Laser Ranging as a Precise Tool to Evaluate GNSS orbital solutions.

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1. Introduction

In this paper from our poster presentation we bring up to date our use of precise laser range observations to carry out independent checks on the accuracy of published orbits of a subset of the GPS and GLONASS navigational satellites. Range measurements obtained by the ILRS tracking network to two GPS satellites and several of the GLONASS satellites are compared in two ways with precise orbits computed by the IGS; by direct comparison between SLR measurements and equivalent ranges computed from the microwave orbits, and by comparison of SLR-based orbits to the microwave orbits. Our previous work, which is outlined here, has shown that in such comparisons it is necessary to understand both the potential for systematic range ambiguity induced by the laser reflector arrays and the need for accurate on-satellite positions of the array phase centres. For the GLONASS and GPS satellites these parameters are now accurately known for the several different types of array currently in orbit, and the SLR results provide an accurate assessment of the radial quality of the IGS orbits, which is currently at a level of about 10cm RMS. Particularly for the GLONASS satellites, this quality has improved in recent months, but the well-known radial offset of a few cm remains between the laser measurements and the ranges computed from the radiometric orbits for the two GPS satellites. We further look forward to using similar techniques on the pilot satellites of the EU GALILEO navigational system, due for launch during 2005.

2. GLONASS Reflector Arrays

Early satellites in the GLONASS constellation carried very large (1m _ 1m) reflector arrays, giving a good link budget but presenting a new challenge for precise interpretation of range data. For the GPS and new GLONASS satellites, the arrays are small and systematic effects much reduced, at the expense of a strong link budget. Laser range measurements to these flat arrays can cause attitude-dependent offsets from the centres of the array, the magnitude of which depends both on the physical size of the array and upon the characteristics of the laser ranging station. In outline, a station working at high levels of return energy will on average measure the distance from the station to some region near the closest, outer edge of the array, since it is reflections from this region that return first and are thus more likely to be detected. A station working at energies close to single photons, on the other hand, will on average measure the distance to the centre of the array since single photons are equally likely to come from any part of the array.

These effects are now fairly well understood and, as expected, depend upon the characteristics of the tracking station (Otsubo *et al,* 2001). They may be detected through precise orbit determination, where in addition to solving for orbital force-model parameters, we also solve for the 'effective size' of the reflector array, as determined by each tracking station. More details and results are given in Otsubo *et al,* 2001 and Appleby and Otsubo, 2003.

3. Using SLR data to monitor radiometric orbits

Two methods can be employed to use SLR data for an independent check on the quality of GNSS orbits; we can either compute independent orbits using SLR data alone and compare them with radiometric orbits, or compare laser ranges directly with satellite-station distances derived from microwave orbits.
For the GLONASS satellites, sufficient SLR data usually exists to compute SLR-only orbits and compare them point-by-point with radiometric orbits. However, for the two GPS satellites, often there are too few laser measurements for this approach. We now discuss in more detail both these approaches.

3.1 SLR-orbit comparisons

7-day orbital arcs are fitted to SLR data from the global ILRS network by adjustment of a standard set of parameters, including 1-per-revolution terms to remove un-modeled non-gravitational perturbations. Post-fit residual RMS values are typically about 5cm. From the fitted orbit, 15-minute geocentric rectangular ephemerides are computed, referred, through the assumed locations of the SLR stations, to the ITRF2000 system. Daily IGS orbits for the GPS and GLONASS satellites are available in the same reference frame from the CDDIS public ftp site. From these ephemerides we compute 15-minute coordinate differences and map them onto in- and out-of-plane directions, taking velocities from the SLR-only orbits.
The results in general imply that the RMS of along- and across-track differences are at a level of about 50cm, with radial differences of between 10 and 20cm RMS, the GLONASS results being somewhat poorer than those of GPS.

3.2 Direct comparison

Orbital comparisons of course contain error contributions from both the SLR and radiometric orbital solutions. However, a comparison of precise SLR normal points with station-satellite distances determined from the radiometric orbit will be close to a direct measure of orbit radial error, since at a level of better than10mm the laser ranges may be assumed to be 'true'. Using a modified version of our SLR orbit determination software SATAN we have computed range differences between each SLR normal-point observation and the corresponding distance to the centre of the reflector array as deduced from the IGS orbits. These differences (o-c) may then be used as measures of the radial error in the IGS orbit.

