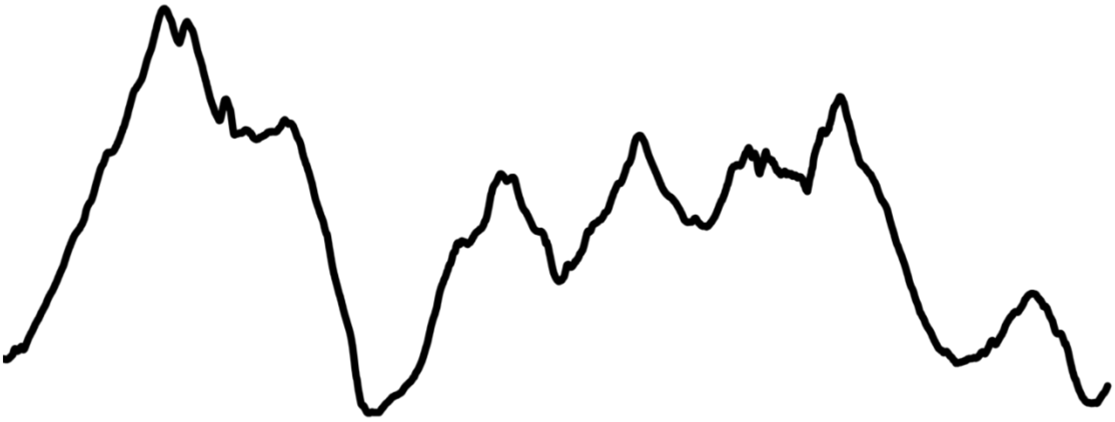

FJÄLLMARATON'S GUIDE TO MEASURING ELEVATION

Introduction

Before each race – and particularly before creating a new route – we try to measure exactly how many metres of elevation are included, but each year we're faced with the same questions after the race: 'How much climbing did we actually do? My watch only shows XXXX metres of elevation. Why did my friend's watch measure more?'

In a bid to get to the bottom of the issue this year, we drafted in the expertise of Sports Tech Research Centre, part of Mid Sweden University and currently leading a research project into Augmented Sports. Along with their input and the most accurate elevation data (grid 1+) from Lantmäteriet, the Swedish mapping, cadastral and land registration authority, we have been able to compare our method, primarily built around open data and freely accessible tools, with the best available.

What follows below is a detailed account of our findings and a guide on how best to measure elevation in the Swedish mountains.

Measuring elevation

Measuring elevation is a lot like measuring the length of a coastline; it's a fractal problem in which the result is dependent on how you choose to measure – there's no one correct answer. It depends on how much truly accurate data you've got, but it doesn't end there: even if you've got meticulous data, you've got to decide whether you're measuring up and over every single stone. Curious? Check out 'coastline paradox' on Youtube.

The website that we use for our elevation calculations has a really great article on measuring elevation: gpsvisualizer.com

Acquiring elevation data

There are two main ways to acquire elevation data and measure the amount of climbing in a race.

- Watch or handheld GPS device
- Digital Elevation Models (DEM)

Watch or handheld GPS with barometer

Watches surely represent the most common way that we as a population have become used to measuring metres of vertical gain, but it's worth saying that accuracy varies from model to model. It comes down to whether your watch contains an in-built barometer, and how intelligently your watch manufacturer or training platform are able to process elevation – particularly if the watch has relied exclusively on GPS satellites to measure the elevation gain.

A watch with a barometer measures changes in air pressure; the higher you are, the less pressure. Barometers tend to be a reliable way to measure changes in altitude; you can get a decent reading just, for example, by knowing what altitude you started at. However, even this method isn't error-free. Here are some straightforward tips to achieve better readings:

Errors:

- Wrong starting point.
- Blocked or obstructed sensor opening for the barometer = inaccuracy. (Usually a hole on the side of your watch face)
- Incoming high or low pressure, fast-changing weather conditions
- Windy days – pull your sleeve over your watch to prevent this from being an issue.

