

Surveys of Beinn Dearg and Creag na h-Eararuidh

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The Team:

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1) Introduction

G&J Surveys has agreed a project with the Scottish Mountaineering Trust (SMT) to measure accurate heights for several Scottish mountains. The aim of the project is the resolution of anomalies that currently exist in several lists of the hills that are of interest to both the Scottish Mountaineering Club (SMC) and the wider hillwalking community. One such list is the Grahams, hills in Scotland of height between 2000 feet and 2500 feet but with 150 metres or more of drop. This list was published by Fiona Torbet (nee Graham) in the November 1992 issue of The Great Outdoors, the same year as the publication of The Relative Hills of Britain by Alan Dawson. Fiona Torbet's list was not identical to the subset of Marilyns termed the Elsie in The Relative Hills of Britain, but the two authors met and decided to unify the lists. The unified list was to be called The Grahams, but the data used would be taken from Alan Dawson's book. Upon Fiona Torbet's death Alan became the sole list author.

Beinn Dearg (Hill number 21, Grid Ref NN696197) and Creag na h-Eararuidh (Hill number 3937, Grid Ref NN685190) are shown on OS 1:50000 Map 57 and OS1:25000 Maps OL47W 368W. Beinn Dearg has a spot height of 706m on the 1:50000 Map and 1:10000 Map while Creag na h-Eararuidh has a spot height of 705m on the 1:50000, 1:25000 and 1:10000 Maps. Since spot heights have an uncertainty of ± 3 m, it is not certain from OS maps which is the higher hill and therefore which is the Graham. These hills were therefore surveyed by Alan Dawson in 2014 who found Creag na h-Eararuidh to be the higher and therefore this becomes the Graham. However, the SMC feels that surveys should be verified by OS, as the authority responsible for the mapping of Britain's geographic features, in order that the results can be produced on their mapping for the benefit of all. The results of the 2014 survey were not verified by the OS, so the aim of this survey was to obtain accurate heights for the summits of Beinn Dearg and Creag na h-Eararuidh using a survey grade Leica Viva GS 15 Professional GNSS (Global Navigation Satellite System) receiver, and then obtain OS verification and report the results to the SMC.

2) Equipment used and Conditions for Survey

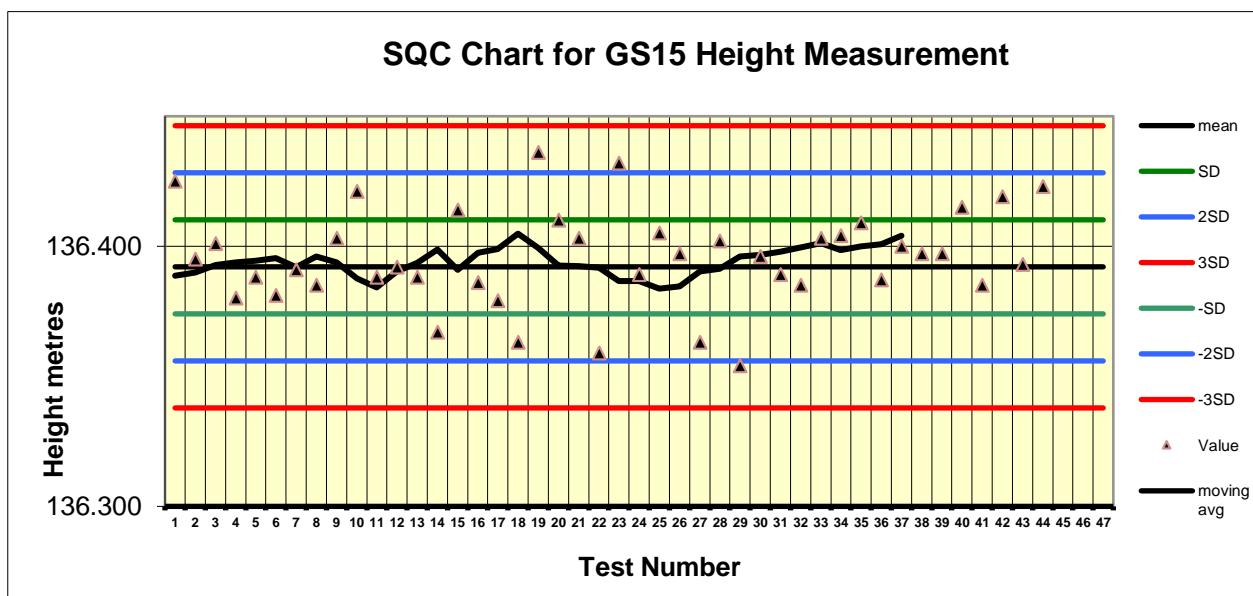
The summit positions were identified using a Leica NA730 Professional Automatic level (X30 telescopic system)/tripod system and a "1m" E-staff extendable to 5m as required by Ordnance Survey.

