SLR-Based Evaluation and Validation Studies of Candidate ITRF2005 Products

Erricos C. Pavlis[1,2], M. Kuzmicz-Cieslak[1] and D. E. Pavlis[3,2]

1. Joint Center for Earth Systems Technology (JCET), Univ. of Maryland Baltimore County, Baltimore, MD, USA
2. NASA Goddard Space Flight Center
3. SGT, Inc.

Contact: epavlis@umbc.edu / Fax: +1 410 455 5868

Abstract

The recent release of candidate solutions for adoption of the new ITRF2005 International Terrestrial Reference Frame (ITRF) initiated numerous tests and comparisons over the past months. This presentation focuses on the evaluation tests we performed with the ITRF2005P and ITRF2005D products, primarily with Satellite Laser Ranging (SLR) tracking data. Since over two decades now, SLR tracking data contribute to the definition of the TRF, primarily in defining its origin and scale. LAGEOS 1 and 2 are the main targets contributing to this, and we use their data, as well as a limited number of independent data to gauge the improvement gained by going from ITRF2000 to either of the two new candidate solutions. An easy and immediate observation is that either of them is only slightly different from ITRF2000, in contrast to what was observed during the release of ITRF2000. This seems natural though, since ITRF2000 dealt with many problems observed with its predecessor and used a uniformly high quality input from nearly all techniques. We concentrate here on the differences between the two and the impact of such factors as the improvements in the analysis methodology, the underlying models, the use of IERS Conventions 2003, and the latest improvements in modelling SLR observations.

Introduction

Since over two decades now, SLR tracking data contribute to the development of the ITRF, primarily in defining its origin and scale. The release of ITRF2000 in 2001 ushered a new era of TRF quality and performance (Altamimi *et al.*, 2002). The recent (mid-2006) release of candidate solutions for adoption of the new ITRF2005 initiated numerous tests and comparisons over the past months. This presentation focuses on the evaluation tests we performed with the ITRF2005P (from IGN) and ITRF2005D (from DGFI) products, primarily with SLR tracking data. In contrast to what was experienced during the release of ITRF2000, the release of the new models did not bring about order-of-magnitude changes, but rather small adjustments and corrections, either for sites that appeared 'after' the release of ITRF2000 or whose ITRF2000 estimates were based on too limited a set of data for meaningful results.

Initial tests for Precision Orbit Determination (POD)

As a first test of the two candidate models we looked at their performance on the LAGEOS and LAGEOS 2 data that were used in their development. From the initial tests on ITRF2005P, which was released first in early summer of 2006, it became obvious that the VLBI-consistent scale imposed on this model because of the observed scale discrepancy between SLR and VLBI, led to a TRF with inferior performance even on the SLR data that were used in its development.

When however we applied a scale adjustment to make it consistent with the intrinsic SLR scale or allowed for a scale adjustment in our tests, the two models performed very similarly, and only marginally better than ITRF2000, except for the few sites that either did not appear in ITRF2000 or had poor ITRF2000 estimates (Table 1).

Table 1*. Weekly RMS values from the weekly operational ILRS products in comparison to the old (ITRF2000) and new (ITRF2005P), ITRFs (results courtesy Cecilia Sciarretta/Telespazio, S.p.A.).*

Group RMS [mm]	ITRF2000	ITRF2005	ITRF2000	ITRF2005	ITRF2000	ITRF2005
	June 3, 2006		*June 10, 2006*		*June 17, 2006*	
All sites (**24**)	40	**8**	36	**9**	32	**9.6**
Core sites (**16**)	13	**7**	13	**8**	12	**8**

Several SLR analysts did similar POD tests and the main conclusion from all of these tests is that the new models perform very similarly, and not much different from ITRF2000, for the well-determined sites common to both TRFs. The POD tests we performed were limited to data from the period 2003 to 2006.5, and only for the sixteen (16) "Core SLR" sites as identified by the ILRS ACs' operational procedures. A summary of the RMS of fit per site for either of the two new models and ITRF2000 are shown in Tables 2 (for LAGEOS) and 3 (for LAGEOS 2).

