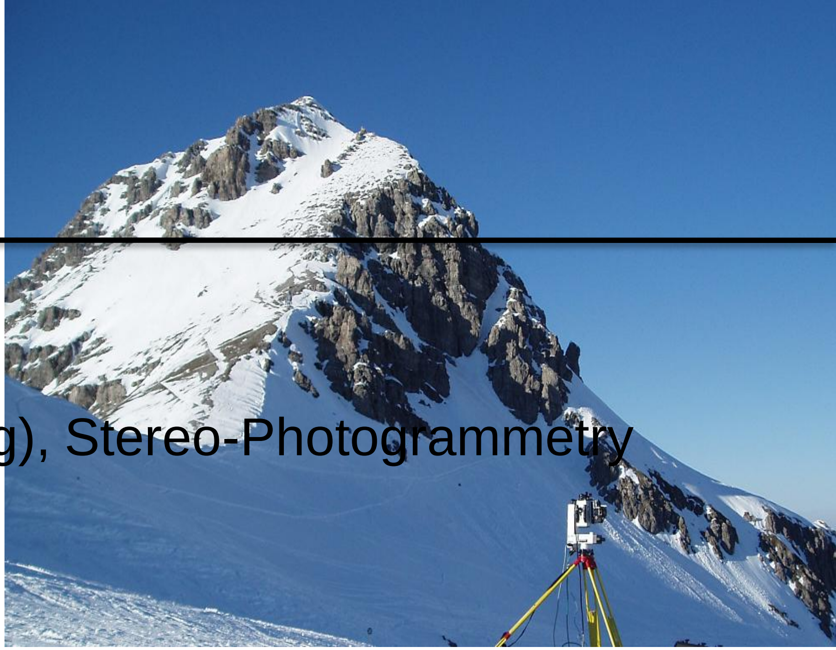
3D-snow mapping, a comparison of methods leading to a standardized measurement and post processing protocol

Alexander Prokop

Snow Scan GmbH, Vienna, Austria

Existing Methods

Terrestrial Laser Scanning (DGPS-Positioning), Stereo-Photogrammetry



- Mobile Laser Scanning GPS, IMU (INS) SfM-Photogrammetry (GPS)

- Airborne Laser Scanning and SfM-Photogrammetry (Helicopter, Aircraft, GPS, IMU (INS))

Lots of development in the past decade

Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements

Alexander Prokop *

Institute of Mountain Risk Engineering, Department of Civil Engineering and Natural Hazards, University of Natural Resources and Applied Life Sciences, A-1190 Wien, Peter Jordanstrasse 82, Austria

Mapping snow depth in alpine terrain with unmanned aerial systems (UASs): potential and limitations

Yves Bühler[1], Marc S. Adams[2], Ruedi Bösch[3], and Andreas Stoffel[1]

[1]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[2]Austrian Research Centre for Forests (BFW), Innsbruck, Austria
[3]Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland

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Lidar measurement of snow depth: a review

Jeffrey S. DEEMS,[1] Thomas H. PAINTER,[2] David C. FINNEGAN[3]

[1]*National Snow and Ice Data Center/NOAA Western Water Assessment, University of Colorado at Boulder, Boulder, CO, E-mail: deems@nsidc.org*
[2]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*
[3]*US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Engineer Research and Developm Centers, Hanover, NH, USA*

ABSTRACT. Laser altimetry (lidar) is a remote-sensing technology that holds tremendous promise for mapping snow depth in snow hydrology and avalanche applications. Recently lidar has seen a dramatic widening of applications in the natural sciences, resulting in technological improvements and an increase in the availability of both airborne and ground-based sensors. Modern sensors allow mapping of

The Airborne Snow Observatory: Fusion of scanning lidar, imaging spectrometer, and physically-based modeling for mapping snow water equivalent and snow albedo

Thomas H. Painter [a,*], Daniel F. Berisford [a], Joseph W. Boardman [b], Kathryn J. Bormann [a], Jeffrey S. Deems [c,d], Frank Gehrke [e], Andrew Hedrick [f], Michael Joyce [a], Ross Laidlaw [a], Danny Marks [f], Chris Mattmann [a], Bruce McGurk [g], Paul Ramirez [a], Megan Richardson [a], S. McKenzie Skiles [a], Felix C. Seidel [a], Adam Winstral [f]

Review

LiDAR remote sensing of the cryosphere: Present applications and future prospects

Anshuman Bhardwaj [a,b,*], Lydia Sam [b,c], Akanksha Bhardwaj [d], F. Javier Martín-Torres [a,e]

[a] *Division of Space Technology, Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Kiruna, Sweden*
[b] *Department of Environmental Science, Sharda University, Greater Noida, India*
[c] *Defence Terrain Research Laboratory, New Delhi, India*
[d] *Banaras Hindu University, Varanasi, India*
[e] *Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR), Armilla, Granada, Spain*

Mapping snow depth from manned aircraft on landscape scales at centimeter resolution using structure-from-motion photogrammetry

M. Nolan[1], C. Larsen[2], and M. Sturm[2]

[1]Institute of Northern Engineering, University of Alaska Fairbanks, 306 Tanana Loop, Fairbanks, AK 99775, USA
[2]Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Drive, Fairbanks, AK 99775, USA

Correspondence to: M. Nolan (matt2013@drmattnolan.org)

Merging terrestrial laser scanning technology with photogrammetric and total station data for the determination of avalanche modeling parameters

Alexander Prokop [a,*], Peter Schön [a], Florian Singer [a], Gaëtan Pulfer [b], Mohamed Naaim [b], Emmanuel Thibert [b], Alvaro Soruco [c]

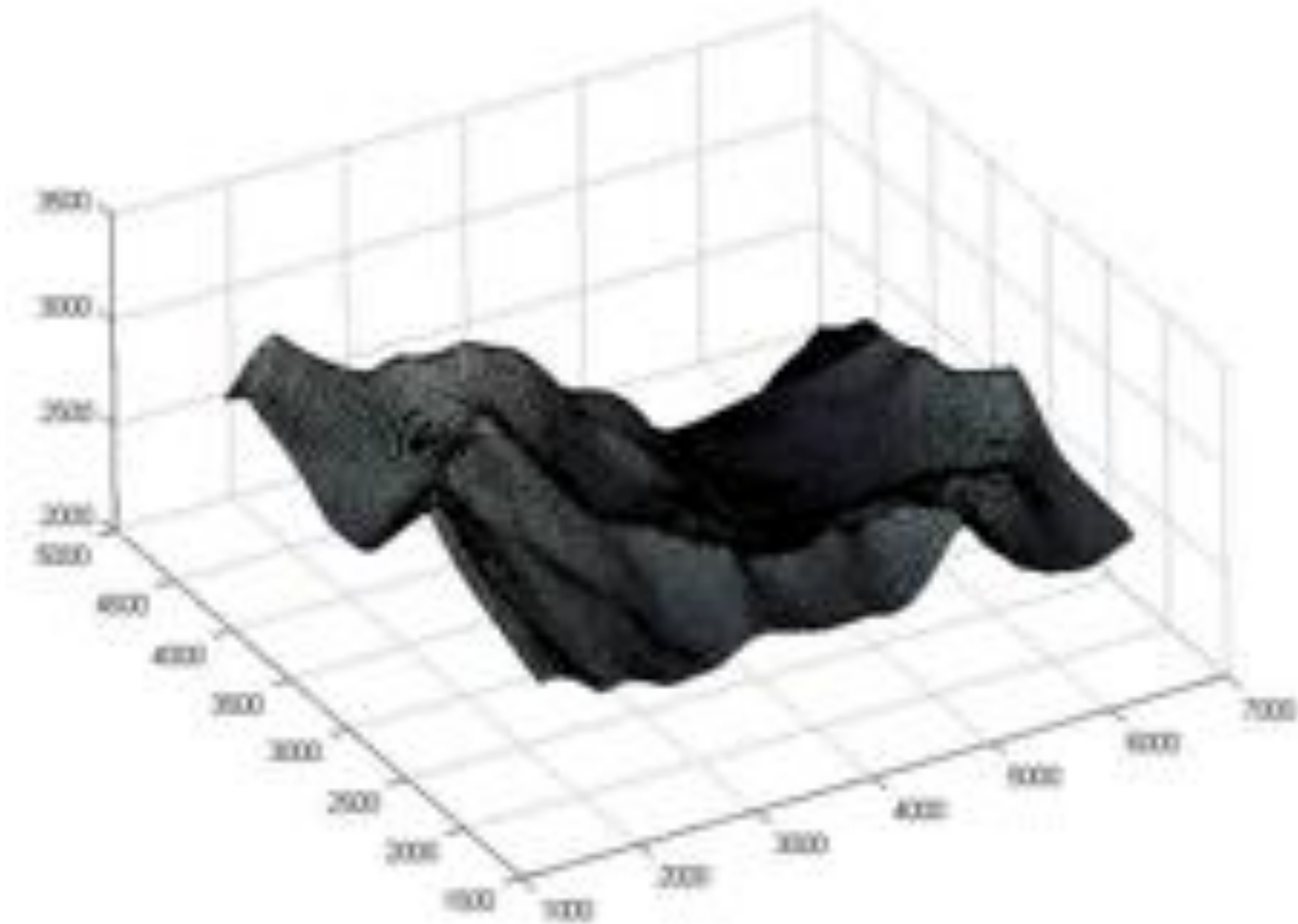
[a] *Institute of Mountain Risk Engineering, Department of Structural Engineering and Natural Hazards, University of Natural Resources and Applied Life Sciences, Vienna, Austria*
[b] *IRSTEA, UR ETGR, Erosion Torrentielle Neige et Avalanche, Grenoble, France*
[c] *Instituto de Geologia y del Medio Ambiante (IGEMA), Universidad Mayor de San Andres, La Paz, Bolivia*

INVESTIGATING SNOWPACK VOLUMES AND ICING DYNAMICS IN THE MORAINE OF AN ARCTIC CATCHMENT USING UAV PHOTOGRAMMETRY

ÉRIC BERNARD* (eric.bernard@univ-fcomte.fr)

