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National geodetic activity in the past year has included:

- the near completion of the 110 station Ordnance Survey OS Net® GNSS network – the network is now fully planned and only 3 stations remain to be built;
- station hardware upgrade of the entire OS Net recently begun;
- geodetic, zero order sub network being planned;
- distribution of national RTK corrections from OS Net data via licensed Ordnance Survey partners;
- the ongoing submission of data to the EPN and an increase in the number of stations contributing real time data via NTRIP;
- development of an improved geoid model;
- the continued development of the NERC BIGF (British Isles GPS archive Facility), housed at the Institute of Engineering Surveying & Space Geodesy (IESSG),University of Nottingham;
- continued space geodesy and gravity observations at Herstmonceux;
- research at GB universities, of interest to EUREF.

The Ordnance Survey's National GNSS network –OS Net® (www.ordnancesurvey.co.uk/gps), has continued to expand and is now almost complete with 107 stations in place (see Figure 1). Only 3 stations remain to be built to complete national coverage – 2 in the western islands of Scotland and 1 on the Isles of Scilly in the far south west of England. These stations are planned to be complete by the end of 2008. In addition, to increase the coverage and improve error modelling, data streams from external stations in Ireland (2), Northern Ireland (2), Belgium (1) and The Netherlands (1) are included in the RTK processing.

A complete refresh of the station hardware has recently begun. All stations are being upgraded to GPS/GLONASS receivers and antennas. The antennas are Galileo ready and the receivers can be upgraded to Galileo when required. The hardware refresh is expected to be complete by the end of 2008.

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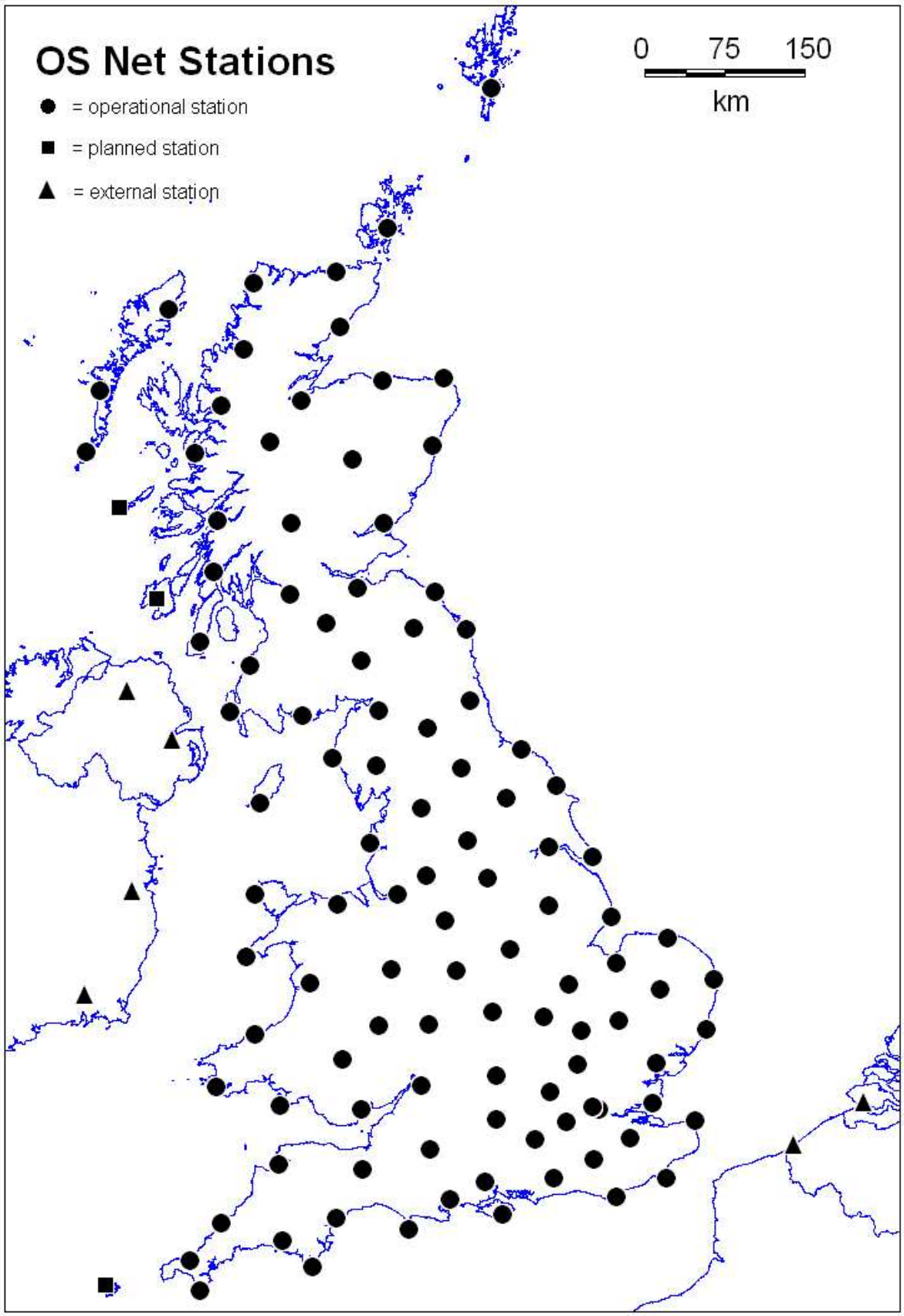

