NERC Space Geodesy Facility, Herstmonceux SGF-09-1

Report on operations for the period 2008 April to 2009 March

Annual summary

The main areas covered during the past year are

- Full coverage of SLR tracking for all ILRS objects.
- Analysis of GPS data produced by HERT and HERS.
- Analysis of SLR data as an ILRS analysis centre.
- Glonass observations and other requested observations for MoD.
- Continued monitoring of GNSS status for MoD.
- Further development of LIDAR system.
- Collect regular Gravimeter data.
- Re-calibrating SR timers as part of the re-analysing SLR data back to 1983
- Investigating behaviour of SPAD detectors wrt arming times
- Significant development of GEOF system and regular observing using system.
- Continued investigation into energy losses through optical paths
- Produce all data output in proposed new ILRS data format, send full data sets for Jason-2 T2L2 experiment.
- Develop software for upcoming LRO launch and participate in test runs for LRO
- Automate kHz/10Hz/LRO system to make switching between the different systems quick and easy.

1 Satellite Laser Ranging

1.1 Annual totals and statistics

Pass totals for the year 2008 April to 2009 March

Altimetry/LIDAR

GFO-1 163; ERS-2 310; ENVISAT 288; Jason-1 477; Jason-2 368;
ICESat 136
(GFO-1 failed during the period and was removed from the SLR tracking list)

Geodetic/Gravity

Lageos-1 465; Lageos-2 363; Etalon-1 61; Etalon-2 58;
Champ 117; Grace-A 131; Grace-B 144;
Ajisai 387; Beacon-c 196; Larets 262; Starlette 353; Stella 188