This process has been carried out for the GLONASS satellites GL80, GL84, GL86 and GL87, when available during the period 2000 July to 2003 April (GL80 ceased operational service in

February 2002) and for the GPS satellites GPS35 and GPS36 for the period 1999 January to 2003 April.

3.2.1 GLONASS Results

We find that long-term systematic radial bias in the radiometric orbits is very variable for GLONASS. Present are annual periodic, 60cm level radial biases in the results for all the GLONASS satellites up to mid 2002. However, a marked improvement in radial orbit quality is evident from 2002 June onwards for all these satellites, suggesting that improvements have been made thereafter in IGS operational orbit determination. It is considered likely that those improvements have been to solar radiation modelling, the most difficult force to model accurately. The improvement in orbital quality as detected using laser measurements is illustrated in the results for GLONASS-84, shown in Figure 1, for the period 2001 February to 2003 April. The large amplitude excursions in the O-C values occur approximately at semi-annual periods, suggesting a lack of accuracy in solar radiation modelling. From 2002 June, when this problem appears to have been solved, the radial accuracy of the IGS orbit approaches 8cm RMS. Shown in more detail in Figure 2 are the O-C values for the final four months of our analysis. Besides the much improved radial precision revealed by these results, interesting is the overall mean O-C value, which at approximately -5cm, is close to those values determined previously in our work with GPS35 and 36, and as discussed below.

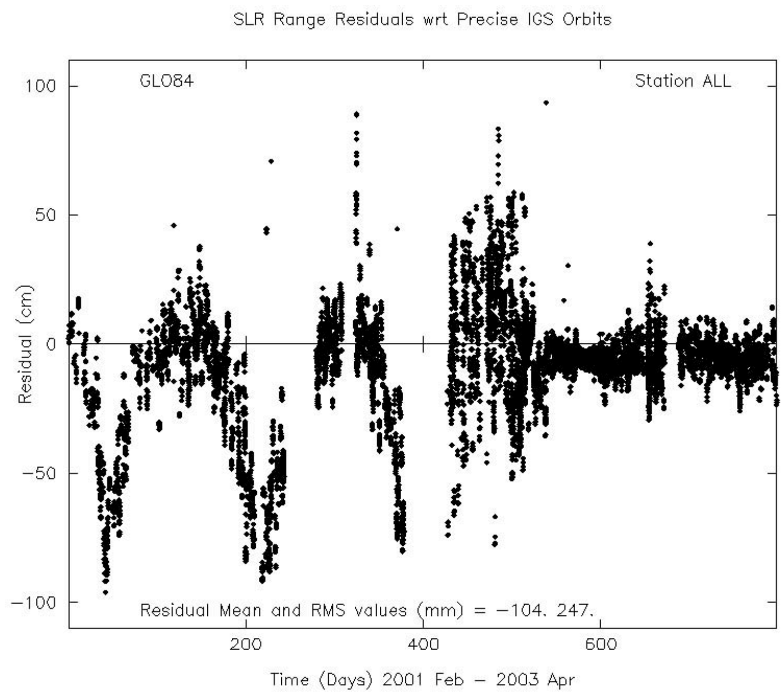

Figure 1: Time series of GLONASS-84 O-C values for 2001 February - 2003 April.

