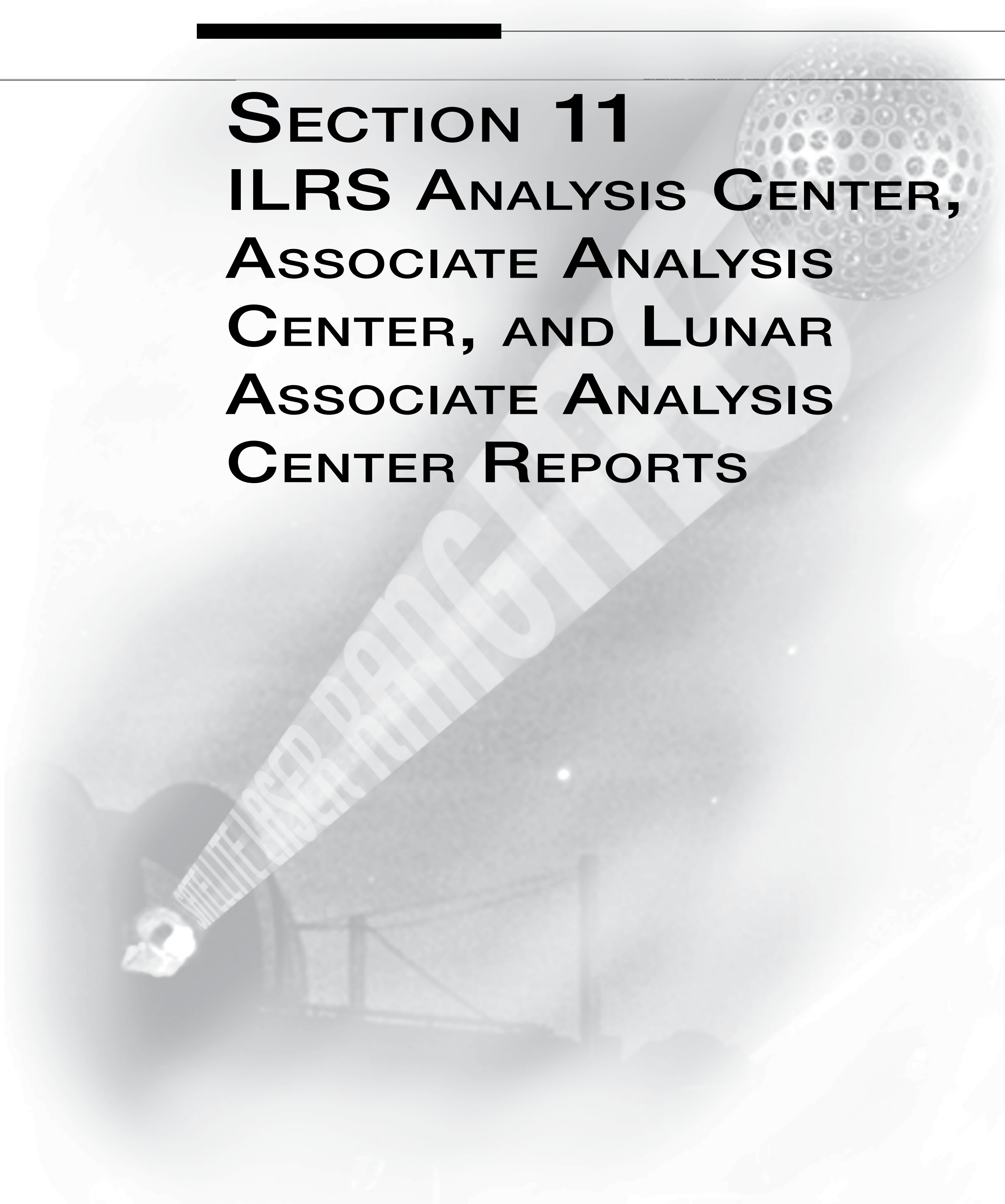
Section 11
ILRS Analysis Center, Associate Analysis Center, and Lunar Associate Analysis Center Reports



SECTION 11

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

ILRS ANALYSIS CENTER REPORTS

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

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

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Introduction

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

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

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

ILRS Analysis Center

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

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

ILRS Primary Combination Center

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

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

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

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

Non - ILRS activities in 2009-2010

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

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

Future Plans

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

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Bundesamt für Kartographie und Geodäsie (BKG)

Bernd Richter, Maria Mareyen/BKG

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

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

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

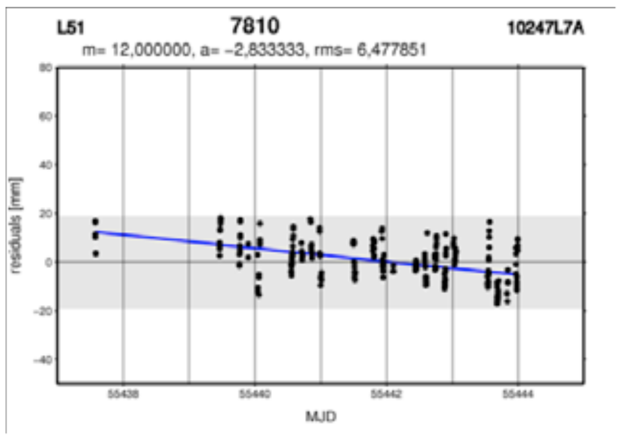

Figure 11-1. Data screening: station 7810, Zimmerwald, week 100904; LAGEOS-1 residuals "o-c" in the course of a week

