National Report of Great Britain 2017

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Abstract. Activities of Ordnance Survey, the national mapping agency of Great Britain. Also activities from NERC British Isles continuous GNSS Facility (BIGF) and Newcastle University.

Keywords. Ordnance Survey, NERC British Isles continuous GNSS Facility (BIGF), Newcastle University.

1 Ordnance Survey activities

1.1 National GNSS network

The OS Net network contains 108 stations, runs on the Trimble Pivot Platform (TPP)™ software and delivers RTK corrections via GSM and GPRS to approximately 250 Ordnance Survey surveyors. Public services are also available via Ordnance Survey commercial partners.

Commercial partners take the raw GNSS data streams from OS Net servers via NTRIP and use them to generate their own correction services.

Current commercial partners offering RTK service in Great Britain are AXIO-NET, Leica, Soil Essentials, Topcon and Trimble. Current partner details can be found at :
http://www.ordnancesurvey.co.uk/business-and-government/products/os-net/index.html.

A receiver upgrade is planned for the next year which should allow for streaming and collection of Galileo and BeiDou observations in addition to GPS and GLONASS. It is intended to retain as many antennas as possible but approximately 30-40% may require replacement due to corrosion (mainly coastal sites).

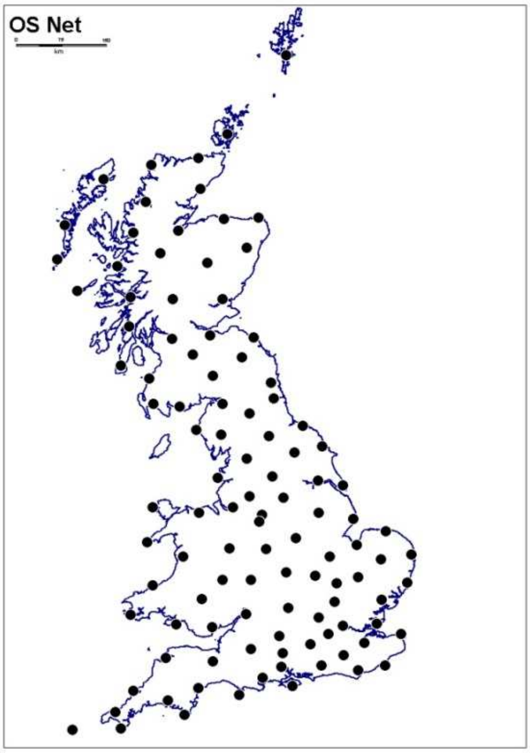

Fig. 1 OS Net GNSS Network

1.2 EPN data submissions

In the last year 9 British stations have been added to the EPN network. The current EPN submissions from GB are now hourly data from: OS Net stations ADAR, ARIS, CHIO, DARE, EDIN, INVR, LERI, PMTH, SCIL, SHOE, SNEO and SWAS; Natural Environment Research Council

(NERC) stations HERS and HERT; Newcastle University station MORP. University of Nottingham station NEWL contributes 24 hour files.

Stations DARE, INVR, HERT and SHOE provide also real time data. Real time data from any other OS Net station is not possible due to conflict with OS Net partner's commercial operations.

1.3 National ETRS89 coordinates update

In conjunction with the release of updated geoid model and transformation (see section 1.4) OS Net ETRS89 coordinates were updated to be fully aligned to the EUREF IE/UK 2009 campaign results. The overall change in OS Net coordinates is shown in Table 1.

Table 1. Differences (m) between old and new OS Net coordinates.

	East	North	Up	2D
Min	-0.025	-0.010	-0.050	0.002
Max	0.030	0.021	0.053	0.034
RMS	0.015	0.008	0.018	0.017

1.4 Geoid and transformation model improvement

A collaboration between Ordnance Survey (GB), Ordnance Survey Ireland and Land & Property Services Northern Ireland resulted in an improved geoid model, OSGM15, across the United Kingdom and Ireland region. The GB horizontal transformation was also updated to OSTN15. The new models were launched on 26th August 2016 along with new OS Net ETRS89 coordinates (see section 1.3).

OSTN15 defines GB's OSGB36 mapping datum in conjunction with ETRS89 coordinates of OS Net stations. So, the transformation update was designed to minimise the impact of the OS Net coordinate change on users' OSGB36 coordinates. OSTN15 was aligned to the EUREF IE/UK 2009 realisation of ETRS89 by applying a transformation to the transformation data set ETRS89 coordinates to shift them to the new ETRS89 realisation. The transformation was computed from common points in both EUREF campaigns.

