

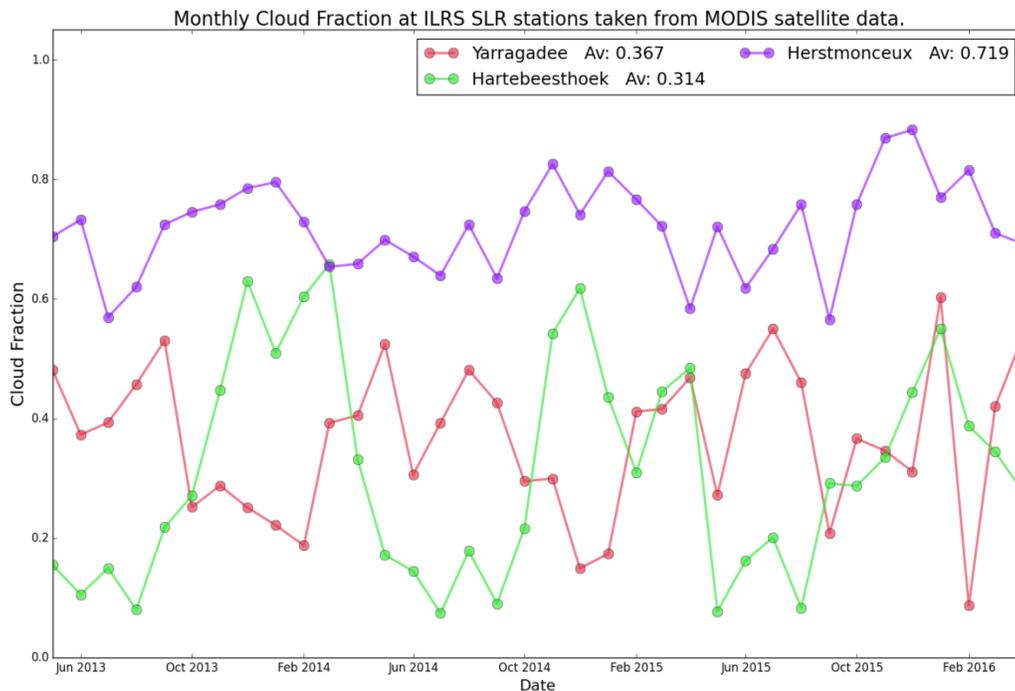
Multi-satellite tracking strategies at SGF Herstmonceux

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Each station of the ILRS network has advantages and disadvantages that affect their potential productivity. To take Herstmonceux as an example; on the positive side we have been historically well supported and system components are relatively new (kHz laser), or refurbished (telescope drives). Additionally, we have a highly trained and long standing team of observers, freedom to innovate, improve and build our own tools and software. We are also able to set our own priorities. Our funding body is content for us to track the full complement of ILRS targets. Our main disadvantages are the weather, only 35% of scheduled time is worked, and funding restrictions limit spending on overtime/observing, meaning we are unable to use the system for large parts of any given period of time.

The plot below illustrates this point by showing monthly cloud fraction data from the MODIS satellite for 3 example ILRS sites. Herstmonceux is typical northern Europe, Atlantic influence gives few stable periods and clear sky tends to come in short bursts. Yarragadee has reasonable sky throughout the year, while Hartebeesthoek demonstrates a very clear seasonal effect.

