

Surveys of Swirl How and Coniston Old Man

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The Team:

Surveyors – John Barnard, Jim Bloomer & Graham Jackson

1) Introduction

The heights of Coniston Old Man and Swirl How have long been the cause of controversy. While Coniston Old Man is recognised to be the Historic County Summit of Lancashire prior to boundary changes, it has been suggested that Swirl How should be the true owner of that accolade. The confusion has arisen from the heights given on maps. The Ordnance Survey (OS) 1:50k and 1:10k maps give the height of Swirl How as 802m while the 1:25k map gives no spot height. The 1:50k and 1:25k OS maps give the height of Coniston Old Man as 803m (the 1:10k map gives no height for this hill). So the OS maps are clear that Coniston Old Man is 1m higher than Swirl How and this is the origin of the Old Man being given as the historic county top and also the Marilyn (the drop from Swirl How to its col with Coniston Old Man is only 120m). However, the 1:40k Harvey map gives the height of Swirl How as 803m and that of Coniston Old Man as 802m, hence the uncertainty of the status of the two hills. Whichever of these views is correct there is nevertheless general agreement that the two hills are very close in height.

This uncertainty was recently raised with us by OS who had received an enquiry about the heights of the two hills. Examination of the relevant photogrammetry plates convinced the Geodesy Team that the OS mapping was correct, but we were asked if G&J Surveys had determined the two heights with our GNSS receiver, or if we had plans to do so. Since the two hills were already on our 'to do' list we confirmed that we planned to survey them this year.

2) Equipment used and Conditions for Survey

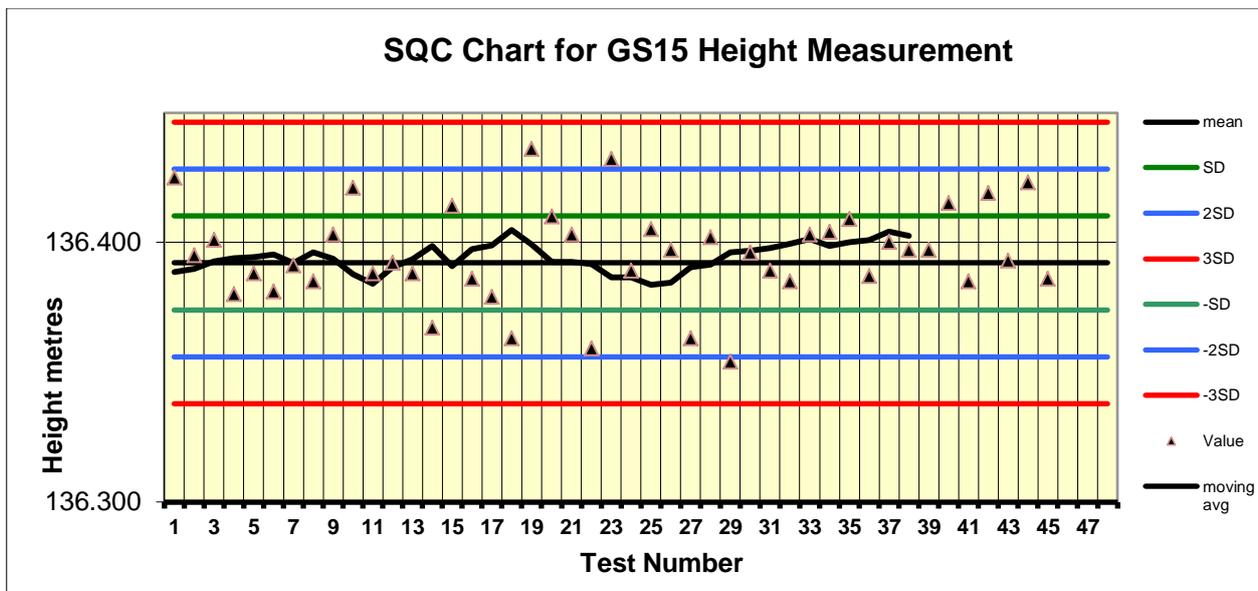
The summit positions were identified using a Leica NA730 Professional Automatic level (X30 telescopic system)/tripod system and a "1m" E-staff extendable to 5m as required by Ordnance Survey.

