SERVICES & FACILITIES ANNUAL REPORT - FY April 2010 to March 2011

SERVICE	FUNDING	AGREEMENT	ESTABLISHED as S&F	TERM
Space Geodesy Facility	Direct from 1999	SLA	1994, operational since 1983	5 years

TYPE OF SERVICE PROVIDED:

SGF is an operational, state-of-the-art observational Facility that makes very accurate measurements of the distances of a constellation of Earth-orbiting artificial satellites and of the local acceleration of gravity in support of national and international research into dynamic Earth processes through enabling precise orbit determination and realisation of a consistent global reference frame. The satellite observations are made available rapidly and freely to the worldwide community through the data centres of two of the Services of the International Association of Geodesy, the International Laser Ranging Service (ILRS) and the International Global Navigational Satellite System Service (IGS), with which Services the Facility is registered. The overarching international body into which this work fits is the IAG Global Geodetic Observing System (GGOS). The Facility carries out an R&D programme, in order both to keep its observational capabilities at an international level of competitiveness and also to keep abreast of and contribute to space geodetic research. In this regard, particular emphasis is placed upon improving the value and accuracy of laser range (SLR) observations, contributing to an international programme as an ILRS Analysis Centre to improve the realisation of the Terrestrial reference frame which underpins many areas of global geodetic research, and seeking new opportunities to increase for the community the geodetic value of the site.

The need, as a member of international observational networks, to make the observations available as quickly as possible to the community means that, as a rule, civil users do not apply directly to SGF for services. However, as part of the global tracking effort, the work of the Facility provides the raw material to underpin most of NERC's science strategy themes. Observations by the SLR system and the two continuously operating GNSS receivers contribute to the definition of a global geocentric reference frame, the ITRF2008 being the most recent realisation. Re-processed laser range observations from early 1980s onwards, including those from Herstmonceux, are a key ingredient in the definition of origin and scale in this latest realisation. Laser observations of remote-sensing satellites allow accurate computation of their orbits within this same, well-defined reference frame. In turn, satellite altimetry and SAR measurements to the oceans, ice caps, land areas and inland water areas as well as space-based observations of variations in the Earth's gravity field, can be reduced accurately using this precise knowledge of the positions of the satellites. Such data and products impact upon ongoing UK studies into for example long-term variation in sea level and ocean circulation/anomaly dynamics (e.g., Newcastle, NOC, BAS), polar ice mass-balance and response to climate change (e.g., NCEO), improvement of global digital elevation models and river and lake-level monitoring (EPRSL), vegetation dynamics (NCEO).

ANNUAL TARGETS AND PROGRESS TOWARDS THEM

Aim: to integrate fully into the time systems of the SLR and HERS primary GNSS receiver the hydrogen maser time and frequency standard. This has been achieved, making the SLR results for JASON-2 and Lunar Orbiter much more valuable by being independent of GPS time. Driving the HERS Septentrio GNSS receiver and Leica AR25 antenna using the maser has been spectacularly successful, with the IGS-derived GPS timescale now using the HERS data with high weight. For most of the IGS weekly time-scale solutions, HERS features among the top 10 best contributing stations in the global network.

Aim: to monitor and quantify SGF-site stability at high precision. Up to four onsite GPS receivers have been used in a multi-year baseline analysis to monitor internal site motion. Small (1mm) annual-periodic signals are present, but the study suggests these may be technique-driven rather than real deformations. A paper has been accepted for publication. The results from ongoing in-house levelling surveys strongly point to the existence of annual-periodic, inter-technique vertical motion of amplitude 0.5mm.