CNRS, University of Franche Comté, UMR ThéMA, Besançon, France

Product: High resolution (cm/dm scale) DSM (Digital Surface Model)



Final product: High resolution (cm/dm scale) Snow Depth Map

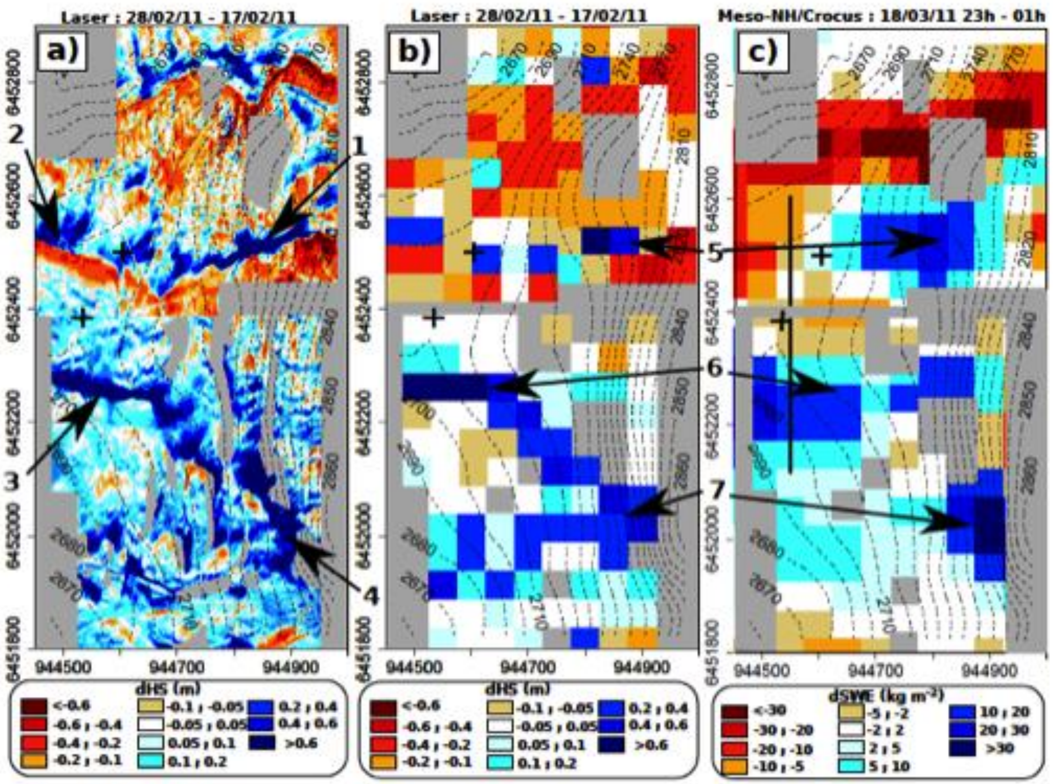
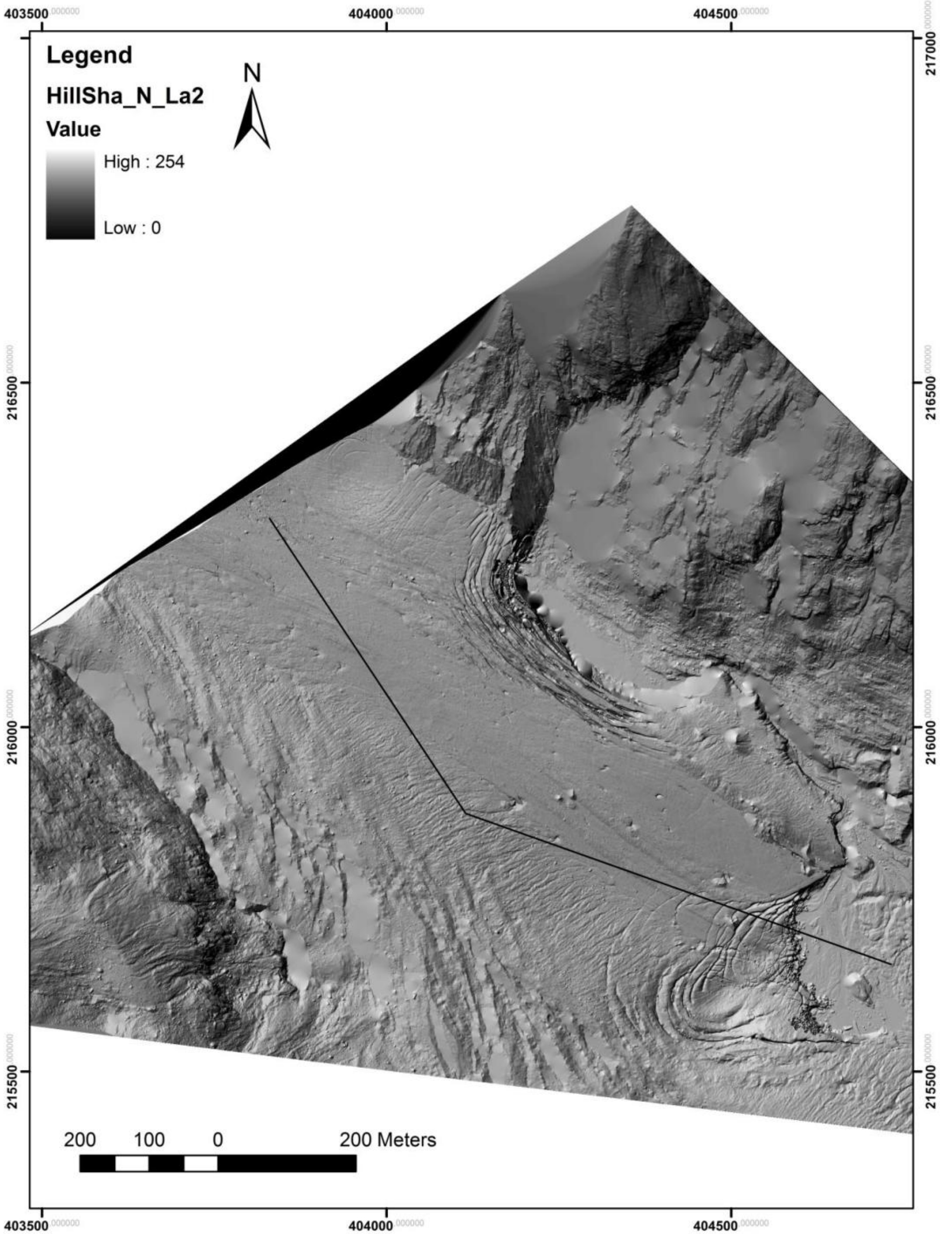


Fig. 10. Maps of snow cover evolution during northern blowing snow events around Col du Lac Blanc (black box on Fig. 9): (a) snow depth difference measured by TLS at an horizontal resolution of 1 m between 28 February 2011 and 17 February 2011, (b) same as (a) but averaged at an horizontal resolution of 50 m and (c) SWE difference simulated by Meso-NH/Crocus between 23:00 and 01:00 on 18 March 2011. The arrow indicate example of snow deposition patterns discussed in the text. Note the difference of colourbars. The spatial coordinates are in m and the dashed isolines correspond to $\Delta z = 10$ m.

Multiple crowd-sourced SfM-DEMs of an Alpine valley glacier: Validation by LIDAR and surface change detection 2012-2017

Bernhard Hynek[1], Alexander Prokop[2], Leon Bührle [1], David Zangerle[3] and Anton Neureiter[1]
[1]Zentralanstalt für Meteorologie und Geodynamik (ZAMG), Climate Research Department, Vienna
[2] The University Centre in Svalbard (UNIS), Longyearbyen
[3] University of Natural Resources and Life Sciences, Vienna
Contact: bernhard.hynek@zamg.ac.at



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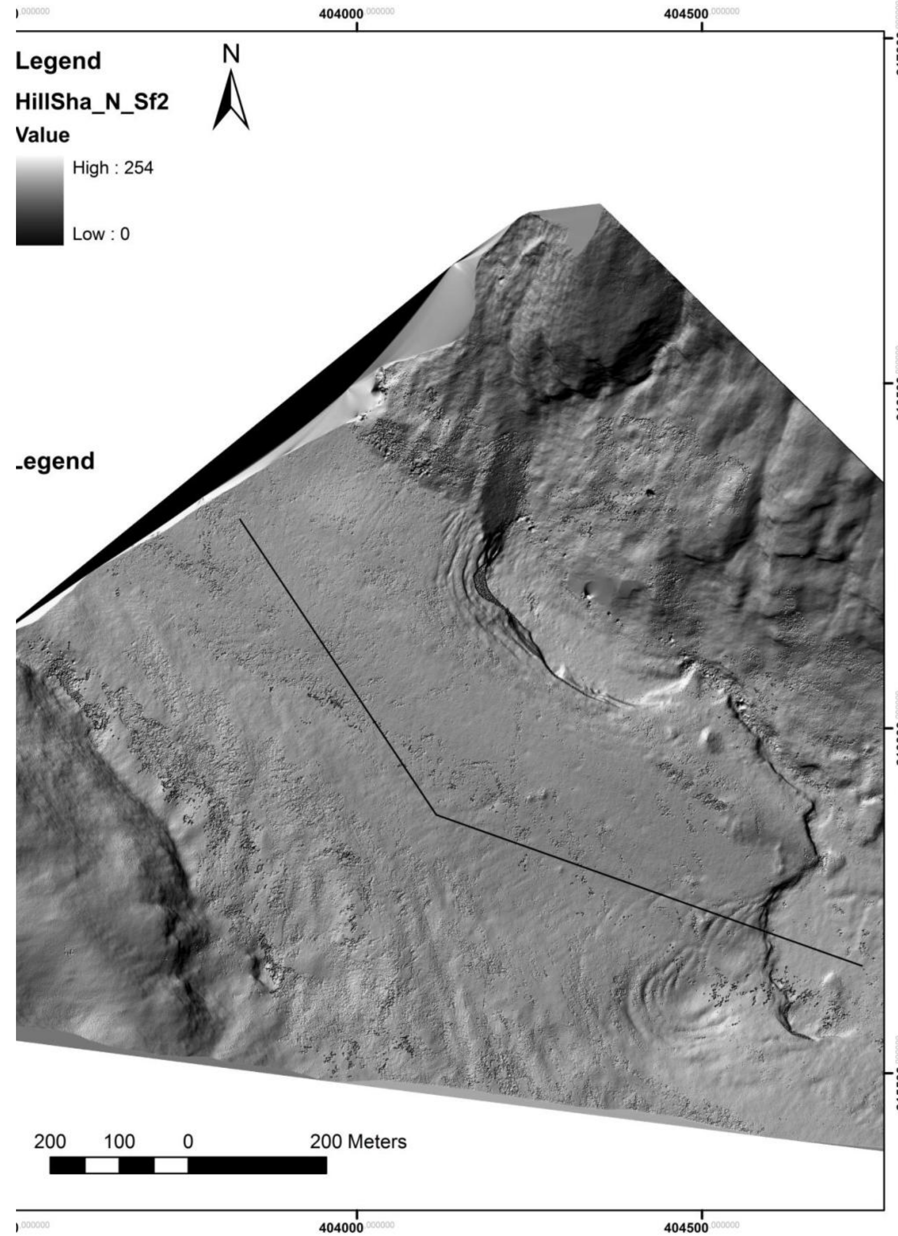

