Supplementary Material

1 CHOICE OF PROCESSING PARAMETERS

To choose the processing parameters that yield the best final DEM, a test pair was processed at full resolution to generate a DEM at 24 m GSD, with varying parameters, and compared to a reference elevation from a close date, both on and off ice. Such reference elevation was only available in the Swiss Alps and therefore, we tested the parameters for the stereo images DZB1216-500312L002001 and DZB1216-500312L003001, which were acquired on 02/09/1980 and have the most overlap with our reference DEM "Hist 1980". The set of parameters that were tested are (Table S1): the matching algorithm (NCC, SGM and MGM), the matching kernel size (3-9 for SGM/MGM, 17-25 for NCC) and the filters (xcorr or stddev, 0 means filter disabled, 1 filter enabled). Additionally, the impact of processing the raw images or orthorectified images has been tested too. For each set of parameters, the elevation difference between both DEMs (reference DEM minus KH-9 DEM) is calculated in order to assess the quality of the KH-9 MC DEM. The median, 68% and 95% intervals and coverage of the elevation differences are reported in Figures S1 and S2 for the raw images and the orthorectified image, respectively.

Table S1. List of stereo parameters tested in this study

Name	Algorithm	Kernel size	xcorr filter	stddev filter
sgm7_xc0	SGM	7	0	0
sgm7_xc1	SGM	7	1	0
sgm7_xc0_std1	SGM	7	0	1
sgm7_xc1_std1	SGM	7	1	1
sgm3_xc1	SGM	3	1	0
sgm5_xc1	SGM	5	1	0
sgm9_xc1	SGM	9	1	0
mgm7_xc0	MGM	7	0	0
mgm7_xc1	MGM	7	1	0
mgm7_xc0_std1	MGM	7	0	1
mgm7_xc1_std1	MGM	7	1	1
mgm3_xc1	MGM	3	1	0
mgm5_xc1	MGM	5	1	0
mgm9_xc1	MGM	9	1	0
ncc17_xc0	NCC	17	0	0
ncc17_xc1	NCC	17	1	0
ncc17_xc0_std1	NCC	17	0	1
ncc17_xc1_std1	NCC	17	1	1
ncc13_xc0	NCC	13	0	0
ncc21_xc0	NCC	21	0	0
ncc25_xc0	NCC	25	0	0

	On ice				Off ice			
	Median	68%	95%	Coverage	Median	68%	95%	Coverage
sgm7_xc0	-3.9	34.9	168.2	75.7	-1.1	10.7	40.8	73.1
sgm7_xc1	-1.3	5.2	13.4	14.7	-3.4	8.5	19.6	36.4
sgm7_xc0_std1	-0.1	18.7	142.5	45.5	-0.9	10.7	41.7	71.0
sgm7_xc1_std1	-1.1	5.2	14.0	10.3	-3.4	8.5	19.6	34.3
sgm3_xc1	-1.9	5.2	13.4	4.7	-4.1	8.5	19.4	20.3
sgm5_xc1	-1.7	5.1	13.3	9.5	-3.7	8.3	19.1	25.0
sgm9_xc1	-1.3	5.2	13.2	15.3	-3.4	8.5	19.7	35.9
mgm7_xc0	-3.4	25.3	141.6	80.9	-1.1	9.8	31.0	73.9
mgm7_xc1	-1.0	6.2	18.1	26.6	-2.7	8.5	19.5	53.1
mgm7_xc0_std1	0.0	16.0	122.9	46.0	-1.0	9.9	32.7	71.7
mgm7_xc1_std1	-0.5	6.0	17.0	16.5	-2.7	8.5	19.5	49.8
mgm3_xc1	-1.6	5.6	15.2	14.1	-3.3	8.7	20.0	41.0
mgm5_xc1	-1.4	5.9	16.6	21.2	-2.8	8.6	19.8	47.3
mgm9_xc1	-1.0	6.3	18.3	27.7	-2.8	8.5	19.5	52.9
ncc17_xc0	0.4	11.0	38.3	55.6	-1.5	9.5	28.2	67.9
ncc17_xc1	-0.6	6.9	19.2	27.9	-2.4	8.4	20.5	52.9
ncc17_xc0_std1	0.0	9.2	32.4	39.6	-1.5	9.4	27.8	66.7
ncc17_xc1_std1	-0.5	6.5	17.6	23.4	-2.4	8.4	20.3	51.7
ncc13_xc1	-0.5	7.3	20.1	22.8	-2.6	8.6	20.6	51.4
ncc21_xc1	-0.5	7.0	20.2	30.9	-2.3	8.5	21.7	53.0
ncc25_xc1	-0.1	9.2	30.6	43.3	-1.8	10.2	28.4	55.6