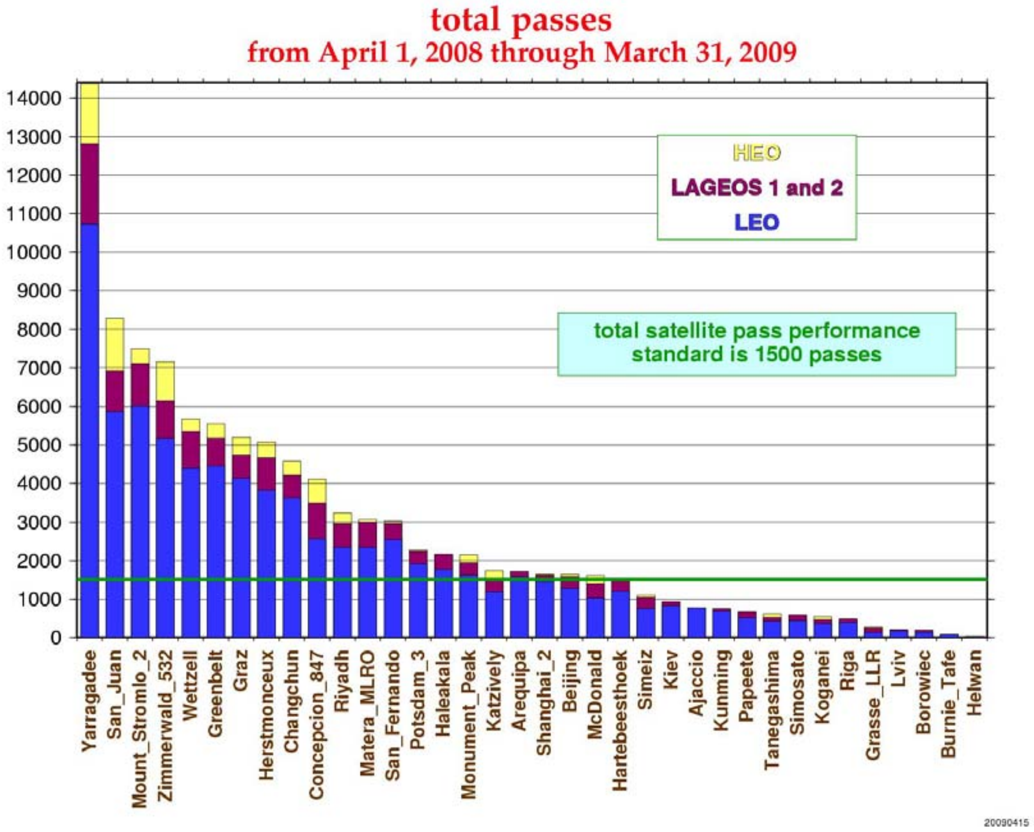
Orbital Support

OICETS 30; SOHLA -1 13; terraSAR-X 137

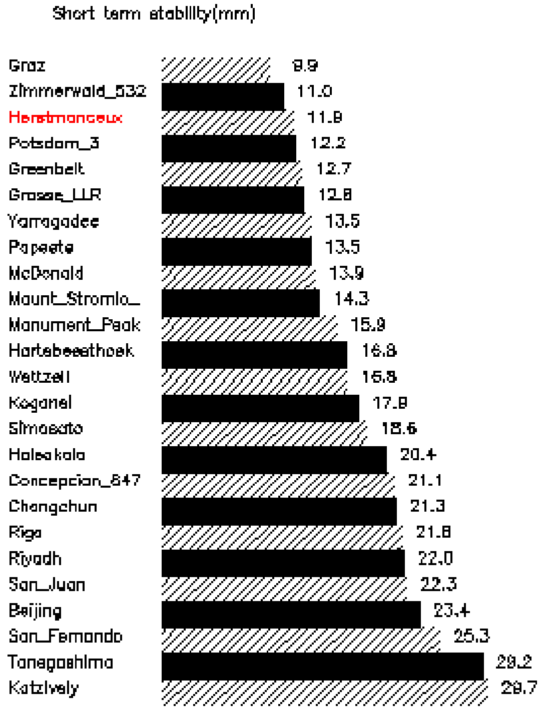
Global Navigation Satellite Systems

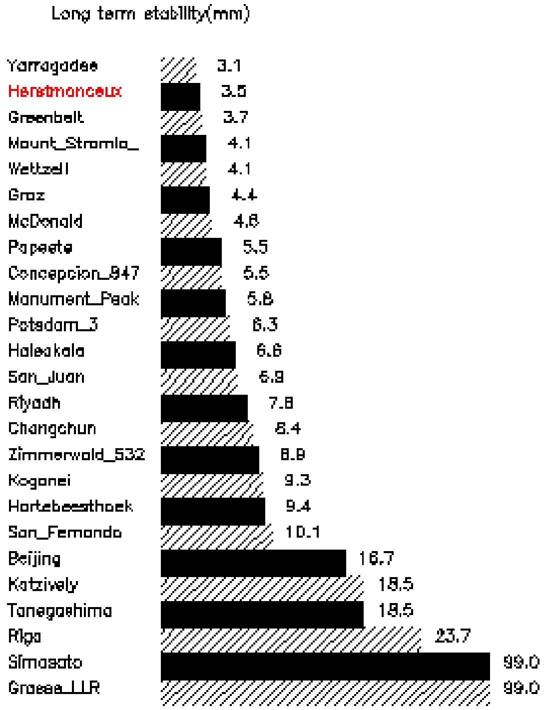
GPS35 25; GPS36 30; CompassM1 22; GIOVE-A 34; GIOVE-B 25; GLONASS 800

Shown below are global totals as compiled by the ILRS central bureau for the period April 2008 to March 2009.



The quality (precision) of the laser data is estimated from the results of five ILRS analysis centres' weekly LAGEOS orbital solutions; orbital fits are performed during which station coordinates are held fixed at their ITRF2005_SLR values, but pass-by-pass range and time bias values are solved-for. Over the previous three-month period the standard deviation about the mean of these pass-by-pass range biases is considered a measure of short-term system stability. Similarly, using results from the previous year, long- term stability is estimated from the standard deviation of the monthly range bias estimates. These metrics do not address range accuracy of course, but are valuable as a method of comparing each station's system stability. The diagram below shows these long-term and short-term RMS range stability estimates, derived from the results of the analysis centres DGFI, Hitotsubashi University, JCET, MCC and SHAO.





1.2 New launches

Jason-2 was launched in 2008 and first SLR data was obtained in June 2008. There were also six new Glonass satellites numbered 110-115.

GOCE was launched but has not yet asked for long-term SLR support, whilst manoeuvres and system checks are carried out by ESA. As part of the pre-launch publicity the SLR at Herstmonceux was featured in a EUROnews broadcast and can be viewed at http://www.euronews.net/2009/02/19/european-scientists-take-the-measure-of-gravity/

The Chinese GNSS satellite **CompassM1** was added to the ILRS list. SGF has been leading an international campaign to test the laser return signal strength of this satellite relative to the other laser-tracked GNSS satellites.

Support SLR tracking was carried out for orbital calibration for SOHLA-1 (JAXA, technical demonstration satellite) and OICETS (JAXA, Optical Inter-orbit Communications Engineering Test Satellite)

1.3 System upgrades.

Hardware.

1. New detector. A cooled SPAD detector with upgraded arming specifications was purchased to replace the failed C-SPAD device. The main advantage of the new unit is that it allows detection of signal much closer to the arming time of the detector and thus reduces the "dead time" between arming and collecting reliable data. The driving force behind this specification was the heavy losses from noise that the kHz system suffers in daytime.
2. Computer-controlled mirror to enable switching between kHz and 10Hz systems.
3. Electronics box to enable switching of all laser control systems between kHz and 10Hz.
4. Hydrogen maser
   During the year a case was made for funding to purchase an active Hydrogen maser clock to use as a site-wide source of frequency and epoch. This application was successful and we are currently nearing the end of the tender exercise to select a supplier. Once completed, we anticipate a 6-12 month lead-time before delivery of the device, by which time we will have the location for the maser and associated equipment installed and ready. We will then be able to use the ultra-stable frequency for our timing systems for SLR to enhance our contribution to the JASON-2 time-transfer experiment to monitor the DORIS frequency (T2L2), to improve the value of our one-way ranging to the Lunar Reconnaissance Orbiter (LRO), and to provide an external frequency input for the HERS GPS receiver. In addition by this time the receiver operating at HERS should be the new timing model which will enable us to take part in IGS time activities and collaboration with NPL on time-transfer and maser performance monitoring. This is a major upgrade to the facility that we anticipate will improve our contribution to a number of programs as well as opening up new areas of activity for the group.

Software.

1. An ILRS working group has developed a general, flexible format for SLR data and a timetable for all the stations to transfer over to the new system, with new missions and experiments being expected to use the new format. The first of these is the Time Transfer by Laser Link (T2L2) experiment on Jason-2 and the second is the LRO. We have updated all our software to produce data in the new format and have been submitting T2L2 data since September and new-format data for all satellites since October 2008.
2. New observing software for upcoming launch of LRO. LRO has a receiver which is spinning at 28Hz. Our aim is to fire our laser at 14Hz such that the laser arrives exactly in the centre of the 9ms window of the LRO receiver. We have participated in several test runs of the simulated LRO system and all our data has arrived within 1ms of the centre of the simulated gate. LRO is due to launch in June 2009.