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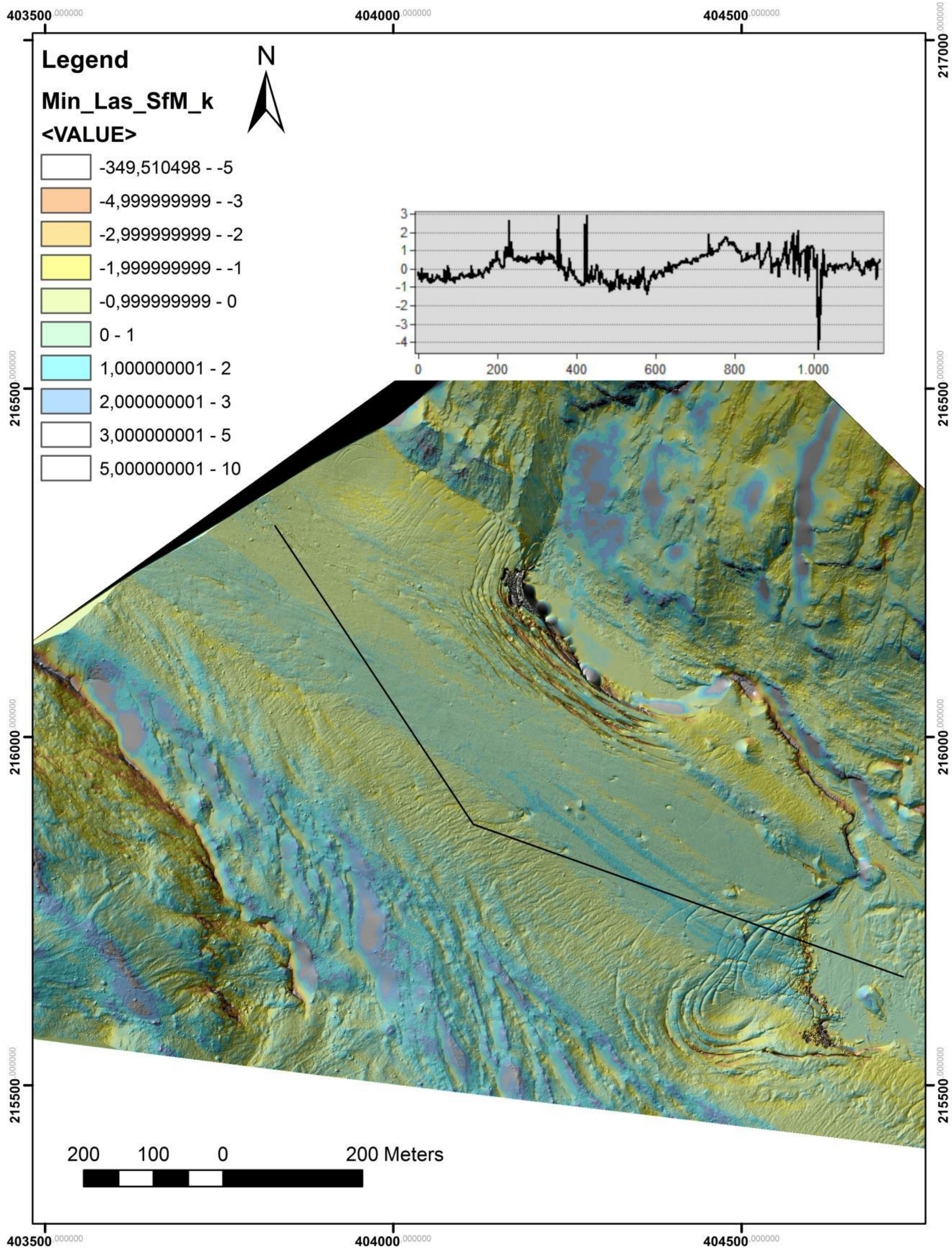
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2,000000001 - 3
3,000000001 - 5
5,000000001 - 10
N
200 100 0 200 Meters

INVESTIGATING SNOWPACK VOLUMES AND ICING DYNAMICS IN THE MORAINE OF AN ARCTIC CATCHMENT USING UAV PHOTOGRAMMETRY

Éric Bernard* (eric.bernard@univ-fcomte.fr)

CNRS, University of Franche Comté, UMR ThéMA, Besançon, France

INVESTIGATING SNOWPACK VOLUMES AND ICING DYNAMICS IN THE MORAINE OF AN ARCTIC CATCHMENT USING UAV PHOTOGRAMMETRY

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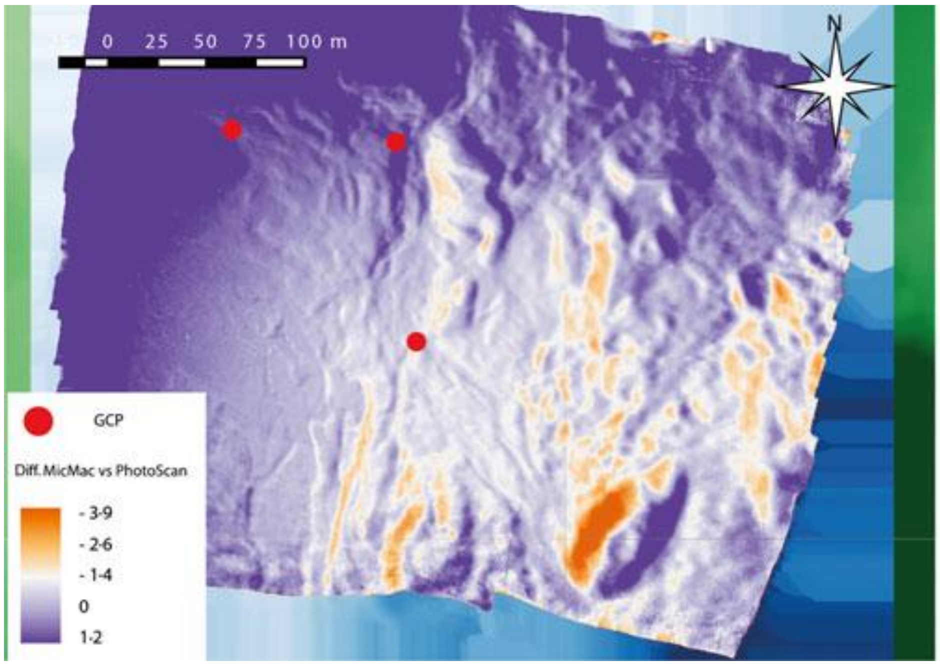
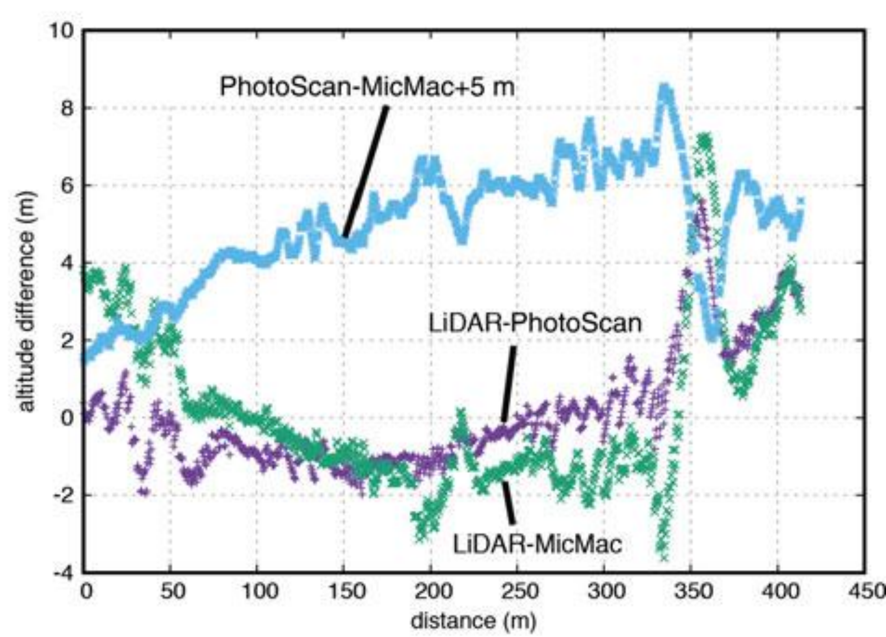
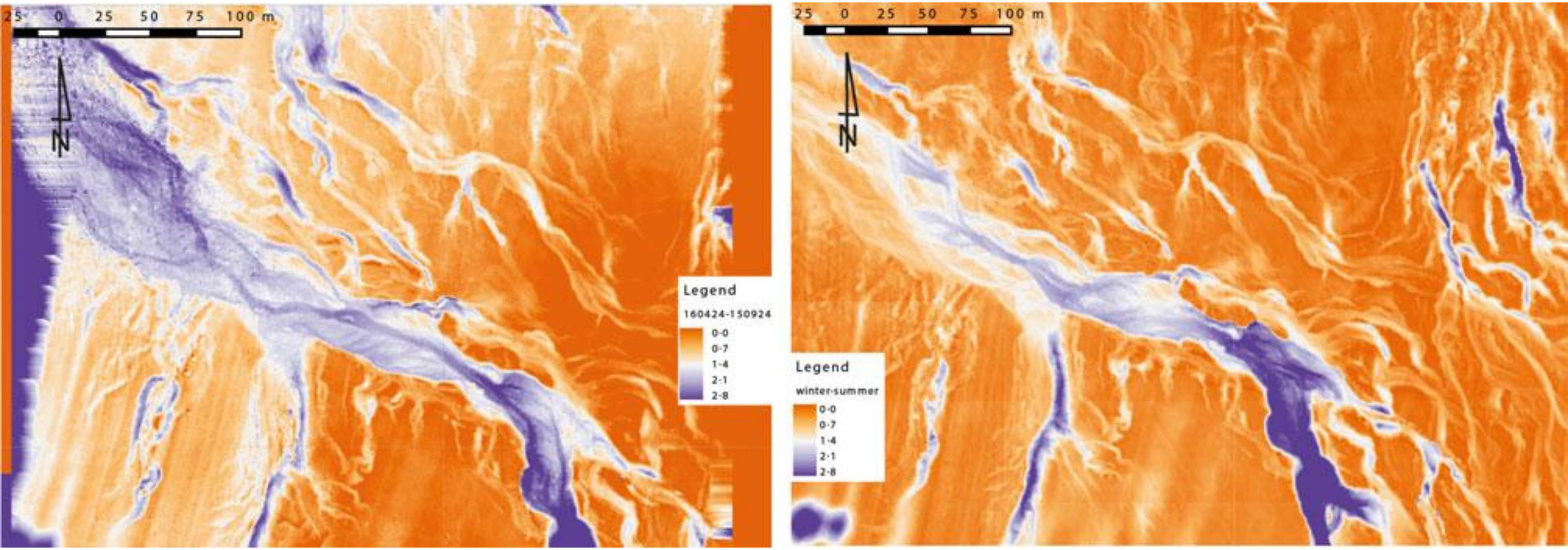


