National Report of Great Britain 2016

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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.

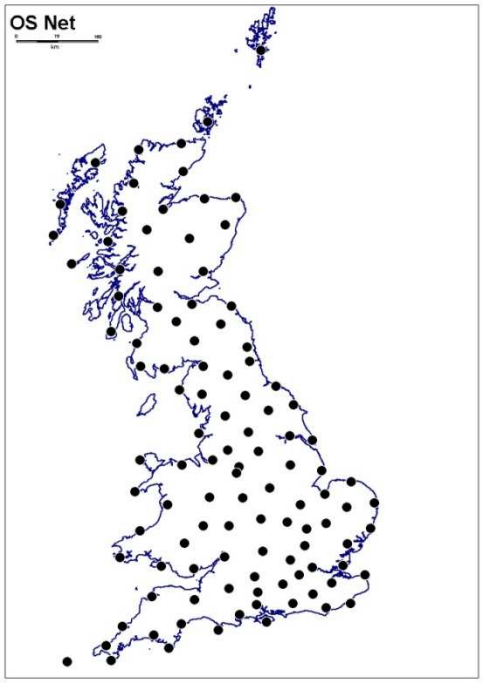

Fig. 1 OS Net GNSS Network

1.2 EPN data submissions

Current EPN submissions from GB are hourly data from HERS, HERT (run by the Natural Environment Research Council, NERC) and MORP (run by Newcastle University) and now also files from DARE, INVR (OS Net stations, previously 24 hour files). Station NEWL (run by University of Nottingham) contributes 24 hour files. Soon additional stations that were part of the ITRF2014 solution will be included in the EPN data

submission : SHOE, SWAS, SNEO, PMTH, CHIO, ADAR, ARIS, LERI, STRN, EDIN, SCIL.

RTCM 3.0 data from EPN stations DARE, INVR and from OS Net station SHOE are streamed in real time via NTRIP. This is in addition to RTK data from HERT.

1.3 Geoid and transformation model improvement

A collaboration between Ordnance Survey (GB), Ordnance Survey Ireland and Land & Property Services Northern Ireland has resulted in an improved geoid model across the United Kingdom and Ireland region.

The model raw date format is unchanged and a new transformation software utility has been produced. The utility can be downloaded from https://bitbucket.org/PaulFMichell/gridinquestii. The utility is open source so the source code can be downloaded also.

National CORS ETRS89 coordinates, aligned to the EUREF IE/UK 2009 campaign will be updated and the new model will go live at the end of August 2016.

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. Figure 2 shows the current network of over 150 continuous GNSS stations, which includes three stations (HERS, HERT, MORP) that are part of the IGS, and eleven stations (BELF, CSTB/CASB, DARE, ENIS, FOYL, HERS, HERT, INVR, MORP, NEWL, 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).

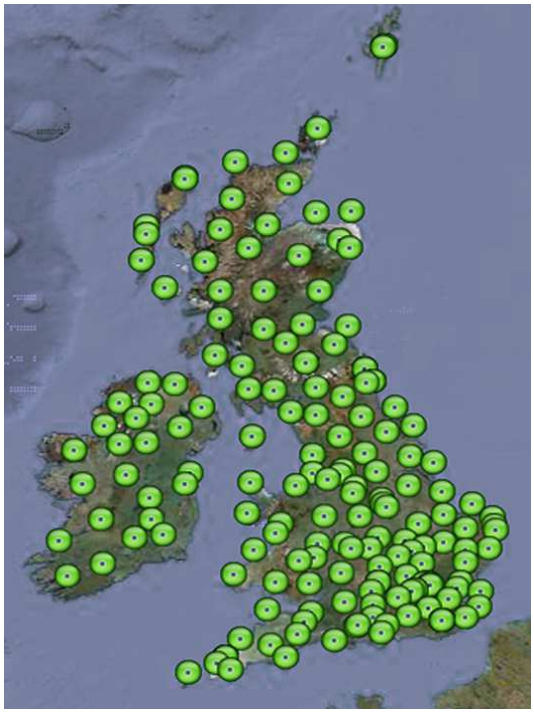

Fig. 2 The BIGF Network 2016

Quality assured RINEX data and derived products can be requested from www.bigf.ac.uk. Cumulative demand on the archive from 1998/9 to 2015/16 was approximately 12,173k station-days (33,328 station-years), comprising approximately 6,687k station-days (18,308 station-years) of 30 second data, 60k station-days (164 station-years) of 1Hz data, and 5,426k station-days (14,856 station-years) of derived products, with the 1Hz data and the derived products having been available for 5.5 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. Tamisiea et al (2014) and 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 Figure 3.

