Automatic DSM generation by digital photogrammetry: Example Morteratsch glacier

Automatic DSM Generation by Digital Photogrammetry: Example Morteratsch Glacier

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Abstract
The paper compares the Leica/Helava DPW 770 and VirtuoZo digital photogrammetric systems and in particular their performance in automatic generation of Digital Surface Models (DSM) in mountainous areas with glaciers.

The aim of this project was twofold. Firstly, we wanted to test whether automated photogrammetric processes, especially for DSM generation, could be applied in mountainous regions that include glaciers. Due to the irregularity of the terrain and partly the form and image texture of glaciers it was not clear whether such approaches could yield usable results. The project was of particular interest to the glaciologists at ETH that regularly monitor the volume and displacement of glaciers in Switzerland and other parts of the world. The second aim was to check the performance and compare two digital photogrammetric systems for this task. The two systems are the Leica/Helava DPW 770, and the software VirtuoZo that has been developed by the Wuhan Technical University of Surveying and Mapping, China and Geonautics Pty Ltd, Australia and is being marketed by VirtuoZo Systems Pty Ltd, Australia.

The Leica/Helava DPW 770 is an advanced system with very extensive functions and a price of over 300,000 SFr. The software runs on a 50 MHz Sun Sparc 10 and uses a second monitor for stereoscopic display of images with passive polarised glasses. The VirtuoZo is purely software based and runs on Silicon Graphics (in our case an IRIS Indigo Elan Graphics) with stereo capabilities using CrystalEyes active shutter glasses. Its functionality is not as extensive as the one of the DPW 770 but its price is correspondingly lower (ca. 50,000 SFr.). In both systems the algorithms for automatic DSM generation use epipolar resampled images, and image pyramids for derivation of approximations for the position of conjugate points. Both systems use crosscorrelation for image matching, whereby VirtuoZo also uses another global relaxation matching technique at the end phase in order to check whether the matching results of each point are consistent with the results in its neighbourhood and thus detect and exclude blunders. DPW 770 matches at a regular grid in object space, VirtuoZo uses a regular grid in image space (thus, a subsequent DSM grid interpolation is necessary). More details on the systems can be found in [1] and [2].

The data source for the study consisted of three photographs along a strip with 85% overlap at 1:10,000 scale. The images were taken in September and included the glacier tongue (the most important glacier part for the glaciologists). The height range in the scene was ca. 700 m. The negatives were scanned on a Zeiss/Intergraph PS 1 with 15 microns and were later subsampled to 30 microns pixel size. The control points were measured geodetically with an accuracy of under 1 dm (3-5 points per stereopair). Due to the terrain difficulty and the movement of the

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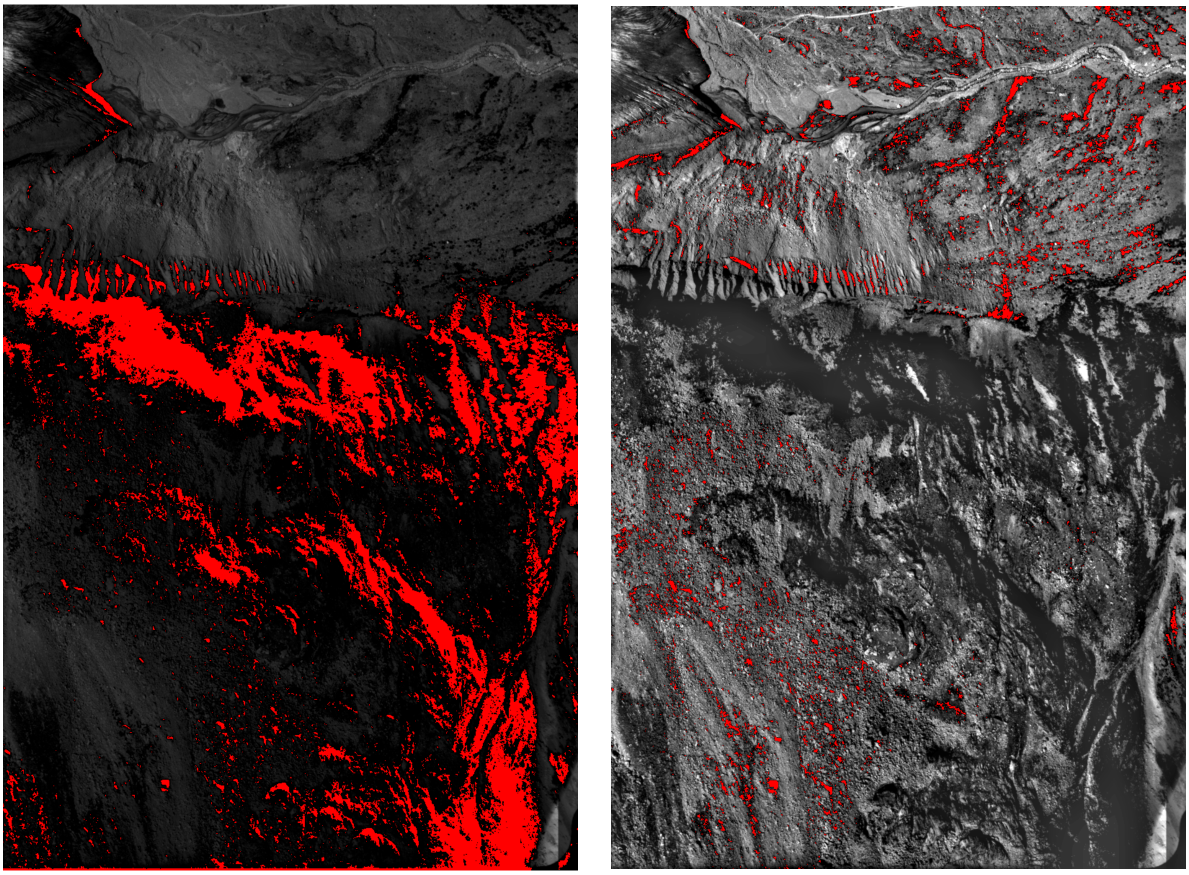

