RETURN ENERGY ESTIMATES DERIVED FROM NORMAL POINT AND FULL-RATE LASER DATA

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To fully understand and model Centre-of-Mass corrections for individual stations one needs to have an understanding of the levels and degree of variation of return energy for each station. The potential range measurement inaccuracy due to such a variation is demonstrated by observations of a number of satellites at high and low levels of return rate. Using full rate data and knowledge of the laser repetition rates for each station we are able to estimate the return rates for different satellites for the major ILRS stations. These values are investigated for repeatability and elevation dependence and some inferences made on relative CoM corrections appropriate for each station.

Introduction

During the routine operation of satellite laser ranging, the strength of the return signal from the observed satellite may not be constant. A stronger return signal is observed for low Earth orbiting satellites, for higher elevations, or as a result of better atmospheric conditions. A weaker signal is observed for higher orbiting satellites, lower elevations or poor sky conditions. Stations may also experience characteristic levels of return energy due to their location and laser pulse energy.

Such variations in return energy may have implications on the range measurements made. For spherical satellites, such as the geodetic Lageos satellites, measurements made at high return rates are made close to the front of the satellite. Range measurements made a low return energy, however, are from across the satellite surface and the effective reflection point is consequently deeper into the satellite. These two different states of observation require two different Centre-of-Mass corrections to refer the range measurement to the centre of mass of the satellite.

In addition, an uncompensated single photon avalanche diode (SPAD) channel experiences a ‘time walk’ error in range measurement, which varies with return energy strength. This could produce cm order errors in the range measurement. A compensated SPAD reduces this time walk error to less than a few millimetres.

High and low return energy experiments

At Herstmonceux, the return energy is maintained at a low, single-photon level using a neutral density wheel. Software detects satellite track, estimates the return energy level and increases or decreases the neutral density filtering accordingly. By removing the neutral density filtering during a satellite observation, the system can be forced to operate at a high level of return energy.

To determine whether return signal strength effects can be seen in range measurements, the satellites Ajisai, Envisat and Lageos 1 were observed at both low and high levels of return energy. Each pass was predominantly observed at low return signal strength and also included periods of high return energy. All measurements taken over the full pass were used to generate an orbit solution from which Observation-Calculation residuals were plotted.

Figure 1 contains the residuals from an observed pass for each satellite using both the uncompensated and compensated C-SPAD channels. The black squares are minute binned residual points and the red stars are an estimation of the return energy. Each plot contains a region that was observed at high return energy.

Ajisai is a large spherical target and for both C-SPAD channels an offset can be seen for the high return energy measurements. There is a difference of about 8cm in the range measurements between the two states for the uncompensated channel. The compensated channel removes the effects from the laser pulse width and detector to leave only the satellite effects. The offset for this channel is about 6cm and is due entirely to the shape of the satellite.

Envisat is a small target and an offset in range measurement can only be seen for the uncompensated channel. The magnitude of the offset if on a much smaller scale than that of the Ajisai offset. The absence of an offset for the compensated channel suggests that there is no satellite effect due to the size of the target.

Lageos is spherical target, yet an offset in the range measurement can only be seen for the uncompensated channel. The return signal only reaches an estimation of about 40% and at this level of return energy the satellite is behaving as a small target. Table 1 summarises these results and includes attempts to quantify the offset from the plots in figure 1.

Table 1. Estimations of the offsets in range measurement at high return energy for three satellite passes.

Satellite	Uncompensated offset	Compensated offset
Ajisai	80+ mm	60+ mm
Envisat	10+ mm	~ 0 mm
Lageos	~ 5 mm	~ 0 mm

