Section 9:

Standing Committee, Study Group, and Board Activities

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Introduction

The ILRS Governing Board established several standing committees (SCs) and study groups (SCs) to carry out the business of the ILRS. The SCs, formerly called ILRS Working Groups, address the continuously evolving tasks of the ILRS; study groups. are formed to work special investigations or tasks of a temporary nature. Currently, the ILRS has five SCs as shown in Table 9-1 below. These groups provide the expertise to make technical decisions and to plan programmatic courses of action and are responsible for reviewing and approving the content of technical and scientific information maintained by the Central Bureau.

Table 9-1. ILRS Standing Committees, Study Groups, and Boards

Standing Committee	Chair/Co-Chair
ASC Analysis Standing Committee	Chair: Erricos Pavlis Co-Chair: Cinzia Luceri
DFPSC Data Formats and Procedures Standing Committee	Chair: Christian Schwatke Co-Chair: Randy Rickleffs
MSC Missions Standing Committee	Chair: Toshi Otsubo (2016-2019) Co-Chair: Scott Wettzel (2016-2019) Chair: Stephen Merkowitz (2019-present) Co-Chair: Rob Sherwood (2019-present)
NESC Networks and Engineering Standing Committee	Chair: Matt Wilkinson Co-Chair: Georg Kirchner
TSC Transponder Standing Committee	Chair: Ulli Schreiber Co-Chair: Jean-Marie Torre
ILRS Study Groups	**Chair/Co-Chair**
Space Debris Study Group	Chair: Georg Kirchner Co-Chair: Daniel Kucharski
ILRS Boards	**Chair**
Quality Control Board	Michael Pearlman

Analysis Standing Committee (ASC)

Author: *Erricos Pavlis/JCET/UMBC, Cinzia Luceri/e-GEOS S.p.A.*

Chair: Erricos C. Pavlis
Co-Chair: Cinzia Luceri

Role of the Analysis Standing Committee

The ILRS is an official Technique Service in the International Association of Geodesy (IAG) and the International Earth Rotation and Reference Systems Service (IERS). To fully and systematically exploit the unique aspects of the SLR observations, the ILRS established the Analysis Standing Committee (ASC) to lead the development of official products, to monitor and qualify the performance of the tracking network, and to address various issues with the SLR data and products. Some of the main duties of the ASC include data quality control, the definition of the estimated parameters group for official data analyses, the selection of the satellite data to be used, the products format definition, the optimization of the underlying processes, and the development of an official combination product on the basis of the individual AC contributions. Additional products being considered are evaluated through a number of so-called pilot projects (PP), with several initiated during the past few years, some of them successfully completed and others still ongoing. This contribution to the ILRS 2016-2019 Report is a review of the main accomplishments during that period and an update on the status and the results of these efforts. General information on ASC activities, membership and more detailed information on the pilot projects can be found on the relevant pages in the ASC section of the ILRS website *https://ilrs.gsfc.nasa.gov/science/awg/index.html*.

Recent Achievements

Over the period covered in this report (2016-2019), the ILRS ASC met on six occasions. ASC meetings are usually planned to take place on dates close to major geophysical meetings (AGU/EGU) or other venues associated with ILRS events, in order both to maximize ASC members' attendance and to also encourage interaction with other scientists. The six occasions are listed below along with the dates and location:

- April 2016 - The 37th ASC meeting was held on April 22 at the TU Wien in Vienna, Austria.
- October 2016 - The 38th ASC meeting was held on October 8 in Potsdam, Germany.
- April 2017 - The 39th ASC meeting was held on April 22 at the TU Wien in Vienna, Austria.
- October 2017 - The 40th ASC meeting was held on October 1 at the University of Latvia in Riga.
- April 2018 - The 41st ASC meeting was held on April 12 at the TU Wien in Vienna, Austria.
- November 2018 - The 42nd ASC meeting was held on November 4 at the Mt. Stromlo Observatory complex in Canberra, Australia.
- April 2019 - The 43rd ASC meeting was held on April 6 at the TU Wien in Vienna, Austria
- October 2019 - The 44th ASC meeting was held on October 1 at the Paris Observatory in Paris, France

Detailed agendas and minutes of the deliberations at these meetings, along with the presentations from each of the participating groups, can be found online at the ASC activities and meeting section of the ILRS website (*https://ilrs.gsfc.nasa.gov/science/awg/awgActivities/index.html*). In addition to these meetings, the chairs and several members of the ASC participated with presentations and contributions to several position papers in the Unified Analysis Workshop of the Global Geodetic Observing System (GGOS) and IERS, in Paris, France, July 10-12, 2017 and October 02-04, 2019.

The prime activity of the ASC is to use the SLR data for the routine, frequent and consistent development of a unique, high-quality analysis product that is in high demand in the science community, e.g., station positions and daily EOP. The entire collection of these products contributes to the development of the ITRF model updates every 5-6 years, along with similar products from the other geometric IAG Services. An official analysis of a 7-day arc provides an estimate for station coordinates and daily EOPs, and it is generated by the ILRS Analysis Centers (ACs) and Combination Centers (CCs) on a daily basis, and submitted to the IERS as an official ILRS contribution. The 7-day arcs comprise data of high-quality laser range observations to LAGEOS, LAGEOS-2 and the two Etalon satellites, and the ILRS network is encouraged to support this valuable work, ideally by tracking these satellites day and night, seven days a week. Two different products are distributed each week: a loosely constrained estimation of coordinates and EOP and an EOP solution, derived from the previous product, fully constrained to the standard ITRF. The distribution of these products in the early days of the ILRS ASC was done on a weekly basis. However, starting in May 2012 the official "position + EOP" product is delivered daily, with the starting day of the 7-day arc shifted forward daily by one day. This was deemed necessary to ensure that our customer USNO, hosting the IERS Rapid Prediction Center would have access to the most fresh SLR-derived EOP possible. The ASC launched an additional official product during the reporting period, starting the weekly distribution of precise orbits for the four satellites used in the development of the official pos+EOP products. The orbits are delivered as 7-day SP3c-formatted files in the standard ITRF frame.

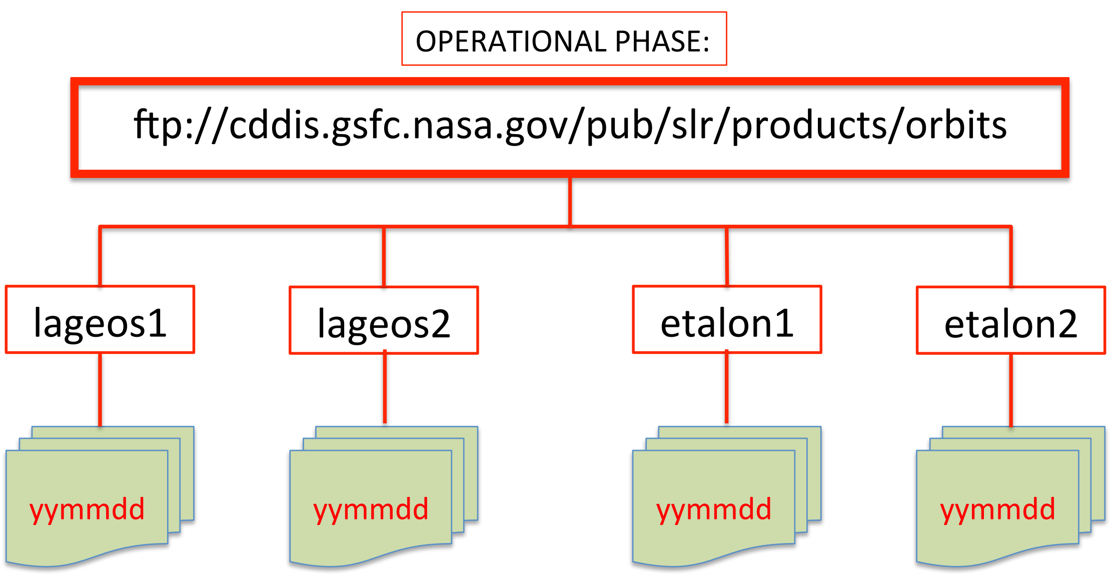

Figure 9-1: Archive structure of the weekly submissions of official ILRS Orbit products at the CDDIS DC (similarly at EDC DC).

In addition to the operational products development, the ASC contributed in the evaluation of the ITRF2014P (preliminary) and ITRF2014 (final) models. Upon release of the final model the ASC planned and executed the implementation of the new model for all ILRS applications. Due to the delayed release of the associated EOP series from IERS, the use of the new model in the official products was only possible in mid-2017. During the reporting period, eight different ACs supported the operational activities providing products routinely: ASI, BKG, DGFI, ESA, GFZ, GRGS, JCET and NSGF. Unfortunately, GRGS stopped delivering its contributions in mid-2016 and after they were given several extensions to recover from their processing system breakdown, they were finally placed in the AAC group until they can demonstrate again a sustained contribution to the official products. Two CCs are routinely delivering the combined products: ASI (primary ILRS-A) and JCET (backup ILRS-B).

In 2016 we had the first results from the Pilot Project (PP) Station Systematic Error Modeling—SSEM, with a very good agreement amongst the individual contributions from each AC for the adopted test period of analysis (2005-2008). This provided a verification that the new approach works as expected through the examination of recovered biases at stations with known issues which had been corrected using engineering measurements, e.g., at Matera (7941) around the middle of 2007 and at Herstmonceux (7840) prior to 2007 (Figure 9-2).

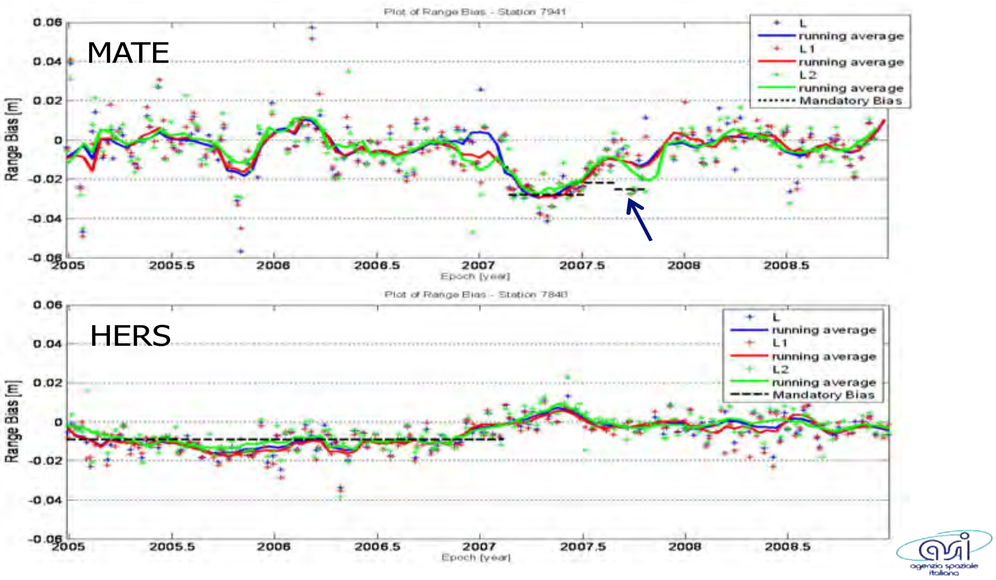

Figure 9-2: Weekly adjusted range biases to LAGEOS and LAGEOS-2 (red and green crosses respectively) at two SLR sites with (independently) well-established estimates (dashed lines).

