

# Evaluation of Potential Systematic Bias in GNSS Orbital Solutions

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## Abstract

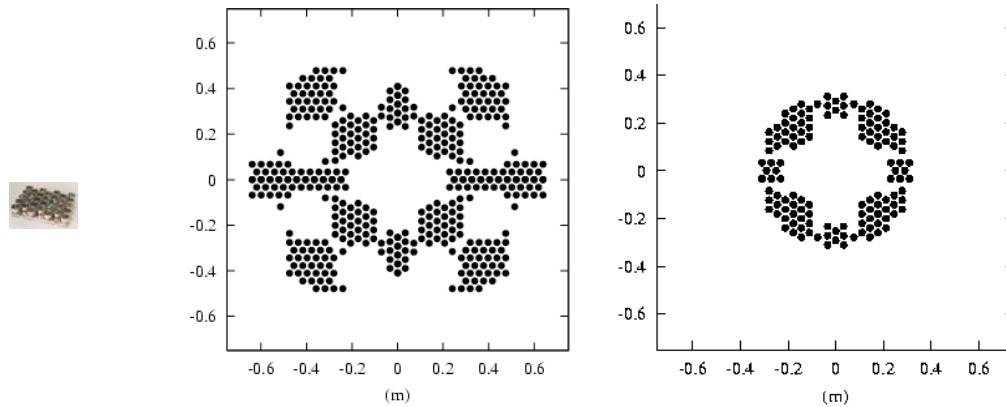
In order to combine results from different space geodetic technologies it is important to explore potential systematic biases between those results. An example of such comparisons is the use of precise laser range observations to carry out independent checks on the accuracy of published orbits of a subset of the GPS and GLONASS navigational satellites. Range measurements to two GPS satellites and a subset of the GLONASS satellites obtained by the tracking network of the International Laser Ranging Service are compared in two ways with precise orbits computed by the International GPS and GLONASS Services; by direct comparison of SLR measurements to ranges computed from the microwave orbits, and by comparison of SLR-based orbits to the microwave orbits. Previous studies have shown that in such comparisons it is vital to understand both the potential for systematic range bias induced by the laser reflector arrays and the need for accurate on-satellite positions of the array phase centers. For the GLONASS satellites these parameters are now accurately known for the two different types of array currently in orbit, and the SLR results suggest that systematic orbital bias is minimal. However, for the two GPS satellites, a radial bias of some 40 mm persists.

## Introduction

During routine orbit determination of GNSS spacecraft using radiometric data, the size or scale of the orbit is *inferred* from the time-like observations and knowledge of  $GM$ . It is therefore of interest to use a direct measurement of satellite distance as a check on the distance computed using the inferred semi-major axis of the orbit. Precise laser range observations, properly treated, can be used to make such independent checks on the accuracy, particularly in the radial component, of published orbits of the centres of mass of a subset of the GLONASS and GPS navigational satellites (e.g., [Otsubo *et al.*, 2001]; [Barlier *et al.*, 2001]).

## GLONASS Reflector Arrays

Early satellites in the GLONASS constellation carried very large (1m x 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 weaker link budget. Figure 1 shows a photograph of the GPS reflector array and schematic representations of the large and smaller arrays on old and newer GLONASS satellites respectively; the relative sizes of the arrays are fairly accurately represented in the figure.



**Figure 1.** Retroreflector arrays on GPS (-35 and -36), GLONASS (old design) and GLONASS (latest design).

### Laser Ranging to a Flat Array

Laser range measurements to the flat arrays on GLONASS and GPS satellites 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.

The plots presented in Figure 2 confirm that the measured ‘effective size’ of the array is largest for the high-energy SLR systems and for large arrays. GLONASS-80 has a large array, whilst GLONASS-84 carries a much smaller array (Figure 1). For the GLONASS-80 results, all the positive values for effective array size are deduced from the observations of high-energy (mainly NASA) SLR systems, whereas zero and slightly negative values result from the observations of stations known to work at low levels of return. Also shown are the results from GLONASS-84, which confirm that for the smaller array the deduced effective array size is also smaller.

