FORTHCOMING IMPROVEMENTS IN SLR DATA ANALYSIS: TOWARDS THE mm-SLR

E.C. PAVLIS, M. KUZMICZ-CIESLAK, P.M. HINKEY
Goddard Earth Science and Technology Center, University of Maryland, BC
e-mail: epavlis@umbc.edu

ABSTRACT. Accuracy requirements for the International Terrestrial Reference Frame (ITRF) are becoming increasingly more stringent, especially with regards to its origin definition and its scale stability. Satellite Laser Ranging (SLR) contributes unique information on the origin, and along with VLBI, for its absolute scale. Advances in our understanding of the coupling between the sub-components of system Earth require that we revisit our current modeling used in the reduction of SLR data. With the recent release of numerous products from global circulation models and satellite and terrestrial observations, we are now able to examine the effect of improved modeling in the analysis of several years of SLR data. We present results from such analyses and compare them to our nominal results, based on the currently accepted ILRS standards. Depending on the outcome of these tests, we anticipate that in the near future, ILRS will formulate a proposal to IERS for modification of the analysis standards related to the products contributing to the establishment of the future ITRFxx.

1. INTRODUCTION

The International Terrestrial Reference Frame (ITRF) accuracy requirements are becoming increasingly more stringent, driven primarily by those dictated by the Global Geodetic Observing SystemGGOS. It is now commonly accepted that the future ITRF should exhibit 1 mm accuracy in the origin of the reference frame at epoch and 0.1 mm/y stability over time (Wilson et al., 2010). SLR determines uniquely the origin of the ITRF and along with VLBI, its scale. For many years now SLR has also observed mass redistribution in the Earth system (Pavlis, 2002), providing unique estimates prior to the launch of GRACE (Tapley et al., 2004). With the proliferation of GRACE products and the availability of global fields of atmospheric, oceanic, and hydrological circulation, it is now high time to consider the forward modeling of these processes in the analysis of SLR data for the establishment of the TRF. Although at present we focus on the analysis of LAGEOS data only, in subsequent stages we will extend these model improvements to LEO targets to make their contribution useful and of acceptable accuracy for inclusion in the development process of the ITRF.

2. CURRENT STATUS OF SLR MODELING

The improvement of the gravitational models, the static as well as time-varying components, thanks to the launch of GRACE, has removed a major source of error in Precise Orbit Determination (POD) for all missions in recent years. As these errors are suppressed, errors that we previously considered insignificant, are now taking central role and limit our ability to fit the SLR data to their inherent 1 mm accuracy. The components that contribute to the total error in the SLR analysis vary with regard to the tracking station, spacecraft target, geophysical model, local survey, etc. from between a few mm to few cm, as it is shown in Figure 1. It is clear that there a lot of areas where improvement by an order of magnitude is required, if we want to reach our goal of a 1 mm accurate technique.

3. FUTURE IMPROVEMENTS IN SLR

Even if the modeling improves with the adoption of state-of-the-art models, SLR is still suffering from two other shortcomings: the unbalanced global distribution of its tracking network and the limited number of suitable targets in orbit.

The first limitation is now addressed within the GGOS initiative, with the international community agreeing to reestablish the geodetic networks in general, using the latest hardware and software available,

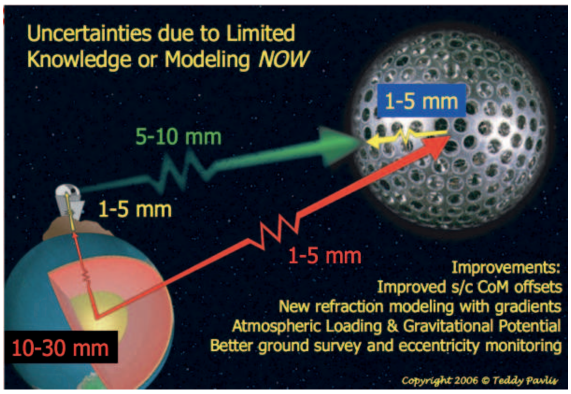

Figure 1: Current state of modeling SLR data to geodetic targets (LAGEOS, ETALON, etc.)

and making every effort to co-locate all space techniques in an as balanced global network as physical limitations permit (Figure 2).

