Improvements in mitigating systematic effects in SLR analyses – satellite centre-of-mass corrections

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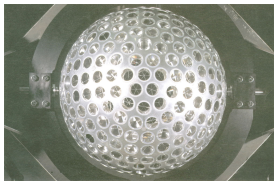
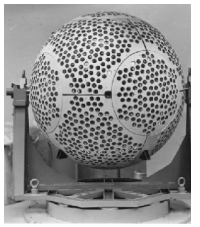
Abstract.

One of the limiting factors in reaching the GGOS-inspired scientific goal of 1-mm accuracy satellite laser ranging to the geodetic satellites is the problem of referring the range observations to the centres of mass (CoM) of the spherical satellites. The cube-corner retroreflectors that are densely distributed over the surfaces of the primary geodetic satellites LAGEOS (diameter 0.60m) and Etalon (diameter 1.29m) give rise to broad, complex distributions in the returning laser pulses that are detected by the stations. Proper treatment of the resulting range measurements that take account of the various laser-station technologies is required in order to minimize potential systematic errors in the range that can reach more that 10 mm for the two LAGEOS and up to several cm for the two Etalon satellites. Earlier theoretical results (Otsubo and Appleby, JGR, 2003) have been used recently to develop tables of CoM corrections and their uncertainties for all the ILRS stations that were or continue to be in operation from the period 1980 onwards. These updated corrections have been used in a 2012 pilot study by the ILRS Analysis Working Group in order to quantify their impact on the determination of the reference frame, in particular its scale, and we report early results of this study. This work is part of the ILRS preparation towards its contribution to the next realization of the ITRF.

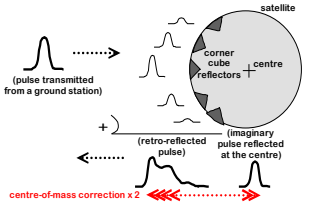
1. The problem realising 1mm range accuracy The LAGEOS and Etalon geodetic satellites provide an extremely stable reference that enables, through precise laser ranging (SLR) observations by the International Laser Ranging Service (ILRS) Network, a host of geodetic studies including precise determination of the Earth-system mass centre, low-order terms of the Earth's variable gravity field and the scale of the terrestrial reference frame. However, the satellites, designed in the 1970s and 80s, do not readily support the now-demanded mm-level SLR accuracy because of their size and consequent pulse-spreading effects which impact in different ways the detection electronics and pre-processing in place at the stations. These effects imply that in order to relate the range measurements to the mass-centres of the satellites, ranging-system-dependent and time-dependent corrections should be added to the raw range measurements. For LAGEOS, the magnitude of these effects reaches 10mm and, for the larger-diameter Etalon, is some 30mm.



LAGEOS-2 (ASI)



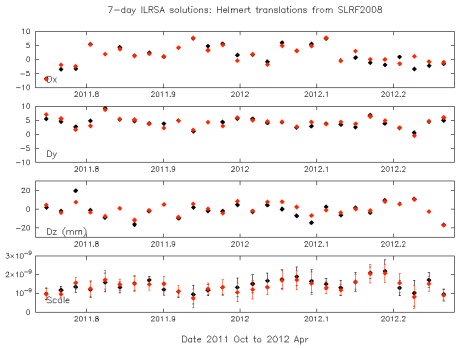
Etalon



Laser pulse (Gaussian) interaction with the extended array on a typical spherical satellite

2. Solution Pre-launch measurements of CoM corrections were carried out for both LAGEOS satellites (1976, 1992), primarily for the detection systems in use at the respective epochs at the NASA stations. Hitherto, the CoM correction derived from the LAGEOS-2 tests (251mm) has been used almost exclusively for all stations by the ILRS analysis centres for daily and weekly orbital solutions to derive tracking station coordinates and daily Earth orientation parameters. The same procedure was adopted by the ACs to compute the ILRS combined solution towards the latest realisation of the ITRF (ITRF2008, Altamimi *et al*, 2011).
A recent effort under the auspices of the ILRS Analysis Working Group (AWG) has resulted in the estimation of station and epoch-dependent CoM values for LAGEOS and Etalon for the period from 1980 to present. The ILRS stations' log files, available through the ILRS website (http://ilrs.gsfc.nasa.gov/) were used as a vital source of information on laser pulse-lengths, detector electronics and data screening. This information was used along with the theoretical work reported in Otsubo and Appleby for LAGEOS and Etalon, and with the LAGEOS pre-launch results, to develop a database of CoM corrections for both satellites throughout the period. Most importantly, an effort was made to include as realistic as possible values for the uncertainties in the corrections themselves, based upon tracking station configuration and, for example, whether or not return energy levels are controlled; in general, a station operating at single photons will be assigned the most *accurate* CoM value, even if the single-shot *precision* is inevitably relatively low.

3. Testing All eight ILRS Analysis Centres carried out in a pilot study (start date October 2011) standard weekly, seven-day-arc solutions for station coordinates and daily EOPs using for one version (v30) the previously-adopted CoM corrections for the satellites, and for the other version (v35) the new station and time-dependent values. For a small subset of the stations a range-error was allowed-for during the solutions, but for the majority of stations the range observations were assumed to be error-free. The ILRS Primary Combination Centre (e-GEOS, Italy) carried out standard combinations of the solutions from all the ACs separately for the v30 and v35 solutions and included 7-parameter Helmert solutions between each week's combined solution and the a-priori coordinates taken from ITRF2008. It is the differences between these sets of Helmert parameters from the v30 and v35 solutions, primarily the three translations and the scale parameter, which we compare in order to assess the impact on the solutions of this change in CoM treatment.



4. Results Shown are the two sets of Helmert parameters from the solutions using standard CoM corrections (in black) and using the new CoM corrections (in red). The Dx, Dy and Dz translation parameters map the Earth system mass-centre variations determined weekly from SLR, relative to ITRF2008 in which the origin is determined uniquely by SLR. The two solutions differ by a maximum of 4mm in a few cases, but mostly less than 2mm and are very similar in signature. Scale, in ITRF2008 determined from the mean of the SLR and VLBI technique solutions, varies between the v30 and v35 solutions by up to 0.3ppb. On average over the 28 weekly solutions the mean difference in scale (v30 to v35) is -0.06ppb.

5 Conclusions The changes in reference frame origin and scale resulting from this short study using a new set of carefully-chosen station- and epoch-dependent satellite CoM values are small, especially in scale (0.06 ppb mean difference). This difference should be compared to the estimate of the accuracy of the scale of ITRF2008 of about 1.2ppb (Altimimi *et al*, 2011).
This study does not contradict the conclusion (Altamimi *et al*, 2011) that future ITRF improvement will depend on improving the consistency between local ties in co-location sites. It is also vital that technical improvements be carried out at some of the SLR sites (e.g., Appleby *et al*, 2010, time-of-flight counter non-linearity).