Figure S1. Median, 68% and 95% intervals and coverage of the elevation difference between the test KH-9 MC DEM and the reference Swiss ”Hist 1980” DEM on ice (left columns) and off ice (right columns) for all the tested parameters (rows). The difference is ”Hist 1980” DEM minus KH-9 DEM. The numbers are also color coded in red (median, 68%, 95%) and blue (coverage) for quick visualization. These results are for the raw images.

	On ice				Off ice			
	Median	68%	95%	Coverage	Median	68%	95%	Coverage
sgm7_xc0	3.9	11.0	26.1	92.4	-0.3	8.2	20.4	92.0
sgm7_xc1	2.1	8.7	19.9	45.0	-0.6	7.6	17.4	83.8
sgm7_xc0_std1	8.3	14.8	29.9	92.6	-0.2	8.2	20.4	91.9
sgm7_xc1_std1	8.7	15.0	29.1	77.1	-0.4	7.7	17.7	84.7
sgm3_xc1	1.8	8.4	19.2	29.3	-0.8	7.5	17.2	80.4
sgm5_xc1	2.9	9.4	21.8	49.5	-0.5	7.7	18.2	84.9
sgm9_xc1	2.1	8.8	20.1	45.8	-0.6	7.7	17.6	83.6
mgm7_xc0	3.6	10.8	25.5	92.1	-0.3	8.1	19.9	91.8
mgm7_xc1	3.1	9.8	22.0	71.1	-0.4	7.7	17.8	86.9
mgm7_xc0_std1	8.4	14.9	29.8	92.5	-0.2	8.1	19.9	91.6
mgm7_xc1_std1	8.6	14.9	29.1	88.2	-0.3	7.8	18.0	87.3
mgm3_xc1	2.8	9.7	22.3	58.7	-0.5	7.8	17.8	86.3
mgm5_xc1	4.1	10.8	24.5	81.1	-0.3	7.8	18.8	88.5
mgm9_xc1	3.1	9.7	21.9	71.0	-0.4	7.8	17.9	86.7
ncc17_xc0	2.4	12.7	36.6	71.4	-0.3	9.2	23.0	89.7
ncc17_xc1	1.5	10.6	29.8	51.0	-0.4	8.9	21.1	85.4
ncc17_xc0_std1	2.5	12.8	36.9	72.1	-0.3	9.2	23.1	89.7
ncc17_xc1_std1	1.7	10.9	30.6	53.0	-0.4	8.9	21.2	85.5
ncc13_xc1	1.2	10.9	32.0	40.0	-0.6	9.2	22.2	82.9
ncc21_xc1	1.9	10.7	28.2	59.9	-0.3	8.9	21.3	86.6
ncc25_xc1	2.3	11.0	29.0	67.5	-0.2	9.0	21.8	87.6

Figure S2. Same as Figure S1 but for the images orthorectified with SRTM.

2 UNCERTAINTY ANALYSIS FOR THE SWISS REFERENCE DEM

We follow the methodology described in section 3.3 to estimate the standard error of the elevation changes obtained by differencing the aerial "Hist 1980" and SwissAlti3D DEMs, for any given area average.

The experimental variogram is shown on Figure S3a. It is fitted using both a double (blue line) and triple nested (orange line) spherical model. The triple nested model does not significantly improve the quality of the fit so we use the double nested model for the uncertainty calculation. We find that spatial correlation lengths of 138 m and 2133 m explain about 47% and 53% of the variance, respectively.