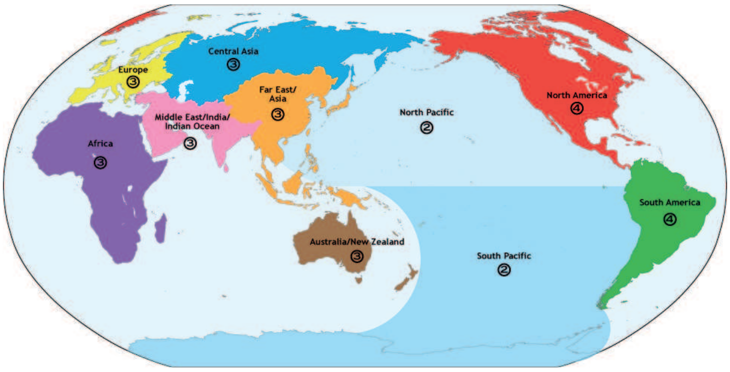

Figure 2: Envisioned space geodetic techniques station distribution for the future GGOS 2020 network)

The second issue, the limited number of targets in orbit is also addressed in more than one ways. First of all the improved modeling is expected to allow us to make use of targets in significantly lower orbits, previously thought prohibited for ITRF work (e.g. Starlette, Stella, LARETS, etc.). New designs of novel approaches for new targets that can in principle support the 1 mm accuracy goal. One example already in orbit is the "Ball Lens In The SpaceBLITS" satellite (Figure 3) designed by the IPIE group under the Federal Space Program of Russia. It is a double Luneburg sphere that acts as a single retroreflector when ranged from the one hemisphere, with a very precisely measured aspect-independent signature. Unlike our other targets that return a signal that is the convolution of multiple reflections from several retroreflectors, BLITS' return signal is distorted only by the propagation media.

The initial results from the reduction of BLITS SLR ranges indicate that there is potential in the development of such targets if the quality of the material can be improved for a much longer life in space and the size of the spacecraft increased so that it can be used in higher, more stable orbits.

A second project that will also enhance our dedicated target collection is the imminent launch of the ASI mission LARES (see Pavlis et al., in these proceedings).

From the purely modeling point of view, one of the first improvements to be considered is of course the time varying gravitational signals that GRACE observes at monthly intervals. With several years of GRACE data accumulated by now, it is even possible to derive sufficiently high-resolution models that can be used even during the time period prior to GRACE's launch, in order to describe at least the dominant signals (secular, annual, semi-annual, seasonal, Figure 4). In this fashion we can benefit and improve the results from reanalysis of historical SLR data collected long before the GRACE era.

Other less obvious improvements can come from the adoption of new and improved models for atmospheric loading (from NCEP or ECMWF), hydrological loading (e.g. from GLDAS), new ocean tides

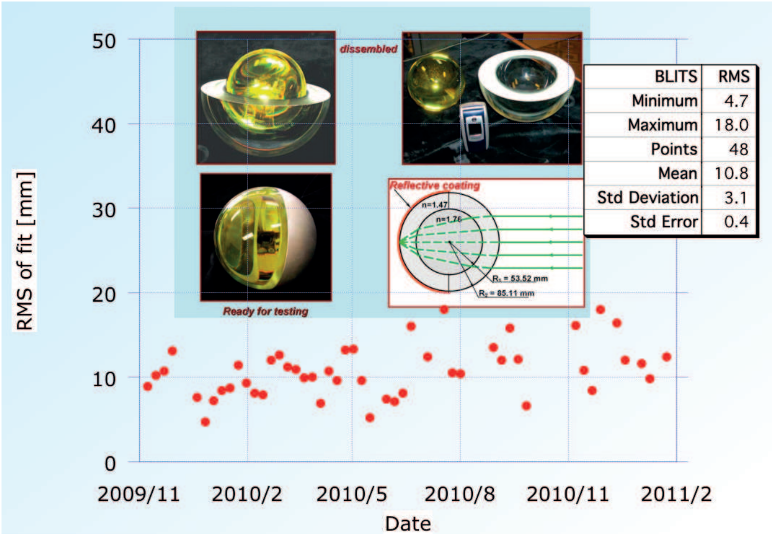

Figure 3: Retroreflector spacecraft BLITS and the RMS of fit for a preliminary analysis of its SLR data)