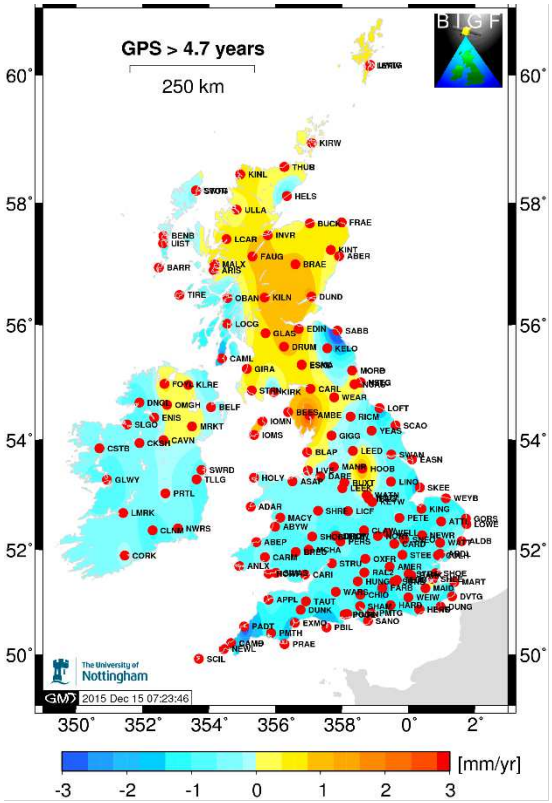

Fig. 3 Map of current vertical station velocities at 162 CGPS stations in the UK, based on CGPS measurements for the period from 1997 to 2015:273

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 data in 2015/16 (UK unless otherwise stated) are:

- Collecte Localisation Satellites (France) - Study on the effects of solar activity on ECAC (European Civil Aviation Conference) zone.
- Cranfield University - Acoustic Doppler current profiler positioning near river engineering structures.
- Defra, Rural Payments Agency - Post processing of farm inspections data by RPA field surveyors to meet the Common Agricultural Policy regulations.
- ETH Zurich (Switzerland) - Monitoring surface deformation in Europe.
- Finnish Geospatial Research Institute (Finland) - 3D spectral reflectance measurement of forest canopies by UAV imaging and passive and active terrestrial measurements for the purposes of improving the estimation of essential climate variables (ECVs).
- Imperial College London - A novel GNSS-based positioning system to support railway operations.
- Imperial College London - High accuracy GNSS processing for a road vehicle.
- Lancaster University - Piloting a cost effective framework for monitoring soil erosion in England and Wales using terrestrial laser scanning, close range photography, and UAV aerial photography.
- Los Alamos National Laboratory (USA) - Understanding atmospheric and ionospheric response to hypersonic objects in the atmosphere.
- National Institute of Information and Communications Technology (Japan) - Ionospheric research using total electron content over Europe.
- NERC British Geological Survey - Geophysical tomography to monitor landslide movement.
- NERC British Geological Survey - Mapping landslide movement using a GPS smart rover.
- NERC National Oceanography Centre, Liverpool - Proof of concept: use of GPS reflection measurements for tide gauge levelling.
- NERC Space Geodesy Facility - South baseline comparison at the NERC Space Geodesy Facility, and of other baselines.
- Newcastle University - Exploring the potential for precision nutrient management in China.

- Newcastle University - GNSS Wave Glider: A new tool for sea level and sea state measurement.
- Newcastle University – Multipath mitigation for GPS and GLONASS with application in earthquake and tsunami early warning systems.
- Plymouth University - Bathymetric data processing to assess the impact of extreme storm conditions in 2013/2014 on the southwest coast of England.
- Royal Observatory of Belgium (Belgium) - Densification of EUREF Permanent Network for ionospheric studies.
- Universitat Autonoma de Barcelona (Spain) - Advanced assistance services of high performance in harsh environments, part of Marie Curie Initial Training Network MULTI-POS.
- University College London - CARDyAL (Cooperative Aerodynamics and Radio-based DYnamic Animal Localisation).
- University of Bath - Space weather effects.
- University of Birmingham - Geophysical methods for identifying streambed structural heterogeneity and implications for groundwater - surface water exchange flow.
- University of California, San Diego (USA) - GNSS high precision data processing.
- University of California, San Diego (USA) - GNSS seismology: investigate how GNSS can contribute to an early warning system.
- University of Highlands and Islands, Millenium Institute. Investigation of remote Viking sites in Shetland for a BBC television program.
- University of Leeds - Strain-rates of crustal deformation in the Betics-Rif ranges (Gibraltar arc).
- 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 Nottingham - Design, develop and implement an advanced mobile scanning system to monitor railway, road and mining infrastructure.
- University of Nottingham - Investigating the effect of constellation geometry on precise point positioning.
- University of Nottingham - Severn Bridge deformation project.
- University of Oxford - EUROPA2 - European Robotic Pedestrian Assistant 2.0.
- University of Wales, Bangor - Assessing the rate of coastal erosion along an exposed, northwest facing glacially derived cliff-line using terrestrial laser scanning.
- University of Wales, Bangor - Evolution of the Menai Strait.
- University of Wales, Bangor - Monitoring the effects of storms on a lagoon backed shingle barrier system using terrestrial laser scanning.