### 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.

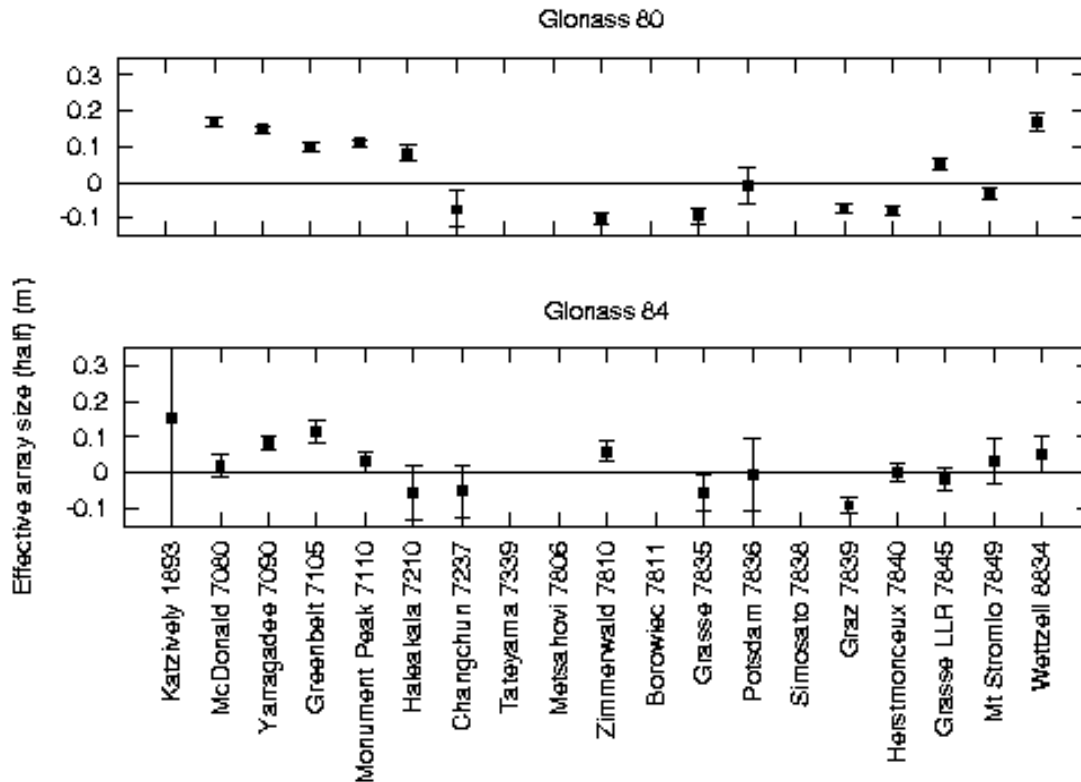


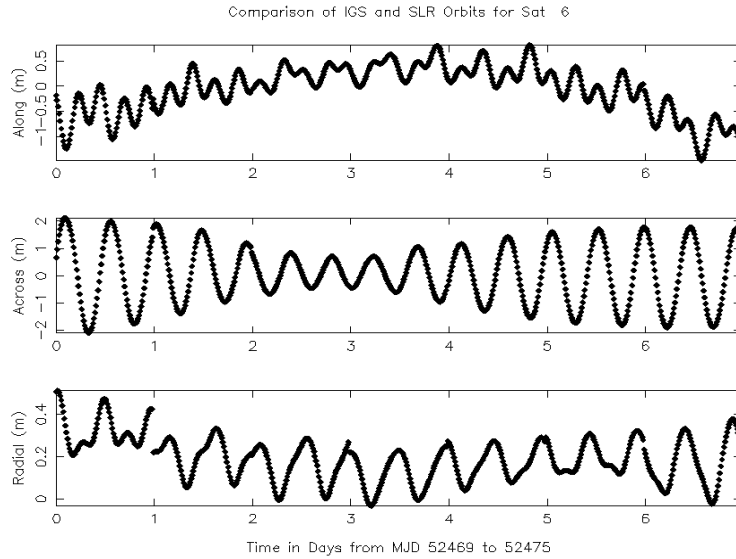
Figure 2. Effective array size derived as a function of SLR station during precise orbit determination.

