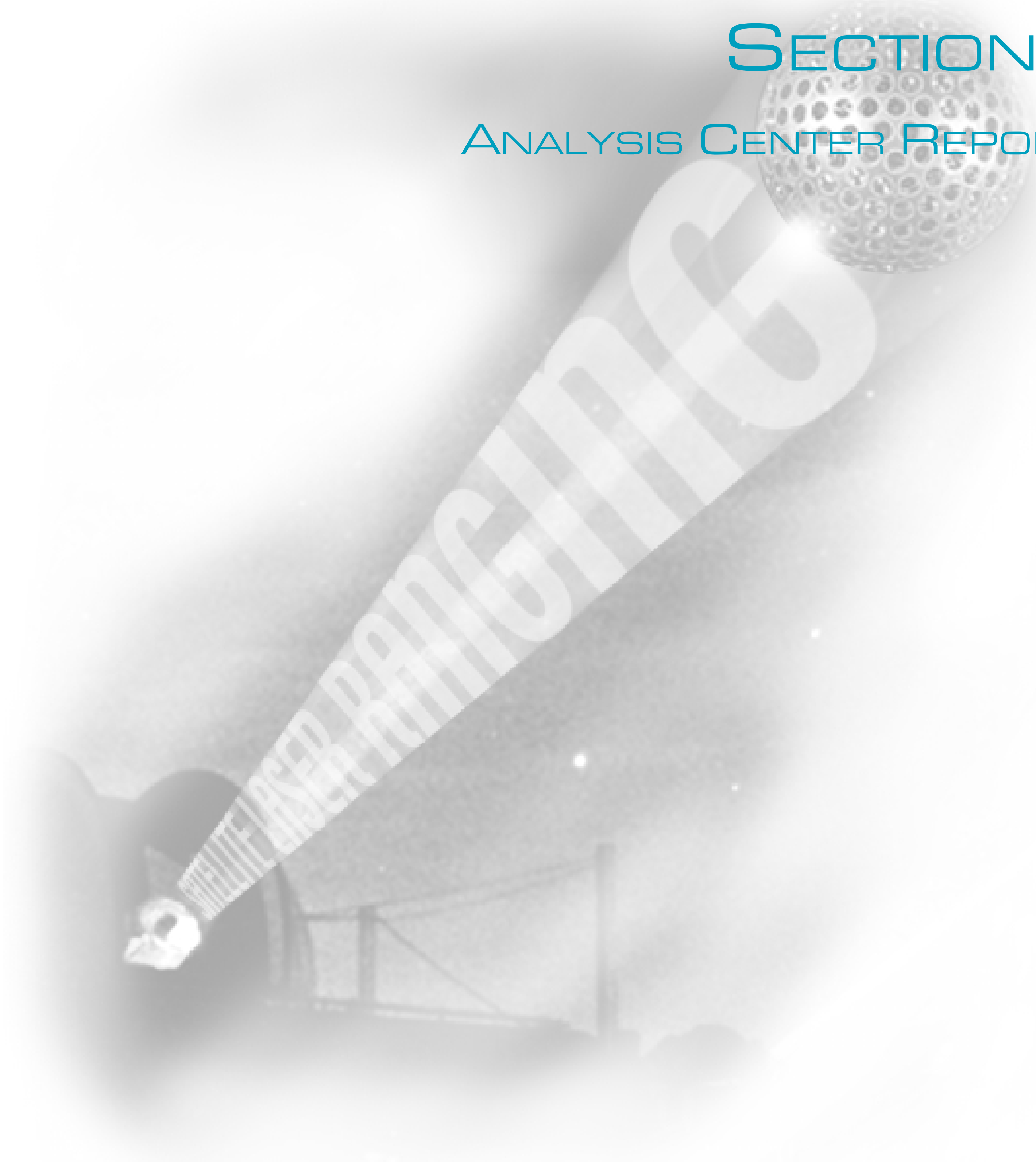
Section 7

Analysis Center Reports



SECTION 7 – ANALYSIS CENTER REPORTS

7.1 SATELLITE LASER RANGING

Peter Dunn, *Raytheon ITSS*

The Analysis Centers receive and process information from the Data Centers and regularly make the results of their analysis available to ILRS participants. Standard products are delivered to the Global Data Centers and to the IERS, among other recipients. The Analysis Centers also provide a level of quality assurance on the global data set by monitoring individual station performance via the fitted orbits used in generating the quick-look science results. The interval and time lag for product delivery specified by the Governing Board determines the credential as Analysis or Associate Analysis Center, and three institutions currently qualify as Analysis Centers.

CSR at the University of Texas monitors and disseminates results on LAGEOS-1 and LAGEOS-2 analysis on a weekly basis. The main element of their analysis is the fitting of 3-day continuous orbits through the last 12-18 days of observations, resulting in an average value for the weighted rms-of-fit of 15-20 mm. CSR also provides evaluation and technical support of new systems in engineering status and supports the determination of the ITRF through the submission of annual SLR tracking station position and velocity solutions.

Delft University of Technology's QLDAC also provides a semi real-time quality control of observations on LAGEOS-1 and LAGEOS-2, and reports to the stations on a regular basis to assist in monitoring the performance of operational systems, as well as for technical support of systems in engineering status. Each analysis basically covers the observations taken during the week prior to the date of the computations: the QC lags the actual data taking by between 3 and 10 days. QLDAC also produces accurate EOPs for inclusion in the USNO/IERS bulletins, and provides information for scientific interpretation and for the motivation of data analysis.

MCC in Moscow provides regular daily values of polar motion and length-of-day, and adds GLONASS analysis to its bulletins of LAGEOS-1 and LAGEOS-2 SLR station data performance, as well as producing precise orbits for GLONASS and Westpac orbits and other low satellites.

Associate Analysis Centers provide a variety of capabilities to complement the products of the main Analysis Centers. The DGFI Associate Analysis Center participates in the ILRS Analysis Working Group pilot projects by submitting station coordinates and EOP solutions, as well as by performing comparison/combination among solutions. DGFI also computes a global SLR solution to contribute to the International Terrestrial Reference Frame. The Russian Academy of Science's IAA Associate Analysis Center has been routinely processing LAGEOS and LAGEOS-2 observations mainly for use in the IAA EOP Service. Both operational (daily) and final (monthly and yearly) ERP solutions are available on a regular basis. IAA also regularly provides experimental solutions for the ILRS Pilot Project "positioning + earth orientation".

Italian Space Agency's CGS provides standard, special and multi-technique analysis products. The Center is mainly involved in the areas of tectonic plate motion, Earth rotation and polar motion, time variations of the Earth's gravitational field and satellite orbit determination. The Matera Laser Ranging Observatory (MLRO) has recently been installed at CGS; it is currently in the validation phase, and some analyses have already been made using its data. The GeoForschungsZentrum (GFZ) Potsdam continues its on-going ILRS activities with the main focus on the CHAMP satellite mission. A daily or usually twice-daily prediction generation has been established for the CHAMP mission, in order to optimally support the community with high quality orbit predictions, in contrast to the procedure adopted for the ERS satellites with a prediction interval of about 2 weeks and daily updates through time bias functions.

The group at the Astronomical Institute of the University of Berne has set up the SLR-GPS Quick-look Service to monitor the SLR observations using IGS rapid and final orbits. These are available only 12 hours after the end of the observation day and thus provide the possibility to give very rapid feedback on the quality of the SLR observations. The prediction and quality control work at the NERC SLR facility at Herstmonceux and Monks Wood, UK was developed to better equip the SLR system. Daily and medium-term predictions are automatically generated for most of the laser-tracked satellites using up-to-date SLR data. For the designated GLONASS satellites the NERC group computes daily predictions in collaboration with the AIUB. The Newcastle group concentrates on the current altimetric satellites, TOPEX/Poseidon, ERS-2 and GFO as well as the GEOSAT mission in the 1980's. Applications include the computation of enhanced orbital positioning and stability of the altimetric range measurements. The group is also active within the ILRS Analysis Group to produce a combination solution of ILRS station positioning.

Potsdam's BKG provides station coordinates, velocities and EOPs to the IERS on an annual basis, and joins the other Analysis Centers and Associate Analysis Centers in contributing to the ILRS Analysis Working Group pilot projects for improving station coordinates and EOPs. The Norwegian Defence Research Establishment's FFI, which is also an IVS Analysis Center, offers the capability to combine VLBI, GPS, and SLR data at the observation level. The AUSLIG Space Geodesy Analysis Center in Canberra is participating in the ILRS Analysis Working Group pilot projects for station coordinates and EOPs, orbit comparison and the software/standards comparison. AUSLIG also continues to submit results to the IERS Time Series Pilot Project, and concentrates on the co-location and combination of SLR with other space geodetic techniques.

7.1.1 ANALYSIS CENTERS

7.1.1.1 CENTER FOR SPACE RESEARCH (UT/CSR)

Richard Eanes and John Ries, *Center for Space Research*

CURRENT ACTIVITIES

Weekly EOP estimation and SLR Network Quality Control

The EOP estimation and SLR network quality analysis continues. The observations are taken from NASA's CDDIS, then merged, time-sorted and edited for double entries. The main element of the weekly analysis is the fitting of 3-day continuous orbits through the last 12-18 days of observations. The fitting results in an average value for the weighted rms-of-fit of 15-20 mm.

Seasonal Variations of the Earth's Gravity Field

The measurement of variations in the Earth's gravity field is important for a variety of studies attempting to understand the interrelations of the different components of the Earth system. We have used LAGEOS-1 and LAGEOS-2 laser ranging data to determine long wavelength seasonal variations of the Earth's gravity field from 1993 to the present. Due to the altitude of these satellites, and the non-continuous nature of the measurements, these data can detect seasonal gravitational variations only for wavelengths of roughly 10,000 km and longer (a degree 4 spherical harmonic expansion). A comparison of the observed annual variations to those predicted from a variety of atmospheric, oceanic, and hydrologic models. The correlation of the maps of the observed and modeled annual geoid variation is as high as 0.8, with an rms difference of close to 1 mm. To enhance the resolution of the time-variable gravity field (up to degree 6 or more), SLR from T/P, Ajisai and Stella are being analyzed, including the recent tracking campaign for the BEC satellite.

Precision Orbit Determination and Verification

SLR and DORIS tracking provide the principal means of precise orbit determination for the T/P altimeter spacecraft, supporting an orbit accuracy of 2 to 2.5 cm in the radial direction. Studies have demonstrated that the DORIS data provides the dominant contribution to the overall orbit accuracy, but variations in the centering of the orbit from cycle to cycle in the Z direction (along the Earth's spin axis) decreased significantly when the SLR data are included. This centering is crucial to avoid introducing hemispheric a symetry in the observed sea surface variations. The Absolute ranging SLR provides, help to center the orbit more precisely and consistently, as well as contribute to the overall orbit accuracy. They also provide an unambiguous determination of the height of the spacecraft above a tracking station, particularly for passes that cross at a high elevation angle. This capability is unique to SLR, and it is crucial for orbit accuracy assessment at the current levels.

It is clear that the SLR data are an important component of the tracking system. In a recent episode, when extreme geomagnetic activity increased the atmosphere drag to well above normal levels, the anomalously high drag that occurred over a short period of time probably would not have been noticed (it is undetectable in the DORIS residuals) was without SLR data.. However, the SLR data clearly indicated a problem that, after further analysis could be addressed, and an orbit of satisfactory accuracy be produced.

Terrestrial Reference Frame

Several terrestrial reference frame solutions were submitted for inclusion in the ITRF2000 reference frame solutions: two SLR-only solutions based on LAGEOS-1 and LAGEOS-2, and a combination solution based on SLR and DORIS tracking to T/P. The principle difference in the two LAGEOS solutions was the inclusion in one case of an adjustment of an atmospheric refraction correction common to all stations.. There are indications that the current model used for the troposphere refraction is biased, so one solution adjustment a bias to accommodate this. The adjustment had a significant effect on the scale of the solution, changing it by about 1.4 ppb. The current uncertainty scale is at the 1 ppb level or better, so this effect is significant and requires further analysis. Such a bias would also tend to bias the estimate of the Earth's gravitational coefficient GM by a small but not insignificant amount.

Outlook for the Future

We will continue to explore the application of multi-satellite analysis to the question of quality control for the SLR network. The question of sub-cm systematic errors in the Marini-Murray refraction model is currently being investigated. In addition, the analysis system needs to be more automated. UT/CSR will strive for a continuous improvement in order to serve the SLR community as well as possible.

Analysis Working Group Members

Richard Eanes, Minkang Cheng, Rick Pastor, John Ries, Bob Schutz

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7.1.1.2 Delft University

Ron Noomen, *Delft University of Technology*

Background

The Quick-Look Data Analysis Center (QLDAC) has been operational at Delft University of Technology since the beginning of 1986, supporting the observational campaigns of the WEGENER-MEDLAS project. QLDAC has evolved into a service for the global network of SLR stations.

The service performed by the current operational analysis system is of high value for the entire community. The QLDAC activities serve a number of goals:

(i) a semi real-time quality control of observations on LAGEOS-1 and LAGEOS-2, taken by the global network of SLR stations;

(ii) production of highly accurate Earth Orientation Parameters (EOPs), for inclusion in the USNO/IERS bulletins;

(iii) evaluation and technical support of (new) systems in engineering status;

(iv) provision of preliminary information for scientific data analyses (e.g. satellite orbits, station coordinates, *etc.*); and

(v) motivation of the data analysts. Many of the goals mentioned here are or will be worked on in coordination with the International Laser Ranging Service (ILRS).