A quick observation from Tables 2 and 3 is that overall, ITRF2005D performs slightly better than ITRF2005P does, especially in the case of LAGEOS 2. Note that unlike ITRF2005P, ITRF2005D ***does not*** require any adjustment to its scale or scale rate in order to achieve this performance. Despite this fact, absent any substantiated errors in the development of ITRF2005D, and ignoring all official objections by the International Laser Ranging Service (ILRS), (Pearlman *et al*., 2002), the final officially adopted model for ITRF2005 was a slightly modified version of ITRF2005P (without any changes with respect to the SLR-VLBI scale issue).

The scale difference between ITRF2005P and SLR

The scale difference between the new and old ITRF (about 1.4 ppb at 2000.0 or ~10 mm, and -0.15 ppb/y or -1 mm/y), intrigued all SLR analysts involved in the evaluation and validation of the new model. Several theories were formed and tested, all of them quickly eliminated following extensive and copious tests, in most cases cross-checked through repetition by more than one group. We list some of the more plausible ones here.

A possible error in the adopted value of GM_E was quickly discarded, since it would require an unreasonably large $\Delta GM_E \approx 0.0025 \times 10^9$ or an equally unreasonable change in the CoM value for the two LAGEOS (~20 mm). Next, the differences in the submitted SLR contributions to ITRF2000 and ITRF2005 were examined closely. The

Table 2. *LAGEOS POD: Core sites' RMS of fit using ITRF2000, ITRF2005P and ITRF2005D, and differences. RMS in red (negative) indicates ITRF2005P performs better than ITRF2005D.*

SITE NAME	SITE ID	ITRF2000 (IGN) RMS [mm]	ΔRMS [mm] 2000-2005P	ITRF2005P (IGN) RMS [mm]	RMS [mm] 2005P-2005D	ITRF2005D (DGFI) RMS [mm]	ΔRMS [mm] 2000-2005D
BEIJING, PRC	7249	22.41	4.90	17.51	1.10	16.41	6.00
GRASSE, FRANCE	7835	10.45	2.54	7.91	-0.12	8.03	2.42
GFZ POTSDAM, DE	7836	13.11	2.60	10.51	-0.84	11.35	1.76
GRAZ, AUSTRIA	7839	9.46	1.48	7.98	-0.19	8.17	1.29
HALEAKALA, HI	7210	17.87	3.29	14.58	2.50	12.08	5.79
MLRO, MATERA, IT	7941	10.87	2.51	8.36	0.67	7.69	3.18
MLRS, TEXAS, USA	7080	13.54	2.00	11.54	1.11	10.43	3.11
YARRAGADEE, AUSTRALIA	7090	11.33	0.48	10.85	1.02	9.83	1.50
GGAO, WASHINGTON, DC	7105	12.35	1.14	11.21	-1.03	12.24	0.11
MON. PEAK, CA	7110	14.41	1.40	13.01	0.92	12.09	2.32
HARTESBESTHOEK, SA	7501	14.45	4.24	10.21	0.43	9.78	4.67
RGO, ENGLAND	7840	9.77	0.78	8.99	0.60	8.39	1.38
SALRO, SAUDI ARABIA	7832	12.59	2.53	10.06	-0.22	10.28	2.31
SIMOSATO, JAPAN	7837	17.13	2.58	14.55	-0.20	14.75	2.38
ZIMMERWALD, CH	7810	8.97	-0.86	9.83	0.51	9.32	-0.35
WETTZELL, DE	8834	11.36	1.75	9.61	0.34	9.27	2.09

Table 3. *LAGEOS 2 POD: Core sites' RMS of fit using ITRF2000, ITRF2005P and ITRF2005D, and differences. RMS in red (negative) indicates ITRF2005P performs better than ITRF2005D*