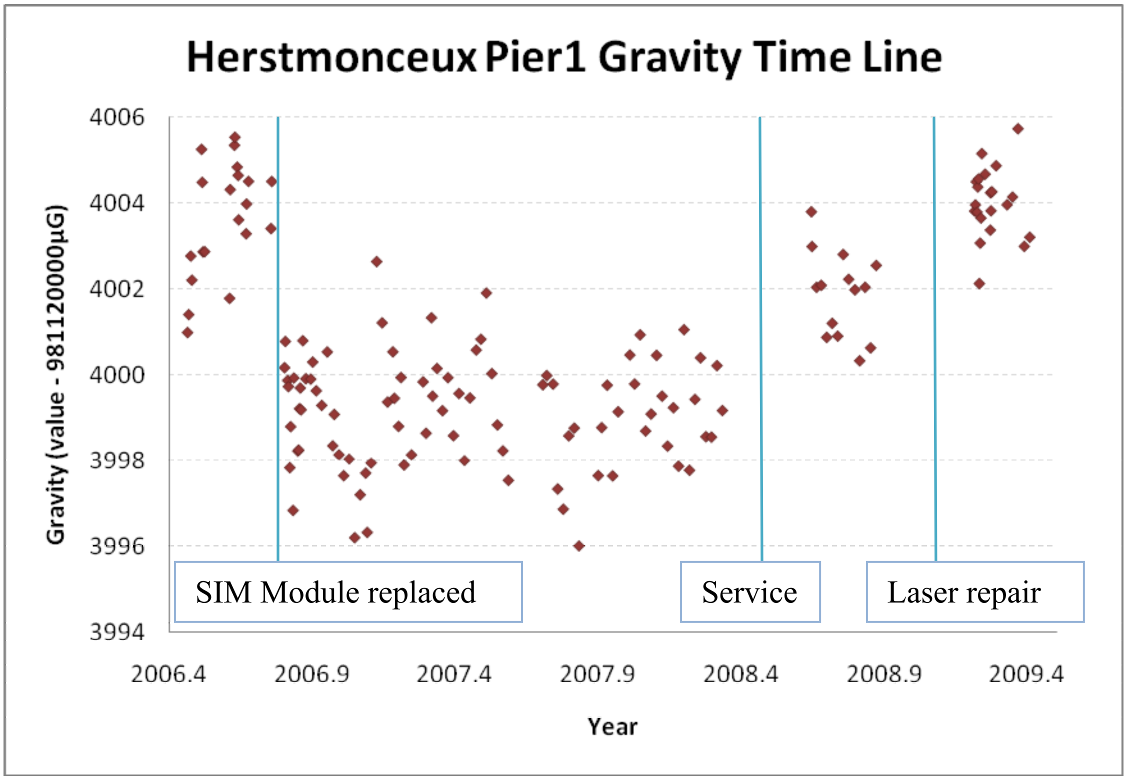
1.4 kHz system

As reported last year, the High-Q kHz laser had been subject to operational problems since an earlier restoration of full-power output. The exit window of the frequency doubler assembly (which converts the primary wavelength of 1064nm to the 532nm used for ranging) was burnt by the laser numerous times, and the frequency doubler crystal itself damaged twice, requiring either new optics or full realignment. This issue caused multiple failures within the year and although the UK distributor attended to repair the damage, it eventually necessitated the manufacturers' specialist to come to resolve the underlying problem of both relative spacing of critical components and apparent lack of hardness of some surfaces. Since that work was carried out (at of course no cost to SGF/NERC) the fault has not reoccurred. In the eventuality that the problem does reoccur, the manufacturers will require the entire laser to be shipped back to Austria for a full rebuild.

The optical path that the laser takes to reach the entrance mirror to the Coudé train has been re-engineered this year. This means that the laser is reflected by fewer mirrors with a consequent reduction of energy losses, and can make use of the natural divergence of the beam prior to passing through the beam expanding telescope situated before the Coudé entrance.

2. Gravimeter

Following the return of the absolute gravimeter from a first service in the US in August 2008, it has been used to build upon the time series of 24-hour data, collected in mid-GPS week. In addition, a special ten-day data collection was carried out, analysis of which has identified some near-14-hour, presumably tidal, residual signals within the data, investigations regarding which are ongoing. In December 2008 the Iodine stabilised He-Ne laser failed and was returned to the manufactures' for repair; the problem was found to be a faulty He-Ne tube (which had been replaced during the service) and by early March the gravimeter was again fully operational. Since March there has been once again a temporary fault with the laser which meant the loss of one of the weekly data collections. Of major concern are the apparent jumps, evident in the plot below, of up to 5μGal in the 24-hour mean values of local gravity following each of the major services/repairs to the AG. The largest of these jumps became apparent after the recent 2008 service, although the gravimeter was off site for over 3 months and therefore it cannot be ruled out that the related vertical height movement is genuine. Investigation of these jumps has not yet yielded any result, although the data has been scrutinized for errors and the manufacturers (Micro-g Lacoste) have been consulted. Future service events will be very closely analysed. Correspondence with other groups suggests that such events do occur, and attempts are being made to understand the circumstances and magnitudes of the jumps. This work again points to the value of a long-term occupation at a single site, since it has implications for those devices used in campaigns over extended time periods and at many different locations.