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

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

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

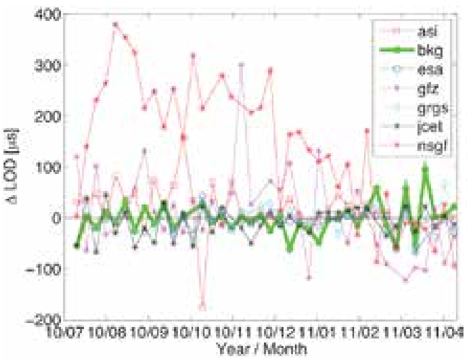

Figure 11-2a: Weighted Mean of "Length of Day" residuals

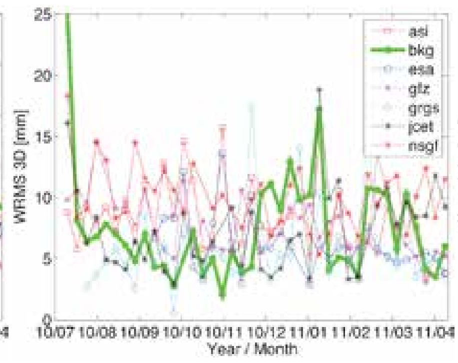

Figure 11-2b: Weighted Root Mean Square of "3D coordinate" residuals

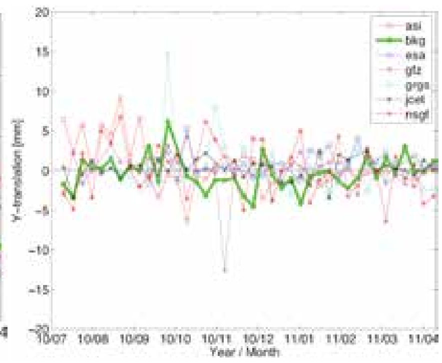

Figure 11-2c: "Y component of the translation vector"

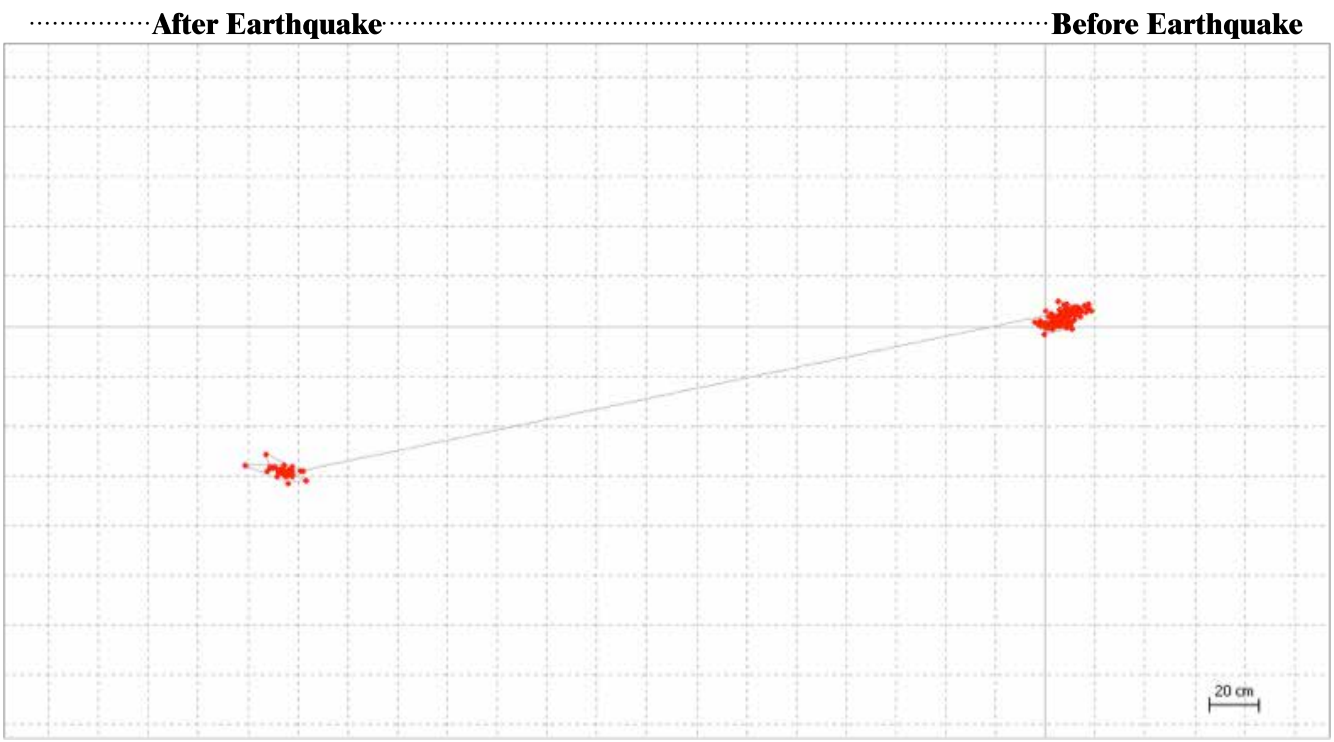

Figure 11-3: Groundtrack (ΔE, ΔN) of Stations Positions of the station Concepcion (Chile) 7405_SLR

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Deutsches Geodätisches Forschungsinstitute (DGFI)