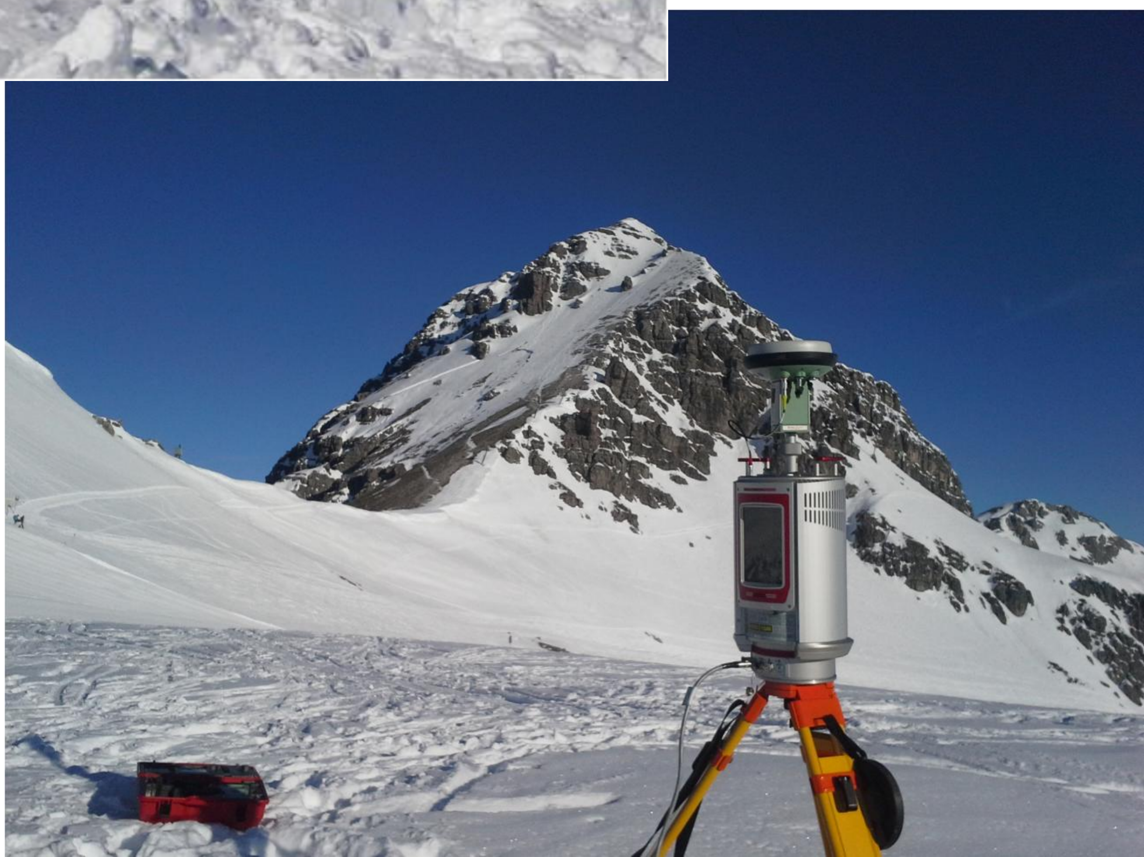


Left: map of the DEM difference. The positioning mismatch is obvious in the lower-right corner where a hill exhibits a positive height difference on the right and negative height difference on the left. Right: cross section of DEM differences between the airborne lidar dataset and two DEMs generated from photogrammetric processing of the same pictures with the same camera GNSS coordinates provided in each picture Exif header, using Agisoft PhotoScan and MicMac. So that the graph is readable, **+5 m was added to the PhotoScan–** MicMac difference

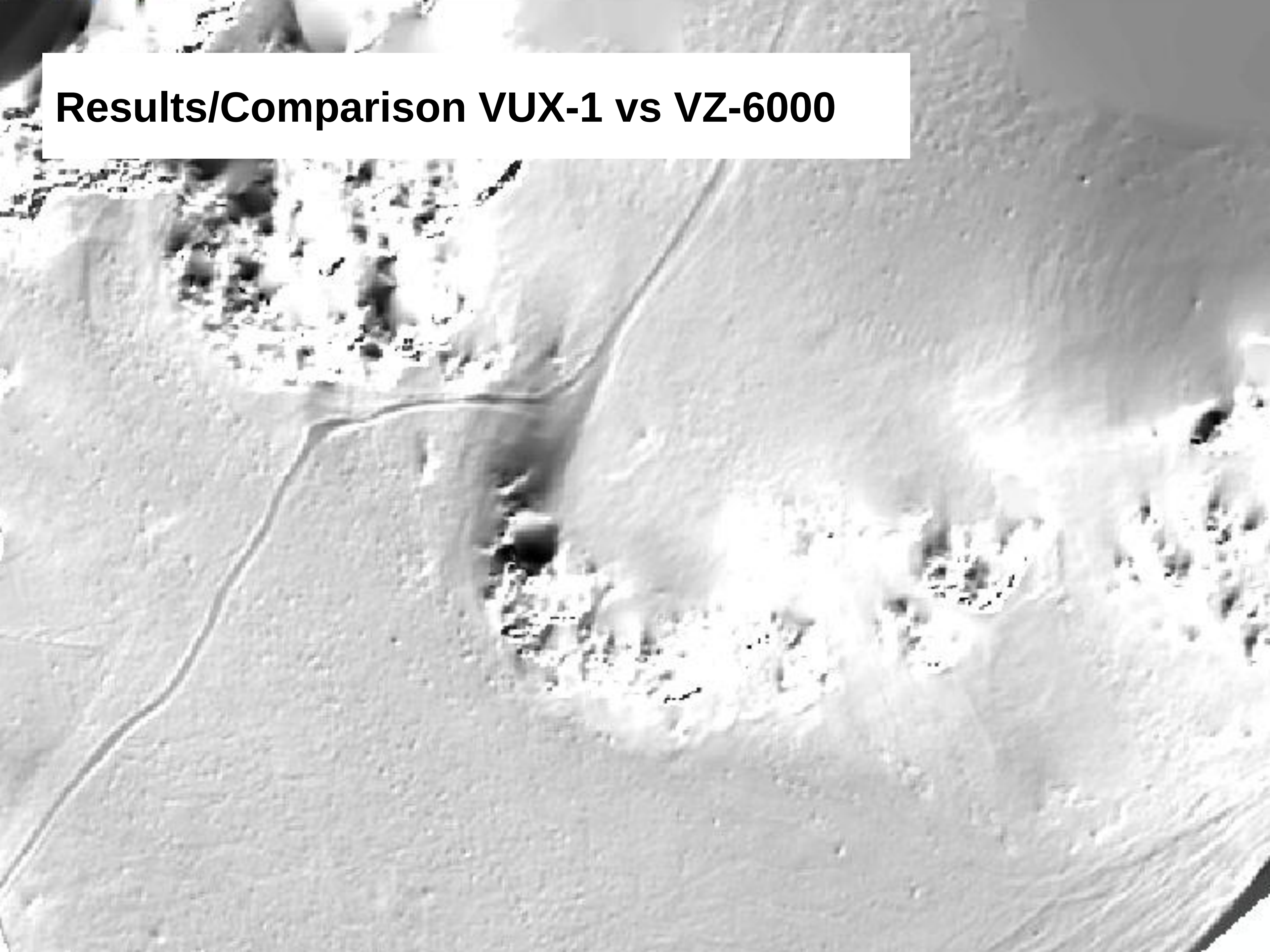


Left: colour-shaded image of the DEMs generated from SfM and adjusted through a translation using GCPs. The two dates at which the data were acquired were 24th September 2015 and 24th April 2016. Right: difference of DEMs generated from Lidar.