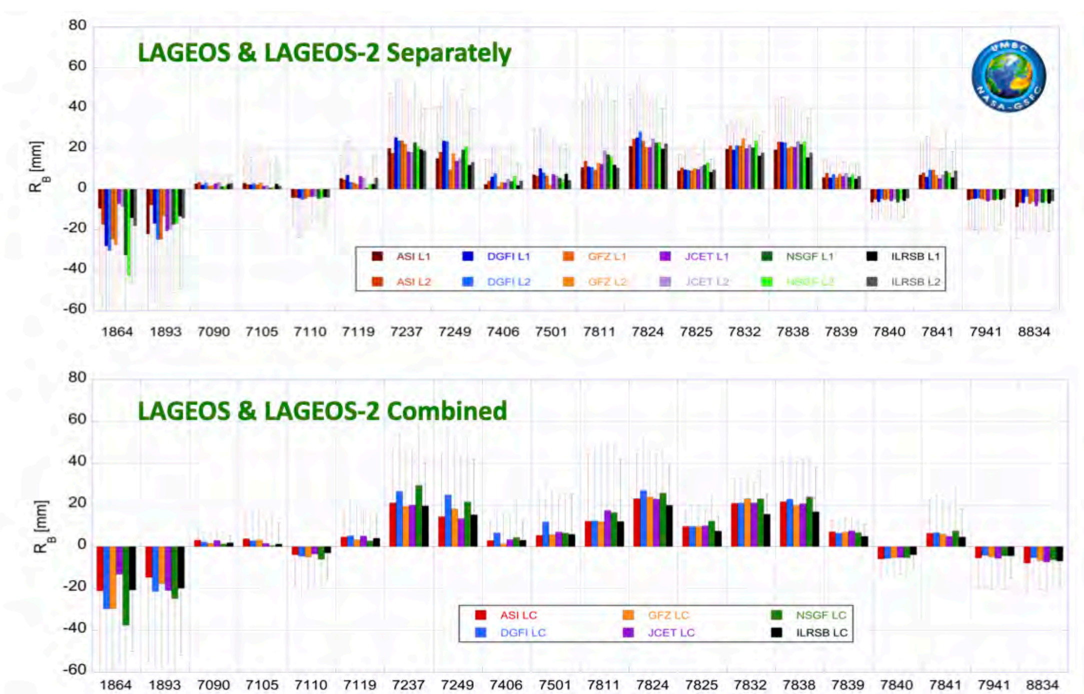

Figure 9-3: Long-term range biases averaged over the test period 2005-2008, estimated separately (top) for LAGEOS and LAGEOS-2 and in combination (bottom), at twenty SLR sites, and from the five participating ACs and the ILRS-B combination (back-up). There is excellent agreement amongst ACs, especially for the stronger, higher yield systems.

The initial approach compared the independent estimation of biases for each of the two LAGEOS and in combination, with the ASC subsequently deciding that due to small but observable differences between the two targets, the estimation of separate biases was deemed more appropriate (Figure 9-3).

The preponderance of significant biases was observed to be positive (Figure 9-3) and when the tests included the Etalon satellites, there was a clear systematic difference between the two targets for nearly all systems (Figure 9-4). This was a clear indication that there were shortcomings with our "target signature" model, the CoG correction for the ranges from each system. By the end of 2016 the SSEM PP had already created great interest due to these findings and the effect of these changes on the official ILRS products was the next task ILRS turned to.

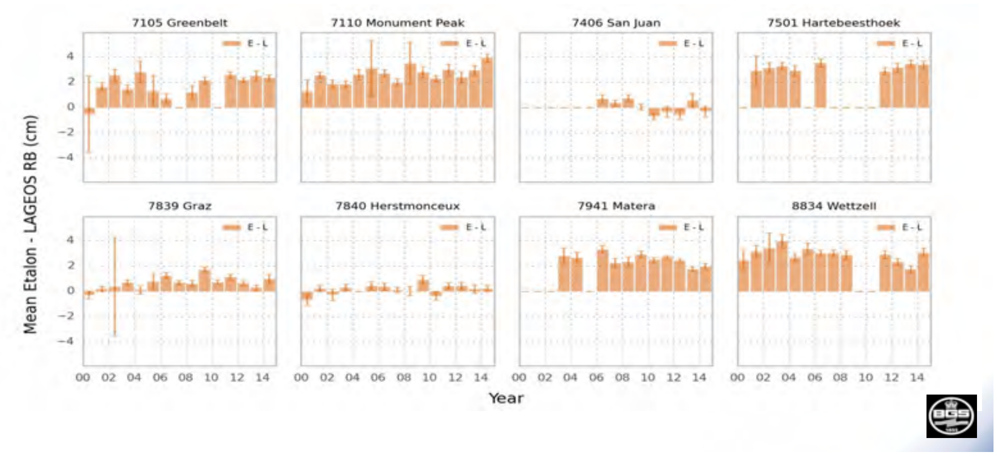

Figure 9-4: Long-term yearly averaged range bias differences Etalon-LAGEOS over the period 2000-2014, at eight SLR sites with very diverse equipment. The fact that some of the best systems showed few-millimeter level LAGEOS biases led to the conclusion that these large differences emanated from the CoG model for the two Etalons.

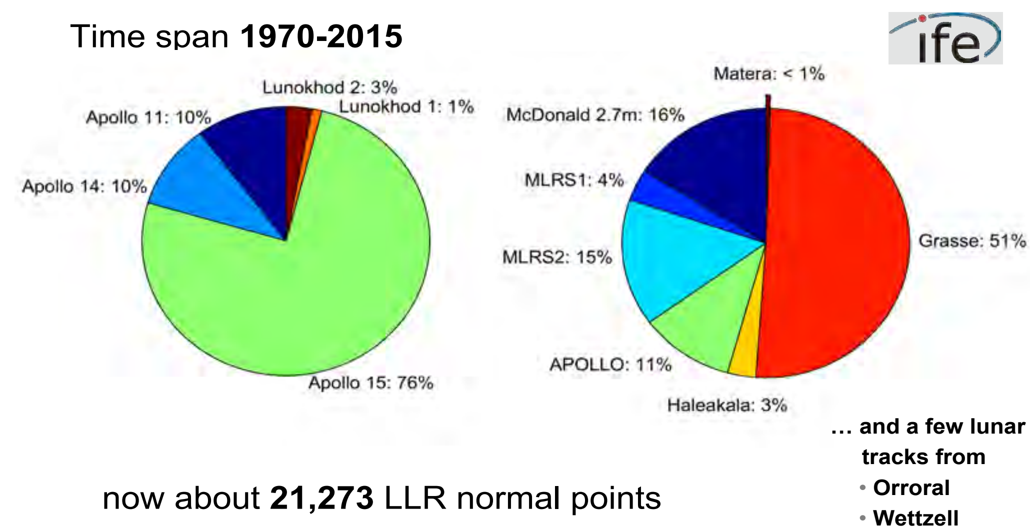

Figure 9-5: LLR NP collected over 1970 - 2015 in terms of their distribution by lunar array and by ground system. The Apollo 15 array and the Grasse station are the most significant contributors in the two categories respectively.

Along with the exciting SLR activities, the LLR group showed increased observations from most of the LLR-capable sites and a steady increase of the yearly accumulated data from all lunar targets, but the majority (>75%) still coming from the large Apollo 15 array and more than half contributed by Grasse (Figure 9-5).

In early 2017, initial tests at NERC showed that the application of the detected biases in the reanalysis would eliminate a large portion of the scale difference between the SLR-based TRF with the current

ITRF2014 (Figure 9-6). The fact that the new approach seemed to imply that biases could remove a great percentage of the scale difference between SLR and VLBI TRF realizations fueled the community that embarked on the completion of the SSEM PP with much more increased urgency, looking forward to the upcoming milestone, the ITRF2020 effort.

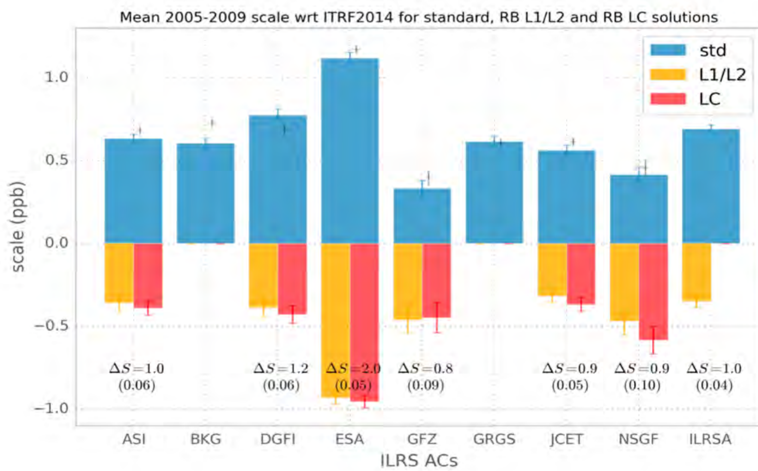

Figure 9-6: Scale differences between ITRF2014 and the standard analysis products by AC/CC over the test period 2005-2009, and between ITRF2014 and two test cases, one with the adjustment of separate LAGEOS range biases and one in combination. On average a ≈1 ppb difference between the two approaches is seen.

Table 9-2: Distribution of attributes of SLR data passes for the main ITRF-supporting targets over the period 2007-2017. Pass duration is in minutes, angles are in degrees [°].

LAGEOS	Pass Duration	Acquisition Elevation	LOS Elevation	Maximum Elevation
Minimum	0	-84.5	-83.9	0
Maximum	99	89.7	89.6	89.65
Points	89582	89582	89582	89582
Median	13	35.2	32.9	49.48
Std Deviation	12.17	15.52	16.61	17.84

LAGEOS-2	Pass Duration	Acquisition Elevation	LOS Elevation	Maximum Elevation
Minimum	0	-88.7	-85.9	0
Maximum	87	89.3	89.5	89.9
Points	79052	79052	79052	79052
Median	14	38.9	38.1	56.0
Std Deviation	13.69	16.67	17.96	18.00

LARES	Pass Duration	Acquisition Elevation	LOS Elevation	Maximum Elevation
Minimum	0	-89.5	-87.6	0
Maximum	23	88.5	88.1	89.4
Points	36485	36485	36485	36485
Median	5	28.0	25.8	43.3
Std Deviation	3.69	14.40	15.58	18.97

As the preparations towards the ITRF2020 reanalysis effort were initiated, several ACs looked into different modeling aspects where inconsistencies amongst techniques larked and could cause systematic differences at the combination step. Questions about the necessity to expand our refraction model were raised, however, a review of the collected data set indicates that the majority of the collected data were mostly taken at elevations ≥ 20° (Table 9-2), therefore the current model is sufficient for sub-mm accuracy.

