SERVICES & FACILITIES ANNUAL REPORT - FY April 2003 to March 2004

SERVICE: SPACE GEODESY FACILITY (SGF)	FUNDING Direct from 1999	AGREEMENT	ESTABLISHED as S&F 1994, operational from 1983	TERM 5 years

TYPE OF SERVICE PROVIDED:

- **Output**: The NSGF delivers accurate laser range and microwave measurements of selected Earth-orbiting satellites to global data banks, from where they are freely available for research. The Satellite Laser Range (SLR) normal points are precise at the mm level, and accurate to better than 1 cm. In terms of quality and quantity of tracking data, the Facility is ranked in the top five of more than 30 stations worldwide. The GPS and GPS/GLONASS receivers operate autonomously and continuously, one of them also feeding information directly into the Internet. The Facility is registered with the International Laser Ranging Service (ILRS) as a Tracking Station and as an Associate Analysis Centre, and with the International GPS Service (IGS) as an IGS Tracking Site. Facility staff are involved in several ILRS Working Groups, and one member is currently serving on the ILRS Governing Board as an analysis representative.

- **The Satellites**. The principal satellites that are tracked by SLR are the series of Earth Observation satellites (including ENVISAT, TOPEX/POSEIDON, JASON, GEOSAT-follow-on and ERS-2) that carry radar altimeters for measuring distances to sea, ice and land. Full exploitation of the altimetry information is achieved by observing the geodetic satellites (including LAGEOS') and gravity-field missions (GRACE, CHAMP, STELLA). SLR is also regularly used to observe two of the constellation of GPS satellites and the GLONASS satellites. Priorities for SGF tracking are set by the Steering Committee, taking account of recommendations from the ILRS. Future missions requiring laser tracking include the ESA CryoSat twin radar polar mission (2004/05), the ESA gravity field mission GOCE (2005) and two Galileo System Test Bed (GSTB-V2) pilot vehicles (2005) for the EU/ESA GALILEO global navigational system.

- **The Science**. The work of the Space Geodesy Facility provides the raw material to underpin several areas of NERC science. Observations of the geodetic satellites by the SLR system, which is collocated with two continuously operating GPS receivers, contribute to the definition of a global geocentric reference frame: Herstmonceux is one of **ten key worldwide reference stations** that define the scale and origin of this frame. 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 and land areas can be accurately calibrated using this precise knowledge of the positions of the satellites. Such data impacts upon ongoing UK studies into for example long-term variation in sea level (e.g., Newcastle), ocean circulation/anomaly dynamics (SOC, POL), polar ice mass-balance and response to climate change (e.g. CPOM, UCL), improvement of global digital elevation models and large-scale river-level monitoring (De Montfort), forest vegetation dynamics (CEH). In addition, UK research is underway (Newcastle and SGF) to make rapid determinations of Earth centre-of-mass variations, using SLR observations of the geodetic satellites and by combining solutions from several ILRS analysis centres. Photometric observations, simultaneous with laser ranging operations, continue to be used to derive spin-vector information for the LAGEOS-2 satellite, which are being used to model non-conservative forces on the satellite (SGF, National Institute of Information and Communications Technology, Japan and DEOS, Delft, The Netherlands.)

SCORES AT LAST REVIEW (each out of 5)		Date of Last Review: 2003		
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	Contract Ends
%	100% of 1 at Band 5, 4 at Band 6, 2 at Band 7	(January 2008)	(31 March 2009)

FINANCIAL DETAILS: CURRENT FY						
Recurrent Allocation £k	Unit Cost £k			Capital Expend £k	Income £k	Full cash cost £k
	Unit 1	Unit 2	Unit 3			
340				100	225	450

FINANCIAL COMMITMENT (by year until end of current agreement) FCC- Income. Numbers assume funding partners continue at current level. Excludes any per-annum Capital Bids.				
2003-04 240	2004-05 240	2005-06 240	2006-07 240	2007-08 240

STEERING COMMITTEE	Independent Members	Meetings per annum	Other S&F Overseen
NSGSC	7	1	BIGF

APPLICATIONS: DISTRIBUTION OF GRADES (Current FY — 2003/04)

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

Pilot

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 who are known to be involved at some level in the space geodesy field and who therefore will be users either directly or indirectly of SGF products. UK: University of Newcastle, IESSG Nottingham, CPOM and Geomatics, University College London, SOC, University of Southampton, De Montfort University, MoD, BNSC. International: ESA, NASA, ILR

USER PROFILE (current FY)

Academic	Centre/Survey	NERC Fellows	PhD	Commercial

USER PROFILE (per annum average previous 3 years)

