Abstracts

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Session 1: Data management, GGOS, Geodesy

Chairs:

Daniela Thaller
and
Mathis Blossfeld

13-0101

ICSU-World Data System, New Scientific Data Management

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[1] NICT/WDS-Scientific Committee
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[3] UCSD/WDS-Scientific Committee

The ICSU World Data System (ICSU-WDS) was established 2008 in ICSU (International Council for Science) reforming the two former scientific data bodies of WDC and FAGS with their more than 50-year's legacy. WDS' s primary goals are to ensure the long-term stewardship of quality-assessed data for research and education, and the provision of such data and related data services to the international science community and other stakeholders. Open sharing of information and data is one of essential components of scientific activity, while data is recognized indispensable information resource for science and society. Today unlike conventional libraries and bibliographic access, online data and journals in digital forms are requiring society to identify new ways of data preservation, certification, sharing, and citation of such digital resources, while new technologies provide potential to solve those problems and moreover new potential to enable new sciences even. ICSU-WDS, now with 75 member institutions including ILRS and IVS, is building a new international federation of system of data systems to target forming the community of excellence and achieving the goals.

13-0102

Dissemination of SLR data-related products through a Virtual Observatory

Florent Deleflie [1], Christophe Portmann [2], Laurent Soudarin [3], Christophe Barache [4], Jerome Berthier [1], and David Coulot [5,1]

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This paper presents the astronomical so-called Virtual Observatory (VO), and gives some examples of Webservices hosted by GRGS Analysis Center webpages, that can be used for Earth sciences applications, and for SLR stations operations.
Astronomers using this VO are now organized within an international association called the International Virtual Observatory Alliance (IVOA), which was formed in June 2002 with a mission to "facilitate the international coordination and collaboration necessary for the development and deployment of the tools, systems and organizational structures necessary to enable the international utilization of astronomical archives."
GRGS now routinely delivers geodetic products to most of the space geodetic services of the International Association of Geodesy. Some of these products are now natively archived following the data format recommended by IVOA, the VO-Table format, an improved version of the XML format. We pay a particular attention on (i) Space Station Coordinates time series deduced from SLR, DORIS and GPS data, (ii) EOP time series deduced from SLR and VLBI data, (iii) SLR station biases.

13-0103

GGOS Global Space Geodesy Networks and the Role of Laser Ranging

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The reference frame is essential to measurements and their interpretation of global change conditions. The improvements in the reference frame and other space geodesy data products spelled out in the GGOS 2020 plan will evolve over time as new space geodesy sites enhance the global distribution of the network, and new technologies are implemented at the sites thus enabling improved data processing and analysis. The GGOS goals include the development of the reference frame to 1 mm accuracy and 0.1 mm stability, an order of magnitude better than the present situation. To achieve the improved reference frame, simulations show that we will need 30 globally distributed core sites with VLBI, SLR, GNSS and DORIS (where available). In addition, co-location sites with less than the full core complement will continue to play a very important role in filling out the network while it is evolving and even after full implementation. The global participation of new technology SLR is a key element to making this work.

GGOS, through its Call for Participation, bi-lateral and multi-lateral discussions, and work through the Technique Services (IGS, ILRS, IVS, and IERS) continues to encourage current groups to upgrade and new groups to join the activity. This talk will give an update on the current and planned expansion of the global space geodesy network with particular attention on SLR.

13-0104

NASA’s Space Geodesy Project

S. M. Merkowitz [1], S. Desai [2] , R. S. Gross [2], L. Hilliard [1], F. G. Lemoine[1], J. L. Long [1], C. Ma [1], J. F. McGarry [1], D. Murphy [2], C. E. Noll [1], E. C. Pavlis [3], M. R. Pearlman [4], D. A. Stowers [2], F. H. Webb [2]

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NASA's Space Geodesy Project (SGP) recently completed a prototype core site as the basis for a next generation Space Geodetic Network that is part of NASA's contribution to the Global Geodetic Observing System (GGOS). This system is designed to produce the higher quality data required to establish and maintain the Terrestrial Reference Frame and provide information essential for fully realizing the measurement potential of the current and future generation of Earth Observing spacecraft. The prototype core site is at NASA's Geophysical and Astronomical Observatory at Goddard Space Flight Center and includes co-located, state of-the-art, systems from all four space geodetic observing techniques: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). A system for monitoring of the “ties” between these four systems is an integral part of the core site development concept and this specific prototype. When fully implemented, this upgraded global network will benefit in addition to the ITRF, all other network products (e.g. Precision Orbit Determination, local & regional deformation, astrometry, etc.), which will also be improved by at least an order of magnitude, with concomitant benefits to the supported and tracked missions, science projects, and engineering applications. We present the results of the prototype site demonstration and describe the NASA plans for implementing its next generation network.

13-0105

SLR-GNSS analysis in the framework of the ITRF2013 computation

Daniela Thaller [1], Ole Roggenbuck [1], Krzysztof Sosnica [2], Peter Steigenberger [3], Maria Mareyen [1], Christian Baumann [2], Rolf Dach [2], Adrian Jäggi [2]

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The call for participation for the ITRF2013 also asked for pre-combined contributions, although they would not be directly included in the ITRF2013 combination.
In the framework of the CODE (Center for Orbit Determination in Europe) consortium, pre-combined GNSS-SLR solutions are computed. The important characteristic of these pre-combined solutions is that the satellite co-location at the GNSS satellites is employed, i.e., the SLR tracking of the GPS and GLONASS satellites is included into the combination, together with the GNSS microwave data and the SLR data to LAGEOS and Etalon satellites.
Since about three years, several SLR stations make an effort to track the full GLONASS constellation, which should ideally provide a stronger connection between GNSS and SLR.
We will show the status of this combination work.

13-0106

Recent Progress and Future Perspectives of the International VLBI Service for Geodesy and Astrometry (IVS)

Shinobu Kurihara, and many colleagues of the IVS

Geospatial Information Authority of Japan

The International VLBI Service for Geodesy and Astrometry (IVS) was established in 1999 to operate or support Very Long Baseline Interferometry (VLBI) components. IVS provides a service which supports geodetic and astrometric work on reference systems, Earth science research, and operational activities. IVS is a Service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU).

In recent months, IVS has made enormous progress advancing towards the realization of the VLBI2010 Global Observing System (VGOS). The key issues of the new generation IVS installations are fast rotating radio telescopes capable of receiving broadband quasar radiation between 2 and 14 GHz in a continuous frequency band. A number of new telescopes have been built or are approved providing a good basis for a thorough refurbishing of the IVS network as a whole. Together with addressing a number of other technique-specific issues, the IVS is on a good path to fulfill the requirements of the Global Geodetic Observing System (GGOS). This presentation will explain the status of VGOS and its future path of development.

13-0107

Deployment of SLR colocation sites with one-way RF systems and VLBI for the improvement of the GLONASS

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Open Joint-Stock Company Research-and-Production Corporation
“Precision Systems and Instruments”

Maintaining of the GLONASS competitive characteristics ensuring decimeter accuracy of navigation requires the deployment of fundamental coordinate/time support and, with the goal to improve the accuracy of navigation field by an order of magnitude.

Therefore, the following specific requirements should be met:

- accuracy of geodynamic data calculation < of 1.5 cm in linear measure,
- coordinate accuracy of stations involved in the ephemeris determination < 1 cm relative to the center of mass, and 0.3 cm in relative binding,
- accuracy of the account for refraction: < 1 cm around the zenith,
- delay calibration accuracy in the GLONASS navigation signals < 3-5 cm.

These problems are solved by colocation of different methods: SLR- one-way RF ranging -VLBI -WVR.

Improving of the GLONASS geodynamic value is achieved by refinement of the actual earth rotation parameters 3-4 times a day. The VLBI network will provide operative definition of World time using antennas of small diameter (about 12m) and new equipment for data collection and correlation.

Combining WVR and one-way RF systems, will provide mutual scaling of direct measurements of the water vapor concentration and verification of the hydrostatic component of refraction in the troposphere.

Geodetic accuracy is also achieved using the advantages of different instruments. To improve the accuracy of GLONASS, the new Federal program includes “BLTS-M” satellites with millimeter target error in 1500 - 3000 km high orbits with simultaneous creation of new generation of submillimeter-accuracy SLR stations.

To calibrate the delays in the GLONASS navigation signals, a one-way laser ranging system is provided. Testing of the first such system is underway on «Glonass-M» № 47.

Deployment of colocation sites SLR, one-way RF system and VLBI provides a new level of accuracy for the GLONASS system as a whole.

13-0117

Laser ranging in Main metrological center of the Russian State service of time, frequency and the Earth rotation parameters determination

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National Research Institute for Physical-Technical and Radio Engineering Measurements (VNIIFTRI)

The report presents condition and development of laser ranging measurements in VNIIFTRI. Special attention is paid to metrological aspects. Considered the issues of comparisons with the standards and rigs of highest accurac

Session 2: Gravity, Earth Model, Reference Frame

Chairs:

Giuseppe Bianco
and
Koji Matsuo

13-0108

Earth gravity field recovery using GPS, GLONASS, and SLR satellites

Krzysztof Sośnica [1], Adrian Jäggi [1], Daniela Thaller [2], Ulrich Meyer [1], Christian Baumann [1], Gerhard Beutler [1], Rolf Dach [1]

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The time variable Earth's gravity field provides the information about mass transport in the system Earth, i.e., the relationship of mass transport between atmosphere, oceans, and land hydrology.

We recover the low degree parameters of the time variable gravity field using microwave observations from GPS and GLONASS satellites and from SLR data to five geodetic satellites, namely LAGEOS-1/2, Starlette, Stella, and AJISAI. The refined orbit modeling of low orbiting geodetic SLR satellites is performed by using pseudo-stochastic orbit parameters. The SLR-derived geopotential coefficients are compared to GRACE and GNSS results.

GPS satellites are particularly sensitive to specific coefficients of the Earth's gravity field, because of the deep 2:1 orbital resonance with Earth rotation (two revolutions of the GPS satellites per sidereal day). The resonant coefficients cause, among other, a "secular" drift (actually periodic variations of very long periods) of the semi-major axes of up to 5.3 m/day of GPS satellites.

We processed 10 years of GPS and GLONASS data using the standard orbit models from the Center of Orbit Determination in Europe (CODE) with a simultaneous estimation of the Earth gravity field coefficients and other parameters, e.g., satellite orbit parameters, station coordinates, Earth rotation parameters, troposphere delays, etc. The weekly GNSS gravity solutions up to degree and order 4 are compared to the weekly SLR and the monthly GRACE gravity field solutions.

13-0109

Temporal variations in the Earth's gravity field from multiple SLR satellites: Toward the investigation of polar ice sheet mass balance

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The Hitotsubashi University and National Institute of Information and Communications Technology of Japan have developed an analysis software package named "c5++" to process systematically various data acquired by space geodetic techniques [Otsubo et al, 1994]. This software implements a system to derive temporal variations in the Earth's gravity field from the SLR tracking data. Using this software and incorporating data from five SLR satellites, we obtain monthly time series of gravitational Stokes coefficients of degree and order up to 4 between September 1986 and May 2013. Here we utilize them to investigate the ice sheet mass balance in Greenland and Antarctica. Our SLR gravity solutions suggest that Greenland mass balance was nearly-balanced prior to 2002 and shifted to decreasing afterwards. The mass balance in West Antarctica also shows similar trends as Greenland. However, that in East Antarctica shows opposite trends: i.e. near-balance prior to 2002 and shifting to increasing afterwards. These mass variabilities agree well with numerical results of mass balance estimate by input output method [Shepherd et al., 2012]. So, the present study demonstrates that the retrospective SLR data allow us to "observe" the mass variability of Greenland and Antarctica prior to the launch of GRACE mission in 2002.

13-0110

Low-frequency gravity change from GPS data of COSMIC and GRACE: potential enhancement from COSMIC-2's GPS and SLR data

Cheinway Hwang [1], Shin-Fa Lin[1,2], Yan-Ti Chen [1], Tzu-Pang Tseng [3], B. F. Chao [4]

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This paper shows the estimation of low-frequency time-varying gravity fields from GPS data from low-earth orbiters. Our current solutions use GPS data from COSMIC and GRACE satellite missions, but will include more data from missions such as CHAMP and future COSMIC-2. Some of the COSMIC-2 satellites will be equipped with SLR retro-reflectors, allowing for orbit validation and extra data to enhance our low- frequency gravity solutions. Our solutions use the analytical orbit perturbation theory and the input data are the residuals between the kinematic orbit and the dynamic orbit, the latter being generated by GEODYN II. The dynamic orbit models all perturbing forces except the time-varying gravity. We will present the preliminary result from COSMIC and GRACE GPS data from September 2006 to December 2007 (16 months), with a possible extension of the gravity time series. Our time-varying gravity filed is complete to spherical harmonic degree 5. The gravity variations from the GPS and GRACE (based on KBR) solutions show consistent patterns over space and time, especially in regions of active hydrological changes. The monthly GPS-derived second, third and fourth zonal gravity coefficients show high correlations with the SLR-derived result.

13-0111

Earth's low degree gravitational variations from space geodetic data

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Geodetic techniques allow to monitor the main mass variations of our planet reflected by variations of the Earth's figure axis and oblateness which are described by the second-degree geopotential coefficients. SLR data have been used in this study to retrieve time series of direct estimates of low degree geopotential coefficients using 7 geodetic satellites: Lageos1, Lageos2, Stella, Starlette, Ajisai, Etalon1 and Etalon2.
SLR, GPS and VLBI can be used to estimate these variations through derived excitation functions from the EOPs estimations. The excitation functions incorporate the influence by earth's atmosphere and oceans, both from their mass and motion components, which can be modelled by the atmospheric and oceanic angular momenta variations provided by the IERS dedicated bureaus.
The C21/S21/C20 long-term geodetic time series, obtained with different methods and using different data, deprived of the modelled atmospheric and oceanic 'motion' terms to isolate their response to the mass variations only, will be presented and inter-compared, to evaluate their consistency. The residual signal contents of the geodetic values will be evaluated too.

13-0112

Geophysical fluid models for atmosphere, ocean and hydrology and their impact on SLR analysis

Ole Roggenbuck, Maria Mareyen

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For a wide range of sciences it is important to know the shape of the earth, the earth gravity field, the earth rotation and their evolution in time. Especially in case of slow moving phenomena like the sea level rise it is important to have access to high quality reference frames. Reference frames like the ITRF describe the position of points with coordinates and velocities related to a reference epoch.

Apart from linear behavior we have to consider a sum of additional time dependent variations. These additional terms are often caused by the ocean, the atmosphere and the hydrology, the so called geophysical fluids. With changes in mass distribution they have an influence on the gravity field and the shape of the earth. Beside the tidal effects there are also non-tidal effects. For modeling these effects, special data sets describing the global mass variations in the atmosphere, the ocean and the hydrology are mandatory.

We analyzed eleven years of Lageos and Etalon data using different loading models for the geometric deformation and the gravity effect. We tested different model combinations and studied the impact on the estimated station coordinates and other parameters, e.g., the geocenter and Earth rotation parameters.

13-0113

Consistent estimation of Earth rotation, geometry and gravity with DGFI's multi-satellite solution

Mathis Blossfeld [1], Vojtech Stefka [2], Horst Mueller [1], Michael Gerstl [1]

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Satellite Laser Ranging (SLR) is the unique technique to determine station coordinates together with Earth Orientation Parameter (EOP) and Stokes coefficients of the Earth's gravity field in one common adjustment. These parameters form the so called "three pillars" (Plag & Pearlman, 2009) of the Global Geodetic Observing System (GGOS). In its function as official analysis center of the International Laser Ranging Service (ILRS), DGFI is developing and maintaining software to process SLR observations called "DGFI Orbit and Geodetic parameter estimation Software" (DOGS). The software is used to analyze SLR observations and to compute multi-satellite solutions.
In this study, up to 12 satellites (ETALON1/2, LAGEOS1/2, STELLA, STARLETTE, AJISAI, LARETS, LARES, BLITS, WESTPAC, BEACON) with different orbit characteristics (e.g. inclination and altitude) are combined. The relative weighting of the satellites is done using a variance component estimation (VCE). The diversity of the orbits allows de-correlating highly correlated parameters such as gravity field coefficients (GFCs) and EOP. The correlations are studied in detail. Together with the Earth's gravity field (GFCs up to degree/order 6) and rotation (terrestrial pole coordinates, UT1-UTC), also the 3D station coordinates are estimated on a weekly and monthly basis. The results are compared to common state-of-the-art products which are provided by the IERS.

13-0114

SLR-derived terrestrial reference frame using observations to LAGEOS-1/2, Starlette, Stella, and AJISAI

Krzysztof Sośnica [1], Adrian Jäggi [1], Daniela Thaller [2], Gerhard Beutler [1], Rolf Dach [1], Christian Baumann [1]

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Currently, the contributions of Starlette, Stella, and AJISAI are not taken into account when defining the International Terrestrial Reference Frame (ITRF), despite the large amount of data collected in a long time-span. Consequently, the SLR-derived parameters and the SLR part of the ITRF are almost exclusively defined by LAGEOS-1 and LAGEOS-2.

We investigate the potential of combining the observations to several SLR satellites with different orbital characteristics. Ten years of SLR data are homogeneously processed using the development version 5.3 of the Bernese GNSS Software. Special emphasis is put on orbit parameterization and the impact of LEO data on the estimation of the geocenter coordinates, Earth rotation parameters, Earth gravity field coefficients, and the station coordinates in one common adjustment procedure.

We find that the parameters derived from the multi-satellite solutions are of better quality than those obtained in single satellite solutions or solutions based on the two LAGEOS satellites. A spectral analysis the SLR network scale w.r.t. SLRF2008 shows that artifacts related to orbit perturbations in the LAGEOS-1/2 solutions, i.e., periods related to the draconitic years of the LAGEOS satellites, are greatly reduced in the combined solutions.