OS Net Stations
= operational station
= planned station
= external station
0
75
150
km

Whilst all the current GNSS stations are of course firmly mounted on solid structures/ground, not many could be classed as being the best possible, zero order, geodetic type of monumentation. To address this issue, a new zero order network of around 12 permanent GNSS stations, anchored to rock and monumented to international geodetic standards, is being developed. Consultation on the monumentation and site location is being held with Geomatics, Geology and Geophysics experts from academia, the British Geological Survey, the Environment Agency and Proudman Oceanographic Laboratory. This new network, called GeoNet, is expected to be complete by Spring 2009. GeoNet will be a sub set of OS Net and the station hardware will be the same. Where possible, GeoNet stations will be collocated with other sensors. Following GeoNet's completion a new EUREF quality campaign will take place to realise an updated ETRF in GB (EUREF GB 2009).

The network is managed via the GPSNet™ software from Trimble and delivers RTK corrections via GSM and GPRS to approximately 130 Ordnance Survey surveyors. Public services are also available via Ordnance Survey commercial partners. Partners take the raw GNSS data streams from OS Net servers via NTRIP and use them to generate their own correction services.

Current EPN submissions from GB are hourly data from HERS, HERT and MORP plus 24 hour files from DARE, INVE, NEWL and NPLD. Data integrity problems currently prevent us from switching DARE and INVE to hourly submissions but some planned new hardware should enable us to do this.

Raw GPS data from DARE, INVE and RTCM 3.0 data from SHOE are also streamed in real time via NTRIP. This is in addition to RTK data from HERT.

Work started last year with colleagues of the French Institut Geographique National to finally come to a common answer for the levelling through the Channel Tunnel carried out in 1994. This will enable a better connection of the GB levelling network to UELN.

Progress on the final connection of the British Tunnel portal bench mark to Ordnance Datum Newlyn has been held back by a delay in the computation of a new British geoid model (see 4 below).