SCORES AT LAST REVIEW (each out of 5)		Date of Last Review: 2007		
Need	Uniqueness	Quality of Service	Quality of Science & Training	Average
5	5	5	5	5

CAPACITY of HOST ENTITY FUNDED by S&F	Staff & Status	Next Review (March)	Contract Ends (31 March)
100%	1 at Band 5, 4 at Band 6, 2 at Band 7	2013	2014

FINANCIAL DETAILS: CURRENT FY						
Total Resource Allocation £k	Unit Cost £k			Capital Expend £k	Income £k	Full Cash Cost £k
	Unit 1	Unit 2	Unit 3			
404	Not applicable	Not applicable	Not applicable	14	100	390

FINANCIAL COMMITMENT (by year until end of current agreement) £k				
2010-11 400	2011-12 400	2012-13 400	2013-2014 400	

STEERING COMMITTEE	Independent Members	Meetings per annum	Other S&F Overseen
NSGSC	6	1	BIGF

Users do not normally apply *directly* to the Facility for any products or services. The raw data from SGF, namely accurate observations of satellite positions, are made freely available in close-to real-time as part of a commitment to two of the Services of the International Association of Geodesy (ILRS and IGS). From these raw observations both UK and international users and agencies derive the principal end products, which include accurate orbits of remote-sensing satellites, a global reference frame and measurements of the Earth's orientation in space. These products then underpin the scientific exploitation of the remote sensing data, such as altimetry and SAR, as well as being of scientific interest in their own right. The absolute gravimeter data is in a different category since it is being used primarily at present in a research collaboration with UCL and POL; in the longer term it is likely that the data will be made available to other research groups on request, as well as a contribution in some form, probably as an annual-mean value, to the International Gravity Field Service.

The laser ranging satellite tracking priorities are set by the steering committee (NSGSC) with UK users in mind, but again with knowledge of ILRS priorities.

Value-added products, such as specialised observations and orbital analyses, are directly solicited from SGF, both in terms of collaborative research work and reports written for the co-funding partner, MoD. Several activities, such as daily laser-range observational quality checks, production of orbital predictions as an official ILRS back-up service and global laser analyses as an ILRS Analysis Centre, are carried out for the ILRS and IERS. This work is detailed later in this Annual Report.

USER PROFILE (current FY)

Since, as discussed, users do not normally apply for services to be carried out by SGF, it is not possible to attribute the bulk of the operation to a well-defined list of users. In an attempt to give as much information as possible here, we list national and international groups and agencies that are known to be international leaders in the space geodesy field and who therefore will be users either directly or indirectly of SGF products. Here, at present, the data from the absolute gravimeter is treated as a special case, being available currently only to SGF, POL and UCL. Likewise, results from the new LIDAR sub-system of the Facility, which was put to good use as a monitoring capability during the recent volcanic ash crisis, is being shared only with Cambridge University and the Met Office. UK: University of Newcastle; Institute of Engineering Surveying and Space Geodesy (IESSG, University of Nottingham); Centre for the Observation and Modelling of Earthquakes and Tectonics (COMET, Universities of Oxford, Cambridge and UCL); National Centre for Earth Observation (NCEO, NERC), which includes Centre for Polar Observation and Modelling (CPOM, UCL, Universities of Bristol and Cambridge); Dept. of Geomatic Engineering, University College London; National Oceanography Centre (Southampton and Liverpool); De Montfort University; Ministry of Defence (incl. DSTL); British Space Agency; Surrey Satellite Technology Ltd.; Ordnance Survey. European: EUREF. International: ESA; NASA; ILRS; IGS, IERS (International Earth Rotation and reference frame Service) and emerging Global Geodetic Observing System GGOS, an overarching Service of the International Association of Geodesy; Inter-governmental: Group on Earth Observations, GEO.

Publications. A comprehensive but non-exhaustive literature search was carried out and discovered 12 reviewed papers published during calendar year 2010 in the major geophysical and geodetic journals by UK (co-) authors. Publications were filtered by being traceable to those underpinning technologies supported by SGF, including precise orbits for altimetry, SAR and gravimetric satellites, continuously operating IGS GPS systems, geodetic satellite tracking, reference frame and Earth orientation and geocentre determination from space and gravimetric geodesy. Journals searched include Journal of Geophysical Research, Geophysical Research Letters, Journal of Geodesy, Marine Geodesy, Geophysical Journal International, Transactions of the Royal Society, Nature and Science, as well as institutions' websites.
In addition, it is known that internationally a large number of geodesy-related publications result from the global network of operational Facilities, of which SGF is a major component, that provides GNSS, DORIS, SLR, VLBI, AG, etc. observations freely to the community.