At this point we set two goals to be completed well before we would start the reanalysis process for ITRF2020:

- The recalculation of the CoG correction model at least for the four targets used for TRF development and LARES (since it would be included in ITRF2020), and
- The re-evaluation of the SSEM series over the entire period 1993-present, using the new CoG model, so that a reference set of biases would be available for the reanalysis.

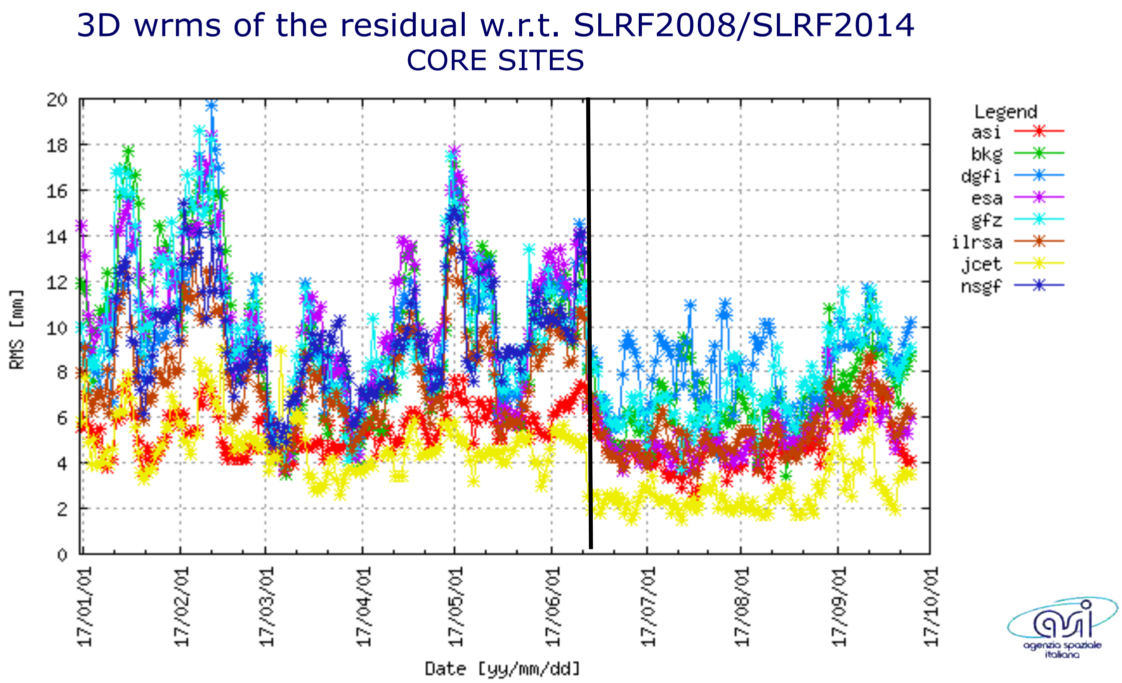

Figure 9-7: 3D WRMS of the residuals of ILRS AC/CC series for Core sites after transformation to SLRF2008 and SLRF2014. After the adoption of SLRF2014 in mid-2017 we can see a significant drop in WRMS for all AC/CC contributing to the comparison.

By the middle of 2017 the IERS released the official EOP series that is consistent with the ITRF2014 and the ASC switched from SLRF2008 to the new version SLRF2014, based on ITRF2014. The adoption of the new model resulted in a very significant improvement of the ASC products (Figure 9-7).

An important model that became also an issue was the consistent adoption of the Mean Pole across all geometric techniques and for all applications. In 2016 it was noticed that the online file of IERS had been changed several times without prior announcement and with no record of how many such changes had taken place and when. On three such occasions the file was downloaded, and the results were compared, indicating large discrepancies over the main period of interest (indicated by the red arrow in Figure 9-8).

To avoid inconsistencies, IERS replaced the tabular series with a FORTRAN routine (*IERS_CMP_2015.f*) that provides the CMP coordinates for a given date. Since the routine was not updated for use during our period of interest, the ILRS ASC created a clone routine (*ILRS_CMP_2016.f*) that included a projected forecast of the CMP for a few years, so that the analysis of current data could proceed.

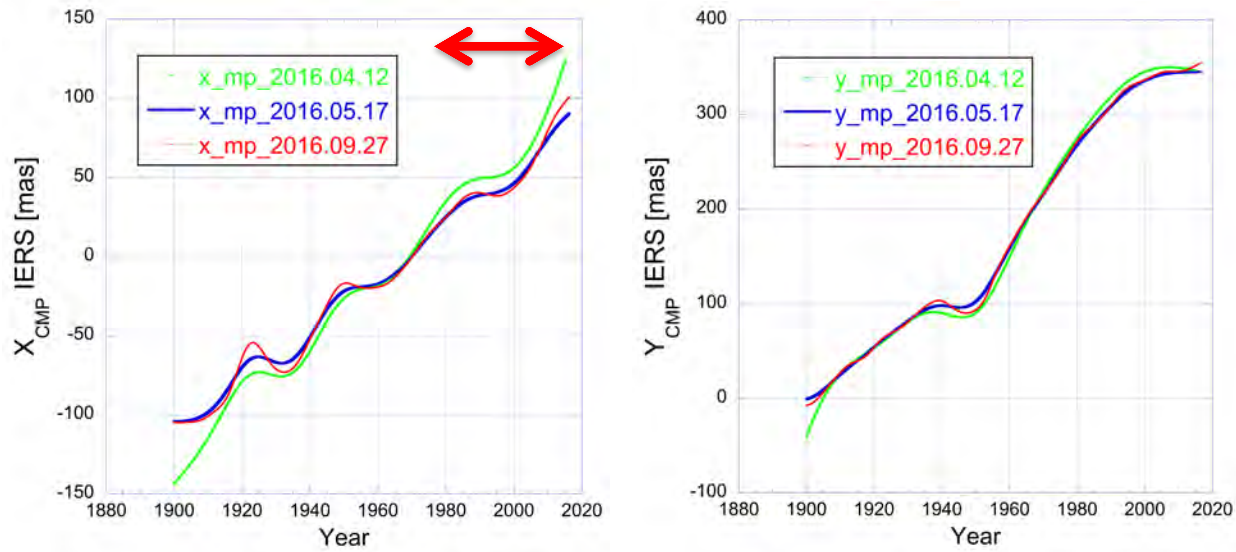

Figure 9-8: Conventional Mean Pole coordinate series downloaded from the IERS web site on three different dates. Over some periods the differences reach 30-50 mas, well above the ±10 mas quoted accuracy.

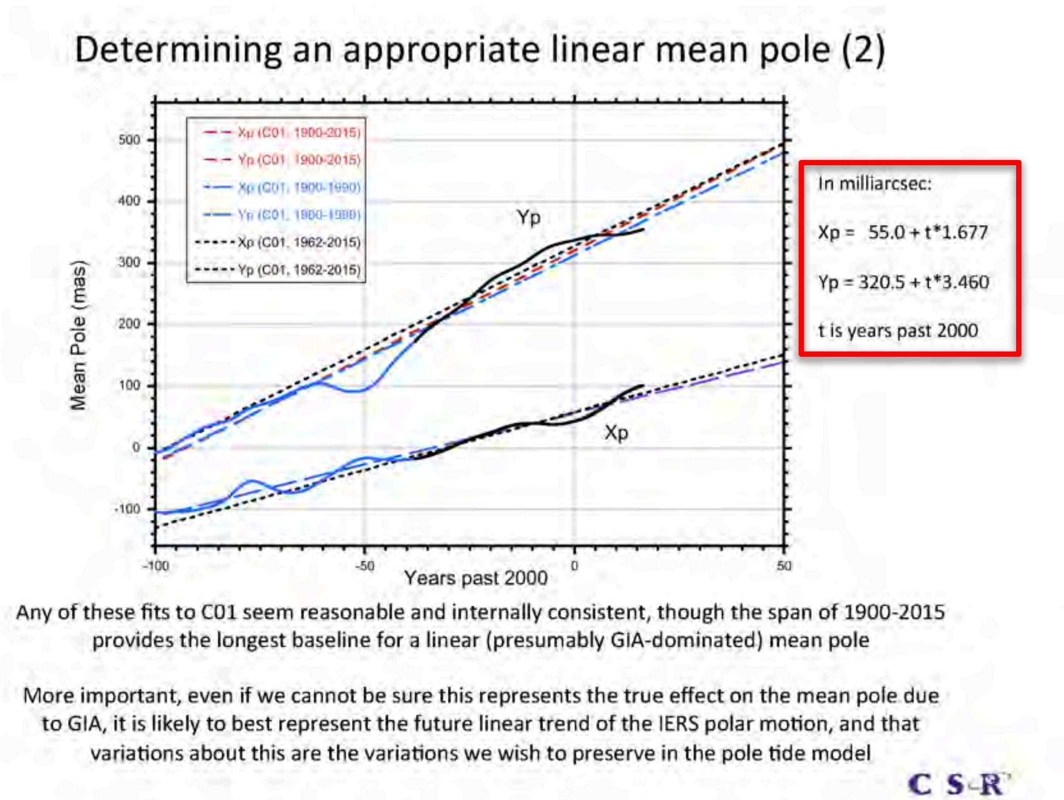

Figure 9-9: Linear fits to IERS C01 series for the development of a linear mean pole model that would replace the CMP. Fitting on subsets of the C01 series resulted in insignificant differences, in the red box the adopted model and parameters.

The lack of a coordinated approach from IERS generated heated discussions in the geometric technique community and eventually, a dedicated session during the 2017 UAW meeting examined the issue and its implications, especially in what concerns the relationship with the degree-2, order-1 gravitational harmonics, and a consensus model was agreed and proposed to IERS. The IERS Directing Board adopted the simple linear model during the Fall 2017 AGU meeting and the appropriate renaming of the CMP to "linear mean pole" to avoid misinterpretations. The actual numerical model was computed and provided to the IERS by the CSR/UT AAC (Figure 9-9), that was instrumental in clearing the confusion associated with this topic for several years.

An important additional resource in tracking and correcting systematic errors in SLR data was added to our arsenal in 2017. The use of the T2L2 experiment products based on FR SLR tracking data from the ILRS network to Jason-2, the oceanographic mission that carried the required instrumentation. Most SLR stations do show significant systematics in their time-keeping record, and even though there is a directive to keep these within ±100 ns from official UTC, this is not easily maintained and sometimes the stations are way outside the limits without even knowing it (Figure 9-10).