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 ($\pm 0.01\text{m}$) and heights ($\pm 0.05\text{m}$), 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 $\pm 10\text{-}15$ 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.

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 +/- three SD (Standard Deviation), in this case one SD is +/-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 within about 0.02-0.03m.

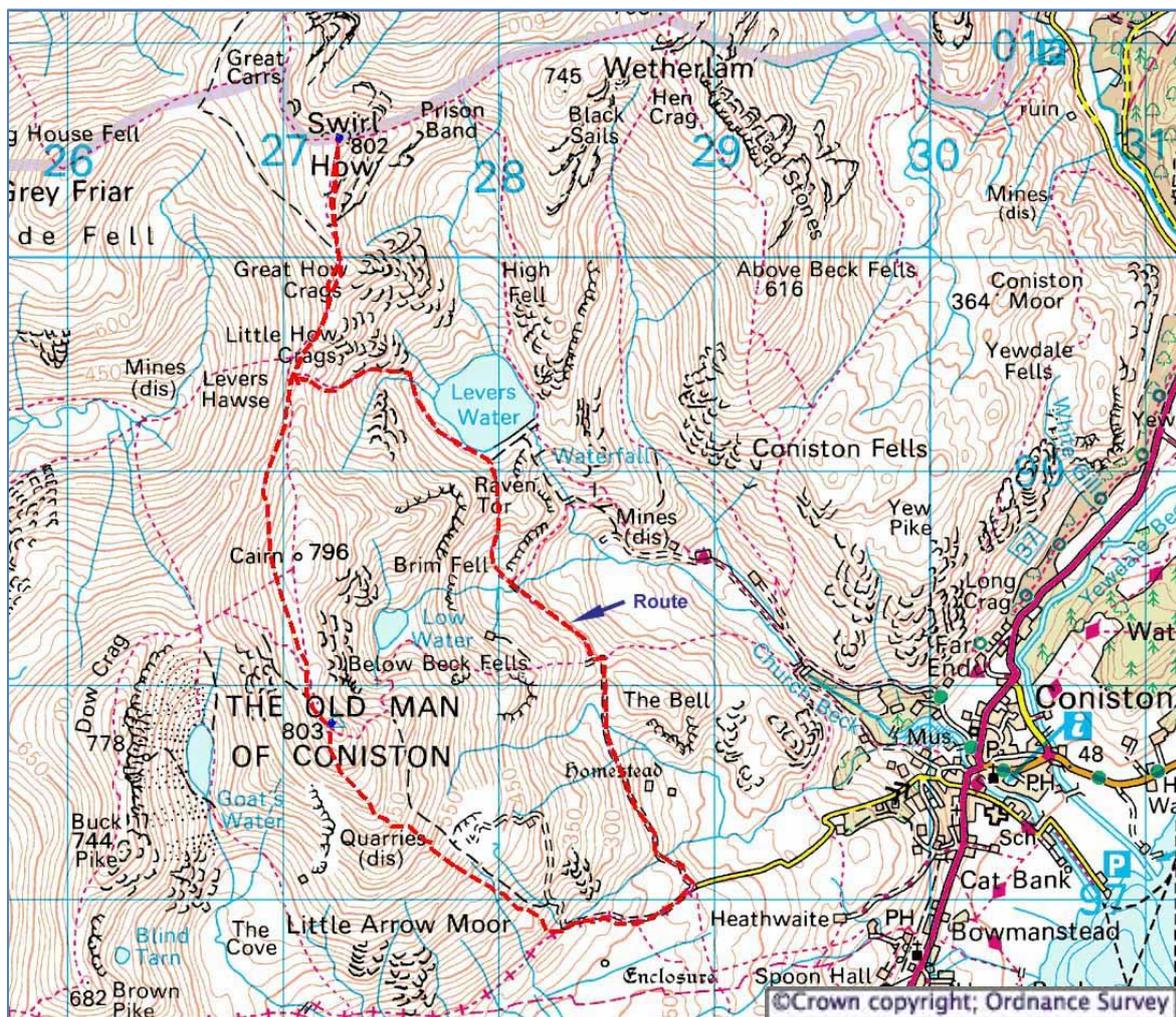
Checks were carried out on 20 November 2017 and 07 June 2018 at the Daresbury Fundamental Bench Mark and the results in the table below show excellent agreement between the Ordnance Survey measurement and our own.