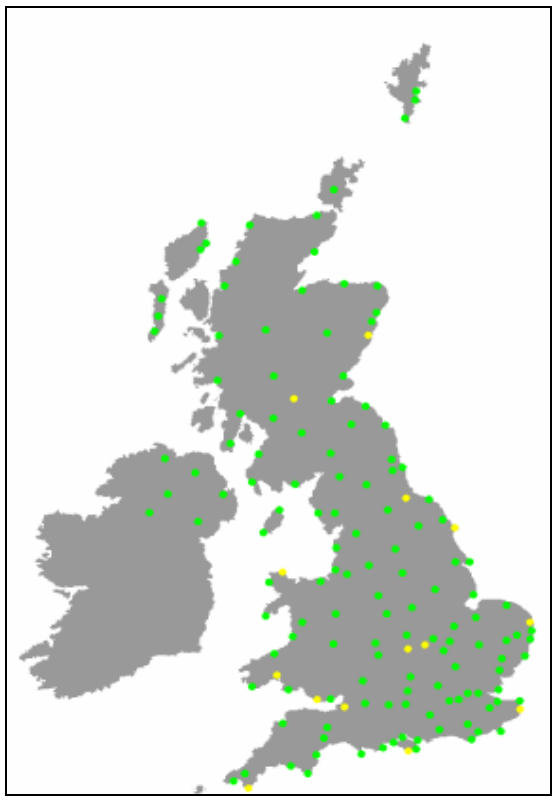
Attempts are being made to recover some of Ordnance Survey's original Tunnel levelling data from printouts and archived files in order to further investigate the discrepancy between the British and the French levelling.

Geodetic GPS observations have been taken at 30+ levelling points in the northwest of Scotland and on the Scottish islands in order to improve the OSGM02 geoid model. These build upon existing observations at the fundamental height bench marks around Great Britain.

A new geoid model (OSGM07) was planned for release last year but preliminary analysis showed that further GPS observations in the western Scottish islands were required. These observations have now been carried out and the new geoid model – OSGM08 is expected to be released this year.

The British Isles GPS archive Facility (BIGF) is operated from the IESSG, with recently renewed funding from the UK Natural Environment Research Council (NERC), until at least 2014. Figure 2 shows the current network.

BIGF is the long-term national archive for GPS data, from a continuously recording network of currently 155 stations sited throughout mainland UK. This network comprises all the Ordnance Survey of Great Britain active stations, all Leica Geosystems Ltd. active stations, 6 Ordnance Survey Northern Ireland active stations and 25 scientific stations. The scientific stations have been established by various agencies and organisations, who are: Defra; the Environment Agency; the Met Office; the National Physical Laboratory; Newcastle University; the NERC Proudman Oceanographic Laboratory; the NERC Space Geodesy Facility at Herstmonceux; and the University of Nottingham's IESSG. Data are provided and transmitted free-of-charge to the archive by these collaborators, with whom long-term agreements to supply are in place.



Cumulative demand on the archive since its inception in 1998 has now exceeded 2,400 station-years. More importantly the number of scientists annually making use of the archive increased from 4 to more around 100 to 150 over the same period. This growing user base has elevated BIGF's profile in the scientific community, increasing the possibilities for infiltration of new scientific fields, the enabling of new applications, and cross-fertilisation and collaboration between experts in satellite positioning technology and experts in other disciplines.

During the period from 1998 to present, there has been a steady net growth in the BIGF network to the current live complement of 155 stations. The current status of the network is shown on the map in Figure 2.

In 2007/8, user-specific continuous data transfer procedures were in place for eight users, who are:

- UK Met Office near real-time atmospheric water vapour, hourly and daily data from over 132 stations.
- EC COST Action 716, hourly data from up to 17 stations.
- EC Framework VI TOUGH, hourly data from up to 2 stations.
- IGS TIGA-PP, daily data from up to 4 stations.
- ESEAS, daily data from up to 4 stations.
- EPN/ECGN, daily data from 1 station.
- University of Leeds, 2 year project considering mechanisms of coastal erosion in Devensian tills on the East Yorkshire Coast, daily data from 4 stations.
- University of Nevada, Nevada Bureau of Mines and Geology, for NASA/JPL funded research towards a global ambiguity resolved precise point solution and time series, daily data from 27 stations.