Horst Müller, Mathis Bloßfeld, Detlef Angermann/DGFI

Introduction

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

ILRS Analysis Center

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

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

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

ILRS Combination Center

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

ILRS/AWG Rapid Service Mail

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

```
*****************************************************************************
ILRS/AWG Rapid Service Mail (HITU) 7249 -1 m range bias     Message No.0001
*****************************************************************************
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Including the analysis center, which has issued the messages, presently HITU (Hitotsubashi University, Japan) and DGFI, a brief description of the error and an incrementing number. The message body will contain a detailed description of the problem if necessary.

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

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

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

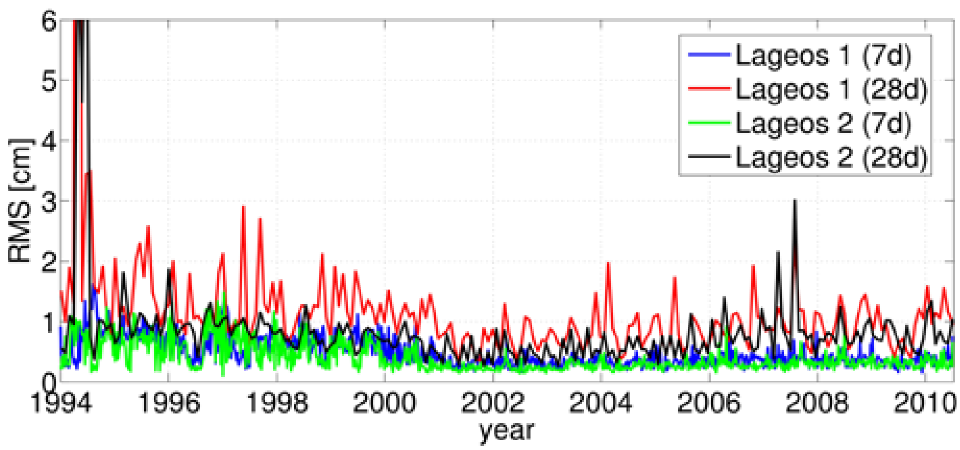

Figure 11-4: Orbit fits of LAGEOS-1 and -2 for the different arc lengths (weekly/4-weekly)

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

Table 11-1: Estimated Parameters of the SLR Solution

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

Gravity Field Parameters

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

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

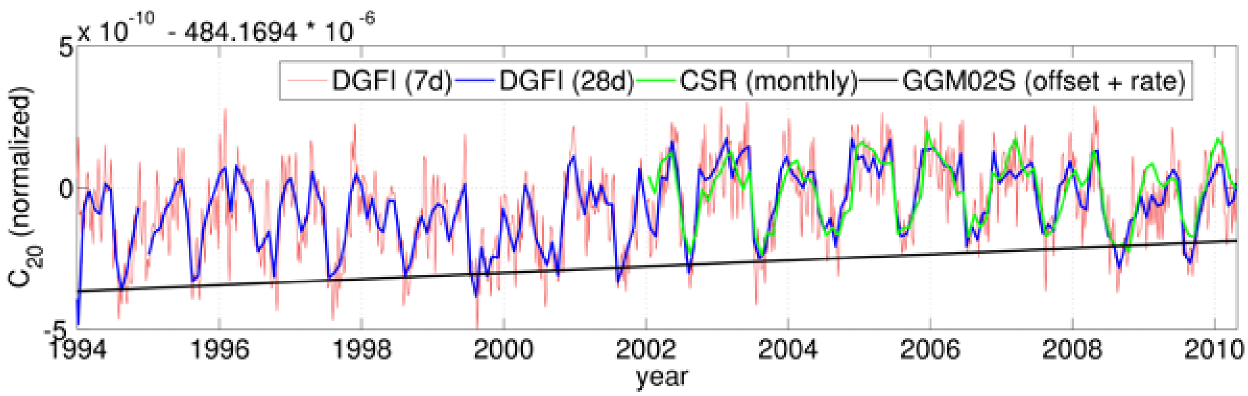

Figure 11-5: Estimated normalized coefficients with different temporal resolution (weekly/4-weekly)

Earth Rotation Parameters (ERPs)

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

Empirical Accelerations

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

Future Plans

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

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

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European Space Operation Center (ESOC)

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

Introduction

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

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

Current Activities

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

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

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

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

New and Future Developments

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

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

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Geoscience Australia (GA)

Ramesh Govind/Geoscience Australia

Introduction

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

Key Accomplishments -- Analysis Activities during 2009-2010:

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

Current Activities

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

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

Related Publications

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

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

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