Processing	Date	Height(m)
OS measurement		73.24
JB/GVJ GeoOffice 8.3	20-11-2017	73.23
JB/GVJ GeoOffice 8.3	07-06-2018	73.23

Conditions for the surveys, which took place between 11.00hrs and 16.40hrs BST on 24 May 2018, were good. The temperature was about 22 degrees Celsius. The wind on the summits was light, blowing between 5 and 10 mph and the sky was clear and sunny all day. The weather conditions were ideal for surveying.

3) **Character of the Hills**

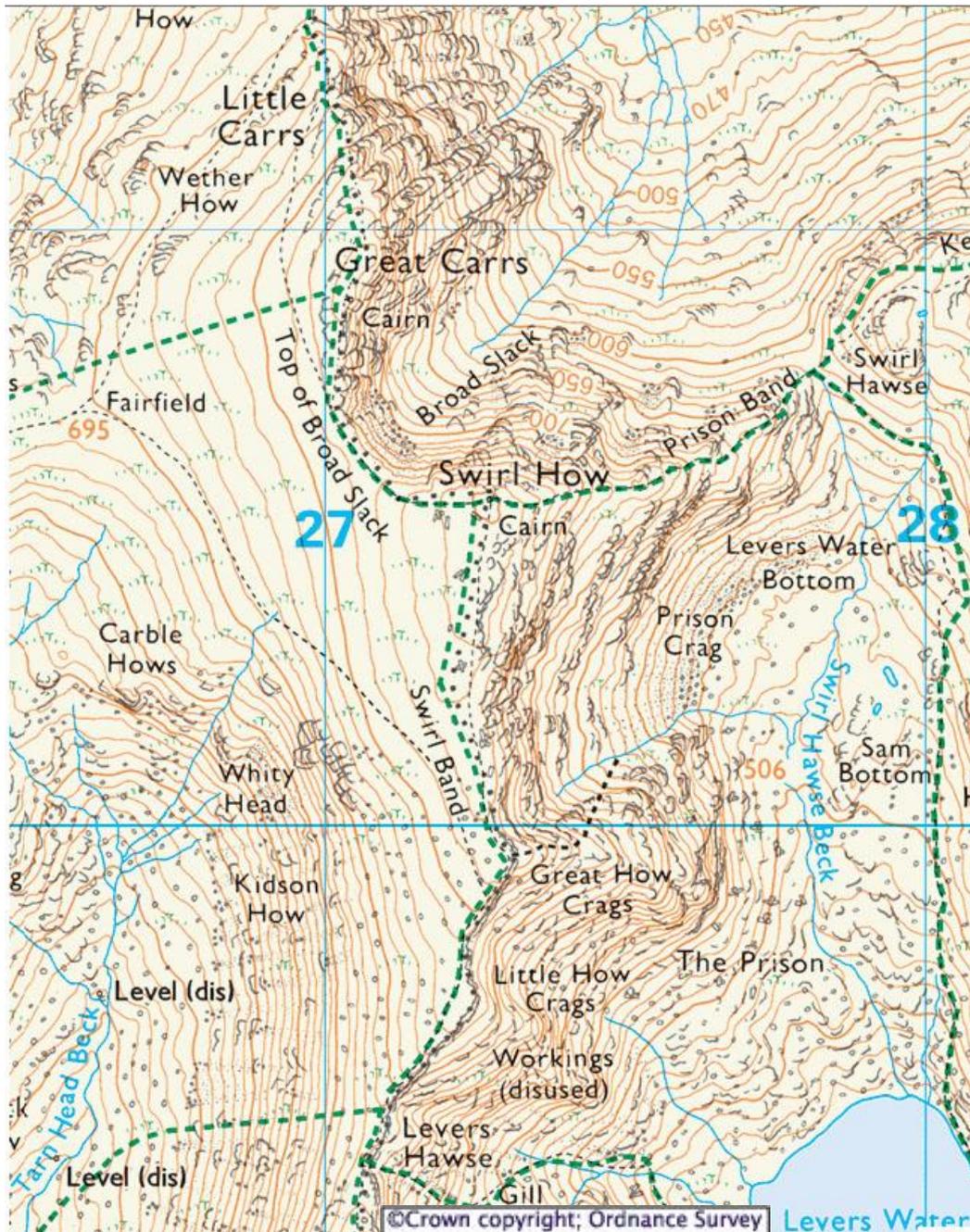
The Coniston fells lie above the village of the same name in the southern Lake District and form a compact group of hills, all of which may be easily climbed in a day's continuous walk. Many well-engineered paths give easy access, but numerous crags add character to the group and indeed Dow Crag itself is a popular venue for rock climbing. The most popular walking routes start from Coniston itself, although access to the group can also be made from Tilberthwaite, Wrynose Pass,