Other research supported by archive data in 2007/8 included, amongst many others:

- Changes in glacier geometry and extent in Svalbard implications for sea level rise during the 20th and 21st centuries; King, Dr M; Newcastle University, Civil Engineering and Geosciences.
- Global loading and deformation at tidal timescales; Clarke, Prof P; Newcastle University, Civil Engineering and Geosciences.
- An assessment of ocean tide loading models for precise GPS positioning in Great Britain; Penna, Dr N; Newcastle University, Civil Engineering and Geosciences.
- Detection of storm surge loading with GPS; Penna, Dr N; Newcastle University, Civil Engineering and Geosciences.
- E-GVAP, the EUMETNET GPS water vapour programme; Nash, Mr J; Network of European Meteorological Services.
- Ionospheric calibration, part of the Advanced Long-Baseline User Software (ALBUS) Project; Anderson, Dr J; Joint Institute for VLBI in Europe.
- Intertidal vegetation, accretion and erosion monitoring; Brown, Dr S; NERC Centre for Ecology and Hydrology.
- Monitoring changes in upland blanket peat surface elevation using Persistent Scatterer Interferometry; Rawlins, Dr B; NERC British Geological Survey.

- Recomputation of GPS/IMU for 2004-6 flying seasons to check accuracy; Philpot, Mr D; NERC British Geological Survey.

- Upscaling of peatland methane emission estimates from small to large scales; Mohammed, Mr A; University of Edinburgh, Geosciences.

- Establishing geodetic control in the monitoring of urban subsidence using InSAR; Leighton, Mr, J; University of Nottingham, IESSG.

- Hydro-ecological modelling of braided rivers; Cox, Ms C; University of Cambridge, Geography.

The long-term nature and increasing spatial density of the BIGF network lends itself to take on a facilitative role as an environmental laboratory, enabling the more incisive determination of spatially dependent environmental variables, and isolation of lower frequency components of parameters such as ocean tide loading and vertical land movement. The availability of six active stations established by the Ordnance Survey of Northern Ireland increases the spatial extent and utility of the archive, which is of particular importance to meteorological scientists.

Seven of the stations are part of the IGS and EPN (DARE, HERS, HERT, INVE, MORP, NEWL and NPLD) and four CGPS@TG stations contribute to ESEAS and the IGS TIGA Pilot Project (ABER, NEWL, NSTG and SHEE).

BIGF has a website at http://www.bigf.ac.uk providing detail of the archive's history, archive users, and the current network. Data can be requested using an online form at this site.

The Space Geodesy Facility is operated at Herstmonceux, UK, with funding from the Natural Environment Research Council and the UK Ministry of Defence. It is an observational and analytical facility with a highly productive and precise Satellite Laser Ranging system, two continuously operating IGS GNSS receivers and a permanent FG5 absolute gravimeter. Frequent, on-site automated meteorological and water table depth observations augment the geodetic observations. The Facility is also an International Laser Ranging Service (ILRS) Analysis Centre.

The system is a core ILRS station, making daytime and night time range measurements to geodetic, gravity-field, altimeter and GNSS satellites at heights of from 500 to 23,000km. The precision of the range normal points is about 1mm, and the station is ranked among the top ten in the ILRS global network in terms of data productivity. Completed during the year has been an upgrade to include a short-pulse, high repetition-rate (2 kHz), laser and a very high-accuracy event timer; this combination is now delivering single-shot ranging precision at the 3mm level. Modelling work done by SGF has improved to the mm-level the corrections required to relate Herstmonceux laser measurements to the centres of mass of the geodetic spherical satellites. The Facility has also undertaken a study and measurement campaign to resolve non-linearity effects that can reach 10mm in range as a result of some stations' counter hardware. A similar problem of magnitude about 6mm with the Herstmonceux data since 1994 has been resolved. A table of corrections for all stations will appear on the ILRS website once a few remaining counters are measured.