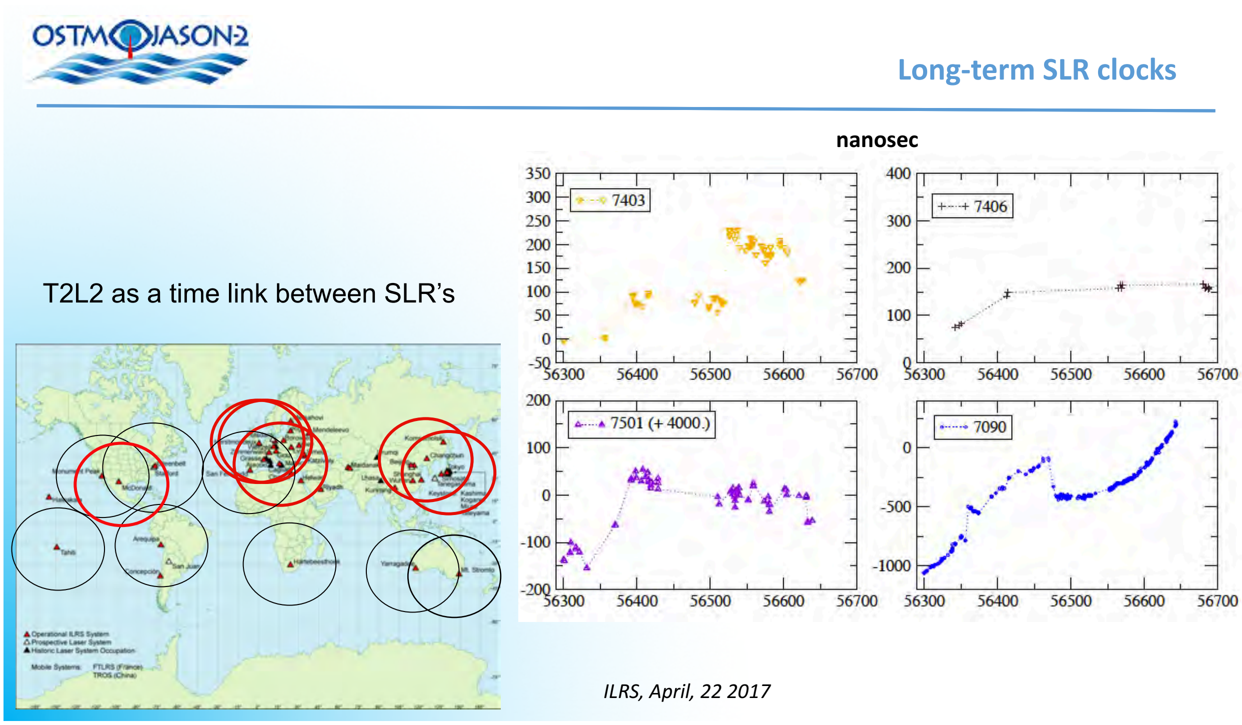

Figure 9-10: Example time series of SLR station clocks records derived from T2L2 comparisons; in some cases (e.g., 7501) the actual time bias is orders of magnitude outside the official ±100 ns limits.

A complete set of time biases for the period 2008-2017 were provided to the ASC and adopted for application in the next reanalysis and all future ones, after an examination of the series to identify the significant ones for ITRF support. The complete set is included in the Data Handling file and the ones recommended for application in the production of the official ILRS products are clearly indicated in the file.

In 2017 the ILRS accepted a new AAC hosted by the Wrocław University of Environmental and Life Sciences with a focus on processing SLR data to GNSS satellite targets. The new AAC demonstrated the contents and use of an online web service (Figure 9-11), capable of providing information related to the data they analyze, for years past, present and promised to maintain it in the years to come.

As we entered 2018, the ASC had decided to repeat the SSEM analysis with the final accepted standards, estimating a separate bias for the two LAGEOS and a combined one for the two Etalons, using the new linear mean pole and an updated version of the CoG tables released on 2017.03.29. The series obtained from this reanalysis were used to initiate the identification, on a site by site case, the periods when that site exhibited a significant, detectable bias, and the adoption of a mean value with an appropriate error-bar as a forward model of the bias in the upcoming ITRF2020 reanalysis (Figure 9-12).

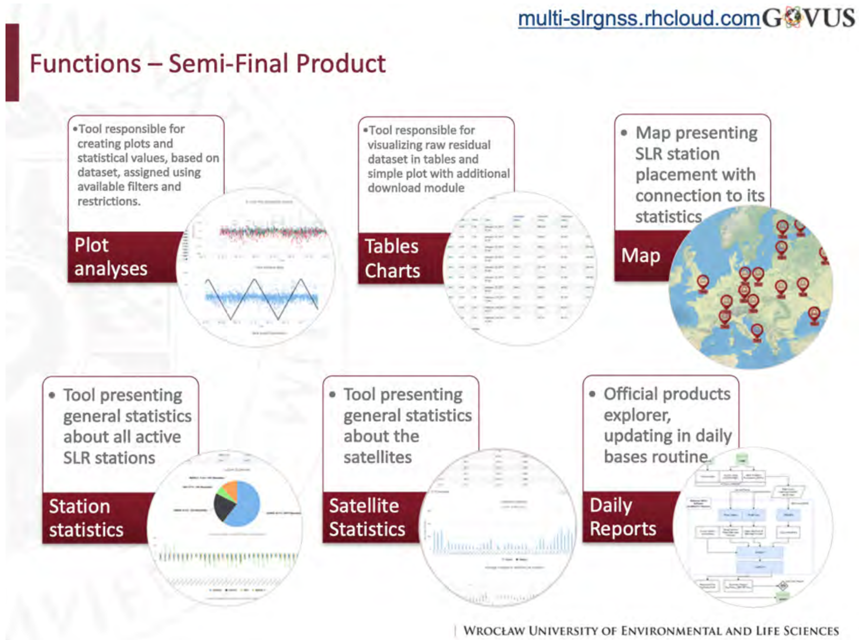

Figure 9-11 : An overview of the available online services from the newly accepted Wrocław University of Environmental and Life Sciences AAC GOVUS site and the link to access it.

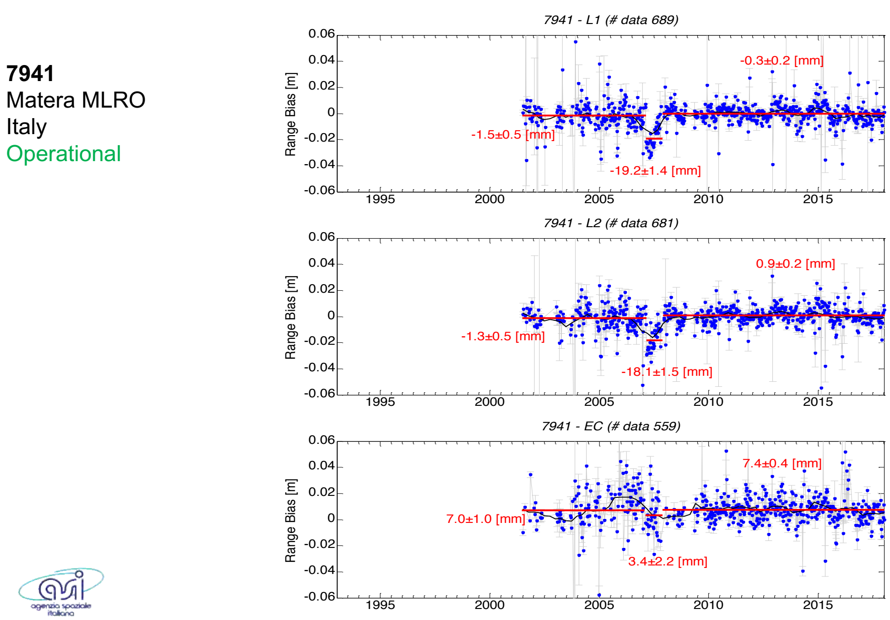

Figure 9-12 : An example with Matera's MLRO (7941) Range Bias series, identifying periods of significant and persistent range biases, and computing their mean and standard deviation for use in forward modeling in future reanalysis.

The application of such biases and reanalysis of the SLR time series of weekly products indicated very clearly that the new approach would result in the change of the scale with respect to the standard approach by about 1 ppb (!) as it is clearly seen in the comparison below (Figure 9-13).

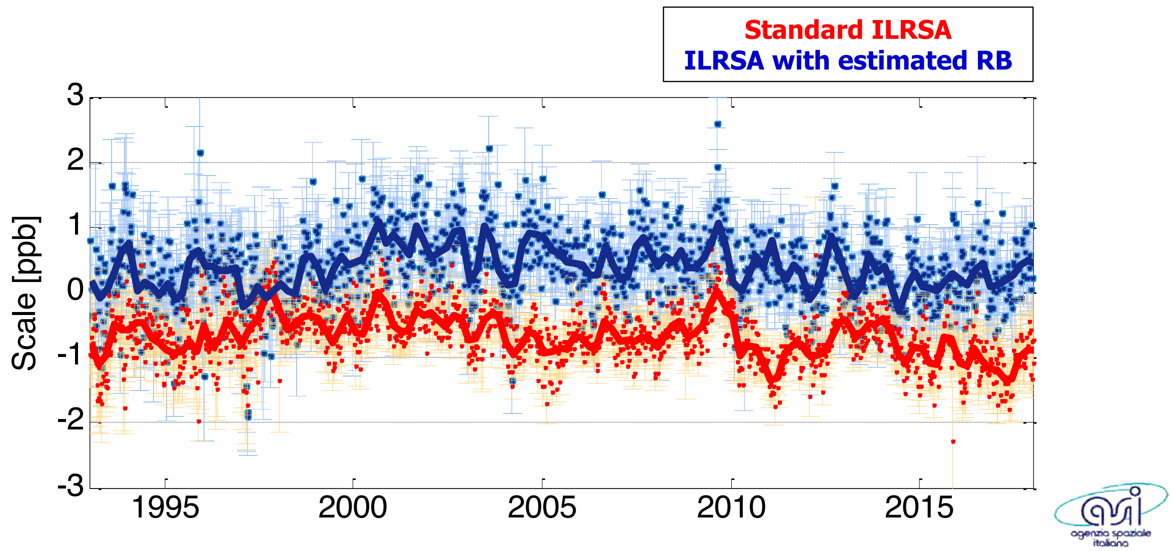

Figure 9-13 : Preliminary results from the comparison of the two ILRS-A weekly series (1993-2017) in terms of scale differences, indicating the significant and systematic scale change between the two approaches of data reduction.