Status

Currently, the computations are done on a weekly basis: every Tuesday, the analysis is performed and the results are disseminated to the SLR stations and other interested people. Each analysis covers the observations taken during the week prior to the date of the computations.

Developments in 2000

Through the aim of quality control best, QLDAC continuously strives for improvements in the procedures, strategies and models to better simulate the satellite orbit and the dynamics of the Earth. Practical and operational issues limit the amount of effort that operational be spent. Manpower is a very practical limit for such developments; on average, QLDAC spends about 2 hours on operational analysis and development work per week and changes in the analysis procedure or models may introduce sudden shifts in the analysis results; in post-fit residuals (measurement systematics), in EOP solutions, or in other adjusted parameters. Stability of the system will serve the community better than continuous modifications.

Therefore, significant changes are planned ahead and are introduced at one single epoch. In the year 2000, developments were mainly in the representation of the analysis results and in the automation of the analysis procedures. In particular, the weekly report was further fine-tuned, and prepatory work was performed to make the results available via the Internet. The latter activity is not yet finalized, but is expected to come on line in 2001. Although invisible for the users, a very important change was made in the internal organization of the analysis system. Until 2000, the system was menu-driven, i.e. semi-automatic with many options and capabilities. Because the available manpower was significantly reduced over the year 2000, the analysis configuration was changed into a fully automatic one, which can run for indefinite periods of time without human interference. Under normal circumstances, the analysis results are checked before the report is generated and disseminated. The new procedures will be effective as of the beginning of 2001.

OPERATIONS IN 2000

As can be expected from a service, QLDAC has been operational throughout 2000. The observations on LAGEOS-1 and LAGEOS-2 are taken from the data centers at NASA's CDDIS and the EDC. Next, they are merged, time-sorted and edited for double entries. On average, the global network weekly produced about 120 and 105 passes for LAGEOS-1 and LAGEOS-2, respectively.

The main element of the weekly analysis is the fitting of a 10-day continuous orbit through 10 days of global observations. Typically, such a data arc starts on Thursday, 00:00 hours, and ends on Saturday evening 24:00 hours. A summary of the computation model currently in use is given in Table 7.1.1.2-1.

The fitting results in an average weighted rms-of-fit of 0.96. An overview of the corresponding rms-of-fit values is given in Figure 7.1.1.2-1, which shows that QLDAC achieves a fit of 38 mm on average. It must be stressed here that this rms-of-fit is not the parameter that is minimized in the estimation process: differences in quality of observations will be compensated for by assigning different values for the weights of the observations in the analysis. Table 7.1.1.2-2 gives a impression of this, showing:results obtained for a 10-day data arc in the beginning of October 2000. The variety in post-fit residuals (rms values range between 13 and 124 mm) generally follow the corresponding measurement weights which are given in the final column. The overall rms-of-fit (again, not the parameter which is minimized) is 31 mm for this arc.

OUTLOOK FOR 2001 AND BEYOND

In order to improve the quality of the QC analysis and the results, QLDAC intends to introduce several new elements in the operational analysis. First, the results will also be made available through the Internet. Users will have the opportunity to look not only at the latest analysis results, but also at time-series of certain performance parameters, both general and station-specific. Second, QLDAC intends to introduce a new model for station coordinates. The model that is currently in use was computed in 1993. In order to achieve mm-level quality assessments, uncertainties in station coordinates of 1 cm or more are not unacceptable. Directly related to this is the inclusion of models for ocean loading and atmopsheric pressure loading deformation, and the modeling of station biases when necessary. QLDAC has gained experience with these issues, doing research on several geodetic satellites.

A long-standing wish is the inclusion of other satellites in the operational analysis. The GPS satellites are likely candidates for this, but considering the developments within ILRS the Etalon satellites have a higher priority. Finally, QLDAC has the intention to increase the frequency of the analysis to 2 or 3 times per week, so that stations will receive a more actual report on their performance. With the 2000 or 2001 implemented full automation of the analysis procedures, this change comes within reach.

The implementation of the issues mentioned here is dependent on the capabilities of QLDAC, particularly in terms of manpower. Irrespective of the actual progress, QLDAC will strive for continuous improvement to serve the SLR community as well as possible.

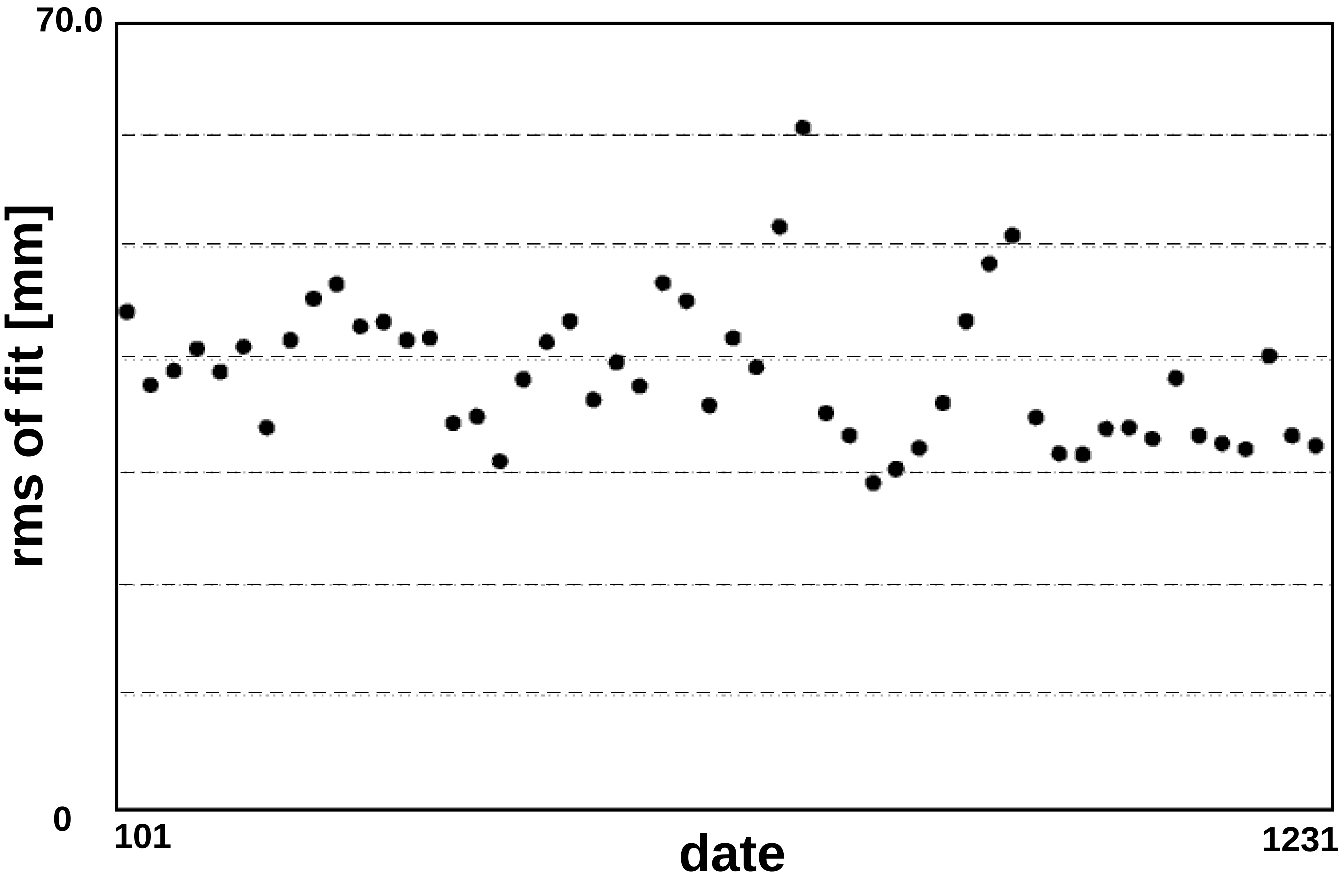

Figure 7.1.1.2-1: The weekly rms-of-fit obtained in the weekly quick-look analysis; note that this value is not minimized.

Observations	Collected from CDDIS and EDC; center-of-mass 251 mm; Marini-Murray model for troposphere; elevation cutoff 20 degrees; data weighting root-summed-square of single-shot precision and overall model uncertainty; relativistic effects not modeled; 3.5-sigma data editing.
Dynamics	NASA/CSR JGM-2 gravity field and tides model; 3rd body attraction of Sun, Venus, Moon, Mars, Jupiter, Saturn; dynamic polar motion; direct solar radiation pressure (scaling coefficient kept fixed at 1.13); albedo and thermal radiation of Earth not modeled; 1 constant and 2 1-cpr along-track acceleration parameters solved for per satellite and per arc; relativistic effects not modeled.
Geometric model	SSC(DUT) 93L05 model for station coordinates (stations of choice solved for); IERS Bulletin A a priori EOPs (EOPs solved for at 3-day intervals); JPL DE200/LE200 ephemerides; Love model for solid Earth deformation; dynamic polar motion; ocean loading and atmospheric pressure loading deformation not modeled.
Integration	Cowell 11th order; step-size 100 sec.

Table 7.1.1.2-1. QLDAC computation model summary.

Station	weight	LAGEOS-1			LAGEOS-2		
		#obs	mean	rms	#obs	mean	rms
Maidanak, Uzbekistan	202	6	-3	19	-	-	-
Simeiz, Crimea	202	23	-3	62	-	-	-
Riga, Latvia	104	17	-33	38	-	-	-
McDonald Observatory, Texas	36	40	1	31	72	-5	21
Yarragadee, Australia	32	143	-23	31	148	-11	27
Greenbelt, USA	32	247	-2	23	132	2	35
Monument Peak, California	32	212	-20	35	138	-20	30
Papeete, Tahiti	32	24	-28	33	70	2	14
Haleakala Observatory, Hawaii	36	12	-22	28	4	53	53
Wuhan, China	58	28	5	52	17	-8	19
Changchun, China	58	36	-3	32	2	22	23
Beijing, China	58	40	9	56	33	-2	69
Kashima, Japan	36	3	-61	62	6	16	20
Tateyama, Japan	36	19	-47	56	44	0	47
Beijing, China	32	179	-8	59	67	-54	65
Arequipa, Peru	32	33	23	34	21	16	20
Hartebeesthoek, South Africa	32	23	-5	21	49	2	13
Metsahovi, Finland	42	32	-8	16	-	-	-
Zimmerwald, Switzerland	67	20	-35	39	8	-8	25
Borowiec, Poland	67	17	-10	19	7	-20	29
Kunming, China	85	36	-24	124	4	0	0
San Fernando, Portugal	50	28	34	43	14	8	21
Grasse, France	42	80	-9	22	17	-4	19
Potsdam, Germany	42	16	-17	26	9	-16	17
Shanghai Observatory, China	58	43	-3	26	12	-33	34
Simosato Observatory, Japan	42	93	1	32	16	49	54
Graz, Austria	32	49	9	32	21	25	32
Herstmonceux, United Kingdom	36	174	-1	19	160	-11	28
Grasse, France (LRR)	36	-	-	-	22	-35	39
Mount Stromlo, Australia	32	245	-8	21	185	6	23
Matera, Italy	124	10	49	74	-	-	-
Wettzell, Germany	32	16	-42	45	-	-	-

Table 7.1.1.2-2. Example of analysis results: the number of observations, mean and rms of the post-fit residuals and the individual data weights [mm], for the period October 5-14, 2000.

7.1.2 ASSOCIATE ANALYSIS CENTERS

7.1.2.1 DEUTSCHES GEODÄTISCHES FORSCHUNGS INSTITUT (DGFI)

Detlef Angermann and Horst Mueller, *Deutsches Geodätisches Forschungs Institut*

INTRODUCTION / DATA PRODUCTS PROVIDED

Deutsches Geodätisches Forschungs Institut (DGFI) has been strongly involved in space-geodetic research for more than 20 years. For that purpose the institute developed the software package DOGS (DGFI Orbit and Geodetic Parameter Estimation Software), and uses it routinely for high precision processing of satellite tracking data. Other information about DGFI, about activities within ILRS and SLR analysis results are available at the DGFI Web-server at: http://www.dgfi.badw.de.

DGFI Associate Analysis Center provided following data products:

(1) Participating in the ILRS Analysis Working Group pilot projects: Submission of solutions (station coordinates and EOP´s) and performing comparison/combination among solutions.

(2) Submission of a global SLR solution (station coordinates and velocities) for ITRF2000.

CURRENT ACTIVITIES

(1) Reprocessing of all available SLR tracking data on LAGEOS-1 and LAGEOS-2 with the newly updated and modified software version DOGS_V4.05.

(2) Research activities related to the accuracy and long-term stability of station coordinates and velocities, SLR reference frame (origin, scale), GM, geocenter variations and EOP´s.

(3) Implementation of an operational Analysis Center to routinely compute SLR products.

FUTURE PLANS

- Continue submitting solutions within future ILRS pilot projects and for ITRS realizations.
- Extend routine processing and analyses to other satellites (e.g. Etalon, Starlette, Ajisai).
- Routinely submitting SLR products to the ILRS (e.g. station coordinates and EOP´s on a monthly basis, multi-years solutions for station coordinates and velocities, range - and time-biases for SLR tracking stations) to become an operational ILRS Analysis Center.