Academic	Centre/Survey	NERC Fellows	PhD	Commercial

OUTPUT & PERFORMANCE MEASURES (current FY)

Publications (by science area & type)

SBA	ES	MS	AS	TFS	EO	Polar	Grand Total	Refereed	Non-Ref/ Conf Proc	PhD Theses

Distribution of Projects (by science areas)

SBA	ES	MS	AS	TFS	EO	Polar

OUTPUT & PERFORMANCE MEASURES (per annum average previous 3 years)

Publications (by science area & type)

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Distribution of Projects (by science areas)

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OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2003/04):

SLR: The Facility remains a major contributor to the global data sets of high-quality SLR observations. Tracking support for the current **altimetry missions** ENVISAT, JASON-1, ERS-2, TOPEX/POSEIDON and GEOSAT Follow-on continued at a high level of priority. For ERS-2, ENVISAT, T/P and JASON-1, SLR measurements supplement for ERS-2 PRARE and for the others GPS/DORIS tracking data, whilst for GFO-1, **satellite laser ranging** remains the only precise tracking method.

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. During the year the ILRS Analysis Working Group (membership includes representatives from Newcastle University and a co-ordinator from SGF) began regular, weekly, computation and combination of SINEX-based solutions for station coordinates and Earth-rotation parameters.

The two vehicles of the **GRACE** gravity mission continue to provide a challenge for SLR tracking and for the rapid dissemination of accurate predictions. SGF is playing a leading role in this effort, via rapid orbital updates made available to the ILRS network. Both continue to be reasonably well tracked by the global SLR network. The role of the SLR technique in this mission, as for the ongoing **CHAMP** mission, is primarily an independent check on the orbital quality derived from the onboard GPS receivers, but the range measurements will also be used to aid precise orbit determination. Laser ranging to the LEO geodetic satellites **STELLA** and **STARLETTE** continue to be of value for determination of temporal variability of low degree terms in the gravity field models. Future ESA gravity field explorer mission **GOCE** will require laser support for its GPS-based orbit determination.

SLR measurements have continued to an ILRS-agreed set of the **GLONASS** satellites and to the two **GPS** satellites that are fitted with retro-reflectors. Future navigational satellites that will require laser tracking are the two Galileo System Test Bed (**GSTB-V2**) pilot vehicles (2005) for the EU/ESA GALILEO system.

Through collaboration and real-time status exchange with the **EUROLAS SLR** facilities, SGF continues to champion the concept of an "intelligent" observing strategy, whereby systems maximise support for the wide range of satellites that require precise tracking.

Surprisingly, the instances within the EUROLAS cluster of given satellite passes being tracked by more than one system are quite low; as a result of local operational conditions, including weather, nearly 60% of tracked passes are unique to a single station in the cluster.

GPS/GLONASS: The **Ashtech Z-18 joint GPS/GLONASS** geodetic receiver (IGS **HERT**) is working extremely well in its relatively new location close to the principal SLR calibration target some 100m distant from the main buildings of the Facility. Via a fibre link to the facility, the **HERT** system is configured to contribute 30-second data to IGS, simultaneously archive 1-second sampled data and, implemented this year, stream differential correction data direct to the internet as part of the EUREF-IP real-time GNSS Pilot Project (http://www.epncb.oma.be/_organisation/projects/euref_IP/index.html). The **Z12, IGS HERS** system continues to supply high-quality 30-second data both hourly and daily to IGS. Daily quality checks on the Z12 and Z18 data are automatically carried out by SGF. Further, we have recently developed the capability to analyse GPS data, using the MIT software GAMIT, in order to monitor both the quality of the HERS and HERT data and potentially the stability of the site itself within the ITRF frame.

COLLABORATIONS:

An MSc student from the **Department of Geomatic Engineering, University College London**, carried out for their thesis a site survey to determine the distances between the SLR fiducial reference point and the phase centres of the three principal range calibration targets and one, experimental, movable target. The results for the distances confirm at the level of about 1-2mm the value currently in use for laser range calibration to the primary target, which was determined some years ago by the OS. These directly measured values are very important also for monitoring the non-linearity in the time-of-flight counters of the laser range system.

The **photometric capability** of the SLR system continues to be used to determine the precise times that SLR-tracked satellites enter or exit from the Earth's shadow. This year, by request, data from high-orbiting satellites were obtained. The results are being used by the UCL group to test both models of shadow boundaries and the effects on precision of orbit determination of the accuracy of those models.

