SERVICES & FACILITIES ANNUAL REPORT - FY April 2009 to March 2010

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. Additionally the Facility is working with the newly-formed AGRAV, a Service of the International Gravimetric Bureau (BGI). The Facility also 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 collocated 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, POL), polar ice mass-balance and response to climate change (e.g. National Centre for Earth Observation NCEO), improvement of global digital elevation models and large-scale river and lake-level monitoring (EPRSL, De Montfort), forest vegetation dynamics (CTCD/NCEO).

ANNUAL TARGETS AND PROGRESS TOWARDS THEM

A local **surveying capability**, recommended by the Steering committee to be put in place, has been fully realised at Herstmonceux. A Leica digital level was purchased and SGF staff have developed a programme of regular levelling between all the primary geodetic instruments on site. This programme will be capable of detecting sub-mm changes in level between the instruments.

One-way ranging support for NASA's **Lunar Reconnaissance Orbiter** has reached operational status. NASA schedules its foreign partners on a pass-by-pass basis depending upon local visibility of the Moon, known down-time of systems (almost never for SGF) and programme need. Extra emphasis was placed on SGF support during a one-month outage of all the NASA systems.

The recently-approved **active H-maser frequency standard** has been purchased, commissioned and installed in the basement of the Facility. It is being used to drive the internal clock of the laser ranging event timer and thus time-tag all observations.

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			
	Not applicable	Not applicable	Not applicable			
570				180	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 15 reviewed papers published during calendar year 2009 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 this year include three collaborative contributions to the International Technical Laser Workshop on SLR Tracking of GNSS Constellations held in Greece in 2009 October; see http://www.ntua.gr/MIRC/ILRS_W2009/mainpage.html
Also published in print and online this year are five mainly collaborative papers in the proceedings of the 16th International Laser Ranging Workshop held in Poznan, Poland in October 2008: http://cddis.gsfc.nasa.gov/lw16/
For UK contribution to EUREF: GREAVES, M., FANE, C., BINGLEY, R.M., BAKER, D.F., **APPLEBY, G.**, KING, M.A., AND IOANNIDES, R., 2009. National report of Great Britain, 2009. *In:* Report on the Symposium of the IAG Subcommission for the European Reference Frame (EUREF). pp. 229-233

OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2009/10):

SLR: The Facility is a major contributor to the global data sets of high-quality SLR observations. During the year the kHz capability maintained its fully operational status and the ability to switch in seconds between kHz and 10Hz has made it both a unique and very powerful Facility. The observer now has the ability to choose which laser to use given the nature of the mission being tracked and the atmospheric conditions at the site. There have on occasions been reliability problems with the 2kHz laser, but the UK distributors provide a valuable remedial service. Tracking support for the current **altimetry missions** ENVISAT, JASON-1, JASON-2, ERS-2 and newly-launched CryoSat-2 continued at a high level of priority. For CryoSat-2, ERS-2, ENVISAT and the two JASON missions, SLR measurements supplement for ERS-2 some PRARE data and for the others GPS/DORIS tracking data. Scheduled by NASA, **Lunar Reconnaissance Orbiter** support has continued since the first successful detections by LRO of SGF photons in July 2009.

The **geodetic satellites** LAGEOS and ETALON (two of each) are observed with high accuracy and frequently enough to provide a major contribution to global reference frame studies, an essential underpinning for global geodetic work. The Facility, as an ILRS Analysis Centre, carries out weekly and daily computation of solutions for station coordinates and Earth-rotation parameters, for input to the rapid results from the IERS.

The two vehicles of the **GRACE** gravity mission provide a challenge for SLR tracking, but both continue to be reasonably well tracked by SGF and the global SLR network. The role of the SLR technique in this mission, as for the ongoing **CHAMP** mission, is primarily an independent, but none-the-less important, check on the orbital quality derived from the onboard GPS receivers and also to aid precise orbit determination. Laser ranging to the LEO geodetic satellites **STELLA** and **STARLETTE** and MEO **LAGEOS**' continue to be of value for determination of temporal variability of low degree terms in models of the Earth's gravity field. The extreme-LEO dedicated gravity-field mission **GOCE** has requested and receives laser ranging support on a regular basis now that operational altitude (~250 km) has been reached.