Absolute heights were measured using a Leica Geosystems Viva GS15 Professional receiver. This instrument is dual-frequency and multi-channel, which means it is capable of locking on to a maximum of 12 GPS and 8 GLONASS satellites as availability dictates, and receives two signals (at different frequencies) from each of these satellites. The latter feature reduces inaccuracies that result from atmospheric degradation of the satellite signals. As a stand-alone instrument it is capable of giving position and height to an accuracy of about two metres and five metres respectively. Despite the on-board features of the Viva GS15 receiver, there are still sources that create residual errors. To obtain accurate positions (± 0.01 m) and heights (± 0.05 m), corrections

were made to the GNSS (Global Navigation Satellite System) data via imported RINEX data from Ordnance Survey and this dataset was post-processed using Leica Geo Office 8.3 software. Confirmation of heights was carried out by Mark Greaves, Geodetic Analyst of Ordnance Survey.

Note that small hand-held GPS receivers used for general navigation can only receive up to 12 GPS satellites and each at a single frequency and therefore these instruments have a poorer positional accuracy of ± 8 metres and a height accuracy of no better than ± 10 -15 metres. Some recently produced hand held GPS Garmin receivers can also receive signals from GLONASS satellites which greatly improve the speed at which these receivers can achieve a satellite “fix”.

The Leica NA730 level is routinely checked to make sure that the line of sight is correct when the instrument is set up horizontally; there is a standard surveying method to do this described in the users’ manual for these instruments. We also regularly check the functioning of the Leica Viva GS15 GNSS receiver against Statistical Quality Control (SQC) charts generated for a marked position. The chart associated with height measurement is shown below. The mean height above ODN (Ordnance Datum Newlyn) for a fixed point (measured on 20 different occasions for 30mins of data collection at each time) was calculated to be 136.392m. Further height measurements have been made on separate occasions over a period of 3 years using the same process parameters. The penultimate and last measurements were carried out before and after the surveys described in this report. The results shown on the graph are all within a range of \pm three SD (Standard Deviation), in this case one SD is ± 0.018 m and the moving average is within 1SD. This demonstrates that our Leica Viva GS15 GNSS receiver is giving consistently precise results within the expected errors for the measurements (all points are within a range of 0.07m of one another).



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 within about 0.02-0.03m.

Checks were carried out on 13 October 2017 and 20 November 2017 at the Daresbury Fundamental Bench Mark and the results in the table below show excellent agreement between the Ordnance Survey measurement and our own.

Processing	Date	Height(m)
OS measurement		73.24
JB/GVJ GeoOffice 8.3	13-10-2017	73.23
JB/GVJ GeoOffice 8.3	20-11-2017	73.23

Conditions for the surveys, which took place between 12.00hrs and 16.35hrs BST on 26 October 2017, were good. The temperature was about 8 degrees Celsius. The wind on the summits was moderate, blowing between 15 and 20 mph. The sky was overcast but with sunny periods and the cloud base was always above the summits. Consequently, the weather conditions did not impede the surveys.

3) Character of the Hills

Beinn Dearg and Creag na h-Eararuidh are situated on the North side of Glen Artney, just to the West of the village of Comrie and about 5km South of Loch Earn. Access to Glen Artney is by a single track road that leaves the B827 near Cultybraggan Camp, just 1km South of Comrie. After 7.5km there is a car park which is situated just after a bridge over the Allt na Gaisge and from here the route to Beinn Dearg is back along the road for about 700m to Dalchruin Farm, where there is a bridge across the Water of Ruchill and access to the hill is gained. Our route took us NW from the bridge and once the track petered out the terrain became wet and vegetated until we reached the foot of steep ground at 350m. From here the ground became drier and easier under foot and the NW route was continued to the summit area which comprises three small tops marked with 700m contours on the 1:50000 map. The view West is dominated by Ben Vorlich and Stuc a' Chroin, while to the South is the massif of Uamh Bheag and its satellite Beinn Odhar. To the SE is the Marilyn Ben Clach and its small but prominent satellite Cnoc Brannan.

