SERVICES & FACILITIES ANNUAL REPORT - FY April 2014 to March 2015

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

TYPE OF SERVICE PROVIDED:

SGF Herstmonceux is the UK's unique ground-based observatory dedicated to satellite and gravitational geodesy. Its highly accurate satellite laser range, global navigational satellite and gravity measurements impact upon a very wide range of international science, from underpinning work essential to global sea-level and ice mass-balance studies, to the realisation of a mm-accuracy global reference frame upon which a huge variety of scientific and commercial activities depend. The state-of-the-art 'new technology' laser ranging system makes mm-accuracy measurements of the distances of a constellation of Earth-orbiting artificial satellites, from dedicated geodetic spheres, to large Earth-monitoring laboratories and an increasing number of global navigation satellites.

The satellite observations are made available rapidly and freely, without application to the Facility, to the UK and 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). Through this fundamental work, many UK and worldwide investigators working on geodetic and geophysical research are able, often unknowingly, to exploit a robust reference frame and precise geo-referenced satellite orbits that are essential for their research. The Facility also carries out an R&D programme, often in collaboration with international colleagues, 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, GNSS and gravity observations, contributing to an international programme as an ILRS Analysis Centre to improve the realisation of the Terrestrial reference frame, and seeking new opportunities to increase for the community the geodetic value of the site.

ANNUAL TARGETS AND PROGRESS TOWARDS THEM

The high-priority installation of the upgraded 2kHz laser has been completed and the system is working extremely well. The laser is again the primary instrument with a subsequent return to high single-shot precision (~3mm) and rapid acquisition of satellites. At the start of operations with the modified laser the system was placed by the ILRS into a short period of 'quarantine', but was released rapidly after a number of LAGEOS passes confirmed to the satisfaction of the ILRS the high quality of the data. The specifications are being finalised for a new narrow-band filter to improve the signal to noise ratio for daytime ranging.

An independent laser ranging event timer has been integrated into the real-time operational system. This will provide an essential verification and partially independent check on the continuing lack of systematic error of the SGF laser range observations.

The new Sun photometer has been deployed on a vantage site near the SLR calibration target. It is fully operational and automatically takes multi-spectral measurements of the direct solar radiance at frequent intervals throughout the daytime. SGF has applied for membership of NASA's international atmospheric robotic aerosol network (AERONET), which includes many sensors worldwide. This capability adds to the SGF's existing atmospheric LiDAR and horizontal visibility measurement systems.

SCORES AT LAST REVIEW (each out of 5)		Date of Last Review:		2008
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)
	NERC/BGS staff: 1 at Band 5, 6 at Band 6, 0.2 FTE at Band 9	2016?	

FINANCIAL DETAILS: CURRENT FY						
Total Resource Allocation £k	Unit Cost £k N/A			Capital Expend £k	Income £k	Full Cash Cost £k
424					109	
FINANCIAL COMMITMENT (by year until end of current agreement) £k						
2015-16 420	2016-17					

STEERING COMMITTEE	Independent Members	Meetings per annum	Other S&F Overseen
NSGFSC	10	2	BIGF, GEF

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 that underpins all precise geodesy including all GNSS-based work 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 NOC, but with a developing 'facility' status. 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 in principle set by the steering committee (NGGFSC) 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 towards reference frame ITRF solutions, for example, as an ILRS Analysis Centre, are carried out for the ILRS and IERS. This work is detailed later in this Annual Report. It is also likely that in the event of a successful EU funding bid led by the UKSA for the UK contribution to the EU Space Surveillance and Tracking (SST) project, that funded tasking for tracking work will be made to SGF through a UK Consortium Strategy Board.

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, NOC and UCL, with a potential future involvement with Durham University. UK: University of Newcastle; BIGF, University of Nottingham; National Centre for Earth Observation (NCEO, NERC); Space Geodesy and Navigation, University College London; National Oceanography Centre (Southampton and Liverpool); De Montfort University; Ministry of Defence (incl. DSTL); UK Space Agency; Surrey Satellite Technology Ltd.; Ordnance Survey. European: EUREF; ESA. International: NASA; ILRS; IGS, IERS and Global Geodetic Observing System GGOS, an overarching Service of the International Association of Geodesy; Inter-governmental: Group on Earth Observations, GEO.