Table 2 shows the expected final impact on user generated OSGB36 coordinates by comparing the old OS Net coordinates passed through the old transformation (OSTN02) with the new ones passed through OSTN15.

Table 2. Differences (m) old OS Net + OSTN02 and new OS Net +OSTN15.

	East	North
Min	-0.037	-0.015
Max	0.019	0.018
RMS	0.009	0.007

The geoid model improvements were more pronounced. Fig. 2 shows the difference between OSGM15 and the old model OSGM02.

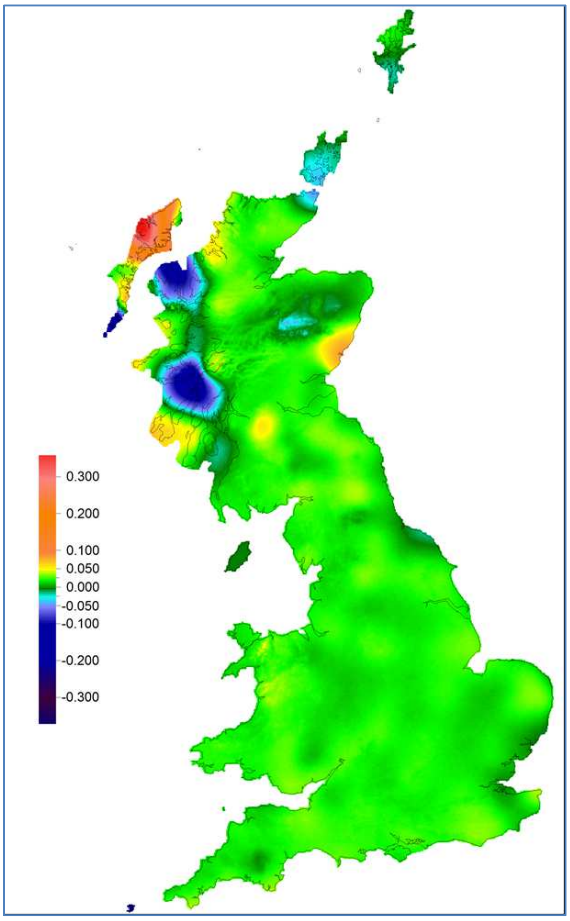

Fig. 2 Differences (m), between OSGM15 derived heights and OSGM02 derived heights (OSGM15 minus OSGM02).

Table 3 shows the differences and accuracies of the new model for the various height datums in GB.

Table 3. Differences (m) between OSGM02 and OSGM15 in GB and accuracy values of OSGM15.

Datum:	Newlyn	St Marys	Douglas02
RMS difference:	0.026	0.365	0.000
Accuracy:	0.008	N/A single offset	0.030

Datum:	Stornoway15	Lerwick	Newlyn (Orkney)
RMS difference:	0.175	0.013	0.021
Accuracy:	0.011	0.018	0.017

The geoid model in GB is, more correctly, a "height corrector surface" and the gravimetric geoid is fitted to the mean sea level based height datums via observed geoid separations at benchmarks. The majority of these observations on the GB mainland for fitting to Ordnance Datum Newlyn (ODN) were from a single campaign in the late 1990s and were aligned to a different realisation of ETRS89 than the one now used for OS Net coordinates. OSGM15 is now aligned to the same realisation as OS Net (from the EUREF IE/UK 2009 campaign) via transformations based on common points in the original benchmark observation campaign and OS Net coordinate set. The realignment has resulted in approximately a 0.025m shift in ODN heights.

A much better fit to ODN has been achieved in north-west Scotland and to the local height datums of the Scottish islands by researching and surveying new benchmarks.

On the Stornoway datum for the Outer Hebrides, OSGM15 now achieves a smoother and consistent fit along the whole island chain and is more closely aligned to the datum mark in Stornoway. However, this has resulted in a bigger jump from OSGM02 heights, especially in the southern part of the island chain, and a tilting of the datum relative to the OSGM02 realisation.

On the Scilly Isles, St Mary's datum the previous fit of OSGM02 was to just one point which was not on St Mary's island. OSGM15 is fitted to two new points on St Mary's island and is therefore more closely aligned to the local datum. This has resulted in a height change of approximately 0.35m.

The OSTN15/OSGM15 model raw data format is unchanged and a new transformation software utility has been produced. The utility and transformation raw data files can be downloaded from Ordnance Survey's web site. The transformation utility is open source so the source code can be downloaded also.

