SERVICES & FACILITIES ANNUAL REPORT - FY April 2008 to March 2009

SERVICE	FUNDING	AGREEMENT	ESTABLISHED as S&F	TERM
Space Geodesy Facility	Direct from 1999	SLA	1994, operational from 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, namely the International Laser Ranging Service (ILRS) and the International Global Navigational Satellite System Service (IGS), with which Services the Facility is registered. Although the gravity measurements are not made freely available, 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 nature of the work and 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 several areas of NERC science. Observations by the SLR system and the two collocated continuously operating GNSS receivers contribute to the definition of a global geocentric reference frame, the ITRF2005 being the most recent realisation: Herstmonceux is one of *ten key worldwide reference stations* that defined the origin of this frame. 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, can be reduced accurately using this precise knowledge of the positions of the satellites. Space-based observations of variations in the Earth's gravity field are also becoming increasingly important. 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. CPOM, UCL and Bristol, part of the 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

Completion of upgrade to kHz laser ranging: The full kHz laser ranging system is now operational, and all satellites have been tracked using it. The hardware and code that allows rapid switching between the kHz and 10Hz lasers has been completed. The observer is able to change lasers in a few seconds depending upon need; the higher peak-power 10Hz laser is often the better choice in daytime or hazy conditions and the system has now reached its design spec as an extremely versatile, unique SLR capability.

Preparation for LRO ranging. SGF prepared a response to the NASA call for participation in a one-way laser ranging programme in support of the Lunar Reconnaissance Orbiter mission due for launch in June 2009. The response was accepted and a software upgrade has been completed and tested to NASA's satisfaction to allow synchronous ranging at 14Hz. Currently, SGF is one of only two stations in Europe to have passed the test and will begin operations as soon as scheduled by NASA.

Active Hydrogen Maser. A written proposal to S&F was approved in December 2008 and work towards specifying the device has been completed in order to solicit competitive bids through the Shared Services Centre. The very stable frequency will be used to drive the SGF GNSS and SLR systems, and thus contribute strongly to the quality of all applications, including LRO tracking, the time-transfer programme (T2L2) on Jason-2 and as a strong input to IGS efforts to realize an international time scale.

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, 3.4 at Band 6, 3 at Band 7	2013	2014

FINANCIAL DETAILS: CURRENT FY						
Total Resource Allocation £k				Capital Expend £k	Income £k	Full Cash Cost £k
400				35	100	450

FINANCIAL COMMITMENT (by year until end of current agreement) £k				
2008-09	2009-10	2010-11	2011-12	2012-2013

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

APPLICATIONS: DISTRIBUTION OF GRADES (current FY — 2008/09)

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 to be determined 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 observational quality checks, production of orbital predictions and global laser analyses, 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 currently available only to SGF, POL and UCL. 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); Centre for Polar Observation and Modelling (CPOM, UCL, Universities of Bristol and Cambridge); National Centre for Earth Observation (NCEO, NERC); Dept. of Geomatic Engineering, University College London; National Oceanography Centre (NOC, University of Southampton); Proudman Oceanographic Laboratory (POL, University of Liverpool); De Montfort University; Ministry of Defence (incl. DSTL); British National Space Centre; 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.

Publications. A literature search was carried out in order to determine numbers of reviewed papers published during calendar year 2008 in the major geophysical and geodetic journals by UK (co-) authors. Publications are strictly 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, 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. Some 20 refereed papers were identified.
It is known that internationally a very large number of geodesy-related publications result from the global network of operational Facilities, of which SGF is a major component.

OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2008/09):

SLR: The Facility is a major contributor to the global data sets of high-quality SLR observations. During the year the kHz capability moved to full operations 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. Tracking support for the current **altimetry missions** ENVISAT, JASON-1, JASON-2 and ERS-2 continued at a high level of priority. For 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.

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. Although launched in February 2009, the extreme LEO dedicated gravity-field mission **GOCE** will request laser ranging support on a regular basis only once operational altitude is reached, probably during June.

