

Survey of Creag Dhubh Mhor

17 July 2019

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1) Introduction

G&J Surveys has agreed a project with the Scottish Mountaineering Trust (SMT) to measure accurate heights for a range of 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 and 2500 feet with a drop of 150m or more. The Ordnance Survey (OS) is the national authority responsible for the maintenance of Britain's geographical features and both the SMT and SMC feel it is in the interest of the hillwalking community that the heights of hills are officially verified by OS for inclusion on their mapping for the benefit of all.

Creag Dhubh Mhor (Hill Number 916, Section 12A, OS 1:50000 Map 25, OS 1:25000 Map 429, Grid Ref. NG982404) is listed in the Database of British and Irish Hills (DoBIH) as a Marilyn, Graham and Sim. Both of the above Ordnance Survey Maps have a spot height of 612m marked for the summit position but the 1:10000 Geograph map has it marked as 611m. Since spot heights measured by photogrammetry have a possible error of up to ± 3 m, there is a small chance that Creag Dhubh Mhor could be below 2000 feet (609.6m), thereby removing its status as a Graham. However, the height of this Graham has been measured by Alan Dawson using a Leica RX1250 and he found it to be 610.97m.

Therefore, the purpose of this survey was to measure accurately the height of Creag Dhubh Mhor so that the result can be verified by Ordnance Survey.

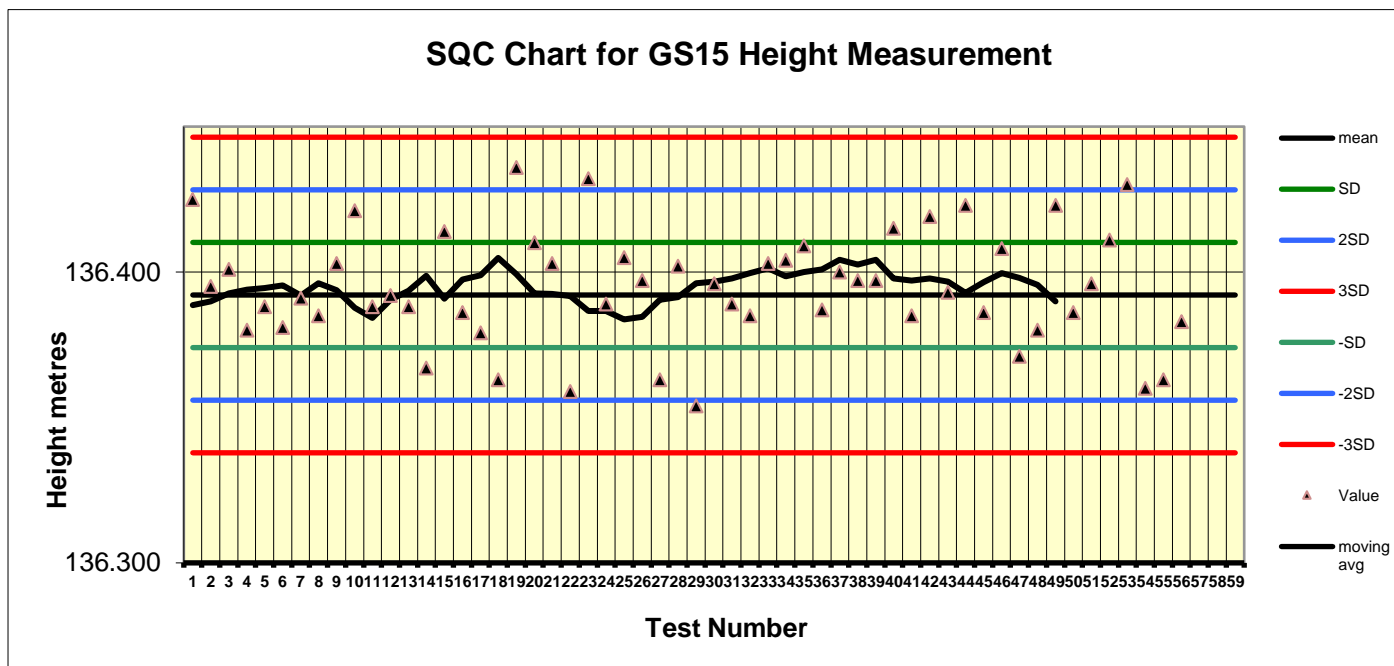
2) Equipment used and Conditions for Survey

The absolute height of the summit was 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.