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

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

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

Key accomplishments

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

Key challenges

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

Products

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

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

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

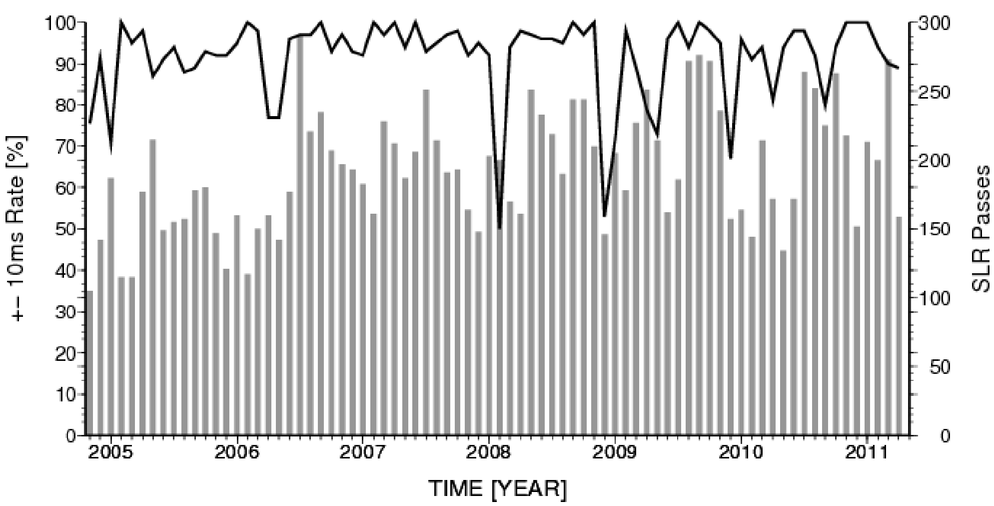

Figure 11-6. 10 ms success rate for GRACE-A (solid line) for a time advance of 12 h, together with SLR passes gathered in the network (gray columns)

POS&EOP Products

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

Data Handling File

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

Contribution to ITRF2008

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

Atmospheric loading and gravitational variations for 2008-2009

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

Other activities of the GFZ AAC include:

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

Reprocessing of ERS-1 and ERS-2 Orbits

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

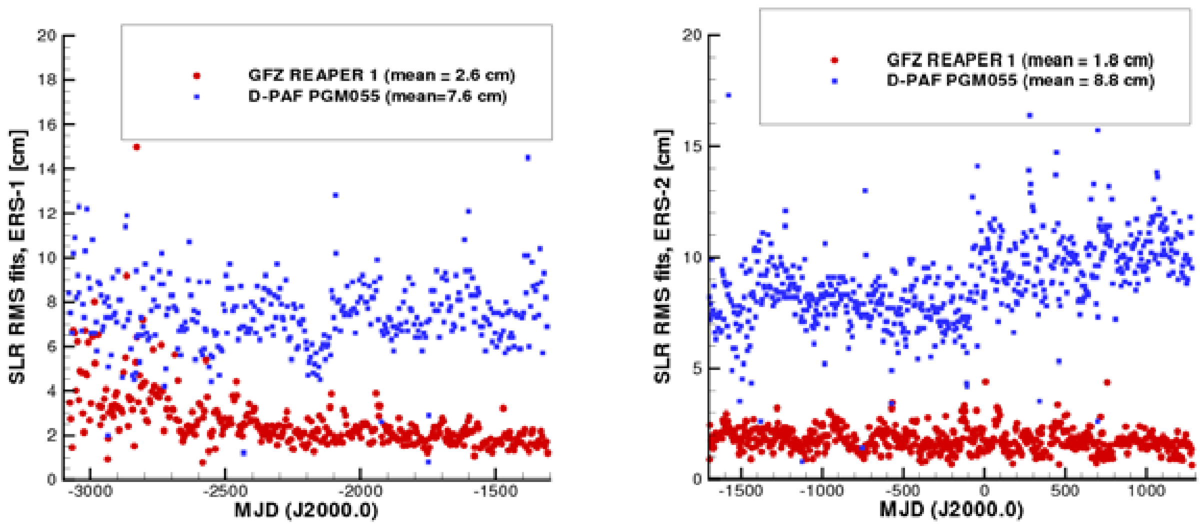

Figure 11-7a and b. Improvements in SLR RMS fits of ERS-1 (left) and ERS-2 (right) GFZ REAPER orbits as compared to D-PAF ones.

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Future Plans

Future activities for the GFZ Analysis Center include:

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

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Groupe de Recherche en Geodesie Spatiale (GRGS)

Florent Deleflie/OCA/GRGS, David Coulot/IGN

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Operational Activities

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

Analysis/Reanalysis Activities

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

Methodological Activities:

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

Fields of Interest

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

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

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

Introduction

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

Background

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

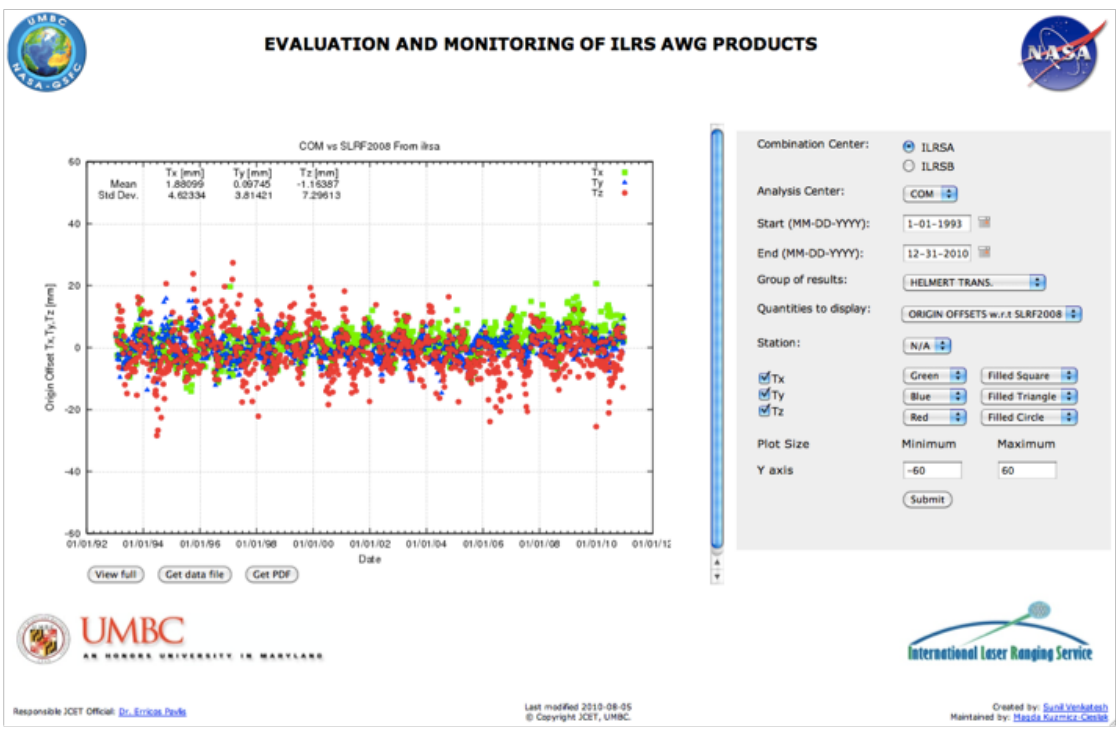

Figure 11-8. Example of JCET's "Evaluation and Monitoring of ILRS AWG Products" page displaying the origin offsets of the weekly combination series ILRS-A with respect to the a priori ITRF.

Facilities/Systems

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

Current Activities

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

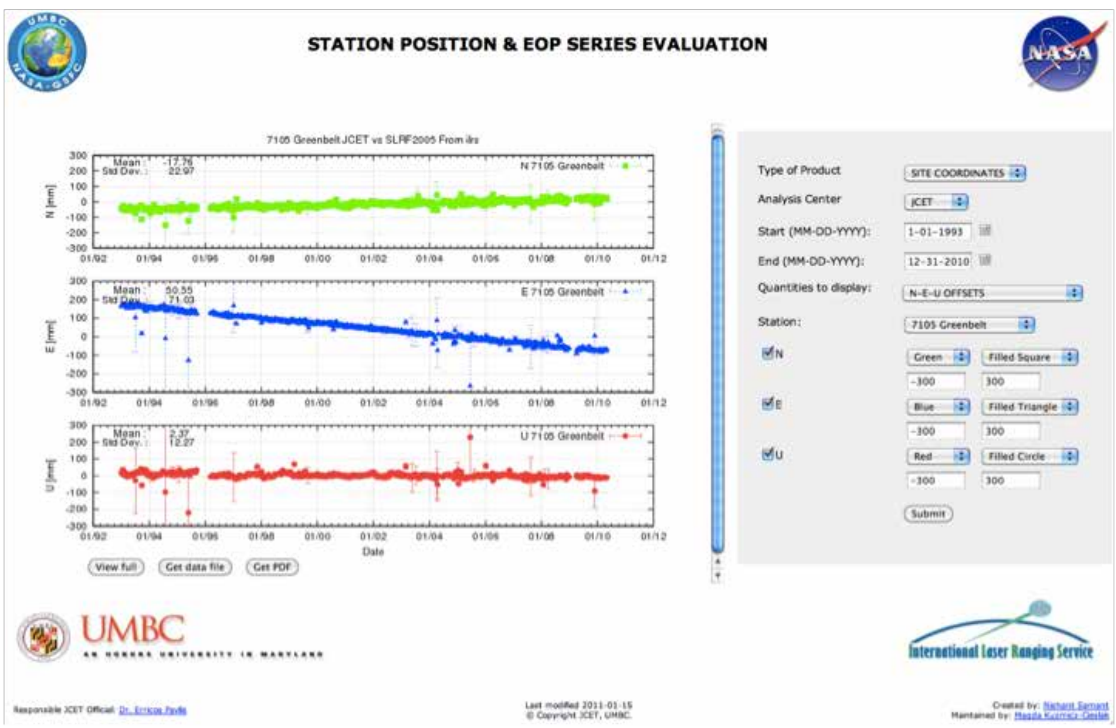

Figure 11-9. Example of JCET's addition to the ILRS AWG Products Visualization page, displaying the weekly series of N-E-U offsets for GGAO, Greenbelt, MD, from the JCET AC contributions with respect to the a priori ITRF.

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

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

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

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

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

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