### SLR Orbit Comparisons

Seven-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 unmodeled non-gravitational perturbations. Post-fit residual RMS values are typically about 5 cm. 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 cross-track differences are at a level of about 50 cm, with radial differences of between 10 and 20 cm RMS, the GLONASS results being somewhat poorer than those of GPS. In all the comparisons, the best agreement occurs near to the centre of the 7-day arcs, where, in general, orbital fits to observations tend to be optimum.

An example of the results is given in Figure 3 for GLONASS-86 for the 7-day arc starting on July 14, 2002, where once-per-revolution periodic differences dominate. Also apparent are small daily discontinuities that must be present in the IGS daily orbital solutions, since the SLR orbit is a continuous 7-day arc.

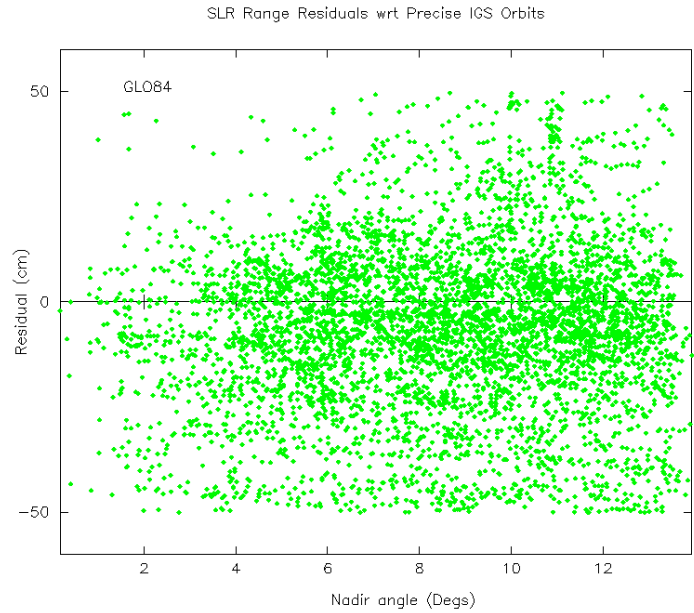


**Figure 3.** Differences between SLR and radiometric orbits: GLONASS-86, slot 6, during July 2002.

### Direct Comparison

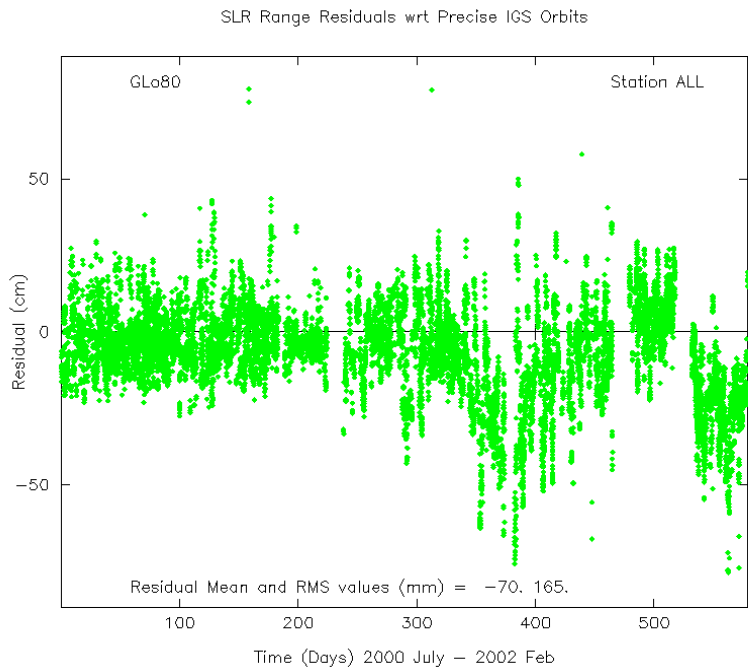
Orbital comparisons of course contain error contributions from both the SLR and radiometric orbital solutions. Cleaner is a direct comparison of precise SLR normal points with station-satellite distances determined from the radiometric orbit, when range differences are (close to) a measure of orbit radial error. Using a modified version of our SLR orbit determination software 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, and plotted against time or ‘impact’ angle at the satellite array. This has been carried out for the GLONASS satellites GL-80, GL-84, GL-86 and GL-87, when available during the period July 2000 to July 2002 (GL-80 ceased operational service in February 2002) and for the GPS satellites GPS-35 and GPS-36 for the period January 1999 to May 2000.