SGF publications 2010

Comparison of height anomalies determined from SLR, absolute gravimetry and GPS with high frequency borehole data at Herstmonceux. Appleby, G.M., Smith, V., Wilkinson, M., Ziebart, M., Williams, S.D. (2010) *Gravity, Geoid and Earth Observation, International Association of Geodesy Symposia*, 135(1):107-113, DOI:10.1007/978-3-642-10634-7_15

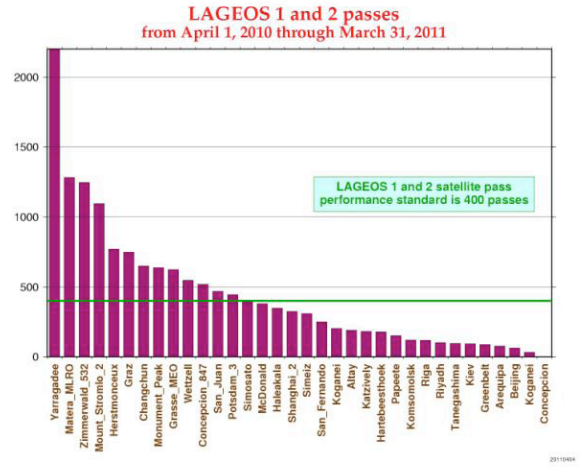
Attempts to separate apparent observational range bias from true geodetic signals. Appleby, G.M., Wilkinson, M., Luceri, V., Gibbs, P., Smith, V. (2010) In Schilliak, S (Ed.), *Proceedings of the 16th International Workshop on Laser Ranging*, Poznan, Poland.

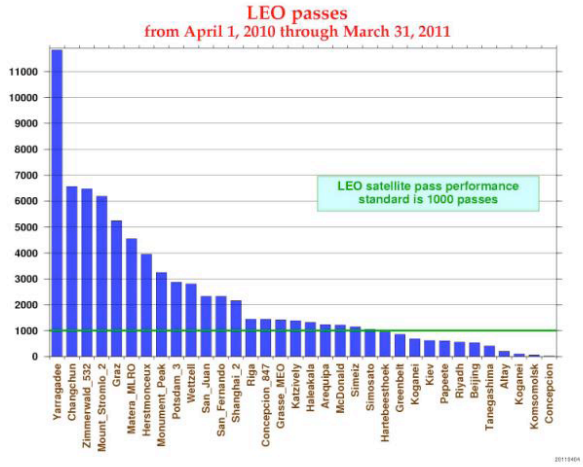
Current Trends in Satellite laser Ranging. Appleby, G.M., Kirchner, G., McGarry, J., Murphy, T., Noll, C., Pavlis, E.C., Pearlman, M., Pierron, F. (2010) EOS AGU, December 2010, (abstract, presentation)

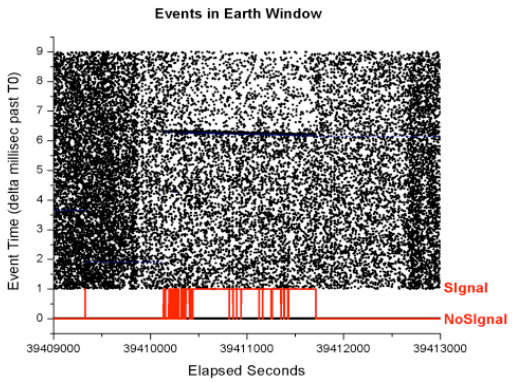
OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2010/11):

SLR: The Facility is a major contributor to the global data sets of high-quality SLR observations. During the year the kHz capability suffered some laser problems that compromised its fully-operational status, but the ability to switch in seconds between kHz and 10Hz continues to make it both a unique and very powerful facility and no loss of data resulted. Tracking support for the current **geodetic** (LAGEOS, Etalon), **altimeter (**ENVISAT, JASON-1, JASON-2, ERS-2 and CryoSat-2) and GNSS (GLONASS, GIOVE, COMPASS, GPS) missions continued at a high level of priority. The extreme-LEO (250 km) dedicated gravity-field mission **GOCE** has requested and receives laser-ranging support on a regular basis.