Figure 1. An image region from the second pyramid level. Pixels in red have grey value zero. Left: the original image ; Right: after Wallis filtering.

glacier only a few permanent control points could be established for glacier monitoring. The image quality of the control points was poor due to their small size, making their identification difficult. A Wild AC3 analytical plotter was used for the measurement of the control and tie points, and the sensor orientation was computed by a bundle adjustment using all three images. This orientation was used in both digital systems, so that the DSM comparison would be more objective. A reference DTM including breaklines covering the glacier and the surrounding mountain slopes was measured on the analytical plotter in order to assess the DSM accuracy of the digital systems (ca. 6900 points). Initial tests for automatic DSM extraction showed that results were poor in regions that had little texture or shadows. This was partly due to the dynamic range of the linear CCD of the scanner which was not high enough to accommodate the high contrast of the scene and the way the photographs were taken (exposure was optimised for glacier, hence the surrounding terrain appeared very dark). Thus, a strong contrast enhancement was performed with a Wallis filter (see Figure 1) which lead to a significant improvement in feature recognition and image matching.

Using the digital photogrammetric systems DSMs, orthoimages and 3D perspective views (see Figure 4) were generated from one model. The 15 micron images were too large to be processed by VirtuoZo, so the automatic DSM generation and the accuracy comparison was based on the 30 micron images. Both systems permit the selection of one out of many matching strategies. In both cases a strategy for “steep terrain” was selected. In VirtuoZo the patch size that was used for crosscorrelation was 9 x 9 pixels and the distance between match points was 9 pixels, i.e. ca. 2.7 m in object space, resulting in 532,000 match points. After matching, a DSM grid with a 2.5 m spacing was interpolated (480,000 points). In DPW 770 the patch size is selected automatically based on the strategy (for the steep terrain strategy it should obviously be small) and the pyramid level. The selected DSM grid spacing was 2.5 m resulting in ca. 591,000 DSM points. VirtuoZo used four pyramid levels and the DPW 770 nine levels. Both pyramids were created with a reduction factor of two.

