updated time bias functions (with respect to available IRV sets) for all ILRS satellites. These time biases are distributed by a TCP/IP server program that accesses the latest time bias functions at NERC and computes time biases for the current epoch (including drag functions, if existing) for all available satellites and IRV sets. For all current predictions, stations can get the best current estimates of time bias for all satellites. Procedures for the usage of this real-time time bias information are available at the ILRS web site.

The ILRS is now examining consolidated laser ranging prediction formats that could be used for ranging to near Earth satellites and the moon, and for transponder ranging to planets and interplanetary spacecraft. Also included are options for standardizing prediction interpolators used at the stations.

Table 5-2. Six Centers provide satellite predictions to the Network Station on a regular basis.

Center	Interval	Satellites
GFZ	Sub-daily	ERS-2, GRACE-A/-B, CHAMP
HTSI	Daily	All
ESOC	Daily	Envisat
NASDA	Daily	LRE, ADEOS-II
MCC	Daily	Meteor-3M, Reflector
NERC	Weekly	All

Section 6 Emerging Technologies

*John J. Degnan/
Sigma Space
Corporation*

The engineering of SLR components is advancing rapidly on all fronts and are largely directed toward three goals: (1) 1 mm ranging accuracy; (2) remote, autonomous, and/or eyesafe operations; and (3) high repetition rate systems. These topics were discussed in more detail at the 13th International Workshop on Laser Ranging, held in Washington D.C. in October 2002.

High Repetition Rate Lasers and Systems

Some of the motivations for developing photon-counting, low energy, high repetition rate systems include: (1) the possibility of eye-safe operations which make remote or autonomous operations more likely; (2) diode-pumped low energy lasers are less prone to optical damage, longer-lived and require less maintenance; (3) range estimates based on photon-counting are totally unbiased and over many measurements accurately reproduce the impulse response of the target array and drive down the instrument systematic error; (4) many low energy range measurements at a high repetition rate substantially reduce normal point random error relative to a high energy, low rate system of equal power; (5) the possibility of generating unbiased estimates of the measured time of flight at two colors combined with a several order of magnitude increase in the range returns per normal point may overcome some of the current obstacles to correcting for the atmosphere via multicolor ranging; (6) large reductions in the replication and operational costs relative to larger manned systems; and (7) such systems pave the way for two-way interplanetary ranging with modest telescope apertures and laser powers and can serve as ranging beacons in future space-to-ground optical communications links.

At the end of 2002, the NASA developmental photon-counting SLR2000 system was undergoing system alignments in preparation for field testing. The Phase III transmitter, recently delivered to GSFC by Q-Peak Inc. (USA), consists of a diode-pumped microchip Nd:YAG oscillator, a diode-pumped passive multipass Nd:YVO4 (vanadate) amplifier, and BBO doubling crystal (Isyanova et al). It is somewhat more compact than the Phase II unit, has no liquid cooling and produces a 2 kHz train of 250 μJ, 290 psec pulses at 532 nm. The outgoing pulse fills the 40 cm aperture telescope and experiences almost a 50% throughput loss making it eyesafe at the telescope output window.

Graz Austria is also in the process of installing a high repetition rate (1-2 kHz) laser built by High Q Laser (Austria) (Kirchner and Koidl, 2003). The laser is expected to produce much shorter 10 psec pulses with energies of 400-500 μJ at 532 nm. The Nd:YVO4 SESAM (Semiconductor Saturable Absorber Mirrors) laser oscillator output is injected into a multipass regenerative amplifier followed by a power amplifier stage, and then frequency doubled to 532 nm. Using a lower energy (80 μJ) demonstration laser, the station obtained a return rate close to 100% from various low Earth orbiting satellites with good range quality. Although the laser was capable of kHz rates, the existing Graz PC controller limited operation to 125 Hz.

CRL in Tokyo also reported preliminary measurements to the TOPEX/Poseidon satellite using a frequency doubled, amplified microchip laser producing relatively high energies (8 mJ) at repetition rates up to 100 Hz, but the high laser jitter and long pulsewidth (2.3 nsec) unacceptably degraded the range accuracy (Amagi et al, 2003).

Detectors

With the growing emphasis on photon-counting and high repetition rate systems, the quantum efficiency (QE) and deadtime of the detector following detection of a "photon event" become increasingly important. The range return rate varies linearly with QE, and a long deadtime implies narrower range gates for operation against a solar background. Conventional bi-alkali or multi-alkali cathodes typically have green QE's in the 10% to 18% range. Actual counting efficiencies are often reduced to 60% or 70% of these numbers due to internal tube losses (e.g. the "dead space" between microchannels).

New gated GaAs photomultipliers with 30% QE from Burle Industries will be tested on MOBLAS 7 at GSFC in the near future (Hink et al, 2003). In a parallel development, Hamamatsu Corporation is now offering micro-channel plate photomultipliers with 40% QE GaAsP photocathodes and overall counting efficiencies of 26% at 532 nm, but the cost is currently about four times that of conventional bialkali tubes. The Hamamatsu tubes are also available in multi-anode configurations for quadrant or 3D imaging applications. Hamamatsu has also recently introduced new photon counting InGaAsP detectors covering the infrared out to 1700 nm (i.e., well into the eyesafe regime), but they must be cooled and counting efficiencies are typically less than 1%. MIT Lincoln Laboratory has recently been touting photon-counting InGaAsP arrays with QE's of 30% to 50% at 1064 nm.

Timers and Frequency Standards

Three quarters of the operational ILRS stations currently use single stop Time Interval Units (TIU's) (Husson and Stewart, 2003). The Hewlett-Packard HP5370B TIU has been the standard timer at NA sites since the mid-1980's whereas an equal number of European and Asian sites favor the slightly newer (1988) Stanford Research SR620 TIU's. A few stations are equipped with the A010 family of TIU's built by the Latvian University.

The remaining stations useulti-stop Event Timers (ET's) manufactured by Thales/PESO Consulting, EOS, HTSI, and Ortec. Although they are more expensive than TIU's, ET's are an absolute necessity for photon-counting systems such as SLR2000 or for lunar or interplanetary ranging applications. Except for the much older Ortec model, the newer ET's all have timing resolution specifications between 0.5 and 2 psec, low jitter, and good linearity. A space-qualified timer is being developed for OCS (France), but the stated 10 μsec recovery time seems too long to be useful for photon counting systems unless the range gate can be kept very narrow during signal acquisition (Samain, 2003).

Timers are ultimately only as good as the stability of their frequency standards. In order of increased frequency stability, commercial clocks include voltage-controlled crystal oscillators or VCO's ($>10^{-11}$), rubidium ($>10^{-13}$), cesium ($>10^{-14}$), and hydrogen maser ($>10^{-16}$). Since the cesium clocks on the GPS spacecraft are monitored and controlled by a ground network of highly accurate masers, the long term performance of a lesser oscillator can be improved by periodically comparing it to the 1 pps output of a GPS receiver and appropriately adjusting the frequency tuning controls of the lesser clock. GPS-steered VCO's and rubidiums are now available from a number of vendors.

A GPS-steered rubidium built by TruTime was chosen for SLR2000 and was installed in the NASA manned network as well. Rubidium oscillators are adequate for mm ranging to both artificial satellites and the Moon, but maser quality devices will be necessary for mm accuracy measurements over interplanetary distances.

Multi-Wavelength Ranging

Multiwavelength ranging has long been proposed as a means of reducing the systematic ranging error introduced by the atmosphere. It is generally believed that modern surface measurements of pressure, temperature, and relative humidity in conjunction with the atmospheric model developed by Marini-Murray over three decades ago can reduce the systematic range error to between about 4 mm at zenith and 12 mm at 20 degrees elevation. Unfortunately, multi-wavelength ranging remains an elusive goal since none of the differential time-of-flight (DTOF) satellite measurements to date have been precise enough to reduce the absolute atmospheric uncertainties below what are believed to be the model limits. In addition to a more complicated receiver technology which must measure differential times of flight with picosecond accuracy (e.g., streak tubes), the available satellite arrays were designed for cm, not mm, accuracy ranging, and the multicube, multiphoton return waveforms are often highly uncorrelated (e.g., different numbers of peaks) at the different wavelengths making the DTOF computation highly ambiguous.