The long-term biases that were obtained from the recent reanalysis (Figure 9-14) indicated that the core network was only affected at the ±10 mm level, however, it became obvious that these biases were not the result of undocumented problems at the stations alone, since they were distributed in a very lopsided fashion, being mostly positive throughout the network. This pointed to a source that is common to all systems and all targets, the applied CoG correction model.

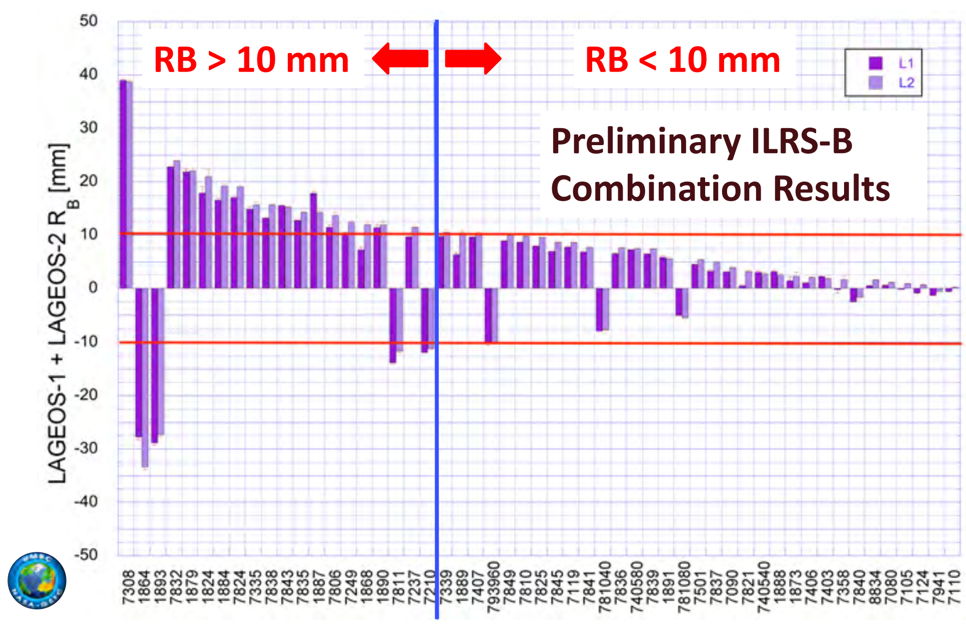

Figure 9-14 : The long-term biases obtained from the reanalysis of the ILRS-B weekly series (1993-2017) for LAGEOS and LAGEOS-2. The majority of the core sites show R_b within ±10 mm and the consistent but small difference between the two targets is clear.

Near the end of 2018 the new, revised CoG model from NERC is about to be released and preliminary results are presented at the Canberra Workshop, where the application of the revised model results in large changes for the Etalon CoG model for almost all stations while the change of the model for the two

LAGEOS results in mm-level individual station bias changes and a more random distribution of the reduced relative (LAGEOS – LAGEOS-2) R_b differences over the network (Figure 9-15).

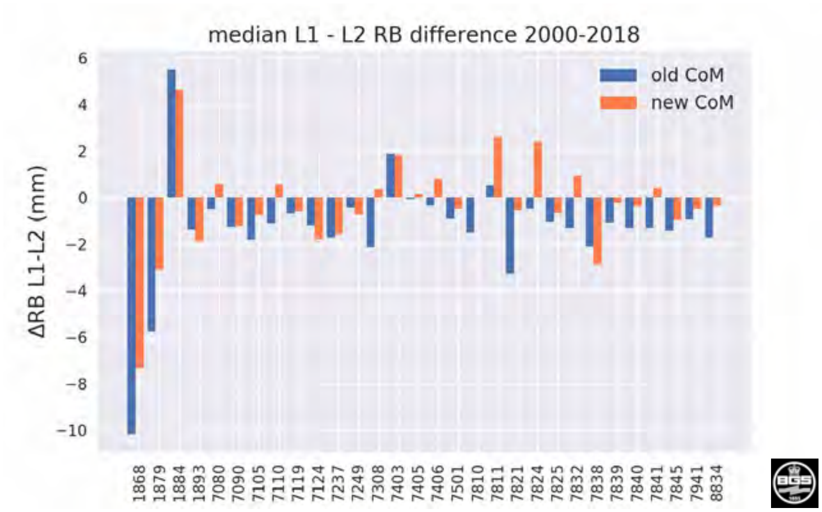

Figure 9-15 : The application of the revised CoG model from NERC resulted in smaller long-term range biases and a more random distribution of the median difference between the two targets LAGEOS and LAGEOS-2 (2000-2018).

In 2018, a discussion between the JCET and DGFI teams for the possible introduction of a new ILRS product based on SLR tracking data to GNSS and other targets creates interest for a closer examination of the existing archived data. The group from ESA, with a long history in GNSS data analysis and applications, presented preliminary results comparing the standard ASC products to possible future combinations with GNSS data (Figure 9-16). Although there is general agreement at the few millimeter level, there are also very clear cases with very significant differences that are clearly the effect of the GNSS contributed data. It is comforting to see that with some additional effort, we could easily reach a level of agreement and a new product would be possible in the near future.

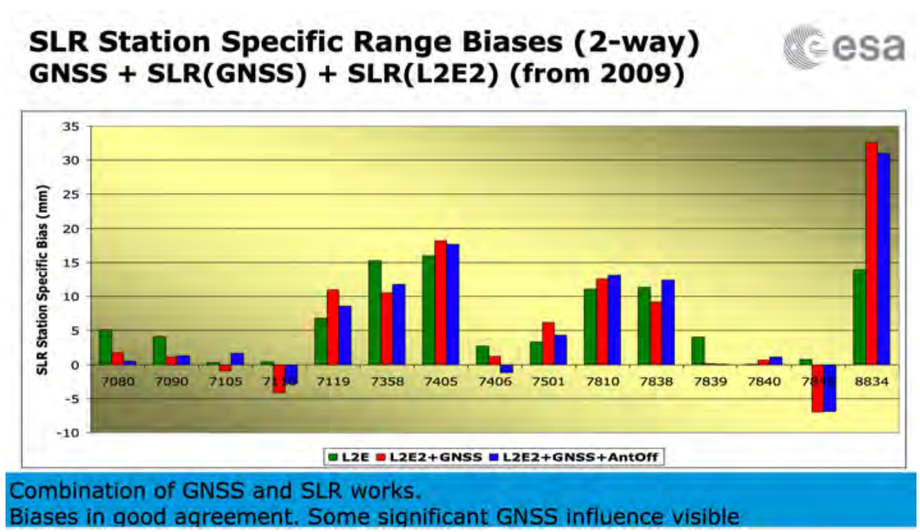

Figure 9-16 : Annual (2009) mean range biases obtained from the standard ASC analysis compared to those obtained from the addition of SLR data to GNSS targets (including tests with antenna offset calibration).

The Lunar AAC hosted by IAA introduced the work that is taking place in their institution and some of the services they provide to the LLR community (Figure 9-17). An eventual joint SLR-LLR solution has always been in the plans, however, it is only at this point that this seems to have a real chance of happening soon.

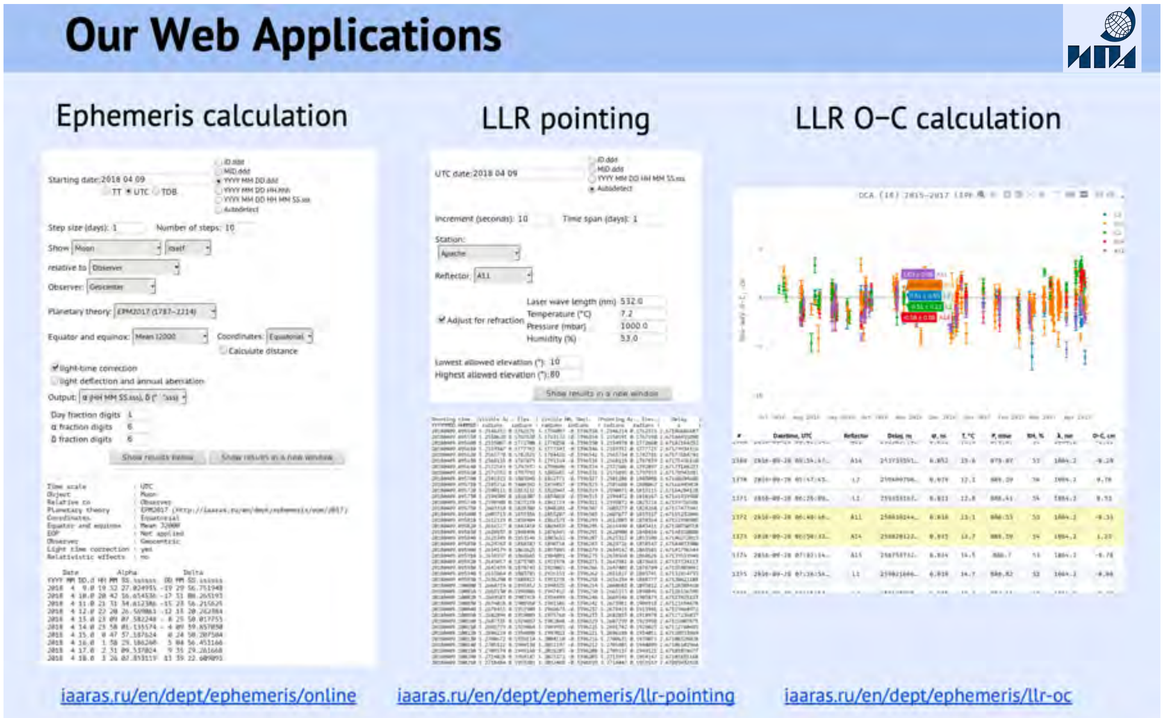

Figure 9-17 : A sample of services and results provided to the LLR community by the IAA/RAS LAAC.

The Shanghai Astronomical Observatory (SHAO) AAC presented work that compared the estimation of atmospheric delay horizontal gradients from GNSS data and SLR data, the results however did not cover the global network neither a large enough period of time. Additionally, the magnitude of the effects seemed a lot smaller than previous works had indicated and it was decided not to extend our efforts at this time given that these effects showed less than 1 mm RMS signature.

At the 2019 IUGG the Wrocław AAC presented an empirical model of horizontal gradient corrections for application to SLR observations. Their model is based on the analysis of eleven years of numerical weather data at each SLR station with a 6-*hr* temporal resolution. The model was applied for evaluation on a limited data set spanning a few years of official ILRS products, with mixed results and very small effect overall. Its application therefore has been postponed for the future, after further improvement in its resolution and accuracy has been achieved. Its application on data from for low-orbiting satellites, such as LARES, Starlette and active LEOs may be especially advantageous.

Unfortunately, lack of a final CoG model well before the end of 2019 prohibited us from finalizing the SSEM PP in time for this report, although the preliminary results on the basis of the provisional model releases were very encouraging. There were no results from the PP related to the introduction of LARES as a fifth target in support of the ITRF development either, therefore, its launch was postponed for after completion of the SSEM PP.