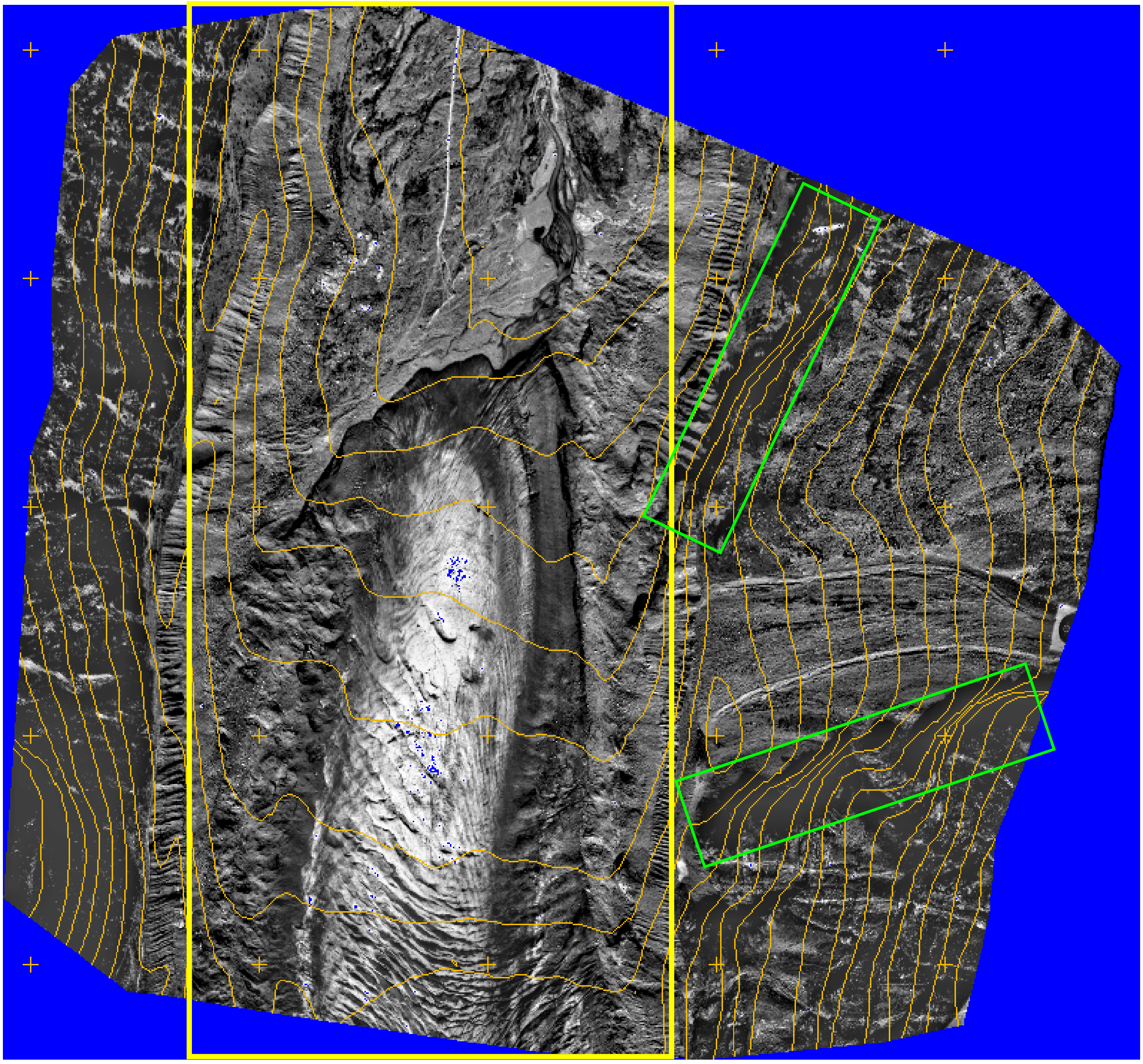

Figure 2. Orthoimage with overlaid contours (with 30 m interval) and tick marks every 400 m. Data are derived from the DPW 770 results. Green rectangles show regions of big blunders, and the yellow rectangle shows the region without big blunders where a separate accuracy analysis was performed.

The manually measured points were interpolated from the automatically generated DSMs in order to evaluate the accuracy of the latter (see Table 1). These results were influenced by several blunders of up to ca. 90 m in different difficult regions (usually regions of little or no texture, and abrupt terrain discontinuities, see green rectangles in Figure 2). Thus, a second accuracy analysis was performed in a region where no big blunders in the matching results occurred (see yellow rectangle in Figure 2). The number of manually measured points in the region was ca. 3,300. The DSM accuracy in this region was much higher (see Table 1) and is an indication of what accuracy can be achieved by automatic DSM generation algorithms, if the results have no big blunders. These differences are shown as pseudocolour images in Figure 3. Note that some of the differences are due to errors of the manual measurements, mostly at the position of breaklines. Some of these errors were detected and excluded from the data set of the region without big blunders. The results of Table 1 are without any editing of the image matching results. In a practical situation all very dark regions could be excluded a priori and thus many blunders could be avoided. Additional reasons that caused differences and errors are due to some vegetation, the crevasses on the glacier (the manual measurements were always on the surface, but the matching points could fall within the glacier cracks), and radiometric differences between the images due to scanner errors. The accuracy of the DPW 770 is clearly better and can be attributed to the greater experience of Helava Assoc. in automatic DSM generation as reflected in the sophistication of the matching strategy. VirtuoZo tends to smooth rough surfaces too much and shows a small bias, as indicated by the average difference over the whole image. DPW 770 shows also a better performance concerning the error distribution (see Table 2). Its performance is quite similar for both test regions, while for VirtuoZo there are big differences between the two tests in the best error class (0 - 2 m). Compared to DPW 770, VirtuoZo shows a long tail error distribution and much less points in the best error class.