SGF Publications 2014

Rovera, G D; Torre, J-M; **Sherwood, R.A**.; Abgrall, M; Courde, C; Laas-Bourez, M; Uhrich, P, Link calibration against receiver calibration: an assessment of GPS Time-transfer uncertainties. Metrologia 51, 5, 476-490 October 2014

Otsubo, T., **Sherwood, R.A., Appleby, G.M**., Neubert, R., Center-of-mass corrections for sub-cm-precision laser ranging targets: Starlette, Stella and LARES 2014, Journal of Geodesy Volume 89, Issue 4, pp 303-312 DOI: 10.1007/s00190-014-0776-y

Appleby, G.M., Rodriguez, J., Altamimi, Z. 2014 AGU invited talk, G11C-04 Assessments of the Accuracy of Global Geodetic Satellite Laser Ranging Observations During the Last Decade and Potential Impact on ITRF Scale

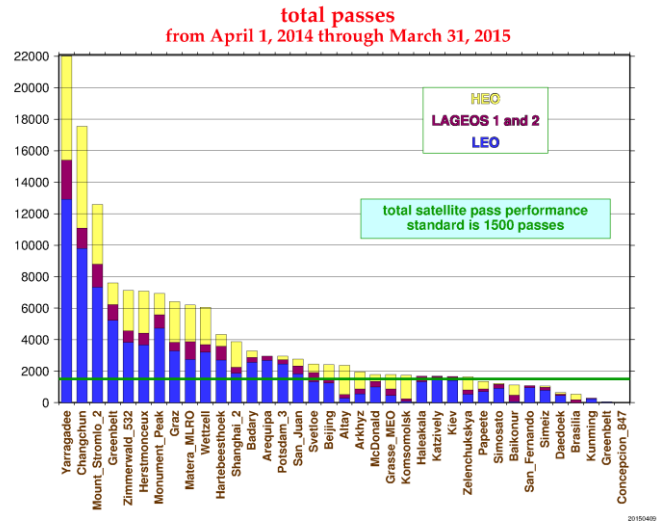
Appleby, G.M., Rodriguez, J., Sherwood, R, Shoobridge, T., Wilkinson, M.J. 2014 AGU Poster G13A-0505 Demonstrating Vertical Stability Between Geodetic Techniques at SGF Herstmonceux, UK

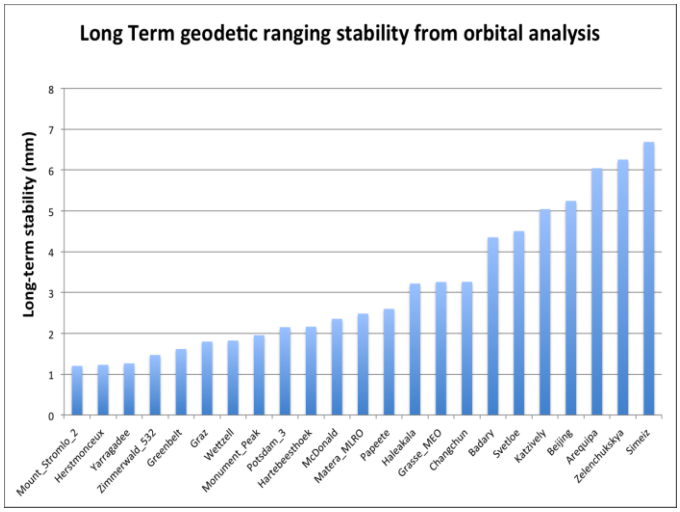
Kucharski, D., Kirchner, G., Koidl, F., Fan, C., Carman, R., Moore, C., Dmytrotsa, A., Ploner, M., Bianco, G., Medvedskij, M., Makeyev, A., **Appleby, G**., Suzuki, M., Torre, J.-M., Zhongping, Z., Grunwaldt, L., Feng, Q. Attitude and spin period of space debris Envisat measured by Satellite Laser Ranging, IEEE Transactions on Geoscience and Remote Sensing, 2014 DOI: 10.1109/TGRS.2014.2316138

Pearlman, M. R., **Appleby, G.M**., Ipatov, A., Jayaraman, V., Noll, C. E., Pavlis, E. C., Shargorodsky, V., Woo, J. Early Results from New Initiatives on SLR Tracking of GNSS and Synchronous Satellites (Paper 3114), proc. 19th Int. Laser Ranging Workshop, Annapolis, MD, October 2014

OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2014/15):