Earlier two color satellite experiments (e.g., GSFC, Wettzell, Graz, etc.) relied on harmonics of Nd:YAG at 1064, 532, and/or 355 nm and in one case (Graz) a Raman-shifted line at 680 nm (Hamal et al, 2003). Later experiments in Tokyo carried out by a multi-national group (Japan, Australia, and Czech Republic) extended two-color measurements to an eyesafe wavelength at 1543 nm using Raman-shifting of Nd:YAG in Methane . Although NASA and German activities in this arena have waned somewhat in favor of technical progress on the SLR2000 and TIGO systems, recent work at 532/355 nm at the new Matera Laser Ranging Observatory (MLRO) suggest that the Marini-Murray model <u>may</u> underestimate the differential delay between the blue and green wavelengths by 10-15 mm (Bianco et al, 2003). Two color experiments with a frequency-doubled Titanium: Sapphire laser operating at 846 and 423 nm have recently been initiated at Zimmerwald (Gurtner, 2003).

Ancillary Hardware

The drive toward remote and totally autonomous operation has not only spurred the development of increasingly sophisticated operational software at a number of stations but also a variety of new sensors and actuators to replace crucial human interactions. NASA's SLR2000 "Smart Meteorological Station" measures all-sky cloud cover, ground visibility, precipitation, and wind speed/direction in addition to the usual temperature, pressure, and relative humidity needed for atmospheric calibrations. A commercialized version of the SLR2000 all-sky cloud camera is available from Raytheon (Mallama et al, 2003). A new photon-counting quadrant detector system is also being used to automate the centering of the satellite image within the SLR2000 receiver field of view (McGarry et al, 2003).

New Applications and Spinoffs

Among the new applications spawned by these technologies are interplanetary ranging and time transfer, laser ranging to orbiting debris, and low power altimetry. In contrast to two-way laser transponder links proposed in previous workshops, a one-way scheme for interplanetary ranging and time transfer utilizing highly accurate clocks was proposed (Samain, 2003). There has also been tracking of decimeter sized space debris using a combination of KW lasers operating at eyesafe wavelengths, guide stars, adaptive optics, and sub-microradian precision tracking mounts, suggesting that the tracking of 1 cm objects was within the realm of possibility (Greene et al, 2003). Early flight results from the first airborne microlaser altimeter, a spinoff of SLR2000 photon-counting technology, were reported (Degnan et al, 2003). Flying at cruise altitudes of up to 6.7 km and transmitting between 7 and 20 mW of laser power from a tiny (8 mm^3) passively Q-switched Nd:YAG microchip laser, the sensor recorded high resolution single photon returns from soil, vegetation, tree canopies, buildings, vehicles, etc and performed shallow water bathymetry to depths of a few meters.

References

Amagi, J., H. Kunimori, H. Kiuchi, T. Taira, "A satellite laser ranging system based on a micro-chip laser", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Bianco, G., T. Oldham, M. Bieneman, C. Clarke, V. Husson, "Two-Color Laser Ranging with the MLRO System", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Degnan, J., J. McGarry, T. Zagwodzki, P. Dabney, "Photon-Counting Airborne Microlaser Altimeter", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Greene, B., Y. Gao, C. Moore, Y. Wang, A. Boiko, I. Ritchie, J. Sang, J. Cotter, "Laser Tracking of Space Debris", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Gurtner, W., E. Pop, J. Utzinger, "Zimmerwald Dual-wavelength Operation: First Experiences", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Hamal, K., I. Prochazka, J. Blazej, Y. Fumin, H. Jingfu, J. Gaignebet, "Lasers for Multiwavelength Satellite Laser Ranging", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Hink, P., C. Tomasetti, J. Wright, J. Martin, "Characterization of a Microchannel Plate Photomultiplier Tube with a High Sensitivity GaAs Photocathode", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Husson V., L. Stewart, "ILRS Timing Devices: Specifications, Error Analysis, BEST Calibration Practices", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Isyanova, Y., K. Wall, J. Flint, P. Moulton, J. Degnan, "High-Power, Short-Pulse Microlaser - Power Amplifier System", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Kirchner, G. and F. Koidl, "Kilohertz Laser Ranging at Graz", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Mallama, A., J. Degnan, F. Cross, J. Mackenzie, "Infrared Sky Camera -- The Production Mode". 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

McGarry, J., T. Zagwodzki, J. Degnan, "SLR2000 Closed Loop Tracking with a Photon-Counting Quadrant Detector", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Samain, E., "An Ultra Stable Event Timer", 13th International Workshop on Laser Ranging Instrumentation, Washington D.C., October 2002.

Section 7

Analysis Pilot Projects

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DEOS

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U. Texas

Introduction

The most important aspect of the SLR/LLR observations is the absolute accuracy, which may now be approaching the level of a few mm for modern stations. This makes it an ideal technique to monitor and study elements of system Earth. For SLR these include geocenter and its motion, absolute scale, global plate tectonics, and vertical station deformations. In the case of LLR, this is fundamental lunar theory (both orbital and internal composition), as well as gravitational theory/relativity. This aspect has led to reliance on SLR for the definition of origin (fully) and scale (together with VLBI) for IERS's ITRF2000 model for global station coordinates and velocities. The SLR community also produces other geophysical products like Earth Orientation Parameters (EOPs), time-variations of the long-wavelength components of the Earth's gravity field, satellite orbit solutions, and others. The ILRS has been given the official status of a Technique Center in the new organization of the IERS. To fully exploit the unique quality aspects of the SLR observations, the ILRS AWG (Analysis Working Group) addresses various issues of SLR products, such as quality control, parameter and format definition/use issues, optimization, and the development of an official combination product. To this aim, a number of so-called pilot projects have been initiated and have come to show good results. This Annual Report contribution presents an update on the development of these projects. 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/working_groups/awg/index.html).

Activities in 2002

An important instrument for contacts and discussions among SLR/LLR analysts proves to be the AWG workshops; in 2002, two were organized, notably in April (Nice, France) and in October (Lanham, MD, USA). The pilot projects were a main element of these meetings.

A number of analysis institutes evaluate the SLR measurements on various artificial satellites on a routine basis. These satellites include: ERS-2, Envisat, TOPEX/Poseidon, Jason-1, Stella, Starlette, Ajisai, LAGEOS-1/2, GPS-35/36, and Etalon-1/2. The QC results are presently distributed in a rather uncoordinated way, i.e., each analysis center produces its own unique analysis report, which is then made available to customers (i.e., stations, satellite managers) typically without comparison or checking with results that are obtained by others. The AWG Pilot Project "Unification of Fast-Turnaround Analysis Results" aims at the improvement of the "quality verdict" in various analysis results. The aim is to reduce possible inconsistencies among the various reports. One technique to do so is to consider time-series of range and/or time biases, rather than absolute values. Furthermore, it is the intention that all individual analysis results will be merged into a single report, with a unique assessment of the data problem(s) and their uncertainties. During the AWG meetings, it was made clear that differences in station coordinates play a major role in the comparison of such QC results. Consequently, all analysis groups involved were strongly encouraged to use ITRF2000. In December 2002, a significant number of analysis groups switched to this representation for station positions. It is expected that the analysis centers that still use another station coordinates model will do so in the course of 2003.

The Pilot Project "Computation of Station Positions and EOPs" deals with two of the fundamental analysis products of ILRS, i.e., station coordinates and EOPs. One of the goals is the development of a unique, best-possible (in terms of quality) analysis product that can be used by specific elements of the science community.

This project has experienced a strong development with time. Initially, it dealt with a temporarily short (28 days) dataset of LAGEOS-1 observations only. The participants now work with SLR observations of LAGEOS-1 and -2, as well as Etalon-1 and -2. This illustrates the shift in emphasis, from procedures and formats to quality and contents. The Etalon targets contribute, in particular, to EOP products, but are also expected to stimulate and facilitate improvements in assessments of global scale, station characterization, temporal variations in zonal terms of the gravity field, among others. The contribution to the quality of the ILRS analysis test products by these satellites has been improved by the organization of an intensive tracking campaign, which was initiated in the beginning of 2001, and which has continued to the present.