Examples of research projects using BIGF derived products in 2015/16 (UK unless otherwise stated) are:

- Environment Agency, Flood and Coastal Risk Management (FCRM) - Land level change for the Thames region possible implications for the Thames Estuary 2100 plan.
- Imperial College London - A novel GNSS-based positioning system to support railway operations.
- Los Alamos National Laboratory (USA) - Understanding atmospheric and ionospheric response to hypersonic objects in the atmosphere.
- NERC Space Geodesy Facility - Inter-technique comparison of coordinate time series as Herstmonceaux examining thermal expansion effects.
- University of Glasgow/Newcastle University - Is Glacial Isostatic Adjustment continuing in Scotland?
- University of Hertfordshire - Aerosol and Clouds Consortium - cirrus climatology from ground-based remote sensing.
- University of Nottingham/University of Birmingham - Earthquake analysis feasibility study: analysing long term time series to identify changes in patterns due to earthquake events.
- University of Nottingham - Investigating the effect of constellation geometry on precise point positioning.
- University of Nottingham - Monitoring ground deformation patterns at London and Thames

Estuary area from 2002 to 2009 by using ISBAS DInSAR results.

• University of Nottingham - Validation and implementation of direct tropospheric slant delay estimation for precise real-time positioning.

References

Ahmed, F., Vaclavovic, P., Teferle, F.N., Dousa, J., Bingley, R.M., and Laurichesse, D (2016). Comparative analysis of real-time precise point positioning zenith total delay estimates. GPS Solutions, 20(2), pp 187-199, DOI 10.1007/s10291-014-0427-z.

Bradshaw, E., Woodworth, P.L., Hibbert, A., Bradley, L.J., Pugh, D.T., Fane, C., and Bingley, R.M (2016). A century of sea level measurements at Newlyn, SW England. Marine Geodesy, 39(2), pp 115-140, DOI: 10.1080/01490419.2015.1121175,.

Tamisiea, M.E., Hughes, C.W., Williams, S.D.P., and Bingley, R.M (2014). Sea level: measuring the bounding surfaces of the ocean. Philosophical Transactions of the Royal Society Series A: Mathematical, Physical, and Engineering Sciences, 372: 20130336, DOI 10.1098/rsta.2013.0336.

3 Newcastle University

3.1 Global Navigation Satellite Systems positioning

[Palamartchouk et al. 2015] examined the use of dual-polarisation GNSS observations for the detection and resulting mitigation of multipath in carrier phase GNSS positioning.

[Morales Maqueda et al. 2016] have applied Precise Point Positioning techniques to GPS data from a wave glider, and shown that it is able to detect short-wavelength variations in water surface topography and the geoid.

[Webb 2015] used a unique kinematic GPS+GLONASS dataset gathered on a repeated trajectory through nearly 1 km altitude range to test the positioning accuracy of kinematic multi-GNSS; this dataset is available online [Webb et al., 2015].

[Penna et al. 2015] used continuous GPS data from across western Europe to demonstrate the ability to recover harmonic displacements at semi-diurnal tidal periods with ~0.2 mm accuracy, and in doing so showed the need to estimate residual tropospheric zenith delays simultaneously with these sub-daily position variations, contrary to previous studies elsewhere.

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

[Andrews et al. [2015] developed and validated a mascon approach for the recovery of basin-scale Antarctic ice mass trends from GRACE range-rate data.

[Martín-Español et al. 2016] reprocessed continuous and campaign GPS data from across Antarctica and assimilated this along with ice sheet altimetry and GRACE gravity products to obtain an empirical model of glacial isostatic adjustment and present-day ice mass change for the continent.

In Greenland, [Murray, Selmes et al. 2015] and [Murray, Nettles et al. 2015] used data from a semi-autonomous network of low-cost GPS receivers temporarily installed on the Helheim Glacier to infer the dynamics of iceberg calving episodes.