4) Survey of the Summit of Beinn Dearg

The first task for the survey team was to identify the position of the summit; the map below shows three 700m ring contours that vie for the title. To the unaided eye the SE top appeared to be lower, but it was unclear which of the centre and WSW tops was the higher. The centre top is crowned with small cairn and the level and staff quickly showed that the highest point lies next to it, while the summits of the other two tops are unmarked. The centre top and WSW top are shown in photographs in the Appendix 1.

The level was set up at a convenient position near to the small cairn on the centre top and a staff measurement was taken by the cairn and then at the summit of the top to the WSW.

staff reading on centre top = 0.418m

staff reading on WSW top = 2.850m

Centre top is $2.850 - 0.418 = 2.432\text{m}$ higher than WSW top

Next attention turned to the SE top. It was quickly established that this was more than 3m lower than the centre top and consequently no further work was carried out. An extract from the OS 1:25000 map (Ordnance Survey Crown Copyright) is shown below.



The Leica Viva GS15 was set up over the summit using the short tripod configuration (see photo in Appendix 1). The height of the receiver above the ground was then measured with the integral tape. The vertical offset from measuring point to the ground was 0.584m plus 0.255m for the tribrach/hook system. GNSS data were collected for 2hr with an epoch time of 15 seconds.

4.1) Results for the Summit of Beinn Dearg

The data for the Leica Viva GS15 were processed in Leica GeoOffice 8.3 using the eight nearest base stations: (Killin – KILN 17km, Glasgow – GLAS 56km, Edinburgh – EDIN 70km, Dundee – DUDE 79km, Oban – OBAN 81km, Drumalbin – DRUM 84km, Braemar – BRAE 87km and Lochgilphead – LOCG 89km, Fort Augustus – FAUG 94km). We used Broadcast Ephemeris data received by the GPS during the survey rather than Precise Ephemeris data, since we have found this makes little difference to the height results. The computed Tropospheric model was chosen for the calculations to suit the data collection times and the wide difference in height between the base stations and the summit of the mountain.

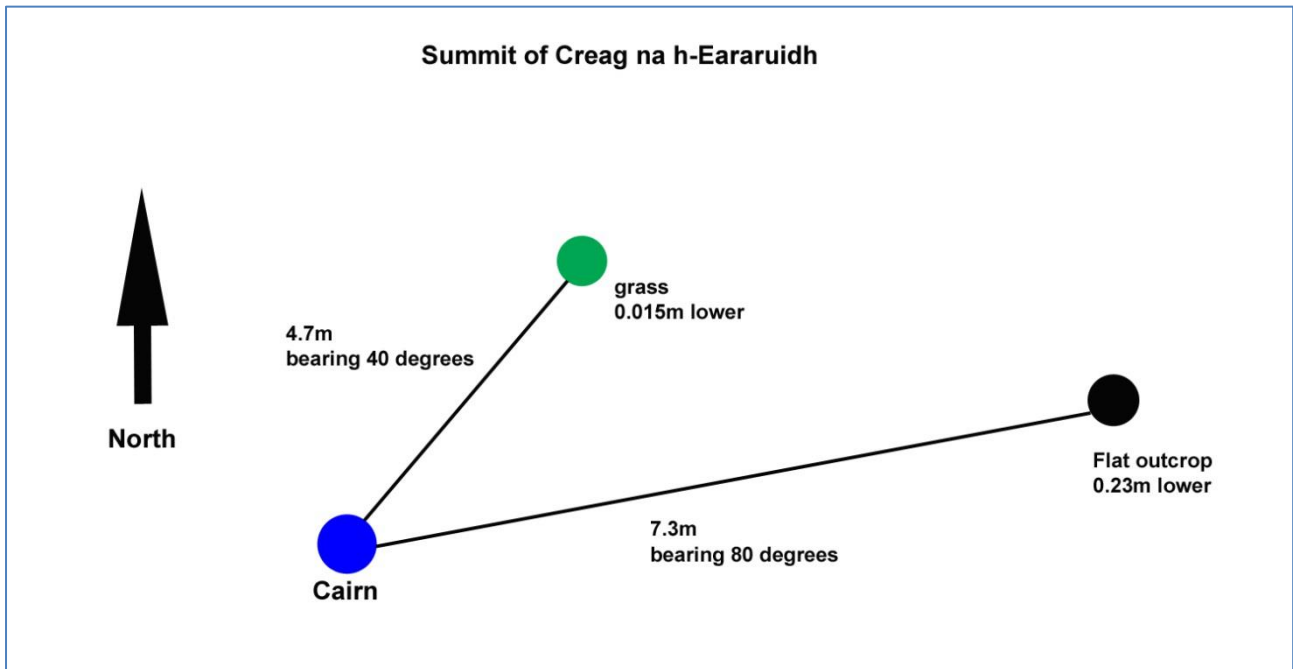
As far as is possible, the base stations are evenly distributed around the survey points and heights measured from each base station were within $\pm 0.03\text{m}$ of the mean result for the summit.

