Challenges for the Swiss Federal Office of Topography swisstopo for the Production of Digital Images and Altimetrical Models using the ADS80 Sensor for the Glacier Monitoring in the Swiss Alps

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Abstract: The Swiss Federal Office of Topography swisstopo produces since 2010 digital data on Swiss glaciers for the Federal Office for the Environment (BAFU) and the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the Swiss Federal Institute of Technology of Zürich. The data comprise digital ADS80 (Airborne Digital Scanner) oriented aerial pictures with a Ground Sample Distance (GSD) of 25 cm, derived Digital Surface Models (DSM) with a 50 – 100 cm grid as well as orthophotos with a 25 cm GSD. These geodata are part of the national glaciers monitoring program GLAMOS (GLacier MOnitoring in Switzerland).

This paper describes specific aspects of the data acquisition (flight planning over glacier areas), the geometrical referencing with the help of Ground Control Points, as well as the DSM production using image matching. Glacier areas are characterized by an important topographical heterogeneity: a big reflectance over glacier areas and lots of shadows due to the mountains. These aspects are a specific challenge for image correlation and the production of accurate and complete DSM.

Details concerning the softwares used and tested by swisstopo are provided here, as well as which bands of the ADS80 scanner and which parameters are used for the production.

This paper provides an overview of swisstopo's tests and criteria (‚Benchmarking') prior to the acquisition of new softwares for image matching using ‚Semi Global Matching' algorithms. The comparison of the performances shows neat differences in data quality, data volume and time performances during the production of derivate products. Those are the criteria which are set for deciding which software offers the best quality and is the most cost-efficient for a future use for the production of DSMs with a higher resolution at a larger scale, for example for the whole swiss territory.

1 Introduction

Global warming causes a world-wide spread glacier withdrawal. The Swiss Alps are located in the south and southeastern part of the country. Their highest elevation reaches 4'500 m a.s.l. The Swiss Alps count numerous glaciers which are actively monitored since 1874, as the first measurement took place on the Rhône Glacier.

The GLAMOS project (GLAcier MOnitoring in Switzerland) conducts each year glacier variations measurements on more than a hundred glaciers of Switzerland (FRANK et al. 2011). This project involves several partners, including the swiss federal office for the Environment BAFU, the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the Swiss Federal Institute of Technology in Zürich (ETHZ), the Swiss Academy of Sciences, the Global Climate Observing System (GCOS) Schweiz and the Swiss Federal Office of Topography swisstopo.

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Fluctuations in glacier length and changes in volume and mass represent key parameters in environmental monitoring. Their measurement is achieved using multiple techniques, including geophysics for bedrock altitude determination (HAUCK et al. 2012) and aerial photogrammetry for determination of the surface altitude with a Digital Surface Model (DSM).

swisstopo provides ADS80 aerial images and derivate DSM material since 2010 for the needs of GLAMOS. The delivered products consist in a derived DSM and ortho-rectified aerial NRGB (16 bits) and RGB (8 bits) images called L2 with a 25 cm Ground Sample Distance (GSD). The actual DSM is produced using SocetSet NGATE 5.6.0 by BAE Systems with a 1 m grid. However, swisstopo is conducting a series of tests to produce a more detailed DSM which means that the resolution has to be enhanced.

Two specific softwares, XPro-DSM 6.3.1 by Leica Geosystems and Socet GXP 4.1.0 by BAE Systems are currently undergoing further investigations.

This study seeks also to initiate an improvement of the production for swissALTI^{3D}. swissALTI^{3D} is a 2 m grid Digital Terrain Model (DTM) covering the whole swiss territory produced by swisstopo and updated in a 6 years cycle. swissALTI^{3D} combines laser data, automatically correlated data in local areas and manually edited areas using 3D devices.

The specific aims of this study are:

(1) To evaluate the performances of XPro-DSM 6.3.1 by Leica Geosystems and Socet GXP 4.1.0 by BAE Systems;
(2) To determine for both softwares which parameters result in the most accurate and detailed Digital Surface Model and at what processing costs;
(3) To discuss the possible applications for both GLAMOS and swissALTI^{3D}.

2 Study area

2.1.1 Study area for this paper

The area of Bis, Hohlicht and Turtmann, located in the canton of Valais was chosen for this specific study for the production of altimetrical models over glaciers (Fig. 1). This area was chosen for multiple reasons: it is a big surface characterized by heterogeneous altitudes ranging from 2’096 meters up to 4509 meters, including the Mattertal Valley and the village of Zermatt.

The mountainous area is covered with glaciers with various expositions to the sun, which in some cases cause a very high light reflectance. Moreover, the mountains provide a lot of shadow areas. The Mattertal Valley offers a good contrast to the glaciers mountainous glacier areas. The reflectance is smaller. These heterogeneous characteristics make this area ideal for testing various parameters, so as to ultimately apply them on bigger areas.

2.1.2 Study area for GLAMOS

The study area is located in the Swiss Alps, in the south – south eastern part of Switzerland. While the GLAMOS project includes over 100 glaciers, aerial imagery material is provided for 23 areas covering some of the biggest Swiss glaciers, as seen on Fig. 1 and Tab.1. Most of them are produced on a yearly basis.