During the meeting in Lanham (October 2002) an official Call for Participation was developed and released directly afterwards. This Call for Participation is a step towards an official ILRS combination product, for EOPs and for station coordinates. In essence, it aims at a weekly analysis of SLR data on the LAGEOS and Etalon satellites, spanning data periods of 28 days. The products that will come out of these successive analyses will be daily EOPs (x-pole, y-pole and LOD) and station coordinates valid for the midpoint of each 28-day interval. Contributions were solicited for two different types of contributions: "analysis" (i.e., the generation of solutions for EOPs and station coordinates by individual analysis centers) and "combination" (i.e., the merging of various solutions generated by individual analysis groups into one, best-possible combination product). As a first customer, this activity will contribute to the IERS Bulletin A. The response to the invitation to tender has been good. A total of seven institutes have indicated their willingness to act as analysis centers (notably ASI, DGFI, Geosciences Australia, GFZ, IAA, JCET, NERC), whereas four analysis groups (ASI, DGFI, JCET, NCL) are interested to act as combination centers. An official test campaign is foreseen for the first months of 2003.

The Pilot Projects "Orbits" and "Software Benchmarking" have effectively been merged into a single activity in the course of 2002. The latter is aimed at quality control of the software in use at the various analysis centers, and deals with typical analysis results (orbits, parameters) obtained at different institutes. Since orbits are already an element here, it was considered as more natural to have these two projects merge. The goal of this project is to make sure that the various software packages, in use at different analysis groups, are free of errors. In the reporting year 2002, a definition of action items for this project was drafted, and first results were generated. It is expected that this project will contribute to the homogeneity of the analysis products coming from the various analysis groups. In this way it will contribute to a better consistency of semi-real-time QC activities as well as the contributions to the "positioning and EOPs" project. This project will very likely develop into a rather standard system for checking several quality control issues of analysis products, and may evolve into a "generator" of an official orbit product at a later stage.

Section 8 Modeling

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Erricos Pavlis/ JCET

Stefan Riepl/ BKG

Refraction Modeling

Traditionally the correction of the atmospheric delay at optical wavelengths has been performed using the formulation of Marini and Murray (1973), a model developed for the 0.6943 µm wavelength. The model includes the zenith delay determination and the mapping function, to project the zenith delay to a given elevation angle, in a non-explicit form. In the last few years, the computation of the refractive index at optical wavelengths has received special attention and as a consequence, the International Association of Geodesy (IUGG, 1999) recommended a new procedure to compute the group refractivity, following Ciddor (1996) and Ciddor and Hill (1999).

Based on this formulation, Mendes et al. (2002) have derived new mapping functions for optical wavelengths, using a large database of ray-tracing radiosonde profiles. These mapping functions are tailored for the 0.532 µm wavelength and are valid for elevation angles greater than 3°, if we neglect the contribution of horizontal refractivity gradients. The new mapping functions represent a significant improvement over other mapping functions available and have the advantage of being easily combined with different zenith delay models. The analysis of two years of SLR data from LAGEOS and LAGEOS 2 indicate a clear improvement both in the estimated station heights and adjusted tropospheric zenith delay biases (Mendes et al., 2002).

For the computation of the zenith delay, the available models seem to have identical precision, but variable biases. Modifying the zenith delay models with updated dispersion factors (Riepl and Schlüter, 2001) given in Ciddor (1996) leads to satisfactory results, but further studies are needed to validate the zenith delay refractivity formulas to avoid possible biases.

The application of the Mendes mapping function with the Saastomoinen zenith delay model, updated with the dispersion formula of Ciddor, permits now an estimation of the total atmospheric delay with an accuracy of about 1mm rms at 90 degree elevation, which corresponds to 5mm rms at 10 degree elevation, if we neglect horizontal refractivity gradients. These estimates apply for the wavelengths 355nm, 425nm, 532nm, 694nm, 850nm and 1064nm. However a detailed study determining the systematic and statistical errors for a global application of this model as well as the influence of anomalous and nonlinear dispersion at near infrared wavelengths is still missing.

As horizontal refractivity gradients are expected to contribute deviations with respect to the refractive delay for a symmetrical model at the order of centimeters, low altitude tracking data will reveal the site specific confidence of the above mentioned accuracy estimates and will contribute to the assessment of horizontal refractivity gradient models.

Up to which extent additional local meteorological data can be trusted to serve as an input to a horizontal refractivity gradient model is currently under investigation. Due to the dependence of meteorological data, taken within the atmospheric boundary layer, on topographic features of the surrounding, the answer on that question is nontrivial.

There has been a lot of effort in the past decade investigating the application of two-color satellite laser ranging (see Hamal (1991), Varghese (1992), Riepl (1997)). Due to it's unique capability of providing real time information on refraction, which is uncorrelated with respect to other parameters which are adjusted in laser ranging analysis, it is indispensable for the verification of refraction models. We welcome the advent of routine operational two color systems like

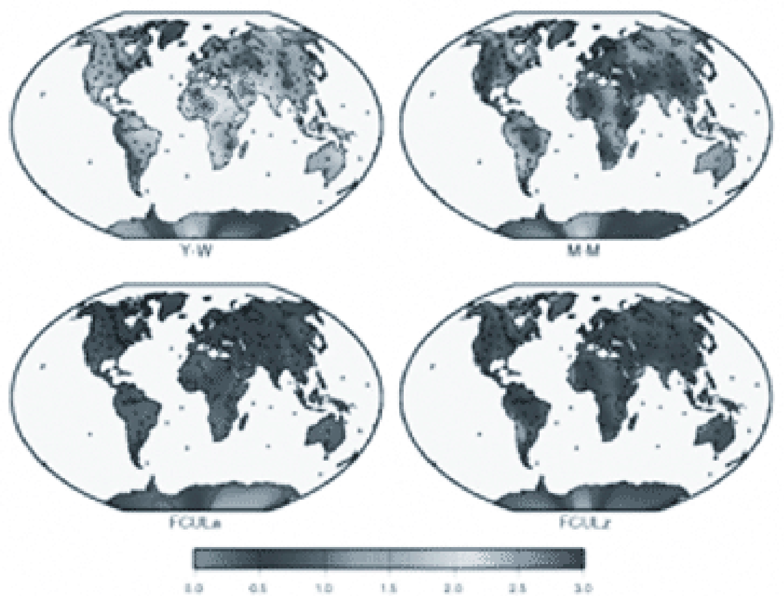

Figure 8-1. Two-year average rms of the differences (model predictions minus ray tracing), at 10º elevation angle. Plots on the left represent Mapping Function (MF) errors for FCULa and Yang-Wang's model; plots on the right represent the combined error of Zenith Delay and MF for Marini-Murray and FCULz (see [Mendes et al., 2002] for details.

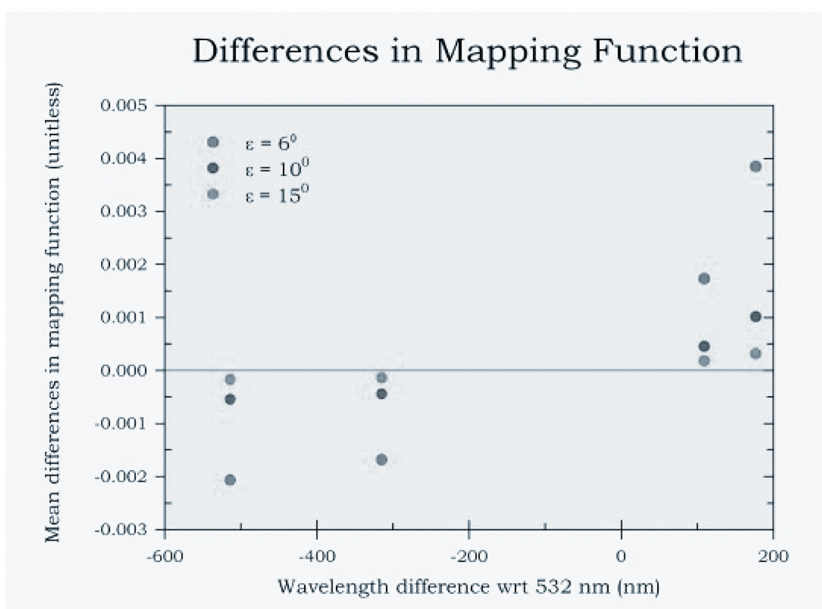

Figure 8-2. Mean differences in mapping function with respect to 532 nm wavelength.

the Matera, the Zimmerwald and the TIGO SLR-station (see Bianco 2002, Gurtner 2002, Riepl 2002) and encourage the future development of this technique incorporating high repetition rate laser systems in order to improve the confidence levels of the results. Until we have such a capability though throughout the network, we should continue the efforts to improve the current model capabilities. In that respect, very low elevation tracking, currently available only from the Grasse LLR system [Torre, private communication 2002], from the entire network will prove a valuable source of validation and experimentation data.