The Facility as an ILRS Analysis Centre computes weekly and now daily global station coordinate and Earth orientation solutions in support of the ILRS' contribution towards ITRF realisation work and rapid Earth orientation results for the IERS. In common with the other Analysis Centres, a re-analysis of all laser data taken since 1983 to the geodetic (two LAGEOS and two ETALON) satellites is underway, taking account of centre-of-mass and system counter issues, which may have a bearing on the scale problems that were evident in the ITRF2005.

The two IGS stations HERS and HERT remain in continuous operation, with HERT also streaming GPS and GLONASS navigation data into the Internet in support of the EUREF-IP and IGS Real-time Projects. During the year and following some reliability problems the HERT Ashtech Z18 receiver was replaced by a GPS/GLONASS 'all in view' Leica GRX GG Pro. The Z18 has been placed on the OS trig point close to the Facility to add a third station (informally 'SOLA') to the ongoing local network study into subtle baseline variations. Daily GAMIT-based solutions for HERS and HERT coordinates and precise HERS-HERT and HERS- and HERT-SOLA baselines inform a rapid quality check on the observations as well as providing a valuable local site-stability solution. Consideration is being given to purchasing a H-maser frequency source to drive at least one of the receivers and thus contribute to IGS GNSS observations that are independent of time derived from the GPS system itself.

Regular weekly operations of the FG5 absolute gravimeter have continued since operations began in October 2006. The baseline observational programme is a 24-hour session centred on mid-GPS week, resulting in hourly average gravity values of precision about 1-2 μgal, equivalent to a vertical precision of around 3mm. Analysis of the results to date, in combination with SGF-derived space geodetic station-height solutions and local groundwater measurements, are underway in collaboration with the Proudman Oceanographic Laboratory and UCL. The gravimeter took part in a successful European inter-comparison workshop in Walferdange, Luxembourg in December 2007.

Contact Matt King [m.a.king@newcastle.ac.uk] in the first instance for further details of these projects.

*Real-time positioning*

Newcastle's Engineering and Physical Sciences Research Council project ("AutoBahn") is focusing on real-time GPS satellite orbit and clock determination and subsequent ground-station positioning. As a first step the deterministic least-squares batch processor in BAHN has been replaced by an Extended Kalman Filter facilitating continuous computation of GPS satellite orbits and clocks and other receiver and satellite parameters. Zhang et al. [2007] describe the underlying methodology behind the Extended Kalman Filter approach as required to handle GPS phase and code data from a global network of GPS tracking stations. In addition, details are presented about the replacement of global, arc-dependent and epoch-dependent deterministic parameters by stochastic processes. Current accuracies for the GPS orbits and clocks achieved with Auto-BAHN are illustrated through

comparisons with IGS final solutions. 3D RMS values of the orbital differences varied between 10.0 and 29.9 cm with a mean RMS value of 13.6 cm. The mean difference compared against the IGS satellite clock corrections is about 0.29 ns with standard deviation of 0.04 ns.

*Systematic Errors*

Extensive studies of the propagation of unmodelled periodic ground displacements into GPS coordinate estimates and time series used in geophysical studies are detailed in Penna and Stewart [2003], Stewart et al. [2005] and Penna et al. [2007]. Building on this work, King et al. [2008] examined sub-daily signals in satellite orbits and clocks and showed how they propagated to longer periods in conventional 24 h solutions. Unmodelled sub-daily signals with amplitudes up to 10-15 mm were observed, including at the frequencies of S1 and S2 and near those of K1 and K2. These were shown to propagate into 24 h solutions with (among other frequencies) annual and semi-annual periods with amplitudes up to 5 mm, with a median amplitude in the height component of 0.8 mm (annual) and 0.6 mm (semi-annual). They are shown to bias low-degree spherical harmonics estimates of geophysical loading at the level of 5–10%, although the exact effect will be network dependent.