Through investigations into the noise sources affecting the gravimeter and the detection of Earthquake signals, collaboration with BGS has been initiated to the effect that the SGF now hosts one of the BGS' new broadband seismometers. The seismometer was installed in late May 2009 and its data are currently being assessed by BGS. Preliminary findings suggest that the site is noisier than BGS was expecting, probably due to the proximity of the trees surrounding the site, but early results are nonetheless encouraging. The heliograph plots for the SGF seismometer can be found at the BGS website, under station HMNX.
http://quakes.bgs.ac.uk/helicorder/heli.html

Community participation - A presentation was made in June 2008 at the IAG conference on Gravity, Geiod and Earth Observation, for which a paper was written and submitted for the proceedings. This paper has since been peer reviewed and been accepted for publication in the Springer series.
The SGF is also now a participating member of the absolute gravimetry subgroup of the e-COST initiative 0701 - Improved constraints on models of glacial isostatic adjustment, and the international gravity database AGRAV.

3. GPS and GLONASS Continuously Operating Receivers

The systems at HERS and HERT have continued to submit data to the IGS/EUREF over the period. There were 2 short gaps in the HERS data, one for a site survey conducted by IGN, the other caused by a power-supply failure. During the IGN survey scaffold was erected around the HERS tower to enable safe access, and the data was not submitted on advice from EUREF contacts in case the data were affected by multi-path from the obstruction. The old Ashtech Z-18 has continued to operate at the solar pillar monument (SOLA) and a useful time series of data have now been collected for which details of the analysis are given below.

In collaboration with and at the expense of the Ordnance Survey (OS) a new OS monument has been installed on the lawn to the West of the facility close to the location of the solar pillar trig point. The site is part of the new OS GeoNet network of up to 12 high-quality, purpose-built GNSS receiver monuments that are being installed around the UK. A novel helical pier system was used to provide the monument, which should make for a very stable position. The data are being made available through BIGF (site name HERO) and we are planning to integrate the site into our own local analysis as part of overall site stability monitoring. On a practical note we are working with the Herstmonceux estate management to remove or at least reduce greatly the heights of the trees to the South of the Facility which are above the elevation cut-off mask for the HERO (and SOLA) receivers. OS have offered to share any costs involved.

A new receiver has recently been purchased for use at the SGF. A Septentrio PolaRx3TR dual frequency GPS/GLONASS timing/reference receiver was eventually selected, primarily because of its time-transfer capability. As mentioned elsewhere in this report we are in the process of obtaining a H-maser clock for the facility, and one of the major applications will be to drive the HERS receiver with the maser-derived frequency and epoch for comparison with and possible contribution to the IGS time products as well as work with NPL. To this end the plan will be ultimately to replace the aging and unsupported Z12 at HERS with the new receiver. First we intend to set up the new system as a continuation of the experiment at the SOLA monument, which as well as a test of the receiver will also help us characterise the antenna currently installed there and decide if a new one is required before the switch to HERS. The lead time of 6-12 months on the H-maser will give us plenty of time to perform these tests and be ready to start using the system fully as soon as the maser is settled.