The plots show the strong SGF support in relation to the entire ILRS network for the MEO and LEO laser-tracked missions during 2010/11.

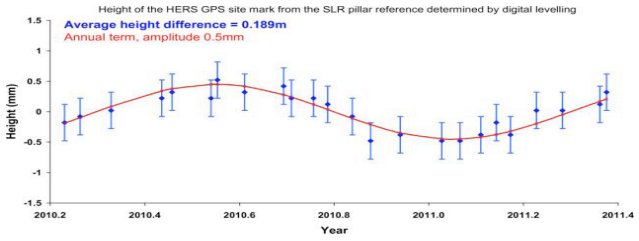






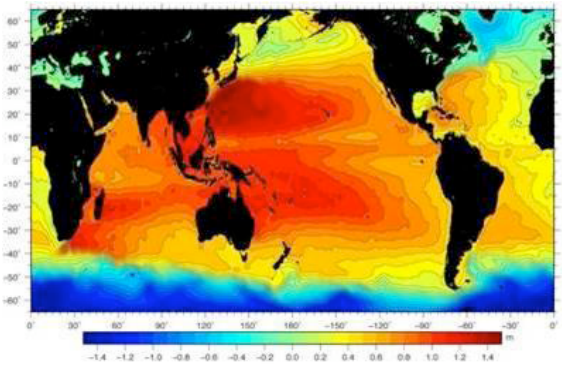
Scheduled by NASA, **Lunar Reconnaissance Orbiter** one-way ranging support has continued since the first successful detections by LRO of SGF photons in July 2009. Some periods of tracking failures have been reported to the mission, and the issue appears to be LRO-pointing related. The plot (left) shows a recent series of detections of SGF 14Hz pulses by the LRO laser receiver, 350,000km from Earth. The 'flat' line of events in the LRO detection window along with many noise events results from the very high stability of the SGF timescale, driven by the hydrogen maser. Such data from the few capable stations of the ILRS is enabling LRO POD at 10cm levels of precision.

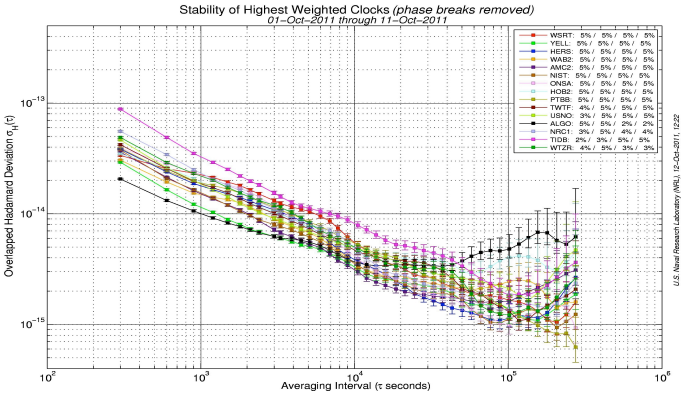
Levelling: In order to monitor inter-technique vertical stability, a regular programme of levelling is underway approximately fortnightly at points across the SGF site using a Leica digital level. This work is enabling a very accurate determination of the relative heights of the different techniques' monuments, and establishing whether or not any changes in heights derived from analysis of the different geodetic measurements are contaminated by real, local, ground motion. A line levelling run of the site includes the AG reference studs, HERS tower (base and half-way-up) and the SLR telescope pillar as well as other points of interest such as the building bench mark, HERT and the new OS site HERO. Results from the first year of observations are very interesting and suggest annual-periodic relative height variations of amplitude about 0.5mm. The most clearly defined results are for the series of relative heights from the base of the HERS tower to the pillar supporting the SLR telescope, shown in the figure, right. Although clearly significant, it is reassuring to note that these results so far suggest that any relative movement between the techniques is close to the sub-mm level. A point midway up the HERS tower has been established recently, and future results that will include it are awaited with interest.