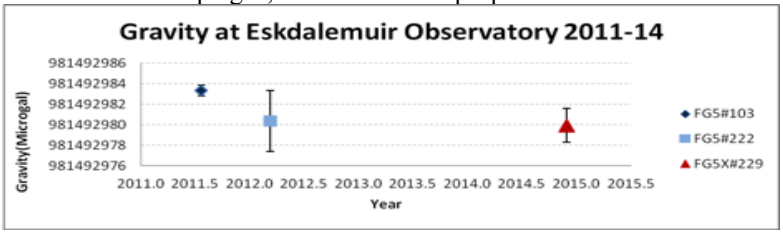
SLR: The Facility is a major contributor to the global data sets of high-quality SLR observations. The ability to switch in seconds between the 1kHz and the 10Hz lasers continues to make it both a unique and very powerful facility, despite the fact that the recently-upgraded kHz laser is performing so well that the legacy 10Hz system is seldom used. Tracking support for the current **geodetic** (LAGEOS, LARES, Etalon), **altimeter (**JASON-2, CryoSat-2 and SARAL, anticipated JASON-3), **GNSS** (GLONASS, GIOVE, Galileo, Beidou) and **gravity** (GRACE, Swarm) missions continued at a high level of priority. The ILRS plot below left confirms this strong support, with SGF ranked 6th in relation to the ILRS network in terms of total passes obtained of the laser-tracked missions during 2014/15. This position reflects again an increase of more than 1,000 passes tracked from Herstmonceux this year compared to last year, as a result of much better weather and careful management of funding restrictions. Not shown is the large number of passive observations being carried out using the tracking telescope at times during nights for MoD. Shown below right is average long-term ranging *precision* for each station as estimated from the station-bias estimates of three ILRS Analysis Centres' weekly LAGEOS' orbital solutions, with station coordinates being held fixed at their ITRF2008 values. By this metric, SGF is the second most stable system of the ILRS.





The newly upgraded kHz laser was commissioned in late September 2014 and has been in continuous and exclusive use since then. Performance has been very good, with almost all SLR targets observable by day and by night in good atmospheric transparency. To ensure that sufficient on-site quality checks may be carried out to maintain its strong position of bias-free data, an independent range measurement capability has been developed based on a Riga event timer. Tests suggest that this new, and relatively very inexpensive, timer is performing slightly better and is less sensitive to small temperature changes than the primary event timer. Data from both systems are routinely collected, and the situation will be kept under review.

Gravity measurements. The SGF absolute gravimeter FG5-X#229 was used in a successful few days' campaign at BGS Eskdalemuir in November 2014 in order to make a comparison with the results previously taken at the site using the two NOC gravimeters that are currently on long-term loan at SGF. The NOC data for 2011/12 has been provided by NOC, and processed at SGF. The graph shows the measured gravity values at the three epochs 2011, 2012 and 2015. Clearly, the results do not support the hypothesis that the SGF AG #229 is reading 'high', which does appear to be the case at a level of approximately +7µGal since 2013 in the laboratory at SGF. Tests using both #229 and a NOC instrument are planned at SGF to provide a rigorous comparison. A capital bid has been made to upgrade the electronics and carry out a service of a NOC instrument in order that it may be used in field observational campaigns, such as a recent proposal from Durham.



The primary work for the SGF ILRS Analysis Center has been the re-analysis of the global LAGEOS data sets for the continuous period 1983-2014 towards the ILRS contribution to the next realisation of the International Terrestrial Reference Frame. Very importantly for this work, in February 2015 the UN General Assembly adopted the resolution ***A Global Geodetic Reference Frame for Sustainable Development*** – the first resolution recognizing the importance of a globally-coordinated approach to geodesy.

Atmospheric monitoring – The Sun photometer has been installed and commissioned on a tower giving excellent horizon-to-horizon visibility and is downloading data on a regular basis. SGF has applied to join the NASA AERONET (Aerosol Robotic Network) Project which is based at GSFC and which archives and makes available to the community Sun photometer data from some 200 sites worldwide (http://aeronet.gsfc.nasa.gov/cgi-bin/site_info). This instrument adds to the existing LiDAR and horizontal visibility techniques at the Herstmonceux site and suggests that interesting analyses projects would be possible for under- or post-graduate work. The visibility data is already a vital element for modelling atmospheric extinction during data processing of photometric observations of satellites.

SCIENCE HIGHLIGHTS. ***To focus on economic and societal impacts and benefits where possible*****:**

Assessment of the Accuracy of Global Geodetic SLR Observations and Estimated Impact on ITRF Scale. Appleby, G., Rodriguez, J., Altamimi, Z. Invited talk at AGU2014. Draft in final stages of preparation for JoG.