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7.1.2.2 INSTITUTE OF APPLIED ASTRONOMY (IAA)

Nadia Shuygina, and Zinovy Malkin, *Institute of Applied Astronomy*

The IAA AAC began its activity in 1994, and has been routinely processing LAGEOS- and LAGEOS-2 observations mainly for use in the IAA EOP Service. Both operational (daily) and final (monthly and yearly) ERP solutions are available on regular basis. Solutions for the ILRS Pilot Project "positioning + Earth orientation" are also done. In 2000, two groups in IAA were involved in the ILRS related activity.

The Laboratory of Space Geodesy and Earth Rotation group continued daily processing of LAGEOS and LAGEOS-2 observations with the GROSS software package. Advances in the computational strategy for EOP in 2000 allowed a 2-day delay in delivery of X_p, Y_p, OD and OT for 97% of the epochs compared with 87% in 1999. Two SLR EOP series were computed and submitted to the IERS 2000 Annual Report: EOP(IAA)01L01 computed using LAGEOS-1 observations only from January 1983, and the EOP(IAA)01 L02 computed using LAGEOS-1 and LAGEOS-2 observations from October 1992.

During last two years in parallel with "standard" operational solution, we also computed a daily every day experimental series investigate the influence of a priori EOP series upon the final result. This experimental times series uses no polar motion as apriori only UT variation with periods greater than about half a year, and nutation from IERS/C04. The nutation series can be replaced with the IERS conventions without loss of EOP accuracy. The "weakly constrained experimental series is much more independent of IERS/C04. The experimental time series is about 1.5 times more noisy than the operational series. We will do two additional experimental EOP time series in 2001 including an estimation of PM rates.

The Laboratory of Ephemeris Astronomy Group continued development of analysis strategies and software for combined processing of SLR and VLBI observations with the ERA package. This group took part in the four ILRS AWG Pilot Projects named "positioning + Earth orientation". These projects were devoted to the computation and comparison/combination of station positions and Earth orientation parameters (EOP) using LAGEOS-1 and LAGEOS-2 SLR observations. Station positions, daily EOP, state vectors for both satellites, one solar radiation pressure scale factor, and along track acceleration once per seven days period were adjusted in the analysis. The weighted rms range residual is about 1.6 cm for the combination solution. The complete solutions "iaak" presented in SINEX format have been submitted to the data center CDDIS. The results of comparison of the "iaak" station coordinates solutions with the other ones participating in the Pilot Project were fulfilled and presented for discussion along with results obtained by other groups of analysts during AWG workshops. Etalon-1 and Etalon-2 SLR data will be added to LAGEOS 1 and 2 to produce combination solution in the next ILRS Pilot Project.

7.1.2.3 AGENZIA SPAZIALE ITALIANA ***(ASI/CGS)***

Giuseppe Bianco, *Agenzia Spaziale Italiana*
Vincenza Luceri, *Telespazio SpA*

INTRODUCTION

As an ILRS Associate Analysis Center, the Space Geodesy Center "G. Colombo" (CGS), of the Italian Space Agency (ASI), is mainly involved in the areas of tectonic plate motion, Earth rotation and polar motion, time variations of the Earth's gravitational field, and satellite orbit determination.

The CGS is also strengthening its geodetic capabilities with the acquisition of a new powerful SLR system: the Matera Laser Ranging Observatory (MLRO). It has been installed and is currently under the validation phase, but some analyses have already been made using its data.

Other information on the CGS and some of the analysis results are available at the CGS WWW server GeoDAF (Geodetical Data Archive Facility, http://geodaf.mt.asi.it).

DATA PRODUCTS PROVIDED

- Estimated coordinates (SSC) of the global SLR tracking network and the Earth Orientation Parameters (EOP) submitted for the AWG pilot project;
- Estimated coordinates and velocity field (SSC/SSV) of the global SLR tracking network and the Earth Orientation Parameters (EOP) submitted to the ITRF-2000 frame realization;
- The monthly estimated EOP provided to the IERS for the Bulletin B;
- Low degree geopotential zonal rates from the analysis of different geodetic satellites as a contribution to the definition of the Earth mantle viscosity profile;
- Estimation of tectonic movements and strain-rates in the Mediterranean area combining SLR, GPS and VLBI results obtained at CGS;
- Test solution of SSC and EOP time series for the IERS pilot project on coordinate and EOP combination;

CURRENT ACTIVITIES

- **AWG Pilot project**: the CGS is currently involved in the activities of the AWG pilot projects with the submission of coordinate/EOP test solutions and great effort is being applied to the comparison/combination of the submitted solutions.
- **International Terrestrial Reference System (ITRS) maintenance**: the production of IERS oriented products (global SSC/SSV and EOP time series) is regularly performed to assure the CGS contribution to the reference frames establishment.
- **Earth's gravitational field**: in cooperation with other universities, the CGS is providing zonal drifts of the gravity field based on a long lasting data set of geodetic satellites. This solution is providing boundary values for the study of the rheology of the Earth.
- **Satellite rotation**: the validation of the MLRO data has been undertaken and the acquired data will be soon available to the scientific community. The high single shot precision of the system gave the opportunity to study satellite rotation: the first LAGEOS observations revealed a strong rotational signal with an accuracy on the order of a few mm RMS.

- **Geodetic solution combination**: the combination algorithms are being tuned with the aim to build a unique SSC/SSV solution for the Mediterranean area, taking into account all the available solutions from different analysis groups.

FUTURE PLANS

- A new solution for geopotential zonal drifts is planned with an updated data set and a new analysis strategy.
- The capability of measuring the rotation of the LAGEOS has been demonstrated and further capabilities of MLRO data have yet to be exploited. The interpretation of streak camera observations could help in estimating the attitude of the tracked satellite.
- The LLR data analysis activities will soon start together with the MLRO lunar tracking.
- Two color SLR observations for tropospheric studies has also been planned for the near future.

MOST RECENT PUBLICATIONS

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7.1.2.4 GeoForschungsZentrum (GFZ) Potsdam

Franz-Heinrich Massman, *GeoForschungsZentrum, Postdam*

Data Products Provided

In 2000 the GeoForschungsZentrum (GFZ) Potsdam has continued its ILRS activities of the previous years, with the main focus on the CHAMP satellite mission, which successfully began on July 15, 2000. Right from the beginning, good quality IRVs have been generated based on all accessible tracking data information (angle tracking, radar tracking from FGAN, SLR and later GPS Nav data). While the prediction interval for the ERS satellites about 2 weeks has been used with daily updates through time bias functions, for the LEO satellite CHAMP, a daily or usually twice-daily prediction generation has been established in order to optimally support the community with high quality orbit predictions.

In March 2000 the product generation for the ERS-1 satellite mission was stopped after almost 9 years (with a 2 year interruption) due to the end of the mission caused by a hardware failure. The ERS-2 product generation has been continued a usual. The following table summarizes the delivered products.

	ERS-1	ERS-2	CHAMP
Orbit Predictions	17	71	314
Time Bias Functions	57	313	-
Drag Functions	57	313	-
Two-Line Elements	17	71	314
SAO Elements	17	71	314

Table 7.1.2.4-1. ERS-2 derived products.

The orbit prediction products enabled the ILRS stations to track all three satellites with excellent success. In total about 28-40 stations tracked 568 passes of ERS-1 (Jan. to Mar.), 4307 passes of ERS-2 and 854 passes for CHAMP (Jul. to Dec.).

Current Activities

In addition to the above mentioned operational products, the systematic generation of ERS preliminary and precise orbits based on SLR and PRARE data under an ESA contract continued. Additional activities in the second half of 2000 concentrated on the commissioning of the CHAMP instruments and the data processing chains. The new accellerometer observations had to be calibrated and tested within the precision orbit determination (POD) process, and. the procedures and algorithms used for CHAMP POD had to be implemented, tested and optimized.

As the Earth gravity field has the largest impact on the POD first gravity field, normals have been computed in order to derive a gravity solution based on the GRIM5-S1/C1 normal equations plus some CHAMP data.

Future Plans

After the end of the CHAMP Commissioning Phase the data and POD products will be available continuously to interested users for their investigations. With the latest available calibration parameters and models updated Earth gravity partials will be computed and an improved CHAMP Earth gravity model will be generated and continuously updated.

7.1.2.5 ASTRONOMICAL INSTITUTE OF THE UNIVERSITY OF BERN (AIUB)

U. Hugentobler, H. Bock, D. Ineichen, *Astronomical Institute of the University of Bern*

CURRENT ACTIVITIES

The Center for Orbit Determination in Europe (CODE) is located at the Astronomical Institute of the University of Berne and is a joint venture of the following four institutes:

- The Swiss Federal Office of Topography (L+T), Wabern,
- The "Bundesamt für Kartographie und Geodäsie" (BKG) in Frankfurt, Germany,
- The "Institut Géographique National" (IGN) in Paris, France, and
- The Astronomical Institute of the University of Berne (AIUB).

CODE is one of the seven Analysis Centers of the International GPS Service (IGS) participating since start of the IGS in June 1992. Precise orbits for the GPS satellites, orbit predictions, Earth orientation parameters, station coordinates and velocities, satellite and station clock corrections, troposphere parameters, and ionosphere models are computed and delivered every day based on the observations of the IGS network of GPS stations. Currently this tracking network includes more than 260 sites. In the framework of the International GLONASS Experiment (IGEX) CODE delivered precise orbits for the GLONASS satellites from January 1999 to June 2000.

As an Associate Analysis Center (AAC) of the International Laser Ranging Service, CODE provides a SLR-GPS quick-look service since December 1996. It is based on the residuals of the SLR observations taken from the two GPS satellites PRN 5 and PRN 6 with respect to the CODE IGS final and rapid orbits as computed from microwave observations. Each day the SLR observations gathered over the last six days and downloaded from CDDIS are evaluated. The last four days are analyzed using the rapid orbits and the two older days using the final orbits. The final orbits have an estimated precision of about 5 cm whereas the rapid orbit precision varies between 5 and 15 cm. The SLR-GPS quick-look results, covering six days, are distributed by e-mail to the SLR-Report mail exploder every day – provided that new data was available – giving rapid feedback on the quality of the SLR observations.

CODE also provides daily orbit predictions for all GPS and GLONASS satellites spanning a time interval of five days. For the GPS satellites, the predictions consist of an extrapolation of the CODE rapid orbits which are based on microwave observations spanning three days. The GLONASS predictions are based on the broadcast messages collected over four days. The predictions are usually available at noon of the day after the last observations used. They are converted from the standard IGS orbit format (SP3) to IRVs by the National Environment Research Council (NERC) and used by several of the (European) SLR tracking stations.

FUTURE PLANS

Following the departure of Tim Springer from the AIUB, the planned combination of SLR and microwave measurements of GPS and GLONASS satellites at our Analysis Center has been deferred. Nevertheless, the main interest of CODE on SLR data – the validation of orbits based on microwave observations – is unchanged although no systematic validation studies are carried out at present. In the future, we plan to use SLR observations not only to GPS and GLONASS but also to low Earth orbiters carrying GPS receiver and SLR retroreflectors – such as CHAMP, GRACE, JASON, GOCE – for an independent verification of GPS based precise orbit determination techniques.

Currently we are not computing GLONASS orbits based on microwave observations. We plan to resume a combined processing of GLONASS and GPS orbits in the framework of the IGS GLONASS Pilot Project (IGLOS-PP). This would allow us to extend the quick-look service for the ILRS stations to GLONASS satellites.

7.1.2.6 THE NATURAL ENVIRONMENT RESEARCH COUNCIL: NERC

G. Appleby, T. Otsubo, P. Gibbs, R. Wood, *National Environment Research Council*

INTRODUCTION

In this short report we outline some of the ongoing analysis and operational activities of the NERC Space Geodesy Facility at Herstmonceux and Monks Wood, UK, in the Facility's capacity as an ILRS Associate Analysis Centre. Work carried out by T. Otsubo during his two-year visit to the UK is also reported here, pending CRL's application to ILRS for AAC status.

SATELLITE PREDICTIONS

Daily and medium-term IRVs along with hourly time bias functions for the latter are automatically generated for most of the laser-tracked satellites using up-to-date SLR data. The quality of these predictions has greatly benefited from the rapid availability of data from the Network that followed ILRS efforts to reduce latency. For the designated GLONASS satellites we compute daily IRVS in collaboration with the CODE, Berne, group. All the predictions are available through EDC and on our own anonymous ftp site (mtuftp.nmt.ac.uk ; directory nercslr/current), acting as a backup for the official HTSI IRVs

DAILY QUALITY MONITOR

Our automatic LAGEOS and LAGEOS-II service continued during the year, with plans in place to include more satellites and short-arc analyses for the whole Network. The results are presented daily at:

http://nercslr.nmt.ac.uk/

A weekly multi-satellite QC service was developed on behalf of CRL, the results being sent to users via SLR Report email.

GLONASS/GPS ORBITAL DETERMINATION

We have continued and extended our study to use SLR observations of the GLONASS and GPS satellites to check the quality of the available microwave-based orbital solutions. The SLR observations are used both to generate independent orbits and compare them to the microwave orbits, and to compare directly to the positions of the satellites given by the microwave orbits. For the GPS satellites the results imply that on average the satellites are some 40mm closer to the Earth than is implied by the microwave-based orbits. For the GLONASS satellites, the offset is close to zero, after taking into account SLR-system-dependent effects due to the large reflector arrays and using a new determination by the satellite owners of the distance between the reflector array phase centre and the satellites' centre of mass.. Unfortunately this work does not impact the question of the location of the phase centres of the satellites' microwave transmitters since the microwave-based orbits are very insensitive to this parameter. The work is, however, a useful independent check on the quality of and presence of systematic bias in those orbits. Results were presented at the EGS (two papers) in Nice, France in April 2000 and at the 12th International workshop on Laser Ranging in Matera, Italy, in November 2000 (two papers).