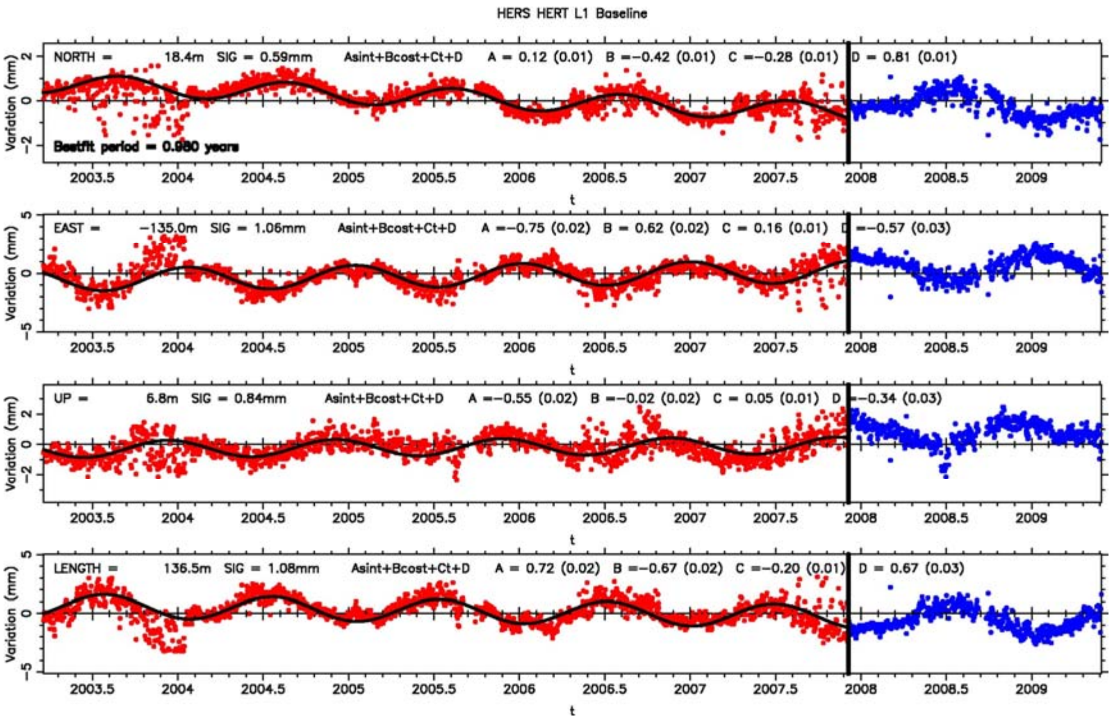
3.1 GPS Analysis

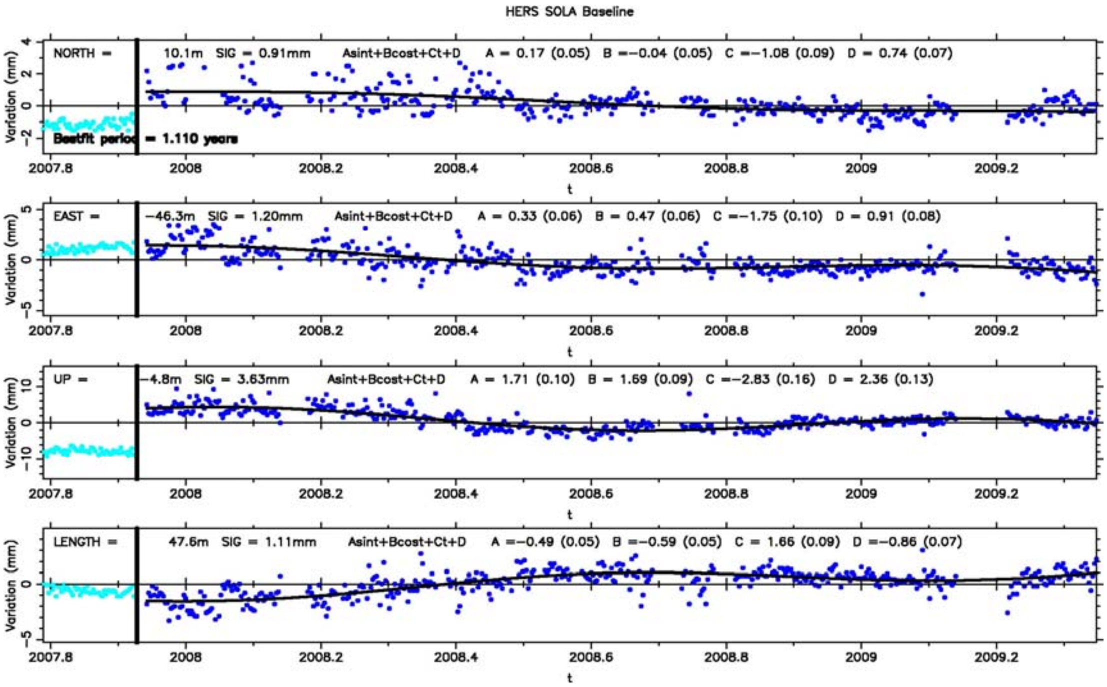
Differential GPS analysis has been used to determine high-precision measurements of the HERS to HERT baseline. We use the GAMIT/GLOBK software package along with IGS orbits, up-to-date Earth Orientation parameters and an absolute phase centre antenna model. This analysis has revealed a close-to-annual (358±3 day) variation in the baseline length with semi-amplitude approximately 1mm. In October 2007 the new SOLA site, situated between HERS and HERT and occupied by the old HERT Z18 receiver, began collecting GPS data and consequently two more baselines were calculated. The SOLA site has now yielded over 17 months of daily solutions from the Z-18 receiver and it is apparent that a quasi-annual variation is present in these two baselines as well, although there are indications that the period may be slightly longer (closer to 1-year) than that of the HERS_HERT baseline. This result is of course tentative at this stage given the relatively short time of operation (17 months) of the SOLA site.

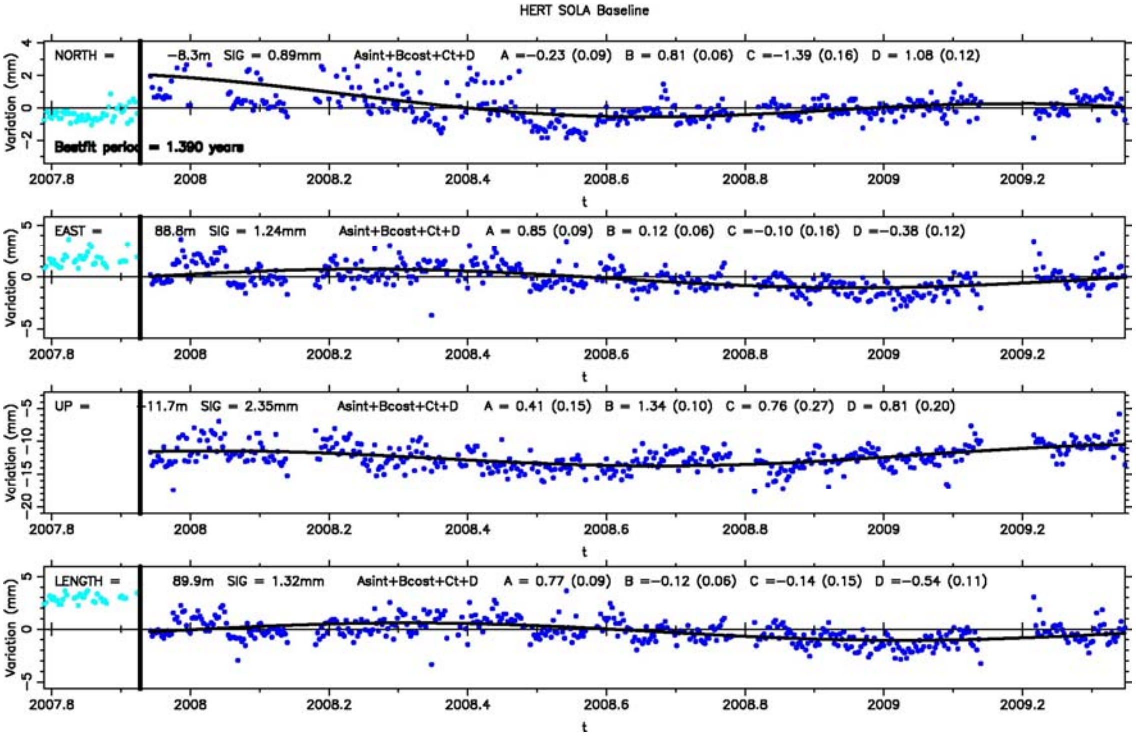
The results for the three baselines are shown in the plots below. In addition, the new permanently-installed Ordnance-Survey GPS site HERO, situated alongside the SOLA site, adds a future opportunity for baseline analysis that will be pursued in the coming months.

