Survey of Pen Coed Mawr

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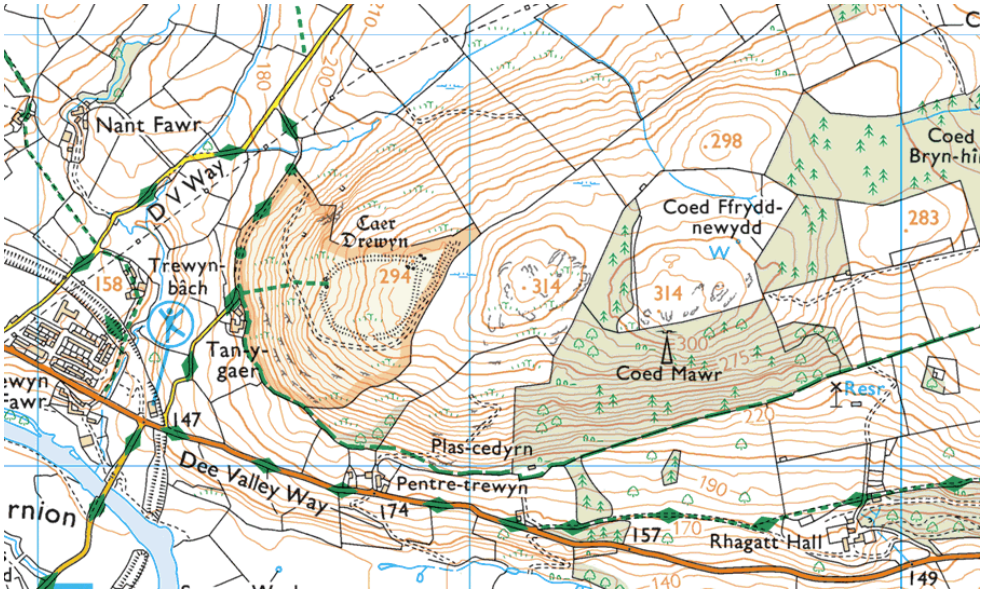
The Survey Team: John Barnard and Graham Jackson

The LIDAR Team: Chris Crocker and George Gradwell

1) Introduction

Pen Coed Mawr (Hill number 7523) lies about 1.5 kilometres northeast of Corwen. It is recorded as a Tump (a hill of thirty or more metres of prominence) in the Database of British and Irish Hills (DoBIH). The 1:25k map, (Fig1: Courtesy Ordnance Survey) shows two tops about 400m apart both with 314m spot heights. The col lies about 1.5km to the north-northeast of Pen Coed Mawr and is close/on the main A5104 road. This point is marked on the OS 1:25000 map with a spot height of 223m. Therefore, the drop for Pen Coed Mawr is measured as 91m, therefore classifying it as a sub-Hump (a hill with 90m to under 100m of prominence).

Figure 1: The Relative Positions of the 314m Spot Heights



While both tops bear 314m spot heights, the drop between them is approximately 15m so only one top can be the summit and have Tump classification, assuming of course that the two tops are not identical in height. The purpose of this survey was to measure accurately the heights of the two tops in order to determine which hill is the higher to qualify as a Tump. The height of the col is irrelevant to this objective.

2) Equipment used and Conditions for Survey

A Leica NA730 Professional Automatic level (X30 telescopic system)/tripod system and a "1m" **E**-staff extendable to 5m were used to determine accurately the positions of the two summits.

Absolute heights were measured using a Leica Viva GS15 receiver. This receiver is a dual-frequency, multi-channel instrument, which means it is capable of locking on to a maximum of 12 GPS, 8 GLONASS satellites and Galileo satellites as availability dictates, and receiving 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.

Note that small hand-held GPS receivers used for general navigation can only receive up to 12 GPS satellites 8 GLONASS satellites and each at a single frequency and therefore these instruments have a poorer positional accuracy of +/-5 metres and a height accuracy of no better than +/-10 metres. More modern instruments can now receive signals from Galileo but this probably has a minimal effect on accuracy where satellite availability is not restricted.

Despite the on-board features of the Leica Viva GS15 receiver, there are still sources that create residual errors. To obtain accurate positions and heights, corrections were made to the GNSS (Global Navigation Satellite System) data via imported RINEX2 and RINEX3 data from Ordnance Survey, which were post-processed using Leica Infinity v4.0.1. Repeated 1hr measurements with the Leica Viva GS15 on the same position with RINEX2 corrected data have shown a height precision of +/-0.06m (to three standard deviations).