Tab. 1: Areas of interest flown for GLAMOS

Area of interest	Flight frequency [year]	Footprint [km^2]	Number of flight lines
Finster- Ober- Lauter- Unteraar	1	150.1	4
Basodino	3-5	77.9	2
Birch	1	22.6	1
Bis Hohlicht Turtmann	1	252.6	2
Findel	1	36.4	1
Gauli	1	18.1	1
Gorner	1	34.9	1
Gries	1	60.8	1
Grosser Aletsch Süd	1	50.3	1
Gutz	1	51.9	1
Oberer, Unterer Grindelwald	1	73.1	2
Plaine Morte	1	203.3	3
Rhone	1	16.6	1
Silvretta	1	50.4	1
Trient-Dolent-Saleina	5	193.9	3
Trift (Gadmen)	1	15.3	1
Trift (Weissmies)	1	8.3	2

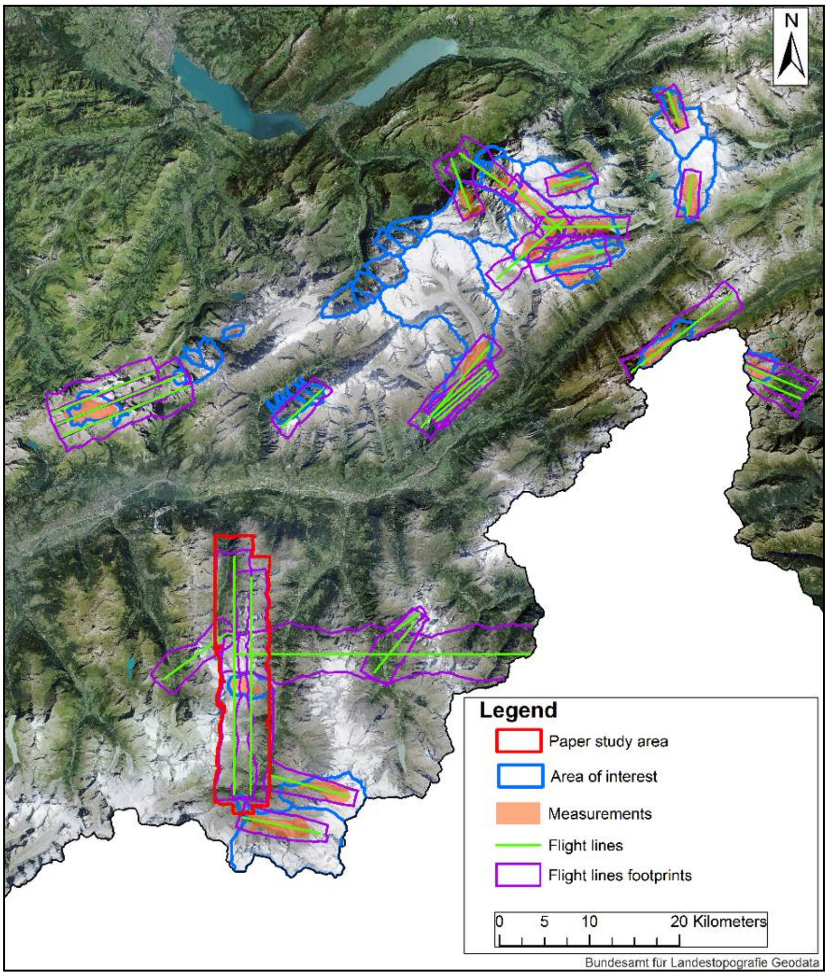

Fig. 1: Areas Of Interest flown by swisstopo for the needs of GLAMOS and for this paper

3 Material, methods and products

No material other than the current sensors were used for this study. This study aims only the software, material's performances are not evaluated. Airborne optical sensors allow large areas of interest to be covered at reasonable costs. Those big areas can only be efficiently processed thanks to automated processing using image matching methods. Derived products include L1 images, DSMs and L2 images.

3.1 ADS80 Stereo Aerial Images

The Leica Geosystems ADS80 camera is an Airborne Digital pushbroom Sensor for line scanning, in our case mounted with a 62.7 mm focal length Sensor Head called SH82. Two cameras have been acquired and used since 2009 by the Swiss Federal Office of Topography swisstopo. This sensor acquires five spectral bands with a radiometric resolution of 12 bits; the GNSS/IMU supports orientation of the image strips achieves a one GSD accuracy (HOBI & GINZLER 2012; WAGNER 2014).

The 12 bits bands are converted to 16 bits. By doing so, no information is added to the image and the quality remains unchanged.

Tab. 2: Technical details of the ADS80 – SH82 sensor head

Sensor	Dynamic range of the CCD	Spectral bands [nm]	CCD elements	Pixel size [µm]	Focal plate configuration
3 – line CCD scanner	12 bits	Panchromatic (PAN) 465-680 Blue (B) 428-492 Green (G) 533-587 Red (R) 608-662 Near infrared (N,NIR) 833-887	12 CCD lines with 12'000 pixel each	6.5	PAN F27° PAN F02° (A,B) PAN B14° Blue N0° Blue B16° Green N0° Green B16° Red N0° Red B16° NIR N0° NIR B16°

3.2 Pre-flight preparation

3.2.1 Flight planning for GLAMOS

The number of flight lines, their orientation and the flight altitude are determined by the glacier's ice tongue axe and the desired pixel size over the main focus area. Whilst a mean GSD of 25 cm is aimed at, the minimum and maximum GSD values may range from 12 cm to 47 cm due to obvious geographical heterogeneities in mountainous areas. The position and length of the flight lines are also determined according to stable areas offering good Ground Control Points (GCPs). The flights occur when the snow cap is at its minimum, from July until September and around midday if possible to minimize shadows.