NERC ARSF. Occasional use of HERT 1-second Z18 GPS/GLONASS data by staff of Monks Wood Section for Earth Observation to aid ARSF image processing. Following a request, SGF also determined the ITRF2000 coordinates of the Monks Wood GPS receiver.

Surrey Satellite Systems Ltd. Correspondence and meeting with SSTL engineers regarding the ideal characteristics of the laser array to be placed on their test satellite for the GALILEO system, to be launched in 2005. Guidance was also given regarding the required application for tracking support to ILRS. Similar correspondence with **ESTEC** engineer regarding the ESA test satellite for the GALILEO system, again due for launch in 2005.

ILRS Analysis Working Group. Collaborating with research groups from some 5 institutes towards an 'official' weekly ILRS station coordinate and EOP product. SGF is currently submitting weekly solutions that are being combined with four other regular solutions. Involved in a joint response to IERS committing ILRS analysis combination groups to this activity, potentially involving Geomatics department, University of Newcastle-upon-Tyne.

ILRS Signal Processing Working Group. Leading the work towards the determination of precise values of centre of mass corrections for the geodetic satellites for the major tracking systems and documenting retro-array characteristics and precise locations. Journal paper published with Japanese collaborator.

National Institute of Information and Communications Technology, Japan. Continuing the programme on analysis of SLR measurements to the ILRS-approved GLONASS and two GPS satellites carrying laser arrays. Papers published in Conference Procs.

Joint programme on determination of LAGEOS' spin vector from analysis of flash measurements made at Herstmonceux. Journal paper published.

ILRS Fall Workshop in Koezting, Germany. Attended by some fifty ILRS associates, three SGF staff members attended to organize sessions and make presentations in a useful, hands-on, forum. A summary report along with copies of all the presentations and recommendations was put together by session organisers and is available on the ILRS website at http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/index.html

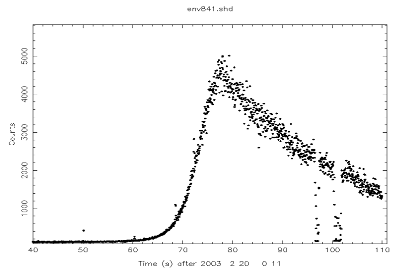
SCIENCE HIGHLIGHTS 2003/04

Rossby waves are large-scale oceanic disturbances that propagate westward across ocean basins carrying information about changes in forcing that have occurred to the east. The first satellite detection was in sea surface height (SSH) from altimetry measurements and then temperature and ocean colour. Recent work has looked at the phase relationship between these three properties for an example location in the southern Indian Ocean (Quartly *et al*., 2003). This has been extended to a global analysis of the signals in SSH and ocean colour (Killworth et al., 2004). This shows that for most locations, the ocean colour signal of Rossby waves is due to north-south advection, but that in some regions other explanations such as raising of nutricline are necessary to explain the observed phase shift between the two datasets.

Quartly, GD, P Cipollini, D Cromwell & PG Challenor, 2003, 'Rossby waves: Synergy in action', *Phil. Trans, Roy. Soc*. A, 361, 57-63.
Killworth, PD, P Cipollini, BM Uz & JR Blundell, 2004, 'Physical and biological mechanisms for planetary waves observed in satellite-derived chlorophyll', to appear in *J. Geophys Res*.

High latitude altimetry: ERS satellite radar altimetry has been used to generate the first spaceborne estimates of Arctic sea ice thickness for an 8 year time period. The results show that the thickness of Arctic sea ice is more variable than previously thought and that inter-annual changes in sea ice thickness are highly correlated with melt season length (Laxon, *et al*., 2003). In the Antarctic ERS data was used to map the height of the Larsen Ice Shelf surface since 1992. After accounting for the movement caused by ocean tides, the data revealed a clear pattern of surface lowering across the majority of the Larsen Ice Shelf. After eliminating other potential causes - such as increased summer melt water production - the team attributed the signal to enhanced melting at the base of the Larsen Ice Shelf. This melting is releasing very large quantities of very cold water into the oceans and may create a disturbance affecting patterns of global ocean circulation. The team predict that in less than a hundred years the remaining Larsen Ice Shelf will thin and further sections will disintegrate and collapse (Shepherd, *et al*., 2003).

Laxon, S. W., Peacock, N. R. & Smith, D. M. High interannual variability of sea ice thickness in the Arctic region. *Nature*, doi:10.1038/nature2050. (2003).
Shepherd A., Wingham D., Payne T. and Skvarca P., Larsen Ice shelf has progressively thinned, Science, Vol. 302, 856-859 (2003).



Orbital Force model development.