To improve measurements:

- Give your watch time to adapt to the weather conditions and location before starting.
- Manually calibrate the starting altitude if you know how high you are. Alternatively, let the watch obtain the initial elevation data using GPS satellites. Compare it to what's written on a map.
- Set your watch to use a high points per second (sampling rate) of 1s instead of SMART/automatic.

Watch or handheld GPS device without a barometer

A watch without a barometer relies on GPS signals for elevation, but a GPS signal's vertical accuracy can vary +/- 100m, while horizontal accuracy is often in the realm of +/- 10m. When your elevation data is this ill-defined, your watch's reading in that moment will reflect the same thing – when you later sync your watch, you may notice further differences.

Take, for example, Garmin CONNECT, STRAVA, and other platforms, which have developed functions to correct elevation gain. They work by substituting the collected data from your watch with an elevation model and then apply any relevant thresholds in the same way that we do. (We'll get onto the topic of models and thresholds later…)

Other deviations in elevation data comes down to the fact that websites and platforms use different elevation models and refer to different threshold values. We've compiled a few examples in the references.

Digital Elevation Models (DEM)

Given the discrepancies between the ways that us runners measure elevation, it is sensible to look outside the sport and refer to nationally or internationally acquired elevation data that comes in various levels of accuracy. The source of the most exact data is, in fact, the same data that is used for flood analysis. Digital elevation models can be created in various ways – through satellites, achingly accurate GPS data, or by low-flying planes equipped with LIDAR technology (find out more about **L**ight **D**etection and **R**anging and the other method here).

How do we do it?

Step 1: GPS file with the route

Use, or create, a GPS file of the route on a horizontal plane. For us, this is usually a mix of recorded runs, previous race editions, and self-sketched sections if new. To generate the GPS files (routing, copying and pasting), we use a combination of tools including gpsvisualizer.com, WTracks, JOSM and QGIS.

Step 2: Replace elevation data

Replace the elevation data in the GPS file with the assistance of a digital elevation model – when possible, using the best one that exists in Sweden: grid 1+ from Lantmäteriet. There are also a number of free elevation models, and we often use the tools available through gpsvisualizer.com where you can both replace the data and create elevation profiles.

Figure 1 | Elevation model options available on gpsvisualizer.com (best available source works well).

Step 3: Calculate and verify the total climbing

In order to obtain a correct calculation of vertical gain throughout a race, we begin by filtering the data horizontally and vertically, then setting the threshold for the calculations. If there's any noise in the GPS file (which comes from someone standing still or moving really slowly at any point), we work from the understanding that a GPS point has to be at least 2 metres from the previous one it'll be calculated against. For a more detailed explanation, check out the guide at gpsvisualizer.com.

When it comes to choosing what vertical threshold to set, there are some useful guides including Tracedetrail/ITRA's 'How to calculate elevation gain' tool, which suggests setting a threshold of 3 metres if you're using a GPS track with a barometer. In short: calculate elevation gains or losses if there's at least 3 metres of altitude difference from the preceding point. If we were to use these values on our GPS tracks with the elevation data from gpsvisualiser, we'd be doing a disservice to the actual vertical gain on the route. As Sports Tech Research Centre have shown us recently, there's a more accurate way to do things…

To investigate what settings we should use, we decided to compare various methods of measuring elevation for the races held during the week of Fjällmaratonveckan 2021. We used GPS tracks from Garmin Fenix watches (with barometers) as the basis and compared those with the elevation that the top finishers recorded on their own watches. This was then compared to grid 1+ data from ©Lantmäteriet using Matlab. Using the values in the table below, we could determine which vertical threshold values on the open DEM data from gpsvisualizer produced results that were closest to Lantmäteriet's data. This also let us check that it was all aligned with the data from those who had raced.