3.2.2 Ground Control Points

The location of the GCPs used for the georeferencing process is determined and measured previously to the flights. The expected accuracy for the final GCPs field coordinate measurements should be smaller than 3 cm, which can be achieved with a GNSS measurement. The GCPs must be easily photo-identifiable, visible and should be located in geologically stable areas. As the pictures for GLAMOS are flown with a 25 cm mean GSD in mountainous areas, 90 times 90 cm black and white squares are painted in stable, obstacle and landslide-free areas, as shown on the picture below. These squares are big enough and offer a good contrast to be recognizable on the raw pictures.

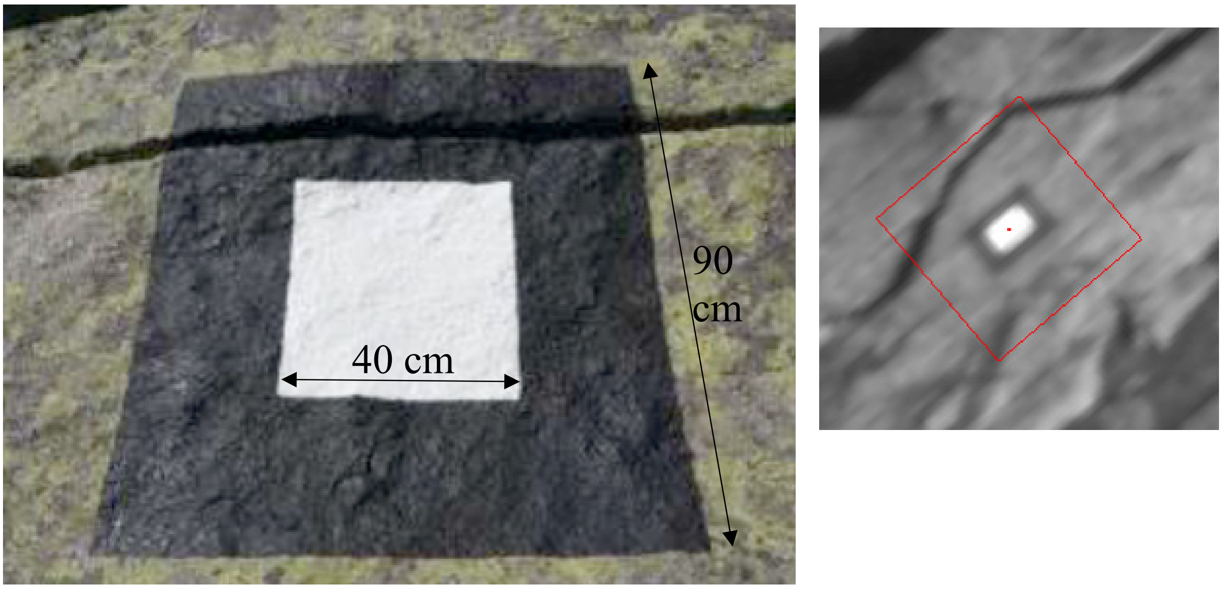

Fig. 2: Example of a typical GCP for GLAMOS on the terrain (left) and on the raw image (right)

3.3 Aerotriangulation

The aerotriangulation is a semi-automated process improving the *a priori* georeference of the images, provided by the GPS/IMU, thanks to tie points and GCPs.

Tie points are determined, in the case of the ADS camera, between the different viewing angles of the same flightline and between neighbor flightlines, in their overlapping area. This process is called relative external orientation and is carried out by Automated Point Matching (APM).

The GCPs are measured in the images. Since the coordinates of these GCPs are known, they provide the absolute external orientation. Having good GCPs is very important for the aerotriangulation. The absence of GCPs, GCPs with a bad precision or a bad geographical distribution of the GCPs on the area can have a ngeative impact on the precision of the aerptriangulation and therefore, on all the derived products too, such as the L1, DSMs and L2 products (see next paragraph).

Fig. 3 provides a schematic view of the production chain for ADS80 pictures and derived products.