Since the beginning of 2022, the Ordnance Survey have made the RINEX correction data available in two forms. RINEX2 data is identical to the RINEX data that has been available for some time and applies only to GPS and GLONASS. However, RINEX3 data is more complex as it provides correction data additionally for Galileo (also BEIDOU) and a range of additional satellite broadcast signals to RINEX2 data. In the authors' limited experience, these additional signals make only a very small change to measured readings when satellite reception is generally good. However, accuracy may be improved in situations where satellite availability is restricted, and shorter collection times with RINEX3 corrected data with improved accuracy may be possible.

The survey of the two summits took place on 6 October between 11.00hr and 15.00hr BST. The weather was mild, 13 degrees Celsius, with a light wind at the start of the survey but this increased significantly during the day. Although cloudy most of the time with rain showers, visibility was good for all the optical measurements.

3) The Survey

3.1) Character of Hills

Pen Coed Mawr lies on the north side of the Dee Valley in a rural area that is used primarily for grazing animals. On the west side of the hill above Corwen lies Caer Derwyn. This is arguably one of the best-preserved Iron Age Hill Forts in Wales and dates back to about 500BC. It occupies the southern end of a range of similar aged Hillforts that extend northwards through the Dee Valley and Clwydian range of hills. This Hill Fort has a long historical record. In 1165 Owain Gwynydd is reputed to have occupied Caer Derwyn in his fight against Henry II who was invading Gwynydd. In 1400 Owain Glyndwr was thought to have gathered his troops here after he had been proclaimed "Prince of Wales" by his followers.

The west top, currently the hill's summit, which is a grassy area, is 20m higher and 200m east of the top of the Hill Fort. The East Top is similar in structure, but is separated from the West Top by a section of woodland through which there is a path with gates for entry and exit.

Access to these hills is quite simple. To the west at the Sports Centre there is currently a free car park. From there a short walk along the roadside leads to a waymarked track to the Hill Fort. The slope of the Hill Fort is quite steep but the path has sections of steps making the ascent easier. However, with the recent rain and the fact that the path is also a well-used sheep track, the ground was very muddy and slippery. Having passed over the stony top of the Hill Fort, a range of indistinct tracks lead over grassy ground to the West Top.

3.2) The West Top

The highest point of the West Top appears to be a low grassy mound topped with a large stone and a few embedded flat stones almost buried in the vegetation, although other points around this area could be as high. We set up the Leica NA730 on a tripod a few metres from this point and took staff readings from candidate summit positions. These observations confirmed that the low mound is the highest point.

The Leica GS15 was set up on a tripod directly over the highest point. (See the photograph in the Appendix). It was noted that the vegetation between the stones was mossy and light. The measuring tape was pushed down between the stones until solid ground was reached. This point was about 0.07m lower than the surface of the stones. The offset of 0.622m plus 0.255m for the tape holder was used as the Antenna Height correction (See the photograph in the Appendix). GNSS data were collected for one hour with an epoch time of 15 seconds. The data were processed in Leica Infinity version 4.0.1 using the ten nearest base stations.

System	RINEX	Easting	Northing	Height(m)
GS15	RINEX2	309127.137	344416.618	313.453
GS15	RINEX3	309127.141	344416.617	313.459

Using the RINEX3 for processing, the height of the West Top was measured to be 313.46m

3.3) The East Top

The East Top was approached from the West Top. Faint tracks lead down to a wall that edges the wood between the two tops. A stile next to a gate leads into the wood and there a track was followed to the opposite of side of the wood where there is another gate. Through the gate, the summit of the East Top is then a short walk up a grassy slope.

The position of the highest point was not clear and there were several contenders. The Leica NA730 level was set up on a tripod at a convenient position where all the possible contenders could be easily observed. Staff measurements were taken at all these points and the highest point was confirmed as the top of an embedded immovable rock that was covered with moss. (See the photograph in the Appendix).

The Leica GS15 was set up directly over the summit. The offset of 0.525m plus 0.255m for the tape holder was used as the Antenna Height correction (See the photograph in the Appendix). GNSS data were collected for one hour with an epoch time of 15 seconds. The data were processed in Leica Infinity version 4.0.1 using the ten nearest base stations.