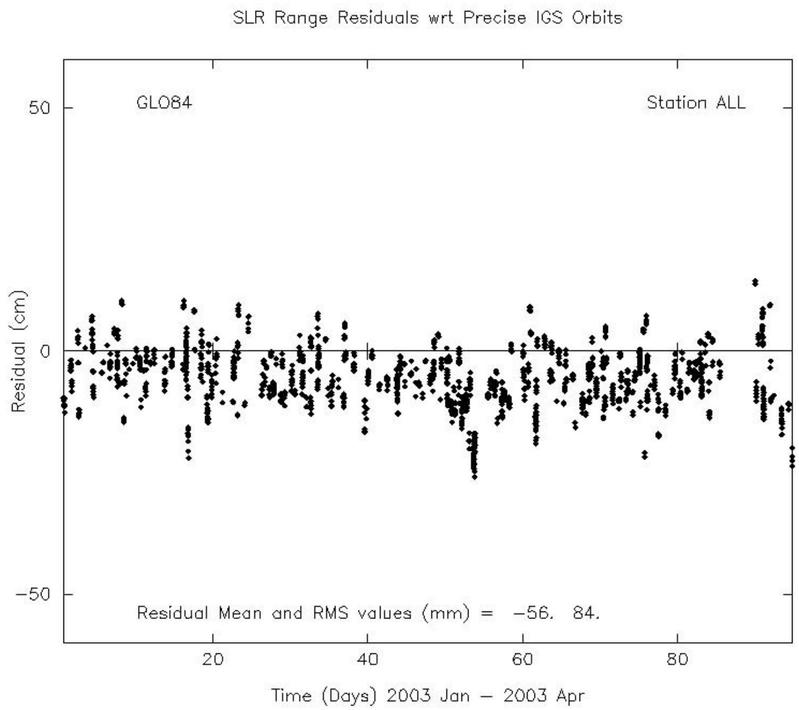

Figure 2: Time series of GLONASS-84 O-C values for 2003 January - April.

3.2.2 GPS Results

The results of comparison of laser range measurements to GPS35 and 36 are now considered. As discussed above, previous studies (e.g. Ineichen *et al*, 2001, Appleby and Otsubo, 2003) reveal a persistent ~5cm radial bias in the IGS orbits; the orbits are 'too big' when checked using SLR data. Such an offset may be attributable to unidentified errors in the assumed locations of the phase centres of the microwave antennae, which to some degree corrupt the orbital determination, or it is also possible that the adopted locations of the GPS laser retro-reflector arrays are incorrect. Shown in Figure 3 are our O-C values for GPS 36 for the period 1999 January to 2003 April. The values are much less scattered and systematic than those shown for GLONASS 84, due no doubt to better orbital monitoring and better global tracking coverage by IGS GPS receivers.

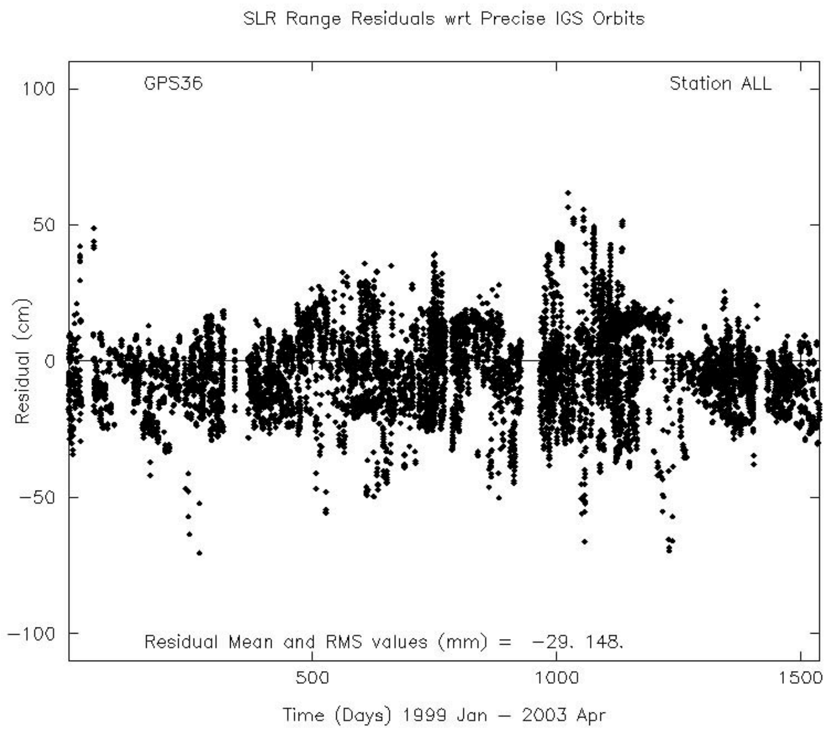

Figure 3: Time series of GPS-36 O-C values for 1999 January - 2003 April.