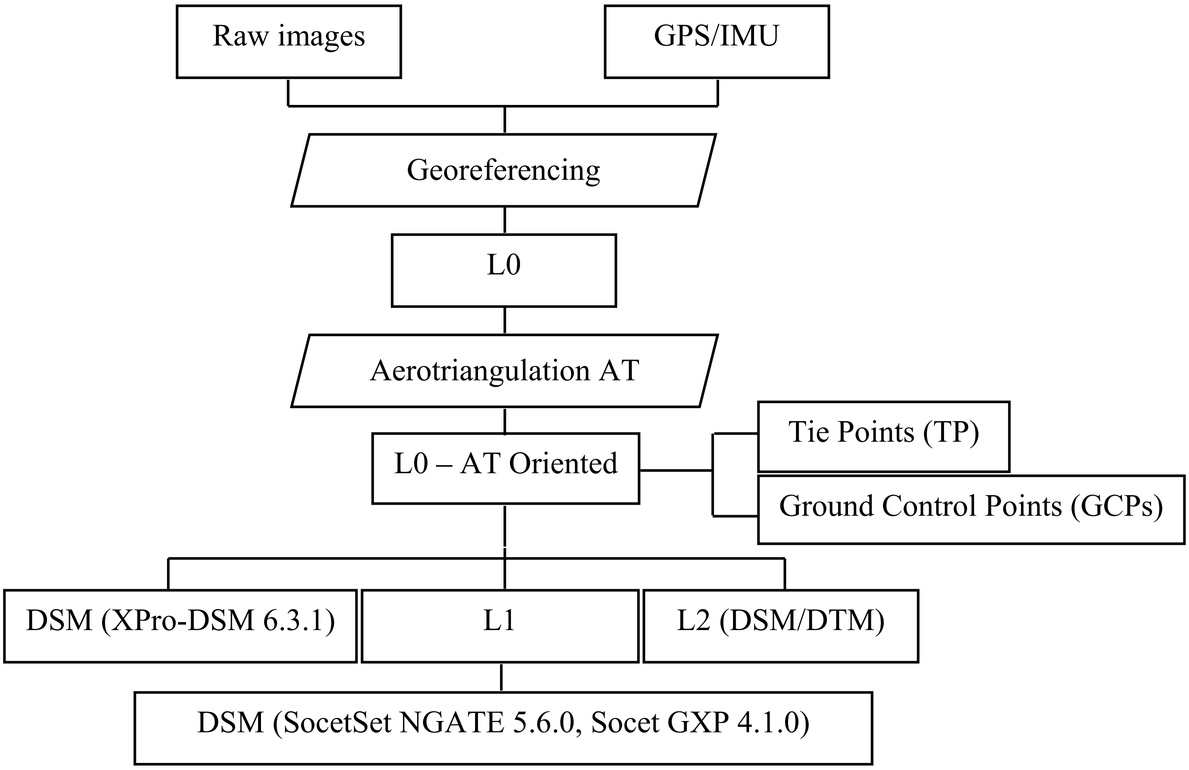

Fig. 3: Schematic production chain from the raw images to the L2 images

3.4 Derivate products

3.4.1 Images

Raw images from the ADS80/SH82 push-broom sensor, also called level-0 L0 images, consist of individual ground scan lines along a defined flight path. Although minimized by an active stabilization system, residual movements of the sensor still affect the raw images during the scanning process.

The system is mounted with a high-frequency IMU system that measures literally all the movements of the sensor for each line. Geometric distortions due to camera movements and present in the L0 raw pictures are corrected during the L1 image generation process with a given mean terrain height, internal and external orientation parameters. L1 oriented image contains 3D information which can be exploited with the stereo principles.

Level-2 L2 are 2D images ortho-rectified on the basis of a given Digital Terrain Model.

3.4.2 DSM Generation

In mountainous areas located at altitudes ranging from 2‘000 to 4’500 m, forests and houses are scarce. It is thus assumed that the Digital Terrain Model (DTM) is equivalent to a DSM. DSM production is a highly automated process. Image-matching softwares identify corresponding pixels for an image pair and reconstruct their position using given extrinsic and intrinsic orientation (BÜHLER et al. 2012). swisstopo actually produces DSMs using SocetSet 5.6.0 by

BAE Systems with the "Next Generation Automatic Terrain Extraction" NGATE module. However, the needs for DSMs offering a higher resolution is increasing. A higher resolution comes along with a set of challenges, processing time being one of the biggest. Therefore, the alternative image matching techniques must be both exact and cost-efficient (DEVENECIA et al. 2007). swisstopo is currently testing softwares to compute ADS80-derived DSM, using Semi-Global Matching (SGM) and Automatic Spatial Modeler (ASM) techniques, which we describe hereafter.

The actual image matching is performed using SocetSet 5.6.0 by BAE Systems with the NGATE module. NGATE computes an elevation for every pixel using an imaging correlation method combining edge and image-matching algorithms. The input images are L1 oriented images. This solution has proven to be both effective and cost-efficient, offering a good compromise between image-matching quality and calculation time on big areas for both GLAMOS and swissALTI^{3D}. A fixed spacing of four times the GSD is defined to resample the internal irregular NGATE point cloud into the desired grid (1 m for GLAMOS, 2 m for swissALTI^{3D}). The near infrared – red – green (CIR) bands combination interpolation with the "low contrast strategy" produces the best quality in high alpine glacier regions and is used for the automated correlation.

Meanwhile, SocetSet tends to be outdated since it has been replaced by the more recent Socet GXP by BAE Systems, which also includes the NGATE algorithm.

Automatic Spatial Modeler (ASM) is based on the same method as NGATE. The former algorithm is however enhanced by using adaptive pixel aggregation, which enforced a local smoothness constraint (ZHANG 2014). To insure a time efficient correlation, the software can profit from the machine's Graphics Processing Units (GPUs) for performant parallel computing. Socet GXP, by using ASM offers point cloud generation possibilities. Point clouds are useful as they provide non-regular spaced point information whereas grids are interpolated terrain heights to fit a regular user-defined grid.

In Semi-Global Matching (SGM) techniques, first, the image's radiometry is calibrated and corrected, then the SGM performs scanline optimization along the horizontal scanline for each pixel at multiple angles. Each pixel is attributed a cost and a dispersion value and is in a matrix and then filtered by linear programming (HIRSCHMÜLLER 2005; HIRSCHMÜLLER 2011). This method provides the user with non-smoothed DSM with a high point density, available in ASPRS LAS format.

swisstopo has tested several DSM extraction softwares to replace SocetSet NGATE 5.6.0. Two of them, XPro-DSM 6.3.1 by Leica Geosystems and Socet GXP 4.1.0 by BAE Systems have provided satisfying first results. Table 3 presents the advantages and disadvantages of the selected softwares. Both softwares are interesting as they can be foreseen for different strategies. In the case of GLAMOS, most of the AOIs are covered by single flight lines, which can be efficiently processed using DSM-XPro. However, some of the AOI have to be covered by several flight lines, which makes Socet GXP interesting, since it is possible to calculate a DSM with multiple flight lines, as for swissALTI^{3D}. Moreover, Socet GXP offers efficient and user friendly DSM merging possibilities using the Figures Of Merit (FOM) information, which is not available with XPro-DSM. FOM gives a quantitative evaluation of the correlation which can also be used to choose the best source DSM for the end product (GINZLER & HOBI 2015).