Current Activities

At the time this quadrennial report is compiled (May 2020), we have reached and surpassed several milestones set over the past year. The final CoG model was delivered by NERC in November 2019 and after some minor adjustments and additions, it has been placed in use. The ASC has adopted that model for all products and applications. We are in the process of revising the ILRS web pages where this will be presented and archived, including past and future versions.

A final reanalysis for the SSEM PP series has been completed and the SINEX collection is now in the process of forming a combination. Once this step is completed the individual series of range biases for each site will be examined and the periods of persistent range biases identified, followed by the computation of the mean bias for each period and its standard error. The ensemble of these series of mean biases and associated epochs of validity will comprise the model for range biases which will become part of the new Data Handling file and the basis for the ITRF2020 reanalysis effort.

An IERS Study Group on High Frequency EOP (HFEOP) completed its testing and ILRS had several participations that supported the testing of a large number of candidate models to replace the outdated model in the IERS Conventions. After careful considerations the IERS adopted the model of Desai and Sibois which is now the one in use by the ILRS ASC. The results from different models were very close as one can see in Table 9-3 which summarizes the tests of all of the submitted models at JCET AC.

Table 9-3: Results of tests performed at JCET for all HFEOP candidate models over 2017. The models are evaluated in terms of their EOP components bias w.r.t. the components of IERS C04 and the scatter about it. The selected/adopted model in the red box.

Model	Libration Not Included						Libration Included					
	Xp_J - IERS C04		Yp_J - IERS C04		LOD_J - IERS C04		Xp_J - IERS C04		Yp_J - IERS C04		LOD_J - IERS C04	
	Mean [µas]	Std Deviation [µas]	Mean [µas]	Std Deviation [µas]	Mean [µs]	Std Deviation [µs]	Mean [µas]	Std Deviation [µas]	Mean [µas]	Std Deviation [µas]	Mean [µs]	Std Deviation [µs]
NONE	82.56	299.08	-18.05	313.03	-10.20	81.24	---	---	---	---	---	---
GSFC-IERS_2018	17.65	183.97	39.64	178.34	3.81	38.21	---	---	---	---	---	---
DESAI	15.19	184.19	38.50	178.54	4.55	38.34	15.67	184.31	38.73	178.05	3.92	38.04
EOT11A	15.39	184.16	39.98	179.26	5.10	38.38	15.27	184.26	39.28	178.82	4.58	38.13
FES2012	16.01	183.79	38.66	178.49	4.66	38.17	16.30	184.00	38.84	178.00	4.03	37.93
HAMTIDE	14.77	184.43	38.53	179.21	4.53	38.99	15.05	184.61	38.63	178.89	3.90	38.68
IERS2010	16.96	183.78	38.39	178.08	3.68	38.06	18.08	184.12	40.69	177.81	3.01	37.81
MAZDAK	15.12	184.26	38.73	178.13	4.93	38.33	15.51	184.42	39.02	177.70	4.31	38.05
VLBI	15.74	184.48	39.46	177.51	4.17	38.05	17.65	183.97	39.64	178.34	3.81	38.21
VLBI+GPS	16.54	184.07	39.09	177.54	3.05	38.08	17.58	184.31	39.33	177.45	2.45	37.88
GIPSON PM & VLBI+GPS UT1	---	---	---	---	---	---	18.22	184.32	39.07	177.18	2.50	37.89
GIPSON	---	---	---	---	---	---	14.96	184.42	38.61	177.46	4.08	38.18
GIPSON-L	14.05	184.35	38.24	178.07	4.74	38.35	14.98	184.41	38.64	177.48	4.05	38.19

During 2019 the ASC adopted a new standard for the SINEX format content to be used with the release of the reprocessed products for ITRF2020. This refers to the full disclosure and documentation of the Range biases, Time biases and CoG corrections applied to each participating station's data which are included in the process of generating the specific SINEX. In doing so, the information is immediately available to any user of the SINEX without the need to resort to looking up separate files, whether online or else. This also allows for a check of what the individual ACs have applied during their analysis, and the detection of errors and discrepancies. The format adopted for these three separate blocks to be included in the SINEX files was adopted during the ASC meeting prior to the 2019 UAW meeting in Paris. An example of what these will look like is shown in Figure 9-18.

```
*        1         2         3         4         5         6         7         8
*234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
*-------------------------------------------------------------------------------
+MODEL/RANGE_BIAS
*SITE PT SOLN T START_DATE__ END_DATE____ M RANGE_BIAS STD_DEV UNIT
 1873 51  501 L 08:288:00000 08:295:00000 R    -0.0193   1.000    m
 7810 51  501 L 08:288:00000 08:290:54321 R     0.0173   1.000    m
 7810 51  501 L 08:290:54321 08:295:00000 R     0.0183   1.000    m
 7810 60  501 L 08:288:00000 08:295:00000 R     0.0163   1.000    m
-MODEL/RANGE_BIAS

*        1         2         3         4         5         6         7         8
*234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
*-------------------------------------------------------------------------------
+MODEL/TIME_BIAS
*SITE PT UNIT T START_DATE__ END_DATE____ M __E-VALUE___ STD_DEV _E-RATE__ CMNTS
 1824 -- us   A 02:084:68460 12:085:00000 T      -24.400   5.000    0.0000 -----
 1873 -- us   A 07:059:00000 09:110:00000 T      -21.750  50.000   -0.2600 drift
-MODEL/TIME_BIAS

*        1         2         3         4         5         6         7         8
*234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
*-------------------------------------------------------------------------------
+MODEL/TARGET_SIGNATURE_GEOMETRY
*SITE PT SOLN T START_DATE__ END_DATE____ M   COM_CORR STD_DEV UNIT
 1873 51  501 L 08:288:00000 08:295:00000 C     0.1234   2.000    m
 1879 52  501 L 08:288:00000 08:295:00000 C     0.1234   2.000    m
 7810 52  501 L 08:288:00000 08:295:00000 C     0.0183   2.000    m
 7810 60  501 L 08:288:00000 08:295:00000 C     0.0163   2.000    m
-MODEL/TARGET_SIGNATURE_GEOMETRY
```

Figure 9-18 : An example of the format adopted for the three new Blocks in the ILRS SINEX format, for reporting corrections pre-applied to the data.

Some of the goals for the work to be done in the near future are summarized in:

- Estimation of low-degree SH of the gravity field
- Inclusion of LARES as a 5th satellite in our operational product development
- Plan for the expansion of the target used in operational products
- Pilot project on NT Atm. Loading and Gravity

The overarching effort is of course the completion and submission of the reanalyzed data set for the development of ITRF2020, however, to achieve this some of the listed topics must be fulfilled first (LARES test) and some of the rest are long overdue (e.g., the low-degree SH product).

One of the most important achievements of 2019 was the completion and publication of the Special Issue of Journal of Geodesy on Laser Ranging, with leading guest editors the two ASC co-chairs. A list of the diversely themed articles included in the SI is shown in Table 9-4. Completion of the SI after a three-year effort was the result of the contributions from the entire ILRS community and provides a reference to the current state of the ILRS as well as a source for information of how we arrived at this point.

Future Plans

The work planned for 2020-2021 is predetermined by the fact that we are in the process of developing a new ITRF model, due for release sometime in late 2021. In the present year we will complete all of the reanalysis of the SLR data from 1983 to present and form combinations of the available weeks before the end of the year. In early 2021 we will complete these steps for the last few weeks of 2020 and a complete set of combined SINEXs should be ready for delivery to ITRS in February 2021.

Table 9-4: Articles included in the Special Issue of Journal of Geodesy on Laser Ranging

- *Preface to the second Special Issue on Laser Ranging*
- The ILRS: Approaching twenty years and planning for the future
- Geodetic Satellites: A High Accuracy Positioning Tool
- Lunar Laser Ranging - A Tool for General Relativity, Lunar Geophysics and Earth Science
- Information Resources Supporting Scientific Research for the International Laser Ranging Service
- The Next Generation of Satellite Laser Ranging Systems
- NASA's Satellite Laser Ranging Systems for the 21st Century
- Modernizing and Expanding the NASA Space Geodesy Network to Meet Future Geodetic Requirements
- Future SLR station networks in the framework of simulated multi-technique terrestrial reference frames
- Impact of network constraining on the terrestrial reference frame realization based on SLR observations to LAGEOS
- Satellite Laser Ranging to Low Earth Orbiters - Orbit and Network Validation
- Rapid Response Quality Control Service for the Laser Ranging Tracking Network
- Transitioning the NASA SLR network to Event Timing Mode for reduced systematics, improved stability and precision
- Systematic errors in SLR Data and their impact on the ILRS products
- Time Bias Service: Analysis and Monitoring of Satellite Orbit Prediction Quality
- Operating two SLR Systems at the Geodetic Observatory Wettzell - from local survey to space ties
- Time and laser ranging: A window of opportunity for geodesy, navigation and metrology
- Laser and Radio Tracking for Planetary Science Missions - A Comparison
- Assessment of the impact of one-way laser ranging on orbit determination of the Lunar Reconnaissance Orbiter
- Version of a glass retroreflector satellite with a sub-millimeter "target error"
- Studies on the materials of LARES 2 satellite

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Twenty articles and the preface, 287 pages

The remainder of 2021 will be devoted to tests and support of the ITRS Combination Centers, addressing any errors or inconsistencies that they might find in our submissions, and when the final ITRF2020 is released, the performance of tests for the evaluation of the new model with SLR data. Although these will be our main activities, we will in parallel address the other topics of the future goals and have not been completed by then. In particular, the generation of the new products of low-degree SH and products that take advantage of the SLR tracking of GNSS and other SLR targets.

Contact


Figure 9-19. ASC Chair Erricos Pavlis and Co-Chair Cinzia Luceri.

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Data Formats and Procedures Standing Committee (DFPSC)

Authors: *Christian Schwatke/DGFI-TUM, Randall Ricklefs/CSR*

Chair: Christian Schwatke
Co-Chair: Randall Ricklefs

Role of the Data Formats and Procedures Standing Committee

The Data Formats and Procedures Standing Committee (DFPSC) is responsible for developing standard procedures which affect the generation of full-rate and normal point data, maximizing the efficiency of the process of generating the laser data, and ensuring that data products contain all the information needed by the analysts

Recent Achievements and Current Activities

New CRD and CPF Formats

The update to the existing Consolidated Laser Ranging Data format (CRD) and Consolidated Prediction Format (CPF) was a major topic in previous years but is still an ongoing topic as the initial format released in 2009 requires upgrades to properly handle new applications. The formats must be updated for the following reasons:

- Additional information for the European Laser Timing (ELT) Experiment will be included in the prediction format;
- Debris tracking will be included to avoid multiple branches of the CRD format; and
- Additional information is included for meteorology, software, camera, calibration, predictions, etc.