MoD The optical Observation Facility (**GEOF**) has been operational throughout the period. Upgrades to the observing software allow the SLR 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. Results in the form of light-curves, raw data and preliminary spectral analyses are communicated regularly.

SCIENCE HIGHLIGHTS: SGF tracking support for ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission The ESA GOCE mission was launched in March 2009, with mission objectives to determine the Earth's gravity-field anomalies with an accuracy of 1 mGal (10^{-5} ms^{-2}), and to determine the geoid with an accuracy of 1-2 cm. The mission goal is to achieve these objectives at a spatial resolution of better than 100 km. An onboard GPS receiver and laser retro-reflector are used for precise orbit determination, the laser range measurements providing an essential cal/val and stabilizing, geocentre-linking element to the GPS-based precise orbit determination efforts. SGF is making high-priority laser measurements to this challenging satellite, supplying many hundreds of normal points of mm-level precision. Accelerometer data from the mission will improve knowledge of ocean circulation and current dynamics, very important in understanding global energy exchanges, sea-level change and Earth-interior processes. Shown is an ESA-derived map of the mean dynamic topography of the oceans (m) derived from an altimeter-based sea-surface model combined with a model of the geoid based on GOCE data. It is also noteworthy that the long-wavelength features of the model of the Earth's gravity field (e.g. J_2 and J_2-dot) cannot be determined by GOCE and are derived instead from SLR-tracking of the LAGEOS satellites.





High weight given to SGF HERS GPS data in the formation of the IGS timescale As soon as the HERS data driven by the maser became available it has been contributing to the IGS timescale via IGS clock combination solutions. The combination of the Septentrio receiver and the hydrogen maser has proved to be very stable, with the HERS clock contribution regularly amongst the top best clocks in the world. A recent plot of the IGS top 15 clocks is given left, showing HERS among the best. This excellent performance is mainly a measure of the very high quality of the maser, as well as the conditions under which it is being housed in the SGF basement. But HERS' geodetic data also performs among the best two or three sites worldwide with respect to its day-boundary discontinuities. These are considered to be quality measures that are more related to the GNSS equipment and in particular to the quality of the multipath environment. This evidence therefore is reassuring that the geodetic as well as the clock data for HERS is now of the highest possible quality.

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK

Internationally, it is recognized that a critical element in **GGOS**-compliant high-accuracy products will be the Fundamental Sites with co-located SLR, VLBI, GNSS, DORIS, and probably other measurement techniques. To assist this coordination, strengthen the current network and build the future networks, a GGOS Inter-Agency Committee (GIAC) has been formed. The GIAC goals are to provide an interface among the world-wide organizations that currently run space geodesy stations and to encourage the implementation of the newer technologies, co-location of techniques, and improved geographic distribution of future networks. John LaBrecque from NASA and Gary Johnston from Geoscience Australia have been elected as the chair and co-chair of GIAC. Fifteen agencies have already joined GIAC, and it is likely that NERC, as the funding agency for SGF, will shortly be contacted by Dr LaBrecque to introduce GIAC and to invite NERC to join.

Given the success of the **LIDAR** capability, and recognising its value in monitoring atmospheric transparency, contrail dynamics and support of SLR operations, it is considered that a collaborative case should be made to develop a stand-alone, vertically pointing, dedicated elastic LIDAR facility. This should be based upon the existing spare 40cm Meade reflecting telescope and dismantled dome roof, and should include a two-channel system for polarisation studies that would aid ash/ice/water discrimination in the data.

Non-Mandatory OPMs:, allocation of capacity etc. The laser ranging system is operated, weather-permitting, on a 24-hour, seven-days-a-week flexible principle that takes account of tracking priorities. Additional ranging activities are carried out on request from the co-funding partner. In practice, some 35% of available passes are tracked, placing the Facility 8th in the top 25 contributing ILRS stations. The GNSS systems work continuously, and at present the gravimeter is operated for one 24-hour period once a week. Further demands on the gravimeter could thus be accommodated, but with a subsequent reduction in time between services, currently estimated to be at two-yearly intervals. The GEOF system will be operated according to demand throughout most clear nights.