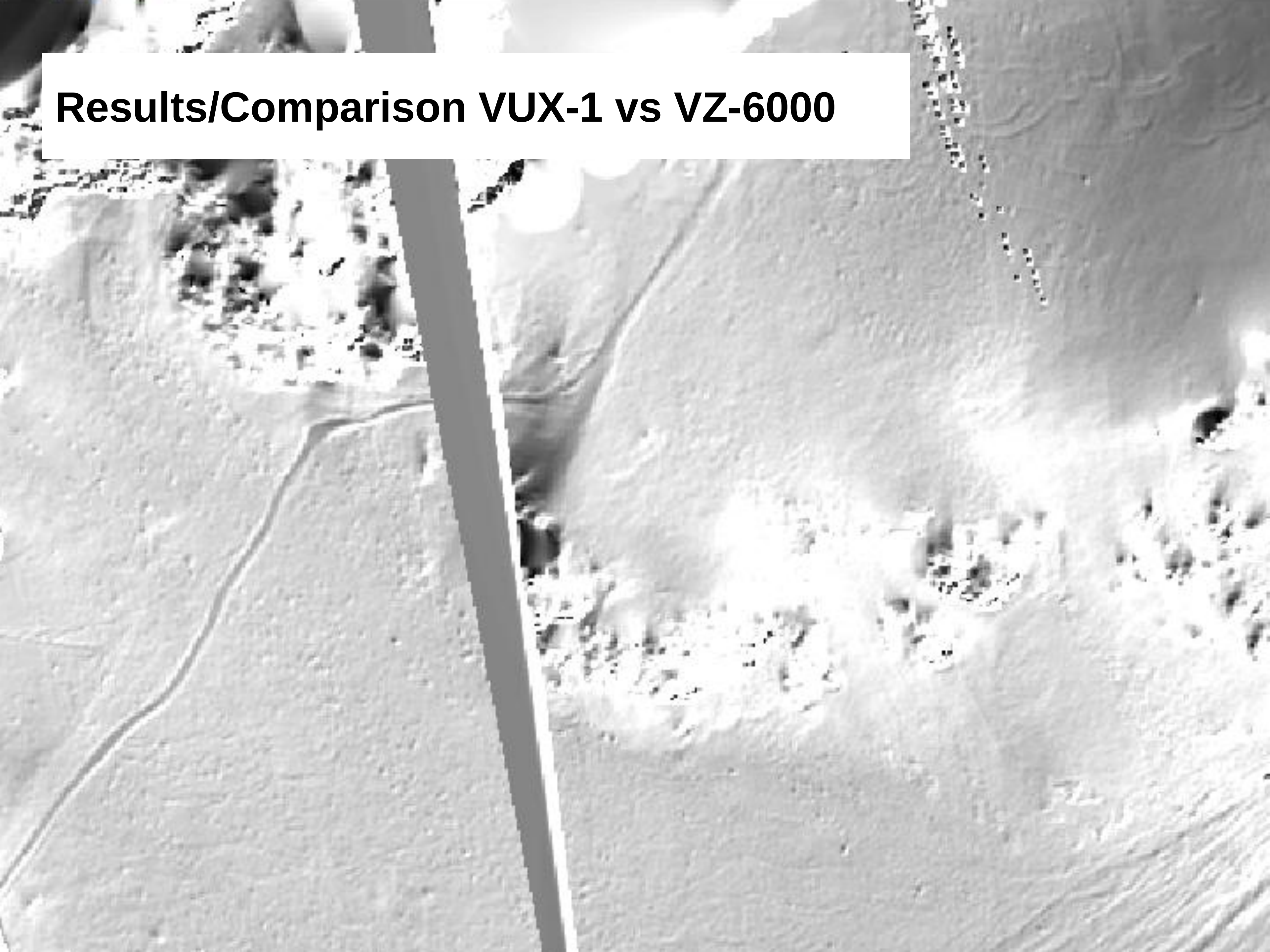
TLS Riegl VZ 6000 vs RiCopter UAV Riegl VUX-1



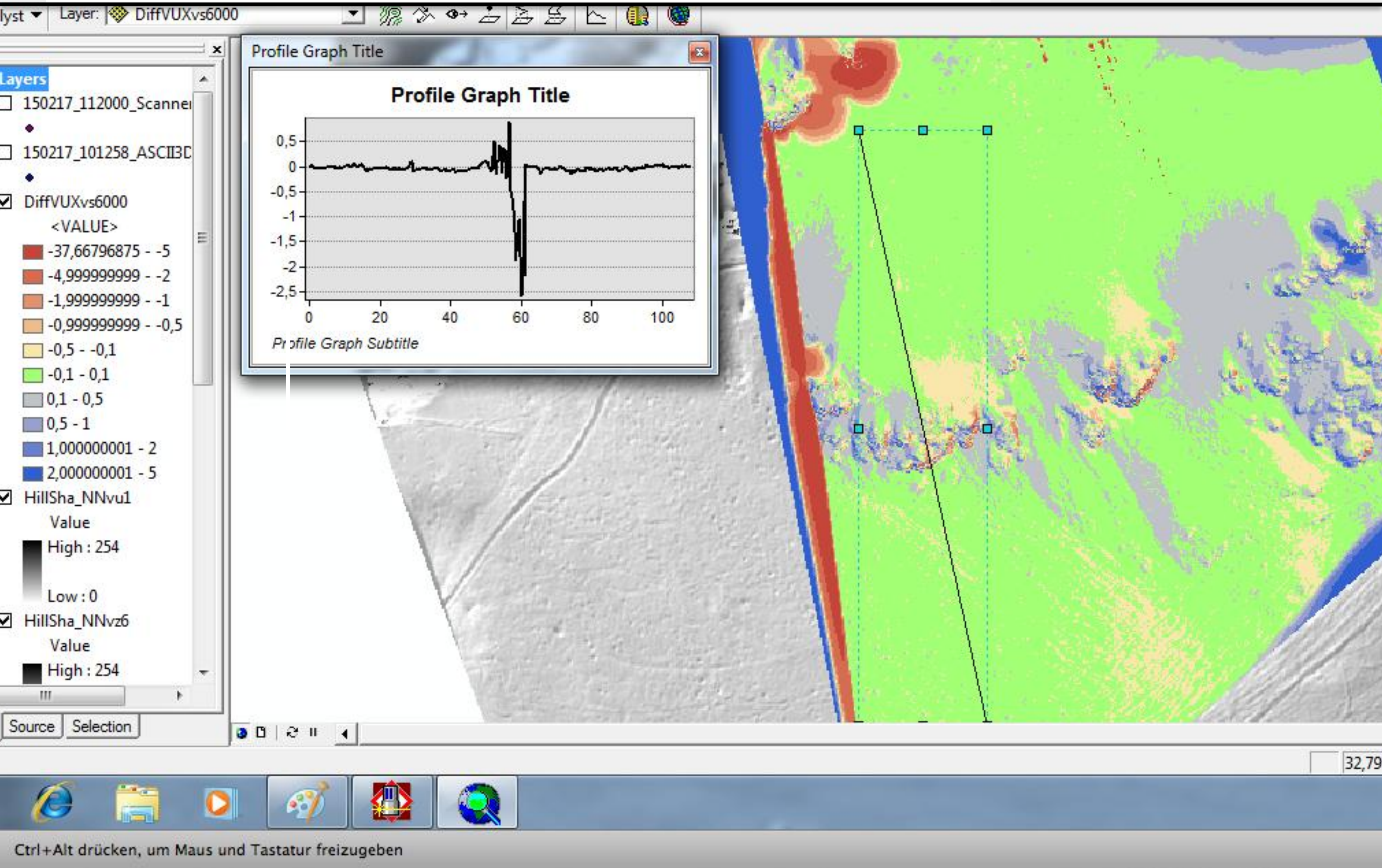
Results/Comparison VUX-1 vs VZ-6000



Results/Comparison VUX-1 vs VZ-6000



Results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Profile Graph Title
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80
100
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0,1 - 0,5
0,5 - 1
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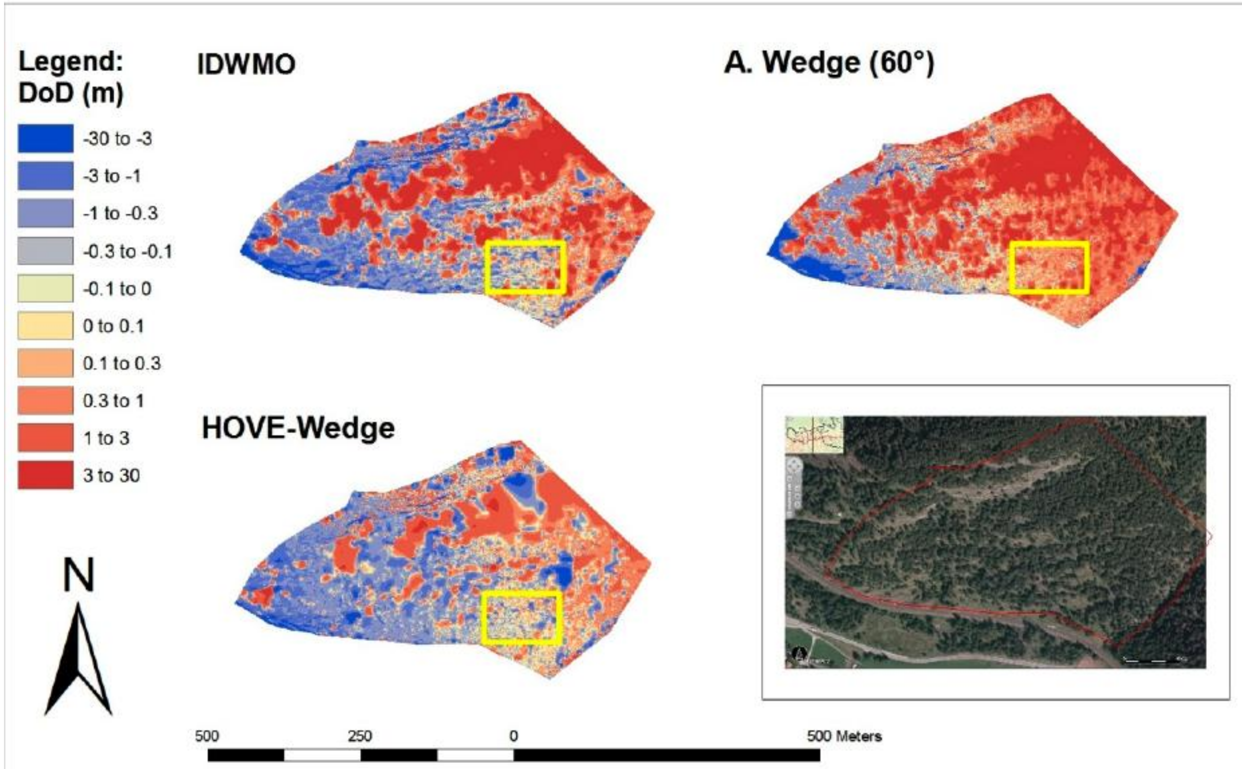
2,000000001 - 5
HillSha_NNvu1
Value
High : 254
Low : 0
HillSha_NNvz6
Value
High : 254
Source
Selection
32,79
Ctrl+Alt drücken, um Maus und Tastatur freizugeben