References

Ciddor, P. E., 1996,"Refractive index of air: New equations for the visible and near infrared," *Applied Optics*, 35, 1566-1573.

Ciddor, P. E., and R. J. Hill, 1999, "Refractive index of air. 2. Group index," *Applied Optics*, 38, 1663-1667.

International Union of Geodesy and Geophysics (IUGG), 1999, "Resolution 3 of the International Association of Geodesy," *Comptes Rendus of the XXII General Assembly*, 19-30 July 1999, Birmingham, 110-111.

Marini, J. W., and C. W. Murray, 1973, "Correction of laser range tracking data for atmospheric refraction at elevations above 10 degrees," NASA-TM-X-70555, Goddard Space Flight Center, Greenbelt, MD.

Mendes, V.B., G. Prates, E.C. Pavlis, D.E. Pavlis, and R.B. Langley, 2002, "Improved mapping functions for atmospheric refraction correction in SLR," *Geophysical Research Letters*, 29, 10, 1414, doi:10.1029/2001GL014394.

Riepl, S., and W. Schlüter, 2001, "Normal point algorithm for reduction of two color SLR observations," *Surveys in Geophysics*, 22, 581-588.

Saastamoinen, J., 1973, "Contributions to the theory of atmospheric refraction," in three parts, *Bulletin Gèodèsique*, 105, 279-298, 106, 383-397, 107, 13-34.

Hamal H., Prochazka I., 1991, "Modular Streak Camera for Laser Ranging,," Proc. SPIE 1358, 55.

Varghese T., Clarke C., Oldham T., Selden M, 1992, "Streak Camera Based SLR Receiver For Two Color Atmospheric Measurements," Proceedings of 8th International Workshop on Laser Ranging Instrumentation, Canberra.

Riepl S.,Schreiber U., 1997, "The WLRS Streak Camera Experiment," in Laser Radar Ranging and Atmospheric Lidar Techniques, Schreiber U., Werner C. (Editors) Proc. SPIE 3218.

Bianco G., Oldham T.,Bieneman M., Clarke C., Husson V., 2002, "Two-color laser ranging with the MLRO system," 13th International Workshop on Laser Ranging Instrumentation, Washington.

Gurtner W., Pop E., Utzinger J., 2002, "Zimmerwald Dual-wavelength Operation: First Experiences," 13th International Workshop on Laser Ranging Instrumentation, Washington.

Riepl S., Ramirez D., Guitano C., 2002, "Validation of Mapping Functions," 13th International Workshop on Laser Ranging Instrumentation, Washington.

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Satellite Center of Mass Corrections

It is now well established that the corrections that must be applied to laser range measurements in order to refer those measurements to the centers of mass (CoM) of the satellites are dependent on laser station configuration (see Figure 8-3). Broadly speaking, high energy, multi-photon systems require larger CoM corrections than low-energy systems, since returning photons in the *leading* edge of a strong, multi-photon return pulse are on average more likely to be detected. For LAGEOS the effect can amount to as much as 10mm, which must be properly accounted for as mm-level accuracy is demanded by the scientific applications of the laser ranging technique.

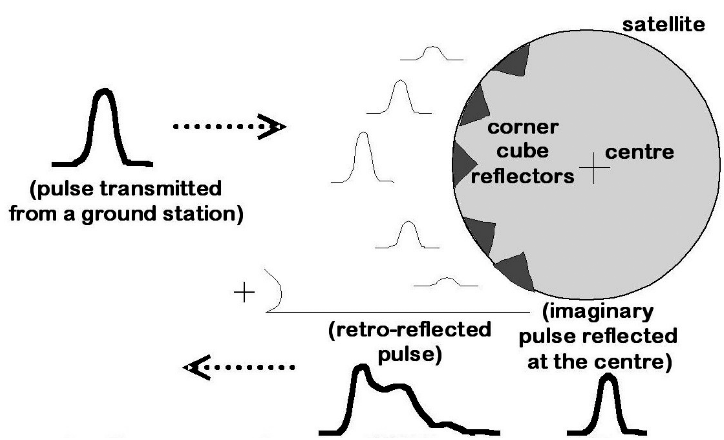

Figure 8-3. Schematic of the laser ranging process: the reflected pulse is 'stretched' and 'distorted' compared to the Gaussian transmitted pulse, due to contributions from several retro-reflection cubes. The value of the centre-of-mass correction to be applied depends on where within the returning pulse the detector triggers; near the leading edge for multi-photon returns; on average at some mean distance within the pulse for very low return energy.

Current Status

In previous work members of the ILRS Signal Processing Working Group have evaluated the characteristics of CoM corrections for the flat laser-retro arrays carried by the GLONASS and two of the GPS satellites (Otsubo, Appleby and Gibbs, 2001). During this year studies have been completed and published on system-dependent CoM values for the primary geodetic satellites LAGEOS (Table 8-1), Etalon and Ajisai (Otsubo and Appleby, 2003). This work involved the sourcing of the characteristics and locations on the satellites of each corner cube reflector, from which accurate response functions were numerically derived. To allow for far-field diffraction effects on these functions, an empirical approach based on the use of single-photon data from the Herstmonceux SLR system has been taken. From the corrected response functions the approximate CoM values have been derived for each of the main types of laser ranging system that currently form the ILRS network, namely the multi-photon C-SPAD and MCP systems and the single-photon SPAD systems, as functions of laser pulse length and average numbers of returning photons. The results for LAGEOS vary from 250mm, close to the current 'standard' value, to about 242mm, depending on system characteristics. Steps are also being taken in collaboration with colleagues in the ILRS Central Bureau to make the CoM corrections available on the ILRS web site.

Table 8-1. The center-of-mass correction depends upon return signal strength, receiver configuration, and data screening criteria.

Single-photon (1-ps FWHM)	
No clipping	242
Iterative 3-rms clipping	245
Iterative 2.5-rms clipping	247
Iterative 2-rms clipping	250
Single-photon	
Herstmonceux	245
C-SPAD (100-ps FWHM; for 0.1/1/10/100 photons)	
Iterative 3-rms clipping	245/247/251/252
Iterative 2.5-rms clipping	246/258/251/252
Iterative 2-rms clipping	249/249/251/252
Leading edge half maximum (Note: all the optical/electronic pulse broadening should be taken into account)	
1-ps FWHM pulse width	256
100-ps FWHM pulse width	252
300-ps FWHM pulse width	248
1-ns FWHM pulse width	244
3-ns FWHM pulse width	243

Next Steps

As work continues, CoM values for each of the major laser systems will be determined using configuration information given in the ILRS site logs. In this work, the most difficult systems to address will be those using C-SPAD detectors. Although inherent energy-dependent calibration bias in C-SPADs has been eliminated (Kirchner and Koidl, 1999), energy-dependent satellite CoM corrections will require some measure of the average return energy. This is an ongoing challenge and subject of discussion in this and in other Working Groups.

References

Kirchner G and Koidl F. Compensation of SPAD time-walk effects. Journal of Pure and Applied Optics, 1 (2): 163-167, March 1999.

Otsubo T and Appleby GM. System dependent centre-of-mass corrections for spherical geodetic satellites. Journal of Geophysical Research, Vol. 108 No. B4, 17 April 2003.

Otsubo T, Appleby GM and Gibbs P. GLONASS laser ranging accuracy with satellite signature effect, Surveys in Geophysics, 22 (6): 509-516, 2001.

Section 9 Science Coordination

Mark Torrence/ RITSS

ILRS in the ITRF

Seven SLR solutions for the terrestrial reference frame were used in the formation of the ITRF2000. The locations and time evolution of SLR tracking stations were key to the definition of the ITRF's scale and scale rate, and origin and translation rate.

