A Performance Evaluation – Trimble GeoXH 6000 vs. Leica Viva GS15 Professional

31 August and 01 September 2013

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1) Introduction

In the UK G&J Surveys carry out hill surveys using Leica Geosystems survey equipment. This equipment carries out two functions, firstly to identify summit or col positions and secondly to measure their absolute heights. Summit and col positions are identified using an automatic optical level (Leica NA730 or Leica Runner 20) set up on a tripod so that measurements can be made from a 1m, extendable to 5m, staff. The absolute height measurements are then made using a Leica Viva GS15 Professional GNSS (Global Navigation Satellite System) held in a supportive tripod system. The total amount of equipment needed to carry out a full survey is extensive, and in addition to other equipment needed to support us for a day on the mountains, requires two to three people to carry it.

In Ireland, Mountain Views carry out surveys using John Fitzgerald's Trimble GeoXH 6000 GNSS receiver. This is a very compact receiver that can be easily carried on a belt. It is lightweight and about 5 times the size of a small handheld Garmin GPS receiver. This instrument has been giving excellent results with a claimed accuracy for height measurements of better than 0.1m. This accuracy is far superior to the information we had received from other sources for this instrument. One of the reasons why people from MountainViews were visiting us was so that we could evaluate the two instruments under the same operating conditions and therefore draw firm conclusions about their relative merits.

Over the two days a number of different points, about 20 in total, which posed a variety of conditions, were surveyed. The area chosen comprised the hills at the eastern end of the Lleyn Peninsular in North Wales and covered Bwlch Mawr, Craig Cae Hir, Yr Eifl, Tre'r Ceiri and Mynydd Carnguwch. None of these hills, perhaps with the exception of Mynydd Carnguwch, which is a HuMP with 104m of drop, were surveyed for any other survey reason other than equipment comparison. This area was also very convenient for its close proximity to where the various teams were located.

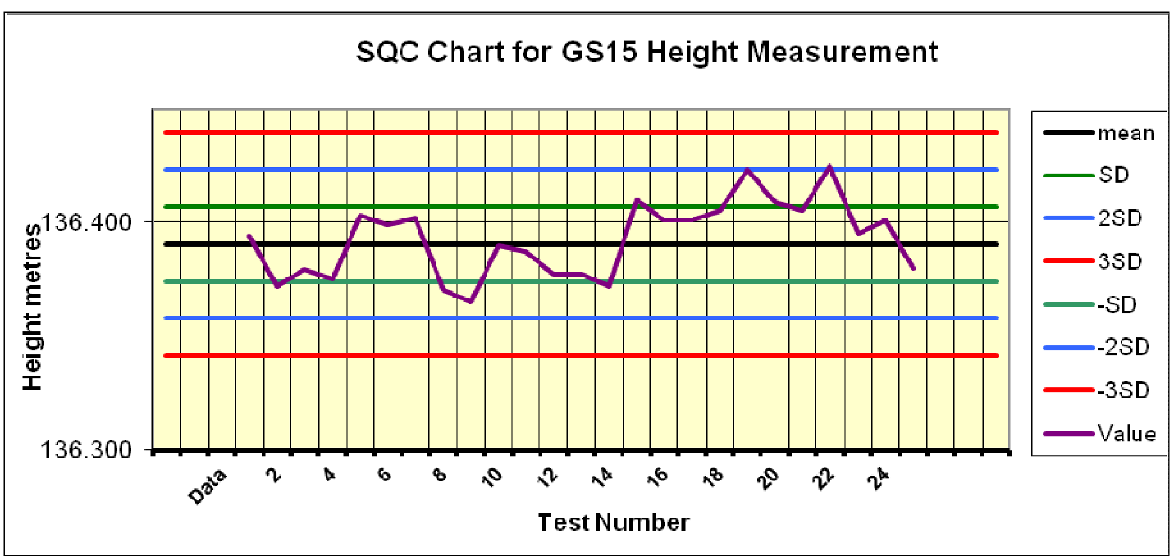
Subsequent to these surveys Myrddyn Phillips has purchased a Trimble GeoXH6000 for his own use that is accessible to the G&J Survey's team. All members of G&J Surveys then attended a training day where Martyn Palmer, the representative acting on behalf of KOREC UK (distributors of Trimble products), educated us in the details of the machine and its post processing software. This allowed us to achieve a much greater insight into the differences between a "mapping" grade instrument like the GeoXH 6000 and survey grade GNSS instruments.

2) <u>Equipment used for Survey Comparison</u>

2.1) Leica Viva GS15 Professional

The Leica Viva GS15 Professional is the latest top of the range GNSS (Global Navigation Satellite System) receiver supplied by Leica Geosystems and has been on the market now for about 2 years. This is a dual-frequency, multi-channel instrument, which means it can lock on to available GPS (Global Position System USA) satellites and GLONASS (Russian) satellites and receive two signals (at different frequencies) from each of these satellites if transmitted. The latter feature reduces inaccuracies that result from atmospheric degradation of the satellite signal. As a stand-alone instrument it is capable of giving position and height to an accuracy of about two metres and five metres respectively. Note that a hand-held GPS receiver can only receive up to 12 GPS satellites and each at a single frequency and therefore it has a poorer positional accuracy of +/-5m and a height accuracy of no better than 10 metres. Some recently produced hand held GPS Garmin receivers can also receive signals from GLONASS satellites which greatly improve the speed at which these units can achieve a satellite "fix". Despite the on-board features of the Viva GS15 receiver, there are still sources that create residual errors. To obtain accurate positions and heights, corrections are made to the data via imported RINEX files available from Ordnance Survey which can then be post-processed using Leica Geo Office software – latest version 8.3.