Figure S3b shows the empirical standard error as a function of the averaging distance (black dots) and the analytical error estimated with the double (blue line) and triple (orange line) nested spherical models. There is a good agreement between both the experimental and analytical estimates, showing that correlation lengths of a few kilometers lead to relatively large uncertainties on average elevation changes calculated over such distances or below.

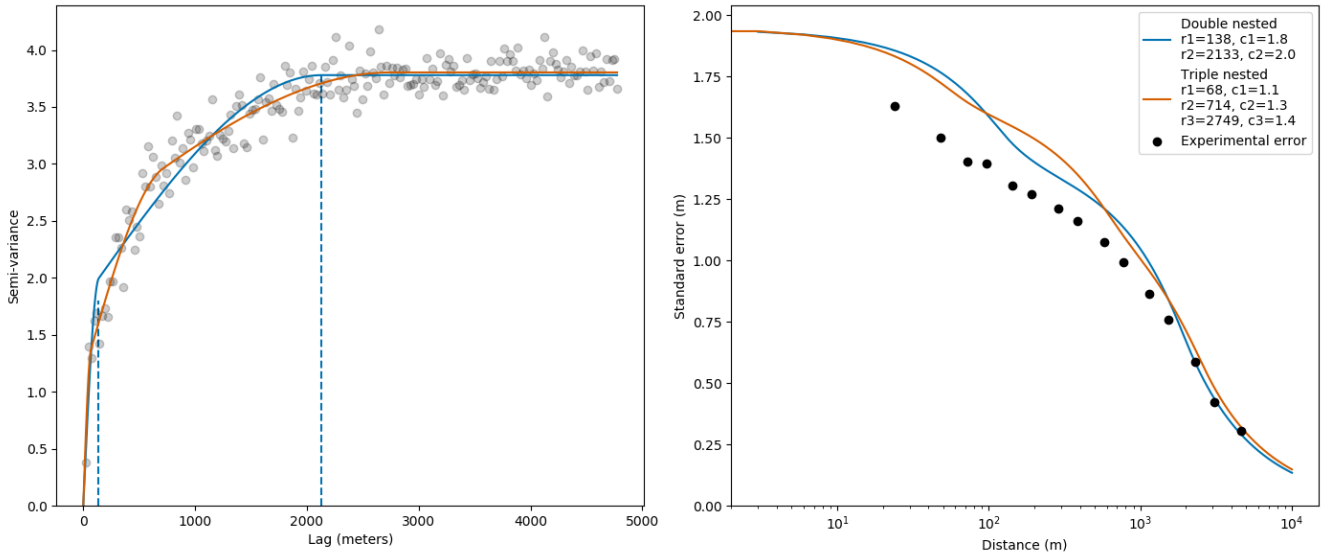

Figure S3. Uncertainty of the Swiss reference DEMs. (a) Experimental variogram of the elevation difference between the "Hist 1980" and SwissAlti3D DEMs (grey dots). A double nested (blue line) and triple nested (orange line) spherical models are fitted to the experimental values. (b) Empirical standard error of the mean (SEM) as a function of the averaging distance (black dots) compared to the analytical estimates using the double and triple nested models.

3 TILING ARTIFACTS

This section shows several examples of ”tiling” artifacts observed in the KH-9 MC images and DEMs generated with them. Slight changes in image intensity, revealed by a 7 x 7 pixel standard deviation filter, are visible in the original scans provided by the USGS **before** any pre-processing (Figure S4). The size of the ”tiles” is similar to that of the photogrammetric Leica DSW700 scanner used by the USGS to digitize the images. This implies that these artifacts are most likely introduced during scanning. These artifacts are most likely associated with a horizontal shift in the pixel positions, which cause a similar ”tiling” pattern in the DEMs generated with those images (Figure S5). However, these two artifacts do not seem to be necessarily both present for a given image pair, i.e. an intensity artifact might not lead to a DEM artifact or vice-versa. Pair DZB1206-500082_018019, shown in Figures S4 and S5 is one example where the artifact is present in both stereo images, which combines in the final DEM to generate a more complex tiling pattern.