ILRS ANALYSIS WORKING GROUP PILOT STUDY (POS+EOP)

A good deal of effort has been put into improving and automating much of the SATAN SLR processing software in order to take part in this pilot project. Station coordinates and Earth orientation parameters have been determined for each stage of the ongoing Pilot Study, and the subsequent comparisons of results from the various analysis groups has greatly aided the development process. Independently the

CRL analysis package, Concerto, has been further developed, and a multi-year solution for coordinates and velocities submitted for inclusion in ITRF2000 on behalf of CRL, Tokyo.

SATELLITE PHOTOMETRY FOR SPIN VECTOR DETERMINATION.

The system that allows simultaneous ranging and photometry (of the sunlit image of the satellite) has been further upgraded at Herstmonceux such that a timing resolution of 1msec can now be achieved. The principal results from the photometer have been accurate determinations of the slow-down in rotation rate of the LAGEOS 2 satellite (Figure 7.1.2.6-1) and of the evolution of the direction of the satellite's spin axis. A paper on this work was presented by Otsubo at the Matera Workshop.

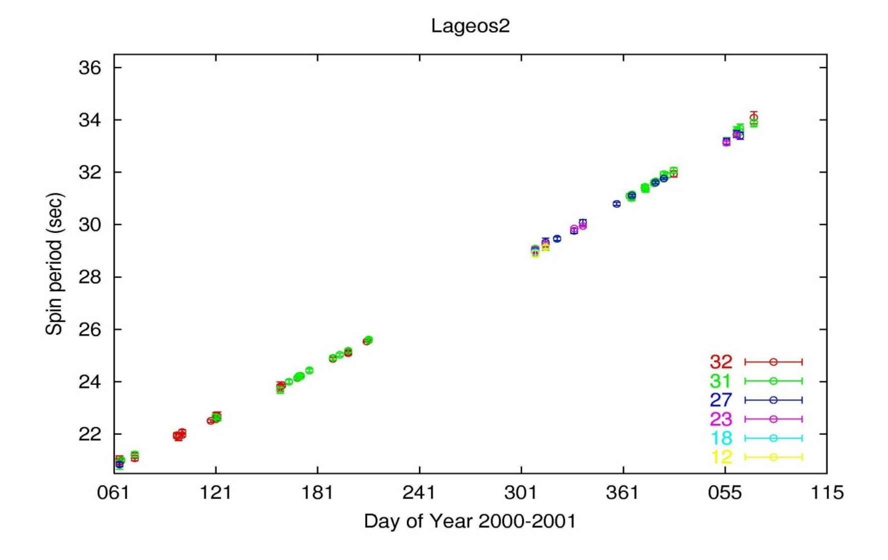

Figure 7.1.2.6-1: Satellite spin period versus time.

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Appleby, G. M., Sherwood, R. and Rooney, E., 2000. The accuracy of GLONASS Broadcast Orbits, MIT Conference Proceedings, 2000.

The NERC Space Geodesy Facility at Herstmonceux and at Monks Wood, UK, is funded by the Natural Environment Research Council in collaboration with the British National Space Centre and the Ministry of Defence. We thank the Communications Research Laboratory, Toyko, Japan, for continuing support.

7.1.2.7 DEPARTMENT OF GEOMATICS, NEWCASTLE UNIVERSITY

Philip Moore, *Newcastle University*

Activities at Newcastle have continued to concentrate on the current altimetric satellites, TOPEX/Poseidon, ERS-2 and GFO as well as the GEOSAT mission in the 1980's. Applications include the computation of enhanced orbital positioning and stability of the altimetric range measurements. The group is also active within the ILRS AWG to produce a combination solution of ILRS station.

Precise orbit determination of altimetric satellites are undertaken using Newcastle's *FAUST* software and all available tracking data. The latter includes Satellite Laser Ranging, DORIS (TOPEX/Poseidon), PRARE (ERS-2) and TRANET (GEOSAT). In addition the altimetry in the form of single (SXO) and dual (DXO) satellite crossovers is used as complementary tracking data. The use of DXO between the relatively high orbit of TOPEX/Poseidon and the other lower altitude satellites allows the precision of TOPEX/Poseidon to be transferred to the other missions. Studies include gravity field tuning for ERS, TOPEX/Poseidon and GEOSAT/GFO using SLR, DORIS, and SXO data with the orbits connected through DXO data. Validation of the orbits is through the tracking residuals; analysis of correlated and anti-correlated orbit errors; and spectral analysis of DXO residuals in the Southern Ocean. Precise ERS-1 and ERS-2 orbits relative to the enhanced gravity field, AGM-98, are available for download. Further information, including the AGM-98 field and ERS orbits are available at:

http://geomatics.ncl.ac.uk/research/sg.htm.

Orbits for the altimetric satellites provide the independent measure required to convert the altimetric range to some reference ellipsoid as required for studies of sea level change. For such studies it is crucial that the altimetric measurements are free from spurious effects that otherwise will be aliased into the sea level change. Calibration of altimetry has been undertaken by comparison against *in situ* tide gauge data from the global network of tide gauges and/or by intercomparison between two altimetric data sets from concurrent or near concurrent missions. In particular, stability analysis of the NASA TOPEX altimeter and of ERS-1 have been undertaken by direct comparison against the tide gauge time series whilst ERS-2 has been inter-calibrated against TOPEX with the resultant signature corrected for the observed TOPEX drift. ERS, and TOPEX/Poseidon altimetry from the 1990's has also been connected with the earlier GEOSAT mission from 1985-89. Further details can be found at:

http://geomatics.ncl.ac.uk/research/projects/stab/stab.htm.

The last year saw the release of GFO altimetry to the wider scientific community. Prior to that, GFO SLR data was utilised to tune a macro-surface model for air-drag and solar-radiation pressure and to improve on the SLR retroreflector array to centre of mass offset. On incorporating SXO and DXO tracking into the GFO orbit determination it has been possible to analyse the altimetric sea-state bias, time-tag bias and relative range bias. GFO is providing precise tracking data which will enable further tuning of the Earth's gravity field at the GEOSAT/GFO inclination and altitude.

As a Global Network Associate Analysis Centre for the International GPS network we continue to produce very precise coordinate solutions for the global IGS network:

http://geomatics.ncl.ac.uk/research/global_geodesy.htm.)

This rigorous approach is also being applied to combination of global SLR data to produce monthly station coordinates that are superior to the individual submissions from the ILRS Analysis and Associate Analysis Centres.

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7.1.2.8 BUNDESAMT FÜR KARTOGRAPHIE UND GEODÄSIE (BKG)

B. Richter, M. Mareyen, *Bundesamt für Kartographie und Geodäsie*

INTRODUCTION

The central task of the BKG geodetic division is to provide and update the Geodetic Reference Networks of the Federal Republic of Germany including: Survey work (Station Wettzell - SLR, VLBI, GPS, GLONASS observations, survey campaigns, and other activities), and theoretical work for collection and preparation of survey data, Cooperation in bilateral and multilateral activities for definition and updating of global reference systems in the framework of ILRS , IVS , IGS, IERS.

Further development of the surveying, observation and analysis technology used as well as representation of the relevant interests of the Federal Republic of Germany on an international level. The BKG Associate Analysis Centre processes routinely LAGEOS-1 and LAGEOS-2 data for satellite orbit determination, station coordinates, Earth Orientation Parameters and SLR station performance monitoring. In addition, special investigation have been made to support the ILRS WG pilot studies.

FACILITIES / SYSTEM

During 2000 the BKG ILRS group moved from Potsdam to Frankfurt am Main. Hardware and software had to be integrated into the Frankfurt BKG computing environment. This period was used to update the program packages too. Orbit, station coordinates, and EOP estimations are performed with UTOPIA (CSR, University of Texas). Moreover the BERNESE Software Engine is used for the network combination of various space techniques. In-house programs have been developed for station coordinate transformations, EOP series generations, and to create updated SINEX files.

CURRENT ACTIVITIES

The BKG contributes to the ILRS AWG station coordinate and EOP pilot projects.. A program for the combination of individual SINEX files with respect to a combined EOP and station coordinate solution was developed and used for the fourth pilot. project. Regarding the analysis of 13 monthly solutions, the investigations were deepened with respect to the time behaviour of the geometrical and numerical quality of the networks. Measures that can be used to quantify the errors and the ability to remove the a priori information from the station network were developed. The measure also provides information on the stability and behaviour of the network. These tools are in particularly useful to check the individual solutions before they are combined.

FUTURE ACTIVITIES

The BKG will continue to participation in the ILRS AWG pilot projects. Orbit regularly determinations, positions, velocities, EOP solutions, geo-centre and GM variations will be provided to the IERS and other services.

PUBLICATIONS

M. Mareyen, Hauck, H.: BKG Contribution to AWG-ILRS: Pilot – 4. Minutes of ILRS Analysis Working Group workshop # 4, Nice, France, March 22-23, 2001;

http://ilrs.gsfc.nasa.gov/awg_pilot_projects.html

M. Mareyen, Becker, M,: On the removal of a priori restrictions from GPS network solutions in a SINEX format. Allgemeine Vermessungs-Nachrichten (AVN), Wichmann, Heidelberg, 11-12/2000, p 405 - 411. (English publication)

7.1.2.9 Forsvarets Forsknings Institutt (FFI)

Per Helga Anderson, *Bundesamt für Kartographie und Geodäsie*

Introduction

During the last 18 years, FFI has developed a software package called GEOSAT (Andersen, 1995) for the combined analysis of VLBI, GPS, SLR and other types of satellite tracking data (DORIS, PRARE and altimetry). The observations are combined at the observation level with a consistent model and consistent analysis strategies. The data processing is automized except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GPS and SLR observations, the data are processed in 24 hour arcs defined by the duration of the VLBI session. The result of each analyzed arc is a state vector of estimated parameter corrections and a Square Root Information Array (SRIF) containing parameter variances and correlations. The individual arc results are combined into a multi-year global solution using a Combined Square Root Information Filter and Smoother program called CSRIFS (Andersen, 2000). With the CSRIFS program any parameter can either be treated as a constant or stochastic parameter between the arcs. The estimation of multi-day stochastic parameters is possible and extensively used in the analyses.

Analysis Strategy

Presently, the most important stochastic parameters of the global level state vector are the following: Geocenter coordinates (3d resolution), Earth orientation parameters (1d), the C_{21} and S_{21}gravity coefficients (6d), satellite independent SLR ranging biases (15d), Solar radiation pressure scaling and empirical drag of the LAGEOS satellites (3d), and GPS receiver antenna eccentricity vectors (station dependent time resolution to account for instrumental changes). The reason for including the two gravity coefficients is to account for the mapping of errors in the gravity field map into the estimates of polar motion derived from satellite tracking data. In order to be consistent with VLBI, which is almost independent of gravity, these parameters must be estimated. The arc length of the GPS and LAGEOS satellites is one day.

The main constant parameters of the global state vector are monument coordinates and velocities, GPS and/or SLR eccentricity vectors relative to the station monument if it's a colocated station, radio source coordinates, relative zenith delay between VLBI and GPS at colocated stations (to account for differences in antenna heights), VLBI antenna axis offsets, and GPS satellite transmitter phase center z-coordinates (relative to the satellite body-fixed reference frame). The latter is important since the commonly adopted z-coordinates for the effective phase center of the GPS transmitter antennas probably are wrong by 1-2 meters. Initial analyses indicate that the z-coordinate can be determined to a formal precision of some centimeters (1 sigma). Using the IGS z-coordinate values will result in a scale inconsistent with SLR and VLBI by approximately 2 ppb.

The status of the analyses is that approximately 2300 daily SLR arcs (with LAGEOS I & LAGEOS II data from 1993 to 1999) have been processed where approximately 550 arcs are combinations with VLBI and approximately 150 arcs are combinations with VLBI and GPS. Typically, 60 GPS stations are included in each arc. These 2300 arcs are currently being combined into a global solution using the CSRIFS program. A new program called CSRIFS-IERS reads the output of CSRIFS and estimates a time dependent transformation from the internal terrestrial and celestial reference frames to an ITRF reference frame (presently ITRF-2000) and an IERS Celestial reference frame. Since the estimated EOP in principle are 100 % consistent with the internal reference frames the time dependent transformation parameters can be applied to transform the EOP estimates to IERS for comparison with the IERS EOP products. A possible inconsistency between the IERS reference frames and the IERS EOP estimates should in principle be detectable. The CSRIFS-IERS automatically generates SINEX files for the terrestrial and celestial reference frames and the EOP's. These files can be directly submitted to the IERS Product Centers.

During the last year a number of improvements have been made in the GEOSAT software. The most important are the following:

- In many cases VLBI observation time tags are not properly synchronized to UTC leading to errors in the UT1 estimates. A procedure to reduce this problem to a minimum has been implemented.
- Estimation of multi-day stochastic parameters.
- A new nutation model has been included.
- The strategy for atmospheric gradient estimation for VLBI and GPS has been improved.
- The NMF mapping function is used for SLR instead of the Marini-Murray tropospheric model.
- A tidal geocenter motion model has been implemented.
- The number of GPS stations used in a combined VLBI, GPS and SLR arcs has been increased from 30 to 60 stations.