We regularly check the functioning of the Leica Viva GS15 against Statistical Quality Control (SQC) charts generated for a marked position. The chart associated with height measurement is shown below. The mean height above Ordnance Datum Newlyn (ODN) for a fixed point (measured on 20 different occasions for 30mins of data collection at each time) was calculated to be 136.391m. Further height measurements have been made at this point on separate occasions over a period of 30 months using the same process parameters. The last and penultimate measurements were carried out after and before the mountain surveys described in this report. The results shown on the graph are all within a range of +/- two SD (Standard Deviation), in this case one SD is +/-0.016m. This demonstrates that our Leica Viva GS15 receiver is giving consistently precise results within the expected range of uncertainty for the measurements.



In addition, we check the instrument periodically by taking measurements on an Ordnance Survey Fundamental Bench Mark, processing the data and comparing it with the OS derived values. Height should agree to within about 0.05m. The latest two measurements are given in the table below.

Processing	**Height(m)**
OS measurement	73.24
JB/GVJ GeoOffice 7	73.22
JB/GVJ GeoOffice 7	73.22

2.2) Trimble GeoXH 6000

Trimble is a USA company that offers a range of specialist GNSS surveying equipment. The GeoXH 6000 is a compact GNSS multichannel receiver that can either be used as a standalone instrument, since it has an inbuilt antenna, or it can be used with an external antenna mounted on a fixed pole as per a conventional GNSS rover system. The key point about this instrument is that it is lightweight and can be easily carried on a waist belt and operated by one person. Therefore it makes it a very useful instrument to take on the hills and with very little effort can be carried at all times. Trimble classes this as a "mapping" rather than a "survey" grade instrument and this distinction is made to reflect the designed use for the instruments. Typically a "mapping" instrument might be used by a non-surveyor operator who wants to obtain a large number of survey results quickly and be able to communicate them as information to others who will then act on the results. A typical example that Trimble quote where the GeoXH 6000 has proved to be very useful is in the accurate location of water pipes within towns so that leaks can be pinpointed quickly and repaired.

The basic technology is similar in all GNSS multi-channel receivers and the GeoXH 6000 can receive signals from both the GPS and GLONASS satellite systems. It can be operated in all the usual ways for a GNSS receiver. It has the capability to utilise SBAS (Satellite-Based Augmentation System). Globally this means a range of systems that are designed to improve the accuracy of GNSS. In Europe EGNOS (European Geostationary Navigation Overlay Service) consists of additional stationary satellites that are continually providing GNSS correction data in real time to the measurement instrument and the system is primarily focussed on the aviation industry. However, in real time with the GeoXH 6000 it should be possible to receive a positional accuracy of +/-0.3 to 0.5m which is far superior to that achieved with signals just from GPS and GLONASS satellites but not as good as RTK (Real Time Kinematic) surveying, where corrections are obtained in real time from a network of Base stations. (EGNOS corrections can also be received on most hand-held Garmin GPS units but the author's experience so far is that this seems to make very little difference to their accuracy).

During this evaluation we were using the GeoXH 6000 and its internal antenna for static GNSS surveys. Operation is very simple. The unit is switched on and placed directly on the point to be measured. Once the receiver has locked into the satellite systems a "horizontal error measurement" is displayed on the screen. When this reaches a figure of 0.1m or less, the receiver is then switched to log data. Typically data is logged for 2 to 5 minutes, but trials were also carried out logging 30 minutes of data. During this period it is important to stand away from the unit to prevent interference with the satellite signals. Once the data has been collected it is then post-processed on a PC using Trimble software (GPS Pathfinder Office) and imported RINEX correction data from Ordnance Survey Base stations – as per the Leica Viva GS15.

3) The Survey

3.1) Bwlch Mawr (SH426478 OS 1:50000 Maps 115/123) (Appendix 1 for photos)

Bwlch Mawr is classified as a Dewey, a hill between 500m and 609.6m in height with a prominence of at least 30m. There is no issue with this hill being a potential reclassification, as its drop and height place it clearly in Michael Dewey's list of hills. An extract from the 1:25000 OS map is shown below and there is a trig in the summit area marked with a spot height of 509m.

The map does not show the detail, but there is a distinct top about 150m south of the trig point and visually it is not clear which is the higher. We approached the hill along the footpath which runs in a South West direction from the minor road to the East. The lower slopes of the hill are fields set aside for grazing livestock. Above this, the hill is typical open moorland with heather, tussock grass and outcrops of rock and scree that become more numerous the nearer the summit of the hill.

We started the comparison of the two instruments in the first field adjacent to the West of the minor road. The purpose of the first test was to see if the GeoXH 6000 were capable of measuring accurately a number of points that differed in height by 1 to 2 metres. Four points, marked by flags, were chosen in a straight line up the hillside with an approximate height difference of 5m from the lowest to the highest. The Viva GS15 was set up on a 2.000m pole and supported by a Quickset tripod over the lowest point. Data were collected for 30 minutes with an epoch time of 15 seconds. Meanwhile, the GeoXH 6000 was placed in turn on each of the points where data were collected from 2 to 5 minutes. Finally the Leica NA730 optical level was set up on a tripod near the highest point and staff readings were taken from all the four points.

Point "1"	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	30	243757.934	347455.003	237.499
GeoXH 6000	3.6	243757.943	347454.727	237.527

Survey Points	Height measured by staff m	Absolute height GS15 m	Absolute height XH6000 m	Height difference m	No of readings (one per sec) XH6000	Vertical error XH6000
1	0.000	237.499	237.527	-0.028	217	0.1
2	1.466	238.965	239.342	-0.377	320	0.7
3	2.924	240.423	240.473	-0.050	145	0.1
4	4.367	241.866	241.893	-0.027	202	0.1

The results for the surveys of Points 1 to 4 are shown in the tables above. The first table gives a comparison of Viva GS15 and GeoXH 6000 data collected on the same point. The Easting, Northing and Height readings differ by 0.01m, 0.3m and 0.03m respectively. The second table shows the comparison of heights for the 4 points measured from Viva GS15/level and staff and GeoXH 6000. Apart from Point 2, agreement between the two sets of data is to 0.05m or better. Point 2 seems to be an anomaly as the height difference is 0.38m but the vertical error recorded just prior to measurement was 0.7m instead of 0.1m or less, and so the GeoXH 6000 was warning that an accurate result would not be obtained.