13-0115

The Error Analysis of SHAO Terrestrial Reference Frame and EOPs

Xiaoya Wang, Bing He, Bin Wu, Xiaogong Hu

Shanghai Astronomical Observatory

SHAO has carried out a new TRF and corresponding EOPs based on the SINEX solutions of the space geodetic techniques such as VLBI, SLR, GNSS and DORIS. The accuracy of EOPs is similar with that of DGFI's EOPs with respect to IERS 08 C04. The accuracy is about 0.142 mas for PMX, 0.139 mas for PMY, 0.010ms for UT1-UTC and 0.02ms for LOD. From the residuals of our EOPs and IERS 08 C04 we can see the mean is very small 0.027 mas for PMX, 0.066mas for PMY, 0.008ms for UT1-UTC and 0.001ms for LOD. And also there are no any significant signals. So we think if we still can improve our EOPs' accuracy. The position and velocity for our TRF are close to that of ITRF2008 for regular space geodetic sites. The accuracy is better than 5mm for positions and 1mm/yr for velocities. There is one question again if we can improve our TRF. Therefore, we analyze the accuracy and residuals in order to look for some regular patterns and methods to improve our EOP and TRF.

13-0116

JCET's Daily-updated State-of-the-art SLR-only TRF

Erricos C. Pavlis, Magdalena Kuzmicz-Cieslak, Daniel König and Keith Evans

GEST/Univ. of Maryland Baltimore County

GGOS requirements for ITRF accuracy are very stringent, especially in the origin definition and scale stability. Additionally, precise monitoring of the geocenter and its variations over increasingly shorter intervals is a priority goal in order to meet these requirements of 1 mm accuracy and 0.1 mm/y stability. To meet the goals of GGOS geodetic techniques need to provide high fidelity data and products, based on, and validated through, the use of the most accurate and up to date standards. At the JCET/GSFC ILRS AC we have been generating incremental TRF updates on a daily basis for several years now, based solely on SLR data. The utility of such a TRF is primarily the delivery of up to date positions and velocities for our tracking sites and the improvement of such information for newly introduced systems, with little or no-data contribution during the development of the available ITRF. The approach can be easily extended to include the contribution from the other techniques, for a trully multi-technique TRF. We will present results from our current operational scheme and compare them to the nominal ITRF products, based on the currently accepted IERS and ILRS standards.

Session 3: Data Quality and its Products, SLR Network

Chair:

Shinichi Nakamura
and
Florent Deleflie

13-0201

Quality of the SLR data 1983-2012

Stanislaw Schillak[1], Pawel Lejba[1], Piotr Michalek[1], Karolina Szafranek[2]

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The presentation shows the results of the orbital analysis of the SLR data for determination of station positions and velocities from September 1983 to December 2012. The computations were realized by Goddard's NASA GEODYN-II orbital program from results of laser observations of the LAGEOS-1 and LAGEOS-2 satellites. The positions were determined for the first day of each month from the monthly arcs computed from 10-20 the best stations (quality and quantity) in each year in ITRF2008. The results for a given station with lower number of normal points than 50 per month were rejected. The station velocities were computed for data span longer than 3 years. The accuracy was estimated as 3D RMS of station position for common epoch 2005.0. The results were divided into 6 groups 5 years each: 1983-1987, 1988-1992 (both only for LAGEOS-1), 1993-1997, 1998-2002, 2003-2007, 2008-2012. In total the positions and velocities of 137 sites were determined including 16 sites longer than 20 years span, velocities for 90 sites and 30 mobile sites with span longer than 3 years. The best results of 3D RMS were obtained on the level of 4 mm (1998-2012) (stations Herstmonceux – the best in 3 spans, Mt.Stromlo, Graz and Zimmerwald), 24 stations had accuracy below 10 mm. The results before 1993 were significantly worse due to only one LAGEOS satellite, after 2005 small deterioration of accuracy were observed mainly due to systematical biases several important stations and earthquakes which are especially often in the last three years (Concepcion, San Juan, Monument Peak, Koganei, Simosato, Changchun). The results will be available soon on Borowiec web page www.cbk.poznan.pl .

13-0202

Quality and possible improvements of the official ILRS products

Horst Mueller, Mathis Blossfeld

DGFI, Munich, Germany

The ILRS is providing a few products for the international community. Seven analysis and two combination centres take care of the quality of the resulting products, station coordinates, EOPs and satellite orbits. Daily and weekly products are provided by the ILRS data centres.

In this paper we are looking for some possible improvements of these products, though the general quality is quite good at the moment. One aspect to improve station coordinates is the consistent handling of station biases and the station coordinates used for processing. We looked into time series of biases, also for core stations, and analysed the influence of individual satellites and the yield of combined biases. An other aspect is the sky coverage over the tracking stations, therefore we tried to get a quality criteria for the minimum number of passes over a station to get good weekly station coordinates. Biases and station coordinates are correlated and especially the height component of a station depends on the range bias estimated. EOPs depend on a homogeneous distribution of observation along the orbit. Especially Etalon is poorly tracked with presently 150 to 200 observation per week only and hence has little influence on the ILRS product.
Furthermore we were investigating the use of the new satellite Lares as an additional target or as replacement for Etalon tracking. This satellite can easily be modelled since he combines a heavy weight with a small diameter. Due to the orbit characteristic Lares can also improve the sky coverage over stations. Besides this satellites can be used to improve low degree harmonics of the earth gravity field. These coefficients, up to degree and order four to six, are not well defined by the present gravity missions GOCE and GRACE.

13-0203

Subdaily Quality Check of Laser Ranging Data at Hitotsubashi Univ.

Toshimichi Otsubo, Mihoko Kobayashi, Shinichirou Takakura

Hitotsubashi Univ.

Rapid quality check analysis has played an important role to improve the quality of satellite laser ranging. Since 1999, the ILRS associate analysis centers in Japan, NICT and later Hitotsubashi University, have issued quality check reports routinely. It had been a weekly service at the beginning, and later switched to a daily service in 2005. Furthermore, in August 2012, we upgraded it to a 6-hourly service. It is now possible for an observer to check his/her tracking data before going home.

The analysis software itself has been upgraded at the same time. The new C++ version of our geodetic analysis software 'c5++' is implemented in the automated sequence. The new software is compatible with the IERS Conventions (2010) and other latest models, and we can provide more stable and more precise analysis reports than the previous version.

When we detect a series of anomalous passes, we report the incident to the station and the 'rapidservicemail' mailing service operated at DGFI. Up to now, we search such incidents by human eyes, but we plan to automate the detection process in the near future.

13-0204

Quality assessment of SLR data-related products

Jean-Michel Lemoine [1], Florent Deleflie [2], Franck Reinquin [1], David Coulot [3,2]

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We draw an assessment of the quality obtained on SLR data – related products that are computed from the analysis of Lageos-1 and Lageos-2 data acquired by the ILRS network over more than 20 years. In particular, we show and analyze time series of post-fit residuals for both satellites, biases and space stations coordinates (SSCs), that are deduced following the recommendations provided by the Analysis Working Group. Moreover, as an update of the SLRF2008 reference file, we perform and analyze the same kind of study from orbit computations (i) where all the a priori parameters are those we submitted to the Combination Centers (SSC, EOPs), (ii) with a modelling accounting as well for atmospheric loading effects over the last few years. We discuss the corresponding results.

13-0205

EUROLAS Data Center - Improvements of the Website for the ILRS Community

Christian Schwatke

DGFI

In 2011, the EDC website (http://edc.dgfi.badw.de) was released. This website provides information about the data flow between stations, prediction providers and the EDC. It also gives detail information about the status of every individual submitted SLR passage.

In this presentation, we introduce new features of the EDC websites which are useful for station managers and users such as

- tool for checking CRD and CPF format,
- individual CPF mailer configuration,
- API for station manager to get information about their submitted data,
- monthly and yearly reports of EDC,
- new statistics about satellites and stations (e.g. daily and monthly number of SLR measurements),
- new statistics about the EDC data holding (e.g. time span between measurement at availability at the DC),
- etc.

13-0206

NASA SLR operational network project overview.

David McCormick

NASA

This paper presents the past and present performance of the NASA SLR network. The NASA SLR network has many legacy systems that need to last or be transitioned to the future network. This paper answers how, at a high project level, NASA will manage component obsolescence in a changing environment to maintain and improve NASA's contribution to the ILRS and Geodesy.

13-0207

Engineering changes to the NASA SLR Network to overcome obsoleteness and improve performance and reliability

Thomas Varghese

NASA/ Cybioms Corporation

NASA SLR network has provided excellent laser ranging data over decades to contribute to ITRF, altimetry support, and transponder measurements. The obsoleteness of hardware and ensuing difficulty to maintain a reliable and sustainable network have prompted an effort to replace, refurbish, and revamp the system for continuity of operations and improved ranging performance. This paper will describe the challenges, issues, and the technical effort currently in progress in pursuit of reliable and state of the art performanc

Session 4: POD and its Application

Chairs:

Erricos C Pavlis
and
Daniel Kucharski

13-0208

Orbit Determination and Analysis for STSAT-2C

Young-Rok Kim, Eunseo Park, and Hyung-Chul Lim

Korea Astronomy and Space Science Institute, Korea

The Korea's first SLR satellite, Science and Technology Satellite (STSAT)-2C was launched on January 30, 2013 by Korea Space Launch Vehicle (KSLV)-1. SLR tracking for STSAT-2C was started on March 29, 2013. However, there are very few SLR measurements because the accuracy of predicted orbit by consolidated prediction format (CPF) is poor. It becomes trouble both tracking and orbit determination for STSAT-2C. In this study, the orbit determination using SLR measurements for STSAT-2C is performed. For orbit determination, NASA/GSFC GEODYN II software is used and various strategies are applied. The period of atmospheric drag coefficients and acceleration parameters estimation and arc length are changed. For orbit quality assessment, post-fit residuals of orbit determination process and orbit overlaps of arcs are analyzed. Additionally, the differences between estimated orbit and CPFs are presented. Finally, we propose better orbit determination strategy to overcome inaccurate initial orbit condition and sparse or insufficient measurements by SLR-only.

13-0209

GNSS Satellite Orbit Validation Using Satellite Laser Ranging

Oliver Montenbruck [1], Peter Steigenberger [2], Georg Kirchner [3]

[1] DLR/GSOC
[2] TUM/IAPG
[3] ÖAW/IWF

With a total of four new regional and global navigation satellite systems that have launched first satellites or even started an operational service, the GNSS landscape has experienced major changes in recent years. As part of the Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS), a global network of multi-GNSS monitoring stations has been established and various analysis centers have started to determine orbits of selected GNSSs on a routine basis. As a key feature, all satellites of the new constellations (i.e. Galileo, BeiDou, QZSS and IRNSS) are equipped with laser ranging reflector arrays enabling high-precision two way ranging measurements. The presentation illustrates the use of SLR observations collected by the ILRS for validation of precise and broadcast ephemerides of the new constellations. As an independent and unambiguous tracking system, SLR helps to gain a better understanding of the new satellites, which still lack a thorough characterization of their orbit and attitude dynamics. SLR tracking is thus considered an essential contribution for a future use of the new GNSSs in space geodesy. The presentation also addresses operational aspects of SLR tracking of the new navigation satellites related to their specific orbits, regional distribution and continuously increasing number.

13-0210

The concept and the preliminary results of the SLR application in the problem of improving the GLONASS accuracy

V.V. Pasinkov[1], V.D. Shargorodsky[1], M.A. Sadovnikov[1], V.V. Sumerin[1]

Russia

We present the concept of one-way and two-way laser ranging to improve the accuracy of ephemeris and time-frequency information of the GLONASS Russian navigation system, as well as the techniques of using laser ranging for:

- calibration of RF one-way measuring systems,
- determination of the differences of on-board and on-ground time scales,
- accuracy control of ephemeris-time data of the navigation message and geodetic data of the GLONASS system measuring sites.

The description is presented of the ground-based and on-board equipment intended for inter-satellite coordinate/time measurements, and for laser one-way and two-way ranging.

Experimental data are presented of the inter-satellite measurements and also of comparison between on-ground and on-board time scales using the equipment installed on the SC "Glonass-728", "GLONASS-729" and "Glonass-747".

13-0211

The Accuracy Verification for GPS Receiver of ZY-3 Satellite by SLR

Zhao Chunmei[1], Tang Xinming [2], Wei Zhibin [1], Li Qian [1]

[1]Chinese Academy of Surveying and Mapping
[2]Satellite Surveying and Mapping Application Center, NASG

The ZY-3 satellite provides stereo and multispectral imagery for topographic mapping, remote sensing and environmental applications. ZY-3 has two dual-frequency homemade GPS receivers to determine the satellite orbit. Based on the satellite dynamics principle and batch processing mode, the orbit of ZY-3 satellite was determined using zero-difference GPS measurements. In order to verify the orbit accuracy by GPS, we carried out a laser restricted ranging campaign with the support of the International Laser Ranging Service (ILRS). Compared with SLR data, the distance bias between the satellite and SLR stations was less than 4cm, which revealed that ZY-3 satellite orbit accuracy can meet the requirement of satellite mission.

13-0213

Multi-Static Laser Ranging to Space Debris Targets: Tests and Results

Georg Kirchner [1], Franz Koidl [1], Martin Ploner [2], Pierre Lauber[2], Johann Eckl [3], Matthew Wilkinson [4], Robert Sherwood [4], Adolf Giessen [5], Martin Weigel [6]

[1]Austrian Academy of Sciences, Space Research Institute
[2]Astronomical Institute, Univ. of Bern
[3]SLR Station Wettzell, Germany
[4]NERC Space Geodesy Facility
[5]DLR Stuttgart, Institute for Technical Physics
[6]DLR Oberpfaffenhofen

Using a strong laser (200 mJ @ 532 nm, 3 ns pulse length, 80 Hz) borrowed from DLR Stuttgart, the SLR station Graz tracked space debris targets up to distances of > 3000 km. Several cooperating SLR stations within Europe – synchronized to the Graz laser firing times - successfully detected and time-tagged these Graz photons, diffusely reflected from the space debris targets.

These quasi-simultaneously measured distances from several laser stations to the same orbital arc allow for better orbit determination using one or only few passes of non-cooperative targets.

13-0214

Progress and Observation of Space Debris Laser Ranging

Zhang Zhongping, Zhang Haifeng, Wu Zhibo, Li Pu, Meng Wendong, Chen Juping, Chen WanZhen

Shanghai Astronomical Observatory

As an increasing number of Space debris, high precise measurement and accurate catalogue for space debris are required to protect payloads against debris collision. Laser ranging is a kind of real-time measuring technology with high precision for space-debris observation. Since 2007, Shanghai Observatory has begun to do researches on the debris laser ranging technology. With a high power laser of 50W at 200Hz repetition rate, and low noise detectors, Shanghai Observatory has the ability to range debris of less than 1m2 at the distance of 1000km. This paper presents the debris laser ranging system, observations and preliminary results of orbit determination to space debris by single station measurement

13-0215

ENVISAT Spin and Attitude Determination Using SLR

Georg Kirchner [1], Daniel Kucharski [2], Franz Koidl [1]

[1]Austrian Academy of Sciences, Space Research Institute
[2]Korea Astronomy and Space Science Institute

During the last few months, several SLR stations of the ILRS network have tracked ENVISAT; the data has been used to enhance orbit prediction accuracy, and to determine attitude and spin of ENVISAT.
While ENVISAT attitude during its active phase was controlled, it now has started to spin with about 120 seconds per revolution; its spin axis seems to have stabilized in such a way, that about 50% of the passes allow the stations to ‘see’ the retro-reflectors – thus enabling routine SLR. Few Passes without ‘visible’ retro-reflectors have been measured by Graz using the strong DLR laser, and detecting the diffuse reflected photons.

Session 5: Laser Time Transfer

Chairs:

Stanislaw Schillak
and
Ivan Prochazka

13-0216

Time Transfer: Sideline or Geodetic Objective?

Anja Schlicht [1], Ulrich Schreiber [2], Ivan Prochazka [3], Pierre Exertier [4]

[1] Technische Universität München
[2] Observatory Wettzell
[3] Technical Univ. of Prague
[4] Observatoire de la Cote d'Azur

Even if this presentation won't answer this question it should give an orientation to the SLR stations which effords are worth to investigate into future activities and which profits can be seen for geodesy as they answer this question by themselves. There are several questions on the way to this main question, where we could give answers:
Which synergies can be used doing ranging and time transfer?
Why are clocks put into orbit?
How can space and ground clocks be compared?
Which clock does a station need?
What's the differnce between T2L2 and ELT?
Which effords are necessary to contribute to ELT?
What's a reference point for time?
What profits can geodesy gain?

13-0217

European Laser Time Transfer (ELT) - System delays calibration

I. Prochazka [1], K. U. Schreiber [2], J. Kodet [2,1], A. Schlicht [2], J.Blazej [1]

[1] Czech Technical Univ. in Prague
[2] Forschungseinrichtung Satellitengeodäsie, TUM Geodetic Observatory Wettzell

The laser time transfer is an attractive technique providing the capability of time transfer ground to space and ground to ground with picosecond precision and several picoseconds accuracy. The technique is relying on the existing ground based infrastructure used for satellite laser ranging (SLR). In order to reach the ultimate precision and accuracy the ground systems participating in time transfer have to be properly calibrated for this purpose. The new tool "ELT Calibration Device" is currently under construction. The device is planned to be operated successively on the participating SLR stations to characterize the ground segment timing performance prior to the mission launch. The Calibration Device is simulating the ELT operation to some extent, thus the calibration campaign will serve as an "exercise" before the real flying hardware will be in operation. The outputs of the calibration campaigns can be used in other laser time transfer missions, as well. The basic concept of this process will be presented along with the overall SLR station requirements.

13-0218

European Laser Time Transfer (ELT) and Laser Safety for the ISS

Ulrich Schreiber [1], Jan Kodet [1,3], Anja Schlicht [1], Ivan Prochazka[3], Johann Eckl [2], Guenther Herold [2]

[1] Geodetic Observatory Wettzell, TUM
[2] Geodetic Observatory Wettzell, BKG
[3] Czech Technical Univ. in Prague

The methods of optical time transfer have been proposed and pioneered by the French group (Exertier, Samain et al.) in Grasse. As a result T2L2 was launched on Jason 2 and demonstrated the viability of this technique. With the Atomic Clock Ensemble in Space (ACES) a follow up mission for the exploitation of time transfer is in preparation at ESA. While the USO of Jason 2 drifts significantly, ACES will provide a stable reference for non common view time comparison. The ILRS has been confronted with challenging tracking restrictions several times in the past. With ACES at the Columbus module of the ISS the challenge of guaranteed eye safety at all times during SLR laser activities is given. This talk reviews the requirements and the currently proposed procedure.