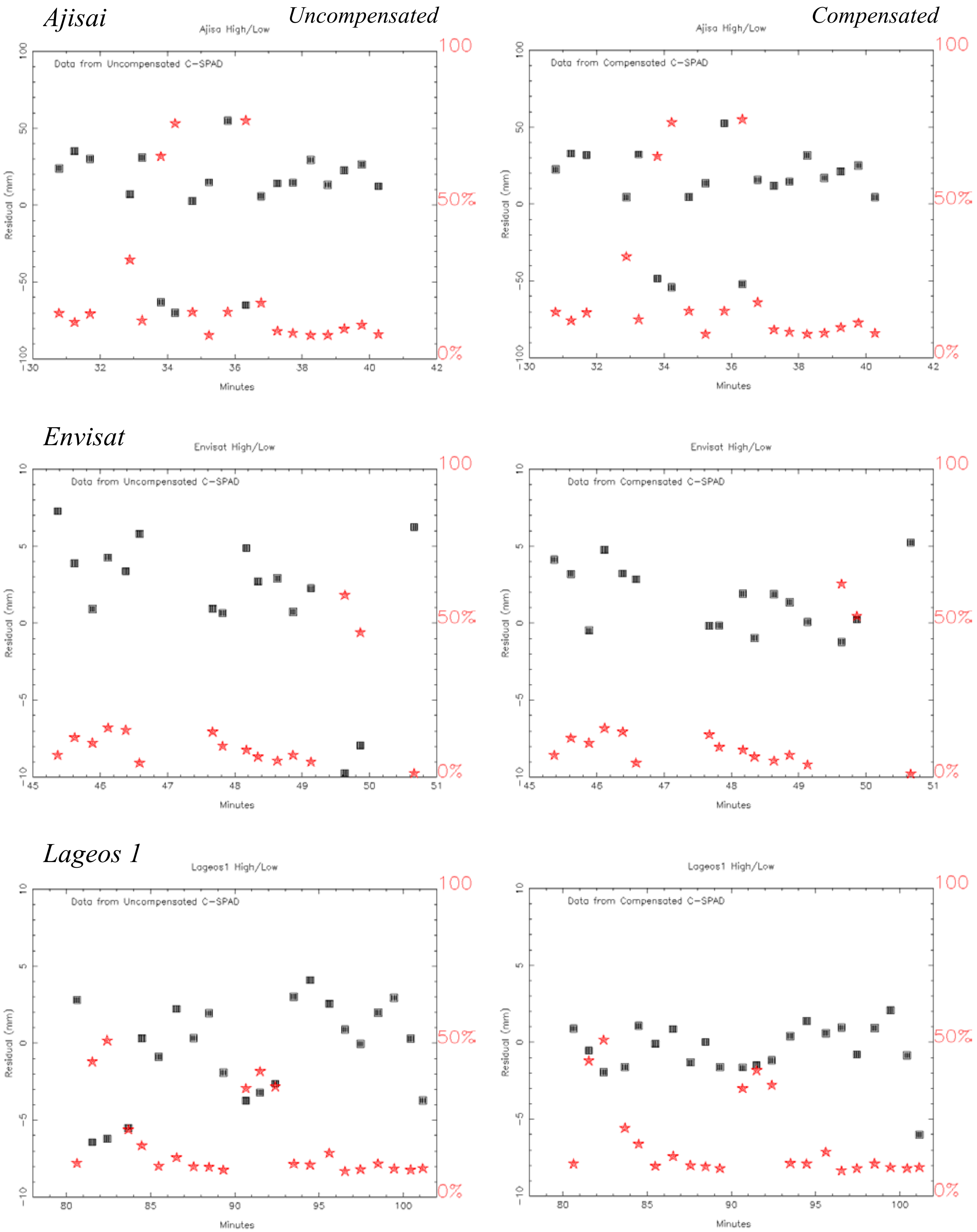

Figure 1. Residual plots for the satellites Ajisai, Etalon and Lageos 1 for both the uncompensated and compensate C-SPAD channels. The black squares on the plots are binned residuals points and the red stars are an estimation of the return energy.

Variable return energy

The residuals in figure 1 show that there is potentially a difference in range measurements observed at high and low return energy. These plots were produced by forcing the system at Herstmonceux to stop observing at the single photon level and instead observe at high energy. The following investigation is concerned with whether there are variations in the return energy in the routine operation of ILRS systems.

It was assumed that an estimation of the return rate can be made from the ratio of the number of range measurements to the number of shots fired. The effective number of shots fired depends on the station firing rate, the use of the semi train and the use of an event or interval timer. The return rate estimation was made using the complete 2003 full rate data volume.