However, we find that care must be taken in interpreting the data. Our SLR – IGS orbital comparisons suggest that along- and across-track errors in either orbit are at a level of at least 50cm RMS. Simple geometric considerations imply that significant contamination from this error source will occur in any determination of radial bias in the IGS orbits using direct comparison with SLR, unless only near-zenith measurements are used. For instance, at a zenith distance of 10º, contamination of any true radial error is at a level of nearly 5% of the along- or across-track error; for an average zenith distance of 40º, the effect is 16%. The plots below, Figure 4, illustrates this, where we show the O-C results for laser ranges made within 2º of the local zenith. These results do represent good determinations of the true mean radial errors in the IGS orbits, namely -6.6 ±0.7cm for GPS35 and –3.1 ±0.4cm for GPS36.

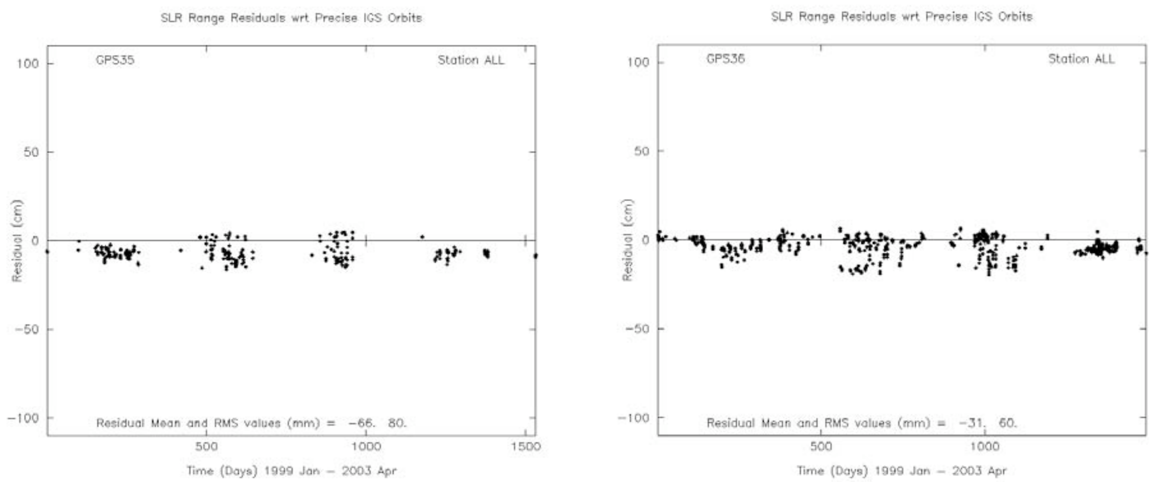

Figure 4: Time series of high elevation GPS-35 and 36 O-C values for 1999 January - 2003 April.

4. Conclusions

Since mid 2002, IGS GPS and GLONASS orbital solutions appear to be of similar accuracy, with radial RMS precision better than 10cm. A persistent ~5cm radial bias exists in the GPS orbits which may be attributable to unidentified errors in the assumed locations of the phase centres of the microwave antennae; such errors could lead to bias during precise orbit determination. It is also possible of course that the assumed locations of the GPS laser arrays are incorrect. However, our discovery in the GLONASS 84 results of a similar mean radial error of approximately -5cm leads us to surmise that if the GPS results are indicative of a scale problem for the whole GPS constellation, then that scale 'error' may have been imposed on the GLONASS orbits also.

5. Acknowledgement

The results presented here depend upon the observations and products of two of the Services of the International Association of Geodesy, namely the ILRS (http://ilrs.gsfc.nasa.gov) and IGS (http://igs.gsfc.nasa.gov). The support of all elements of these Services is gratefully acknowledged.

6. References

Appleby GM & Otsubo T
Evaluation of Potential systematic Bias in GNSS Orbital Solutions. In, Proc. 13th Int. Workshop on Laser Ranging, Washington, DC, NASA/CP-2003-212248, October 2003

Otsubo T, Appleby GM, Gibbs P
GLONASS laser ranging accuracy with satellite signature effect
Surveys in Geophysics 22 (6): 509-516 2001

Ineichen D, Springer T, Beutler G
Combined processing of the IGS and the IGEX network
J GEODESY 75 (11): 575-586 NOV 2001