Penna et al. [2008] assessed the prediction accuracy of various ocean tide loading displacement software packages, including the widely used online ocean tide loading provider based on the OLFG/OLMPP software. The accuracy of ocean tide loading (OTL) displacement values has long been assumed to be dominated by errors in the ocean tide models used, with errors due to the convolution scheme used considered very small (2–5%). However, this paper shows that much larger convolution errors can arise at sites within approximately 150km of the coastline, depending on the method used to refine the discrete regularly spaced grid cells of the ocean tide model to better fit the coastline closest to the site of interest. As a result of this study, the coastal refinement approach used in the OLFG/OLMPP software was therefore changed in August 2007 to use bilinear interpolation only.

*Basis functions*

Inversion of geodetic site displacement data to infer surface mass loads has previously been demonstrated using a spherical harmonic representation of the load. Clarke et al. [2007] investigated basis functions that allow variability of the load over continental regions, but impose global mass conservation and equilibrium tidal behaviour of the oceans. Compared to standard spherical harmonics, these basis functions yield a better fit to the model loads over the period 1997–2005, for an equivalent number of parameters, and provide a more accurate and stable fit using the synthetic geodetic displacements. In particular, recovery of the low-degree coefficients is greatly improved.

*Tidal loading displacements*

Thomas et al. [2007] continued Newcastle's development of GNSS techniques for measuring tidal loading displacements. Comparing estimates of periodic displacement (dominated by ocean tide loading displacements) at ~20 GPS sites with previously published VLBI estimates and those from recent numerical tide models, GPS-derived estimates were shown to be generally as accurate as VLBI, except at K1 and K2 where GPS-related systematic errors dominate. This is the first time that GPS-derived periodic motions have been shown to be as accurate as those from VLBI.

Clarke PJ, DA Lavallée, G Blewitt and TM van Dam (2007). Basis functions for the consistent and accurate representation of surface mass loading, Geophysical Journal International, doi:10.1111/j.1365-246X.2007.03493.x.

Penna NT and MP Stewart (2003). Aliased tidal signatures in continuous GPS height time series, Geophysical Research Letters, 30(23), doi:10.1029/2003GL018828.

Penna NT, MA King and MP Stewart (2007). GPS height time series: Short-period origins of spurious long-period signals, Journal of Geophysical Research - Solid Earth, 112(B2), B02402, doi:10.1029/2005JB004047.

Penna NT, MS Bos, TF Baker and H-G Scherneck (2008), Assessing the accuracy of predicted ocean tide loading displacement values, Journal of Geodesy, doi:10.1007/s00190-008-0220-2, published on-line Apr 2008.

Stewart MP, NT Penna and DD Lichti (2005). Investigating the propagation mechanism of unmodelled systematic errors in coordinate time series estimated using least squares, Journal of Geodesy, 79(8): 479-489, doi:10.1007/s00190-005-0478-6.

Thomas ID, MA King and PJ Clarke (2007). A comparison of GPS, VLBI and model estimates of ocean tide loading displacements, Journal of Geodesy, 81(5): 359-368, doi:10.1007/s00190-006-0118-9.

Zhang Q, P Moore, J Hanley and S Martin (2007). Auto-BAHN: Software for near real-time GPS orbit and clock computations, Advances in Space Research, 39(10): 1531-1538.

Contact Richard Bingley [richard.bingley@nottingham.ac.uk] for further details of these projects.

A project titled “Absolute fixing of tide gauge benchmarks and land levels: measuring changes in land and sea levels around the coast of Great Britain and along the Thames Estuary and River Thames using GPS, absolute gravimetry, persistent scatter interferometry and tide gauges” was completed in 2007. It was funded by the UK government’s Defra and Environment Agency and was carried out by a consortium led by the University of Nottingham’s IESSG and including the NERC Proudman Oceanographic Laboratory (POL), Nigel Press Associates Ltd. (NPA) and the NERC British Geological Survey (BGS).