SLR measurements have continued to the **GLONASS**, the two **GPS,** 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. Through the ILRS Missions Working Group, SGF ran a month-long network campaign to increase laser tracking to all the GNSS satellites including COMPASS in order to test the effectiveness of this Chinese system's retro-array. SGF's analysis showed that the **COMPASS** array of 56 uncoated cubes performed nearly as well as the larger GLONASS arrays. The ILRS 'fall' technical workshop will this year explore all aspects of laser tracking of GNSS vehicles.

GPS/GLONASS: The **Leica GRX GG Pro joint GPS/GLONASS** geodetic receiver (**IGS HERT**) has been operating nominally during this first year and the Ashtech Z18 that it replaced last year has worked well on the OS pillar midway between HERS and HERT. Data analysis using absolute antenna phase models and all three receivers for short-baseline studies has confirmed that mm-level near-annual periodic (358±3 days) variations are present in all baselines. The periodic variations are close to the GPS draconitic (orbital precession) period of 351 days, so the behaviour is likely a GPS artefact rather than a true lack of stability of the site. The **Z12, IGS HERS** system continues to supply high-quality 30-second data both hourly and daily to IGS and to BIGF.

Absolute gravimeter (AG): 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, 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 instrumental cause, although the data has been scrutinized for errors and the manufacturers (Micro-g Lacoste) have been consulted. Analysis work, reported later, has used AG, GPS and SLR results to investigate the residual vertical motion of the site, preliminary results being presented at an IAG symposium and at the AGU and in press in an IAG Springer volume.

COLLABORATIONS:

Cambridge University Chemistry Department The LIDAR programme has moved to operational status. The in-house system is independent from standard SLR work, but can rapidly be deployed for short intervals during a satellite pass and thus sample the backscatter and hence atmospheric transparency along the track. The system is also being used to test the feasibility to determine optical depth of aircraft contrails. In a related study we are using return-rate statistics from the LAGEOS satellites to investigate temporal variations in atmospheric transparency at the global laser sites, and revealing some interesting seasonal signals.

Ordnance Survey. In collaboration with and at the expense of the 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.

IGN, France. An Institut Geographique National (Paris) survey team carried out measurements of inter-technique ties at SGF in late June 2008. The results are awaited with interest, particularly to compare with the currently-adopted vector between HERS and the laser fiducial point.

HITU, Japan. Finishing the work towards determination of precise values of centre of mass corrections for the large ETALON geodetic satellites for the major tracking systems. The aim is to provide a table on the ILRS website for use by all analysts. Collaborator Dr Toshi Otsubo has secured funding to visit SGF in June 2009 to work with the team to pursue some related issues.

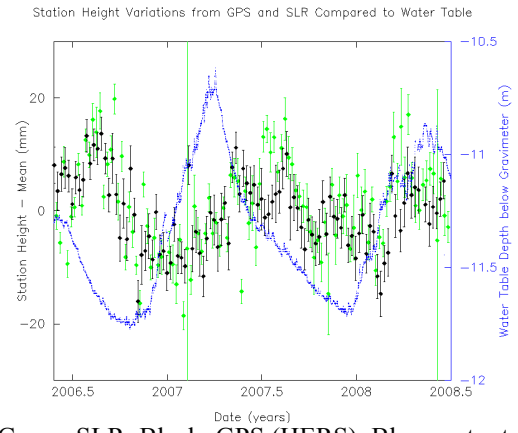
MoD The photometric optical GEostationary satellite Observation Facility (GEOF) has been operational throughout the period. Major upgrades to the observing software during the year allow the SLR observer at the beginning of the night to input a schedule for that night. The telescope, dome and camera will then switch between target satellites without any further input from the observer. 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 on the data and results 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

ILRS. G Appleby is an elected 'at large' representative on the governing board, heading the Missions Working Group which sifts applications from satellite operators for laser tracking support. Recent successful applications include GOCE and Lunar Reconnaissance Orbiter (LRO). It is assumed, though not yet confirmed, that CRYOSat-2 will request laser tracking support.