	Barowatch example			STRAVA Average Top		LM - VT=3	GPSv Settings HT=2. VT=1		Error	
Race	Watch	Distance	Elev.	Distance	Elev.	Elev.	Distance	Elev.	%Off	mOff
VK	Fenix 5X	4.92	1028	4.87	1037	1021	4.97	1016	0,5	5
8K	Fenix 6s Pro	7.41	189	7.41	189	172	7.41	185	-7,6	-13
12K	Fenix 5s	12.28	317	12.26	308	321	12.25	309	3,7	12
27K	Fenix 5X	26.14	958	26.08	940	942	26.22	924	1,9	18
45K	Fenix 5X	45.61	1915	45.33	1886	1873	45.89	1863	0,5	10
100K	Fenix 5X	100.15	3133	100.25	3209	3091	100	3071	0,6	20

Figure 2 | Comparison of different ways of calculating total elevation

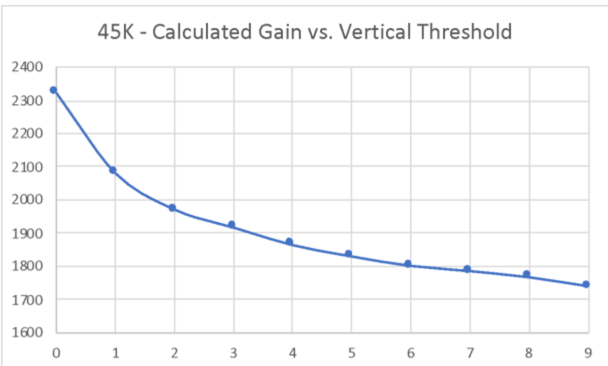

Figure 3 | Example of how a threshold that's too low overestimates the elevation gain, whereas a threshold set too high underestimates the figure

Results

By having a good GPS track, replacing the elevation data with the best available data through gpsvisualizer.com and setting the thresholds (horizontal 2 metres, vertical 1 metre), we ended up with an elevation discrepancy of 20 metres at max across all the races from 5 km to 100 km.

The reason we need to use such a low threshold (1 metre) is apparent when you look at the 8 km race route, shown below – the black line is the elevation data taken directly from a watch; it is fairly effective when it comes to detecting changes in altitude, but it wasn't calibrated at the beginning of the run so the whole line is shifted upwards. The blue line shows the accurate data from Lantmäteriet and the red line is the less accurate data from gpsvisualizer. Looking closely at the red line, you can see it's a little bit more mellow than the blue one and not capturing the intricacies of the ups and downs in the same way. This is why we need to use a 1 metre threshold for this data, while Lantmäteriet works effectively with a 3 metre threshold. How did we work out that 3 metres of vertical is suitable for Lantmäteriet data? That's from looking closely at the Vertical K route, which starts at Åre torg (396 masl) and basically finishes at the very top of Åreskutan (1,417 masl), which equates to 1021 metres of elevation gain.

However, to get an even more accurate impression, there are two slight downhills on the route of the Vertical K, which should result in a few more vertical metres to the total.