3.1.1) Bwlch Mawr South and North Tops

The survey team moved to Bwlch Mawr South Top. The Leica NA730 level was set up on a tripod at a convenient point away from the summit and adjusted so that its height was level with the South Top, a pointed rock. A staff reading positioned on the North Top showed it to be approximately 0.35m higher; an accurate reading was not possible because of the distance involved. A measurement was also taken on the South Top with the GeoXH 6000, Point 5, but not with the Viva GS15 and so an accurate comparison of the two instruments was not made for this point.

Point 5 South Top	Data collection time mins	Easting	Northing	Height(m)
GeoXH 6000	5.0	242639.046	347717.796	509.926

The Leica NA730 level was then set up at a convenient position near the summit of the North Top, whose position was then indentified as the top of a flat rock about 12m WNW of the trig point. A point was also chosen away from the summit where the Viva GS15 would be set up and staff readings were taken at this point, the summit of the hill and to the Flush Bracket on the trig point. The height of the Flush Bracket to the top of the trig point was measured with a tape to be 0.854m.

The Viva GS15 was set up on the "short tripod" system (tripod/tribrach/hook), recorded as "Leica Base", and the tape reading for the vertical offset was 0.435m. Data were collected for 30 minutes at an epoch time of 15 seconds.

A range of readings was taken with the GeoXH 6000; Point 6 the summit, Point 7 and 7.1 the top of the trig point and the "Leica Base"

"Leica Base"	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
Viva GS15	31	242663.090	347837.931	507.390
GeoXH 6000	3.4	242663.132	347837.954	507.427

Survey Points	**Height measured by staff and tape m**	**Absolute height GS15 m**	**Absolute height XH 6000 m**	**Height difference m**	**No of readings (one per sec) XH 6000**	**Vertical error XH 6000**
"Leica Base"	3.105	507.390	507.427	-0.037	202	0.1
6 (Summit)	0.146	510.349	510.373	-0.024	346	0.1
Flush Bracket	0.838	509.657	509.653	0.004		
7 (Top trig)	0.838-0.854= -0.016	510.511	510.537	-0.026	317	0.1
7.1 (Top trig)	0.838-0.854= -0.016	510.511	510.507	0.004	1964	0.1

The results are shown in the tables above. For the measurements taken at the "Leica Base" Eastings, Northings and Heights measurements agree to 0.02m, 0.04m and 0.04m respectively between the two survey instruments. Height agreement for Point 6 (the summit) and Point 7/7.1 are better than 0.03m. Two measurements were taken on the top of the trig point with the GeoXH 6000 to investigate the effect of a longer collection time. Point 7 is just over 5 minutes but point 7.1, in the same position on the top of the trig point, was for just under 33 minutes. At the longer collection time, the difference between the height measurements for the Viva GS 15 and GeoXH 6000 improved to just 0.004m, so therefore are in excellent agreement.

The OS database quotes the height of the Flush Bracket as 509.63m. The Viva GS15 and GeoXH 6000 measurements at 509.66m and 509.65m are in excellent agreement with the OS database; particularly as this trig point is an Order 3 measurement (Orders 1 and 2 are the most accurate).

3.2) Craig Cae Hir (SH430475 OS 1:50000 Maps 115/123) (Appendix 2 for photos)

Craig Cae Hir is a small excrescence approximately 500m SE of the summit of Bwlch Mawr. This can be seen on the map extract shown in the previous section for Bwlch Mawr, as a summit with a 490m spot height. About midway between the two summits is a broad and flat grassy bwlch. There was no compelling reason to survey the bwlch or summit of Craig Cae Hir other than the comparative evaluation of the two GNSS receivers.

3.2.1) Craig Cae Hir Bwlch

The bwlch for Craig Cae Hir is quite flat and its position would be visually difficult to identify although because of its flatness, several metres of positional error would probably make very little difference to vertical height. In order to identify the position of the bwlch, we carried out our standard procedure of taking automatic level and staff measurements from a grid of flags laid out across the bwlch area. In this case three rows of flags, each 10m apart, were laid out in the valley to valley direction. The highest point of each of these rows then represents the line of the bwlch in the hill to hill direction. Finally, the bwlch position was marked, and the Leica Viva GS15 setup with tripod support on a 2.000m pole over this point. Data were collected for 30mins with an epoch time of 30seconds.

Independently, John Fitzgerald, the operator of the GeoXH 6000 used his own method to locate the bwlch. This involved traversing the area systematically with the GeoXH 6000 switched to SBAS mode which gives the most accurate height readings in real time if RTK to Base stations is not available. Observation of the height measurements allows a picture of the shape of the bwlch to be visualised leading to an identification of its position. This procedure gave a position (point 8) about 15m NE of the point identified by the systematic survey with level and staff.

Bwlch	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
Viva GS15	32	242779.653	347560.975	471.697
GeoXH 6000	2.05	242779.797	347560.980	471.801
Point 8 (identified by JF)	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
GeoXH 6000	1.97	242790.041	347574.292	471.653

The results shown in the table above for the bwlch position show the Eastings, Northings and Vertical Height for the two instruments differing by 0.14m, 0.01 and 0.1m respectively. The height difference is greater than seen in most of the previous results but the vertical height error indicated by the GeoXH 6000 was recorded as 0.2m, so again a warning was being given that the result might not be as accurate as it could be. The bwlch position indentified by the GeoXH 6000, Point 8, is 15m from the bwlch and differs in height by 0.05m and 0.15m respectively from the Viva GS15 and GeoXH 6000 measurements. Unfortunately a staff reading was not taken at Point 8 to verify the exact height difference between Point 8 and the bwlch.