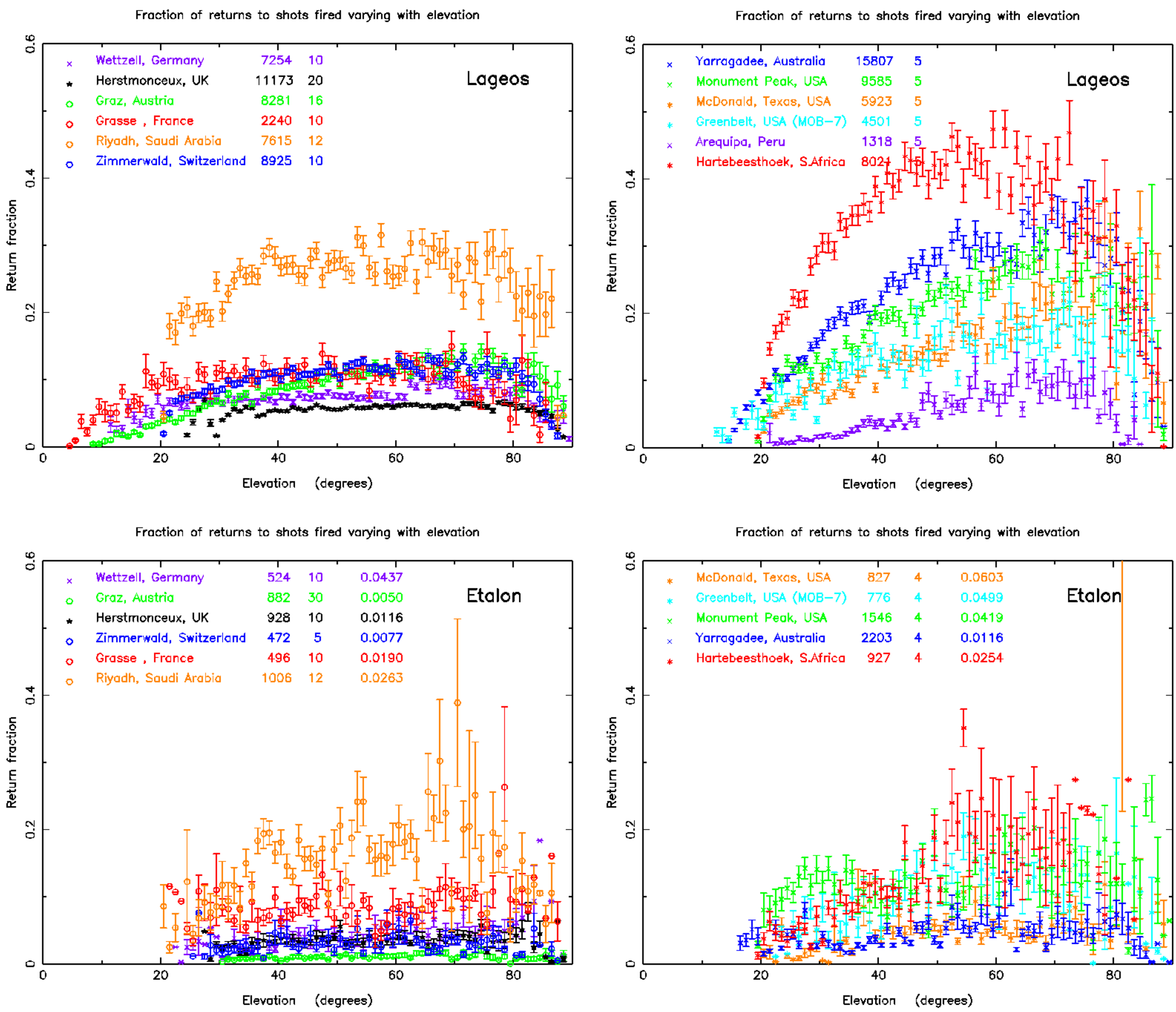

Figure 2. Return rate estimation from 2003 full rate data volume against elevation for combined Lageos and Etalon satellites for C-SPAD and NASA MCP systems. Each plot contains standard error bars

Figure 2 contains plots of estimated return rate against elevation. The top left plot contains the combined Lageos 1 and 2 data from stations using C-SPAD systems. Each colour represents an ILRS station and the plot shows most stations operating at a consistent low return rate with increasing elevation. Riyadh in Saudi Arabia operates at a higher rate of return. All stations observe at a lower return rate at low and high elevations, where the satellite may be lost due to the atmosphere or zenith tracking respectively.