The combined global analyses are not completed yet and the plan is to present results at the IAG-2001 meeting in Budapest and at the AGU-2001 fall meeting in San Francisco.

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Andersen, P. H. Multi-level arc combination with stochastic parameters. Journ. of Geod., 2000, Vol. 74, No. 7-8, pp. 531-551.

7.1.2.10 *AUSTRALIAN LAND SURVEY AND INFORMATION GROUP (AUSLIG)*

Romesh Govind, *Australian Land Survey and Information Group*

BACKGROUND/INTRODUCTION

The AUSLIG Associate Analysis Centre has been routinely processing LAGEOS-1 and LAGEOS-2 data for satellite for orbit determination, station coordinates, EOP and SLR station performance monitoring In addition, on an opportunity or project basis, Stella, Starlette, Etalon and GLONASS data is also processed. This work to-date has been reported in the publication list available on:

http://www.auslig.gov.au/geodesy/techrpts/techrpts.htm.

There is an ongoing emphasis on the co-location and combination of SLR with other space geodetic techniques. The annual activities of observations and processing (since 1997), for the Asia – Pacific Regional Geodetic Project (APRGP) of the Permanent Committee for GIS Infrastructure for Asia and the Pacific (PCGIAP) continues. The SLR observation campaign is coordinated through the WPLTN. Nine years of LAGEOS-1 and LAGEOS-2 results were submitted to the IERS as a contribution for the definition and densification of the ITRF2000.

FACILITIES/SYSTEMS

The current computation facilities in the AUSLIG Space Geodesy Analysis Centre comprises of four HP workstations [C160, C180, C360 and 2XL2000]. The processing system uses the MicroCosm suite of programs for orbit determination and geodetic parameter estimation as the engine. NASA's SOLVE program is used for the combination solutions. A suite of programs have been developed in-house for analysis and re-formatting. Final results are provided in the SINEX format.

CURRENT ACTIVITIES

The current activities are:

- Participating and contributing to the ILRS AWG pilot projects [station coordinates and EOPs, Orbit comparison and the software/standards comparison].
- Continue monthly solutions for LAGEOS-1 and LAGEOS-2. The results both as a time series and as SINEX files are available from http://www.auslig.gov.au/geodesy/sgc/product.htm.
- Station time and range bias solutions determined from 3-day arc LAGEOS-1 and LAGEOS-2 data and based on ITRF2000 set of station coordinates are now available from the above web page.
- There has been significant development of the processing software to estimate LOD and pole rates, and inclusion of new troposheric mapping functions.

FUTURE PLANS

- Plans are to continue to provide both the one-month and the three day arc LAGEOS-1 and LAGEOS-2 solutions.
- Provide global solutions as a full analysis centre to the ILRS when the AWG coordination structures are established.
- Extend routine processing and analysis to Stella, Starlette, Etalon, GLONASS and LEOs.
- Compare the SLR solutions for LEOs with the GPS and DORIS determined solutions.
- Continue to provide a station monitoring service using the 3-day arc solutions described above.

- Preparations are progressing to rigorously compare and combine individual SLR solutions submitted by the various analysis centres.

Related Publications

The key publications appear on AUSLIG's Space Geodesy Analysis Centre Web page at:

http://www.auslig.gov.au/geodesy/techrpts/techrpts.htm.

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7.1.2.11 OBSERVATOIRE DE LA CÔTE D'AZUR / CENTRE D'ETUDES ET DE RECHERCHES GÉODYNAMIQUES ET ASTROMÉTRIE (OCA/CERGA)

Pierre Exertier, *OCA/CERGA*

INTRODUCTION

Besides its involvement in the SLR data acquisition through operation of the Grasse stations (SLR, LLR (high altitude satellites and Moon), and technical developments on the FTLRS), the OCA/CERGA is actively contributing to the ILRS as an Associate Analysis Center (AAC). Nevertheless, our activities have been slowly decreasing with the activities we had originally proposed to the ILRS. The problem is primarily the result of retirements of people, between 1999 and 2000, since these persons were in charge of SLR data analysis for a long time (Y. Boudon, F. Barlier, and Ch. Berger). As a consequence, we did not participate in the IERS/ITRF Pilot Project for TRF definition. However, we have completed a substantial analysis part of what we intended to contribute to the ILRS in 2000.

We have participated in:

(1) The analysis of SLR data for calibration/validation (CAL/VAL) activities (TOPEX/Poseidon project in view of the next Jason-1, GPS, CHAMP, etc.

(2) The analysis of LAGEOS (-1 and -2) SLR data for carefully analyzing site coordinate time series - in addition to instrument stability including uncertainties relative to atmospheric propagation - in view of participating in the IERS/ITRF.

BACKGROUND

The activities of the OCA/CERGA AAC are primarily focused on the analysis of SLR data from altimeter satellites such as TOPEX/Poseidon (T/P). We have developed a short arc orbit technique for orbit validations and positioning-collocation experiments (geometric approach). This method is based on rigorous adjustment criteria, which can be applied to the entire laser network. These developments and capabilities have been put in a dedicated web site in order to permit the quasi-immediate and continuous validation of T/P orbits. This site can be used to evaluate results of the overall mission; local Radial, Tangential, and Normal orbit residuals and SLR residuals, eventually per station, are also presented. Figure 7.1.2.11-1 shows an example of results available on this web site.

In cooperation with GRGS/CNES and GFZ (Potsdam, Germany), SLR data from the CHAMP satellite have been analyzed in order to provide a validation of GPS-based 1-day orbits. Furthermore, the idea is to contribute to the CHAMP accelerometer measurement calibration using these orbits (based on GRIM5 standards and gravity solution).

The OCA/CERGA has been routinely processing LAGEOS data for satellite orbit determination, station coordinate computation and instrument performance monitoring. This year our work was mainly focused on collocation experiments and the combination of SLR with other space or ground geodetic techniques. In particular, for the Grasse geodynamic site we compared the vertical seasonal signals coming from GPS and SLR positioning (both SLR and LLR stations are involved) with absolute gravity measurements made around two times per year since 1998 with an FG5 portable instrument.

FACILITIES/SYSTEMS

The current computation facilities in the OCA/CERGA consist of two Compaq (DEC-Alpha) workstations. The processing system uses the GINS (GRGS/CNES) software for orbit determination and a suite of locally developed programs for space geodesy analysis.

Concerning geodetic techniques, our AAC is supporting several instruments in collaboration with CNES (Toulouse) and IGN (Paris). These instruments are:

- 3 laser ranging stations: SLR, FTLRS, and LLR,
- 1 two color laser experimental site,
- 1 permanent GPS receiver,
- several absolute transportable gravimeter campaigns.

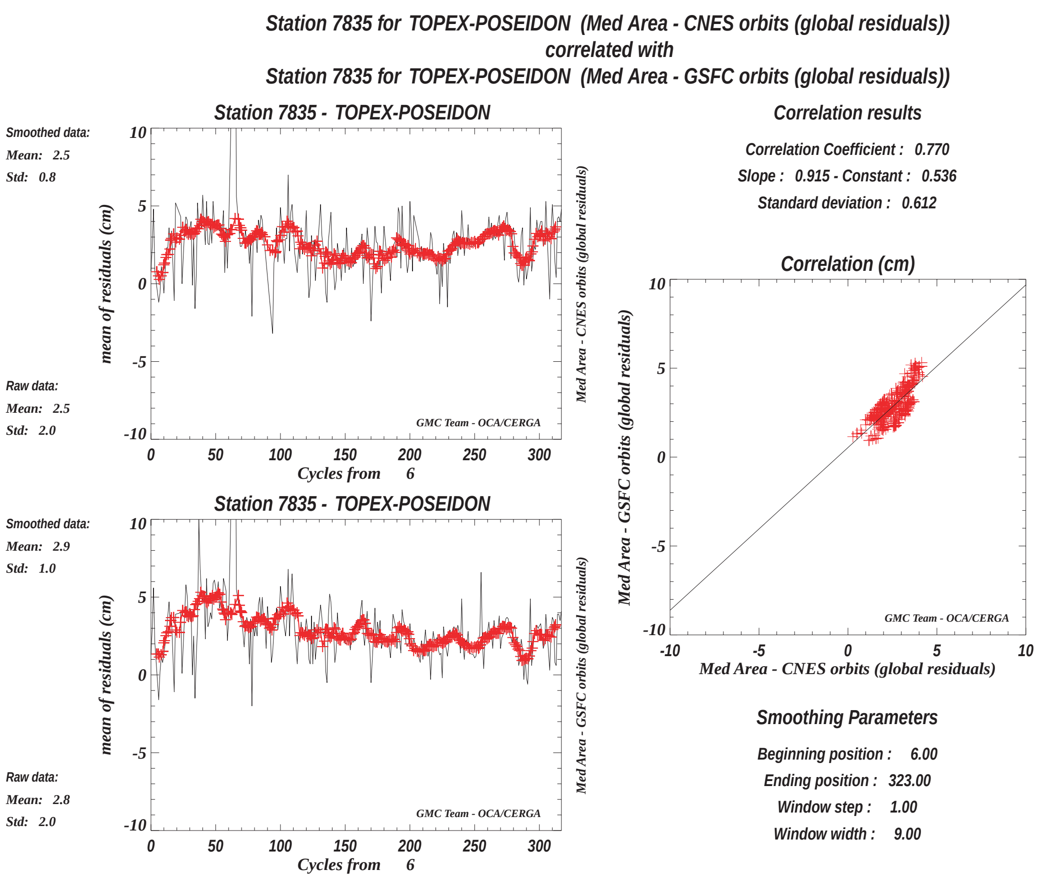

Figure 7.2.1.11-1: Correlation of Grasse (7835) SLR residuals computed using GSFC and CNES TOPEX/Poseidon orbits.

CURRENT ACTIVITIES

The current activities are :

- Collocation experiment between the FTLRS, which has been improved from a technologicl point of view (better stability, detection and timing), and the fixed laser ranging stations at Grasse. This experiment is carried out in order to check the FTLRS new performances after its major modifications realized in 2000, before the launch of the Jason-1 mission,
- Combination of SLR, GPS and gravimetry time series. Analysis of possible regional sources of seasonal variations of g and of the vertical positioning component,
- Preparation for the Jason-1 CAL/VAL campaign which will be carried out in Corsica (the official site of CNES),

- Two color laser ranging on ground targets and comparison with current tropospheric propagation models andanalysis of uncertainties coming from azimutal and vertical distributions of temperature and humidity.

FUTURE PLANS

The OCA/CERGA AAC will continue to develop the same kind of laser data analysis. Our activities for 2001-2002 will be centered on :

(4) Continuation of the collocation experiment at Grasse Observatory,

(5) Realization and data processing for the JASON-1 CAL/VAL campaign.

RELATED PUBLICATIONS

Barlier François, Christiane Berger, Pascal Bonnefond, Pierre Exertier, Olivier Laurain, Jean-François Mangin, and Jean-Marie Torre, *Laser-based validation of GLONASS orbits by short-arc technique*, Journal of Geodesy, in press, 2000.

Exertier Pierre, Joëlle Nicolas, and Pascal Bonnefond, *Géodésie spatiale : avancées récentes*, INCT, Bulletin des Sciences Géographiques, N° 6, pp. 3-15, 2000.

Exertier Pierre, Pascal Bonnefond, Joëlle Nicolas, and François Barlier, *Contributions of Satellite Laser Ranging to past and future radar altimetry missions*, Surveys in geophysics, in press, 2000.

Gaignebet Jean, Jean-Louis Hatat, and Jean-Louis Oneto, *Two color laser ranging on ground targets - First results and projected developments*, Proceedings of the 12th International Workshop on Laser Ranging, Matera - Italy, in press, 2000.

Nicolas Joëlle, La Station Laser Ultra Mobile : De l'obtention d'une exactitude centimétrique des mesures à des applications en océanographie et géodésie spatiales, Ph.D. Thesis, University of Nice-Sophia Antipolis, 2000.

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7.1.2.12 EUROPEAN SPACE OPERATION CENTRE (ESOC)

John Dow, *ESOC*

INTRODUCTION

One of the tasks of the Navigation Research Office of the European Space Operation Centre (ESOC) is the processing and application of SLR data for the computation of high-precision restituted orbit data for ERS-2 (also ERS-1 before its demise). These orbits are based on the automatically retrieved quick look laser ranging data and reprocessed fast-delivery altimeter height measurements. This task not only supports the provision of the routinely determined and predicted ERS-2 orbits for operational purposes and use in fast-delivery products of the scientific instruments on ERS-2, but also the computation of monthly sea level anomaly solutions from ERS-2 altimeter data. To accomplish this task, a batch least squares orbit determination sequence is run automatically, outside working hours, including the retrieval and preprocessing of tracking data and the generation of residual and orbit comparison plots. The orbit solutions are being generated in 4-day arcs, with a delay of typically one week to allow collection of most of the laser tracking. After each solution, updated reports are made available on the Near-Earth Navigation and Geodesy (NNG) web site (nng.esoc.esa.de), and a comparison of the solution is made against the routine orbit to determine the accuracy of the routinely determined orbit. Figure 7.1.2.12-1 shows the rms of fit and number of points for these orbits since January 2000.