One concern is that this behaviour represents a true physical movement of either the HERS or HERT site, but it may be an artefact of the local environment (multi-path) or satellite/receiver antenna effects. Important in this is a determination of the precise period of the oscillation, as results so far show that it is close to the GPS draconitic (orbital precession) period of 351 days. This work is being prepared for publication.

HERS-HERT Baseline



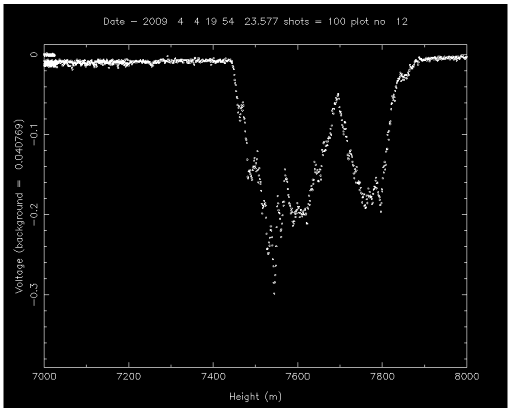




The GPS analysis also takes a global network of GPS sites and uses the GAMIT/GLOBK software along with downloaded IGS orbits and EOPs, to produce daily and weekly co-ordinates for the HERS and HERT sites. These include an 'UP' component for comparison with SLR analysis, absolute gravimetry and water table heights.

4. LIDAR

The experimental LIDAR system is now fully operational. The PMT detector was relocated to the detector box in order to allow the neutral density wheel to be used to control the energy of the returning light and avoid detector saturation. A redesign of the detector box was undertaken to accommodate a third port for the PMT and simpler selection between detectors. In addition, software to control data collection with the digitiser board was written in Labview and data files in a standard format for further processing are now created. What was lost in the switch of PMT position was the ability to perform truly simultaneous LIDAR with laser ranging, but various options are under discussion for solving this in the future if required. In the meantime the ranging software has been adapted to allow fast switching between ports and interleaving of SLR and LIDAR data. One immediate application of this work is with the T2L2 experiment on Jason-2 which has the capability of recording on a shot-by-shot basis the energy received at the satellite. We plan to work with the French group in calibration mode, using the SGF LIDAR observations to measure atmospheric backscatter losses at intervals through each pass, for comparison with the fluctuating energy levels detected on board. In addition, and in collaboration with the Chemistry department at Cambridge University, we are developing techniques to measure the optical density and evolution of aircraft contrails, a major atmospheric pollutant in the SE of the UK. The plot, shown right, is the result of a scan of a contrail at a height of 7.5km above the Facility, from which an optical density and physical depth will be extracted.

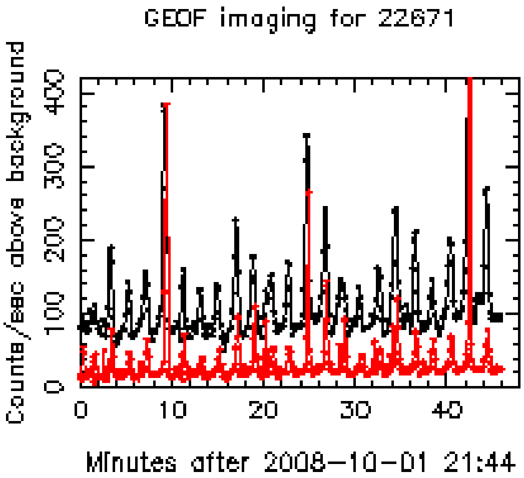


In a related study, data from a number of ILRS stations are being analysed for the presence of potential seasonal and long-term atmospheric signals as revealed by varying numbers of returns in each normal point and in variations of shot-by-shot signal strength.

5. GEOF

The photometric optical GEOstationary satellite Facility (GEOF) has been operational throughout the period. Major upgrades to the observing software allow the observer at the beginning of the night to input a schedule for that night. The telescope, dome and camera will then switch between target satellites without any further input from the observer. The observer also has the ability to monitor (from anywhere in the world, but usually from the laser ranging platform!) the data being collected by GEOF as a check to ensure that the system is pointed accurately at the satellites.