3.2.2) Craig Cae Hir Summit

The summit of Craig Cae Hir consists of a number of rocky outcrops. The Leica NA730 was set up on its tripod close to the one that appeared to be the highest and staff readings were taken from this and other possible highest points. In fact the actual summit was the top of a rock about 30m NW. On the ascent of this hill we passed over an intermediate point (Point 9) about 150m WNW of the summit but observation through the level showed this to be about 4m lower than the summit.

The Viva GS15 was set up on the short tripod/tribrach system (Vertical offset on tape = 0.443m) a few metres away from the summit having taken a staff reading at this point to measure the height difference between this point and the summit. Data were collected for 30minutes with an epoch time of 15 seconds.

Data were also collected with the GeoXH 6000 at the intermediate Point 9, the lower summit Point 10 and the summit Point 11. The results for the GNSS measurements are shown in the table below.

Point 9 (intermediate top)	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
GeoXH 6000	1.88	242870.099	347530.502	496.069
GS15 Set up position	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
Viva GS15	32	243011.517	347485.838	488.875
Point 10 (lower summit)	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
GeoXH 6000	3.67	243008.048	347480.564	490.642
Point 11 (summit)	**Data collection time mins**	**Easting**	**Northing**	**Height(m)**
GeoXH 6000	3.47	243019.602	347508.480	490.662

The relevant staff readings were:-

Staff reading at Viva GS15 setup point = 2.166m

Staff reading at lower summit point 10 = 0.414m

Staff reading at summit point 11 = 0.363m

Survey Points	Height correction for GS15 m	GS15 Height m	Absolute height XH6000 m	Height difference m	No of readings (one per sec) XH 6000	Vertical error XH 6000
"Leica GS15 setup"	0.000	488.875				
10 (lower summit)	1.752	490.627	490.642	-0.015	220	0.1
11 (summit)	1.803	490.678	490.662	0.016	208	0.1

The summary of height measurements shown in the table above again demonstrates excellent agreement between the two GNSS receivers.

So far all of the measurements taken with the GeoXH 6000 had been in positions where there was a clear view of the sky and so satellite signals would not have been impeded. In order to see if the accuracy of the GeoXH 6000 were affected for this case, readings were taken from a position on the side of a large rock pile with a cairn on the top, Point 12. We estimated that up to about 180 degrees of satellite reception had been restricted depending on the horizontal angle. The Viva GS15 was set up on this point supported by the tripod/tribrach system (Vertical offset on tape = 0.402m). Data were collected for 30mimutes with an epoch time of 15 seconds. Data were also collected at this point with the GeoXH 6000.

Point 12	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	31	243035.691	347513.848	487.303
GeoXH 6000	15.78	243035.700	347513.772	487.323

In order to check the data collected at Point 12, staff measurements were made from a convenient position of the Leica NA730 to Point 12 and the previous Viva GS15 set up position used to measure Points 10 and 11.

The relevant staff readings were:-

Staff reading at previous Viva GS15 setup point = 0.617m

Staff reading at GeoXH 6000/Viva GS15 measurement Point 12 = 2.198m

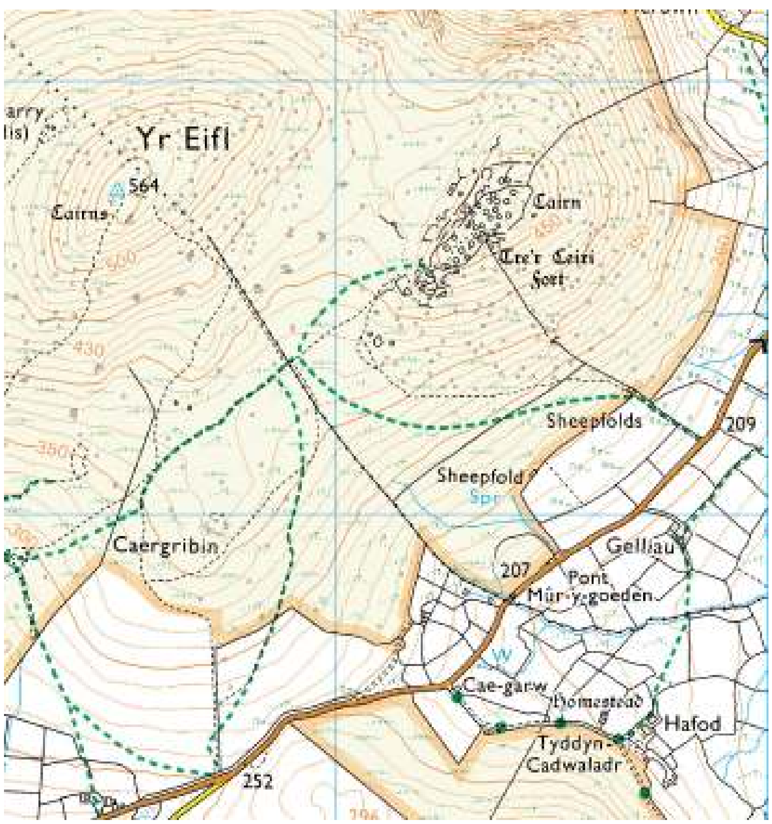
A summary of the height data is shown in the table below.

Survey Point	GS15 measured height m	GS15 height from previous position with staff correction	Absolute height XH6000 m	Height difference m	No of readings (one per sec) XH 6000	Vertical error XH 6000
Point 12	487.303	487.294	487.323	-0.020	947	0.1

The Viva GS15 and GeoXH 6000 measurements taken at Point 12 are within 0.02m of height difference and therefore the partial obstruction of the sky in this case does not appear to have caused any difference in the measurements. There is also excellent agreement between the two Viva GS15 measurements where the height difference has been verified by staff measurements. These two sets of data give a height for Point 12 to within 0.009m and therefore confirm the consistency of the datasets.