The DTM accuracy that was requested by the glaciologists (0.5 m) was not achieved. However, for the low base/height ratio of the stereo model and the poor control point configuration, the pointing accuracy in height that could be achieved was one meter, as indicated by simulation of intersection and error propagation using the covariance matrix of the sensor orientation that was estimated in the bundle adjustment. This accuracy was almost achieved by the best digital approach but only after exclusion of the big blunders. Thus, it can be stated that glaciers (or other type of terrain with similar difficulties) can be measured by automated DSM procedures, but efficient, fast and comfortable methods for the automatic detection and exclusion of blunders are still missing. As an example big errors (so called spikes) could be easily detected and corrected by a median filtering but such functions are not provided by these two systems. Since some blunders may always remain in the data set, a manual editing will still be necessary. The tools provided by digital photogrammetric systems must be such that all blunders are included in a set of suspicious points that is presented to the user, permitting him an easy manual or semiautomatic remeasurement. Otherwise, the user must visually control hundred thousands of points. Both systems provide certain indications of the matching quality and means to edit the data. DPW 770 stores in a file a quality code from 0 to 100. Points with code less than 32 are considered unreliable and are mostly interpolated from other good points. In a test all these points were deleted and then the accuracy comparison to the manual measurements was repeated. However, the statistics as listed in Table 1 did almost not improve at all. This indicates that DPW 770 performs a good interpolation but on the other hand it also means that most blunders are considered reliable points. VirtuoZo divides the points in three quality classes that are displayed on the screen with different colours. The worst class includes points that have been interpolated. Again many blunders are included in the “reliable” classes and additionally this quality code is not saved in any file for user access. Both systems provide tools to indicate errors (contours, 3D views, overlay of contours on orthoimages or in the stereomodel) and means to edit the data pointwise or regionwise, but since the blunders are not reliably highlighted, the user must control the whole data set. Nevertheless, automatic DSM generation does have certain advantages over manual measurements like processing speed (over 100 points per sec) and the possibility to derive a very dense DSM. This is significant because it leads to a much more accurate terrain representation (implicit measurement of breaklines, form lines etc.).

Table 1: Statistics of height differences between manual and automatic measurements.

Version	Number of points compared	Time* required for matching (sec)	Maximum absolute (m)	Average (m)	RMS (m)
DPW 770 (whole image)	6329	5340	93.9	-0.3	3.2
DPW 770 (region with no big blunders)	3302		8.2	-0.3	1.2
VirtuoZo (whole image)	6546	860	88.4	-1.3	4.9
VirtuoZo (region with no big blunders)	3381		14.0	-0.03	2.7

* For DPW 770 the elapsed time is given, for VirtuoZo the CPU time. For VirtuoZo the time also includes the generation of the image pyramid ; the times for epipolar resampling and DSM interpolation were 340 sec and 110 sec respectively.

Table 2: Percentage of points for various classes of differences (in m) between manual and automatic measurements.

Version	0 - 2	2 - 3	3 - 4	4 - 6	6 - 9	9 - 15	> 15
DPW 770 (whole image)	88.2	5.9	1.8	1.4	0.7	0.7	0.6
DPW 770 (region with no big blunders)	90.8	6.1	1.1	0.7	0.1		
VirtuoZo (whole image)	46.1	16.7	12.3	13.4	6.4	3.4	1.1
VirtuoZo (region with no big blunders)	60.8	15.9	10.3	9.1	3.2	0.7	