The study of long-term phenomena in the Earth system requires the definition and realisation of a global reference frame (ITRF) that enables the comparison of multidisciplinary observations based on ground, airborne and satellite techniques made in different locations over the course of several decades. The accuracy and stability requirements of the reference frame needed to meet these scientific demands are very stringent, driving continuous efforts towards technological and theoretical improvements of the space geodetic techniques underpinning the ITRF. We conducted a study on the long-term accuracy of the global ILRS network, revealing the presence of significant biases in the observations of many tracking stations. Our work implies that the SLR derived reference frame scale in the ITRF2008 and in previous realisations has been biased by nearly 1 ppb and goes a long way toward resolving a persistent, unexplained scale difference between the SLR and VLBI techniques. It is also discovered that there was an origin offset forced onto previous ITRF solutions through the bias effect, such that the new work implies a change of origin of up to 6 mm. As uncertainties in the reference frame are one of the main error sources in the characterisation of long-term sea-level change, this work is relevant to its understanding and that of related processes, such as hydrology and continental water storage, mass balance of ice sheets, glacial isostatic adjustment, ocean circulation, crustal motion, weather and climate.

Volume loss from Antarctic ice shelves is accelerating. Paolo F. S. et al. 2015. Science, Vol. 348, no. 6232, pp.327-331.

This report from Fernando Paolo et al shows long-term ice shelf thickness trends for different Antarctic coastal regions. The study used radar altimeter records from 3 consecutive satellite missions (ERS-1, ERS-2 and Envisat), spanning 18 years from 1994 to 2012. Comparisons were made to analyses based on data from the ICEsat laser altimetry mission for the years 2003-2008, showing good agreement over this period, although this was not necessarily so for the long-term trends, highlighting the importance of long-term records for determining the state of the ice shelves. The floating ice shelves surrounding the Antarctic ice restrain grounded ice-sheet flow. Thinning of an ice shelf leads to an increase in ice discharge to the ocean. Overall, average ice shelf volume change was observed at 25±64 km3/year for 1994–2003, increasing to 310±74 km3/year for 2003–2012. This study highlights both the need to directly support satellite altimeter missions with precise orbits and the paramount importance of having an accurate, stable global reference frame to link the multi-decadal data it draws upon.

Preliminary Orbital Analysis of the LARES Space Experiment. Ciufolini, I. et al. 2015, Eur. Phys. J. Plus 130: 133.

Successful tracking by the global ILRS network of the LAser RElativity Satellite since its launch in 2012 has enabled preliminary testing of the frame-dragging effect predicted by General Relativity with lower uncertainty levels than in previous attempts. These results are encouraging and indicate that future calculations including the most recent gravity models and longer time spans, as tracking data become available, will allow for the testing of frame-dragging with about 1% accuracy.

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK

The EU Commission Implementing Decision of 12th September 2014 set out the 'procedure for participation of the Member States in the **Space Surveillance and Tracking Support Framework**'. The UKSA is taking the lead in pulling together a UK consortium and is working within Europe to provide a multi-state bid to this funding opportunity. The SGF satellite tracking sensors are included in the UK consortium. The UK has set up a Strategy Board to be the interface to the EC and lead the UK contribution and funding bids. BIS chair the Board, with representatives from UKSA, STFC, MoD and NERC. A Technical and Security Committee is also in place, with representation from the UK sensor community including STFC, MoD, the UK operations centre and UKSA. SGF is involved in both these UK consortium entities.

In order to progress the MoD-funded dedicated LEO tracking capability, a need has been identified to build a small dome enclosure with a 'clamshell' lid, ideally close to the existing GEOF dome. The existing telescope and fast CCD camera combination, purchased through MoD funding, will be housed in the enclosure and greatly improve the ease with which testing can be carried out on bespoke software to drive both the mount and the camera. Early tests with the instrument on a large, but just-portable tripod are very encouraging but not practical for regular work. Local BISC management has visited the site and approved the SGF proposal regarding placement and appearance of the new enclosure. It is hoped that the EU SST project will fund this new work.

To progress the geodetic capability of the site, and to remain competitive in the GGOS era of global core sites, the SGF will continue to make the case to include geodetic VLBI at the site, and to engage the UK community in seizing such an opportunity.

Non-Mandatory Facility-specific OPMs: utilisation, allocation of capacity etc. The laser ranging system is operated, weather-permitting on an approximately 18-hour, seven-days-a-week flexible principle that takes account of tracking priorities. Care is taken during the scheduling process to focus out-of-hours observing upon the high-priority passes of geodetic and EO satellites, as well as on the work for MoD, with a view to economising on out-of-hours payments. This year, much better than last year, some 1000 extra passes were observed, with the Facility 6th in the top 25 contributing ILRS stations. The GEOF optical photometric system is operated according to demand throughout most clear nights, being initiated by the SLR observer then left unattended to close down automatically at dawn. The GNSS systems work continuously, and at present the SGF gravimeter is operated for one 24-hour autonomous period once a month, a change from the previous weekly run prompted by the need to extend intervals between instrumental services.