Tab. 3: Advantages and disadvantages of SocetSet 5.6.0 by BAE Systems, of Socet GXP 4.1.0 by BAE Systems and of XPro-DSM 6.3.1 by Leica Geosystems

Software	Available correlation methods	Chosen correlation method	Advantages	Disadvantages
SocetSet 5.6.0 BAE Systems	ATE, NGATE	NGATE	• Figures Of Merit (FOM) • Processes simultaneously several overlapping lines • Merging handled • Seed DTM option • Automated processing possible • Interpolation for the no data area	• No las output • Does not work with oriented L0 • No support available since replaced by Socet GXP • Works with L1 which must be previously oriented and processed
Socet GXP 4.1.0 BAE Systems	ATE, NGATE, ASM	ASM	• Figures Of Merit (FOM) • Processes several lines • Merging handled • Compatible with SocetSet NGATE files • Seed DTM option • Automated processing possible • Interpolation for the no data area	• No las output • Does not work with oriented L0 • Works with L1 which must be previously oriented and processed
XPro-DSM 6.3.1 Leica Geosystems	SGM	SGM	• Las output • Seed DTM option • Automated processing possible • Works with L0 • Good results on both bright (glaciers) and dark (shadows) areas	• Processes flights lines individually • Merging required • No FOM • No interpolation for the no data area

4 Results

Socet GXP 4.1.0 by BAE Systems and XPro-DSM 6.3.1 by Leica Geosystems are actually undergoing a series of tests to determine which one is the most accurate and cost-efficient, as well as which parameters and strategies should be used to satisfy GLAMOS' and swissALTI^{3D}'s needs. The tests are to be carried out until august 2016. In this paper, we present our first results, which up to this date have been essentially executed with XPro-DSM 6.3.1. Further tests and results with Socet GXP 4.1.0 will be available during summer 2016. All the tests are done on machines with similar characteristics, so that the performances for each calculation can be compared.

Hereafter are presented the results of tests using different viewing angle combinations, seed DTMs and comparisons of diverse image resolutions and extraction strategies (see Table 4).

Tab. 4: Methods and parameters tested on XPro-DSM 6.3.1

Software	Input image	Viewing Angle combination	Correlation method	Parameters
XPro-DSM 6.3.1	ADS80, L0, GSD 25cm	Green N0°- Green B16°	SGM	• No terrain option, normal exposure settings • No terrain option, bright settings • No terrain option, dark settings • Terrain option (swissALTI3D – 2m grid), normal exposure settings • Terrain option (GTOPO – 1 km grid), normal exposure settings
		Green N0°- Green B16°- PAN F27°		
		NIR N0° - NIR B16°		
		NIR N0° - NIR B16°- PAN F27°		
		PAN F27°- PAN F02°- PAN B14°		

4.1 Viewing Angle combination effect

Correlations executed with two viewing angle combination are overall 2.3 times faster as correlations with three viewing angle combination, with a mean speed of 9.55 km^2/h for the two viewing angle combination and 4.0 km^2/h for the three viewing angle combination. All the calculations were done using a machine equipped with 16 cores with a CPU frequency of 2.59 GHz.

The DSM coverage ranges from 92.5% to 96.2% for all the viewing angle combination except for the PAN F27°- PAN F02°- PAN B14° which ranges from 78.9% to 89.5%.

The results with the combinations NIR N0° - NIR B16°, NIR N0° - NIR B16°- PAN F27° and PAN F27°- PAN F02°- PAN B14° present more noise and artefacts and are thus qualitatively less accurate than the Green N0°- Green B16° and Green N0°- Green B16°- PAN F27° combinations.

4.2 Terrain option

In XPro-DSM 6.3.1, the quality of a DSM can be improved by using the “terrain option”, as shown below (Fig.4). When not using the “terrain option”, the software correlates a DSM based on a given mean altitude. However, in mountainous areas, the difference between the mean altitude and the real altitude can exceed 1’000 m. The “terrain option” allows the user to provide the software with a seed DTM with a more or less big grid spacing which is integrated during the DSM calculations. In addition to local DTM, global models are also available, such as GTOPO30 and SRTM3, both produced by the U.S. Geological Survey (USGS). GTOPO30 is a worldwide model derived from data issued by several sources, with a horizontal grid spacing of approximately 1’000 meters. SRTM3 is the result of a campaign called Shuttle Radar Topography Mission Global Coverage providing a global model from 56 degrees south latitude to 60 degrees north latitude, with a grid spacing of approximately 90 meters.

The results of a correlation using swissALTI^{3D} with a 2 meter grid spacing as seed DTM were compared to those obtained using GTOPO30 which has a 1'000 meter grid. Other tests are planned using SRTM3.