The top right plot is the combined Lageos observations for the NASA MCP stations. Each station can be seen to operate at a characteristic level of return rate at any particular elevation. Also, each station produces a characteristic return rate variation with elevation. The degree of this variation is different between stations, all have reduced return rate at low and high elevations.

The bottom left plot in figure 2 contains combined Etalon 1 and 2 return rate data. Each station operates at a low level of return rate and is more consistent with increasing elevation. This is due to the greater height of the Etalon satellites and the consequent difficultly to observe at a high level of return rate. The bottom right plot in figure 2 is the combined Etalon NASA MCP data and shows a reduced return signal and, consequently, a reduced variation of return signal with elevation.

Receive Amplitude

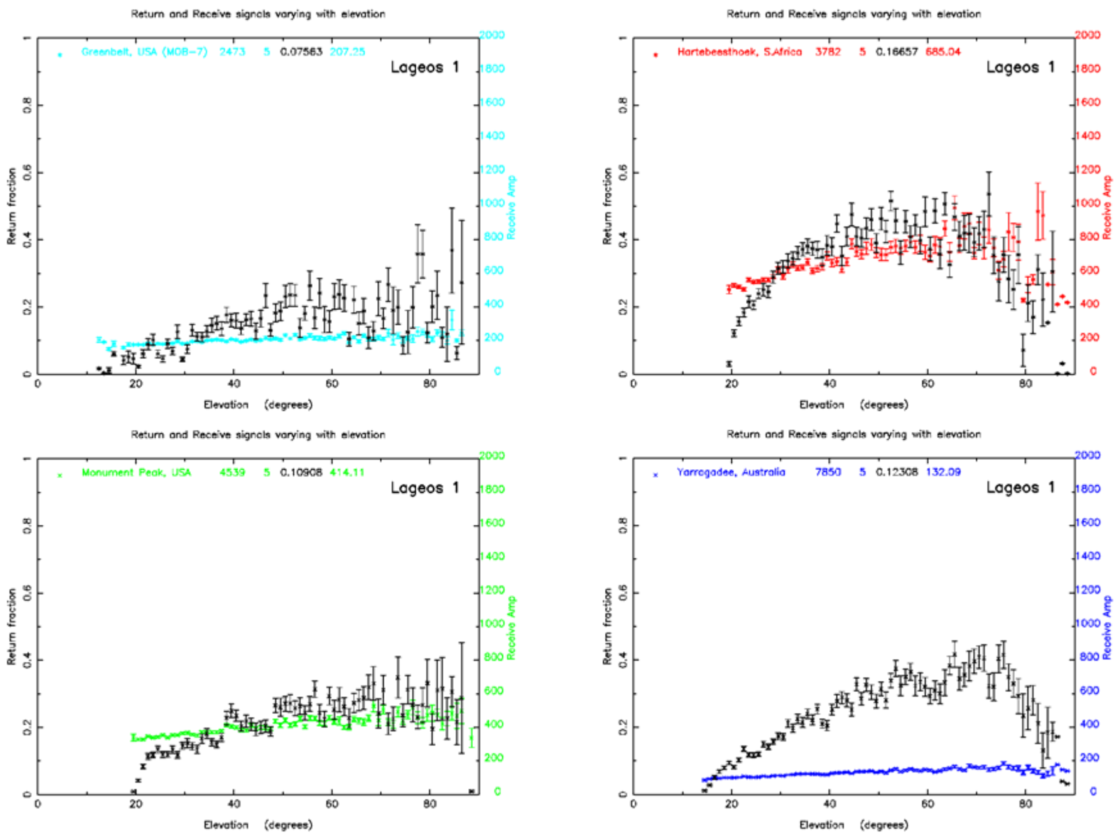

Figure 3a). A comparison between the receive amplitude entry in the full rate data volume and an estimation of the return rate for the Lageos 1 satellite.