Cockley Beck, Seathwaite and Torver. Our route started from the end of the minor road that rises very steeply WSW from Coniston village to its terminus at 220m where there is off-road parking for at least thirty vehicles. From here the tarmac road becomes a wide track known as the Walna Scar Road and finally terminates at Seathwaite, but this section is not navigable by car. From the car park we took a track North which after a kilometre became a well-engineered footpath that passed Levers Water before striking steeply to the summit ridge. At this point we struck North for a kilometre to the summit of Swirl How.

4) Survey of the Summit of Swirl How

The summit area comprises two adjacent vertical slabs of rock about 1.5m high around and over which has been constructed a large cairn. Approximately 8m away and on a bearing of 280 degrees is an outcrop of rock that, to the naked eye, appears to be lower and the area is also littered with several smaller outcrops and boulders. The OS 1:25k map shows the small extent of the summit area.



The first task for the survey team was to confirm the position of the summit and identify a convenient location to set up the Leica GS15 receiver. We correctly predicted the arrival of many visitors and therefore wished to set the instrument up well away from the immediate summit. The Leica NA730 level was set up by the outcrop 8m West of the cairn and staff readings were taken on the highest vertical slab in the cairn, the outcrop and the location chosen for setting up the Leica GS15 receiver (see photographs in Appendix 1).

staff reading on vertical slab by cairn = 0.289m

staff reading on outcrop (8m away and on bearing of 280 degrees)= 0.479m

staff reading on set-up position for Leica GS15 = 1.668m

vertical slab in cairn is $0.479 - 0.289 = 0.19\text{m}$ higher than outcrop

Leica GS15 set-up position is $1.668 - 0.289 = 1.379\text{m}$ lower than vertical slab in cairn.

The Leica Viva GS15 was set up by 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 0.729m plus 0.255m for the tribrach/hook system. GNSS data were collected for 2hr with an epoch time of 15 seconds.

Ten figure grid references for the highest natural ground acquired with hand-held GPS receivers are:

Garmin Montana 600	NY 27282 00553	Accuracy: averaged	Height = 809m
Garmin Etrex 20	NY 27280 00555	Accuracy: averaged	Height = 807m
Garmin Oregon 450	NY 27281 00554	Accuracy: averaged	Height = 813m

4.1) Results for the Summit of Swirl How

The data for the Leica Viva GS15 were processed in Leica GeoOffice 8.3 using the eight nearest base stations: (Shap – SHAP 31km, St Bees – STBE 33km, Carlisle – CARL 57km, Giggleswick - GIGG 64km, Blackpool – BLAP 69km, Wearhead – WEAR 70km, Kirkcudbright– KIRK 78km and Catterick– CATT 92km). 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 +/-0.04m of the mean result for the summit.

The results for Swirl How are tabulated below:

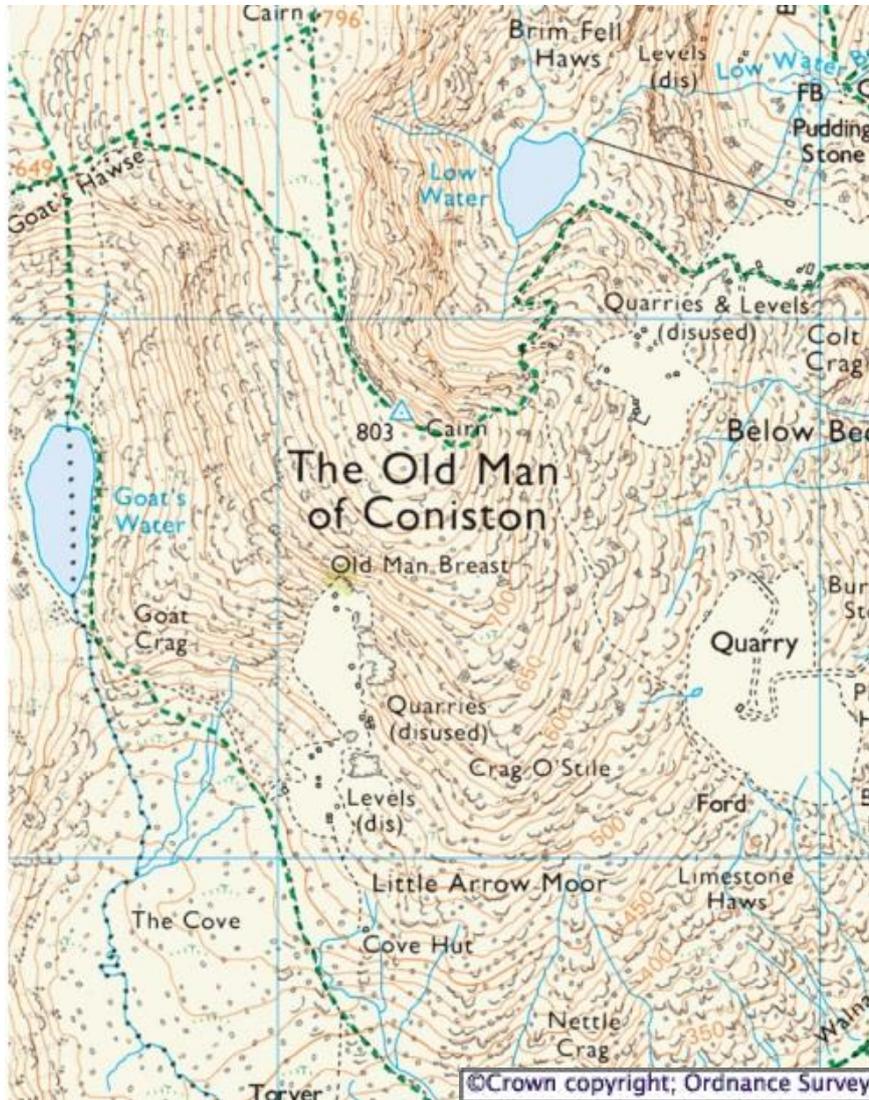
System	Easting	error(1SD)	Northing	error(1SD)	Height(m)	error(1SD)
GS15	327270.113	0.003	500548.339	0.002	801.045	0.012

Height of Swirl How is $801.045 + 1.668 - 0.289 = 802.42\text{m}$

Height of outcrop 8m West of cairn is $801.045 + 0.479 - 0.289 = 801.64\text{m}$

5) Survey of the Summit of Coniston Old Man

Having completed the survey of Swirl How, we now moved to the summit of Coniston Old Man. The summit is adorned by a very large stone plinth measuring very approximately 15m by 10m and near its North East edge it is about one metre in height. On this structure there is a very large cairn. About 15m NW and on lower ground near the edge of the summit plateau is a trig point. Views of the summit area are shown in Appendix 2.



The first task was to find the highest natural ground, which clearly lay somewhere along the perimeter of the plinth. With the level set up at a convenient location on the plinth staff readings were taken of several candidates. The highest natural ground was found on the North East edge of the plinth. Its position is shown in the photograph, where one of the team is holding the staff during the preliminary survey. The rock strata on this position were at an angle of about 30 degrees and pointing into the plinth. Two other positions measured were just a few centimetres lower. These observations led us to conclude it was very likely that higher ground lay beneath the plinth.

During the preliminary survey with the level and staff we also took a reading on the flush bracket of the trig point to enable a comparison with the published Ordnance Survey height for the flush bracket.

The area around the summit was busy with visitors and consequently a suitably quieter location for setting up the Leica GS15 receiver was chosen.