Note that most small hand-held GNSS receivers used for general navigation in the UK can receive signals from up to 12 GPS and 8 GLONASS satellites and each at a single frequency. Therefore, these instruments have a poorer positional accuracy of ± 8 metres and a height accuracy of no better than ± 10 -15 metres – accuracy reported as three times standard deviation. Some older and “bottom of the range” handheld receivers can only receive signals from GPS satellites. However, their accuracy is very similar but GLONASS greatly improves the speed at which modern receivers can achieve a satellite “fix”, particularly in areas where the view of the sky may be limited. Satmap Active instruments are more accurate than the current Garmin models.

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 5 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 \pm 0.018m 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 to within about 0.02-0.03m.

Checks were carried out on 15 July 2019 and 22 July 2019 at the Daresbury Fundamental Bench Mark and the results in the table below show excellent agreement between the Ordnance Survey measurement and our own.

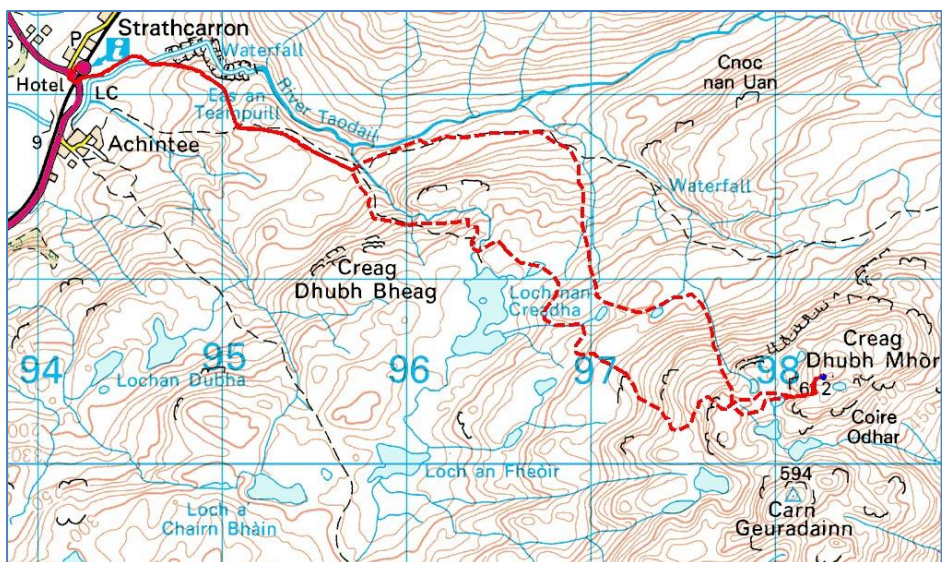
Processing	Date	Height(m)
OS measurement		73.24
JB/GVJ GeoOffice 8.3	15-07-2019	73.23
JB/GVJ GeoOffice 8.3	22-07-2019	73.22

Conditions for the survey, which took place between 10.00hr and 17.00hr BST, were fair. The temperature was about 15 degrees Celsius. Although cloudy, the cloud base was over 900m so visibility was good. The wind speed was gusting to about 25mph and the weather was mostly dry during the survey, although rain began to set in near the end of the 2 hours.