Synergy with Other Techniques

Satellite Laser Ranging observations acquired from a global international complement of tracking stations have been used synergistically with other types of tracking and space-borne systems to improve our basic understanding of geophysics and astrodynamics. The SLR data have formed the core of geopotential models for over twenty years, not only through their unique unambiguous range measurement, but also in support of a stable reference frame. A stable reference frame is critical when measuring deformation and topographic change at the mm-level. SLR, altimeter, DORIS, TDRSS, radar range, and TRANET Doppler systems have underpinned geopotential modeling efforts for the last 25 years with the strengths of each data type reinforcing one another. Currently, the Global Positioning System (GPS) is becoming ubiquitous in near-Earth. This includes both site positioning on the Earth surface and the kinematic determination of aircraft and spacecraft trajectories. Despite the increasingly stronger contribution of GPS for these purposes, SLR continues to play an important role in the unambiguous validation and calibration of satellites being positioned using GPS. For example, SLR observations on Jason have been invaluable in assessing the optimal introduction of empirical parameters for reduced-dynamic GPS-based orbit techniques employed for this mission. SLR data is still critically important as the only means to independently verify altimeter biases and instrument/radiometric drifts. In an era of GRACE and GOCE, the SLR data will at a minimum be required to help define the reference frame in which these satellites analyze data. The SLR data remains essential to validate the orbit quality and perform independent checks on the time variations in the long-wavelength gravity field

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Bibliography

The online bibliography of SLR science and engineering related publications is continually being updated. There are 142 citations for 2002. The entire list of citations can be found at: *http://ilrs.gsfc.nasa.gov/about_ilrs/bibliography/* and in Section 11 of this publication.

* Altamimi Z, Sillard P, Boucher C., TRF2000: A new release of the International Terrestrial Reference frame for earth science applications, Jnl of Geoph Rsch 107 (B10), 2214, Oct, 2002

Science Applications

Recent, exciting, and unique results in monitoring the mass flux in the Earth's environmental system have been derived from the analysis of SLR data. The J_2 time series recovered from SLR analyses was compared to the largest geophysical sources of the mass transport signals such as the globally integrated surface pressure changes predicted by atmospheric circulation models, and to those expected from post-glacial rebound and ice sheet mass imbalance models. Overall, the comparisons were favorable. A major results from recent SLR analysis efforts was published in Science by Chris Cox and Ben Chao. They evaluated over 20-years of the J_2 time series (Figure 9-1).

These results indicate a large unpredicted mass movement towards the equator starting beginning 1998. Much of this signal may be due to melting of the ice sheets and mountain glaciers and/or bottom pressure changes in the ocean due to long-term variations in its circulation. What is not known is the relative strength of these contributing signals. There are interesting time varying gravity signals that are best understood when evaluated against a long-term trend, which SLR uniquely provides.

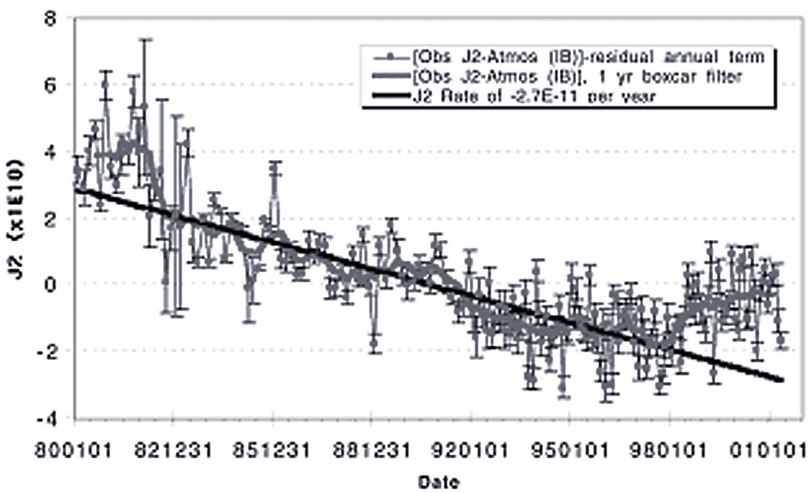

Figure 9-1. Twenty years of the J2 time series indicate a large upredicted mass movement toward the equatorial region starting in 1998.

Lunar Laser Ranging

Peter Shelus/ University of Texas

Analysis of Lunar Laser Ranging (LLR) data provides information on the lunar orbit, rotation, solid-body tides, and retroreflector locations. Lunar rotational variations have strong sensitivity to moments of inertia and gravity field while weaker variations, including tidal variations, give sensitivity to the interior structure, physical properties, and energy dissipation. A fluid core of about 20% the Moon's radius is indicated by the dissipation data. The second-degree Love numbers are detected, most sensitively k2. Lunar tidal dissipation is strong and its Q has a weak dependence on tidal frequency. Dissipation-caused acceleration in orbital longitude is dominated by tides on Earth with the Moon only contributing about 1%, but lunar tides cause a significant eccentricity rate. The lunar motion is sensitive to orbit and mass parameters. The very low noise of the lunar orbit and rotation also allows sensitive tests of the theory of relativity. Moon-centered coordinates of four retroreflectors are determined. Extending the data span and improving range accuracy will yield improved and new scientific results.

Section 10 Meetings and Reports

Carey Noll/ GSFC

In October 2002, the ILRS, in conjunction with NASA and the Smithsonian Institution, sponsored the 13th International Workshop on Laser Ranging in Washington D.C. The ILRS and the laser ranging community organizes this event on a biannual basis to discuss progress in satellite and lunar laser ranging and their application to international scientific programs. The theme of this year's workshop was "Toward Millimeter Accuracy". Over 150 people from 22 countries participated in the workshop, which included oral and poster presentations on laser system hardware, software, operations, analysis, as well as scientific applications of the technique. A large contingent of colleagues from Russia and China were unable to attend the conference due to difficulties in obtaining U.S. visas; the organizers regret these problems as their participation in the meetings was greatly missed. Proceedings from the workshop will be published in 2003 on CD; a hardcopy version of the science session papers will also be printed. More details about the workshop can be found at the web site http://cddisa.gsfc.nasa.gov/lw13.

The ILRS organizes semi-annual meetings of the Governing Board and General Assembly. General Assembly Meetings are open to all ILRS Associates and Correspondents. The 7th ILRS General Assembly was held in April 2002, in Nice, France in conjunction with the EGS Symposium. The 8th ILRS General Assembly was held in October 2002 in Washington, D.C. in conjunction with the 13th International Workshop on Laser Ranging. Detailed reports from past meetings can be found at the ILRS web site.

The 2001 ILRS Annual Report was issued in 2002 and can be viewed on the ILRS web site at URL http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrs_2001.html. ILRS Analysis Center reports and inputs are used by the Central Bureau for weekly review of station performance and to provide feedback to the stations when necessary. These reports as well as special weekly reports on on-going campaigns are issued by email. The Central Bureau also generates Quarterly Performance Report Cards and posts them on the ILRS web site at URL http://ilrs.gsfc.nasa.gov/stations/site_info/global_report_cards/. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. A catalogue of diagnostic methods, for use along the entire data chain starting with data collection at the stations, has emerged from this process and will be made available on the ILRS web site. The evaluation process has been helpful in comparing results from different Analysis and Associate Analysis Centers, a role soon to be assumed by the Analysis Working Group.

Section 11 Bibliography

Mark Torrence/ RITSS

Below is a list of some of the papers and presentations about SLR technology and scientific findings based upon SLR data were made in 2002:

Al-Saud, T., “Status of the KACST SLR Program - Past, Present and Future”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Altamimi, Z., “SLR Contribution to the International Terrestrial Reference Frame (Invited),” Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Altamimi, Z., Sillard P, Boucher C, ITRF2000: A new release of the International Terrestrial Reference frame for earth science applications, Jnl. Geophys. Res., A 107 (B10): art. no. 2214 OCT 2002.

Altamimi, Z., Sillard, P., Boucher, C., The impact of a No-Net-Rotation Condition on ITRF2000, Geophys. Res. Lett. Vol. 30 No. 2, 24 January 2003.Dupuy D, Lescure M, Improvement of the FMCW laser range-finder by an APD working as an optoelectronic mixer IEEE T INSTRUM MEAS 51 (5): 1010-1014, OCT 2002.

Andersen, P.H., “High-precision station positioning and satellite orbit determination”, Ph.D. Thesis, NDRE/ publication-95/01094, FFI/E, Box 25, N-2007, Kjeller, Norway, 2002.

Angermann D., Kaniuth, K., Müller, H. and Tesmer, V., “Contribution of Individual Space Techniques to the Realization of Vertical Reference Systems”, In: Drewes, H., et al, Vertical Reference Systems, IAG Symposia (124), Springer, in print, 2002.

Angermann D., Müller, H. and Gerstl, M., “Geocenter Variations Derived From SLR Data to LAGEOS 1 and 2”, In: Adam, J. and Schwarz, K.-P., Vistas for Geodesy in the New Millennium, IAG Symposia (125), Springer, in print, 2002.