Staff reading for highest visible natural ground = 1.559m

Staff reading at NE Base of cairn = 0.446m

Staff reading at flush bracket of trig pillar = 1.743m

Staff reading at rocks by the entrance to the plinth = 1.733m

Staff reading at GS15 setup point = 2.156m

Base of cairn on plinth is $1.559 - 0.446 = 1.113\text{m}$ higher than highest natural ground

Ground at NW entrance to plinth is $1.733 - 1.559 = 0.17\text{m}$ lower than highest natural ground

Flush bracket on trig pillar is $1.743 - 1.559 = 0.18\text{m}$ lower than highest visible natural ground

Set-up position of Leica GS15 is $2.156 - 1.559 = 0.60\text{m}$ lower than the highest visible natural ground

Ten figure grid references for the highest visible natural ground acquired with hand-held GPS receivers are:

Garmin Oregon 450	SD 27244 97822	Accuracy: averaged	Height = 813m
Garmin Montana 600	SD 27246 97814	Accuracy: averaged	Height = 802m
Garmin Etrex 20	SD 27245 97818	Accuracy: averaged	Height = 805m

The Leica Viva GS15 was set up over the chosen position 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 0.732m 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 Highest Natural Ground on Coniston Old Man

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

The results are tabulated below:

System	Easting	error(1SD)	Northing	error(1SD)	Height(m)	error(1SD)
GS15	327229.173	0.003	497827.718	0.003	801.821	0.002

The highest natural ground on Coniston Old Man is: $801.821 + 2.156 - 1.559 = 802.42\text{m}$

The height of the flush bracket is: $801.821 - 1.743 + 2.156 = 802.23\text{m}$ cf OS value of 802.23m

The height of the ground on the plinth by the cairn is $801.821 + 2.156 - 0.446 = 803.53\text{m}$