Article

HOVE-Wedge-Filtering of Geomorphologic Terrestrial Laser Scan Data

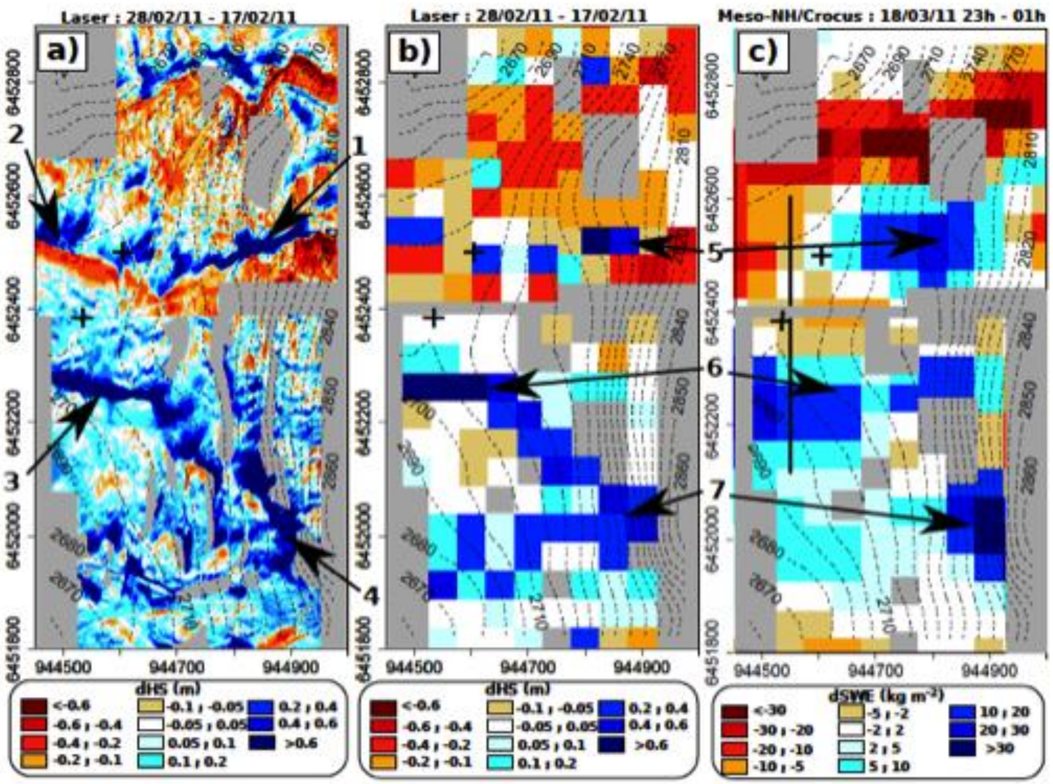
Helmut Panholzer [1,*] and Alexander Prokop [2]

and



Statistic	Modified Wedge-Filtering	Wedge Absolut-Filtering (60°)	IDWMO Method
Groundpoints	2703	3014	1346
Mean error	−0.142	1.296	0.361
RMSE	0.555	1.855	1.366
Standard deviation	0.536	1.537	1.366
Median	−0.061	0.456	−0.054
NMAD	0.510	1.529	1.057
68.3% quantile	0.053	0.828	0.125
95% quantile	0.509	4.390	1.876

Resolution is reported but what else is to mention?



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Precision of the device used

Impossible to be more accurate than the precision!

Laser Product Classification	Class 3B Laser Product according to IEC60825-1:2007
The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007	

Range Measurement Performance [1]

Measuring Principle	time of flight measurement, echo signal digitization, online full waveform analysis, full waveform export capability (optional)
Mode of operation	single pulse ranging

Laser Pulse Repetition Rate PRR (peak) [2]	30 kHz	50 kHz	150 kHz	300 kHz
Effective Measurement Rate (meas./sec) [2]	23,000	37,000	113,000	222,000
Max. Measurement Range [3]				
natural targets $\rho \geq 90$ %	6,000 m [4]	6,000 m [4]	4,200 m [4]	3,300 m [4]
natural targets $\rho \geq 20$ %	3,600 m	3,600 m [4]	2,400 m [4]	1,800 m [4]
Max. Number of Targets per Pulse		practically unlimited [5]		
NOHD (Nominal Ocular Hazard Distance) [6]	85 m	85 m	45 m	28 m
ENOHD (Extended Nominal Ocular Hazard Distance) [6]	1,050 m	1,050 m	690 m	245 m

Accuracy [7,9]	15 mm
Precision [7,9]	10 mm
Minimum Range	5 m
Laser Wavelength	near infrared
Laser Beam Divergence	0.12 mrad [10]
Laser Beam Footprint (Gaussian Beam Definition)	15 mm @ exit, 60 mm @ 500 m, 120 mm @ 1000 m, 240 mm @ 2000 m

1) With online waveform processing.
2) Rounded values, selectable by measurement program.
3) Typical values for average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter, perpendicular angle of incidence and for atmospheric visibility of 23 km. In bright sunlight, the operational range may be considerably shorter than under an overcast sky.
4) Ambiguity to be resolved by post-processing.
5) Details on request.
6) ENOHD values only applicable for 3D scan patterns with minimum angular stepwidths ≥ 0.01 degrees. Rectangular scan patterns with angular stepwidths < 0.01 degrees and/or line scans (2D scans) have higher ENOHD values.
7) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
8) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
9) One sigma @ 150 m range under RIEGL test conditions.
10) Measured at the $1/e^2$ points. 0.12 mrad corresponds to an increase of 12 mm of beam diameter per 100 m distance.

Scanner Performance

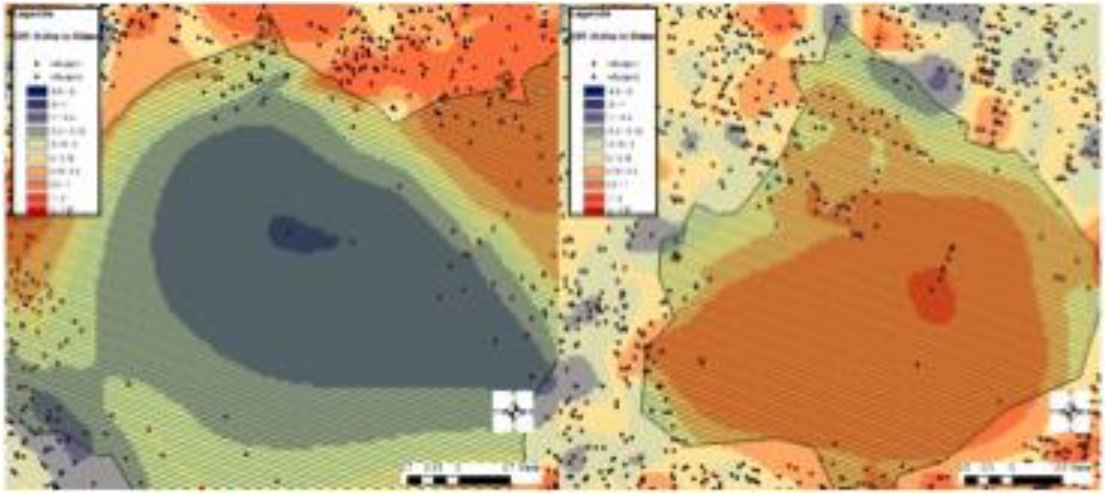
	Vertical (Line) Scan	Horizontal (Frame) Scan
Scanning Mechanism	lightweight mirror	rotating head
	rotating / oscillating / step-by-step	
Field of View (selectable)	total 60° (+30° / -30°)	max. 360°
Scan Speed (selectable)	100°/sec to 14,400°/sec (+ 20 rotations/sec), full FOV	0°/sec to 60°/sec [10]
Angular Step Width $\Delta\vartheta$ (vertical), $\Delta\varphi$ (horizontal)	$0.002° \leq \Delta\vartheta \leq 0.280°$ [11] between consecutive laser shots	$0.002° \leq \Delta\varphi \leq 3°$ [11] between consecutive scan lines
Angle Measurement Resolution	better 0.0005° (1.8 arcsec)	better 0.0005° (1.8 arcsec)
Inclination Sensors	integrated, for vertical scanner setup position, details see page 2	
GNSS Receiver	integrated, L1, with antenna	
Compass	integrated, for vertical scanner setup position, details see page 2	
Laser Plummet	integrated	
Internal Sync Timer	integrated, for real-time synchronized time stamping of scan data	
Scan Sync (optional)	scanner rotation synchronization	
Waveform Data Output (optional)	providing digitized echo signal information for specific target echoes	

10) Frame scan can be disabled, providing 2D scanner operation.
11) Selectable.