3.4 Geodetic Measurement of Tectonic Strain

[Feng et al. 2016], [Li, Shen et al. 2016], [Lin et al. 2015] and [Li, Feng et al. 2015] used InSAR to observe co-seismic and inter-seismic strain associated with fault movements at locations in Nepal, Pakistan and USA.

3.5 Other Geodetic Deformation Monitoring

[Dai et al. 2015)], [Li, Zhang et al. 2016] and [Liu et al. 2016] used InSAR imagery to observe vertical land motion associated with hydrocarbon extraction in China.

[Featherstone et al. 2015] used GPS to investigate local subsidence associated with groundwater extraction near to the tide gauge at Fremantle, Australia.

[Tomás et al. 2015] used InSAR observations to identify the triggering factors of landslides with the assistance of wavelet tools.

[Bos et al. 2015] used the GPS tidal harmonic displacement estimation method developed by [Penna et al. 2015] and applied it to a 259-site network of continuous GNSS receivers spanning western Europe (many of them being EUREF Permanent Network sites). They showed that modelling of ocean tide loading (OTL) using a standard elastic Earth model derived from seismology, such as PREM, leads to residual vertical errors at the dominant M2 period of up to several millimetres around the British Isles and near the Atlantic coasts of continental Europe. These errors, which cannot be explained by plausible ocean tide model uncertainties, can be reduced to below the noise floor if anelastic dispersion in the asthenosphere is incorporated into the Earth response model.

3.6 Synthetic Aperture Radar (SAR) data processing

[Du et al. 2015] reviewed two advanced machine learning methods for polarimetric SAR image classification, and showed distinct advantages of the Random Forest approach.

3.7 Satellite Laser Ranging (SLR) analysis

[Spatar et al. 2015] examined the sensitivity of SLR solutions to the geocentre coordinates, and showed that the inclusion of Stella, Starlette, Ajisai and LARES (but not Etalon) data in addition to LAGEOS could improve the ability of SLR to sense geocentre motion.

3.8 Atmospheric studies in geodesy

[Lu et al. 2016] developed a procedure to employ static multi-GNSS to precisely retrieve high-resolution tropospheric gradients.

References

Andrews SB, Moore P, King MA (2015). Mass change from GRACE: a simulated comparison of Level-1B analysis techniques. Geophysical Journal International, 200(1), 503-518. doi:10.1093/gji/ggu402

Bos MS, Penna NT, Baker TF, Clarke PJ (2015). Ocean tide loading displacements in western Europe: 2. GPS-observed anelastic dispersion in the asthenosphere. Journal of Geophysical Research: Solid Earth, 120(9), 6540-6557. doi:10.1002/2015JB011884

Dai K, Liu G, Li Z, Li T, Yu B, Wang X, Singleton A (2015). Extracting Vertical Displacement Rates in Shanghai (China) with Multi-Platform SAR Images. Remote Sensing, 7(8), 9542-9562. doi:10.3390/rs70809542

Du P, Samat A, Waske B, Liu S, Li Z (2015). Random Forest and Rotation Forest for fully polarized SAR image classification using polarimetric and spatial features. ISPRS Journal of Photogrammetry and Remote Sensing, 105, 38-53. doi:10.1016/j.isprsjprs.2015.03.002

Featherstone WE, Penna NT, Filmer MS, Williams SDP (2015). Nonlinear subsidence at Fremantle, a long-recording tide gauge in the Southern Hemisphere. Journal of Geophysical Research: Oceans, 120(10), 7004-7014. doi:10.1002/2015JC011295

Feng W, Lindsey E, Barbot S, Samsonov S, Dai K, Li P, Li Z, Almeida R, Chen J, Xu X (2016, online). Source characteristics of the 2015 MW 7.8 Gorkha (Nepal) earthquake and its MW 7.2 aftershock from space geodesy. Tectonophysics, in press. doi:10.1016/j.tecto.2016.02.029

Li Y, Feng W, Zhang J, Li Z, Tian Y, Jiang W, Luo Y (2015). Coseismic slip of the 2014 Mw 6.1 Napa, California earthquake revealed by Sentinel-1A InSAR. Chinese Journal of Geophysics - Chinese Edition, 58(7), 2339-2349. doi: 10.6038/cjg20150712

Li Y, Shen W, Wen Y, Zhang J, Li Z, Jiang W, Luo Y (2016). Source parameters for the 2015 Nepal earthquake revealed by InSAR observations and strong ground motion simulation. Chinese Journal of Geophysics - Chinese Edition, 59(4), 1359-1370. doi:10.6038/cjg20160417