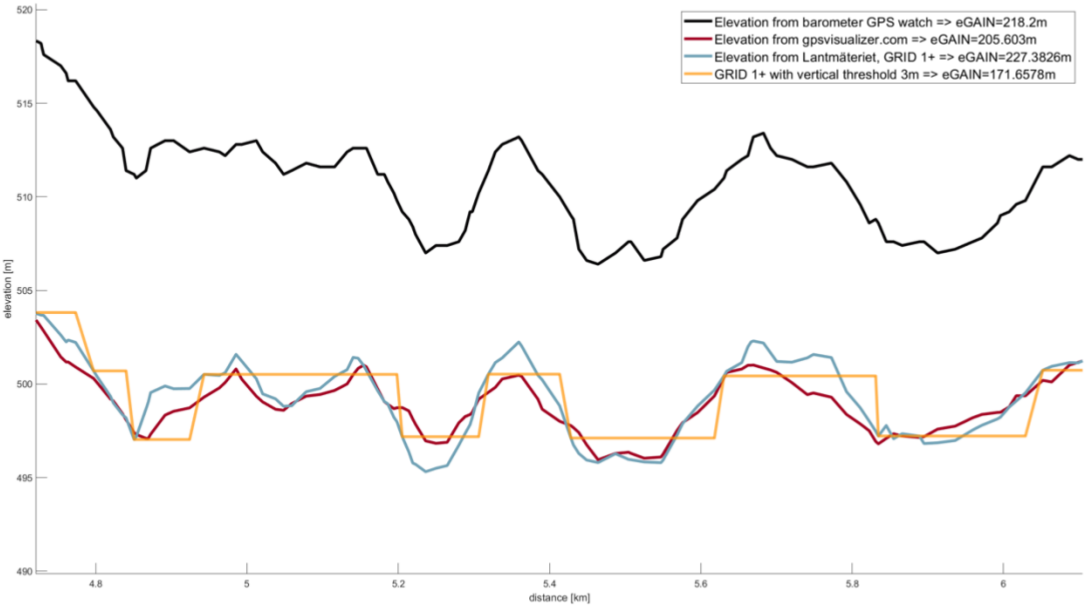

Figure 4 | Detailed comparison of elevation data from various sources. © Lantmäteriet.

Conclusion

We are now completely confident in how we measure elevation and we've even had an insight into how our races would be judged by ITRA/UTMB.

What matters most is that you, as athletes, also have the same confidence and awareness of what awaits. A few races will now be updated with corrected elevation data so that they should align even more closely with what's on your watches. However, it's still likely that certain figures will be rounded up to the closest 50 or 100 metres.

Huge thank you to the Sports Tech Research Centre for helping us carry out this analysis.

Examples from the Fjällmaratonveckan 2021

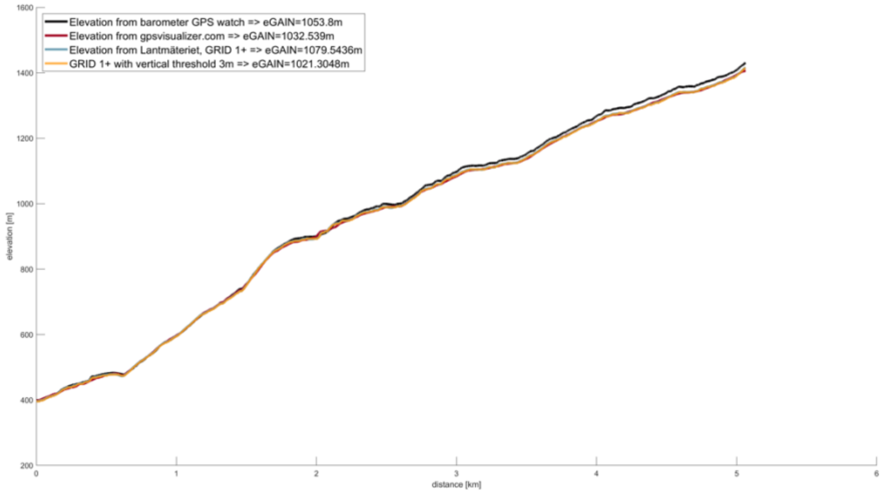

Figure 5 | Vertical K, the reference for determining the threshold with Lantmäteriet's data. ©Lantmäteriet