13-0219

Progress Report on the WLRS: Getting ready for GGOS, LLR and Time Transfer

Guenther Herold [1], Johann Eckl [1], Matthias Muehlbauer [1], Andreas Leidig [2], Ulrich Schreiber [2]

[1] Geodetic Observatory Wettzell, BKG
[2] Geodetic Observatory Wettzell, TUM

The goals set forward by the GGOS have stringent implications for the SLR stations. Most prominently this requires a good control over systematic effects reducing the accuracy on the range measurements. At the same time the observation load on the system increases as more satellites are endorsed for tracking by the ILRS. We have taken up the challenges and remodeled the WLRS. A new laser with shorter pulse duration and higher reliability and stability is currently being integrated as well as a new ground target providing higher accuracy. We also concentrated on the support for high altitude satellites in order to get back to LLR observations. Last but not least, we have improved our control system to support satellite interleaving. A lot of effort went into the construction of a calibrated timing link between the WLRS and the master clock of the Geodetic Observatory Wettzell in order to support optical time transfer between T2L2 on Jason 2 and eventually ELT on the ISS.

13-0220

Local ties control in application of laser time transfer

Jan Kodet [1,3], Ulrich Schreiber [1], Johann Eckl [2], Ivan Prochazka[3], Petr Panek [4]

[1]TUM, Wettzell Observatory
[2]BKG, Wettzell Observatory
[3]Czech Technical Univ. in Prague
[4]Institute of Photonics and Electronics, Academy of Sciences of the Czech Republic

In many fundamental physical experiments time plays an important role. The standard way for the comparison of time and frequency is the application of GNSS signals and the Two-Way Satellite Time and Frequency Transfer - TWSTFT. Recently, there is a rapid increase of the optical time comparison development, which uses the Satellite Laser Ranging network (SLR). Currently the French project T2L2 operating on board Jason 2 and the LTT project on board of Compass GNSS are operational. European Space Agency project ELT in support of the Atomic Clock Ensemble in Space (ACES) is under development. The main aim of these projects is the time synchronization with a precision below 40 ps rms and an absolute error well below 100 ps. A lot of effort went into the development of a symmetric two-way measurement technique to identify unaccounted system delays between the WLRS and the master clock of the Geodetic Observatory Wettzell. The paper discusses the obtained results and proposes how to deal with the timing system
and calibration in applications of the optical time transfers.

Session 6: Space Mission

Chairs:

Zhang Zhongping
and
Ludwig Grunwaldt

13-0221

Russian free-space laser communication experiment “SLS”

Grechukhin I.A.[1], Grigoriev V.N. [1], Danileiko N.O. [1], Ivlev O.A. [1], KovalevV.V. [1], Manzheley A.I. [3], Nabokin P.I. [1], Slagoda V.V. [2], Sorokin I.V. [2], Shargorodsky V.D. [1], Shevchik A.S.[1], Sumerin V.V.[1]

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“Precision Systems and Instruments”
[2]Rocket and Space Corporation “Energia”
[3] Mission Control Center of TSNIIMASH

The Russian experiment "Space LaserComm System" (SLS) was operated from August 2011 till July 2013 and had demonstrated the Russian space laser information transfer technology. In “SLS” space experiment were used: an onboard laser communication system (BLS), mounted on the International Space Station (ISS), and a ground laser system (GLS) sited at “Arkhyz” SLR-station (ID1886). SLS technique was developed and produced at RPC "PSI".

More than 100 LaserComm sessions were carried out with the results achieved:

• Precision laser beam targeting with an error less than few angular seconds at high target speeds (more than 8 deg/s)

• High volume of information data transfer technology, at 125 Mbit/s downlink data-rate, which includes real scientific information transfer at 125 Mbit/s downlink and 3 Mbit/s uplink with BER=1e-9 bit-1;

• Information transfer technology on 622 Mbit/s downlink rate, with BER=1e-7 bit-1;

• Research of BLS-GLS link performance capabilities in night and daylight conditions, in circumsolar zone, in haze and clouded sky up to 80%.

Hardware components and technology of intersatellite LaserComm systems were tested out during SLS experiment.

Space experiment was carried out by RPC "PSI" in cooperation with RSC “Energy” and Mission Control Center of TSNIIMASH under control of ROSKOSMOS as a part of long-term science-applied research and experimental program on Russian ISS section.

13-0222

Laser Ranging to Nano-Satellites in LEO Orbits: Plans, Issues, Simulations

Georg Kirchner [1], Ludwig Grunwaldt [2], Reinhard Neubert [2], Franz Koidl [1], Merlin Baschke [3], Zizung Yoon [3], Hauke Fiedler [4]

[1]Austrian Academy of Sciences, Space Research Institute
[2]GFZ Potsdam
[3]Technical Univ. Berlin, Department for Aeronautics and Astronautics
[4]DLR Oberpfaffenhofen

Several small satellites in the class of pico- and nano-satellites will be equipped with multiple small corner cubes: OPS-SAT (ESA), S-Net and TechnoSat (8 kg resp. 15 kg; Technical University Berlin). The size of these satellites is in the range of 10x10x30 cm, up to about 40 x 40 x 30 cm; the planned circular orbits are in the 500 – 600 km range.
Commercially available 0.5” corner cubes will be used for SLR; a single corner cube of this size will be sufficient for SLR to the planned LEO orbits.
Placing several of these corner cubes on each side of the satellites will not only allow for standard SLR and POD, but also for an independent attitude determination with < 1° accuracy, even after the end of the satellites lifetime, or in case of problems or satellite failure.

13-0223

SpinSat Mission Overview

Andrew Nicholas

Naval Research Laboratory

The SpinSat flight is a small satellite mission proposed by the Naval Research Laboratory and Digital Solid State Propulsion (DSSP) LLC to demonstrate and characterize the on-orbit performance of electrically controlled solid propellant technology in space. This is an enabling technology for the small satellite community that will allow small satellites to perform maneuvers. The mission consists of a spherical spacecraft fitted with Electrically Controlled Solid Propellant thrusters and retro-reflectors for satellite laser ranging (SLR). The spacecraft will be deployed from the International Space Station. This paper presents a mission overview and emphasis will be placed on the design, thruster design, optical layout, and unique SSA observationr opportunities of the mission.

Session 7: SLR Technology and Synergy

Chairs:

Ulrich Schreiber
and
Matthew Wilkinson

13-0301

The Collocation of NGSLR with MOBLAS-7 and the Future of NASA Satellite Laser Ranging

J. McGarry [1], S. Merkowitz [1], H. Donovan [2], J. Horvath [2], C. Clarke [2], J. Degnan [3], J. Cheek [3], A. Nelson [2], D. Patterson [2], A. Mann [2], F. Hall [2], R. Ricklefs [4], T. Varghese [4], T. Zagwodzki [4], E. Pavlis [5]

[1] NASA GSFC, [2] HTSI
[3] Sigma Space Corporation
[4] Cybioms Corporation
[5] Univ. of Maryland

In July 2013 NASA's prototype Next Generation Satellite Laser Ranging System (NGSLR) completed a five week successful collocation with the NASA SLR Network station MOBLAS-7. This was the final system test to validate the NGSLR design.

During collocation NGSLR demonstrated its ability to perform day and night tracking to satellites from LEO to GNSS altitudes, even through thin clouds and between thick clouds. The system has tracked almost all of the ILRS satellites from GRACE and TanDEM-X to GLONASS and Galileo. The ground calibration stability was shown to be better than 1 mm RMS over 1-2 hour periods. Preliminary analysis of the system range bias, for the LAGEOS and LAGEOS-2 satellites, shows that NGSLR is somewhat long when compared to the collocated MOBLAS-7 ranges, but is very stable, and this is confirmed by independent analysis performed with SLR Network generated orbits.

NGSLR has performed extremely well and at the required levels for future NASA SLR systems. Within the next year the NGSLR automation will be completed and this prototype system will be made more operational. Future NASA systems are planned to be fabricated in the next few years and these systems will build upon the foundation laid by NGSLR.

13-0302

Evaluation of the 2013 NGSLR and MOBLAS-7 Co-location Dataset at GGAO

Erricos C. Pavlis [1], Magdalena Kuzmicz-Cieslak [1], Jan F. McGarry [2], Christopher B. Clarke [3], Julie Horvath [3] and Howard Donovan [3]

[1] GEST/Univ. of Maryland Baltimore County
[2] NASA GSFC
[3] HTSI

NASA Goddard's NGSLR system participated in a co-location campaign during June 2013, tracking along with the local fixed system MOBLAS-7 as many common view passes of various missions, as the schedule permitted. Part of the new system (NGSLR) validation and acceptance process was the evaluation of that data set against the concurrent tracking of the ILRS network, and in particular, the commonly observed passes between the two co-located systems. This presentation will focus on the results we obtained from the analysis of LAGEOS, LAGEOS 2, LARES and a few other select satellite targets, of the NGSLR data vis-à-vis with the complete set of tracking data on these targets from the entire ILRS network. We will focus also on a comparison of the data from NGSLR versus data collected by similar systems around the world and on the same targets, with emphasis on the level of systematic differences between NGSLR and these systems.

13-0303

The results of two-color observations

Stanislaw Schillak

Space Research Centre PAS

The two-color SLR measurements were realized so far by two SLR stations: Zimmerwald (7810) from August 2002 to January 2008 and Concepcion (7405) from May 2003 to November 2009. Both stations used Titanium-sapphire lasers with primary wavelength 423 nm and secondary 846 nm. In stop channel both colors were divided and return signals were detected independently for each color by two detectors and time interval counters or event timers. The results for both colors were treated as for two stations: 7810B (7405B) – blue and 7810IR (7405IR) – infrared. The station positions were computed by Goddard's NASA GEODYN-II program from the data LAGEOS-1 and LAGEOS-2 satellites. In the period of study were 47 common monthly points for both colors in Zimmerwald and only 8 common points in Concepcion, hence the detailed analysis were performed only for Zimmerwald data. The NEU positions 3D RMS were equal to 3.5 mm (N), 3.2 mm (E), 16.5 mm (U) for blue and 3.2 mm (N), 2.9 mm (E), 14.6 (U) for infrared. In the period of study were 47 common monthly points for both colors. The difference between N, E, U components in blue and infrared for common points were equal to 0.8±2.0 mm, 0.4±1.9 mm and -4.8±8.7 mm respectively. The differences between Range Biases for both colors independently for LAGEOS-1 and LAGEOS-2 were equal to -5.7±8.6 mm and -5.0±9.5 mm respectively. The same for both satellites annual wave with amplitude 10 mm was detected. This effect can to be explain by differences in atmospheric correction for each color. This same analysis for station Concepcion (7405) couldn't to be performed due to only 8 common points. Unfortunately the station Zimmerwald operated from March 2008 with neodymium laser and Concepcion from 2009 use only infrared (846 nm) and verification of presented results is impossible. In future very important should be laser ranging in two-colors 532 nm and 1064 nm for confirmation presented here results, especially that a new sensitive APD detectors for 1064 nm are now available.

13-0304

Modeling spin parameters of Ajisai, LARES and the other geodetic satellites with SLR data

Daniel Kucharski [1], Hyung-Chul Lim [1], Georg Kirchner [2], Toshimichi Otsubo [3], Giuseppe Bianco [4], Franz Koidl [2], Joo-Yeon Hwang [1,5]

[1] KASI
[2] Space Research Institute, Austrian Academy of Sciences
[3] Hitotsubashi Univ.
[4] Agenzia Spaziale Italiana, Centro di Geodesia Spaziale G. Colombo
[5] Yonsei Univ.

The SLR data allows for the spin parameters determination of the fully passive, geodetic satellites. We have spectrally analyzed the long time series of the Full Rate SLR data delivered by the global network of the SLR stations and obtained information about the spin parameters, and the spin evolution, of the following satellites: Ajisai, BLITS, Etalon-1, Etalon-2, LAGEOS-1, LAGEOS-2, LARES, Larets, Stella. The satellites made of the conducting materials are exponentially losing the rotational energy over time with the rate depending on the intensity of the Earth's magnetic field at the altitude of an orbit. Our results show that the Low Earth Orbiting satellites Larets and Stella lose spin with the fastest rate - it takes only 38 days for the spin period of Larets to double, while for Ajisai - 46.7 years.
This presentation will show the differences in the observed spin dynamics between the above mentioned satellites and the results of the spin modeling of the spacecrafts.

Session 8: SLR Technology and Safety

Chairs:

Graham Appleby
and
Georg Kirchner

13-0305

Upgrade of the NGSLR optical bench and resulting performance improvements

H. Donovan, T. Zagwodzki, J. Annen, J. Horvath, F. Hall, D. Patterson, A. Nelson, E. Hoffman, J. Degnan, J. McGarry, J. Cheek

NASA/HTSI

After several years of field development and satellite laser ranging operations, the Optical Bench has under gone many incremental changes to accommodate increased demands on the capabilities of the NGSLR.

Initially designed for low energy, eyesafe laser ranging, the Optical Bench has been modified to handle energies needed to perform daytime GNSS tracking as well as meet newly developed American National
Standards Institute (ANSI) and Federal Aviation Administration (FAA) safety requirements.

In time, it was realized that an overall design change was essential to better accommodate iterative upgrades, allow for full use of increased laser power, provide more precise and efficient optical alignments, and incorporate lessons learned thus far from SLR operations. We will review the initial design of the Optical Bench and its implementation as well as discuss the upgrades, the supporting reasons, and the improvements in system performance because of this upgrade.

13-0306

Proposed beam divergence estimation procedure for the ILRS

R. Burris[1], J. Rodriguez[2], R. Smith[1], L. Thomas[1], D. Huber[1]

[1] U.S. Naval Research Laboratory
[2] NERC Space Geodesy Facility

Link budgets for many of the ILRS sites are estimated using divergence values that are derived from the site logs. Actual data for calculating the station divergence is often incomplete or very optimistic and based on diffraction theory from the full size of the primary mirror for monostatic systems or the full size of the Coude path and beam expander for bistatic systems.

Accurate divergence measurements and a standard method of measuring the divergence is needed by the ILRS for several reasons, including GNSS array requirements and performance prediction and reliable prediction of the energy density delivered on target for the entire ILRS network to deal with requests for information for potential new satellites.

A procedure was developed and presented at the last ILRS meeting for scanning over azimuth and elevation on two satellites and using an equation derived from the laser radar equation for estimating the site divergence. A new method has been developed which requires scanning a single satellite and performing transmit power measurements to estimate the site divergence. This method will be presented here with some preliminary results.

13-0307

Integration of a SBS-3 ADS-B receiver into the SGF, Herstmonceux aircraft safety system

Matthew Wilkinson, Jose Rodriguez

NERC Space Geodesy Facility

The SBS-3 receiver decodes ADS-B transmissions, which include positions and velocities, picked up from nearby aircraft.
Following the experience of other SLR stations, the unit was purchased to inform the observer and to be integrated into the SLR safety system to further avoid laser collisions with aircraft. SBS- 3 connects to the network and allows the raw data stream to be accessed directly .This is an efficient and reliable way to handle the plane transmissions, which are broadcast 1-2 times a second. The data must be properly interpreted to give the latitude, longitude, altitude, plane ID and velocities from each message.
A TCP/IP server was built to permanently connect to the SBS-3 translate the raw data to the position and velocity messages and to then provide the data to multiple client connections .An additional connection to the server provides the real time SLR telescope and laser direction.
This server proved to be very reliable and has enabled an aircraft audio alarm client to be developed as well as a visual display client. The safety system is highly accurate with alarms coinciding closely with the sounding of the radar safety system.
Further integration into the SLR system is underway.

13-0308

The new ADS-B based aircraft avoidance system at the MLRO

Domenico Iacovone [1], Giuseppe Bianco [2]

[1] e-Geos/MLRO
[2] ASI/MLRO

The Matera Laser Ranging Observatory (MLRO), since the beginning of operations, has been equipped with a pulsed radar system which stops the ranging activity in case of possible collision between the laser beam and flying aircrafts. The MLRO safety standards have recently been improved with the integration of a new safety device based on the Automatic Dependent Surveillance – Broadcast (ASD-B) technology, on which the new Air Traffic Management (ATM) standards, to be enforced in Europe from January 2015, will be based. This presentation gives a thorough description of the capability of the new virtual radar system and its integration in the MLRO.

13-0309

Hazards & Risks @ SLR Network, Updates and New Challenges

Jorge R. del Pino

Institute of Astronomy Univ. of Latvia

As a follow-up of the related 17th Workshop's presentation, new examples of Hazards and its outcomes affecting the SLR network are presented. The SLR network seismic risk ranking is expanded to include new stations and upgraded with seismic data up to October 2013. Several proposals are presented with the purpose to improve the SLR Network Hazards & Risks management including in In-The-Sky-Laser-Safety

Session 9: Moon & Deep Space

Chairs:

Hiroshi Araki
and
Jürgen Müller

13-0401

Status of LLRRA-21 and Simulation of Apollo Behavior

Douglas Currie [1], Bradford Behr [1], Giovanni Delle Monache [2], Simone Dell'Agnello [2] and Tom Murphy [3]

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The current status of the "Lunar Laser Ranging Retroreflector for the 21st Century" will be discussed. This will address the latest simulations and the resultant challenges, particularly in the choice of optimal thermal coatings. The plans for a thermal vacuum test will also be described. Finally, the current work on the pointing mechanism, being conducted in both at Sant'Anna University in Italy and at the University of Maryland will be illustrated. The second part will address the simulation of the Apollo retroreflectors and the relation between the simulations and the observation and the APOLLO station in general and during the lunar eclipse. This will particularly address the role of the dust and the implications of the lunar eclipse observations as they imply limitations and new directions for the next generation retroreflector packages.

13-0402

Lunar Laser Ranging – What is it Good for?

Jürgen Müller [1,2], Liliane Biskupek [1], Franz Hofmann [1], Enrico Mai [1]

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In 1969, a new era for studying Earth-Moon dynamics has started. Since the first returns of laser pulses sent from observatories on Earth to reflector arrays on the Moon, a new space geodetic technique – Lunar Laser Ranging (LLR) – provides an ongoing time series of highly accurate Earth-Moon distance measurements. This data can be used to carry out relativity tests and to potentially support various GGOS objectives.

LLR data analysis is realized at the cm level of accuracy, for which the whole measurement process is modeled at appropriate post-Newtonian approximation, i.e. the orbits of the major bodies of the solar system, the rotation of Earth and Moon, signal propagation, but also the involved reference and time systems as well as the time-variable positions of the observatories and reflectors.