SITE NAME	SITE ID	ITRF2000 (IGN) RMS [mm]	ΔRMS [mm] 2000-2005P	ITRF2005P (IGN) RMS [mm]	ΔRMS [mm] 2005P-2005D	ITRF2005D (DGFI) RMS [mm]	ΔRMS [mm] 2000-2005D
BEIJING, PRC	7249	19.11	3.60	15.51	0.89	14.62	4.49
GRASSE, FRANCE	7835	10.58	3.47	7.11	0.34	6.77	3.81
GFZ POTSDAM, DE	7836	11.96	1.23	10.73	0.91	9.82	2.14
GRAZ, AUSTRIA	7839	8.63	1.34	7.29	0.30	6.99	1.64
HALEAKALA, HI	7210	16.33	3.61	12.72	1.68	11.04	5.29
MLRO, MATERA, IT	7941	10.60	2.37	8.23	0.62	7.61	2.99
MLRS, TEXAS, USA	7080	13.21	1.93	11.28	1.32	9.96	3.25
YARRAGADEE, AUSTRALIA	7090	10.87	0.09	10.78	2.22	8.56	2.31
GGAO, WASHINGTON, DC	7105	11.80	1.24	10.56	0.10	10.46	1.34
MON. PEAK, CA	7110	12.73	0.53	12.2	1.33	10.87	1.86
HARTESBESTHOEK, SA	7501	16.53	5.19	11.34	1.33	10.01	6.52
RGO, ENGLAND	7840	8.74	-0.08	8.82	1.15	7.67	1.07
SALRO, SAUDI ARABIA	7832	11.22	1.95	9.27	0.25	9.02	2.20
SIMOSATO, JAPAN	7837	17.35	3.10	14.25	-0.60	14.85	2.50
ZIMMERWALD, CH	7810	9.23	-0.09	9.32	0.90	8.42	0.81
WETTZELL, DE	8834	10.92	1.20	9.72	0.83	8.89	2.03

SLR contribution to ITRF2005 had some basic differences from what was submitted to ITRF2000:

- The new submission used the Mendes-Pavlis (2004) refraction model.
- Only the data spanning 1993 to end of 2005 were used instead of the 1976 -2000 that was used in ITRF2000.

The first difference was quickly discarded since the same SLR contributions were used in both ITRF2005 versions, P and D. Additionally, tests that were done to quantify the effect of the new refraction model (~0.4 ppb at most), gave no indication of any such large systematic scale differences between the two solutions with the character of the observed scale differences between the two TRFs. Considering the magnitude of the change in the VLBI-SLR scale difference between the two TRFs, a possibly missing relativistic correction in the formulation of the SLR-modeled time-delay advocated by Ashby (2003), was also investigated. Despite the close agreement in magnitude, this correction was also rejected as the cause of the scale differences, a conclusion that was also supported by Ashby himself (2006, personal communication). The POD tests were extended to include other SLR targets with orbits markedly different from LAGEOS, such as JASON-1 and Starlette. A corollary benefit from these POD tests was that while LAGEOS data were satisfactorily reduced with the scaled version of ITRF2005P, Starlette data for example showed a slight degradation. This implies either a certain distortion in the ITRF2005P solution, or a significant error in the CoM value used for Starlette. The latter is highly unlikely, but cannot be outright discarded.

A final plausible cause investigated as a possible explanation was the fact that the SLR contribution to ITRF2005 did not contain the historical LAGEOS data from the period 1976-1992. To test this last theory, we reduced all of that data and generated solutions that included that data, which we later compared to the two ITRF2005 solutions. Figure 1 shows the LAGEOS data distribution (weekly resolution) for the ILRS network from 1976 to early 2006. It can be seen that there is no dramatic difference between the two networks that supported the two ITRFs.

The SLR data for the period 1976-1992 is certainly not of the same quality as for the recent years, and the network had undergone several upgrade stages during that period. The initial predominantly NASA-supported network from 1976 to 1980 was more of a research and test-bed outfit than an operational one. The two international MERIT campaigns in the early 80s forced the upgrade of the network, its expansion and strengthening with the addition of several stations outside North America and