System	RINEX	Easting	Northing	Height(m)
GS15	RINEX2	309432.972	344362.495	312.999
GS15	RINEX3	309432.973	344362.495	313.004

The height of the East Top is 313.00m which is 0.46m lower than the height of West Top.

4) Summary of Operating Conditions

	GS15
Data collection on West Top (mins)	62
Data collection on East Top (mins)	61
Number of Base Stations used in Processing	10
Epoch Time (sec)	15
Tropospheric Model	VMF with GPT2
Cut off Angle (degs)	15
Geoid Model	OSGM15

5) LIDAR

LIDAR data at 2m horizontal resolution is available for both summits, courtesy of Natural Resources Wales.

5.1) West Top

DTM summit is 313.065m at SJ 01924 44410. DSM 313.091m.

The DTM summit is 7m SSW of the surveyed summit and 0.39m lower. The DTM height at the surveyed location is 312.9m, c.0.55m than the surveyed height; note it falls between points on the 2m grid.

The average of the two GPS submissions predating the survey, which are 1m apart, are only 2m from the surveyed location.

The transects in the Appendix capture most of the ground above 312.5m. They show the summit as an approximately circular shallow mound rising by *ca.* 0.6m over an 18 x 16m area.

The DSM heights in the summit area are 0-3cm above the DTM heights, consistent with grass. 10m SE of the surveyed location is an area of c.7m^2 where the DSM is 20cm higher, suggesting taller vegetation.

5.2) East Top

DTM summit is 312.990m at SJ 09438 44364. DSM 313.008m.

The DTM summit is 5m W of the surveyed location and 1.4cm lower. The DTM height at the surveyed location is 312.9m, 0.1m lower than the surveyed height. Here again it falls between points on the 2m grid; the point 1.8m NW is 312.975m.

The solitary GPS submission is closer to the LIDAR summit (2m). However the variation in DTM heights is less than 0.1m hereabouts.

The summit is on a shallower mound than the West Top, the central part rising by *ca.* 0.6m within a 30 x 22m area.

DSM heights are 0-5cm above the DTM in the summit area.

6) Discussion of Results

6.1) Survey

For GNSS results from the Leica Viva GS15, a 1-hour data collection time gives results with a measurement uncertainty of +/-0.06m (3SD) where there is a clear view of the sky. This measurement uncertainty therefore applies to both the West and East Tops. However, for the West Top we estimated that there was an additional measurement uncertainty of +/-0.05m in the height measurement associated with the location of the summit position. Since the summit position for the East Top was the highest point of an embedded rock, the height uncertainty is much less and we estimated it to be less than +/-0.01m.

Combining the uncertainties estimated above we give the overall values as: -

West Top: $\sqrt{(0.06^2 + 0.05^2)}$ = +/-0.08m (3SD)

East Top: $\sqrt{(0.06^2 + 0.01^2)}$ = +/-0.06m (3SD).

Since the West Top is higher than the East Top by 0.46m and using the above uncertainties, we can conclude confidently from these measurements the summit position of Pen Coed Mawr.

6.2) LIDAR

The error in the LIDAR height at the West Top is unusually large for grassy terrain. The summit position is also 7m out. It is not due to the DTM algorithm incorrectly removing height, as often happens with rock, because the DSM is barely higher.

The mound on the West Top resembles the remains of an old cairn with stones firmly embedded. The *ca.* 0.2m high stone in the foreground of the photo (Appendix) was disregarded as it was moveable. The surveyors dug down into the mossy/grassy growth to reach firmer ground *ca.* 0.1m lower than the surface on the mound. They estimate this location was no more than 0.1m above the ground surrounding the mound. We can therefore exclude the possibility of the 0.5-0.6m LIDAR error arising from a rock or a steep rise that might not be picked up at 2m horizontal resolution.

The statement on vertical accuracy on the website portal reads:

Our specifications require the absolute height error to be less than ±15cm. This is the root mean squared error or RMSE. It quantifies the error or difference between the Ground Truth Survey and the LIDAR data. With our more recent surveys we see this fall to about ±5cm. We expect the relative height error (random error) to be no more than ±5cm.

From similar statements published by the Environment Agency for English data we can assume the 5cm figure for relative height error is also the RMSE. The ± prefix, though often seen in the literature, is incorrect and can be misleading as the RMSE statistic is a positive number and a type of average, not a confidence interval. An individual error could be considerably higher, up to *ca.* 3 times the RMSE if the error is mostly random rather than systematic. It should be noted that the Ground Truth Survey is conducted on bare ground at selected locations. The specification does not include errors arising from the DTM algorithm's attempts to remove vegetation and man-made objects, though that is not a significant factor here.