For illustration, the results from global SLR tracking of GLONASS-84 during the period February 2001 and July 2002 are given in Figure 4. We note that there appears to be little dependence in the values of o-c as a function of impact angle, which is as expected for the relatively small array carried by this satellite and is in agreement with the results shown in Figure 2. Previous studies using observations of GLONASS satellites that carry the large ‘old design’ arrays [Appleby and Otsubo, 2000] have shown clear elevation-dependent radial trends that can be attributed to the attitude dependent effects discussed in the section on laser ranging to a flat array.

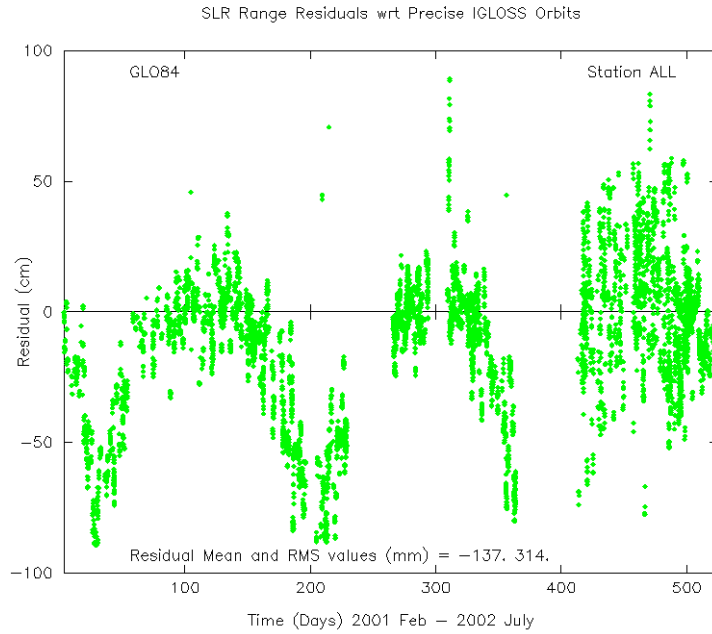


**Figure 4.** SLR ranges – satellite range deduced from radiometric orbit (GLONASS-84).

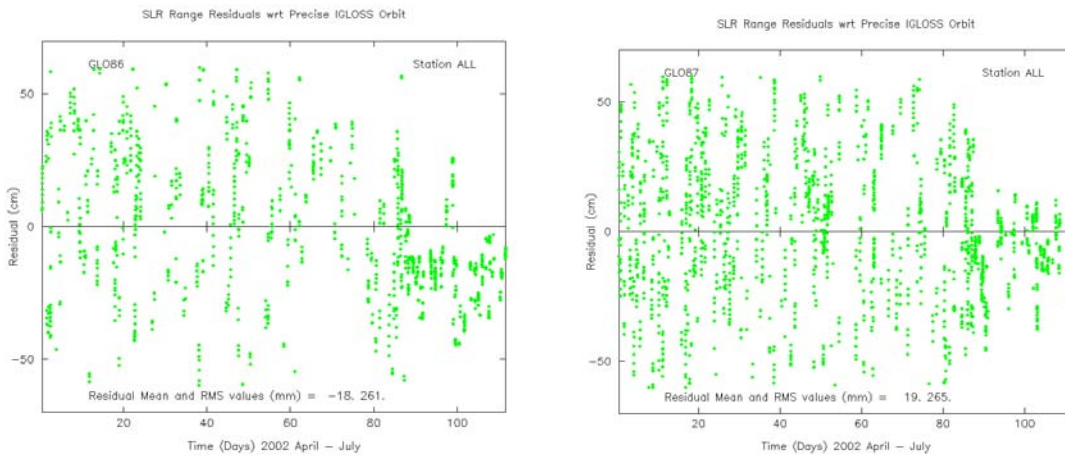
Shown in the following figures are o-c plots with respect to time for all four GLONASS and the two GPS satellites in the study.



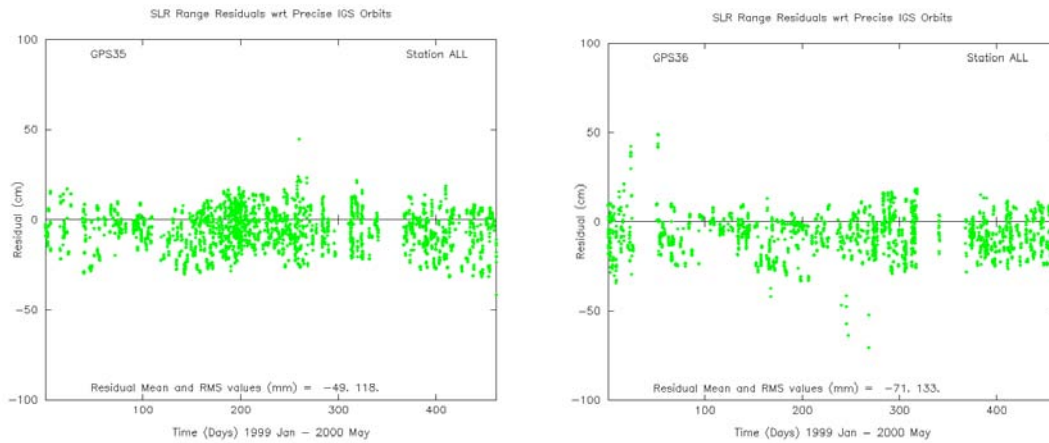
**Figure 5.** Time series of GLONASS-80 results for July 2000 - February 2002.



**Figure 6.** Time series of GLONASS-84 results for February 2001 - July 2002.



**Figure 7.** Time series of GLONASS-86 and 87 results for April 2002 - July 2002.



**Figure 8.** Time series of GPS35 and GPS36 results for January 1999 - May 2000.

## Conclusions

GPS orbital solutions appear to be the more accurate, but a persistent ~5 cm radial bias exists [Ineichen *et al.*, 2001], which may be attributable to unidentified errors in the assumed locations of the phase centres of the microwave antennae; such errors could lead to biases during precise orbit determination. It is also possible of course that the assumed locations of the GPS laser arrays are incorrect.

Long-term systematic radial bias in the radiometric orbits is very variable for GLONASS. There are significant, 60 cm level, radial biases with annual periodicity in two of the GLONASS satellites (GLONASS-80, plane 1, slot 1 and GLONASS-84, 3/24)

Consideration should be given to whether a combination of ILRS and IGS data during operational orbit determination processing could significantly improve the orbital accuracy.

## 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 the IGS (<http://igsb.jpl.nasa.gov>). The support of all elements of these Services is gratefully acknowledged.

## References

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