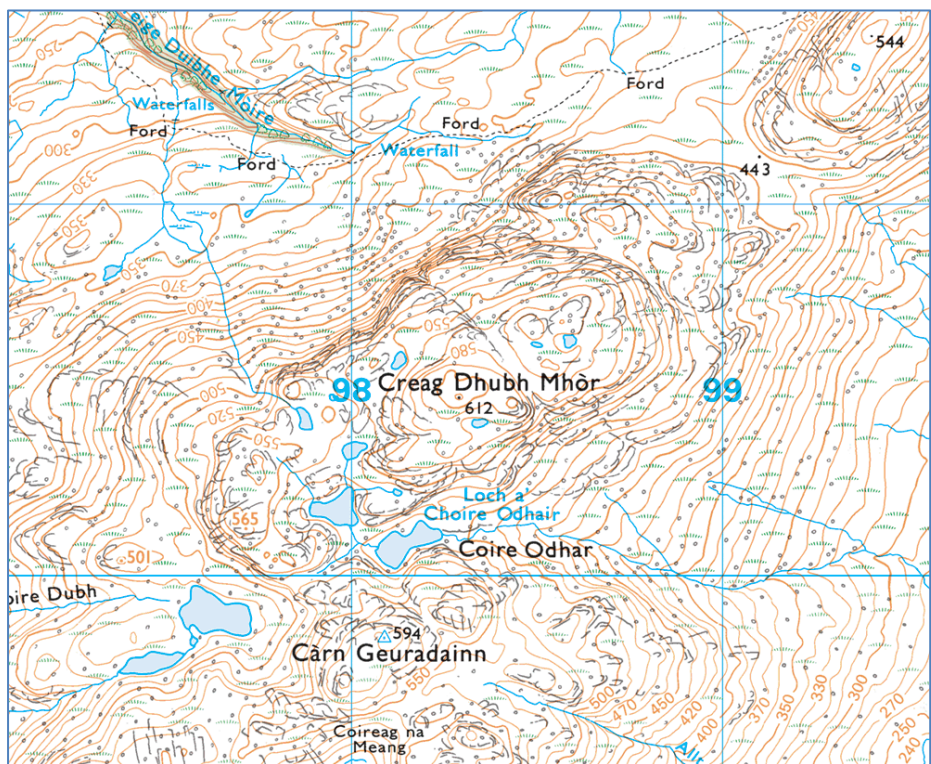
3) Character of Hill

Creag Dhubh Mhor lies about 4km ESE of the village of Strathcarron in the NW Highlands and its summit crags can be seen from the village, rising behind the intervening rough moorland. The village itself is situated at the head of Loch Carron and lies on the railway line from Inverness to Kyle of Lochalsh. There is a hotel and also a small village car park by the station. The traditional route to the summit of Creag Dhubh Mhor starts from the hamlet of Achintee just half a kilometre south of Strathcarron, where a hill path

winds its way through the moorland to the foot of the mountain. However, recent work on a hydro scheme has created a vehicle track that starts just across the railway line at Strathcarron station. This track winds up the hillside and joins (and replaces) the original path after about a kilometre, eventually terminating at NG961417, which is about 500m beyond a new bridge over the stream that issues from Loch nan Creadha.



We chose to follow this track but crossed the bridge to follow a second hill path towards the loch. This path disappears before the loch, but the going underfoot is fair and the vegetation becomes quite short as the steeper slopes of the hill are gained. Our route brought us to a small lochan at NG979404 from where it was just 500m of undulating terrain to the summit. We varied the descent to explore the path that continued from the termination of the new vehicle track. We found the old hill path still to exist until near the bridge and to lie about 20m south of the vehicle track and about 5m in height above it. Our route is shown in the map above (Crown Copyright Ordnance Survey).



An extract of the Ordnance Survey 1:25000 scale map (Crown Copyright Ordnance Survey) showing Creag Dhubh Mhòr is presented above. As this map shows, the summit area is quite complex and undulating and provides several minor summits for those wishing to explore the terrain in more detail. The tops themselves