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

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

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

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

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

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

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

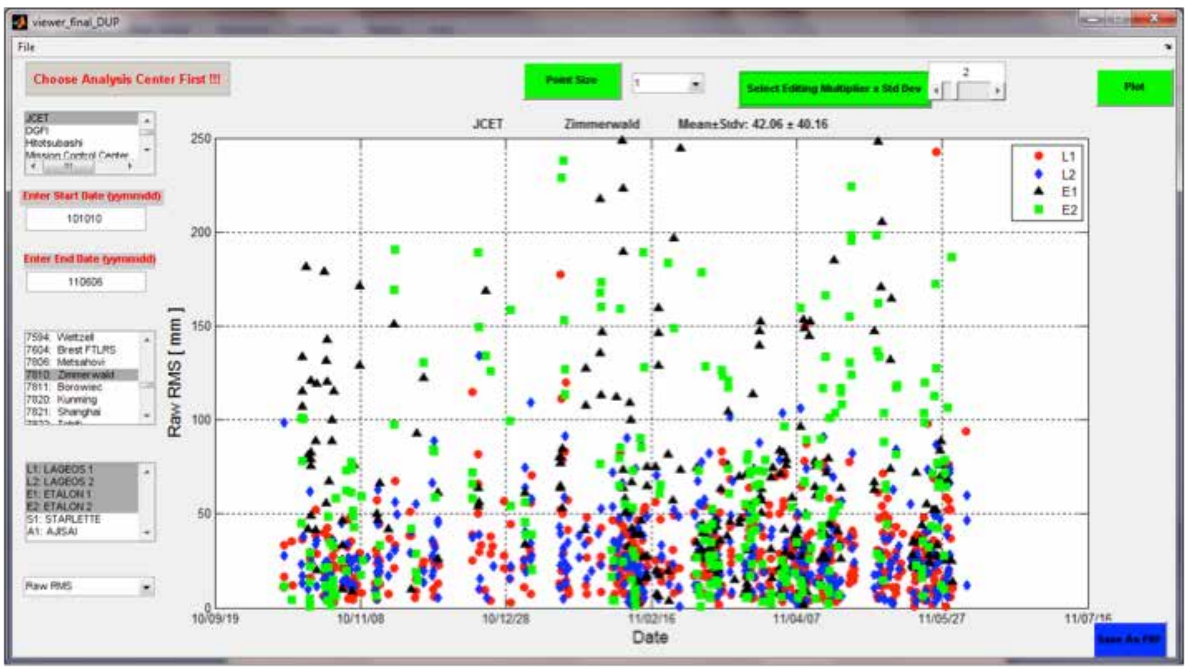

Figure 11-10. Example of JCET's QC Viewer GUI that allows users interested in the performance of ILRS sites to examine their statistics based on all available QC reports over any period of time that these are available for and for all satellites which are present in these reports.

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

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

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

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

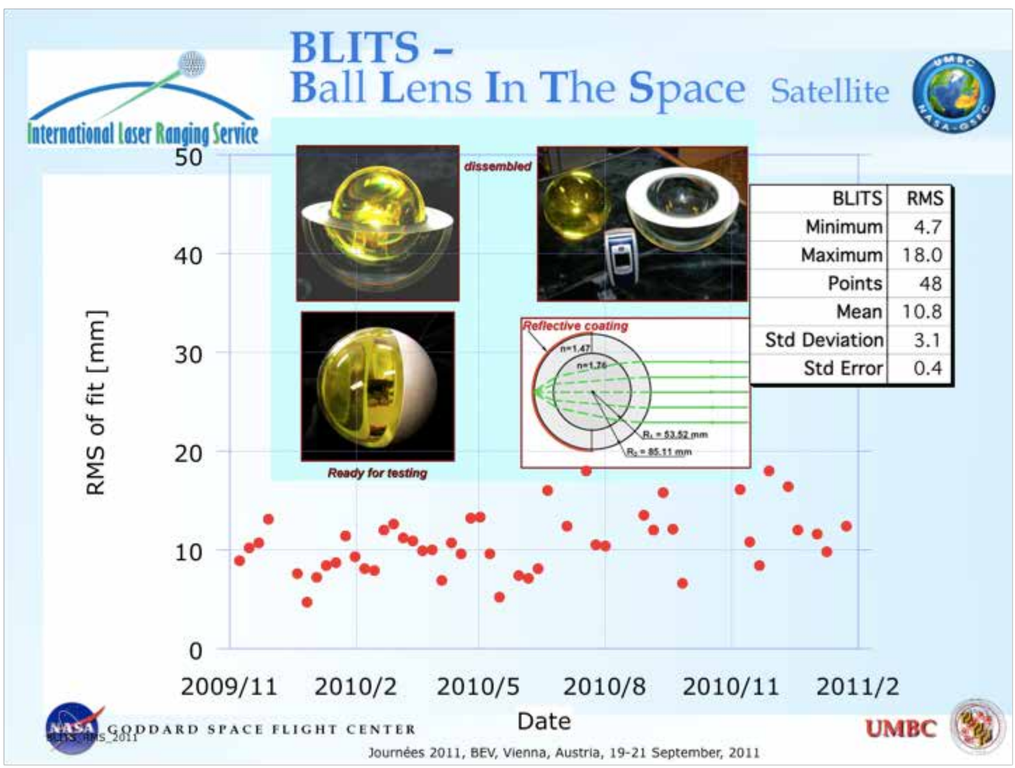

Figure 11-11. JCET's orbital fits of BLITS 7-day arcs over 2009 – 2010 using the original CoM correction.

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

Future Plans

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

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

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

Overview

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

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

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

Contribution Solution to ITRF2008

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

Centers-of-mass (CoM) Corrections

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

Site-Stability from GPS Analysis

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

Elastic LiDAR

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

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ILRS ASSOCIATE ANALYSIS CENTER REPORTS

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

Center for Orbit Determination in Europe (CODE)

Daniela Thaller/Astronomical Institute, University of Bern, Switzerland

Introduction

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

Two types of activities are done for the ILRS:

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

Predictions for GPS and GLONASS Satellites

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

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

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

CODE Quick-Look Reports

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

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

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

Scientific Analysis

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

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

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The University of Texas Center for Space Research (CSR)

John Ries, Minkang Cheng, Richard Eanes/UTCSR

Introduction

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

Geocenter Motion

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

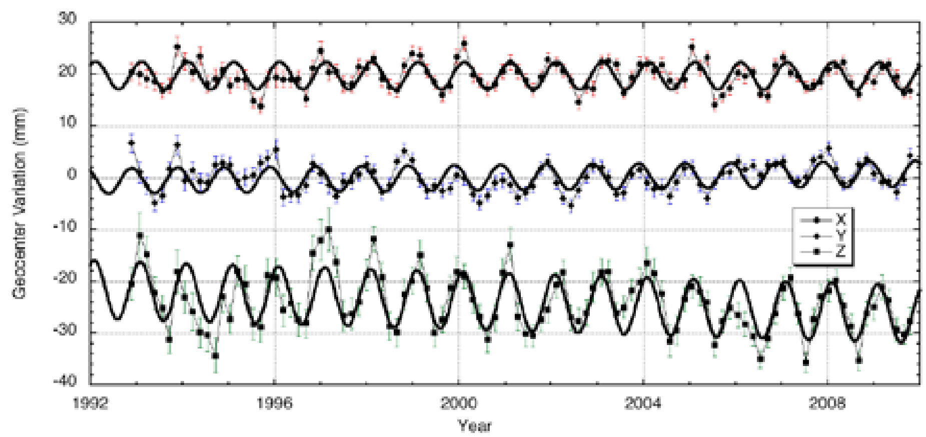

Figure 11-12. Geocenter variations estimated every 60 days from LAGEOS-1/-2. X and Z have had 20 mm added and subtracted, respectively. The fit curve is a bias, slope and annual term. A small slope of -0.3 mm/y is observed in Z.