The full rate data contains an entry named 'receive amplitude' and is used by some NASA systems in their operation. It is a linear scale from 0 to 2000 relating to the return energy and could be used as a substitute in analyses. However, the information is supplied by only a few stations and we believe it is incorrectly scaled for Yarragadee, Australia. Figure 3 contains plots of the two values on a scaled y axis for Lageos 1 and Etalon 1. Al plots exhibit reasonable agreement, except for Yarragadee for Lageos 1.

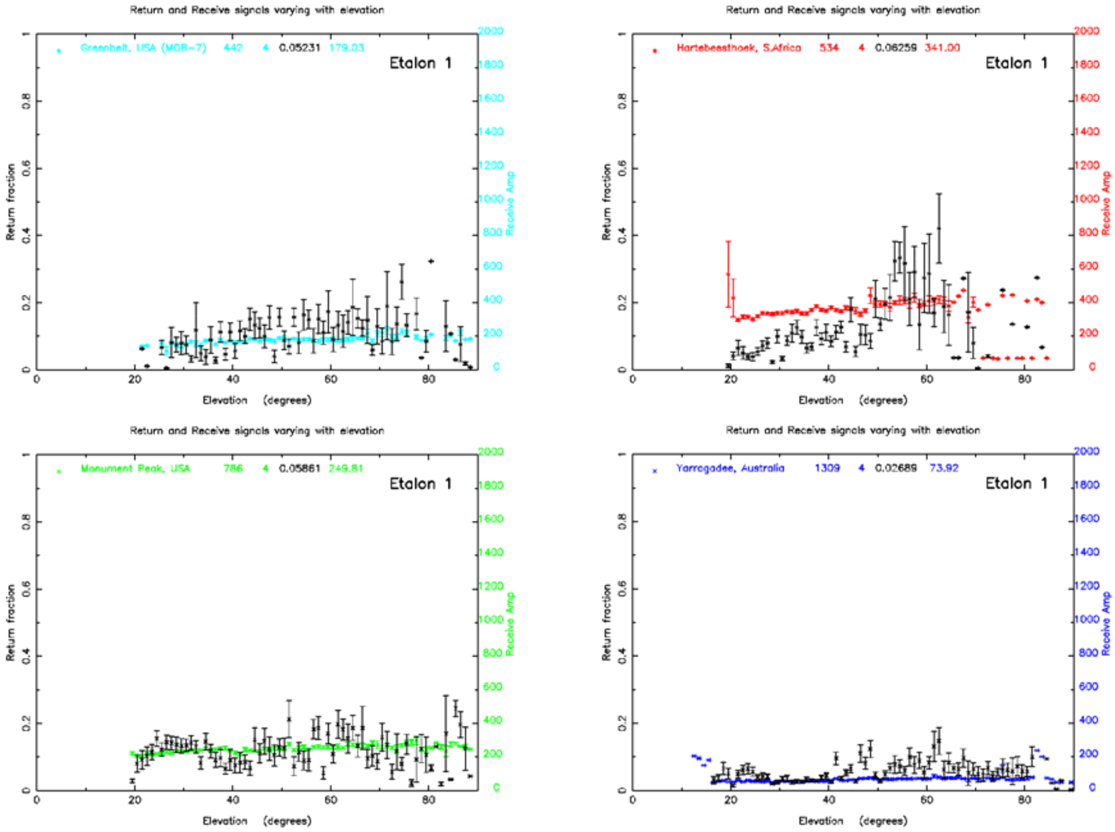

Figure 3b). A comparison between the receive amplitude entry in the full rate data volume and an estimation of the return rate for the Etalon 1 satellite.

Conclusions

The strength of the return signal from a satellite can affect the accuracy of the resulting range measurement. A range difference is present in O-C residuals when a satellite is observed at both high and low levels of return. This difference depends upon the shape and size of the satellite and can be quantified for large targets using the residual plots.

All stations experience a variation in return signal strength when observing between different satellites and at different elevations. These variations are individual to the station. Maintaining a consistent return rate during all observations will provide more consistent measurements.