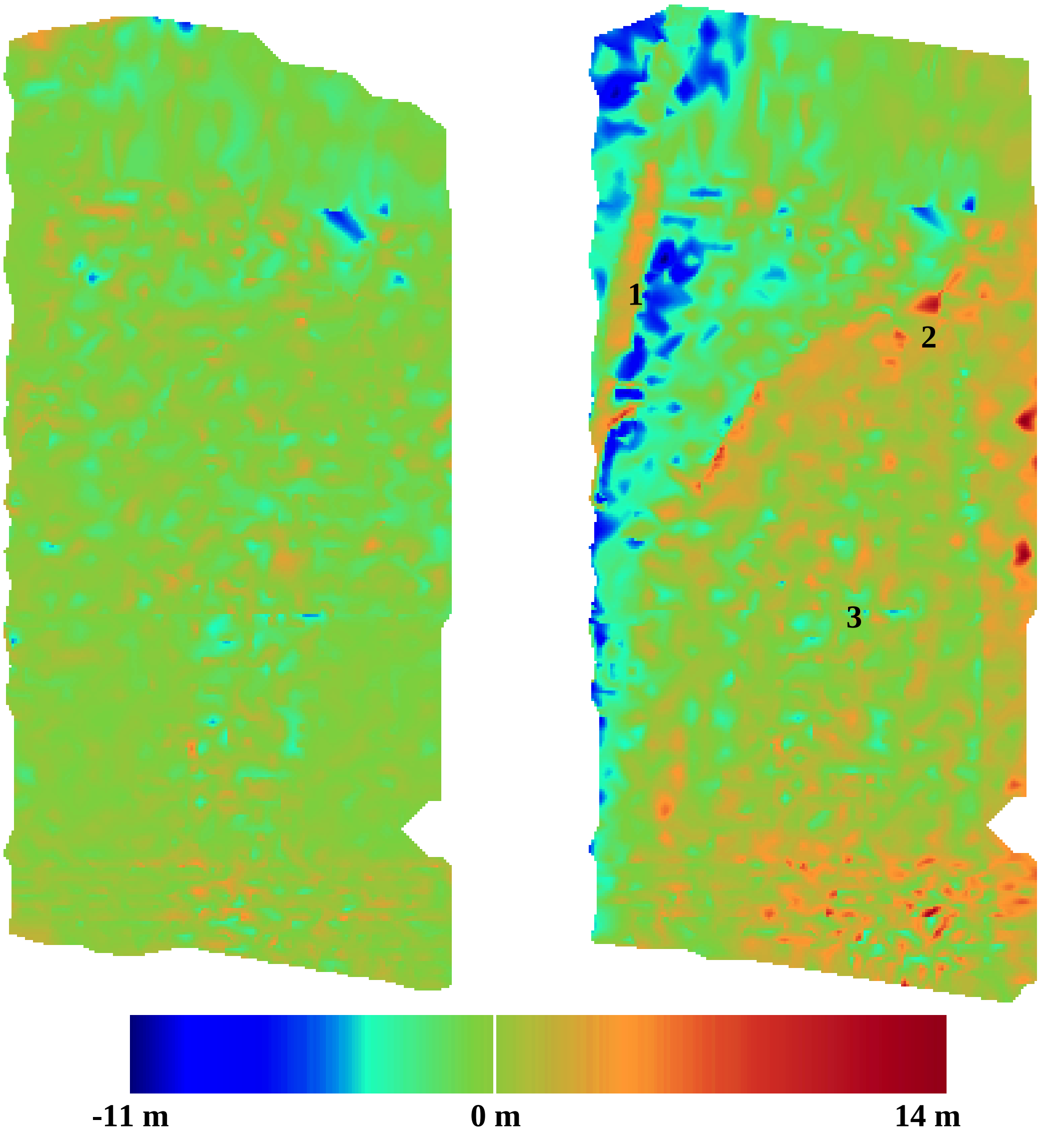

Figure 3. Accuracy analysis in the region without big blunders. The differences between manual results and DPW 770 (left) and VirtuoZo (right) are displayed in pseudo-colour using the same colour representation. In the right image: 1 ...a region of big errors due to steep slopes, 2 ...errors at the tip of the glacier tongue, 3 ...a horizontal line is visible due to the fact that the manual measurements were performed in several separate steps which were not fitting perfectly to each other.

Compared to analytical plotters digital photogrammetric systems show following characteristics. The price of digital photogrammetric systems is similar to much lower that the one of the analytical plotters. They also offer additional functionality like geometric sensor models for satellite imagery, image rectification, orthoimage and orthoimage map generation, mosaicking, 3D perspective views, animation and flyovers, image processing etc. The cheaper systems however do not have all these functions (VirtuoZo does not have for example triangulation, and mapping software). Deficiencies that were observed during this project include the following:

- A priori known external information, like the exterior orientation of the images, can not be imported and used (in our case this became possible through use of programs that are not delivered to the customers).