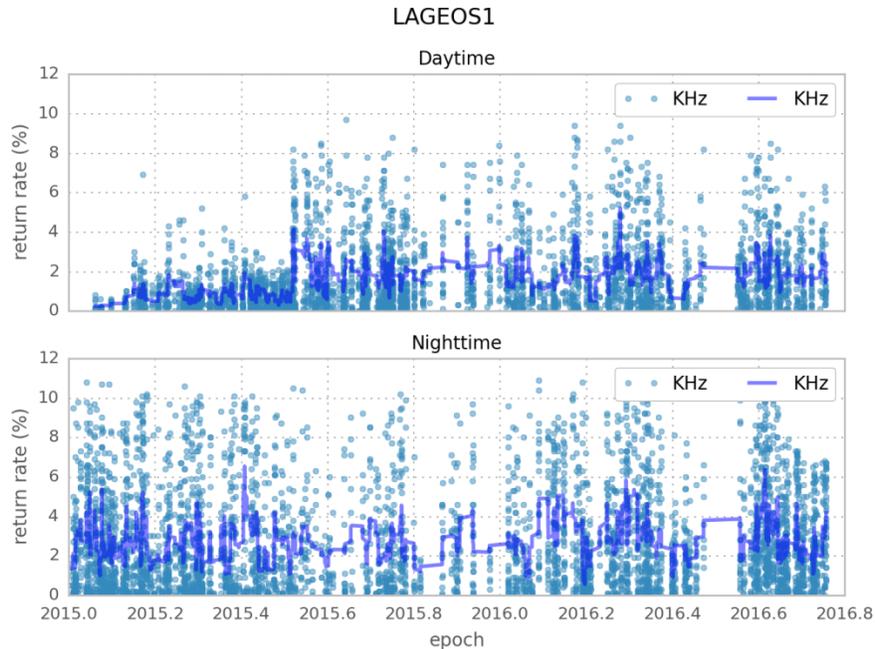


Flexible scheduling process

We generate a month in advance listing of all LEO and LAGEOS passes from TLE's, all GNSS satellites are tracked by the system but excluded for clarity at this stage. Two duties per day are formed by editing this list, keeping in mind satellite priority and available funds. Natural gaps in satellite passes are used to shorten shifts, the key is to look for places you can lose time (cost) from the schedule while minimising impact on outputs. For reasons related to this cost/benefit process observing is much reduced at weekends. Each scheduled observer then decides if the sky is good enough to work and only attends in clear weather. This process means we can exploit short clear spells with high density of priority satellites.

Efficient observing practise

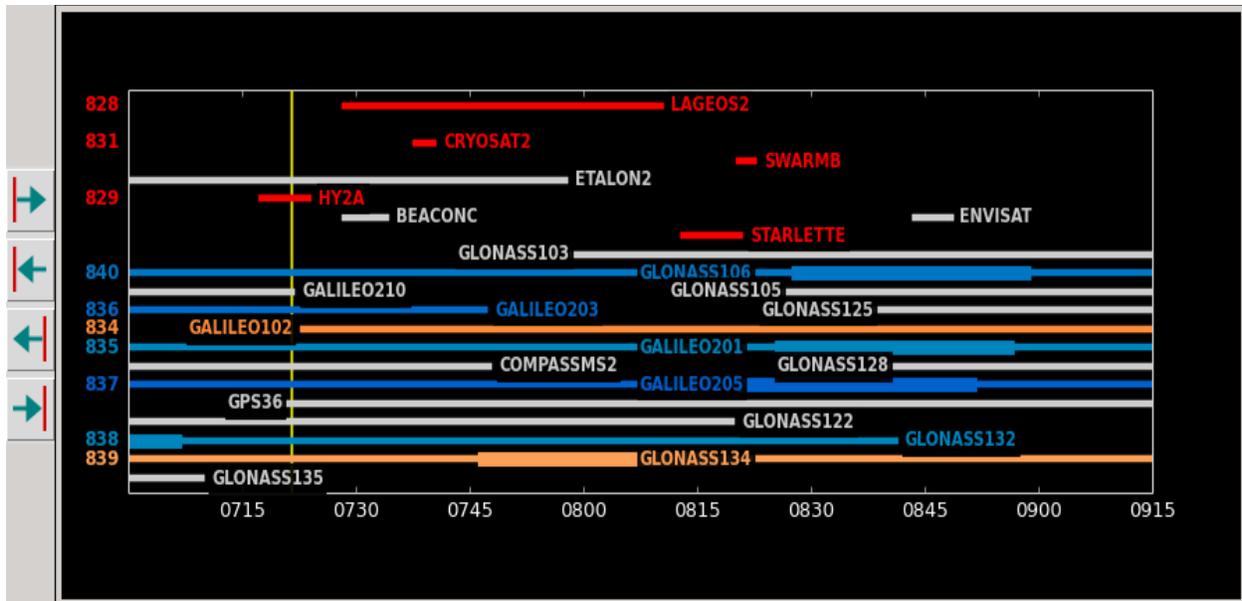
The aim is to achieve the highest quantity of high accuracy normal points possible. Fast switching between satellites is limited for us by mount slew speed, but needs to be quick enough to interleave Jason satellites for example. Our upgraded kHz laser allows less time on each satellite to gain the required number of points for a high precision normal point. This is particularly important for GNSS tracking where multiple satellites can be tracked within a single NP 5 minute window. This general process isn't a new kHz invention, we worked the same way at 10Hz, it's just faster now. Another recent change at SGF that improved performance has been our daytime blocking filter upgrade; this gives better transmission and a large improvement in daytime GNSS tracking capability, for a very modest investment. The following plot illustrates this change using return rates to Lageos1. The change in mid-2015 gives a marked increase in return rates even approaching night-time performance. Note that the highest return rate is controlled by our filter system to limit multi-photon returns; hence even the night time results don't exceed 10-12%. While higher return rate for Lageos is useful, it is the improvement in the ability to track GNSS in daytime that is most significant. This is a good example of a change that is focused on improving the most difficult tracking.