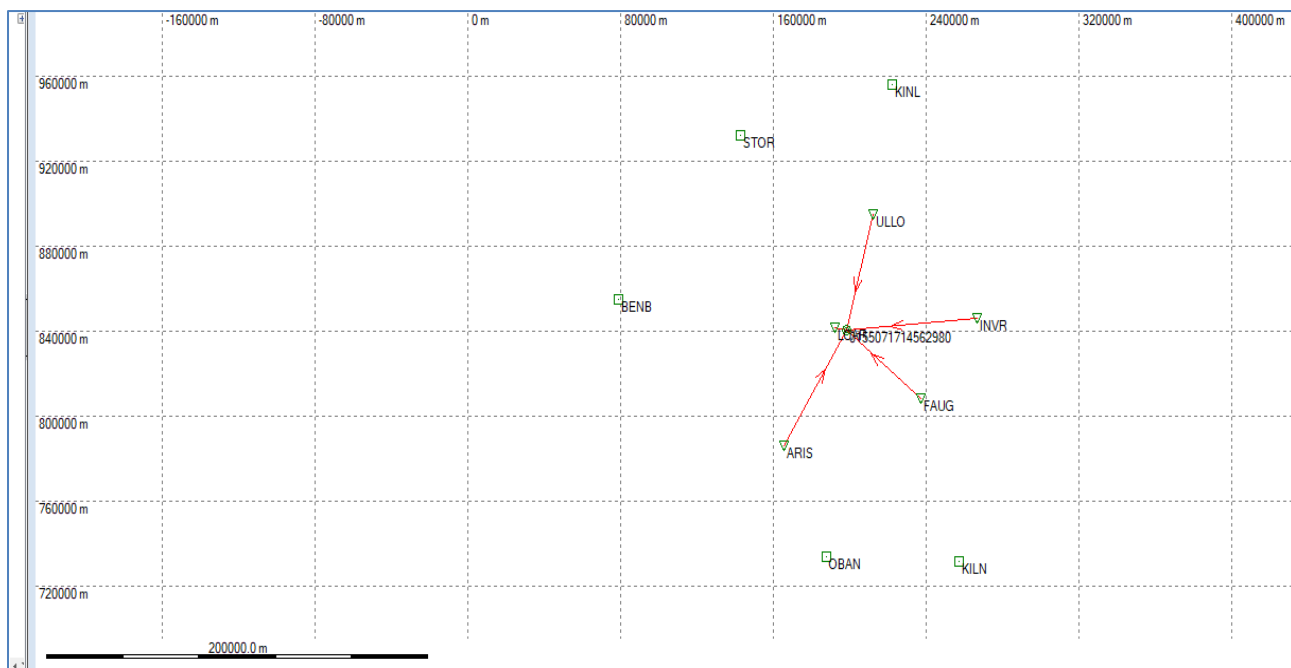
are rocky and scree, many outcrops and small lochans make the summit terrain complex and potentially confusing in mist.

4) Survey of the Summit of Creag Dhubh Mhor

The first task was to locate the position of the summit. Normally this would be done with a Leica NA730 level and staff, but in this case the summit is clearly at the top of a large outcrop with no other candidate positions. This outcrop supported a summit cairn which was removed to make sure there was no hidden higher ground. (The cairn was rebuilt after the survey). The north side of the outcrop was slightly overhanging and dropped about 3m to the grass below, thus providing a sheltered position for us while the Leica Viva GS15 was collecting data.

To obtain an absolute measurement of height the Leica Viva GS15 receiver was mounted on the short tripod assembly directly over the summit position (see photograph in the Appendix). Because of the unstable position of the tripod in this position, its legs were weighted with rocks to improve the support. GNSS data were collected at the point for 2 hours with an epoch time of 15 seconds. A photograph is shown in the Appendix of the tape reading, 0.273m, for the short tripod set up.

The data for the Leica Viva GS15 were processed in Leica GeoOffice 8.3 using the five nearest base stations under 100km distance: (Lochcarron – LCAR 6km, Fort Augustus – FAUG 51km, Ullapool – ULLO 57km, Arisaig – ARIS 63km, and Inverness - INVR 69km). 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 resulting height measurement. The computed Tropospheric model was chosen for the calculations to suit the data collection time and the wide difference in height between the base stations and the summit of the mountain. The vertical offset from measuring point to the summit rock was 0.273m plus 0.255m for the tribrach/hook system and this was used in the calculations. The spatial distribution of the base stations around the the survey point used in the calculations is shown below.



