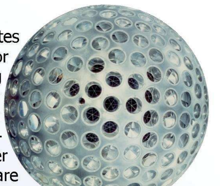
Natural Environment Research Council

Space Geodesy Facility

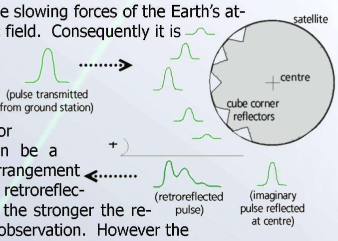
The **NERC Space Geodesy Facility** is located close to the village of Herstmonceux in East Sussex. On-site is a state of the art Satellite Laser Ranging System and two Global Navigation reference sites. The facility is regularly tracking some 30 artificial satellites and the full GPS and GLONASS constellations.

Satellite Laser Ranging is an accurate and direct measurement to satellites as they pass overhead. A SLR measurement is made by firing a short, 100 picosecond, pulse of green, 532nm wavelength, laser light to target onboard the satellite that reflects the light back along its outgoing path. The returning light is observed through a telescope and a time-of-flight measurement is accurately recorded along with the time of fire. The facility is allowed to operate through the day as well as the night by the single wavelength property of laser light so that noise, including daylight, can be filtered out and only the green laser light reaches the detector. The technique is capable of tracking a satellite to an accuracy of a centimetre. Furthermore by collectively using data produced by similar stations elsewhere in the world orbit solutions are produced to a centimetre precision. The facility also operates two Global Navigation reference sites, which complement SLR to make the NSGF an important and well known global location. The facility is currently undergoing an upgrade which will improve the quantity and quality of its output. The single shot precision of a SLR observation is anticipated to improve from 10mm to 3mm.

Satellite



The satellites available for SLR ranging exist between 400km to 20 000 km in height above the Earth's surface. Each must have an onboard retroreflector array which allows tracking using laser light. The main satellite groups that are tracked using SLR are geodetic, gravitational, altimetry and navigation. An example of a geodetic satellite is Lageos which is a passive sphere of retroreflectors. It has large mass and small volume with an aluminium shell making it resistant to the slowing forces of the Earth's atmosphere and magnetic field. Consequently it is in a very stable orbit.

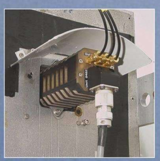


Observing an SLR satellite accurately depends upon the retroreflector target array, which can be a single reflector or an arrangement of hundreds. The more retroreflectors onboard a satellite the stronger the return signal and ease of observation. However the larger the retroreflector arrangement the greater presence of an array signature in the return signal and the increased difficulty in relating the range measurement to the centre of mass of the satellite. Observing a retroreflector array at high energy will produce a measurement at the front of the target made on the leading edge of the return signal. However an observation at low energy could be made from anywhere on the array. To achieve a consistent centre of mass correction the return energy must be controlled and consistent. The NSGF observes routinely at a single photon level.

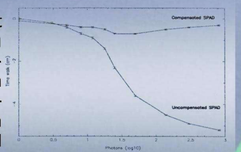
Atmosphere

All SLR observations must be corrected for the effects of the atmosphere. Light is refracted as it leaves and re-enters the atmosphere increasing the optical path and slowing down the speed at which it travels. Each laser shot uses a recording of local temperature, pressure and humidity to produce a corrected range measurement using an atmospheric model. The atmospheric uncertainty is 2 metres in the zenith with the model being accurate to 1mm.

Detector

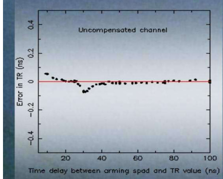


The returning laser signal reflected from the satellite is captured in a 50cm aperture telescope through which the light is focused on to a Compensated Single Photon Avalanche diode (C-SPAD).



A SPAD is so sensitive it is capable of detecting single photons incident on its surface. However when multiple photons are detected a significant bias is apparent. Without a consistent level of return energy for each detection an error is introduced. The Compensated channel of the C-SPAD corrects for this error. The NSGF controls the return energy reaching the C-SPAD by including and adjusting neutral density in front of the detector, maintaining a consistent return energy.