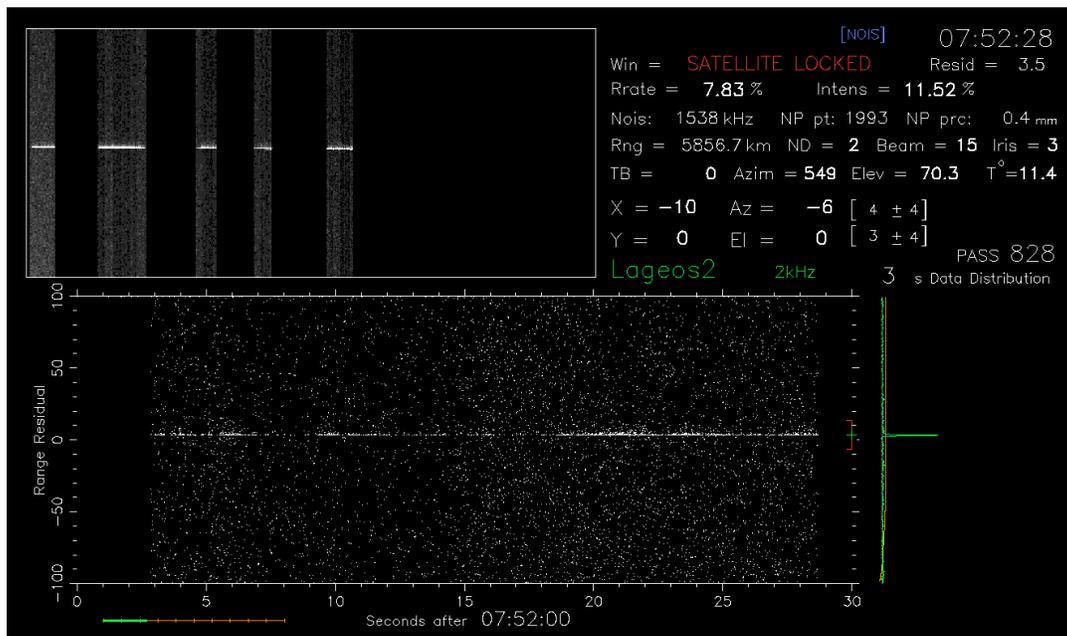
Real time display and tracking tools

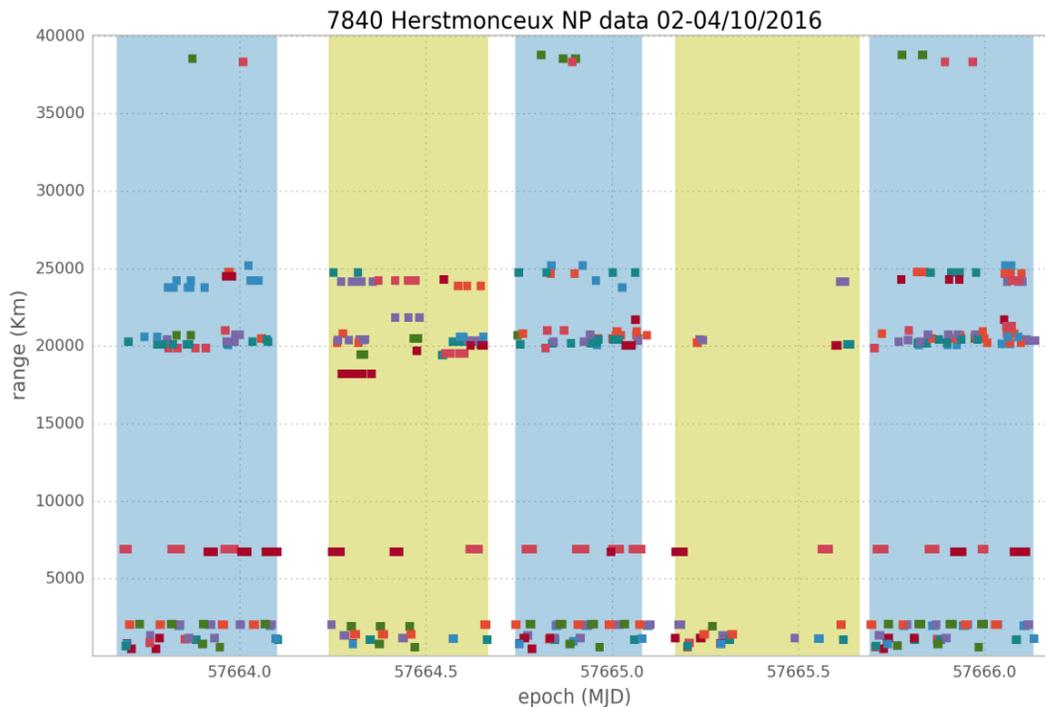
The next step is to provide the observer with information to help them make good decisions on what to track and when. The schedule of upcoming and current passes is available, along with detailed pass listing and information, shadow times for example. An audible alarm system is available for warning that a pass is about to start. Then during tracking, the display shows the track (or lack of), and current return rate, pointing offsets etc. Of particular note here is the display of number of points in current NP and real time estimate of precision is displayed. This helps the observer make a decision to move on once 1mm NP precision or 1000 points is obtained.