The plot on the left shows a series of photometric measurements taken by SGF of ENVISAT as it emerged from the Earth's shadow. These observations are being used at the Department of Geomatic Engineering UCL as part of their development of a non-gravitational force model, to include shadow transit effects. Both the photometric observations and a precise short-arc orbit derived from laser data are delivered by SGF.

As highlighted in last year's Report, analyses of SLR observations, principally of Lageos-1 and latterly Lageos-2 also, from 1979 to the present show how the **dynamic oblateness, J_2**, of the Earth has steadily decreased with time, in line with post-glacial rebound theory up until about 1998. However, analysis of the SLR observations made since early 1998 show initially that J_2 started to increase dramatically, indicating a reversal of mass redistribution from high latitudes to the equatorial regions, but has recently returned to 'normal'. This phenomenon continues to cause interest in the community, with recent detection from laser satellite (LAGEOS, Starlette, Stella and Ajisai) solutions of signatures in shorter wavelength zonal terms that are correlated with independent estimates of atmospheric gravity variations.

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK

Last year's forward look argued that to improve the accuracy of the laser range measurements, the relatively inexpensive Stanford counters should be replaced by an accurate epoch timing system and that a short pulse, high repetition rate laser should replace the original, Ny-YAG system. A subsequent bid to purchase the modules and build an epoch timer was successful and work to achieve this is underway within SGF. Plans for future upgrade and expansion of the Facility's capability are summarised here and are the subject of a recent response by SGF and collaborators to a NERC Capital Bid initiative directed to NERC's Services and Facilities.

A modern high-repetition rate laser, that will bring two distinct advantages to the laser operations, is one subject of the capital bid. The proposed laser, which will generate very short, 10ps pulses at a rate of up to 2kHz, will increase the single shot precision by a factor of about six to ~ 2mm, a point where it will be dominated by target signature effects, well understood by the team. Secondly, the high rate will increase by a factor of at least three the numbers of observations for compression into normal points, thus increasing their precision to the single mm level and also greatly improve the speed of acquisition. This proposal, in conjunction with the event timer that is currently under construction, will maintain the SGF laser system fully competitive with upcoming high performance systems, such as the **NASA SLR2000** system.

In a joint bid with Prof Trevor Baker and Dr Simon Williams of POL, SGF is proposing **an absolute gravimeter (AG) for permanent installation in the basement at Herstmonceux**. This proposal would expand the scope of the observational capability of the SGF into very accurate gravity monitoring. Key to earth-system monitoring is maintenance of a terrestrial reference system with an accuracy of 1 part per billion (10^9) in global scale. In order to develop such a capability within the European and global community, an initiative to establish a European Combined Geodetic Network (ECGN, Ihde, Baker, *et al*, 2003) is underway within the auspices of EUREF, a European sub-commission of the International Association of Geodesy. One of the objectives of ECGN is the combination of geometric positioning (GPS/GLONASS/SLR) with the physical height and gravity field components in the cm-accuracy range. The SGF site at Herstmonceux has already been accepted as a 'station' within ECGN following a first call for proposals. However, we strongly consider that given its long record of precise space geodetic and ancillary measurements, the station would best meet the scientific needs of the community if it were to integrate a permanent AG. Linked to the space geodetic techniques by precise site-ties, the AG would contribute absolute gravity values from a site of precisely known location within the international terrestrial reference frame. In addition, the site would be very valuable for side-by-side inter-comparison of the POL, and other, AGs. Given such a concentration of precise equipment at Herstmonceux, SGF would become a key station within ECGN and undoubtedly strengthen absolute gravimetry work within the UK.

Annex 5 to SGF Annual Report, 2003: Summary of Performance information.

The conventional form of OPI giving numbers of applications received is not relevant to this facility, as users of the facility access the data and high level data products directly from international data centres and other sources. This applies both to the SLR data and derived orbital products and to GPS/GLONASS data and products. However, there is a large UK user community whose work depends upon the current and future availability of precise orbits of the applications satellites such as ERS, TOPEX/POSEIDON, GEOSAT-follow-on, ENVISAT and JASON. All these missions are tracked with high priority by the SGF.