This task is supported by the precise orbit determination (POD) system of ESOC that has been developed from the routine orbit determination software. While the routine system was *frozen* at the start of the ERS-2 mission (1995), the POD system has been constantly improved.

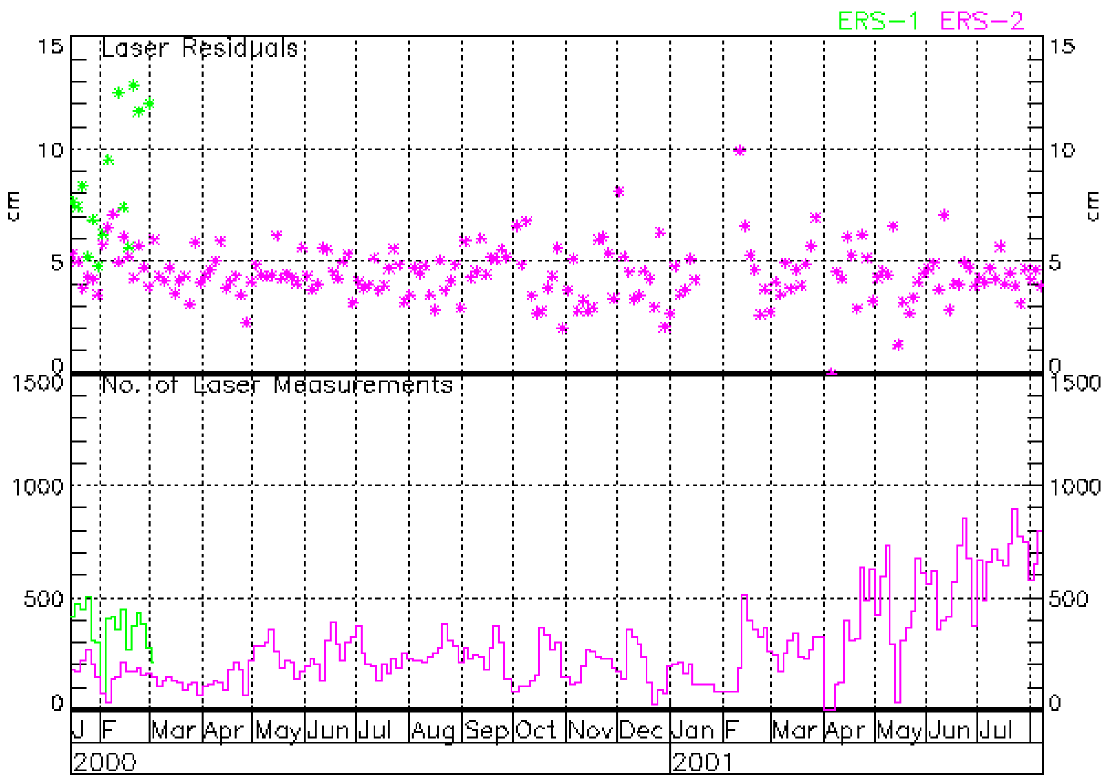

Figure 7.1.2.12-1: Plot of range residuals and number of laser measurements (per arc) used in the precise orbit determination starting January 2000.

FACILITIES/SYSTEMS

The computation facilities in the Navigation Research Office and the Flight Dynamics Division of ESOC are currently being upgraded to SunBlade 100 workstations, replacing older-generation SUN/Sparc systems. The systems are shared by numerous projects. The operating system has recently been changed from Solaris 5.1 to Solaris 8.0, anticipating the launch of Envisat.

CURRENT ACTIVITIES

The operational activities for the ERS-2 satellite are ongoing as the satellite is still performing well, despite continued degradation of the satellite's gyros (ERS-2 is now operated successfully in gyro-less mode); thus SLR tracking data are still required for the precise orbit determination.

To prepare for Envisat and other future Earth Observation missions, the team has developed a new generation of orbit determination, prediction and control software: the Navigation Package for Earth Observation Satellites (Napeos). The software, coded in Fortran 90, will support both the routine and precise orbit determination of Envisat. Napeos is now ready to support the Envisat operational phase, but improvement of the precise orbit determination capabilities will remain a continuous effort.

FUTURE PLANS

The experience gained at ESOC with the routine and precise orbit determination of both ERS-1 and ERS-2 will be exploited to its maximum for the future Envisat mission. This mission is very similar to those of ERS-1 and ERS-2, but imposes new challenges. The Napeos software can meet these challenges.

SLR data processing will be performed for all current and future ESA satellites equipped with a LRR array, and in addition for a number of other Earth Observation missions, such as Jason.

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7.1.2.13 JOINT CENTER FOR EARTH SYSTEMS TECHNOLOGY/GSFC (JCET/GSFC)

Erricos Pavlis, *Joint Center for Earth Systems Technology, University of Maryland*

INTRODUCTION

The AAC at JCET/GSFC continued to support the activities of ILRS and several of its Working Groups during the year 2000. We continued to participate in the IERS/ITRF Pilot Project for TRF definition and the ILRS Pilot Project for the standardization of the SLR data analysis and its products for site and EOP in the form of SINEX file submissions. This past year we submitted to IERS a complete 8-year solution based on LAGEOS and LAGEOS 2 data. This solution was used for the new major TRF realization, ITRF2000, with a high weight factor due to its high internal consistency and its high degree of agreement with the results from independent techniques such as VLBI and GPS (Fig. 7.1.2.13-1). In addition to these solutions, we have worked with a group of refraction experts to develop and validate a new mapping function for laser wavelengths to update the 1973-vintage Marini-Murray model.

BACKGROUND

The activities of the AAC are primarily focused on the analysis of SLR data from LAGEOS 1 and LAGEOS 2, with analyses for SLR data obtained on additional satellite targets during specific campaigns of interest (e.g. SUNSAT, GPS, GLONASS/IGEX, ETALON 1 & 2, CHAMP, etc.). The main products are the updated station positions and velocities and the Earth Orientation Parameters, x_p, y_p, and *LODR,* as well as their rates x_p-*dot* and y_p-dot*,* at daily intervals. In support of the ITRF Pilot Project we also form weekly solutions which are transformed into SINEX format for general distribution. 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. These series were examined in terms of their spectral content by estimating periodic signals at long and intermediate periods. Comparing them to those obtained from primarily geophysical model predictions, we conclude that they are mostly due to the seasonal redistribution of geophysical fluids in the Earth system.

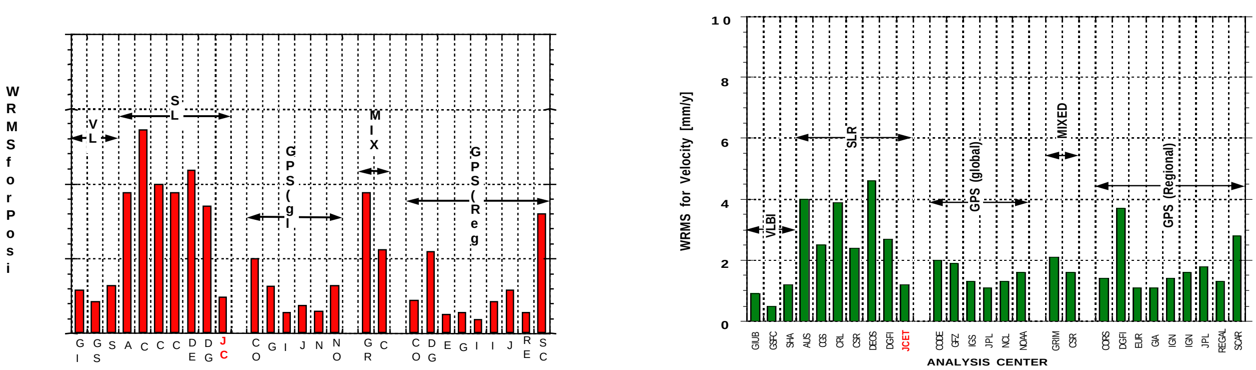

Figure 7.1.2.13-1: Weighted Root Mean Square error for position (left) and velocity (right) components of all contributed solutions for the development of ITRF2000. The numbers associated with the JCET/GSFC contribution are: 2.4 mm and 1.2 mm/y.

FACILITIES/SYSTEMS

These are the same as for last year.

CURRENT ACTIVITIES

We continue the generation of our weekly solutions as a contribution to the IERS/ITRF Pilot Project and our own activity of monitoring the episodic and seasonal variations in the definition of the geocenter with respect to the origin of the conventional reference frame. We are also continuing our support for the ILRS Pilot Project, by including EOP rate estimation, utilization of the new mapping function for atmospheric delay, and the analysis of tracking data from ETALON 1 and 2. We have also completed a re-analysis of the 8-year series using the new mapping function and we are studying its impact on the deliverable products. A web site is soon to be operational to aid in disseminating these and other AAC products.

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FUTURE PLANS

LAGEOS-related activities continue, with emphasis on the near-real-time generation of weekly products and their dissemination via the web. We will also expand our activities to include the data of the new geodetic and oceanographic missions recently or soon to be launched during 2001-2002, (e.g. CHAMP, JASON, and GRACE). With regards to the second one, our proposal to the European Union to establish an absolute altimeter calibration site at Gavdos/Crete, Greece was accepted and in that capacity, we will participate with the SLR data analysis for the CAL-VAL activities during the first six months of the mission.

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7.2 LUNAR LASER RANGING

Peter Shelus, *University of Texas*

INTRODUCTION

Lunar laser ranging (LLR) continues to be a modern and exotic form of astrometry. It accurately measures the round-trip travel time for a laser pulse that is emitted from an observing station on the Earth and returns, after being reflected off of a retroreflector array on the surface of the Moon. The analysis of this constantly changing distance, using several observatories on the Earth and several retroreflectors on the Moon, provides for a diversity of terrestrial, lunar, solar system, and relativistic science [Bender, et al 1973; Mulholland, 1980; Dickey, et al 1994]. But, even after almost 35 years of routine operation, LLR is still a non-trivial and technically challenging task. Signal loss, caused mainly caused by the inverse 4th power of the Earth-Moon distance but also the result of optical and electronic inefficiencies in the observing equipment, requires the detection of single photoelectron events. With the present laser firing rate of 10 hertz, at a station like the MLRS, fewer than 25 photoelectrons/minute are routinely detected. Timing precision is measured in ten's of picoseconds with the total range accuracy being about an order of magnitude larger. Were the moon to be just 25% farther from the Earth than it is, this experiment probably could not be performed with present equipment. It is quite exciting to realize that it is more than a trillion times more difficult to range to the Moon than it is to range to TOPEX-Poseidon. Even though there are several tens of highly efficient artificial satellite ranging stations around the world, only two of them have the capability of ranging to the Moon. One of them is located in the United States, at McDonald Observatory. The other is in the south of France, near Nice, at the Observatoire de la Cote d'Azur. A third station, the MLRO, in Matera, Italy is on the verge of becoming operational.

The data that is gathered by the LLR stations form a foundation upon which a large number of astronomical disciplines rely. They provide a valuable multi-disciplinary analytical tool, the benefits of which are registered in such areas as the solid Earth sciences, geodesy and geodynamics, Solar System ephemerides, terrestrial and celestial fundamental reference frames, lunar physics, general relativity and gravitational theory. They contribute to our knowledge of the precession of the Earth's spin axis, the 18.6 year lunar induced nutation, polar motion and Earth rotation, the determination of the Earth's obliquity to the ecliptic, the intersection of the celestial equator and the ecliptic (the equinox), lunar and solar solid body tides, lunar tidal deceleration, lunar physical and free librations, as well as energy dissipation in the lunar interior. They determine Earth station and lunar surface retroreflector location and motion, the Earth-Moon mass ratio, lunar and terrestrial gravity harmonics and Love numbers, relativistic geodesic precession and the strong equivalence principle of general relativity.

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7.2.1 ANALYSIS CENTERS

7.2.1.1 PARIS OBSERVATORY LUNAR ANALYSIS CENTER (POLAC)

J. Chapront, M. Chapront-Touze, G. Francou, P. Bidart, *Observatoire de Paris*

INTRODUCTION

POLAC is settled in the department of fundamental astronomy at Paris Observatory (DANOF) and works in cooperation with the LLR team of CERGA at Grasse, France. Its main goals are: to improve the analytical solutions of the orbital and rotational motions of the Moon, to determine the orientation of the dynamical frame and to produce universal time and variation of latitude series (UT0-UTC and VOL).

BACKGROUND

For many years our team has been involved in celestial mechanics studies, especially in the development of analytical solutions of lunar and planetary motions in view of the publication of solar system bodies ephemerides. Since 1997, we have cooperated with the IERS in the determination of the dynamical celestial reference frame, and we now produce Earth rotation parameters.

FACILITIES

The computing equipment consists of individual microcomputers connected to the DANOF local network. This environment is being managed by the data processing department of Paris Observatory. The two operational LLR stations, Grasse (France) and McDonald (Texas), send their observations directly to us by e-mail.

ACTIVITIES

Two kinds of analyses

Global analyses of all the observations available since January 1972. the observations allowed an estimation of several parameters of the lunar motions (including the tidal secular acceleration, parameters of the free libration, and parameters of the Earth-Moon barycenter motion), and the orientation parameters of the mean ecliptic of J2000.0 with respect to the mean Celestial Ephemeris Pole (MCEP) of J2000.0 and to the International Celestial Reference System (ICRS);

Nightly analyses, using the results of the global analyses, for the determination of Earth orientation parameters. Values of UT0-UTC and VOL (variation of latitude) have been estimated since January 1995 using the observations of the two active LLR stations: McDonald (MLRS2) and Grasse (CERGA).