3.3) Yr Eifl Summit (SH364447 OS 1:50000 Map 123) (Appendix 3 for photos)

The summit of Yr Eifl is crowned with a large pile of stones, an ancient cairn, on the top of which is a trig point. This trig point was rebuilt in this position after the original was destroyed in 1961. This summit was chosen for the equipment evaluation because of its convenience in position to the following two hills that were surveyed and also another opportunity to compare measurements with an OS trig point. An extract of the 1:25000 OS Map is shown below. The hill is easily accessed by footpaths from the road that passes South of this hill and this was the route chosen by the survey team.



The large pile of stones on the summit of Yr Eifl was considered to be man-made and therefore the first task was to find the highest natural ground around this pile of stones. The Leica NA730 level was set up on a tripod near the top of the cairn so that it was about 0.5m higher than the flush Bracket on the trig point. Staff readings were taken around the pile of stones and it was established that the highest point lay to the SW next to the stones. Staff readings were also taken to the GNSS set up position, to the highest point on the pile of stones, to the flush bracket on the trig point and also to the base of the trig point.

The relevant staff readings were:-

Staff reading at Viva GS15 setup position = 3.800m

Staff reading at highest point around pile of stones = 3.786m

Staff reading at highest point of pile of stones = 3.500m

Staff reading to flush bracket on trig point = 0.425m

Staff reading to base of trig point = 0.841m

Tape measurement of Flush Bracket to top of trig point = 0.845m

The Viva GS15 was setup on the short tripod/tribrach system and the measured vertical offset was 0.577m. GNSS data were collected for 30minutes with an epoch time of 15 seconds. Two sets of measurements were taken with the GeoXH 6000 placed on the top of the trig point. These two sets (Points 1 and 1.2) differed in collection times which were 34minutes and 3.6 minutes respectively. A further set of data were collected with the GeoXH 6000 at the Viva GS15 setup position (Point 2).

Point 2	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	34	236482.983	344734.924	560.657
GeoXH 6000	3.85	236483.197	344735.018	560.570

Survey Point	Height Correction for GS15 from staff readings m	GS15 measured height m	Absolute height XH6000 m	Height difference m	No of readings (one per sec) XH 6000	Vertical error XH 6000
Point 1	4.220	564.877	564.927	-0.050	2022	0.1
Point1.2	4.220	564.877	564.859	0.018	218	0.1
Point 2	0.000	560.657	560.570	0.087	231	0.2
Flush Bracket	3.375	564.032	564.082			

The Viva GS15 and GeoXH 6000 measurements taken at the Viva GS15 setup position differ by 0.087m. This is a little higher than for previous results but not unexpected as the predicted vertical error for the GeoXH6000 was higher at 0.2m instead of 0.1m. The agreement with the Viva GS15 measurement for the top of the trig point with the GeoXH 6000 measurement is closer for the shorter timed measurement Point 1.2 although agreement for both measurements is still good. Since Point 1.2 was measured after Point 1 the instrument had not been switched off (?), then effectively the GeoXH 6000 would have had more than 30 minutes to achieve maximum accuracy before data had been collected.

The OS Database gives the height of the Flush Bracket on the trig point as 564.184m and quotes its "accuracy" as order 3. The respective measurements for the Viva GS15 and GeoXH 6000 receivers were 564.032m and 564.082m and differ from the OS database by 0.15m and 0.10m. These differences for Flush Bracket measurements are higher than usual but perhaps not surprising with the position of the trig point on a pile of rocks and that it is of order 3.

3.3.1) Tre'r Ceiri Summit (SH374447 OS 1:50000 Map 123) (Appendix 4 for photos)

The summit of Tre'r Ceiri lies about 1km to the East of Yr Eifl and therefore provided an easy continuation of the surveys to compare the Viva GS15 and GeoXH 6000. The hill is crowned with an Iron Age hill fort and notice boards were positioned at the bottom of the hill explaining its archaeology. It is likely that most of the ground near the summit is not natural since the whole area is covered with broken rocks. The highest point is at the top of a large broad cairn.

The Leica NA730 level was set up on the cairn so that staff readings could be taken around its perimeter. It was assumed that this ground was more likely to be natural, although that may not be the case. The staff measurements showed that a small grassy area on the north side of the cairn was the highest point being about 0.03m higher than the highest point on the South side of the cairn.

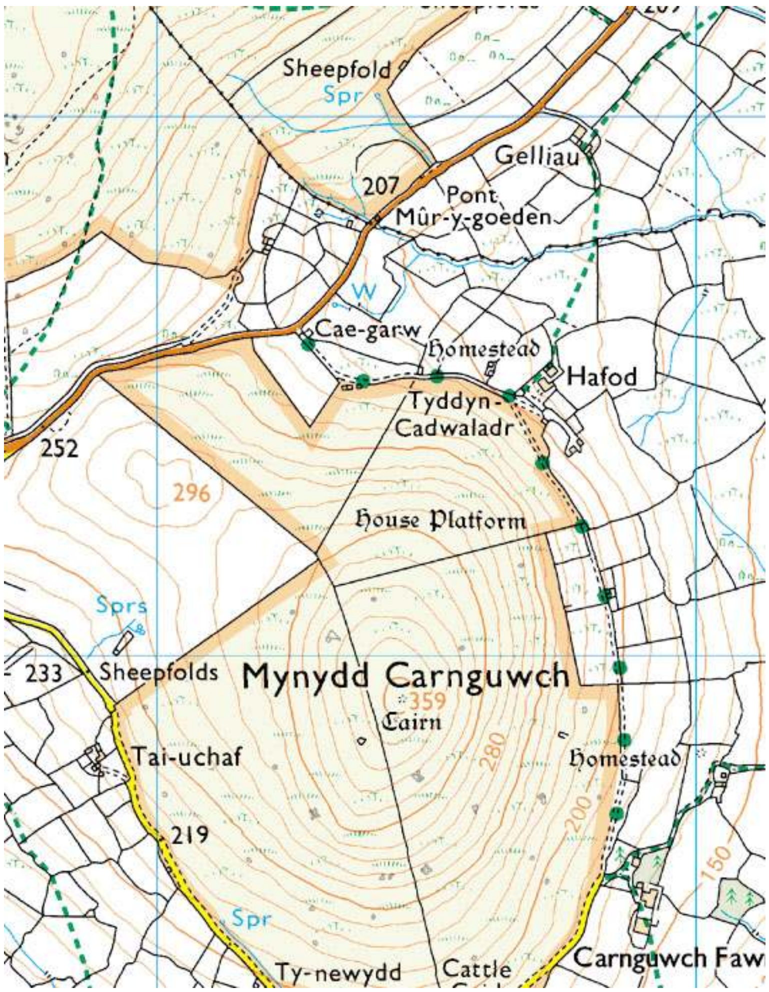
The Viva GS15 was set up on the short tripod/tribrach system directly over the highest point and the vertical offset was measured to be 0.594m. Data were recorded for 32minutes with an epoch time of 15 seconds. Subsequently data were collected with the GeoXH 6000 at the same position – Point 3.