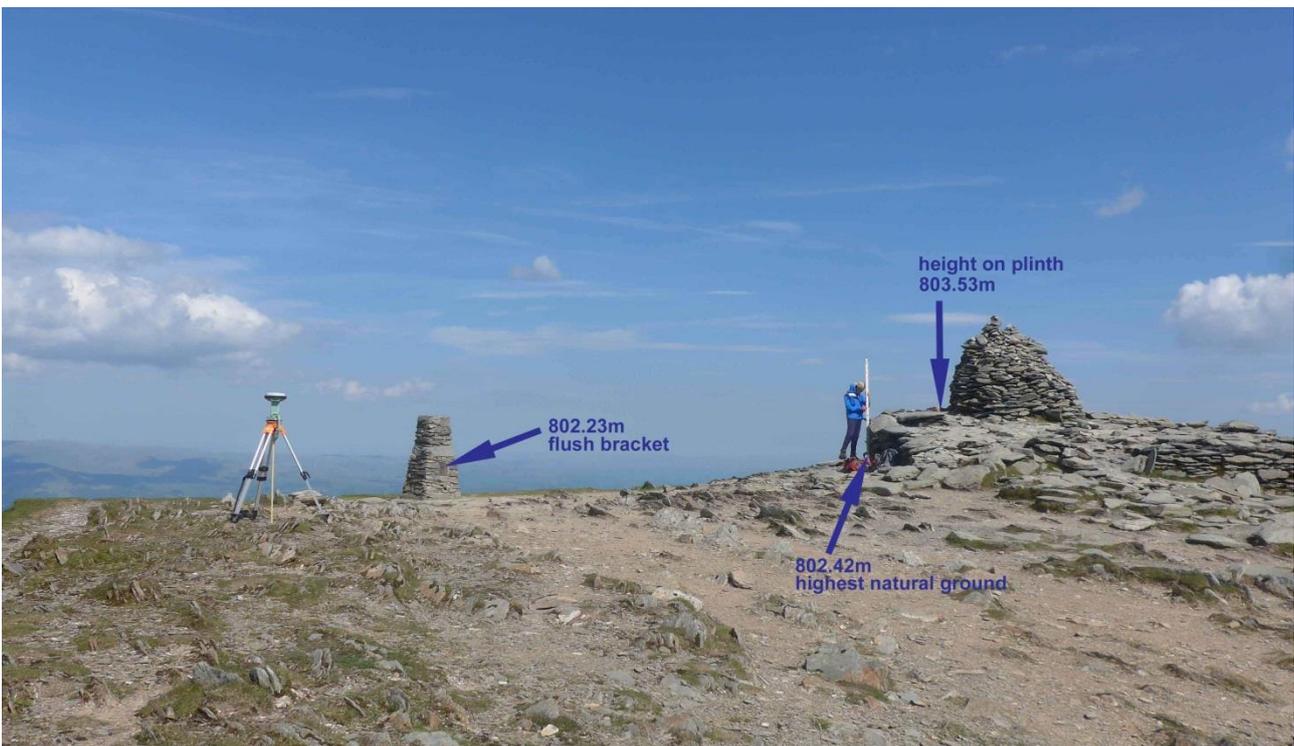
6) **Summary of Operating Conditions**

Variable	Swirl How	Coniston Old Man
Data collection summit (min)	122	121
Number of Base Stations used in Processing for all points	8	8
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 rock, we would estimate the height uncertainty associated with their correct locations to be +/-0.02m. The height uncertainty associated with a 2hr dataset has been measured by us and is +/-0.05m for data processed in proprietary software. The measurement uncertainty for the height of each summit is therefore $(0.02^2 + 0.05^2)^{0.5} = +/-0.05m$.

The height of the highest visible natural ground on Coniston Old Man is 802.42m, identical to the height obtained for Swirl How. The height of the ground on the NE side of the plinth by the cairn is 803.53m; this is man-made ground. The measured value for the height of the flush bracket on the trig point is 802.23m identical to the OS value of 802.23m.



8) 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 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.

Base Station	Code	Distance to Survey Point km.	Swirl How		Coniston Old Man	
			Height Difference U metres	Separation D_{ij} metres	Height Difference U metres	Separation D_{ij} metres
Shap	SHAP	31				
St. Bees	STBE	33	0.0161	0.0231	0.0005	0.0175
Carlisle	CARL	57	-0.0015	0.0062	0.0010	0.0157
Giggleswick	GIGG	64	0.0001	0.0165	-0.0127	0.0142
Blackpool	BLAP	69	-0.0624	0.0644	-0.0090	0.0176
Wearhead	WEAR	70	0.0043	0.0052	0.0063	0.0106
Kirkcudbright	KIRK	78	-0.0158	0.0213	-0.006	0.0200
Catterick	CATT	92	-0.0891	0.0891	-0.0929	0.0936
Eskdalemuir	ESKD	103	0.0009	0.0059	0.0200	0.0256
Manchester	MANR	114	-0.0787	0.0796	-0.0007	0.0146

Apart from Catterick (CATT) at 0.09m for both Swirl How and Coniston Old Man and Manchester (MANR) at 0.08m for Swirl How, all of the datasets have recovered to 0.06m 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) Summary of Heighting Results

The summit of Swirl How is at Grid Reference *NY 27280 00555 and is the top of a natural rock slab around which is built a large cairn.

The highest natural ground on Coniston Old Man is at *SD 27244 97819 and is an outcrop by the NE wall of the plinth.

Both **Swirl How** and **Coniston Old Man** were measured to be **802.42m \pm 0.05m**. However, if one considers the area covered by the plinth on Coniston Old Man and the observation that the highest rock is probably covered by it then we believe the evidence strongly suggests there is higher ground beneath it and that, therefore, Coniston Old Man should retain its current status.

The height of man-made ground on the plinth and by the cairn is 803.53m.

The results have been accepted by Mark Greaves of Ordnance Survey.

*grid references are OSTN15

10) Acknowledgements

Many people contributed to the success of this survey.

We 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, Jim Bloomer & Graham Jackson, 4 June 2018

Appendix 1: Swirl How



Surveying the summit of Swirl How



Summit area with lower outcrop just behind Jim and John and cairn behind camera



Summit position of Swirl How



Measuring the offset, 0.729m, for the Leica Viva GS15

Appendix 2: Coniston Old Man



Summit area of Coniston Old Man



View west from plinth of Coniston Old Man



Leica Viva GS15 collecting data



Measuring the offset, 0.732m, for the Leica Viva GS15