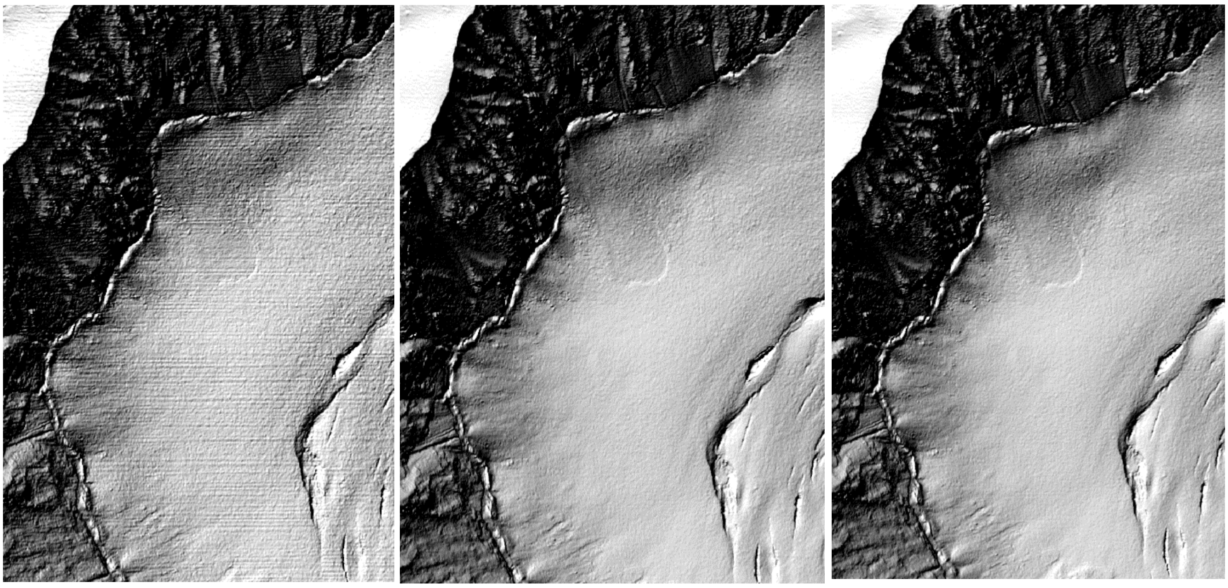

Fig. 4: DSM calculation with and without terrain option. On the left, there is no seed DTM. In the middle, swissALTI^{3D} with a 2m grid was used. On the right, GTOPO30 was used as seed DTM

Small wave artefacts with a 10 cm amplitude affecting the DSM with no terrain option are lessened by using a seed DTM, even with a 1'000 meter grid. The terrain option improves the quality, but does not necessarily provide a better accuracy. However, this quality improvement comes with very important time costs. Calculations time using swissALTI^{3D} with a 2 m grid as seed DTM are 30 times greater as calculations without the terrain option. Calculations with GTOPO30 as seed DTM are 7 times greater as without seed DTM. Qualitative results using swissALTI^{3D} 2m are comparable to those using GTOPO30. As the DSM quality definitely can be enhanced by the use of the terrain option, further investigations are currently been carried out using SRTM3 and swissALTI^{3D} with a bigger grid.

4.3 Normal, bright, dark extraction parameters

XPro-DSM comes with a set of strategies for specific scenes. For example, when set on "bright setting", the software focuses on the bright pixels of the image, such as glaciers, providing a better quality on the bright areas. When set on "dark setting", the software focuses on the dark pixels of the image and offers a better correlation in shadow areas. Results show that the coverage percentages using a normal, a bright or a dark extraction parameter are comparable (96.5%). The dark setting clearly does improve the interpolation quality in shadow areas, without deteriorating the quality over bright areas such as glaciers. Fig. 5 shows that void areas of the DSM calculated with the "bright" setting (circled in red) were successfully completed by the DSM calculated with the "dark" setting. Moreover, the correlation in shadow areas is improved by using the dark setting (green circle).