The results shown in the table below are in good agreement with the GeoXH 6000 being 0.04m higher than the Viva GS15 measurement.

Point 3	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	32	237438.483	344722.771	485.332
GeoXH 6000	3.98	237438.426	344722.670	485.375

3.4) Survey of Mynydd Carnguwch (SH 374429 OS 1:50000 Map 123) (Appendix 5 for photos)

Mynydd Garnguwch lies just to the South East of Yr Eifl and to the South of Tre'r Ceiri on the opposite side of the B4417. It is listed as a HuMP (Mark Jackson's list of hills with a prominence of at least 100m) with 104m of drop. Although the survey was essentially a comparison of the two GNSS receivers, this hill did provide a small possibility for reclassification if the drop were measured to be less than 100metres. An extract from the OS 1:25000 map is shown below. The summit is marked with a 359m spot height. The critical bwlch lies to the North West and probably lies on the B4417. There is a spot height marked on this road at a height of 252m but visually the road seemed higher to the North East.



Mynydd Carnguwch is easily ascended from the North West up the grass and heather covered flank. Depending on the route taken a number of stone walls/fences need to be crossed. The summit of the hill is crowned with a very large cairn and a wind shelter.

3.4.1) The Summit

On the East side of the summit cairn there is a natural rocky rib that leads up to a small grassy plateau which at first inspection appeared to be the highest natural ground.

The Viva GS15 was set up on the short tripod /tribrach support, vertical offset 0.399m, on this grassy plateau and data were collected for 31 minutes with an epoch time of 15 seconds. Data was also collected with the GeoXH 6000 at this position – Point 4.

Once the Viva GS15 had been positioned it was noticed that a point about 4m distant on the East side of the cairn appeared to be natural rock with the stones of the cairn. Using an Abney level this rock was measured to be about 0.185m higher. Subsequently this height difference was measured to be 0.176m with the Leica NA730 level and staff. Therefore this position, Point 5, was considered to be the summit of Mynydd Carnguwch. Another data set was collected at the summit with the GeoXH 6000.

Point 4	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	31	237462.638	342921.791	357.456
GeoXH 6000	3.98	237462.605	342921.776	357.469

Survey Point	Height Correction for GS15 from staff readings m	GS15 measured height m	Absolute height XH 6000 m	Height difference m	No of readings (one per sec) XH 6000	Vertical error XH 6000
Point 4	0.000	357.456	357.469	-0.013	348	0.1
Point 5 (Summit)	0.176	357.632	357.688	-0.056	1849	0.2

Again the agreement between the two GNSS receivers is good. It was a little surprising that the measurement taken for 30minuts on the summit for the GeoXH 6000 recorded a vertical error of 0.2m whereas the shorter time for Point 4 was 0.1m. The fact that the summit position was on the sloping face of the cairn may have meant that satellite signals could have been partially compromised. However, agreement between the two summit measurements is still to within 0.06m

From the two summit measurements the height of Mynydd Carnguwch is 357.65+/-0.05m.

3.4.2) The Bwlch

The critical bwlch for Mynydd Carnguwch lies on the B4417 about 600m NW of the hill's summit. The B4417 lies in a steep cutting with near vertical sides of about 2m in height. The road was too busy and narrow to setup the Viva GS15 on its tripod so an arbitrary point was chosen on the embankment on the South side of the road. From near this point the Leica NA730 automatic level was setup on a tripod and staff readings were taken along the edge of the road until the highest point was found. As the road runs in the valley to valley direction this highest point is then the position of the bwlch. Data were collected with the GeoXH 6000 at this position – Point 6. Data were collected for the Viva GS15 set up on a 2.000m pole for 30minutes at an epoch time of 15 seconds.

The relevant staff readings were:-

Staff reading to Viva GS15 setup position = 0.926m

Staff reading to bwlch = 2.380m

GS15 setup position	Data collection time mins	Easting	Northing	Height(m)
Viva GS15	31	236859.500	343483.531	257.044

Bwlch Point 6	Data collection time mins	Easting	Northing	Height(m)
GeoXH6000	8.40	236852.192	343487.384	255.671

The height of the bwlch measured by the Viva GS15 is therefore 257.044 - 2.380 + 0.926 = 255.590m

Using the average of the two bwlch measurements of 255.63m, the drop for Mynydd Carnguwch is calculated to be 102.0+/-0.2m and therefore its status as a HuMP is confirmed.

4) <u>Summary of Results and Conclusions from Surveys</u>

The two days of surveying in a range of different environments had given us an excellent opportunity to make a performance comparison of the Leica Viva GS 15 Professional survey GNSS receiver with the Trimble GeoXH 6000 GNSS "Mapper" receiver. So what are the conclusions we can draw from this comparison?