As far as is possible, the base stations should be evenly distributed around the survey points, but in this case there are no Base Stations within 100km, apart from Arisaig ARIS, on the western side of the survey point. Nevertheless, heights measured from each base station were within $\pm 0.07\text{m}$ of the mean result for the summit.

The results are given in the table below: -

System	Easting	Northing	Height(m)
GS15	198284.859	840477.253	610.930

If in order to obtain an improved distribution of Base Stations BENB and STOR are included in the calculations, even though they are more than 100km distant, the height of Creag Dhubh Mhor calculates to be 610.944m which is about 1.5cm higher.

5) Summary of Operating Conditions

Parameter	GS15 Summit
Data Collection summit (min)	122
Number of Base Stations used in Processing for all points	5
Epoch Time (sec)	15
Tropospheric Model	Computed
Geoid Model	OSGM15
Cut off Angle (degs)	15

6) Coordinate Recovery Analysis

In order to verify the precision and consistency of a GNSS dataset, Ordnance Survey (OS) 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 are first processed with reference to only the nearest Base Station, in this case Lochcarron (LCAR). The data are 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 summit measurement for Creag Dhubh Mhor calculated using the Computed tropospheric model are presented below.

Base Station	Code	Distance to Survey Point km.	Height Difference U metres	Separation D_{ij} metres
Lochcarron	LCAR	6	Reference	Reference
Fort Augustus	FAUG	51	-0.0226	0.0260
Ullapool	ULLO	57	-0.0234	0.0319
Arisaig	ARIS	63	-0.0809	0.0809
Inverness	INVR	69	0.0226	0.0292
Oban	OBAN	106	-0.0560	0.0612
Stornoway	STOR	107	0.0579	0.0607
Kinlochbervie	KINL	119	-0.0331	0.0359
Benbecula	BENB	120	0.0277	0.0319
Killin	KILN	124	-0.0157	0.0314

The results show a consistent dataset, as all measured OS Base Stations are within 0.08m distance and height of the OS actual values for Base Station distances up to about 140km. and are below the 0.1m requirement of OS. Normally coordinate recovery is only considered up to 100km distance but there are only five Base stations in this part of Scotland that can satisfy that requirement. Therefore, for this survey we extended the distance to 124km to increase the number of Base Stations used to ten with no apparent loss in accuracy.

7) Discussion of Results

For the Leica Viva GS15, two independent repeatability studies have shown that a 120-minute data collection time with good satellite reception gives heights with a measurement uncertainty of $\pm 0.05\text{m}$ (3 standard deviations).

Since the summit position was easily identified as the top of a rock, we estimate the corresponding uncertainty in height to be $\pm 0.01\text{m}$. Combined with the above data, the overall uncertainty in the height measurement of the summit is $\pm 0.05\text{m}$.

However, the Coordinate Recovery results gave the height of one Base Station to be 0.08m different from the Ordnance Survey value, and therefore we believe a more prudent estimate of the overall accuracy of the height measurement of Creag Dhubh Mhor to be $\pm 0.08\text{m}$.

8) Verification by Ordnance Survey

The GNSS data for the height of Creag Dhubh Mhor and the Coordinate Recovery Data were sent to Mark Greaves at Ordnance Survey. The height has been verified by Ordnance Survey and will result in changes to Ordnance Survey maps.

9) Summary and Conclusions

The **summit** of **Creag Dhubh Mhor** is at grid reference *NG 98284 40477 and is the top of rock supporting a small cairn. Its height is **$610.93 \pm 0.08\text{m}$** .

*Grid References in OSTN15

10) 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 the late 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. We also thank Mark for his support and advice that has helped us carry out our mountain heighting work over the past nine years.

John Barnard and Graham Jackson, 20 July 2019

Appendix 1

The Leica GS15 on the summit of Creag Dhubh Mhor



Tape Reading for vertical Offset