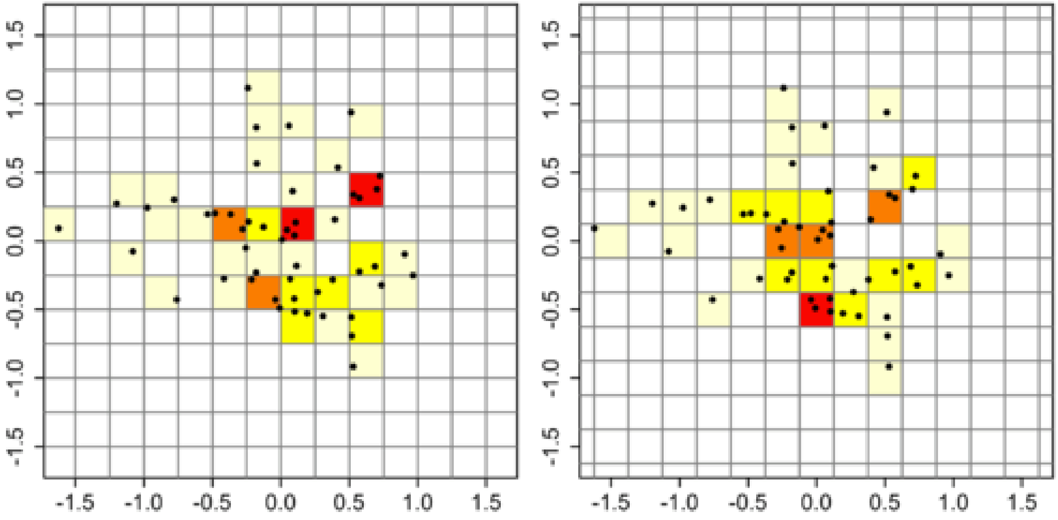
General Technical Data

Power Supply Input Voltage / Power Consumption	11 - 32 V DC / typ. 75 W (max. 90 W)
Main Dimensions / Weight	248 x 226 x 450 mm (length x width x height), approx. 14.5 kg
Humidity / Protection Class	max. 80 % non condensing @ +31°C / IP64, dust- and splash-proof
Temperature Range	
Storage / Operation	-10°C up to +50°C / 0°C up to +40°C (standard operation)
Low Temperature Operation [12]	-20°C: continuous scanning operation if instrument is powered on while internal temperature is at or above 0°C and still air

Point density (SfM How many pairs did the algorithm really find on snow surfaces?)

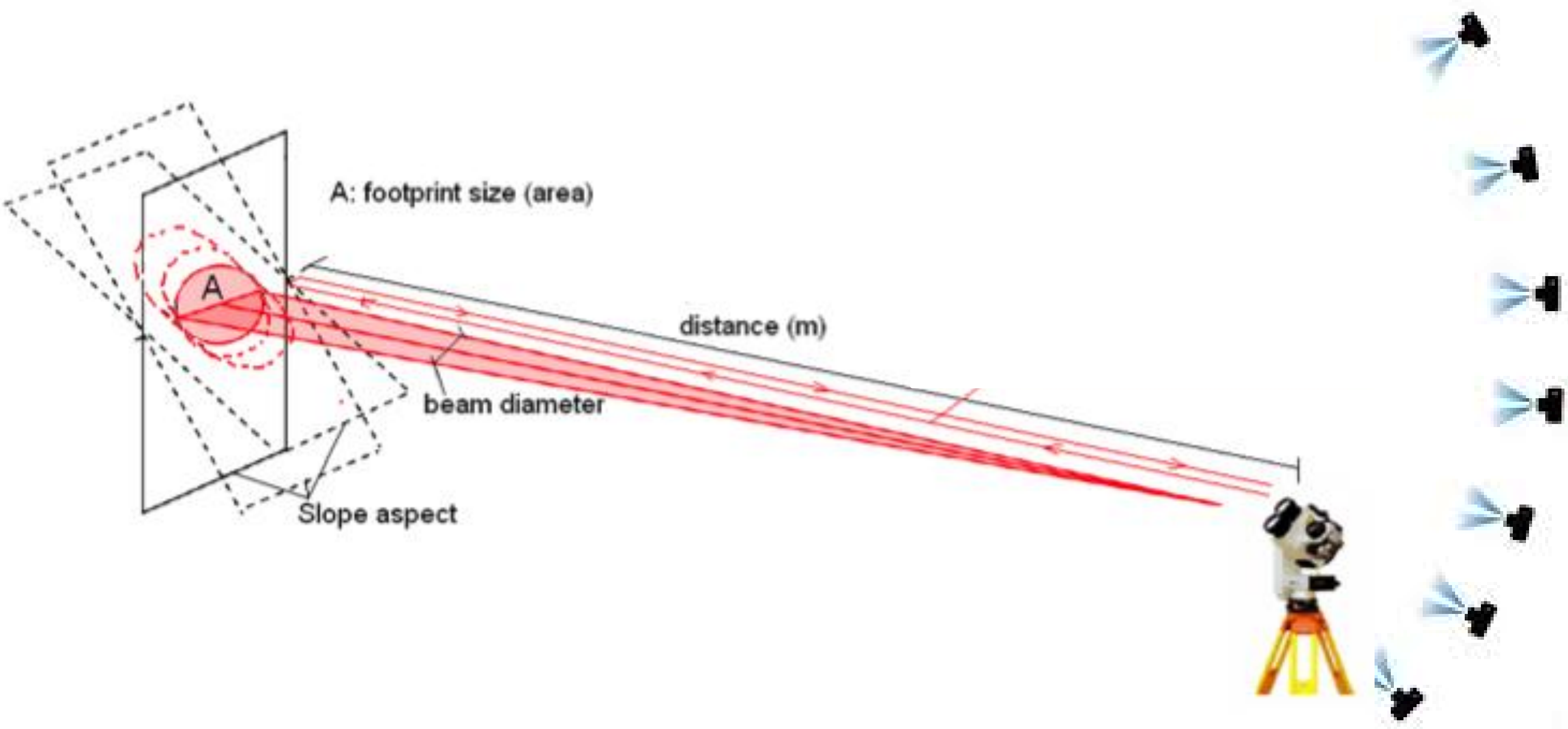


How many minimum points / grid cell?



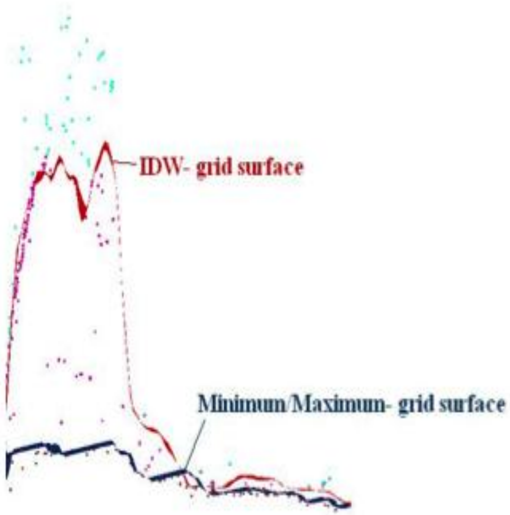
Actual foot print size?

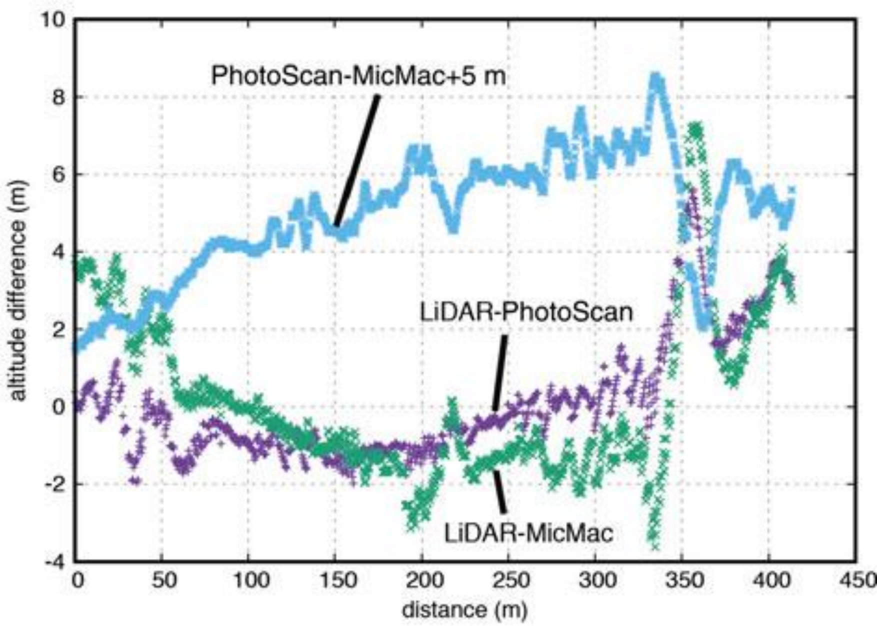
Not at exit of the device, the actual footprint size at the target is needed!



Interpolation method / SfM software (algorithm used)

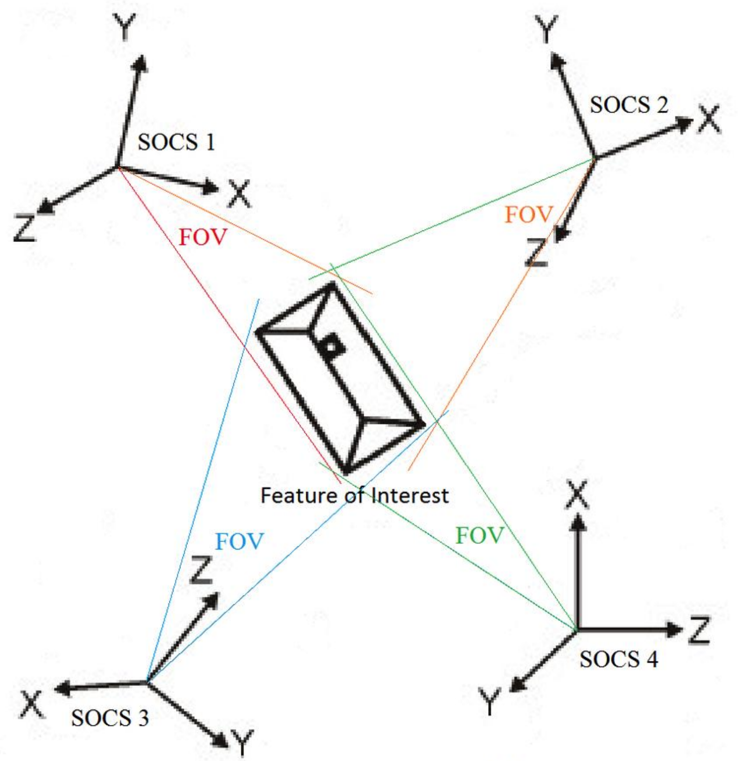
- Triangulation (Delauney Algorithm)
- Kriging (ordinary/ universal)
- Natural Neigbour
- Minimum surface
- Maximum surface
- IDW





Registration error / coordinate system

The same or different source of measurement? Coordinate system matching? DGPS or GPS referencing?