We will show where relativity enters the LLR analysis and what the major classical (Newtonian) effects are such as gravity field of Earth and Moon, tidal effects, ocean loading, lunar tidal acceleration (that causes the increase of the Earth-Moon distance by about 3.8 cm/year), etc.

By analyzing the 43-year record of range data, LLR is able to provide, among others, a dynamical realization of the International Celestial Reference System, parameters related to the selenocentric and terrestrial reference frames, (long-periodic) Earth Orientation Parameters as well as quantities testing General Relativity (e.g. strong equivalence principle, Yukawa-like perturbations or time-variability of the gravitational constant).

We will present results for a selection of those parameters.

13-0403

Lunar Laser Ranging : Recent activities of Paris Observatory Lunar Analysis Center

S. Bouquillon[1], G. Francou[1], H. Manche[2], J-M Torre[3], C. Le Poncin-Lafitte[1] & C. Lhotka[4]

[1] Observatoire de Paris
[2] Observatoire de Paris Astronomie et Systèmes Dynamiques
[3] Université de Nice Sophia-Antipolis Observatoire de la Côte d’Azur Géoazur Caussols
[4] Department of Mathematics Univ. of Rome Tor Vergata

The lunar analysis center POLAC is located at SyRTE laboratory of “Observatoire de Paris” (France). It works in close cooperation with the laser ranging team of the “Observatoire de la Côte d'Azur” (GRGS analysis center), with the two IERS centers based at the “Observatoire de Paris” (EOP and ICRS centers) and with the group in charge of the development of INPOP planetary ephemeris. The aim of this presentation is to review the recent activities of our group and more particularly to focus on the two main efforts done to support respectively LLR observers and LLR data users. Concerning the support to LLR observer, we present the recent improvement achieved in the “LLR data Prediction and Validation tools” (http://polac.obspm.fr/PaV/). Concerning the support to LLR data users, we present a set of LLR observations (from the 20th of August 1969 until the 30th of May 2013) based on a critical analysis of an extended LLR data gathering which includes the two databases of ILRS (hosted by DGFI and GSFC) and the archives maintained by POLAC, by the GRASSE Station and by the APOLLO station.

13-0404

Analysis and application of 1-way laser ranging data from ILRS ground stations to LRO

S. Bauer [1], D. Dirkx [2], J. Oberst [1,3], H. Hussmann [1], P. Gläser [3], U. Schreiber [4], D. Mao [5], G. Neumann [6], E. Mazarico [6], M. Torrence [7], J. McGarry [6], D. Smith [8], M. Zuber [8]

[1] DLR Berlin, [2] TU Delft , [3] TU Berlin
[4] Geodätisches Observatorium Wettzell
[5] Sigma Space Corporation, [6] NASA GSFC
[7] SGT Inc., [8] MIT

One-way LR (Laser Ranging) is being performed routinely from ILRS (International Laser Ranging Service) ground stations to LOLA (Lunar Orbiter Laser Altimeter), onboard NASA's LRO (Lunar Reconnaissance Or-biter). The high accuracy spacecraft range measurements can be used for positioning, characterization of the LRO clock, in particular the long-term behavior and referencing of MET (Mission Elapsed Time) and TDB (Barycentric Dynamical Time) with high precision. We use automated tools to process LR data from the various ranging stations over the entire LRO science mission. Based on the ranging data we have developed a clock model that is including variations of the LRO clock due to aging as well as environmental effects. In a next step, we have simulated artificial LR to LRO data utilizing information from the processed data to analyze possibilities and limits of orbit determination based on LR data. The current status of the LRO clock model, the LR to LRO data simulation and the orbit determination as well as their interdependences will be described.

13-0405

LRO-LR: four years of history making laser ranging

J. McGarry [1], X. Sun [1], D. Mao [2], J. Horvath [3], H. Donovan [3], C. Clarke [3], E. Hoffman [3], J. Cheek [2], T. Zagwodzki [4], M. Torrence [5], M. Barker [2], E. Mazarico [6], G. Neumann [1], D. Smith [6], M. Zuber [6]

[1] NASA GSFC
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[4] Cybioms Corporation
[5] Stinger Ghaffarian Technologies
[6] MIT

The Lunar Reconnaissance Orbiter launched in June 2009. The first laser ranging attempted from NASA's Next Generation Satellite Laser Ranging (NGSLR) system was on June 30th, and it was also the first successful ranging to LRO. Since that time ten ILRS systems around the world have participated in ranging to LRO and we have accumulated over 3000 hours of laser ranging data. These data have been used to very accurately determine the clock rate and drift and to produce precision orbits. By using the high-resolution GRAIL gravity models, the LRO orbits determined from LR data alone have a total position error of 10 meters in average, and show the same quality as those generated using conventional radiometric tracking data.

Many LR passes have been taken simultaneously between two, three and four stations and often global tracking achieves close to 24 hour coverage. This has opened up new opportunities for other laser timing and communication technology demonstrations. In 2013 we demonstrated the first uplink lasercom from NGSLR to LRO. We are currently conducting laser time transfer tests between SLR stations using LRO as a common receiver in space.

13-0406

Frequency-dependence of the tidal dissipation on the Moon: Effect of the low-viscosity zone at the lowermost mantle

Yuji Harada [1], Sander Goossens [2], Koji Matsumoto [3], Jianguo Yan [4], Jinsong Ping [5], Hirotomo Noda [3], and Junichi Haruyama [6]

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[2] Univ. of Maryland
[3] National Astronomical Observatory of Japan
[4] Wuhan Univ.
[5] National Astronomical Observatories, Chinese Academy of Sciences
[6] JAXA

Tidal heating due to viscous dissipation in a planetary body is an important energy conversion process, depending on its internal structure, and connected to its thermal and orbital states. Our moon is not an exception. Previous studies have calculated the tidal response including dependence of the dissipation on the lunar interior structure, but these studies did not completely explain the geodetically-observed dependence of the dissipation on the lunar tidal period. One possibility to interpret this frequency-dependence is a low-viscosity layer inside the mantle as a natural consequence of the strong seismic attenuation zone, because such a viscosity contrast affects this dependence. However, previous studies have not considered its potential impact. Here we show that the explicit influence of the low-viscosity zone successfully provides the frequency-dependent dissipation on the Moon consistent with the geodetic observables. We found that the above-mentioned high-attenuation zone is equivalent to the low-viscosity layer. Furthermore, we also found that the resultant viscosity value is remarkably low, signifying a relaxation time close to the tidal period. This ultralow viscosity implies partial melting as formerly suggested. Our result demonstrates that the most effective dissipation is localised to this layer, indicating a blanket effect on the core.

13-0407

Numerical geodesy experiments for a Phobos laser ranging mission concept

D.Dirkx, L.L.A. Vermeersen, R. Noomen, P.N.A.M. Visser

Delft Univ. of Technology

We have developed a software system for simulating interplanetary tracking system performance, with a focus on planetary laser ranging systems. Using this software, we analyze the performance of a Phobos lander equipped with an active laser system conducting two-way asynchronous direct-to-Earth ranging. We assume one 30 min tracking arc per day from 6 SLR stations, providing single two-way range normal points at 1 min intervals with a precision of 1 mm, simulated as Gaussian noise. The analysis focuses on the estimation quality of physical parameters of the Martian system, such as gravity field coefficients, Love numbers and rotational parameters of Mars and Phobos. We present the estimation results, which indicate that significant improvement on knowledge of the interiors of both Phobos and Mars can be achieved, both compared to current knowledge and potential radiometric tracking results. However, assuming purely Gaussian noise yields overly optimistic estimation results. We employ consider covariance analysis to investigate the influence of errors in both range accuracy and SLR station positions (modeled as systematic errors). The results of this analysis indicate that these types of errors will dominate the error introduced by the assumed 1 mm range precision by more than an order of magnitude.

Session 10: Retroreflectors (1)

Chair:

Jan McGarry
and
Linda Thomas

13-0408

Transfer Function of the Lares Satellite

David Arnold

SAO

This paper presents a transfer function for the LARES satellite in the form of cross section and range correction matrices in the far field. The coordinate axes of the matrices are the x and y components of the velocity aberration. The matrices are computed using a model of the diffraction pattern of each cube corner as described in SAO Special Report 382. The variations and uncertainties in the range correction are estimated as a function of the incidence angle on the satellite, velocity aberration, and manufacturing errors in the dihedral angle offsets. These theoretical calculations can be compared to observed cross section and range measurements. Accurate range corrections are important since LARES is one of the satellites being used to develop the reference frame.

13-0409

The ring retroreflectors system

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OJC «RPC «Precision Systems and Instruments», Moscow, Russia

Reflection characteristics of retroreflector systems (RRS) define energy balance of laser ranging in great degree. At inclined incidence of light, RMS of the single measurement is 1 cm in the case of cube-corner reflectors flat panels. To reduce the RMS it is needed to use the ring retroreflector system, which is composed by CCR with DAO and with special interference coating on its sides.

In this case, a diffraction pattern looks like two spots at the angular distance of about 11". The size of the CCR aperture should be 42 – 48 mm. The retroreflector array consists of 36 – 48 CCR, placed as a ring. The cross-section can reach up to 180•106 m2 and the ring-shaped diffraction pattern is formed.

The ring retroreflector system, composed by “two-spot” CCRs, has the same qualities. Firstly the cross-section increases. Secondly the reflect signal is formed by few CCRs. This CCRs are located on the opposite sides of the ring at a considerable distance from each other. So it allows to determine retroreflector array’s center more accurately and to reduce RMS.

13-0410

Status of the GPS III Laser Retroreflector Array

Linda Thomas [1], Stephen Merkowitz [2]

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[2] NASA GSFC

Systematic co-location in space through the precision orbit determination of GPS satellites via satellite laser ranging will contribute significantly towards improving the accuracy and stability of the Terrestrial Reference Frame. GPS will then provide a means to accurately and uniformly distribute this new accuracy to all systems utilizing GPS. NASA is partnered with the Naval Research Lab on the development and testing of a flight model Laser Retroreflector Array. Early validation of the design is critical to provide confidence that fight units will meet the requirements. Status to date and an updated plan will be presented.

13-0411

Development of the Retro-reflector on the Moon for the Future Lunar Laser Ranging

Hiroshi Araki[1], Shingo Kashima[1], Hirotomo Noda[1], Hiroo Kunimori[2], Hitomi Mashiko[3], Toshimichi Otsubo[4], Makoto Utsunomiya[5], Yoshiaki Matsumoto[6]

[1]NAOJ
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[3]Iwate Univ.
[4]Hitotsubashi Univ.
[5]JAXA
[6]PLANET INC.

Lunar Laser Ranging (LLR) data are important for the investigations of the lunar rotation, tide, and lunar deep interior structure. The range accuracy of LLR has been less than 2 cm for the last 20 years due to the progress of laser transmit/receive system on the ground stations and the atmospheric signal delay model, however, one order or more accurate ranging than 2cm is needed for better understanding of the lunar deep interior. We are developing 'single aperture and hollow' retro-reflector (corner cube mirror; CCM) to be aboard future lunar landing missions. The aperture of CCM is 20cm because the reflection efficiency of that size is found to be higher than that of Apollo 11 array CCP. For the CCM 'ultra low expansion glass-ceramic (CCZ-EX; OHARA Inc.)' or 'single crystal Si' is selected for candidate material of CCM in terms of small |CTE|/K (Thermal expansion coefficient over thermal diffusivity)and large specific Young modulus. The optical performance of CCM deformed by lunar gravity or solar illumination in the gimbal model will be presented for some cases. We are now trying to fabricate CCM test model made from CCZ-EX using the optical contacting method that is applicable to single crystal Si, too.

13-0412

Completion of ETRUSCO2, thermal test results and thermal optical simulation of the standard GNSS Retroreflector Array (GRA)

C. Cantone [1], Simone Dell'Agnello [1], G. Delle Monache [1], A. Boni [1], G. Patrizi [1], M. Tibuzzi [1], E. Ciocci [1], C. Lops [1], M. Martini [1], L. Salvatori [1], S. Contessa [1], L. Palandra [1], M. Maiello [1], M. Marra [1], F. Piergentili [1], G. Capotorto [1], G. Bianco [3], R. Vittori[1]& [2]

[1] INFN- Laboratori Nazionali di Frascati (INFN-LNF)
[2] Aeronautica Militare Italiana (AMI)
[3] ASI, Centro di Geodesia Spaziale "G. Colombo" (ASI-CGS)

The SCF (Satellite/Lunar/GNSS laser ranging/altimetry Characterization Facility) and SCF-Test are an innovative OGSE (Optical Ground Support Equipment) and innovative industrial test procedure to characterize and model the detailed thermal behavior and optical performance of cube corner laser retroreflectors (CCRs) for the Satellite Laser Ranging (SLR) to GNSS in accurately laboratory-simulated space conditions. They were developed by INFN-LNF and are in use by NASA, ESA, ASI, ISRO and the Italian Ministry of Defence. This is done with specialized instruments measuring and modeling optical Far Field Diffraction Pattern (FFDP), Wavefront Fizeau Interferogram (WFI) and temperature distribution of Laser Retroreflector Arrays (LRAs) of CCRs under accurately representative and/or critical space conditions produced also with close-match solar simulators.
Under ASI-INFN contract n. I/077/09/0 ETRUSCO-2 (Extra Terrestrial Ranging to Unified Satellite COnstellations-2) we: built a second SCF optimized for GNSS and in particular for Galileo and GPS-III (SCF-G) and a GNSS Retroreflector Array (GRA) based on standards of the ILRS (International Lase Ranging Service); developed an orbit-realistic SCF-Test for GNSS and applied it to Galileo IOV. The new SCF-G will be described and results of the GRA characterization and of its integrated thermal and optical modeling will be reported.

13-0413

Processing Single Photon Data for Maximum Range Accuracy

Christopher B. Clarke [1], John J. Degnan[2], Jan F. McGarry [3], Erricos Pavlis [4]

[1] HTSI
[2] Sigma Space Corporation
[3] NASA/GSFC
[4] GEST/UMBC

When ranging with single photons, the probability distribution for photon returns is given by the convolution of the laser pulse, receiver response, and the target signature. Even for picosecond laser pulses and single cube calibration targets, the probability distribution for NGSLR returns will be dominated by the non-Gaussian PMT/receiver response. For dynamic satellites, the target contribution is represented by an average response over the duration of a satellite normal point. The target range is best estimated by the centroid of the distribution, which generally falls well behind the peak. Thus, choosing a tight iterative sigma filter during data editing results in a RMS cutoff near the peak and biases the range measurement toward shorter values. This effect was clearly demonstrated during the recent collocation of NGSLR with MOBLAS-7. For a 1.8 sigma RMS filter, both short arc collocations and global orbital fits of LAGEOS and LEO satellites showed a centimeter or greater bias between NGSLR and MOBLAS-7. However, when a 3 sigma RMS filter was applied, the LEO biases were reduced to a few millimeters while the LAGEOS bias was about one centimeter, in good agreement with prior analyses.

Session 11: Retroreflectors (2) and CoM

Chairs:

John Degnan
and
Scott Wetzel

13-0414

SLR energy density estimations and measurements for the Herstmonceux station

Matthew Wilkinson, Jose Rodriguez

NERC Space Geodesy Facility

The energy budget for an individual station must take into account system losses, atmospheric transparency and turbulence, target reflectivity and laser and detector characteristics. Treating these factors correctly will enable the estimation of return energy densities that approximate those experienced during SLR observation.

The team at the Space Geodesy Facility, Herstmonceux are investigating a number of areas regarding energy density. The first is the investigation into the optical aspects of the SLR system to identify under-performance. The second uses SLR return rates to calculated the returning energy density and these values are investigated for a series of ILRS targets using the 12Hz and 2kHz SLR systems. Finally, close attention is given to all aspects of the link budget equation, using real measurements where possible, to give the best energy estimations. A comparison of the theoretical and observed return rates will be an indication for system performance and link budget accuracy.

In particular interest is the Jason-2 satellite, launched in 2008 as part of the OCA/CNES time transfer by laser link (T2L2) payload. Jason-2 records energy densities of incoming SLR laser pulses. These are compared with the returning energy densities at the Herstmonceux station.

13-0415

Optical FFDP and interferometry measurement and modeling of retroreflector payloads at SCF_LAB

Boni A. [1], Dell'Agnello S.[1], Delle Monache G. O. [1], Cantone C. [1], Intaglietta N. [1], Lops C. [1], Maiello M.[1], Martini M.[1], Patrizi G.[1], Salvatori L.[1], Tibuzzi M.[1], Contessa S.[1], Palandra L.[2], Capotorto G.[2], Marra M.[2], Piergentili F.[2], Bianco G.[4], Vittori R.[3]

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[2] Univ. of Rome "Tor Vergata"
[3] Aeronautica Militare Italiana
[4] ASI-CGS

INFN (Istituto Nazionale di Fisica Nucleare), in the framework of the r&d project ETRUSCO-2 (Extra Terrestrial Ranging to Unified Satellite COnstellations), designed and tested a full scale retroreflector array for GNSS applications, the GRA. This payload was designed in order to optimize optical performance in orbit. The standard test procedure we developed and optimized for other retroreflectors we tested before this project, is conceived of three steps. First we measured each retroreflector of the array in air, to check compliance with design specifications. Second we performed a standard SCF-Test on representative CCRs of the array, checking for the variation of FFDP intensity at the correct velocity aberration due to thermal stresses. Third we measured some CCRs on a simulated Galileo orbit in order to check variation of performance, in terms of FFDP and wavefront interferogram, in a more realistic environment. We repeated this last test for a simulated thermal/optical model of the GRA. A fine tune between simulations and measurements would allow us to simulate the array in conditions difficult to replicate in laboratory. We will apply tests here described to other GNSS retroreflector payloads such as a few other retroreflectors of the Galileo IOV satellites and an array of the IRNSS constellation.