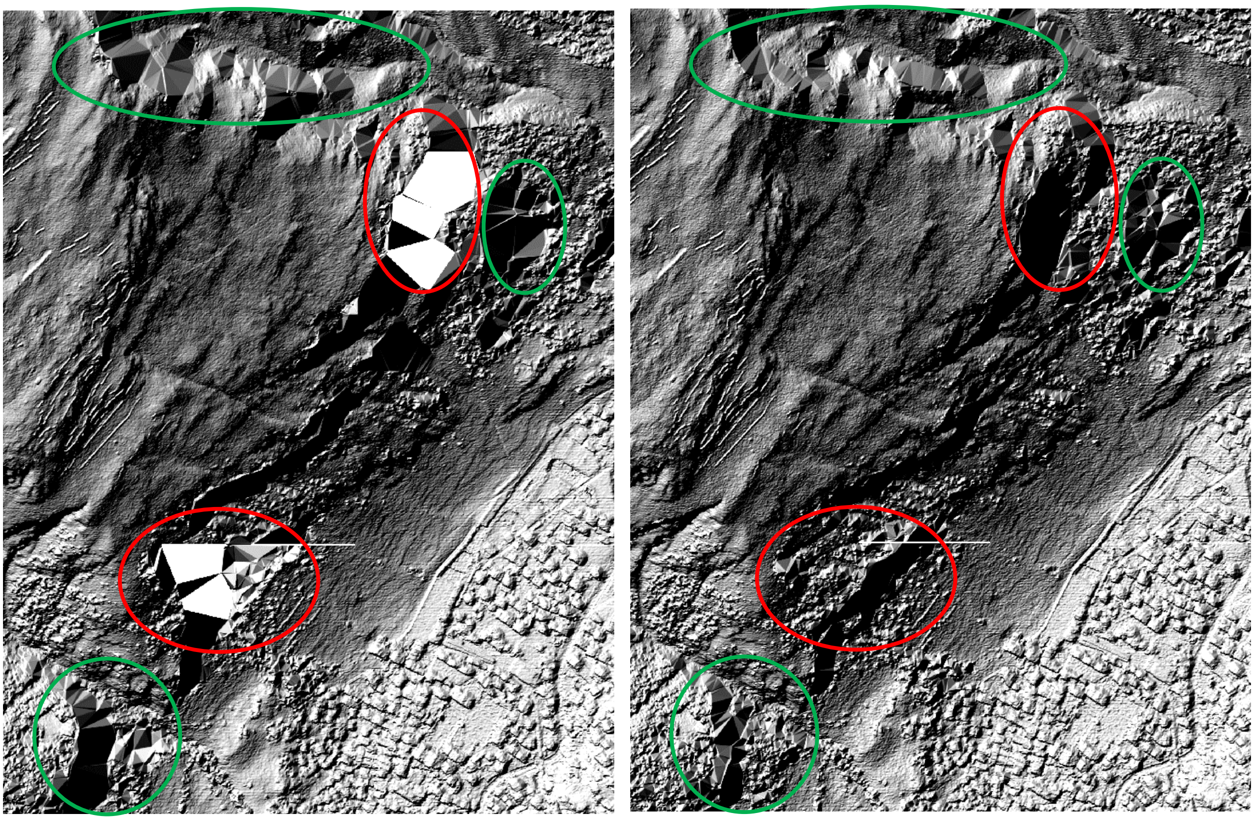

Fig. 5: DSM calculation with a bright setting on the left and with a dark setting on the right. A clear improvement can be observed as the dark settings allows void areas calculated with the bright setting to be filled (red circles). Moreover, the quality of the correlation in other shadow areas is improved by using the dark settings (green circles)

Processing time using a normal exposure setting, a bright or a dark setting are equivalent (Fig. 6).