The accuracy of the LIDAR data on uneven ground is limited by the 2m resolution. Nevertheless, the error in the West Top is well outside the expected range both from the specification and from

previous results. In 24 LIDAR vs. GNSS comparisons on other hills in grassy terrain, 12 at each LIDAR resolution, the mean absolute error in summit height was 7cm for 1m data and 8cm for 2m data. Most of the errors are below 0.1m, with the maximum error 0.28m and 0.29m respectively.

The LIDAR error is much lower at the East Top, well within the range seen in previous work. Yet the terrain is similar at the two summits.

We can only conclude that data quality was poor at the West Top. If not a data processing error, it might arise from a low point cloud density, leading to interpolation between more widely separated laser returns than would be satisfactory for 2m data. It is possible, though rather unlikely given the geographical separation, that the data at the two summits come from different surveys, but the difference in errors is too large to be accounted for by systematic error alone.

7) Summary and Conclusions

The **summit** of **Pen Coed Mawr** is the **West Top** at grid reference * **SJ 09127 44416** and is ground within a small vegetated stone mound. Its height is **313.46m+/-0.08m**.

The **East Top** of **Pen Coed Mawr** is at * **SJ 09432 44362** and is the top of a moss-covered rock. Its height is **313.00m+/-0.06m**. This is **0.46m lower** than the **West Top.**

The LIDAR data is unusually poor at the West Top, though good at the East Top. The data would have led us to conclude the West Top is most likely higher, but far from conclusive given the difference of 0.075m.

*NB: Grid references to OSTN15 are quoted in the summary.