Angermann, D., H. Muller, M. Gerstl, Geocenter variations derived from SLR data to LAGEOS 1 and 2. In: J. Adam and K.-P. Schwarz (Eds.). Vistas for Geodesy in the New Millennium, International Association of Geodesy Symposia, Vol. 125, pp. 30-35, Springer, 2002.

Angermann, D., K. Kaniuth, H. Müller, V. Tesmer, Contribution of individual space techniques to the realization of vertical reference systems. In: H. Drewes, A. Dodson, L. Fortes, L. Sanchez, P. Sandoval (Eds.), Vertical Reference Systems, International Association of Geodesy Symposia, Vol. 124, 91-96, Springer, 2002.

Angermann, D., M. Gerstl, R. Kelm, H. Müller, W. Seemüller, M. Vei, Time evolution of an SLR reference frame, Advances in Space Research, Vol. 30/2, pp. 201-206, Elsevier, 2002.

Appleby, G., “Evaluation of Potential Systematic Bias in GNSS Orbital Solutions”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Appleby, G., “Operational Issues from the Viewpoint of the SLR Data Analysis”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Arnold, D., “Retroreflector Array Transfer Functions”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Arnold, D., “Velocity Aberration (Poster Summary)”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Arnold, D., “Wavelength Dependence of Range Correction”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Azzeer, A., “Improving SALRO Accuracy”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Bianco, G., “The MLRO Project: a Status Report”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Bianco, G., “Two-color laser ranging with the MLRO system”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Capanov, J. and Georgiev, I., “Secular Drift of the Low Degree Zonal Coefficients Obtained from Satellite Laser Ranging to the Geodynamic Satellites LAGEOS-1 and LAGEOS-2”, Accepted in Bulgarian Geophysical Journal, 2002.

Carter, D., “System Upgrades of the NASA SLR Network”, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Chapront, J., Chapront-Touzé, M. and Francou, G., "A new determination of lunar orbital parameters, precession constant and tidal acceleration from LLR measurements", Astronomy and Astrophysics. Vol. 387, p. 700, 2002.

Clarke, C., "Intelligent Scheduler, Prioritize on the Fly", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Cox, C., "Time-Variable Gravity Analysis Using Satellite-Laser-Ranging as a Tool for Observing Long-Term Changes in the Earth's Systems (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Cuff, T., "Testing of MCP PMTS: Use of Fiber Optic Coupled Gbps Laser Drivers to Create Ersatz Laser Return Pulses", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Degnan, J. J., "Asynchronous laser transponders for precise interplanetary ranging and time transfer" (invited), Geodynamics, Special Issue on Laser Altimetry, Vol. 34, pp. 551-594, October/ November 2002.

Degnan, J. J., "Photon-Counting Microlaser Rangers, Transponders, and Altimeters" (invited), Surveys in Geophysics, Special Issue on Evolving Geodesy, Vol. 22, Nos.5-6, pp. 431-447, 2002.

Degnan, J. J., "Photon-counting multikilohertz microlaser altimeters for airborne and spaceborne topographic measurements", (invited), J. Geodynamics, Special Issue on Laser Altimetry, Vol. 34, pp.503-549, October/ November 2002.

Degnan, J.J., "A conceptual design for a spaceborne 3D imaging lidar" (invited), Jnl. Elektrotechnik und Informationstechnik, Vol. 4, pp. 99-106, April 2002.

Degnan, J.J., "Optimization of the Correlation Range Receiver Parameters in SLR2000", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Degnan, J.J., "Photon-Counting Airborne Microlaser Altimeter (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Degnan, J.J., "SLR2000: Progress and Future Applications", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Devoti, R., Ferraro, C., and Gueguen, E., et al., "Geodetic control on recent tectonic movements in the central Mediterranean area", TECTONOPHYSICS 346 (3-4): 151-167 March 15, 2002.

Dickey, J., "Lunar Geophysics, Geodesy, and Dynamics (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Donovan, H., "NASA SLR Network MCP PMT Upgrade", 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Dunn, P., "Absolute Earth Scale from SLR Measurements (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Dupuy, D., and Lescure, M., "Improvement of the FMCW laser range-finder by an APD working as an optoelectronic mixer", IEEE T INSTRUM MEAS 51 (5): 1010-1014, OCT 2002.

Elango, K., "Laser Retroreflector Array (LARA) for IRS Mission (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Feng, C.G., Zhang, F.P., and Zhu Y.L., "Application of a no-fiducial approach to SLR data reduction", CHINESE ASTRON ASTR, v. 26, num 3, pp. 372-377 JUL-SEP 2002.

Filikov, S., "Upgrading of the Simeiz-1873 SLR Station", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Fumin, Y., "Upgrades of Shanghai Satellite Laser Ranging Station", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Galkin, Y., "Preliminary estimation of the atmospheric nonlinear frequency dispersion and absorption effects on the pulse SLR accuracy (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Georgiev, I., and Chapanov, J., "Analysis of Laser Ranging to the Geodynamic Satellites LAGEOS-1 and LAGEOS-2 for the Period 1984-2000", Accepted in Bulgarian Geophysical Journal, 2002.

Gibbs, P., "Range comparison results for various EUROLAS SR timers", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Greene, B., "Laser Tracking of Space Debris", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Gross, R., "Laser Ranging Contributions to Monitoring and Interpreting Earth Orientation Changes (Invited)", Presentation to 13th

International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Grunwaldt, L., "First Laser Ranging Results of the new Potsdam SLR System", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Grunwaldt, L., "SLR and the CHAMP Gravity Field Mission (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Gurtner, W., "Counter Calibrations at Zimmerwald", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Gurtner, W., "Improvements in the Automation of the Zimmerwald SLR Station", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Gurtner, W., "Operational Issues from the Stations", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Gurtner, W., "Zimmerwald Dual-wavelength Operation: First Experiences", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Hamal, K., "Lasers for Multiwavelength Satellite Laser Ranging", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Hamal, K., "Portable Calibration Standard Mission Review", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Husson, V., "Absolute and Relative Range Bias Detection Capabilities", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Husson, V., "ILRS Timing Devices: Specifications", Error Analysis, BEST Calibration Practices, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Husson, V., "MyStationPerformance.COM", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Husson, V., "Operational Issues from an ILRS Central Bureau Perspective", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Iorio, L., Recent developments in testing general relativity with satellite laser ranging, RIV NUOVO CIMENTO 25 (5): 1-73 2002.
Kaniuth, K., H. Muller, W. Seemuller. Displacement of the space geodetic observatory Arequipa due to recent earthquakes. Zeitschrift fuer Vermessungswesen, Heft 4, pp. 238-243, Wittwer, 2002.
Kaniuth, K., Müller, H., and Seemuller, W., "Displacement of the space geodetic observatory Arequipa due to recent Earthquakes", Zeitschrift fur Vermessungswesen, Germany, accepted, 2002.
Kessel, R., "Development and on-orbit performance of moderate-cost spherical retroreflector arrays for the STARSHINE program", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Kim, S., "Design of a laser retro-reflector for the first satellite ranging mission in S. Korea on an elliptical orbit (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Kirchner, G., "Kilohertz Laser Ranging at Graz", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Kirchner, G., "New Detection Package at Graz", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Klokocník, J., Reigber, Ch., Schwintzer, P., Wagner, C.A. and Kosteleck, J., "Evaluation of pre-CHAMP gravity models 'GRIM5-S1' and 'GRIM5-C1' with satellite crossover altimetry", Journal of Geodesy Vol. 76, Num. 4, pp. 189-198, 2002.
Krasinsky, G.A., "Selenodynamical parameters from analysis of LLR observations of 1970-2001", (accessible via anonymous FTP at quasar.ipa.nw.ru/incoming/era/LLR.ps), Communications of IAA RAS, 148, 2002.
Kunimori, H., "A Satellite Laser Ranging System Based on a Micro-Chip Laser (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Kunimori, H., "Integration of 1.5m Telescope and Ranging System in CRL", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
LaBrecque, J., "Space Geodesy Overview (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Lapushka, K., "A010 Family of Time interval Counters Adapted to SLR Applications", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.
Lemoine, F., "The Development of NASA Gravity Field Models and their Dependence on SLR (Invited)",

Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Liu, C.Z., Zhao, Y., and Fan, C.B., et al, "Performance and observation summary of Changchun Satellite Laser Ranging Station", CHINESE SCI BULL 47 (13): 1070-1072 July 2002.