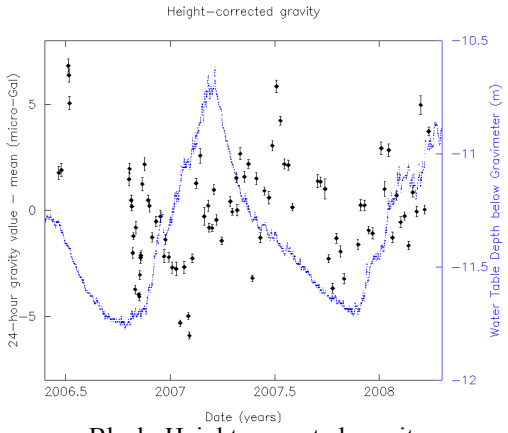
SCIENCE HIGHLIGHTS:

Arctic sea ice is getting thinner as well as receding. Results published in October 2008 show that during winter 2007, the thickness of sea ice in large parts of the Arctic fell by nearly half a metre (19 per cent) compared with the average thickness of the previous five winters. This followed the dramatic 2007 summer low when Arctic ice extent dropped to its lowest level since records began. Up until last winter, the thickness of Arctic sea ice showed a slow downward trend during the previous five winters, but after the summer 2007 record low extent, the thickness of the ice also decreased rapidly. Particularly alarming is that sea ice is not just receding but it is also thinning. The team from CPOM, UCL, is the first to measure ice thickness throughout the Arctic winter, from October to March, over more than half of the Arctic, using radar altimeter observations from ENVISAT. The team will continue to monitor the thickness of the ice during winter 2008, following another summer of low ice extent. The inclination of ENVISAT prevents observations north of about 800km from the North Pole, but CryoSat-2, developed by CPOM and due for launch in December 2009, will observe very close to the Pole. Giles *et al*, GRL, doi:10.1029/2008GL035710

Height signals from SLR, GPS and AG. Analysis of residual height signals has been carried out using all three on-site techniques, in 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, implying that the clay substrate is much more compacted that had been expected. Further work will look at atmospheric loading effects on the results from all three techniques (in press in a Springer series) and in Appleby, *et al*, proc. LR Workshop, Poznan, Poland, 2008.

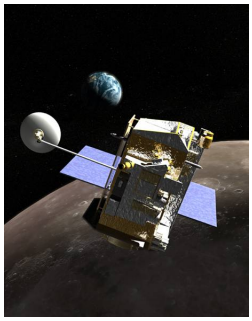


Green: SLR; Black: GPS (HERS); Blue: water table



Black: Height-corrected gravity

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK



New Missions that will require laser-ranging support include the NASA **Lunar Reconnaissance Orbiter**. Following the NSGSC support for SGF involvement, a proposal from SGF was accepted by the Mission for one-way laser range tracking on occasions to be scheduled by NASA. The LRO is due for launch on 2009 June 17, and will represent a significant operational challenge.
The **BLITS** (Ball Lens In Space) Russian geodetic sphere is due for launch in mid-2009. It should have zero 'signature' and thus represent the most accurate geodetic satellite currently in orbit. Previous SGF work on this subject will be used to test the effectiveness of this novel mission.
CRYOSat-2 is due for launch at the end of 2009, and will be tracked with high-priority.

On the assumption that the active **H-maser** is delivered by the end of 2009, the system will be used initially to supply very stable 10MHz frequency signals to the laser ranging event timer. This will dramatically improve the value to onboard DORIS monitoring of laser ranging to the time-transfer system on Jason-2. Much future work will then be required in order to develop the capability to determine and monitor an independent SGF timescale (UTC), and it is known that possibilities, which will be explored, exist for collaboration with NPL in this strategy.

Non-Mandatory Facility-specific OPMs: utilisation, 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 ILRS and Steering Committee priorities. Additional ranging activities are carried out according to requests from the co-funding partner. In practice, some 35-40% of available passes are tracked, placing the Facility in the top 10 of 25 or so 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.