For this task, a new study group, “Data Format Update”, was initiated, working on the update of the existing CRD and CPF specification, which was finally released in 2018. Since then, operation centers, data centers, stations, prediction providers, analysis centers, etc. have been encouraged to implement the new CRD and CPF specification.

Data Harmonization between OCs and Quality Assessment for CRD

The ILRS operates two global data and operation centers. In order to achieve homogeneous data validation, the applied quality checks by the OCs must be identical. Using the updated processes, the OCs check not only the data format but also performs analysis of the content of the fields. The DFPSC and the NESC have worked together in order to define reliable boundaries for all fields. The new data screening procedures were implemented at the OCs on August 15, 2019.

Station History Logs and Site Logs

The DFPSC worked on the automation of the station history log and site log management in order to improve and clarify the update process. This was realized by the site log manager which allows stations to update their log on-line on the EDC website. In this step, the site log format (version 2) was released which contains 18 updated and 100 new fields. The site logs from all stations have now been converted to version 2, which is now the standard format.

New Leap Second Procedure

The inconsistent handling of leap seconds in CPFs from different prediction providers and in different stations' software led to confusion and data loss around the time of the introduction of a leap second. Therefore, the DFPSC formulated a new procedure which proposed to stop tracking during leap seconds – the "coffee break approach".

Future Plans

The main objective of the DFPSC through the end of 2021 is to coordinate the implementation phase of the new CRD and CPF, which contains several milestones shown in Table 9-5.

Table 9-5. Implementation Plan for Version 2 of CRD/CPF Formats

January 2019	–	OCs, DCs should be able to handle v2 CPFs and CRDs
	–	At least one prediction provider should be producing v2 CPFs
	–	Some analysts should be able to process v2 CRD files
February 2019	–	OCs, DCs should be able to handle v2 CRDs
March 2019	–	Some analysts should be able to process v2 CRD files
December 2019	–	Almost all stations should be able to use v2 CPFs (required for those tracking ELT)
December 2020	–	All prediction providers should be producing v2 CPFs All analysts should be able to process v2 CRD files
December 2020	–	Almost all stations should be producing v2 CRDs
December 2021	–	Goal for discontinuing CPF v1 distribution

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Missions Standing Committee (MSC)

Author: *Toshimichi Otsubo/Hitotsubashi University, Scott Wetzel/NASA GSFC, KBRwyle*

Chair: Toshimichi Otsubo (Stephen Merkowitz starting mid-2019)
Co-Chair: Scott Wetzel (Toshimichi Otsubo starting mid-2019)

Summary

In the 2016-2019 period, the ILRS Missions Standing Committee (MSC) hosted three annual meetings in Potsdam, Riga and Canberra, all in conjunction with the ILRS-hosted workshops. A large majority of the standing committee discussions are conducted via email communications. In 2016, the name of this group is changed from Missions Working Group to Missions Standing Committee. In 2017, we largely updated the member list by removing six persons and adding three persons. In mid-2019, Stephen Merkowitz took over the role of MSC Chair with Toshimichi Otsubo remaining as the co-chair until 2020 when Robert Sherwood will take over co-chair responsibilities.

Two significant activities occurred during the 2016-2019 timeframe and are summarized in this report: the revision of Mission Support Request Form and the reconstruction of GNSS webpages. A list of newly approved missions is also included.

Revision of the ILRS Mission Support Request Form

The Mission Support Request Form (MSRF) was developed by the MSC, with concurrence of the ILRS Central Bureau (CB). Missions requesting SLR tracking support must complete this form in order to provide information required to enable the ILRS to determine if future laser ranging to the satellite is warranted. The form allows for the mission to provide important information, including key contacts, mission descriptions, and satellite and laser retroreflector array characteristics that will allow the ILRS to assess the use of the SLR data in the development of science data products and to provide the mission with the SLR data that supports their goals. The MSC also reviewed submitted MSRFs and provided recommendations and feedback to the CB and GB for future mission support.

In 2016, the Standing Committee revised the MSRF. Based on past experience with mission approval, the MSC re-designed the form to help mission sponsors more easily complete the form and to remove some ambiguous questions. An additional improvement to the form simplifies the approval process for follow-on missions, enabling an "incremental submission" in which only renewed information is required. The revised MSRF can be downloaded from the ILRS website (*https://ilrs.gsfc.nasa.gov/missions/mission_support*).

The MSC also updated the MSR submission scheme in 2018: the Mission Support Request Form must now be submitted at least six months prior to launch or from when mission expects tracking support to begin. The MSC clearly specified seven critical points which the ILRS must consider through the review stage. The new support guidelines are available on the ILRS website at URL: *https://ilrs.gsfc.nasa.gov/missions/mission_support/new_mission_support.html.*

Updates to GNSS Mission Webpages

Each mission supported by the ILRS has its own set of webpages within the ILRS website. These pages include detailed information about the satellite's retroreflectors. For GNSS, however, there are a number of satellites with the same or similar configurations, and the ILRS website had not always contained updated information. Collaborating with the ILRS CB, in 2018, we reconstructed the mission webpages for GNSS satellites with the links to the Mission Support Request Forms, or the submitted supplementary information containing retroreflector details. We completed the updates for Galileo, BeiDou, and QZSS; updates for GLONASS and IRNSS have not yet been completed.

Recently Approved Missions

Missions approved during the reporting period include: Sentinel-3A/B, Lomonosov, COSMIC-2, QZS, BeiDou, TechnoSat, ICESat-2, S-NET, GRACE Follow-On, GEO-IK-2, LightSail-2, RANGE, CHEFSat, Tiangong-2, HY-2B, PAZ, Astrocast, and BLITS-M. It should be noted that small satellites are being planned with retroreflectors and some mission sponsors are new to the ILRS.

Future Plans

The observability of laser ranging is limited: a laser ranging station can observe only under a clear sky and track one satellite at a time. Having nearly one hundred targets in space (and increasing) and only a few tens of busy stations, we will not be able to approve every mission proposal as suggested in the newly adopted guideline. At the same time, a new topic “Mission Tracking Feedback” has been created within the Networks and Engineering Standing Committee Forum (special thanks to M. Wilkinson, NERC UK):

http://sgf.rgo.ac.uk/forumNESC/index.php?board=23.0

which is designed to exchange observing experiences not just among laser ranging stations but also with mission sponsors.

It is also important to strengthen the collaboration with other services, such as the IGS, the IDS, and the GGOS Standing Committee on Satellite Missions, since the “space tie” among different techniques nowadays has great value.

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Networks and Engineering Standing Committee (NESC)

Author: *Matthew Wilkinson/NERC Space Geodesy Facility*

Chair: Matthew Wilkinson
Co-Chair: Georg Kirchner

Role of the Networks and Engineering Standing Committee

The Networks and Engineering Standing Committee (NESC) exists in the ILRS to draw on the experience, knowledge, and creativity in the global network in order to advance the satellite laser ranging technique and boost the performance of every station. It aims to strengthen the network links to promote collaboration, information sharing and best practice. The diversity that exists in the network is advantageous because by comparing and contrasting station performance and data quality, alongside the different hardware and software used, the best techniques and instrumentation can be identified. Any upgrade at one station could also potentially benefit others. The NESC can offer a network, technical perspective to other ILRS bodies (such as the Governing Board, Central Bureau, or other SCs) that is informed by the operational experience of its members.

Recent Achievements

The Beam Divergence Procedure was carried out by the majority of SLR stations in the ILRS network. It was shown to be an efficient and reliable method to determine the emitted laser beam divergence and the results largely agreed with the values recorded in the ILRS site logs, as shown in the bar chart below. The results are available on the ILRS website: *https://ilrs.gsfc.nasa.gov/docs/2018/BeamDiv_writeup.pdf*.

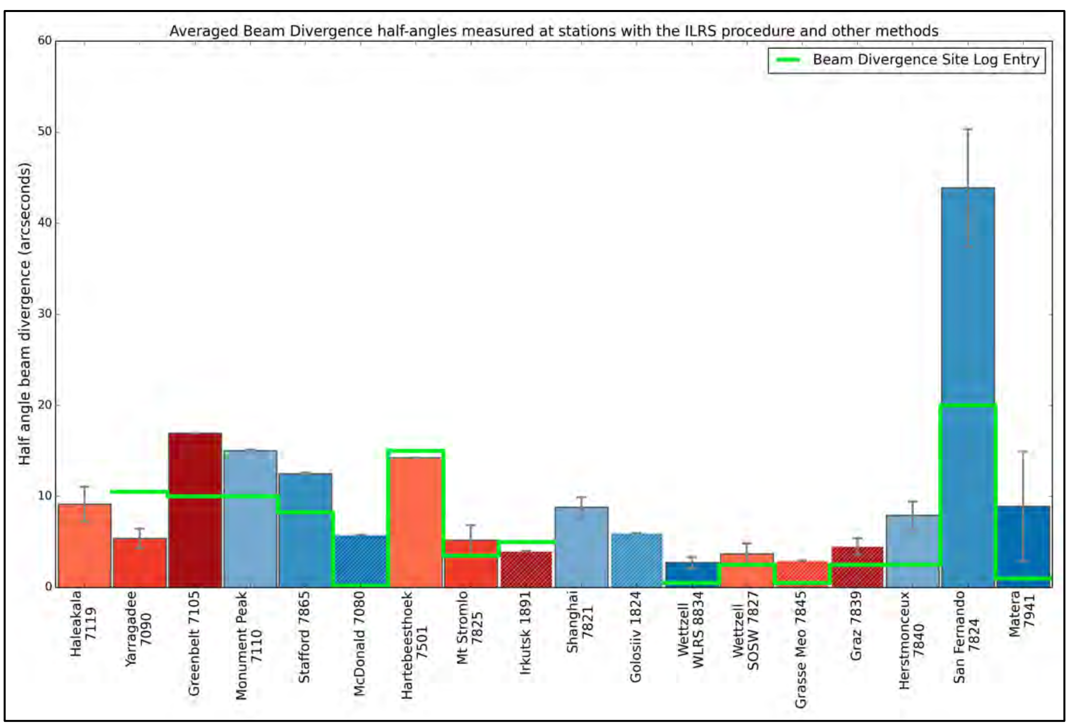

Figure 9-20. Results of the NESC's beam divergence procedure implemented at stations in the ILRS network.

An online forum for the NESC, and for the wider ILRS community, was launched (*http://sgf.rgo.ac.uk/forumNESC*) to encourage knowledge sharing, collaboration and community support. It currently has 84 members and is open for registration. A series of discussions now exist under the two main categories of 'General Topics' and 'Questions to the NESC Forum'. The topics for discussion are organized in 'boards', such as 'Station Performance' and 'Station Equipment Questions'. Members can start new topics and post replies to existing topics. All members of the NESC are encouraged to be active participants and to invite their colleagues to join this online community.