As well as being delivered in a projected 1km square grid format, OSTN15 is also available in the popular NTv2 format (latitude, longitude graticule). A version of OSTN15/OSGM15 is also being developed for delivery via the RTCM 3 Transformation Message protocol, messages (1021 to 1027).

A comprehensive article on the new models is available on the OS web site at:

https://www.ordnancesurvey.co.uk/docs/gps/Updated transformations for UK and Ireland - Geomatics World copy.pdf

2 BIGF – NERC British Isles continuous GNSS Facility

BIGF is operated from the University of Nottingham, and is funded by the UK Natural Environment Research Council (NERC). BIGF archives quality-assured RINEX data and creates derived products, based on a network of continuous GNSS stations sited throughout the British Isles. This network includes the active stations of OSGB plus those of Leica Geosystems, Ordnance Survey Ireland and Ordnance Survey Northern Ireland. It also includes a number of 'scientific' stations established by: the UK Met Office; the University of Nottingham; the UK Environment Agency Thames Region; the NERC Space Geodesy Facility; Newcastle University; and the University of Hertfordshire, with the University of Nottingham's contribution being carried out in collaboration with the NERC National Oceanography Centre, Liverpool and the NERC British Geological Survey. Fig. 3 shows the current network of around 150 continuous GNSS stations, which includes three stations (HERS, HERT, MORP) that are part of the IGS, and 21 stations (ADAR, ARIS, BELF, CHIO, CSTB/CASB, DARE, EDIN, ENIS, FOYL, HERS, HERT, INVR, LERI, MORP, NEWL, PMTH, SCIL, SHOE, SNEO, SWAS, TLLG) that are part of the EPN. In addition, ten stations at tide gauges (ABER, DVTG, LWTG, LIVE, LOWE, NEWL, NSTG/NSLG, PMTG, SHEE, SWTG) are included in the IGS TIGA Project, and all stations are included in the EUMETNET (Network of European Meteorological Services) GNSS water vapour programme (E-GVAP).

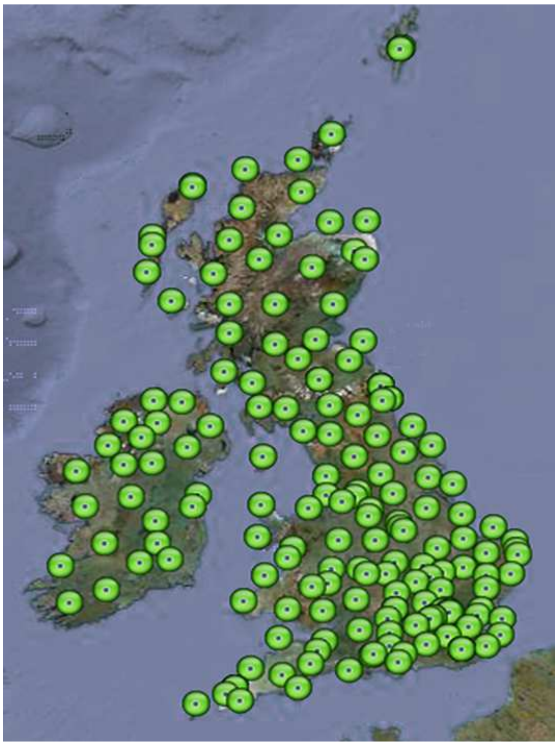

Fig. 3 The BIGF Network 2017

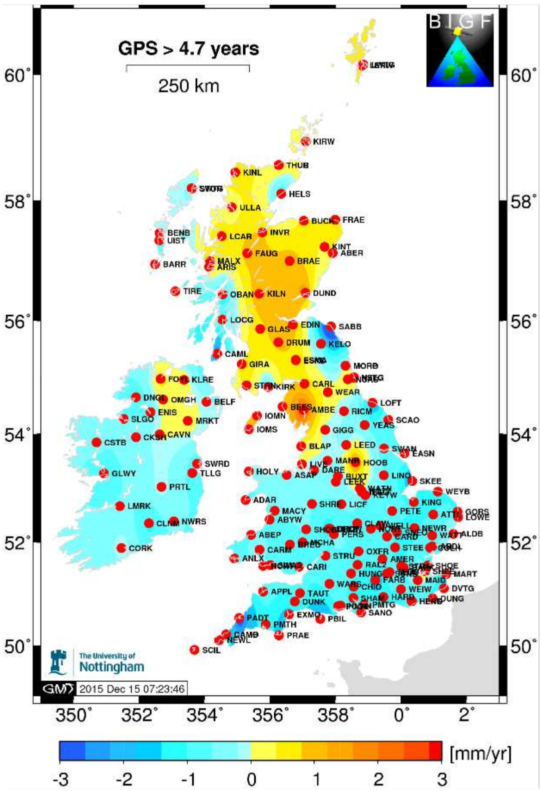

Fig. 4 Map of current vertical station velocities at 162 CGPS stations in the UK, based on CGPS measurements for the period from 1997 to 2015:273.