SLR measurements have continued and expanded to all the **GLONASS**, the now only one-active **GPS vehicle,** two **pre-Galileo** and one **COMPASS** satellites that are fitted with retro-reflectors; SGF and others' analyses suggest that there are still unresolved radial differences of about 20mm between laser range measurements and distances computed from IGS orbits for the two GPS vehicles. M. Wilkinson and G. Appleby attended the **2009 ILRS Technical Workshop** in Greece on **SLR Tracking of GNSS Constellations**. Wilkinson presented his paper on In-Orbit Comparison of Laser Retro-Reflector Efficiency Onboard High Orbiting Satellites, which is about to be submitted to ASR for publication. Appleby developed and presented a Position Paper on Network Capability for multi-GNSS laser tracking and co-authored a paper on the Chinese COMPASS system.

GPS/GLONASS/H-maser: The receivers HERS and HERT continue to operate normally. The new Septentrio receiver purchased as a time-transfer-capable replacement for the unsupported Ashtech Z12 operating at HERS has been tested at the SOLA marker. We have also undertaken a calibration procedure at NPL using their maser time signals to determine a relative offset for our receiver and antenna. This NPL project has been carried out as a no-cost collaborative effort as NPL is interested in the opportunities for direct time transfer links between themselves and SGF, as well as in our laser time-transfer involvement with T2L2. The Hydrogen maser is now fully installed and tested and data have been collected using the Septentrio receiver driven by the maser signals since March 2010. This has been very useful, and we are now ready to install the new Septentrio + maser system at the HERS reference which will enable SGF to contribute to the definition of the IGS time-scale and open up the availability of useful time-checks on UTC(Hx). The slow drift in time of UTC(Hx) with respect to UTC(GPS) is monitored daily in-house, but the great advantage enabled by using the maser is that there are no longer any 'jumps' placed in the time-scale due to regular steering of UTC(GPS) by the mission operation (US DoD).

Absolute gravimeter (AG): Apart from a laser failure in September 2009, the instrument continues to work extremely well in a programme to obtain a series of mid-week, 24-hour averaged gravity values for comparison with the space-geodetic site motion solutions. However, there exist apparent jumps 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, and even though the gravimeter was off site for over 3 months, the space geodetic results (laser and GPS) do not support the hypothesis that the AG-implied vertical height movement is genuine. Investigation of these jumps has not yet yielded any instrumental cause, although the data has been scrutinized for errors and the manufacturers (Micro-g Lacoste) have been consulted.

Levelling: In order to monitor vertical inter-technique stability, a Leica digital level was purchased in March 2010. In particular this instrument will allow a very accurate determination of the relative heights of the different techniques' monuments, and so establish 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 gravimeter room, HERS and the SLR pillar as well as other points of interest such as the building bench mark, Solar pillar and the new OS site HERO. To date only a few complete runs have been carried out, but so far very good results have been achieved, with small (less than 0.5mm) closure errors and no detections of relative height changes greater than the instrument accuracy. Levelling work will continue on an approximately monthly basis.

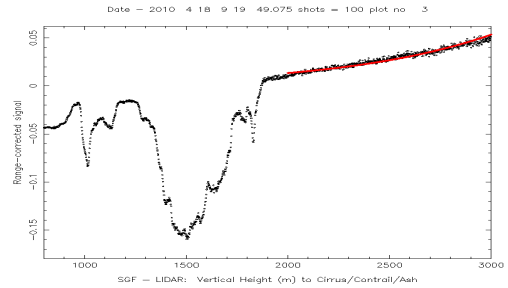
COLLABORATIONS:

Cambridge University Chemistry Department The elastic **LIDAR** system has been developed as a versatile addition to the observational capability of the site. During the year, effort has been expended on improving operational ease, data post-processing and in application of the technique in three main areas, two in collaboration with Cambridge University. These projects are monitoring aircraft contrails, monitoring atmospheric transparency during ranging support of LRO and most importantly and interestingly, monitoring the ash plume following the Icelandic volcanic eruption.