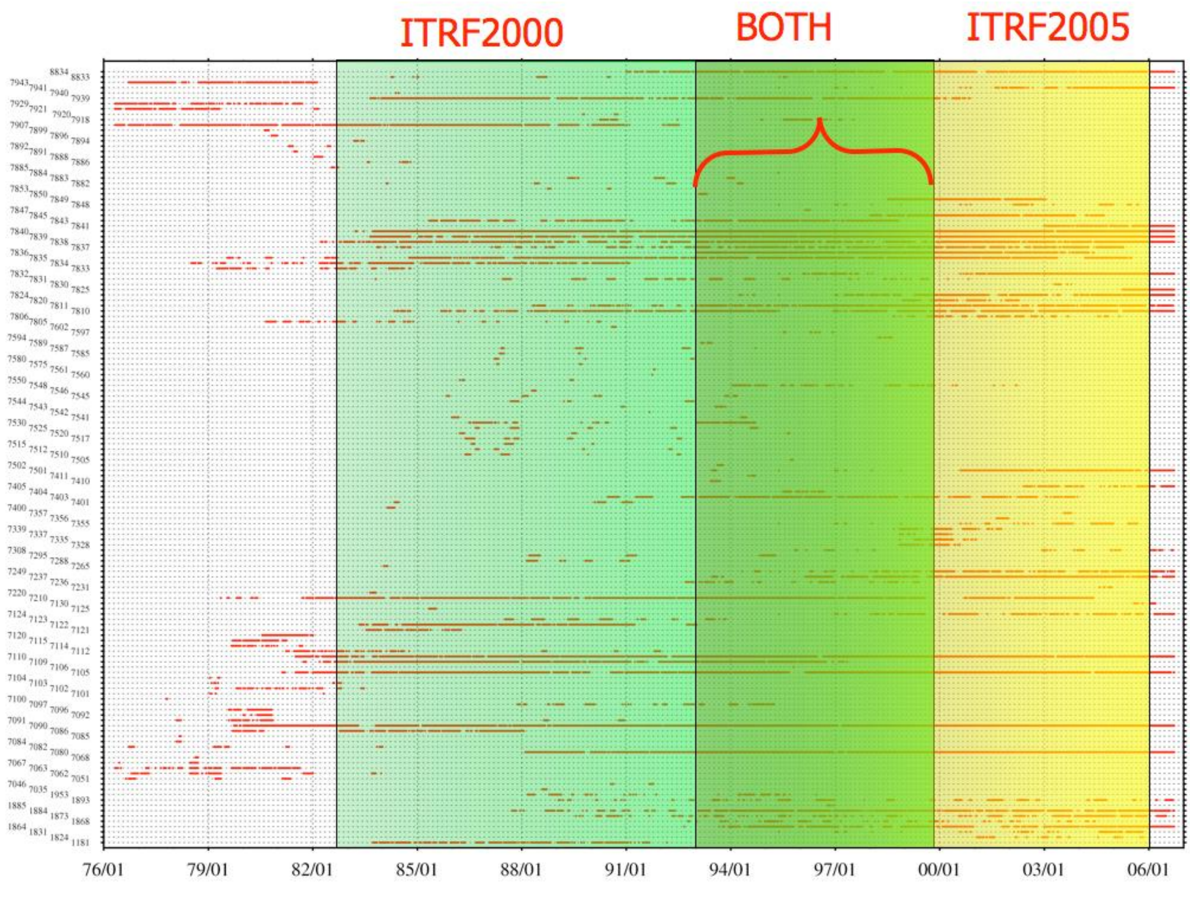

Figure 1. *The LAGEOS and LAGEOS 2 data distribution for 1976 – 2006, and the portions used in the SLR submissions for the development of ITRF2000 (green) and ITRF2005 (yellow).*