Quality assured RINEX data and derived products can be requested from www.bigf.ac.uk. Cumulative demand on the archive from 1998/9 to 2016/17 was approximately 15,297k station-days (41,880 station-years), comprising approximately 8,170k stations-days (22,368 station-years) of 30 second data, 71k station-days (195 station-years) of 1Hz data and 7,055k station-days (19,316 station-years) of derived products, with the 1Hz data and the derived products having been available for 6 years now and with a broadening of the science annually making use of the archive, such as ongoing studies of land movement and sea level, e.g. Bradshaw et al. (2016), and atmospheric work in both the ionosphere and troposphere, e.g. Ahmed et al (2016), facilitated by both historic data and ongoing hourly and daily data from this dense network.

BIGF's derived products include re-processed station coordinates and velocities, near real-time tropospheric parameters (15 minute estimates of zenith total delay, zenith wet delay and integrated water vapour) and re-processed tropospheric parameters, and are aimed at facilitating the scientific research of non-GNSS specialists. The most recent BIGF map of current vertical station velocities is shown in Fig. 4.

This map is based on a re-processing of data from 1997 to 2015:273 with Bernese Software version 5.2, connecting the BIGF network to the IGB08 via a global network of reference stations, and using C13 (CODE repro2/repro_2013) re-analysed satellite orbit and earth orientation parameter products; mitigation of 1st and higher order (2nd and 3rd order and ray bending) ionospheric effects; a-priori modelling of troposphere effects using VMF1G and mitigation using zenith path delay and gradient parameters; I08.ATX models for antenna phase centre variations; and models for Solid Earth tides, ocean tidal loading and atmospheric tidal loading that are consistent with IERS (2010) conventions.

In addition to EPN, IGS TIGA and E-GVAP, examples of research projects using BIGF quality-assured 30 second data in 2016/17 (UK unless otherwise stated) are:

- Cranfield University - [PhD] Soil erosion control using cover crops in maize.
- Istituto Nazionale Geofisica Vulcanologia (Italy) -Crustal deformation of the European Plate and its boundaries.

- Met Office - Near real-time atmospheric water vapour for numerical weather prediction in the UK.
- National Institute of Information and Communications Technology (Japan) - Ionospheric research using total electron content over Europe.
- NERC British Geological Survey - Geophysical tomography - Monitoring landslide at Hollin Hill.
- NERC Space Geodesy Facility - South baseline comparison at the NERC Space Geodesy Facility, and of other baselines.
- Orkney Research Centre for Archaeology - Yesnaby Art & Archaeology Research Project.
- Royal Observatory of Belgium (Belgium) - Densification of European Permanent GNSS Network for ionospheric studies.
- University of Luxembourg (Luxembourg) - The potential of precipitable water vapour measurements from GNSS in Luxembourg.
- University of Nevada, Reno (USA) - Towards a global ambiguity resolved precise point solution and time series.
- University of Wales, Bangor - SEACAM - Wind turbine effects on the marine habitat.
- University of Wales, Bangor - SEACAM - To test the functionality of our multi beam sonar head.
- Wuhan University, China - GPS/GLONASS precise point positioning and undifferenced ambiguity resolution.

Examples of research projects using BIGF quality-assured 1Hz data in 2016/17 (UK unless otherwise stated) are:

- Imperial College London - [PhD] A novel GNSS-based positioning system to support railway operations.
- NERC National Oceanography Centre, Liverpool - Proof of concept: use of GPS reflection measurements for tide gauge levelling.
- Newcastle University - [PhD] Multipath mitigation for GPS and GLONASS with application in earthquake and tsunami early warning.
- Newcastle University - GNSS Wave Glider: A new tool for sea level and sea state measurement.
- Newcastle University - [PhD] Integrity and reliability analysis of PPP ambiguity resolution.
- University College London – Hopscotch.
- University of Luxembourg (Luxembourg) - GNSS-multipath reflectometry.
- University of Nottingham - [PhD] Assessment of the accuracy and the contribution of multi-GNSS in structural monitoring.
- University of Nottingham (for ESA) - Validation and implementation of direct tropospheric slant delay estimation for precise real-time positioning.
- University of Oxford - 1 Year, 1000km: The Oxford RobotCar Dataset (GNSS Ground Truth).
- University of Southampton - [PhD] Development of 4D Chirp.