The results of the project were published in July 2007, as a Technical Report of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme which is available as FD2319 at

(www.defra.gov.uk/environ/fcd/research/RandDcompproj.htm). This led to a variety of media interest including articles on the BBC News website (news.bbc.co.uk/1/hi/sci/tech/6231334.stm) and in the Independent newspaper on 14 July 2007.

The results of the project were new estimates for the rise in sea level (decoupled from changes in land level) around the coast of Great Britain over the past few decades/past century, a map of current changes in land level for the Thames Region correlated with geoscience data sets, and new estimates for the rise in sea level with respect to the land along the Thames Estuary and River Thames over the past few decades/past century.

During August and September 2007, the University of Nottingham's IESSG installed two short drilled braced monuments for continuous GNSS measurements at two sites of the seismic network operated by the BGS, including the seismic site at the Eskdalemuir Observatory which is part of a global seismic network. These two installations are the first two geodetic monuments of this kind in the British Isles and they will enable highly accurate measurement of both short and long-term motions of the underlying Earth's crust.

Although a network of over 150 GNSS stations is already in operation in the British Isles, it is the critical connection of the monumentation to the bedrock that sets the two new stations apart from most sites of the existing GNSS network. Both at the Eskdalemuir Observatory in Dumfries and Galloway and at Michaelchurch Escley in Herefordshire, the stainless steel legs of the braced monuments were fixed to bedrock, by cementing them into up to one metre deep holes drilled into the exposed rock. The short drilled braced monument used gains additional stability from extra horizontal braces between the slanted and vertical stainless steel legs, and is therefore a modified version of those installed in large numbers by the Plate Boundary Observatory (PBO) in the western United States and Alaska.

The GNSS equipment which will be installed, after calibration, at the new stations allows the tracking of signals transmitted by satellites of both GPS and GLONASS, and can be upgraded to also observe those of Galileo satellites. It is envisaged that their data are streamed in real-time at one second interval via broadband to the IESSG, from where it can be distributed to various scientific real-time projects of the international GNSS community and archived in BIGF.

Contact Jon Iliffe [jiliffe@cege.ucl.ac.uk] or Marek Ziebart [marek@ge.ucl.ac.uk] for more information.

*A New Methodology for Incorporating Tide Gauge Data in Sea Surface Topography Models.*

As part of the Vertical Offshore Reference Frames (VORF) project sponsored by the U. K. Hydrographic Office, a new model for Sea Surface Topography (SST) around the British Isles has been developed. For offshore areas (greater than 30 km from the coast), this model is largely derived from satellite altimetry. However, its accuracy and level of detail have been enhanced in coastal areas by the inclusion of not only the 60 PSMSL tide gauges with long-term records around the coasts of the United Kingdom and Ireland but also some 385 gauges established at different epochs and for different observation spans by the U. K. Admiralty. All tide gauge data were brought into a common reference frame by a combination of datum models and direct GPS observations, but a more significant challenge was to bring all short-term sea level observations to an unbiased value at a common epoch. This was achieved through developing a spatial-temporal correlation model for the variations in mean sea level around the British Isles, which in turn meant that gauges with long-term observation spans could be used as control points to improve the accuracy of Admiralty gauges. It is demonstrated that the latter can contribute point observations of mean sea level (MSL) with a precision of 0.078 m. A combination of least squares collocation and interpolation was developed to merge the coastal point and offshore gridded data sets, with particular algorithms having to be developed for different configurations of coastal topology. The resulting model of sea surface topography is shown to present a smooth transition from inshore coastal areas to offshore zones. Further benefits of the techniques developed include an enhanced methodology for detecting datum discontinuities at permanent tide gauges.

Iliffe,J.C., Ziebart,M.K., Turner,J.F. (2007). A New Methodology for incorporating tide gauge data in Sea Surface Topography models. Journal of Marine Geodesy 30(4), 271-296. ISSN: 0149-0419, http://www.informaworld.com/smpp/content~db=all?content=10.1080/01490410701568384