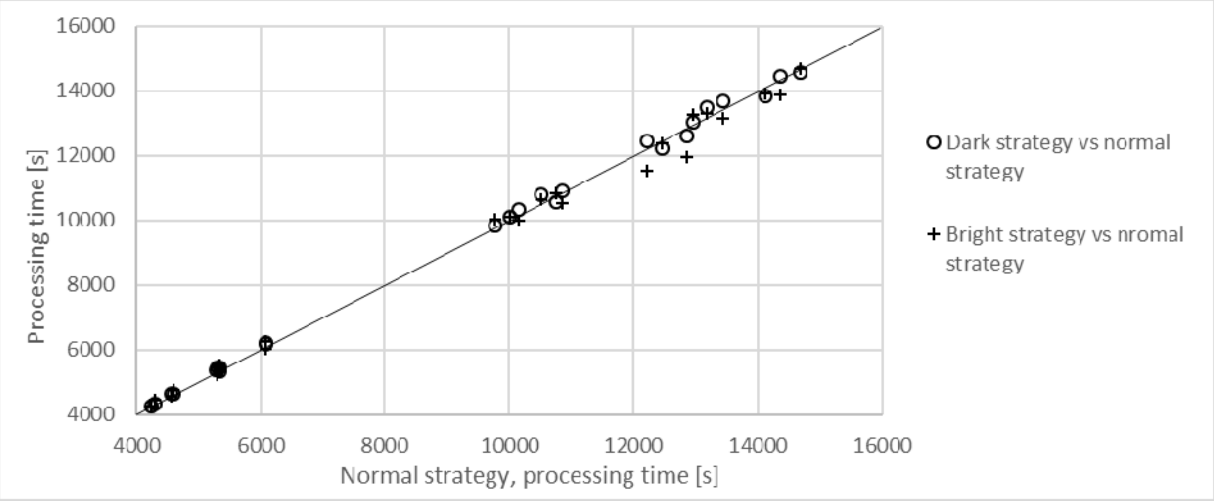

Fig. 6: Processing time [s] using normal, bright and dark settings

4.3.1 Resolution

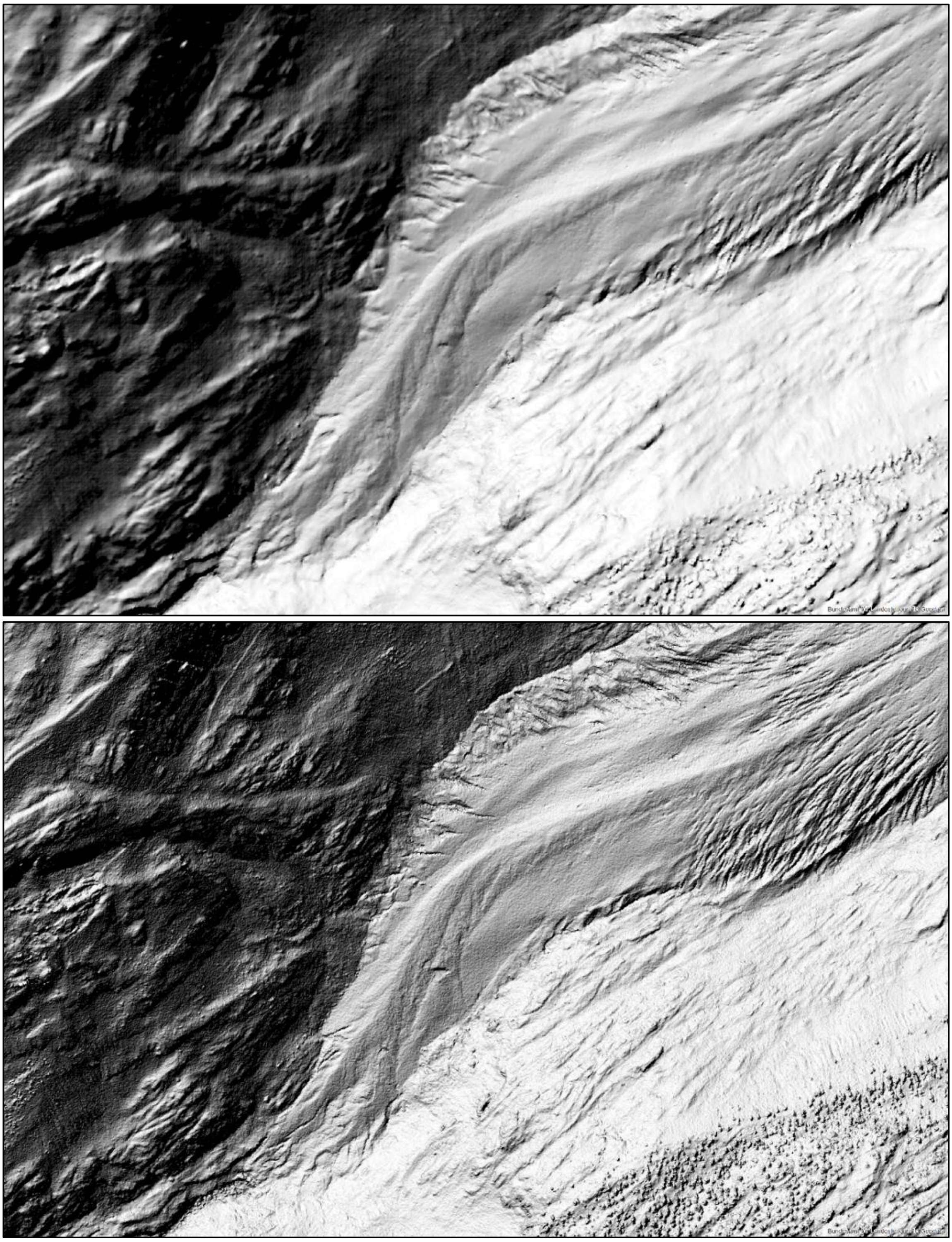

Fig. 7: The upper picture shows the DSM of the Aletsch ice tongue correlated with a 1 m grid spacing using SocetSet NGATE 5.6.0. The bottom picture shows the las output on the same area using XPro-DSM 6.3.1

XPro-DSM produces two sets of data, one with non-thinned xyz values and another one with thinned xyz values. Only the non-filtered xyz DSMs are considered. Fig. 7 shows two DSMs correlated over the Aletsch ice tongue. The data was collected during two flights, one in 2014 and the other in 2015, both with the ADS80 and with a 25 cm GSD. The upper picture shows a DSM extracted with SocetSet NGATE 5.6.0 with a 1 meter grid spacing with data from the 2014 flight. The bottom picture shows a DSM extracted with XPro-DSM 6.3.1.

Obviously, a higher resolution results provides more details especially for smaller objects. Glacier edges, structures and crevasses are more defined and detailed. Trees are easily identifiable from houses whereas they could in some cases be mistaken for one another using SocetSet NGATE 5.6.0 with a 1 meter grid. Other terrain features are more detailed, such as boulders, faults or meandering channels of rivers. The overall quality is enhanced, although the accuracy is equally enhanced since the point cloud gives a xyz value for a given point whereas a grid is an interpolation of the altitude onto a given xy point.

The height difference between correlations carried out with SocetSet NGATE 5.6.0 and XPro-DSM 6.3.1 with the same input images range from -0.2 to 0.2 meters.

5 Discussion

Due to clearly poor results, the three PAN combination is excluded for further production. Although better, DSMs calculated with NIR N0° - NIR B16°, NIR N0° - NIR B16°- PAN F27° still present noise and artefacts. The two most accurate DSMs are obtained by using the Green N0°- Green B16° or Green N0°- Green B16°- PAN F27° viewing angle combination. Although the Green N0°- Green B16° combination is 2.4 times faster than the Green N0°- Green B16°- PAN F27° combination, the accuracy and overall visual quality of the latter make it really interesting for further production. Less areas are void, especially in mountainous areas.

Using the terrain option improves the visual quality, even by using a 1’000 meters grid GTOPO30 seed DTM. However, the terrain option does not enhance the precision of the correlation in comparison to the “no terrain option”. The process is moreover very time consuming. The use of a seed DTM could be recommended for mountainous areas because of their topographical disparities, but is not necessary in other areas. The use of the terrain option can therefore not be recommended as a systematical process, but could be locally used on specific, problematic mountainous areas.

The dark setting definitely enhances the quality of the DSM in shadow areas without deteriorating the quality on bright areas. Moreover, the time costs for this process can be neglected. The dark setting can be integrated as a fix parameter.

Finally, a smaller DSM resolution results in a more detailed DSM and accuracy in comparison to the actual SocetSet NGATE 1 meter production strategy, since the output is a point cloud and not a grid.

6 Conclusion

The replacement of the actual SocetSet NGATE 5.6.0 software is a necessity. The tests carried out up to this date have been mostly focused on DSM-XPro 6.3.1, further results with SocetSet GXP 4.1.0 will be available during summer 2016.

An enhanced resolution comes along with logical longer processing time.

Another concern is the merging of the data. Since XPro-DSM 6.3.1 does not offer merging possibilities of several DSMs, this process must be manually done, which is not time and cost-efficient. Therefore, the future tests with Socet GXP 4.1.0 might bring satisfying automated merging opportunities which are not available with XPo-DSM 6.3.1.

A way of optimizing the production would be to eventually use both DSM-XPro 6.3.1 for local areas and glaciers entirely covered by a single flight line. Socet GXP 4.1.0 could be used for merging multiple flights lines as well as for change detection. However, using two methods is not the most efficient strategy for a large scale production and involves undesirable further infrastructure and licenses costs.

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