Long, J., "Local Surveys at Goddard (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Lucchesi, D. M., Reassessment of the error modelling of non-gravitational perturbations on LAGEOS II and their impact in the Lense-Thirring derivation - Part II, PLANET SPACE SCI 50 (10-11): 1067-1100 Aug-Sep 2002.

Lucchesi, D.M., "Reassessment of the error modelling of non-gravitational perturbations on LAGEOS II and their impact in the Lense-Thirring derivation-Part II", PLANET SPACE SCI 50 (10-11): 1067-1100 Aug-Sep 2002.

Luck, J., "LLR Developments at Mount Stromlo: Towards Millimeter Accuracy", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Luthcke, S., "The SLR Contribution to Precision Orbit Determination in the GPS Era", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Mallama, A. J. and J. J. Degnan, "A thermal infrared cloud mapper for observatories", Publications of the Astronomical Society of the Pacific", Vol. 114, pp.913-917, August, 2002.

Mallama, T., "Infrared Sky Camera - The Production Model", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Martin, J., "Characterization of a Microchannel Plate Photomultiplier Tube with a High Sensitivity GaAs Photocathode", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

McGarry, J., "SLR2000 Software: Current Test Results and Recent Developments", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

McGarry, J., "SLR2000: Closed Loop Tracking with a Photon-Counting Quadrant Detector", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Mendes, V.B., Prates, G., Pavlis, E.C., Pavlis, D.E., and Langley, R.B., "Improved Mapping Functions for Atmospheric Refraction Correction in SLR", Geophys. Res. Let., 29 (10), 2002.

Meyer, F., Seitz, F., and Muller, J., "An Algorithm for Reliable Normal Point Calculation of Noisy LLR Measurements", in: Laser Radar: Ranging and Atmospheric Lidar Techniques III, SPIE-Proc., Vol. 4546, No. 29, Eds. U. Schreiber, C. Werner, G. Kamerman, U. Singh, P. 154-159, 2002.

Moore, P., and Kilby, G.T., "Orbital inferences from GFO with applications to GEOSAT", Adv. Space Res., v 30, num 2, pp. 393-399, 2002.

Moulton, P., "High-Power, Short-Pulse Microlaser-Power Amplifier System", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Murphy, T., "APOLLO: Multiplexed Lunar Laser Ranging", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Muller, J., Chapront, J., Ries, J.G., and Williams, J., "LLR and Tidal Effects", Bulletin D, Informations Marees Terrestres (BIM), Vol. 134, ed. by B. Ducarme, P. 10553-10557, 2002.

Muller, J., and Tesmer, V., "Investigation of Tidal Effects in Lunar Laser Ranging", Journal of Geodesy, Vol. 76, P. 232-237, 2002.

Nicholas, A., "The Atmospheric Neutral Density Experiment: a Mission Overview", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Nicolas, J., "Difference of LAGEOS satellite response from raw data analysis of the collocation experiment between the Grasse Satellite and Lunar Laser Ranging stations", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Nicolas, J., "First Results of the French Transportable Laser Ranging Station during the 2002 Corsica Campaign for the JASON-1 Calibration and Validation Experiment", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Nicolas, J., "Results of the triple laser ranging collocation experiment at the Grasse observatory", France (September-November 2001), Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

O'Gara, D., "Replacement of the LURE Telescope Controller Using COTS Components Using Commercial Off-The-Shelf Components", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Oldham, T., "GUTS - A New SLR System for Japan", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Oneto, J.L., "Mechanical measurement of laser pulse duration", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Oneto, J.L., "Use of free surface of liquids in interferometric methods: application to split corner cubes", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Otsubo, T., "Range Bias vs. Applied System Delay", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Otsubo, T., "Recovery of target response function for centre-of-mass corrections of spherical satellites", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Otsubo, T., "Reflector arrangement on H2A-LRE satellite", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Patterson, D., "Overview of Data for the SLR2000 Tracking Mount Performance Testing", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Paunonen, M., "An experimental common detector, coaxial Cassegrain laser telescope and its calibration", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Pavlis, E., "Atmospheric Refraction at Optical Wavelengths: Problems and Solutions", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Pavlis, E., "Monitoring the Origin of the TRF with Space Geodetic Techniques (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Pavlis, E.C., "Dynamical Determination of Origin and Scale in the Earth System from Satellite Laser Ranging", in Proc. of the 2001 IAG Scientific Assembly: Vistas for Geodesy in the New Millennium, the International Association of Geodesy, Budapest, Hungary, September 2-7, 2001, electronic publication (CD), 2002.

Pavlis, E.C., "Geodetic Contributions to Gravitational Experiments in Space", Book chapter, to appear in Recent Developments in General Relativity, Genoa 2000, R. Cianci, R. Collina, M. Francaviglia, P. Fré (eds), Springer-Verlag, Milan, to be published Jan. 2002.

Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The international laser ranging service", Adv. Space Res., v 30, num 2, pp. 135-143, 2002.

Pierron, F., "Improvements of the French Transportable Laser Ranging Station to high accuracy level", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Pierron, M., "Ultra mobile station FTLRS: Software Control", Presentation to 13th International Workshop on Laser Wiant, J., The New MLRS Encoder System: Progress Report, Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Prochazka, I., "Atmospheric Contribution to the Laser Ranging Jitter", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Prochazka, I., "Millimeter Ranging Accuracy - The Bottleneck", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Prochazka, I., "Portable Calibration Standard Capabilities", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Prochazka, I., "SPAD Detector Package for Space Born Applications", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Ricklefs, R., "Creating a Consolidated Laser Ranging Prediction Format", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Riepl, S., "Installing TIGO in Concepcion", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Riepl, S., "Validation of Mapping Functions", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Ries, J., "McDonald Ranging: 30 Years and Still Going", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Ries, J., "Prospects for an Improved Lense-Thirring Test with SLR and the GRACE Gravity Mission (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Rowlands, D.D., Ray, R.D., Chinn, D.S. and Lemoine, F.G., "Short-arc analysis of intersatellite tracking data in a gravity mapping mission", Journal of Geodesy, Vol. 76, Num. 6-7, pp. 307-316, 2002.

Samain, E., "Time Transfer by Laser Link (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Samain, E., "Time walk compensation of a SPAD with linear photo detection", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Scharroo, R., "Contributions of SLR to the Success of Satellite Altimetry Missions (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Schillak, S., "The stability of the SLR stations coordinates determined from monthly arcs of LAGEOS-1 and LAGEOS-2 laser ranging in 1999-2001", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Schreiber, U., "Biaxial Rayleigh- and Raman-LIDAR for applications in atmospheric sounding and SLR", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Schreiber, U., and Schneider, M., "Is there a next generation SLR-technology?", Adv. Space Res., v 30, num 2, pp. 157-161, 2002.

Shelus, P., "Recent contributions to LLR analysis", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Smith, D., "Seasonal Changes in the Icecaps of Mars from Laser Altimetry and Gravity", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Sperber, P., "High accuracy short range laser rangefinder for system calibration and installation", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Stevens, P., "Local Survey Relationships to System Calibration and Bias Identification (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Stewart, L., "Operational Performance of GPS Steered Rubidium Oscillators (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Strasburg, J., "The advantages of Avalanche Photodiode (APD) arrays in laser ranging applications", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

de la Torre Juárez, M., "A Database of Atmospheric Refractivities from GPS Radio Occultations", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Vasiliev, V., "International experiment in space for investigation of a novel-type laser retroreflector", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Vigouroux, G., "The OCA LLR Station: An Update", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Visser, P.N.A.M., Scharoo, R, and Ambrosius, B.A.C., "Application of ERS-2 PRARE data for orbit determination and gravity field and station coordinate estimation", Adv. Space Res., 30, 2, pp. 249-254, 2002.

Wahr, J., "Geophysical Applications of SLR Tidal Estimates (Invited)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Wnuk, E., Schillak, S., and Kuzmicz-Cieslak, "Stability of coordinates of the Borowiec SLR station (7811) on the basis of satellite laser ranging", Adv. Space Res., v 30, num 2, pp. 413-418, 2002.