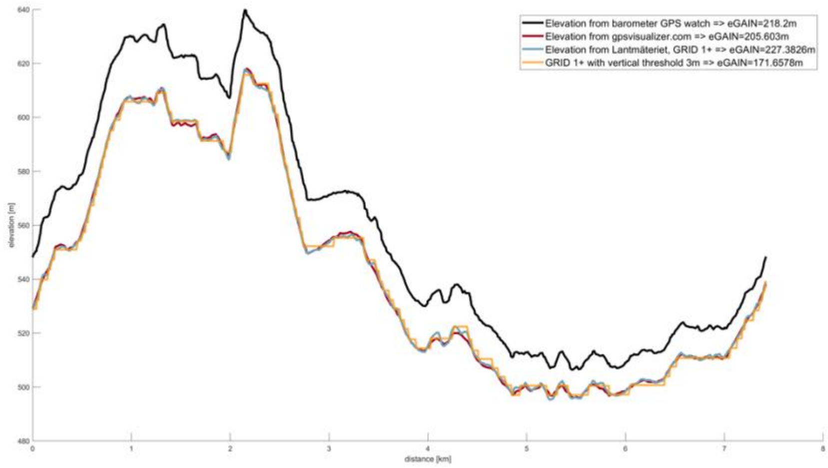

Figure 6 | 8K, an example of an un-calibrated GPS watch. ©Lantmäteriet

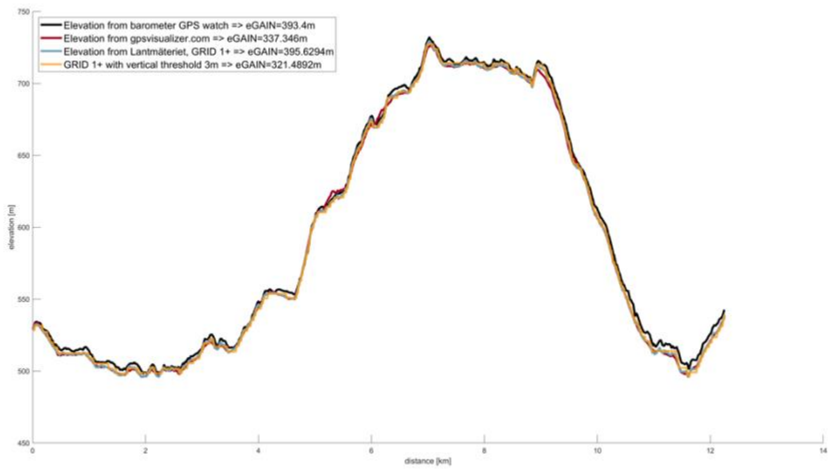

Figure 7 | 12K. ©Lantmäteriet

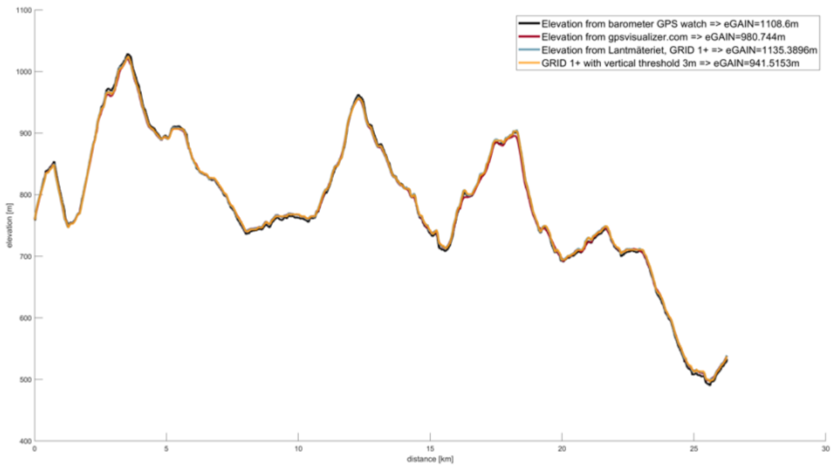

Figure 8 | 27K ©Lantmäteriet

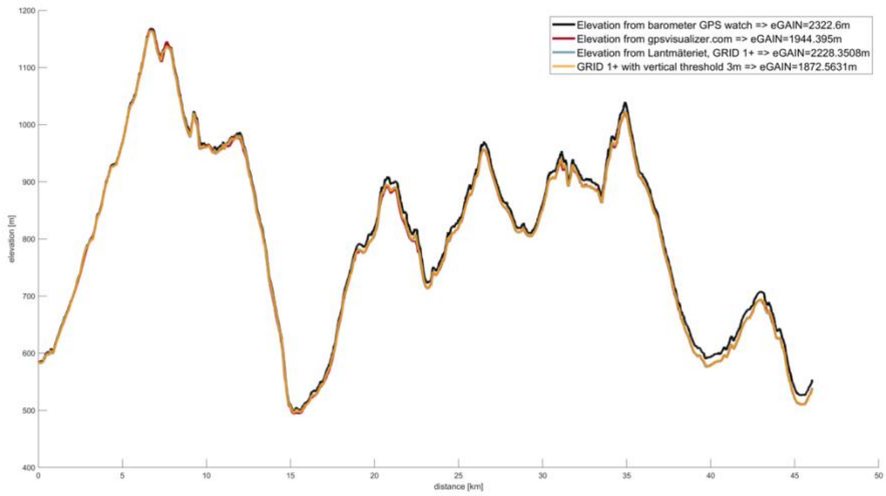

Figure 9 | 45K, an example of a watch that correctly records elevation in the first 15k but then drifts slightly ©Lantmäteriet

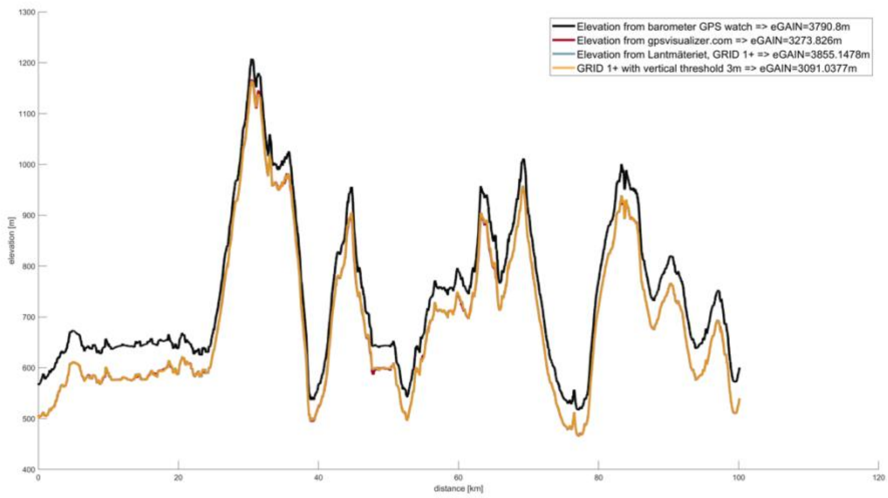

Figure 10 | 100K, an example of an un-calibrated watch. The recorded vertical gain is correct, but actual altitude, such as at the summits, is incorrect. ©Lantmäteriet.

References

General

Research Project Augmented Sports
https://www.miun.se/Forskning/forskningsprojekt/pagaende-forskningsprojekt/augmented-sports/

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GARMIN elevation correction
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Trainingpeaks elevation correction
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STRAVA elevation correction
https://support.strava.com/hc/en-us/articles/216919447-Elevation-for-Your-Activity

COROS elevation
https://support.coros.com/hc/en-us/articles/360040008132-Why-the-elevation-may-not-be-accurate-

Elevation models and thresholds

Lantmäteriet's Elevation Models
https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/produktlista/markhojdmodell-nedladdning-grid-1/

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Norway's Elevation Models
https://hoydedata.no/LaserInnsyn/

Tracedetrail/ITRA – How to calculate elevation gain
https://tracedetrail.fr/en/accueil/help/calcul

Everything you need to know about Digital Elevation Models
https://up42.com/blog/tech/everything-you-need-to-know-about-digital-elevation-models-dem-digital

GPS Visualizer
https://www.gpsvisualizer.com/tutorials/elevation_gain.html

GPS Visualizer: Link with settings
https://www.gpsvisualizer.com/profile_input?format=svg&legend_placement=none&lightness=0&margin=50&margin_bottom=40&margin_left=60&margin_right=50&margin_top=20&profile_axis_titles=0&profile_trk_separators=0&profile_x_div=20&profile_x_labels_horizontal=1&profile_x_max=50&profile_x_min=0&profile_y_div=15&profile_y_max=1200&profile_y_min=450&saturation=0&text_size=20&trk_colorize=none&trk_elevation_gain=1&trk_elevation_threshold=1&trk_stats=1&trk_width=5&units=metric&width=800&trk_distance_threshold=2