The results for Beinn Dearg are tabulated below:

System	Easting	error(1SD)	Northing	error(1SD)	Height(m)	error(1SD)
GS15	269669.483	0.002	719752.904	0.001	706.664	0.008

5) Survey of the Summit of Creag na h-Eararuidh

Having completed the survey of the summit of Beinn Dearg, we now moved onto the summit of Creag na h-Eararuidh. The area around the small cairn appeared quite flat, but there were two points adjacent to the cairn that, to the unaided eye, vied for summit position. The Leica NA730 level was set up on a tripod a few metres from the cairn and staff readings were taken on all three candidate positions after any vegetation had been removed at each position. A schematic diagram of the summit area is shown below.



Staff reading at ground by cairn = 0.505m

Staff reading at ground 4.7m from cairn on bearing of 40 degrees = 0.520m

Staff reading at ground 7.3m from cairn on bearing of 80 degrees = 0.735m

The summit was thus identified as ground immediately adjacent to the cairn. A photograph of the Leica GS15 set up at this position is shown in Appendix 2.

Ten figure grid references for these positions acquired with hand-held GPS receivers are:

Ground on bearing of 40 degrees

Garmin Oregon 450	NN 68519 19000	Accuracy: averaged	Height = 715m
Satmap Active 20	NN 68519 18999	Accuracy: 1.8m	Height = 712m

Ground on bearing of 80 Degrees

Garmin Oregon 450	NN 68523 18999	Accuracy: averaged	Height = 713m
Satmap Active 20	NN 68523 18999	Accuracy: 1.5m	Height = 711m

Ground by cairn

Garmin Oregon 450

NN 68515 18995

Accuracy: averaged Height = 714m

The Leica Viva GS15 was set up over the summit using the short tripod configuration (see photo in Appendix 2). The height of the receiver above the ground was then measured with the integral tape. The vertical offset from measuring point to the ground was 0.596m plus 0.255m for the tribrach/hook system. GNSS data were collected for 2hr with an epoch time of 15 seconds.

5.1) Results for the Summit of Creag na h-Eararuidh

The GNSS Data were processed as described in Section 4.1 using the same nearest Base stations as for Beinn Dearg.

The results for Creag na h-Eararuidh are tabulated below:

System	Easting	error(1SD)	Northing	error(1SD)	Height(m)	error(1SD)
GS15	268513.108	0.002	719000.610	0.003	708.329	0.009

6) Summary of Operating Conditions

Variable	Beinn Dearg	Creag na h-Eararuidh
Data collection summit (min)	120	115
Number of Base Stations used in Processing for all points	9	9
Epoch Time (sec)	15	15
Tropospheric Model	Computed	Computed
Geoid Model	OSGM15	OSGM15
Cut off Angle (deg)	15	15

7) Discussion of Results

Since the positions of the summits were clearly defined and on short grass, we would estimate the height uncertainty associated with their correct locations to be $\pm 0.02\text{m}$. The height uncertainty associated with a 2hr dataset has been measured by us and is $\pm 0.05\text{m}$ for data processed in proprietary software. The measurement uncertainty for the height of each summit is therefore $(0.02^2 + 0.05^2)^{0.5} = \pm 0.05\text{m}$.