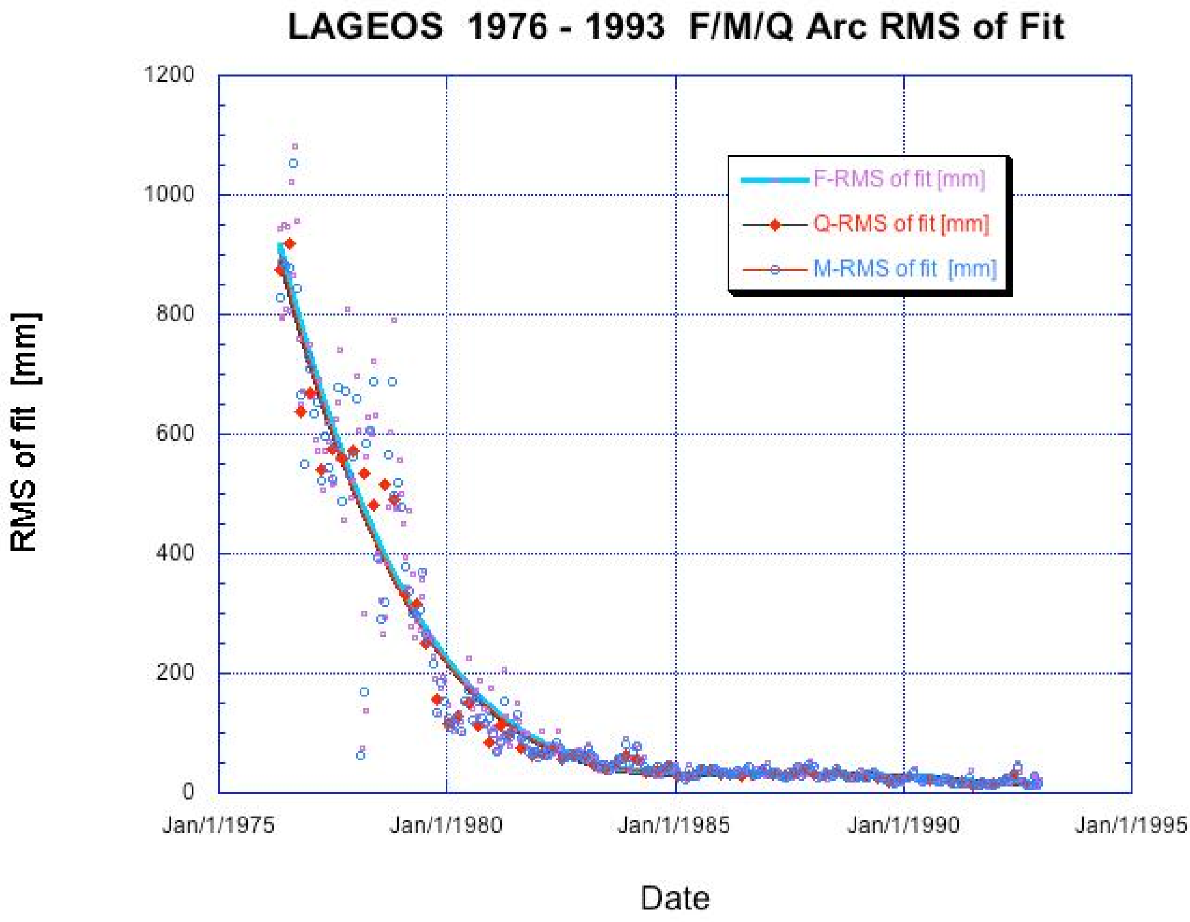

Figure 2. *Orbital arc RMS of fit to LAGEOS data, 1976 – 1992. Results from reductions with three different arc-lengths are shown here, fortnightly (F), monthly (M) and quarterly (Q).*

Europe, and ushered an era of operational mentality across continents, countries and agencies supporting these stations. As a result, the quality of the data improved by an order of magnitude, the quantity increased too, and internationally coordinated scheduling of operations was initiated for improved data yield. The result of these changes is reflected directly in the improved RMS of fit to the collected data, using the same models across all periods of time, as this is illustrated by the graph in Figure 2.

The development of TRFs that included the SLR data from the 1976-1992 period made little difference in their intrinsic scale and scale rate (~10% at most). On the other hand, it does improve the error statistics for sites that span both periods of time and it resulted in capturing in a single consistent frame all SLR sites that ever tracked either or both LAGEOS satellites. This result left the question about the SLR-VLBI scale difference in ITRF2005 open and unanswered, despite the fact that it eliminated a large number of serious candidate explanations.

Recent (spring 2007) developments

During the 2007 General Assembly of the European Geosciences Union (EGU) in Vienna, Austria, MacMillan (2007) brought to the attention of the ITRF community the finding that the official International VLBI Service (IVS) submission to ITRF2005 had an error in the application of the pole tide, which generated a scale bias with respect to the true scale of ITRF.