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

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

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

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

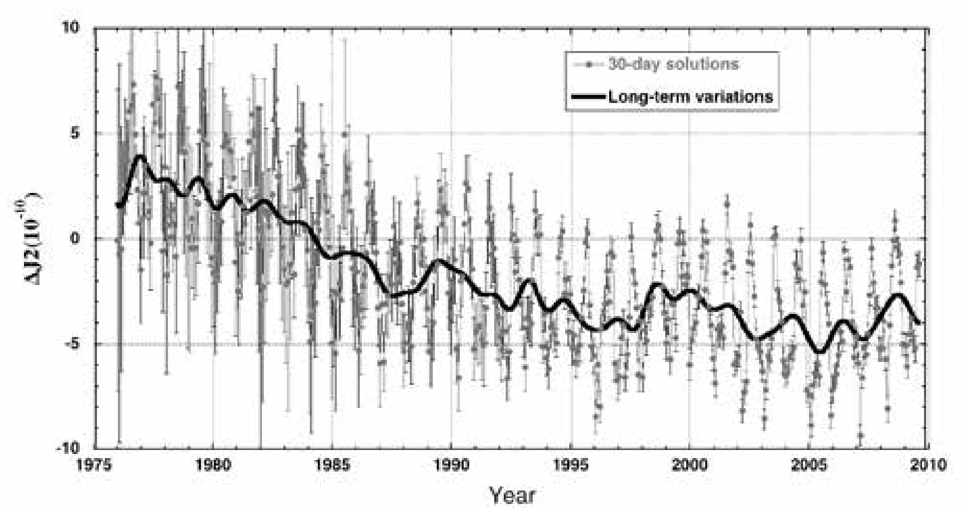

Figure 11-13. Monthly estimates showing the seasonal and long-term variations in J2.

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

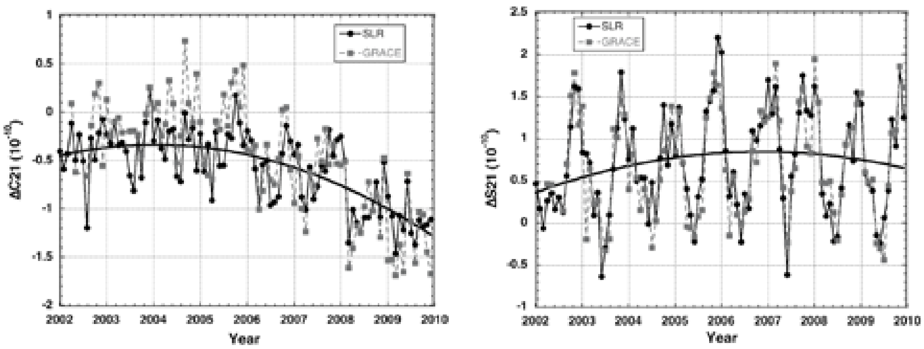

Figure 11-14. Monthly estimates of C21 and S21 from SLR and GRACE (a reference value has been removed). A quadratic fit to the time series is also shown to highlight the departure from the more linear motion observed in the past.

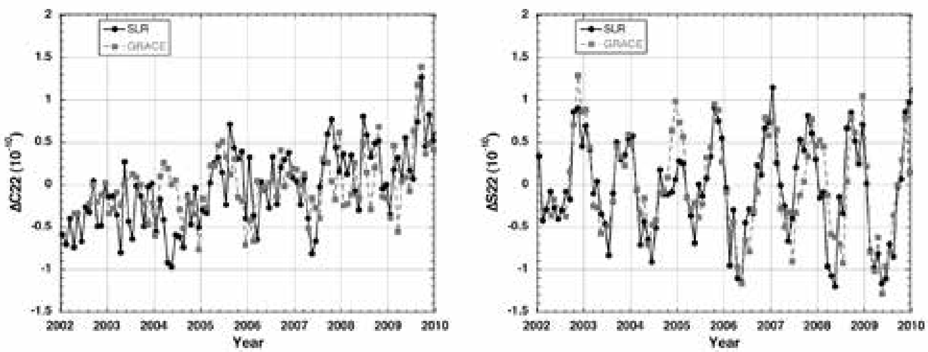

Figure 11-15. Monthly estimates of C22 and S22 from SLR and GRACE (a reference value has been removed).

Future Plans

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

Analysis Working Group Members

John Ries, Minkang Cheng, Richard Eanes, Bob Schutz

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Delft University of Technology (DUT)

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

Introduction

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

CryoSat-2

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

REAPER

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

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

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

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

GOCE HPF

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

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

Publications

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

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

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

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Forsvarets Forskningsinstitutt (FFI)

Per Helge Andersen/FFI

Introduction

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

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

Activities

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

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

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

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

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

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

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

Future Plans

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

Acknowledgement

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

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

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

Introduction

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

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

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

Scientific Results

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

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

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Hitotsubashi University

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

Introduction

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

Multi-Satellite Analysis Report

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

New Statistics “Hit rate”