13-0416

Thermal/Optical Analysis of Cube Corner Retroreflectors for the Lunar Environment

Giovanni O. Delle Monache [1], Douglas Currie [2], Simone Dell' Agnello [1], Bradfor Bher [2]

[1] INFN-LNF Frascati Italy
[2] Univ. of Maryland College Park MD

Over the past 40 years, the Lunar Laser Ranging Program (LLRP) to the Apollo Cube Corner (CCR) Retroreflector Arrays (ALLRRA) has supplied almost all of the significant tests of General Relativity. This is the only Apollo experiment that is still in operation. Initially the ALLRRAs contributed a negligible fraction of the ranging error budget. Over the decades, the ranging capabilities of the ground stations have improved by more than two orders of magnitude. Now, because of the lunar librations, the existing Apollo retroreflector arrays contribute a significant fraction of the limiting errors in the range measurements. The University of Maryland, as the Principal Investigator for the original Apollo arrays, is now proposing a new approach to the Lunar Laser Array technology. The investigation of this new technology, with Professor Currie as Principal Investigator, is currently being supported by two NASA programs, two INFN experiments led by INFN-LNF Italy and, in minor part, by the Italian Space Agency. Thus after the proposed installation during the next lunar landing, the new arrays will support ranging observations that are a factor 100 more accurate than the current ALLRRAs. One of the most critical challenges is the issue of heat flows or thermal gradients inside the CCR. Since the index of refraction of the fused silica depends upon temperature, thermal gradients in the CCR will cause the index of refraction to vary within the CCR and thus it will not act as a diffraction-limited mirror. For this reason, we need to understand in detail the magnitude of the gradients caused by the various effects, and then adjust the design to control these gradients and finally evaluate the performance with the control procedures in place. We first need to determine the heat deposition. This is accomplished using dedicated programs developed in parallel at Frascati and at the University of Maryland. To perform these simulations, we use Thermal Desktop®. This analysis yields a three dimensional matrix describing the temperature distribution in the CCR for a given configuration and set of parameters. A program developed at the University of Maryland using IDL of RSI Inc. converts the three dimensional temperature matrixes into a two-dimensional phase front, which captures the error induced by the temperature gradients. Results of an integrated model, which contains the passive thermal controlled experimental package, the model for the behavior of the regolith and the coupling of these effects are presented. The model has been parameterized to agree with the Heat Flow Experiment (HFE) deployed during the Apollo 16 mission by means of a Thermal Desktop® model of the Regolith down to 3 m depth developed by correlation to Apollo data and related articles. In addition this Regolith model is used to investigate current optical performance of Apollo 11 ALLRRA during eclipse, to evaluate degradation by possible lunar dust deposition. Preliminary results on Apollo 11 "dusted" ALLRRA model will be presented as well as preliminary thermo-optical test of the Moonlight package will be presented.

13-0417

Attempt to further enhance ranging accuracies to Lageos through de-convolution of the target response

Thomas Varghese, Thomas Zagwodzki, Thomas Oldham, Randall Ricklefs

Cybioms Corporation

In our continuing quest to improve the ranging accuracy to Lageos, a detailed analysis of the integrated response to the satellite was examined for a state of the art ranging system. Target response, which is a convolution of the spread function of the satellite convolved with the transmitter and receiver temporal characteristics and the signal processing schema, was computed. These computed responses were then compared with the high resolution (2 picoseconds) experimental data for the satellite optical response. Results are discussed.

13-0418

Centre of Mass corrections for precise analysis of LAGEOS, Etalon and Ajisai data

Graham Appleby [1] and Toshimichi Otsubo [2]

[1] Space Geodesy Facility, Herstmonceux
[2] Hitotsubashi Univ.

One of the limiting factors in reaching the scientific goal of 1-mm accuracy satellite laser ranging to the geodetic satellites is referring the range observations to the centres of mass (CoM) of the spherical satellites. The cube-corner retroreflectors that are distributed over the surfaces of the geodetic satellites LAGEOS (diameter 0.60m), Etalon (1.29m) and Ajisai (2.14m) give rise to broad, complex temporal distribution of the return laser pulses. Accurate modeling of the characteristics of the detection of those pulses that takes account of the various laser station technologies is required in order to minimize the potential for attributing error in the computed value of the CoM correction to apparent range error. Such systematic effects can be more than 10 mm for the two LAGEOS and up to several cm for Ajisai and the two Etalon satellites. Earlier theoretical results (Otsubo and Appleby, JGR, 2003) have been used to develop tables of CoM corrections and their uncertainties that are applicable in a simple way when analyzing range data from all the ILRS stations that have operated from 1980 onwards. The ILRS Analysis Centres will use the corrections for re-processing work during 2013 towards the ILRS contribution to ITRF2013

13-0419

Centre-of-mass Corrections of sub-cm-precision Targets, STARELTTE and LARES

Toshimichi Otsubo [1], Robert A Sherwood [2], Graham M Appleby [2], Reinhart Neubert [3]

[1] Hitotsubashi Univ.
[2] NERC SGF Herstmonceux
[3] GFZ Potsdam

The target signature effects of small spherical satellites, LARES and STARLETTE are investigated. Otsubo and Appleby (2003) had looked into the effects for larger satellites such as AJISAI and LAGEOS, where the system dependence of the centre-of-mass correction amounts to 5 cm and 1 cm, respectively. Recent enhancement in precision and repetition rate makes it possible and necessary to study the effects for smaller targets STARLETTE and LARES. Note that the STARLETTE satellite is followed by its twin STELLA, optically identical, in 1993. Using kHz fullrate laser ranging data obtained at Herstmocneux, UK, and Potsdam, Germany, and comparing the residual profile with optical simulations, it is revealed that the center-of-mass correction can vary within 128 to 135 mm for LARES, and 75 to 82 mm for STARLETTE. The result of STARLETTE indicates that the current standard value 75 mm is too small in general for STARLETTE and also for STELLA. Assuming a 3 mm shift of STARLETTE and STELLA, the impact can be up to 0.5 ppb for the terrestrial reference frame scale and up to 1.7 ppb for the gravity constant (GM) of the Earth.

Session 12: SLR Technology and Development, Misc

Chairs:

Hyung-Chul Lim
and
Anja Schlicht

13-0420

Simulation and Research of Transmitting and Receiving Epoch Overlapping Phenomenon on Co-Optical Path kHz Laser Ranging System

Zhai Dong-sheng, Li zhu-lian, Fu Hong-lin, Li Yu-qiang, Zhang Yun-cheng, Xiong Yao –heng

Yunnan Astronomical Observatory, Chinese Academy of Sciences

High Frequency Laser Ranging is one of effective methods to increase the measurement frequency and improve the accuracy of normal point(NP). The principle and method of Yunnan Observatory Common Optical–Path High Frequency Laser Ranging system will be introduced. There are transmitting and receiving epoch overlapping phenomenon in high frequency laser ranging system. By analyzing this phenomennon and computer simulation,the overlap rate under different orbit satellite in ranging process is obtained.In order to decrease the probability of overlap in 1.2m telescope satellite co-optical Path KHz Laser ranging system, rotating shutter control algorithm will be researched here.

13-0421

The new CMOS Tracking Camera used at the Zimmerwald Observatory

M. Ploner, P. Lauber, M. Prohaska, P. Schlatter, T. Schildknecht, J. Utzinger, A. Jäggi

Astronomical Institute, Univ. of Bern

During the last years the use of tracking cameras for SLR observations became less important due to the high accuracy of the predicted orbits. Upcoming new targets like satellites in eccentric orbits and space debris objects, however, require tracking cameras again. Since a few months the interline CCD (Charge Coupled Device) camera was replaced at the Zimmerwald Observatory with a so called scientific CMOS (Complementary Metal Oxide Semiconductor) camera. This technology compromises a better performance for this application than all kind of CCD cameras. After the comparison of the different technologies the focus will be on the integration in the Zimmerwald SLR system. First experiences could be gained during the bistatic experiments carried out together with the SLR station Graz Lustbühel.

13-0422

RECENT ADVANCES IN PHOTON-COUNTING 3D IMAGING LIDARS

John J. Degnan, Christopher Field, Roman Machan, Ed Leventhal, David Lawrence,Yunhui Zheng, Robert Upton, Jose Tillard, Spencer Disque, Sean Howell

Sigma Space Corporation

Over the last several years, Sigma Space Corporation has been extending single photon sensitive (photon-counting) 3D imaging lidar to higher and higher altitudes. Scanning systems to date have operated at aircraft AGLs up to 8.6 km. With laser repetition rates between 20 and 32 kHz and a Diffractive Optical Element (DOE) to split the laser beam into 100 low power beamlets and a precision timing channel assigned to each beamlet, we have achieved measurement rates up to 3.2 million 3D pixels per second. Laser pulsewidths between 100 and 700 picoseconds have typically been employed, yielding high range resolution. The result has been large area coverage with high resolution horizontal (decimeter) and vertical (centimeter) 3D imagery. Our systems are presently being deployed on a variety of aircraft to demonstrate their utility in multiple applications including large scale surveying and surveillance, bathymetry, forestry, etc. Our smallest unit , the Mini-ATM (Miniature Airborne Topographic Mapper) , designed for NASA to fit in a mini-UAV for wide swath cryospheric measurements, features a 90o full conical scan, measures approximately 0.03 m3 (1 ft3) in volume, weighs 12.7 kg (28 lbs), and consumes ~168 W of 28 VDC prime power.

13-0424

Recent achievements in detector and timing technology for SLR and laser time transfer

I. Prochazka [1], K. U. Schreiber [2], J. Kodet [2,1], Petr Panek [3], J. J. Eckl [2]

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[3] Academy of Sciences of Czech Republic, Institute of Photonics

We are presenting the work progress and recent results in the development and construction of new devices for sub – millimeter laser ranging and picosecond accuracy laser time transfer. The devices applicable both in space and on a ground will be presented. The key hardware components are: the Start detector and discriminator, photon counting detector and the timing device. The optical detectors along with the latest version of NPET timing system enable laser ranging on single photon signal level with sub-picosecond long term stability and < 200 fs precision. In addition the NPET timing system provides the timescale synchronization within the observatory campus on a picosecond level. For space debris laser tracking we have developed a photon counting detector package providing 70% photon detection efficiency at the wavelength of 532 nm. The key performance of the devices will be presented.

13-0425

Investigation and Compensation of Detector Time Delays caused by Receive Signal Intensity Fluctuations

Johann Eckl [1], Guenther Herold [1], Rudolf Motz [1], Andreas Leidig [1], Ulrich Schreiber [2]

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Systematic errors are limiting the achievable accuracy in satellite laser ranging. Apart from the effects caused by the intensity dependent apparent depth of the target structure also the intensity dependent delays in the detector response are of great concern. These can be as large as several 100 picoseconds in extreme cases. We have investigated the typical fluctuations of the receive signal intensity caused by the limited pointing accuracy of the laser telescope on a collimated beam and the dynamic atmosphere around the ranging site. Satellite ranging measurements as well as laboratory data were taken and compared to a theoretical model of the detector response. The paper discusses the obtained results and provides a strategy for the mitigation of intensity dependent detector delays.

13-0426

Event Timer A033-ET: Advancement of Performance Characteristics

Boole Eugene, Bespal'ko V., Vedin V.

Institute of Electronics and Computer Science

The A033-ET is commercially available from 2010 but it is permanently being improved in performance and stability. Up to now more than 20 devices have been manufactured and carefully tested, which provided sufficient statistic to reliably specify the A033-ET performance. The special attention is paid at resolution and epoch stability for time event measurements in the external temperature change. The second problem is to increase the performance of the interface with the application software.

The main achieved results are presented in this report. Specifically, it is shown that the A033-ET stably provides the time interval RMS resolution less than 3 ps, epoch variation in temperature about 1-2 ps/oC and average measurement rate more than 1 MSPS. Taking into account the reasonable price of A033-ET, these results allow considering that A033-ET can be the basic measurement instrument for the most of ground-based SLR stations.

13-0427

Towards Integrated Communication and Ranging system using 1.5um wavelength fiber technology

Hiroo Kunimori[1], Mikio Fujiwara[1] and Tetsuo Hosokawa[2]

[1] NICT
[2] Kyoei Optronics Co. Ltd.

Synergy of optical communication and ranging system in space is one of future applicatioon for exploration to moon or beyond mission where satellite resources getting limited. Common resources of laser and optics as well as electronics are to be used.

The National Institute of Information and Communications Technology (NICT) has developed of the optical space communication measurement evaluation system. One of them is namely the optical space communication photon counting equipment system in which FPGA based Pulse Position Modulation (PPM) communication system, using key devises such as a super-conducting single photon detector, laser diode and optical fiber transmit and receive devices for the communication wavelength as well as electronics such as precise timing system for ranging instruments. We describe the outline of conceptual design about the PPM optical communication by a wavelength of 1.5um single photon detector and will discuss integration into laser ranging system.

Session 13: Operational Aspects and Recent Progress

Chairs:

Hiroo Kunimori
and
Chris Moore

13-0501

Status of SLR Upgrades at the U.S. Naval Research Laboratory's Optical Test Facility

Reed Smith, Ray Burris, Linda Thomas

U.S. Naval Research Laboratory

The Naval Research Laboratory's satellite laser ranging facility was originally installed in 2001. Over the last decade many of the components of this system have become hard or impossible to find replacements for. Two years ago NRL began to seek funding for repairs and upgrades to bring the system back to full functionality. L3 Brashear was contracted to evaluate the existing system and repair or replace all degraded or obsolete hardware and software.
Additionally, NRL has been working towards installing two additional laser ranging systems. A 1 kHz system transmitting at 1550nm and a 50 Hz system transmitting at 1560nm are currently being developed and installed.
The details of these repairs and upgrades will be presented here.

13-0503

Preserving history and technical “know-how” - experience at SLR station Riga

Kalvis Salminsh, Jorge R. del Pino

Institute of Astronomy Univ. of Latvia

With the satellite observational start dates: visual – 1957; photographic - early 60’s; SLR testing and integration - early 70’s; regular SLR - 1988 and GPS - 1996, Riga 1884 is one of the oldest continuous operating station in the world. Now we have to deal with the 53 years of heritage including history, “know-how” and technical information in different formats and several languages and a lot of the old hardware. This situation is complicated due to the change of generations and loss of knowledge. We present our experience on recovering the historical information and "know-how" to support the current station upgrade and the steps taken to preserve information in the future. The preservation of the old hardware components and documents of historical interest is also under way.

13-0504

Challenges and progress with the development of a Lunar Laser Ranger for South Africa

Ludwig Combrinck, Roelf Botha

Hartebeesthoek Radio Astronomy Observatory

The development of a Lunar and Satellite Laser Ranger at the Hartebeesthoek Radio Astronomy Observatory, South Africa, in collaboration with the Observatoire de la Côte d'Azur (France) and NASA(GSFC) is progressing well. Complete refurbishment of the ex-French telescope is underway, this includes a complete strip-down of the telescope, re-aluminising and re-coating of the main and secondary mirrors, gearbox overhauls and new drive motors, encoders and servo system. We describe the development and algorithms of the telescope steer and tracking software system as well as the software approaches used to control and access various subsystems via micro-controllers. As far as possible, the Lunar Laser Ranger will be software operated. The focus of this approach is on efficiency, safety and optimal use of tracking time. Subsystems will be monitored continuously, flagging out of bound parameters for possible human intervention, or automatic system shutdown. An integrated but independent GNSS/electronic laser distance measuring system will provide continuous and automated inter-vector ties between the telescope's invariant reference point and pre-surveyed reference piers. The laser system being constructed in collaboration with NASA(GSFC)is described and some technical parameters are brought into context with expected system performance.

13-0505

On Objectives and Some Results of Russian Laser Ranging Network Operation in 2013

Vladimir Glotov [1], Nataly Parkhomenko [2]

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[2] Research-and-Production Corporation Open Joint-Stock Company

The Russian Laser Ranging Network will include some 20 laser optical stations to be used for solving various tasks in satellite navigation, geodesy and geodynamics. To effectively operate the Russian Laser Ranging Network the following specific actions should be taken:
- coordinating operation of the station network aimed at enabling measurements according to the unified spacecraft observational programs;
- collecting and processing of measurement results in Data Analysis Centers as well as comparing results obtained from different Centers;
- operational monitoring of the network measurement quality and its compliance with the requirements as to the measurement data content based on the common procedure for measurement data quality analysis.
The presentation provides the update on the issues stated above, gives recommendations on how to overcome the existing challenges and also provides some statistical overview of the Russian Laser Ranging Network operation in 2013.

13-0506

Technical Aspects and Progress of Korean SLR Systems

Hyung-Chul Lim, Man-Soo Choi, Eunseo Park, Eunjung Choi, Seung-Cheol Bang, Seong-Yeol Yu, Tae-Keun Kim, Young-Rok Kim, Dong-Jin Kim, Ki-Pyung Seong, Neung-Hyun Ka, Chul-Hee Choi, Ju-Hyun Hwang

Korea Astronomy and Space Science Institute

Korea Astronomy and Space Science Institute (KASI) has been developing two satellite laser ranging (SLR) systems; mobile and fixed SLR system. The mobile SLR system is now in operational test phase in KASI headquarter, which will be moved to Sejong site for the establishment of fundamental station. The fixed SLR system will be developed in 2015 and then installed at the Gamak site which is about 150km far from Sejong site. The mobile SLR system has bistatic optical path with 40cm receiving telescope and 10cm transmitting telescope. It was joined to International Laser Ranging Service(ILRS) network in November 2012 and its 2kHz measurement date will be released from October 2013. Two RMS(Root Mean Square) values, single-shot calibration and Lageos satellite, are analyzed to investigate the system performance. The fixed SLR system has common coude optical path with more than 100cm telescope. It has two functions; satellite laser ranging to geostationary satellites and space objects imaging using an adaptive optics. Additionally, it will be upgraded to space debris laser ranging using high power laser in 2017.

13-0507

Japanese SLR activities and Challenges

Shinichi Nakamura [1], Kyohei Akiyama [1], Sachiyo Kasho[1], Ann Mori [1], Hiroo Kunimori[2], Toshihiro Kubooka[2], Mariko Sato[3], Shun-ichi Watanabe[3], and Toshimichi Otsubo[4]

[1] JAXA
[2] NICT
[3] JCG
[4] Hitotsubashi Univ.

Since 1986 in which AJISAI was lounched, JAXA, NICT, Hitotshubashi Univ. JCG, and GSI made a local consortim whose purpose is share orbital data and analysical results. In 2010, when GSI pulled out of an agreement, AJISAI consortium has restructured as Japanese ILRS committee.
Example of its activities is evaluation of prediction file of ETS-8 before starting ILRS campaign, evaluation of long term tred of AJISAI spin rate, and shareing operational know-how and how to fix mechanical failure. Additionary, this workshop has been organized as well.
As you recognized, generational shift was started at each SLR stations. We are about to keep knowledge succession absolutely. On the other hands, we are trying introducing new technology. At presentation, we will explain our activities and challenges briefly.