Examples of research projects using BIGF derived products in 2016/17 (UK unless otherwise stated) are:

- GeoEnergy Research Centre (GERC), University of Nottingham - [PhD] Application of satellite InSAR data in the assessment of ground motion in areas of historic mining to aid environmental and resource management.
- NERC British Geological Survey - Environmental baseline monitoring project.
- NERC British Geological Survey - Assessing the feasibility of a National InSAR ground deformation map of Great Britain with Sentinel-1 data.
- Scripps Institution of Oceanography (USA) - [PhD] Terrestrial water storage anomalies as estimated using GPS and GRACE observations.
- University of Hertfordshire - Aerosol and Clouds Consortium - cirrus climatology from ground-based remote sensing.
- University of Nottingham - [PhD] Monitoring ground deformation patterns at London and Thames Estuary area from 2002 to 2009 by using ISBAS DInSAR results.
- University of Nottingham - Evaluate peatland sensitivity to global change (BIGF product suitability testing).

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3 Newcastle University

3.1 Techniques in Global Navigation Satellite Systems and Synthetic Aperture Radar

Peppa et al. (2016) fused GNSS and inertial sensor observations to position an unmanned aerial vehicle used for landslide detection and monitoring at Hollin Hill, northern England.

Li et al. (2016b) provided a review of the opportunities afforded by the new Sentinel-1 satellites, in particular the reduction in ground track repeat time that will take place once the constellation is complete.

3.2 National and international geodetic networks

Newcastle University has continued to contribute to the International GNSS Service as an Associate Analysis Centre, providing daily and weekly global coordinate combinations in parallel with the official IGS product. We continue to operate IGS sites 'MORP' (Morpeth, England) and 'ROTH' (Rothera, Antarctica) and TIGA site 'NSLG' (North Shields Tide Gauge, England). MORP and NSLG both contribute to the NERC 'BIG F' data repository www.bigf.ac.uk; the former is also part of the EUREF Permanent Network.

3.3 Glaciological and cryospheric geodetic applications

Nield et al. (2016) showed how uncertainties in ice sheet history and ice stream stagnation could cause significant variations in present-day bedrock uplift rates along the Siple Coast of west Antarctica. Martín-Español et al. (2016) assessed the range of forward and inverse models of glacial isostatic adjustment (GIA) across Antarctica, and their effect on the inference of present-day ice mass changes from GRACE gravity products.

In the UK, Murray, Stockamp et al. (2016) reviewed the observational datasets and models relating to GIA in the British Isles.

3.4 Geodetic measurement of tectonic strain

Liu et al. (2016) used InSAR to study the time-dependent post-seismic motion following the 2009 Dachaidan (China) earthquake, and thence to infer the viscosity of the lower crust in this region. Wang et al. (2016) also used InSAR to observe a 17-year earthquake sequence under the Tibetan plateau, and to investigate the extent to which Coulomb stress triggering governed this sequence.

Amouzgar et al. (2016) used fault slip models of the 2011 Tohoku earthquake, derived from GPS, within a highly-efficient numerical model of tsunami propagation optimised for use on Graphical Processing Units (GPUs).

3.5 Other geodetic deformation monitoring

Tomás & Li (2017) provided a review of the suite of Earth Observation data including InSAR, which could be applied to monitoring efforts and scientific investigations into geohazards, as part of a special issue of Remote Sensing that they co-edited. Dai et al. (2016) used Sentinel-1 InSAR to monitoring the Daguangbao mega-landslide in China, whereas Chen et al. (2016) used InSAR to study groundwater extraction subsidence in Beijing. Zhou et al. (2016) also used InSAR imagery, to observe peat subsidence related to carbon emissions in Indonesia.

3.6 Atmospheric studies in geodesy

Yu et al. (2017) developed a procedure to generate high-resolution tropospheric water vapour models from GPS data, which could be used in near-real-time to correct InSAR measurements.

3.7 Other geodetic applications

Sadeq et al. (2016) used RTK GNSS to validate high-resolution digital surface models (DSMs) in an urban area (Glasgow), and demonstrated the superiority of a Bayesian probabilistic approach to merging DSMs derived from different sources of high-resolution satellite imagery. Li et al. (2016a) performed a similar validation exercise on medium-resolution global digital elevation models (DEMs) available in mainland China, and showed that significant negative biases exist here for all such global DEMs.

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