A measure of the large impact that the Facility has on the global tracking effort can be seen by noting the strong contribution of the Herstmonceux system to the large numbers of satellite range measurements made by the stations of the ILRS Network. These numbers are given as histograms of total numbers of 'normal point' ranges for all of the satellites that are currently being tracked for the year 2003 January to December, in three categories, in Figures SGF 1 - 3. Firstly, in **Figure SGF 1**, the low Earth orbiting satellites (LEO), which include the altimetry and SAR remote sensing satellites ENVISAT, ERS-2, TOPEX/POSEIDON, GEOSAT-follow-on and JASON which are of direct relevance to UK research groups in the areas of Earth Observation and Marine Sciences, and the Gravity-field missions CHAMP, GRACE, STELLA, STARLETTE. It should be noted that tracking of the NASA **IceSat** mission is at present restricted to just a few NASA SLR stations, because of the extreme sensitivity of and hence potential for damage to the on-board detector by laser pulses of 532nm wavelength.

Then are given in **Figure SGF 2** the results for the two major geodetic satellites LAGEOS-1 and -2, whose observations are crucial for the maintenance of a global reference frame within which the orbits of the remote sensing satellites are derived. Finally are shown in **Figure SGF 3** the results for the high-orbiting (HEO, at heights of about 20,000 Km) ETALON, GPS and GLONASS satellites. SLR observations of the navigational satellites continue to be important in monitoring the quality and potential radial bias in their orbits as determined operationally from analyses of the radiometric tracking data. The value of observations of the ETALON satellites in a complementary role to those of LAGEOS continues to be enforced by the ILRS Analysis Working Group.