Poster Session

13-Po01

A Multi-platform Package for the Visualization of the ILRS QC Reports

Erricos C. Pavlis [1], Peter Hinkey [2] and Keith Evans [1]

[1] GEST/Univ. of Maryland Baltimore County
[2] ProObject, Hanover

We developed a software package based on MATLAB™ that allows users to query a data base with ILRS-sanctioned QC reports and visualize the reported information as a function of the tracking site, tracked satellite target and reporting Analysis Center, over the selected period of interest. The user can perform simple statistics on the windowed data set. The “JCET QC Viewer” software works on multiple platforms (e.g. Windows, Linux and Mac OS), and does not require ownership or local availability of MATLAB™. The software will be distributed by the ILRS along with a data base of all the available QC reports up to the release date and from all ACs. The users will be responsible for updating the data base by including the reports released beyond the date of release of the package. We will present the capabilities offered by this package and examples for each application. As long as there are no format or content changes in the distriduted QC reports the software requires little maintenace. We plan to maintain the QC Viewer as resources and time permits and extend it to include any future additions or modifications to the current suite of distributed reports.

13-Po02

A Report on JAXA Tanegashima Station (GMSL)

Sachiyo Kasho, Kyohei Akiyama, Anne Mori

JAXA

JAXA conducted the 2nd QZS-1 tracking campaign from February 25 to March 7, 2013. In this period, a lot of SLR tracking data were obtained through cooperation of many ILRS stations. This poster reports on a summary of this tracking campaign and evaluation results of QZS-1 orbits using SLR observations. Also presented is an operation status of Tanegashima station (GMSL) for the last one year. Although this station has been suspending its operation for a failure of the telescope since July 2013, a plan of its resumption is underway. Furthermore JAXA is currently examining a possibility of tracking debris by leveraging our SLR system, of which latest status is also shared.

13-Po03

Accident in orbit

Natalia Parkhomenko , Victor Shargorodsky, Vladimir Vasiliev, Vasily Yurasov

Open Joint-Stock Company Research-and-Production Corporation
“Precision Systems and Instruments”

Late January 2013, the BILTS nanosatellite has been lost - supposedly as a result of its collision with a small uncatalogized fragment of space debris. The collision caused a change in the BLITS orbit parameters as well in its spin rate and spin axis orientation. The BLITS optical retroreflector cross-section value has decreased more than 500,000 times, thus preventing its use as a laser ranging target.
Currently, the OJC “RPC “PCI” has started a development of a new spherical retroreflector nanosatellite where zero signature is combined with a considerably enhanced efficiency. Introduction into the ball lens structure of an intermittent layer of a high-refraction glass for spherical aberration correction will, as follows from calculations, increase the cross-section value by nearly an order of magnitude with only modest (20 percent) increase of the ball lens external diameter relative to the BLITS.

13-Po04

Accuracy and Stability Assessment of the ILRS Stations Over Two Decades

Erricos C. Pavlis, Keith Evans and Magdalena Kuzmicz-Cieslak

GEST/Univ. of Maryland Baltimore County

The development of the ITRF depends on the quality of the contributions from the four geometric techniques. With the GGOS requirements for ITRF accuracy and stability becoming exceedingly stringent, ITRS requests that each technique generate and deliver an assessment of the performance of each system over time, covering as much of the period spanned by their contribution as possible. Since the ITRF relies on the combination of the techniques at the co-located sites, these information can be used to sort out cases where a discrepancy is observed between the techniques and the local survey information, isolating the most likely culprit and taking appropriate steps to avoid distorting the final result. In response to an ITRS request we have developed a historical qualification index based on the long-term and short-term performance information available to ILRS, a consistently-derived set of systematic error estimates from the analysis of LAGEOS and LAGEOS 2 SLR data and all the engineering information reported to ILRS by the stations. We propose to establish and maintain this index to serve as input to ITRS for the ITRF2013 development as well as for the future realizations.

13-Po05

Advanced Telescopes, SLR, and Radar capability to support IRNSS at GEO ranges

Thomas Varghese

Cybioms Corporation

ISRO has started the deployment of its seven regional navigational GEO/GSO satellites. The radar tracking data for orbit determination will be significantly enhanced by the high ranging accuracies provided by SLR data. In this regard, the process of establishing two remotely controlled Satellite Photometry and Ranging (SPR) facilities separated by nearly 2000 km has begun with a master control facility at a third location. The near term plan is to deploy 2 SLR systems in the next 2 years to create the required local observation geometry. The planned SLR systems have state of the art (1) telescopes with adaptive optics, (2)high resolution imaging capability to support photometry and debris tracking, (3)SLR hardware and software to support high precision normal points, and (4)capability to add a Ground Terminal for laser communications in the future. An overview of the systems is presented.

13-Po06

Alignment measurement with optical transponder system of Hayabusa-2 LIDAR

Hirotomo Noda [1], Takahide Mizuno [2], Hiroo Kunimori [3], Hiroshi Takeuchi [2], and Noriyuki Namiki [4]

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[3] NICT
[4] Chiba Institute of Technology

The laser altimeter called “LIDAR” aboard Hayabusa-2 asteroid mission is a ranging instrument which measures the distance between spacecraft and the target asteroid called 1999JU3. It is also equipped with a function of “optical transponder”, in which LIDAR receives the laser from a ground SLR station and sends back to the same ground station. The experiment will be carried out when the satellite is near the Earth for gravity assist. It will be not only the first full-operation of LIDAR, but also it will provide an opportunity of in-flight measurement of the alignment of LIDAR boresight after the launch. The SLR telescope of 1.5m aperture in NICT Koganei will be used as a ground station. A 1-micron laser with power of 1.2J and repetition rate of 10Hz will be installed for this purpose. The spacecraft will scan the Earth at a certain rate so that each of footprint of LIDAR (1mrad) can overlap each other. Taking into account the attitude determination error of 0.5mrad, the boresight of LIDAR to the spacecraft body will be determined within accuracy of 1.5mrad.The opportunity of the experiment is restricted according to the position of Sun, spacecraft, and Earth due to thermal condition of spacecraft.

13-Po07

Broadening of SLR Network in Chinese Mainland

Liping Ji

Satellite Observatory, Chinese Academy of Surveying & Mapping

Chinese mainland should broaden it SLR network ,to determine and check up the orbits of its Compass/Beidou satellites.At least 3 new stations should be located in west China's Urumqi,Xining and Lhasa. Three broadening plan of SLR network can be thought about,and more mobile system may be disigned.Three mathods can be used in overcoming its main difficulty.

13-Po08

Collaboration of ranging and optical communication mission RISESAT

Toshihiro Kubo-oka [1], Hiroo Kunimori [1], Tetsuharu Fuse [1], Hideki Takenaka [1], Morio Toyoshima [1],Toshinori Kuwahara [2], Kazuya Yoshida [2], Yoshihiro Tomioka [2], Kazufumi Fukuda [2], Junichi Kurihara [3] and Yukihiro Takahashi [3]

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A 50kg-class micro satellite RISESAT, the second satellite in the Japanese "Hodoyoshi" project, has various missions for space research: a laser communication terminal called VSOTA, a 5m GSD multi-spectral high-resolution telescope called HPT, a corner cube retro reflector, and so on. VSOTA aims to demonstrate satellite-to-ground laser communication by means of accurate attitude control of the satellite body itself. HPT can be used to send the coordinate information of the light spot from laser on the ground to the attitude control system. CCR will be used to make sure to keep acquisition and pointing for ground station as well as laser ranging. In this presentation, collaborate experiment plan of VSOTA, HPT, CCR and ground SLR stations for satellite attitude determination is introduced.

13-Po09

COMMISSIONING OF THE NEW LASER STATION IN IRKUTSK

V.A. Emelyanov [1], G.I. Modestova [1], V.V. Kaplenko [1], S.I. Raschetin [1], E.P. Gladkevich [1], E.N. Myasnikova[1], I.N. Bobrik [1], I.Yu. Ignatenko [2]

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It describes the history of the development of laser observations in Irkutsk. Are the main characteristics of the station and the first results of observations.

13-Po10

Comparison of orbit precisions on different types of navigation satellites based on SLR tracking data

Zhao Gang, Zhou Shanshi, Zhou Xuhua, Wu Bin

Shanghai Astronomical Observatory

SLR-derived orbits of certain navigation satellites, including parts of GPS, GLONASS, Galileo and China's BeiDou (Compass) are evaluated and compared quantitatively. Given the amount of SLR tracking data, 7-day arcs are calculated. The post-fit residuals are a few centimeters universally. For MEO, the 3-D RMS of orbit overlaps (2-day over 7-day) or comparisons with radio-derived orbits (7-day) are tens of centimeters, and the radial precisions are around 4-10 centimeters. The results of GLONASS satellites are slightly better than those of GPS or BeiDou in this analysis, which may be caused by different quantities of tracking data. The orbit precisions of MEO are better than GEO/IGSO (in BeiDou system) generally. Sparse observational data and non-homogeneous tracking network throw serious effects on SLR-only orbit determination of navigation satellites.

13-Po11

Definition and Realization of the MLRS Calibration Point

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Laser ranging measurements are usually defined to be the range that would be measured if one were firing through an infinitesimally small telescope that is located at the first non-translating point along the receive path. In the case of the MLRS, this point is the center of the #6 mirror, at the center of rotation of the x-axis. This point is defined to be the MLRS Calibration Point. This must not be confused with the term “Conventional Reference Point” which usually refers to the intersection of the axes of rotation of a conventional telescope. The MLRS telescope employs an X-Y mount and its axes do not intersect. How this affects the “eccentricity” of the MLRS will be discussed.

13-Po12

Demonstration of portable frequency transfer using SMF-coupled free-space optical terminal

Miho Fujieda, Yoshinori Arimoto, Nobuyasu Shiga, Kohta Kido, Yuko Hanado, and Hiroo Kunimori

NICT

Stable frequency signal dissemination is demanded by various users, such as particle accelerators, radio astronomy and so on. Frequency generation using GPS receiver becomes popular, which stability is not enough in some cases. Frequency transfer using optical fibers is a well-established technique and most promising to perform highly accurate optical clock comparison. However it requires a physical connection between two sites by optical fibers. The securement is not easy and it sometimes costs a lot. NICT has developed frequency transfer systems using optical fibers for dissemination. A free-space optical communication terminal has been developed for multi-Gigabit wireless links. It can be a true replacement of a single-mode-fiber (SMF) with its direct SMF coupling design. Toward a portable and stable free-space frequency transfer system, we have started an experiment combined with them. The recent result will be reported.

13-Po13

Detection and timing of laser pulses from Lunar Reconnaissance Orbiter

Szymon Stuglik, Xiaoli Sun

Former NASA intern

NASA Goddard Space Flight Center (GSFC) established in 1959 in Greenbelt, Maryland is the NASA biggest center for unmanned space missions. GSFC is a home to nearly 10,000 scientists and engineers involved in almost every aspect of NASA space exploration and exploitation program.

Space Lidars are one of many instruments designed and developed at NASA Goddard for use in Earth observation satellites as well as in deep space mission spacecrafts. In space calibration of optical instruments such as laser altimeters is currently being investigated at GSFC. The calibration requires complex aperture for detecting and time tagging the laser pulses emitted by space born Lidar on the ground. This paper will describe the project at NASA GSFC during which NASA internship students supervised and supported by NASA scientists attempted detecting and time taging the Lunar Reconnaissance Orbiter laser pulses using the GuideTech GT668PCI-2 CTIA (Continuous Time Interval Analyzer) for calibration and validation purposes.

13-Po14

Development of software for high-precision LLR data analysis

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For the purpose of determining the lunar orbital/rotational motion and tidal deformation using lunar laser ranging (LLR) observation data, analysis software is being developed.

As the first step of this study, we construct an LLR observation model, combining the newest physical models. The observation model consists of the lunar orbit and libration obtained from DE430 (provided by NASA JPL), and the other physical models compatible with IERS Conventions (2010) such as Earth orientation, solid Earth/Moon tides, and some factors affecting propagation delay. In order to calculate these components precisely, we use the modules of the geodetic data analysis software "c5++" (Otsubo et al., JpGU, 2011). LLR observation data are provided as normal points obtained at Apache Point, Grasse, Matera and McDonald. In this calculation, there are 3372 normal points distributed from June 1996 to August 2012. Comparing the observed and predicted one-way range, the mean and the standard deviation of the residuals are about 5.7 cm and 4.8 cm respectively.

We are working on development of software for parameter estimation of lunar orbit, libration, and solid-body tides. We will report a result of the above-mentioned modeling and our current status of the software development.

13-Po15

Development of the High Speed Differentiation Discriminator for Laser Ranging System

Yuji Miura,Yasuji Suzaki

Universe Ltd.

The timing discriminator is one of equipments consisted of Laser Ranging System and it is required to minimize walk error.

Constant Fraction Discriminator (CFD) has been used in a many observation sights to achieve the purpose, but current CFD are difficult to follow to speed-up of the system in the future.

Moreover, there is annoyingness that it is necessary to exchange a delay line corresponding to the input pulse width in CFD.

Therefore we have been developing new high speed discriminator that adopts a differentiation circuit as a method to overcome these.

The principle of the Differentiation Discriminator is as follows.

When a negative pulse passes through a differentiation circuit, an output waveform swings from a negative side to a positive side.

If the input pulse waveforms are a similar figure, the zero crossing timing point does not depend on the input pulse height and it is constant.

Target specifications of new discriminator are as follows.

Minimum input pulse width : 100ps FWHM

Walk : <+/-10ps over 50:1 dynamic range

Input pulse height range : -20mV to -2V

We would like to report the present state of the prototype.

13-Po16

Educational Activities Related to Satellite Laser Ranging at Hitotsubashi Univ.

Toshimichi Otsubo [1], Mihoko Kobayashi [1], Hiroo Kunimori [2], Daniel Kucharski [3], Graham M Appleby [4]

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Satellite/lunar laser ranging (SLR/LLR) is full of educational materials. We present several examples actually used at Hitotsubashi University.

Although Hitotsubashi University has no department of science or technology, SLR/LLR and its many components have been actively taught in lectures such as "Earth Science I/II" (approx. 100 students for each), "Junior Seminar" (8 students; 1st and 2nd grade) and "Senior Seminar" (3 to 7 students; 3rd and 4th grade).

In addition to the overview of the large-size class lectures, the interactive teaching in the small-size seminars is focused in the presentation. We have invited guest speakers at the university or connected globally via Skype, and we have also visited the NICT Koganei laser ranging station located nearby. The students have also experienced a handmade corner-cube reflector from a sheet-type mirror.

We would like to encourage the worldwide university teachers in this field to make use of SLR/LLR in educational activities.

13-Po17

Estimation of geocenter motion using GRACE precise orbits

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This study provides an alternative approach to determine the geocenter motion by using both kinematic and dynamic orbits of GRACE satellites. The concept originates from the different reference frames for dynamic and kinematic orbits. The former refers to the geocenter (center of mass of the Earth) and the latter refers to the origin of International Terrestrial Reference Frame (ITRF). With such two orbits, the geocenter motion with respect to the origin of ITRF can be estimated by using a network shift method. For the first time, we demonstrate that the geocenter motion can be achieved by a PPP-based technology using GRACE precise orbits. In this paper, we will present the monthly annual geocenter motions over 2003-2012, which will be expected to be consistent with the SLR-derived and GPS-derived geocenter solutions.

13-Po18

Estimation of the Earth's gravity field combining SLR and GRACE data

**Christoph Haberkorn, Mathis Bloßfeld, Johannes Bouman,
Martin Fuchs and Michael Schmidt**

Deutsches Geodätisches Forschungsinstitut, München, Germany

Since 2002, GRACE observes the Earth's gravity field with a spatial resolution up to 150 km. The main goal of this mission is the determination of temporal variations in the Earth's gravity field to detect mass displacements. The GRACE mission consists of two identical satellites, which observe the range and its first and second derivative (range-rate and range-acceleration) along the line of sight of both satellites. Despite these observations, additional data like accelerometer and GPS data are needed to compute an accurate orbit.

Using the integral equation approach (IEA), GRACE observations can be linked with the Earth's gravitational potential, which is expressed in terms of spherical harmonics for global solutions. However, the estimation of low degree coefficients is difficult with GRACE. In contrast, Satellite Laser Ranging (SLR) data from multiple missions allow to estimate these lower degree coefficients with high accuracy. In this study, the combination of GRACE and SLR normal equation matrices is used to estimate a set of spherical harmonics. Thereby the benefit of SLR data compared to the GRACE-only solution is analyzed.

We will present the mathematical model on which our solution is based. Furthermore, we will discuss first results of the combination.

13-Po19

EUROLAS Data Center - Status Report 2012-2013

Christian Schwatke

DGFI

The EUROLAS Data Center (EDC) operates as ILRS Data Center. Since 2010 the EDC operates also as ILRS Operation Center. On 2012-05-02 the "Consolidated Laser Ranging Data (CRD)" became the official data format at the ILRS. In the year 2012 the transition from the old CSTG/MERIT-II format to the new CRD format was performed.
In this poster, statistics of Normal Points (NPT) and Full-Rate data (FRD) in the new CRD format at the EDC are shown. Furthermore statistics of predictions (CPF) and ILRS products are provided. Concluding information about stations and satellites are shown.

13-Po20

Expanding the SLR space segment with the Galileo constellation?

Jose Rodriguez, Graham Appleby

NERC Space Geodesy Facility

Data from four geodetic satellites (Lageos 1/2 and Etalon 1/2) are currently used by the ILRS analysis centres to compute station coordinates and Earth orientation parameters. A good coverage of these targets by the SLR network is therefore required to ensure high quality solutions are obtained. While Lageos satellites are routinely tracked by most stations, much less data are available for Etalon targets, translating into overall poorer solutions.

Here we investigate the possibility of expanding the geodetic targets with the Galileo constellation, to strengthen or replace the role played by the Etalon satellites. Despite their lower ILRS priority, current Galileo laser ranging coverage is similar to that of Etalon, suggesting these are easier targets for the network. We compare station coordinates obtained from Lageos + Galileo and the standard Lageos + Etalon, and discuss issues such as potential coverage and attitude modelling.