Li Y, Zhang J, Li Z, Luo Y, Jiang W, Tian Y (2015, online). Measurement of subsidence in the Yangbajing geothermal fields, Tibet, from TerraSAR-X InSAR time series analysis. International Journal of Digital Earth, in press. doi:10.1080/17538947.2015.1116624

Lin NY, Jolivet R, Simons M, Agram PS, Martens HR, Li Z, Lodi SH (2015). High interseismic coupling in the Eastern Makran (Pakistan) subduction zone. Earth and Planetary Science Letters, 420, 116–126. doi:10.1016/j.epsl.2015.03.037

Liu P, Li Q, Li Z, Hoey T, Liu G, Wang C, Hu Z, Zhou Z, Singleton A (2016). Anatomy of Subsidence in Tianjin from Time Series InSAR. Remote Sensing, 8(3), 266-288. doi:10.3390/rs8030266

Lu C, Li X, Li Z, Heinkelmann R, Nilsson T, Dick G, Ge M, Schuh H (2016). GNSS tropospheric gradients with high temporal resolution and their effect on precise positioning. Journal of Geophysical Research: Atmospheres, 121(2), 912-930. doi:10.1002/2015JD024255

Martín-Español A, Zammit-Mangion A, Clarke PJ, Flament T, Helm V, King MA, Luthcke SB, Petrie E, Remy F, Schön N, Wouters B, Bamber JL (2016). Spatial and temporal Antarctic ice sheet mass trends, glacio-isostatic adjustment and surface processes from a joint inversion of satellite altimeter, gravity and GPS data. Journal of Geophysical Research: Earth Surface, 121(2), 182-200. doi:10.1002/2015JF003550

Morales Maqueda MA, Penna NT, Williams SDP, Foden PR, Martin I, Pugh J (2016, online). Water surface height determination with a GPS Wave Glider: a demonstration in Loch Ness, Scotland. Journal of Atmospheric and

Oceanic Technology, in press. doi:10.1175/JTECH-D-15-0162.1

Murray T, Nettles M, Selmes N, Cathles LM, Burton JC, James TD, Edwards S, Martin I, O'Farrell T, Aspey R, Rutt I, Bauge T (2015). Reverse glacier motion during iceberg calving and the cause of glacial earthquakes. Science, 349(6245), 305-308. doi:10.1126/science.aab0460

Murray T, Selmes N, James TD, Edwards S, Martin I, O'Farrell T, Aspey R, Rutt I, Nettles M, Bauge T (2015). Dynamics of glacier calving at the ungrounded margin of Helheim Glacier, southeast Greenland. Journal of Geophysical Research: Earth Surface, 120(6), 964-982. doi:0.1002/2015JF003531

Palamartchouk K, Edwards SJ, Clarke PJ (2015). Dual-polarization GNSS observations for multipath mitigation and better high precision positioning. Proceedings of the 28th International Technical Meeting of the ION Satellite Division, ION GNSS+ 2015, Tampa, Florida, 2772-2779.

Penna NT, Clarke PJ, Bos MS, Baker TF (2015). Ocean tide loading displacements in western Europe: 1. Validation of kinematic GPS estimates. Journal of Geophysical Research: Solid Earth, 120(9), 6523-6539. doi:10.1002/2015JB011882

Spatar CB, Moore P, Clarke PJ (2015). Collinearity assessment of geocentre coordinates derived from multi-satellite SLR data. Journal of Geodesy, 89(12), 1197-1216. doi:10.1007/s00190-015-0845-x

Tomás R, Li Z, Lopez-Sanchez JM, Liu P, Singleton A (2015, online). Using wavelet tools to analyse seasonal variations from InSAR time-series data: a case study of the Huangtupo landslide. Landslides, in press. doi:10.1007/s10346-015-0589-y

Webb SR (2015). Kinematic GNSS tropospheric estimation and mitigation over a range of altitudes. PhD thesis, Newcastle University. Available online at http://hdl.handle.net/10443/2823

Webb SR, Penna NT, Clarke PJ (2015). Snowdon Mountain Railway Global Navigation Satellite Systems (GNSS): repeatable kinematic dataset collection from Snowdonia. Centre for Environmental Data Archival, 06 September 2015. doi:10.5285/AEE6A3D7-A5F7-41D5-85D8-BEB5640E5AFB

Webb SR, Penna NT, Clarke PJ, Webster S, Martin I, Bennitt GV (2016). Kinematic GNSS estimation of zenith wet delay over a range of altitudes. Journal of Atmospheric and Oceanic Technology, 33(1), 3-15. doi:10.1175/JTECH-D-14-00111.1