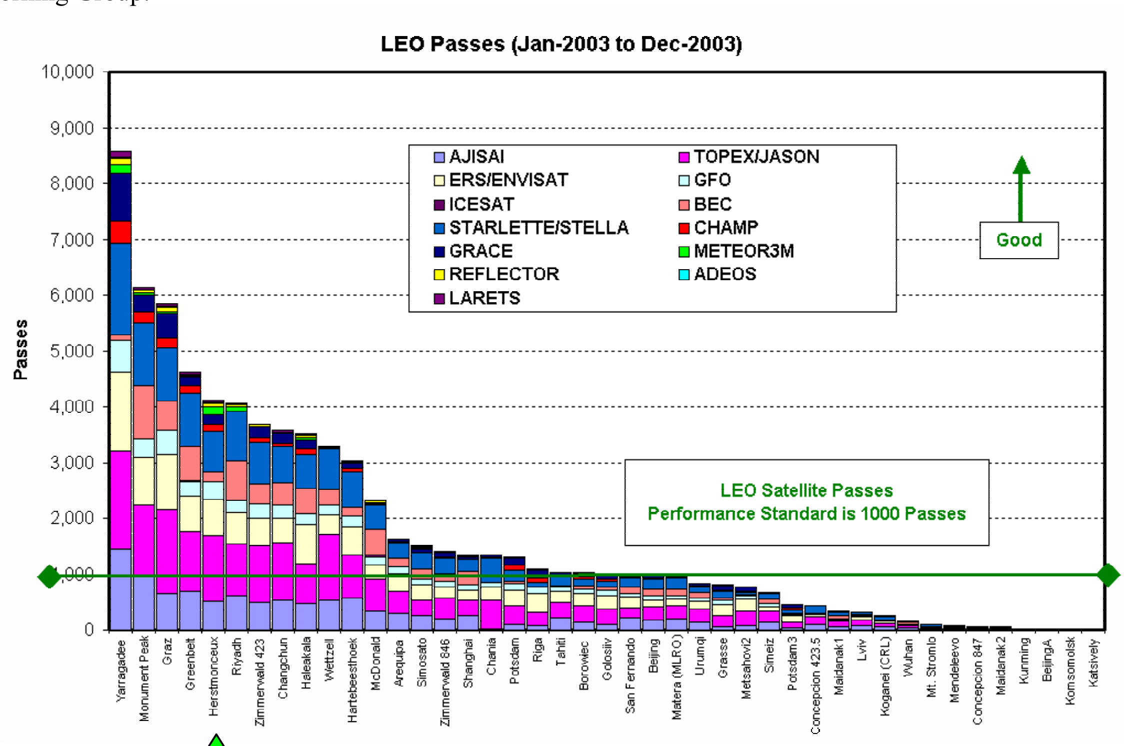


Figure SGF 1

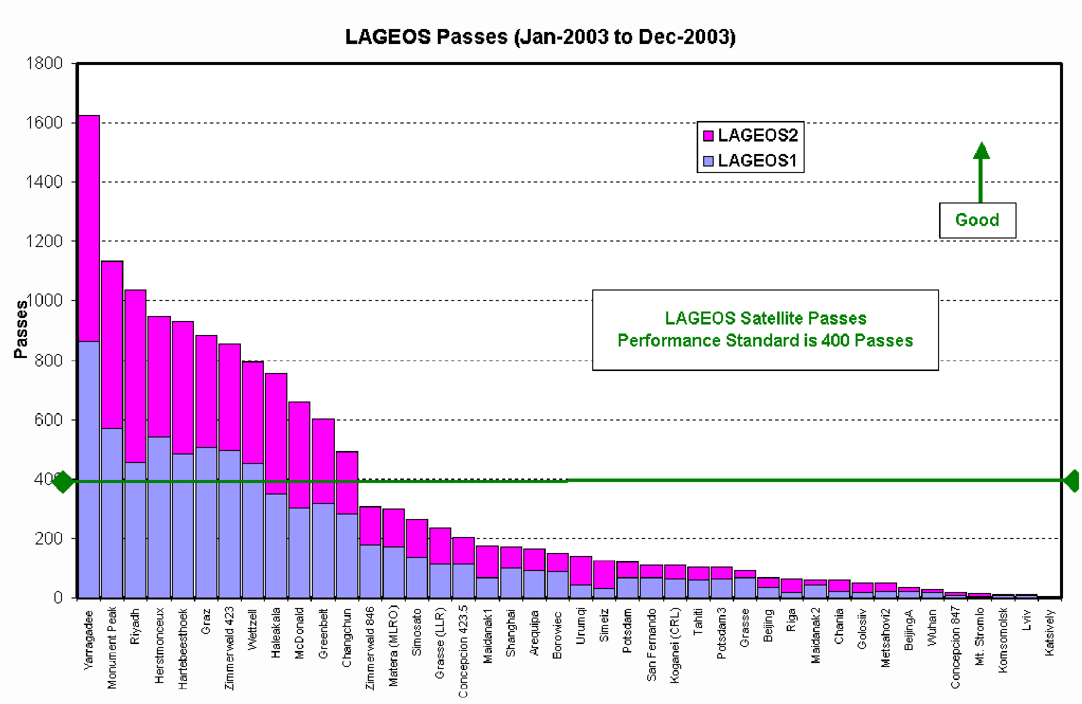


Figure SGF 2

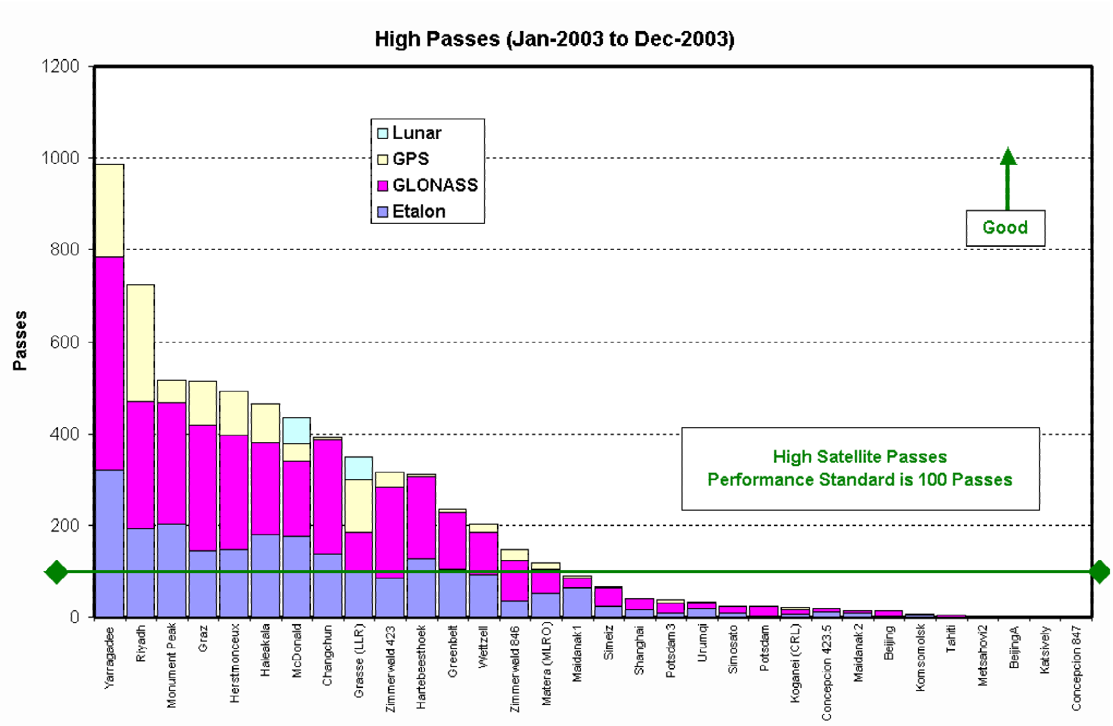


Figure SGF 3

The last two plots below, Figures SGF 4 and 5, may be used to give an indication of the precision and stability of the measurements from the Herstmonceux system relative to all the other stations. The first plot, **Figure SGF 4**, shows the single-shot precision of calibration ranging, ranging to ERS-2 and ranging to LAGEOS. The results given for Herstmonceux are exactly in line with previous theoretical considerations for the system, which is controlled to work strictly at single-photon levels of return. For a calibration precision of about 10mm, set mainly by the laser pulse length and precision of the detector, we expect for the extended reflector array of LAGEOS a single-shot precision of about 17mm and close to calibration precision for the small array on ENVISAT (and JASON, ERS-2 and GFO). These expectations are confirmed by the results shown in the plot. As discussed in the Future Developments section of this annual report, if we were to decrease significantly the laser pulse length (currently about 100ps FWHM), we would be able to improve considerably the single-shot precision. It is notable that GRAZ, for instance, has a much better performance *precision*, due primarily to its use of a very short pulse (35ps FWHM).