John Barnard, Chris Crocker, George Gradwell and Graham Jackson, 11 October 2022

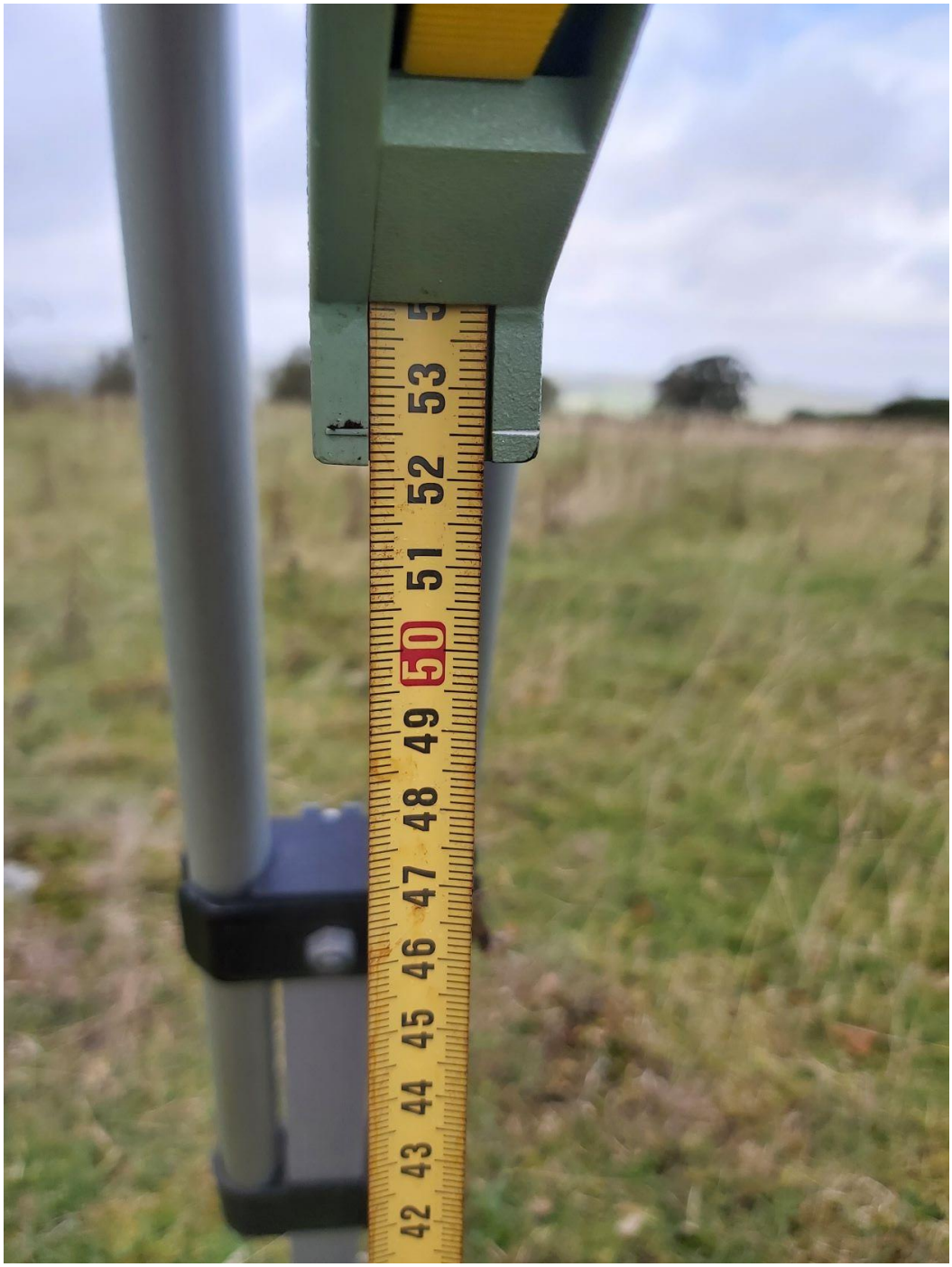
Appendix

The set-up position of the Leica GS15 on Pen Coed Mawr West Top (Looking southeast)

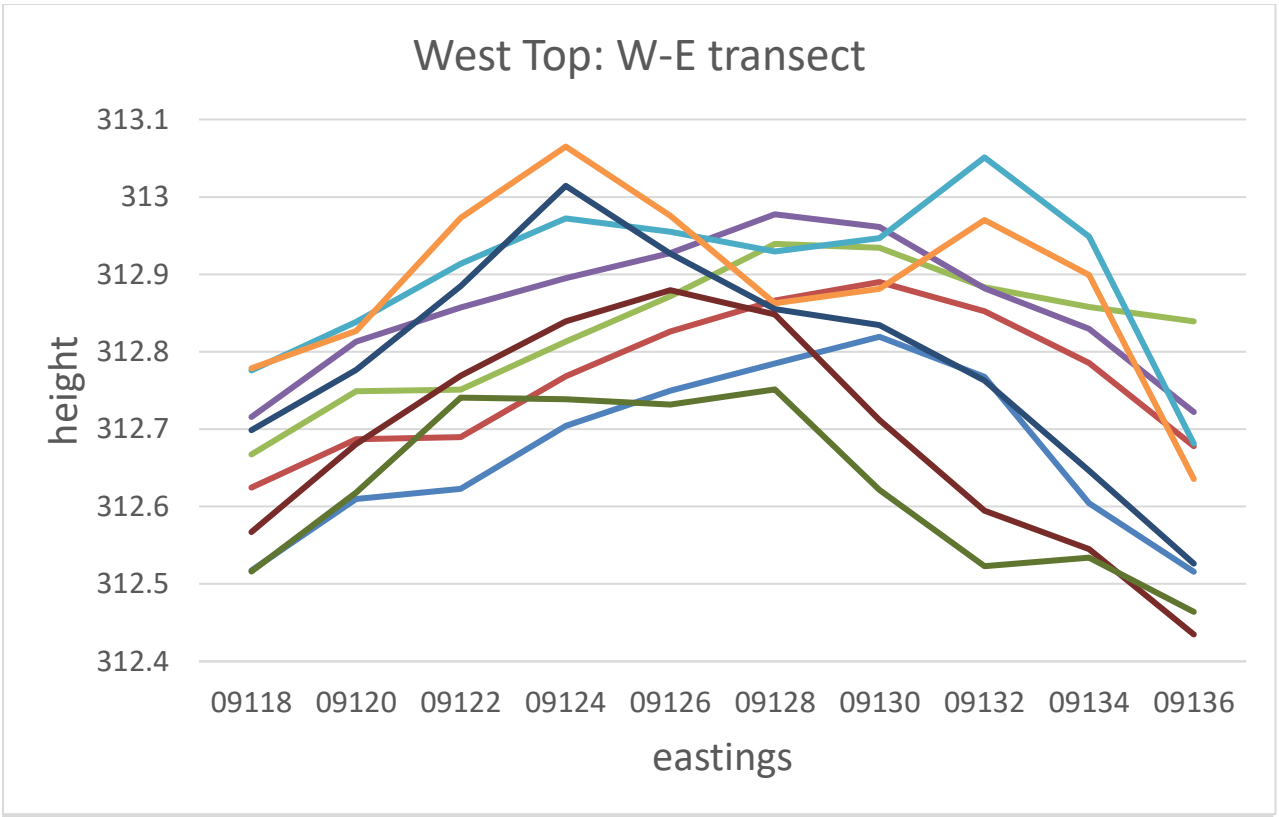
Tape reading for Leica GS15 on Pen Coed Mawr West Top