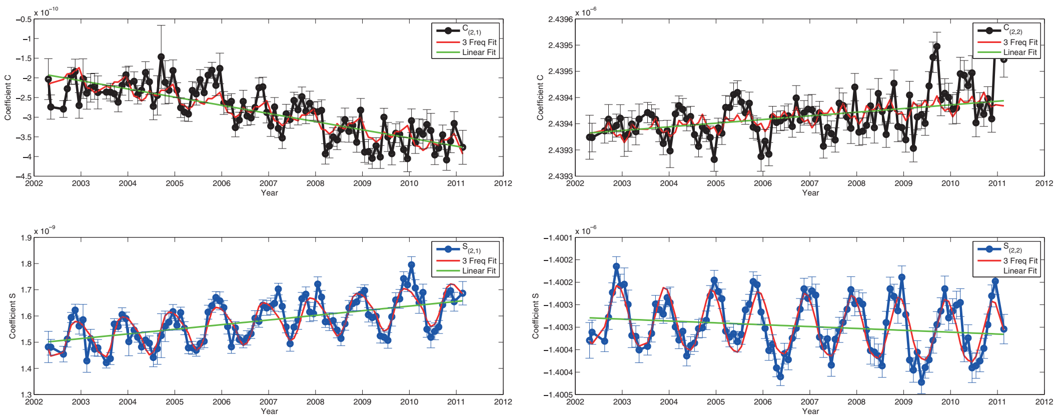

Figure 4: Temporal variations in the degree two harmonics for orders 1 and 2 observed by GRACE, and the linear (green) and harmonic (red) analytical model fitted to them. Note the significantly better fit for the sine terms (S_{2m})

models (e.g. GOT04.7 or more recent) with proper treatment for the atmospheric tides, upgrading our atmospheric refraction modeling from an analytic model (Mendes and Pavlis, 2004) to using 3-D atmospheric ray tracing (ART) that will include atmospheric gradients (Hulley and Pavlis, 2007), albedo models from global satellite-based fields, etc.

The effect of atmospheric circulation (mass redistribution) to each station's position due to its loading of the crust can be modeled with corrections derived from global atmospheric fields such as NCEP or ECMWF. A service providing such corrections was pioneered a few years ago by Petrov and Boy (2004), and results are available for various operational and experimental fields from ECMWF, as well as from NCEP.

We chose to test these in 2001 and 2006, so that we can investigate the maximum possible number of versions of these fields. The results were compared to those obtained without atmospheric modeling, and indicate an average reduction in the overall RMS of fit of the order of 3 mm in the mean and a similar level scatter over the test period.

SLR unlike other space geodetic techniques is marginally affected by atmospheric refraction. Nevertheless, when we strive for mm-level accuracy, even the otherwise small effects of horizontal gradients in the lower atmosphere must be accounted for. Hulley and Pavlis (2007) demonstrated how to compute refraction corrections along the laser beam path directly from three-dimensional ray tracing through the meteorological fields, now routinely available. The SLR data for 2004–2005 were corrected using using the 3D ART approach, based on three different global fields: ECWMF, NCEP and the satellite observations from the AIRS instrument on board NASA's AQUA platform.

The results indicated that 3D ART with AIRS-observed fields is the best approach, explaining almost 25% of the residual variance versus an alternate approach, where the isotropic delay is modeled through the analytical model of (Mendes and Pavlis, 2004) and the gradients are obtained from 3D ART, which only accounts for 14% of the variance for the same data.

4. CONCLUSIONS AND FUTURE PLANS

The stringent accuracy requirements of GGOS are a strong incentive for the improvement of the models underlying the reduction of space geodetic data. One of the most significant errors in techniques sensitive to gravitational variations are the temporal signals caused by the continuous mass redistribution in the Earth system. Using the available GRACE monthly fields we can generate models for these variations that can be used in orbital modeling along with consistent improved tidal models, to significantly reduce the residual variance. Similarly, the use of meteorological fields to derive the corresponding loading effects at the tracking stations can further explain part of the remaining variance. Additional improvement comes from the computation of the entire atmospheric delay using meteorological fields, especially those obtained from global satellite observations, in order to properly account for the horizontal gradients which are otherwise ignored. Implementing these changes in the future reduction of SLR data will result in significantly improved products with emphasis on consistency over time. Other improvements specific to SLR are the new network to be established in support of GGOS and the use of additional well-designed targets, either already in orbit or soon to be launched. These enhancements will allow us to meet the GGOS requirements and reach our millimeter SLR goal.

Acknowledgements. Erricos Pavlis gratefully acknowledges the support of NASA Grant NNX11AI44G.

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