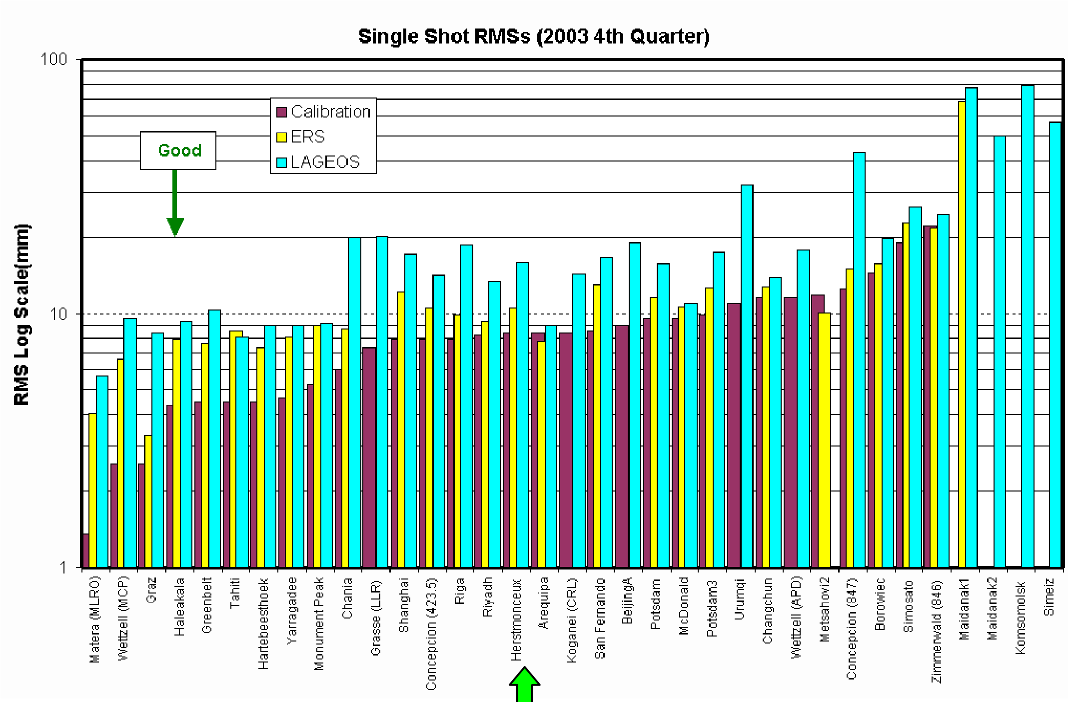


Figure SGF 4

Finally in **Figure SGF 5** is shown a measure of the long-term stability of the range measurements from the SLR systems, obtained from a US analysis of pass-by-pass residuals from a precise orbital determination. Those residuals are used to determine possible range bias for each station in the global network; the stability of that bias estimate from week-to-week indicates the stability of the system. The absolute bias of the SGF system has been determined by the team and is thought to be below 1cm. The plots of these results show that the SGF SLR system is performing very well in all these categories in relation to the entire tracking network. Among ILRS analysts the Facility, along with just 10 other stations, has the status of a core tracking station, which is seen as a guarantee that the data from the system can be relied upon in terms of high quality. As such it is a major contributor to the scale and origin of the International Terrestrial Reference Frame; the orientation of the reference frame is determined mainly by VLBI through the IVS and by GPS through the IGS.