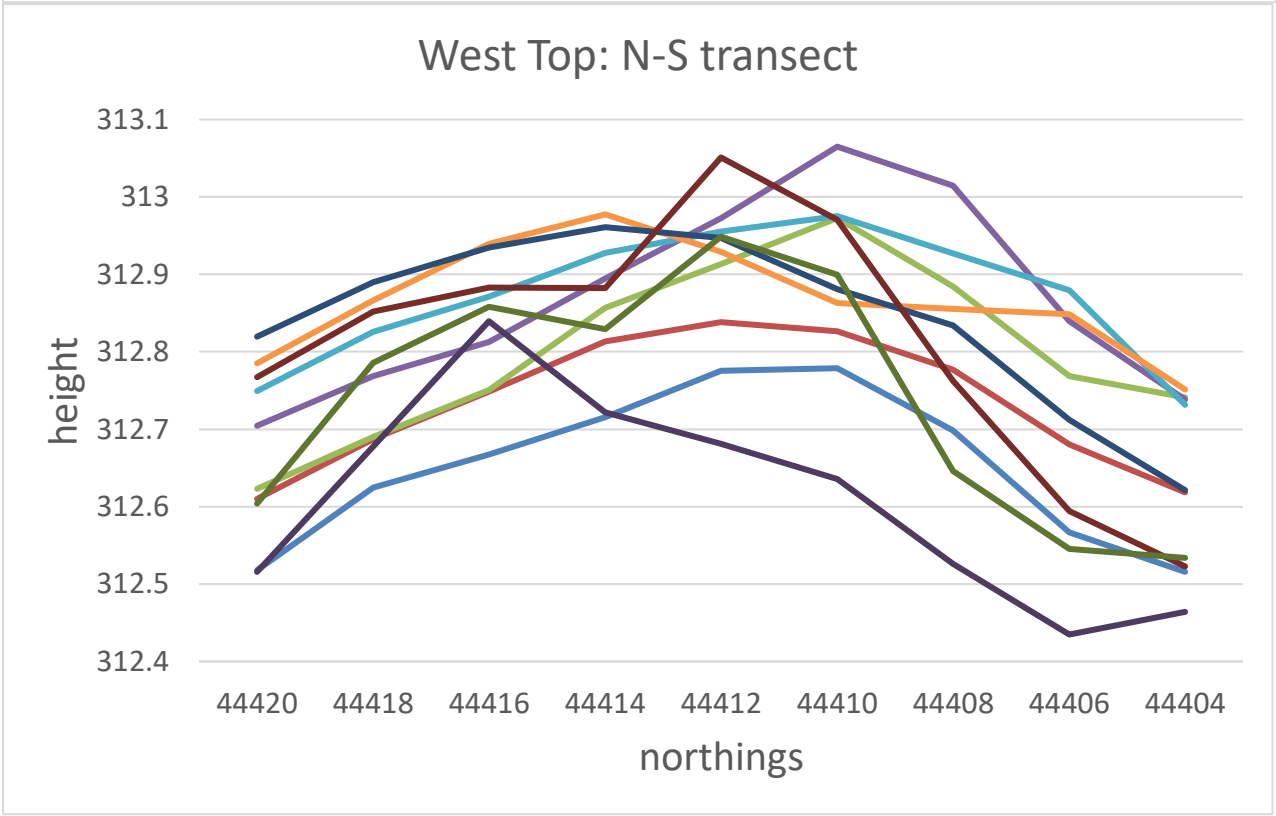
Leica GS15 collecting data on Pen Coed Mawr East Top.

(looking south)



Tape Reading for Leica GS15 on Pen Coed Mawr East Top





Transects in the LIDAR DTM data over the 9 x 8m summit area of the West Top