- The GeoXH 6000 has given excellent results for position and height compared with the Viva GS15 and Trimble's claim for decimetre accuracy seems to be justified. On the occasions when the difference appeared to be larger than this, a warning had already been flagged up on the vertical accuracy reading that the result would not be as accurate as could usually be obtainable.
- It is interesting to note than in the majority of the height comparisons the GeoXH 6000 gave a slightly higher result for vertical height.
- In general we do not collect datasets for less than 30 minutes with the Viva GS15 because from our experience this is about the minimum time required to obtain consistent data when processed with 5 to 8 Base stations. However the GeoXH 6000 seemed able to produce data in good agreement with the Viva GS15 with much shorter data sets typically with collection times of 2 to 5 minutes.

- There is no doubt that once the operating procedure has been mastered and the GeoXH 6000 parameters setup for use, operation in the field is very simple and convenient. This is particularly true if the internal antenna is being used as was the case in these surveys.
- Although not proven in these surveys, one might expect a survey grade GNSS receiver to outperform the GeoXH 6000 in accuracy? If this were not the case, then why does Trimble sell a whole range of survey grade GNSS receivers similar to the Leica Viva range? However, from our knowledge of hill surveys, this ultimate accuracy is most often not needed, or other factors limiting accuracy are more important, and therefore the GeoXH 6000 would perform well enough for the requirements of the vast majority of hill surveys.

5) General Summary and Conclusions

Partly based on the survey work carried out as described in this report, Myrddyn Phillips has purchased a Trimble GeoXH6000 for his own use that is accessible to the tam of G&J Surveys and this has given us a further opportunity to evaluate the performance of this GNSS receiver. Particularly useful was the training day organised by Martyn Palmer from KOREC UK who are the agents for Trimble in the UK. We were able to question him in much more detail to get a greater understanding on how the GeoXH 6000 works and is used, and also to understand details about how the data it collects is processed in Trimble's dedicated "Pathfinder Office" software.

There is no doubt the performance of the GeoXH 6000 for very short data collection times, for example 2 minutes, is excellent. For static surveys with the Leica Viva GS15 a collection time this short would not be feasible. This is even more puzzling when one considers that correction data from OS Base stations for post processing GNSS data is only available every 30seconds.. This means that the GeoXH 6000 data is being processed for a 2 minute dataset with only 4 individual sets of correction data from the Base stations and that seems far too little to adequately model the atmospheric conditions to make accurate corrections?

Martyn's answer to the above question was that this was due to the power of Trimble's H Star technology. Martyn was not able to tell us even the principles of this technology but claimed it was all down to the clever algorithms invented by Trimble scientists! It also seemed strange that if H Star technology is so good, then why is it not incorporated into their range of survey grade GNSS receivers? It seems that the Trimble Division that makes the GeoXH 6000 is a different group from the Survey grade GNSS group and that they go their own ways! His answer was less than convincing.

Another feature built into the GeoXH 6000 is "Floodlight Technology". This technology is claimed to give superior performance when data are collected in positions where the satellite signals are weak; for example in trees or in areas that are heavily built up. We were not able to evaluate this feature and therefore can make no further comments on its efficiency, but one would be very surprised if it was not helpful to obtaining more accurate measurements. Of course an additional feature that is present on both the Leica Viva GS15 and the Trimble GeoXH6000 is the ability to receive signals from GLONASS satellites. Although this does not improve accuracy if there is a clear view of the sky, it will certainly help a great deal if the sky view is limited.

Another excellent feature of the XH 6000 is its ability to receive SBAS (Satellite-based Augmentation System) which is EGNOS in Europe. When this feature is switched on it is claimed to improve real time accuracy to about 0.3-0.5m in position. Therefore, without the need for RTK (expensive annual licence to a real time correction service) the GeoXH 6000 can become a quite accurate handheld GNSS receiver with a much better performance than a Garmin receiver.

However, it is questionable whether this type of accuracy for hill surveying work is useful for the price tag on the GeoXH 6000 exceeding £10k.

Surveying summits and cols is a two part process. Firstly the position of the summit or col must be found before its height can be measured. This requires additional bulky equipment, for example an automatic level, staff and tripod, and cannot be achieved with a GNSS receiver unless RTK is available to give an accurate readout of position and height. In most cases the positions will be fairly obvious but we have experienced a number of situations where this is not true. In these cases a systematic mapping approach is required that can give the result in the field so that the GNSS receiver can then be placed in the most suitable position to collect data. A Trimble GeoXH 6000 does not solve this problem.

If one assumes that the additional equipment that needs to be carried is the same for either the Viva GS15 or the GeoXH 6000, what are the relative merits of the two receivers? It is possible to use the GeoXH 6000 with an external antenna mounted on a 2m "rover" pole (this is supplied with the receiver) and then the two receivers look and weigh almost the same so there is no advantage here. If a long static survey is needed then both of the antennae would need tripod support as well, so there are no advantages here. In terms of minimum requirements for operation the GeoXH 6000 can be used on its own and just placed on the ground. However, the Viva GS15, although not weighing significantly more, is more bulky and therefore more difficult to carry. Also it would not be possible to use the Viva GS15 without tripod support.

The data collected with Trimble GeoXH 6000 can only be processed with dedicated Trimble software. Data from the satellites, for example the GPS system, is transmitted at two frequencies and the signals are known as L1 and L2. These two signals are required to reduce errors from ionospheric distortions. If the Trimble data were processed on non-dedicated software, then the data would need to be changed to a new format, typically RINEX. However, if one attempts to change the data to this format, all data from the L2 signal is lost. This seems a deliberate ploy by Trimble to differentiate the "mapping" and "surveying" grade GNSS receivers? This would also mean that we would not be able to send a dataset collected on the GeoXH 6000 to Ordnance Survey to be processed on Bernese software to have verification of results to effect map changes.