Two extensive reports have been produced for the MoD during this period dealing with observed variations in brightness of each of a large set of satellites that we have been asked to monitor. The plot below gives an indication of the type of results obtained from a high-orbiting satellite; the data plotted are mean values (in red) and maximum values (in black) of satellite brightness estimated from a large number of 5-second CCD frames taken with the GEOF camera. An FFT analysis shows a clear 120-second flash-period



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6. Geodetic Analyses

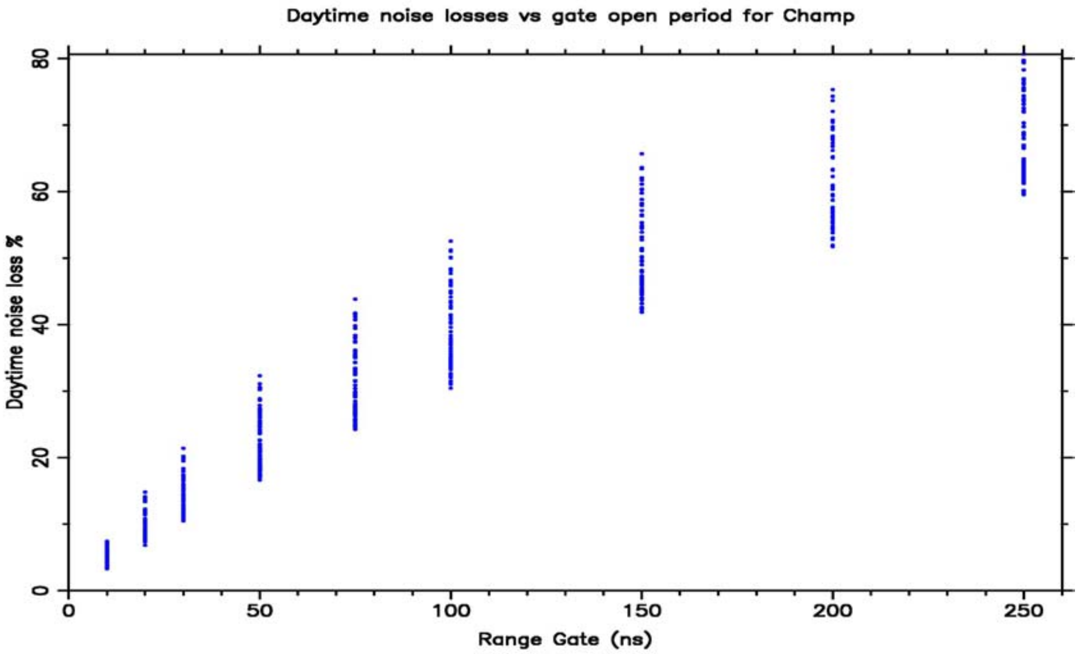
Availability of laser range, GPS and absolute gravity data from the same site, plus the ability to analyse each data set, has opened up some exciting opportunities for research, especially into vertical signals at this important site. Support data in the form of high-time-resolution water table depth measurements are also available continuously from 1996 to date, and have been used in some recent investigations, as outlined below.

6.1 Possible systematic bias in laser range data. SGF, as one of the ILRS Analysis Centres, has been re-analysing global laser range data to the geodetic satellites from 1983 to present, for later combination into the ILRS contribution to the forthcoming ITRF2008. During the course of this work, it became apparent that either there was a dramatic decrease in the height of the station of some 15mm from early 2007, or some systematic error had entered the laser range data from that date. This was the time that the new, highly-accurate event timer was introduced operationally into the ranging system, and we are confident that the extensive tests showed no problems, certainly of the magnitude experienced with the Stanford counters used from 1993 to 2007. We also received reports from other users of the SGF data, especially those doing precise orbital determination of the altimeter missions, that a jump had occurred in the laser ranges to those satellites as well. To test whether we indeed had a data problem or a site-motion problem, we carried out a vertical analysis of the site from 2006 to 2008 using GPS, SLR and AG data, and reported the results at the International Laser Ranging Workshop in Poznan, Poland, in October 2008 and at the AGU in December. Neither the GPS nor the AG results supported the proposed anomalous vertical motion of the site implied by the laser data, and indeed we were able to conclude that it is the data *prior* to the installation of the event timer that is in error. A careful analysis of the range corrections due to non-linearity in the Stanford counters led to the release to the community of a table of corrections for the SGF data. However, more recently the corrections in this table have been found in some instances to be themselves in error by up to 8mm due to high-frequency non-linearity of the counters, and in those instances empirical range corrections have had to be used. This is unfortunate since some long-term, small, geodetic signals, such as GIA effects, will likely be lost from the data set. It is also clear that SGF attempts to improve the data from other stations that used Stanford counters will also be of less value than previously considered

6.2 Height signals from SLR, GPS and AG. Analysis of residual height signals has proceeded using all three on-site techniques, in a collaboration between SGF and UCL (Prof. M. Ziebart) and POL (Dr S. Williams). The space geodetic height time series (SLR and GPS) have been used to remove vertical signals from the gravimeter results. A comparison of this height-corrected gravity time series with the local water table shows very little agreement and a simple, Bouguer-based computation of the magnitude of the water table effect overestimates the observed gravity amplitude by some five times. A paper on this initial work was presented at an IAG symposium on Gravity, Geoid and Earth Observation, and is now in press in a Springer series.
Future work will involve a more thorough investigation into the local geology including the use of soil-moisture probes to better quantify hydrological effects on local gravity. It will also be very important to measure the dry and wet densities of the local clay, as errors in the values assumed in this investigation will directly impact the modelled affect on gravity variation. To improve the understanding and versatility of the analysis of the AG data, we will implement a POL package written by S. Williams; particular areas of interest are the treatment of atmospheric attraction and site loading. This effort should improve the value of gravimetry in the interpretation of the SGF space geodetic results and have wider implications for similar multi-technique space geodetic facilities.