During observations the detector is not armed until just before the returning signal is expected. This could be as late as 100ns before the signal, corresponding to the light being 30m away. The detector takes 50 nanoseconds to arm and then waits for the first photon to reach it. Upon detection an Interval timer is stopped and a range measurement is made. Should the detection occur before C-SPAD has fully armed a non-linear uncertainty is present in the measurements.



Laser

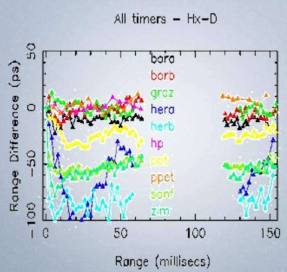
Laser light is produced by exciting a ND-YAG crystal to produce a narrow spectrum of infra-red light which oscillates in a cavity about 1m long. Once enough energy is held in the cavity a dye at one end turns transparent, releasing the light to travel through a series of amplifiers and finally a frequency doubler to convert the infra-red light to green light of 532 nm wavelength. This light is expanded through a series of telescopes and travels to the emitting telescope mounted on the side of the receiving telescope. This process happens 13 times a second. Each firing of the laser starts a counter and represents the beginning of the range measurement. The laser is held in an environmentally controlled room to maintain consistent measurements.

Each laser pulse has a width of 100ps. A returning photon could have come from anywhere in this distribution therefore having an uncertainty of 3cm. A strong return signal will be detected at the leading edge of the laser pulse resulting in a shorter range measurement than if the detection was made at the peak of the pulse. To make consistent measurements the return signal strength has to be controlled. By keeping to a single photon regime the NSGF system records range measurements from anywhere in the laser pulse, resulting in a mean result at the peak of the pulse. The measurements have an accurate mean but a larger RMS.

The NSGF has recently installed a new semi-conductor laser that will produce laser light at 532nm with a pulsewidth of 10ps and a repetition rate of 2 kHz. This will greatly reduce the RMS of the measurements because of the reduced uncertainty of the narrower pulse and the much greater number of observations.

Timer

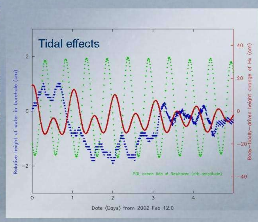
On firing the laser, the time is accurately recorded and a high speed counter is triggered. The time is linked to UTC by GPS and is accurate to 1 microsecond. After a short delay the return signal is detected through the telescope and the counter is stopped. The more accurately the interval between fire and detection can be determined the more accurately the distance to the satellite can be measured. The counter currently used is capable of recording the interval to an accuracy of a few picoseconds, equivalent to about 1 millimetre in distance. At this level of accuracy many timers show non-linearity in their measurements. The plot to the right shows other timers compared to our main Stanford interval counter.

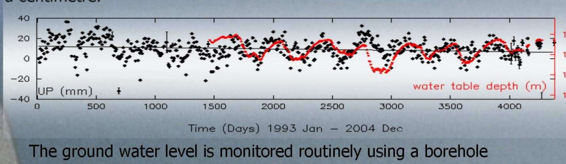


The NSGF is currently building and installing an epoch timer. Instead of accurately measuring an interval an epoch timer records the epochs of many events. By matching the epochs of laser fires to return signal detections range measurements can be made at a much higher rate because multiple shots are in flight at any moment. The event timer is expected to be linear over all distances and accurate to 1 picosecond. This upgrade is essential to use the new kHz system.

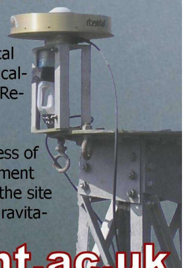
NSGF Site

The NSGF site is an accurately determined location on the Earth's surface. It is one of the 10 core reference sites that define the scale and origin of the International Terrestrial Reference Frame (ITRF). The importance of the site is complemented by the co-location of two IGS Global Navigation reference receivers. These are HERT and HERS and are separated by a distance of 136m. On-site processing determines the coordinates of these sites on a daily basis to better than a centimetre.





The ground water level is monitored routinely using a borehole beside the SLR telescope. Every 5 minutes the water table height is recorded. A changing water table height can relate to a change in the site's vertical coordinate. The site stability is also monitored by calculating baselines between the Global Navigation Receiver sites.



The site has recently received and is in the process of commissioning a Absolute Gravimeter to complement the other techniques in long term monitoring of the site and to make the NSGF an important site in the gravitational reference frame.

http://nercslr.nmt.ac.uk