The dedicated Trimble software (Pathfinder Office) appears to be very inflexible compared with Leica's GeoOffice. Essentially you feed in the raw data and RINEX corrections from the OS, and the software gives you the answer, albeit with some quite useful statistics on how good the software believes the data to be. However, you have no flexibility to choose, for example, the atmospheric model as we have with GeoOffice or indeed a number of other important processing parameters. Another drawback is that if you process from a number of OS Base stations simultaneously, as is best practice, you cannot view the individual results for each Base station to assess the internal consistency of the dataset. We would suspect that the software designed to process data collected for the "survey" grade Trimble receivers would be more akin to GeoOffice. This must be a question of Trimble's business model for selling "mapping" grade GNSS receivers to a market where ease of obtaining the result rather than ultimate accuracy is the more important.

Finally it is worth considering the possible uses of the two receivers. Most of the survey work we do is focussed on hill heights and drops to investigate if a particular hill should have a certain classification. Our "in tray" of hills to survey is very large and seems to grow faster than we carry out surveys. The GeoXH 6000, because of its one man operation, speed and lightness would make an excellent instrument for screening a specific hill list so that the very marginal ones could be identified for more detailed accurate surveys.

As stated earlier in this report Myrddyn Phillips has purchased a GeoXH 6000 and this should give us the opportunity to carry out further comparative measurements to obtain a much better understanding of the capabilities of the two systems. In particular we would like to set up an SQC

(Statistical Quality Control) test for the GeoXH 6000 where we measure a known point regularly once a batch of 20 individual measurements have been taken. This will enable us to obtain a standard deviation for height measurements as has already been carried out with the Leica GS15.

John Barnard, Graham Jackson and Myrddyn Phillips, 05 February 2014.

Appendix 1 – Bwlch Mawr

Trimble GeoXH6000 on summit with John Fitzgerald

Leica Viva GS15 setup position with members of the survey group

Vertical Offset of 0.435m for Leica Viva GS15 setup on short tripod

Appendix 2 –Craig Cae Hir

Viva GS15 setup at bwlch with G Jackson, J Barnard, J Fitzgerald and S Stewart

Surveying for summit position

Viva GS15 setup position with G Jackson

GS15 setup position on short tripod showing 0.443m vertical offset

Appendix 3 – Yr Eifl

Viva GS 15 setup position with G Jackson, S Stewart, C Crocker and J Barnard

Viva GS15 setup position in relation to the trig pillar

Viva GS15 setup showing 0.577m vertical offset

Appendix 4 – Tre'r Ceiri

Surveying for summit position; G Jackson with Leica NA730

Viva GS15 setup on summit; G Jackson, J Barnard and J Fitzgerald

Viva GS15 setup on short tripod showing 0.594m vertical offset

Appendix 5 – Mynydd Carnguwch

Viva GS15 setup position near the summit

Viva GS15 setup showing 0.399m vertical offset

Survey for Bwlch position: J Barnard at Leica NA730

Viva GS15 setup position on edge of road: G Jackson and J Barnard

John Fitzerald with GeoXH6000 on bwlch position

Appendix 6

Surveys carried out on 31 August 2013

point	easting	northing	altitude	horz error	vert error	Std dev	No of rdgs.		easting	northing	altitude
	Trimble GeoXH 6000 Data								**Leica GS15 /NA730 Data**		
1.0	243757.943	347454.727	237.527	0.100	0.100	0.000	217	*	243757.934	347455.003	237.499
2.0	243749.538	347456.246	239.342	0.300	0.700	0.600	320	*			238.965
3.0	243741.122	347456.283	240.473	0.100	0.100	0.000	145	*			240.423
4.0	243733.293	347456.884	241.893	0.100	0.100	0.000	202	*			241.866
5.0	242639.046	347717.796	509.926	0.100	0.200	0.000	301	*			
6.0	242669.765	347847.418	510.373	0.100	0.100	0.000	346	*			510.349
7.0	242659.110	347850.833	510.537	0.100	0.200	0.000	317	*			510.511
7.1	242659.172	347850.738	510.507	0.100	0.100	0.000	1964	*			510.511
leica base	242663.132	347837.954	507.427	0.100	0.100	0.000	202	*	242663.090	347837.931	507.390
dbh col	242779.797	347560.980	471.801	0.100	0.200	0.000	123	*	242779.653	347560.975	471.697
8.0	242790.041	347574.292	471.653	0.100	0.100	0.000	118	*			
9.0	242866.749	347527.142	486.094	0.100	0.100	0.000	113	*			
10.0	243008.048	347480.564	490.642	0.100	0.100	0.000	220	*			490.627
11.0	243019.602	347508.480	490.662	0.100	0.100	0.000	208	*			490.678
12.0	243035.700	347513.772	487.323	0.100	0.100	0.000	947	*	243035.691	347513.848	487.303

Surveys carried out on 01 September 2013

	Trimble GeoXH 6000 Data								Leica GS15 /NA730 Data		
point	**easting**	**northing**	**altitude**	**horz error**	**vert error**	**Std dev**	**no. of readings**	*****	**easting**	**northing**	**altitude**
1.0	236491.011	344743.790	564.927	0.100	0.100	0.000	2022	*			564.877
1.2	236491.017	344743.799	564.859	0.100	0.100	0.000	218	*			564.877
2.0	236483.197	344735.018	560.570	0.200	0.200	0.200	231	*	236482.983	344734.924	560.657
3.0	237438.426	344722.670	485.375	0.100	0.100	0.000	239	*	237438.483	344722.771	485.332
4.0	237462.605	342921.776	357.469	0.100	0.100	0.000	348	*	237462.638	342921.791	357.456
4.1	237462.708	342922.033	357.397	0.100	0.100	0.000	502	*			
5.0	237461.273	342919.047	357.688	0.100	0.200	0.100	1849	*			357.632
6.0	236852.192	343487.384	255.671	0.100	0.100	0.000	504	*			255.590