13-Po21

ILRS Website Update

C. Noll [1], M. Torrence [2], L. Tyahla [2]

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The ILRS website, http://ilrs.gsfc.nasa.gov, is the central source of information for all aspects of the service. The website provides information on the organization and operation of ILRS and descriptions of ILRS components, data, and products. Furthermore, the website and provides an entry point to the archive of these data and products available through the data centers. Links are provided to extensive information on the ILRS network stations including performance assessments and data quality evaluations. Descriptions of supported satellite missions (current, future, and past) are provided to aid in station acquisition and data analysis. The website was recently redesigned. Content was reviewed during the update process, ensuring information is current and useful. This poster will detail the completed design including specific examples of key sections, applications, and webpages.

13-Po22

Impact of Earth radiation pressure on LAGEOS orbits and on the global scale

Krzysztof Sośnica [1], Carlos Javier Rodríguez-Solano [2], Daniela Thaller [3], Adrian Jäggi [1], Gerhard Beutler [1], Rolf Dach [1]

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The indirect solar radiation pressure caused by reflected or re-emitted solar radiation by the Earth's surface is an important non-gravitational force perturbing the orbits of geodetic satellites. In the case of LAGEOS this acceleration may be of the order of 15% of the direct solar radiation pressure. Therefore, Earth radiation pressure has a non-negligible impact not only on LAGEOS orbits, but also on the SLR-derived terrestrial reference frame.

We assess the impact of Earth radiation pressure on the LAGEOS orbits and on other parameters derived from SLR observations, e.g., the global scale, geocenter variations, and station coordinates. Independently, two radiation forces of different origins are considered:

(1) Reflected visible radiation (albedo reflectivity),

(2) Emitted radiation (infrared emissivity).

Earth radiation pressure has a remarkable impact on the semi-major axes of the LAGEOS satellites by causing a systematic reduction of 1.5 mm. The infrared Earth radiation causes a reduction of about 1.0 mm and the albedo reflectivity of 0.5 mm of the LAGEOS' semi-major axes.

The global scale defined by the SLR network is changed by 0.17 ppb, when applying Earth radiation pressure modeling. The resulting station heights differ by 0.5-0.6 mm in the solution with and without modeling of the Earth radiation pressure. However, if range biases are estimated, the differences in modeling are absorbed by them, and thus, the station heights are not affected by missing or wrong models.

13-Po23

Improvements of System Stability at Changchun Observatory

HAN Xingwei[1], FAN Cunbo[2], SONG Qingli[3], DONG Xue[4], ZHANG Haitao[5], LIU Chengzhi[6]

Changchun Observatory, NAO

Changchun Station (7237)'s routinely KHz SLR operation since July 2009 has undergone a lot of improvement on system stability. A new near target was installed for system calibration. Auto-Gate-Identification was applied to enhance the detect probability of return pulse signal. The A032-ET was replaced with A033-ET to increase timing precision. Also an additional delay cable was connected to A033-ET channel B in order to adjust measured delay from near target. The correlation between the detector operation temperature and system delay was particularly analyzed.

13-Po24

Japanese Altimetry Mission, COMPIRA

Akihisa Uematsu, Kyohei Akiyama, Norimasa Ito,
and the JAXA COMPIRA team

JAXA

Japan Aerospace Exploration Agency (JAXA) has proposed a new altimetry mission, COMPIRA (Coastal and Ocean Measurement mission with Precise and Innovative Radar Altimeter). There are three main purposes of the COMPIRA mission; ocean currents forecast for various human activities over the ocean including ship navigation, fishery for estimating fishing places, and scientific outcomes including ocean submesoscale phenomena, sea-level rise phenomena, and improvement of Tsunami forecast model. To obtain sea surface height data over the coastal region, wide-swath measurement is effective. COMPIRA will carry a wide-swath altimeter with two synthetic aperture radar antennas, named SHIOSAI (SAR Height Imaging Oceanic Sensor with Advanced Interferometry), having 80 km swath in both left and right sides. To meet the accuracy requirement of sea surface (~7.5 cm, with spatial resolution of 5 km), precise orbit determination is important. In addition to GPS receiver, LRA (Laser Retroreflector Array) will be mounted, to calibrate biases of GPS-determined orbits and to obtain combined precise orbits from SLR/GPS measurements with the cooperation of ILRS stations. In the poster, we will present purposes, requirements, and several studies related to the COMPIRA mission.

13-Po25

Linux/RTAI Real-time Control System at MLRS

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The Univ. of Texas at Austin, Center for Space Research

The McDonald Laser Ranging Station (MLRS) has for 2 decades used a proprietary, unix-like real-time operating system to control tracking, ranging, and timing. With the availability of a 7 year duration Long Term Support version of Ubuntu Linux, as well as the Real Time Application Interface (RTAI) and Real Time Device Driver interface (RTDM) add-ons for real-time control, there came an opportunity to convert to a stable, modern, open-source alternative. We will review the architecture and development of this system and describe recent experience with its installation and operation.

13-Po26

LRO Orbit Determination with Laser Ranging Data

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[3] MIT.
[4] NASA Goddard Space Flight Center

The Laser ranging (LR) experiment to the Lunar Reconnaissance Orbiter (LRO) has been in operation for more than 4 years, since the launch of the spacecraft in June 2009. Led by NASA's Next Generation Satellite Laser Ranging (NGSLR) station at Greenbelt, Maryland, ten laser ranging stations over the world have been participating in the experiment and have collected over 3,200 hours of ranging data. These range measurements are used to generate precise orbital solutions for LRO and monitor the behavior of the LRO clock.
To achieve high-quality range measurements, the NGSLR and four other ground stations are using H-maser clocks to obtain a stable and continuous time-base for the orbit solutions. In January 2013, an All-View GPS receiver was included at NGSLR which monitors the H-maser time against the master clock at the United States Naval Observatory (USNO) via GPS satellites. With these improvements, NGSLR established nano-second level epoch time accuracy and 10^-15 clock stability.
By using a high-resolution gravity model from the GRAIL Discovery mission, the LRO orbits determined from LR data alone have a total position error of 10 meters on average, and show the same quality as those generated using conventional radiometric tracking data. In this approach, 2-week long arcs were used with LR biases adjusted once per arc. A timing bias was also adjusted to compensate both the ground and spacecraft clock characteristics for each arc. Another approach to LRO orbit determinations is to take advantage of the knowledge we have gained through LR of the long-term stability of the LRO clock. That allows the spacecraft clock behavior to be separated from the ground station clocks and modeled over a 6-month time span in our latest POD process. We shall present the results from both approaches, and an assessment of the quality of the orbital reconstruction.

13-Po27

Near Ground Target for 1.2m Telescope SLR System

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Because of laser and electronic delay, a ground target is used for calibration the system delay. In 1.2m telescope Satellite Laser Ranging (SLR) system of Kunming station, we used a ground target which has about 200m distance with telescope for a long time, but recently we found that the system delay has changed and the accuracy is not very good. The reason might be that station coordinate has changed because of earthquake, the ground target position has changed or system delay has changed. Therefore, we try to set a near ground target in front of telescope in order to decrease the effect of far ground target and atmospheric delay. Though it is difficult to set a super short distance target for transmitting and receiving common optical path SLR system, we successfully did it for our system by many research and experiments.

13-Po28

New gatable MCP-PMTs and their performances in comparison to semiconductor type detectors for SLR applications

Takeshi Taguchi, Masahiro Nakamura

Hamamatsu Photonics K. K.

Gatable MCP-PMT (Micro Channel Plate Photo Multiplier Tubes) and semiconductor detectors such as APD (Avalanche Photo Diode) are commonly used for SLR applications. Performance of these detectors are compared on parameters such as sensitivity, noise, temporal response, timing jitter and other characteristics. The Gatable MCP-PMTs we have developed show improvements in especially sensitivity and noise induced by gating pulse We also focus on signal processing technic to optimize detector performance and introduce other possible detector modules for different applications. Other possible applications using MCP-PMTs are discussed as well for general laser ranging.

13-Po29

New telescope and observatory building to Metsähovi, Finland

Arttu Raja-Halli , Jyri Näränen , and Markku Poutanen

Finnish Geodetic Institute

Finnish Geodetic Institute is currently performing a large update of the research infrastructure at Mets テ、hovi Fundamental Geodetic Station with dedicated funding from the Government. As a part of that project, we will procure a new SLR telescope capable of 2 kHz operation that is able to meet the challenges set up by the ever increasing demand for higher data production rates. The aim for finalizing the contract for the new telescope is at the end of 2013 and the expected first light by the end of 2015. To house the new telescope, a new observatory building will be designed and built. Most of the electronics and software of the SLR system, including a High-Q 2 kHz laser and a C-SPAD detector, have already been acquired and have been presented previously. A new addition is an Alcor-system OMEA all-sky camera and AirNav Radarbox that will be used as aids in both observation planning and aircraft detection. The latter is an important issue at Metsähovi as the use of radar is prohibited due to the proximity of an astronomical radio telescope.

We will present the current status and future plans of the Metsähovi SLR-station update project.

13-Po30

NGSLR Collocation Analysis

Julie E. Horvath [1], Christopher B. Clarke [1], Jan F. McGarry [2], Howard L. Donovan [1], John J. Degnan [3], Alice Nelson [1], Donald Patterson [1], Anthony Mann [1], Felipe Hall [1], Thomas Zagwodzki [4]

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After 2 years of intensive engineering development, NASA's Next Generation Satellite Laser Ranging System (NGSLR) was collocated against the NASA Network standard, MOBLAS-7. Collocation, a method of direct comparison testing developed by NASA and Honeywell in the 1980's, is used to identify laser system ranging anomalies by utilizing geometry to isolate station dependent, systematic ranging errors from other external sources of systematic errors. The completed collocation was the final step for the NGSLR system performance and design validation.
During collocation, the NGSLR and MOBLAS-7 systems operated in good weather simultaneously for 12 hours per day / 5 days a week, day and night, from May 29th through July 5th, 2013. The systems tracked a total of 81 simultaneous passes, including 28 simultaneous LAGEOS passes during the collocation. This comparison test was the first NASA Collocation conducted between a single photon system (NGSLR) and a multi-photon (MOBLAS-7) system. Because there are known differences with satellite CoM corrections between single photon and multi-photon detection systems, it was assumed prior to collocation that NGSLR would measure long to MOBLAS-7. We will provide details of the NGSLR / MOBLAS-7 collocation analysis and describe the processing methods used to show NASA's Next Generation SLR performance.

13-Po31

Ranage Gate Generator Development for 10kHz Laser Ranging

Seung-Cheol Bang, Nung-hyun Ka, Hyung-Chul Lim

Korea Astronomy and Space Science Institute

Korea Astronomy and Space Science institute (KASI) is developing the new range gate generator, called A-RGG, for 10kHz laser ranging. The A-RGG is designed based on GRAZ ISA Card but range gate (RG) is computed in FPGA H/W of A-RGG using Lagrange interpolation instead of PC program. The A-RGG consists of RG signal generator for C-SPAD, FIRE signal generator, 3 OUTPUT ports to control external device and LED indicator. The RG signal generator calculates the expected laser arrival time returned from satellites by using lookup table transferred from the operation system. It can also support the calibration ranging even though the ground target has short distance. The FIRE signal generator controls the laser system to fire a laser pulse and conducts laser collision avoidance against backscattering. The period and pulse width of FIRE signal is controlled by external program. The pulse start time and width of signals in 3 OUTPUT ports are also programmable, which can be synchronized with RG or FIRE signal. The LED indicator shows internal operation status. The all functions of A-RGG are controlled through serial communication.

13-Po32

Remote Control Southern Hemisphere SSA Observatory

Ian Ritchie

EOS Space Systems Pty Limited

EOS Space Systems (EOSSS) is a research and development company which has developed custom observatories, camera and telescope systems for space surveillance since 1996, as well as creating several evolutions of systems control software for control of observatories and laser tracking systems. Our primary research observatory is the Space Research Centre (SRC) at Mount Stromlo Australia. The current SRC control systems are designed such that remote control can be offered for real time data collection, noise filtering and flexible session management. Several fields of view are available simultaneously for tracking orbiting objects, with real time imaging to Mag 18. Orbiting objects can have the centroids post processed into orbital determination/ orbital projection (OD/OP) elements. With or without laser tracking of orbiting objects, they can be tracked in terminator conditions and their OD/OP data created, then enhanced by proprietary methods involving ballistic coefficient estimation and OD convergence pinning, using a priori radar elements. Sensors in development include a thermal imager for satellite thermal signature detection. Extending laser tracking range by use of adaptive optics beam control is also in development now. This Southern Hemisphere observatory is in a unique position to facilitate the study of space debris, either stand-alone or as part of a network such as Falcon. Current national and international contracts will enhance the remote control capabilities further, creating a resource ready to go for a wide variety of SSA missions.

13-Po33

Results and Analyses of Debris Tracking from Mt Stromlo

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In the last 2 years, EOS Space Systems has conducted three debris tracking campaigns using its Space Debris Tracking System at Mt Stromlo. The first one was an optical (passive) tracking campaign undertaken between 8 May and 23 May 2012. The second one was a laser tracking mission in July/August 2012, and the third was also a laser tracking campaign in April/May 2013. One of the main objectives of these campaigns was to assess the performance of the short-term (1-2 days) debris orbit prediction (OP), from tracking data at a sole station. This paper presents the results and analyses of the short-term OP performance assessments. It shows that the 1-day OP accuracy better than 20 arc seconds is achievable using only 2 passes of tracking data over 24 hours.

13-Po34

Riga SLR station upgrade and status report

Kalvis Salminsh, Maris Abele, Jorge R. del Pino

Institute of Astronomy Univ. of Latvia

This paper discusses currently ongoing upgrades at the station Riga including telescope receiver channel, system calibration, telescope mount model, modernization of time and frequency service and other activities.

13-Po35

Satellite Laser Ranging at the Shimosato Hydrographic Observatory

Mariko Sato, Shun-ichi Watanabe, Takashi Kurokawa, Hiroko Fukura, Miyuki Fujisawa, Mikuto Koike, Masayuki Fujita, and Arata Sengoku

Japan Coast Guard

The Shimosato Hydrographic Observatory in Wakayama Prefecture, central Japan, has been carrying out Satellite Laser Ranging (SLR) observation for AJISAI, LAGEOS-1, LAGEOS-2 and other geodetic and earth observation satellites since 1982. More than 33,000 passes have been obtained as of Aug. 31, 2013. Through the SLR observation, the precise position of Japan has been determined on the international reference frame such as ITRF. Based on this, we determined the transformation parameters from the Tokyo Datum to the world geodetic system. Furthermore, we have detected the intraplate deformation caused by the subduction of the Philippine Sea Plate off Shimosato in the interseismic phase and the coseismic crustal movements associated with the 2004 off the Kii Peninsula earthquake (Mw 7.5) and the 2011 off Tohoku earthquake (Mw 9.0). In this presentation, we summarize the observation equipment and results of our observation.

13-Po36

Satellite Tracking Near Japan 50 Years Ago

Jerry R. Wiant [1], Judit Gyorgyey Ries [2]

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As an undergraduate Jerry Wiant tracked satellites while participating in a work-study program at New Mexico State University, Las Cruces, NM. During the summer of 1963 Jerry doppler-shift tracked satellites while on Marcus Island and Iwo Jima Island southeast of Japan. Photos of the station, equipment, living conditions, local cuisine, and few artifacts are presented.

13-Po37

SLR configuration and data management software (Debit) using WEB and relational data base

Hiroo Kunimori [1], Reiko Iwafune, Koji Ohi[2]

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Koganei Ranging Engine (KRE) related software is under development in which all resouces in laser station and parametեters to be administrated.
Open source based software based o webb and data base integrates the configuration set parameter management of station subsystem such as telecope, Range Gate Generator, Event timer,laser and meteorological subsystem.
Non-dedicated SLR laser station like Koganei but also to apply synergy application such as Laser Communication experiment will be discussed.

13-Po38

SLR data processing status of Korean SLR system

Eunseo Park [1], Young-Rok Kim [1], Jay Hyungjik Oh [2], Eun-Jung Choi [1], Mansoo Choi [1], Hyung-Chul Lim [1]

[1] Korea Astronomy and Space Science Institute
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Korea Astronomy and Space Science Institute (KASI) installed SLR station (Daedeok) and joined the ILRS network in 2012. In addition, from early in 2013, KASI planed to prepare the SLR data processing. In this paper, we present current status and results of precise orbit determination (POD) and geodetic parameter estimations using satellite laser ranging (SLR) observations. The NASA/GSFC GEODYN II and SOLVE softwares were used for processing the normal point observation data set of LAGEOS-1, LAGEOS-2, ETALON-1 and ETALON-2. A weekly-based orbit determination strategy was employed to process SLR observations and the coordinates of ILRS sites were determined.

13-Po39

SLR Station Potsdam Software Upgrade based on a Linux Real Time System

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[2] GFZ German Research Centre for Geosciences

After the successful migration to a Kilohertz system in 2011 there was a growing need for a major redesign of the software ensemble running the Potsdam SLR station. Like in most of the older SLR stations there where a couple of computers and a various number of loosely coupled software components developed over decades, which made it very hard to maintain and integrate new features. To ensure the long-term maintainability and extensibility of the station GFZ contracted in 2011 SpaceTech GmbH for the redesign and implementation of a new SLR operation software. The new software was designed as a client-server application comprising a real-time daemon which controls all hardware components and performs all timing-critical operations and a GUI software for commanding the real-time daemon and serving as an easy to use interface for the operator.
Both components of the software are running on a single Linux machine with a real-time kernel. The Potsdam SLR station is successfuly operated by the new software since September 2012.

13-Po40

SLR Tracking of Envisat Past its End-of-Life

Martin Weigel [1]
, Georg Kirchner [2], Hauke Fiedler [1]

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After more than twice of the scheduled life-time, contact with the Envisat satellite was lost in April 2012. Since then, the satellite has been moving uncontrolled in a Sun-synchronous orbit of about 770 km altitude. In the absence of telemetry and active tracking, satellite laser ranging measurements provide an important means for monitoring both the orbit and attitude of Envisat. Since public orbit information (in the form of twoline elements) is generally too coarse to enable a seamless SLR tracking, DLR has taken initiative to determine the orbit of Envisat from SLR tracking and to generate station predicts for the ILRS. Starting from a small initial set of tracking points collected by the Graz laser station after visual search and acquisition of Envisat, a routine processing chain has been established in May of this year. This has enabled a large number of volunteer stations to contribute Envisat observations, which in turn supported a routine orbit processing. The poster focuses on the assessment of the orbit determination and prediction performance and relates it to the achieved SLR coverage. It complements other presentations addressing the benefit of SLR tracking for studies of Envisat attitude behavior.