Wood, R., "Berne/Herstmonceux Timebias Service", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Wood, R., "LAGEOS-2 spin rate and orientation (Poster Summary)", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Yaoheng, X., "Modification of Laser Ranging Equation", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Zhao, Y., "System Stability Improvement of Changchun SLR System", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

Zielinski, J., "Preliminary Orbit Determination of GRACE Satellites using Laser Ranging Data", Presentation to 13th International Workshop on Laser Ranging, Washington, DC, USA, October 7-11, 2002.

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Central Laboratory for Geodesy, Bulgarian Academy	Bulgaria
Academia Sinica	China
Chinese Academy of Surveying and Mapping	China
State Seismological Bureau	China
Yunnan Observatory	China
Technical University of Prague	Czech Republic
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Finnish Geodetic Institute	Finland
Observatoire de la Côte d'Azur/Centre d'Etudes et de Recherches Géodynamiques et Astrométrie (OCA/CERGA)	France
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Hydrographic Department/Japan Coast Guard	Japan
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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
Mission Control Centre (MCC)	Russia
Russian Space Agency (RSA)	Russia
Space Research Insitute (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, Unversity of Berne (AIUB)	Switzerland
Delft University of Technology (DUT)	The Netherlands
Crimean Astronomical Observatory	Ukraine
Lebedev Physical Institute in the Crimea	Ukraine
Main Astronomical Observatory (MAO) of the National Academy of Sciences of Ukraine	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
National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC)	USA
Naval Center for Space Technology (NCST)	USA
University of Hawaii	USA
University of Texas at Austin	USA
University of Texas, Center for Space Research (CSR)	USA

LIST OF ACRONYMS

ADEOS	Advanced Earth Observing Satellite
AIUB	Astronomical Institute of Berne (Switzerland)
ALOS	Advanced Land Observing Satellite
ANDE	
APOLLO	Apache Point Observatory Lunar Laser-ranging Operation (USA)
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
AWG	Analysis Working Group
BAS	
BE-C	Beacon Explorer C
BGI	International Gravimetric Bureau
BIPM	International Bureau of Weights and Measures
BKG	Bundesamt für Kartographie und Geodäsie (Germany)
CB	Central Bureau
CDDIS	Crustal Dynamics Data Information System (USA)
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astrométrie (France)
CfA	Center for Astrophysics (USA)
CHAMP	CHAllenging Mini-Satellite Payload
CLG	Central Laboratory for Geodesy (Bulgaria)
CNES	Centre National d'Etudes Spatiales (France)
CoM	Center of Mass
CRL	Communications Research Laboratory (Japan)
C-SPAD	Compensated Single Photoelectron Avalanche Detector
CSR	Center for Space Research (USA)
CSTG	International Coordination of Space Techniques for Geodesy and Geodynamics
DGFI	Deutsches Geodätisches ForschungsInstitut (Germany)
DoD	Department of Defense (USA)
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DTOF	Differential Time-Of-Flight
DUT	Delft University of Technology (The Netherlands)

EDC	EUROLAS Data Center (Germany)
EGS	European Geophysical Society
EOP	Earth Orientation Parameter
EOS	Electro Optical Systems (Australia)
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESOC	ESA Space Operations Center (Germany)
ET	Event Timer
ETS	Engineering Test Satellite
EUROLAS	European Laser Consortium
FCUL	Faculdade de Ciências da Universidade de Lisboa (Portugal)
FESG	Forschungseinrichting Satellitengeodäsie (Research Facility for Space Geodesy, Germany)
FFI	Forsvarets ForskningsInstitutt (Norwegian Defense Research Establishment)
FTLRS	French Transportable Laser Ranging System
FWHM	Full-Width Half-Maximum
GA	Geosciences Australia
GB	Gigabyte
GEOS	Geodetic and Earth Orbiting Satellite
GFO	GEOSAT Follow-On (USA)
GFZ	GeoForschungsZentrum (Germany)
GLONASS	Global Navigation Satellite System
GLONASS	Global'naya Navigatsionnay Sputnikovaya Sistema
GOCE	Gravity Field and Steady-state Ocean Circulation Explorer
GP-B	Gravity Probe B
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GSFC	Goddard Space Flight Center (USA)
GUTS	Global and High Accuracy Trajectory Determination System
H2A/LRE	Laser Ranging Experiment
HartRAO	Hartebeesthoek Radio Astronomy Observatory (South Africa)
NCST	Naval Center for Space Technology (USA)
HTSI	Honeywell Technology Solutions, Inc. (USA)
IAG	International Association of Geodesy
IAA	Institute of Applied Astronomy (Russia)
IA/RAS	Institute of Astronomy/Russian Academy of Sciences

IBS	IAG Bibliographic Service
ICC	Inter-commission Committees
ICESat	Ice Cloud and Land Elevation Satellite
ICET	International Center for Earth Tides
IERS	International Earth Rotation 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)
IGOS	Integrated Global Observing Strategy
IGS	International GPS Service for Geodynamics
ILRS	International Laser Ranging Service
IMVP	Institute of Metrology for Time and Space (Russia)
INASAN	Institute of Astronomy of the Russian Academy of Sciences
InSAR	Interferometric Synthetic Aperture Radar
IPIE	Science Research Institute for Precision Instrument Engineering (Russia)
IRS	Indian Research Satellite
IRV	Inter-Range Vector
ISGN	Integrated Space Geodetic Network
ISRO	Indian Space Research Organization
ISTRAC	ISRO Telemetry Tracking and Command Network (India)
ITRF	International Terrestrial Reference Frame
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)
JGR	Journal of Geophysical Research
JPL	Jet Propulsion Laboratory (USA)
KACST	King Abdulaziz City for Science and Technology (Saudi Arabia)
LAGEOS	LAser GEOdynamics Satellite
LEO	Low Earth Orbit
LLR	Lunar Laser Ranging
LOD	Length Of Day
LRE	Laser Retroreflector Experiment

MAO	Main Astronomical Observatory (Ukraine)
MCC	Mission Control Center (Russia)
MF	Mapping Function
MLRO	Matera Laser Ranging Observatory (Italy)
MLRS	McDonald Laser Ranging System (USA)
MOBLAS	MOBile LASer Ranging System
MSTI	Miniature Sensor Technology Integration
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency (Japan)
Nd: YAG	Neodymium Yttrium Aluminum Garnet
NCL	University of Newcastle Upon Tyne (UK)
NERC	Natural Environment Research Council (UK)
NMD	National Mapping Division (Australia)
NOAA	National Oceanic and Atmospheric Administration (USA)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRIAG	National Research Institute of Astronomy and Geophysics (Egypt)
NRL	Naval Research Laboratory (USA)
OCA	Observatoire de la Côte d'Azur (France)
PAS	Polish Academy of Sciences
PMSL	Permanent Service for Mean Sea Level
POD	Precise Orbit Determination
PPET	Portable Pico-Second Event Timer
PRARE	Precise Range and Range-rate Equipment
QC	Quality Control
QE	Quantum Efficiency
RITSS	Raytheon Information Technology and Scientific Services (USA)
RSA	Russian Space Agency
SAGE	Strategic Aerosol and Gas Experiment
SC	Sub-Commission
SINEX	Software Independent Exchange Format
SLR	Satellite Laser Ranging
SPAD	Single Photoelectron Avalanche Detector
SPIE	International Society for Optical Engineering
SRI	Space Research Institute (Russia)
SST	Satellite-to-Satellite Tracking

STARSHINE	Student Tracked Atmospheric Research Satellite for Heuristic International Networking Experiment
SUNSAT	Stellenbosch UNiversity SATellite (South Africa)
TCP/IP	Transmission Control Protocol/INTERnet Protocol
TDRSS	Tracking and Data Relay Satellite System
TIGO	Transportable Integrated Geodetic Observatory
TiPS	Tether Physics and Survivability Experiment
TIU	Time Interval Unit
TLRS	Transportable Laser Ranging System
TOPEX	Ocean TOPography Experiment
TRANET	TRAnsit NETwork
TRF	Terrestrial Reference Frame
TROS	TRansportable Observation Station
TROS	Transportable Range Observation System
UFP	Université de la Polynésie Française (French Polynesia)
UK	United Kingdom
UMBC	University of Maryland Baltimore County (USA)
UNSA	Universidad Nacional de San Augustin (Peru)
USA	United States of America
VCO	Voltage-controlled Crystal Oscillator
VLBI	Very Long Baseline Interferometry
WESTPAC	Western Pacific Laser Tracking Network Satellite
WG	Working Group
WPLTN	Western Pacific Laser Tracking Network