8) Coordinate Recovery Analysis

In order to verify the precision and consistency of a GNSS dataset, Ordnance Survey recommends a procedure called Coordinate Recovery Analysis. Instead of processing the data with reference to all

the nearest OS Base Stations under approximately 100km distance, as used in this report, the data is first processed with reference to only the nearest Base Station. The data is then reprocessed with the survey point taken as a Reference Point and all the remaining Base stations taken as survey points. These measured values for the OS Base Stations can then be compared directly with the actual OS values for Position and Height. (This has been carried out via an Excel Spreadsheet supplied to us by OS).

Although the spreadsheet calculates a number of different parameters, two important ones are presented in the tables below. “Height Difference **U** metres” is the vertical height difference between the height of the Base Station as measured in this survey compared with the actual OS value. “Separation **D_{ij}** metres” is the distance in 3-d space between the measured and actual OS values for each Base Station.

The results for the survey are presented below.

			Beinn Dearg		Creag na h-Eararuidh	
Base Station	Code	Distance to Survey Point km.	Height Difference U metres	Separation D_{ij} metres	Height Difference U metres	Separation D_{ij} metres
Killin	KILN	17				
Glasgow	GLAS	56	-0.008	0.011	-0.031	0.031
Edinburgh	EDIN	70	-0.005	0.010	-0.009	0.014
Dundee	DUDE	79	0.077	0.077	0.055	0.056
Oban	OBAN	81	0.000	0.006	-0.031	0.032
Drumalbin	DRUM	84	-0.004	0.013	-0.013	0.015
Braemar	BRAE	87	0.004	0.004	-0.006	0.015
Lochgilphead	LOCG	89	0.037	0.038	0.022	0.024
Fort Augustus	FAUG	94	-0.011	0.011	-0.002	0.009

Apart from Dundee (DUDE) at 0.08m for Beinn Dearg and 0.06m for Creag na h-Eararuidh, all of the datasets have recovered to 0.04m or better in terms of distance and height of the OS actual values, but all are below 0.1m which is considered acceptable by OS. Raw data are processed with base stations up to 100km from the survey point. Beyond this distance the models used to determine atmospheric corrections begin to break down because the atmosphere (in terms of pressure, temperature and composition) is less likely to be uniform over distances greater than this. Of course 100km is somewhat arbitrary but has become generally accepted through surveying working practice.

9) Ordnance Survey Verification

The results for this survey were submitted and have been validated on 10 November 2017 by Mark Greaves at Ordnance Survey. The OS Cartography Department has been informed and 708m will appear as the spot height on OS maps for Creag na h-Eararuidh and 707m for Beinn Dearg.

10) Summary of Heighting Results

Beinn Dearg was measured to be **706.7m \pm 0.05m** and the summit at Grid Reference ***NN 69672 19746** is ground by the small cairn on the centre top.

Creag na h-Eararuidh was measured to be **708.3m \pm 0.05m** and the summit at Grid Reference ***NN 68515 18993** is ground by the cairn.

Creag na h-Eararuidh is the higher hill and therefore qualifies as the Graham.

The results have been accepted by Ordnance Survey and forwarded to OS Cartography for relevant map changes.

*grid references for use with Garmin hand-held receivers

11) Acknowledgements

Many people contributed to the success of this survey.

We would especially like to thank the Scottish Mountaineering Trust for generously supporting the work and Rab Anderson and Andy Nisbet of the Scottish Mountaineering Club for their guidance and encouragement.

We also wish to thank Mark Greaves of the Ordnance Survey, who accepted the data and forwarded the results to OS Cartography for map changes. We also thank Mark for his support and advice that has helped us carry out our mountain heighting work over the past seven years.

Chris Crocker, Graham Jackson and Dave Marshall, 1 November 2017

Appendix 1
Beinn Dearg



Leica GS15 collecting data on the summit



Measuring the offset, 0.584m, for the Leica Viva GS15 on the summit



Determining the height difference between the centre top and the WSW top

Appendix 2

Creag na h-Eararuidh



Leica Viva GS 15 collecting Data on the summit,



Measuring the offset, 0.596m, for the Leica Viva GS15 on the summit