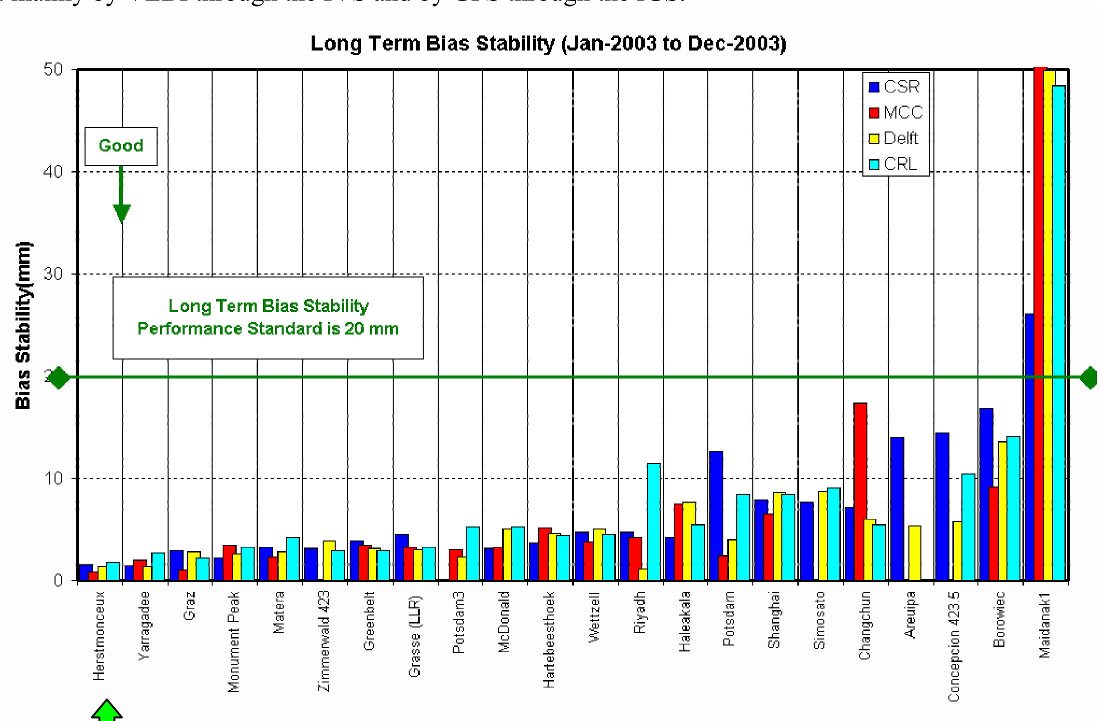


Figure SGF 5

The figures SGF 1-5 used here are all available on the ILRS website at
http://ilrs.gsfc.nasa.gov/stations/site_info/global_report_cards/perf_2003q4.html

NERC SERVICES & FACILITIES

NERC SPACE GEODESY FACILITY

MISSION STATEMENT

- To make laser range measurements to the special satellites that carry retro-reflectors, according to priorities assigned by the NERC Space Geodesy Steering Committee, and in accordance with international projects and priorities.
- To ensure that the range measurements are of the highest possible accuracy.
- To contribute the data promptly to the international SLR data centres.
- To operate geodetic GPS and GLONASS receivers on the site and contribute the data regularly to the international GPS/GLONASS data centres
- To maintain and develop the software and hardware of the systems in order to give high reliability and to keep the precision of the systems at the current state of the art.
- To achieve a high productivity level of numbers of satellite passes tracked.
- To assist and collaborate with UK analysts in their use of satellite tracking and related data.

In order to fulfil its mission the Space Geodesy Facility will :

- maintain an up-to-date knowledge of international developments of hardware and software in satellite tracking technology
- contribute to the international advancement of the technology, particularly in the areas of orbital predictions, software data processing, and the use of photo-diode detectors
- maintain a constant vigilance for sources of measurement error
- participate fully in UK and international co-ordination of SLR and GPS/GLONASS activities
- carry out data analysis and research, in order to maintain a real awareness of what the users require from the data

User Communities :

The observations from the facility are contributed to international data centres, together with data from other geodetic facilities around the World. The data are used in combination with data from all precise space geodetic techniques by analysis groups world-wide and within the UK for a variety of studies, including oceanography, glaciology, the gravity field of the Earth, tides in the Earth and oceans, a global reference frame, and crustal motion. These data products are used widely by the oceanographic and solid earth science groups within the UK and worldwide.

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Dr R Bingley, BIGF
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Dr D. Holland, MoD
Mr. M. Ryan, NERC S&I