The figure below shows a screenshot of the observers real time schedule information screen. Having the upcoming schedule presented visually helps with planning the most effective path through the observing opportunities available. The priority order runs from top to bottom and is deliberately kept simple, LAGEOS then LEO's, then GNSS based on number of recent passes. Different colours are used to highlight more intense tracking requirements, for example during an ILRS campaign.



The screen shot below shows the real time tracking window part way through the Lageos satellite shown in the schedule above. Current points in the NP are shown, along with approximate precision, at this point we are set to switch to a GNSS satellite. The top half of the plot shows the whole Lageos pass, the gaps in the track are periods where the observer has interleaved a GNSS satellite. Good conditions are needed for this in daytime, but it can be routine at night.



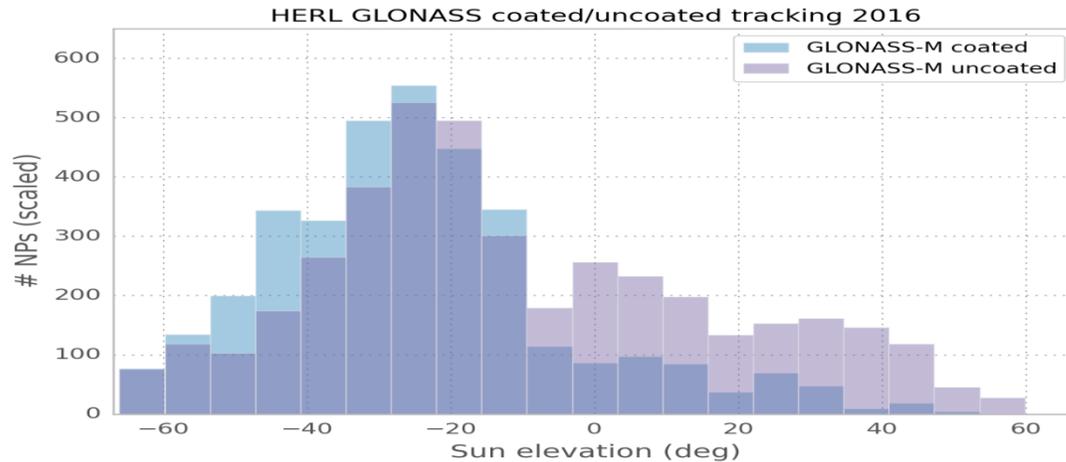


The figure above shows NPs plotted against satellite mean range for a few days last week. Night shifts are coloured blue, days in yellow and white gaps are unscheduled periods. This is an example of the density of tracking that is possible in good conditions and the remaining limitations, GEO satellites in daytime the next challenge for us.

Importance of a good LRR array

We would like to reiterate the importance of a sufficient LRR array for efficient operations, to obtain the best tracking data for a satellite it needs an array that yields solid daytime returns for kHz stations. For example the latest uncoated GLONASS arrays offer good performance, while the new GALILEO satellites have a reduced array size. Not to the point that ranging to GALILEO is badly compromised, but certainly any further reductions for future satellites would be unwelcome. Excessive difficulty (failures) reduces observer ambition: there are always other less time wasteful GNSS satellites to attempt.

The plot below illustrates this point by showing how the majority of daytime NPs from SGF in 2016 for GLONASS satellites have been from the newer uncoated (better performing) LRR arrays.



Increasing numbers of satellites present a challenge

Ever increasing numbers of LRR equipped satellites, in particular large numbers of GNSS satellites represent a challenge for observing. SLR systems are increasingly finding funding routes in non-traditional areas as well, for example debris, SST. These alternative funders will want telescope time for their money and this can only have a negative impact on the time available for core geodetic activity. We currently feel there is still capacity for more satellites, given the capabilities described here, but certainly must recognise that a limit may be reached. What this limit is will be entirely dependent on the tracking density required by the missions; this is why input from mission operators is critical. It would be possible to increase tracking on individual satellites by observing whole constellations but prioritising within them, for example as in ILRS GNSS campaigns. Or we could decide to only track a subset of satellites, but this isn't what the GNSS missions are currently saying they want. A flexible scheduling approach, station by station or across the network as a whole to share out the workload might also be useful for certain constellations, but again only with the support and guidance of the missions. We should remember that it's better to have the 'problem' of too much demand.