7. Detector investigations

The move to kHz SLR meant that the data volume greatly increased and the shot-by-shot signal-to-noise ratio is significantly reduced. This is due to the high repetition rate and lower pulse energy of the new laser. In addition, the SPAD detector can only make a single detection each time it is gated and needs a delay of 50ns after gating in order to stabilise. If in this short time after gating a noise point reaches the detector before the satellite signal then the range measurement cannot be made. This effectively reduces the firing rate of the system and is most significant for daytime observing. An investigation was carried out to quantify the effect: below is a plot showing the percentage of shots lost for a daytime pass at different intervals after the SPAD gating. During normal operations the detector is gated 100ns before the return signal and, as shown in the example below, results in about 40% of shots being lost.



This loss of sensitivity caused a significant problem for the kHz SLR and led to an investigation into new detector system solutions, including fast shutters and MCP-PMT detectors. This work was presented at the LR workshop in Poland in October 2008, and a paper will appear in the proceedings. The results were also taken on board by the equipment developers and led, as well as to an improved performance for the SPAD detector which was delivered to SGF in December 2008, to a joint SPIE publication.

In order to monitor this improved performance during kHz ranging, we developed a fast method to plot a SPAD detector's range-error profile. The detector introduces an error into the range measurement if the detection is made too soon after the gating. During what is otherwise a standard calibration session, the SPAD arming is varied in hardware and true returns are detected automatically from the large volume of background noise.
This method was used both for the original C-SPAD and the newly-acquired fast-gating SPAD. The results are shown below in that order, and give range error against the time interval between gating and detection.
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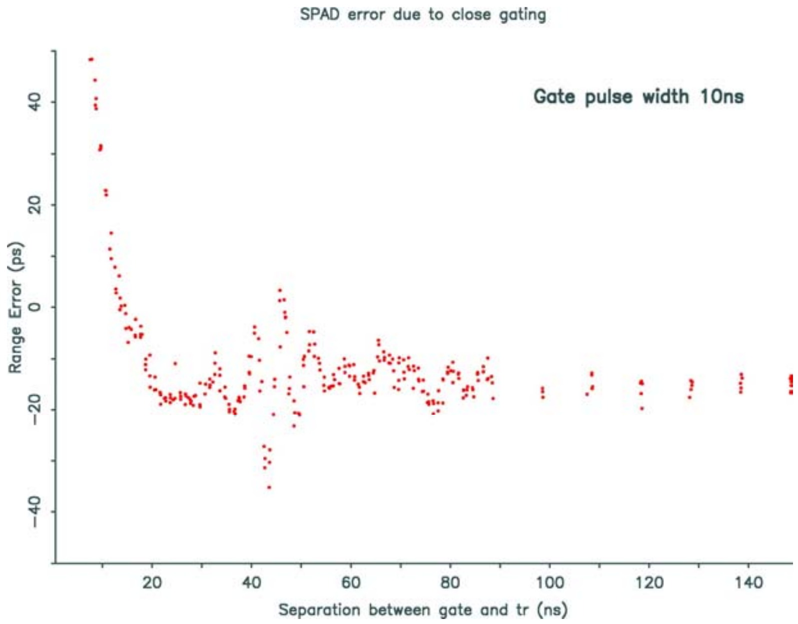

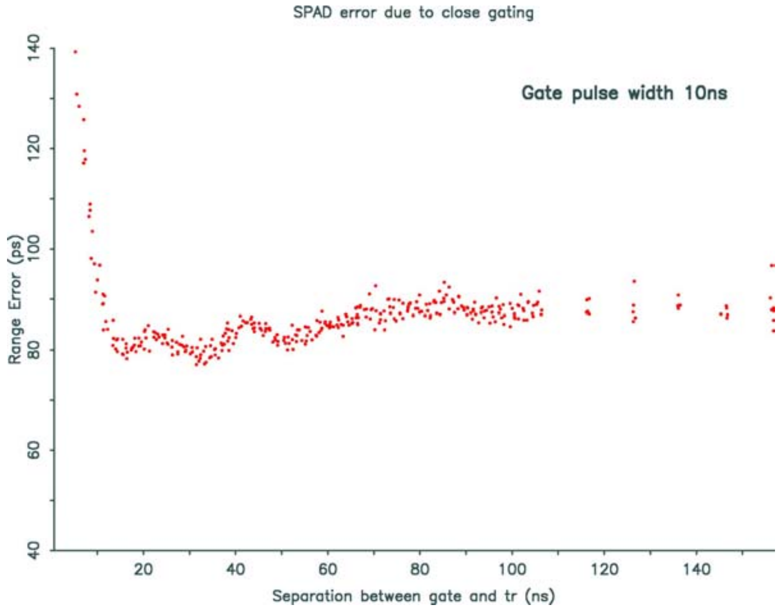

There is a clear improvement in the SPAD detector profiles from the older C-SPAD to the new SPAD, with a much smoother, and therefore predictable, range error which can be removed from real data. However the new SPAD profile still contains two small error ‘peaks’ at 20ns and 40ns, meaning that the minimum safe gate will be at about 50ns.

8. Public relations.

We hosted a visit from a group of students from Newcastle University Geomatic department. We also gave tours of the facility to about 100 people during the Astronomy weekend organised by the Herstmonceux Science Centre.

Two invited talks on the ILRS were given; one in Bordeaux was part of the IVS 10th Anniversary meeting and focused on synergies between the two Services. The second talk was part of a celebration in Grasse, France, to inaugurate the newly-refurbished lunar and satellite-laser ranging system MEO, an important addition to the Network. This 24-hour visit was funded by the Observatoire de la Cote d’Azur.

A couple of guest lectures on space geodesy and the work of the SGF were given to ISC students taking the undergraduate astronomy option.

We are involved in the work experience project. During 2008 we gave four 15-year old students and one A-level student one week’s work experience.