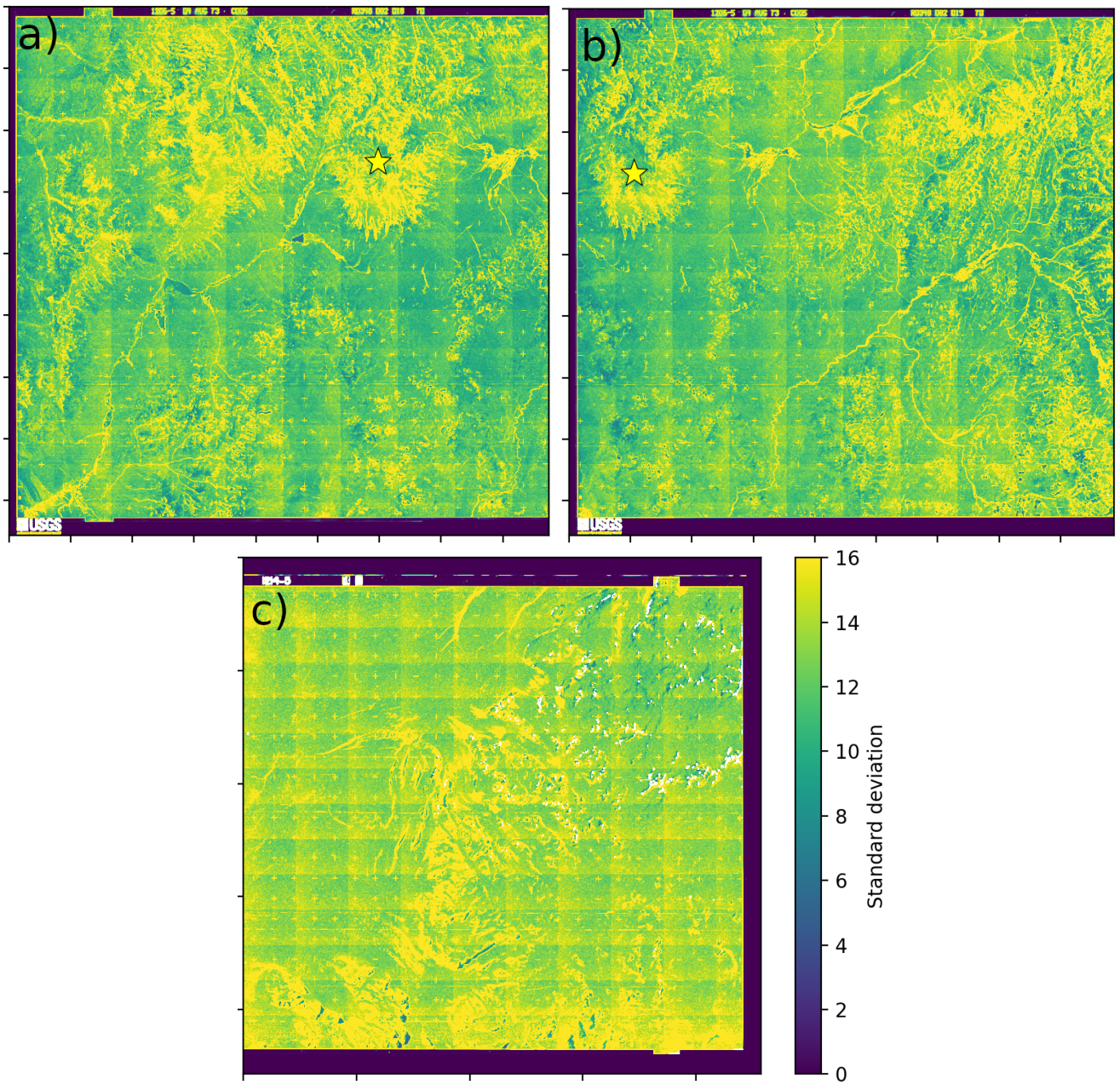

Figure S4. Standard deviation, calculated on a moving 7 x 7 pixel window, of the original scans **before** any pre-processing for half images DZB1206-500082L018001_a (a), DZB1206-500082L019001_a (b) and DZB1214-500011L001001_b (c). Slight changes in intensity occur in a regular ”tiling” pattern. The location of the yellow star is identical between this figure and figure S5.