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

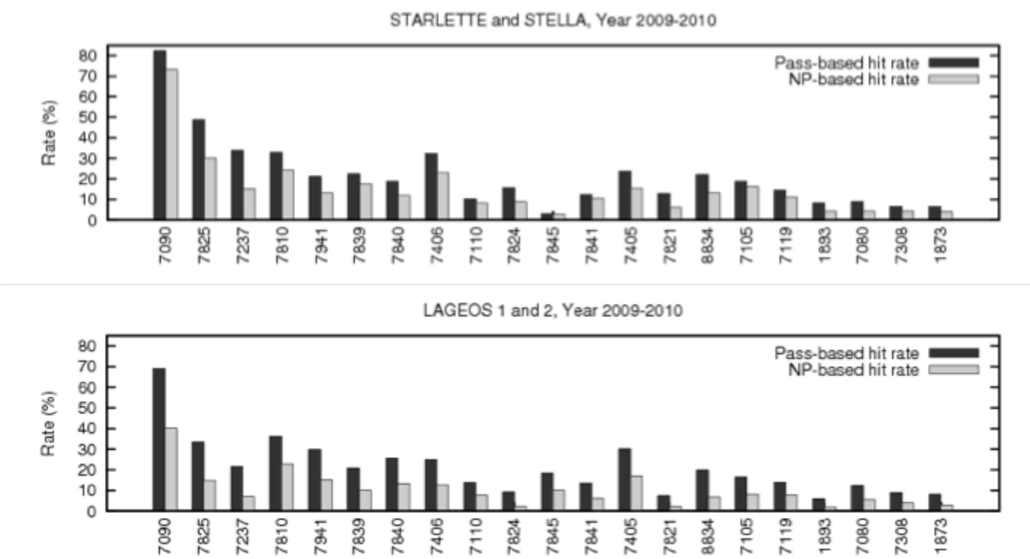

Figure 11-16. Hit rate of ILRS stations in 2009-2010. Top: Starlette and Stella. Bottom: LAGEOS-1 and LAGEOS-2.

Future Plan for 2011-12

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

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Information-Analytical Center (IAC)

Vladimir Glotov/Information-Analytical Center

Introduction

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

Facilities/systems

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

Current Activities

Weekly EOP Estimation and SLR Network Quality Control

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

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

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

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

GLONASS Orbit Determination and Verification

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

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

Future Plans

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

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Japan Aerospace Exploration Agency (JAXA)

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

Introduction

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

Current Activities

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

Current Satellite Missions

ETS- 8

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

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

QZS-1

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

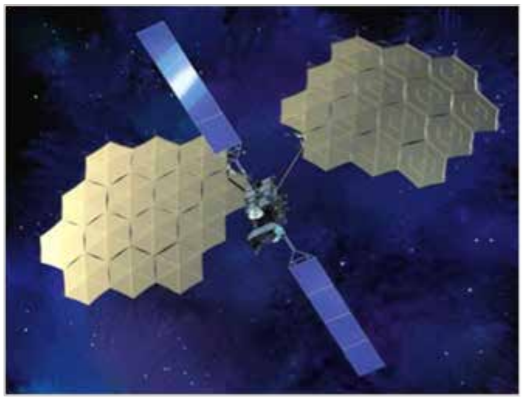

Figure 11-17. ETS-8 satellite.

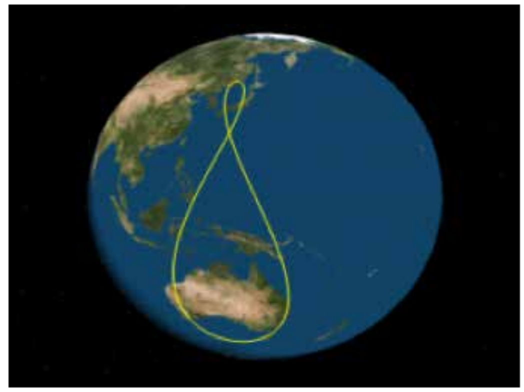

Figure 11-18. The QZSS constellation

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National Institute of Information and Communications Technology (NICT)

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

Activities in 2009-2010

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

Future Plans from 2011 to 2012

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

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

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Introduction/Data Products Provided

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

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

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

Current Activities

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

Future Plans

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

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Shanghai Astronomical Observatory (SHAO)

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

Introduction

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

Facilities/Systems

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

Current Activities

Weekly Quick-look Data Analysis

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

Range and Time Biases Comparison

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

COMPASS Orbit Determination and Verification

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

Weekly SLR SINEX EOP and Coordinate Solutions

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

Future Plans

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