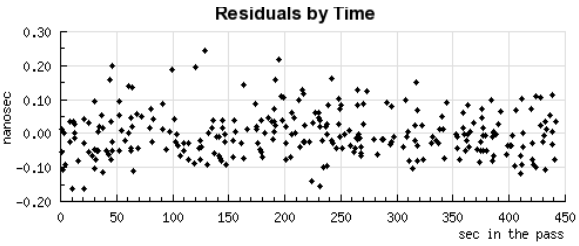
MoD The photometric optical GEostationary satellite Observation Facility (**GEOF**) has been operational throughout the period. Continuing upgrades to the observing software during the year allow the SLR observer at the beginning of the night to input a schedule for that night. The telescope, dome and 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 to the customer.

SCIENCE HIGHLIGHTS:

SGF LIDAR work. As was well-publicised, in April 2010 the Icelandic volcano Eyjafjallajökull erupted, sending a plume of volcanic dust and ash up into the atmosphere over most of the European continent. The SGF began LIDAR observations a day before the ash cloud was expected to arrive over the South East of England and then routinely every hour as requested by the Met Office. Many observations showed increased backscatter due to the ash and dust particles at variable heights and thickness. The plot below shows that there are reflective layers of material, most likely ash particles from the volcano, at heights of from 1.1 to 1.6 km. The smooth curve (in red) that has been fitted to the data from 2-3 km shows that at those heights there are no further aerosol layers and that atmospheric density decreases as expected exponentially with height.



Making some assumptions about the characteristics of the ash (e.g., that its mass attenuation coefficient is about 0.6 m^2 g^{-1}), we use the observed attenuation and physical depth of the plume to infer a concentration of the ash particles of about 150 micro-grams per cubic m. A full analysis of this data set is underway in collaboration with Cambridge University and the UK Met Office.



Ground-to-satellite clock comparisons. Comparison of the SGF time-scale to the on-board JASON-2 DORIS-driven time-scale (T2L2 experiment, OCA/CNES). Each on-board detection of the SGF laser pulses results in a comparison of the station clock with the JASON-2 clock. There is dramatic improvement in precision of the comparison when the SGF data are time-tagged using the maser; the residuals appear random, with an estimated precision (1-σ) of 50 ps (plot at left, a pass over Herstmonceux). This provides a check on the stability of the on-board DORIS oscillator and on the quality of the SGF maser, which is being used to drive the HERS GNSS receiver as well as time-tagging laser ranging observations.

Ice-sheet Thinning. The most comprehensive picture of the rapidly thinning glaciers along the coastline of both the Antarctic and Greenland ice sheets has been created using a satellite laser-altimeter. A team from the British Antarctic Survey and the University of Bristol have analysed millions of ICESat laser altimeter measurements from both of these vast ice sheets and found that the most profound ice loss is a result of glaciers speeding up where they flow into the sea. As communicated in a BAS press-release, the authors conclude that this 'dynamic thinning' of glaciers now reaches all latitudes in Greenland, has intensified on key Antarctic coastlines, is penetrating far into the ice sheets' interior and is spreading as ice shelves thin by ocean-driven melt. Ice shelf collapse has triggered particularly strong thinning that has endured for decades. NASA's ICESat is a high-priority laser ranging target for SGF operations, the mission operators using its onboard GPS receiver in conjunction with ILRS laser range observations in order to determine precise orbits, critical for reduction of the laser-altimeter measurements. The satellite itself is a 'sensitive' target since damage of the onboard detector would result if ground-based laser pulses were able to reach it. Thus NASA set up special tracking scheduling for a subset of the most capable laser ranging facilities, each of which, including the SGF, signed an MoU that agreed adherence to the schedule. ICESat re-entered Earth's atmosphere at the end of its life in 2010 August. Ref: Pritchard, *et al*, *Nature* **461**, 971-975 (15 October 2009) doi:10.1038/nature08471

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK

Given the success of the new **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 40cm, ex-PIMS, 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.

From the Global Geodetic Observing System (**GGOS**), an organizational component of the IAG structure, it is likely that a global Call for Participation will emerge in order to develop the concept of a global distribution of 'GGOS-core', multi-technique, geodetic sites that will set the standard in observational precision and accuracy. SGF is in a good position already to apply for this status, but we consider it vital that the UK community should support the response which may also offer the opportunity for SGF, in collaboration with NASA, to add a modern, 10m-class VLBI capability to the site. As this situation becomes clearer, SGF will ensure that the Committee is informed of developments. A proposal, ready for the expected CfP, will be drafted by SGF over the next few months.

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.