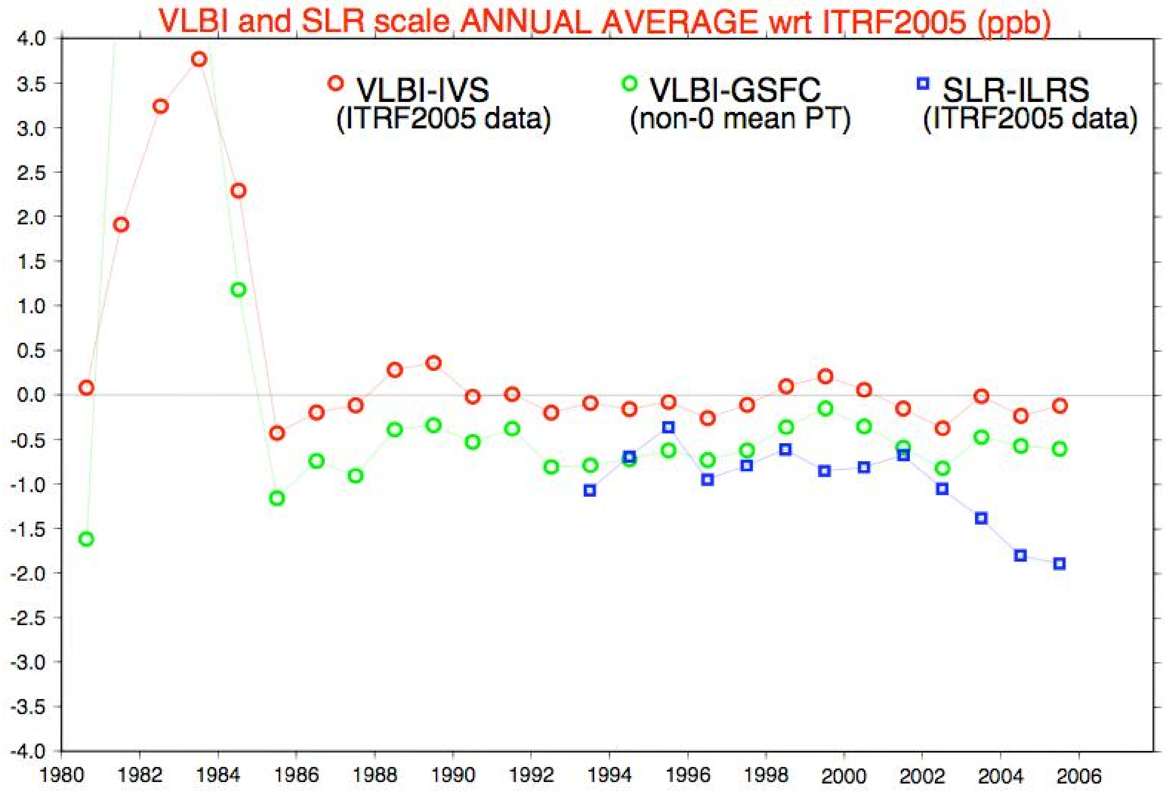

Figure 3. *Time series of annual scale differences between various VLBI solutions and the SLR submission to ITRF2005, with respect to the ITRF2005 frame, (Altamimi, 2007).*

After an exchange of corrected submission files, Z. Altamimi generated new test solutions that indicate that indeed, this error causes about 0.5 ppb scale bias between the SLR and VLBI frames of reference. This can be seen in the graph that Altamimi (2007) circulated via email on June 18, 2007, under the subject matter: "Pole tide effect on VLBI scale". As you can verify from Figure 3, except for the period after 2004 when the SLR network covers only the one hemisphere of the globe, the scale difference between the two techniques is at the same level of discrepancy as it was during the development of ITRF2000. This means that there is really no reason for the exclusion of SLR from the definition of the scale of ITRF2005. The "significant"scale rate is also a result of the poor network configuration in the latter years and the consideration of some questionable site tie vectors (as pointed out by the DGFI combination center), and could have been dampened by appropriate weighting of the weekly contributions for that period of time, or editing of the ties (as DGFI did for ITRF2005D).

Summary

The release of ITRF2005 in mid-2006 created a great commotion within the geodetic community with its departure from prior tradition, to adopt the scale implied by VLBI only, excluding SLR from the usual 50-50 sharing of this privilege. Additionally, the indication that SLR scale was not only off by more than 1 ppb from the true scale but also suffered from a significant rate change of -0.15 ppb/y, sent SLR analysts scrambling for answers. As we have seen here, none of the most plausible causes could be found responsible for the observed discrepancy. The matter was never closed, and it was always suspected that in addition to the acknowledged effect of the deteriorating SLR network, either an error in another technique's submission were the cause, or the new way of constructing the ITRF, or a combination of all. The April 2007 findings of MacMillan's investigation in the VLBI scale definition explained for the most part the constant scale offset. The remaining scale rate effect seems to be the result of the new way the ITRF is constructed and the deterioration of the SLR network during 2004- 2006. The recent re-establishment of the SLR sites at Haleakala, Hawaii and Arequipa, Peru, and the new and improved re-analysis of the SLR data this year are expected to resolve many of these remaining issues and restore the faith of the ITRF community in SLR's unique ability to define the ITRF scale in the absolute sense.

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