13-Po41

Some aspects of the budget of uncertainty in measurement laser station.

I.Ignatenko

National Research Institute for Physical-Technical and Radio Engineering Measurements (VNIIFTRI)

Increases of requirements to accuracy of measurements causes consider even minor factors affecting the result. The report examines some of these factors. The analysis of influence of these factors on the results and outline the ways to improve the quality of measurements.

13-Po42

Stability of the SGF, Herstmonceux site and SLR calibration

Graham Appleby
, Christopher Potter, Jose Rodriguez, Robert Sherwood
, Toby Shoobridge, Victoria Smith, Matthew Wilkinson

NERC Space Geodesy Facility

The NERC BGS Space Geodesy Facility, Herstmonceux operates a very precise, kHz-capable Satellite Laser Ranging station, two modern GNSS receivers, one of which has contributed to IGS for over 15 years and, since late 2006, an Absolute Gravimeter which provides a weekly time-series of local gravity acceleration. In line with GGOS recommendations, site inter-technique stability is of prime concern, and precise levelling and short-baseline GPS analyses are carried out at regular intervals. In this poster we discuss the results of these monitoring measurements, and in addition report on an exhaustive investigation into small, occasional abnormal variations in the laser ranging calibration results, which were flagged as being significant. Steps were taken to minimize the effects of these anomalies in the laser range data delivered by this prolific station. The investigation revealed a very subtle cause of the effect, which has now been eradicated. Designs for a future SLR calibration target to enable local tie surveys to be carried out more easily are also presented.

13-Po43

Status of the Zimmerwald SLR station

M. Ploner, J. Utzinger, P. Lauber, M. Prohaska, P. Schlatter, P. Ruzek, T. Schildknecht, K. Sosnica, A. Jäggi

Astronomical Institute, Univ. of Bern

The Zimmerwald SLR station is operated in a monostatic mode with 532nm laser pulses emitted at adjustable frequencies of 90-110Hz with energies slightly less than 10mJ. A rotating shutter protects the CSPAD receiver from the backscatter of the transmit beam. These systems are located below the telescope in an operator room housed within the observatory building with the laser system located in a separated, air-conditioned part of the room. All hardware components may be automatically accessed by the control software and from remote if required. Thanks to the fully automatic and remotely controllable SLR operations, the Zimmerwald station is one of the most productive stations in the ILRS network. Key characteristics of the target scheduling, acquisition and tracking, and signal optimization as used in Zimmerwald for a fully autonomous operation are presented, and their impact on the station performance and quality of the collected SLR data is shown. Specialities like the tracking of the full GLONASS constellation, one-way ranging to the Lunar Reconnaissance Orbiter, and photon reception from bi-static experiments with the Graz SLR station are highlighted as well.

13-Po44

Superconducting single photon detectors for near infrared wavelength with high sensitivity, low noise, and high timing resolution

Shigehito Miki [1], Taro Yamashita [1], Zhen Wang [1][2], and Hirotaka Terai [1]

[1]NICT [2]SIMIT

Recently, superconducting nanowire single photon detector (SNSPD or SSPD) is becoming a promising detector to achieve excellent performances as compared to semiconductor avalanche photo diode which is mostly used at present. In laser sensing research area, SSPD should be an attractive because of its high single photon sensitivity, low dark count, and short timing jitter. In this paper, we introduce the mechanism and features of SNSPD and report on the recent progress of our SNSPD system.

13-Po45

System design of the South African Lunar Laser Ranger

RC Botha, WL Combrinck

Hartebeesthoek Radio Astronomy Observatory

The development of a Lunar Laser Ranging system for South Africa is progressing well. During the system design phase a lot of attention was given to incorporate ideas that worked at other laser ranging stations, as well as avoid things that proved to be problematic.

Implementing a industry-standard systems communications and interlink backbone is of utmost importance since it will reduce initial development time and should ensure long-term support and component availability. Central software control systems are being developed in-house to monitor and control the complete laser ranging system from the control room. These approaches allow us to place equipment directly where it must measure or provide signals, rather than in one large control room. This drastically cuts down on cabling, potential timing calibration problems and the number of different interfaces that must be interacted with.

An overview of the system design, depicting both current and planned systems, will be presented.

13-Po46

T/R switch development utilizing optical fiber technology

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T/R switch utilizing well established optical fiber communication technology has been developed in order to use Synergy of Optical Communication and Ranging System.

The switch utilize the optical fiber circulator concept, and enlarge the clear aperture from 10 micro m to 2.2mm in order to handle the high power laser pulse.

The switch can handle the ps to ns-pulse, 10kw peak power, 1MHz pulse repetition rate laser and operate in C-band wavelength range.

We describe the configuration, operation principle, and evaluation data such as insertion loss, and T/R isolation characteristics vs. beam size.

The switch will be used in eye-safe laser ranging and long distance optical communication.

13-Po47

T2L2 : Microwave link comparison

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D. Rovera [4], M. Abgrall [4], J. Achkar [4] R. Sherwood [5], G. Appleby [5]
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T2L2 (Time Transfer by Laser Link), developed by both CNES and OCA permits the synchroni-zation of remote ultra stable clocks over intercontinental distances. The principle is derived from laser telemetry technology with dedicated space equipment deigned to record arrival time of laser pulses at the satellite. T2L2 permits to realize some links between distant clocks with time stability a few picoseconds and accuracy better than 100 ps.
Several campaigns were done to demonstrate both the ultimate time accuracy and time stability capabilities. Some campaigns have been done to accurately compare T2L2 with microwave time transfer GPS. These comparisons are based on a global calibration of both laser stations and GNSS equipment.
The presentation is focused on the recent campaign done between Hertsmonceux, Obs-Paris, OCA and Wettzell.

13-Po48

Terrestrial Reference Frame Realization from GPS and SLR

Jan P. Weiss, Willy Bertiger, Shailen D. Desai, Bruce J. Haines, Aurore Sibois

JPL, California Institute of Technology

We present terrestrial reference frame (TRF) realizations based on precise orbit determination of the GPS constellation and low-Earth orbiters (LEOs). Our solutions rely on accurate and consistent GPS orbit determination tuned for reference frame realization: we use multi-day orbit arcs to capitalize on the spacecraft dynamics, estimate once- and twice-per-revolution accelerations in the spacecraft-sun coordinate system, utilize a homogeneous network of ground stations equipped with choke-ring antennas, and apply 1-km a priori constraints to the station positions. Receiver and transmitter antenna phase variation (APV) calibrations are derived from test range measurements and LEO data processed with a fiducial-free network. The resulting TRF is therefore realized without a priori ties to the International Terrestrial Reference Frame (ITRF).

The orbit solutions and reference frame realizations span 19 years, from 1994-2012. The baseline solution includes only microwave measurements from the ground network and GPS constellation. Relative to ITRF2008, this solution yields a 3D origin offset and rate of 9 mm and 0.7 mm/yr, respectively, and scale bias and rate of 2 ppb and 0.06 ppb/yr. Next, we include GRACE-A from 2002 onwards. The spacecraft's near polar orbit greatly improves the spatio-temporal distribution of the observations over the oceans and in the north-south direction. Including the LEOs in the global precise orbit solutions further reduces the Z-origin bias and scatter relative to ITRF2008 by more than 50%. We also include laser range tracking of GRACE during select time periods. Here we rely on fixing the "space tie" between the GRACE GPS antenna and laser retro-reflector to relate the two techniques and continue to estimate all ground station positions with loose apriori constraints. We evaluate the impact of including SLR on all transformation parameters with respect to ITRF2008 and discuss sensitivity to the space-tie vector.

13-Po49

The design of laser retro-reflectors and its application in the docking mission of Chinese Tiangong-1 space lab module

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Shanghai Observatory, Chinese Academy of Sciences

In the first Chinese spacecraft docking mission of Tiangong-1 space lab module, the onboard lidar technology is adopted for searching and precisely measuring the distance between the involved two spacecrafts. Shanghai Observatory has designed and developed laser retro-reflector for the onboard lidar system. The retro-reflector is installed on the surface of Tiangong-1 space lab module to reflect the laser signal from the Shenzhou spacecraft which can obtain the azimuth, elevation and distance of Tiangong-1 spacecraft. To meet the requirements of measuring system, the reflectors are composed of two kind components, the far field cooperative object and the near field cooperative object. The former is assembled with multi sets of different dimension corner cube arrays to make its field of view up to 90°×105° and the minimum reflective area over 100cm2 at the distance of more than 20km for the purpose of searching object. The later is one single large corner cube for the high precise distance measurement when the range of two spacecrafts is near. This paper introduces the design of laser retro-reflectors for the onboard lidar and its application in the Chinese docking mission

13-Po50

The Ground Calibration System of Korean SLR System

Sung-Yeol Yu, Seung-Cheol Bang, Eun-Jung Choi, Tae Kenu Kim, Hyung-Chul Lim, Yoon-Kyung Seo, Mansoo Choi, Eunseo Park

Korea Astronmy and Space Science Institute

Since 2008 Korea Astronomy and Space Science Institute (KASI) is developing two SLR systems under the ARGO project (Accurate Ranging system for Geodetic Observation) in Korea. The finished mobile SLR station (40 cm), ARGO-M, is now under the starting phase, while the fixed system (1 m class), ARGO-F, is in the design phase. The ARGO-M operates with the kHz repetition rate laser and is equipped with the near ground calibration target mounted under of the dome. The ground calibration allows evaluation of the SLR system delay, which depends on the configuration of the hardware, but also on the temporary atmospheric conditions. The calibration correction is applied to the raw range measurements during the course of the post-processing. We conducted the finite element analysis (FEA) to examine the structure error of the ground target, and performed 3D distance measurement between the virtual reference point of the mount and the ground target. We also measured the environment vibrations which are able to affect the calibration process. This presentation describes design of the ARGO-M ground calibration target, as well as the conditions of its environment and the results of the system calibration.

13-Po51

The Laser Enable Box (LEB) – A tool for local and In-Sky-Laser-Safety

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In-Sky-Laser-Safety as well as local laser hazard prevention is of great importance in SLR in particular when autonomous and semi-autonomous tracking operations are employed. The situation is further exacerbated when SLR is operated on more complex ranging missions, where tracking restrictions apply.
We have designed a general laser safety concept that addresses the requirements of a modern autonomous SLR facility. It comprises a management system that can handle all the different local safety components. A diverse variety of sensor and logical state input instances are rated within an overall safety scheme. From that a safety status is generated, which ensures secure operations at all times. This paper outlines the basic concept.

13-Po52

The preliminary Results of Laser Ranging to Satellites with 10 kHz Laser System at Shanghai Station

Chen Juping, Wu Zhibo, Zhang Haifeng,
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Since September 2009 Shanghai Observatory has started routinely kHz repetition rate SLR and now the kHz SLR system can track to satellites (from 400km to 36000km) in daylight and at nighttime. Based on the kHz SLR system, Range Gate Generator, SLR data acquisition, controlling software and data post-processing software are upgraded to meet the requirement of 10 kHz repetition rate SLR. 10kHz laser system with the power of about 3W, pulse-width 30ps built by the North China Research Institute of Electro-Optics (NCRIEO) is installed at Shanghai SLR Station. Through adopting the working mode of the two computers, Event Timer and CSPAD detector, which are used in the kHz SLR, the SLR measurement to satellites with the 10 kHz laser are implemented. The results show 10kHz system has several times as many returns as the kHz to range low orbit satellites.

13-Po53

The switching device for external and internal calibration at the station «Katziveli»

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Crimean Laser Observatory, Katzively.

The paper presents one of the ways to improve the results of the location. For this purpose developed and included in the optical scheme SLR-system of a special device. It allows you to quickly switch with internal calibration mode in mode calibration external without additional adjustment procedures. Detail the well-established optical scheme of the approval system laser-telescope.

13-Po54

Time Transfer between two Satellite Laser Ranging Stations via Lunar Reconnaissance Orbiter Laser Ranging

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Several satellite laser ranging (SLR) stations routinely range to the Lunar Reconnaissance Orbiter (LRO) at the same time during a one-way LRO Laser Ranging (LR) session. These simultaneous laser ranging data can be used to compare the station times or transfer time between them using the range information obtained from the radio frequency (RF) tracking. The error in the time transfer depends on the difference of the ranges from the SLR stations to LRO but not the absolute ranges. Nanosecond accuracy and precision are expected with the qualities of LRO Laser Ranging (LR) data and routine LRO RF tracking data.
The time base at NGSLR has recently been improved to nanosecond precision and accuracy to improve the LRO LR measurements and prepare for the time transfer tests. The timing signals from the hydrogen maser at Goddard's Very Long Baseline Interferometry (VLBI) site is now transmitted to the Next Generation Satellite Laser ranging (NGSLR) via optical fibers. An All-View GPS receiver is used at NGSLR to monitor the hydrogen maser time against the GPS time. By comparing our All View GPS data with those from the nearby United State Naval Observatory (USNO), we can largely cancel out the effect of ionosphere delays to the GPS signals and reference our hydrogen maser time to the master clock at USNO.
Time transfer tests were successfully conducted on ground between two nearby SLR stations, NGSLR and the Mobile Laser System (MOBLAS-7) at NASA Goddard Space Flight Center, ranging to a fixed target and recording the laser pulse arrival times at the target as in LRO. In addition, a number of simultaneous LRO laser ranging measurements were conducted from NGSLR and MOBLAS-7 and the results are currently being analyzed. Several time transfer tests are planned between NGSLR in Maryland and McDonald Laser Ranging Station (MLRS) in Texas, later in the year.

13-Po55

Ultra-low timing jitter optical pulse trains from mode locked Er-fiber lasers

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For the outstanding characteristics, such as high gain, low noise, good thermal property, compactness and convenience in building and operation, femtosecond mode locked fiber lasers are finding more and more applications. Especially, ultralow noise characteristics of mode locked fiber lasers can be expanded to various time applications. According to the noise theory, ultralow timing jitter of mode-locked fiber lasers can be achieved at short pulse duration, high intra-cavity pulse energy and nearly zero net-cavity dispersion conditions. Stretched-pulse type mode locked Er-fiber lasers have femtosecond level short pulse duration and high intra-cavity pulse energy. Net-cavity dispersion of a stretched-pulse mode-locked Er-fiber laser, consisting mostly of fibers, is controlled by changing the fiber length in cavity. So the timing jitter of laser is reduced by dispersion control. At the optimal dispersion conditions obtained by changing the length of SMF-28 fiber in the cavity, sub-100 attosecond timing jitter can be achieved from a mode locked fiber laser.

13-Po56

Upgrade of SLR station 7841 Potsdam

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The SLR station 7841 was upgraded to kHz operation in 2011. Laser repetition rates of 2 or 4 kHz are feasible. The range gate generator is based on an ARM-7 microprocessor with a clock frequency of 60 MHz. A Hamamatsu 5320 PMT tube or alternatively a 100 micro m (non-compensated) MPD SPAD are used for signal detection. The system is operated in strict single photoelectron mode under both day and night conditions with return rates not exceeding few per cent. The tracking software is based on a RT Linux system [cf. the related paper by Steinborn et al.].

13-Po57

Combined LARES-LAGEOS solutions

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The geodetic satellite LARES (Laser RElativity Satellite) is in Earth's orbit since February 13, 2012. We use LARES SLR-measurements up to August 2013 to investigate different approaches to parameterize LARES' orbit and to assess its impact on the quality of SLR-derived parameters such as station coordinates, Earth rotation parameters and geocenter coordinates. We study in particular the impact of the arc length and the number and types of empirical orbit parameters to exploit the very small area-to-mass ratio of LARES.

The solutions of the combination of LARES with the two LAGEOS satellites will be analyzed, as well. Specific emphasis will be given on the impact of LARES on the SLR-derived parameters in a combined solution. In the framework of the determination low degree coefficients of the Earth's gravity field, the contribution of LARES will be addressed, too.

Lessons learned from LARES orbit modeling will give evidence about LARES' contribution to the standard products generated by the Analysis Centers of the International Laser Ranging Service.

13-Po58

NASA SLR Network Key Safety Elements

Chris Quinn, David McCormick

EXELIS Inc., NASA

This paper will present the key elements of an effective safety program for the NASA Network of SLR stations

13-Po59

ILRS Station Reporting

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Network stations provided system configuration documentation upon joining the ILRS. This information, found in the various site and system log files available on the ILRS website, is essential to the ILRS analysis centers, combination centers, and general user community. Therefore, it is imperitive that the station personnel inform the general ILRS community when changes to the system occur in a timely fashion. This poster provides some information about the various documentation that must be maintained.

13-Po60

Ukraine SLR stations: the current state and future

Zhaborovskyy Vitaliy

Main Astronomical Observatory of NAS of Ukraine

Ukraine have feasible participation in SLR. We have 3 active station. The current state of Ukraine network, successes and troubles are presented. The futures plans and perspectives are described.

13-Po61

Space Debris Removal

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Space Debris poses an ever-increasing threat to spaceflight. The amount of space debris may have reached a critical point, where without an active removal system the amount of space debris will keep increasing through collisions. In order to preserve the space environment, an active space debris removal system is essential.

A possible candidate for an active space debris removal system would entail a ground laser which deorbits space debris by means of Laser Propulsion (LP). Pointing a laser beam onto a debris particle ablates its surface, causing a jet of material vapor whose thrust can be used for deorbiting the particle. The feasibility of using LP for deorbiting space debris in the size range of 1 to 10 cm has been assessed here. It is shown that the orbital lifetime of space debris objects can be significantly reduced using LP. The potential for deorbiting debris by means of LP becomes apparent for higher LEO and MEO orbits, where the orbital lifetime ranges from a hundred years practically up to infinity. For example, for the altitude regime of GNSS missions, typically around 20000 km, the orbital lifetime can be reduced to approximately 7 years using LP. Preferred Presentation Type Poster presentation Research Area Synergy (Time Transfer, Optical Communications, Space Debris, Multi-technique Combination and GGOS, Various Applications)