- Intermediate results like pixel and photo coordinates can not be accessed.
- DPW 770 requires very good approximations when solving for the exterior orientation ; otherwise the solution diverges.
- Output and transformation of the results in other formats is not always supported.

Fully fledged systems like the DPW 770 are quite complicated to handle and require significant training, whereby VirtuoZo is easy-to-use and its user interface quite intuitive. The size of digital data is still a problem. Large images can only be processed a few at a time or not at all. Many processes appear as a blackbox to the user, case which is not always desirable especially in education and research. Digital photogrammetric systems have to a large extent transferred the working mode of the analytical plotters in the digital domain. Thus, for example they concentrate on processing of stereo images without exploiting the existing possibility of simultaneous processing of multiple images in order to improve accuracy and reliability of the results (especially for DSM generation and automated feature extraction). A comparison between DPW 770 and VirtuoZo shows that both systems have their strong and weak points. DPW 770 has more functions, is more accurate but also more expensive and complicated to use. VirtuoZo on the other hand offers the advantage of user-friendliness and low price. Even with their present weaknesses digital photogrammetric systems offer significant advantages in comparison to analytical plotters and can be fully employed in research and professional practise. The expected improvement of their performance, especially in the algorithms and the user interface, will expand their use even further.

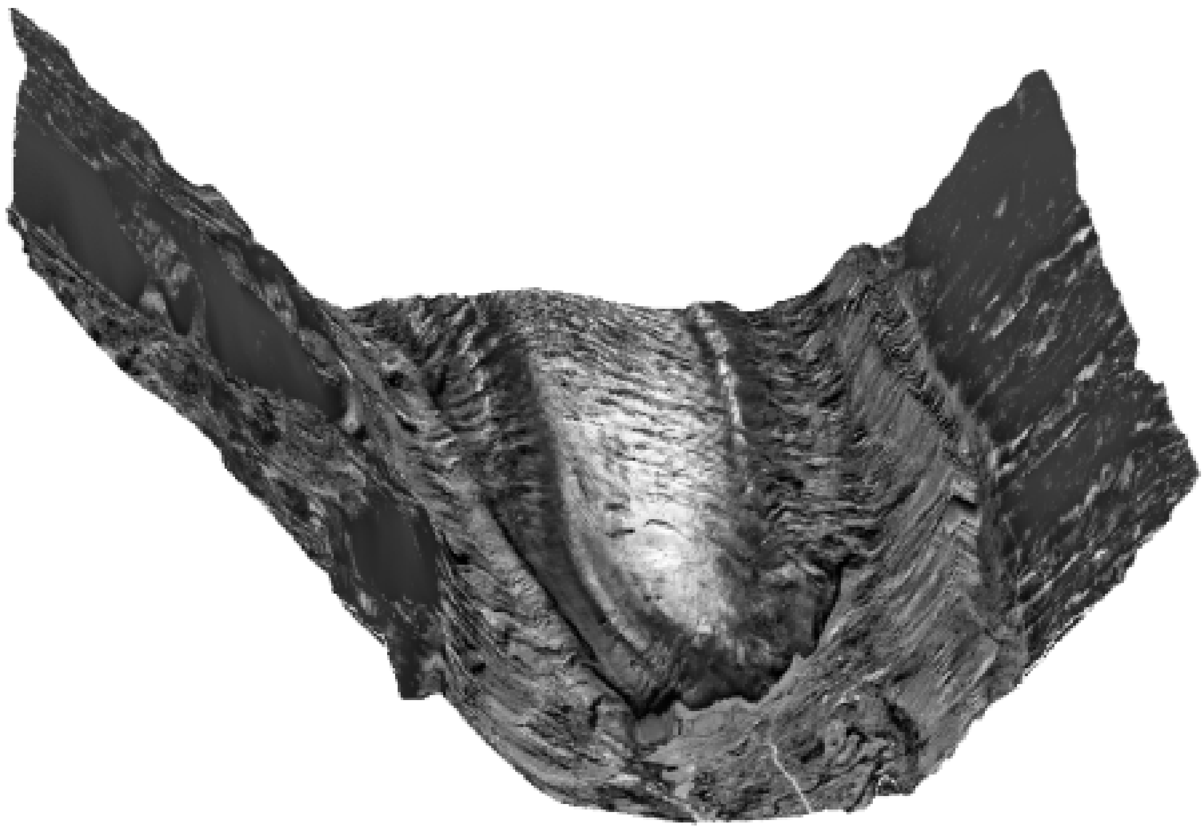

Figure 4. 3D parallel view of the Morteratsch glacier (exaggeration factor 1.5).

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