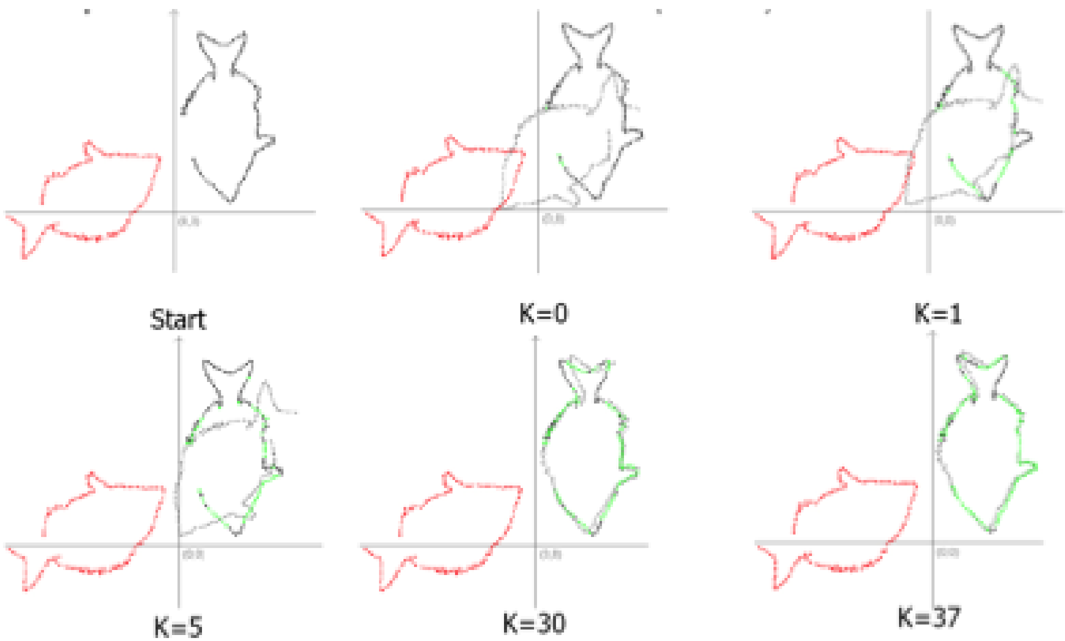


Modified Image from Riegl et. al., 2004

Additional co-registration method

Iterative closest point algorithm (ICP)

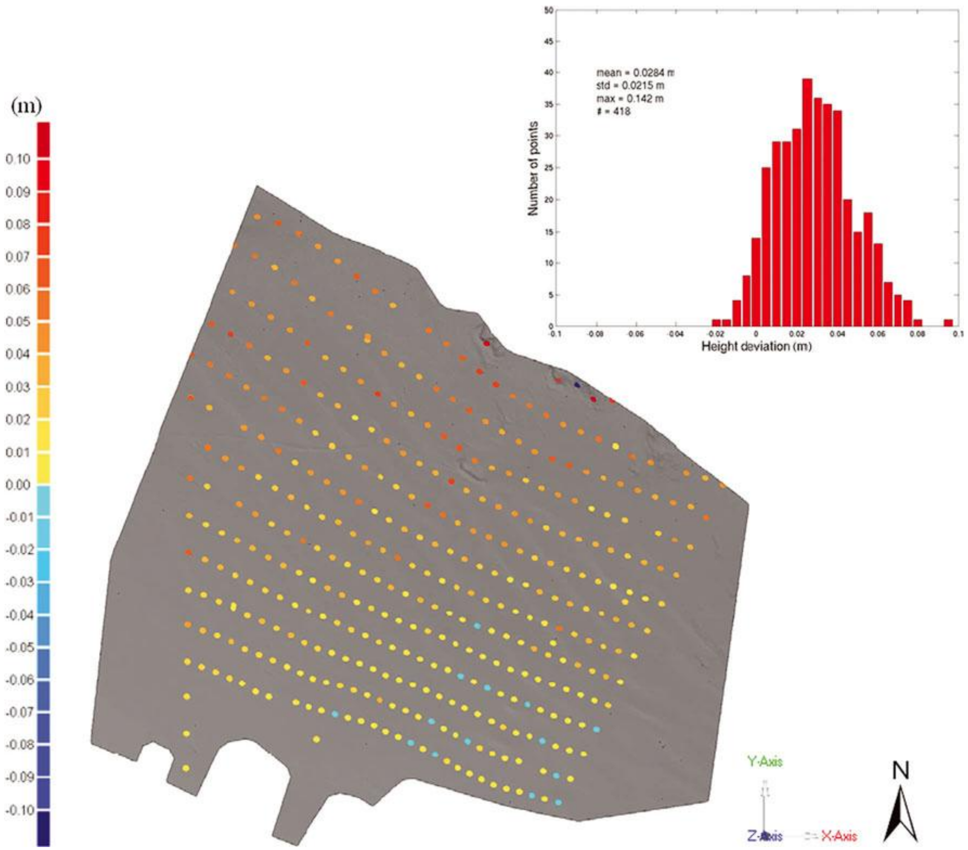
The ICP algorithm is an iterative alignment algorithm that works in three phases: 1) establish correspondence between pairs of features in the two structures that are to be aligned based on proximity, 2) estimate the rigid transformation that best maps the first member of the pair onto the second and then 3) apply that transformation to all features in the first structure. These three steps are then reapplied until convergence is concluded.



Distance method –minimizing method- error function

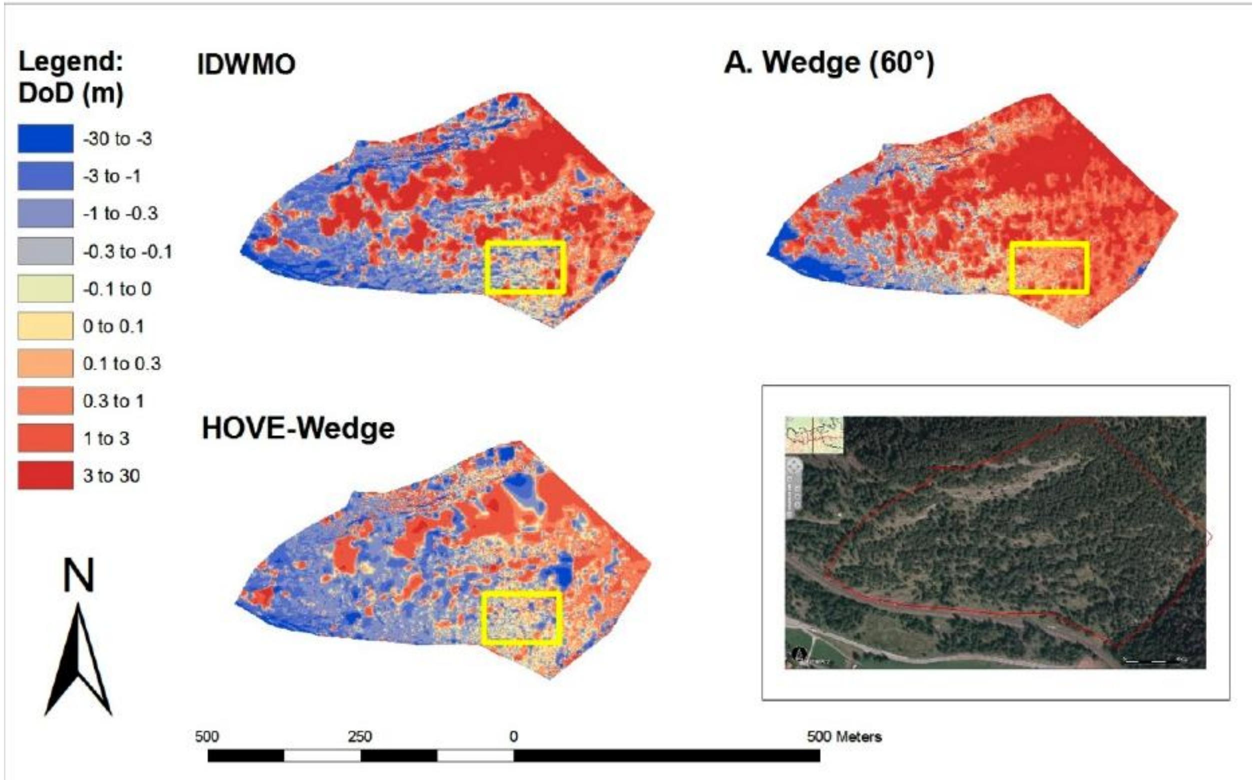
Reproducibility test results (usually of snow free areas)

Reproducibility is defined as the closeness of two results of measurements based on the same object carried out under changed measurement conditions.



Groundpoints 2,703
3,014 1,346
Mean error −0.142
1.296 0.361
RMSE 0.555 1.855
1.366
Standard deviation
0.536 1.537
1.366
Median −0.061 0.456
−0.054
NMAD 0.510 1.529
1.057
68.3% quantile 0.053
0.828 0.125
95% quantile 0.509
4.390 1.876

Any filter applied? Manual or automated, type of filter?



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95% quantile	0.509	4.390	1.876

Conclusions

The following information should be added to a high resolution snow depth map product :

Coordinate system
Resolution
Precision of the instrument
Foot print/pixel size (at target area, range of values)
Point density (minimum and average point density per grid cell)
Interpolation method /SfM software (algorithm used)
Registration error, Global coordinate system matching by GPS or DGPS
Additional co-registartion methods (ICP)
Reproducibility test results (statistical values; RMSE!)
Filter used (type and area coverage of the filter)

Uptake of the data into models easy but needs to be customized!

Any questions or recommendations ?

Snow Scan GmbH