The new Moon solution S2000

The previous solution, called here S1998, was ELP2000-96 that resulted from the improved analytical theory ELP2000-82B plus numerical complements (Chapront & Chapront-Touzé, 1997). The adopted solution of the libration was Moons' theory (1982, 1984) with analytical and numerical complements (Chapront et al., 1999a). On these bases, a new analysis has been performed using the LLR observations of McDonald and Grasse until 2000 with several improvements in the lunar ephemeredes (circulation and libration) and in the numerical precision of the model. In this new solution, called S2000, we have also introduced other changes such as the nutation model of the IERS Conventions 1996 instead of ZMOA 90 and a new distribution of the weights for the observations.For both solutions S1998 and S2000, we used the method described in (Chapront et al., 1999b).

In Table 7.2.1.1-1 we put in evidence quantitatively the increase of precision on the residuals (RMS on the distance Station-Reflector). Clearly, in each group, the recent observations have a greater weight than the oldest one. Hence the unknowns are sensibly determined with a better accuracy.

Observatory and instrument	Sub-group	rms (1)	rms (2)	Sub-group	rms (3)	N
McDonald,				1972-1975	43.0	1487
Tel 2.70 m	1972-1986	34.7	34.5	1976-1979	27.3	1029
& MLRS1				1980-1986	29.5	992
CERGA, Rubis	1984-1986	18.2	18.8	1984-1986	19.6	1166
Haleakala	1987-1990	11.1	8.0	1987-1990	7.9	455
McDonald,				1987-1991	5.6	230
MLRS2	1987-1998	5.0	3.8	1991-1995	4.3	581
				1995-2000	3.4	1621
CERGA,				1987-1991	5.1	1570
Yag	1987-1998	4.8	3.8	1991-1995	3.8	2040
				1995-2000	3.1	2754

(1) S1998 : 1 sub-group per observatory
(2) S2000 : 1 sub-group per observatory
(3) S2000 : Same as (2) with several sub-groups per observatory
N : Number of normal points in each sub-group

Table 7.2.1.1-1. Distribution of the LLR residuals (rms in centimeter).

In order to appreciate the global gain of precision of our new solution S2000 compared to S1998, we show the lunar range residuals for the observations made at Grasse between 1987 and 2000 with S2000 on Fig. 7.2.1.1-1a and with S1998 on Fig. 7.2.1.1-1b. We note for S2000 dispersion less important on the whole interval and a better fit for the two last years (in case of S1998 the solution was extrapolated). A comparable statement can be done with the observations made at McDonald.

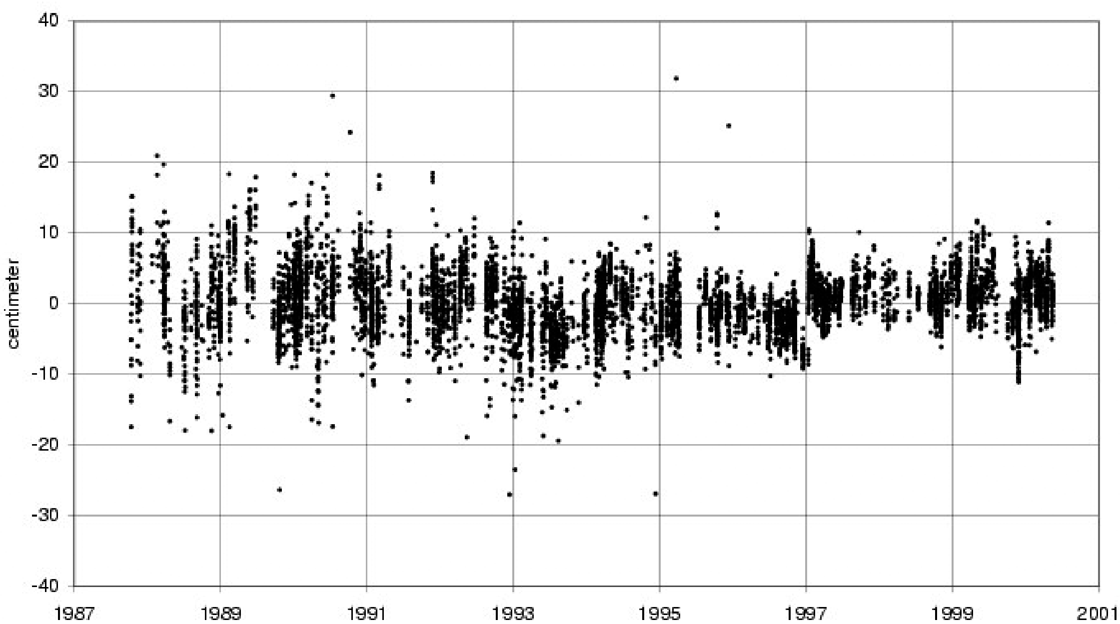

Figure 7.2.1.1-1a: LLR residuals S2000 (CERGA observations).

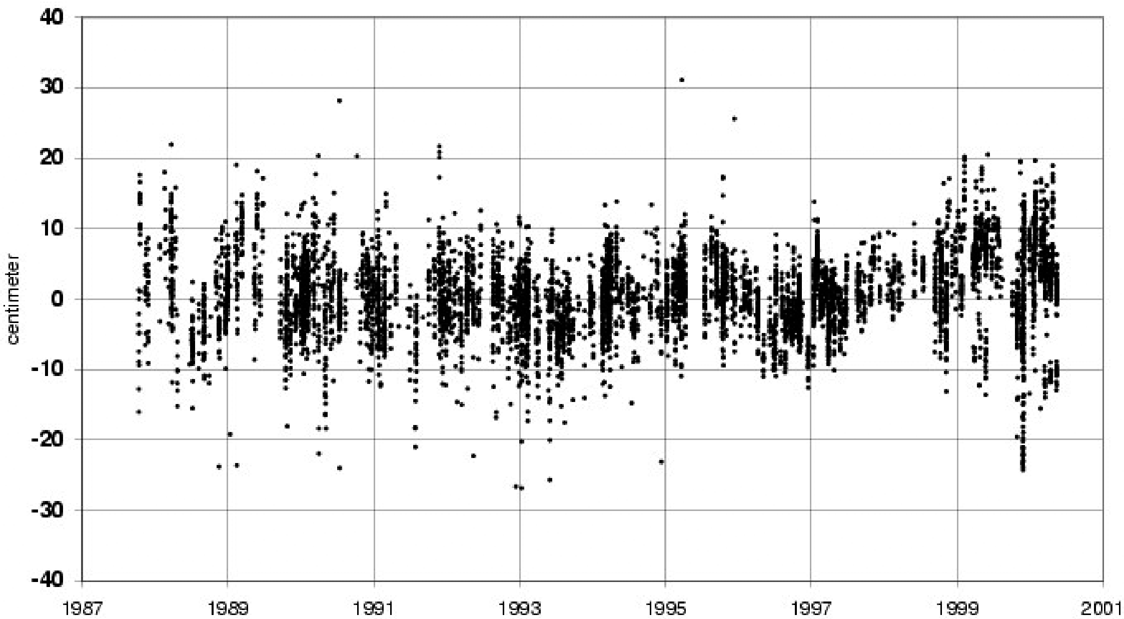

Figure 7.2.1.1-1b: LLR residuals S1998 (CERGA observations).

Results of the global analyses: orientation of reference systems

Following are the last results obtained for the orientation of the inertial mean ecliptic of J2000.0 with respect to the frame tied to the mean Celestial Ephemeris Pole of J2000.0 (MCEP) and to the International Celestial Reference System (ICRS). The errors represent the formal uncertainties resulting from the least squares adjustment. Realistic uncertainties are estimated to be between five and ten times these values.

ε(MCEP) = 23°26’21.405 62" ± 0.000 05" ϕ(MCEP) = - 14.5 mas ± 0.2 mas

ε(ICRS) = 23°26’21.411 08" ± 0.000 05" ϕ(ICRS) = - 55.3 mas ± 0.1 mas

ψ(MCEP) = 44.5 mas ± 0.4 mas Δp = - 3.36 ± 0.03 mas/yr

with :

ε(R)	Inclination of the J2000.0 inertial mean ecliptic to the equator R
γ^{I}_{2000}(R)	Ascending node of J2000.0 inertial mean ecliptic on the equator R
o(R)	Origin of right ascensions in the equator R
ϕ(R)	Arc o(R) γ^{I}_{2000}(R) in the equator R
ψ(R)	Arc γ^{I}_{2000}(ICRS) γ^{I}_{2000}(R) in J2000.0 inertial mean ecliptic
Δp	Correction to the IAU 1976 precession constant

Results of analyses by night : Earth orientation parameters UT0-UTC and VOL.

These results are based on the analysis of a set of 3625 LLR observations (normal points) from Grasse (CERGA) and 1831 observations from McDonald (MLRS2) covering the time span from January 1995 until December 2000. The couples of values (UT0-UTC, VOL) are determined by station and by reflector for the mean date of each night of observation. Appolo 15 is the reflector that contributes the bulk of the observations. We have rejected the nights/reflector with less than 4 observations and those with just 4 observations over a span shorter than 1.5 hour.

Over the time span 1995-2000, 460 values of (UT0-UTC, VOL) have been produced, 282 values from CERGA observations and 178 values from MLRS2 observations. Fig. 7.2.1.1-2 shows the differences between the UT1-UTC deduced from POLAC values (UT0-UTC, VOL) and those edited by IERS (EOP Series C04). Over this time span, the RMS of the differences is 0.099ms for the CERGA observations and 0.115 ms for the MLRS2 observations.

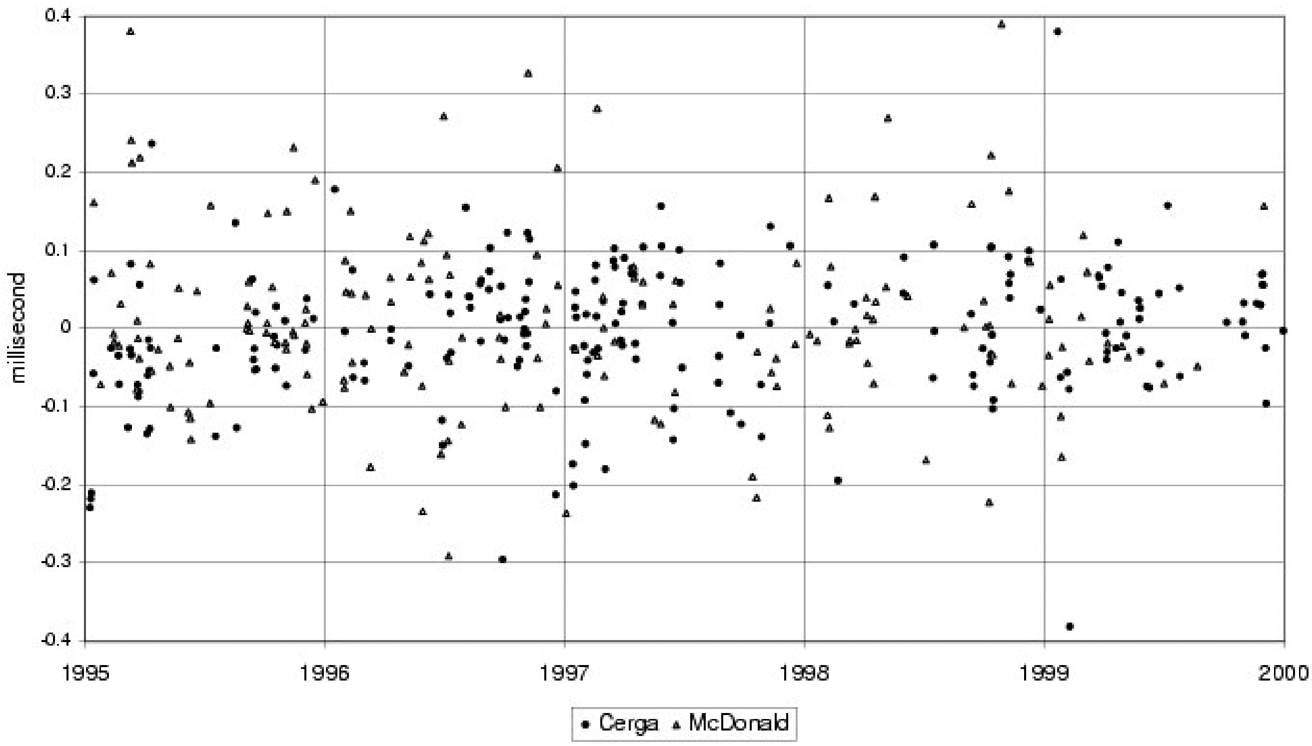

Figure 7.2.1.1-2: UT1-UTC – Comparison POLAC-IERS(1995-2000).

FUTURE PLANS

We shall continue to develop the lunar solution and to produce regularly values of UT0-UTC and VOL. We plan to introduce improvements concerning the Earth tides, and positions and motions of the LLR stations.