The NESC provided input to the new ILRS site log format over the course of its review. A recommendation was made by the NESC to encourage a standard approach to the full-rate data files that would ensure that all successful SLR returns are recorded. The NESC approved a list of criteria to be used in the quality control of CRD SLR data submitted to the ILRS Data Centers.

Current Activities

A reorganization of the NESC is underway. It is proposed that small panels are formed to address specific issues and to drive progress on important topics. The NESC meetings will be focused on reviewing the work of these panels and making decisions and recommendations accordingly. A schematic of how the NESC would work is shown below.

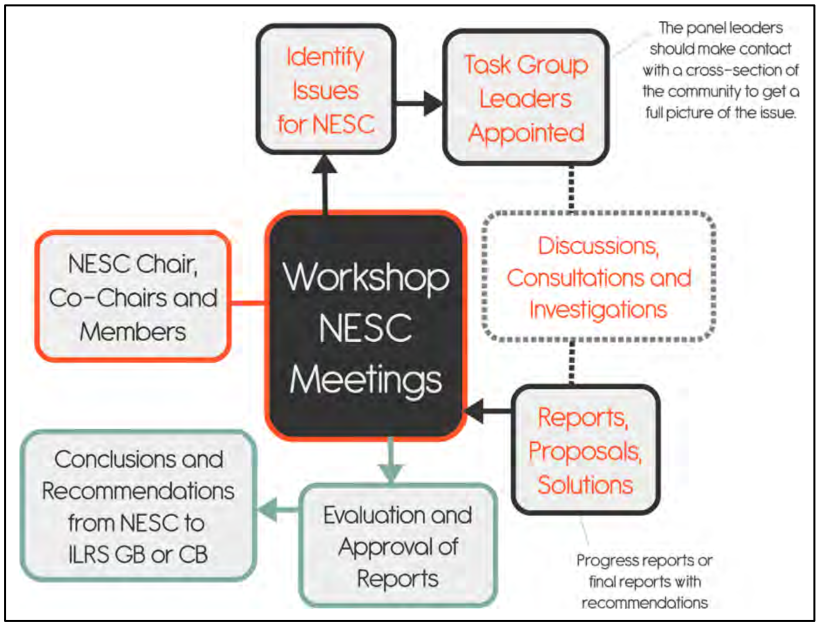

Figure 9-21. Plans for the reorganization of the NESC processes.

The NESC operations, including the annual meetings, could better serve the needs of the ILRS. The strength of the NESC is its membership, who can identify the important issues, hold discussions and arrange experiments, find solutions and make reports back to the NESC. The NESC meetings would then include:

- Determining priorities and problems
- Identifying individuals to work on the issues
- Reviewing reports to the NESC that detail how an issue was considered and resolved.
- Once an issue is resolved, recommendations can be drafted and sent to the appropriate ILRS body.

Future Plans

Once the restructuring of the operations of the NESC is complete, the NESC should aim to make progress and find resolutions to the most pressing issues. For illustration, these issues could include:

- Monitoring a station invariant point and the impact of temperature change
- Alternative methods to calculate a normal point
- Tracking scheduling for the GNSS and the increasing number or targets
- Station performance criteria to reflect all of the work done at stations
- Meteorological measurements at SLR stations
- Accuracy of the timing references at SLR stations

It would currently not be at all possible to address these questions, as valid as they may be, in the annual one-hour NESC meetings. The NESC online forum offers some space to advance discussion, but the NESC needs to operate in a way that it can help to address these concerns and others.

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Transponder Standing Committee (TSC)

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Chair: Ulrich Schreiber
Co-Chairs: John Degnan, Jan McGarry

Summary

Over the last several years there were three major activities on the agenda of the Transponder Standing Committee. These were the one-way ranging to the Lunar Reconnaissance Orbiter (LRO), the preparations of the upcoming time transfer mission “Atomic Clock Ensemble in Space” (ACES) and the time transfer by diffuse reflection on selected space debris items.

Recent Achievements and Current Activities

One-way ranging supported the LRO mission by improving the clock on the satellite. LRO also carried a cube corner reflector, which was eventually successfully tracked in a two-way ranging configuration by the MeO station in Grasse. Earlier ranging attempts from the Apache Point Observatory Lunar Laser ranging Operation (APOLLO) station failed. Retrospectively, it turned out that this was due to erroneous orbit predictions.

The ACES mission has faced many delays. These delays are mostly caused by technical issues in the two-way microwave link. The launch date has now been shifted to the second half of 2019. Current committee activities are still dealing with laser safety requirements. While the general safety concept is approved, a formal acceptance test of the implementation is still required. The Wettzell Laser Ranging System (WLRS) is acting as a model station in this respect, both for a high power and a low power operation setting. Once this system has been cleared for ISS tracking, other stations have a much-simplified acceptance procedure.

Laser time transfer is a key technology for a future relativistic geodesy, where highly resolved time, tied rigidly to geometric frame of reference is a key feature. Small and varying system delays are not detectable unless they can be referenced to time. Improving the time transfer capability therefore allows the quantification and an improvement of the long-term station stability.

Within the activities of the Transponder Standing Committee are also alternative ground to ground optical clock synchronization techniques. One promising approach is the asynchronous laser time transfer by diffuse reflection on suitable space debris items, where two laser station in common view are tracking a debris object like a burned-out upper stage of a launch vehicle. Each of the laser stations are obtaining their own ranges as well as the respective diffusely scattered laser pulses from the other station. Modeling the tumbling motion of the space debris item removes most of the experienced delay from the apparent target depth of the reflecting surface of the debris object. The first results from the observations of one station are encouraging.

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Space Debris Study Group (SDSG)

Author: *Georg Kirchner/Austrian Academy of Sciences, Daniel Kucharski/SERC*

Chair: Georg Kirchner
Co-Chair: Ludwig Grunwaldt

Summary

The mission of the Space Debris Study Group (SDSG) is to coordinate efforts of the SLR stations interested in the development, operation and utilization of the space debris laser ranging capabilities for the benefit of space science (Pearlman, et al., 2018).

Recent Achievements and Current Activities

The group has conducted a joint tracking campaign to the decommissioned TOPEX/Poseidon (T/P) satellite and collected a significant amount of full-rate laser range observations that are deposited on an open-access data server established and operated by the Space Research Institute of the Austrian Academy of Sciences (Graz, Austria) (*ftp://sddis.oeaw.ac.at*). The collected data have been used to investigate the Solar Radiation Pressure effects on the passive satellite treated as a sensor of the environmental forces and torques that perturb its orbital dynamics (Kucharski, Kirchner, Bennett, 2017). It has been found that the photon pressure torque exerted on the defunct T/P does not exceed 150 µNm and is responsible for the observed spin-up of the body from the stable nadir pointing position to a fast spinning state with a period of nearly 10 s. The laser ranges are also collected on other cooperative and non-cooperative space debris objects including rocket bodies and decommissioned GNSS satellites.

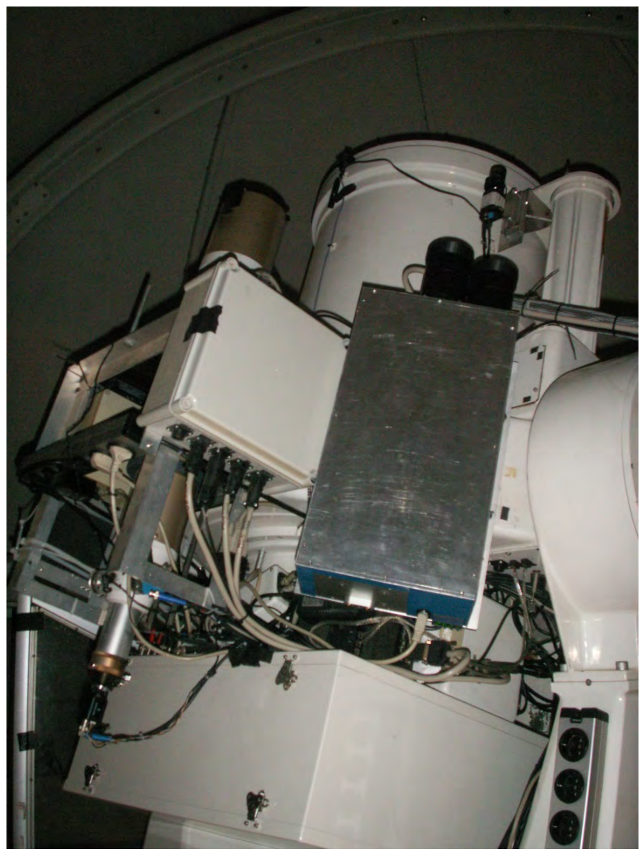

Figure 9-22. Space debris laser ranging system installed directly on Graz main laser telescope.

The Graz SLR station continues the development of the technology solution that brings the laser ranging capabilities to the astronomical telescopes (Figure 9-21). The compact laser system delivers 532 nm / 16 W / 200 Hz / 10 ns pulses; OR 1064 nm / 1064 nm / 32 W / 200 Hz / 10 ns); it is mounted directly on the telescope, avoiding the usual Coudé path. This setup improves the pointing stability and strengthens the link budget during the space debris laser ranging. The solution has been successfully tested in multiple tracking sessions and delivered hundreds of passes of various debris targets (Steindorfer et al., 2019). The achievable range accuracy is in the order of 0.5 m RMS and is limited by the ns laser pulses and large target sizes. The insufficient ephemeris accuracy restricts the debris laser ranging to the nighttime operation, but the work is in progress to extend the debris laser tracking to a full day activity by improving predictions and target visibility.

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Steindorfer M., Kirchner G., Koidl F., et al. Recent space debris related activities at the SLR station Graz. ESA 1st NEO and Debris Detection Conference, 2019.

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Quality Control Board

Author: *Michael Pearlman/ILRS Central Bureau*

Chair: Michael Pearlman

Summary

System biases have plagued SLR since its inception. Both short and long-term biases can degrade the quality of the ILRS data products and alienate the ILRS user community. As an example: short-term biases reduce the available data and corrupt orbits on supported altimetry missions; long-term systematic effects can be aliased into geophysical data products, in particular reference frame products.

The Quality Control Board was organized at the 19th International Workshop on Laser Ranging, held in Annapolis, MD in October 2014, to address SLR systems biases and other data issues that have degraded the ILRS data and data products. The board is a joint activity under the Analysis Standing Committee (ASC) and the Networks and Engineering Standing Committee (NESC). The board meets periodically by telecon or in person. Activities and notes from board meetings are provided on the ILRS website: *https://ilrs.gsfc.nasa.gov/science/qcb/index.html*.

Recent Achievements and Current Activities

Current activities include:

- Study on what return pulse statistical information can reveal about ranging systematic errors (Peter Dunn)
- Comparison of Normal Points generated at the field stations with those generated by an open source Normal Point program (Randy Ricklefs, Matt Wilkinson)
- Examination of systematic data issues revealed by Analysis Center generated data products (Van Husson)

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