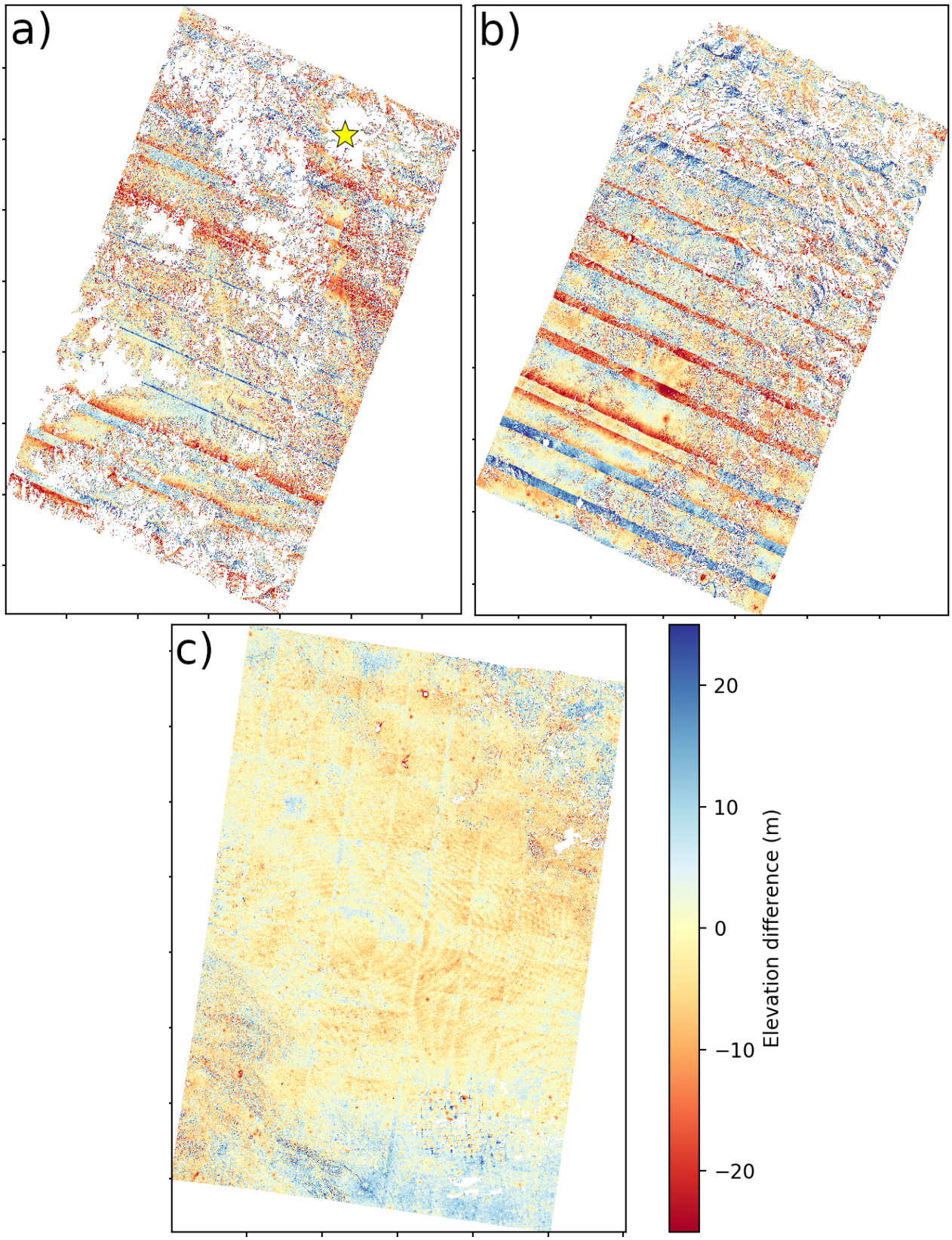

Figure S5. Elevation change obtained with KH-9 MC image pairs DZB1206-500082_018/019 (a) DZB1209-500092_001/002 (b) and DZB1214-500379_002/003 (c) showing various ”tiling” artifacts most likely introduced during the scanning. Note that glaciers are masked in these figures. The location of the yellow star is identical between this figure and figure S4.