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KEY POINTS OF CONTACT

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7.2.1.2 FORSCHUNGSEINRICHTUNG SATELLITENGEODÄSIE (FESG/TUM)

Jergen Muller, *FESG/TUM*

STATUS

At the FESG (Forschungseinrichtung Satellitengeodäsie = Research Facility for Space Geodesy), the LLR data have been analysed in March 2000 to provide a set of station coordinates (SSC) in SINEX format as well as Earth orientation parameters (EOP) for the realization of the ITRF2000 and the IERS annual report, respectively. The parameter determination was based upon all LLR data available since 1970, about 13500 normal points. The FESG solution was the only LLR solution, which was accepted for the ITRF2000, where the right constraining of the site velocities was the most critical point.

At the beginning of 2000, we started an investigation to better understand the differences in the results of the four main LLR analysis centers. In a first step we concentrated on the modelling of tidal effects. In Müller and Tesmer (2001) the tidal models used in the various LLR software packages of the four lunar analysis centers are listed/compared (see also Tables 7.2.1.2-1 and 7.2.1.2-2).

	JPL (J. Williams)	**UTXMO** (J. Györgyey Ries)	**OBSPM** (J. Chapront)	**FESG** (J. Müller)	**FESG 2000**
Earth tides (no corr, of the permanent tide, Eq.17)	IERS Conv. 1996, Eq. 8 (degree 2) + corr. of K_1	Alsop and Kuo (1964)	IERS Conv. 1996, Eq. 8 (degree 2)	IERS Conv. 1996, Eq.8,9 (degree3) + corr. of K_1	Matthews et al. (1997)
Ocean loading	?	-	IERS Conv. 1996 without corr. due to lunar node	IERS Conv. 1996	IERS Conv. 1996
Atmospheric loading	?	-	IERS Conv. 1996 (p_{t0} vs p_0, simplified)	-	IERS Conv. 1996 (p_t vs p_{avg}, simplified)
Pole tide	yes	-	?	yes	yes
(Sub-)diurnal UT1 variations	yes	-	?	yes	yes

Table 7.2.1.2-1. Tidal effects implemented in the various lunar analysis softwares (recommended by the IERS Conventions 1996).

	JPL (J. Williams)	**UTXMO** (J. Györgyey Ries)	**OBSPM** (J. Chapront)	**FESG** (J. Müller)
Secular tidal acceleration of the Moon (+ 3.8 cm/y)	diurnal (k_{20}, k_{21}, _$_{21}$), subdiurnal (k_{22}, _$_{22}$) (det. with eph. DE330)	-	diurnal (k_{20}, k_{21}, _$_{21}$), subdiurnal (k_{22}, _$_{22}$) (det. with eph. DE245)	diurnal (k_2, _$_2$)
potential Love$_{earth}$ k, lag angle _ estimation	k_{21}_$_{21}$; k_{22}_$_{22}$	-	k_2_	k_2_
Moon as an elastic, dissipative body	yes	-	yes	yes
potential Love$_{moon}$ k_m, dissipation param. _$_m$ estimation	yes	-	?	yes

Table 7.2.1.2-2. Further Tidal effects implemented in the various lunar analysis softwares which are also relevant for LLR.

In a further step, we investigated the capability of LLR to determine tidal parameters, e.g. Love numbers or the amplitudes of the main tides (Müller and Tesmer, 2001), which show up with a semi-diurnal or diurnal signature. Some of the tidal parameters (e.g. K_2, S_2 or Q_1) can be determined well within (realistic) error bars, others not at all, which depends on the inhomogeneous observational coverage. The Moon is always near or in the meridian, whereas the Sun must be far away not to perturb the LLR measurements. Therefore we have systematic data gaps which prohibit the determination of some diurnal and sub-diurnal tidal amplitudes with sufficient accuracy.

CURRENT ACTIVITIES AND FUTURE PLANS

We enlarged our efforts to improve the S/W for the detection of the real lunar returns in the raw observations at Wettzell which are very noisy. We used the semi-train structure for separating the noise and the real measurements and began to standardize and automatize the computation of the normal points. More details on this subject will be published this year.

We will continue our activities, i.e. to derive realistic errors of the estimated LLR parameters as well as to provide input for the ITRF2001 (station coordinates and velocities) and for the IERS annual report (EOP parameters from LLR).

As already mentioned in the last annual report, we will be prepared for a renaissance of lunar missions like the planned Japanese mission SELENE II.

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7.2.1.3 JET PROPULSION LABORATORY (JPL)

J. Williams, D. Boggs, J. Dickey, T. Ratcliff, *Jet Propulsion Laboratory*

INTRODUCTION/BACKGROUND/DATA PRODUCTS PROVIDED

Analyses of laser ranges to the Moon are used for a variety of investigations: lunar science, gravitational physics, geodesy, geodynamics and astronomy. Unique contributions from LLR include: detection of a molten lunar core; measurement of tidal dissipation in the Moon; an accurate test of the principle of equivalence for massive bodies (strong equivalence principle); and detection of lunar free librations. LLR analyses provide tests of gravitational physics, measurements of the Moon's tidal acceleration and the Earth's rotation and precession, and orders-of-magnitude improvements in the accuracies of the lunar ephemeris and three-dimensional rotation. Lunar and planetary ephemerides and lunar physical librations are available to the scientific community at http://ssd.jpl.nasa.gov/horizons.html.

CURRENT ACTIVITIES

Lunar Laser Ranges are regularly received from the Observatoire de la Côte d'Azur and McDonald Observatory sites. These ranges are processed at regular intervals for Earth rotation information. UT0 and variation of latitude for the two stations are input to the JPL Earth rotation filter.

The tidal acceleration of the Moon has been computed for several ephemerides based on iterated solutions. The acceleration in mean longitude due to dissipative effects is -25.7 "/cent^2, of which -26.0 "/cent^2 is due to tides on Earth and +0.3 "/cent^2 is due to tidal and fluid core dissipation in the Moon. The tidal increase in semimajor axis is 38 mm/yr.

Dissipation in the Moon is discussed in (4). The solid-body tidal Q is low and a fluid core is detected. An oblate core-mantle boundary will influence the determination of the Love number k_2. First attempts allowing for CMB oblateness give k_2=0.026, with uncertainty 0.003 (6, 7).

Uncertainties continue to tighten for tests of gravitational physics. The Earth and Moon are accelerated alike in the Sun's gravitational field to 1.5 parts in 10^{13} (1). This equivalence principle test is sensitive to differences between Earth and Moon due to both composition and self-energy. The relativistic geodetic precession of 19 mas/yr is confirmed within 0.35%. Based on point mass interactions, the uncertainties for Parameterized Post Newtonian beta and gamma are both 0.004 (2). The equivalence principle test limits the beta uncertainty further to 0.0005 (1). The gravitational constant G has no detectible rate for dG/dt / G within 1.1×10^{-12} /yr (2, 8).

FUTURE PLANS

Continue investigation of lunar science and gravitational physics utilizing LLR data. Generate Earth rotation results. Continue lunar ephemeris and physical libration developments.

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ABSTRACTS

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7.2.1.4 UNIVERSITY OF TEXAS MCDONALD OBSERVATORY LUNAR ANALYSIS CENTER (UTXM)

Judit Györgyey Ries, *University of Texas*

STATUS

The University of Texas McDonald Observatory Lunar Analysis Center (UTXM) is operating within the Department of Astronomy of the University of Texas at Austin, in conjunction with the McDonald Laser Ranging Station (MLRS) near Ft. Davis Texas. The Center has been providing monthly Earth Orientation Parameters (EOP) since 1989 through 2000, and also supplies predictions for lunar data acquisition and carries out internal quality control.

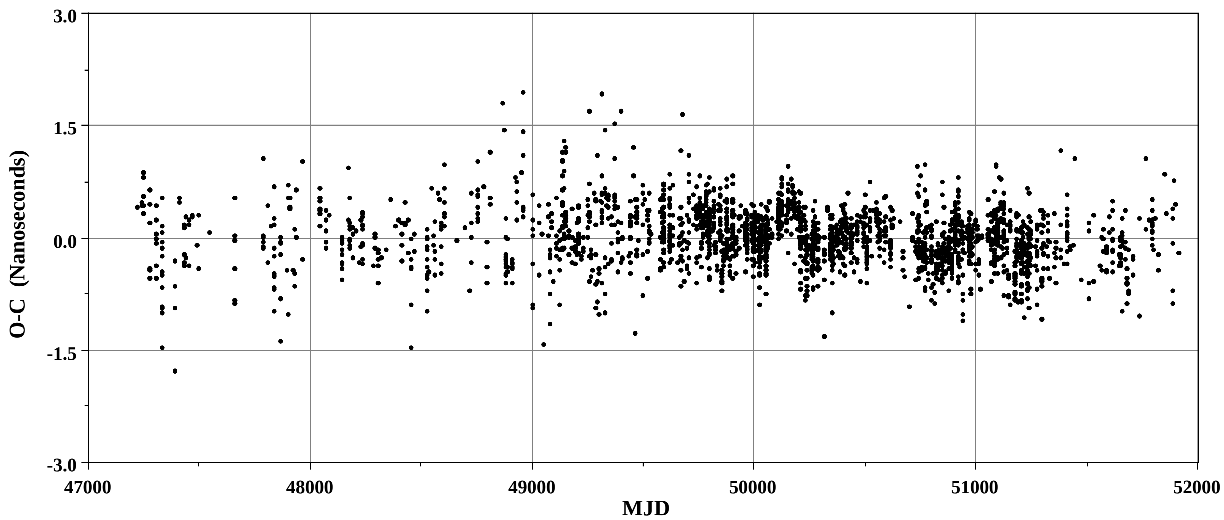

Figure 7.2.1.4-1: Residuals for 2493 MLRS normal points including all retro-reflectors February 1988 to December 2000

ACTIVITIES

Using all available the LLR data, we adjust a number of global parameters of the Earth Moon system and station and reflector parameters. The resulting fit of the data from the Mt. Fowlkes site is shown on Figure 1. The mean of the residuals is 3.5×10^{-4} nsec with 0.30 nsec RMS about the mean. (The slope of the linear fit to the residuals is practically zero, 4×10^{-5} nsec/day). We assume that the remaining nightly signature is due to UT1R error in the smoothed a priori series we use. For nights with sufficient data we can remove this signal. Then the mean becomes 1.1×10^{-2} nsec, and the RMS is reduced to 0.22 nsec.

We have provided a total of 75 UT0 -UTC values in 2001, 64 from OCA and 11 from MLRS reflector 3 (Hadley, Apollo 15), data, based on 696 normal point provided by the two active stations. Only nights with at least 3 normal points and at least 1.5 hours span were accepted, and UT0 - UTC and $\Delta\phi$ were calculated using an iterative least square analysis.

We converted the UT0 and variation of latitude estimates to UT2-TAI using the apriori polar motion values to compare our results with IERS Bulletin A EOP series, as seen on Figure 7.2.1.4-1.

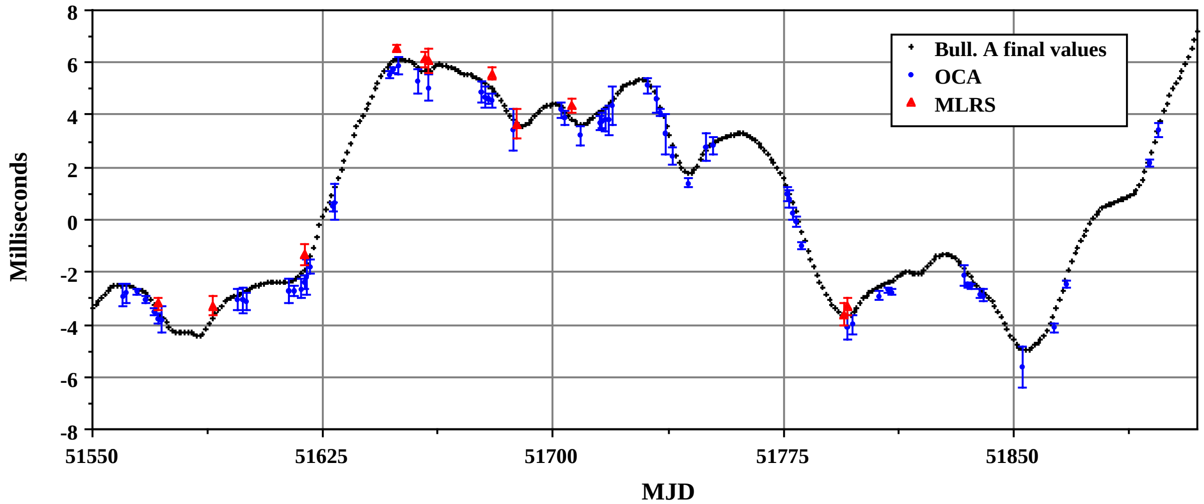

Figure 7.2.1.4-2: UT2-TAI with -0.753 msec/day slope removed (January 1 – December 31, 2000).

We provided a total of 75 UT0 -UTC values in 2001, 64 from OCA and 11 from MLRS reflector 3 (Hadley, Apollo 15), data, based on 696 normal point provided by the two active stations. Only nights with at least 3 normal points and at least 1.5 hours span were accepted, and UT0 - UTC and $\Delta\phi$ were calculated using an iterative least square analysis. This we converted to UT2-TAI using the apriori polar motion values to compare our results with IERS Bulletin A EOP series, as seen on Figure 7.2.1.4-2.

FUTURE PLANS

We will continue to provide annual EOP series to the community, while improving the quality and the stability of our solution. We hope to work on the simultaneous processing of LLR data and SLR data as the second step in truly unifying laser data handling.

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