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ILRS LUNAR ASSOCIATE ANALYSIS CENTER REPORTS

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

Institut Fuer Erdmessung/Forschungseinrichtung Satellitengeodaesie (IFE/FESG)

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

Recent Activities

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

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

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

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

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

Ongoing Activities and Future Plans

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

Acknowledgement

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Jet Propulsion Laboratory (JPL)

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Analysis and Science Activities 2009-2010

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

The computer code for lunar laser ranging data analysis continues to evolve. The model for perturbations from Earth tides has been upgraded. UT0 and variation of latitude solutions have been made for a 40 yr LLR data span .
Standard solution parameters now include ranging station coordinates and motions, Earth orientation, lunar orbit, tidal acceleration, GM of Earth+Moon, lunar orientation, Love numbers, tidal Qs, dissipation at and flattening of the lunar fluid-core/solid-mantle boundary (CMB), mantle moment differences, gravity coefficients and retroreflector array positions. In addition, solutions were made for any equivalence principle violation (related to PPN beta and gamma), dG/dt, geodetic precession and scale change. Gravitational physics results are in agreement with general relativity.

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

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

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

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

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Paris Observatory Lunar Analysis Center (POLAC)

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

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

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

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

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

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

R0 Apollo 11  : 00176     Bias:       0.014 m       0.091 ns     St.dev.:      0.051 m      0.341 ns
R1 Lunokhod 1 : 00029     Bias:       0.000 m      -0.001 ns     St.dev.:      0.027 m      0.181 ns
R2 Apollo 14  : 00180     Bias:       0.026 m       0.175 ns     St.dev.:      0.048 m      0.323 ns
R3 Apollo 15  : 00506     Bias:      -0.008 m      -0.051 ns     St.dev.:      0.049 m      0.325 ns
R4 Lunokhod 2 : 00051     Bias:       0.006 m       0.043 ns     St.dev.:      0.054 m      0.360 ns
   Global     : 00942     Bias:       0.004 m       0.026 ns     St.dev.:      0.051 m      0.339 ns
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Figure 11-19. The POLAC web interface screen shot for the 942 Apache Point LLR observations (2006-2010): for each retro-reflector, the bias and the standard deviation of residuals for distances (in meter) and for round-trip times of laser-pulses (in nanosecond).

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